for searches at LHC-14

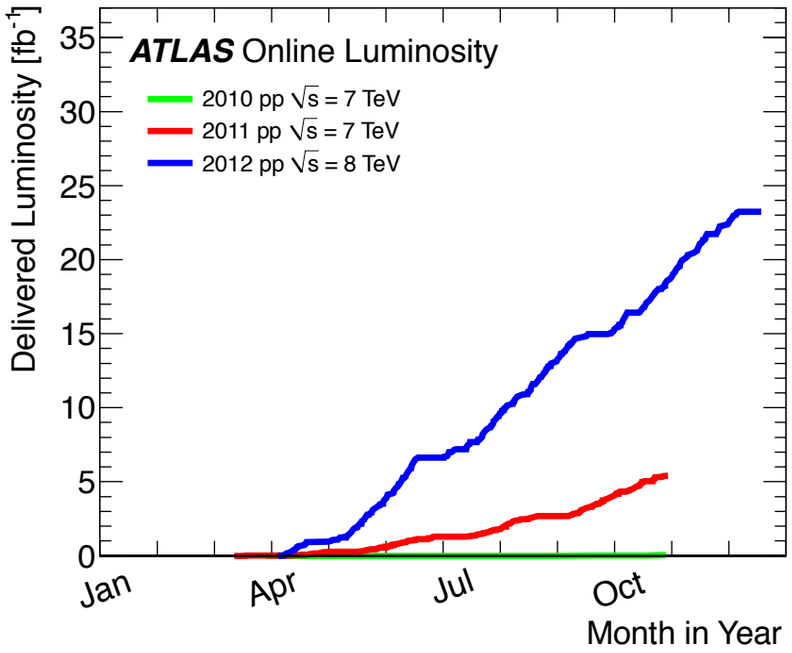
Physics Challenges in the face of LHC-14

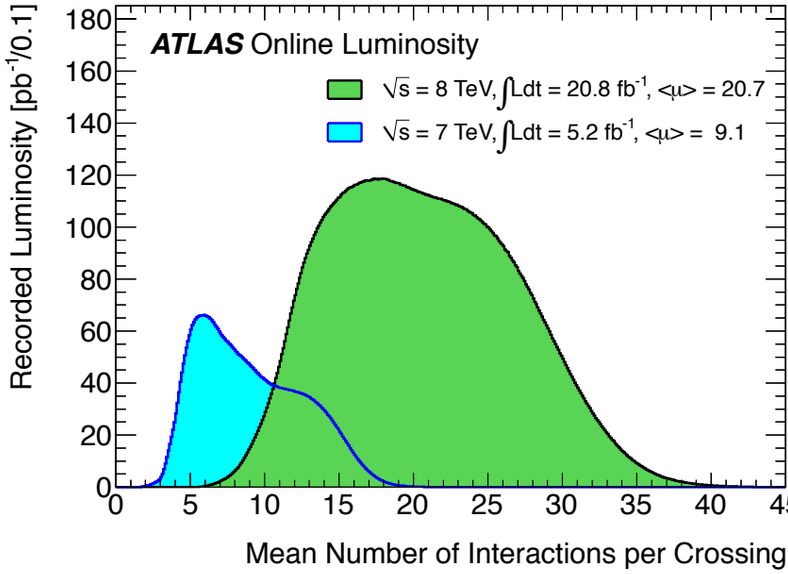
The Institute of Theoretical Physics UAM/CSIC
Madrid, September 2014

Erez Etzion, Tel Aviv University

LHC, Three years at Energy Frontier

- 2010, $\sqrt{s}$ =7 TeV, 36 pb^{-1} / 44 pb^{-1}
- 2011, $\sqrt{s}$ =7 TeV
  - Peak luminosity 3.65x10^{33} $cm^{-2}s^{-1}$
  - Peak of 140 pb^{-1} of data per day
  - Integrated luminosity 5.62/ 6.1 fb^{-1}
  - 50 ns bunch spacing
  - Pile up - collisions/bunch crossing
    $<\mu>$ =6.3 (11.6) before (after) September
- 2012, $\sqrt{s}$ = 8 TeV
  - Peak luminosity 7.73x10^{33} $cm^{-2}s^{-1}$
  - Integrated luminosity (ATLAS/CMS) 23 fb^{-1}
  - Data taking effi. 93%, good quality 95%
  - Pile up - $<\mu>$ =20
- Total : ~5 billion events, ~25 fb^{-1}
- 120 PB data and MC on disk!





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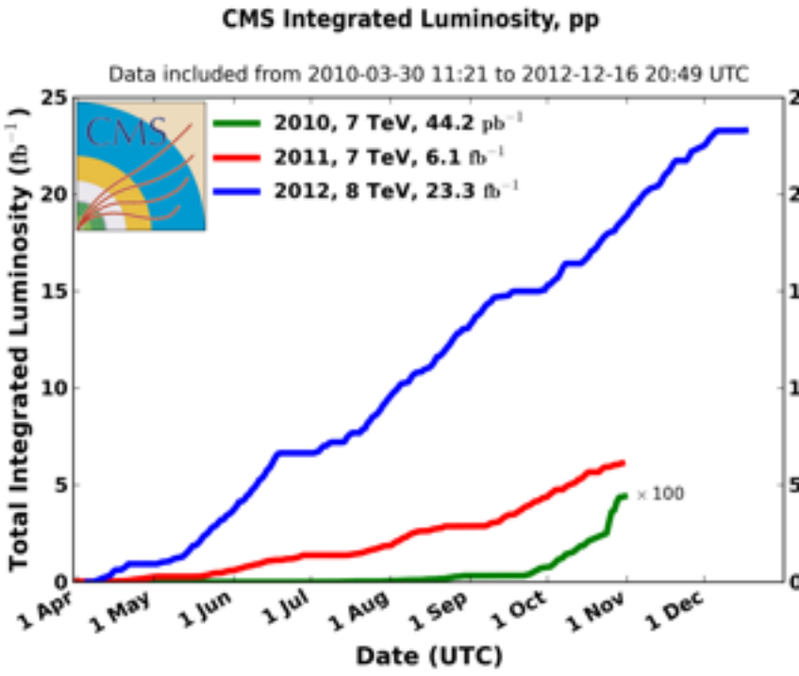
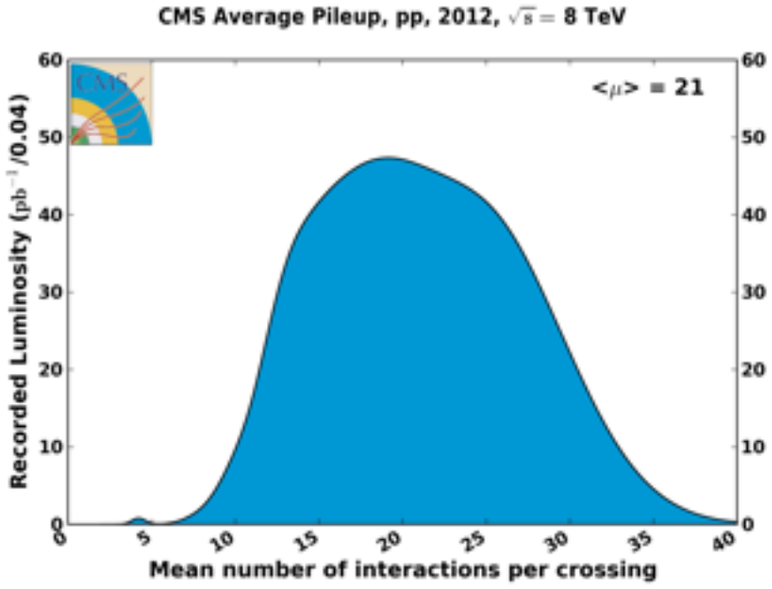


Month in Year



Q&A

Hierarchy / fine tuning problem
Fermions mass structure
Matter vs. Antimatter
Cosmology -> Dark M & Dark E
Unification of electroweak (EW) & QCD
Number of generations
Neutrinos are Massive

SUSY
Extended Higgs sector
Baryogenesis
GUT
Extra dimension
Quantum loop gravity
Minimal DM
Theory of everything (Strings)

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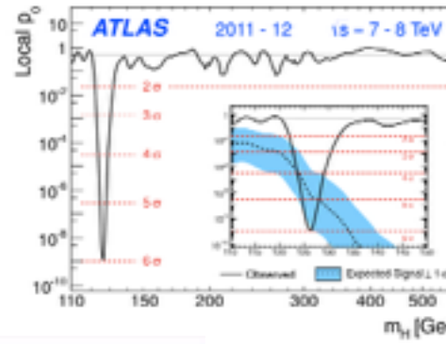
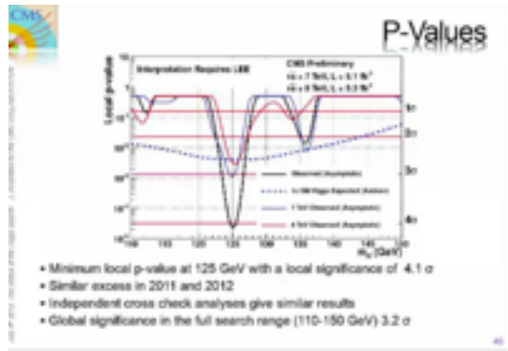
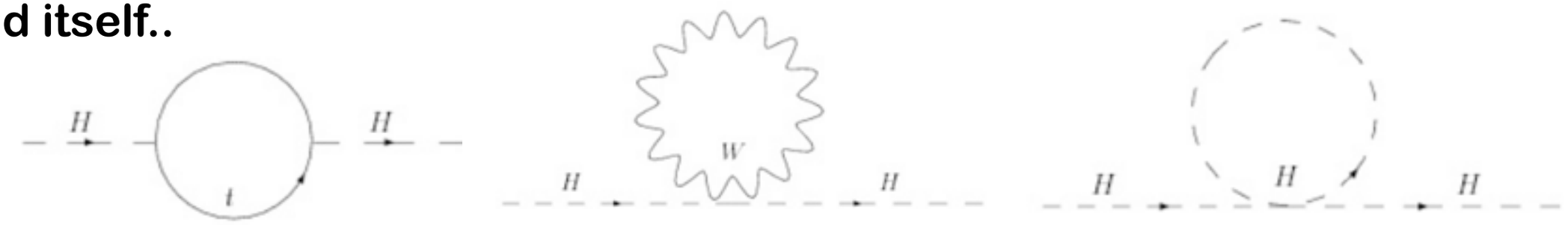
LHC is a discovery machine!

Run-2, new era for LHC Physics?

- Impact of 125 H on our measurements and searches strategy?
- SM Higgs related measurements:
  - Measure everything: mass, width and BR to SM particles
  - Look for other decay channels and measure their BR
  - Measure its spin (angular distributions)…
- Exotics decays, does it couple to new particles??
  - ➡ Invisible Higgs → (MonoX analyses..)
  - ➡ Higgs to Exotics objects, e.g. Hidden valley to dark photons (LLP or lepton jets)
  - ➡ Other Higgses? might (should?) be more than one (SUSY)
- Lessons from run-1: Technicolor and SM4 are less likely, however other models including SUSY live well with a light Higgs.
- As the Higgs acquires mass from loops of fermions (tops!), Gauge bosons and itself..

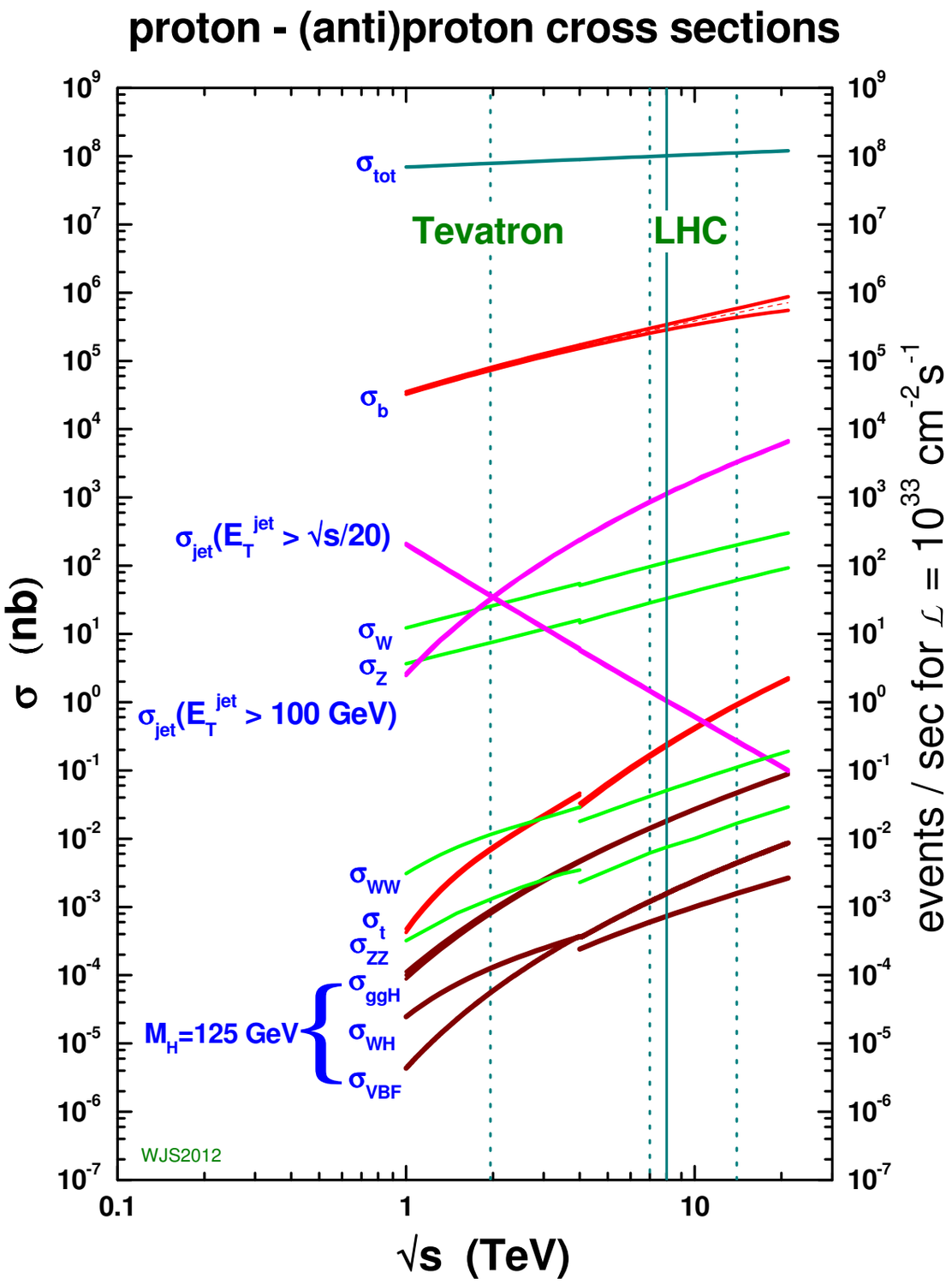






➡ New physics may appear close to the Higgs mass

Theoretical motivation : proton - (anti)proton



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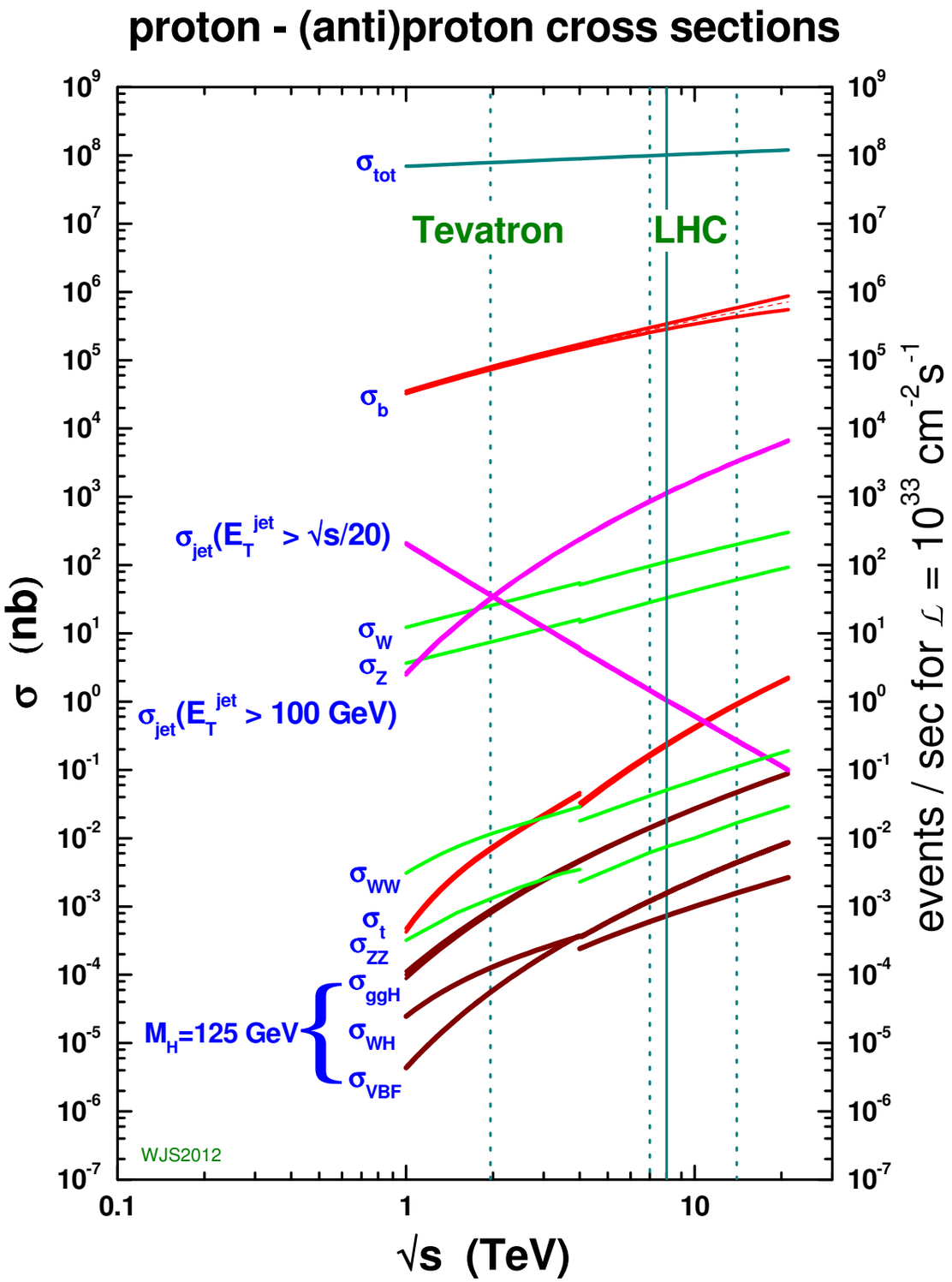
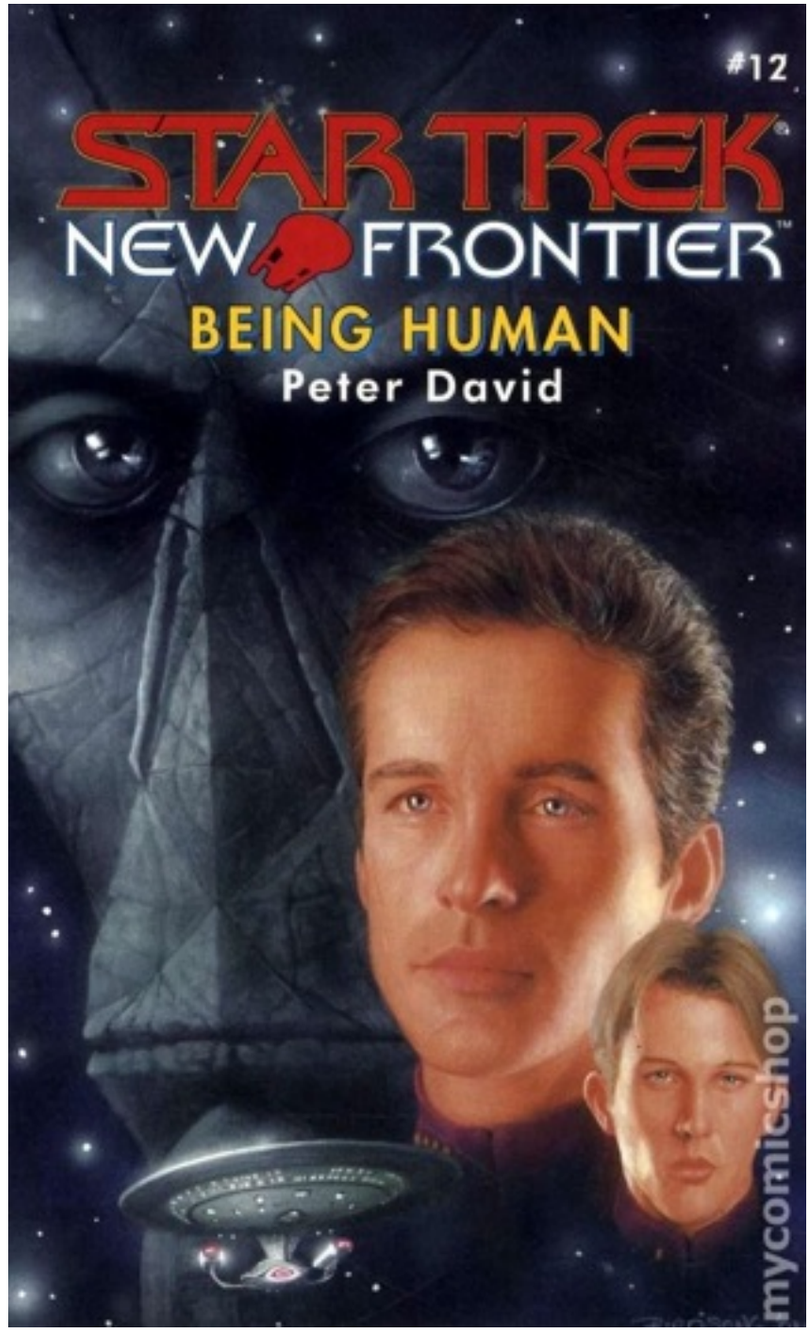
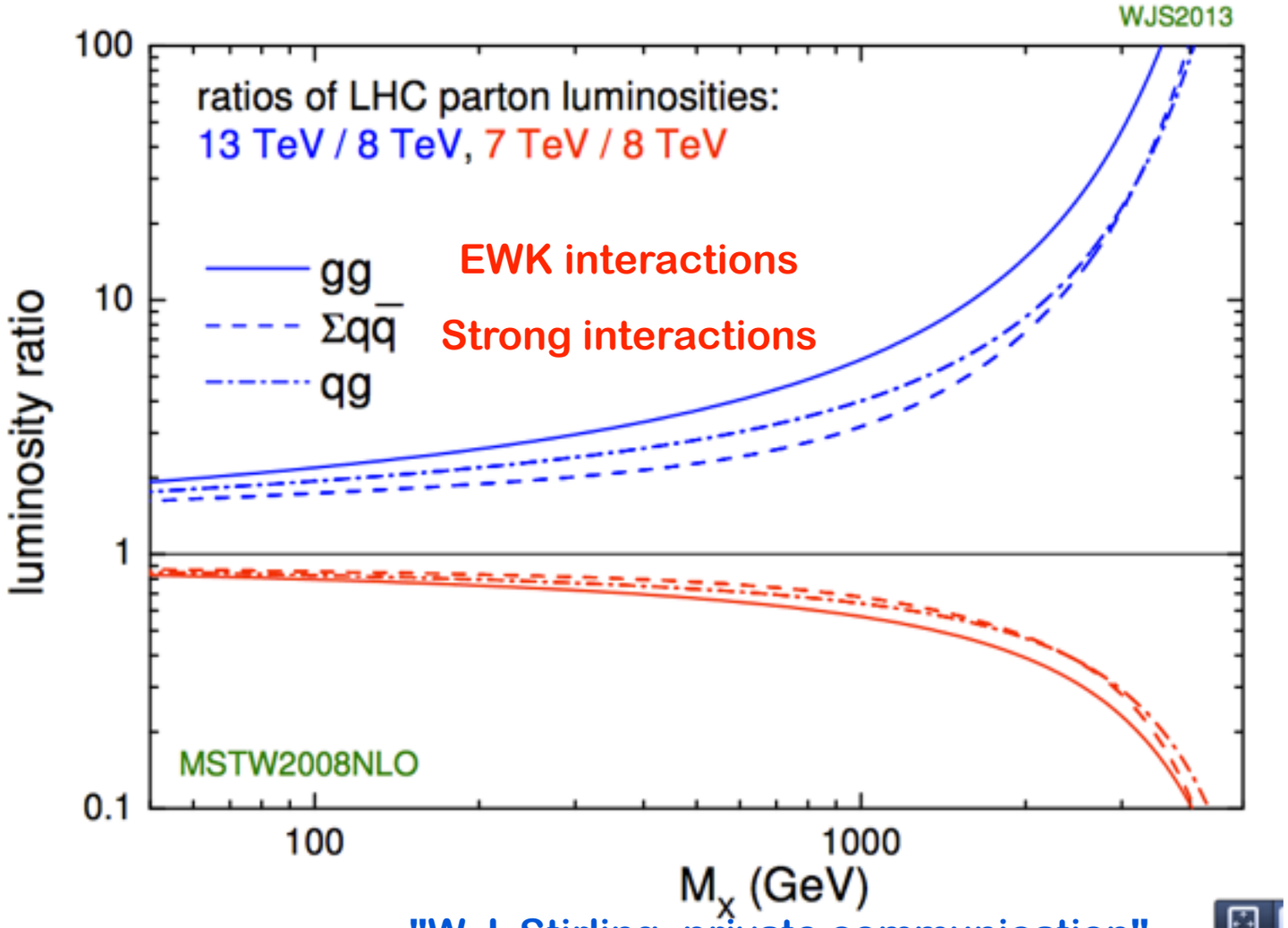




Theoretical motivation: parton

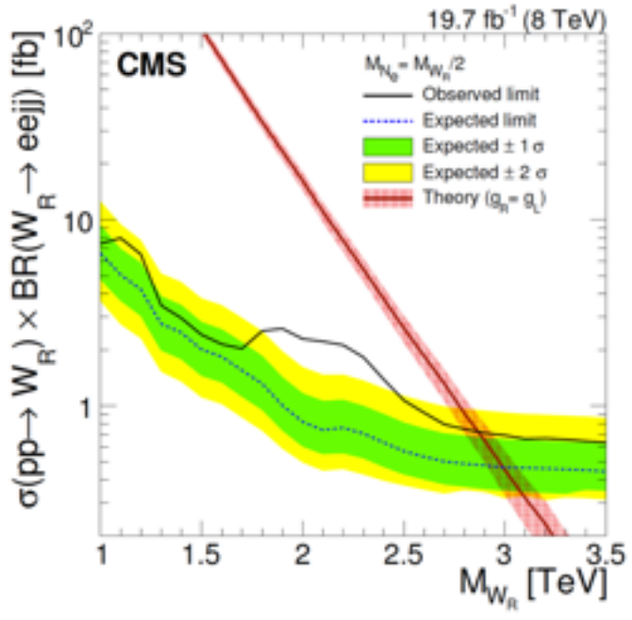
- Increase of E_{CM} results in large increase in qq parton luminosity more than 7->8 TeV.
- More pronounce even for gg process (graviton searches)
- Additional opportunities for New Physics!



"W.J. Stirling, private communication"

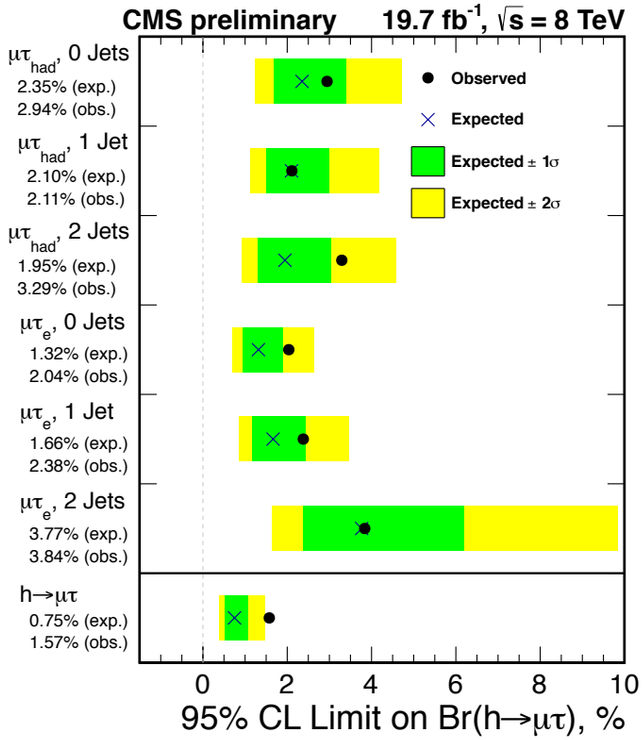
“CMS discoveries”

WOW



Search for Heavy Neutrinos and Right-Handed W

arXiv:1407.3683



Search for Lepton Flavour Violating Decays of the Higgs Boson

CMS-PAS-HIG-14-005

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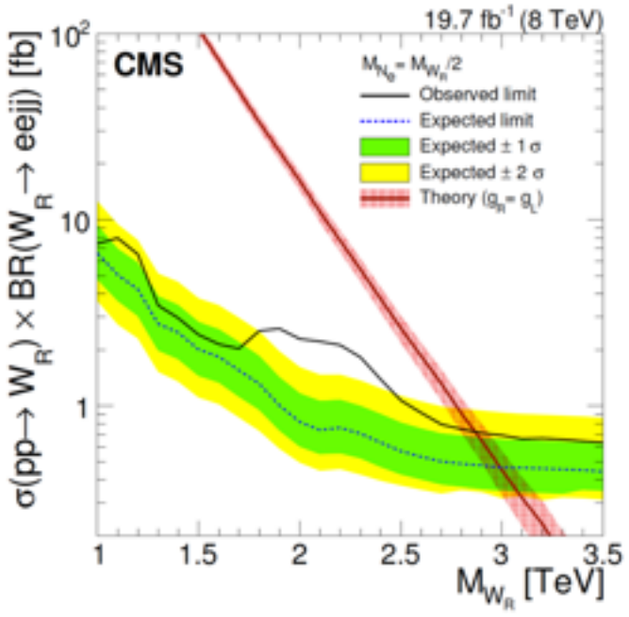

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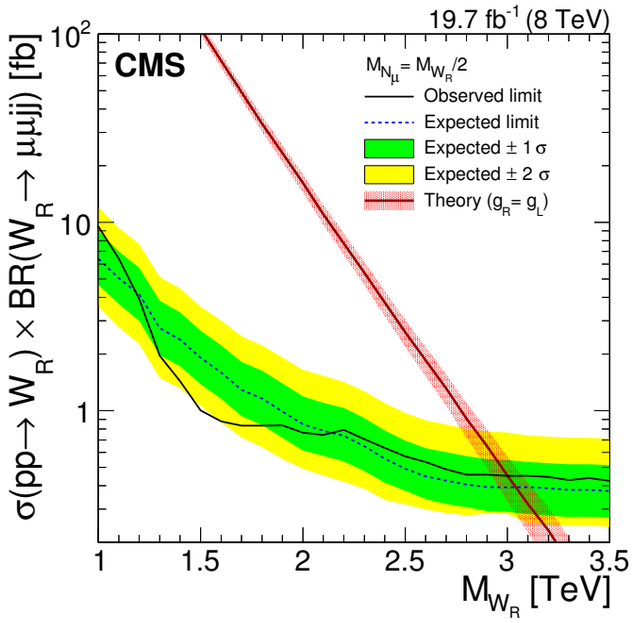

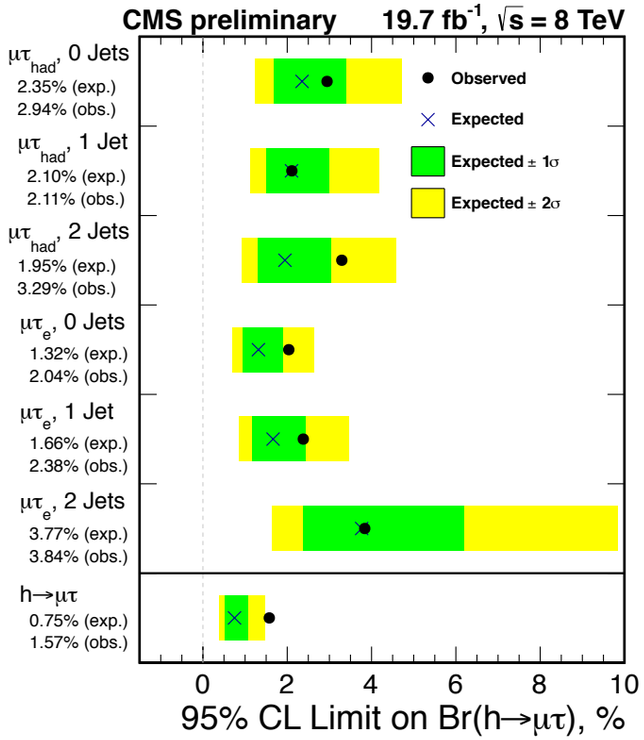

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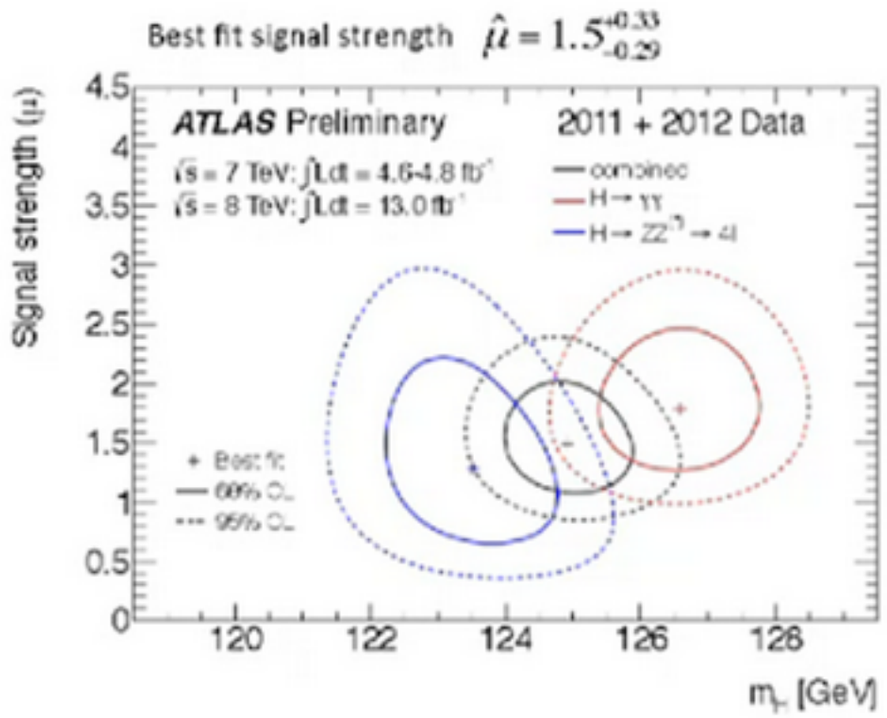
CMS-PAS-HIG-14-005

“A slight excess of signal events with a significance of 2.5σ is observed.”

ATLAS doesn't stay behind

- 2-3 sigma excess in some signal / control regions
  - In some cases result of low stat.
  - Some due to being at the end of the spectrum
  - We **expect** to have a few 3 sigma effects
  - The current strategy of the experiments is to check carefully and when certain publish.
  - LOOK again with run II !!

ATLAS "Twin peak"…



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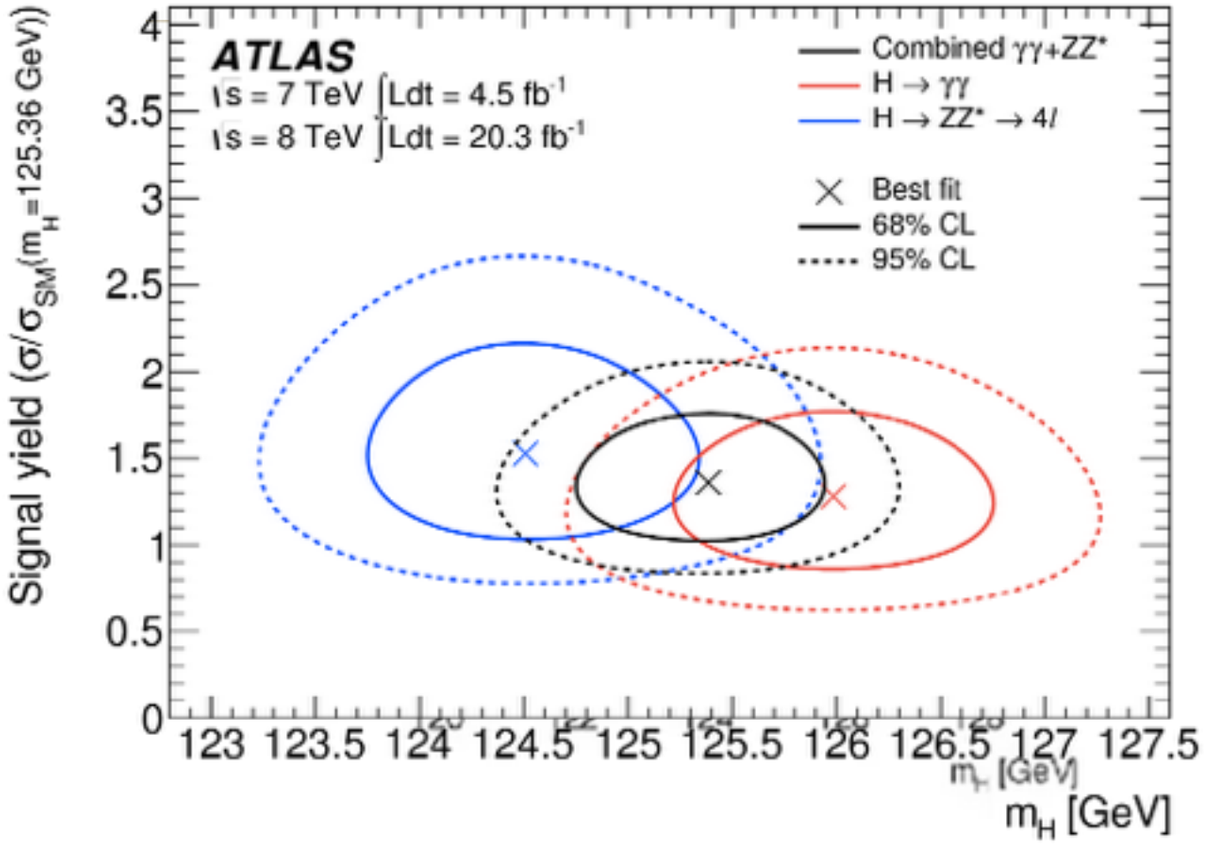
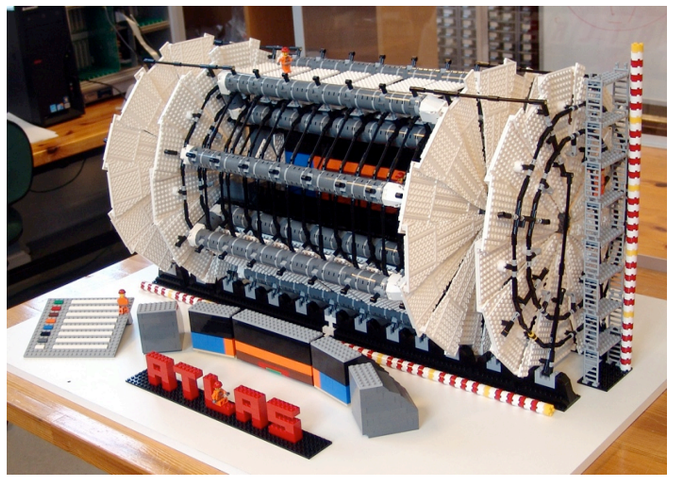
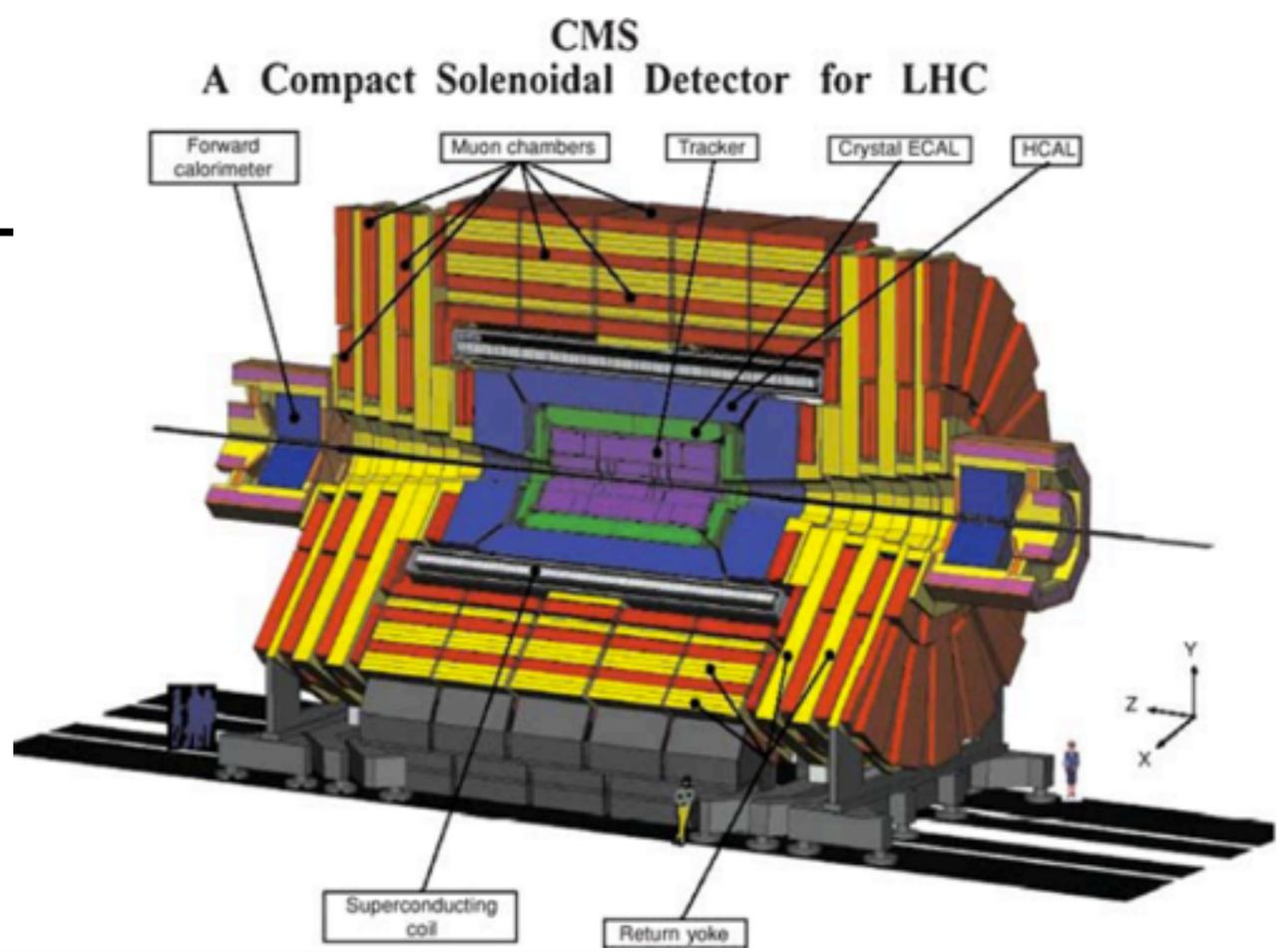


ATLAS vs CMS





Parameter	ATLAS	CMS
Weight (tons)	7000	12500
Diameter (m)	22	15
Magnetic field (T)	2 (Solenoid) + Toroid: 0.5 (1)	4 (Solenoid)
Trigger	L1, L2+EF (HLT)	L1, L2+L3 (HLT)
Tracker	pixel & strips + TRT	full silicone tracker
σ/p_T	$\approx 5^{-4} p_T + 0.01$	$\approx 1.5^{-4} p_T + 0.005$
E Cal	L_{Ar}	PbWO
σ/E	$\approx 10\%/\sqrt{E} + 0.007GeV$	$\approx 3\%/\sqrt{E} + 0.003GeV$
H Cal	Fe +scintilators / Cu +L	Brass + scintilator
σ/E	$\approx 50\%/\sqrt{E} + 0.03$	$\approx 100\%/\sqrt{E} + 0.005$
Muon (+inner tracker)	stand alone tracking	
σ/p_T	$\approx 2\%$ @ 50 GeV; 10% @ 1 TeV	$\approx 1\%$ @ 50 GeV; 10% @ 1 TeV

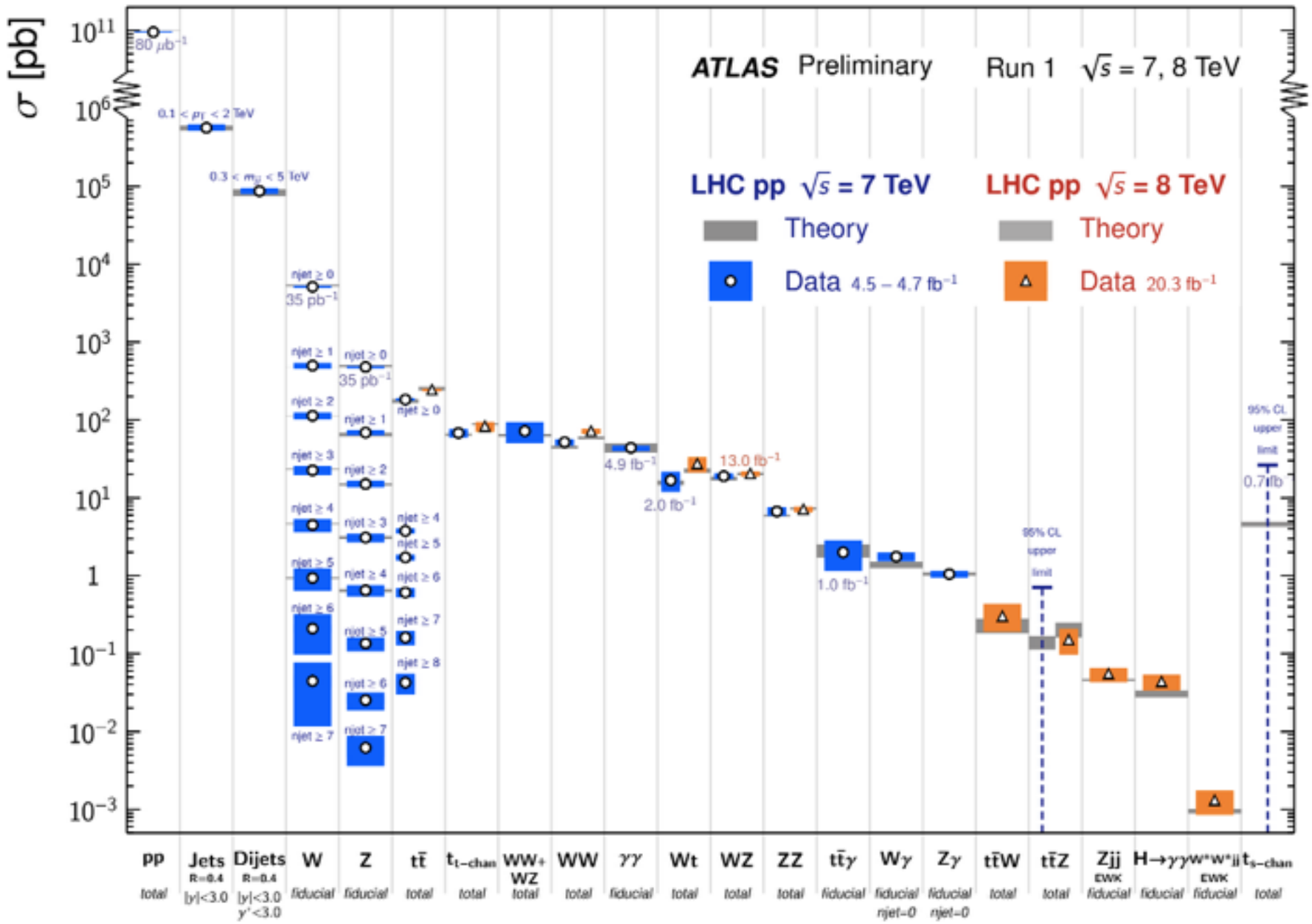
The return of the LHC!

	50ns	2015.1	2015.2
beta*	80	80	40
lumi	4.6E+33	7.4E+33	1.3E+34
days	21	44	51
intL	1/fb	5.1/fb	10.2/fb
pileup	27	22	39

Conservative rough estimate..
Actual plan to be decided in 2 weeks at Chamonix

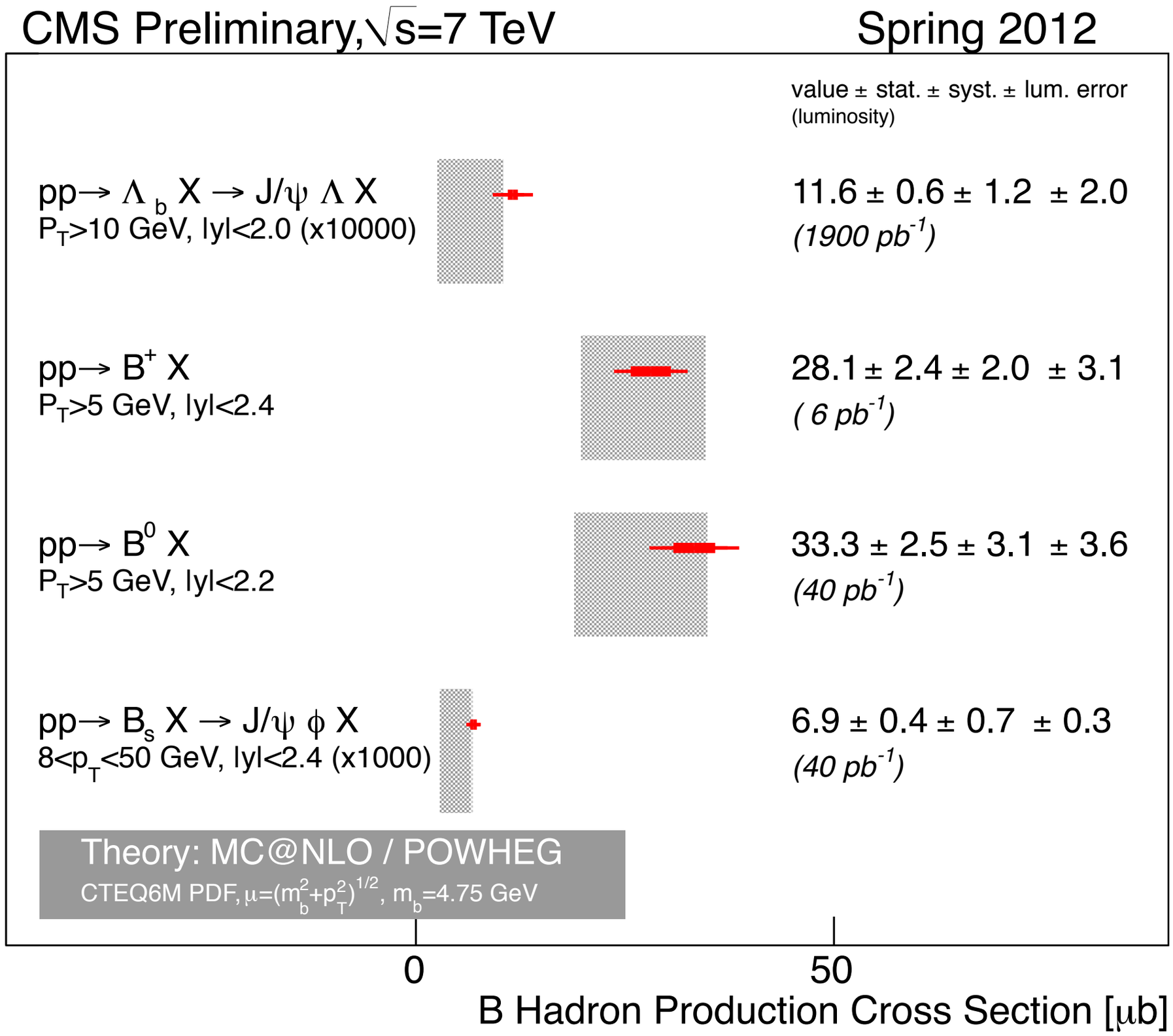
https://espace.cern.ch/be-dep/BEDepartmentalDocuments/BE/LHC_Schedule_2015.pdf

SM Measurements



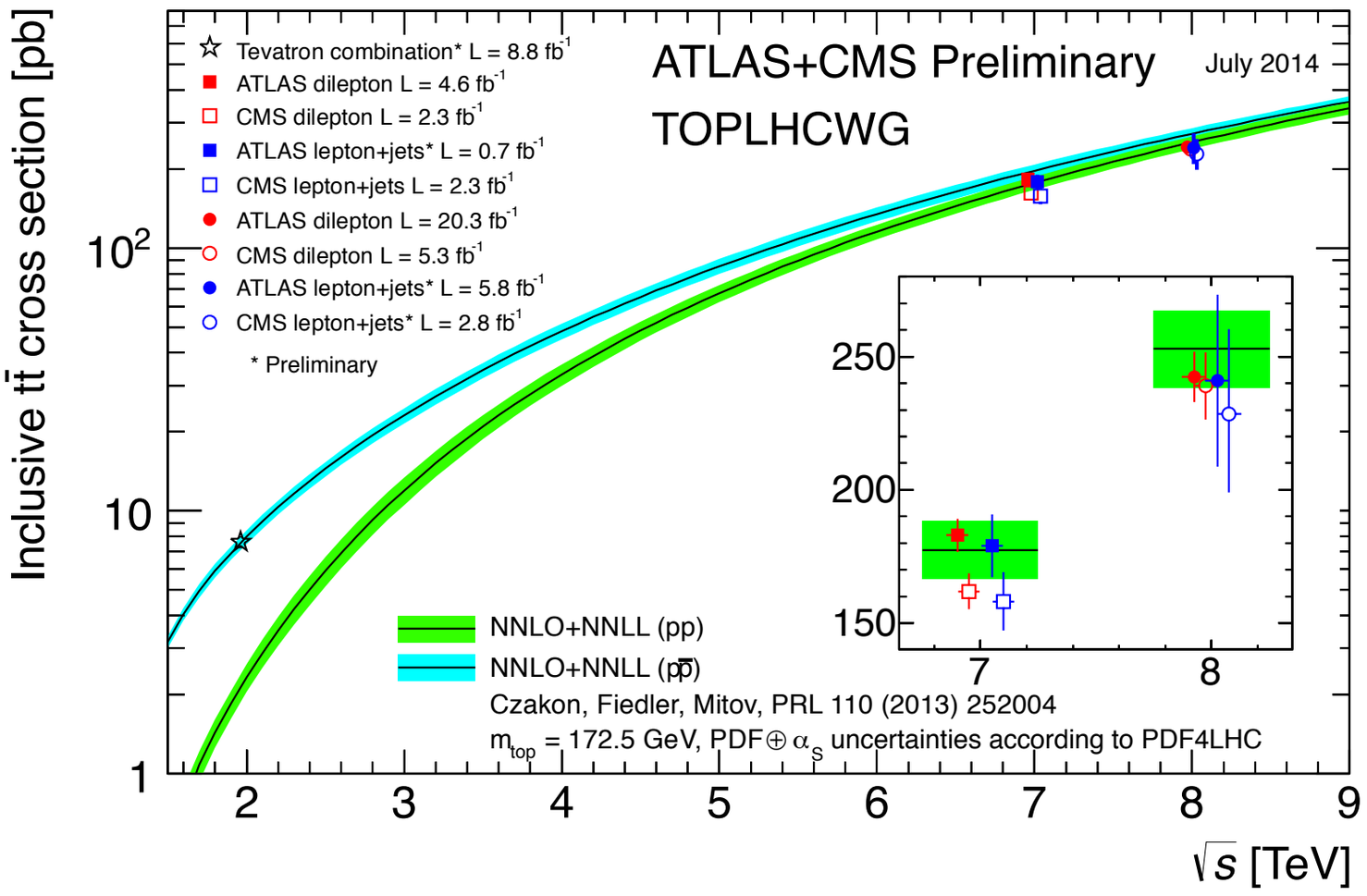
- Great success of Next-to .. calculations and extremely precise simulation
- Huge data sample 100M W(lν), 10M Z(ll)
- Testing the SM at 7 & 8 TeV, calibrating the detectors and the MC

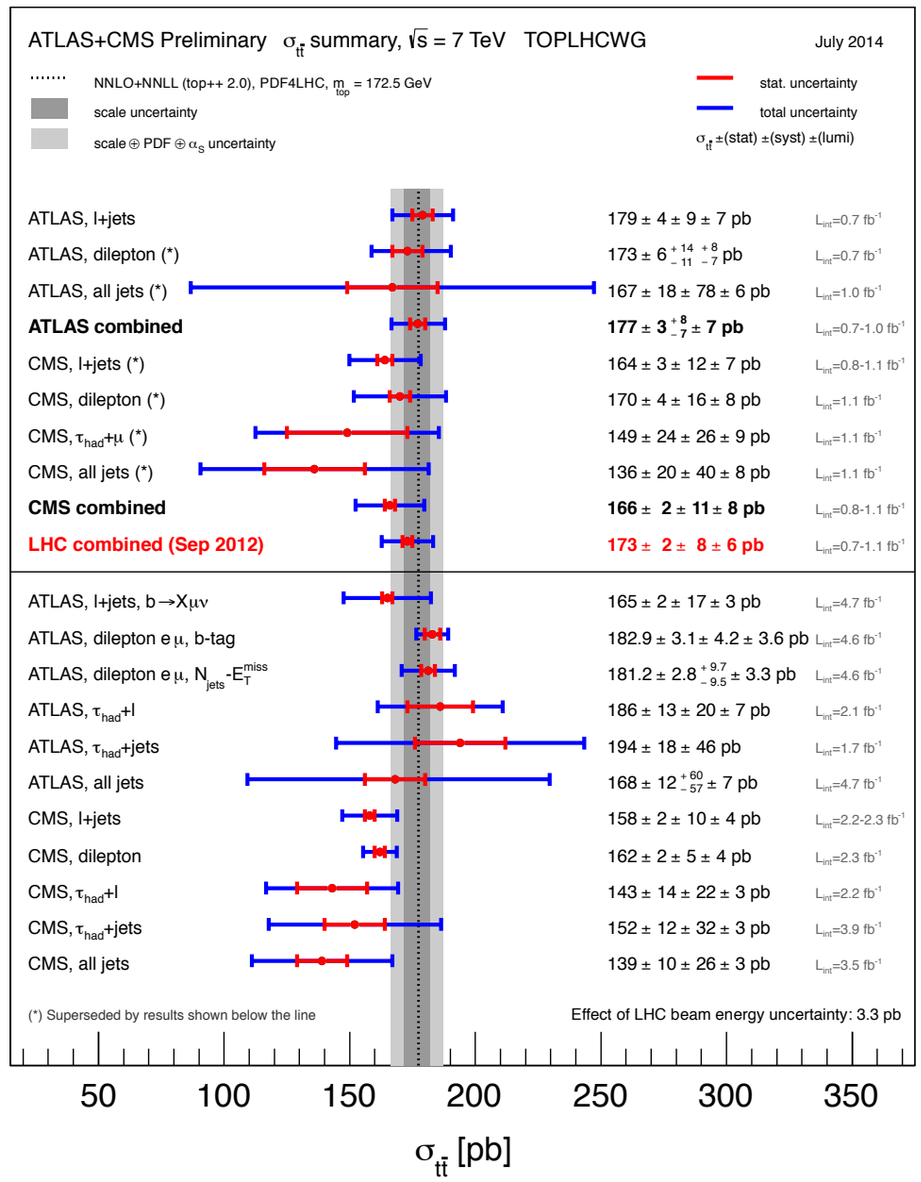
B-Physics, CMS



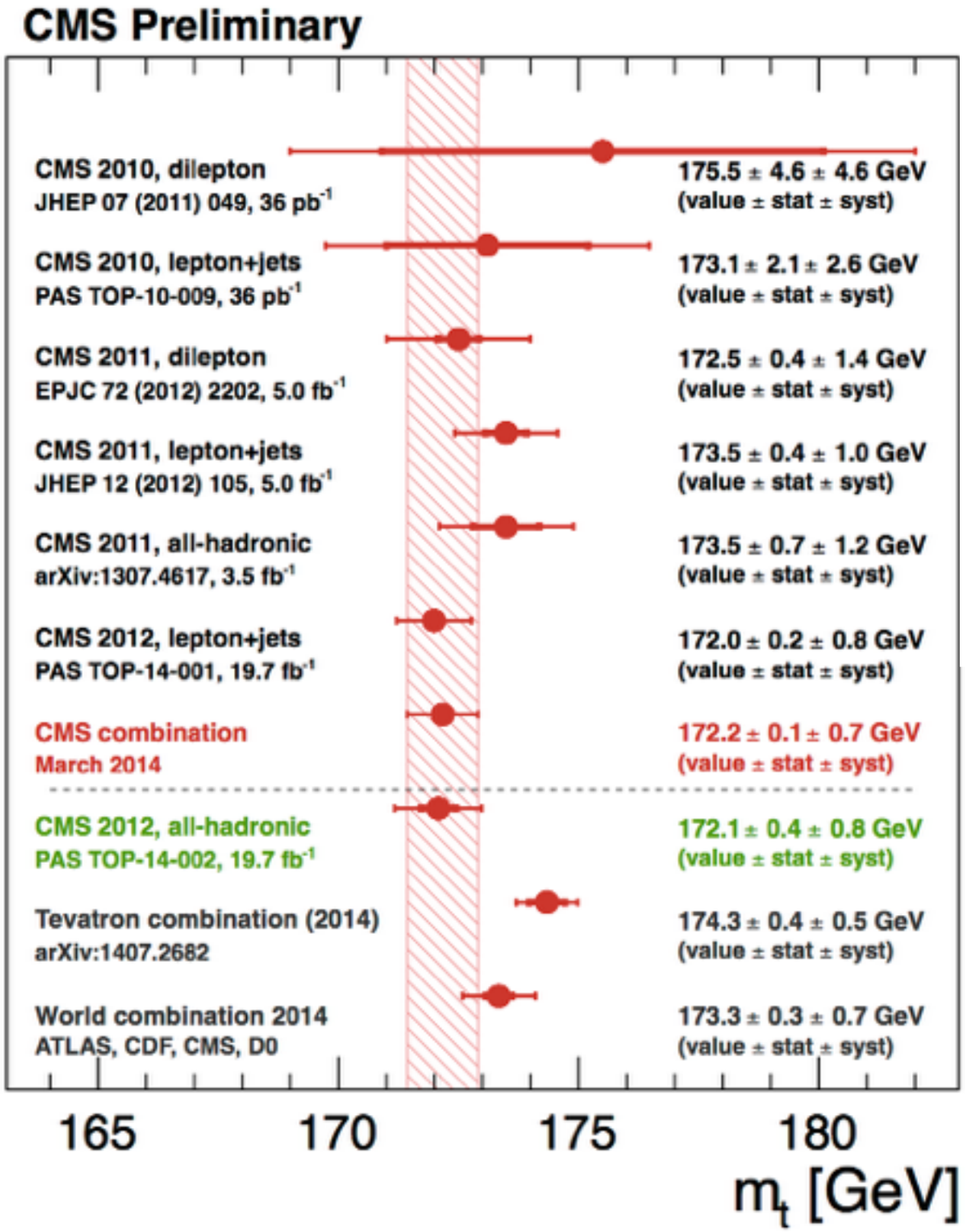
Top ATLAS CMS cross section

- **TOP Factory ! (400K ttbar (l+x) written in ATLAS!)**





Top mass


CMS Preliminary
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JHEP 07 (2011) 049, 36 pb-1
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173.1 ± 2.1 ± 2.6 GeV
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CMS combination
March 2014
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Tevatron combination (2014)
arXiv:1407.2682
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World combination 2014
ATLAS, CDF, CMS, D0
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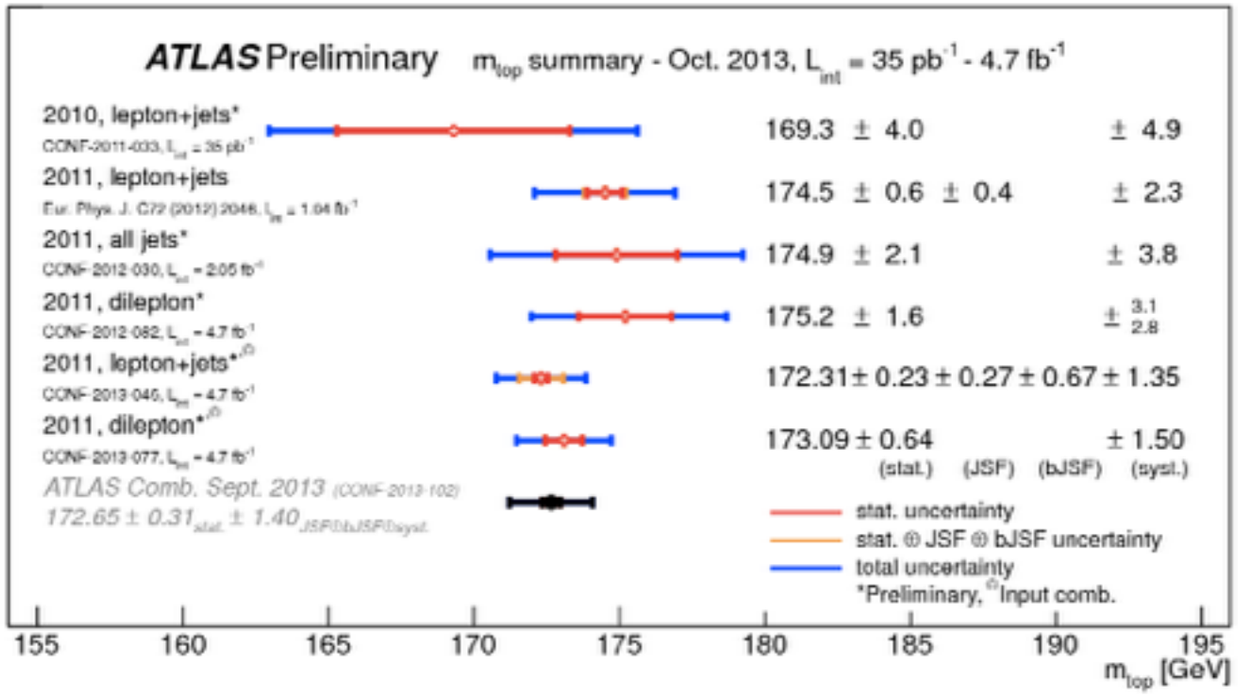
(value ± stat ± syst)
165
170
175
180
mt [GeV]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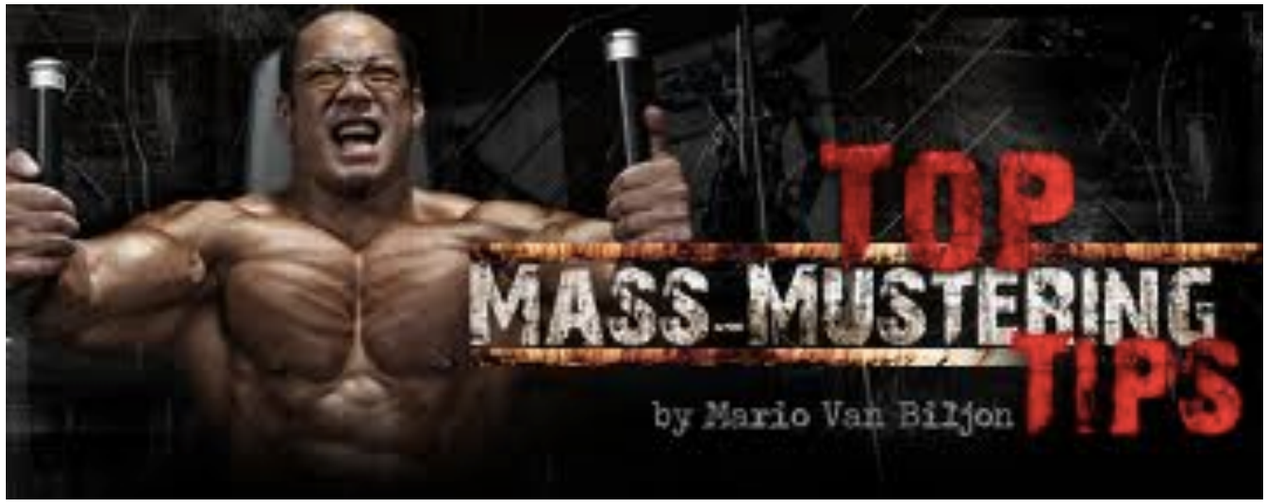
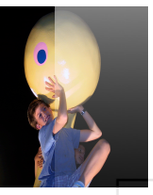

TOP
MASS-MUSTERING
TIPS
by Mario Van Biljon



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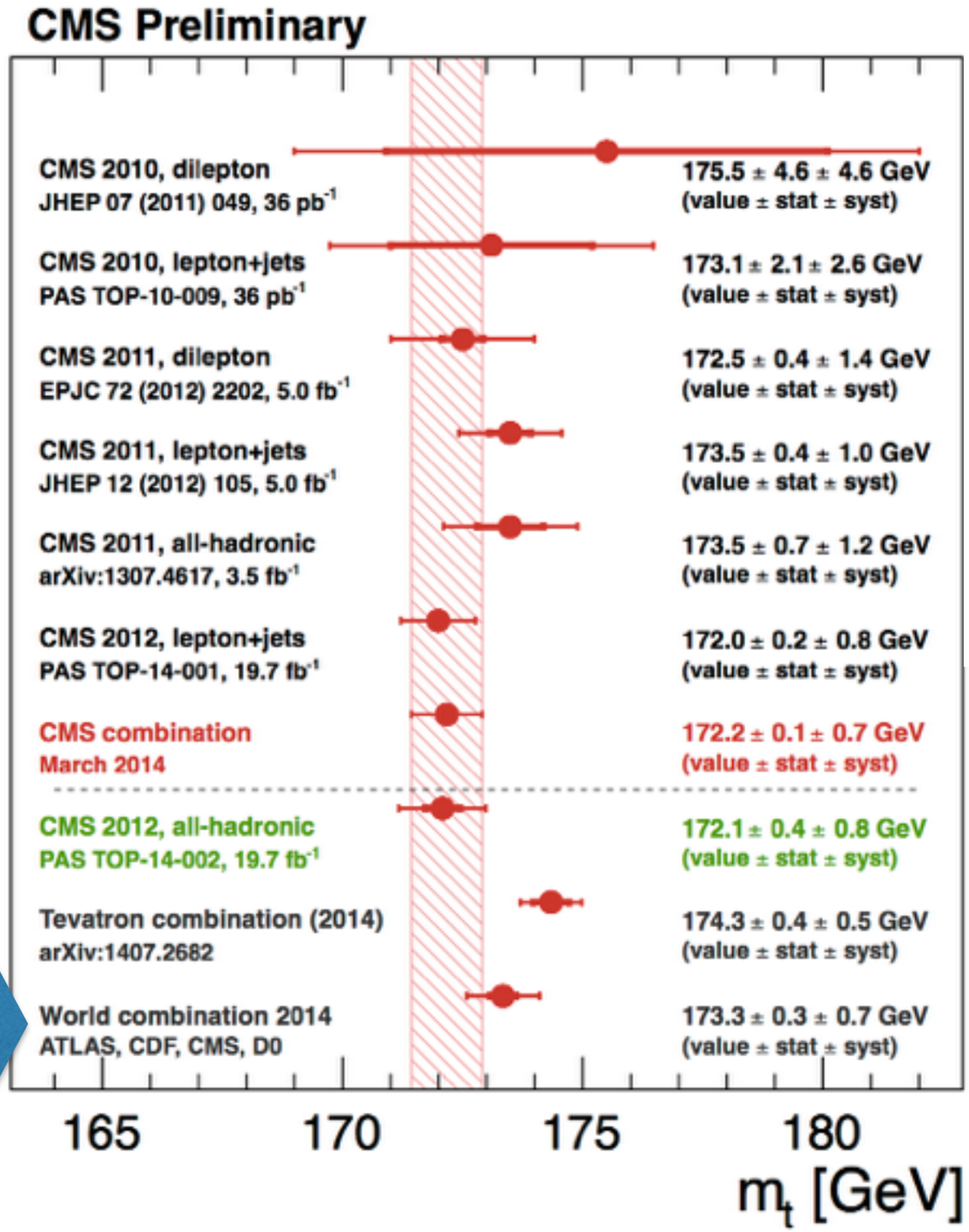
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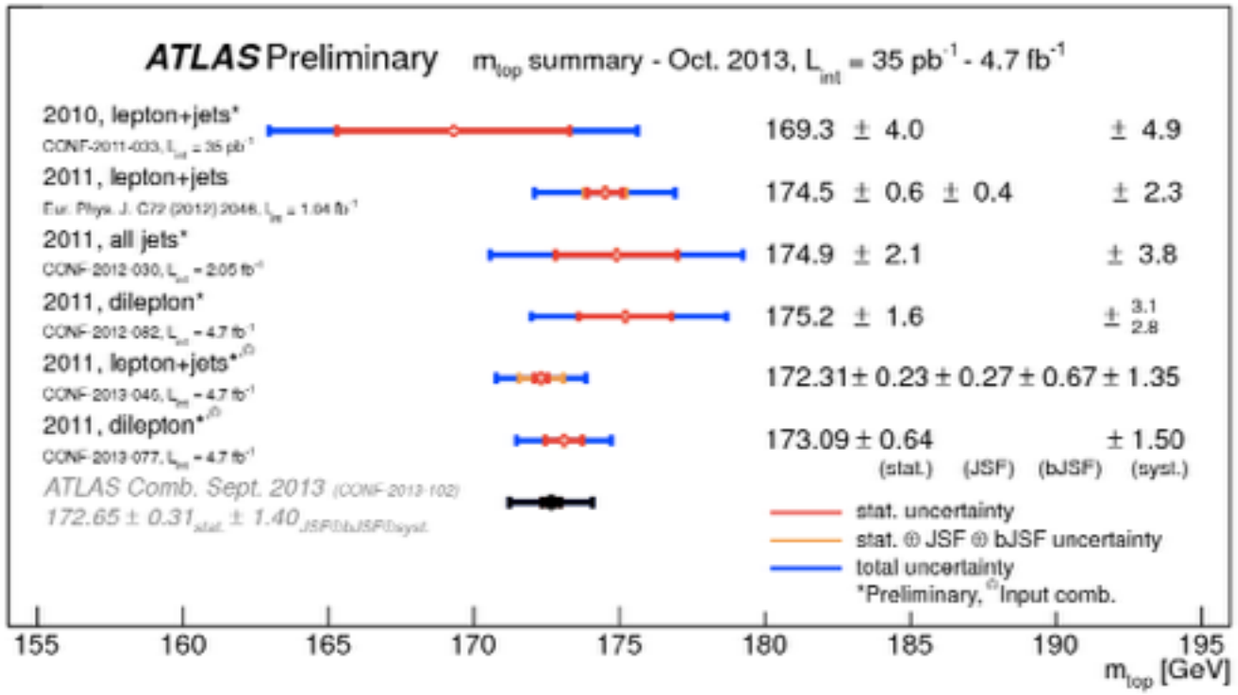
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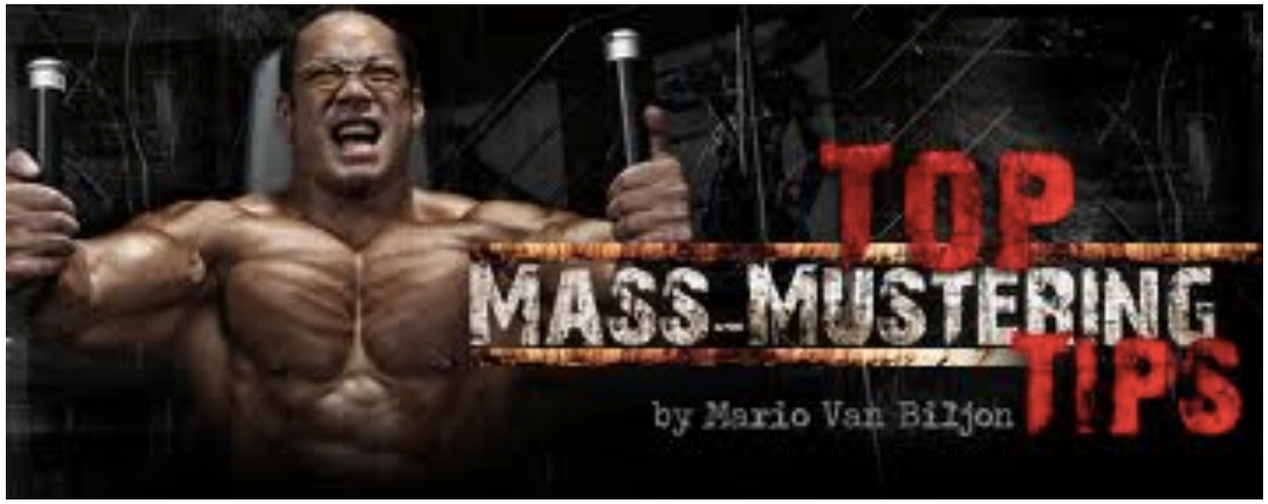
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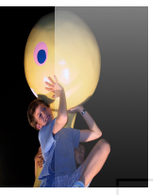
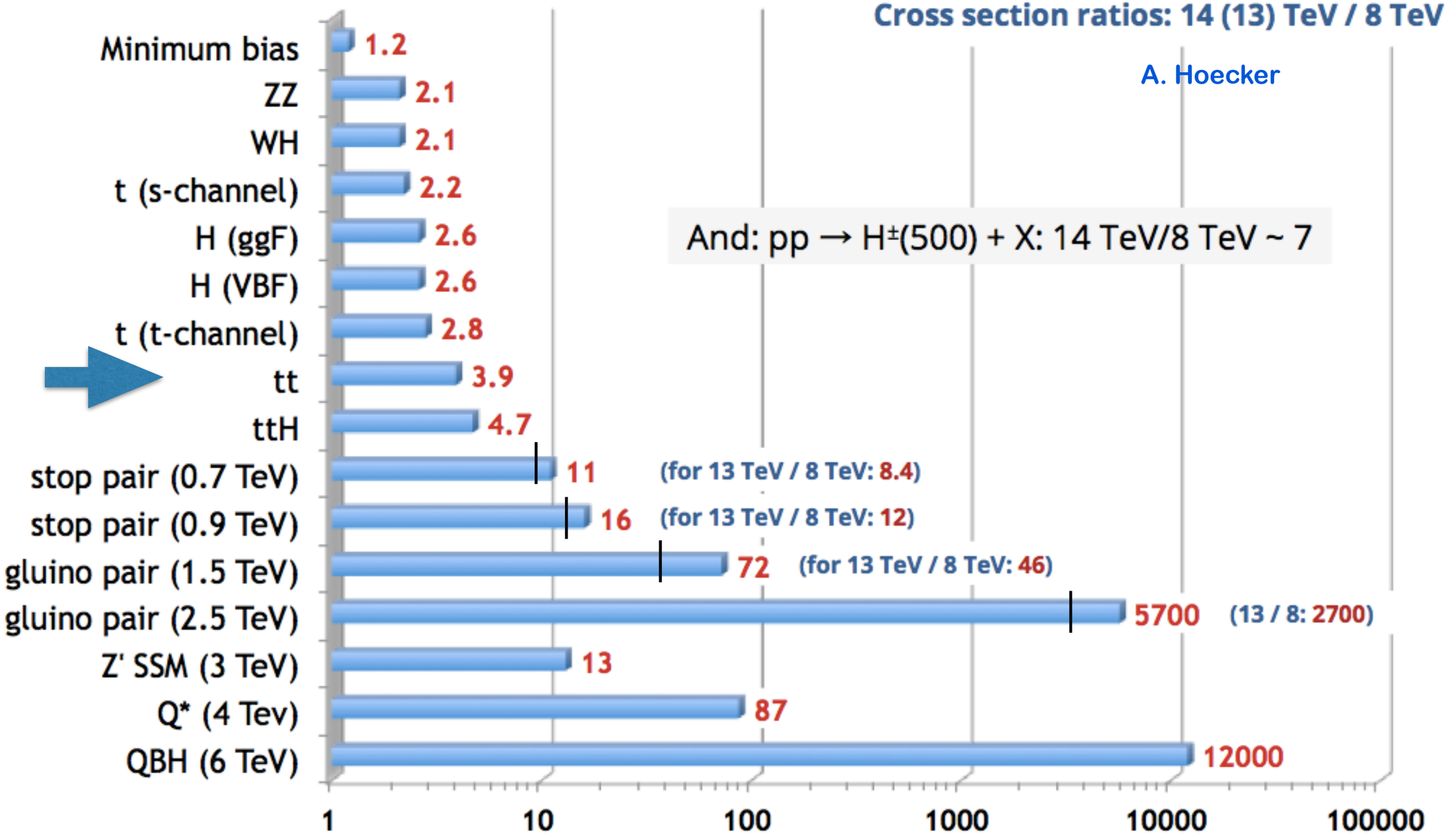


Next round: Cross section ratios

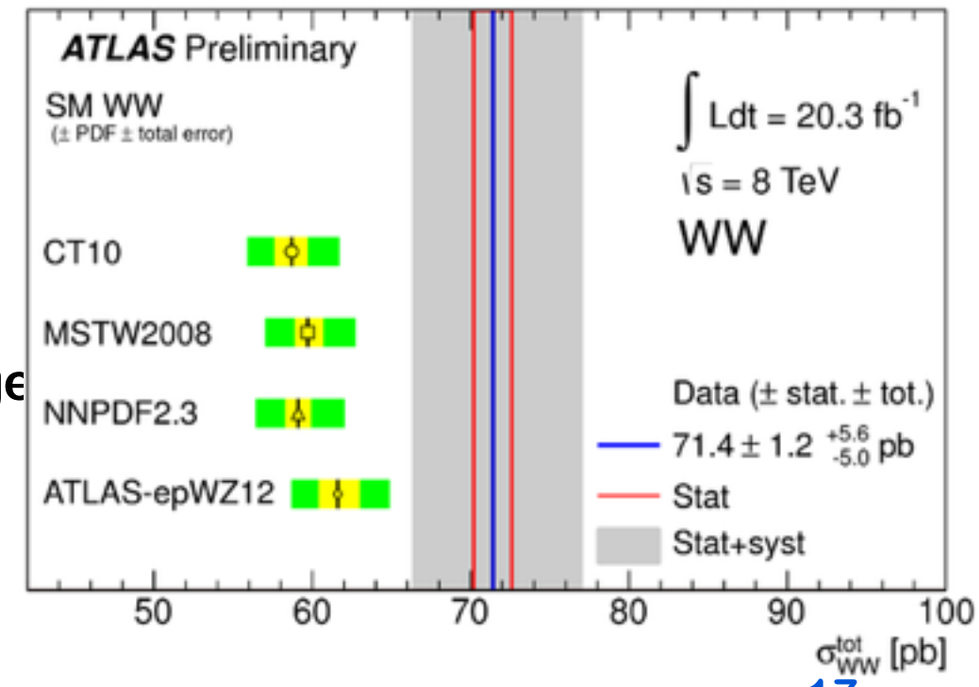


SM prospective

- ATLAS & CMS are finalising the SM 7 / 8 TeV measurements.
- Prepare for data with very low μ = 0.01 (and 0.5). Useful for various soft QCD and diffractive measurements
  - MB @ 13 TeV, Inelastic Xsec, Diffractive jet production, UE, Diffractive Physics synched with ALFA
  - Useful for JETMET and tracking for tuning w/o pileup
- For summer - quick look at "simple channels" @ 13 TeV
  - Single Z (qqbar dominated), ZZ (significant gg)
  - WZ can follow soon and WW later (due to MET, new BG conditions)
- SM Xsec expectations @ 13 TeV
  - Increase of gg vs qqbar may increase discrepancies vs NLO dibosons calculations (see already at the 8 TeV ->)....
  - Studies of Vector Boson Scattering @ 14 TeV high luminosity)

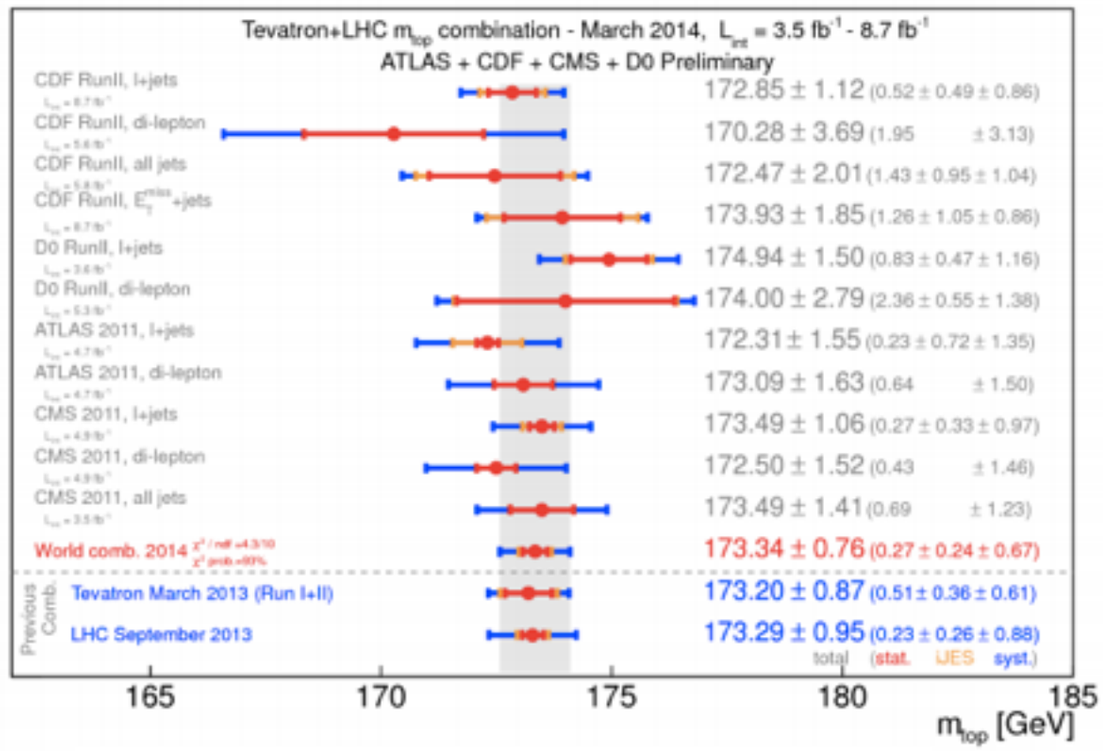
➡ Most of the 8 TeV effort is still ongoing, will probably delay 13 TeV effort

Fiducial, differential and total Xsec improve our knowledge SM, and determination of PDF



Top in Run-2

- Searches - ttbar resonances, top partners, NP in precision measurements
- Entering further to boosted regime
- Would be interesting to repeat ALL 7 & 8 TeV @ higher E_{CM} (& pileup)
- Crucial for the stability of the SM…
- The top groups are also still working on 8 TeV ..



$m_{top} = 173.34 \pm 0.27\ (stat) \pm 0.71\ (syst)\ GeV.$

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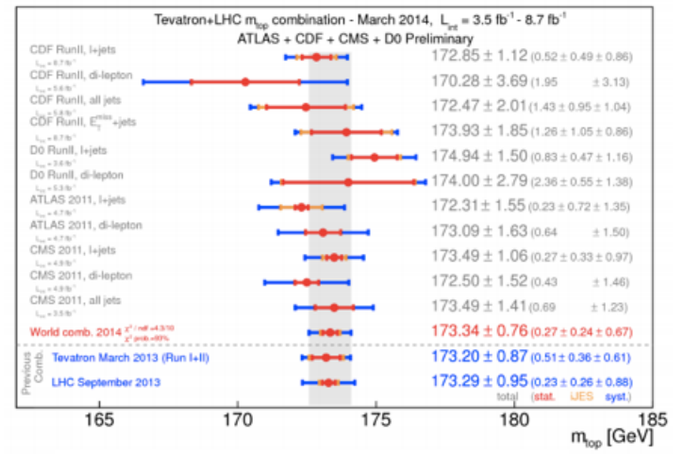

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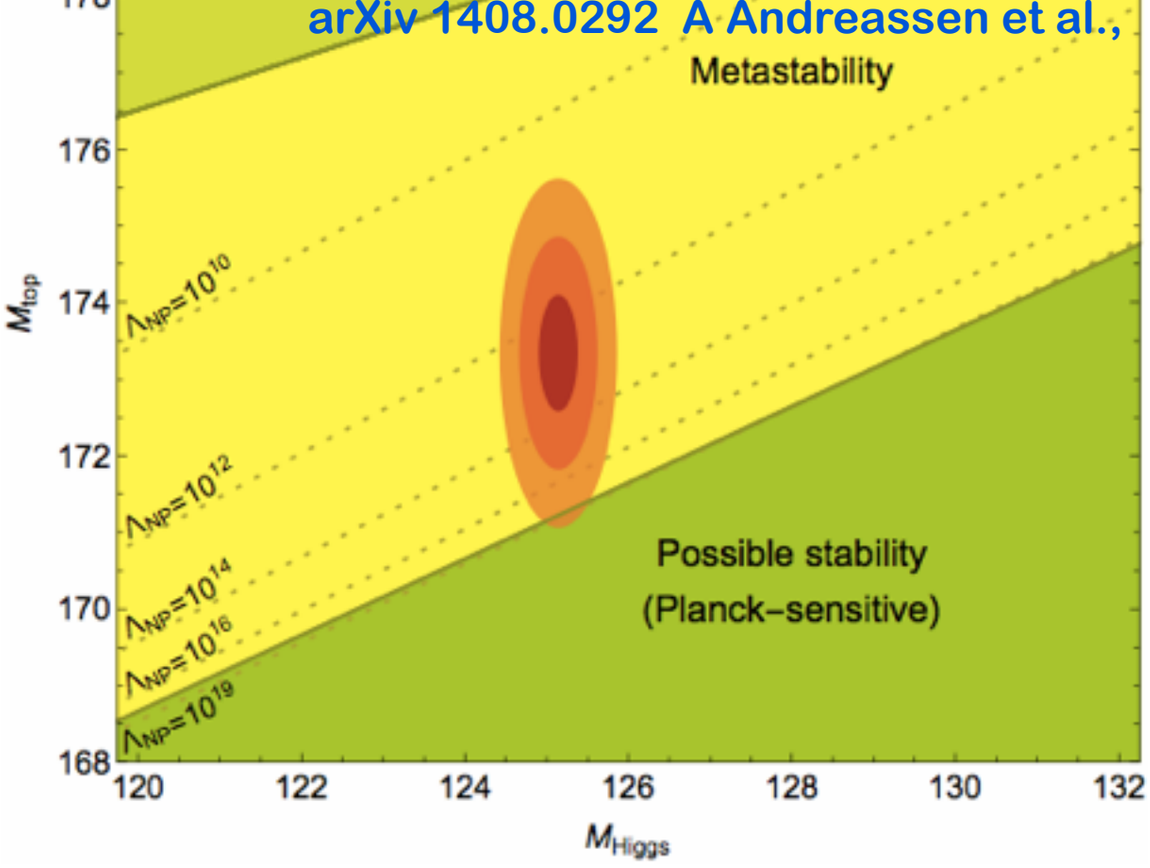

Run-2 Physics first goals

- SM
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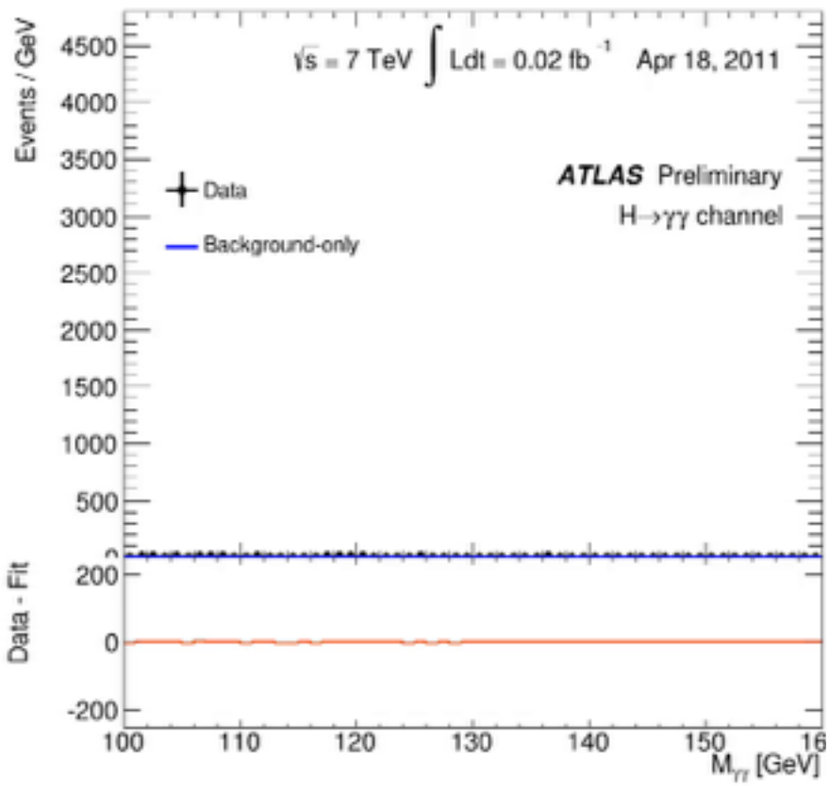
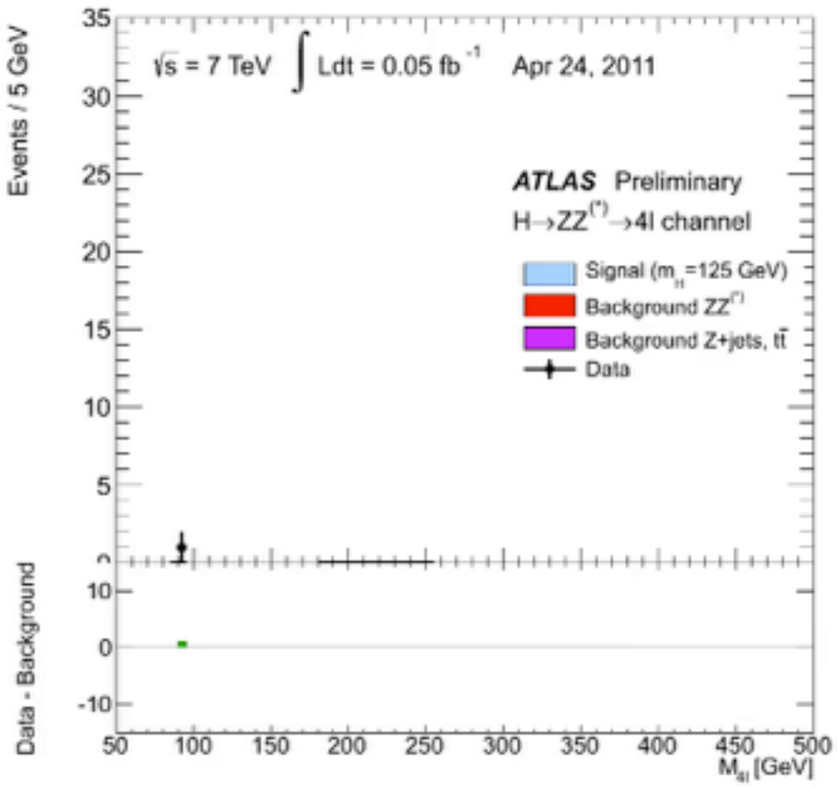
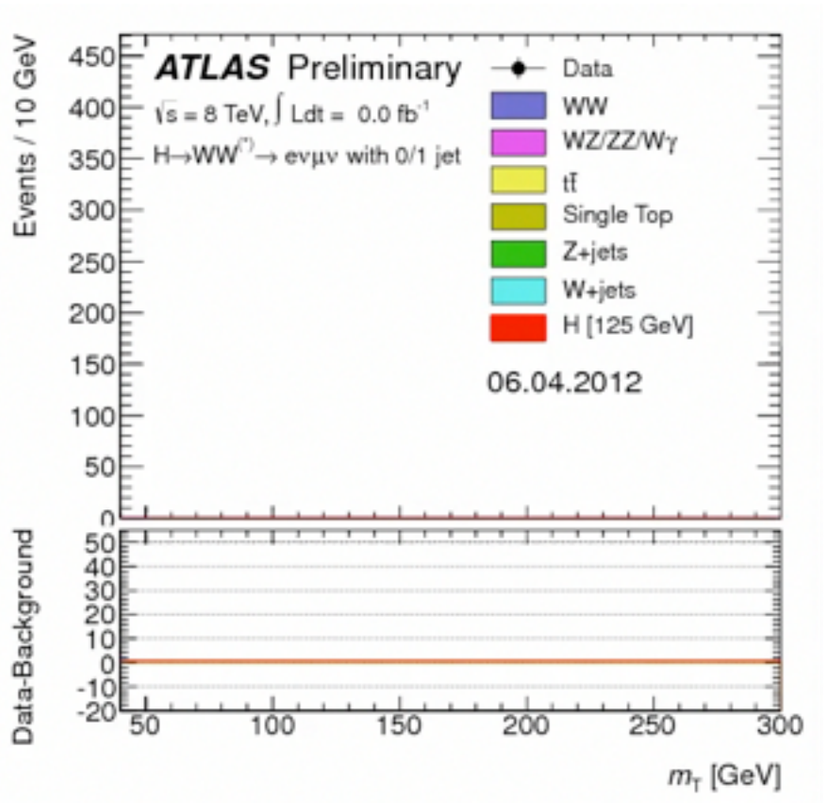
- Bottom
  - Results with full 2015 dataset
- Higgs
- Exotics
- SUSY
- HI

Higgs

Higgs Search





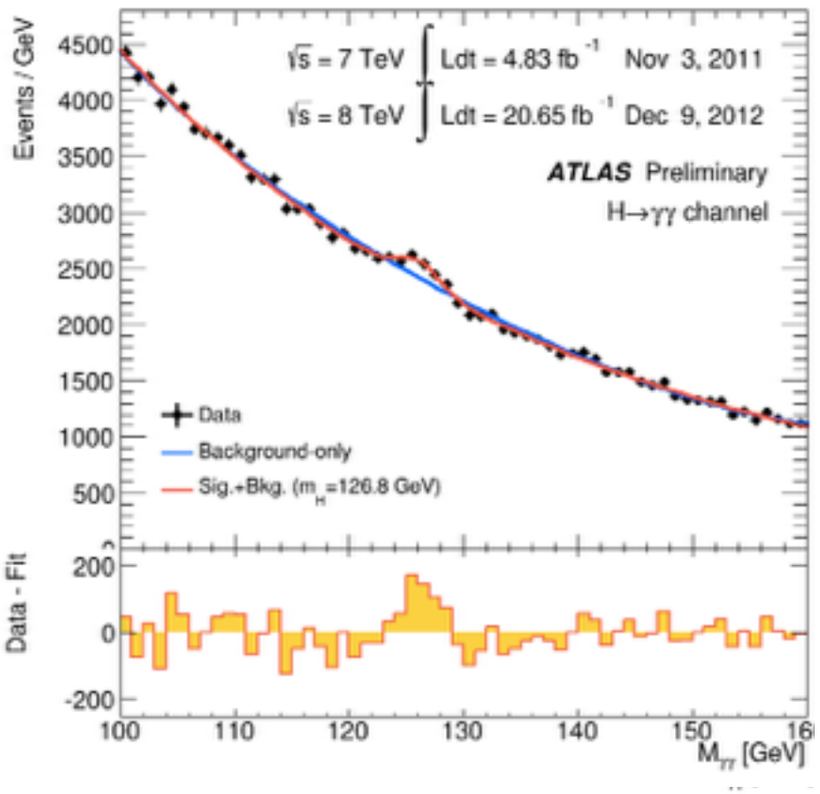


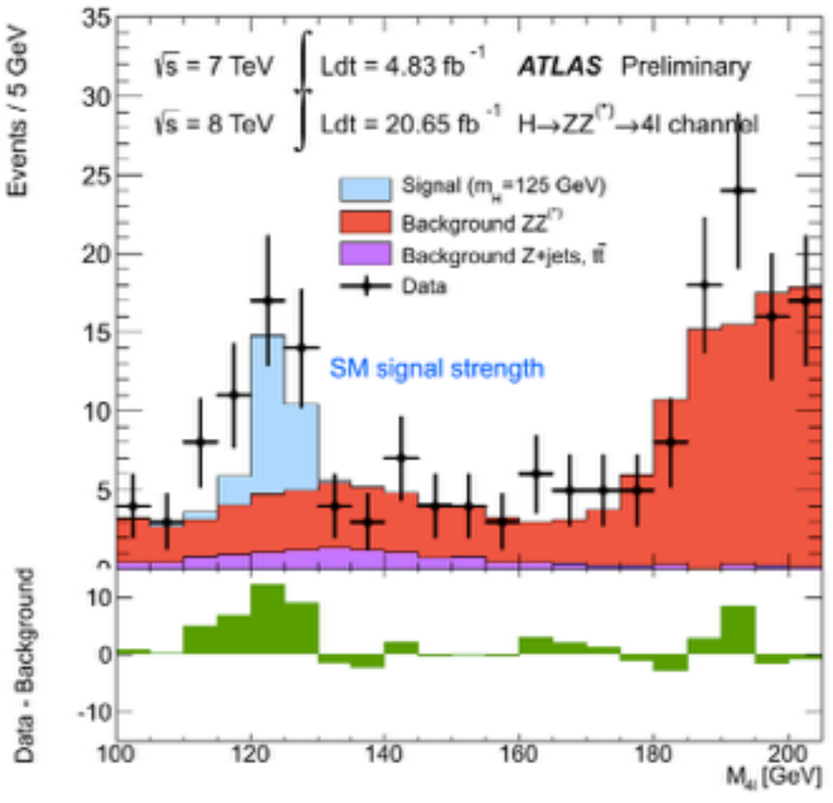
CERN-PH-EP/2014-001
2014/01/21

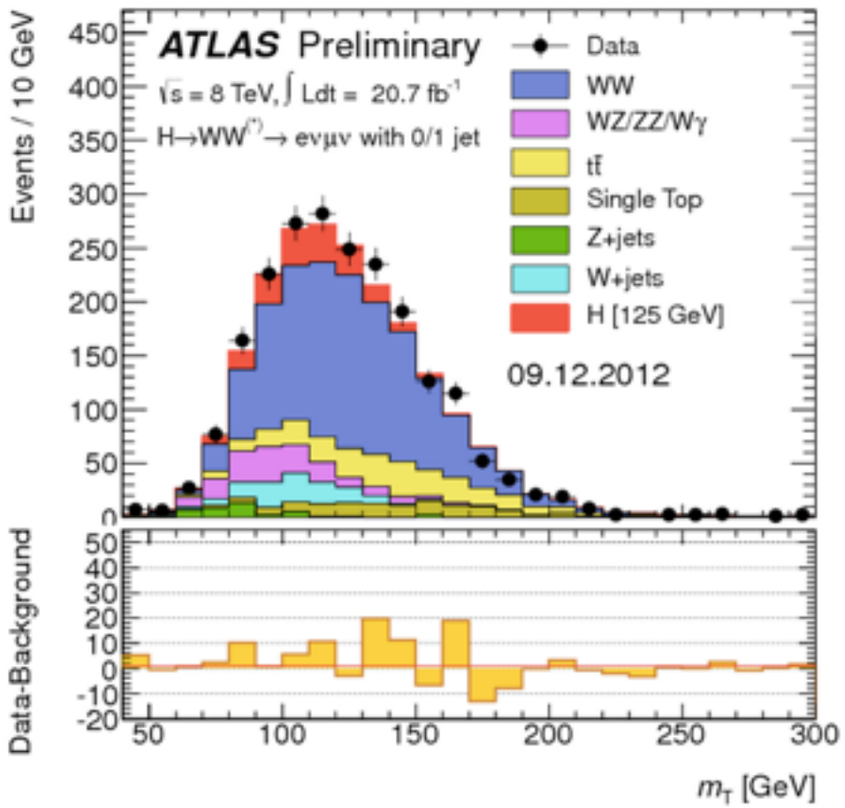
CMS-HIG-13-004

Evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons

Higgs Search







	ATLAS		CMS	
	Observed	Expected	Observed	Expected
ZZ	6.6	4.4	6.8	6.7
γγ	7.4	4.3	3.2	4.2
WW	3.8	3.8	4.3	5.8
ττ	4.1	3.2	3.4	3.6
bb	1.	1.5	2.1	2.2

CMS-HIG-13-004

CERN-PH-EP/2014-001
2014/01/21

Evidence for the 125 GeV Higgs boson decaying to a pair of τ leptons

3.8 σ combined

Discovery was just the beginning

- After the discovery in the ZZ, WW, gamma gamma
- Run-1 provided precision measurements of mass, couplings
- The particle found to be consistent with $J^{PC}=0^{++}$
- Evidence for coupling to fermions (taus..)
- Study top Yukawa couplings with ttH channels
- Rich program of search for yet unseen channels
- Search for BSM with the Higgs as a portal

Discovery was just the beginning

- Precision measurements
  - Mass, width
  - Couplings
  - Quantum numbers (spin, CP)
  - Differential cross sections
  - Off shell couplings and width
- Rare decays search
  - Z gamma
  - Muons
  - LFV tau-mu, tau-e
  - j/psi, ZY …
- Is is just minimal SM ?
  - 2HDM, MSSM, NMSSM
  - Doubly charged..
- Portal for new physics
  - DM
  - hidden sector
  - BSM including H^0 (ZH^0, WH^0,H^0H^0)
  - Off shell couplings and width
- Additional new Physics
  - FCNC top decays
  - di-Higgs
  - trilinear coupling
- And more
  - …

Higgs plans for Run-2

- ATLAS & CMS currently combine the 8 TeV analyses.
- Systematics attempt to improve knowledge of trigger and detector effects
- A scalar was discovered … need to measure everything that is measurable:
  - Precision Higgs physics (mass, width, μ, coupling optimisation, CP mixing..)
  - Search for signatures we haven't seen (μμ..)
- Run extensive BSM search program
  - Look for additional scalars
  - Cover wide range of final states and a large parameter space in coordination with the other BSM groups.
  - Various possible extensions of SM (Additional EWS-> heavy SM-like CP-even H, 2HDM-> 5 Higgses (.. charged..)
  - Constraints from the observed state (mass, coupling, CP)
- Higher mass reach
  - Overlapping with other BSM studies

Higgs BSM program

High mass 2HDM, MSSM

- H to yy
- H to WW to lvlv
- H to WW to lvqq
- H to ZZ to 4l
- H to ZZ to llvv
- H to ZZ to llqq
- H to ZZ to vvbb
- (b)tau tau (leplep, lephad, hadhad)
- (b)bb
- (b)mumu
- very high mass tautau

NMSSM

- a to mumu
- 2a to 4y (multiphoton)
- 2a to 4taus
- (bb)a to (bb)tautau to (bb)emu
- 2a to tautaumumu
- H+ to aW

Heavy Higgs decays

- Zh to lltautau (leplep, lephad, hadhad)
- Zh to (ll/vv)bb
- hh to yybb
- hh to 4b
- hh to bbtautau
- hh to yyVV to yy4j
- top pair
- Doubly charged Higgs

LFV

- tau mu
- tau e
- e mu

Charged Higgs

- taunu+jets
- taunu+lep
- tb
- cs
- AW
- Wh
- WZ to (lvqq, qqll)
- very high mass tb (allhad, lep+jets)
- H+ to Wgamma

Other BSM

- mono photon
- mono Higgs
- Cascade decays H to H+W to hWW to bbWW

Invisible Higgs decays

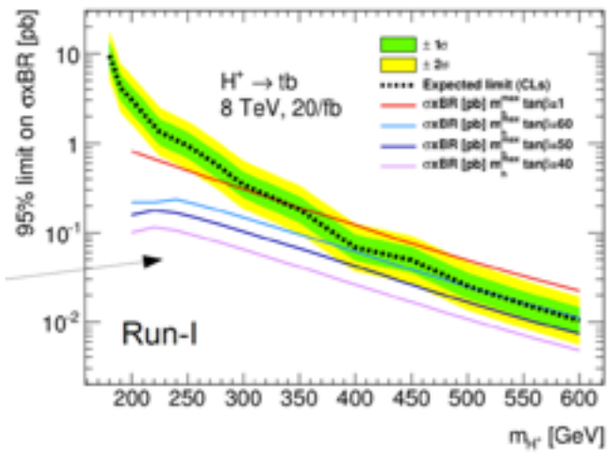
- Mono jet.
- ZH to (ll)inv
- VBF H to inv
- VH to (jj)inv
- Mono-W analysis substructure

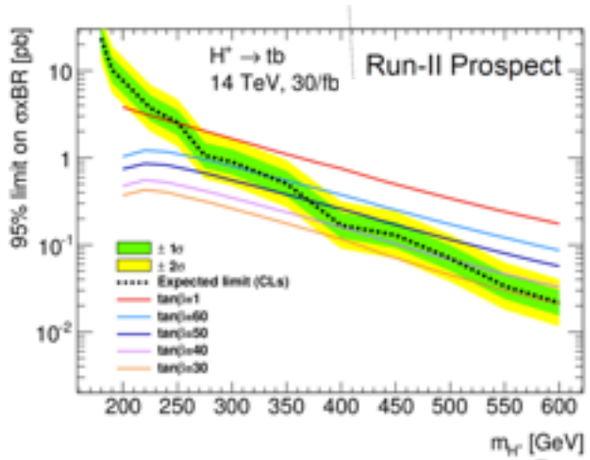
Exotic Higgs

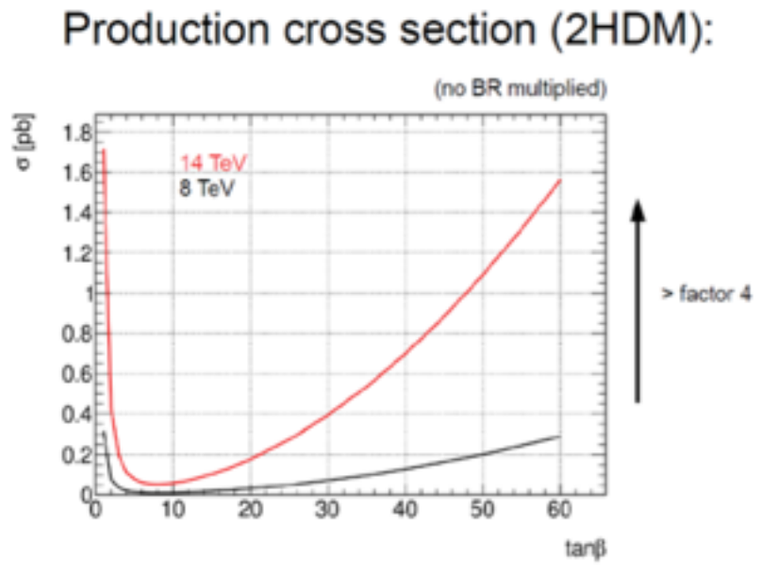
- Hidden valley pions
- Dark Z, H to ZdZ(d) to 4l

BSM Higgs prospective

Charged Higgs -> tb







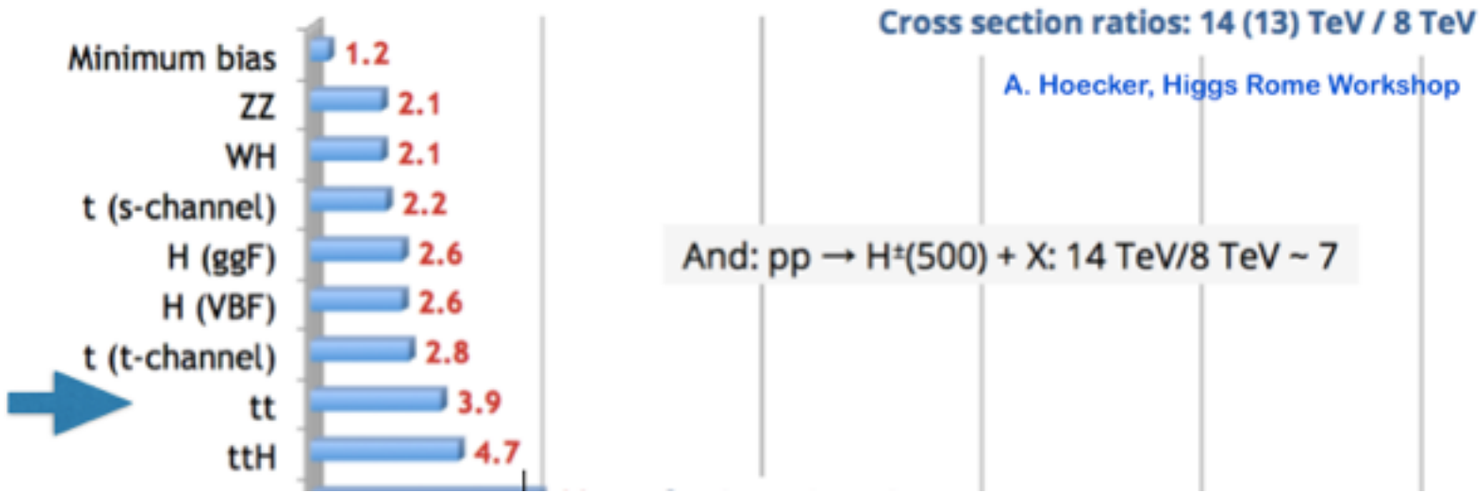
Systematically dominated, now exclude tan β = 60 may reach tan β = 30 @ high mass, small gain from 300 fb-1

First year (summer, Moriond..)

- **50 ns run will be useful to start understanding the detector**
- **Most measurements: meaningful results (competitive with run-1) will require full 2015 dataset**
- **Searches, with larger increase in cross section of heavy states could target summer (1-3/fb). However some new searches require time to develop, understand conditions**
- **LHC will be required to show that Higgses are accumulated between summer and Moriond timescale…**

Higgs preparations

- Some techniques and tools can benefit from better detector understanding: trigger (b-jet trigger), UE modelling, Jets and mainly b-jet, boosted top jets
- 8 TeV-> 13 TeV changes S/B. Improve channels
- like $\sigma(ttH)_{14TeV} \sim 5\sigma(ttH)_{8TeV}$, VBF, but increase top BG.
- Some channels will very soon switch from search mode to precision measurement (ttH) - exciting !



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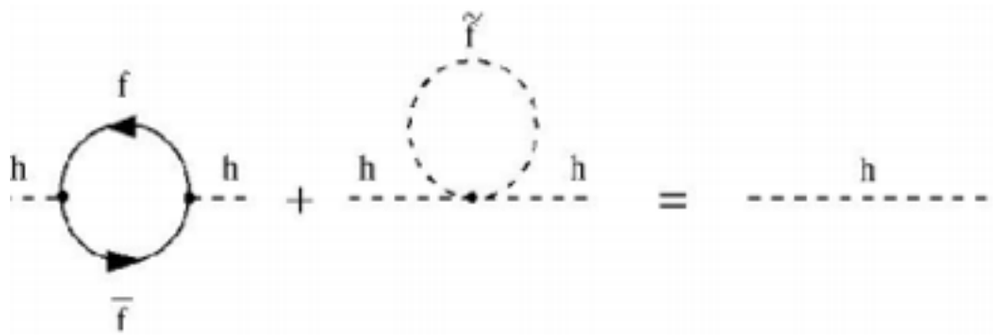
- Bottom
  - Results with full 2015 dataset
- Higgs
  - Confirmation of $\gamma\gamma$ and ZZ peaks in summer 2015? ("Higgs rediscovery"). Early Higgs cross section measurements @ 13 TeV with $\gamma\gamma$ and ZZ. Other SM channels will be more challenging. Priority for ttH, end of 2015? also high mass NSM Higgs searches, expect results at 2015? With full dataset: new results for all channels and in combination with run-1; results on BSM Higgs.
- Exotics
- SUSY
- HI

Searches:

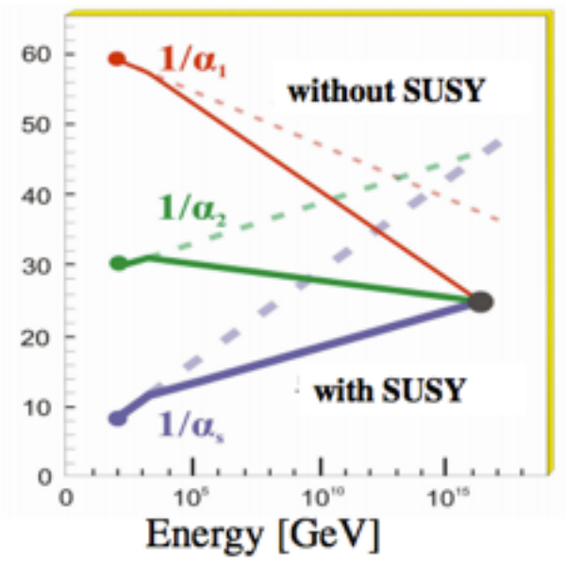
SUSY, Exotics

TeV scale SUSY Motivations

- A unique extension of Lorentz symmetry
- SUSY can solve the hierarchy problem (Weak >> gravity) by symmetry cancellations between fermionic and bosonic fields.

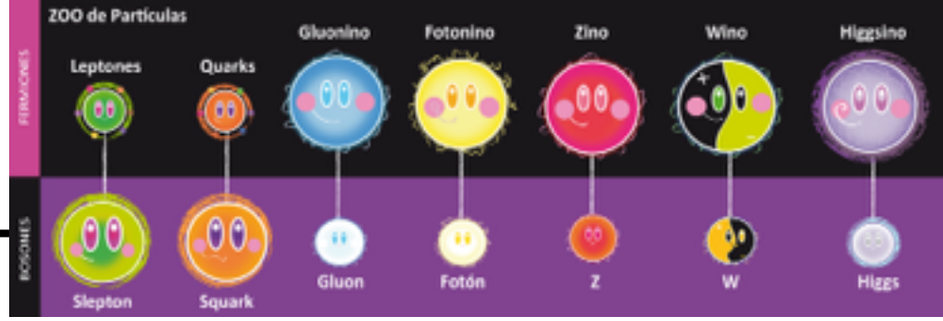


- Models like MSSM calculations result in Gauge coupling unifications.



- R-parity MSSM provide DM candidate.
- Can generate EWSB dynamically.

SUSY - Natural fine tuning solution?



- **MSSM (Weak scale SUSY) every bosonic and fermionic d.o.f gets SUSY d.o.f**
  - **spin 1/2 gaugino for each SM gauge boson**
  - **scalar partner for each fermion helicity so left handed and right handed selectrons ..**
  - **Two complex Higgs doublets cancel triangle anomalies;**
- **$R_{parity} = (-1)^{3(B-L)+2s}$ conservation? (sparticle -1)-> lightest SUSY (LSP) stable (DM candidate)**

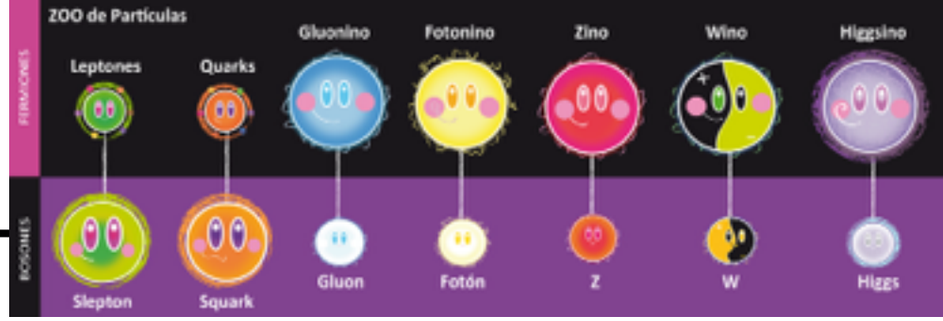
Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	(same) (same) $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	(same) (same) $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$
gluino	1/2	−1	$\tilde{g}$	(same)
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)

Strong SUSY

Weak SUSY

Strong SUSY

SUSY - Natural fine tuning solution?



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Missing :

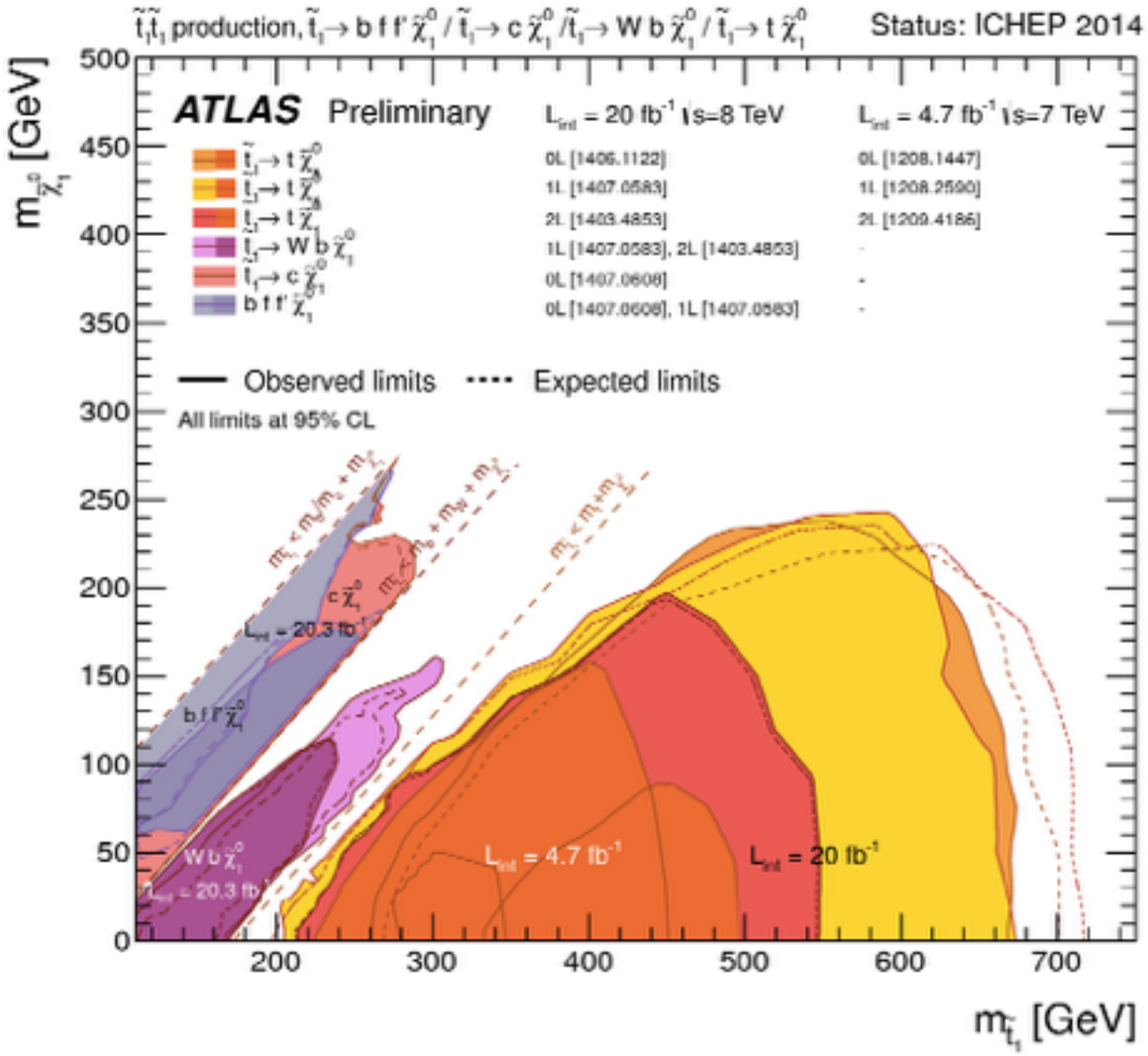
29 sparticles and

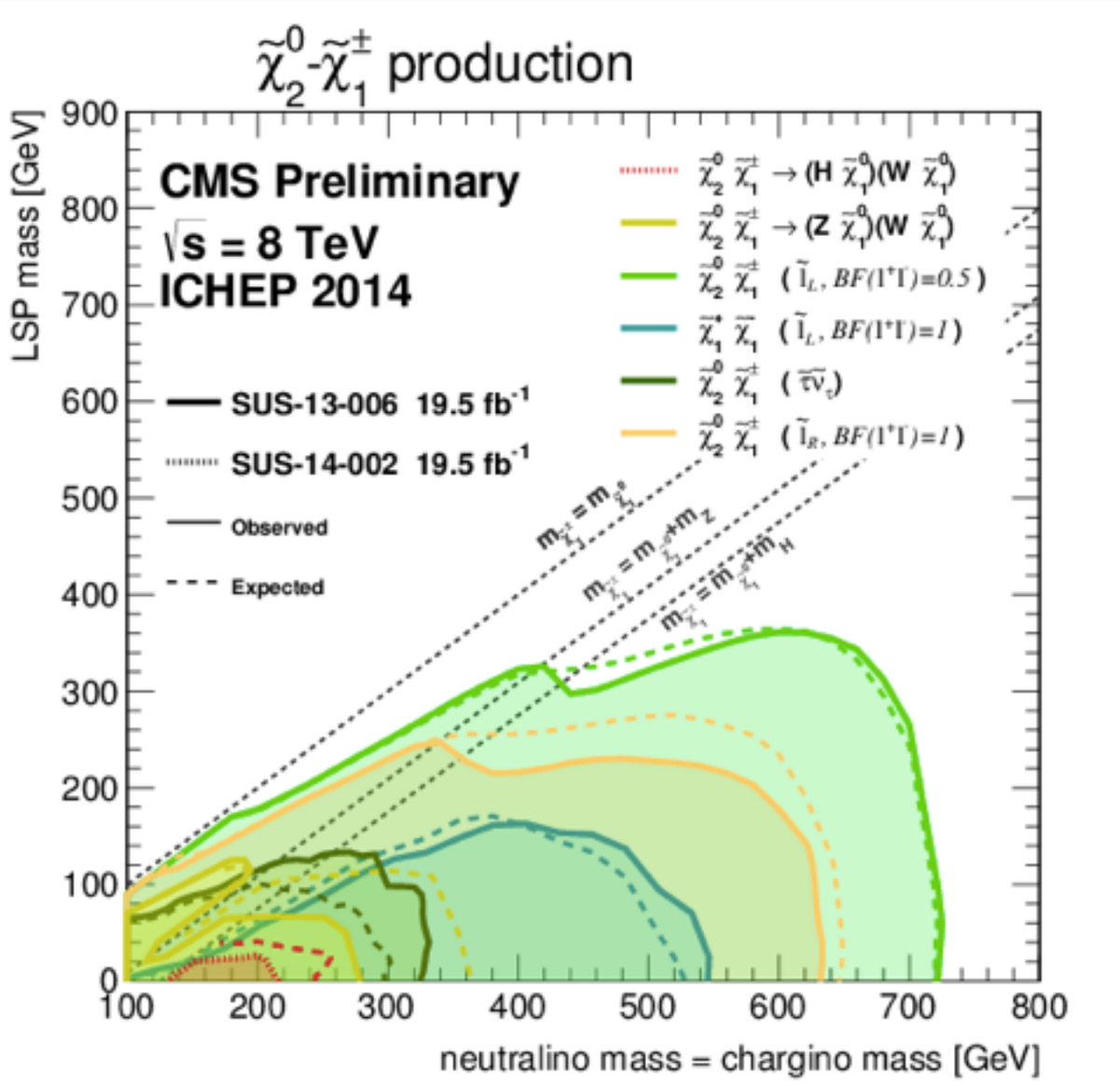
4 undicovered Higgs

Last seen ···?

Names	Spin	P_R	Gauge Eigenstates	Mass Eigenstates	
Higgs bosons	0	+1	$H_u^0\ H_d^0\ H_u^+\ H_d^-$	$h^0\ H^0\ A^0\ H^\pm$	
squarks	0	−1	$\tilde{u}_L\ \tilde{u}_R\ \tilde{d}_L\ \tilde{d}_R$ $\tilde{s}_L\ \tilde{s}_R\ \tilde{c}_L\ \tilde{c}_R$ $\tilde{t}_L\ \tilde{t}_R\ \tilde{b}_L\ \tilde{b}_R$	(same) (same) $\tilde{t}_1\ \tilde{t}_2\ \tilde{b}_1\ \tilde{b}_2$	Strong SUSY
sleptons	0	−1	$\tilde{e}_L\ \tilde{e}_R\ \tilde{\nu}_e$ $\tilde{\mu}_L\ \tilde{\mu}_R\ \tilde{\nu}_\mu$ $\tilde{\tau}_L\ \tilde{\tau}_R\ \tilde{\nu}_\tau$	(same) (same) $\tilde{\tau}_1\ \tilde{\tau}_2\ \tilde{\nu}_\tau$	Weak SUSY
neutralinos	1/2	−1	$\tilde{B}^0\ \tilde{W}^0\ \tilde{H}_u^0\ \tilde{H}_d^0$	$\tilde{N}_1\ \tilde{N}_2\ \tilde{N}_3\ \tilde{N}_4$	
charginos	1/2	−1	$\tilde{W}^\pm\ \tilde{H}_u^+\ \tilde{H}_d^-$	$\tilde{C}_1^\pm\ \tilde{C}_2^\pm$	
gluino	1/2	−1	$\tilde{g}$	(same)	Strong SUSY
goldstino (gravitino)	1/2 (3/2)	−1	$\tilde{G}$	(same)	

Some SUSY exclusion in Run-1





ATLAS SUSY Searches* - 95% CL Lower Limits

Status: ICHEP 2014

ATLAS Preliminary

$\sqrt{s}$ = 7, 8 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0	2-6 jets	Yes	20.3	$\tilde{q}, \tilde{g}$ 1.7 TeV	$m(\tilde{q})=m(\tilde{g})$	1405.7875
	MSUGRA/CMSSM	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.2 TeV	any $m(\tilde{q})$	ATLAS-CONF-2013-062
	MSUGRA/CMSSM	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	any $m(\tilde{q})$	1308.1841
	$\tilde{q}\tilde{q}, \tilde{q}\to q\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{q}$ 850 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(1^{st}$ gen. $\tilde{q})=m(2^{nd}$ gen. $\tilde{q})$	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to q\bar{q}\tilde{\chi}_1^0$	0	2-6 jets	Yes	20.3	$\tilde{g}$ 1.33 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	1405.7875
	$\tilde{g}\tilde{g}, \tilde{g}\to qq\tilde{\chi}_1^\pm\to qqW^\pm\tilde{\chi}_1^0$	1 e,μ	3-6 jets	Yes	20.3	$\tilde{g}$ 1.18 TeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}^*)=0.5(m(\tilde{\chi}_1^0)+m(\tilde{g}))$	ATLAS-CONF-2013-062
	$\tilde{g}\tilde{g}, \tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}_1^0$	2 e,μ	0-3 jets	-	20.3	$\tilde{g}$ 1.12 TeV	$m(\tilde{\chi}_1^0)$=0 GeV	ATLAS-CONF-2013-089
	GMSB ($\tilde{\ell}$ NLSP)	2 e,μ	2-4 jets	Yes	4.7	$\tilde{g}$ 1.24 TeV	tanβ<15	1208.4688
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.6 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.28 TeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2014-001
	GGM (wino NLSP)	1 e,μ + γ	-	Yes	4.8	$\tilde{g}$ 619 GeV	$m(\tilde{\chi}_1^0)$>50 GeV	ATLAS-CONF-2012-144
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	4.8	$\tilde{g}$ 900 GeV	$m(\tilde{\chi}_1^0)$>220 GeV	1211.1167
	GGM (higgsino NLSP)	2 e,μ (Z)	0-3 jets	Yes	5.8	$\tilde{g}$ 690 GeV	m(NLSP)>200 GeV	ATLAS-CONF-2012-152
	Gravitino LSP	0	mono-jet	Yes	10.5	$F^{1/2}$ scale 645 GeV	$m(\tilde{G})>10^{-4}$ eV	ATLAS-CONF-2012-147
3rd gen. $\tilde{g}$ med.	$\tilde{g}\to b\bar{b}\tilde{\chi}_1^0$	0	3 b	Yes	20.1	$\tilde{g}$ 1.25 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0	7-10 jets	Yes	20.3	$\tilde{g}$ 1.1 TeV	$m(\tilde{\chi}_1^0)$ <350 GeV	1308.1841
	$\tilde{g}\to t\bar{t}\tilde{\chi}_1^0$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.34 TeV	$m(\tilde{\chi}_1^0)$<400 GeV	1407.0600
	$\tilde{g}\to b\bar{t}\tilde{\chi}_1^+$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.3 TeV	$m(\tilde{\chi}_1^0)$<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to b\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{b}_1$ 100-620 GeV	$m(\tilde{\chi}_1^0)$<90 GeV	1308.2631
	$\tilde{b}_1\tilde{b}_1, \tilde{b}_1\to t\tilde{\chi}_1^-$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{b}_1$ 275-440 GeV	$m(\tilde{\chi}_1^\pm)$=2 $m(\tilde{\chi}_1^0)$	1404.2500
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	1-2 e,μ	1-2 b	Yes	4.7	$\tilde{t}_1$ 110-167 GeV	$m(\tilde{\chi}_1^0)$=55 GeV	1208.4305, 1209.2102
	$\tilde{t}_1\tilde{t}_1$(light), $\tilde{t}_1\to Wb\tilde{\chi}_1^0$	2 e,μ	0-2 jets	Yes	20.3	$\tilde{t}_1$ 130-210 GeV	$m(\tilde{\chi}_1^0)$ =m($\tilde{t}_1$)-m(W)-50 GeV, m($\tilde{t}_1$)<<m($\tilde{\chi}_1^+$)	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to t\tilde{\chi}_1^0$	2 e,μ	2 jets	Yes	20.3	$\tilde{t}_1$ 215-530 GeV	$m(\tilde{\chi}_1^0)$=1 GeV	1403.4853
	$\tilde{t}_1\tilde{t}_1$(medium), $\tilde{t}_1\to b\tilde{\chi}_1^\pm$	0	2 b	Yes	20.1	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$<200 GeV, $m(\tilde{\chi}_1^+)$-$m(\tilde{\chi}_1^0)$=5 GeV	1308.2631
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	1 e,μ	1 b	Yes	20	$\tilde{t}_1$ 210-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1407.0583
	$\tilde{t}_1\tilde{t}_1$(heavy), $\tilde{t}_1\to t\tilde{\chi}_1^0$	0	2 b	Yes	20.1	$\tilde{t}_1$ 260-640 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1406.1122
	$\tilde{t}_1\tilde{t}_1, \tilde{t}_1\to c\tilde{\chi}_1^0$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-240 GeV	$m(\tilde{t}_1)$-$m(\tilde{\chi}_1^0)$<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-580 GeV	$m(\tilde{\chi}_1^0)$>150 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2, \tilde{t}_2\to\tilde{t}_1+Z$	3 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_2$ 290-600 GeV	$m(\tilde{\chi}_1^0)$<200 GeV	1403.5222
EW direct	$\tilde{\ell}_{1,R}\tilde{\ell}_{1,R}, \tilde{\ell}\to\ell\tilde{\chi}_1^0$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-325 GeV	$m(\tilde{\chi}_1^0)$=0 GeV	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\ell}\nu(\ell\tilde{\nu})$	2 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm$ 140-465 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1403.5294
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 100-350 GeV	$m(\tilde{\chi}_1^0)$=0 GeV, $m(\tilde{\tau},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1407.0350
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to\tilde{\ell}_{1,L}\nu\tilde{\ell}_{1,L}\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_{1,L}\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 700 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_1^\pm)+m(\tilde{\chi}_1^0))$	1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$	2-3 e,μ	0	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 420 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}_1^\pm\tilde{\chi}_2^0\to W\tilde{\chi}_1^0 h\tilde{\chi}_1^0$	1 e,μ	2 b	Yes	20.3	$\tilde{\chi}_1^\pm,\tilde{\chi}_2^0$ 285 GeV	$m(\tilde{\chi}_1^\pm)=m(\tilde{\chi}_2^0)$, $m(\tilde{\chi}_1^0)$=0, sleptons decoupled	ATLAS-CONF-2013-093
	$\tilde{\chi}_2^0\tilde{\chi}_3^0, \tilde{\chi}_{2,3}^0\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}_{2,3}^0$ 620 GeV	$m(\tilde{\chi}_2^0)=m(\tilde{\chi}_3^0)$, $m(\tilde{\chi}_1^0)$=0, $m(\tilde{\ell},\tilde{\nu})=0.5(m(\tilde{\chi}_2^0)+m(\tilde{\chi}_1^0))$	1405.5086
Long-lived particles	Direct $\tilde{\chi}_1^+\tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^\pm$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}_1^\pm$ 270 GeV	$m(\tilde{\chi}_1^\pm)$-$m(\tilde{\chi}_1^0)$=160 MeV, $\tau(\tilde{\chi}_1^\pm)$=0.2 ns	ATLAS-CONF-2013-069
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 832 GeV	$m(\tilde{\chi}_1^0)$=100 GeV, 10 μs<$\tau(\tilde{g})$<1000 s	1310.6584
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}_1^0\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	15.9	$\tilde{\chi}_1^0$ 475 GeV	10<tanβ<50	ATLAS-CONF-2013-058
	GMSB, $\tilde{\chi}_1^0\to\gamma\tilde{G}$, long-lived $\tilde{\chi}_1^0$	2 γ	-	Yes	4.7	$\tilde{\chi}_1^0$ 230 GeV	0.4<$\tau(\tilde{\chi}_1^0)$<2 ns	1304.6310
	$\tilde{q}\tilde{q}, \tilde{\chi}_1^0\to qq\mu$ (RPV)	1 μ, displ. vtx	-	-	20.3	$\tilde{q}$ 1.0 TeV	1.5 <$c\tau$<156 mm, BR(μ)=1, $m(\tilde{\chi}_1^0)$=108 GeV	ATLAS-CONF-2013-092
RPV	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e+\mu$	2 e,μ	-	-	4.6	$\tilde{\nu}_\tau$ 1.61 TeV	λ'_{311}=0.10, λ_{132}=0.05	1212.1272
	LFV $pp\to\tilde{\nu}_\tau+X, \tilde{\nu}_\tau\to e(\mu)+\tau$	1 $e,\mu+\tau$	-	-	4.6	$\tilde{\nu}_\tau$ 1.1 TeV	λ'_{311}=0.10, $\lambda_{1(2)33}$=0.05	1212.1272
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.35 TeV	$m(\tilde{q})=m(\tilde{g})$, $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 750 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^\pm)$, $\lambda_{121}\neq0$	1405.5086
	$\tilde{\chi}_1^+\tilde{\chi}_1^-, \tilde{\chi}_1^+\to W\tilde{\chi}_1^0, \tilde{\chi}_1^0\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 $e,\mu+\tau$	-	Yes	20.3	$\tilde{\chi}_1^\pm$ 450 GeV	$m(\tilde{\chi}_1^0)$>0.2×$m(\tilde{\chi}_1^\pm)$, $\lambda_{133}\neq0$	1405.5086
	$\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 916 GeV	BR(t)=BR(b)=BR(c)=0%	ATLAS-CONF-2013-091
	$\tilde{g}\to\tilde{t}_1 t, \tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 850 GeV		1404.250
Other	Scalar gluon pair, sgluon$\to q\bar{q}$	0	4 jets	-	4.6	sgluon 100-287 GeV	incl. limit from 1110.2693	1210.4826
	Scalar gluon pair, sgluon$\to t\bar{t}$	2 e,μ (SS)	2 b	Yes	14.3	sgluon 350-800 GeV		ATLAS-CONF-2013-051
	WIMP interaction (D5, Dirac χ)	0	mono-jet	Yes	10.5	M* scale 704 GeV	$m(\chi)$<80 GeV, limit of<687 GeV for D8	ATLAS-CONF-2012-147

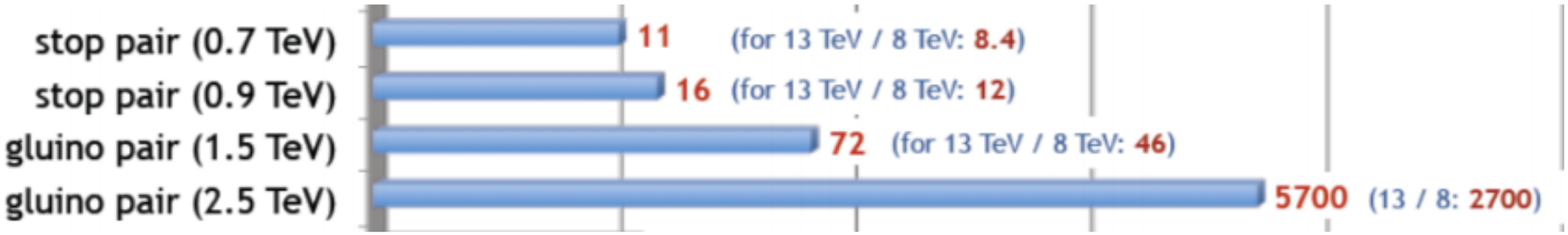
$\sqrt{s}$ = 7 TeV full data | $\sqrt{s}$ = 8 TeV partial data | $\sqrt{s}$ = 8 TeV full data

10^{-1} 1

Mass scale [TeV]

**Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.*

SUSY preparations



3rd generation

- Motivated by naturalness (cancel 1 loop top to Higgs mass)
- sbottom and stop - May exceed 8 TeV with the first 5/fb !

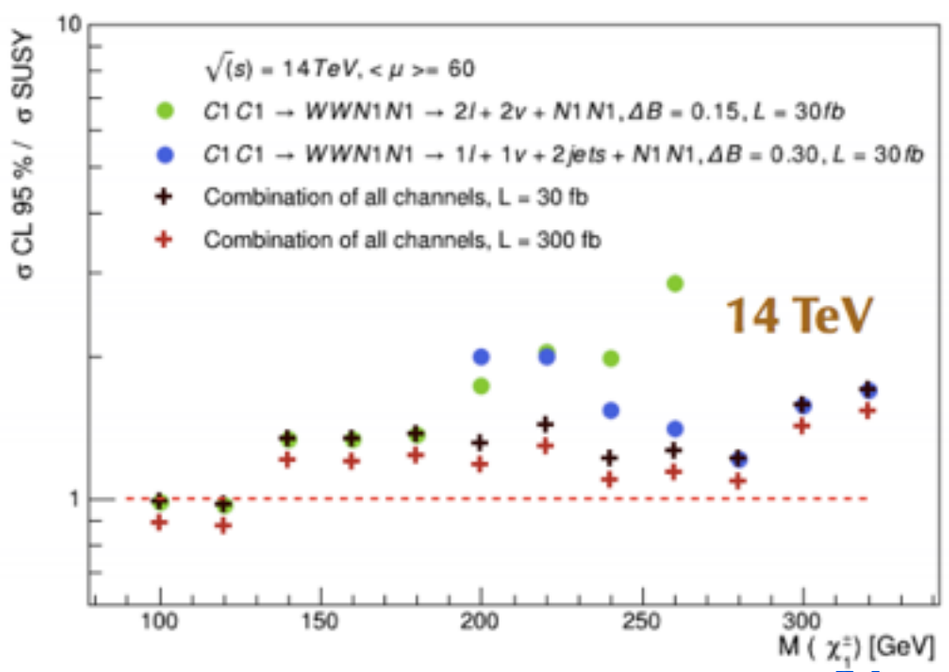
EWK Production (Chargino & Neutralino)

complementary to DM search

RPVLLP

- Require complex dedicated techniques

prel. prospect for chargino searches

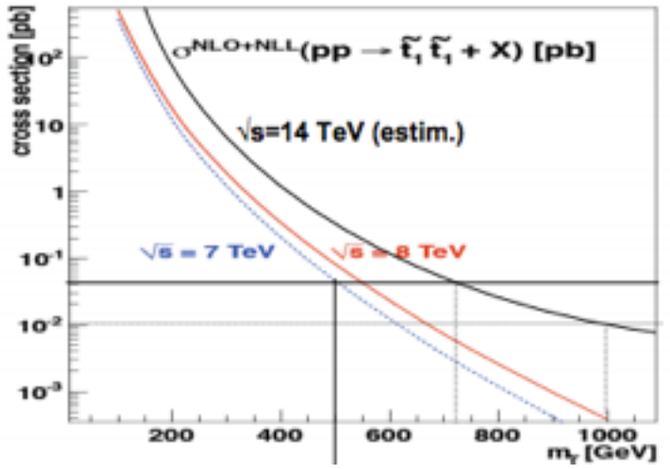


SUSY prospects

- Data analysed so far shows no hint for weak scale SUSY partners.
- Going from 8 to 14 TeV or adding 10 times more data increase the reach for squarks / gluino masses by 100 GeV

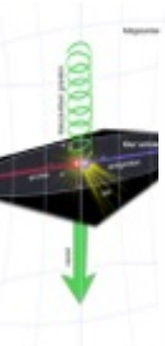
Limits for LSP mass

- Aided by the discovery of a Higgs boson, focus of the experimental search strategy and corresponding interpretation moves towards "Natural SUSY" scenarios:
  - Expect to see dedicated 3rd generation searches
  - Electroweak studies towards Higginos (with Higgs in the final state)



- Weak scale SUSY is still a natural extension to SM
- However various options, cross section might be low
- RPV might be the right (though complicated …LLP) route.
- As there still no hint could be .. wrong… SPLIT SUSY (~~natural~~) or even ~~SUSY~~

(partial) List of Exotic Models



Extra dimensions:

- RS Kaluza Klein (KK) Graviton (dibosons, dileptons, diphotons)
- RS KK gluons (top antitop)
- ADD (monojets, monophotons, dileptons, diphotons)
- KK Z/gamma boosns (dileptons)

Grand Unification (GUT) symmetries

- (dielectons, dimuons, ditaus)
- Leptophobic topcolor Z' boson (top antitop to dileptons, l+j, all had)

S8- color octet scalars (dijets)

String resonance (dijets,)

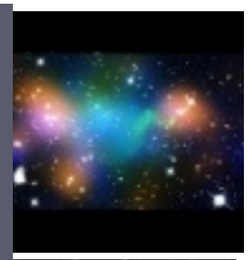
Benchmark Sequential SM (SSM) Z', W'

- W' (lepton+MET, dijets, tb)
- W* (lepton+MET, dijets)

Quantum Black Holes (dijet, l+j)

Black Holes (l+jets, same sign leptons)

Technihadrons (dileptons, dibosons)



Dark Matter

- WIMPs (monojet, monophotons,monoX..)

Excited fermions

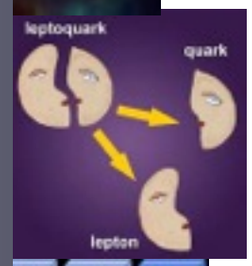
- q*, Excited quarks (dijets, photon+jet)
- l*, excited leptons (dileptons+photon)

Leptoquarks (1st, 2nd, 3rd generations)

higgs -> hidden sector (displaced vertices, lepton jets)

Contact Interaction

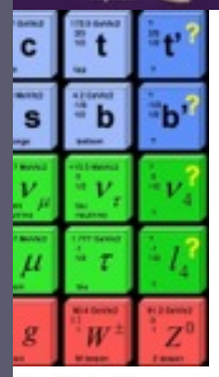
- llqq CI
- 4q CI (dijets)



Doubly charged Higgs (multi leptons, same sign lepton

4th generation

- t'->Wb, t'->ht, b'-Zb, b'->Wt (dileptons, same sign leptons, l+J)



VLQ-Vector Like quarks

Magnetic Monopols (and HIP)

Heavy Majorana neutrino and RH W

Search for heavy resonances

- Strategy
  - Search in tails of the SM distributions (lower m excluded ? hidden by SM "BG"?)
  - S-channel - easy to detect, higher cross section, but high BG
  - Pair production - clearer signal but lower cross section
  - BG estimate - main BG data driven techniques, smaller BG with MC
  - Acceptance and efficiency - model dependent
  - Sometime start with SM cross section measurement
  - Alway start with SEARCH Phase!!
  - Plan B, turn to limits on typical benchmarks
  - and / or "model independent" mass / width limit
  - Blind analyses
- Typical Models
  - QCD like signal
  - EW like signal
  - EWSB

Jet + X

- JETS, thats what we have at LHC, and there is enough of them ..
- Searches for Exotics models involve jets as the most prominent, analysis selection which heavily rely on jets or MET.
- The signatures include: resonances and enhancements in angular distributions in dijets, multijets or photon + jet, single-jet or single-photons
- Exotics model considered are:
  - ED (ADD)
  - DM, (and SUSY signals)
  - TeV-scale gravity
  - Contact Interaction
  - Model independent searches

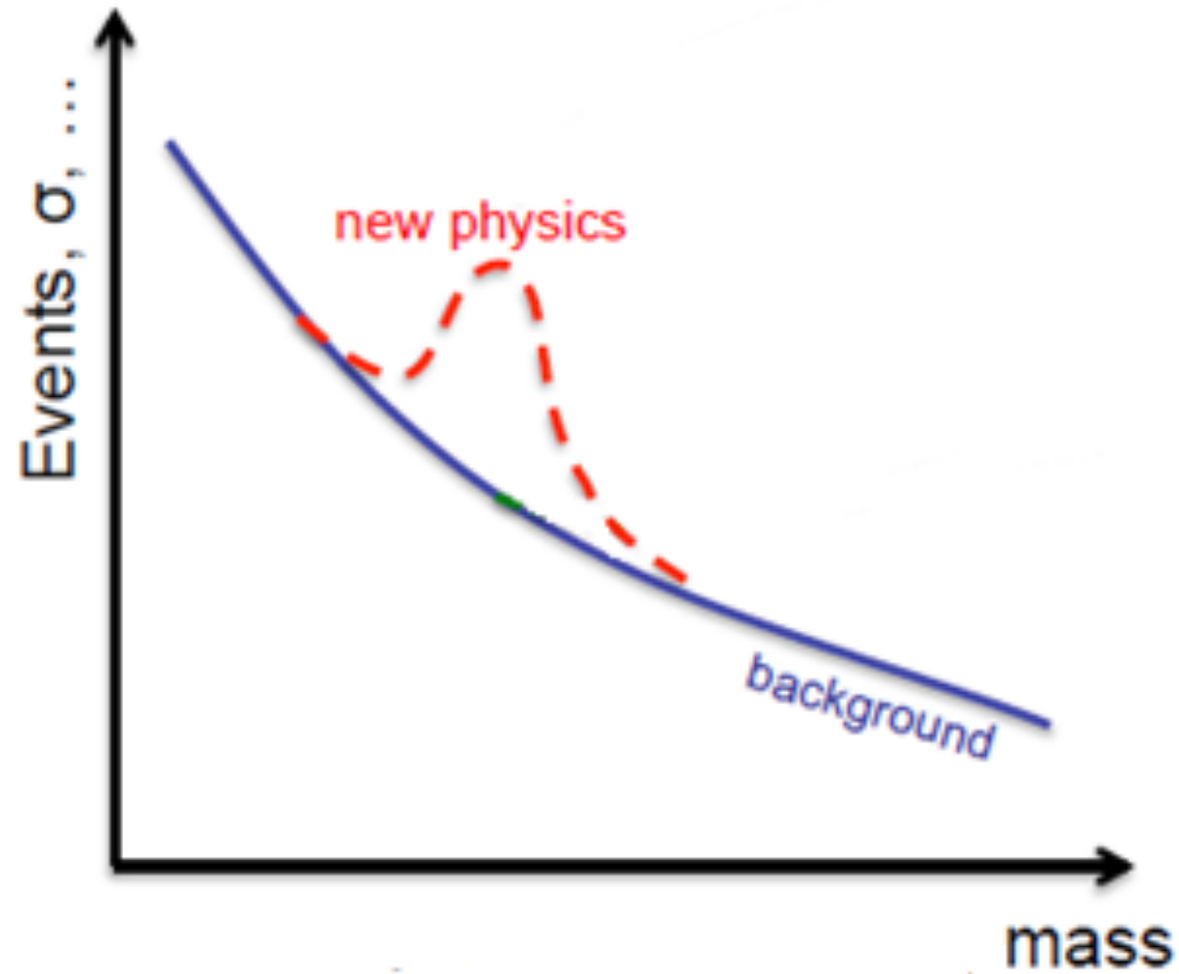
- QCD like signal: (excited quarks, axigluons..) usually couple to jets, the EW background (BG) is small but has irreducible Jets BG calculated at NLO or fit the data in control regions (CR)

Search for heavy resonance: dijets

- Excited quarks, strong gravity, contact interaction
- Larger branching fractions compared to dileptons
- However higher background (QCD rate)
- Looks for resonance above phenomenological fit of

$$f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x}$$

$$x \equiv m_{jj}/\sqrt{s}$$



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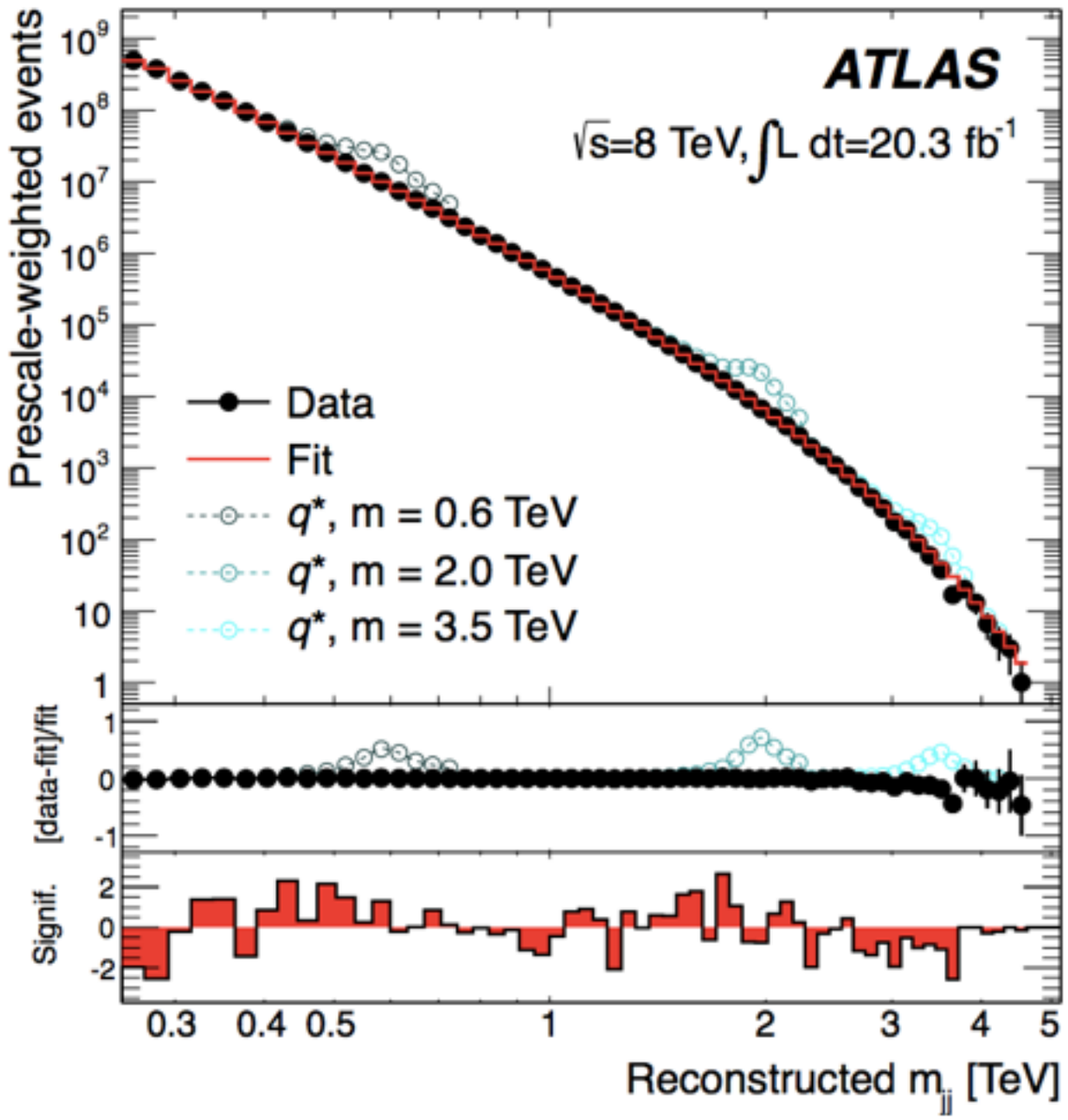
arXiv:1407.2410

20/fb



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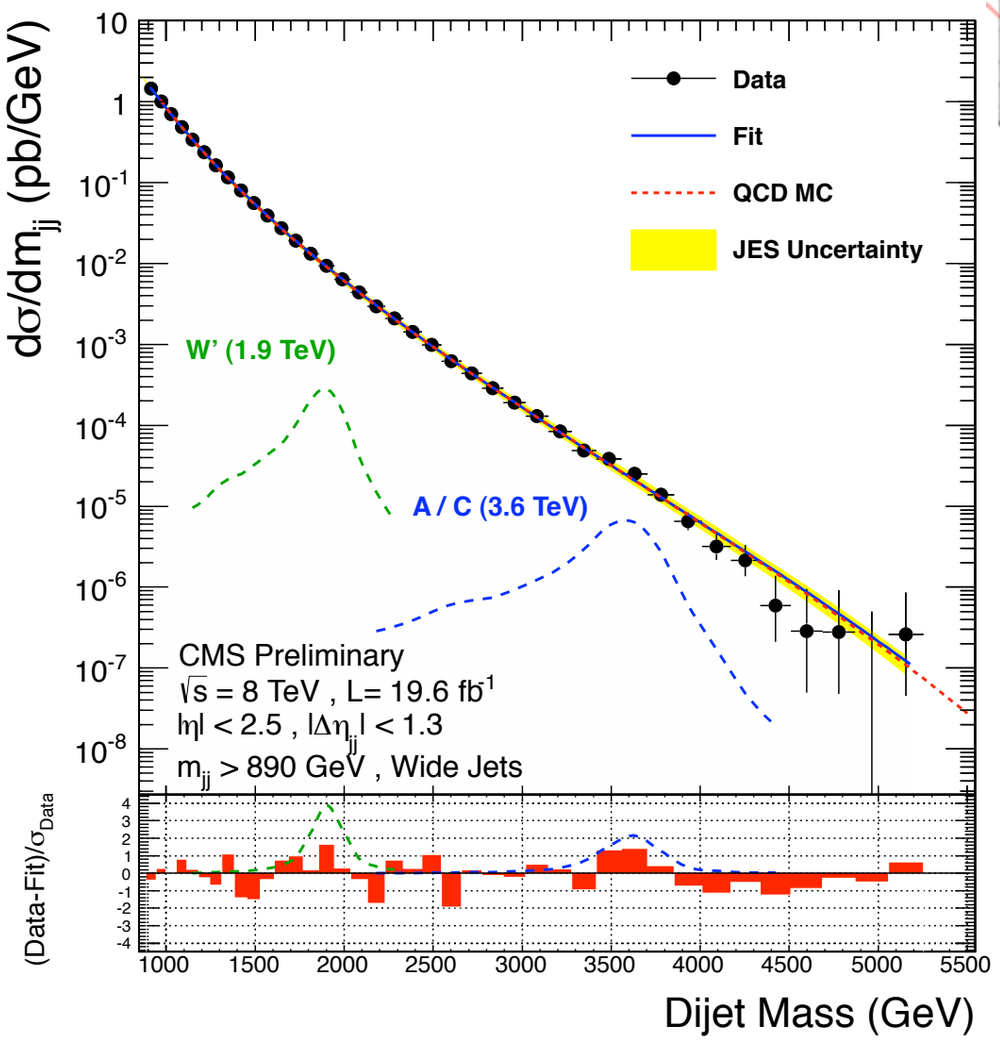
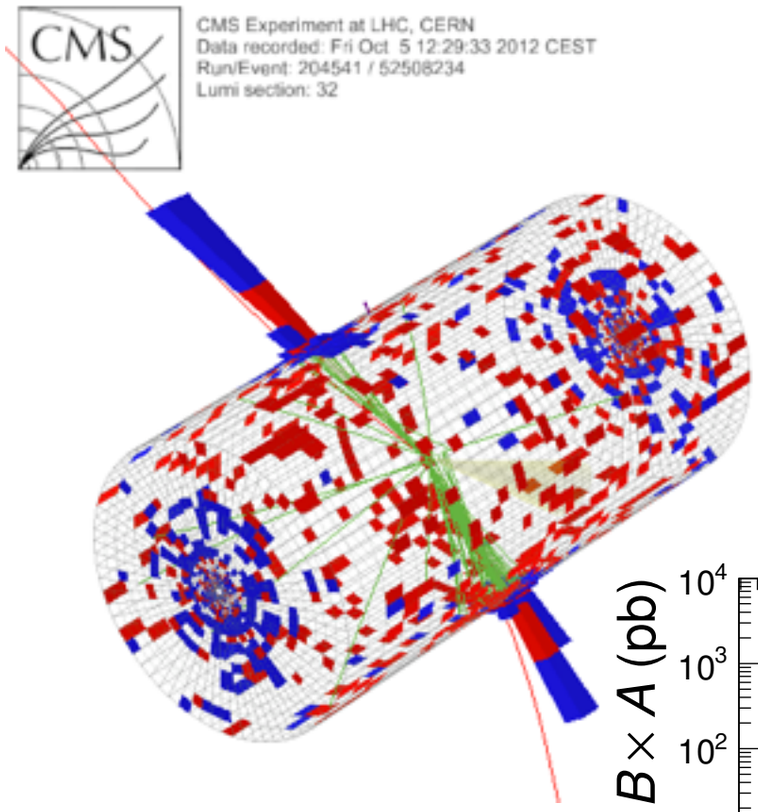
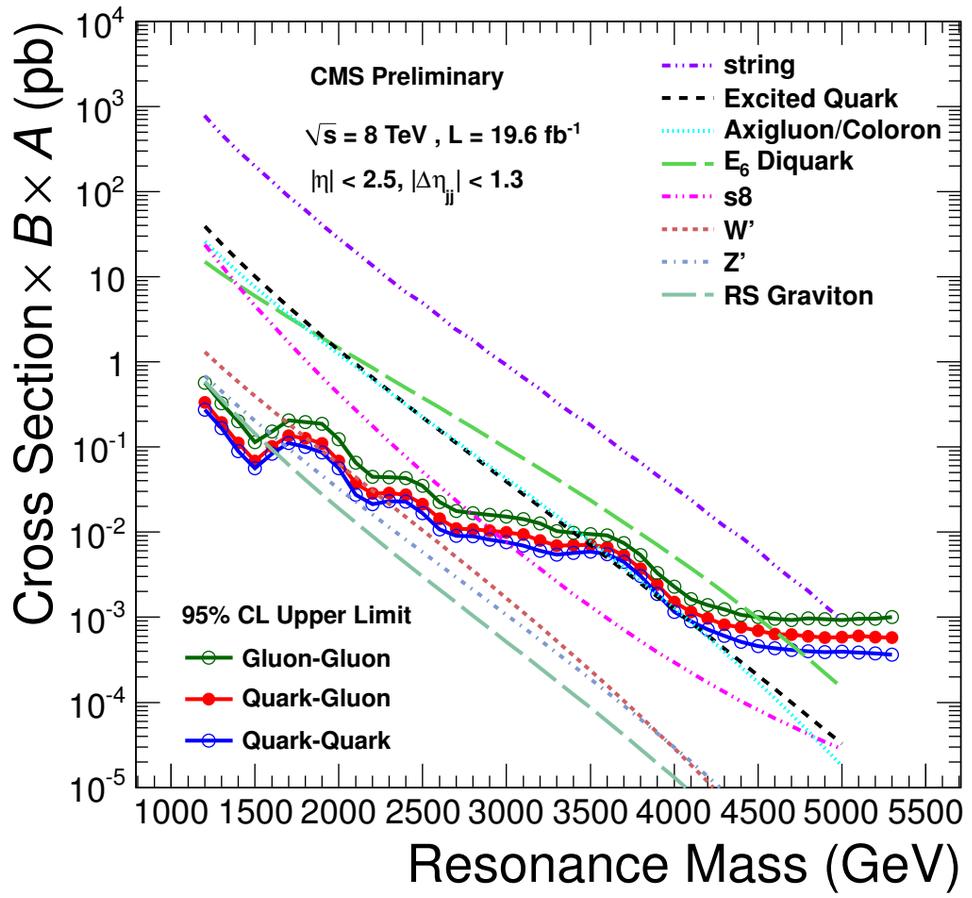




CMS EXO-12-059



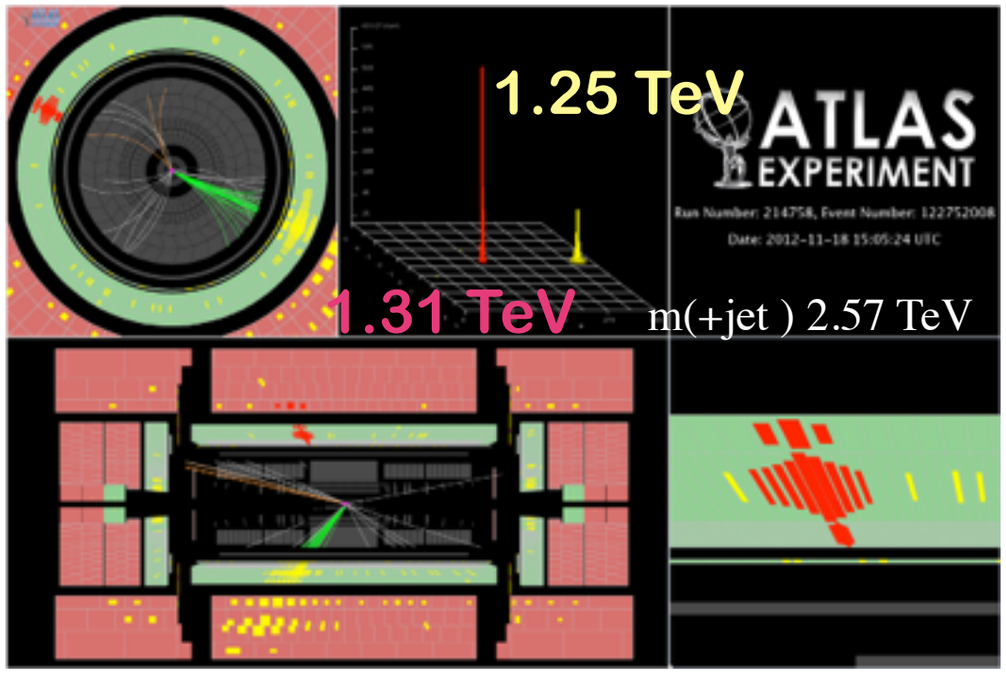
m(q*) 95% CL	int Lumi. [/ fb]	Expected [TeV]	Observed [TeV]
ATLAS 2011	4.8	>3.09	>3.55
CMS 2011	5.0	>3.27	>3.05
CMS 2012	19.6	3.75	3.84
ATLAS 2012	20.3	3.99	4.09

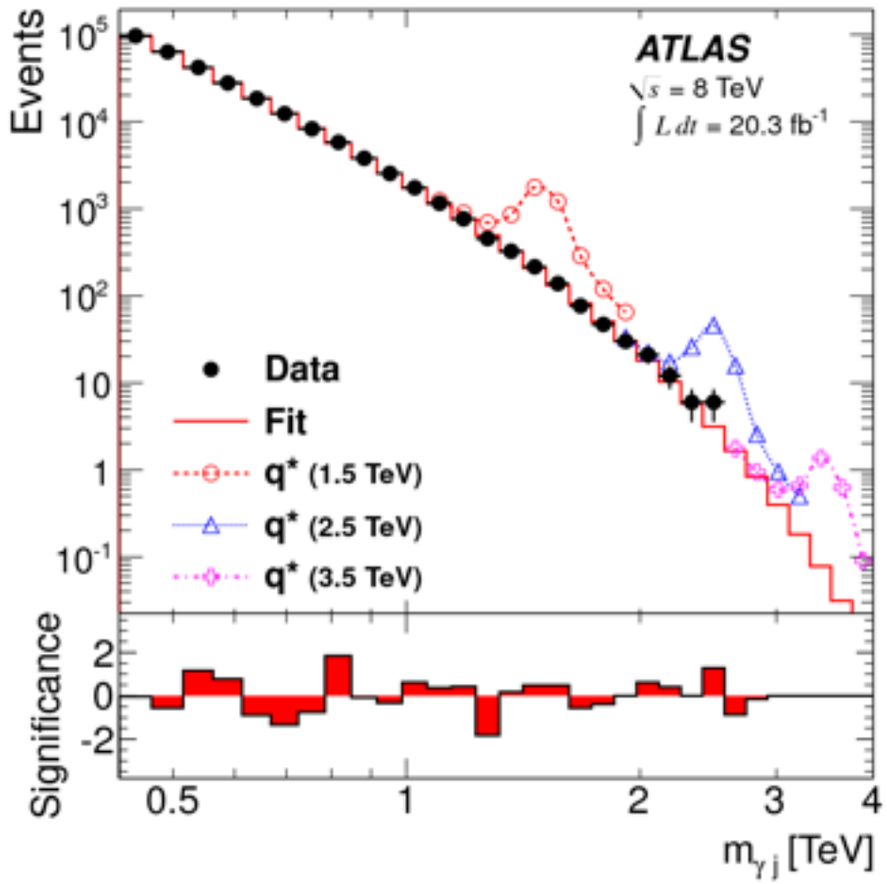
Search for heavy resonance: γ +jet

- Complementary analysis study fermion compositeness in γ+jet events

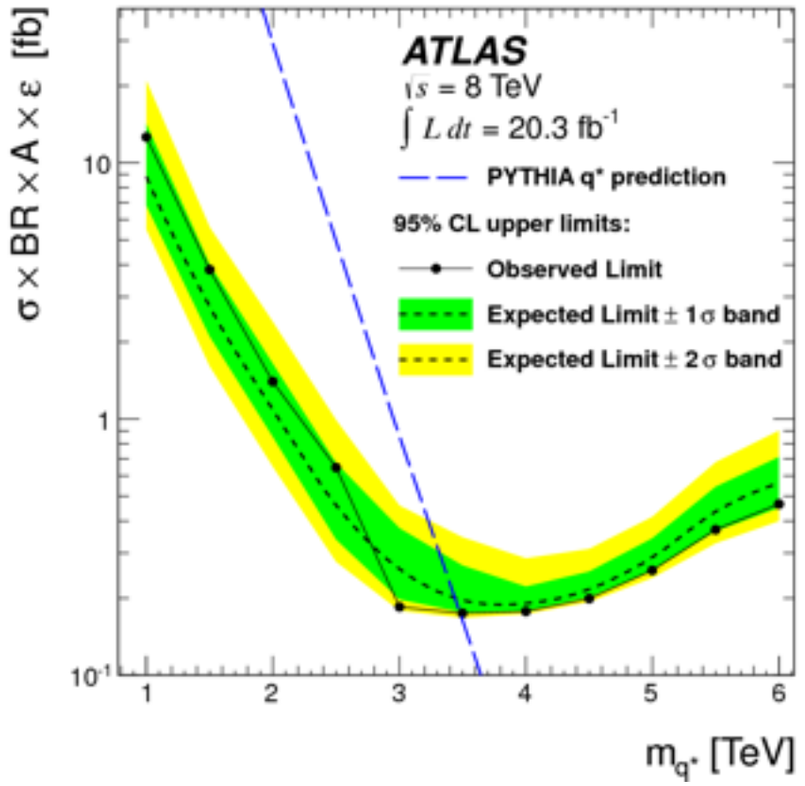
arXiv:1309.3230

- Select high p_T jet and γ in central events $|\eta_j - \eta_\gamma| < 1.6$
- smooth fit to data $p_1(1-x)^{p_2} x^{p_3+p_4 lnx}$
- set limit on q^*, QBH and Gaussian like resonance





Exclude
- **q* bellow 3.5 TeV**
- **QBH bellow 4.6 TeV**



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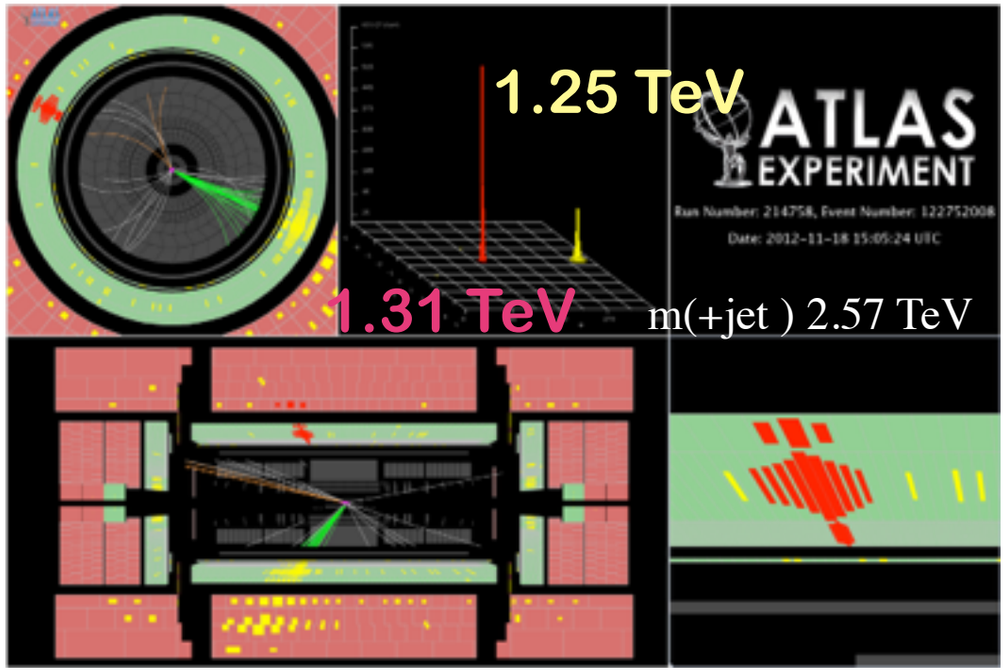

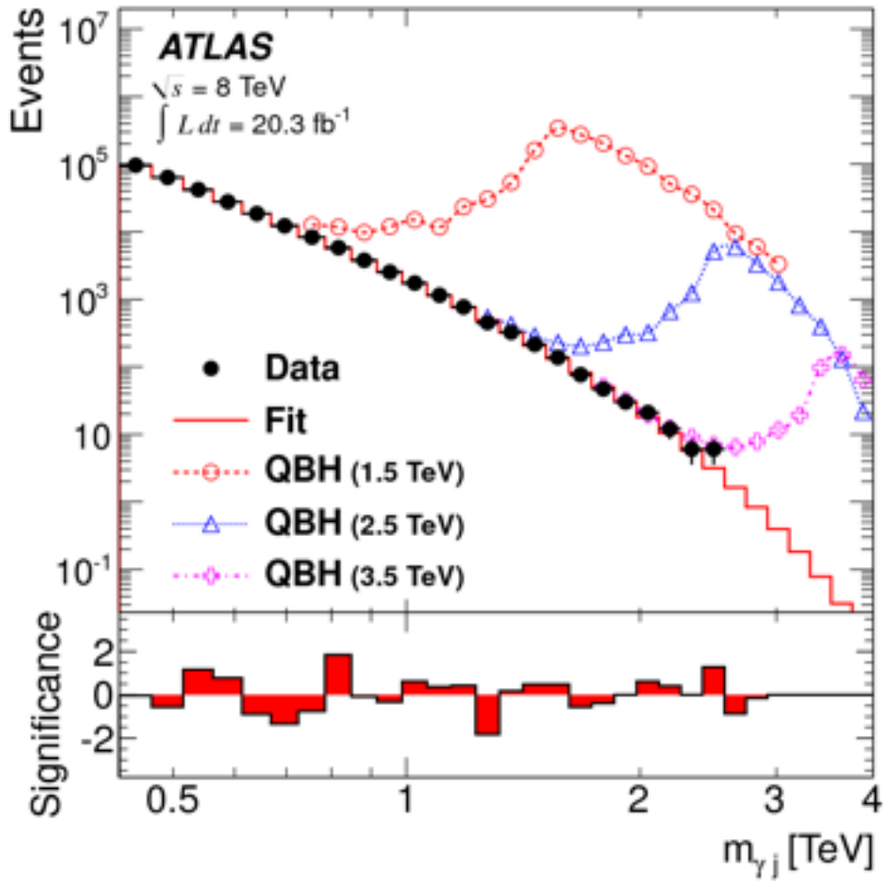

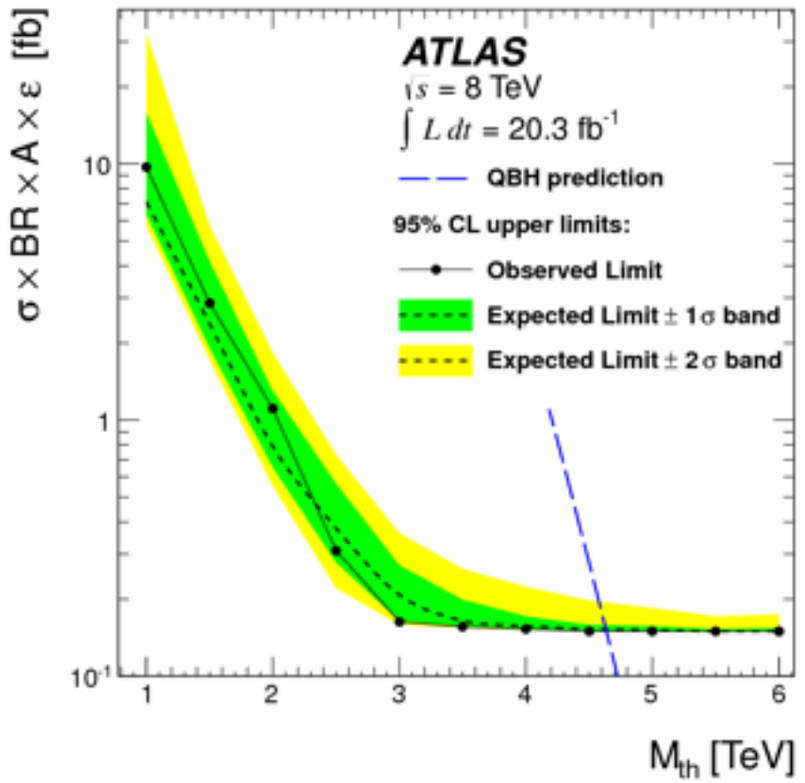

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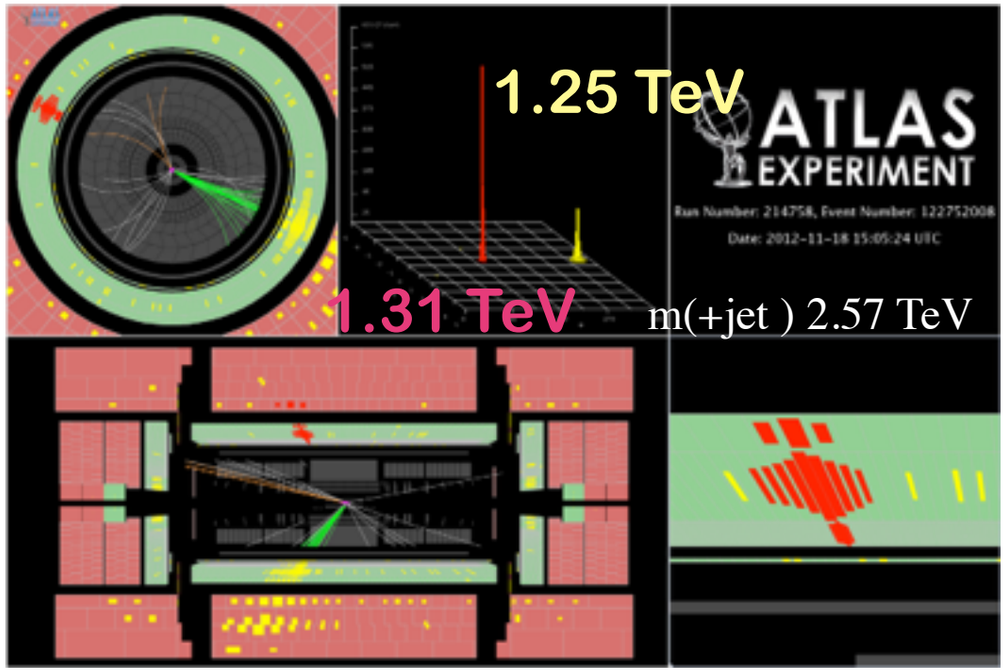

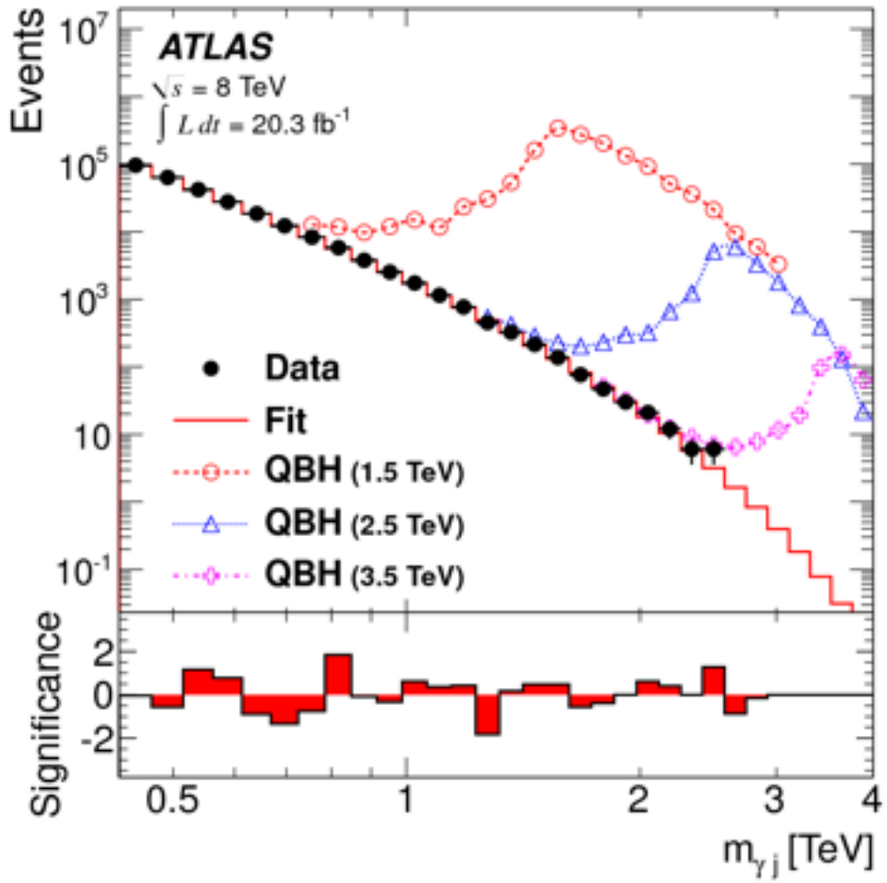

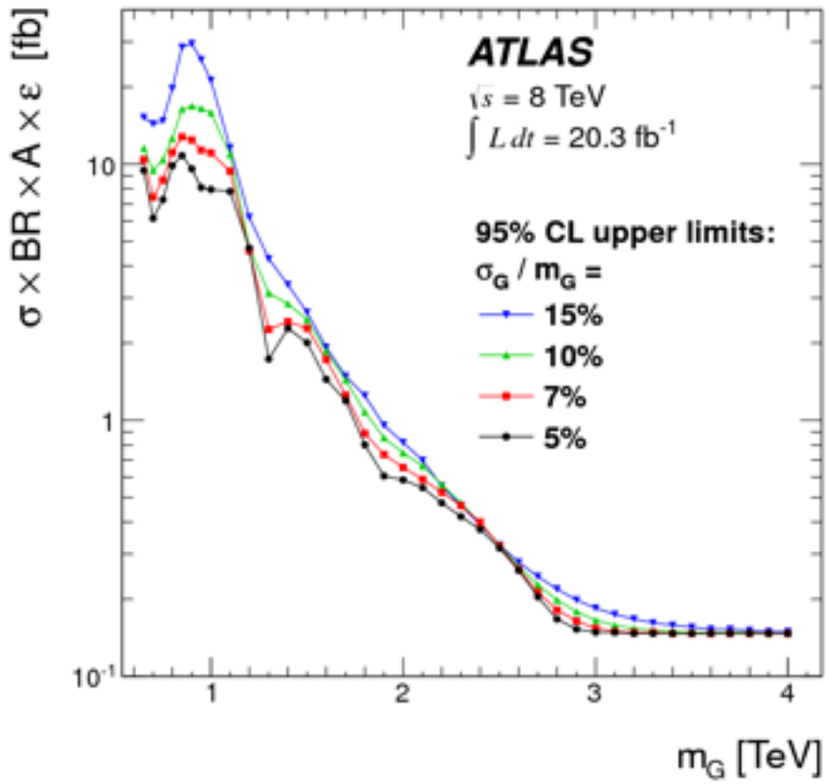

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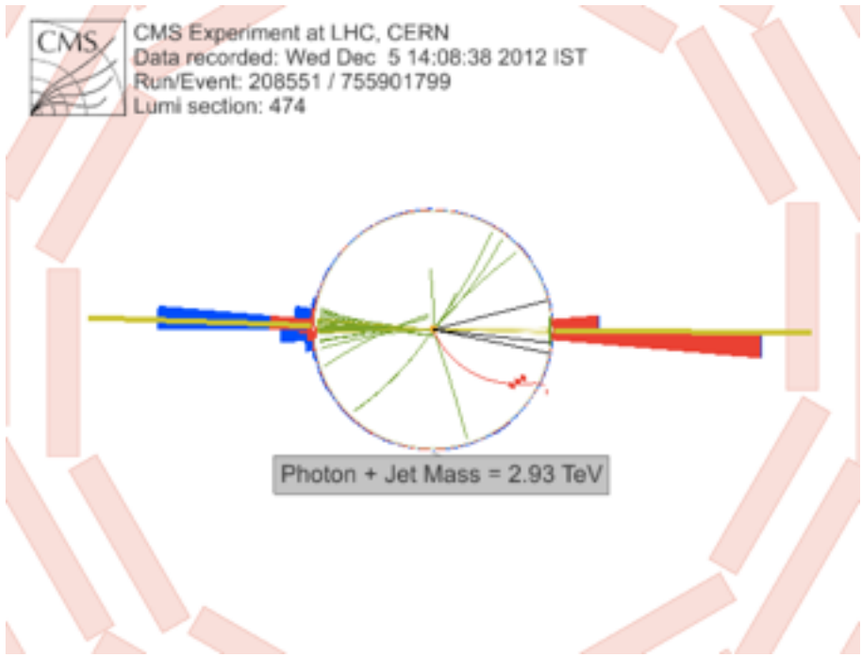
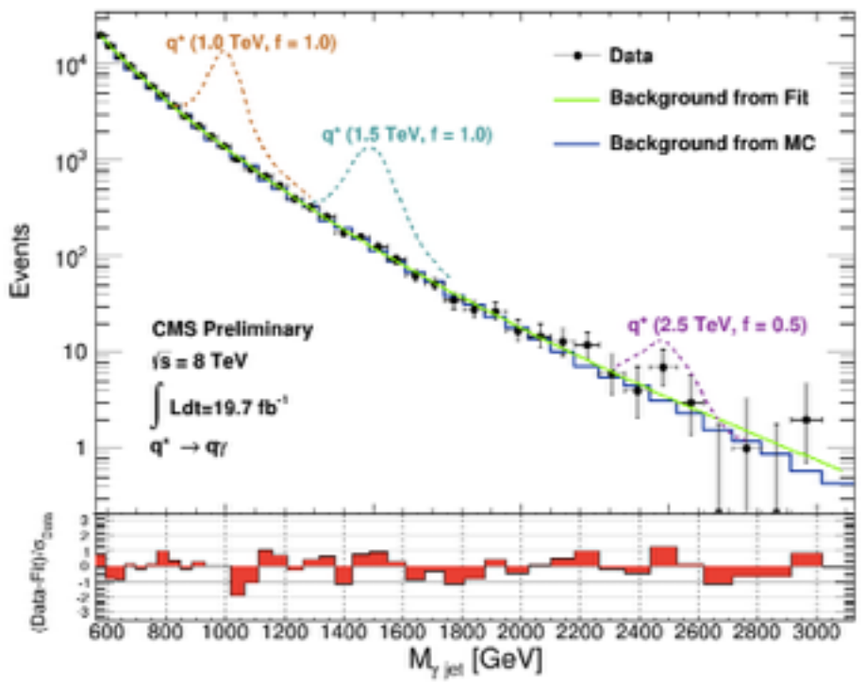
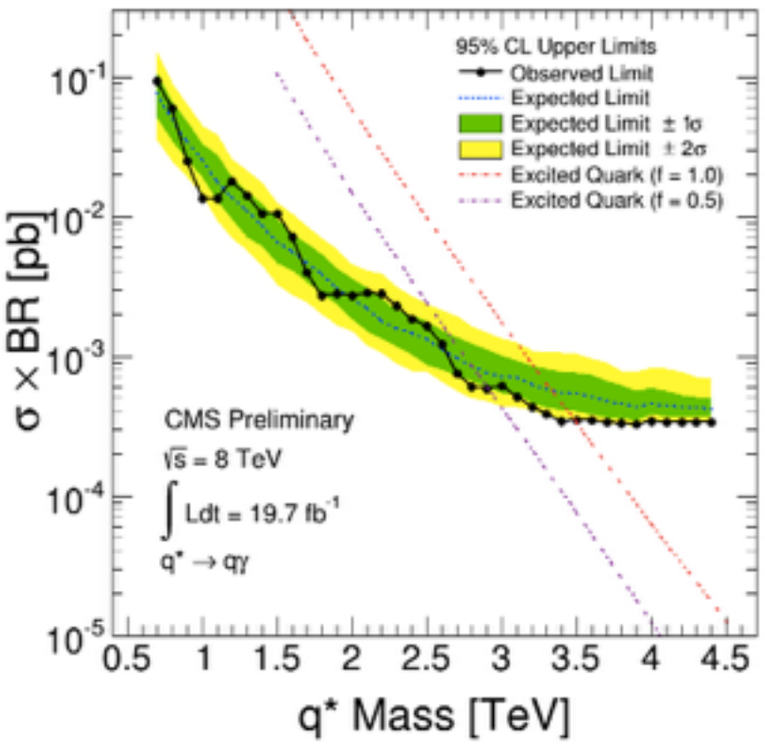
- CMS set limit on q^* also as function of the couplings versus mass

EXO-13-003



Exclude
- **0.7 <q*< 3.5 TeV**
- **Exclude coupling vs q* mass**





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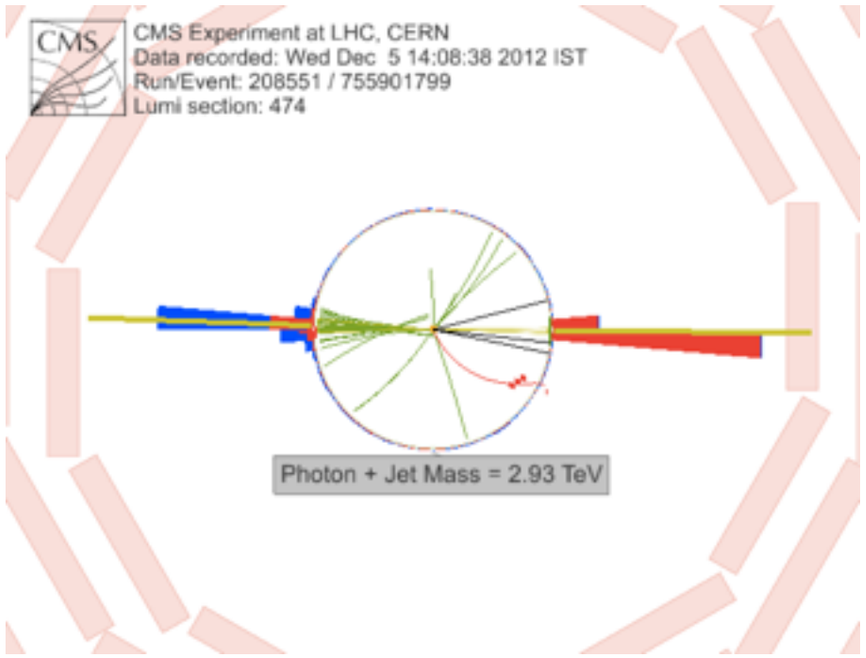

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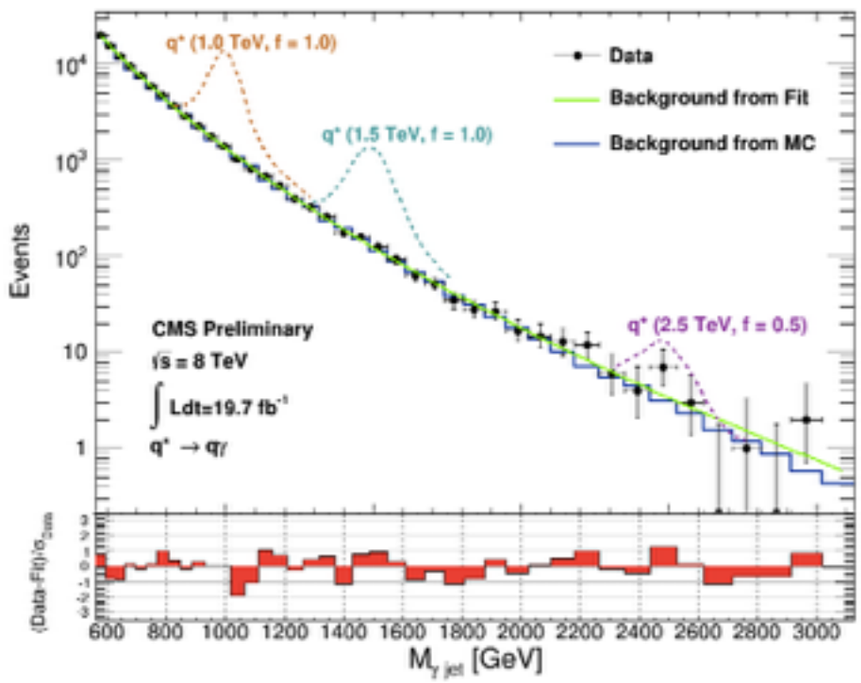
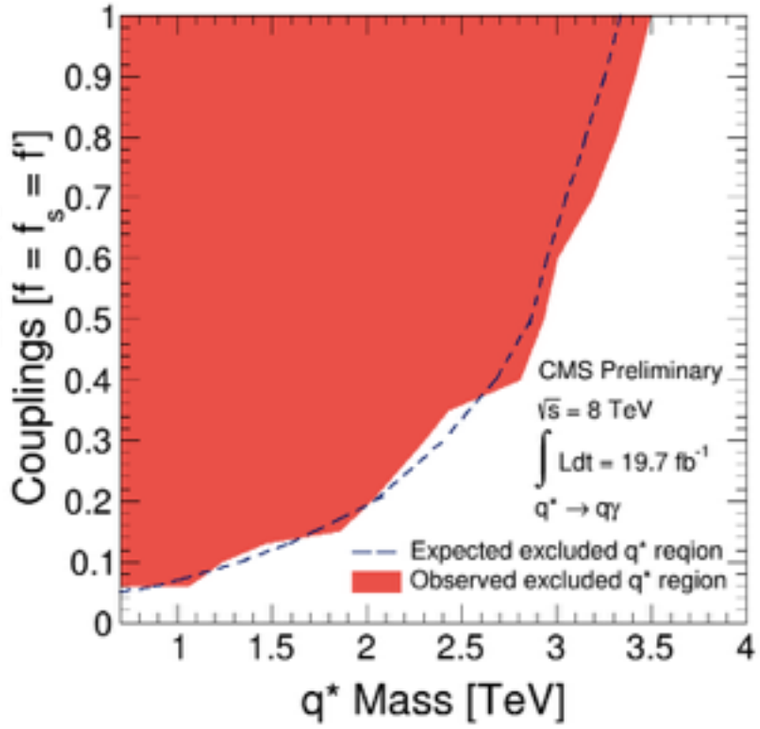
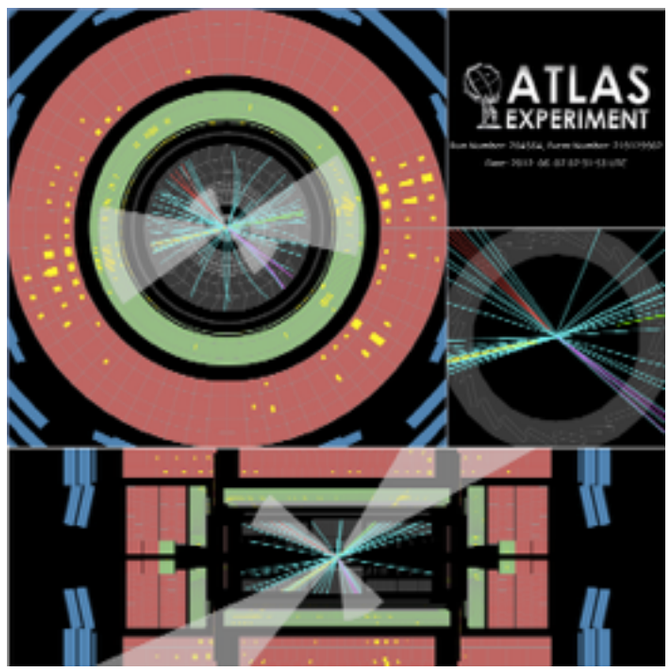
- **0.7 <q*< 3.5 TeV**
- **Exclude coupling vs q* mass**





Resonance in X→HH→bbbb

- Search for TeV scale resonances that decay via two SM Higgs to four b jets
- Event selection
  - 2 pairs of b-tagged jets, jet $p_T > 40$ GeV,
  - Δ R(jets)< 1.5, Dijets $p_T > 200$ GeV
  - $t\bar{t}$ veto $\sqrt{(\frac{m_W-80.4}{0.1m_w})^2+(\frac{m_t-172.5}{0.1m_t})^2} > 3.2$
  - HH masses ellipse: $\sqrt{(\frac{m_1-124}{0.1m_1})^2+(\frac{m_2-115}{0.1m_2})^2} < 1.6$; $m_{1(2)}$ leading (sub-leading) dijet.
- Background multi jets (90%) and $t\bar{t}$ (10%)
  - multi jets modelled compare data that passes the "2-tag" (only one dijets has b-tag) to standard "4-tag"
  - define regions to normalise, rewirght and test (exclude signal or mixed HZ regions)
  - $t\bar{t}$ shape taken from MC, normalised to data using "4-tag" when one or both dijets fail the $t\bar{t}$ veto



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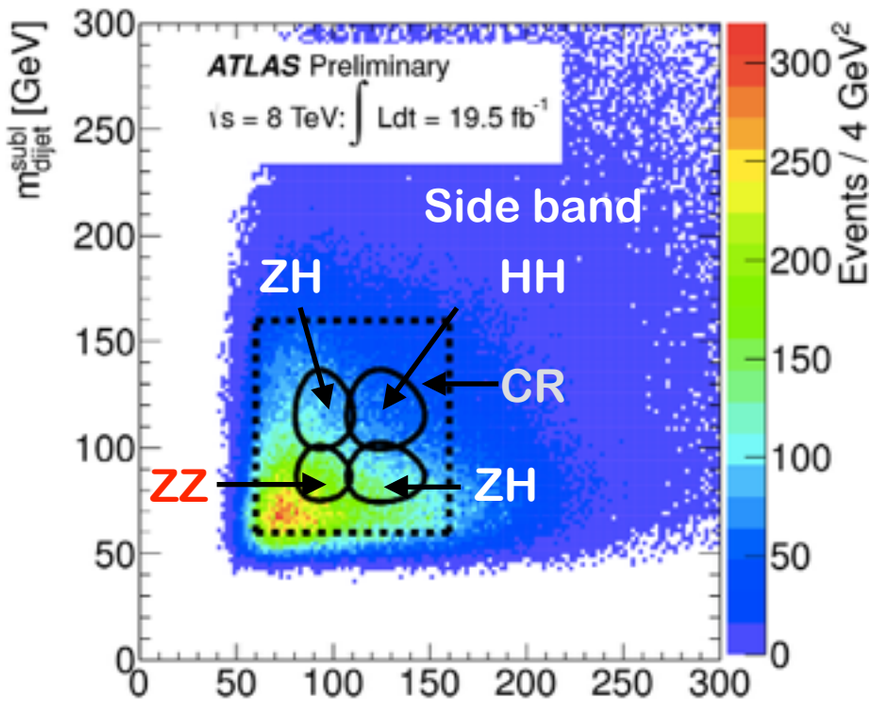
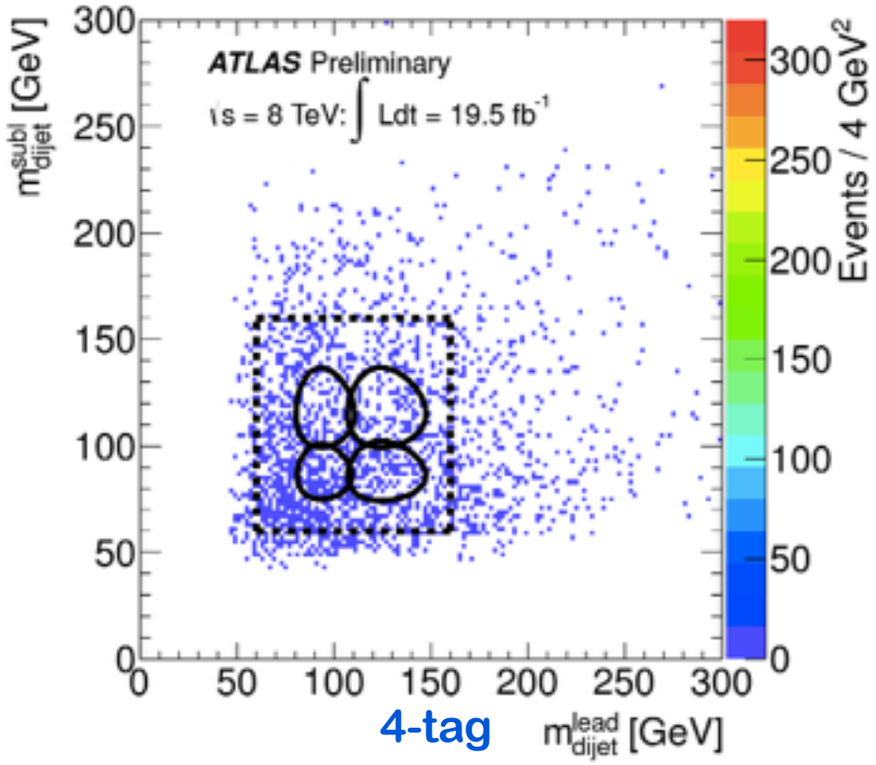


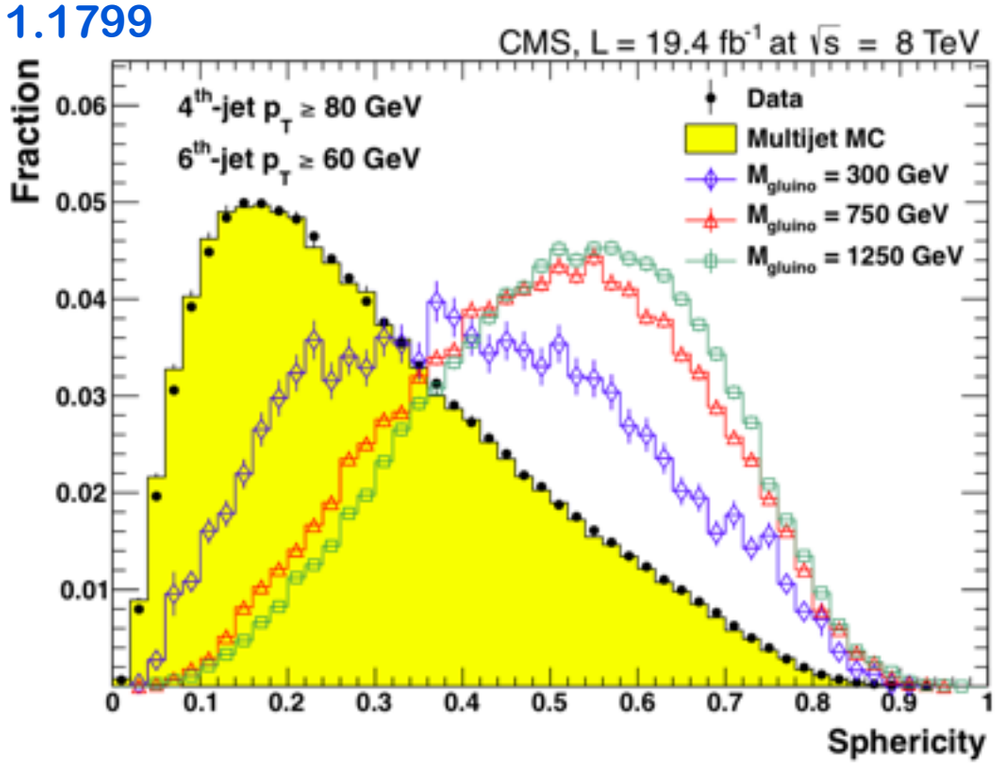
2-tag m_{dijet}^{lead} [GeV]

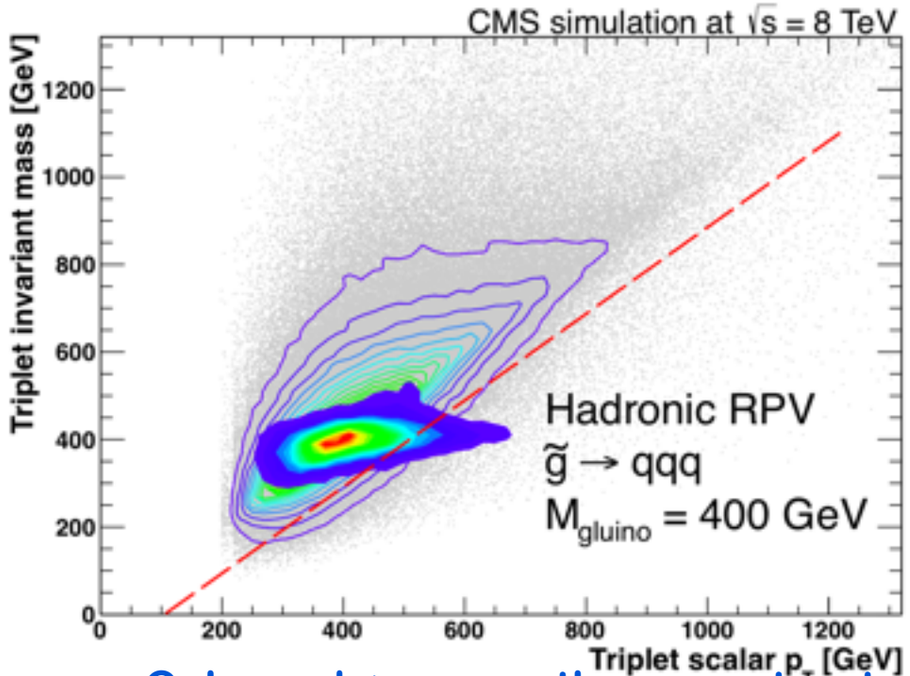


Pair produced three jets resonances

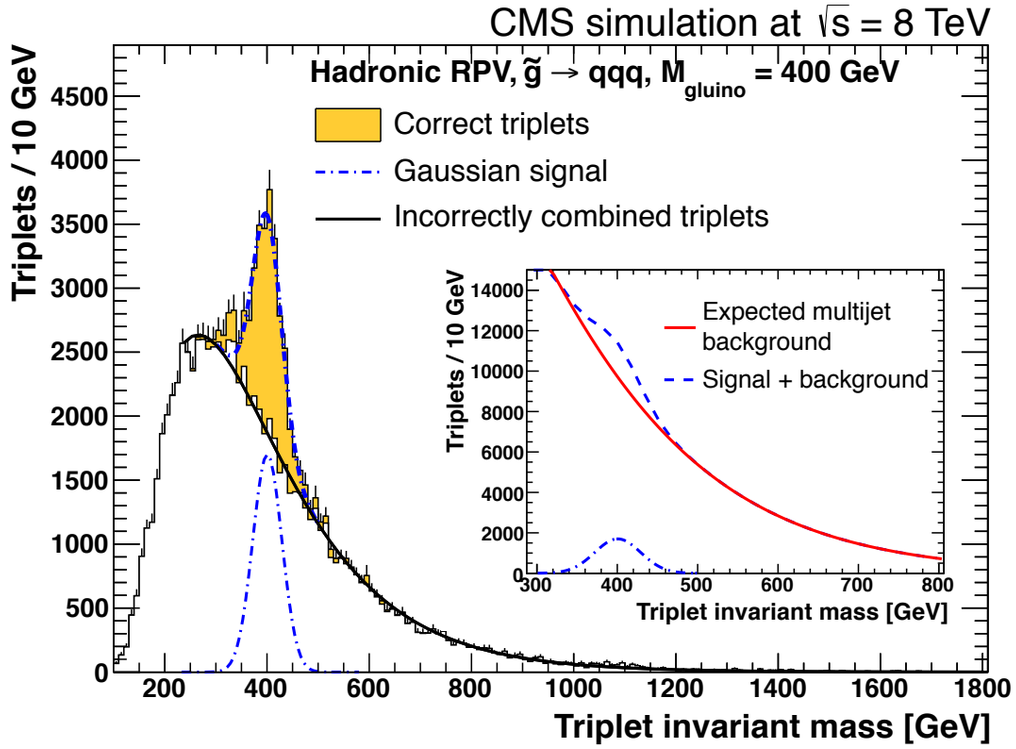
- Search strongly coupled resonances decaying each to 3-jets
- Benchmark model pair production of gluino decaying to 3-jets through RPV couplings
- Event selection:
  - ≥ 6 jets; 1-4 jets (5-6) $> 80 (> 60)$ GeV
  - Supress bg at high mass with sphericity
  - Use b-tagging for gluino $\rightarrow$ udb/csb cases
- Try 20 unique triplet combinations of the 6 highest p_T jets
- Suppress wrong combinations and QCD by requiring $m_{3j} = \sum_{i=1}^{3} |p_T|_i - \Delta; \Delta = 110$ GeV

arXiv: 1311.1799



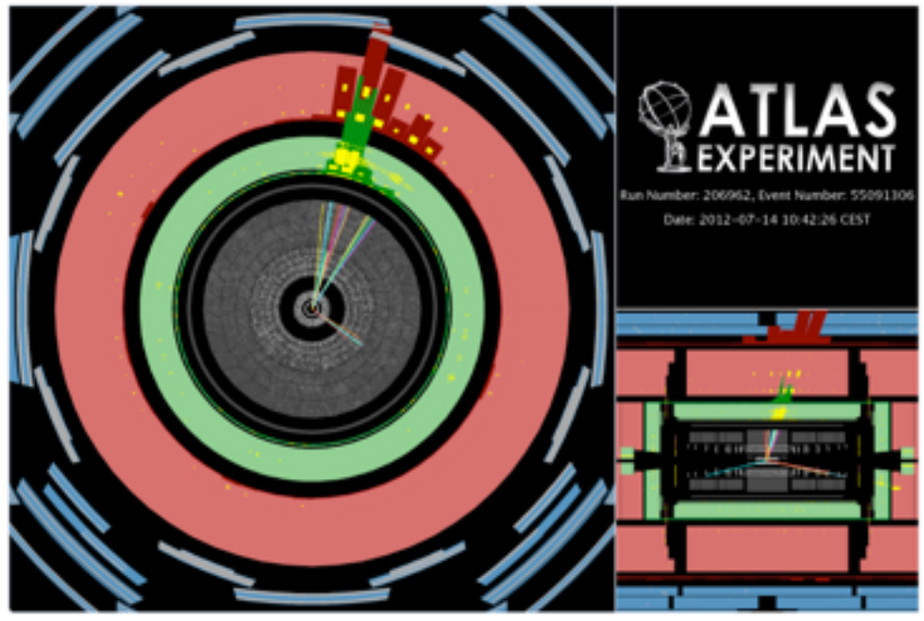


Coloured -> correctly reconstructed triplets, contour lines and points -> incorrectly combined triplets. Dashed line -> Δ=110 GeV



Single objects + missing transverse energy

- Single high p_T (jet, photon, W, Z, lepton) and MET predicted by:
  - DM (associated with ISR),
  - Graviton in ED
  - Gluino (squark) to gluon (q) +gravitino
  - H->invisible
- Simple final state, known EWK BG
- Reject:
  - ➡ Events with identified lepton (EWK BG)
  - ➡ More than 1 extra jet (top or multijet BG)
  - ➡ MET pointing toward 2nd jet (mis-measured jets)
- Data driven BG estimate:
  - Z(->νν)+X (irreducible)
  - W(->lν)+X or Z with 1 undetected l
  - multijets, γ+jets with fake MET
  - non-collision data
  - top, dibosons and γγ (MC based rejection)



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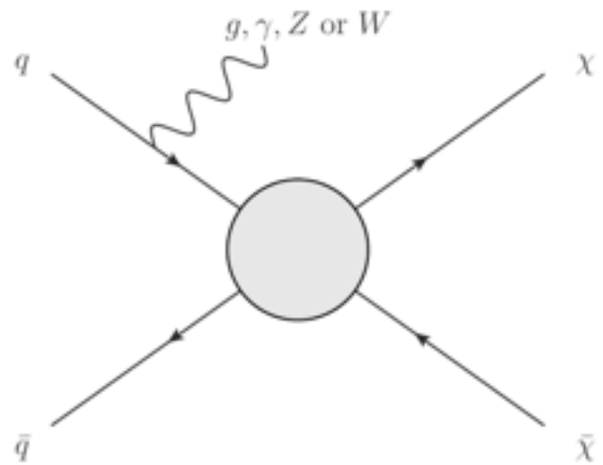

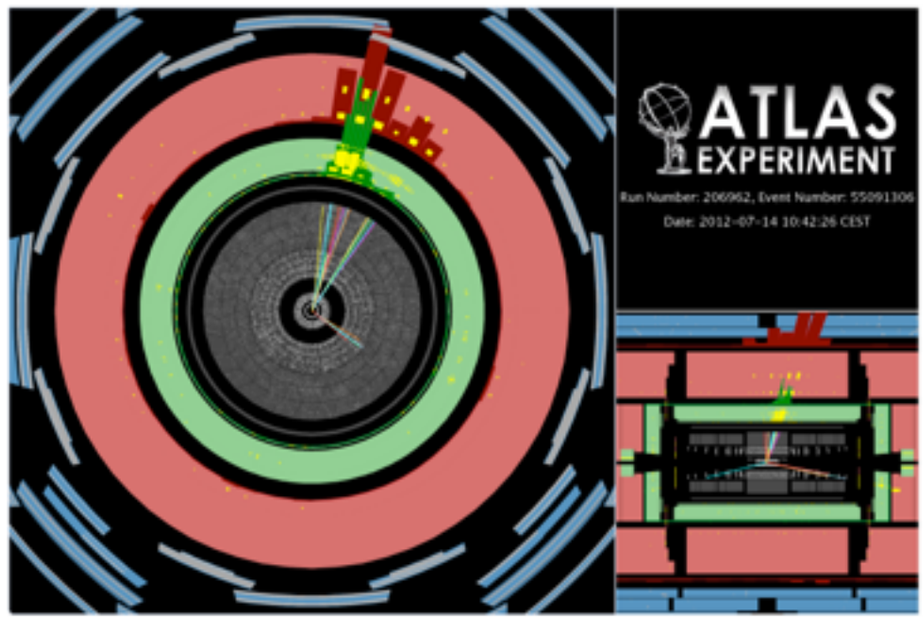

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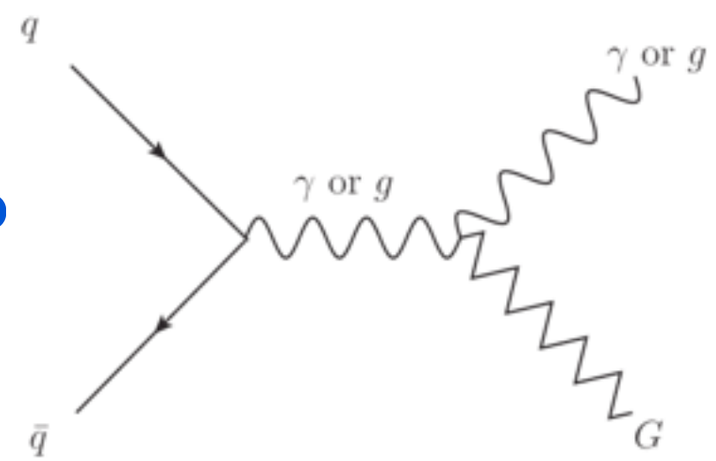

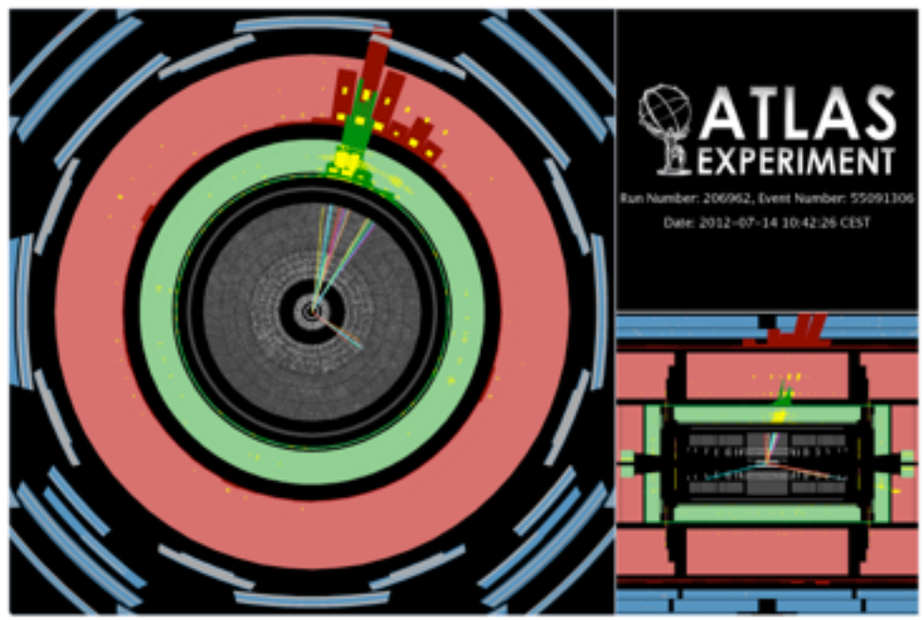

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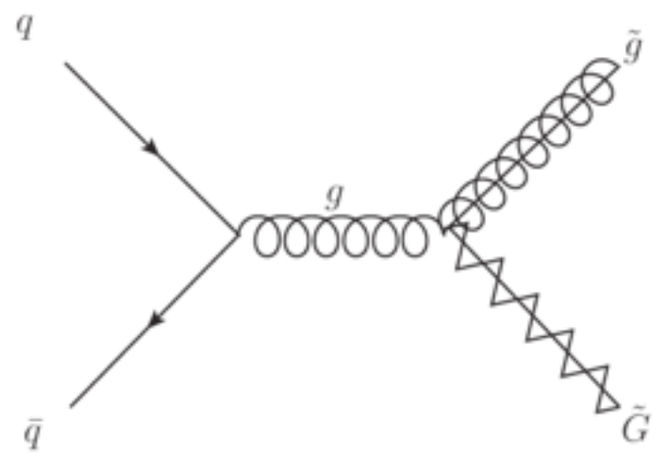
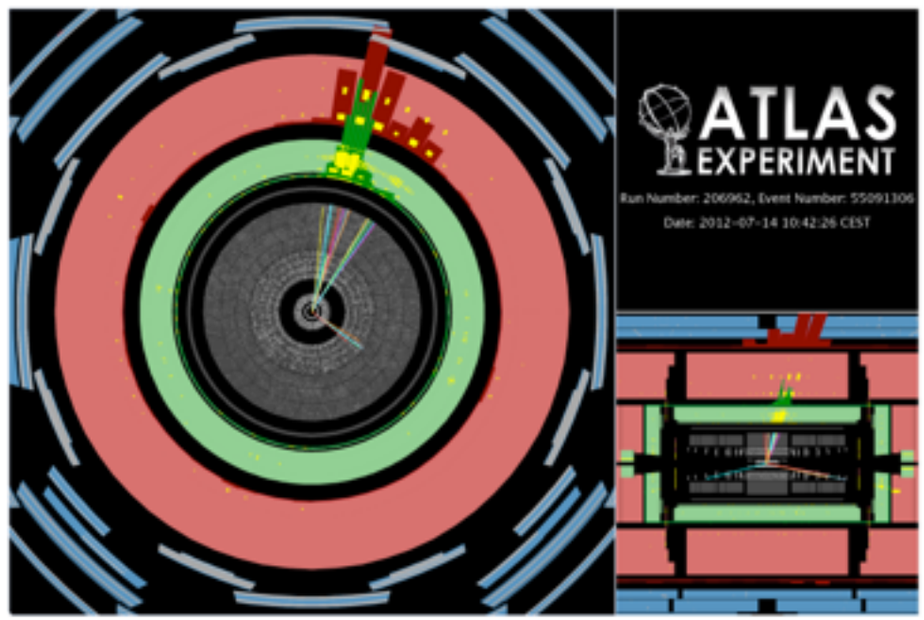
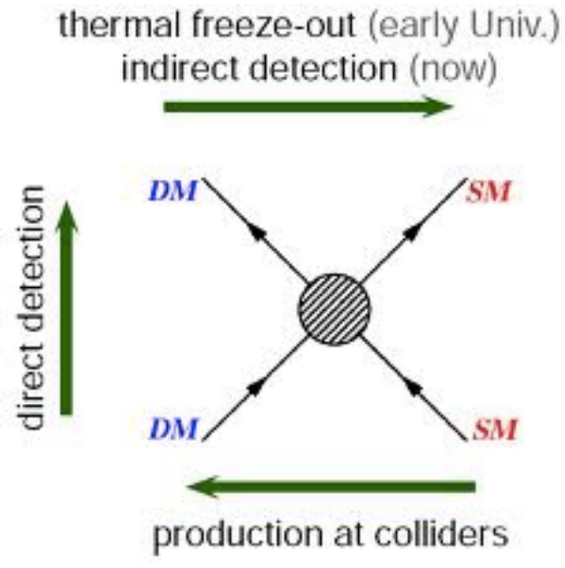


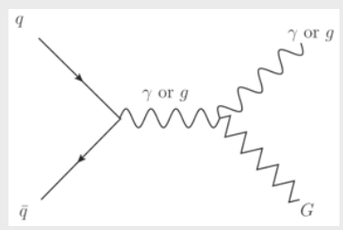


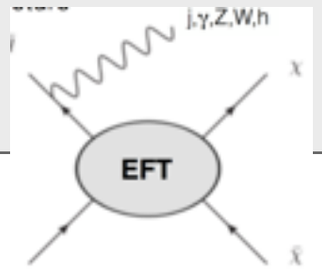
Mono X

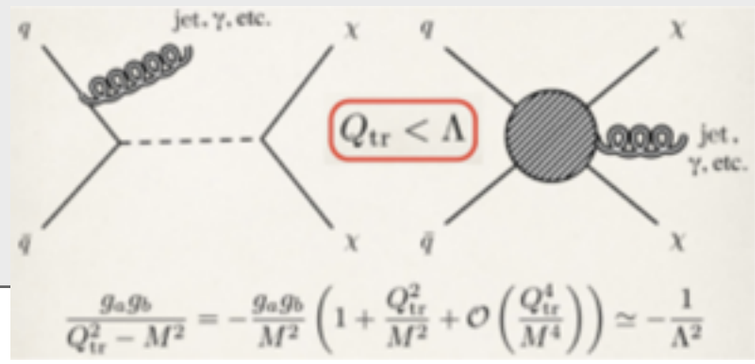
- **Motivation**
  - Galaxies rotation velocities, Gravitational lensing, CMB -> DM cover 25% of universe? may have complex physics.
  - Common couplings at unknown higher scales ?
- **Searches for SM<->DM**
  - Direct detection: (XENNON, LUX, DaMa, CDMS)
  - Indirect detection: (AMS, LAT, AMANDA, IceCube)
  - Production: LHC (complimentary at low masses)
- **Search strategy**



Large ED	EFT	Simplified models
● If MD<< the energy scale, particle may interact via gravity ● ED -> KK graviton tower ● Gravitons can escape detection	• Contact interaction with mediator too heavy to be generated • Suppression scale $M^* \approx \frac{M}{\sqrt{g_{\chi} \times g_{SM}}}$ where M^* is the mediator mass and g_{χ} and g_{SM} are the DM and SM couplings	● EFT has limited validity when mediator mass is light ● UV- theories - valid everywhere ● Use ad-hoc fields, interactions to model the possible DM







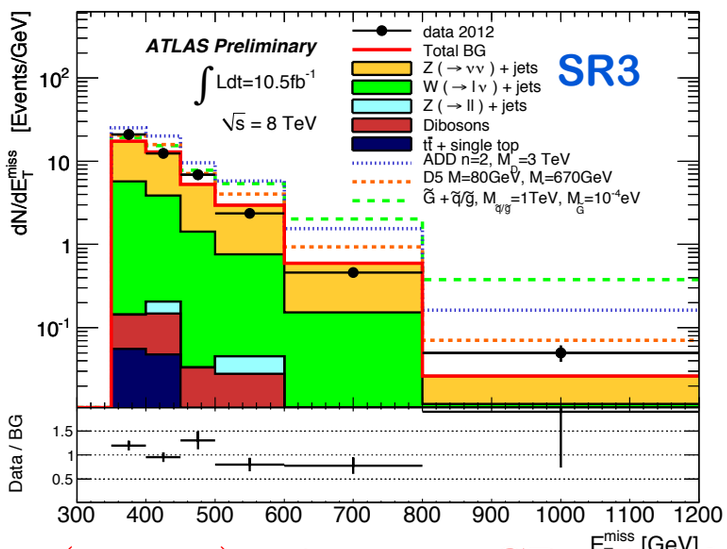
Search for Monojet

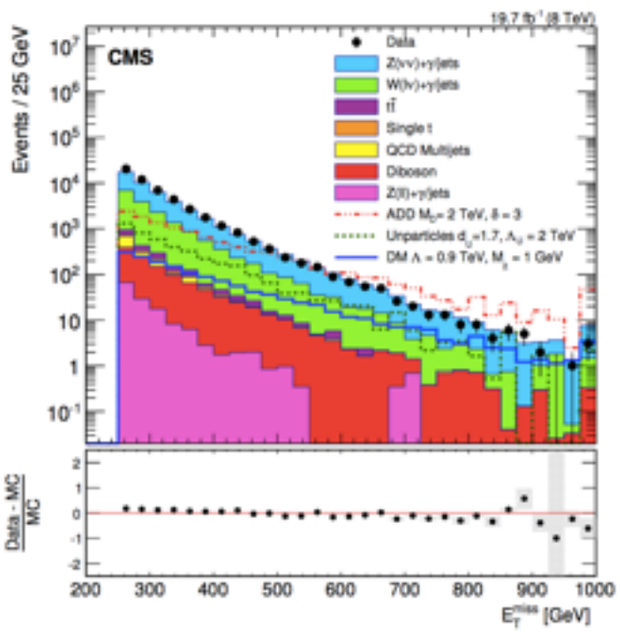
Event Selection

- $>= 1$ jet with $p_T > 120$ GeV $|\eta| < 2.0$
- < 3 jets with $p_T > 30$ GeV $|\eta| < 4.5$
- veto electrons and muons
- $\Delta\phi(jet2, MET) > 0.5$

BG Estimate

- $Z \to \nu\bar{\nu}(e\bar{e}, \mu\bar{\mu}, \tau\bar{\tau})+$ jets and $W \to e\nu(\mu\nu, \tau\nu)+$ jets use CR with leptons enriched in $W \to \mu\nu+$ jets or $Z \to \mu\bar{\mu}+$ jets CR
- Multijet use MET $+2(3)$ jets CR where $\Delta\phi(jet2(3), MET) < 0.5$



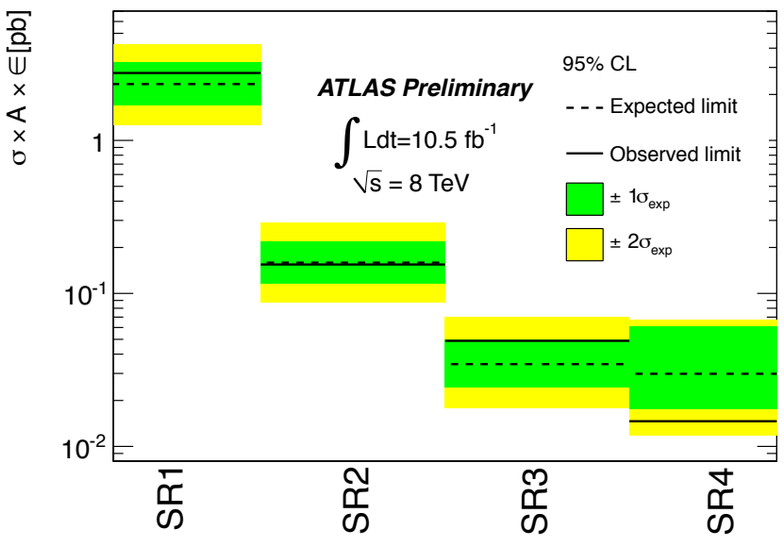


7 TeV: CMS JHEP 09 (2012) 094

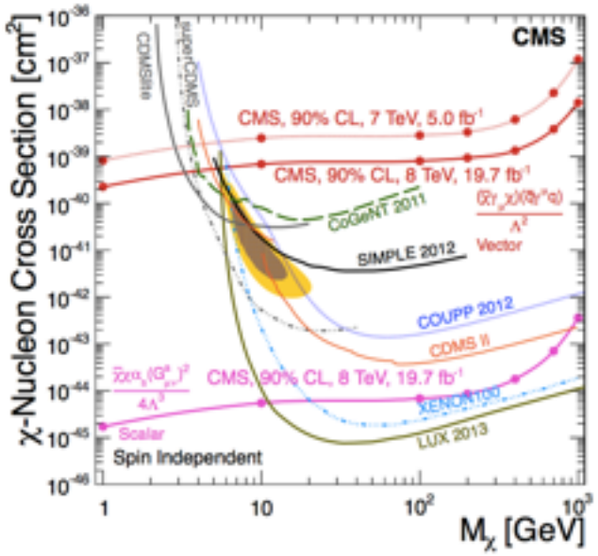
ATLAS JHEP 04 (2013) 075

8 TeV:CMS arXiv:1408.3583 (20/fb)

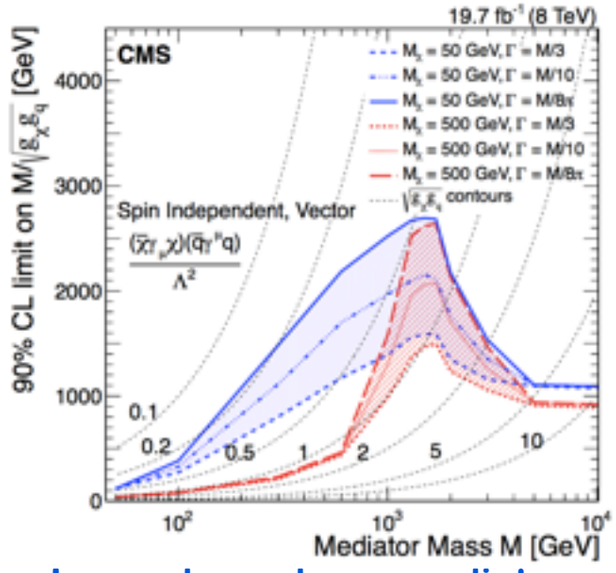
ATLAS-CONF-2012-147 (10.5/fb)



Model independent



EFT scale bounds (vector & scalar) translated to Xsec limit

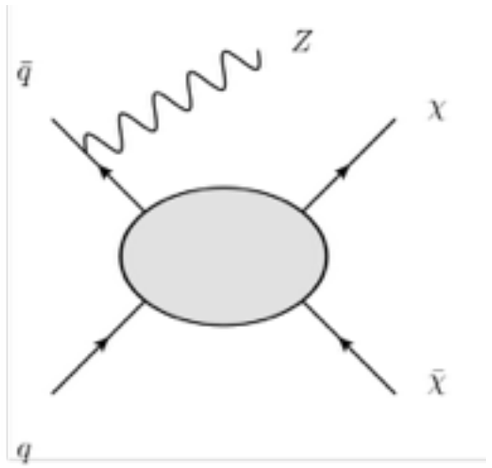


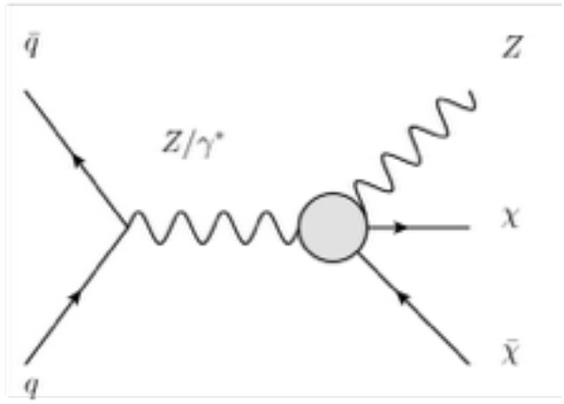
Lower bounds on mediator mass/sqrt(coupling) of simplified model

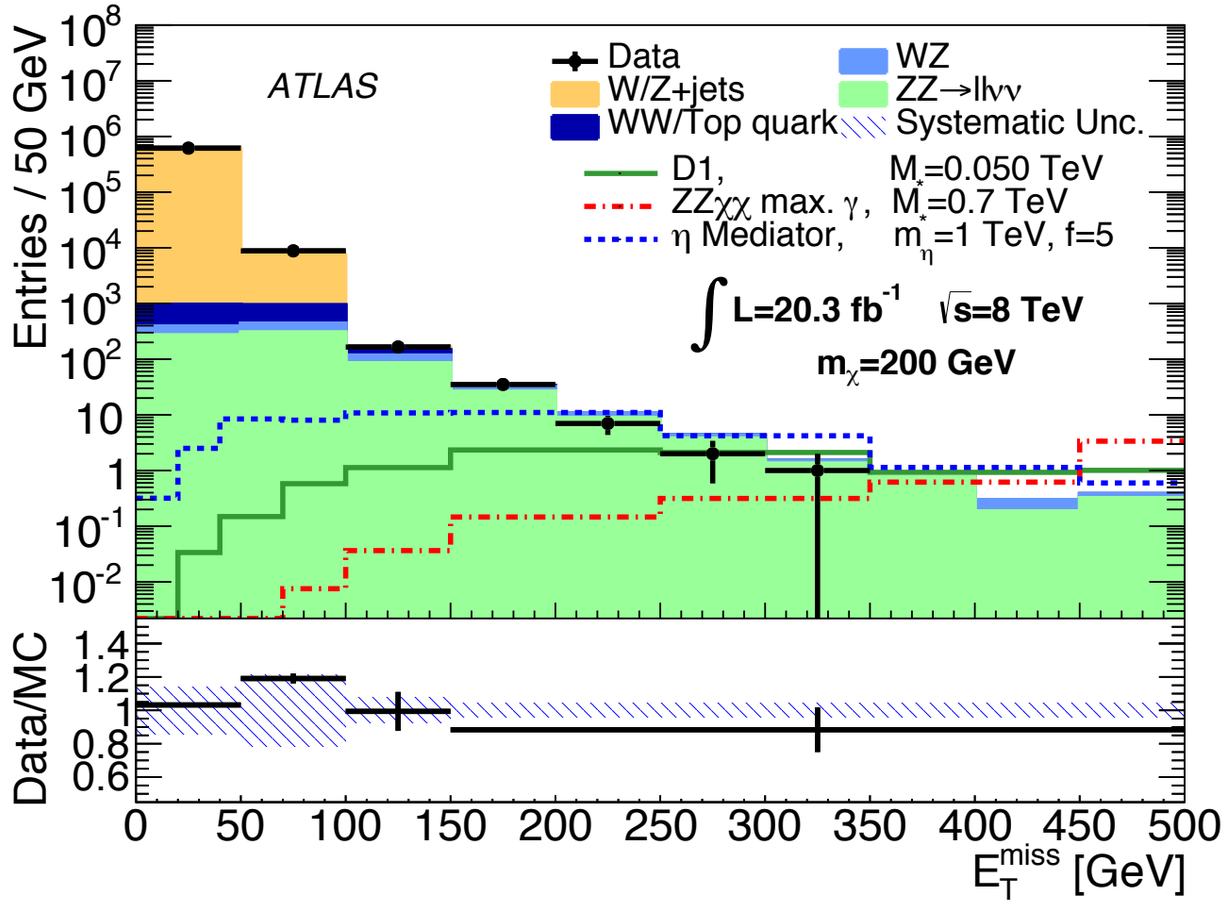
Mono Z (-> dileptons)

arXiv:1404.0051 [hep-ex]

- Appears as ISR Z or Z couples to the DM
- Look for OS ee or $\mu\mu$ with mass around Z
- Reject 3rd lepton or jet
- No E_T^{miss} from mismeasured jet:
  $\Delta\phi(E_T^{miss}, p_T^{ll}) > 2.5, |\eta^{ll}| < 2.5,$
  $|p_T^{ll} - E_T^{miss}|/p_T^{ll} < 0.5$
- No 3^{rd} lepton and no jets
- SR: $E_T^{miss} > 150, 250, 350, 450$ GeV
- Dominant BG $Z \to l^+l^-\nu\nu$



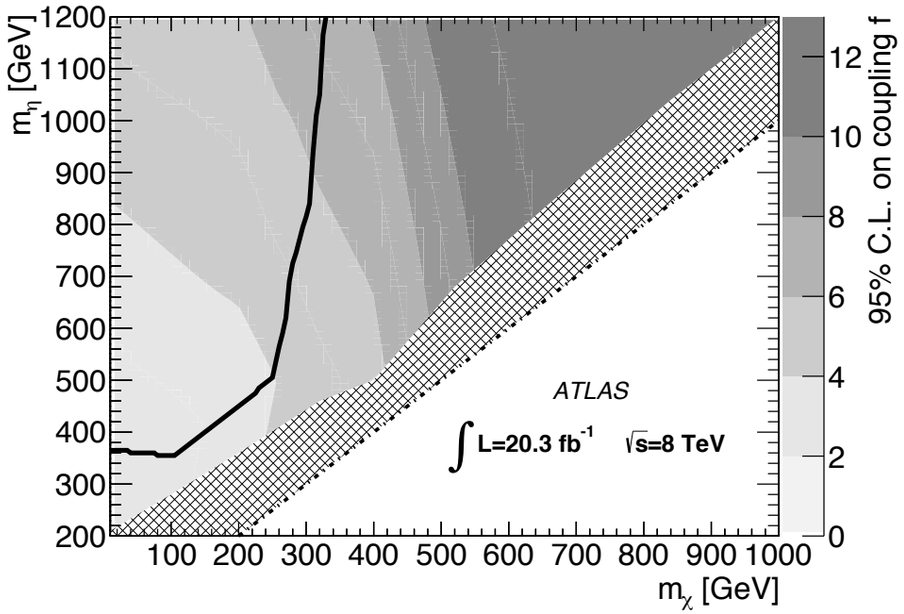




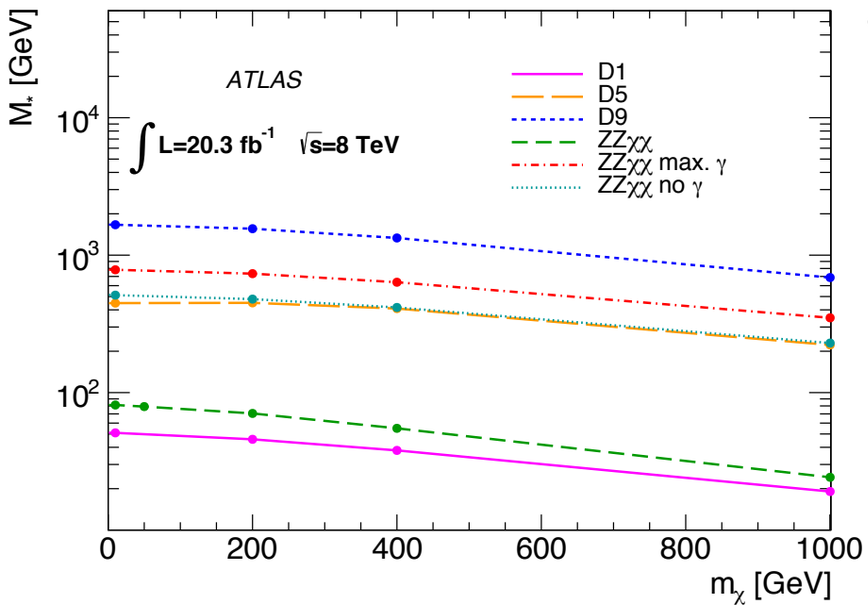
Mono Z (-> dileptons)

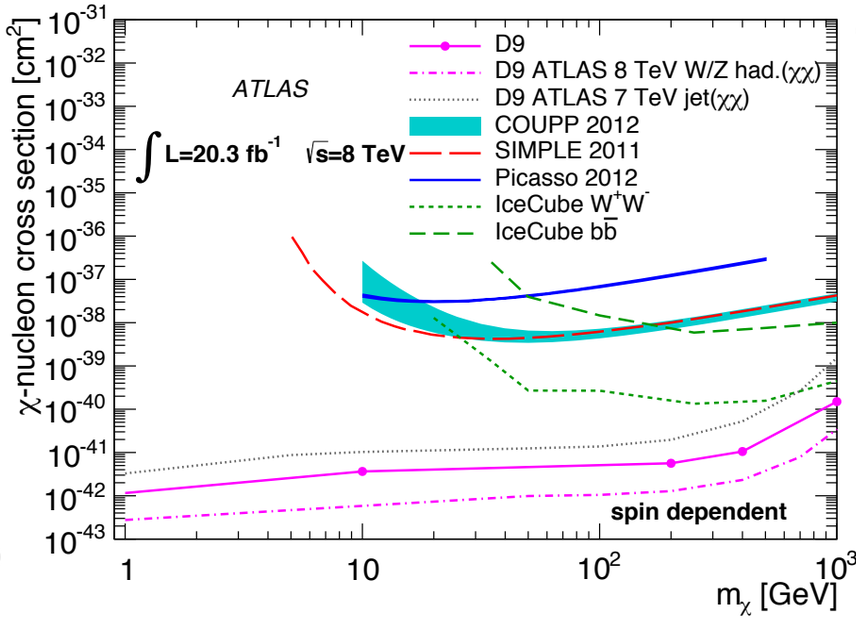
arXiv:1404.0051 [hep-ex]

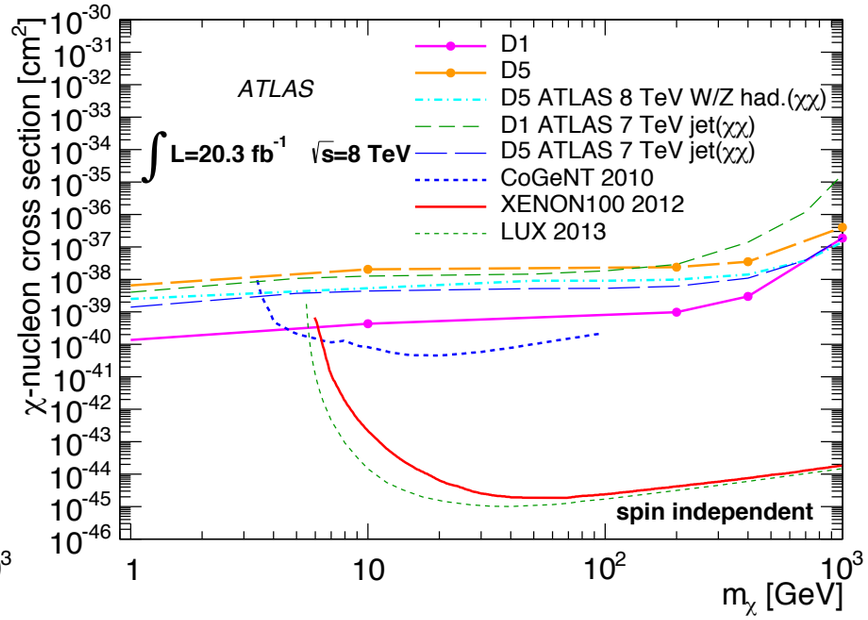
- 95% C.L. upper limits on $\chi\eta$ coupling, f, as a function of m_χ and the mediator mass, m_η. The cross-hatching shows the theoretically accessible region outside the analysis coverage. The white region is phase space beyond the model's validity. Above the black line smaller than lower limit from our relic abundance calculations.



- Below: limits on EFT scale and upper bounds on $\sigma(\chi - N)$







Leptons + X

- We have fewer leptons, but they are easy to trigger and measure
- Signatures include: pairs of e, μ, τ, γ, l+jet and l+MET
- Models include:
  - ➡ Extra dimensions (ADD and RS)
  - ➡ GUT E6 heavy bosons (Z',)
  - ➡ Benchmark models SSM ...
  - ➡ Excited leptons
  - ➡ Leptoquarks
  - ➡ Tev Gravity
  - ➡ Quantum Black Holes

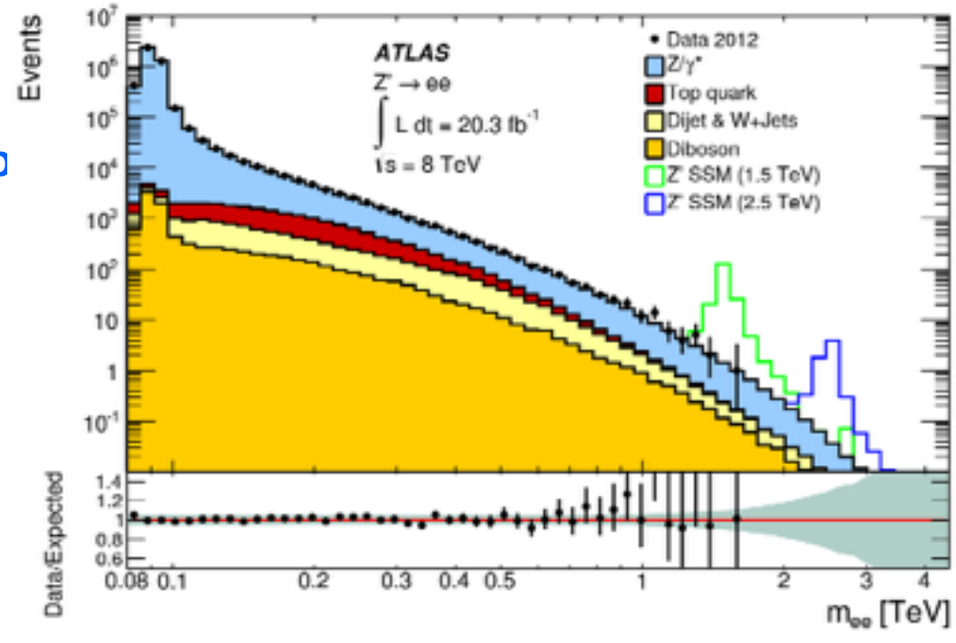
- **Multileptons**
  - Signatures are 3+, 4+ leptons, like-sign leptons
  - Inclusive searches and interpretations in models like:
    - ➡ Doubly charged Higgs
    - ➡ Heavy Neutrino
    - ➡ Seesaw models
    - ➡ Higgs to Dark Z
  - EW like signal: usually leptonic final states, dominated by irreducible EW BG calculated at (N)NLO or fit the data in CR

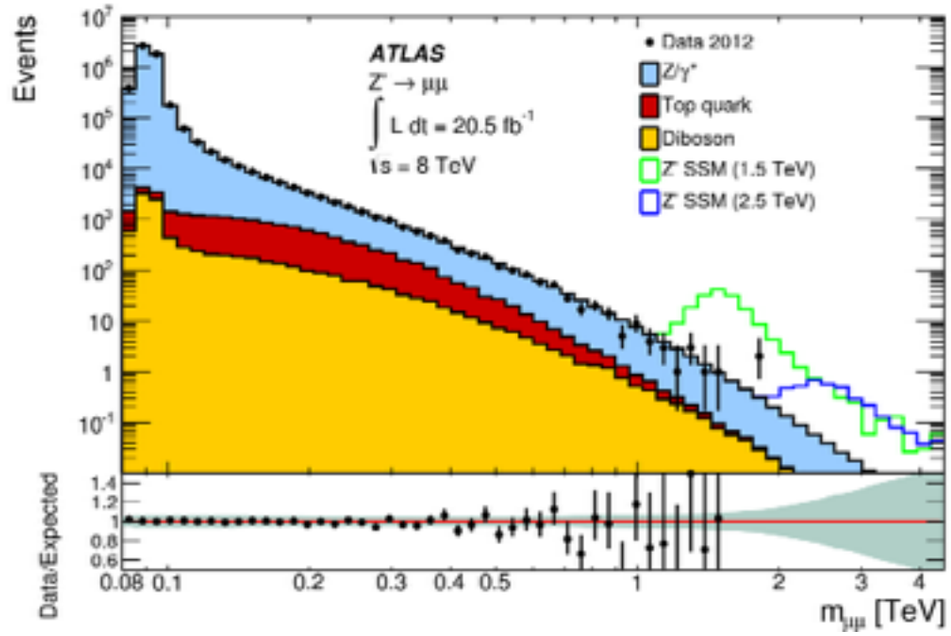
Search for heavy resonance: dileptons

arXiv:1405.4123

- Models
  - Z', Z*, E6 , SSM Z', RS graviton, Minimal Walking Technicolor, Minimal Z', QBH
  - Contact interaction
- Dominant BG: DY
- Signal and BG evaluated with MC and rescaled using known Xsect
- Jets BG in e estimated with data
- QCD shape from loose selection extrapolated to high ET, normalized using data in CR
- NNLO k-factors correct the LO MC
- Calculate p-value of observed vs expected events

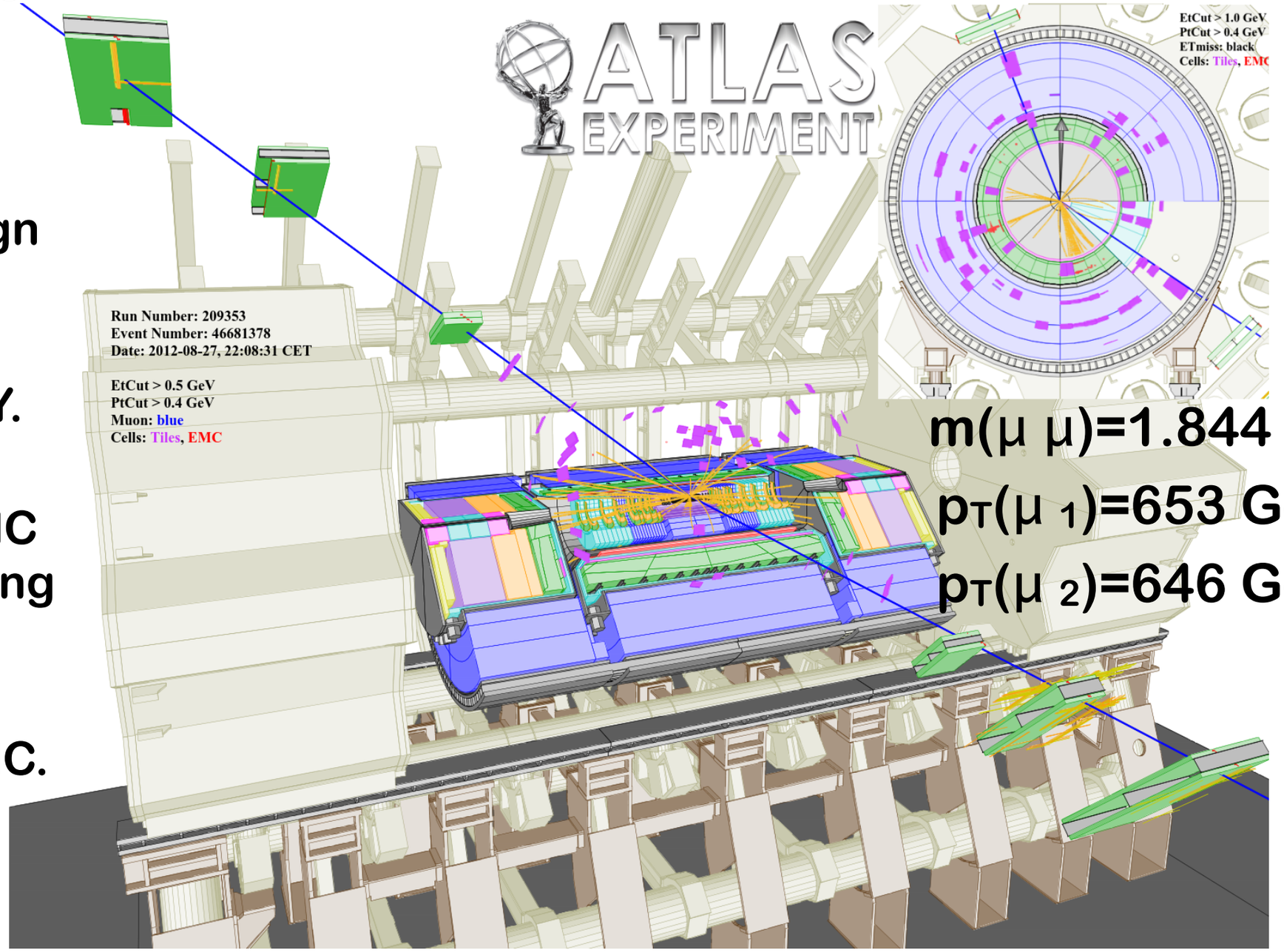
20/fb





Search for heavy resonances: di-muons

- Track muon in MS and ID
- Require muon isolation
- Use muon op. sign with highest sum(p_T)
- Dominant BG: DY.
- Signal and BG evaluated with MC and rescaled using known Xsect.
- NNLO K-factors correct the LO MC.



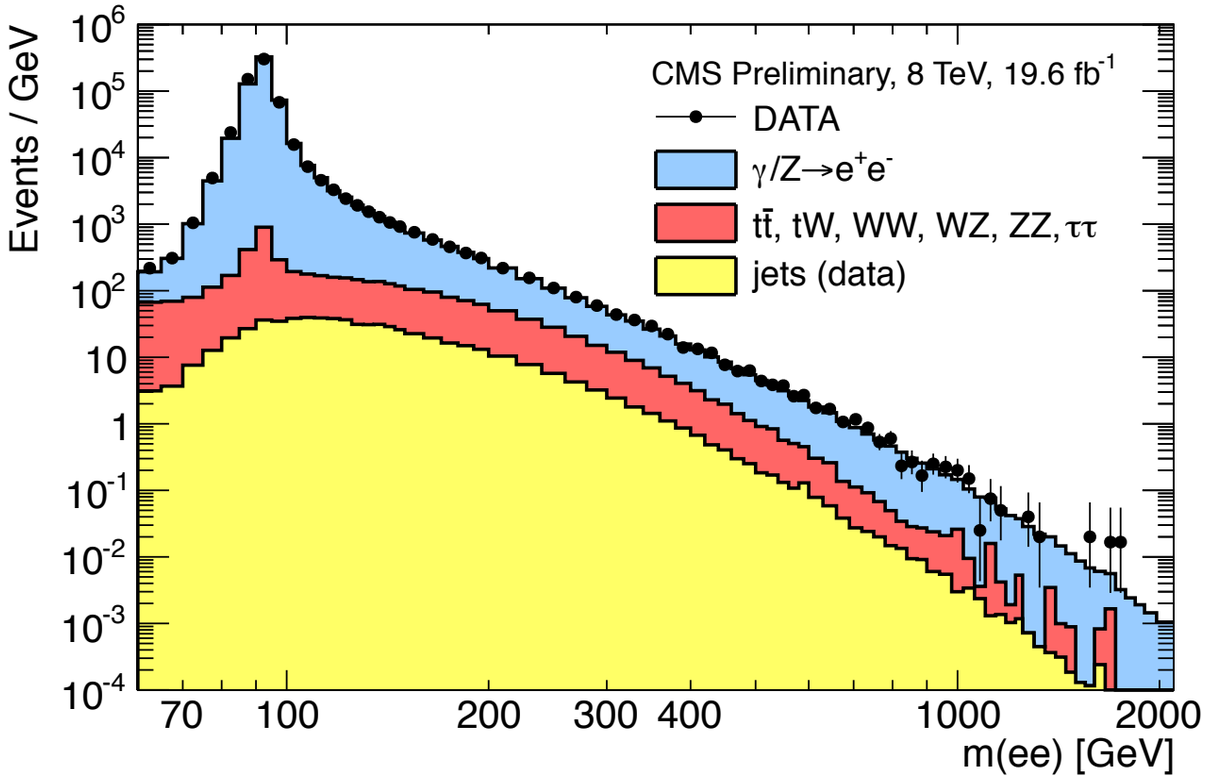
m(μ μ)=1.844 TeV

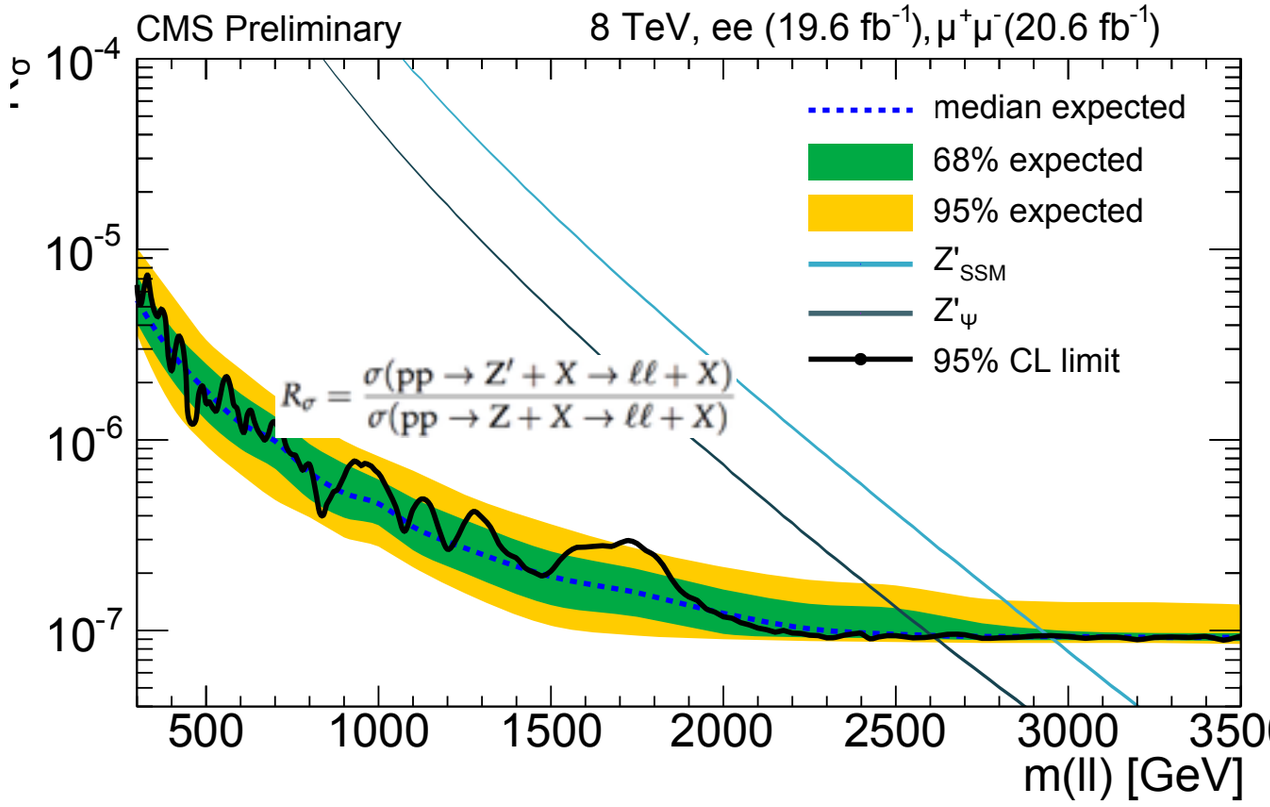
$p_T(\mu_1)$=653 GeV,

$p_T(\mu_2)$=646 GeV

Search for heavy resonance: dileptons

- CMS also has preliminary results from 8 TeV full data set in ee and μμ channels [CMS EXO-12-061]
- No excess seen; exclude variety of narrow resonances (Z'SSM, Z'ψ, etc.)
- Event selection
  - CMS: ET (e1,e2) > 35 GeV, pT (μ1,μ2) > 45 GeV, plus isolation criteria
  - ATLAS: ET (e1,e2)> (40,30) GeV, pT (μ1,μ2) > 25 GeV, plus isolation criteria





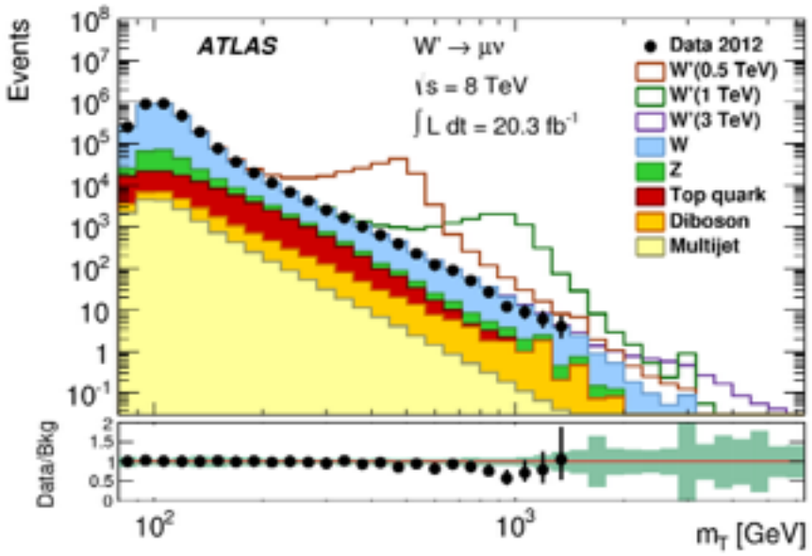
M(Z'	expected	observed
CMS	> 2.96 TeV	> 2.96 TeV
ATLAS	> 2.87 TeV	> 2.90 TeV

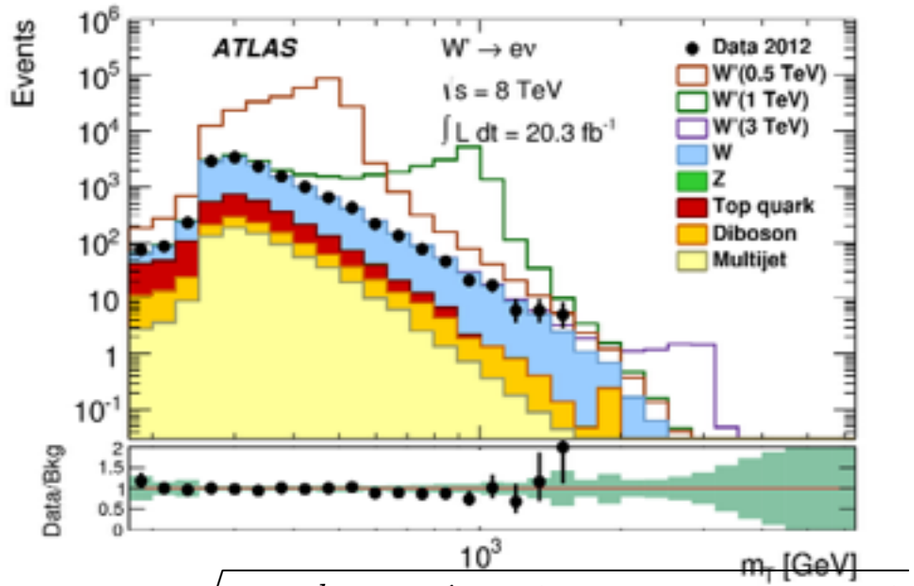
Searches in single Lepton states

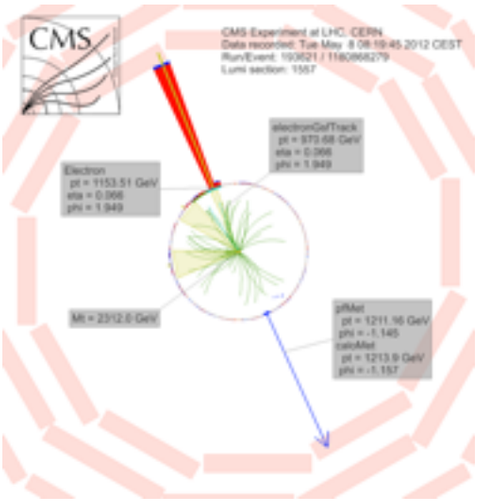
- Search for excess in transverse mass of e or μ with low mass neutrino
- Interpret as SSM W' (no interference with SM W) but also SSMS, SSMO, UED ..
- Interpret as Excite chiral boson (W*) with equivalent couplings

ATLAS arXiv:1407.7494

CMS arXiv:1408.2745







$$M_T = \sqrt{2 \cdot P_T^l \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{l,E_T^{miss}})}$$

	$e\nu$		$\mu\nu$	
$W \to \ell\nu$	2.65	± 0.10	2.28	± 0.21
$Z \to \ell\ell$	0.00163	± 0.00022	0.232	± 0.005
Diboson	0.27	± 0.23	0.46	± 0.23
Top	0.0056	± 0.0009	0.0017	± 0.0001
Multi-jet	0.066	± 0.020	0.046	± 0.039
Total	2.99	± 0.25	3.01	± 0.31

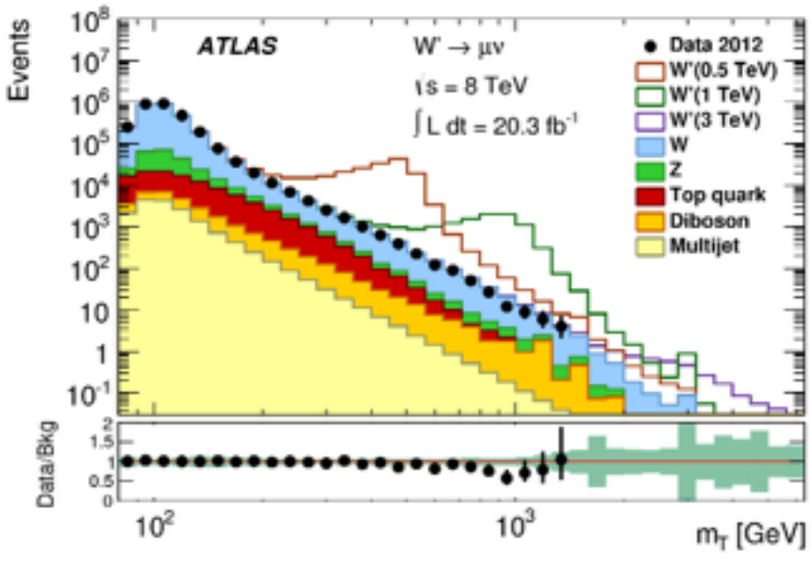
Low stat analysis (ATLAS expected events > 1.5 TeV)

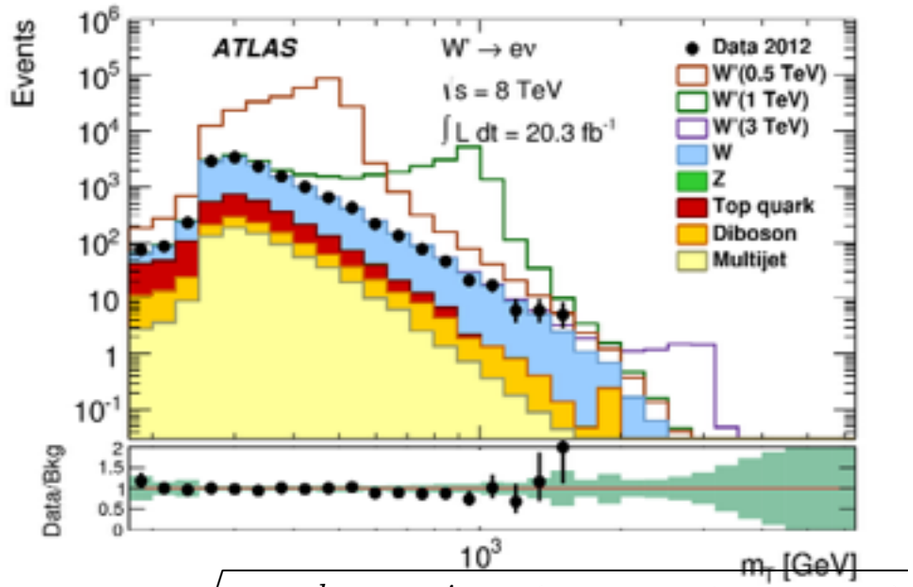
Searches in single Lepton states

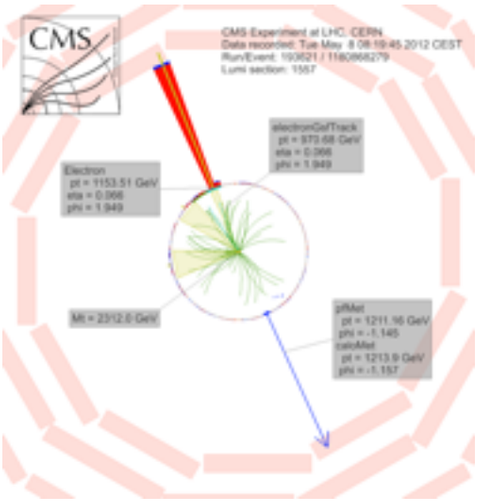
- Search for excess in transverse mass of e or μ with low mass neutrino
- Interpret as SSM W' (no interference with SM W) but also SSMS, SSMO, UED ..
- Interpret as Excite chiral boson (W*) with equivalent couplings

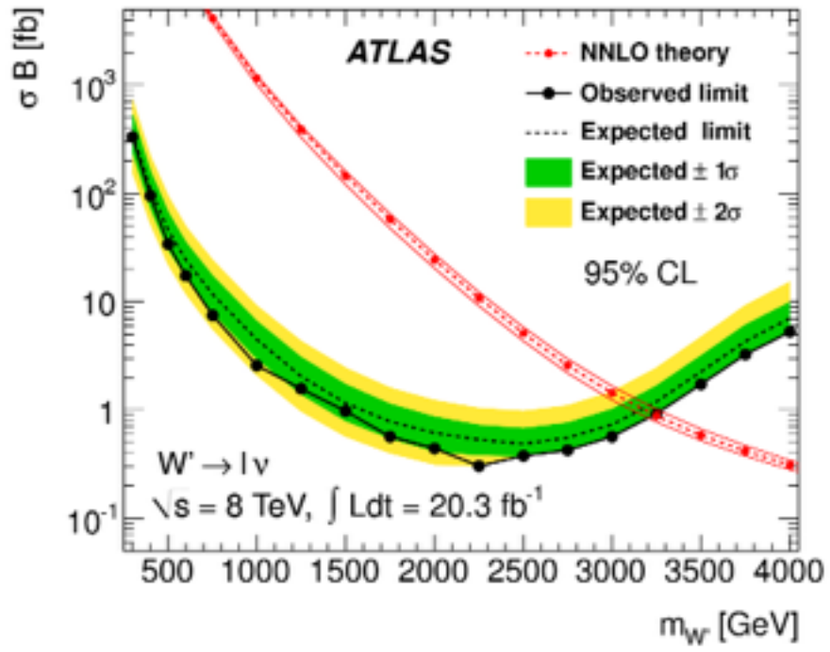
ATLAS arXiv:1407.7494

CMS arXiv:1408.2745









$$M_T = \sqrt{2 \cdot P_T^l \cdot E_T^{miss} \cdot (1 - \cos \Delta\phi_{l,E_T^{miss}})}$$

Decay	$m_{W'}$ [TeV] Exp.	Obs.	m_{W^*} [TeV] Exp.	Obs.
$e\nu$	3.13	3.13	3.08	3.08
$\mu\nu$	2.97	2.97	2.83	2.83
Both	3.17	3.24	3.12	3.21

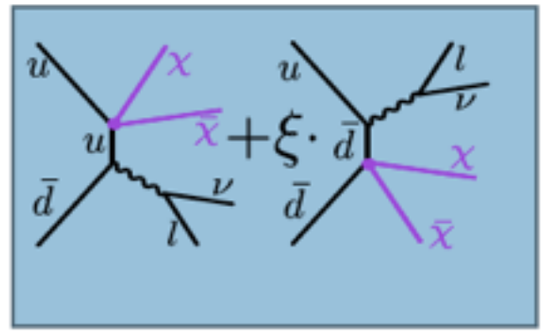
M(W'	expected	observed
CMS	> 3.26 TeV	> 3.28 TeV
ATLAS	> 3.17 TeV	> 3.24 TeV
ATLAS 7 TeV		> 2.55TeV

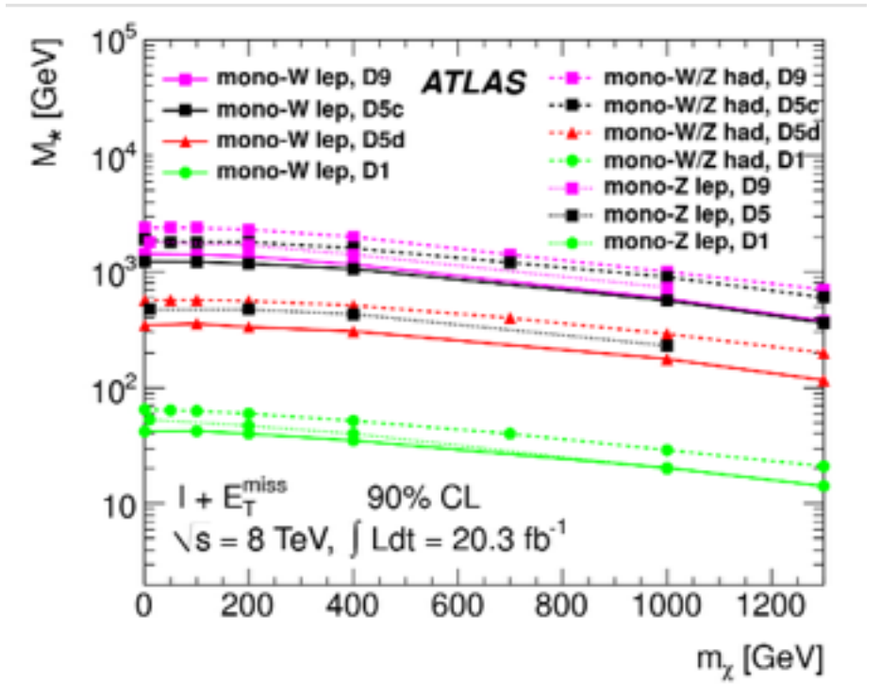
Searches in single Lepton states

- New interpretation: MONO W recoiling against pair produced DM
- Consider three couplings, interference
  - D1 Scaler, D5 -Vector (con/dis interference) and D9 tensor couplings
  - unlike mono jets, affected by interference effects
  - interference parametrised by ξ (see diagram)
  - M* Scale of unknown mediating interaction

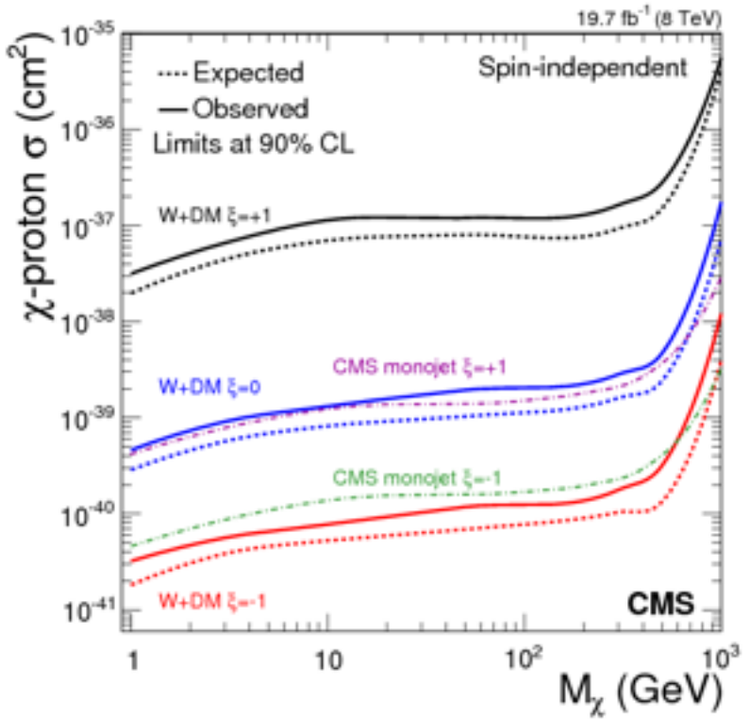
ATLAS-CONF-2014-017

[CMS EXO-13-004]

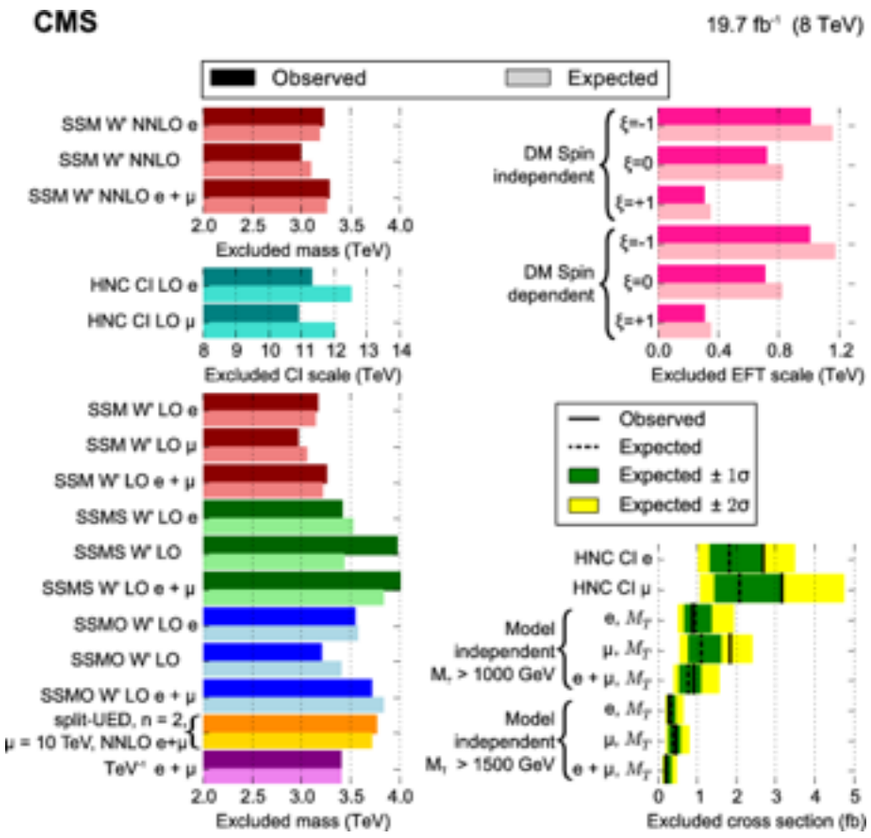




Observed limits on M* as a function of the mass of DM particle (mχ)



Excluded nucleon-DM cross section for vector-like and ξ =+1,0,-1

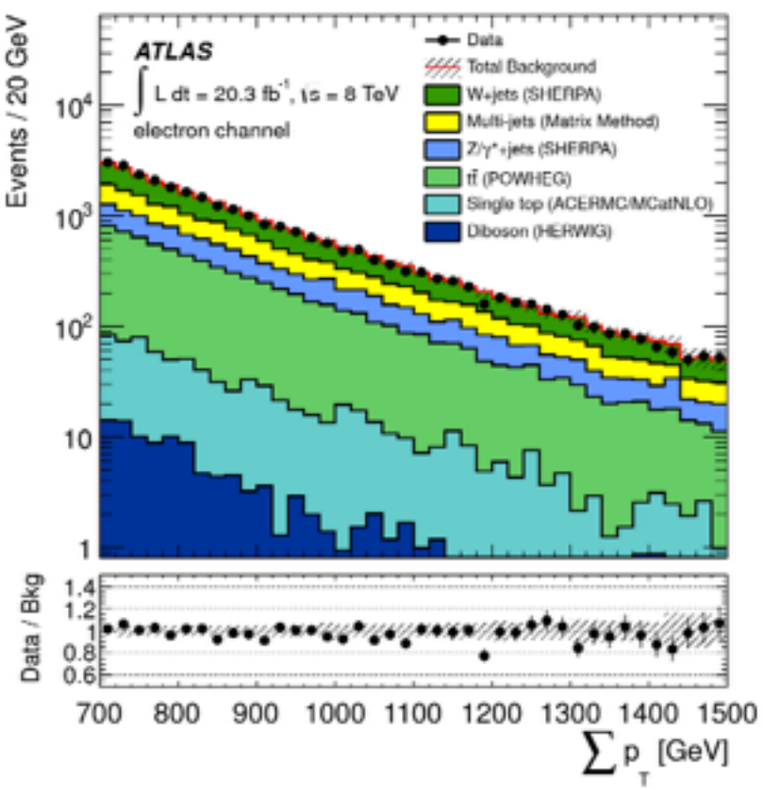


Summary e and mu and combinations.

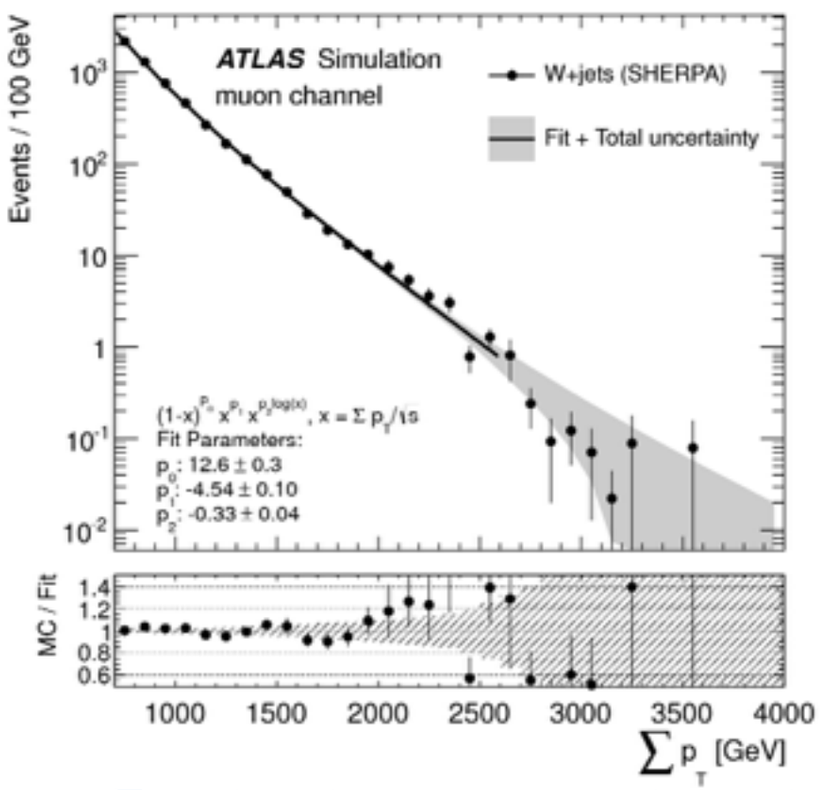
Microscopic BH & string balls in leptons + jets

arXiv:1405.4254

- ED with low scale gravity (ADD) allow prod of strong gravitational states decaying via Hawking radiation
- BH - high mass, high object multiplicity (reasonable BF to leptons)
- Require at least 3 high pT objects (jets + leptons)
- Construct scalar pT sum of selected objects
- Main BG W/Z+jets, ttbar, Multijets (to the e channel)
- Shape and relative fraction of BG with MC
- Derive scale factors for dominant BG in CR
- Fit each BG component to “dijets” function, systematics - choice of fit function



∑pT distribution for electron channel Pre-selection region.



Fit to ∑pT distribution, muon channel, W+jets background.

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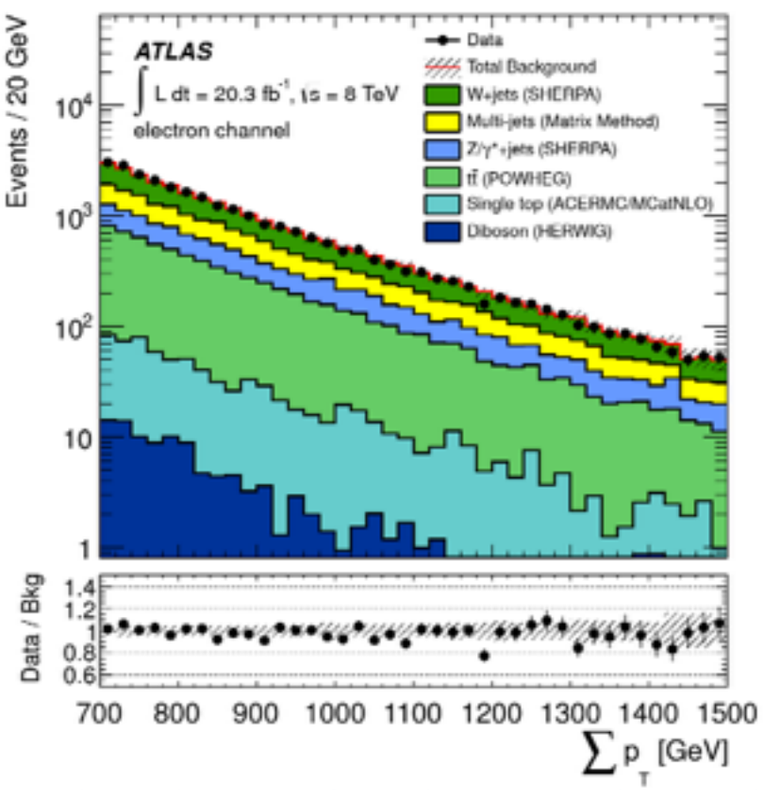
Different signature:
Like sign dimuons



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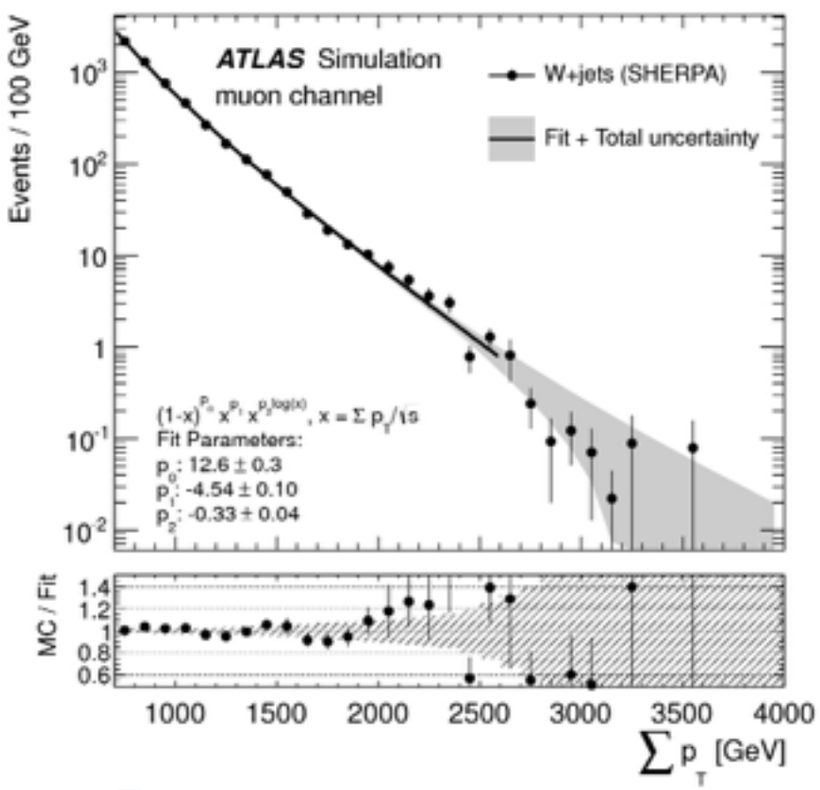
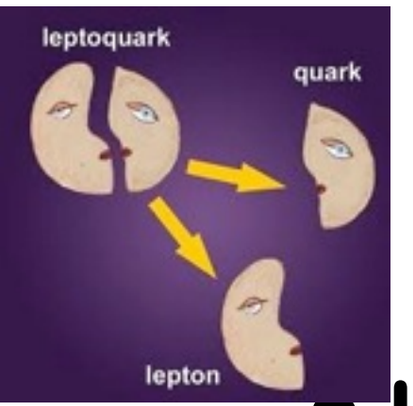
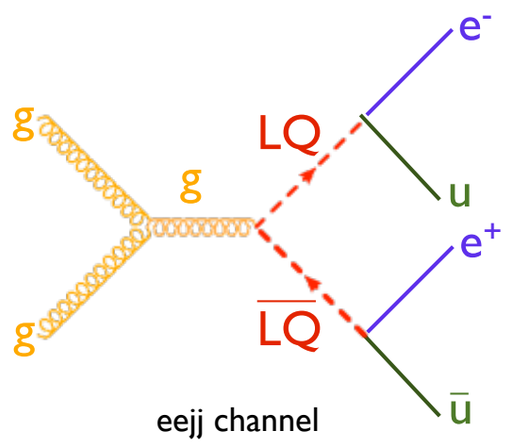


Fit to ∑pT distribution, muon channel, W+jets background.

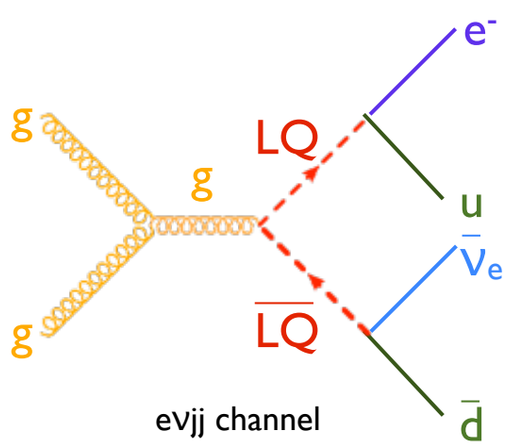
Exotics new particles



- **LeptoQuarks**
  - Select a data sample with **high signal and background acceptance**
  - Use **control regions** with (almost) no signal contamination to derive the major backgrounds normalization
  - Combine the variables which give the best signal - background discrimination into a **Log Likelihood Ratio (LLR)**, which is then used as the variable to look for the LQ signal

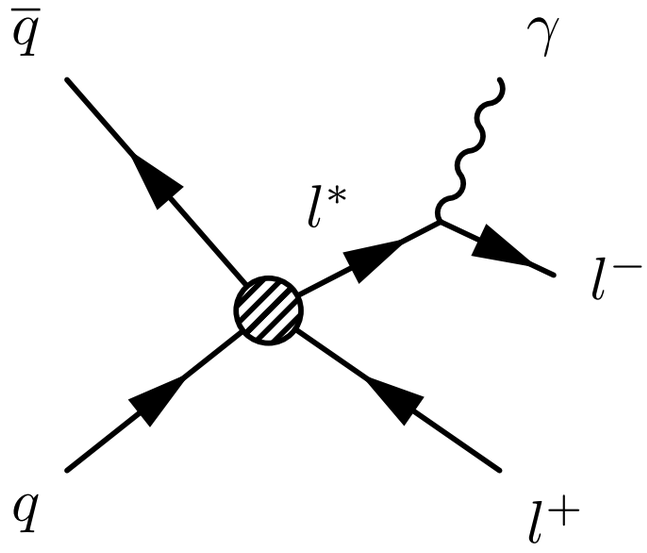


eejj channel



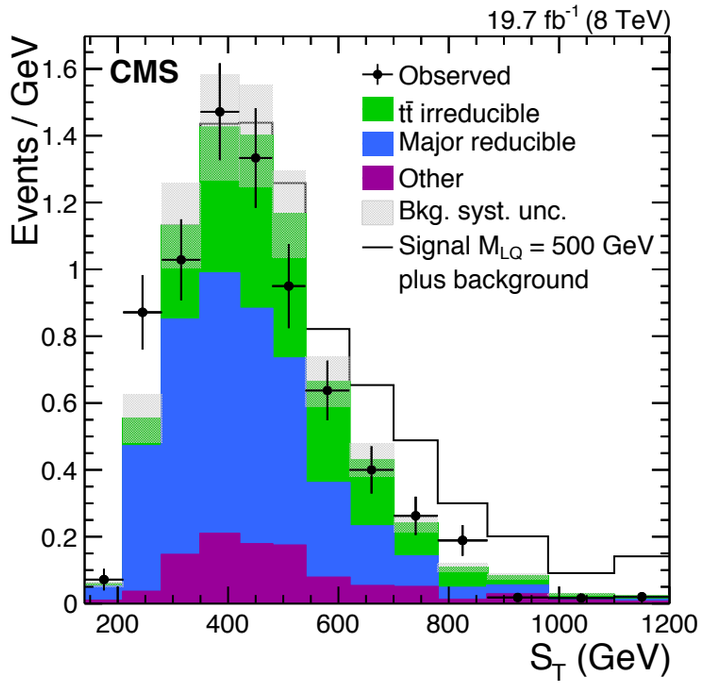
eνjj channel

- **Excited leptons**
- **…..**

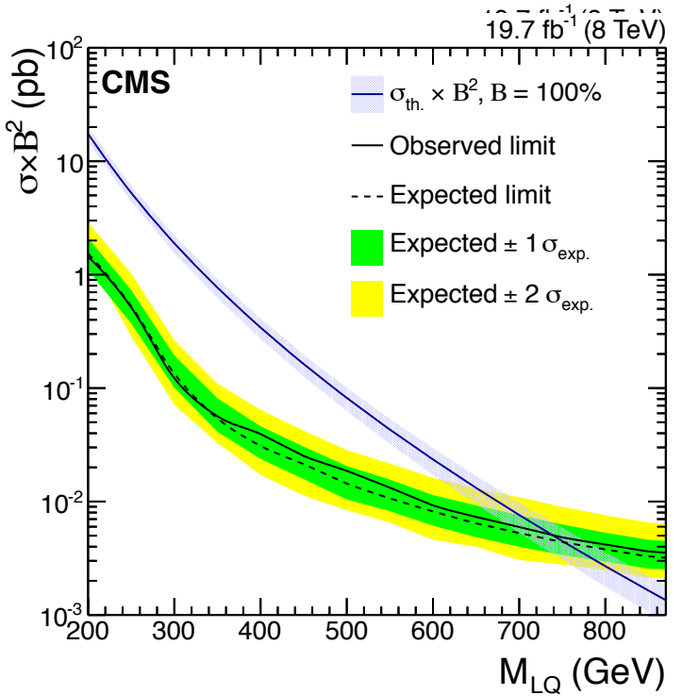


Search for scalar LQ3

- Search for scalar LQ pair each decaying to τ and b
- One τ decays hadronically and one leptonically
- Require two jets at least one tagged as bv jet
- Pair to minimise the difference $|M(\tau_h, j_m) - M(l, j_n)|$
- As no excess is found use the S_T distribution to extract limits on leptoquark (as well as stop scenarios)
- $S_T^{LQ)} = p_T(l) + p_T(\tau_h) + p_T(b-jet) + p_T(jet)$
- Major irreducible BG $t\bar{t}$ decaying to τ_h and τ_l
- Major reducible BG events with jet misidentified as τ_h



arXiv:1408.0806



LQ3 with masses bellow 740 GeV (and stops with masses below 576 GeV) is excluded at 95% CL

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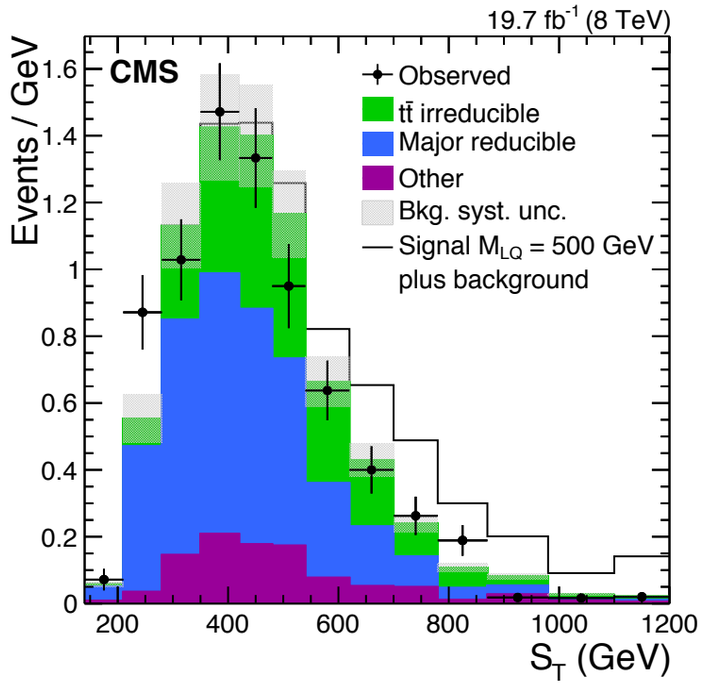

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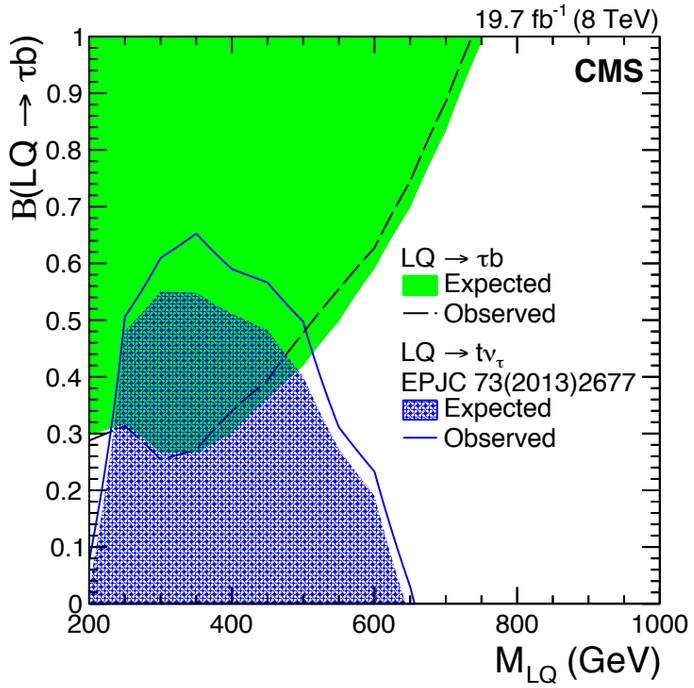

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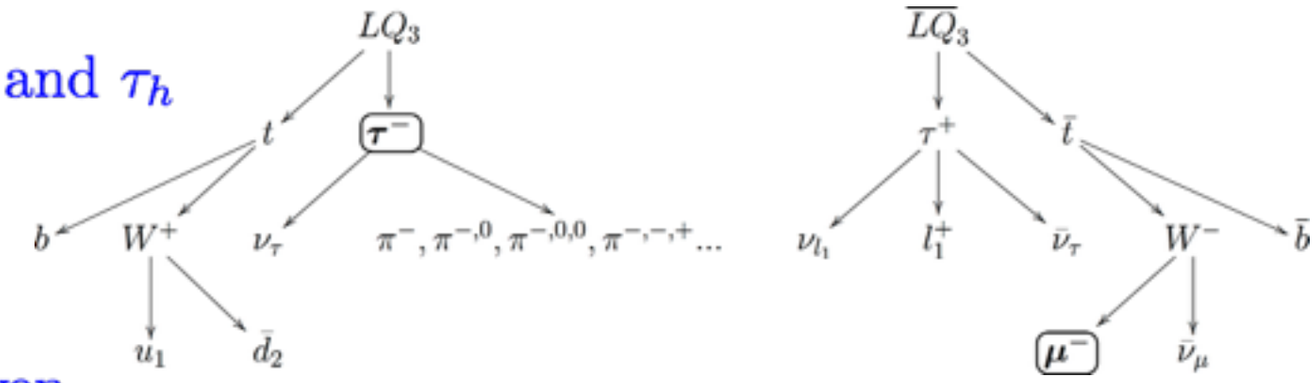
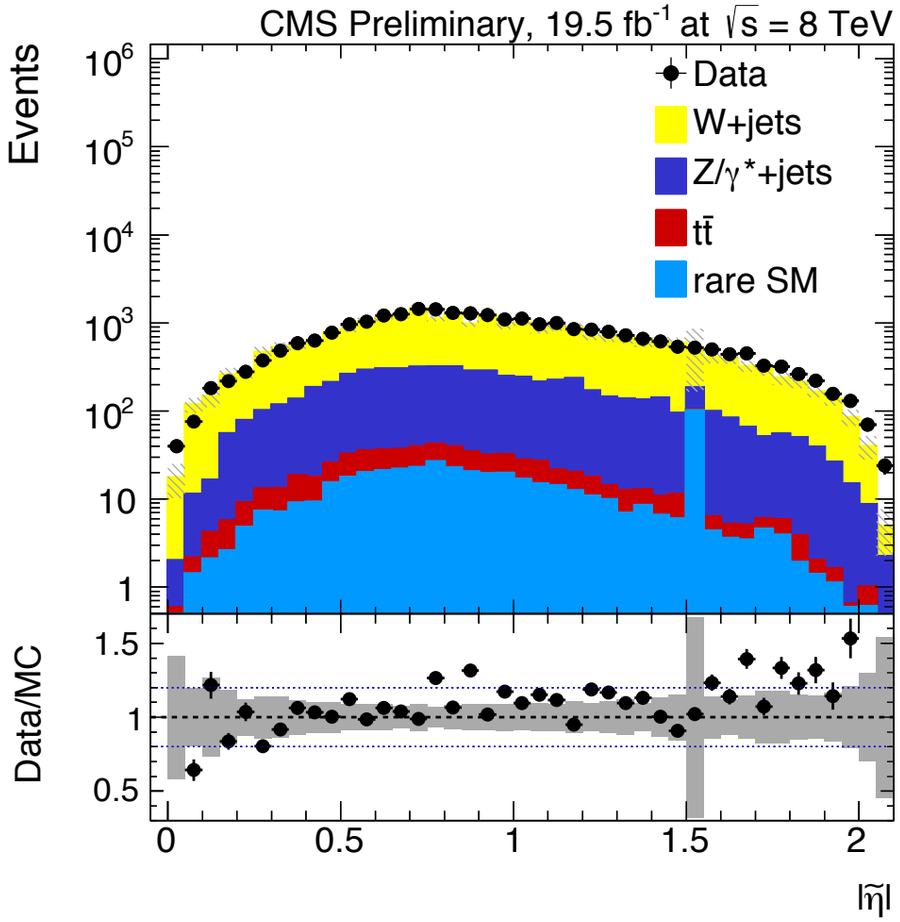
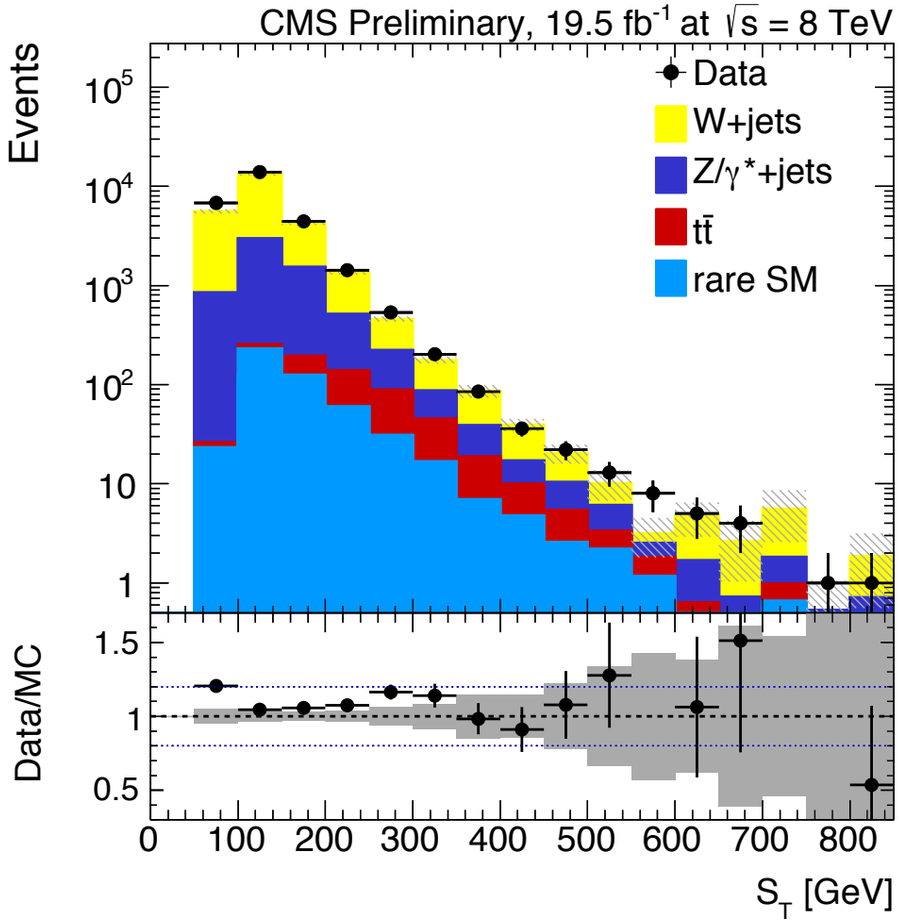
Search for LQ3 -> to top tau pairs

- Search for scalar LQ pair each decaying to τ and top
- The signature is like sign W (decaying to μ) and τ_h
- Require $S_T > 400$ GeV, additional two jets, reject dimuon around Z maas
- Centrality $|\tilde{\eta}|$ - average of all e, μ, τ in the even
  Split to central (forward) $|\tilde{\eta}| < 0.9$ (> 0.9) events







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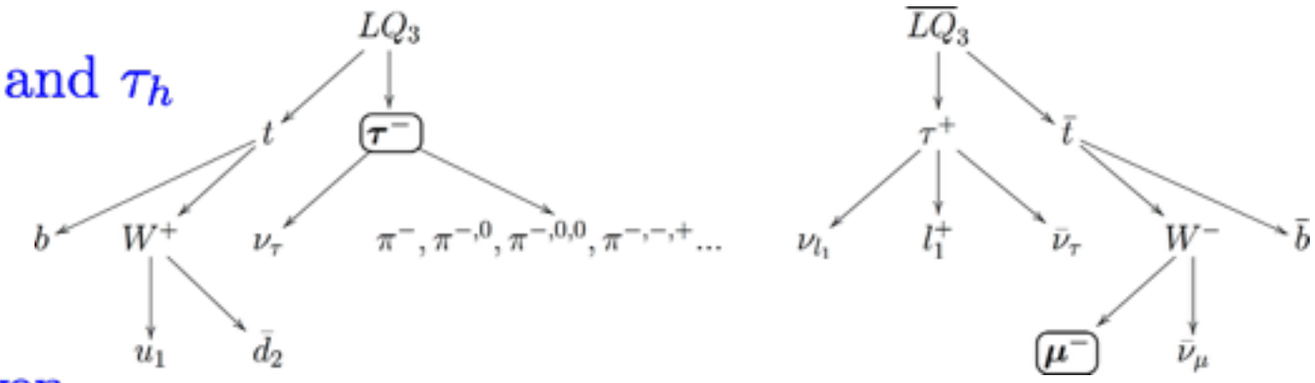

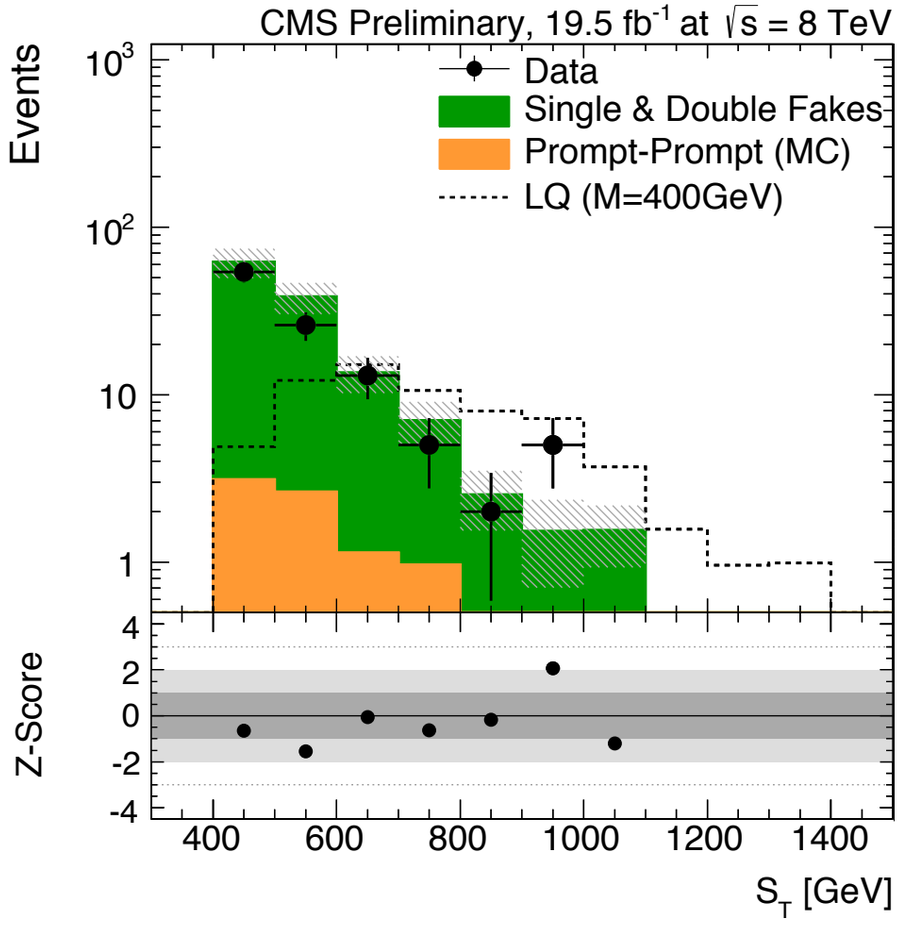

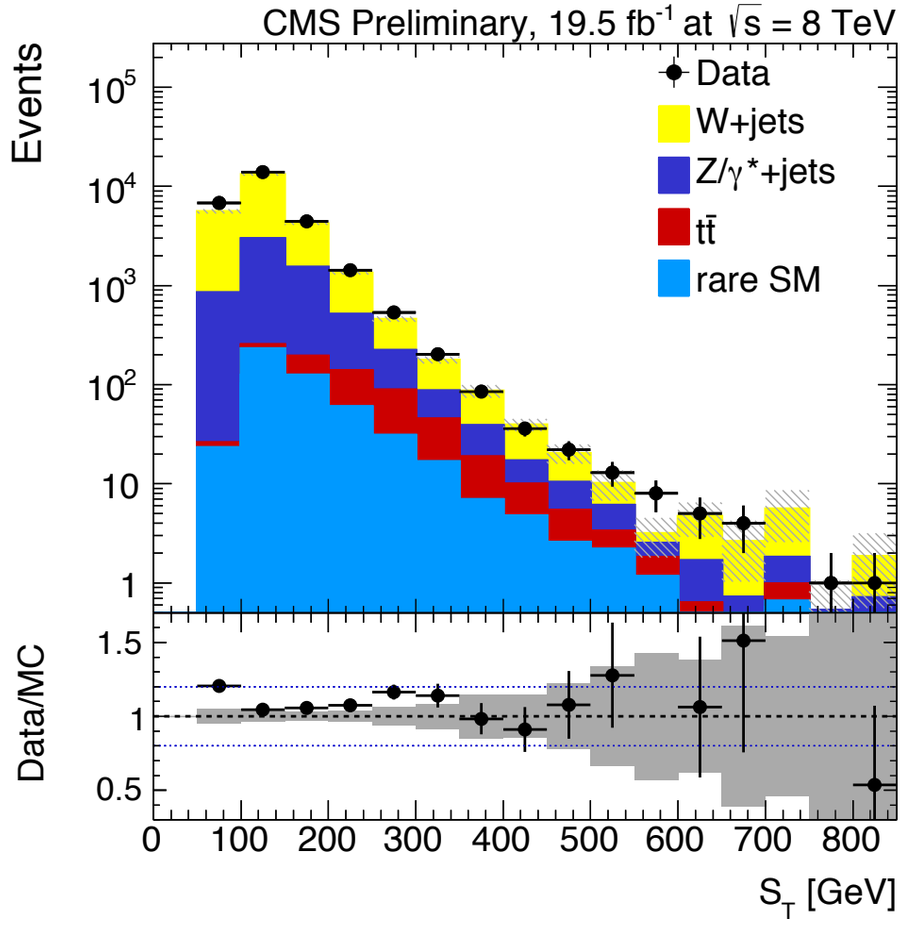

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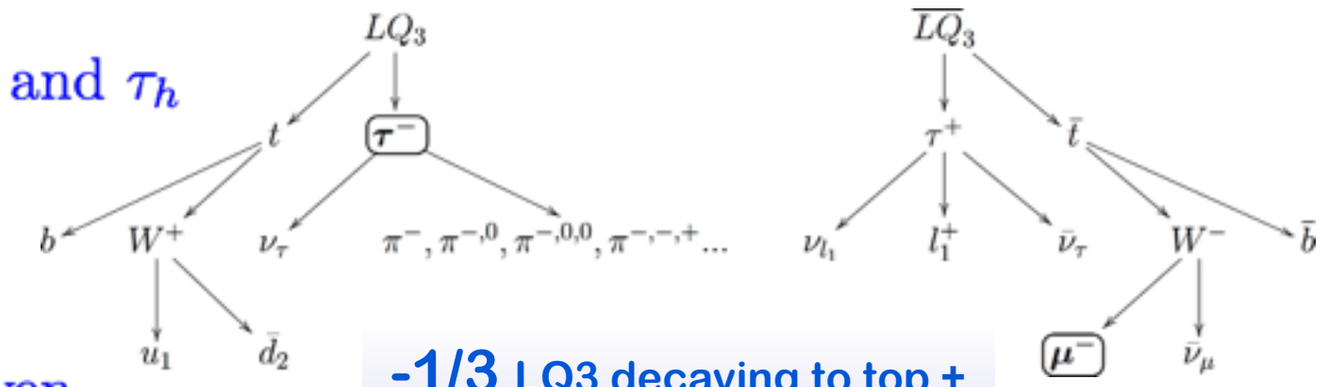
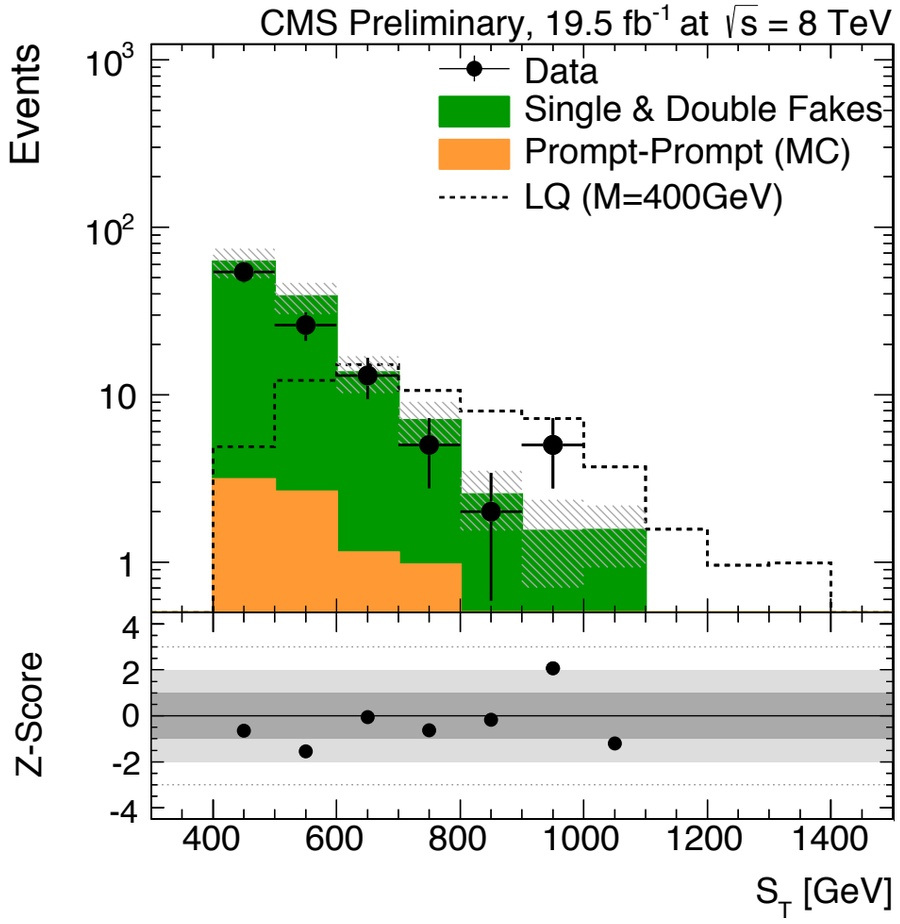
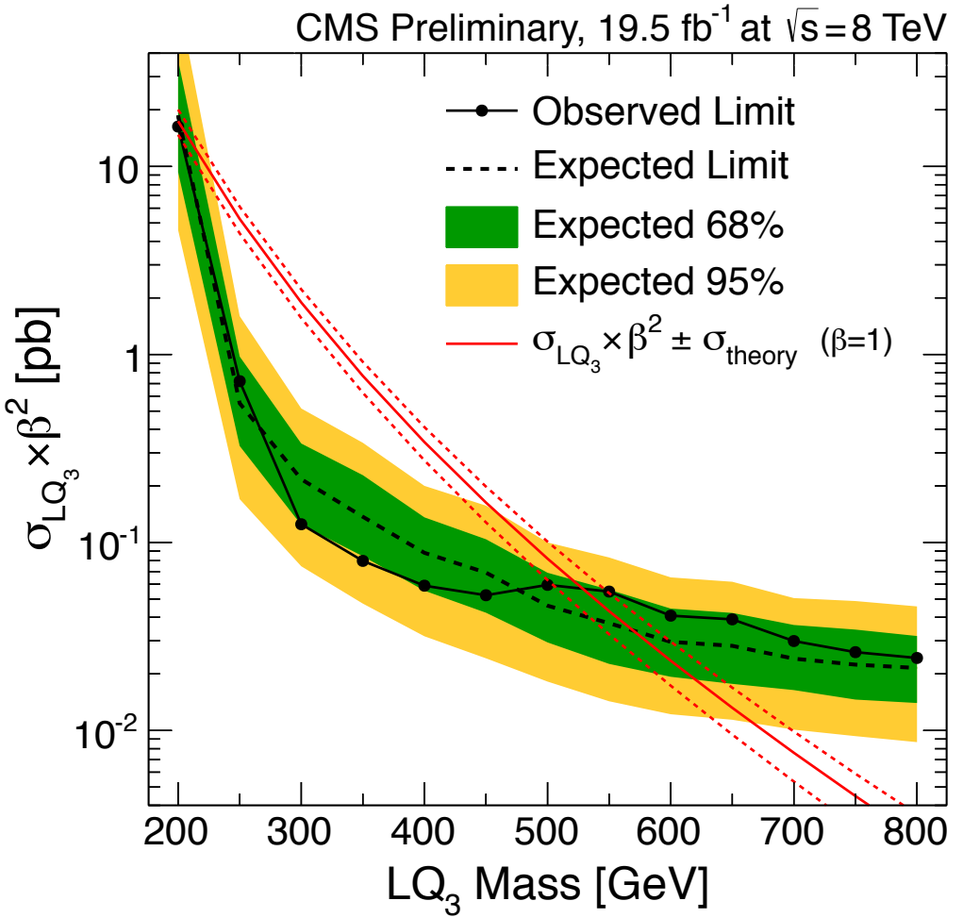


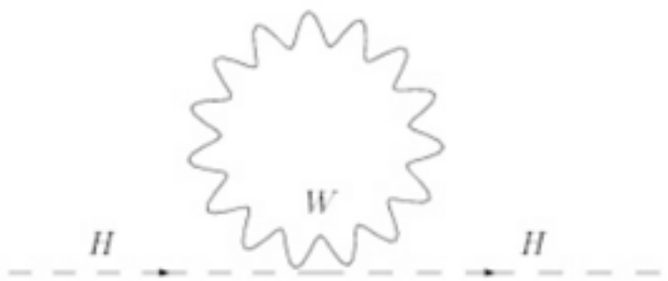
-1/3 LQ3 decaying to top + tau with mass bellow 550 GeV is excluded at 95% CL

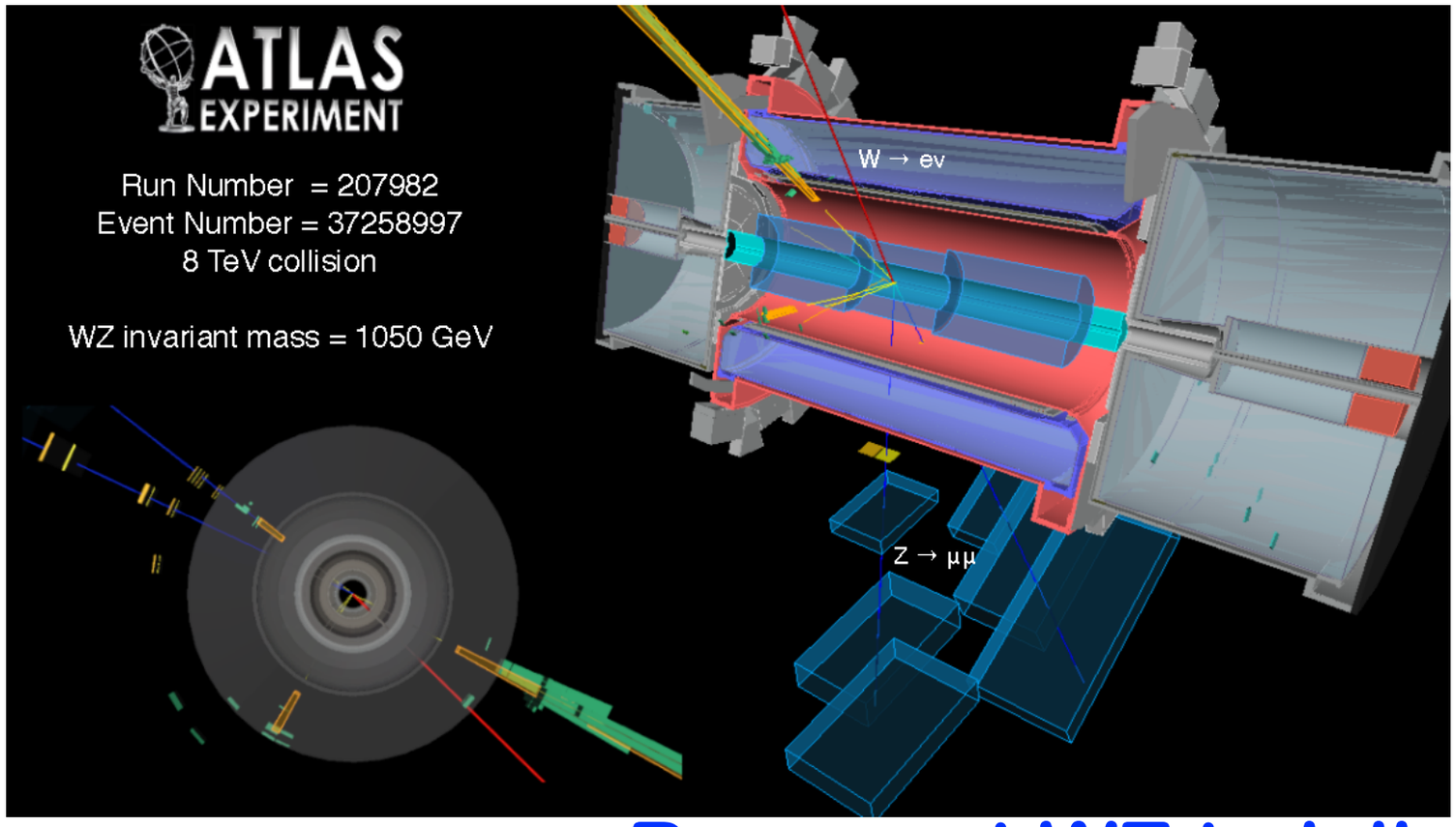




Dibosons

- **Dibosons**
  - Search for new Physics with two or more EW bosons
  - Signatures are various combinations of diboson: lljj, lvjj, lvll, lvlv, W/Z +photon,jjjj and JJ, monoZ
  - Main Physics interests are:
    - ➡ New heavy Gauge bosons
    - ➡ RS gravitons
    - ➡ Composite Higgs
    - ➡ Extended Guage Model (EGM)



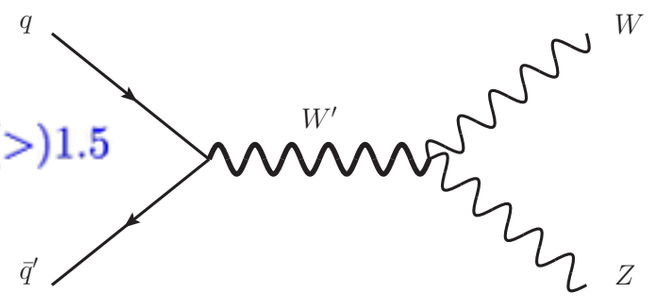


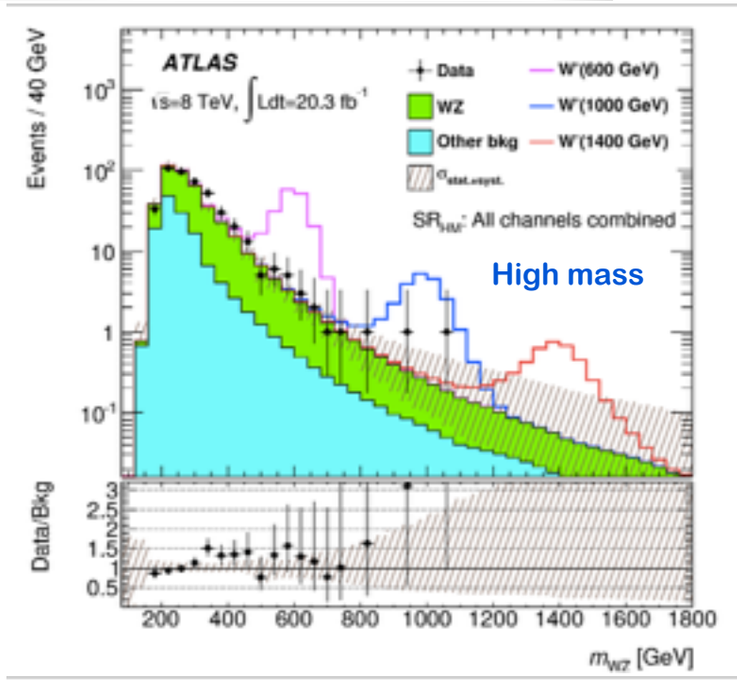
Resonant WZ to lvll

Resonant WZ to lvll

- Event Selection
  - Exactly 3 leptons
  - 2 OS SF $|m_{ll} - m_Z| < 20$ GeV
  - $E_T^{miss} > 25$ GEV
  - $\Delta y(W, Z) < 1.5$
  - High (low) mass region $\Delta\phi(l^W, E_T^{miss}) < (>)1.5$
- Reconstruct m_{WZ} using $m(l^W, E_T^{miss}) = m_W$
- Background estimation
  - Prompt BG, 3 or more prompt leptons, MC: WZ, ZZ (Powheg), $t\bar{t} + W/Z$ (Madgraph)
  - non prompt BG: photon conversation MC $Z\gamma$ (Sherpa), where leptons from hadron decays Data driven: ll+jets, ($t\bar{t}$, single t, Z+jets)

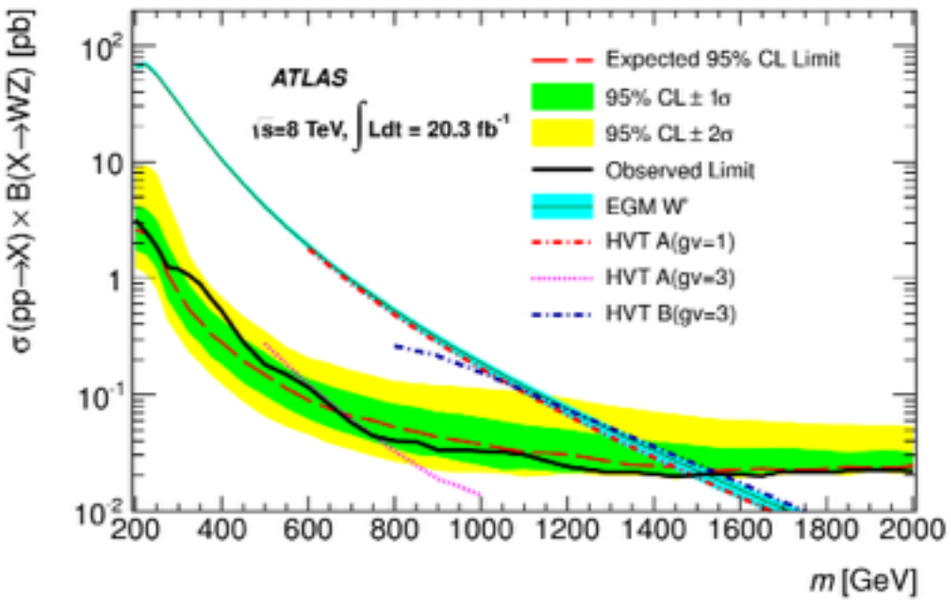
arXiv:1406.4456

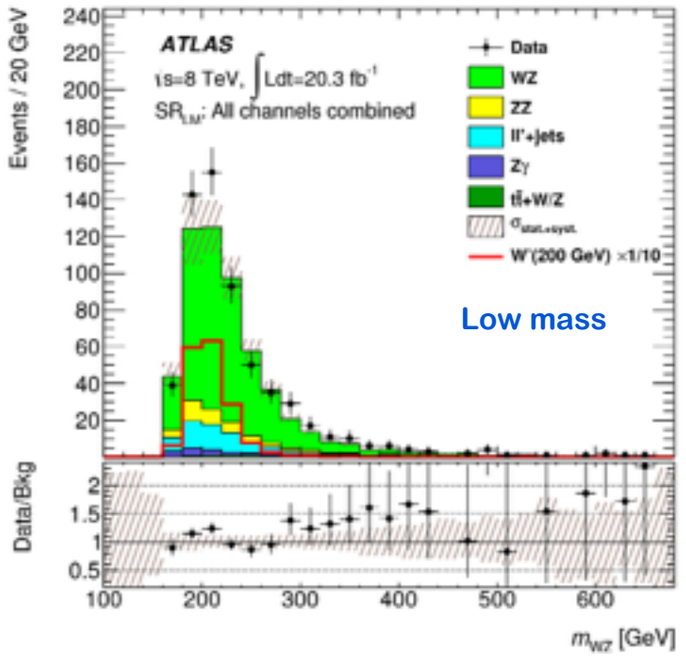




Limits are set on the signal σ × BR(WZ) using CLs method for the EGM W′ and heavy vector triplets (HVT) models.

Related searches 8 TeV:
CMS:
ZZ -> lvqq EXO-12-022
WW -> lvqq EXO-12-021
WZ -> lvll EXO-12-025
ATLAS
ZZ -> lljj CONF-2012-150





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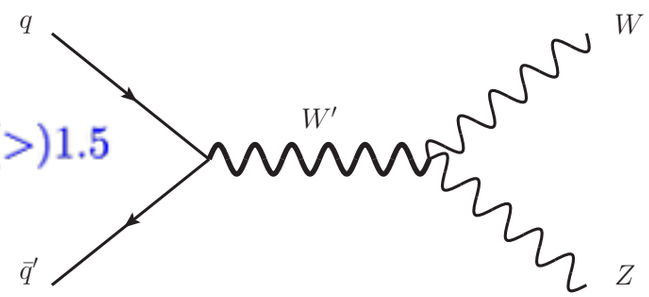

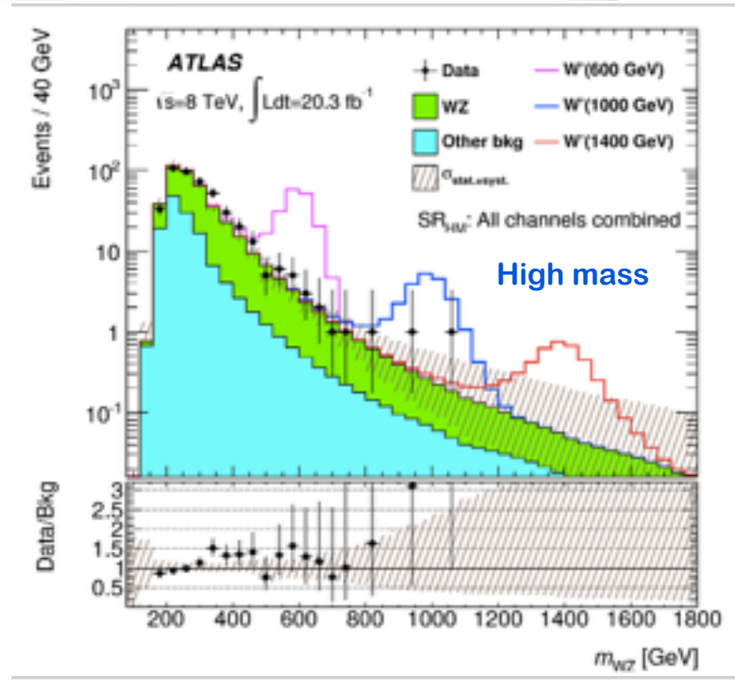

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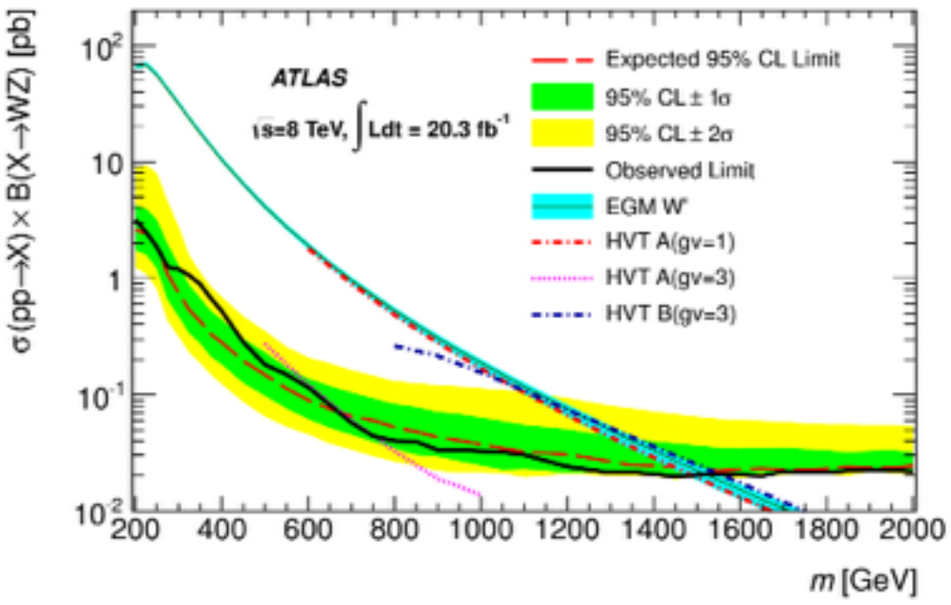
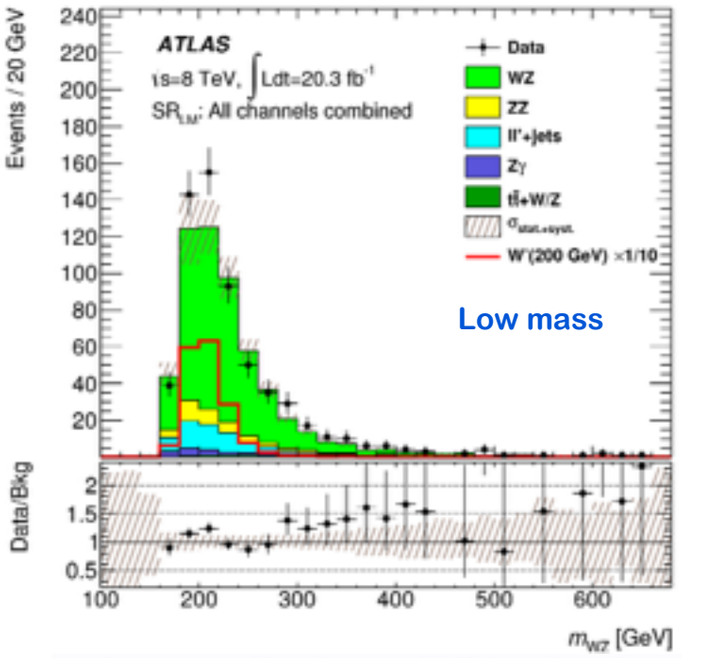
ZZ -> lljj CONF-2012-150





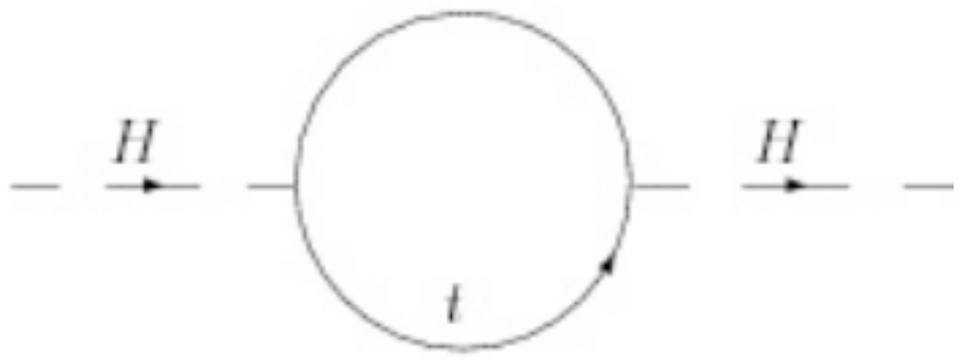
Lower limit on W' is 1.52 (observed 1.49) TeV

CMS: exclude between 0.17 to 1.45 TeV

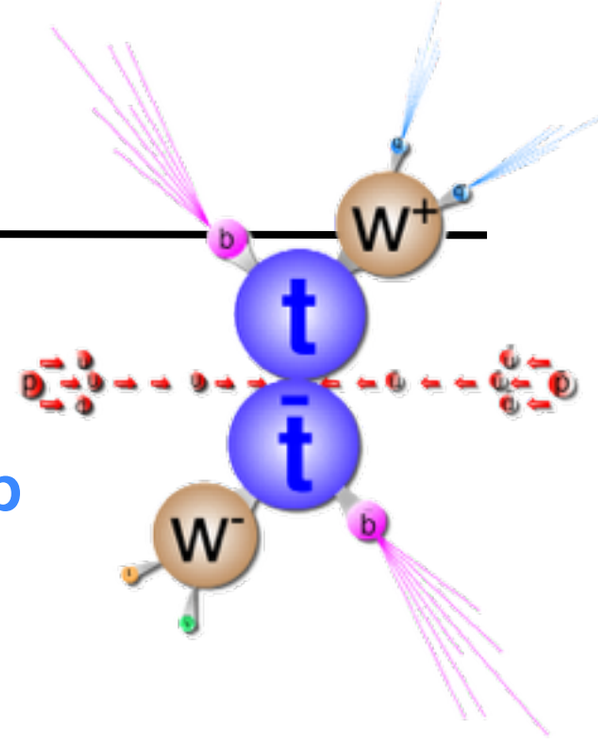
Heavy Quarks & Top like signal

Heavy top mass may point to a special role in EWSB

- Look for BSM with top or top-like particles
- Signatures include: ttbar resonances decaying leptonically and hadronically, pairs and single production of heavy b-like and top-like particles decaying to Wb, Wt, Hb and Ht. The events include resolved and boosted top jets.
- Models include:
  - ➡ Leptophobic topcolor resonances
  - ➡ RS KK gluons
  - ➡ Heavy W' decay to t-b
  - ➡ 4th generations .. VLQs

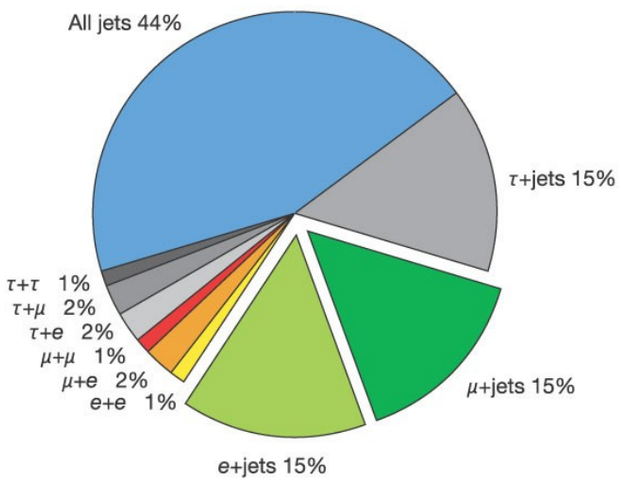


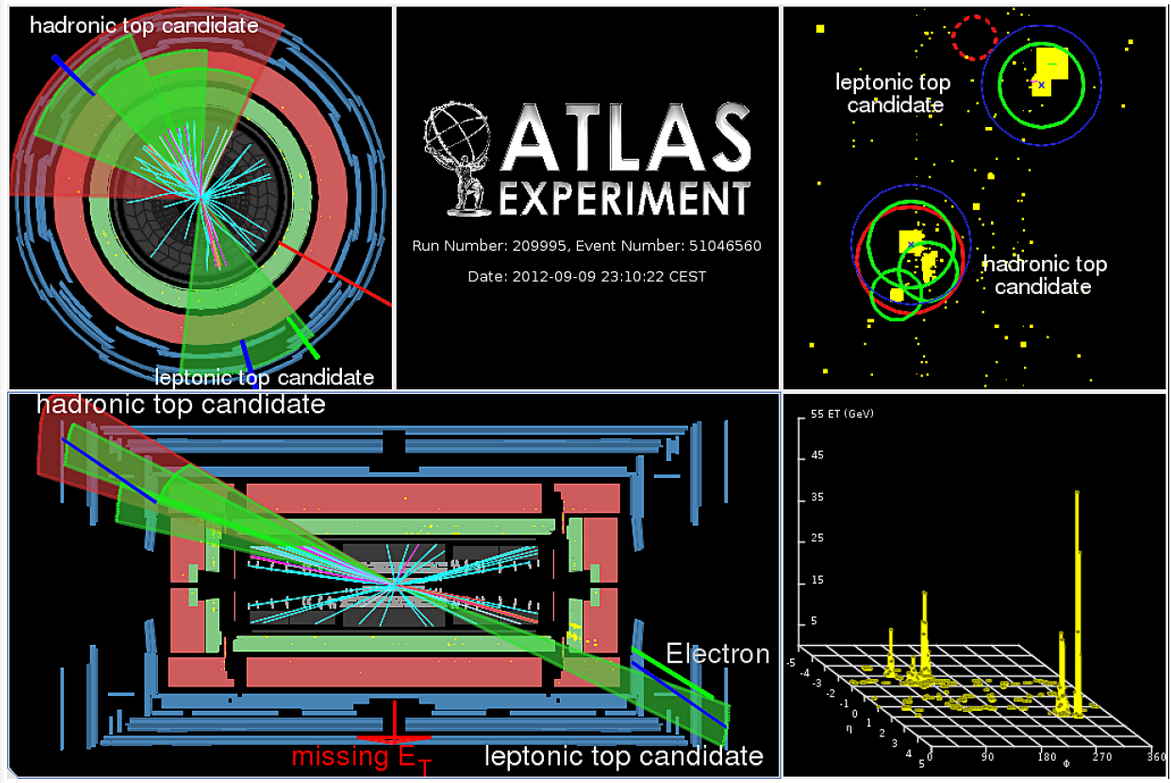
Top antitop resonance



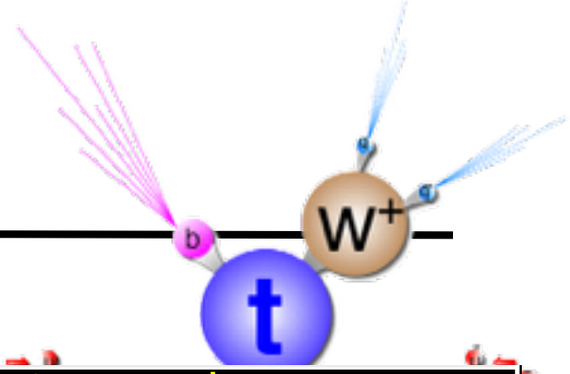
$t\bar{t}$ -> WbWb

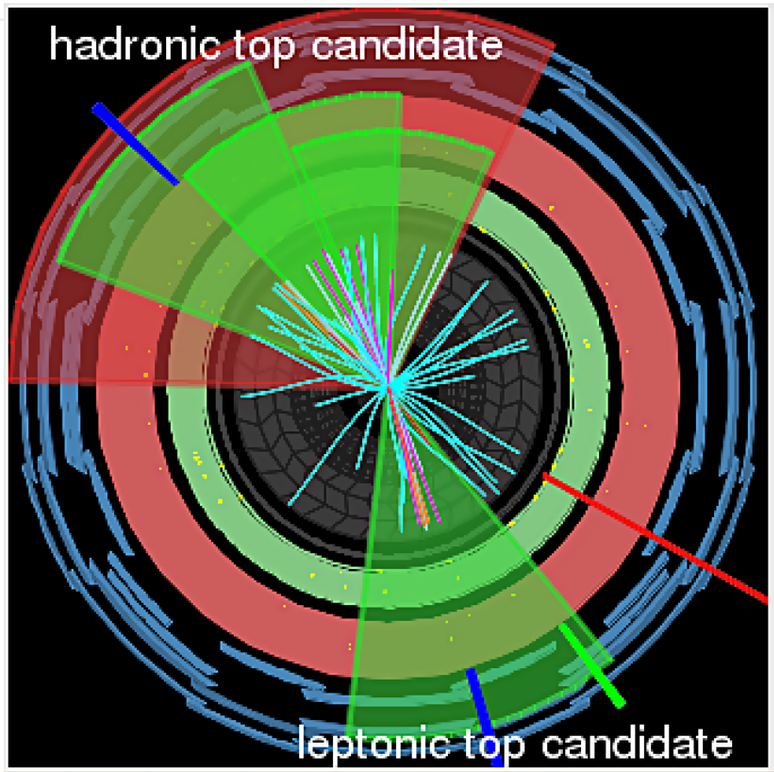
- Many models favor resonance decay to $t\bar{t}$: Z' top-color, bulk RS (KK gluon)
- Various decay channels:
  - $t\bar{t}$ ->dileptons, 2 X b+ W->lv
  - $t\bar{t}$-> lepton + jet resolved and boosted, W->lv, W->jj +2b
  - $t\bar{t}$-> hadronic BOOSTED

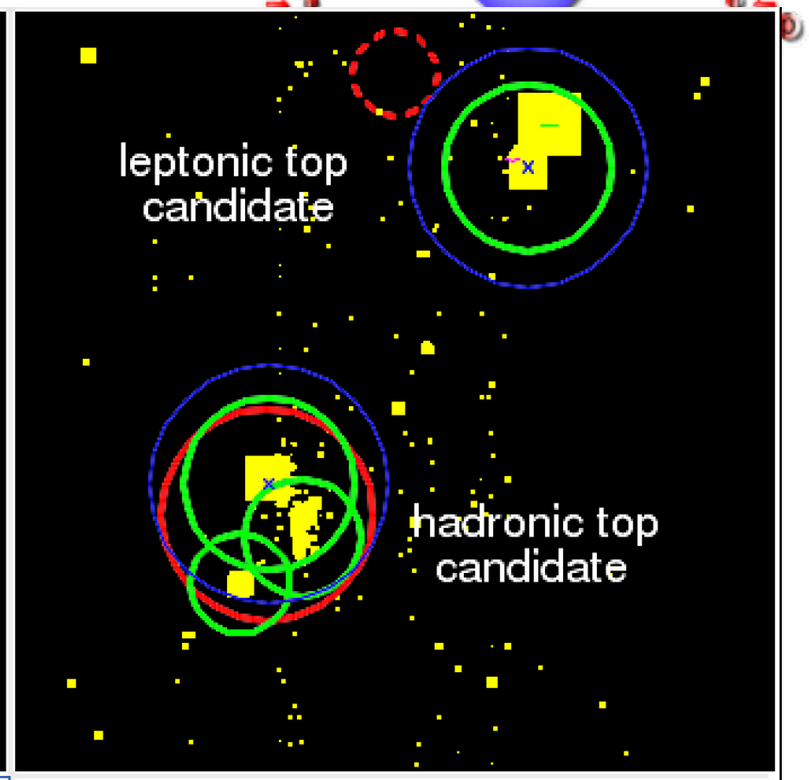


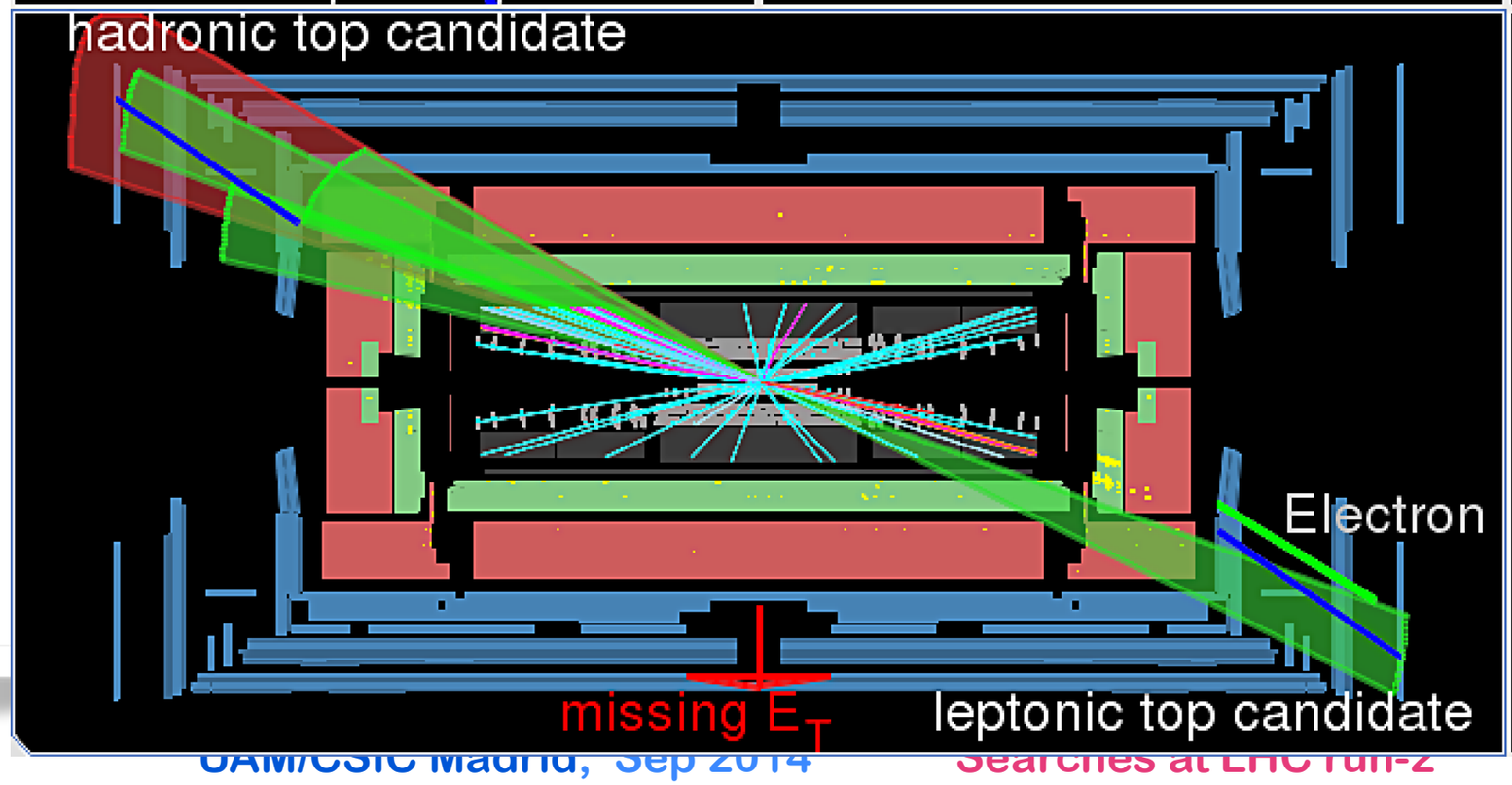


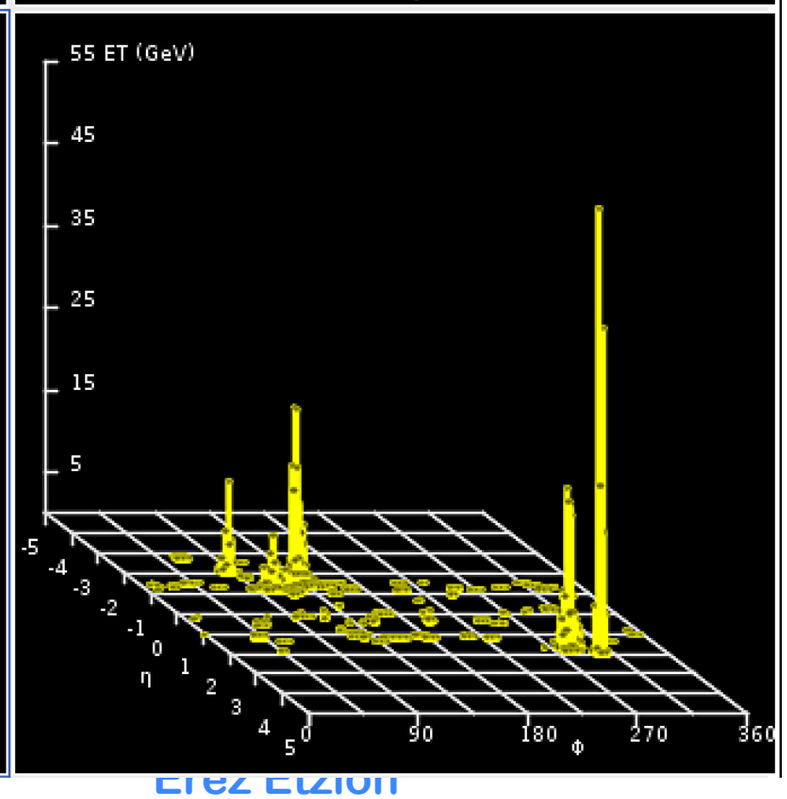
Top antitop resonance









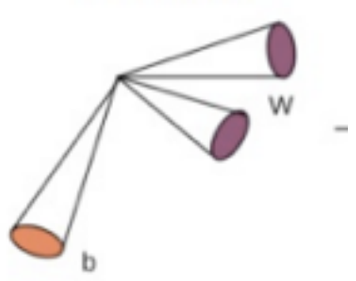


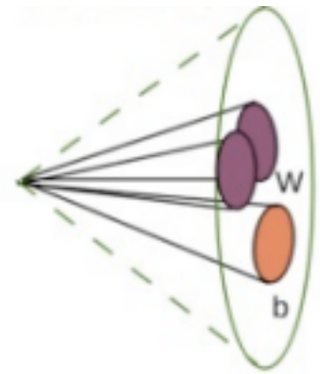
Top antitop resonance (lepton+jet)

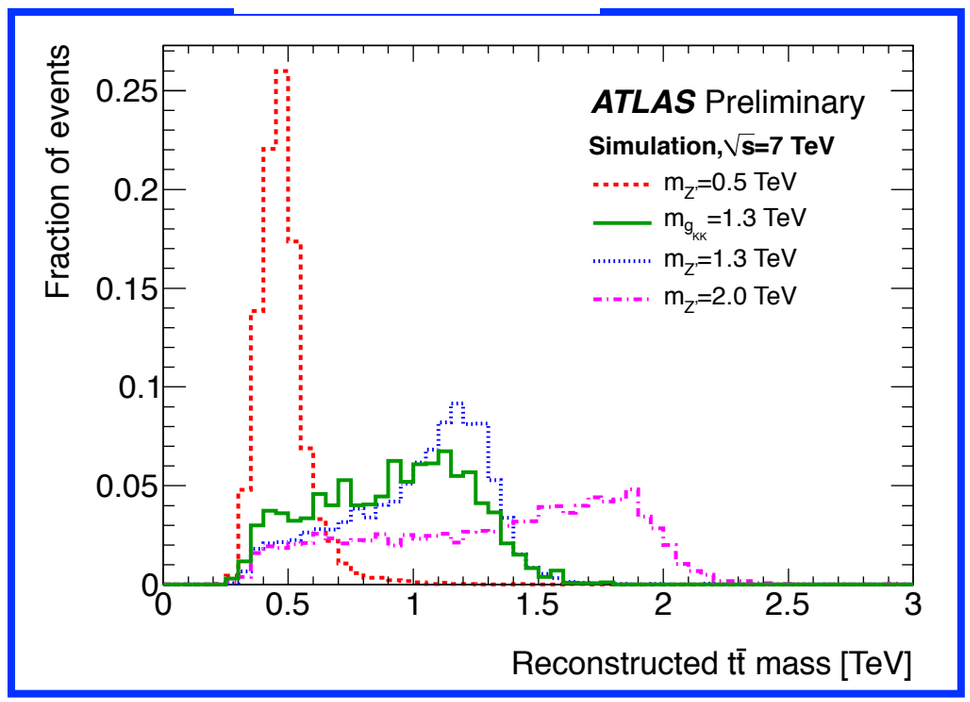
ATLAS-CONF-2013-052

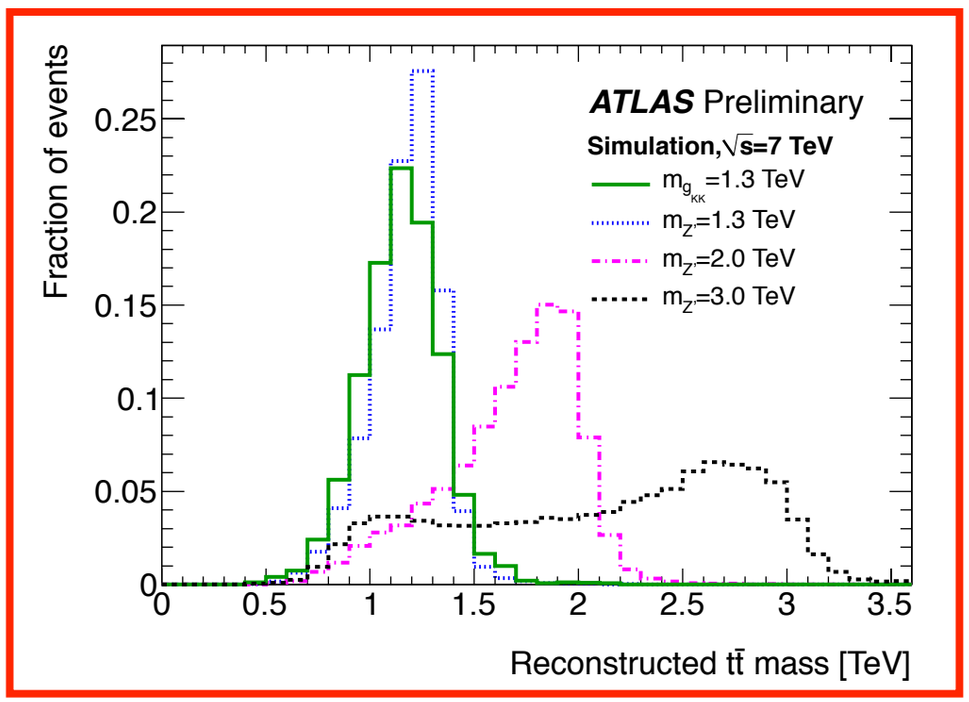
Recently Improved efficiency at high $t\bar{t}$ mass with tuning lepton isolation (shrinking the cone at high momentum), using Fat (R=1 anti-Kt) jets trigger which performs better than lepton trigger at high mass

combine resolved and boosted selection (choose the better mass resolution on an event base)

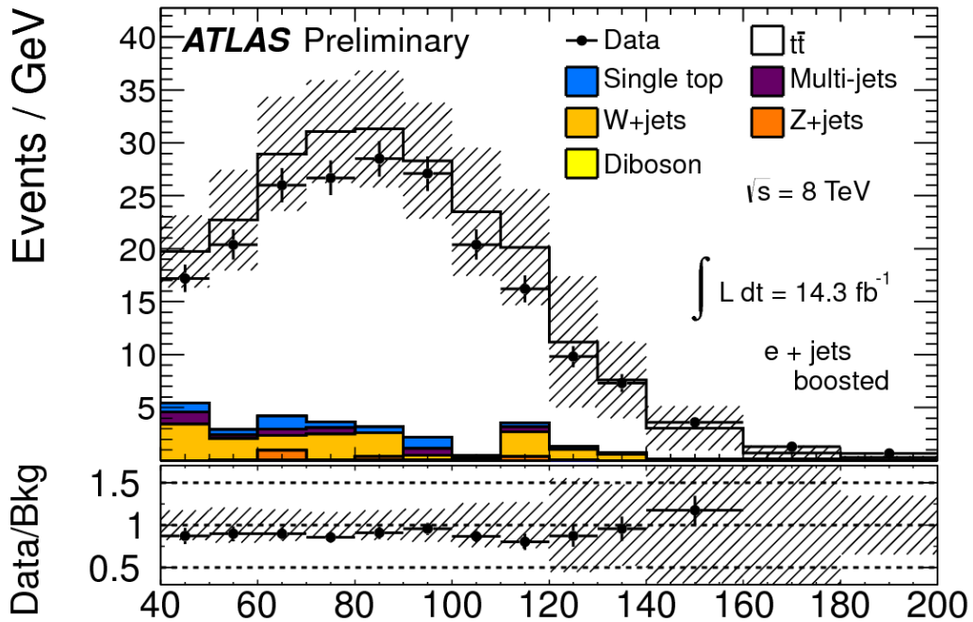


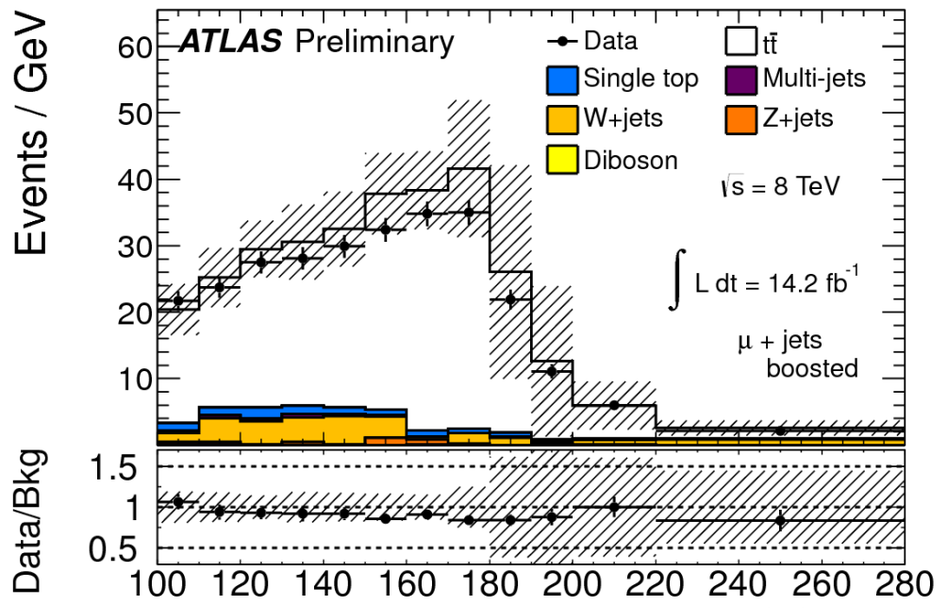




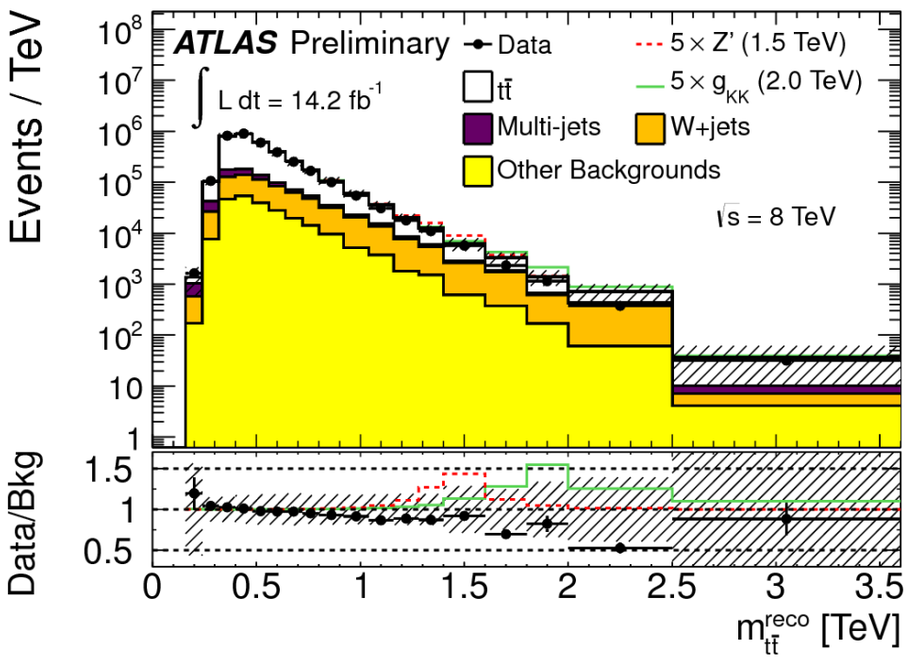


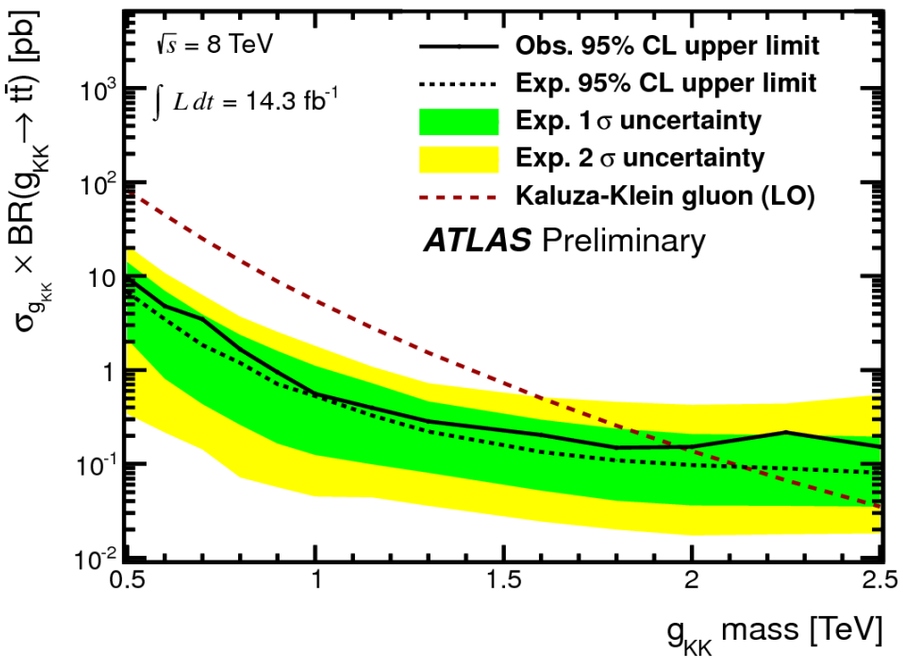
Top antitop resonance (lepton+jet)





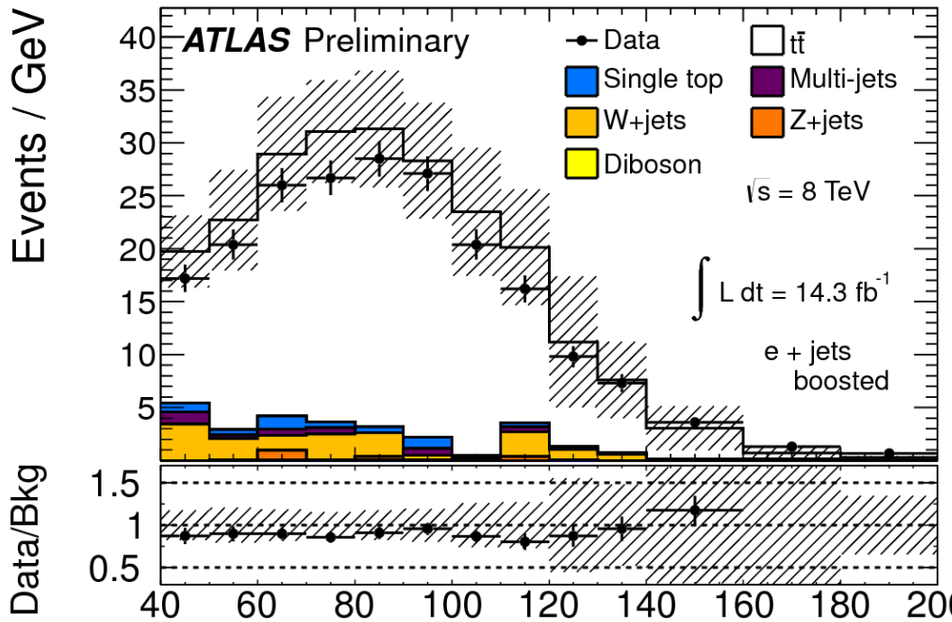
$$\sqrt{d_{ij}} = \min(p_{Ti}, p_{Tj}) \times \Delta R_{ij}$$

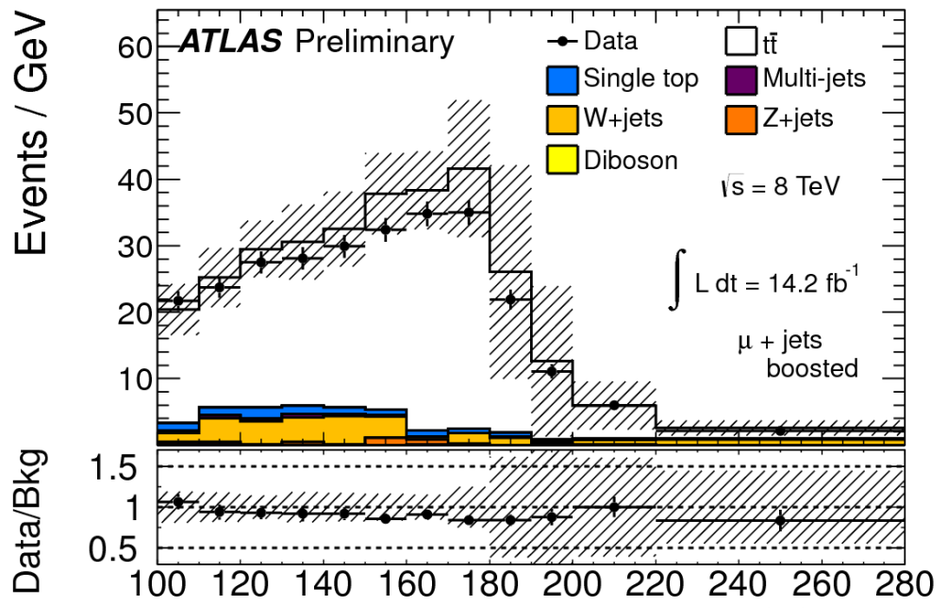




Exclude $m(g_{kk}) < 2.0$ TeV 95% CL
$\Gamma m(g_{kk}) = 15\%$

Top antitop resonance (lepton+jet)





$$\sqrt{d_{ij}} = \min(p_{Ti}, p_{Tj}) \times \Delta R_{ij}$$

	95% CL on 1-3% width		95% CL on 10% width		95% CL on Kaluza-Klein gluon	
	Expected	Observed	Expected	Observed	Expected	Observed
CMS lepton+jets	2.0 TeV	2.1 TeV	2.6 TeV	2.7 TeV	2.2 TeV	2.5 TeV
CMS all-hadronic	1.7 TeV	1.7 TeV	2.5 TeV	2.3 TeV	2.1 TeV	1.8 TeV
CMS combined	2.1 TeV	2,1 TeV	2.6 TeV	2.7 TeV	2.4 TeV	2.5 TeV
ATLAS lepton+jets	1.9 TeV	1.8 TeV	-	-	2.1 TeV	2.0 TeV

Novel boosted tagging techniques (jet+jet)

- **HEPTopTagger**
  - start with Fat (1.5) C/A jets
  - split, re-cluster test for top compatibility
- **TopTemplate**
  - compare jets topology to 300k templates
  - use AKT (R=1.0) jets
  - top quark efficiency ~75%
- **Modeling**
  - ttbar MC@NLO, Herwig,
  - signal Z'-Pythia, kk-gluon Madgraph
  - multijet BG - data driven (loose b and t tagging)

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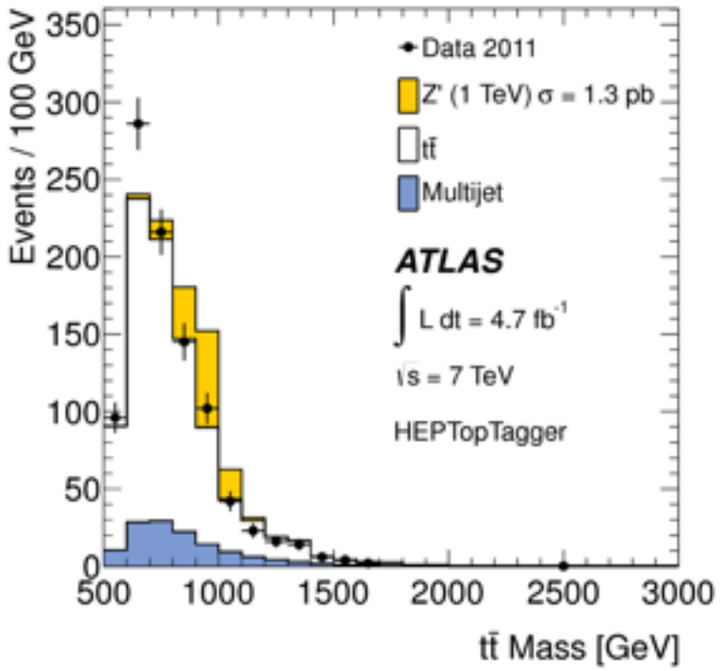
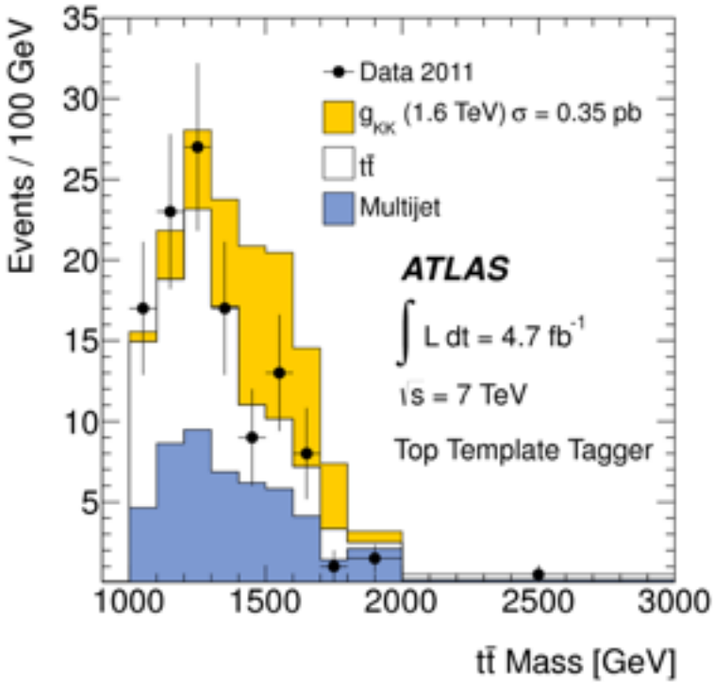
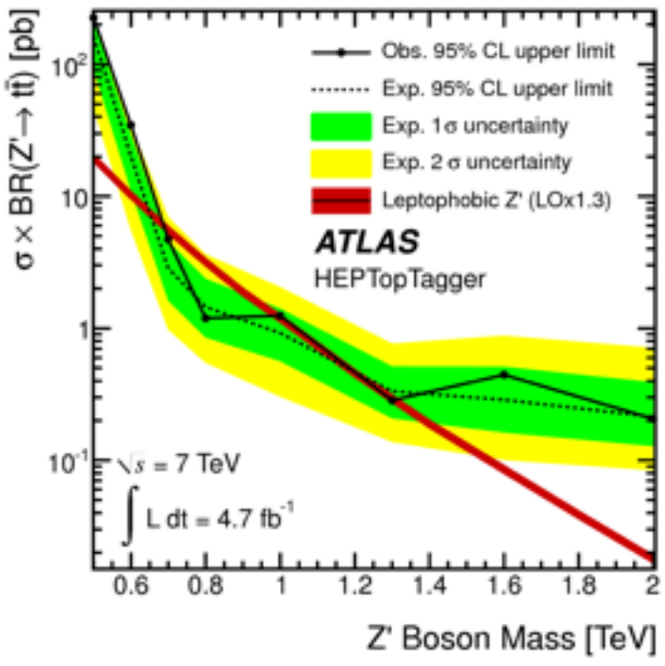
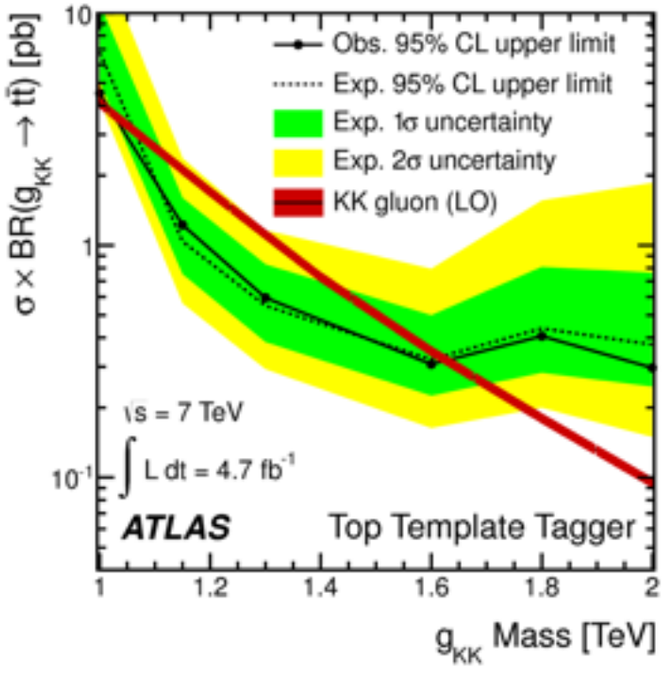




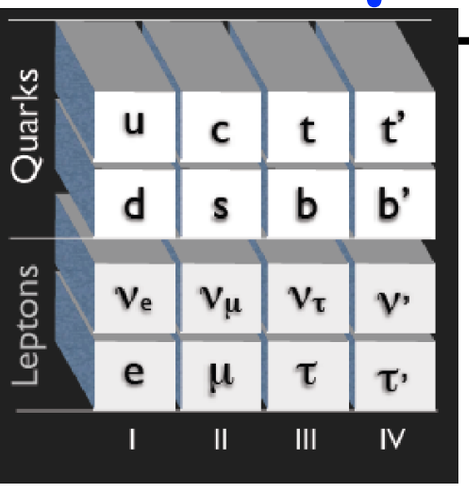
HEPTopTagger

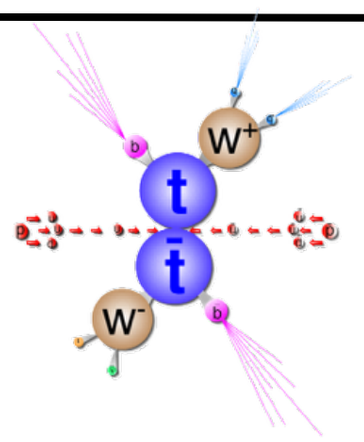


TopTemplate Tagger



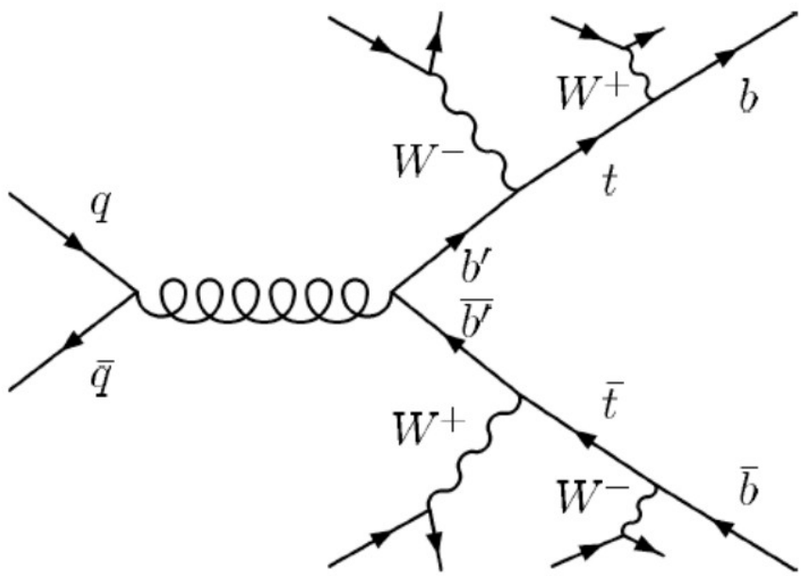
4th Generation and Heavy Quarks





"Standard" SM4

- **t't'->WbWb: like heavier $t\bar{t}$**
- **b'b'->WtWt messier than $t\bar{t}$ (extra 2 x W)**
- **Single production: important at very large mass, with large BG.**



- **4th generation would significantly enhance Higgs production cross section**
  - ➡ **(almost) excluded by observed Higgs cross-section**
- **Beyond 4th generation: Vector-like quarks (VLQ) in composite Higgs theories**
  - **diverse phenomenology**
  - **The left– & right handed components of VLQs transform the same way under SU(2)**
    - ➡ **Allows for a gauge invariant mass term independent of the Higgs and of some unspecified BSM origin.**

$$T_L\ ,\ T_R$$

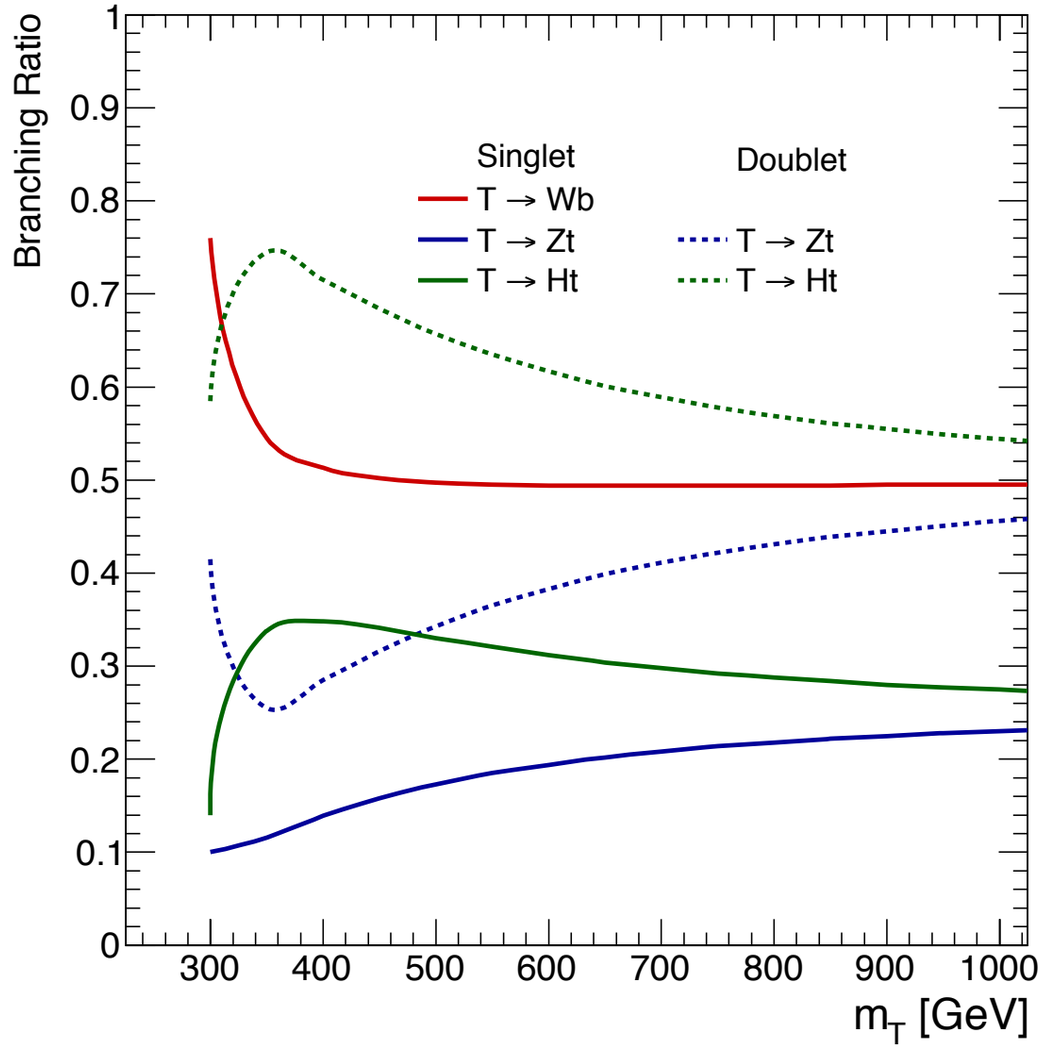
$$\begin{pmatrix} T_L \\ B_L \end{pmatrix}, \begin{pmatrix} T_R \\ B_R \end{pmatrix}$$

$$M\bar{Q}Q$$

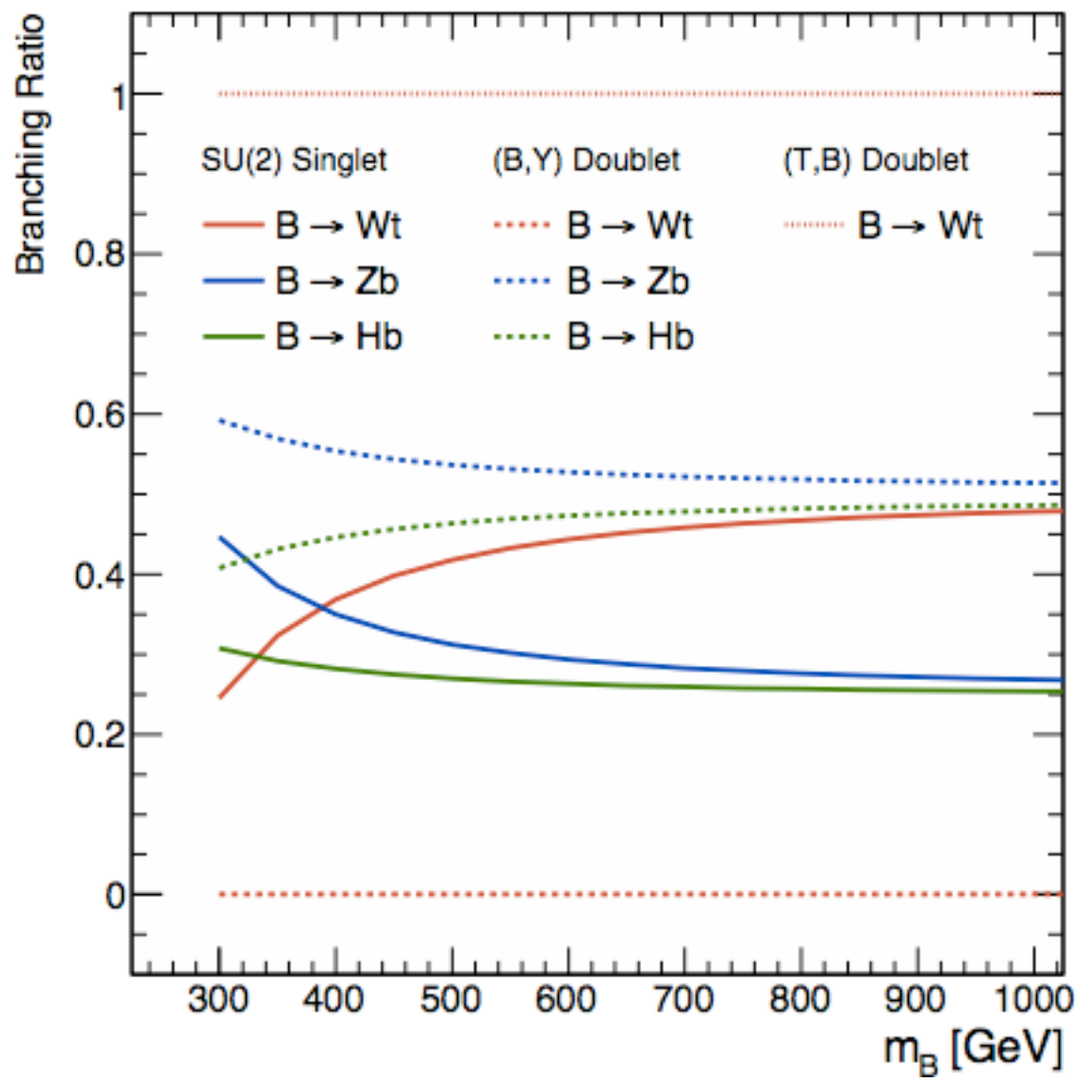
- **VLQ appear in many BSM theories, mainly with strong EWSB.**
  - **Loose constraints on CKM4**
    - ➡ **decays to light quarks possible!**

Vector Like Quarks

- GIM mechanism is broken, tree level FCNC arises.
- Vector like multiplets with new charge quarks (+5/3 X, 4/3 Y).
- Mixing primarily with third generation, but not required.

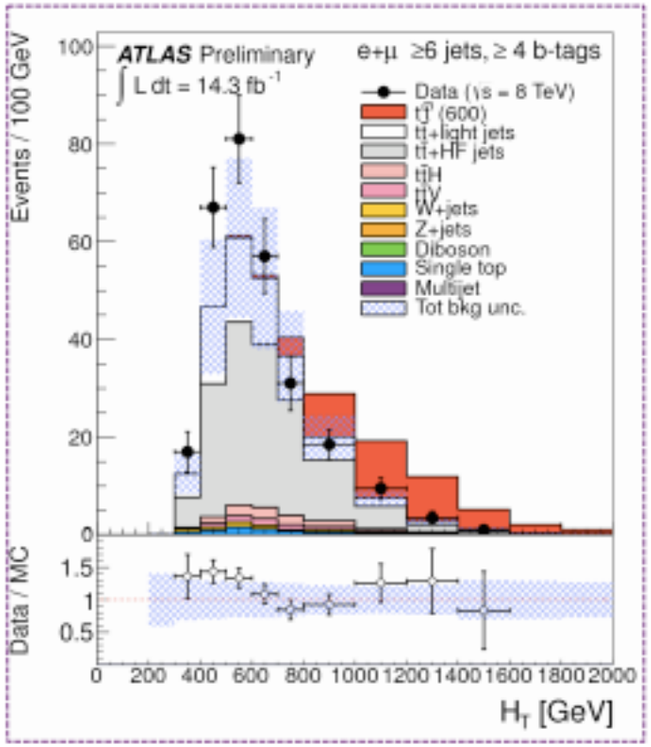


VL-top



VL-B

Vector Like Quarks



Ht+X

ATLAS-CONF-2013-018

- Single lepton + missing E_T
- At least 4 jets, one or (many) more b-jets

≥ 6 jets

≥ 4 b-tags

Test H_T(all)

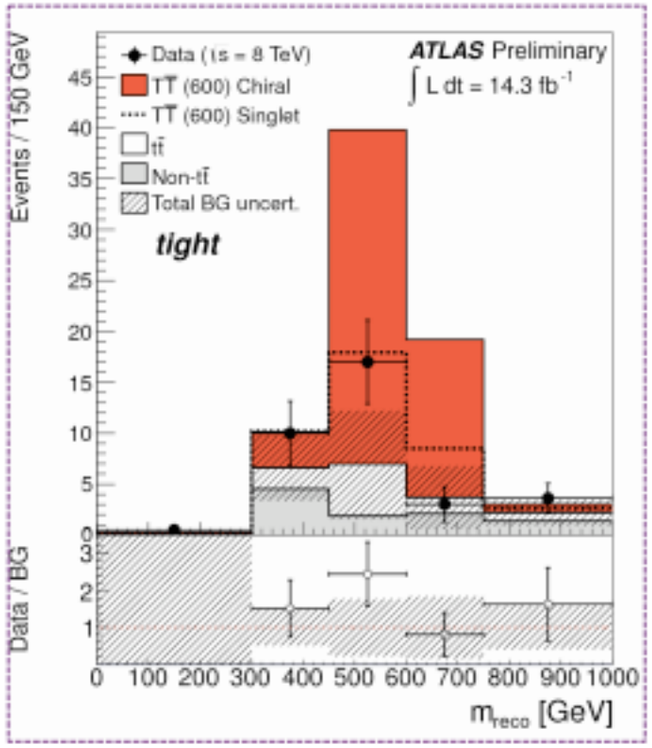
Wb+X

ATLAS-CONF-2013-060

Reco W_{had}

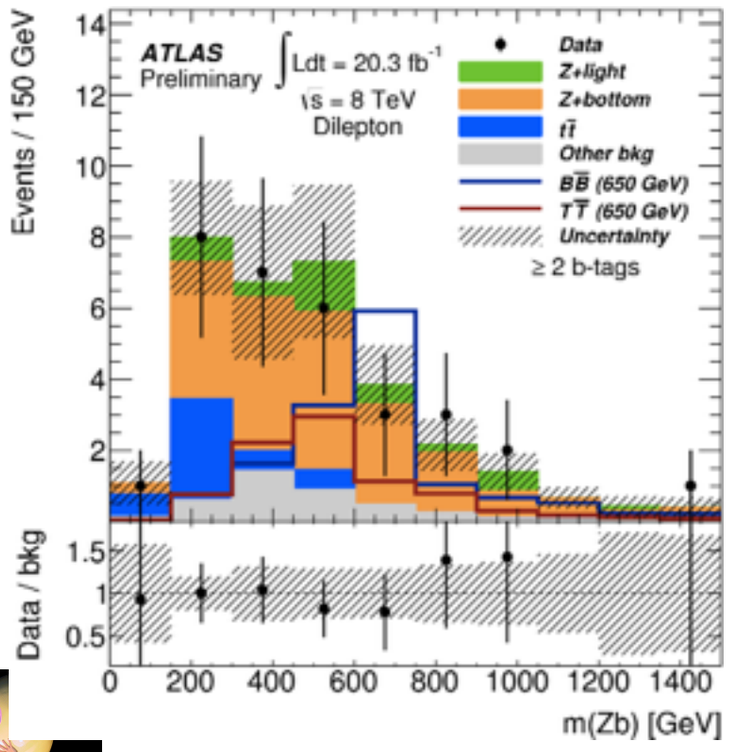
Reco WbWb

Test Mass



Zb/t+X

ATLAS-CONF-2014-036



- OS/SF leptons
- Z candidate
- High p_T(Z)
- ≥ 2 b-jets
- Large H_T(jets)

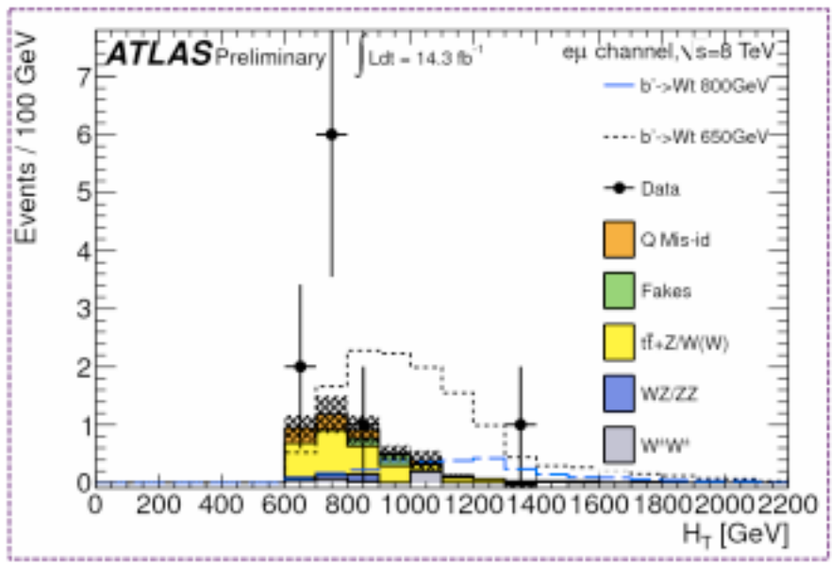
Test m(Zb)

Same-Sign

ATLAS-CONF-2013-051

- SS leptons
- Missing E_T
- ≥ 2 jets
- ≥ 1 b-jets
- Large H_T(all)

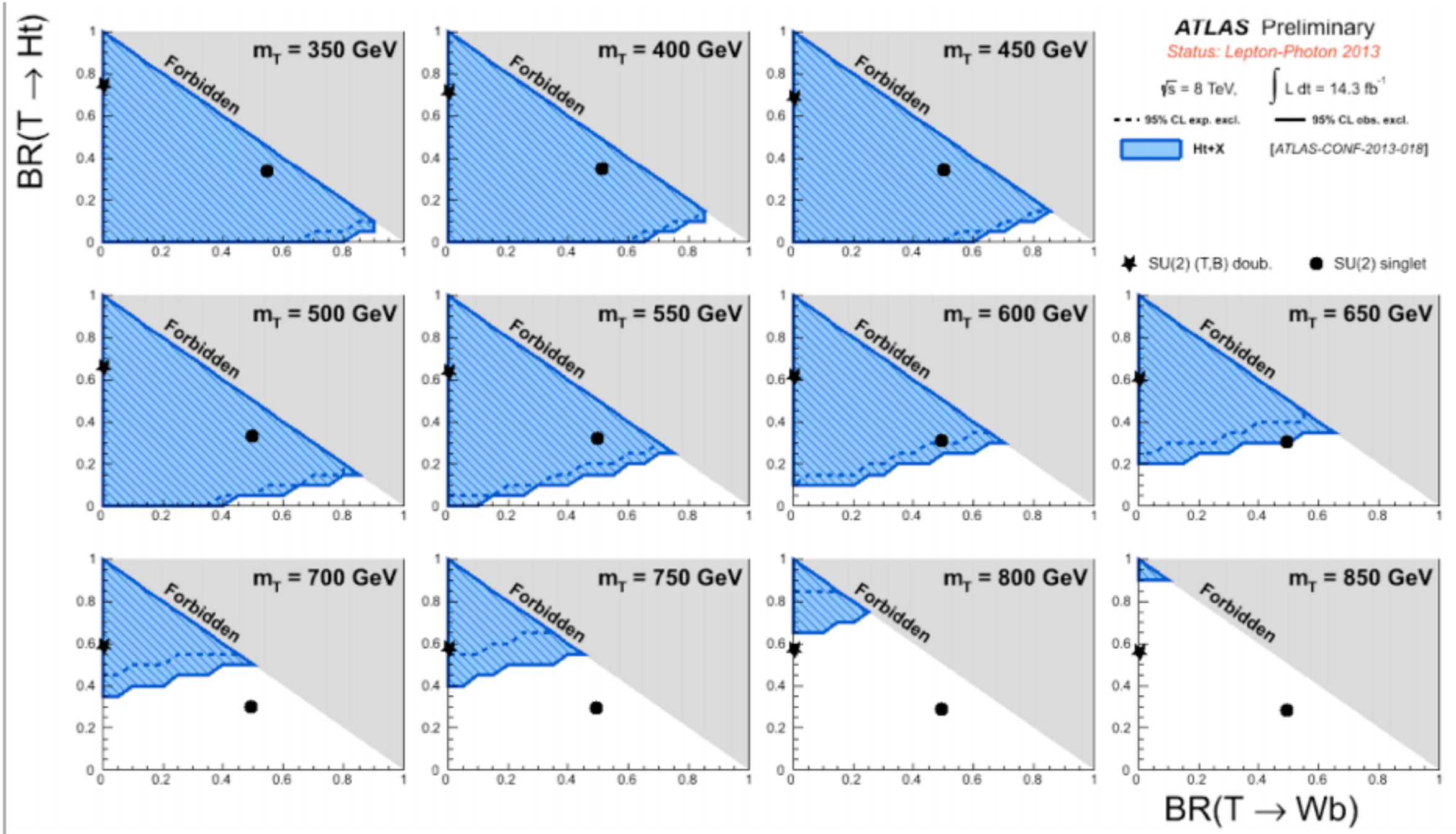
Count



Vector Like TOP

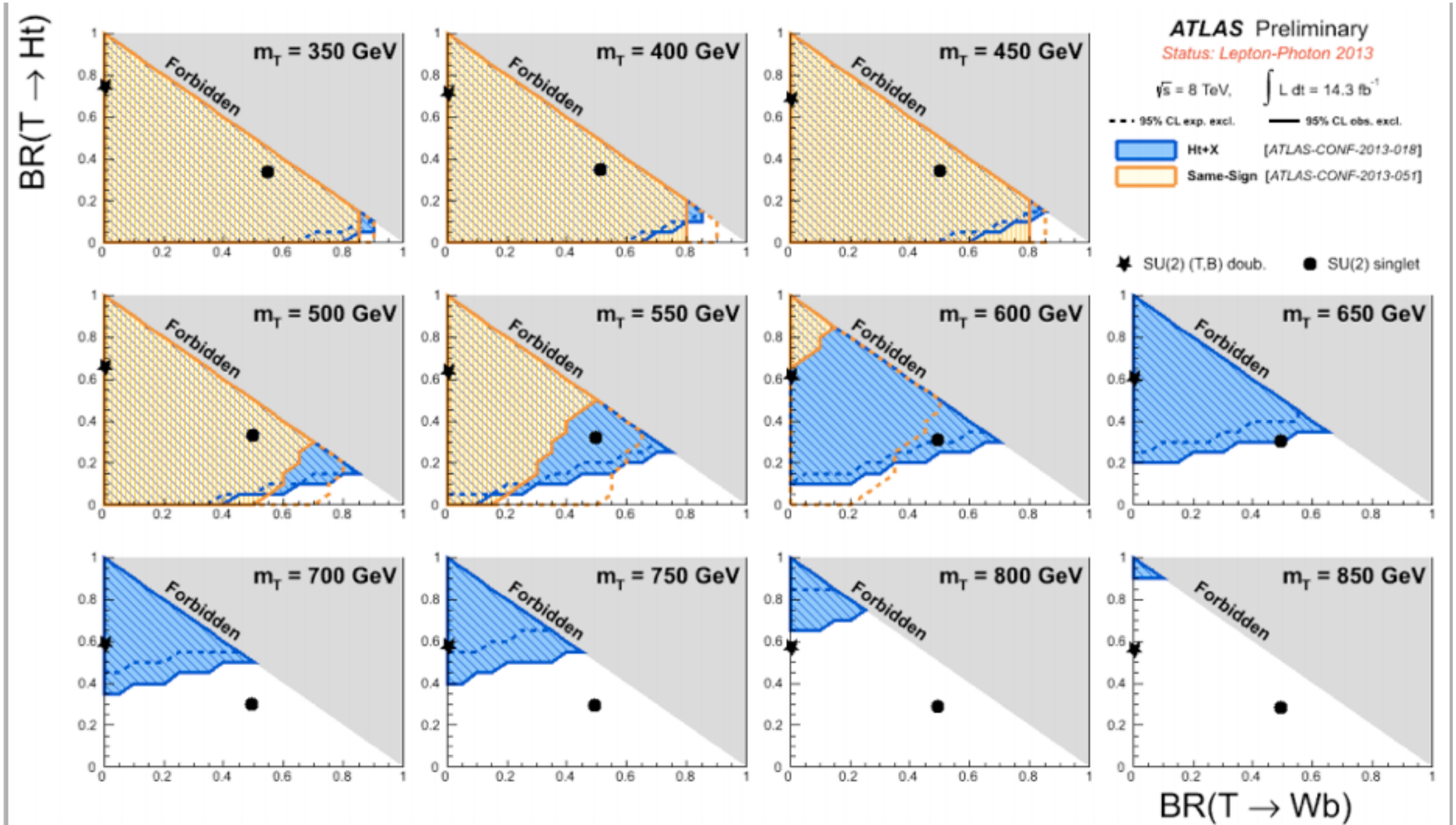
95% CL exclusion in BR(t' -> Wb) vs. BR(t' -> Ht), for different VLQ t' quark mass.

Vector Like TOP



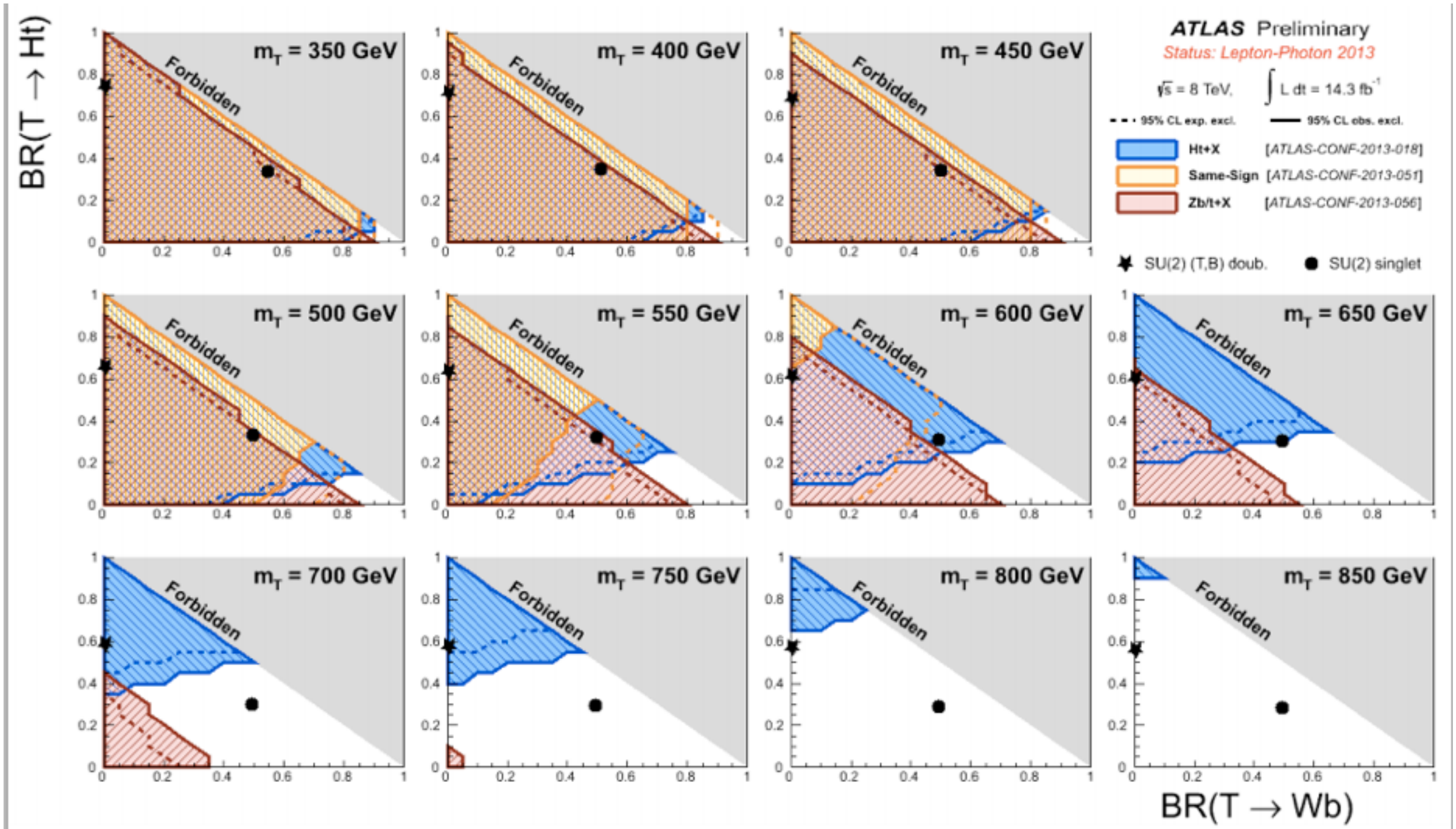
- In the T plane, the Ht+X analysis is particularly powerful in the Ht corner, but also has considerable sensitivity over a good portion of the full plane.

Vector Like TOP



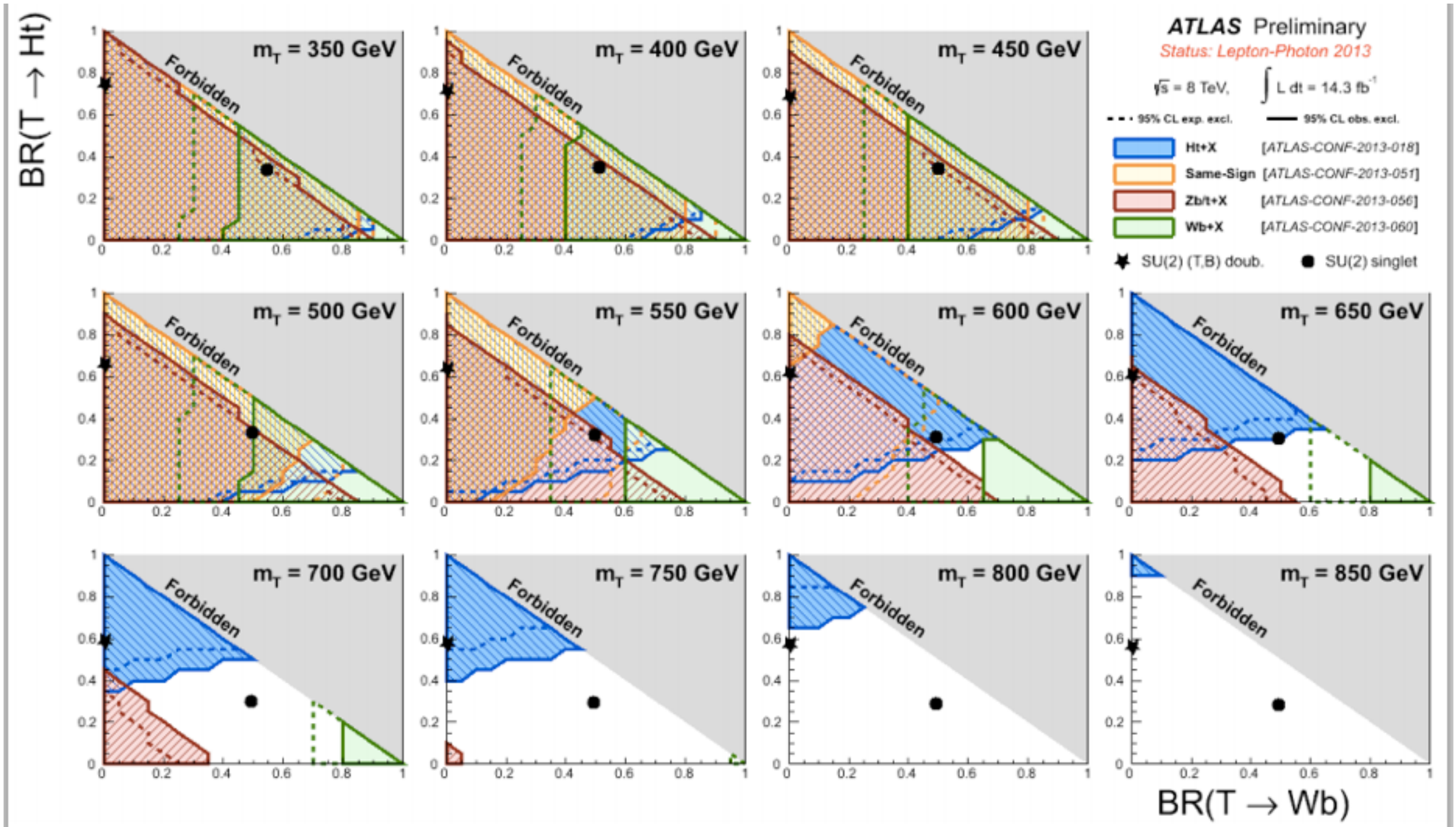
- In the T plane, the SS analysis complements the Ht+X analysis, adding a little more reach at low BR(Ht) for lower masses.

Vector Like TOP



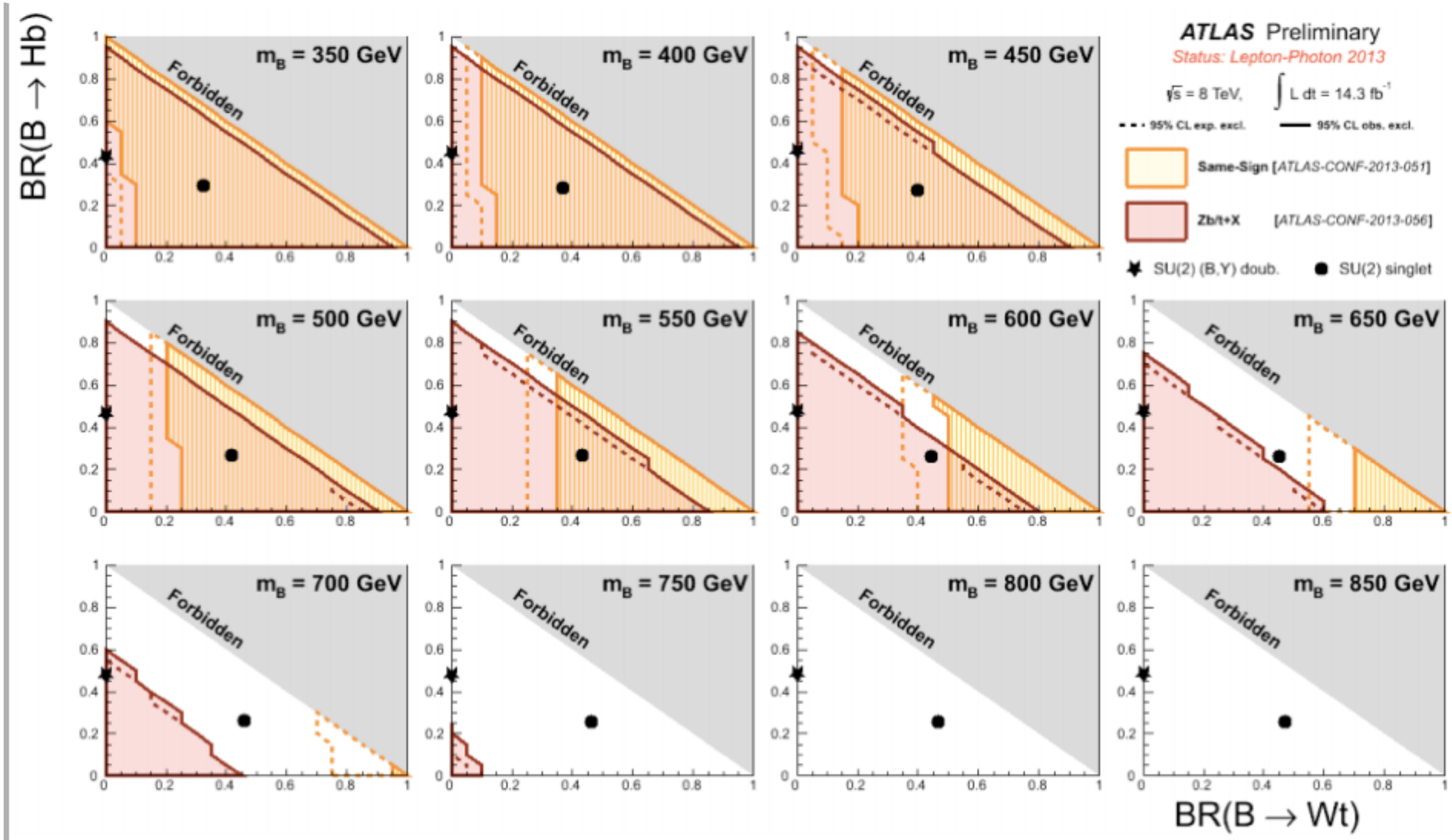
- However, the Zb/t+X provides the best sensitivity at low BR(Ht) in the T plane.

Vector Like TOP



- And Wb+X fills in the remaining uncovered region, the charged-current corner.

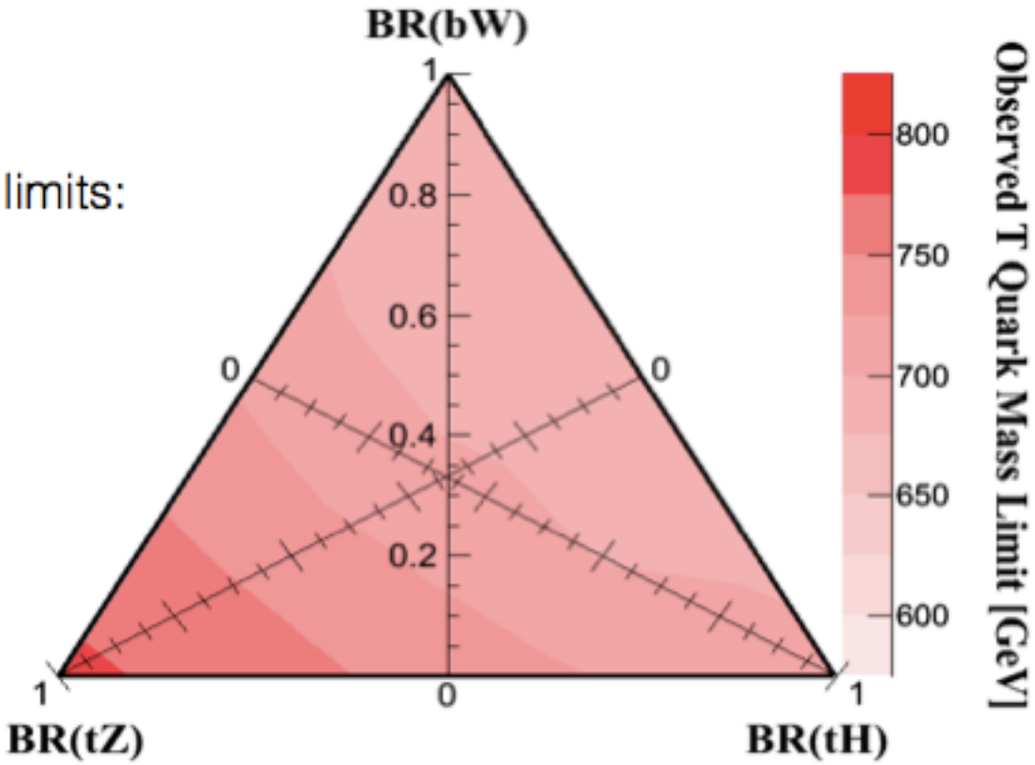
Vector Like Bottom



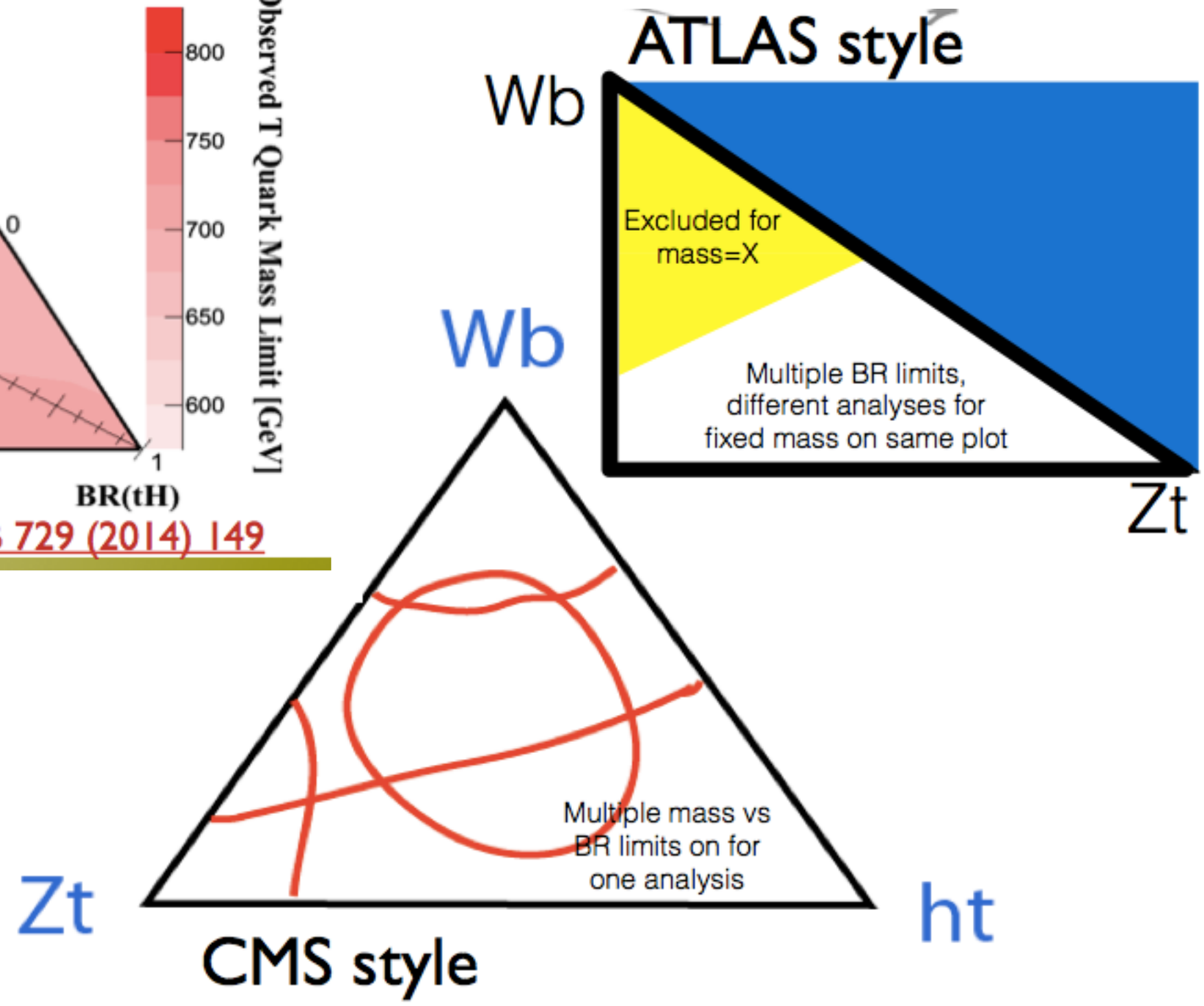
- And the Zb/t+X covers well the neutral current side of the B plane.

ATLAS vs CMS plots..

Observed limits:



hep-ex:1311.7667 Physics Letters B 729 (2014) 149

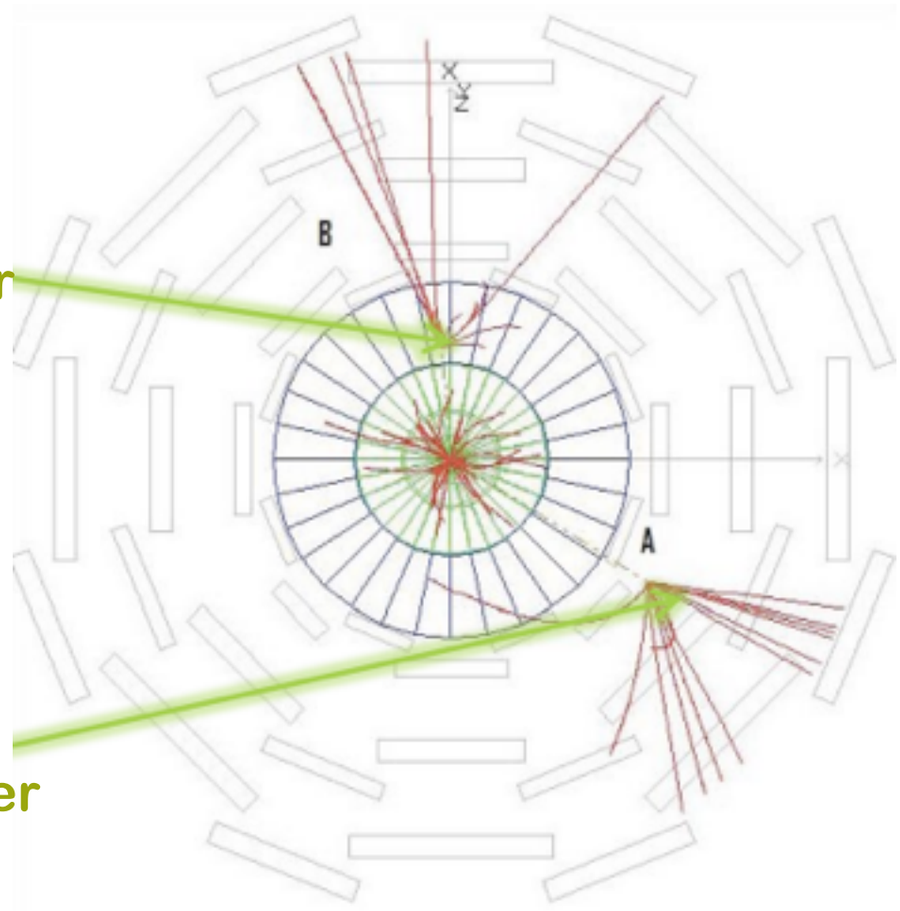


Long lived particles and Lepton jets

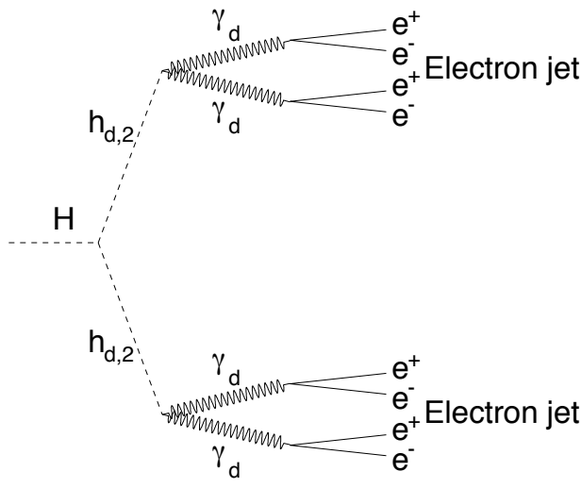
- What if the BSM Physics is there, but hidden behind a large barrier?
- Searches for decays in the detector, heavily ionizing particles ..
- Signatures: prompt or displaced lepton jets, displaced jets, high TRT ionization, high p_T "muons" with high dE/dx, or tracks with anomalous ionization and bending
- Physics model include
  - ➡ Higgs & Z' decays -> hidden valley particles
  - ➡ Associated production of W/Z & H to l-jets
  - ➡ Monopoles
  - ➡ High charges
  - ➡ Quirks

Lepton/pion jets

- WIMP-like DM
- Predicts massive dark photon (γ_d) decay to pairs of e, mu or pions.
- Appear as collimated sets of leptons (pions) at LHC.
- The strength of the SM and γ_d mixing determines the vertex distance
- ATLAS set limits on Sigma X BR of Higgs to prompt e-jets as well as to prompt and displaces mu-jets and LLP pseudoscalar dark pions, π_v and on SUSY lepton-jets production.



- Dedicated triggers and tracking
- Associated production e.g. W+H -> e-jets



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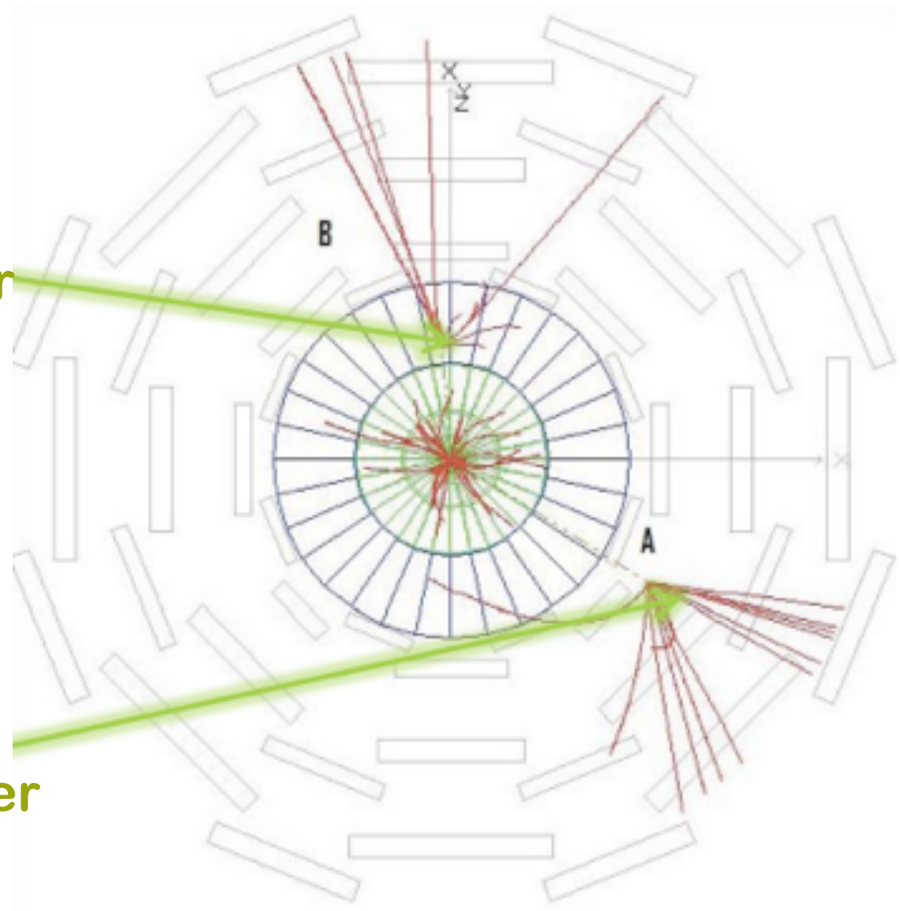

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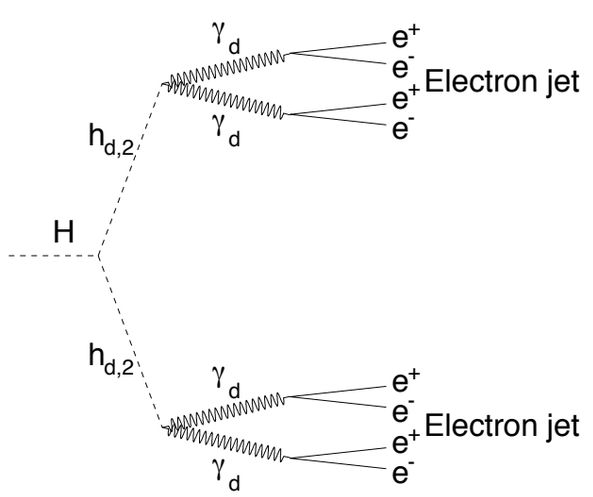
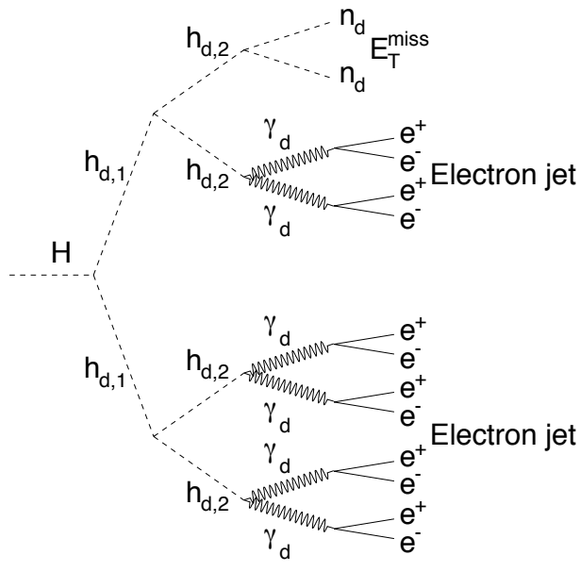


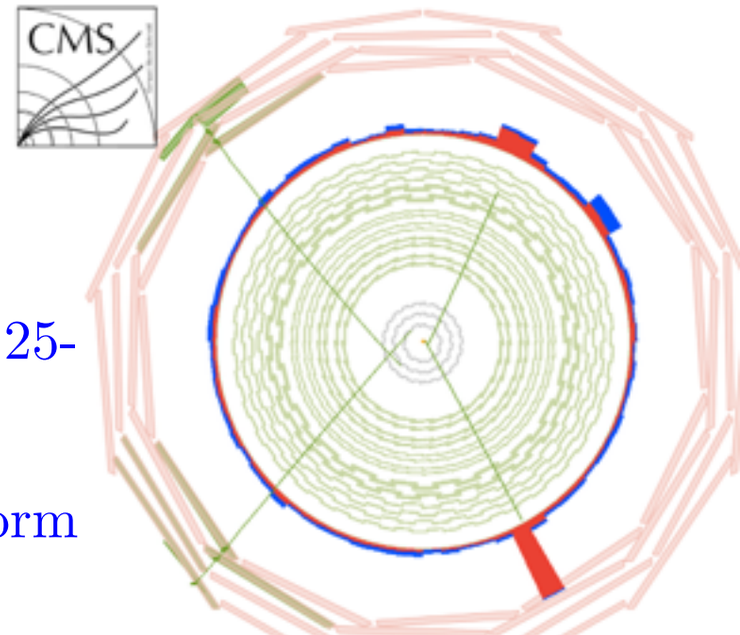


Search for displaced dilepton pairs

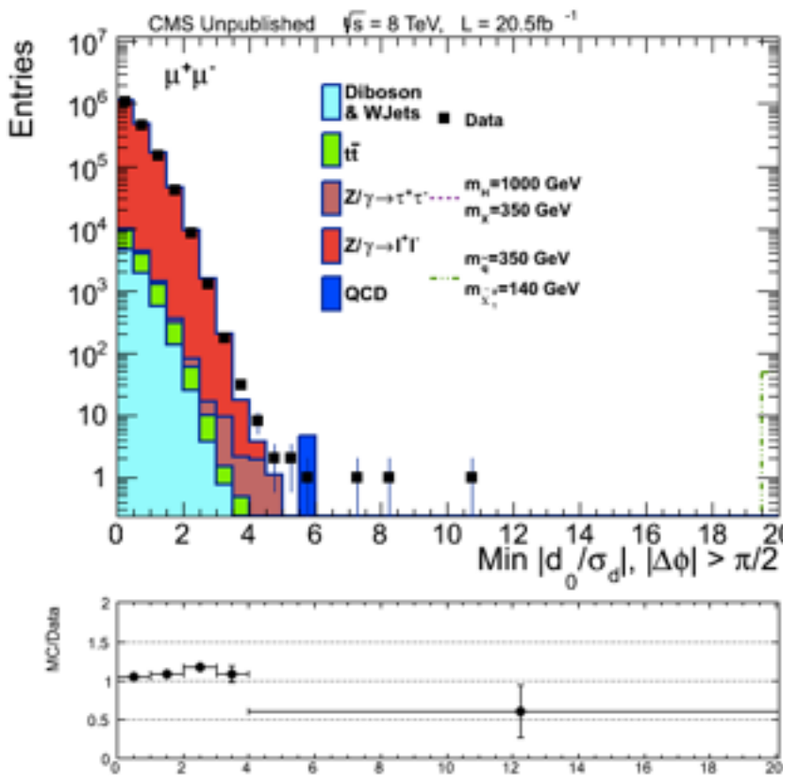
- Search for massive long-lived particles (LLP)decaying to leptons

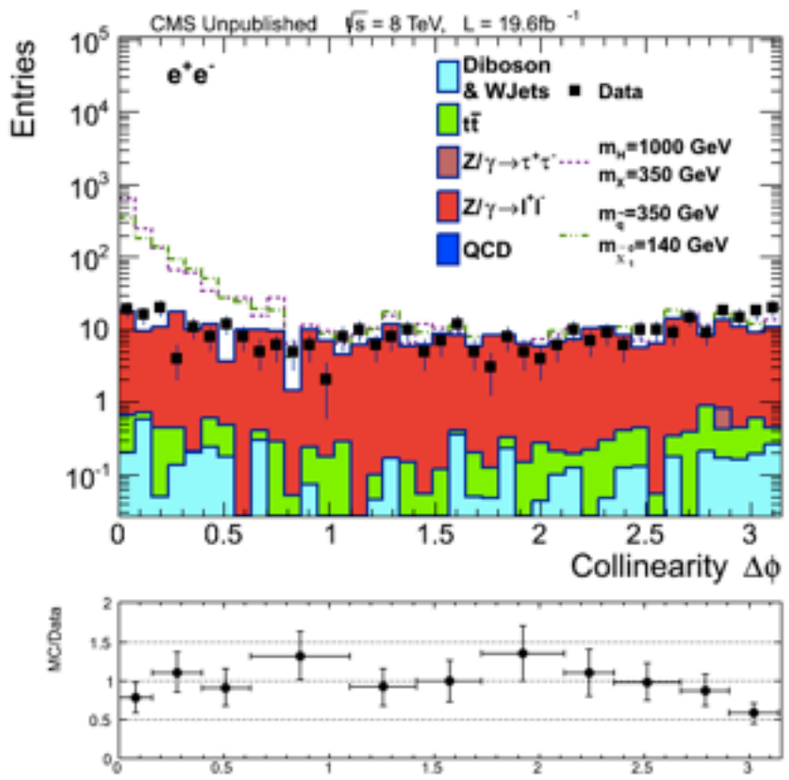
EXO-12-037

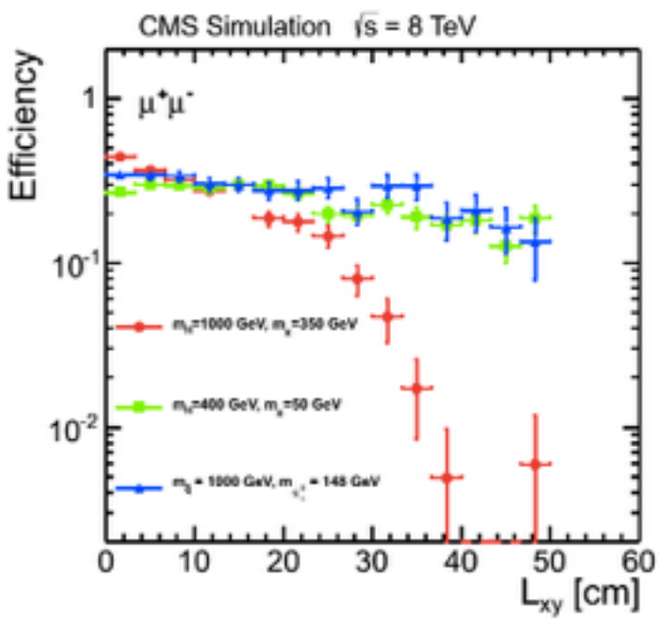
- Predicted e.g. by split or RPV SUSY, hidden valley, Z' with LLP ν's
- Look for BSM Higgs $H^0 \to \chi\chi, \chi \to l^+l^-$ or
  squark pair production $\tilde{q} \to q\tilde{\chi}^0$ RPV $\tilde{\chi}^0 \to l^+l^-\nu$
- Signal MC H^0 (masses 125-1000 GeV) decaying to LLP with masses 25-350 GeV.
- Isolated lepton tracks (with significant transverse impact parameter) form good secondary vertex with mass > 15 GeV.



- $\delta\phi$ between the dilepton vertex and their momentum sum vector is $< \pi/2$







Search for displaced dilepton pairs

EXO-12-037

- Search for massive long-lived particles (LLP)decaying to leptons
- Predicted e.g. by split or RPV SUSY, hidden valley, Z' with LLP ν's
- Look for BSM Higgs $H^0 \to \chi\chi, \chi \to l^+l^-$ or
  squark pair production $\tilde{q} \to q\tilde{\chi}^0$ RPV $\tilde{\chi}^0 \to l^+l^-\nu$
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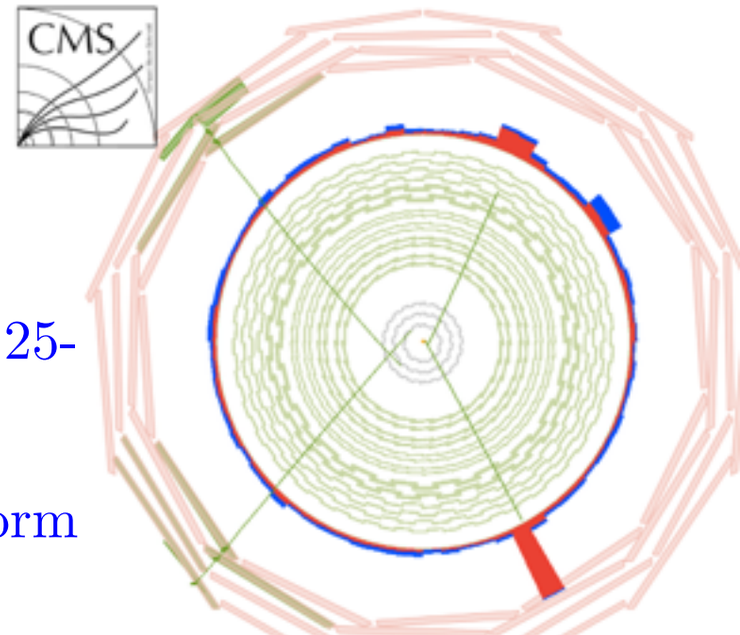

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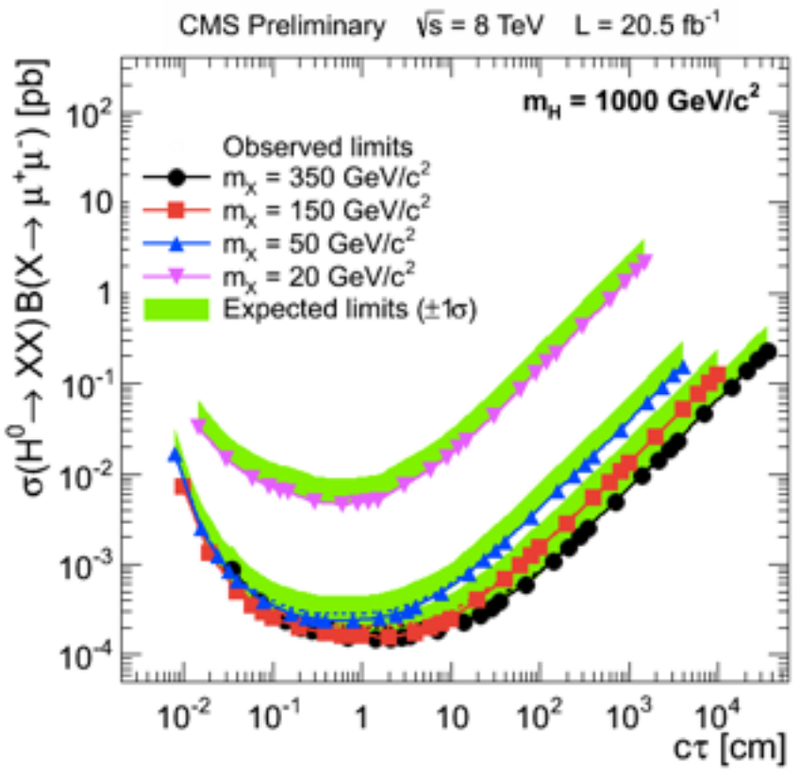
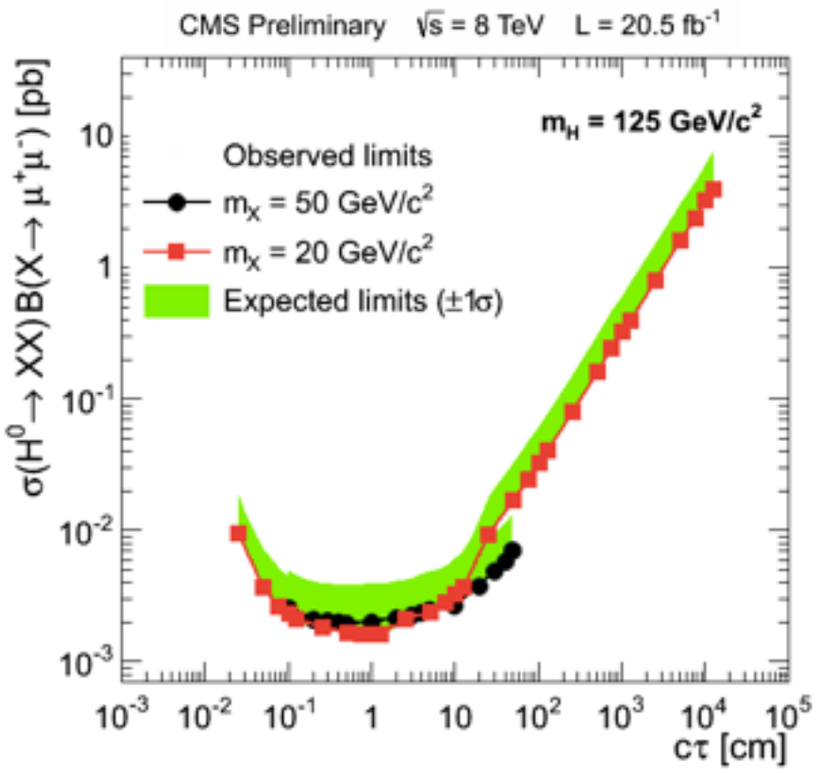


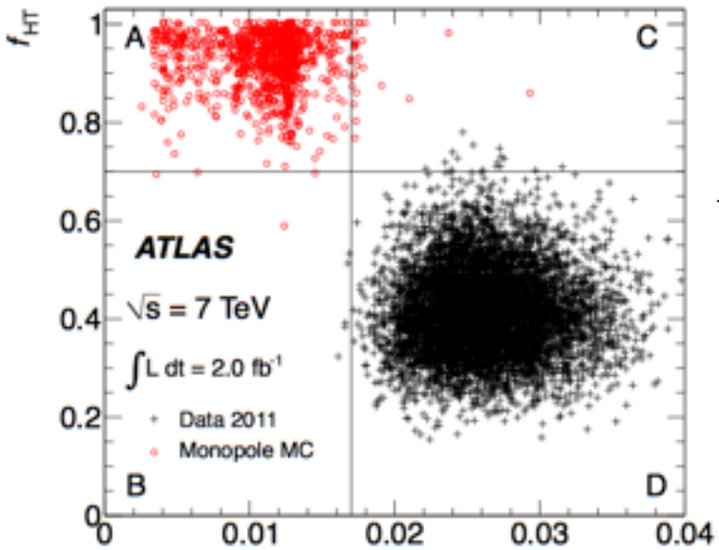


A Higgs boson, m_H =125 – 1000 GeV decays to pair of 20–350 GeV X bosons, decaying to dileptons.
The upper limits are between 0.1 – 5 fb for lifetimes of $0.01 < ct < 100$ cm, weaken to 5 – 50 fb for m_H=125 GeV

Other exotics searches

- **Magnetic monopoles and highly ionizing particles**

PRL 109 (2012) 261803

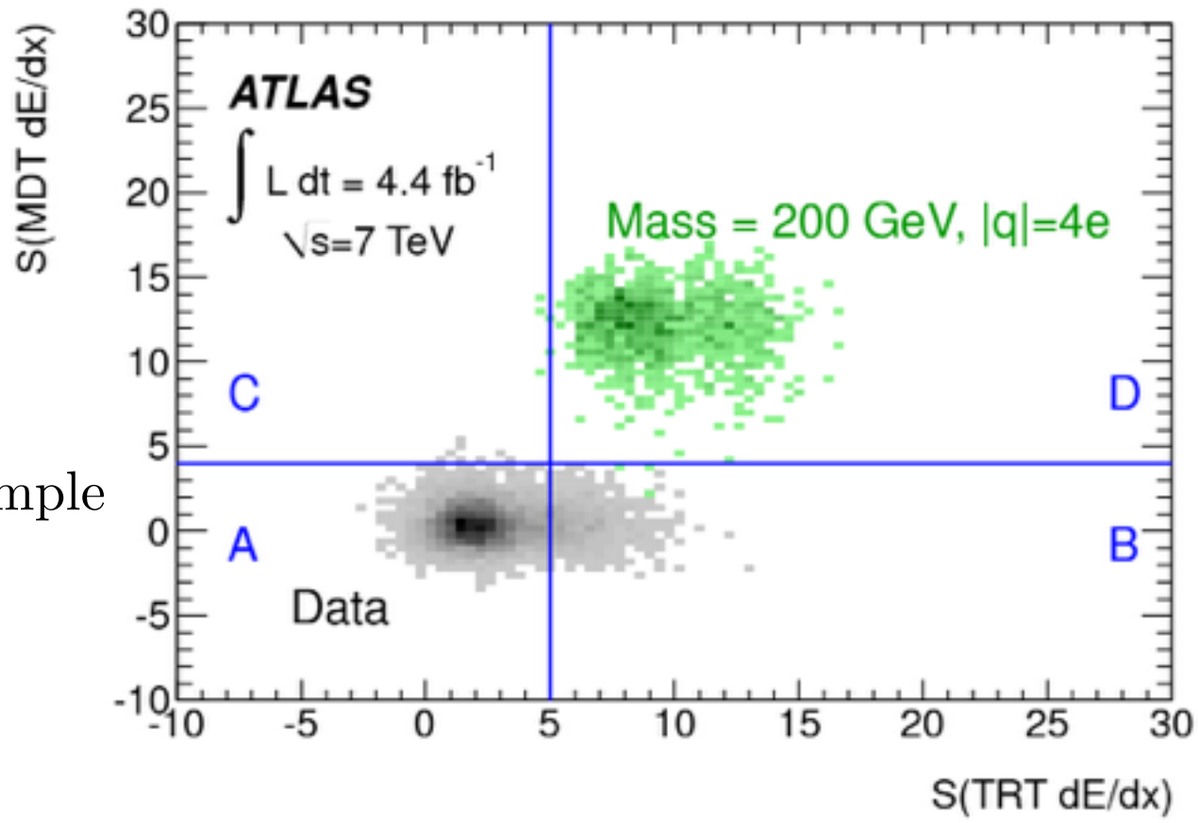


High-threshold TRT hit fraction, f_{HT}, versus EM cluster dispersion, σ_R

- **Multi-charges**

PLB 722, 305 (2013)

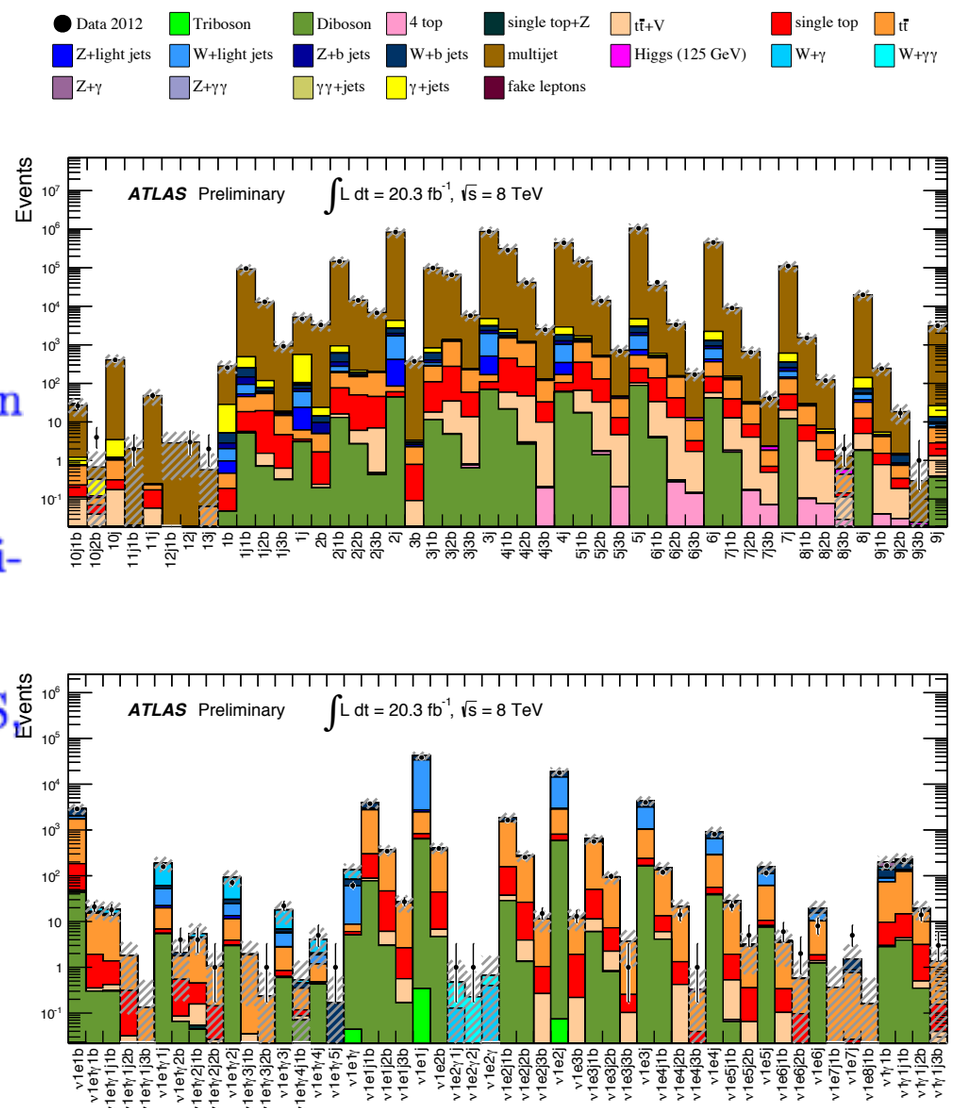
The plane of TRT and MDT dE/dx significances after the $|q| > 2e$ selection.
The distributions of the 2011 data and the signal sample (mass of 200 GeV and $|q| = 4e$)



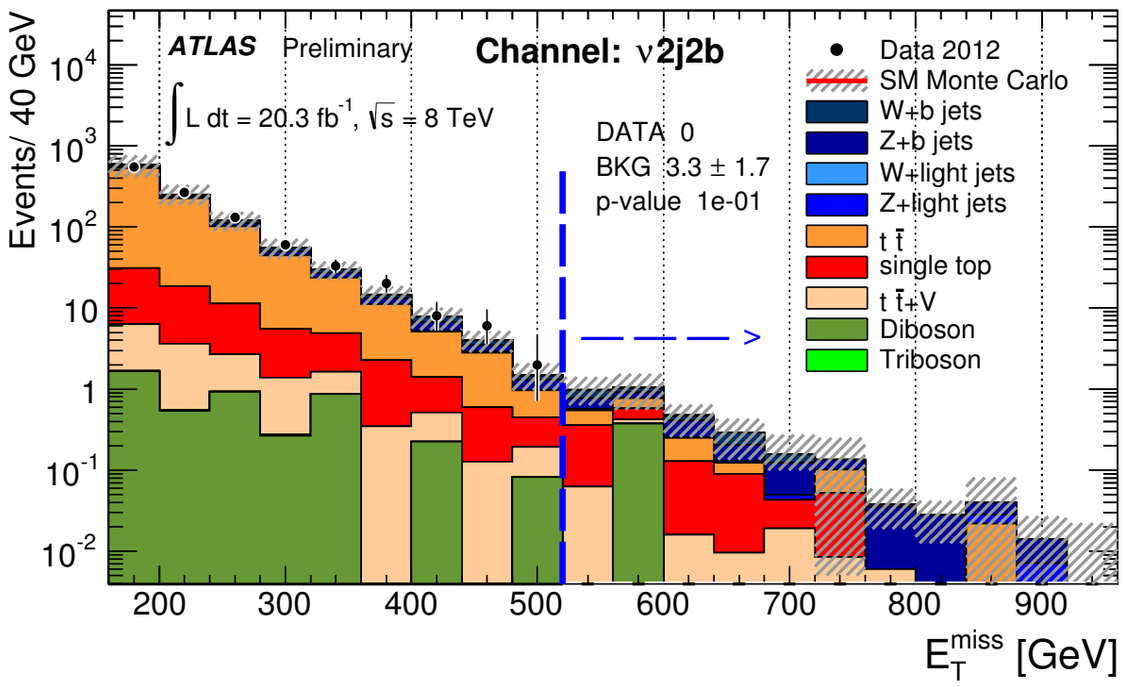
Model-independent generic search

ATLAS-CONF-2014-006

- Not optimised for specific signal
- Provides comprehensive investigation for new physics
- Study topologies with isolated e's, μ's, γ's, Jets, b-jets, MET
- Search in 697 classes with SM expectation greater than 0.1 events
- BG estimated with MC, except for single fake leptons using data driven ("ABCD" method)
- Test compatibility of data to MC in three kinematic BSM sensitive variables (m_{eff}, visible inv. mass and E_T^{miss}).
- Systematics dominated by MC stat and experimental uncertainty (JES, JER, b-tagging, γ-id..)



MET for the class with (nu2j2b). The dashed vertical line indicate the region with the smallest p-value (0.097) for this class.



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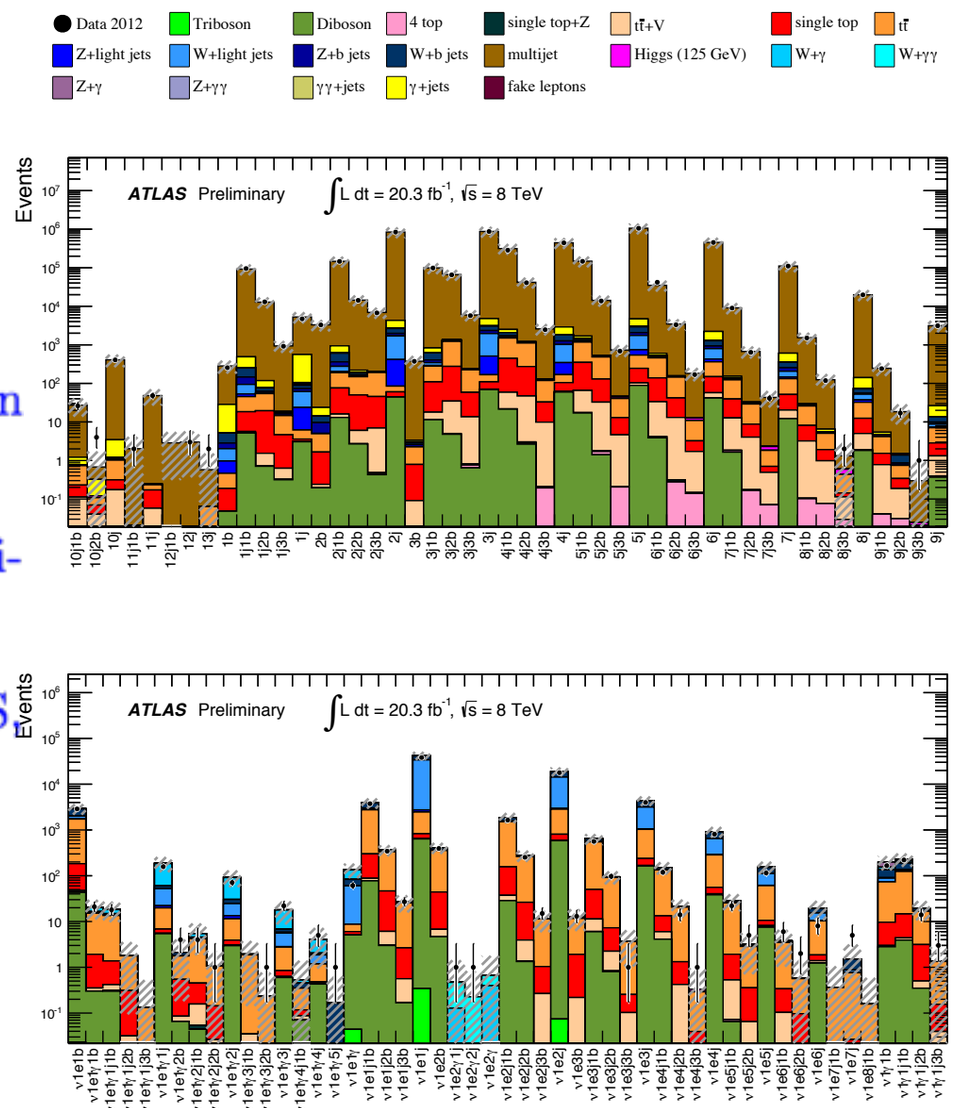

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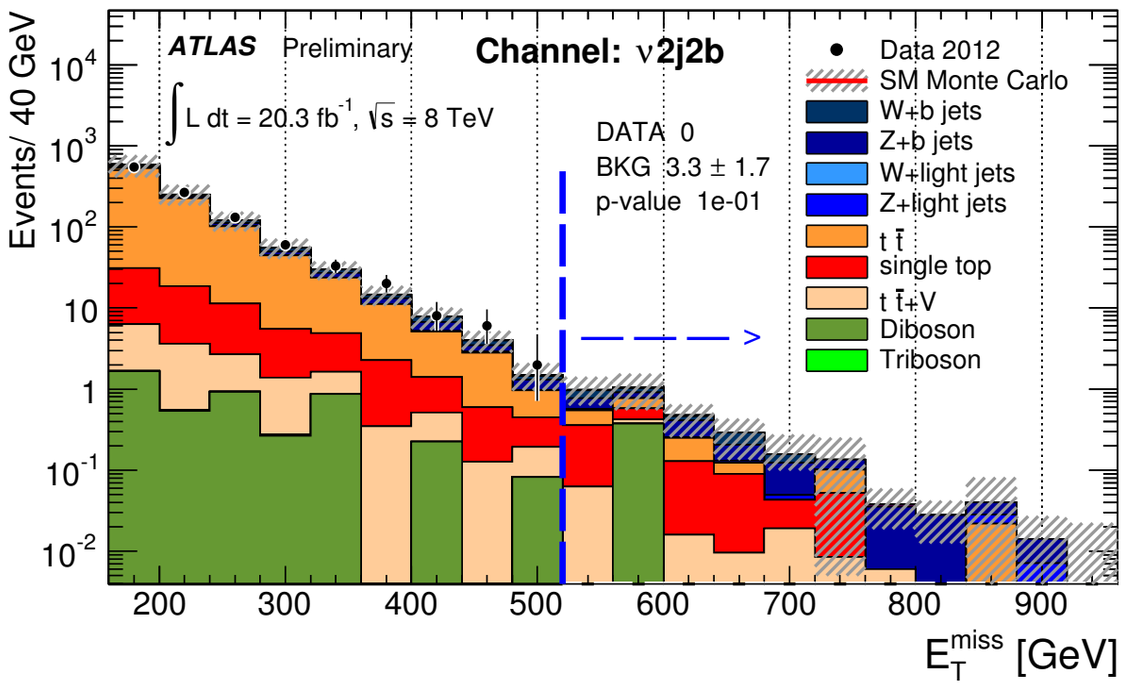
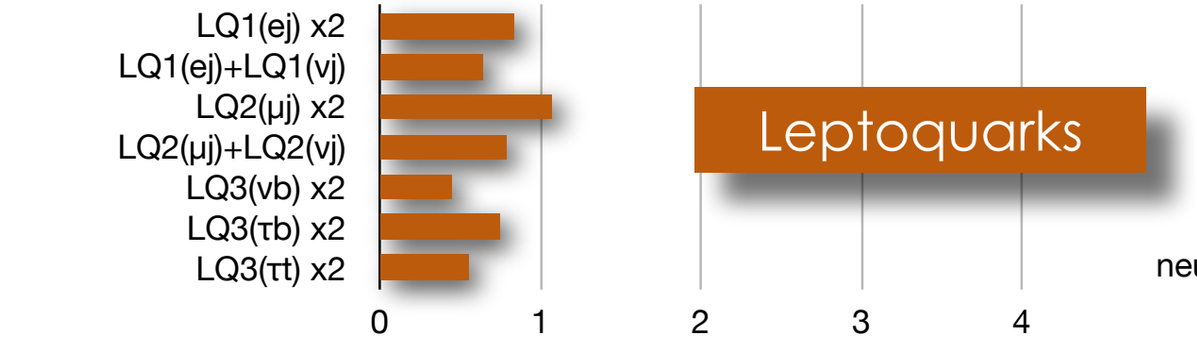
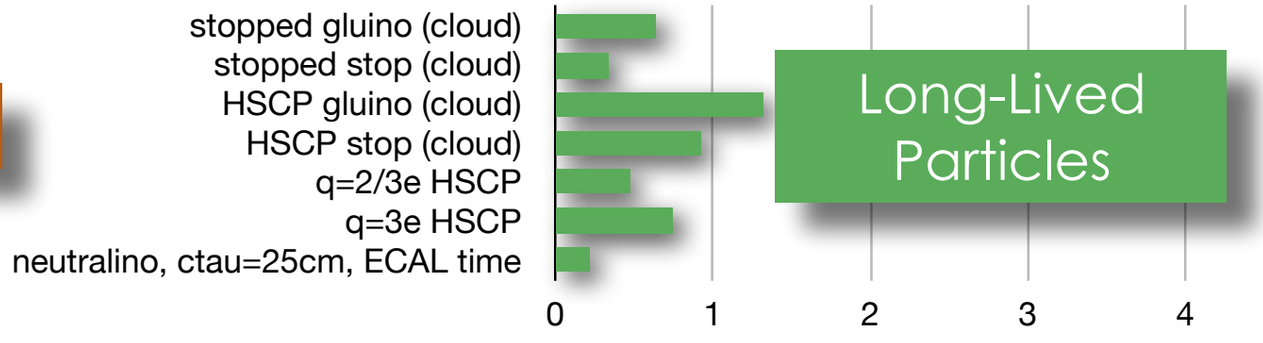


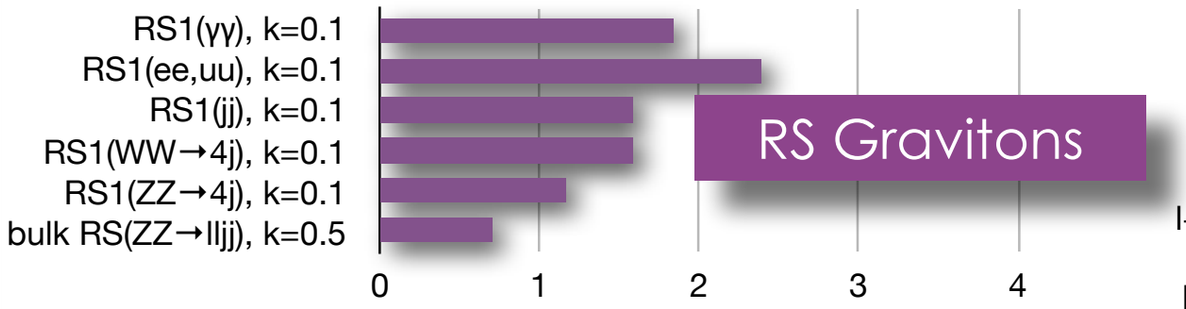
No excess in all search regions
A clear demonstration of our MC precision



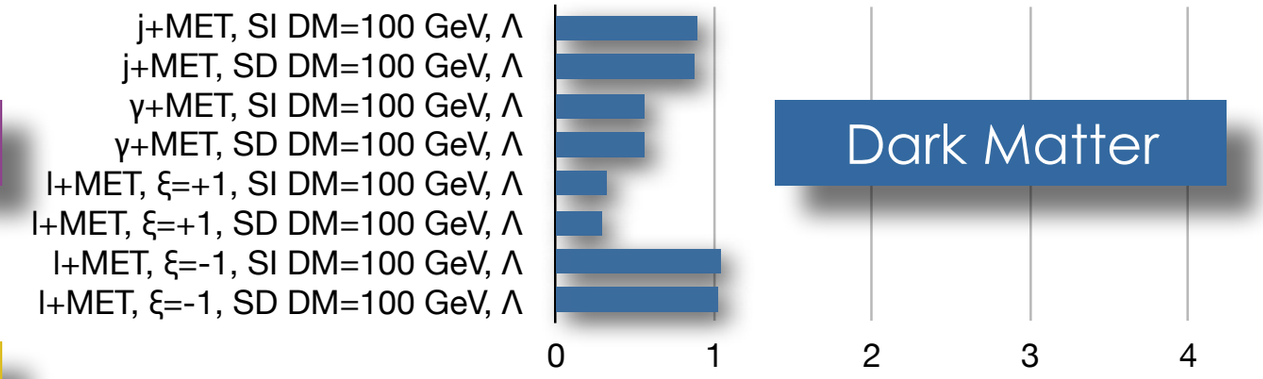
Leptoquarks



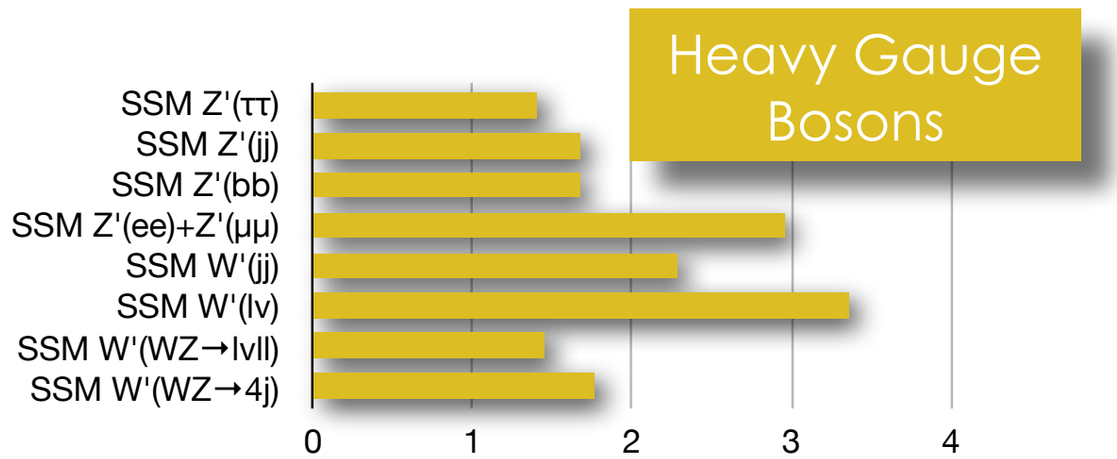
Long-Lived Particles



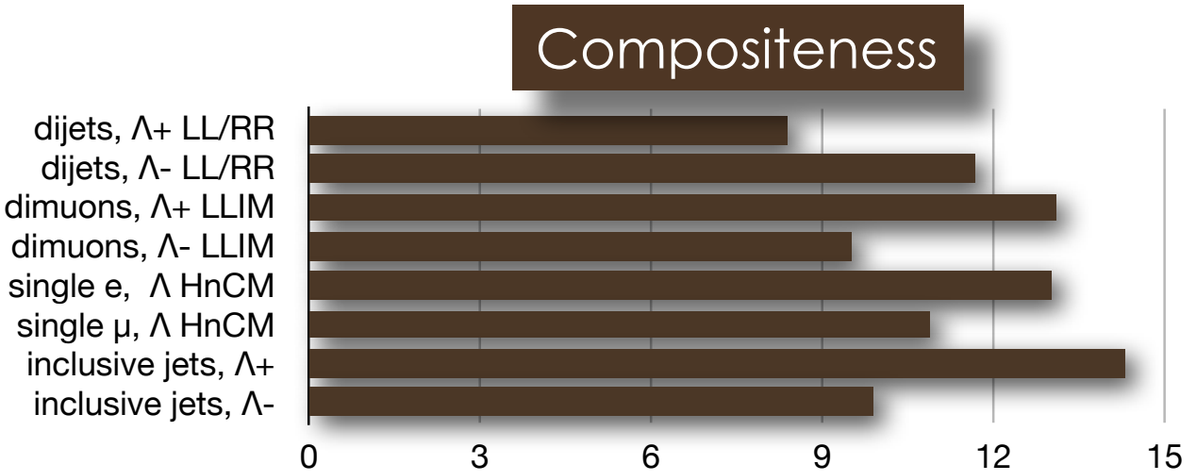
RS Gravitons



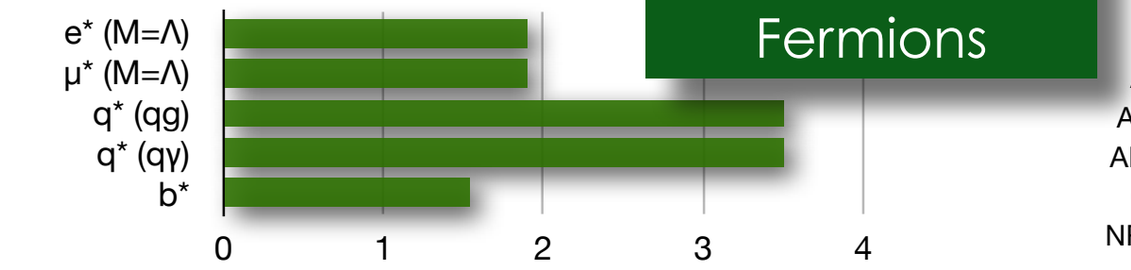
Dark Matter



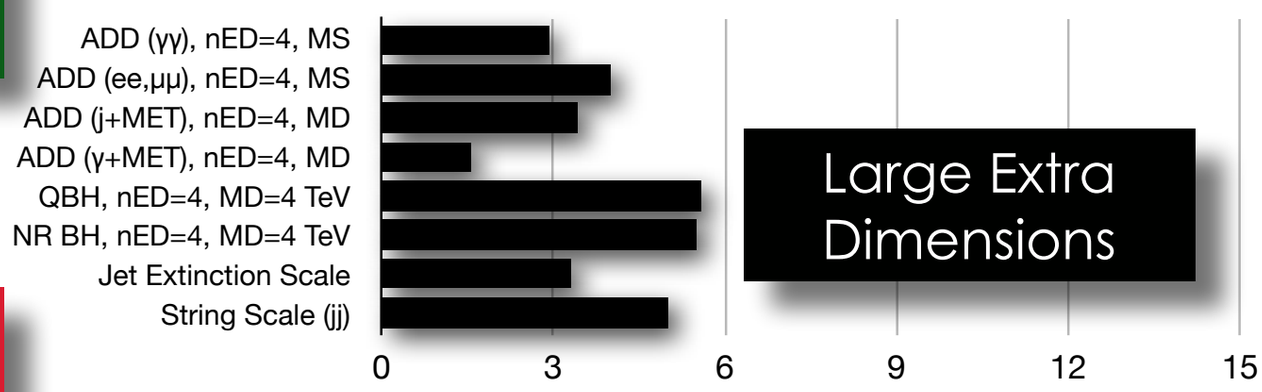
Heavy Gauge Bosons



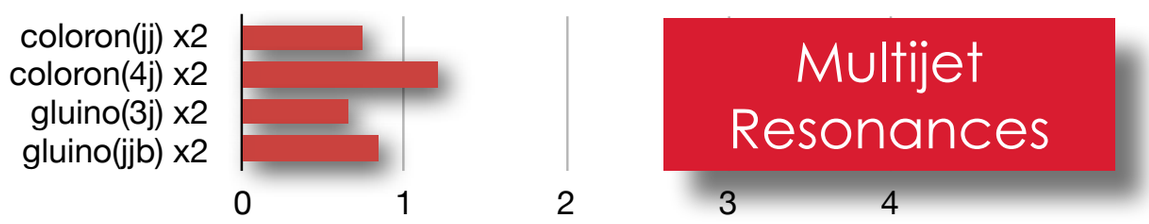
Compositeness



Excited Fermions



Large Extra Dimensions

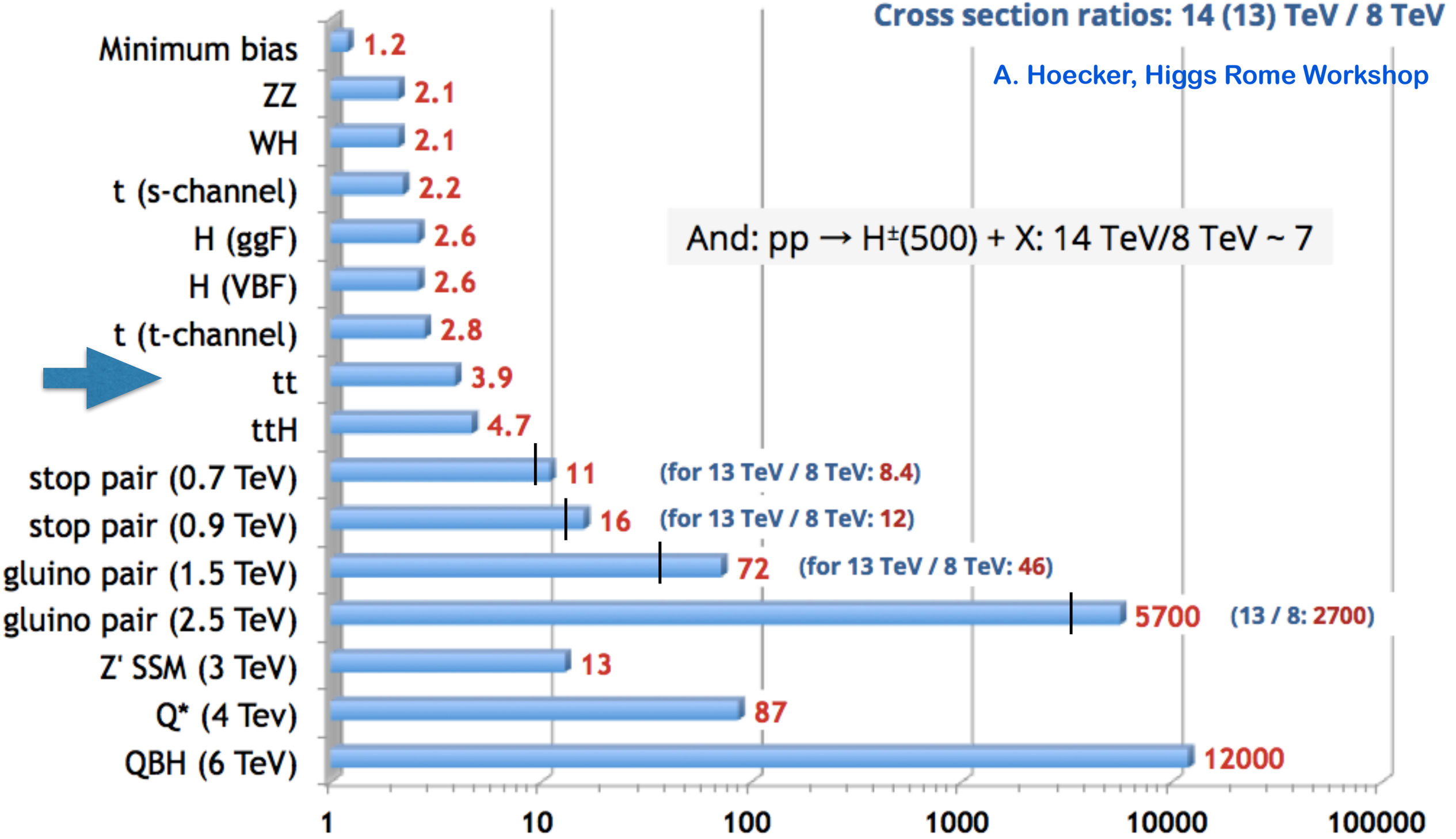


Multijet Resonances

CMS Preliminary

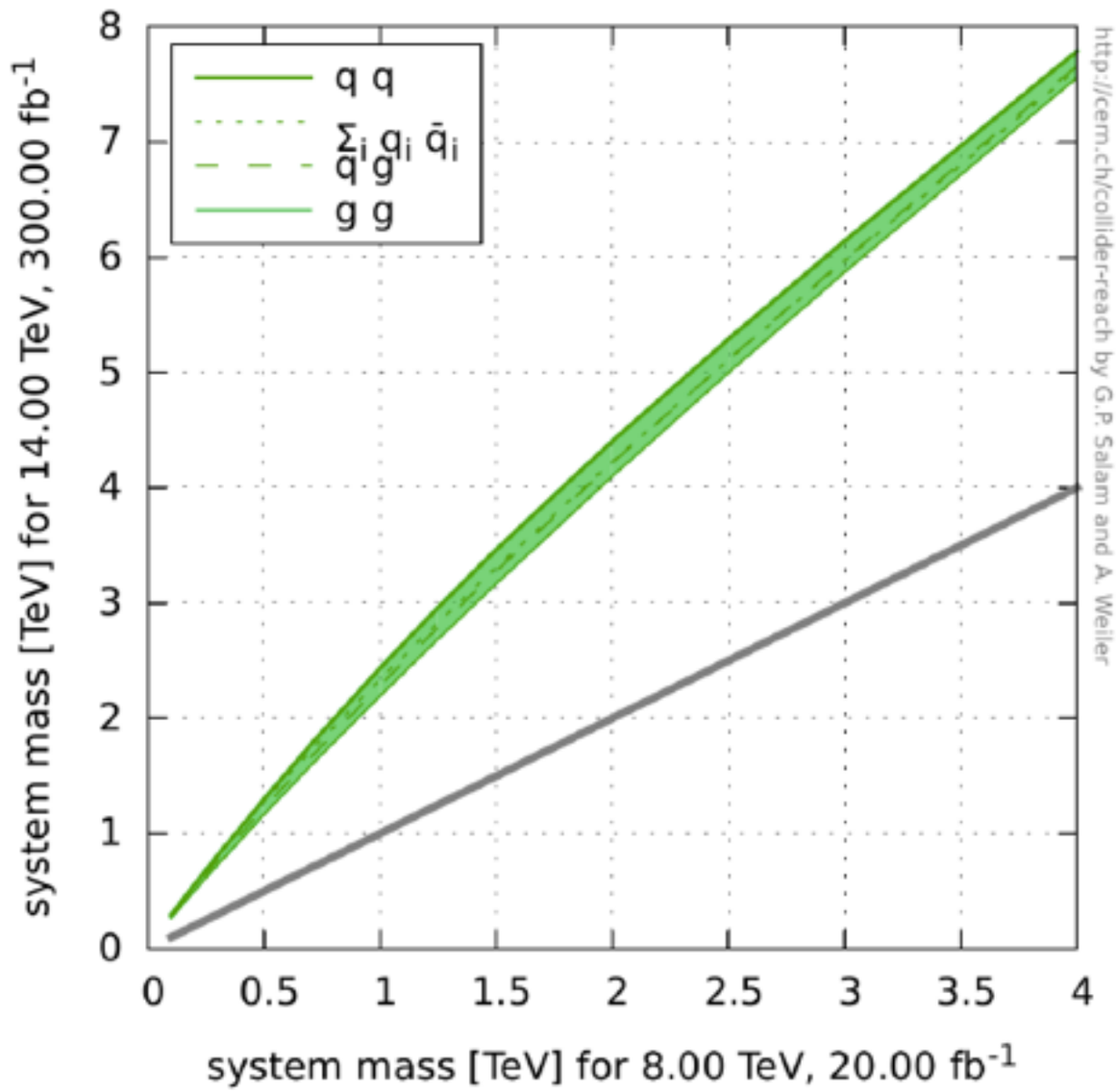
CMS Exotica Physics Group Summary – March, 2014

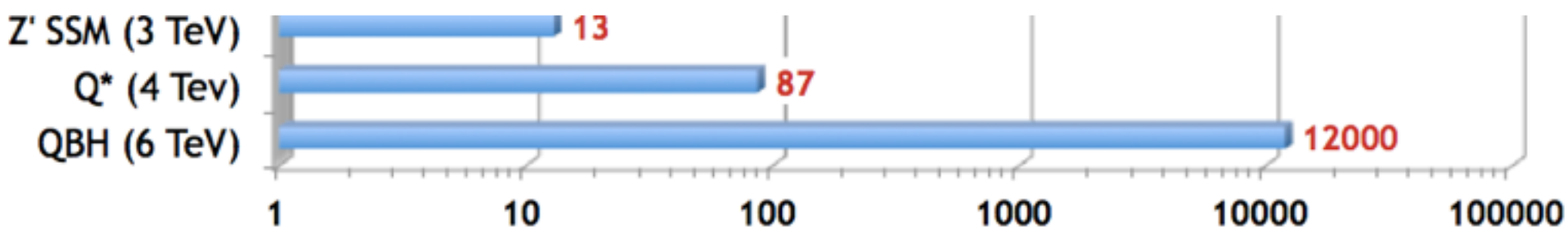
Cross section ratios

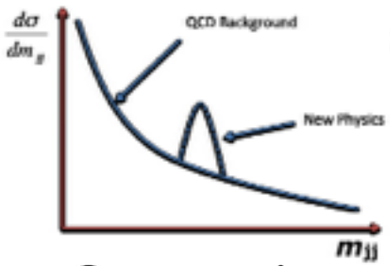


Run-II new opportunity for discovery

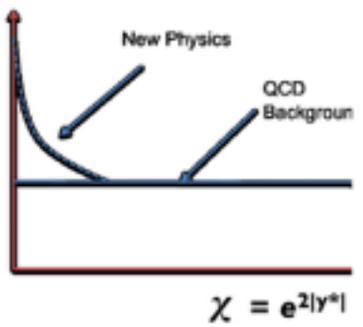
- New opportunity for discoveries:
  - Increase in CM energy -> Increase the mass discovery reach
  - Increase in integrated Luminosity - Enhance sensitivity for rare processes
  -





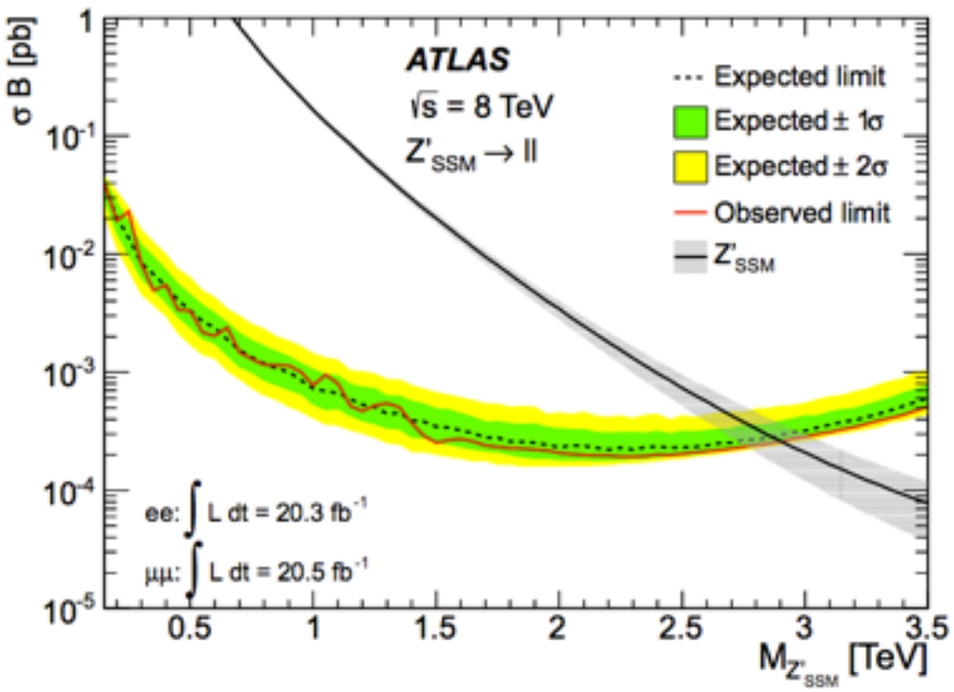


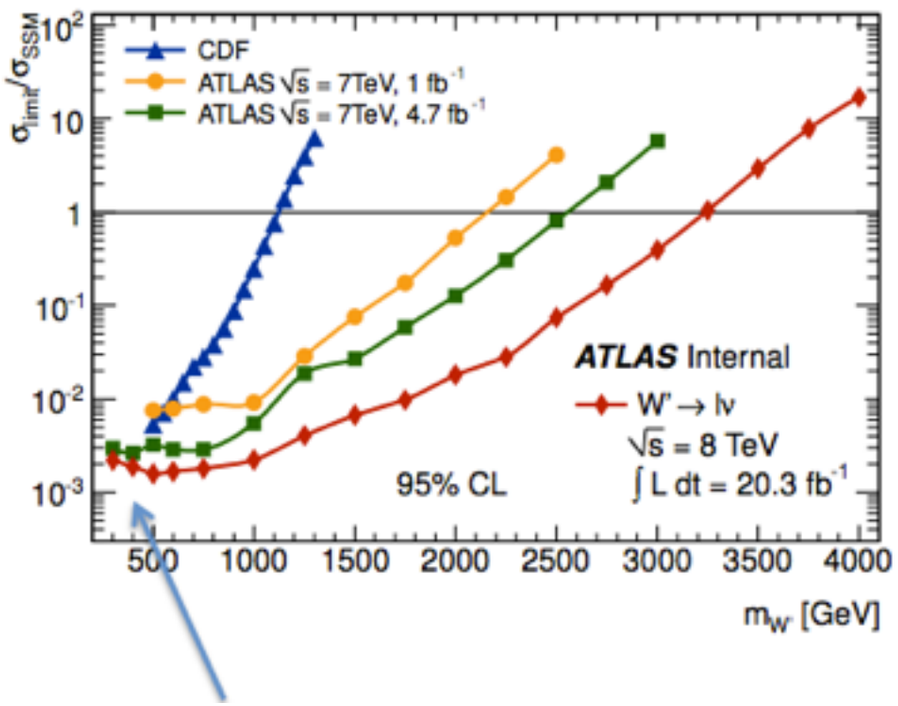
Jets analyses



- Searches for high mass resonances
- Model like q* the discovery reach of 14 TeV in 1/fb is what we excluded with the 8 TeV, from there the sky is the limit..
- Deviation in angular distribution as a sign for new forces and dimensions
- Searches at high jet multiplicity
- Additional studies
  - low m 3-jets, paired dijets
- Crucial JETMET, e-Gamma:
  - JES calibration, uncertainty
  - Jet cleaning
  - trigger
- Data driven BG, depends on fit function stability

Reach of searches in leptons / photons





13 TeV

- Early studies of searches with dileptons, diphoton, lepton + E_T^{miss}
- $q\bar{q}$ yield of signal at 3 TeV is x20 higher at 13 TeV compared to 8 TeV
- The reach of 1-2/fb at 13 TeV is comparable to 8 TeV with 20/fb (for BG free region and no systematics..)
- Should try to improve the low mass region as well
- Require further studies of lepton performance, E_T^{miss}, theory (high order corrections).

Run-2 Physics priorities

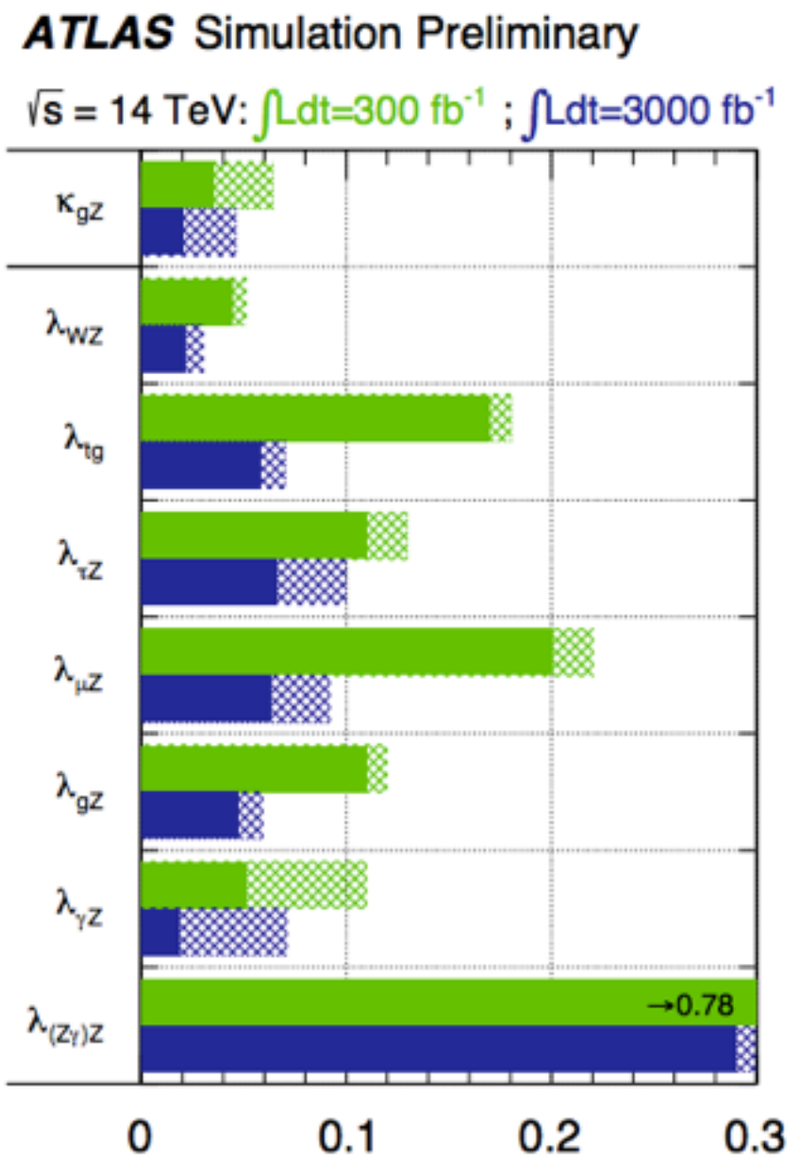
- **SM**
  - Fast track W/Z, ZZ (more difficult: WZ, WW, Vg); inclusive cross sections, and dijet differential cross sections (detector level, comparison with MC); total inelastic cross section measurements-> possible by summer? initial MB studies and MC comparisons for pile simulation validation
- **Top**
  - High priority measurements are top pair and single top (t-channel) inclusive and fiducial cross sections-> possible by summer (inclusive)? update of precision results with full 2015 dataset
- **Bottom**
  - Results with full 2015 dataset
- **Higgs**
  - Confirmation of $\gamma\gamma$ and ZZ peaks in summer 2015? ("Higgs rediscovery"). Early Higgs cross section measurements @ 13 TeV with $\gamma\gamma$ and ZZ. Other SM channels will be more challenging. Priority for ttH, end of 2015? also high mass NSM Higgs searches, expect results at 2015? With full dataset: new results for all channels and in combination with run-1; results on BSM Higgs.
- **Exotics**
  - Updates of very high-pT searches (eg. dijets resonance) in summer 2015 (1/fb). Majority of the analyses should produce results with first 5/fb accumulated
- **SUSY**
  - Majority of analyses should produce results with 5/fb accumulated

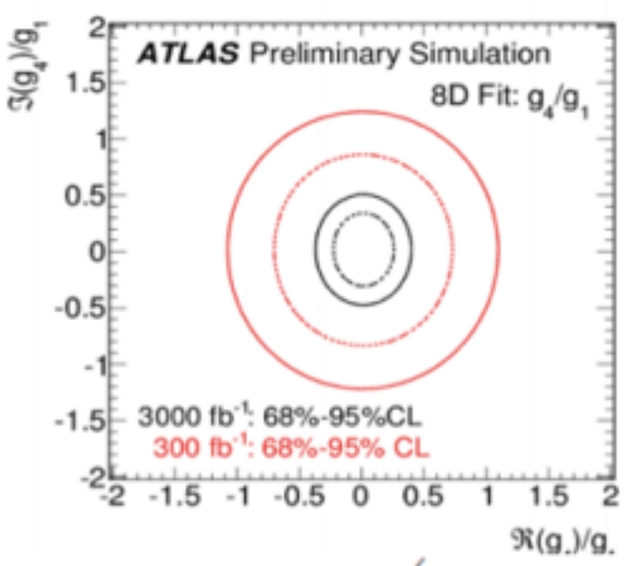
Summary

- Run-1
  - 125 Higgs: Do we understand the theory of particle Physics?
  - Large number of Precision measurements and BSM searches in various topologies and theoretical scenarios resulted in excellent (too good?) data/MC agreement and NO significant hint for NP.
  - Superseded previous exclusions, reach a few TeV scale!
  - Some models now less favoured (RS1->Bulk RS, 4th generations->VLQ, technicolor..). Some got more attention (Exotics+Higgs, DM)
- Run-2
  - High expectations from the dramatic energy and luminosity increase
  - Challenges for the new run (TeV leptons boosted objects, higher pile up..) ?...
  - Will need to start with the foundations (understanding of trigger, detector, physics objects) -> continue the precision measurements effort, focus on Higgs (& top)
  - Look fast for NP hints in the obvious directions
  - Rediscover the SM / 8 TeV, later improve the precision and search for NP in all possible directions
  - We will need to be faster, smarter and improve our efficiency and collaborative effort

Still long way to go

ATL-PHYS-PUB-2013-014





$$\Delta\lambda_{XY}=\Delta\left(\frac{\kappa_X}{\kappa_Y}\right)$$

ATL-PHYS-PUB-2013-033

Exploring the complexe structure of couplings

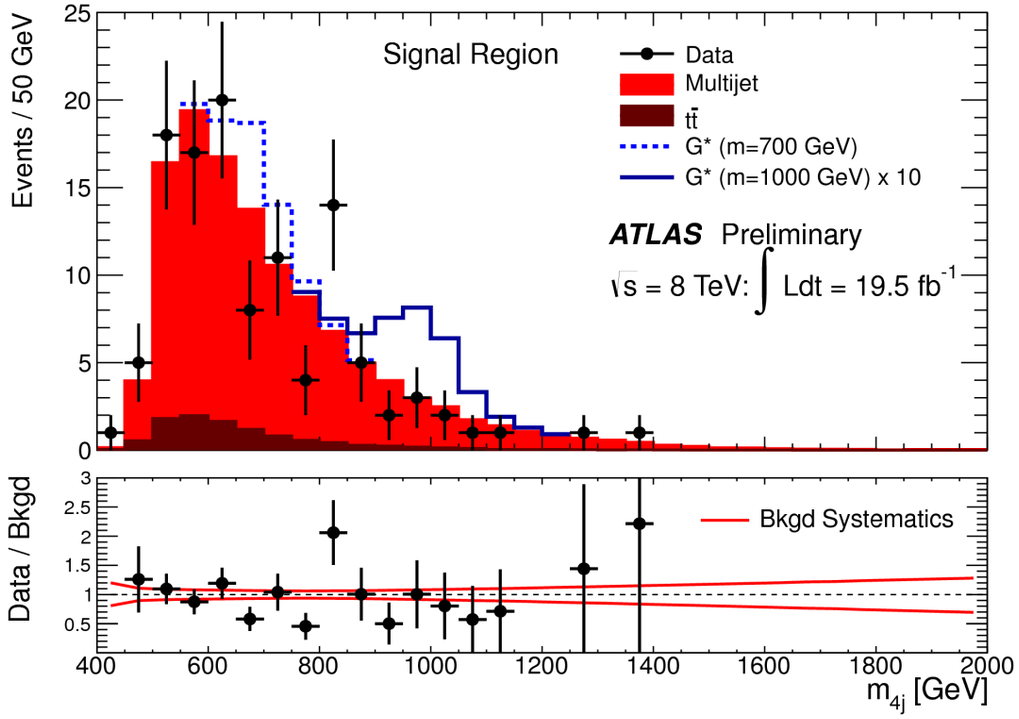
$$A(X_{J=0}\to VV)=v^{-1}\left(g_1 m_V^2\epsilon_1^*\epsilon_2^* + g_2 f_{\mu\nu}^{*(1)} f^{*(2),\mu\nu} + g_3 f^{*(1)\mu\nu} f_{\mu\alpha}^{*(2)}\frac{q_\nu q^\alpha}{\Lambda^2} + g_4 f_{\mu\nu}^{*(1)}\tilde{f}^{*(2),\mu\nu}\right)$$

CP even Higgs SM tree process	Anomalous CP even Higgs cont. Loop induced. BSM?	CP odd Higgs cont. BSM

Search for heavy resonances

- There are famous precedents
- Theoretical challenges: predicted by numerous BSM extensions
  - GUT - inspired theories Z' from broken E6, SO(10)..
  - Little Higgs->heavy gauge boson(s) Z' (W')
  - Technicolor->narrow technihadrons
  - Extra Dimensions-> RS warped KK graviton, KK gauge bosons
  - Benchmark model Sequential SM (Z^0, $W^{+/-}$ couplings)
- Experimental challenges:
  - Detector effects (trigger, resolution, efficiency) at high E.
  - Theoretical (mass) predictions not uniquely defined
  - Reach the TeV scale - a few CRs, extrapolate from low E, MC
  - However expect clean signal

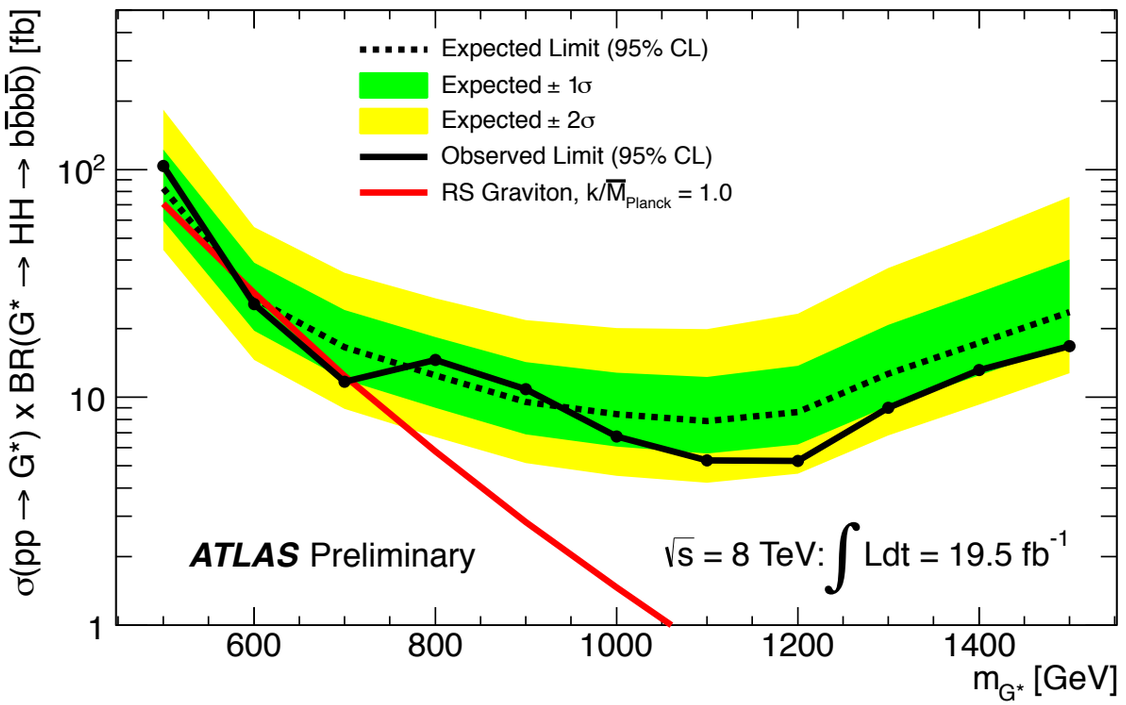
Resonance in X→HH→bbbb



ATLAS-CONF-2014-005

Type	Sideband Region	Control Region
Multijet	903 ± 3	935 ± 3
$t\bar{t}$	19.0 ± 0.2	26.7 ± 0.3
Z+jets	11 ± 1	17 ± 1
Total Bkgd	933 ± 3	979 ± 3
4-tag Data	933	933
G^* (m_{G^*} = 500 GeV)	0.75 ± 0.10	3.9 ± 0.2
G^* (m_{G^*} = 700 GeV)	0.48 ± 0.04	3.0 ± 0.1

- the signal benchmark model is spin-2 KK graviton in the bulk RS model (G^*) decaying this way.
- The observed data is compatible with the SM background hypothesis
- Given that there is no evidence of a signal, the result is used to set upper limits on $\sigma(pp \to G^*) \times BR(G^* \to HH \to b\bar{b}b\bar{b})$ as a function of m_{G^*}
- The model is excluded for m_{G^*} between 590 GeV and 710 GeV at 95



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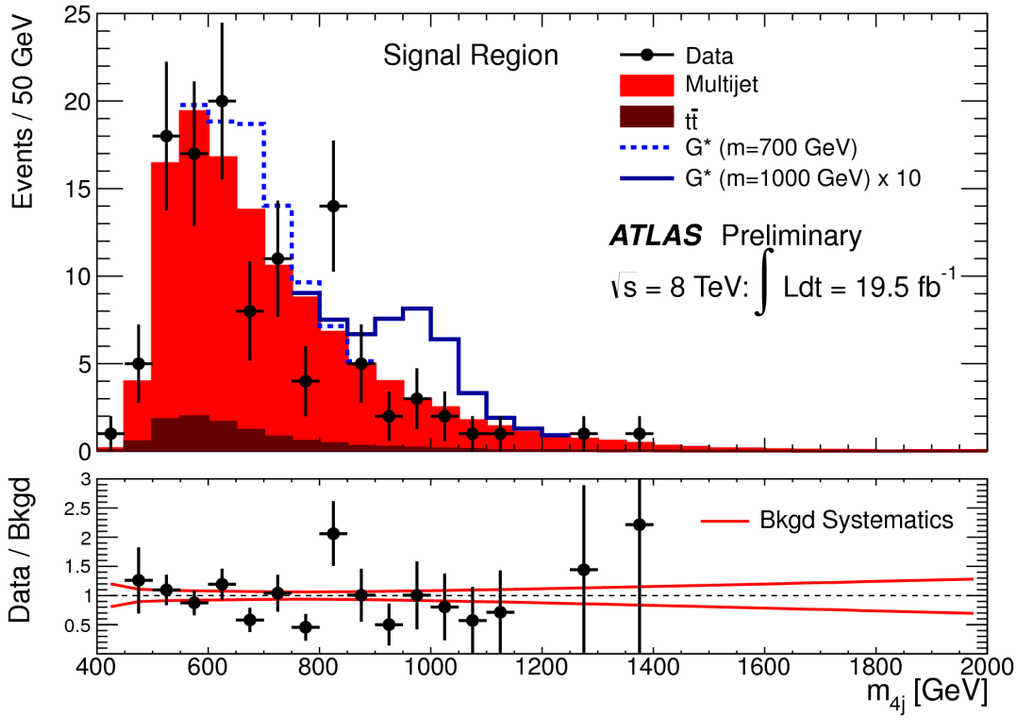

ATLAS-CONF-2014-005

Type	Signal Region
Multijet	109 ± 5
$t\bar{t}$	10 ± 6
Z+jets	0.7 ± 0.2
Total Bkgd	120 ± 8
Data	114
G^* (m_{G^*} = 500 GeV)	12.5 ± 0.4
G^* (m_{G^*} = 700 GeV)	12.5 ± 0.2

- the signal benchmark model is spin-2 KK graviton in the bulk RS model (G^*) decaying this way.
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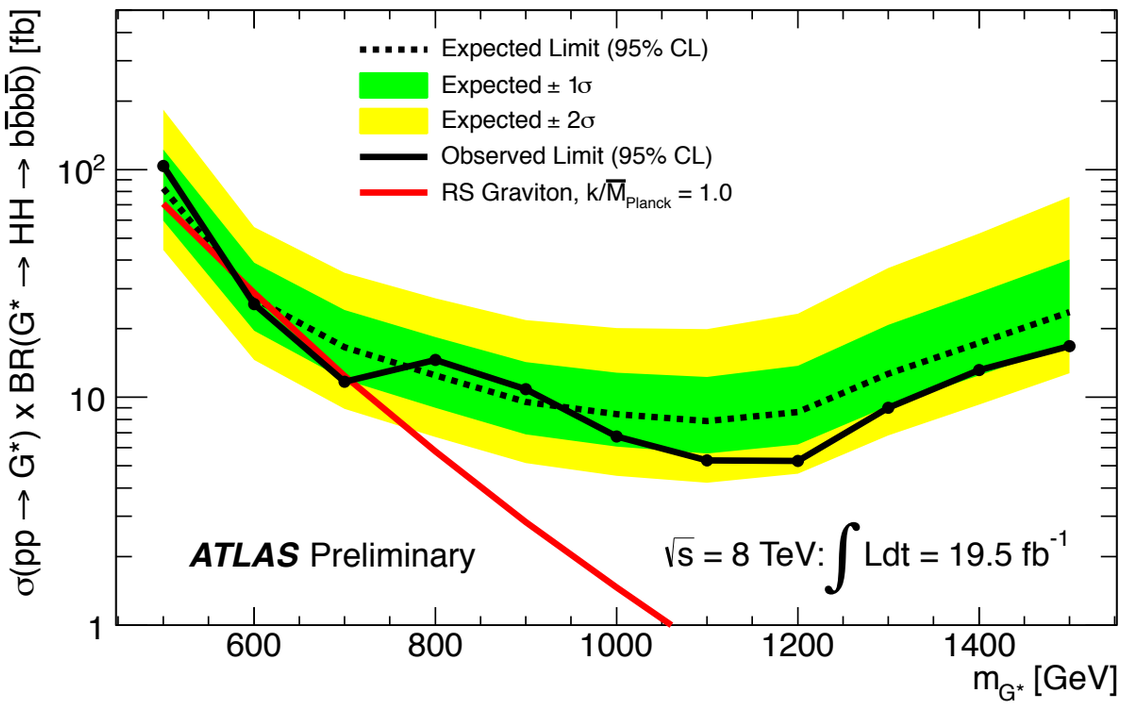
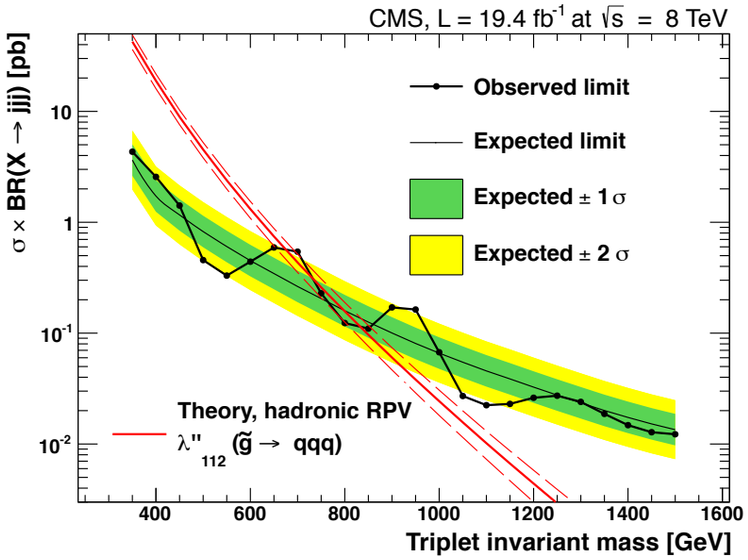
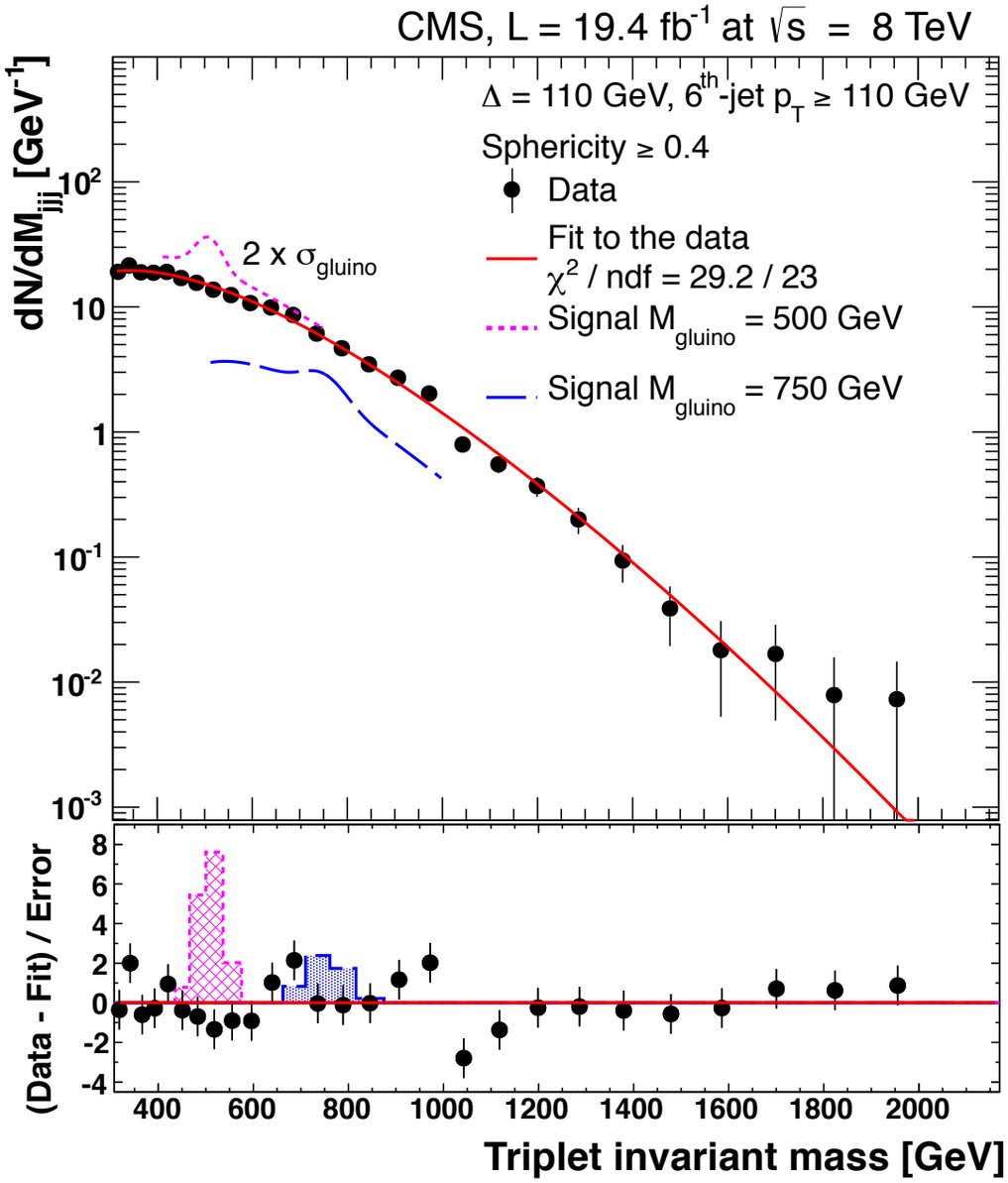


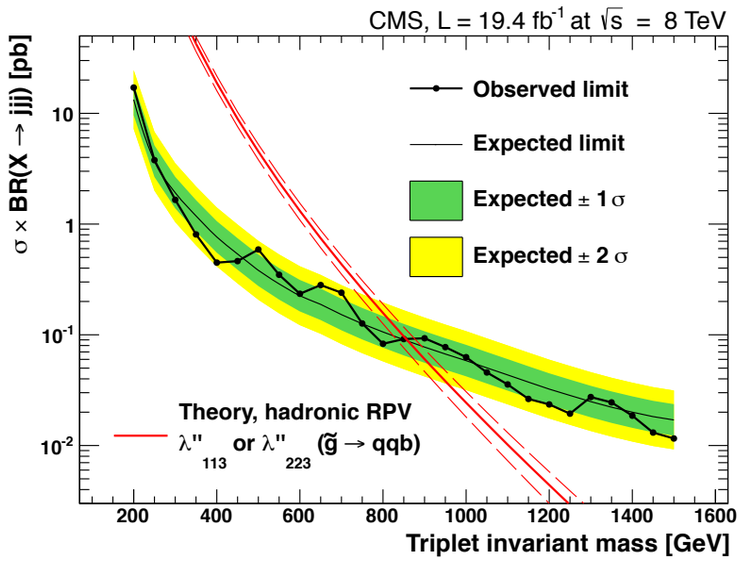
Pair produced three jets resonances

- **Search for 3 jet resonance in falling spectrum** arXiv: 1311.1799
  - Model independent search
  - Signal model: RPV SUSY gluino pair decay to light jets or light+heavy jets.
  - For b-tagged results, QCD shape from b-vetoed data



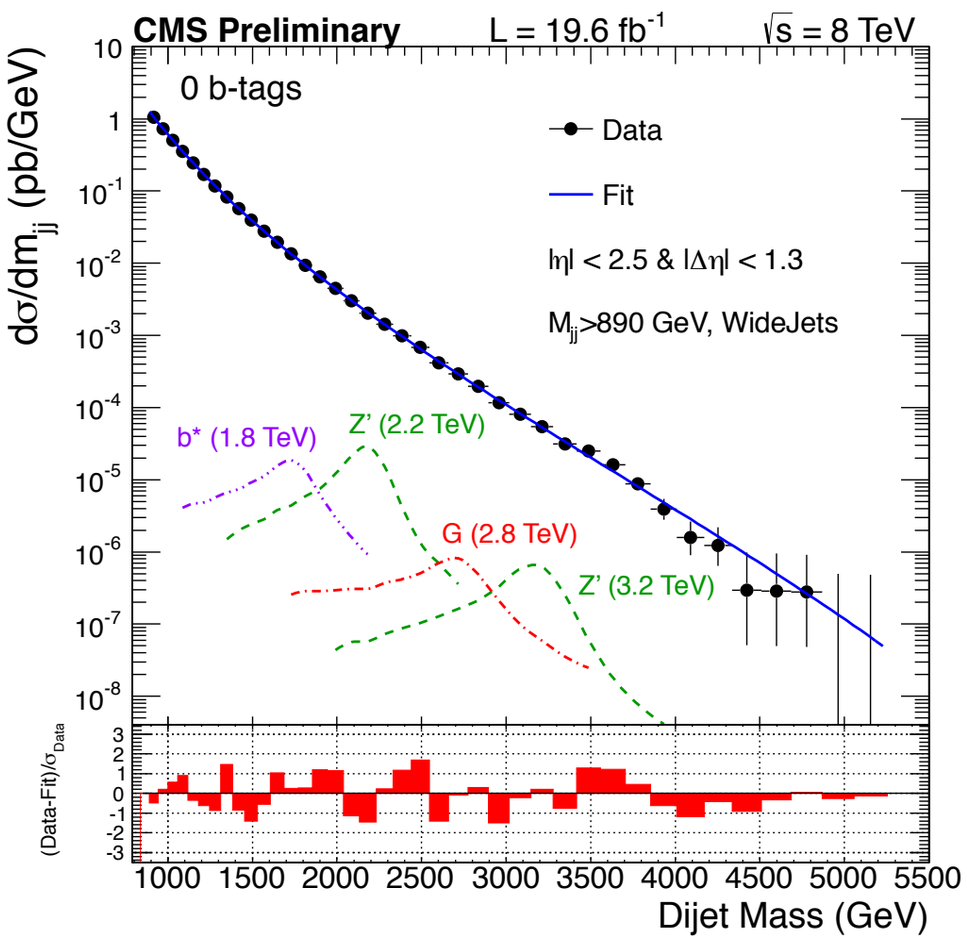


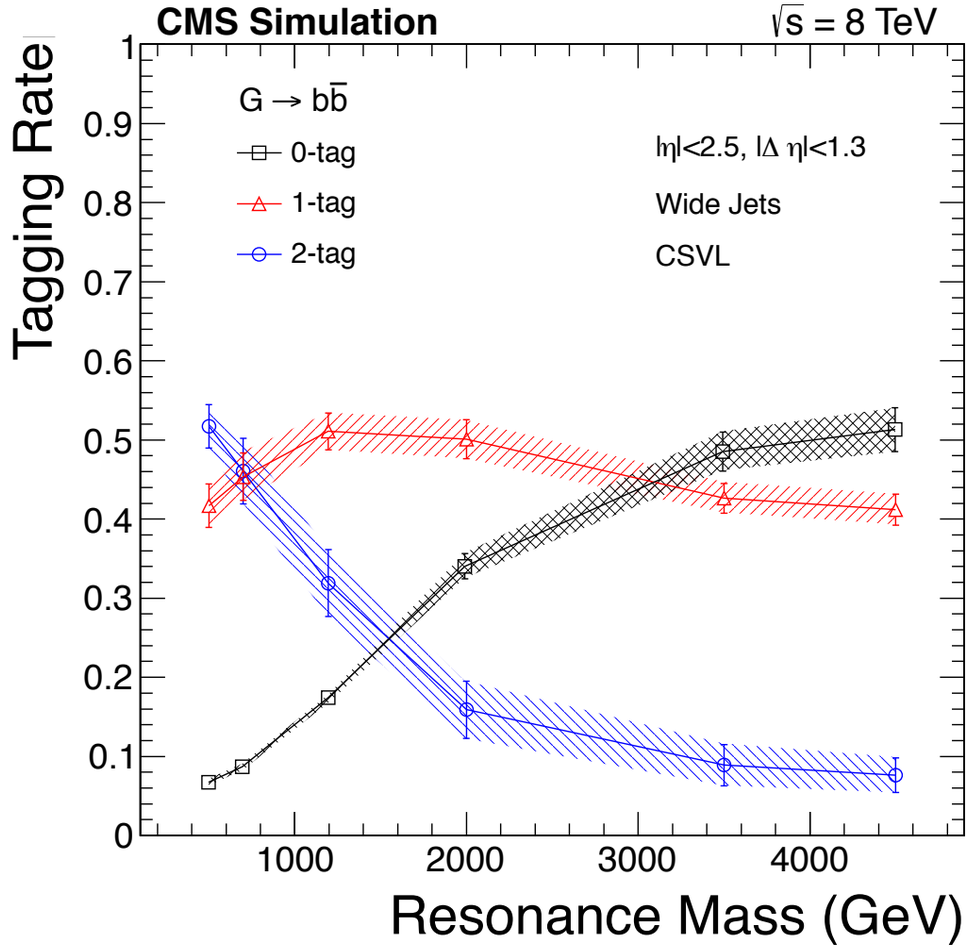
Exclude RPV gluinos< 650 GeV (light quarks) and between 200 to 835 GeV (heavy quarks)



Dijets with bb and bg final states

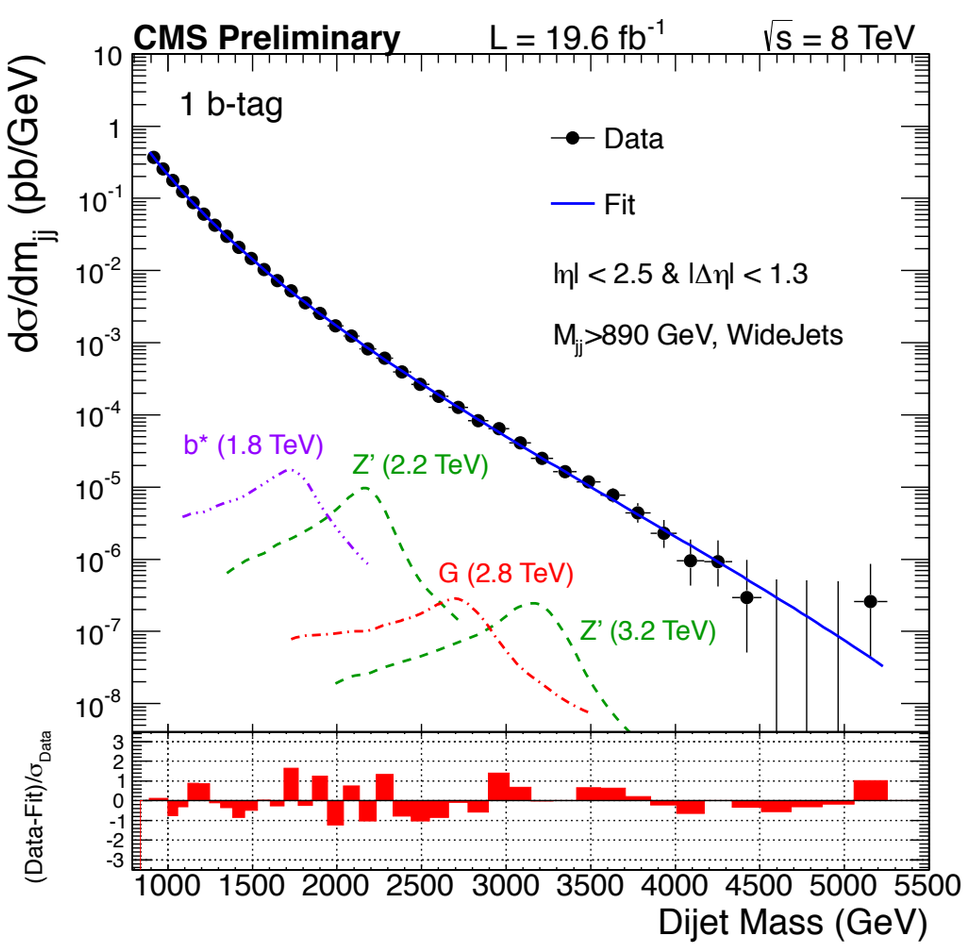
- Simultaneous search in 0, 1, 2 b-tags (essentially requiring secondary vertices.)
- Model independent limits vs. Br
- Interpreted in qq, gg, and bg (Z', G_{RS} and b* models)

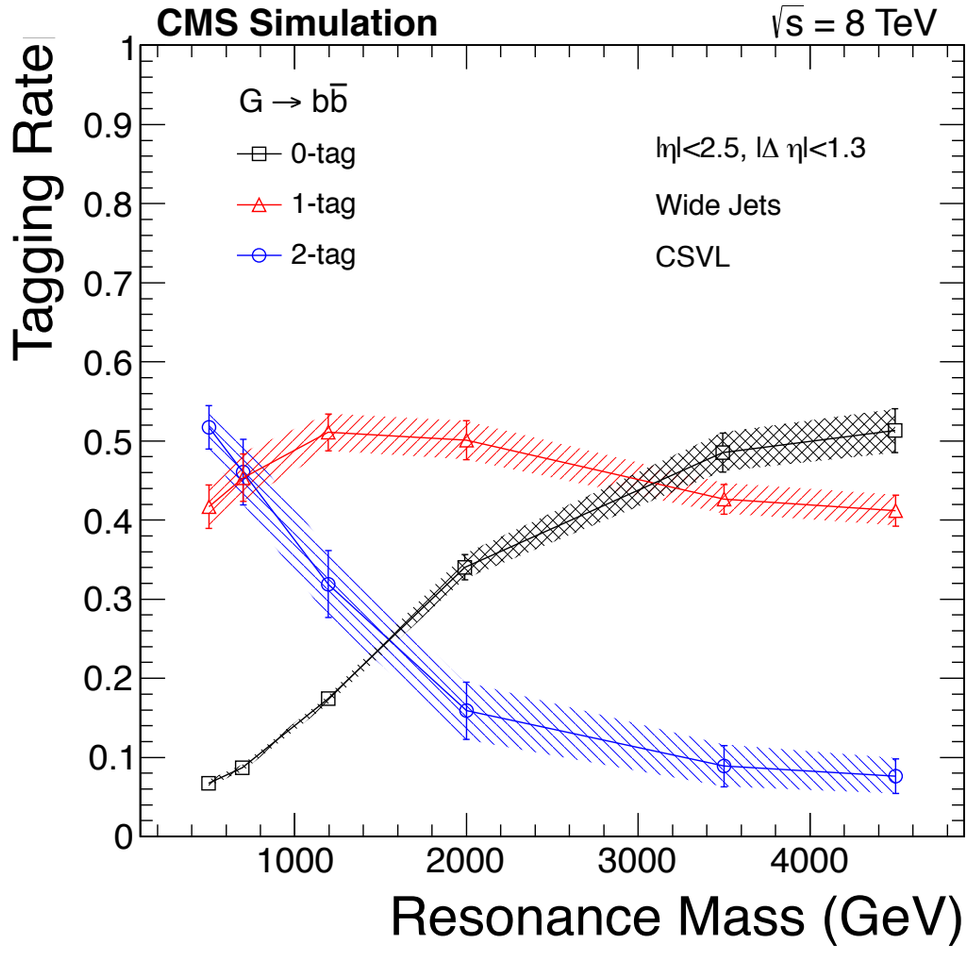




Dijets with bb and bg final states

- Simultaneous search in 0, 1, 2 b-tags (essentially requiring secondary vertices.)
- Model independent limits vs. Br
- Interpreted in qq, gg, and bg (Z', G_{RS} and b* models)





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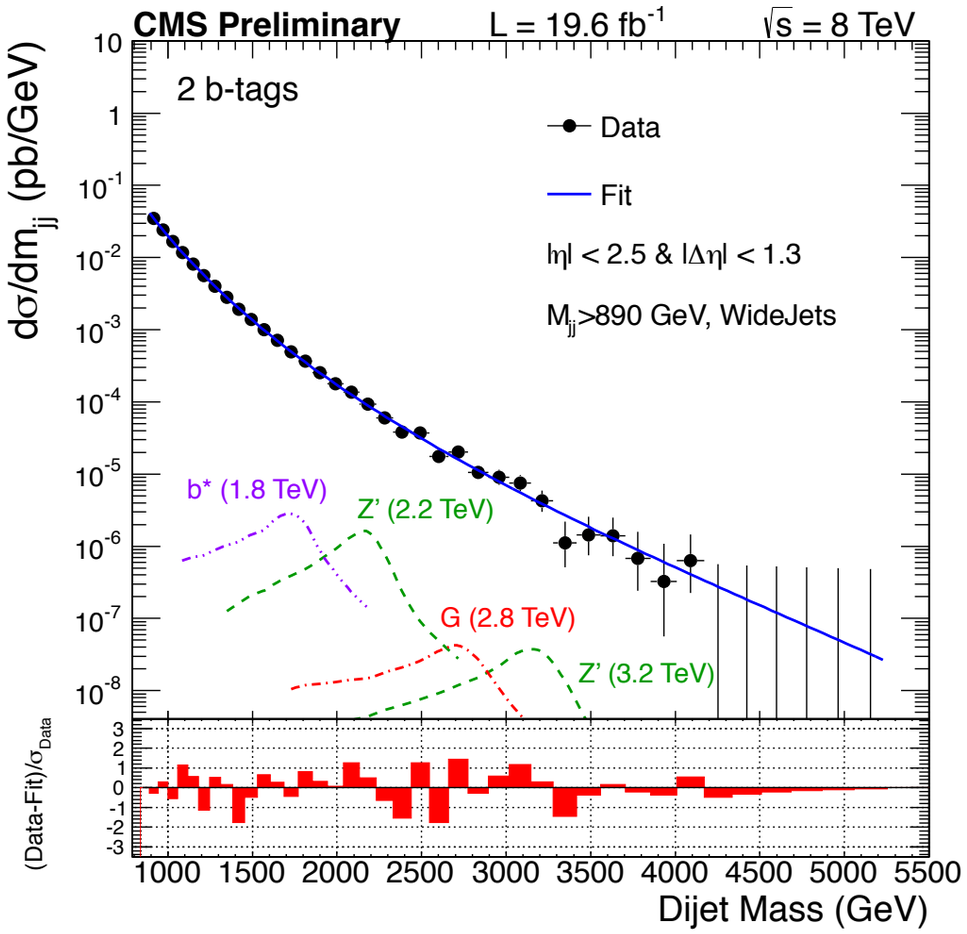

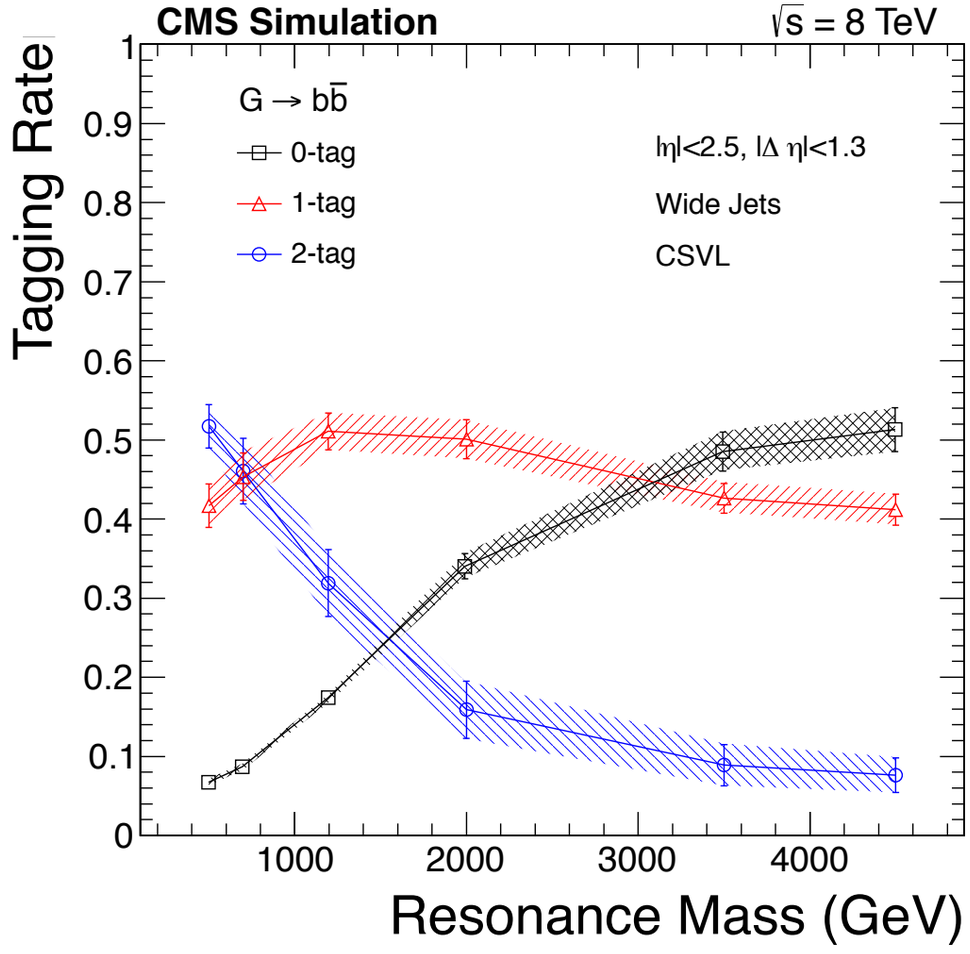

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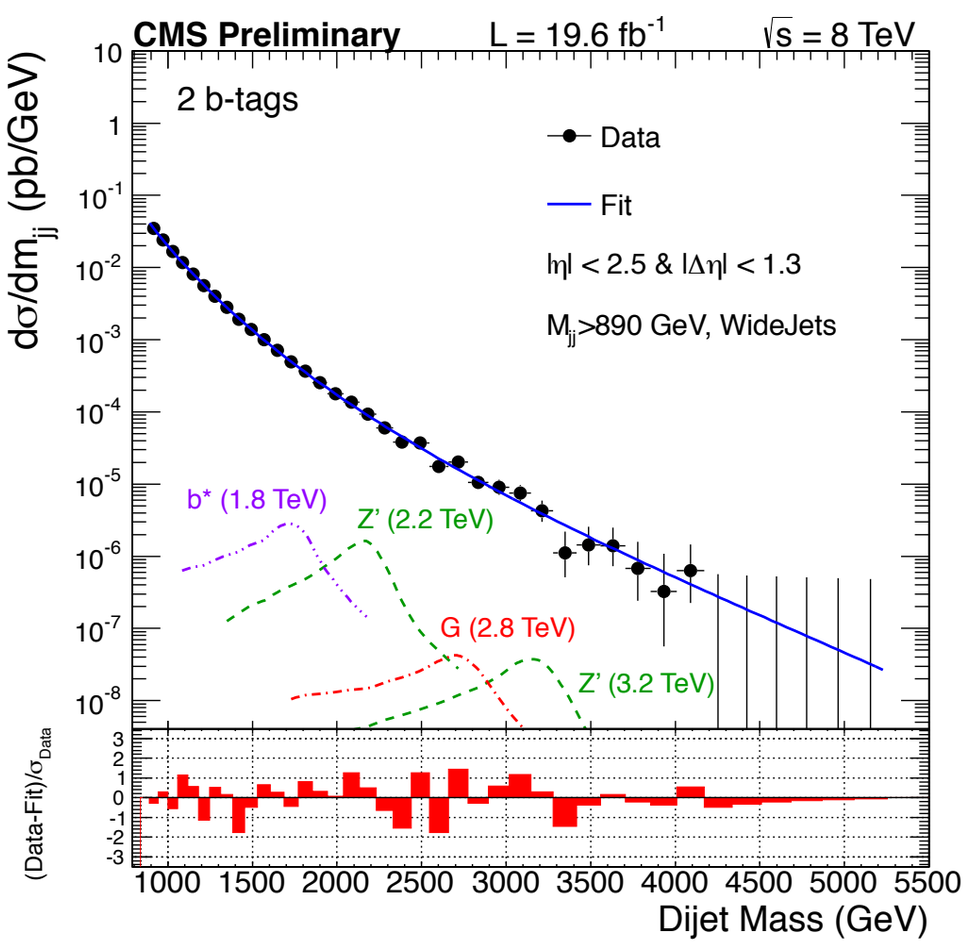
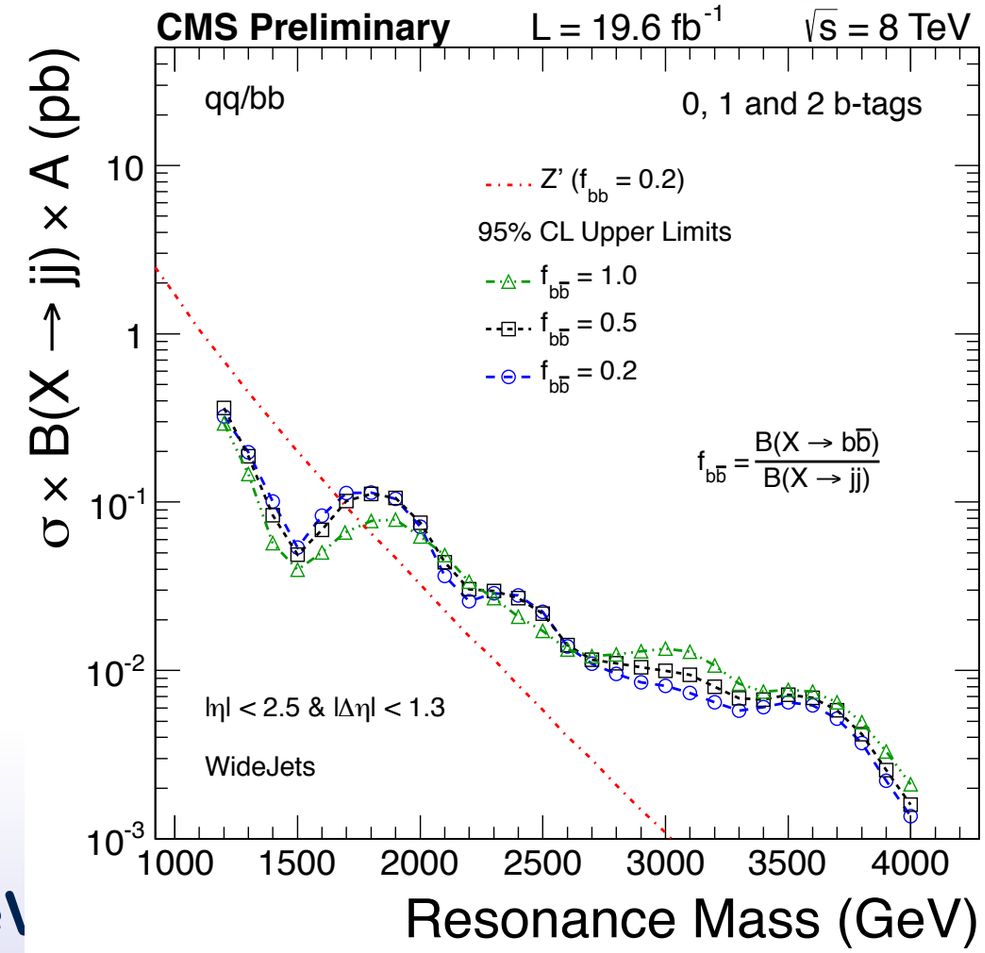




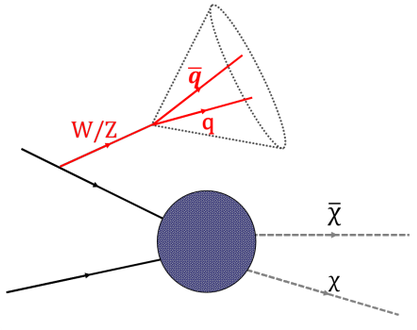
Exclude

- **SSM Z' : 1.2-1.68 TeV**
- **RS graviton: 1.42-1.57 TeV**
- **b* : 1.34 to 1.54 TeV**

MonoW/Z

Event Selection

arXiv:1309.4017



- One "fat" C/A (R=1.2) jet $p_T > 250$ GeV, 50 GeV $< M_{jet} <$ 120 GeV, require momentum balance of two leading sub jets
- max 1 additional anti-k_T R=0.4 jet ($p_T > 40$ GeV $\Delta R(j_{narrow}, j_{fat}) > 0.9$
- veto leptons or photons

Signal regions:

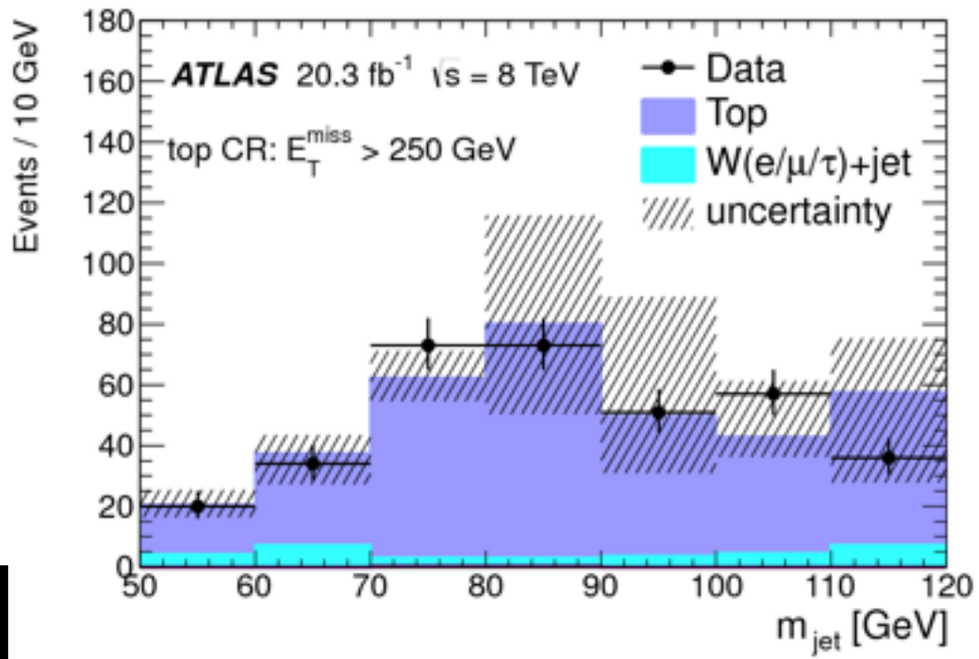
- $MET > 350$ GeV or $MET > 500$ GeV

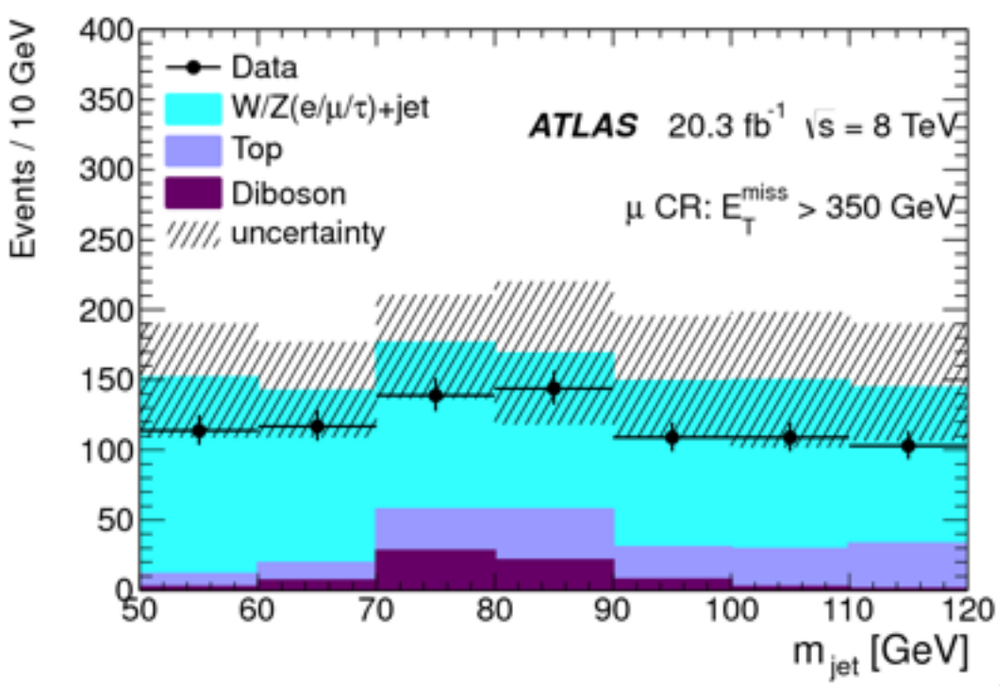
BG estimate

- **Main Z(nu,nu)+jet with W(mu,nu) +jets**
- **ttbar, single top, diboson from MC**
- **Multijet - negligible**

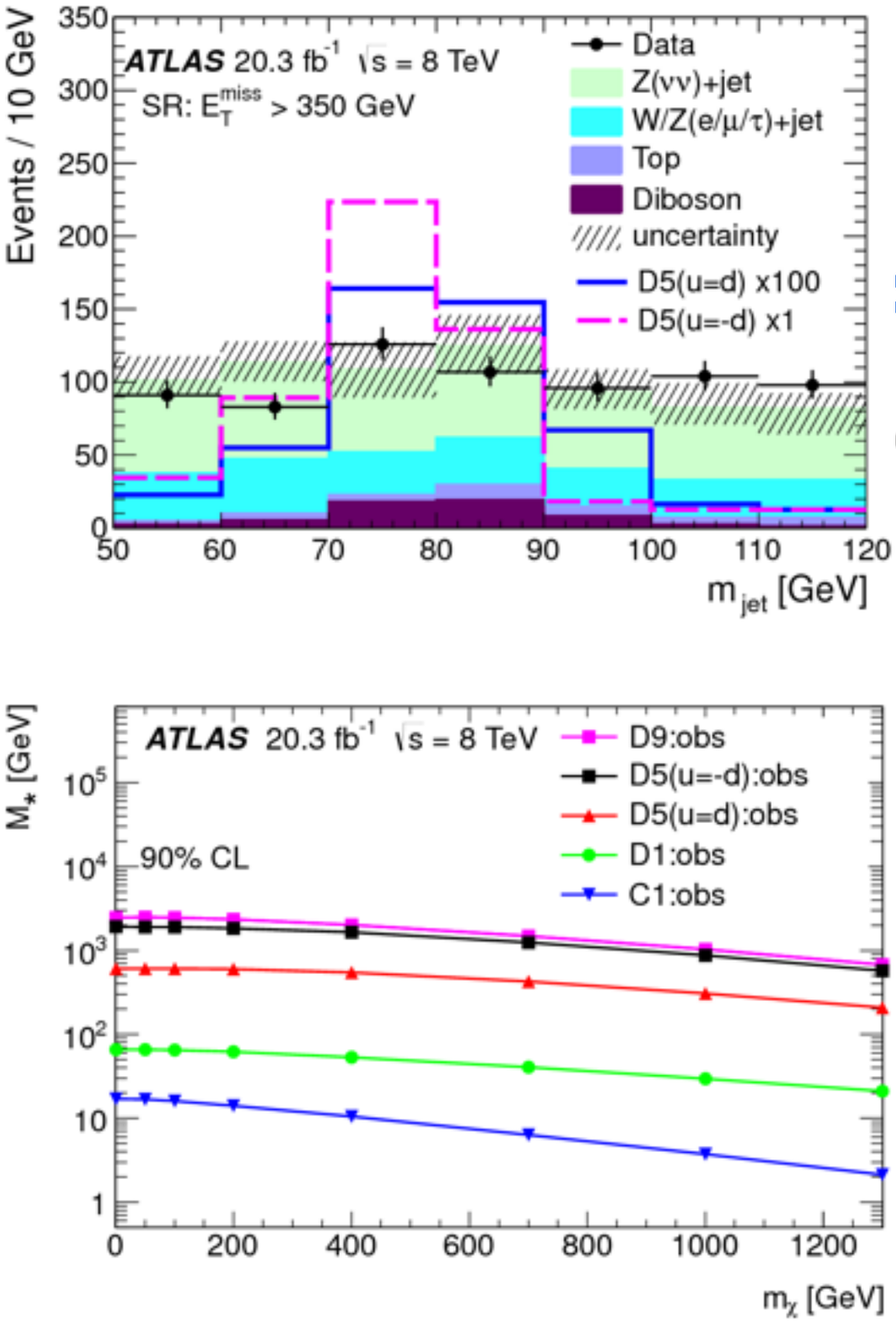
Estimate dominant BG: W/Z+jets from mu+jet+MET CR

Validate W reco with fat jets in top dominated m+MET+b-jet CR

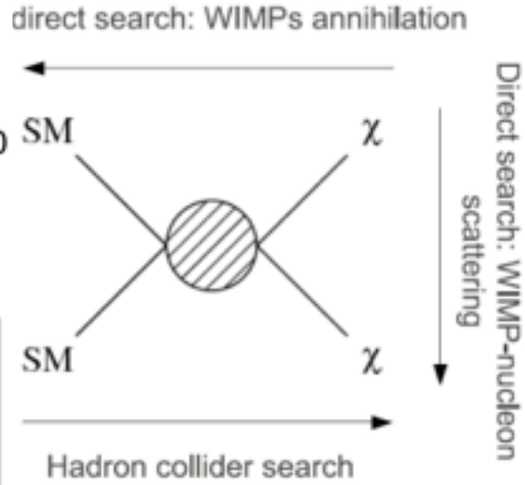


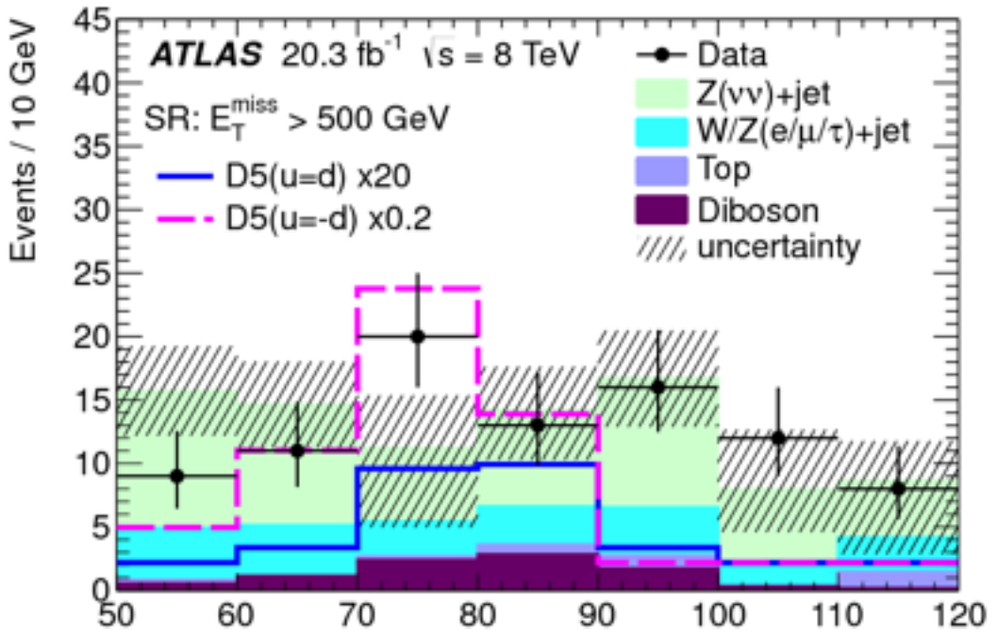


MonoW/Z

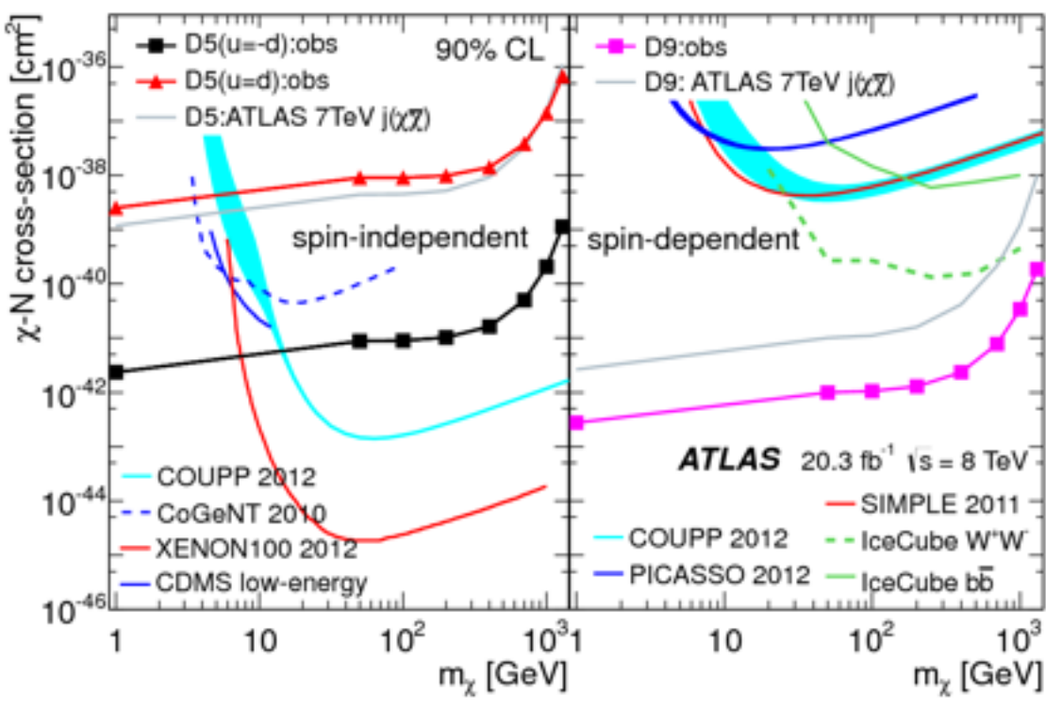


Signal regions





Probe relative coupling to u and d quarks. Stronger than monojet for opposite sign case.



Microscopic BH & string balls in leptons + jets

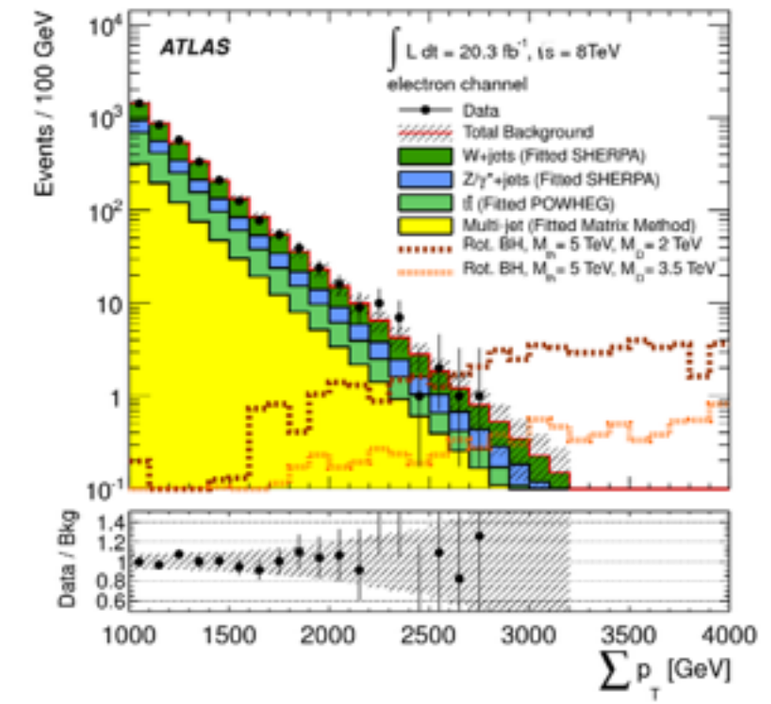
arXiv:1405.4254

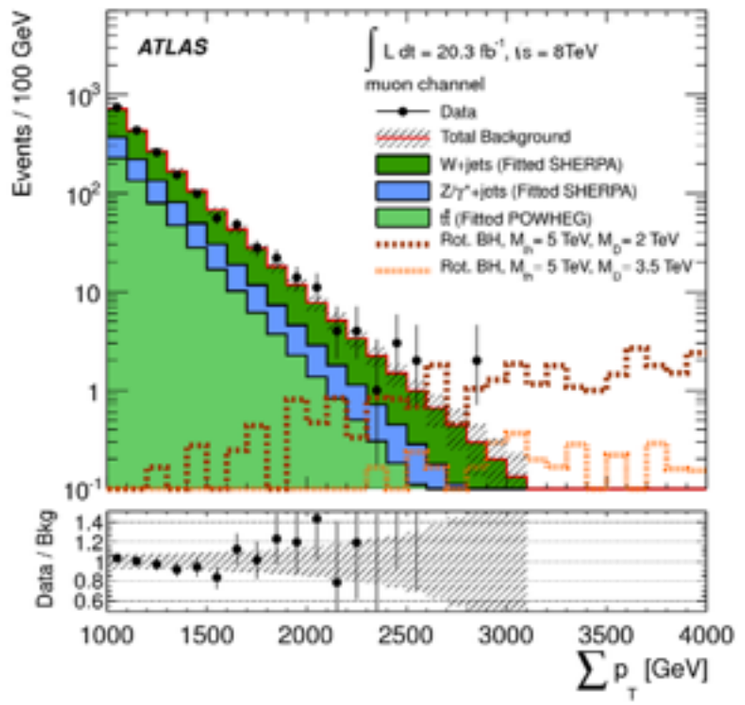
- Combine shapes from fit with relative fractions of each background for final estimate
- Slice signal region in order to be sensitive to wide range of signal phenomenologies
  - Model independent limits on signal cross-section.
  - Limits on 11 Black Hole/String Ball models.

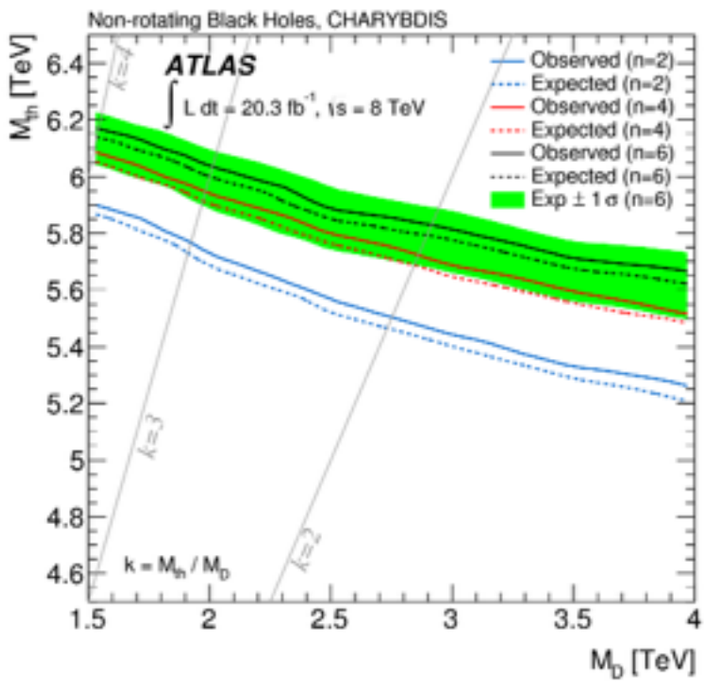
Previous searches

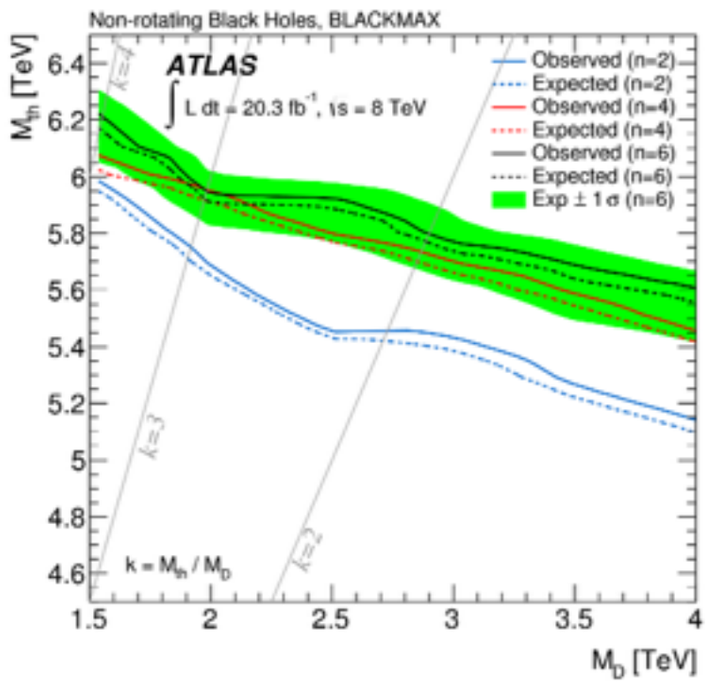
CMS multiplicity vs sum pT
[arXiv:1303:5338, EXO-12-009]

ATAS SS muons + jets
arXiv:1308.4075









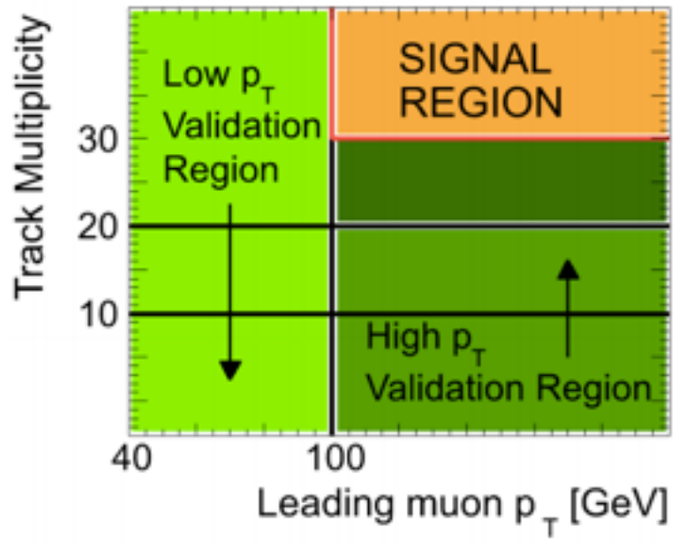
The exclusion limits in the M{th} -M{D} plane

Search for microscopic Black Holes

- BH in ADD, M_D = Planck scale, $D = n + 4$, $M_{TH}(> M_D)$ BH mass

arXiv:1308.4075

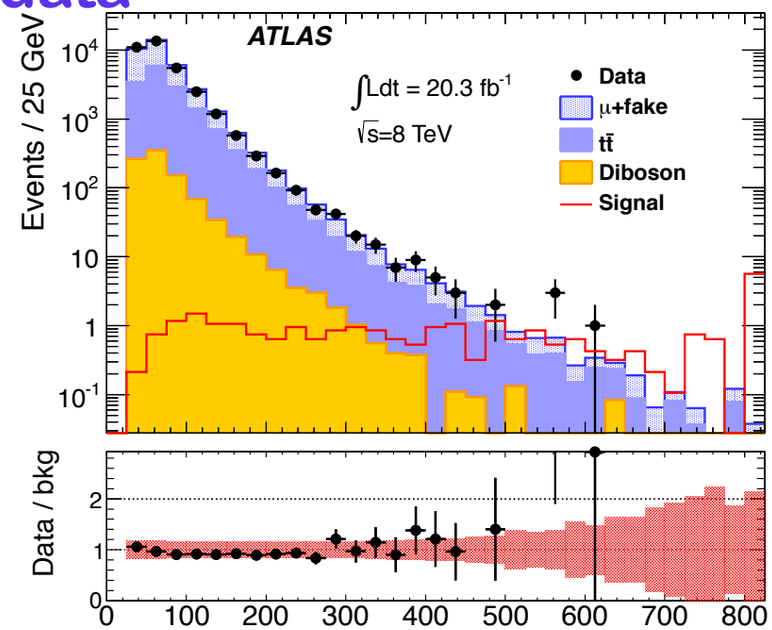
- Striking signature multiple highp_T objects
- Search like-sign $\mu\mu$ and multiple high p_T tracks
- Counting experiment in pre-defined signal region
- If no signal exclude TeV gravity models in $M_{TH} - M_D$ plane



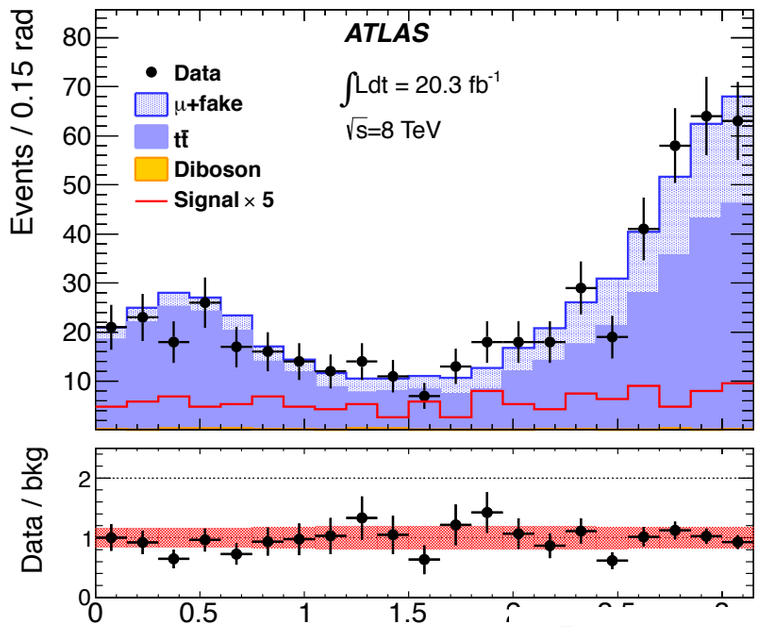
BG estimate:

•tt, Wt, WW, Wz, ZZ - MC

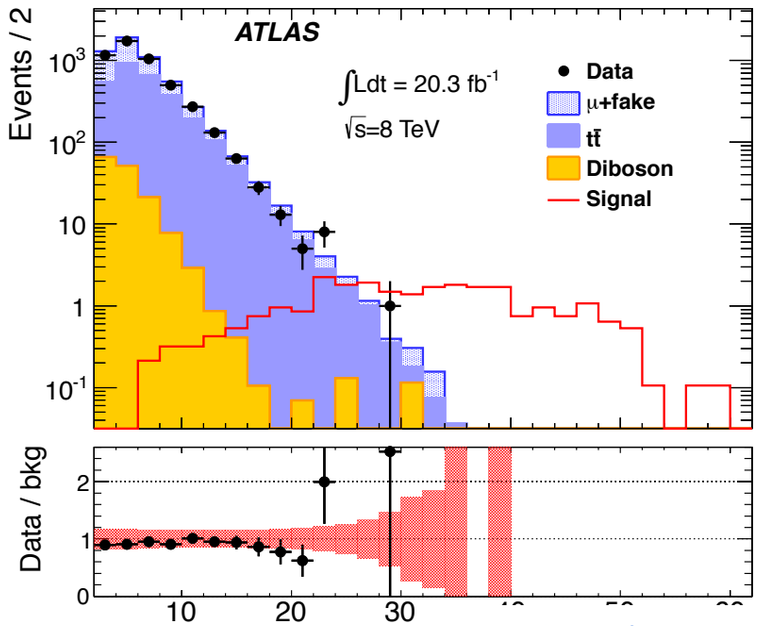
• Fake Rate track→μ in photon+jets data



Leading muon pT



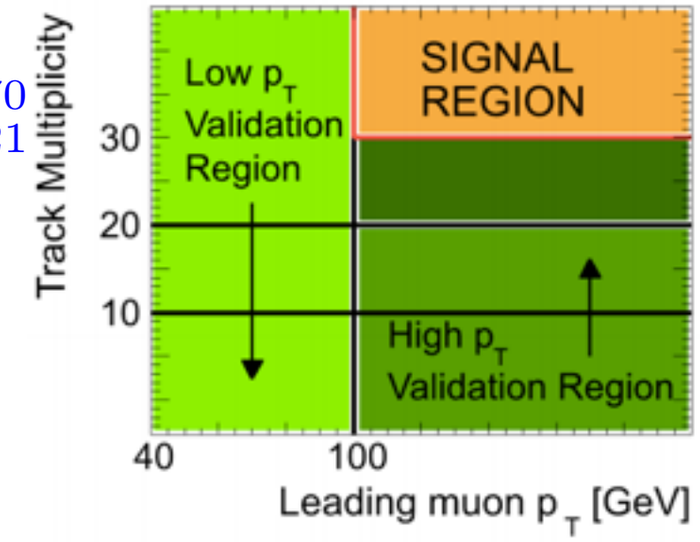
Dimuon ΔΦ



track multiplicity

Search for microscopic Black Holes

- See no excess in the SR
- 95% CL upper limit on $\sigma \times BR \times A \times \epsilon$: 0.145 (exp $0.159^{+0.070}_{-0.021}$
- Exclude contours in $M_{TH} - M_D$ plane n=2, 4, 6 for rotating and non-rotating BH
- Constrain Stringball production



Source	Signal Region
μ+fake	$0.21 \pm 0.09 \pm 0.09$
$t\bar{t}$	$0.20 \pm 0.08 \pm 0.04$
Diboson	$0.12 \pm 0.08 \pm 0.03$
Wt	0.02 ± 0.02
Total	$0.55 \pm 0.15 \pm 0.10$
Data	0
Signal	$14.2 \pm 1.3 \pm 2.7$

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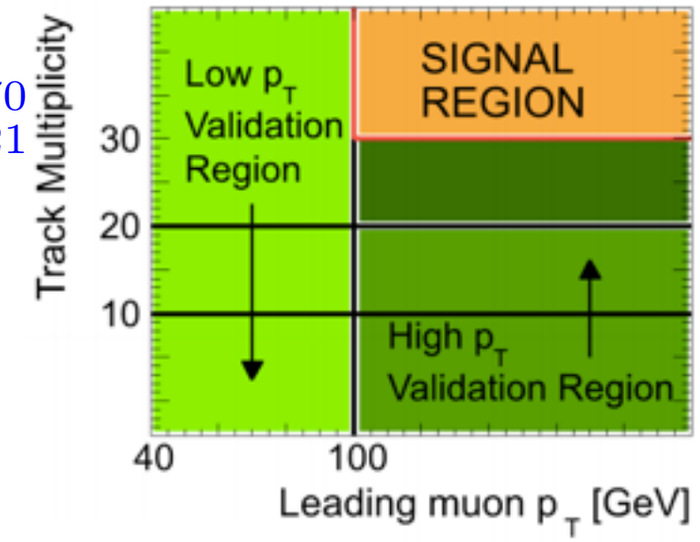

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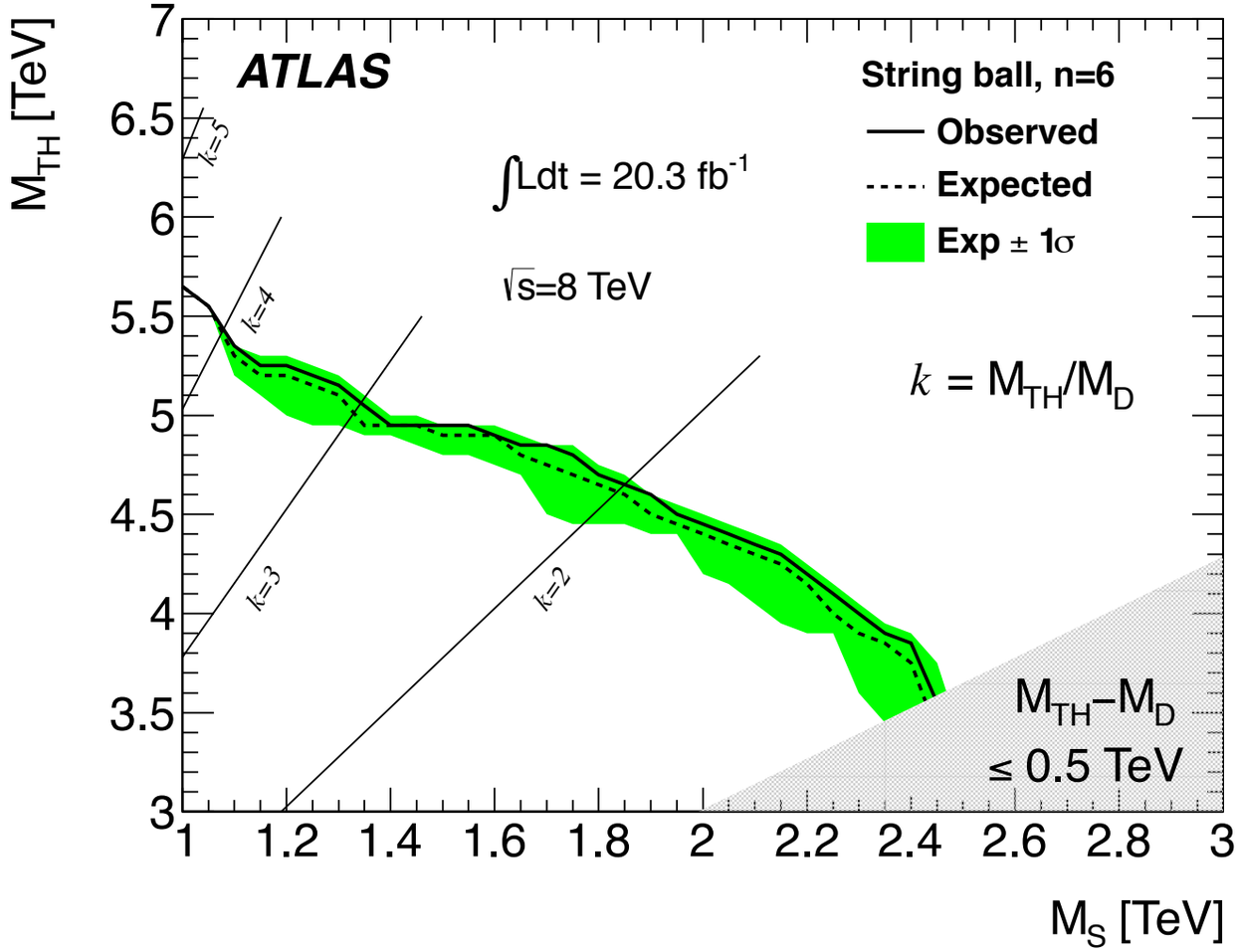

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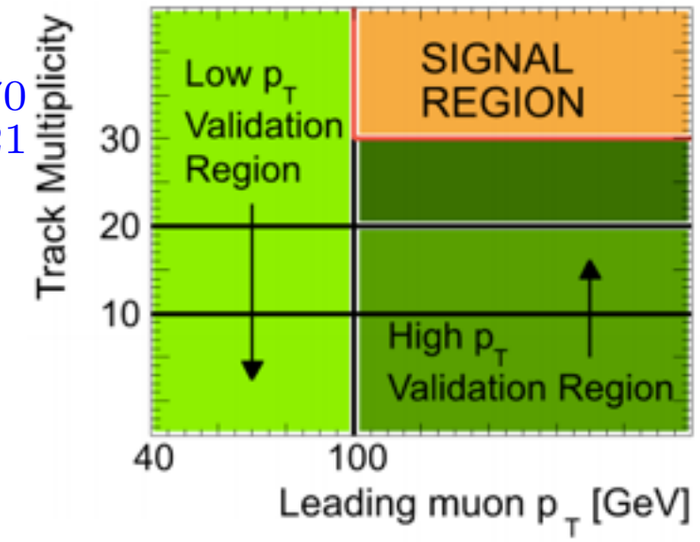

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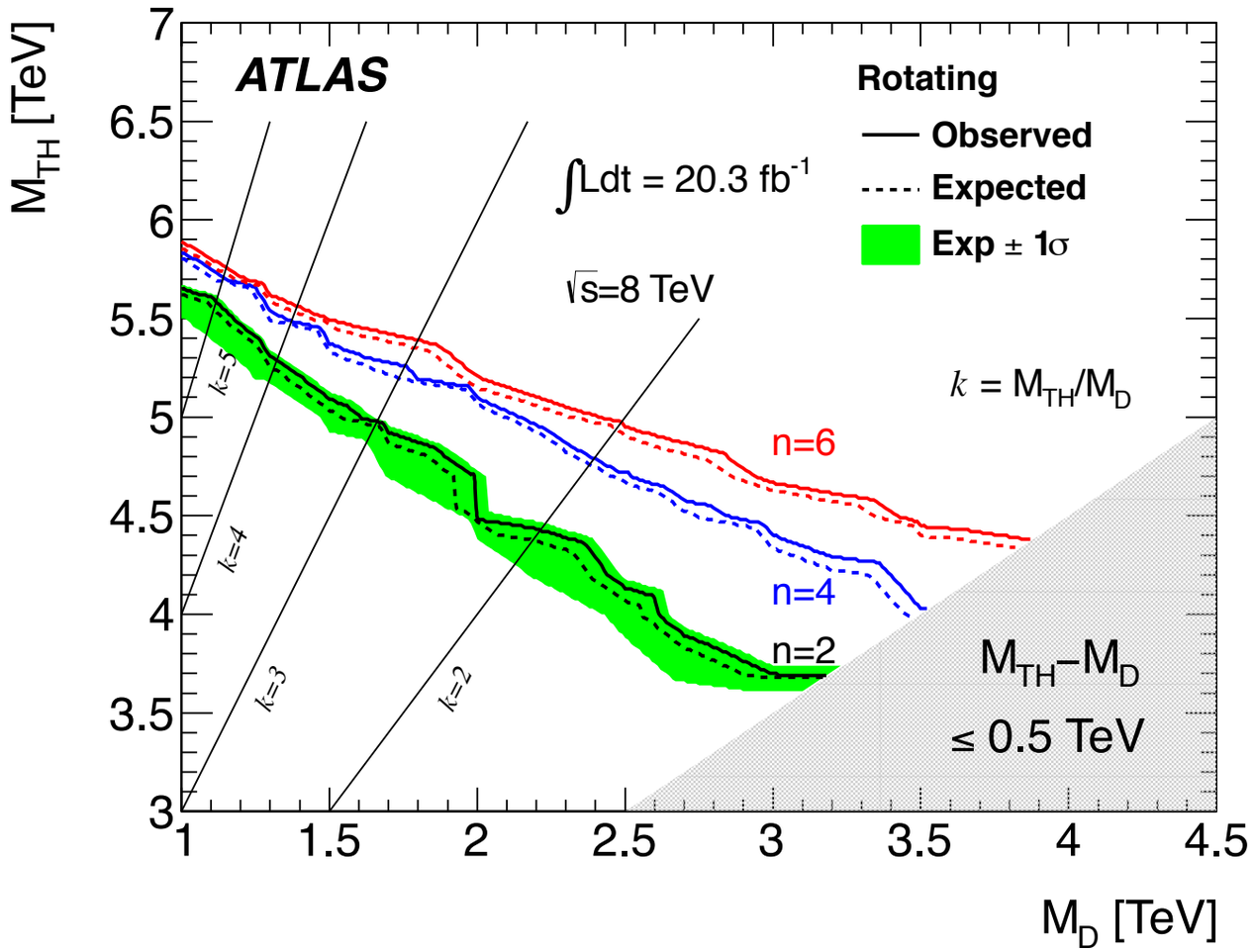

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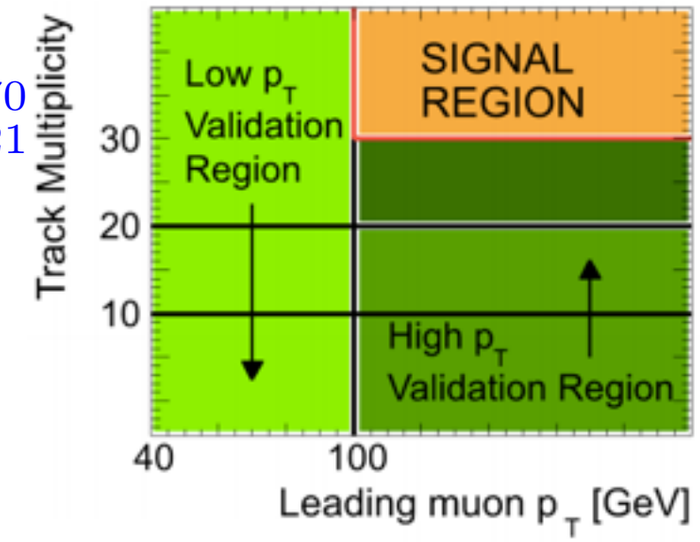

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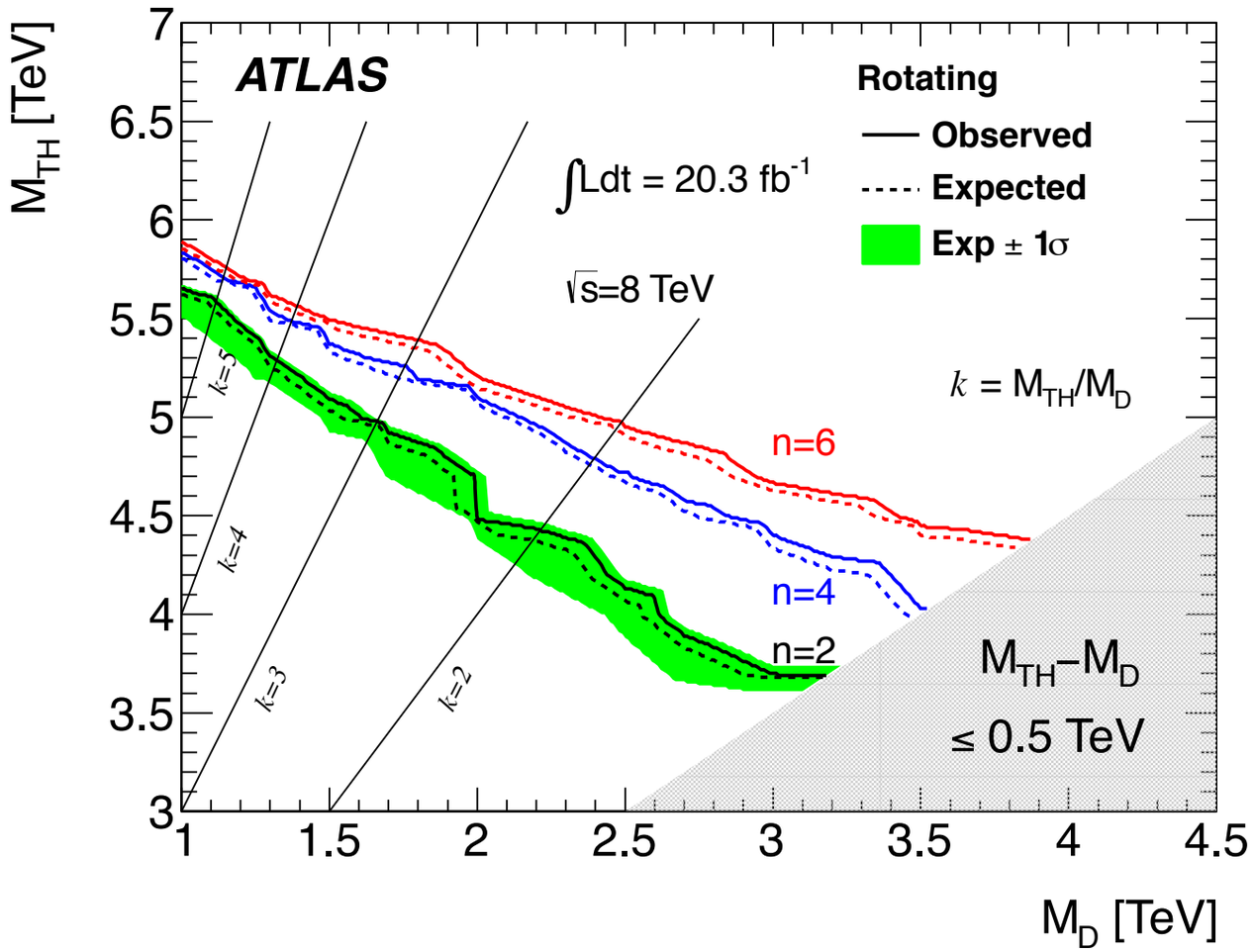
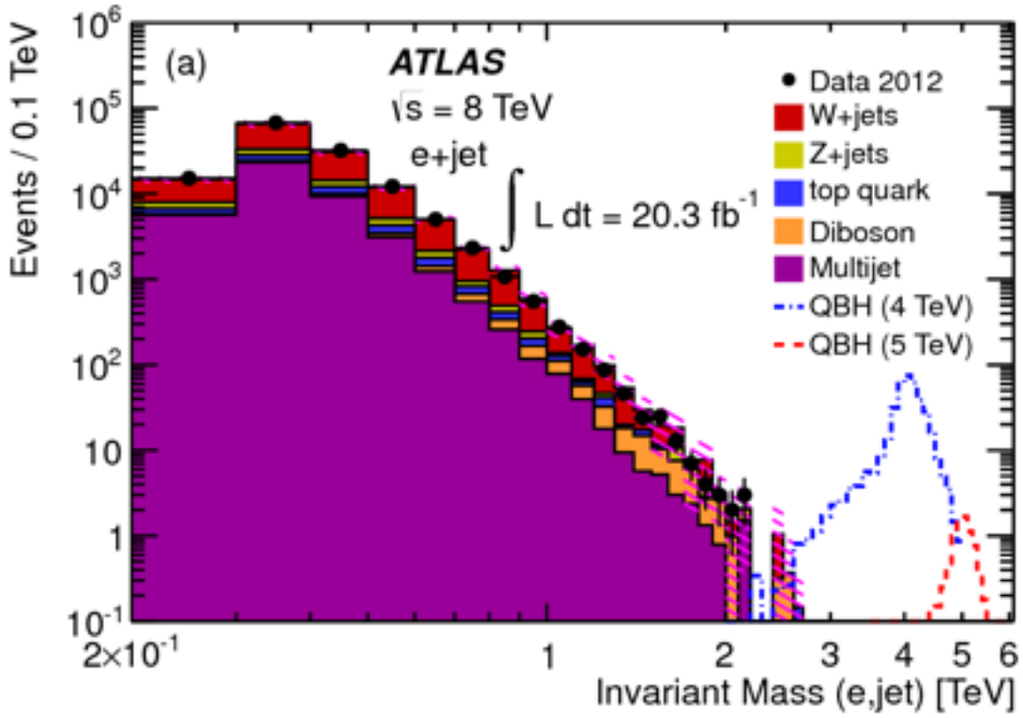
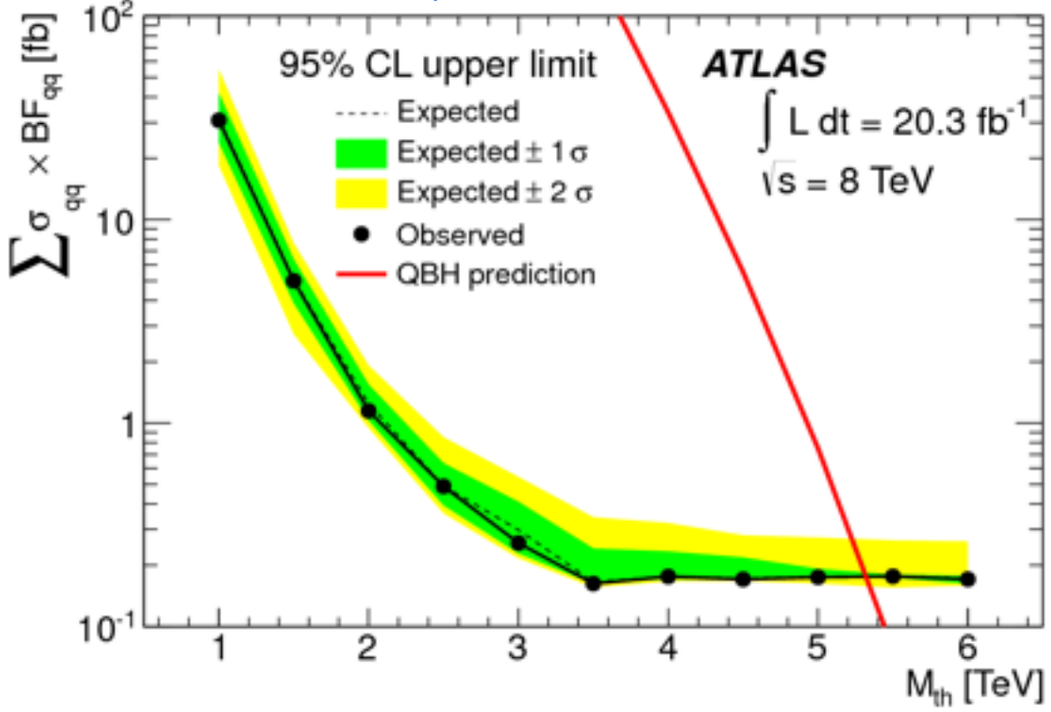


Quantum BH search in lepton+jet

- QBH predicted in low-scale quantum gravity (QG) explaining mass hierarchy by lowering the QG scale (M_D) from Planck to TeV scale
- QBH near M_D will conserve angular momentum, color, charge and may decay to two particles.
- Search in l+j (violation of lepton and baryon conservation) above threshold M_{th} (equivalent to the inverse gravitational radius)



Limits on Σ σqq × BFqq for QBHs to l+J jet function of Mth, assume M_D = Mth and n = 6 ADD



➡Above 3.5 TeV expected BG drops below one event.
➡95% CL upper limit on e (mu)+jet Σ σqq × BFqq is 0.27 (0.49) fb.
➡Assuming lepton universality the limit is 0.18 fb.

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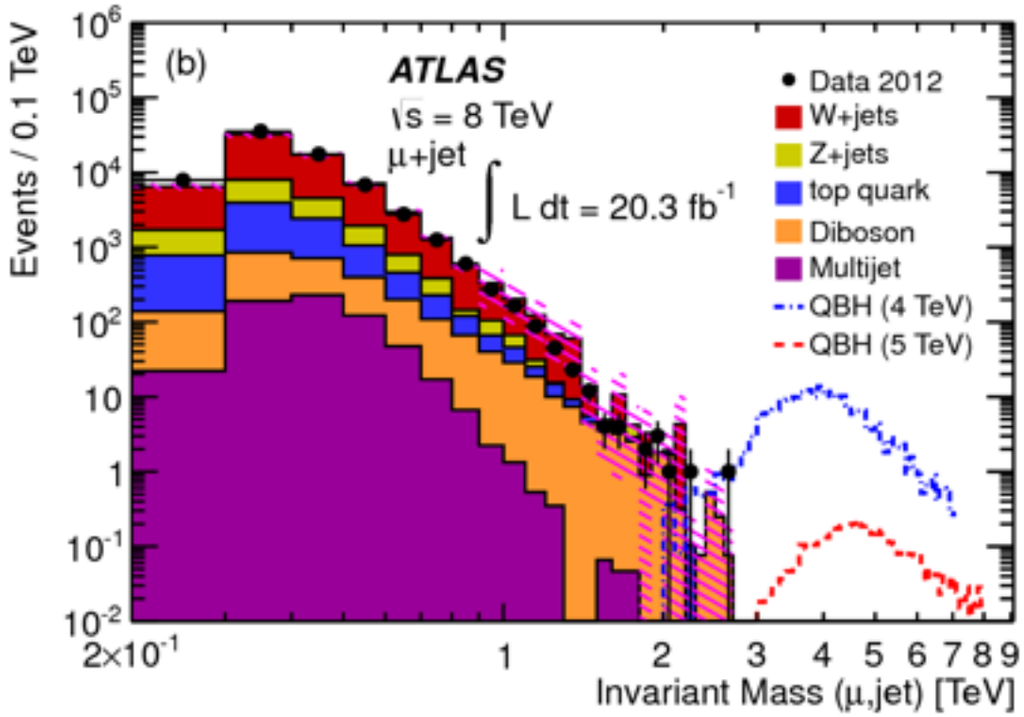

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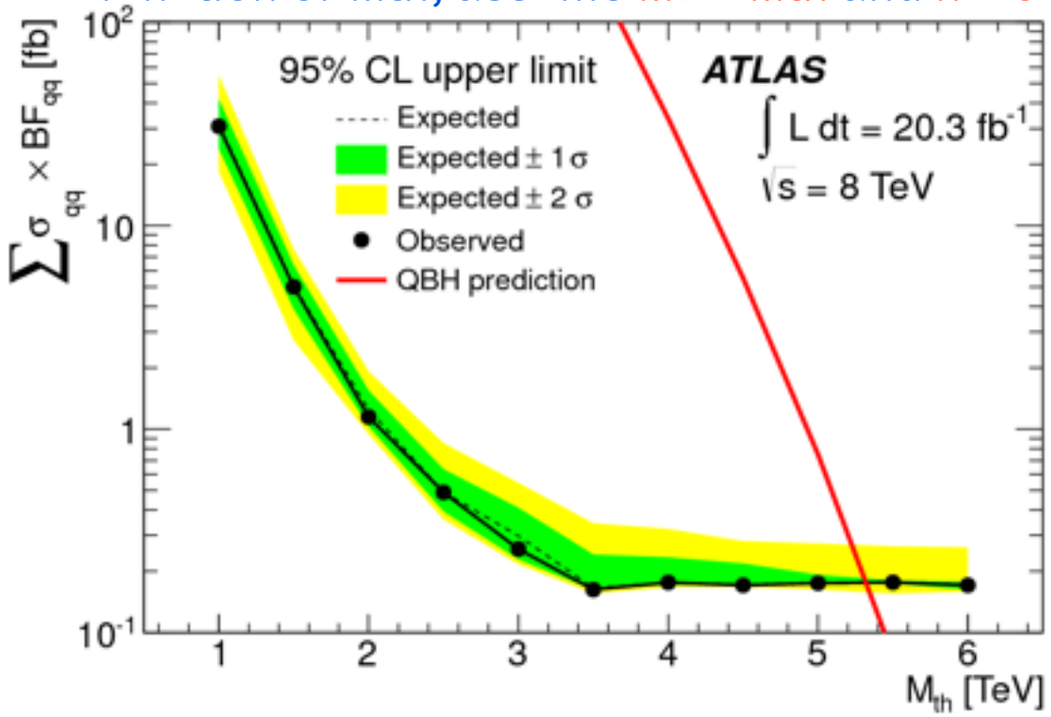

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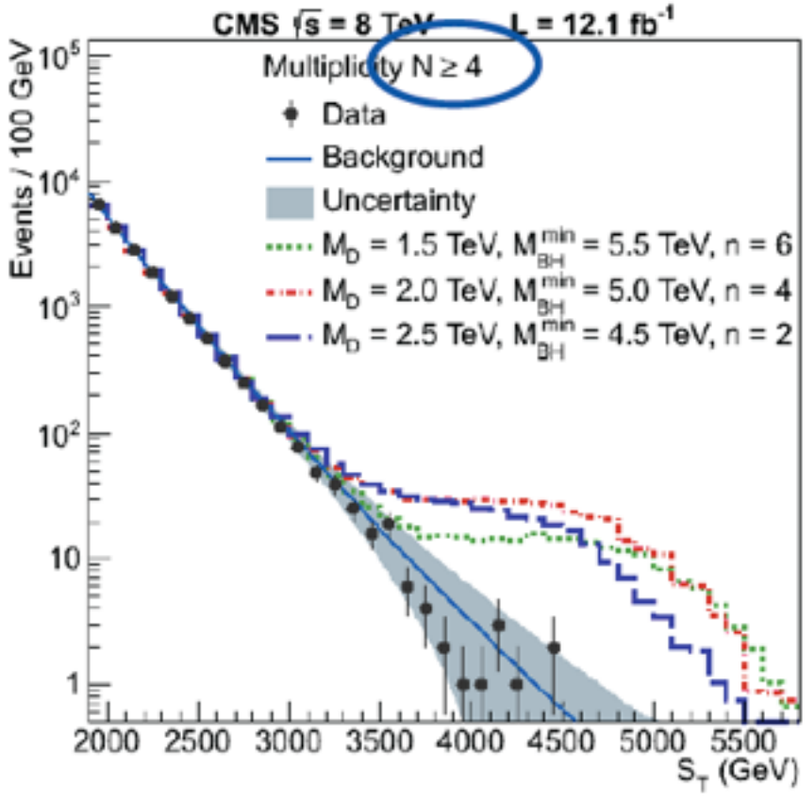
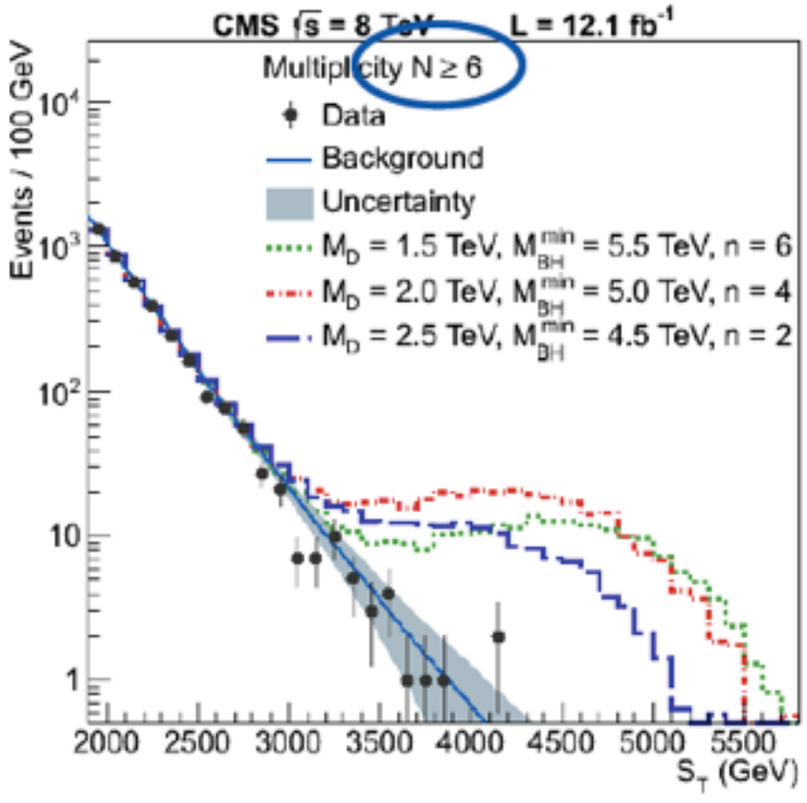
Search for Black Holes

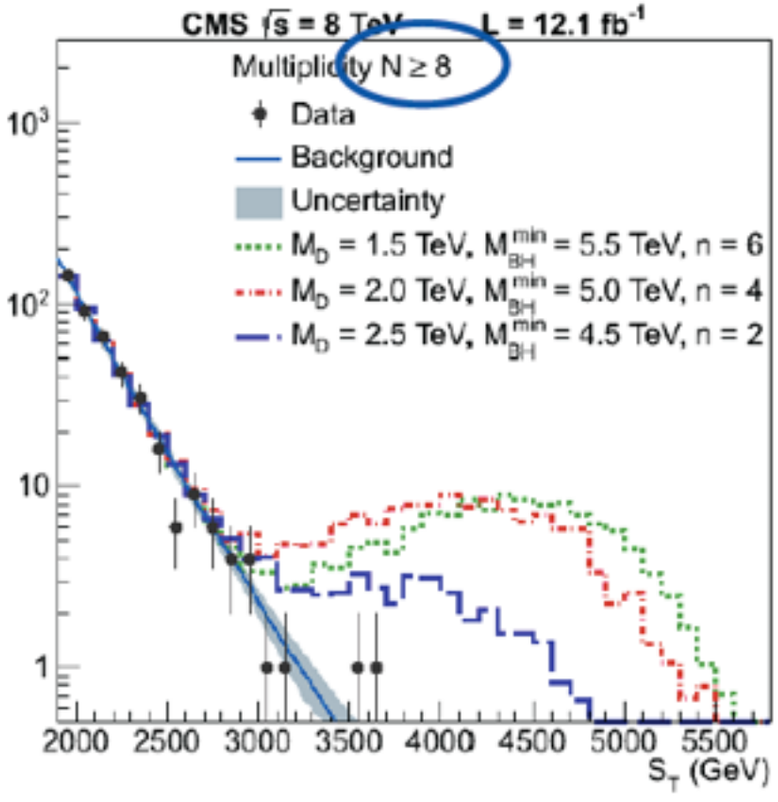
- Search for hypothetical BH that would evaporate into many high p_T objects
- Estimate by s_T :p_T sum of all objects with pT>50 GeV)
- Estimate main (QCD) bg by fit to n=2 distribution
  - Normalised for each multiplicity bin separately at s_T=1.8-2.2 TeV
  - Model independent limits vs s_T and multiplicity

[arXiv:1303:5338, EXO-12-009]

$$S_T = \sum_{j,e,\mu,\gamma,MET}^{N} p_T$$







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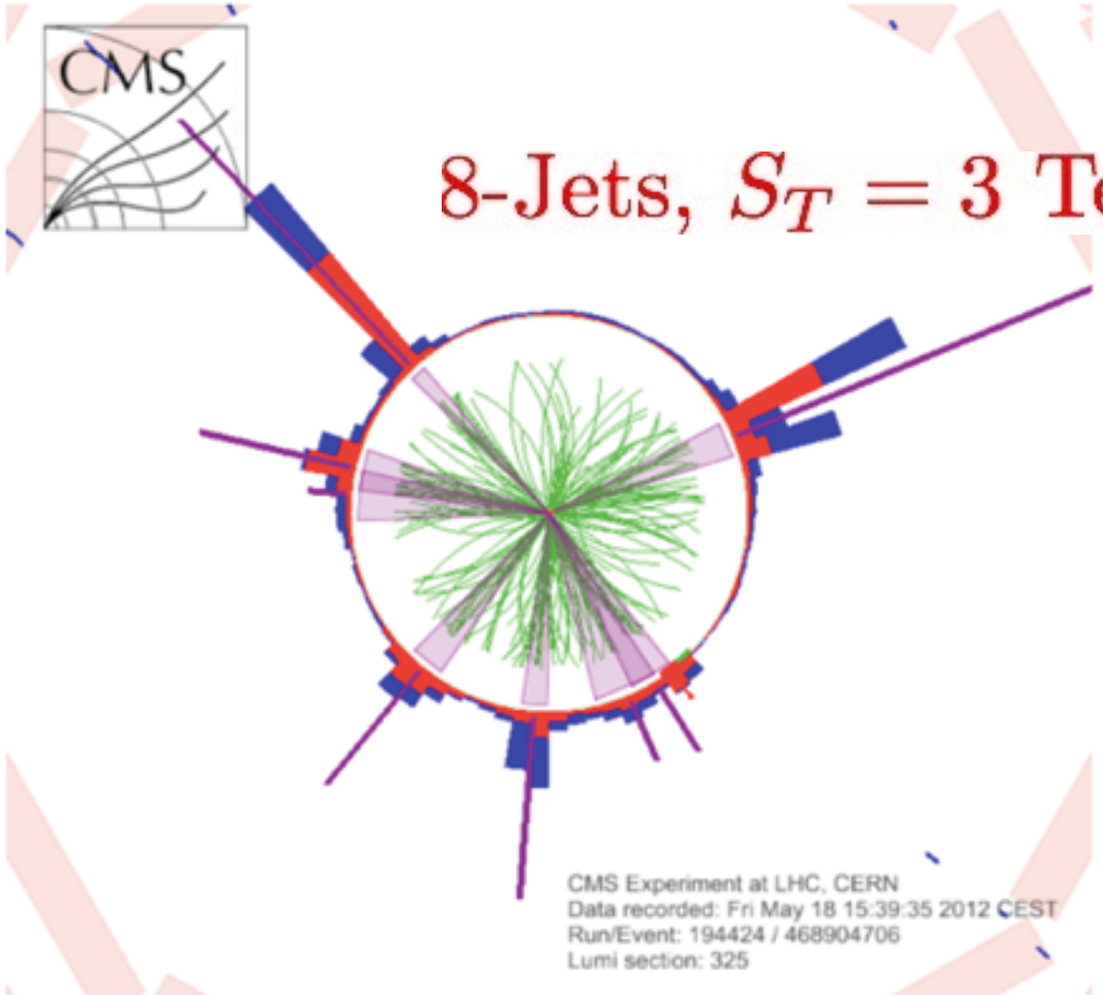
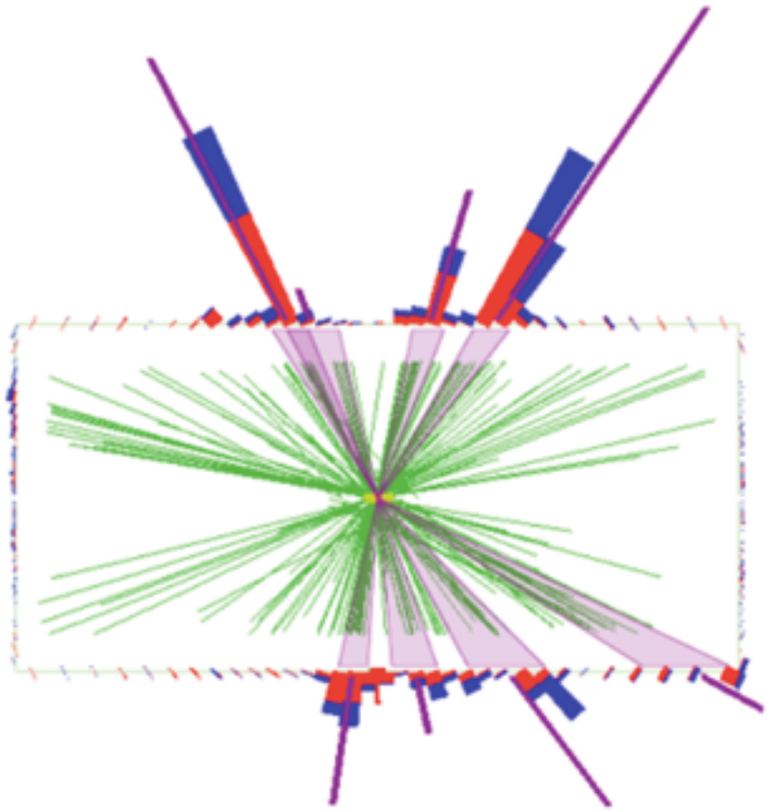


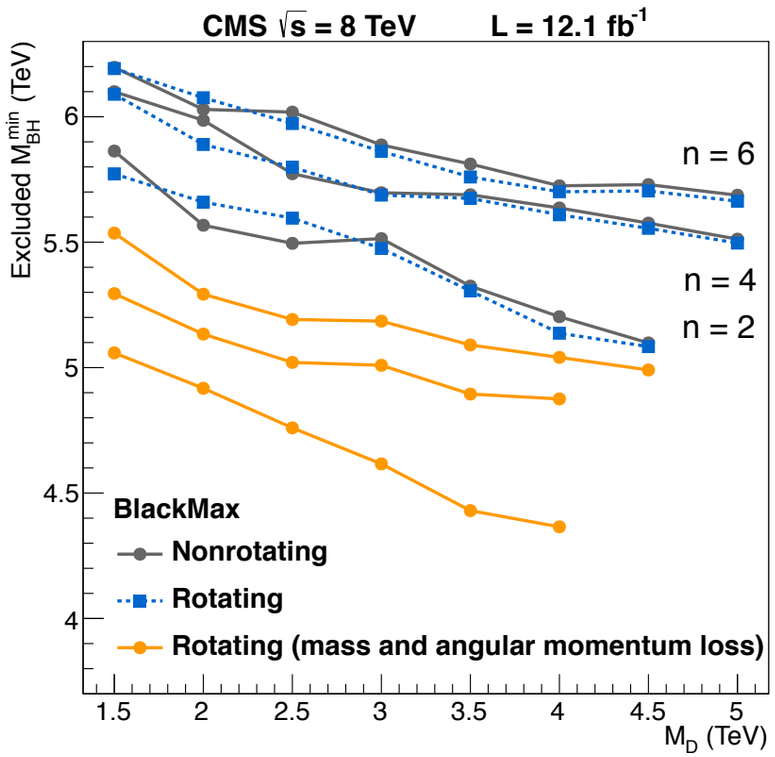


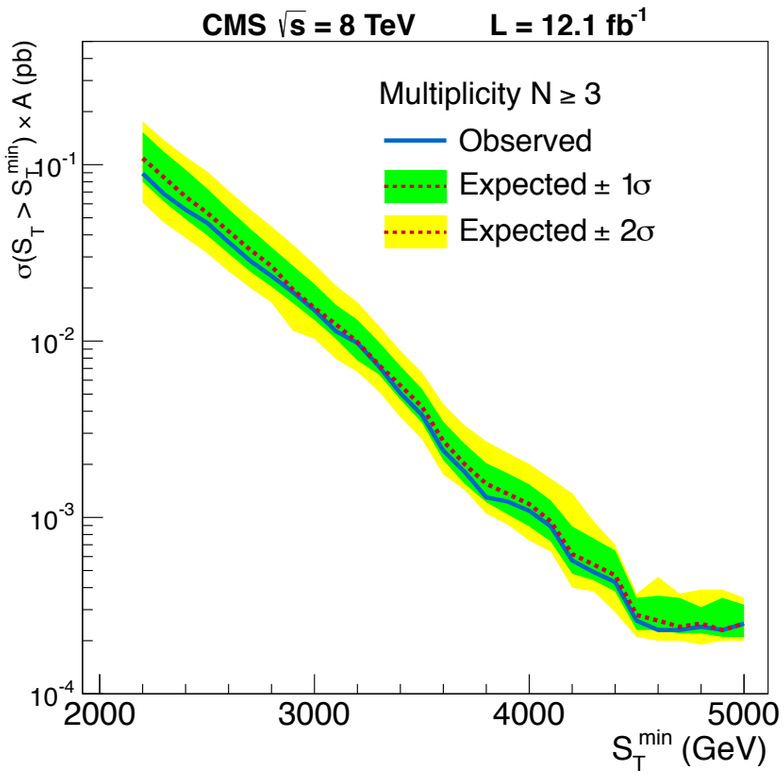
Search for Black Holes

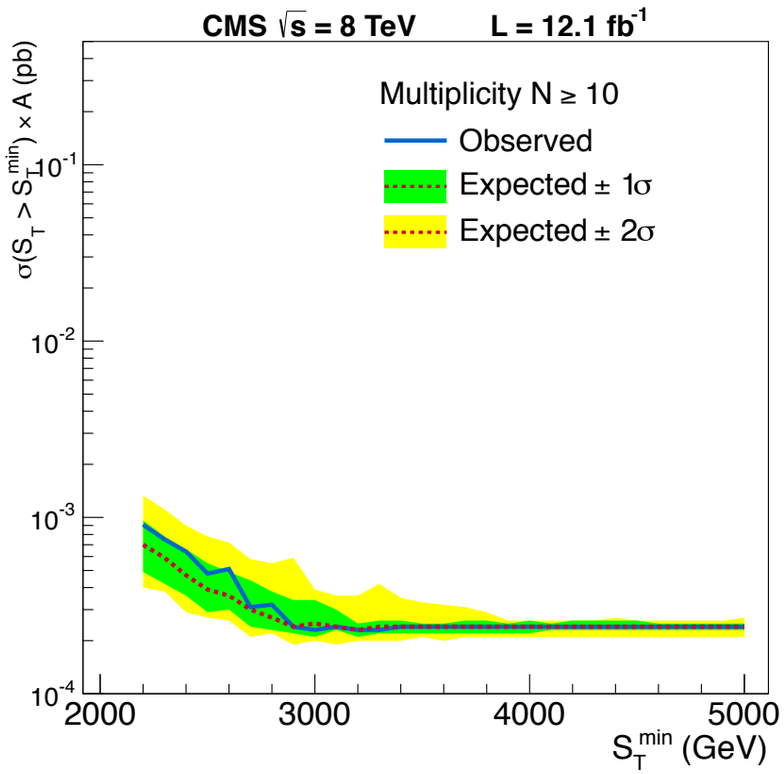
- Haven't seen excess above expected bg
  - Set limits on ADD MD parameter assuming specific BH model (BlackMax, Charybdis)
  - Model independent limits vs S_T and multiplicity
- Also interesting as model independent search vs. multiplicity and S_T

[arXiv:1303:5338, EXO-12-009]

$$S_T = \sum_{j,e,\mu,\gamma,MET}^{N} p_T$$

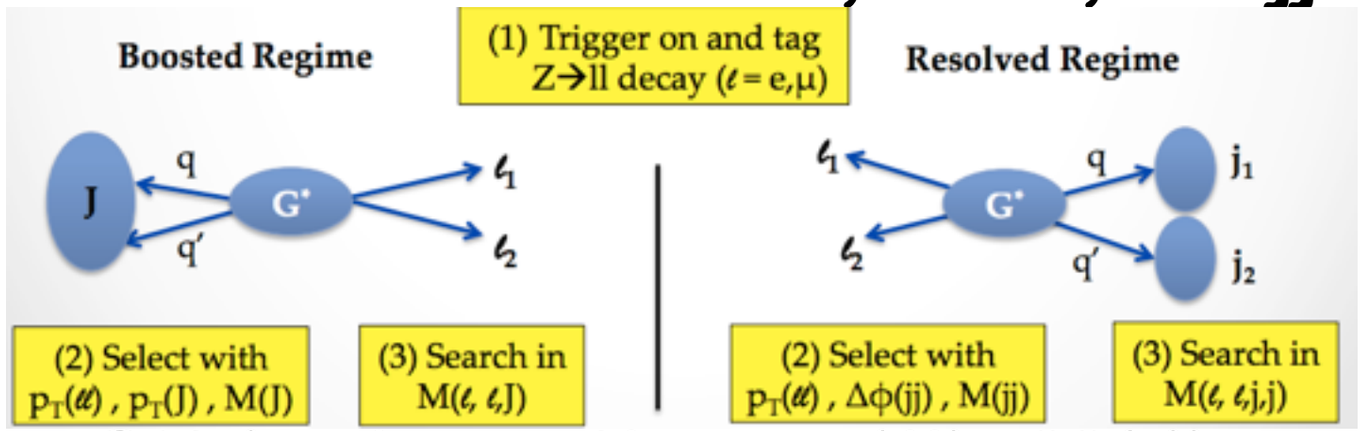






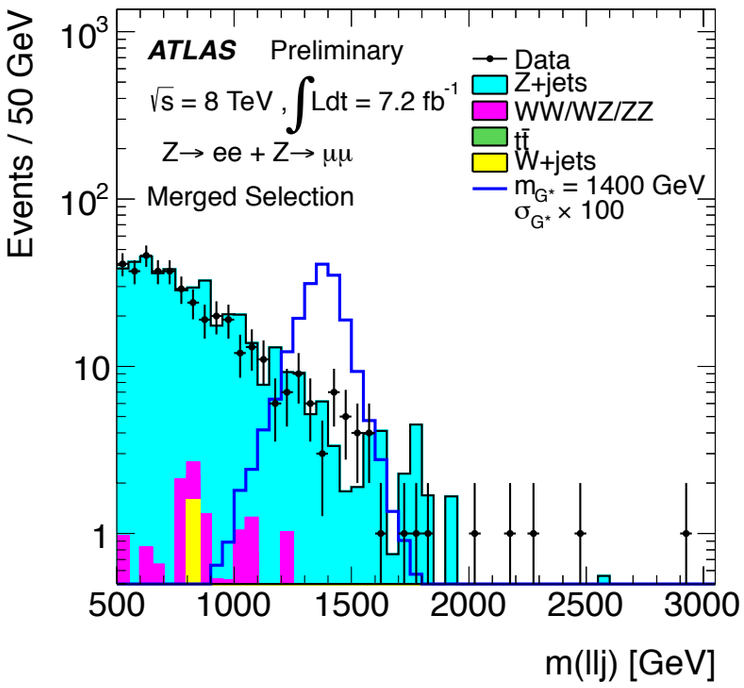
Resonant ZZ -lljj search

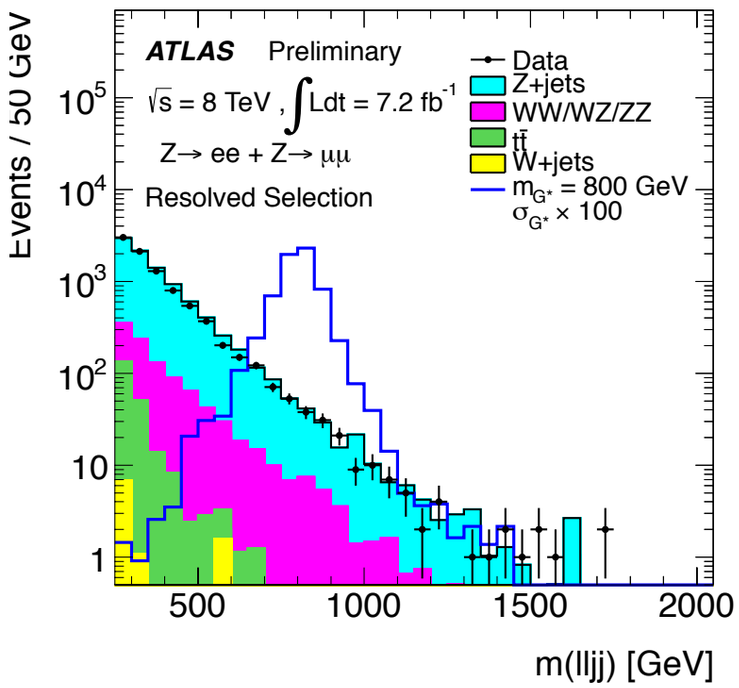
- Search for G->ZZ, Z->ll, Z->jj

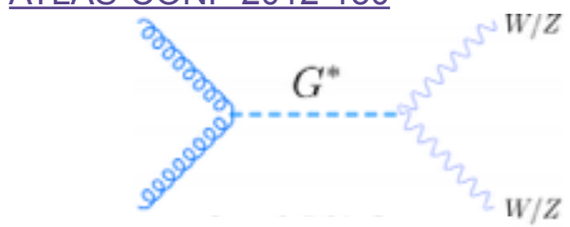


- CR by inverting m(jj), M(J)
- BG estimate - fit to data

$$f(x) = p_1(1-x)^{p_2}x^{p_3+p_4\ln x}$$





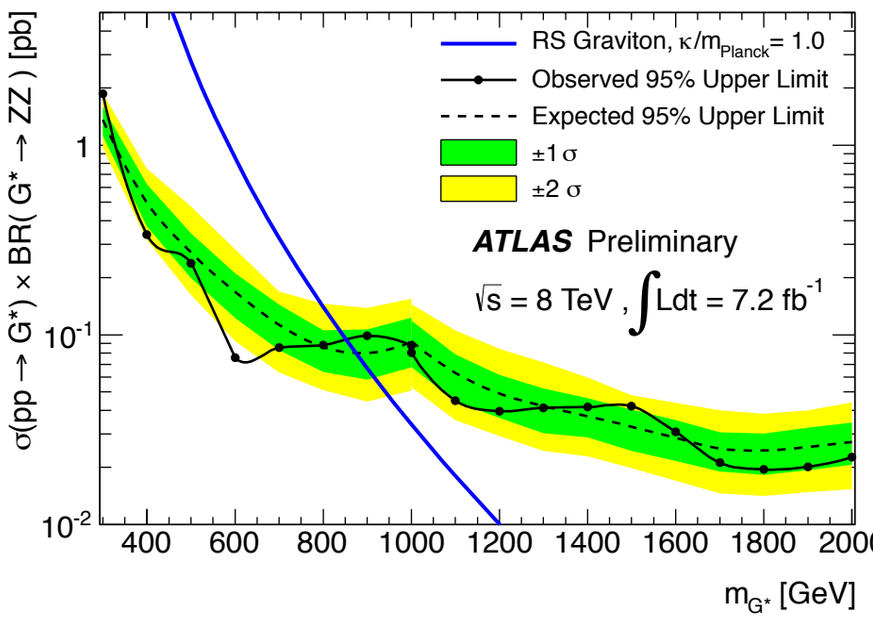


ATLAS-CONF-2012-150

7.2/fb

Bulk RS Graviton

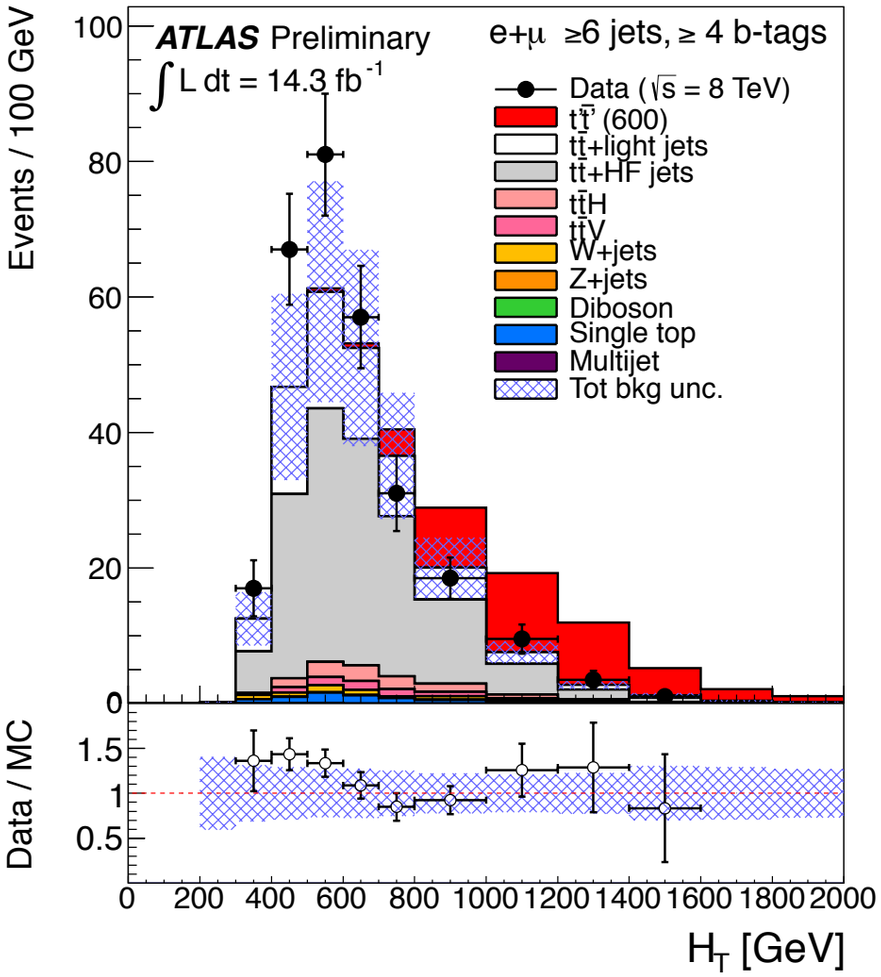
SM fermions and boson can propagate to th
Production and decay via light fermions << l
BR for top, Z, W and H is enhanced.
G* production Xsection is 3-7% of RS1,
G*->ZZ is 7-2 times of RS1 in m(G*) 300-200

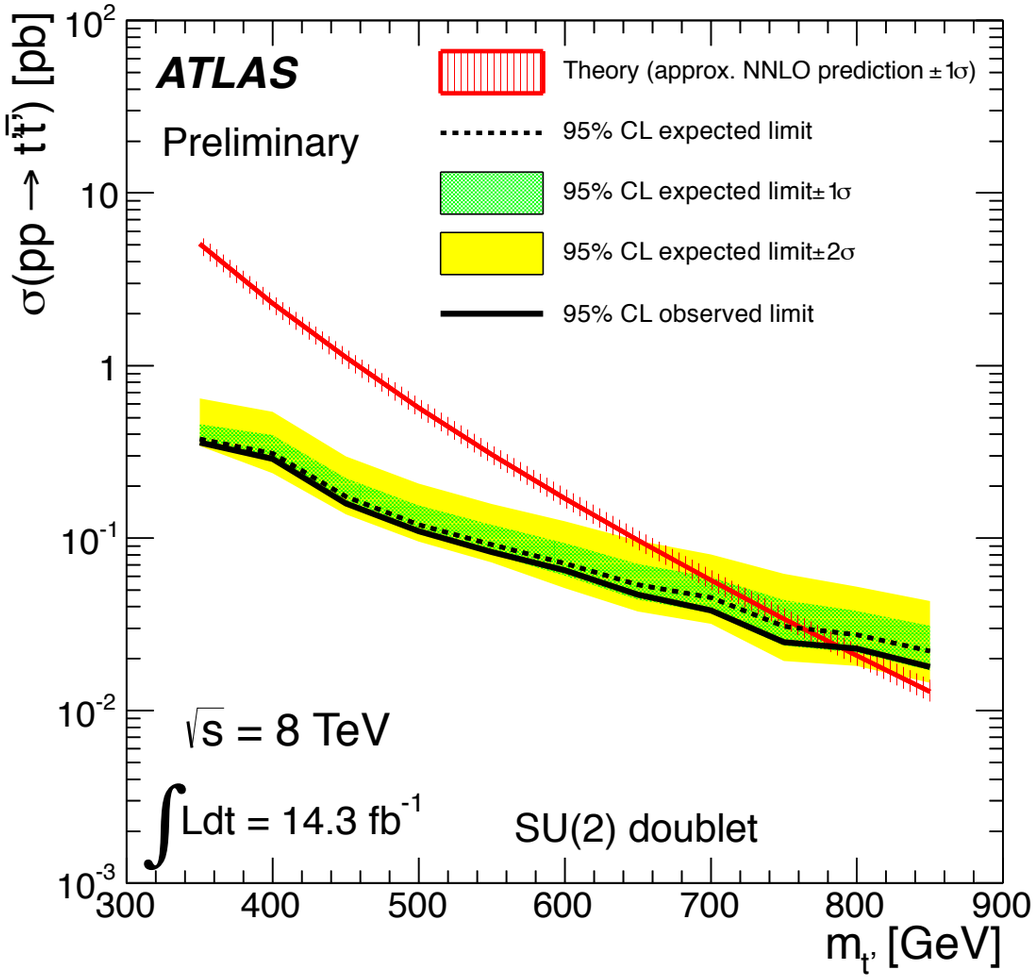


Excluding RS Graviton
(k/m_{Pl} = 1.0)
m <850 (exp. 870) GeV
@ 95% CL

Vector Like Quarks HtHt

- Search for heavy up-type quark pair, assuming a significant BR to Higgs and a top quark, as predicted by VLQ models.
- Look for isolated lepton with moderately high p_T, significant MET, and >= 6 jets.
- The search exploits the high total p_T of all final state objects and the high multiplicity of b-jets characteristic of signal events with at least one Higgs boson decaying into bbar to discriminate against the dominant BG from top quark pair production.





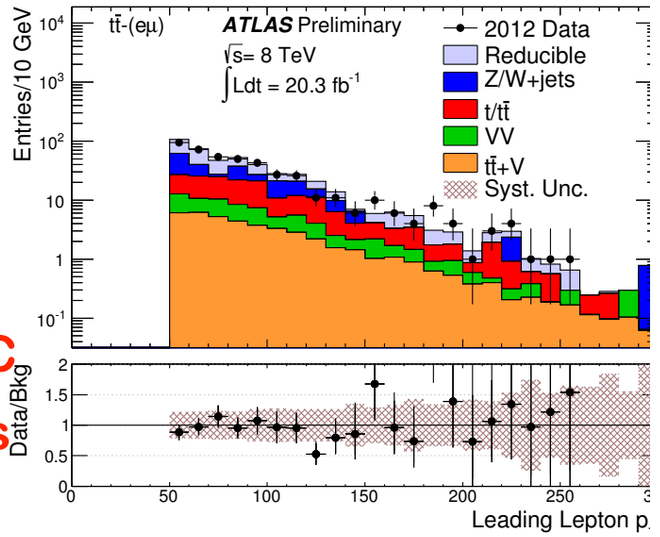
Model independent searches

- **multi-leptons**
  - Search for anomalies
  - Models:
    - Doubly charged higgs, Excited neutrino, SUSY, 4th generation
  - BG:
    - irreducible WZ,ZZ, ttW, ttZ from MC
    - fake factors for non prompt leptons
    - Validation in CR

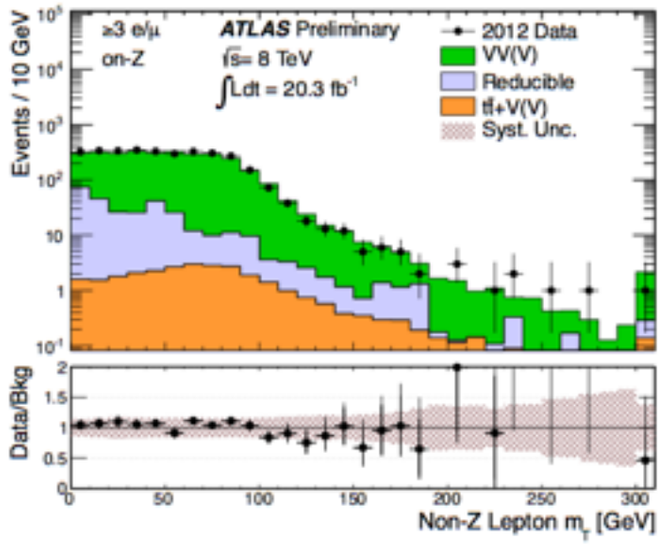
≥ 3 e/μ onZ	≥ 3 e/μ offZ
2 e/μ ≥1 τ onZ	2 e/μ ≥1 τ offZ

ATLAS-CONF-2013-070

tt CR



on-Z SR



- **Multi signal regions:**

Variable		Signal Region Definition			Additional Requirements
$H_{\mathrm{T}}^{\mathrm{leptons}}$	Inclusive	≥200 GeV	≥ 500 GeV	≥ 800 GeV	
Min. p_{T}^{ℓ}	Inclusive	≥ 50 GeV	≥ 100 GeV	≥ 150 GeV	
$E_{\mathrm{T}}^{\mathrm{miss}}$	Inclusive	≥100 GeV	≥ 200 GeV	≥ 300 GeV	$H_{\mathrm{T}}^{\mathrm{jets}}$ < 150 GeV
$E_{\mathrm{T}}^{\mathrm{miss}}$	Inclusive	≥100 GeV	≥ 200 GeV	≥ 300 GeV	$H_{\mathrm{T}}^{\mathrm{jets}}$ ≥ 150 GeV
m_{eff}	Inclusive	≥600 GeV	≥1000 GeV	≥1500 GeV	
m_{eff}	Inclusive	≥600 GeV	≥1200 GeV		$E_{\mathrm{T}}^{\mathrm{miss}}$ ≥ 100 GeV
m_{eff}	Inclusive	≥600 GeV	≥1200 GeV		m_{T}^{W} ≥ 100 GeV, on-Z
b-tags	Inclusive	≥ 1	≥ 2		

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ATLAS-CONF-2013-070

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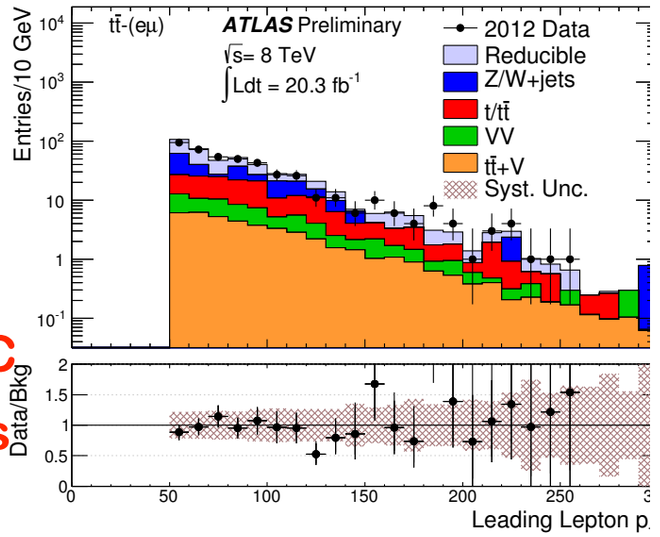
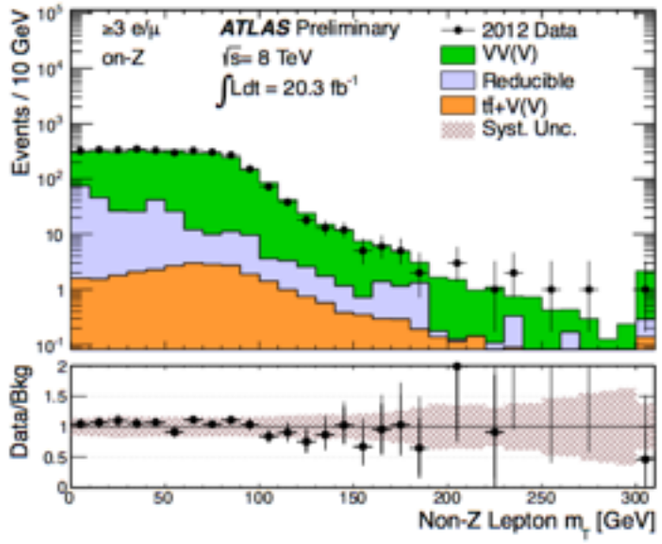
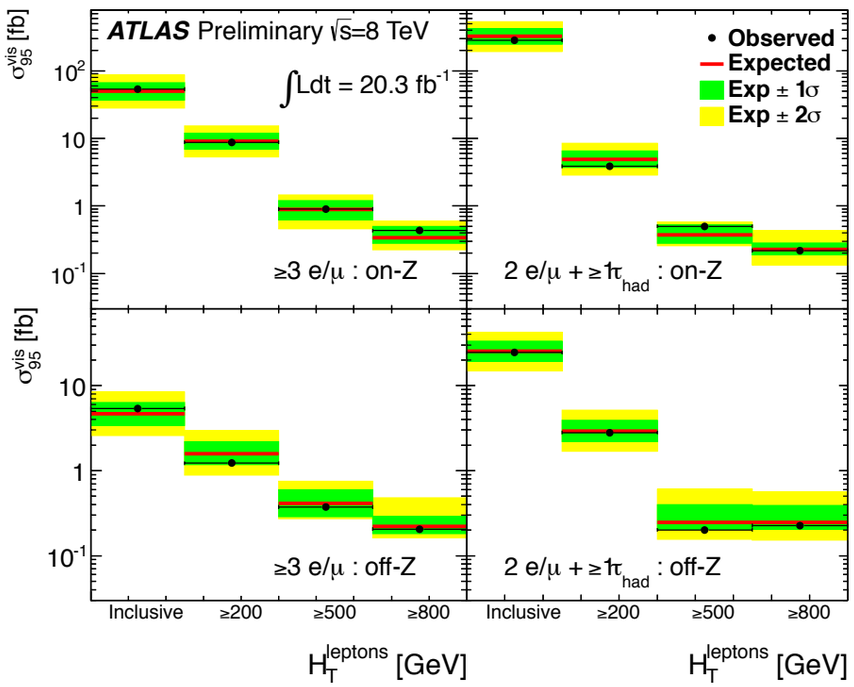


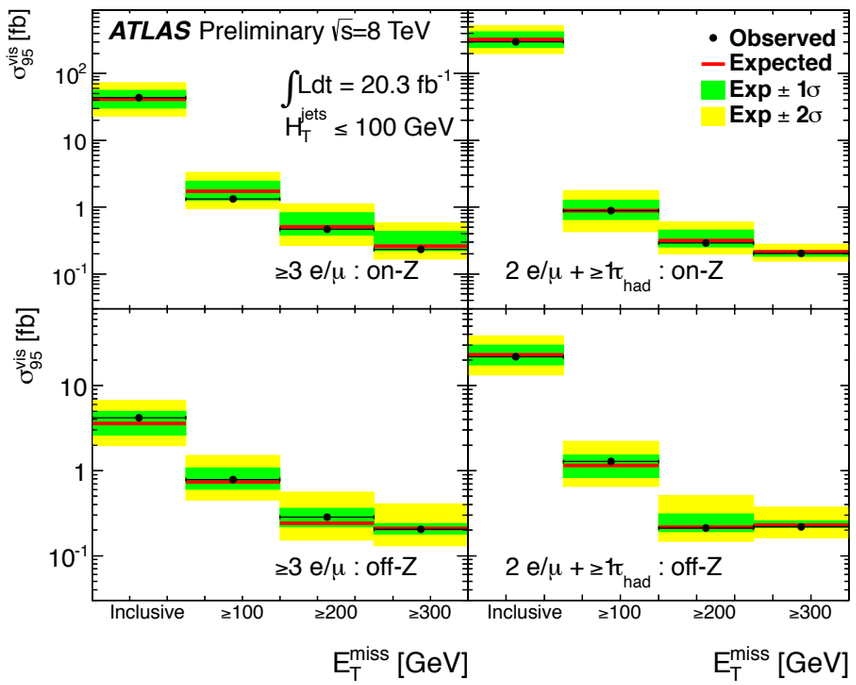
on-Z SR



- **Multi signal regions:**

Exclusions





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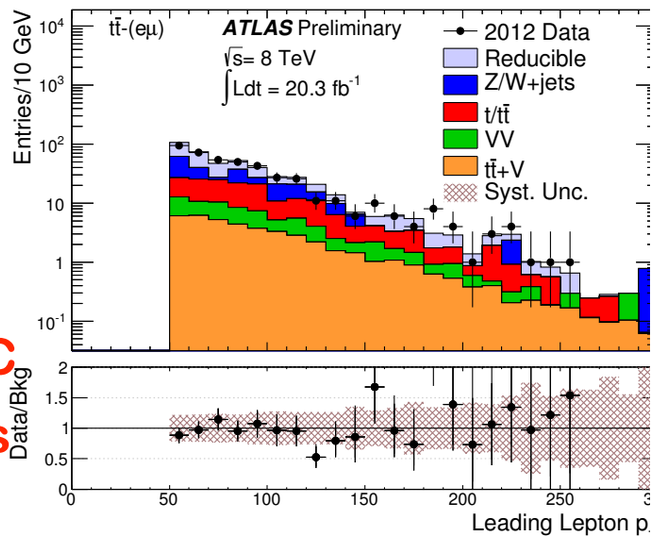
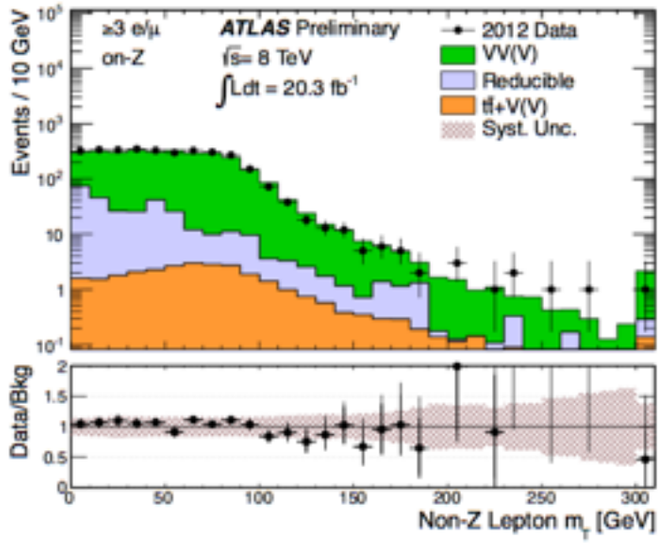
ATLAS-CONF-2013-070

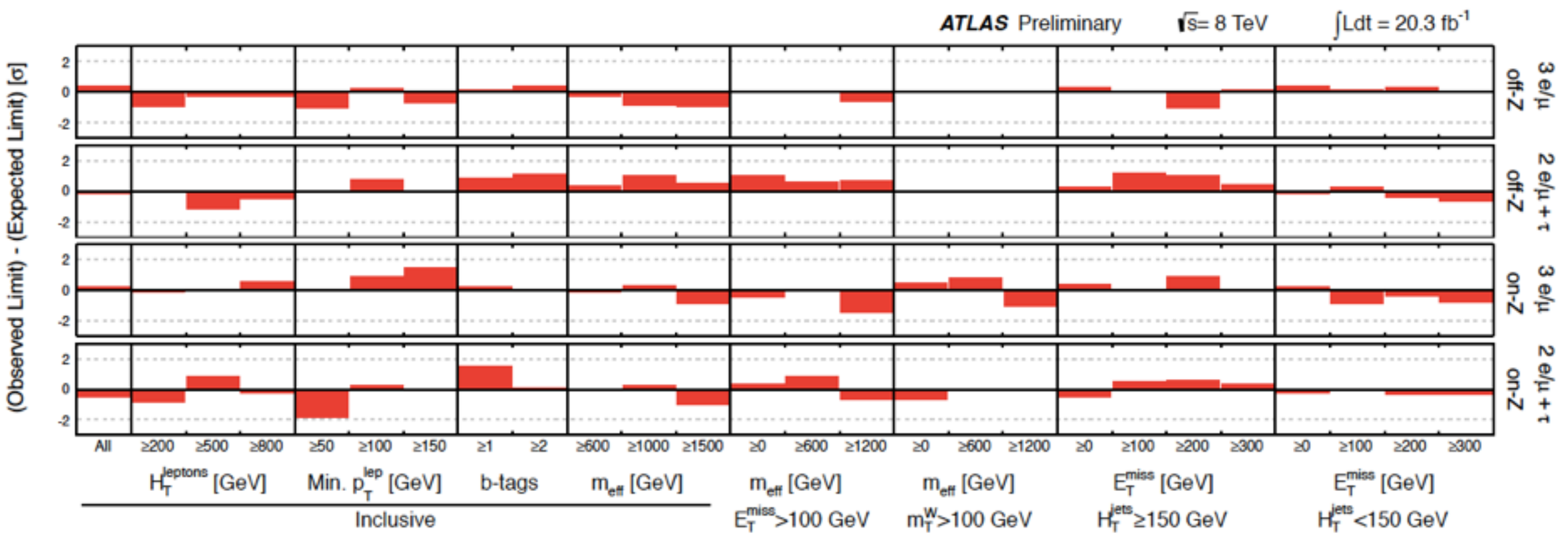
tt CR



on-Z SR



- **Multi signal regions:**



Model independent searches

ATLAS-CONF-2013-070

9 Model testing

Use our visible cross section limit to test the reach on your favourite model

The σ_{95}^{vis} limits can be converted into upper limits on the cross section of a specific model as follows:

- Events from the new model are examined at the particle (MC-generator) level and kinematic requirements on the particles are applied. These include the p_{T} and η requirements for leptons and jets, and isolation requirements for the leptons. No special treatment for pileup is necessary.
- The number of events passing this selection determines the cross section for the model given the fiducial constraints, σ^{fid}.
- A correction factor must be applied to take into account detector effects. This correction factor, called ϵ_{fid}, is model-dependent, and is subject to uncertainties from detector resolution, reconstruction efficiency, pileup, and vertex selection. This correction factor represents the ratio of the number of events satisfying the selection criteria after reconstruction to all those satisfying the fiducial acceptance criteria at the particle level.
- A 95% CL upper-limit on the cross section in the new model is then given by

$$\sigma_{95}^{\text{fid}} = \frac{N_{95}}{\epsilon_{fid} \int L dt} = \frac{\sigma_{95}^{\text{vis}}}{\epsilon_{fid}}.$$

Fiducial efficiencies

p_{T} [GeV]	Prompt e	$\tau \to e$	τ_h
10–15	0.045±0.001	0.027±0.002	-
15–20	0.484±0.003	0.384±0.005	0.071±0.003
20–25	0.571±0.003	0.470±0.006	0.251±0.006
25–30	0.628±0.002	0.518±0.007	0.321±0.007
30–40	0.681±0.002	0.573±0.006	0.313±0.006
40–50	0.713±0.002	0.597±0.009	0.326±0.007
50–60	0.746±0.002	0.64±0.01	0.309±0.009
60–80	0.767±0.002	0.67±0.01	0.295±0.009
80–100	0.799±0.003	0.67±0.02	0.32±0.02
100–200	0.820±0.003	0.63±0.03	0.33±0.02
200–400	0.835±0.009	0.72±0.08	0.29±0.05
400–600	0.819±0.043	-	-
≥ 600	0.829±0.104	-	-

ATLAS Exotics Searches* - 95% CL Exclusion

Status: April 2014

ATLAS Preliminary

$\int \mathcal{L}\, dt$ = (1.0 - 20.3) fb^{-1} $\sqrt{s}$ = 7, 8 TeV

	Model	ℓ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt$[fb^{-1}]	Mass limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	1-2 j	Yes	4.7	M_D 4.37 TeV	$n = 2$	1210.4491
	ADD non-resonant $\ell\ell/\gamma\gamma$	2γ or 2e, μ	–	–	4.7	M_S 4.18 TeV	$n = 3$ HLZ NLO	1211.1150
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD BH high N_{trk}	2 μ (SS)	–	–	20.3	M_{th} 5.7 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	1308.4075
	ADD BH high $\sum p_T$	$\geq$ 1 e, μ	$\geq$ 2 j	–	20.3	M_{th} 6.2 TeV	$n = 6$, $M_D = 1.5$ TeV, non-rot BH	ATLAS-CONF-2014-016
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.47 TeV	$k/\overline{M}_{Pl} = 0.1$	ATLAS-CONF-2013-017
	RS1 $G_{KK} \rightarrow ZZ \rightarrow \ell\ell qq/\ell\ell\ell\ell$	2 or 4 e, μ	2 j or –	–	1.0	G_{KK} mass 845 GeV	$k/\overline{M}_{Pl} = 0.1$	1203.0718
	RS1 $G_{KK} \rightarrow WW \rightarrow \ell\nu\ell\nu$	2 e, μ	–	Yes	4.7	G_{KK} mass 1.23 TeV	$k/\overline{M}_{Pl} = 0.1$	1208.2880
	Bulk RS $G_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$	–	4 b	–	19.5	G_{KK} mass 590-710 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2014-005
	Bulk RS $g_{KK} \rightarrow t\bar{t}$	1 e, μ	$\geq$ 1 b, $\geq$ 1J/2j	Yes	14.3	g_{KK} mass 0.5-2.0 TeV	BR = 0.925	ATLAS-CONF-2013-052
	S^1/Z_2 ED	2 e, μ	–	–	5.0	$M_{KK} \approx R^{-1}$ 4.71 TeV		1209.2535
	UED	2 γ	–	Yes	4.8	Compact. scale R^{-1} 1.41 TeV		ATLAS-CONF-2012-072
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	20.3	Z' mass 2.86 TeV		ATLAS-CONF-2013-017
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	Z' mass 1.9 TeV		ATLAS-CONF-2013-066
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	20.3	W' mass 3.28 TeV		ATLAS-CONF-2014-017
	EGM $W' \rightarrow WZ \rightarrow \ell\nu\,\ell'\ell'$	3 e, μ	–	Yes	20.3	W' mass 1.52 TeV		ATLAS-CONF-2014-015
	LRSM $W'_R \rightarrow t\bar{b}$	1 e, μ	2 b, 0-1 j	Yes	14.3	W' mass 1.84 TeV		ATLAS-CONF-2013-050
CI	CI $qqqq$	–	2 j	–	4.8	Λ 7.6 TeV	$\eta = +1$	1210.1718
	CI $qq\ell\ell$	2 e, μ	–	–	5.0	Λ 13.9 TeV	$\eta_{LL} = -1$	1211.1150
	CI $uutt$	2 e, μ (SS)	$\geq$ 1 b, $\geq$ 1 j	Yes	14.3	Λ 3.3 TeV	$\lvert C\rvert = 1$	ATLAS-CONF-2013-051
DM	EFT D5 operator	–	1-2 j	Yes	10.5	M_* 731 GeV	at 90% CL for $m(\chi) < 80$ GeV	ATLAS-CONF-2012-147
	EFT D9 operator	–	1 J, $\leq$ 1 j	Yes	20.3	M_* 2.4 TeV	at 90% CL for $m(\chi) < 100$ GeV	1309.4017
LQ	Scalar LQ 1st gen	2 e	$\geq$ 2 j	–	1.0	LQ mass 660 GeV	$\beta = 1$	1112.4828
	Scalar LQ 2nd gen	2 μ	$\geq$ 2 j	–	1.0	LQ mass 685 GeV	$\beta = 1$	1203.3172
	Scalar LQ 3rd gen	1 e, μ, 1 τ	1 b, 1 j	–	4.7	LQ mass 534 GeV	$\beta = 1$	1303.0526
Heavy quarks	Vector-like quark $TT \rightarrow Ht + X$	1 e, μ	$\geq$ 2 b, $\geq$ 4 j	Yes	14.3	T mass 790 GeV	T in (T,B) doublet	ATLAS-CONF-2013-018
	Vector-like quark $TT \rightarrow Wb + X$	1 e, μ	$\geq$ 1 b, $\geq$ 3 j	Yes	14.3	T mass 670 GeV	isospin singlet	ATLAS-CONF-2013-060
	Vector-like quark $BB \rightarrow Zb + X$	2 e, μ	$\geq$ 2 b	–	14.3	B mass 725 GeV	B in (B,Y) doublet	ATLAS-CONF-2013-056
	Vector-like quark $BB \rightarrow Wt + X$	2 e, μ (SS)	$\geq$ 1 b, $\geq$ 1 j	Yes	14.3	B mass 720 GeV	B in (T,B) doublet	ATLAS-CONF-2013-051
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	20.3	q^* mass 3.5 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1309.3230
	Excited quark $q^* \rightarrow qg$	–	2 j	–	13.0	q^* mass 3.84 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2012-148
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2 j or 1 j	Yes	4.7	b^* mass 870 GeV	left-handed coupling	1301.1583
	Excited lepton $\ell^* \rightarrow \ell\gamma$	2 e, μ, 1 γ	–	–	13.0	ℓ^* mass 2.2 TeV	$\Lambda = 2.2$ TeV	1308.1364
Other	LRSM Majorana ν	2 e, μ	2 j	–	2.1	N^0 mass 1.5 TeV	$m(W_R) = 2$ TeV, no mixing	1203.5420
	Type III Seesaw	2 e, μ	–	–	5.8	$N^\pm$ mass 245 GeV	$\lvert V_e\rvert$=0.055, $\lvert V_\mu\rvert$=0.063, $\lvert V_\tau\rvert$=0	ATLAS-CONF-2013-019
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	2 e, μ (SS)	–	–	4.7	$H^{\pm\pm}$ mass 409 GeV	DY production, BR($H^{\pm\pm} \rightarrow \ell\ell$)=1	1210.5070
	Multi-charged particles	–	–	–	4.4	multi-charged particle mass 490 GeV	DY production, $\lvert q\rvert = 4e$	1301.5272
	Magnetic monopoles	–	–	–	2.0	monopole mass 862 GeV	DY production, $\lvert g\rvert = 1g_D$	1207.6411

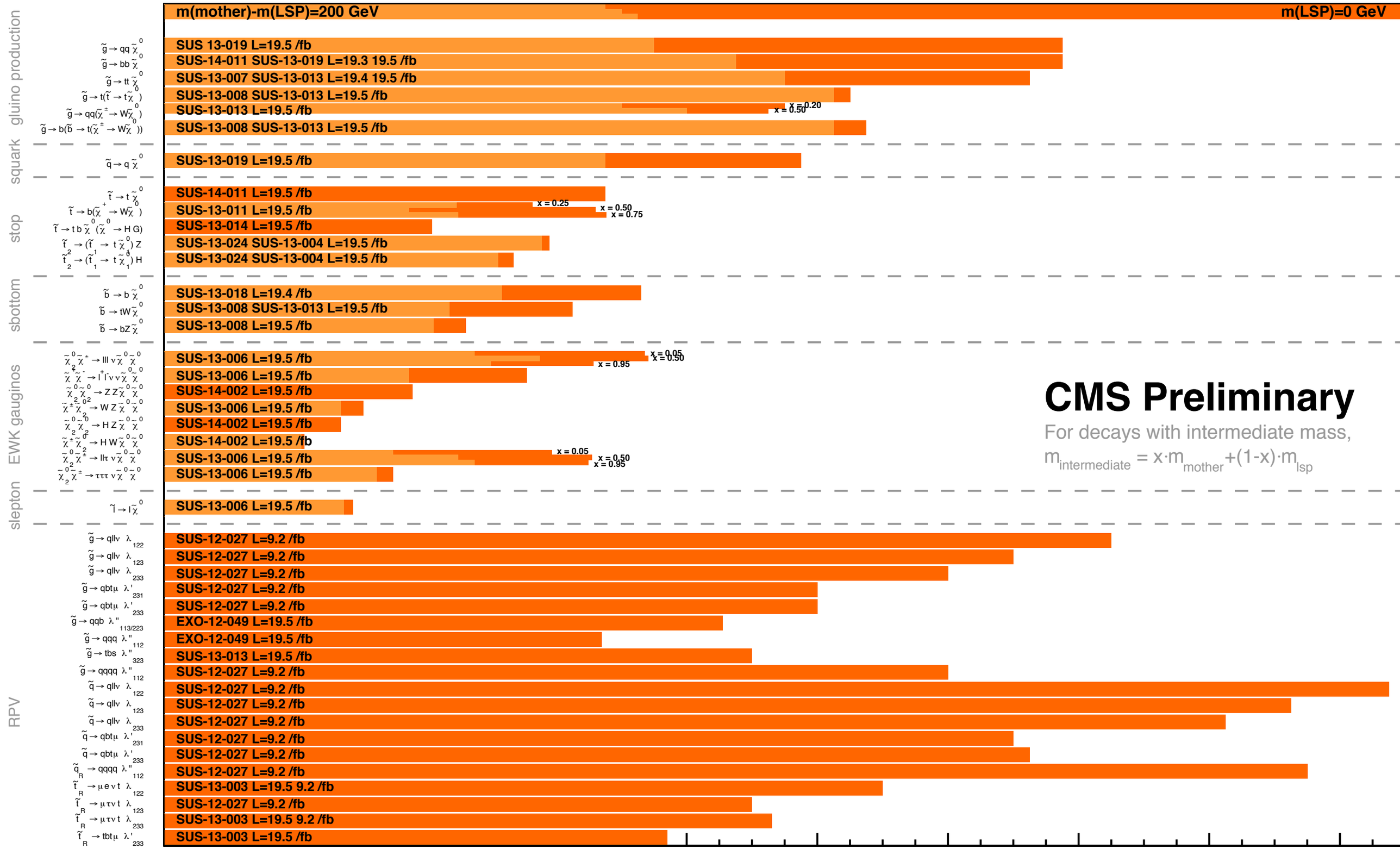
$\sqrt{s}$ = 7 TeV $\sqrt{s}$ = 8 TeV

10^{-1} 1 10 **Mass scale [TeV]**

**Only a selection of the available mass limits on new states or phenomena is shown.*

Summary of CMS SUSY Results* in SMS framework

ICHEP 2014



CMS Preliminary

For decays with intermediate mass,

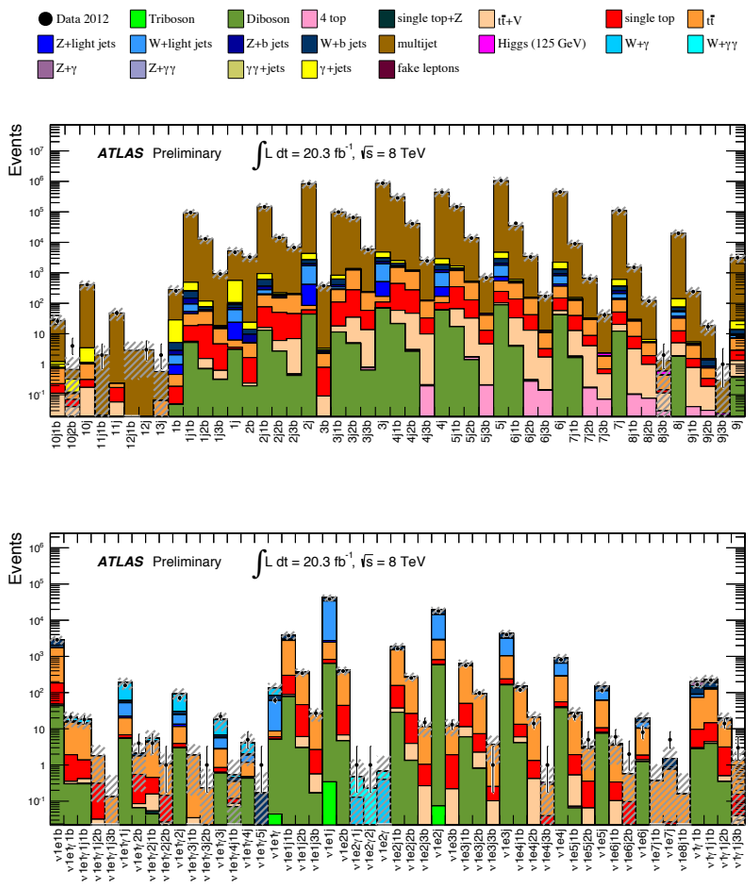
$m_{intermediate} = x \cdot m_{mother} + (1-x) \cdot m_{lsp}$

*Observed limits, theory uncertainties not included

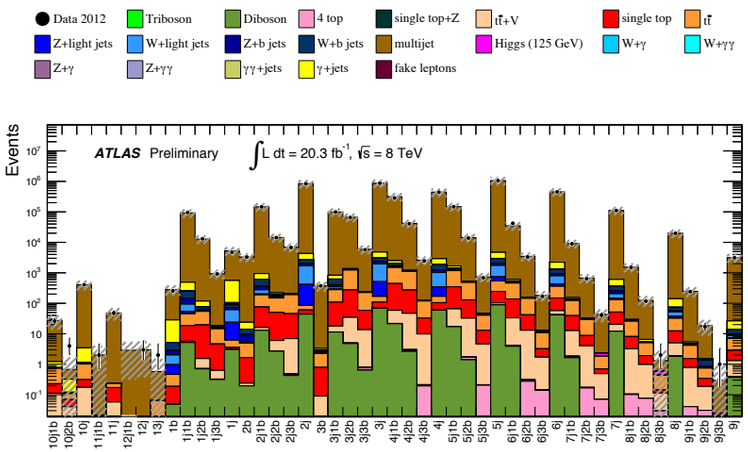
Only a selection of available mass limits

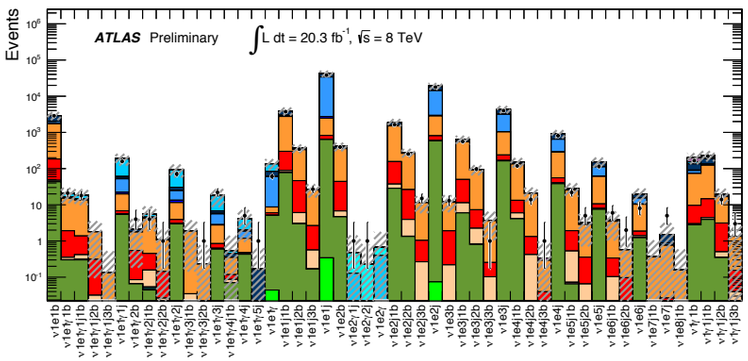
Probe *up to* the quoted mass limit

Run-1 left us with ..



Run-1 left us with ..





No significant excess in so many search regions.
A clear demonstration of our MC precision..

Some of our searches may require more thinking.
We were looking for simple signatures, following the models builder.
However Physics may be more complicated!
For instance DM may be complex sector, (see e.g. Reece's suggestion to look for DM + disappearing tracks..)

Some open point to decide before run-2

- **Model choices**
  - -Consistent models
  - -Benchmark model (SSM, Gaussian resonances)
  - -Effective theories?
- **Comparison between experiments**
  - -Statistical tools (Frequentist vs Bayesian)
  - -Systematic uncertainties
  - -Nuisance parameters and profiling
- **Where are the results (web sites, HEPDATA)**
- **Results presentation and interpretations**
  - -"Model independent"
  - -Visible cross section
  - -Fiducial cross section
  - -Acceptance & efficiency
- **1M$ question**
  - -There is more than resonances (asymmetries, angular dist)
    - ➡Are we missing something?

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Some of the recent measurements

- CMS (Exo+ b2G: 20 8 TeV papers, 33 conf notes)
  - monojet
  - L+MET
  - LQ3
  - Heavy neutrino
  - Excited quark (gamma+jet)
  - W' -> tb (l+jets)
- ATLAS (16 8 TeV papers, 29 conf notes)
  - Neutral LLP -> lepton jets
  - LFV z_>e mu
  - W' -> tb (qq'bb)
  - resonances in Z gamma or W gamma
  - ....