Higgs Search at the LHC in the $ZZ^{(*)}$ decay channel

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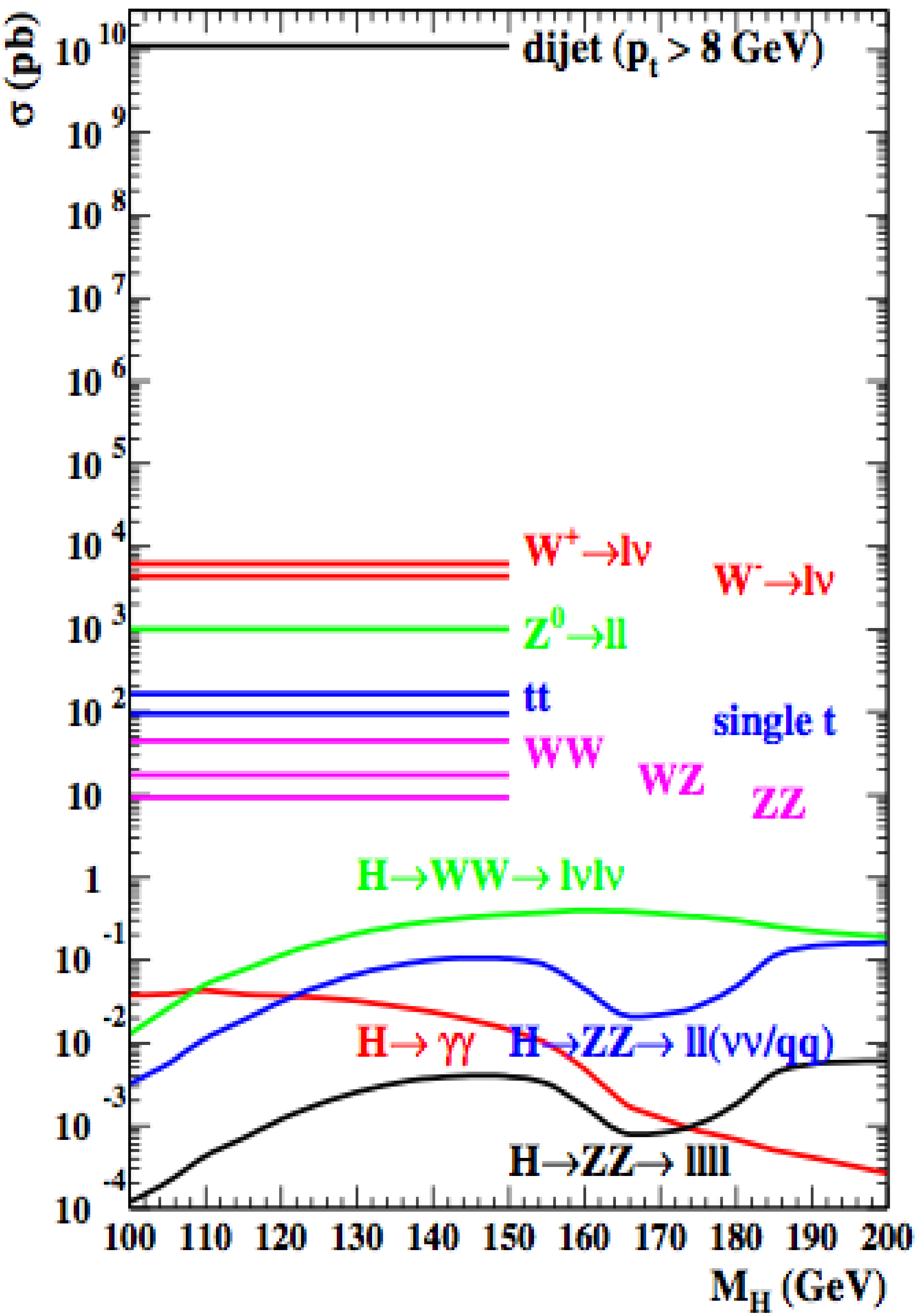
Outline

- Introduction, the path to the Standard Model Higgs @ LHC
  - Standard Model Higgs production and decay
- Data taking in 2011
- The $H \to ZZ^{(*)}$ channel
  - High mass region in brief:
    - $H \to ZZ \to llqq$ and $H \to ZZ \to ll\nu\nu$
    - $H \to ZZ^{(*)} \to llll$
  - Low mass region:
    - $H \to ZZ^{(*)} \to llll$
- Results of the 2011 data analysis

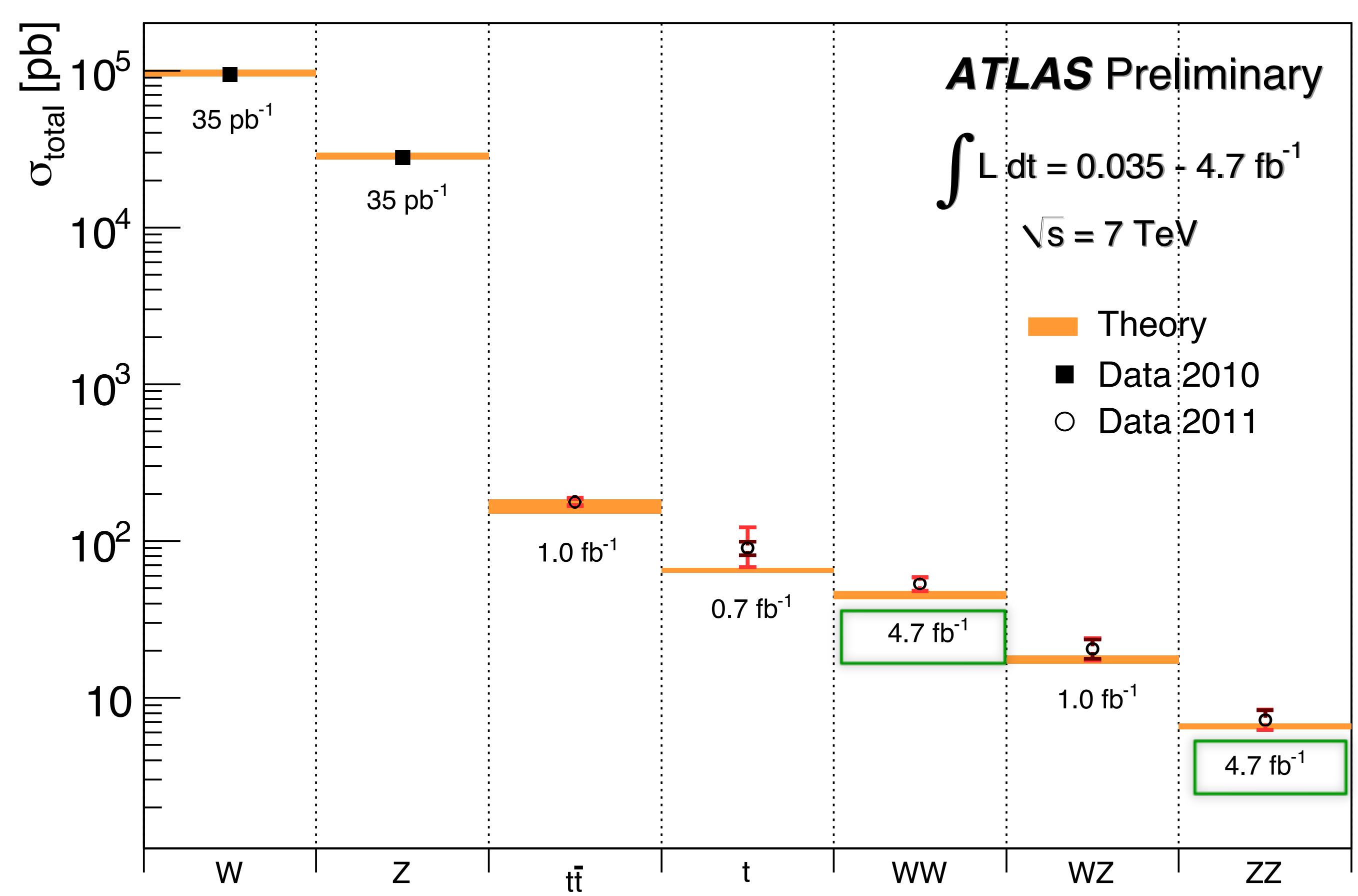
The path to the Standard Model Higgs search



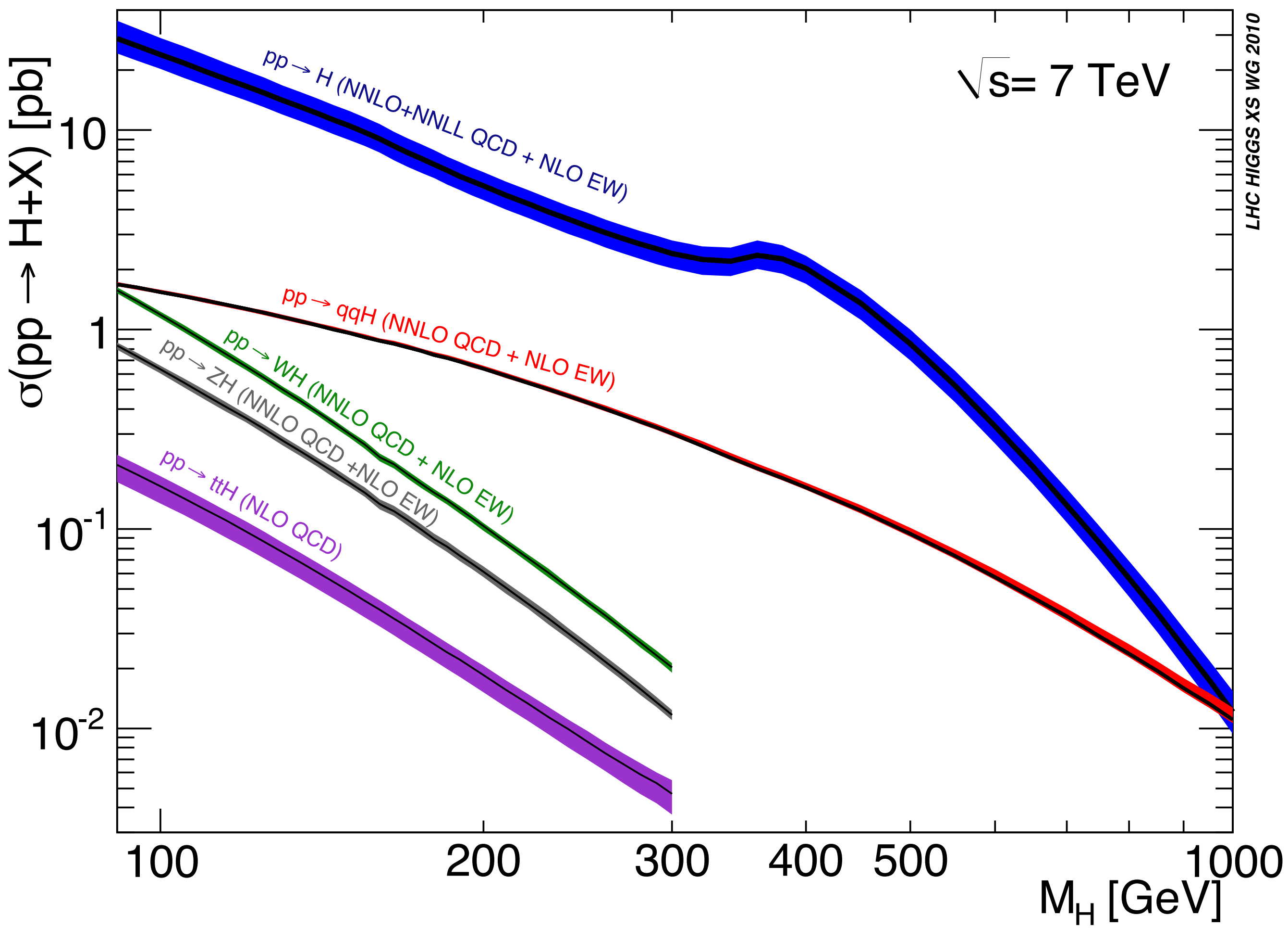
Standard model processes have been the first benchmark for the preparation of Higgs searches
→cross sections are orders of magnitude larger than the SM Higgs ones

Assess detector performance, refine calibrations, correct MC, constrain PDFs

SM processes are also backgrounds to Higgs searches:
→measured as precisely as possible with 2010/2011 data

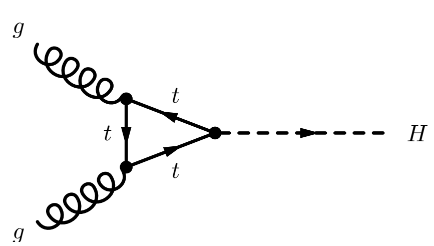


Standard Model Higgs @ LHC

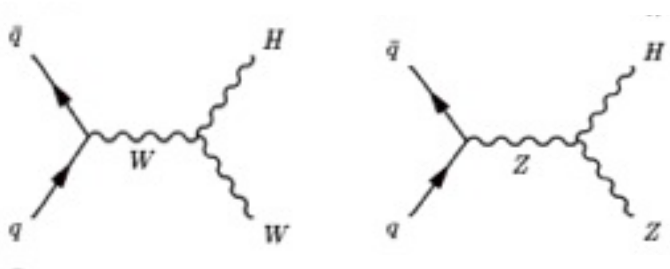


- Common effort (ATLAS, CMS, Theorists) for cross sections determination (Yellow Report CERN-2011-002)

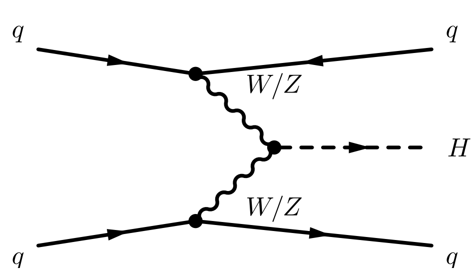
- Backgrounds mostly determined from data
→ use N(N)LO signal cross sections for exclusion



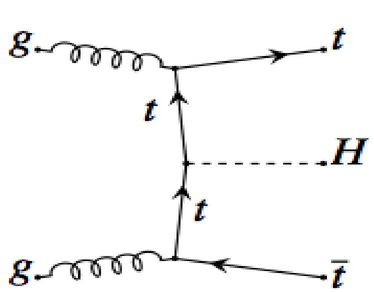
Gluon fusion: known at NNLO with large uncertainty ~15-20% on gluon processes



Associated production with W / Z:
Known at NNLO uncertainty ~5%



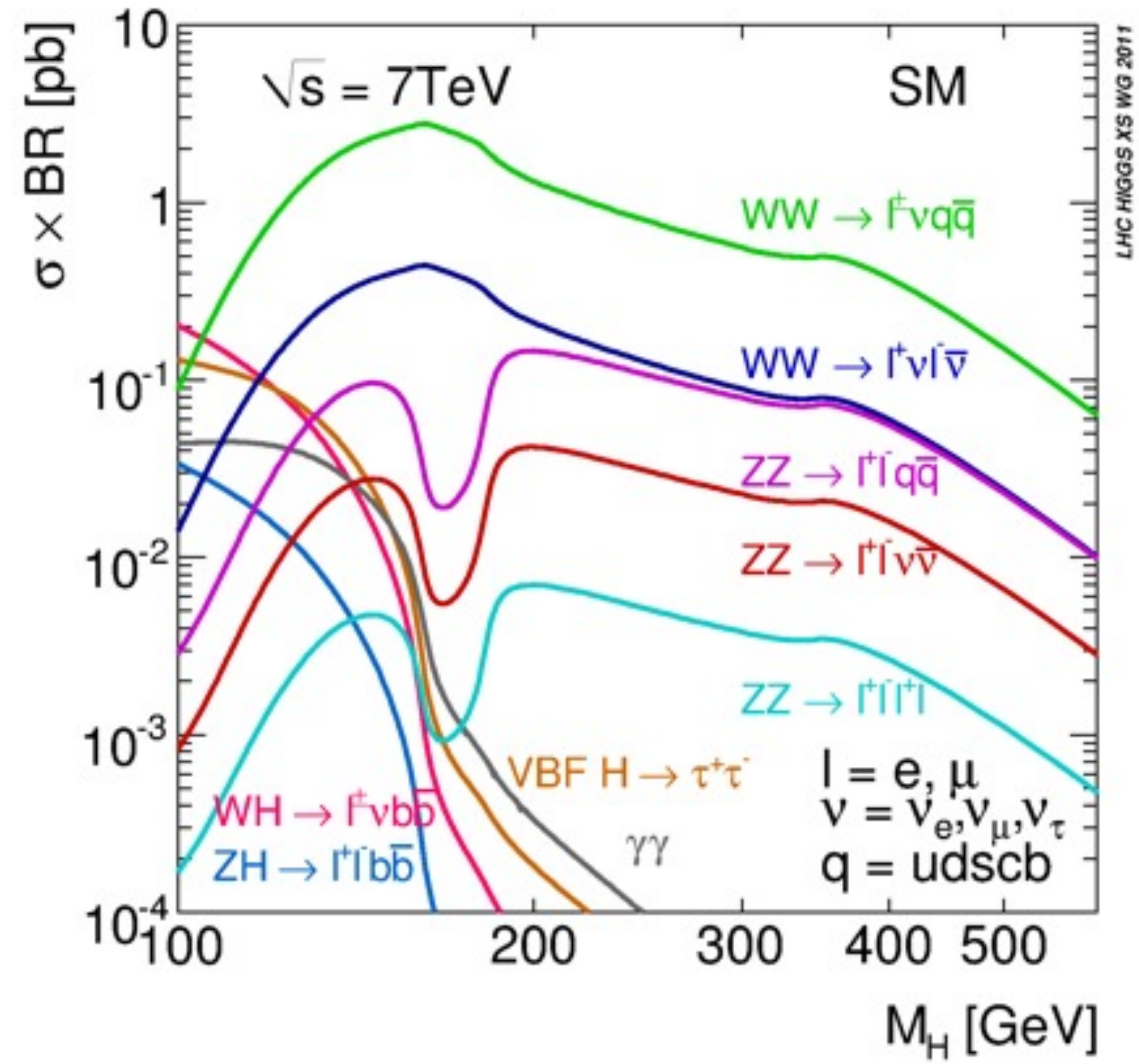
Vector Boson Fusion:
Known at NNLO QCD+NLO EW, uncertainty ~ 5%



Associated production with ttbar:
Known at NLO uncertainty ~15%

Higgs decay channels

- $H \to \gamma\gamma$: small BR, but most important for the low mass region
- $H \to \tau\tau$:
  - low mass region, good signal/background, use VBF signature
- $H \to bb$:
  - associated production, low mass region
- $H \to WW$:
  - $WW \to l\nu l\nu$: intermediate mass range
  - $WW \to l\nu qq$: high BR, difficult at low-masses, becomes relevant at high masses
- $H \to ZZ^{(*)}$:
  - $ZZ^{(*)} \to 4l$ (l=e,μ): small BR but very clear signature
  - $ZZ^{(*)} \to ll\nu\nu$: relevant at high mass
  - $ZZ^{(*)} \to llqq$: also relevant at high mass, higher background
  - $ZZ \to ll\tau\tau$: new, can help at high mass

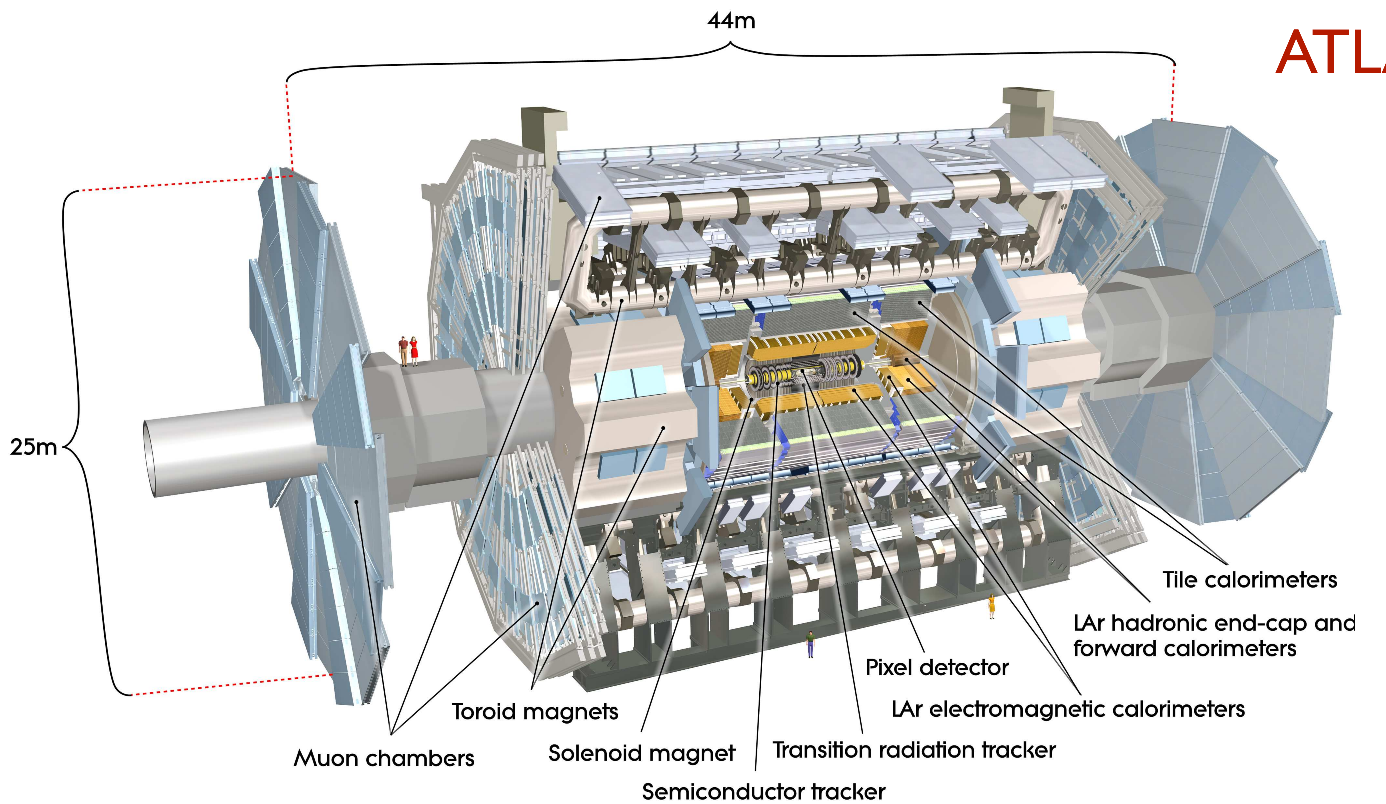


Signal events expected in 1 exp. for 1 fb^{-1}

m_H, GeV	$WW \to l\nu l\nu$	$ZZ \to 4l$	$\gamma\gamma$
120	127	1.5	43
150	390	4.6	16
300	89	3.8	0.04

Dataset analysed 4.7 - 4.9 fb^{-1}

ATLAS and CMS detectors

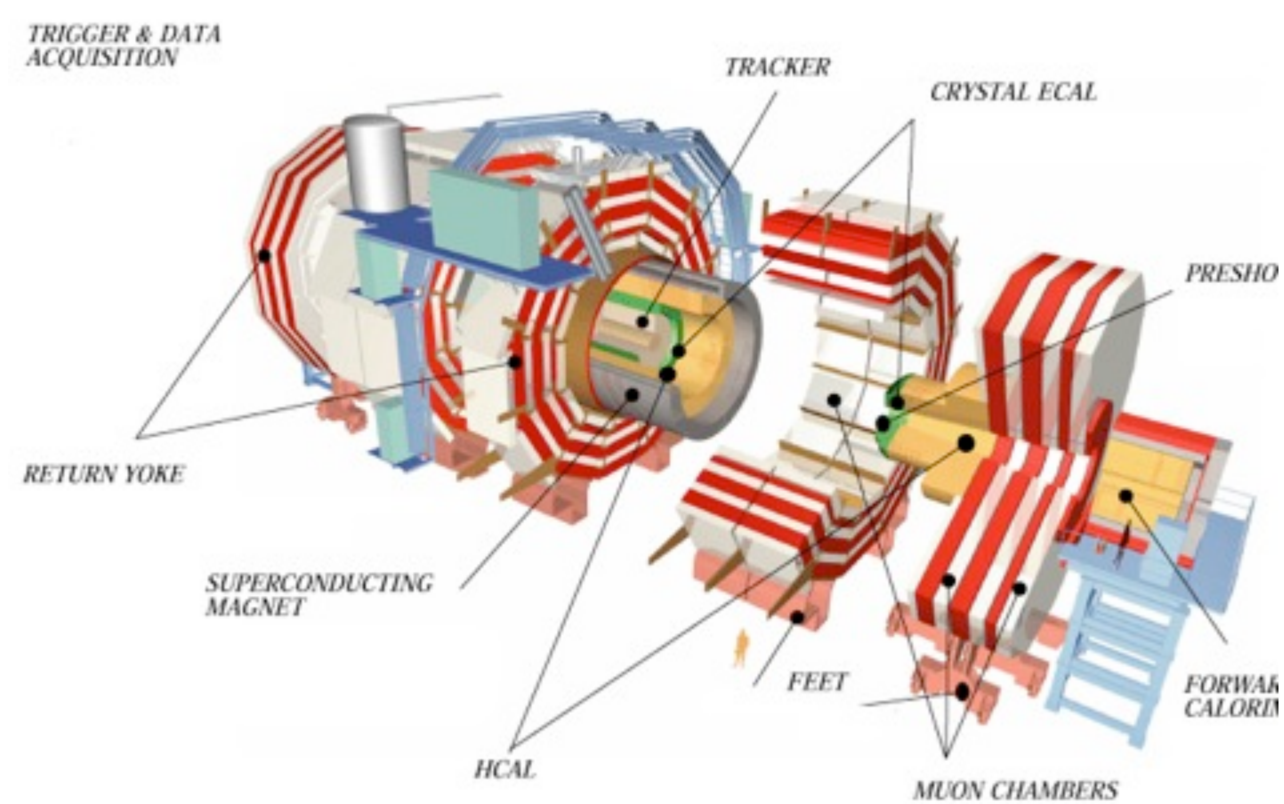


ATLAS

Magnets	1 Central Solenoid (2 T) + 3 air-core toroids
Tracking	Silicon+Transition radiation tracker
EM calo	Sampling LAr calo
HAD calo	Plastic scintillator (barrel) LAr technology (endcap)
Muon	Reco and trigger Standalone reco capabilities

CMS

Magnets	3.8 T Solenoid Iron return
Tracking	Silicon trackers
EM calo	Homogeneous scintillating crystals
HAD calo	Plastic scintillator
Muon	Reco and trigger detectors

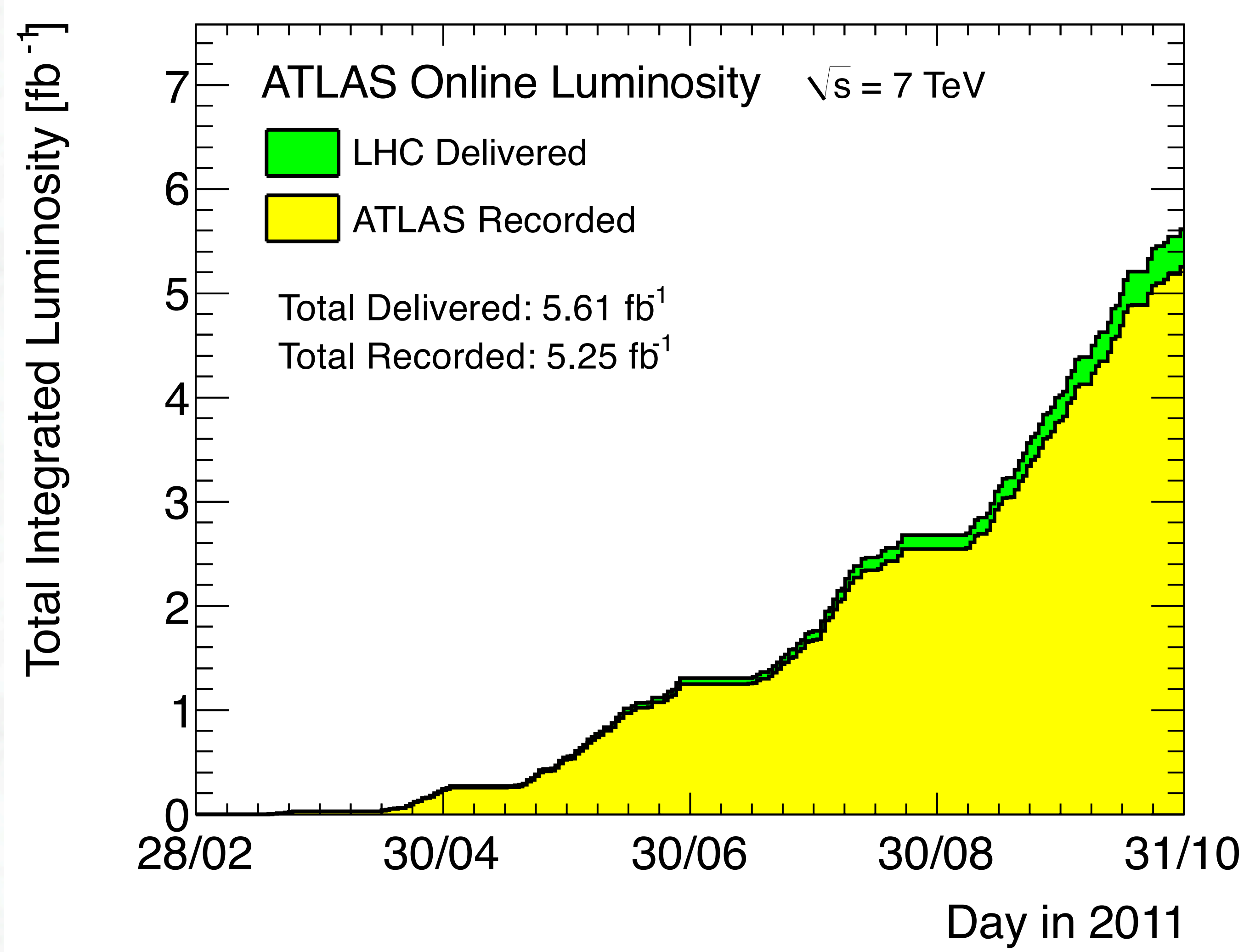


Data taking in 2011

Peak lumi $3.6 \cdot 10^{33}$ $cm^{-2}s^{-1}$

Detectors delivering good quality data for 90% or more of the (good quality choices depend on the analysis)

Total int. luminosity delivered: 5.61 fb^{-1}



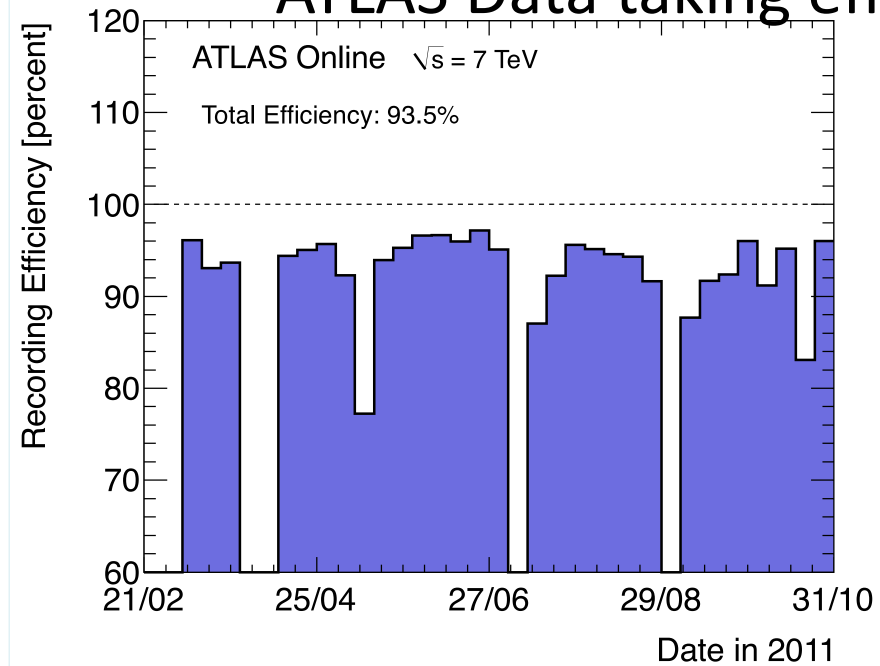
Increased pileup is a challenge:

50 ns bunch trains for ~all 2011 data

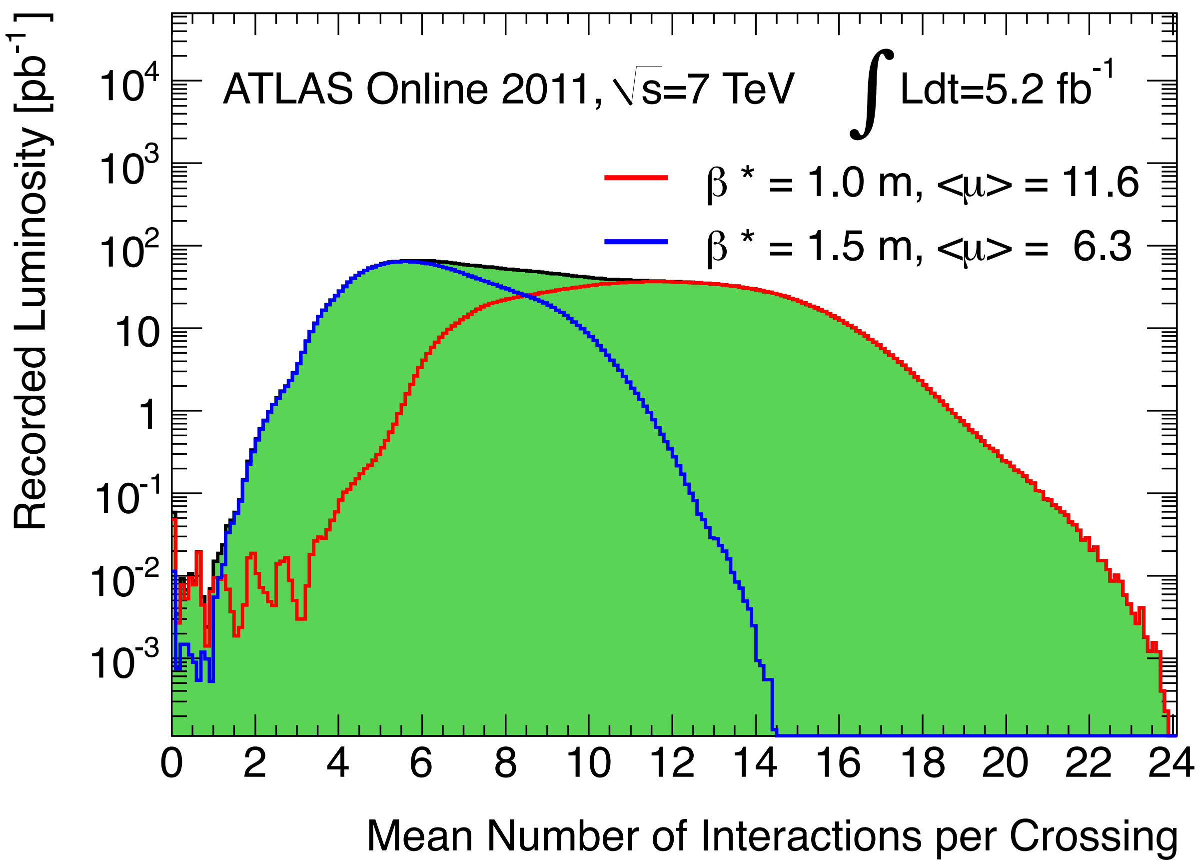
Impact on trigger and reconstructed objects, in particular MET, Jets, Leptons isolation...

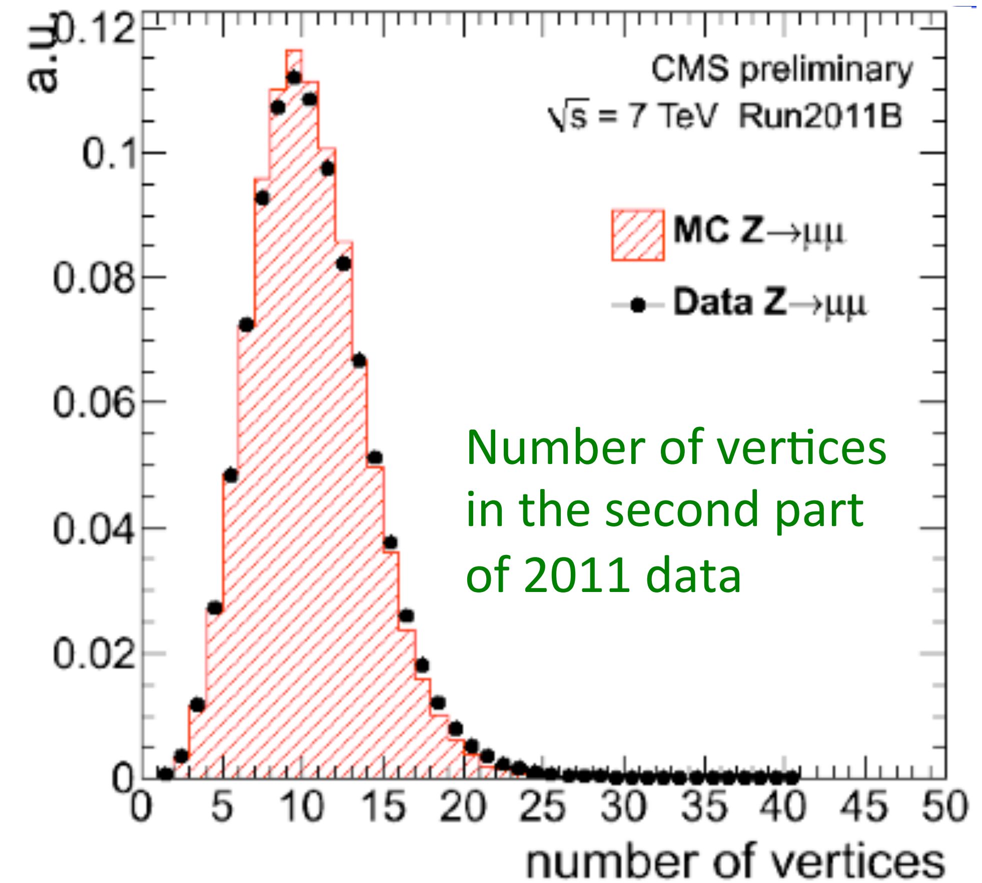
A precise modeling in simulation of both in-time and out-of-time pileup effects is very important

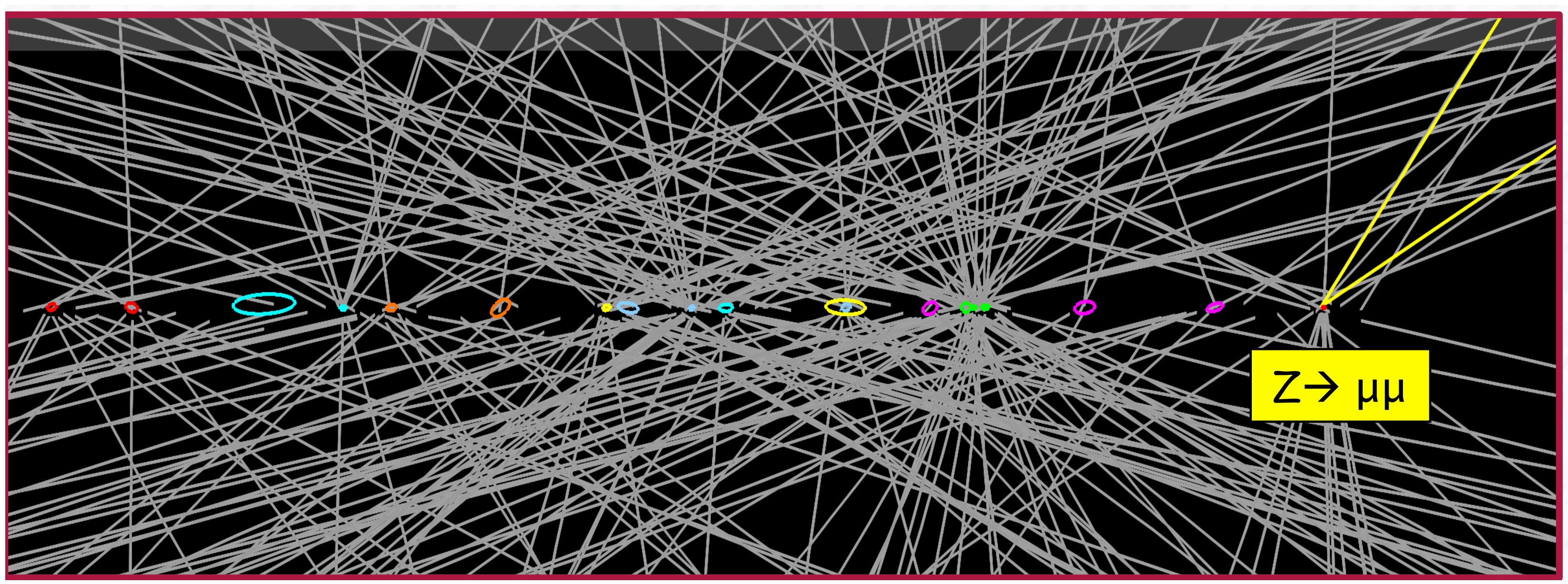
ATLAS Data taking eff.



Pileup







- 50 ns bunch spacing: high pileup

- Two running periods with different settings

- Many effects have been deeply studied (e.g. pileup time profile due to the bunch-train structure)

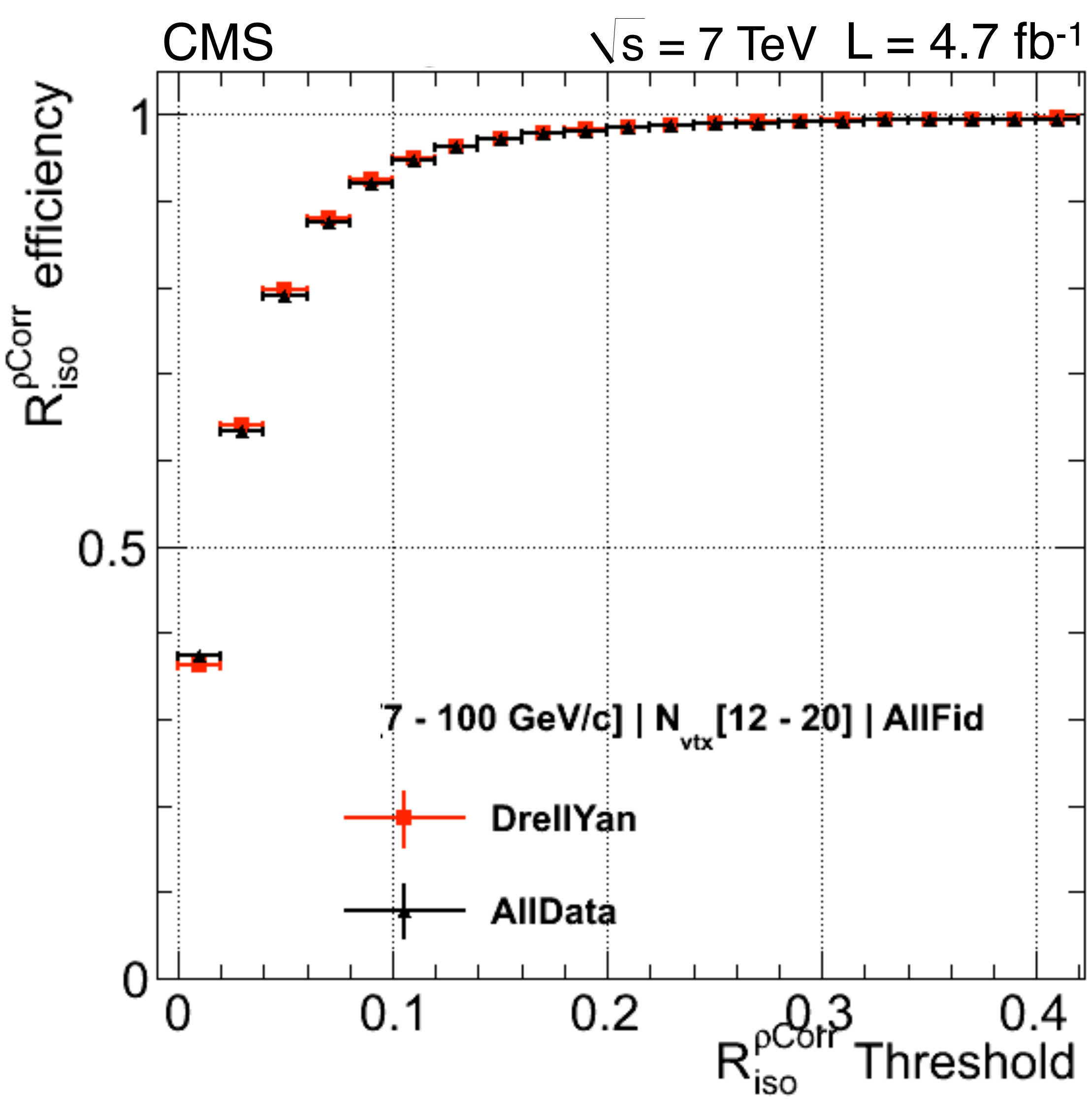
Example Z→μμ event with 20 vertices (errors x20)

Electron reconstruction performance

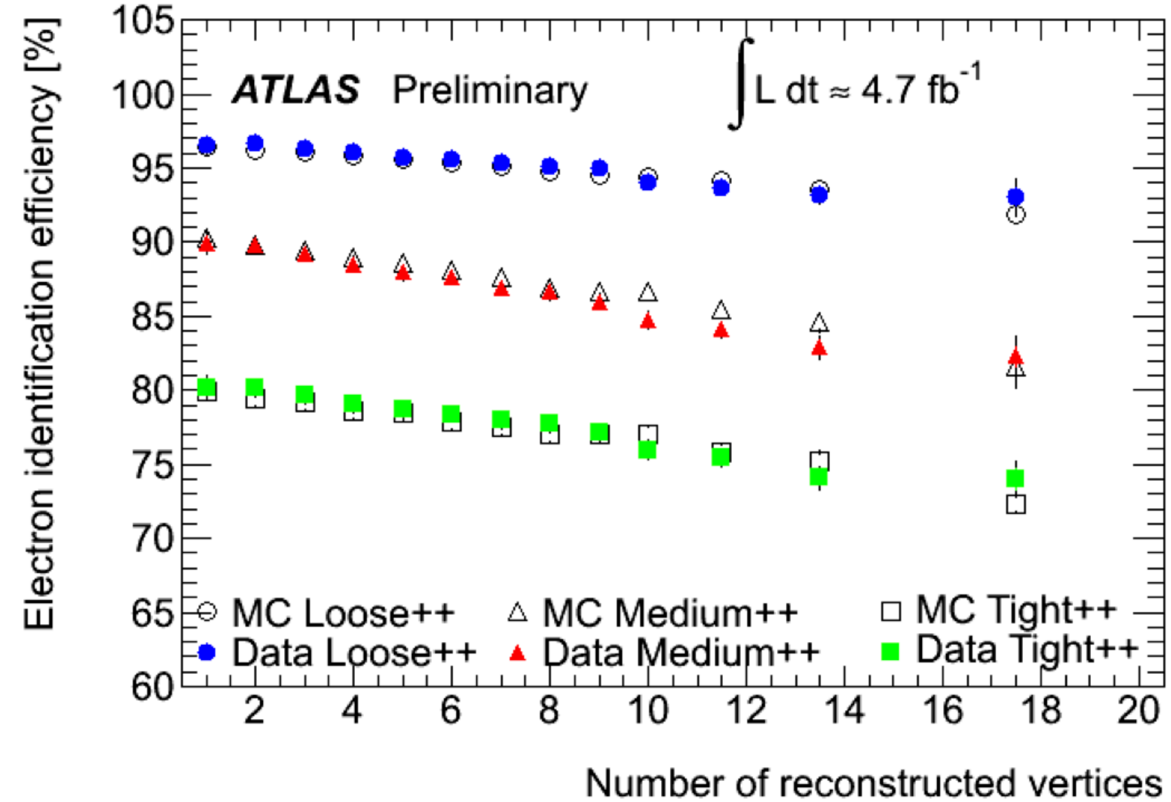
- Electron ID efficiency measured with Z→ee, J/ψ→ee events using tag-and-probe methods

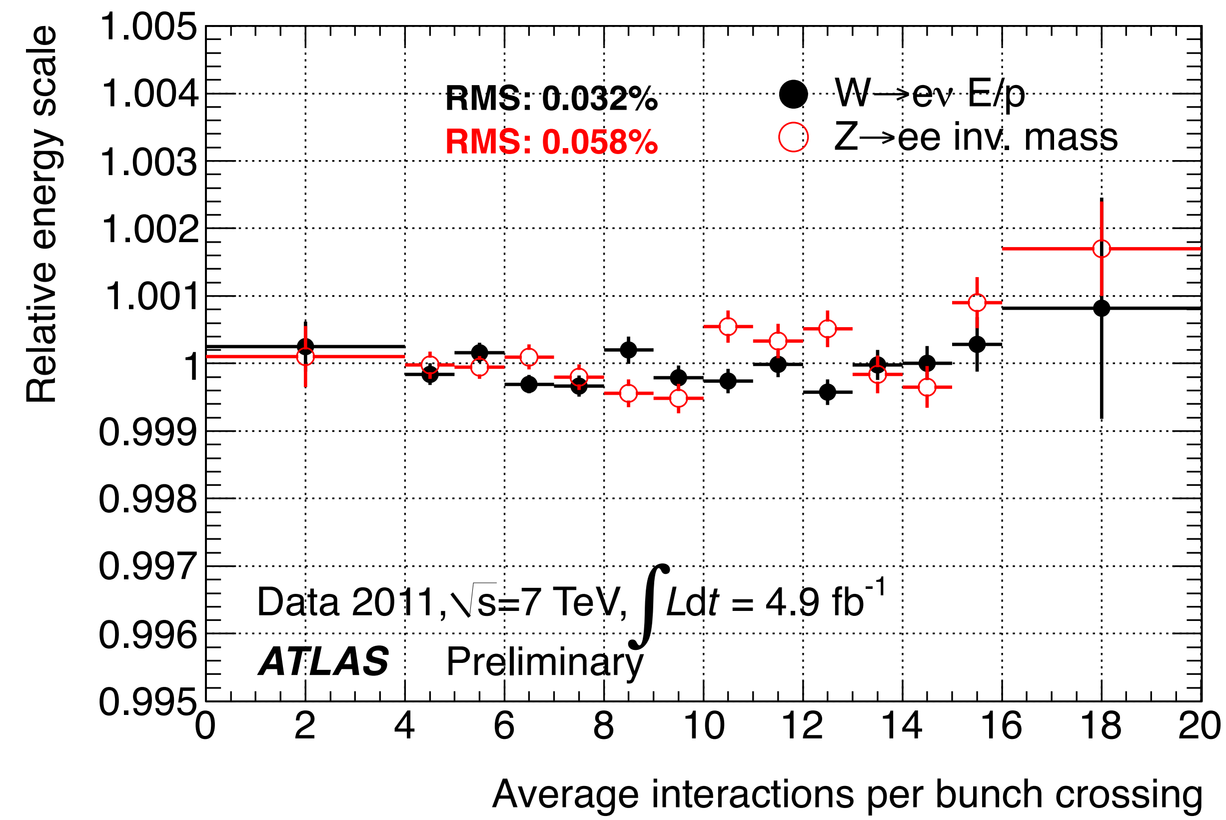
- Systematics on efficiencies <3%

- Energy scale and resolution at M_Z at ~0.5% level



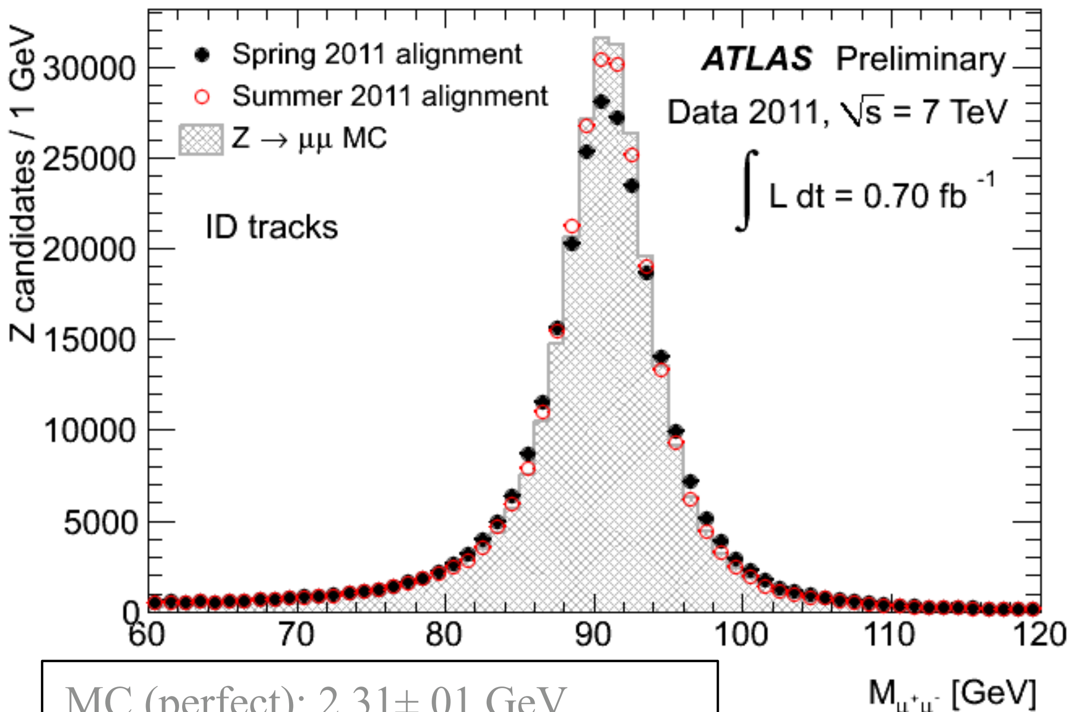
Efficiency vs number of vertices (cuts now retuned)
Very good data/MC agreement





Muon reconstruction performance

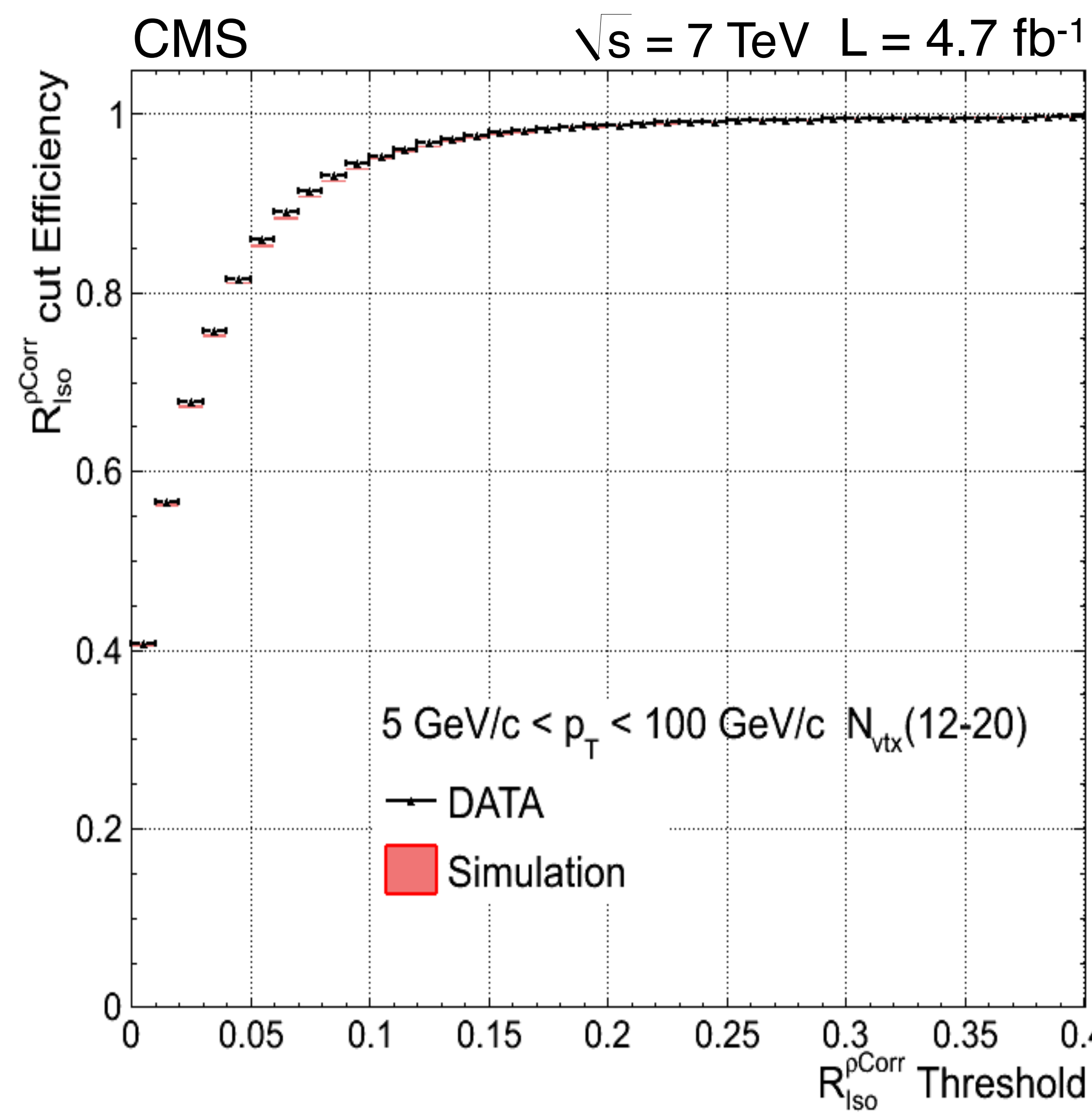
Z→μμ reconstructed mass with improved alignment vs MC with ideal alignment



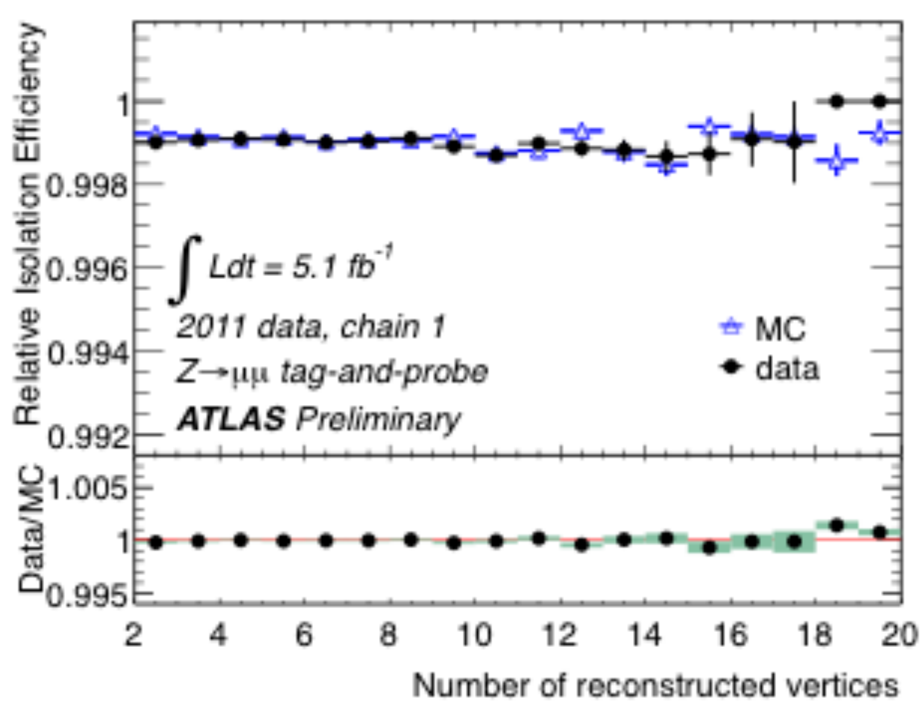
MC (perfect): 2.31±.01 GeV
Data Spring 2011 : 2.89±.01 GeV
Data Summer 2011: 2.45±.01 GeV

Muon isolation efficiency in high pileup conditions Nvtx (12-20)

Data MC comparison



Systematics on efficiency, isolation efficiency <1%



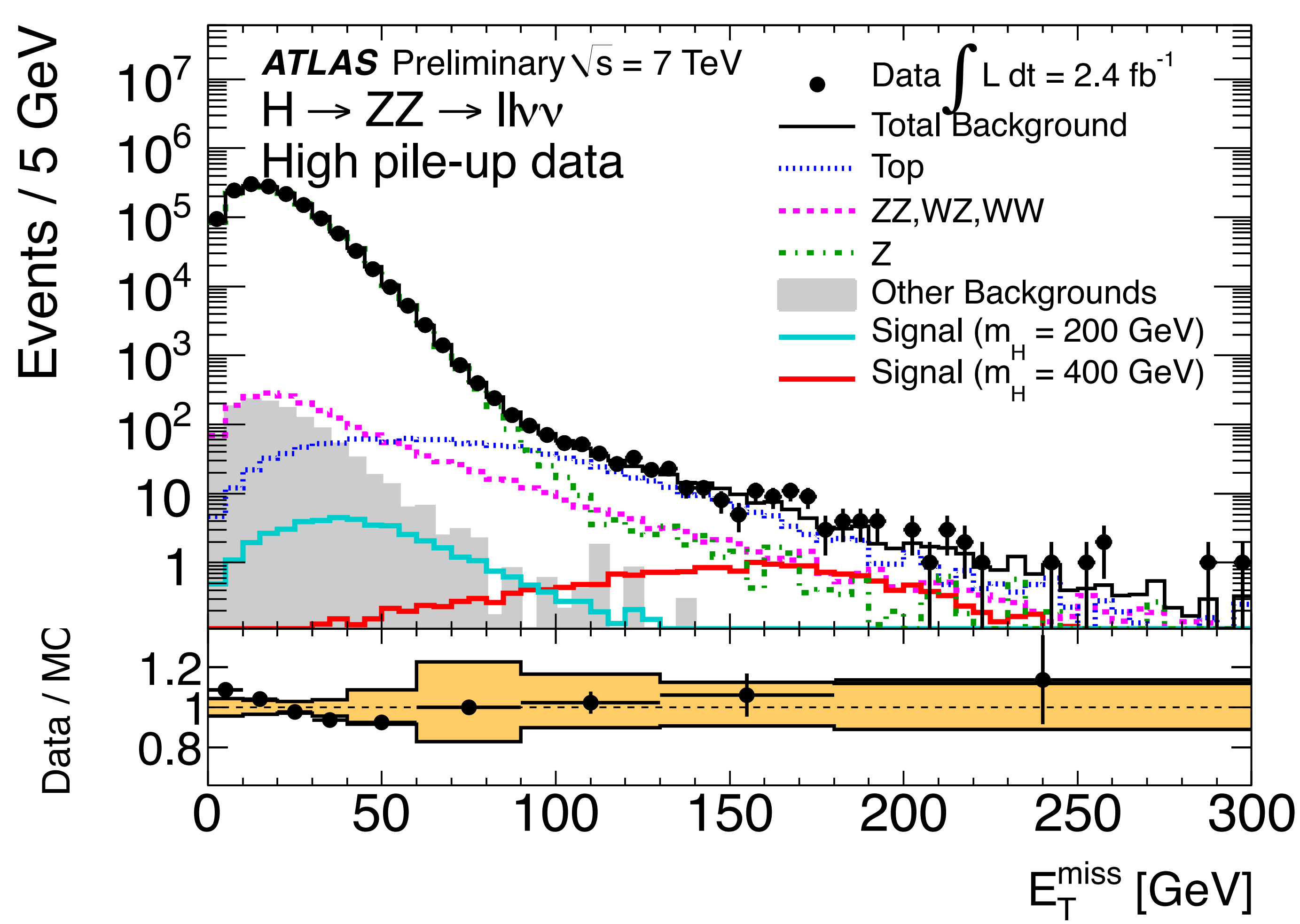
High mass region: H→ZZ→llνν

Most powerful channel in the high-mass region (M_H>200 GeV)
Common selection with llqq: start from Z→ll events

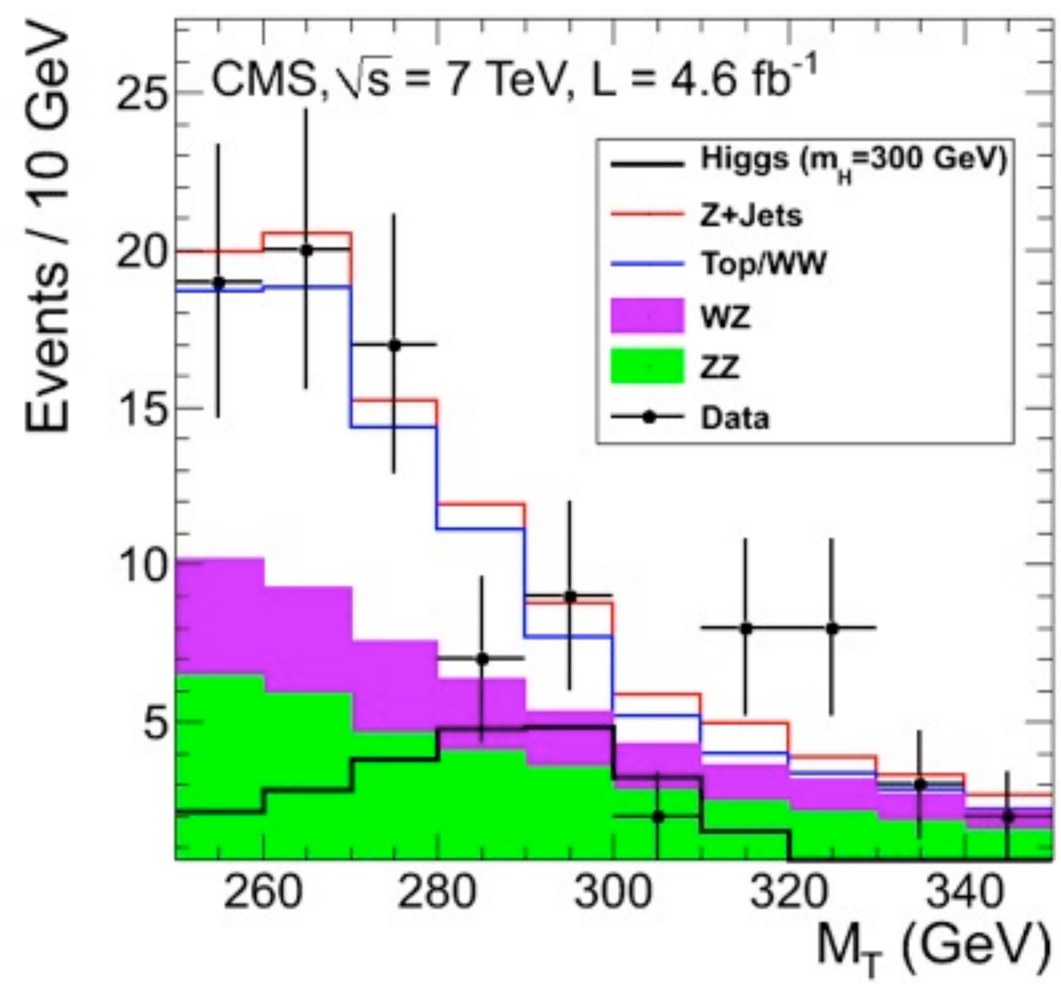
- llνν requires additionally high Missing transverse energy (H mass dependent cut)
- Main backgrounds are QCD, W/Z+jets, top (reducible), di-boson (irreducible)
- Discriminating variable is the transverse mass:

$$m_T^2 \equiv \left[\sqrt{m_Z^2 + |\vec{p}_T^{\,\ell\ell}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\,\mathrm{miss}}|^2}\right]^2 - \left[\vec{p}_T^{\,\ell\ell} + \vec{p}_T^{\,\mathrm{miss}}\right]^2$$

MET after event preselection, for the high pileup period



Transverse mass of the selected events



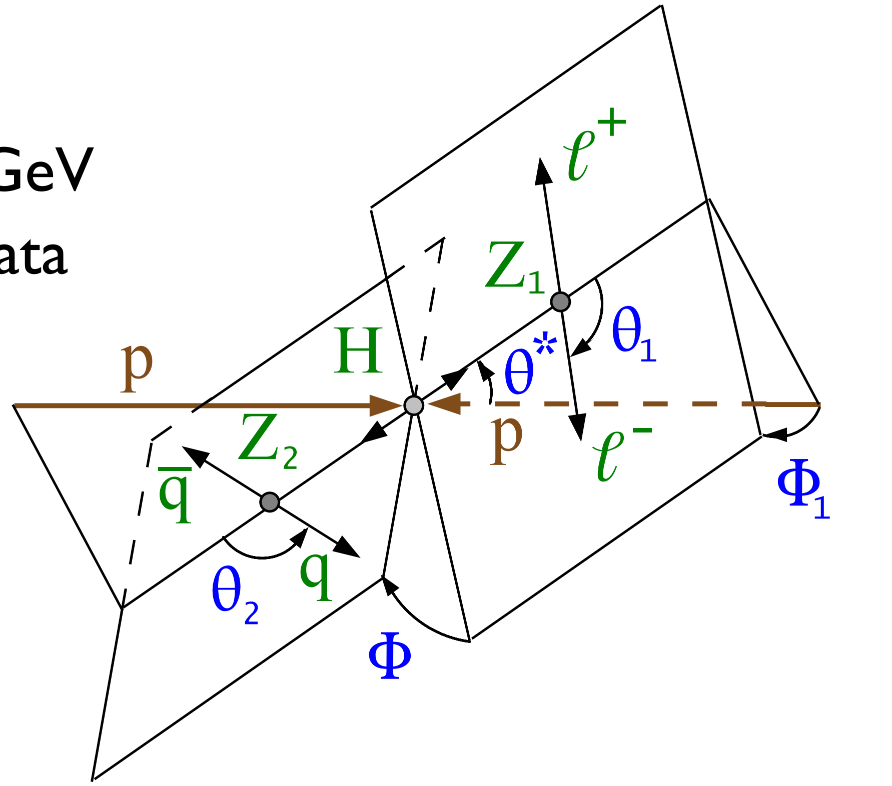
High mass region: H→ZZ→llqq (llbb)

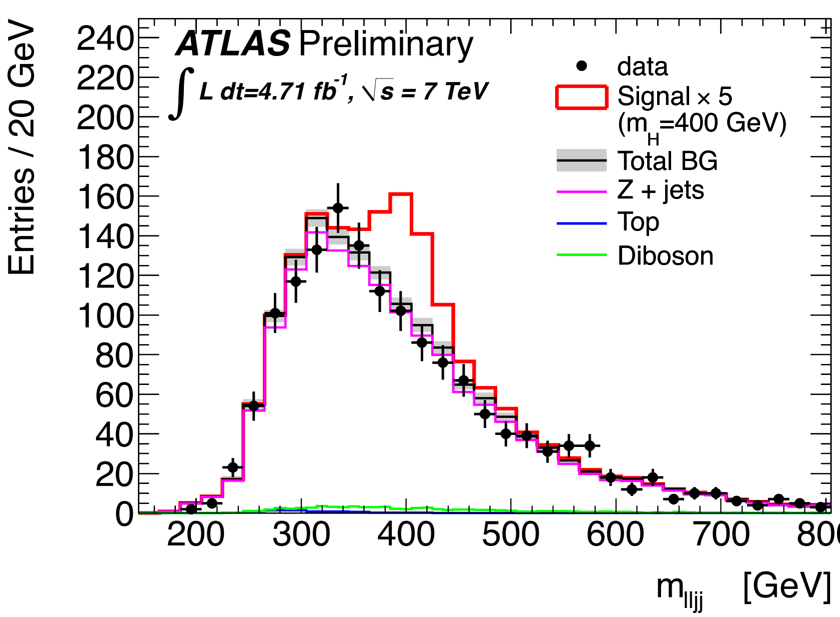
Higher BR than llνν but also higher background

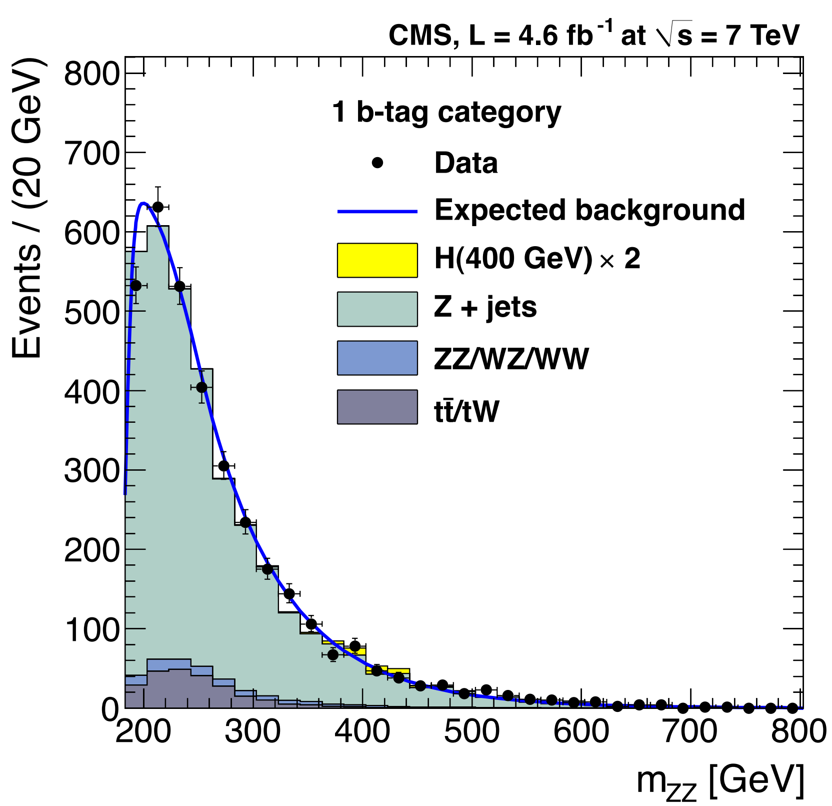
Still quite helpful in the high mass region

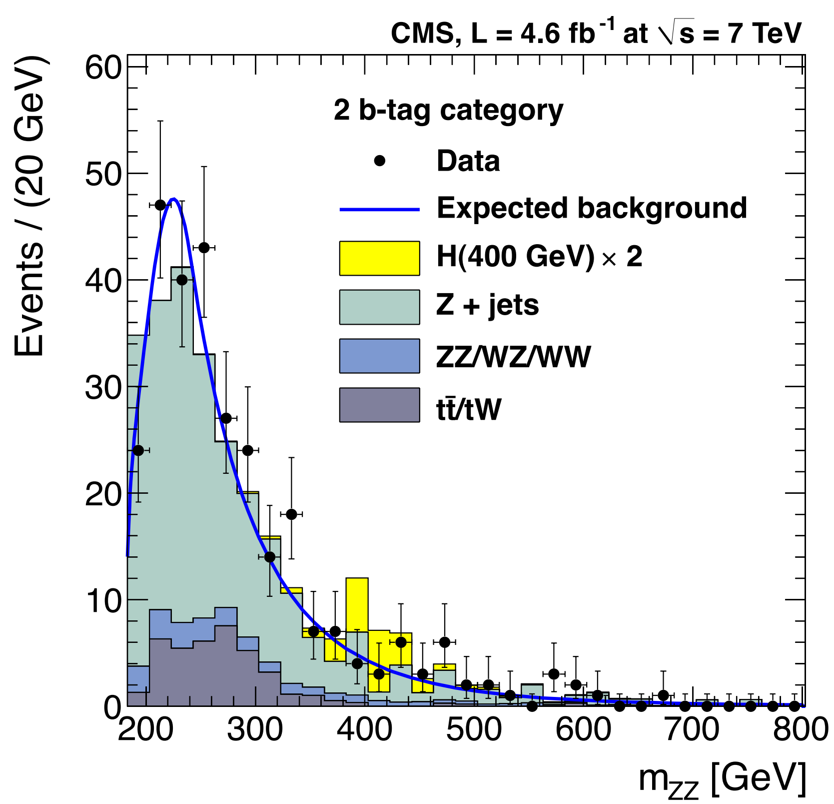
Common selection with llνν: start from Z→ll events

- Require two jets in the final state:
  - e.g. for ATLAS: ≥2 Jets, p_T> 20 GeV , mass cut 70<m_{jj}<105 GeV
- Main backgrounds are Z+jets and QCD: both determined from data using distributions in control regions
  - ttbar removed by cut on MET
- Discriminating variable is the lljj mass
- CMS: likelihood discriminant using 5 angles (scalar Higgs)
- CMS: extended analysis to the low-mass region
- characterize events according to b-tagged jets

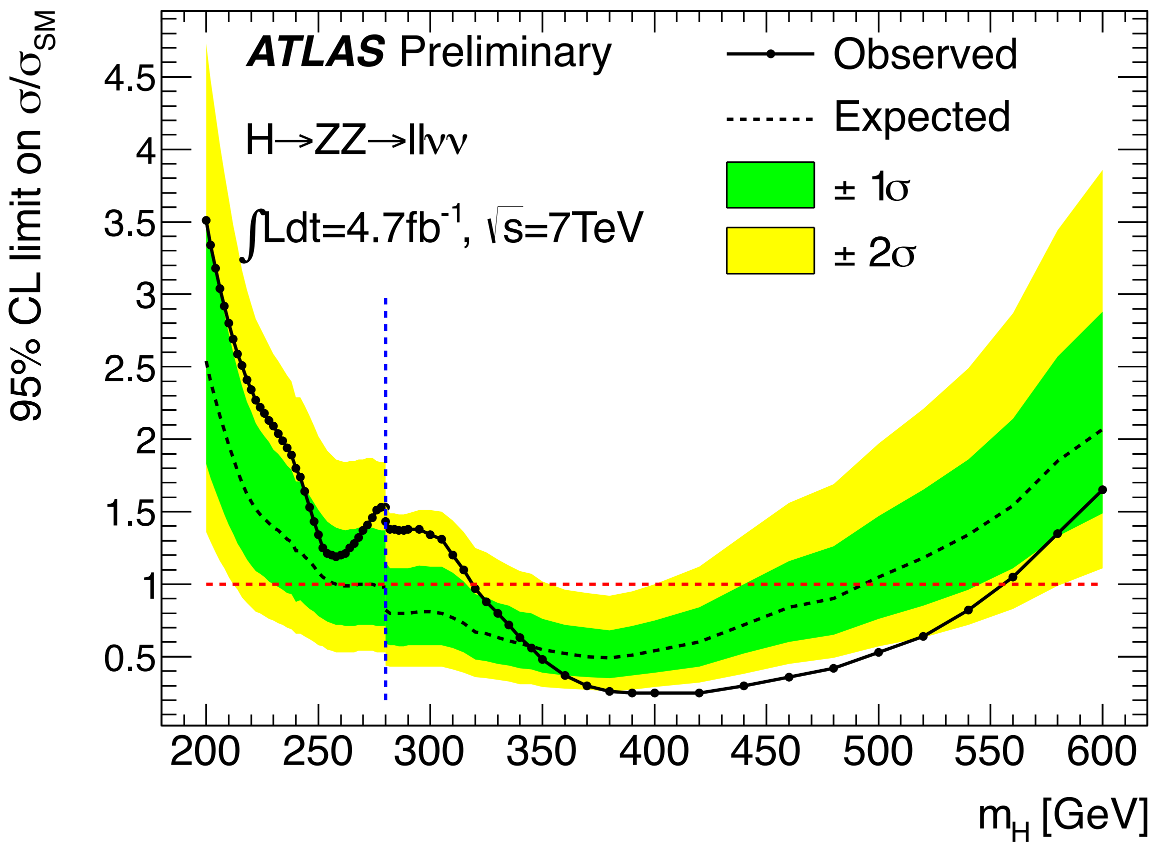


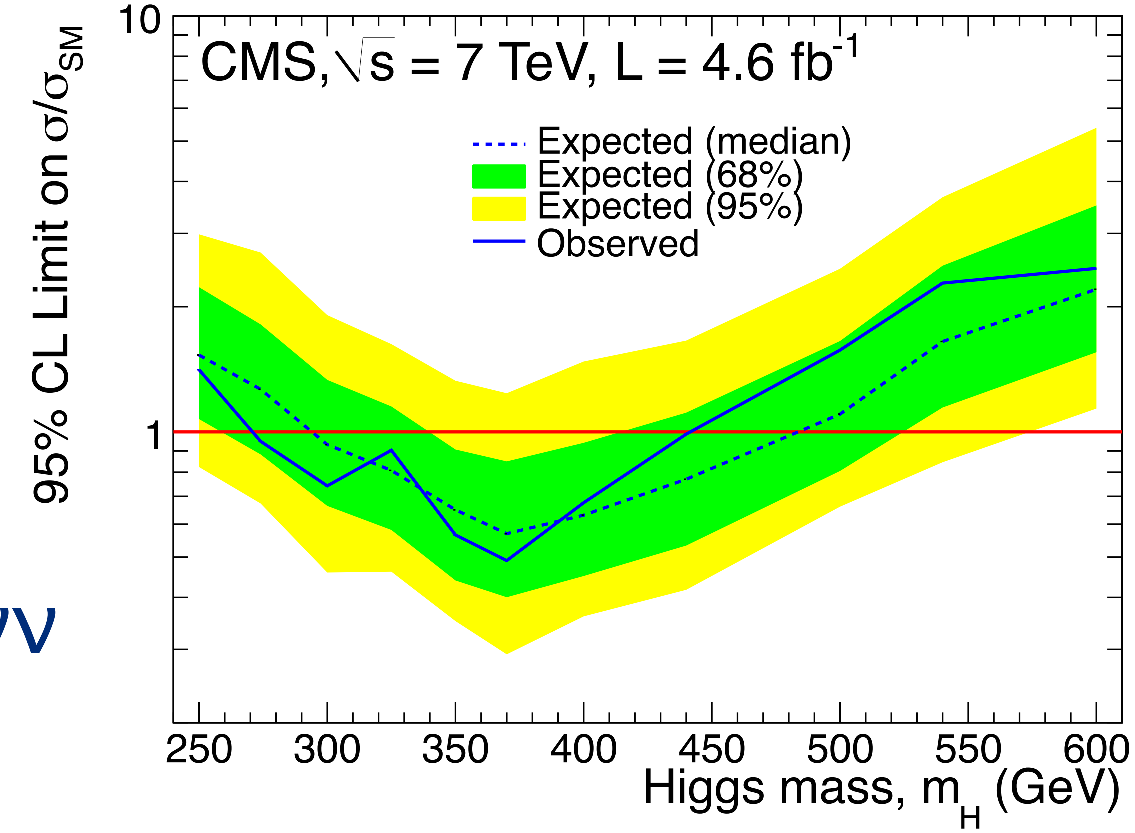




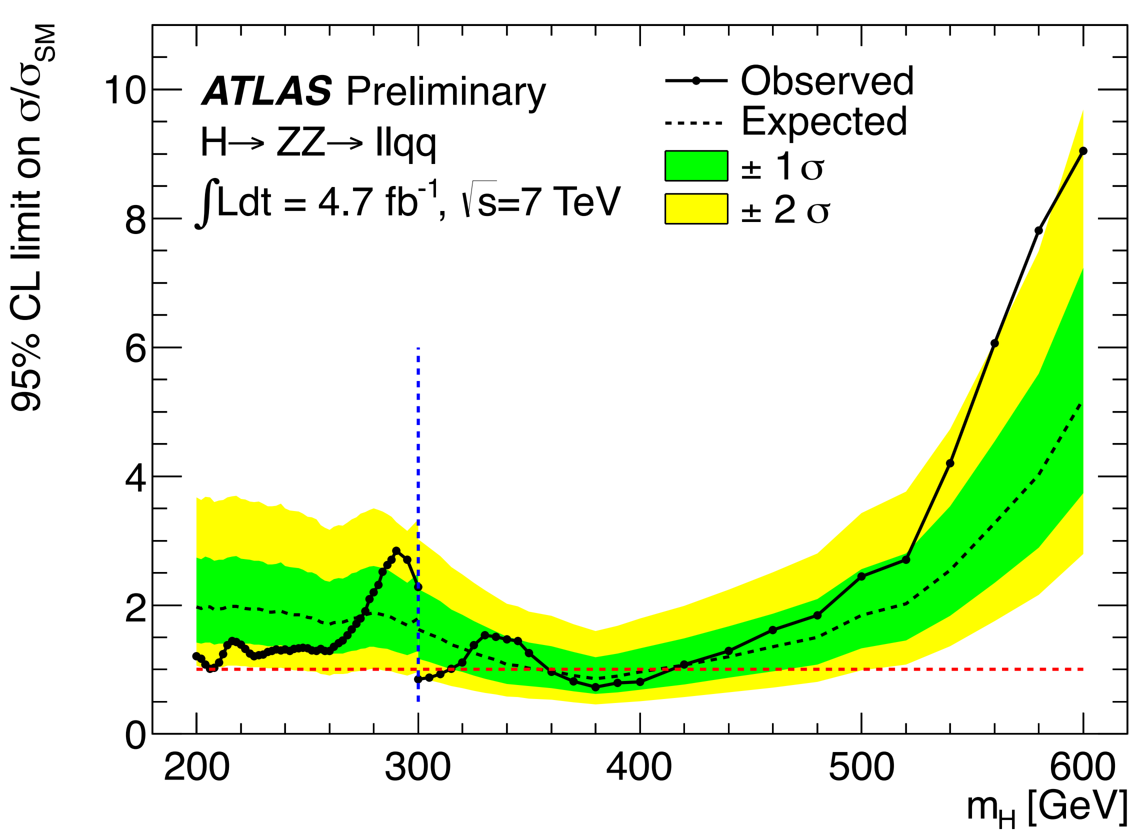


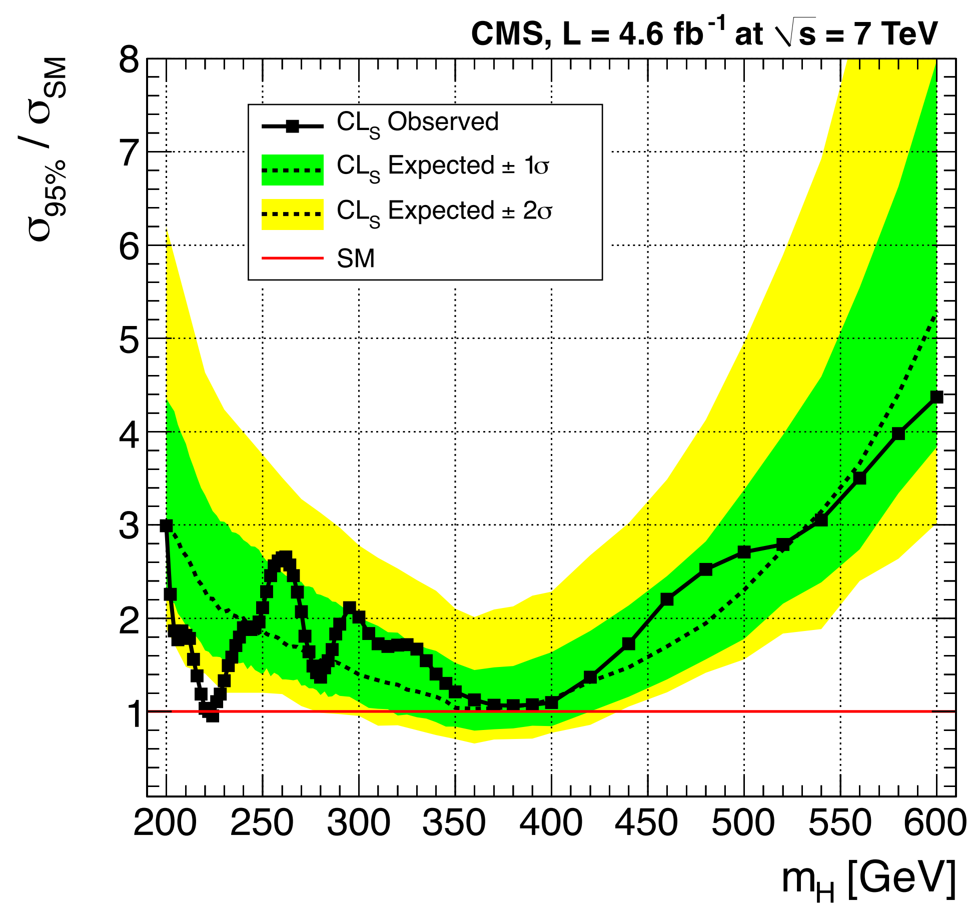
Limits from ZZ in the high mass region





llνν



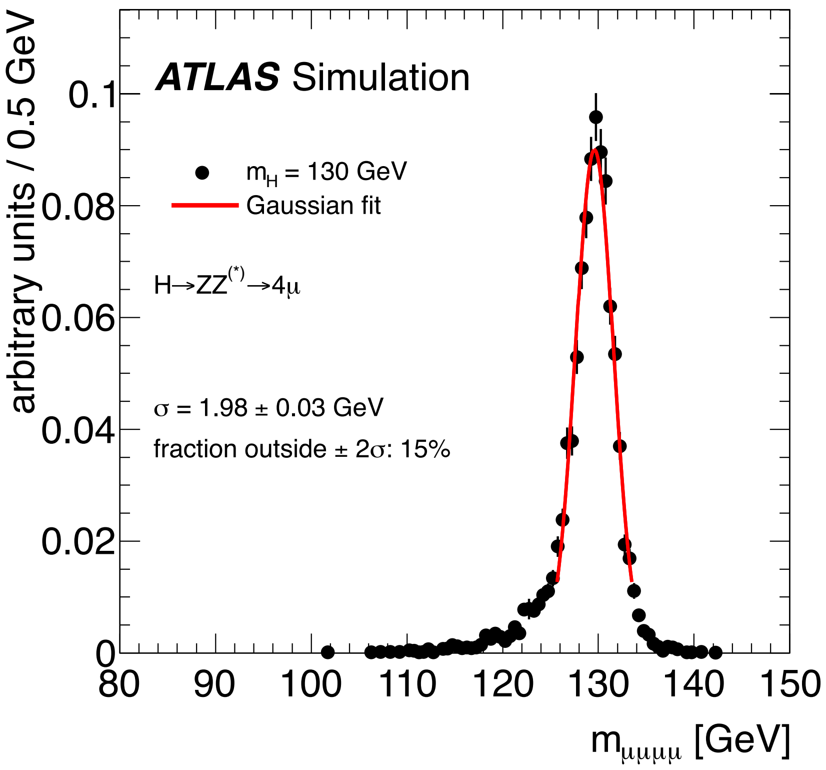


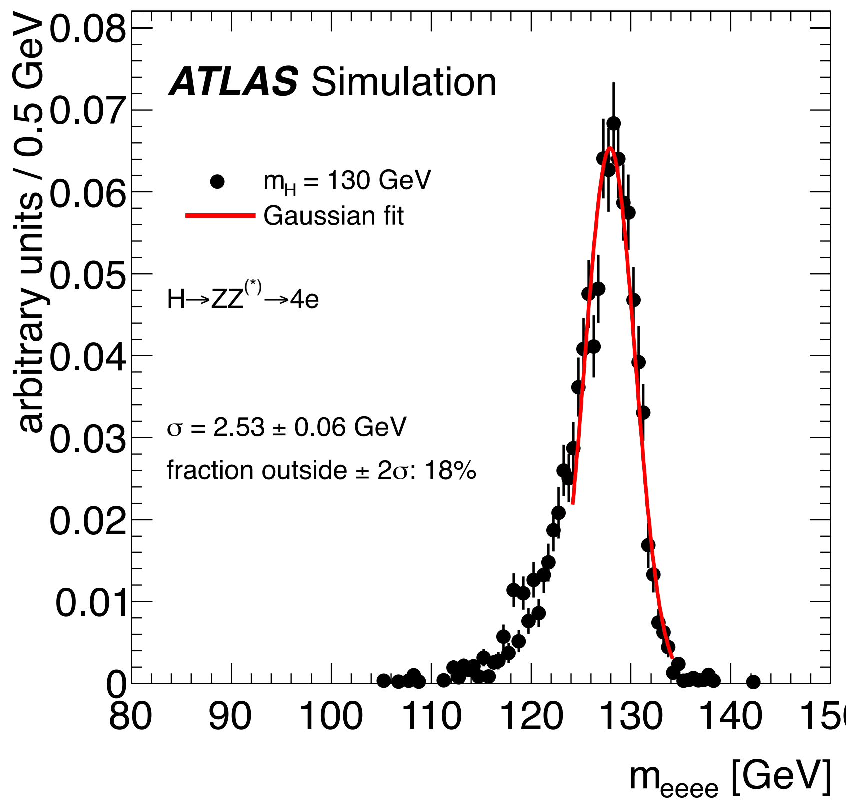
llqq

The $H \to ZZ^{(*)} \to 4l$ (e,μ) channel

- Small cross section · BR (2-5 fb), but among the most important channels over the whole mass range
  - Mass peak can be fully reconstructed
  - Very good Signal/Background ratio (~1 at low mass)
- Main backgrounds are:
  - Reducible, in the low-mass region: Zbb, ttbar, Z+jets
  - Irreducible: $ZZ^{(*)}$
- Event selection:
  - 4-leptons with p_T> 20,20,7,7 GeV (ATLAS), p_T> 20, 10, 7 (5) (CMS)
  - 2 di-lepton pairs with $|M_1 - M_Z| < 15$ GeV , $M_1 > 50$ (CMS) , $M_2 > 12$-60 GeV
  - Lepton isolation and impact parameter cuts to reject reducible backgrounds
- Crucial for this analysis are:
  - High reconstruction efficiencies for electrons and muons
  - 4-lepton mass resolution
  - Control regions for reducible backgrounds

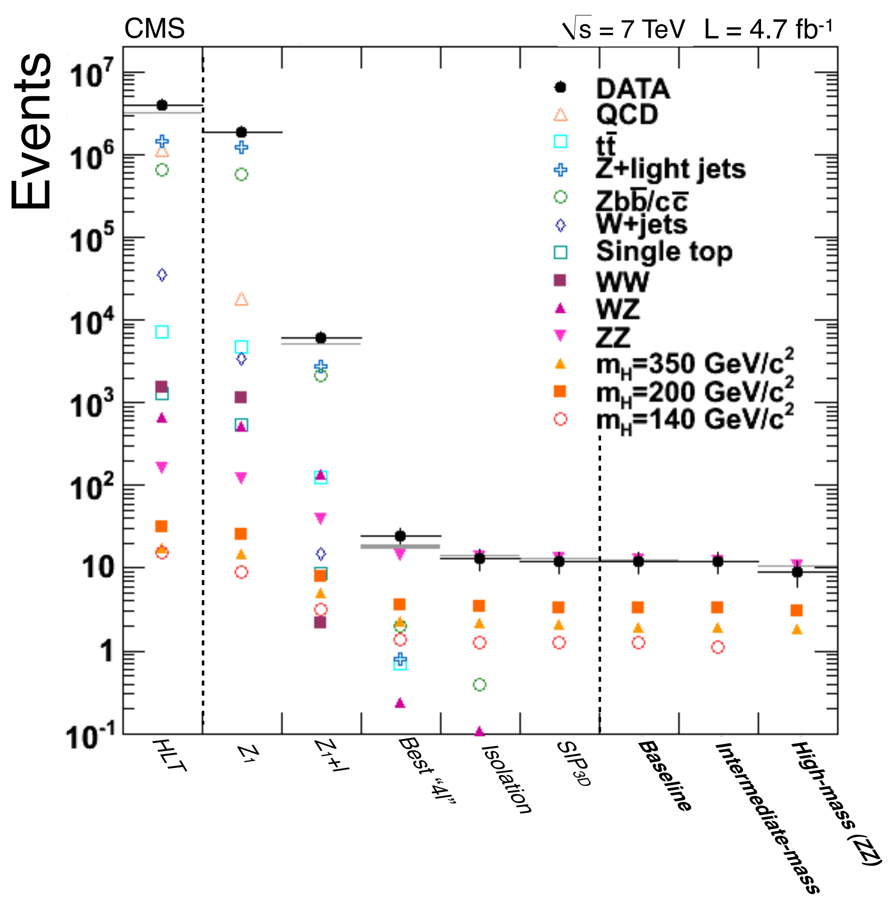
$H \to ZZ^{(*)} \to 4l$ events

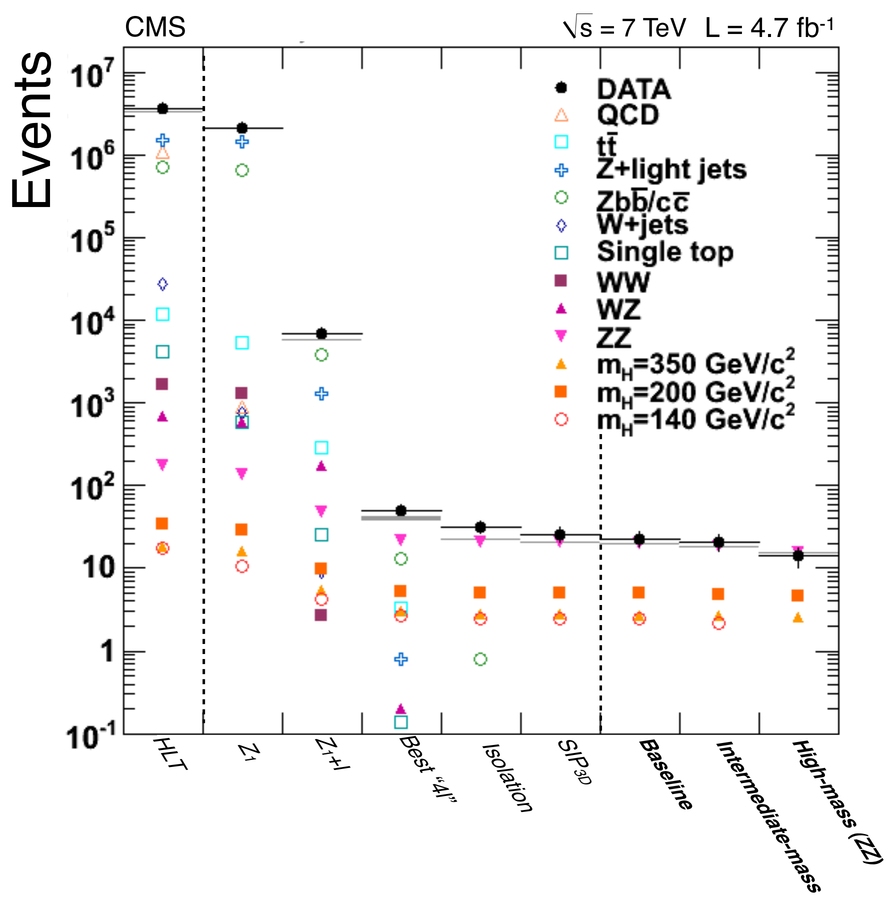




H mass resolution
(no Z mass constraint)
85% and 82% of events
within ±2σ
for 4mu and 4e channel

Signal acceptance·eff
is ~15% at ~125 GeV



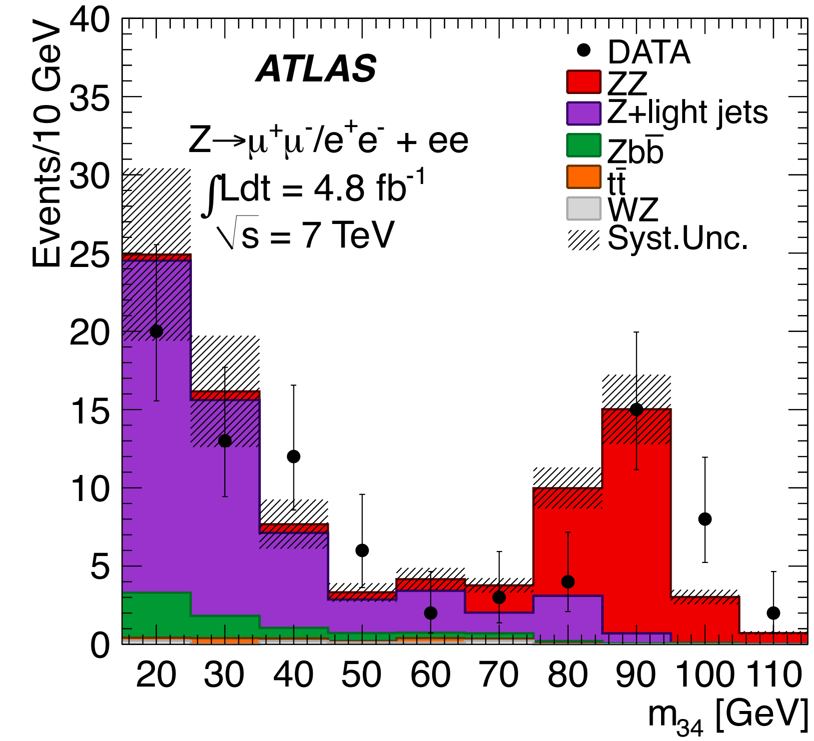


$H \to ZZ^{(*)} \to 4l$: background control regions

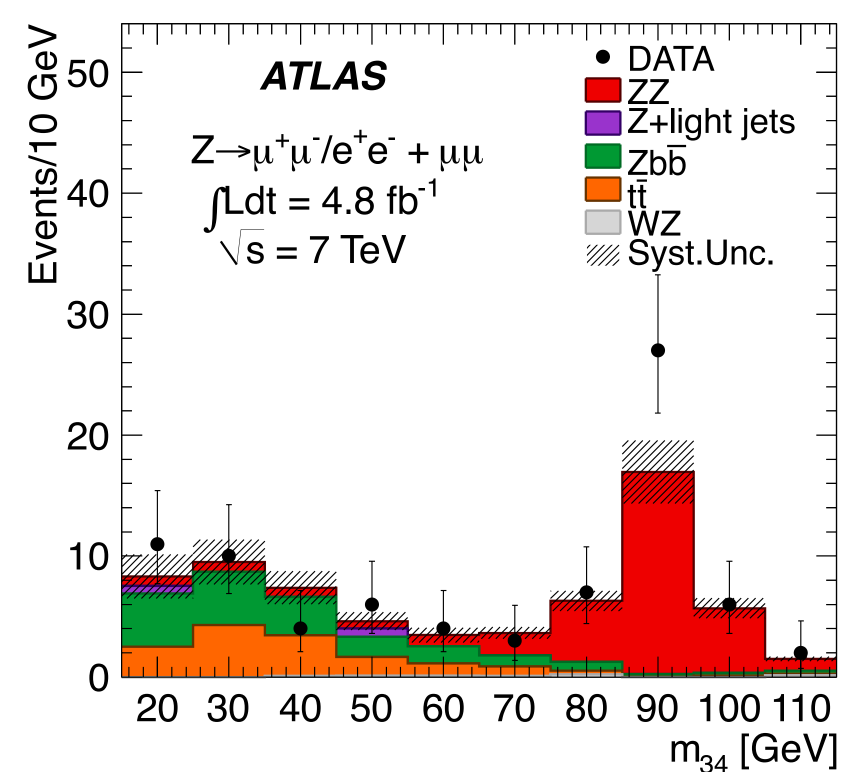
- Build background-enriched control regions for the reducible backgrounds:
- Z+jets control region (mainly to 4e, 2μ2e):
  - Invert electron selection criteria (shower shape)
- Z+bb control region:
  - Invert lepton isolation and impact parameter cuts
- Check data/MC background in the control regions, extrapolate to the signal region using MC efficiencies
- ZZ irreducible background from MC (Pythia / MCFM / PowHeg)
  - CMS: cross check of the normalization with inclusive single-Z rate. use MC ratio Z/ZZ to get expected ZZ rate (correct for lepton efficiencies)

No isolation and charge cuts on the second lepton pair

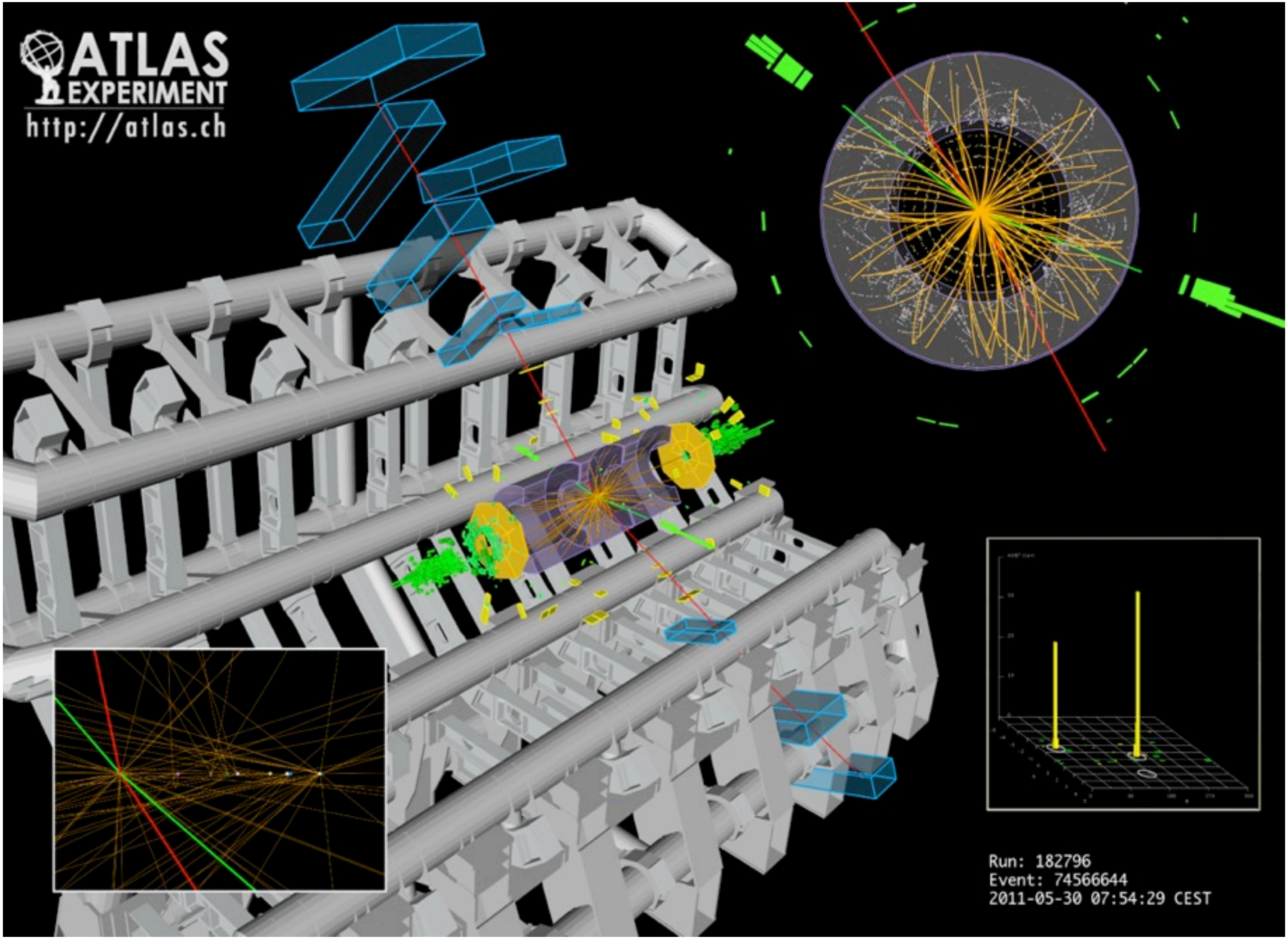
Z+ee



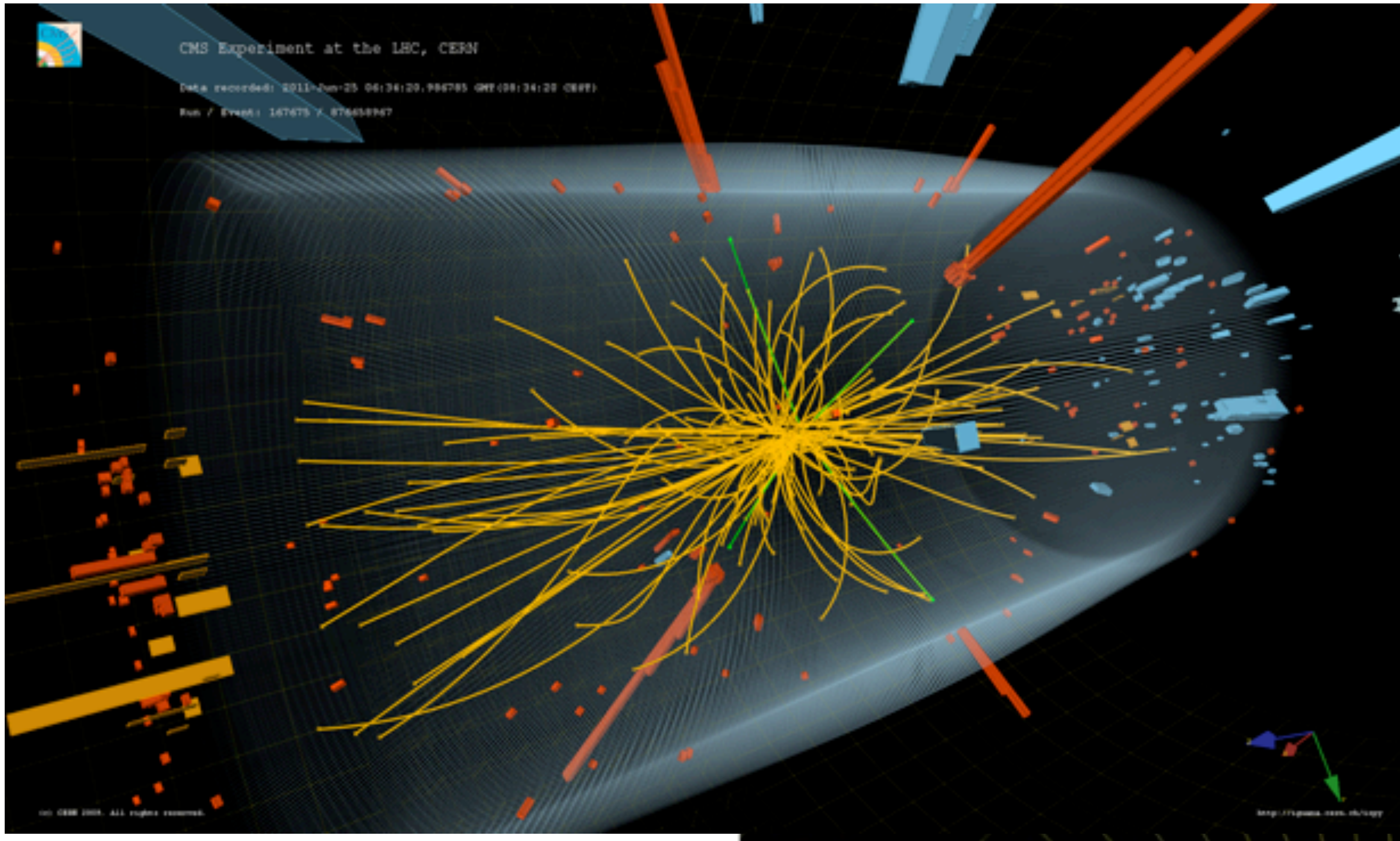
Z+μμ

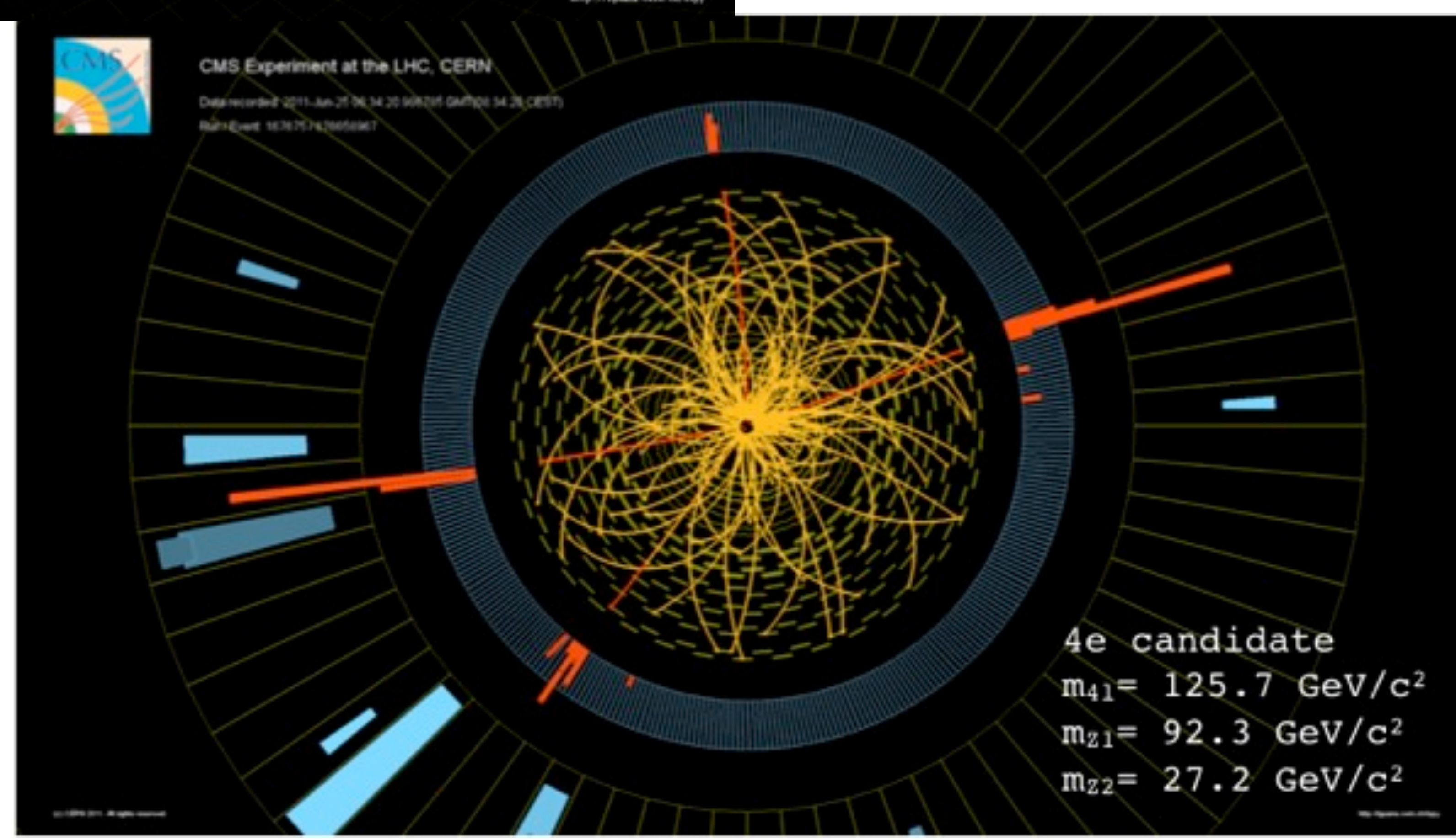


A 2e2μ candidate

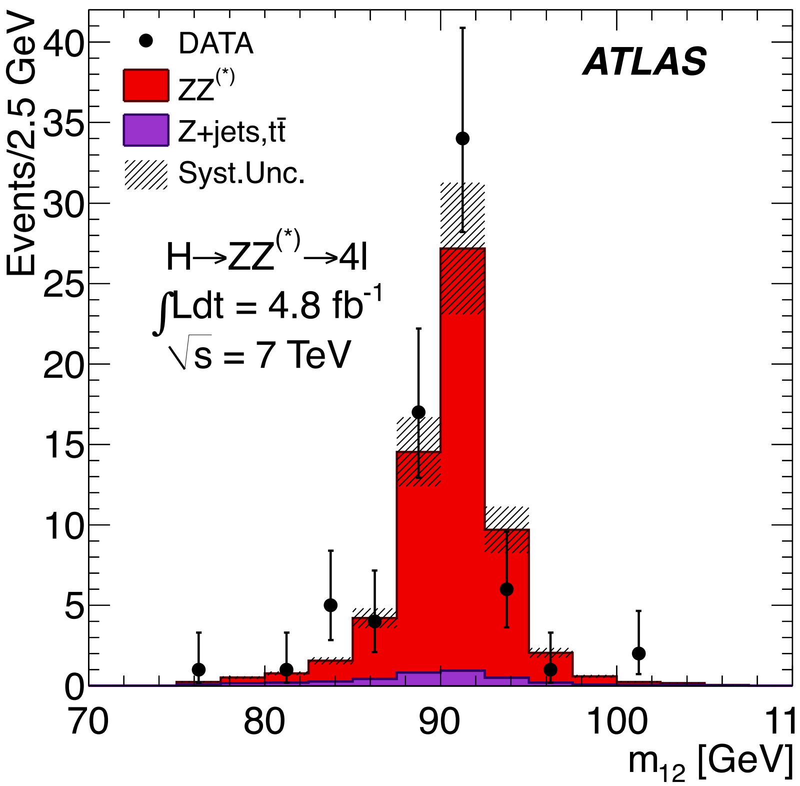


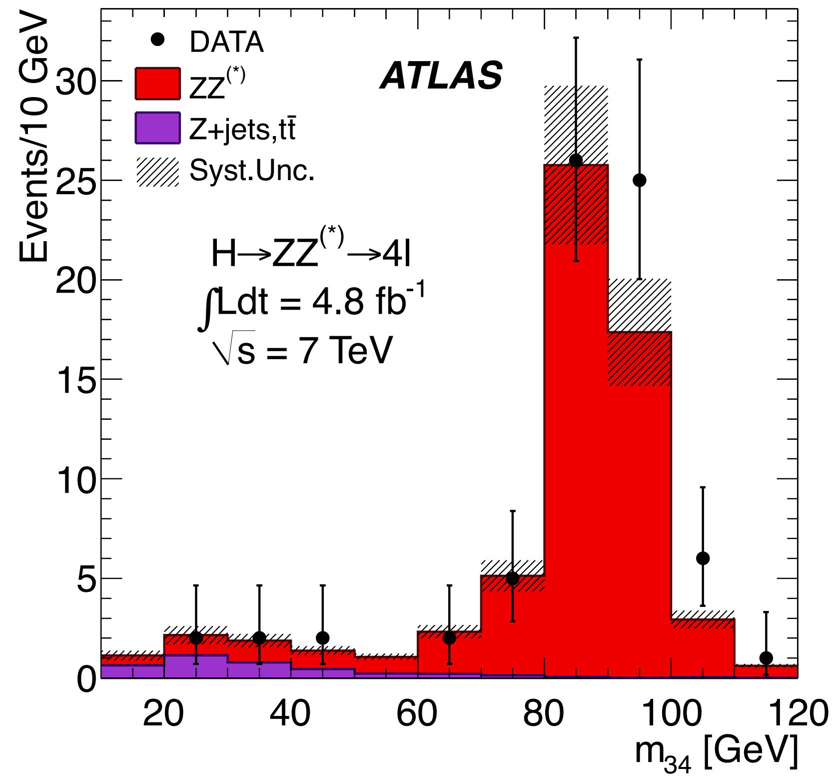
A 4e candidate

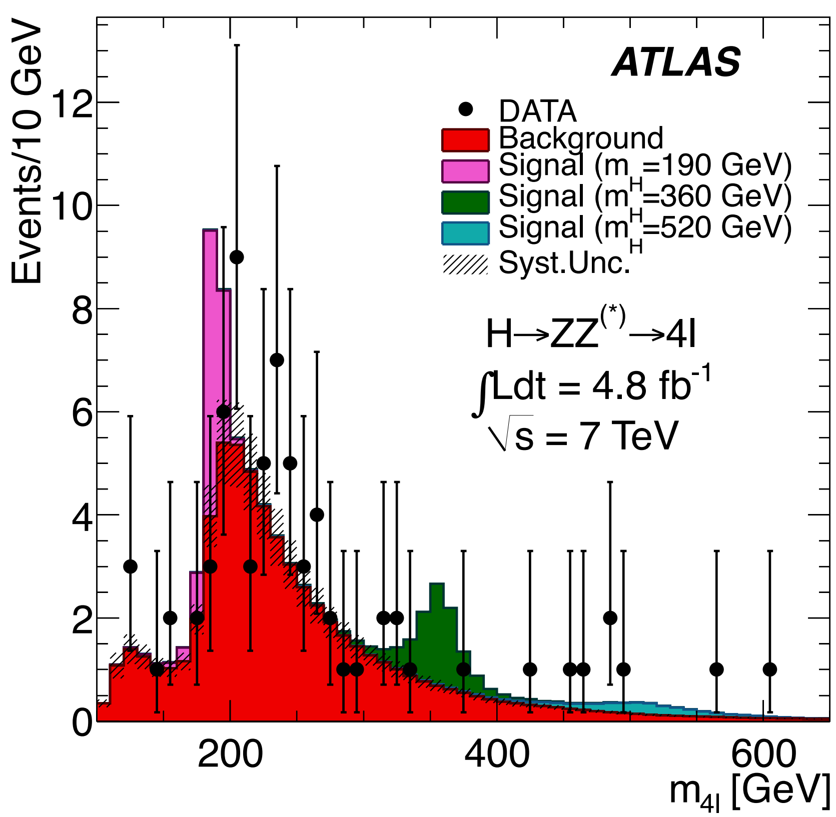


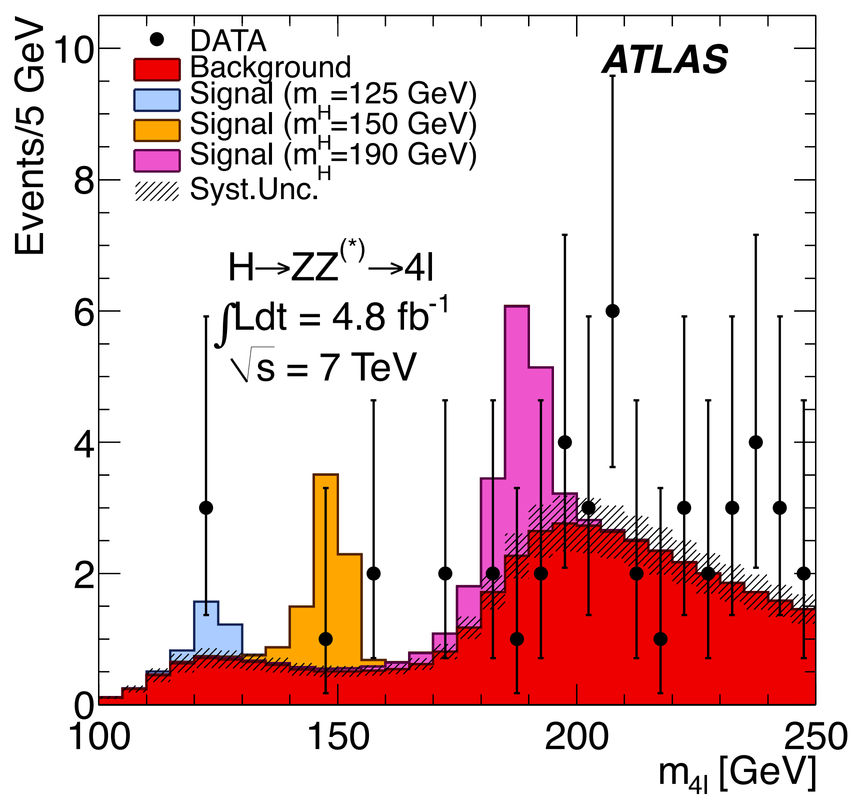


H→ZZ$^{(*)}$→4l: ATLAS results









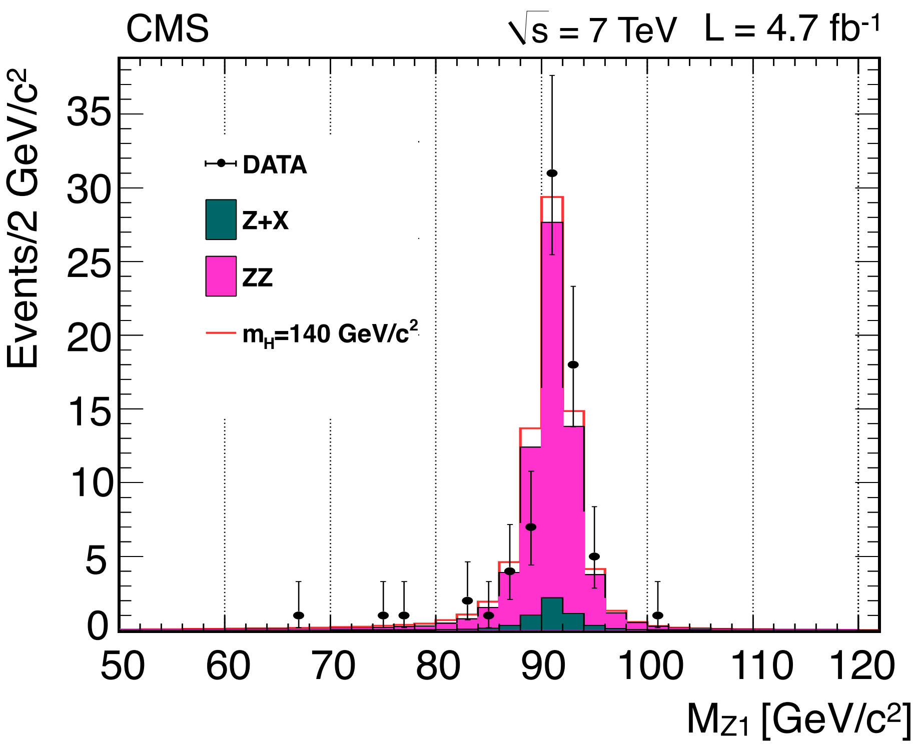
Full mass range

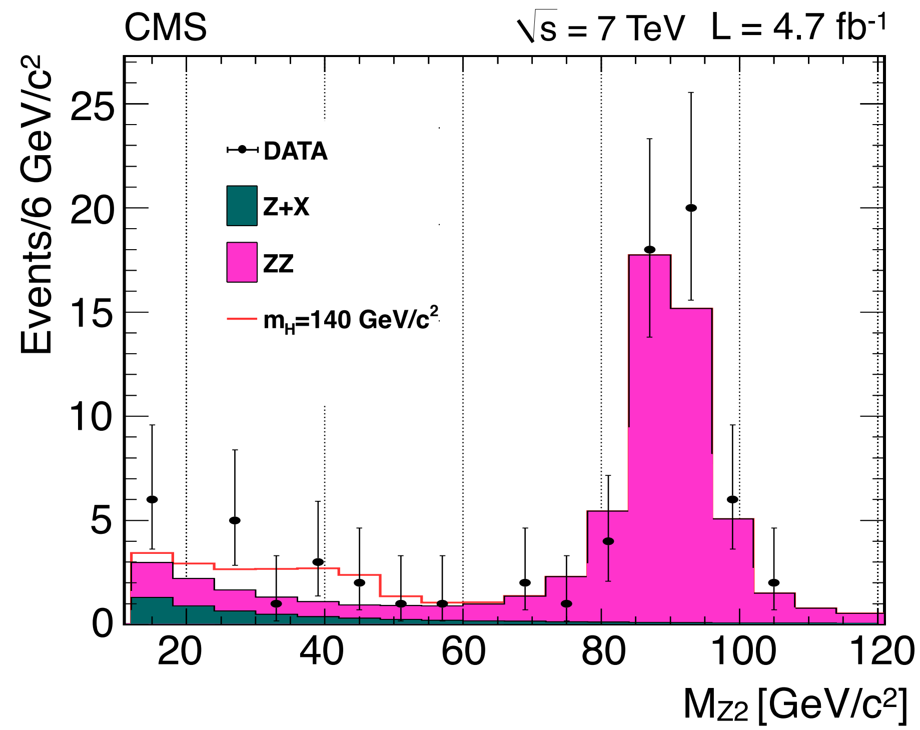
Data	Expected SM
71	62±9

Low mass range
M_H<180 GeV

Data	Expected SM
8	9.3±1.2

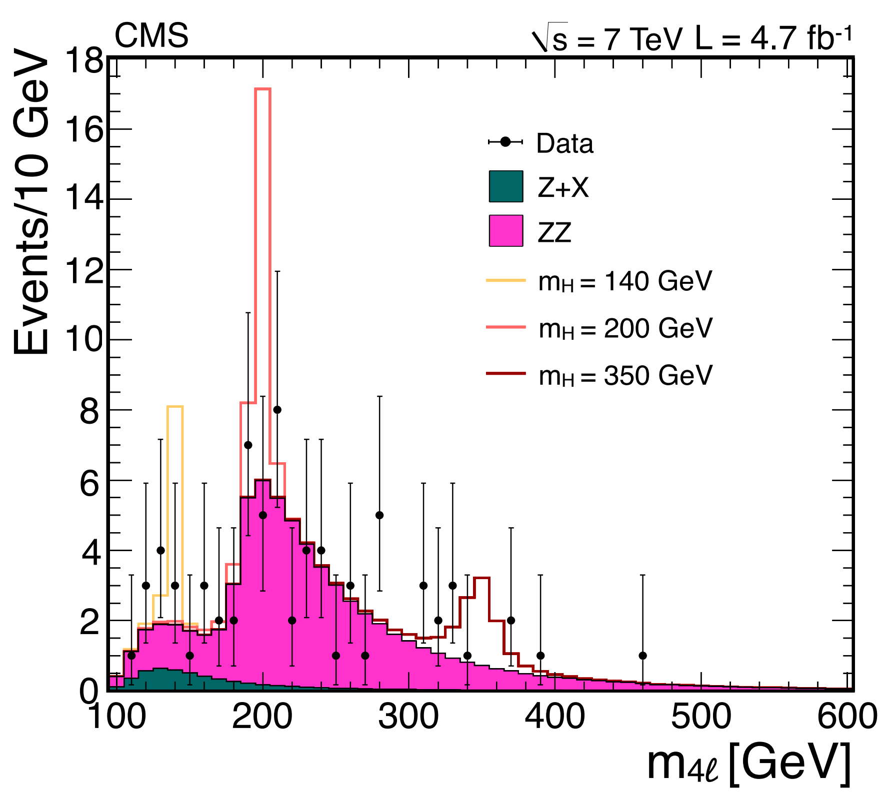
$H\rightarrow ZZ^{(*)}\rightarrow 4l$: CMS results

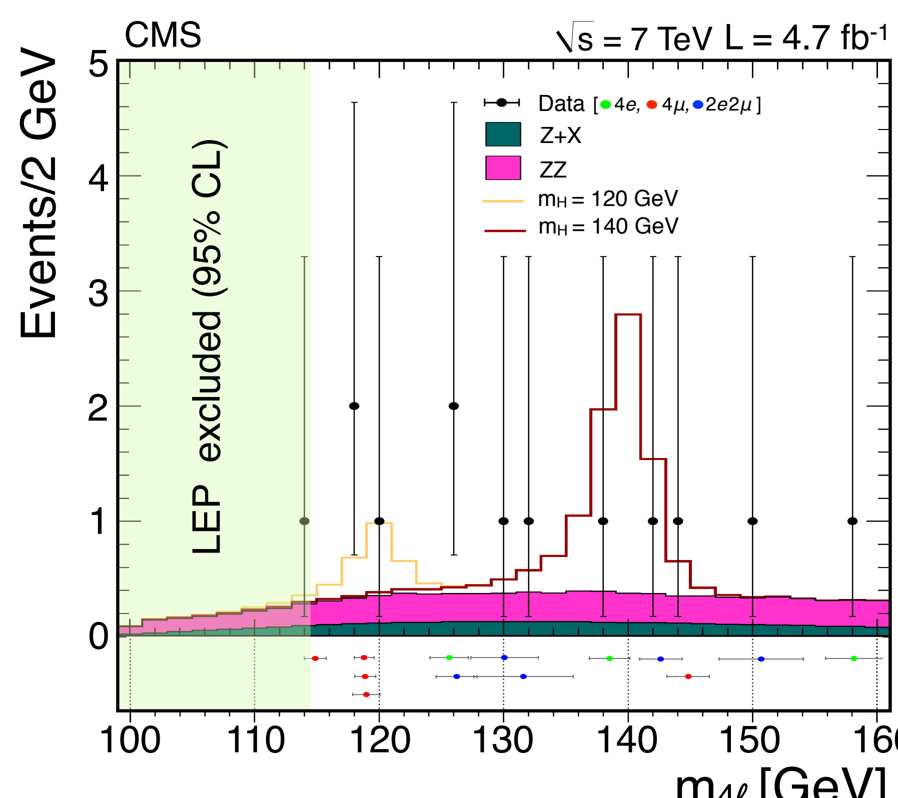




Full mass range

Data	Expected SM
72	67.1±6.0



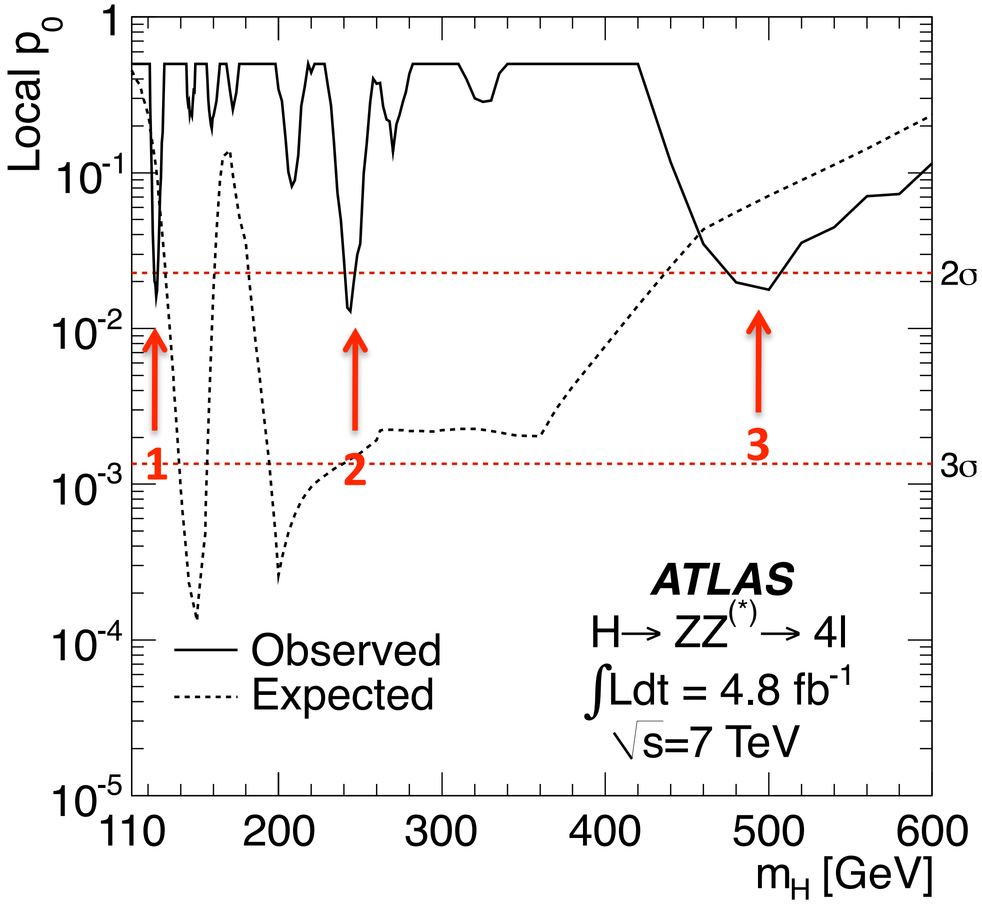


Low mass range

$100 < M_H < 160$ GeV

Data	Expected SM
13	9.5±1.3

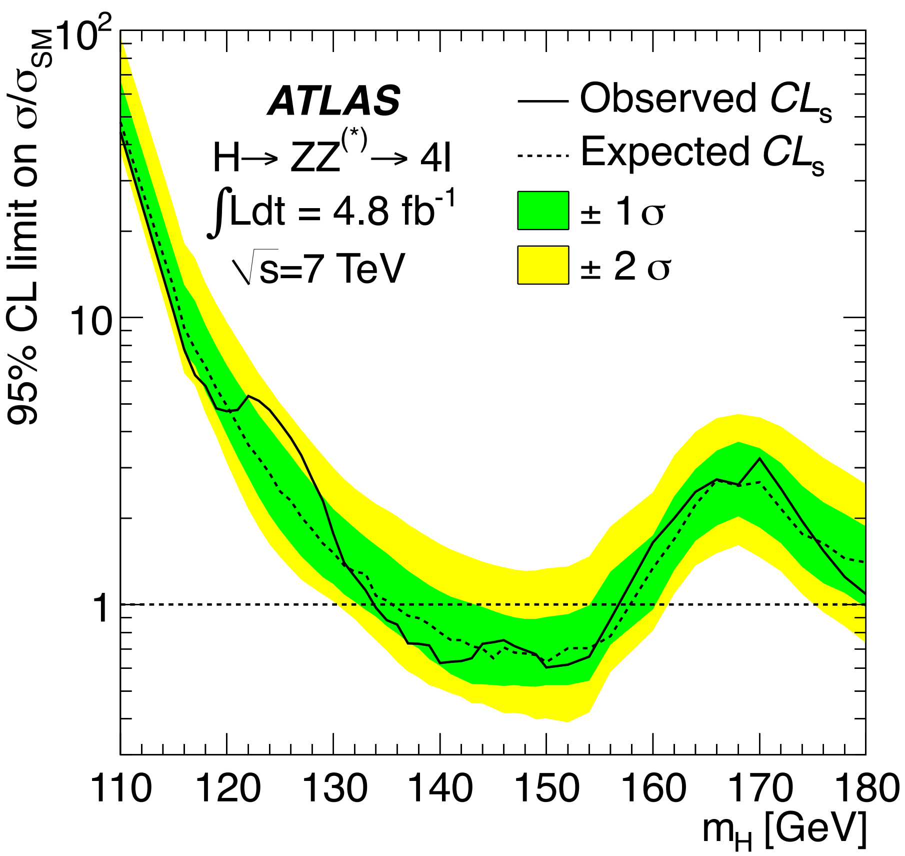
ATLAS results

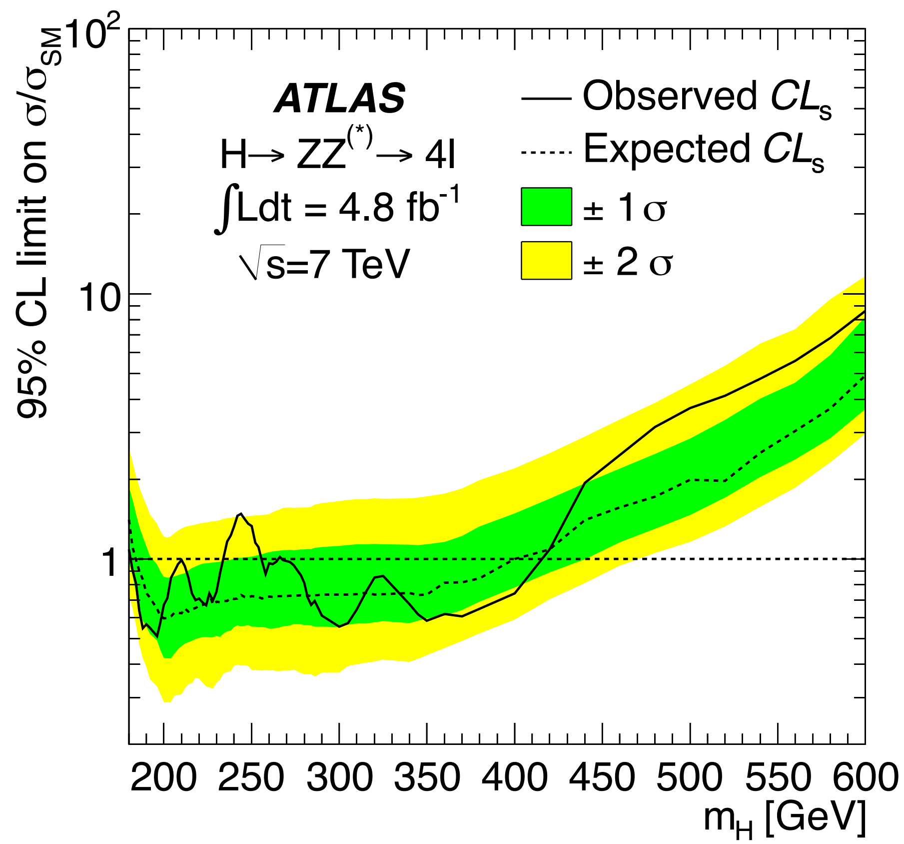


- Local p_0 : probability to have an experiment more signal-like than observed, when only background is expected

- Three main upward deviations:
1) 125 GeV: p_0 = 1.6% (2.1 σ, expected 1.3 σ)
2) 244 GeV: p_0 = 1.3% (2.2 σ, expected 3.0 σ)
3) 500 GeV: p_0 = 1.8% (2.1 σ, expected 1.5 σ)

- Taking into account the look-elsewhere-effect, the global p0 of each of these deviations becomes O(50%)
→ None of the observed local excesses is significant

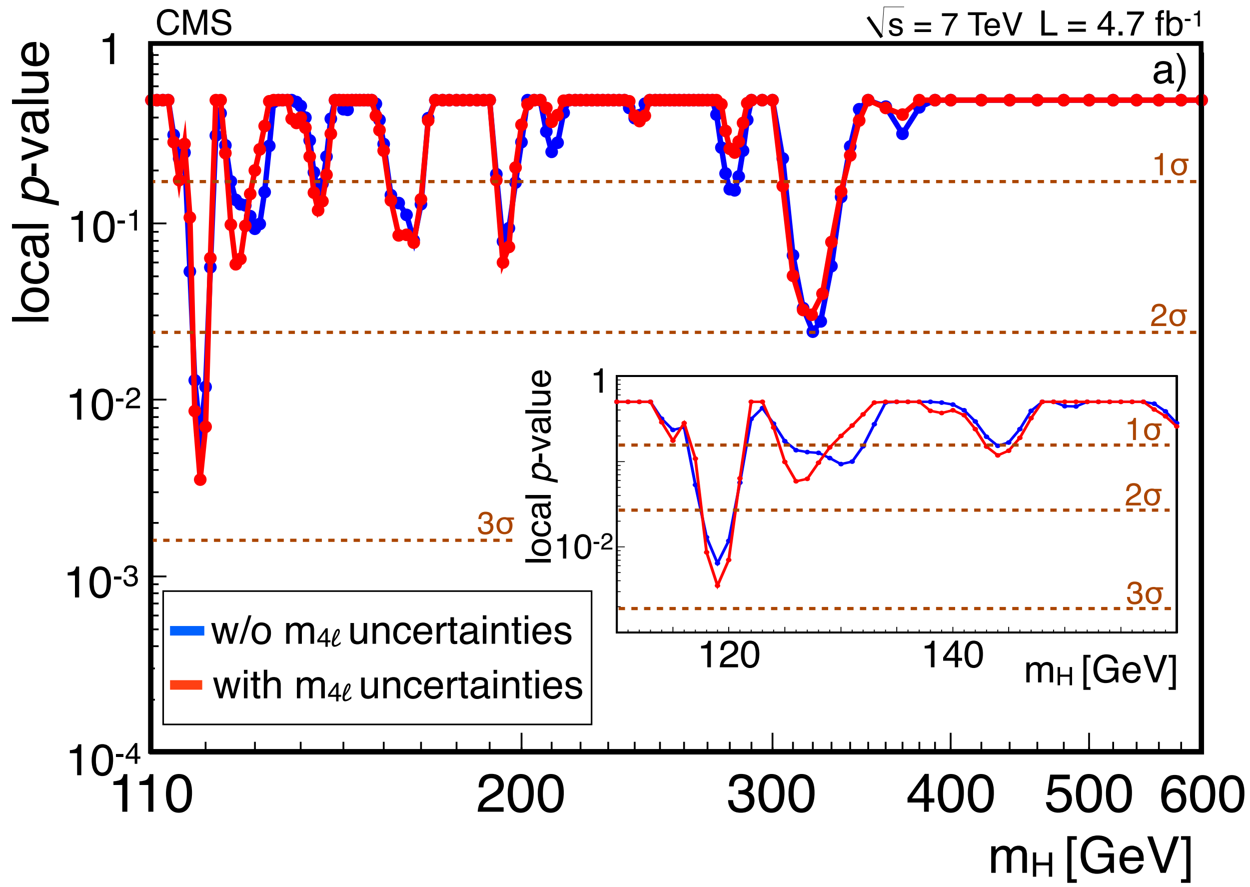


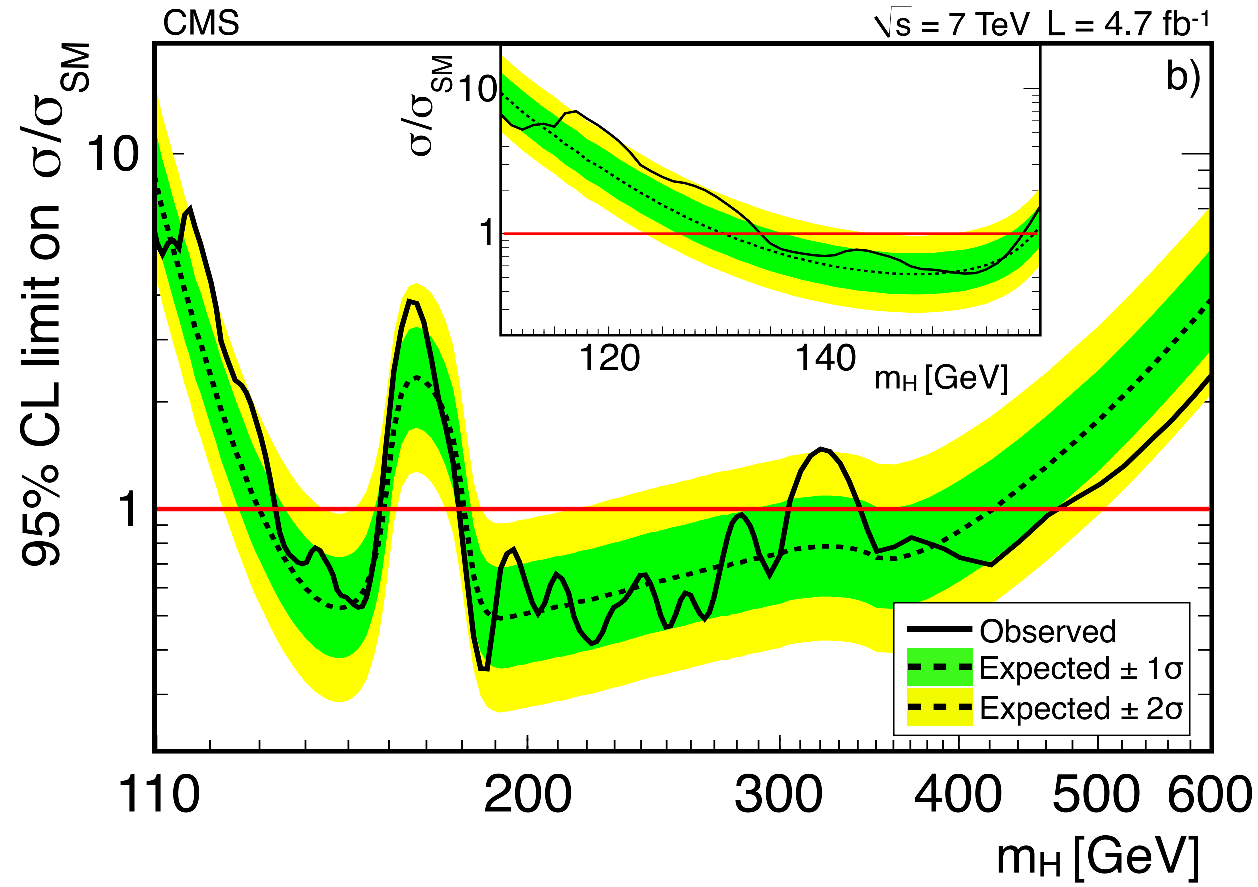


Excluded @95% CL:
134 < M_H < 156 GeV
182 < M_H < 415 GeV
except 233-256 GeV

Expected @95% CL:
136 < M_H < 157 GeV
184 < M_H < 400 GeV

CMS results





Most significant upward deviations are observed for masses near 119 GeV and 320 GeV, with significances respectively 2.5 σ and ~2.0 σ

The 119 GeV significance becomes 1.0 σ (1.6) when taking into account the look elsewhere effect over the whole mass range (or low-mass range)

Excluded @95% CL:

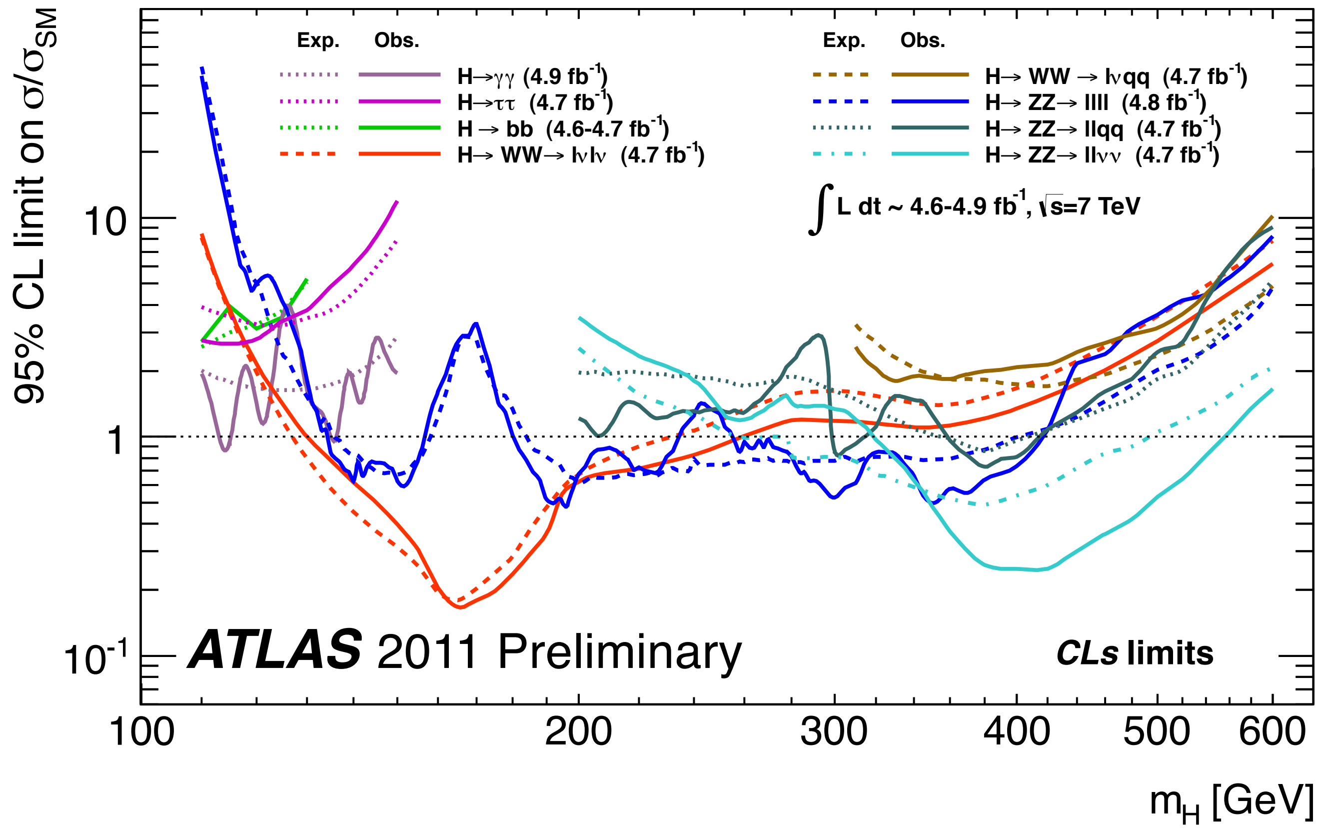
$134 < M_H < 158$ GeV

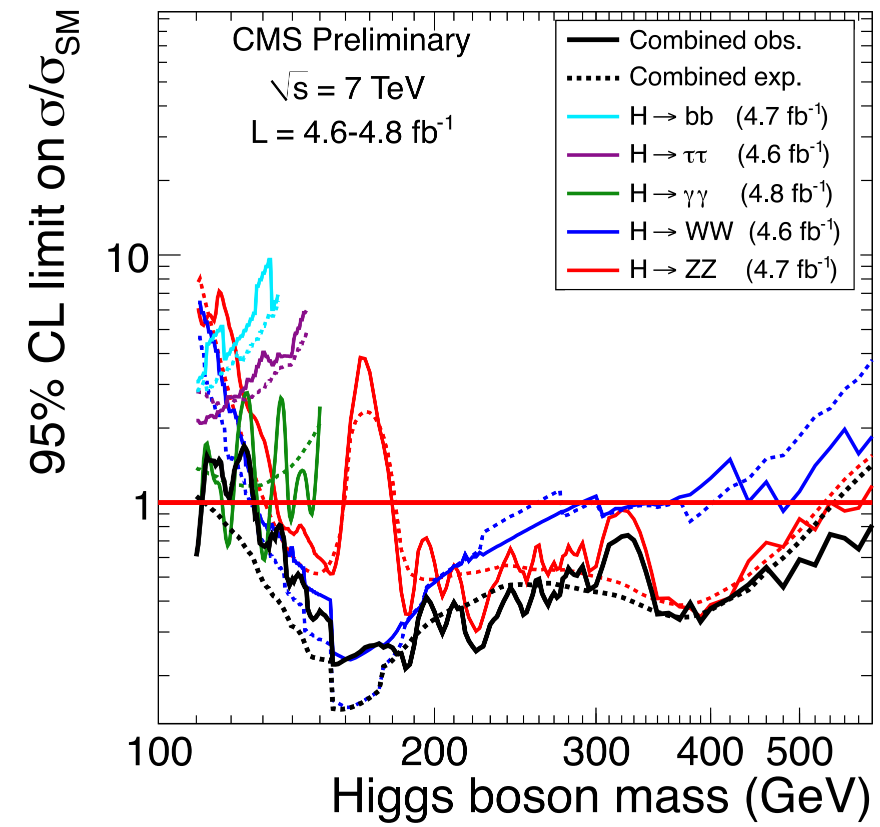
$180 < M_H < 305$ GeV

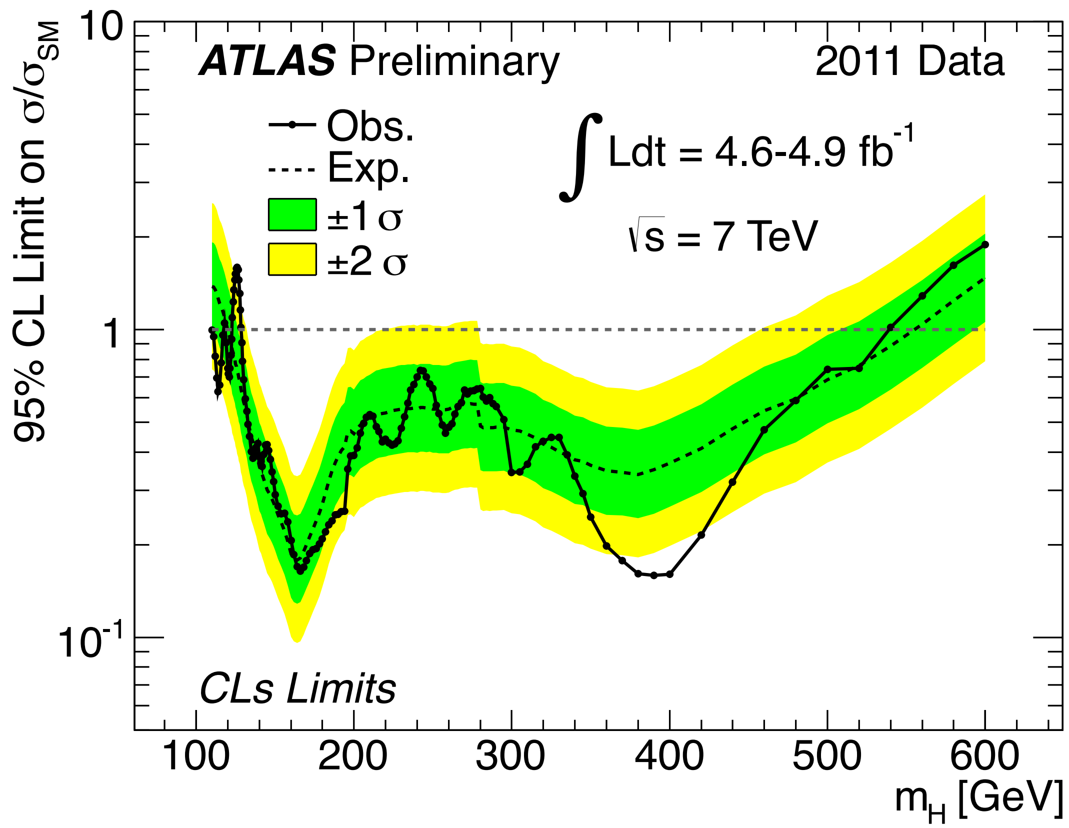
$340 < M_H < 465$ GeV

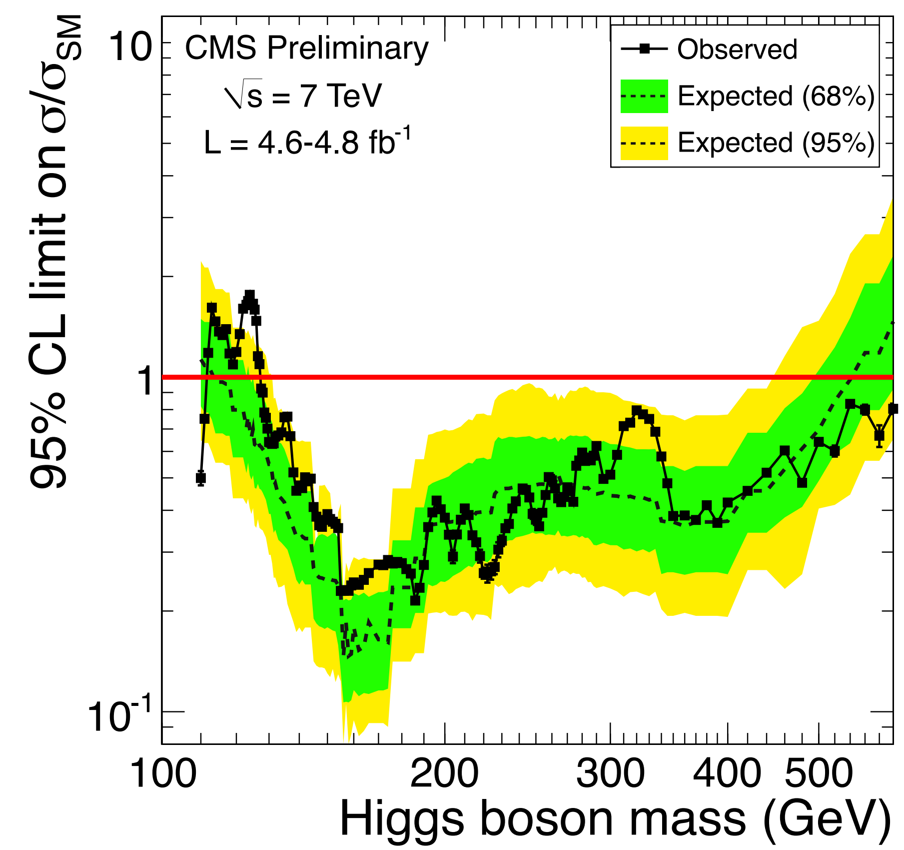
ZZ$^{(*)}$ and the other Higgs decay channels

More details on the combinations will be given in the last talk today









Conclusions

- 2011 has been a great year for LHC, that has performed in many cases beyond design parameters
- ATLAS and CMS detector performance in high pileup conditions has been understood and optimized
    - Performances very close to design in many areas !
- With ~4.8 fb^{-1} of good quality data collected by each experiment, ATLAS and CMS have studied in detail the search for a Brout/Englert/Higgs Boson(see Moriond 2012) in the $ZZ^{(*)}$ channel
- The $H\rightarrow ZZ^{(*)}$ channel alone, including the $ll\nu\nu$, llqq and llll signatures, allows to exclude a wide range of mass values, and has great relevance in the combination
    - No significant excess observed yet in this channel alone
- The range of allowed values for a Brout/Englert/Higgs Boson has become very narrow - see last talk today for each experiment combinations results -
- The 2012 run will give us the answer !