Discovery of the new Higgs-like particle

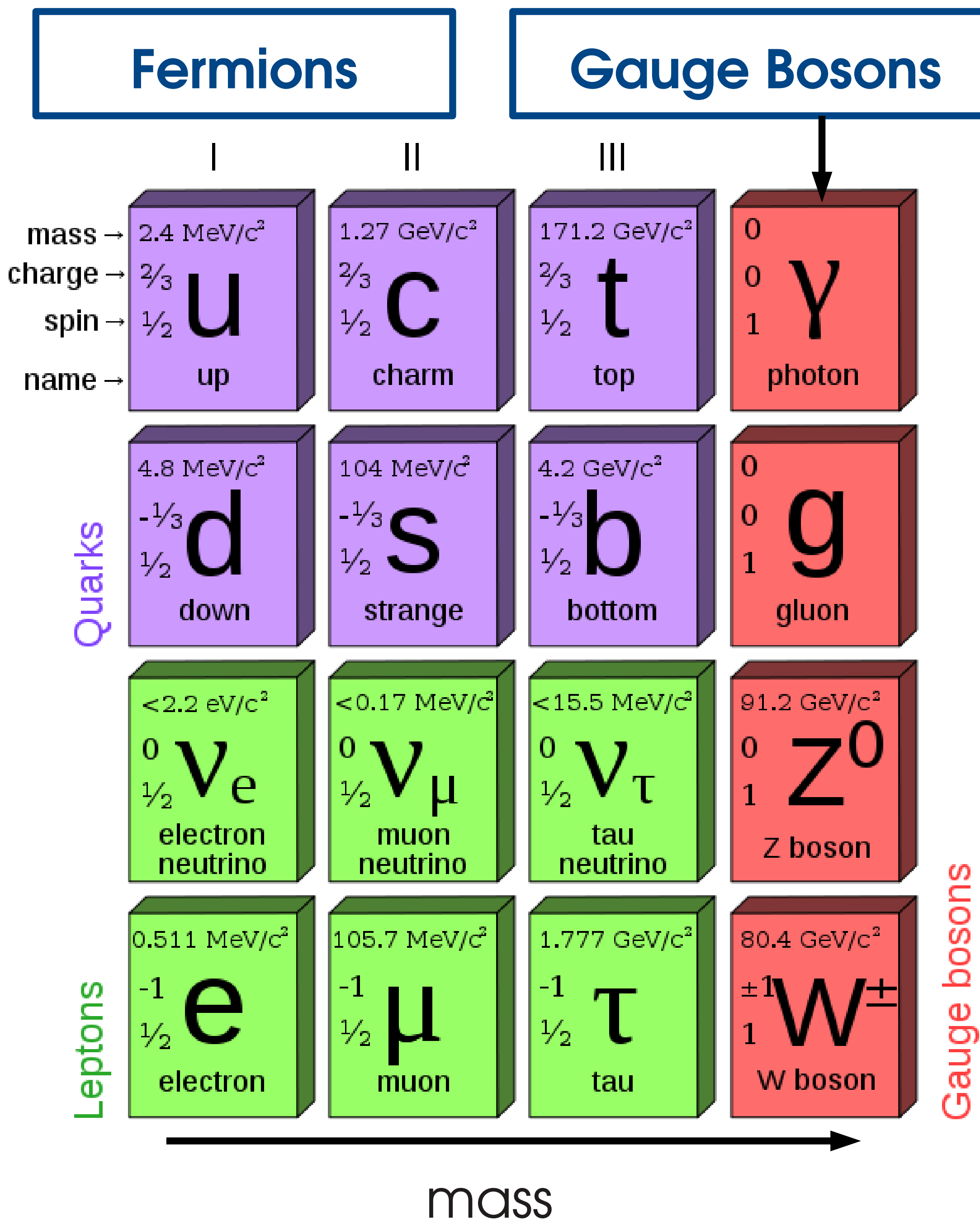
Nicolas Berger (LAPP)

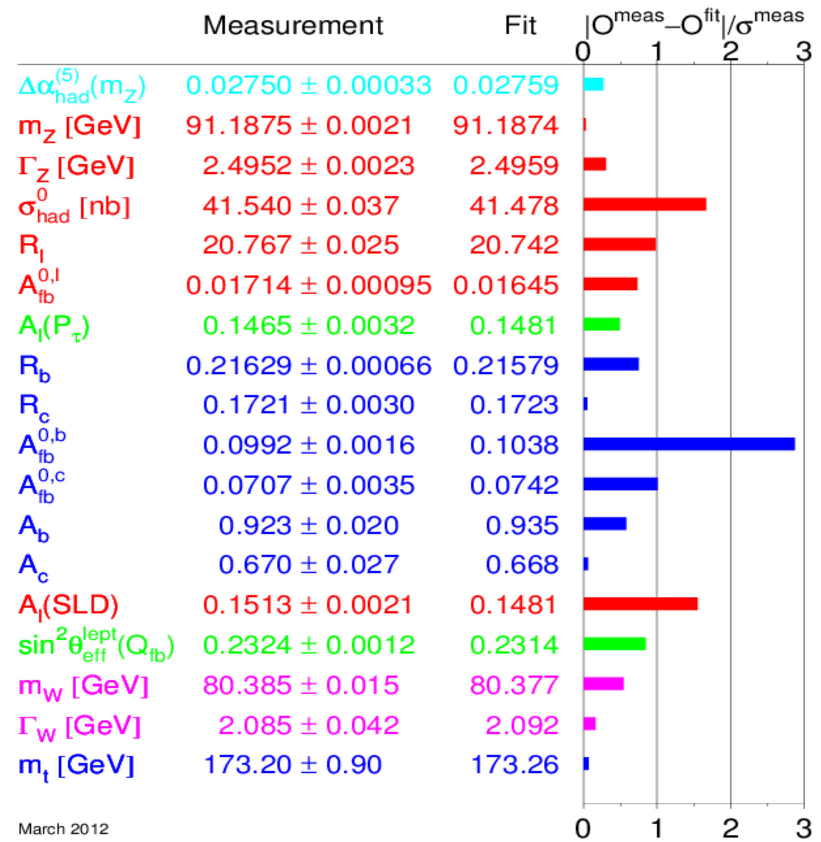
Outline

- The standard model and the Higgs boson
- The X(126) particle and its properties

The Higgs boson

The Standard Model





	Measurement	Fit	$\lvert O^{meas}-O^{fit}\rvert/\sigma^{meas}$
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02750 ± 0.00033	0.02759	
m_Z [GeV]	91.1875 ± 0.0021	91.1874	
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959	
σ^0_{had} [nb]	41.540 ± 0.037	41.478	
R_l	20.767 ± 0.025	20.742	
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01645	
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481	
R_b	0.21629 ± 0.00066	0.21579	
R_c	0.1721 ± 0.0030	0.1723	
$A^{0,b}_{fb}$	0.0992 ± 0.0016	0.1038	
$A^{0,c}_{fb}$	0.0707 ± 0.0035	0.0742	
A_b	0.923 ± 0.020	0.935	
A_c	0.670 ± 0.027	0.668	
A_l(SLD)	0.1513 ± 0.0021	0.1481	
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314	
m_W [GeV]	80.385 ± 0.015	80.377	
Γ_W [GeV]	2.085 ± 0.042	2.092	
m_t [GeV]	173.20 ± 0.90	173.26	

Excellent agreement with measurements!

Some open questions:

→ **What gives mass to the fermions ?**

→ **What breaks electroweak symmetry (And gives mass to the gauge bosons) ?**

Electroweak symmetry breaking

Classic mechanism for EWSB:

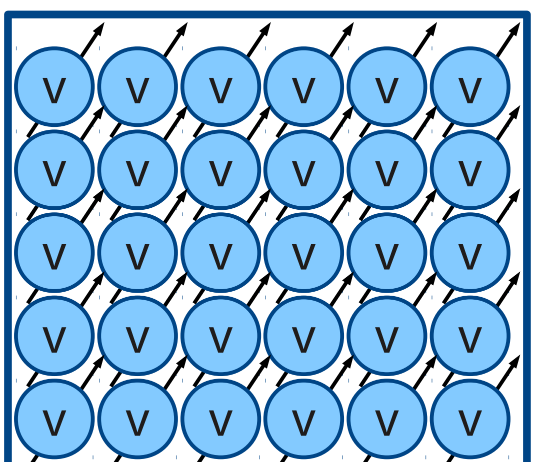
introduce a **new scalar doublet:**

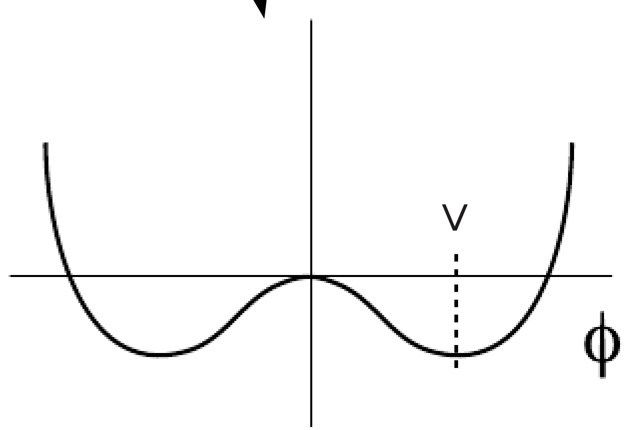
$$\varphi = \begin{pmatrix} \varphi^{p} + i\varphi^{m} \\ \varphi^{0} + i\varphi'^{0} \end{pmatrix}$$

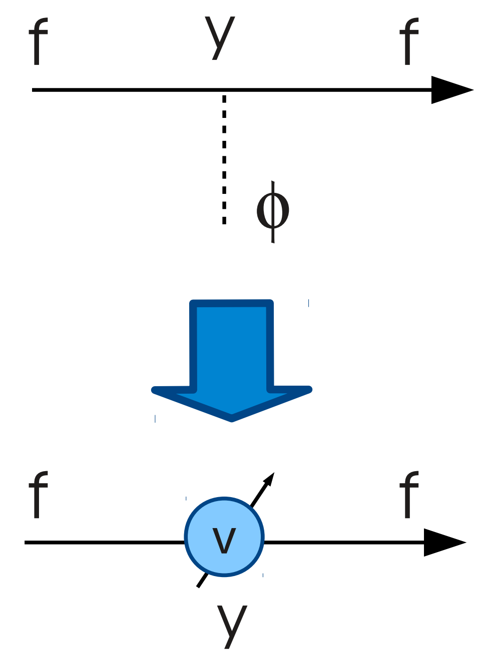
Give it a "Mexican hat" potential

Then the field acquires a VEV:

$$\langle \varphi^{0} \rangle = v = 246\, GeV$$







Fermion interactions with φ give mass terms

m µ y

mass goes like Higgs coupling

Electroweak symmetry breaking

Classic mechanism for EWSB:

introduce a **new scalar doublet:**

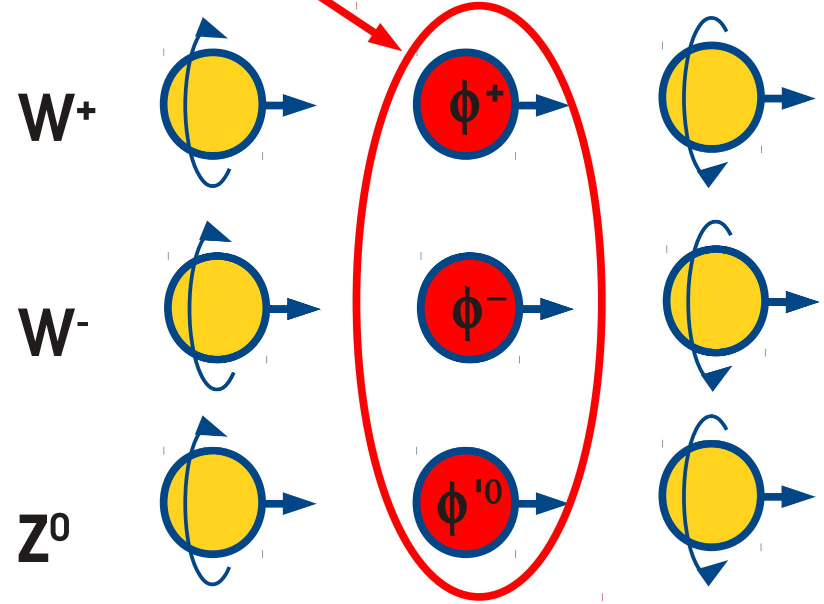
$$\varphi = \begin{pmatrix} \varphi^{+} + i\,\varphi^{-} \\ \varphi^{0} + i\,\varphi'^{0} \end{pmatrix}$$

Give it a "Mexican hat" potential

Then vacuum acquires a VEV:

$$\langle \varphi^{0} \rangle = v = 246\,GeV$$

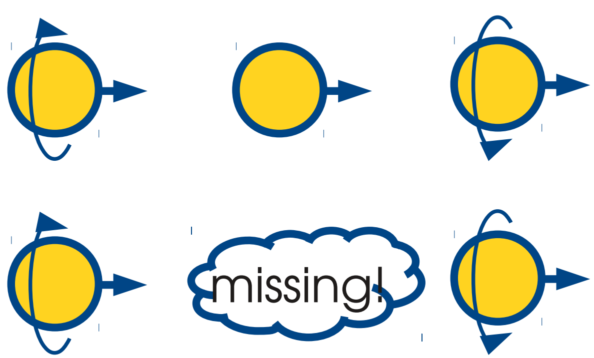
3 fields provide the longitudinal W^+, W^- and Z^0



Remaining field: $H^{0} = \varphi^{0} - v$

Massive vector Boson

Gauge Boson

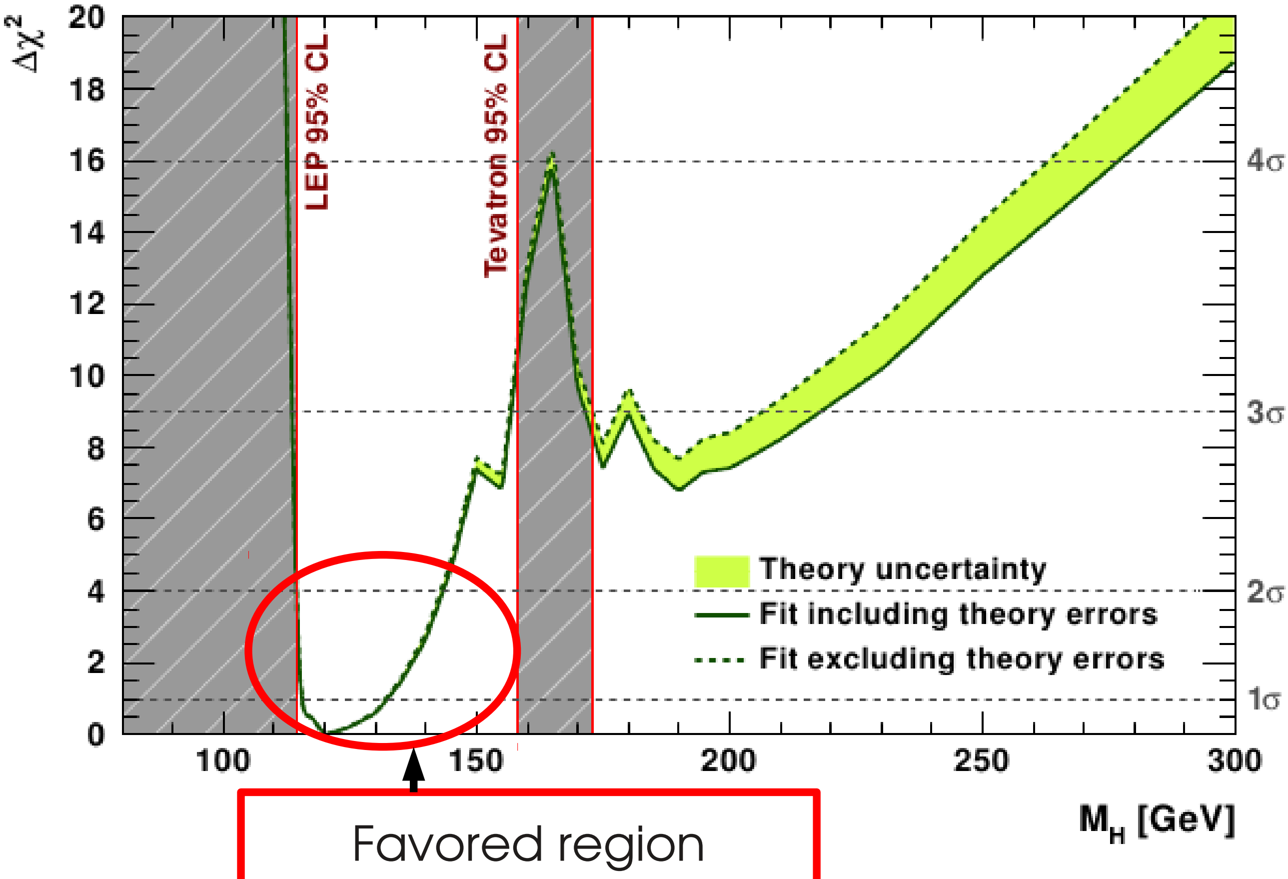


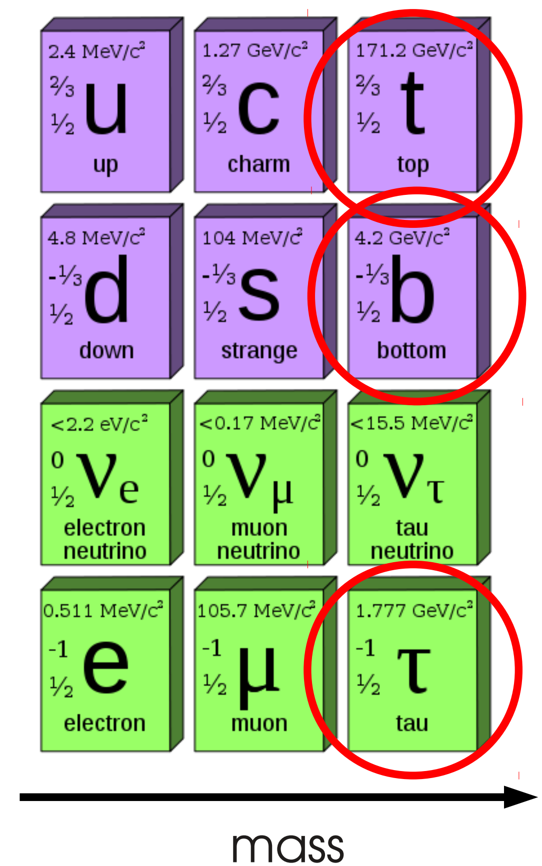
Forbidden by gauge invariance

Higgs Boson Properties

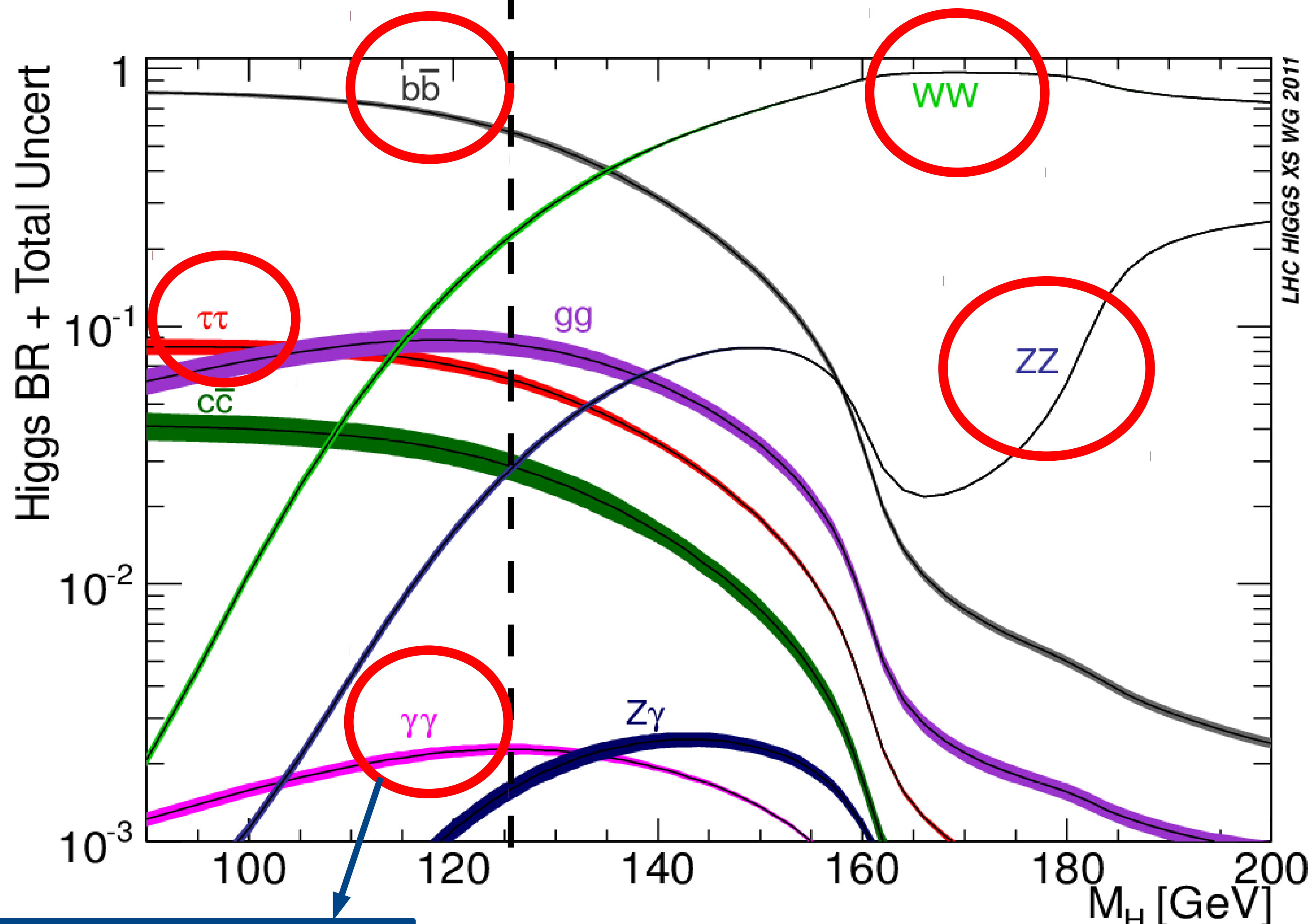
- → Quantum numbers of vacuum: **0^+ scalar boson.**
- → Couplings to fermions go like mass => **mostly couples to 3rd generation**
- → Precision electroweak and m_t, m_W measurements

  + LEP and Tevatron direct searches : **$114 < m_H < \sim 150$ GeV**
- → It should be **narrow** in the favored mass range

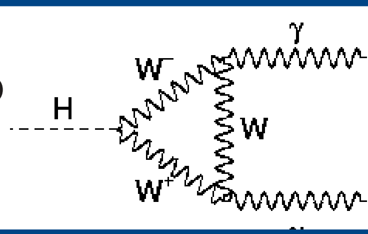




Higgs decays



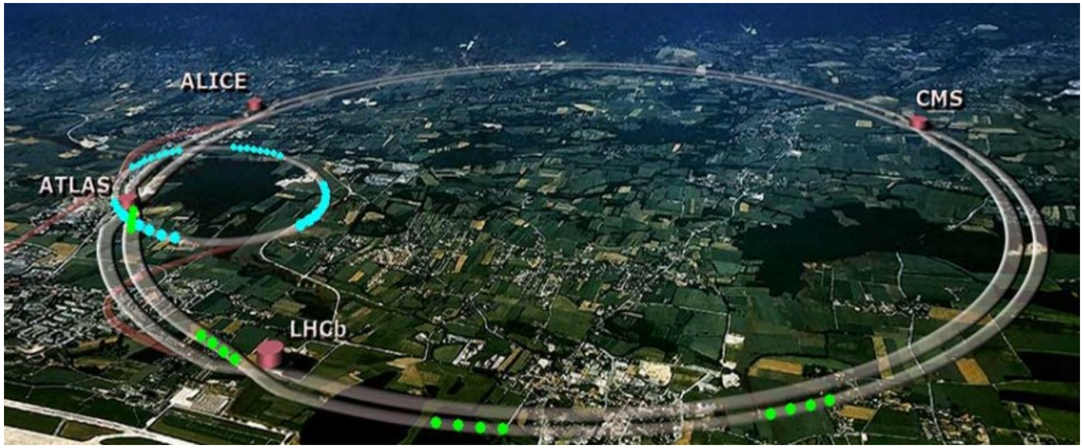
Through loop diagram



Many decay channels
→ good for determining properties!

Searches at LHC

LHC

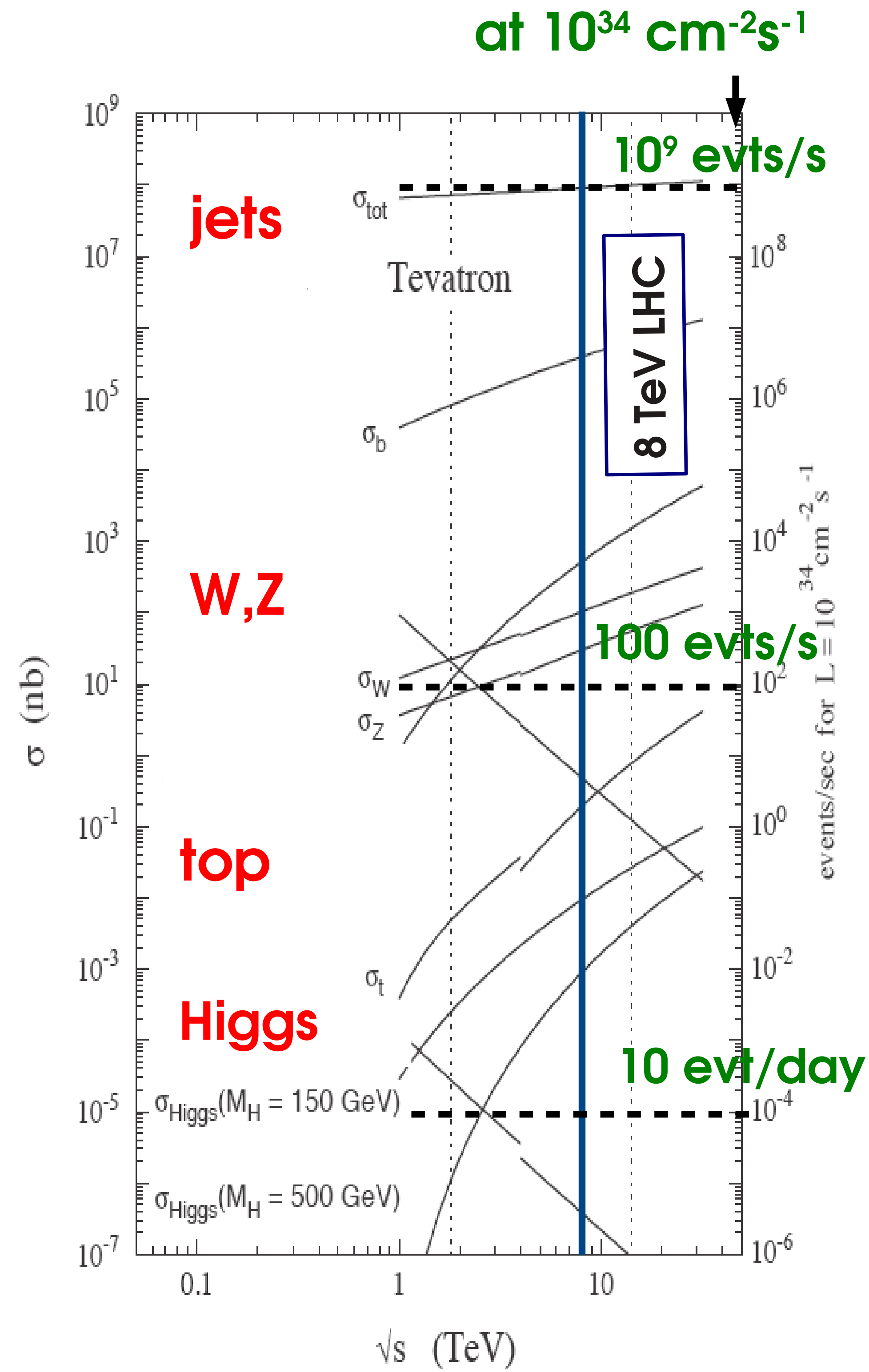


Proton-proton collider with **$\sqrt{s}$ = 8 TeV in 2012**. 4 main experiments, 2 relevant here (**ATLAS** and **CMS**)

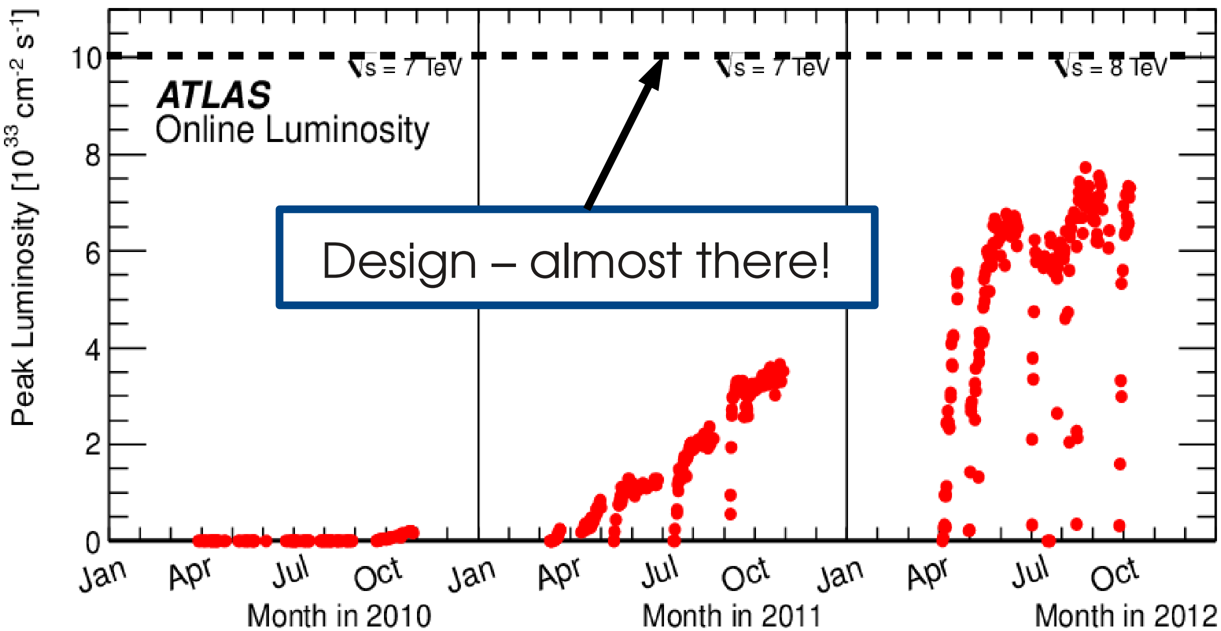
→ Proton made up of light particles: u,d, g
⇒ **small couplings to Higgs.**

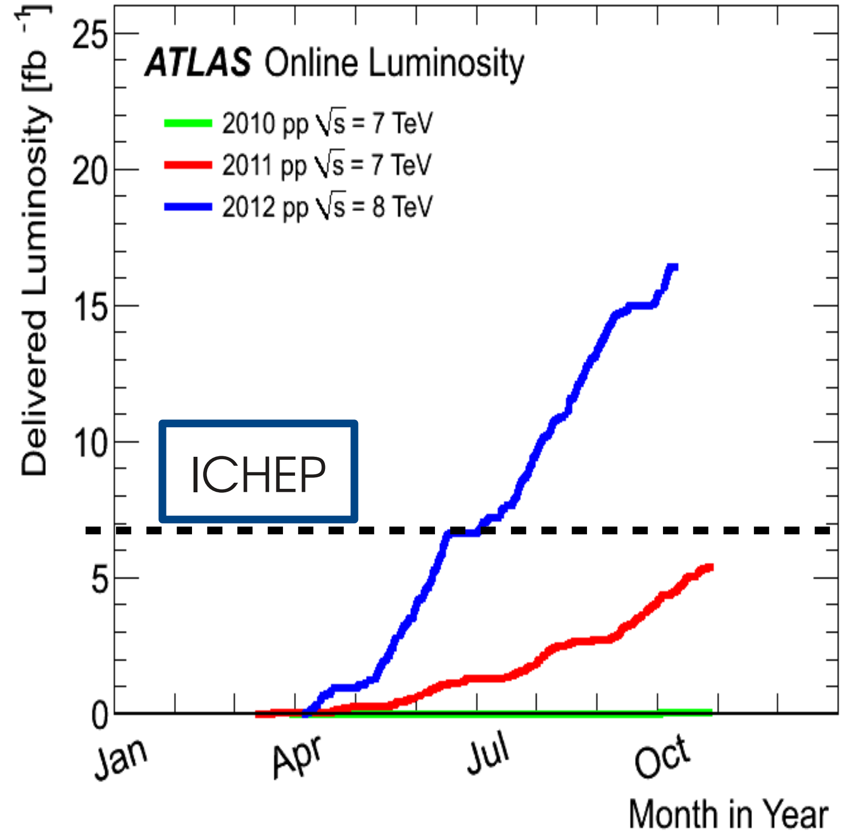
→ **8 TeV >> m_H** : Higgs produced in low-energy collisions => mostly gluons

⇒ **Need high lumi!**



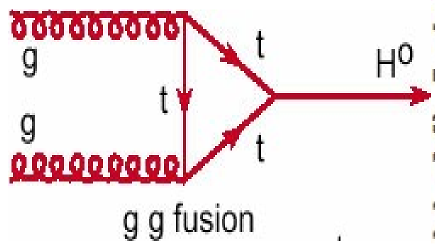
LHC Luminosity



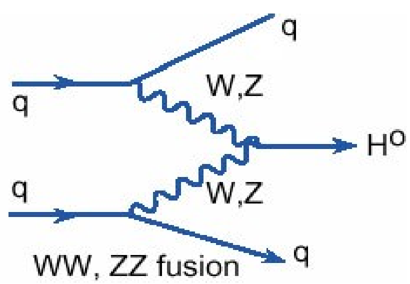


Higgs Production at the LHC

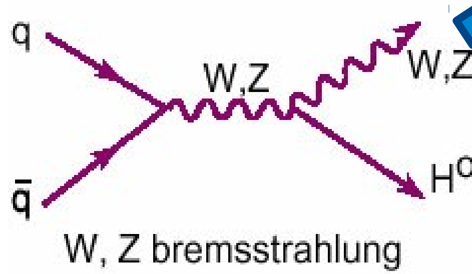
Gluon fusion: loop-suppressed, but large due to gg initial state



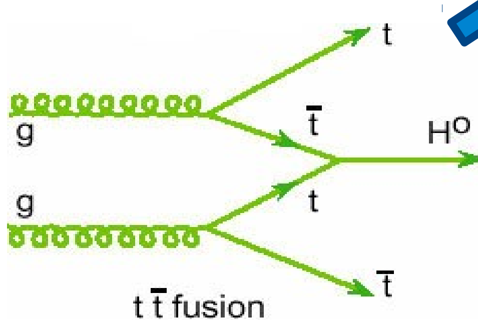
Vector boson Fusion: low backgrounds (tagging jets)

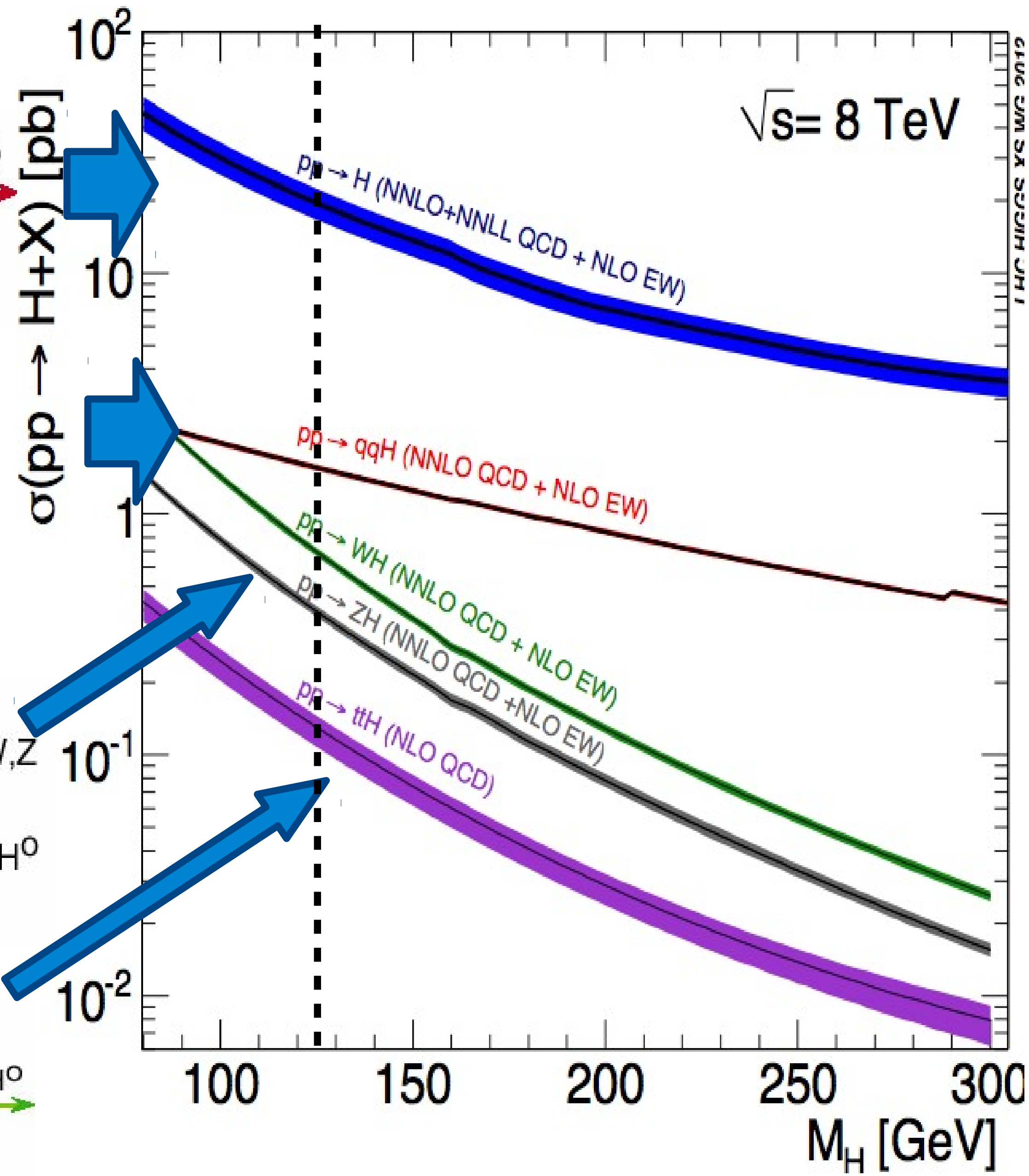


Radiation from W's and Z's. Low bkg, small rate



Radiated from top quarks: **Small rate**



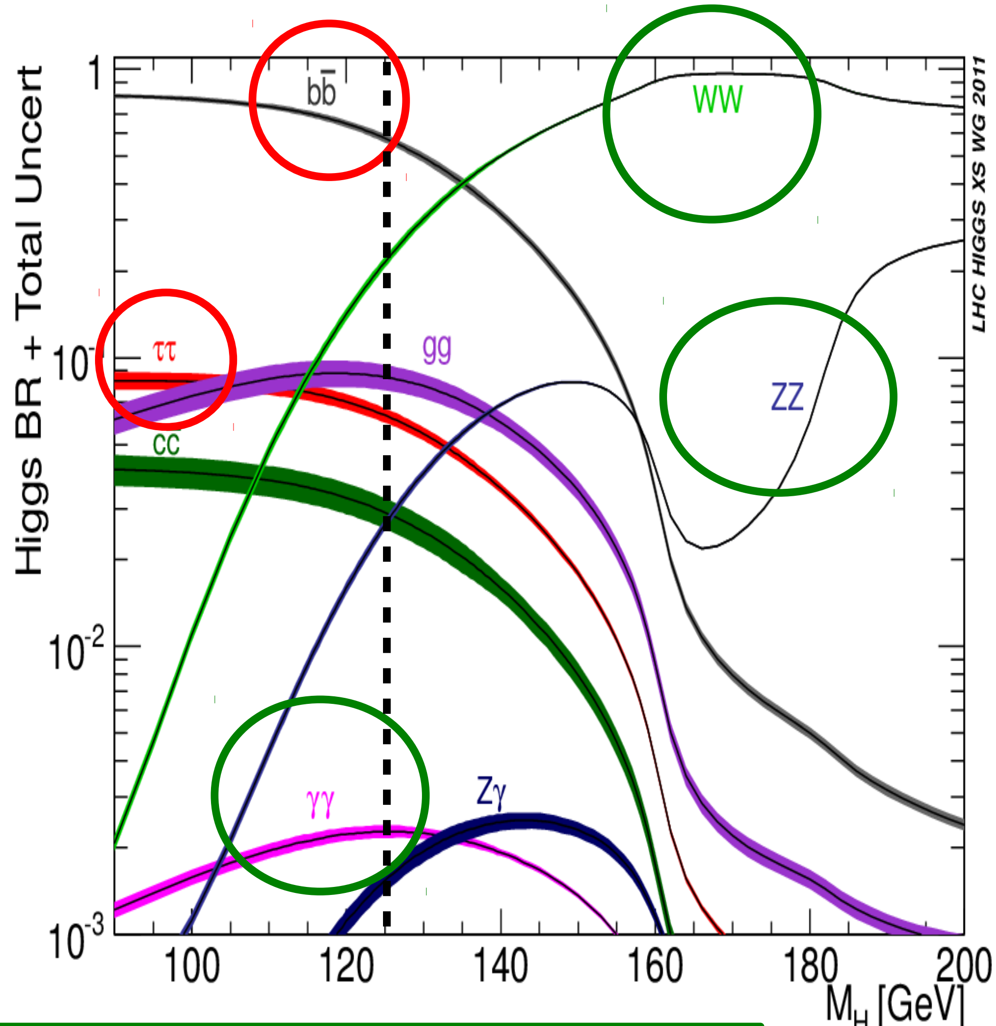


Search strategy

WW: Look for **WW*** (below threshold)
Mainly with **WW*→lνlν** to reduce bkg
Neutrinos => **cannot reconstruct mass**

bb:
High QCD bkgs
Look for **WH or ZH** production with boosted Higgs

ττ:
High QCD bkgs,
concentrate on **VBF** production



ZZ : Look for **ZZ*** (below threshold)
Mainly in
ZZ→4 leptons

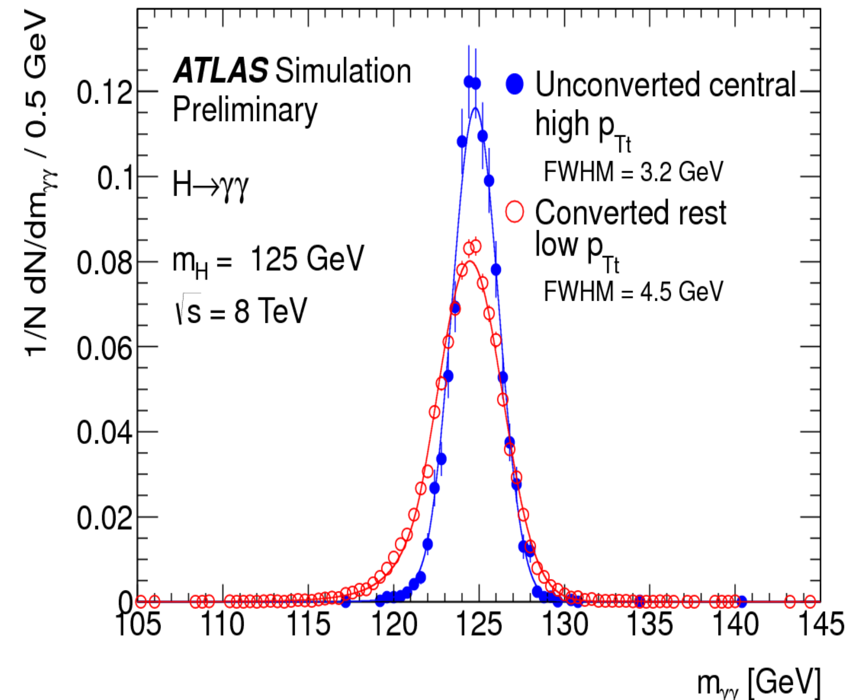
Excellent mass resolution,
low event yield
low backgrounds

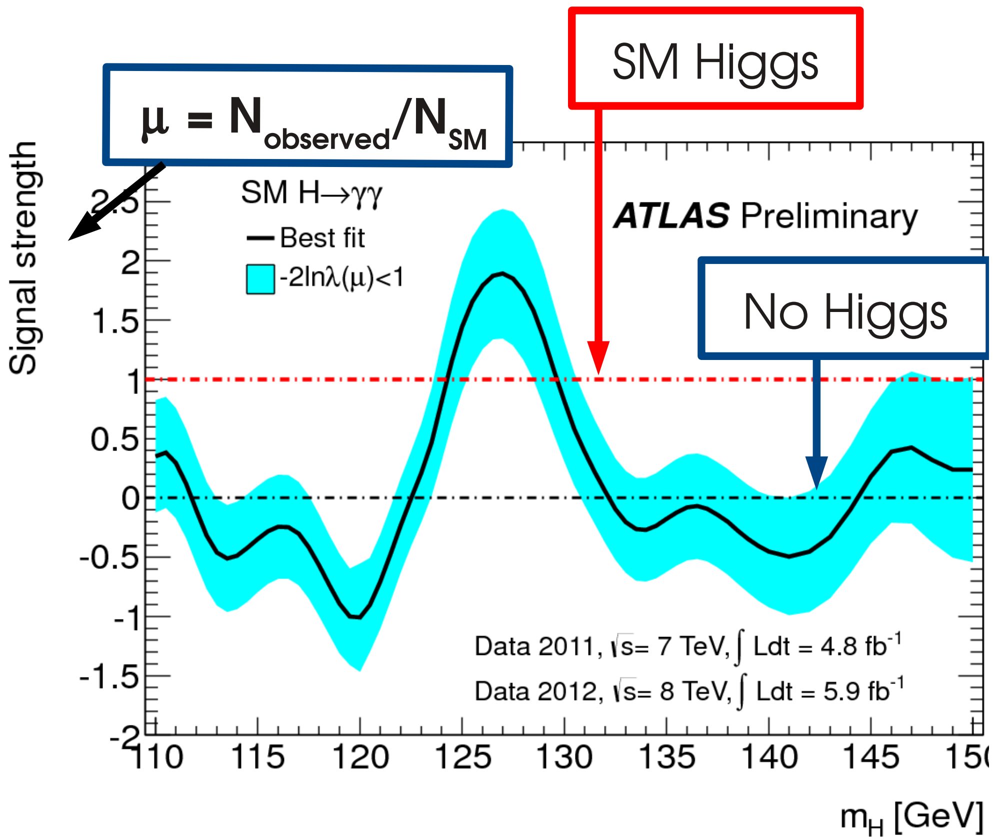
γγ: Small BF => small event yield,
High SM γγ, γjet backgrounds, but smooth shape
Excellent mass resolution

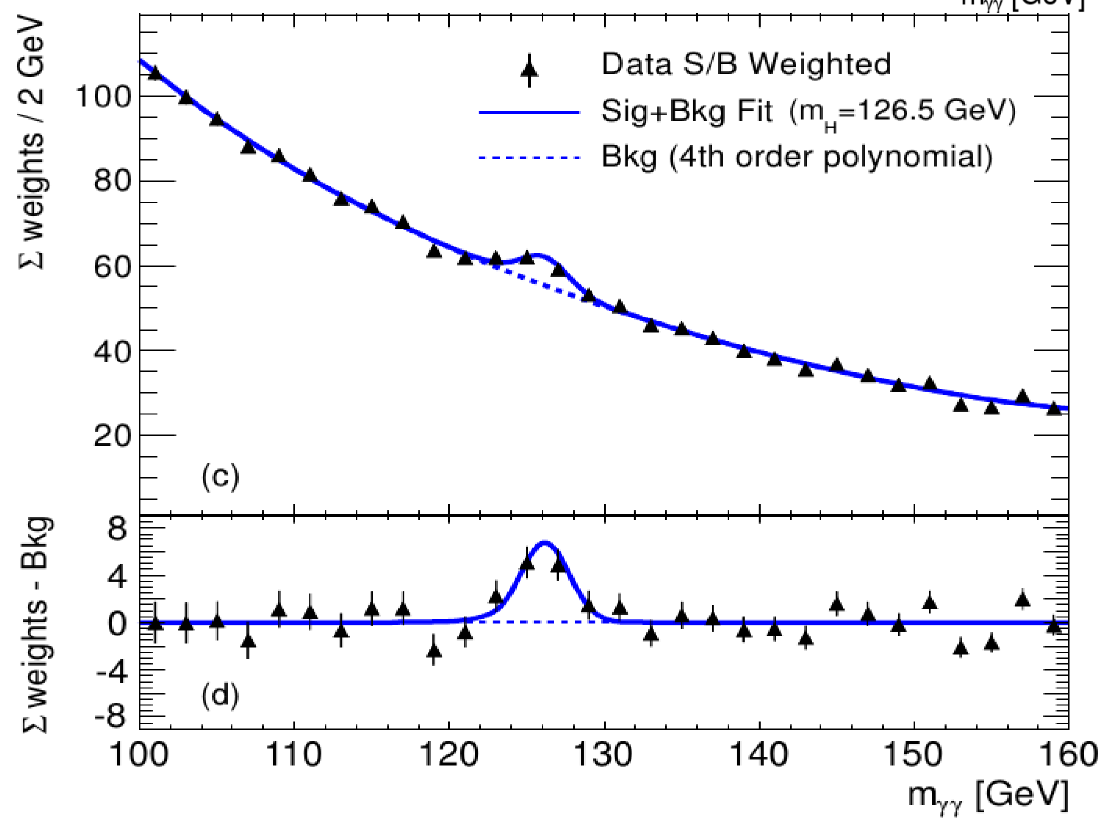
Need to combine all the channels!

H→γγ

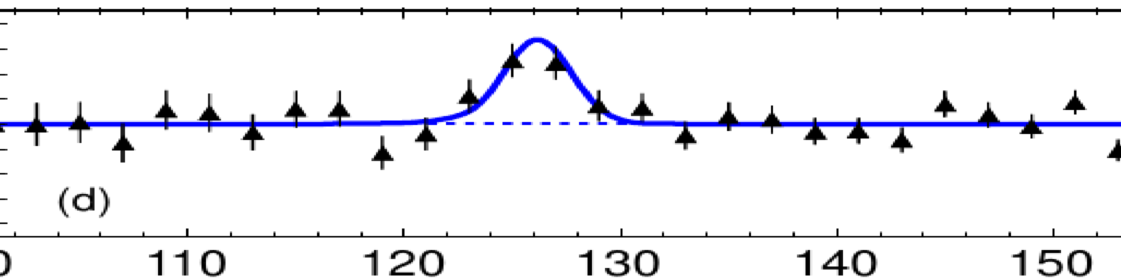
- → **Small, narrow** signal over large, smooth bkg
  - **Calorimeter performance is crucial**
- → Data split to isolate "good" regions
  - **high-pT photon pairs,**
  - **VBF production with forward jets,**
- → Background mostly γγ, some γ+jet
- → See excess at ~**126 GeV**



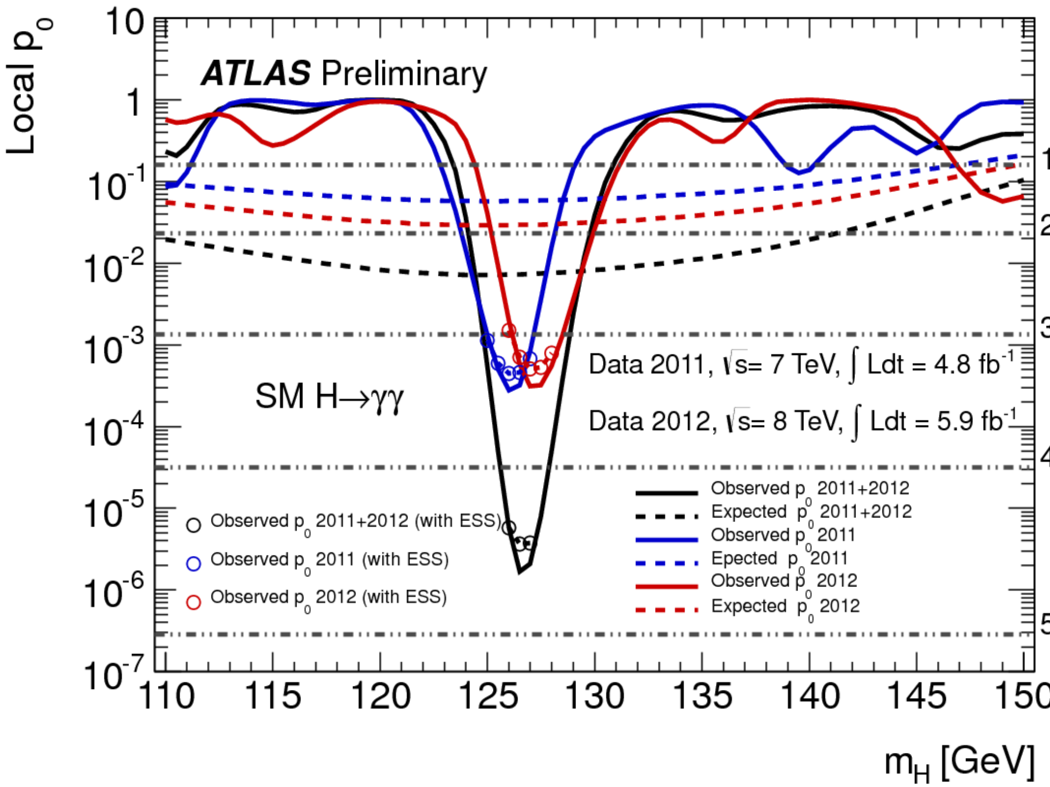


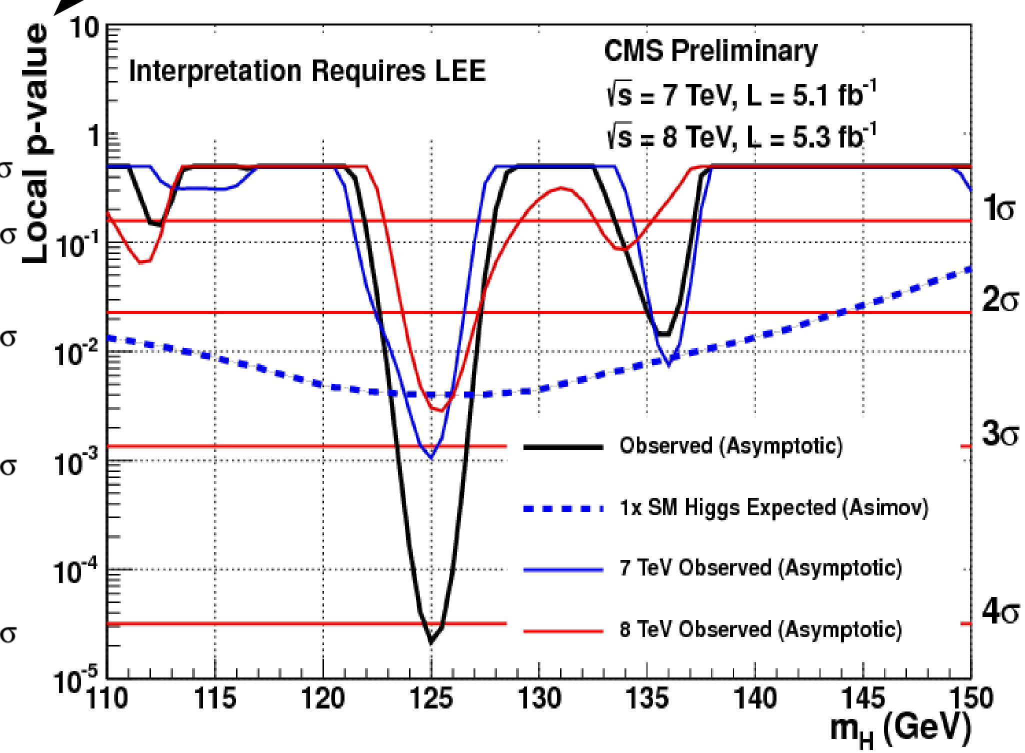


H→γγ results



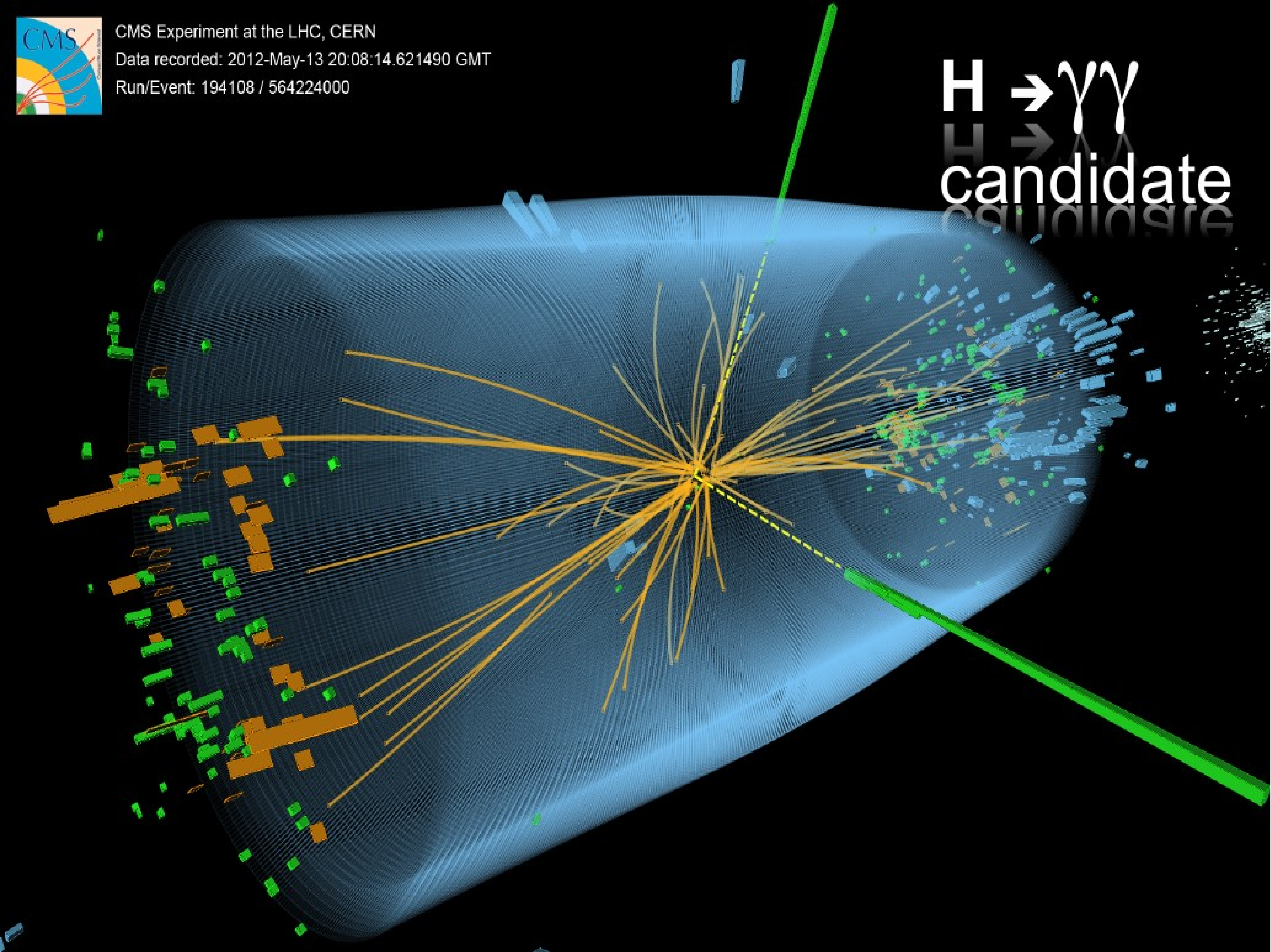
p_0/p-value : probability that deviations are due to background fluctuations





ATLAS : **4.5σ** at **126.5 GeV**

CMS : **4.1σ** at **125 GeV**


CMS Experiment at the LHC, CERN
Data recorded: 2012-May-13 20:08:14.621490 GMT
Run/Event: 194108 / 564224000
H → γγ
candidate

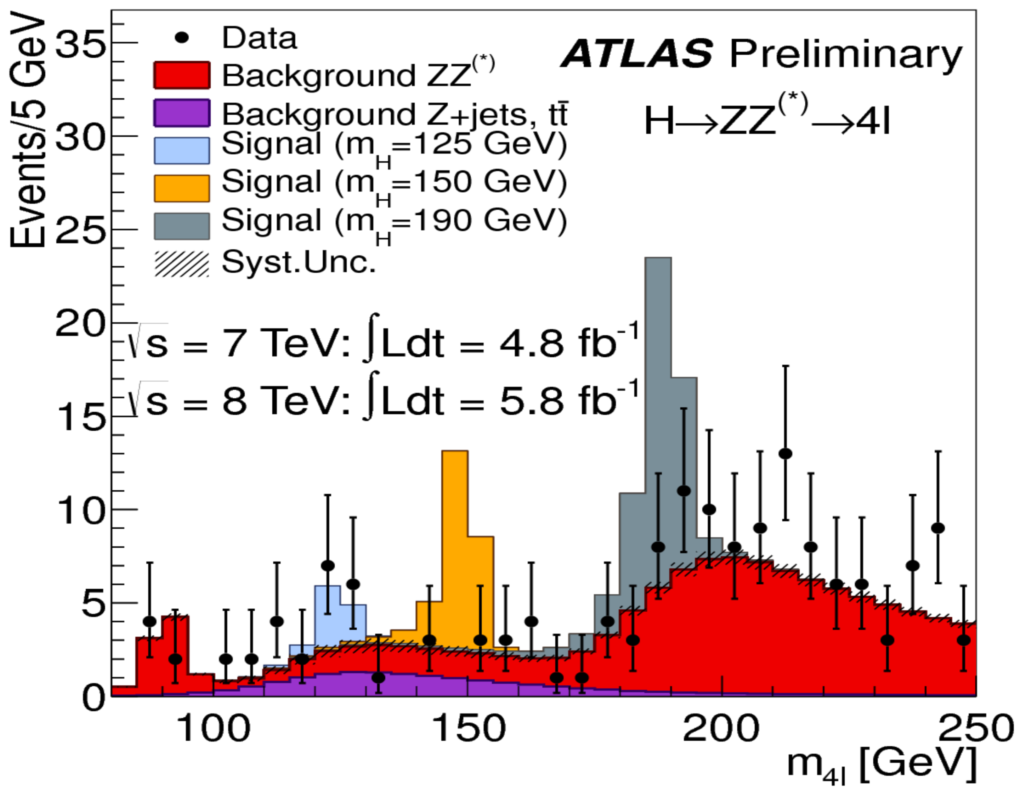
H→ZZ*→4l

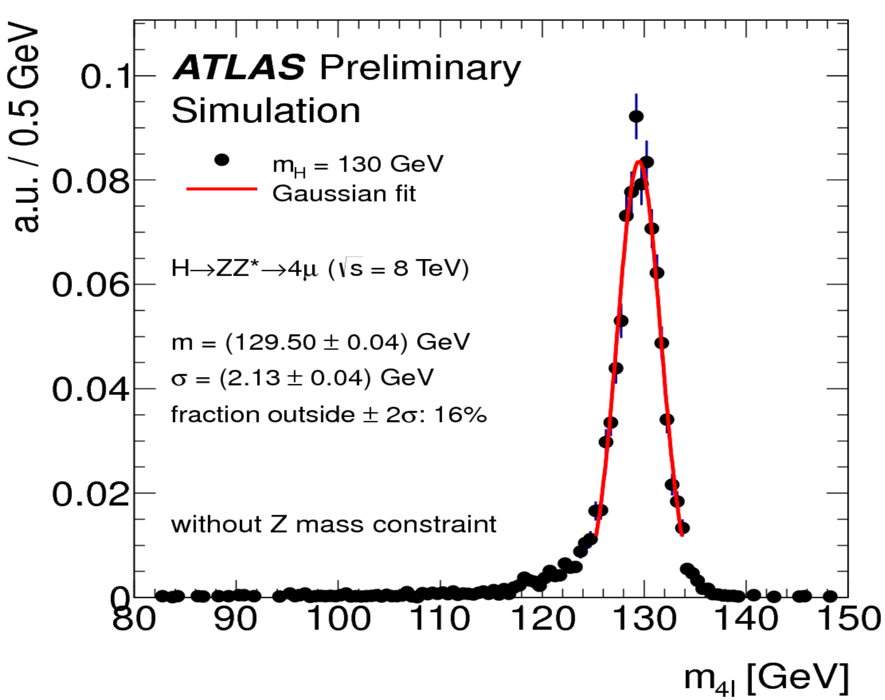
→ Look at **ZZ→4e, Z→4μ** and **ZZ→2e2μ** separately

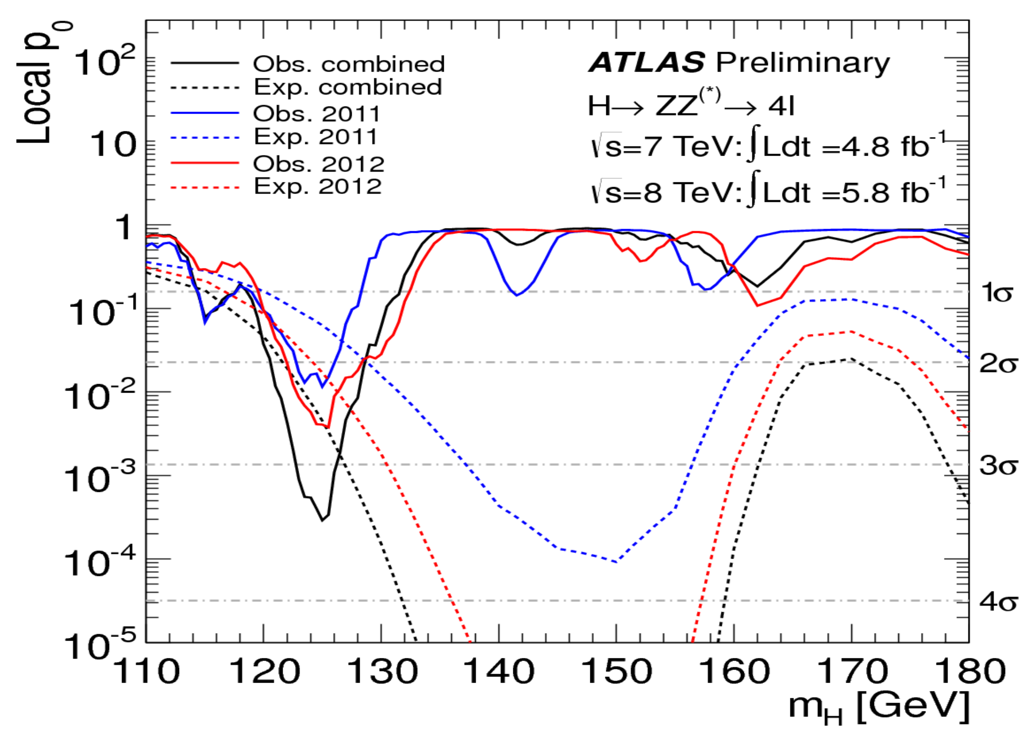
→ Background mostly real ZZ

→ ATLAS : **3.6σ** at **125 GeV**

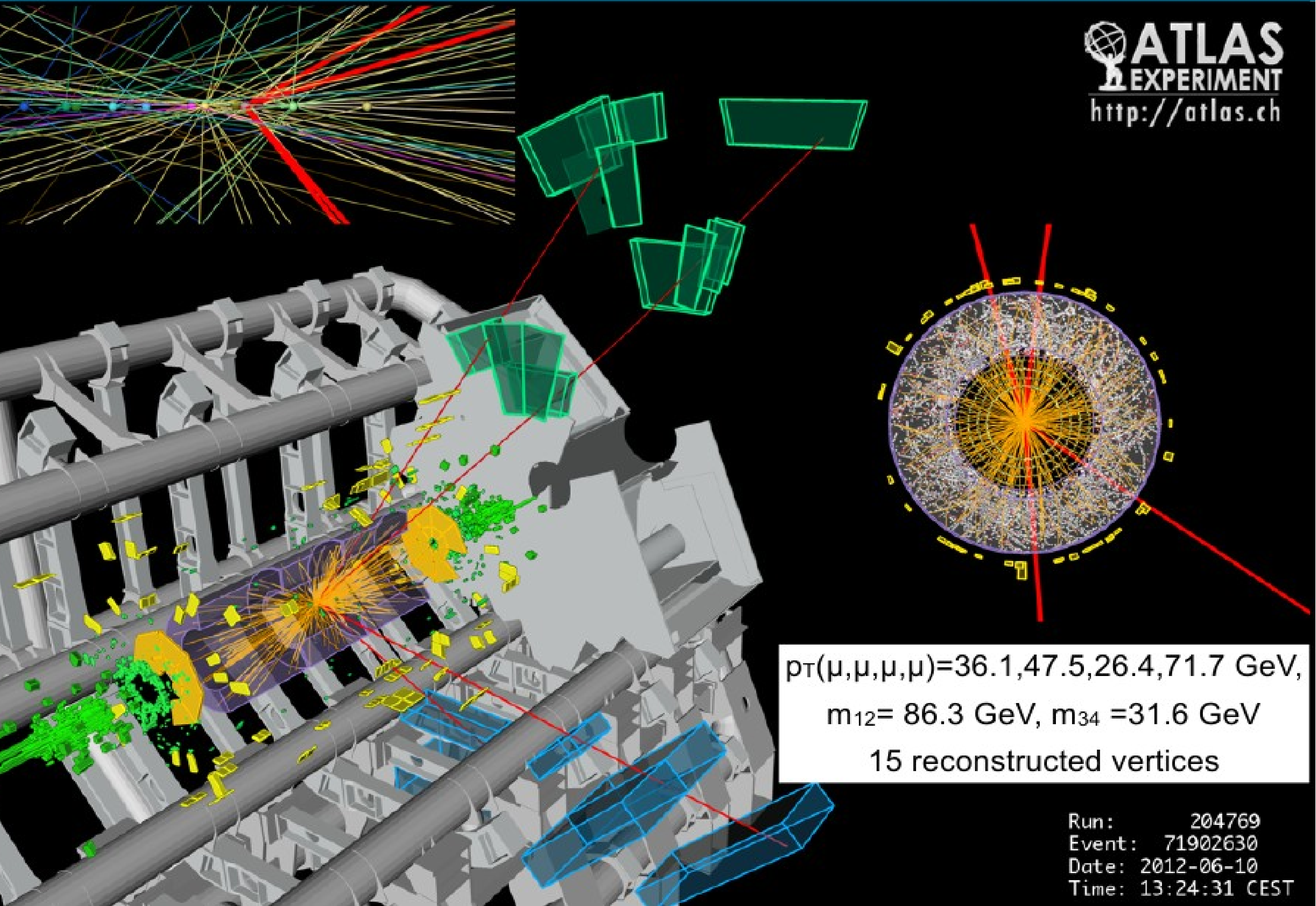
→ CMS : **3.2σ** at **125.6 GeV**







μμμμ candidate with m_{4l} = 125.1 GeV



H→WW

2 ν's in final state => poor m_H resolution

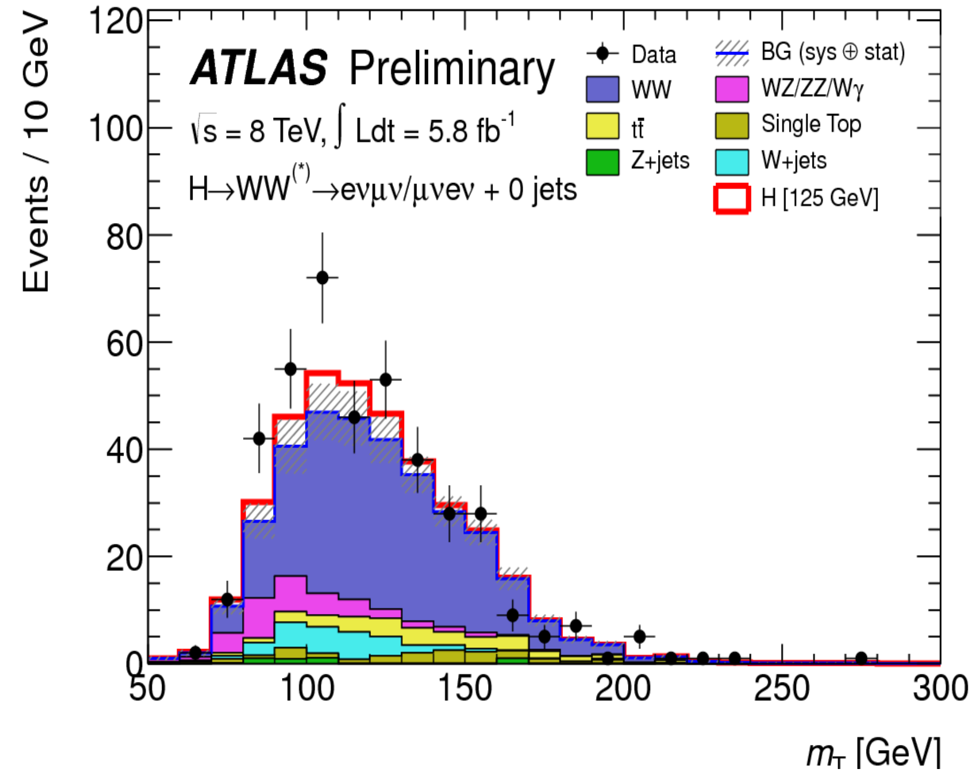
→ ATLAS uses **m_T**:

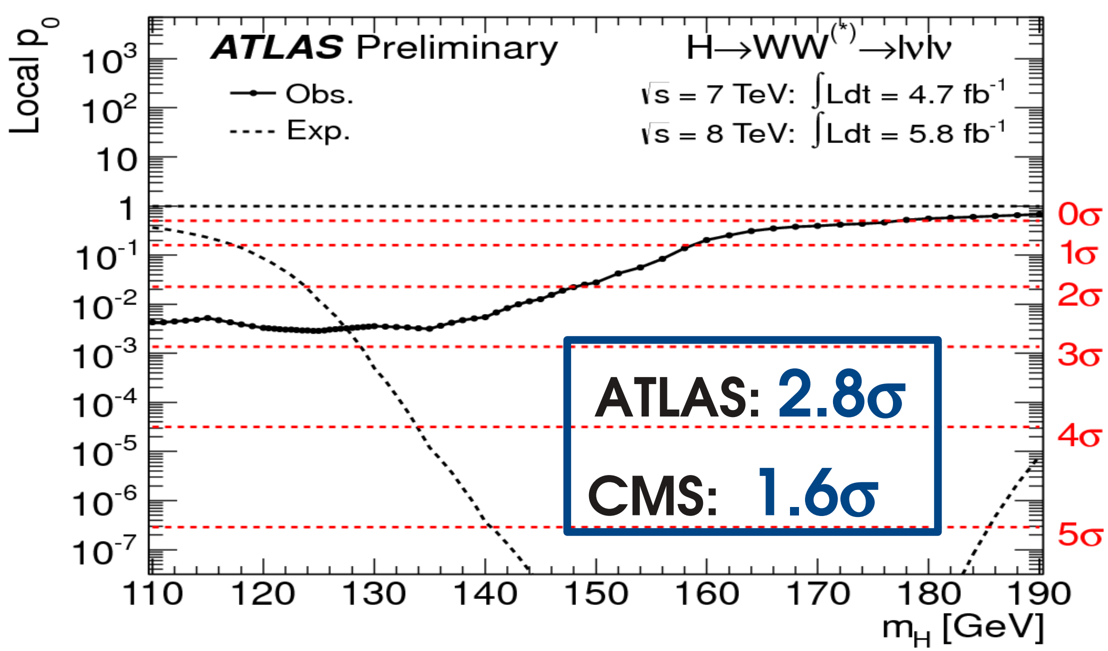
$$m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - |\mathbf{p}_T^{\ell\ell} + \mathbf{E}_T^{\text{miss}}|^2}$$

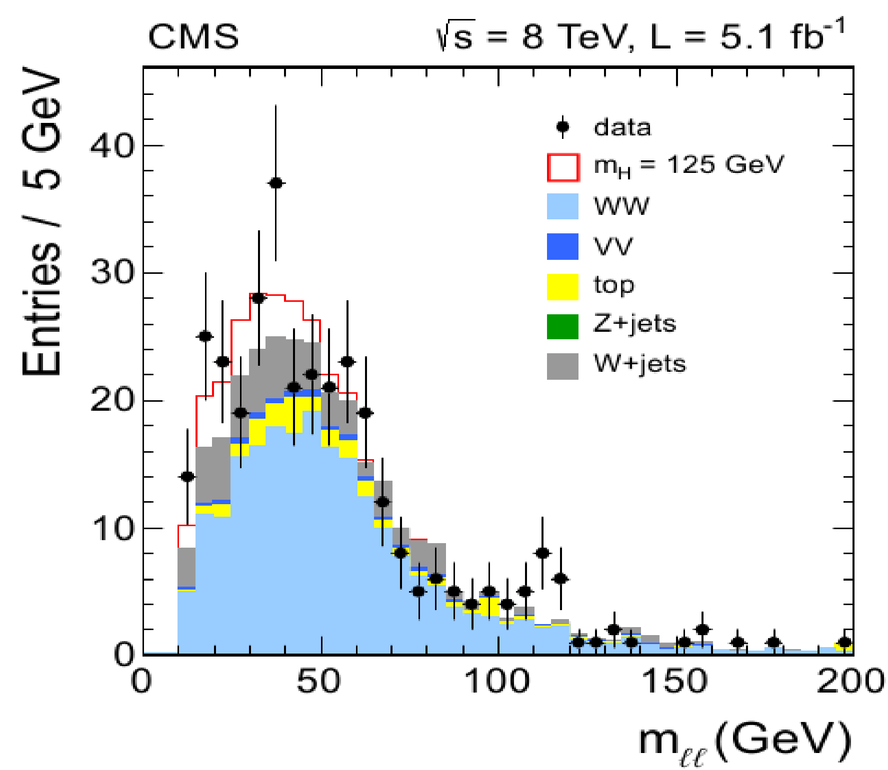
→ CMS uses **m_{ll}** or a BDT.

→ Separate categories for **0,1,2 jets**, and **ee, eμ, μμ**. Best is **0-jet eμ.**

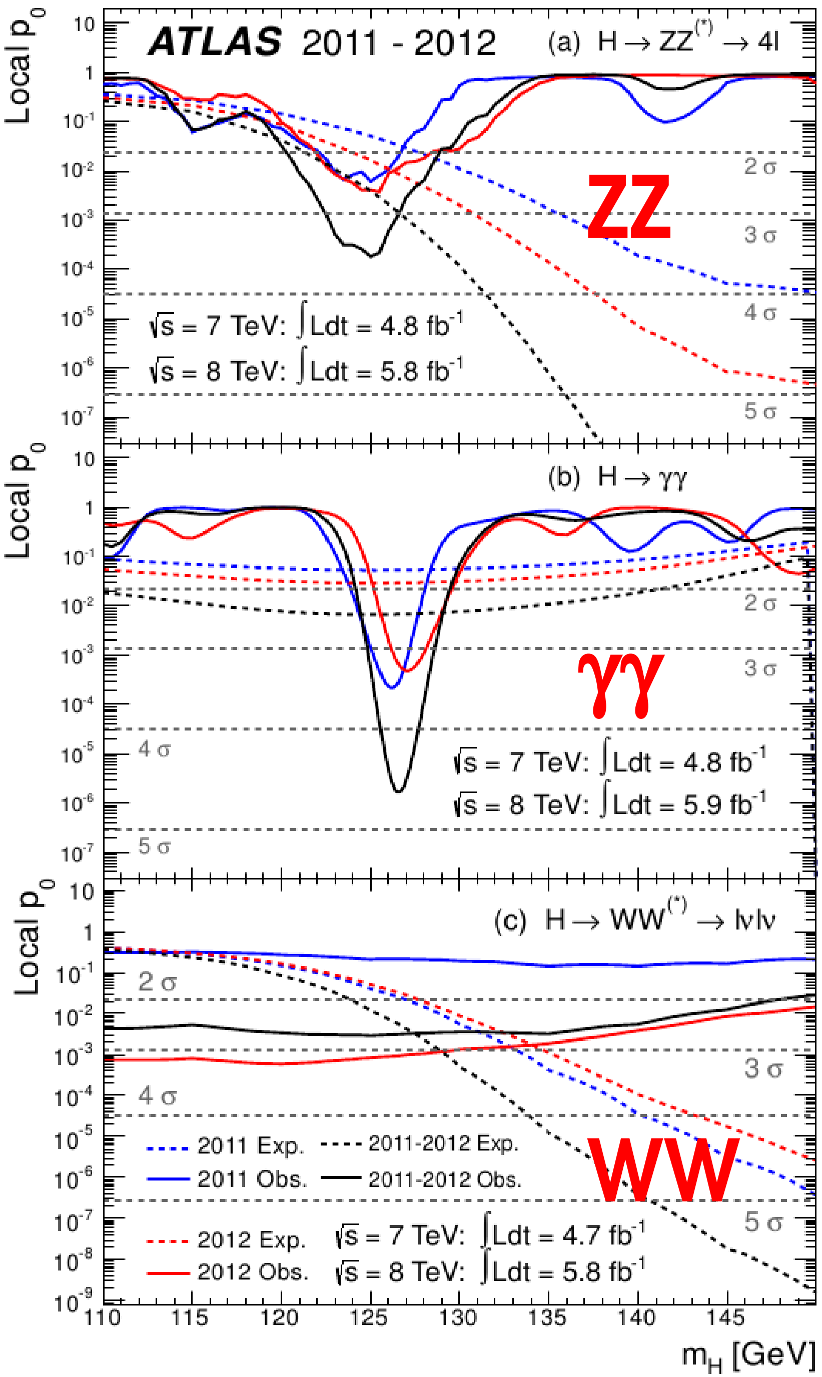
→ Main bkgs: **SM WW, W+jets, top**. determined from sidebands, MC

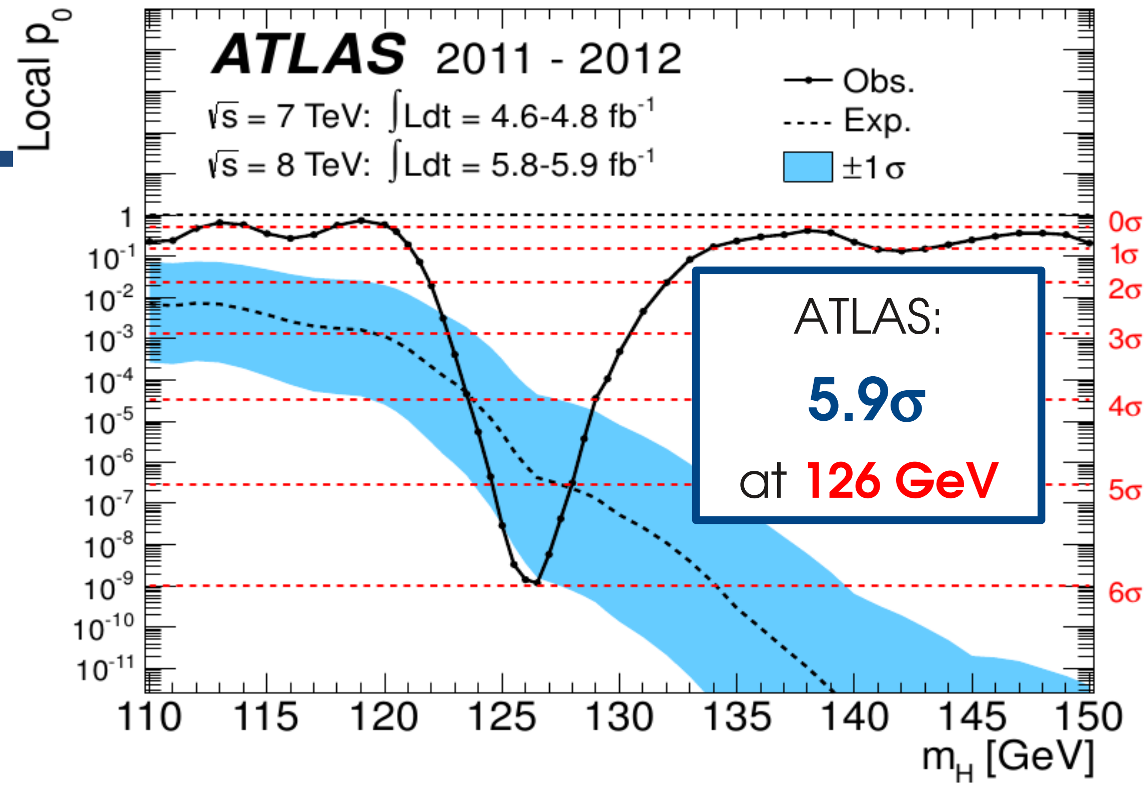


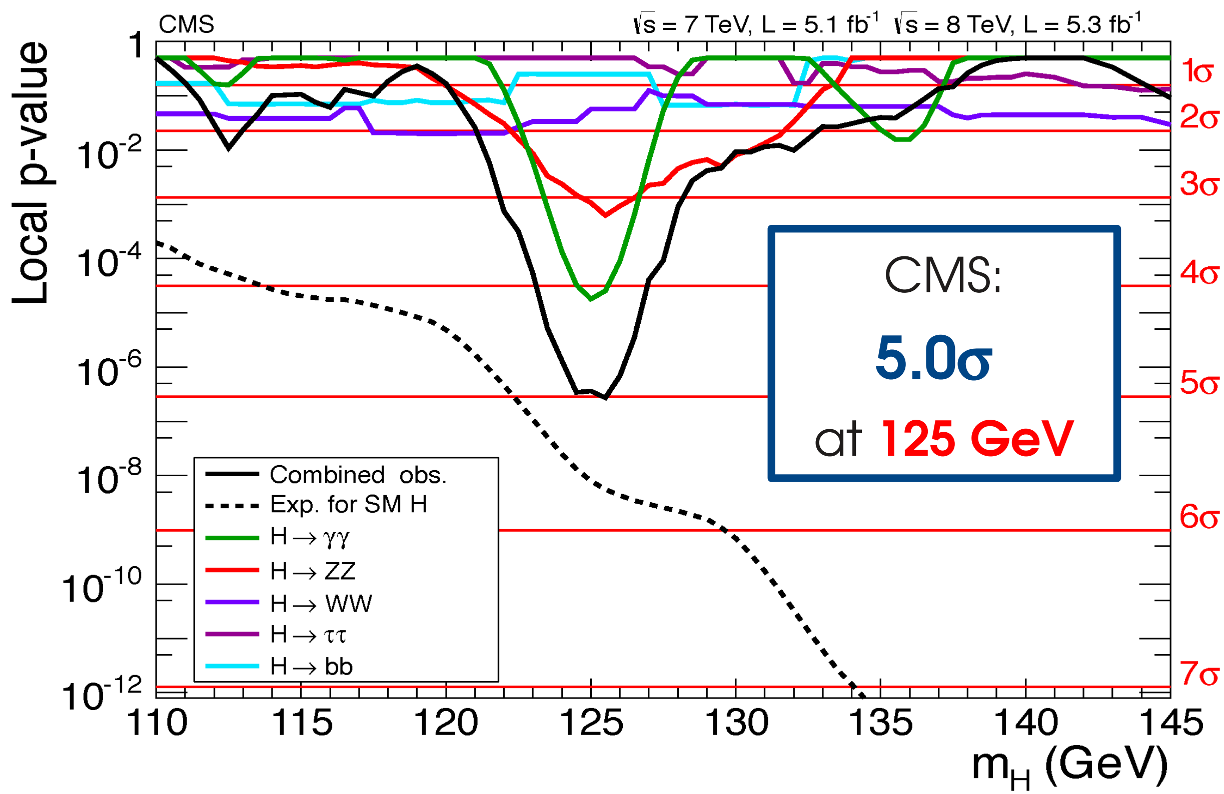




Combination

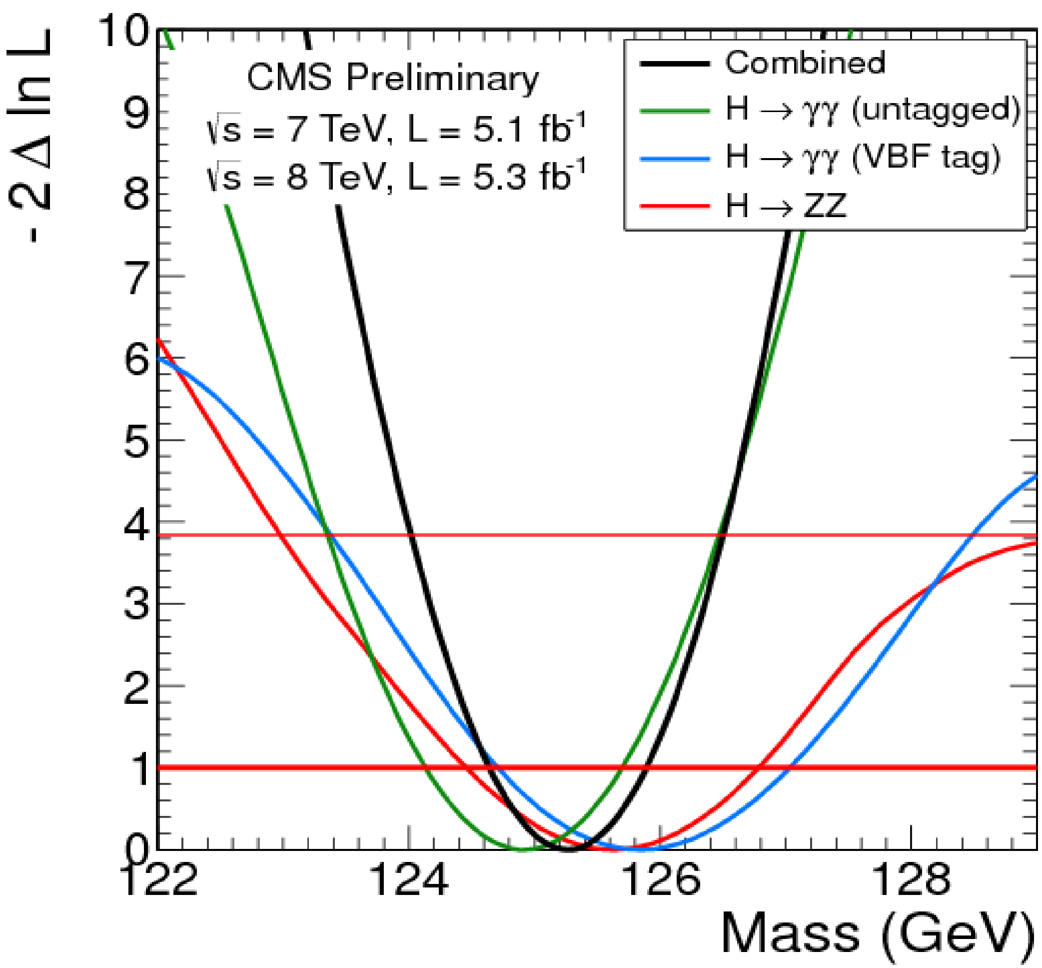


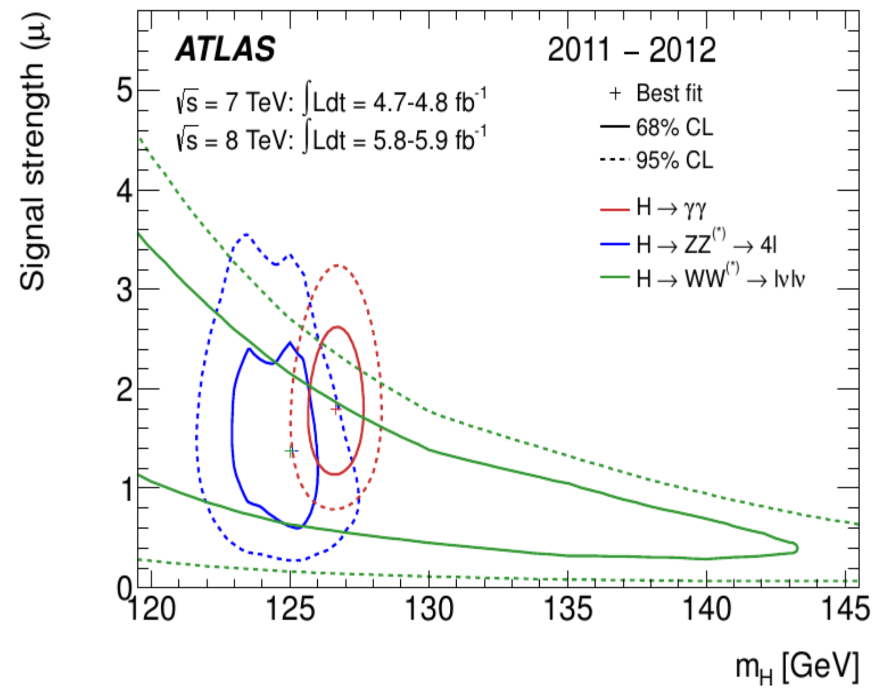




Is it the Higgs boson ?

Mass measurement

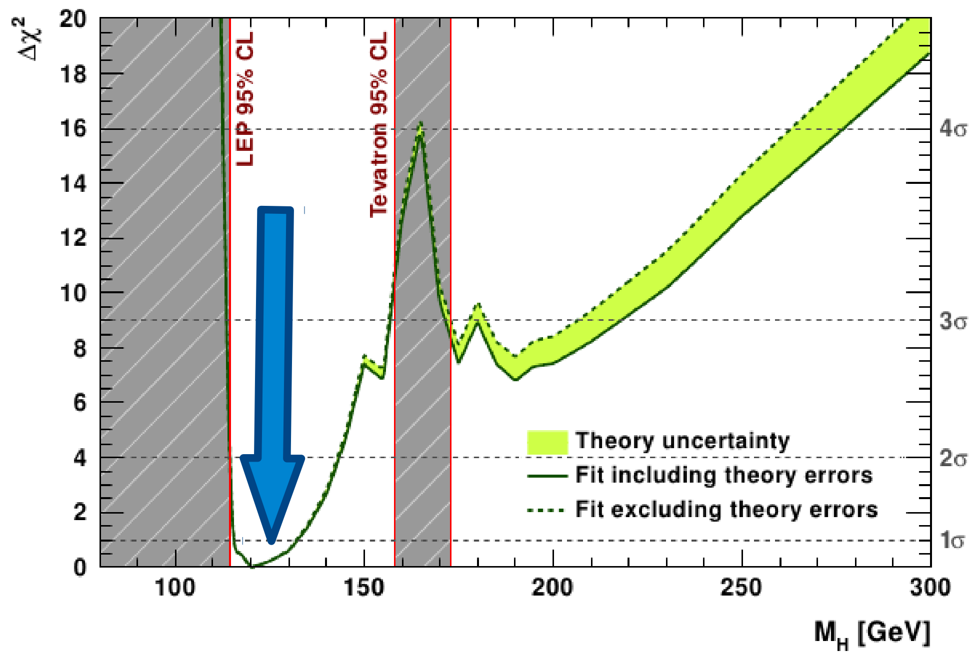




ATLAS: 126.0 ± 0.4 ± 0.4 GeV

CMS: 125.3 ± 0.4 ± 0.5 GeV

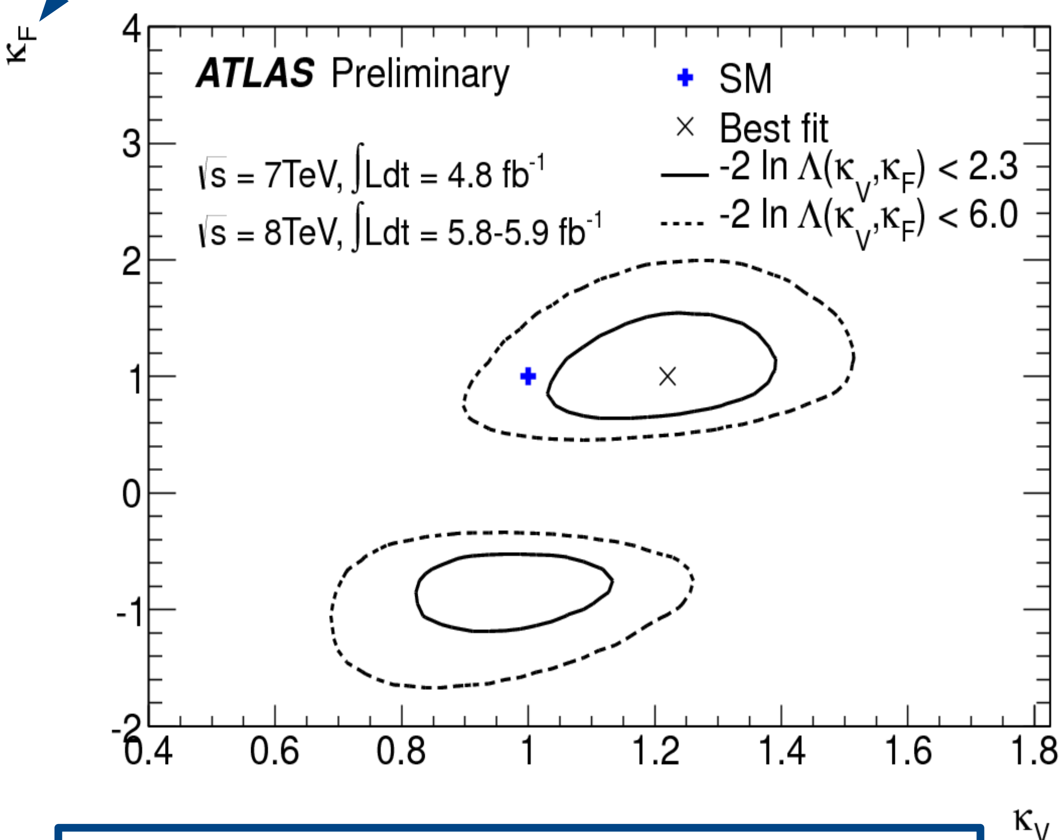
Very good agreement!



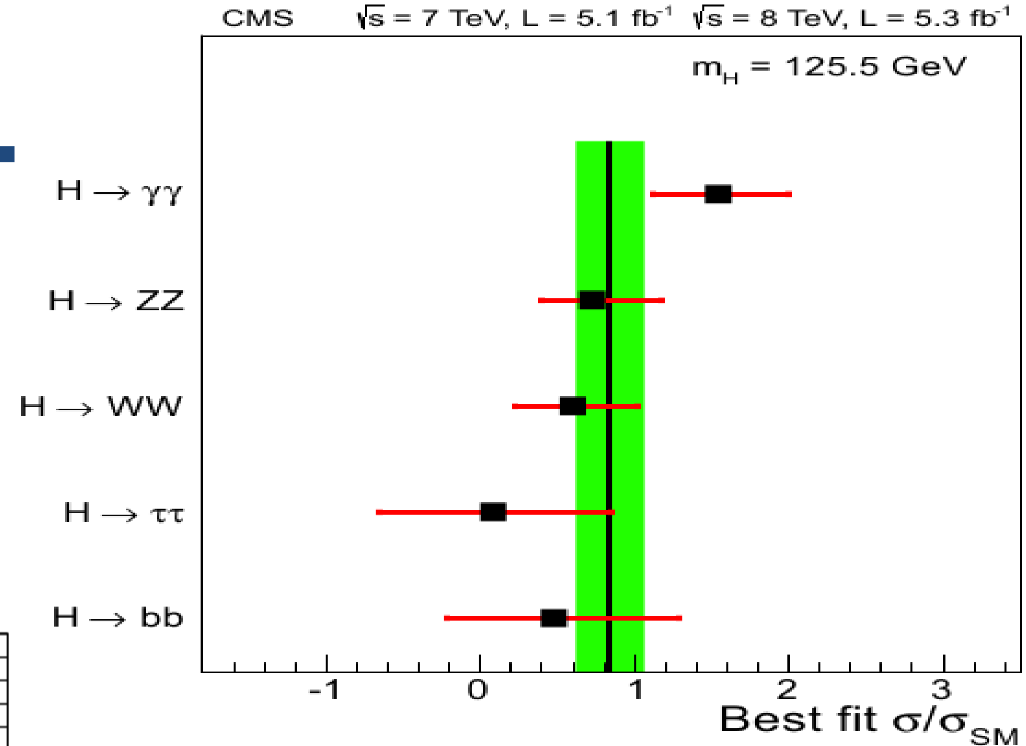
Couplings

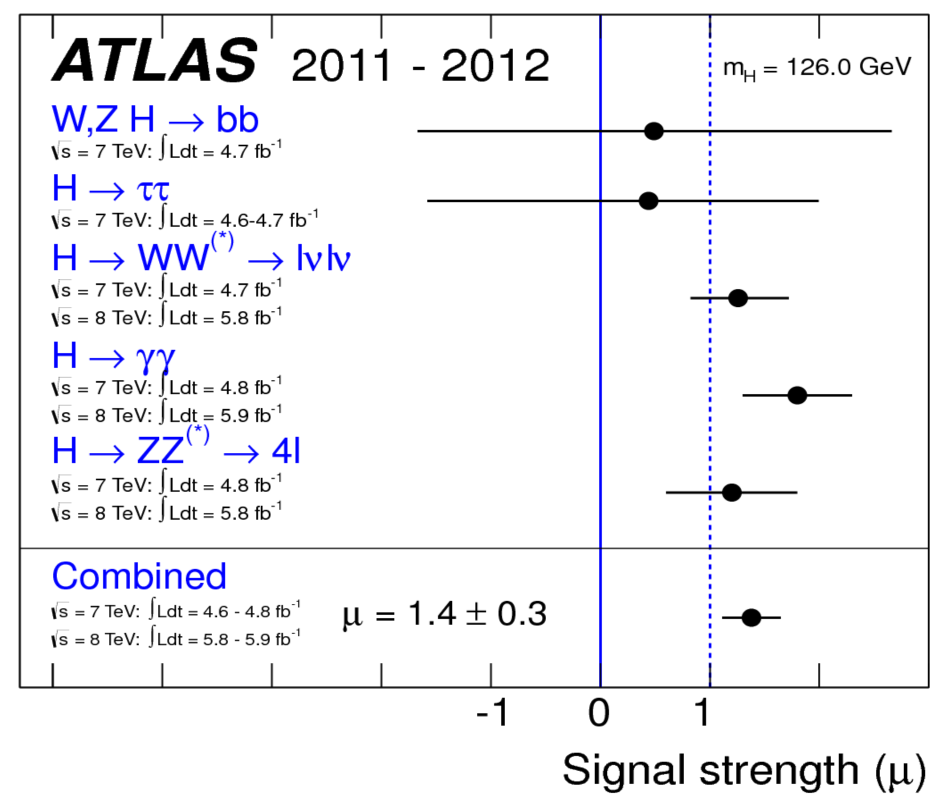
So far everything in in agreement with SM (**H→γγ ? H→ττ ?**)

Correction to fermion couplings



Correction to gauge boson couplings



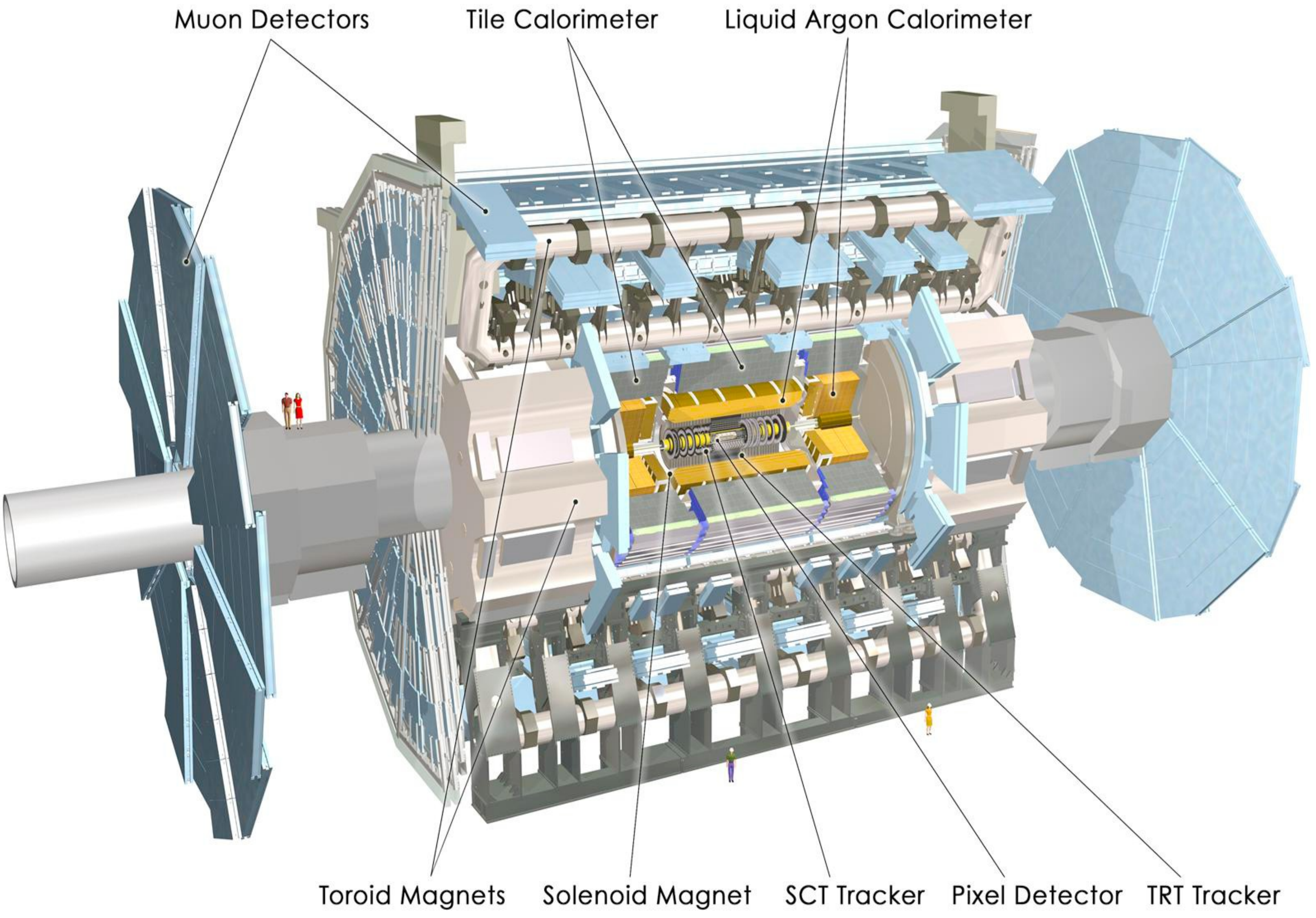


Conclusion

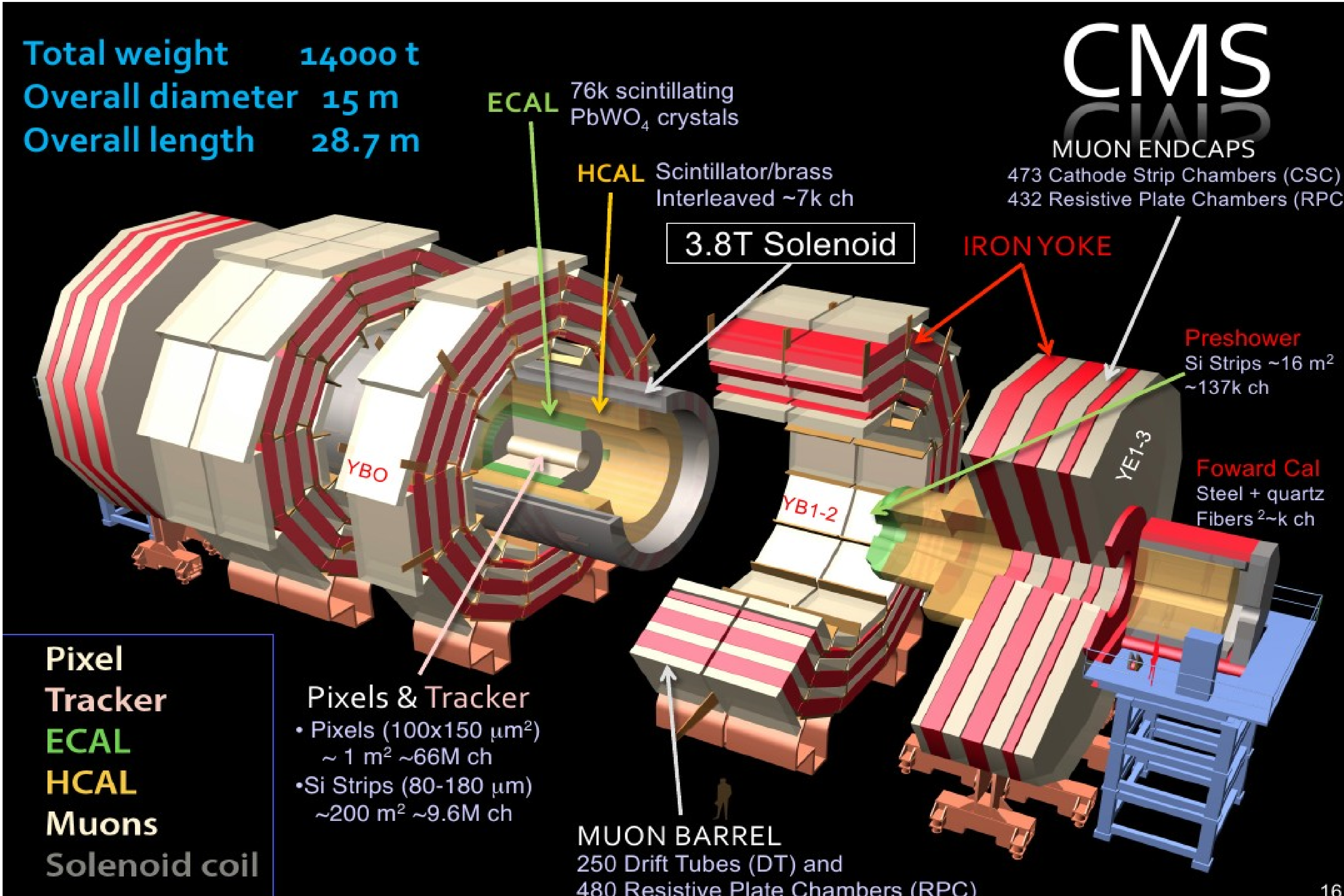
- A new particle, "X(126)", has been observed by ATLAS and CMS
- It is a boson, and not with spin=1
  - Spin measurements coming soon...
- Its couplings are consistent with that of an SM Higgs
- In the next few months we should learn much more about its properties – and hopefully some deviations from the SM will show up!

Backup Slides

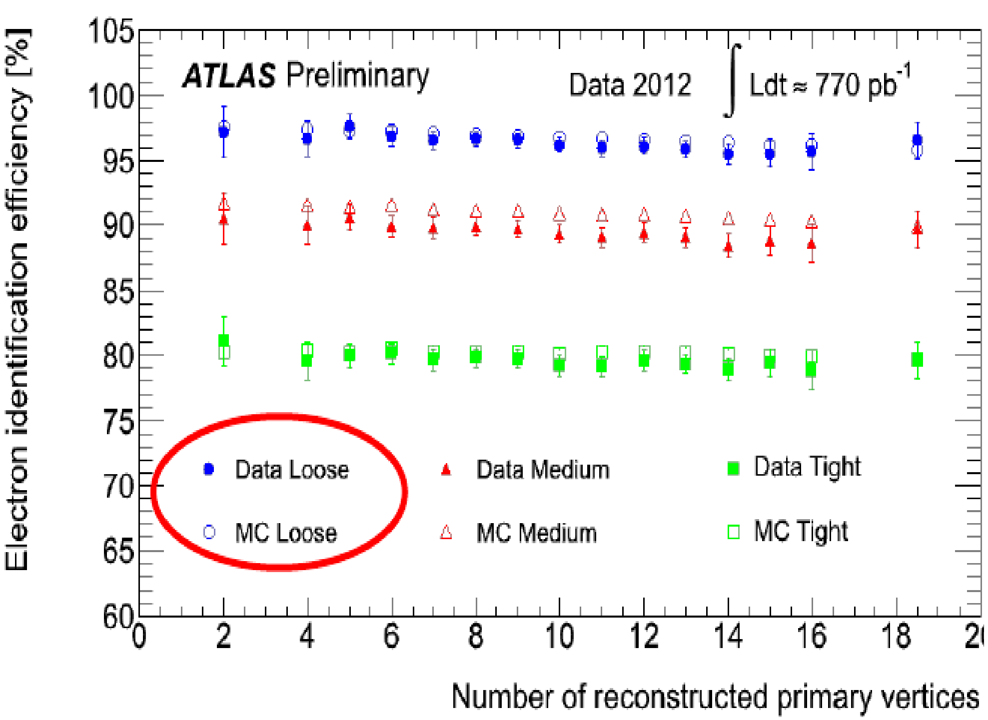
The ATLAS experiment

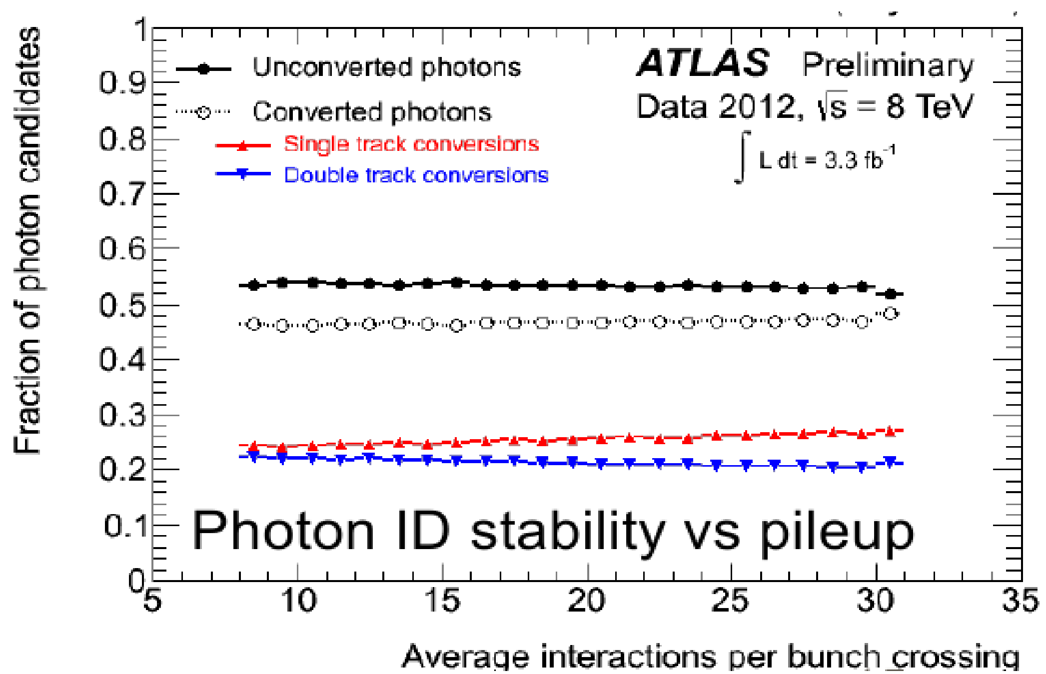


The CMS experiment



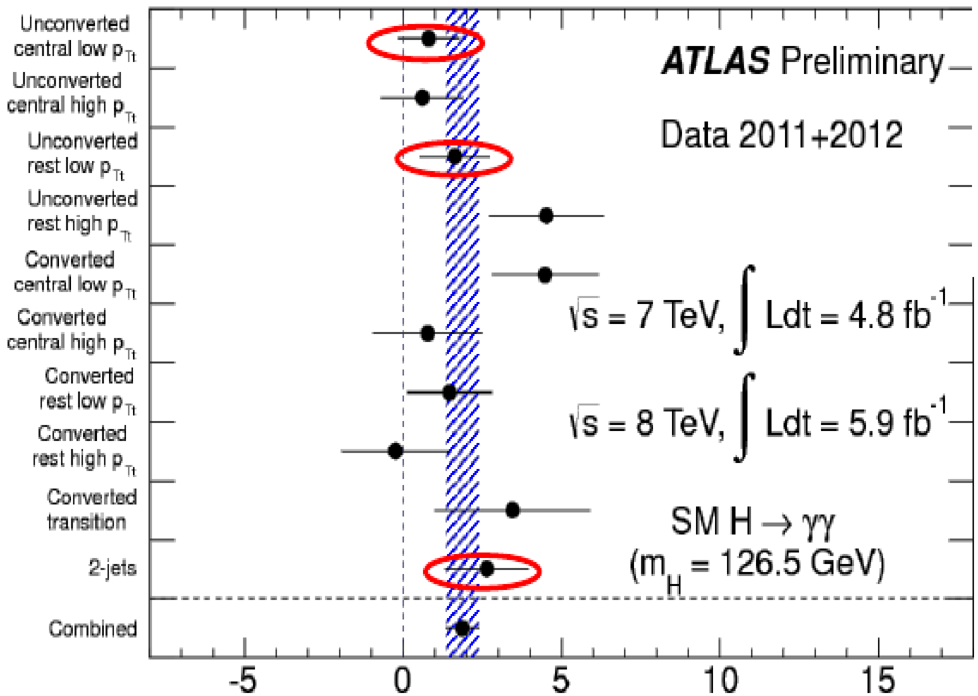
Pileup

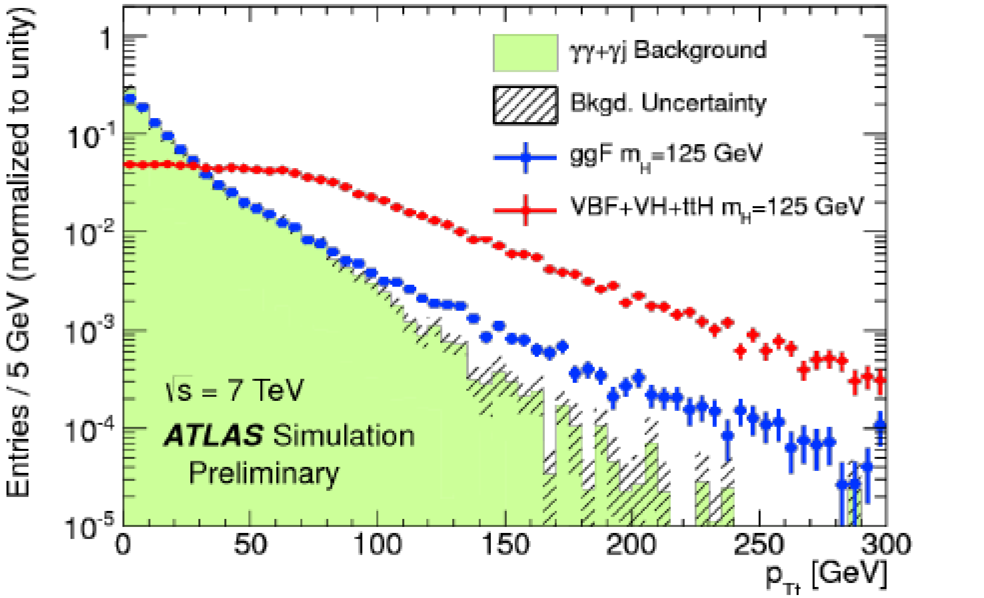

ATLAS Preliminary
Data 2012
∫Ldt ≈ 770 pb-1
Electron identification efficiency [%]
Number of reconstructed primary vertices
Data Loose
MC Loose
Data Medium
MC Medium
Data Tight
MC Tight

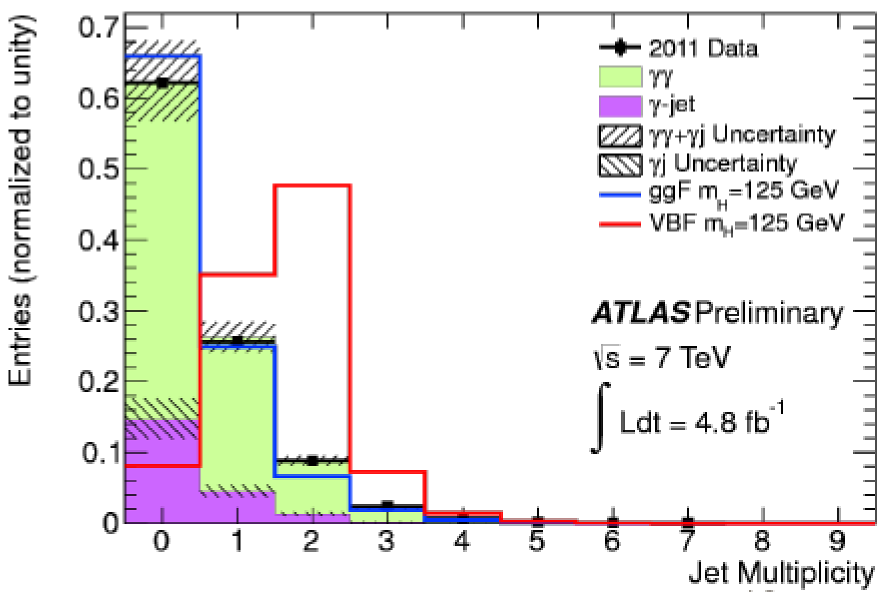

Unconverted photons
Converted photons
Single track conversions
Double track conversions
ATLAS Preliminary
Data 2012, √s = 8 TeV
∫L dt = 3.3 fb-1
Fraction of photon candidates
Average interactions per bunch crossing
Photon ID stability vs pileup

Hgg Categories

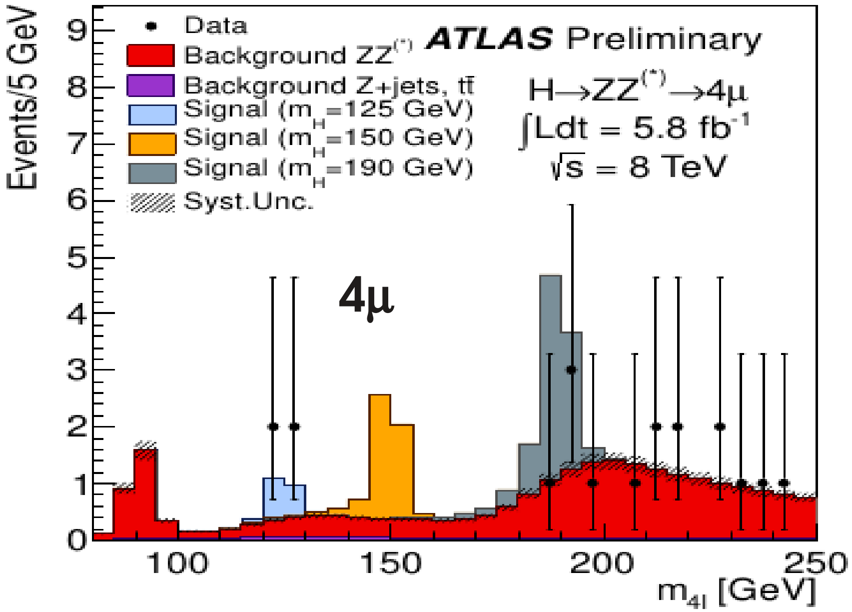
- Diphoton transverse momentum wrt thrust



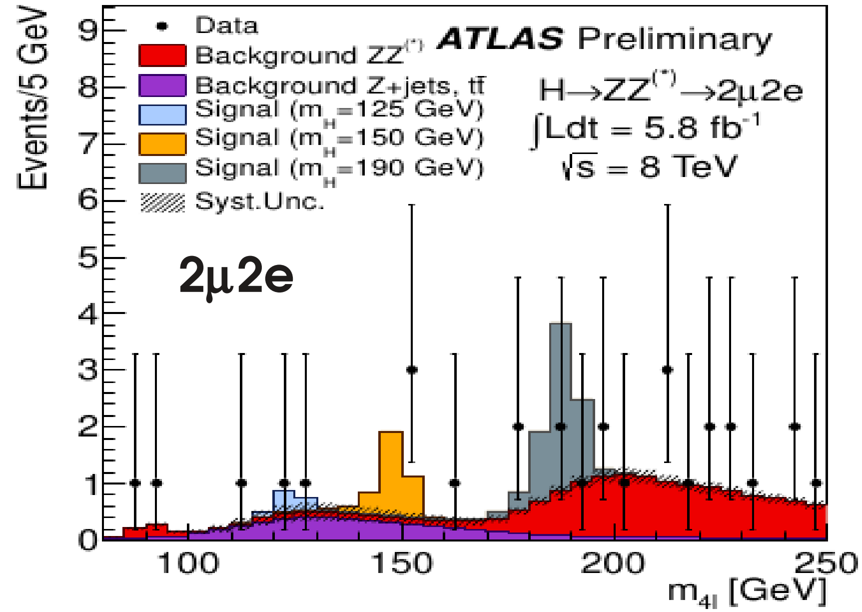




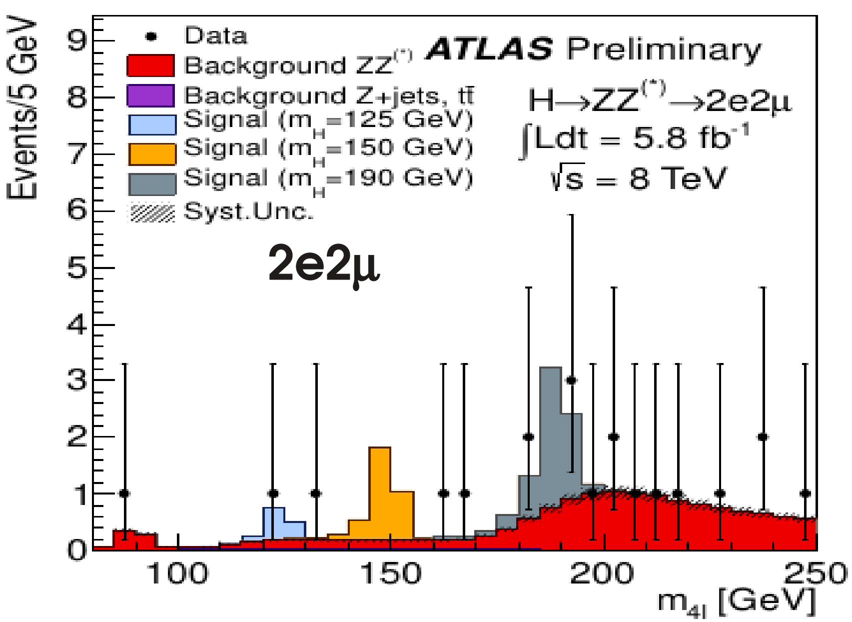
ZZ

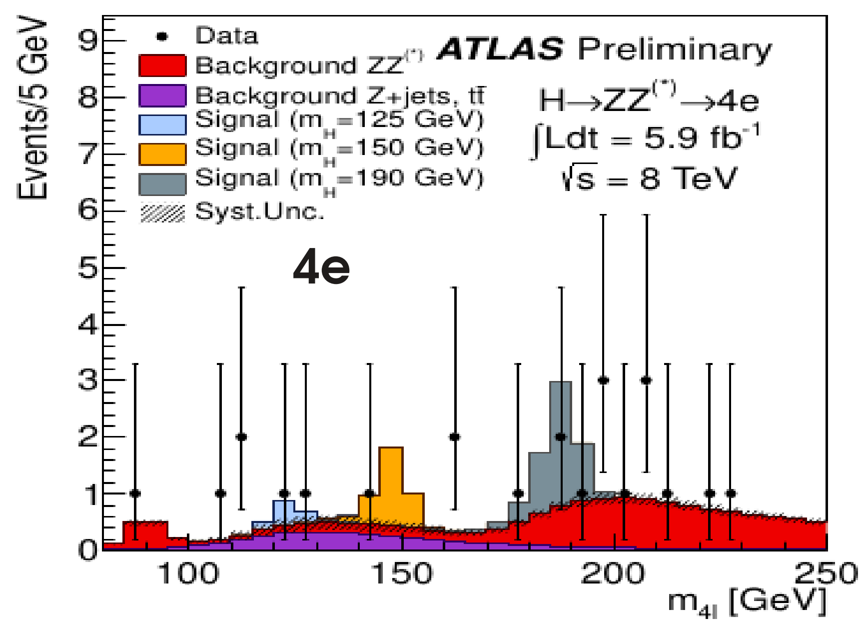

Events/5 GeV
Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→4μ
∫Ldt = 5.8 fb-1
√s = 8 TeV
4μ
m4l [GeV]

(a)

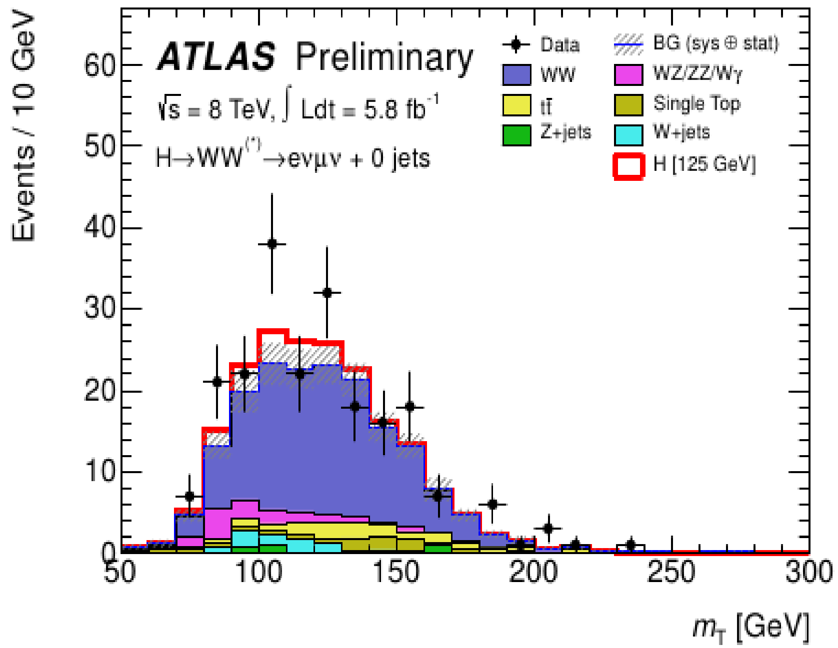

Events/5 GeV
Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→2μ2e
∫Ldt = 5.8 fb-1
√s = 8 TeV
2μ2e
m4l [GeV]

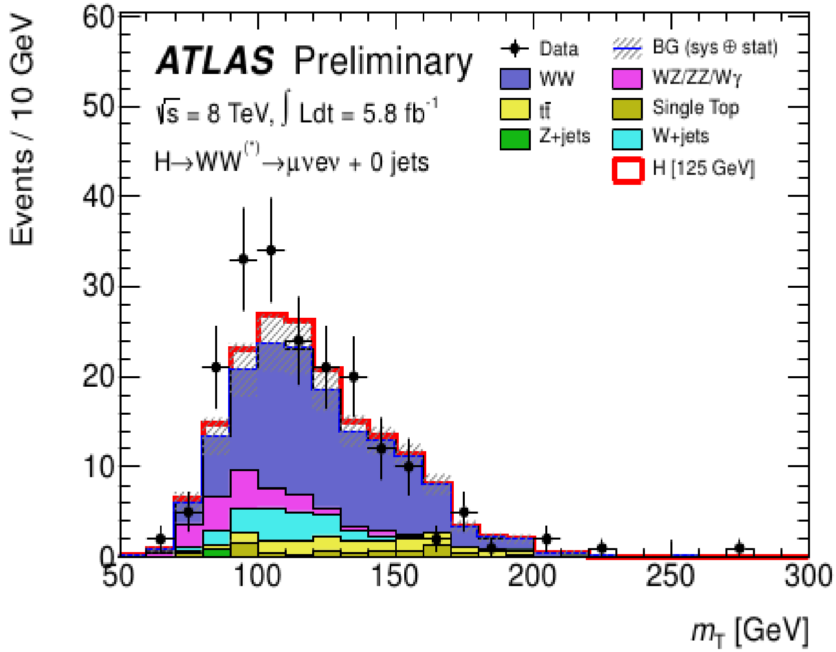
(b)

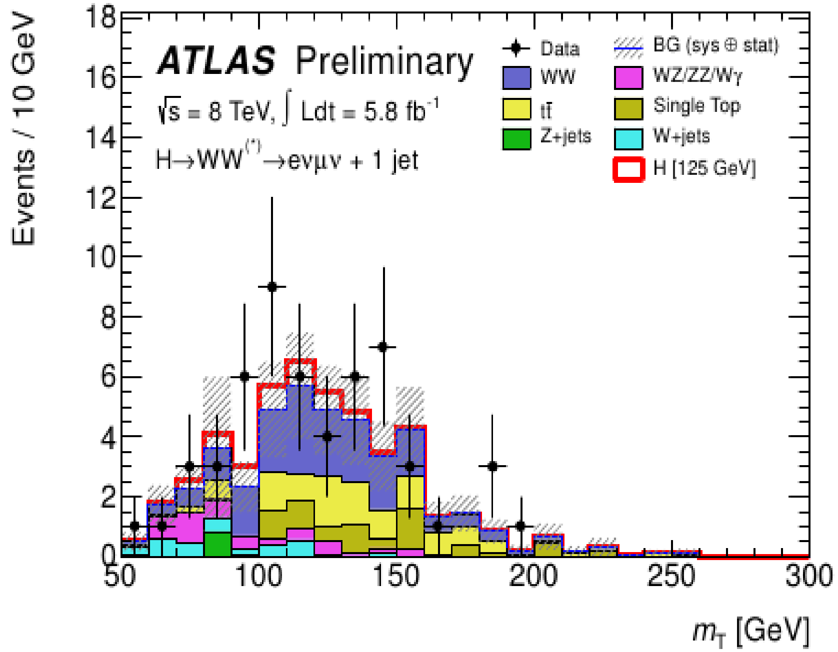

Events/5 GeV
Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→2e2μ
∫Ldt = 5.8 fb-1
√s = 8 TeV
2e2μ
m4l [GeV]

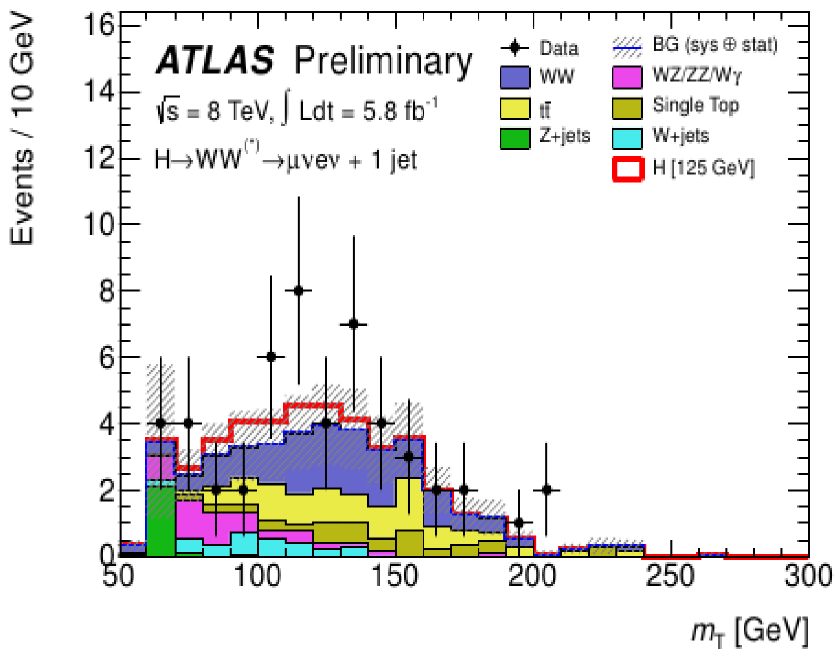

Events/5 GeV
Data
Background ZZ(*)
Background Z+jets, tt̄
Signal (m_H=125 GeV)
Signal (m_H=150 GeV)
Signal (m_H=190 GeV)
Syst.Unc.
ATLAS Preliminary
H→ZZ(*)→4e
∫Ldt = 5.9 fb-1
√s = 8 TeV
4e
m4l [GeV]

WW


ATLAS Preliminary
√s = 8 TeV, ∫ Ldt = 5.8 fb⁻¹
H→WW(*)→eνμν + 0 jets
Data
WW
tt̄
Z+jets
BG (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [125 GeV]
Events / 10 GeV
m_T [GeV]

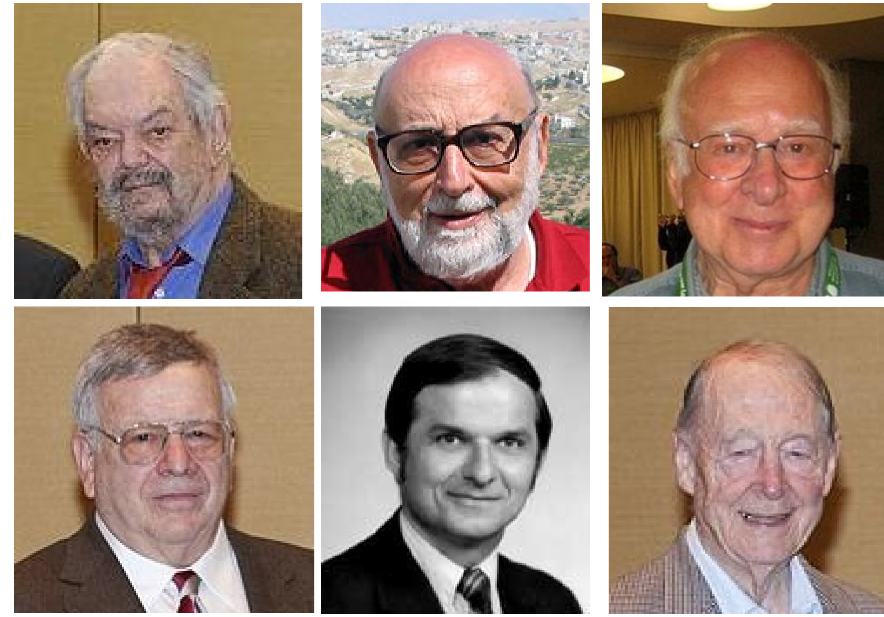

ATLAS Preliminary
√s = 8 TeV, ∫ Ldt = 5.8 fb⁻¹
H→WW(*)→μνeν + 0 jets
Data
WW
tt̄
Z+jets
BG (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [125 GeV]
Events / 10 GeV
m_T [GeV]


ATLAS Preliminary
√s = 8 TeV, ∫ Ldt = 5.8 fb⁻¹
H→WW(*)→eνμν + 1 jet
Data
WW
tt̄
Z+jets
BG (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [125 GeV]
Events / 10 GeV
m_T [GeV]


ATLAS Preliminary
√s = 8 TeV, ∫ Ldt = 5.8 fb⁻¹
H→WW(*)→μνeν + 1 jet
Data
WW
tt̄
Z+jets
BG (sys ⊕ stat)
WZ/ZZ/Wγ
Single Top
W+jets
H [125 GeV]
Events / 10 GeV
m_T [GeV]

Naming issues

- BEGHHK ?
- BEH ?
- Higgs ?



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