Measurement of cross sections and properties of the Higgs Boson using the ATLAS detector

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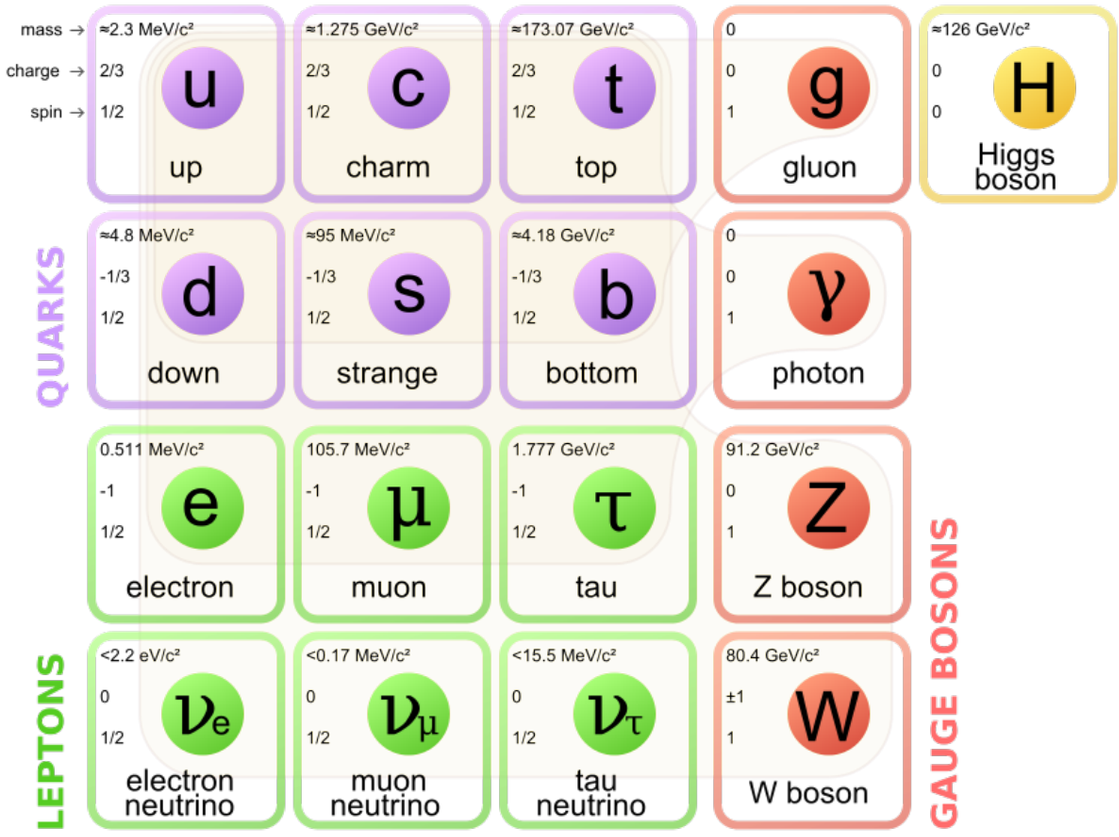
On behalf of the ATLAS collaboration

1. Higgs properties
2. Run1 legacy results
3. New results for H→γγ & ZZ
4. New results for H→μμ

Introduction

- The Higgs boson was the last undiscovered particle in the SM
- Its discovery was the culmination of decades of effort
- First fundamental spin-0 particle
- The precision measurement of the Higgs properties provides a new and rich research program



- Couplings to the Higgs scalar field give the fundamental particle masses

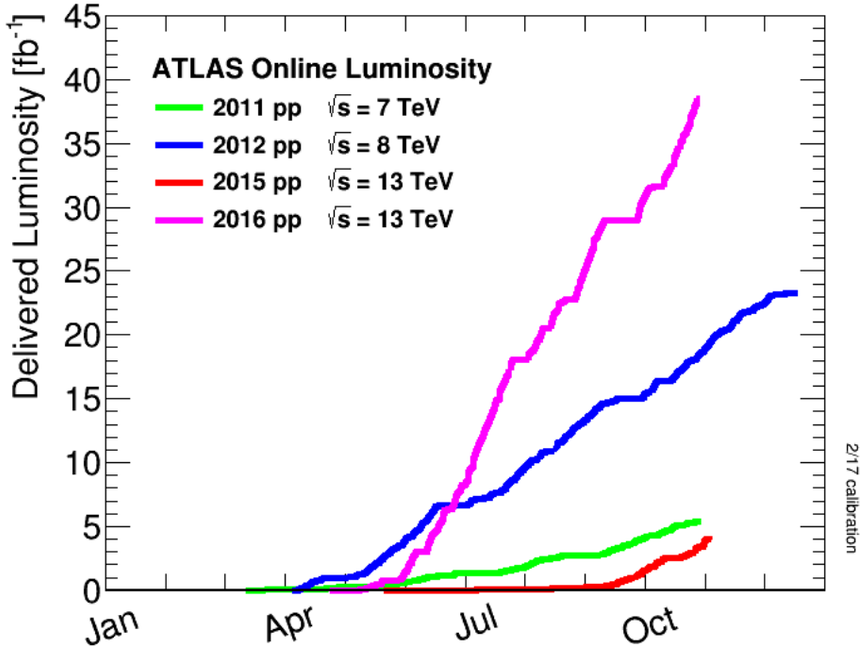
$$m_W = \frac{g_W v}{2}, \quad m_Z = \frac{\sqrt{g_W^2 + g'^2} v}{2}, \quad m_H = \sqrt{2\lambda} v, \quad m_f = \frac{g_f}{\sqrt{2}} v$$

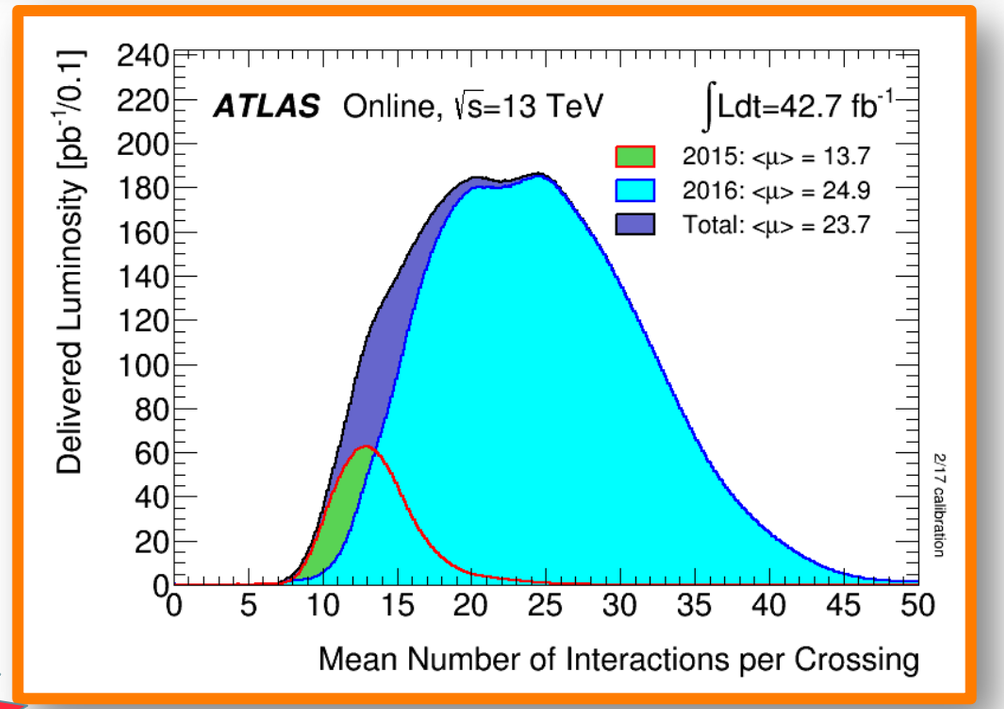
- So far no significant deviations from the SM predictions have been observed

$$v = 246\,\mathrm{GeV}$$

LHC and ATLAS performance

- Excellent LHC performance in 2016
  - More data than all other years combined!
  - Peak Lumi = 1.4 x 10^{34} $cm^{-2}s^{-1}$ (exceeded design)
  - Higher pileup conditions





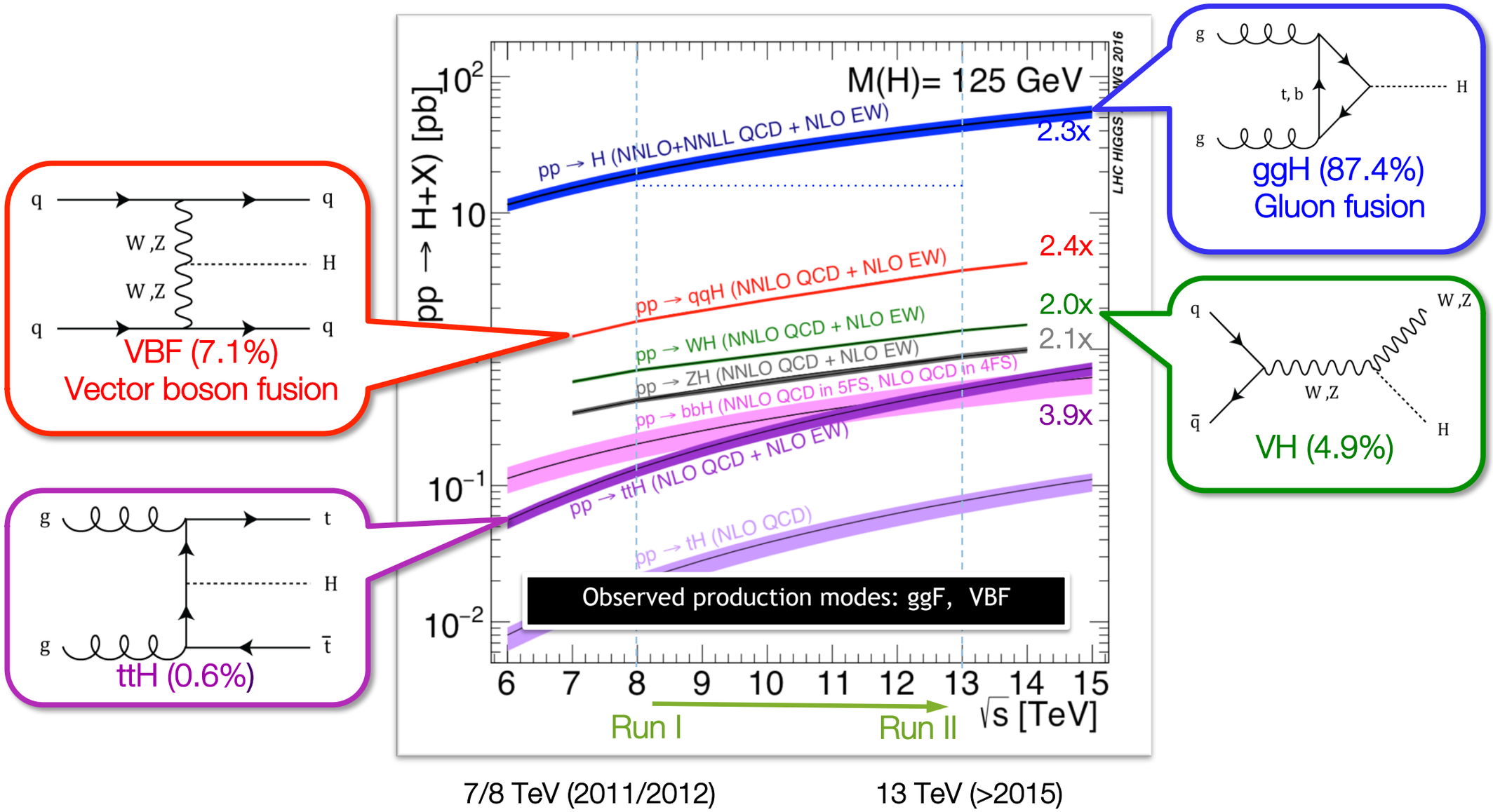
Run1

Run2

Ecm	Year	Luminosity used in analyses	Luminosity uncertainty
7 TeV	2011	4.5 fb^{-1}	1.8% final
8 TeV	2012	20.3 fb^{-1}	2.8% final
13 TeV	2015	3.2 fb^{-1}	2.1% final
13 TeV	2016	32.9 fb^{-1}	3.2% prel

new

Higgs Boson Production at 125 GeV



- More than 100 fb^{-1} expected for Run 2 (~25 fb^{-1} in Run 1)
- Therefore we expect ~10 times more Higgs events than Run1!

Higgs Boson Decays at 125 GeV

Observed decay modes:
γγ, ZZ, WW, ττ

Missing bb,cc, μμ, Zγ

H→ττ
Abundant (6%)
S/B<1
ΔM/M ~ 10-20%

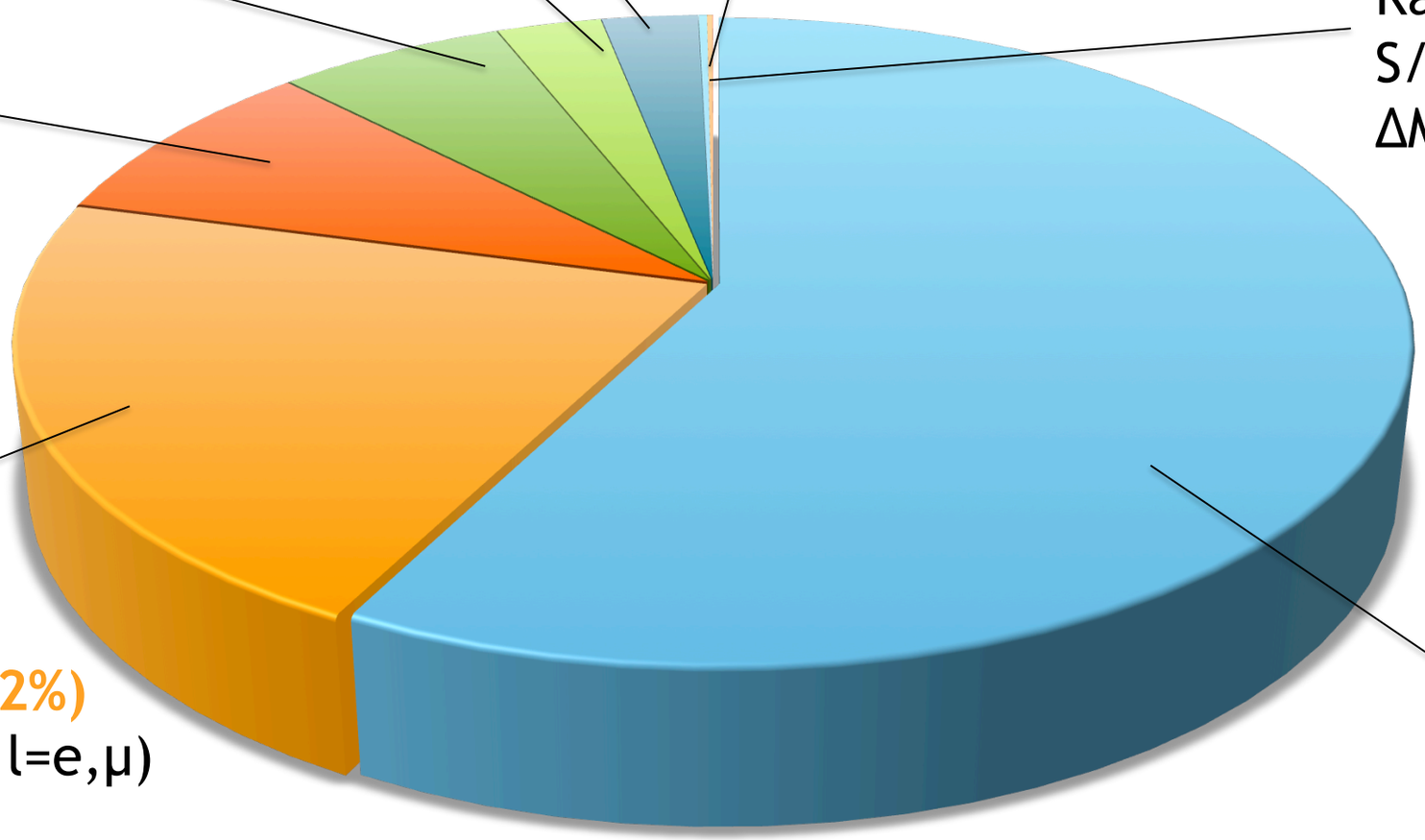
H→ZZ*→4l (3%)
Very rare (0.0124% l=e,μ)
S/B>>1
ΔM/M ~ 1-2%

H→cc (2.9%)

H→γγ
Rare (0.23%)
S/B<1
ΔM/M ~ 1-2%

H→μμ
Rare (0.022%)
S/B<1
ΔM/M ~ 2-4%

H→gg (8.5%)



H→WW*→2l2v (22%)
Abundant (1.06% l=e,μ)
S/B<1
ΔM/M ~ 30%

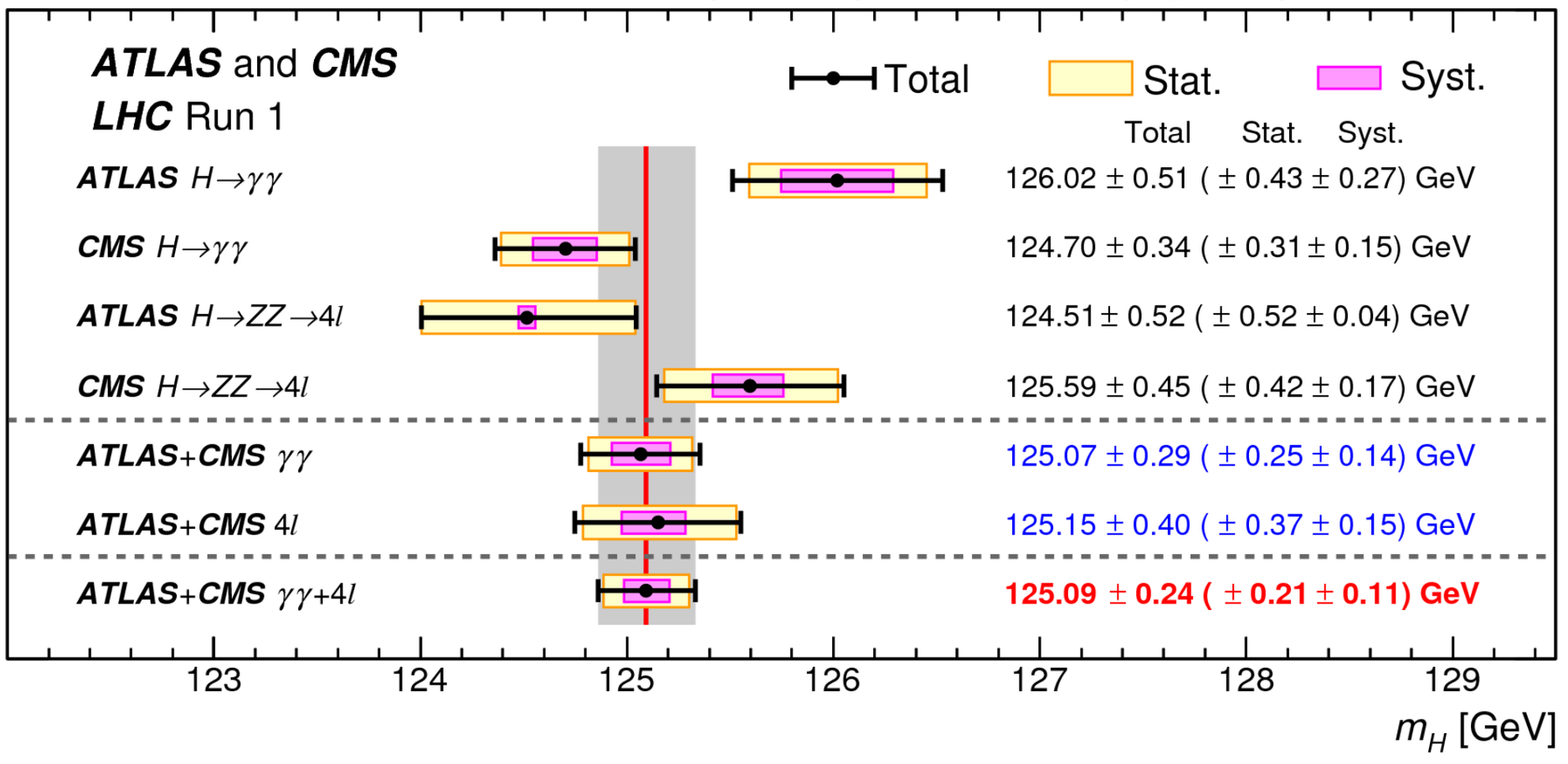
H→bb
Very Abundant (58%)
S/B<<1
ΔM/M ~ 10-20%

Phys. Rev. Lett. 114, 191803

Run 1 mass results

- Determination of the Higgs potential $m_H = \sqrt{2\lambda}v$
- Not predicted by the Standard Model (like many params)
- It was constrained by EW precision fit, but it is very difficult to measure precisely without Higgs measurements.
- Combination of the ATLAS and CMS results

125.09 ± 0.21 (stat.) ± 0.11(syst.) GeV



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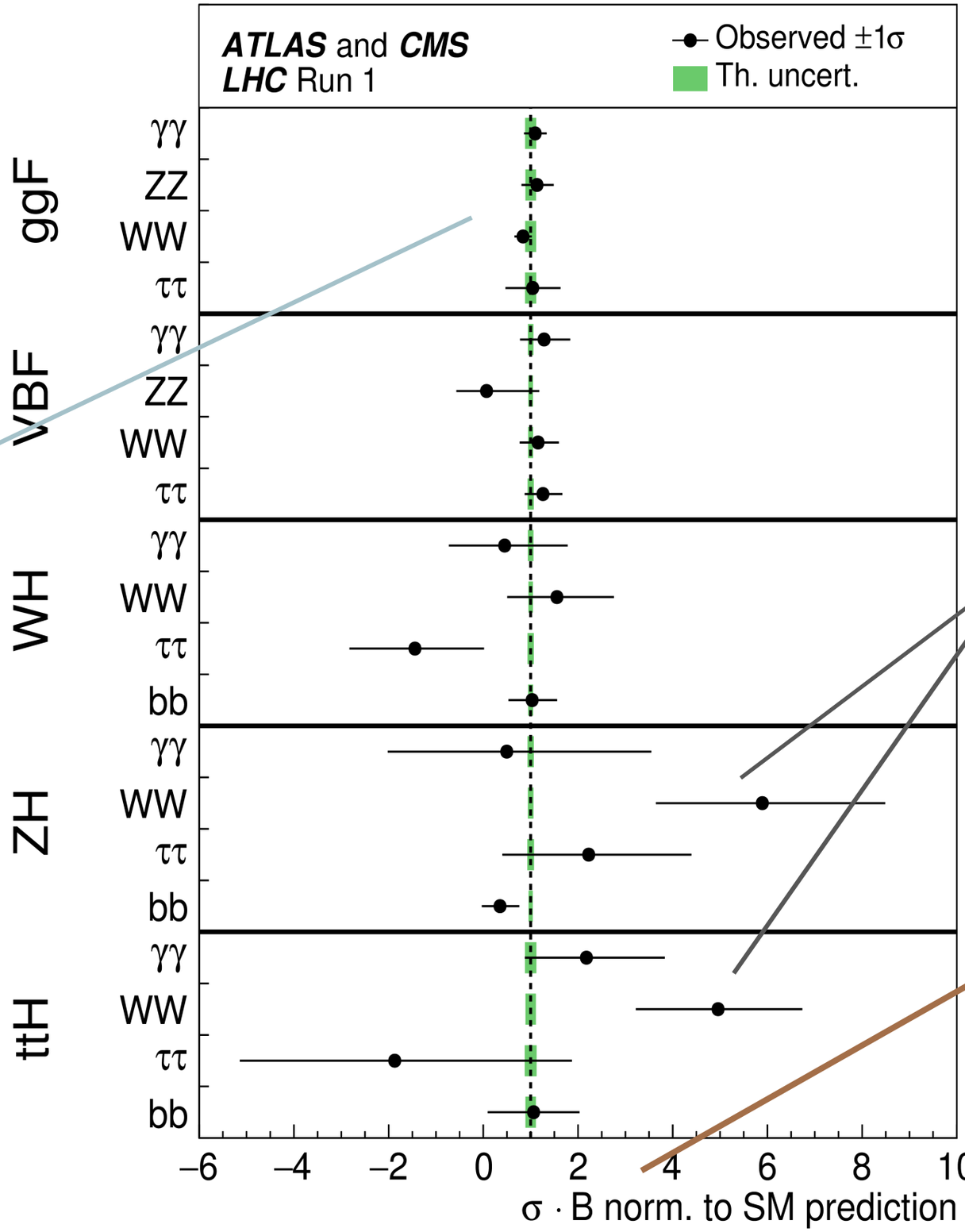
Run1 precision test of Higgs boson coupling strengths

Gluon fusion measurements, starting to approach SM theory uncertainties: 15%



Mild excess in ttH and ZH production modes

Coupling strengths

$$\mu = \frac{\sigma}{\sigma_{SM}}$$

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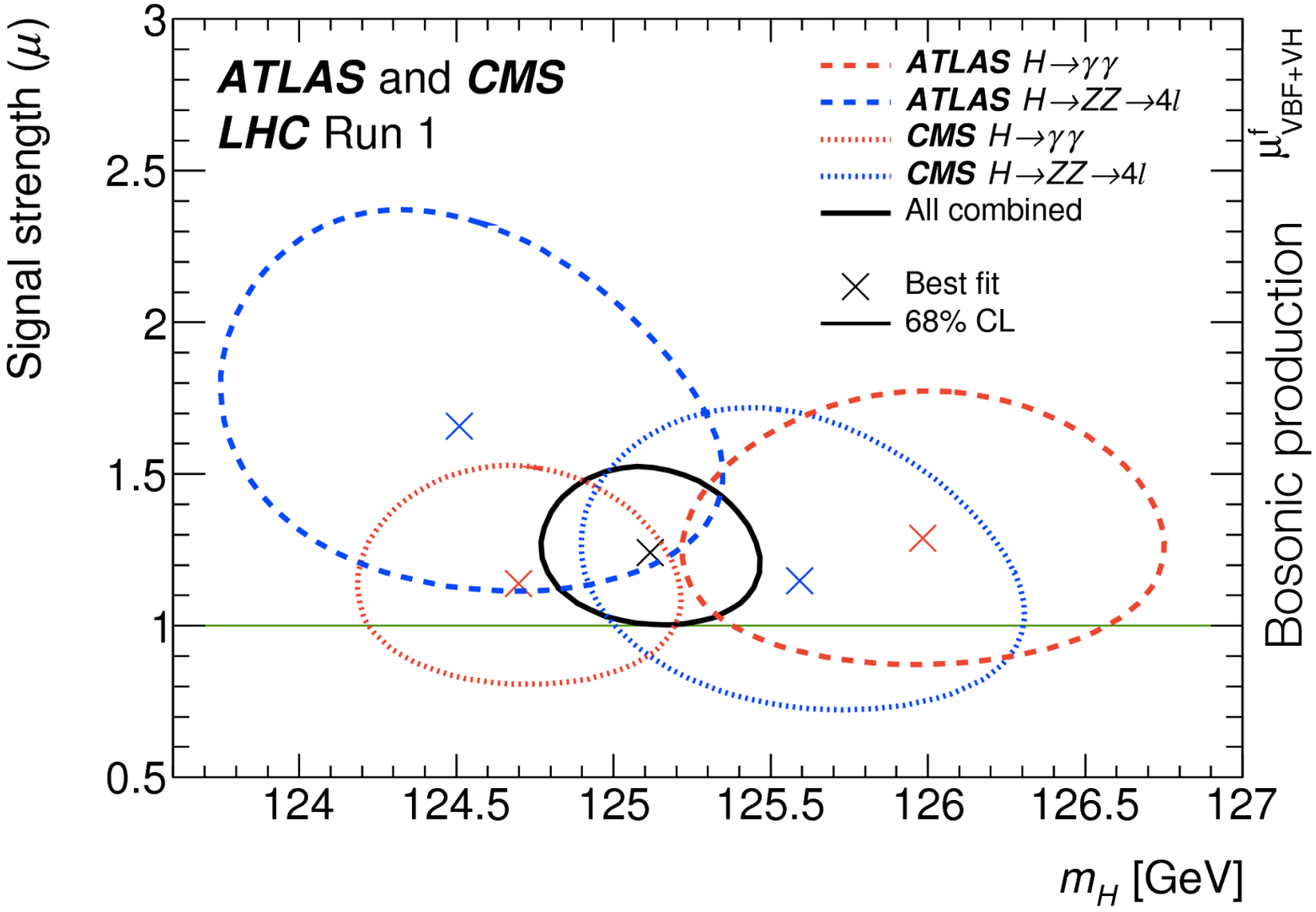
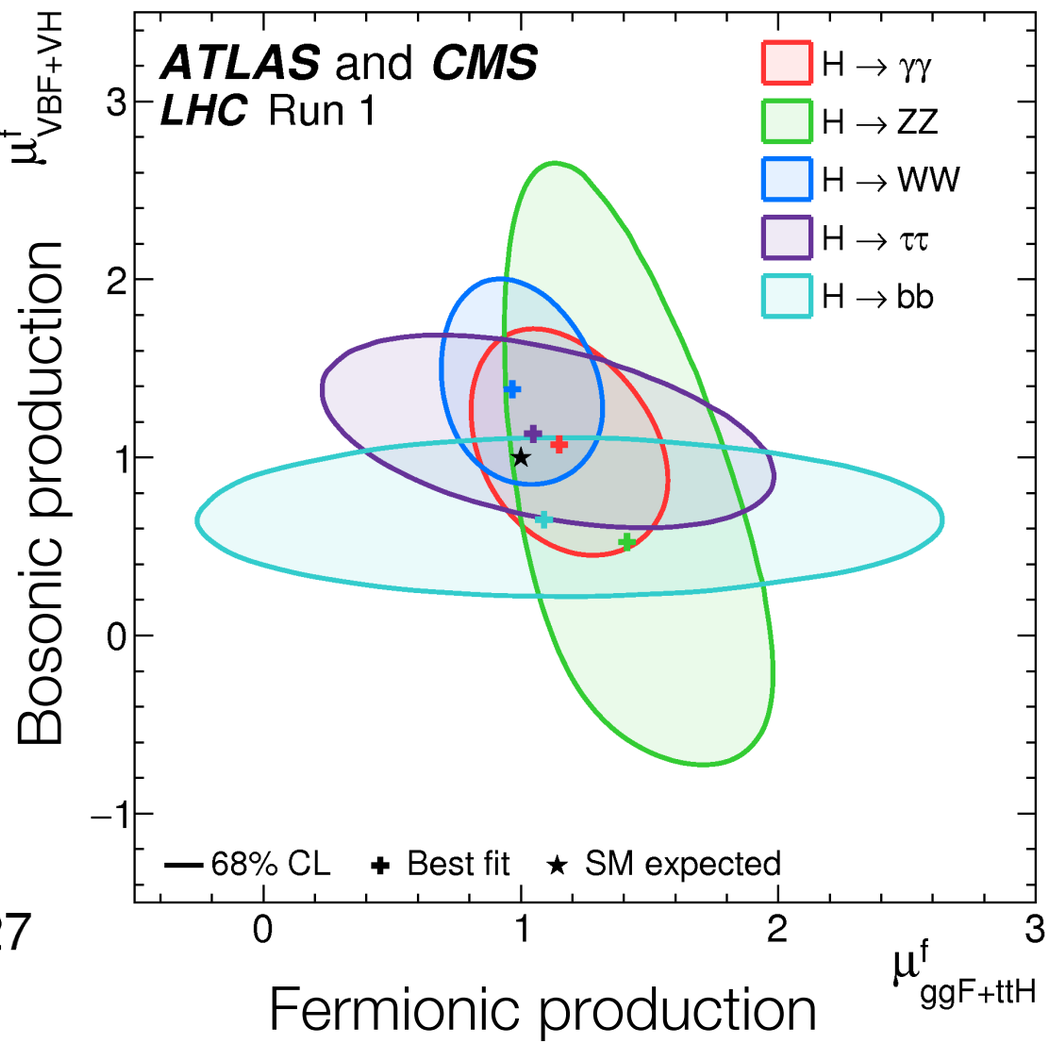
Run 1 mass and coupling results





Everything consistent with the Standard Model

Aside: angular distributions also show consistency with $J^P=0^+$ for couplings to gauge bosons (see R. Tanaka's talk)

(CP odd contribution to fermions is still possible)

Run II results

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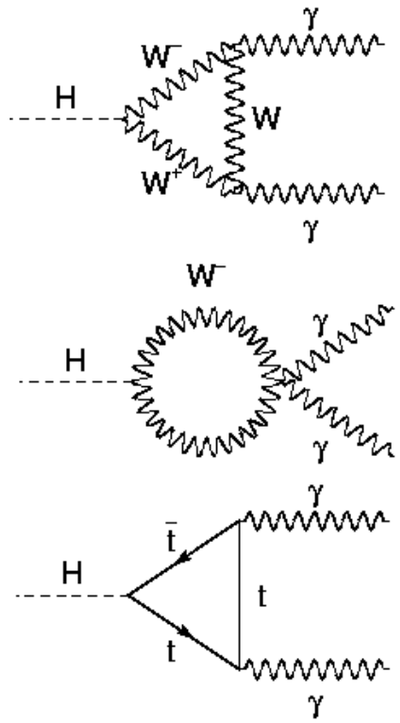
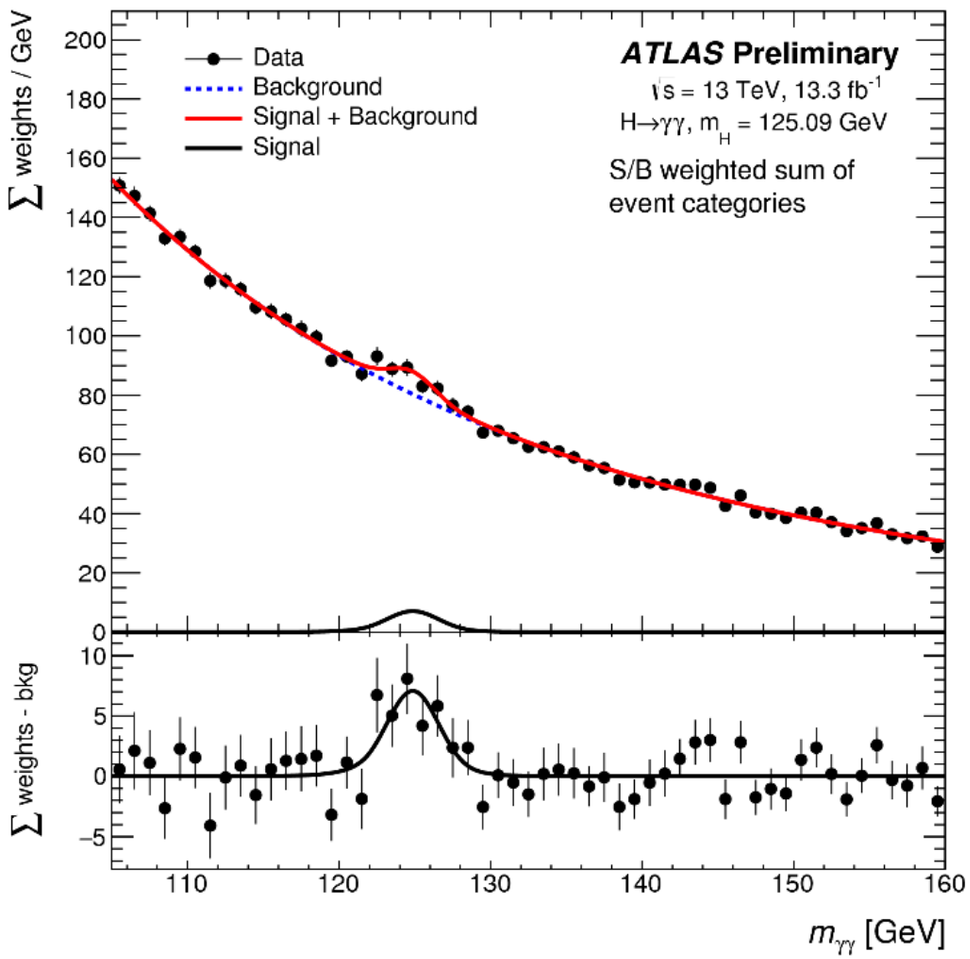
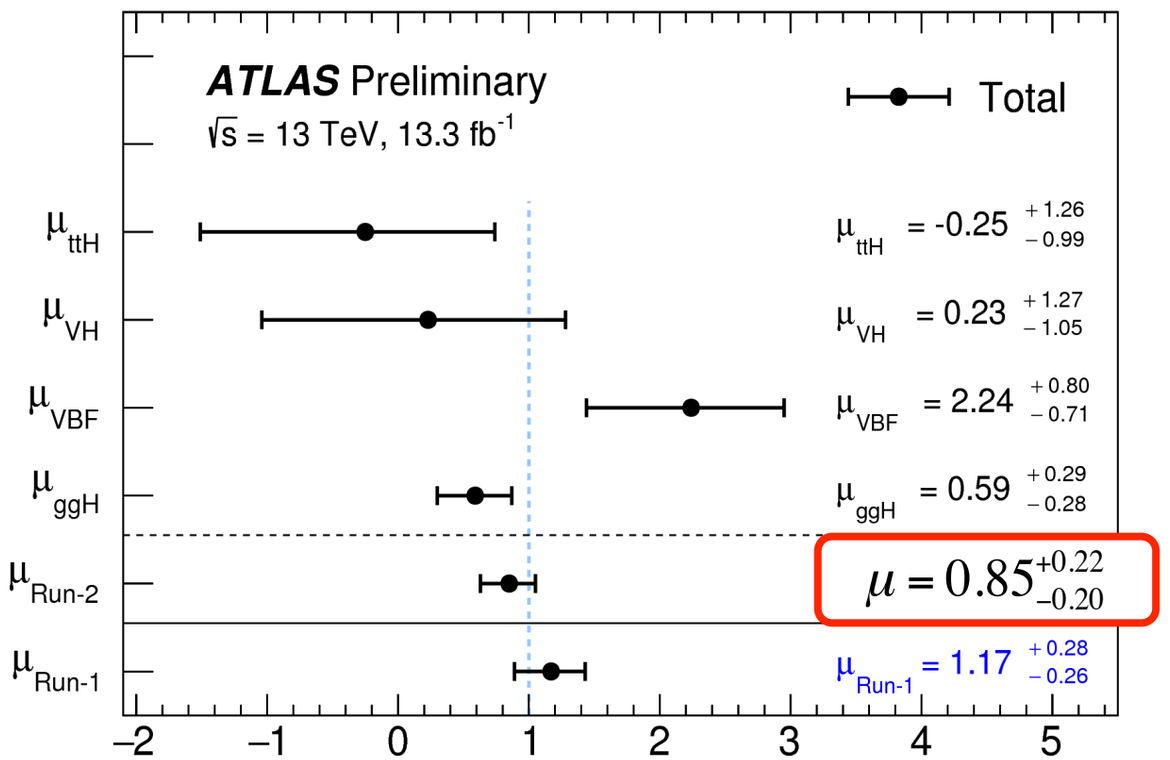
Higgs → γγ

- High resolution channel and rare decay (0.2%)
- Narrow resonance on top of falling background
- Signature: 2 isolated photons
- All production modes targeted (ggF, VBF, VH and ttH)
- Signal extracted by fit of $m_{\gamma\gamma}$ spectrum in different event categories
  - ➢ **Observed Significance 4.7 σ**

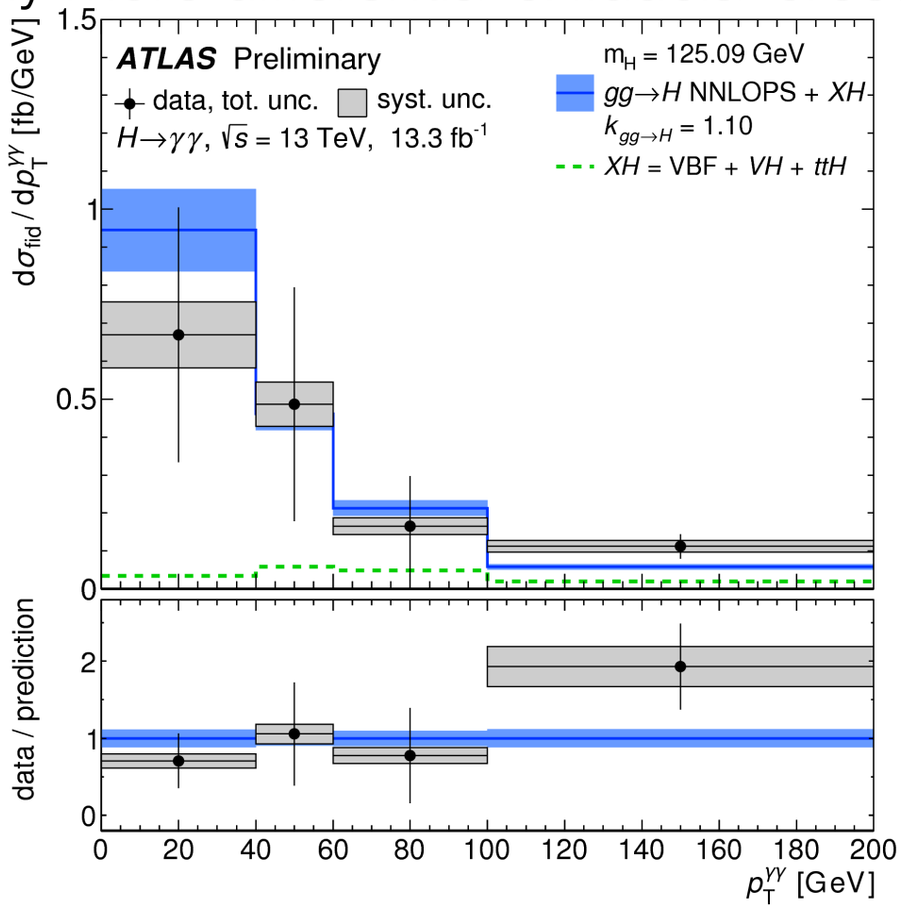


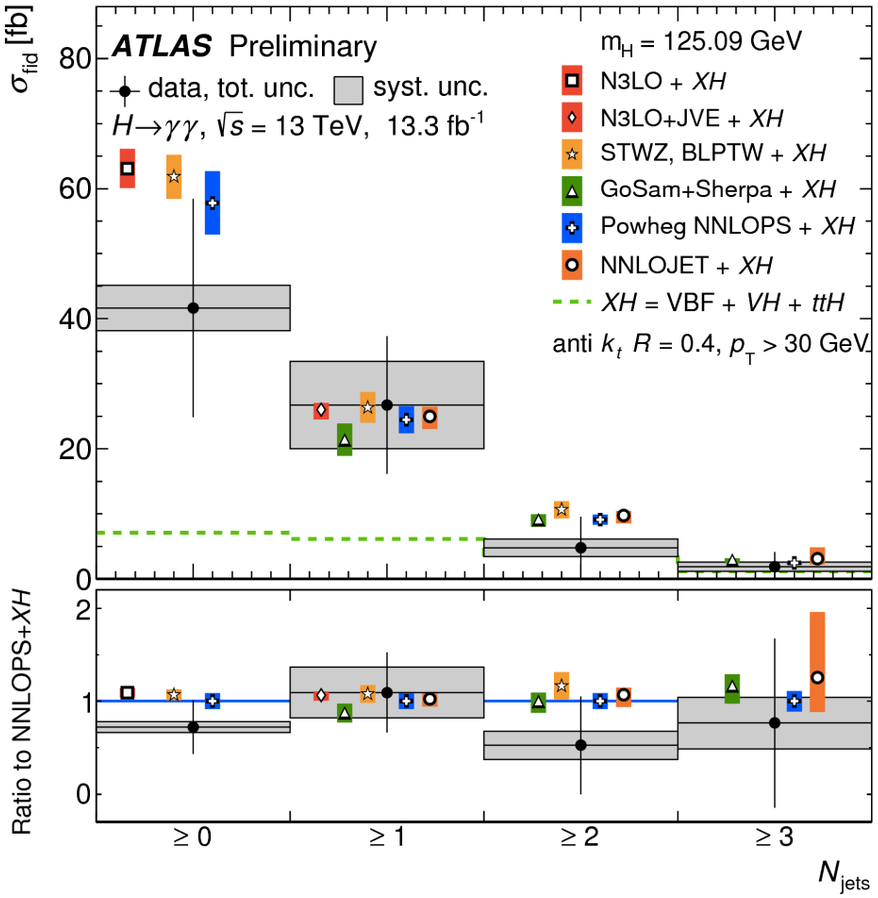




Higgs → γγ differential & fiducial cross sections

- Transverse momentum (p_T) of diphoton
  - Good agreement between data and theory
  - Data slightly undershoot (overshoot) theory prediction at low (high) p_T
- Number of jets, N_{jets}
  - Data are in agreement with state-of-art theory predictions
- Many more differential & fiducial cross sections in the conference note





13 TeV	Fiducial σ (fb)	SM prediction (fb)
ATLAS (13.3 fb^{-1})	43.2±14.9(stat)±4.9(syst)	$62.8^{+3.4}_{-4.4}$ (N^{3}LO+XH)

Fiducial σ:
Event yields corrected for detector inefficiency and resolution for minimal theoretical modeling

$$\sigma_i = \frac{\nu_i^{sig}}{c_i \int L\,dt}$$

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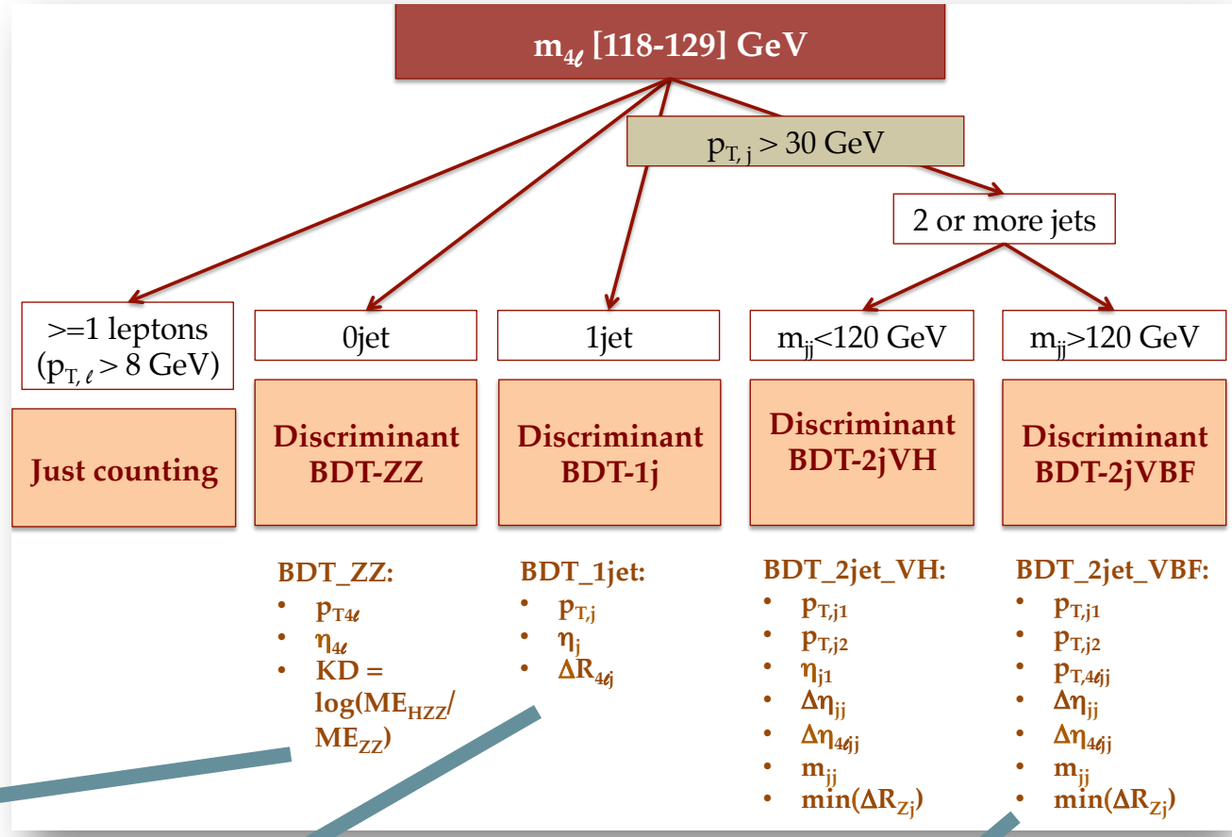
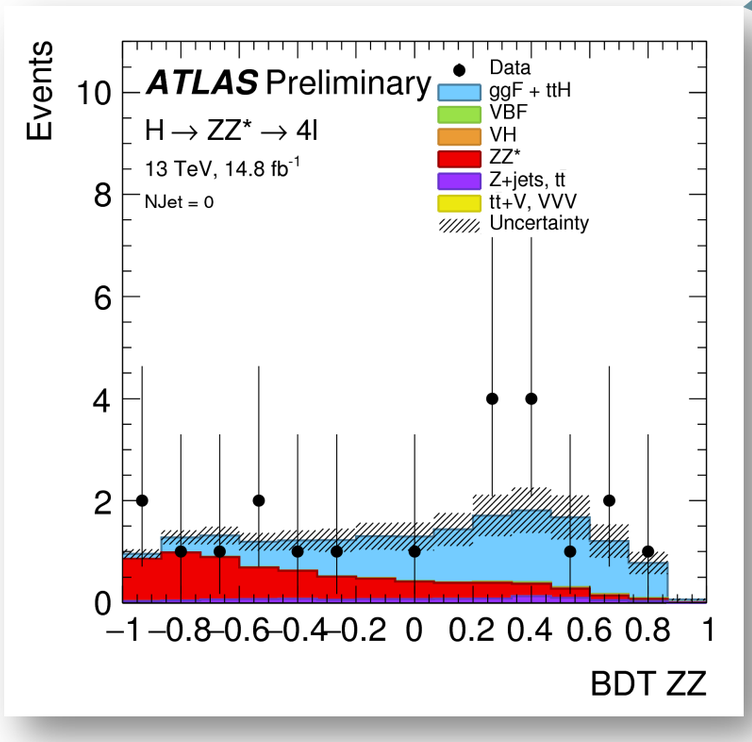
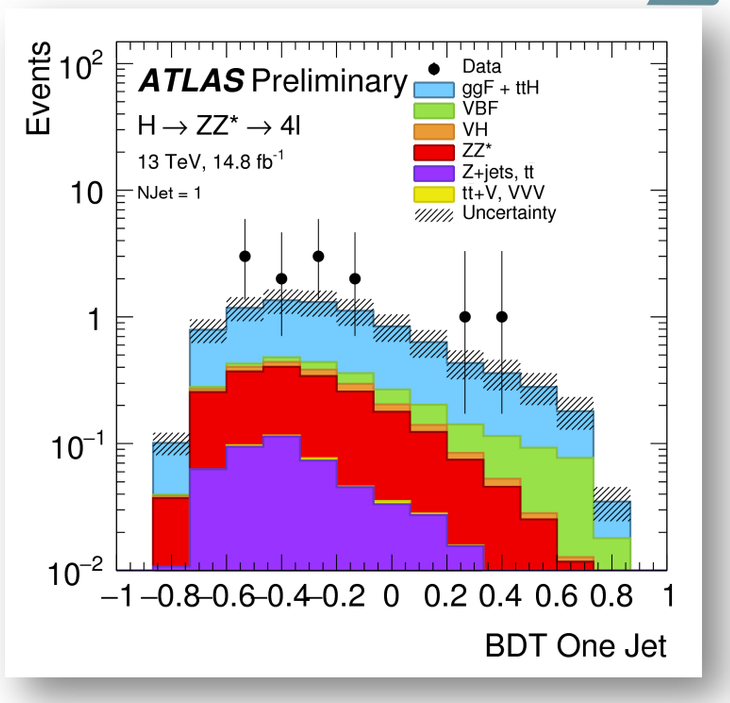
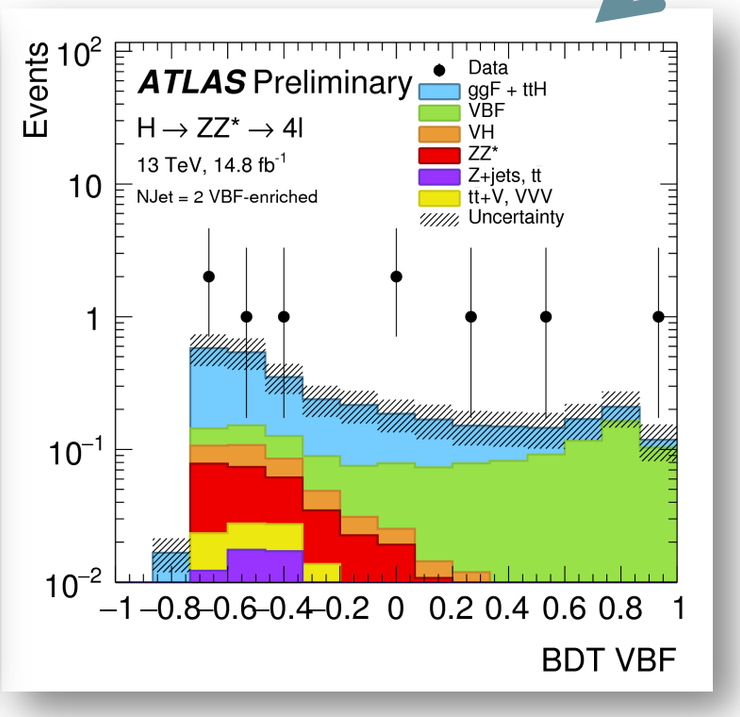
Higgs →ZZ*→(4l),l=e,μ

- High res. channel, good S/B ≥2, but low yield
- Narrow peak over a flat background
- Signature:
  - two pairs of same flavour, opposite sign, isolated leptons
- Event categorization to measure cross section per production mode
- Production modes targeted (ggF, VBF, VH)
- Signal extracted by fitting the shape of discriminants in each category









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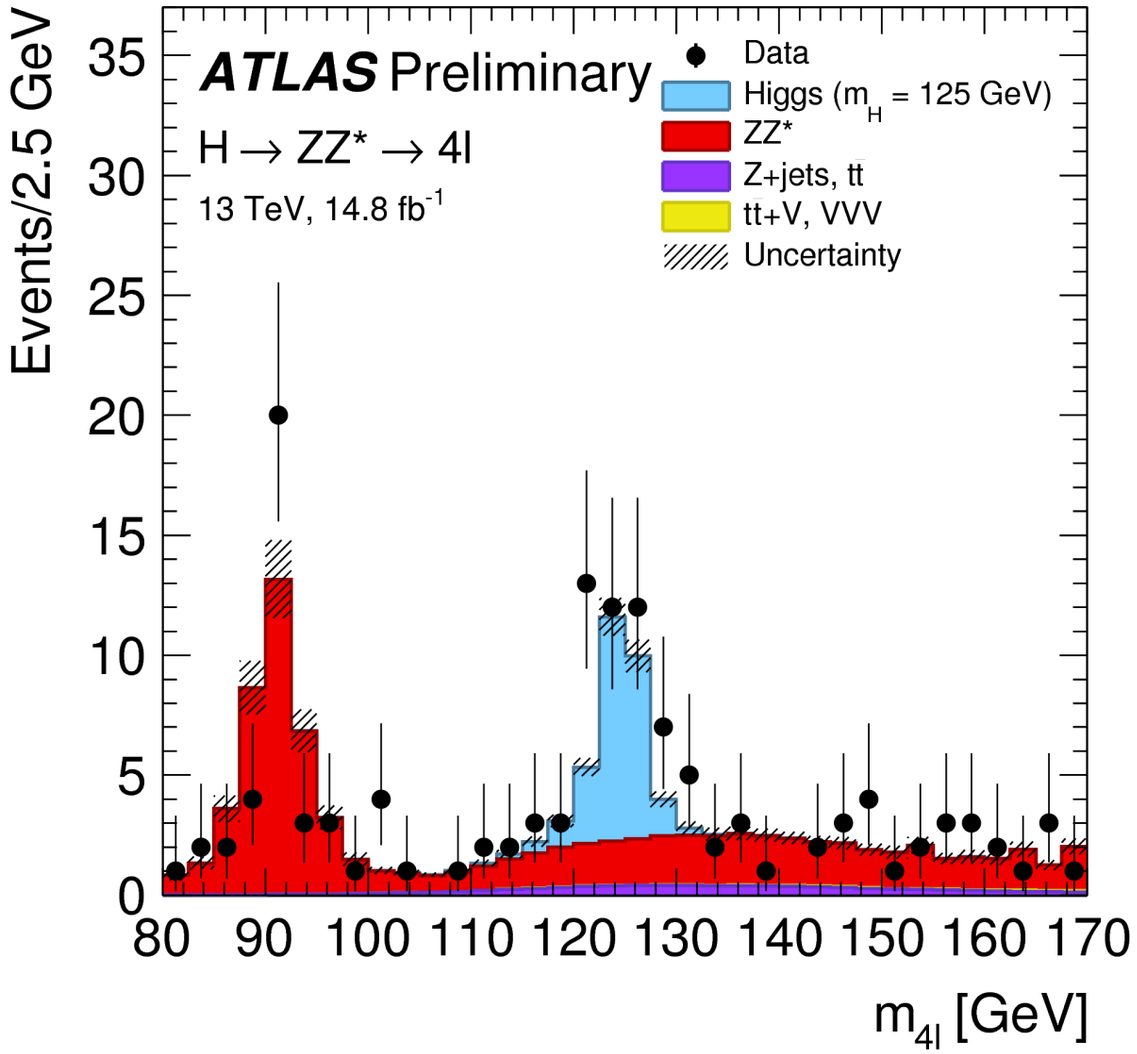
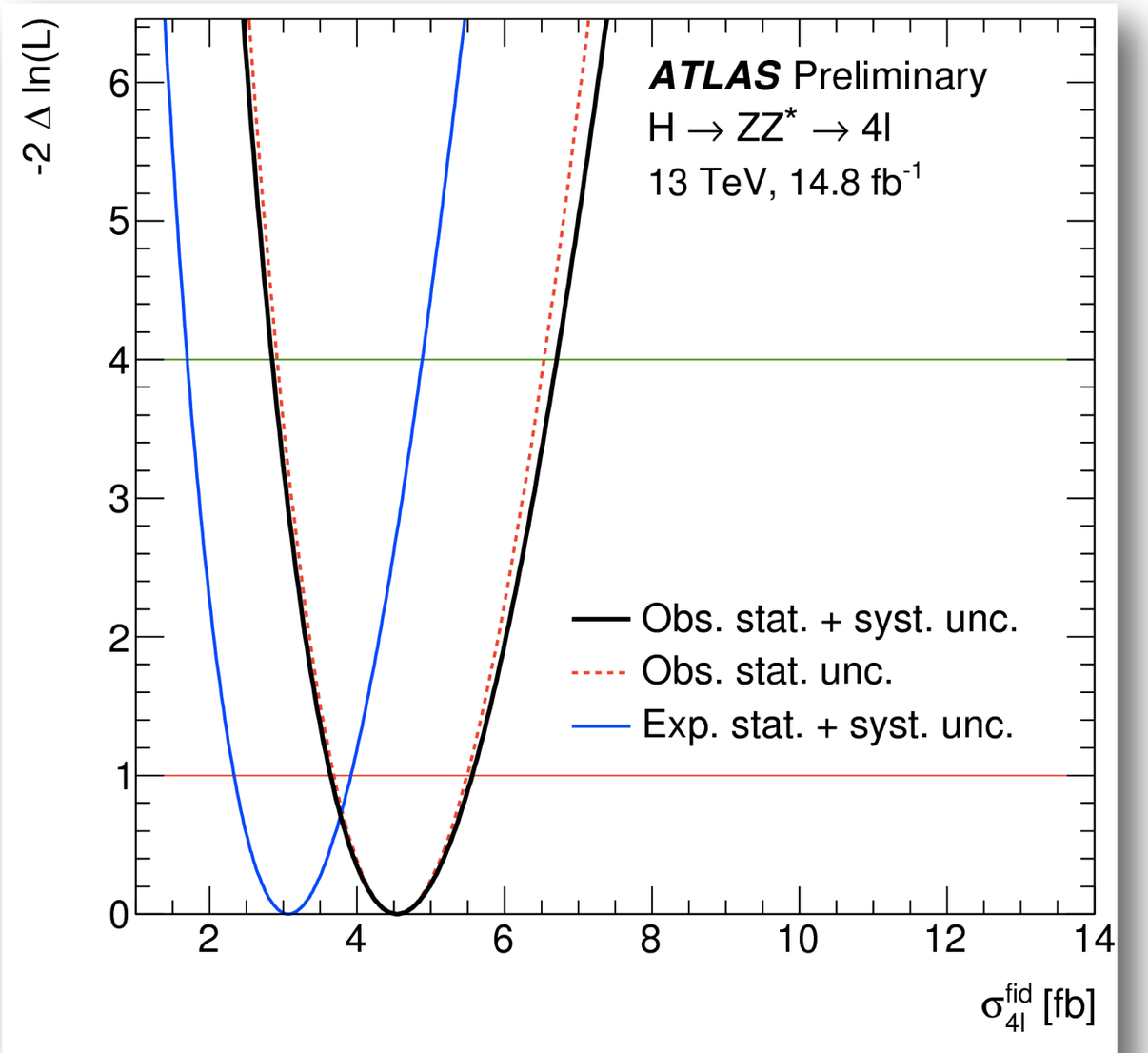
Higgs →ZZ*→(4l),l=e,μ





13 TeV	Fiducial σ (fb)	SM prediction (fb)
ATLAS (14.8 fb^{-1})	$4.54^{+1.02}_{-0.90}$	$3.07^{+0.21}_{-0.25}$

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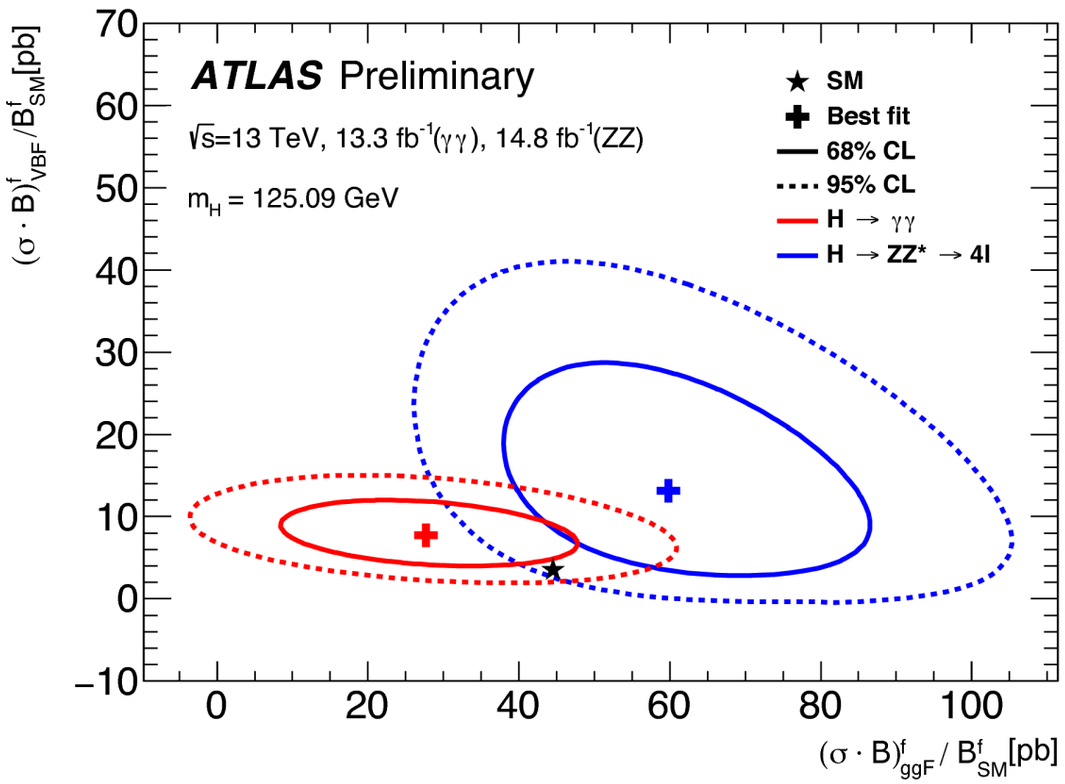
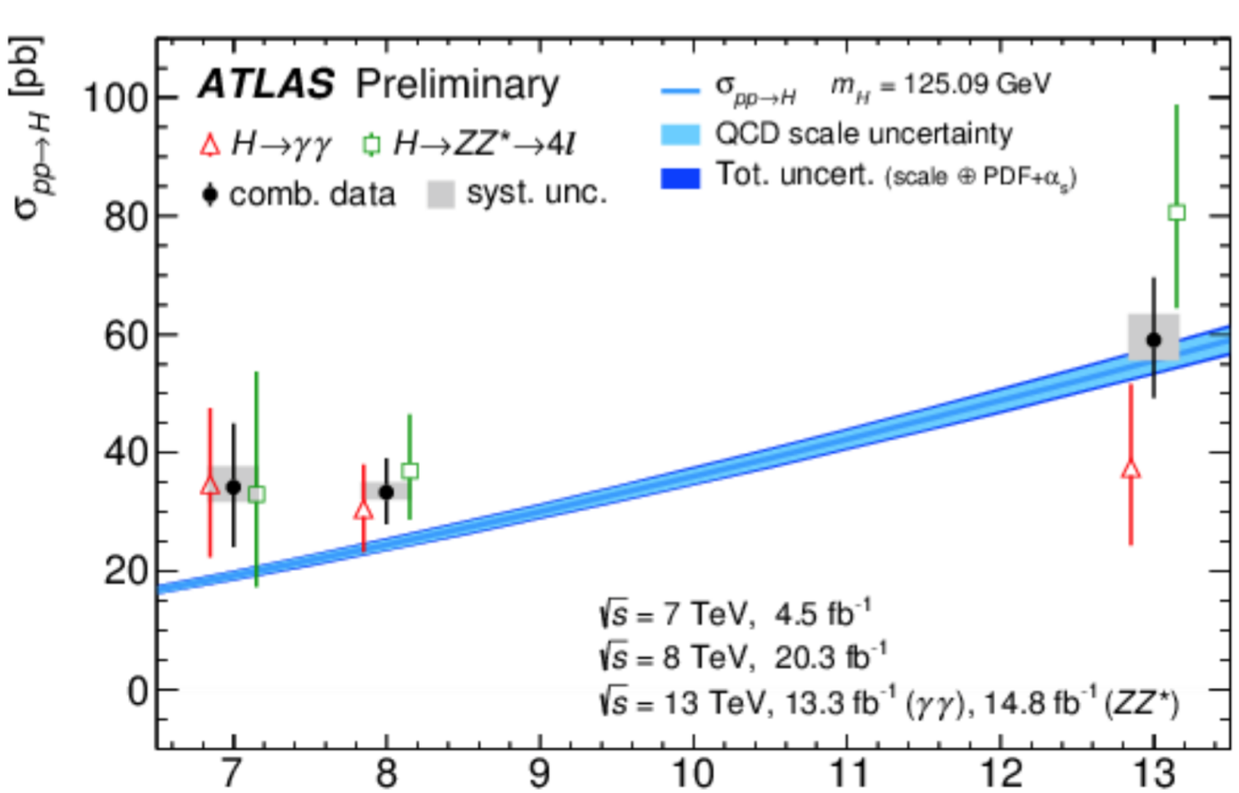
Combination of H→γγ & H→ZZ*

- Combine H→γγ and H→ZZ*→4l inclusive samples, with no categorization
- Higgs production is observed with 10σ significance (8.6σ expected) with 13 TeV data in agreement with SM expectations

	Measurement at 13 TeV	SM prediction at 13 TeV
σ (pb)	$59.0^{+9.7}_{-9.2}(\text{stat})^{+4.4}_{-3.5}(\text{syst})$	$55.5^{+2.4}_{-3.4}$
μ	$1.13^{+0.18}_{-0.17}$	1





Comparable precision to Run 1

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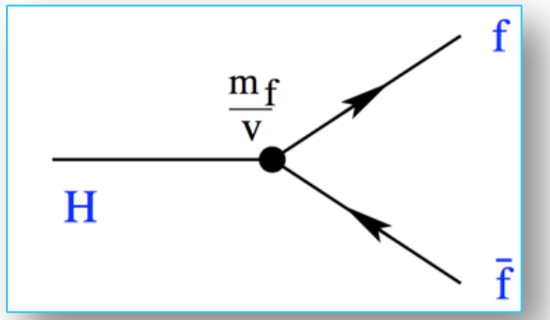
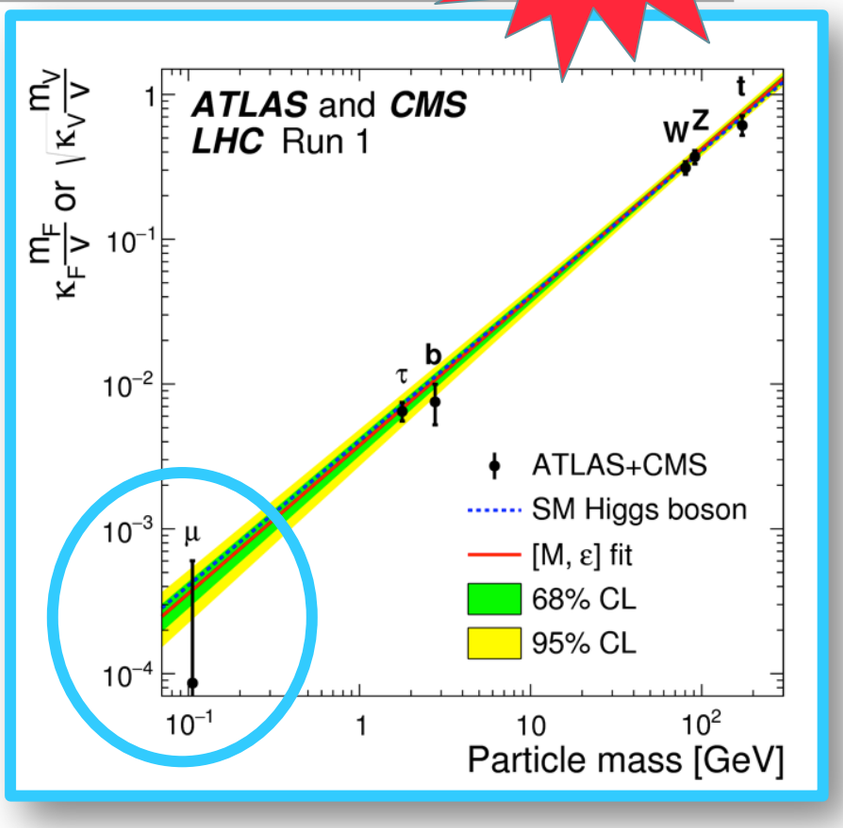
H→μμ decays

new

Motivation :

- The only sensitive channel to measure Higgs couplings to second generation fermions





Characteristics of the channel:

- Clean experimental signature, small BR ~2.18 x 10^{-4}
- Dominant background Drell Yan Z/γ*→ μμ

Analysis strategy:

- Event classification in orthogonal categories for ggF and VBF production
  - Distinguish VBF characteristics by using discriminating variables in a BDT and the score is split into tight and loose categories
  - Different ggF categories based on η_μ, $P_T^{\mu\mu}$ to account for different mass resolutions
- Fit dimuon spectra (very good signal resolution, smooth $m_{\mu\mu}$ around m_H)
  - Simultaneous fit to the observed $m_{\mu\mu}$ in all categories (110 GeV<$m_{\mu\mu}$<160 GeV) to extract signal strength and determine background normalization and shapes

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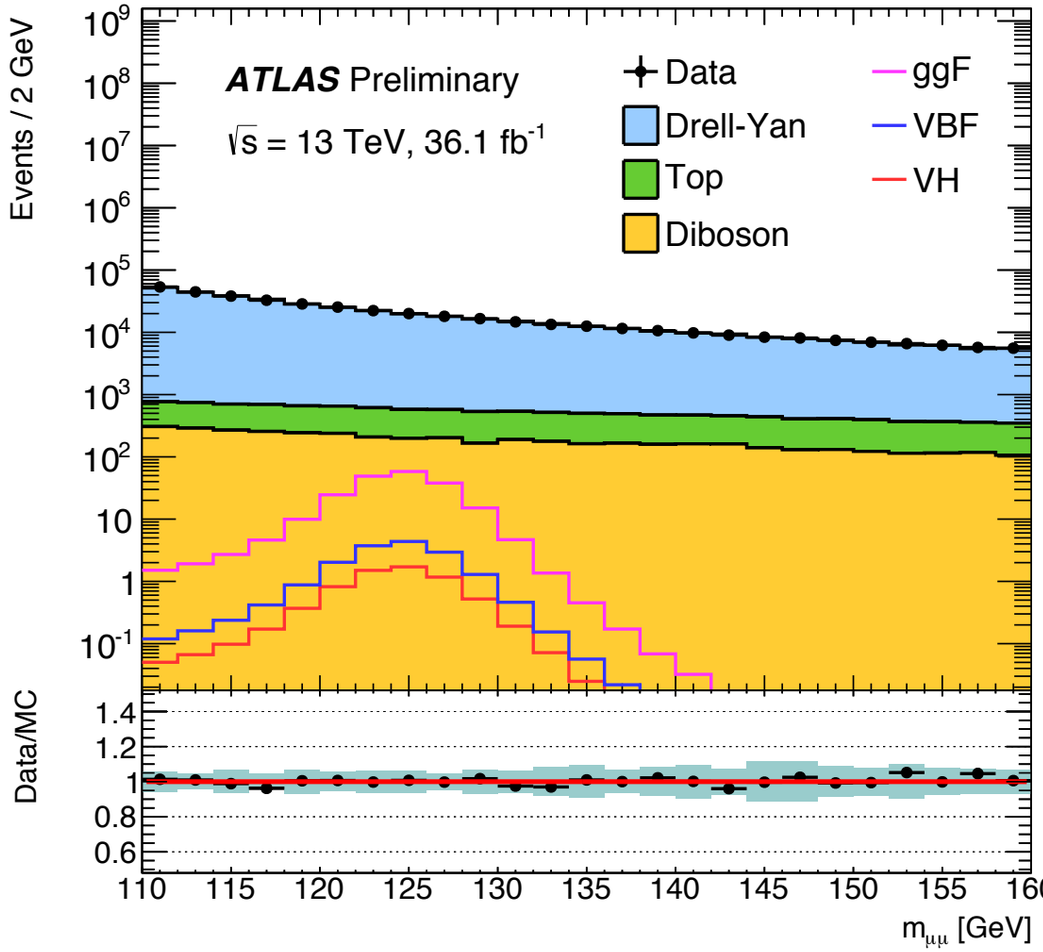
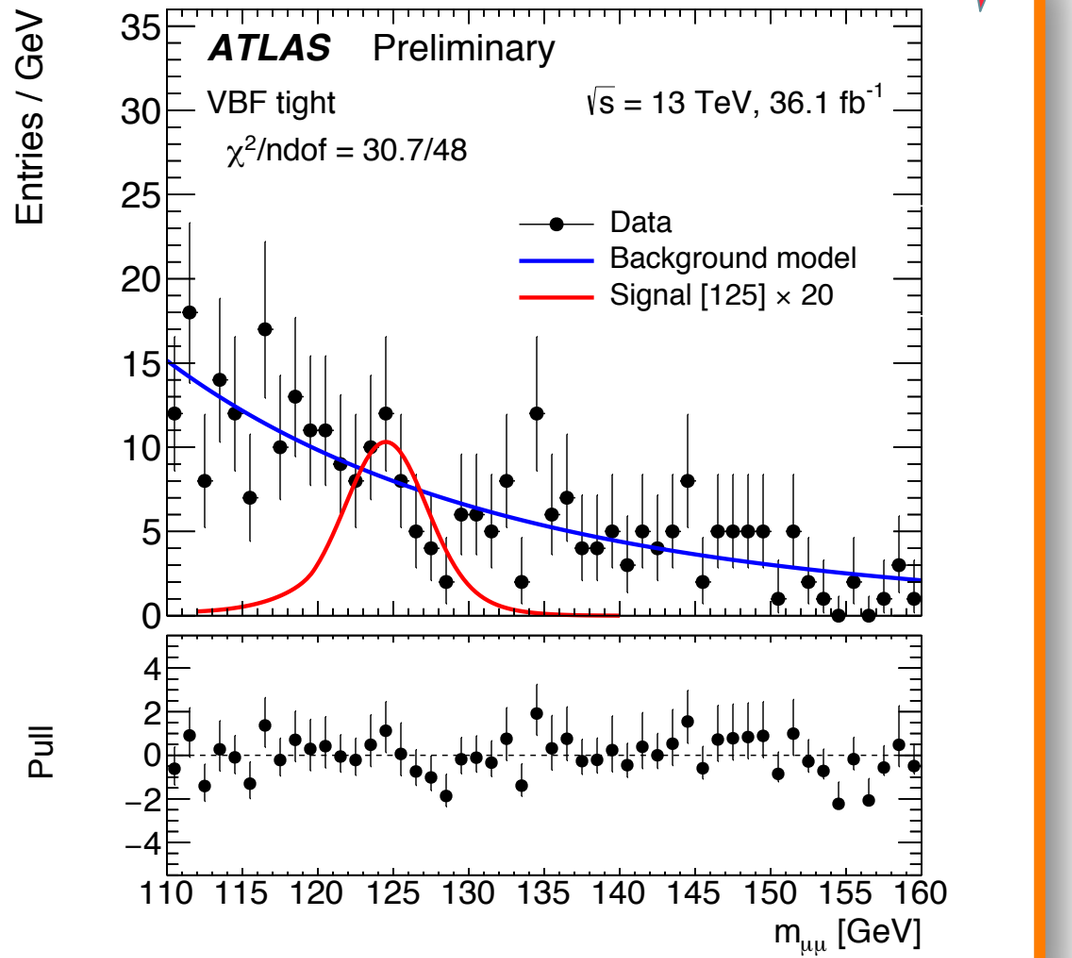
H→ μμ decays

new





Inclusive preselection, background MC used for BDT training and spurious signal uncertainty

Data set	Upper Limit @95 C L Observed (expected)		Signal Strength μ_s
Run2 (13 TeV)	3.0	(3.1)	-0.07 ± 1.5
Run1+Run2 (7+8+13 TeV)	2.7	(2.8)	-0.13 ± 1.4

Summary

- Precision measurements of Higgs properties are key to testing the Standard Model
- Results with Run 2 data at 13 TeV are shown and more results with 36 fb^{-1} expected soon
- All results are compatible with the SM expectations
- Run2 uncertainties are already becoming smaller or comparable to Run1
- Acknowledgements: Florencia Canelli, Susumu Oda, Rosy Nikolaidou

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Run 1 coupling results

- Scale factors κ_j are introduced to quantify deviations of couplings from the SM.
- One benchmark model uses two scale factors of κ_V for vector bosons and κ_F for fermions.
- SM corresponds to $\kappa_V=1$ and $\kappa_F=1$
- Result are consistent with SM expectations all measured processes in agreement with SM within 2σ