Higgs and More: Results from the LHC

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Loops and Legs
in Quantum Field Theory
Leipzig, 27. April 2016

Outline

The Higgs boson (based on full Run 1 datasets)

Introduction

Status of analyses: Decays and production modes
Differential measurements

Properties: Mass, Spin, CP, Width, Couplings

Other decays

Searches for additional Higgs bosons

ATLAS and CMS published > 65 papers related to Higgs boson physics in 2015 and 2016!

Results from Run 2 at $\sqrt{s}$ = 13 TeV (started in June 2015)

W/Z, Dibosons

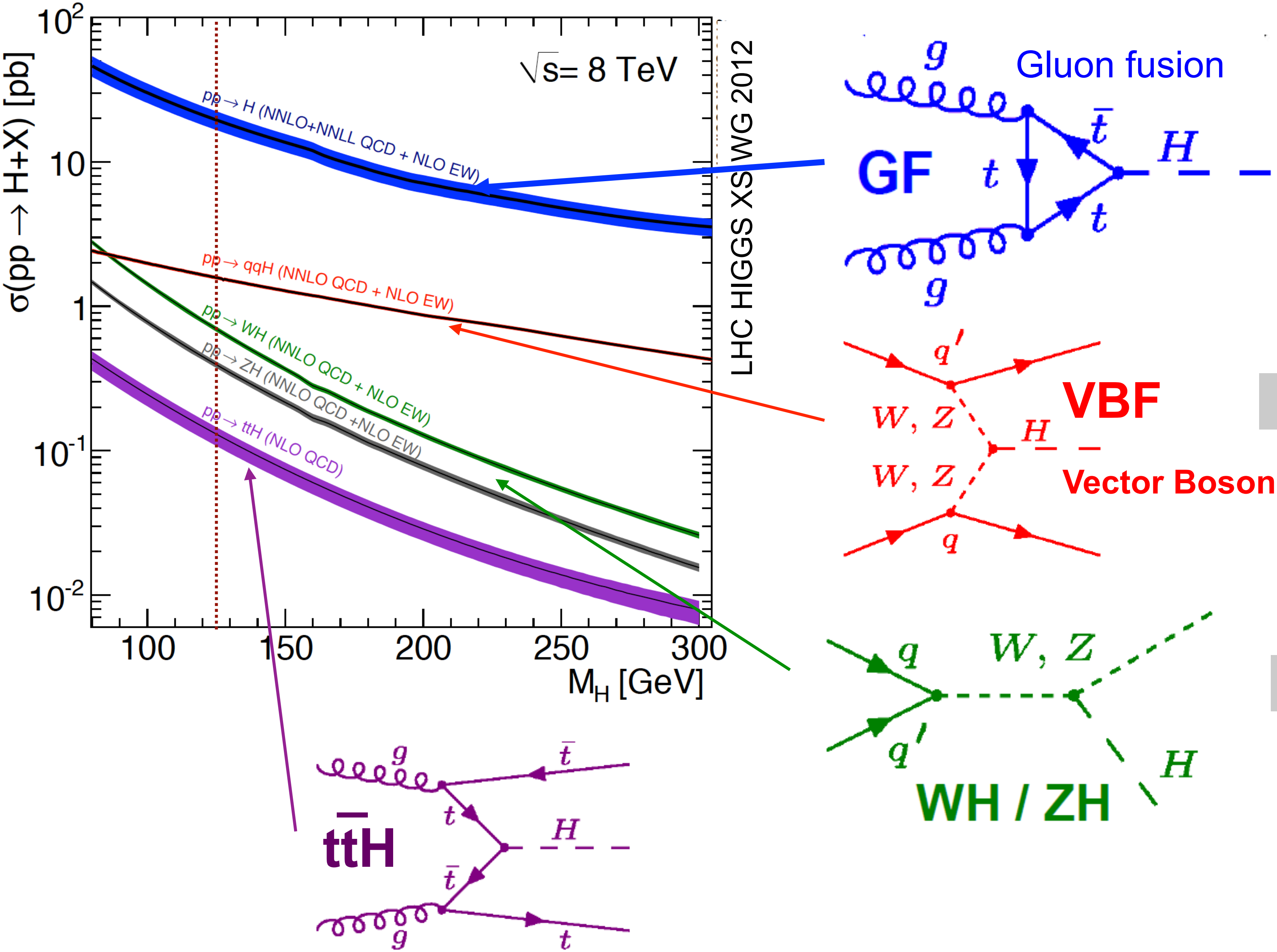
Top

Higgs

Searches

Summary

Higgs-Boson Production



m_H=125 GeV:

σ=19.2 pb (~10-15%)

1.58 pb (~3%)

1.12 pb (~3%)

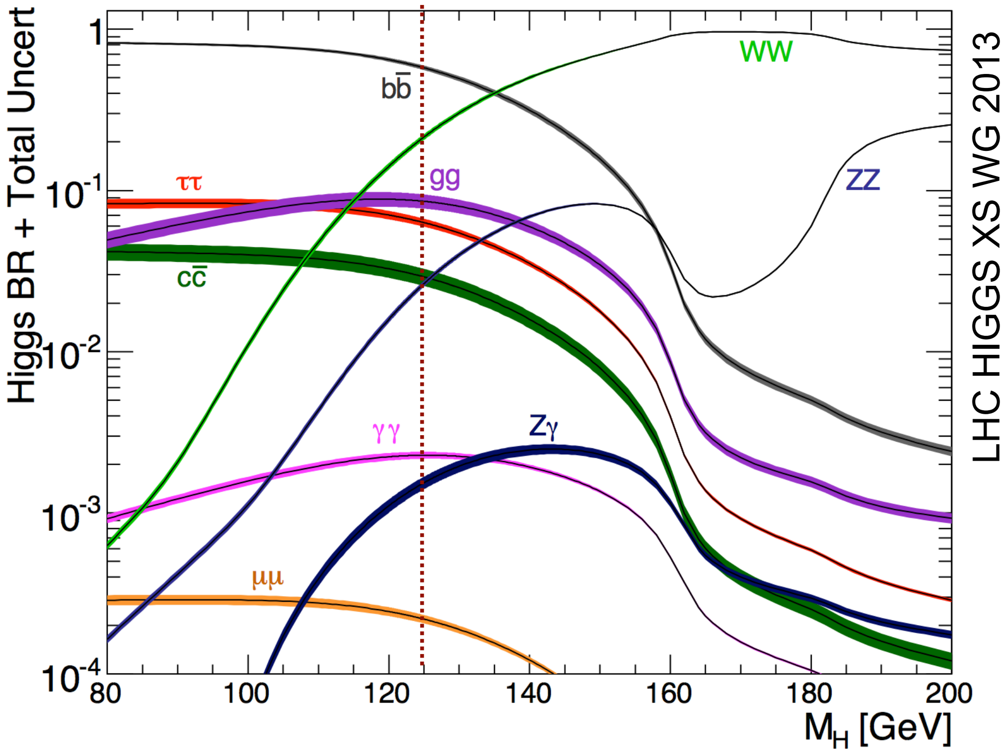
0.13 pb (~10%)

Higgs-Boson Decays

SM predictions for m_H=125.09 GeV (fermions, bosons):

BR($H \rightarrow bb$)	≈	57.5%
BR($H \rightarrow WW$)	≈	21.6%
BR($H \rightarrow \tau\tau$)	≈	6.3%
BR($H \rightarrow ZZ$)	≈	2.7%
BR($H \rightarrow \gamma\gamma$)	≈	0.23%
BR($H \rightarrow Z\gamma$)	≈	0.16%
BR($H \rightarrow \mu\mu$)	≈	0.022%

→ ~88% of decays are observable at this mass!



Experimentally best suited, *clean* channels:
- Final states with leptons from ZZ and WW decays
- $\gamma\gamma$ final state

→ can be analysed (also) in dominant gluon fusion process

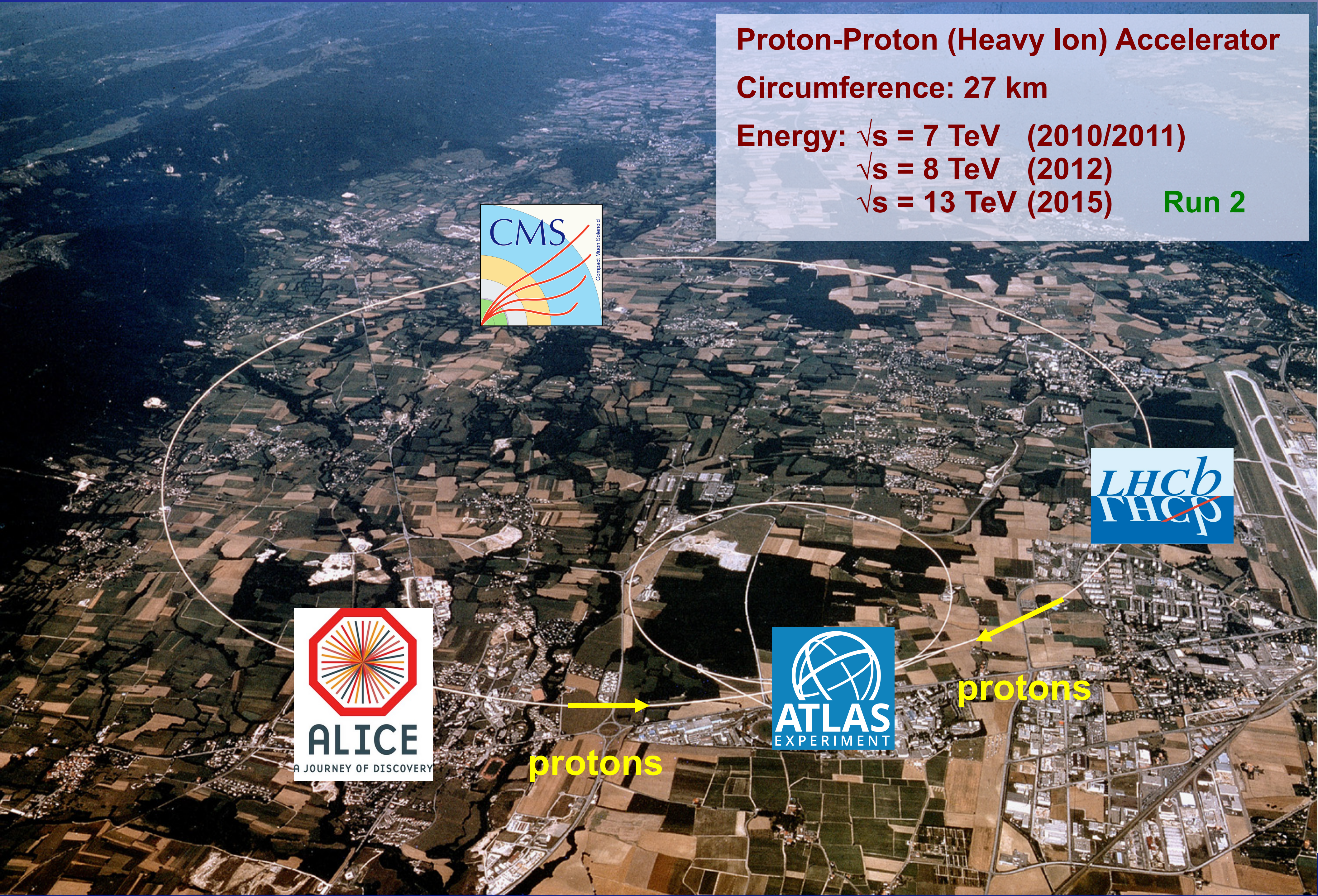
$\tau\tau$ and bb final states more difficult, typically need VBF or associated production modes

The Large Hadron Collider: LHC

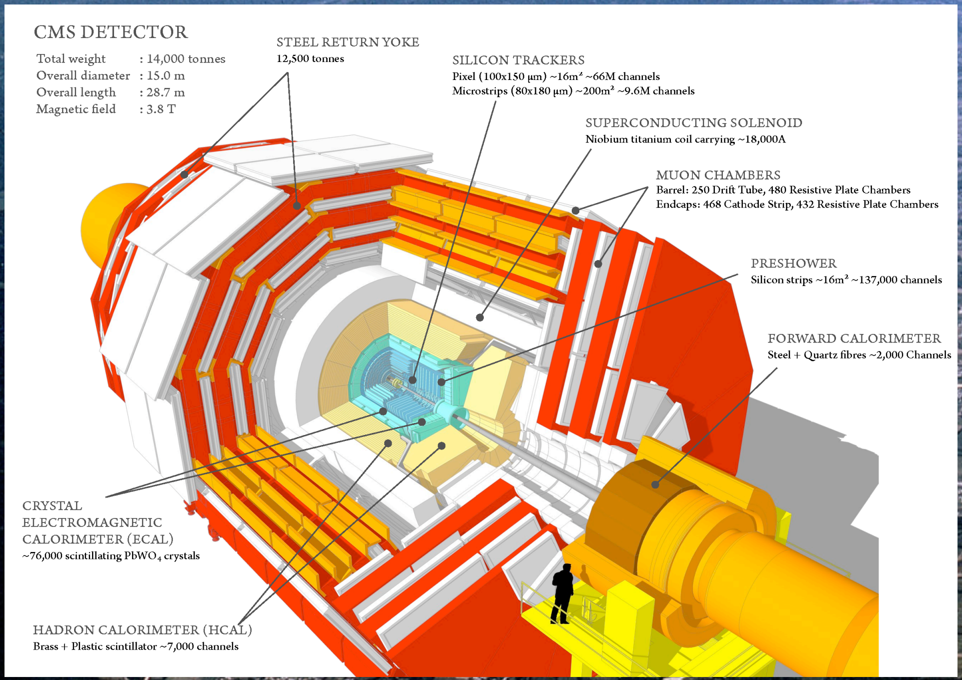
Proton-Proton (Heavy Ion) Accelerator

Circumference: 27 km

Energy: $\sqrt{s}$ = 7 TeV (2010/2011)
$\sqrt{s}$ = 8 TeV (2012)
$\sqrt{s}$ = 13 TeV (2015) Run 2



LHC, ATLAS and CMS

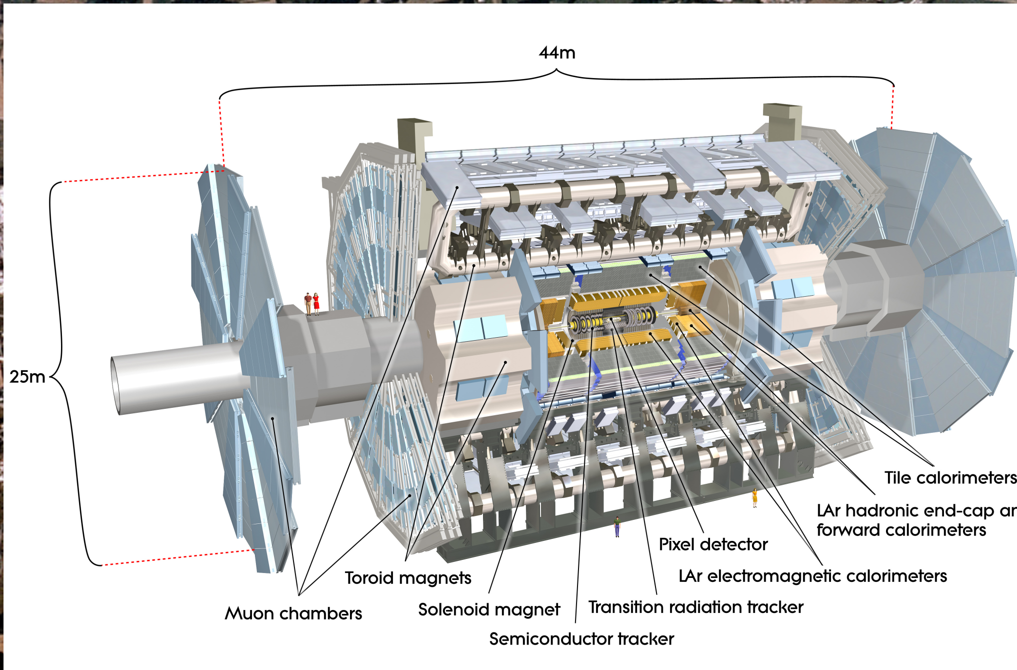


Proton-Proton (Heavy Ion) Accelerator

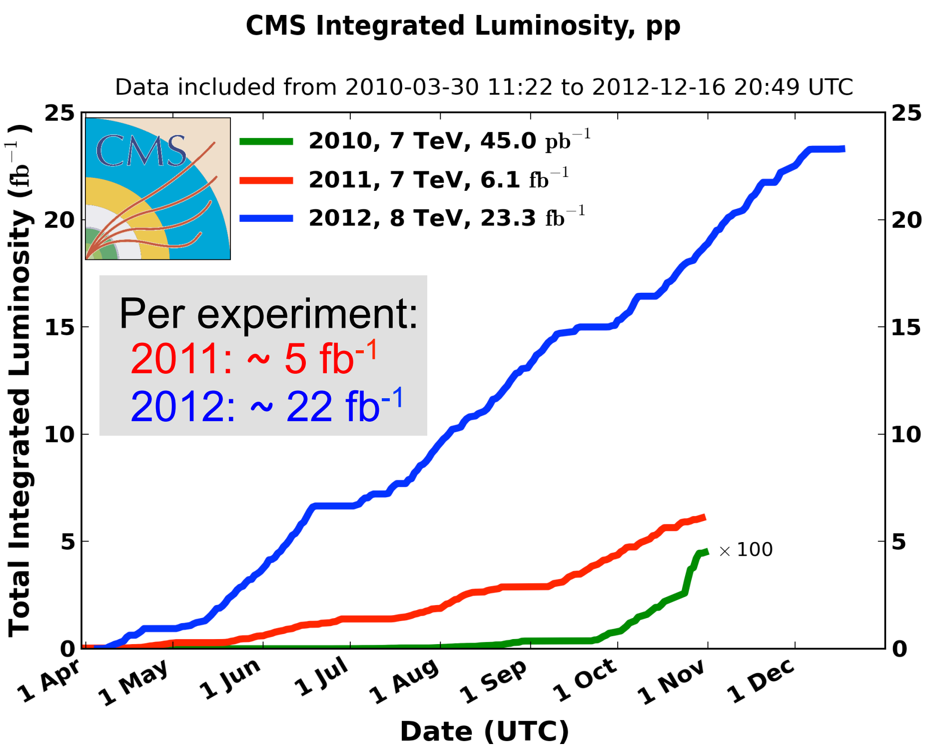
Circumference: 27 km

Energy: $\sqrt{s}$ **= 7 TeV (2010/2011)**
$\sqrt{s}$ **= 8 TeV (2012)**
$\sqrt{s}$ **= 13 TeV (2015) Run 2**

ALICE
A JOURNEY OF DISCOVERY



LHC Run 1 Data Taking



→ ≈ 2×10^{15} collisions during Run 1

→ ≈ 500.000 Higgs bosons produced

→ ≈ 1000 $H \to \gamma\gamma$ decays

→ ≈ 65 $H \to ZZ \to 4\ell$ decays (ℓ=e,μ)

→ ≈ 5000 $H \to WW \to \ell\nu\ell\nu$ decays

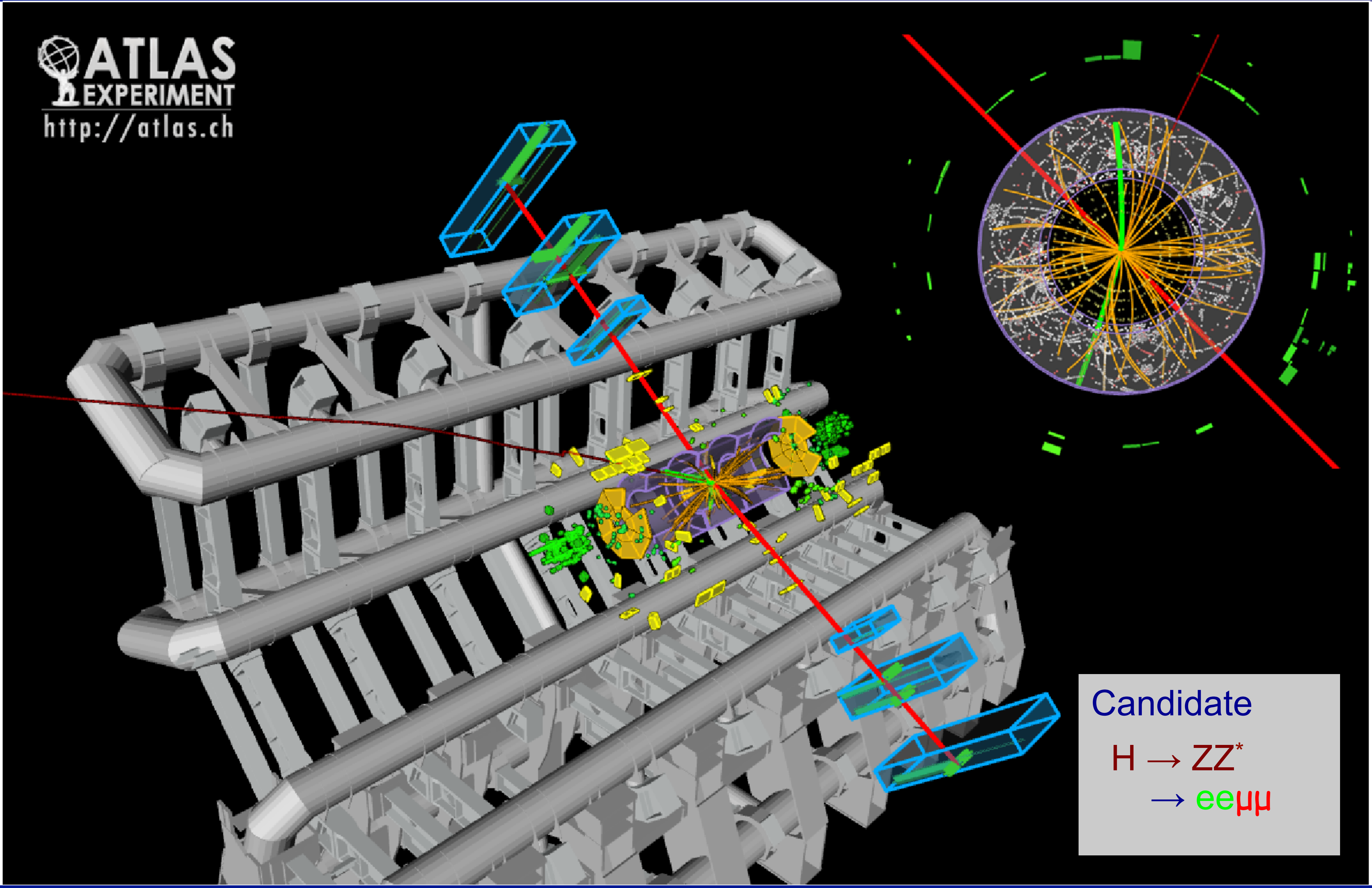
→ ≈ 30.000 $H \to \tau\tau$ decays

→ ≈ 300.000 $H \to bb$ decays

(but QCD b-jet production 10^7 x larger!)

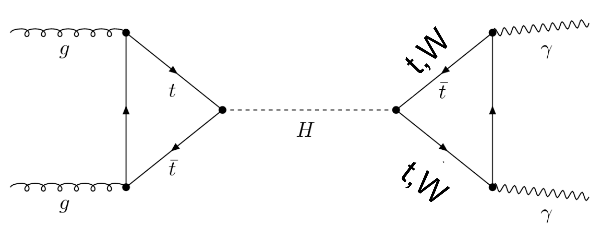
+ acceptance and reconstruction efficiencies!

Decays into Bosons

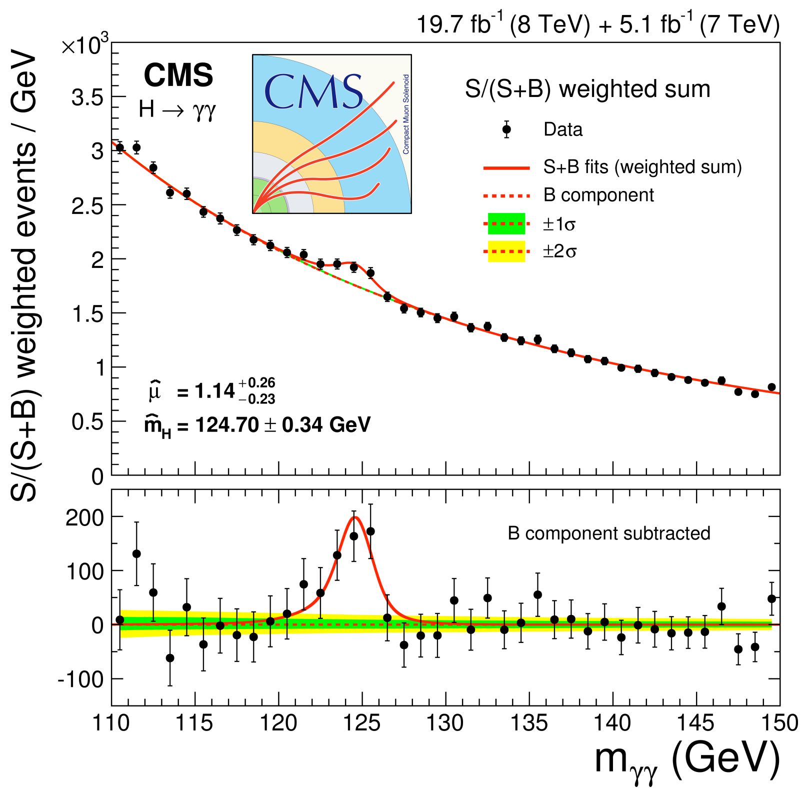


Decays into Bosons: $H \to \gamma\gamma$, $H \to ZZ^* \to \ell\ell\ell\ell$

$BR(H \to \gamma\gamma) \approx 0.23\%$ tiny, but very clean signature and good mass resolution



Coupling to photons via W/t loop

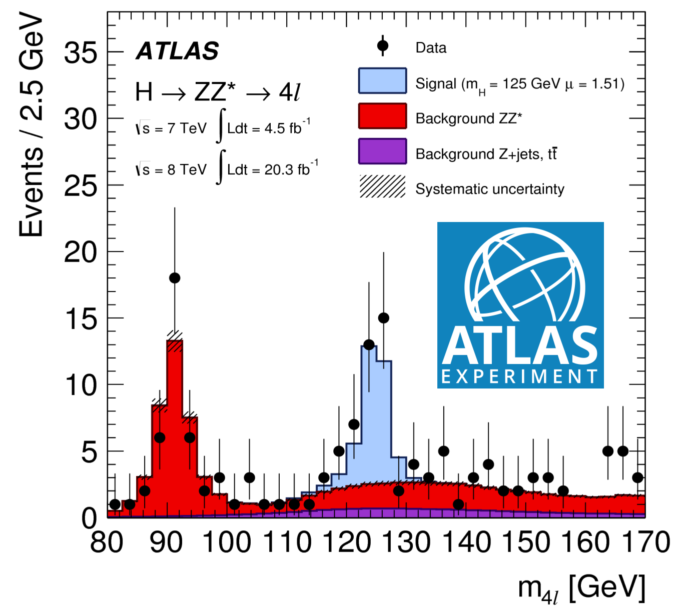


[EPJ C74 (2015)]

$H \to ZZ^* \to \ell\ell\ell\ell$: *Golden* Channel

$BR(H \to ZZ \to 4\ell) \approx 0.013\%$

+ intermediate Z boson, good mass resolution



[PRD 91 (2015)]

Significance of excess:

γγ: 5.6 σ (5.1 exp.)

ZZ: 6.6 σ (5.5 exp.)

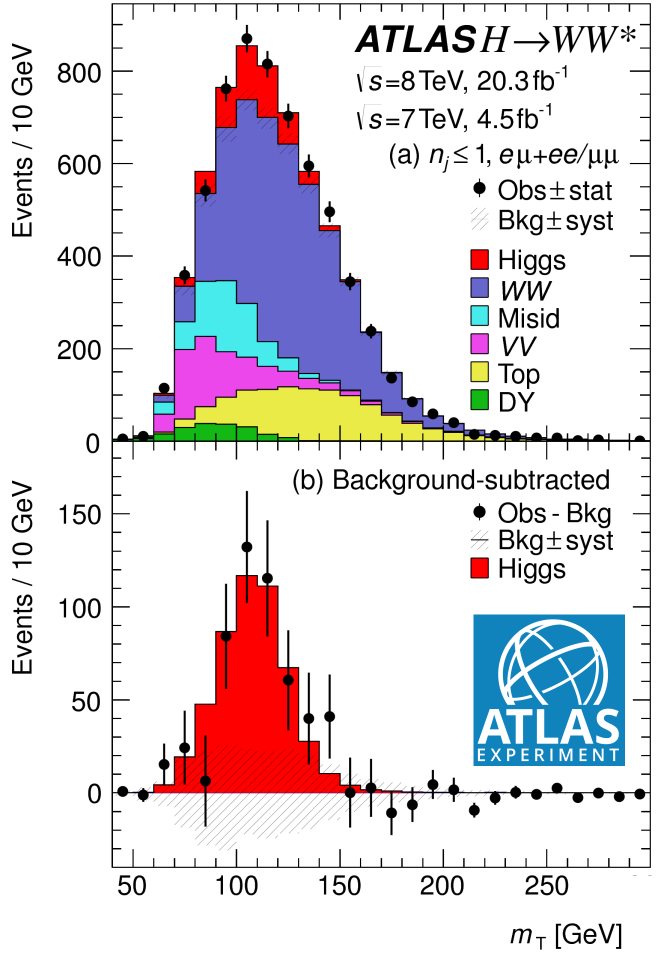
Signal strength $\mu = \sigma_{obs} / \sigma_{SM}$

$$\mu = 1.12^{+0.25}_{-0.23}$$

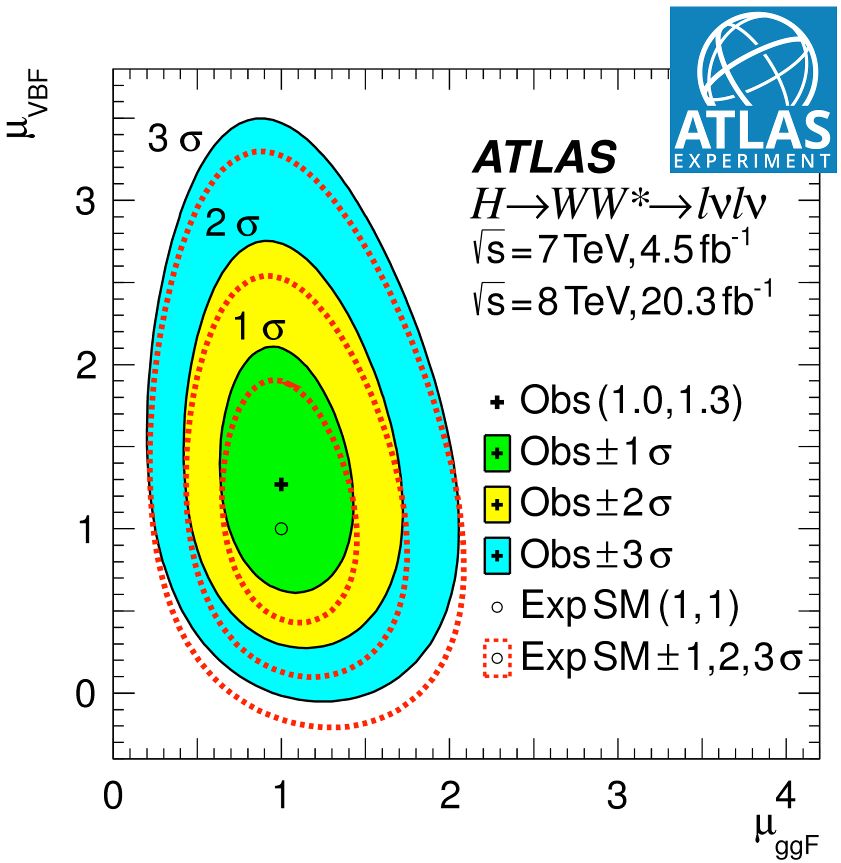
$$\mu = 1.51^{+0.39}_{-0.34}$$

H → WW → $\ell\nu\ell\nu$

BR(H → WW → $\ell\nu\ell\nu$) ≈ 1.1%, but 2 neutrinos
→ missing transverse energy
→ poor mass resolution



Analysis categories:
Separate gluon fusion and
vector-boson-fusion production processes



→ 6.8 σ (5.8 exp.)

$$\mu = 1.23^{+0.23}_{-0.21}$$

[PRD 92 (2015)]

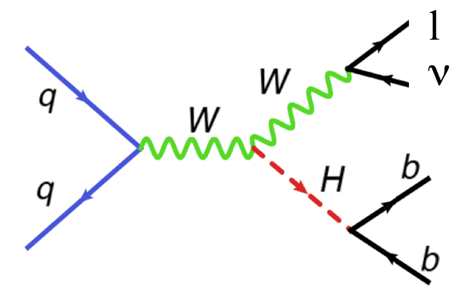
Decays into Fermions: bb

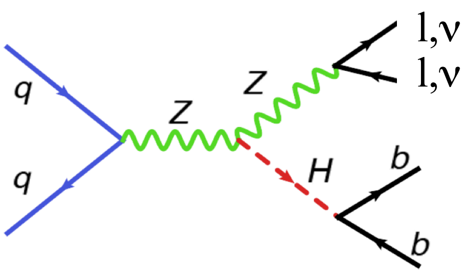
Fermions acquire mass via Yukawa couplings, different to vector bosons!

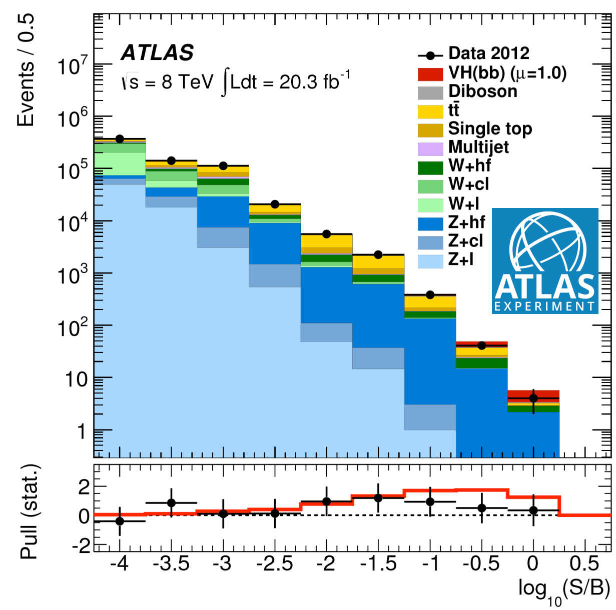
Largest BRs expected for b quarks and τ leptons

Very complex final states, exploit dedicated topologies, apply multivariate analyses

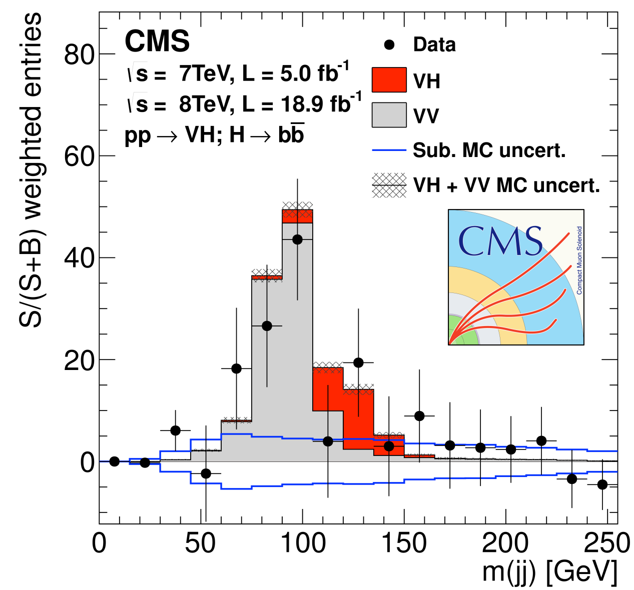
H → bb: Associated production with W/Z







[JHEP 01 (2015)]



[PRD 89 (2014)]

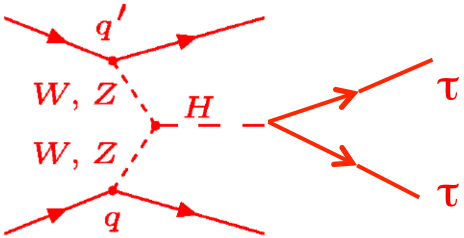
ATLAS: Significance	1.7 σ (2.7 σ exp.)
CMS:	2.0 σ (2.5 σ exp.)

Signal strength: $\mu = 0.62^{+0.37}_{-0.36}$

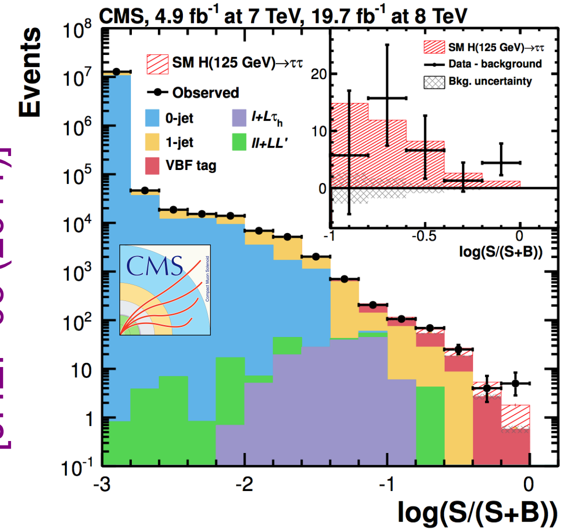
$\mu = 0.81^{+0.45}_{-0.42}$

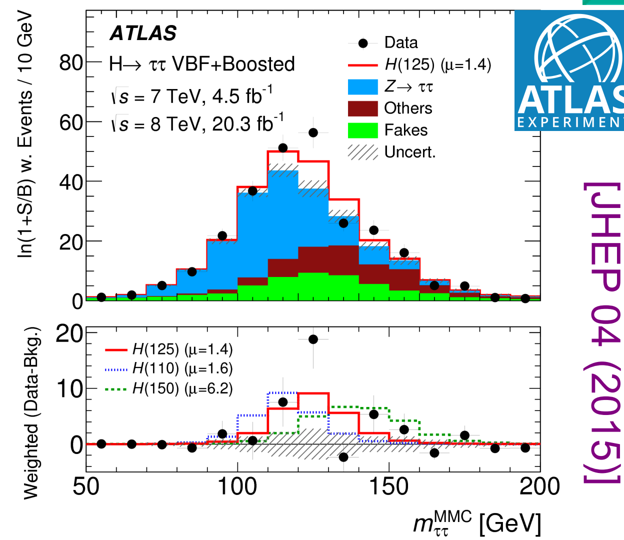
Decays into Fermions: Leptons

H → ττ: Vector-Boson Fusion (mainly)



[JHEP 05 (2014)]





[JHEP 04 (2015)]

ATLAS: Significance 4.4 σ (3.3 σ exp.)

CMS: 3.4 σ (3.7 σ exp.)

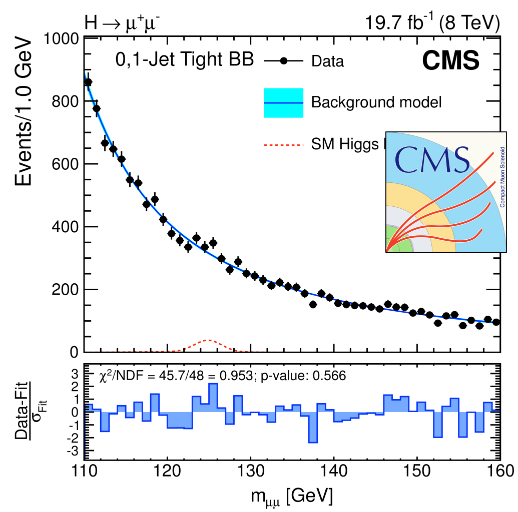
ATLAS + CMS combination: > 5 σ !

$\mu = 1.41^{+0.40}_{-0.35}$

$\mu = 0.89^{+0.31}_{-0.28}$

H → μμ and H → ee:

BR(H→μμ) ~ 2.2 x 10^{-4}
BR(H→ee) ~ 5 x 10^{-9}



BR(H → μμ) < 1.6x10^{-3}
(ATLAS: < 1.5x10^{-3})

BR(H → ee) < 1.9x10^{-3}

Couplings to fermions NOT flavour-universal!

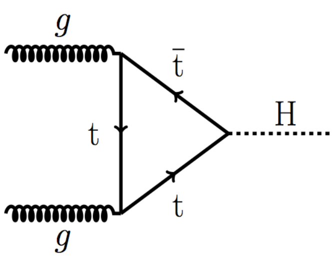
(BR(H→ττ) = 6.3%)

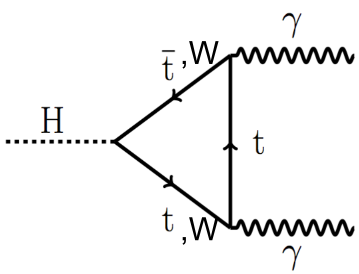
[PLB 744 (2015)]

ttH Production

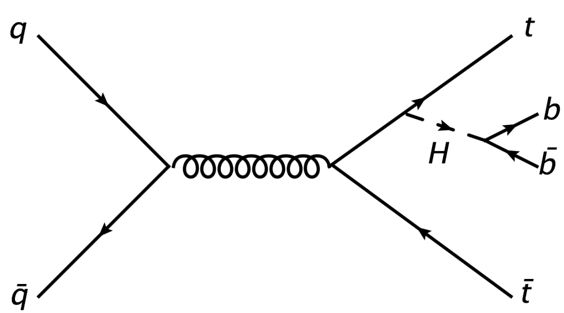
- Top-Higgs Yukawa coupling ($y_t \sim 1$) cannot be measured in decays into top quarks (too heavy)

- Within SM, coupling to top quarks via loops already seen:



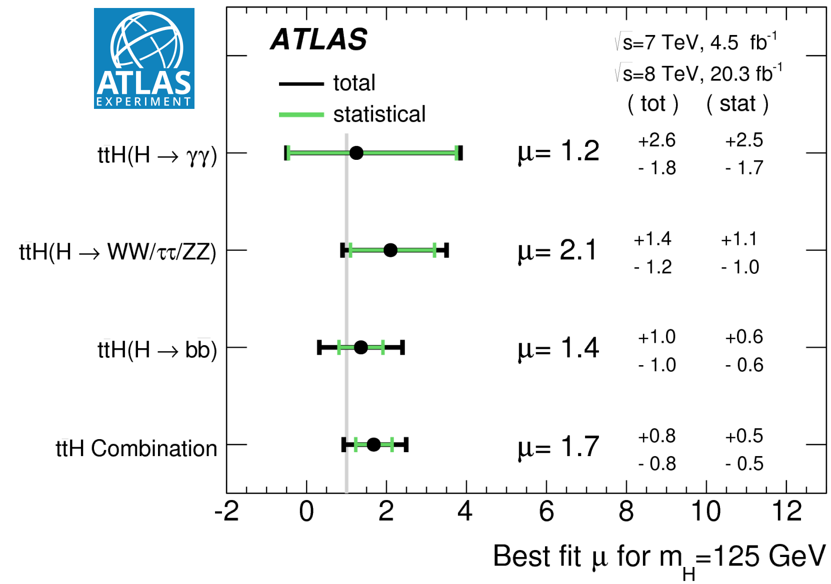


- DIRECTLY probing this coupling needs both t and H in final state
  → ttH important for model-independent determinations of couplings

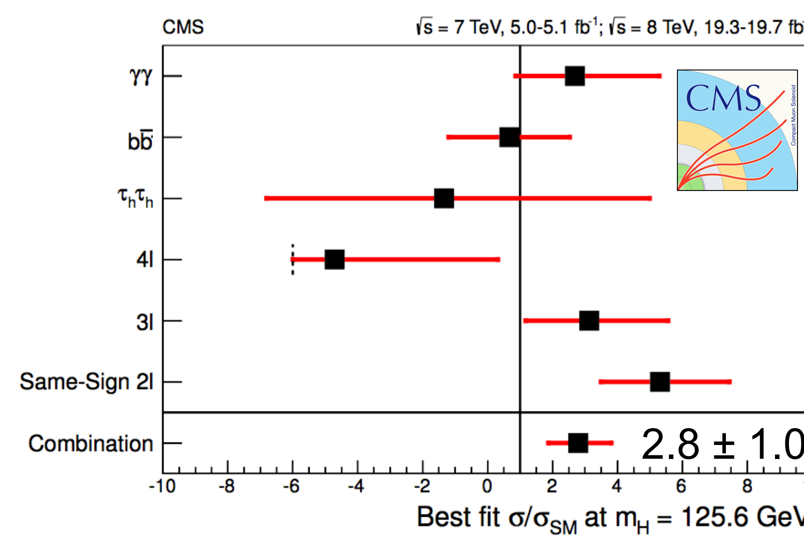


- Small production cross section, very complex final states

Many different final states studied, sensitive to H → bb, γγ, WW, ZZ, ττ



[arXiv:1604.03812 (2016)]



[JHEP 09 (2014)]

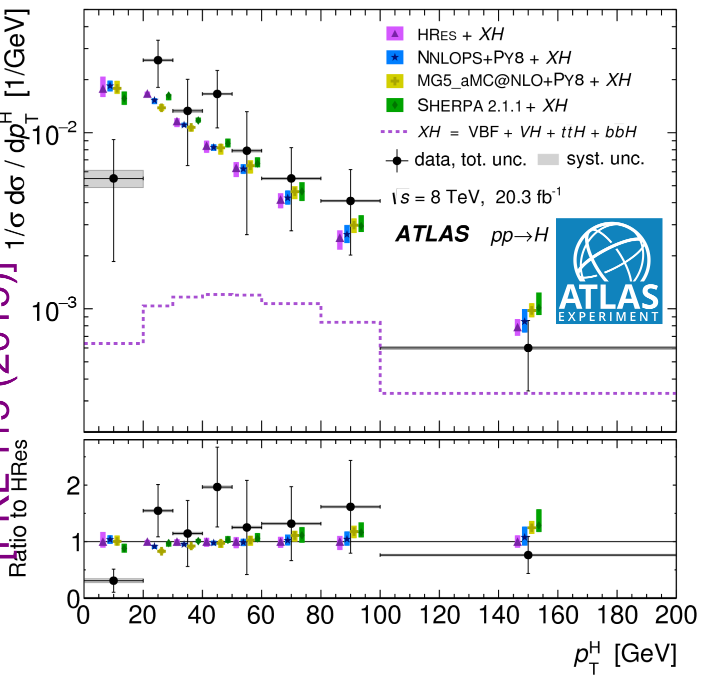
Differential Measurements

Size of datasets allow measurements of differential cross sections

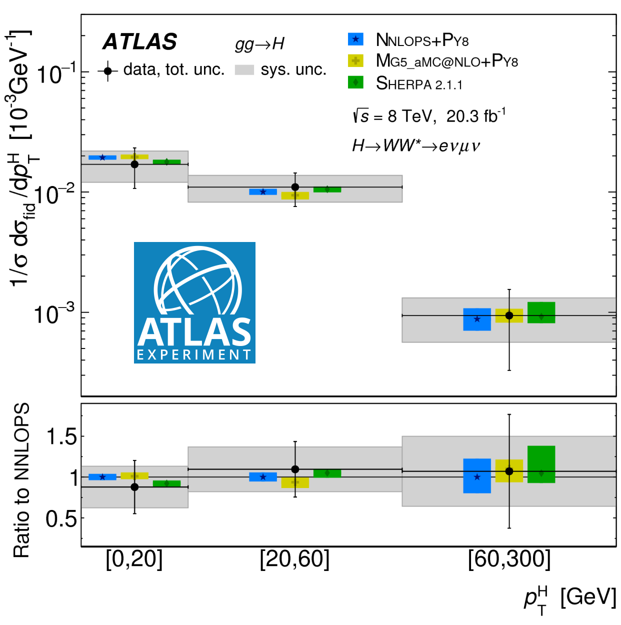
→ Allows tests beyond event yields (QCD effects, ….),

ATLAS: γγ and ZZ(4ℓ) combined, NEW: WW; CMS: γγ (and ZZ(4ℓ), WW prelim.)

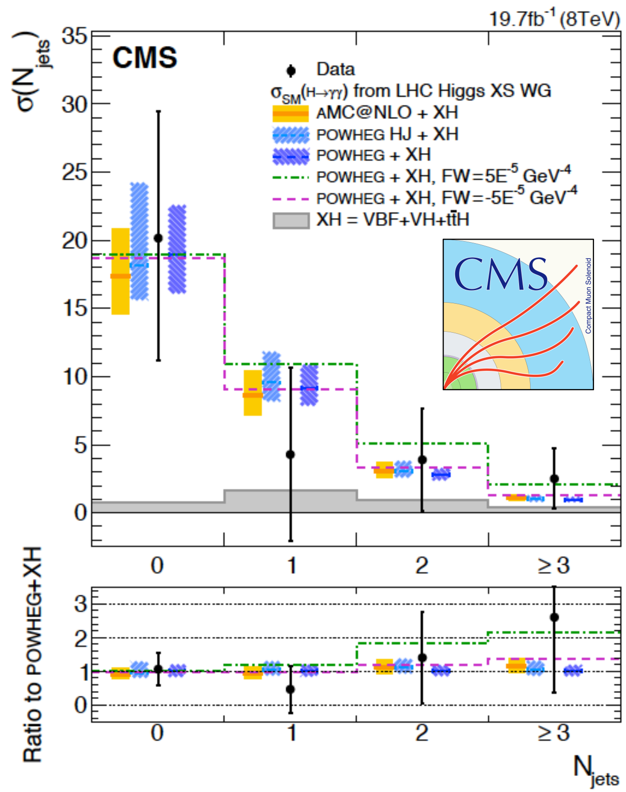
[PRL 115 (2015)]



(Cross-section normalised
→ Shape comparison)



[arXiv:1604.02997 (2016)]



[EPJ C76 (2016)]

- Good agreement within (experimental and theoretical) uncertainties
- Will become more and more important in the future for parameter determinations

PROPERTIES

The Higgs boson in the 2015 PDG Review of particle physics

H^0 $J = 0$

Mass $m = 125.09 \pm 0.24$ GeV

H^0 Signal Strengths in Different Channels

See Listings for the latest unpublished results.

Combined Final States $= 1.17 \pm 0.17$ (S = 1.2)
$WW^* = 0.81 \pm 0.16$
$ZZ^* = 1.15^{+0.27}_{-0.23}$ (S = 1.2)
$\gamma\gamma = 1.17^{+0.19}_{-0.17}$
$b\bar{b} = 0.85 \pm 0.29$
$\mu^+\mu^- < 7.0$, CL = 95%
$\tau^+\tau^- = 0.79 \pm 0.26$
$Z\gamma < 9.5$, CL = 95%
$t\bar{t}H^0$ Production $= 2.5^{+0.9}_{-0.8}$

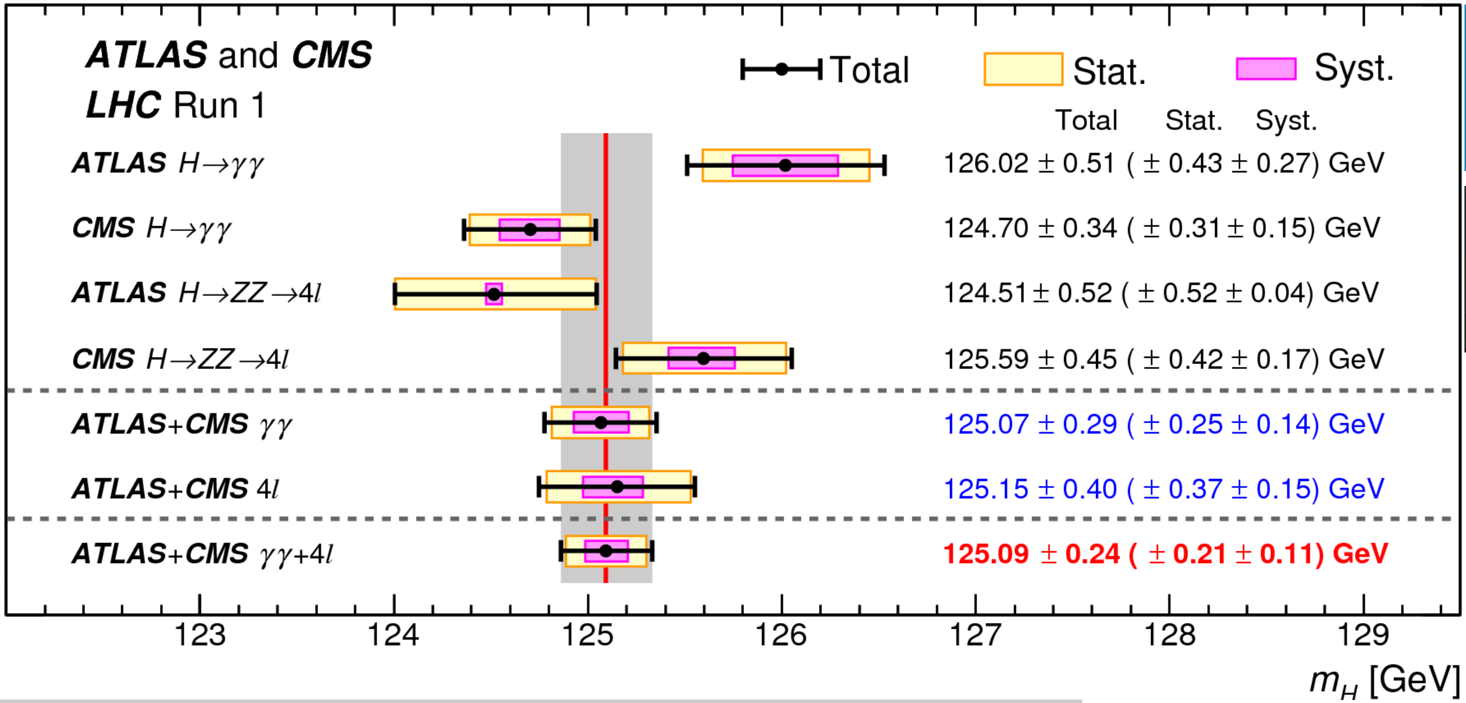
H^0 DECAY MODES	Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
invisible	<58 %	95%	–

Mass

The only *unknown* parameter of the Higgs boson in the SM

[PRL 114 (2015)]

ATLAS $\left(m_H = 125.36 \pm 0.37_{\text{stat}} \pm 0.18_{\text{syst}}\right)$ + CMS $\left(m_H = 125.02^{+0.26}_{-0.27,\text{stat}}\,{}^{+0.14}_{-0.15,\text{syst}}\right)$ combined measurement of Higgs-boson mass in high resolution channels $H \to \gamma\gamma$ and $H \to ZZ \to \ell\ell\ell\ell$:



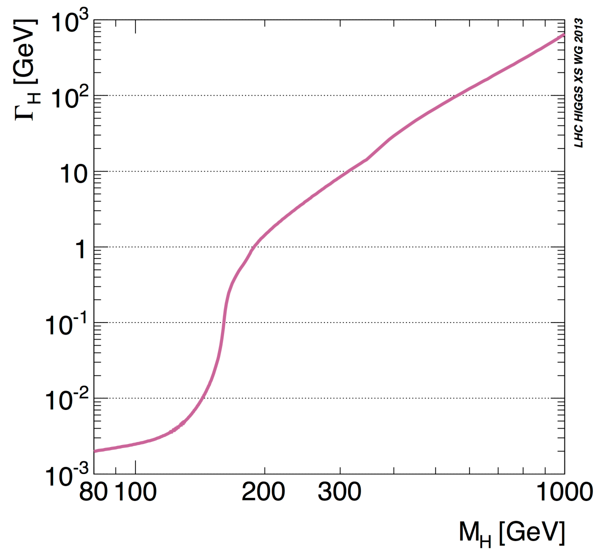
$$m_H = 125.09 \pm 0.21_{\text{stat}} \pm 0.11_{\text{syst}}\ \text{GeV}$$
$$= 125.09 \pm 0.24\ \text{GeV}$$

→ 0.2% precision!

- Statistical uncertainty dominating
- Dominant systematic uncertainties: energy/momentum measurements of leptons and photons

The Higgs Boson Width: Γ_H

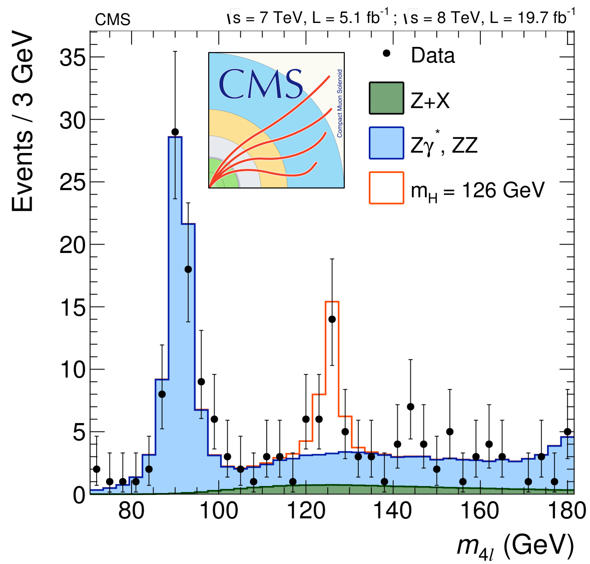
$$BR(H \to f) = BR^f = \frac{\Gamma^f}{\Gamma_H}$$



In the SM for m_H = 125.1 GeV: Γ_H = 4.15 MeV (τ_H = 16 x 10^{-8} fs)

→ tiny compared to typical experimental mass resolution

Limit from direct measurements of width of mass distributions (channels $\gamma\gamma$ and $ZZ \to 4\ell$, σ_m ~ 1-2 GeV)



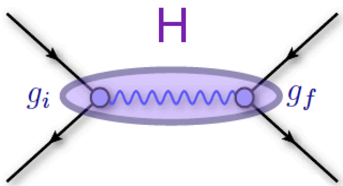
[PRD 89 (2014)]

CMS $\gamma\gamma$ and ZZ combined:
Γ_H < 1.7 GeV
(2.3 GeV exp.)

ATLAS [PRD 90 (2014)]:
ZZ: Γ_H < 2.6 GeV
$\gamma\gamma$: Γ_H < 5 GeV

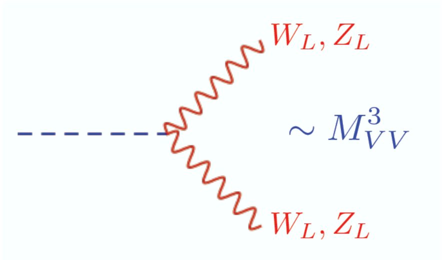
→ O(1000) missing to SM!

Width: Off-Shell Cross Section

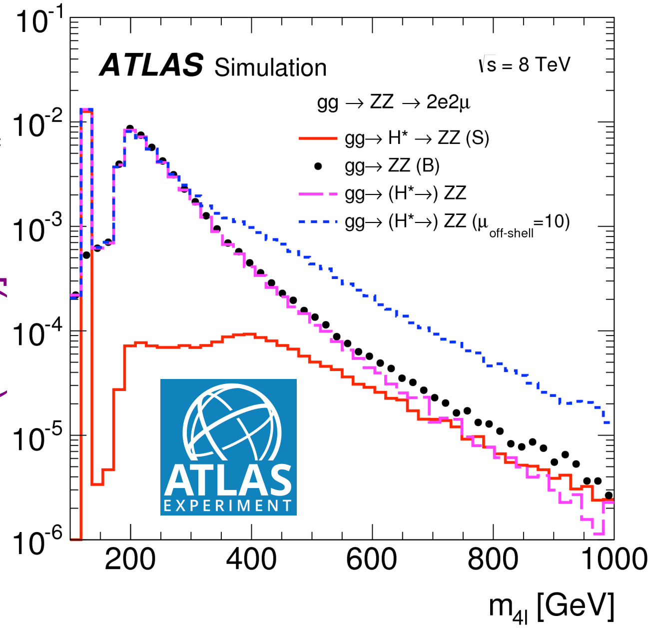


$$\frac{d\sigma_{i\to H\to f}}{dm_f^2} = \frac{g_i^2\, g_f^2}{(m_f^2 - m_H^2)^2 + m_H^2 \Gamma_H} \quad \rightarrow \quad \frac{\mu^{off}}{\mu^{on}} = \frac{\Gamma_H}{\Gamma_H^{SM}}$$

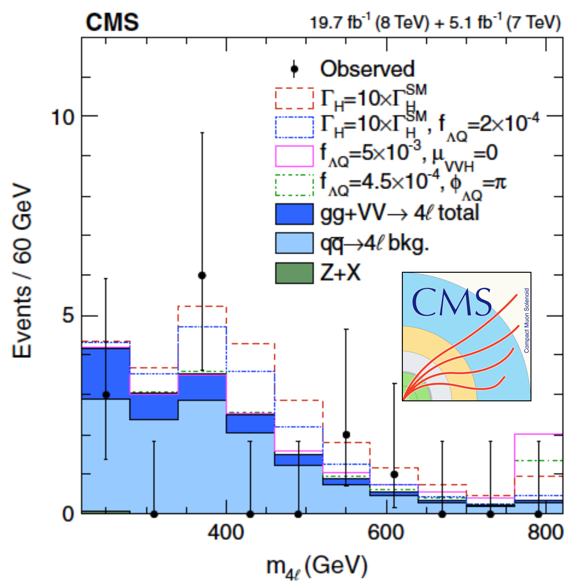
Caveat: Assuming no change of couplings, no new physics at high masses, no anomalous couplings!



Above threshold (> $2m_{Z,W}$):
enhanced production of longitudinally polarised vector bosons



EPJ C75 (2015)]



[PRD 92 (2015)]

CMS *:
Γ_H < 26 MeV (41 MeV exp.)

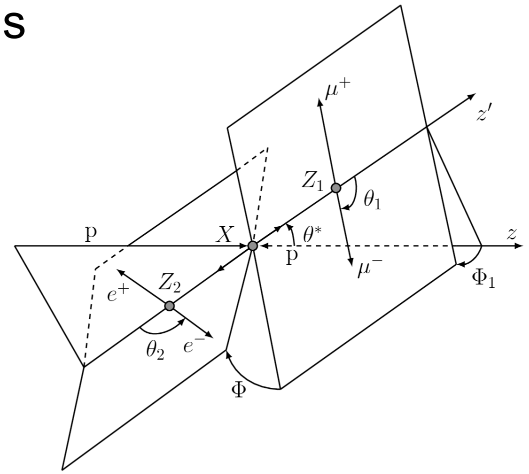
ATLAS:
Γ_H < 23 MeV (31 MeV exp.)

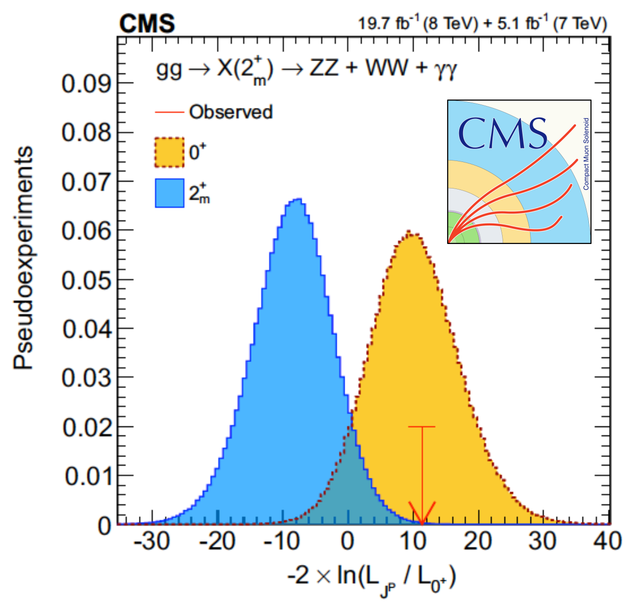
*: (Γ_H < 46 (73) MeV with floating anomalous coupling parameter)

Spin and Parity

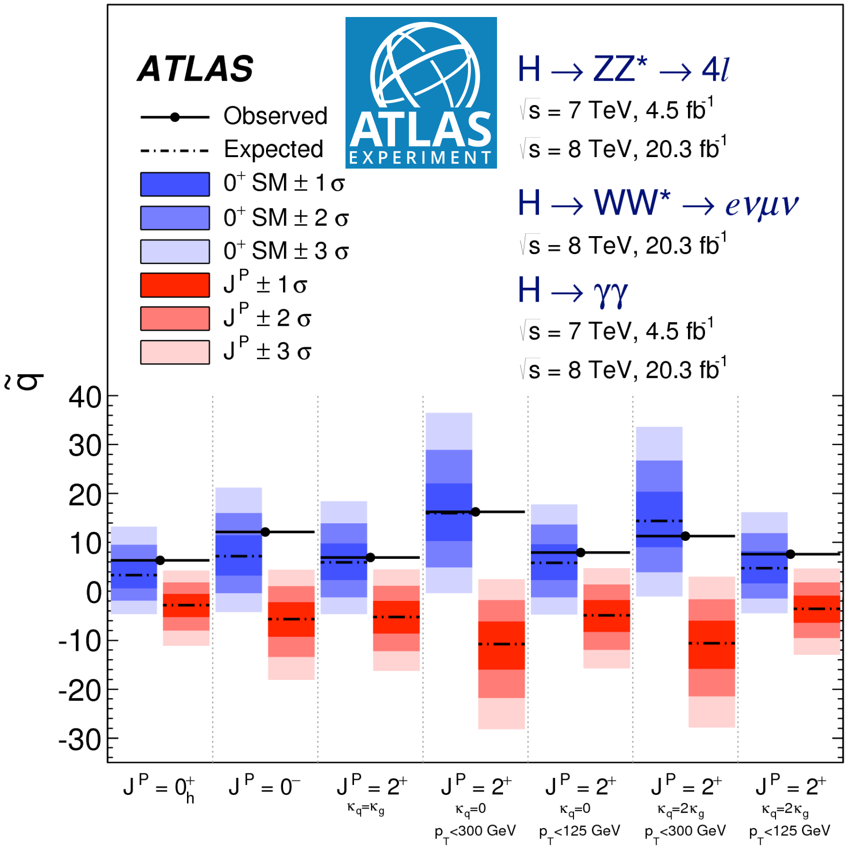
Variables sensitive to spin and parity, typically angular variables, often combined using multivariate tools

Compare SM hypothesis ($J^P=0^+$, well defined couplings) to alternative scenarii (probe a wide range of *models*, defined by their couplings)





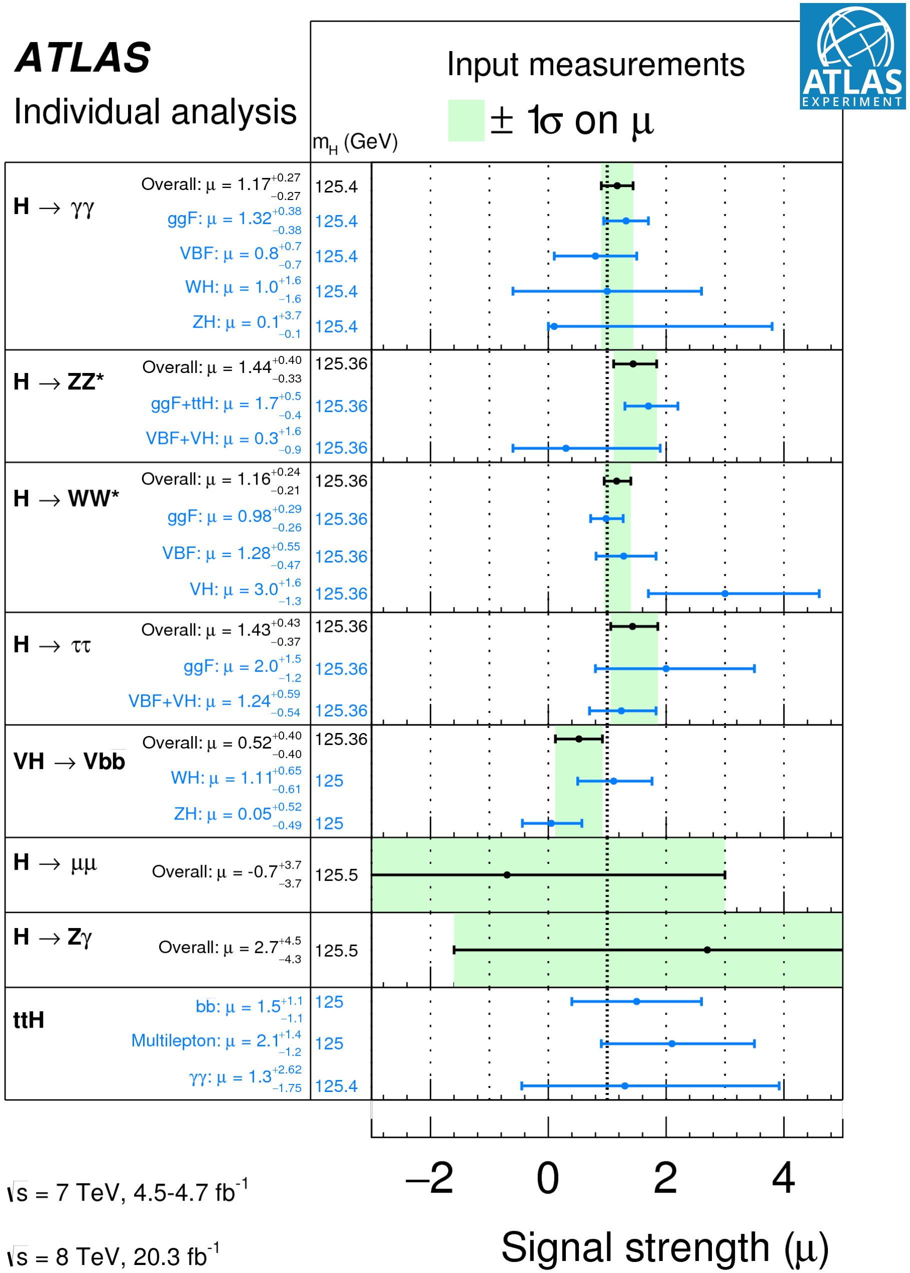
[PRD 92 (2015)]

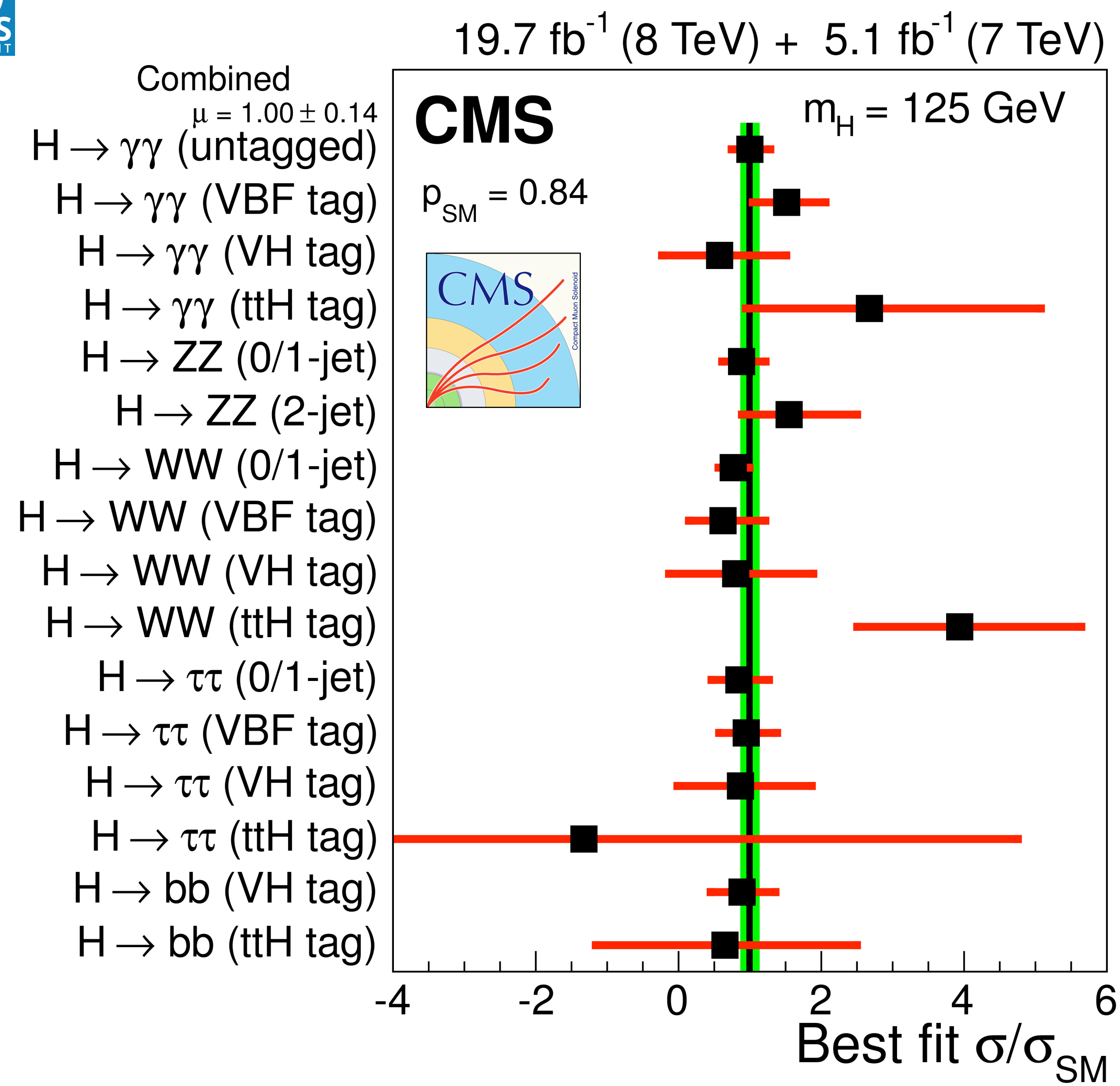


[EPJ C75 (2015)]

Observe consistency with SM hypothesis. Other models excluded with large confidence levels (typically > 99%)

ATLAS & CMS Combination: μ, Couplings

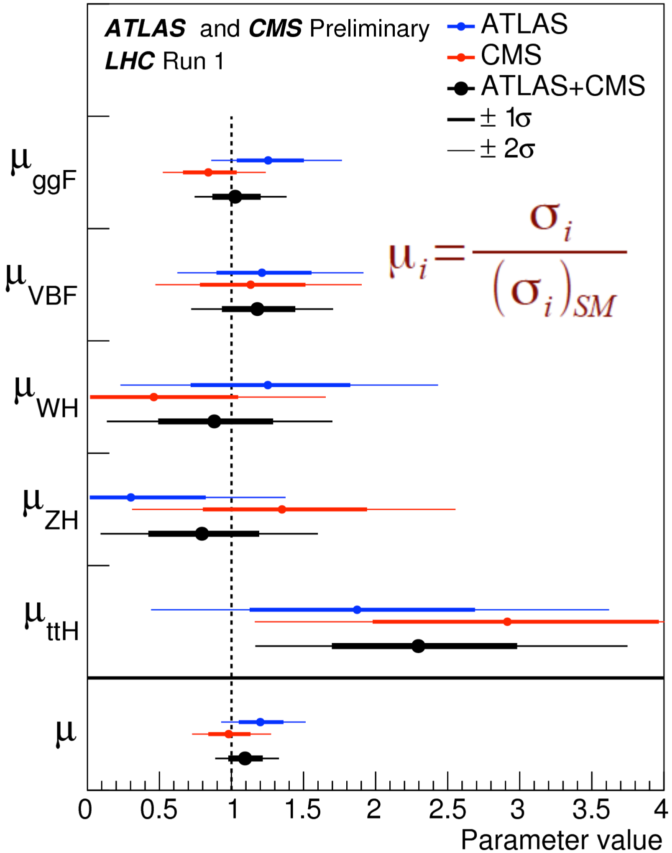




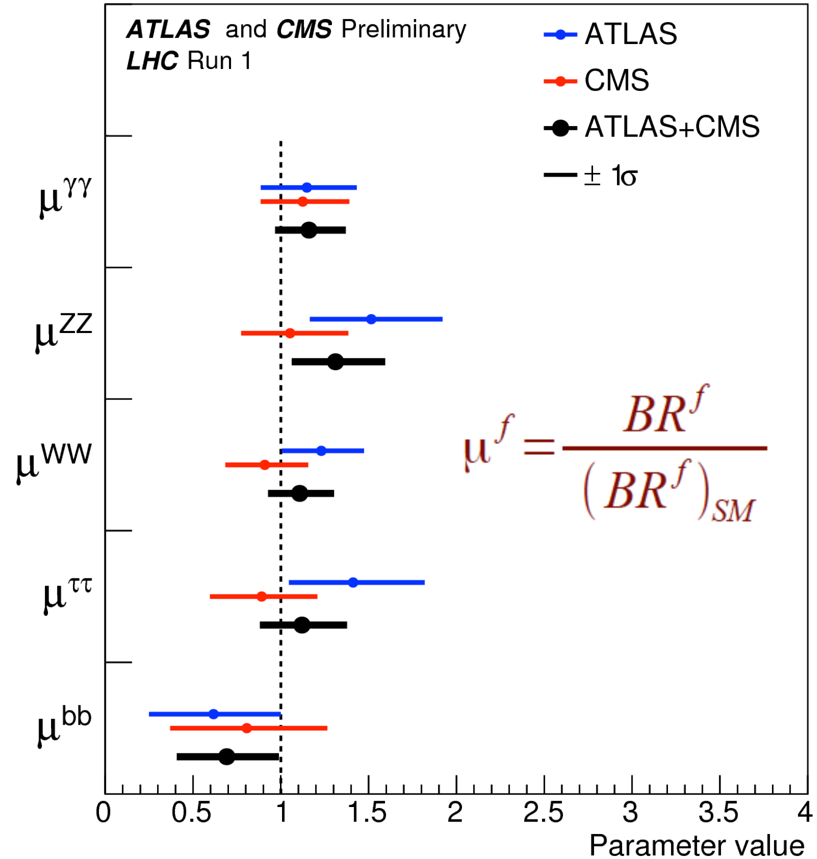
[ATLAS-CONF-2015-044
CMS-PAS-HIG-15-002]

Production Processes and Decay Modes

Assume SM decay BRs: $\mu_f = 1$



Assume SM production cross sections: $\mu_i = 1$



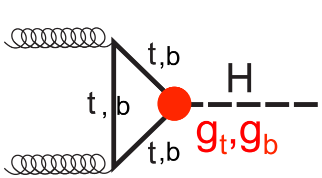
Global signal strength μ
(all μ_i and μ_f are the same):

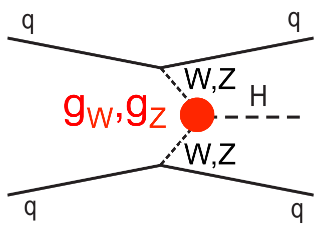
$$\mu = 1.09^{+0.11}_{-0.10}$$

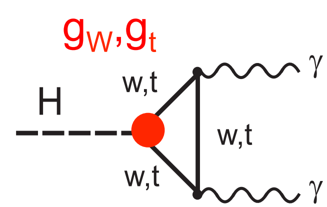
→ 5.4 σ observation of the vector boson fusion process
→ 5.5 σ observation of the $\tau\tau$ decay mode
→ bb decay mode still < 3 σ (sensitivity 3.7 σ)
→ ttH production 2.3 σ above SM expectation

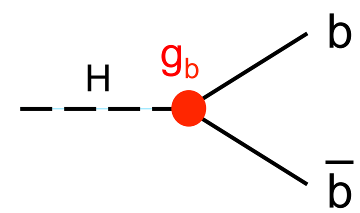
Higgs-Boson Couplings: ATLAS + CMS

Production and decay involve couplings of Higgs boson to different particles:









Narrow width approximation:

Factorize cross section into production process *i* and decay into final state *f*

$$\sigma_i^f = \sigma(i \rightarrow H \rightarrow f) = \sigma_i \times BR^f = \sigma_i \times \frac{\Gamma^f}{\Gamma_H}$$

$BR^f = BR(H \rightarrow f)$

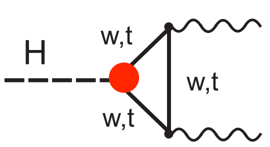
Γ^f, Γ_H: partial width, total Higgs width

→ The Higgs width Γ_H scales all observed cross sections!

→ Cannot interpret cross sections in terms of couplings without assumptions on Γ_H

- *Kappa framework* (observed signals from single resonance; coupling structure as in SM):
  Introduce LO coupling modifiers: $g_x \rightarrow \kappa_x \cdot g_x$

$$\boxed{\sigma_i^f \rightarrow \frac{\sigma_{i,SM} \cdot \Gamma_{SM}^f}{\Gamma_{H,SM}} \times \frac{\kappa_i^2 \cdot \kappa_f^2}{\kappa_H^2}}$$



$\kappa_\gamma = \kappa_\gamma(\kappa_t, \kappa_W)$

$$\kappa_H^2 \propto \sum_f \kappa_f^2 \cdot BR(H \rightarrow f)$$

$$\kappa_\gamma^2 \propto 1.59 \cdot \kappa_W^2 + 0.07 \cdot \kappa_t^2 - 0.66 \cdot \kappa_w \kappa_t$$

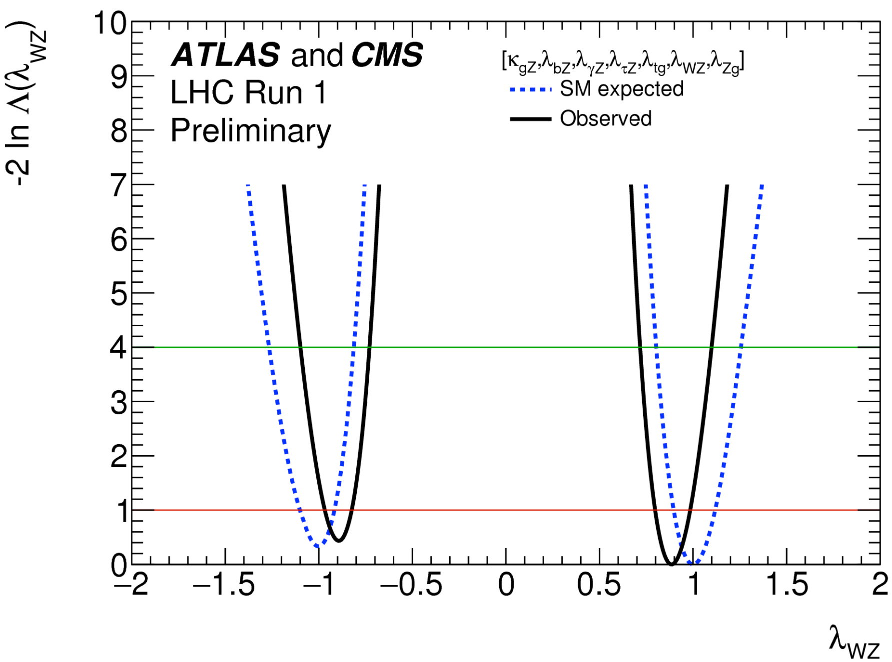
ATLAS & CMS Combination: μ, Couplings

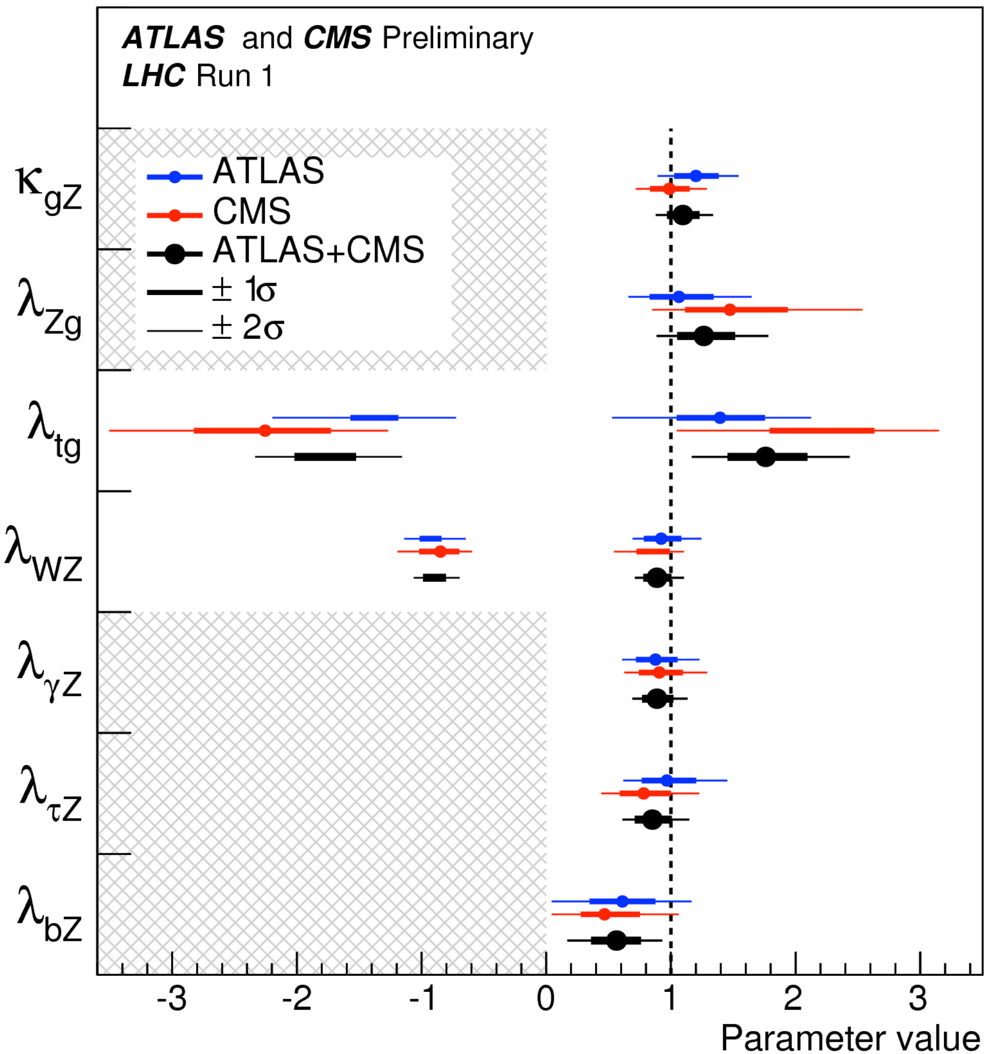
Model independent (Γ_H cancels):

(Reference process gg → H → ZZ:
clean, smallest systematic uncertainties)

Measurements of ratios of coupling modifiers

$\lambda_{ij} = \kappa_i/\kappa_j$

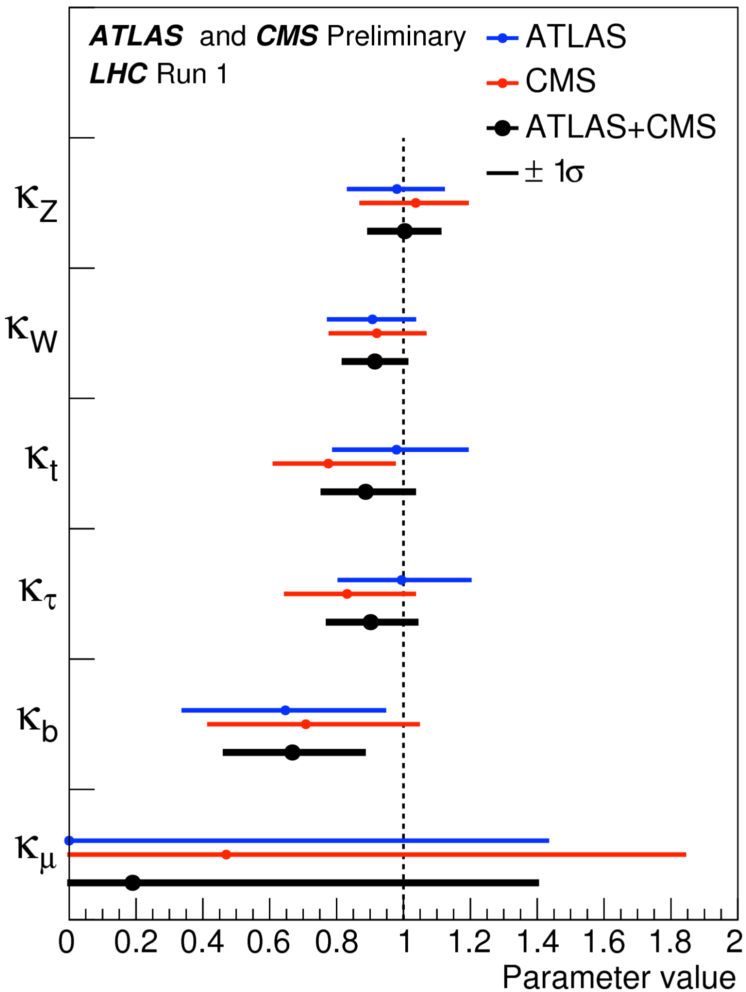


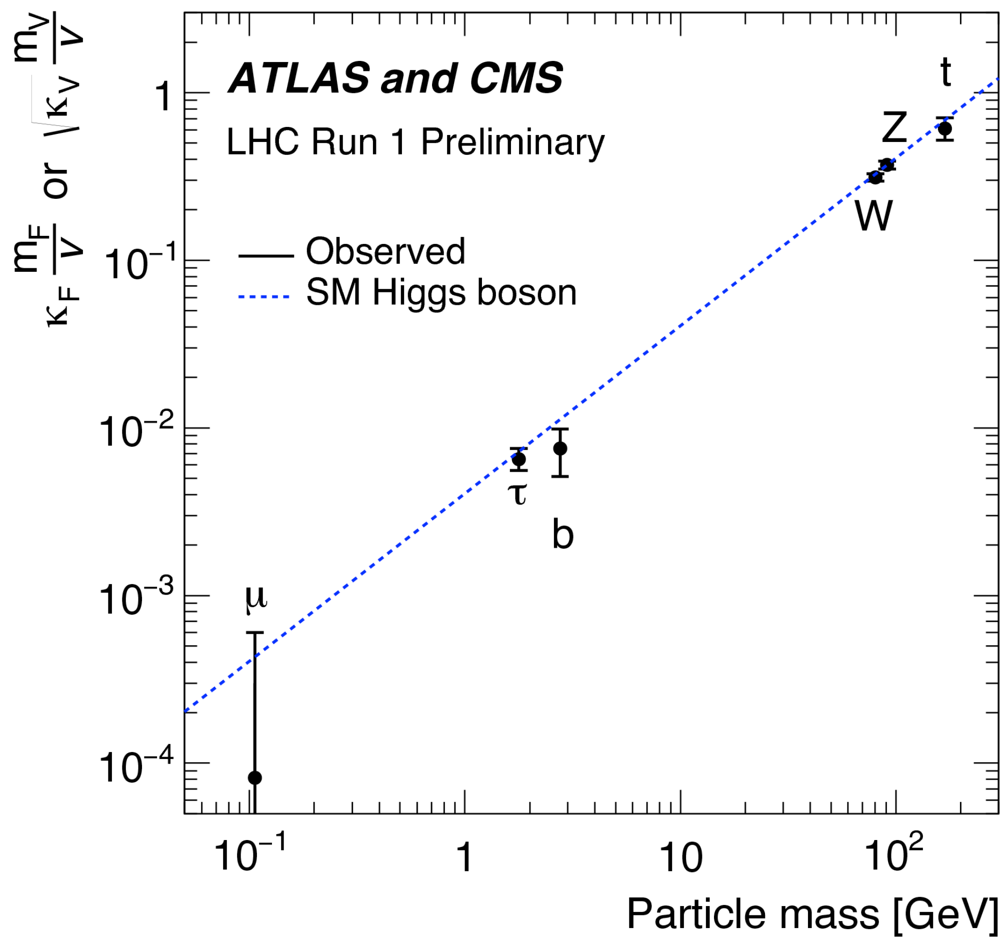


Individual Couplings

Fit within the SM (only SM particles in loops and decays, no new physics) of *absolute* couplings

→ express effective couplings to photons and gluons and Higgs width via SM couplings





Mass dependent couplings, as predicted by the BEH mechanism!

BSM Contributions in Loops/Decays

Allow new (heavy) BSM particles to contribute via loops:

→ effective coupling modifiers κ_g, κ_γ

Study two scenarii:

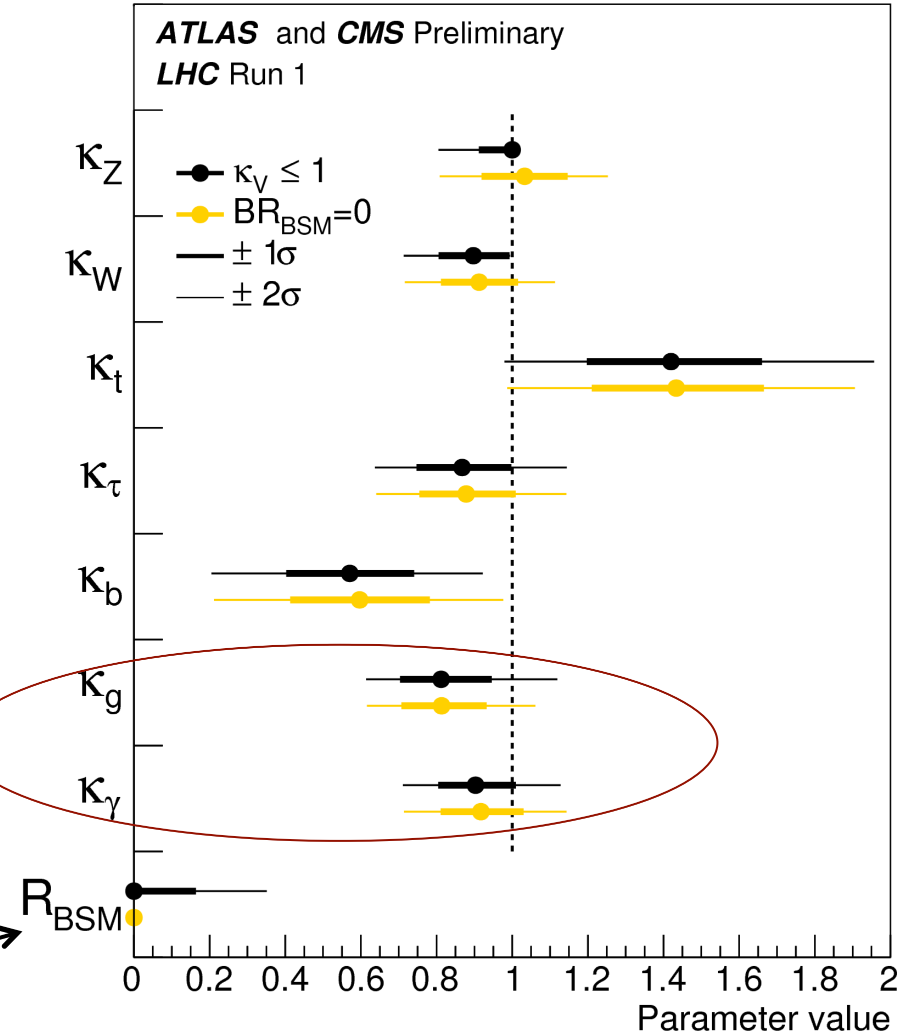
1) BR_{BSM} = 0: only SM decays

2) Allow BSM decays
impose κ_V (V=W,Z) ≤ 1
→ set limit on BR_{BSM}

→ Effective couplings κ_g, κ_γ compatible with SM!

From 2)

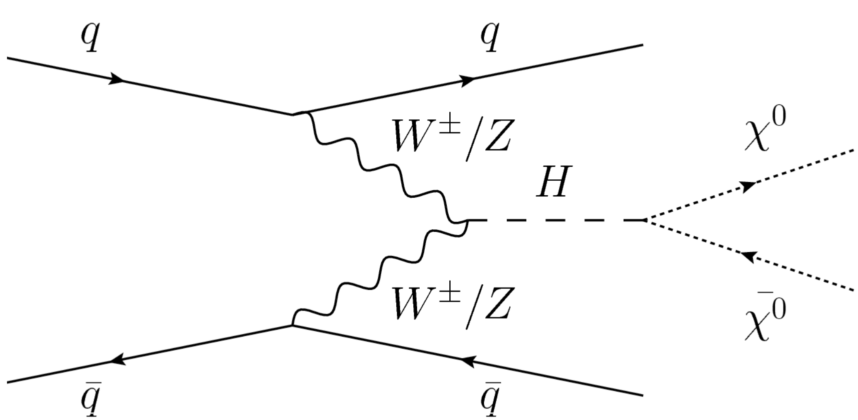
BR_{BSM} < 0.34 (95% CL)

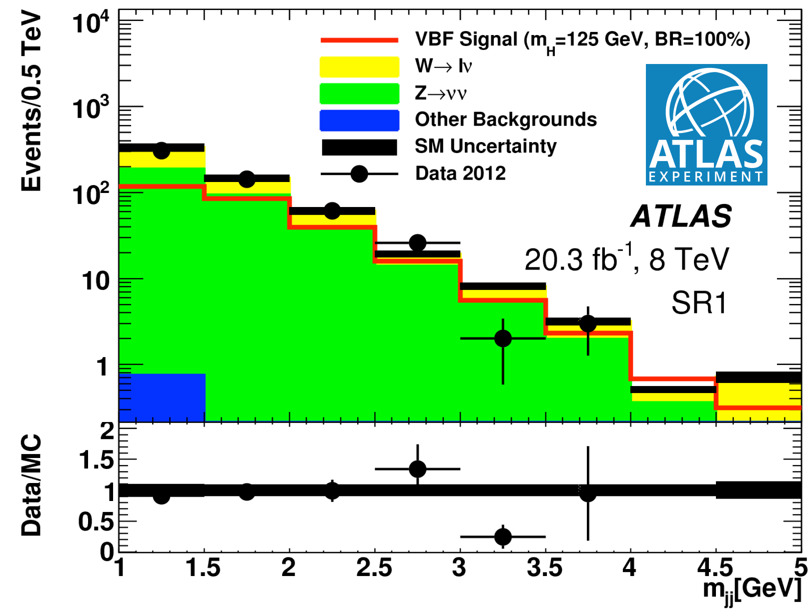


Invisible Higgs Boson Decays

Higgs boson decays into BSM particles → *invisible* if final state particles escape detector
(no sensitivity to *invisible* SM decay: H→ZZ→4ν ~ 0.1%)

Direct Measurements: need a recoil system → VBF, W/Z H production modes





[JHEP 01 (2016)]

Combination of all channels
(assuming SM production rates):

BR(H→invisible) < 0.25 (0.27 exp.)
@ 95% CL

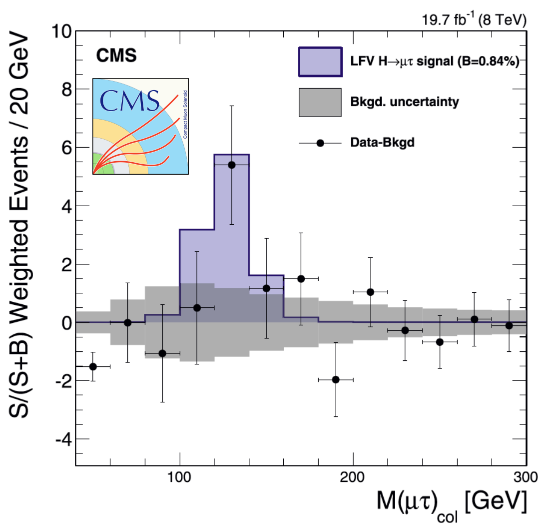
CMS: < 0.36 (0.30)

Lepton Flavour Violating Decays: H→τμ

- Not allowed in SM (if valid for all scales), but can occur e.g. in 2HDM and other models

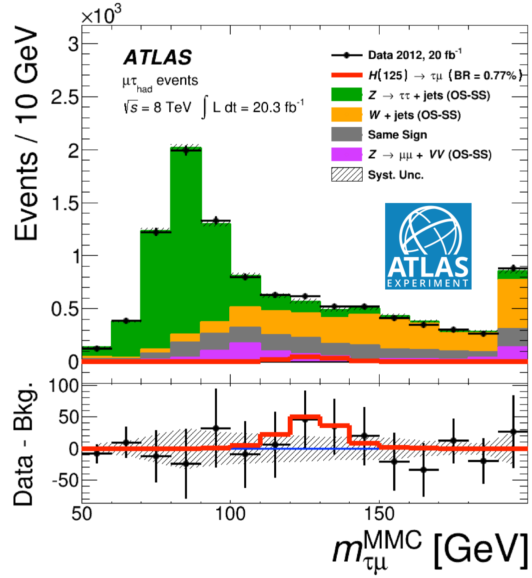
- Indirect limits from other measurements (τ → e/μγ via virtual H): BR(H→τ + e/μ) ≤ 10%

CMS: H→ $\mu\tau_e$, $\mu\tau_h$



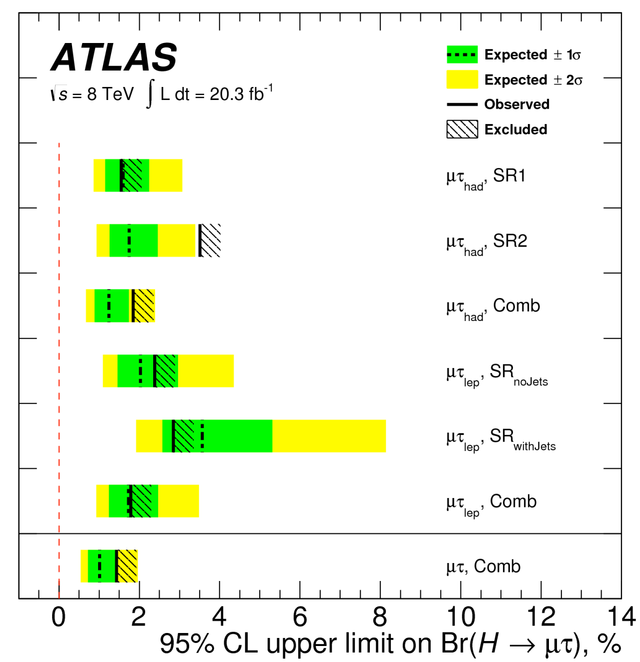
[PLB 749 (2015)]

ATLAS: H→ $\mu\tau_h$



[JHEP 11 (2015)]

New: H→ $\mu\tau_l$ + combination



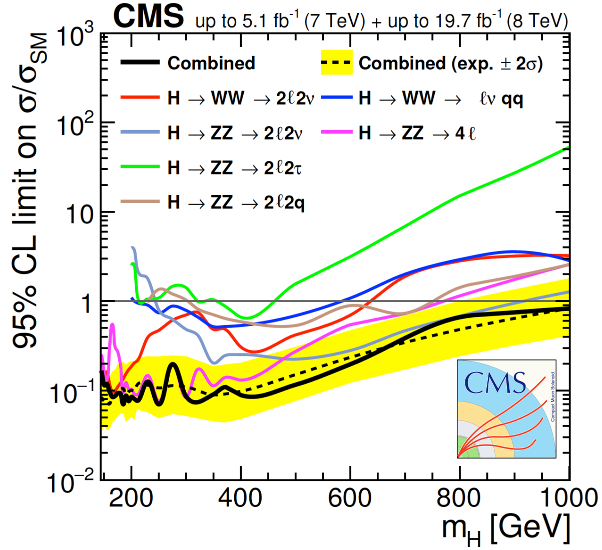
Excess of 2.4 σ (CMS) 1.3 σ (ATLAS)

CMS: BR(H→τ + μ) < 1.51% @ 95% CL BR(H→τ + e) < 0.69% @ 95% CL

ATLAS: BR(H→τ + μ) < 1.43% BR(H→τ + e) < 1.04%

Searches for Additional Higgs Bosons

Heavy Higgs boson search in H→ZZ+WW



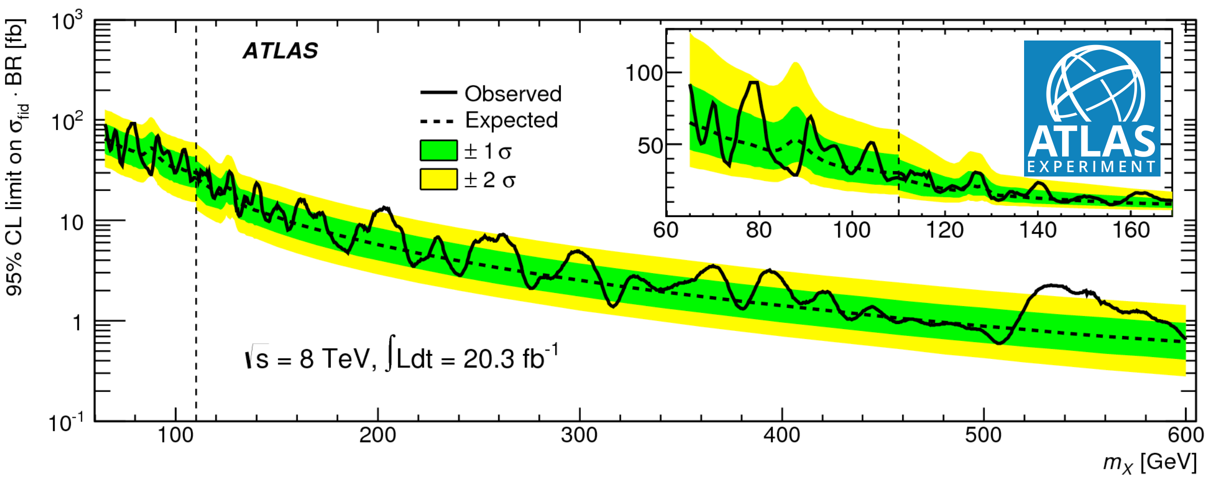
← For a Higgs boson with SM-like couplings: Exclusion over mass range 145 – 1000 GeV

(also interpretations in other models)

[JHEP 10 (2015)]

…. and H→γγ

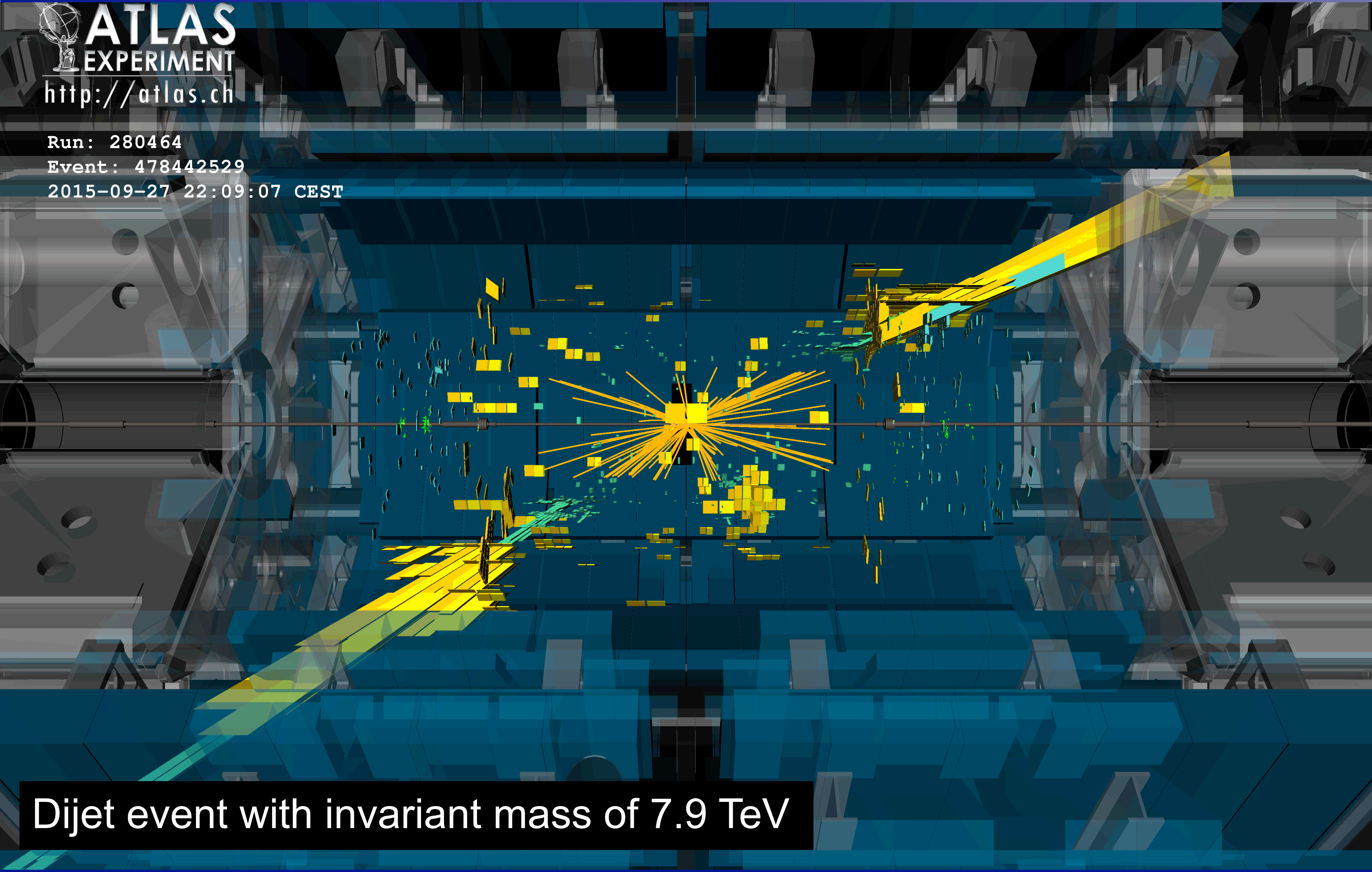
No significant excess observed!



[PRL 113 (2014)]

+ many other searches with negative outcome.

LHC Run 2 has started at 13 TeV



Dijet event with invariant mass of 7.9 TeV

LHC Run 2 Has Started at 13 TeV

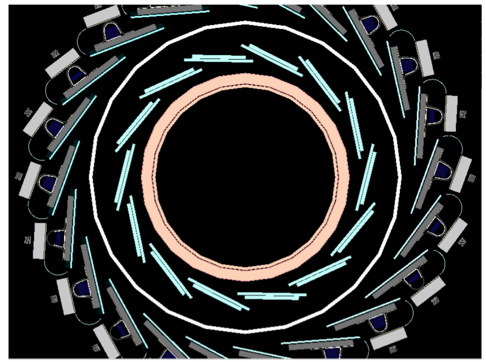
LHC Run 2:

$L = 1.5 \times 10^{34}\ cm^{-2}s^{-1}$

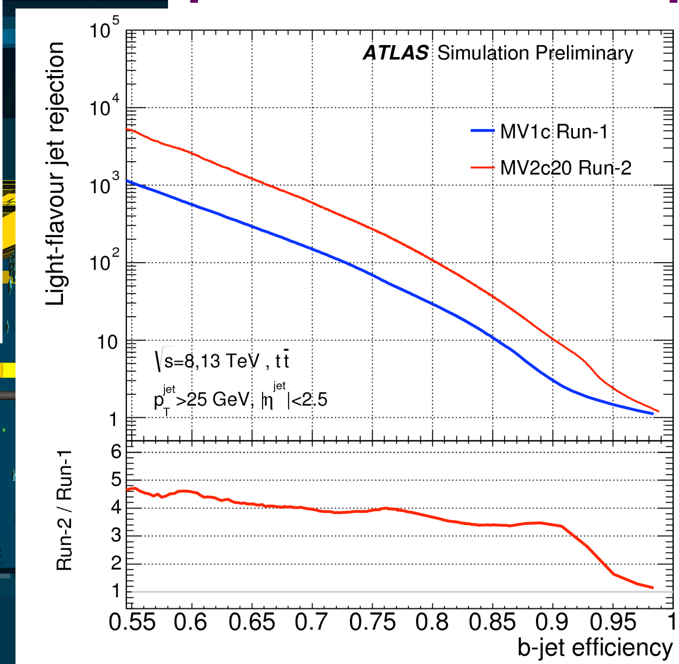
bunch spacing Δt = 25 ns
→ Pile-up: <N> ~ 40

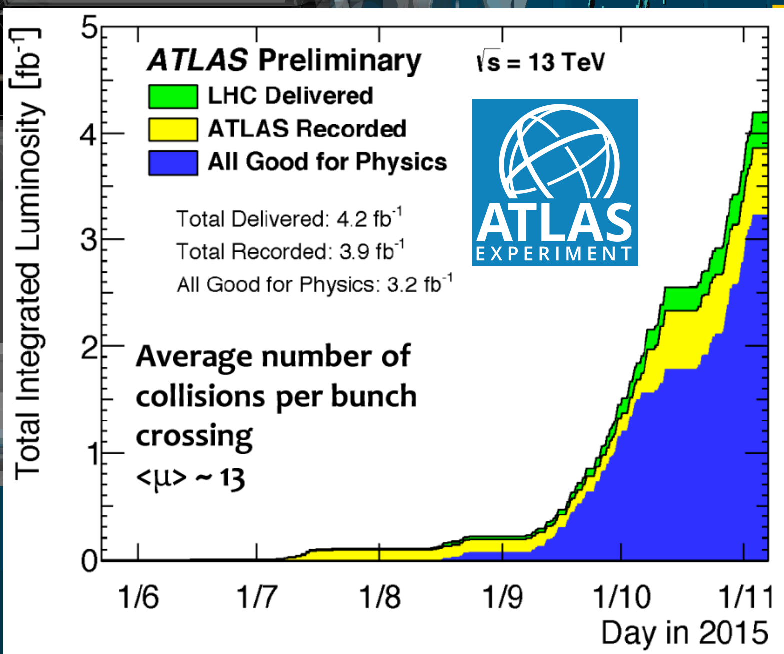
Collect L_{int} ~ 100 fb^{-1} until 2018

Several upgrades, e.g. fourth pixel layer in ATLAS



[ATL-PHYS-PUB-2015-022]

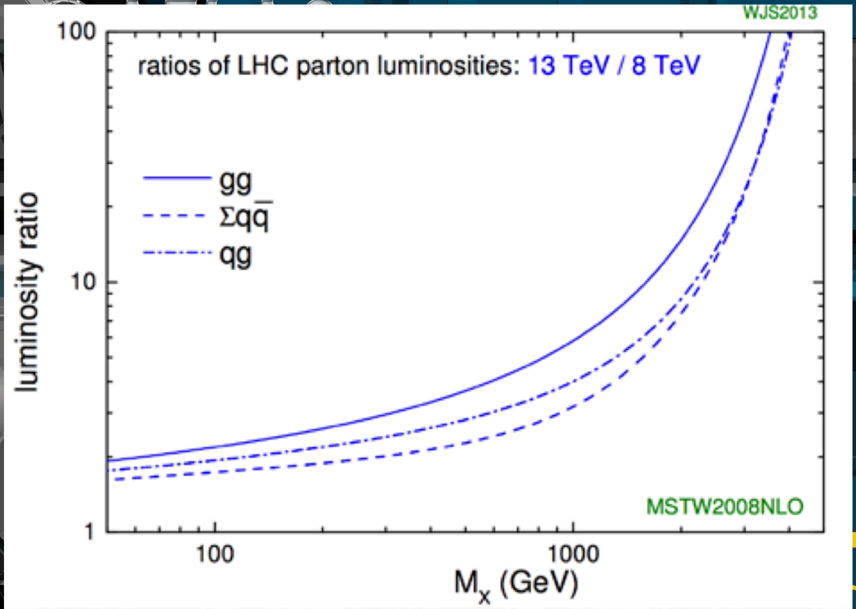


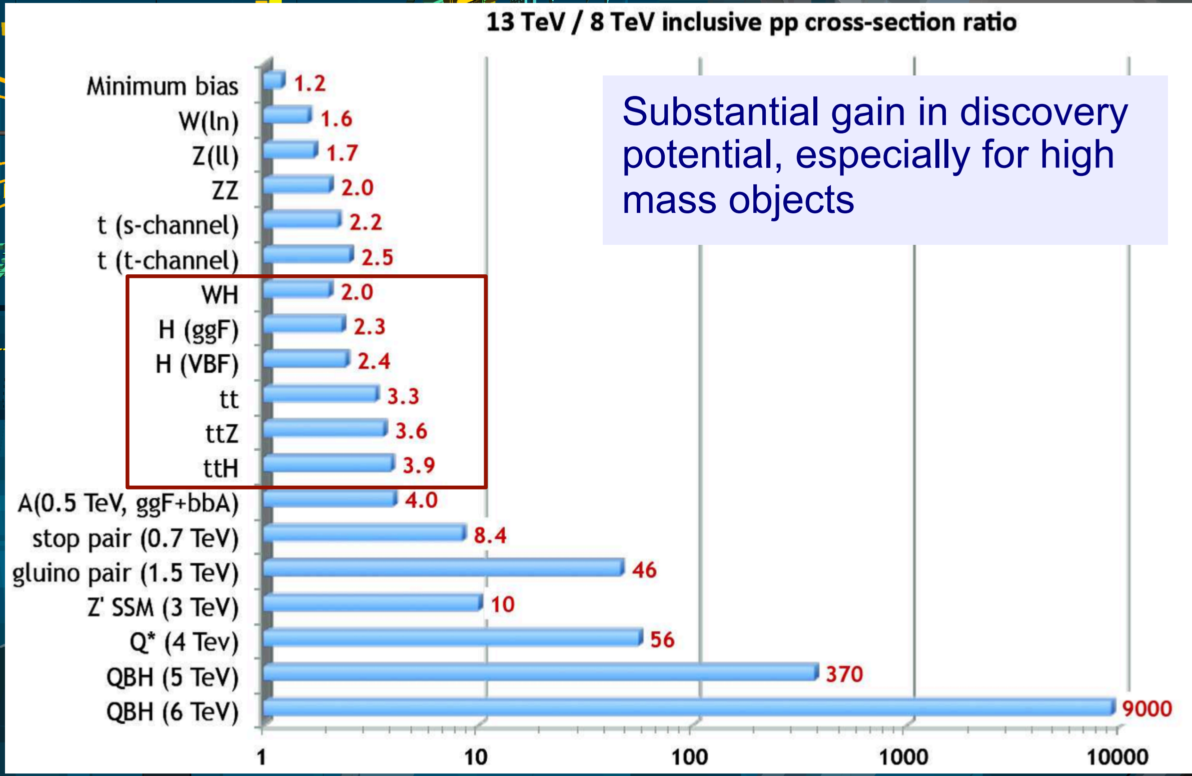


~ 3 fb^{-1} for physics analyses

Plenty of public results produced by ATLAS and CMS!

LHC Run 2 Has Started at 13 TeV

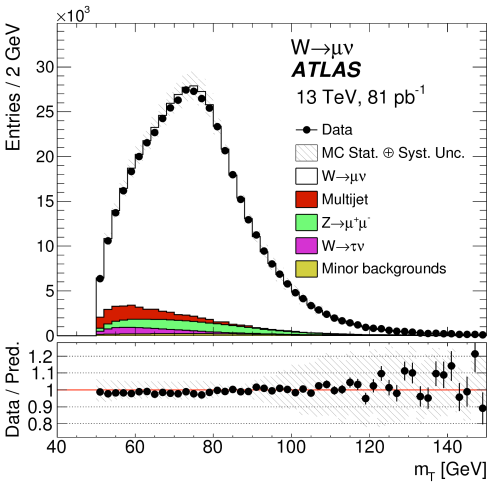


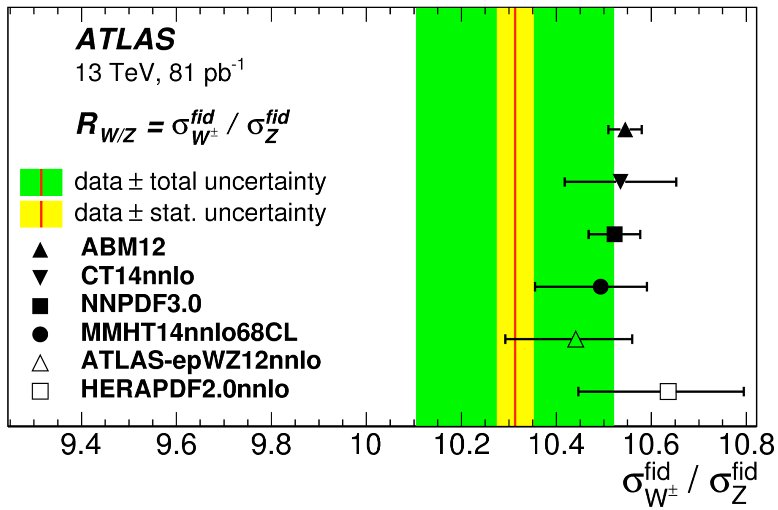


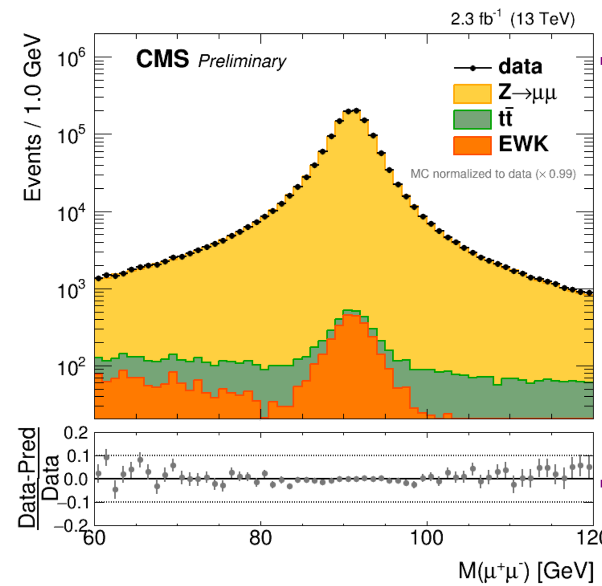
Substantial gain in discovery potential, especially for high mass objects

W/Z Production

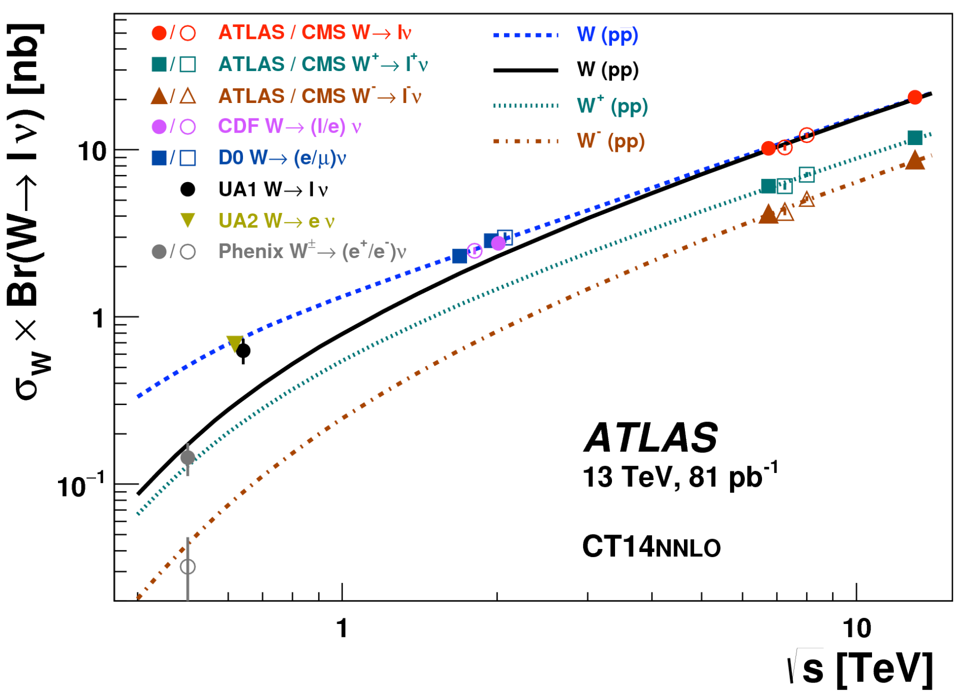
The *Standard Candles* not only for physics



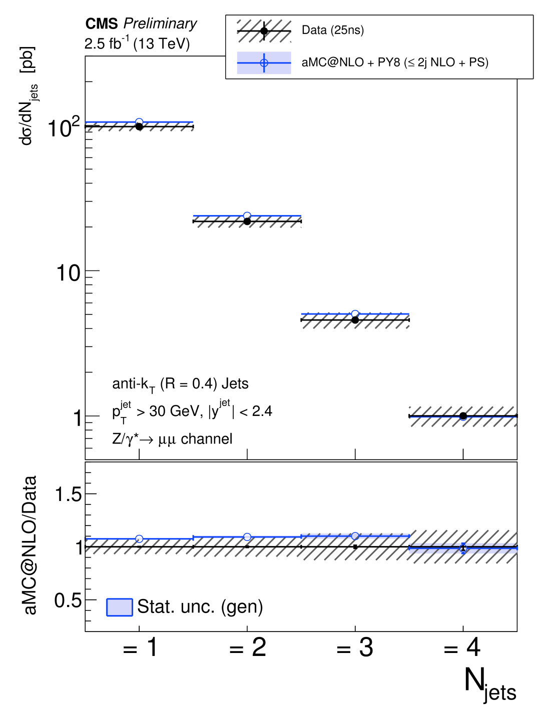




[CMS-PAS-SMP-15-011]



[arXiv:1603.09222]

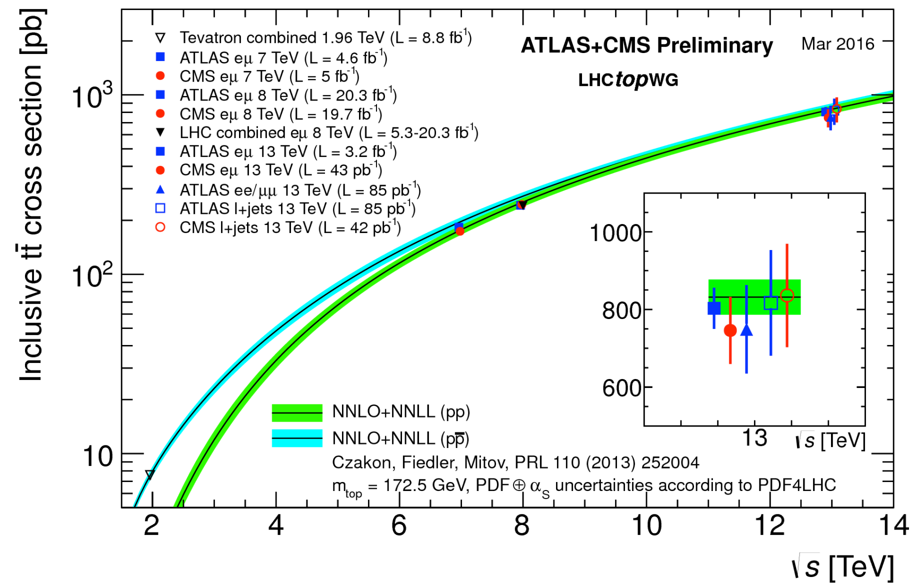


[CMS-PAS-SMP-15-010]

Top Production

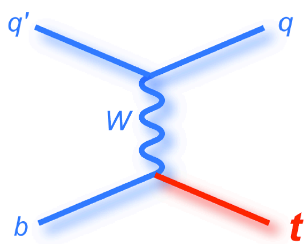
tt-production primarily
gg-induced at the LHC:

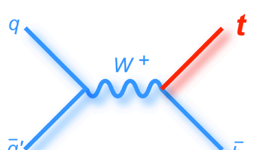
Already several measurements in Dilepton and lepton+jets channels (also differential) →



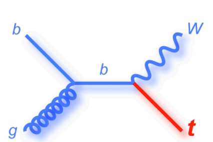
Single Top:

t-channel:



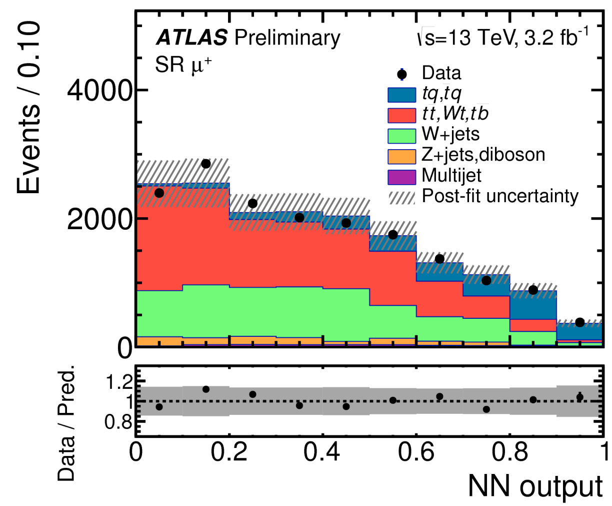


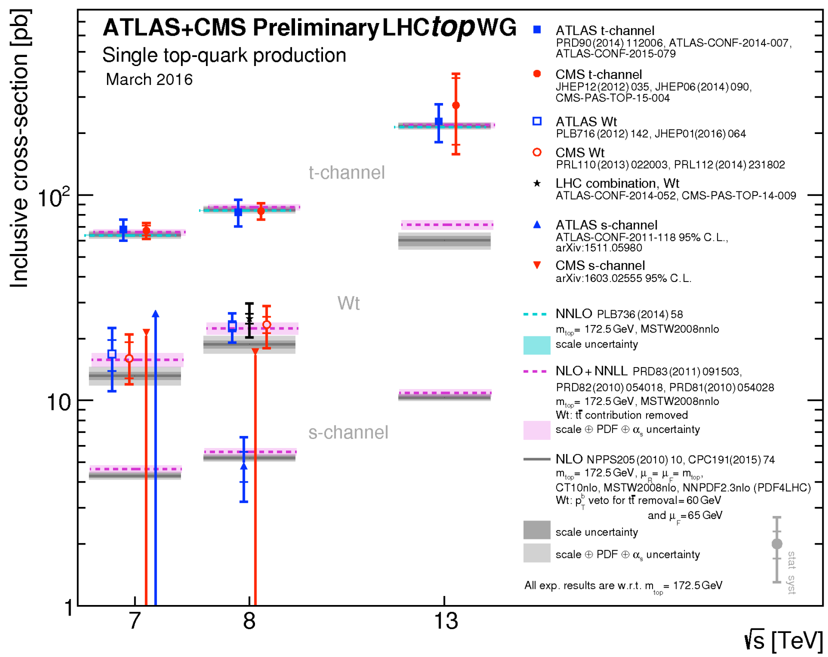
Wt-channel



s-channel

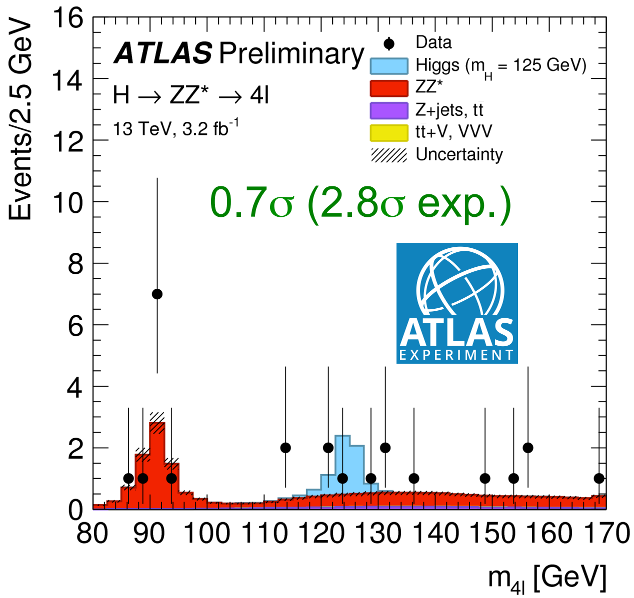
[ATLAS-CONF-2015-079]

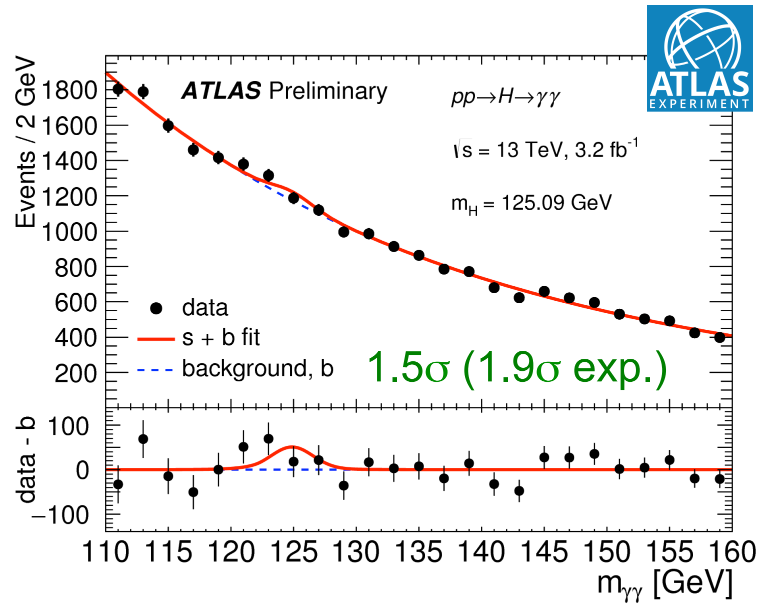




$H \to ZZ \to 4\ell$, $H \to \gamma\gamma$

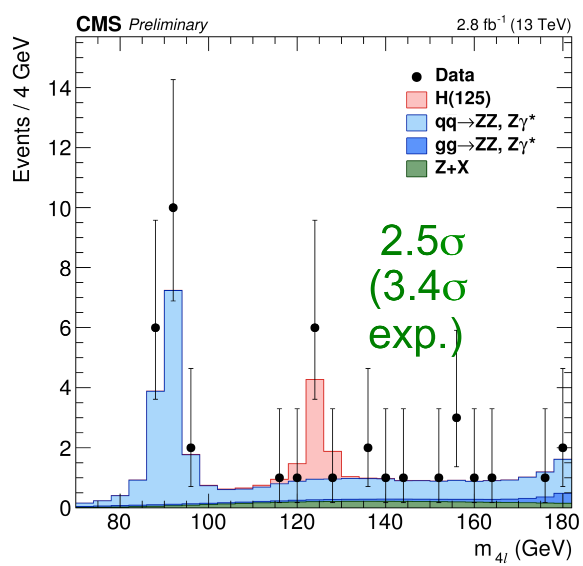
[ATLAS-CONF-2015-059]

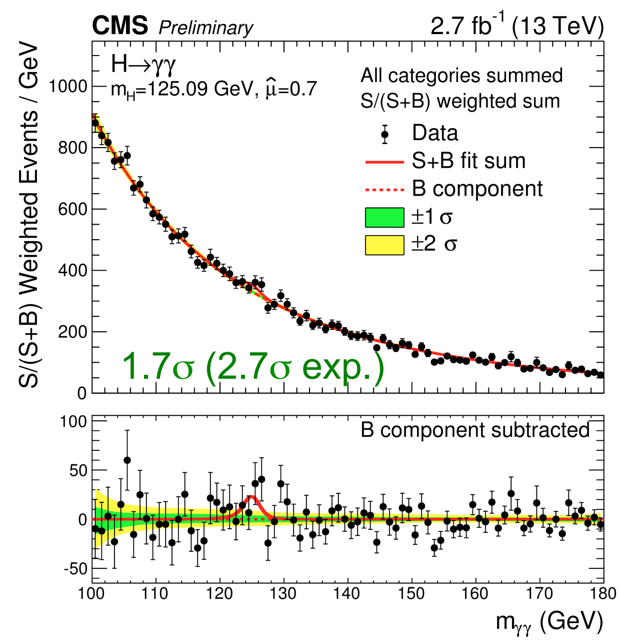




[ATLAS-CONF-2015-060]

[CMS-PAS-HIG-15-004]

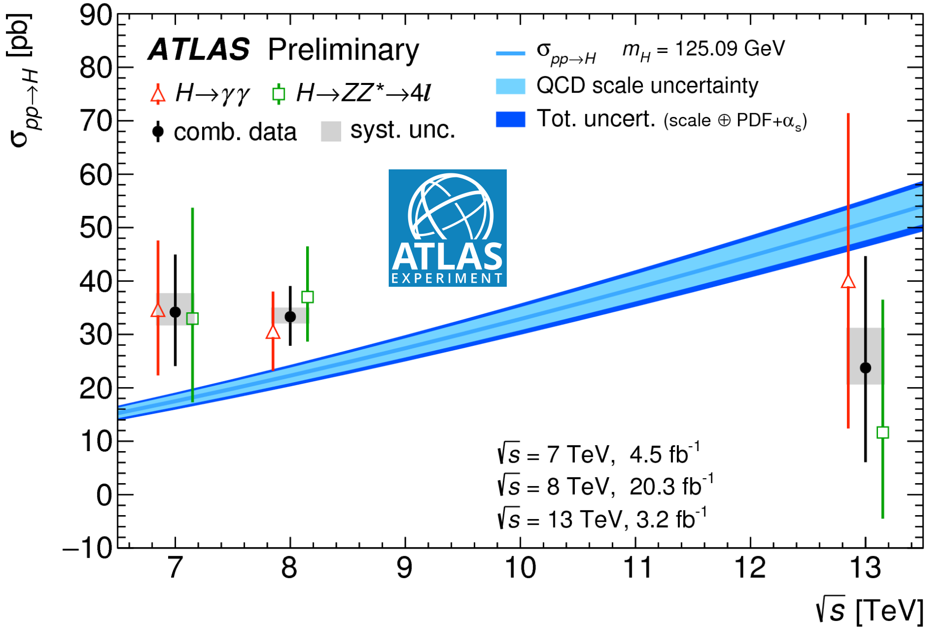




[CMS-PAS-HIG-15-005]

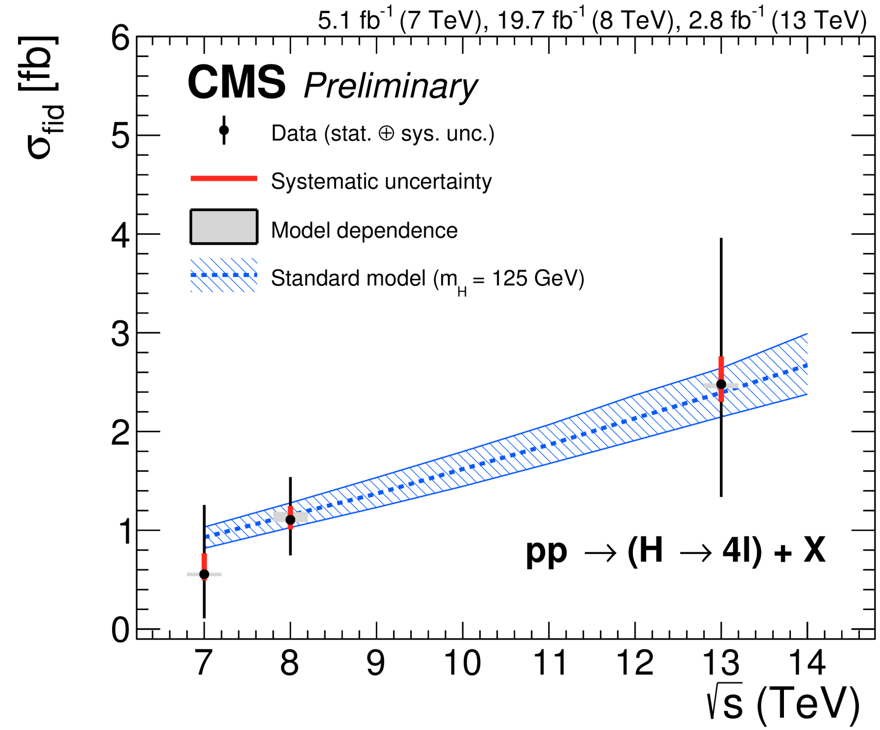
H → ZZ → 4ℓ, H → γγ

Combined γγ + 4l cross section:



[ATLAS-CONF-2015-069]

H → ZZ* → 4l

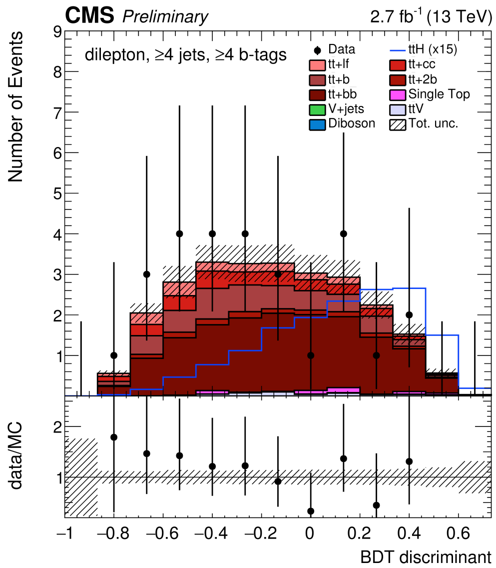


[CMS-PAS-HIG-15-004]

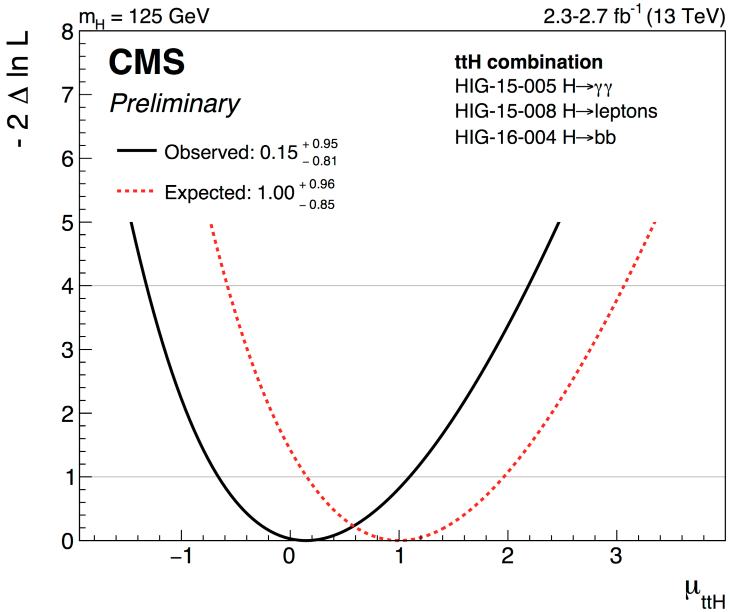
ttH @ 13 TeV

ttH benefits enormously from increased √s (σ x 3.9)!

H → bb

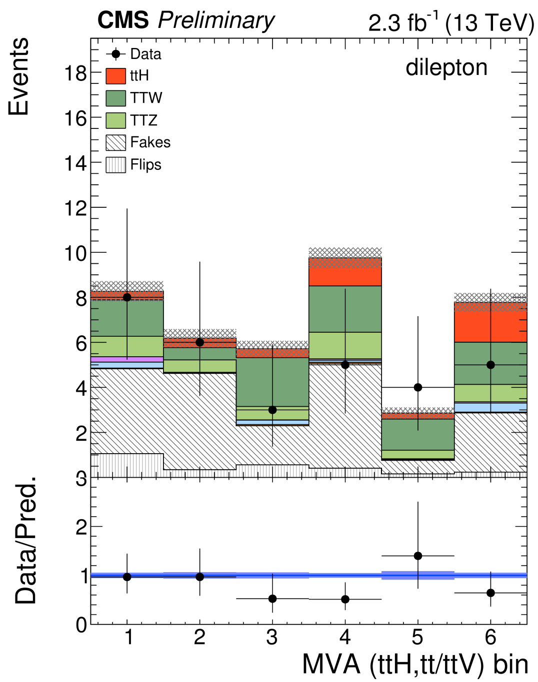


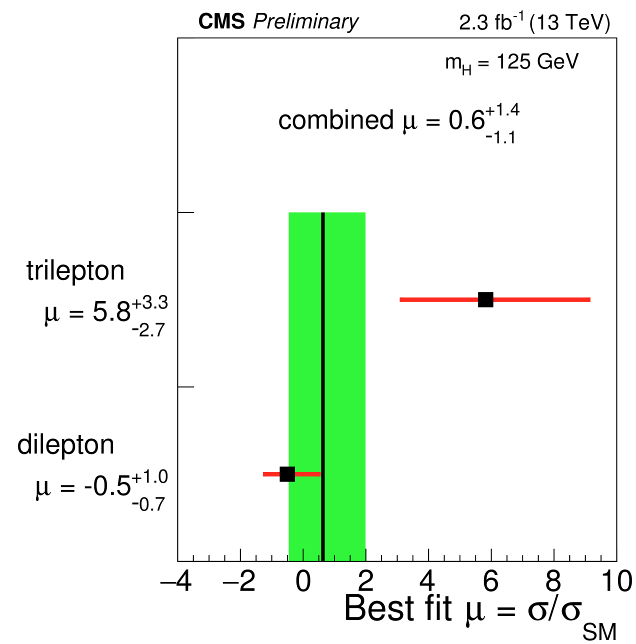
[CMS-PAS-HIG-15-004]



Multilepton final state

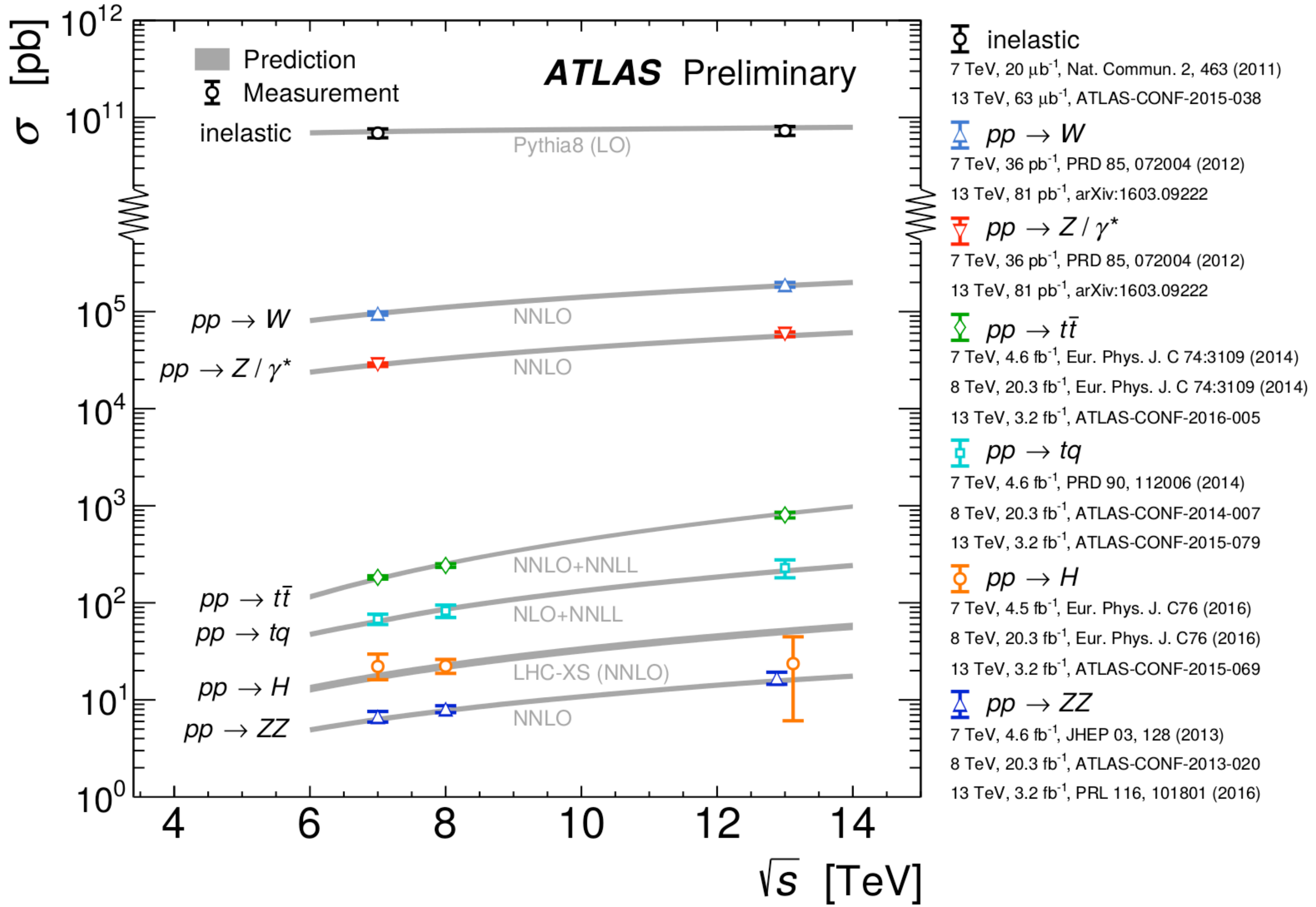
[CMS-PAS-HIG-15-008]





Remember: There was some excess in Run 1 …..

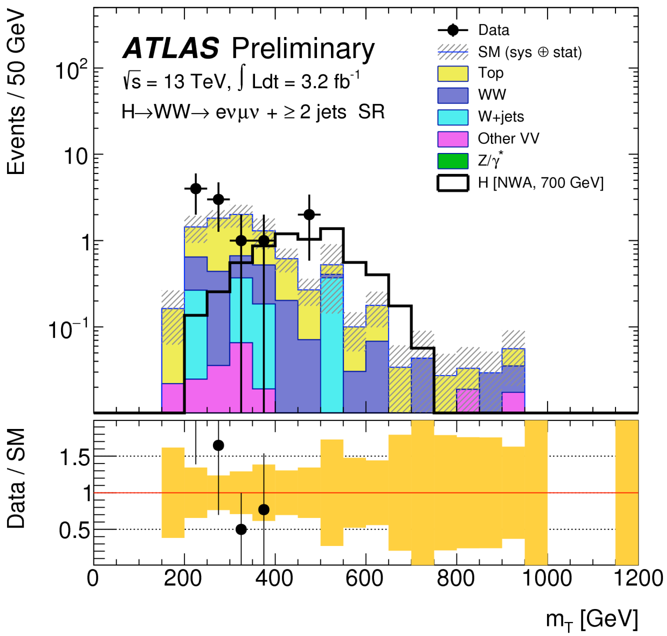
Cross Section Summary

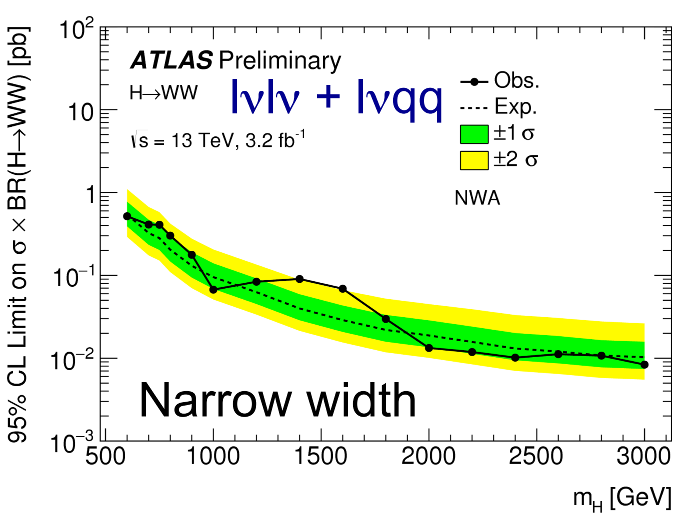


Heavy Resonances → ZZ, WW

WW → eνμν

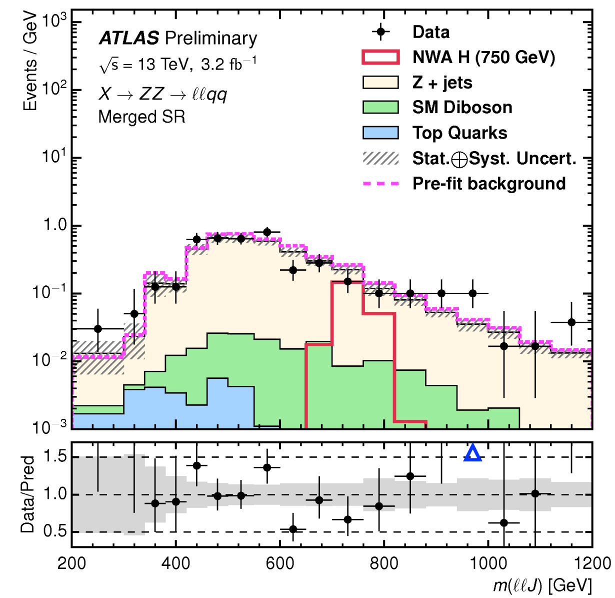
[ATLAS-CONF-2016-021]

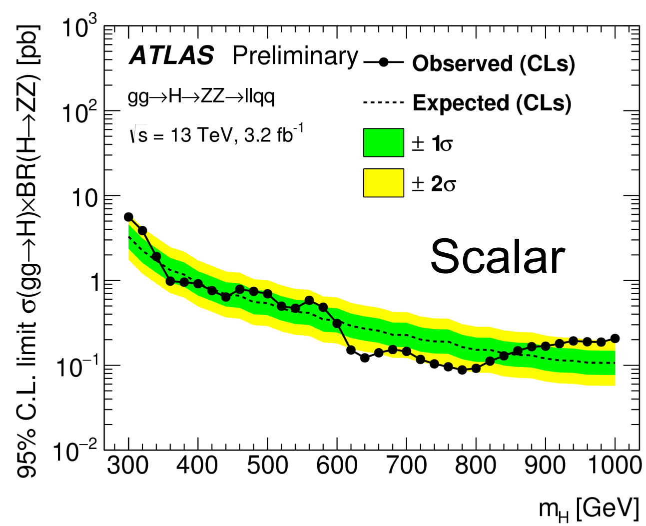




ZZ → llqq: *merged* and *resolved* analyses

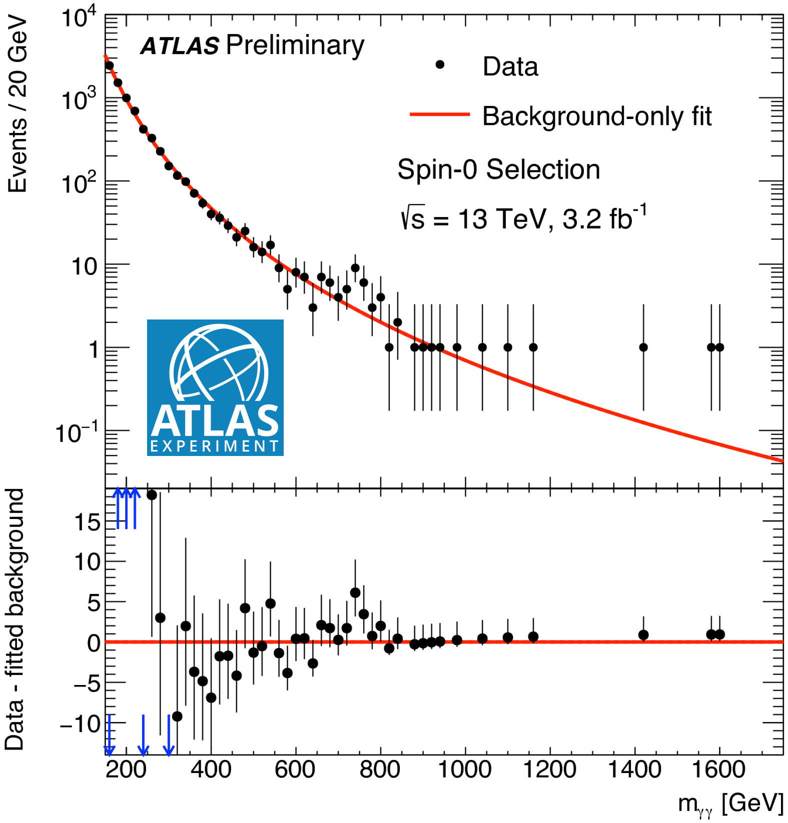
[ATLAS-CONF-2016-016]

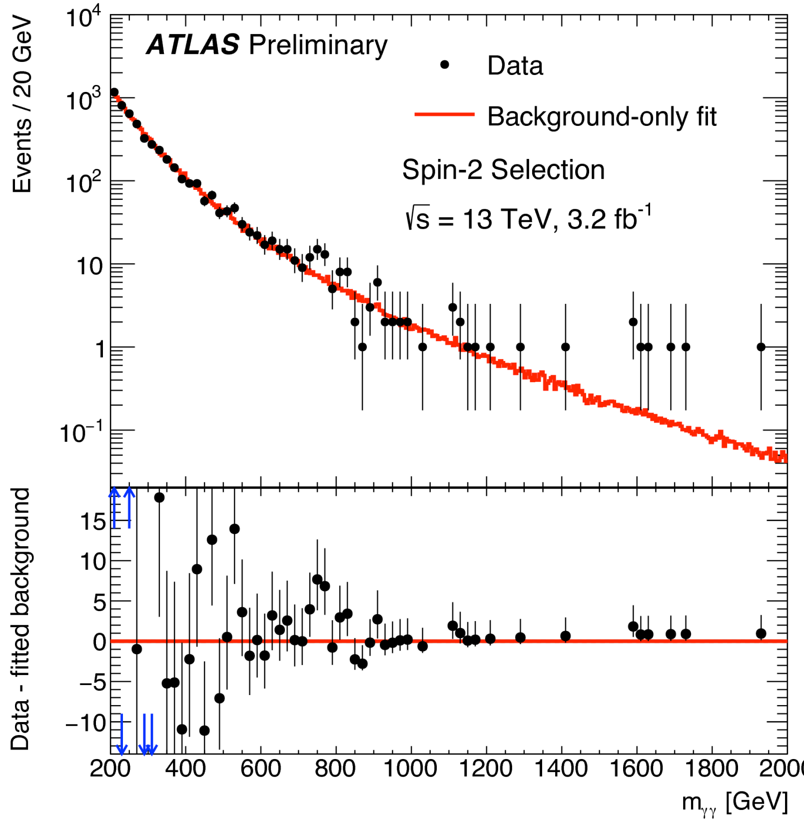




Resonance Search in γγ

[ATLAS-CONF-2016-018]





Analyses optimised for resonances with

Spin-0

γ_1: $E_T > 0.4 \times m_{\gamma\gamma}$
γ_2: $E_T > 0.3 \times m_{\gamma\gamma}$

→ ~ 2900 γγ events ($m_{\gamma\gamma}$ > 200 GeV)

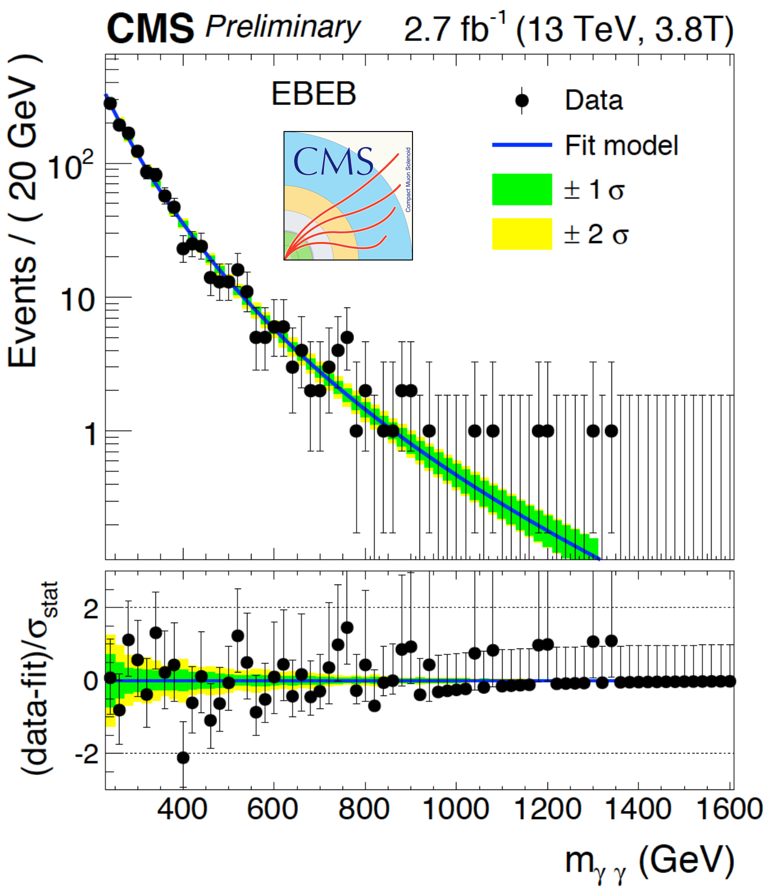
Spin-2

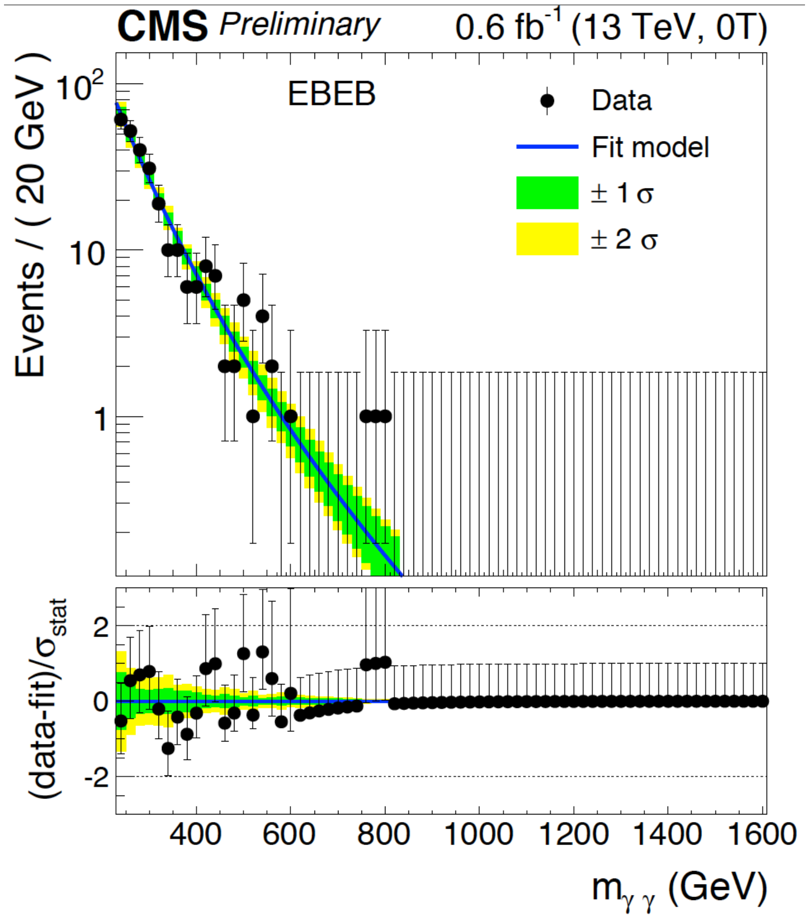
γ_1, γ_2: E_T > 55 GeV

→ ~ 5100 γγ events ($m_{\gamma\gamma}$ > 200 GeV)

Resonance Search in $\gamma\gamma$

Also analysed data with magnet off ("0 T") → ~ 20% sensitivity increase



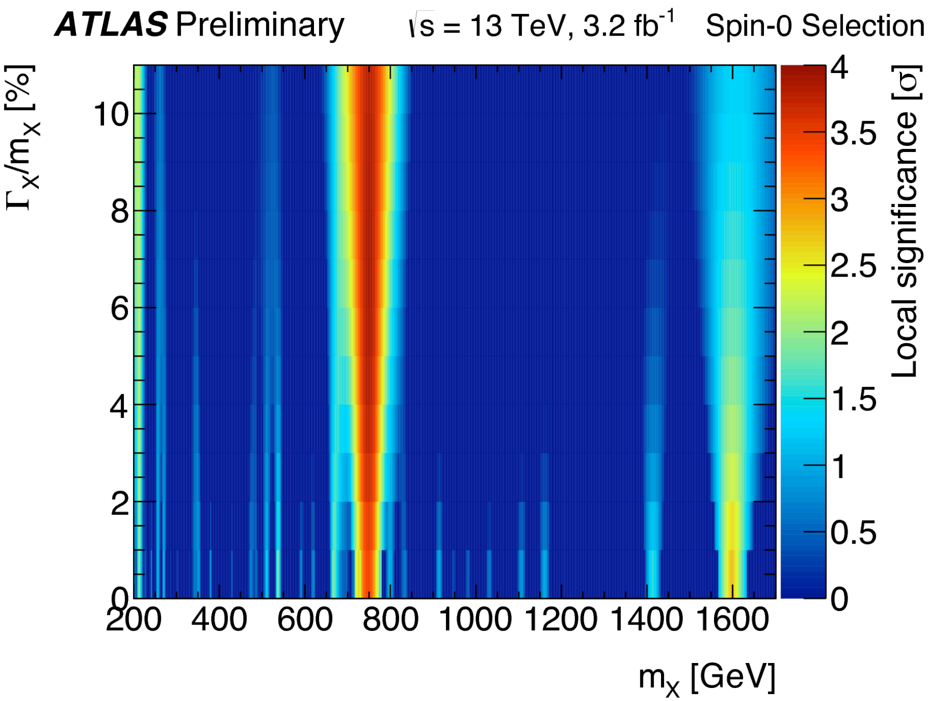


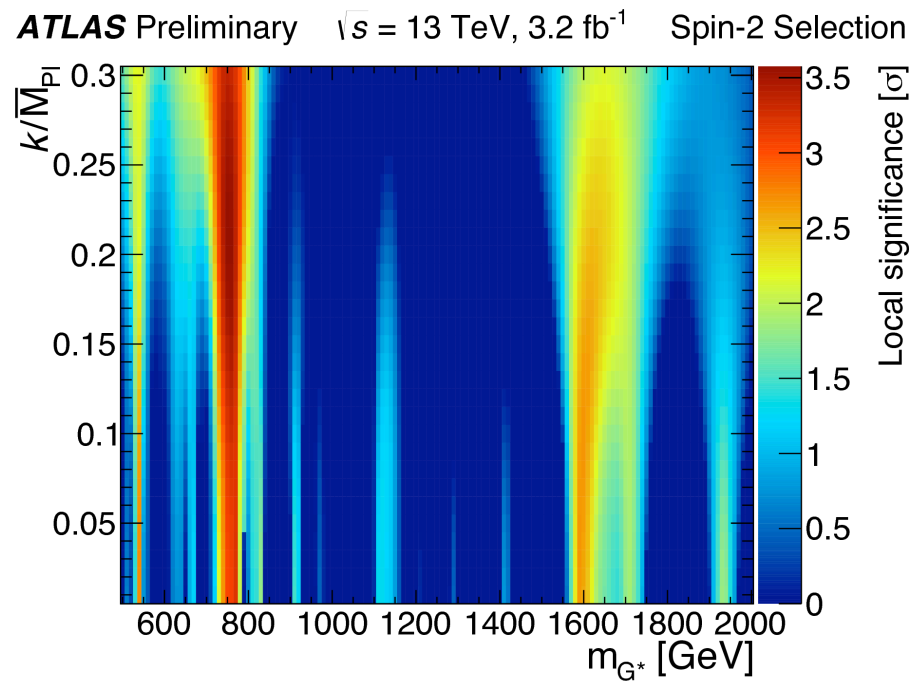
[CMS-PAS-EXO-16-018]

γ_1, γ_2: $E_T > 75$ GeV

Resonance Search in γγ

[ATLAS-CONF-2016-018]

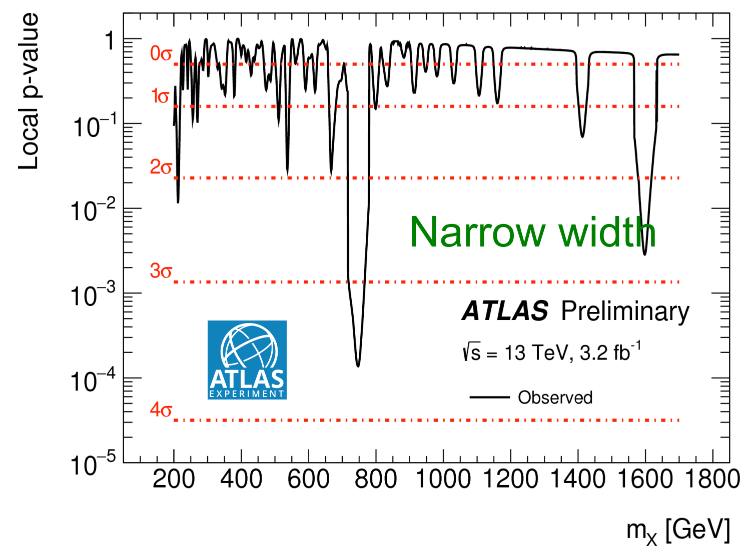




Spin-0: 3.9 σ excess (local) at 750 GeV for a width of 6%

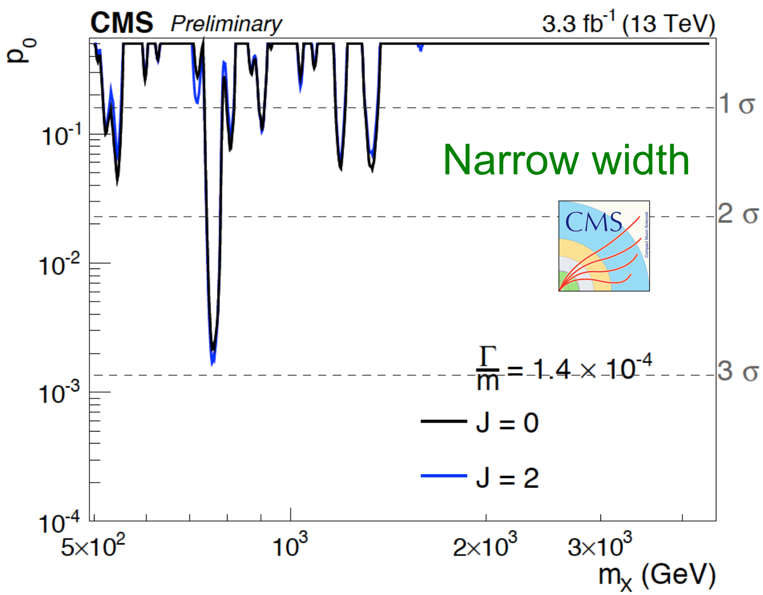
Spin-2: 3.6 σ excess (local) at 750 GeV

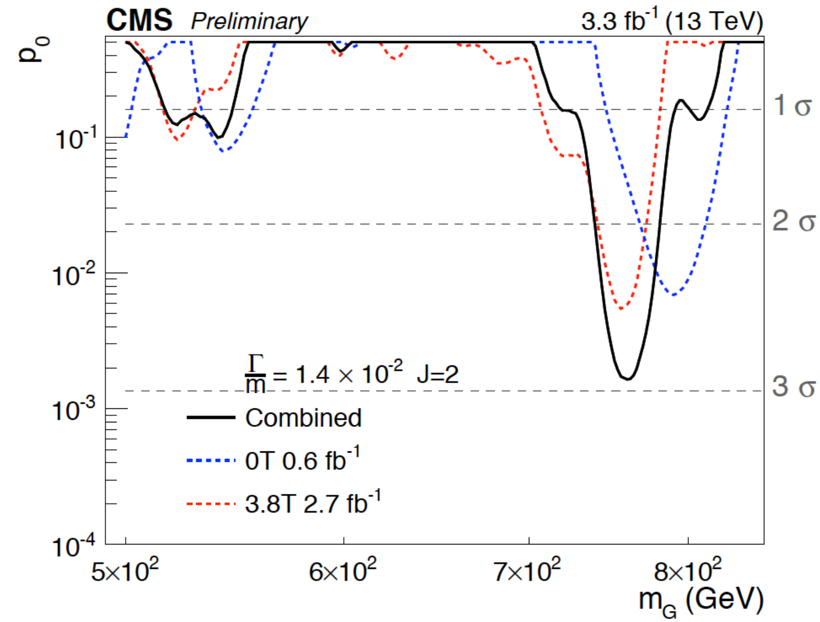
Look Elsewhere Effect:
→ Spin-0: 2.0 σ in [200 GeV, 2000 GeV]
Spin-2: 1.8 σ



[ATLAS-CONF-2015-081]

Resonance Search in γγ





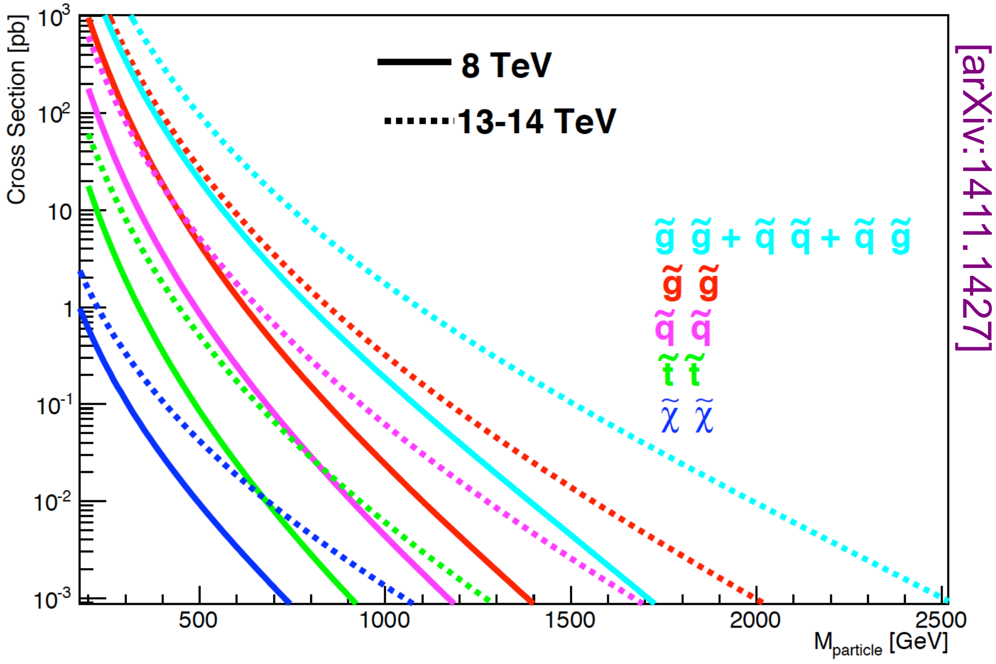
[CMS-PAS-EXO-16-018]

2.9 σ excess (local) at 760 GeV

Look Elsewhere Effect:
→ 1 σ in [500 GeV, 4500 GeV]

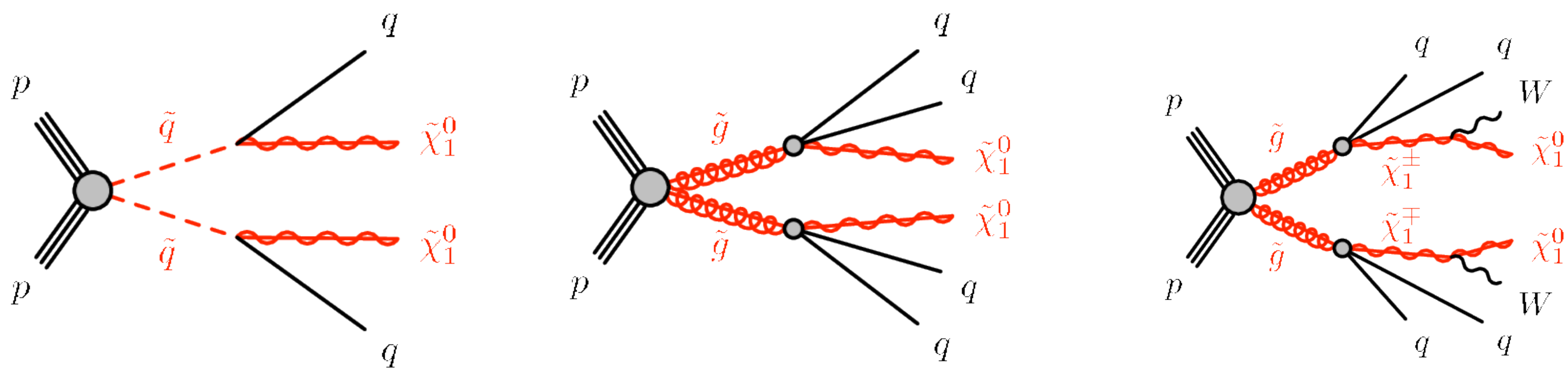
→ Looks interesting, eagerly awaiting new data for clarification

Supersymmetry



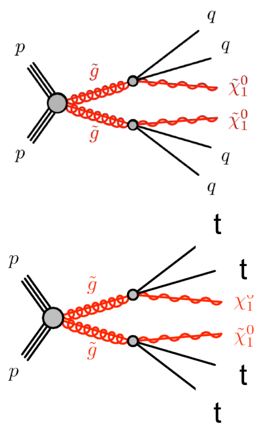
Strong production of squarks and gluinos

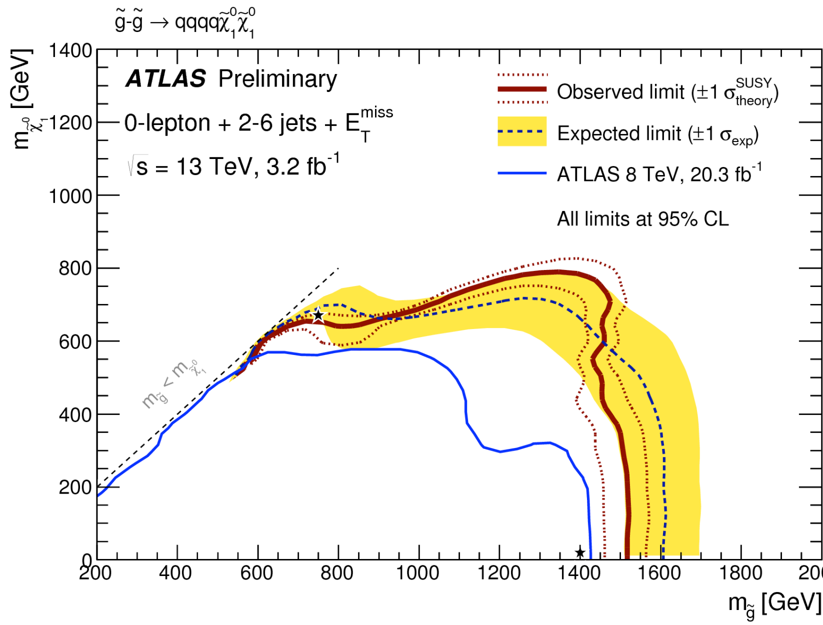
Typically cascade decays with
- multiple (b-) jets
- missing transverse energy
- leptons (W/Z bosons)
- (top quarks)



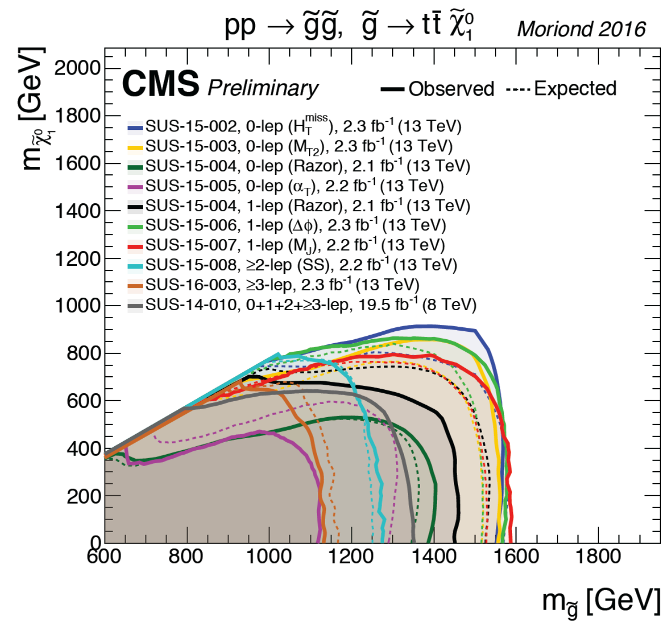
SUSY Searches

Gluinos:
0 leptons + multiple (b) jets

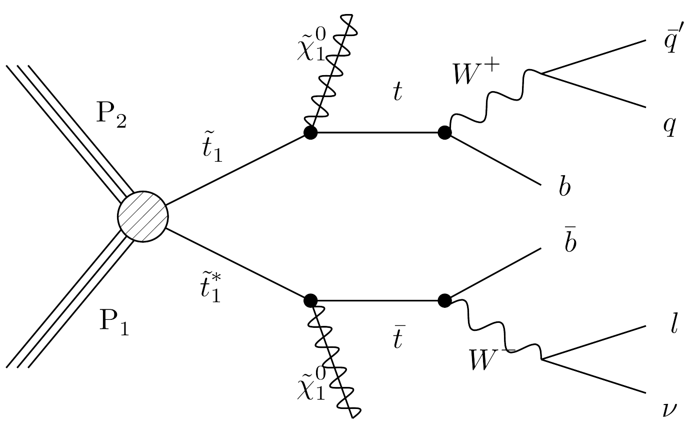


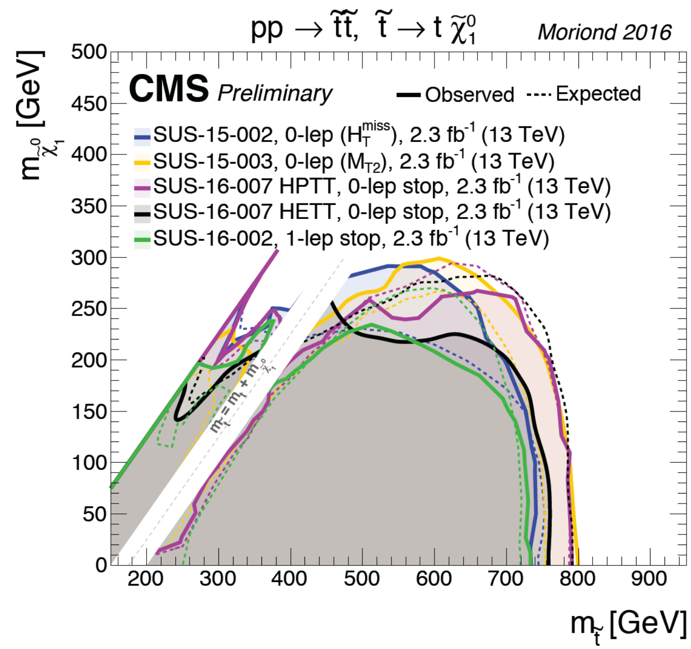


[ATLAS-CONF-2015-062]



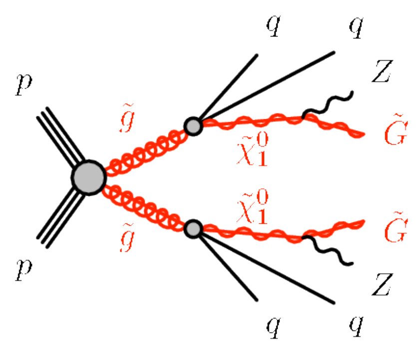
Stop pair production
(several final states)

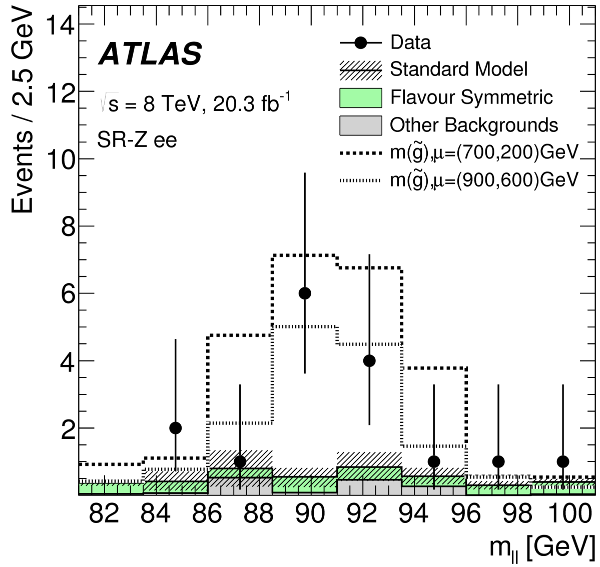




SUSY: Dilepton(Z) + Jets + MET

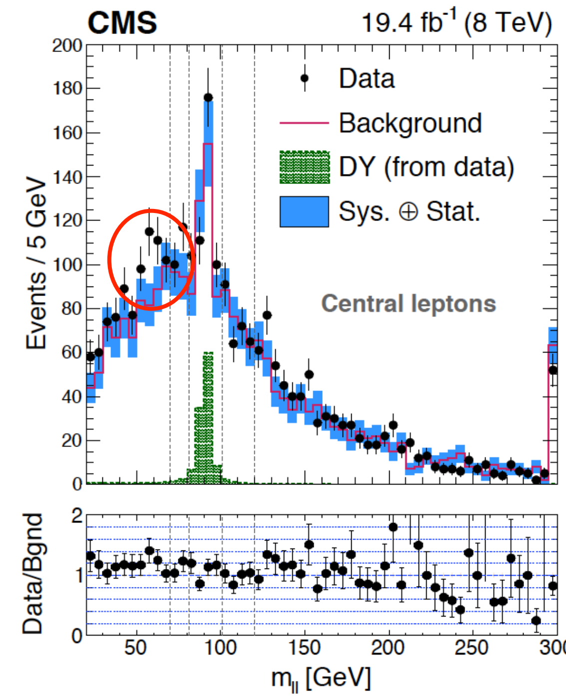
Some excesses observed in Run 1 by ATLAS and CMS





[EJP C75 (2015)]

Z → ee: 3 σ (1.7 in μμ)

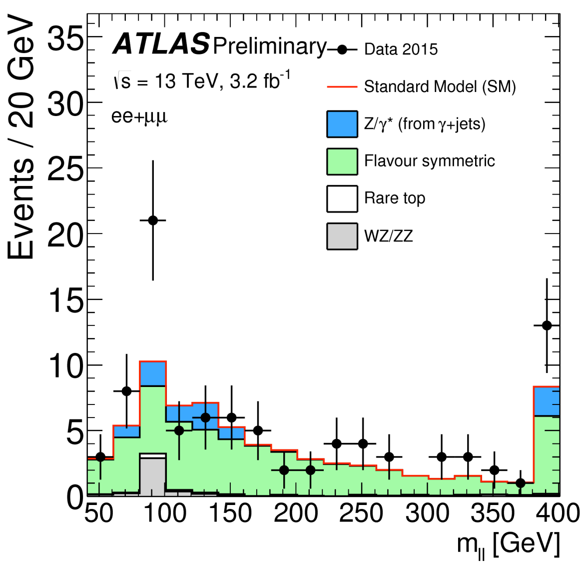


[JHEP 04 (2015)]

2.6 σ at low dilepton masses

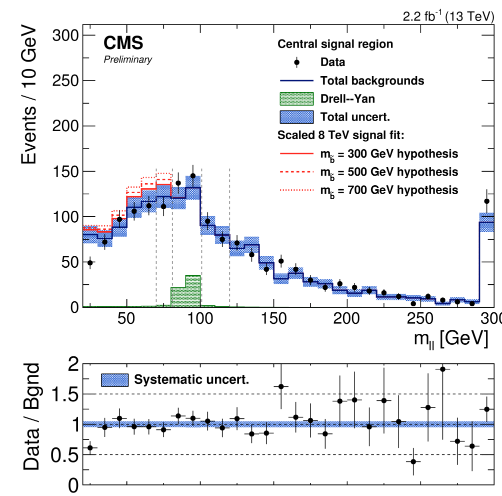
Run 2:

[ATLAS-CONF-2015-082]



Expected events: **10.3 ±2.3**
Observed: **21 (2.2σ)**
10 in ee, 11 in μμ

Run 1 excess not confirmed



[CMS-PAS-SUS-15-011]

SUSY Summary

ATLAS SUSY Searches* - 95% CL Lower Limits

Status: March 2016

ATLAS Preliminary

$\sqrt{s}$ = 7, 8, 13 TeV

$\sqrt{s}$ = 7, 8 TeV | $\sqrt{s}$ = 13 TeV

	Model	e, μ, τ, γ	Jets	E_T^{miss}	$\int \mathcal{L}\, dt [fb^{-1}]$	Mass limit		Reference
Inclusive Searches	MSUGRA/CMSSM	0-3 e,μ/1-2 τ	2-10 jets/3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.85 TeV	m($\tilde{q}$)=m($\tilde{g}$)	1507.05525
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$	0	2-6 jets	Yes	3.2	$\tilde{q}$ 980 GeV	m($\tilde{\chi}^0_1$)=0 GeV, m(1st gen. $\tilde{q}$)=m(2nd gen. $\tilde{q}$)	ATLAS-CONF-2015-062
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q\tilde{\chi}^0_1$ (compressed)	mono-jet	1-3 jets	Yes	3.2	$\tilde{q}$ 610 GeV	m($\tilde{q}$)-m($\tilde{\chi}^0_1$)<5 GeV	*To appear*
	$\tilde{q}\tilde{q}$, $\tilde{q}\to q(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ (off-Z)	2 jets	Yes	20.3	$\tilde{q}$ 820 GeV	m($\tilde{\chi}^0_1$)=0 GeV	1503.03290
	$\tilde{g}\tilde{g}$, $\tilde{g}\to q\bar{q}\tilde{\chi}^0_1$	0	2-6 jets	Yes	3.2	$\tilde{g}$ 1.52 TeV	m($\tilde{\chi}^0_1$)=0 GeV	ATLAS-CONF-2015-062
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^{\pm}_1\to qqW^{\pm}\tilde{\chi}^0_1$	1 e,μ	2-6 jets	Yes	3.3	$\tilde{g}$ 1.6 TeV	m($\tilde{\chi}^0_1$)<350 GeV, m($\tilde{\chi}^{\pm}$)=0.5(m($\tilde{\chi}^0_1$)+m($\tilde{g}$))	ATLAS-CONF-2015-076
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq(\ell\ell/\ell\nu/\nu\nu)\tilde{\chi}^0_1$	2 e,μ	0-3 jets	-	20	$\tilde{g}$ 1.38 TeV	m($\tilde{\chi}^0_1$)=0 GeV	1501.03555
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqWZ\tilde{\chi}^0_1$	0	7-10 jets	Yes	3.2	$\tilde{g}$ 1.4 TeV	m($\tilde{\chi}^0_1$) =100 GeV	1602.06194
	GMSB ($\tilde{\ell}$ NLSP)	1-2 τ + 0-1 ℓ	0-2 jets	Yes	20.3	$\tilde{g}$ 1.63 TeV	tanβ >20	1407.0603
	GGM (bino NLSP)	2 γ	-	Yes	20.3	$\tilde{g}$ 1.34 TeV	$c\tau$(NLSP)<0.1 mm	1507.05493
	GGM (higgsino-bino NLSP)	γ	1 b	Yes	20.3	$\tilde{g}$ 1.37 TeV	m($\tilde{\chi}^0_1$)<950 GeV, $c\tau$(NLSP)<0.1 mm, μ<0	1507.05493
	GGM (higgsino-bino NLSP)	γ	2 jets	Yes	20.3	$\tilde{g}$ 1.3 TeV	m($\tilde{\chi}^0_1$)<850 GeV, $c\tau$(NLSP)<0.1 mm, μ>0	1507.05493
	GGM (higgsino NLSP)	2 e,μ (Z)	2 jets	Yes	20.3	$\tilde{g}$ 900 GeV	m(NLSP)>430 GeV	1503.03290
	Gravitino LSP	0	mono-jet	Yes	20.3	$F^{1/2}$ scale 865 GeV	m($\tilde{G}$)>1.8 × 10^{-4} eV, m($\tilde{g}$)=m($\tilde{q}$)=1.5 TeV	1502.01518
3rd gen. $\tilde{g}$ med.	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{b}\tilde{\chi}^0_1$	0	3 b	Yes	3.3	$\tilde{g}$ 1.78 TeV	m($\tilde{\chi}^0_1$)<800 GeV	ATLAS-CONF-2015-067
	$\tilde{g}\tilde{g}$, $\tilde{g}\to t\bar{t}\tilde{\chi}^0_1$	0-1 e,μ	3 b	Yes	3.3	$\tilde{g}$ 1.76 TeV	m($\tilde{\chi}^0_1$)=0 GeV	*To appear*
	$\tilde{g}\tilde{g}$, $\tilde{g}\to b\bar{t}\tilde{\chi}^+_1$	0-1 e,μ	3 b	Yes	20.1	$\tilde{g}$ 1.37 TeV	m($\tilde{\chi}^0_1$)<300 GeV	1407.0600
3rd gen. squarks direct production	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to b\tilde{\chi}^0_1$	0	2 b	Yes	3.2	$\tilde{b}_1$ 840 GeV	m($\tilde{\chi}^0_1$)<100 GeV	ATLAS-CONF-2015-066
	$\tilde{b}_1\tilde{b}_1$, $\tilde{b}_1\to t\tilde{\chi}^{\pm}_1$	2 e,μ (SS)	0-3 b	Yes	3.2	$\tilde{b}_1$ 325-540 GeV	m($\tilde{\chi}^0_1$)=50 GeV, m($\tilde{\chi}^{\pm}_1$)= m($\tilde{\chi}^0_1$)+100 GeV	1602.09058
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\tilde{\chi}^{\pm}_1$	1-2 e,μ	1-2 b	Yes	4.7/20.3	$\tilde{t}_1$ 117-170 GeV, 200-500 GeV	m($\tilde{\chi}^{\pm}_1$) = 2m($\tilde{\chi}^0_1$), m($\tilde{\chi}^0_1$)=55 GeV	1209.2102, 1407.0583
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to Wb\tilde{\chi}^0_1$ or $t\tilde{\chi}^0_1$	0-2 e,μ	0-2 jets/1-2 b	Yes	20.3	$\tilde{t}_1$ 90-198 GeV, 205-715 GeV, 745-785 GeV	m($\tilde{\chi}^0_1$)=1 GeV	1506.08616, ATLAS-CONF-2016-007
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to c\tilde{\chi}^0_1$	0	mono-jet/c-tag	Yes	20.3	$\tilde{t}_1$ 90-245 GeV	m($\tilde{t}_1$)-m($\tilde{\chi}^0_1$)<85 GeV	1407.0608
	$\tilde{t}_1\tilde{t}_1$(natural GMSB)	2 e,μ (Z)	1 b	Yes	20.3	$\tilde{t}_1$ 150-600 GeV	m($\tilde{\chi}^0_1$)>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	$\tilde{t}_2$ 290-610 GeV	m($\tilde{\chi}^0_1$)<200 GeV	1403.5222
	$\tilde{t}_2\tilde{t}_2$, $\tilde{t}_2\to\tilde{t}_1 + h$	1 e,μ	6 jets + 2 b	Yes	20.3	$\tilde{t}_2$ 320-620 GeV	m($\tilde{\chi}^0_1$)=0 GeV	1506.08616
EW direct	$\tilde{\ell}_{L,R}\tilde{\ell}_{L,R}$, $\tilde{\ell}\to\ell\tilde{\chi}^0_1$	2 e,μ	0	Yes	20.3	$\tilde{\ell}$ 90-335 GeV	m($\tilde{\chi}^0_1$)=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	$\tilde{\chi}^{\pm}_1$ 140-475 GeV	m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}^{\pm}_1$)+m($\tilde{\chi}^0_1$))	1403.5294
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to\tilde{\tau}\nu(\tau\tilde{\nu})$	2 τ	-	Yes	20.3	$\tilde{\chi}^{\pm}_1$ 355 GeV	m($\tilde{\chi}^0_1$)=0 GeV, m($\tilde{\tau},\tilde{\nu}$)=0.5(m($\tilde{\chi}^{\pm}_1$)+m($\tilde{\chi}^0_1$))	1407.0350
	$\tilde{\chi}^{\pm}_1\tilde{\chi}^0_2\to\tilde{\ell}_L\nu\tilde{\ell}_L\ell(\tilde{\nu}\nu)$, $\ell\tilde{\nu}\tilde{\ell}_L\ell(\tilde{\nu}\nu)$	3 e,μ	0	Yes	20.3	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$ 715 GeV	m($\tilde{\chi}^{\pm}_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}^{\pm}_1$)+m($\tilde{\chi}^0_1$))	1402.7029
	$\tilde{\chi}^{\pm}_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1 Z\tilde{\chi}^0_1$	2-3 e,μ	0-2 jets	Yes	20.3	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$ 425 GeV	m($\tilde{\chi}^{\pm}_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, sleptons decoupled	1403.5294, 1402.7029
	$\tilde{\chi}^{\pm}_1\tilde{\chi}^0_2\to W\tilde{\chi}^0_1 h\tilde{\chi}^0_1$, $h\to b\bar{b}/WW/\tau\tau/\gamma\gamma$	e,μ,γ	0-2 b	Yes	20.3	$\tilde{\chi}^{\pm}_1,\tilde{\chi}^0_2$ 270 GeV	m($\tilde{\chi}^{\pm}_1$)=m($\tilde{\chi}^0_2$), m($\tilde{\chi}^0_1$)=0, sleptons decoupled	1501.07110
	$\tilde{\chi}^0_2\tilde{\chi}^0_3$, $\tilde{\chi}^0_{2,3}\to\tilde{\ell}_R\ell$	4 e,μ	0	Yes	20.3	$\tilde{\chi}^0_{2,3}$ 635 GeV	m($\tilde{\chi}^0_2$)=m($\tilde{\chi}^0_3$), m($\tilde{\chi}^0_1$)=0, m($\tilde{\ell},\tilde{\nu}$)=0.5(m($\tilde{\chi}^0_2$)+m($\tilde{\chi}^0_1$))	1405.5086
	GGM (wino NLSP) weak prod.	1 e,μ + γ	-	Yes	20.3	$\tilde{W}$ 115-370 GeV	$c\tau$<1 mm	1507.05493
Long-lived particles	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^{\pm}_1$	Disapp. trk	1 jet	Yes	20.3	$\tilde{\chi}^{\pm}_1$ 270 GeV	m($\tilde{\chi}^{\pm}_1$)-m($\tilde{\chi}^0_1$)~160 MeV, τ($\tilde{\chi}^{\pm}_1$)=0.2 ns	1310.3675
	Direct $\tilde{\chi}^+_1\tilde{\chi}^-_1$ prod., long-lived $\tilde{\chi}^{\pm}_1$	dE/dx trk	-	Yes	18.4	$\tilde{\chi}^{\pm}_1$ 495 GeV	m($\tilde{\chi}^{\pm}_1$)-m($\tilde{\chi}^0_1$)~160 MeV, τ($\tilde{\chi}^{\pm}_1$)<15 ns	1506.05332
	Stable, stopped $\tilde{g}$ R-hadron	0	1-5 jets	Yes	27.9	$\tilde{g}$ 850 GeV	m($\tilde{\chi}^0_1$)=100 GeV, 10 μs<τ($\tilde{g}$)<1000 s	1310.6584
	Metastable $\tilde{g}$ R-hadron	dE/dx trk	-	-	3.2	$\tilde{g}$ 1.54 TeV	m($\tilde{\chi}^0_1$)=100 GeV, τ>10 ns	*To appear*
	GMSB, stable $\tilde{\tau}$, $\tilde{\chi}^0_1\to\tilde{\tau}(\tilde{e},\tilde{\mu})+\tau(e,\mu)$	1-2 μ	-	-	19.1	$\tilde{\chi}^0_1$ 537 GeV	10<tanβ<50	1411.6795
	GMSB, $\tilde{\chi}^0_1\to\gamma\tilde{G}$, long-lived $\tilde{\chi}^0_1$	2 γ	-	Yes	20.3	$\tilde{\chi}^0_1$ 440 GeV	1<τ($\tilde{\chi}^0_1$)<3 ns, SPS8 model	1409.5542
	$\tilde{g}\tilde{g}$, $\tilde{\chi}^0_1\to ee\nu/e\mu\nu/\mu\mu\nu$	displ. $ee/e\mu/\mu\mu$	-	-	20.3	$\tilde{\chi}^0_1$ 1.0 TeV	7 <$c\tau$($\tilde{\chi}^0_1$)< 740 mm, m($\tilde{g}$)=1.3 TeV	1504.05162
	GGM $\tilde{g}\tilde{g}$, $\tilde{\chi}^0_1\to Z\tilde{G}$	displ. vtx + jets	-	-	20.3	$\tilde{\chi}^0_1$ 1.0 TeV	6 <$c\tau$($\tilde{\chi}^0_1$)< 480 mm, m($\tilde{g}$)=1.1 TeV	1504.05162
RPV	LFV $pp\to\tilde{\nu}_\tau + X$, $\tilde{\nu}_\tau\to e\mu/e\tau/\mu\tau$	$e\mu$,$e\tau$,$\mu\tau$	-	-	20.3	$\tilde{\nu}_\tau$ 1.7 TeV	λ'_{311}=0.11, $\lambda_{132/133/233}$=0.07	1503.04430
	Bilinear RPV CMSSM	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{q},\tilde{g}$ 1.45 TeV	m($\tilde{q}$)=m($\tilde{g}$), $c\tau_{LSP}$<1 mm	1404.2500
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to ee\tilde{\nu}_\mu, e\mu\tilde{\nu}_e$	4 e,μ	-	Yes	20.3	$\tilde{\chi}^{\pm}_1$ 760 GeV	m($\tilde{\chi}^0_1$)>0.2×m($\tilde{\chi}^{\pm}_1$), λ_{121}≠0	1405.5086
	$\tilde{\chi}^+_1\tilde{\chi}^-_1$, $\tilde{\chi}^+_1\to W\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to\tau\tau\tilde{\nu}_e, e\tau\tilde{\nu}_\tau$	3 e,μ + τ	-	Yes	20.3	$\tilde{\chi}^{\pm}_1$ 450 GeV	m($\tilde{\chi}^0_1$)>0.2×m($\tilde{\chi}^{\pm}_1$), λ_{133}≠0	1405.5086
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 917 GeV	BR(t)=BR(b)=BR(c)=0%	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to qq\tilde{\chi}^0_1$, $\tilde{\chi}^0_1\to qqq$	0	6-7 jets	-	20.3	$\tilde{g}$ 980 GeV	m($\tilde{\chi}^0_1$)=600 GeV	1502.05686
	$\tilde{g}\tilde{g}$, $\tilde{g}\to\tilde{t}_1 t$, $\tilde{t}_1\to bs$	2 e,μ (SS)	0-3 b	Yes	20.3	$\tilde{g}$ 880 GeV		1404.2500
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to bs$	0	2 jets + 2 b	-	20.3	$\tilde{t}_1$ 320 GeV		1601.07453
	$\tilde{t}_1\tilde{t}_1$, $\tilde{t}_1\to b\ell$	2 e,μ	2 b	-	20.3	$\tilde{t}_1$ 0.4-1.0 TeV	BR($\tilde{t}_1\to be/\mu$)>20%	ATLAS-CONF-2015-015
Other	Scalar charm, $\tilde{c}\to c\tilde{\chi}^0_1$	0	2 c	Yes	20.3	$\tilde{c}$ 510 GeV	m($\tilde{\chi}^0_1$)<200 GeV	1501.01325

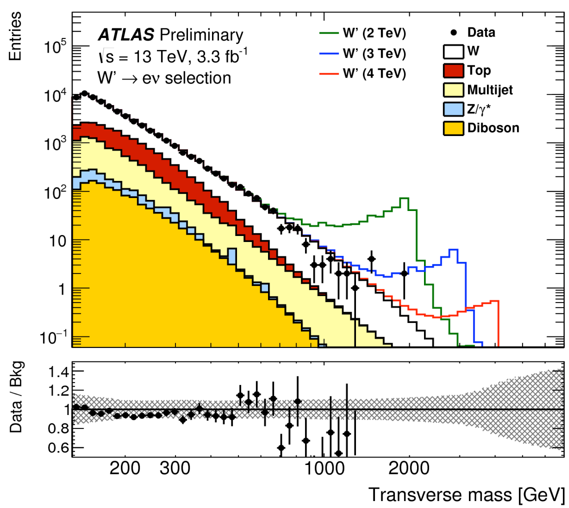
10^{-1} 1 Mass scale [TeV]

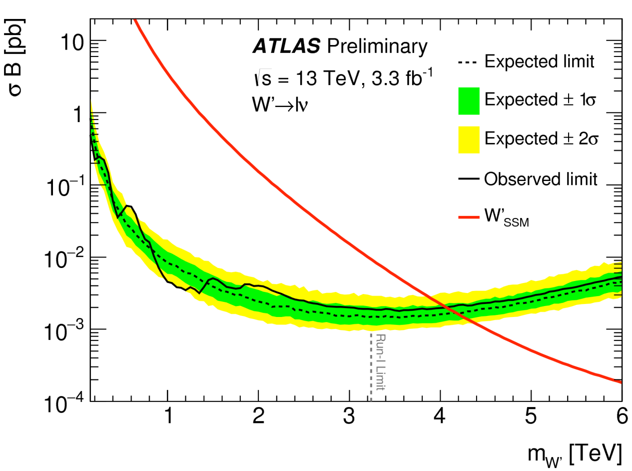
*Only a selection of the available mass limits on new states or phenomena is shown.

Other Searches for New Physics

Search for resonances in dilepton and lepton + MET events

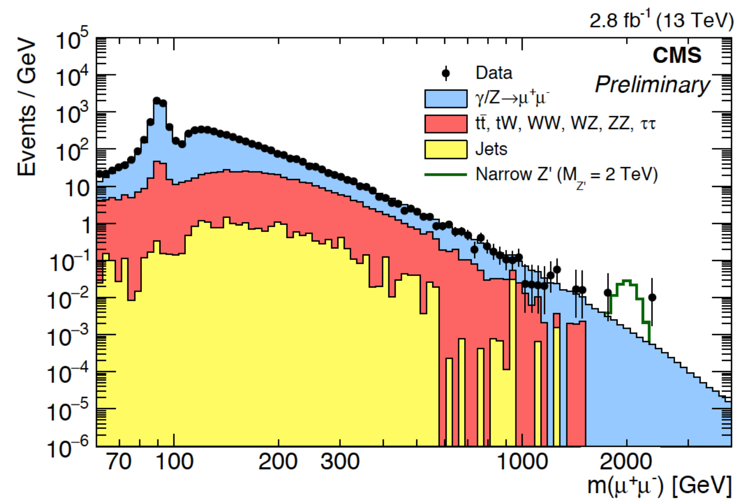
W' → lν

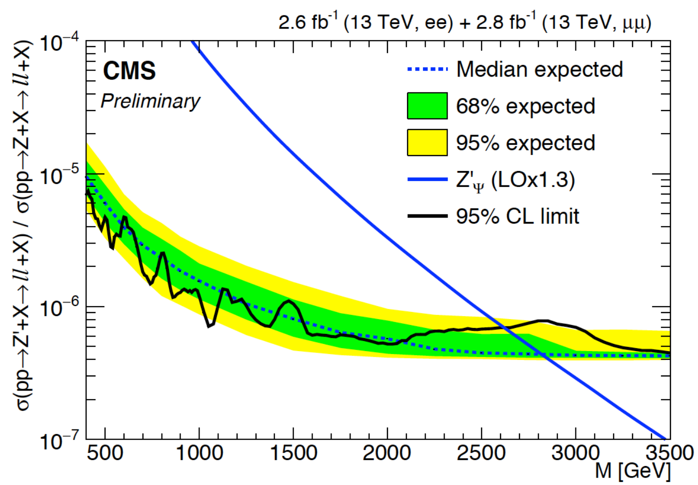




[ATLAS-CONF-2015-063]

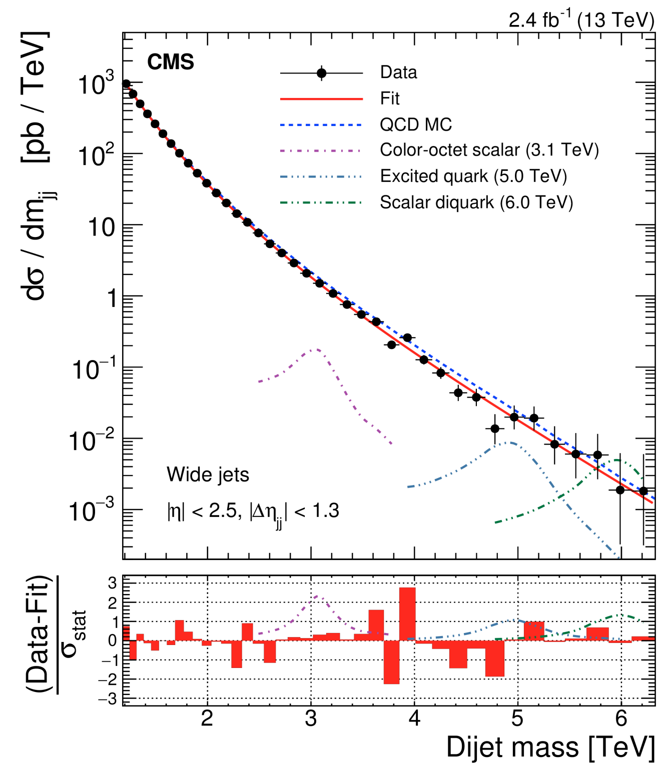
Z' → ll





[CMS-PAS-EXO-15-005]

Dijet resonances

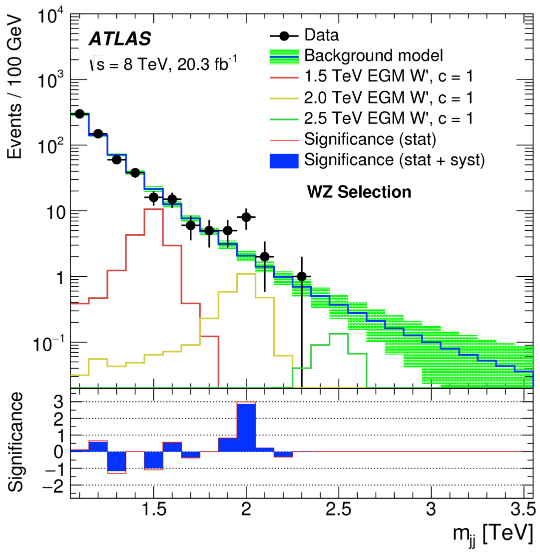


[PRL 116 (2016) 071801]

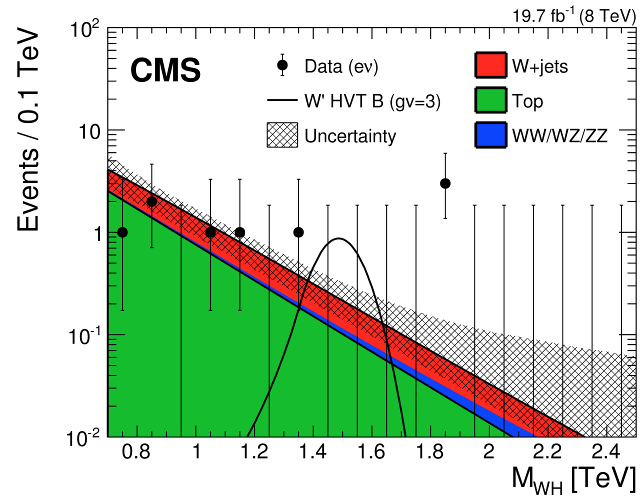
Decays to heavy bosons W/Z/H

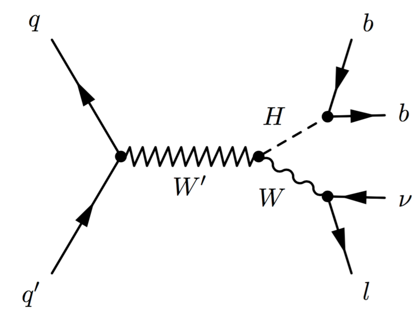
Run 1 showed a few excesses around 2 TeV …..

W' → WZ (jets)

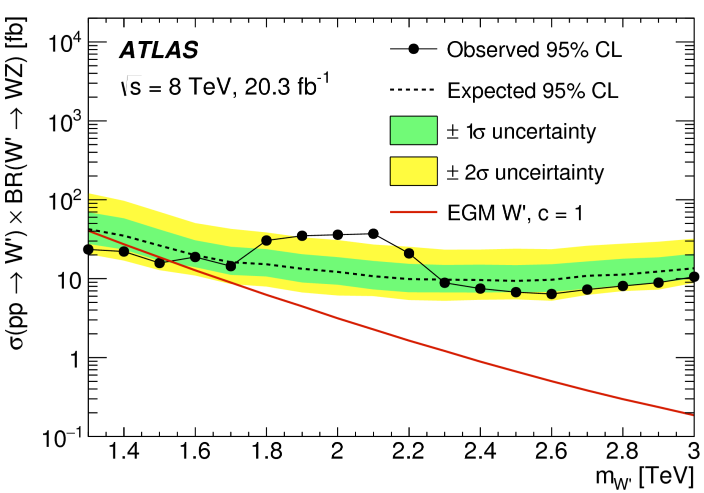


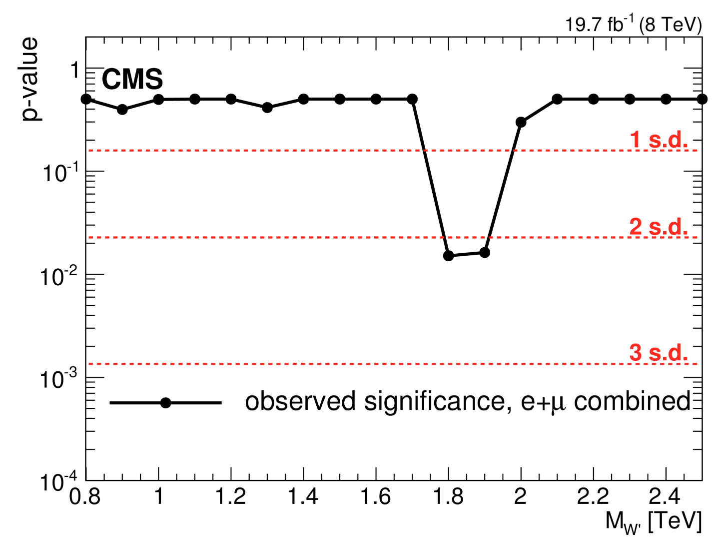
W' → WH





[JHEP 12 (2015)]





[arXiv:1601.06431]

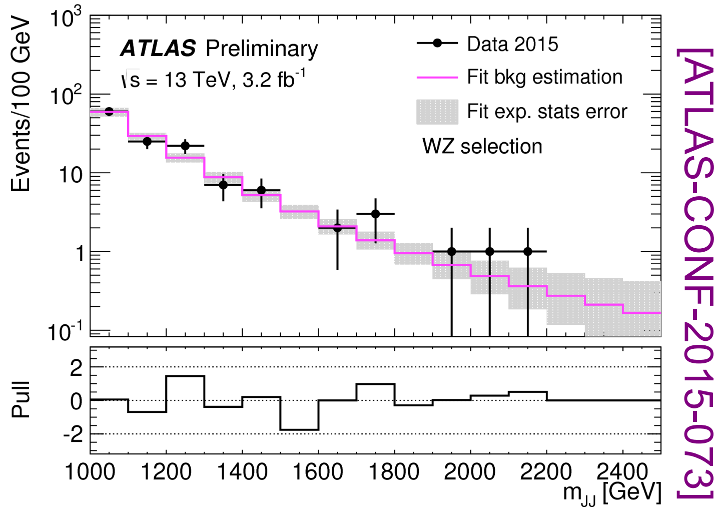
~ 2.5 σ for m ~ 2 TeV

However, no coherent picture across experiments and channels …..

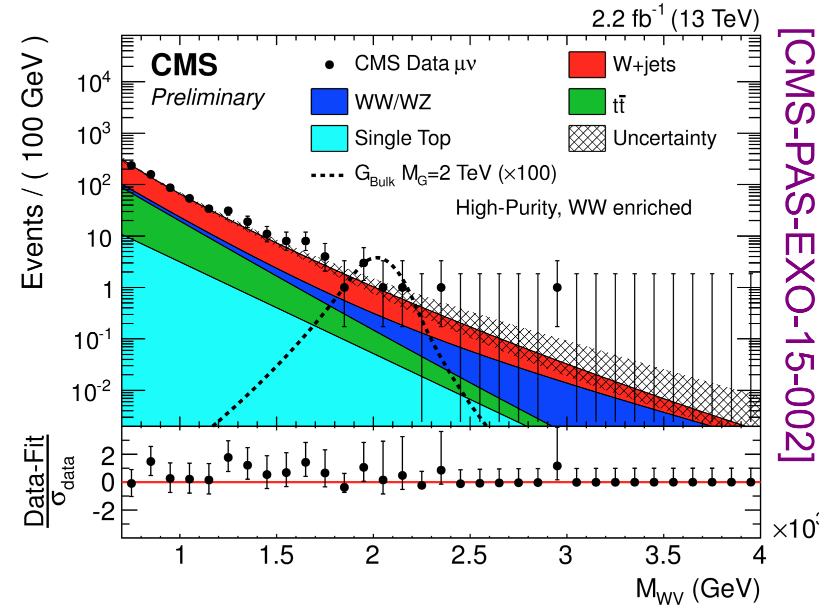
Decays to heavy bosons W/Z/H

Run 2:

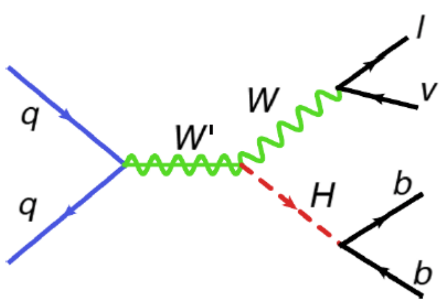
W' → WZ (jets)

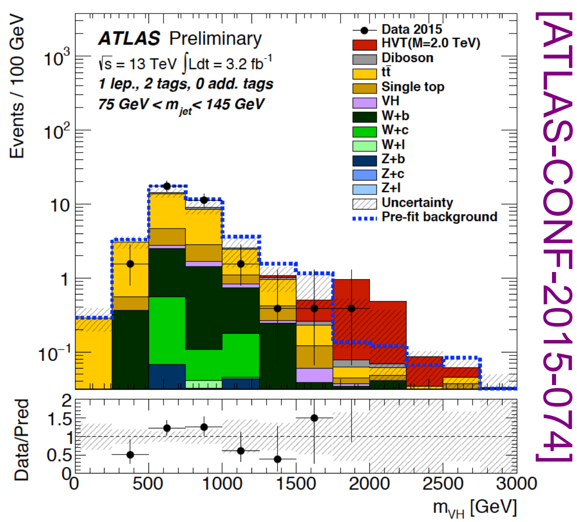


lνqq final state

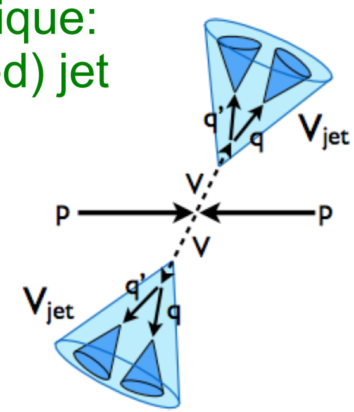


W' → WH





Important technique:
Boosted (merged) jet topologies!



No significant excesses observed!
(also other final states investigated)

Exotics Summary

ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2016

ATLAS Preliminary

$\int \mathcal{L}\, dt = (3.2 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int\mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	M_D 6.86 TeV	$n = 2$	Preliminary
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\to \ell q$	1 e, μ	1 j	–	20.3	M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	3.6	M_{th} 8.3 TeV	$n = 6$	1512.01530
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	ATLAS-CONF-2016-006
	ADD BH multijet	–	≥ 3 j	–	3.6	M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \to \ell\ell$	2 e, μ	–	–	20.3	G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \to \gamma\gamma$	2 γ	–	–	20.3	G_{KK} mass 2.66 TeV	$k/\overline{M}_{Pl} = 0.1$	1504.05511
	Bulk RS $G_{KK} \to WW \to qq\ell\nu$	1 e, μ	1 J	Yes	3.2	G_{KK} mass 1.06 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2015-075
	Bulk RS $G_{KK} \to HH \to bbbb$	–	4 b	–	3.2	G_{KK} mass 475-785 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-017
	Bulk RS $g_{KK} \to tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \to tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \to \ell\ell$	2 e, μ	–	–	3.2	Z' mass 3.4 TeV		ATLAS-CONF-2015-070
	SSM $Z' \to \tau\tau$	2 τ	–	–	19.5	Z' mass 2.02 TeV		1502.07177
	Leptophobic $Z' \to bb$	–	2 b	–	3.2	Z' mass 1.5 TeV		Preliminary
	SSM $W' \to \ell\nu$	1 e, μ	–	Yes	3.2	W' mass 4.07 TeV		ATLAS-CONF-2015-063
	HVT $W' \to WZ \to qq\nu\nu$ model A	0 e, μ	1 J	Yes	3.2	W' mass 1.6 TeV	$g_V = 1$	ATLAS-CONF-2015-068
	HVT $W' \to WZ \to qqqq$ model A	–	2 J	–	3.2	W' mass 1.38-1.6 TeV	$g_V = 1$	ATLAS-CONF-2015-073
	HVT $W' \to WH \to \ell\nu bb$ model B	1 e, μ	1-2 b, 1-0 j	Yes	3.2	W' mass 1.62 TeV	$g_V = 3$	ATLAS-CONF-2015-074
	HVT $Z' \to ZH \to \nu\nu bb$ model B	0 e, μ	1-2 b, 1-0 j	Yes	3.2	Z' mass 1.76 TeV	$g_V = 3$	ATLAS-CONF-2015-074
	LRSM $W'_R \to tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	W' mass 1.92 TeV		1410.4103
	LRSM $W'_R \to tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	W' mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	3.6	Λ 17.5 TeV	$\eta_{LL} = -1$	1512.01530
	CI $qq\ell\ell$	2 e, μ	–	–	3.2	Λ 23.1 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2015-070
	CI $uutt$	2 e, μ (SS)	≥ 1 b, 1-4 j	Yes	20.3	Λ 4.3 TeV	$\lvert C_{LL}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 140$ GeV	Preliminary
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	m_A 650 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 10$ GeV	Preliminary
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	LQ mass 1.07 TeV	$\beta = 1$	Preliminary
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	LQ mass 1.03 TeV	$\beta = 1$	Preliminary
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \to Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \to Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \to Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \to Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \to WqWq$	1 e, μ	≥ 4 j	Yes	20.3	Q mass 690 GeV		1509.04261
	$T_{5/3} \to Wt$	1 e, μ	≥ 1 b, ≥ 5 j	Yes	20.3	$T_{5/3}$ mass 840 GeV		1503.05425
Excited fermions	Excited quark $q^* \to q\gamma$	1 γ	1 j	–	3.2	q^* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \to qg$	–	2 j	–	3.6	q^* mass 5.2 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.01530
	Excited quark $b^* \to bg$	–	1 b, 1 j	–	3.2	b^* mass 2.1 TeV		Preliminary
	Excited quark $b^* \to Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	b^* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \to W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \to \ell\ell$	2 e, μ (SS)	–	–	20.3	$H^{\pm\pm}$ mass 551 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\ell$)=1	1412.0237
	Higgs triplet $H^{\pm\pm} \to \ell\tau$	3 e, μ, τ	–	–	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \to \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

$\sqrt{s}$ = 8 TeV $\sqrt{s}$ = 13 TeV

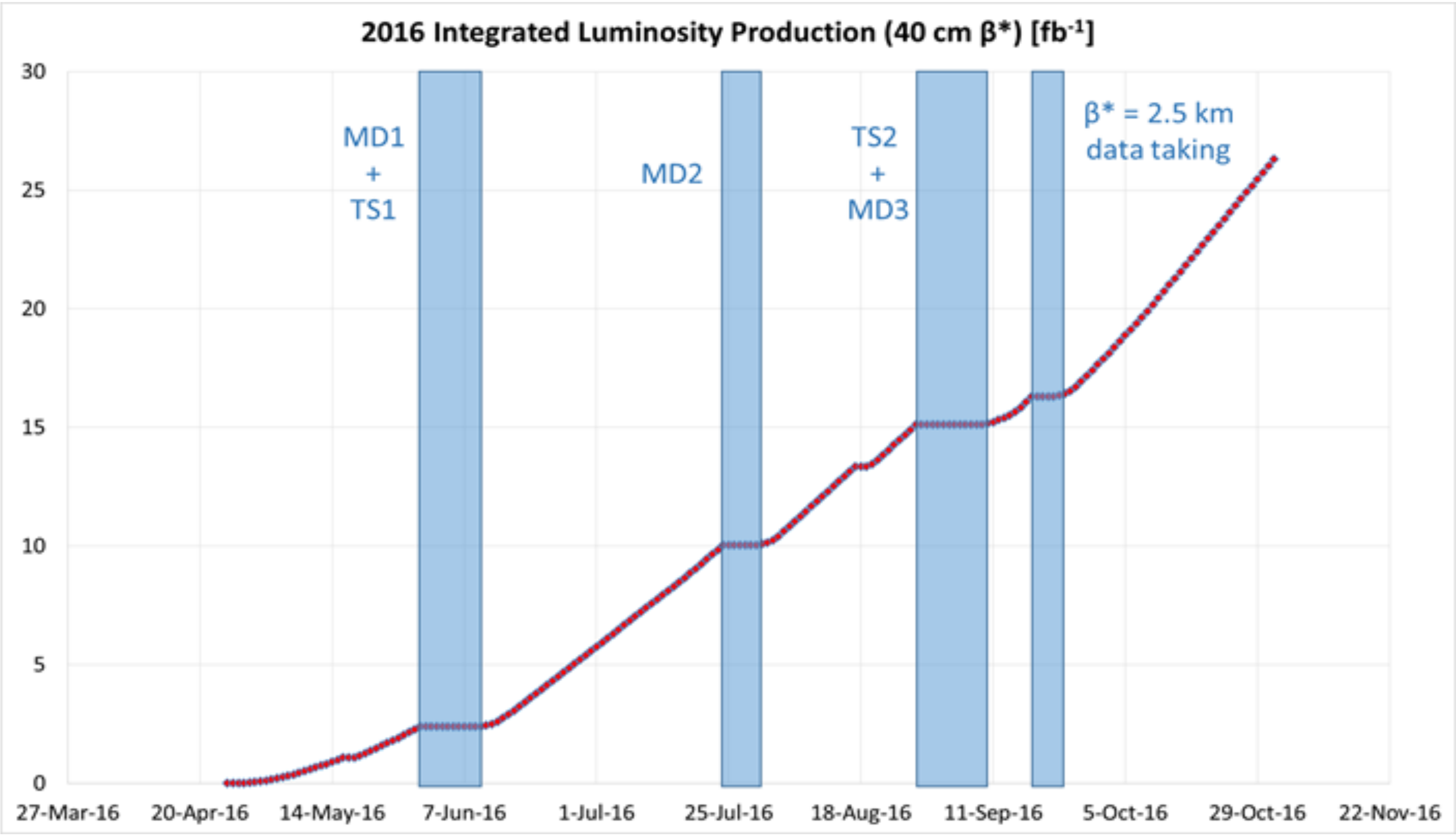
10^{-1} 1 10 **Mass scale [TeV]**

**Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.*

†Small-radius (large-radius) jets are denoted by the letter j (J).

LHC Schedule for 2016

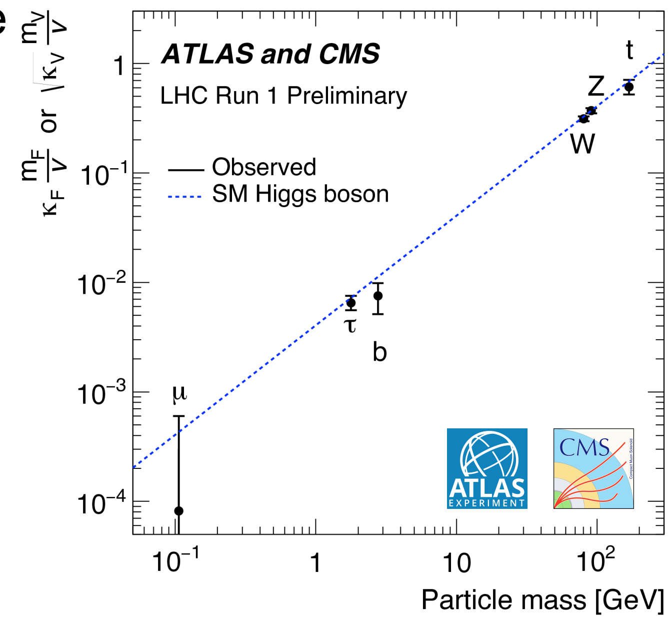
Goal for 2016: 25 fb^{-1}



(from F. Bordry, Moriond QCD 2016)

Summary

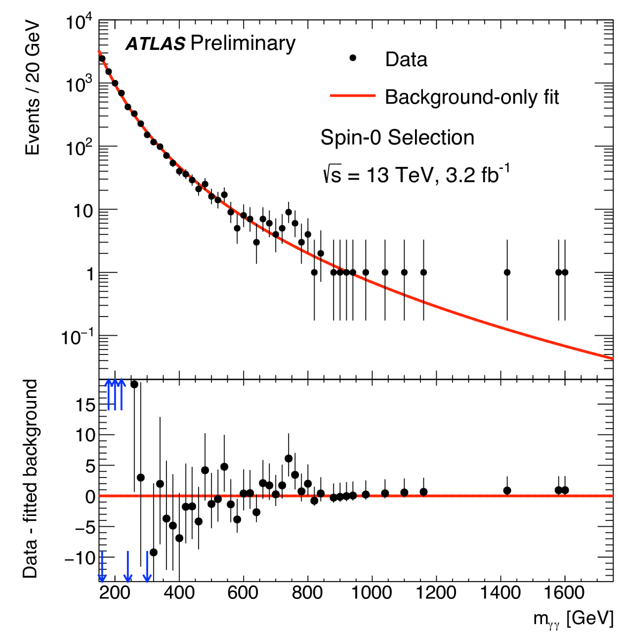
Analyses based on full Run 1 dataset consolidated the milestone discovery of a Higgs boson and extended our knowledge, e.g.
-observations of more production (VBF) and decay modes ($H \rightarrow \tau\tau$), measurements of differential distributions.



Properties (mass, J^{CP}, couplings) of the Higgs boson have been measured with increased precision and
are in agreement with expectations for a Standard Model Higgs boson.

First combinations of results of ATLAS and CMS.

Run 2 of the LHC has started:
- Many measurements are still statistically limited
- Enormous extension of mass reach for BSM searches



Plenty of physics results from SM, Top, Higgs, Searches!

Very interesting excess observed in $\gamma\gamma$ final state at ~ 750 GeV
Expect ~ 5-8 fb^{-1} (25 fb^{-1}) by summer (end of) 2016

→ As experimentalist: Wait and see

No other significant excesses observed so far

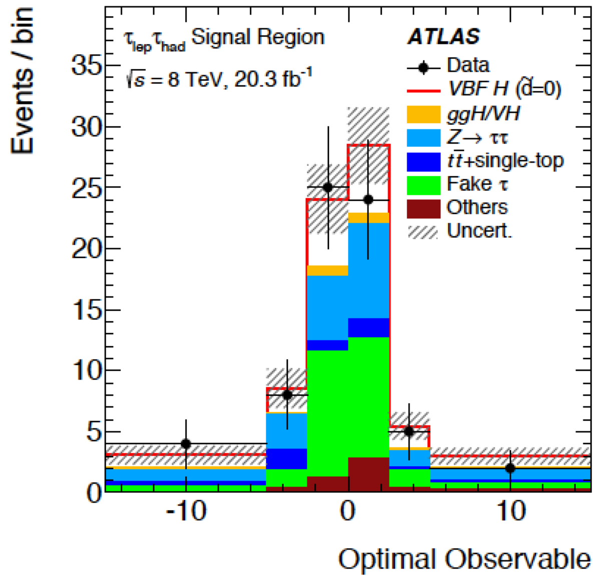
BACKUP

Pseudoscalar Couplings in H→ττ (VBF), VH

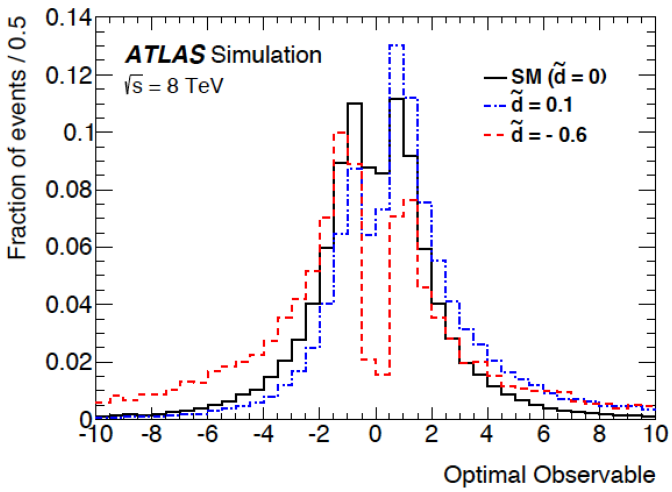
Probe admixtures of anomalous couplings

$$\mathcal{M} = \mathcal{M}_{\mathrm{SM}} + \tilde{d}\cdot\mathcal{M}_{\mathrm{CP\text{-}odd}}$$

VBF
H → ττ

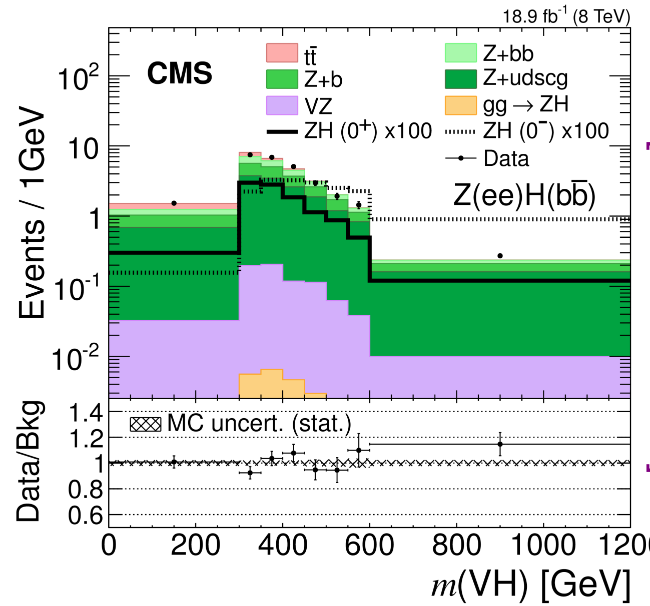


[arXiv:1602.04516]



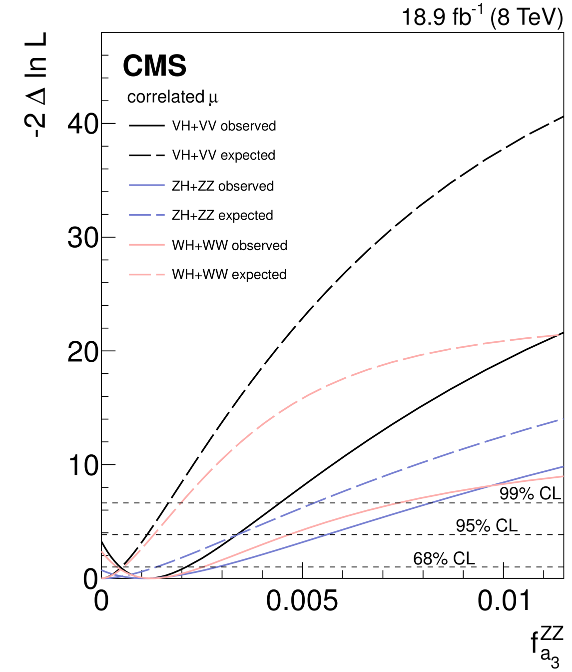
Exclude $\tilde{d}$ < -0.11 and $\tilde{d}$ > 0.05 @ 68% CL

VH
H → bb



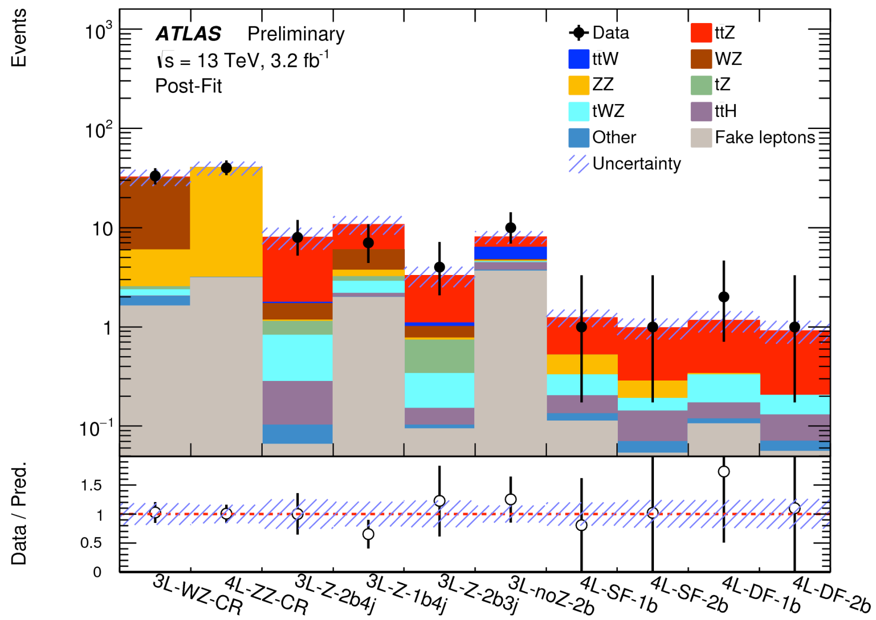
[arXiv:1602.04305]

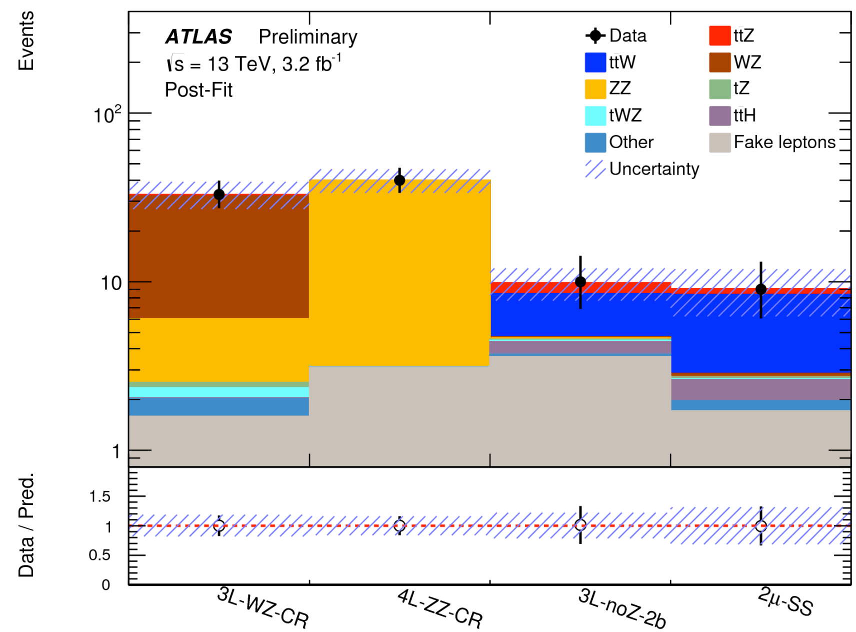
Combination with H → VV significantly improves sensitivity on pseudoscalar fraction



tt + V

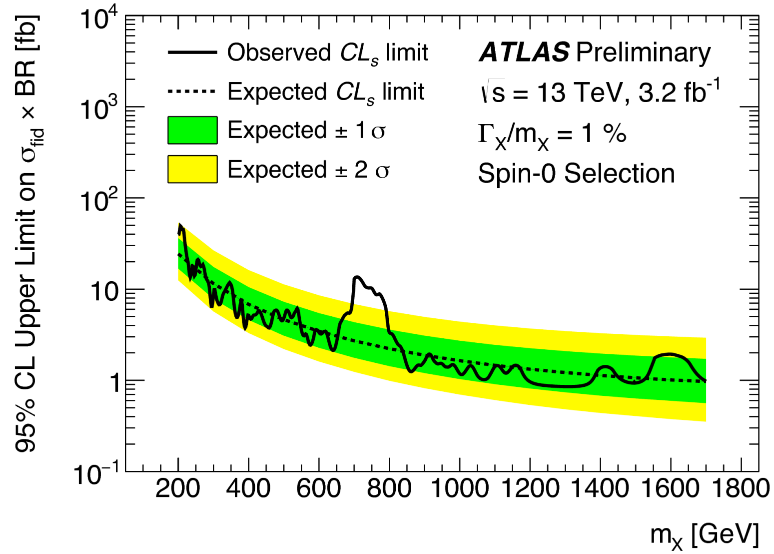
Investigate tt + Z/W production in multi-lepton final states (same sign 2-lepton, 3/4-lepton)

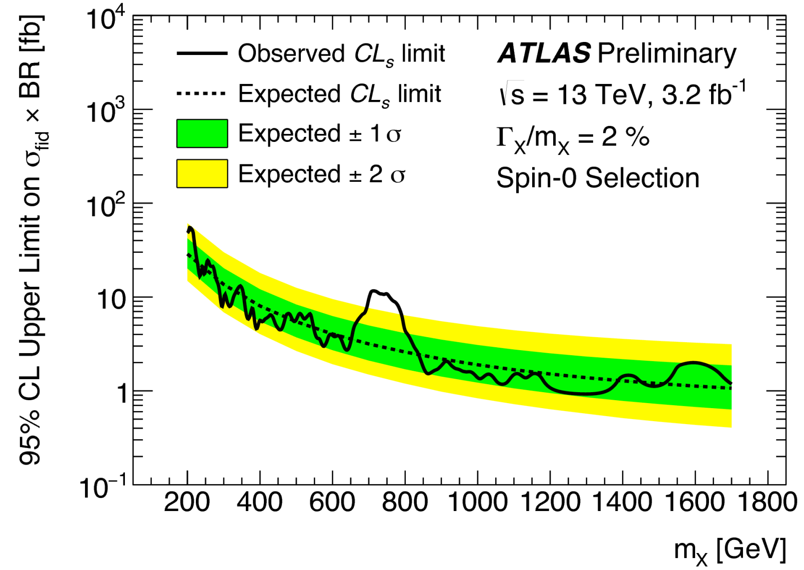


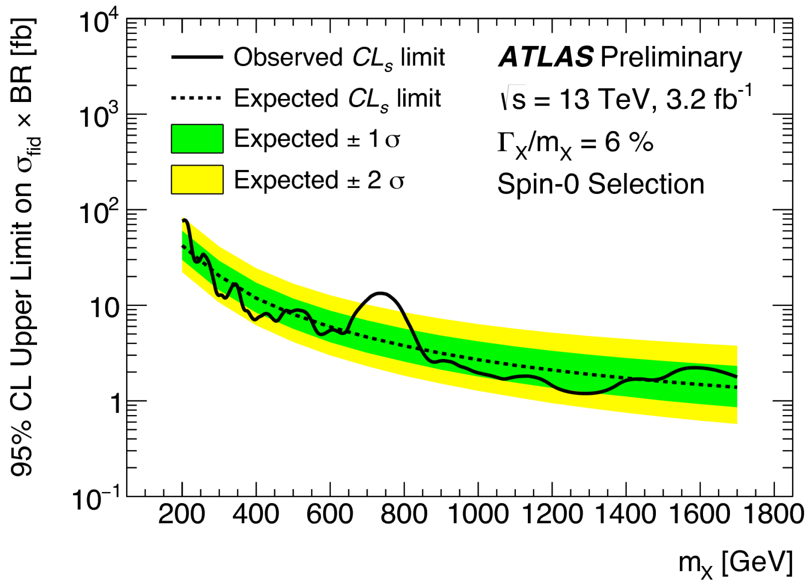


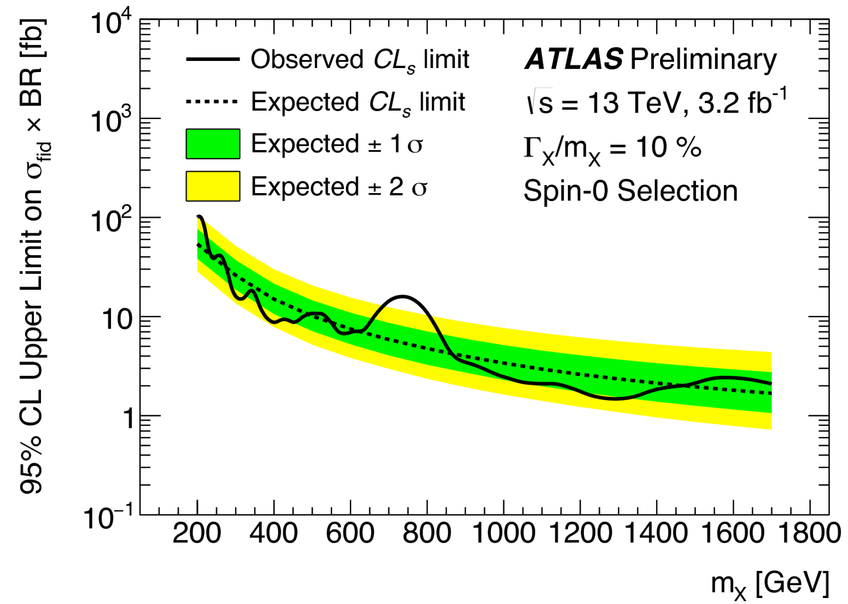
13 TeV	$\sigma(t\bar{t}W)$	$\sigma(t\bar{t}Z)$
aMCatNLO	0.57 ± 0.06 fb	0.76 ± 0.08 pb
ATLAS	1.38 ± 0.70 (stat) ± 0.33 (syst) pb	0.92 ± 0.30 (stat) ± 0.11 (syst) pb

Resonance Search in γγ

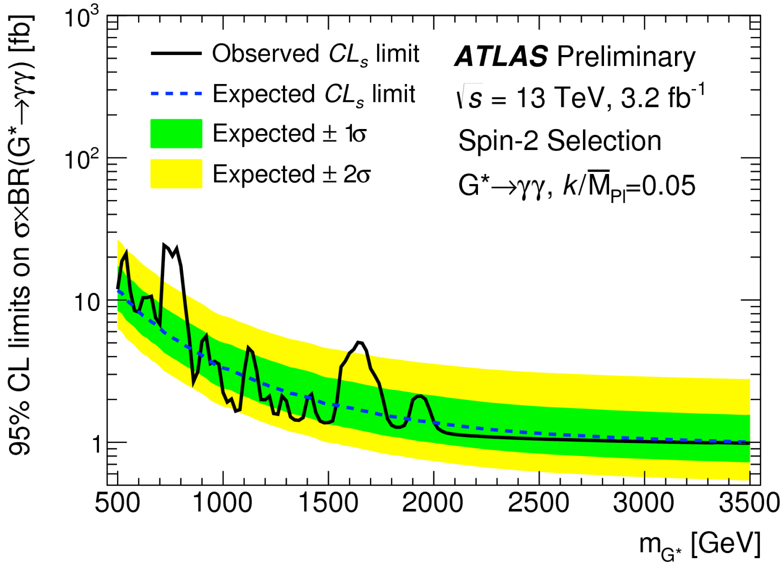


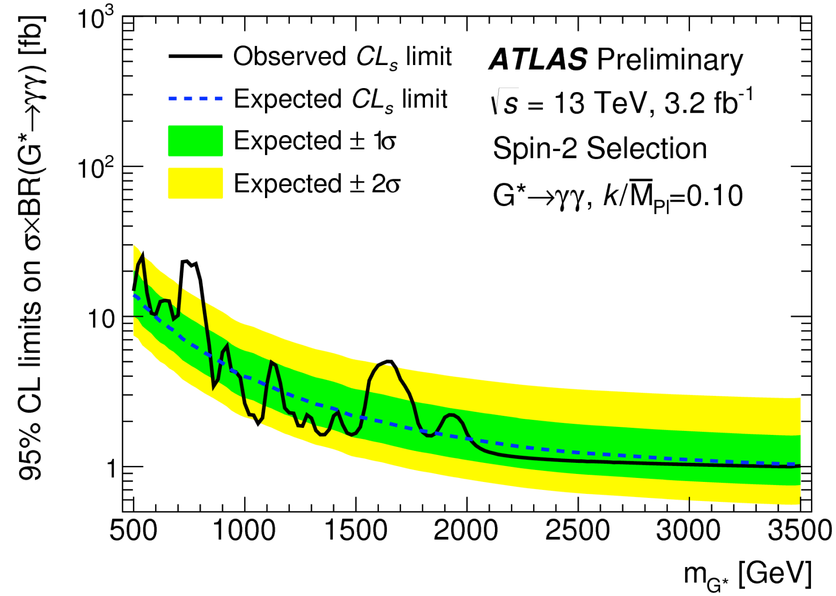


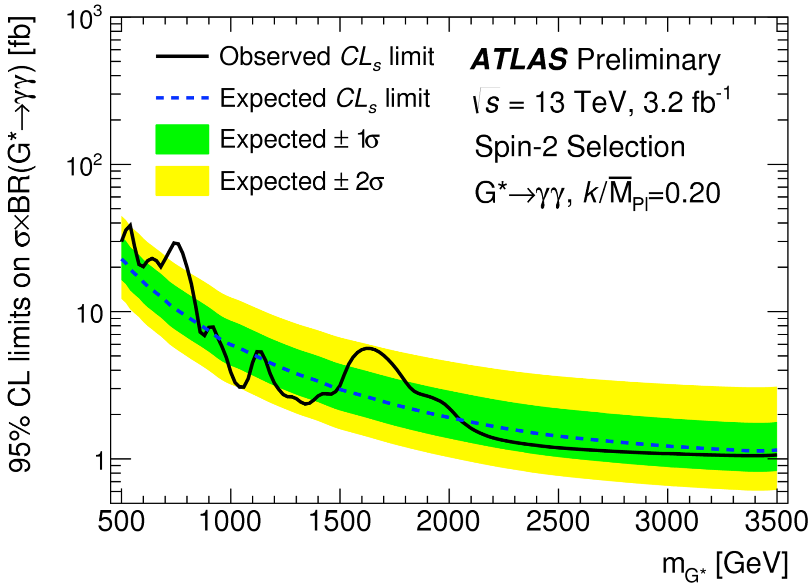


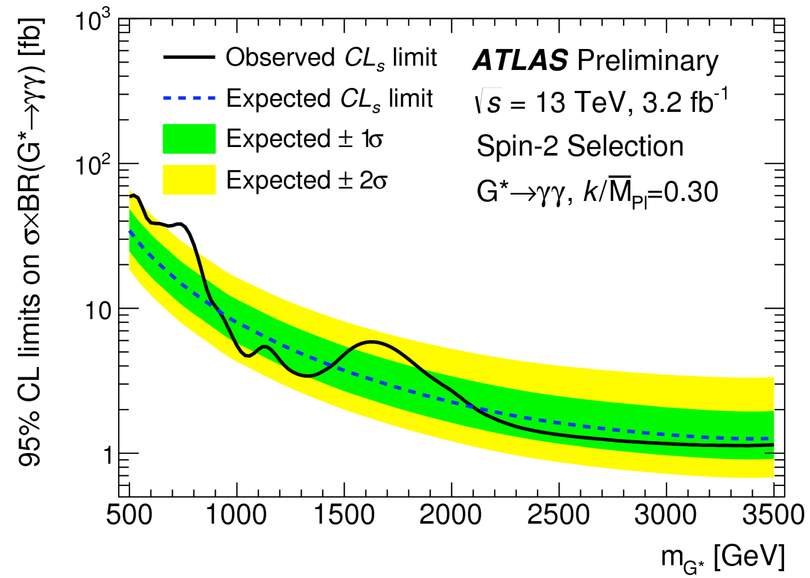


Resonance Search in γγ

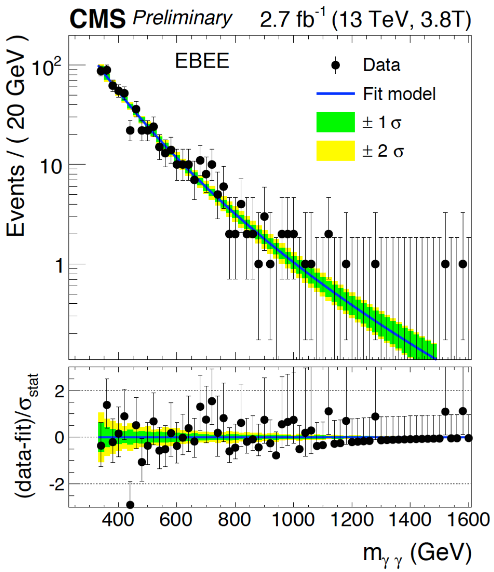


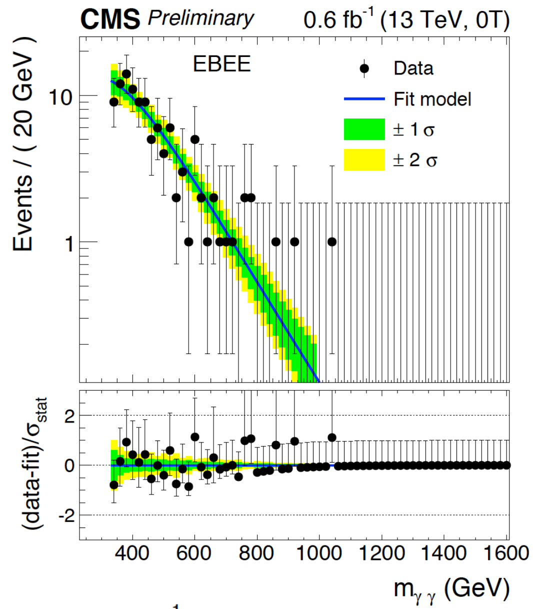


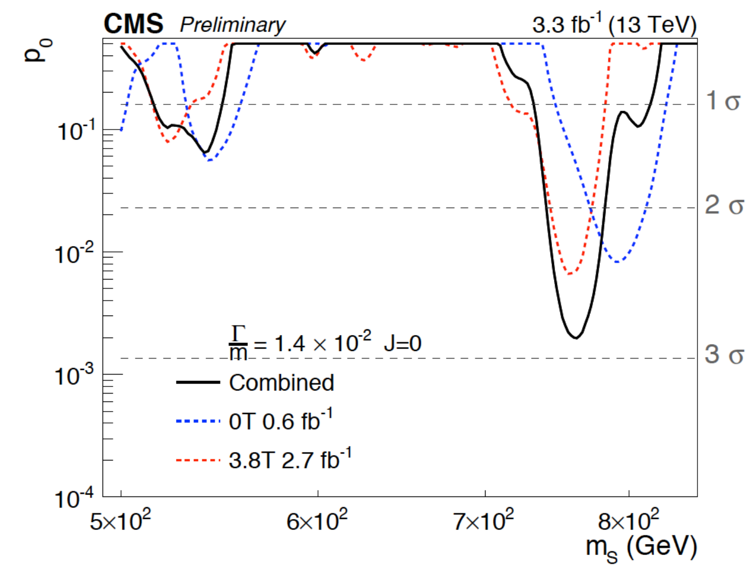


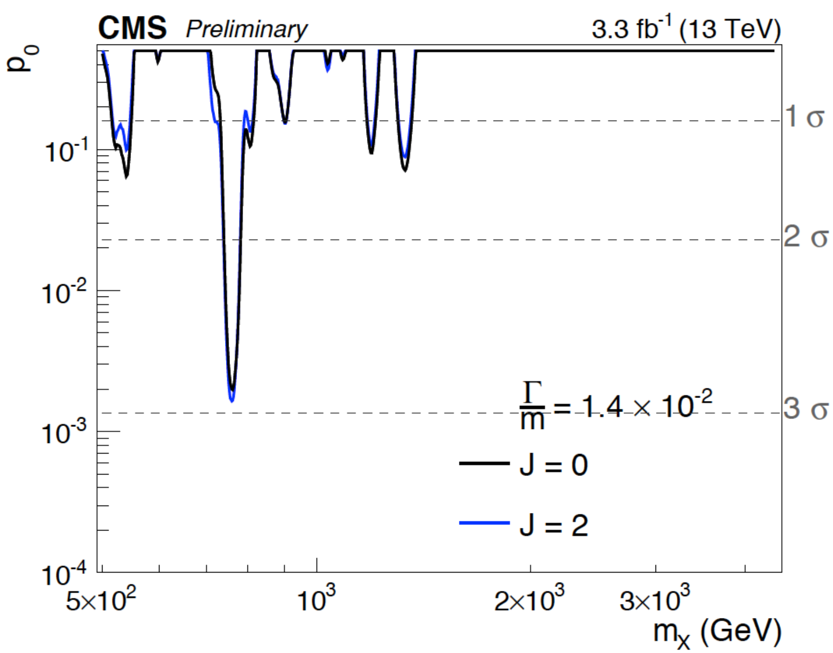


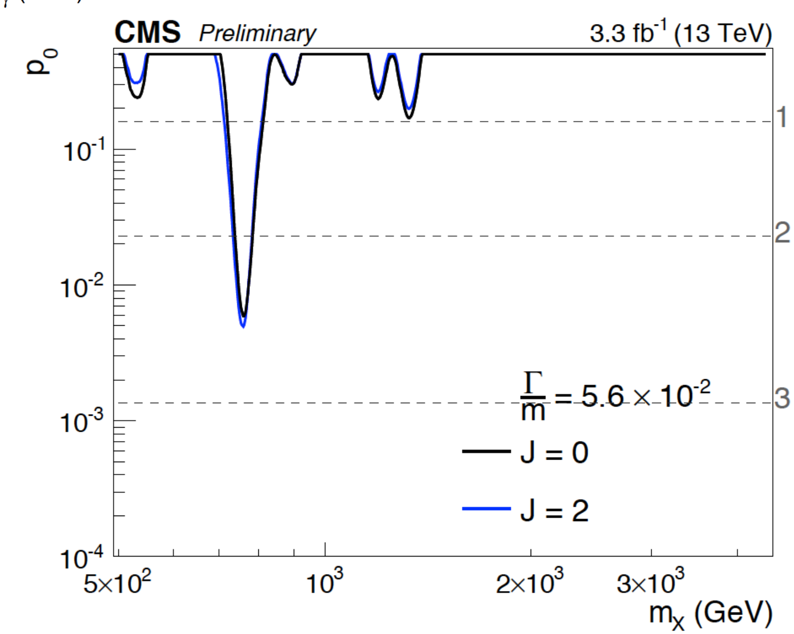
Resonance Search in γγ





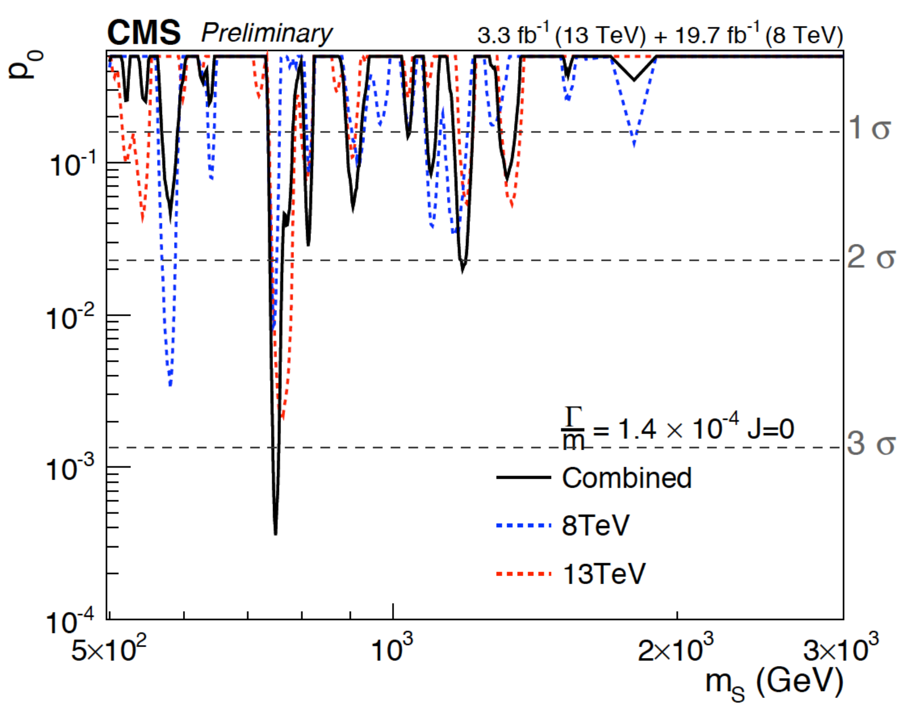


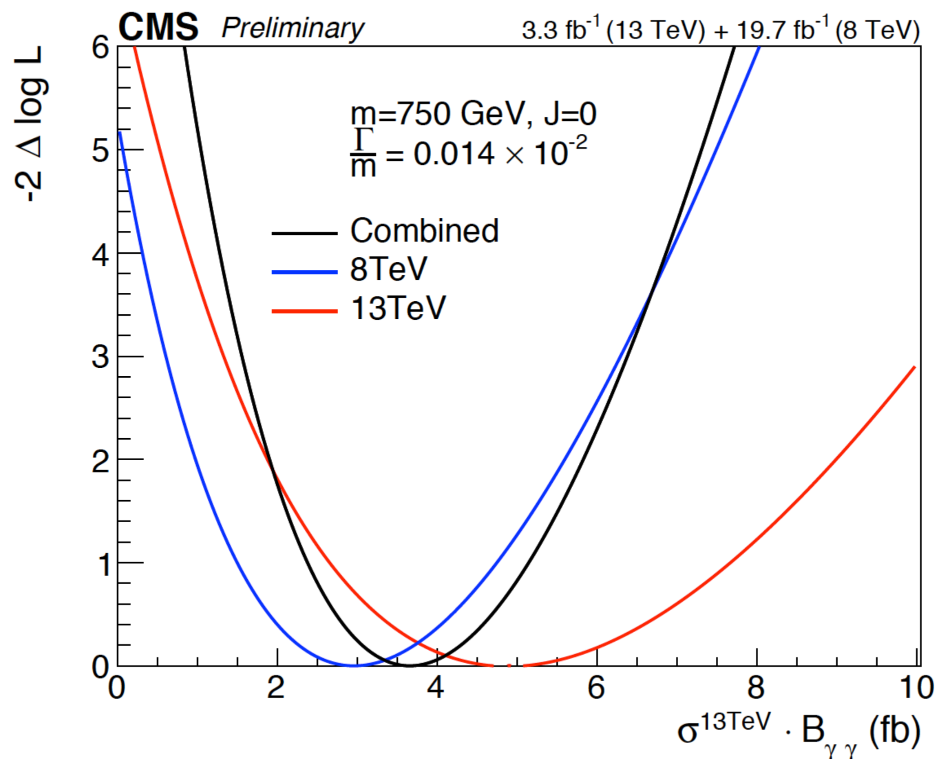




Resonance Search in γγ

Combination with Run 1 results



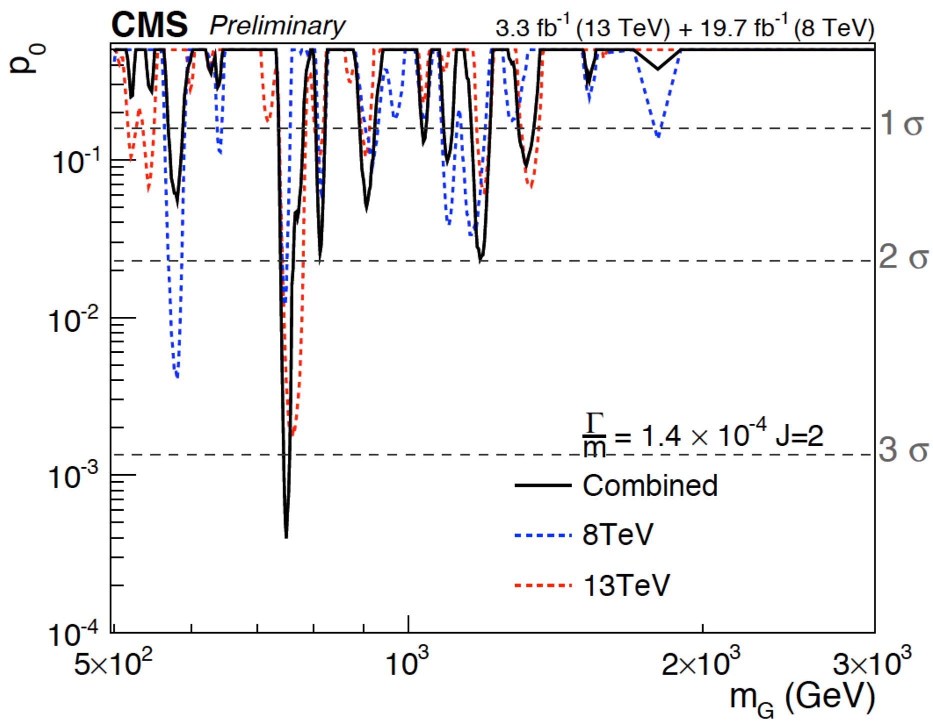


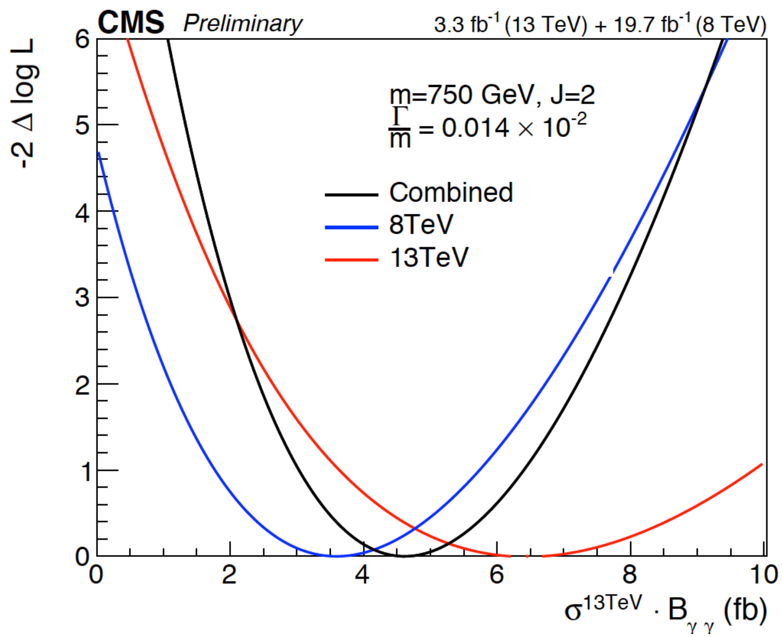
Combined: 3.4 σ local @ 750 GeV
(1.6 σ global)

Assumed coss-section ratio
8/13 TeV @ 750 GeV: 0.22 (Spin-0)

Resonance Search in γγ

Combination with Run 1 results





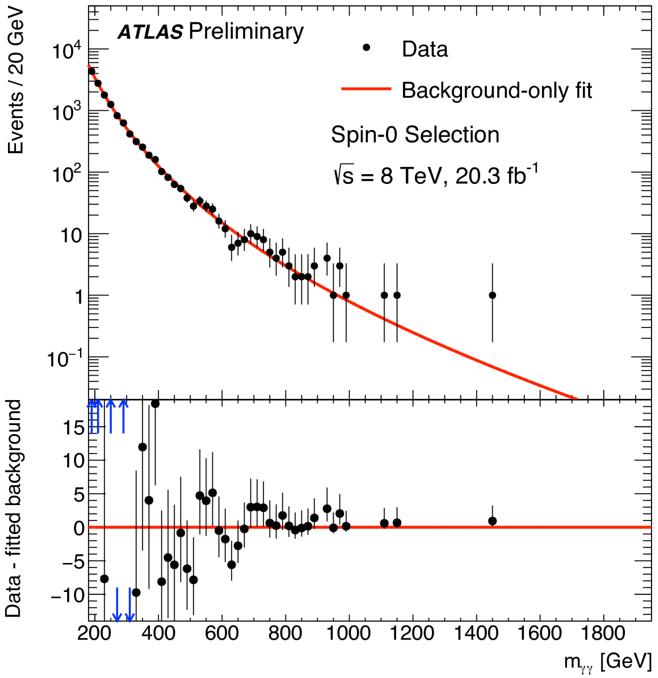
Assumed coss-section ratio
8/13 TeV @ 750 GeV: 0.24 (Spin-2)

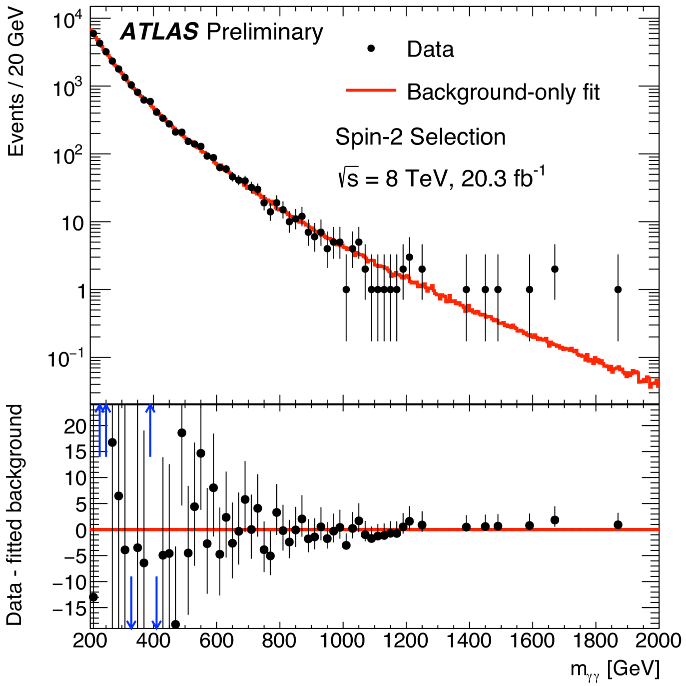
Resonance Search in γγ

ATLAS: - extend Run 1 measurement beyond 600 GeV
- cross-section ratio 13/8 TeV @ 750 GeV: 4.7 (gg-initiated process)
2.7 (light qq initiated process)

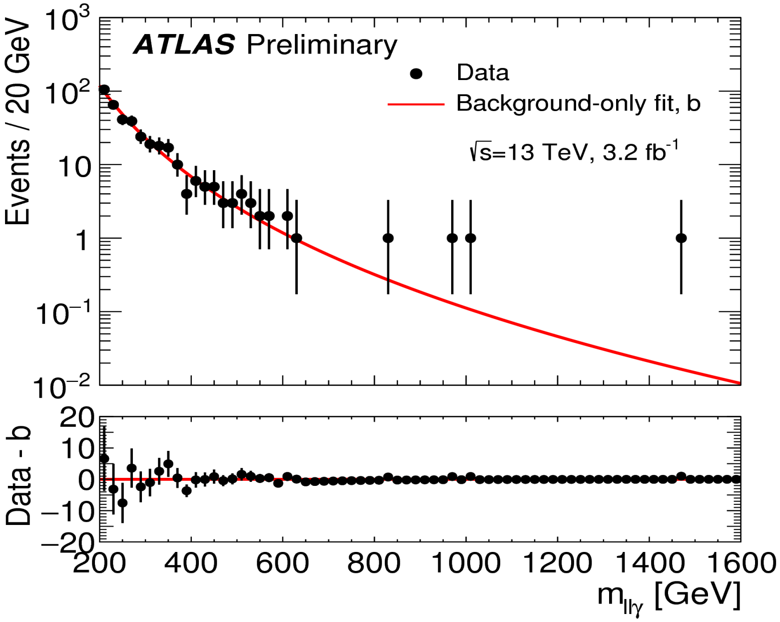
→ Spin-0: 1.9 σ @ 750 GeV, 6% width
Spin-2: no excess

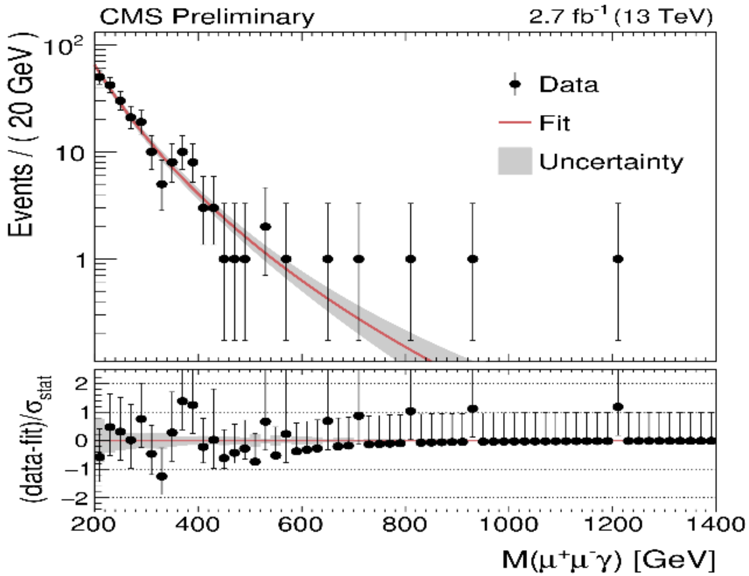
→ compatibility at level of:
Spin-0: 1.2 σ (2.1 σ) gg (qq) process
Spin-2: 2.7 σ (3.3 σ) gg (qq) process

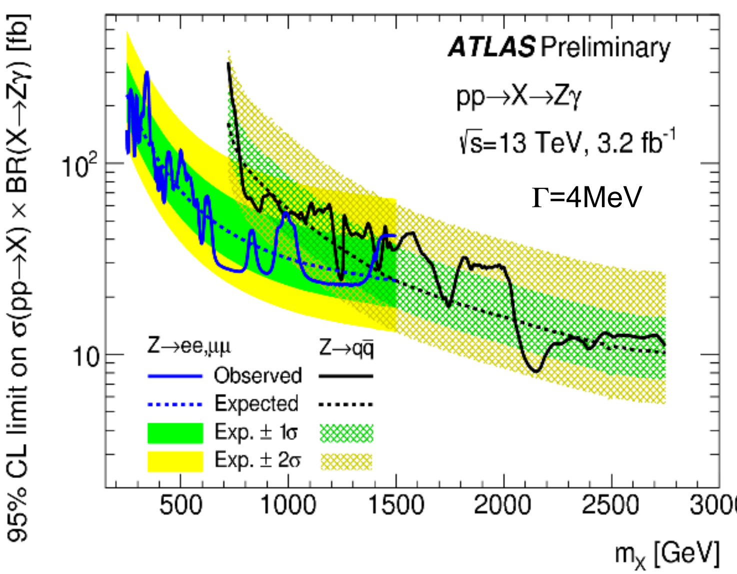


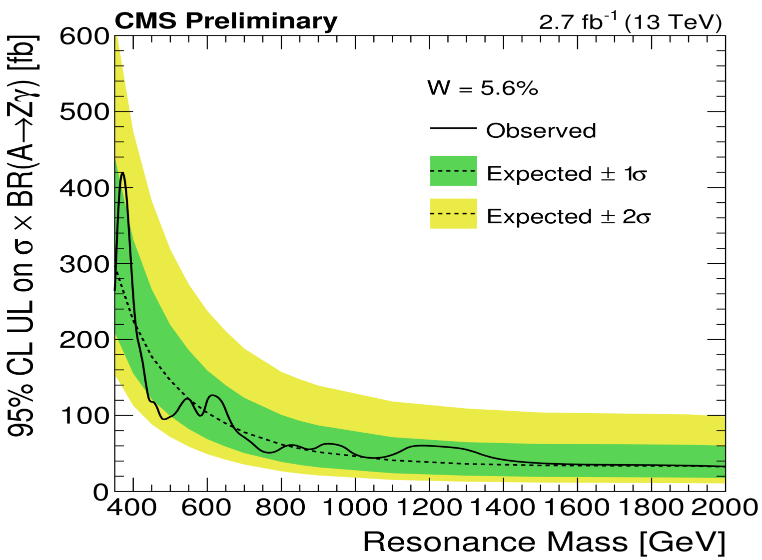


Zγ









Z → ll most sensitive in < 1 TeV range

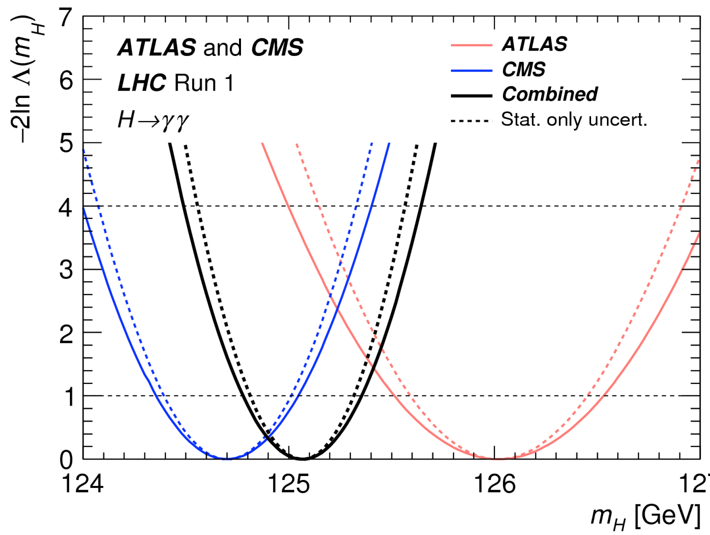
Mass

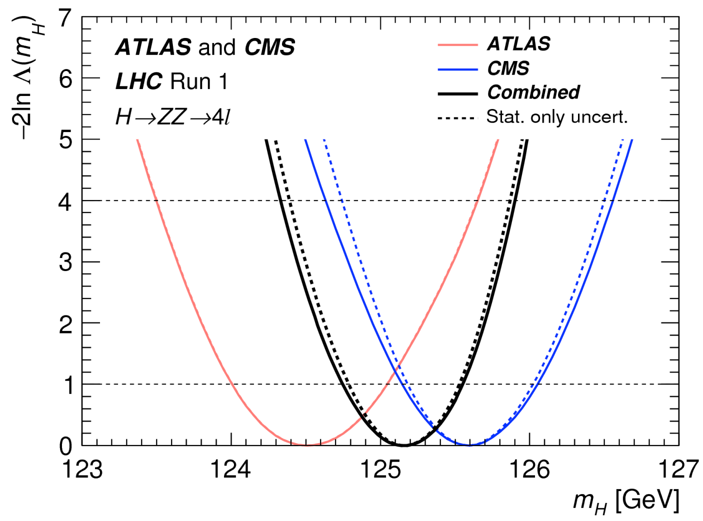
Compatibility tests:

- Allow for 4 floating masses: p ~ 10%
- Decay channels: combined H→γγ versus combined H→4l: Δm = -0.1 ± 0.5 GeV → < 1 σ
- Experiments: combined ATLAS vs. combined CMS: Δm = 0.4 ± 0.5 GeV → < 1 σ
- Individual channels and experiments:

  ATLAS H→γγ vs. CMS H→γγ : Δm = 1.3 ± 0.6 GeV → 2.1 σ

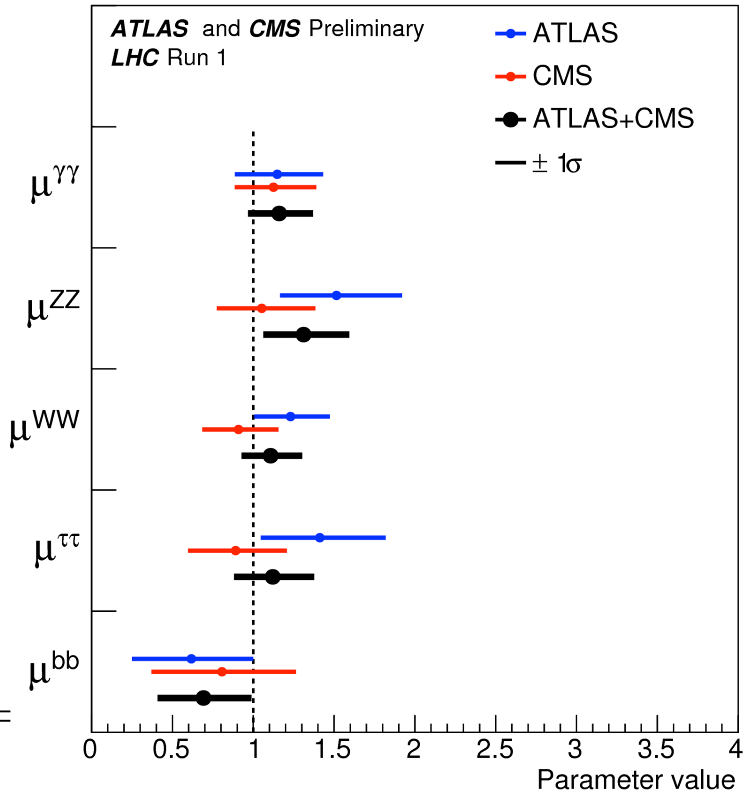
  ATLAS H→4l vs. CMS H→4l: Δm = -0.9 ± 0.7 GeV → 1.3 σ





ATLAS & CMS Combination: μ, Couplings

Decay channel	ATLAS+CMS	ATLAS	CMS
$\mu^{\gamma\gamma}$	$1.16^{+0.20}_{-0.18}$	$1.15^{+0.27}_{-0.25}$	$1.12^{+0.25}_{-0.23}$
μ^{ZZ}	$1.31^{+0.27}_{-0.24}$	$1.51^{+0.39}_{-0.34}$	$1.05^{+0.32}_{-0.27}$
μ^{WW}	$1.11^{+0.18}_{-0.17}$	$1.23^{+0.23}_{-0.21}$	$0.91^{+0.24}_{-0.21}$
$\mu^{\tau\tau}$	$1.12^{+0.25}_{-0.23}$	$1.41^{+0.40}_{-0.35}$	$0.89^{+0.31}_{-0.28}$
μ^{bb}	$0.69^{+0.29}_{-0.27}$	$0.62^{+0.37}_{-0.36}$	$0.81^{+0.45}_{-0.42}$



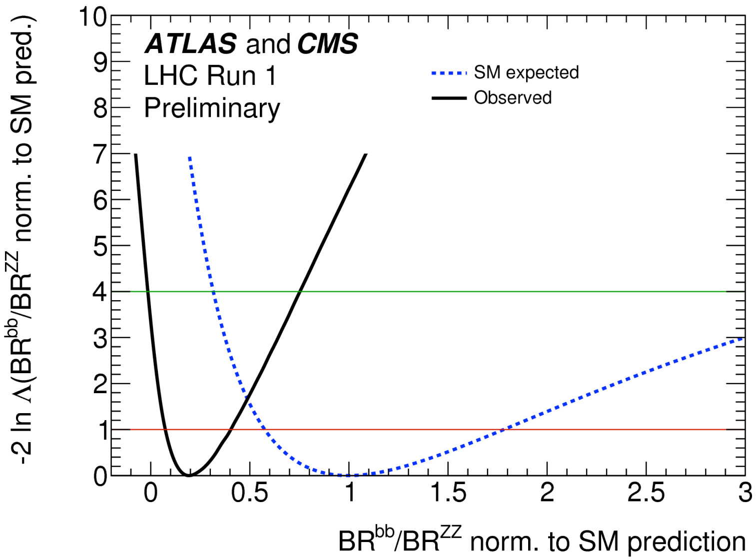
Production process	Measured significance (σ)	Expected significance (σ)
VBF	5.4	4.7
WH	2.4	2.7
ZH	2.3	2.9
VH	3.5	4.2
ttH	4.4	2.0
Decay channel		
$H \to \tau\tau$	5.5	5.0
$H \to bb$	2.6	3.7

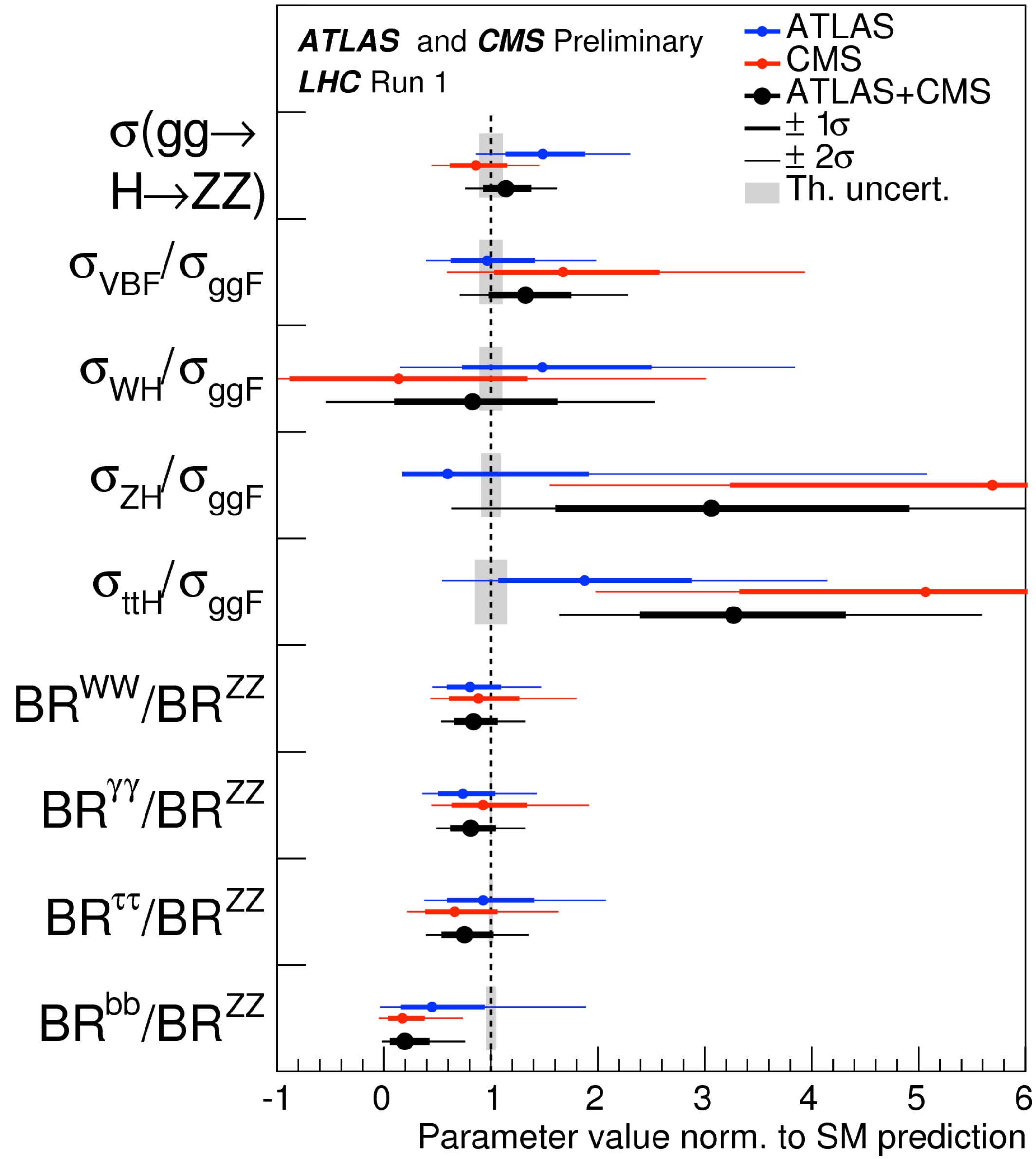
Ratios of σ and BRs

Model independent (Γ_H cancels):

Measurements of ratios of production cross sections and decay BRs
(Reference process gg → H → ZZ: clean, smallest systematic uncertainties)

Largest deviation from SM prediction in BR(H→bb)/BR(H→ZZ), ~ 2.4 σ:

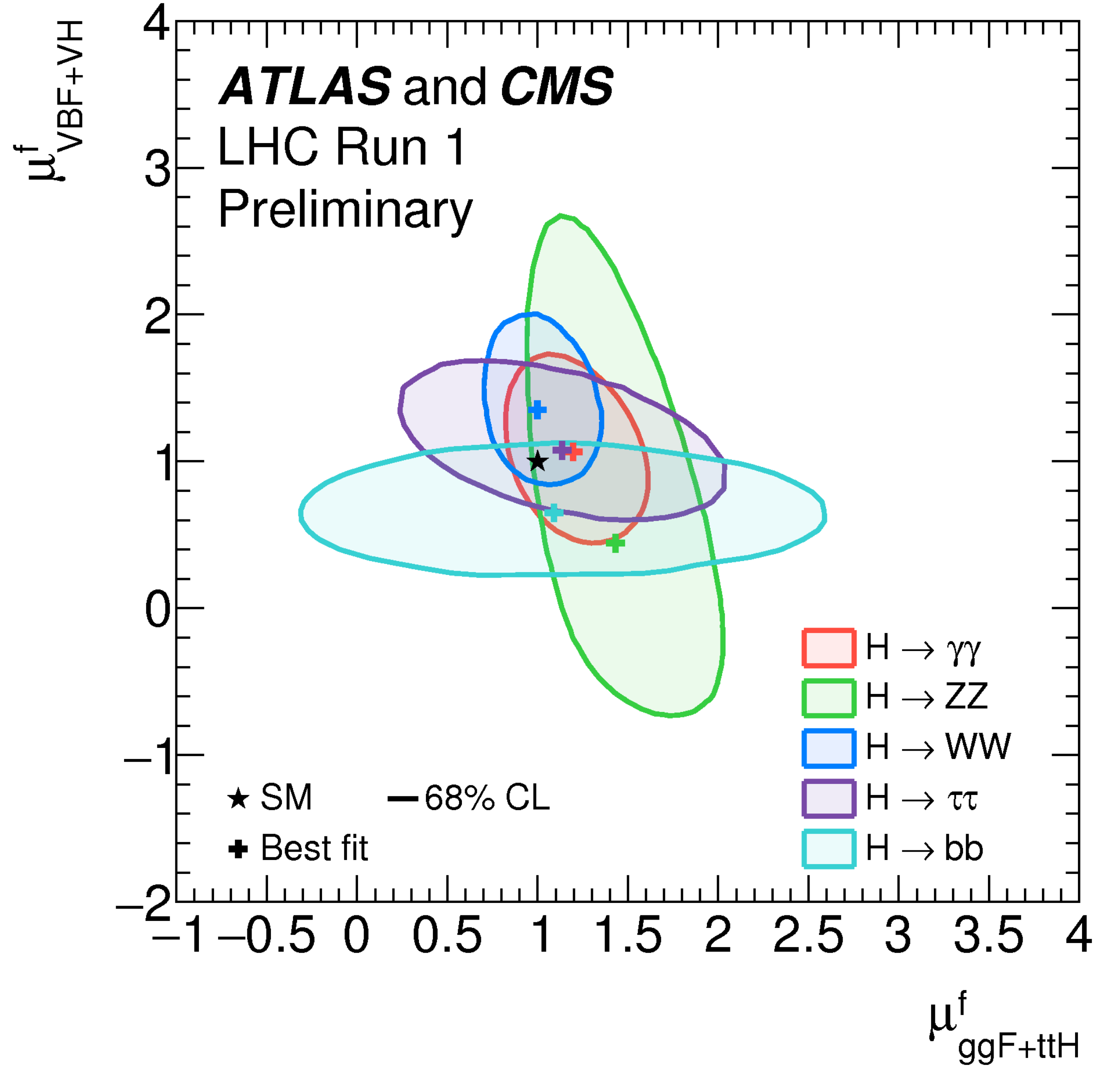




ATLAS & CMS Combination: μ, Couplings

Fermion (gluon fusion, ttH) and vector boson (VBF, VH) mediated production processes:

No assumption on SM production cross section or decay rates needed



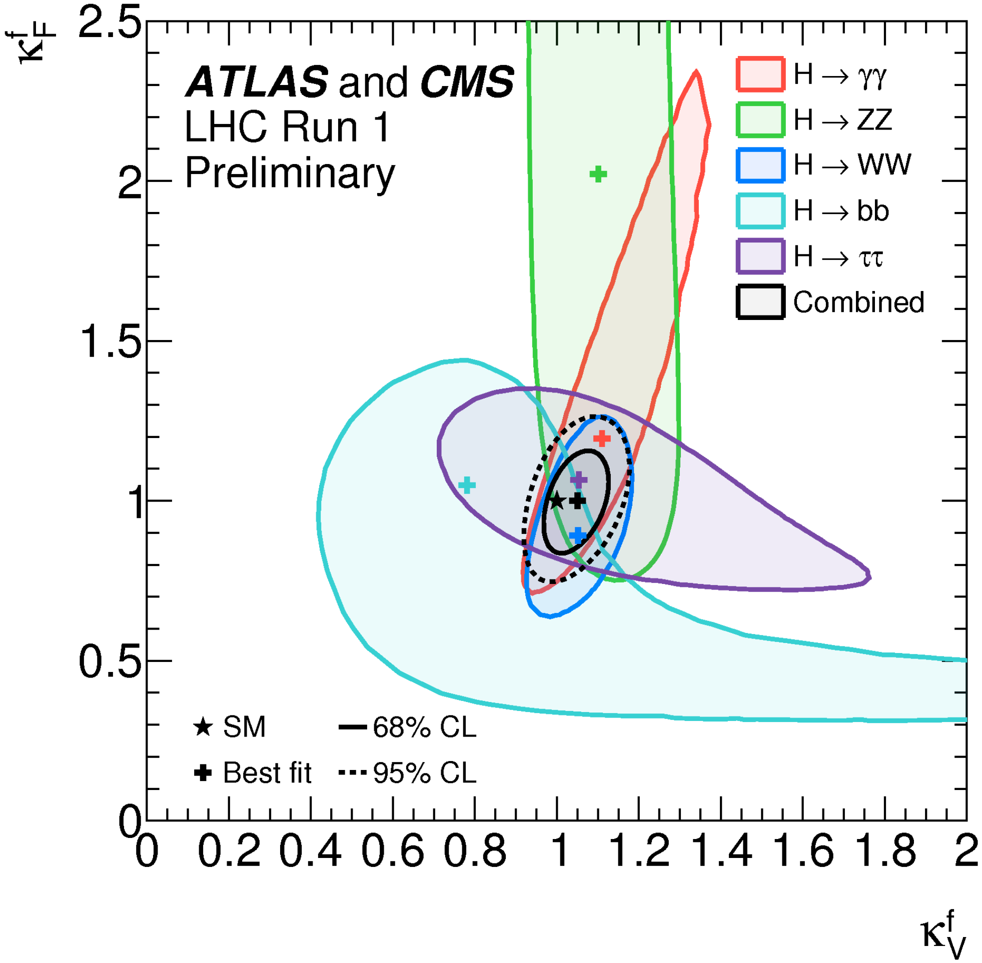
Can also fit for combined ratio:

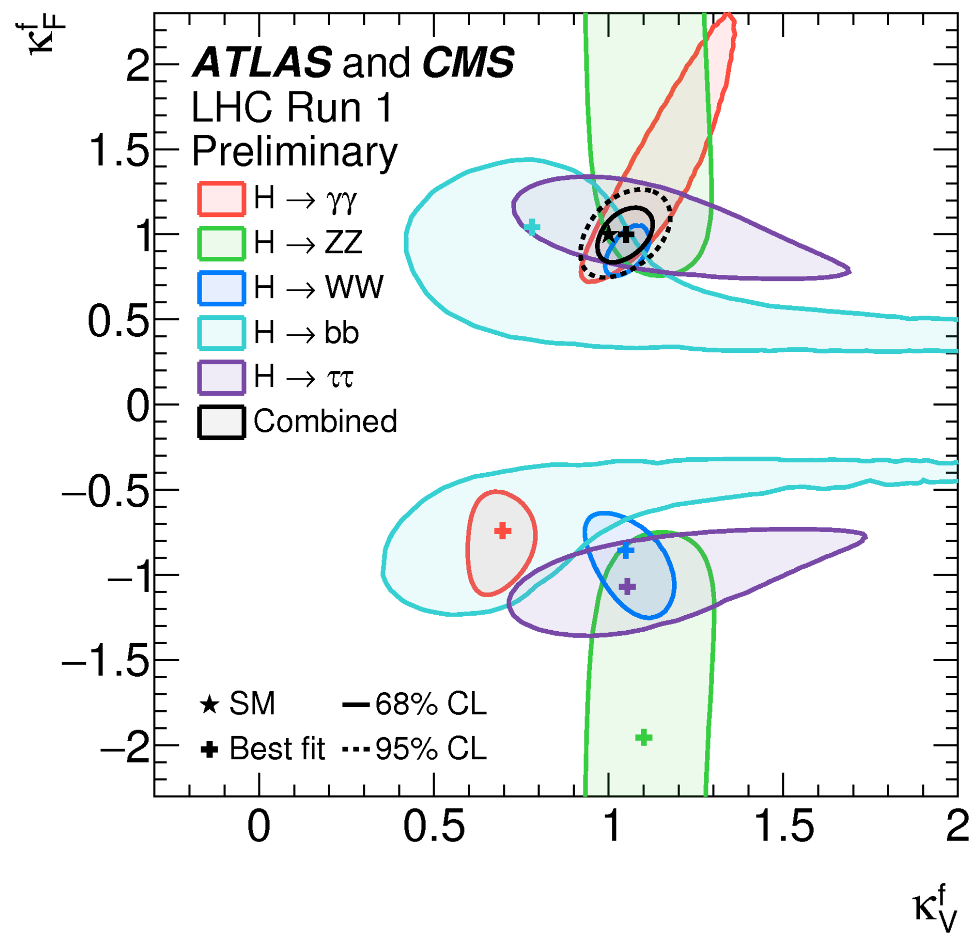
$$\mu_{VBF+VH}/\mu_{ggF+ttH} = 1.06^{+0.35}_{-0.27}$$

ATLAS & CMS Combination: μ, Couplings

Different coupling structure for bosons and fermions
→ common universal coupling modifiers for vector bosons (κ_V) and fermions (κ_f)

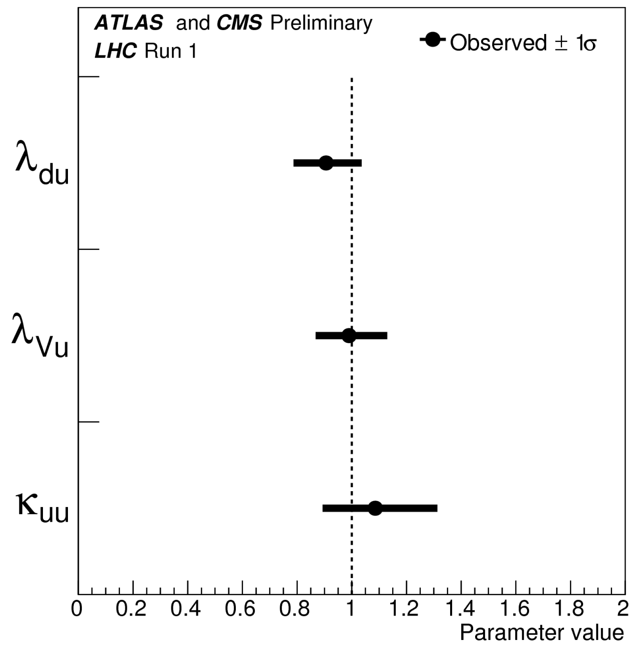
Only SM particles in loops and decays

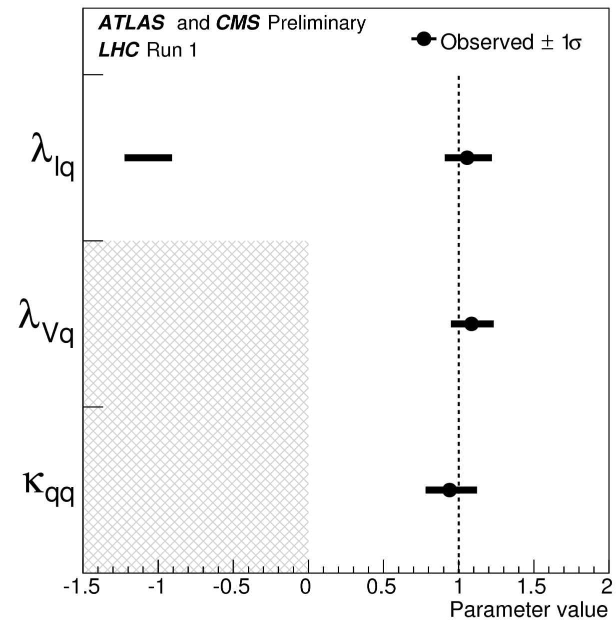


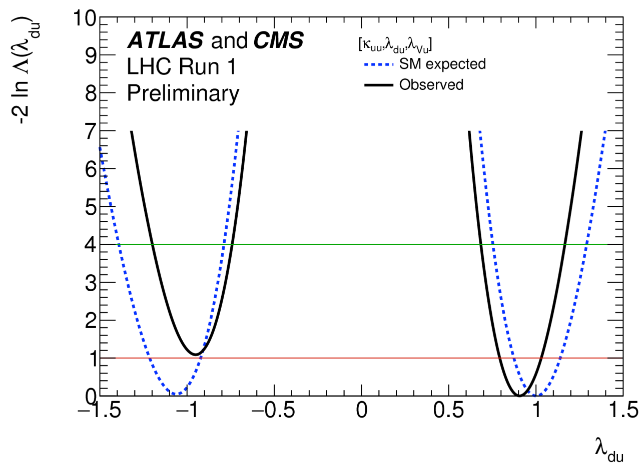


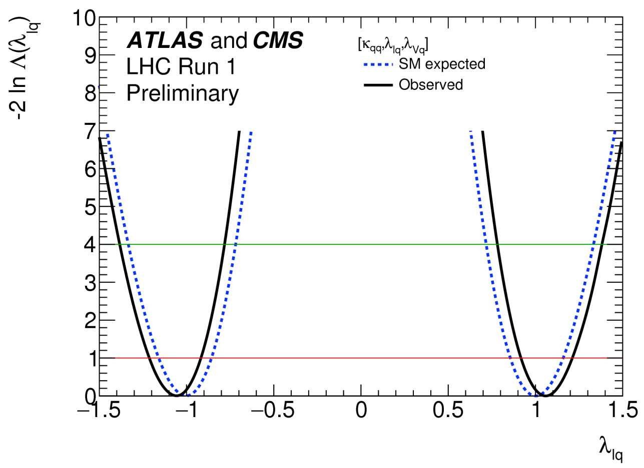
ATLAS & CMS Combination: μ, Couplings

Fermion sector: common coupling modifiers for up- and down-type fermions or leptons and quarks



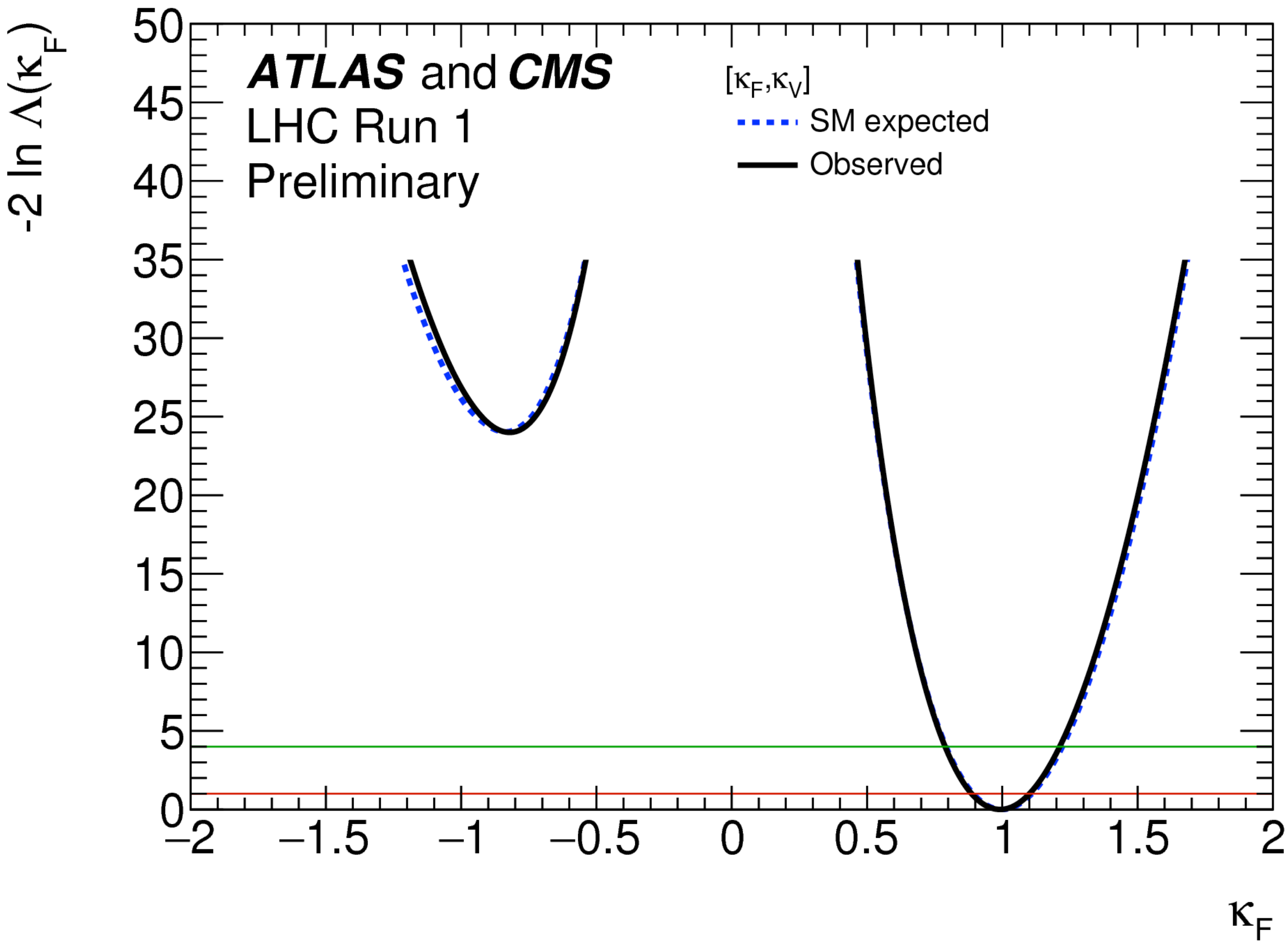






~blind to sign because no significant contributions with lepton-quark interference

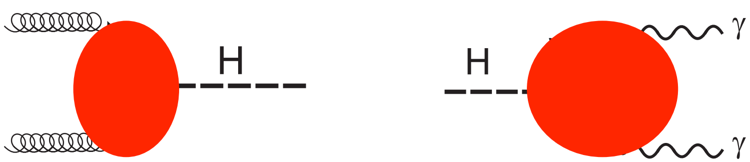
ATLAS & CMS Combination: μ, Couplings



BSM Contributions in Loops

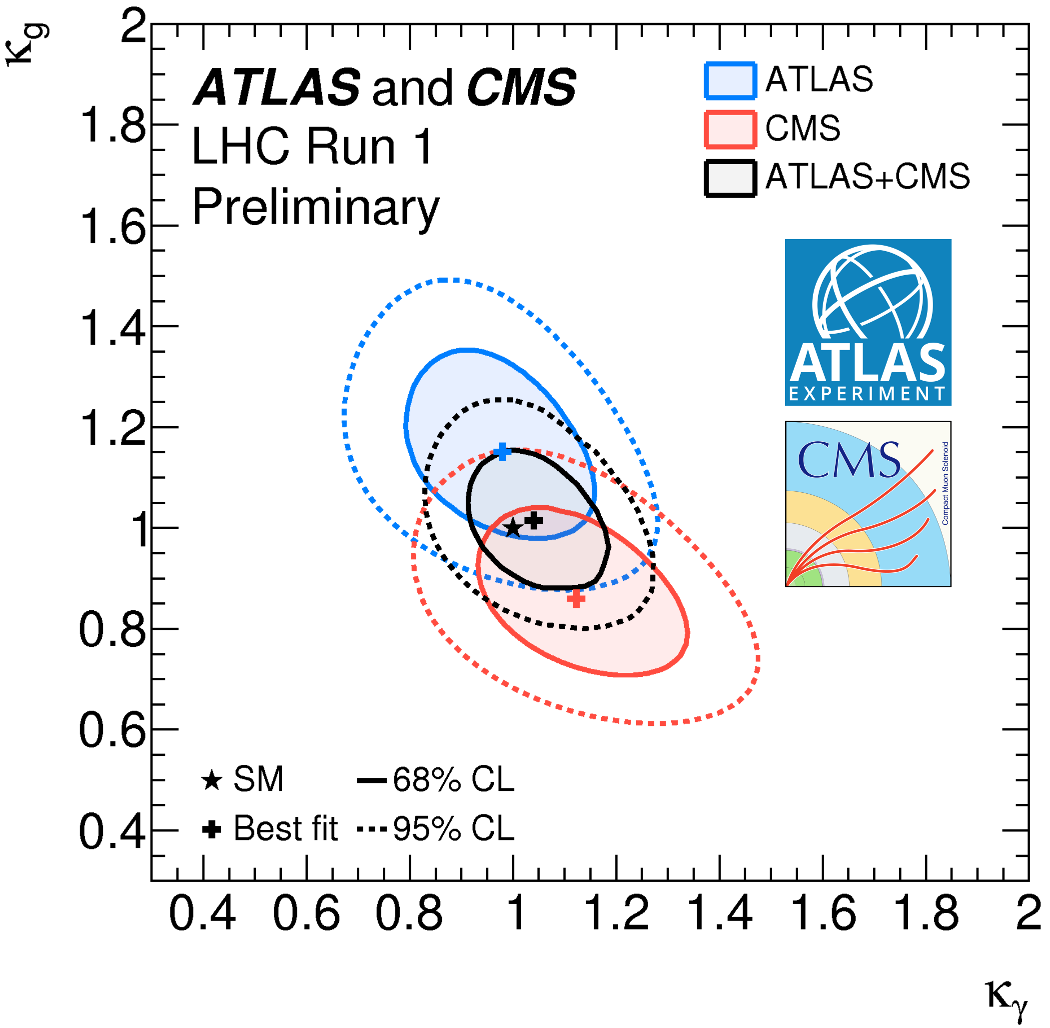
Allow new (heavy) BSM particles to contribute via Loops, but no BSM decays

→ effective coupling modifiers κ_g, κ_γ



Assume couplings to SM particles as in SM.

→ Effective couplings κ_g, κ_γ compatible with SM!



With additional assumptions, can derive:

$BR_{BSM} < 0.34$ (95% CL)

ATLAS & CMS Combination: μ, Couplings

Model	p-value	DoF	Parameters
Global signal strength	34%	1	μ
Production processes	24%	5	μ_{ggF}, μ_{VBF}, μ_{WH}, μ_{ZH}, μ_{ttH}
Decay modes	60%	5	$\mu^{\gamma\gamma}$, μ^{ZZ}, μ^{WW}, $\mu^{\tau\tau}$, $\mu^{b\bar{b}}$
μ_V and μ_F per decay	88%	10	$\mu_V^{\gamma\gamma}$, μ_V^{ZZ}, μ_V^{WW}, $\mu_V^{\tau\tau}$, $\mu_V^{b\bar{b}}$, $\mu_F^{\gamma\gamma}$, μ_F^{ZZ}, μ_F^{WW}
μ_V/μ_F ratio	72%	6	μ_V/μ_F, $\mu_F^{\gamma\gamma}$, μ_F^{ZZ}, μ_F^{WW}, $\mu_F^{\tau\tau}$, $\mu_F^{b\bar{b}}$
Ratios of σ and BR relative to $\sigma(gg \to H \to ZZ)$	16%	9	$\sigma(gg \to H \to ZZ)$, $\sigma_{\text{VBF}}/\sigma_{\text{ggF}}$, $\sigma_{WH}/\sigma_{\text{ggF}}$,
Ratios of σ and BR relative to $\sigma(gg \to H \to WW$	16%	9	$\sigma(gg \to H \to WW)$, $\sigma_{\text{VBF}}/\sigma_{\text{ggF}}$, $\sigma_{WH}/\sigma_{\text{ggF}}$
Coupling ratios	13%	7	κ_{gZ}, λ_{Zg}, λ_{tg}, λ_{WZ}, $\lambda_{\gamma Z}$, $\lambda_{\tau Z}$, λ_{bZ}
Couplings, SM loops	65%	6	κ_Z, κ_W, κ_t, κ_τ, κ_b, κ_μ
Couplings, BSM loops	11%	7	κ_Z, κ_W, κ_t, κ_τ, κ_b, κ_g, κ_γ
BSM loops only	82%	2	κ_g, κ_γ
Up vs down couplings	67%	3	λ_{du}, λ_{Vu}, κ_{uu}
Lepton vs quark couplings	78%	3	λ_{lq}, λ_{Vq}, κ_{qq}
Fermion and vector couplings	59%	2	κ_V, κ_F