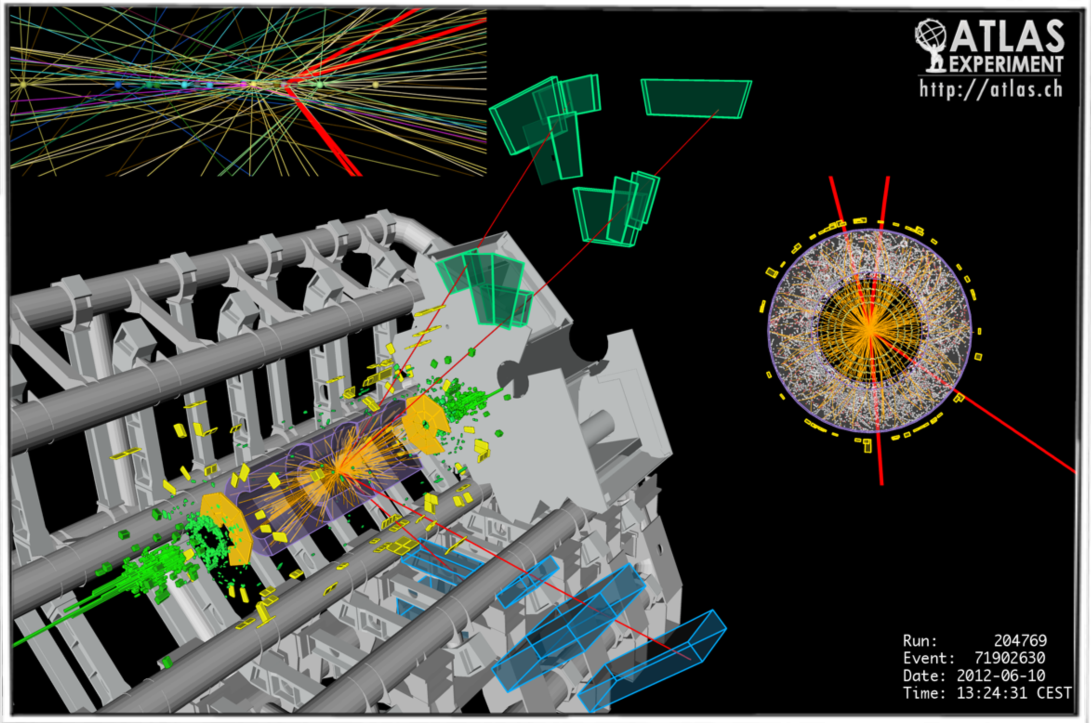
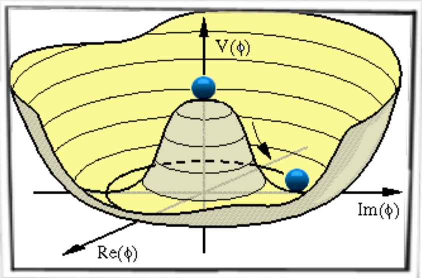
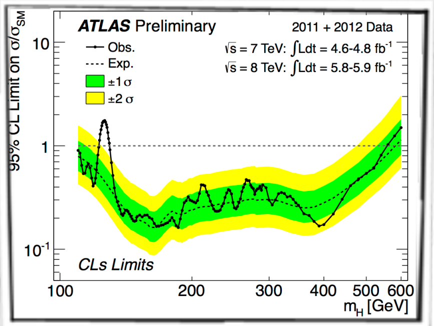
Discovery of the Higgs Boson







Guilherme Nunes Hanninger

CoEPP Annual Workshop

Cairns – July 8th 2013

CoEPP
ARC Centre of Excellence for
Particle Physics at the Terascale

POSTERA CRESCAM LAUDE
THE UNIVERSITY OF
MELBOURNE

News on 04/07/2012

la Repubblica.it Cern, scoperta la "particella di Dio"

« PRECEDENTE Foto 1 di 19 SUCCESSIVO

Higgs boson-like particle discovery claimed at LHC

THANH NIÊN ONLINE

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Cỡ chữ : A- A

Sân bóng của các hạt nhân

06/07/2012

Ngày 4.7 tại Geneva, Thụy Sĩ, Viện Nghiên cứu hạt nhân châu Âu (CERN) công bố đã phát hiện ra một loại hạt cơ mới được cho là tương ứng với hạt Higgs - còn gọi là "hạt của Chúa" mà các nhà khoa học dày công tìm kiếm tr 5 thập niên qua. Nếu thông tin này hoàn toàn chính xác, khám phá trên sẽ có tầm ảnh hưởng ành vật lý tương đương với việc Christophe Columbus tìm ra châu Mỹ.

ZEIT ONLINE WISSEN

CIENZA

Scoperto il Bosone di Higgs
la particella di Dio esiste davvero

PHYSIK

Haarscharf am gottverdammten Teilchen vorbei

Die Belege scheinen überwältigend: Forscher könnten ein neues Teilchen gefunden haben. Unklar ist, ob es das Higgs-Boson ist, der letzte Baustein im Weltbild der Physik.

© L. Taylor/T. McCauley/

The New York Times

U.S. | N.Y. / REGION | BUSINESS

Le boson de Higgs découvert avec 99,9999 % de certitude

Le Monde.fr | 04.07.2012 à 13h39 • Mis à jour le 04.07.2012 à 13h39

Physicists Find Elusive Particle Seen as Key to Universe

Scientists in Geneva on Wednesday applauded the discovery of a

theguardian

News | Sport | Comment | Culture | Business | Money | London

Comment is free

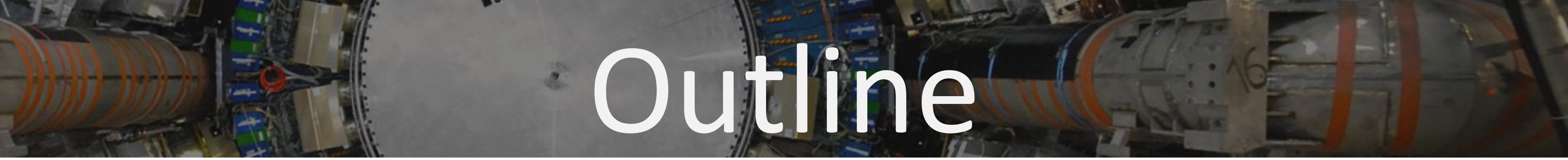
The Higgs boson discovery is another giant leap for humankind

The Cern discovery of the Higgs particle is up there with putting man on the moon – something all humanity can be proud of

la Repubblica.it | Cern, scoperta la "particella di Dio"

Higgs boson-like particle discovery

Is this the SM Higgs boson?



Outline

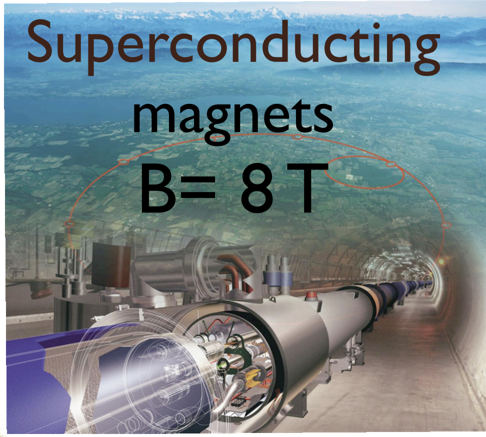
- Large Hadron Collider and the ATLAS detector
- Higgs boson studies
  - Di-boson decays
  - Decays into fermions

New! July 4th 2013:

- Higgs boson parameters (arXiv:1307.1427v1)
- Spin and parity (arXiv:1307.1432v1)

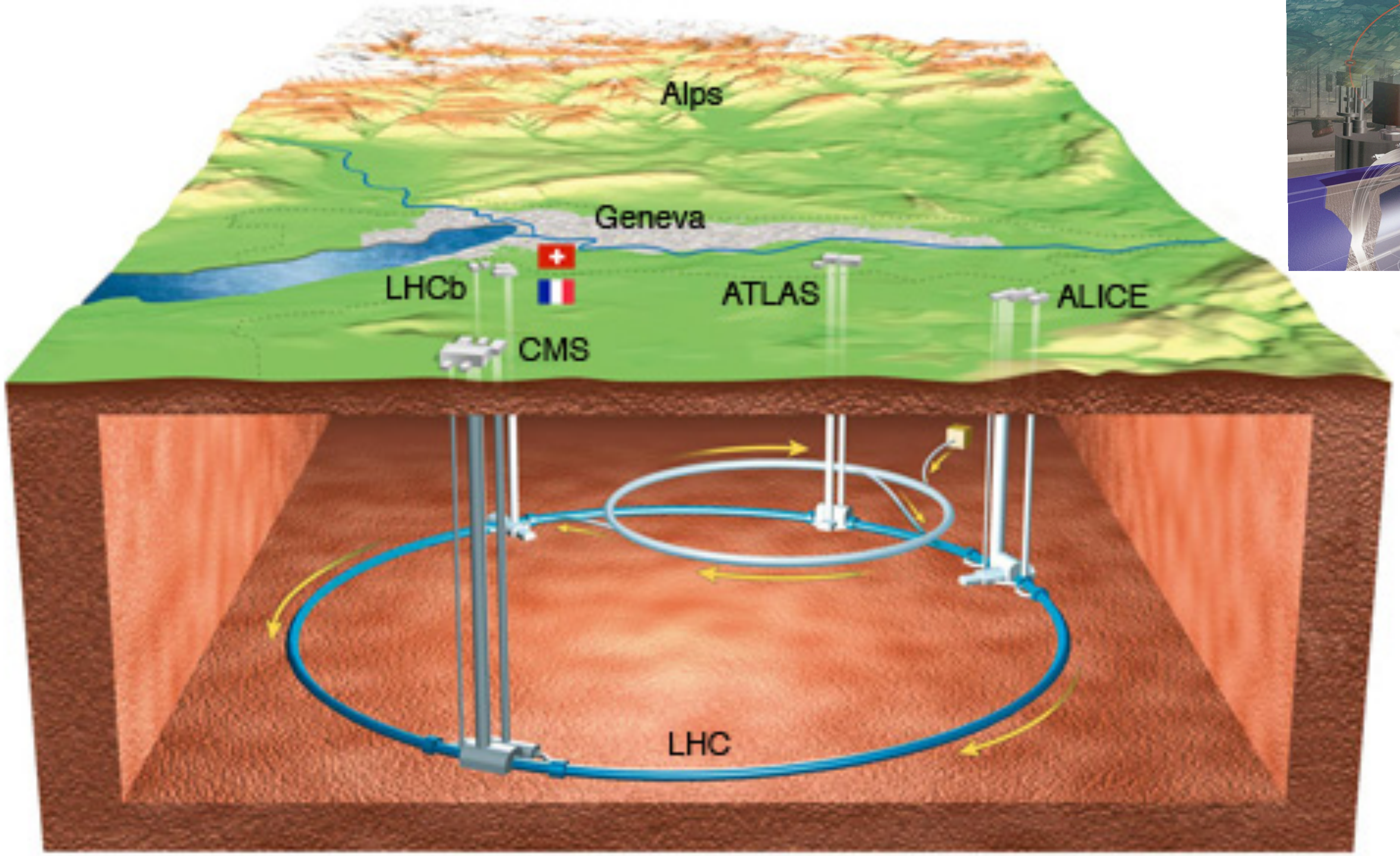
The Large Hadron Collider

1232 Dipoles at a temperature of ~ 1.9 K
26.7 km circumference



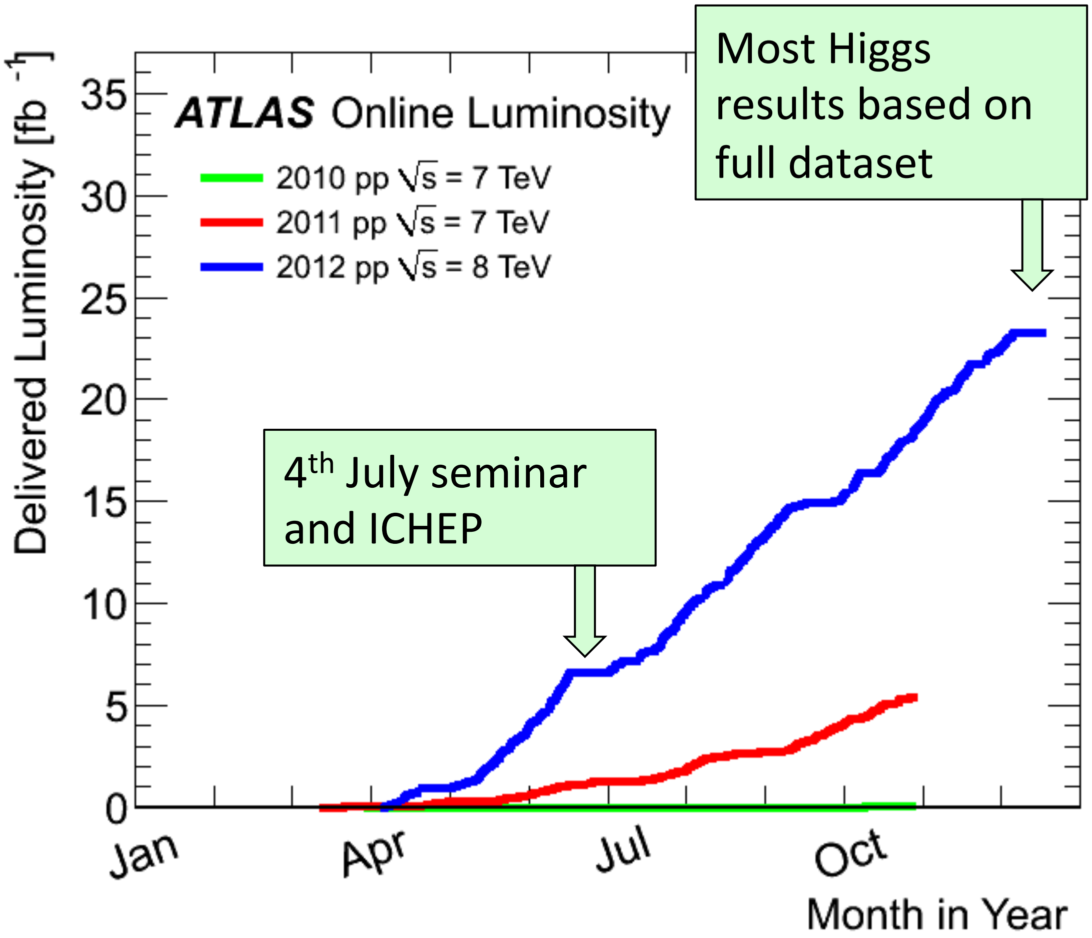
Superconducting magnets

B= 8 T



≈ 100m

Luminosity Delivered to ATLAS



Most Higgs results based on full dataset

4th July seminar and ICHEP

2012:
24 fb^{-1}
at 8 TeV

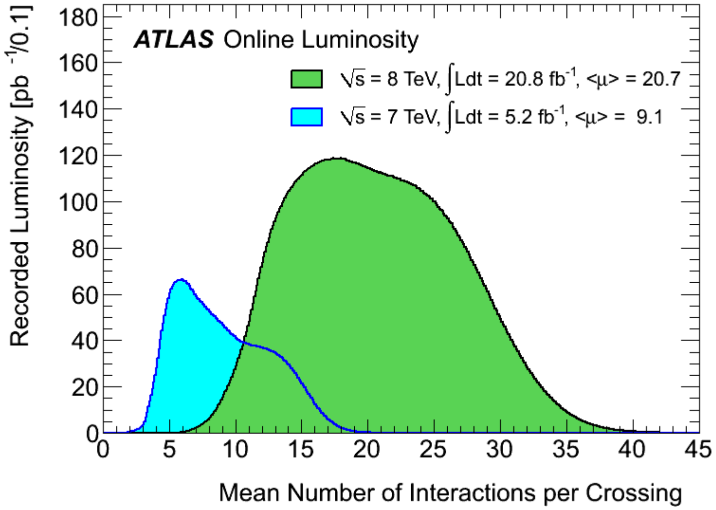
2011
5.6 fb^{-1}
at 7 TeV

2010
0.05 fb^{-1}
at 7 TeV

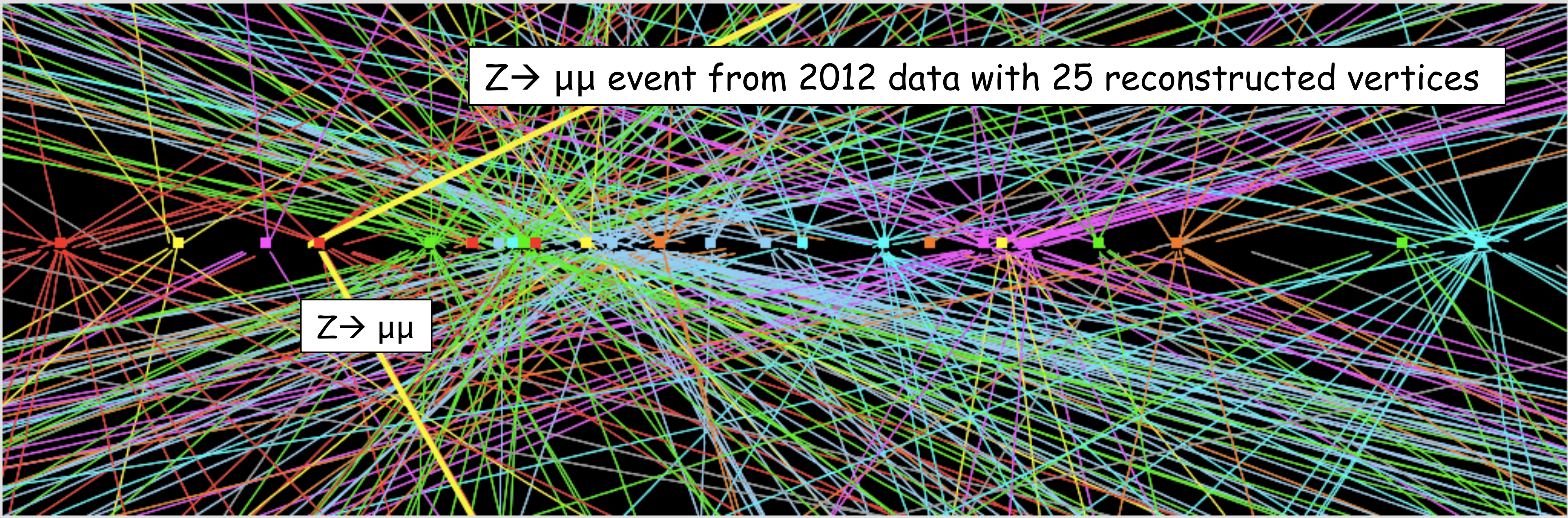
Excellent LHC performance in 2011 and 2012

Excellent performance of the ATLAS experiment: Data recording efficiency ~ 93.5%, working detector channels > 99% for most sub-detectors, high data quality

Pile-up Challenge

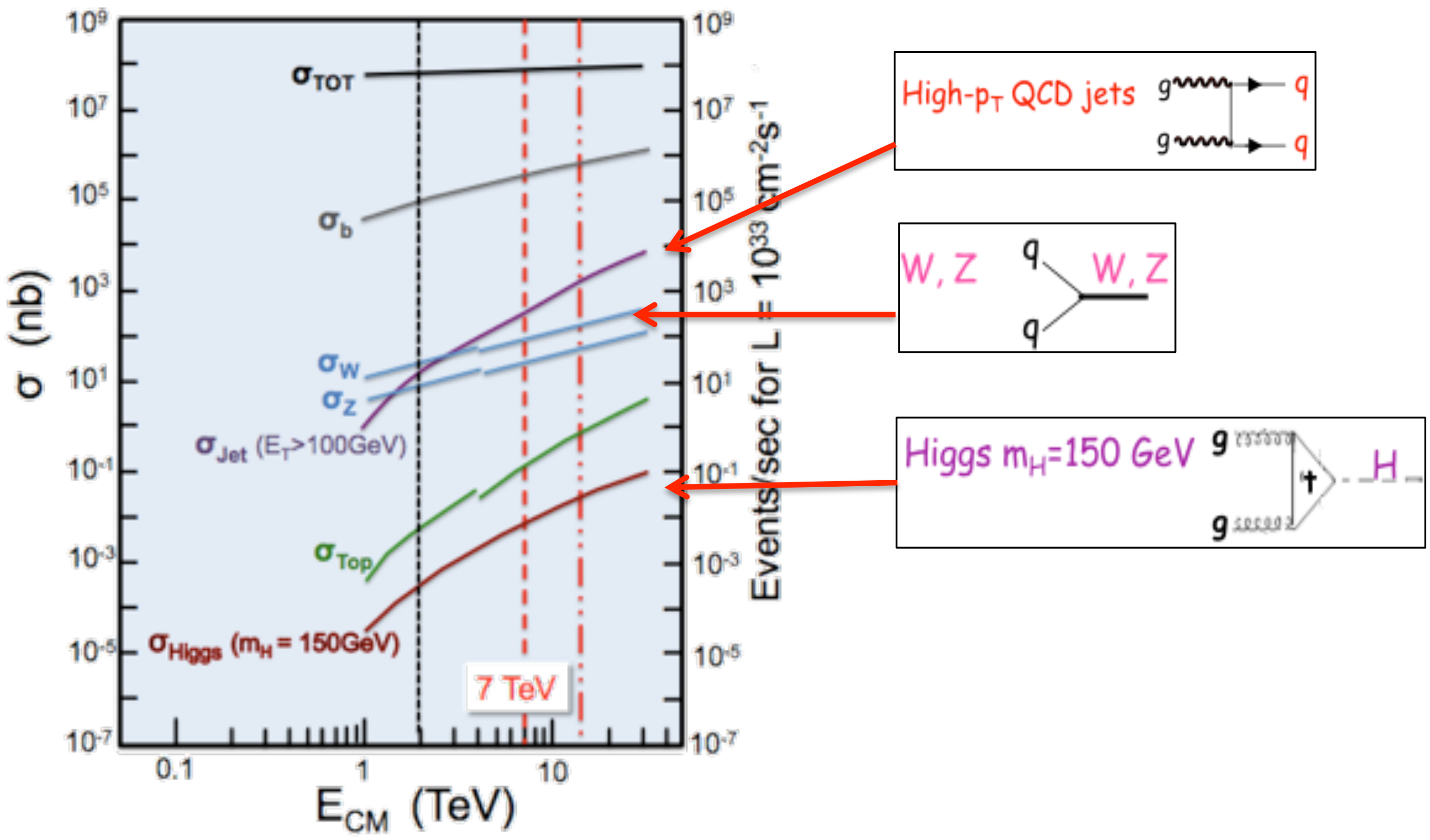


- ⇒ Pile-up: number of interactions per crossing
- ⇒ Peak luminosity > 7 × 10^{33} $cm^{-2}s^{-1}$
- ⇒ High level of pile-up: mean ~ 21 interactions / beam crossing in 2012


Z→ μμ event from 2012 data with 25 reconstructed vertices

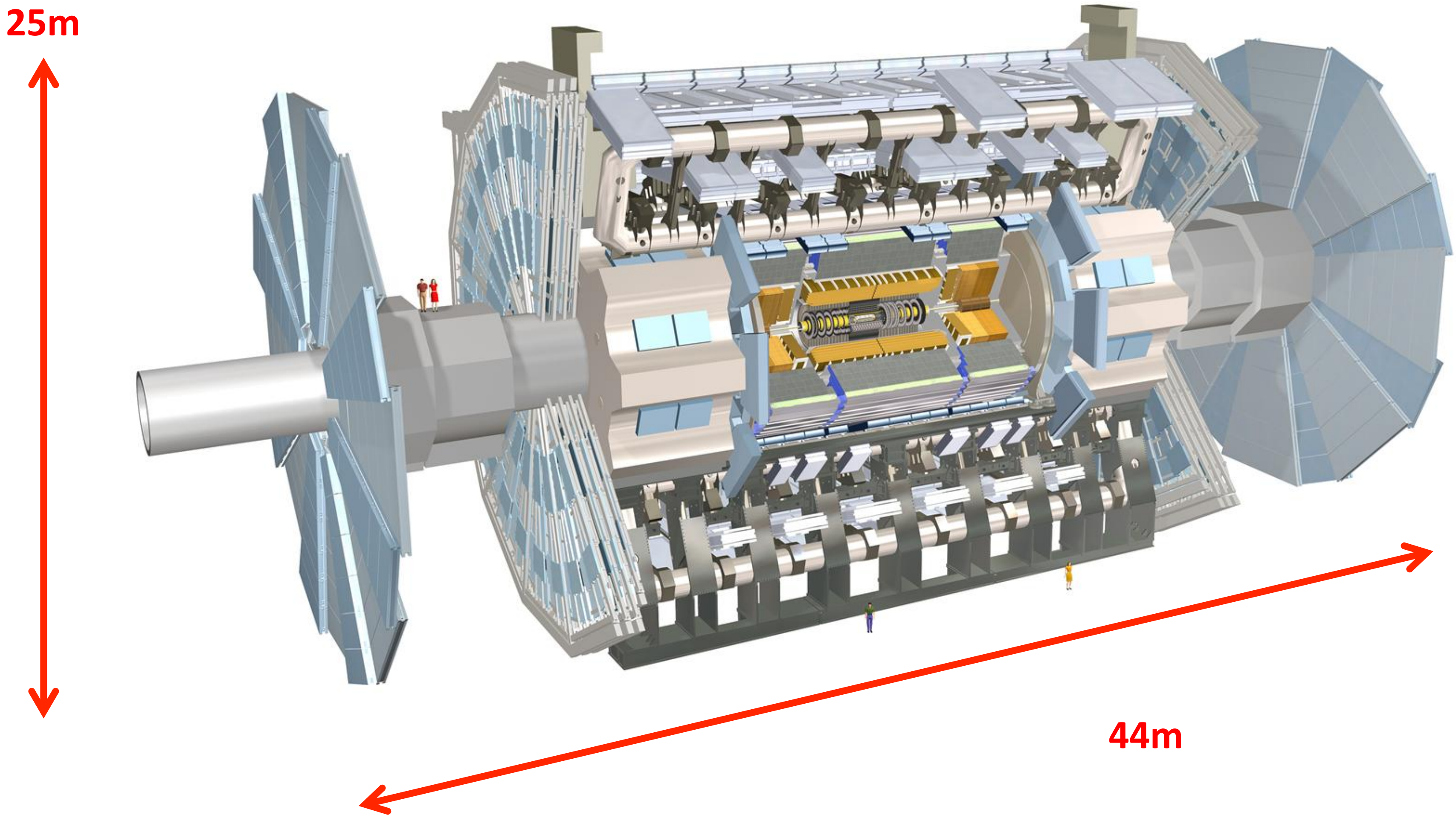
Z→ μμ

Never Forget Background

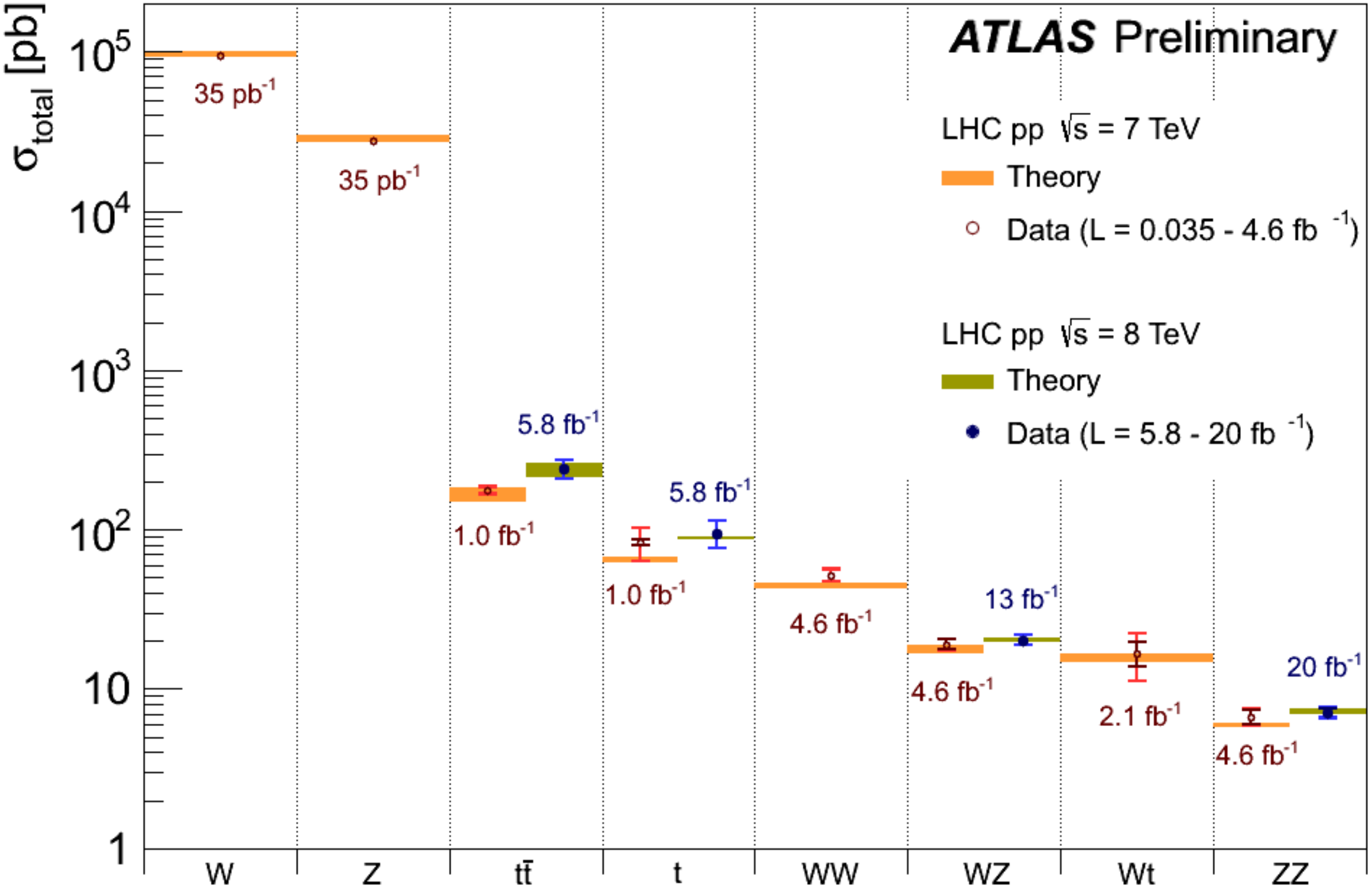


LHC is all about background rejection

ATLAS Detector



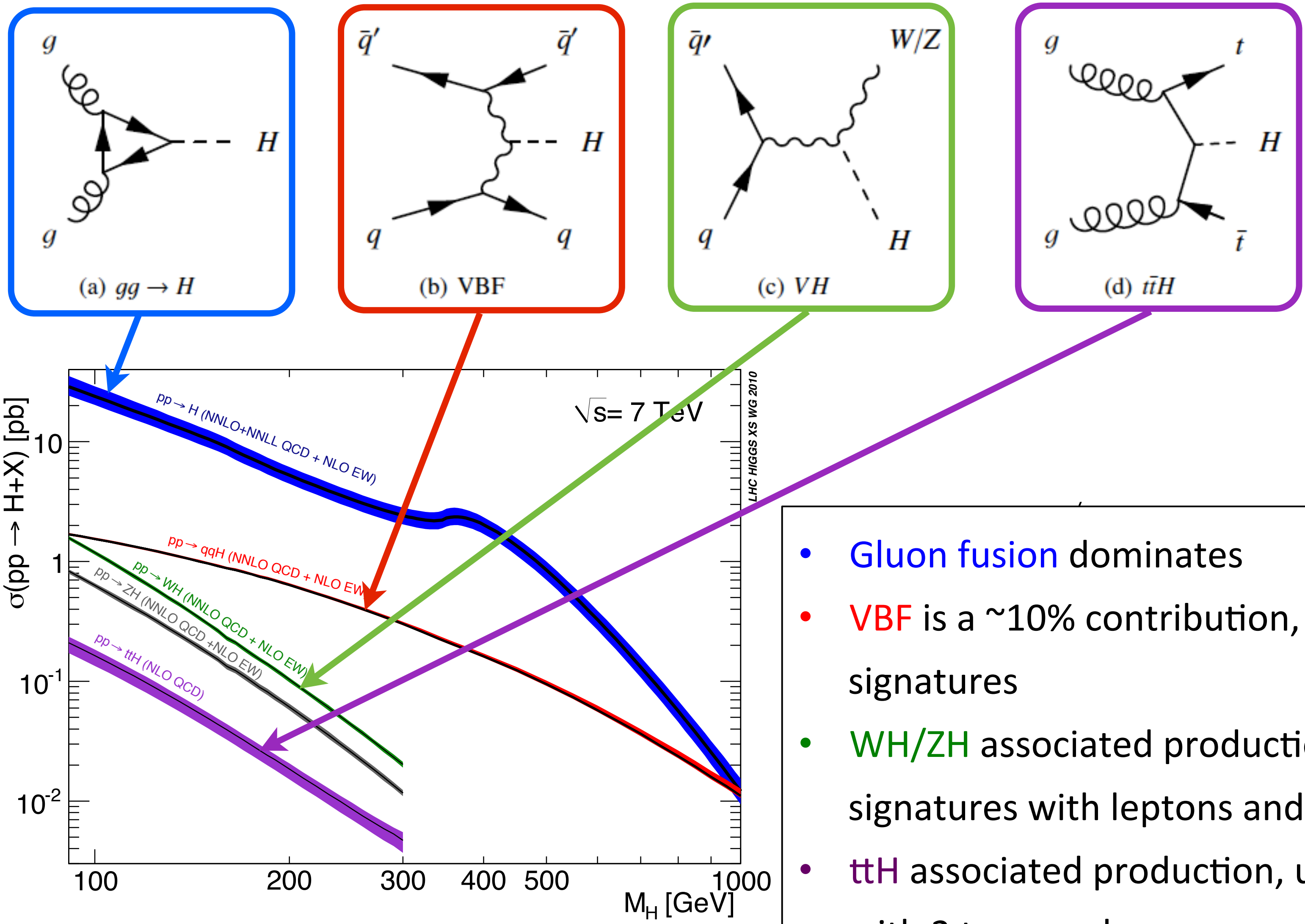
Standard Model Measurements



Good understanding of the detector and accurate theory predictions

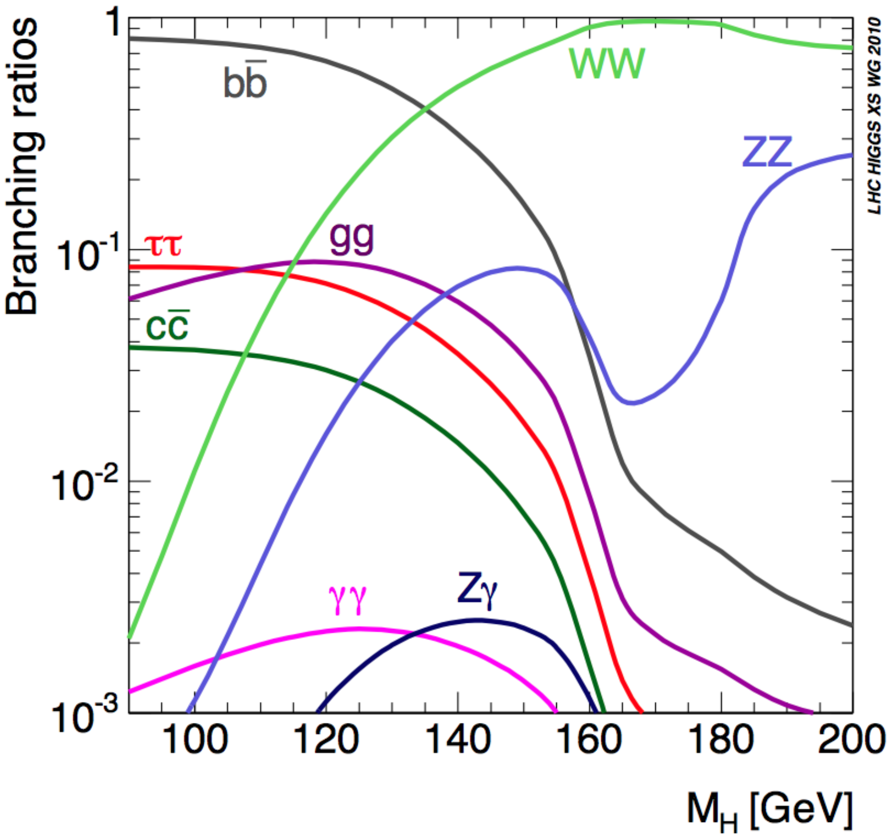
- Precise measurements of the SM processes in a large range
- Good knowledge of the backgrounds to the Higgs analyses

SM Higgs Production at the LHC



- Gluon fusion dominates
- VBF is a ~10% contribution, unique signatures
- WH/ZH associated production, unique signatures with leptons and neutrinos
- ttH associated production, unique signature with 2 top quarks

SM Higgs Decays



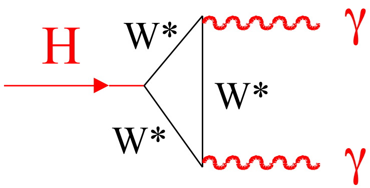
Useful decays at a hadron collider:

- Final states with leptons via WW and ZZ decays
- γγ final states (despite small branching ratio)
- ττ final states (more difficult)
- In addition: H→bb decays via associated lepton or jet signatures (VBF, VH or ttH production)

SM predictions (m_H = 125.5 GeV):

BR (H→WW) = 22.3% BR (H→bb) = 56.9%
BR (H→ZZ) = 2.8% BR (H→tt) = 6.2%
BR (H→gg) = 0.24% BR (H→μμ)=0.022

H→γγ

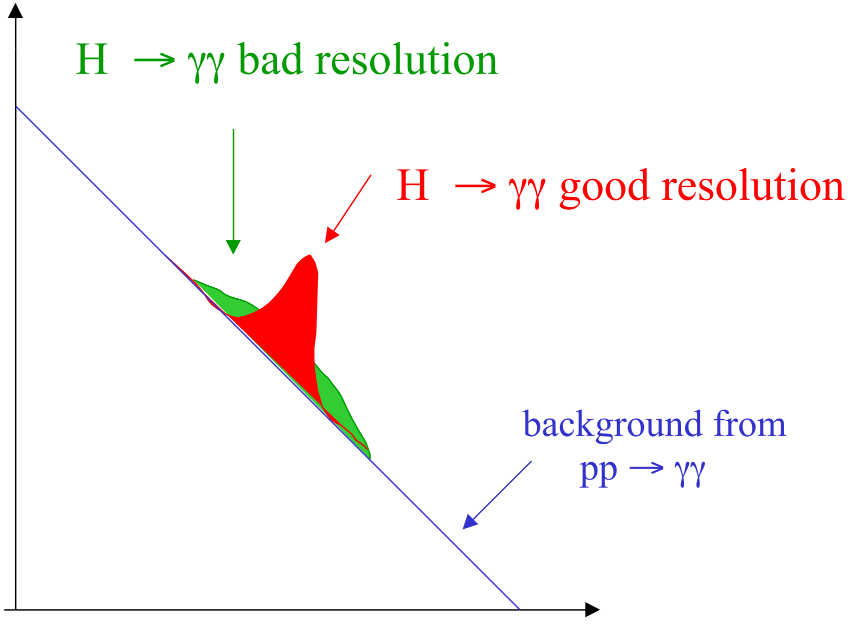


- Select events with two photons in the detector

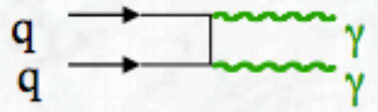
- Measure energy and direction of each photon
- Measure invariant mass of photon pair

$$m_{\gamma\gamma} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

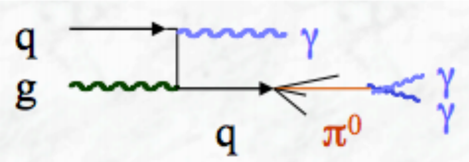
- Plot distribution of $m_{\gamma\gamma}$ → Higgs should appear as a peak at m_H



- We need to identify γγ events over three backgrounds…
  - Irreducible background from γγ events:

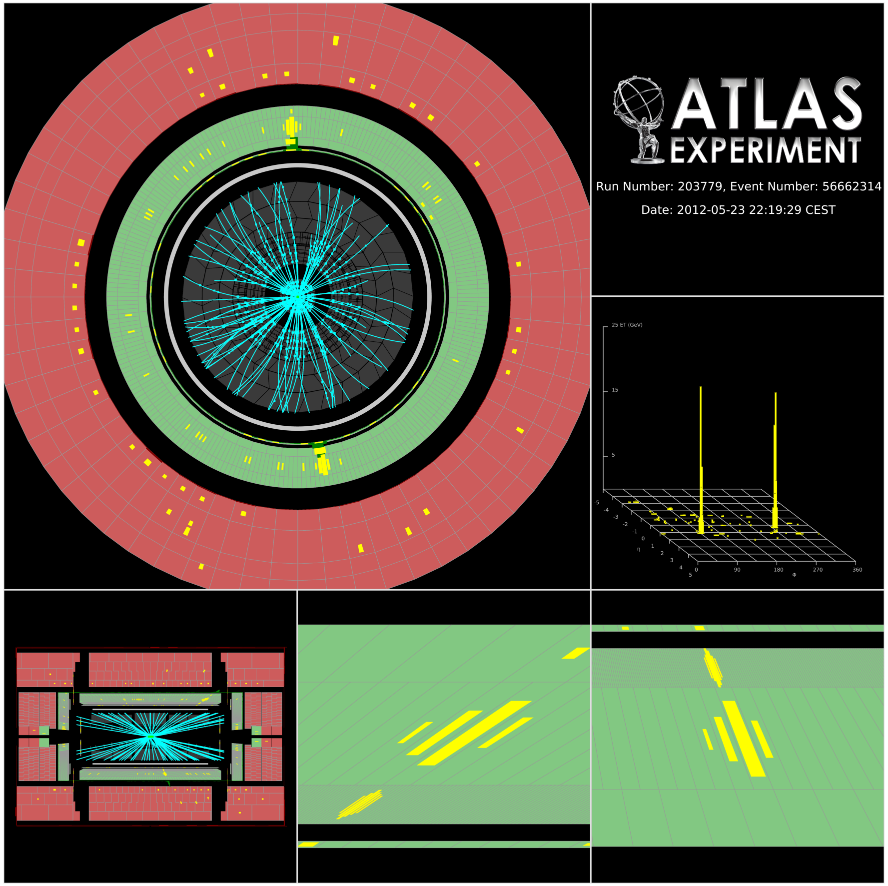


  - Reducible background from j+γ and jj:



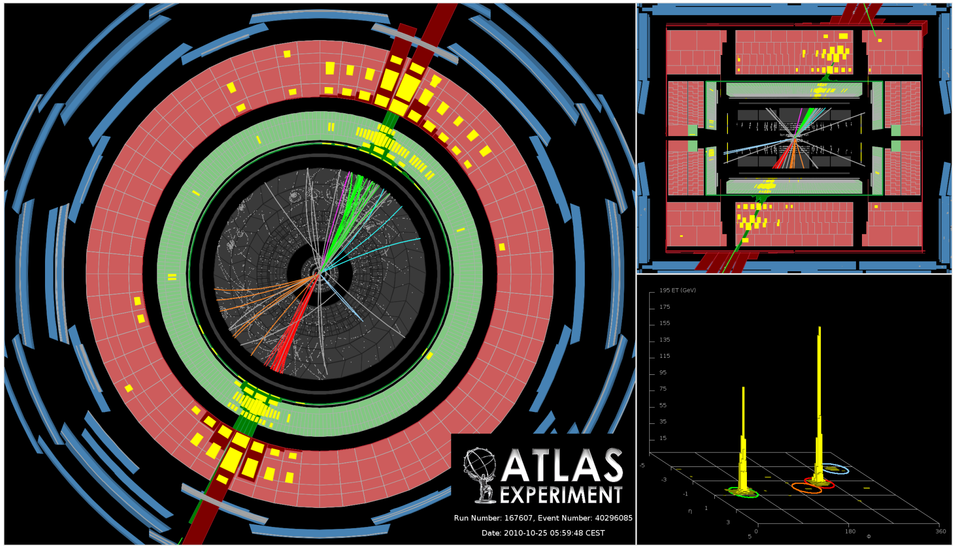
… in the face of a large number of pile-up events

Identifying Photons



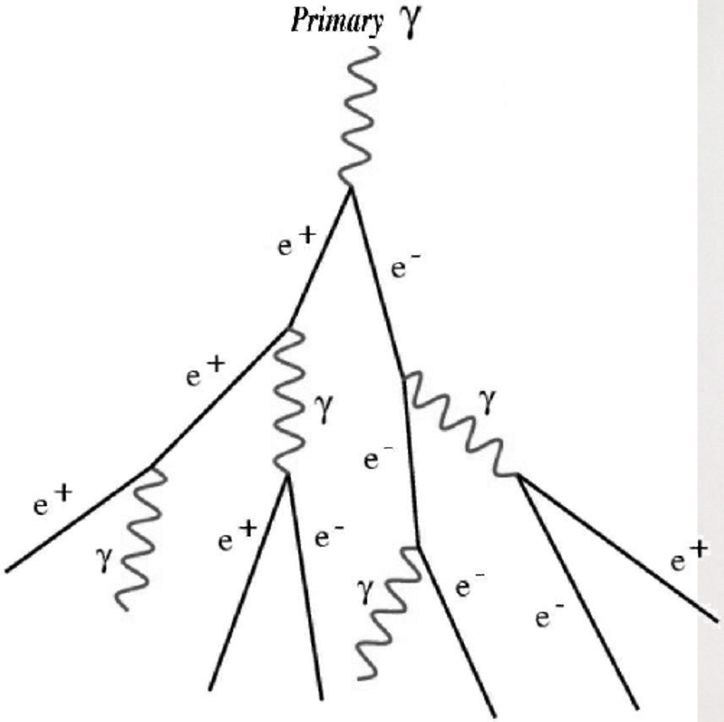
We need to separate this…

From this…

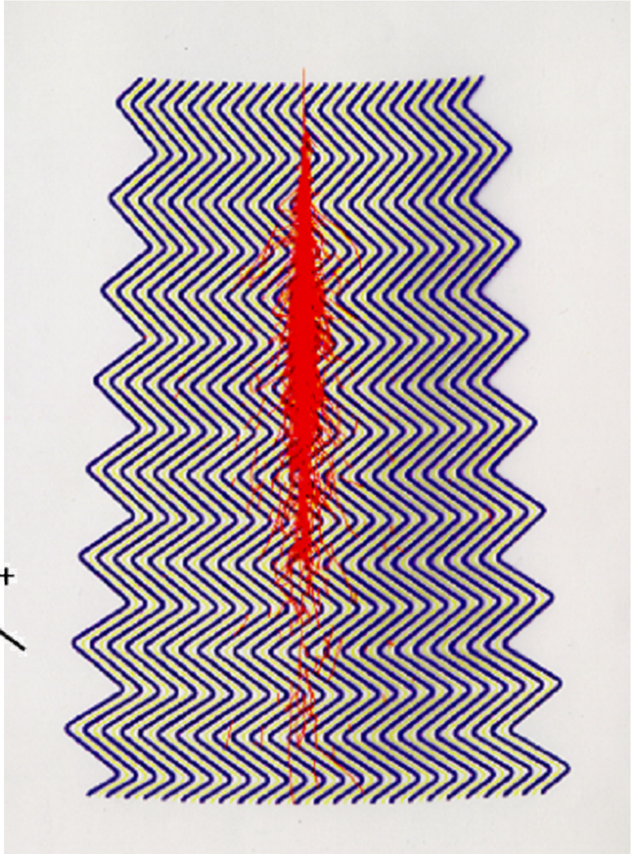


Only a small fraction of jets can mimic a photon – but there are a lot of jets!

Identifying Photons: Basics of Calorimeter Design



A schematic of an electromagnetic shower



A GEANT simulationof an electromagnetic shower

Not too much or too little energy here.

You want exactly one photon – not 0 (a likely hadron) or 2 (likely π^0)

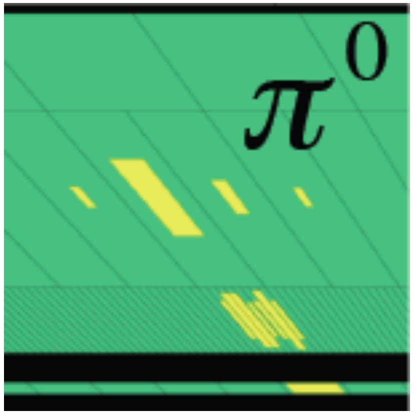
Not too wide here.

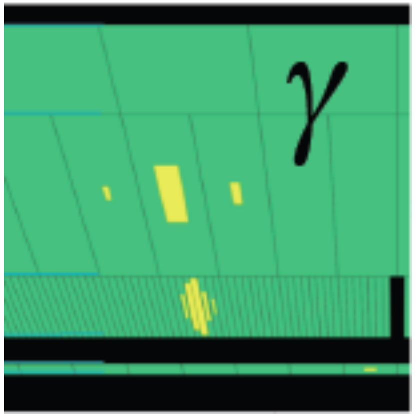
One photon and not two nearby ones (again, a likely π^0)

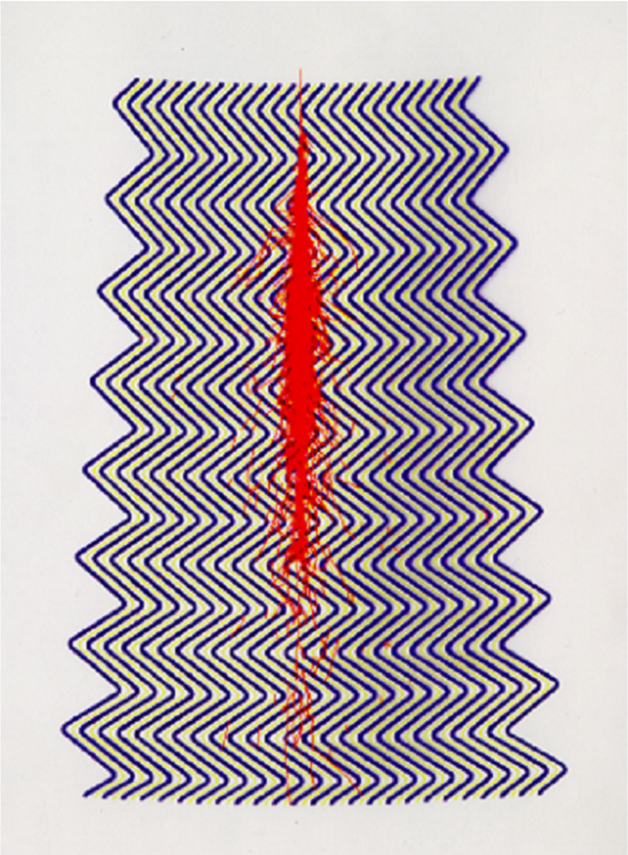
Not too much energy here.

Indicative of a hadronic shower: probably a neutron or K_L.

Identifying Photons: Basics of Calorimeter Design







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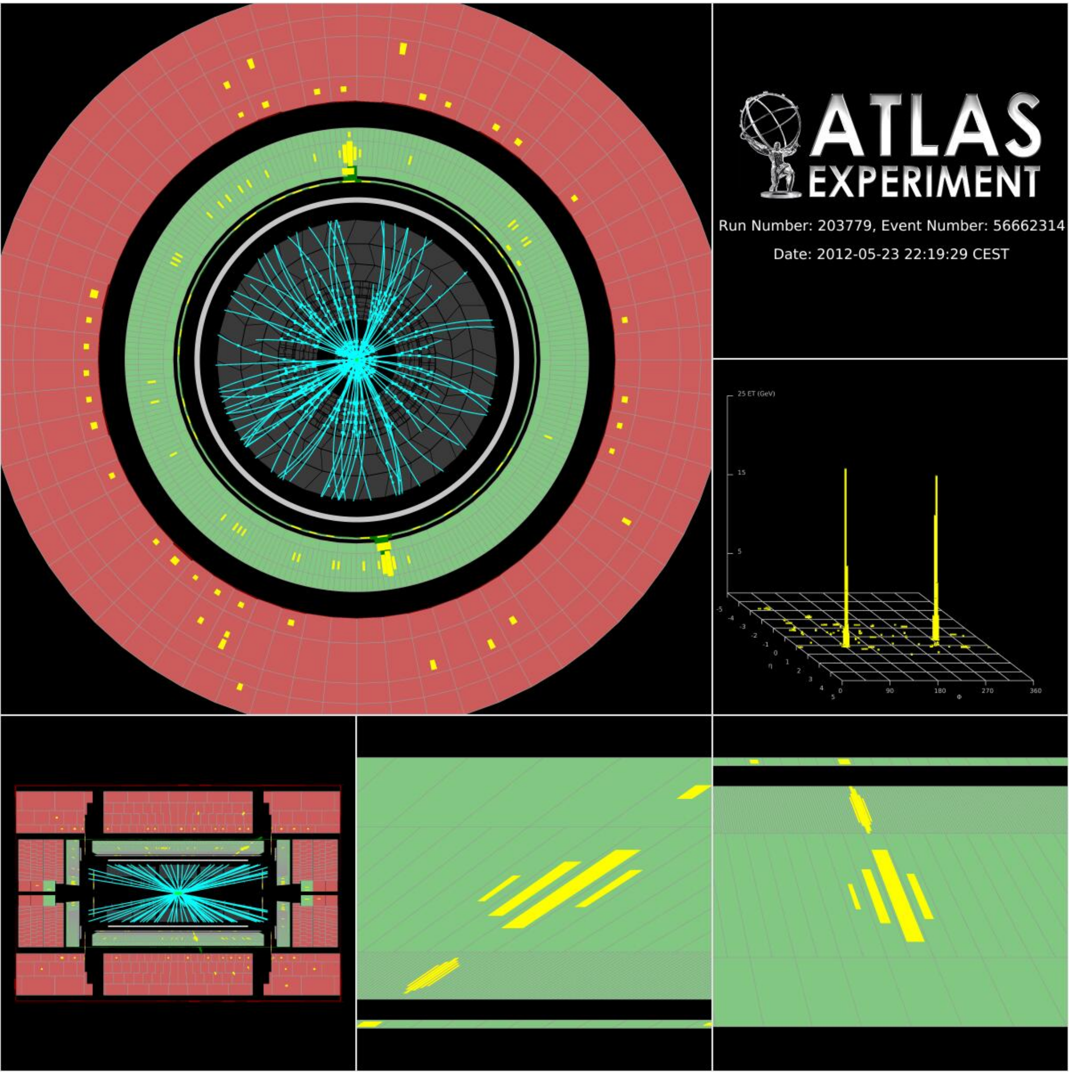
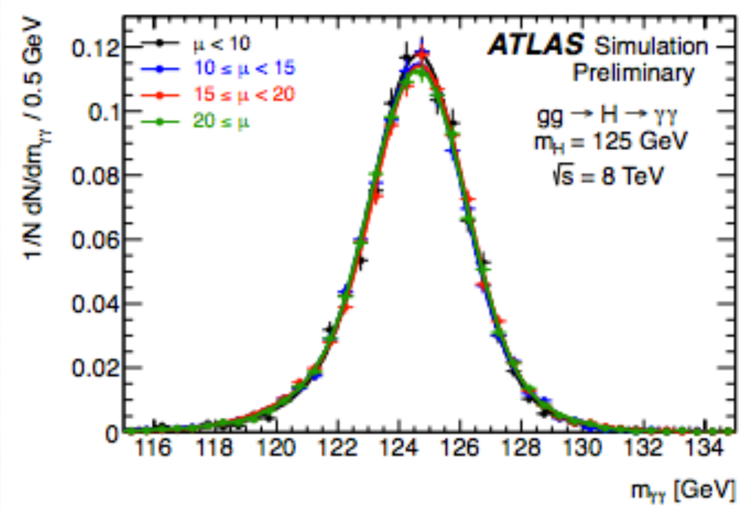
Indicative of a hadronic shower: probably a neutron or K_L.

A ~~Typical~~ Pretty Two Photon Event



- Photons are obvious, even with pile-up

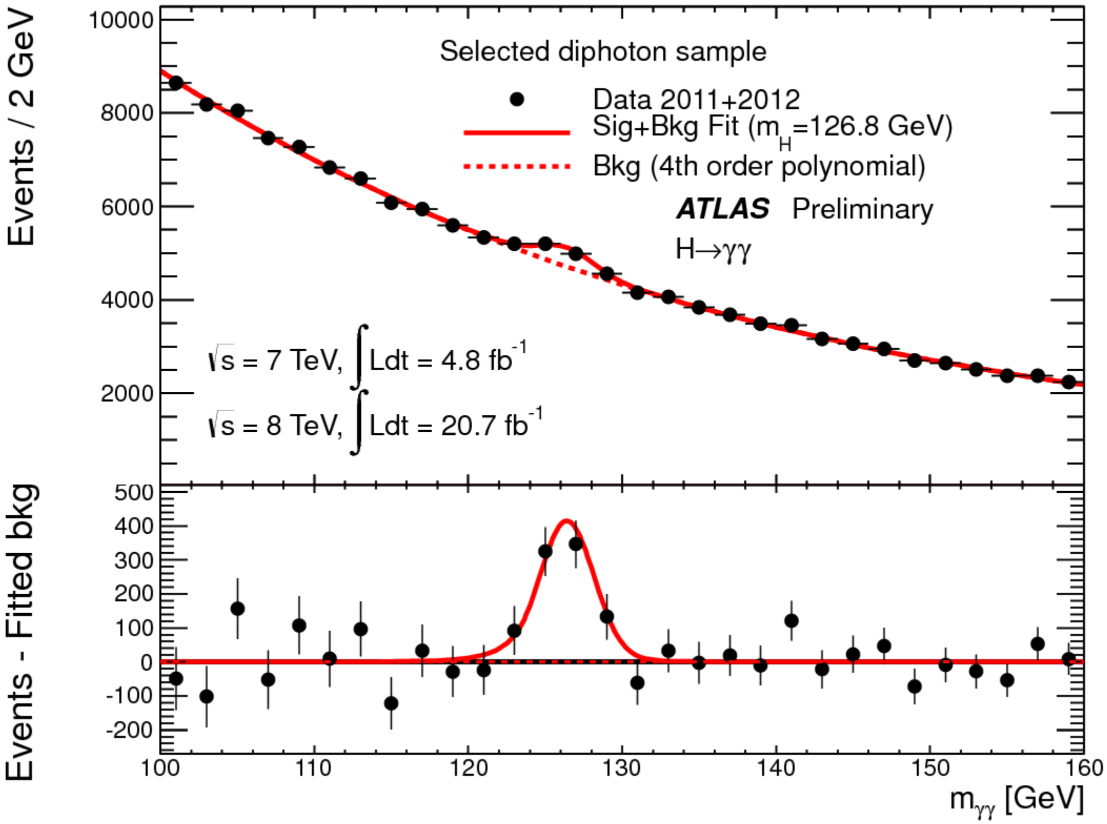


- One can see how the EM showers can be used to point back to the primary vertex

Result of the ATLAS Search for H→γγ

Full dataset

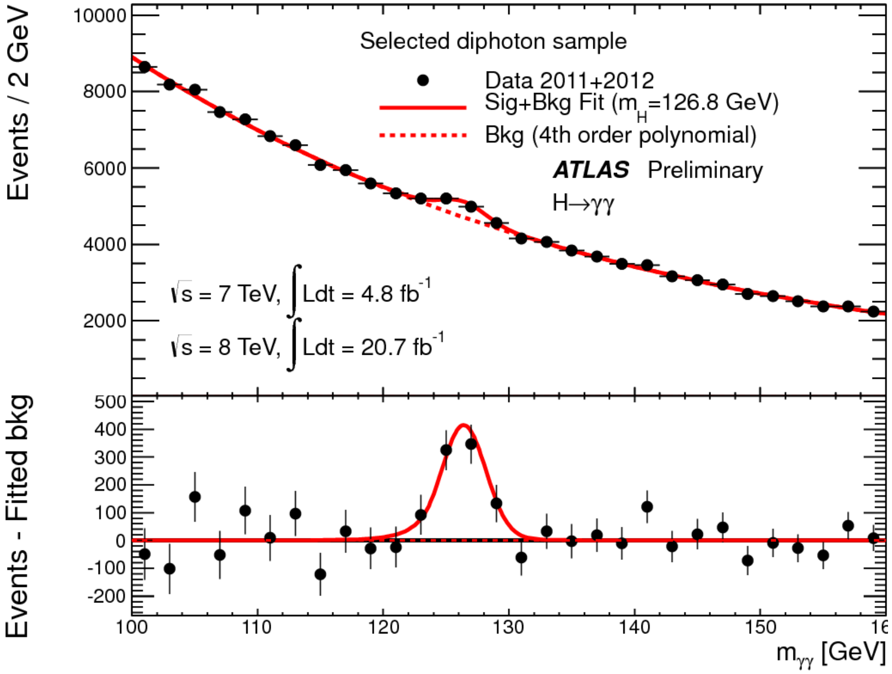
ATLAS-CONF-2013-012



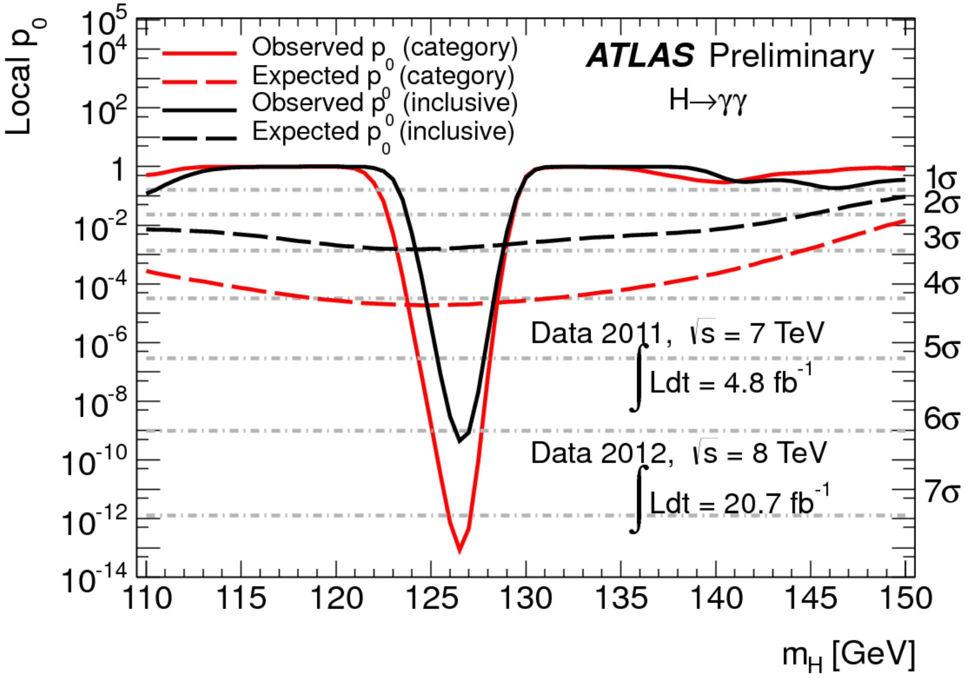
Background interpolation in the region of the excess (obtained from sidebands)
Reducible g+jet and jet-jet background at the level of 25%

Result of the ATLAS search for H→γγ

Full dataset ATLAS-CONF-2013-012



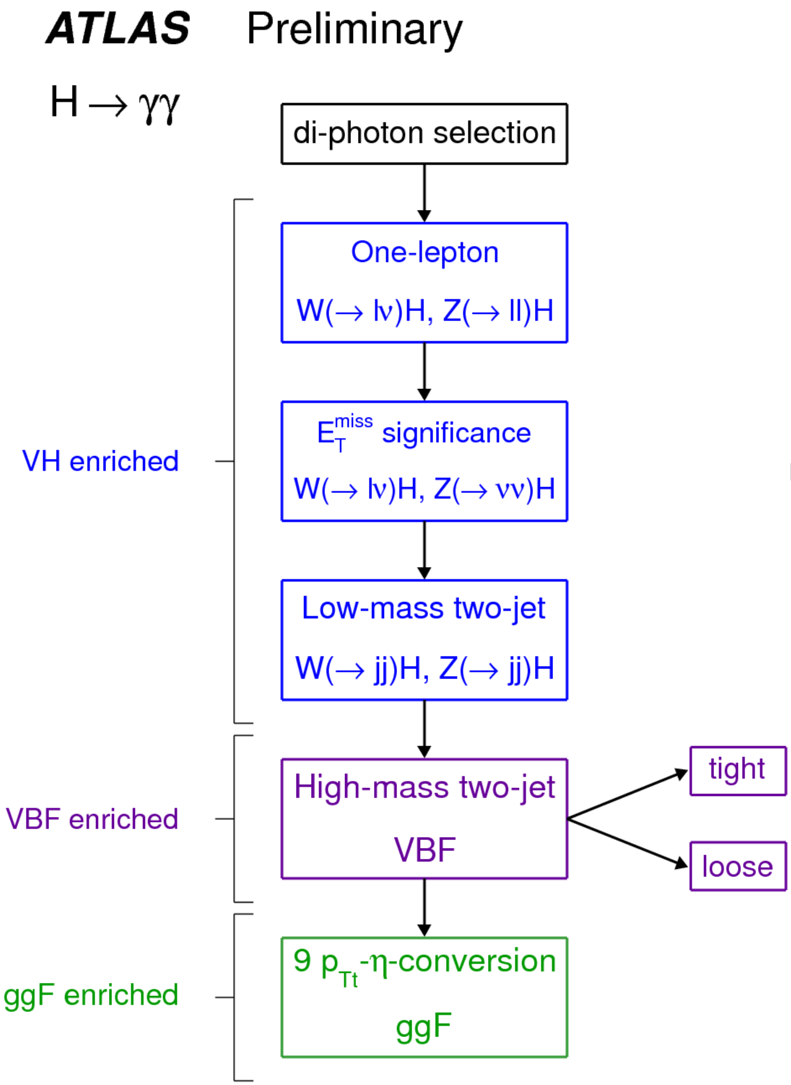
This plot asks the question "Could μ=0?"
It shows the probability of this.



p_0 value for consistency of data with background-only: ~10^{-13} (7.4σ observed)
For the combined 7 TeV and 8 TeV data; (4.1σ expected)
(minimum found at $m_{\gamma\gamma}$=126.5 GeV)

Establishes the discovery of the new particle in the γγ channel alone

Categorization of H→γγ Candidate Events



ATLAS Preliminary

H → γγ

di-photon selection

VH enriched

One-lepton

W(→ lν)H, Z(→ ll)H

E_T^{miss} significance

W(→ lν)H, Z(→ νν)H

Low-mass two-jet

W(→ jj)H, Z(→ jj)H

VBF enriched

High-mass two-jet

VBF

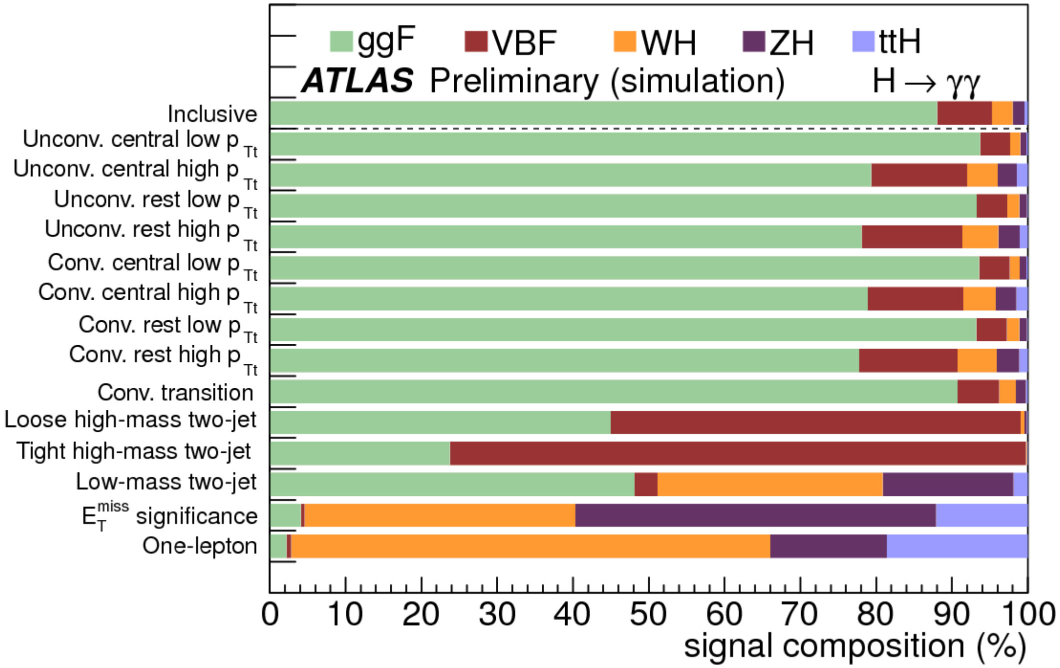
tight

loose

ggF enriched

9 p_{Tt}-η-conversion

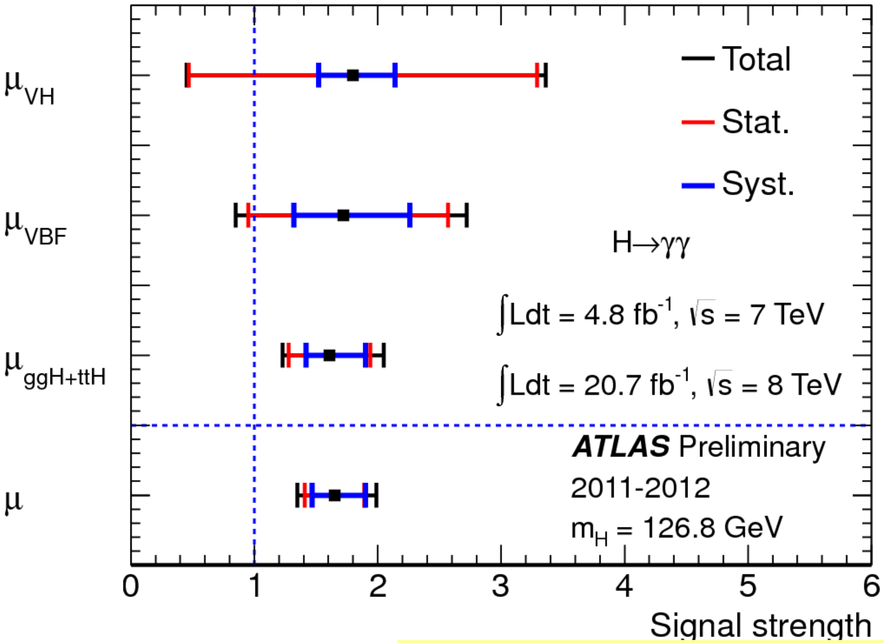
ggF

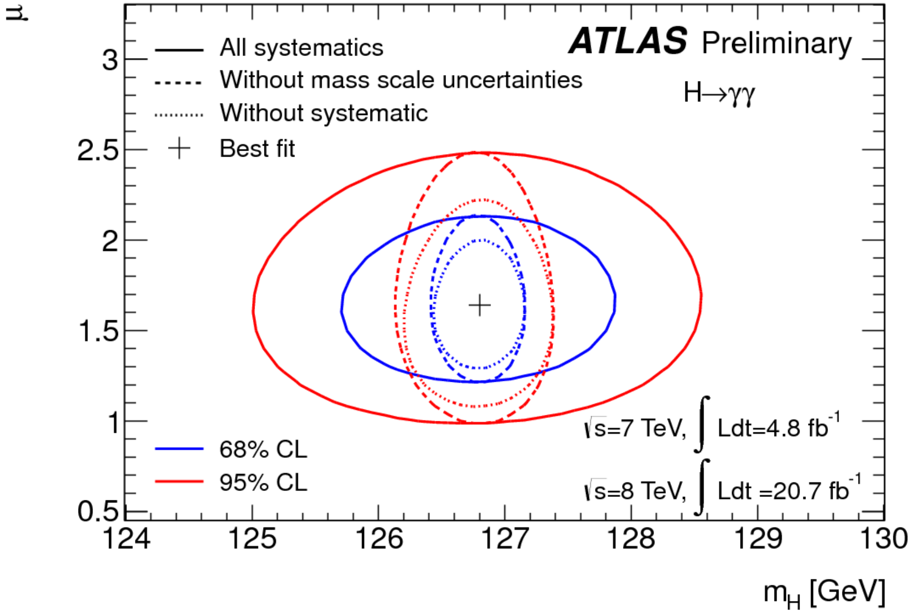


- VH enriched: one-lepton, E_T^{miss}, low-mass di-jets
- VBF enriched: tag-jet configuration, $\Delta\eta_{jj}$,m_{jj}
- Gluon fusion: 9 categories, exploit different mass resolution for different detector regions, γγ conversion status and p_T

Mass and Signal Strength

Measured signal strengths $\mu_{ggF+ttH}$, μ_{VBF} and μ_{VH} for the different $H\rightarrow\gamma\gamma$ production modes, as well as overall strength μ.

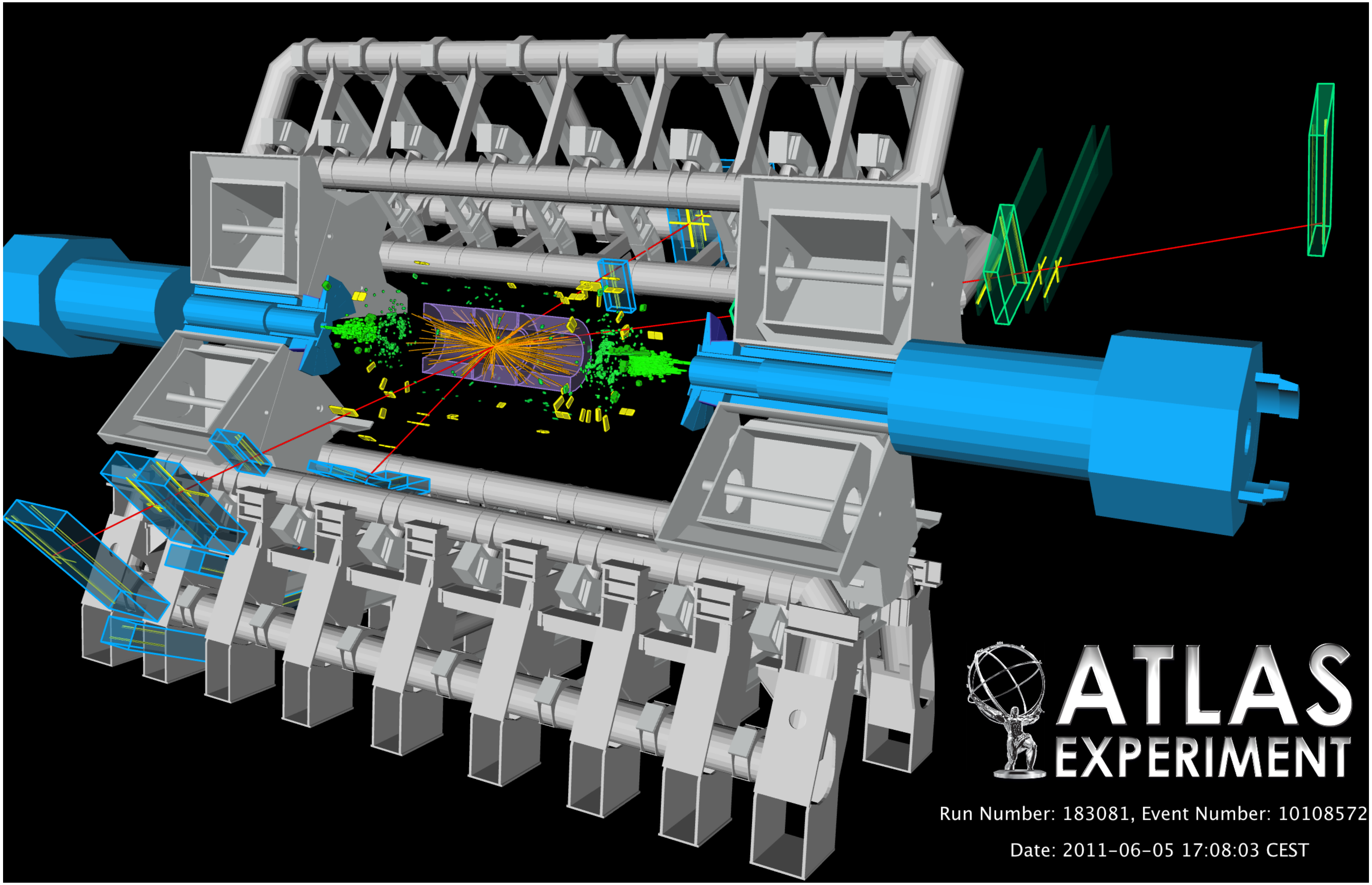




$$m_H = 126.8 \pm 0.2\ (\text{stat}) \pm 0.7\ (\text{syst})\ \text{GeV}$$

$$\mu := \sigma / \sigma_{SM} = 1.57 \pm 0.22 (\text{stat})^{+0.24}_{-0.18} (\text{syst})$$

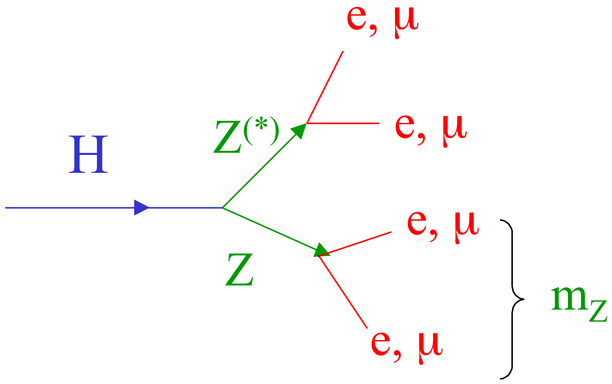
$H \rightarrow ZZ^{*} \rightarrow 4\ell$



Run Number: 183081, Event Number: 10108572

Date: 2011-06-05 17:08:03 CEST

$H \rightarrow ZZ^* \rightarrow 4\ell$



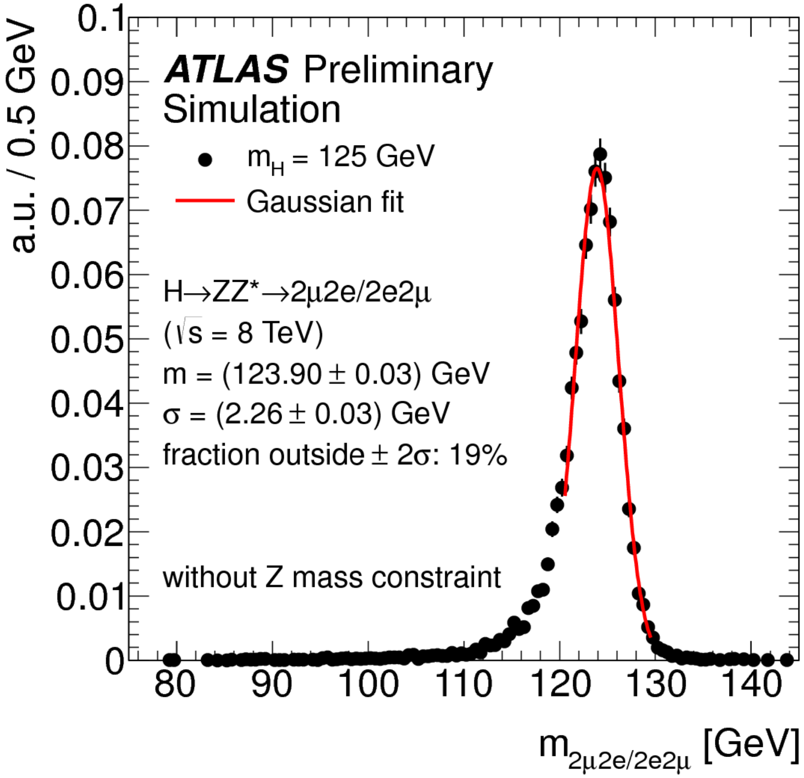
Mass of the Higgs boson can be reconstructed $m_{4\ell}$

Good mass resolution $m4\ell$;
For m_H = 125 GeV:
4e: ~2.7 GeV
4μ: ~2.0 GeV

- "Gold-plated" channel for Higgs discovery at LHC
- Select events with 4 high-p_T leptons (τ excluded): $e^+e^- \, e^+e^-$, $\mu^+\mu^- \, \mu^+\mu^-$, $e^+e^- \, \mu^+\mu^-$
- Require at least one lepton pair consistent with Z mass
- Plot 4ℓ invariant mass distribution :

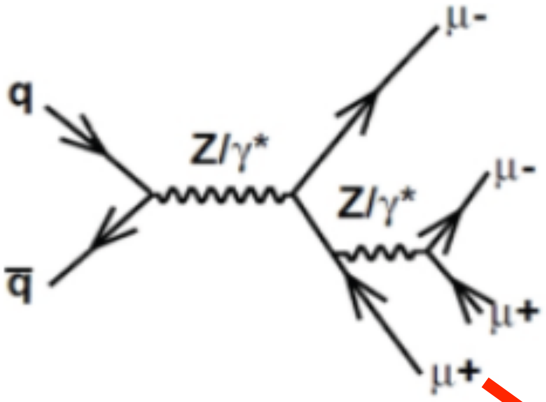
$$m^2 = \sum_i E_i^2 - (\sum_i \vec{p}_i)^2$$

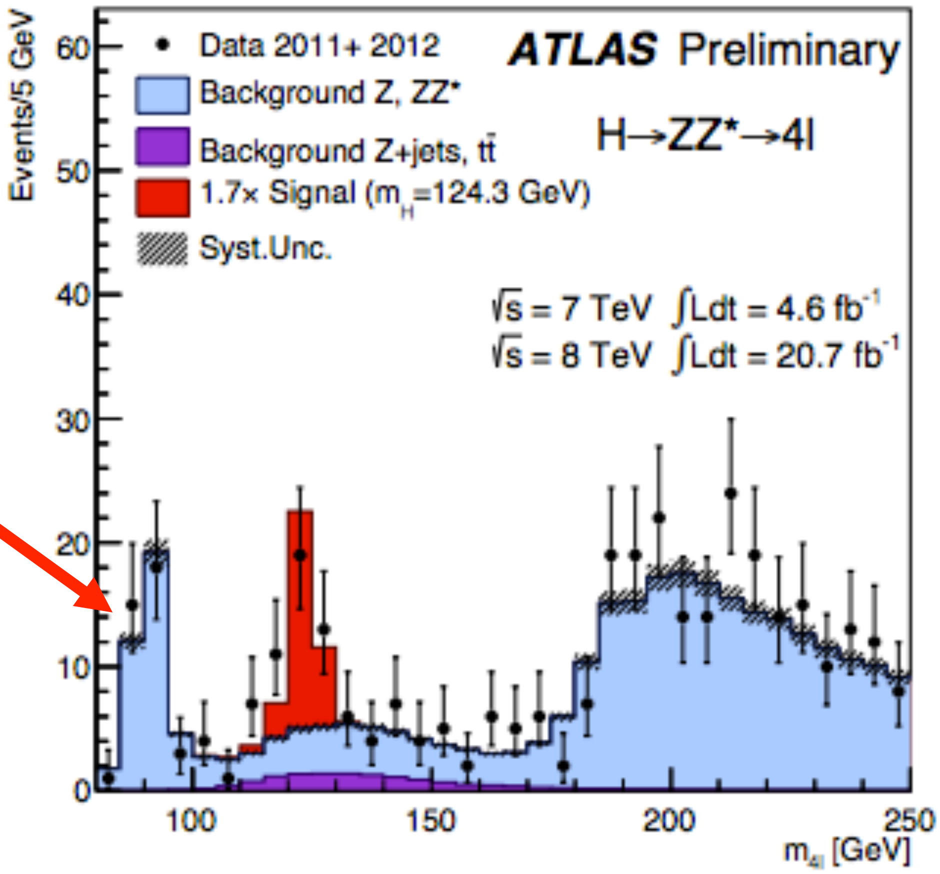
⇒ Higgs signal should appear as peak in the mass distribution



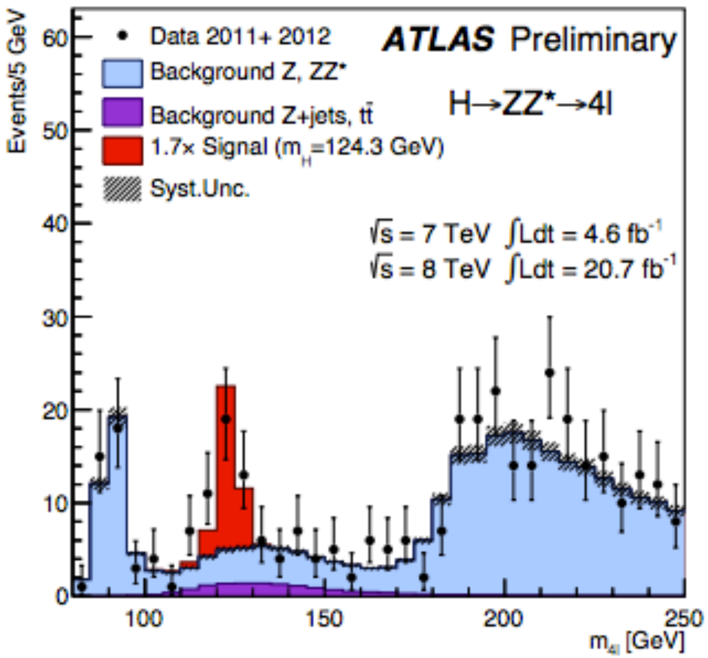
4ℓ Invariant Mass Spectra

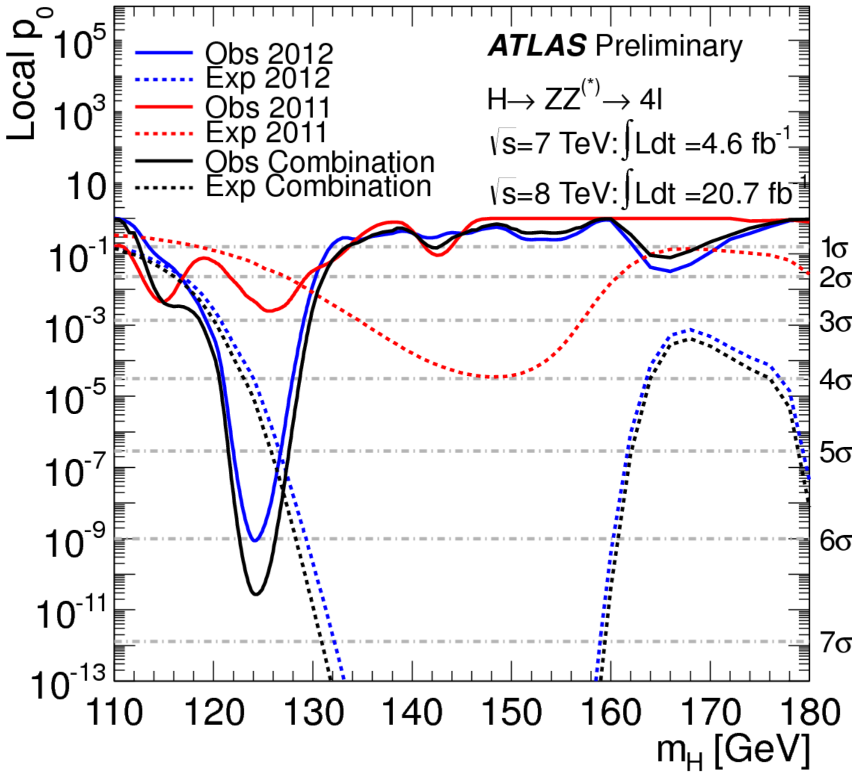
- The background is almost entirely ZZ and ZZ*
  - Except under the peak at 125GeV





4ℓ Invariant Mass Spectra





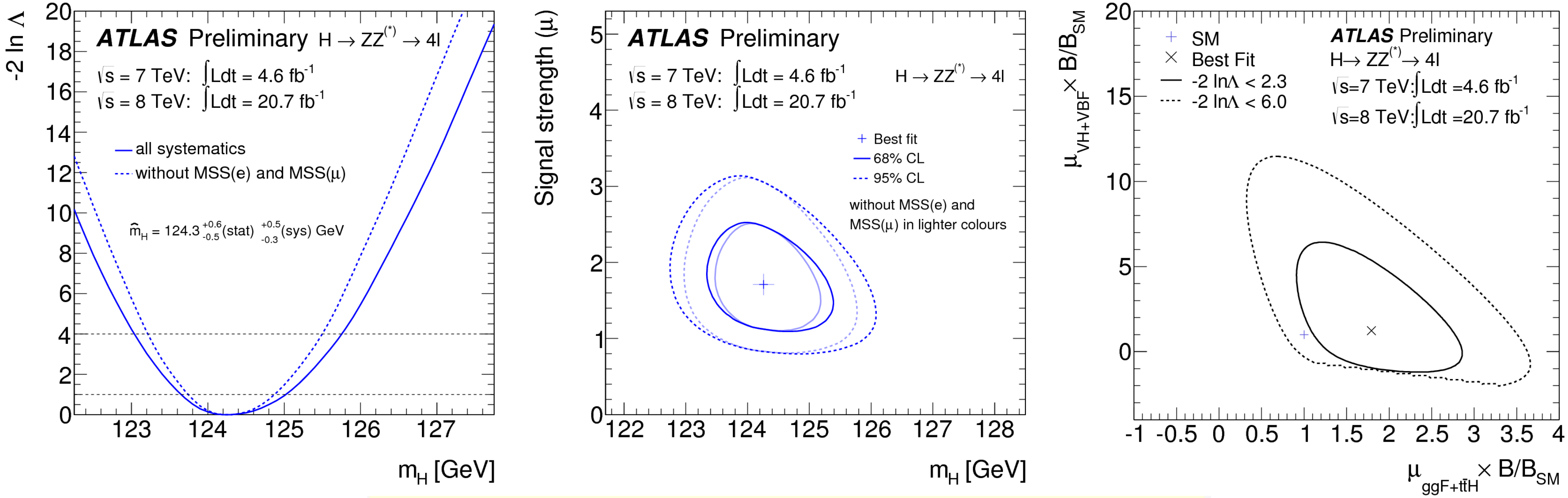
Mass range 120 – 130 GeV	Expected signal	Background	Data
√s = 7 TeV	2.2	2.3	5
√s = 8 TeV	13.7	8.8	27

$m_{4\ell}$ > 160 GeV: 376 events observed
348 ± 26 expected from
√s = 7 + 8 TeV background (mainly ZZ)

maximum deviation at 124.3 GeV
p0 value: ~2.7 10^{-11} (6.6σ obs.)
(4.4σ exp.)

- Independent discovery-level observation

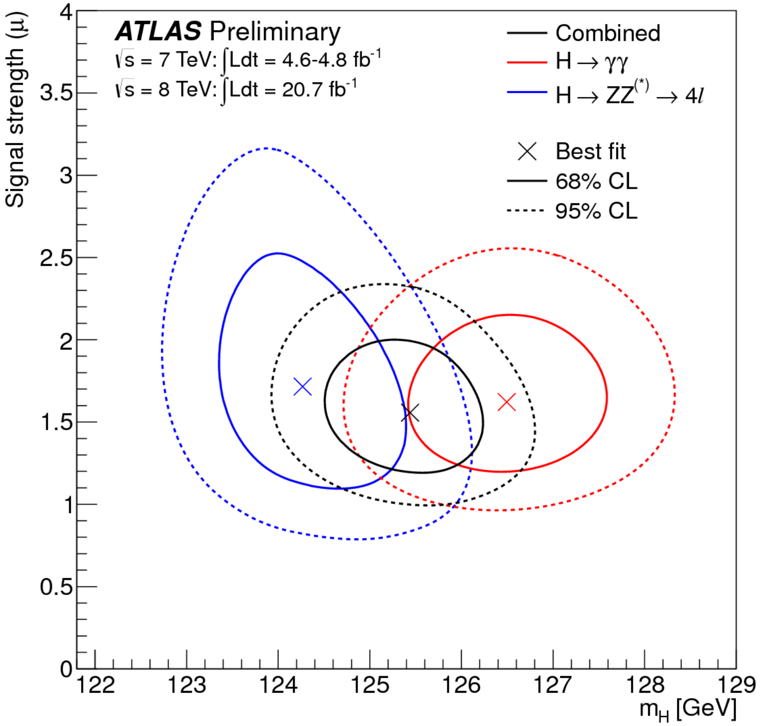
Mass and Signal Strength for H→ZZ*

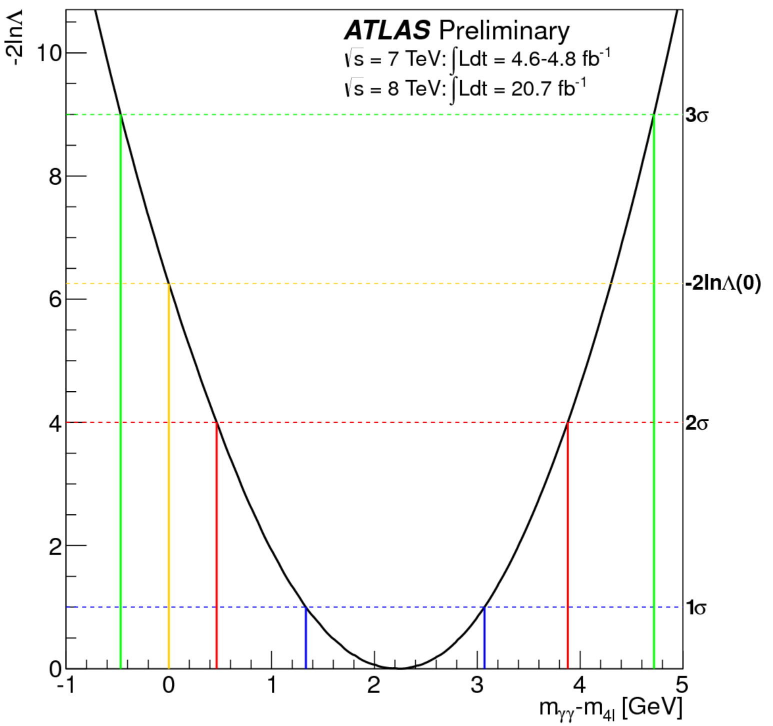


$$m_H = 124.3^{+0.6}_{-0.5}\,(\text{stat})^{+0.5}_{-0.3}\,(\text{syst})\ \text{GeV}$$

$$\mu = 1.7 \pm 0.5$$

Determination of the mass, compatibility of channels





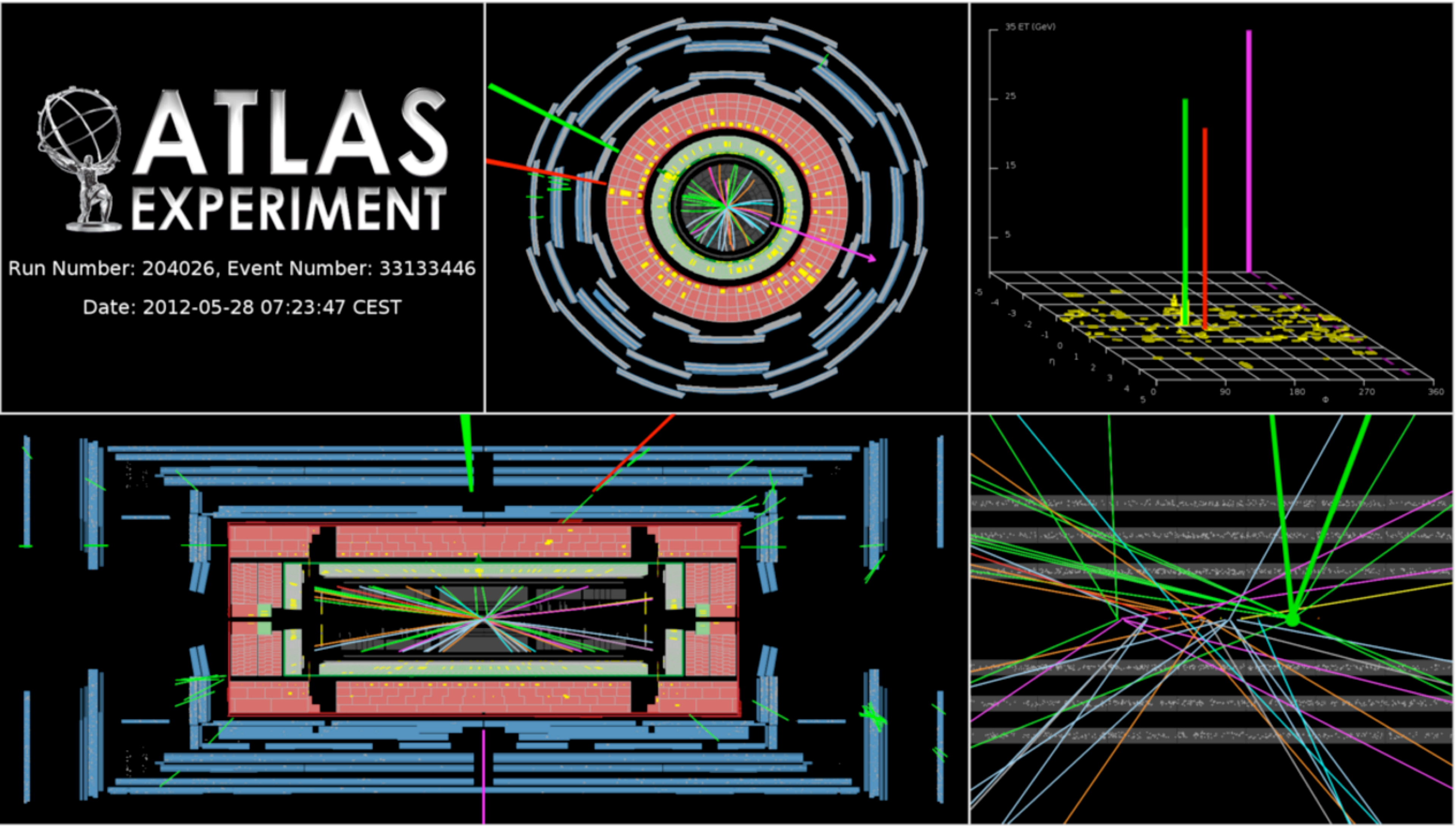
$$m_H = 125.5 \pm 0.2(\text{stat})^{+0.5}_{-0.6}(\text{syst})\ \text{GeV}$$

Consistency between the fitted masses from likelihood value for Δm=0 w.r.t. best fit value for Δm.

$$\Delta m = 2.3^{+0.6}_{-0.7}(\text{stat}) \pm 0.6\ (\text{syst})\ \text{GeV}$$

- Probability for disfavoring the Δm=0 hypothesis by mode than observed: 1.5% (2.4σ)

$H \to WW^* \to \ell\nu\ell\nu$



Run Number: 204026, Event Number: 33133446

Date: 2012-05-28 07:23:47 CEST

$H \rightarrow WW^*$ ($\ell\nu\ell\nu$) – Not as Elementary as It Looks

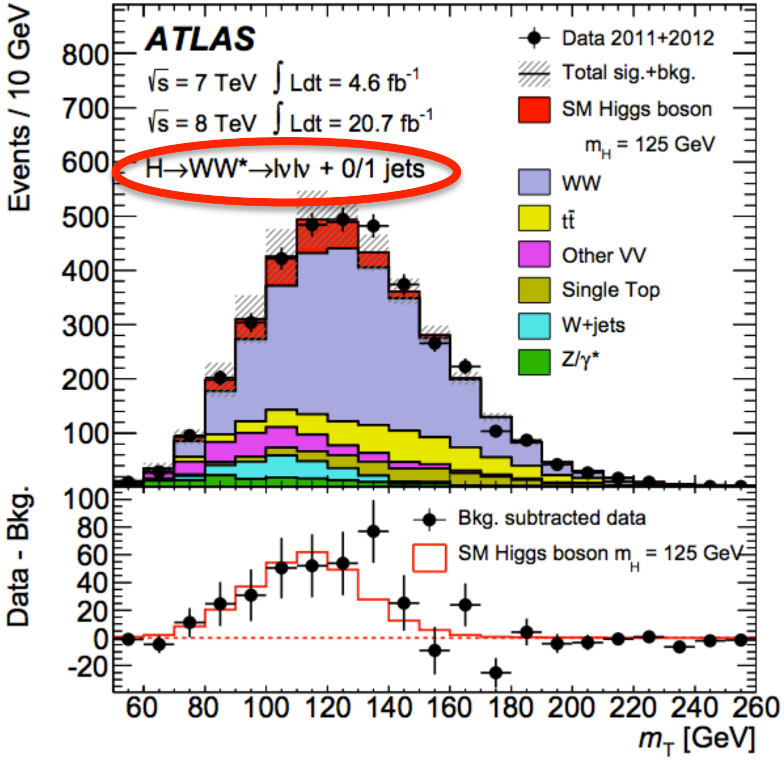
Why is it so hard?

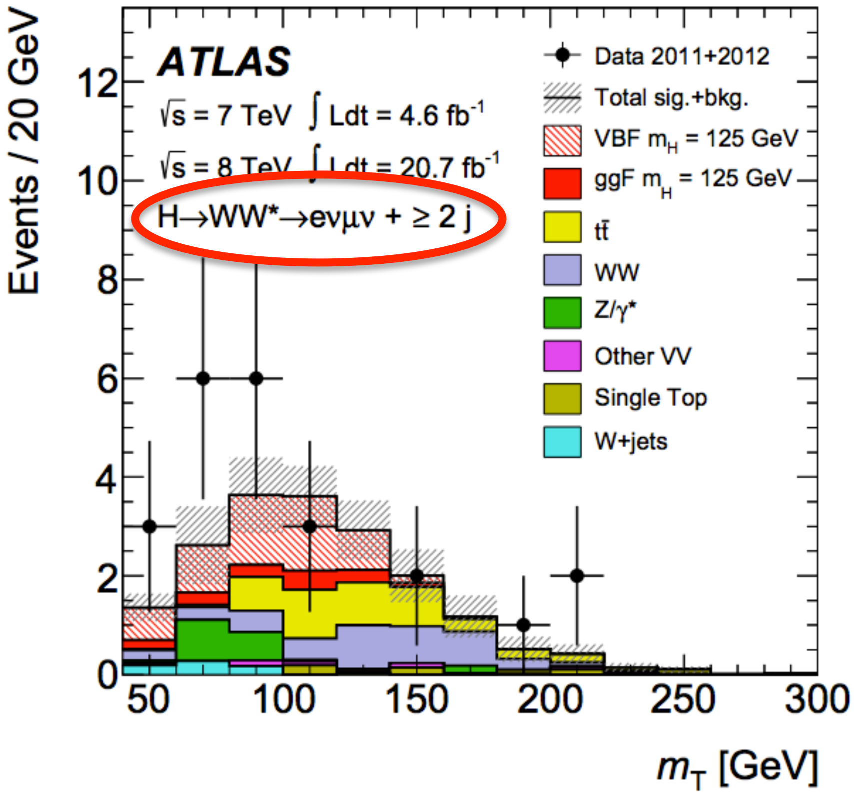
- The two missing neutrinos mean you have poor mass resolution: about 30 GeV
  - Too many unknowns for a mass constraint to help you
  - Use transverse mass
  - Perform analysis in bins of jet multiplicity

- Main Backgrounds (normalization in control regions):
  - WW pair production
  - tt background
  - Z+jets

- This analysis works better at 160 GeV than 125 GeV
  - Can reconstruct the kinematics on both W's

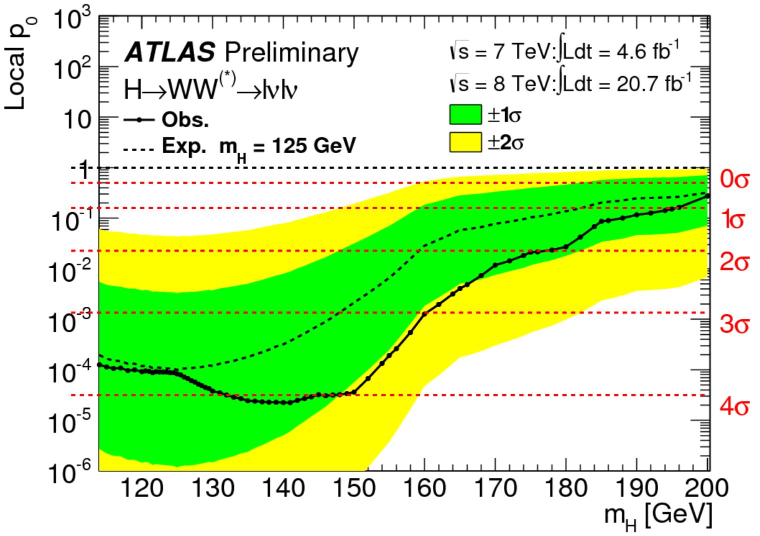
Transverse Mass Distributions





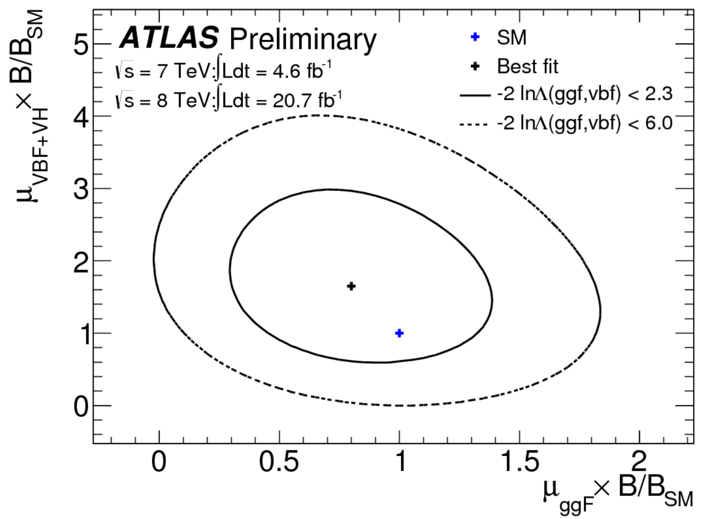
Clear excess above backgrounds in all sub-channels (jet multiplicities)

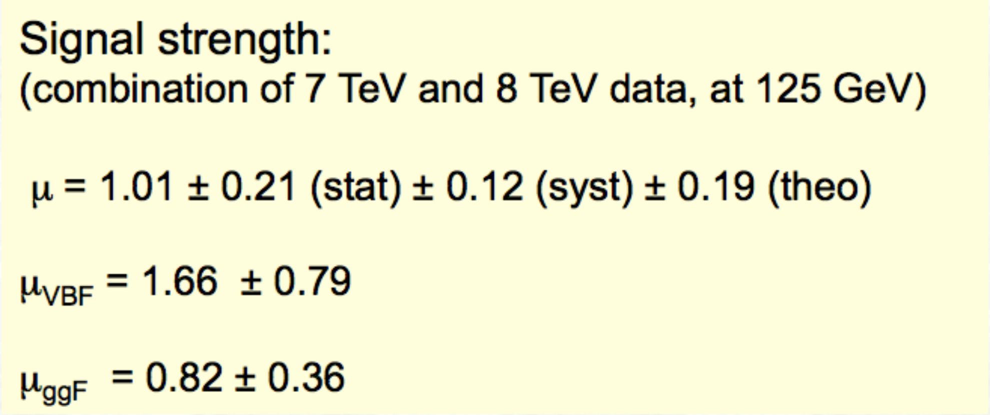
Results on the Search for H→WW* (ℓνℓν) Decays



Shallow minimum of p_0 value at 140GeV

p_0 (125 GeV) = 8 10^{-5} (3.8σ observed)
(3.7σ expected)





Signal strength:
(combination of 7 TeV and 8 TeV data, at 125 GeV)

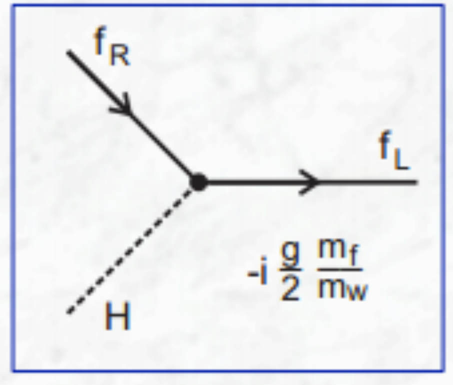
$\mu = 1.01 \pm 0.21$ (stat) ± 0.12 (syst) ± 0.19 (theo)

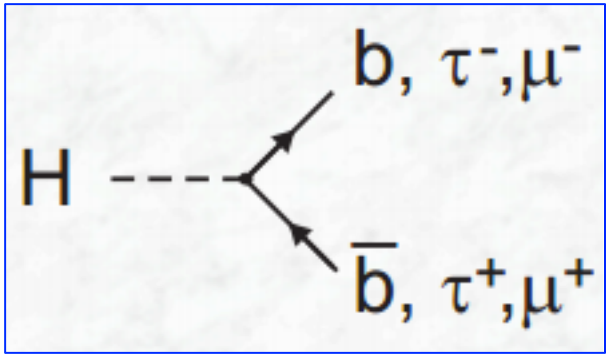
$\mu_{VBF} = 1.66 \pm 0.79$

$\mu_{ggF} = 0.82 \pm 0.36$

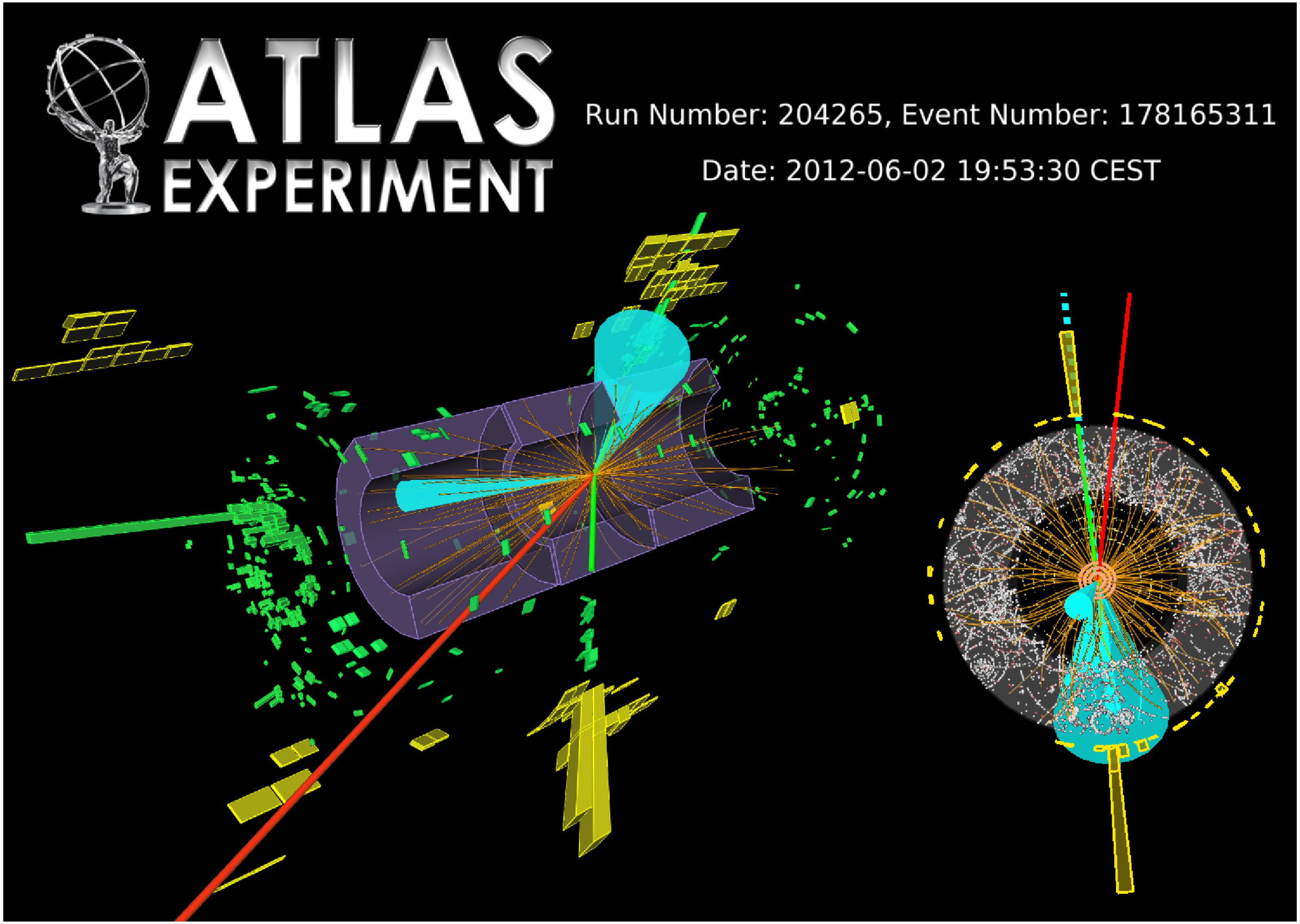
Couplings to Quarks and Leptons?

- Search for H→ττ and H→bb decays
- Search for the (rare) H→μμ decay (not discussed in this talk)

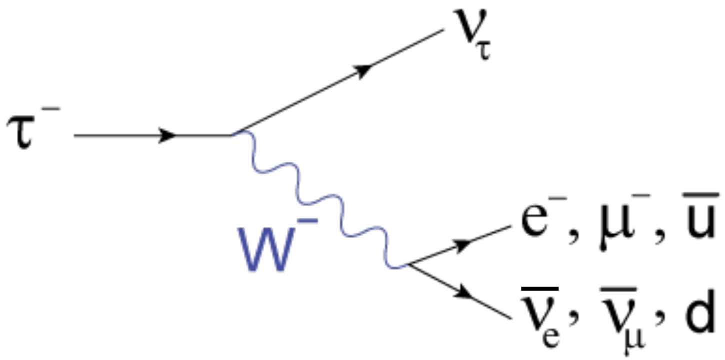




Search for $H \rightarrow \tau\tau$ Decays



Identification of τ_h Decays



⇒ Mass: ≈ 1.8 GeV

⇒ Lifetime: 291×10^{-15} s

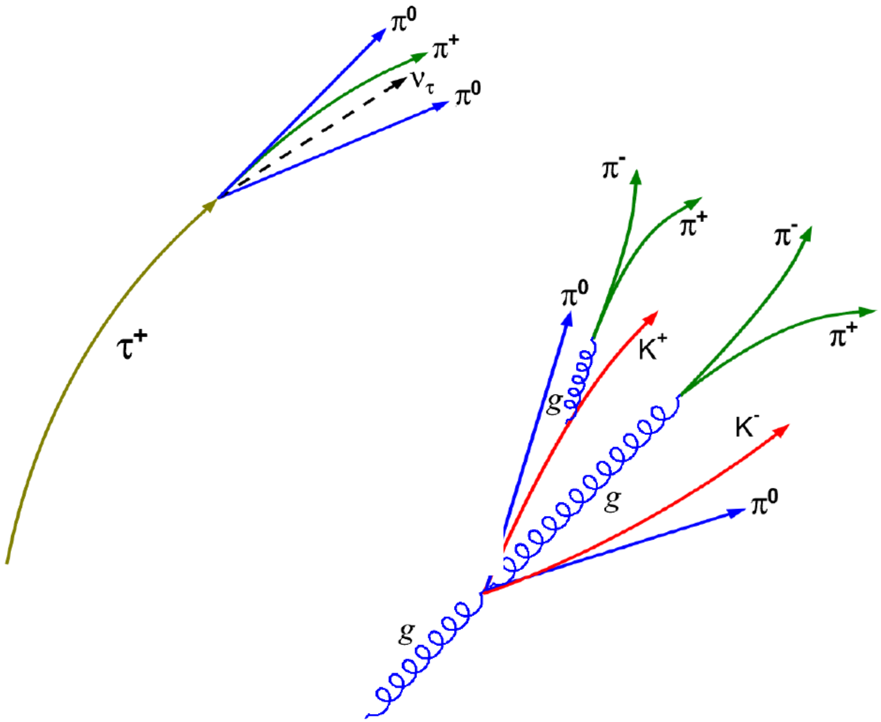
⇒ Decay length: ≈ 87 μm

⇒ **Identification through its decay products**

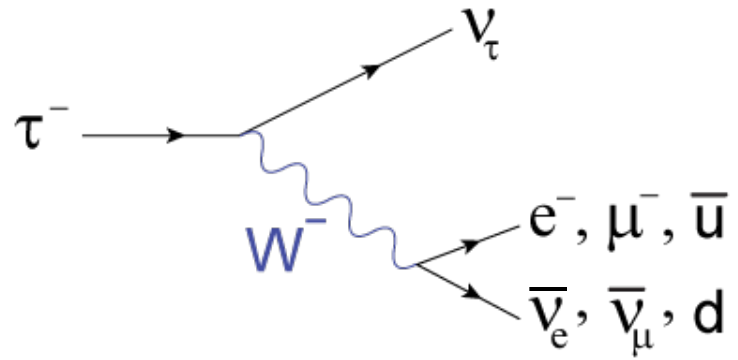
Discrimination of τ_h from QCD Jets?

Hadronic τ decay (~2/3 of **branching ratio):**

- Low track multiplicity (1 or 3)
- Narrow, collimated jet
- Large electromagnetic component
- High leading-track momentum fraction
- Use multivariate technique to separate τ decays from jets from QCD production



Identification of τ_h Decays



$\Rightarrow$ Mass: ≈ 1.8 GeV
$\Rightarrow$ Lifetime: 291×10^{-15} s
$\Rightarrow$ Decay length: $\approx 87\ \mu$m
$\Rightarrow$ **Identification through its decay products**

Discrimination of τ_h from QCD Jets?

Hadronic τ decay (~2/3 of **branching ratio):**

- Low track multiplicity (1 or 3)
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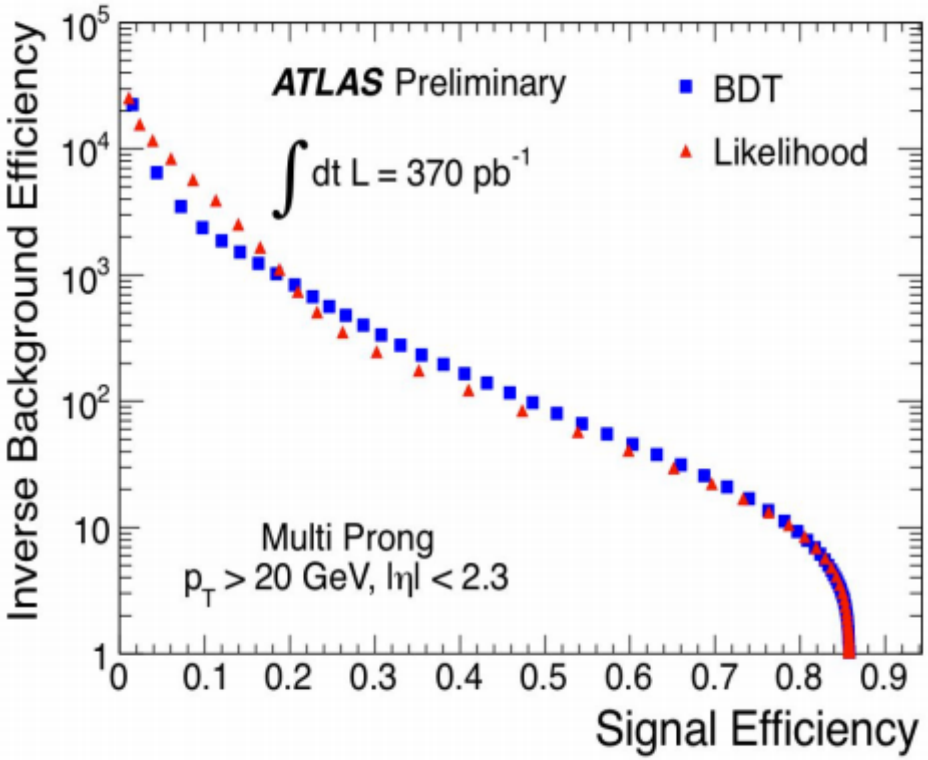
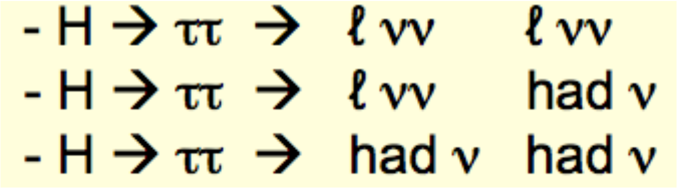


Search for $H \rightarrow \tau\tau$ Decays

- Analysis is split into three sub-channels:



- $H \rightarrow \tau\tau \rightarrow \ell\nu\nu \quad \ell\nu\nu$
- $H \rightarrow \tau\tau \rightarrow \ell\nu\nu \quad \mathrm{had}\,\nu$
- $H \rightarrow \tau\tau \rightarrow \mathrm{had}\,\nu \quad \mathrm{had}\,\nu$

- 2-4 neutrinos in final state, mass reconstruction difficult;
  (Using Missing Mass Calculation*)

- Major background: $Z \rightarrow \tau\tau$ decays;
  Accurate background modeling is very important

- Signal-to-background ratio improves for VBF-topology or high-p_T Higgs ("boosted" category)

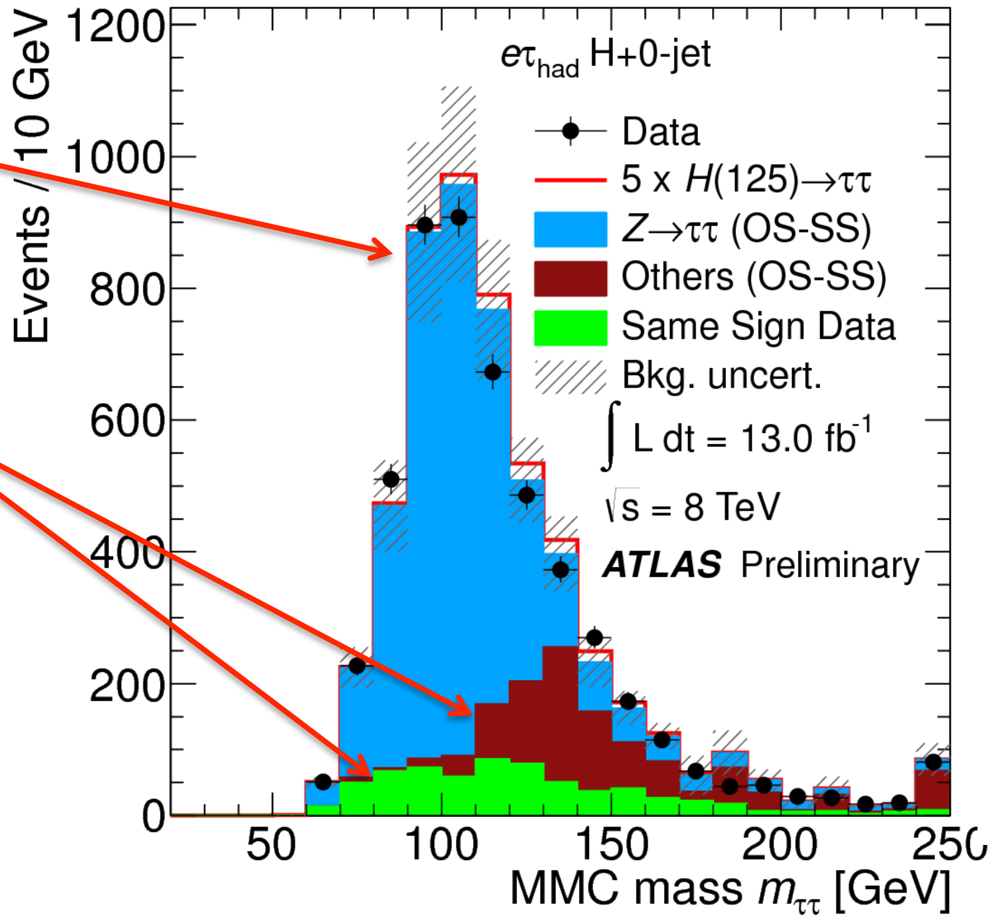
*Nucl. Instrum. Methods A654 (2011) 481

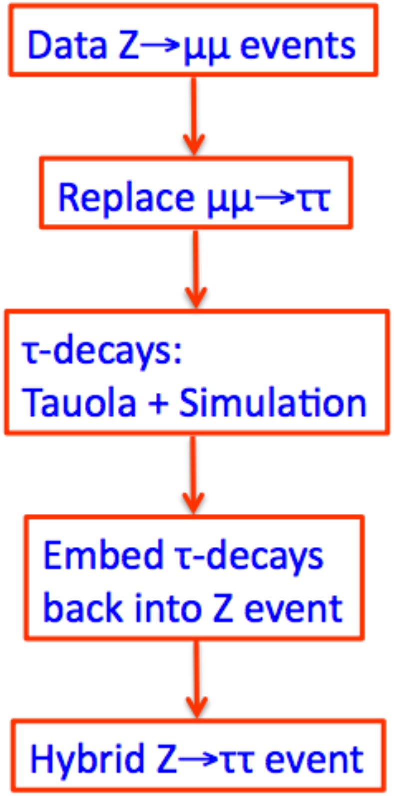
Controlling Major Backgrounds in $H\to\tau\tau$ Decays

$Z\to\tau\tau$:
major background;
modeled by data
(embedding)

"Fakes":
QCD, $Z\to\ell\ell$, W+jets,
top; data-driven or
modeled by data

Di-boson production:
smallest background,
modeled by MC




Data $Z\to\mu\mu$ events

Replace $\mu\mu\to\tau\tau$

τ-decays:
Tauola + Simulation

Embed τ-decays
back into Z event

Hybrid $Z\to\tau\tau$ event

$Z\to\tau\tau$ embedding: except for tau-decays,
all properties of a $Z\to\tau\tau$ event are modeled by actual data

Reconstructed Mass Distributions

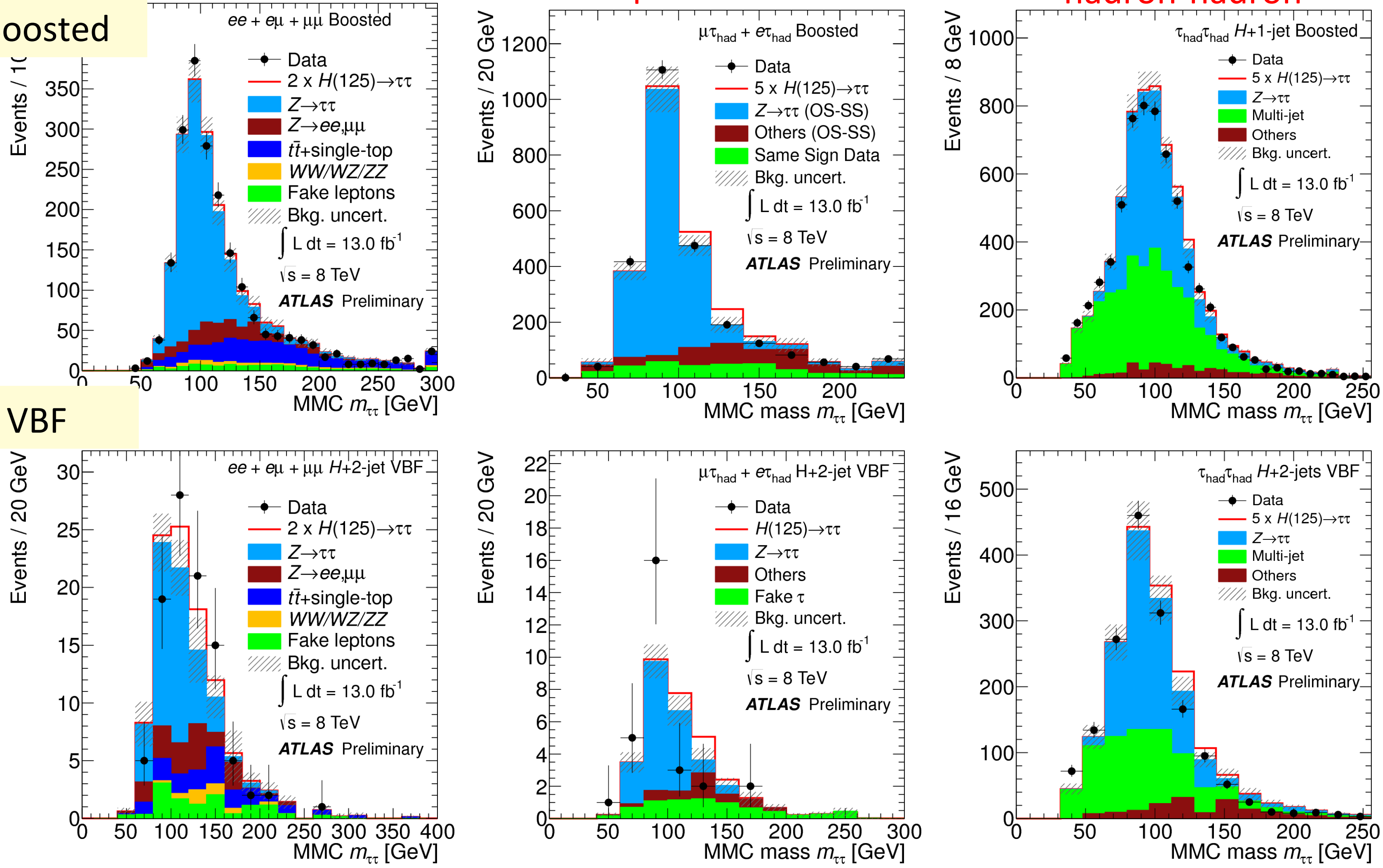
lepton-lepton

lepton-hadron

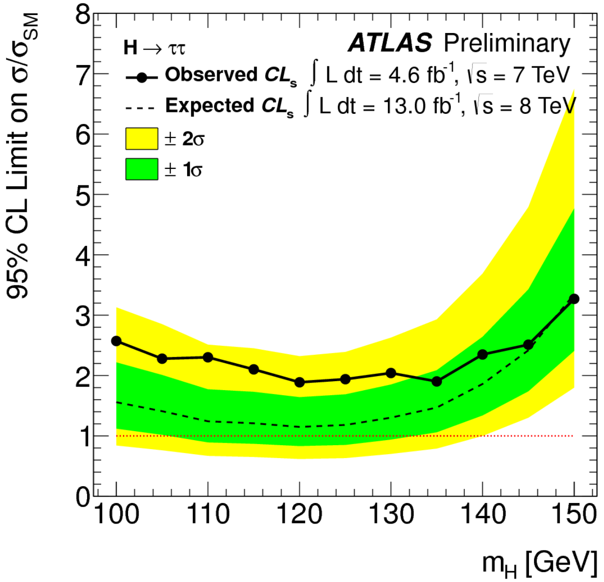
hadron-hadron

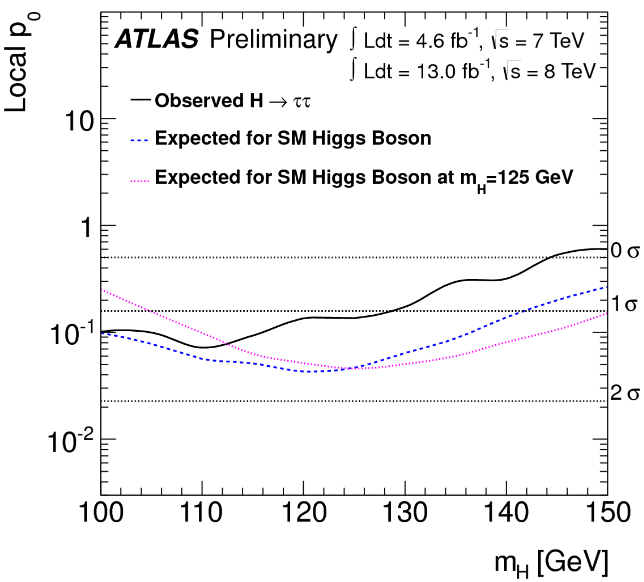
Boosted

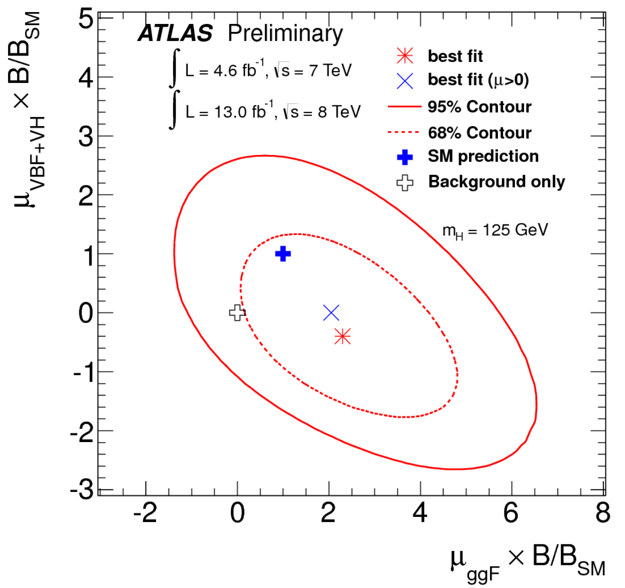
VBF



Results on the Searches for H→ττ Decays







m_H = 125 GeV:

Observed 95% CL: 1.9 σ_{SM}
Expected (no Higgs): 1.2 σ_{SM}

p_0=1.1σ (observed)
p_0=1.7σ (expected)

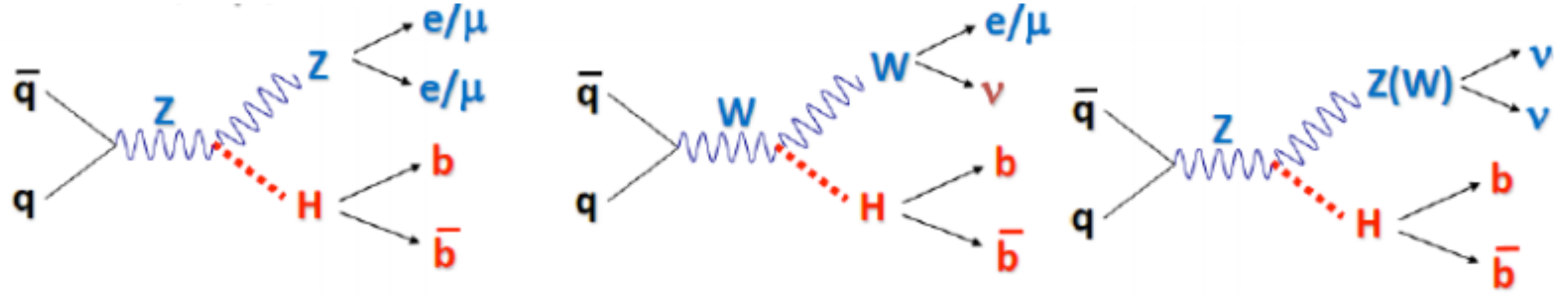
Fitted signal strength (all sub-channels):

$\mu = 0.7 \pm 0.7$

Updated analysis, including the full data sample, expected soon; Major updates expected:

- Improved τ identification performance, τ energy scale uncertainty
- MVA analysis
- Include later on ZH→ℓℓττ and WH→ℓνττ analyses

Search for VH Production in H→bb Decays



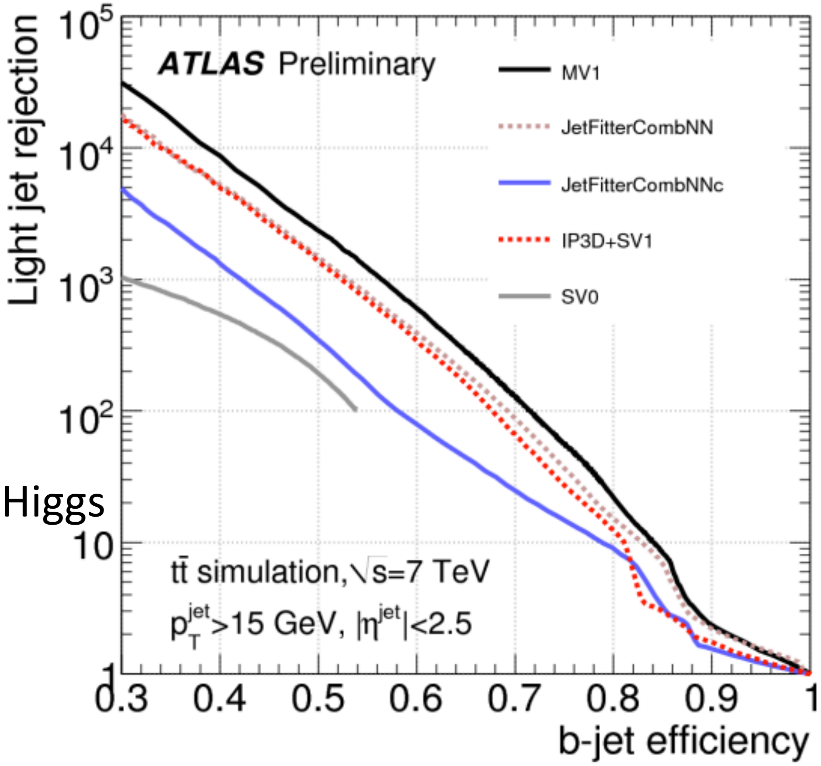
- Exploit three leptonic vector boson decay modes
- ➔ split analysis in 0, 1, and 2-lepton categories

- Require 2 b-tagged jets (work point for 70% efficiency)

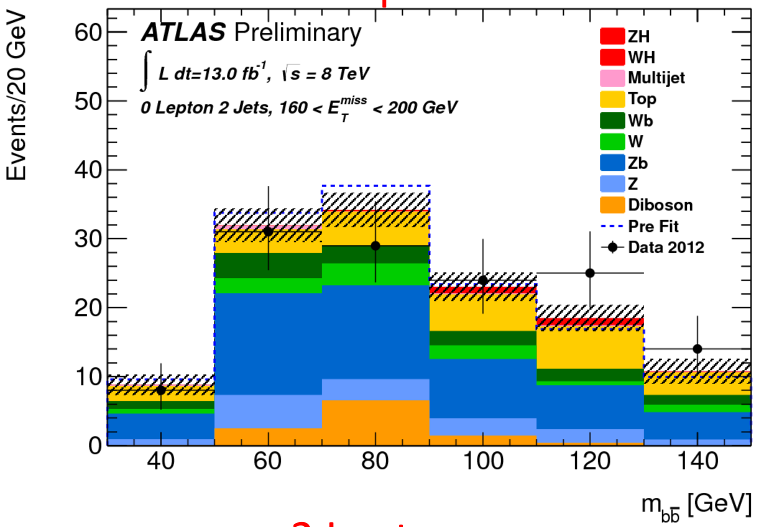
- Major background: W/Z→bb, W+jets, tt

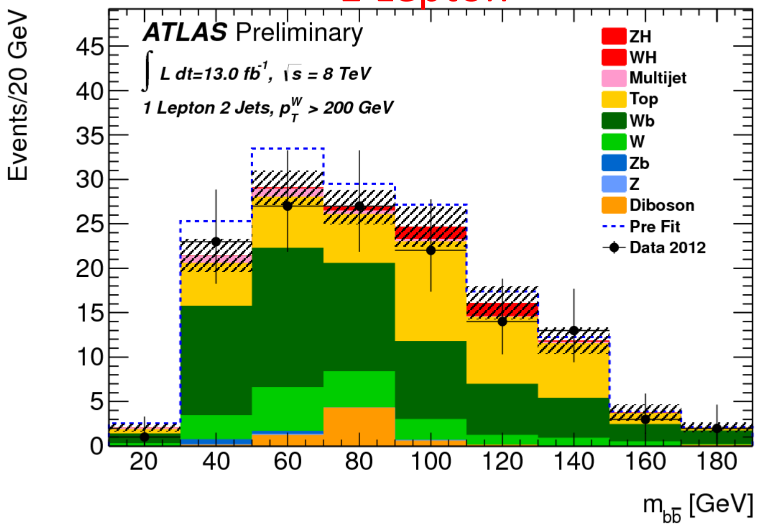
- Signal-to-background ratio improves for “boosted Higgs boson”, split analysis in bins of $p_T(V)$

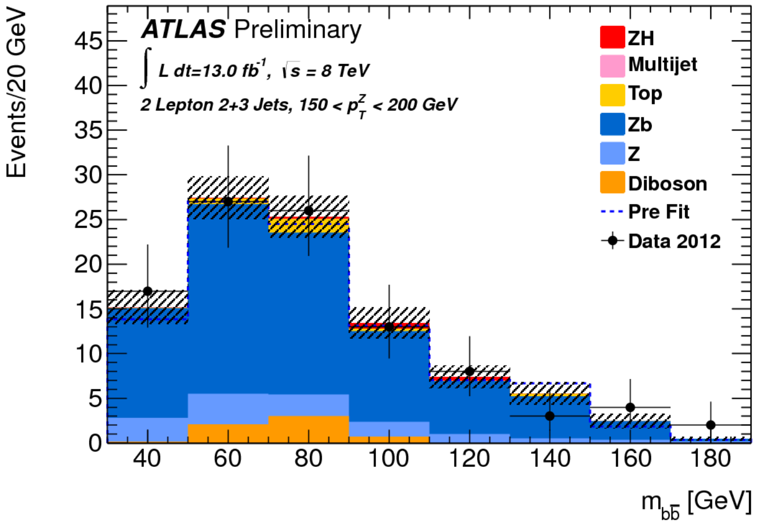
- In total: 15 categories (0,1,2 jets x p_T bins)



Reconstructed Mass Distributions


0 Lepton

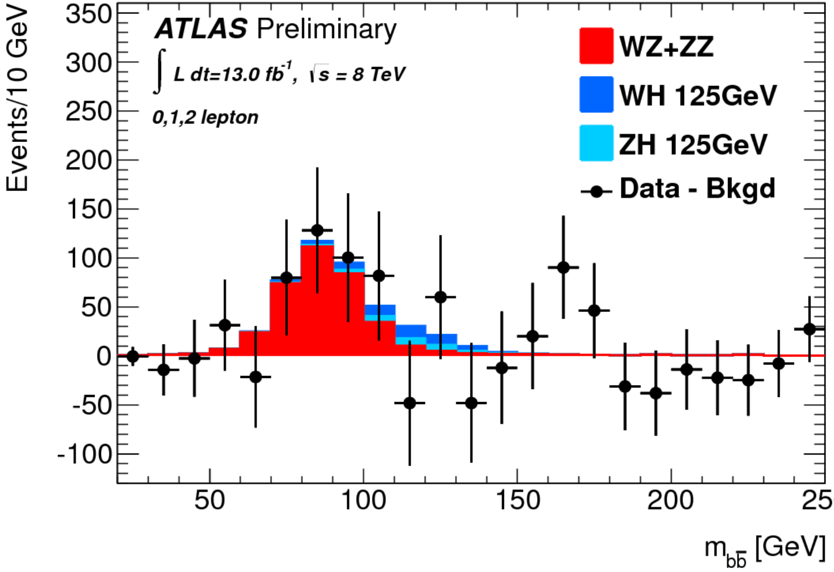

1 Lepton

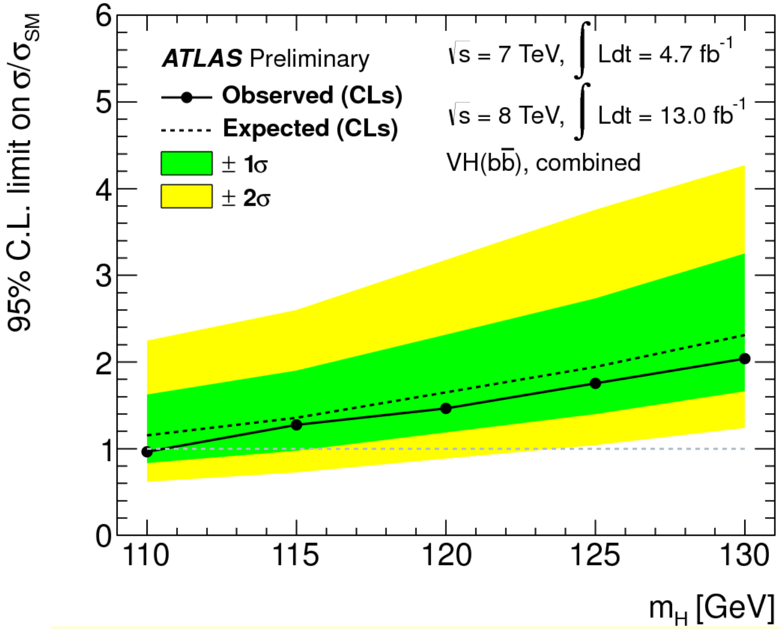

2 Leptons

8 TeV, L=13fb^{-1} (a selection, high p_T bins)

Result on the Search for VH, H⟶bb Decays

Combination: data-background





Di-boson signal established
(important "calibration" signal)

Significance 4.0σ

m_H = 125 GeV:

Observed 95% CL: 1.8 σ_{SM}
Expected (no Higgs): 1.9 σ_{SM}

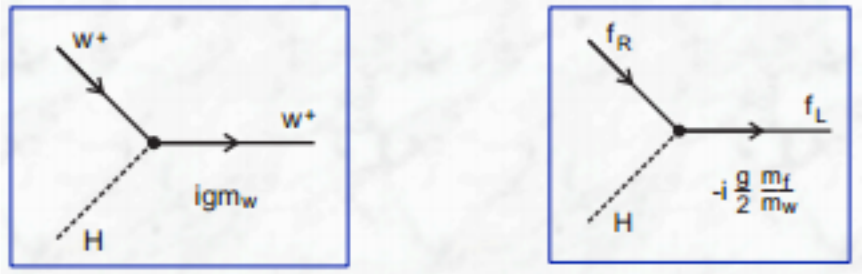
$\mu_{WZ+WW} = 1.09 \pm 0.20$ (stat) ± 0.22 (syst)

$\mu_H = -0.4 \pm 0.7$ (stat) ± 0.8 (syst)

Updated analysis, including the full data sample, expected soon

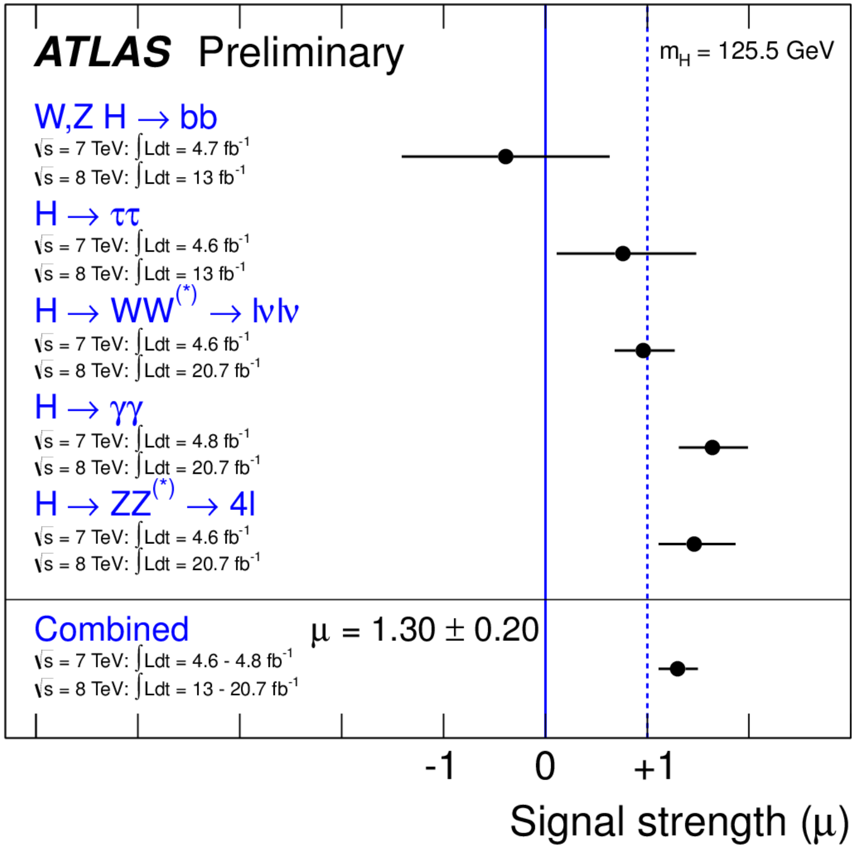
Is the New Particle the Higgs Boson?

- Production Rates?
  Couplings to bosons and fermions



- Spin, J^P quantum number

Signal Strength

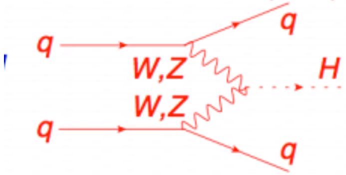


Ratios of production cross sections for the various processes (ggF, VBF, ZH, WH, ttH) fixed to SM values

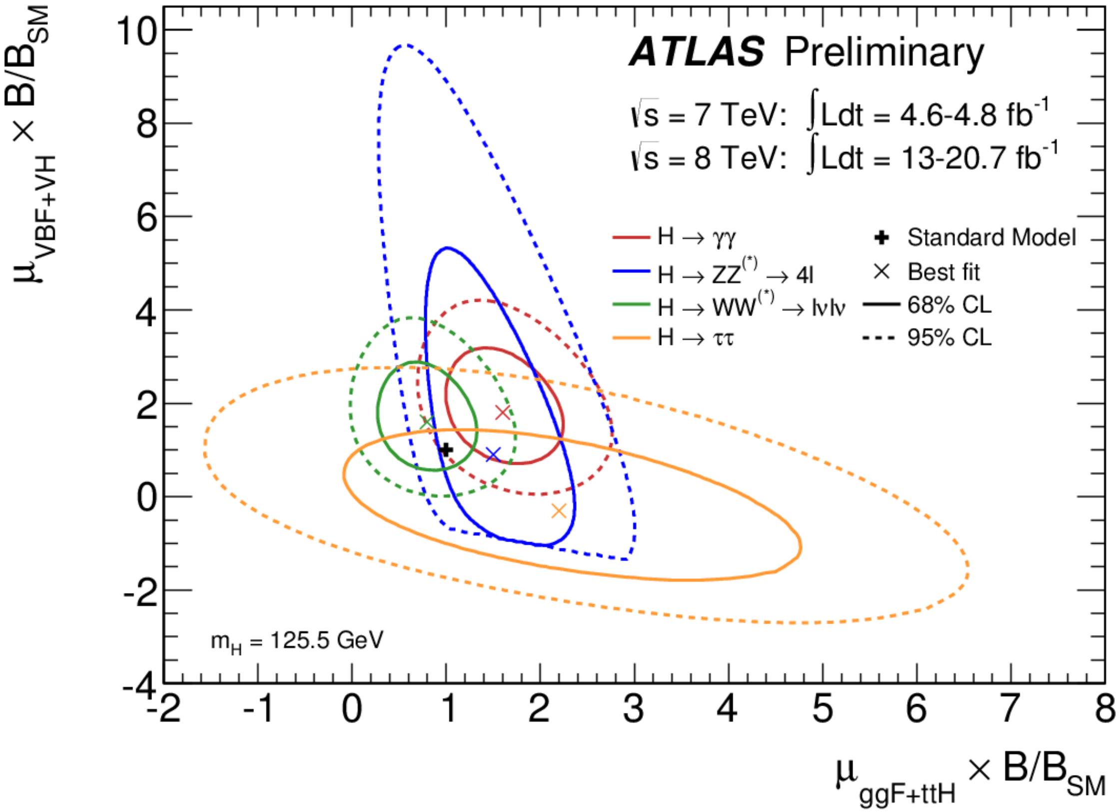
- Data are consistent with the hypothesis of a Standard Model Higgs boson:
    - μ = 1.30 ± 0.20
- Experimental uncertainties are still too large to get excited about “high” γγ signal strength
- Signal strengths in fermionic decay modes have large uncertainties, but are compatible with SM value of 1

Gluon Fusion *vs.* Vector Boson Fusion

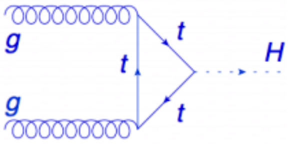
vector boson fusion (VBF)



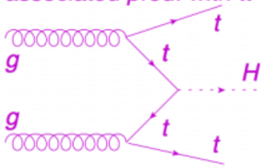
associated prod. with W/Z



gluon fusion

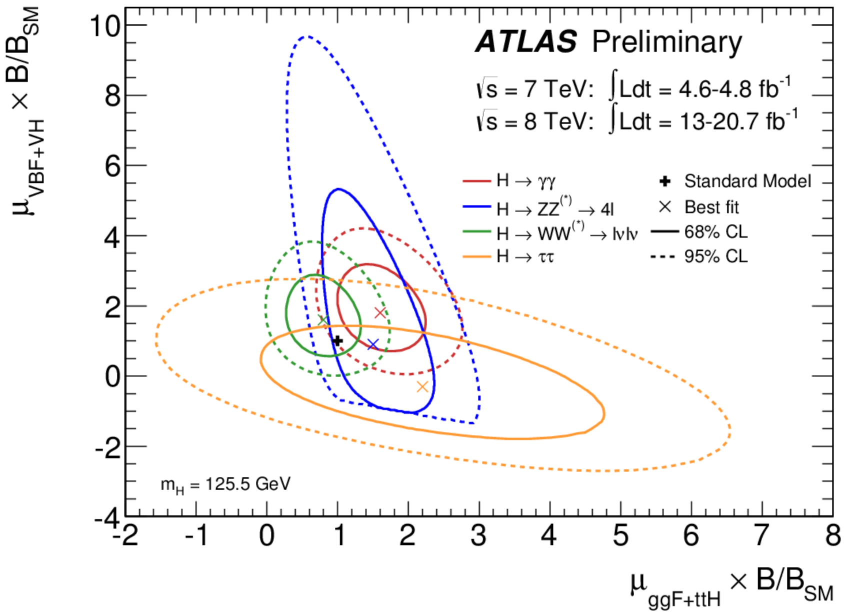


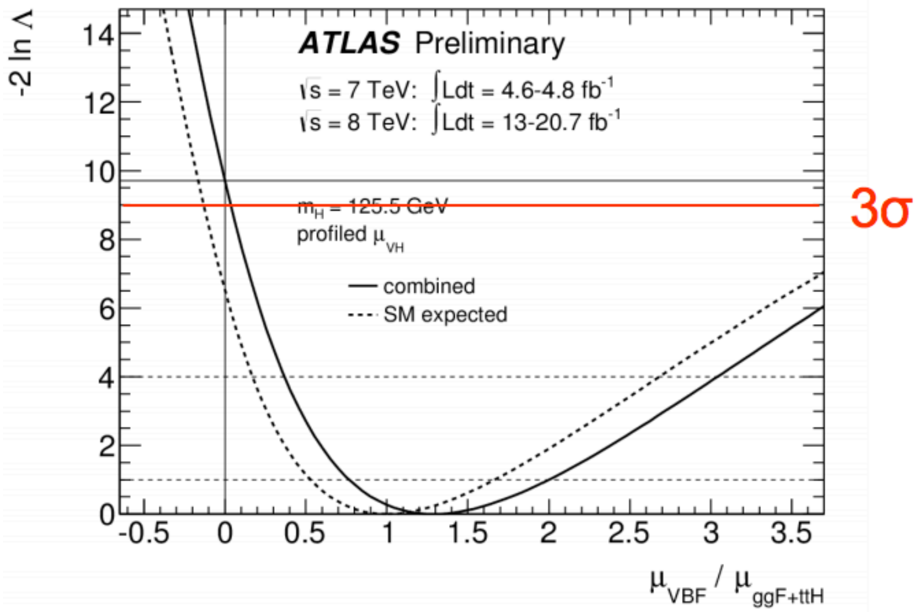
associated prod. with tt



Sensitivity to (ggF+ttH) and (VBF+VH) production fractions, modulo branching ratio factors B/B_{SM}

Evidence for Production via Vector Boson Fusion





- Use the ratio of production modes to eliminate the B/BSM dependence
- Good agreement with SM expectation

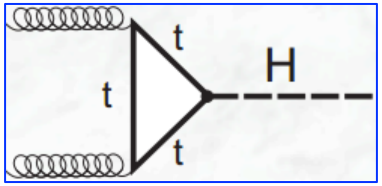
$$\mu_{VBF} / \mu_{ggF+ttH} = 1.4^{+0.4}_{-0.3}\,(\text{stat})^{+0.6}_{-0.4}\,(\text{syst})$$

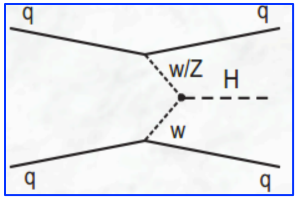
3.3σ evidence for VBF production

Higgs Boson Couplings

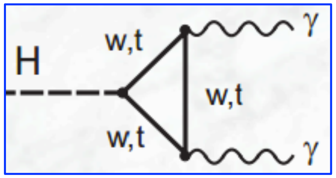
- **Production and decay involve several couplings**

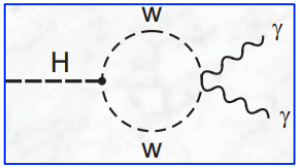
Production:





Decays: e.g. H→γγ (best example)





- Benchmark defined by LHC cross section working group (leading-order tree-level framework):
  - Signals observed originate from a single resonance;
    (mass assumed here is 125.5GeV)

  - Narrow width approximation: rates for given channels can be decomposed as:

$$\sigma\mathcal{B}(ii \to H \to ff) \sim \frac{\Gamma_{ii}\Gamma_{ff}}{\Gamma_{tot}} = \sigma_{SM} \cdot \mathcal{B}_{SM}\frac{k_i^2 \cdot k_f^2}{k_H^2}$$

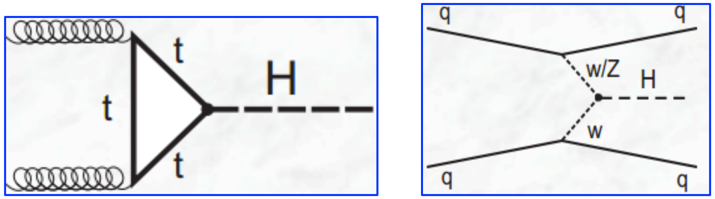
i, f = initial, final state
Γ_f, Γ_H = partial, total width

  - **Modifications to coupling strength are considered (coupling scale factors κ)**

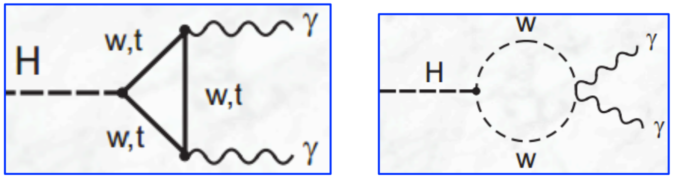
Higgs Boson Couplings

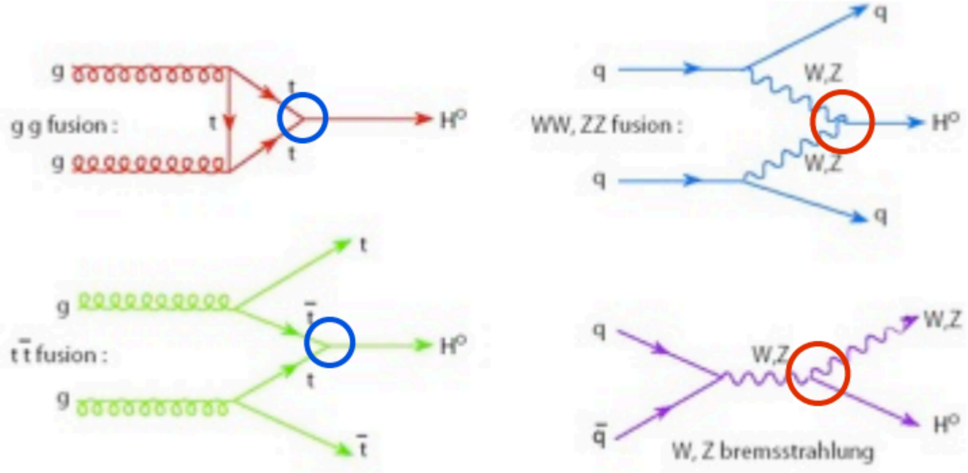
- **Production and decay involve several couplings**

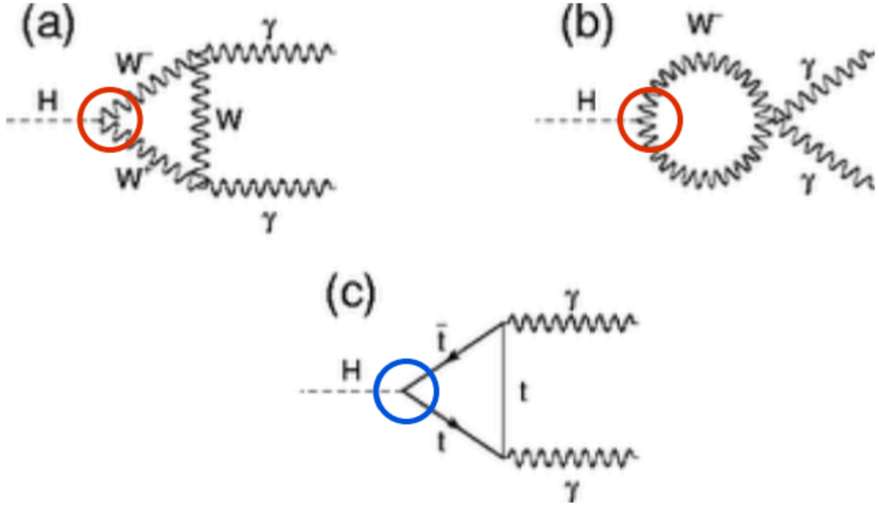
Production:



Decays: e.g. H→γγ (best example)







Couplings to Fermions and Bosons

- Assume only one scale factor for fermion and vector couplings:

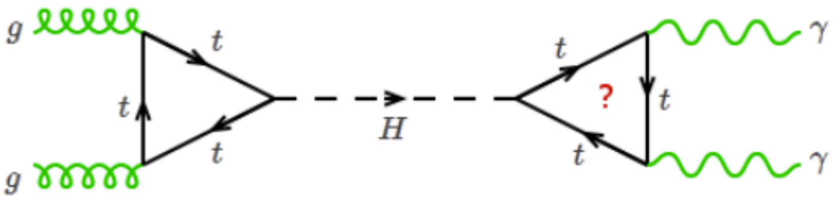
  $\kappa_V = \kappa_W = \kappa_Z$

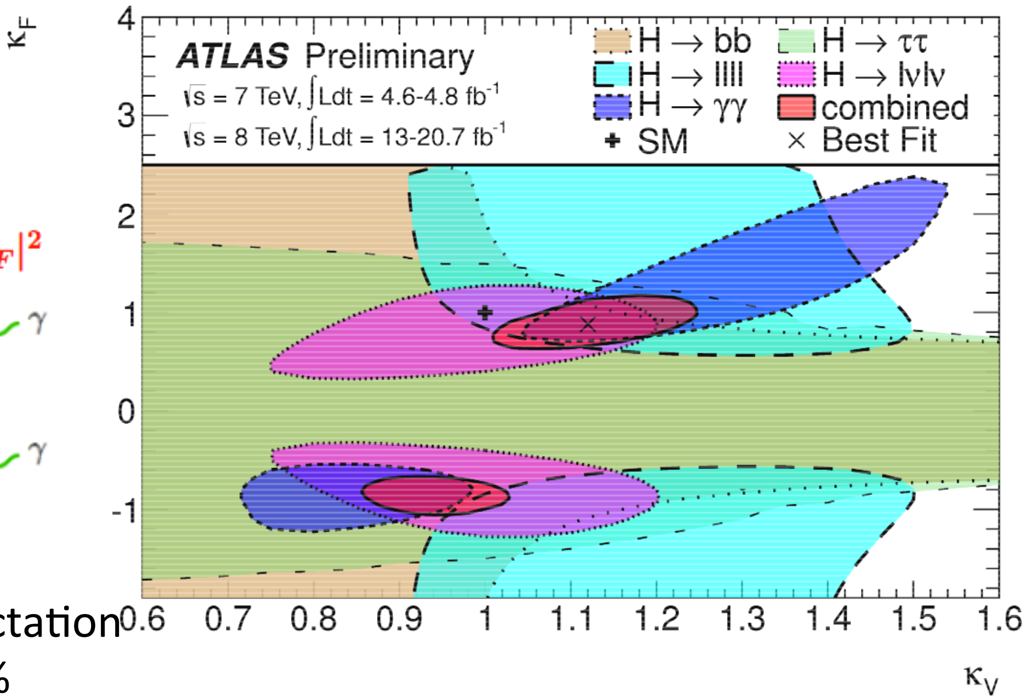
  $\kappa_F = \kappa_t = \kappa_b = \kappa_\tau$

- Assume that H→γγ and *gg*→H loops and the total Higgs boson width depend only on κ_V and κ_F (no contributions from physics beyond the Standard Model)

- Sensitivity to relative sign between κ_V and κ_F only from interference term in H→γγ decays (assume $\kappa_V>0$)

$$\Gamma_{gg} \sim k_F^2 \qquad \Gamma_{\gamma\gamma} \sim |\alpha k_V + \beta k_F|^2$$





Results:

- Data consistent with the SM expectation
- Two-dimensional consistency: 12%

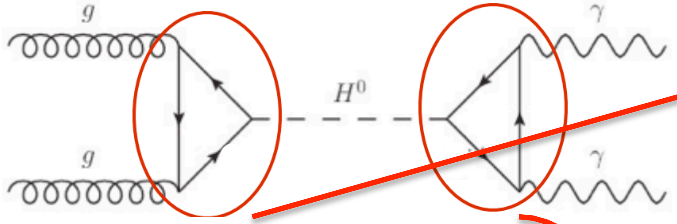
- 68% CL intervals: $\kappa_F \in [0.76,1.18]$; $\kappa_V \in [1.05,1.22]$

Constrains on Production and Decay Loops

Test on contributions from other particles contributing to loop-induced processes

- Assume nominal couplings for all SM particles $\kappa_i = 1$ and that the new particles do not contribute to the Higgs boson width

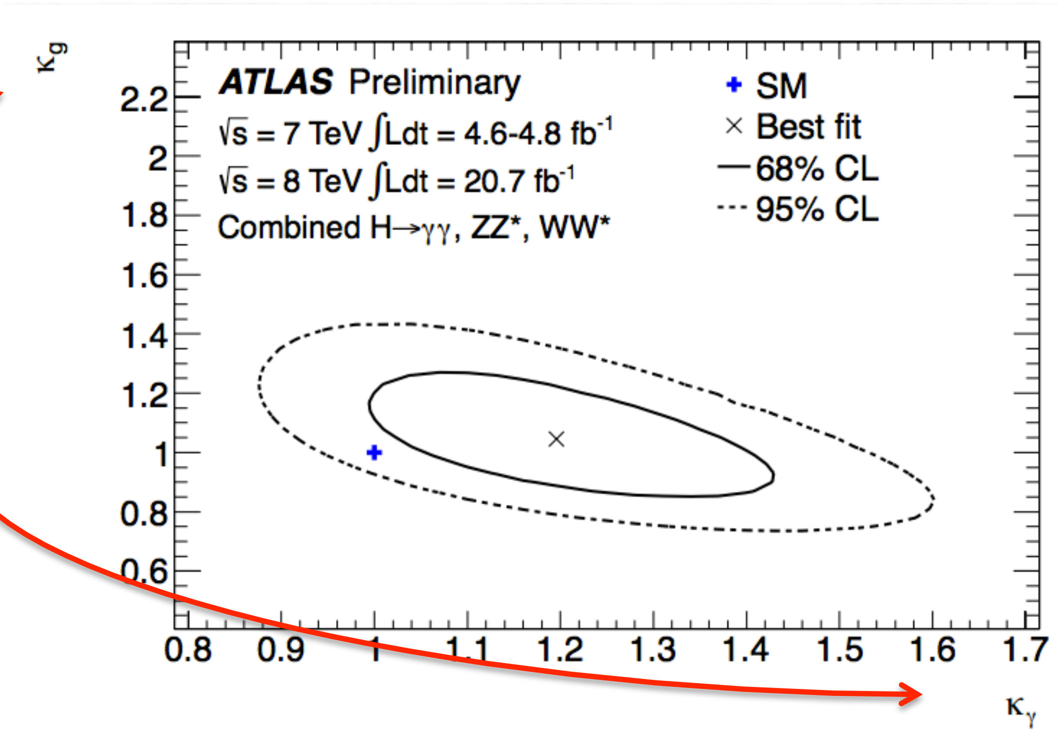
- Introduce effective scale factors κ_g and κ_γ



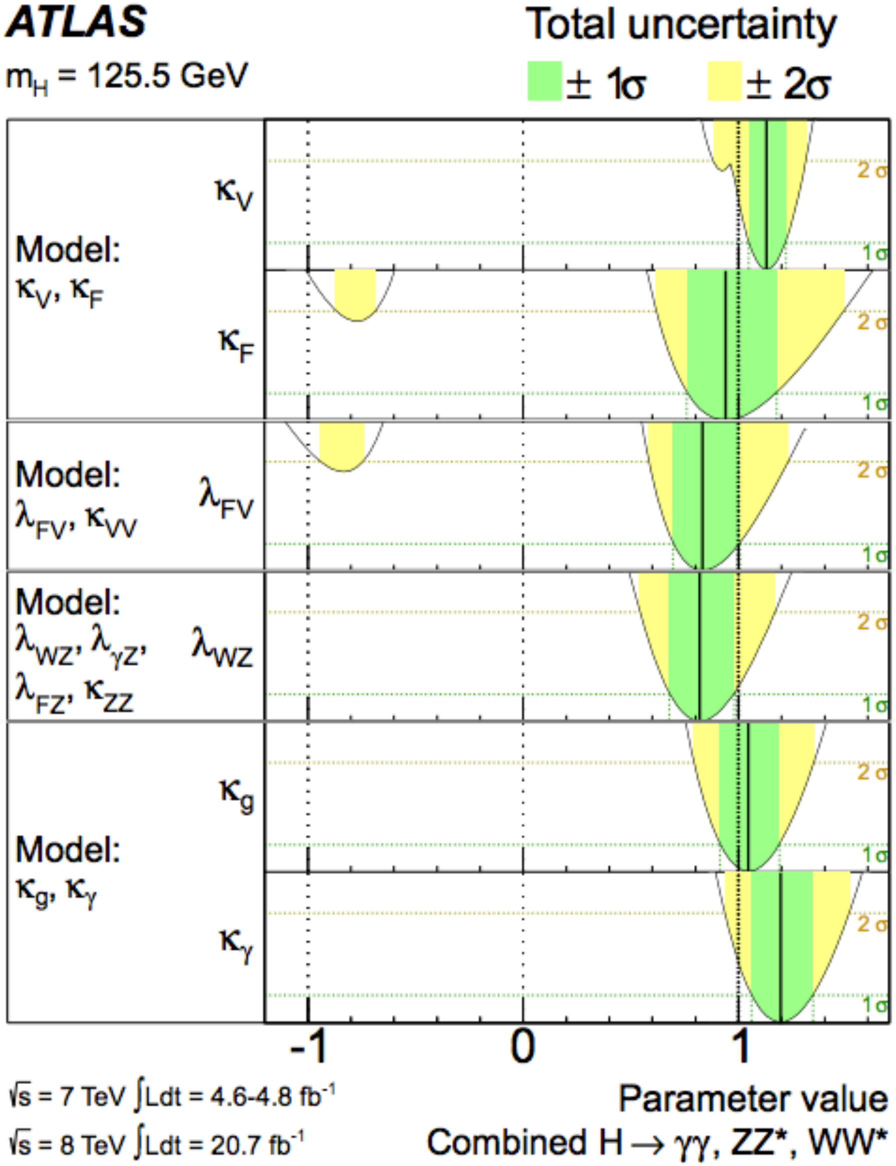
Best fit values:

$\kappa_g = 1.04 \pm 0.14$

$\kappa_\gamma = 1.20 \pm 0.15$



Summary of Coupling Scale Factor Measurements



$\lambda_{FV} = \kappa_F/\kappa_V$
$\lambda_{WZ} = \kappa_W/\kappa_Z$

- κ_V constrained at ±10% level
- κ_W/κ_Z found to be consistent with one
- No evidence for significant anomalous contributions to the gg→H and H→γγ loops

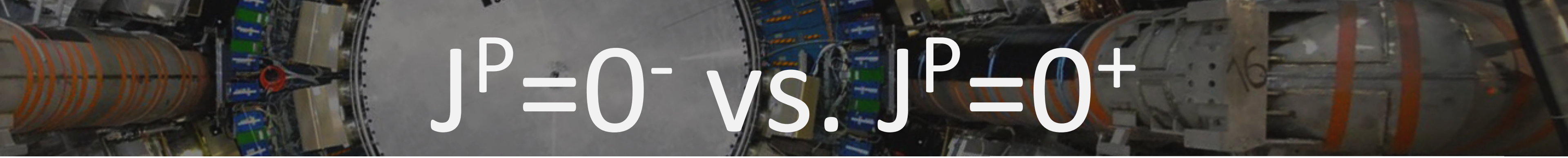
(for fixed nominal couplings of SM particles and not BSM contributions to Higgs width)

Spin and Parity

Standard Model Higgs boson: $J^P=0^+$

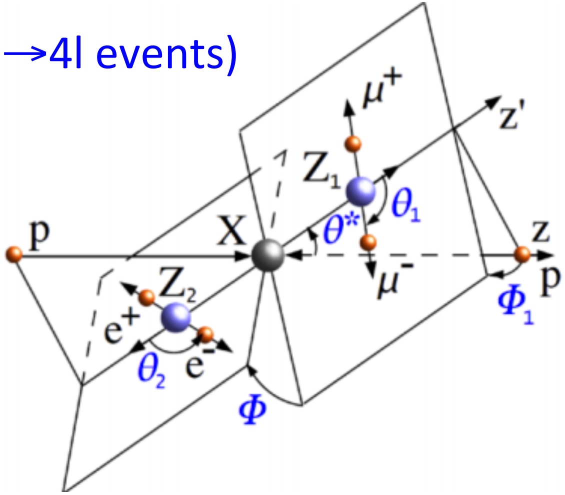
➔ strategy is to falsify other hypotheses $(0^-,1^-,1^+,2^-,2^+)$ and demonstrate consistency with the 0^+ hypothesis

Spin 1: strongly disfavored by observed $H\rightarrow\gamma\gamma$ decays, Landau-Yang theorem



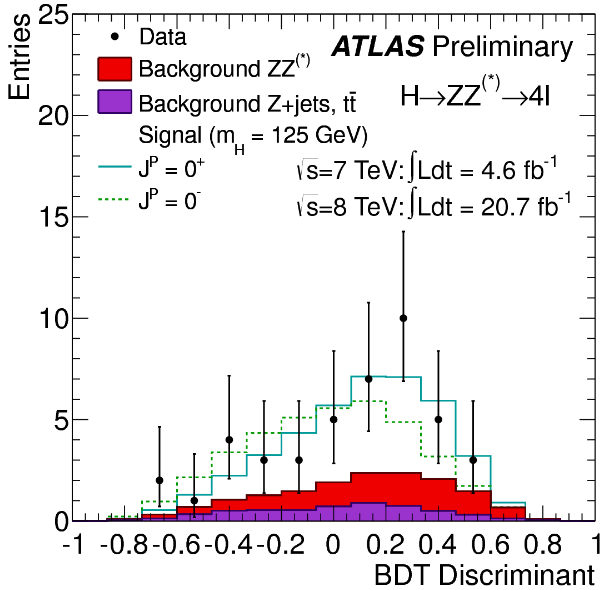
$J^P=0^-$ vs. $J^P=0^+$

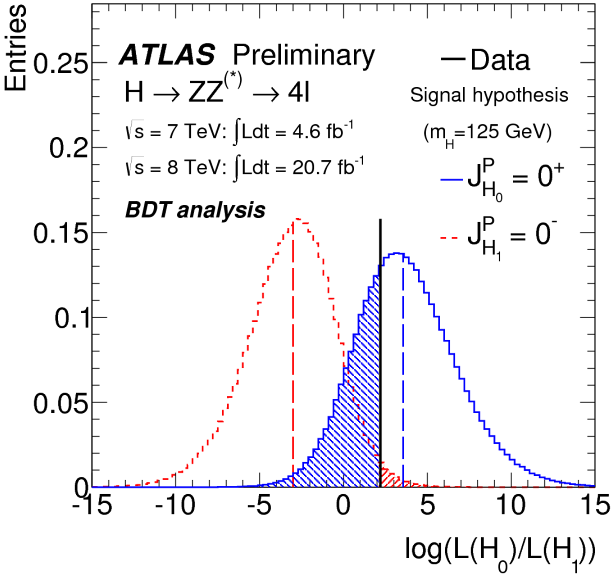
(H→ZZ*→4l events)



- Sensitive variables:
  - Masses of the two Z bosons
  - Production angle θ*
  - Four decay angles Φ_1, Φ, θ_1, θ_2
- Perform multivariate analysis (BDT)

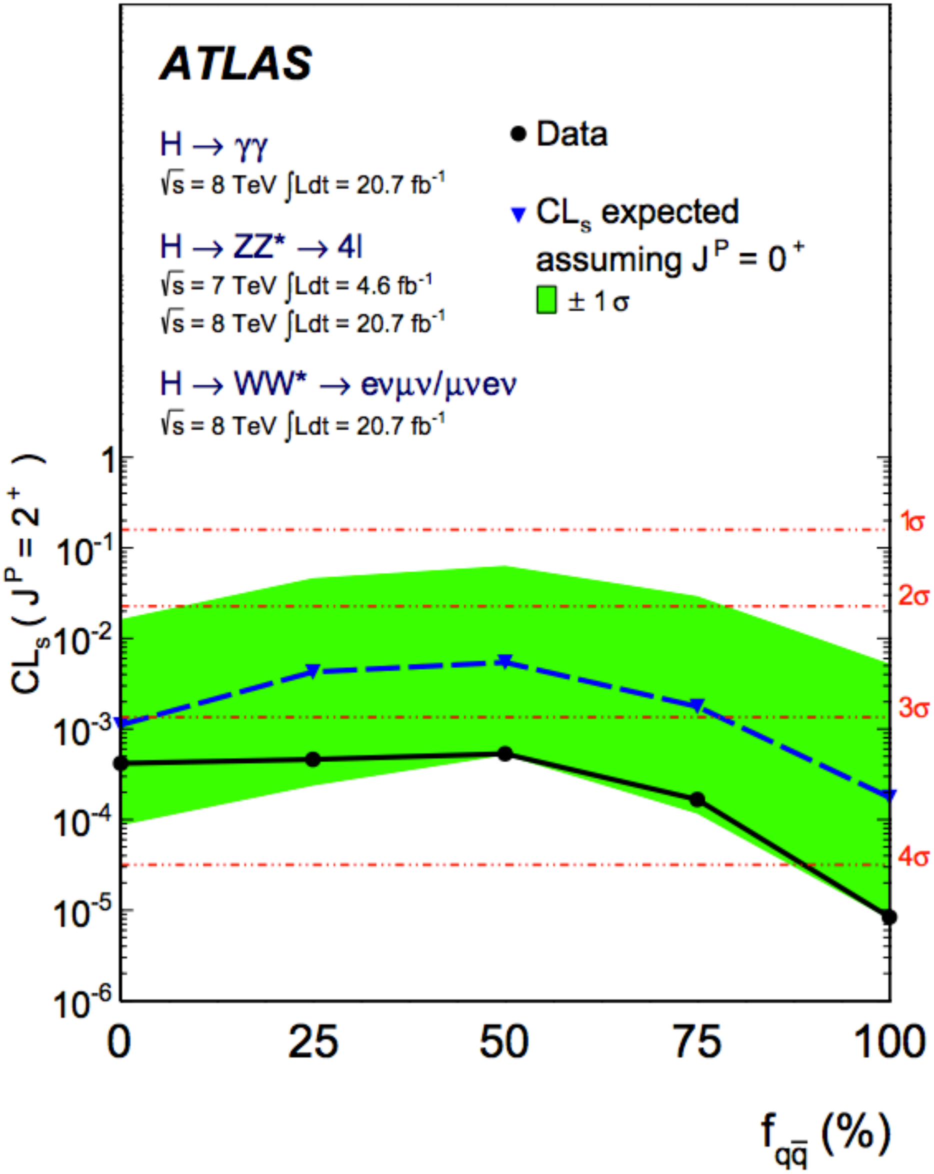
Exclude $J^P=0^-$ (vs. 0^+) with 97.8% CL





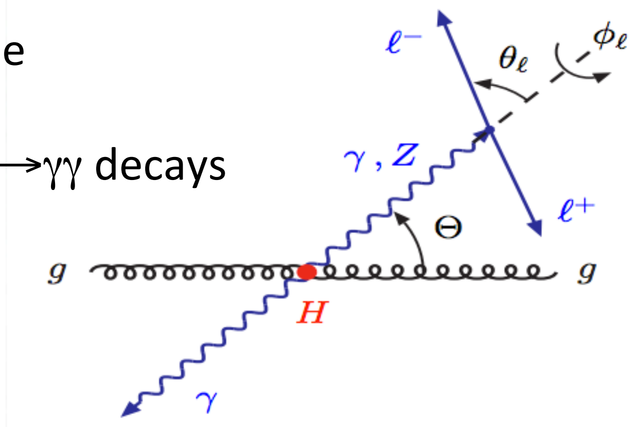
$J^P=2^{+/-}$ vs. $J^P=0^+$

- Spin 2: consider graviton-like tensor, equivalent to a Kaluza-Klein graviton
  (Y, Gao et al, Phys. Rev. D81 (2010) 075022)
- Production via gluon fusion and qq annihilation possible; Studies performed as a function of the *qq* annihilation fraction (f_{qq})
- Specific model 2^+_m:
  minimal couplings to SM particles
- Observed exclusion (combination of γγ, ZZ* and WW*) of $J^P=2^+$ (versus the SM $J^P=0^+$) exceeds 99.9%, independent of f_{qq}; complementary behavior of the different channels



Example: H→γγ Contribution

- Use decay angle w.r.t. collision axis in the Collins-Soper frame
- Exclude $J^P=2^+$ (produced via gluon fusion, $f_{qq}=0$) (vs. 0^+) via H→γγ decays with 99.3% CL



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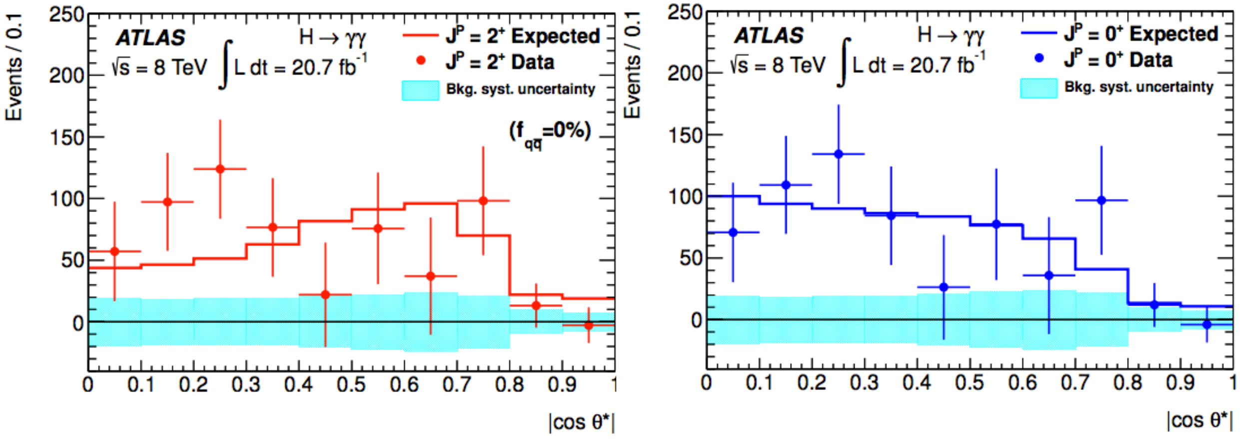
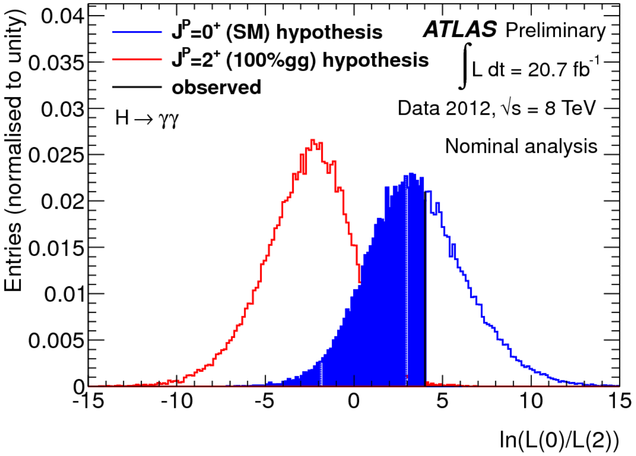


|cosθ*| distribution in signal region, after background subtraction



Conclusions

- A milestone discovery announced a year ago
- Signals have been impressively confirmed with additional data
- Discovery phase has turned into the measurement phase
- ATLAS data are consistent with the expectations for the Standard Model Higgs boson (within present uncertainties)
  - Production rates and couplings strengths
  - Evidence for spin-0 (0^- disfavored)
- Exciting times ahead of us to study the Higgs boson with higher precision (>2015) and look for surprises