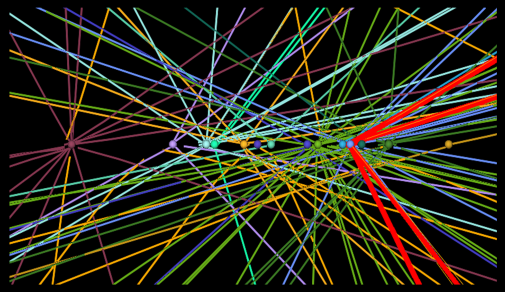


New measurements of x-sections and width of H→ZZ$^{(*)}$ in ATLAS

Gabriella Sciolla

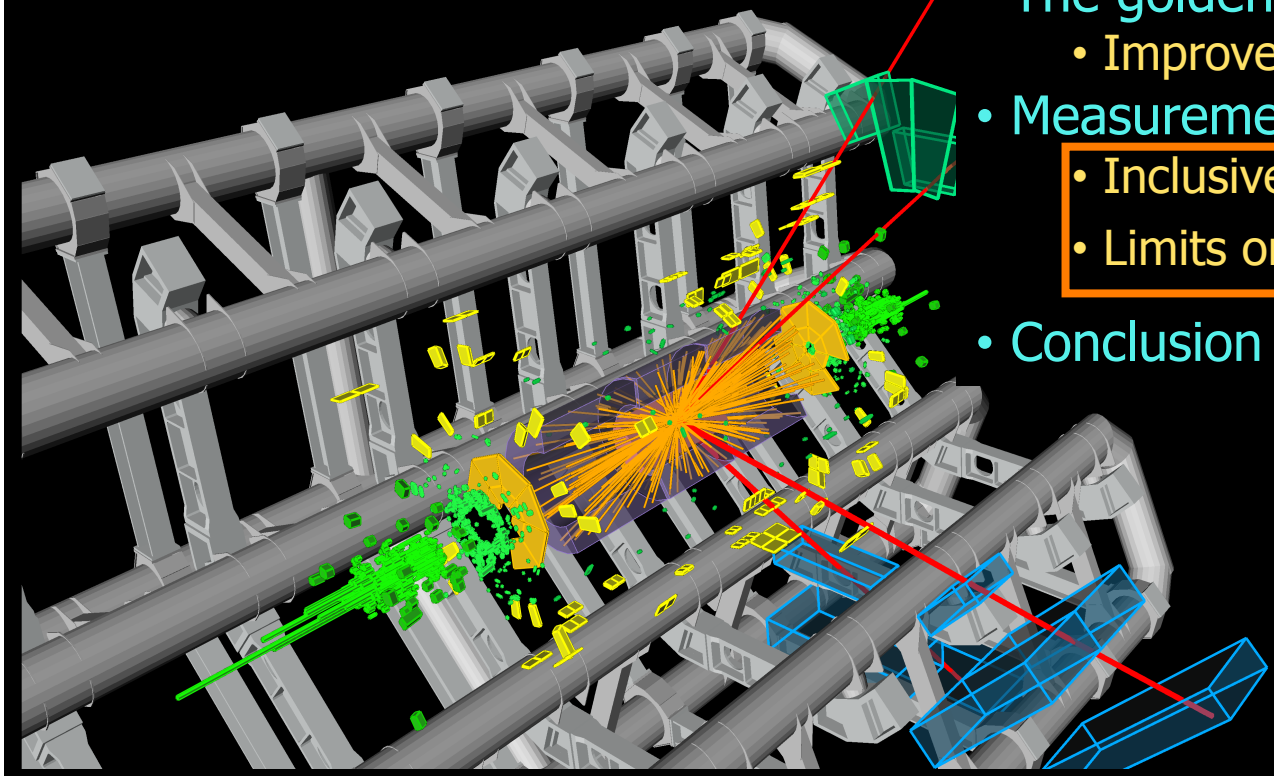
Brandeis University

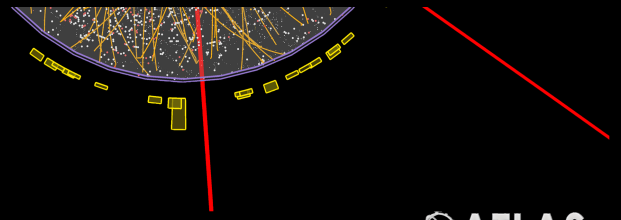
On behalf of the ATLAS Collaboration

Outline

- The golden channel: H→ZZ→4l
  - Improved reconstruction strategy
- Measurements of Higgs properties
  - Inclusive & differential cross section
  - Limits on Γ_H from off-shell production
- Conclusion

New



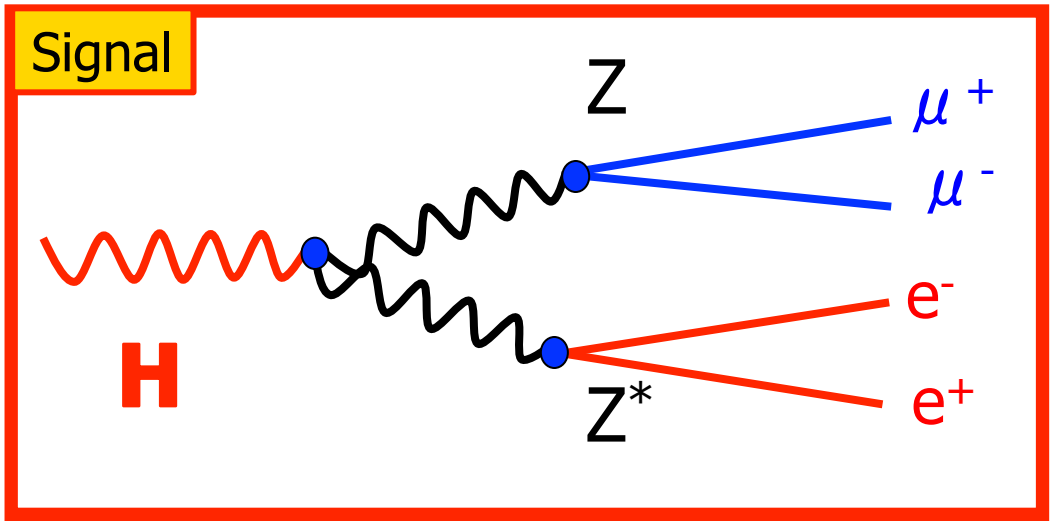


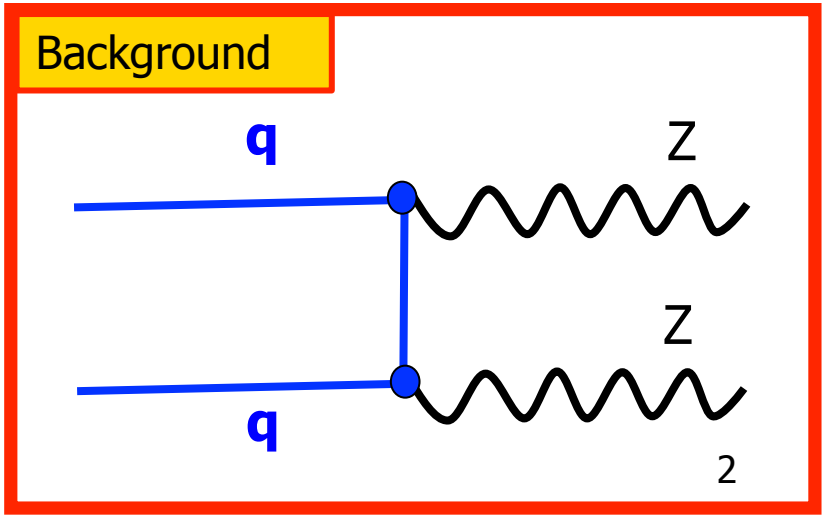
Run: 204769
Event: 71902630

ICHEP 2014, Valencia, July 4, 2014

$H \rightarrow ZZ^{(*)} \rightarrow 4$ leptons (e or μ)

- The golden channel
  - Very small rates (σ x BR ~ 2.5 fb)
  - Very small backgrounds (SM diboson, Z+jets, t-tbar)
    - S/B ~ 2:1
  - Final state is fully reconstructed
    - Can measure mass, x-sections, angular distributions





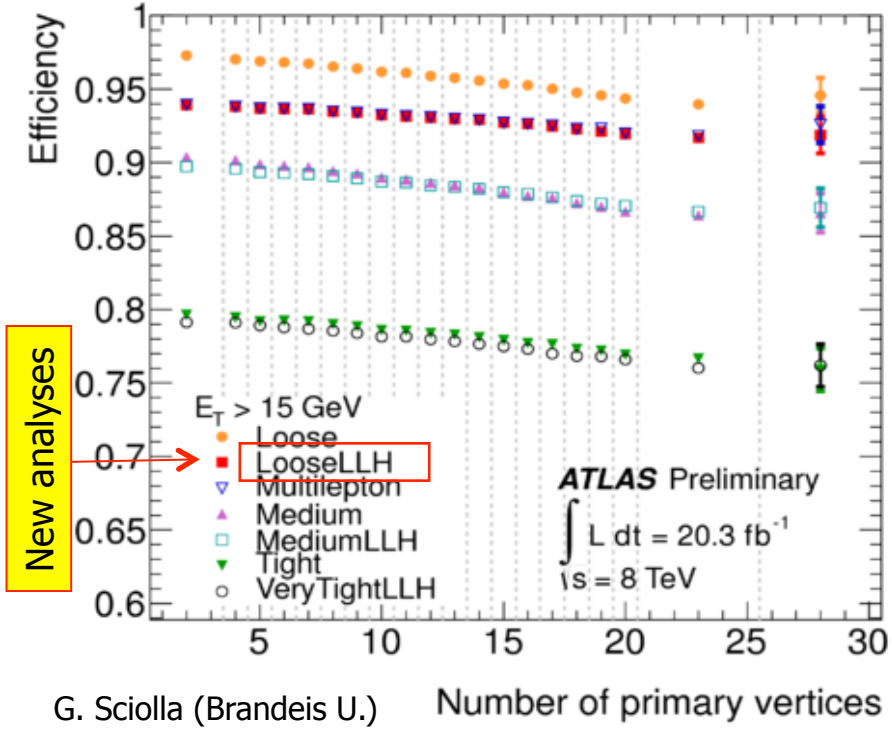
ATLAS-CONF-2014-032

ATLAS-PERF-2014-05

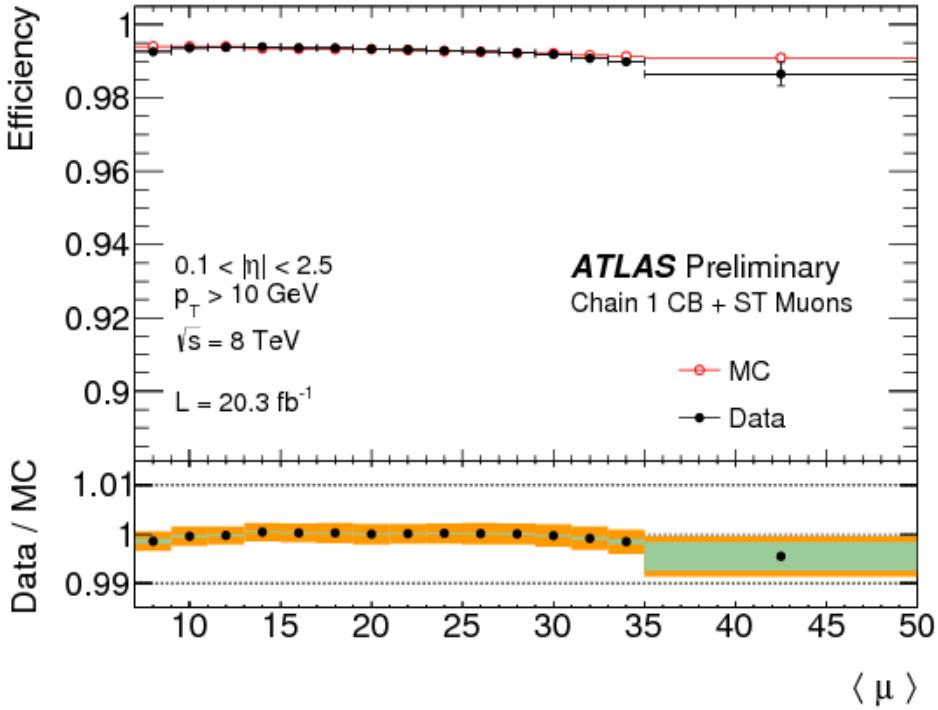
ATLAS performance in Run-1

- All results presented in this talk are based on
  4.5 fb^{-1} at 7 TeV (2011) and 20.3 fb^{-1} at 8 TeV (2012)
- ATLAS data taking efficiency: 94%
- μ/e ID performance almost independent of pile-up conditions

Electron ID efficiency vs pileup



μ reconstruction efficiency vs pileup

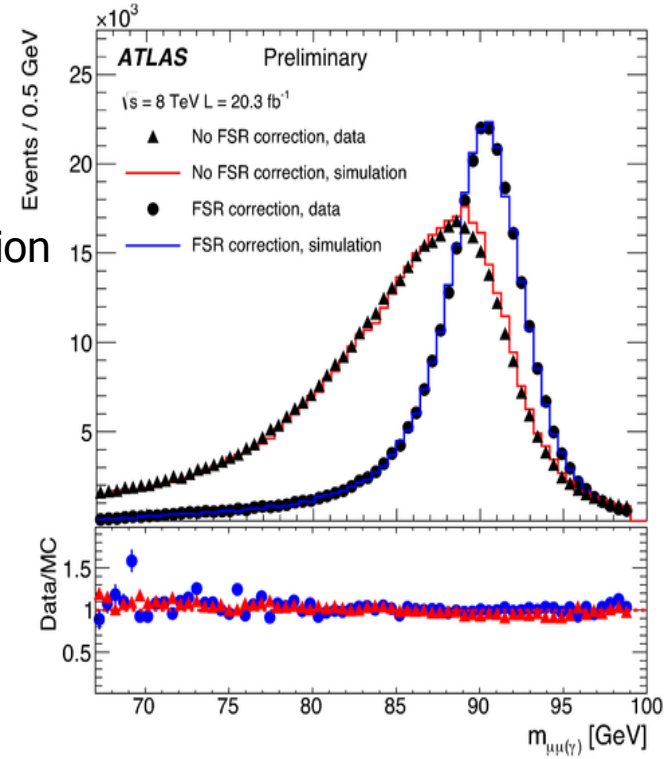


New for ICHEP 2014

arXiv:1406.3827

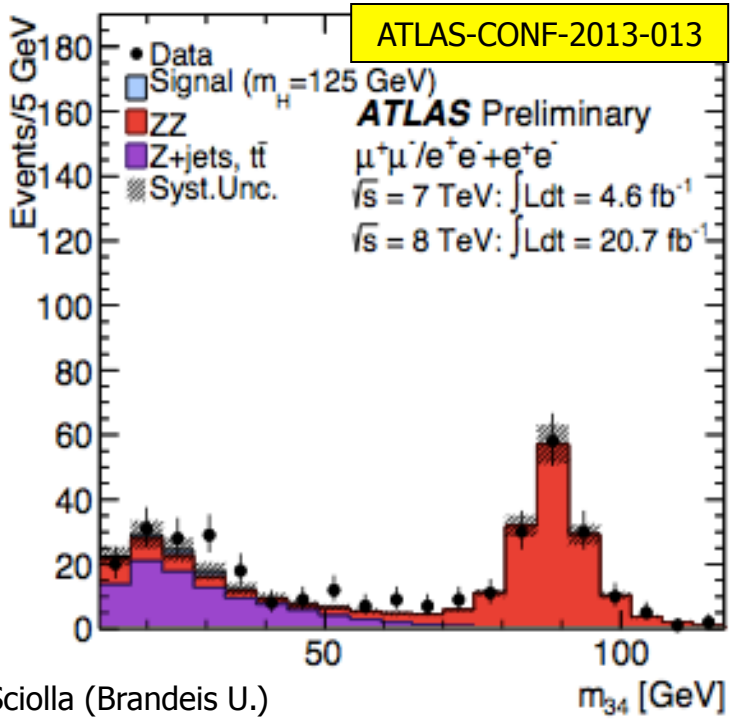
H→4l: inclusive selection

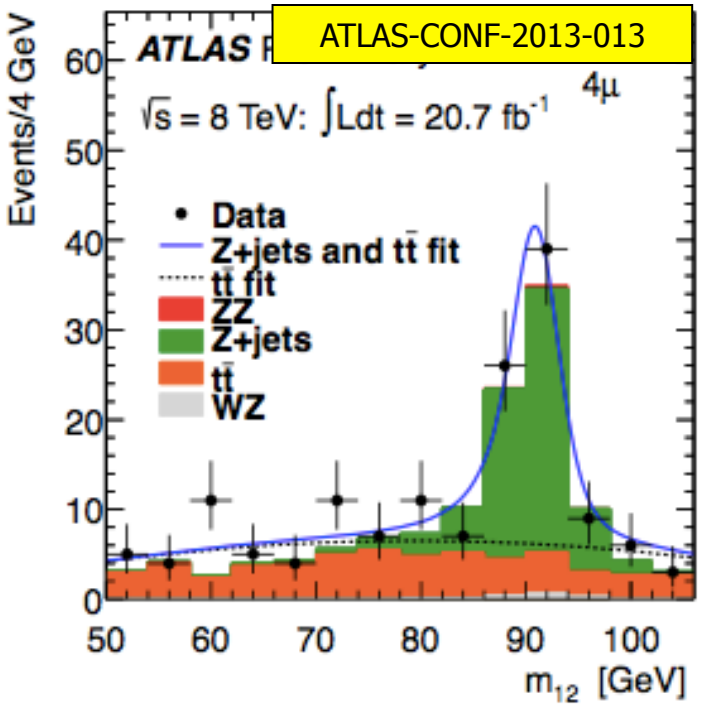
- 4 isolated leptons from primary vertex
  - p_T>20, 15, 10, 6 (7) GeV, $|\eta|$<2.7 (2.5)
  - ⇨ New EM calibration, $p_T^e + E_{cluster}$ combined fit
  - ⇨ New likelihood-based electron ID
    - Improved energy resolution and background rejection
- Two pairs of same flavor, opposite sign leptons
  - m_{12}=[50,106] GeV, m_{34}=[m_{min},115] GeV
    - m_{min}= 12↔50 GeV depending on m_{4l}
- FSR recovery when $Z_{on\text{-}shell}$→μμ ⟶
  - ⇨ Collinear (4%) and non collinear (1%) of events
- Z mass constrained fit on $m_{Z\_on\text{-}shell}$
  - Improves m_{4l} resolution by 15%
    - σ_{4l} = 1.6 (4μ), 2.2 (4e) GeV
- ⇨ Multivariate discriminant to suppress ZZ bkg



Backgrounds

- SM ZZ: dominant, irreducible
  - Estimated from MC (POWHEG+gg2ZZ+SHERPA) normalized to σ_{MCFM}
- Z+jets and $t\bar{t}$
  - Estimated using data-driven methods
    - Background enriched / signal depleted control regions
    - Use transfer factors to extrapolate to signal region





New for ICHEP 2014

arXiv:1406.3827

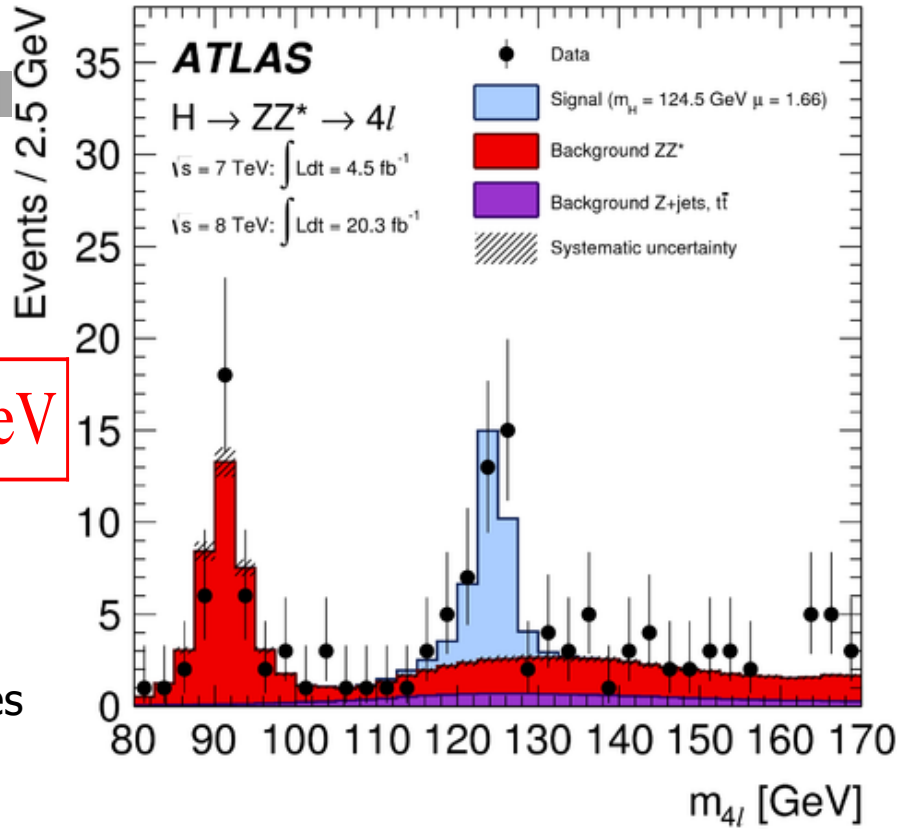
$H \rightarrow ZZ^* \rightarrow 4l$

Very significant excess of events observed at

$$m_H^{4l} = 124.51 \pm 0.52(stat) \pm 0.06(syst)\ \text{GeV}$$

Much more in R. Harrington's talk

Systematic error drastically reduced thanks to improved calibration of e and μ momentum scales

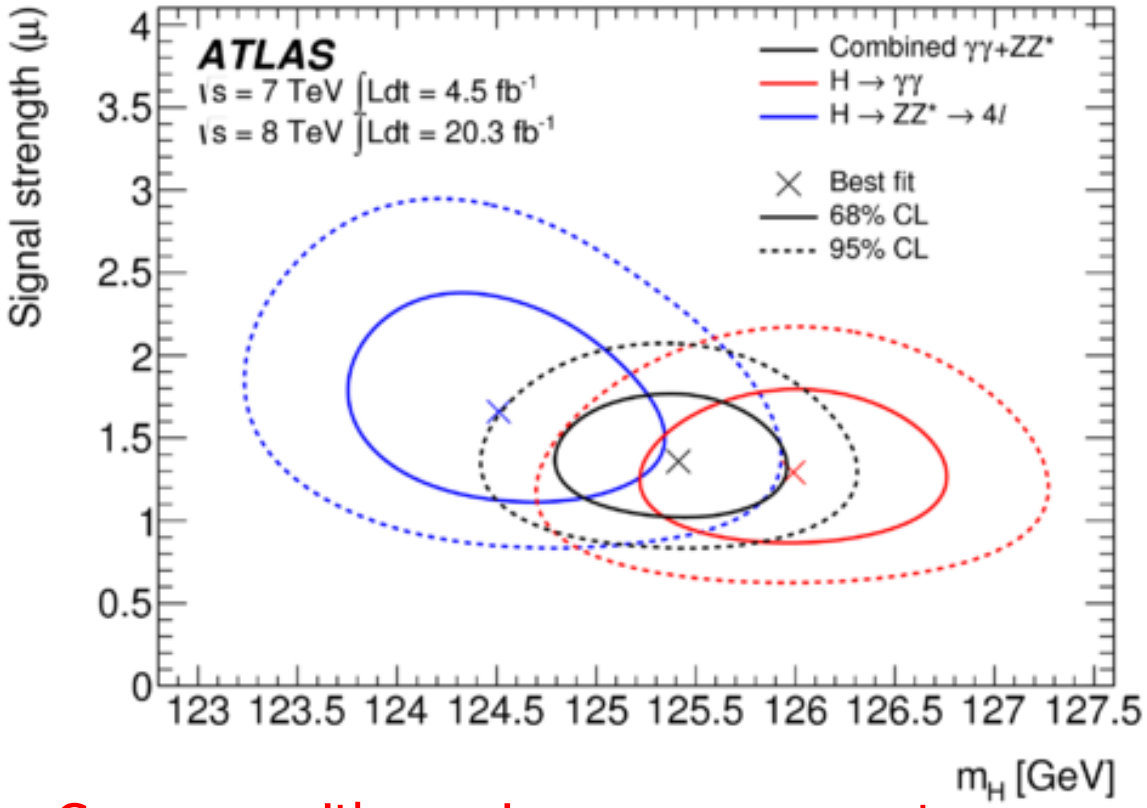


120-130 GeV	Signal	ZZ^*	Z + jets, $t\bar{t}$	s/b	Expected	Observed
4μ	6.20 ± 0.61	2.82 ± 0.14	0.79 ± 0.13	1.7	9.81 ± 0.64	14
$2e2\mu$	4.04 ± 0.40	1.99 ± 0.10	0.69 ± 0.11	1.5	6.72 ± 0.42	9
$2\mu 2e$	3.15 ± 0.32	1.38 ± 0.08	0.72 ± 0.12	1.5	5.24 ± 0.35	6
$4e$	2.77 ± 0.29	1.22 ± 0.08	0.76 ± 0.11	1.4	4.75 ± 0.32	8
Total	16.2 ± 1.6	7.41 ± 0.40	2.95 ± 0.33	1.6	26.5 ± 1.7	37

New for ICHEP 2014

arXiv:1406.3827

Signal strength and significance



Signal strength: $\mu = \sigma_{obs}/\sigma_{SM}$

New measurement:

$$\mu = 1.66^{+0.45}_{-0.38}$$

$$\text{at } m_H = 124.5$$

Compare with previous measurement:

$$\mu = 1.7^{+0.5}_{-0.4} \quad \text{at } m_H = 124.3 \text{ GeV}$$

Observed: 6.6 σ

Single channel discovery

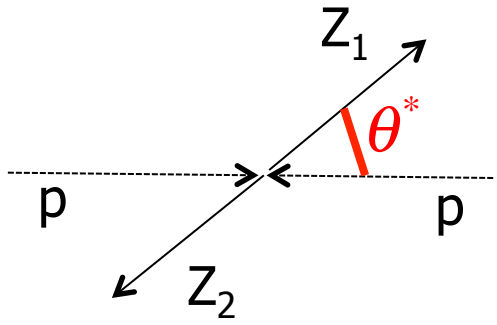
(expected: 4.4 σ)

New for ICHEP 2014

ATLAS-CONF-2014-044

Fiducial cross-sections $\sigma_{fiducial}$

- Minimize model dependence due to acceptance corrections
  - Compare measurement and theory in fiducial region
- Measure inclusive and differential x-sections
  - $d\sigma/dX$ with X= p_T^H, y_H, cos θ^*, m_{34}, p_T^{jet}, njets
- Three generators are compared
  - POWHEG: ME generator used for ggF and VBF, up to NLO
  - HRES 2.2: up to NNLO in QCD +NNLL re-summation in ggF
  - MINLO: Multiscale Improved NLO, better jet-related variables in ggF
- Fiducial region and analysis strategy
  - Standard H→4l selection with signal extraction in m_{4l}=[118-129] GeV
  - Inclusive fiducial cross-section extracted from fit to mass spectrum
  - Cut-and-count method used for differential measurements
    - Bin-by-bin yields estimated by subtracting expected background and correcting for detector efficiency and resolution effects



New for ICHEP 2014

ATLAS-CONF-2014-044

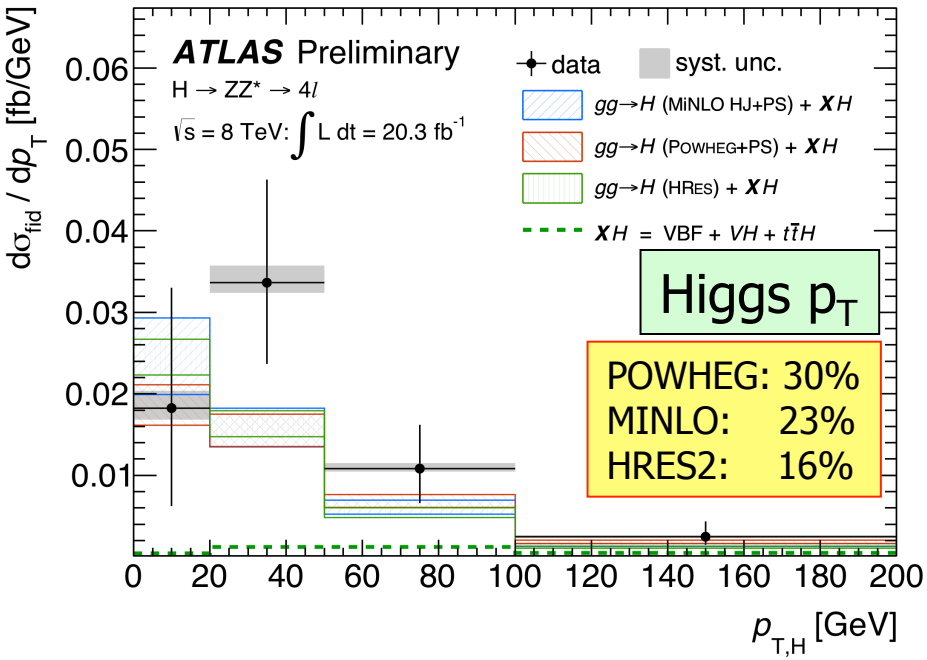
Fiducial cross-sections

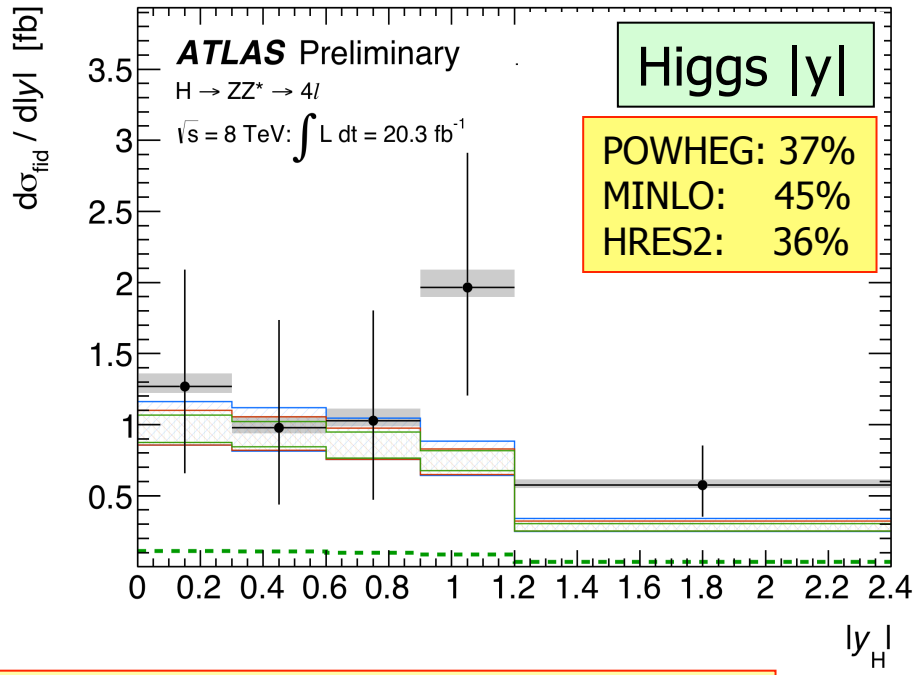
Inclusive x-section in fiducial region

$$\sigma_{fid} = 2.11^{+0.53}_{-0.47}(stat) \pm 0.08(syst) \text{ fb}$$

- SM prediction from LHC σ_H WG: $\sigma^{SM}_{fid} = 1.30 \pm 0.13$ fb

Differential x-sections



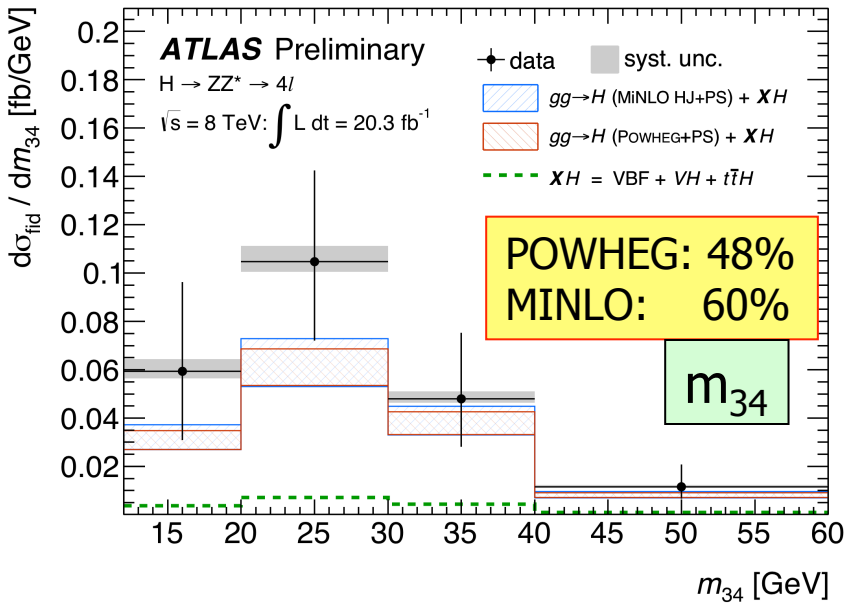


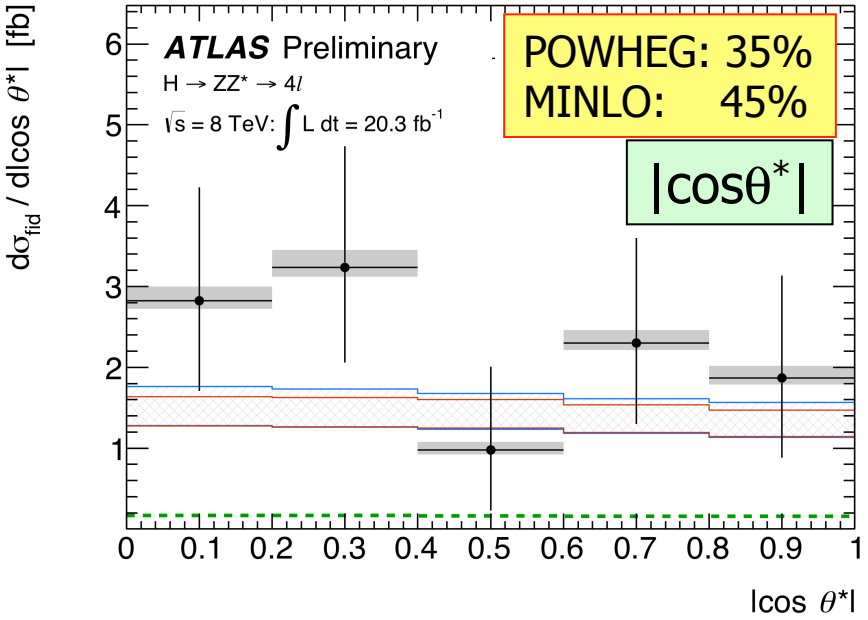
Compatibility computed from difference between 2NLL from fit and fixing σ to SM.
This variable behaves as a χ^2 distribution with $N_{DOF}=N_{bins}$

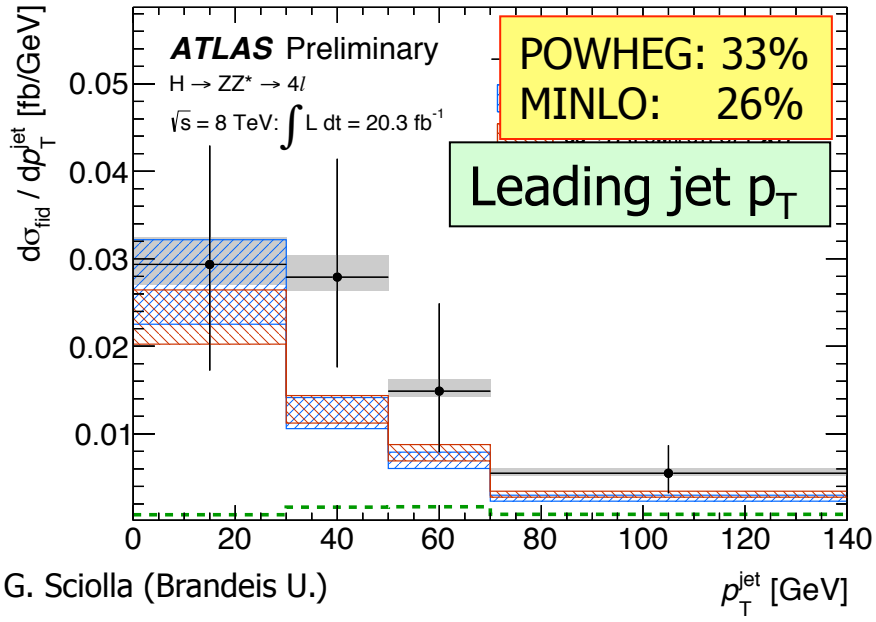
New for ICHEP 2014

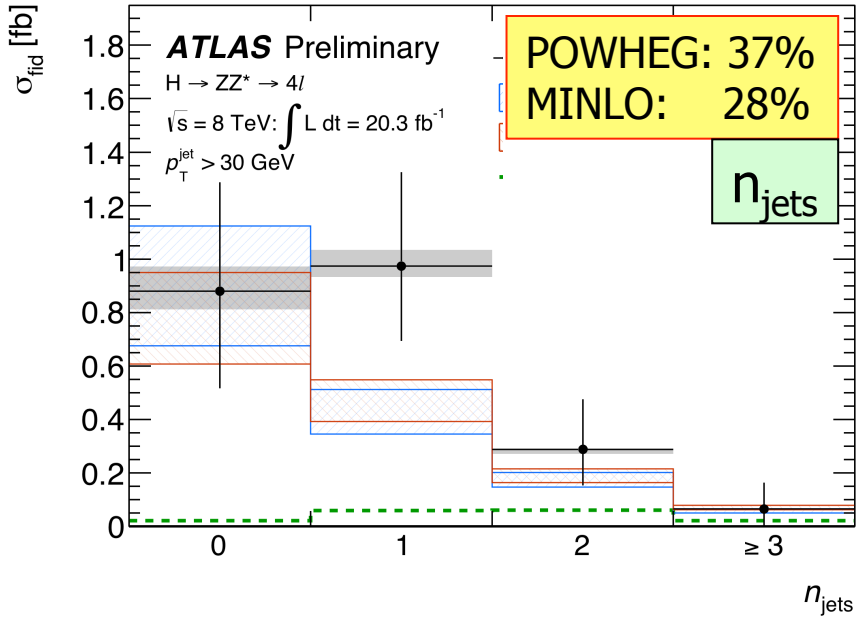
ATLAS-CONF-2014-044

Differential fiducial cross-sections









New for ICHEP 2014

ATLAS-CONF-2014-042

Constraints on Γ_H from $\sigma_H^{\text{off-shell}}$

- High-mass H→ZZ ($m>2m_Z$) provides strong constraints on Γ_H
  - Kauer and Passarino, JHEP 1208 (2012) 116
  - Caola and Melnikov, PRD 88 (2013) 054024
  - Campbell, Ellis, and Williams, PRD 89 (2014) 053011
  - CMS arXiv:1405.3455

$$\sigma^{gg\to H^*\to ZZ}_{off-shell} \propto g^2_{Hgg(off-shell)} g^2_{HVV(off-shell)}$$

$$\sigma^{gg\to H^*\to ZZ}_{on-shell} \propto \frac{g^2_{Hgg(on-shell)} g^2_{HVV(on-shell)}}{\Gamma_H / \Gamma^{SM}_H}$$

- Assuming on-shell and off-shell couplings are the same:

$$\Rightarrow \quad \frac{\sigma^{gg\to H\to ZZ}_{off-shell}}{\sigma^{gg\to H\to ZZ}_{on-shell}} \propto \frac{\Gamma_H}{\Gamma^{SM}_H}$$

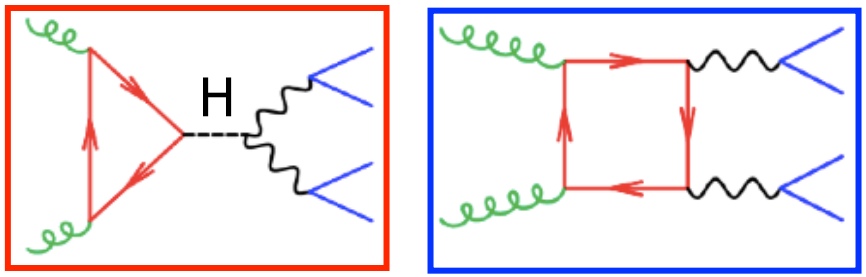
New for ICHEP 2014

ATLAS-CONF-2014-042

Differential cross-section for gg→(H→)ZZ

Contributions at $m_{ZZ}>2m_Z$

- Signal: gg→H→ZZ
- Background: SM gg→ZZ
- S-B interference:
  - Large and negative



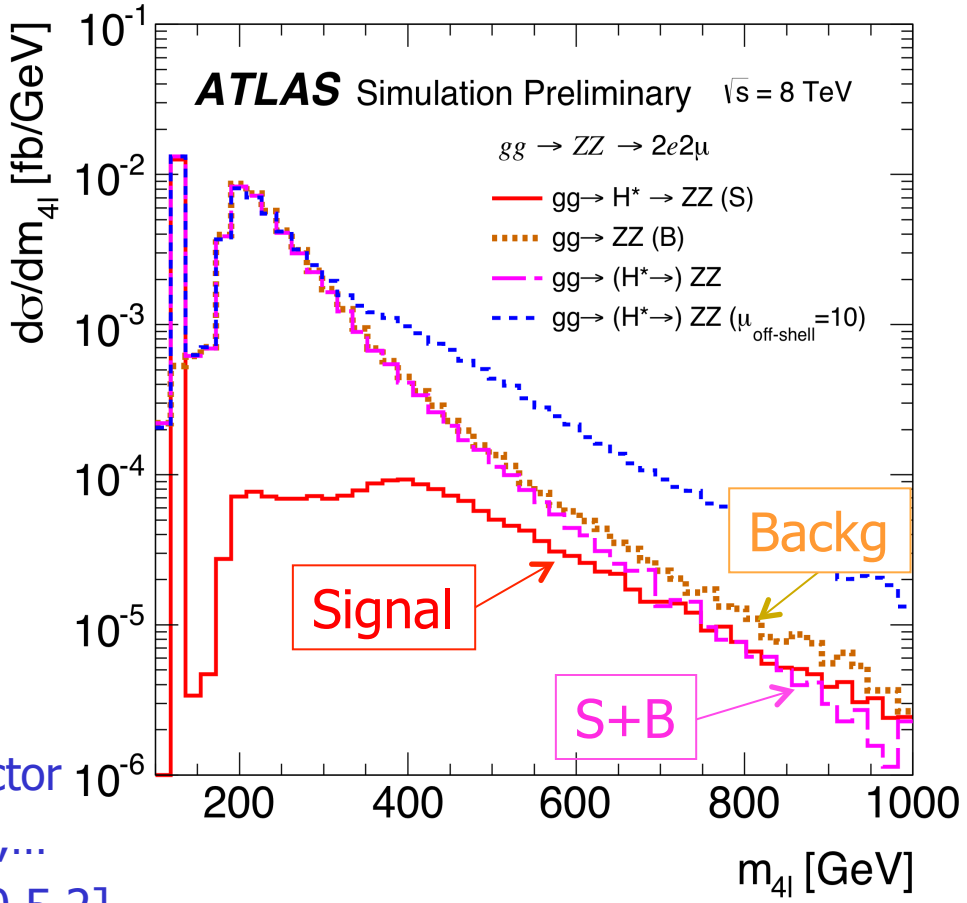
Large theory uncertainties

- gg→ZZ known to LO: no (N)NLO K factor

→ Inclusive analysis: no cuts in n_{jets}, p_T^{ZZ},...

→ Results for $R_H^B = K_{gg\to ZZ}/K_{gg\to H\to ZZ}=[0.5,2]$

- Soft-collinear approx.: $K_{gg\to ZZ} \sim K_{gg\to H\to ZZ}$
- Main result quoted for $R_H^B = 1$



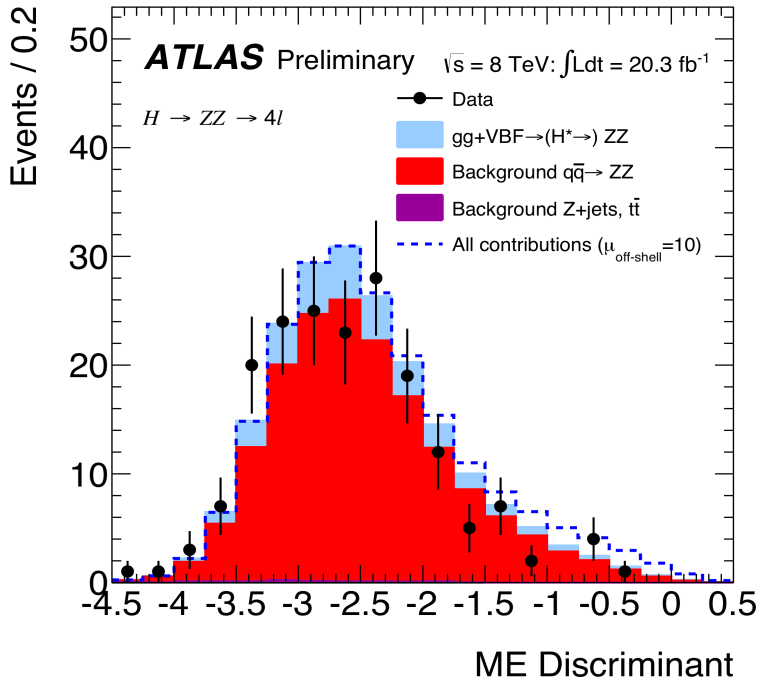
To increase statistics, reconstruct ZZ in both 4l and 2l2ν

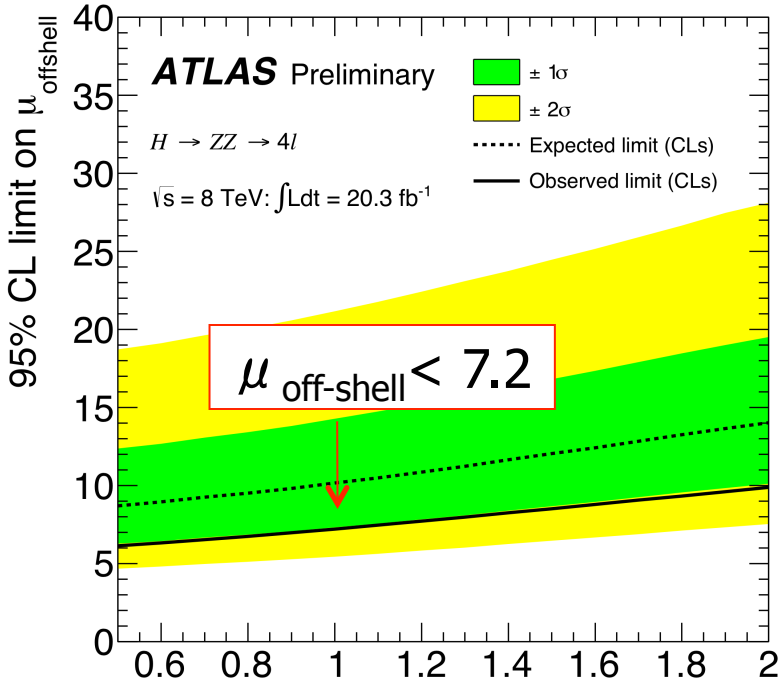
New for ICHEP 2014

ATLAS-CONF-2014-042

$\mu_{\text{off-shell}}$ from H→ZZ→4l

- H→4l reconstruction as in arXiv:1406.3827
  - Define off-peak region as m_{4l}=[220,1000] GeV
- Matrix element (ME) kinematic discriminant
  - Using 8 kinematic variables to separate gg→H→ZZ from gg→ZZ and $q\bar{q}$→ZZ
- Max likelihood fit to ME discriminant; limits on $\mu_{\text{off-shell}}$ from CL_s method





Systematics dominated by QCD scale of gg→ZZ, gg→(H→)ZZ and qq→ZZ

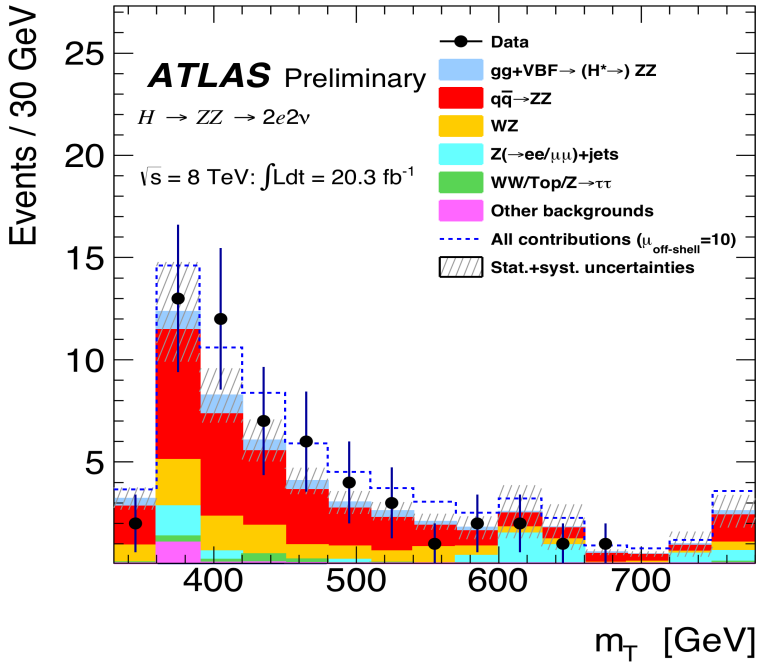
$$R^{B}_{H^*} = \frac{K(gg\to ZZ)}{K(gg\to H^*\to ZZ)}$$

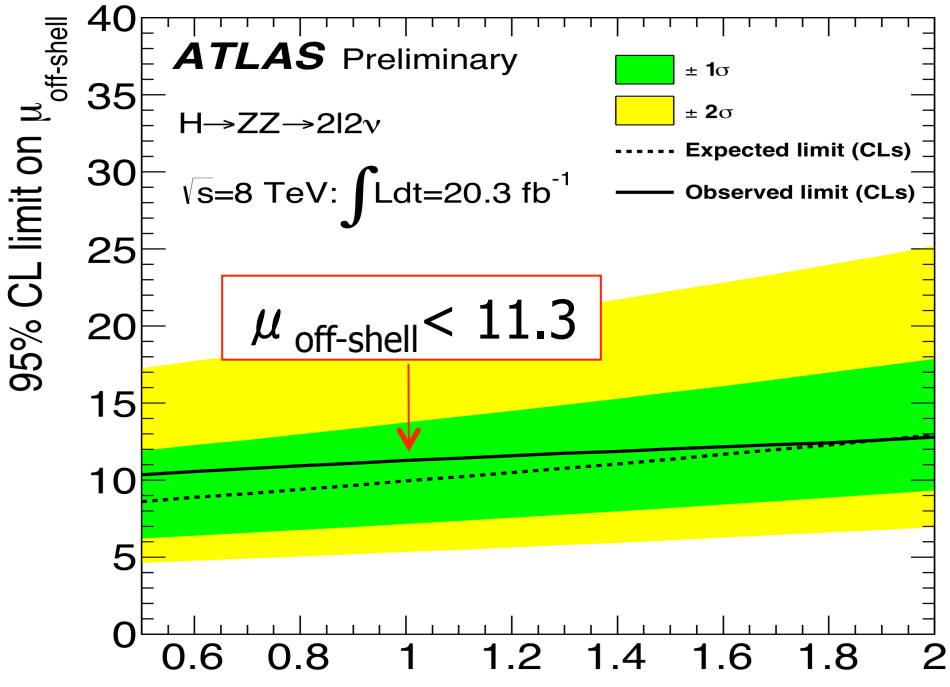
New for ICHEP 2014

ATLAS-CONF-2014-042

$\mu_{\text{off-shell}}$ from H→ZZ→llνν

- Reconstruction as in PRL 112(2014)201802
  - $76<m_{ll}<106$, MET>150 GeV
  - Veto on 3rd lepton to reject WZ; b-jet veto to reject top
  - $|p_T(Z) - \text{MET}|/p_T(Z) < 0.3$; $\Delta\phi(\text{MET}, p_T^{\text{miss}}) < 0.5$ to reject top and Z+jets
- Off-peak region: $m_T^{ZZ} > 350$ GeV
- Limits on $\mu_{\text{off-shell}}$ from CL_s method





Systematics dominated by QCD scale of gg→ZZ, gg→(H→)ZZ and qq→ZZ

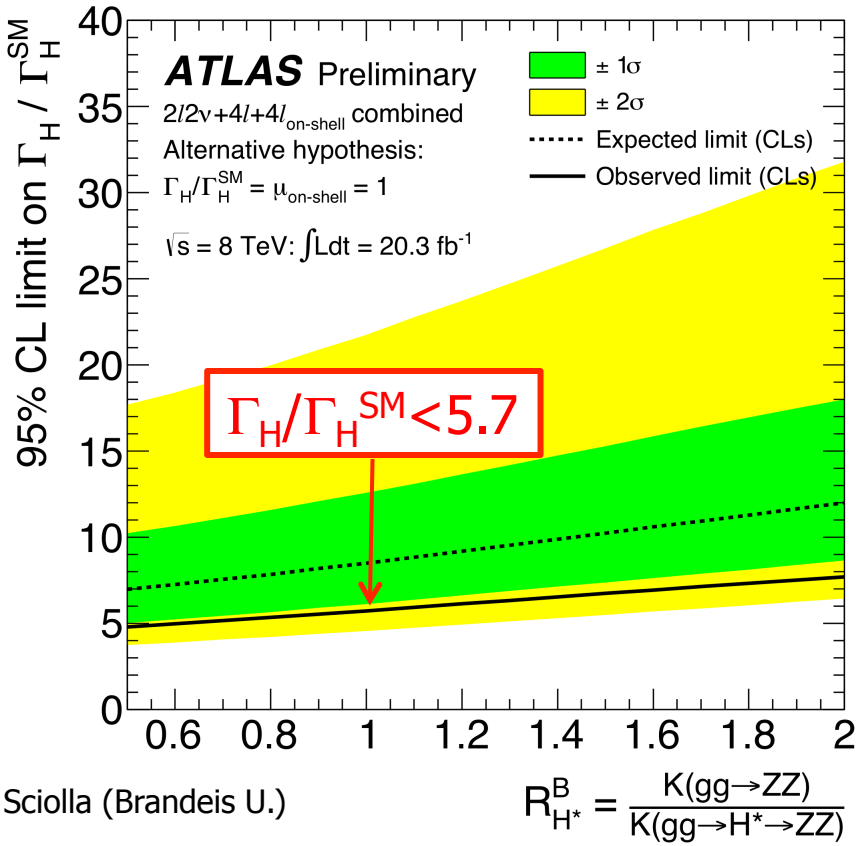
$$R^{B}_{H^*} = \frac{K(gg\to ZZ)}{K(gg\to H^*\to ZZ)}$$

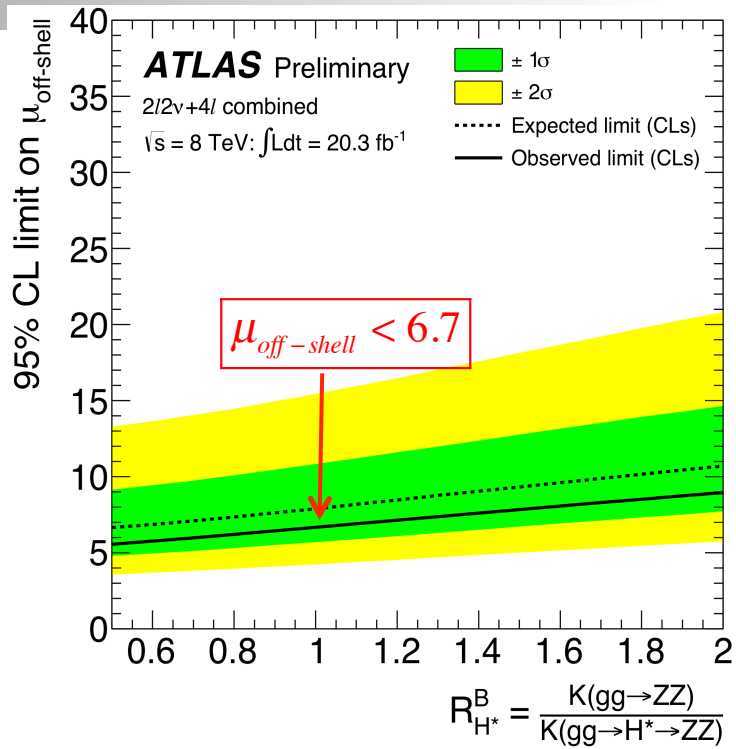
New for ICHEP 2014

ATLAS-CONF-2014-042

Combined results

- Combine 4l and 2ν2l to fit $\mu_{\text{off-shell}}$
- Include low-mass region (4l) to fit $\mu_{\text{on-shell}}$
  - Assuming $g_{\text{on-shell}} = g_{\text{off-shell}}$
- Ratio of $\mu_{\text{on-shell}}$ / $\mu_{\text{off-shell}}$ yields Γ_H





Γ_H/Γ_{SM}	Observed	Expected μ =1
R_H^B=0.5	4.8	7.0
R_H^B=1	5.7	8.5
R_H^B=2	7.7	12.0

Conclusion

- The search for H→4l has paid off in Run-1
  - Single channel discovery
  - New H→4l selection allows us to further suppress backgrounds
    → Excellent S/B ratio!
- Many Higgs properties measured in H→4l
  - Fiducial inclusive and differential x-sections (New)
  - Off-shell x-section and limit on Higgs full width (New)

  } This talk

  - Couplings ← S. Banerjee (on Friday afternoon)
  - Mass (New) ← R. Harrington (this session)
  - Spin and Parity ← K. Prokofiev (on Fri afternoon)

  → all seems to be consistent with SM expectation so far…
- Run-2 will be particularly beneficial to H→4l
  - Systematics are low in H→4l, statistical error dominates
  - The fun is just beginning…