Results from the Higgs Searches at the LHC

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COMPETE
PROGRAMA OPERACIONAL FACTORES DE COMPETITIVIDADE

Overview

- Production and decay modes at the LHC
- Higgs searches: example of the HWW channel at ATLAS
- Summary of the main results at ATLAS and CMS
  - Will cover most sensitive channels

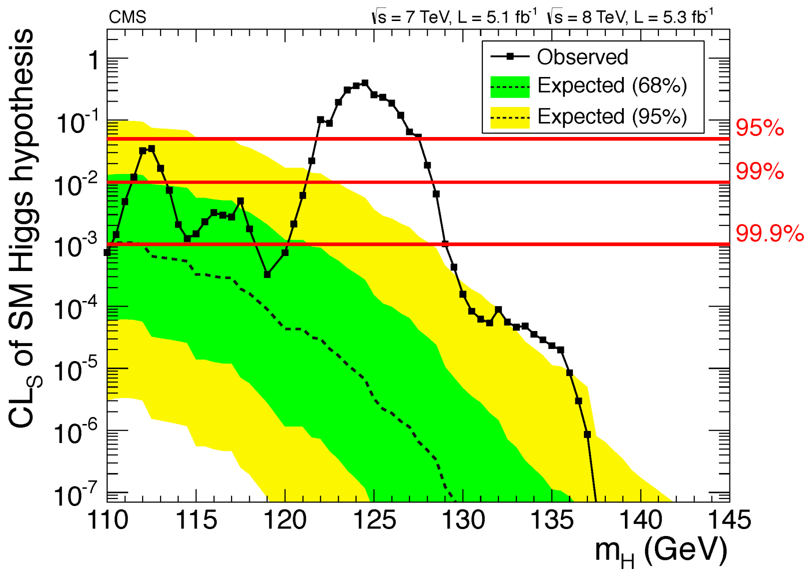
New boson observed in Higgs searches

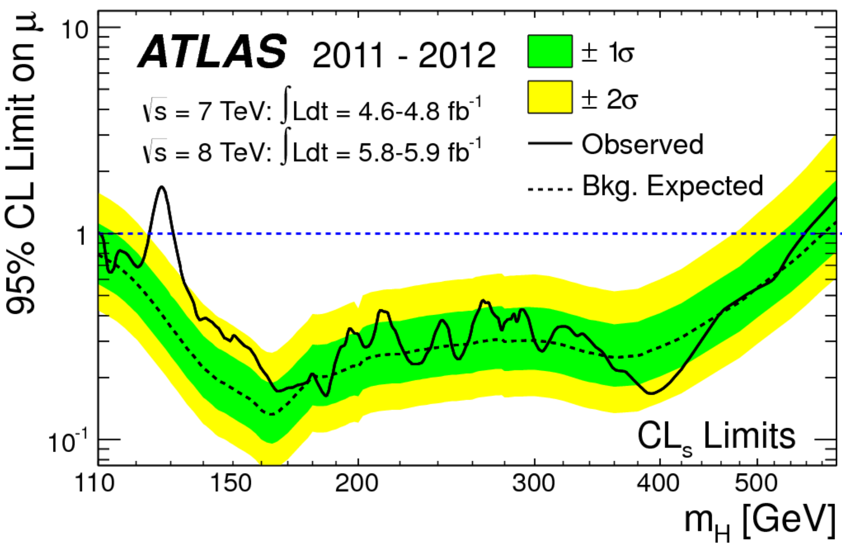
July 2012

- CMS and ATLAS observe a new boson at

  m~125 GeV

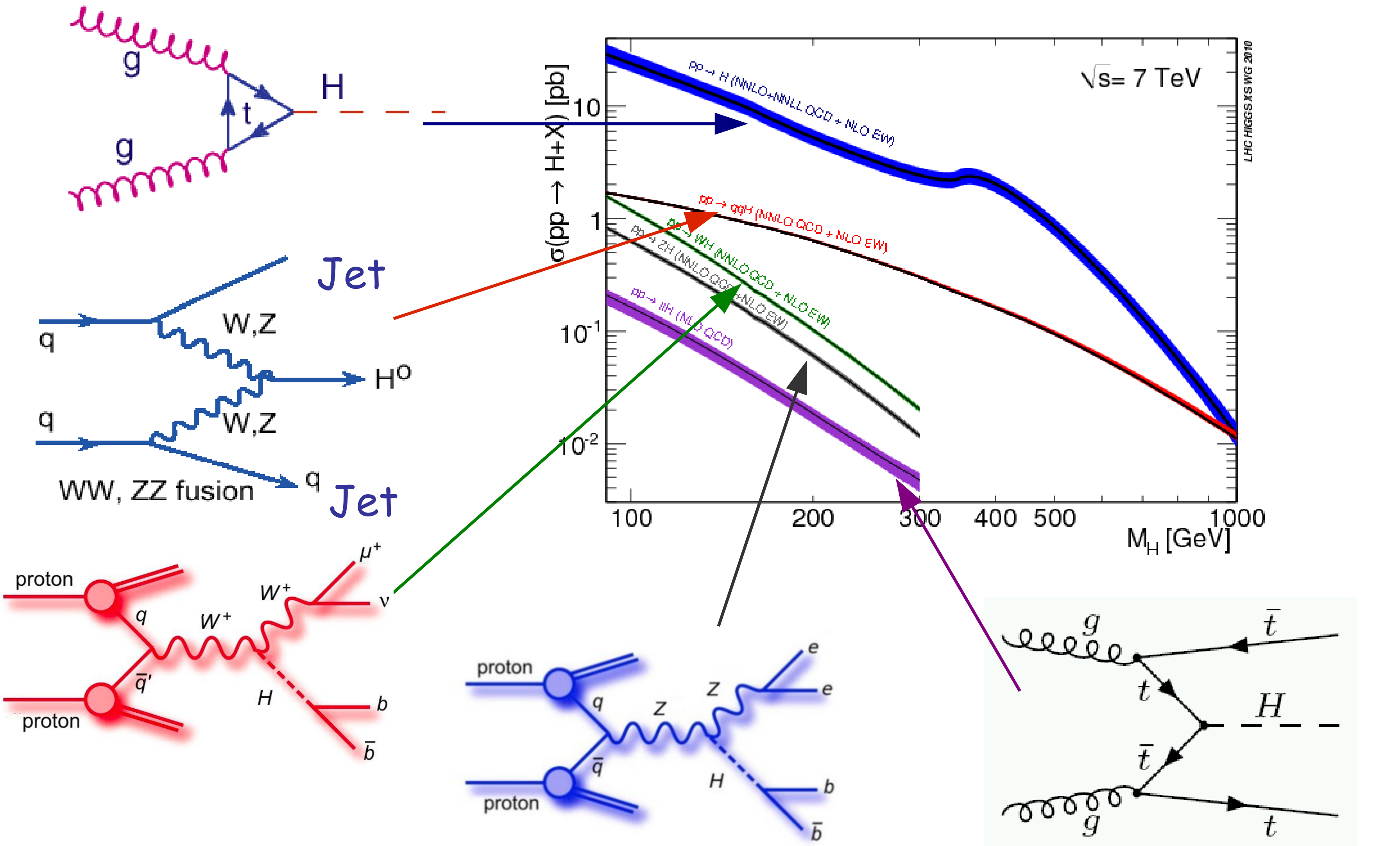
  - More than 5σ evidence in both experiments



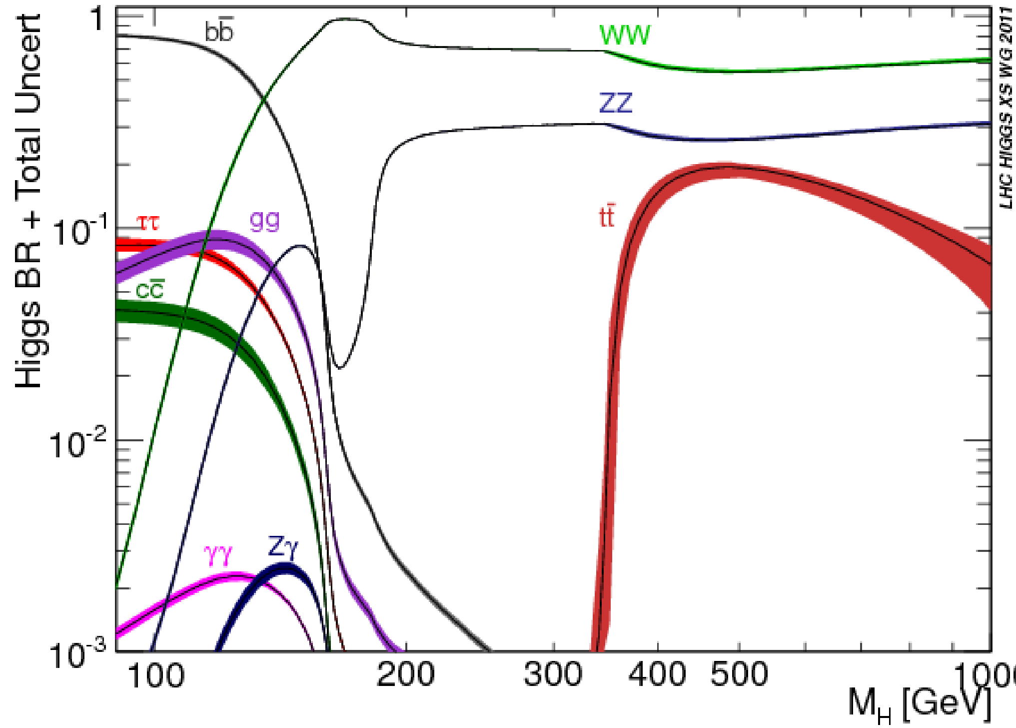


- No other excess observed in a very large mass range (up to ~600 GeV)

Higgs production



Higgs decays

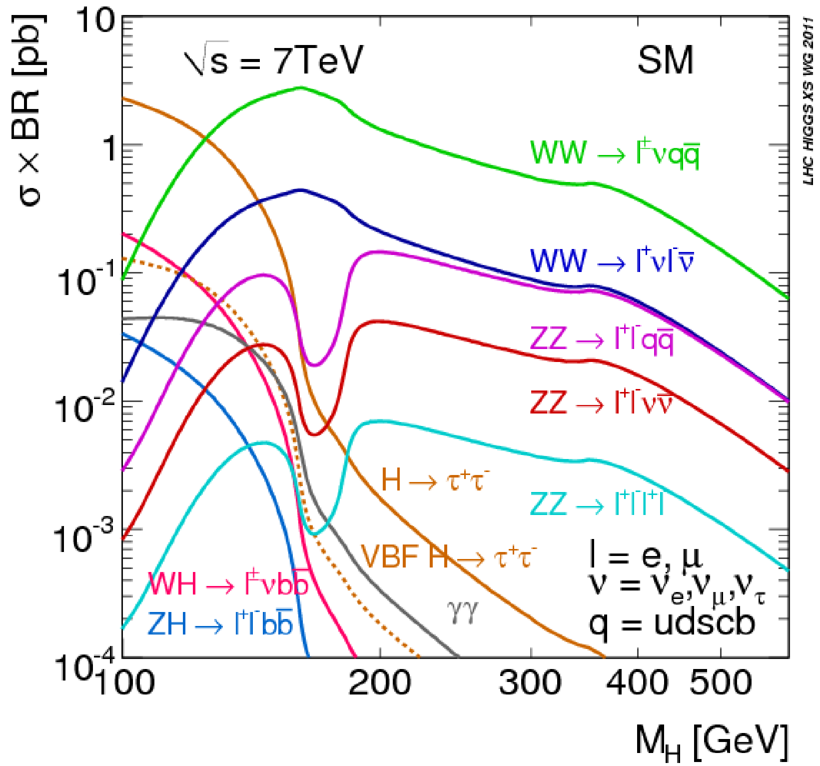


- 5 different decay modes
  - High mass: ZZ, WW
  - Low mass: bb, γγ, WW, ZZ, ττ
- Low mass very challenging
  - Large backgrounds

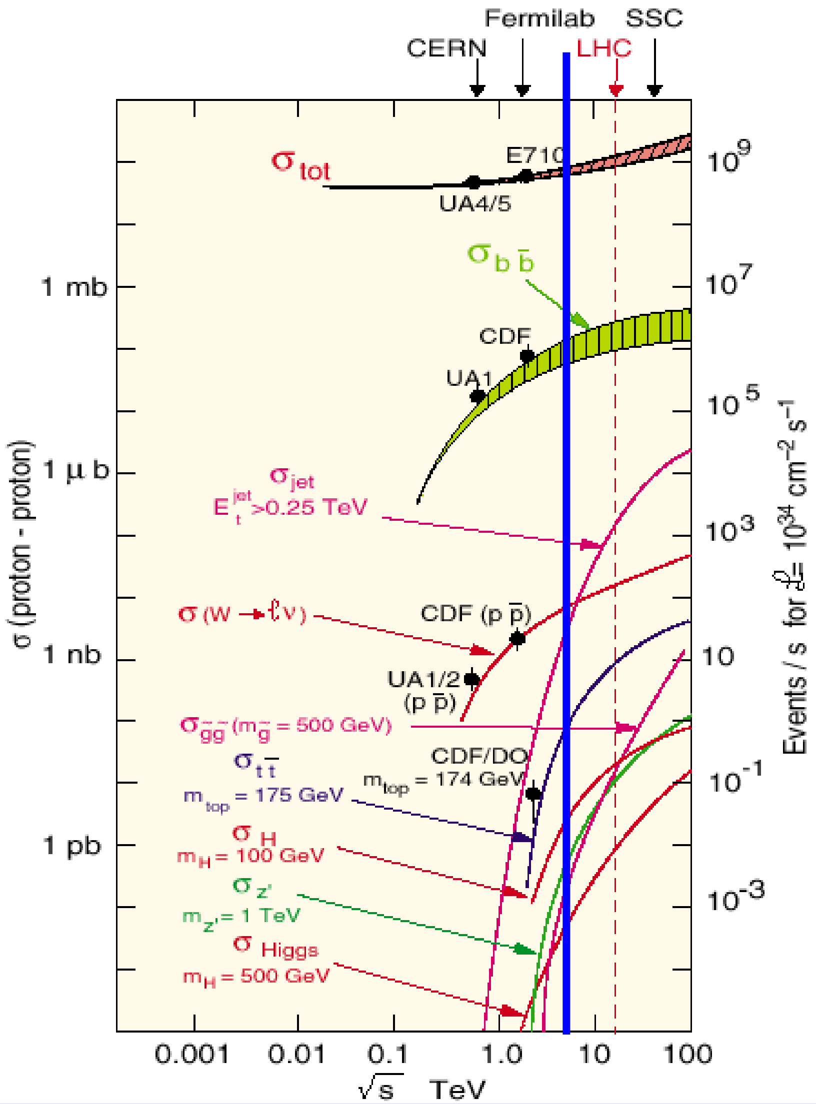
Best mass resolution: H→γγ, H→ZZ→llll

Search channel

- It normally implies a production mode plus a decay mode, characterized by some experimental signatures



Cross sections at the LHC



Total production cross section at LHC:

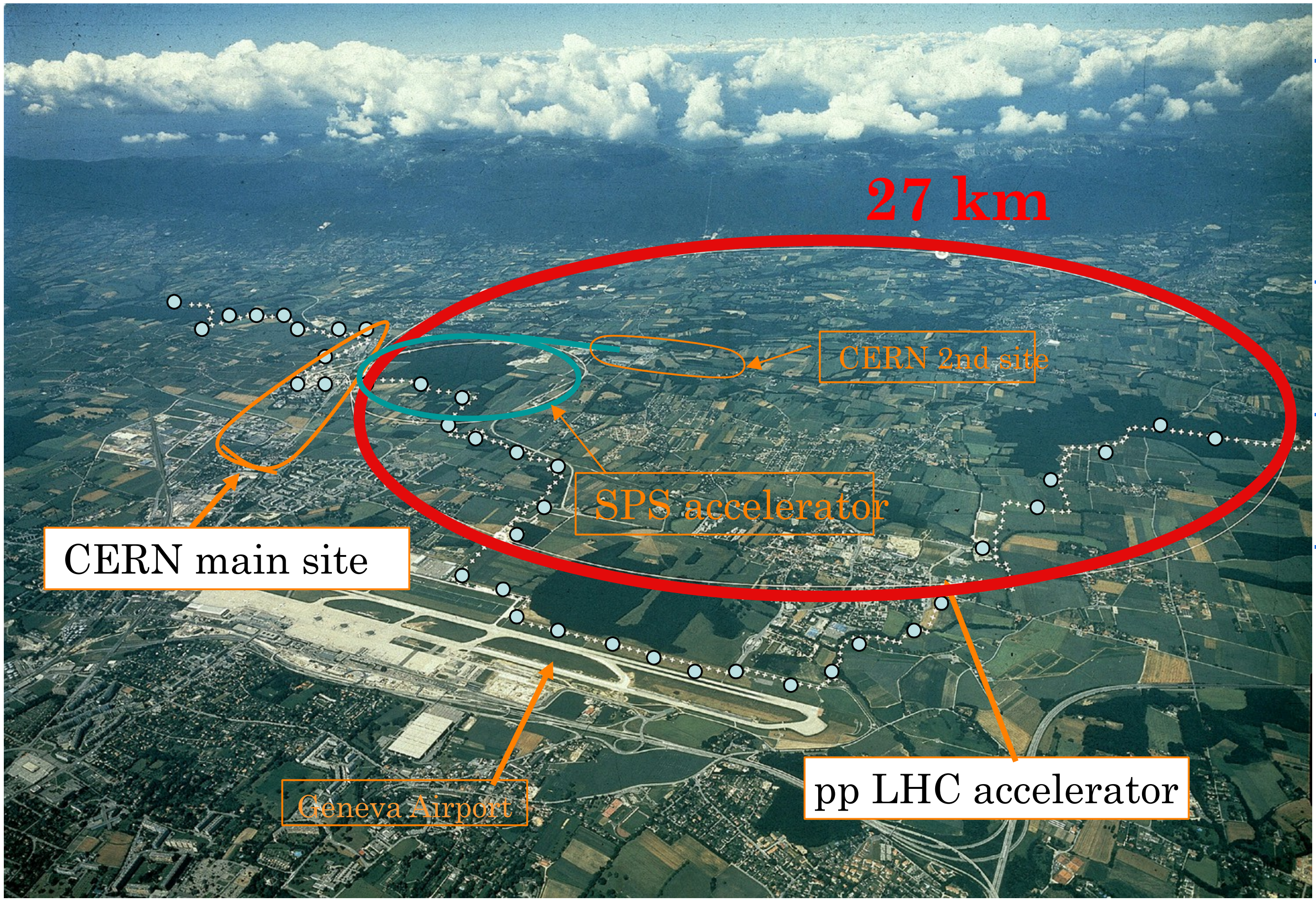
~ 10^3 x σ(bb)

- ~10^7 x σ(W→μν)
- ~10^8 x σ(tt)
- ~$5x10^{10}$ x σ(H) (m_H ~ 100 GeV)

σ(di-jet) for jets with E_T > 7 GeV is ~ 50% of σ(tot)

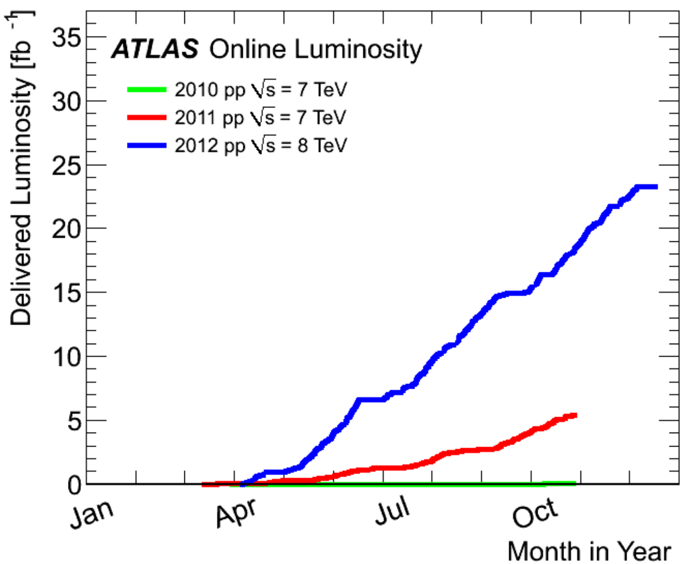
- Most interactions produce jets
  - Either quarks or gluons
- Need to identify clear signatures that distinguish the processes of interest from this background

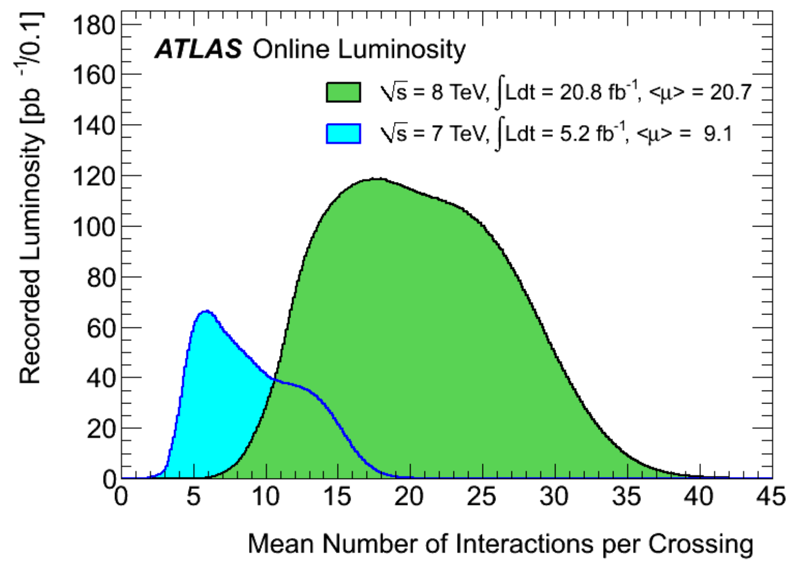
The Large Hadron Collider



- pp collisions at
  - 8 TeV in 2012
  - 7 TeV in 2010/11
- 20 MHz p bunch crossing rate
- Up to ~40 collisions per bunch crossing!
- Four experiments: ATLAS, CMS, LHCb, ALICE

LHC delivered data (2011-2012)



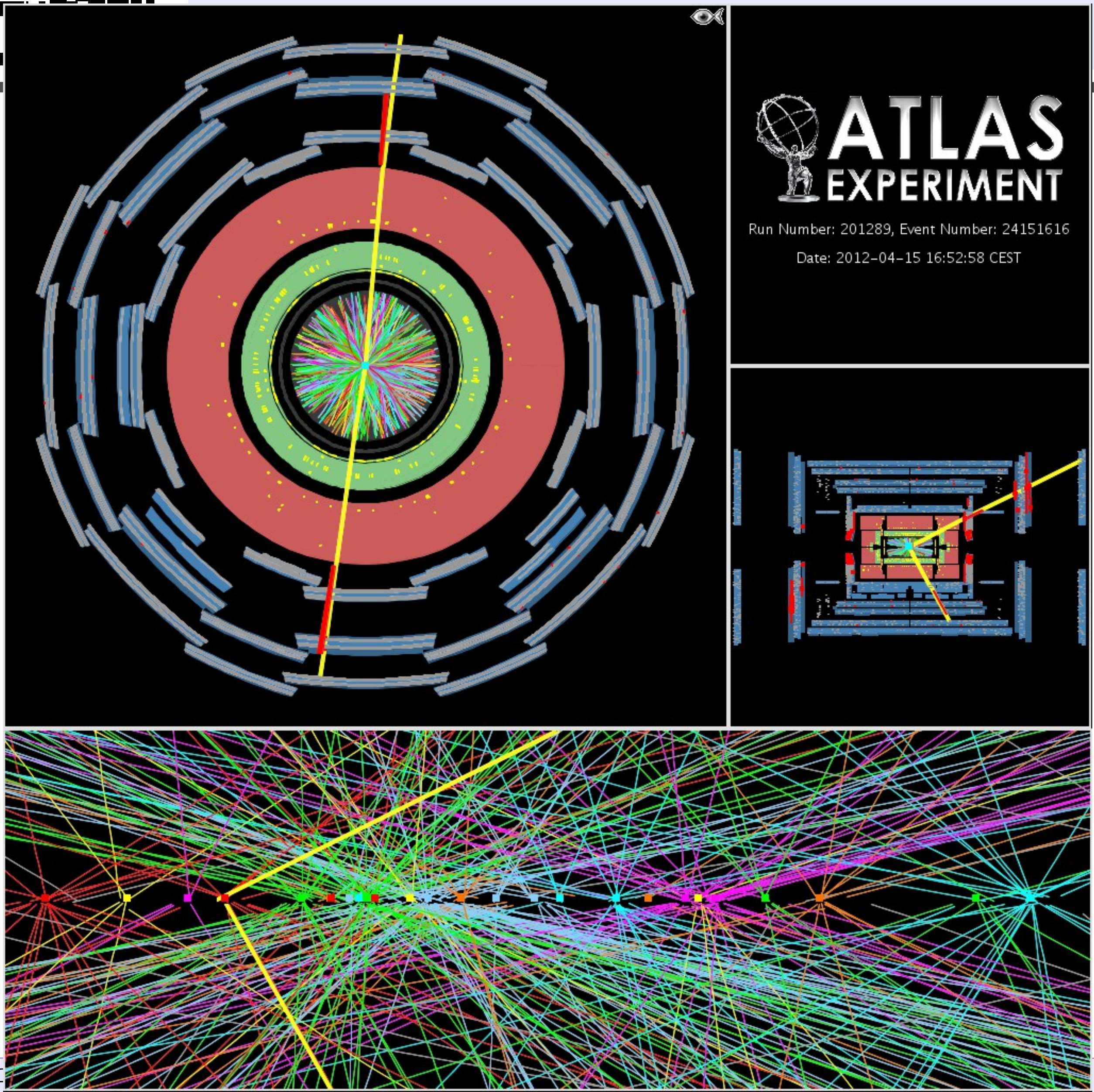


ATLAS p-p run: April-December 2012										
Inner Tracker			Calorimeters		Muon Spectrometer				Magnets	
Pixel	SCT	TRT	LAr	Tile	MDT	RPC	CSC	TGC	Solenoid	Toroid
99.9	99.4	99.8	99.1	99.6	99.6	99.8	100.	99.6	99.8	99.5
All good for physics: 95.8%										

Luminosity weighted relative detector uptime and good quality data delivery during 2012 stable beams in pp collisions at √s=8 TeV between April 4th and December 6th (in %) – corresponding to 21.6 fb^{-1} of recorded data.

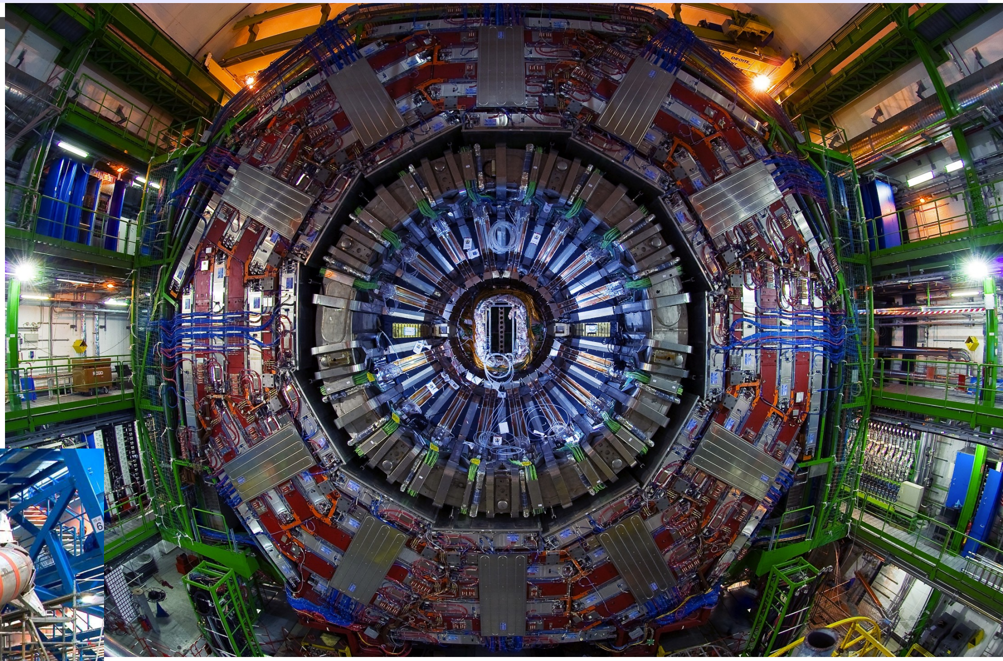
- 20.8 fb^{-1} 8 TeV pp collisions
- 5.2 fb^{-1} 7 TeV pp collisions
- 95.8% physics quality data

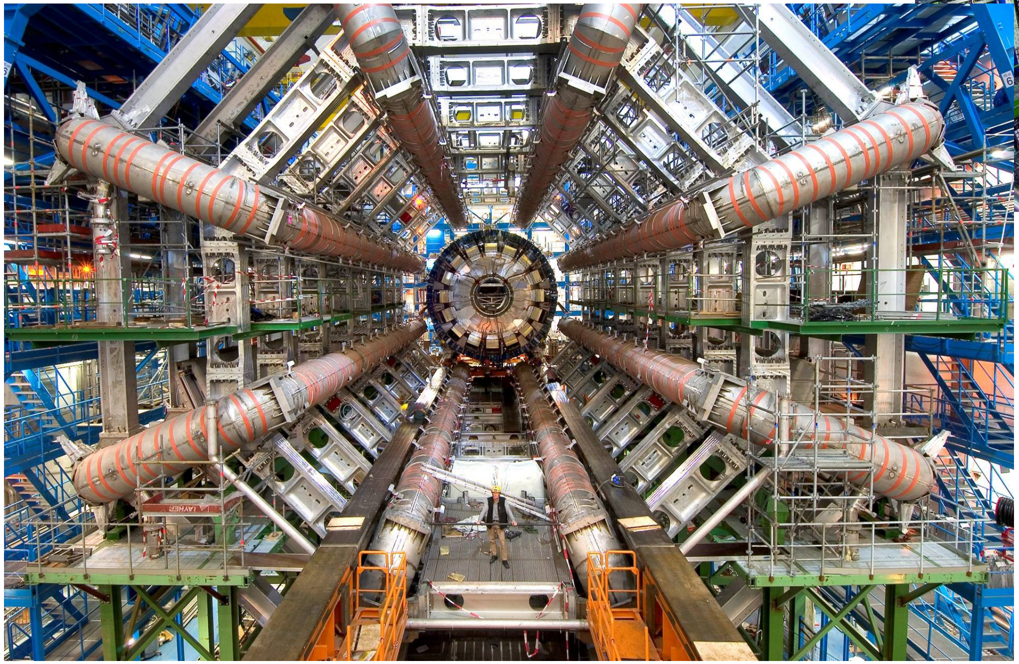
Pile-up



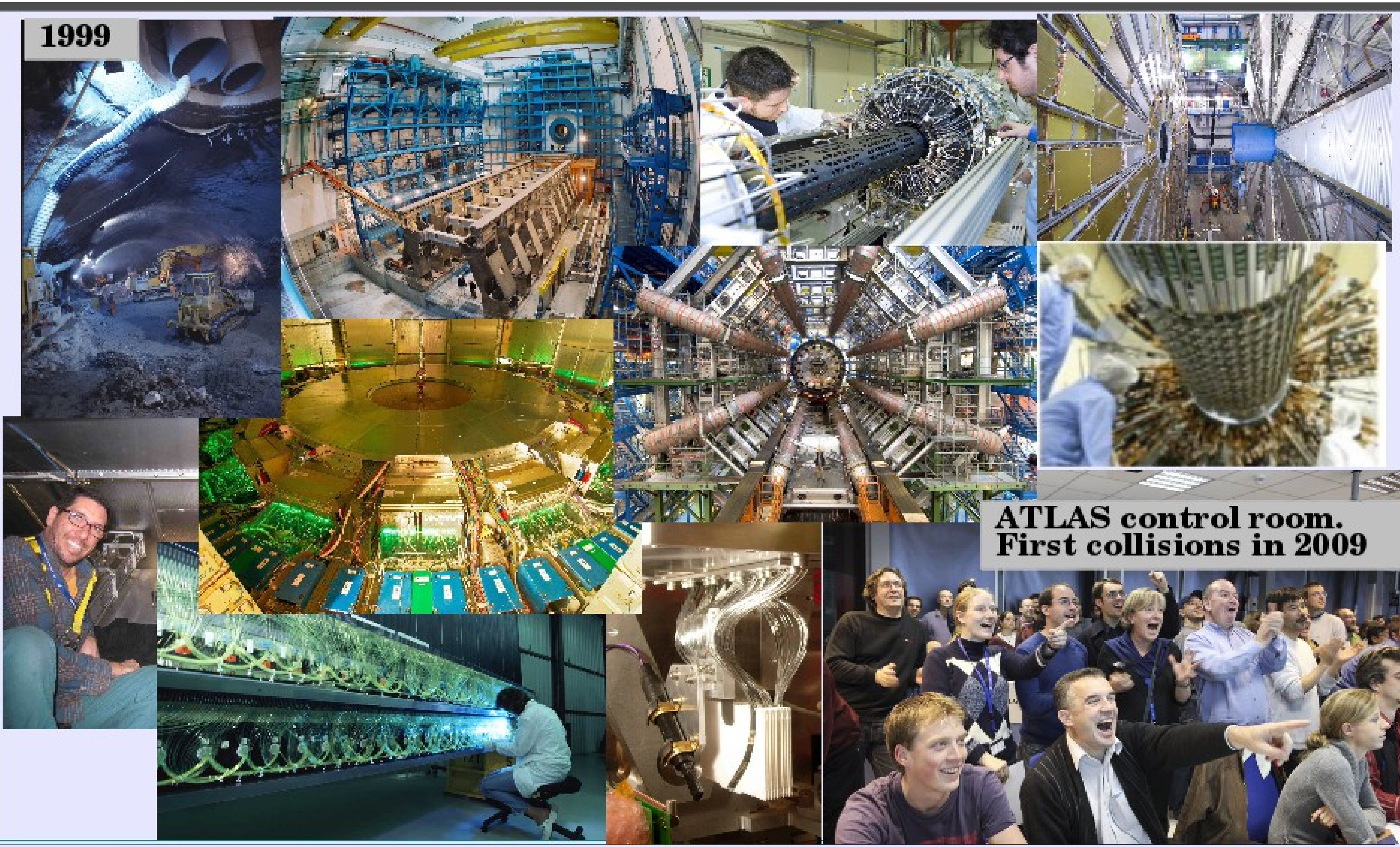
- $Z \rightarrow \mu\mu$ event with 25 additional interactions
- Typical average event in the second half of 2012

The ATLAS and CMS detectors



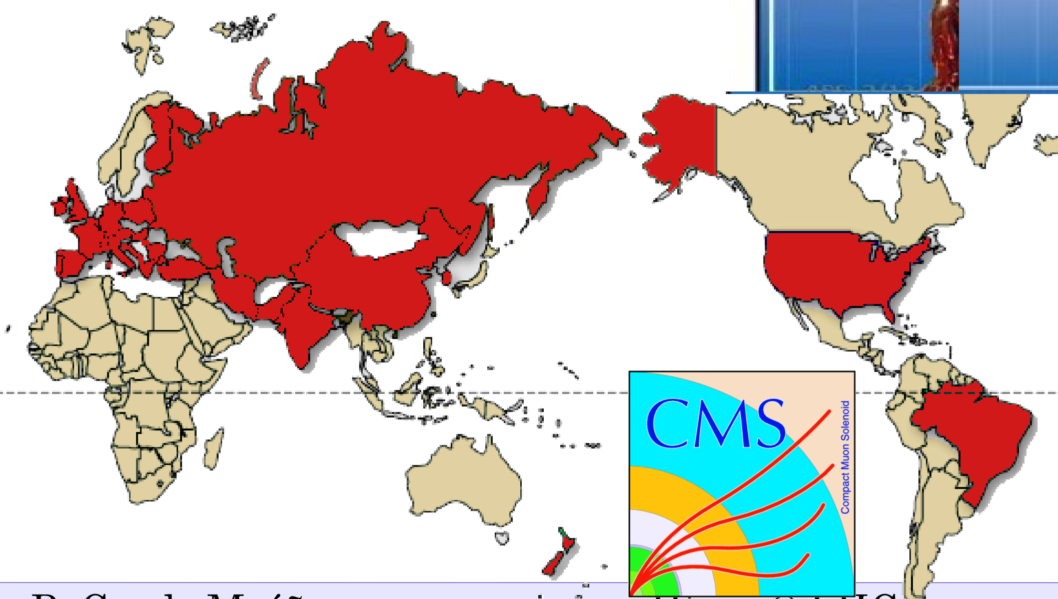


More than 20 years of continuous work...



ATLAS and CMS Collaborations

- Each of them composed of
  - >4000 members
  - >3000 physicists
  - ~180 institutions
  - ~40 countries



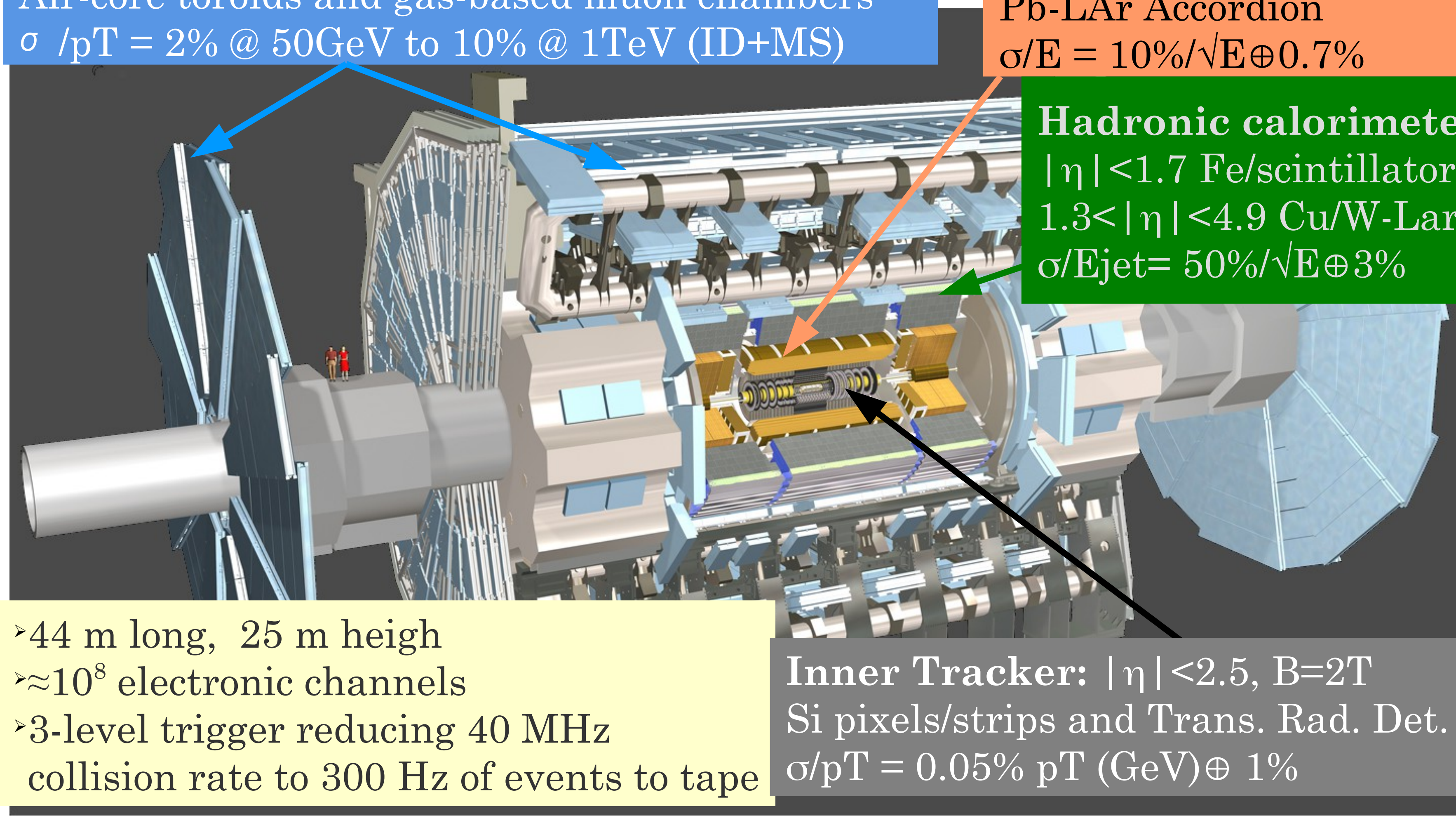
- Examples of a truly global collaboration!

The ATLAS detector

Muon Spectrometer: $|\eta|<2.7$
Air-core toroids and gas-based muon chambers
σ /pT = 2% @ 50GeV to 10% @ 1TeV (ID+MS)

EM calorimeter: $|\eta|<3.2$
Pb-LAr Accordion
$\sigma/E = 10\%/\sqrt{E} \oplus 0.7\%$

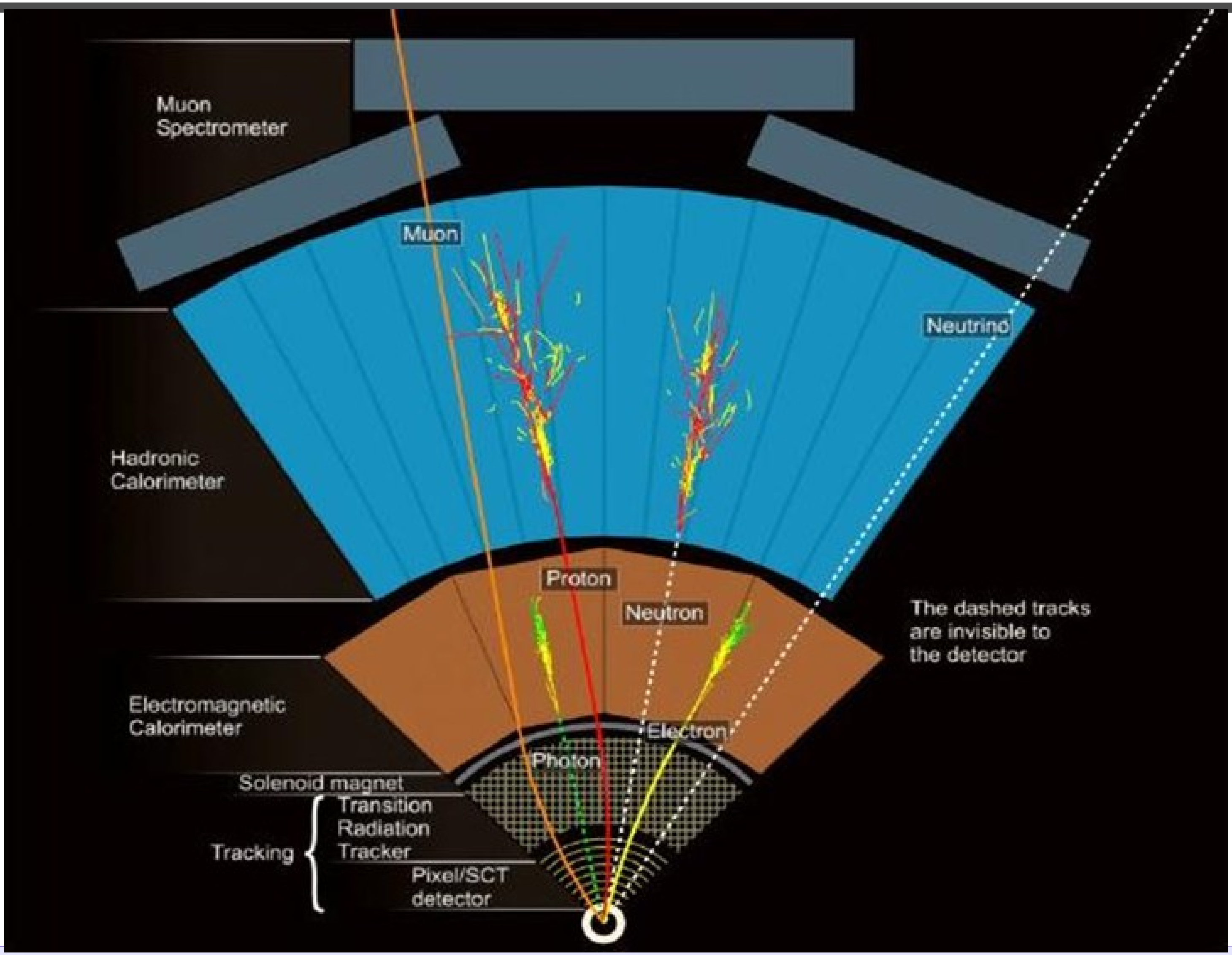
Hadronic calorimeter:
$|\eta|<1.7$ Fe/scintillator
$1.3<|\eta|<4.9$ Cu/W-Lar
$\sigma/E_{jet} = 50\%/\sqrt{E} \oplus 3\%$



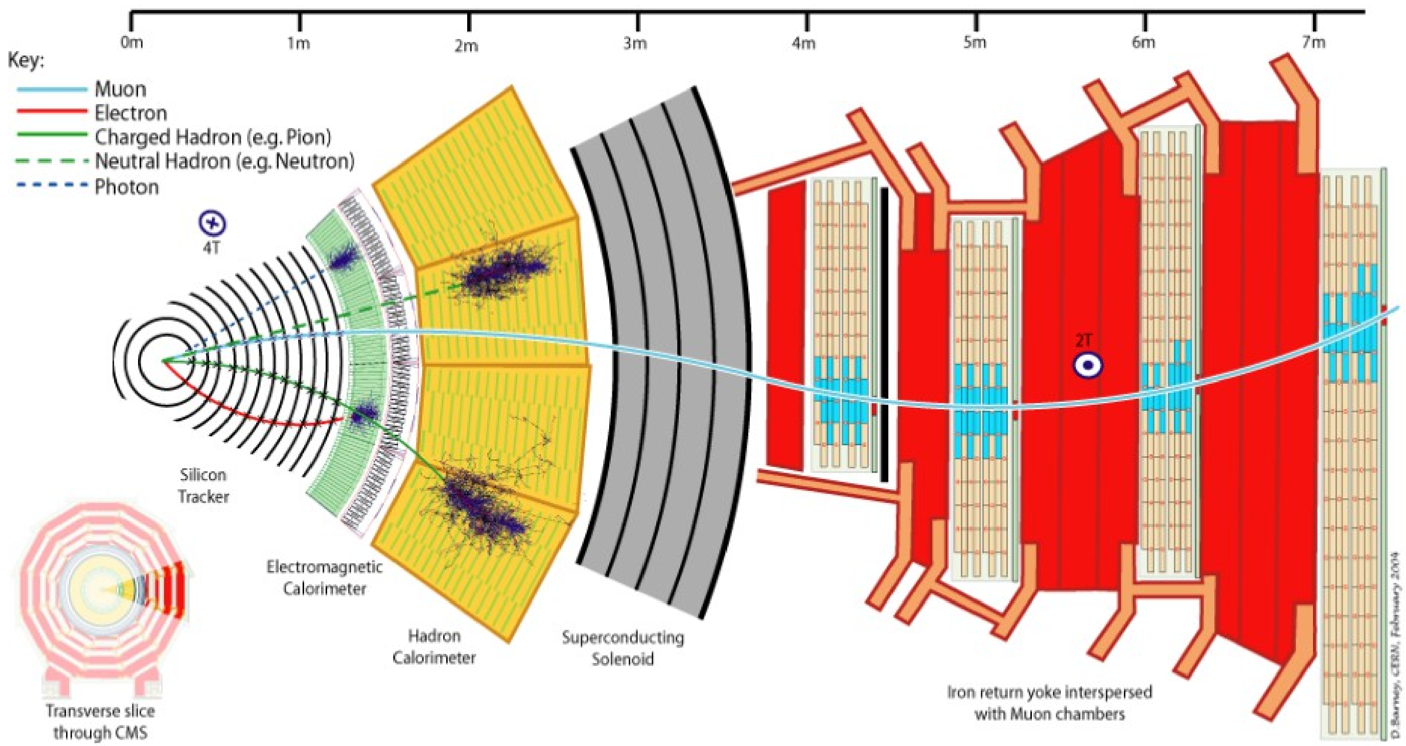
- 44 m long, 25 m heigh
- $\approx 10^8$ electronic channels
- 3-level trigger reducing 40 MHz collision rate to 300 Hz of events to tape

Inner Tracker: $|\eta|<2.5$, B=2T
Si pixels/strips and Trans. Rad. Det.
$\sigma/p_T = 0.05\%\ p_T\ (GeV) \oplus 1\%$

Particle identification



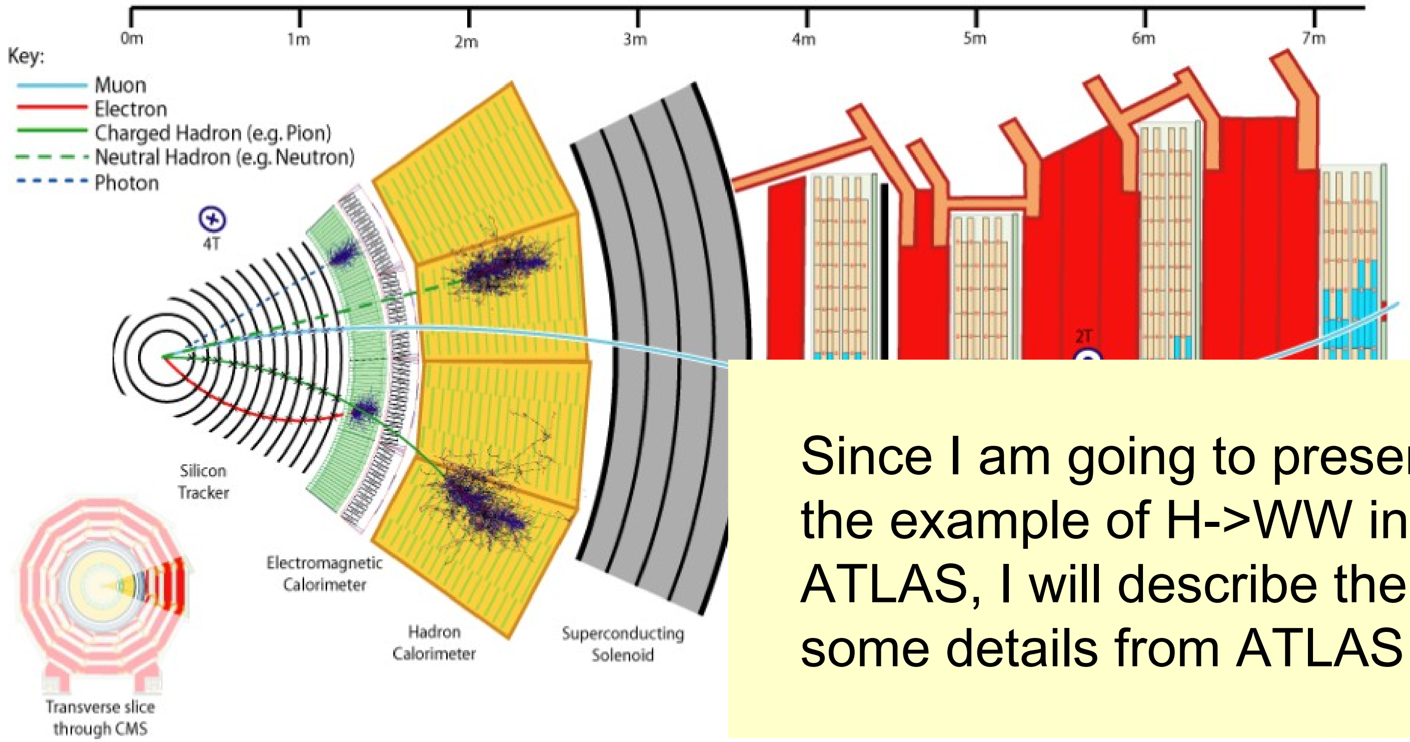
Particle identification @CMS



Global Event Description—Particle flow algorithm

- Combines and links signals from different sub-detectors
- Provides optimal event description for a list of particles (e, μ, γ, hadrons, missing transverse energy)

Particle identification @CMS

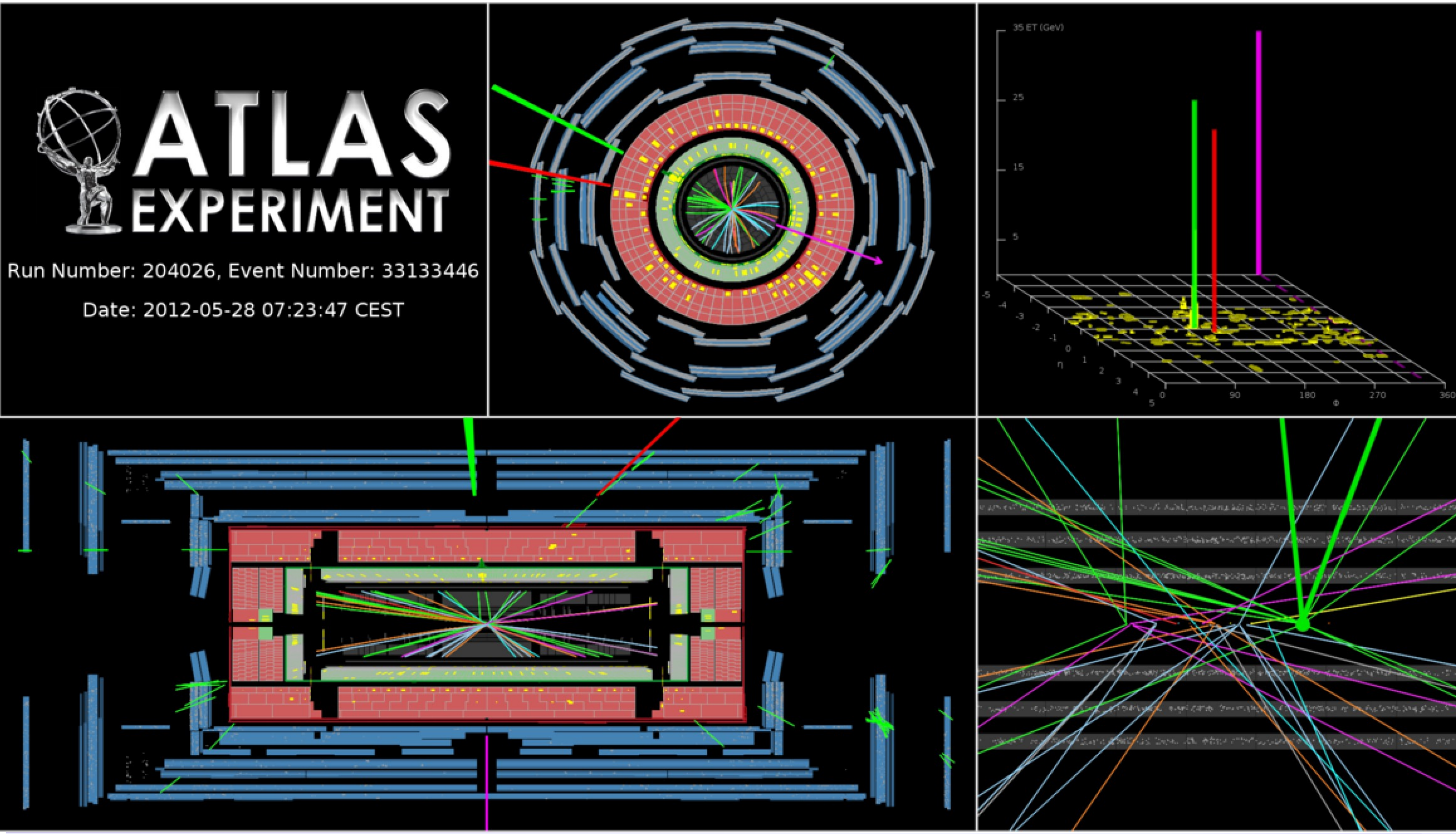


Since I am going to present the example of H->WW in ATLAS, I will describe the some details from ATLAS

Global Event Description—Particle flow algorithm

- Combines and links signals from different sub-detectors
- Provides optimal event description for a list of particles (e, μ, γ, hadrons, missing transverse energy)

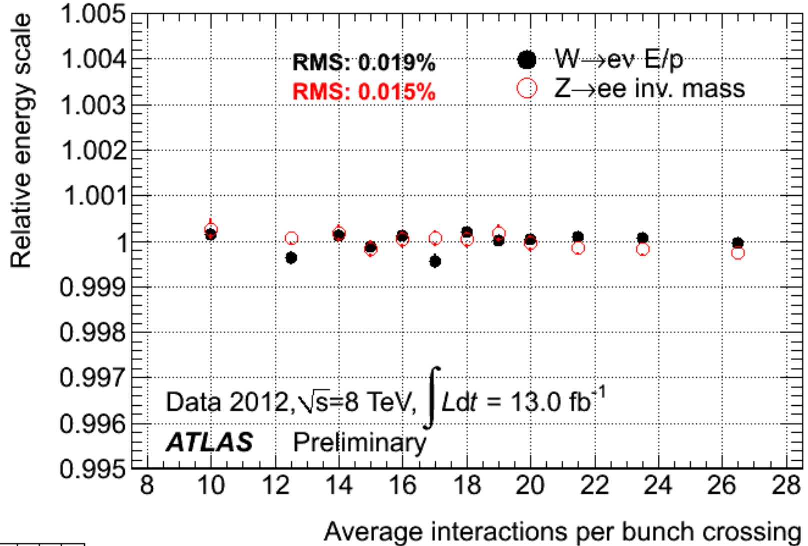
H→WW→lνlν

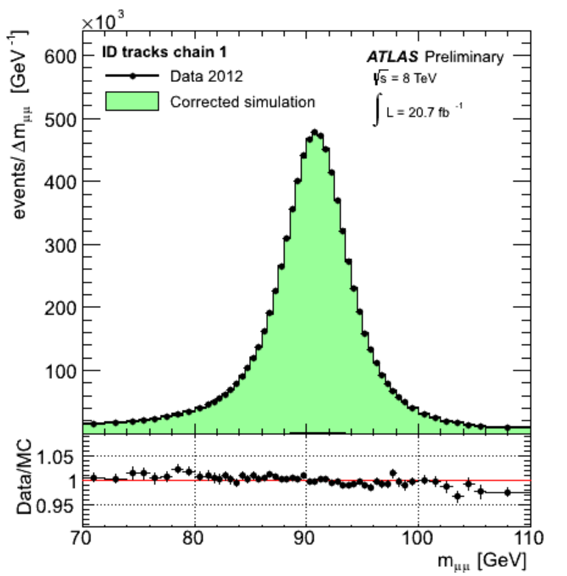


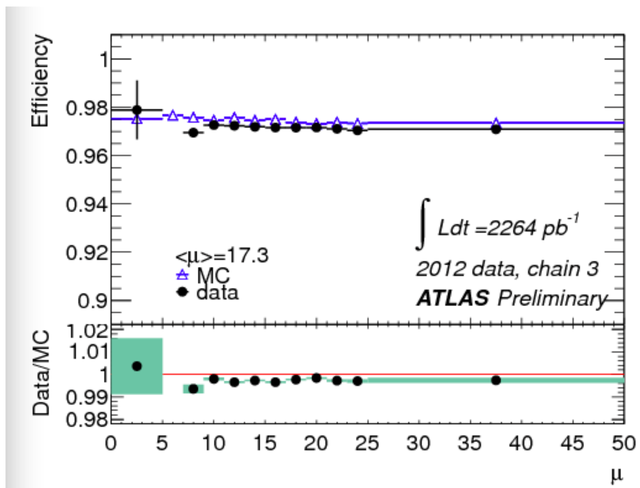
ATLAS EXPERIMENT
Run Number: 204026, Event Number: 33133446
Date: 2012-05-28 07:23:47 CEST
35 ET (GeV)
25
15
5
η
Φ
0
90
180
270
360

e and μ reconstruction

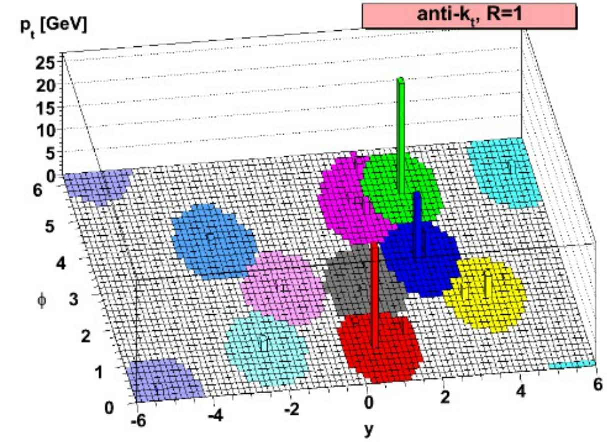
- Electrons: combine shower shape information from calorimeter with tracking information (including transition-radiation in TRT)
- Muons: combined tracks in inner detector and muon chambers
- MC simulation corrected to reproduce the detector resolution, energy scale and efficiency precisely

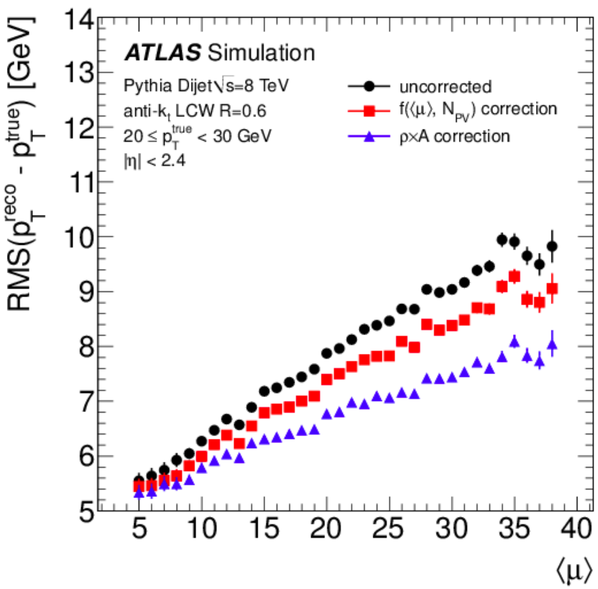


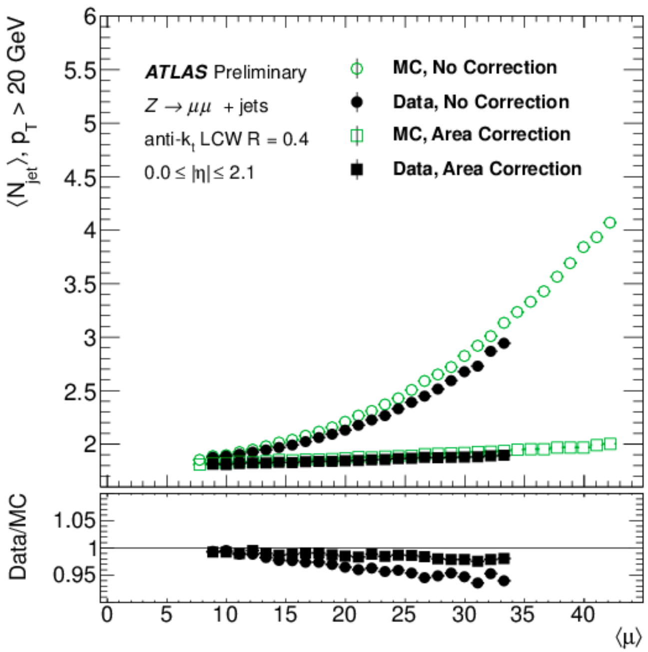




- Use Anti-kT with R = 0.4
  - Constituents: 3D clusters in calorimeter
- Calibrate to hadronic scale
- Sensitive to pile-up
  - Apply pile-up corrections

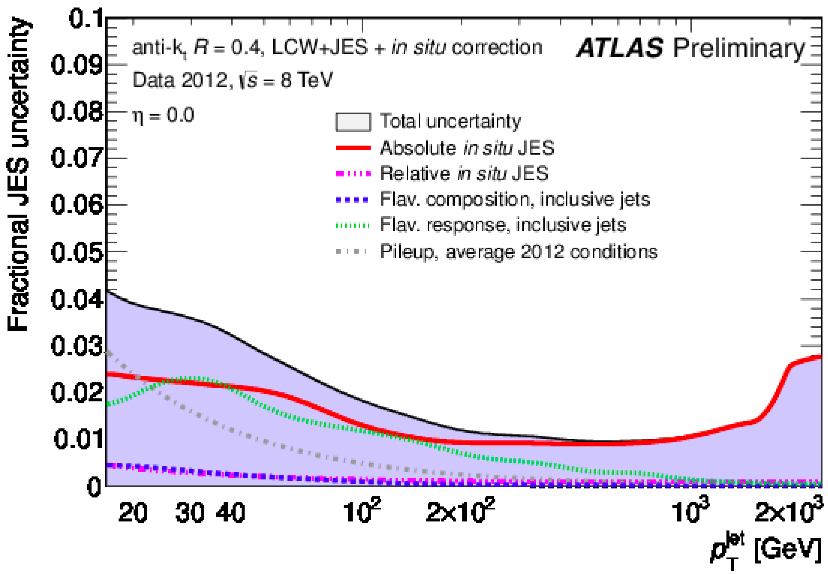


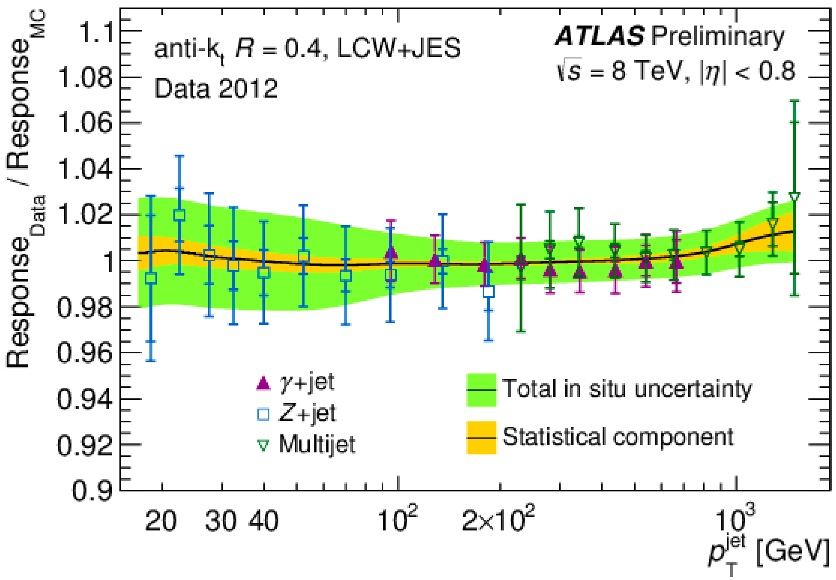




Jet energy scale uncertainty

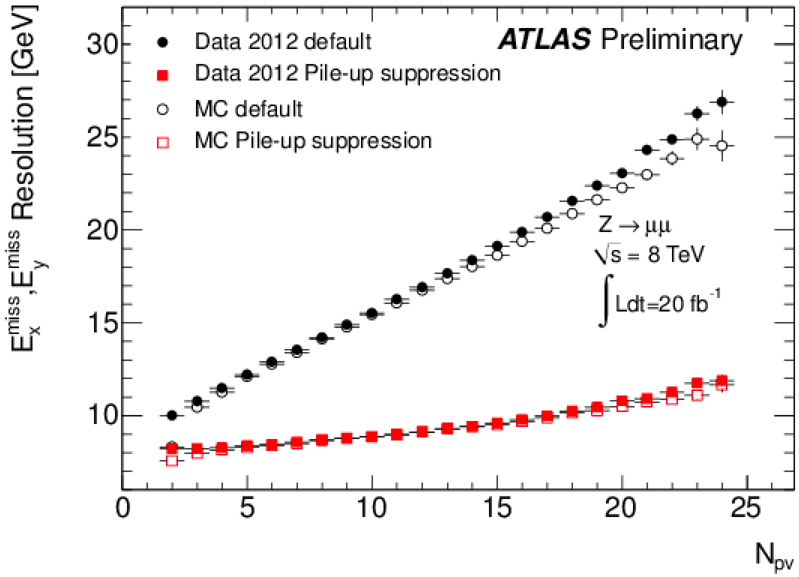
- At high pT JES uncertainty dominated
  - In-situ uncertainties
- At low pT: combination of several uncertainties
- Pile-up
  - Affects mainly low pT jets

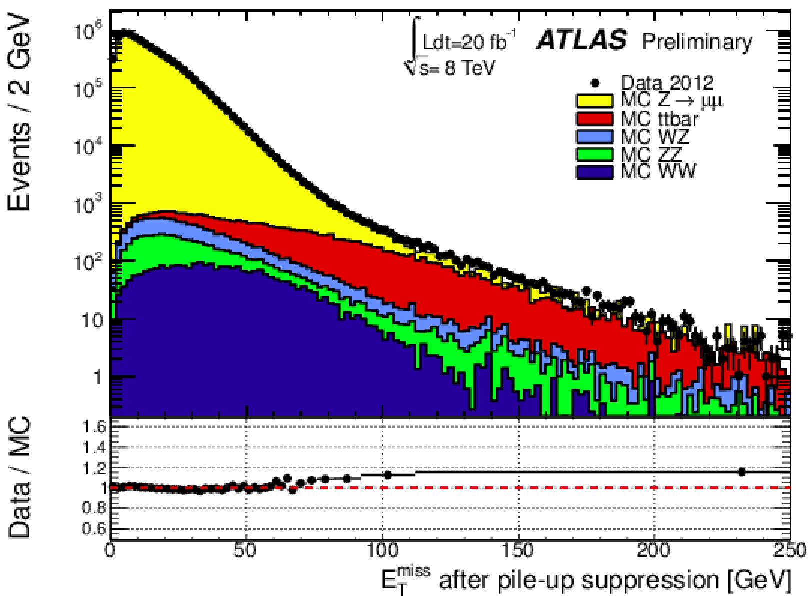




Missing ET performance

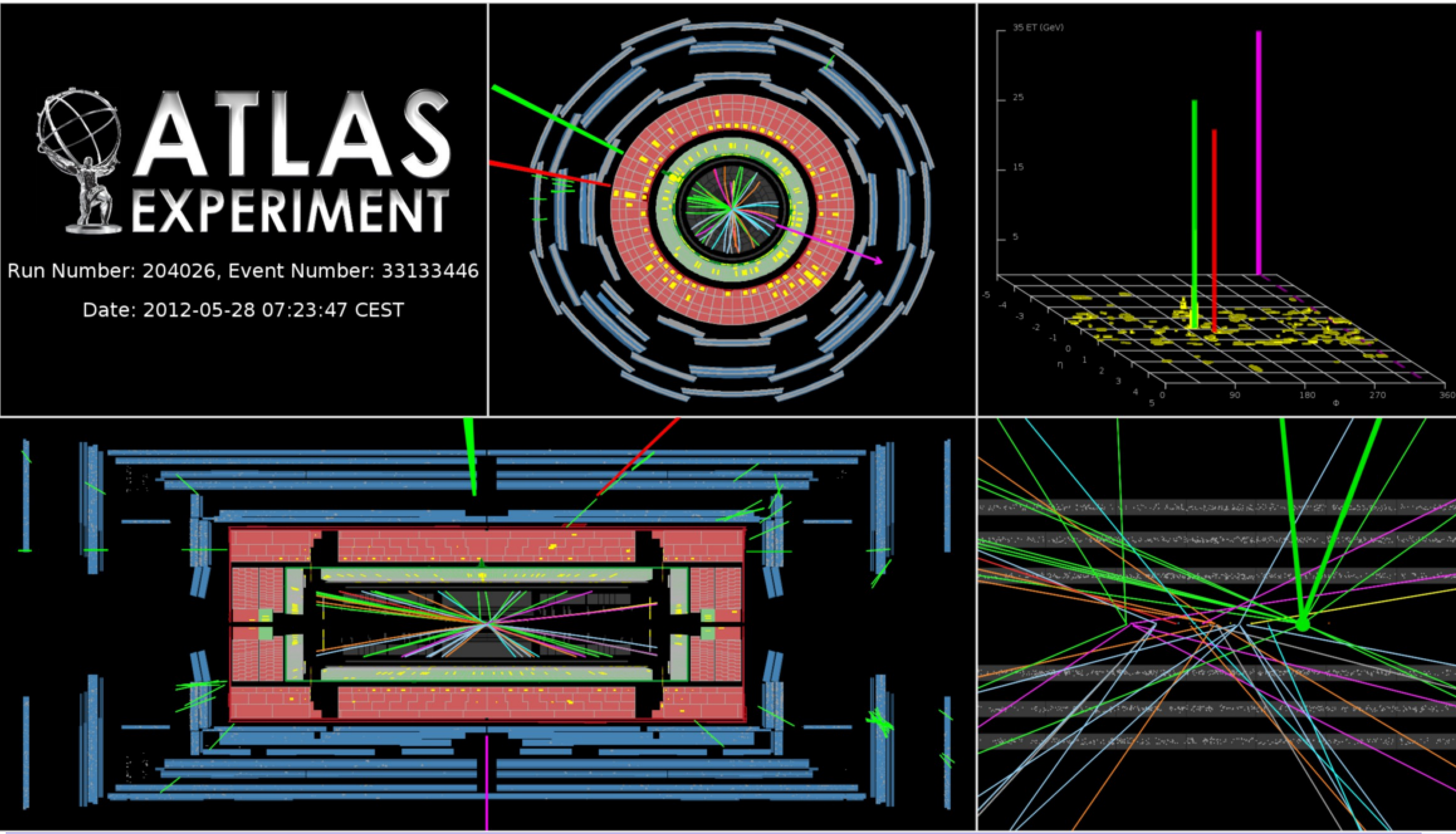
- Calculated as the sum of the energy of all the identified objects (e, γ, μ, τ, jets) and energy not associated to objects





- ETmiss resolution worsens significantly with increasing pile-up
  - Correct it using tracking information
- Good data-MC agreement

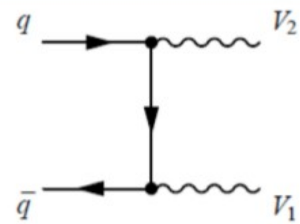
$H \rightarrow WW \rightarrow l\nu l\nu$



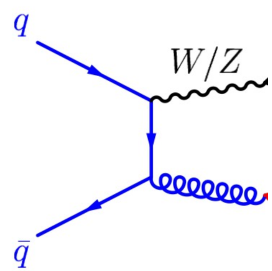
Main backgrounds

- Di-boson production

  WW, WZ, ZZ



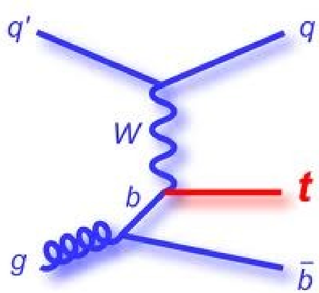
- Others: W+jets, Wγ, Drell-Yan

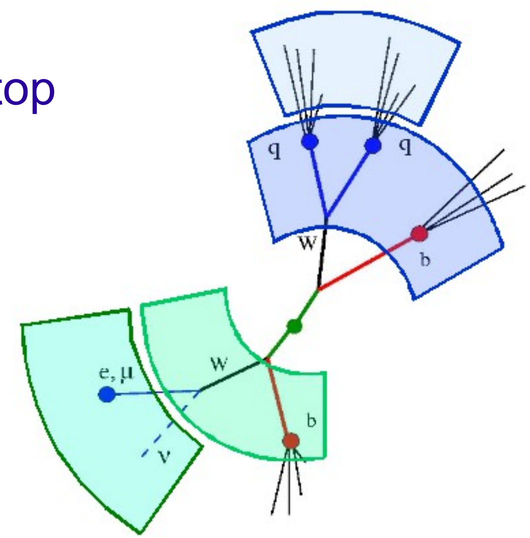


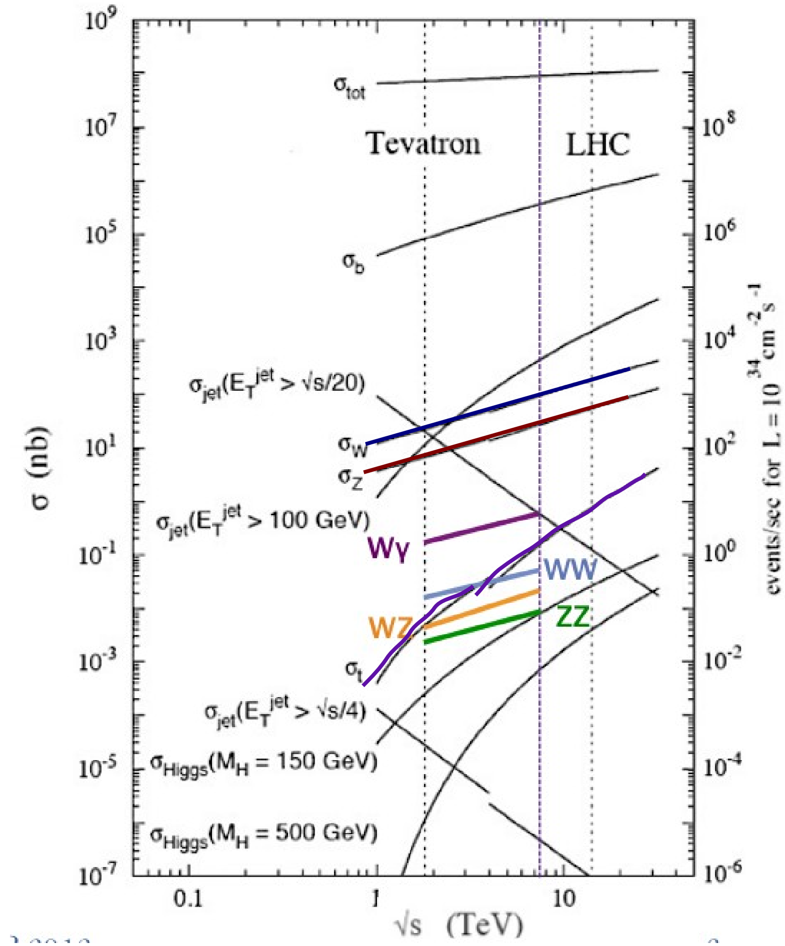
- Top production:

  t-tbar

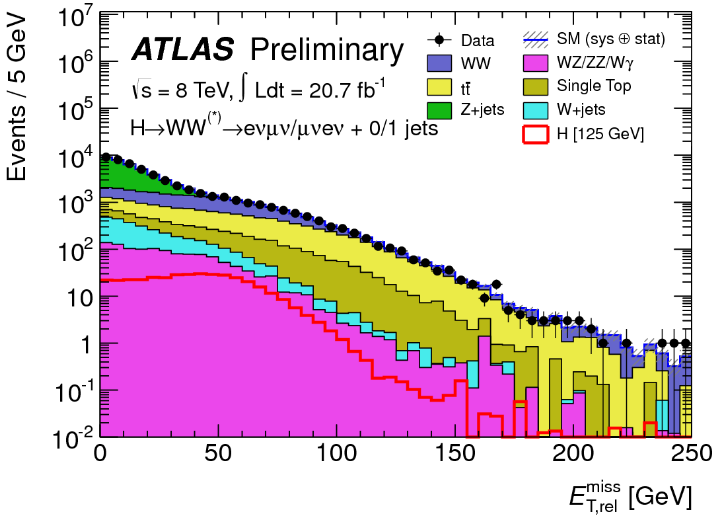
  Single top



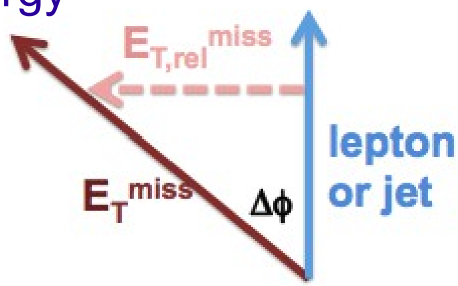


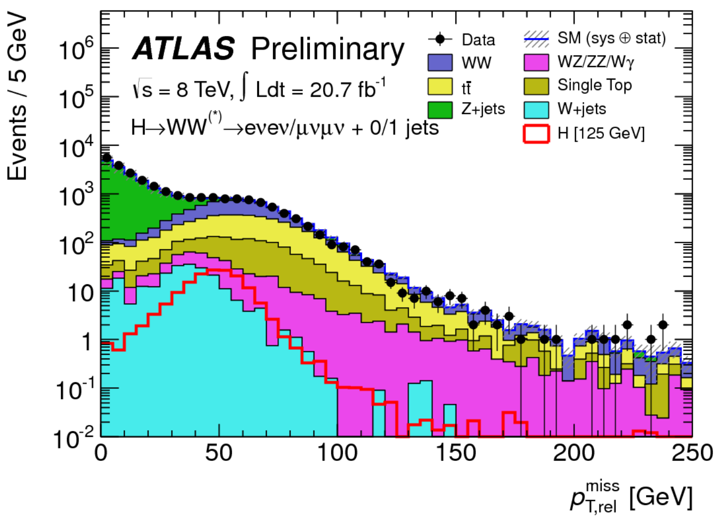


- Exploit the properties of the Higgs events to separate the signal from the backgrounds
- Different channels affected by different backgrounds
  - Small selection differences in opposite/same flavour final states



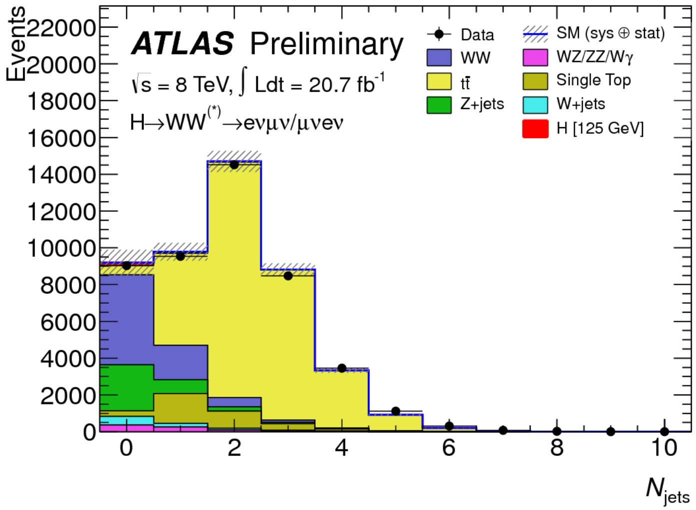
- Reject Z/Drell-Yan background
  - Require large missing transverse energy



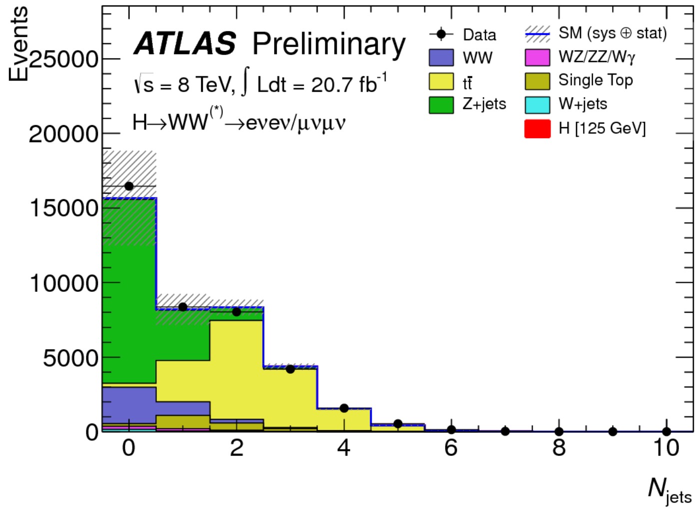


Use calorimeter and tracking systems

- Opposite flavour final state

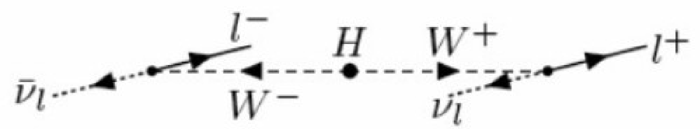


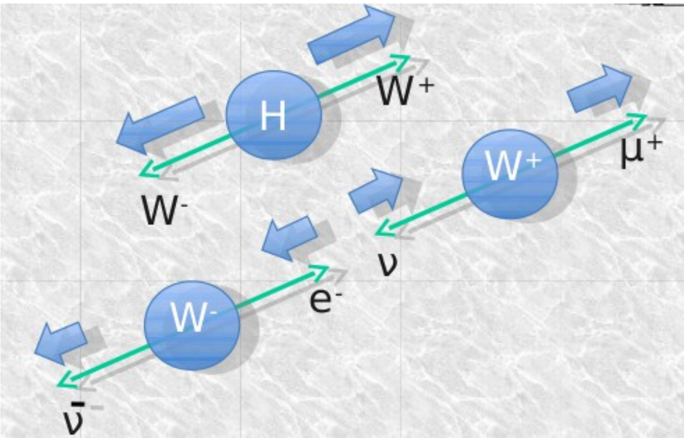
- Same flavour final state

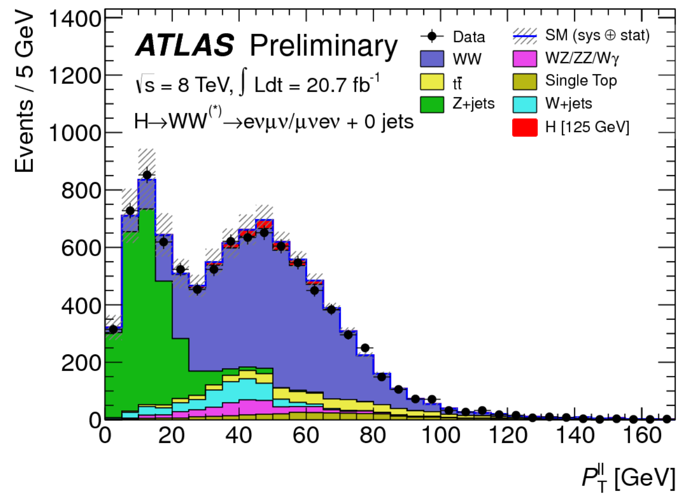


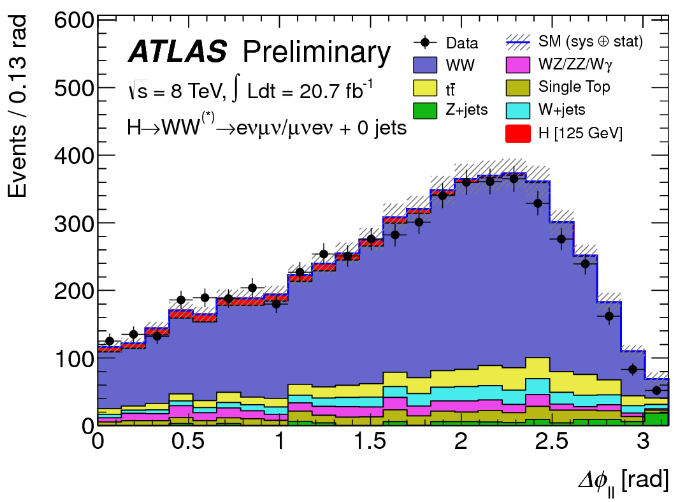
- Consider separately different categories: 0, 1, 2 jets
  - Sensitive to different production mechanisms
    - Gluon gluon fusion dominates the 0-jet category
    - VBF dominate the 2-jet category
  - Affected by different backgrounds

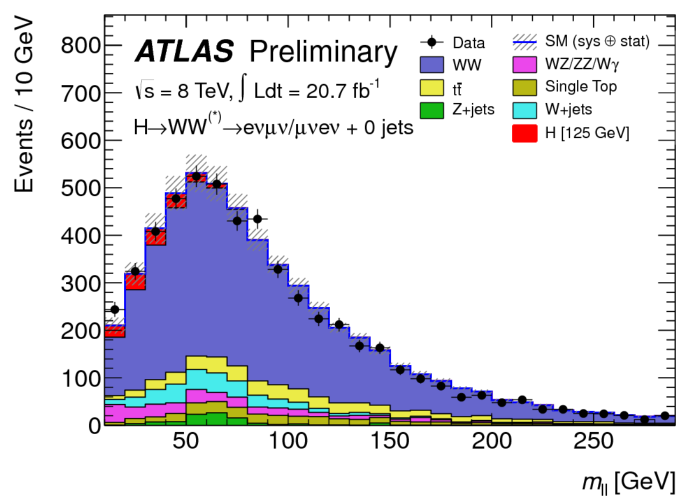
Further selection





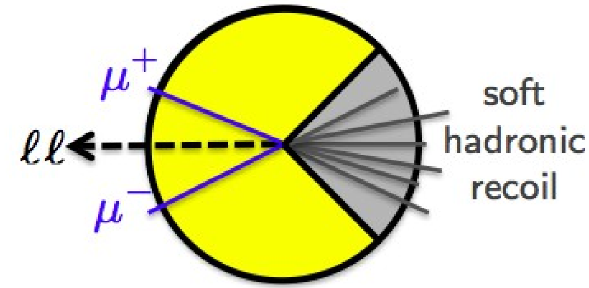




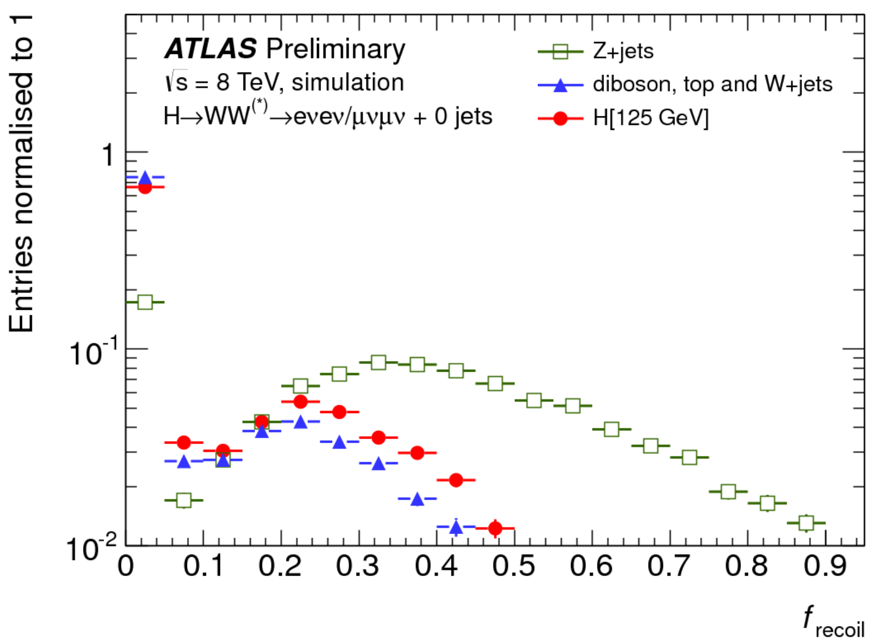


Further selection (II)

- Same flavour final state:
  - Drell-Yan background still large
    - Affected by pile-up
    - Hard to model it with MC
  - Use recoil energy for further rejection



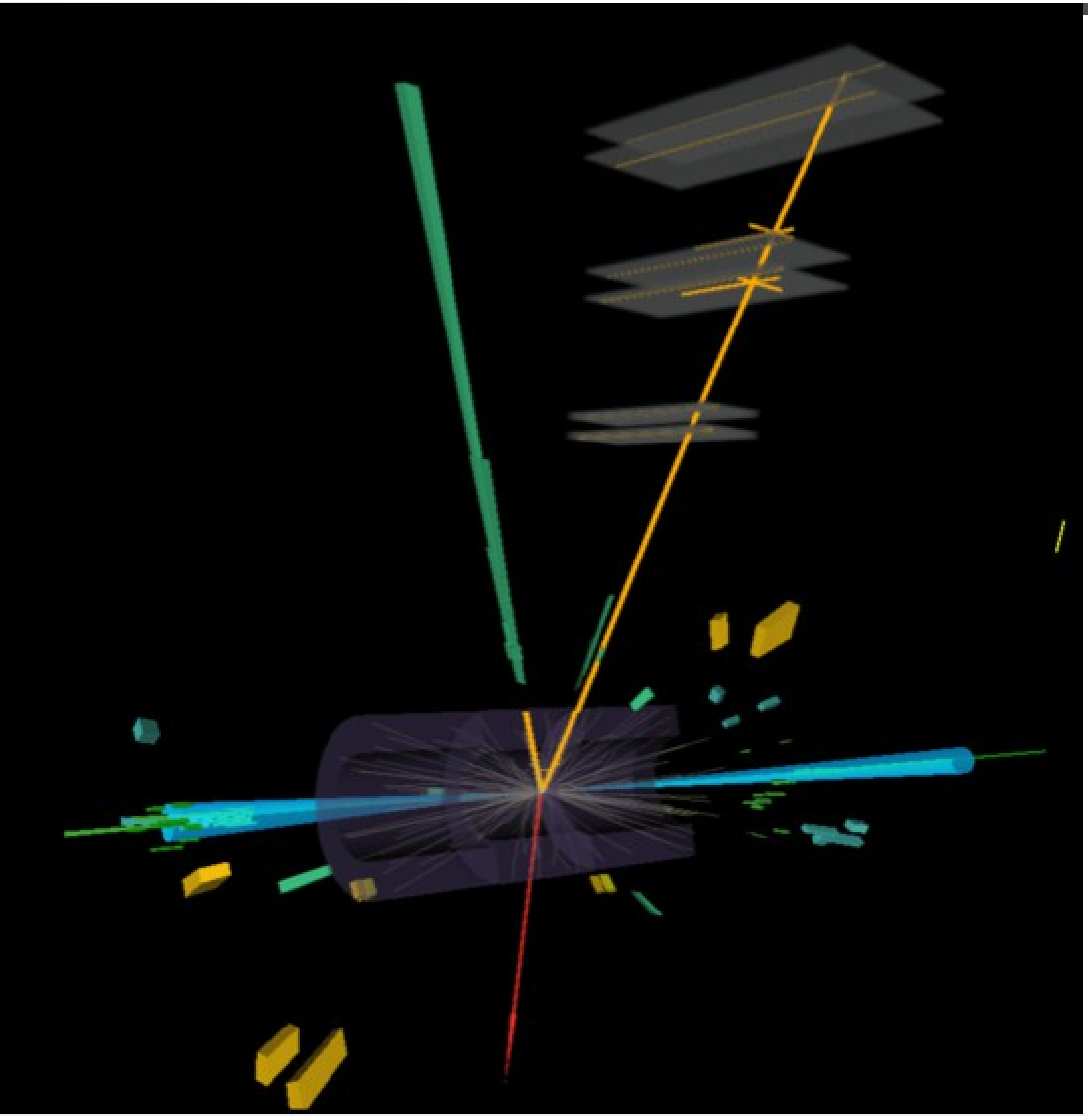
$$f_{recoil} = \frac{|\sum |JVF| \times \vec{p_T}|}{p_T^{\ell\ell}}$$



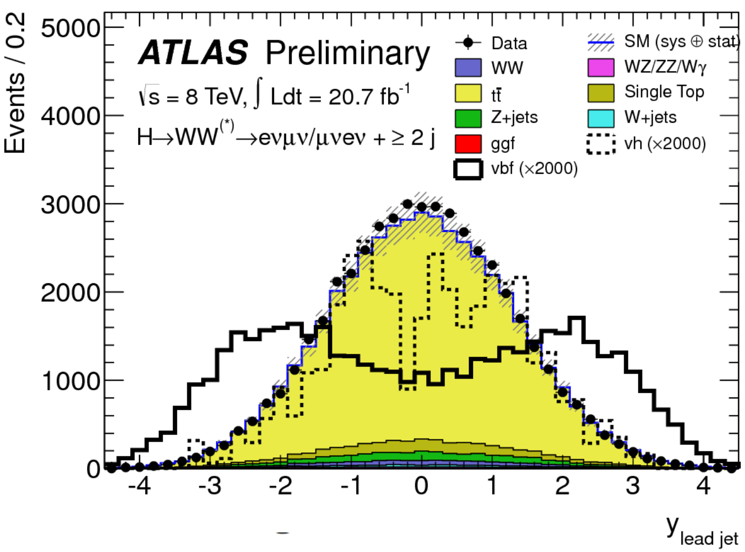
- Require

$f_{recoil} < 0.05/0.2$ for 0/1-jet.

2-jet analysis

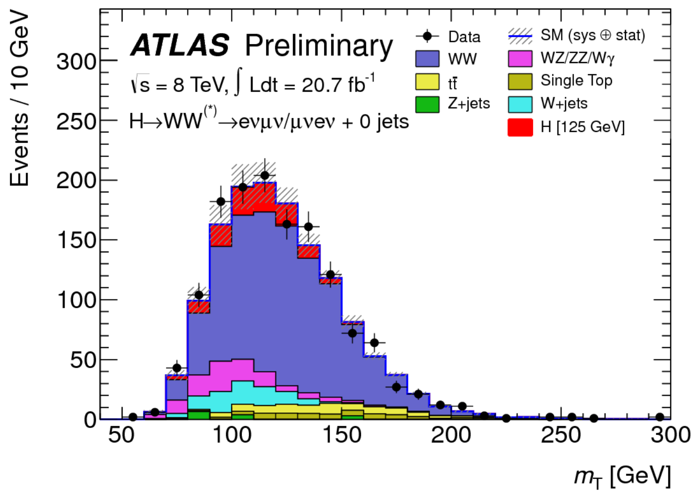


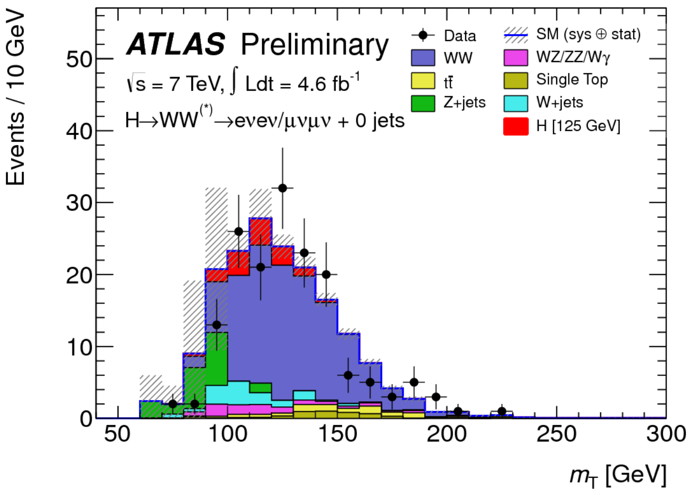
- Dominated by VBF
- Large rapidity gap between jets



$$|\Delta y_{jj}| > 2.8$$

$$m_{jj} > 500\ \mathrm{GeV}$$

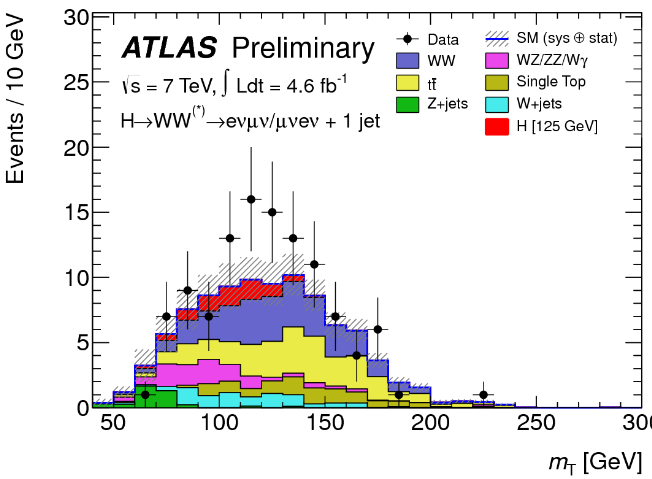




- Define the transverse mass:

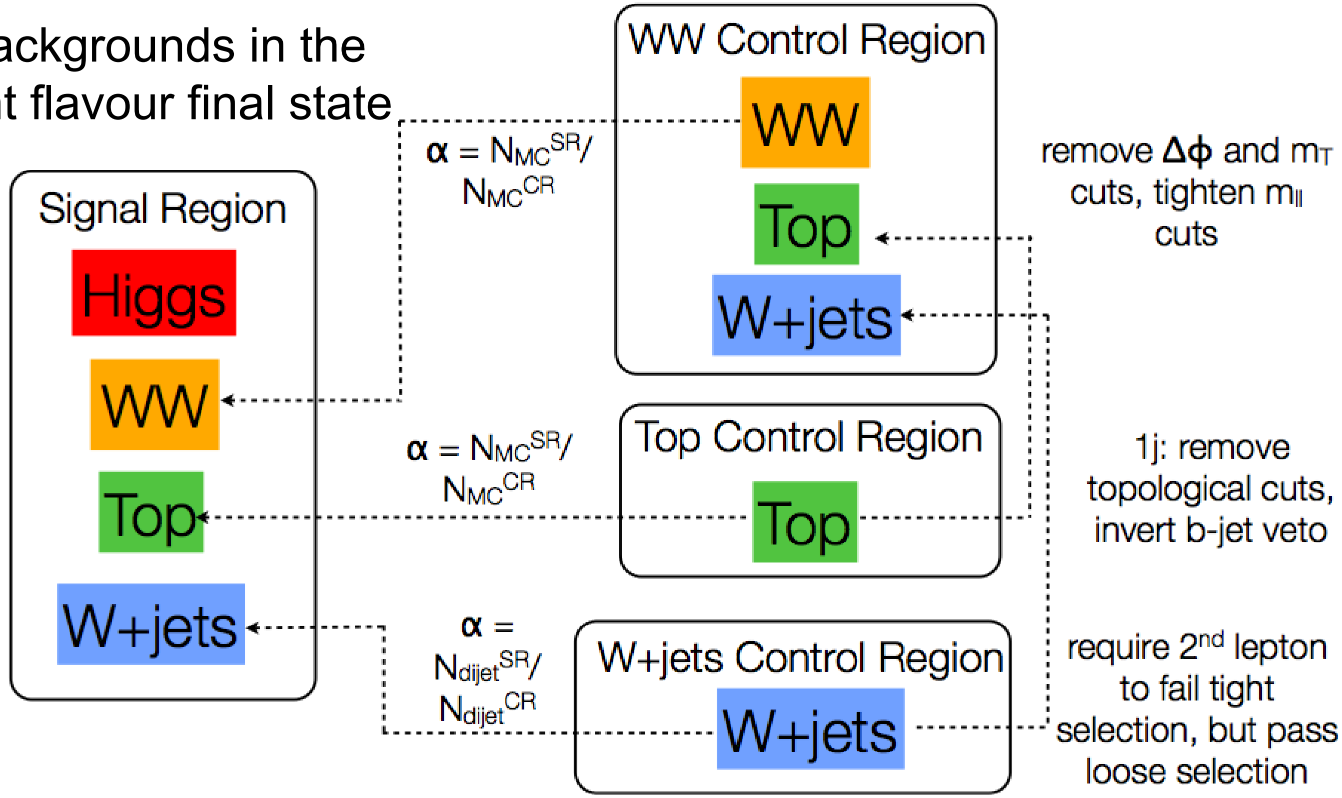
$$m_T = \sqrt{(E_T^{\ell\ell} + |\vec{p}_T^{miss}|)^2 - (\vec{p}_T^{\ell\ell} + \vec{p}_T^{miss})^2}$$

- Equivalent to the mass, but considering only transverse variables
- Sensitive to the Higgs mass in the high edge



- Since it is not possible to reconstruct a narrow peak backgrounds have to be measured carefully!

Main backgrounds in the different flavour final state



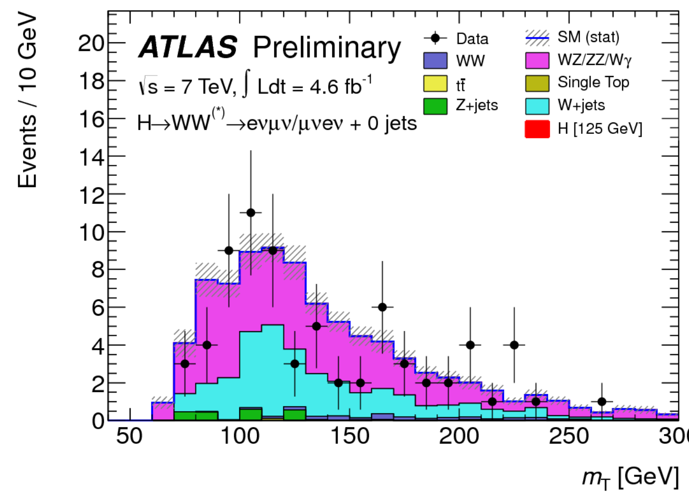
W+jets:

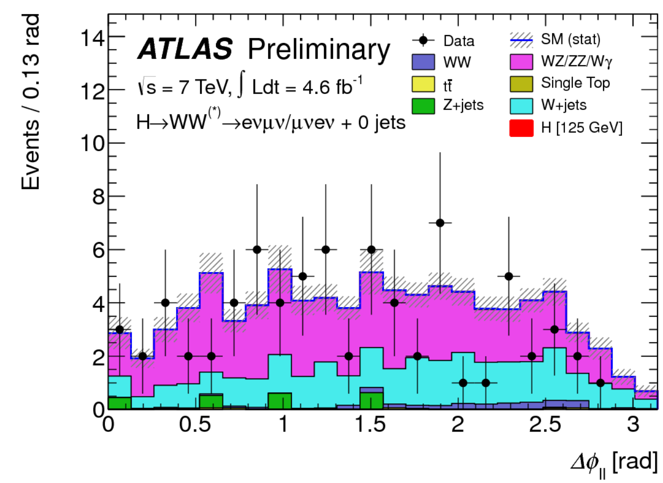
- Control sample: one loosely identified lepton
- Transfer factor to signal region evaluated with a data sample dominated by QCD jets
  - Probability of a jet faking a lepton
- ~30% uncertainty
  - Dominated by jet flavour composition in QCD versus W+jet events

Dibosons (Wγ, ZZ, WZ)

- Taken from MC
- Validated with the same sign validation region
- ~20% uncertainty

Same sign validation region





Background estimation

Top:

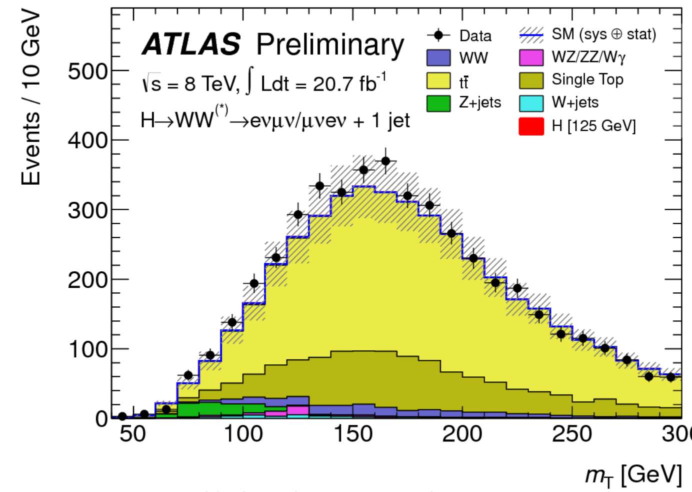
- Control sample: remove jet multiplicity or b-tagging conditions depending on the channel
- Correction factors applied to a purely MC-based estimation: 1.07±0.03, 1.04±0.02, 0.59±0.07 for the 0-,1-,2-jet analysis
- Systematics from extrapolation to signal region

WW:

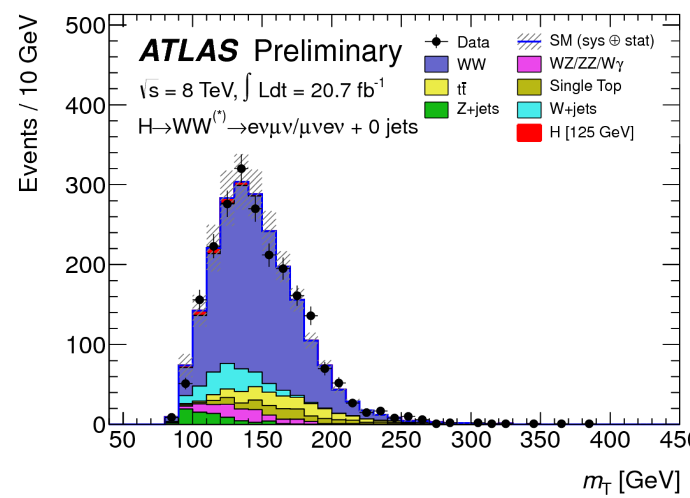
- Remove $\Delta\phi_{ll}$ cut, require $50<m_{ll}<100$ GeV
- Use measurements of other backgrounds
- NF = 1.16±0.04 (stat)
- Uncertainty ~7%, dominated by extrapolation to SR

	old	new
scale	2.5%	0.9%
PDF	3.7%	1.1%
PS	4.5%	0.8%
model	3.5%	1.4%
Total	∼ 7.2%	∼ 2.1%

Top control region



WW validation region



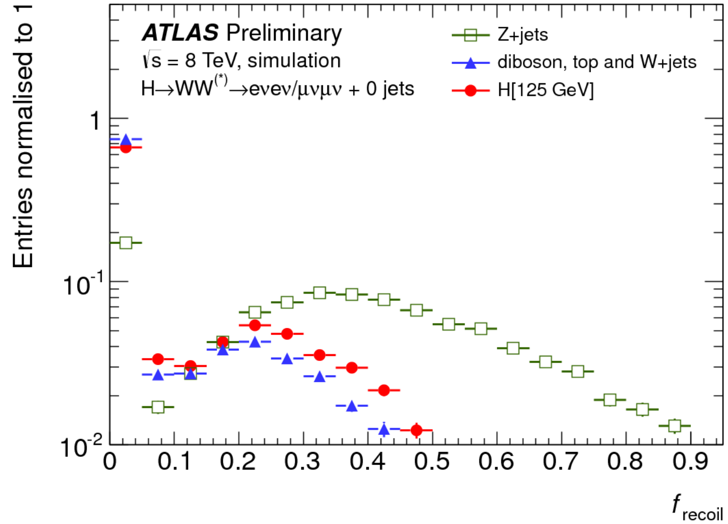
Z/γ* background

- Count events before/after f_{recoil} cut

$$N^{data}_{pass} = N^{Z/\gamma^*}_{pass} + N^{non\text{-}Z/\gamma^*}_{pass}$$

$$N^{data} = \frac{N^{Z/\gamma^*}_{pass}}{\epsilon^{Z/\gamma^*}} + \frac{N^{non\text{-}Z/\gamma^*}_{pass}}{\epsilon^{non\text{-}Z/\gamma^*}}$$

- Solve for N^{Z/γ^*}_{pass}



- Where:

  $\varepsilon^{non\text{-}Z/\gamma*}$ - fraction of eμ + μe data events passing the cut (pure in non-Z /γ*)

  $\varepsilon^{Z/\gamma*}$ - fraction of ee + μμ events passing the cut in the Z peak (dominated by Z/γ*)

- Systematics:

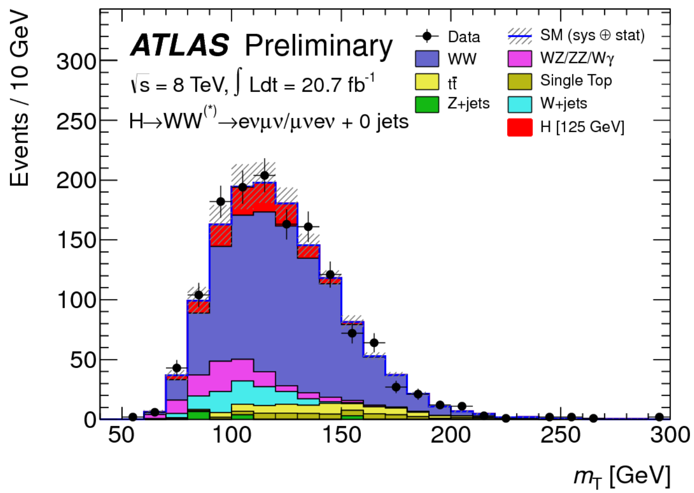
  Compute differences between true and measured efficiencies

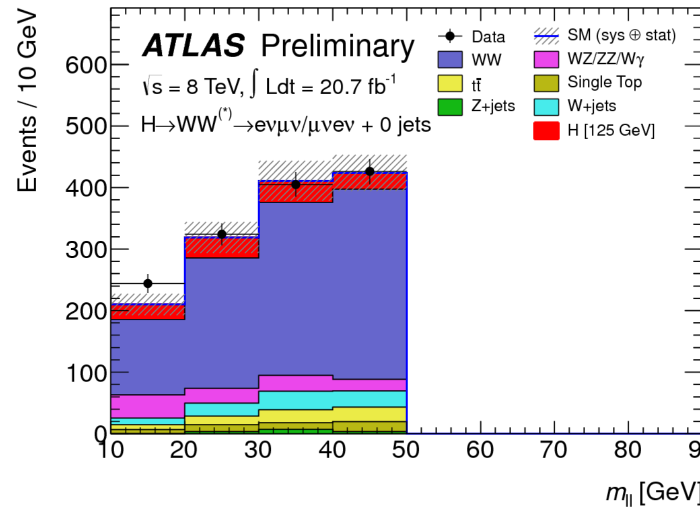
  ~60% for 0-jet and ~80% for 1-jet analysis

Leading systematic uncertainties

Source	Signal processes (%) $N_{jet}=0$	Signal $N_{jet}=1$	Signal $N_{jet}\geq 2$	Background processes (%) $N_{jet}=0$	Background $N_{jet}=1$	Background $N_{jet}\geq 2$
Theoretical uncertainties						
QCD scale for ggF signal for $N_{jet}\geq 0$	13	-	-	-	-	-
QCD scale for ggF signal for $N_{jet}\geq 1$	10	27	-	-	-	-
QCD scale for ggF signal for $N_{jet}\geq 2$	-	15	4	-	-	-
QCD scale for ggF signal for $N_{jet}\geq 3$	-	-	4	-	-	-
Parton shower and UE model (signal only)	3	10	5	-	-	-
PDF model	8	7	3	1	1	1
$H\rightarrow WW$ branching ratio	4	4	4	-	-	-
QCD scale (acceptance)	4	4	3	-	-	-
WW normalisation	-	-	-	1	2	4
Experimental uncertainties						
Jet energy scale and resolution	5	2	6	2	3	7
b-tagging efficiency	-	-	-	-	7	2
f_{recoil} efficiency	1	1	-	4	2	-

Signal extraction

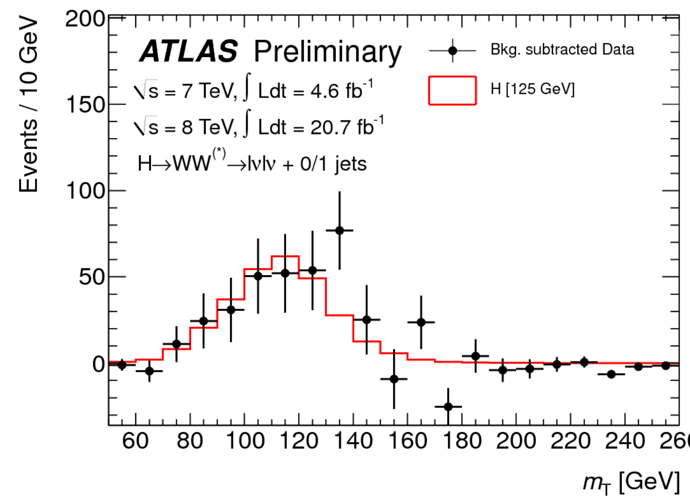


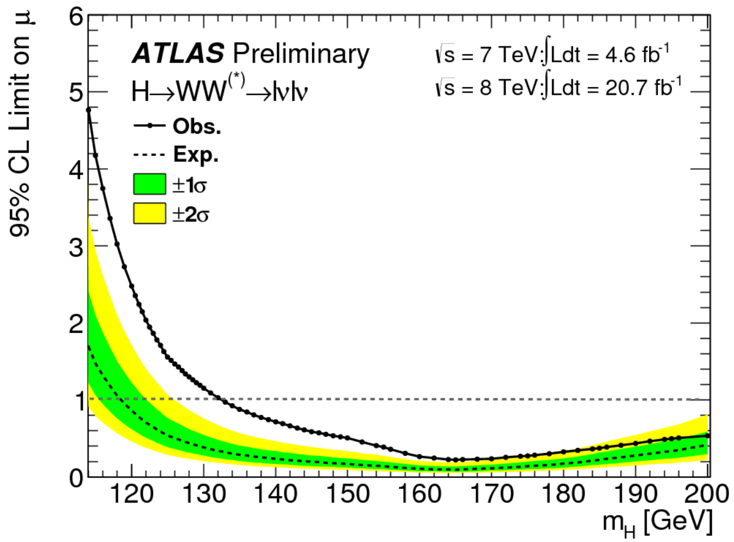


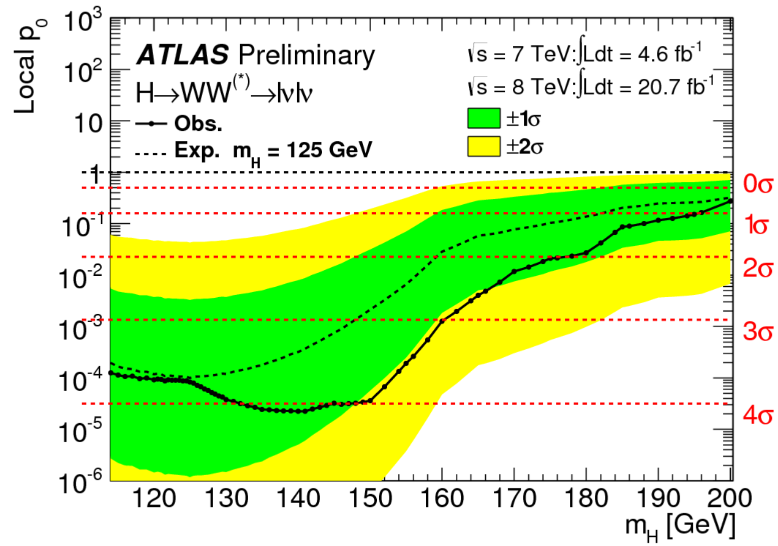
- Fit the transverse mass

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

- Separate different analysis categories: 0-, 1 2-jets
- Split signal region at $_{mll}$ = 30 GeV





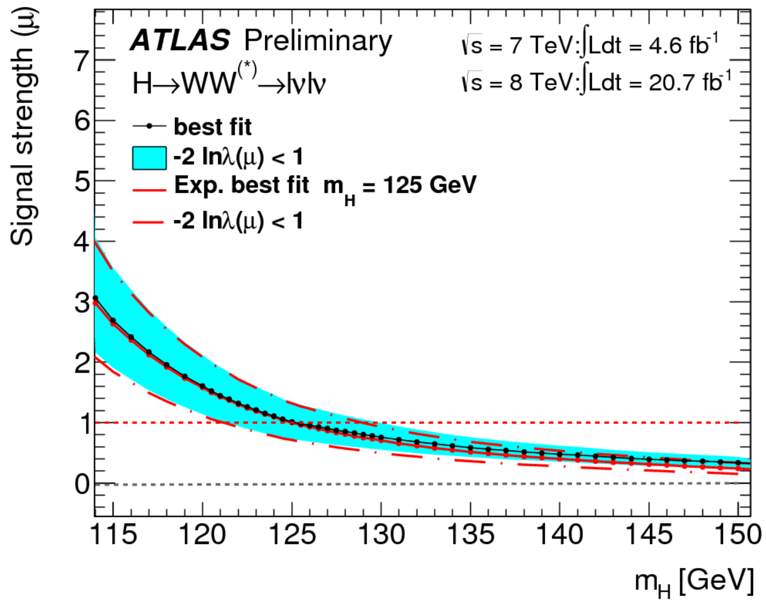


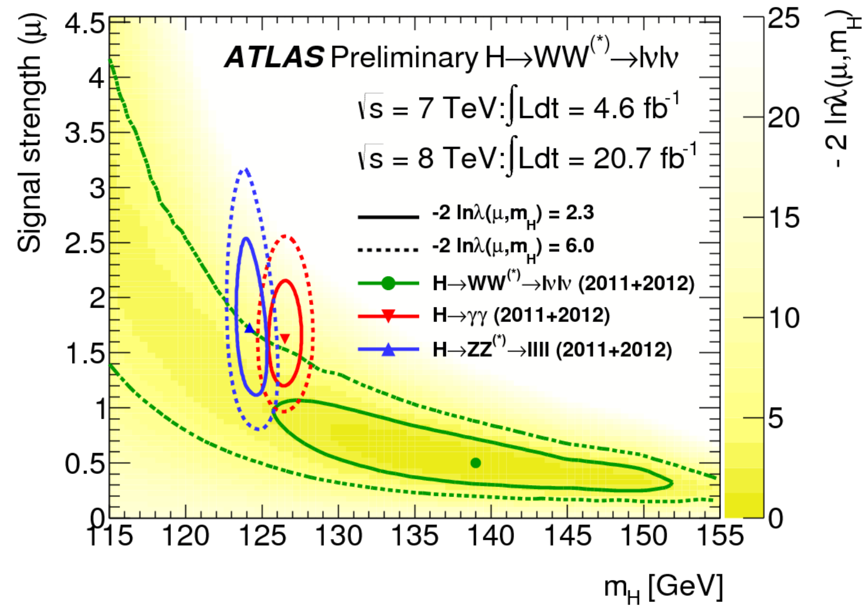
- Exclusion limits at 95% CL
  - Expected: down to 119 GeV
  - Observed: m_H>133 GeV

- p_0 = probability that the observed excess of events is due to a background fluctuation

$$p_0^{\text{expected}}(125) = 1 \times 10^{-4} \Rightarrow 3.7\sigma$$

$$p_0^{\text{observed}}(125) = 8 \times 10^{-5} \Rightarrow 3.8\sigma$$

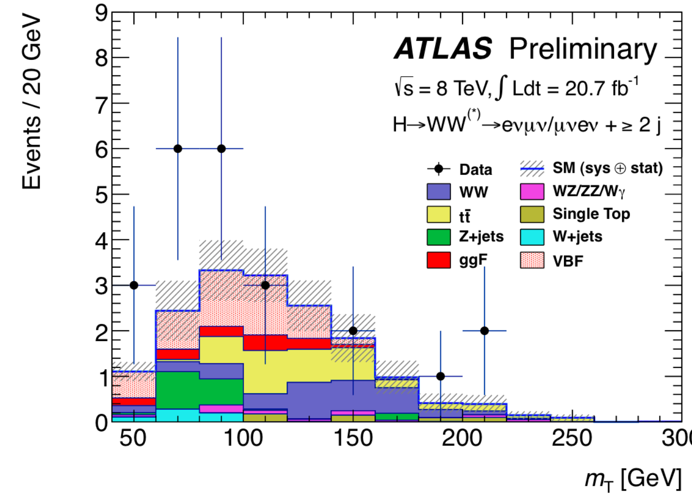


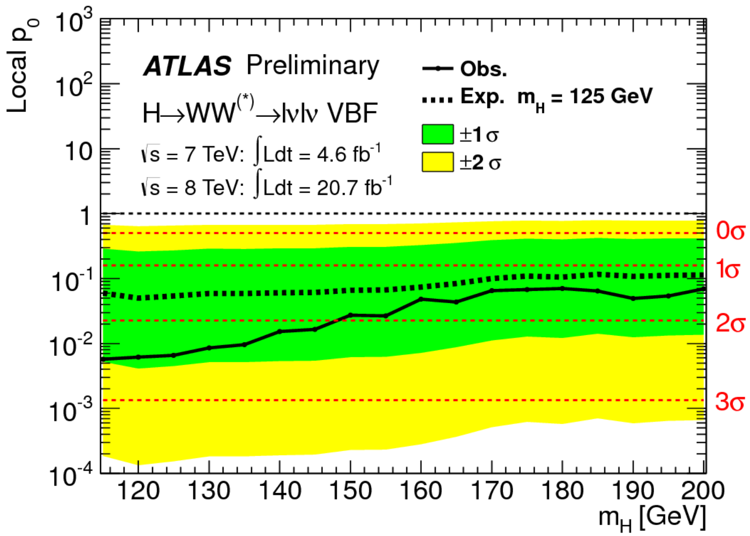


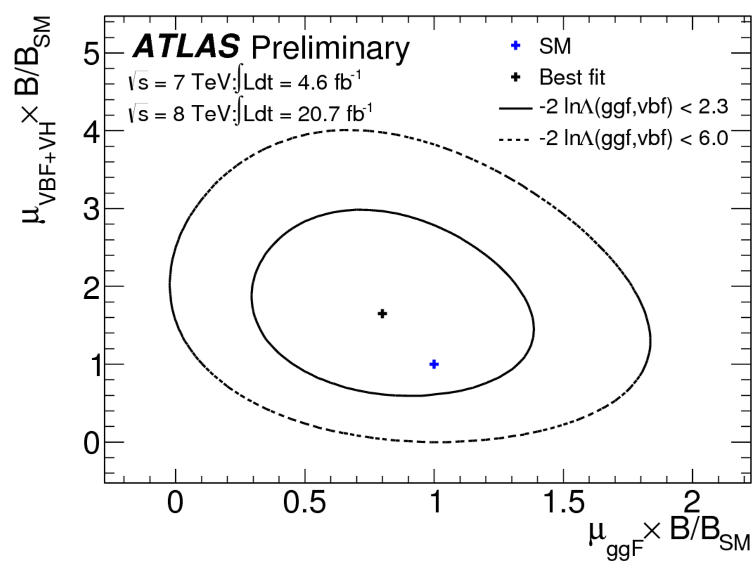
- Signal strength compared to the expected SM value
  - Observed signal perfectly compatible with expectations
  - Results for HWW compatible with Hgg and HZZ
- μ^{125}_{obs} = 1.01 ± 0.21(stat) ± 0.19(theo) ± 0.12 (syst) ± 0.04(lumi) = 1.01 ± 0.31

Vector boson fusion H→WW

- Test VBF signal considering gg->H as a background
  - gg fusion constrained on the fit with the 0-,1-jet signal regions

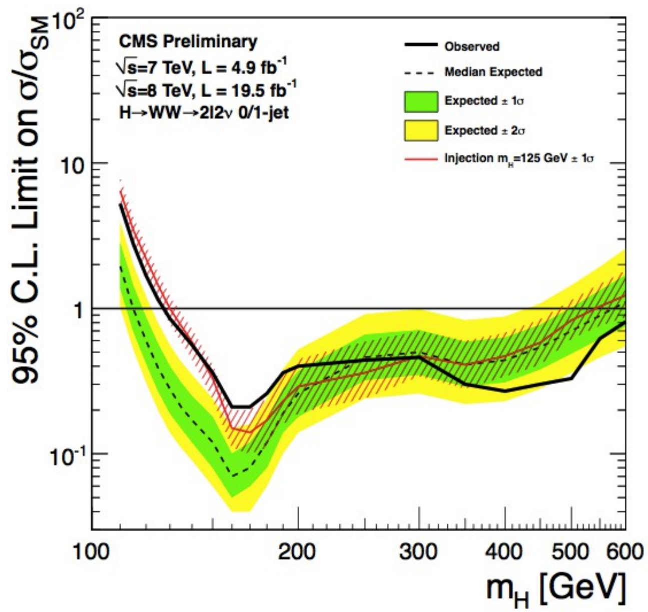


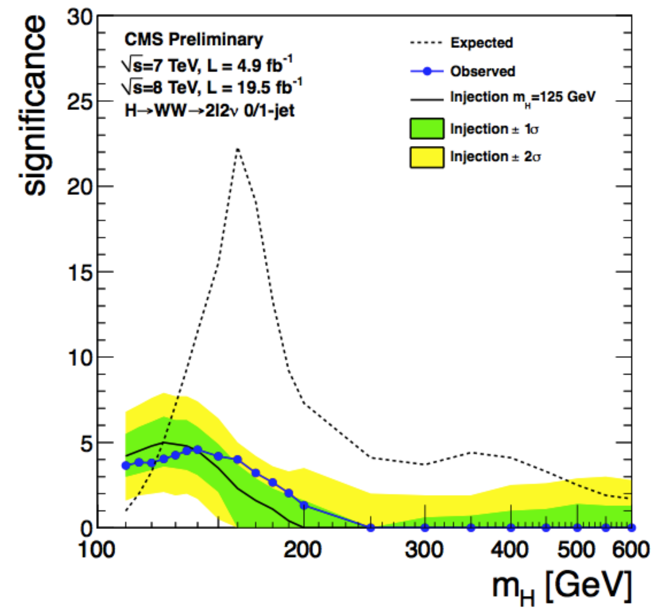




$$\mu_{\text{obs, VBF}} = 1.66 \pm 0.67\,(\text{stat.}) \pm 0.42\,(\text{syst.})$$
$$= 1.66 \pm 0.79.$$

CMS HWW results

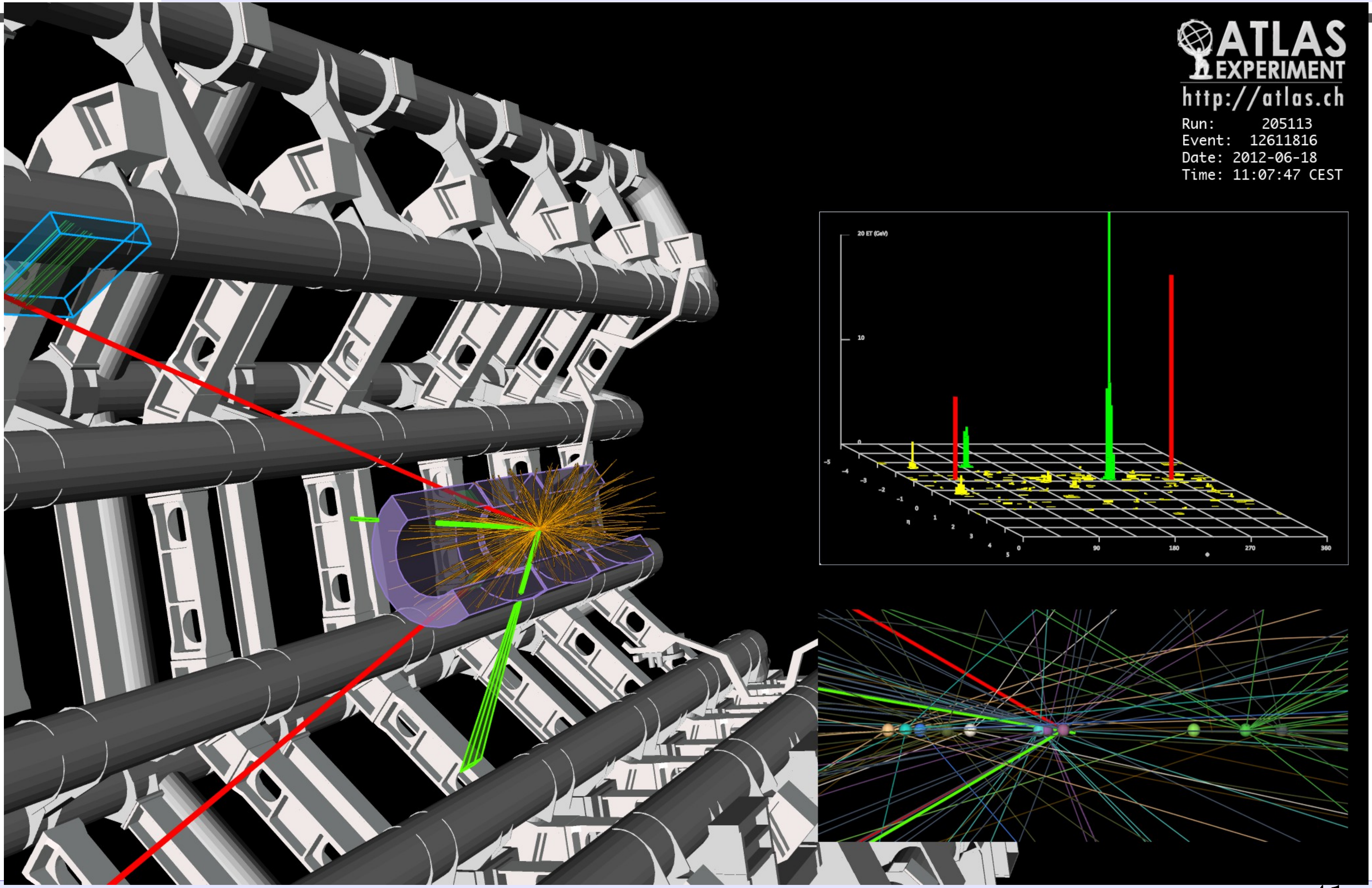




Significance (σ) for m_H = 125 GeV:

observed 4, expected 5.1

σ/σ_{SM} = 0.76 ± 0.21



ATLAS
EXPERIMENT
http://atlas.ch
Run: 205113
Event: 12611816
Date: 2012-06-18
Time: 11:07:47 CEST

H→ZZ→4l analysis

arXiv:1207.7214

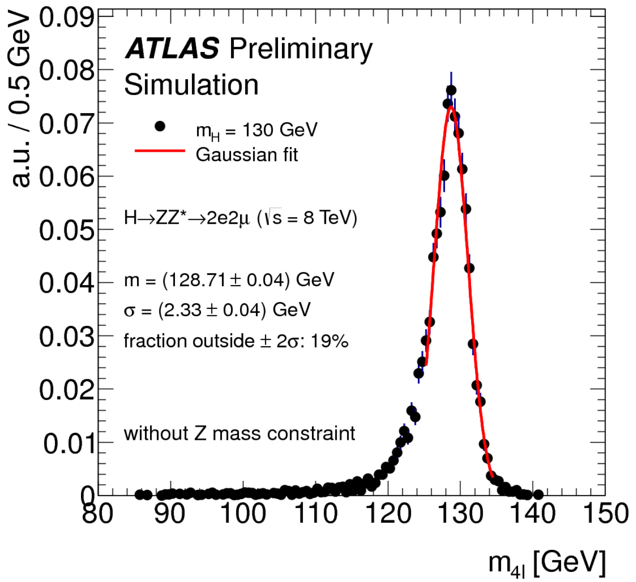
Selection:

- 4 isolated leptons with high p_T
- Z mass constraint on one l pair

Main backgrounds:

- Continuum ZZ^*→4l production
- Z+jets, tt

Discriminating variable: m_{4l}



Excellent mass resolution

- 1.8-2.5 GeV (4μ , 4e)

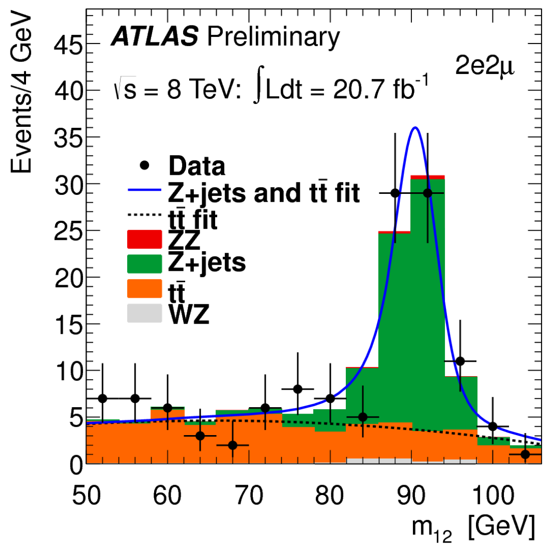
Very good e/μ reconstruction efficiency

- ~97% for muons with p_T>6 GeV
- ~98% (95%) for e reconstruction (identification)

Background estimation

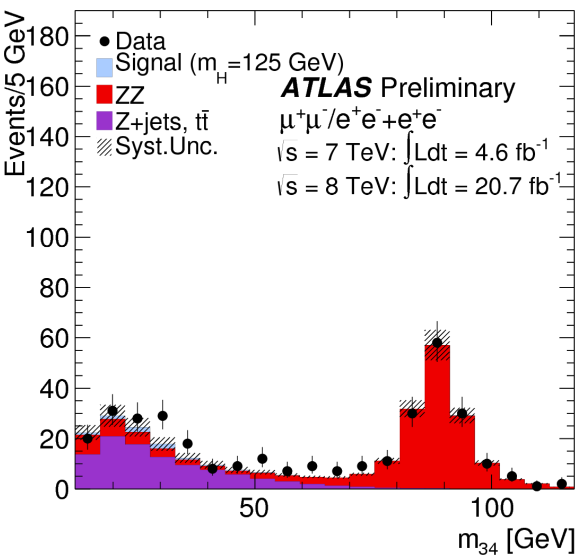
- ZZ continuum estimated with MC simulation
- Z+jets and tt backgrounds estimated using control regions
  - Transfer factors from control to signal regions from MC

Z+jets, tt control region:



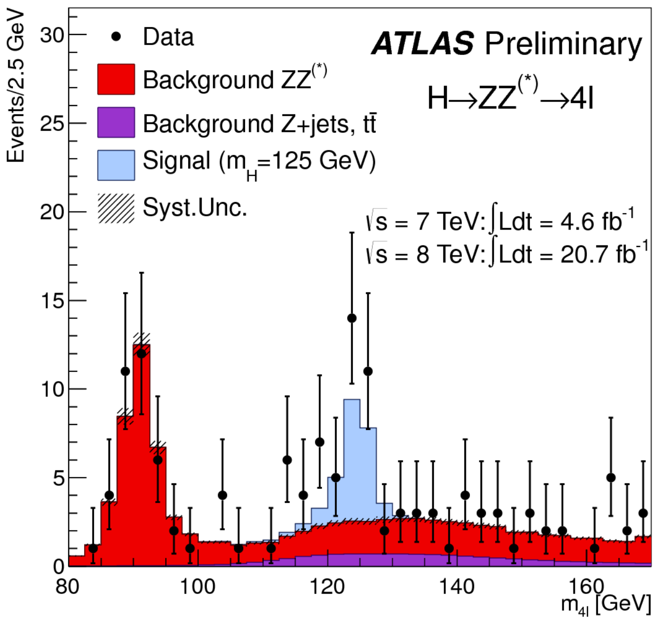
- No isolation & transverse impact parameter requirements on the sub-leading lepton pair

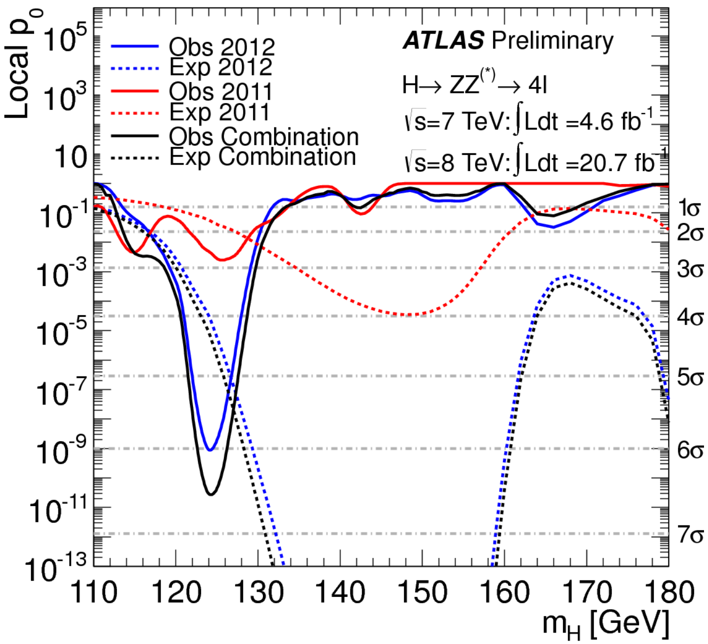
ZZ control region:



- Control region: Z boson candidate + same flavour lepton pair

- 4l mass spectrum (7+8 TeV)



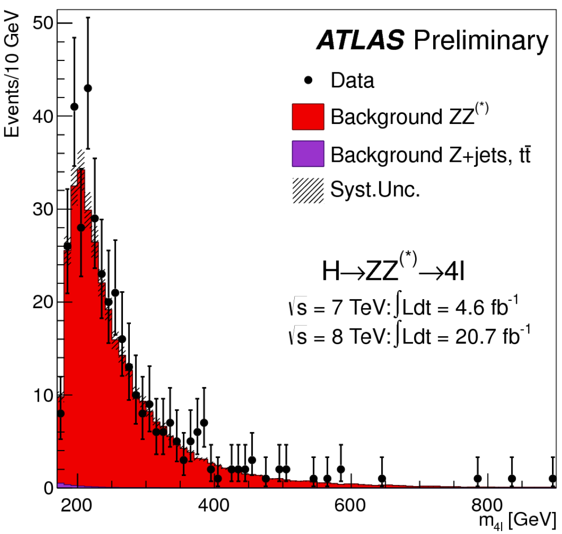


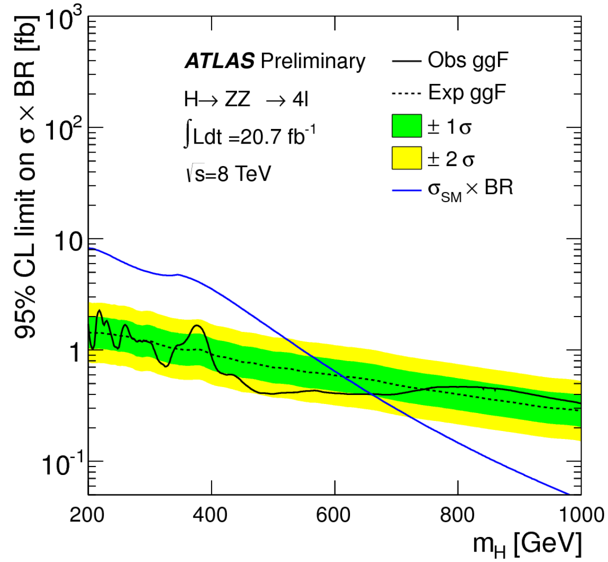
- Minimum combined p0 value for m_H= 124.3 GeV

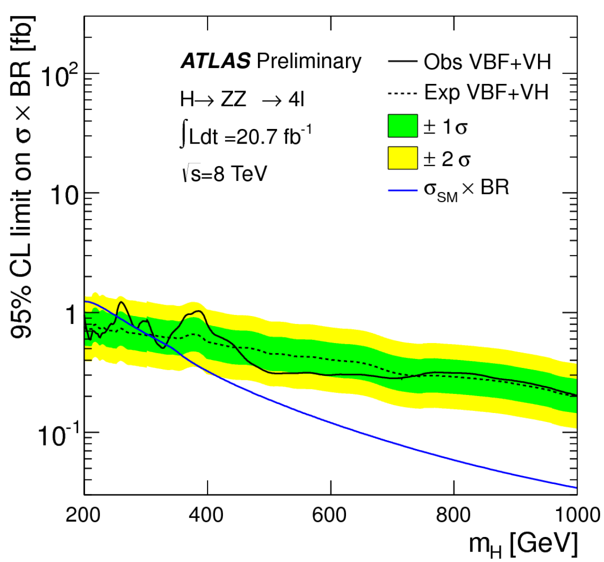
  Expected p0: 5.7×10^{-6} (4.4 σ)

  Observed p0: 2.7×10^{-11} (6.6 σ)

H→ZZ→4l results larger masses



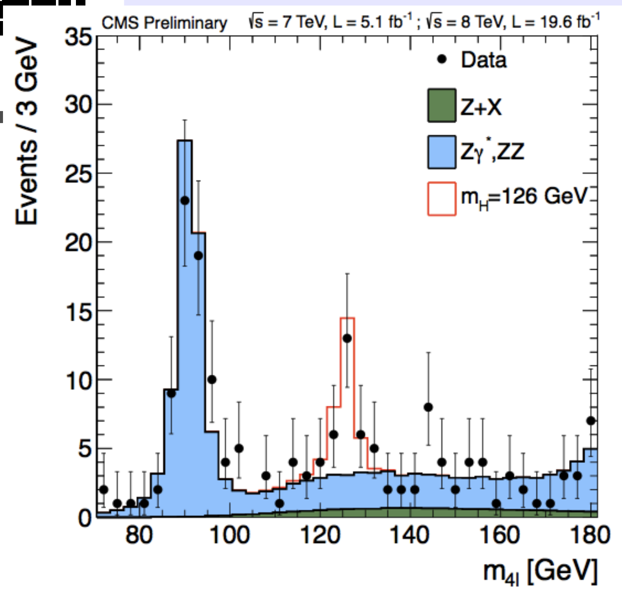


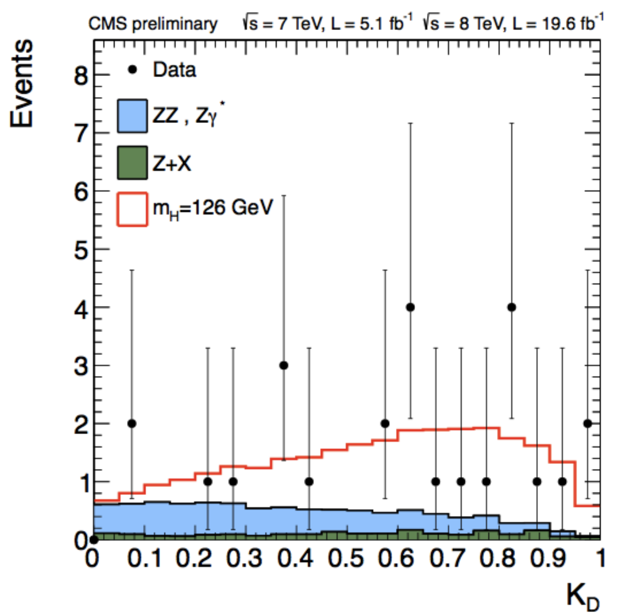


Search for other SM Higgs-like resonance in a large mass regime

- Assume SM width
- Test independently VBF and ggF to allow constraint new resonances that might have different production rates

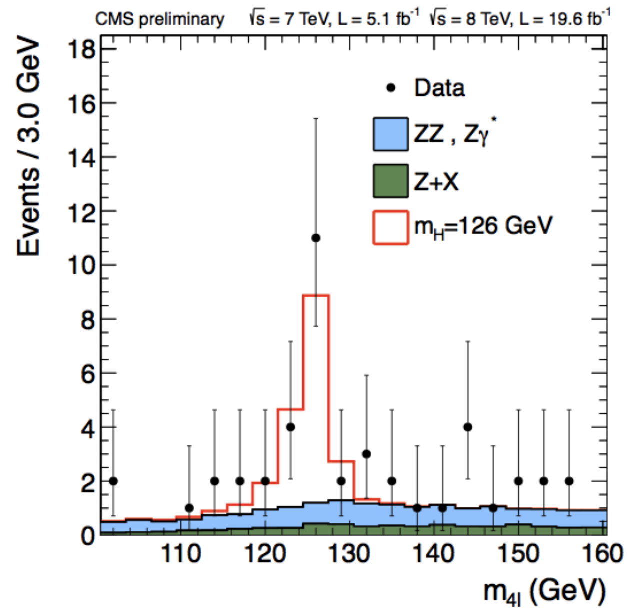
CMS H→ZZ→4l results





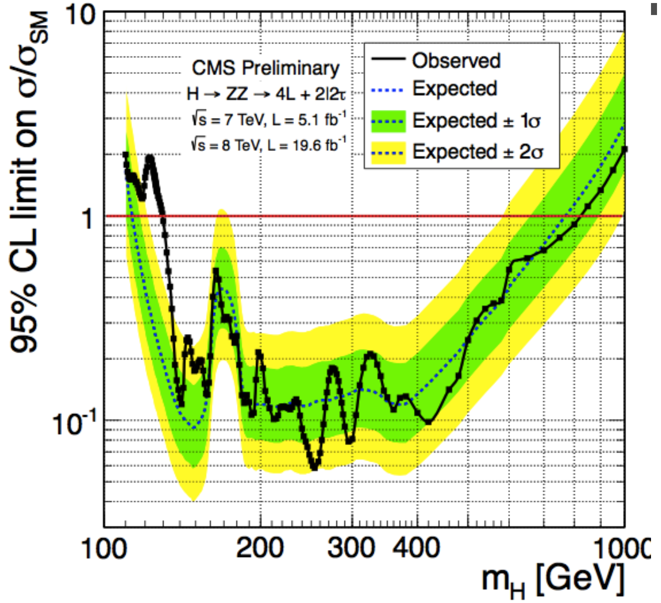
- Kinematic discriminant to further separate signal and background

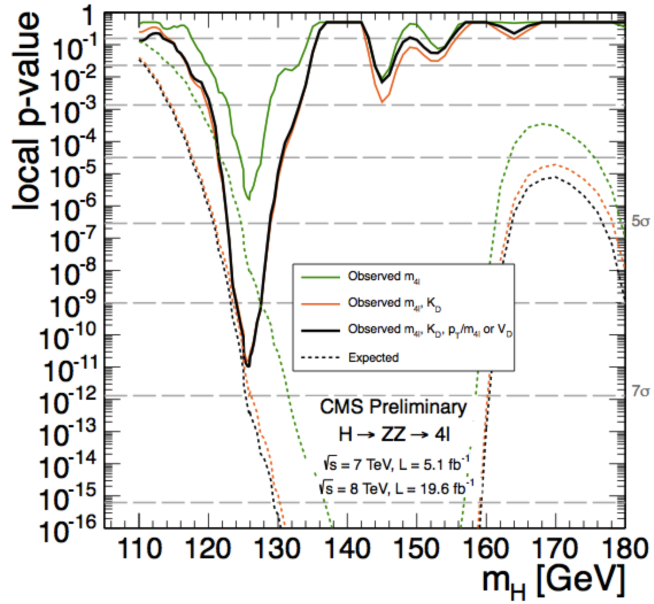
$$K_D(\theta^*, \Phi_1, \theta_1, \theta_2, \Phi, m_{Z_1}, m_{Z_2}) = \mathcal{P}_{sig}/(\mathcal{P}_{sig} + \mathcal{P}_{bkg})$$

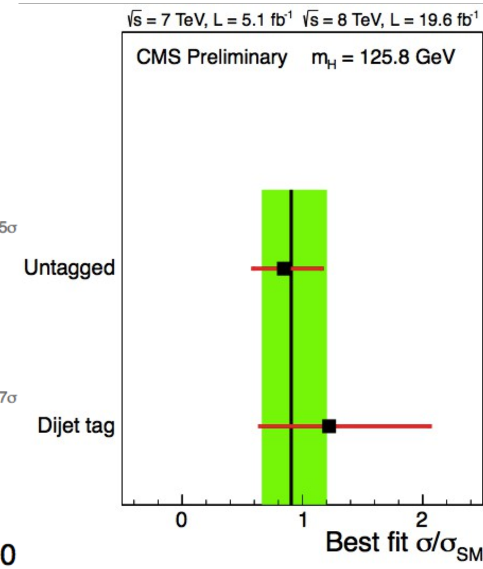


- Consider also a VBF enriched category: +2jets and use of a Fisher discriminant to select it

CMS H→ZZ→4l results

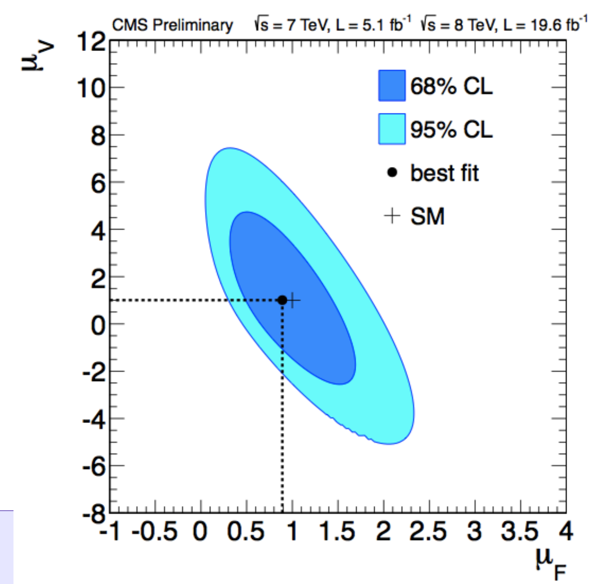


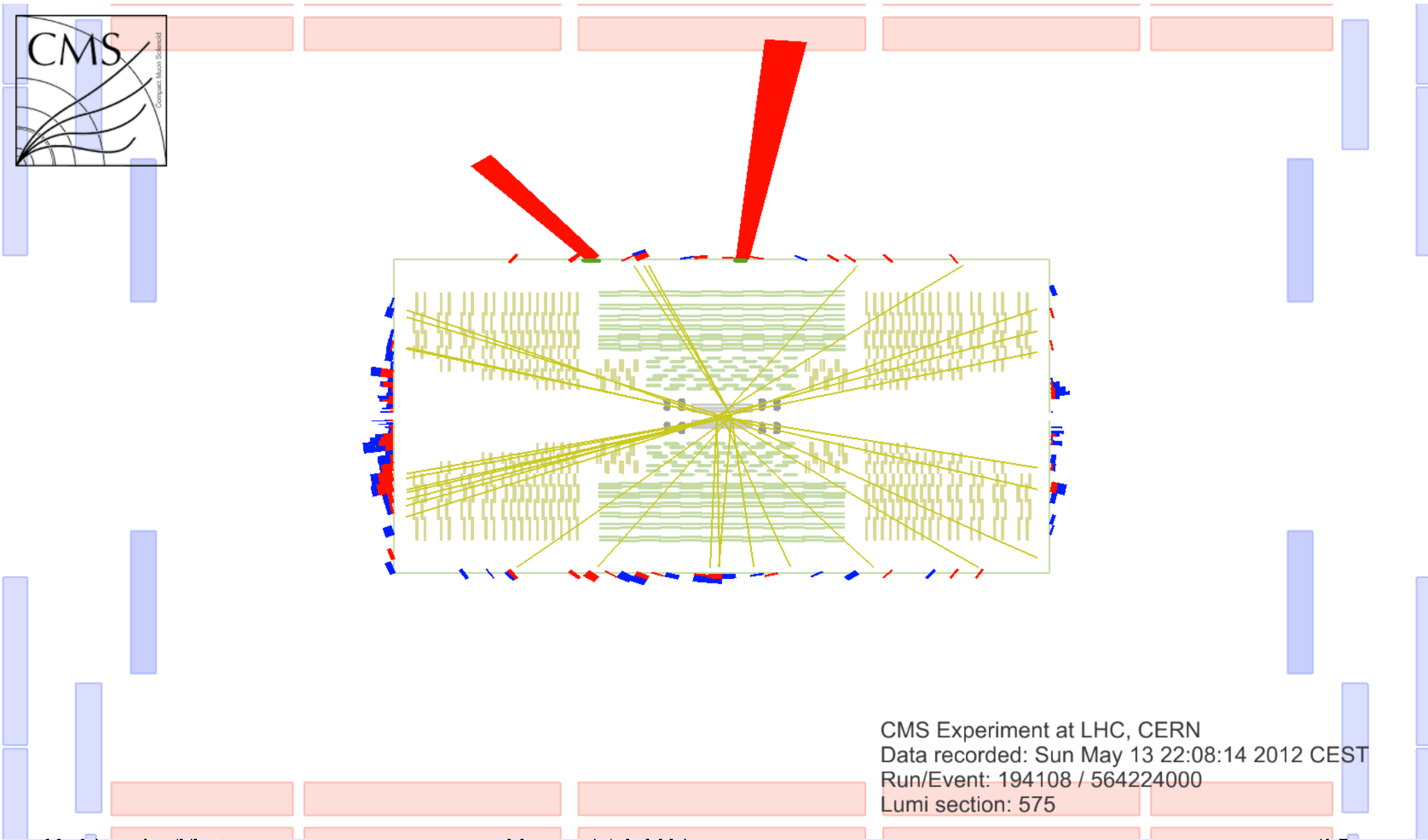




- Clear signal observed, compatible with SM expectations
- Best mass fit:

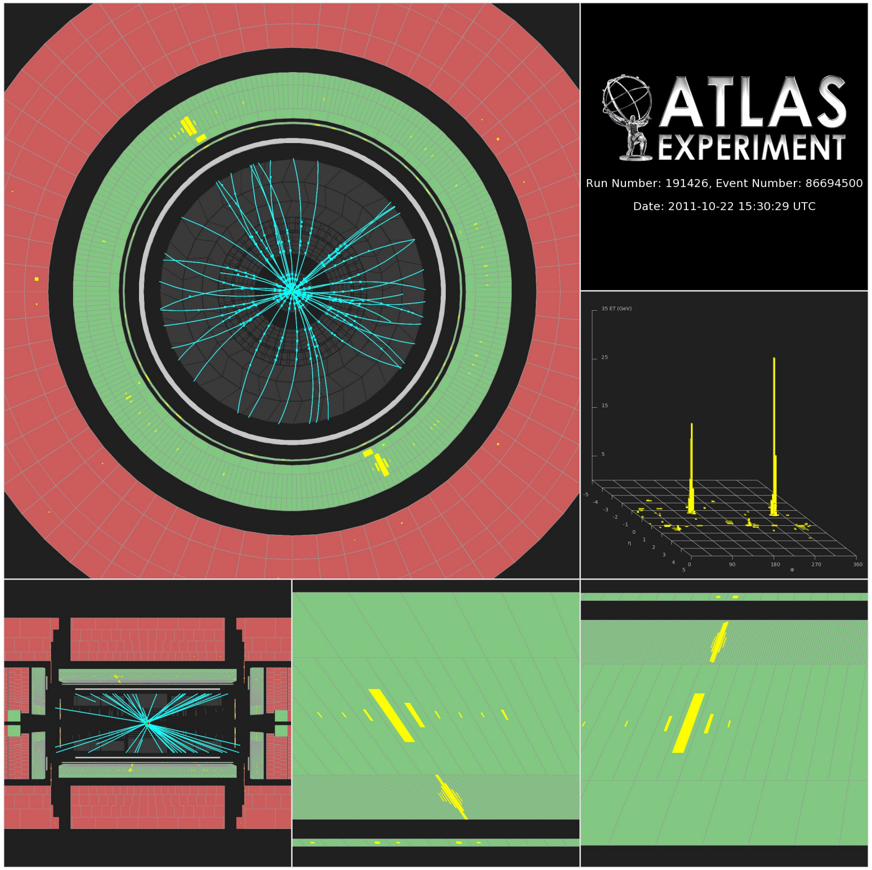
$$m_H = 125.8 \pm 0.5(stat.) \pm 0.2(syst.)\ \text{GeV}$$




CMS
CMS Experiment at LHC, CERN
Data recorded: Sun May 13 22:08:14 2012 CEST
Run/Event: 194108 / 564224000
Lumi section: 575

H→γγ analysis

arXiv:1207.7214

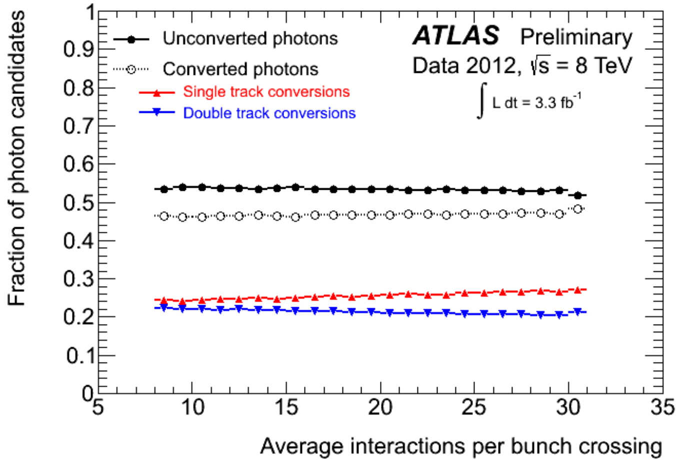


H→γγ candidate event

- Two isolated photons
- Search for a narrow peak on a large continuum

Main background:

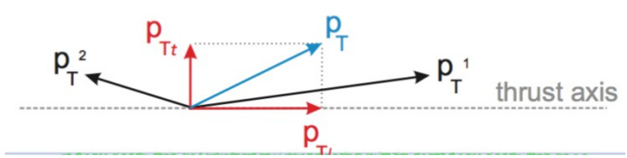
- Continuum γγ production
- γ+jet, jet+jet

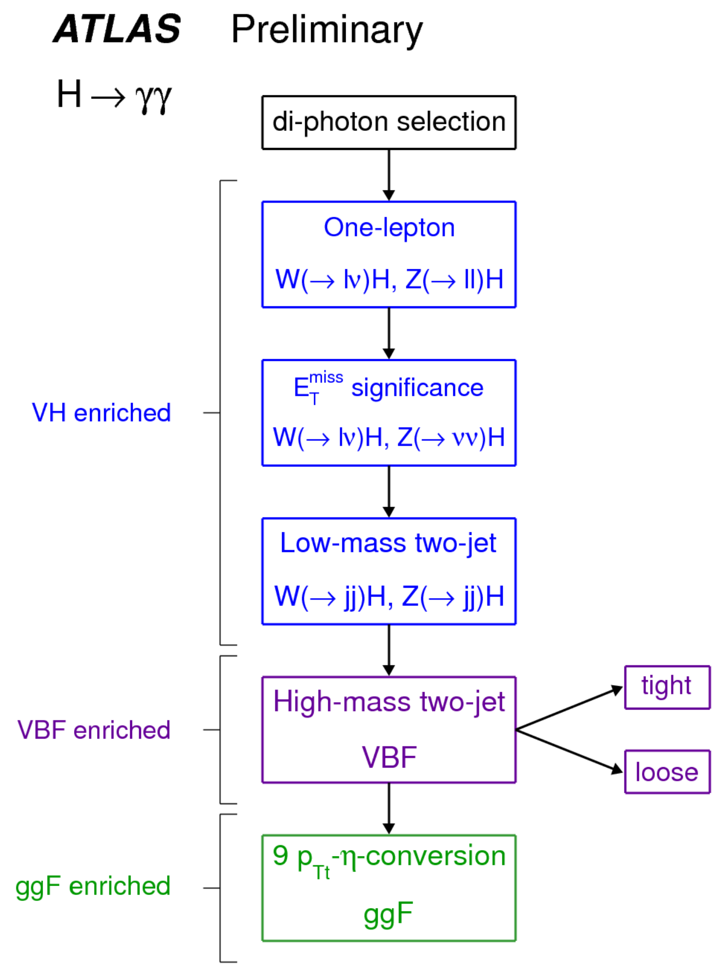


$H \to \gamma\gamma$ analysis categories

Different analysis categories based

- Converted/unconverted photons
- Photon location in the detector
- Di-photon transverse momentum with respect to thrust
- Production mechanism
  - VBF: use BDT
  - VH enriched
  - ggF enriched





H→γγ background modelling

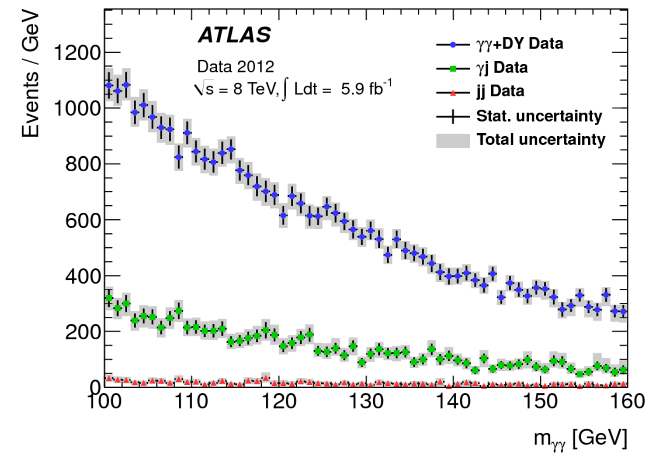
Background composition:

- Dominated by continuum γγ production (75%), followed by γ+jet, jet+jet

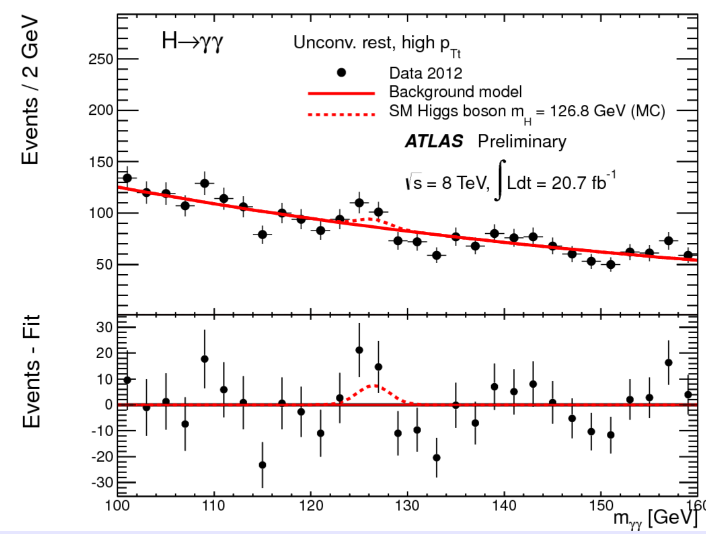
Background estimated by fitting the di-photon mass distribution

- Studied for each category with high-statistics MC before looking at data
- Considered: n-order Bernstein polynomial, exp(P2), exponential
- Choice based on largest expected sensitivity for 125 GeV signal

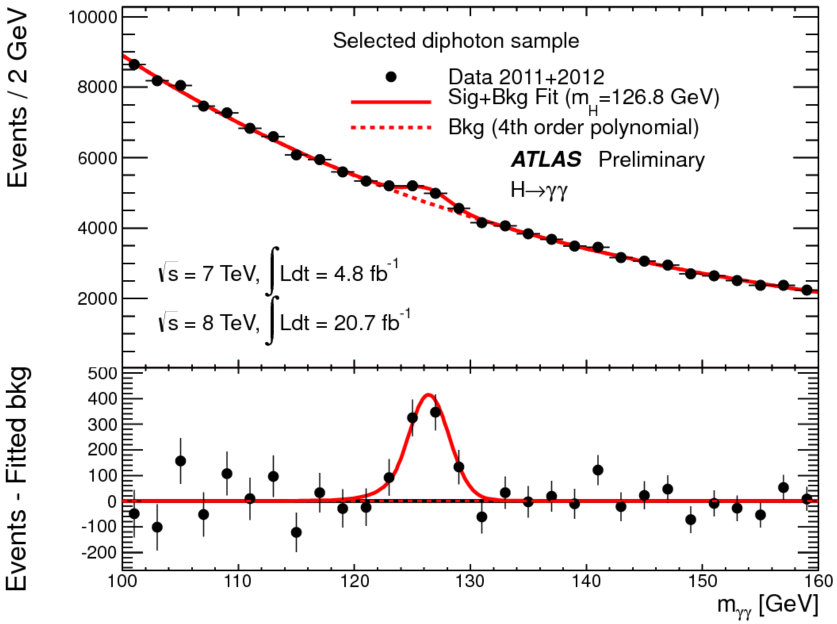
  Largest residual bias seen in MC experiments over 110-150 GeV taken as signal yield systematic

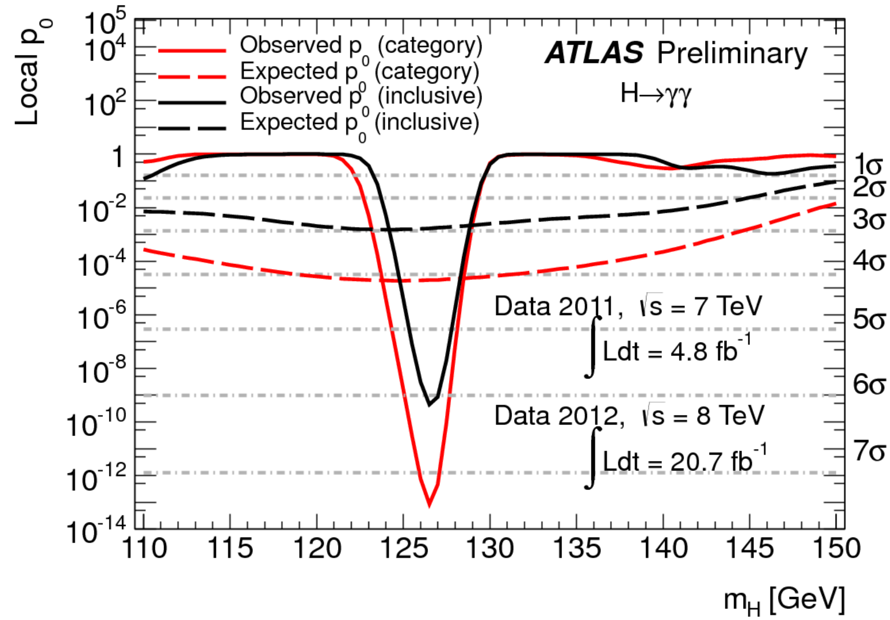


Example of a fit



H→γγ results

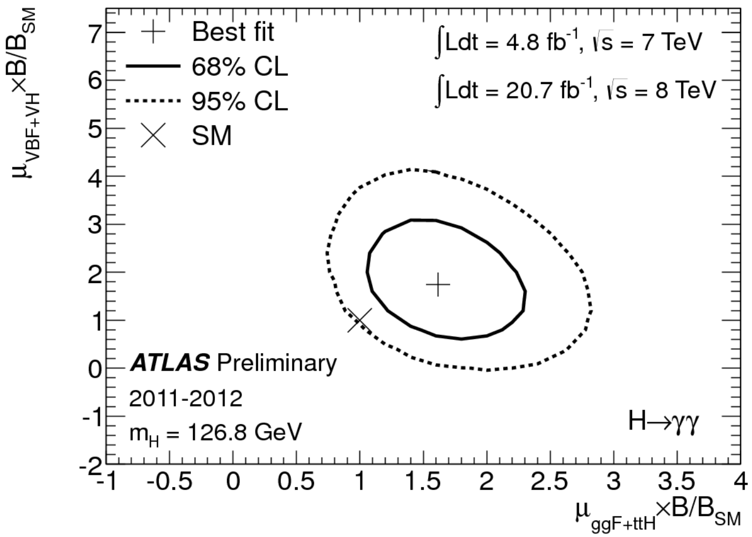


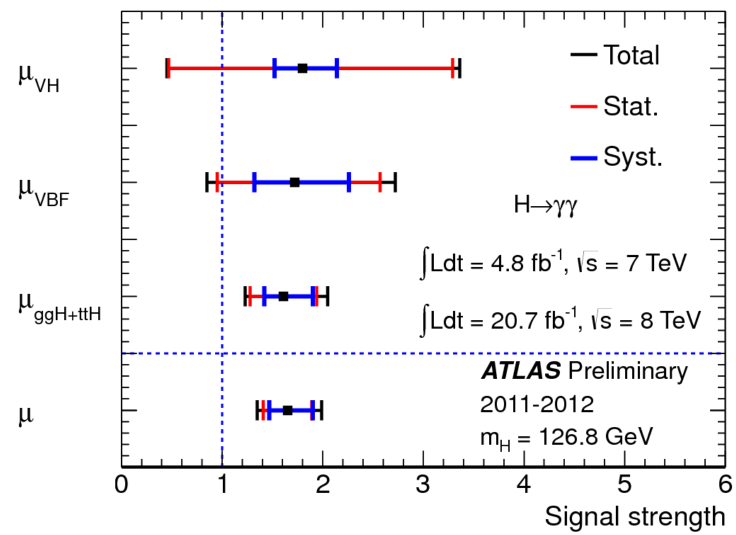


- Largest significance (2011+2012): 7.4σ for m_H = 126.5 GeV
- Best fit mass: 126.8 ± 0.2 (stat) ± 0.7 (sys) GeV
- Best value for signal strength at 126.8 GeV: $1.65^{+0.34}_{-0.30}$

  Compatibility with SM at 2.3σ level

VBF and VH, $H \rightarrow \gamma\gamma$ results



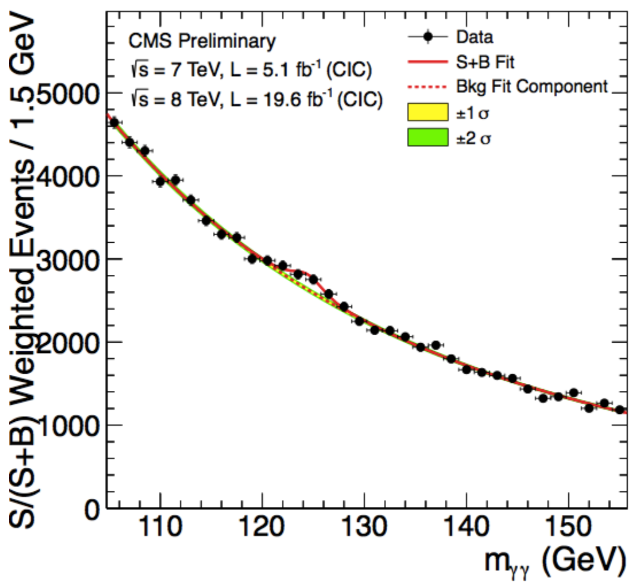


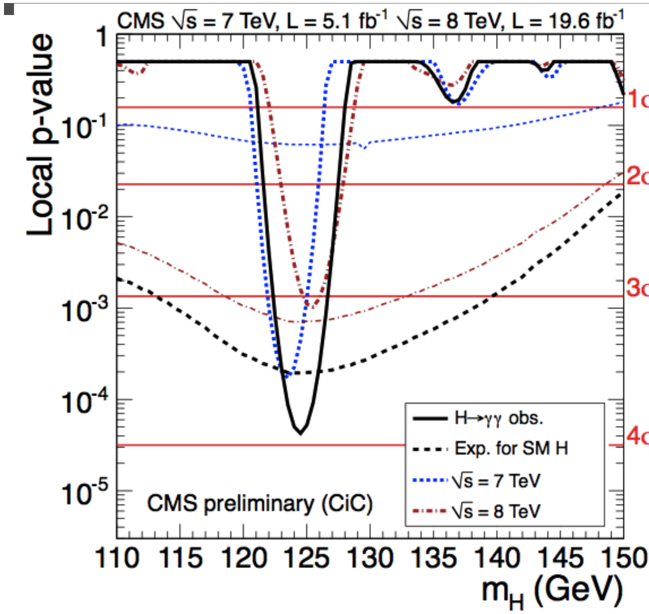
$$\mu_{\mathrm{ggF+ttH}} \times B/B_{\mathrm{SM}} = 1.6^{+0.3}_{-0.3}(\mathrm{stat})^{+0.3}_{-0.2}(\mathrm{syst})$$

$$\mu_{\mathrm{VBF}} \times B/B_{\mathrm{SM}} = 1.7^{+0.8}_{-0.8}(\mathrm{stat})^{+0.5}_{-0.4}(\mathrm{syst})$$

$$\mu_{\mathrm{VH}} \times B/B_{\mathrm{SM}} = 1.8^{+1.5}_{-1.3}(\mathrm{stat})^{+0.3}_{-0.3}(\mathrm{syst})$$

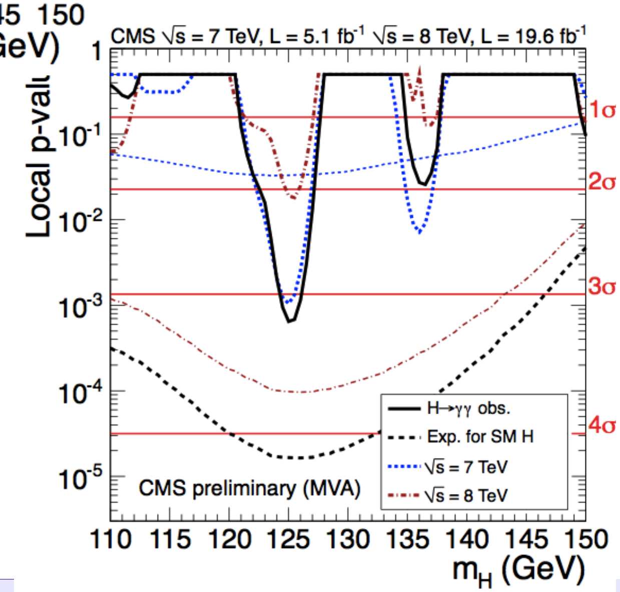
CMS H→γγ results





Local significance: 3.9σ at 124.5 GeV (expected: 3.5σ)

Both analysis compatible within 2σ

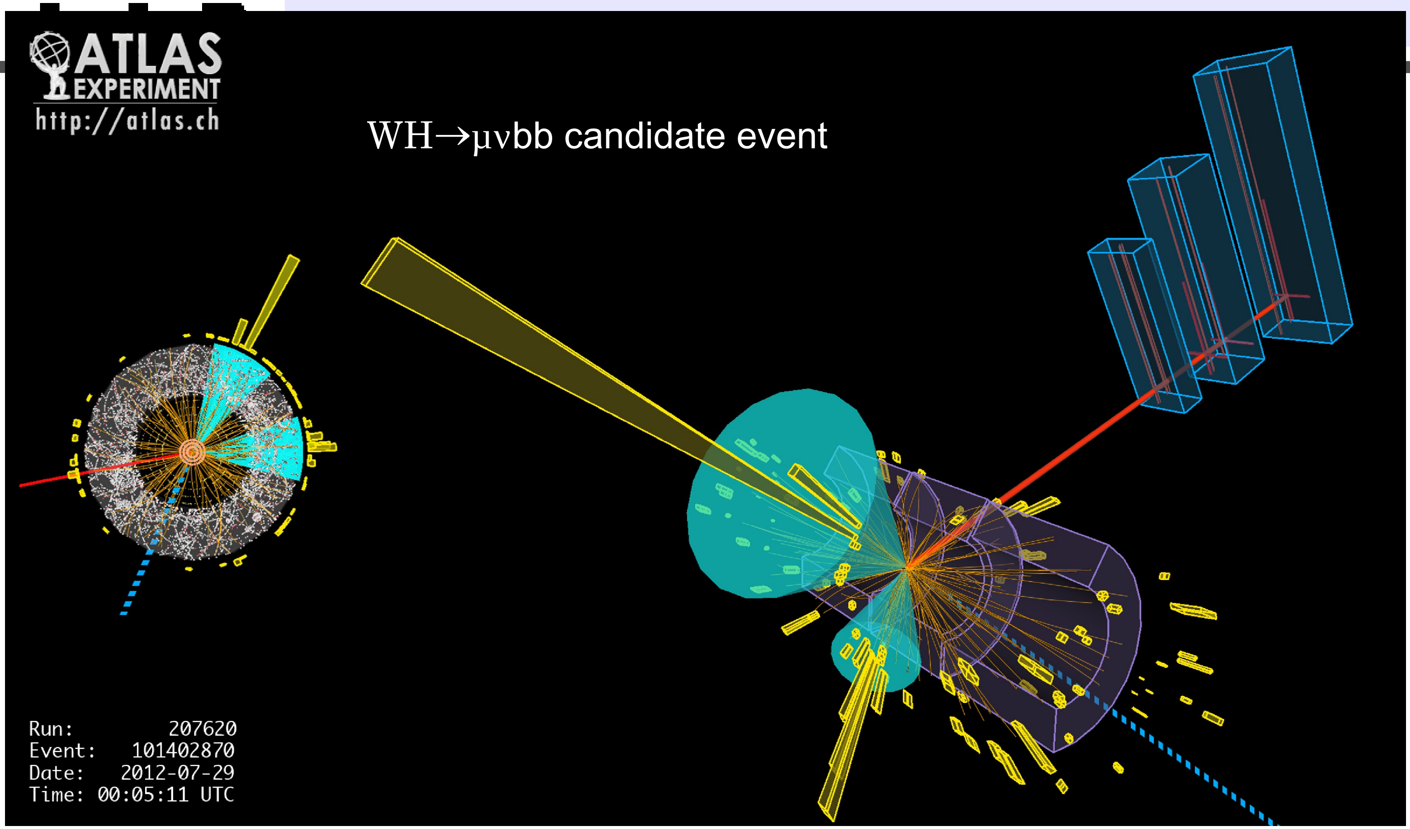


- Signal strength in agreement with SM expectations for the cut based analysis

  $1.11^{+0.32}_{-0.30}$ for 7 & 8 TeV data

- Mass: $125.4 \pm 0.5(stat.) \pm 0.6(syst.)\,\text{GeV}$

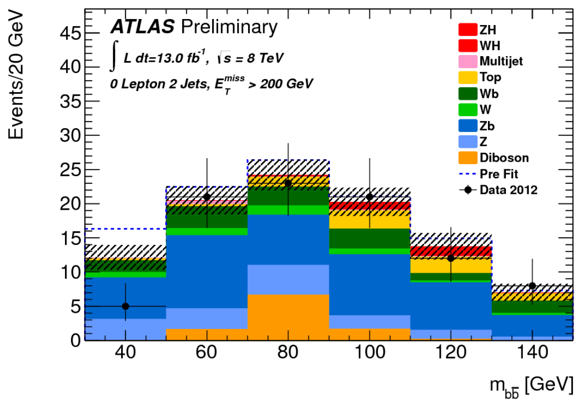
VH→bb ATLAS search

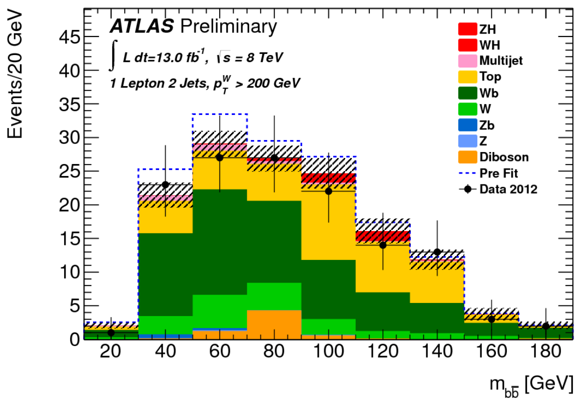


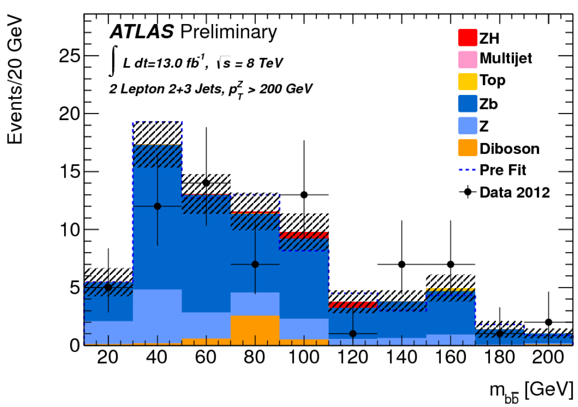
- Three channels
  - WH → lν bb
  - ZH → llbb
  - ZH → ννbb
- Signatures
  - High p_T isolated leptons, 2 b-jets, Large missing E_T (lνbb, ννbb)
- Different categories based on p_T^V/E_T^{miss}
- Backgrounds: W/Z+jets, top, di-boson, QCD jets

VH→bb

ATLAS-CONF-2012-161





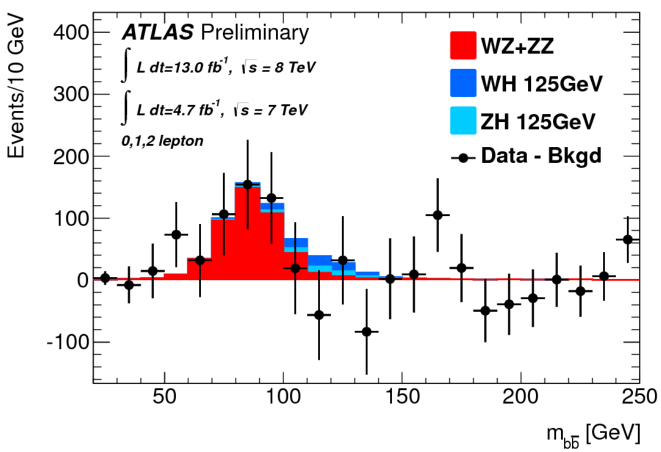


- Di-bjet invariant mass for the most sensitive p_T^V bin
- WZ & ZZ production with Z→bb similar signature, but 5 times larger cross-section

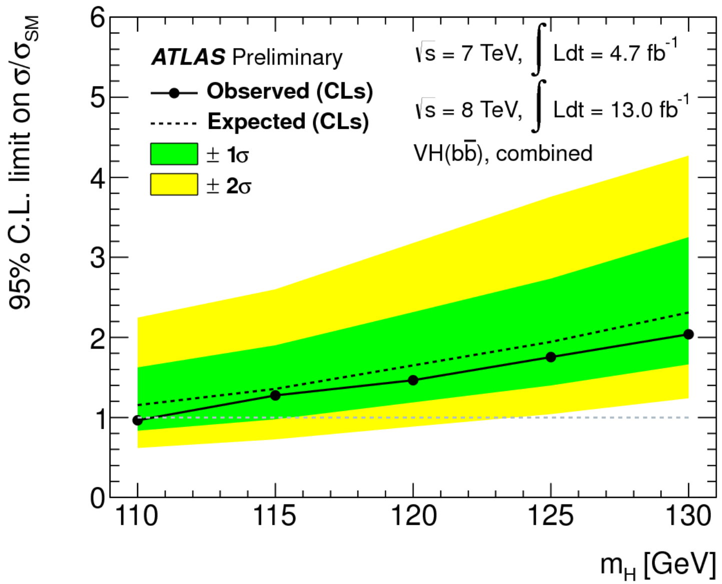
Analysis strategy validated by searching for di-boson signal

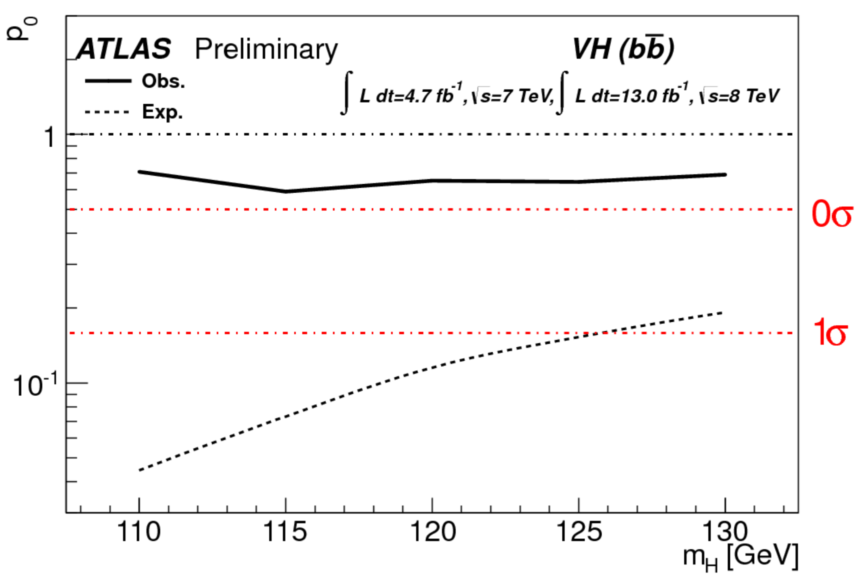
σ/σ_{SM} = 1.09 ± 0.20 (stat) ± 0.22 (syst)

Significance: 4.0σ



VH→bb results



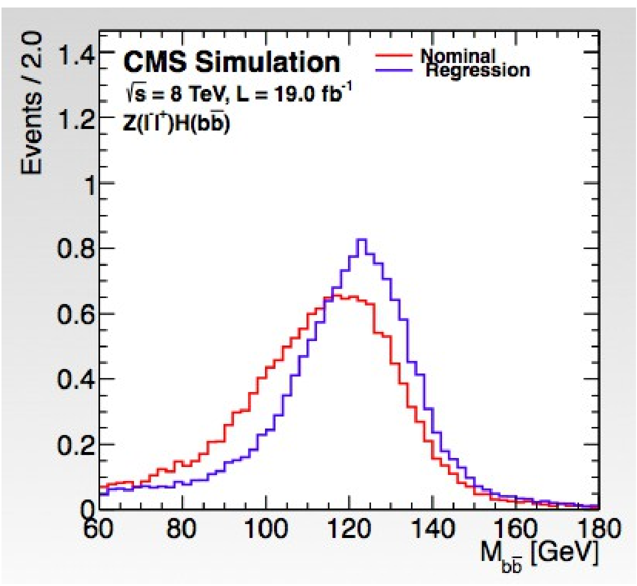


- Observed (expected) limit at m_H =125 GeV

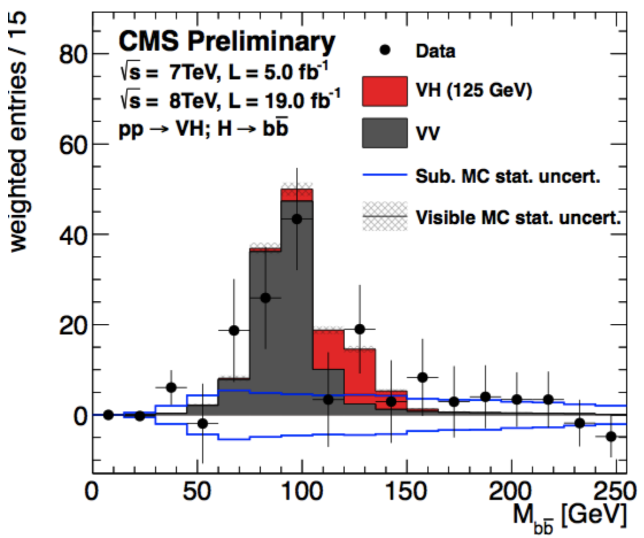
  1.8 (1.9) x SM prediction
- $\sigma/\sigma_{SM} = \mu = -0.4 \pm 0.7(\text{stat.}) \pm 0.8(\text{syst.})$
- Observed (expected) p^0 value: 0.64 (0.15)

CMS VH→bb

- BDT to
  - Improve mass resolution
  - Optimize signal to background separation

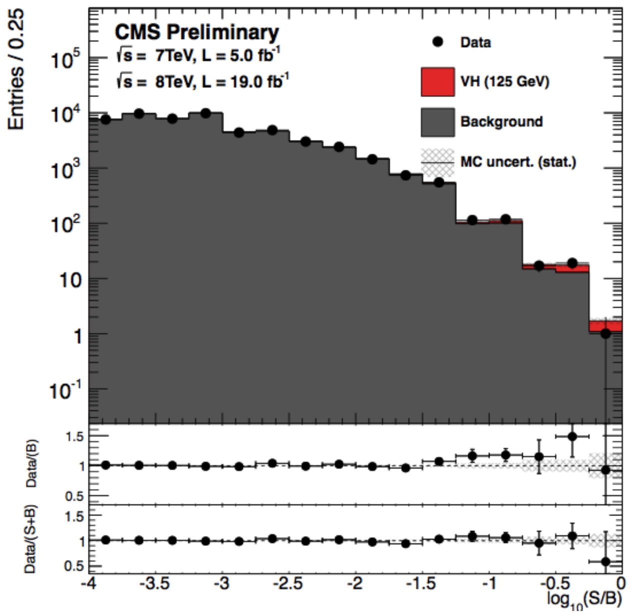


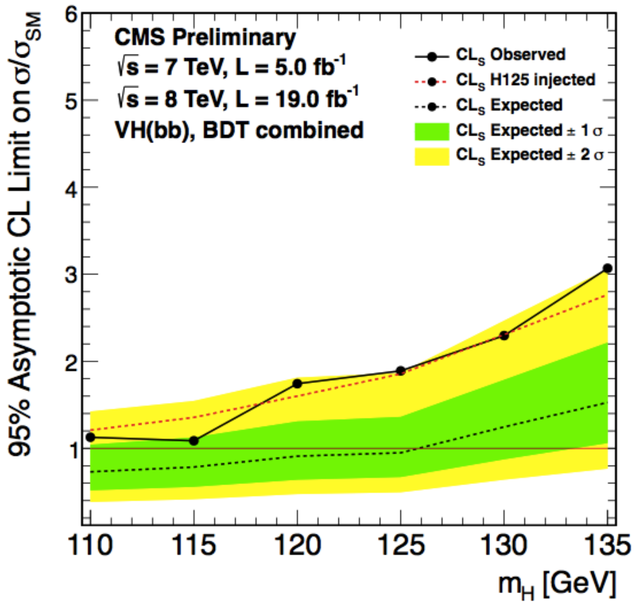
- VZ, with Z→bb, analysis:



	BDT VZ(bb)
Exp. Sig	6.3 σ
Obs. Sig	7.5 σ
μ	$1.19^{+0.27}_{-0.23}$

CMS VH→bb results



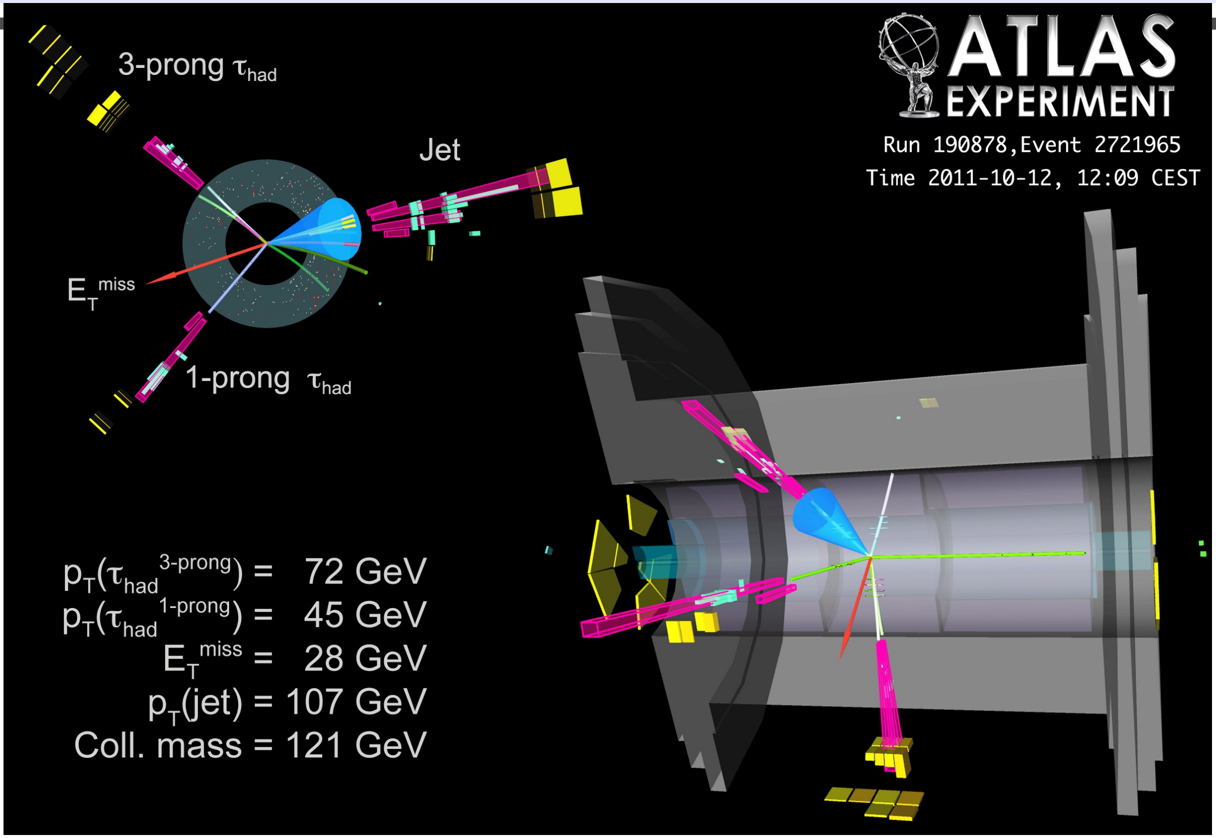


- Observed limit: 1.89xSM

  In agreement with the expectations of a SM Higgs boson at 125 GeV

- Expected: 0.95xSM

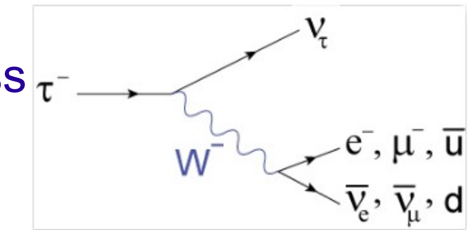
H→ττ ATLAS search

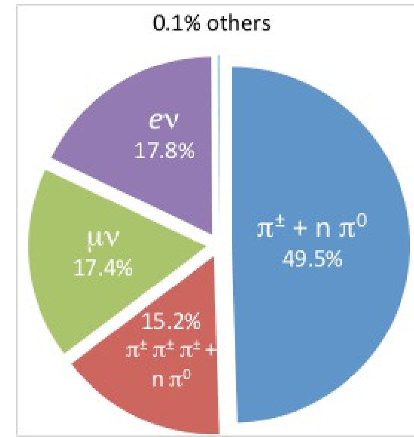


- Analysis categories:
  - 0,1 jet (dominated by gg fusion), 2 jet (VH and VBF)
- Backgrounds
  - Z→ττ (irreducible), estimated from embedded Z→μμ data
  - τ/lepton fakes, data control regions

Tau reconstruction

- Neutrinos in the final state
  - Difficult to reconstruct di-τ mass
  - Challenging to suppress jet background





- Constrain the neutrino momenta using tau decay kinematics to improve di-τ mass resolution

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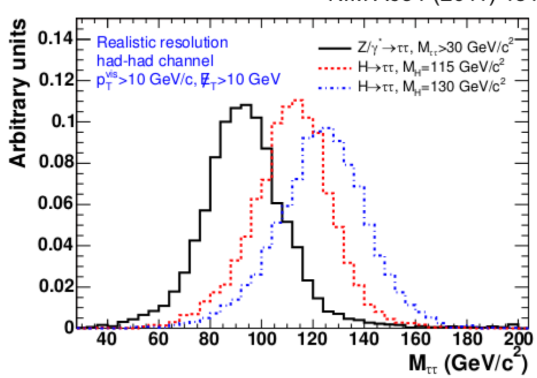

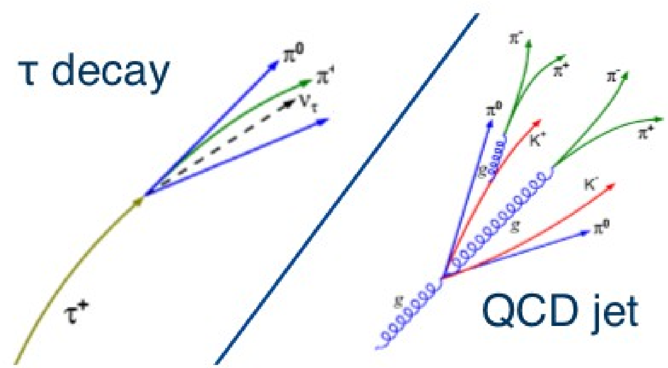

- Use a MVA to select hadronic τ's
- Efficiency: 60% (h/H/A), 30%(H^+)
- Miss-identification: 5% (h/H/A) 0.1-1% (H^+)

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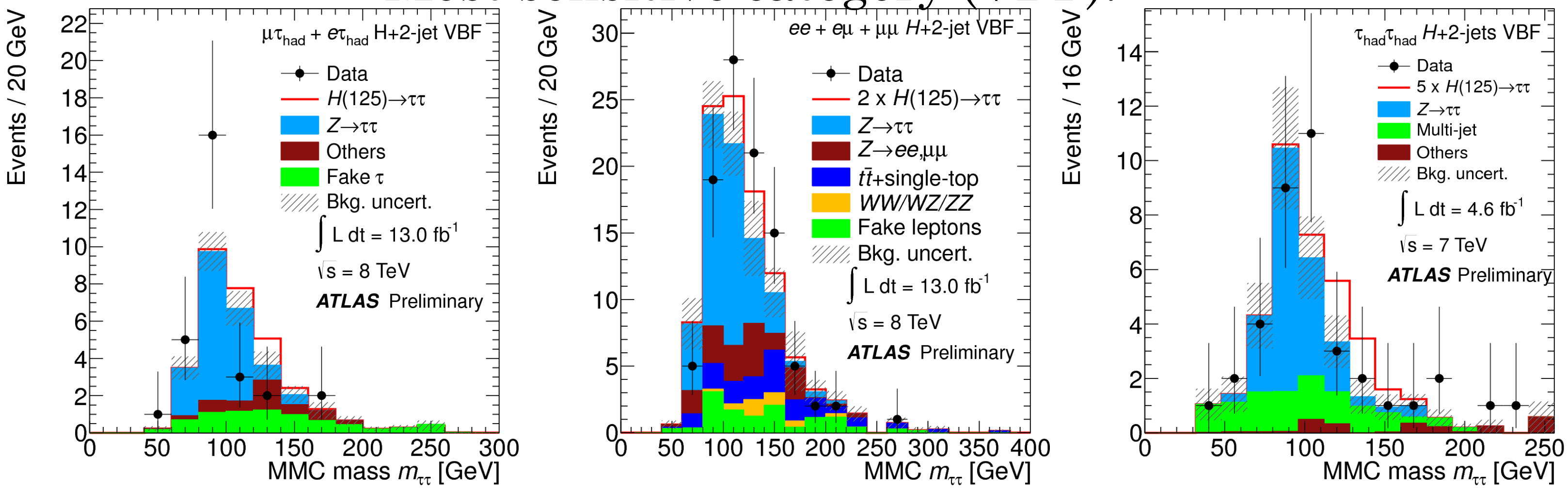
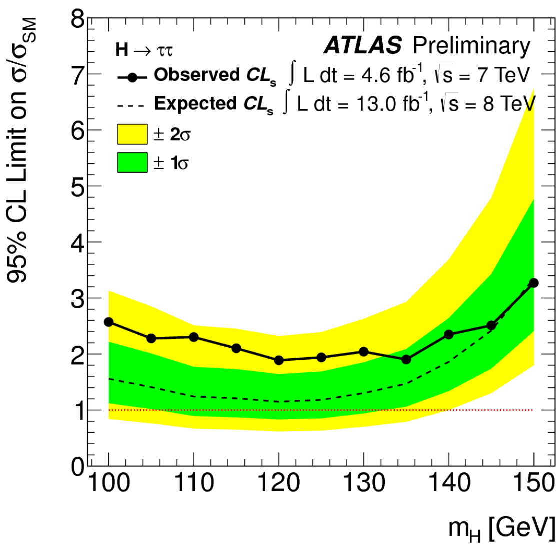
H→ττ results

Most sensitive category (VBF):

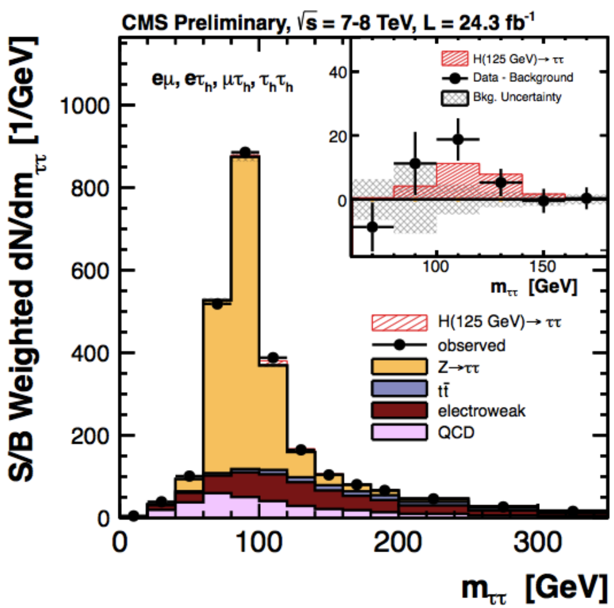


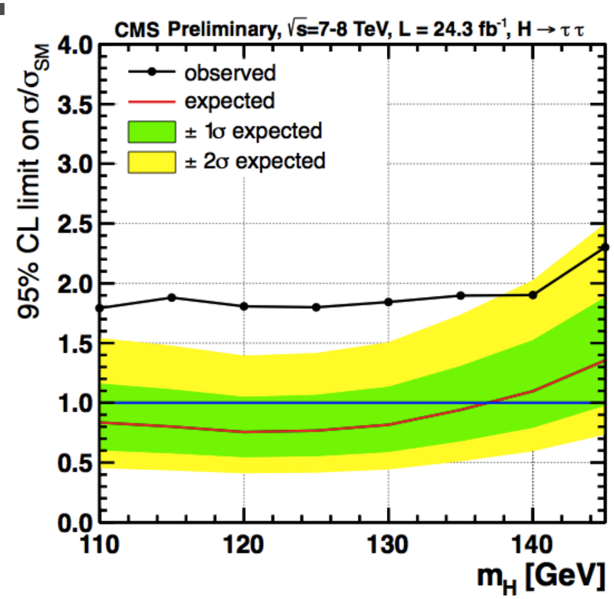


- Broad excess observed
- Observed (expected) limit at 125 GeV:

  1.9 (1.2) x SM value
- Results consistent with either background or SM Higgs hypothesis

CMS H→ττ results



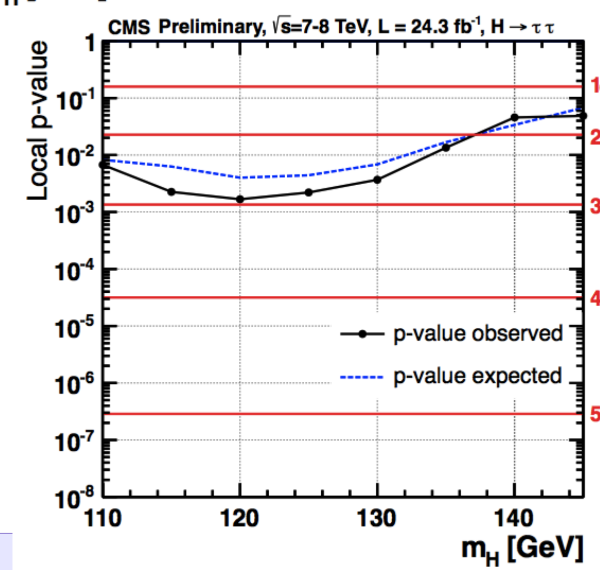


Observed significance 2.9σ

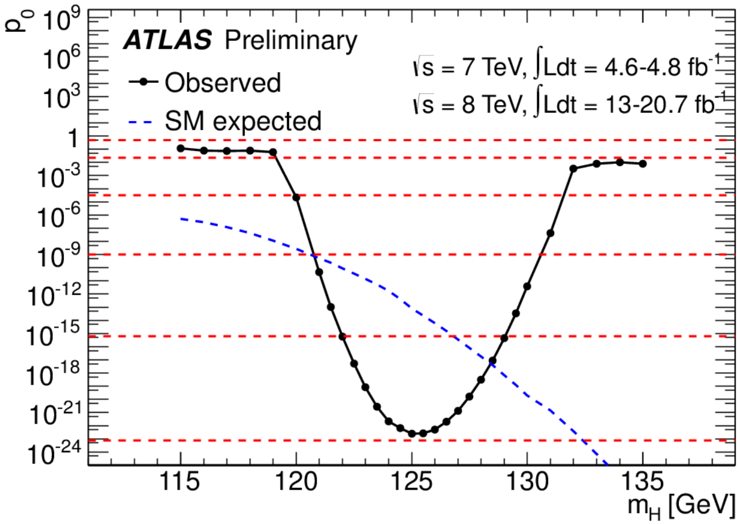
Expected significance: 2.5σ

Best fit signal strength:

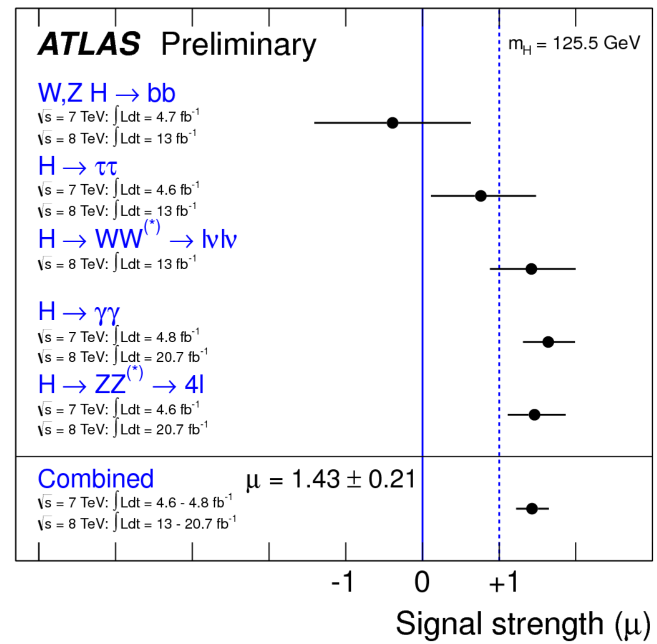
$\mu = 1.1 \pm 0.4$ @125 GeV



Combination of all search channels



- The new particle is now very clear: probability that it is due to a background fluctuation ~10^{-23}!



- Combined mass fit:

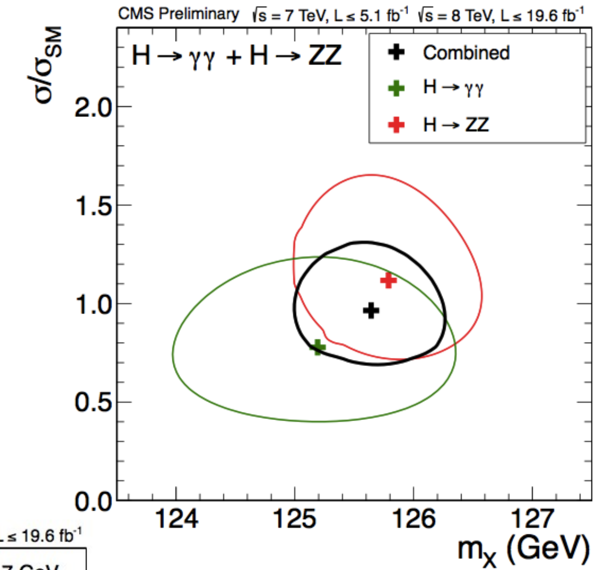
$$m_H = 125.5 \pm 0.2\,(\text{stat})\,^{+0.5}_{-0.6}\,(\text{sys})\ \text{GeV}$$

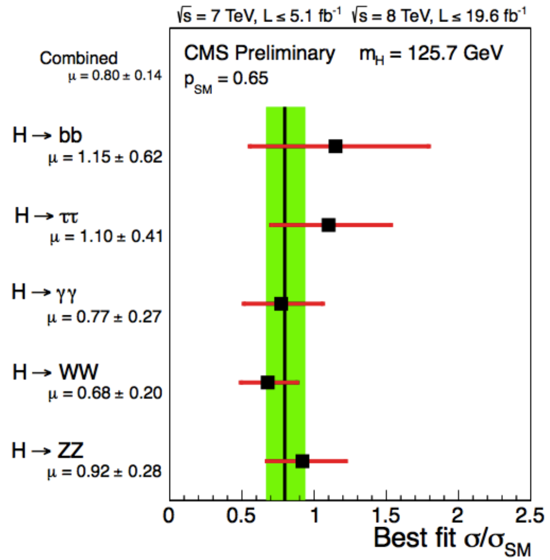
- Compatibility of the two measurements at 2.5σ level (1.2%) = probability that a single Higgs-boson like particle produces the two peaks

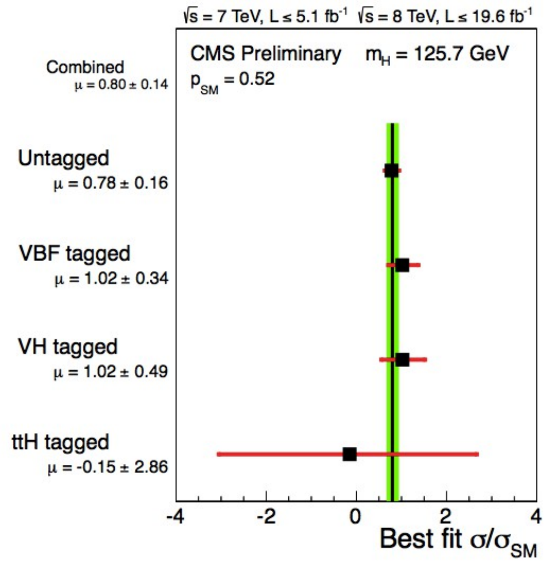
CMS combination

- Mass:

$$m_x = 125.7 \pm 0.3\ (stat.) \pm 0.3\ (sys.)\ \text{GeV}$$
$$= 125.7 \pm 0.4\ \text{GeV}$$





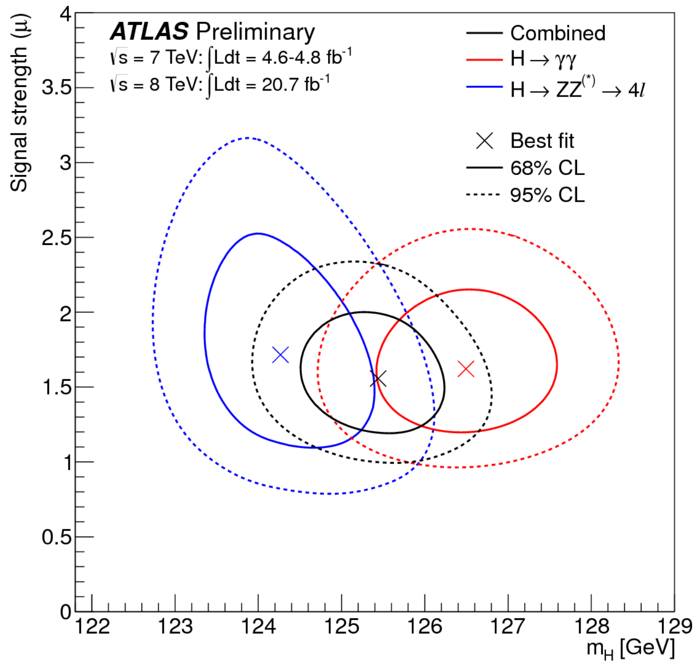


Summary and conclusions

- Both, ATLAS and CMS, collaborations have observed a new boson
  - Signal confirmed with data acquired after July last year
  - Observation in individual decay channels
- Work continues now to understand if this is the SM Higgs boson or any other boson
  - Measure all its properties accurately (production and decay rates, spin, C and P, …)

- Measurement of the new boson properties will be the subject of the next Higgs lecture

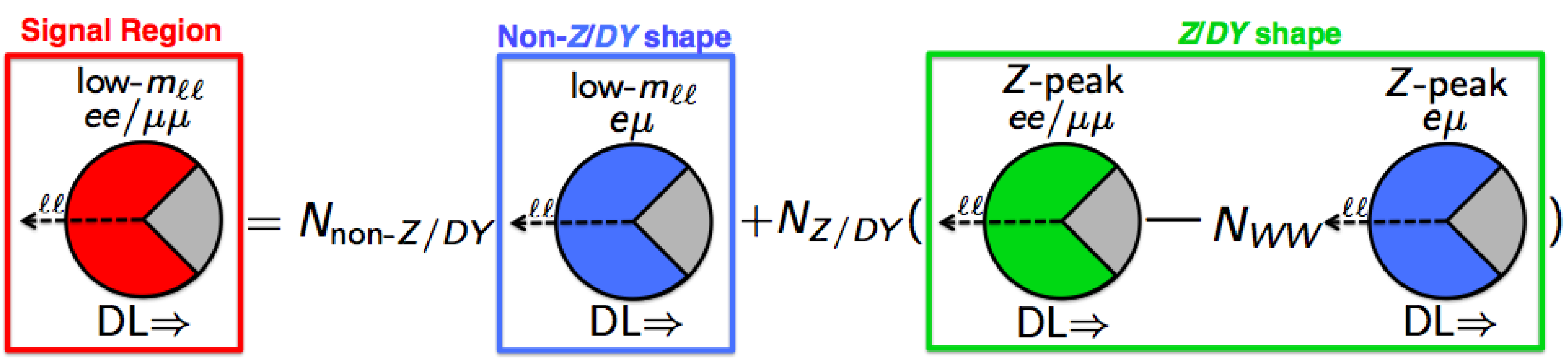
Backup



ATLAS Preliminary
√s = 7 TeV: ∫Ldt = 4.6-4.8 fb-1
√s = 8 TeV: ∫Ldt = 20.7 fb-1
Combined
H → γγ
H → ZZ(*) → 4l
Best fit
68% CL
95% CL
Signal strength (μ)
4
3.5
3
2.5
2
1.5
1
0.5
0
122
123
124
125
126
127
128
129
mH [GeV]

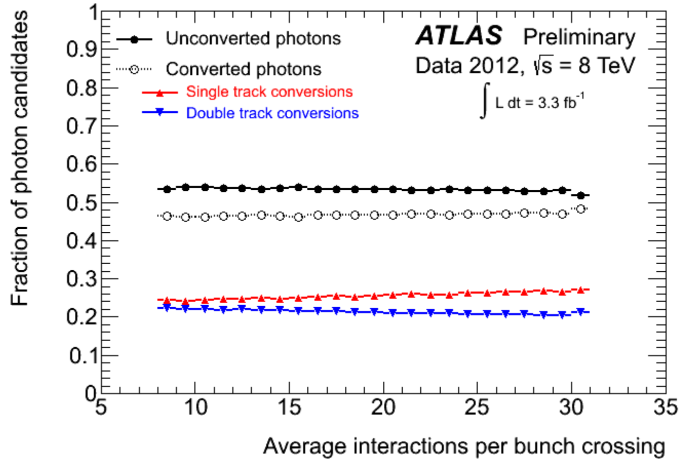
Pacman method - systematic uncertainties and advantages

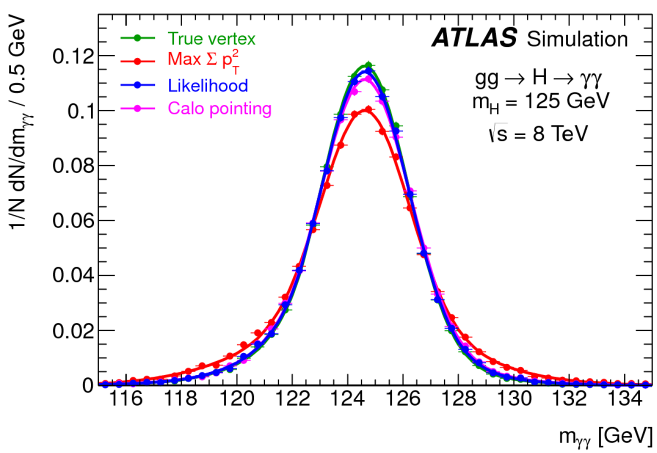
- Assign systematic uncertainties on ϵ by computing difference between measured efficiencies and true efficiencies:
  - different flavour $\rightarrow$ same flavour extrapolation for $\epsilon^{\text{non-}Z/\gamma^*}$
  - Z peak $\rightarrow$ signal region extrapolation for ϵ^{Z/γ^*}
  - Largest systematic 27% on Z/γ^* efficiency.
- Final uncertainity on Z/γ^* estimate obtained by propagating:
  - Systematic uncertainties on the efficiencies.
  - Statistical uncertainty on the data.
  - $\sim$ 60% uncertainty for 0-jet and $\sim$ 80% uncertainty for 1-jet.
- Advantages of this method:
  - Uses directly the final signal region.
  - Estimate is insensitive to the presence of signal.
  - Does not rely on MC modelling.
  - Final uncertainty on the estimate dominated by data statistics.

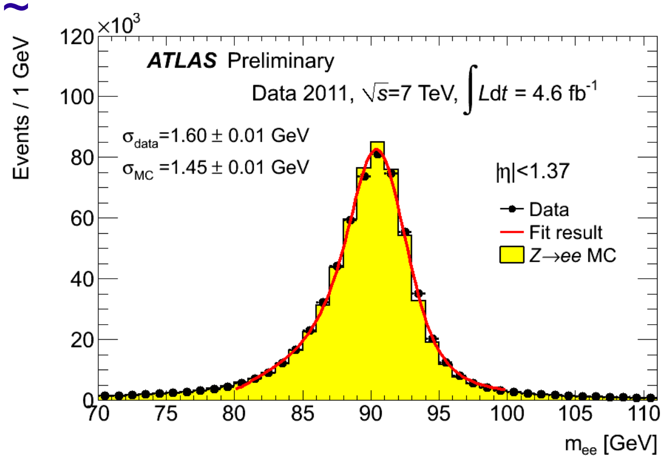


γ identification & energy measurement

- Stable photon ID peformance with pile-up
- Calorimeter E response studied with Z, J/ψ and W decays
  - Energy scale at m_Z known to ~ 0.5%
  - Linearity better than 1%
- Excellent mass resolution (1.6-3.1 GeV)
  - Use calorimeter segmentation to associate photon to primary vertex (σ ~







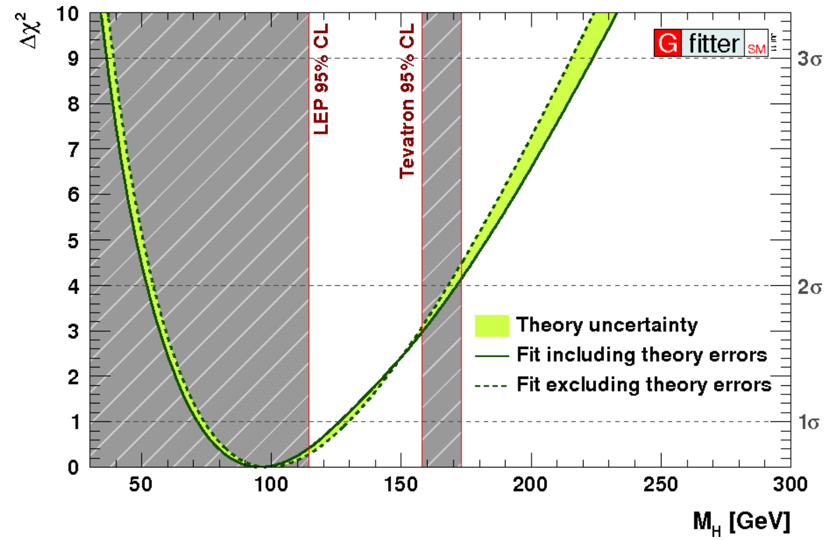
Experimental constraints before the LHC

Fits to the EW observables predict:

- Best Fit mass: $m_H = 94^{+25}_{-22}$ GeV
- Upper limit at 95% CL from fits:

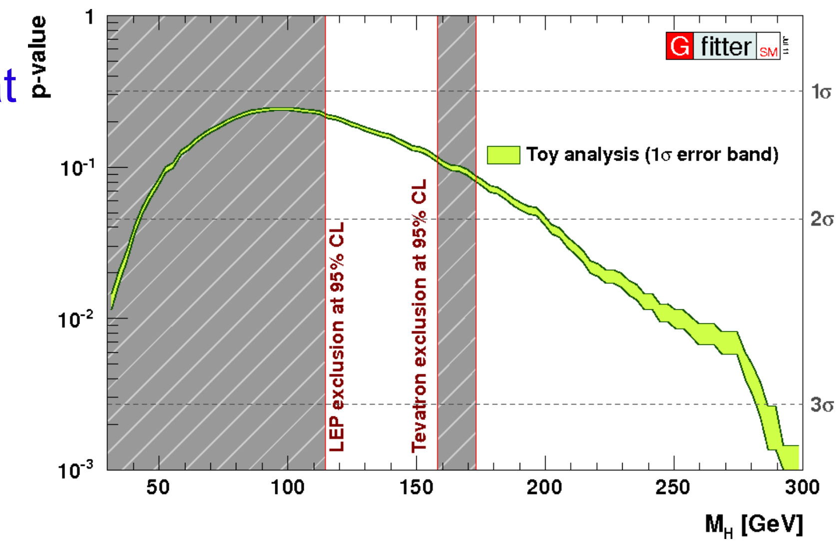
  $m_H < 169$ GeV

But the fit is not too bad for masses up to 200 GeV or so.



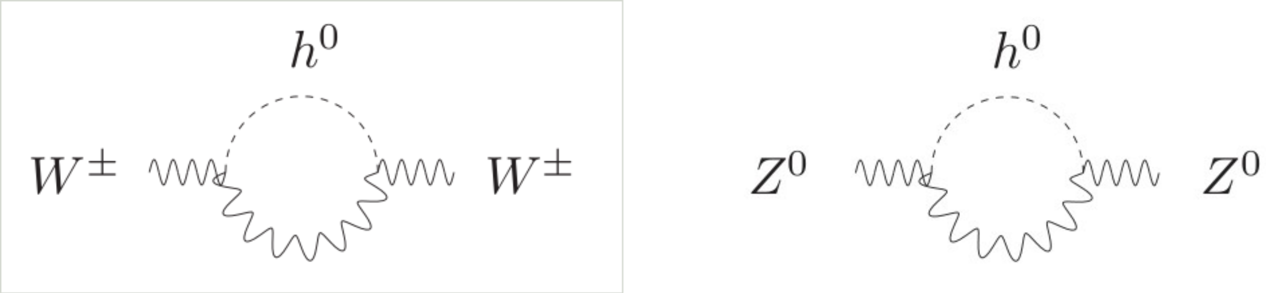
Direct searches excluded the regions at 95% CL:

- LEP: $m_H < 114.5$ GeV
- Tevatron: $147 < m_H < 180$ GeV



Corrections to EW observables

- Electroweak observables are sensitive to masses of top quark and Higgs through radiative corrections



$$M_W^2 = \rho\, M_Z^2 \cos^2\theta_W$$

$$(\rho-1) \sim M_{top}^2$$

$$(\rho-1) \sim \ln M_H$$

- Precise measurements of electroweak observables can be used to constraint the Higgs boson mass

Sensitivity to Higgs mass is only logarithmic: Need ultra-precise measurements!

Experimental constraints before the LHC

- Large list of observables used in global fits to the electroweak precision data