SUSY searches in ATLAS

I.Vivarelli

University of Sussex

"Is SUSY alive and well?"

Madrid - 28th-30th September 2016

Is SUSY alive and well?

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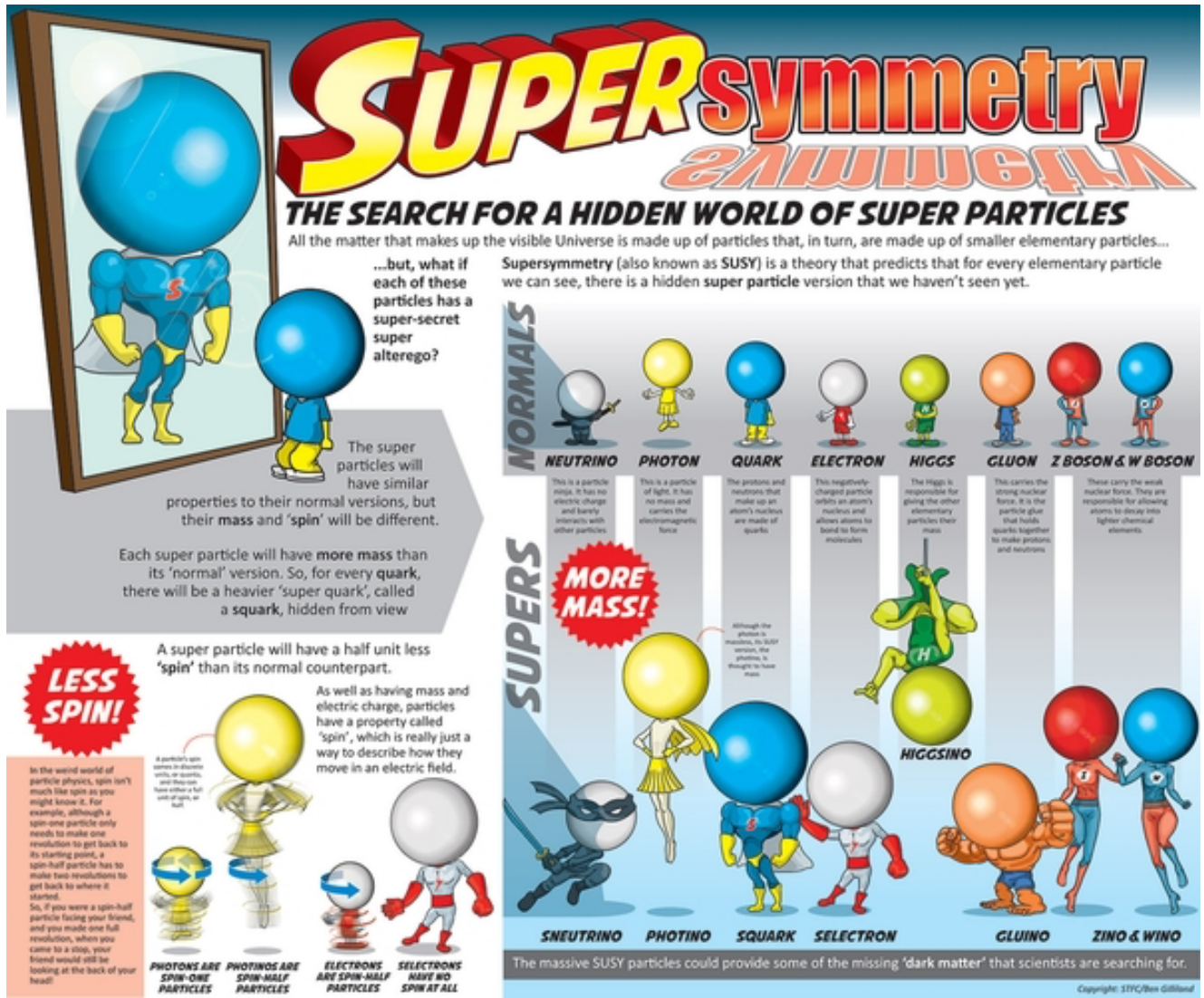

credits: STFC/Ben Gilliland

Is SUSY alive and well?

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Is SUSY alive and well?

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ATLAS 2016 data taking in a nutshell

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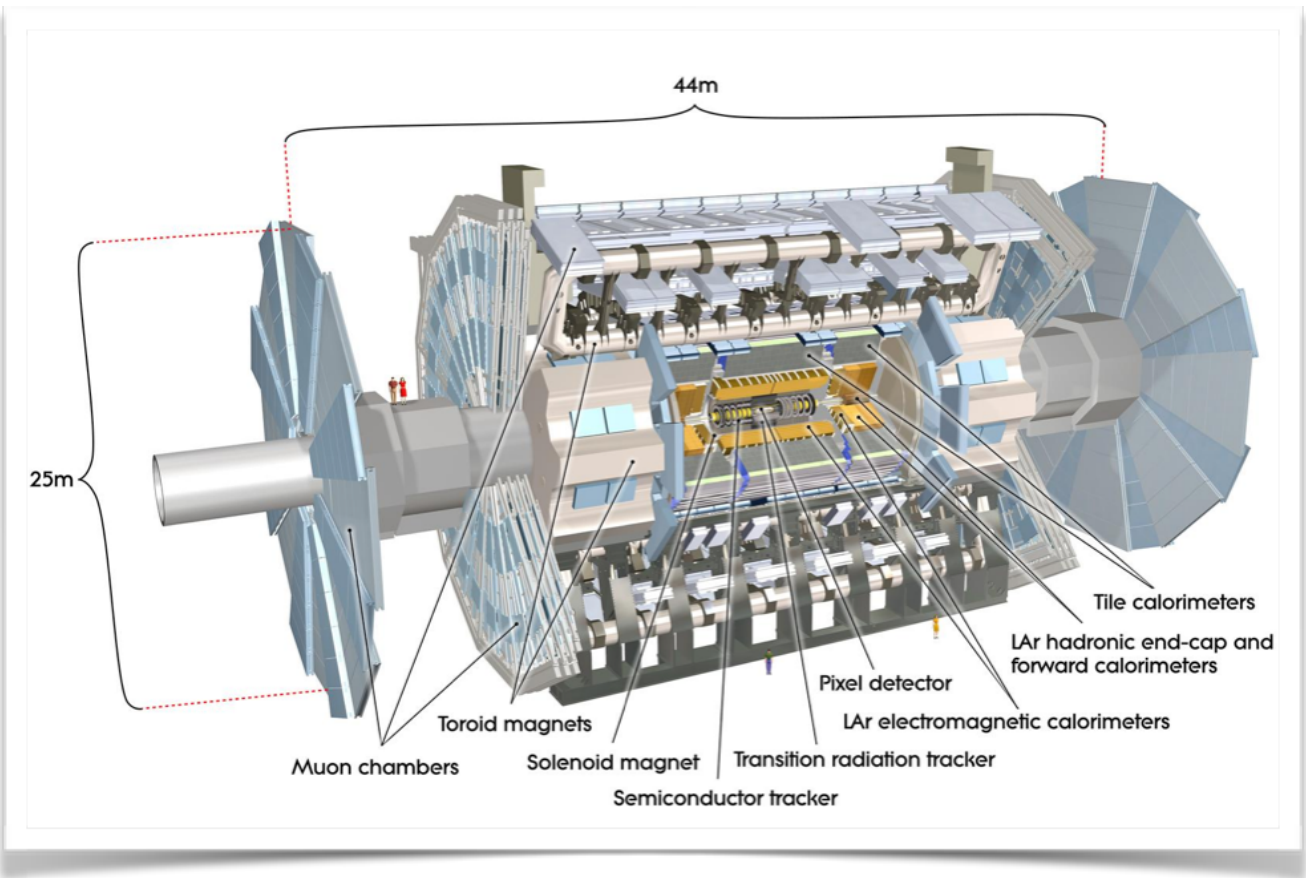
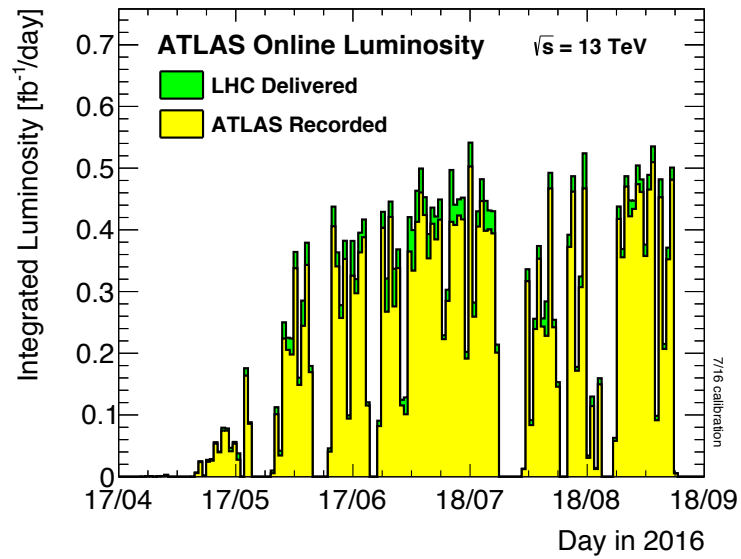
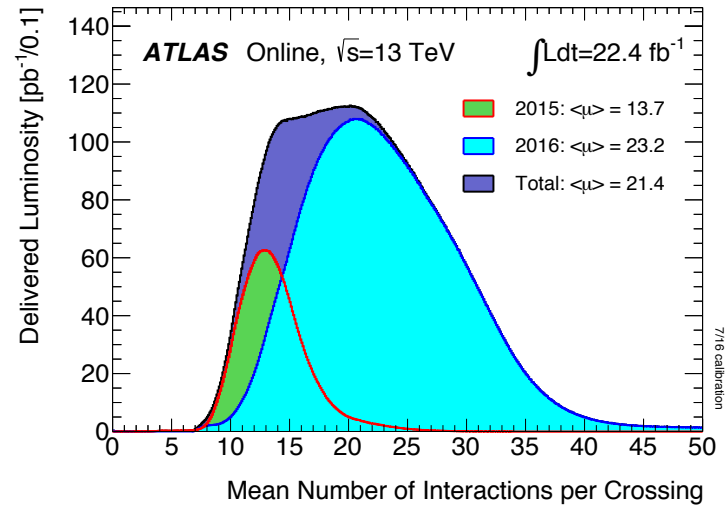
- Outstanding LHC performance
  - and outstanding ATLAS data taking



Total recorded integrated luminosity to date: 27.5 fb^{-1}





ATLAS performance

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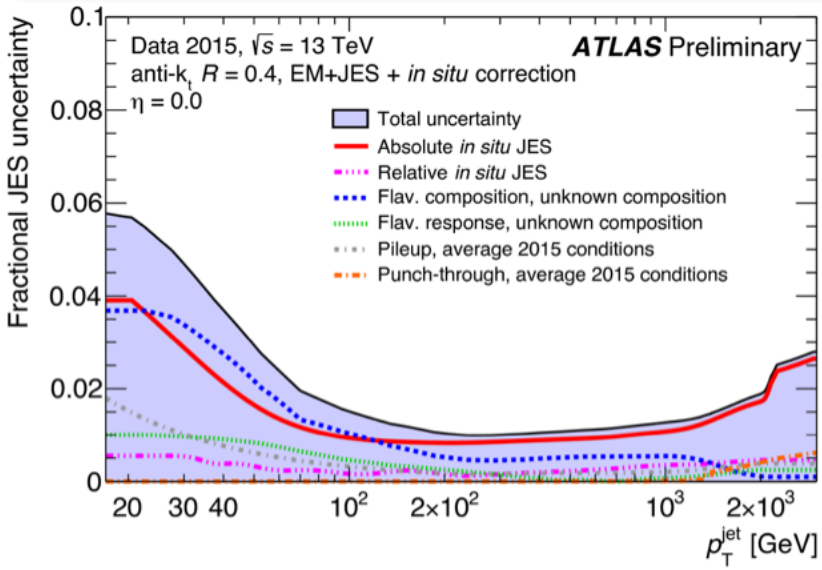

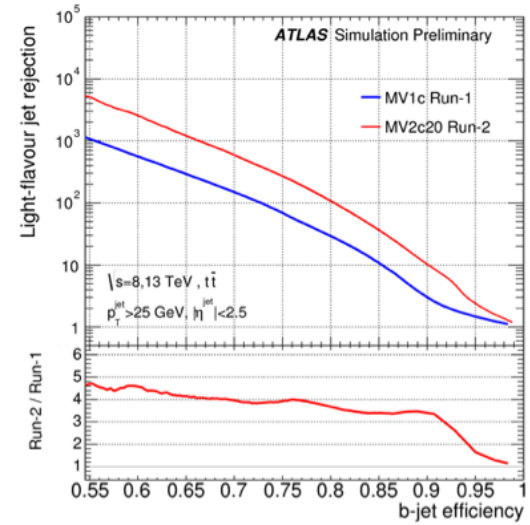

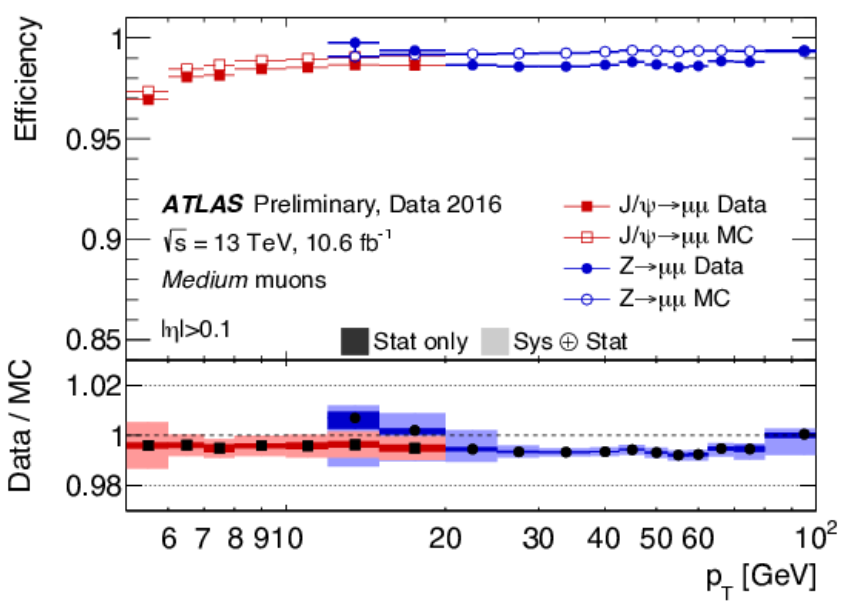

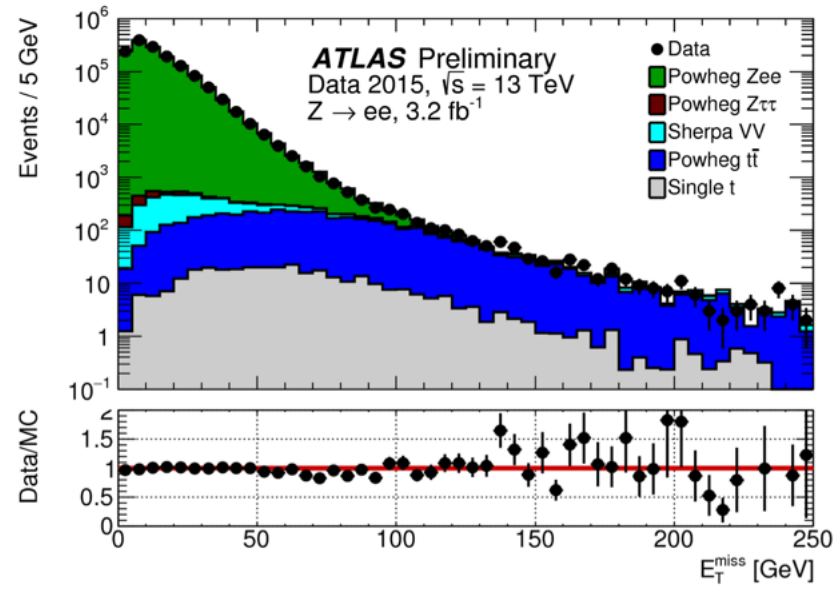

Summer 2016 - a quick overview

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●	2L+jets+MET (Z/edge)	9/2016	13	14.7	ATLAS-CONF-2016-098	Link
●	EWK 2/3L	9/2016	13	14.8	ATLAS-CONF-2016-096	Link
●	EWK di-tau	9/2016	13	14.8	ATLAS-CONF-2016-093	Link
●	0L 8-10 jets (RPC gluinos)	9/2016	13	18.2	ATLAS-CONF-2016-095	Link
○	RPV 1L+jets	9/2016	13	14.8	ATLAS-CONF-2016-094	Link
●	0L 2-6 jets (squark/gluinos)	8/2016	13	13.3	ATLAS-CONF-2016-078	Link
●	1L 2-6 jets (squark/gluinos)	8/2016	13	14.8	ATLAS-CONF-2016-054	Link
○ ● ●	SS/3L + jets (squarks/gluinos)	8/2016	13	13.2	ATLAS-CONF-2016-037	Link
●	0/1L + 3b jets (squarks/gluinos)	8/2016	13	14.8	ATLAS-CONF-2016-052	Link
●	photon + jets	8/2016	13	13.3	ATLAS-CONF-2016-066	Link
● ●	stop 0L	8/2016	13	13.3	ATLAS-CONF-2016-077	Link
● ●	stop 1L	8/2016	13	13.3	ATLAS-CONF-2016-050	Link
● ●	stop 2L	8/2016	13	13.3	ATLAS-CONF-2016-076	Link
●	stop2 (3L)	8/2016	13	13.3	ATLAS-CONF-2016-038	Link
●	stop stau	8/2016	13	13.3	ATLAS-CONF-2016-048	Link
○	4 lepton (RPV EWK)	8/2016	13	13.3	ATLAS-CONF-2016-075	Link
○	multijet (RPV)	8/2016	13	14.8	ATLAS-CONF-2016-057	Link
○	Stop to bs (RPV)	8/2016	13	15.6	ATLAS-CONF-2016-084	Link

- ● RPC SUSY
- ○ RPV SUSY
- EW production
- strong production
- 3rd generation
- Dark Matter

- Nice overviews:
  - Michele Weber (ATLAS) - SEARCH 2016 - link
  - Wolfgang Adam (CMS + ATLAS) - ICHEP 2016 - link
  - Christian Ohm (ATLAS) - CERN seminar - link

Simplified models and mass exclusions

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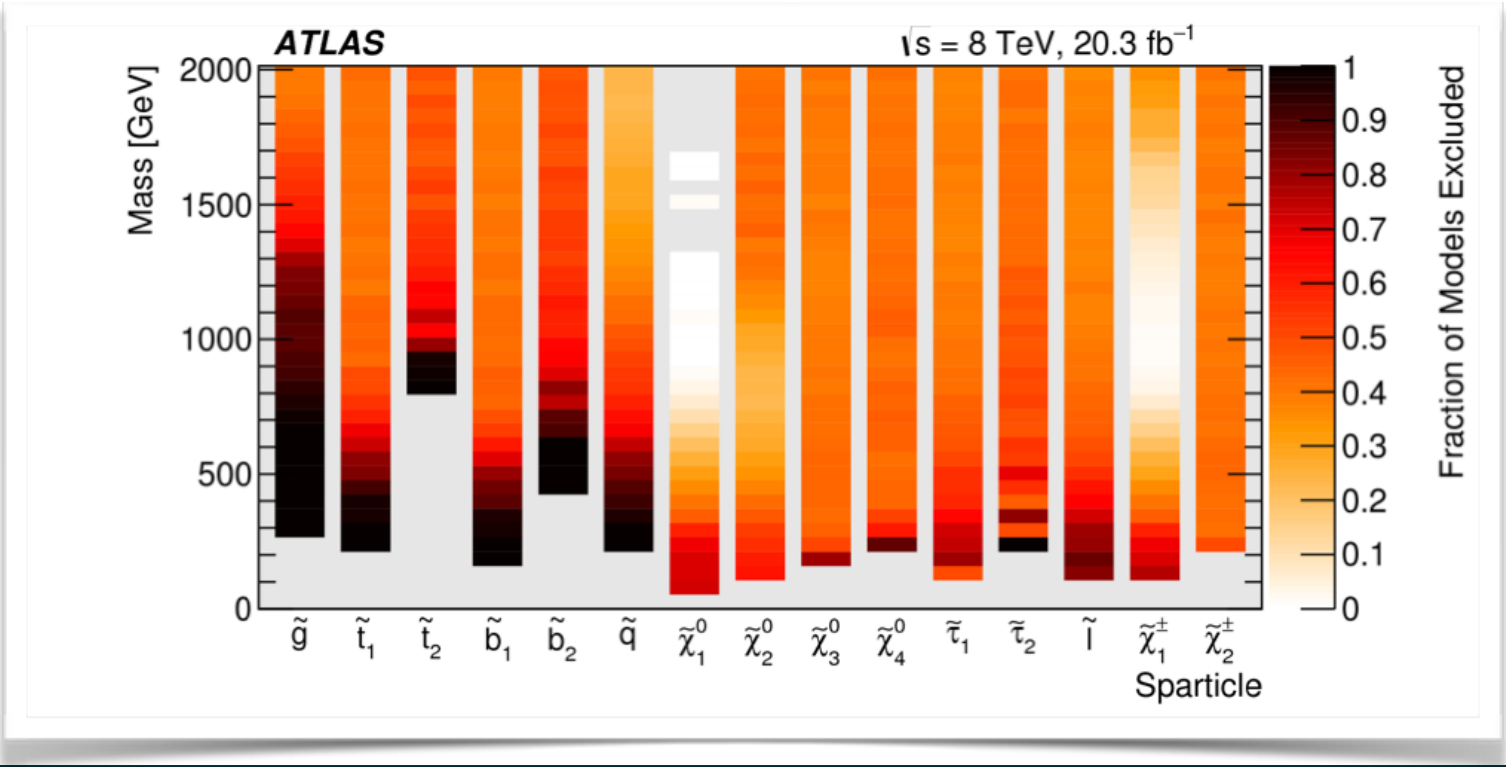
- Hopefully **no need to remind to this audience**…:
  - We use simplified models to **optimise our analyses** and (often) to **interpret the result**
  - The translation to actual models **not always straightforward.** "Absolute" exclusion (when they exist) limits **<u>are weaker.</u>**
  - Take our limits *cum grano salis*



Highlights (RPC strong production)

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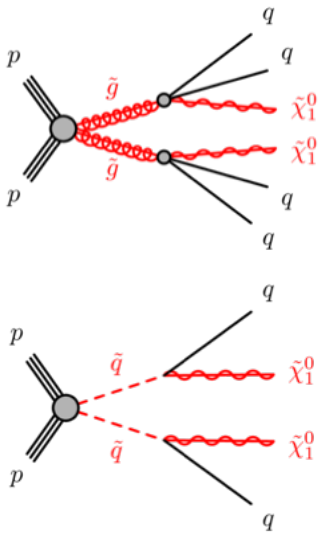
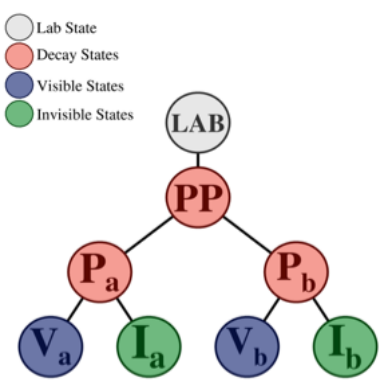
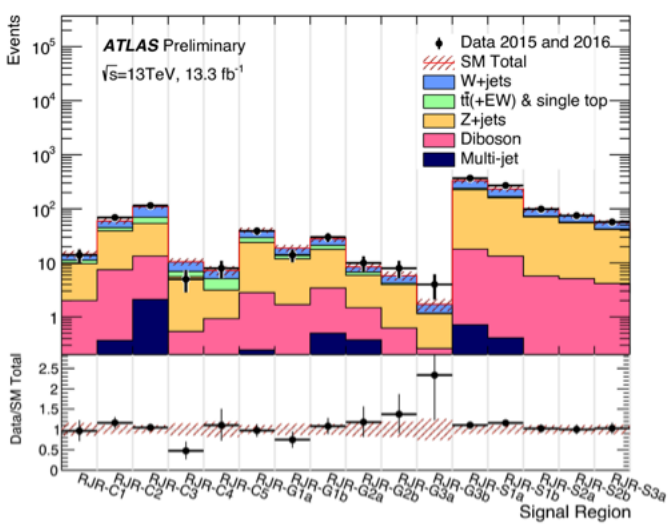
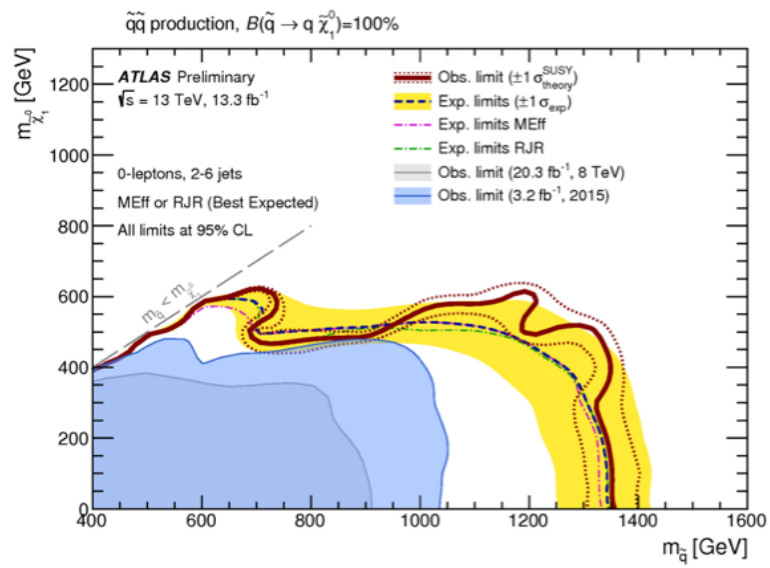
ATLAS-CONF-2016-078



- 0L + jets + E_T^{miss} : traditionally **the flagship** of the ATLAS SUSY
- Innovative approach using **R-Jigsaw techniques** in parallel with more **traditional M_{eff}-based**
  - R-jigsaw: Reconstruction of the **full event, including longitudinal part**, under certain assumptions, allows defining variables in **any reference frame**
- Dominant W and ttbar production normalised in **dedicated 1L regions** kinematically close to signal region. Z normalisation from a **single photon sample**







Highlights (RPC strong production)

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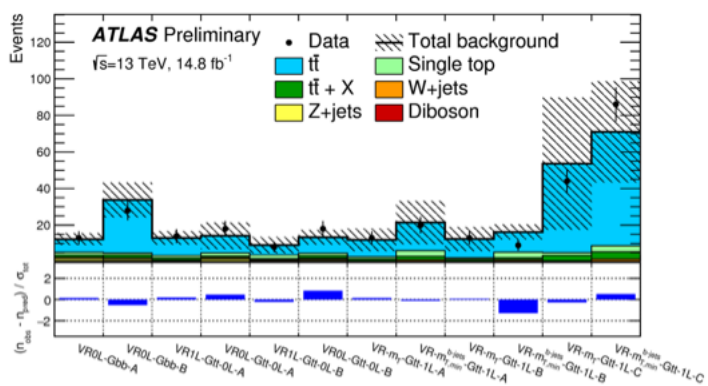
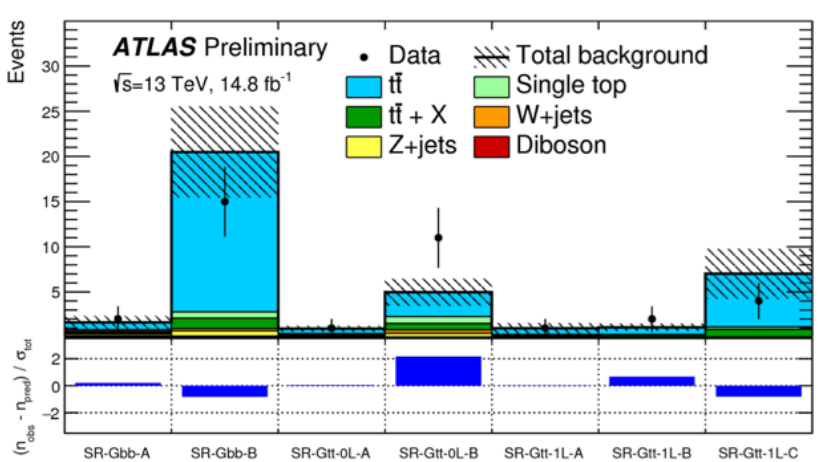
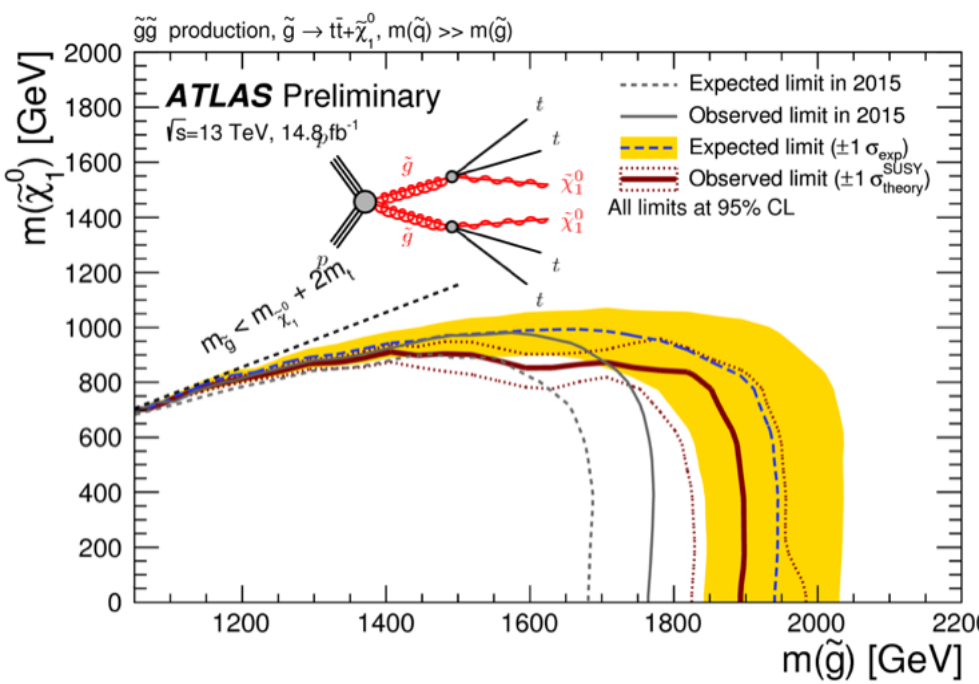
ATLAS-CONF-2016-052

- Multi-b analysis: **define 0- (Gbb and Gtt) and 1- (Gtt) lepton regions** with many b-jets
  - tt normalised and validated in dedicated regions

Criteria common to all Gtt 0-lepton regions: $p_T^{jet} > 30$ GeV, $N_{b\text{-jets}} \geq 3$					
	Variable	Signal region	Control region	VR1L	VR0L
Criteria common to all regions of the same type	$N^{\text{Signal Lepton}}$	$= 0$	$= 1$	$= 1$	$= 0$
	$\Delta\phi_{\min}^{4j}$	> 0.4	–	–	> 0.4
	$m_{T,\min}^{b\text{-jets}}$	> 80	–	> 80	> 80
	m_T	–	< 150	< 150	–
Region A (Large mass splitting)	N^{jet}	≥ 8	≥ 7	≥ 7	≥ 6
	E_T^{miss}	> 400	> 250	> 200	> 300
	m_{eff}^{incl}	> 2000	> 1750	> 1750	> 1300
	M_J^{Σ}	> 200	> 200	> 200	< 200







Gluino exclusion summary

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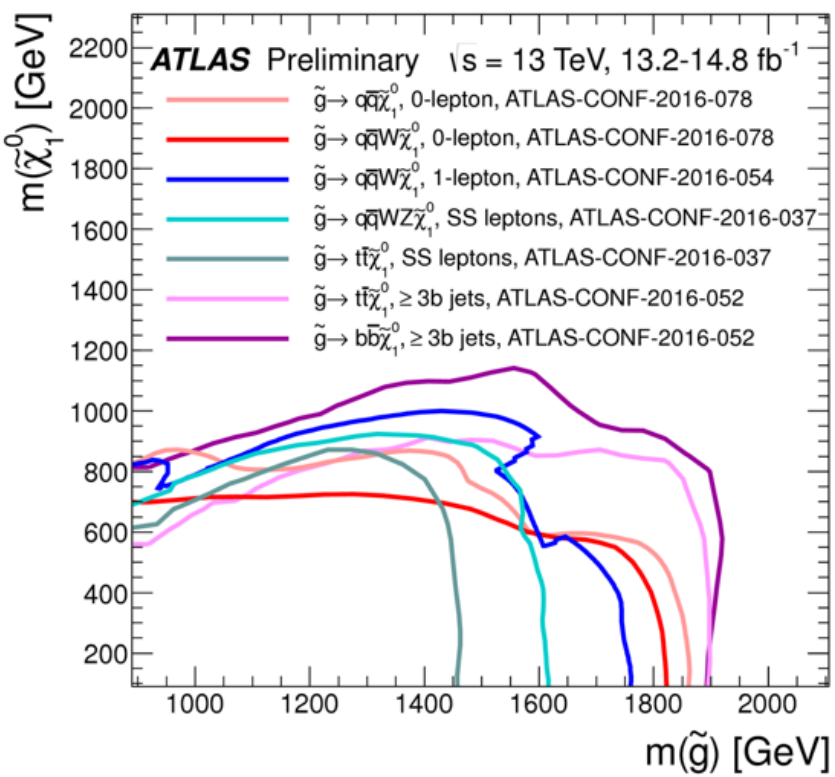

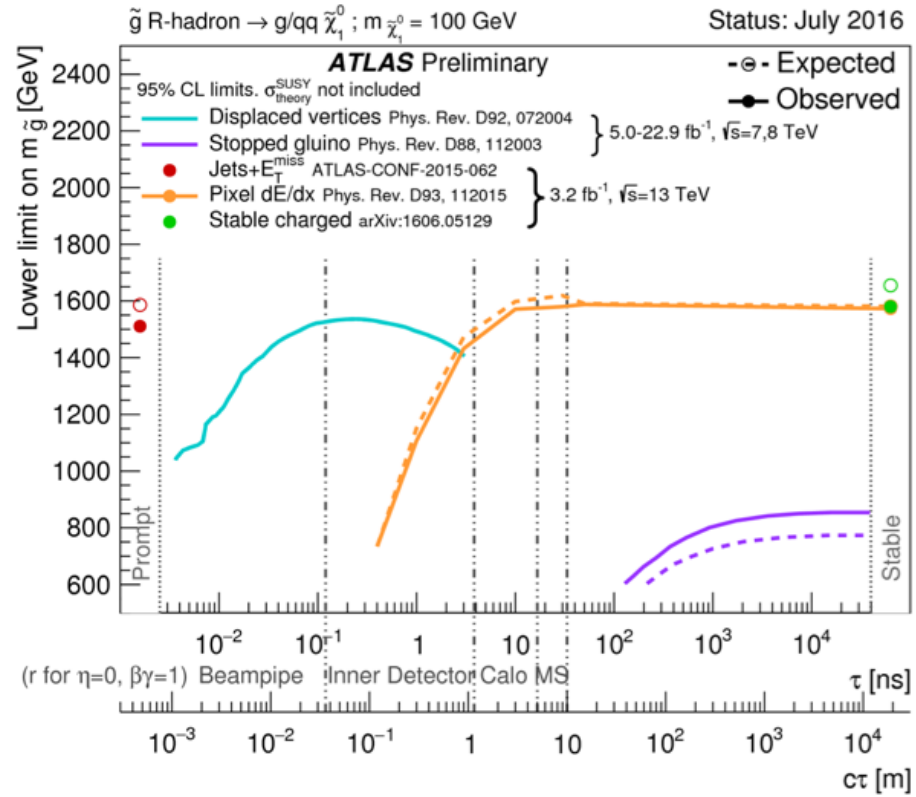

Highlights (RPV strong production)

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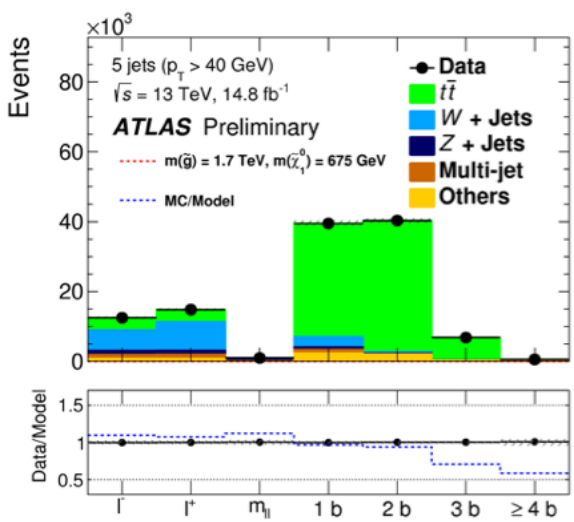
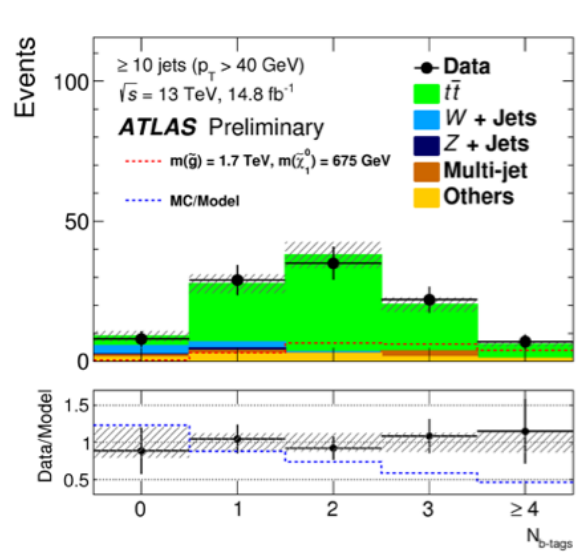
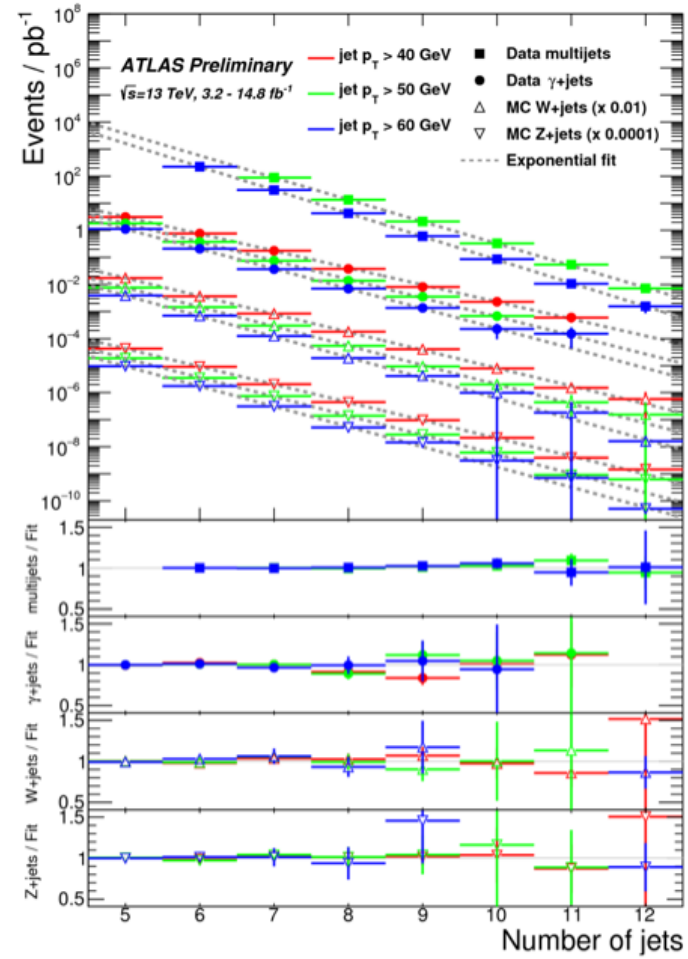
ATLAS-CONF-2016-094

- 1L multi-jet - a **new, and versatile**, analysis
- Bin the phase space in **jet and b-jet multiplicity:**
  - (nearly) **fully data-driven** background estimate
    - W+jets assumes **scaling in jets multiplicity**
    - ttbar assumes nearly constant probability that an **additional jet is b-tagged**
- **No excess** above predictions







Highlights (RPV strong production)

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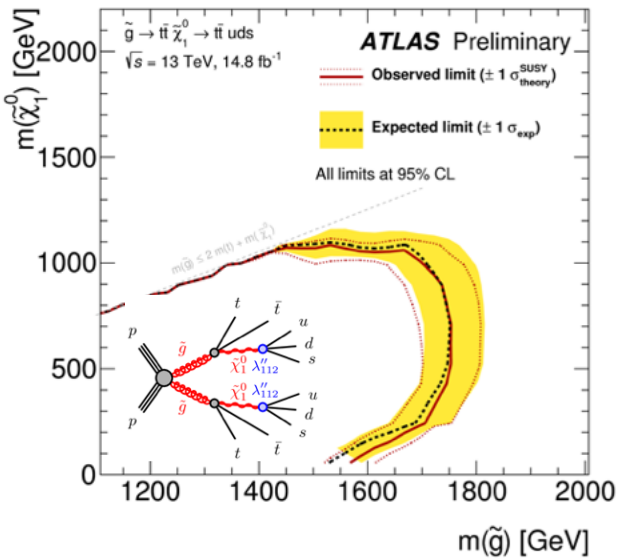
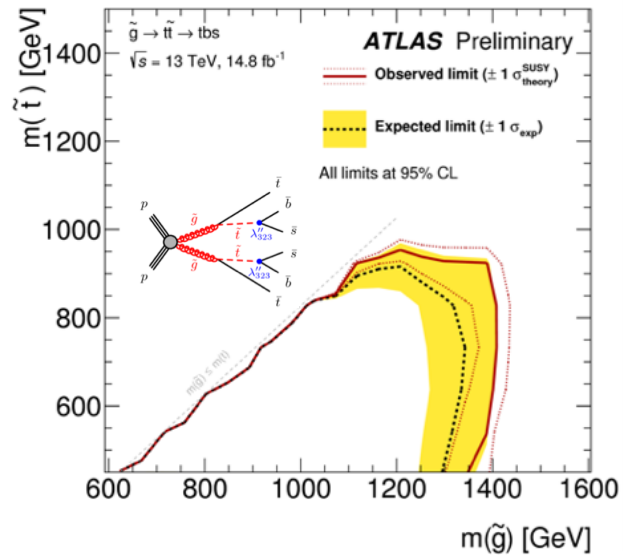
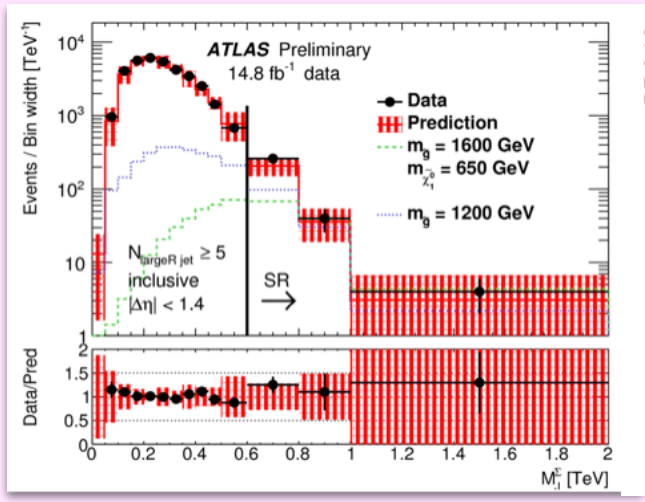


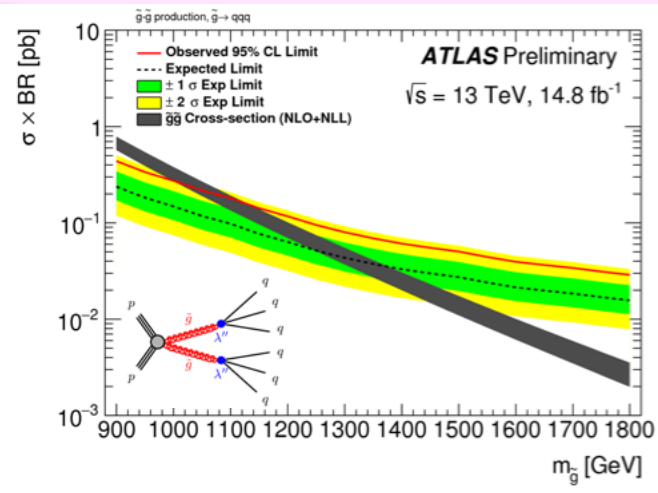


0L multi-jet RPV analysis

ATLAS-CONF-2016-057

- Use **fat jets with R = 1.0**
- Data driven background estimation uses the **jet mass template method** to predict the distribution of the **sum of jet masses**
- jet mass template extracted in a **low jet multiplicity** control region





Highlights (3rd generation)

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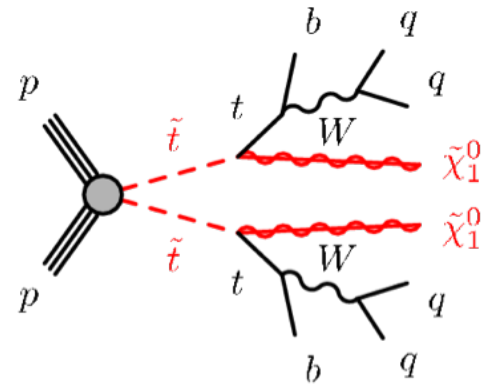
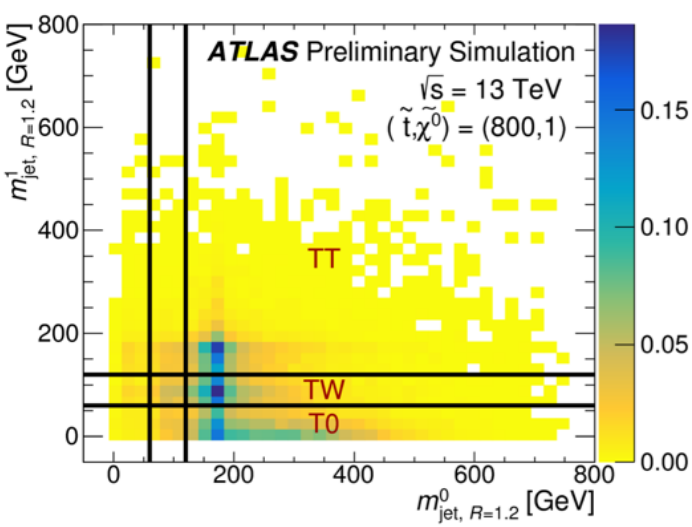
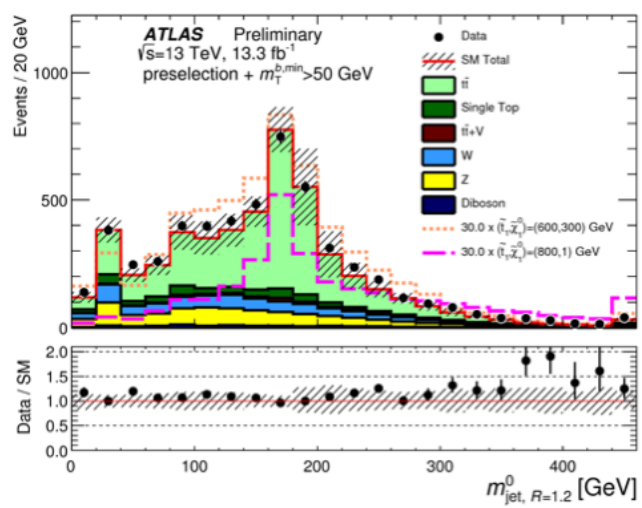
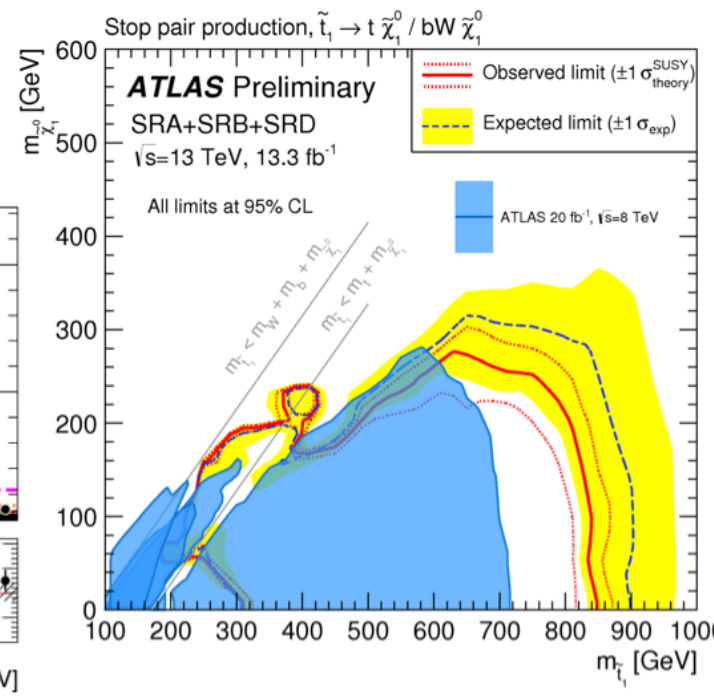
ATLAS-CONF-2016-077

- 0L stop:
  - **4 sets** of signal regions **for stop pair production** (plus **one for DM and one for strong production**)
  - Categorisation largely based on **reclustered jet masses**
  - Dedicated signal regions for **diagonal region** based on recoil against ISR jet









Summary plots stop

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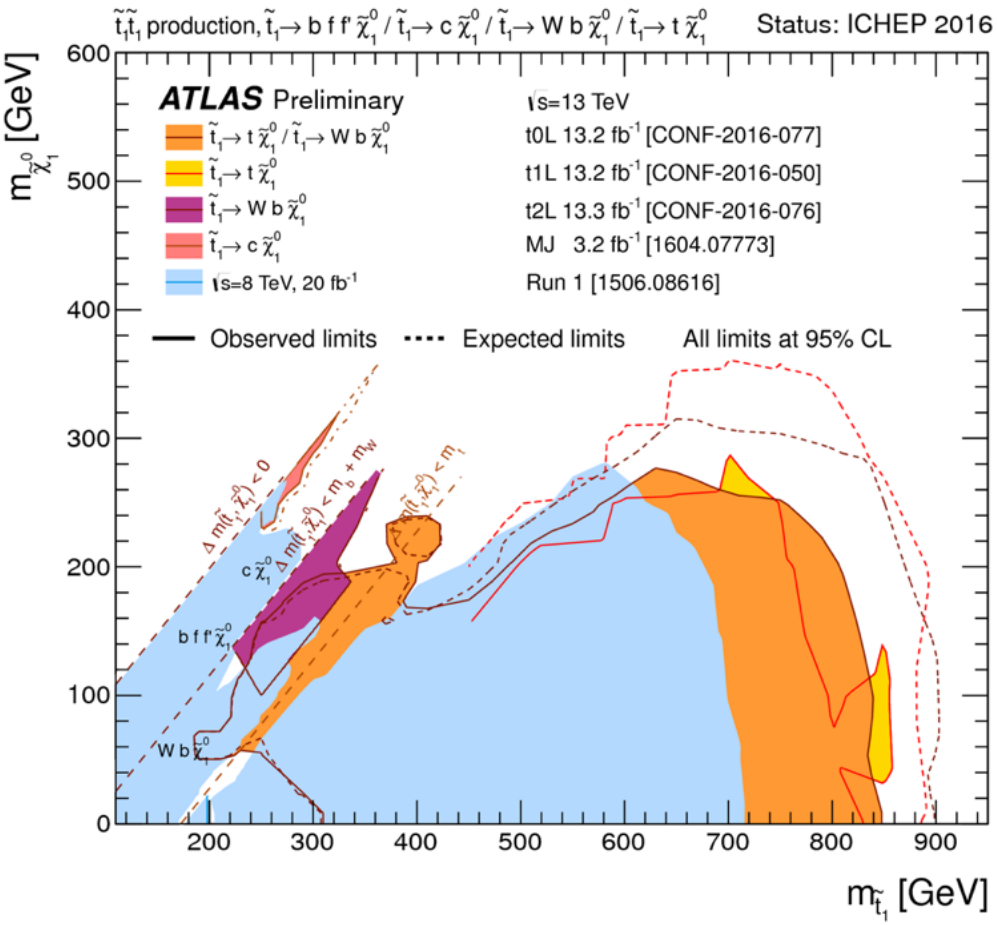

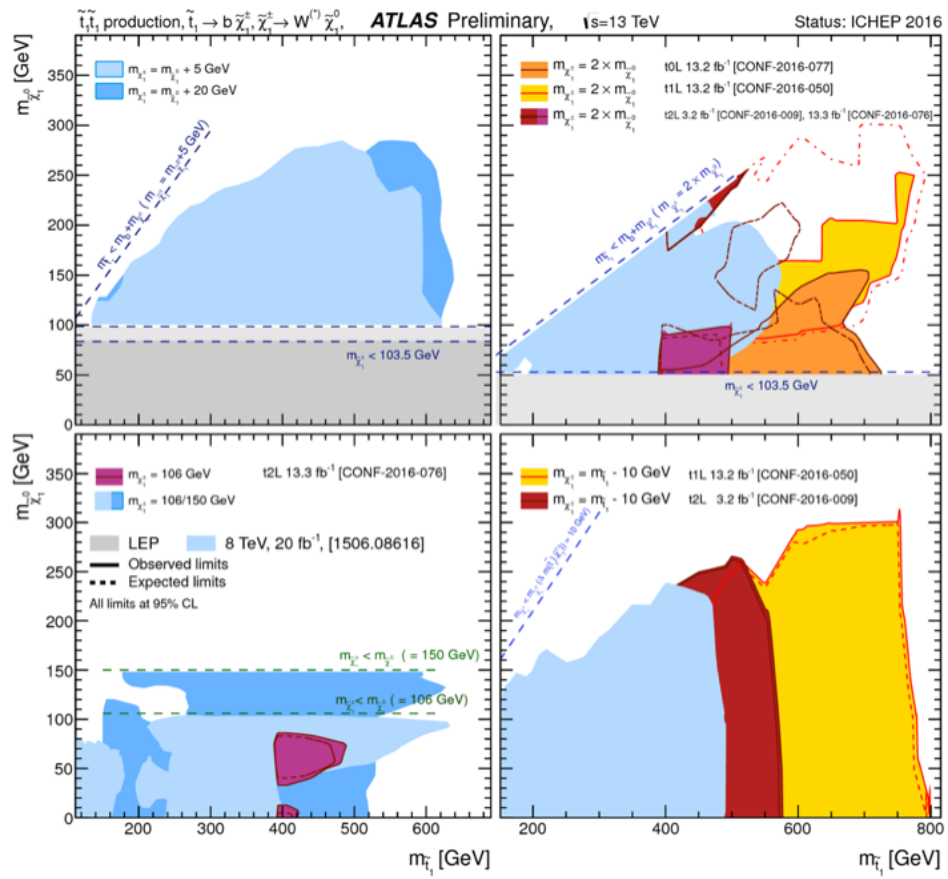

EW SUSY in run 2

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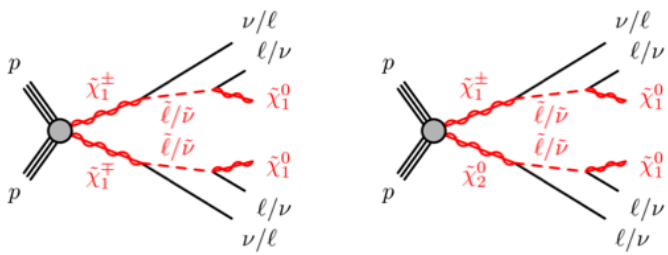
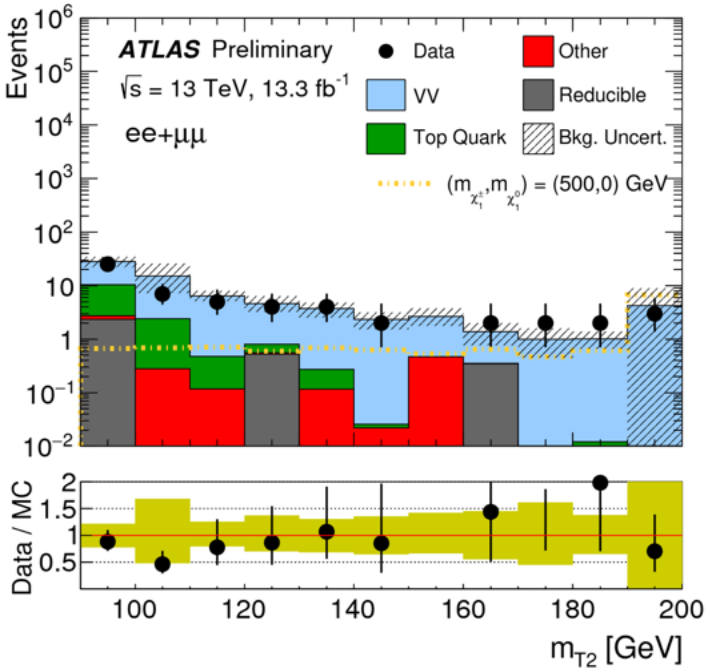
ATLAS-CONF-2016-096

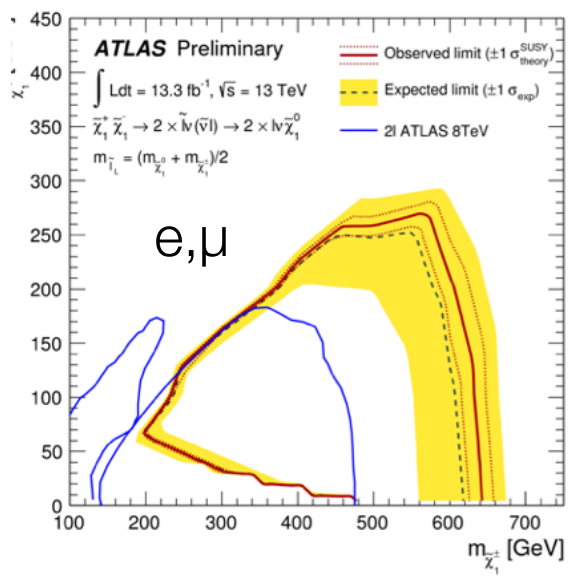
- We started producing results on **electroweak production** (wino-like cross-sections, decay via sleptons - including staus)

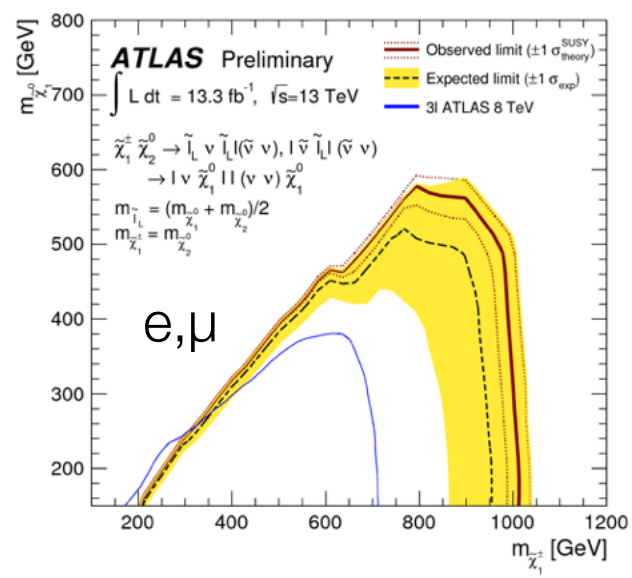


Variable	SR2ℓ	
lepton	$\ell^+\ell^-$	
lepton flavour	SF	DF
central light jets	0_{20}	0_{30}
central b-jets	0_{20}	0_{20}
forward jets	0_{30}	0_{30}
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV]	> 10	–
m_{T2} [GeV]	$> 90, 120, 150$	

Variable	SR3ℓ-I	SR3ℓ-H
lepton	$\ell^+\ell^-\ell$	
b-tagged jet	veto	
$m_T >$	110	
m_{SFOS}	$\notin [81.2, 101.2]$	>101.2
$p_T^{3rd\ell} >$	30	80
$E_T^{miss} >$	120	60







EW SUSY in run 2

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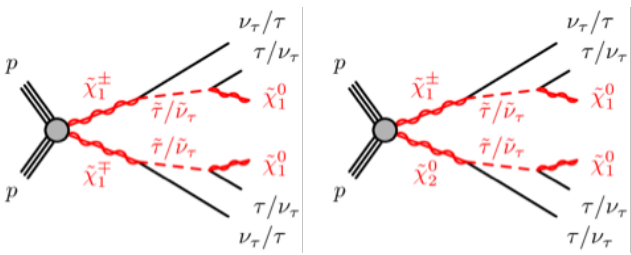
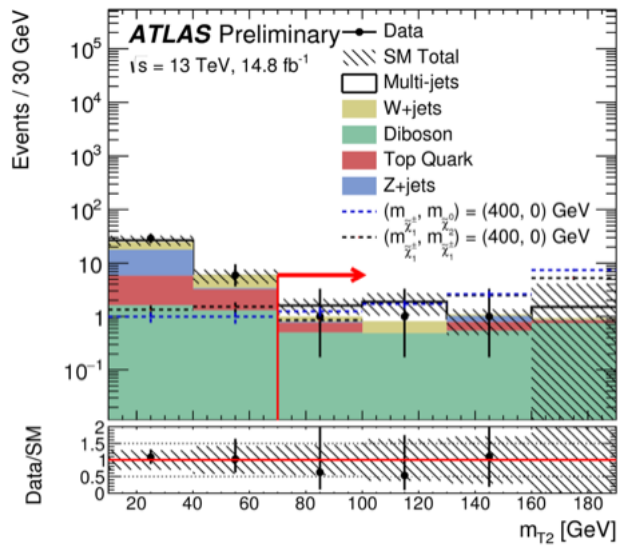
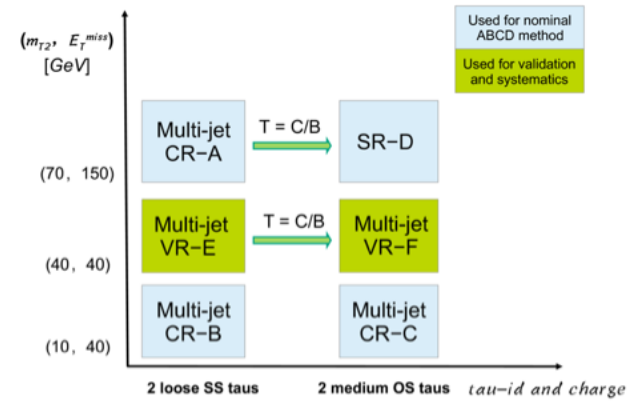
ATLAS-CONF-2016-093

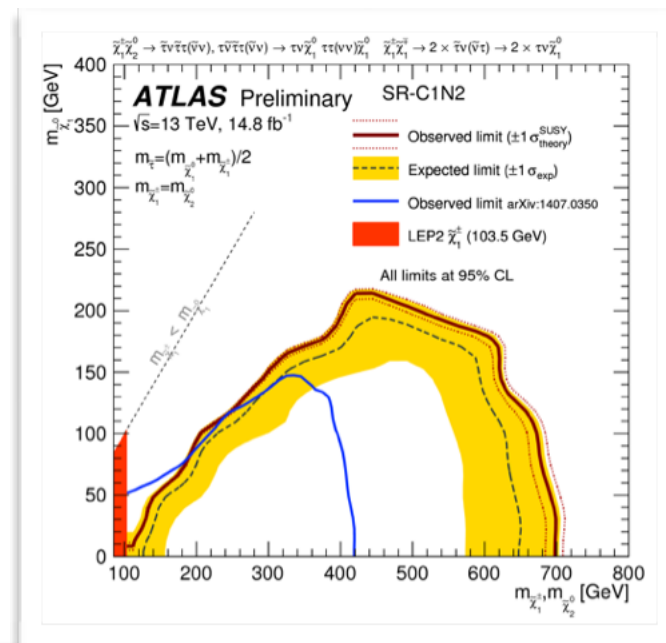
- Dedicated analysis exploiting **two hadronic** taus in the final state for C1C1 and C1N2 production and **decay via staus**
- Main background processes: **diboson and multijet**
- The latter derived with a **data-driven ABCD method**



SR-C1C1	SR-C1N2
light lepton veto	-
at least two medium taus	
at least one opposite sign tau pair	
b-jet veto	
Z-veto	
$E_{\mathrm{T}}^{\mathrm{miss}} > 150$ GeV	
$m_{\mathrm{T2}} > 70$ GeV	







Summary EW production

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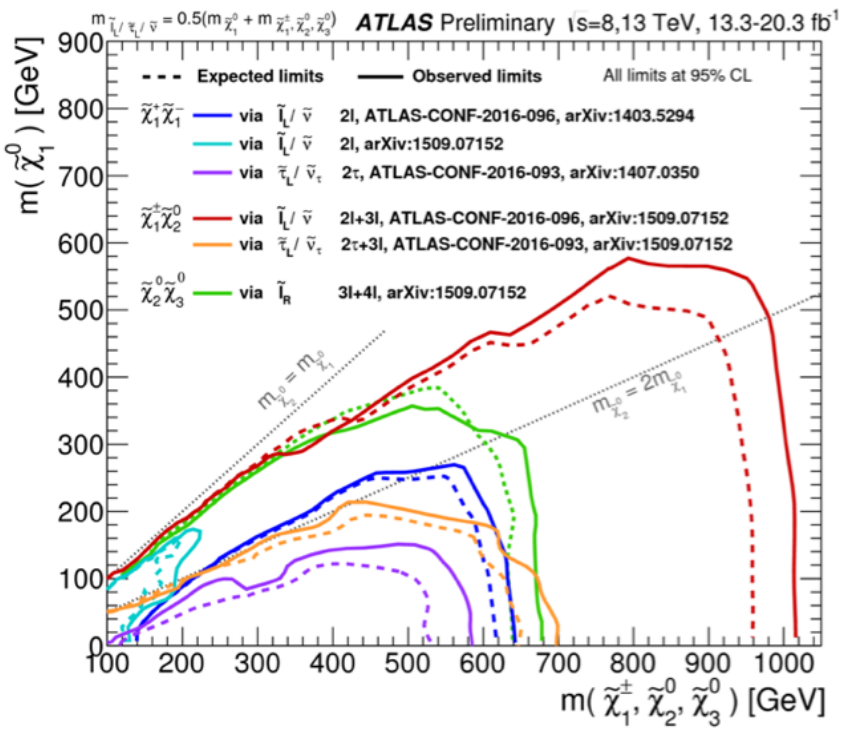
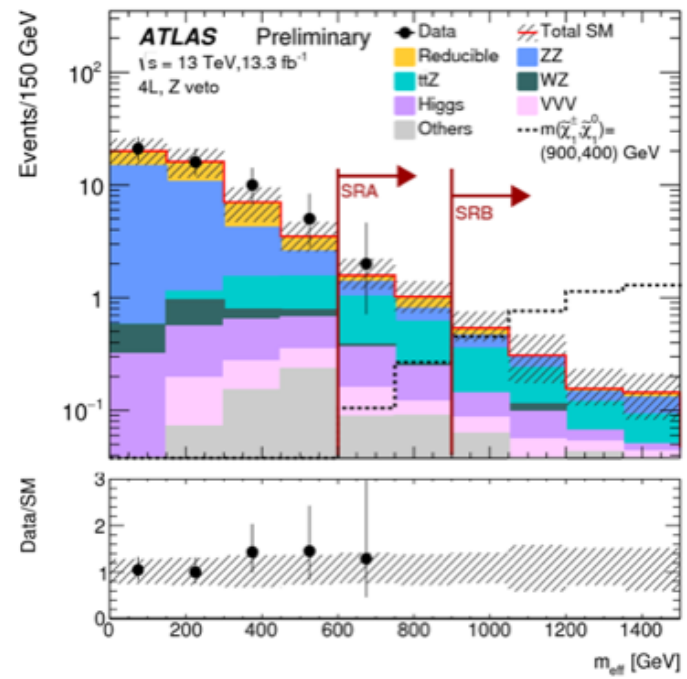


4L EW analysis

- Ask for **4 leptons**, with a **Z-veto**
- Define two signal regions **based on m_{eff}**
- Background dominated by ttZ
- Reducible background determined from a loose-tight matrix method

ATLAS-CONF-2016-075



Excesses

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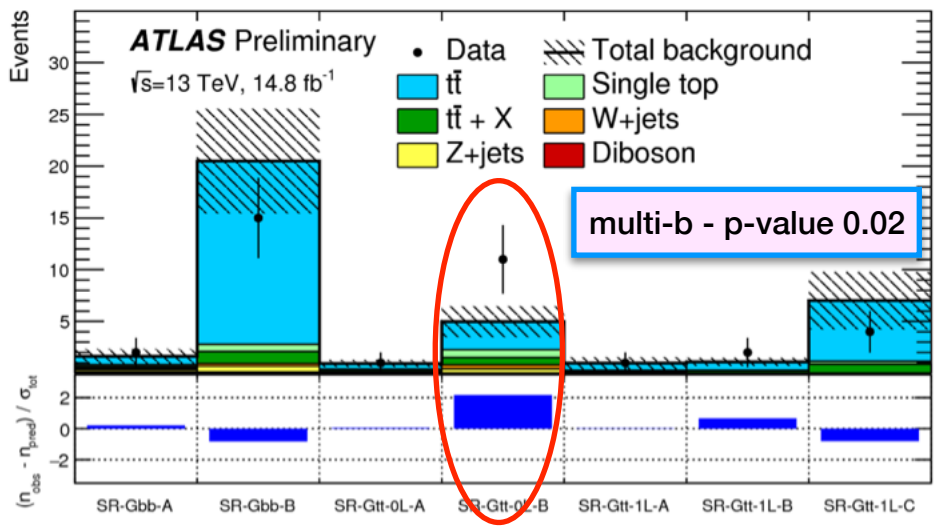
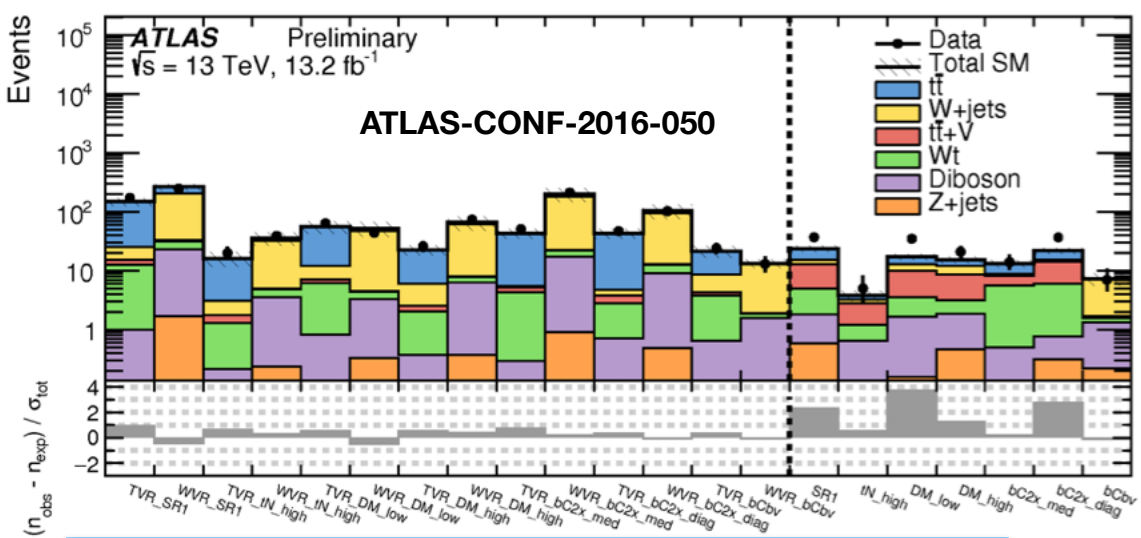
ATLAS-CONF-2016-052



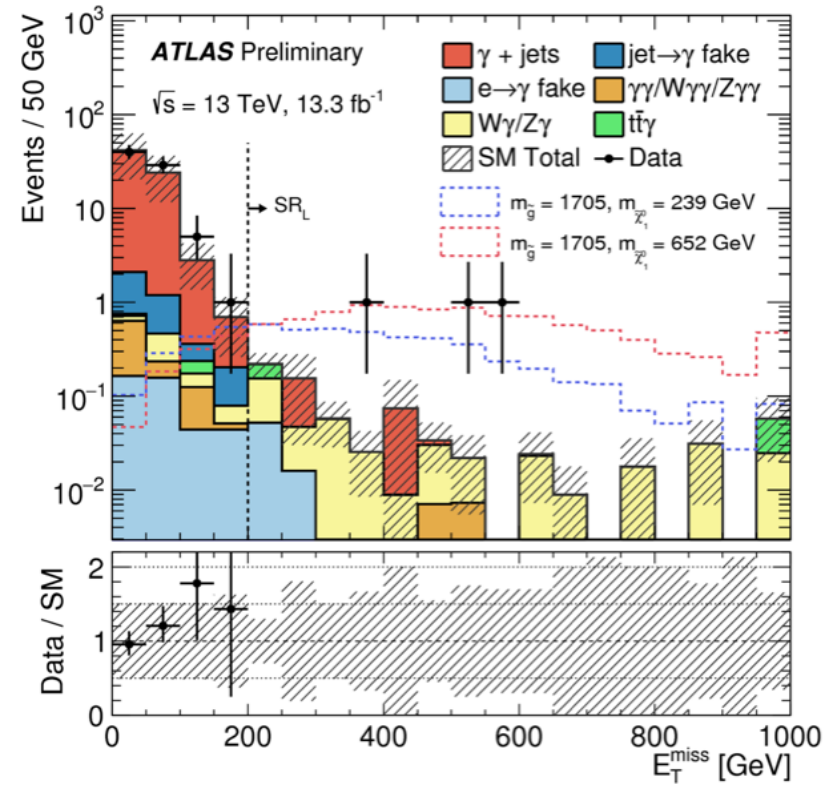
multi-b - p-value 0.02



1L stop - maximum deviation with p-value 0.0004

ATLAS-CONF-2016-066

single photon + E_T^{miss} - p-value 0.02 - 2 correlated signal regions in total



More details

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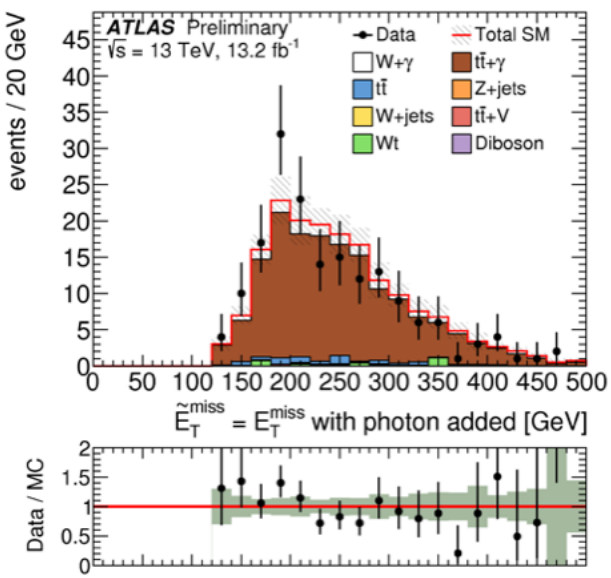
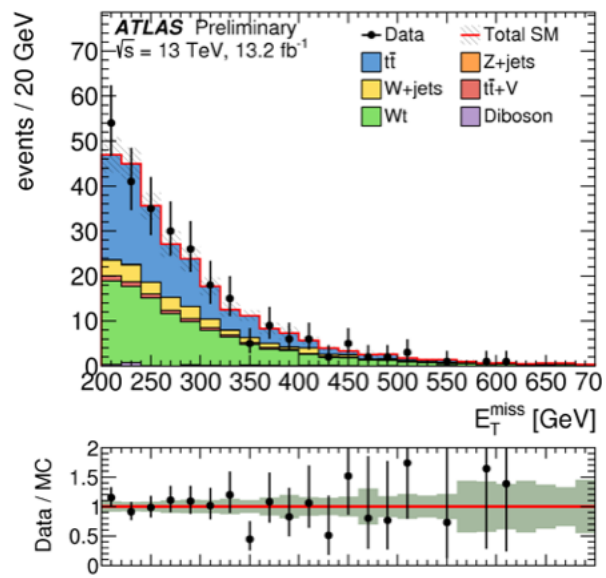
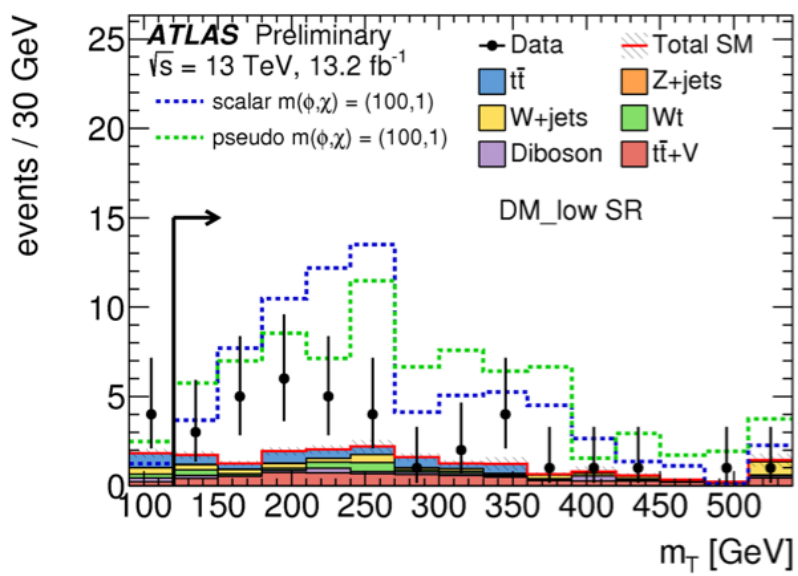
Variable	DM_low
$\geq$4 jets with $p_{\mathrm{T}} >$ [GeV]	(60 60 40 25)
$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]	> 300
$H_{\mathrm{T,sig}}^{\mathrm{miss}}$	> 14
m_{T} [GeV]	> 120
am_{T2} [GeV]	> 140
$\min(\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \mathrm{jet}_i))$ $(i \in \{1-4\})$	> 1.4
$\Delta\phi(\vec{p}_{\mathrm{T}}^{\mathrm{miss}}, \ell)$	> 0.8
$\Delta R(b_1, b_2)$	–
Number of b-tags	≥ 1

- main background **ttZ with Z→νν** normalised in a **ttγ control region.**
- top pair production normalised in a CR at low m_T
- Excesses in other signal regions, **significantly overlapping** with DM_low







SF OS dilepton analysis

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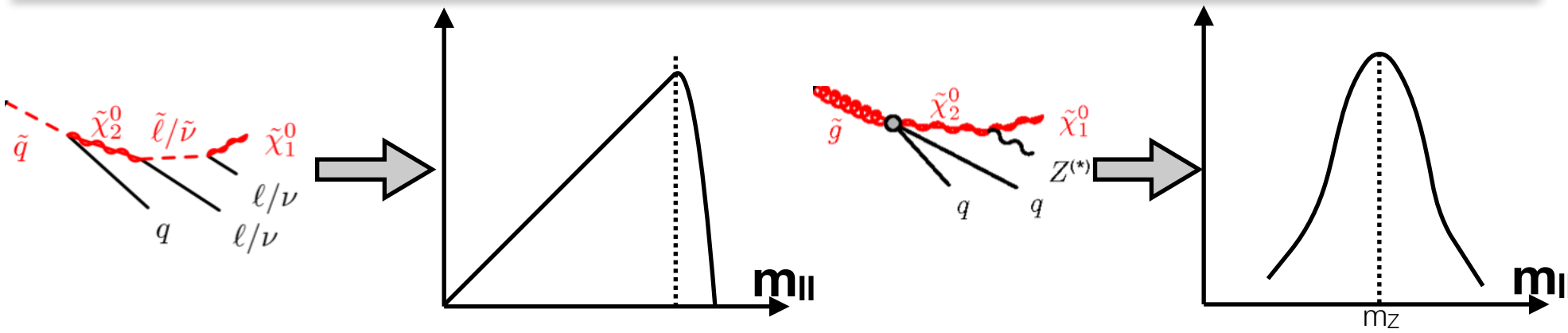
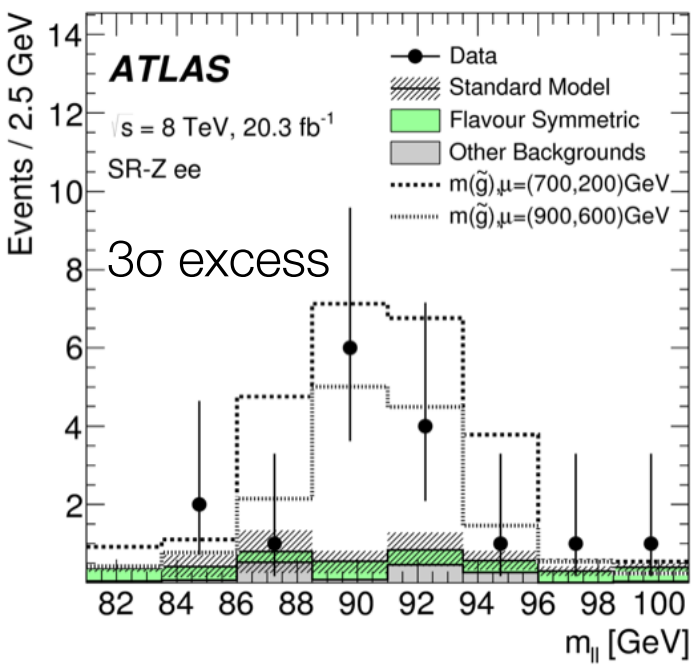
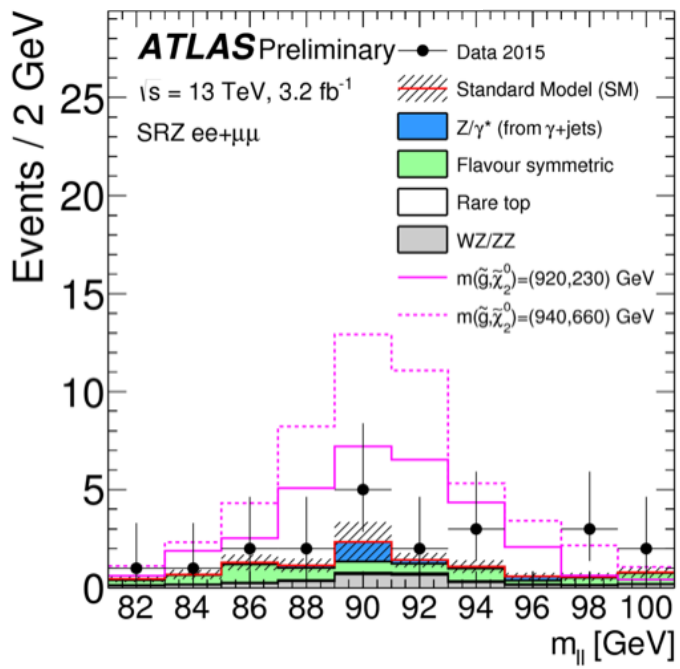
ATLAS-CONF-2016-098



arXiv:1503.03290



ATLAS-CONF-2015-082



Excess in run 1 and run 2 on the Z peak

The selection for these plots is 2 jets, E_T^{miss} > 225 GeV, H_T > 600 GeV

SF OS dilepton analysis

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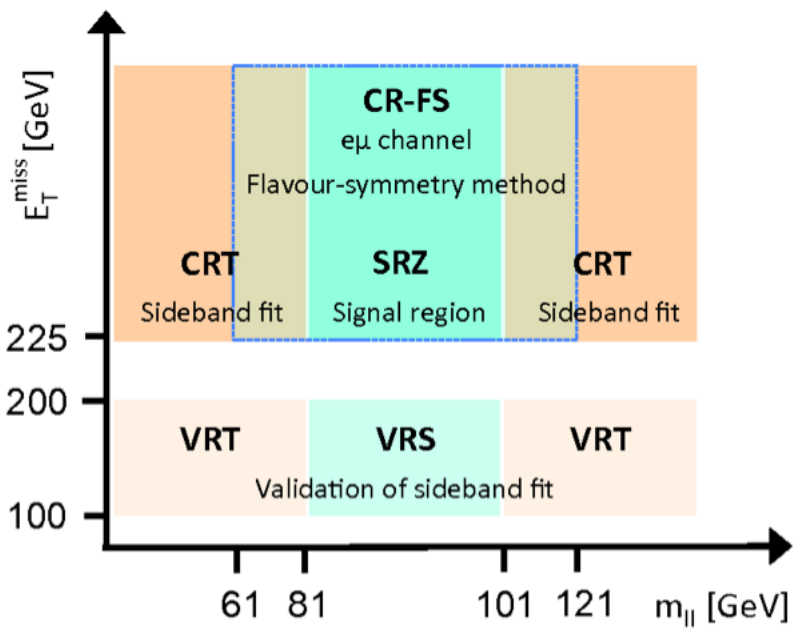
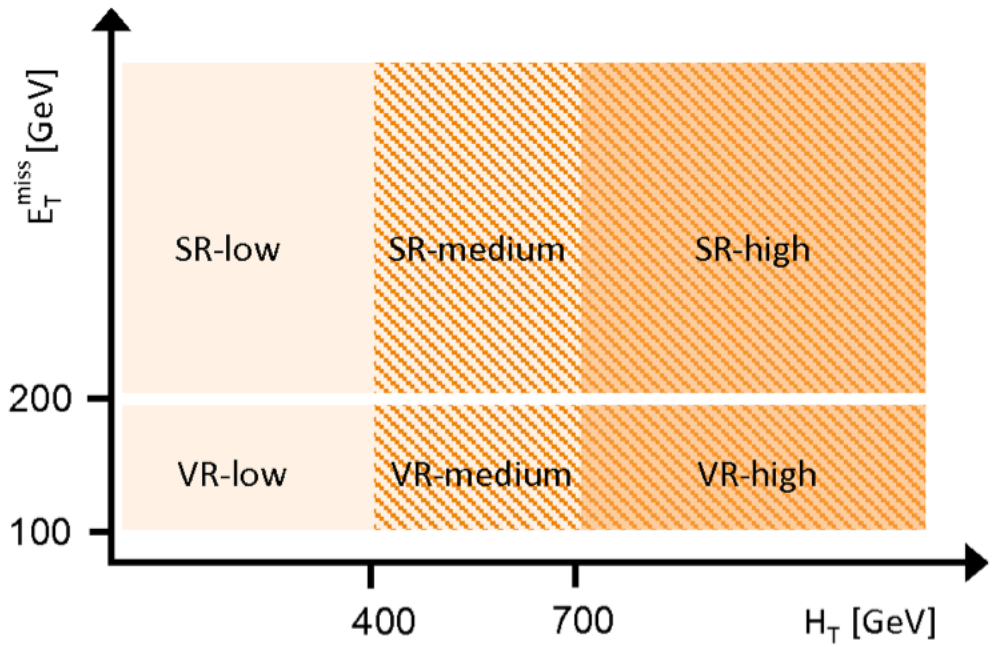
- Analysis **extended to include full m_{ll} spectrum** in different regions of H_T and E_T^{miss}

On-Z analysis



Off-Z analysis



SF OS dilepton analysis

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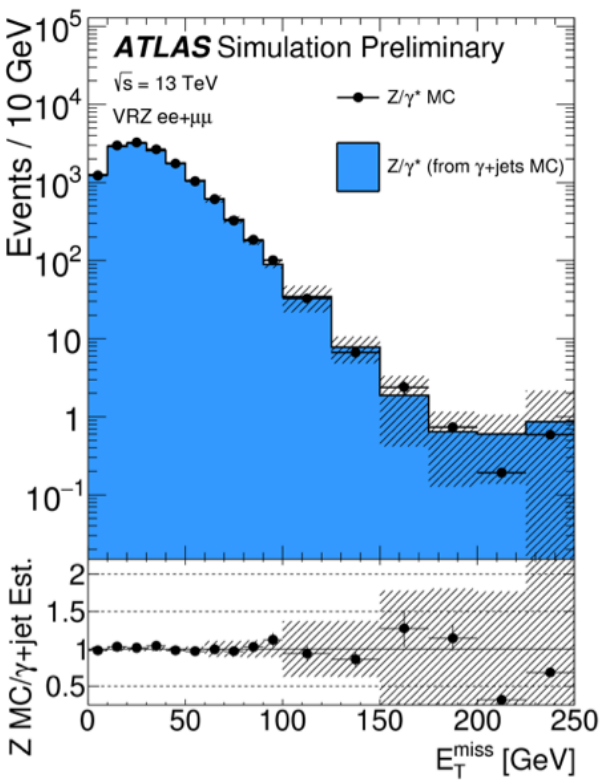
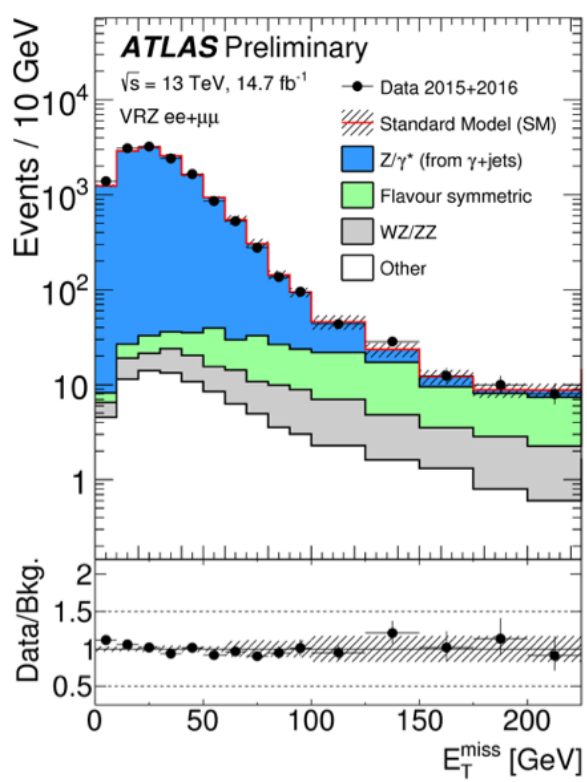
- Analysis **extended to include full m_{ll} spectrum** in different regions of H_T and E_T^{miss}
- **Z + jets E_T^{miss} template** taken from a **γ+jets control** region.

Closure in MC



Closure in data



VRZ:

81 GeV< m_{ll} < 101GeV

E_T^{miss} < 225 GeV

H_T^{incl} > 600 GeV

N_{jet} > 2

$\Delta\Phi(jet, E_T^{miss})$ > 0.4

SF OS dilepton analysis

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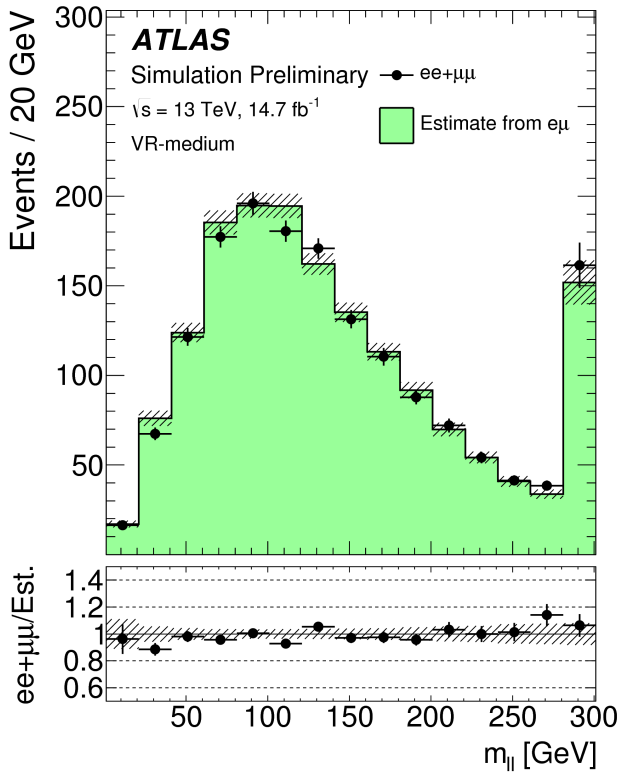
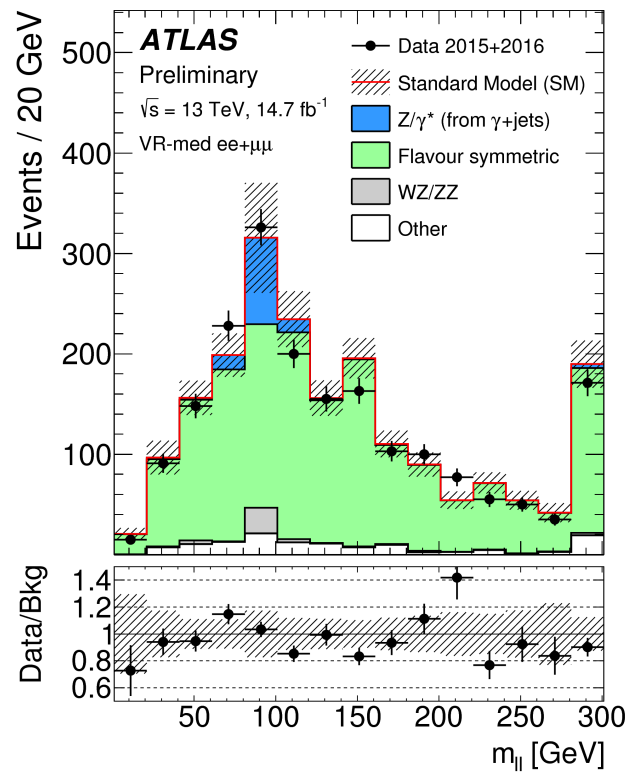
- Analysis **extended to include full m_{ll} spectrum** in different regions of H_T and E_T^{miss}
- **Z + jets E_T^{miss} template** taken from a **γ+jets control** region.
- **Flavour symmetric background** (mostly top pair production) determined from **eμ control region**





SF OS dilepton analysis

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- Analysis **extended to include full m_{ll} spectrum** in different regions of H_T and E_T^{miss}
- **Z + jets E_T^{miss} template** taken from a **γ+jets control** region.
- **Flavour symmetric background** (mostly top pair production) determined from **eμ control region**
- Diboson background taken from MC and validated with data

	VR-S	VR-WZ	VR-ZZ	VR-3L
Observed events	236	698	132	32
Total expected background events	224 ± 41	613 ± 66	139 ± 25	35 ± 10
Flavour-symmetric ($t\bar{t}$, Wt, WW, $Z \to \tau\tau$)	99 ± 8	-	-	-
WZ/ZZ events	27 ± 13	573 ± 66	139 ± 25	25 ± 10
Rare top events	11 ± 3	14 ± 3	0.44 ± 0.11	9.1 ± 2.3
Z/γ^* + jets events	84 ± 37	-	-	-
Fake lepton events	4 ± 4	26 ± 6	-	0.6 ± 0.3

	VR-low	VR-medium	VR-high
Observed events	16253	1917	314
Total expected background events	16500 ± 700	1990 ± 150	340 ± 60
Data-driven flavour symmetry events	14700 ± 600	1690 ± 120	250 ± 50
WZ/ZZ events	250 ± 80	40 ± 19	9 ± 6
Data-driven Z/γ^* + jets (γ + jets) events	1100 ± 400	130 ± 70	50 ± 29
Rare top events	87 ± 23	27 ± 7	6.5 ± 1.8
Data-driven fake lepton events	270 ± 100	98 ± 35	20 ± 11

SF OS dilepton analysis

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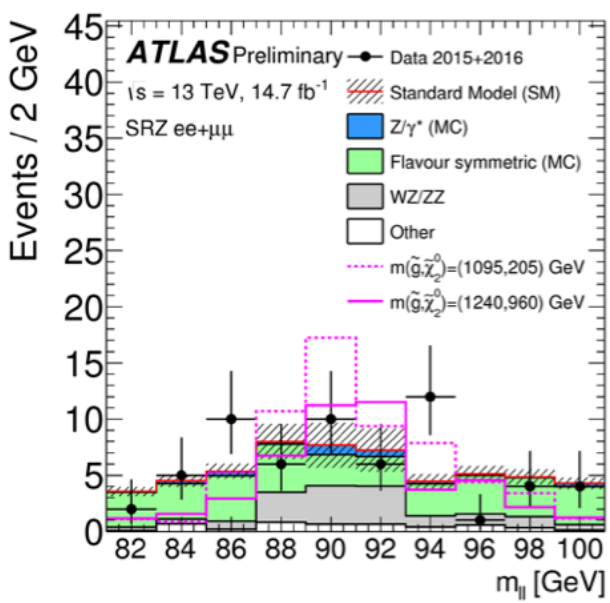
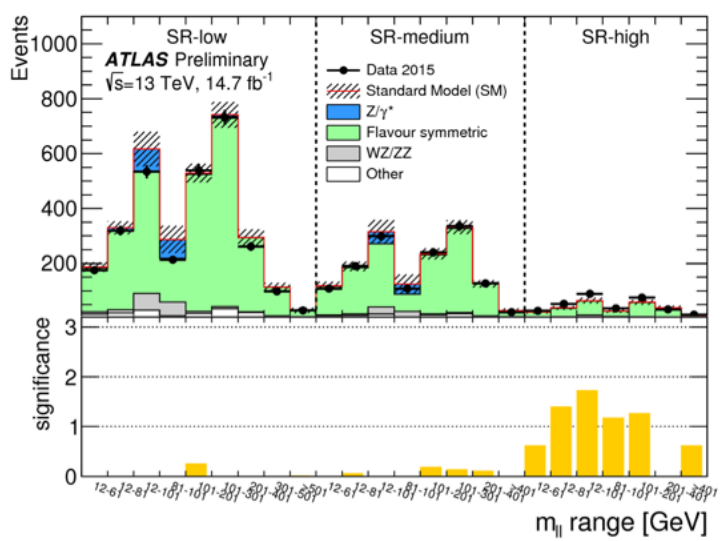
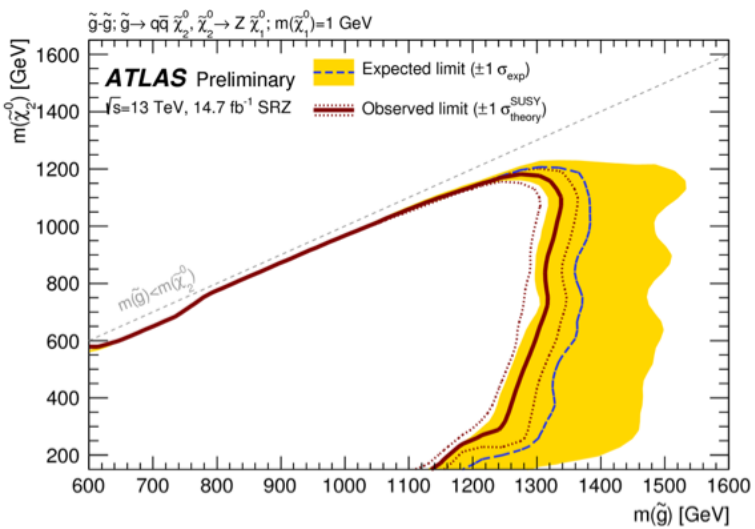
	SRZ	SRZ ee	SRZ $\mu\mu$
Observed events	60	35	25
Total expected background events	53.5 ± 9.3	27.1 ± 5.1	26.8 ± 4.4
Flavour-symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	33.2 ± 3.9	16.5 ± 2.1	16.7 ± 2.0
Z/γ^* + jets events	3.1 ± 2.8	$1.0^{+1.3}_{-1.0}$	2.1 ± 1.4
WZ/ZZ events	14.2 ± 7.7	7.8 ± 4.3	6.4 ± 3.5
Rare top events	2.9 ± 0.8	1.4 ± 0.4	1.5 ± 0.4
Fake lepton events	$0.1^{+0.8}_{-0.1}$	$0.5^{+0.7}_{-0.5}$	$0^{+0.2}$
$p(s = 0)$	0.32	0.15	0.5
Significance (σ)	0.47	1.00	0
Observed (Expected) S^{95}	28.2 ($24.5^{+8.9}_{-6.7}$)	22.0 ($15.8^{+6.5}_{-4.5}$)	12.9 ($14.0^{+5.7}_{-3.9}$)
$\langle \epsilon\sigma \rangle^{95}_{\text{obs}}$ [fb]	1.9	1.5	0.88

No significant excess found

Result interpreted in gluino and squark pair production, with decay to χ_2^0 followed by decay through Z or sleptons



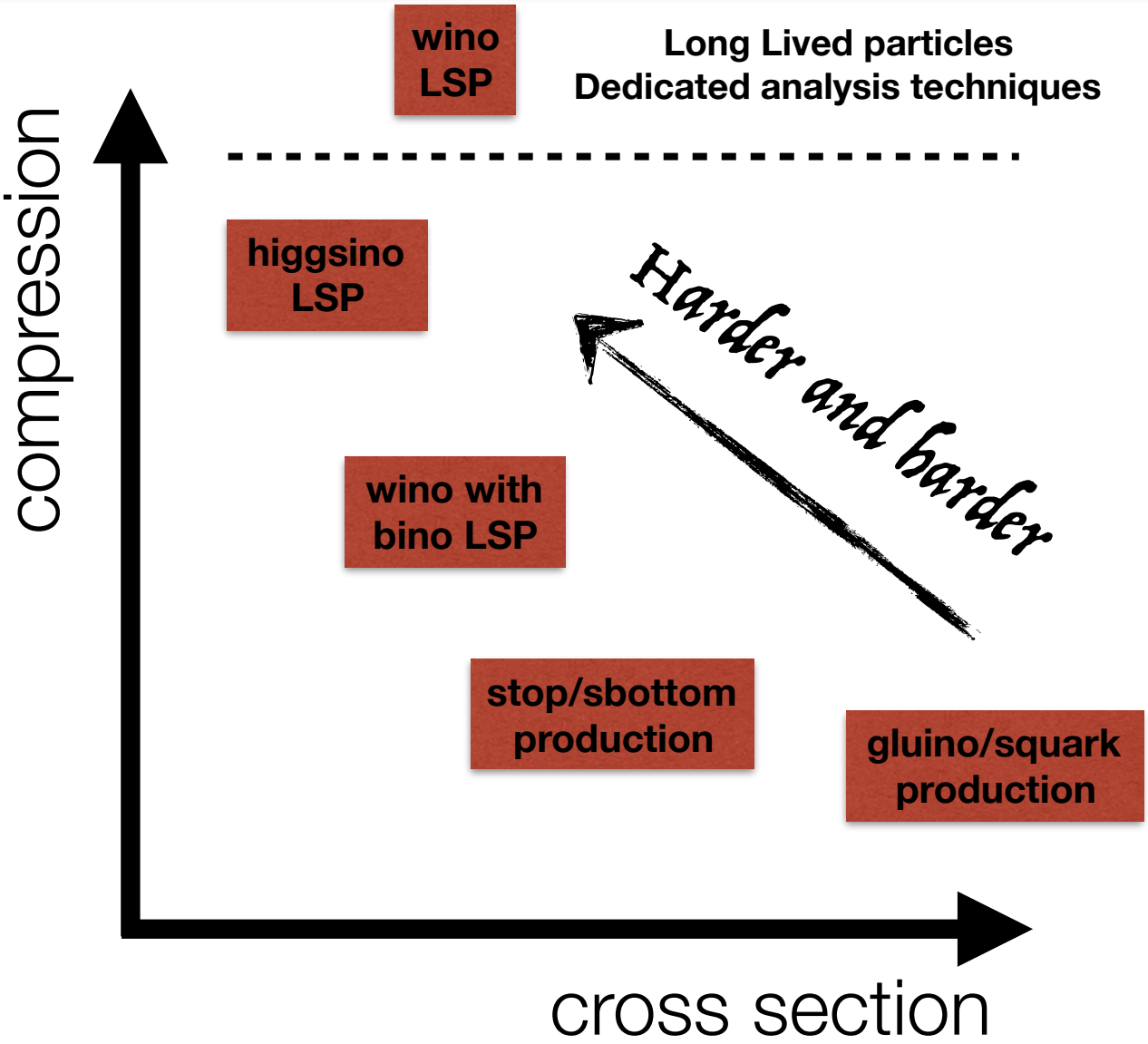




Summary

- A **nice harvest of results** during summer. No superhero found.
  - **Largest excess** in an analysis looking for **stop pair production in 1-lepton** final states (3.3σ)
- In general, **striking agreement with the Standard Model predictions**
- The time for large increases of **CM energy and/or integrated luminosity** is nearly over…
- Will we leave our superheroes undiscovered?

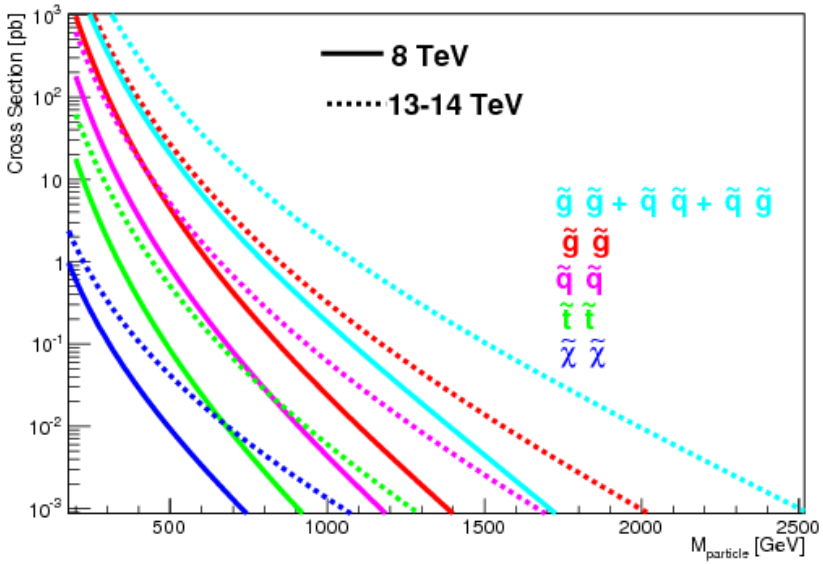
Backup


wino
LSP
Long Lived particles
Dedicated analysis techniques
higgsino
LSP
Harder and harder
wino with
bino LSP
stop/sbottom
production
gluino/squark
production
compression
cross section

SUSY production and decay

University of Sussex

SUSY production



Structure of SUSY group (strong, 3rd generation, EW) follows from differences in cross section and topology for these processes

… and decay

Generic **R-parity conserving** (RPC) SUSY predicts **large E_T^{miss}**

R-parity violating SUSY predicts **large object multiplicity**

Gluino and squark production leads to **jets plus stuff**

stop/sbottom production leads to **b-jets plus stuff**

EW production leads to **stuff**

---

stuff is W, Z, h, γ, e, μ, τ

stop 1L - more details

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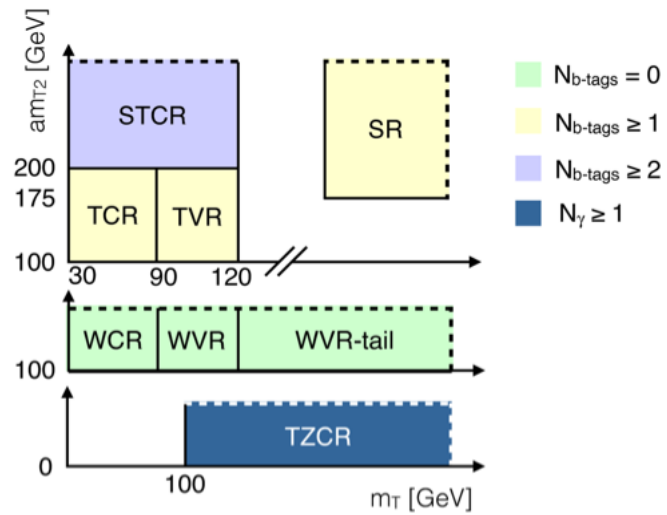
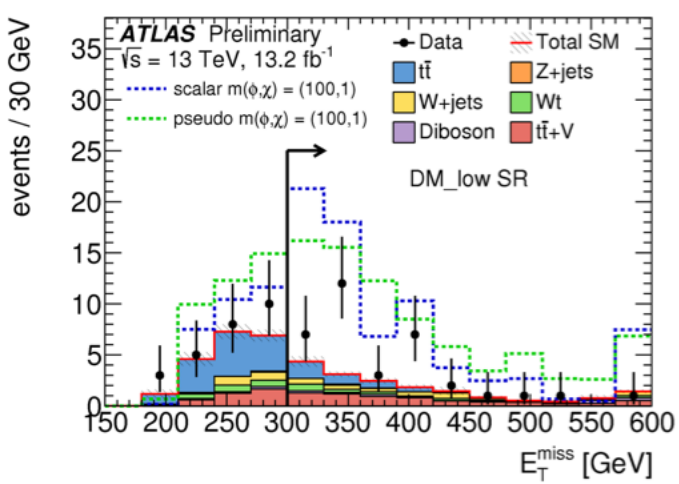
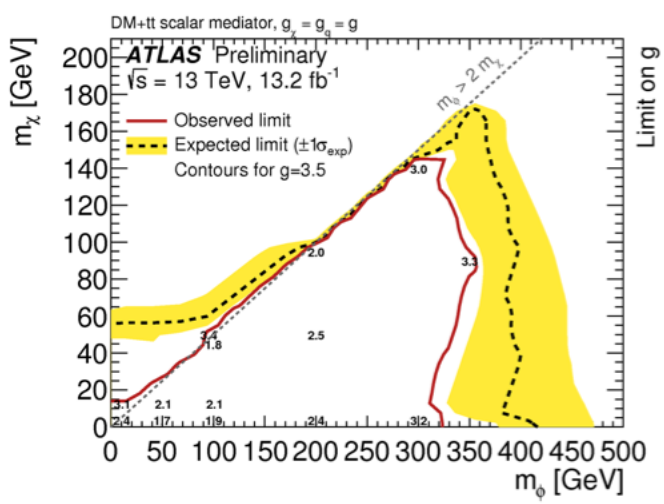
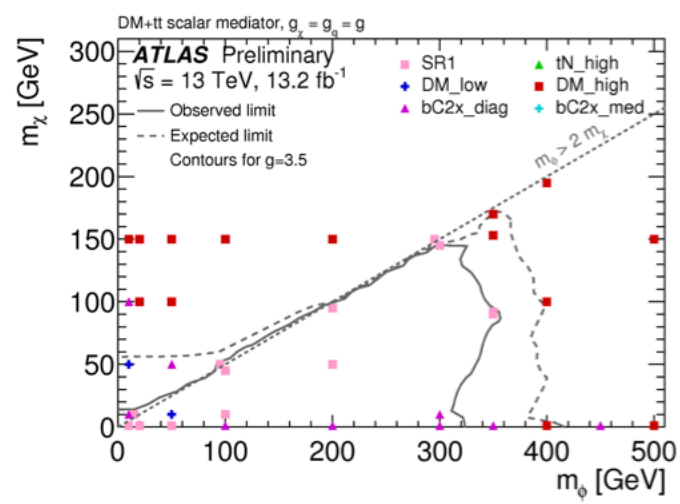
Signal region	SR1	tN_high	bC2x_diag	bC2x_med	bCbv	DM_low	DM_high
Observed	37	5	37	14	7	35	21
Total background	24 ± 3	3.8 ± 0.8	22 ± 3	13 ± 2	7.4 ± 1.8	17 ± 2	15 ± 2
$t\bar{t}$	8.4 ± 1.9	0.60 ± 0.27	6.5 ± 1.5	4.3 ± 1.0	0.26 ± 0.18	4.2 ± 1.3	3.3 ± 0.8
W+jets	2.5 ± 1.1	0.15 ± 0.38	1.2 ± 0.5	0.63 ± 0.29	5.4 ± 1.8	3.1 ± 1.5	3.4 ± 1.4
Single top	3.1 ± 1.5	0.57 ± 0.44	5.3 ± 1.8	5.1 ± 1.6	0.24 ± 0.23	1.9 ± 0.9	1.3 ± 0.8
$t\bar{t}+V$	7.9 ± 1.6	1.6 ± 0.4	8.3 ± 1.7	2.7 ± 0.7	0.12 ± 0.03	6.4 ± 1.4	5.5 ± 1.1
Diboson	1.2 ± 0.4	0.61 ± 0.26	0.45 ± 0.17	0.42 ± 0.20	1.1 ± 0.4	1.5 ± 0.6	1.4 ± 0.5
Z+jets	0.59 ± 0.54	0.03 ± 0.03	0.32 ± 0.29	0.08 ± 0.08	0.22 ± 0.20	0.16 ± 0.14	0.47 ± 0.44
$t\bar{t}$ NF	1.03 ± 0.07	1.06 ± 0.15	0.89 ± 0.10	0.95 ± 0.12	0.73 ± 0.22	0.90 ± 0.17	1.01 ± 0.13
W+jets NF	0.76 ± 0.08	0.78 ± 0.08	0.87 ± 0.07	0.85 ± 0.06	0.97 ± 0.12	0.94 ± 0.13	0.91 ± 0.07
Single top NF	1.07 ± 0.30	1.30 ± 0.45	1.26 ± 0.31	0.97 ± 0.28	–	1.36 ± 0.36	1.02 ± 0.32
$t\bar{t}+W/Z$ NF	1.43 ± 0.21	1.39 ± 0.22	1.40 ± 0.21	1.30 ± 0.23	–	1.47 ± 0.22	1.42 ± 0.21
p_0 (σ)	0.012 (2.2)	0.26 (0.6)	0.004 (2.6)	0.40 (0.3)	0.50 (0)	0.0004 (3.3)	0.09 (1.3)
$N^{\text{limit}}_{\text{non-SM}}$ exp. (95% CL)	$12.9^{+5.5}_{-3.8}$	$5.5^{+2.8}_{-1.1}$	$12.4^{+5.4}_{-3.7}$	$9.0^{+4.2}_{-2.7}$	$7.3^{+3.5}_{-2.2}$	$11.5^{+5.0}_{-3.4}$	$9.9^{+4.6}_{-2.9}$
$N^{\text{limit}}_{\text{non-SM}}$ obs. (95% CL)	26.0	7.2	27.5	9.9	7.2	28.3	15.6









stop 1L - more details

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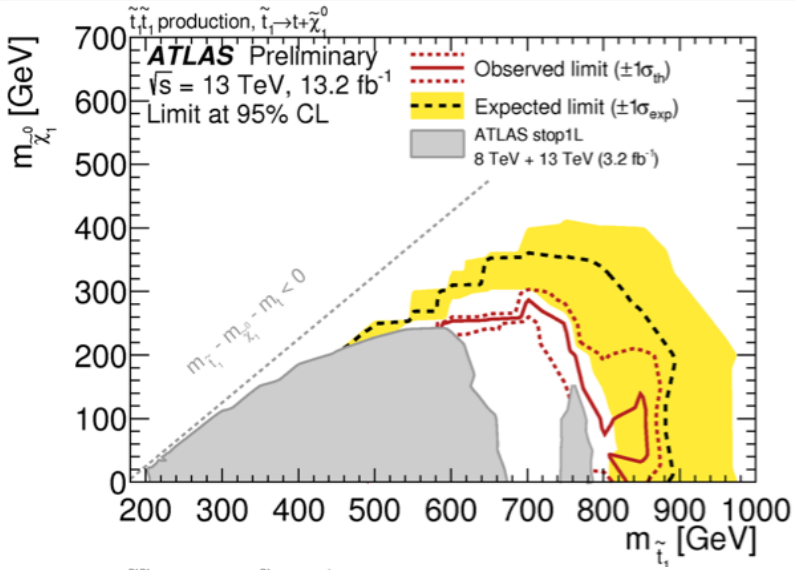

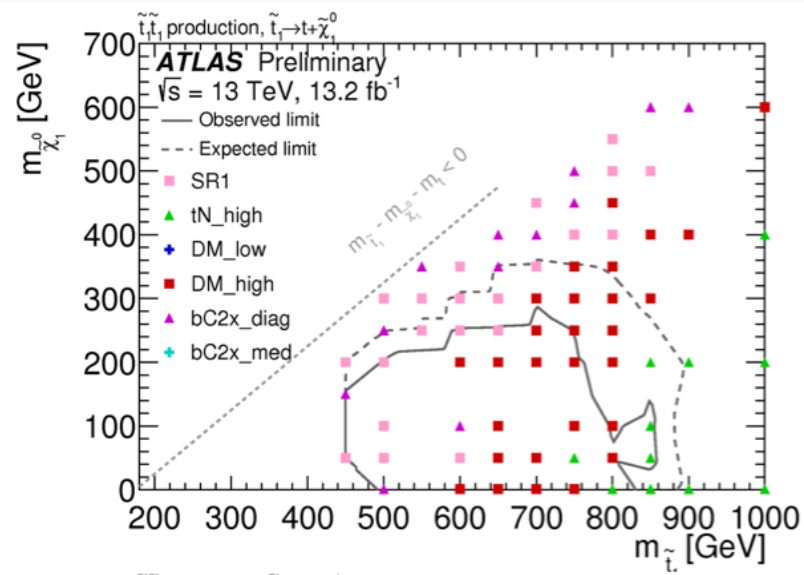

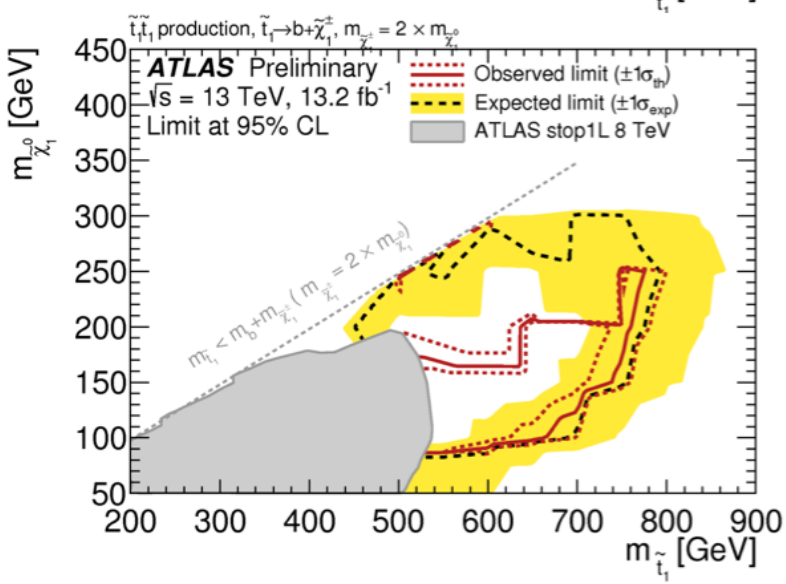

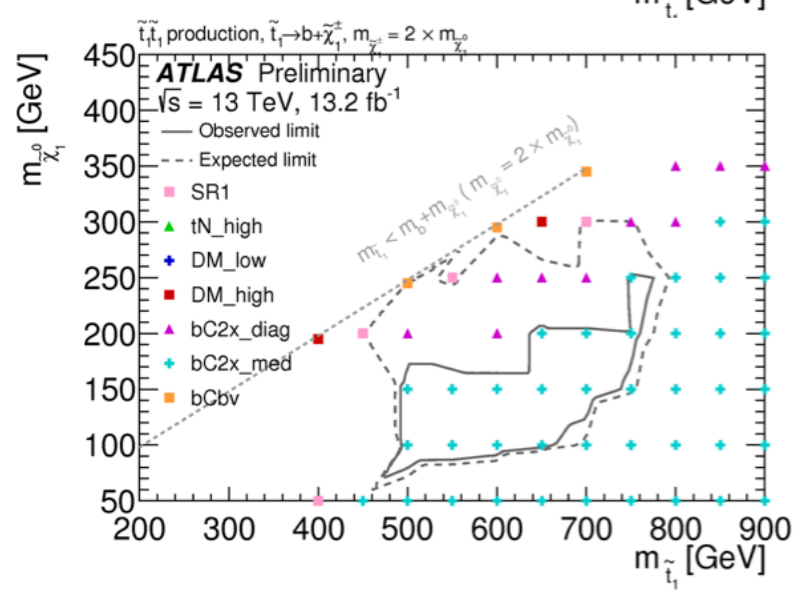

Other stop results

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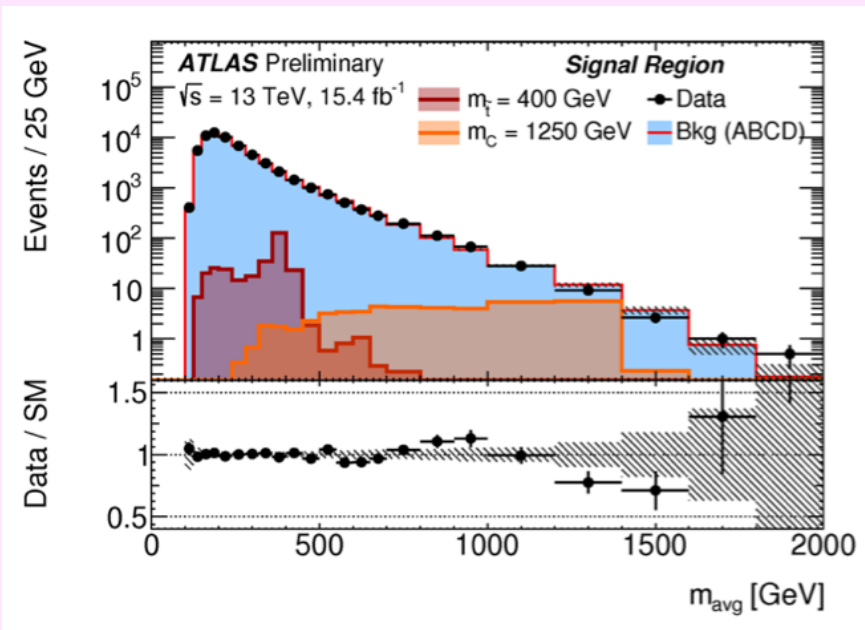
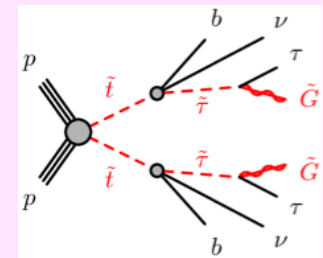
RPV stop

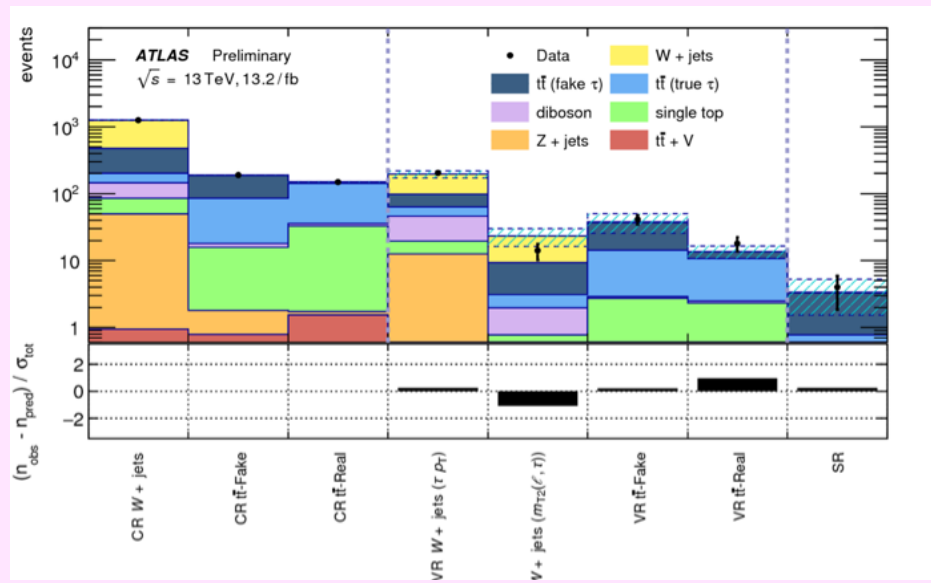
- Look for **stop decay into a pair of light quarks**
- Reconstruct two **di-jet resonances** of roughly the same mass
- Background: **multijet production**, estimated from data with a **data-driven ABCD method**
- stop masses up to ~ 500 GeV are excluded (assuming $\tilde{t} \longrightarrow qq$ with BR = 1)



stop to stau

- Require one lepton, hadronic tau, one b-jet, EMT's
- Selection based on $m_{T2}(l,\tau)$
- Main backgorund from semileptonic top pair production with a fake tau
- Stop up to 850 GeV excluded (assuming all BR = 1)





On-shell Z: comparing 3.2 Vs 14.7 fb^{-1}

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Bacground	3.2 fb^{-1} (ATLAS-CONF-2015-082)	3.2 fb^{-1} scaled to 14.7 fb^{-1}	14.7 fb^{-1} (ATLAS-CONF-2016-098)
Flavour-symm	5.1(2.0)	23.4 (9.2)	33.2 (3.9)
Z/gam + jets	1.9 (0.8)	8.7 (3.7)	3.1 (2.8)
WZ/ZZ	2.9 (0.8)	13.3 (3.7)	14.2 (7.7)
total	10.3 (2.3)	47.3 (10.5)	53.5 (9.3)