Recent results on Higgs studies at ATLAS and CMS

Why m_H=126 GeV ?

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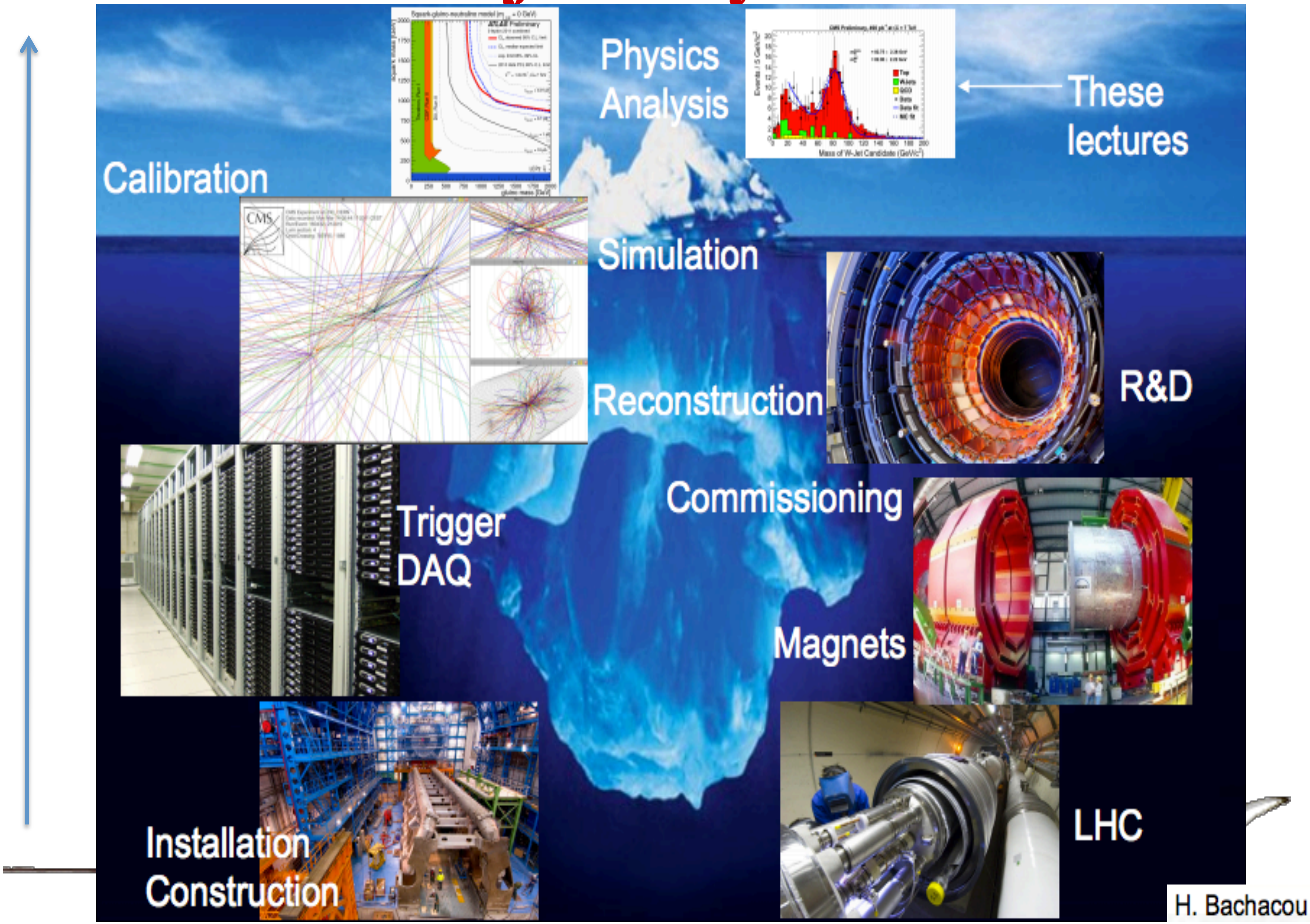
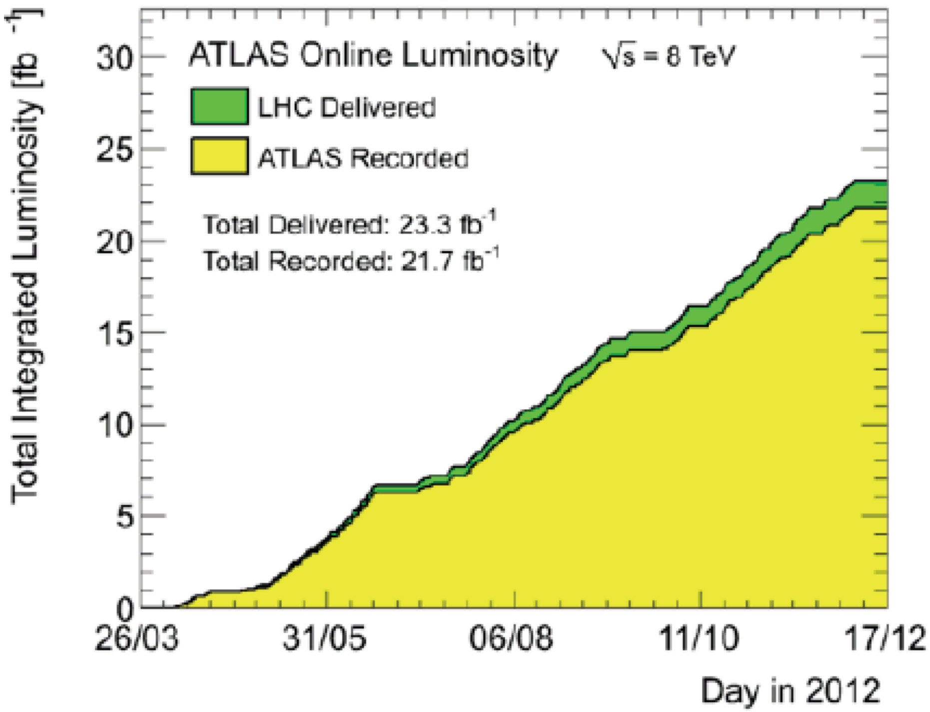
The SM: a long journey

- 54 Yang & Mills
- 61 Glashow
- 64 Borut, Englert, Higgs et al
- 67-68 Weinberg and Salam
- 70 ‘t Hooft
- 73 Gargamelle : discovery of the week neutral current
- 83: W and Z discovery
- 89-2000 LEP: the triumph of the SM
- 95: top quark discovery
- 2012: discovery of a Higgs like boson

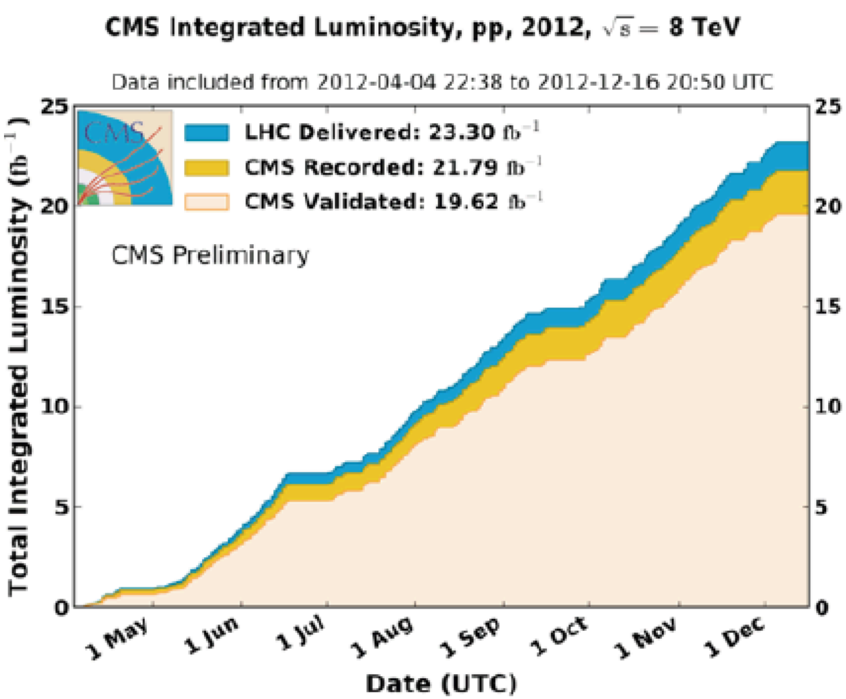
..and the LHC, Atlas and CMS long journey



LHC in 2010-2011-2012



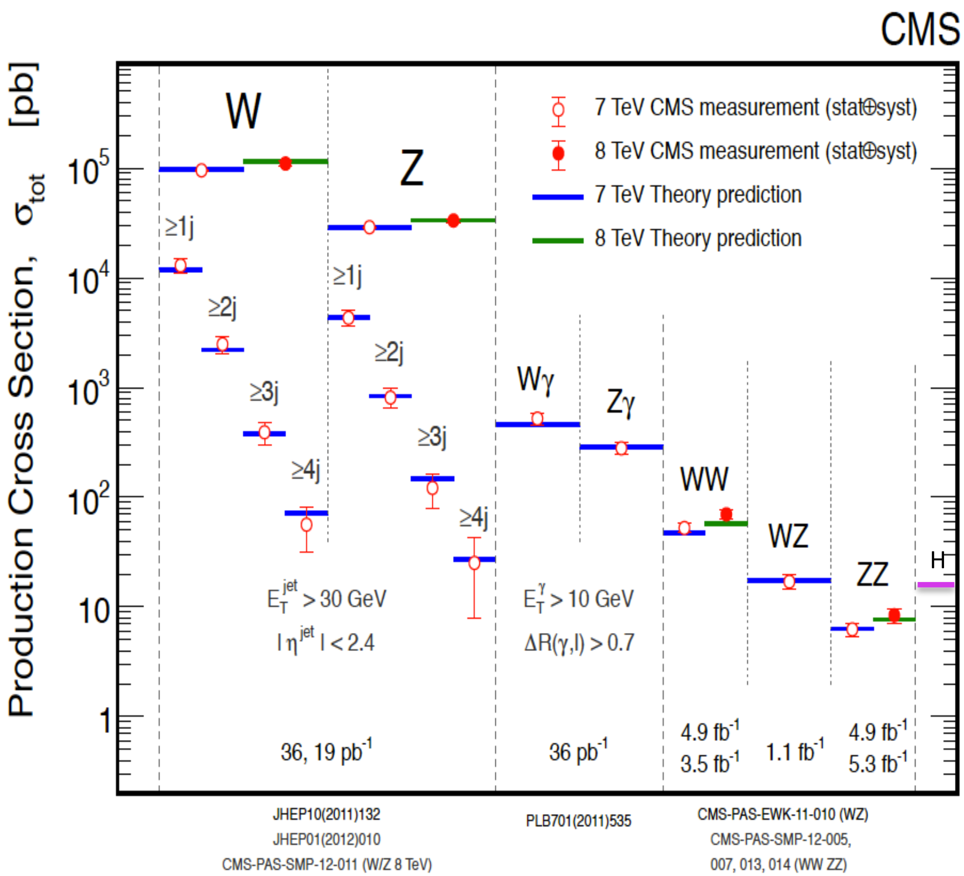
Simply magnificent !!!



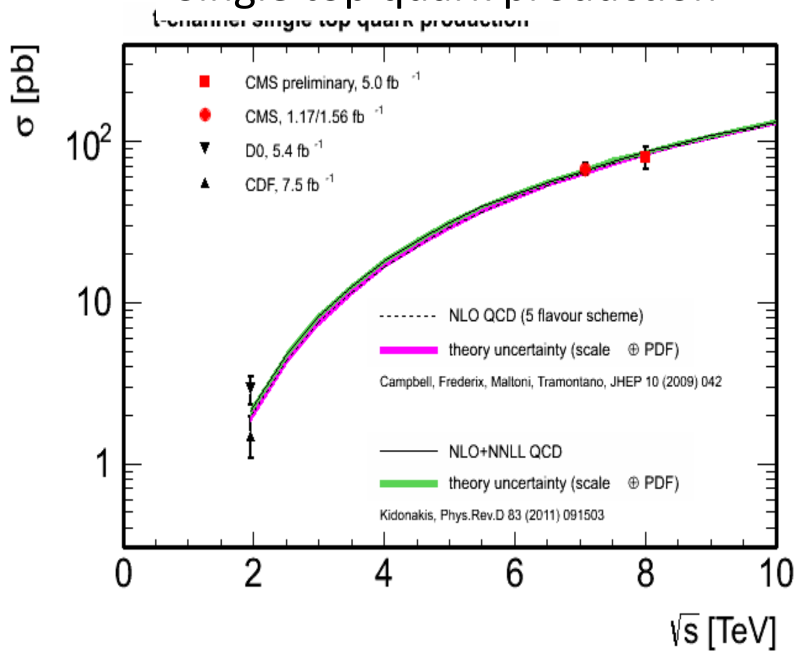
Peak Lumi 7 x 10^{33}
Run can last up 24 hours

L = 0.07 fb^{-1}	in 2010	@ 7 TeV
L = 5.6 fb^{-1}	in 2011	@ 7 TeV
L = 23.3 fb^{-1}	in 2012	@ 8 TeV

Precise SM measurements



Single top quark production



Good understanding of the detector + accurate theory predictions

→ Precise measurements of the SM processes over many orders of magnitude

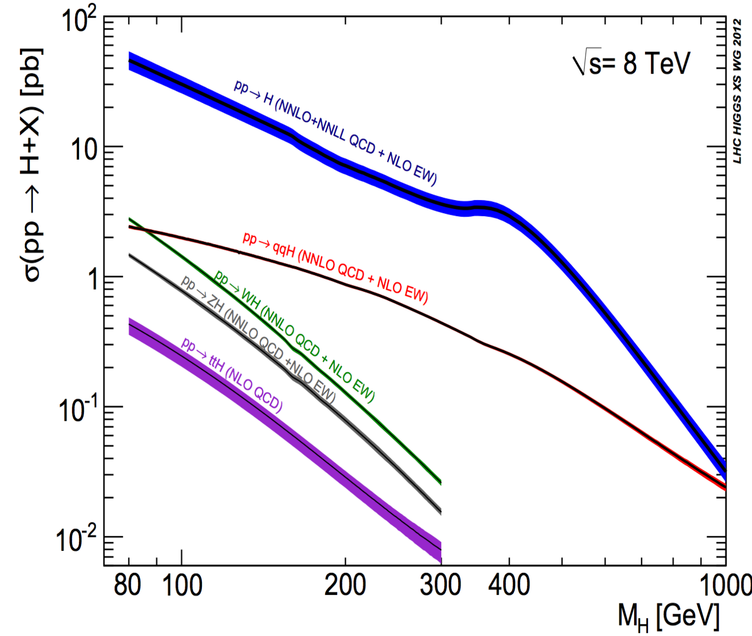
→ Good knowledge of the background to Higgs analyses

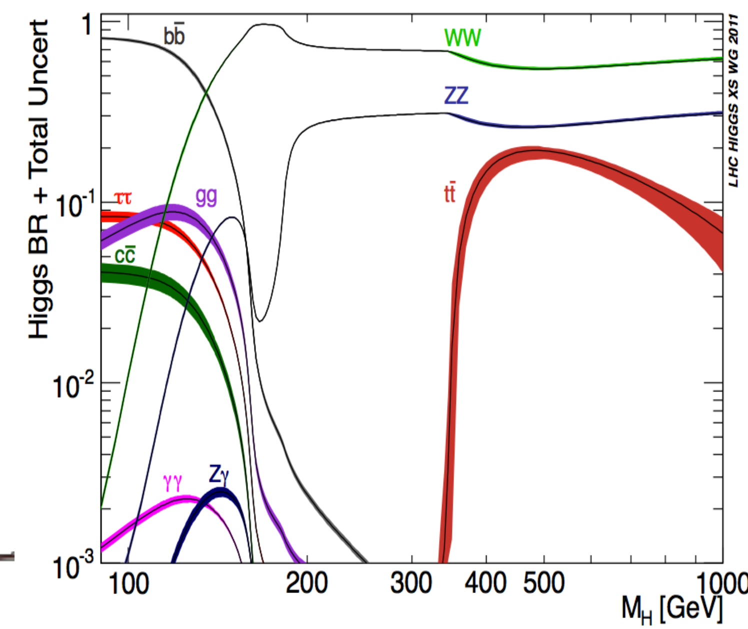
The LHC Higgs Cross Section WG

- Created at the end of 2009, the exact day the LHC delivered the first pp interactions has provided from “day 0” the best theory predictions on XS, BR and their uncertainties

- Experiments are coherently using the **COMMON INPUTS** based on the interaction with the TH community. This facilitates the comparison and the combination of the individual results

“Yellow Reports”: YR1 (inclusive XS),
YR2 (differential XS)
YR3 (properties)



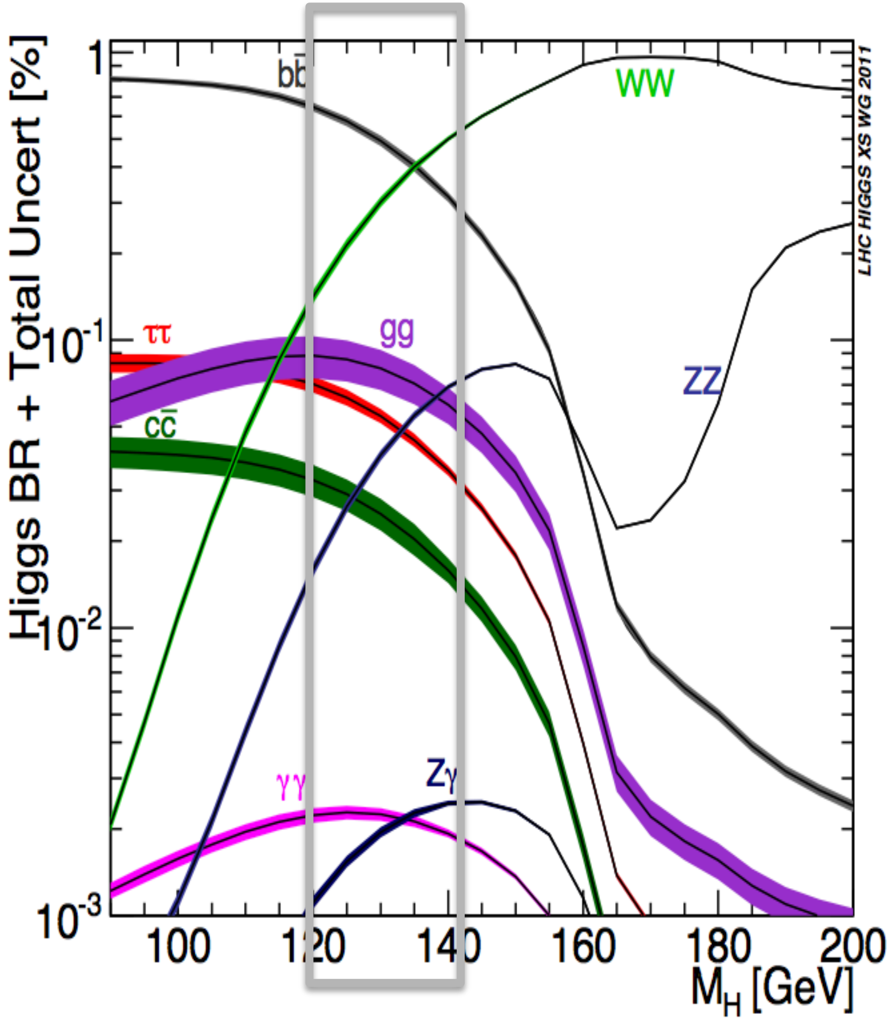


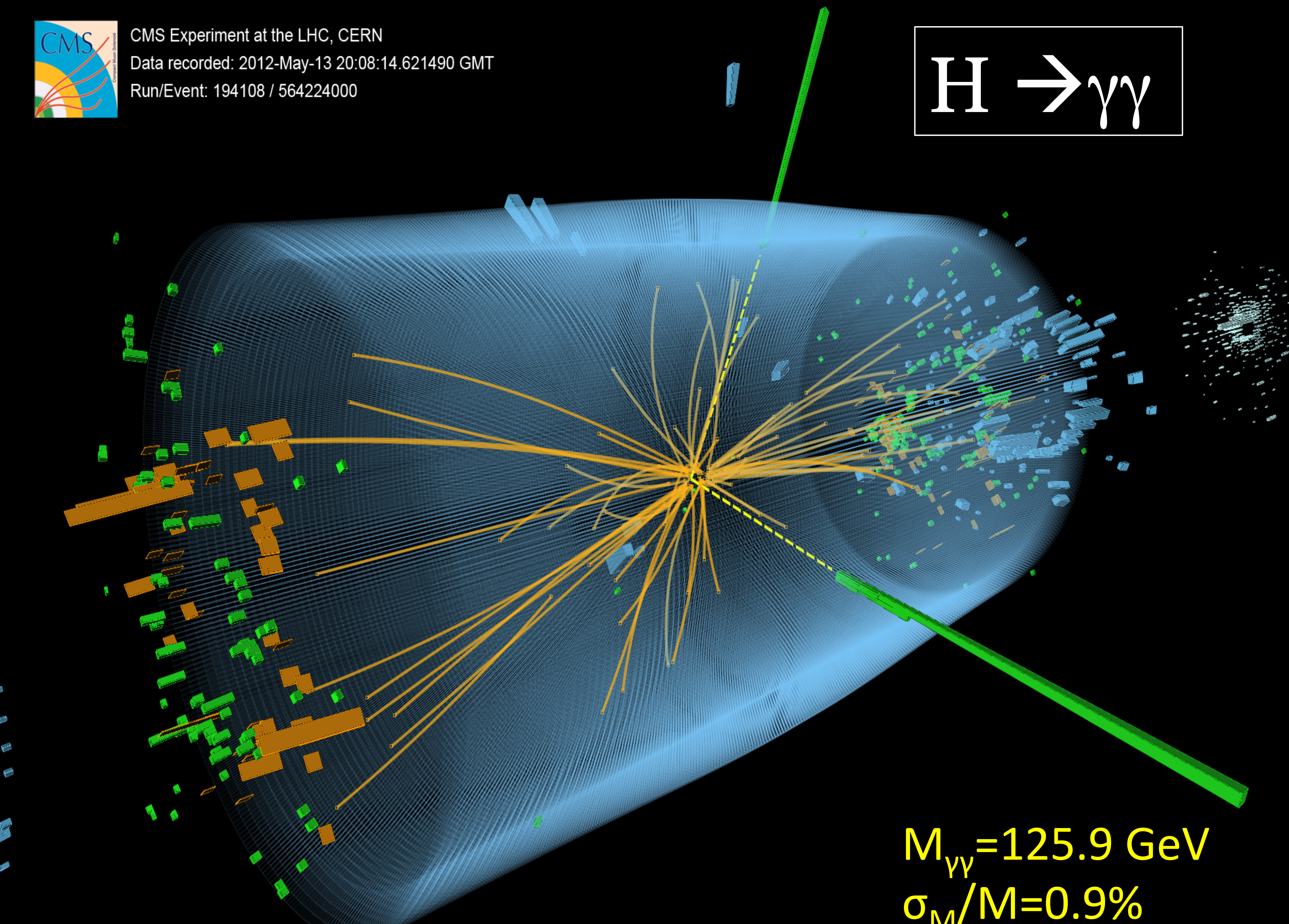
The channels at LHC

5 decay modes exploited

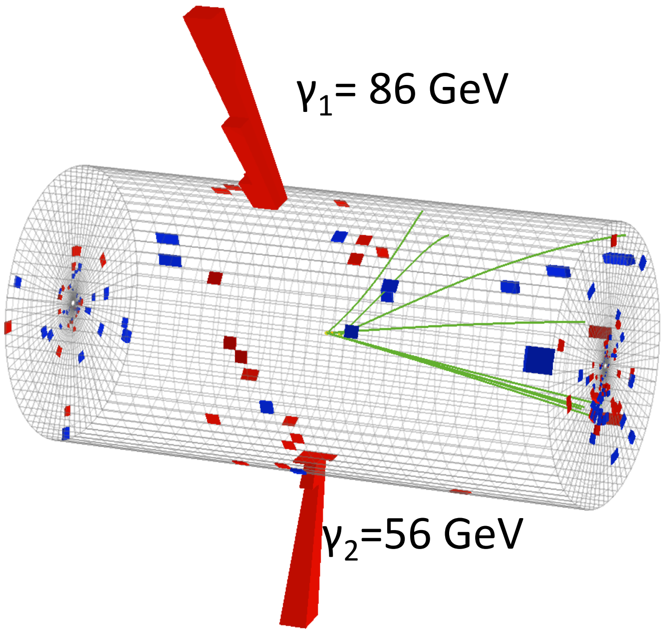
	Exp Sig @125.7	σ_M/M
• bb	2.2σ	10%
• ττ	2.7σ	10%
• WW	5.1σ	20%
• ZZ	7.1σ	1-2%
• γγ	4.2σ	1-2%

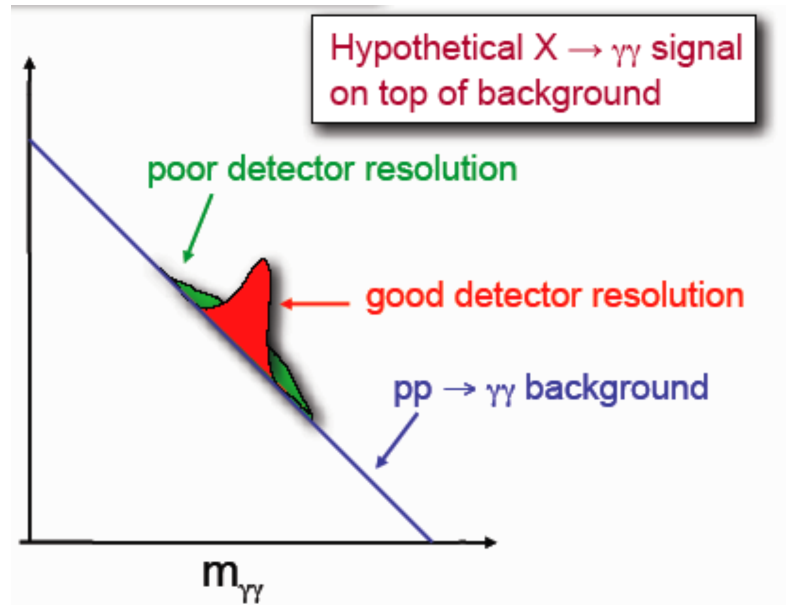
- and searches in Zγ, μμ




CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H →γγ
$M_{\gamma\gamma}$=125.9 GeV
σ_M/M=0.9%

H → γγ

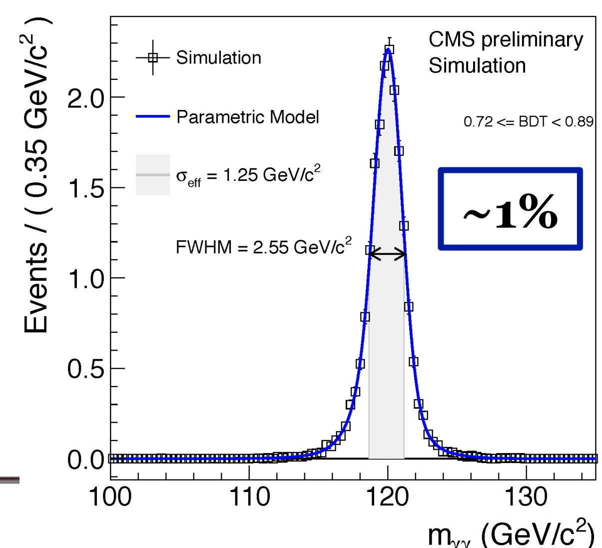




Signature: 2 energetic, isolated γ, in a narrow mass peak on top of a steeply falling spectrum

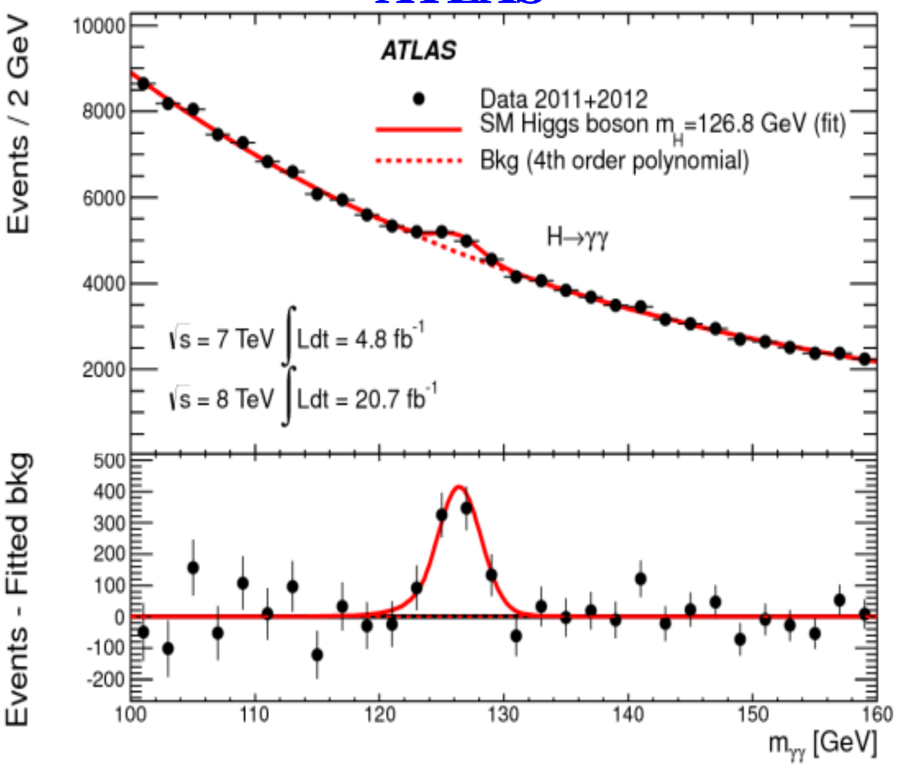
Relevant aspects:

- Photon identification/ background rejection
- Di-photon mass spectrum
- Background estimation
- Primary vertex determination (pile-up!)

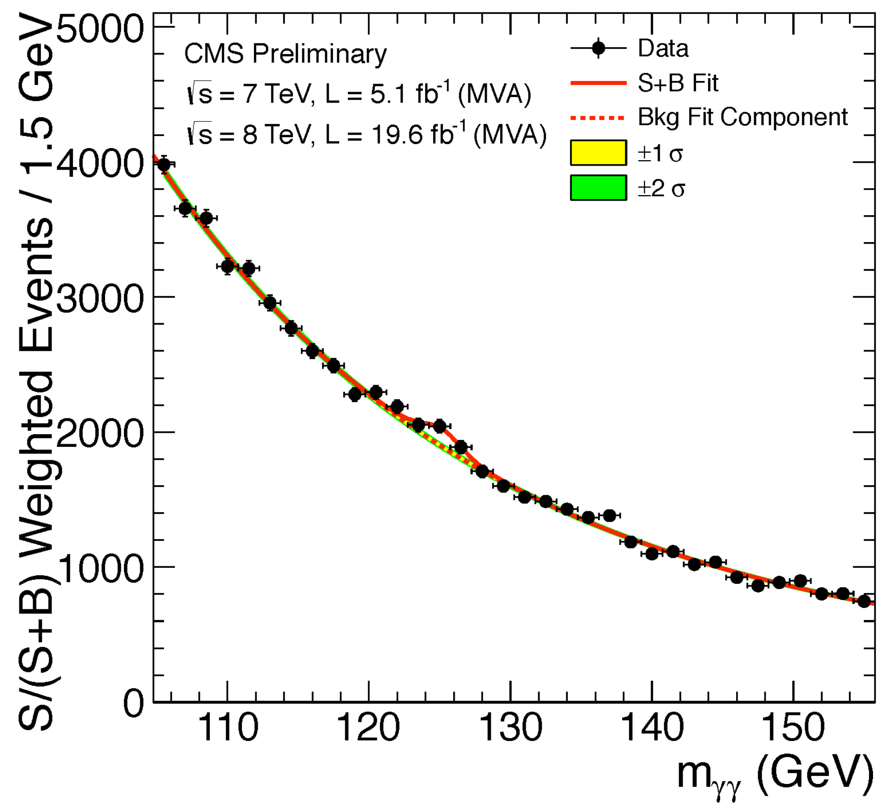


The mass distribution

ATLAS

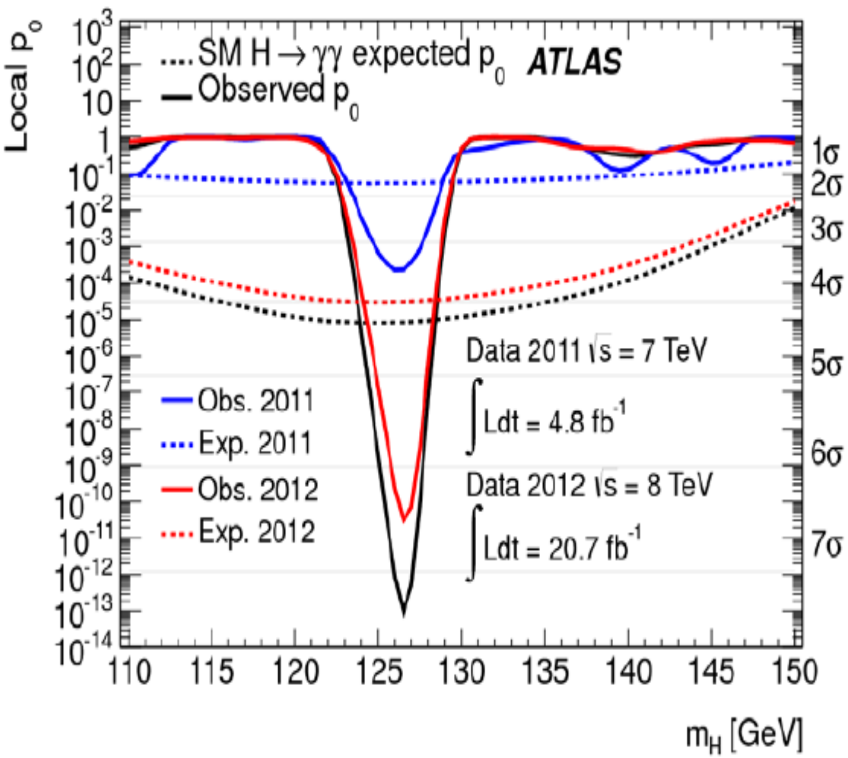


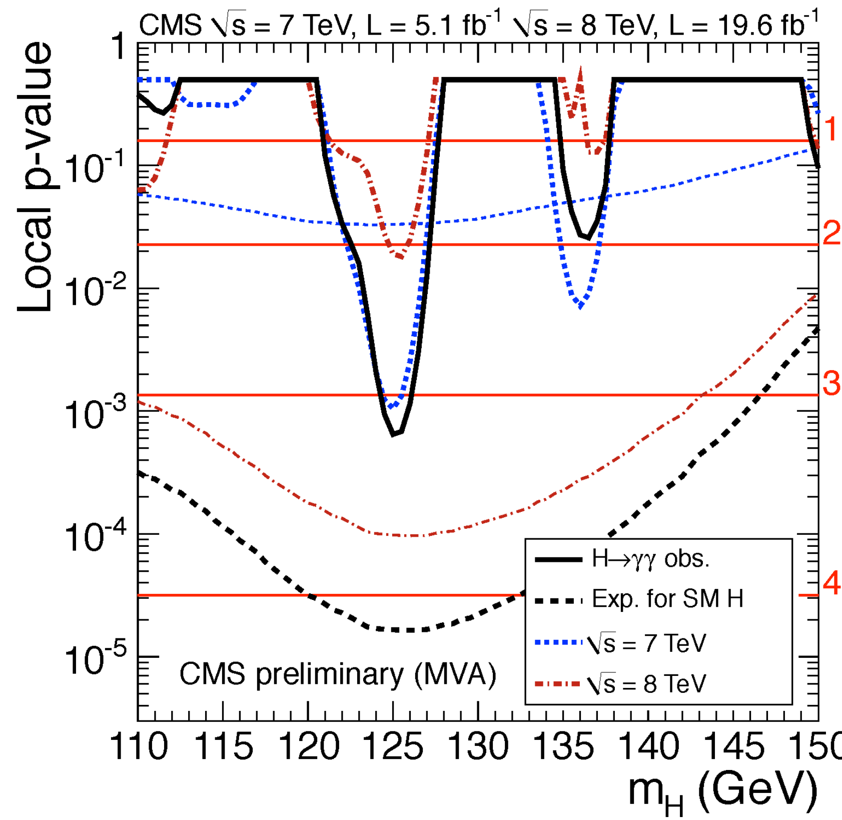
CMS



High level analysis very, very similar between Atlas and CMS:
– Categorization by S/B, resolution and p_T (ATLAS using cuts, CMS using a BDT)
– Similar di-jet categories with O(70%) purity
– Mass fit with polynomial background chosen to minimize the bias on the signal

Compatibility with the background only hypthesis

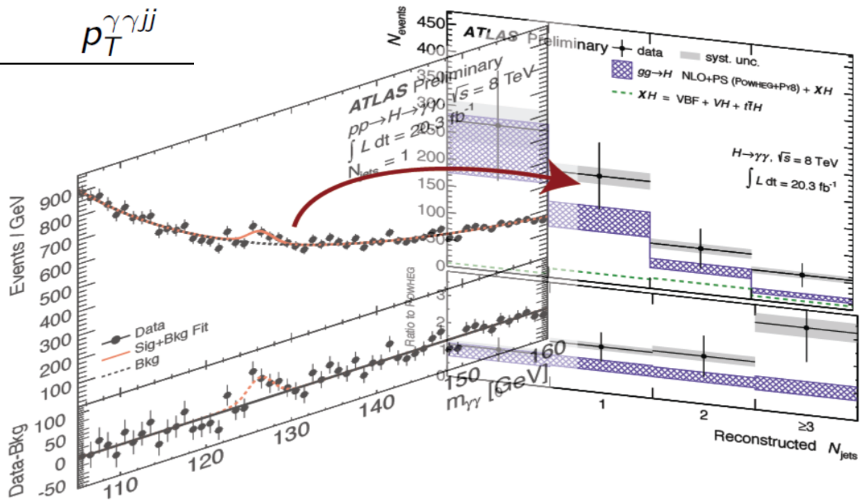


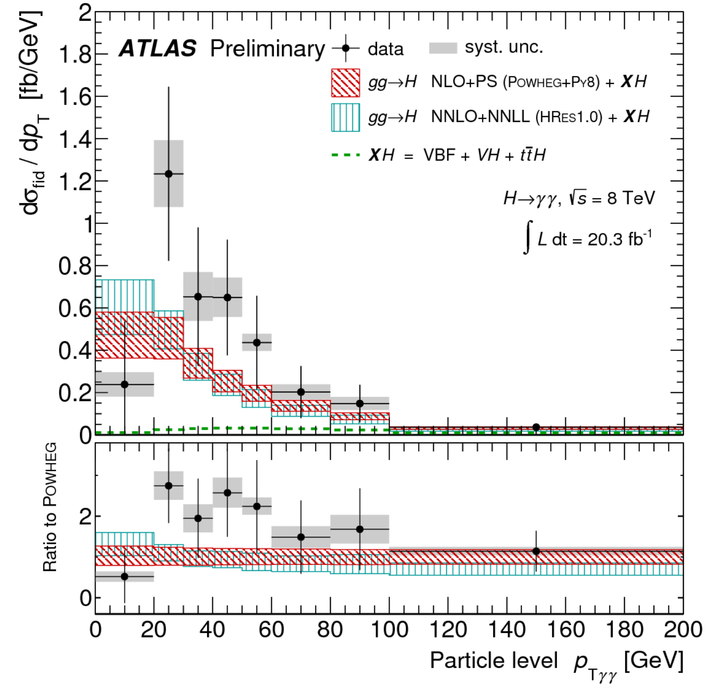


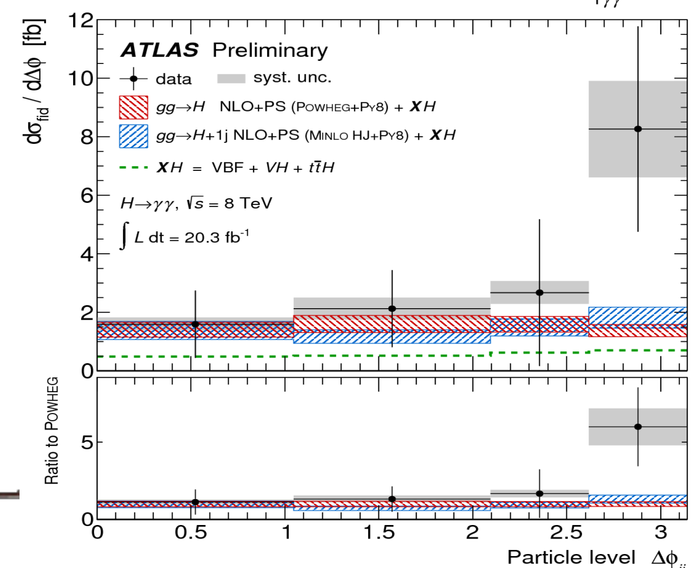
	ATLAS	CMS
• Largest excess around	127 GeV	125 GeV
• Significance	7.4σ (4.3σ expected)	3.2σ (4.2σ expected)
• Signal Strenght	μ = 1.57±0.24(stat) ±0.22(syst)	0.78 ±0.27

ATLAS: Differential XS

	Variable
Inclusive	$p_T^{\gamma\gamma}$
	$\lvert y^{\gamma\gamma} \rvert$
	$\lvert \cos\theta^* \rvert$
	N_{jets}
	p_T^{j1}
2-jets	$\Delta\varphi_{jj}$
	$p_T^{\gamma\gamma jj}$

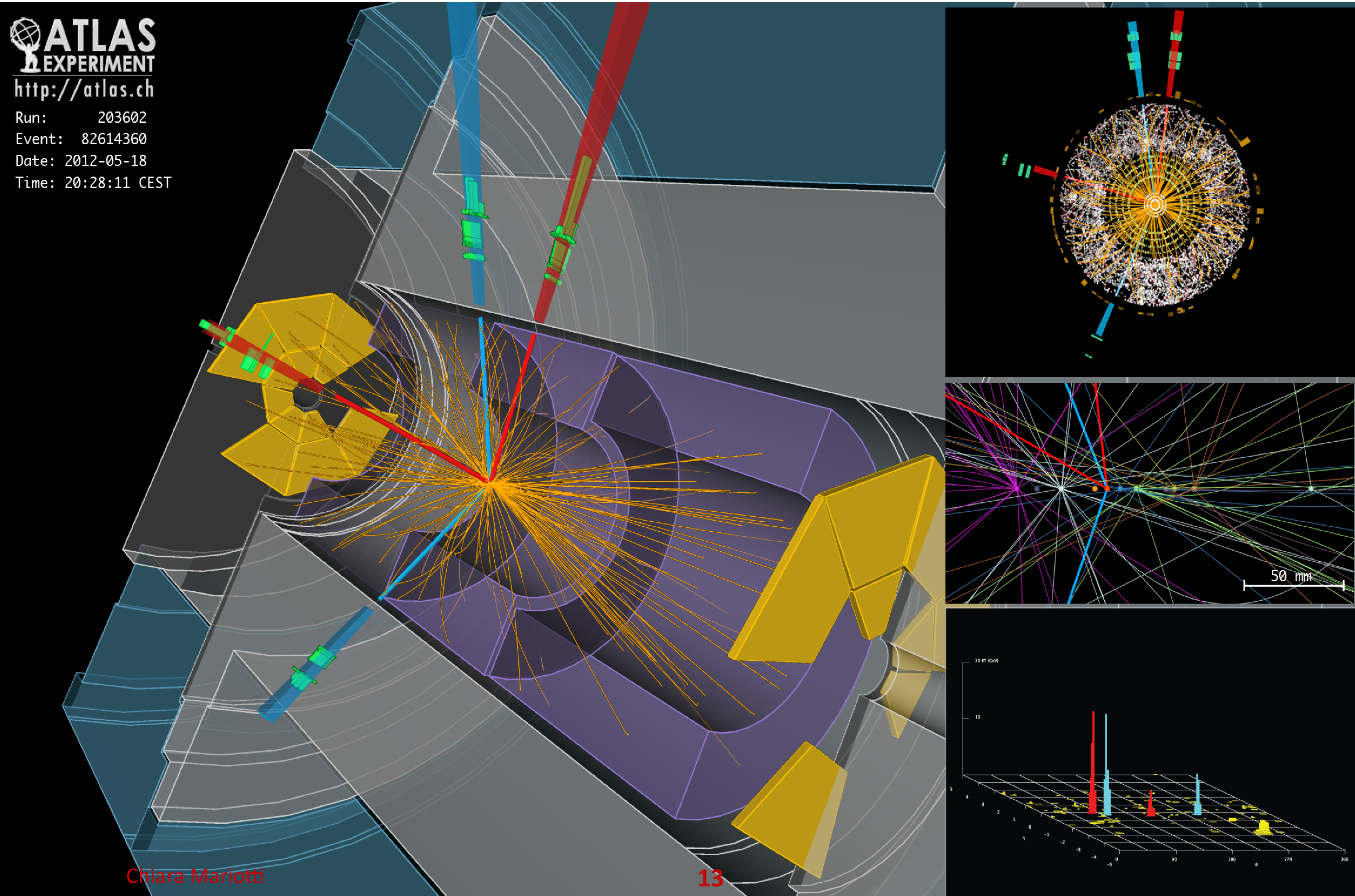






- Bin events in variables of interest
- Background estimations from the $m_{\gamma\gamma}$ side-band fit in each bin
- Unfold the reconstructed distributions to truth distributions (→ differential cross-sections)

The golden channel

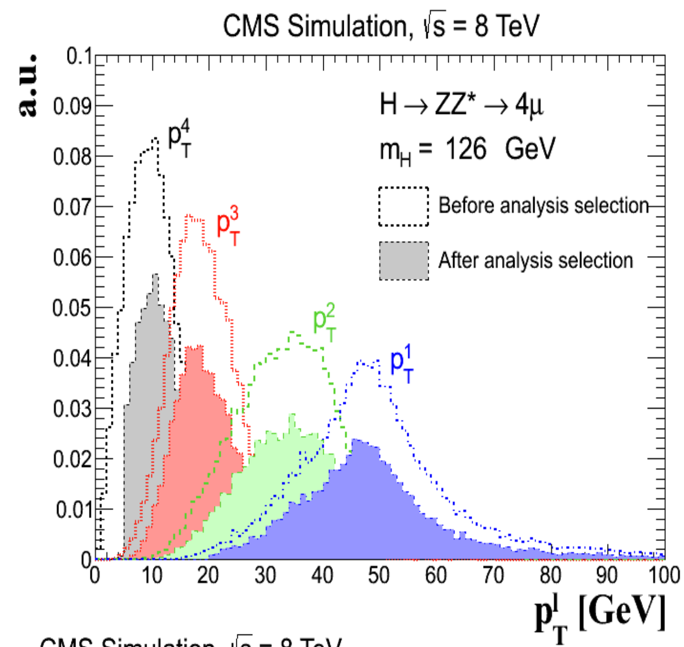


$H \rightarrow ZZ \rightarrow 4l$

The final states considered are 4μ, 4e, $2e2\mu$

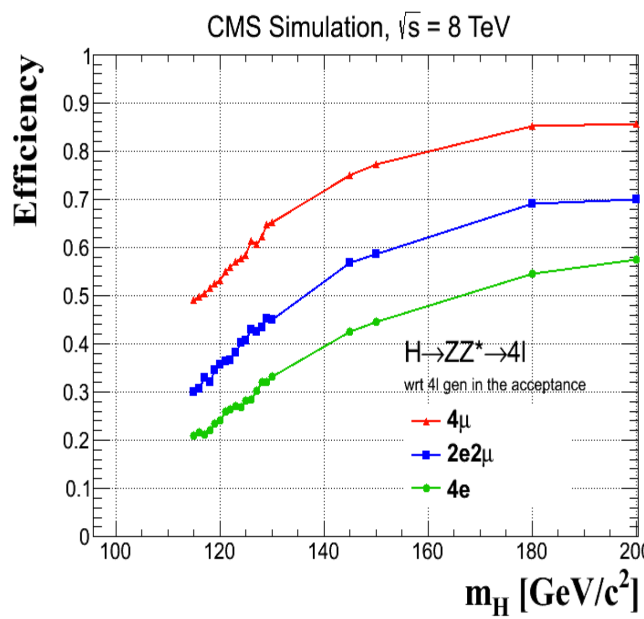
Very clean final state:

- 4 leptons of high p_T,
- isolated
- coming from the primary vertex

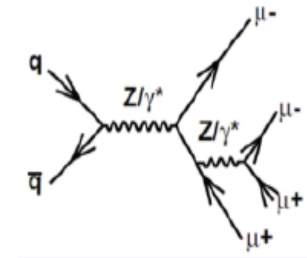


Very tiny cross section →
thus highest efficiency must be conserved

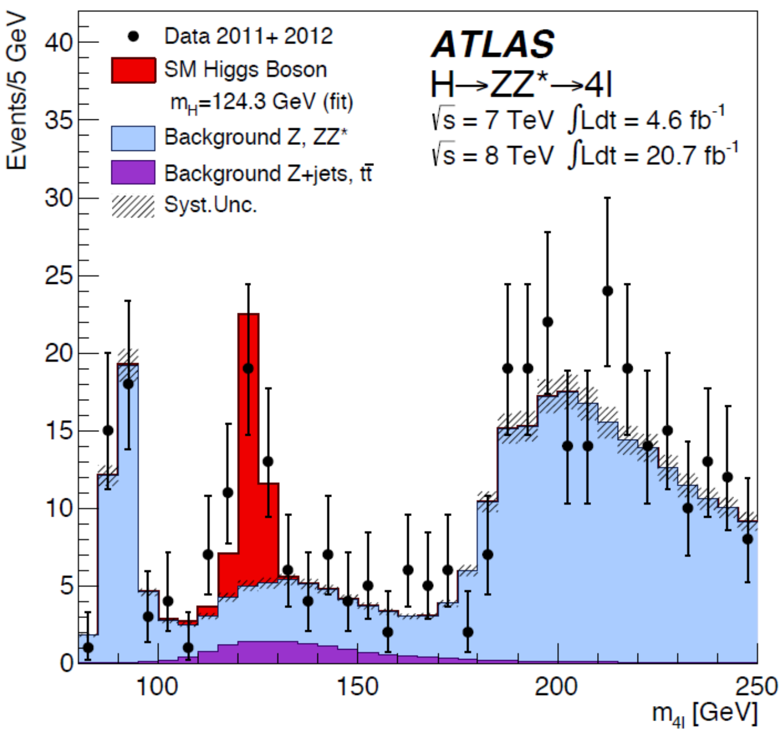
huge effort on lepton ID and efficiency
2l / 4l mass resolution



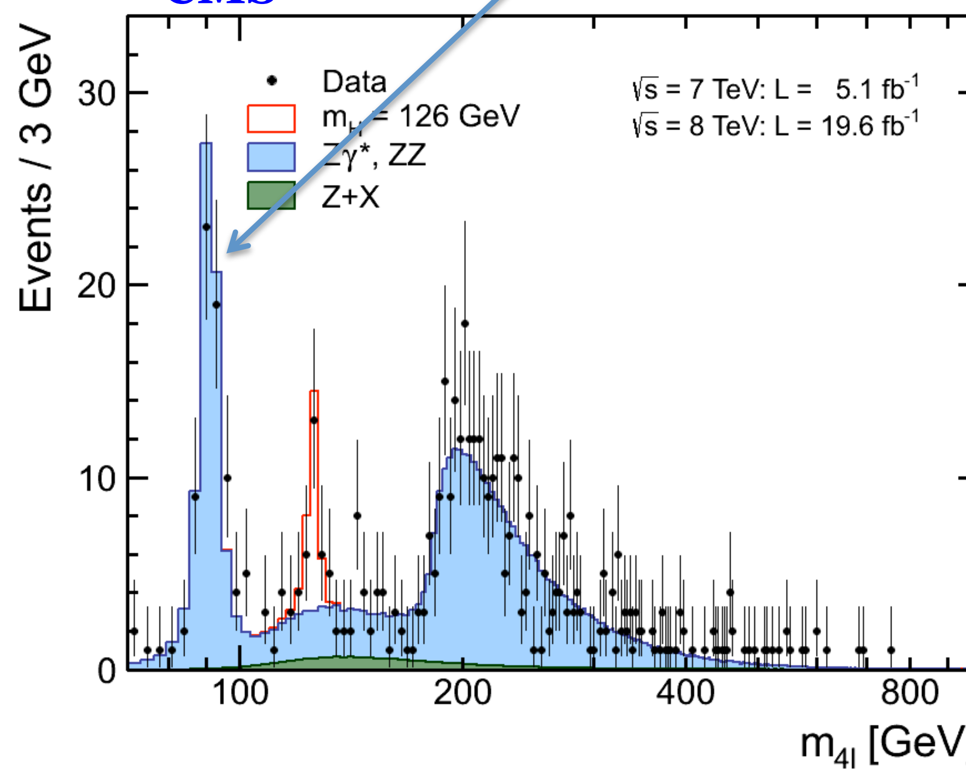
pp → 4l



ATLAS



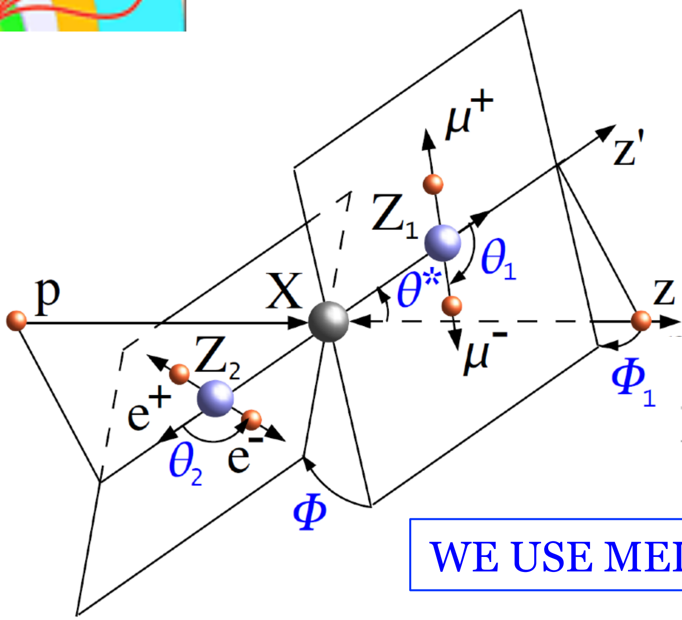
CMS



Significance 6.6 σ (4.4σ expected)

Significance 6.7σ (7.1σ expected)

Kinematic Discriminant

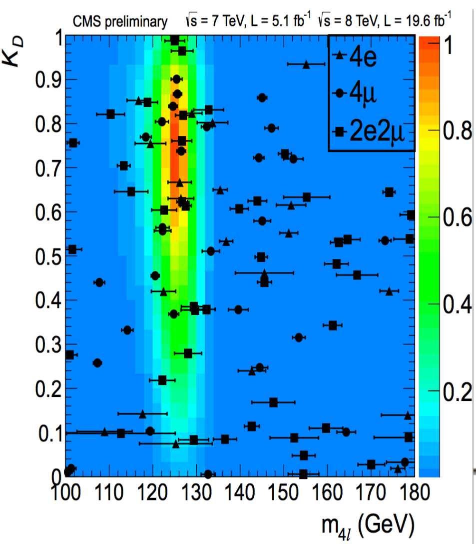


Matrix **E**lement **L**ikelihood **A**nalysis:
uses kinematic inputs for
signal to background discrimination
$\{m_1, m_2, \theta_1, \theta_2, \theta^*, \Phi, \Phi_1\}$

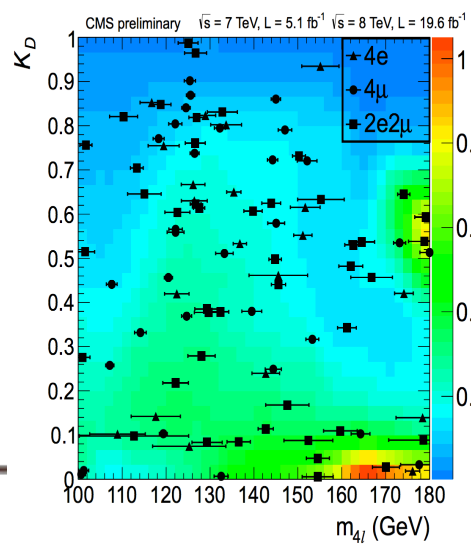
$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

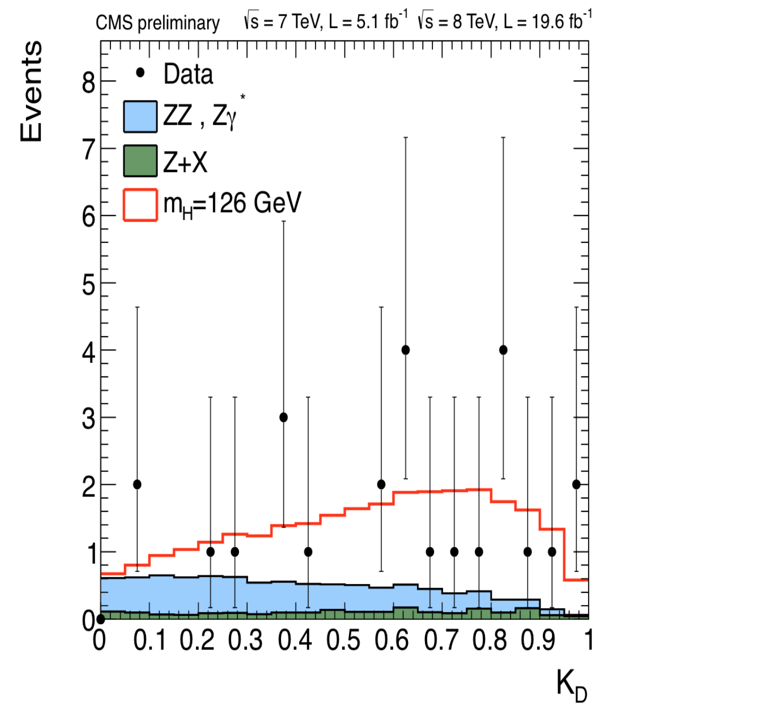
WE USE MELA IN THE FIT

SIGNAL



BACKGROUND





Kinematic Discriminant

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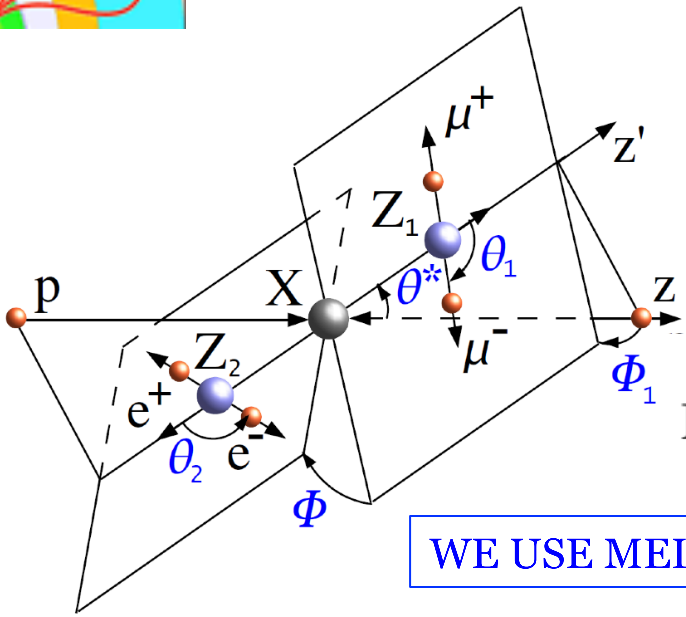
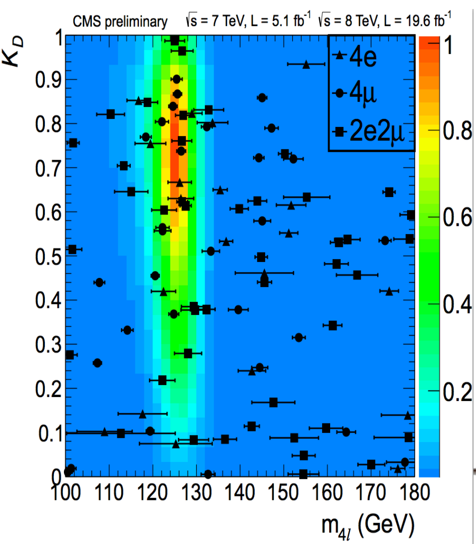


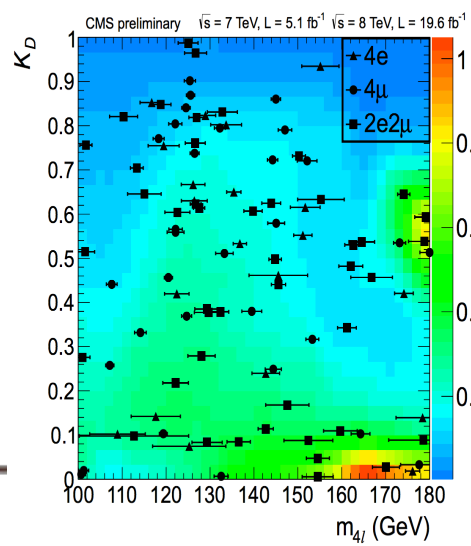
$$\mathrm{MELA} = \left[1 + \frac{\mathcal{P}_{\mathrm{bkg}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}{\mathcal{P}_{\mathrm{sig}}(m_1, m_2, \theta_1, \theta_2, \Phi, \theta^*, \Phi_1 | m_{4\ell})}\right]^{-1}$$

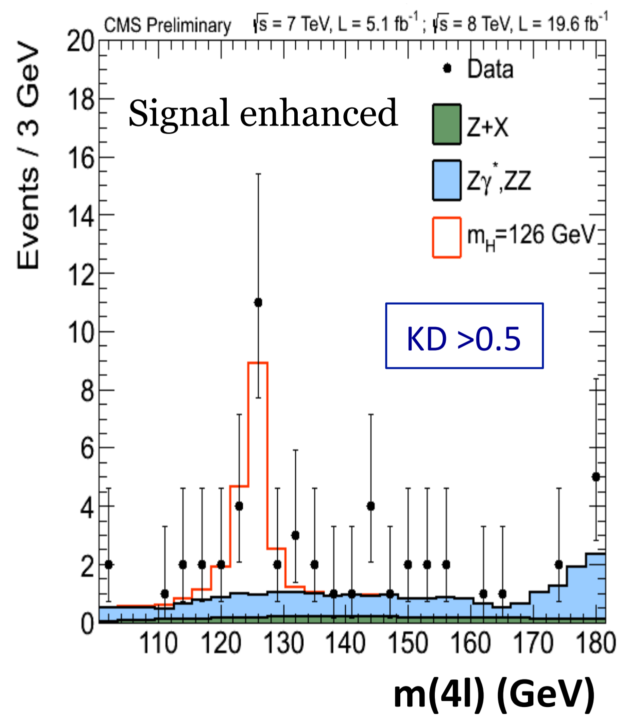
WE USE MELA IN THE FIT

SIGNAL



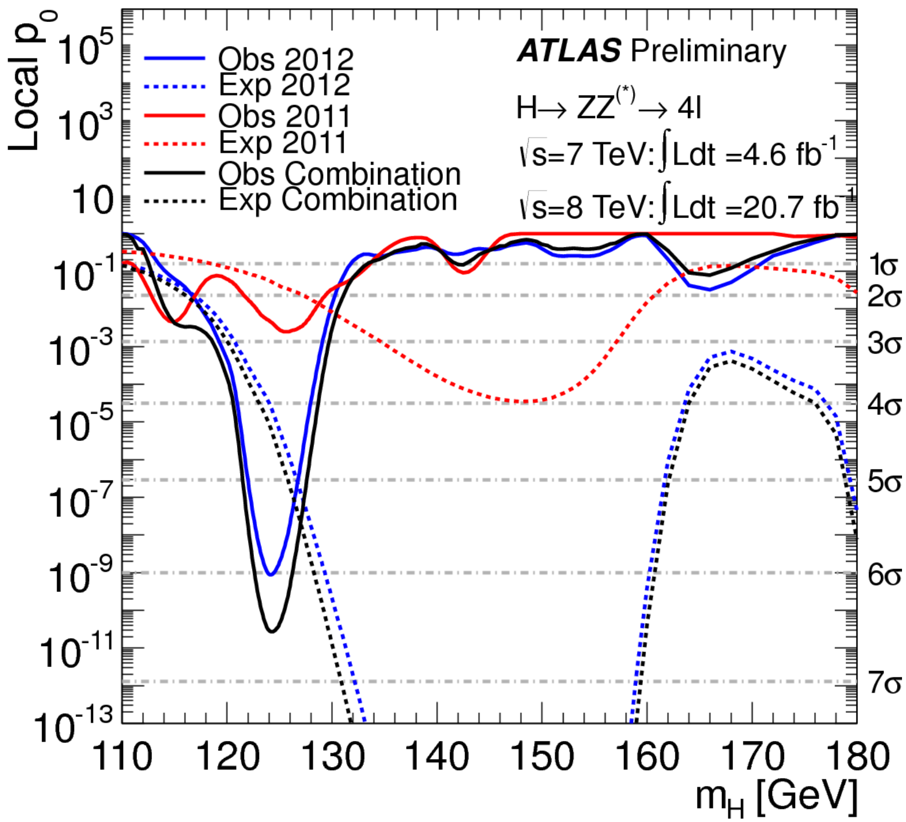
BACKGROUND





Results

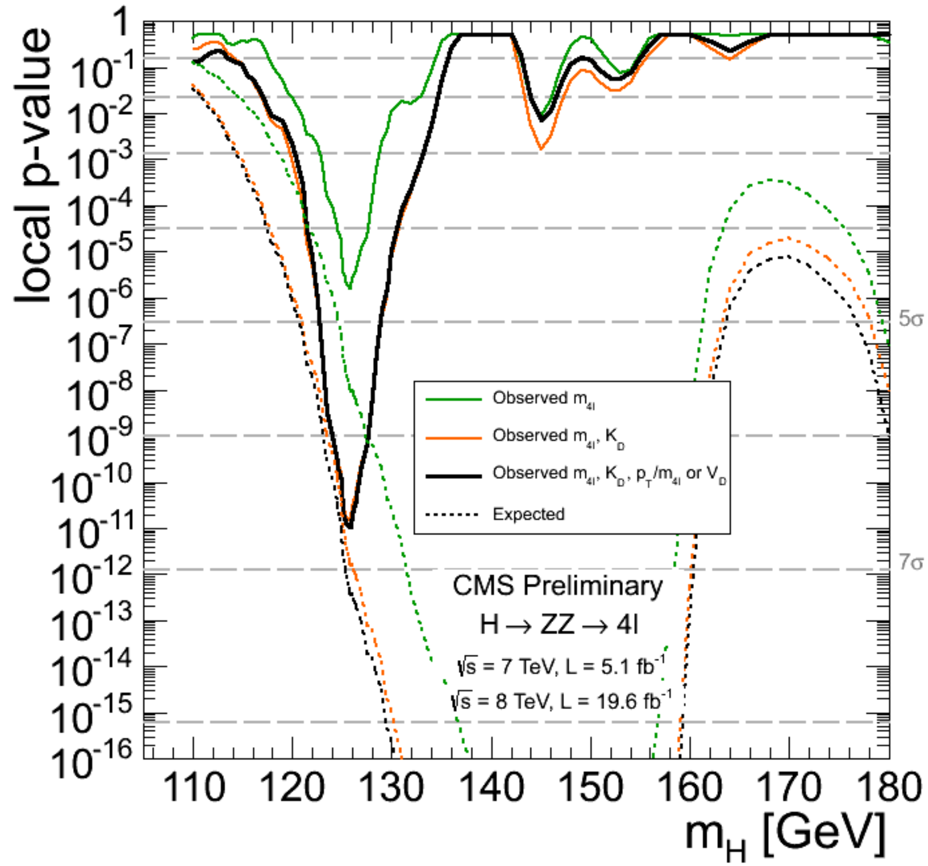
ATLAS



p-value	Expected:	4.4 σ
	Observed:	**6.6 σ**

σ/σ_{SM} @ 124.3 GeV = 1.7 +0.5-0.4

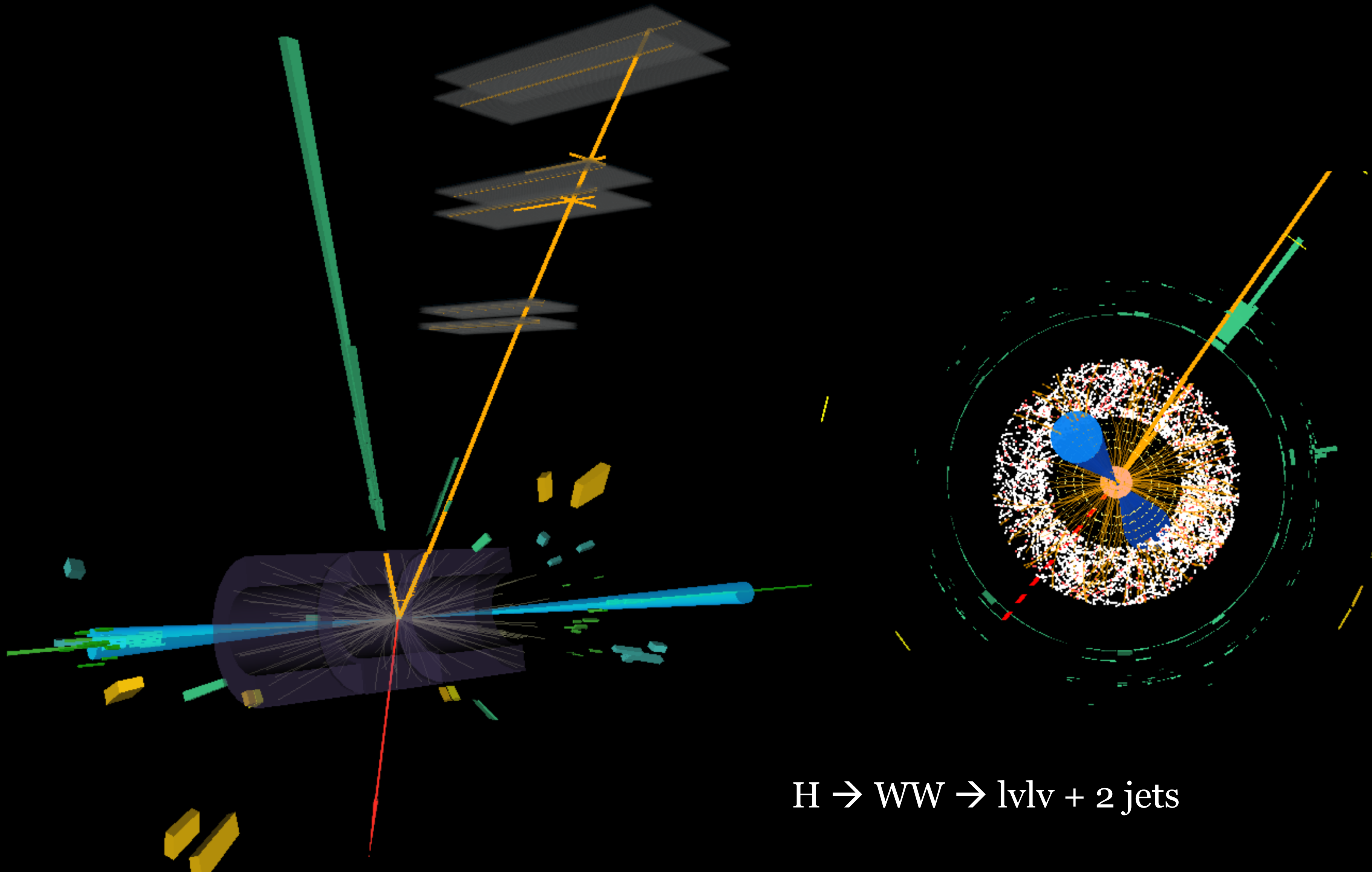
CMS



p-value	Expected:	7.1 σ
	Observed:	**6.7 σ**

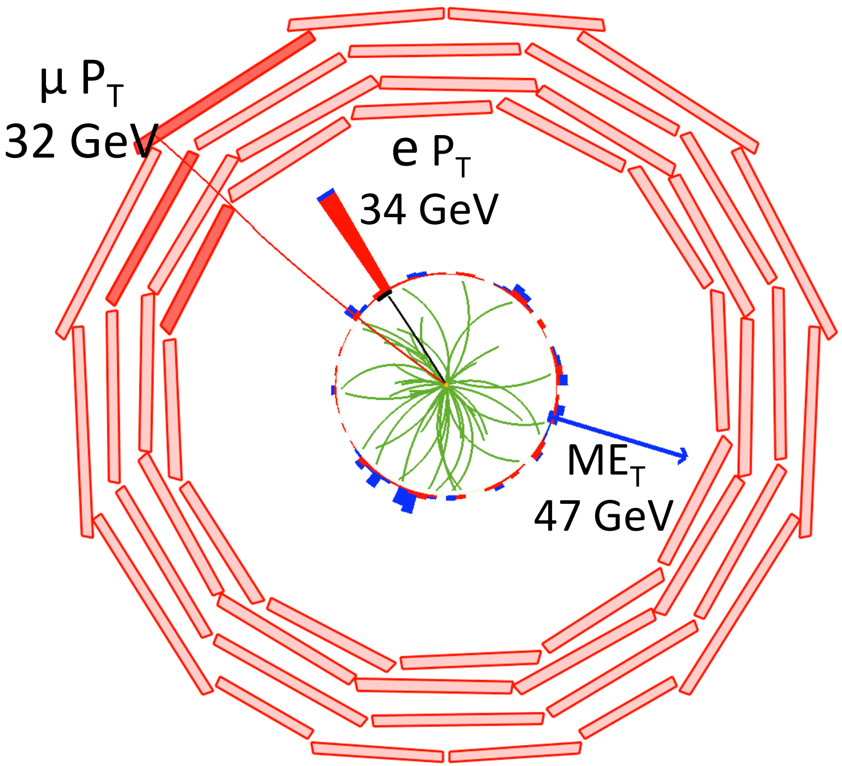
σ/σ_{SM} @ 125.7 GeV = 0.92 ± 0.28

H → WW → lνlν



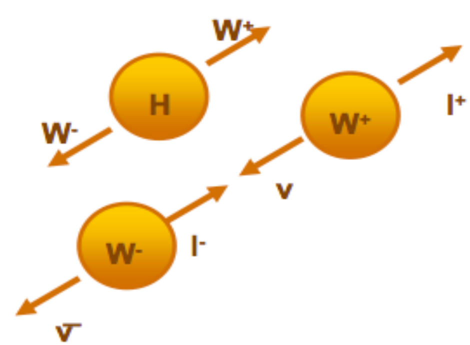
H → WW → lνlν + 2 jets

$H \rightarrow WW \rightarrow l\nu l\nu$



- Channel with very high sensitivity
- No mass reconstruction, signal extraction from event counting
- Clean signature:
  - 2 isolated, high p_T leptons with small opening angle
  - High ME_T
  - Analysis performed on exclusive jet multiplicities (0, 1, 2-jet bins)
- Analysis optimized depending on the Higgs mass hypothesis
  - p_T^l, M_{ll}, M_T, $\Delta\phi$ as discriminating variables
  - VBF selections for the 2-jets case

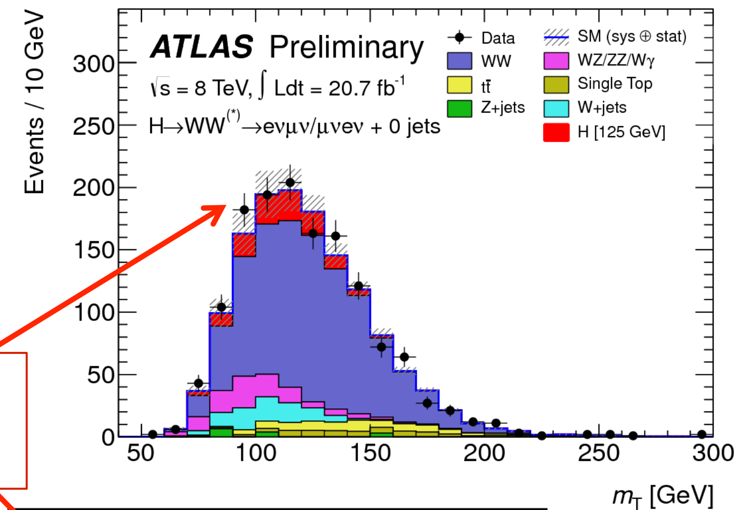
Vectors from the decay of a scalar and V-A structure of W decay lead to small leptons opening angle (especially true for on-shell Ws)



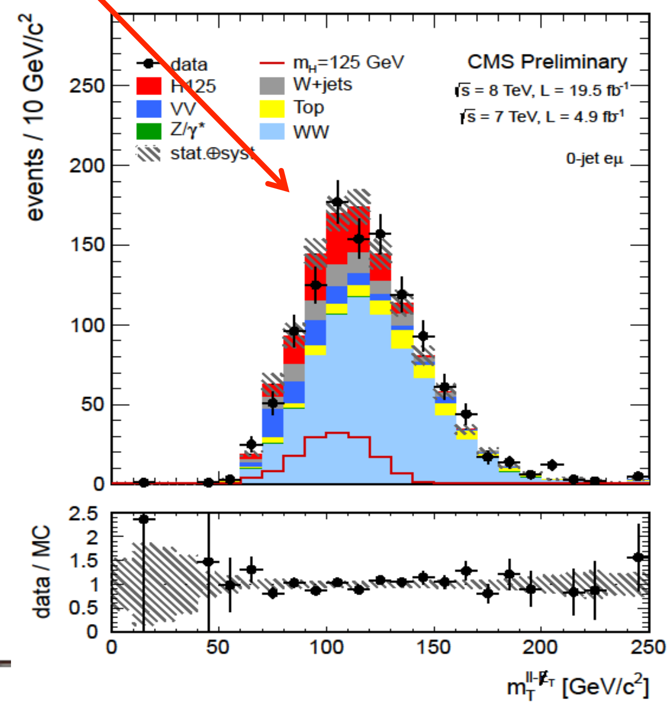
H →WW→lνlν

0-jet ee/eμ/μμ

- **Drell –Yan:**
  Suppressed by M_{ll} and ME_T cuts (pileup affect MET)
- **W+jets (with one jet faking a lepton):**
  lepton ID is important
- **Top (tt and single top):**
  b-tag veto (or additional soft muon)
- **WW:**
  M(ll), MT and Δφ

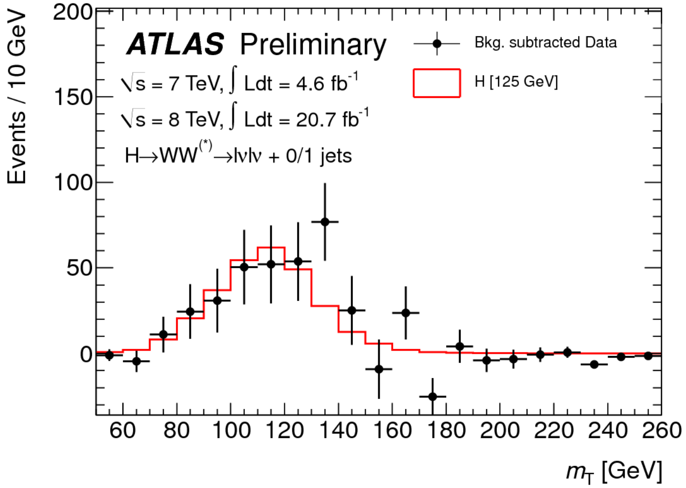


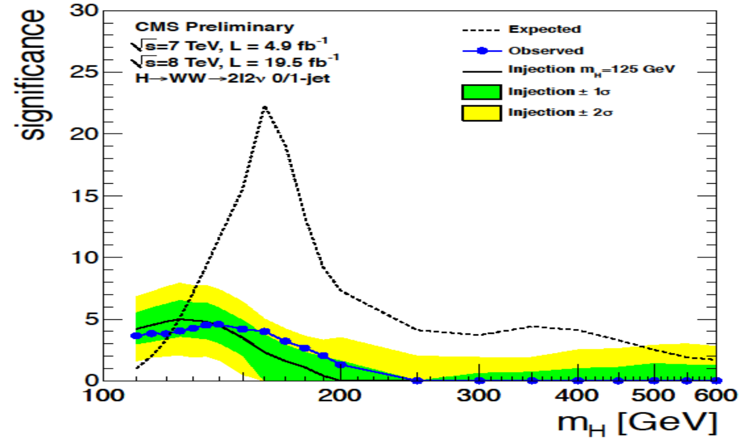
Clear excess

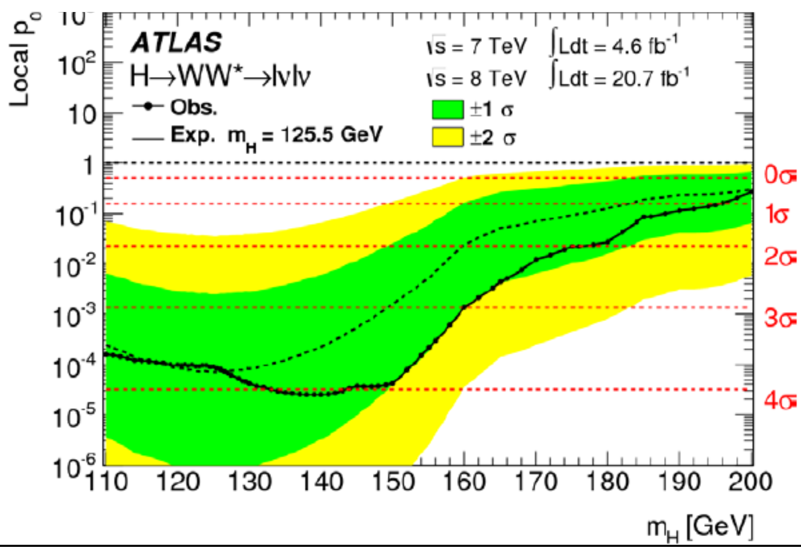


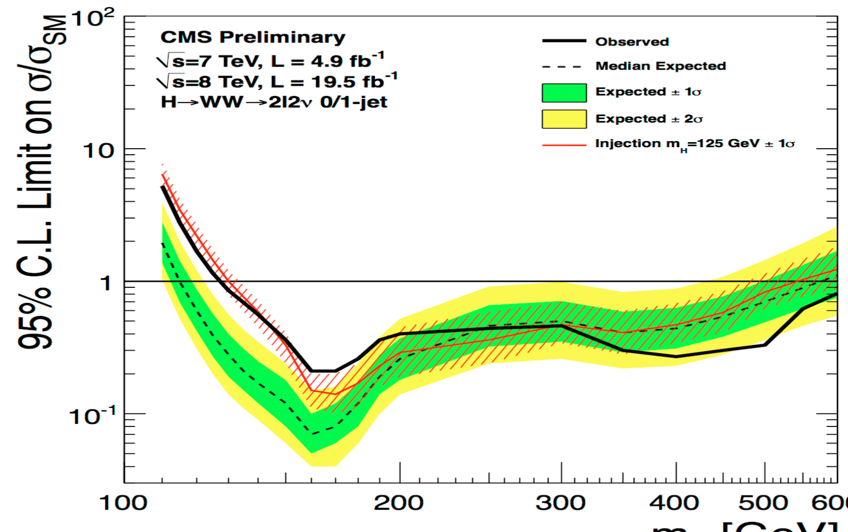
All the background are estimated from DATA in "control regions"

H →WW→2l2ν: Results









ATLAS: Broad excess consistent with 125 GeV

Significance: 3.8 σ (3.8σ expected)

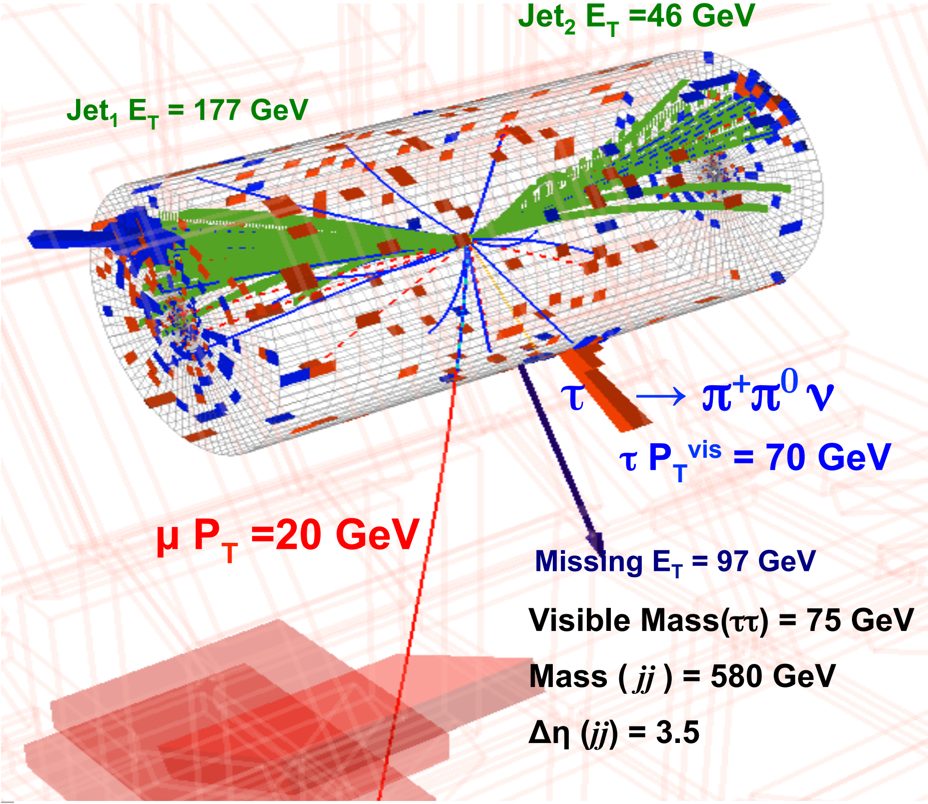
Fitted σ/σ_{SM} = 0.99 ± 0.30

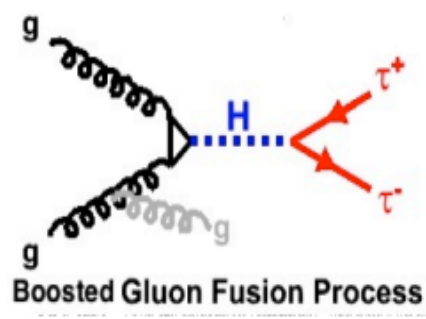
CMS: Broad excess consistent with 125 GeV

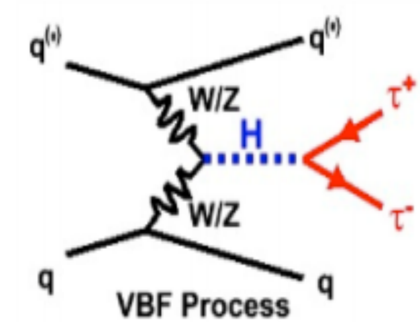
Significance: 4.0 σ (5.1 σ expected)

Fitted σ/σ_{SM} = 0.76 ± 0.21

$H \rightarrow \tau\tau$





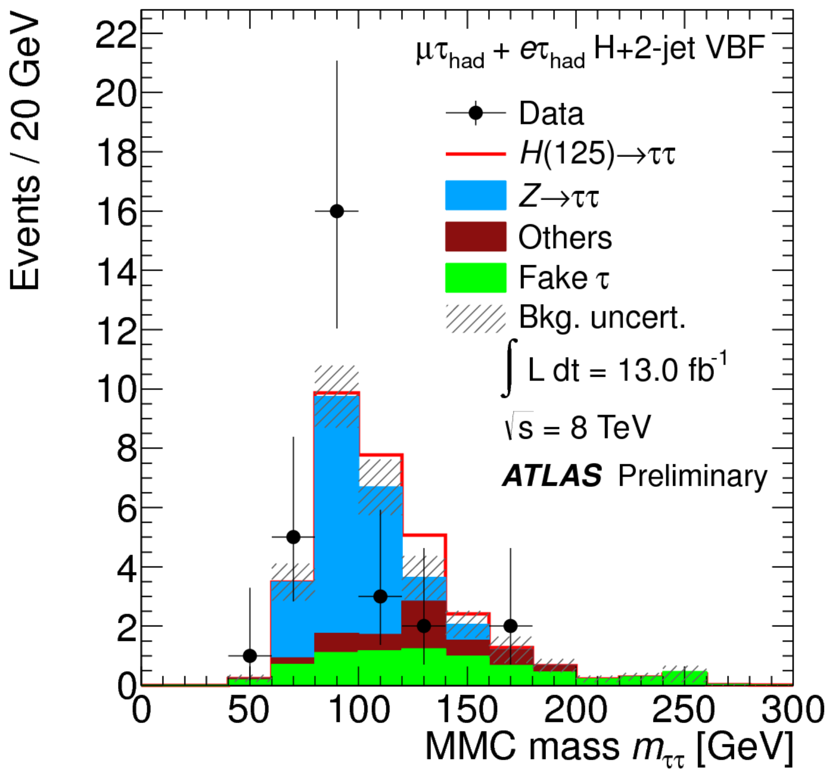


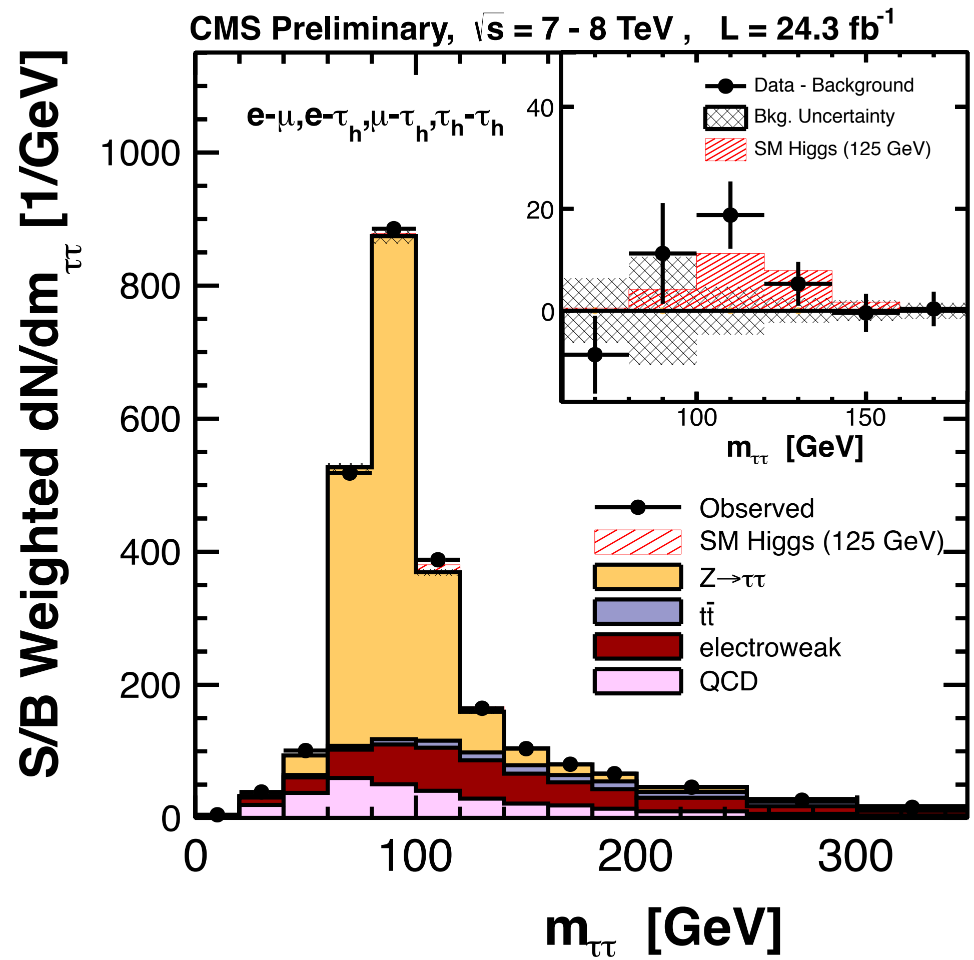
ggF, VBF production: $\mu\mu, e\mu, \tau_h\tau_h, e\tau, \mu\tau_h$

VH production: $l\tau_h\tau_h, ll\tau_h\tau_h, ll\tau_h$

jet categories:
0-jet: used only to constrain the background
1-jet: low pT / high pT
2-jets (VBF).

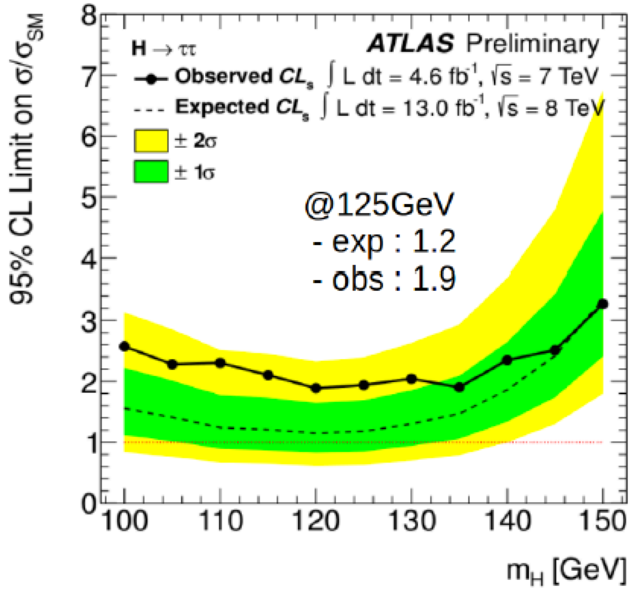
H → ττ

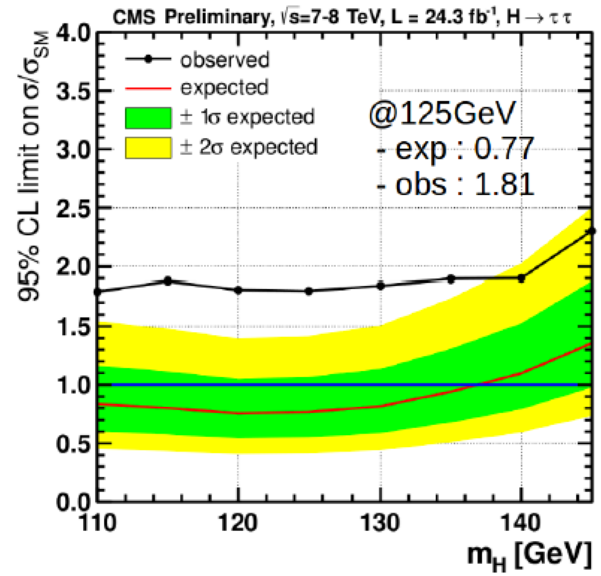


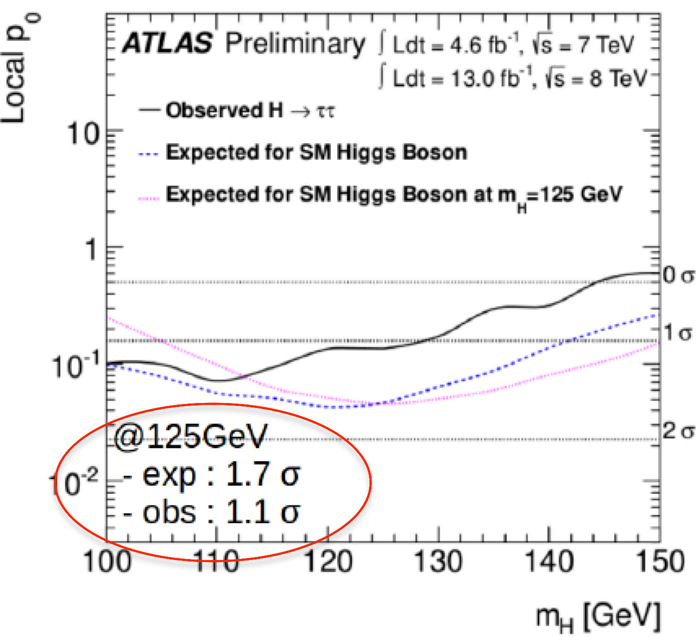


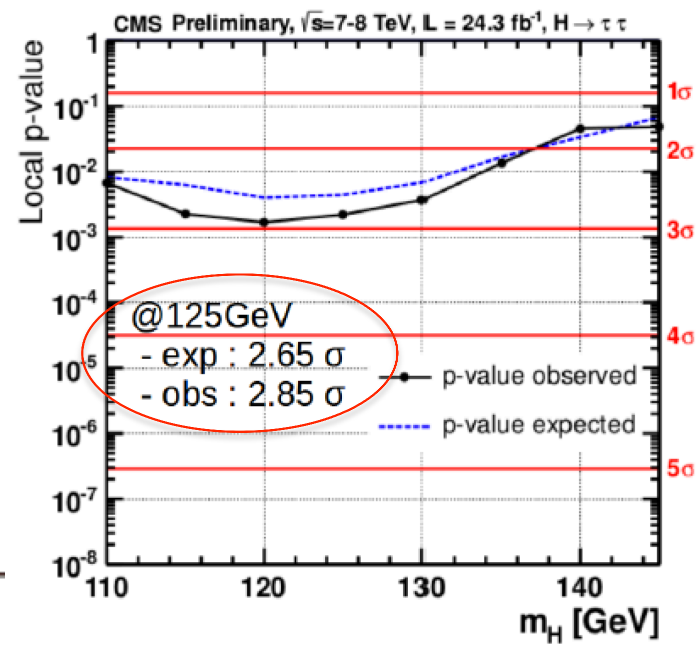
Combine the sensitive categories of all channels with a S/B weight

H → ττ : Results

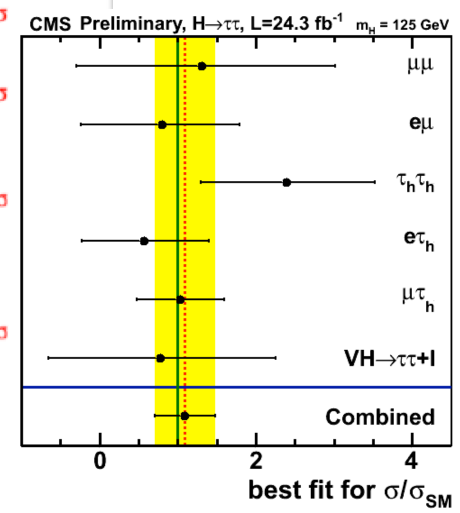




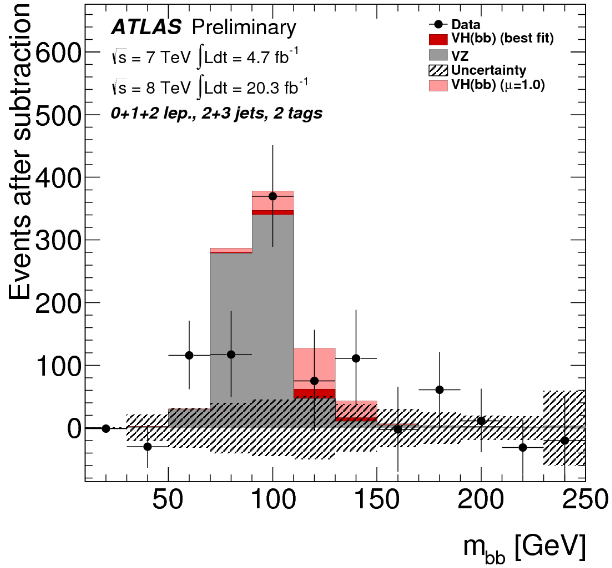


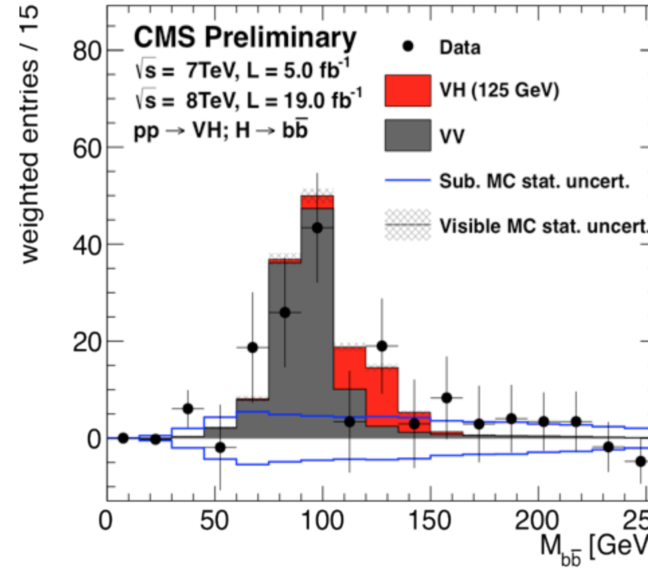


μ = 1.1 ± 0.4

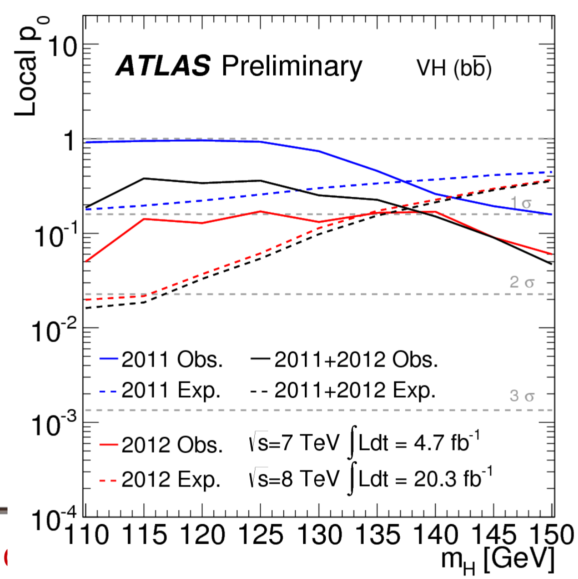


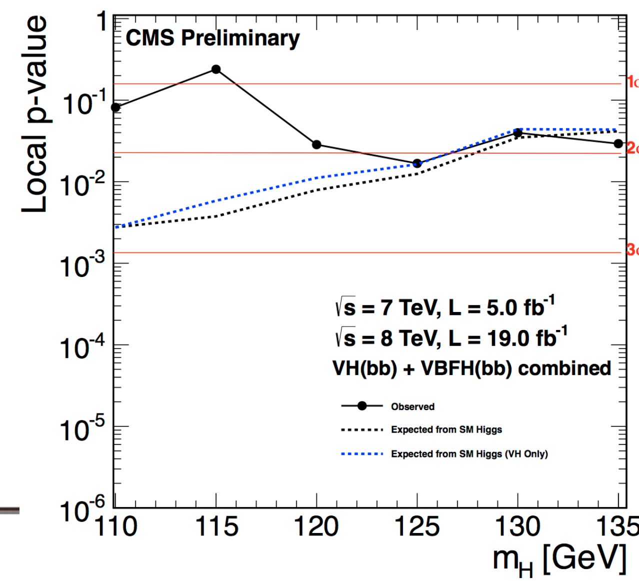
VH → bb results



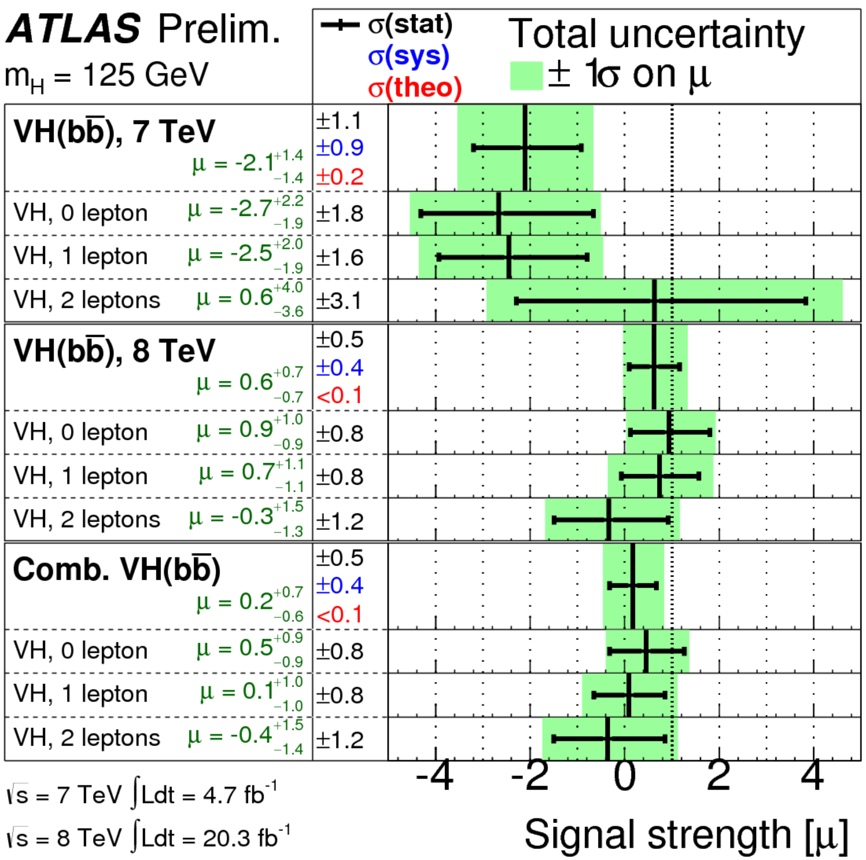


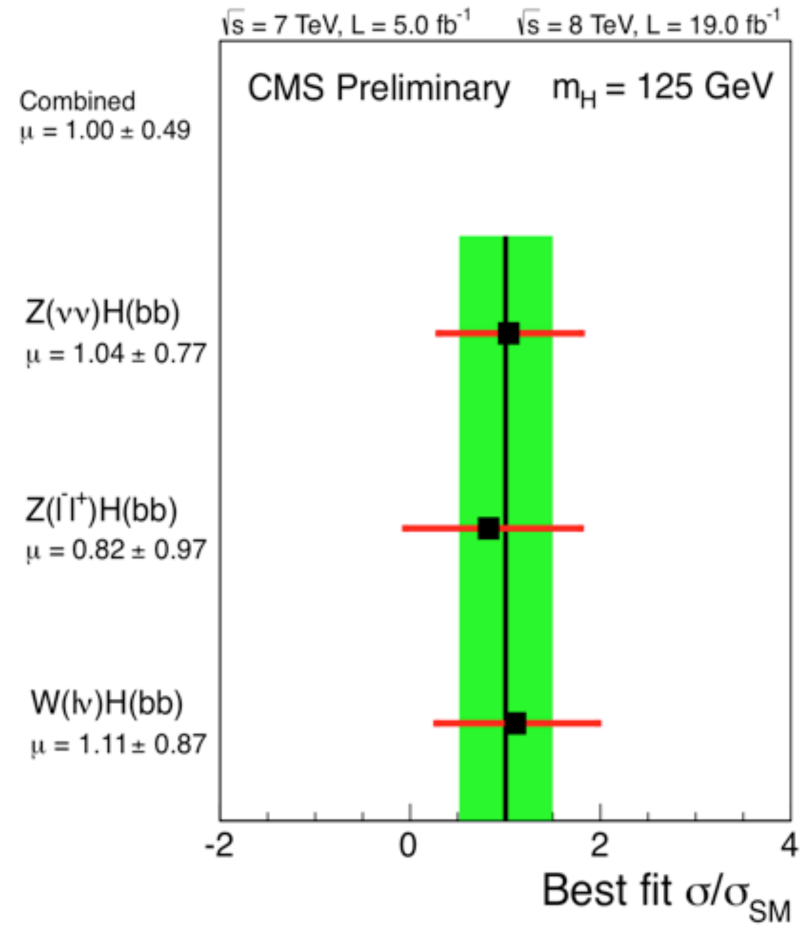
ATLAS : cut then look at *mbb* ; **CMS** : MVA (+cut based as cross check)





VH → bb results

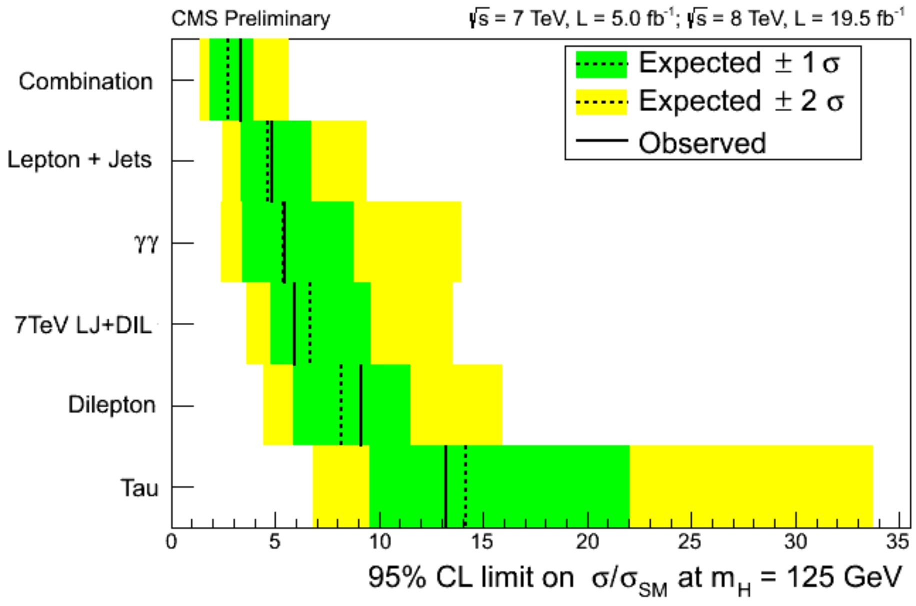




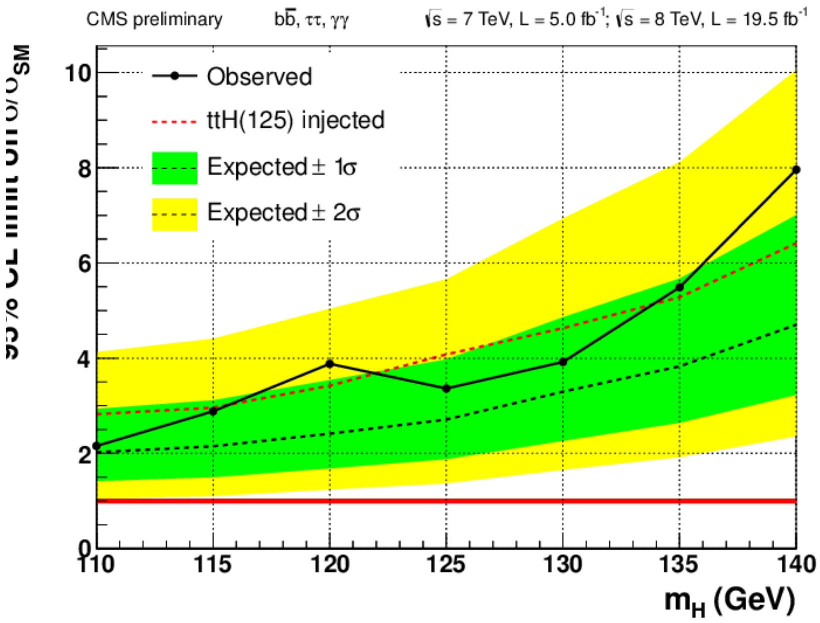
$\mu = 0.2\ {}^{+0.7}_{-0.6}$ (μ = 0.2 +0.7 −0.6)

$\mu = 1.0 \pm 0.49$

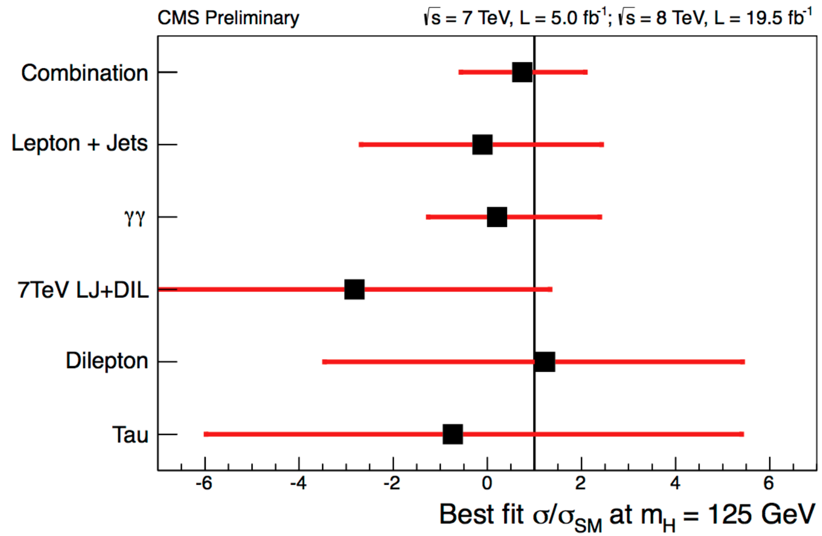
ttH, H→bb,γγ,ττ



CMS Preliminary
√s = 7 TeV, L = 5.0 fb-1; √s = 8 TeV, L = 19.5 fb-1
Combination
Lepton + Jets
γγ
7TeV LJ+DIL
Dilepton
Tau
Expected ± 1 σ
Expected ± 2 σ
Observed
95% CL limit on σ/σSM at mH = 125 GeV



CMS preliminary
bb̄, ττ, γγ
√s = 7 TeV, L = 5.0 fb-1; √s = 8 TeV, L = 19.5 fb-1
Observed
ttH(125) injected
Expected ± 1σ
Expected ± 2σ
mH (GeV)



CMS Preliminary
√s = 7 TeV, L = 5.0 fb-1; √s = 8 TeV, L = 19.5 fb-1
Combination
Lepton + Jets
γγ
7TeV LJ+DIL
Dilepton
Tau
Best fit σ/σSM at mH = 125 GeV

Summary of the five main channels

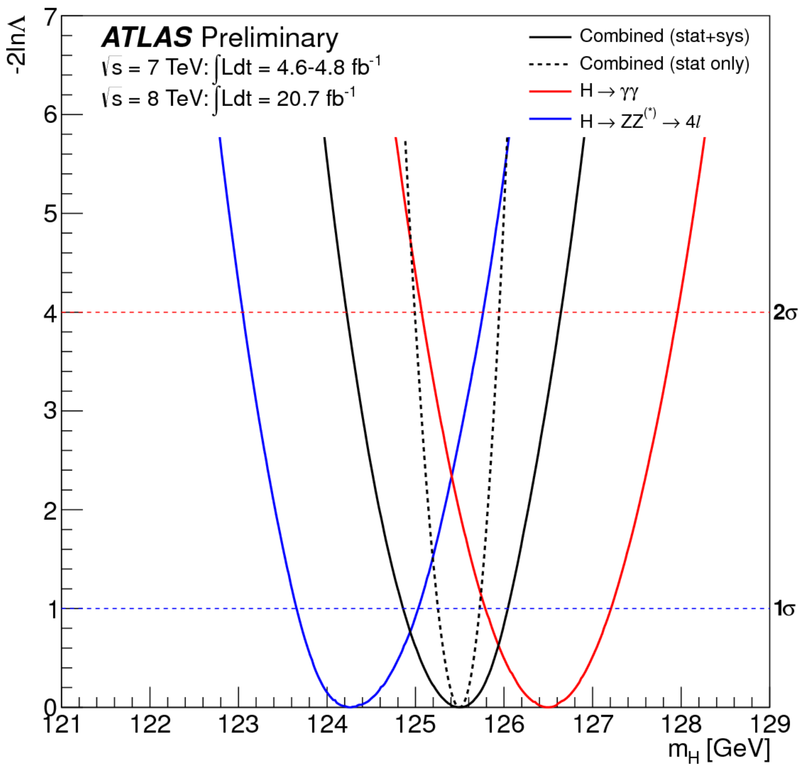
	ATLAS		CMS	
	Observed	Expected	Observed	Expected
ZZ	6.6	4.4	6.7	7.1
γγ	7.4	4.3	3.2	4.2
WW	3.8	3.8	4.0	5.1
ττ	1.1	1.7	2.9	2.7
bb	1.	1.5	2.1	2.2

3.6 σ combined

Combination

The Mass

ATLAS

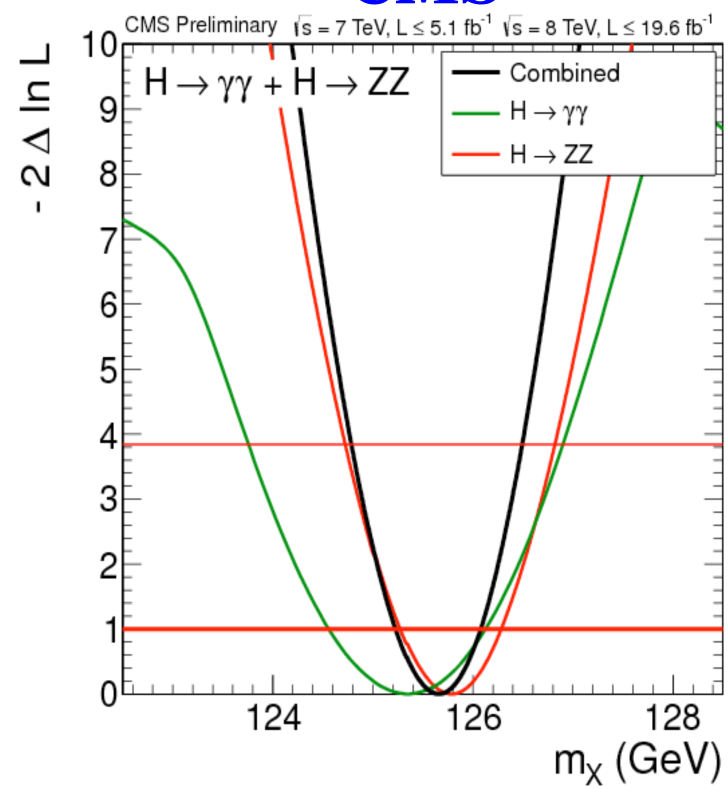


$m_H = 125.5 \pm 0.2^{(stat)} \pm 0.6^{(syst)}$ GeV

$= 125.5 \pm 0.6$ GeV

$\Delta m_H = 2.3 \pm 0.7^{(stat)} \pm 0.6^{(syst)}$ GeV ~2.5 σ

CMS



$m_H = 125.7 \pm 0.3^{(stat)} \pm 0.3^{(syst)}$ GeV

$= 125.7 \pm 0.4$ GeV

The mass

Collaboration	channel	mass (GeV)
ATLAS	$\gamma\gamma$	$126.8 \pm 0.2 \pm 0.7$
CMS	$\gamma\gamma$	$125.4 \pm 0.5 \pm 0.6$
ATLAS	4ℓ	$124.3^{+0.6+0.5}_{-0.5-0.3}$
CMS	4ℓ	$125.8 \pm 0.5 \pm 0.2$
ATLAS	combination	$125.5 \pm 0.2^{+0.5}_{-0.6}$
CMS	combination	$125.7 \pm 0.3 \pm 0.3$

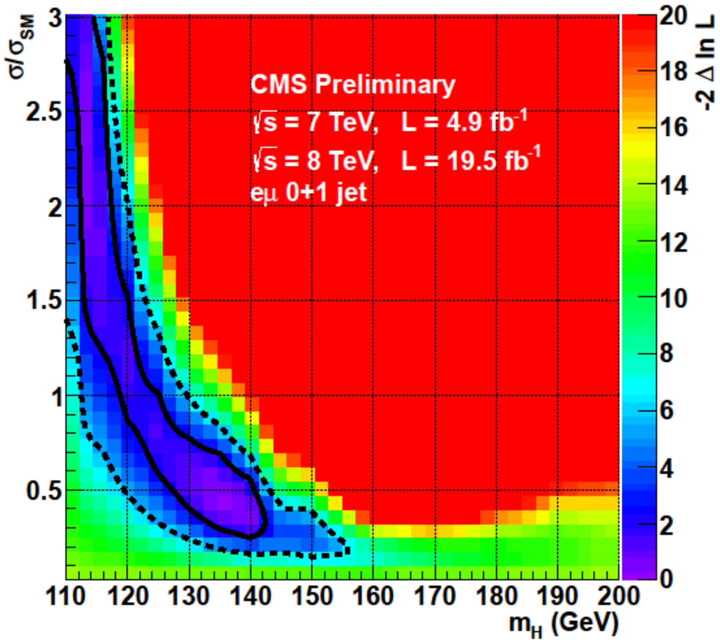
H →ZZ→4l:

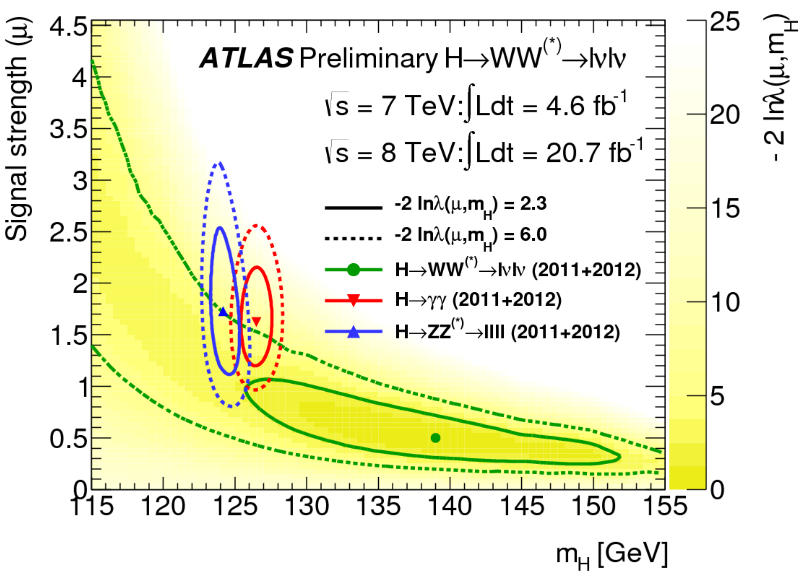
Very small systematics due the very good control of the leptons scale and resolution.
In CMS: Mass estimation with m_{4l}, KD and $\sigma(m_{4l})$.

H →γγ:

Systematics on the extrapolation from the $Z \to ee$ to $H \to \gamma\gamma$
(0.25% from e to γ, 0.4% from Z to H)

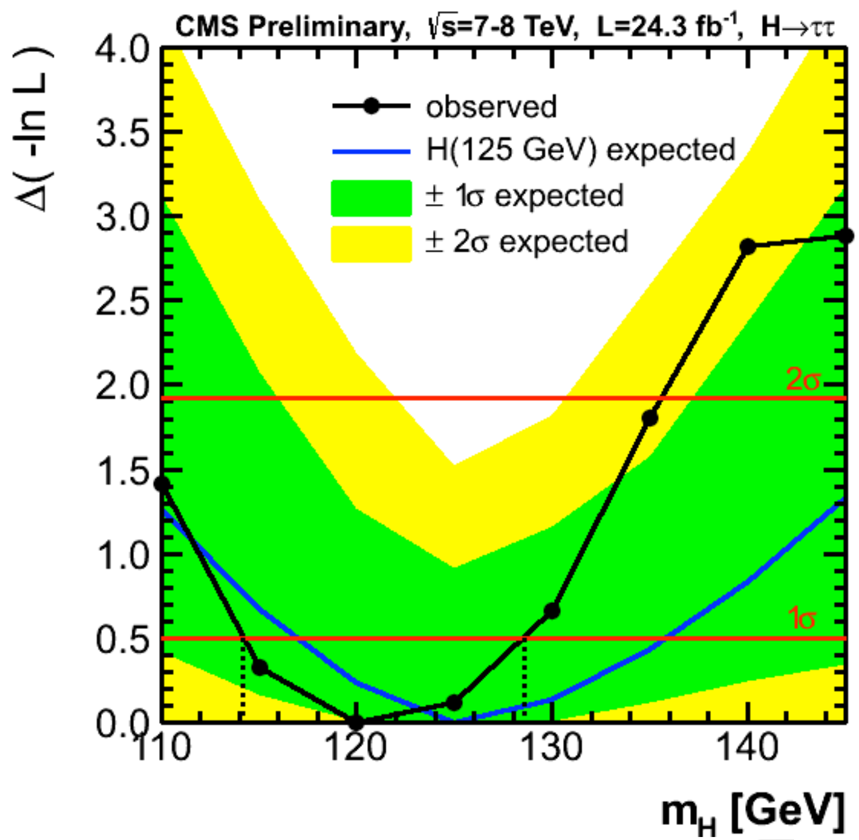
H → WW and H → ττ : Results



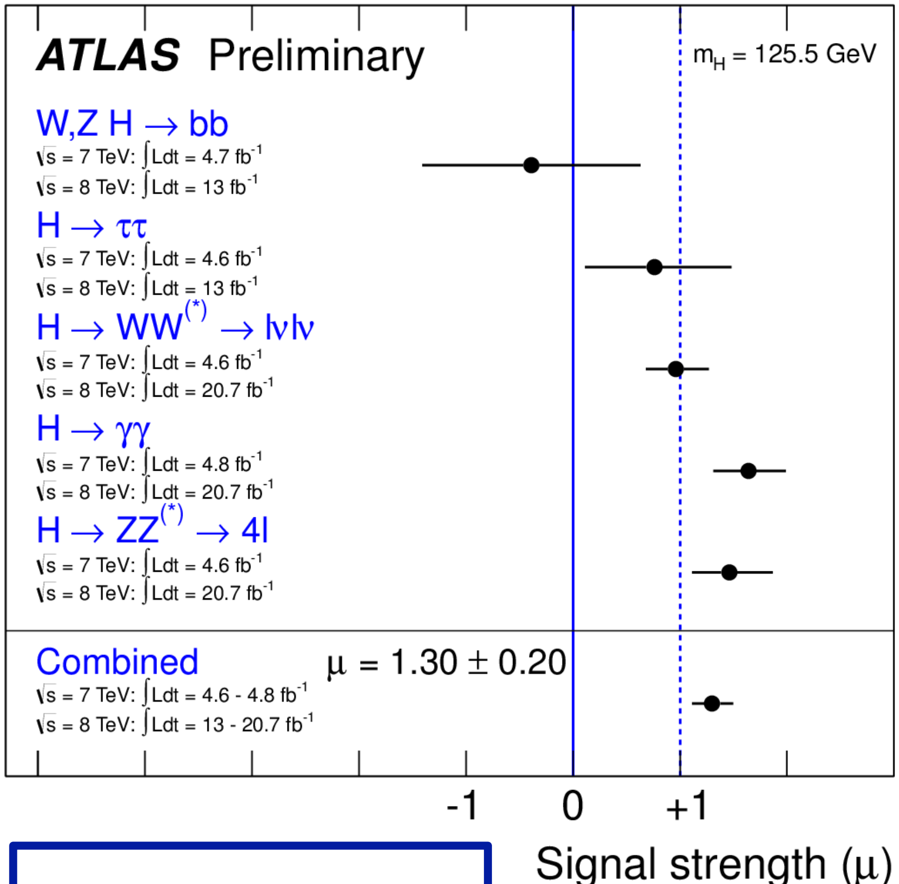


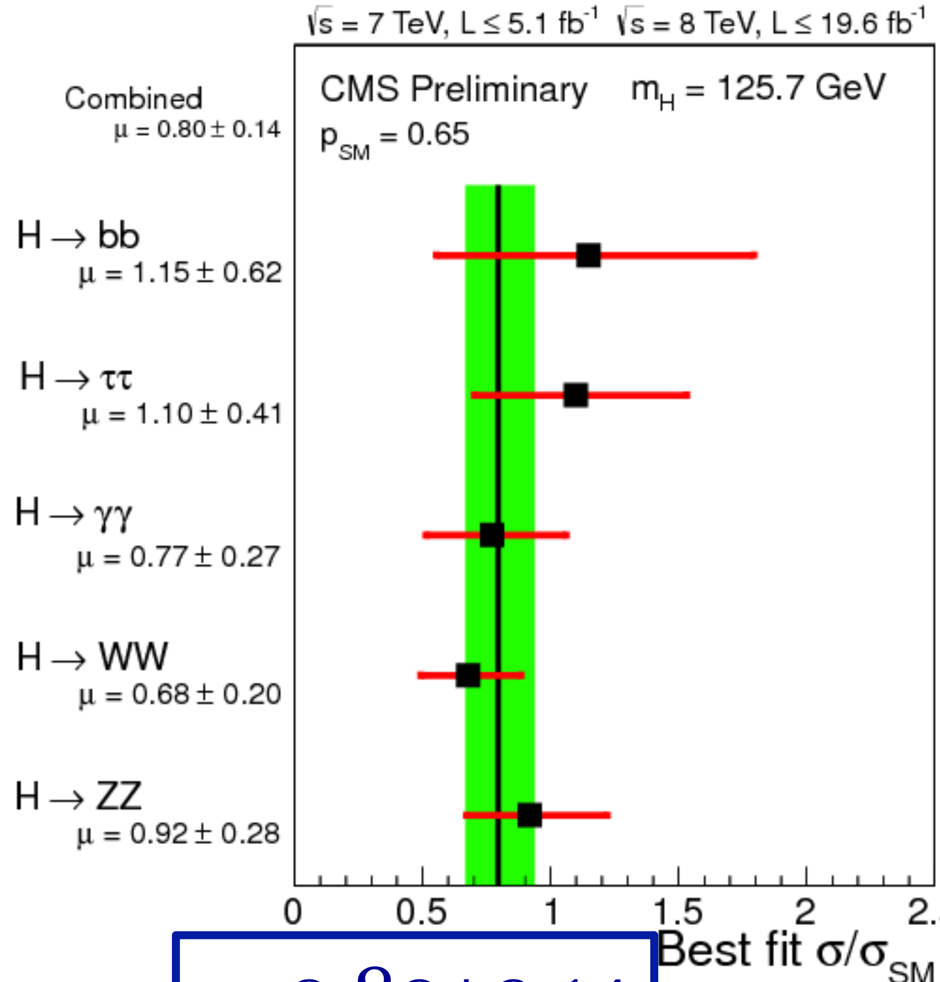
Mass: all ττ channels combined:

$m_H = 120^{+9}_{-7}$ (stat+syst) GeV



Consistency with SM hypothesis $\mu = \frac{\sigma \cdot \mathrm{BR}}{(\sigma \cdot \mathrm{BR})_{\mathrm{SM}}}$



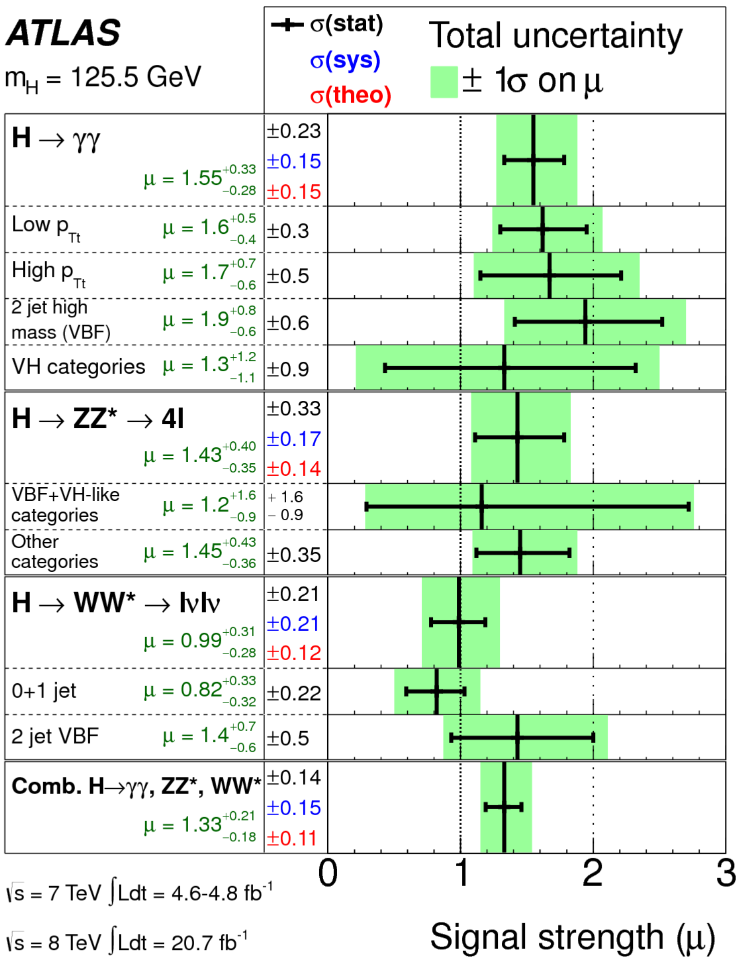


μ=1.30±0.20

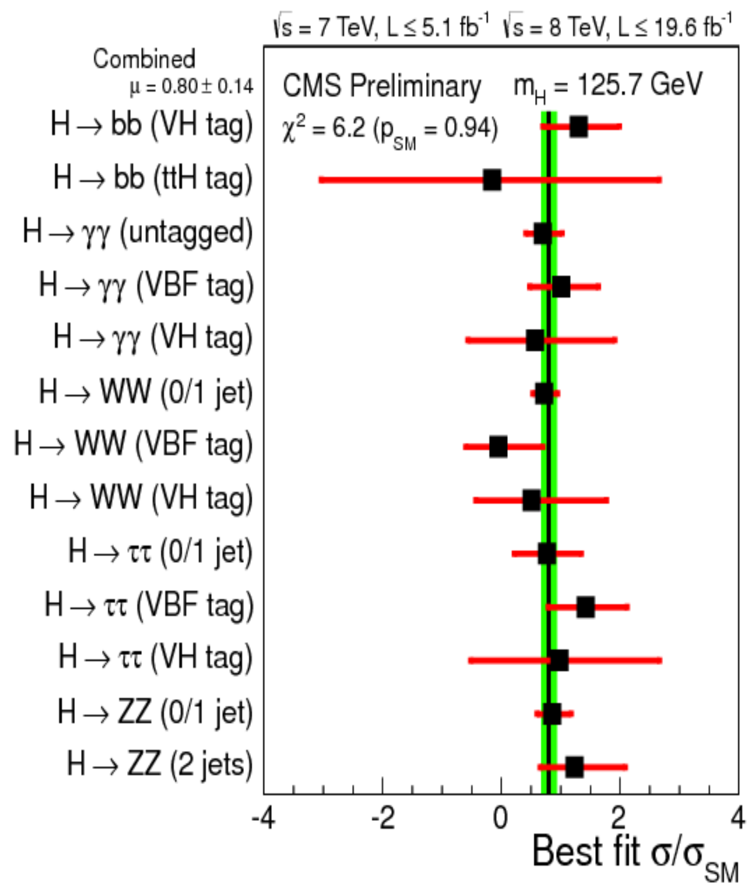
μ=0.80±0.14

Consistent with the SM prediction for both ATLAS and CMS, with ~15% precision.
Theory uncertainty (QCD scale ±8%@NNLO and PDF+α_s ±8%) is comparable to experimental.

Consistency with SM hypothesis



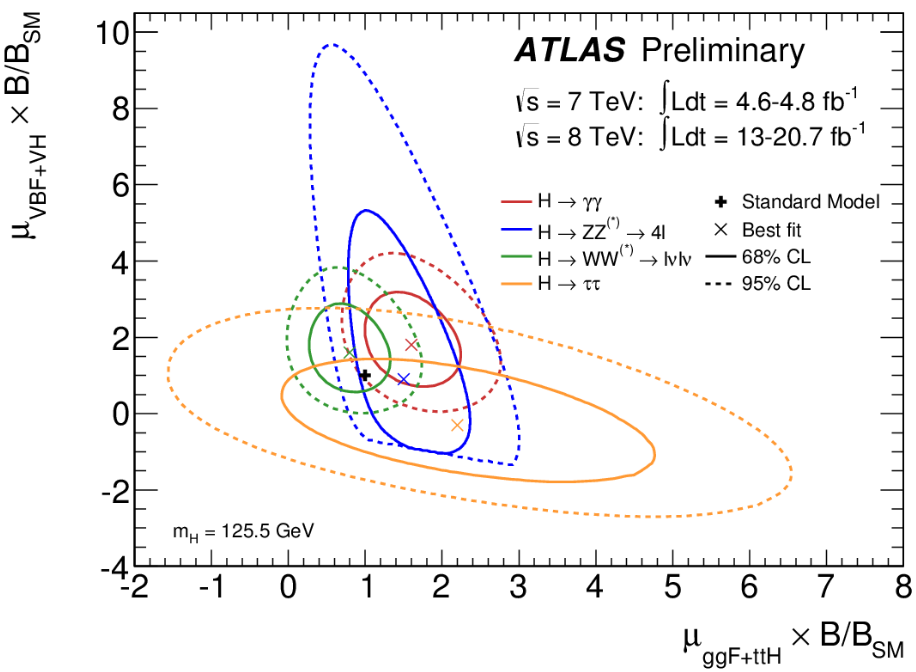
μ=1.30±0.20

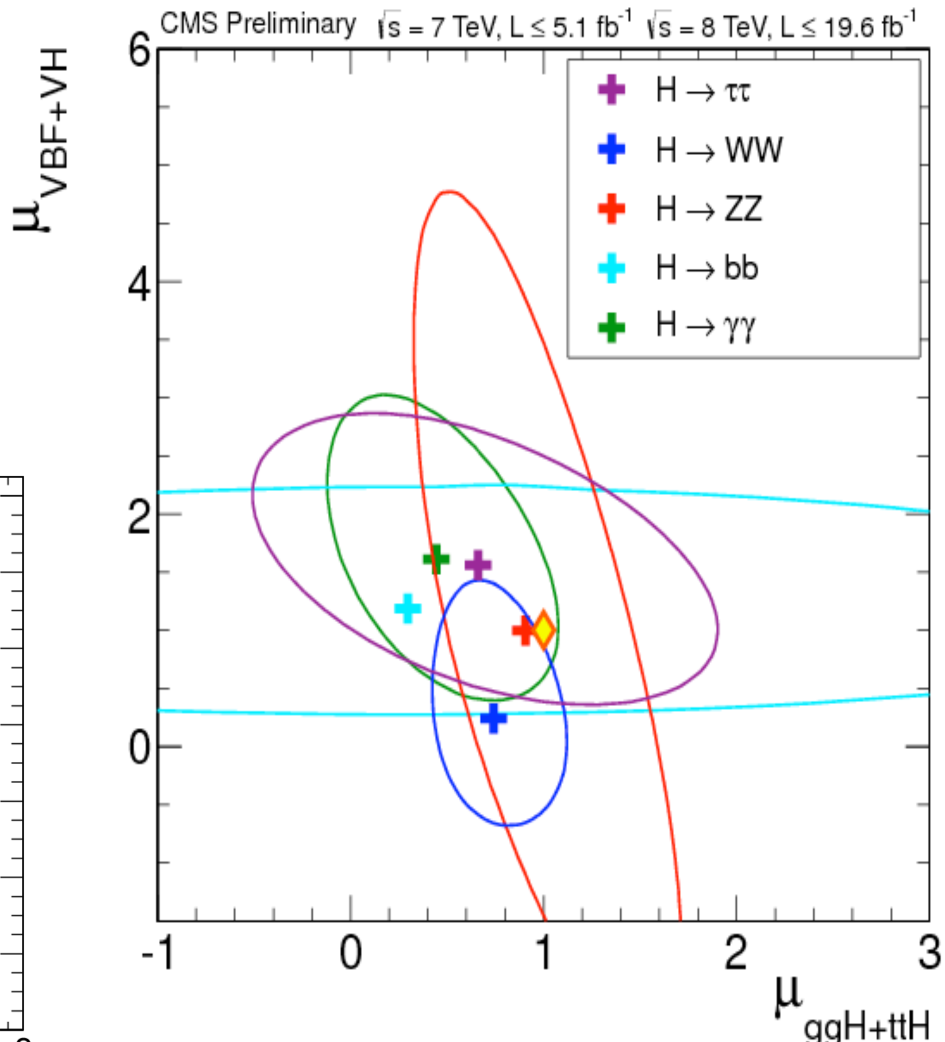


μ=0.80±0.14

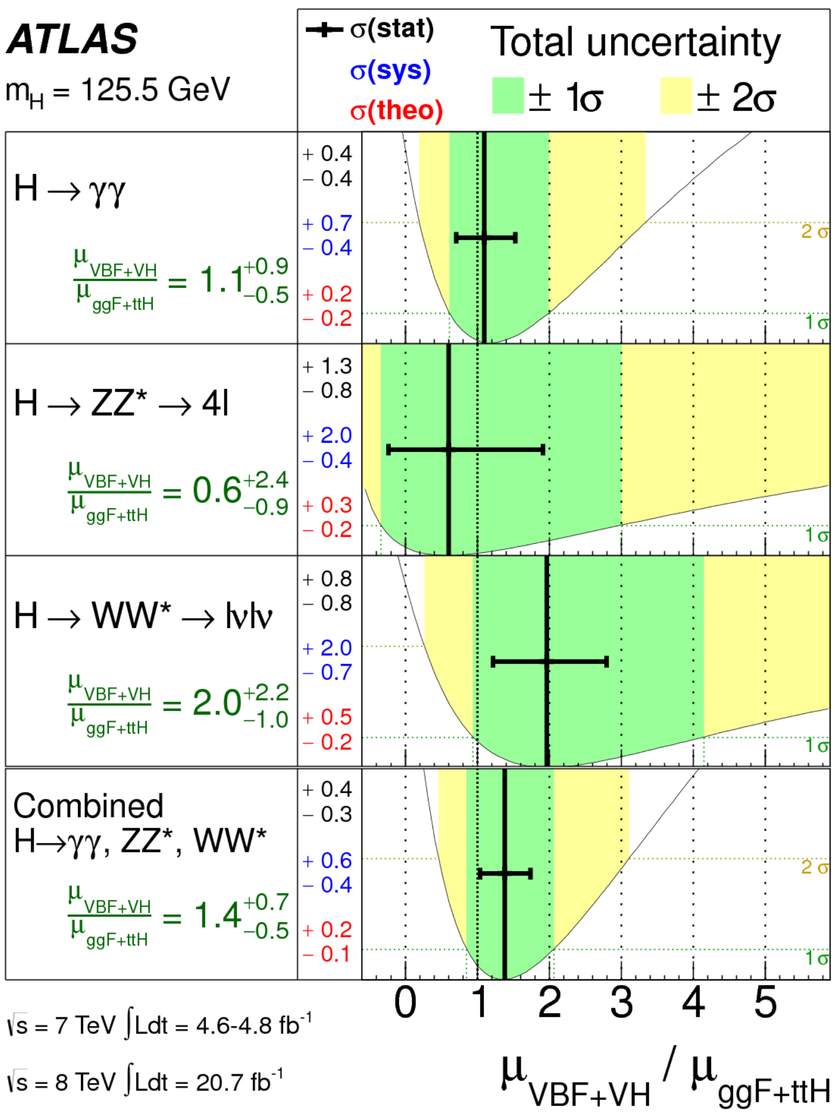
Consistency in 2D

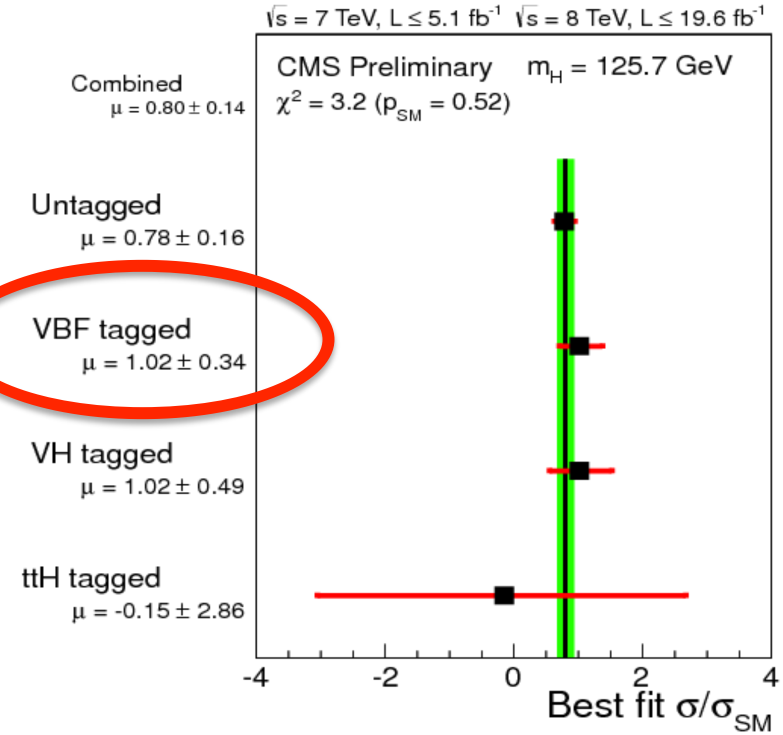
- Test production modes in the various decay modes.





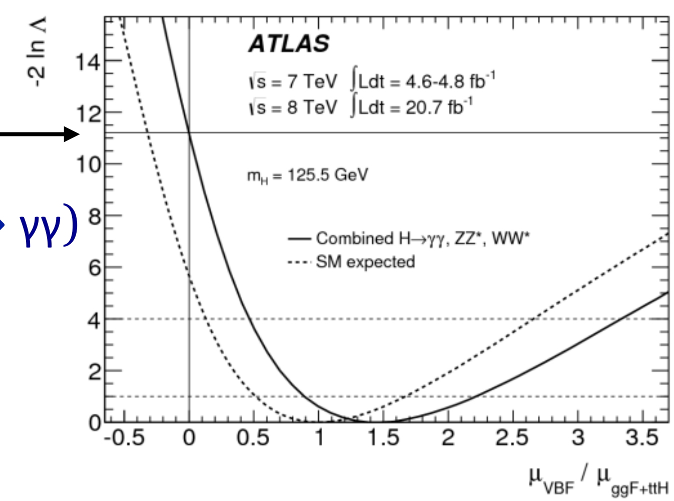
VBF production





$\mu_{VBF+VH} / \mu_{ggF+ttH}$ = 1.4+0.4-0.3(stat)+0.6-0.4(sys)

3.3σ evidence for VBF production (driven by H → γγ)



The couplings

They can be extracted from the different final states at the LO EW and NLO QCD approximation:

$$\sigma(H) \text{ x BR}(ii \rightarrow H \rightarrow xx) = \sigma_{ii} \text{ x } \Gamma_{xx} / \Gamma_H$$

We can measure deviations from the SM couplings, by measuring ratios w.r.t. to the SM prediction.

As an example for the $gg \rightarrow H \rightarrow \gamma\gamma$ process:

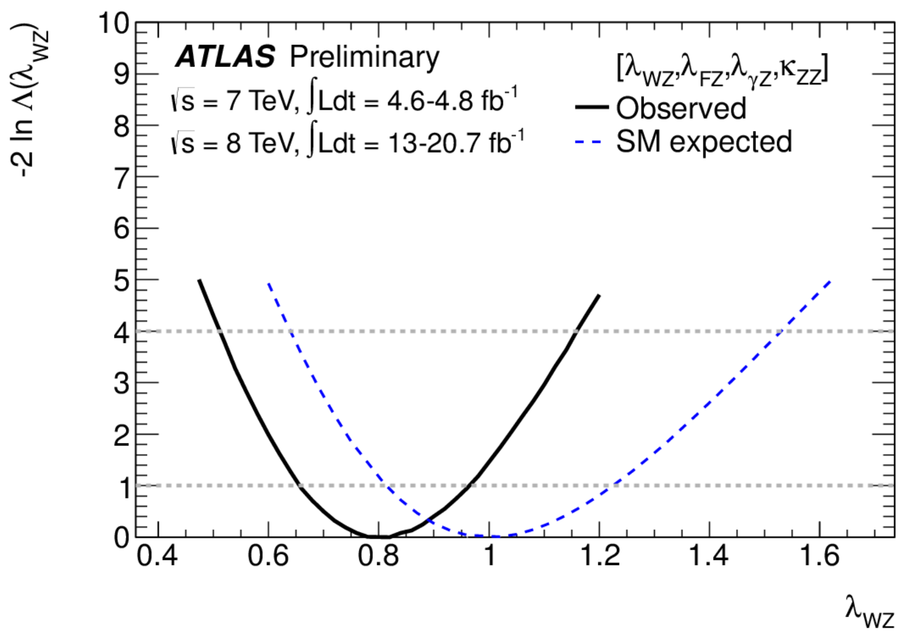
$$(\sigma \text{ x BR}) (gg \rightarrow H \rightarrow \gamma\gamma) = \sigma_{SM}(gg \rightarrow H) \, BR(H \rightarrow \gamma\gamma) \bullet \kappa_g^2 \; \kappa_\gamma^2 / \kappa_H^2$$

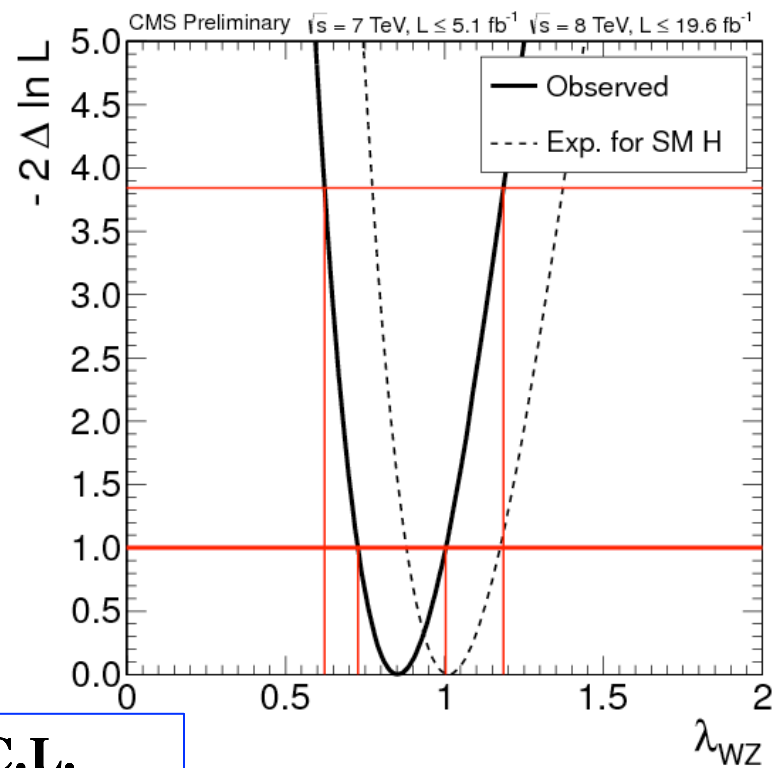
- LHC XS WG benchmark models (arxiv:1209.0040):
  - Fermionic vs bosonic couplings: $\kappa_V \, \kappa_f$
  - Search for asymmetries: λ_{WZ}, λ_{du}, λ_{lq}
  - Search for new physics in loops: $\kappa_g \, \kappa_\gamma \, BR_{BSM}$

Custodial symmetry

Testing custodial symmetry (measuring HWW/HZZ couplings) will tell us if the the object produced is Higgs-like.

All channels. κ_f profiled



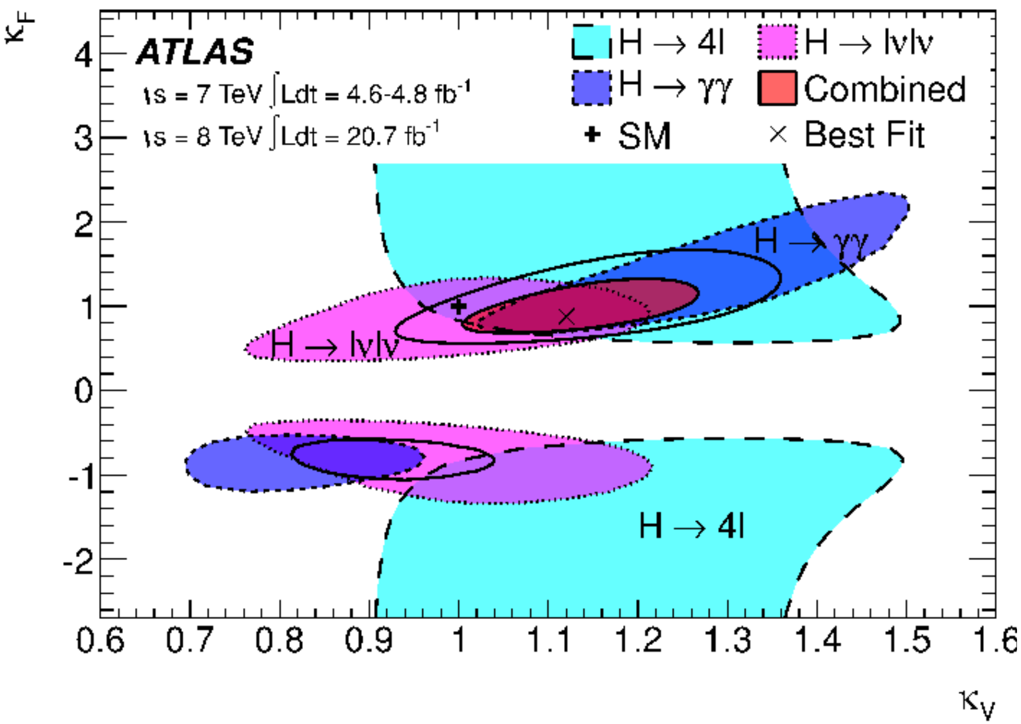


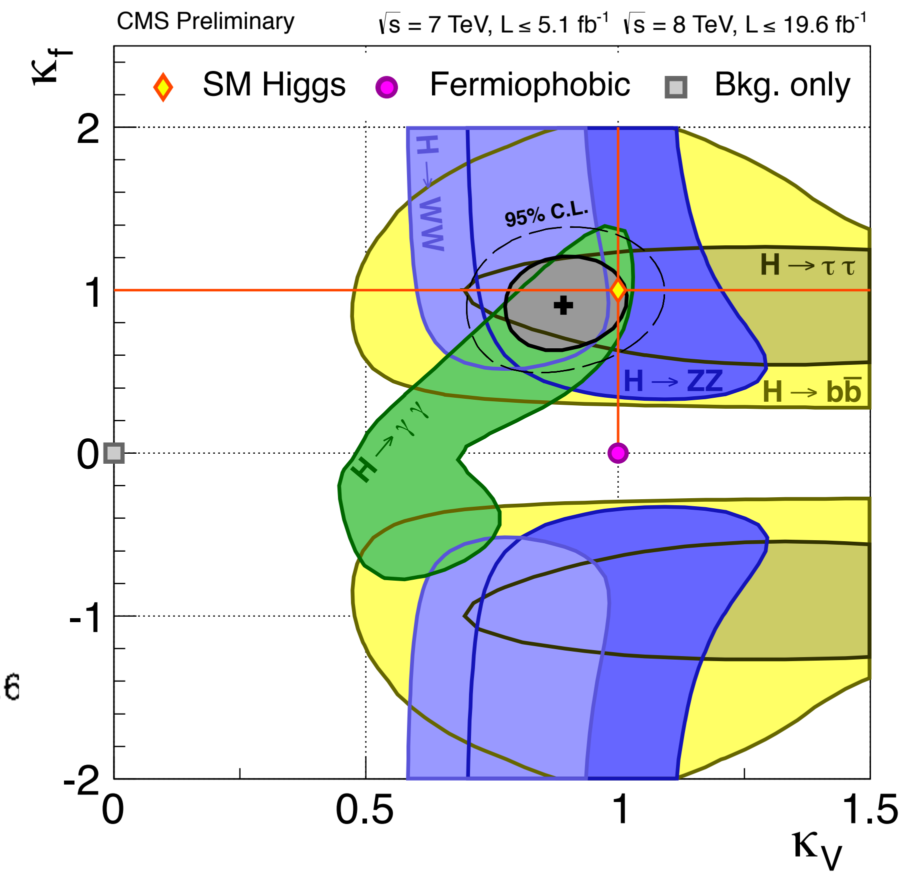
ATLAS: $\lambda_{WZ} \in [0.61,1.04]$ at 68% C.L.
CMS $\lambda_{WZ} \in [0.73,1.00]$ at 68% CL

three degrees of freedom:
λ_{WZ}, κ_Z, and κ_f.
$\Gamma_{BSM} = 0$.
fitted m_H

Couplings: κ_V, κ_f

Assume all fermion couplings scale as κ_F while all vector boson couplings scale as κ_V.





@ fitted m_H

$\Gamma(H \rightarrow \gamma\gamma) \sim |\alpha\, \kappa_V + \beta\, \kappa_f|^2$, $\alpha/\beta = -0.2$

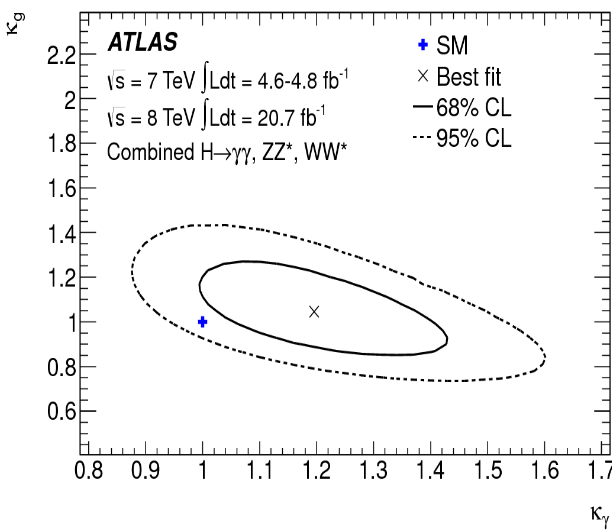
$\Gamma_{BSM} = 0$

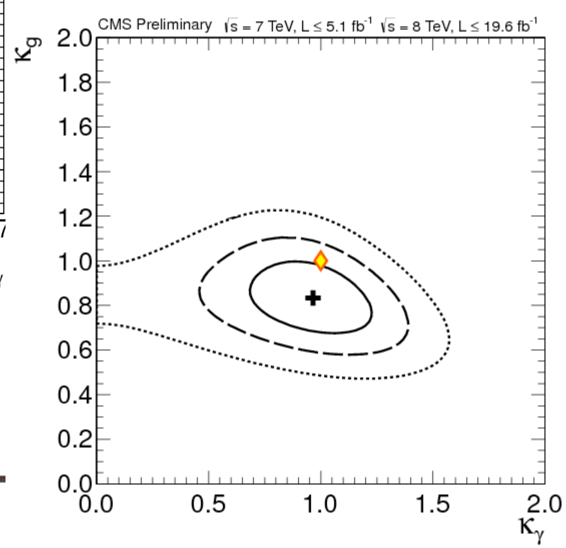
Search for new physics in loops and decays

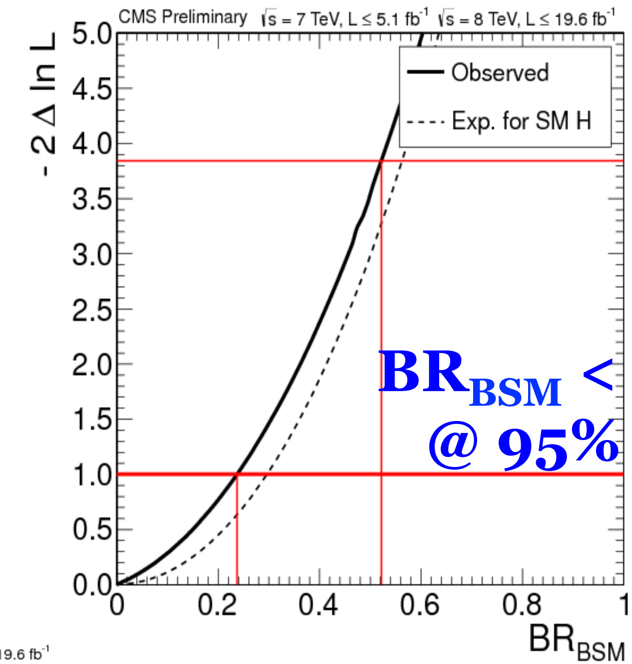
Effective couplings to gluons and photons.

Note best fit $\kappa_\gamma \sim 1$, with $\kappa_g < 1$ in line with $\mu < 1$ in VV modes as well.

$\Gamma_{BSM} = 0$.





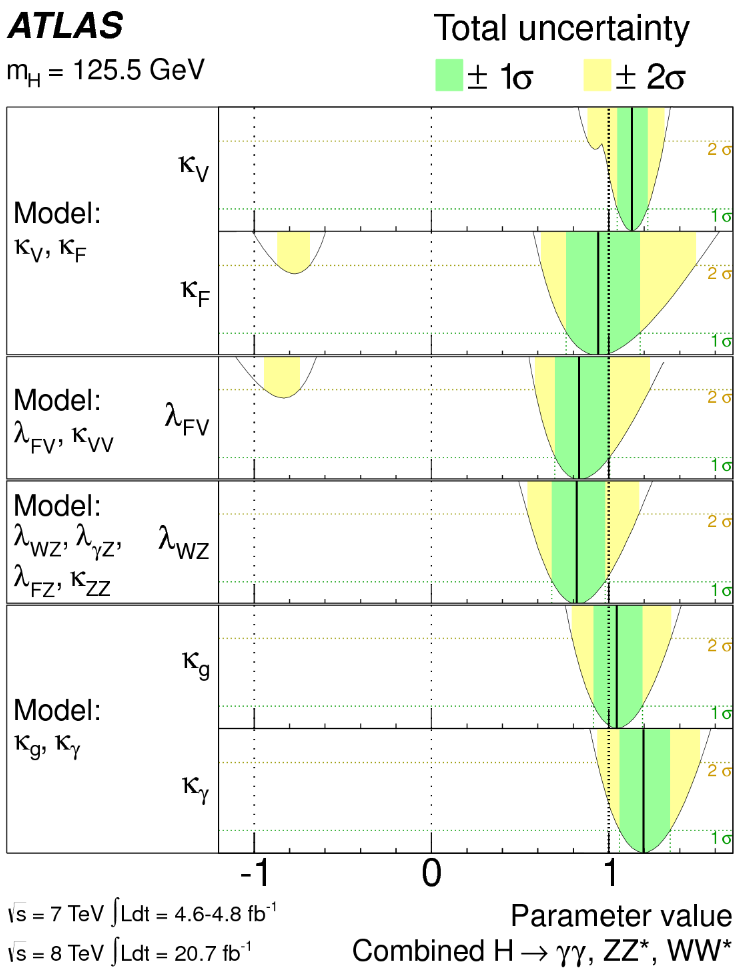


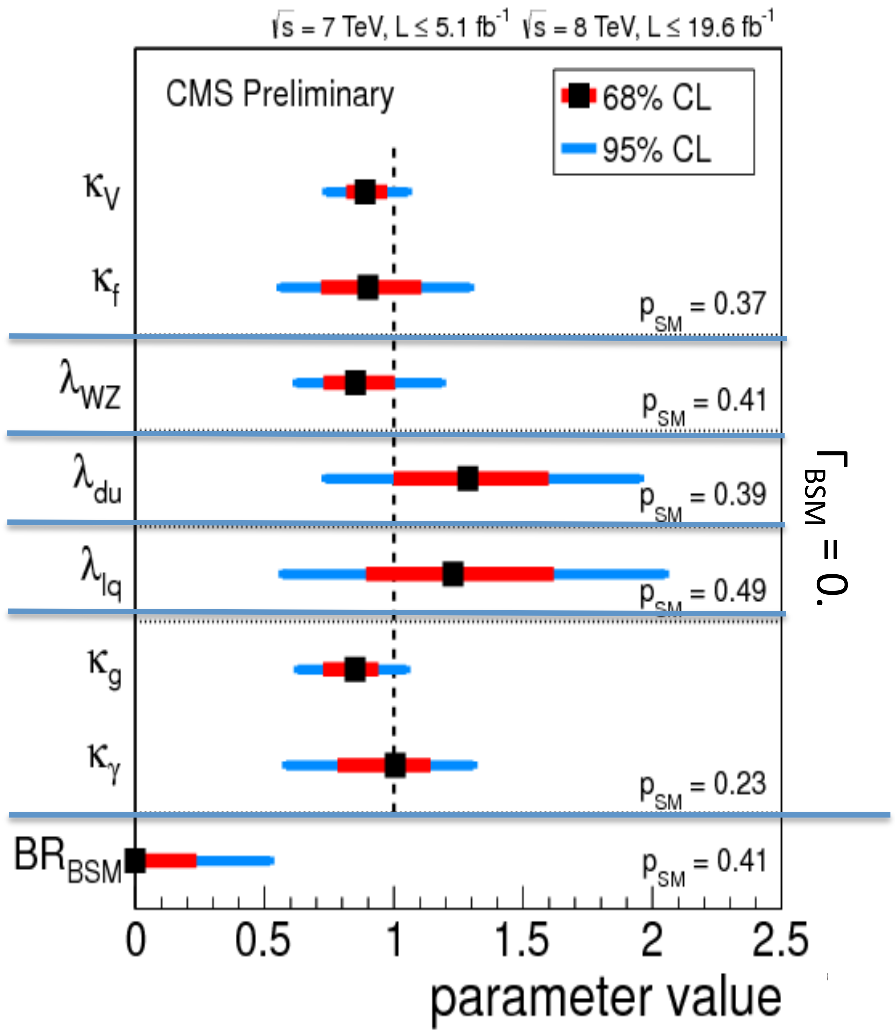
$BR_{BSM} < 0.52$ @ 95% CL

Loop-induced couplings free (κ_γ , κ_g profiled).

Allowed for extra particles in loop, i.e. extra width.

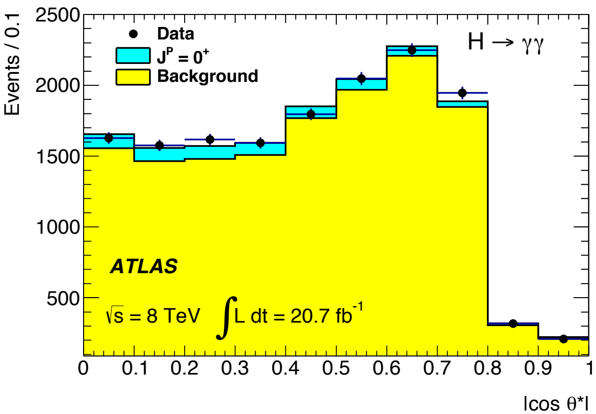
Summary of all searches for coupling deviations

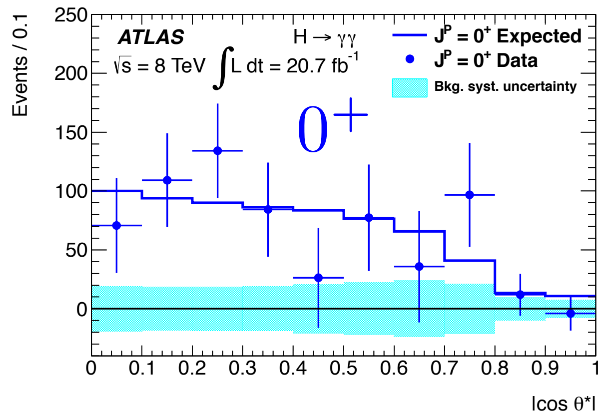


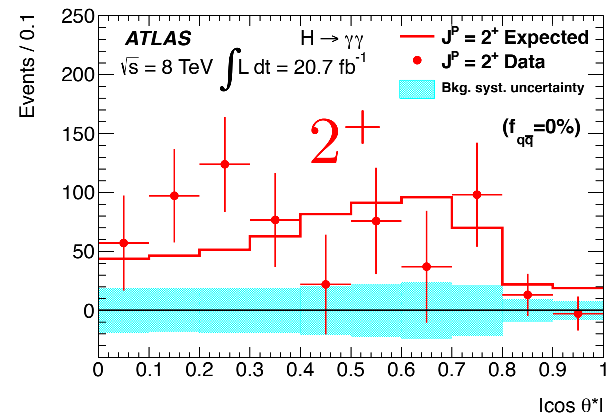


Spin studies in H→γγ

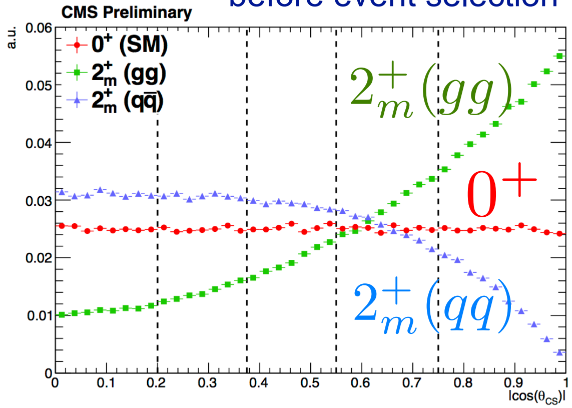
Decay angle cosθ* in diphoton rest frame: $|\cos\theta^*| = \frac{|\sinh(\Delta\eta^{\gamma\gamma})|}{\sqrt{1+(p_T^{\gamma\gamma}/m_{\gamma\gamma})^2}}\frac{2p_T^{\gamma 1}p_T^{\gamma 2}}{m_{\gamma\gamma}^2}$



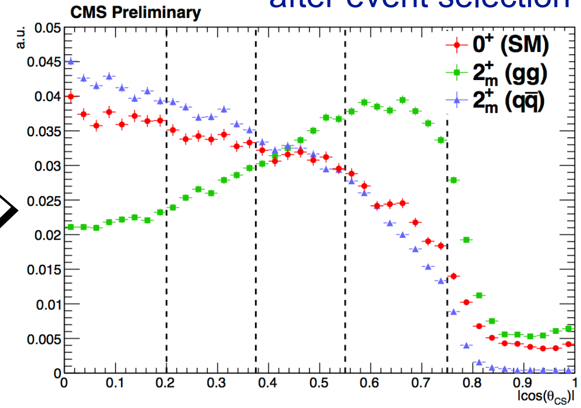


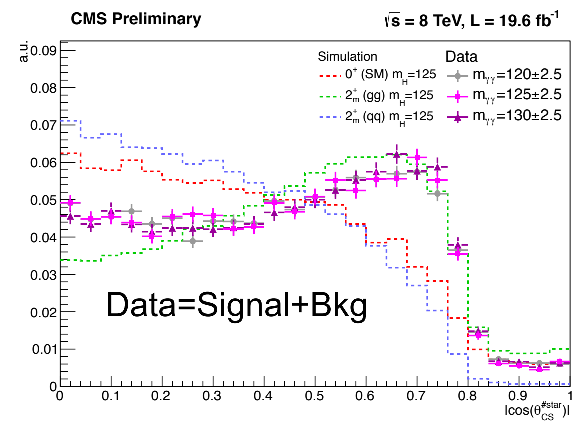


before event selection



after event selection



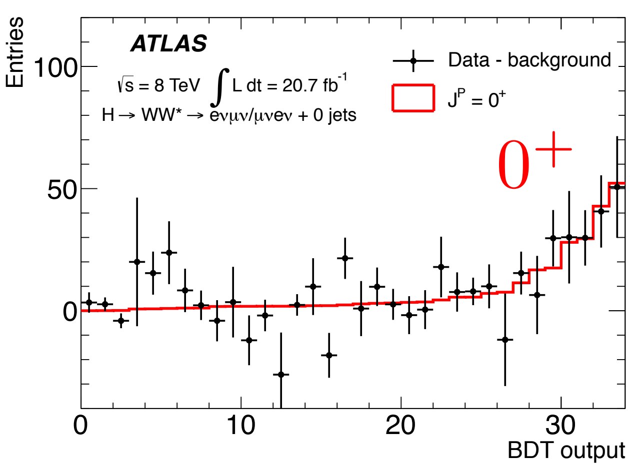


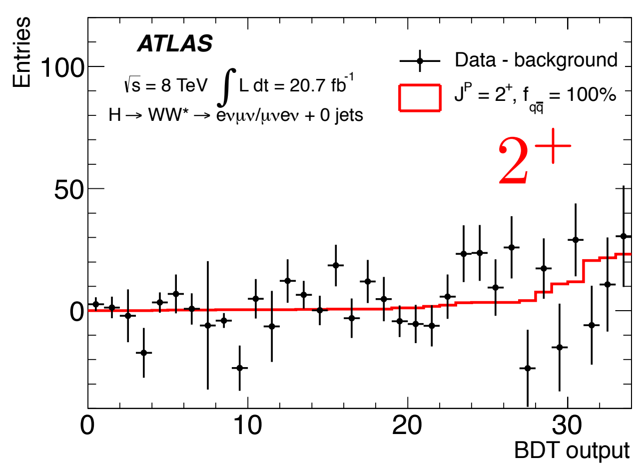
No event yield information (cross section) is used but shape only.

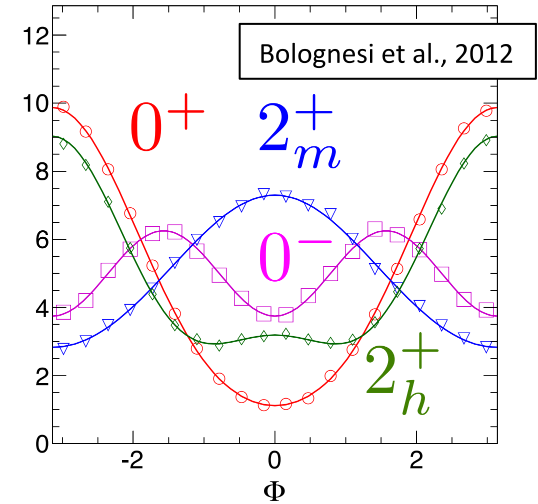
Spin studies in H→WW→lνlν

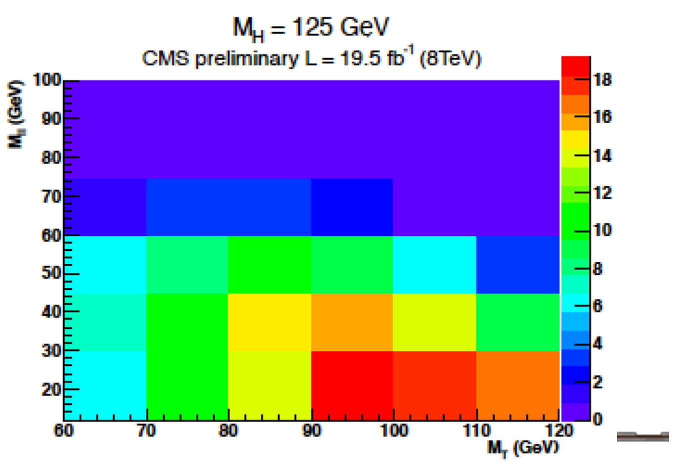
Kinematical variables sensitive to J^P: $\Delta\phi_{ll}$, M_{ll}, m_T ...

Make use of spin correlation in $H \to WW^* \to l\nu l\nu$ decay.

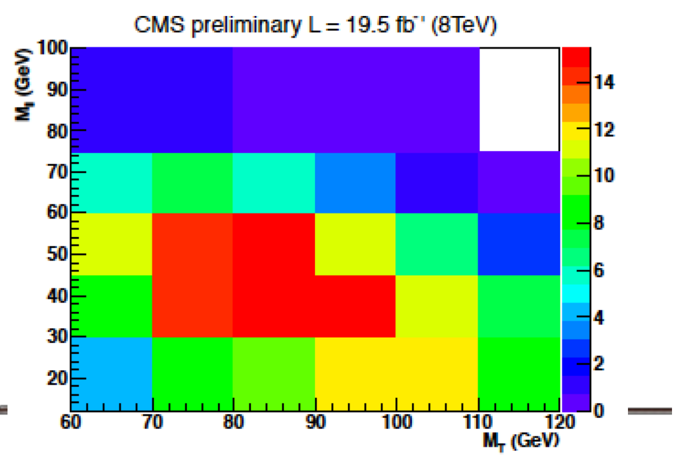


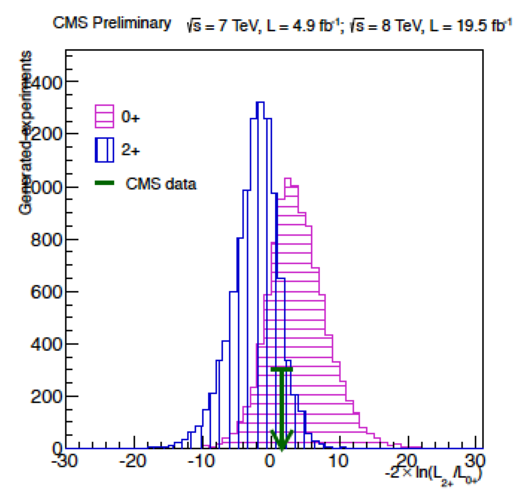






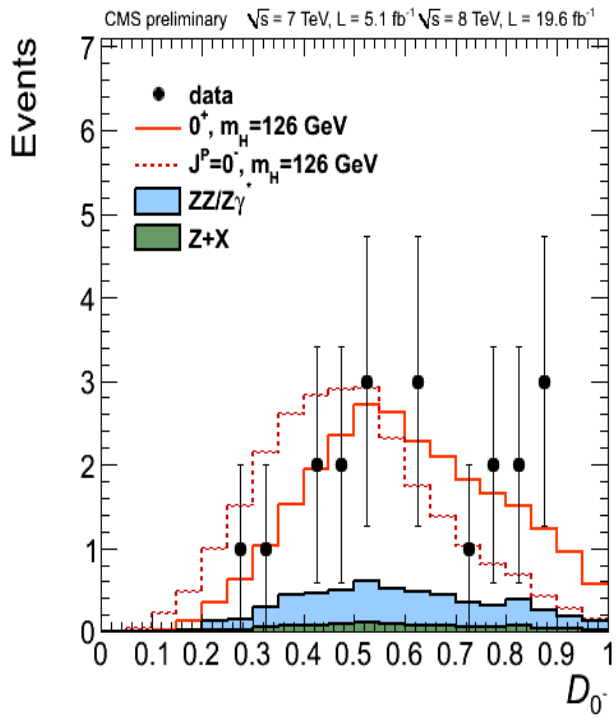
2^+_{min} (125 GeV)

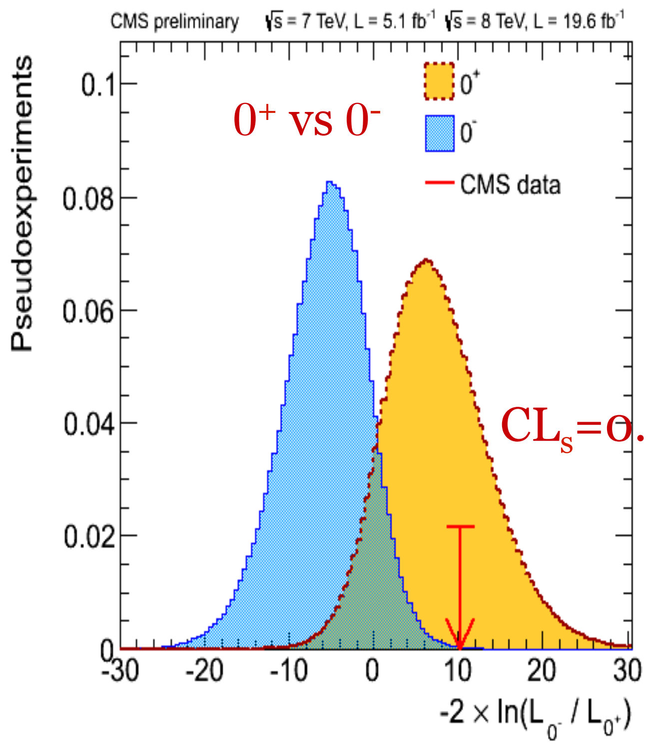


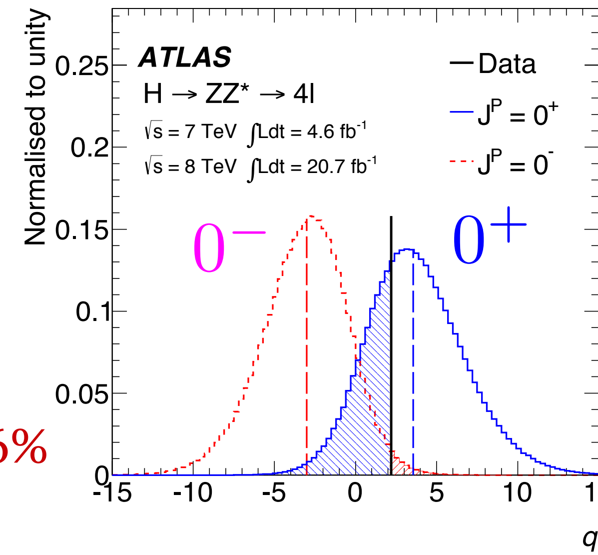


J^P

Kinematic discriminant built to describe the kinematics of production and decay of different J^P state of "Higgs"





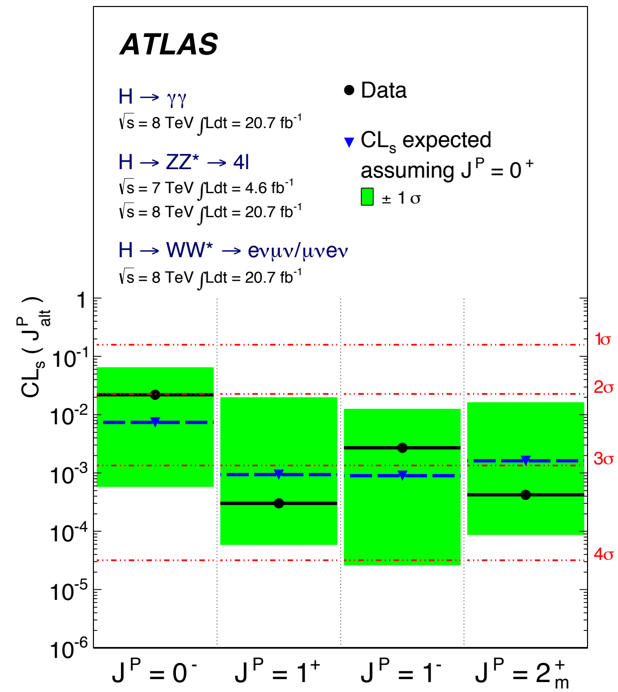


More J^P hypotheses have been tested in a similar way →

J^P	CL_s
0^-	0.16%
0_h^+	8.1%
2^+_{mgg}	1.5%
$2^+_{mq\bar{q}}$	<0.1%
1^-	<0.1%
1^+	<0.1%

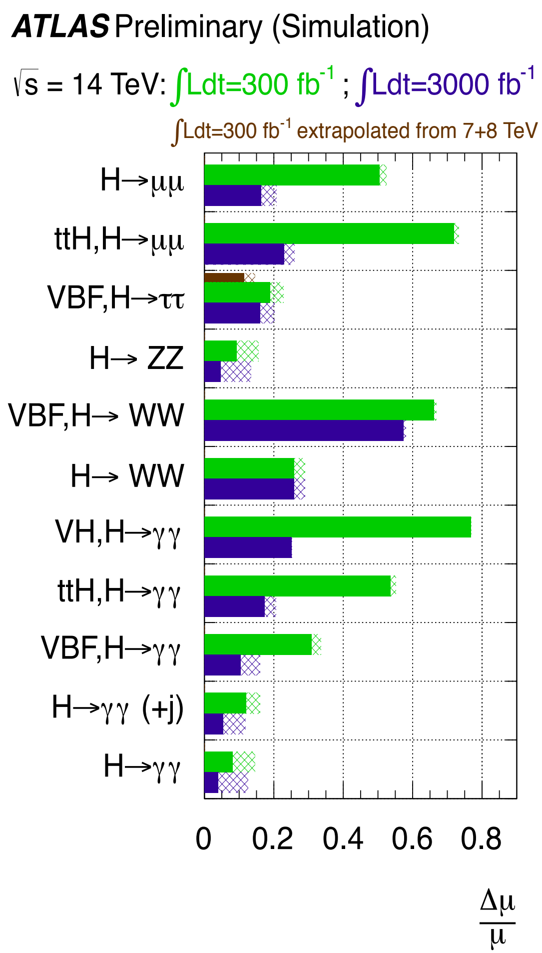
Combination

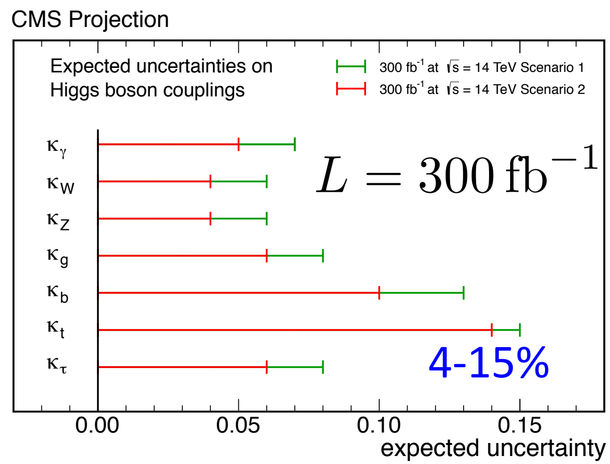
J^P	production	particle	ATLAS CLs	CMS CLs
0^-	gg→X	pseudoscalar	2.2% (H→ZZ*)	0.16% (H→ZZ*)
1^+	qq→X	exotic pseudovect.	0.030% (H→ZZ*,WW*)	<0.1% (H→ZZ*)
1^-	qq→X	exotic vector	0.27% (H→ZZ*,WW*)	<0.1% (H→ZZ*)
2^+	gg/qq→X	graviton minimal coupl	0.042% (gg) (H→γγ,ZZ*,WW*)	0.6% (gg) (H→ZZ*,WW*) 60% (H→γγ)

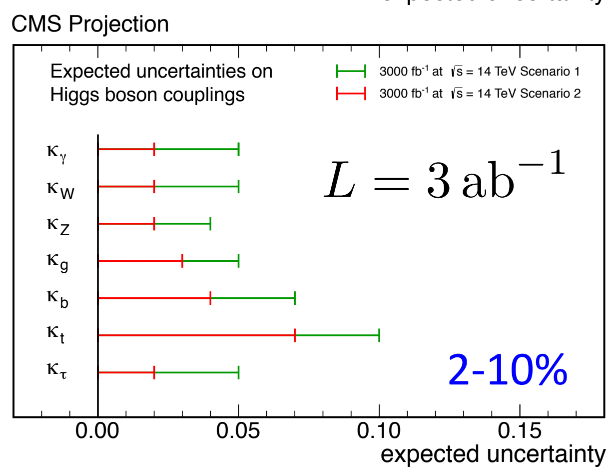


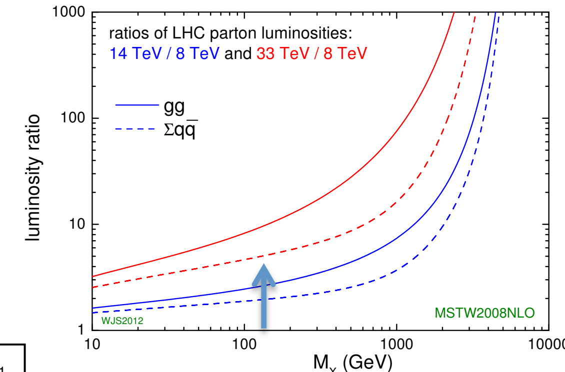
High luminosity LHC: HL-LHC

HL-LHC with L=300 fb^{-1} (3 ab^{-1})
Higgs mass precision ΔM_H ~100 (50) MeV.
Access to top-Yukawa coupling via ttH, and rare decay $H \to \mu\mu$.
Coupling precision ~5% reachable (even few% in κ_γ/κ_Z).
Theory uncertainty dominates









	σ(14TeV)/σ(8TeV)
gg→H	2.6
qq→qqH	2.6
qq→VV	2.1
gg→ttH	4.7

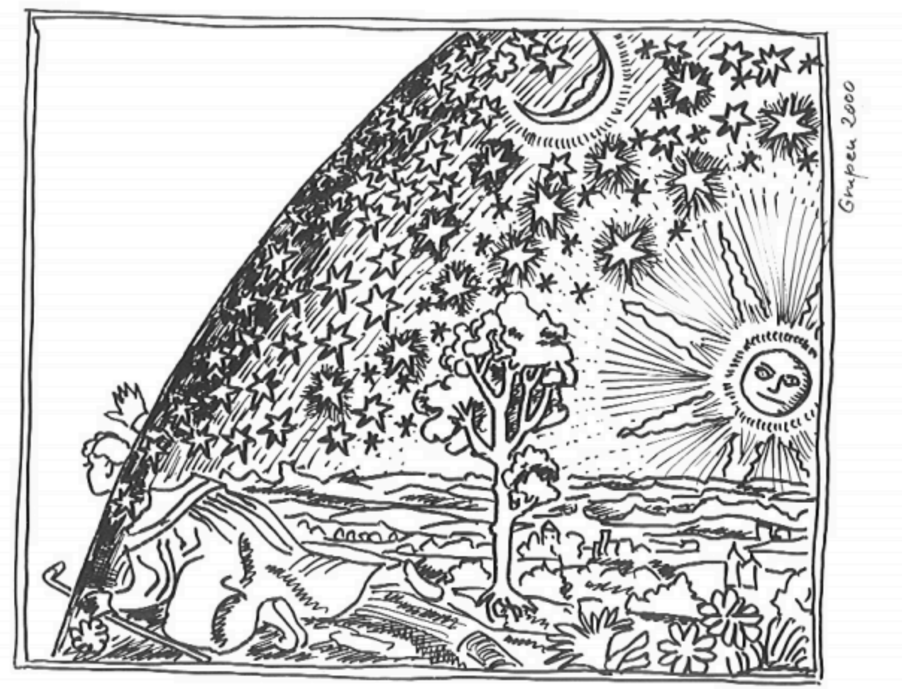
Scenario 1:
current systematic uncert.
Scenario 2:
theory uncert. ↘ 1/2
other systematics ↘ 1/√L

Conclusion

A discovery of the whole experimental and theoretical community:

a "Higgs boson" particle
at m_H~126 GeV

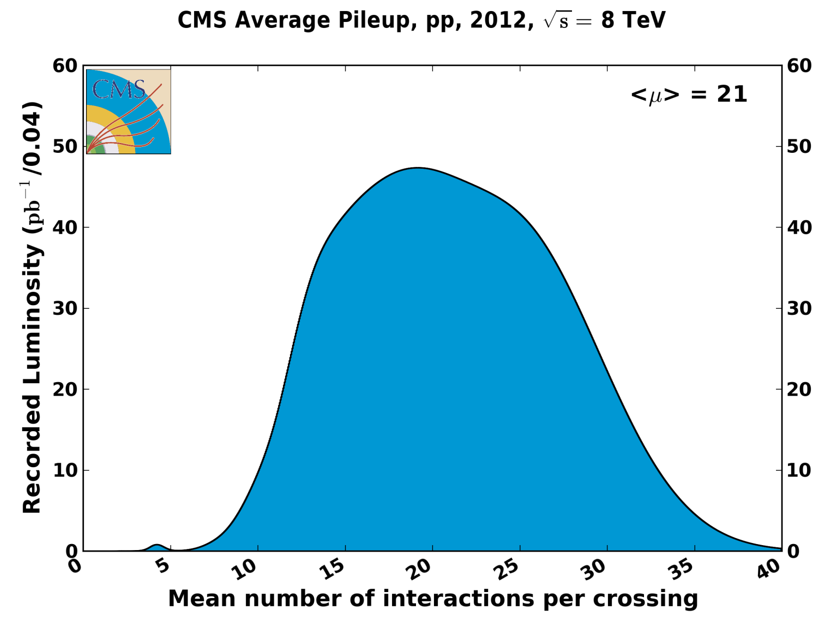
A new era is beginning…

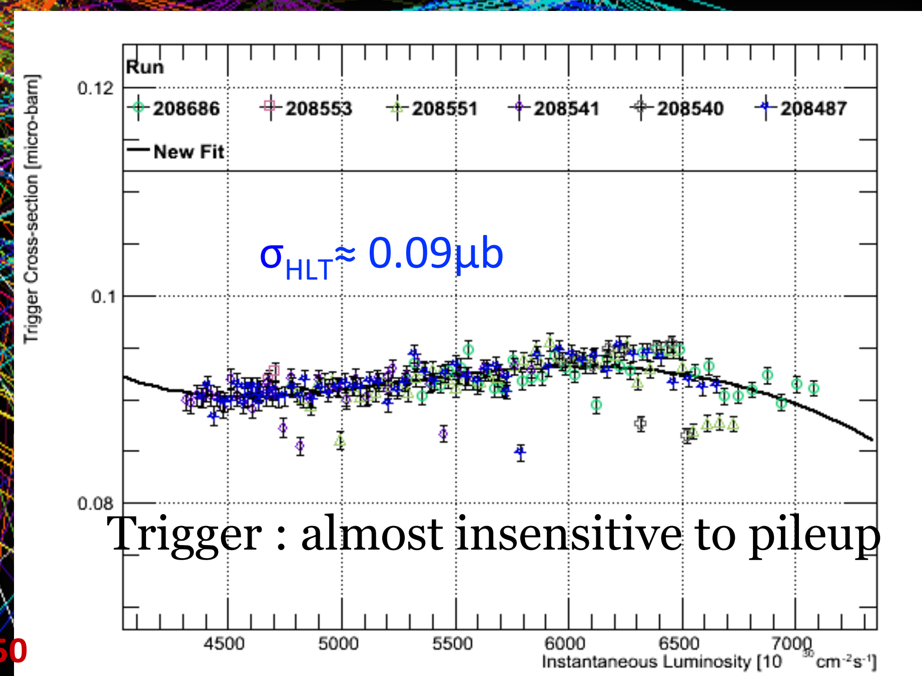


Is there anything beyond the Standard Model?

backup

Pileup

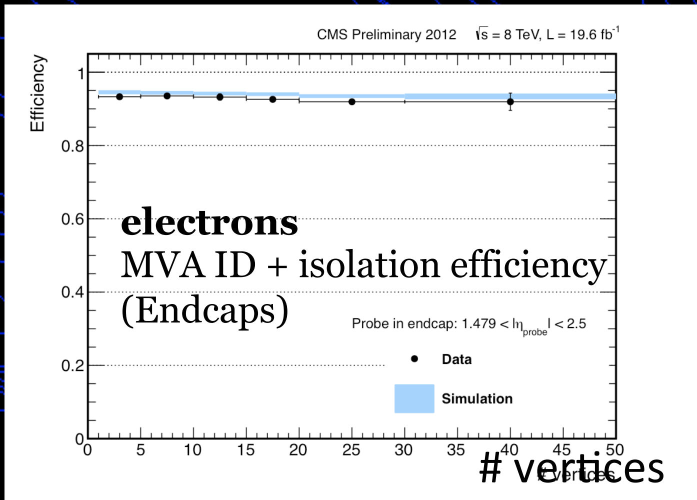


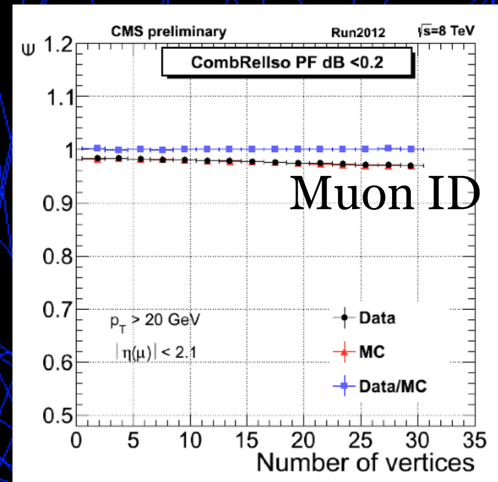


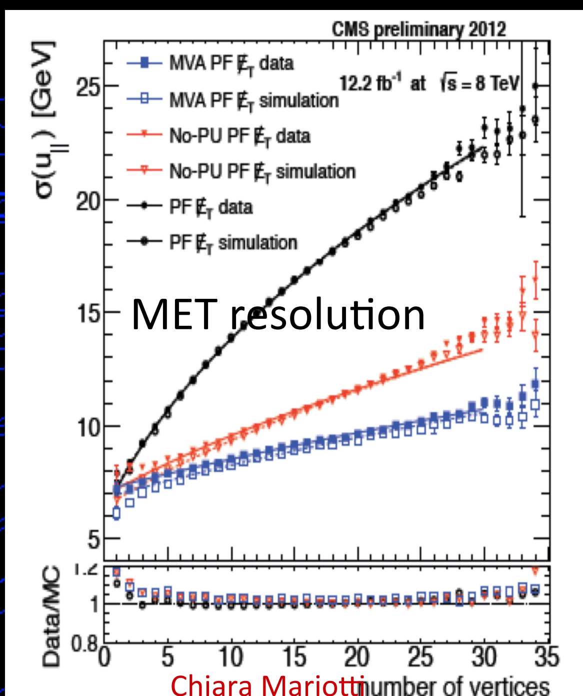
$\sigma_{HLT} \approx 0.09 \mu b$

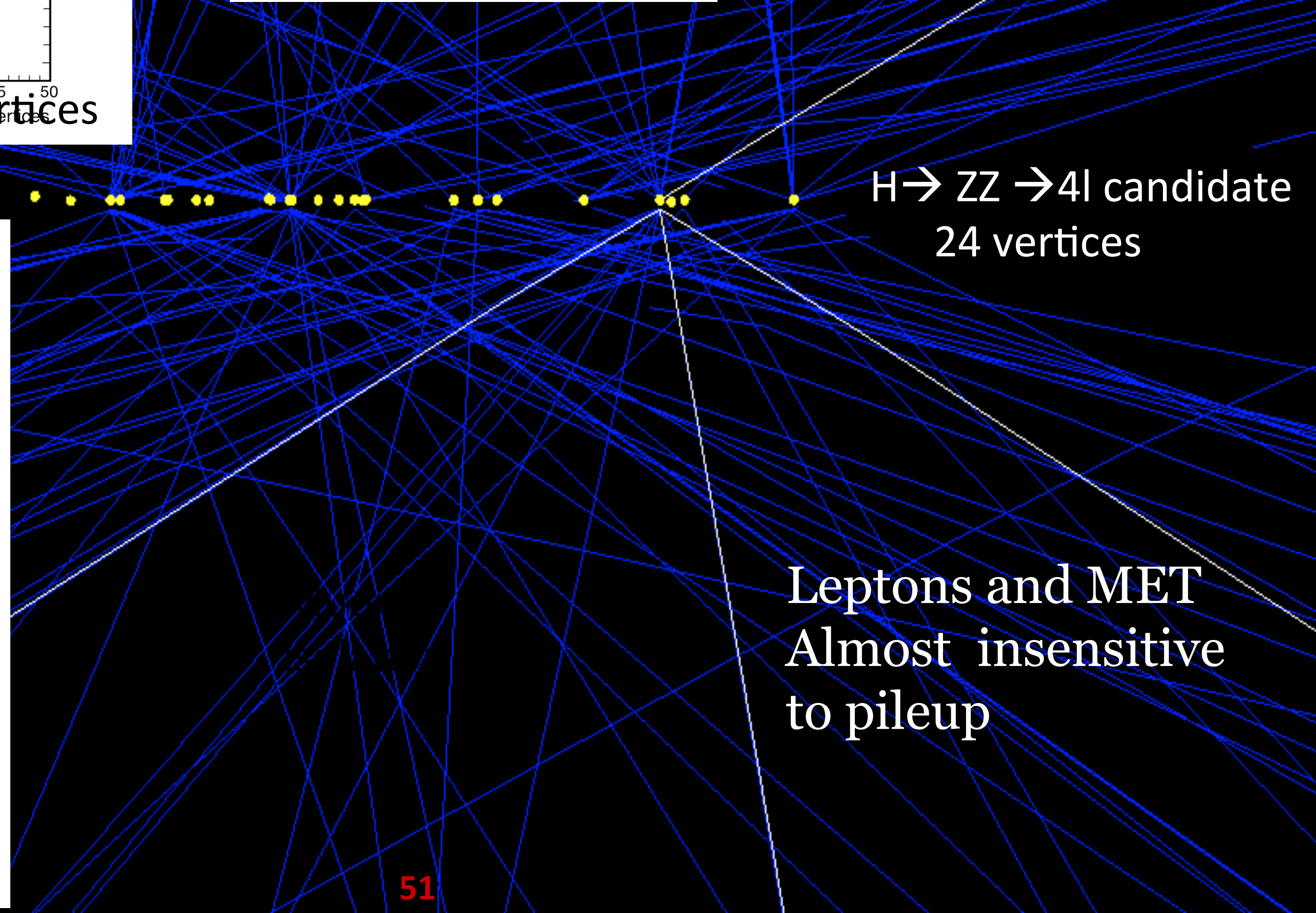
Trigger : almost insensitive to pileup

PU control





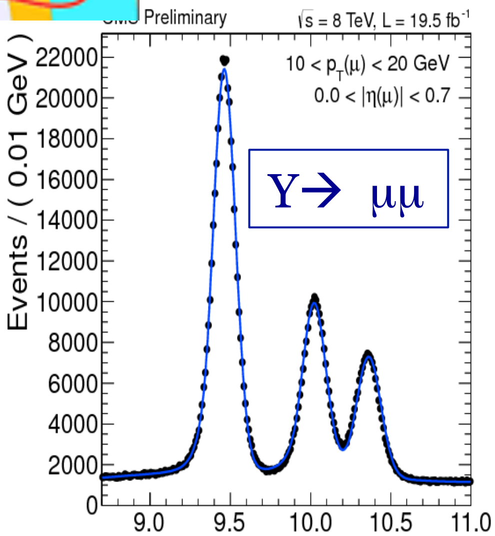


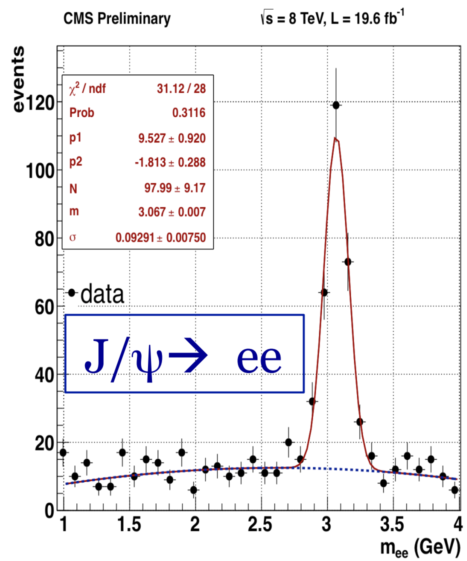


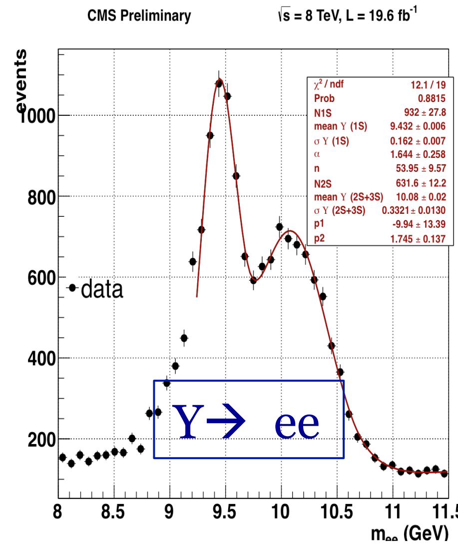
H→ ZZ →4l candidate
24 vertices

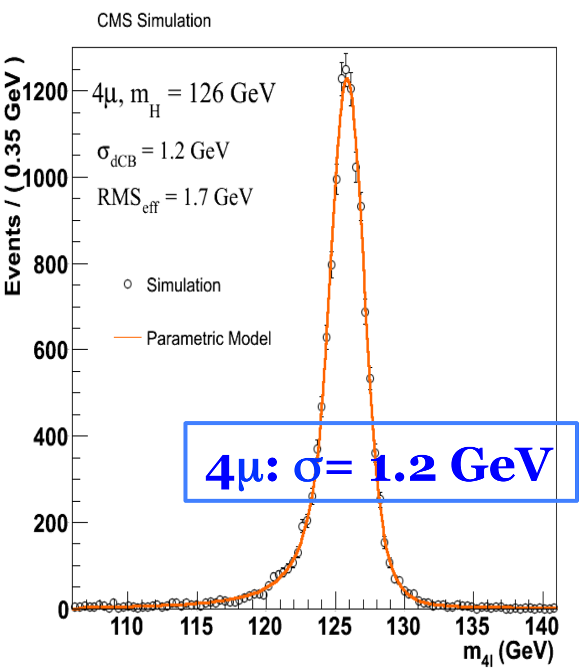
Leptons and MET
Almost insensitive
to pileup

Electrons and Muons





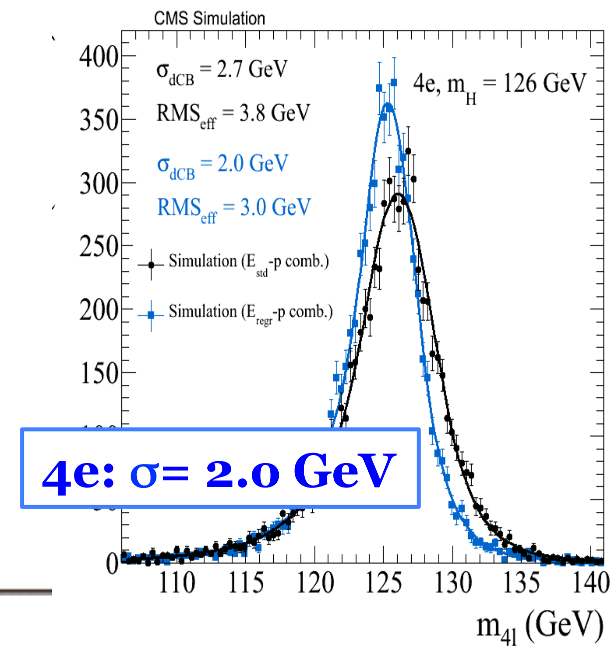




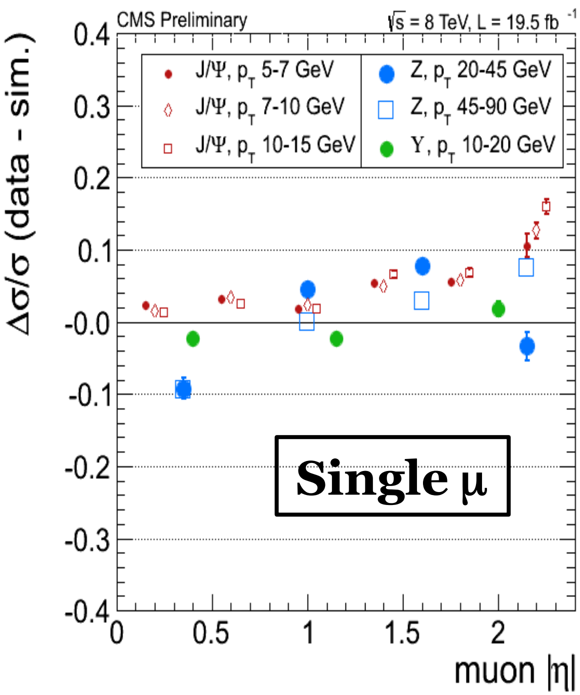
momentum scale:

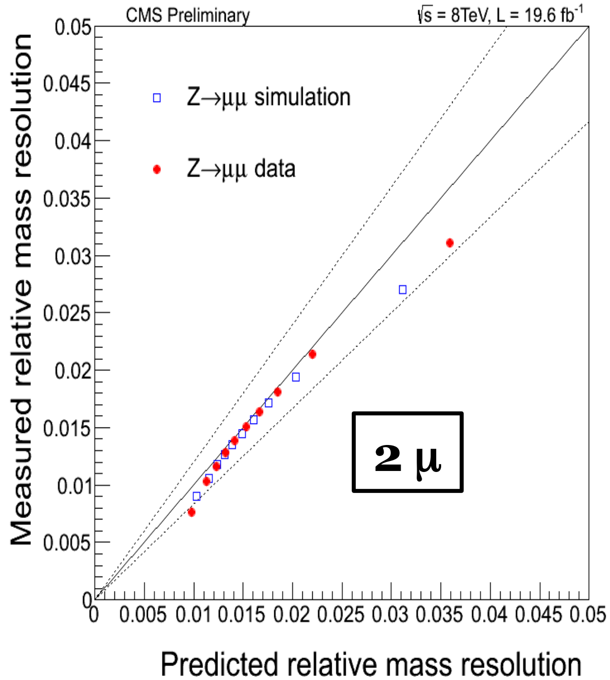
0.1% for muons

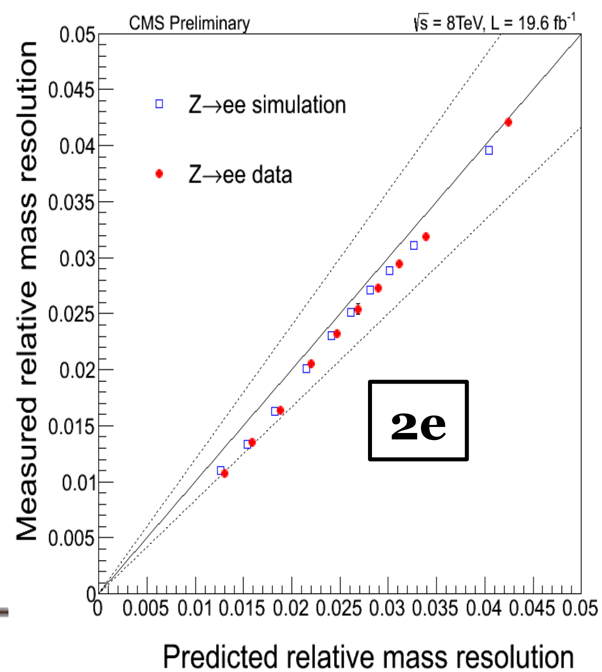
0.2% for electrons of 35<pT<50
up to 1.5% at low pT

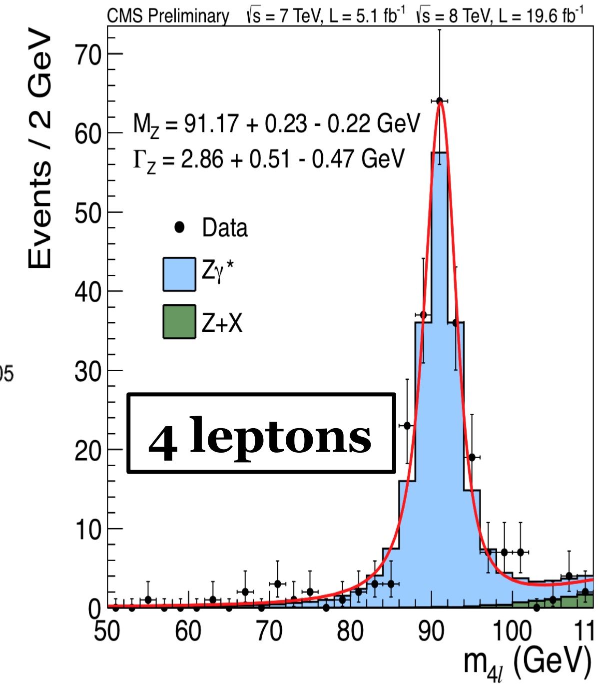


Resolution







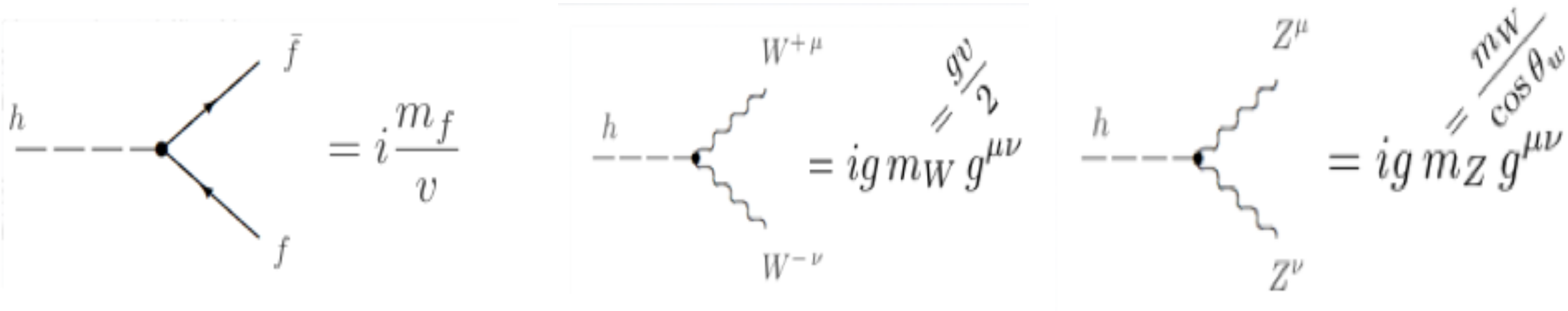


Good understanding of the lepton, dilepton and 4 lepton resolution

Lepton resolution= 1 - 2%
uncertainty: 20%

Validated in situ with Z(4l)

Higgs couplings

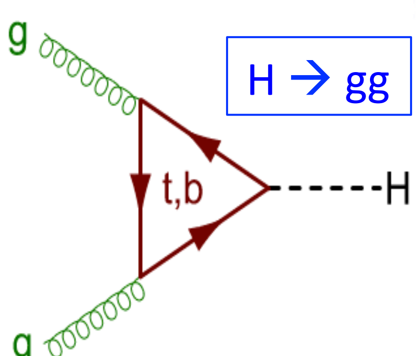


$$= i\frac{m_f}{v}$$

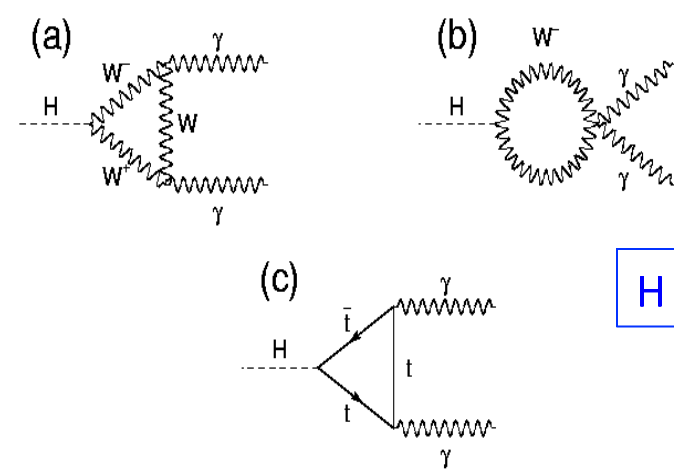
$$= ig\, m_W\, g^{\mu\nu} \quad (= gv/2)$$

$$= ig\, m_Z\, g^{\mu\nu} \quad (= m_W/\cos\theta_w)$$

No direct coupling to massless particles



Top is dominating



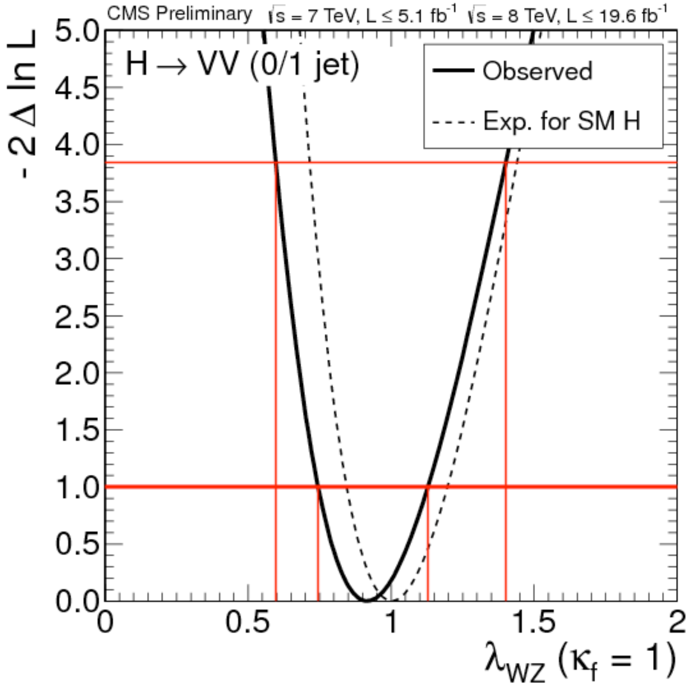
$|\alpha\, \kappa_V + \beta\, \kappa_f|^2$, $\alpha/\beta = -0.2$

destructive interference between W and top

Custodial symmetry

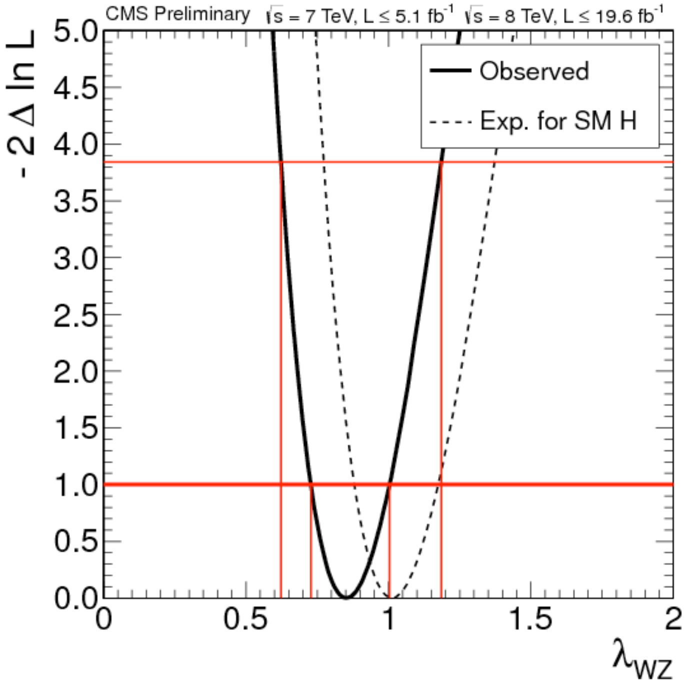
Testing custodial symmetry (measuring HW/HZ couplings) will tell us if the the object produced is Higgs-like.

Only 0/1 jet ZZ, WW. κ_f fixed to SM



[0.75,1.13] @ 68% CL

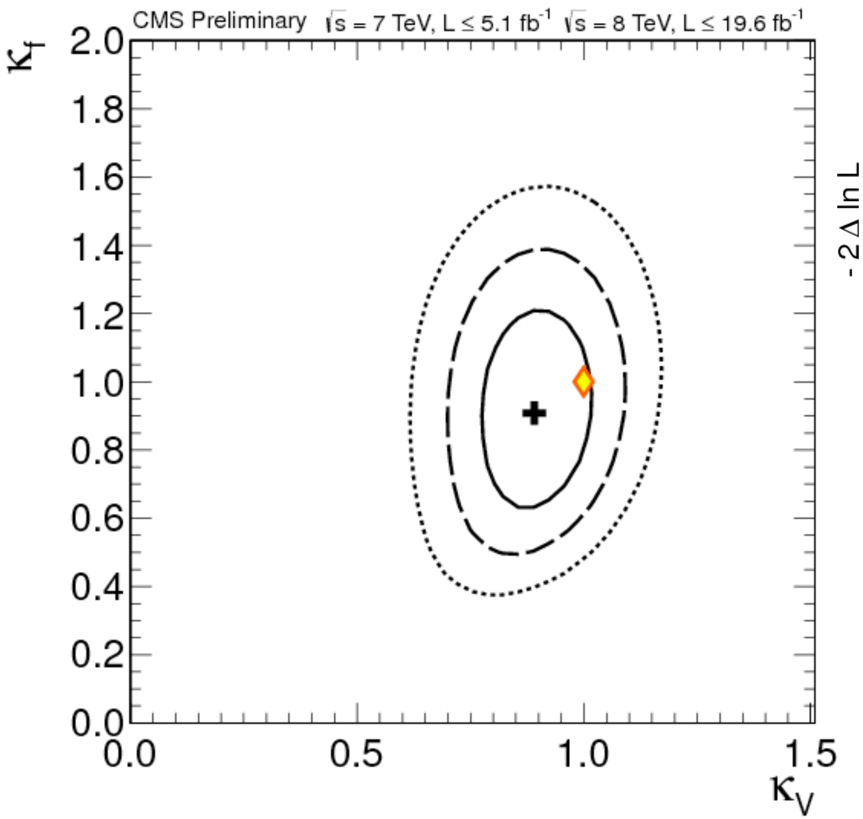
All channels. κ_f profiled.



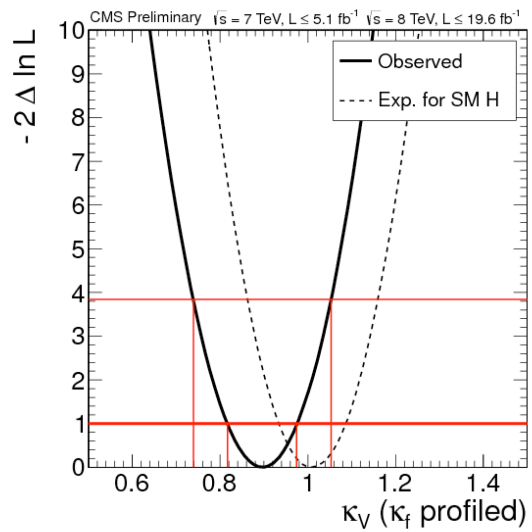
[0.73,1.00] @ 68% CL

Consistent results with the two approaches.

Couplings: κ_V, κ_f



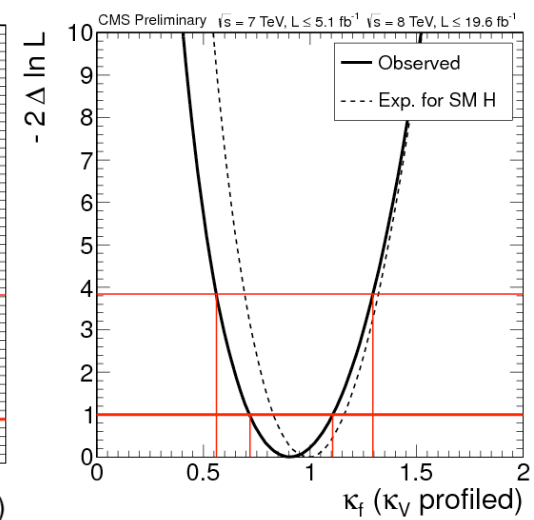
W/Z bosons



[0.81, 0.97] @ 1σ

[0.73, 1.05] @ 95%

Fermions

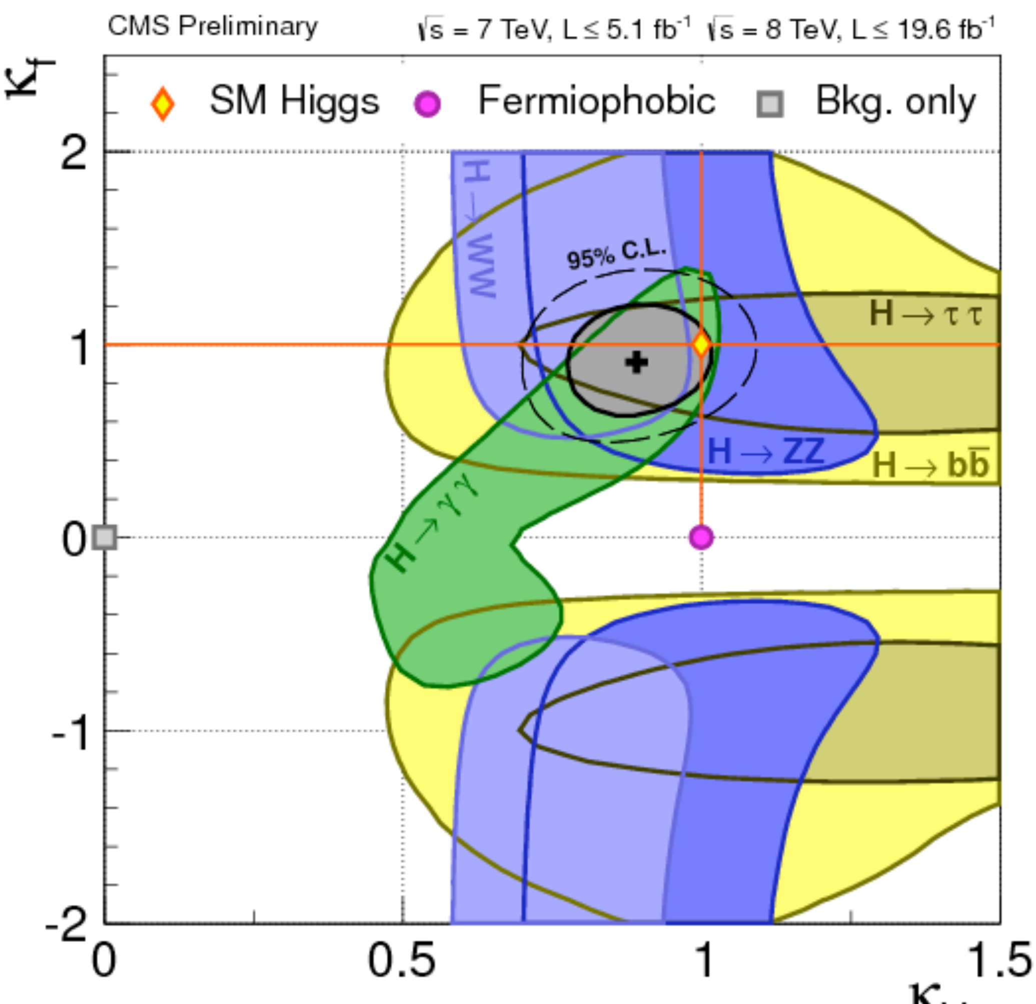


[0.71, 1.11] @ 1σ

[0.55, 1.31] @ 95%

- Good consistency with SM hypothesis.

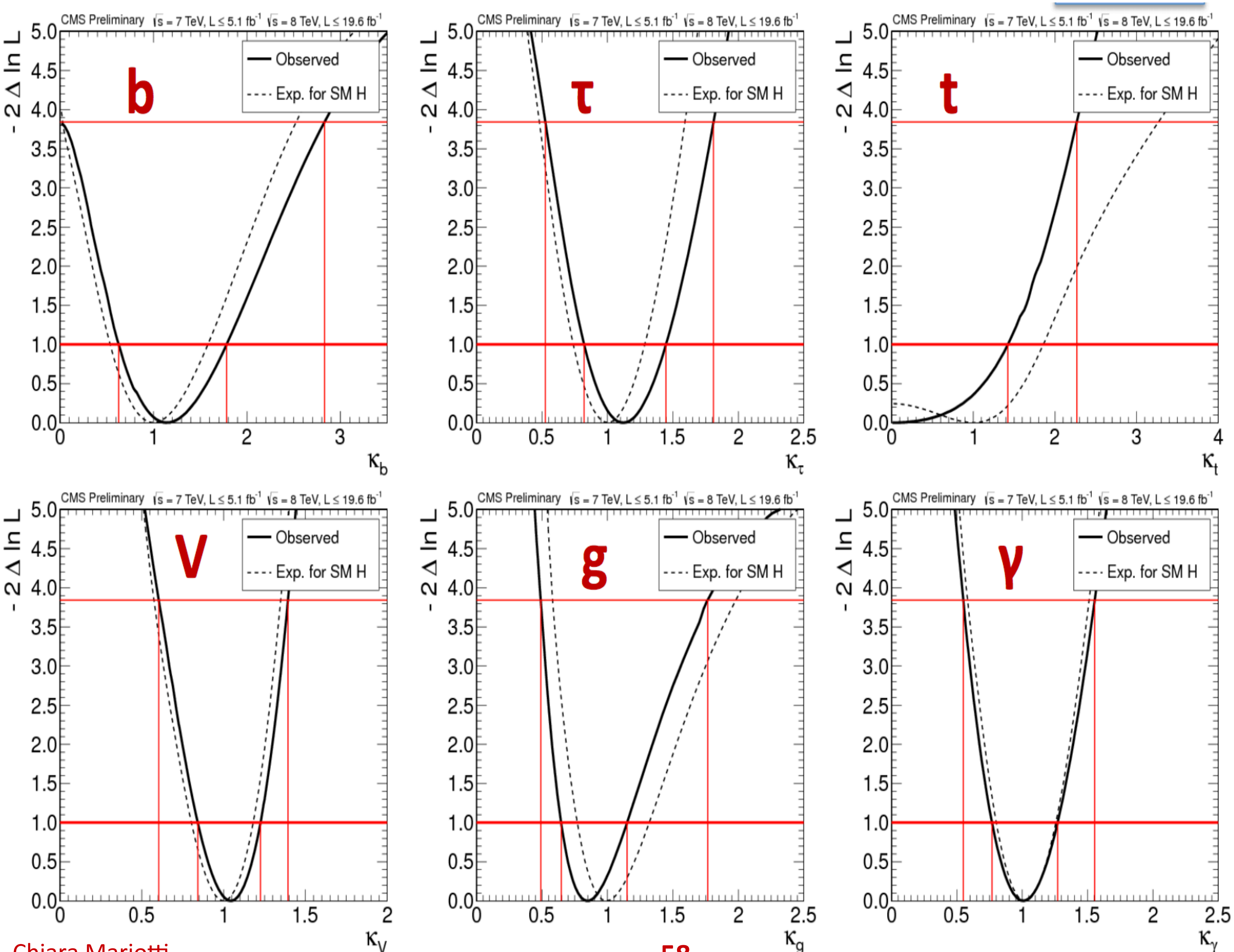
Couplings: κ_V, κ_f teamwork



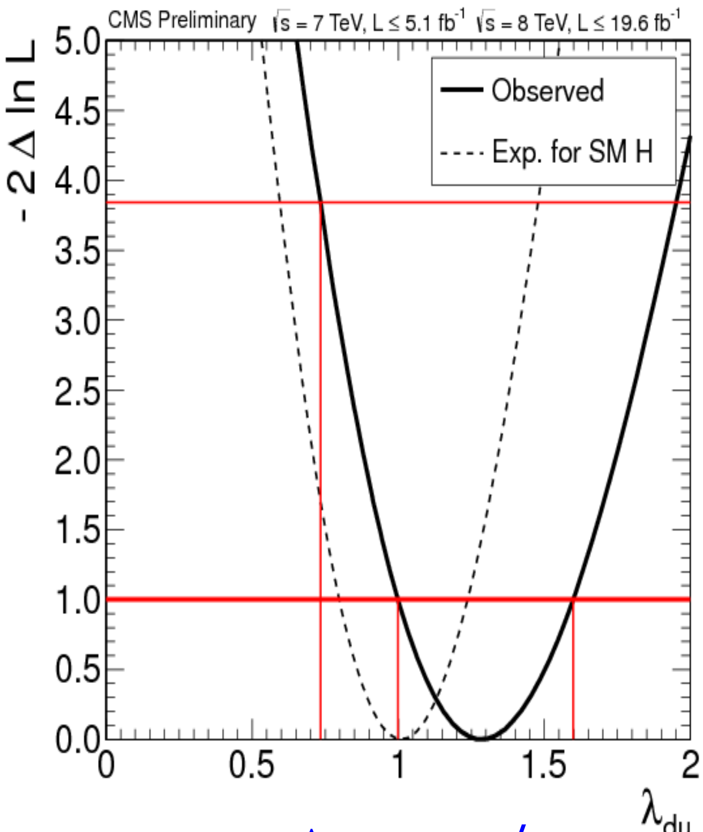
Exclusion of $\kappa_f < 0$ from combination of:

- VV modes: $\kappa_V > 0.7$
- ττ boosted: $|\kappa_f| \sim 1$
  (ττ VBF sensitive to κ_V)
- γγ: $\kappa_f = -1$, $\kappa_V = 1$ would require BR(γγ) ~2.3*SM

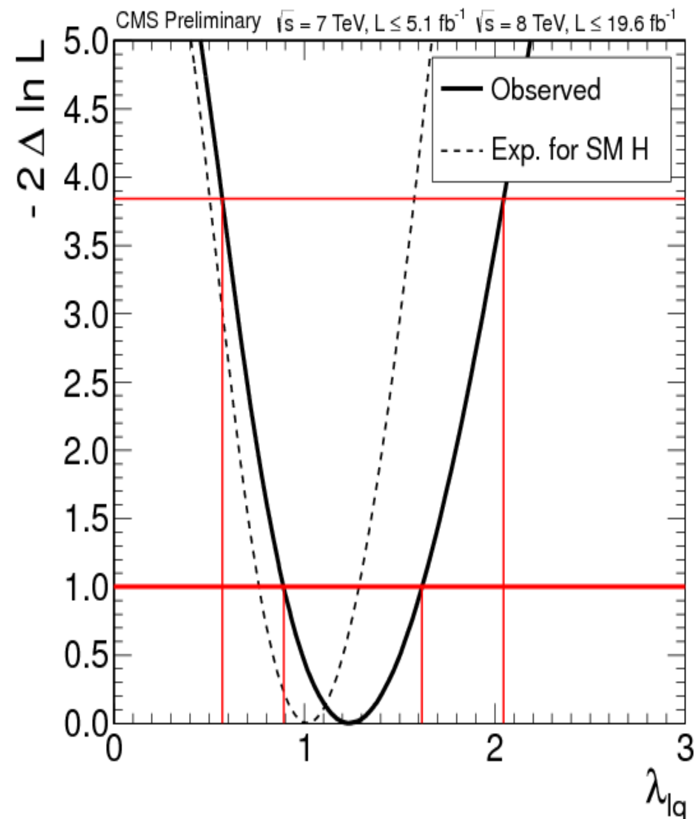
Fit all couplings at once



Fermion universality



$\Lambda_{du} = \kappa_d/\kappa_u$



$\Lambda_{lu} = \kappa_l/\kappa_u$

Total width with free couplings

- If no assumption is made, all couplings are degenerate with the total width:

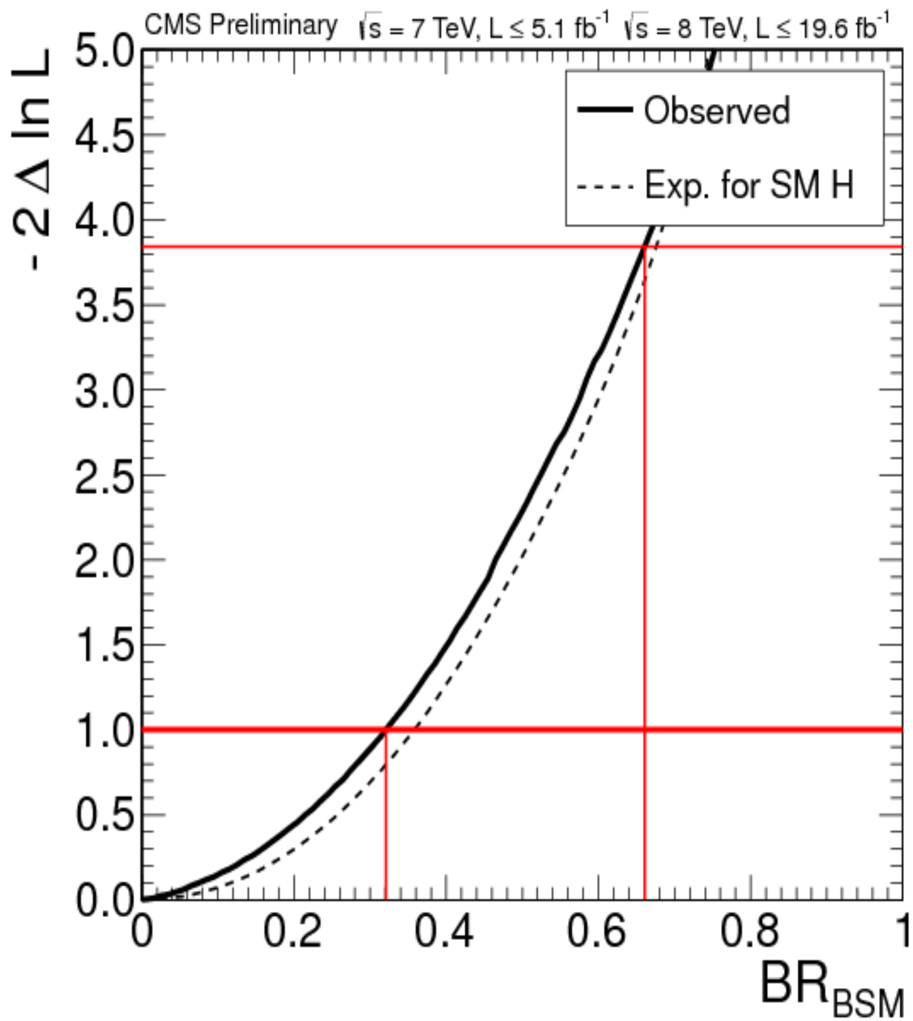
  All $\sigma \cdot BR$ scale as $\kappa^4 / (\kappa^2 \Gamma_{SM} + \Gamma_{BSM})$

- However, in most EWSB models

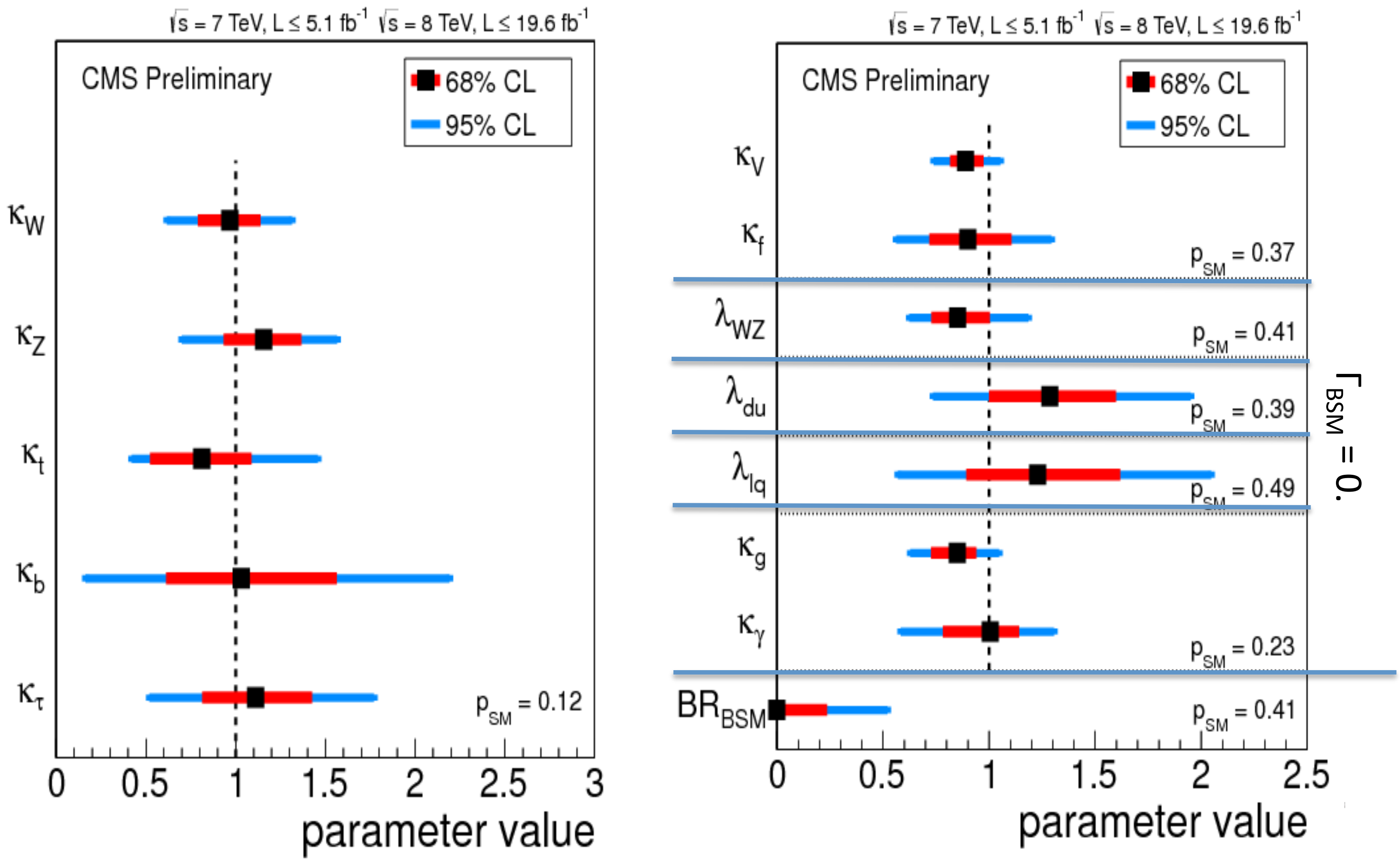
  $\kappa_V \leq 1$
- If that constraint is imposed, one can put an upper limit on the total width with no other assumption on the other couplings.

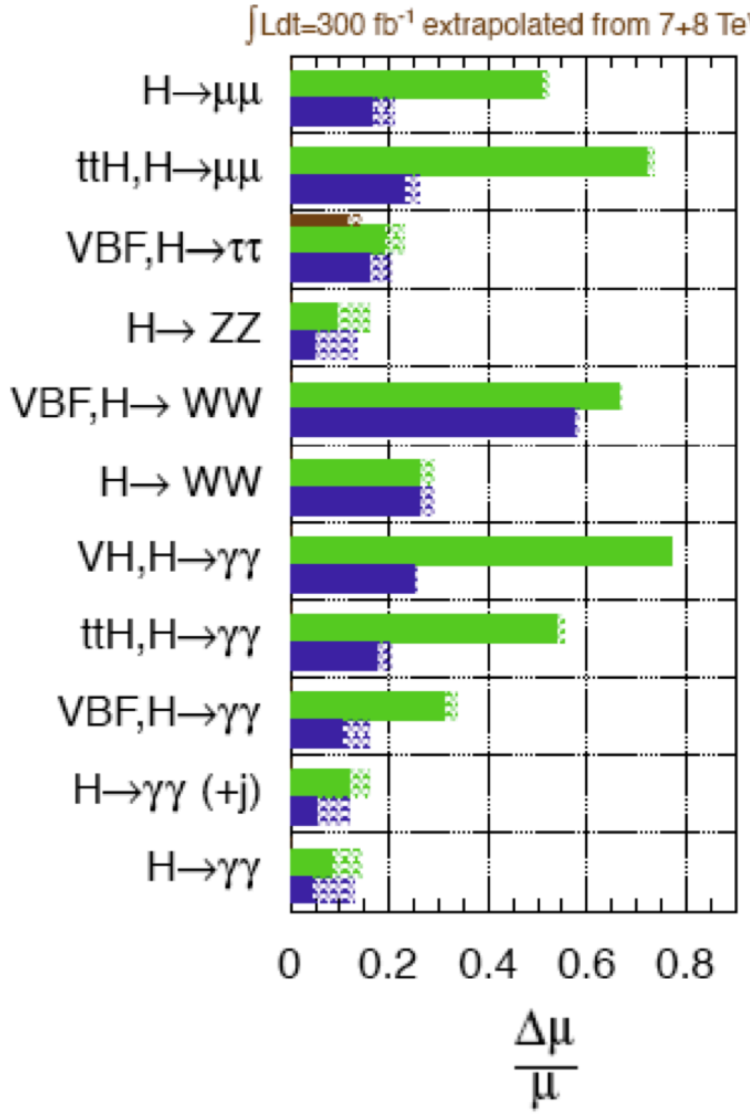
- Upper limit to BSM decays imposing $\kappa_V \leq 1$:

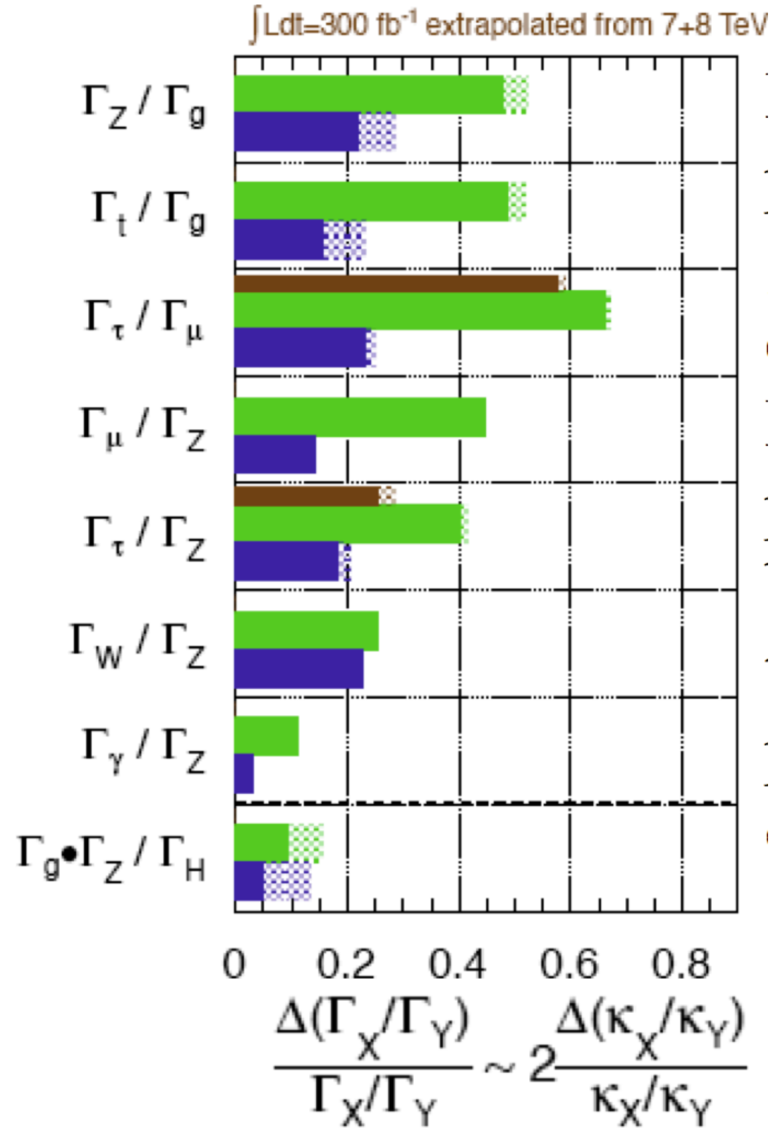
  $BR_{BSM} < 0.64$ @ 95% CL



Summary of all searches for coupling deviations





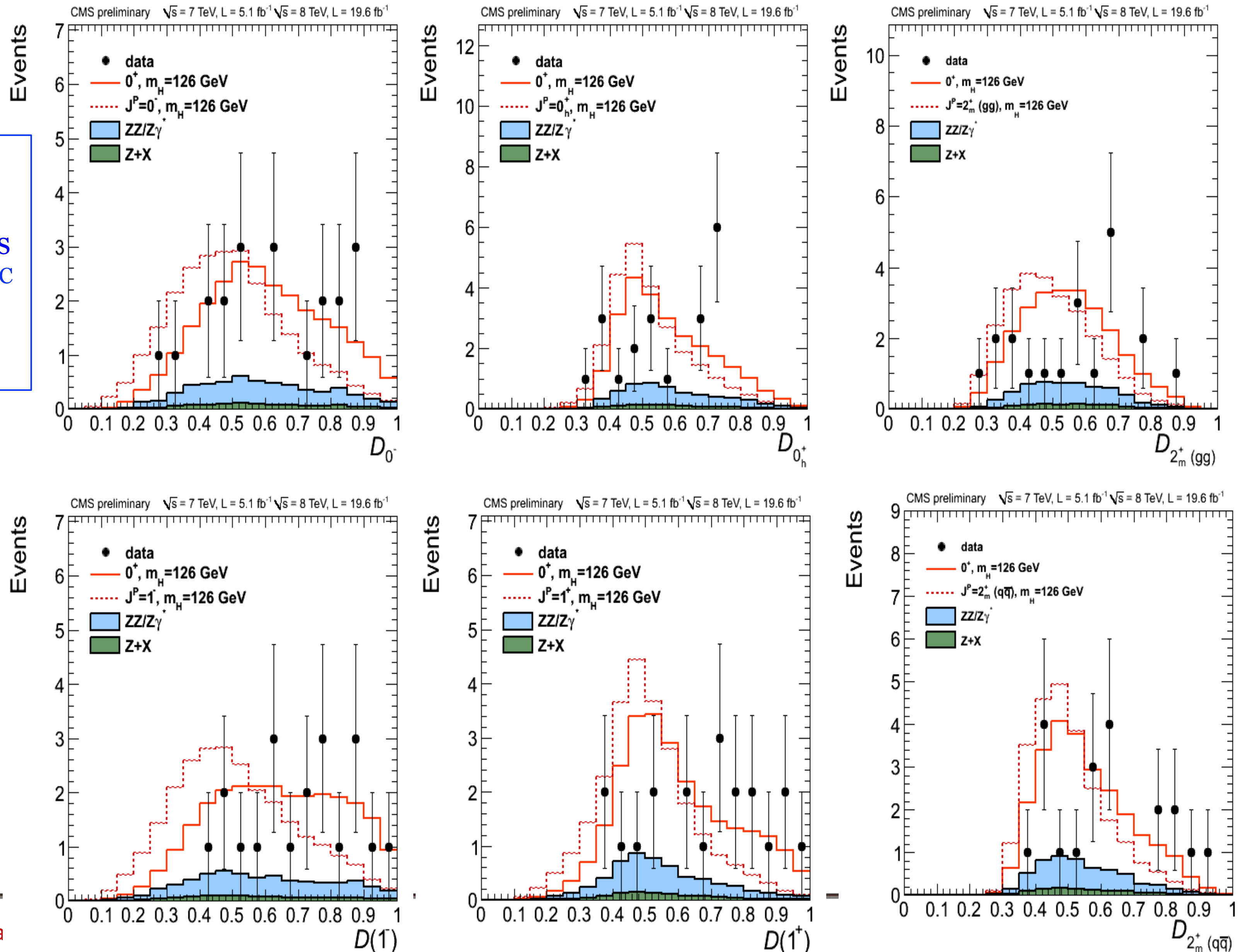


	$300\ \mathrm{fb}^{-1}$	$3000\ \mathrm{fb}^{-1}$
κ_V	3.0% (5.6%)	1.9% (4.5%)
κ_F	8.9% (10%)	3.6% (5.9%)

J^{PC}

$$\mathcal{D}_{J^P} = \frac{\mathcal{P}_{\rm SM}}{\mathcal{P}_{\rm SM} + \mathcal{P}_{J^P}} = \left[1 + \frac{\mathcal{P}_{J^P}(m_{Z_1}, m_{Z_2}, \vec{\Omega} | m_{4\ell})}{\mathcal{P}_{\rm SM}(m_{Z_1}, m_{Z_2}, \vec{\Omega} | m_{4\ell})}\right]^{-1}$$

MELA:
can describe
the kinematics
of different J^{PC}
boson decay



Spin 2 combination: results

CLs values for $2^+_m(gg)$

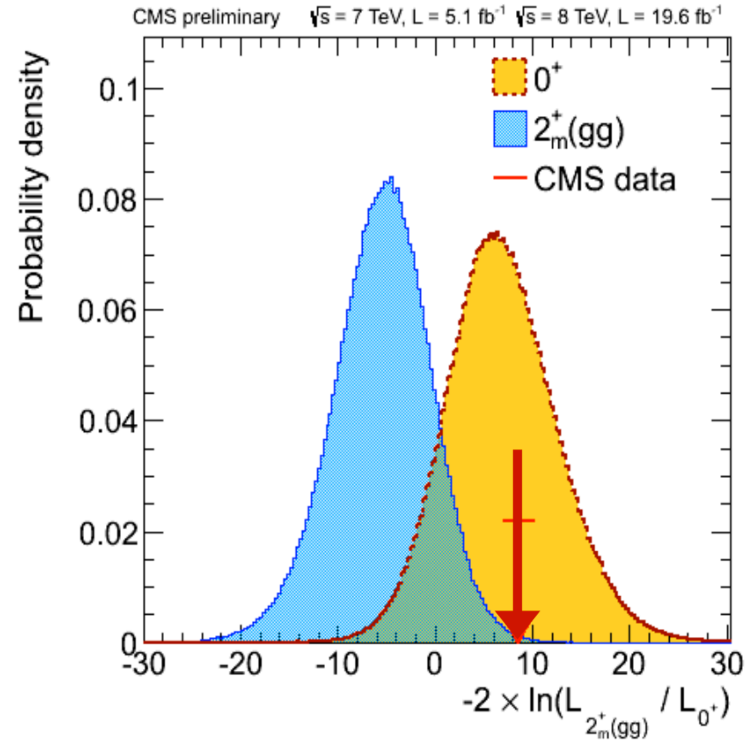
- Expected results with μ=1"

ZZ	WW	Comb
6.8%	1.4%	0.2%

- Observed results at measured μ

ZZ	WW	Comb
1.4%	14%	0.6%

- Observed results weaker than expected especially for WW due to best fit μ < 1 (like having less luminosity)
- Observed better than expected for ZZ due to a fluctuation



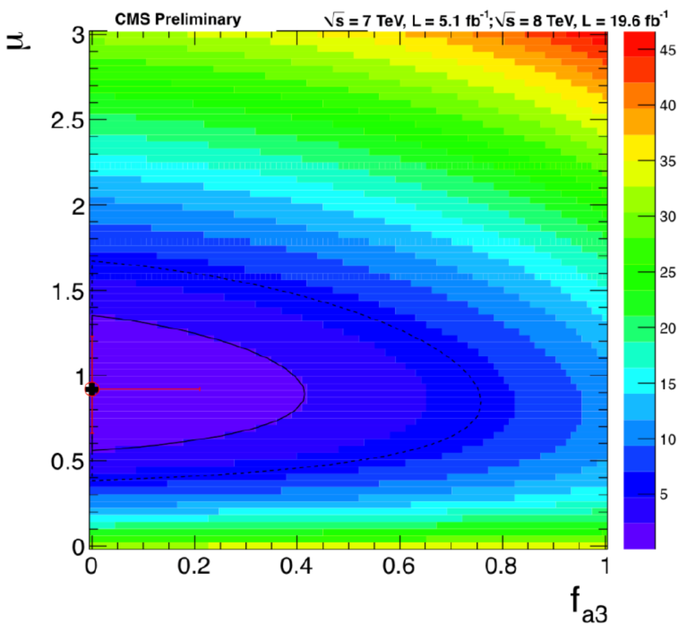
The observation is well compatible with SM Higgs expectations (0^+).

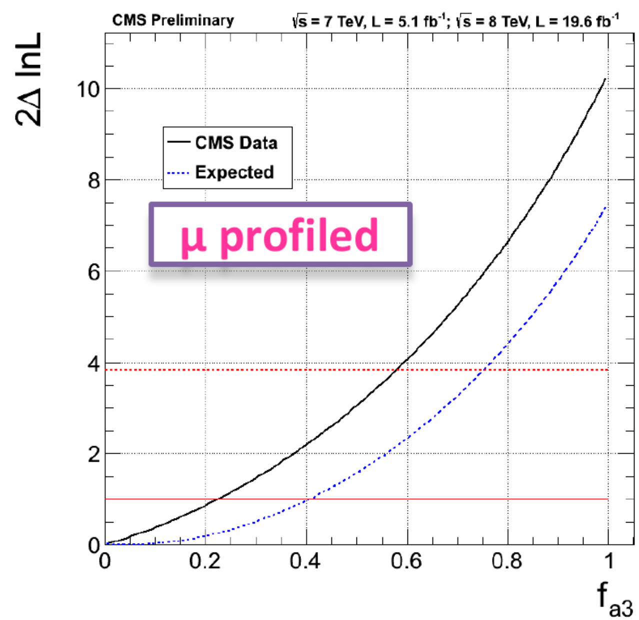
The data disfavours the the 2^+_m(gg) hypothesis with a CLs value of 0.6%

H→ZZ →4l: Mixed parity

$$A(X \to V_1 V_2) = v^{-1} \epsilon_1^{*\mu} \epsilon_2^{*\nu} \left(a_1 g_{\mu\nu} m_X^2 + a_2\, q_\mu q_\nu + a_3 \epsilon_{\mu\nu\alpha\beta}\, q_1^\alpha q_2^\beta \right)$$

$$f_{a3} = |A_3|^2/(|A_1|^2+|A_3|^2)$$



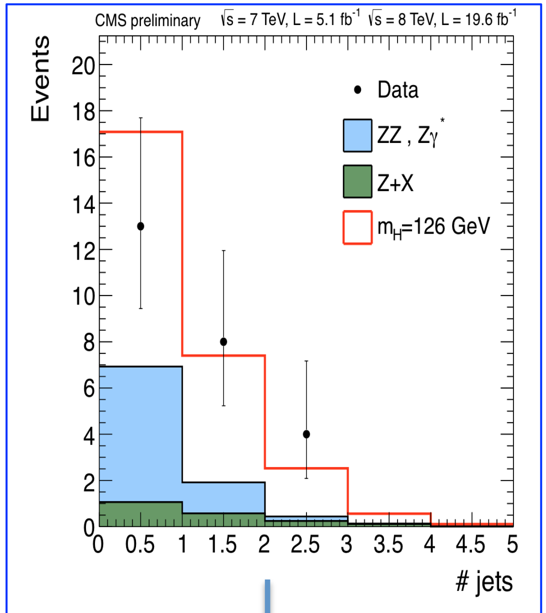


$f_{a3} = 0.00^{+0.23}_{-0.00}$

$f_{a3} < 0.58$ @ 95% C.L.

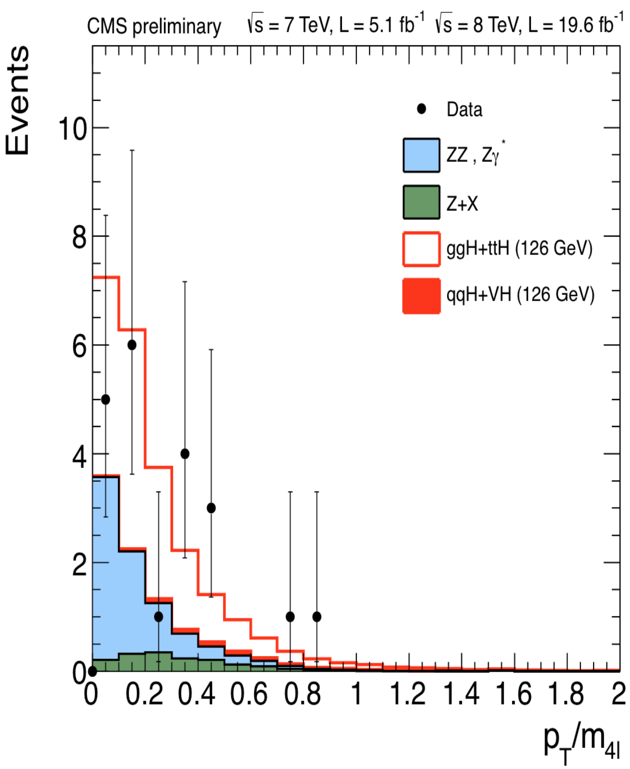
- SM 0+ decay dominated by A1
- 0- decay dominated by A3

Jet categories



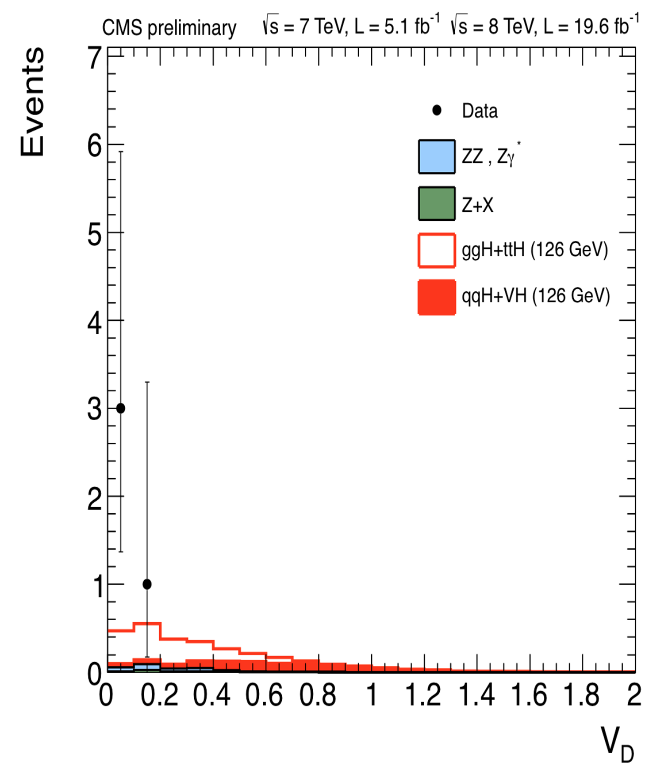
Un-tagged (0/1 jet)
Use $pT_{m_{4l}}/m_{4l}$

(VBF fraction~5%)



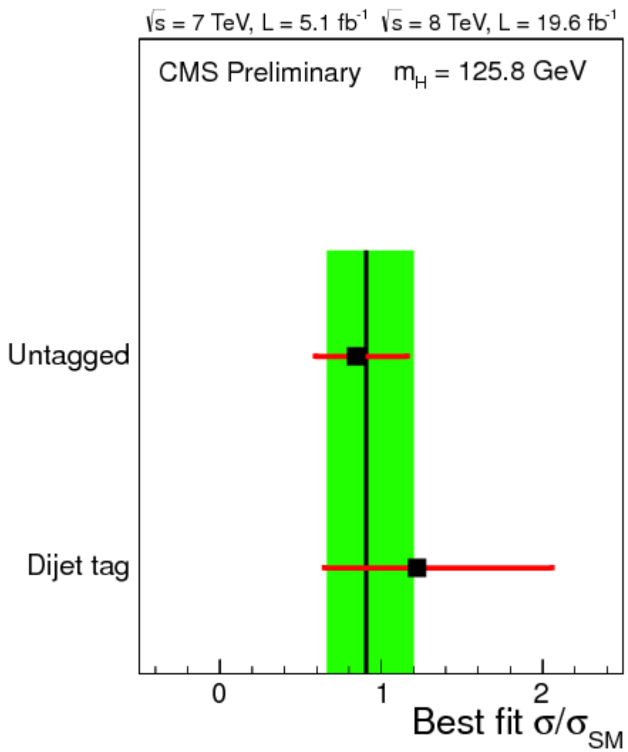
Di-jet Tagged (>=2 jets)
Use Fisher Discriminant (m_{jj}, $\Delta\eta_{jj}$)

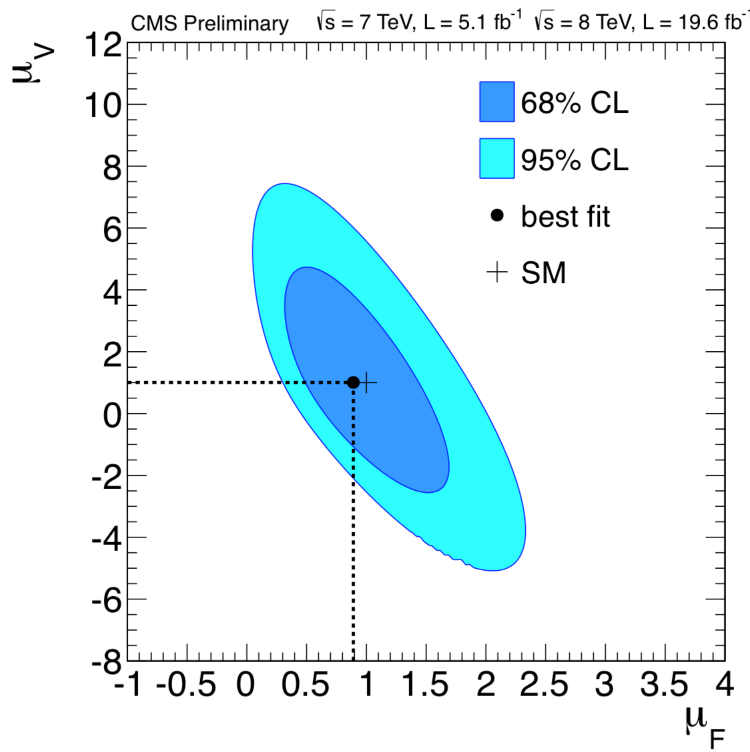
(VBF fraction~20%)



121.5 < M(4l) < 130.5 GeV

Jet categories to measure couplings

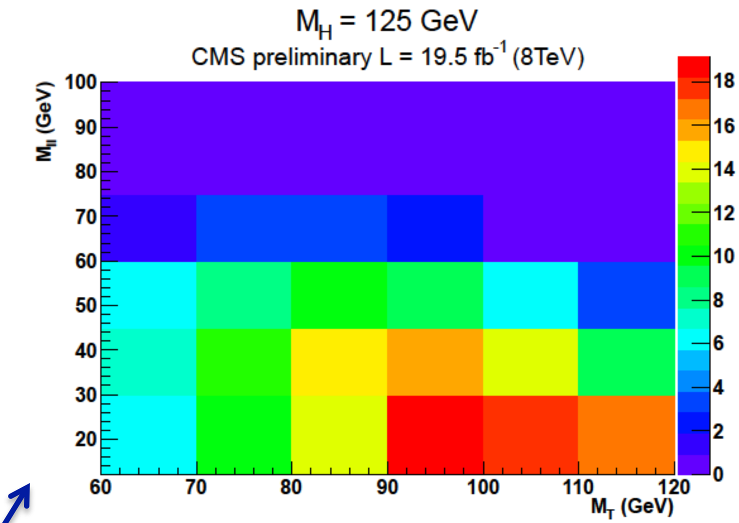


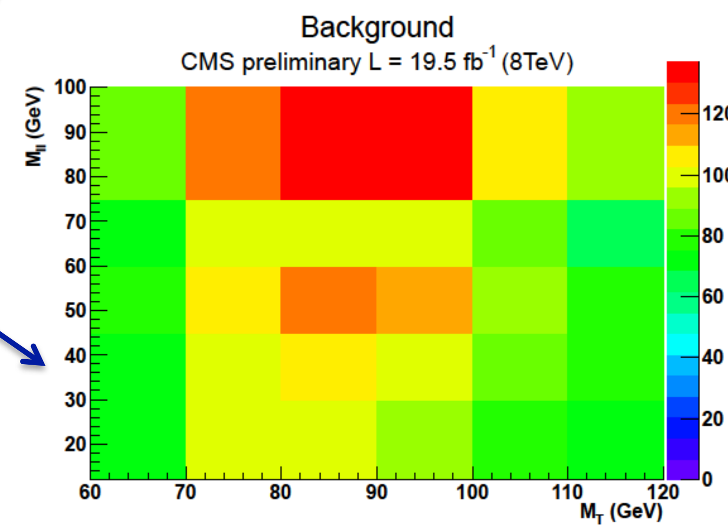


σ/σ_{SM} @ 125.7 GeV = 0.92 ± 0.28

H →WW→2l2ν: strategy

- Pre-selection cuts:
  (on lepton p_T, MET, anti-b-tag..)
- Jet categories: 0 Jet
  1 Jet
  2 Jets with VBF topology
- 0 & 1 jet category subdivided in:
  - Different Flavour (DF)
    2D (M_T, m_{ll}) shape analysis
  - Same Flavour (SF)
    Cut-based analysis

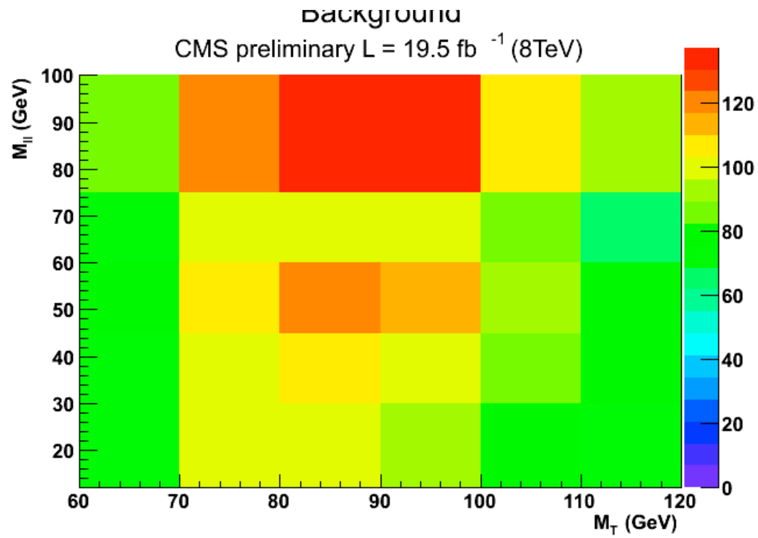




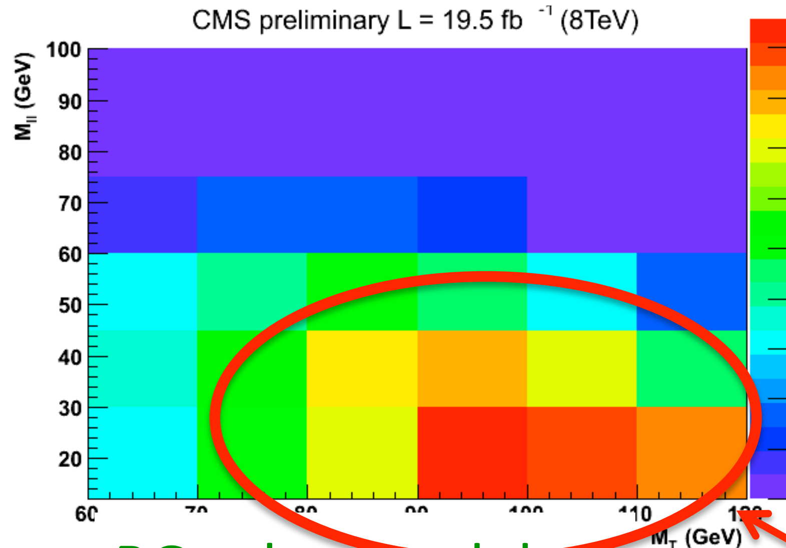
$$M_T = \sqrt{2 p_T^{\ell\ell} E_T^{miss} \cos(\Delta\phi_{\ell\ell} - E_T^{miss})}$$

WW→ℓνℓν 2D analysis (0 jet bin)

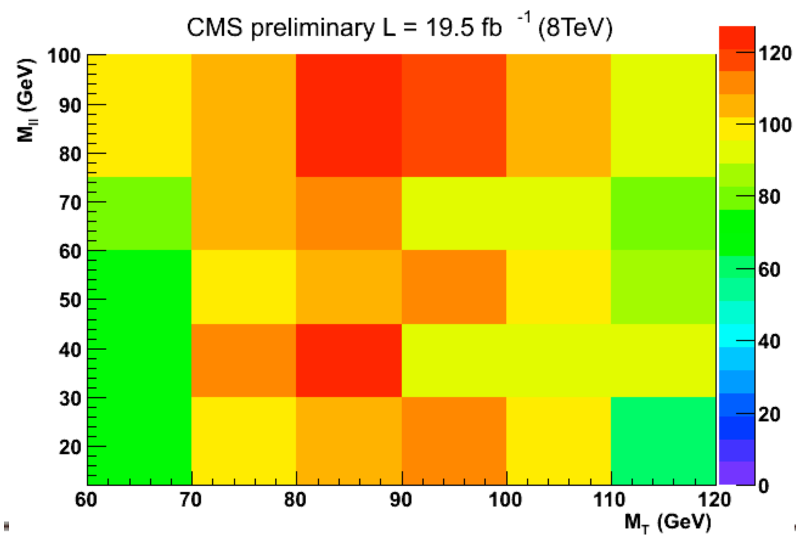
MC Background



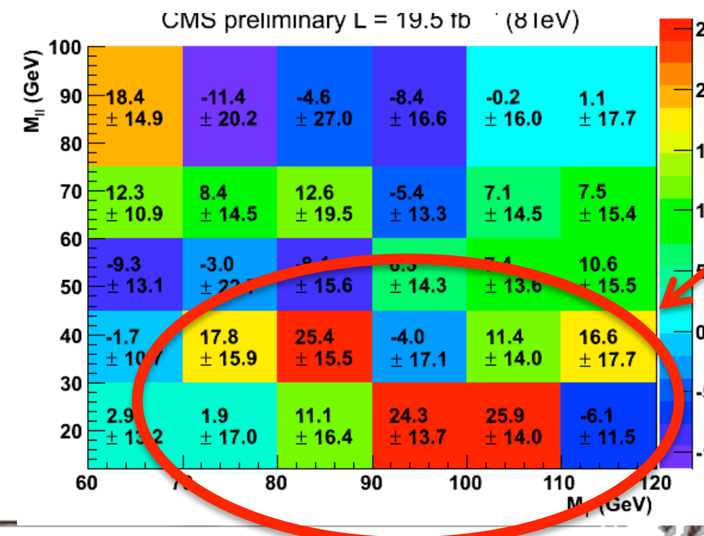
Higgs signal at 125 GeV



Data



BG subtracted data

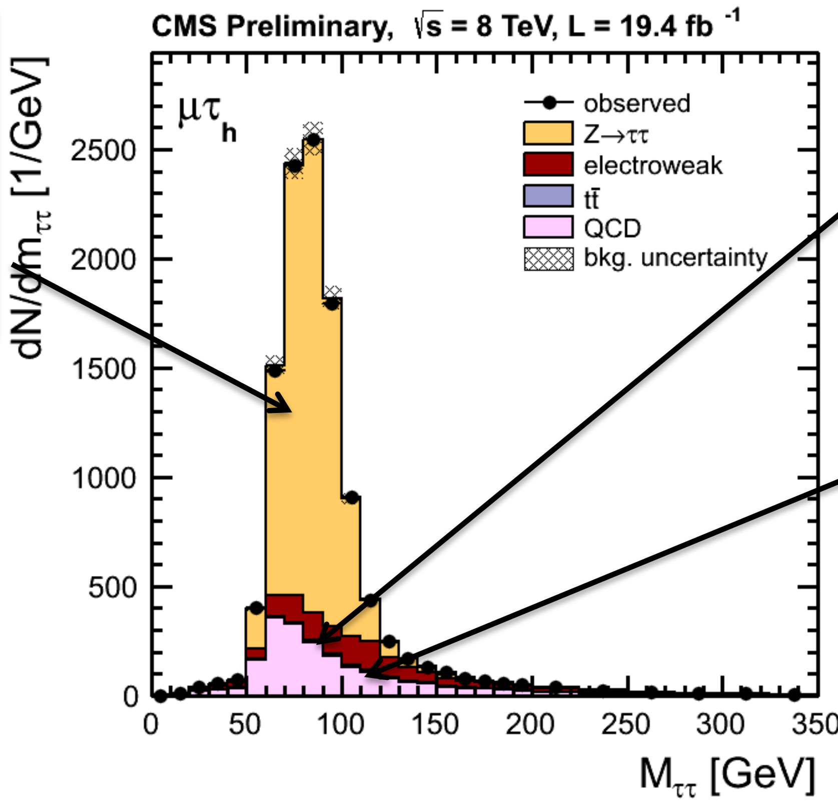


Signal region

Chiara Mariotti

Anatomy of the analysis

$Z\to\tau\tau$ Embedding:
$Z\to\mu\mu$ data, replace μ with simulated τ decay
Normalization from $Z\to\mu\mu$ data
Syst: 5%



W+jets
Shape from simulation
Normalization from control region
Syst: 10-20%

QCD
SS data, corrected for SS/OS ratio
Syst: 10%

Strategy:
- Select isolated, well-identified **leptons**, $\boldsymbol{\tau_h}$
- Topological cuts (e.g. m_T in $\boldsymbol{l\tau_h}$) to suppress backgrounds
- Categorize events based on number of jets, $\tau\ p_T$
- Template fit to $m_{\tau\tau}$ shape