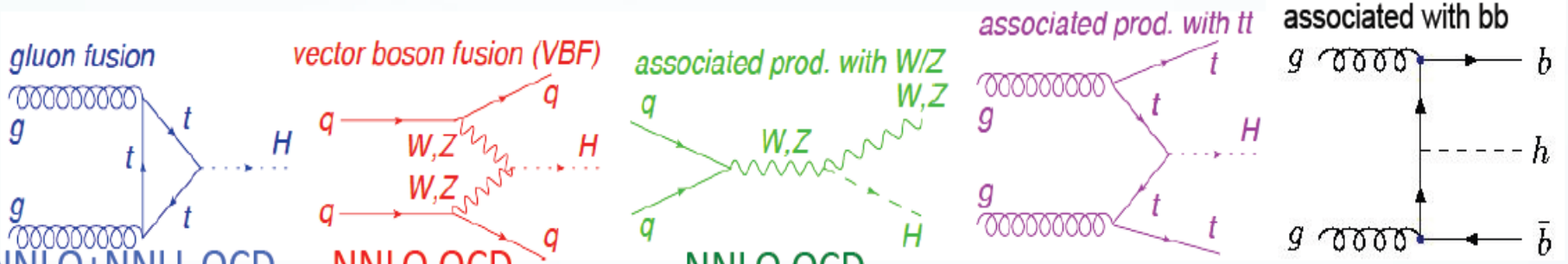
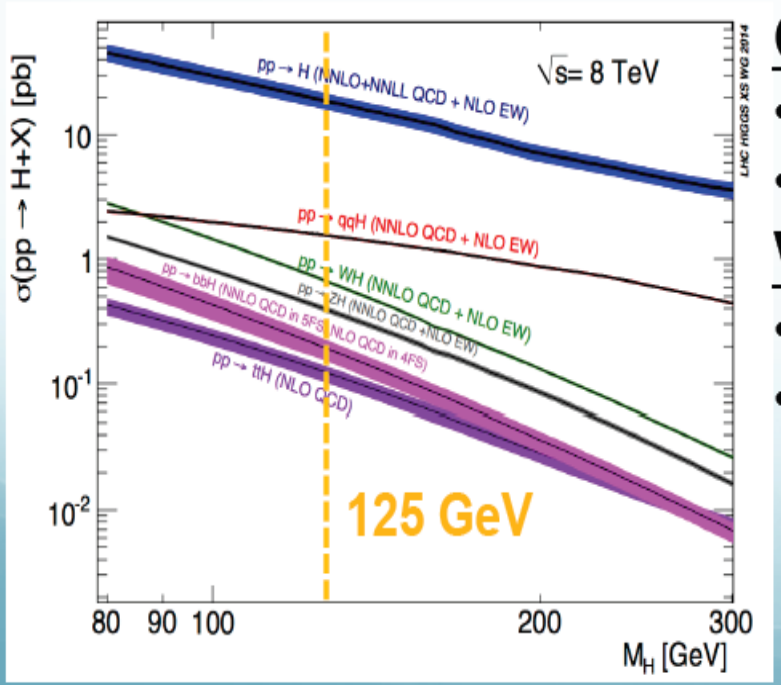
Higgs Production at LHC





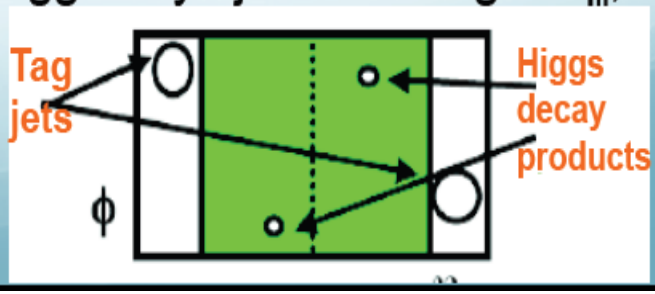
Gluon fusion process

- Largest cross section : 19.27pb at 125 GeV
- Large theory uncertainty : ~10%

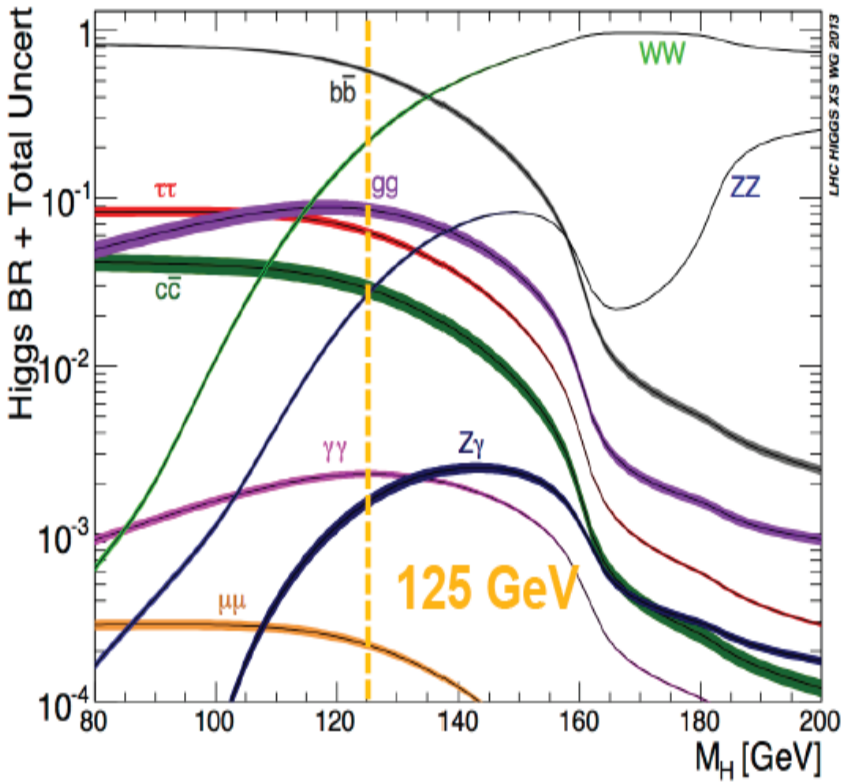
Vector boson fusion (VBF) process

- Second largest cross section : 1.58pb
- VBF topology : tagged by 2jets with large $\Delta\eta_{jj}, m_{jj}$

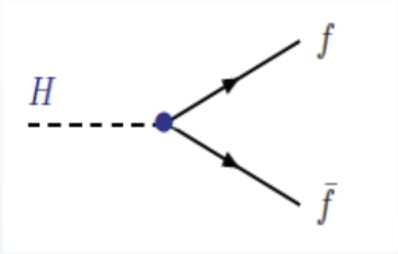
➔ Background suppression

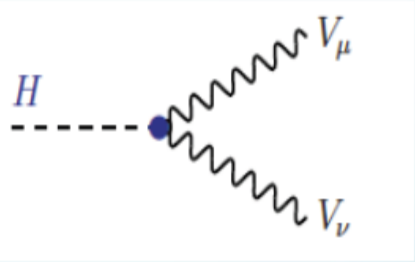


Higgs Decay Branching Ratio

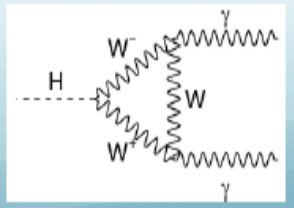


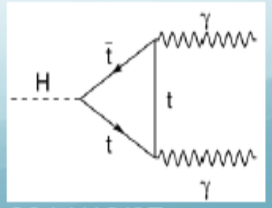
- 125 GeV is "ideal" for Higgs hunter!!
  ➔ Accessible to Higgs sector with various final states (crucial for Higgs property measurement)
- Fermion decay (bb, ττ, μμ)
- Boson decay (WW,ZZ)
- Loop diagram (γγ,Zγ)





Branching ratio at 125 GeV						
bb	WW	ττ	ZZ	γγ	Zγ	μμ
58%	22%	6.3%	2.6%	0.23%	0.15%	0.02%



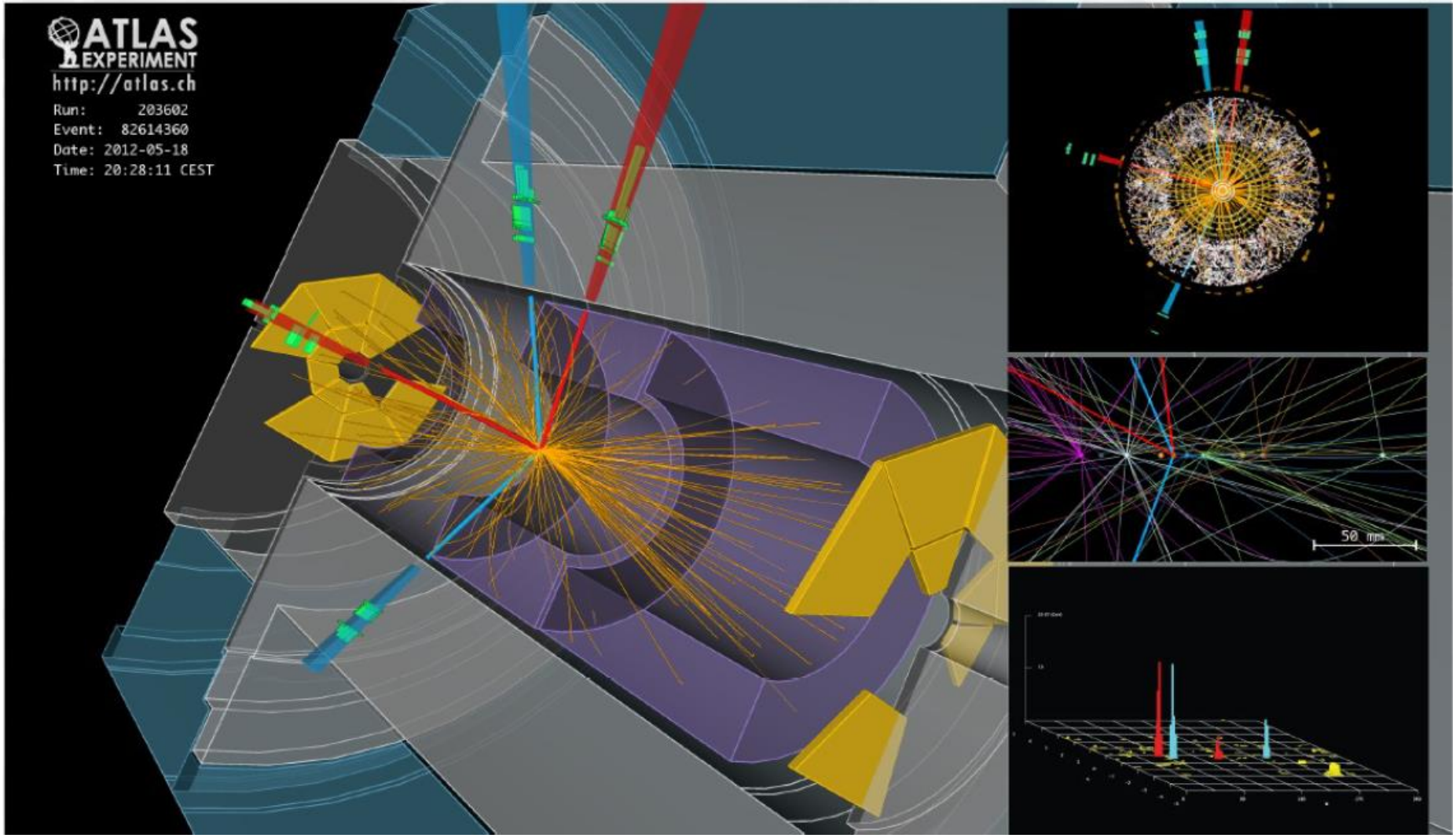


2014/10/07

$4e$ candidate. $m_{4\ell} = 124.6$ GeV, $m_{12} = 70.6$ GeV, $m_{34} = 44.7$ GeV.

e_1: $P_T = 24.9$ GeV, $\eta = -0.33$, $\phi = 1.98$ e_2: $P_T = 53.9$ GeV, $\eta = -0.40$, $\phi = 1.69$

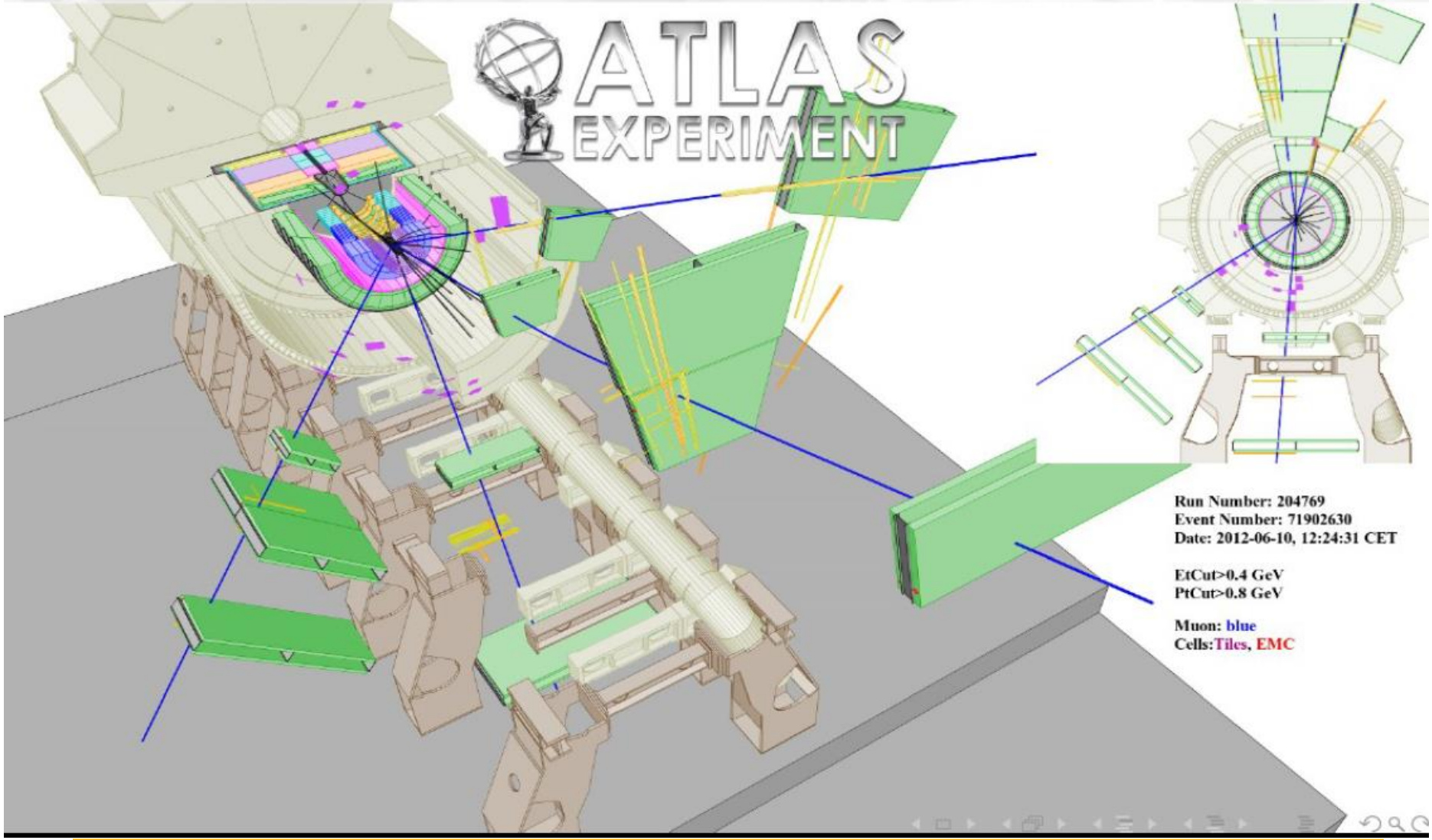
e_3: $P_T = 61.9$ GeV, $\eta = -0.12$, $\phi = 1.45$ e_4: $P_T = 17.8$ GeV, $\eta = -0.51$, $\phi = 2.84$



4μ candidate. $m_{4\ell} = 125.1$ GeV, $m_{12} = 86.3$ GeV, $m_{34} = 31.6$ GeV.

μ_1: $P_T = 36.1$ GeV, $\eta = 1.29$, $\phi = 1.33$ μ_2: $P_T = 47.5$ GeV, $\eta = 0.69$, $\phi = -1.65$

μ_3: $P_T = 26.4$ GeV, $\eta = 0.47$, $\phi = -2.51$ μ_4: $P_T = 71.7$ GeV, $\eta = 1.85$, $\phi = 1.65$

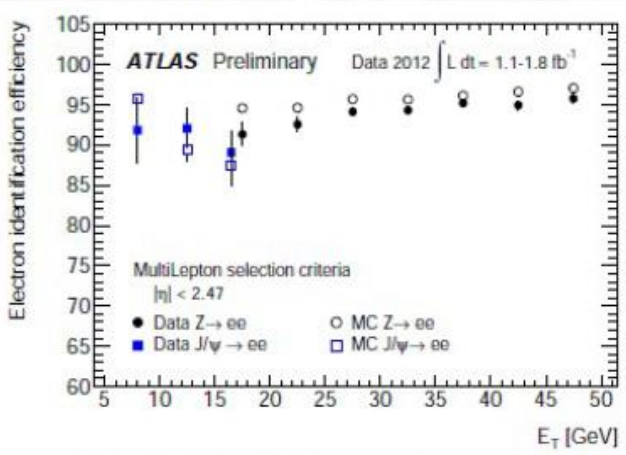


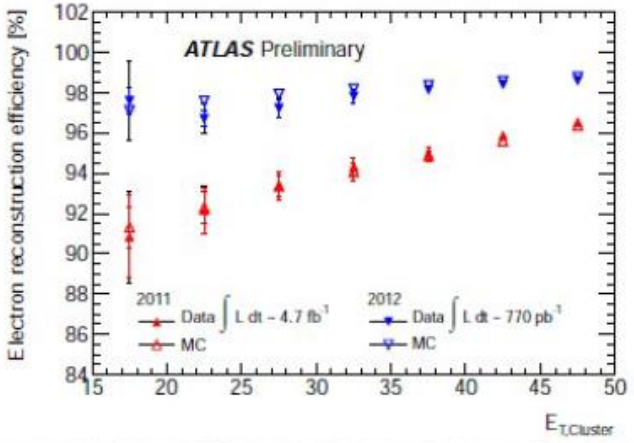
The golden channel

- 4-lepton (coming from Z decays: same-flavour, opposite charge) $\rightarrow$ very good resolution, high reconstruction and trigger efficiencies $\rightarrow$ mass peak can be reconstructed
- **Almost background free:** s/b between 0.9 ($4e$) and 1.6 4μ
- Very robust against systematic uncertainties
- Very small yield: signal cross section $\times$ branching ratio ($Z \rightarrow \ell\ell \sim 3\%$).
- Low P_T objects needed to maximise signal acceptance

Kinematic requirements:

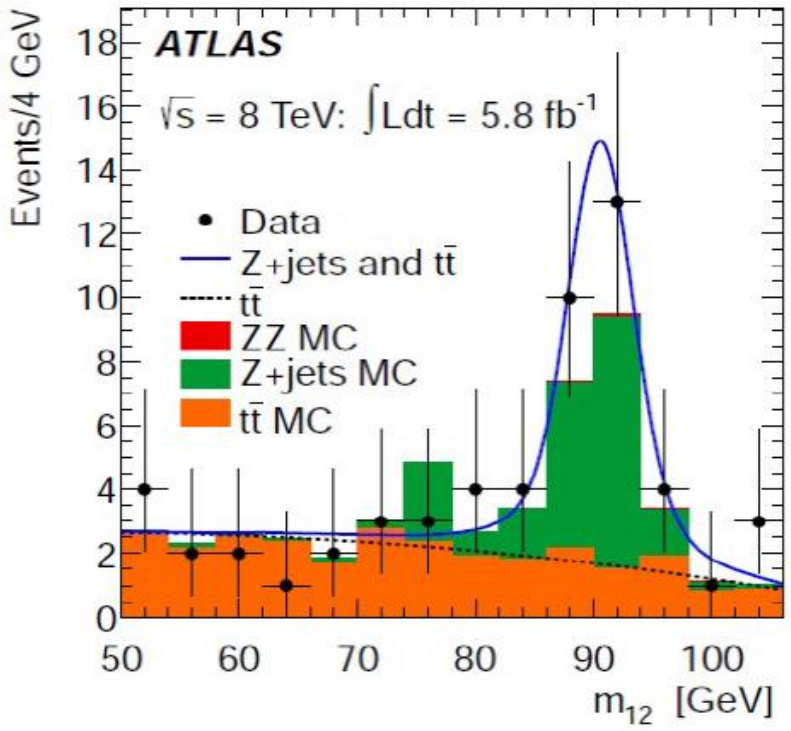
- Muons:
  $P_T > 6$ GeV,
  $|\eta| < 2.7$
- Electrons:
  $P_T > 7$ GeV,
  $|\eta| < 2.47$

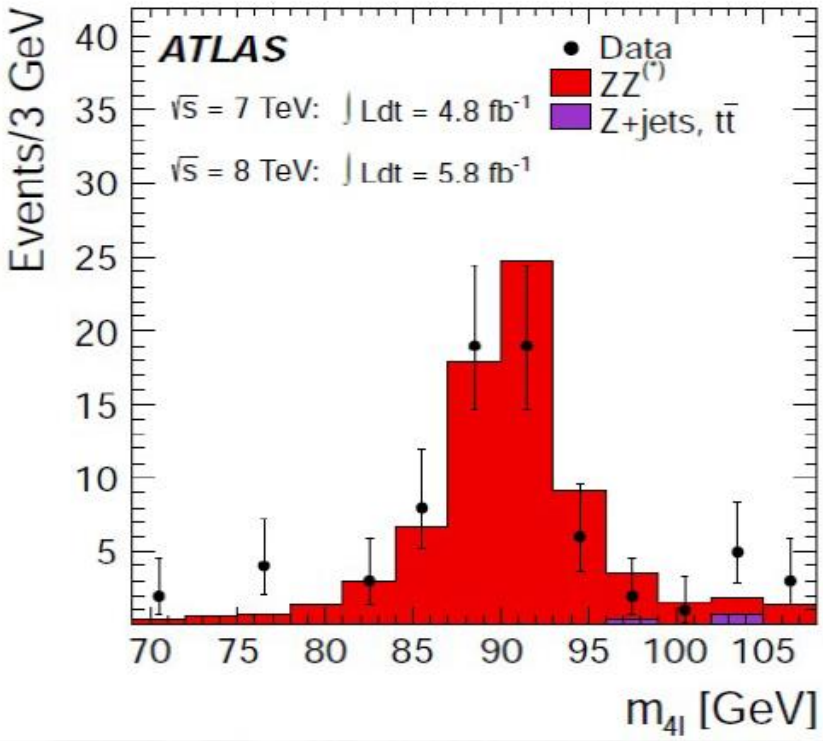




The golden channel

- Various control samples are used to measured contributions of reducible backgrounds (**Z+jets and $t\bar{t}$**), depending on the flavour of the sub-leading pair.
- Irreducible background (**ZZ**), constraint by fit on the full $m_{4\ell}$ range.
  Cross checked by the single-resonant production peak.

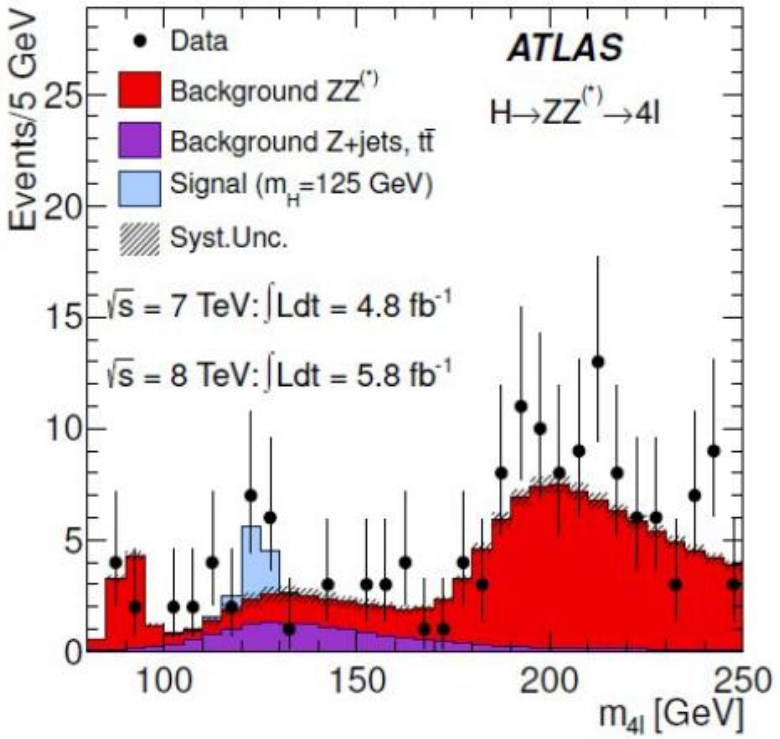


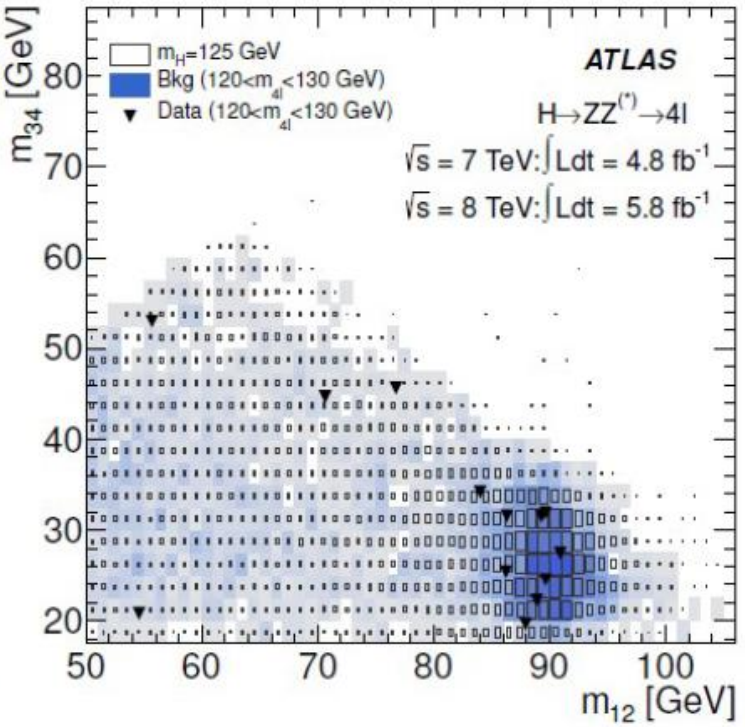


Inverted d_0 requirement for one of the two subleading leptons

Relaxed kinematic cuts

Final expected and observed yields

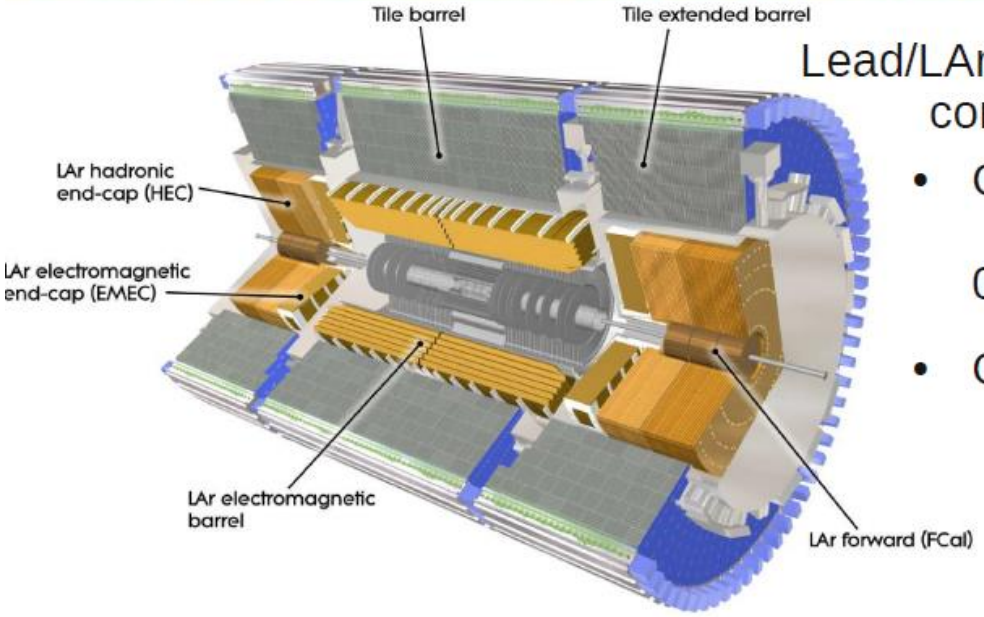




In a $m_{4\ell}$ window around 120-130 GeV:

	Signal	$ZZ^{(*)}$	$Z+\text{jets}, t\bar{t}$	Observed
4μ	2.09±0.30	1.12±0.05	0.13±0.04	6
$2e2\mu/2\mu2e$	2.29± 0.33	0.80±0.05	1.27±0.19	5
$4e$	0.90±0.14	0.44±0.04	1.09±0.20	2

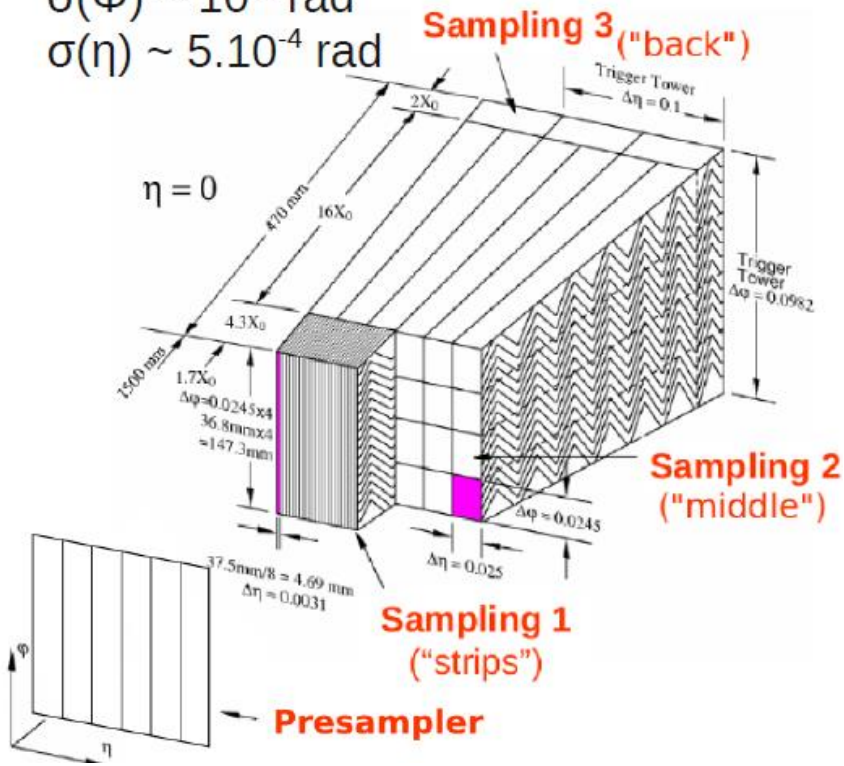
The ATLAS electromagnetic calorimeter



Lead/LAr EM calorimeter divided in 3 longitudinal compartments + Pre-sampler in front

- Good energy resolution :
  $\sigma(E)/E = a/E \oplus b/\sqrt{E} \oplus c$ (with a ~ 0.3 GeV, b ~ 10%, c ~ 0.7%)
- Good angular resolution :
  $\sigma(\Phi) \sim 10^{-3}$ rad
  $\sigma(\eta) \sim 5.10^{-4}$ rad

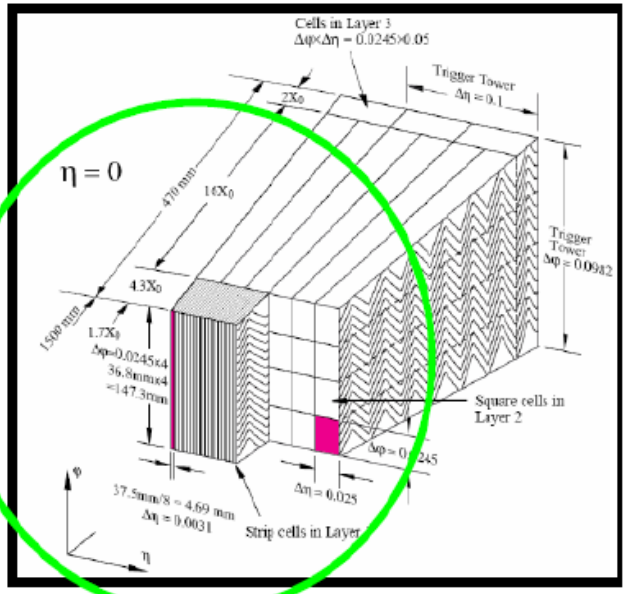
Layer	Granularity $\Delta\eta \times \Delta\varphi$	Radiation length
Pre-sampler	0.025 x 0.1	
Strips	0.003 x 0.1	4.3 X_0
Middle	0.025 x 0.025	16 X_0
Back	0.05 x 0.025	2 X_0

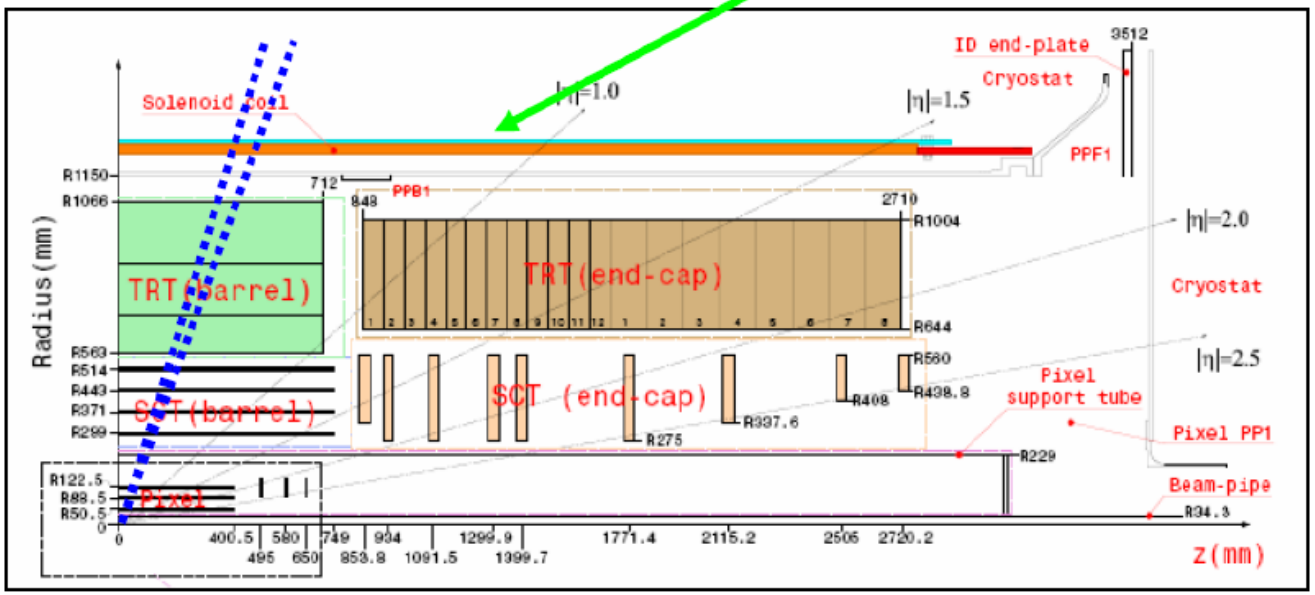


This will be very useful to reject the background from π^0

opening of photons coming from a π^0 (p_T=40 GeV)

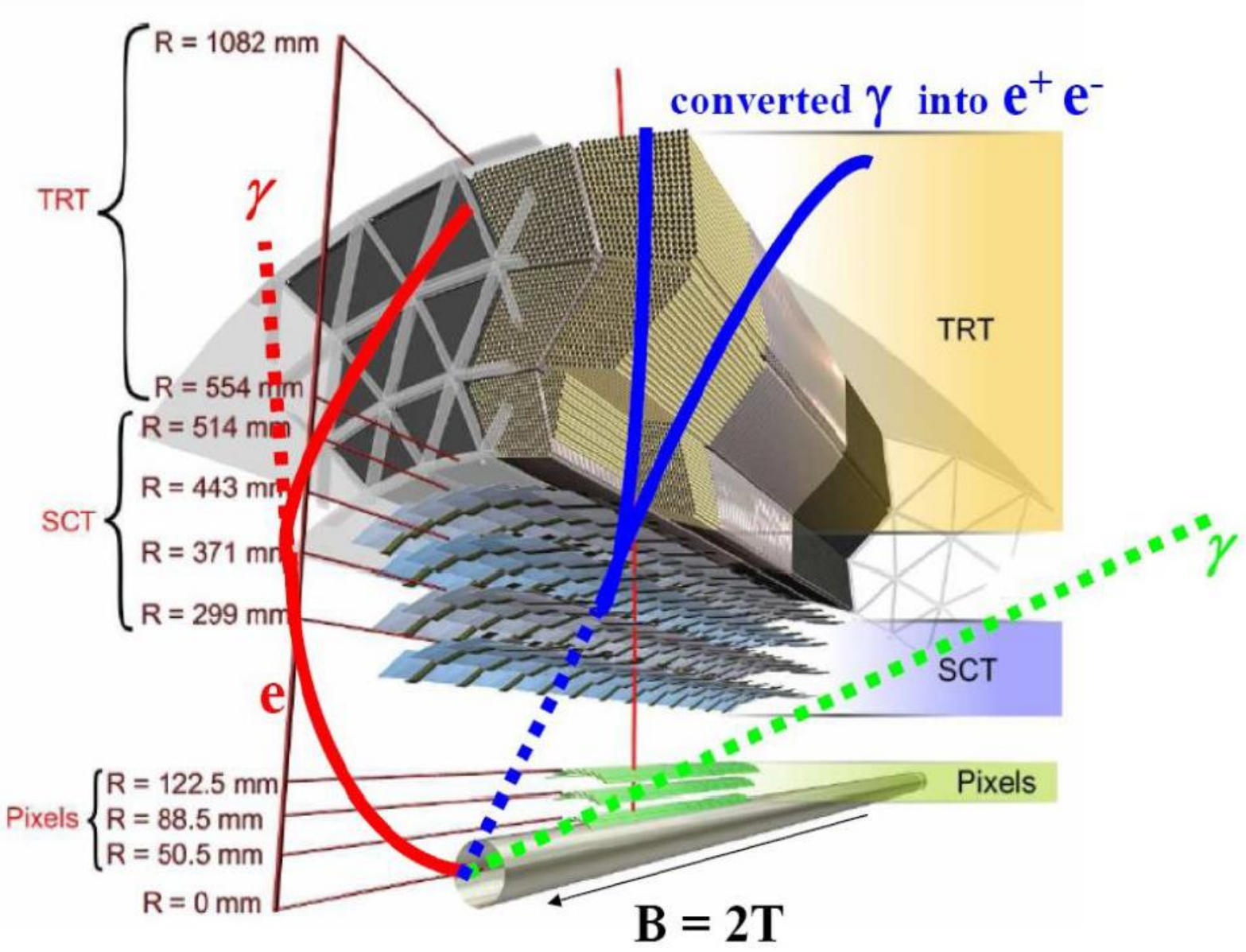
$\Delta R > .007$





granularity of 1st sampling of calorimeter

$\Delta\eta \sim .003$


converted γ into e+ e-
R = 1082 mm
TRT
γ
R = 554 mm
R = 514 mm
R = 443 mm
SCT
R = 371 mm
R = 299 mm
e
R = 122.5 mm
Pixels
R = 88.5 mm
R = 50.5 mm
R = 0 mm
TRT
SCT
Pixels
γ
B = 2T

$H \rightarrow ZZ^{(*)} \rightarrow 4l$ (l=e,μ) : Overview

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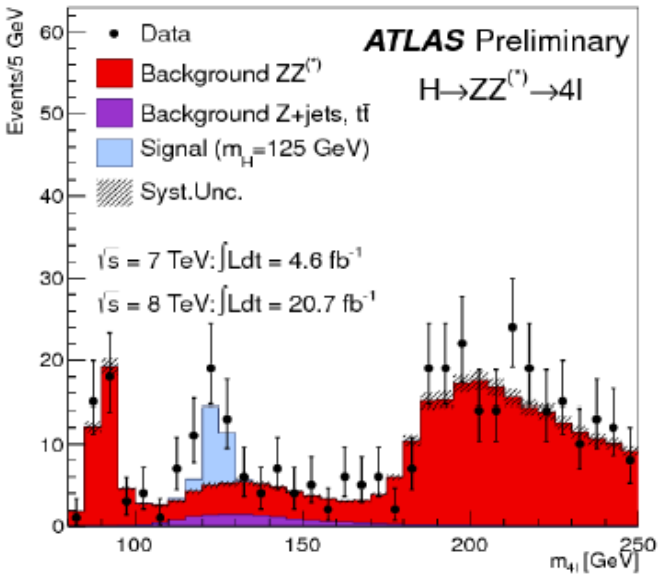
The golden channel, with small cross-section but very good S/B ratio and fully-reconstructed mass

Signal reconstruction

- Maximise acceptance → high reco/ID efficiency down to low-p_T 6/7 GeV μ/e [ε_{event}~40/20% 4μ/4e]
- FSR γ candidate (E_T>1 GeV) added if $66<M_{12}^{\mu\mu}{}_{[GeV]}<89$ - ~4% of events
- Mass resolution 1.3/1.9% for 4μ/4e @125 GeV using Z-mass constraint on leading lepton pair



Two pairs of opposite-sign same-flavor isolated leptons

Background control

- Irreducible background: continuum $ZZ^{(*)}$ (from MC)
- Reducible bknd @ low mass: Z+bb/jets, ttbar

►reduced using isolation and impact parameter cuts

►measured using various background-enriched control regions in data & transfer factors from MC (+checks)

[Improved selection w.r.t last results: lepton pairing, tighter electron ID, relaxed m_{34} cut]

➔ In region 125±5 GeV: 32 events observed [11.1±1.3 expected from bknd & 15.9±2.1 from SM Higgs]

In region m_{4l}>160 GeV: 376 events observed, 348±26 expected from bknd (mainly ZZ)

Lepton energy scale & linearity and identification efficiencies (+ systematics) measured on data down to low p_T

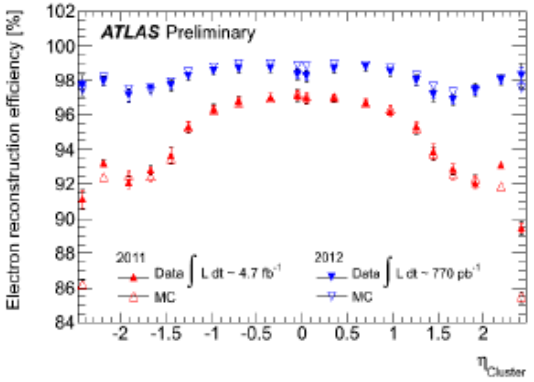
H→ZZ(*)→4l (l=e,μ) : Overview

ATLAS-CONF-2013-013

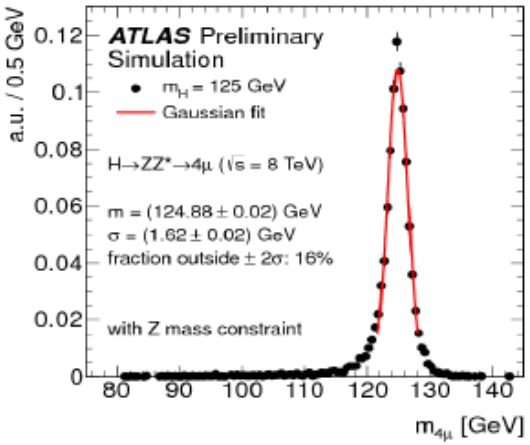
The golden channel, with small cross-section but very good S/B ratio and fully-reconstructed mass

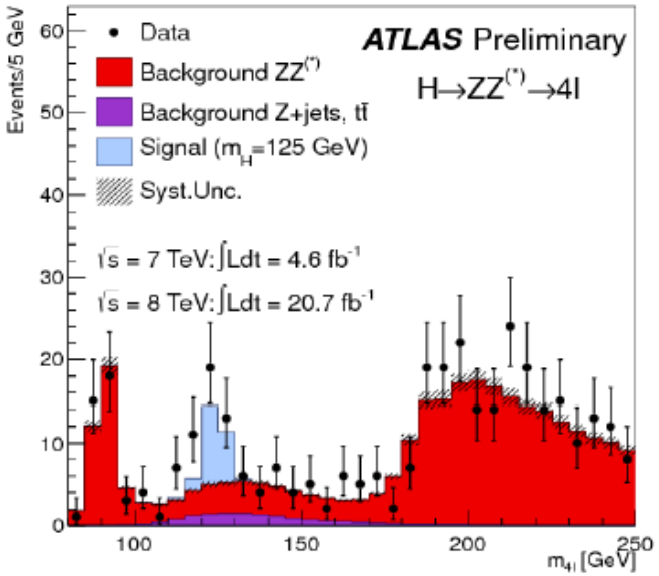
Signal reconstruction

Electron reco ε measured with Z→ee



Mass resolution in 4-μ channel

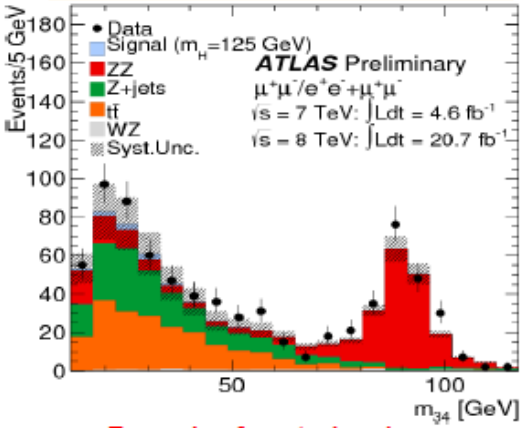




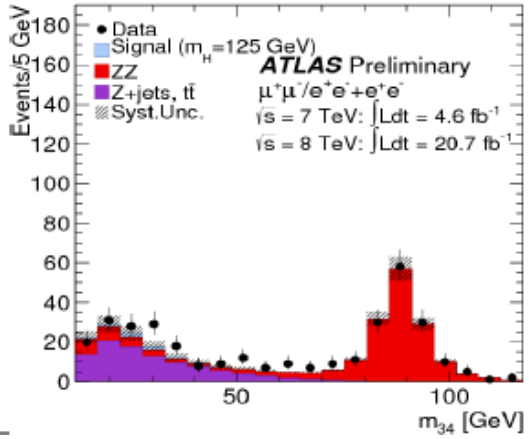
Two pairs of opposite-sign same-flavor isolated leptons

➔ In region 125±5 GeV: 32 events observed [11.1±1.3 expected from bknd & 15.9±2.1 from SM Higgs]

Background control

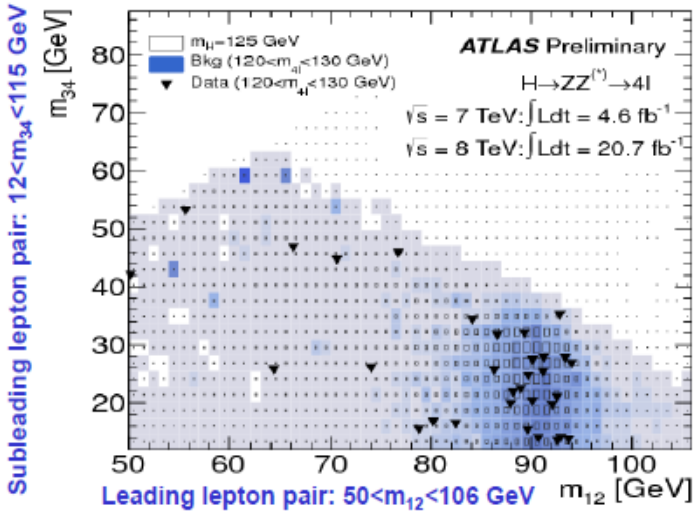


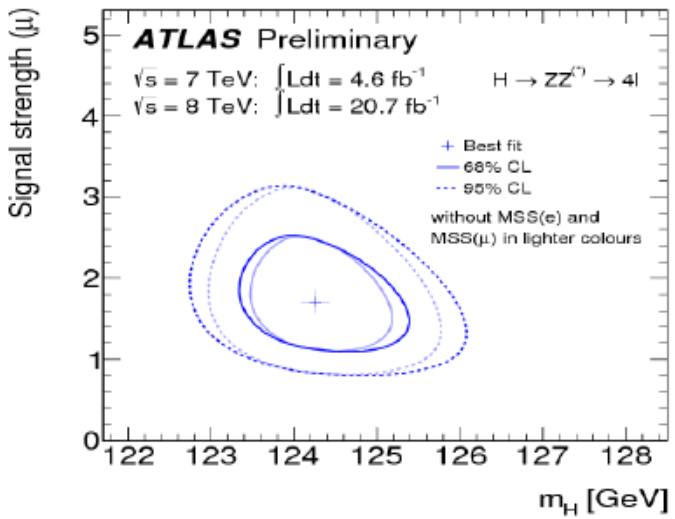
Example of control regions: no isolation nor IP cuts on softest leptons

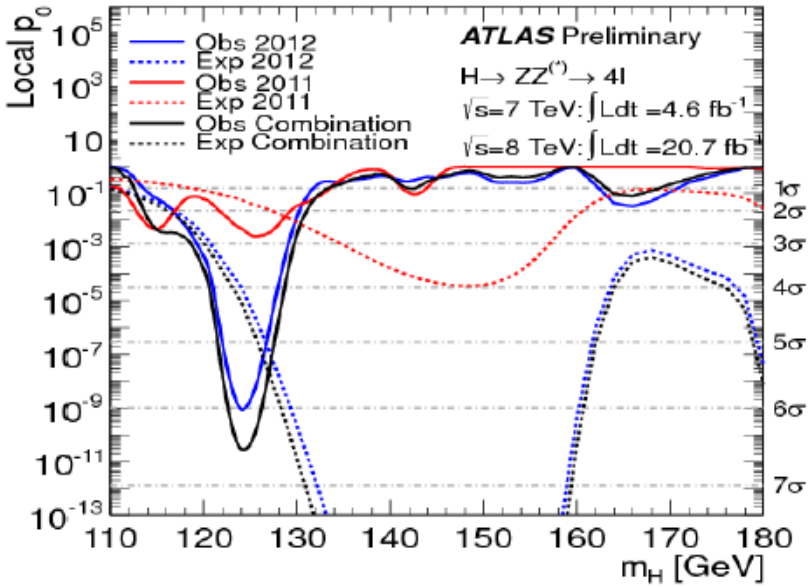


H→ZZ(*)→4l (l=e,μ) : Results

ATLAS-CONF-2013-013



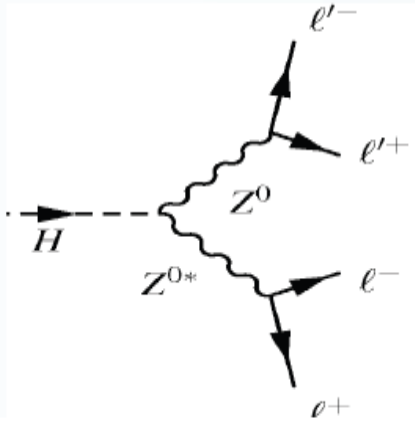




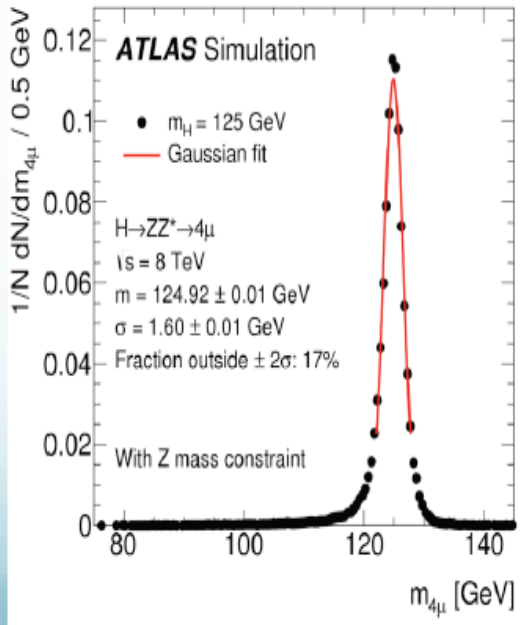
- Observed local significance of the excess: **6.6σ**
  (4.4σ expected for SM Higgs)
- Best mass fit **124.3** $^{+0.6}_{-0.5}$ **(stat)** $^{+0.5}_{-0.3}$ **(syst) GeV**
  [measurement dominated by 4**μ** – 0.2% systematics from p_T-scale]
- Signal strength @ this mass: **μ=1.7** $^{+0.5}_{-0.4}$
  [@ 125.5 GeV: **μ** =1.5 ± 0.4]

H→ ZZ→4l Analysis Overview

- Excellent S/B due to 4lepton (4e,4μ, 2e2μ) final state, but small rate
  - ➔Important to obtain high detection efficiency for leptons
  - ➔$p_T^{1,2,3,4}$>20,15,10,(7 for electron, 6 for muon) GeV
  - ➔Likelihood-base electron ID (reject fake bkg by factor 2)

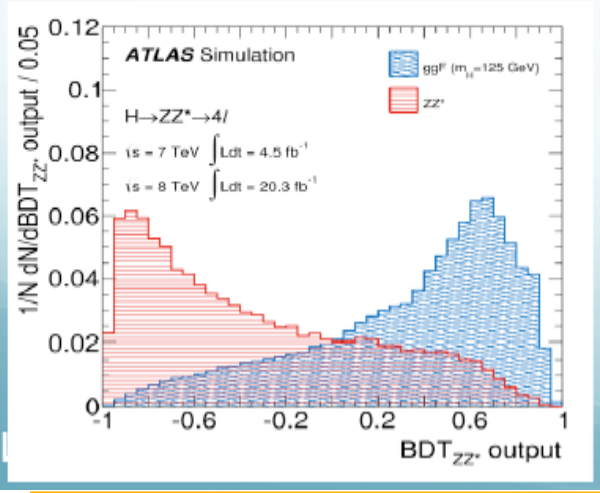


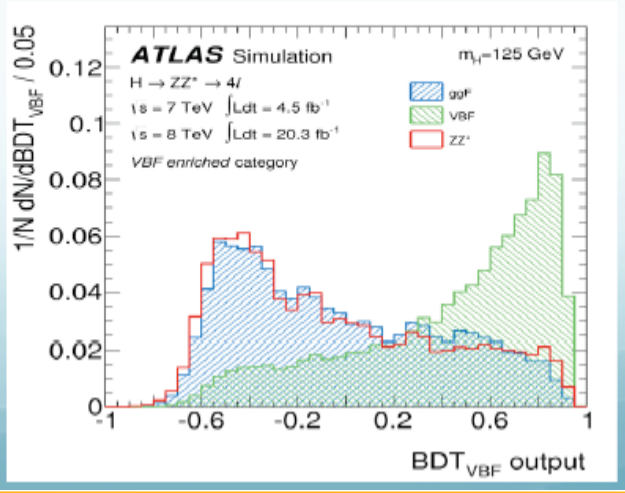
- 50 < m_{12} < 106 GeV, 12 < m_{34} < 115 GeV
  - Recover FSR photon from muon
  - Z-mass constraint for m_{12} (improve m_{4l} resolution ~15%)
  - ➔$\sigma(m_{4l})$ ~ 1.60 GeV for 4μ, 2.18 GeV for 4e
- Dominant background :
  - ZZ : MC simulation
  - Z+jets, ttbar (fake lepton) : Data-driven method

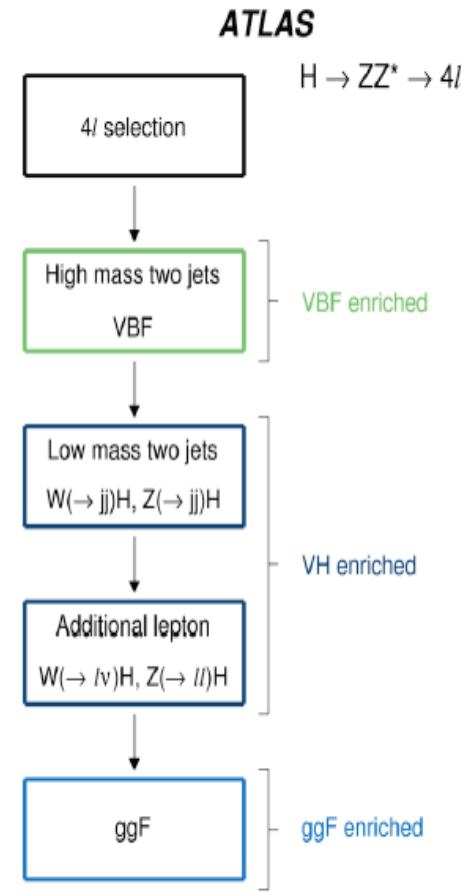


H→ZZ→4l Analysis Overview

- Event categorization
  - VBF enriched category : At least 2 jets, m_{jj} > 130 GeV
  - VH hadronic category : 40 < m_{jj} < 130 GeV
  - VH leptonic category : Additional 1 lepton (p_T > 8 GeV)
- MVA discrimination (BDT)
  - signal vs ZZ bkg (p_T^{4l}, η^{4l}, Matrix element discriminant D_{ZZ^*})
  - ggF vs VBF signal (m_{jj}, $\Delta\eta_{jj}$, jet p_T, jet η)



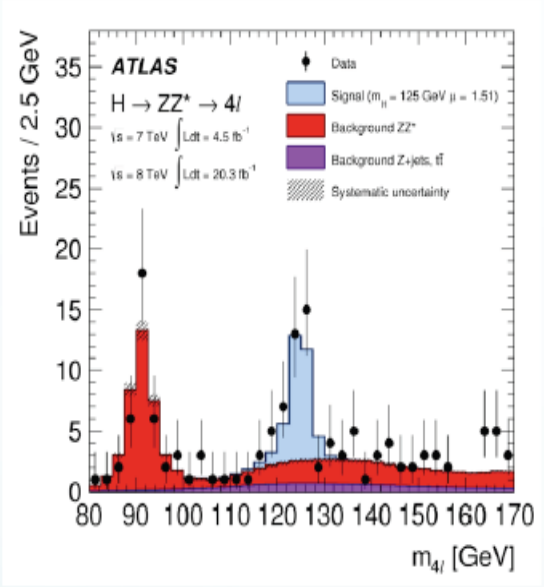


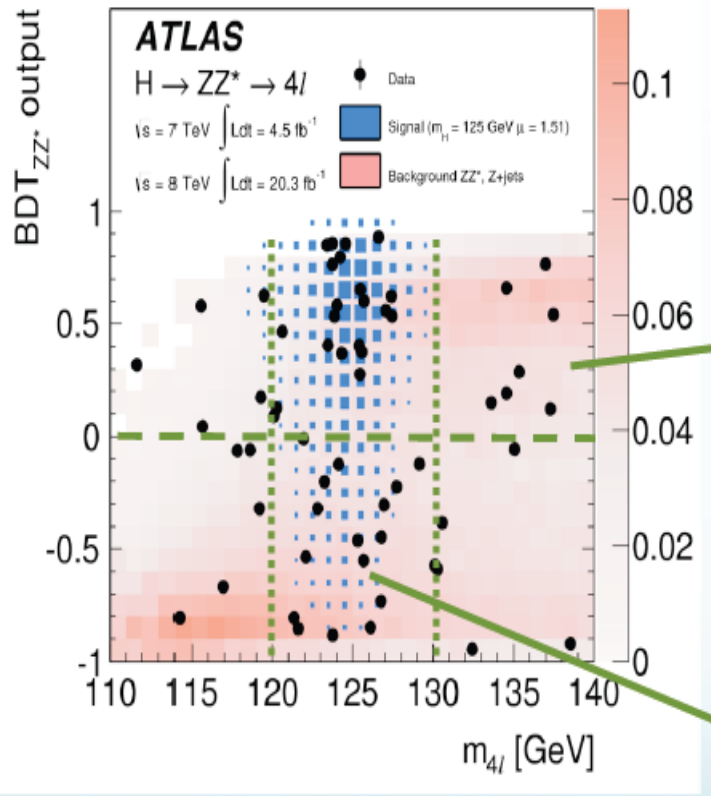


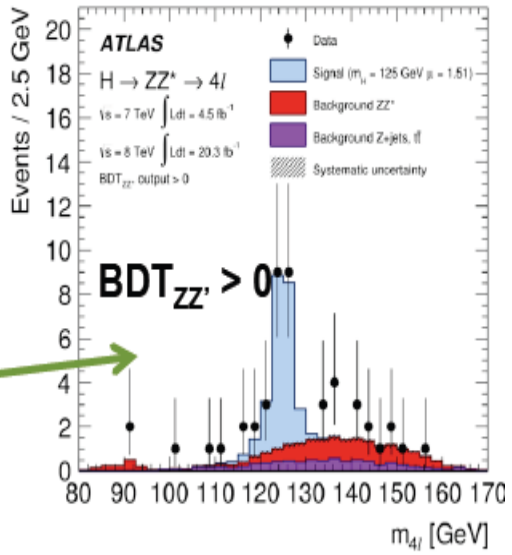
H→ZZ→4l Results

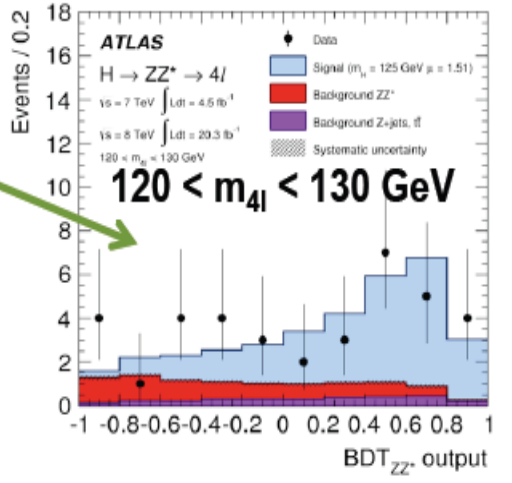
New

- Inclusive analysis (m_{4l} vs BDT_{ZZ} 2D fitting)









Observed significance at 125.36 GeV
8.1σ(Exp. 6.2σ)

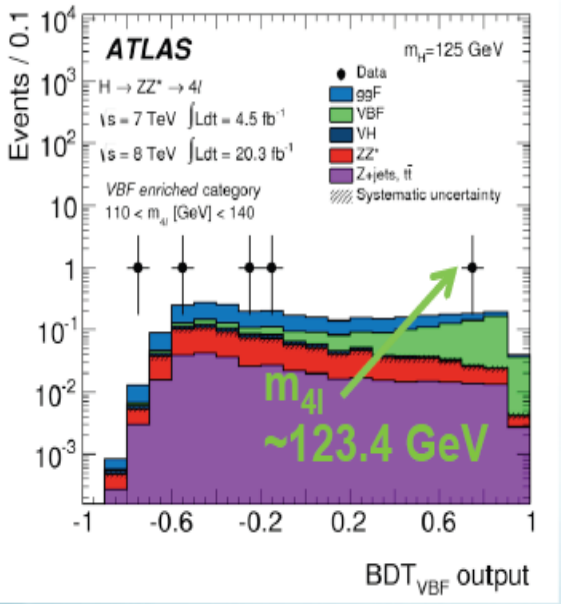
20% improvement from previous analysis (BDT and new electron ID)

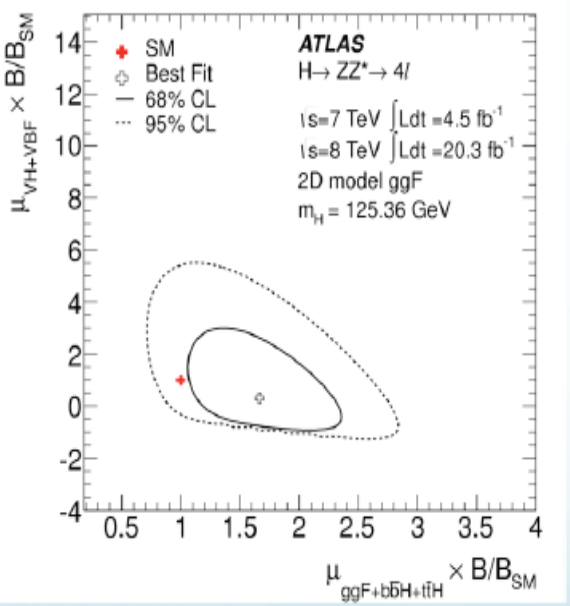
H→ZZ→4l Results

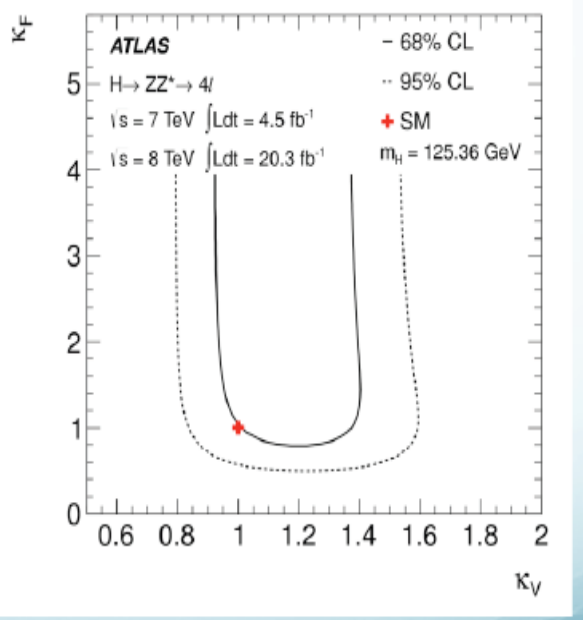
New

- Coupling results using categorization
  - Combined $\mu = 1.44^{+0.34}_{-0.31}(\text{stat})^{+0.21}_{-0.11}(\text{sys}) = 1.44^{+0.44}_{-0.33}$
  - BDT_{VBF} to extract VBF signal (BDT_{VBF} vs m_{4l} fitting)

Compatibility with SM ~30%







Purity in BDT_{VBF} ~0.7

60% VBF, 25% ggF

$\mu_{ggF+bbH+ttH} = 1.66^{+0.45}_{-0.41}(\text{stat})^{+0.25}_{-0.15}(\text{sys})$

$\mu_{VBF+VH} = 0.26^{+1.60}_{-0.91}(\text{stat})^{+0.36}_{-0.23}(\text{sys})$