Measurements of Zγ and Zγγ Production in pp Collisions at 8 TeV with the ATLAS Detector

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On behalf of the ATLAS Collaboration

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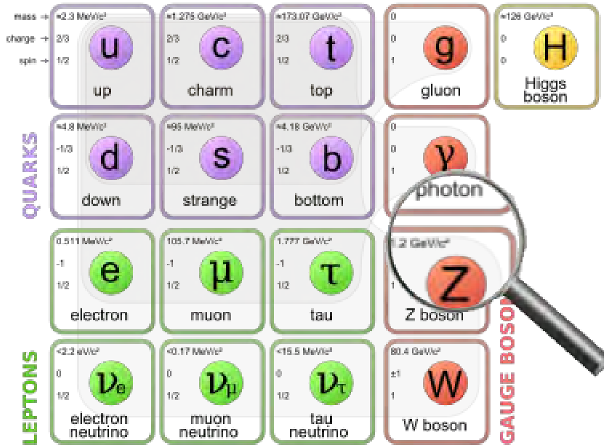
Physics overview and motivation

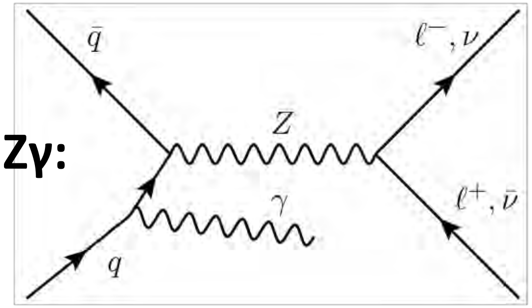
Two main goals of Standard Model (SM) measurements in ATLAS are: to test theory with high precision and to find any signs of new physics.



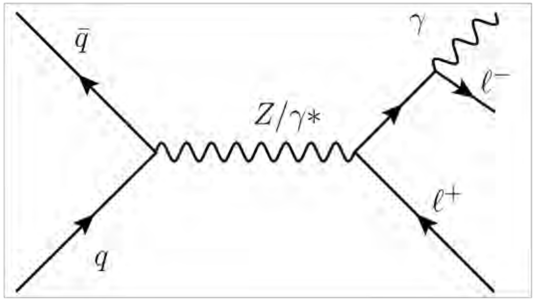
Study of Zγ and Zγγ production probes EW sector via interactions between two types of neutral bosons.

<u>SM diagrams</u>

Zγ:



Initial state radiation (ISR)

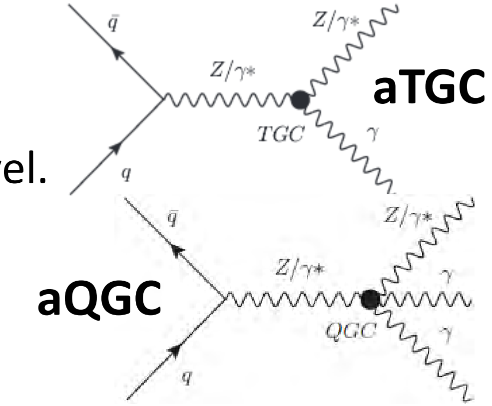


Final state radiation (FSR)

Zγγ: 2 ISR / 2 FSR / 1 ISR and 1 FSR photons in diagrams

- ➢ New physics can be probed **indirectly** via study of interactions between EW gauge bosons.
- ➢ SM **doesn't predict** any neutral triple or quartic vertex at tree level.
- ➢ Anomalous triple or quartic gauge couplings (aTGCs and aQGCs) can occur only due to physics beyond Standard Model.
- ➢ ATGC/AQGC modify total cross sections and kinematics.

<u>aGC diagrams:</u>

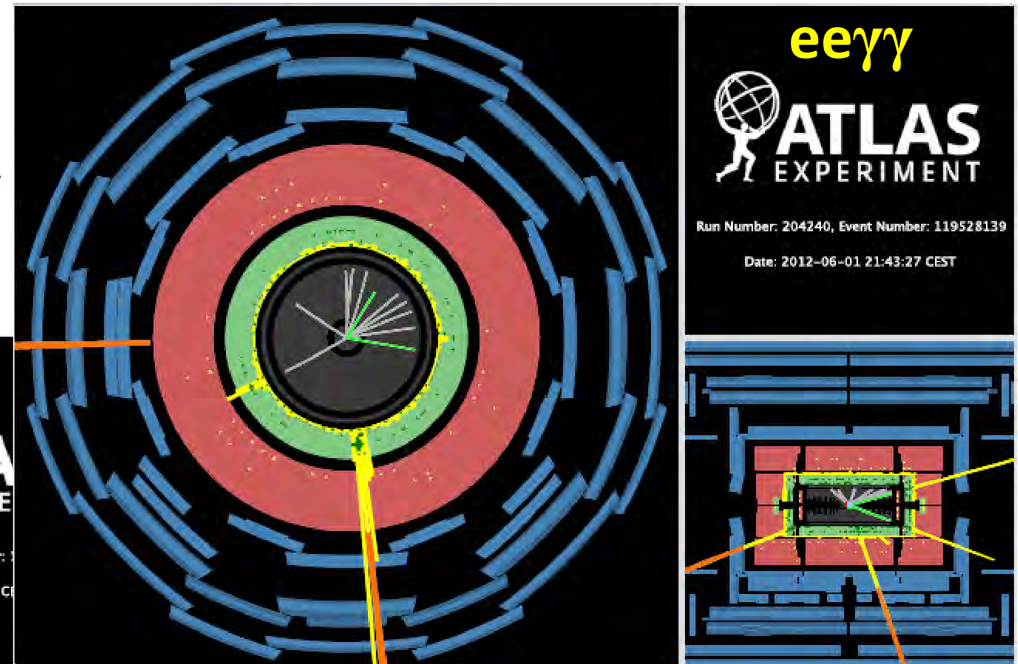


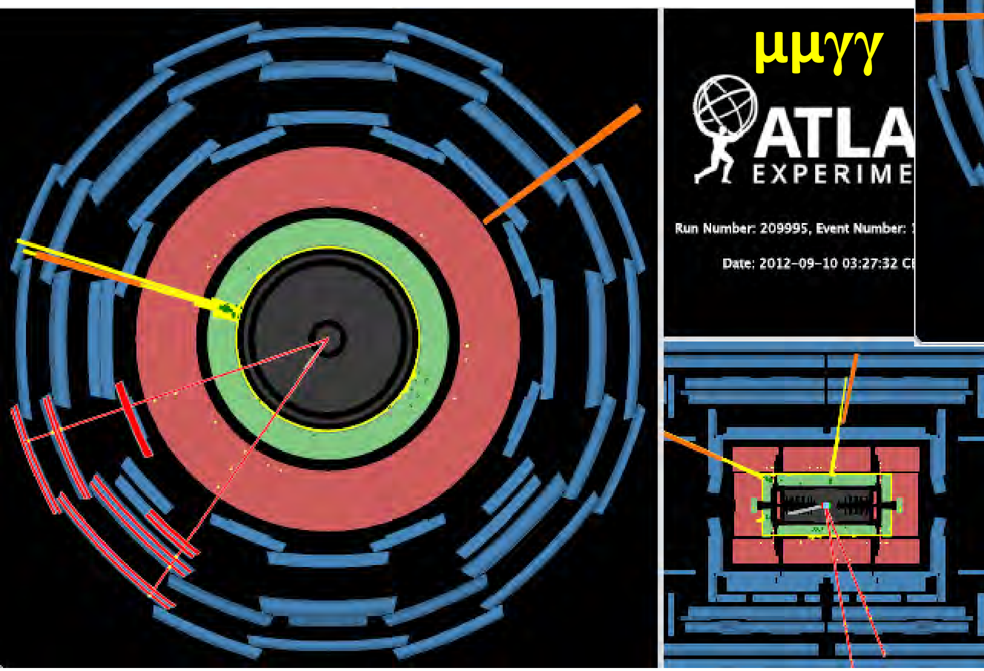
Events signatures

- Zγ events
  - *llγ* has signature of two good identified leptons (e or μ) and one isolated photon
  - *ννγ* has signature of high missing transverse momentum and one isolated photon

llγ: $p_T(l)>25$ GeV; $E_T(\gamma) > 15$ GeV
ννγ: $E_T(\text{miss}) > 100$ GeV; $E_T(\gamma) > 130$ GeV

- Zγγ events signatures differ from Zγ by presence of one more isolated photon





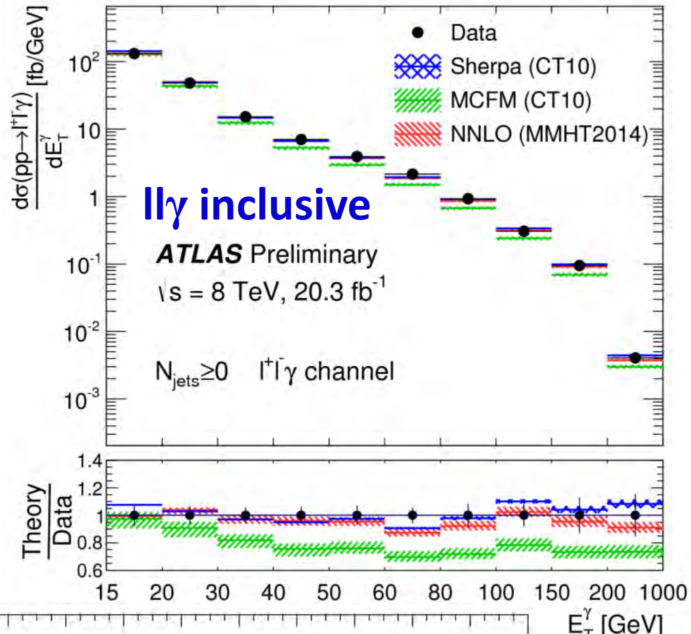
llγγ: $p_T(l)>25$ GeV; $E_T(\gamma) > 15$ GeV
ννγγ: $E_T(\text{miss}) > 110$ GeV; $E_T(\gamma) > 22$ GeV

Inclusive selection: without and constraints on hadronic activity; Exclusive selection: $N_{jets} = 0$

Cross sections measurement for Zγ

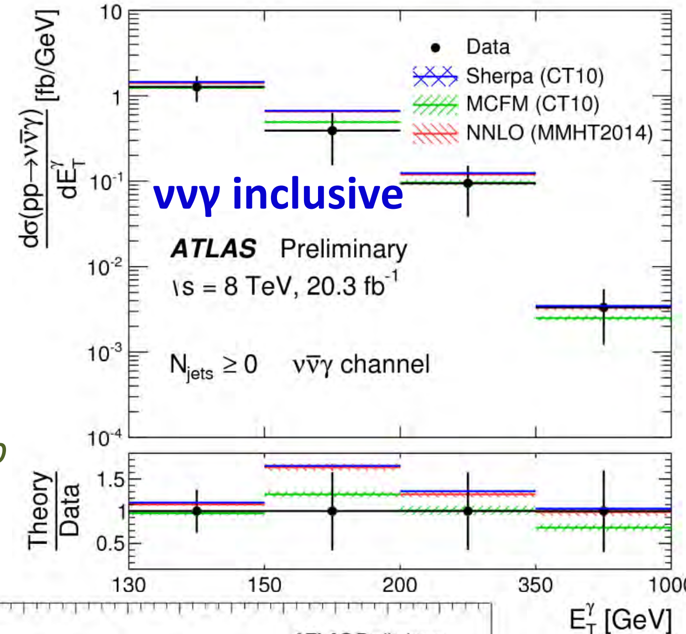
llγ channels have 1 data-driven background Z+jets, which is dominant and estimated using 2D sideband.

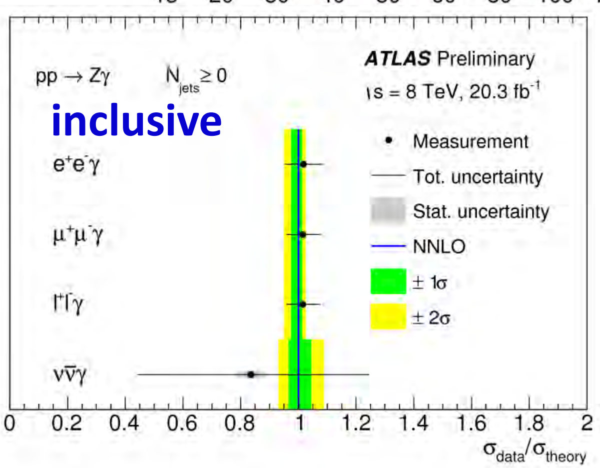
ννγ channel has several data-driven backgrounds: γ+jets, W(lν/τν)+γ, W(eν) and Z+jets, which are estimated either by CRs constructions or by 2D sideband.



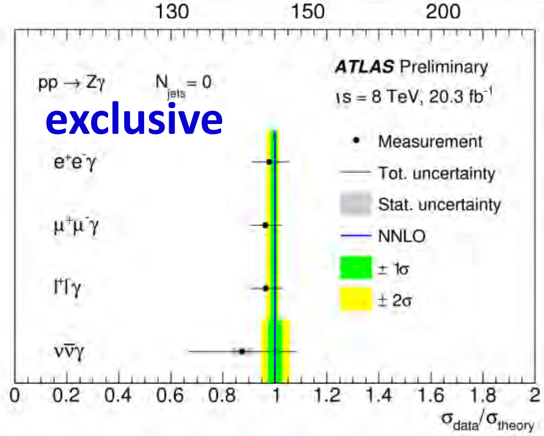
Differential measurement $E_T(\gamma)$ distribution

m[Zγ] and N_{jets} differential distributions for llγ are in back-up (sl. 24-25)





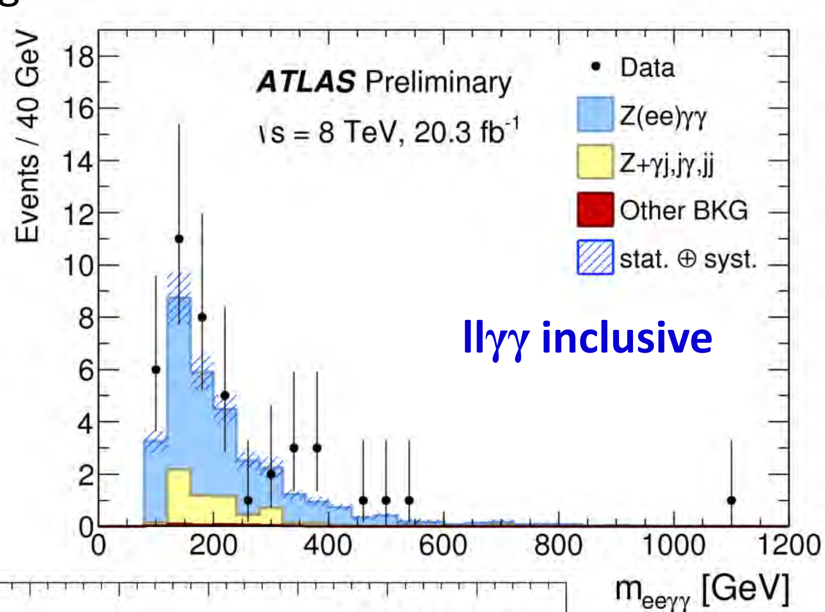
Integrated measurement

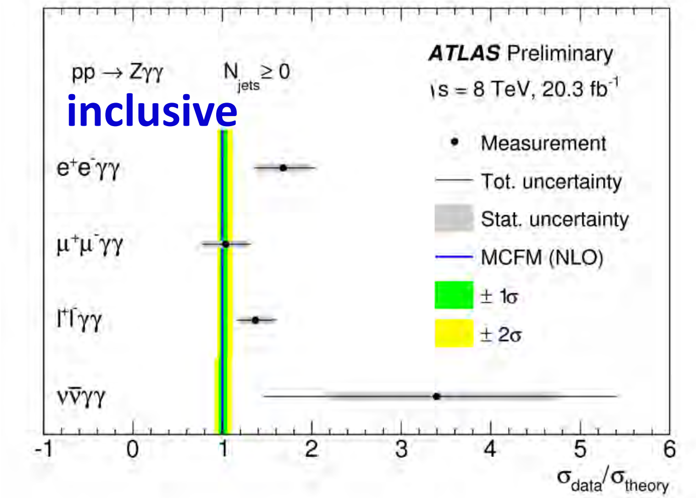


Agrees well with SM within uncertainties

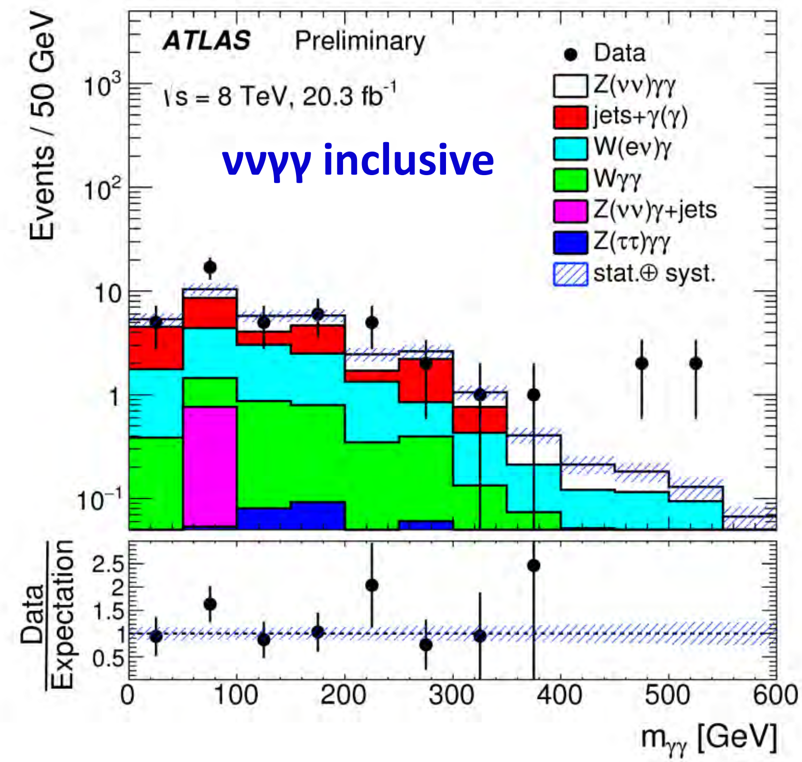
Observation for Zγγ

llγγ channels have 1 data-driven background Z+jets/γjets, which is dominant and estimated using matrix CRs method.





ννγγ channel has several data-driven backgrounds: γ+jets, W(lν/τν)+γγ and W(eν)γ, which are estimated either by CRs constructions or by 2D sidebands.

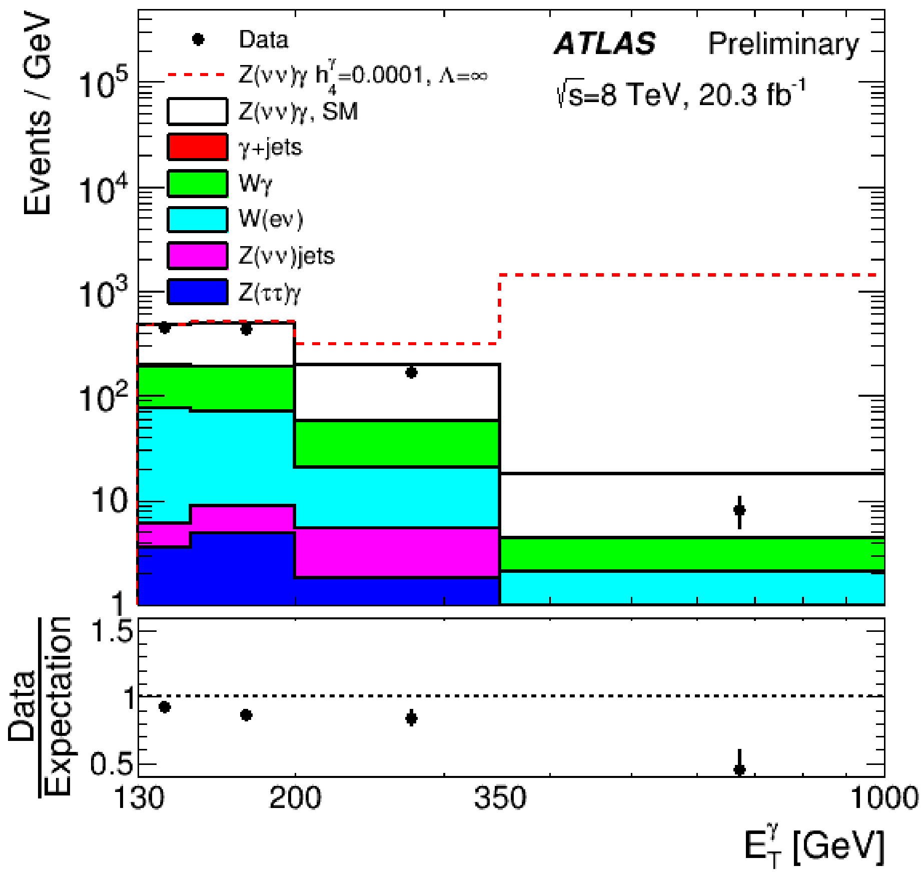


The shapes agree well for *llγγ* and fairly well for *ννγγ* between Zγγ data candidates and the expectations within uncertainties

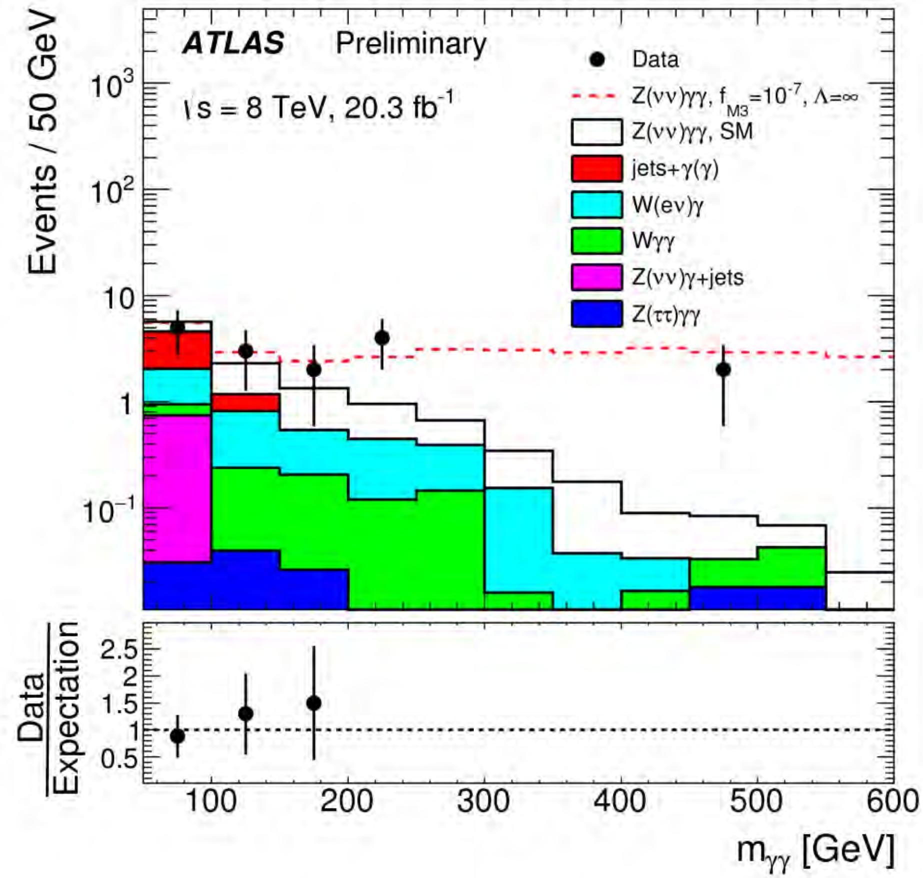
Significance for *llγγ* combination is more than 5 sigma.

Limits on Anomalous Gauge Couplings: Distributions

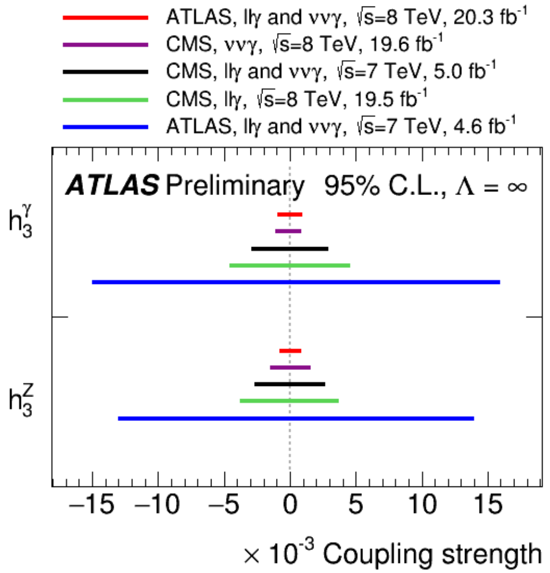
$E_T(\gamma)$ distributions are used for aTGC limit setting



$m_{\gamma\gamma}$ distributions are used for aQGC limit setting

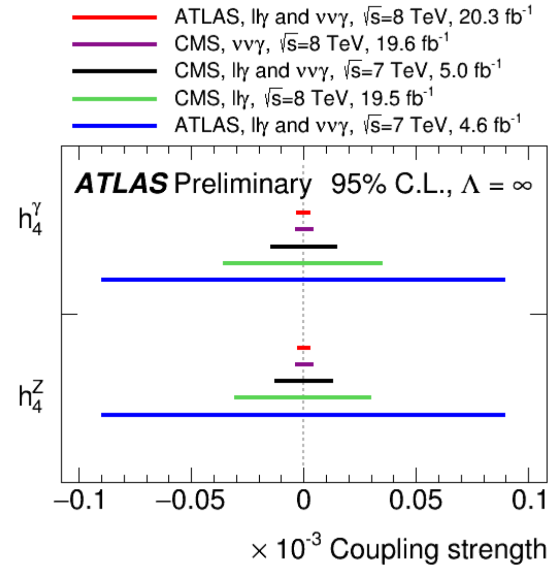


Limits on Anomalous Gauge Couplings: Results

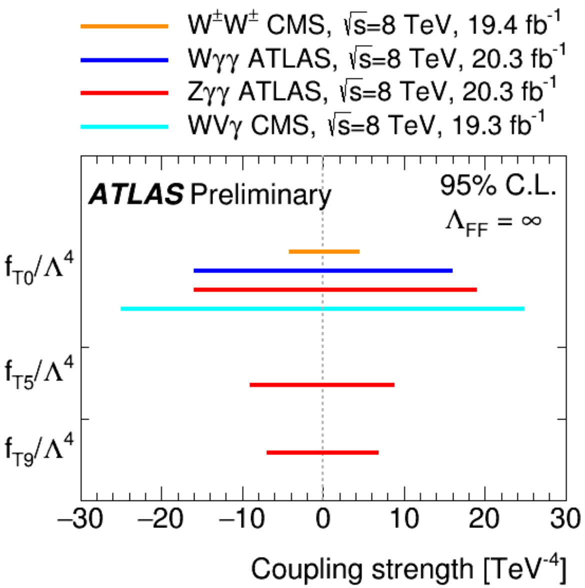


aTGC

Vertex function approach



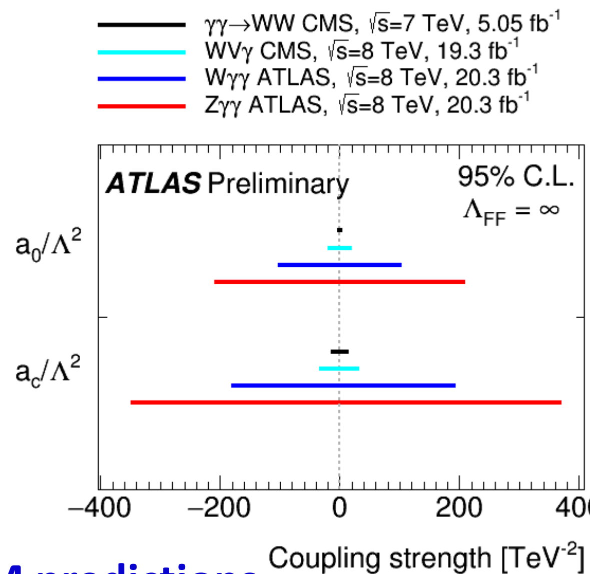
Best limits obtained!



aQGC

EFT approach

Limits for ft5 and ft9 were obtained first time in ATLAS!



No sign of deviation from SM predictions

Conclusions

- Zγ analysis
  - Precise measurement of the integrated and differential cross sections for llγ and ννγ final states. Good agreement for most channels
  - Comparison of the measured cross sections with NLO and NNLO predictions

- Zγγ analysis
  - First measurement of llγγ and ννγγ final states cross sections in ATLAS
  - Good agreement of integrated Zγγ cross sections with theory predictions (deviations of the integrated observed cross section from SM one for all of the channels are less than 2σ)

- aGC limit setting
  - **No sign of deviation from SM predictions**
  - Limits on aTGC parameters accessible with this final state are better than all other results
  - aQGC limits are comparable to those obtained from other measurements in ATLAS and CMS. Limits for f_{T5}/Λ^4 and f_{T9}/Λ^4 obtained for the first time in ATLAS

Back-up slides

Event selection

- *llγ* and *llγγ*:

  Exactly 2 selected leptons {p_T > 25 GeV, |η| < 2.5}, m[l^+l^-] > 40 GeV
  llγ: ≥ 1 photons {E_T > 15 GeV, |η| < 2.37}, take the photon with highest E_T
  llγγ: ≥ 2 photons {E_T > 15 GeV, |η| < 2.37} with ΔR(γ,γ) > 0.4. If > 2 photons, take two with highest sum of E_T

- *ννγ* and *ννγγ*

  lepton-veto

  - To suppress W (→ lν/τν)γ background in *ννγ* channel and W (→ lν/τν)γγ background in *ννγγ* channel

  E_T (miss) > 100 (*ννγ*), 110 (*ννγγ*) GeV

  - To suppress γ+jets background

  ννγ: ≥ 1 photons {E_T > 130 GeV, |η| < 2.37}, take the photon with highest E_T
  ννγγ: ≥ 2 photons {E_T > 22 GeV, |η| < 2.37} with ΔR(γ,γ) > 0.4. If > 2 photons, take two with highest sum of E_T
  ννγ: γ and p_T(miss) back-to-back : |Δϕ(p_T (miss),γ)| ≥ π/2
  ννγγ: γγ system and p_T (miss) back-to-back : |Δϕ(p_T (miss), γγ)| ≥ 5π/6

  - To suppress γ+jets and W(→ eν)(γ) backgrounds

Inclusive selection: without and constraints on hadronic activity
Exclusive selection: N_{jets} = 0 {p_T(jet) > 30 GeV, |η(jet)| < 4.5}

Background estimation in llγ and llγγ

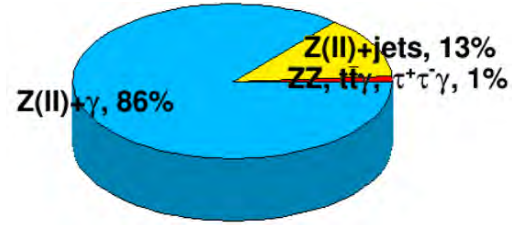
***llγ* channel backgrounds:**

Z(→ll)+jets {where jet is misidentified as γ} is estimated using two-dimensional side-band method (data-driven):

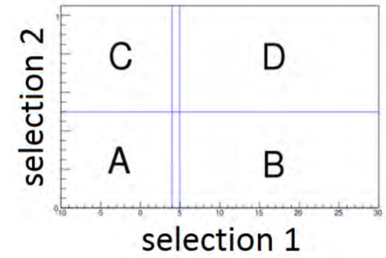
Using two independent discriminating variables *(photon isolation and photon shower shapes in the first EM layer)* to define four regions A/B/C/D, background in the signal region A can be easily obtained.

$$\frac{N_A^{Z+jets}}{N_B} = \frac{N_C}{N_D}$$

$t\bar{t}\gamma$, *$\tau^+\tau^-\gamma$* and *WZ* are estimated from MC simulation.



Inclusive/Exclusive



***llγγ* channel backgrounds:**

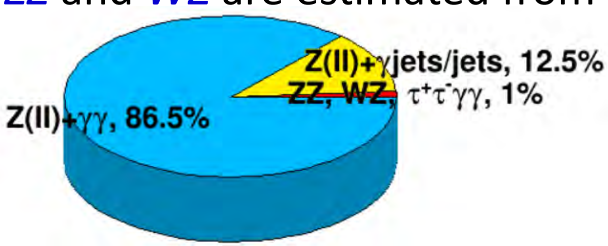
Z(→ll)+jets/γjets is estimated using matrix method (data-driven):

$$\begin{pmatrix} N_{\mathrm{TT}} \\ N_{\mathrm{TL}} \\ N_{\mathrm{LT}} \\ N_{\mathrm{LL}} \end{pmatrix} = \begin{pmatrix} \epsilon_1\epsilon_2 & \epsilon_1 f_2 & f_1\epsilon_2 & f_1 f_2 \\ \epsilon_1(1-\epsilon_2) & \epsilon_1(1-f_2) & f_1(1-\epsilon_2) & f_1(1-f_2) \\ (1-\epsilon_1)\epsilon_2 & (1-\epsilon_1)f_2 & (1-f_1)\epsilon_2 & (1-f_1)f_2 \\ (1-\epsilon_1)(1-\epsilon_2) & (1-\epsilon_1)(1-f_2) & (1-f_1)(1-\epsilon_2) & (1-f_1)(1-f_2) \end{pmatrix} \begin{pmatrix} N_{\gamma\gamma} \\ N_{\gamma\mathrm{jet}} \\ N_{\mathrm{jet}\gamma} \\ N_{\mathrm{jetjet}} \end{pmatrix}$$

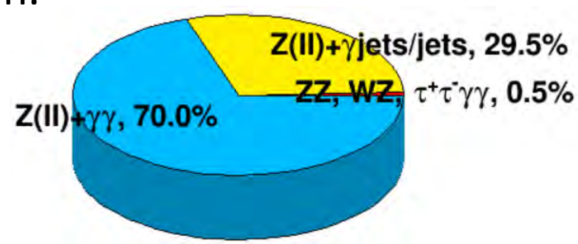
T/L – tight/loose photon ϵ - signal efficiency f – fake rate

$$N_{\mathrm{TT}}^{j\to\gamma} = \epsilon_1 f_2 \times N_{\gamma\mathrm{jet}} + f_1\epsilon_2 \times N_{\mathrm{jet}\gamma} + f_1 f_2 \times N_{\mathrm{jetjet}}$$

$\tau^+\tau^-\gamma\gamma$, *ZZ* and *WZ* are estimated from MC simulation.



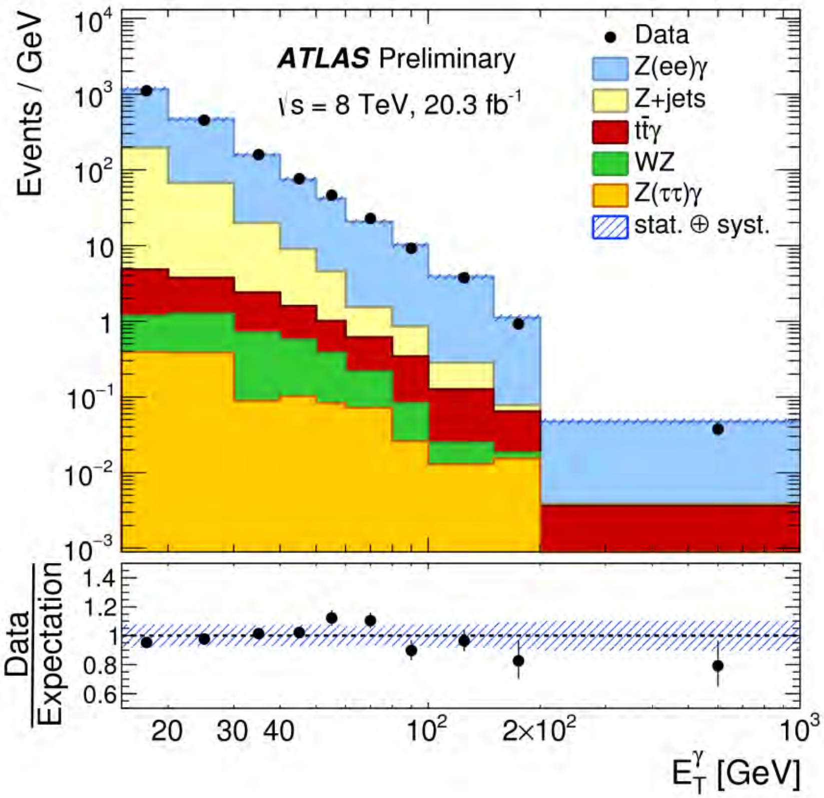
Inclusive

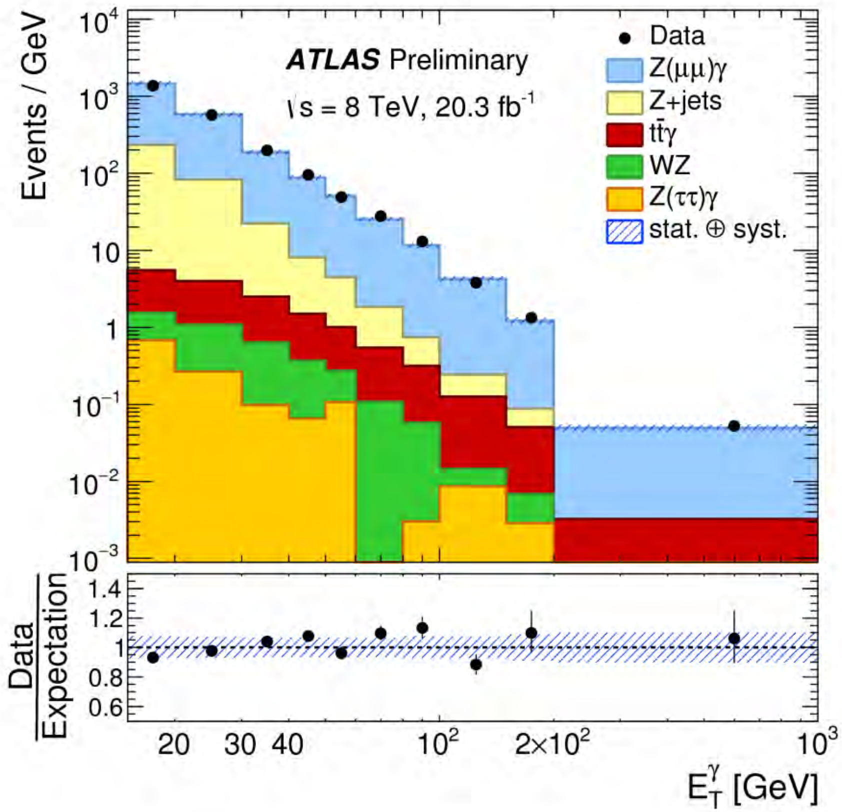


Exclusive

Kinematic distributions for llγ

Photon transverse momentum spectra for inclusive selection

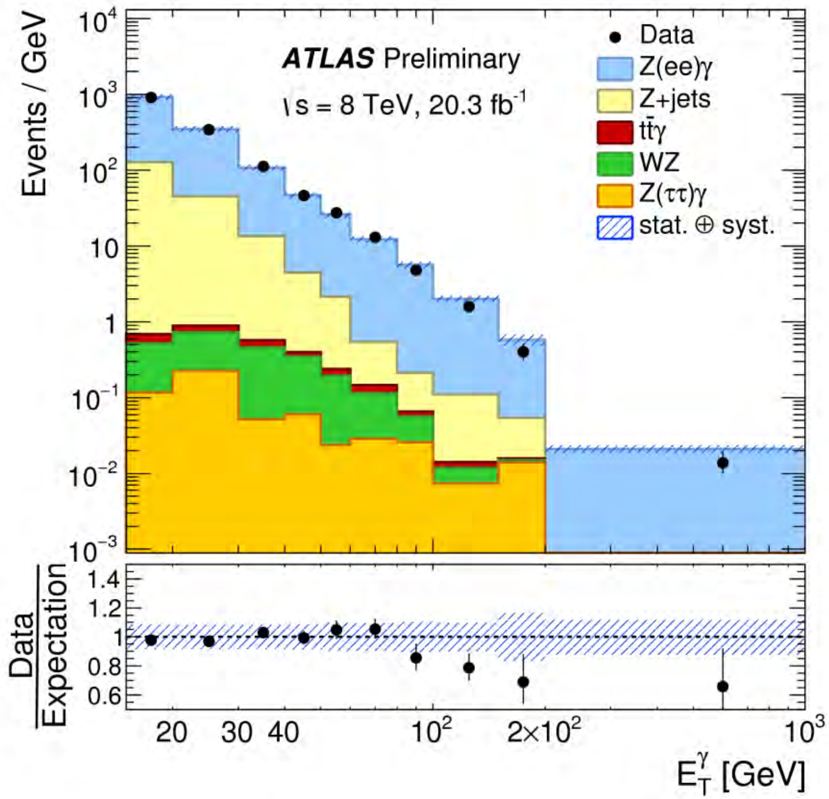


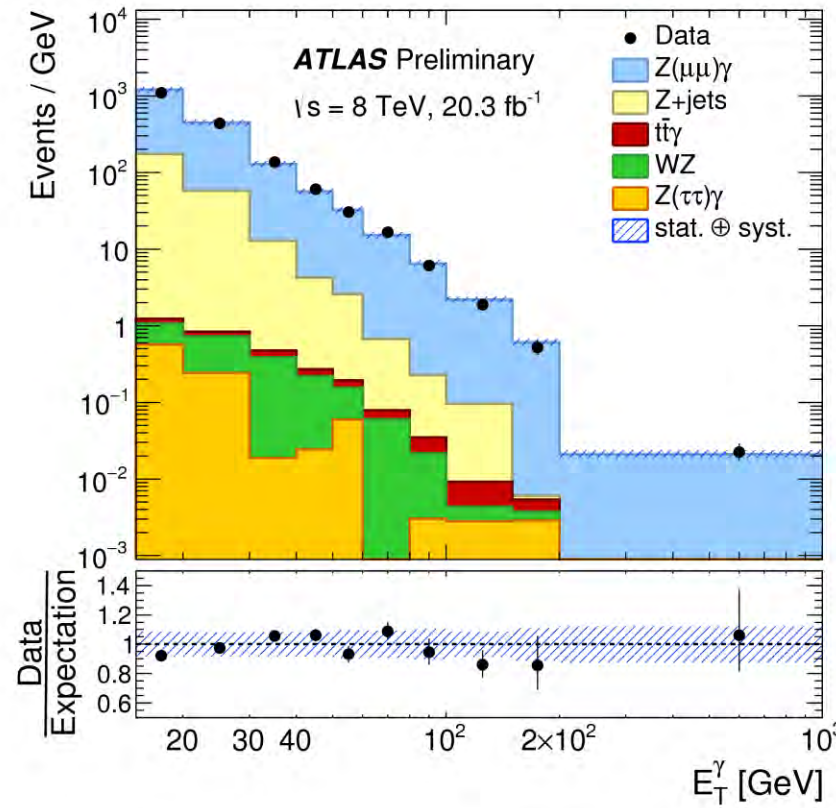


The shapes agree very well between Zγ data candidates and the expectations

Kinematic distributions for llγ

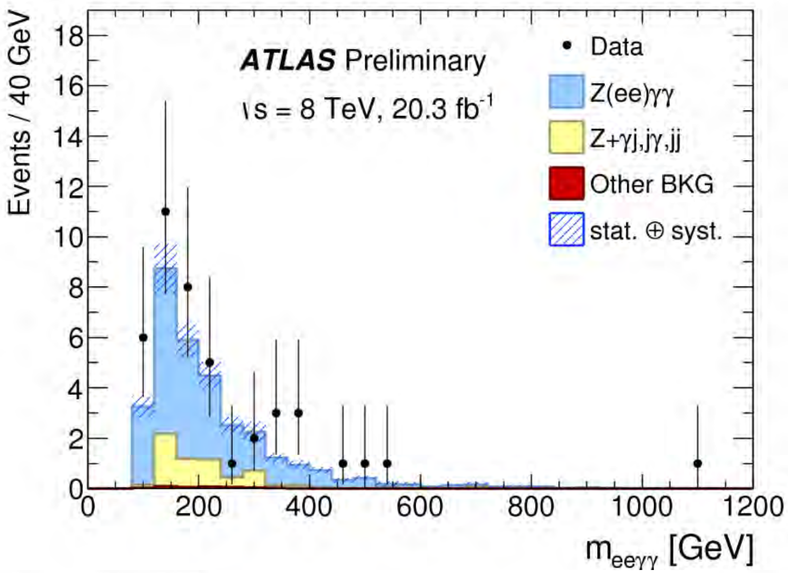
Photon transverse momentum spectra for exclusive selection

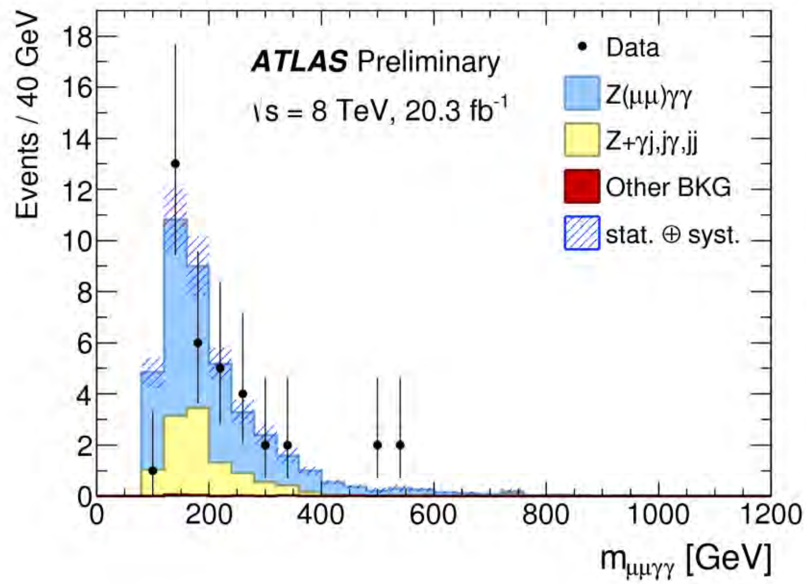


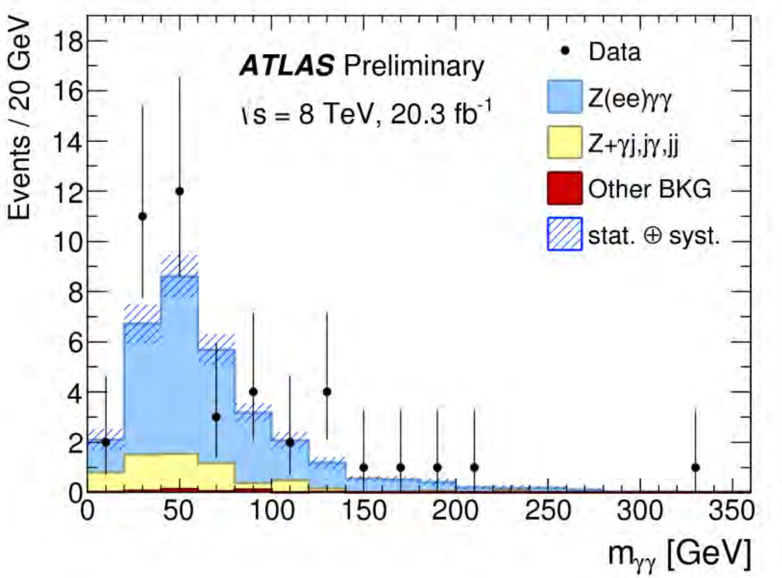


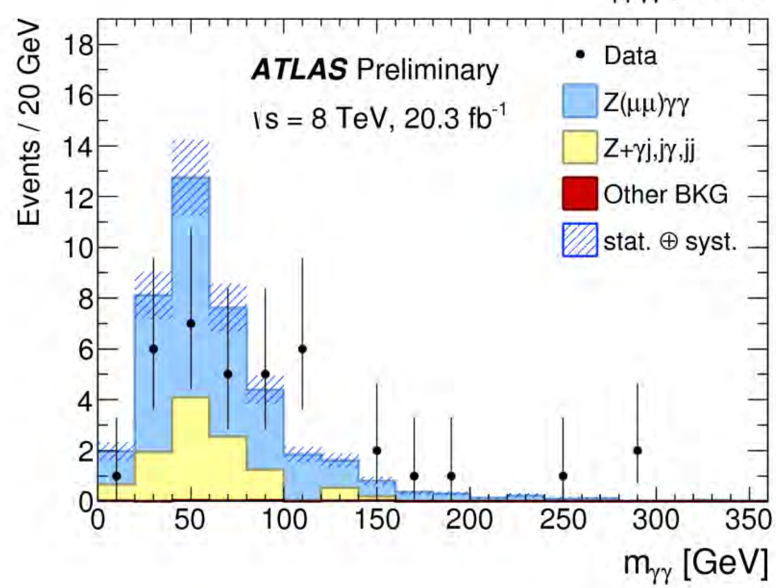
Kinematic distributions for llγγ

m[llγγ] and m[γγ] spectra for inclusive selection



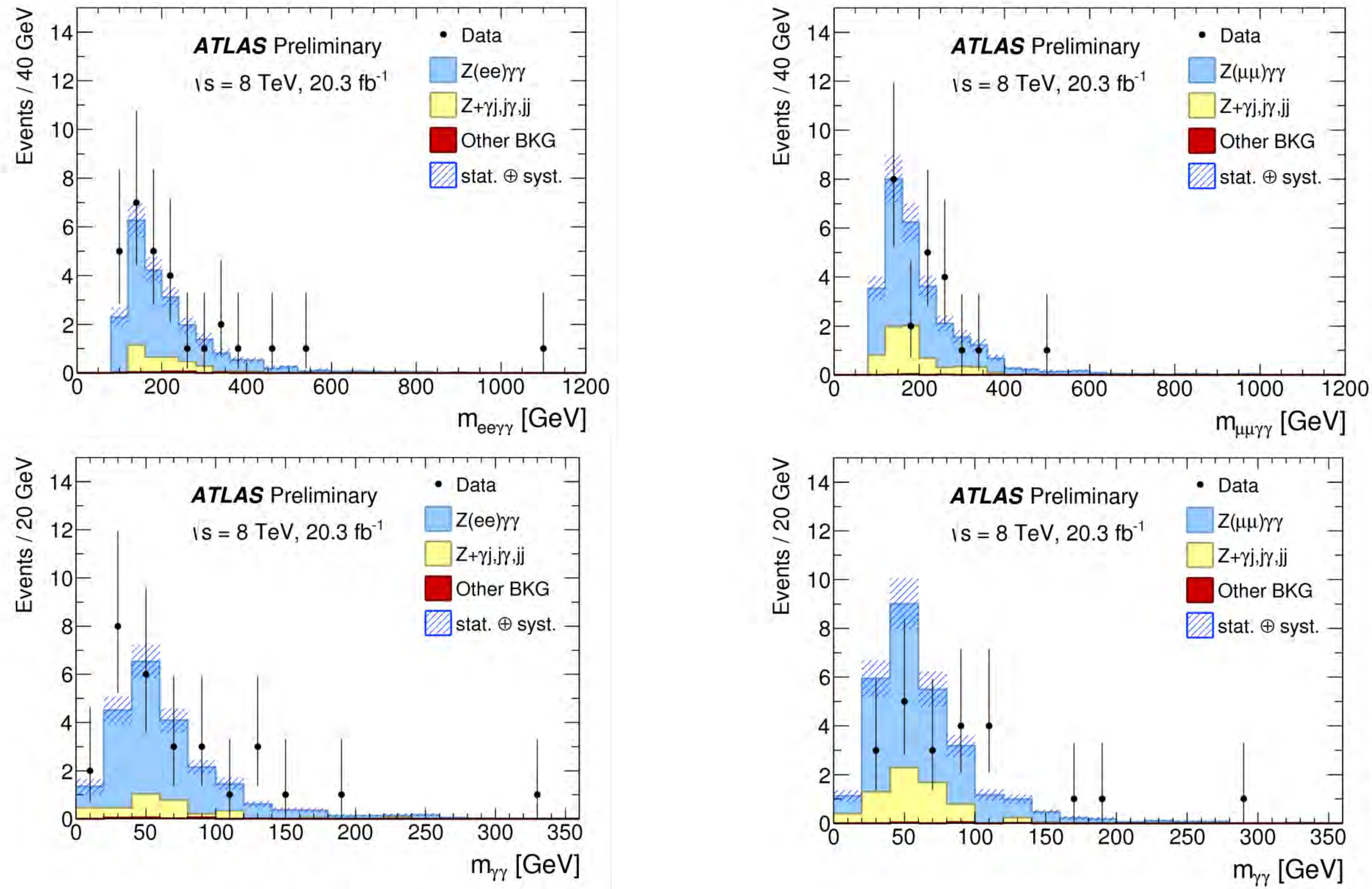






Kinematic distributions for llγγ

m[llγγ] and m[γγ] spectra for exclusive selection



Background estimation in ννγ and ννγγ

Data-driven

ννγ channel backgrounds:

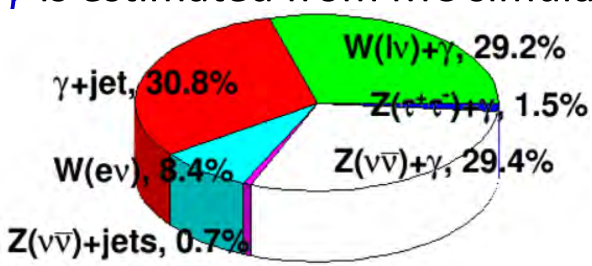
γ+jets {fake E_T(miss)} is estimated using CR region $|\Delta\phi(p_T(\text{miss}),\gamma)| < \pi/2$;

W(→lν/τν)γ – from CR region with ==1 lepton {e/μ} (normalization, shape from MC);

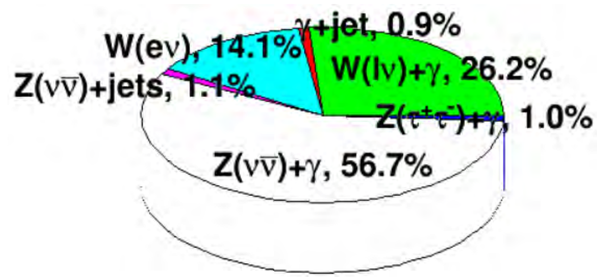
W(→eν) {e misidentified as γ} – from CR with selecting a electron instead of photon, normalization from e→γ fake rate, obtained using Z(ee) events;

Z(→ll)+jets is estimated using two-dimensinal side-band method (as for llγ);

$\tau^+\tau^-\gamma$ is estimated from MC simulation.



Inclusive

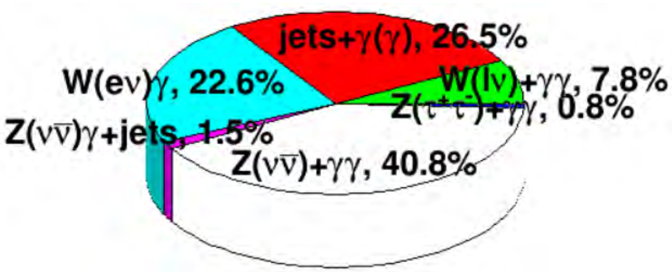


Exclusive

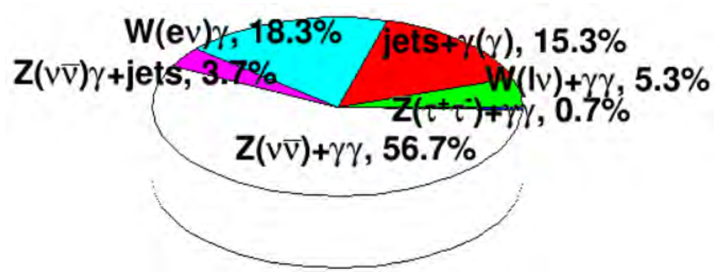
ννγγ channel backgrounds:

jets+γ(γ) is estimated using two-dimensional sideband method with E_T(miss) and photon shower shapes in the first EM layer as the two discriminants.

W(→lν/τν)γγ, W(→eν)γ, $\tau^+\tau^-\gamma\gamma$ – estimated using the same methods as for *ννγ* analogs.



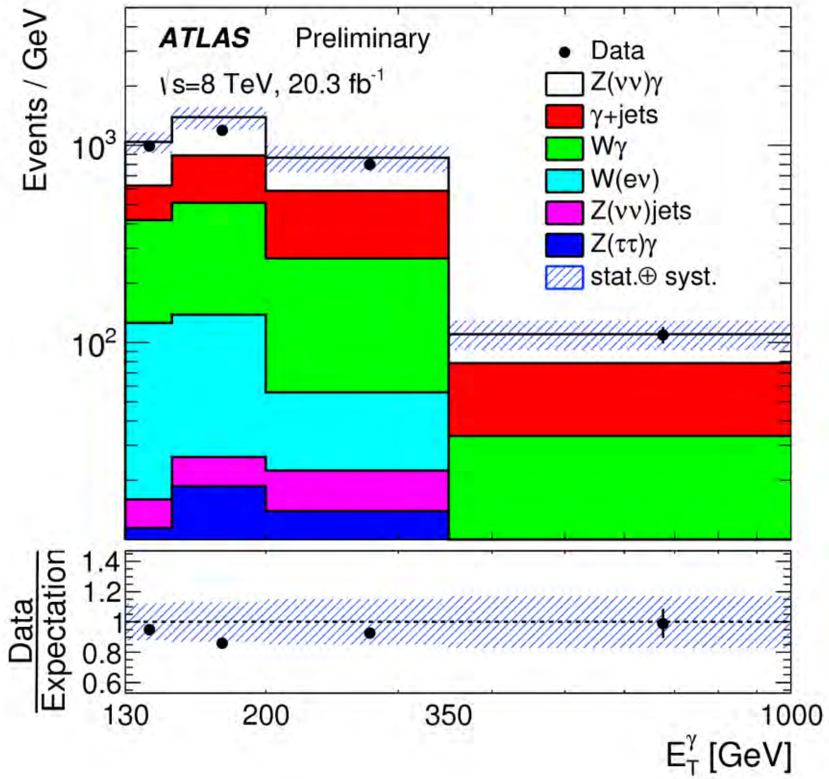
Inclusive

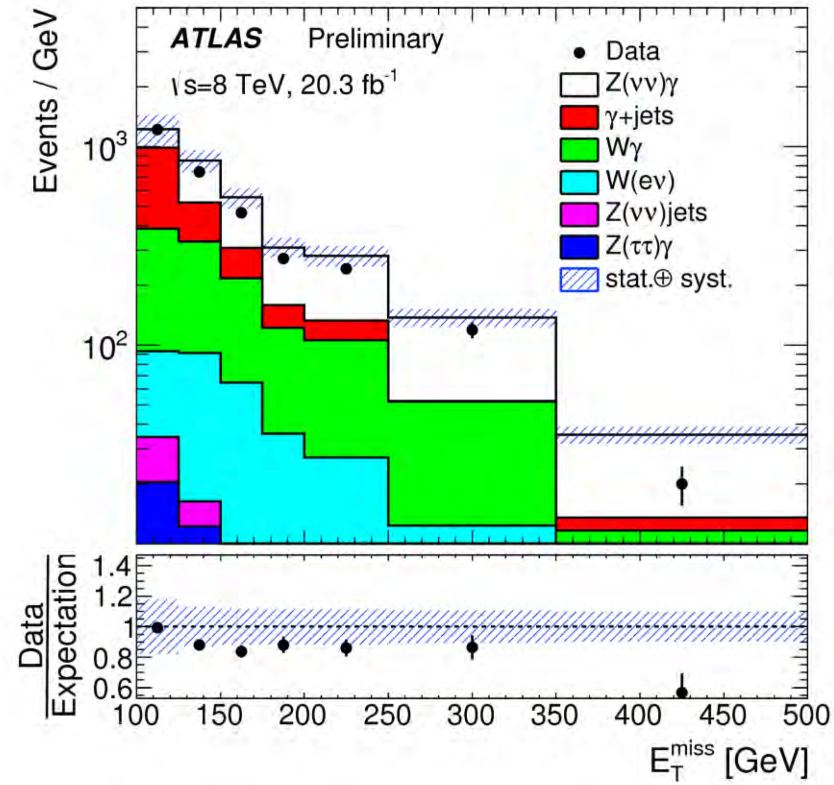


Exclusive

Kinematic distributions for $\nu\nu\gamma$

Photon transverse momentum and missing E_T spectra for inclusive selection

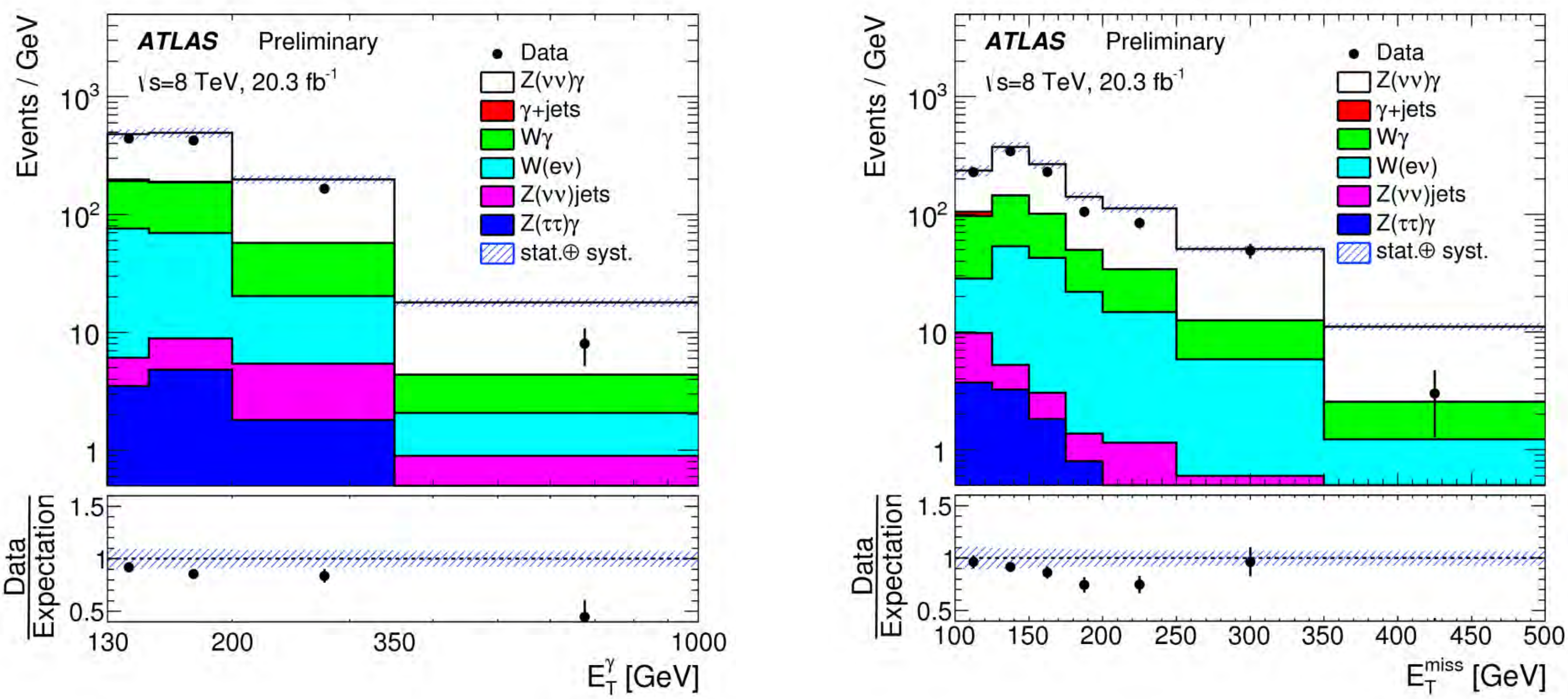




The shapes agree between Zγ data candidates and the expectations within uncertainties for most of the bins

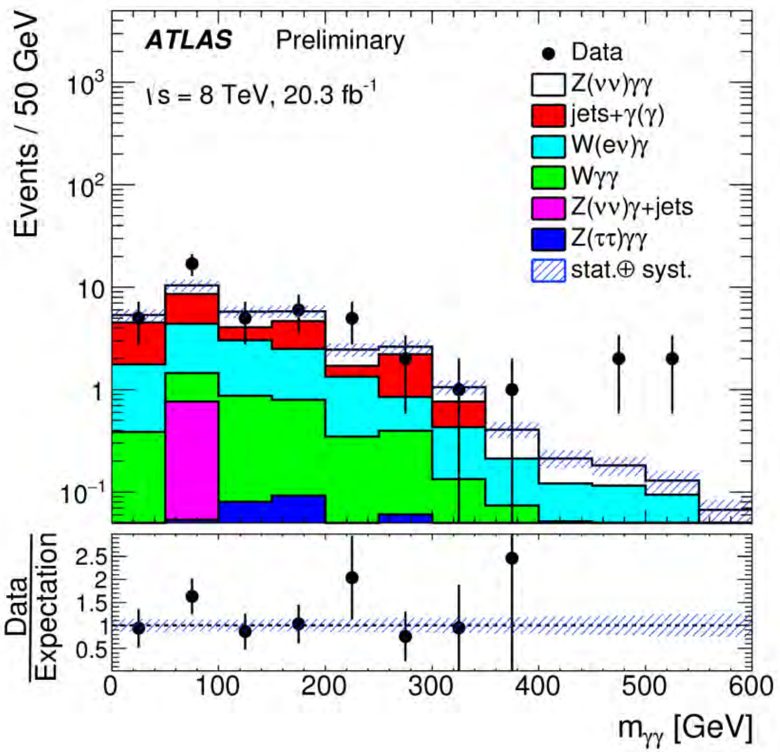
Kinematic distributions for $\nu\nu\gamma$

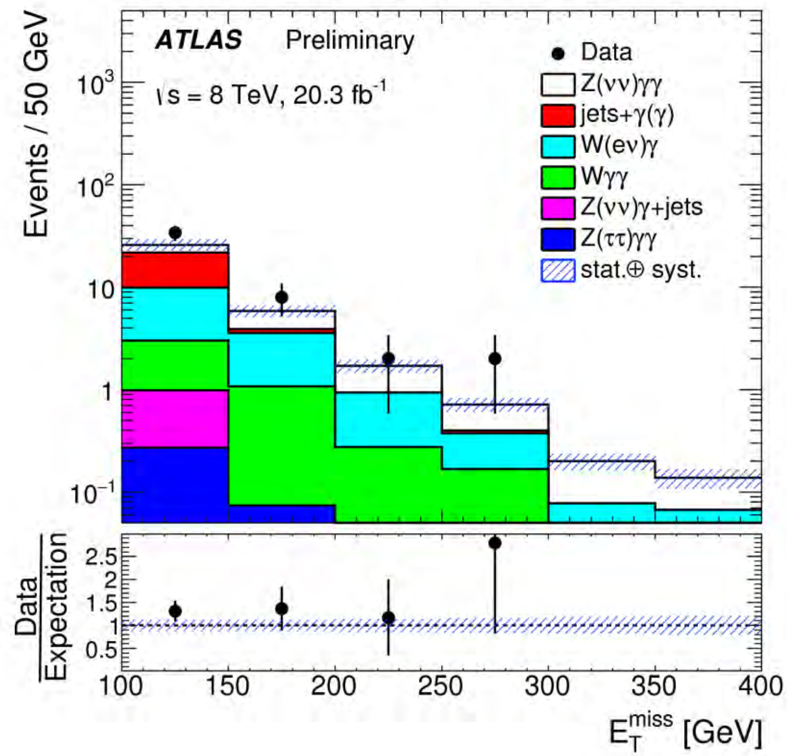
Photon transverse momentum and missing E_T spectra for exclusive selection



Kinematic distributions for ννγγ

m[γγ] and missing E_T spectra for inclusive selection

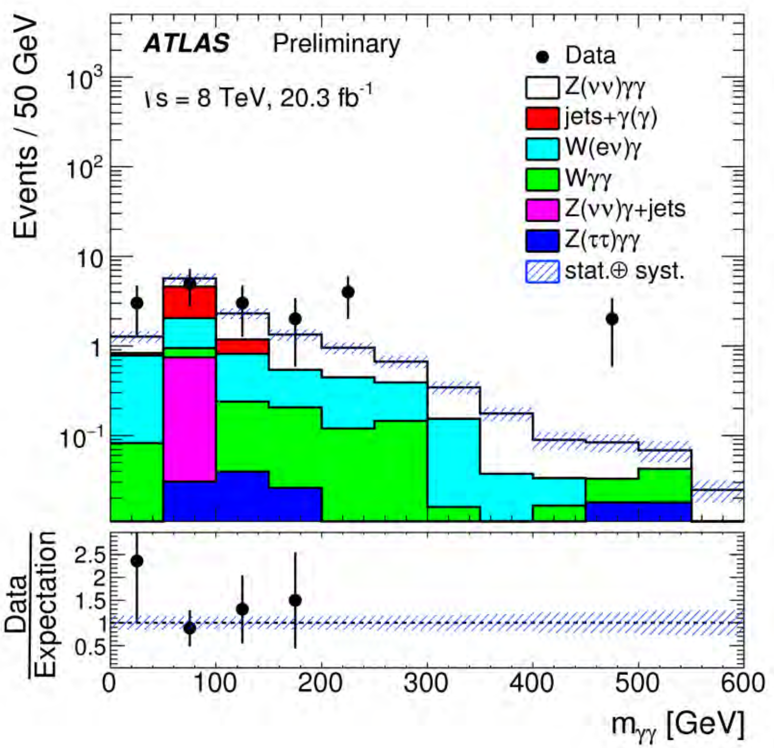


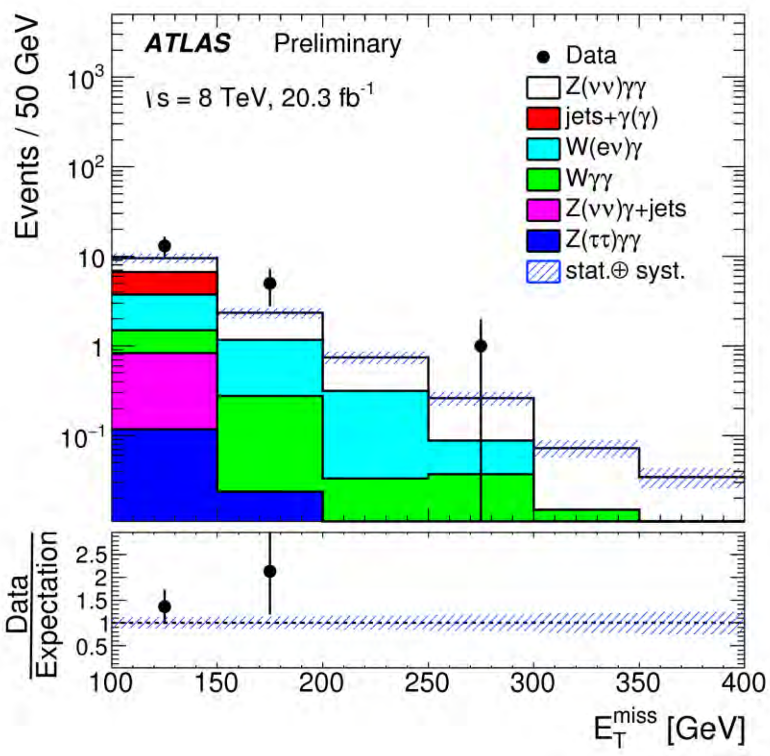


The shapes agree fairly well between Zγγ data candidates and the expectations within uncertainties

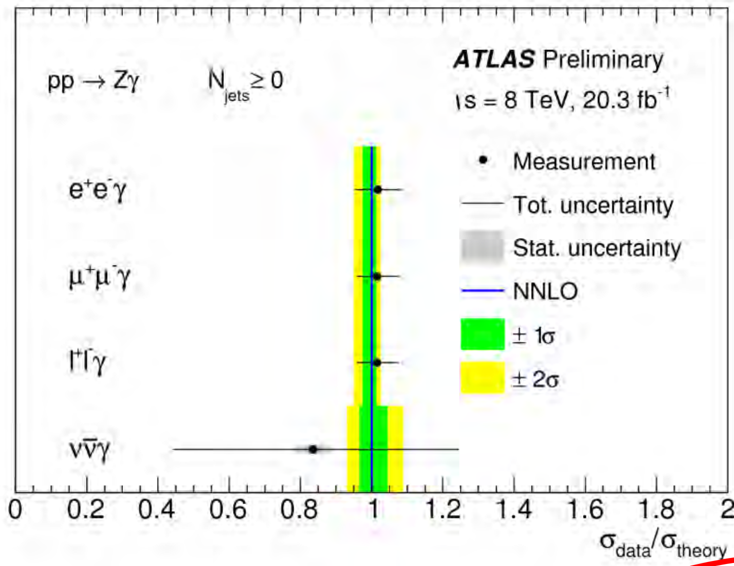
Kinematic distributions for ννγγ

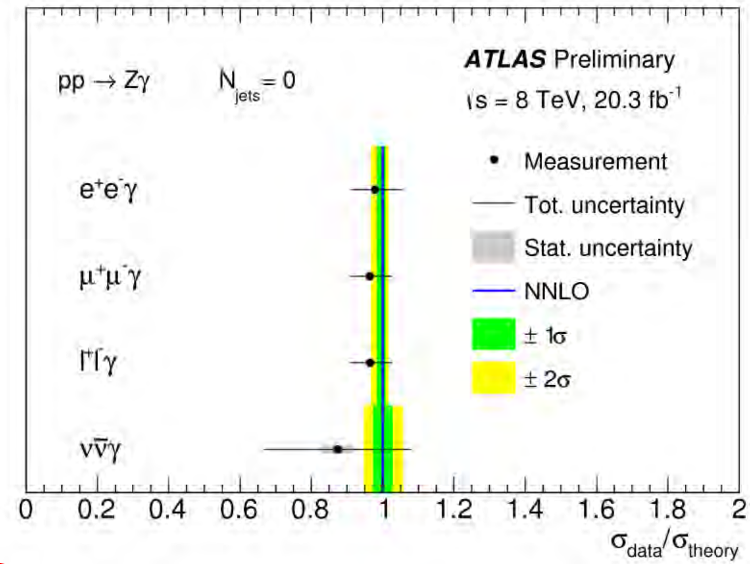
m[γγ] and missing E_T spectra for exclusive selection





Cross-sections

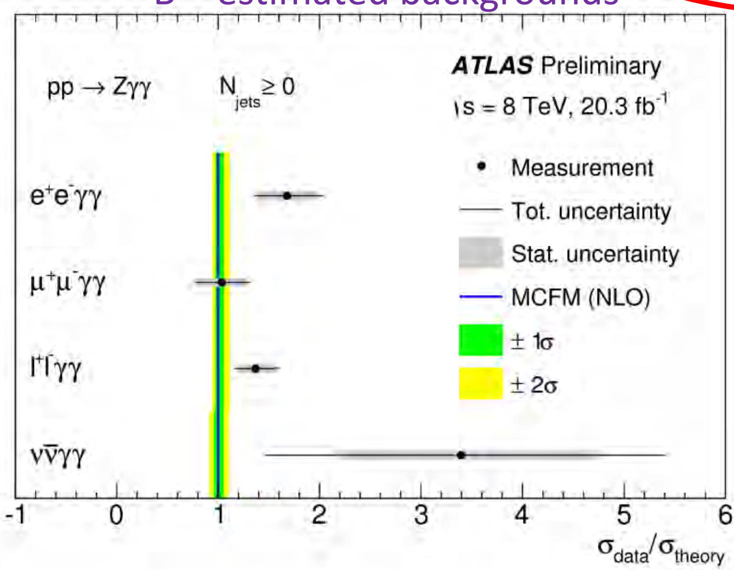


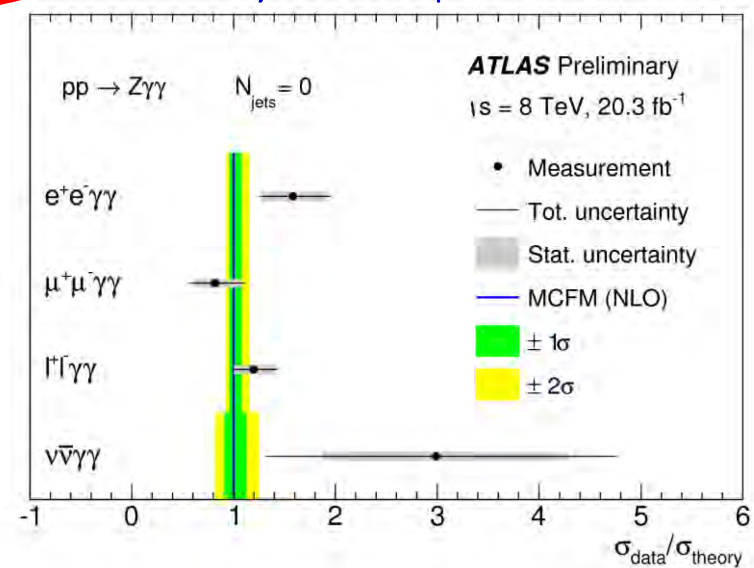


$$\sigma_{\text{ext-fid}} = \frac{N - B}{A \cdot C \cdot \int L dt}$$

B – estimated backgrounds

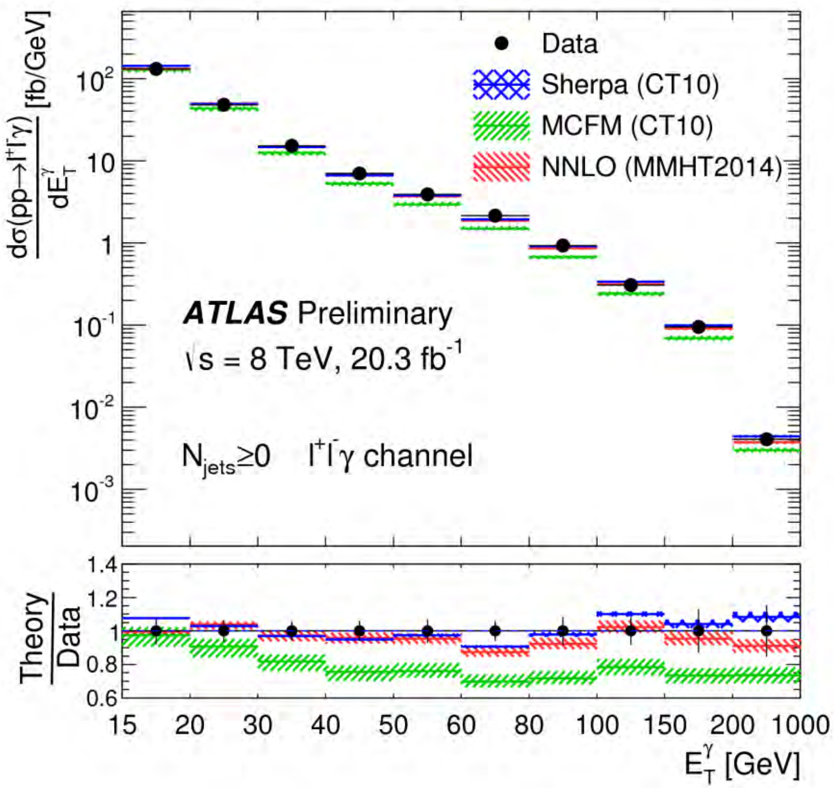
A&C – factors to correct for detection efficiency and acceptance

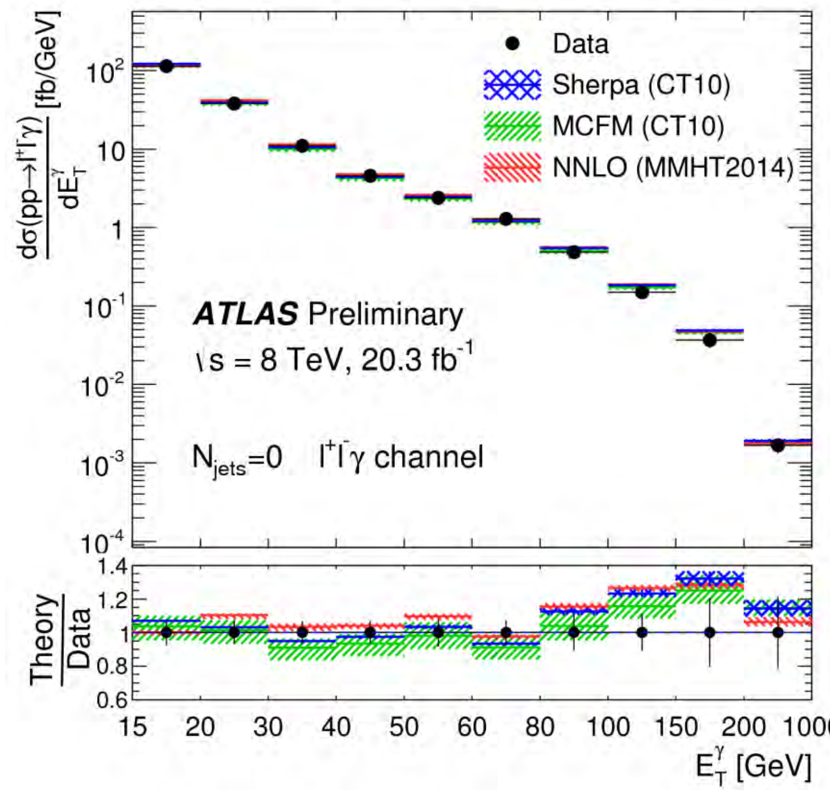




Differential cross-sections for llγ

Unfolded photon transverse momentum spectra for inclusive and exclusive selection



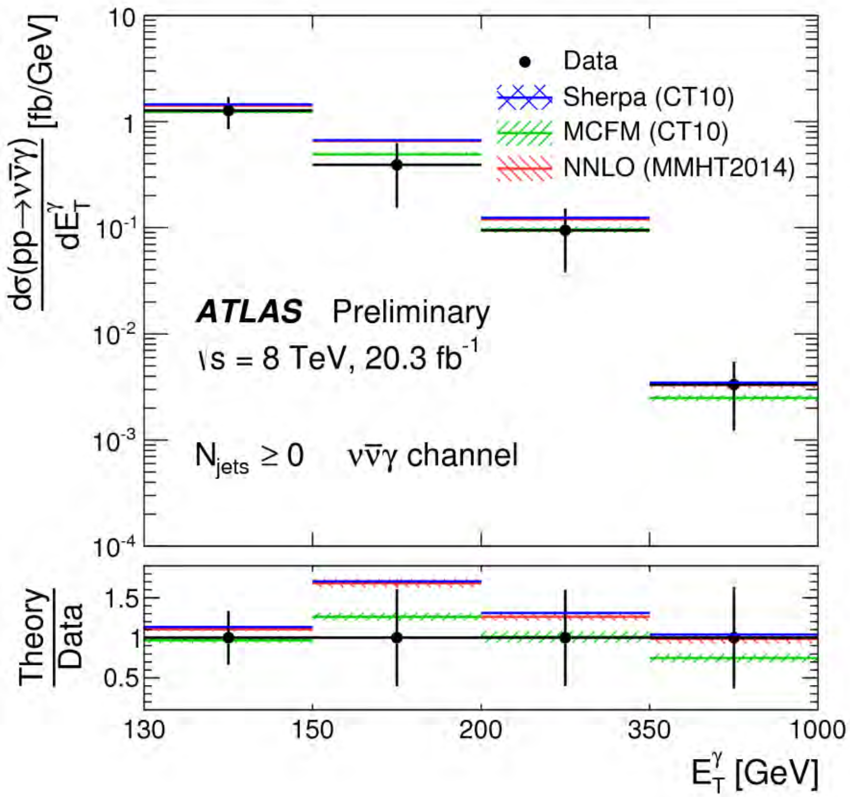


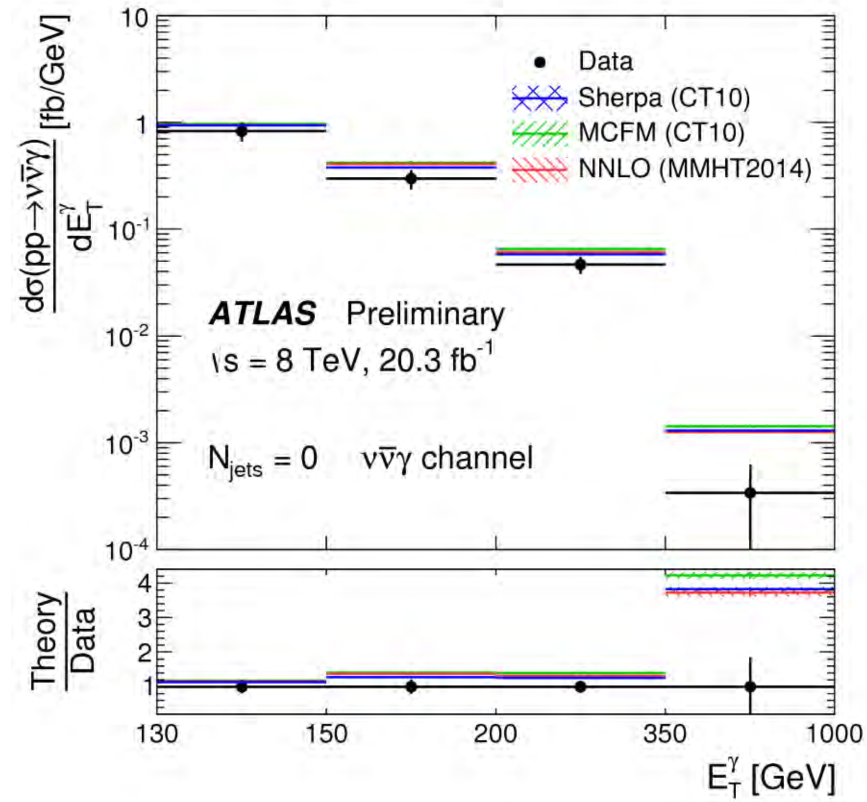
Comparison to Sherpa, MCFM and MMHT (NNLO)

Good agreement with Sherpa and MMHT NNLO for most of bins, bad agreement with MCFM NLO predictions for inclusive measurement.

Differential cross-sections for ννγ

Unfolded photon transverse momentum spectra for inclusive and exclusive selection





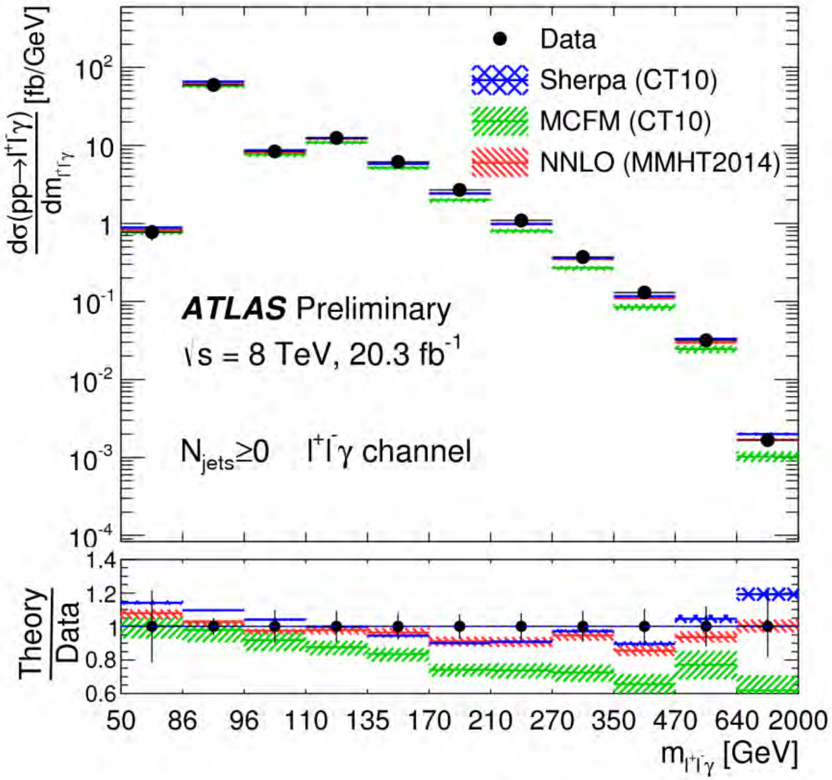
Comparison to Sherpa, MCFM and MMHT (NNLO)

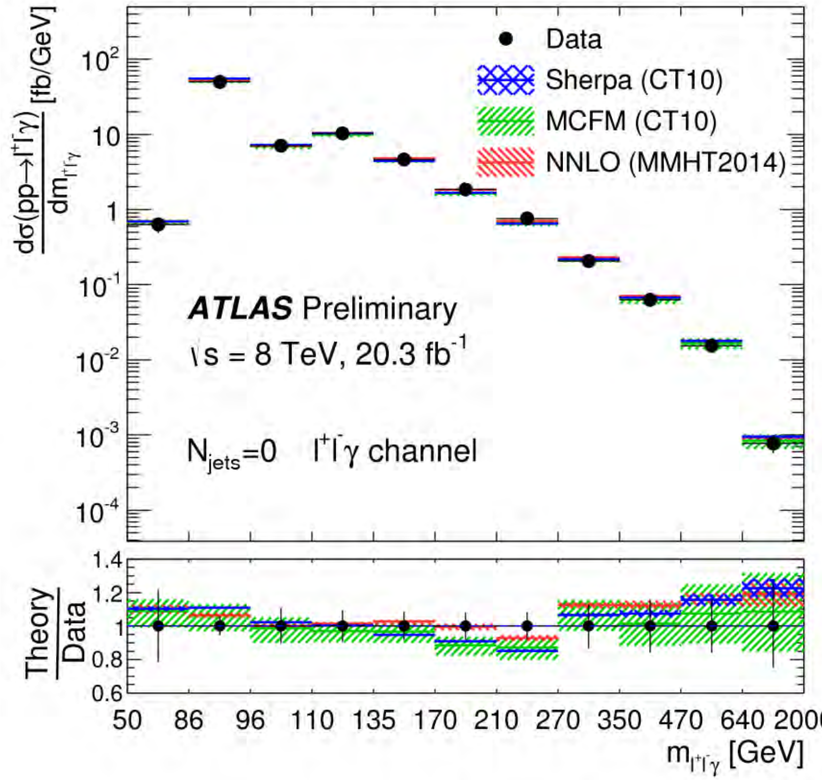
First ATLAS Z(νν)γ differential measurement

Good agreement with NLO MCFM and fair agreement with Sherpa and MMHT NNLO for most of bins within uncertainties.

Differential cross-sections for llγ

Unfolded m[llγ] spectra for inclusive and exclusive selection

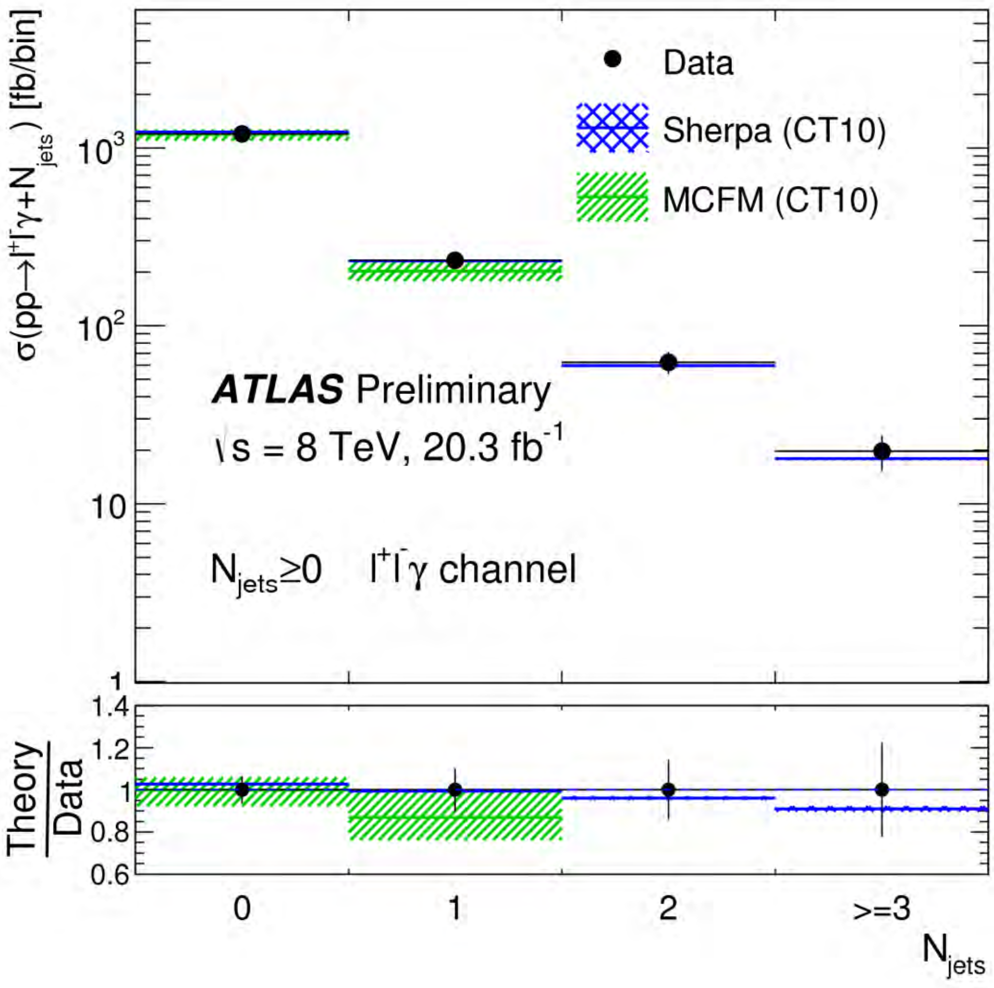




Comparison to Sherpa, MCFM and MMHT (NNLO)

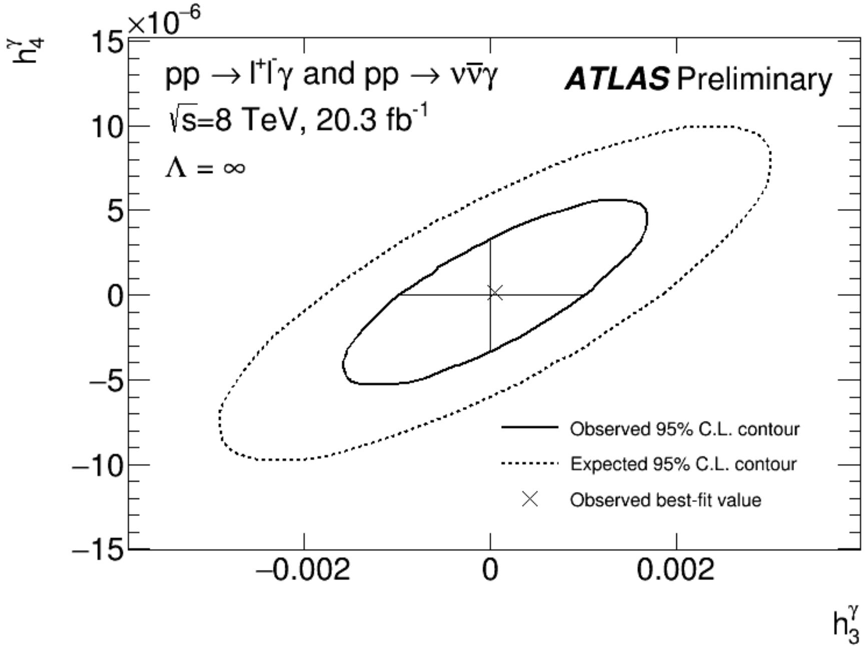
Differential cross-sections for llγ

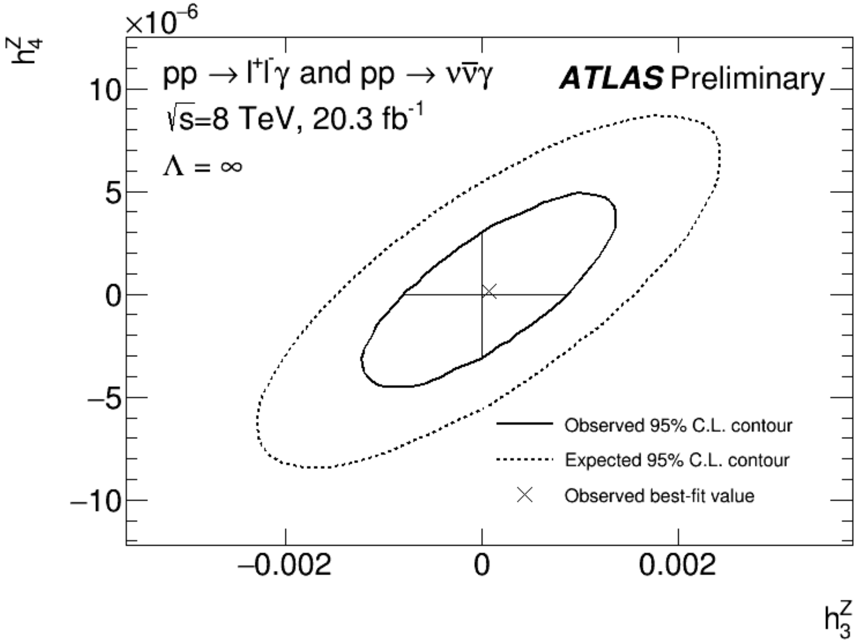
Unfolded jet multiplicity distribution



Comparison to Sherpa and to MCFM (two first bins only)

2D Limits on Anomalous Triple Gauge Couplings

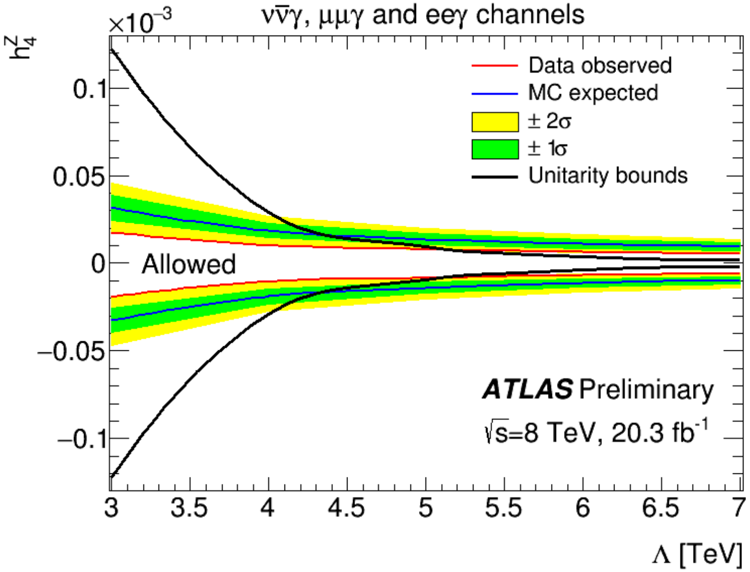


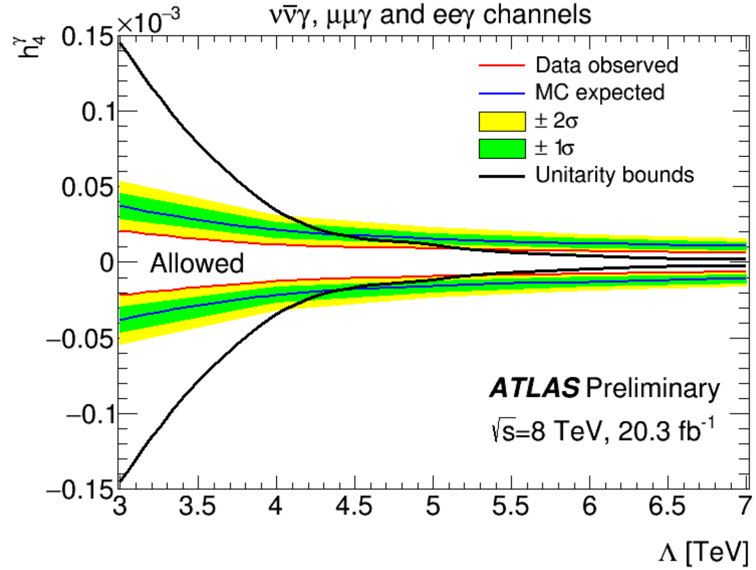


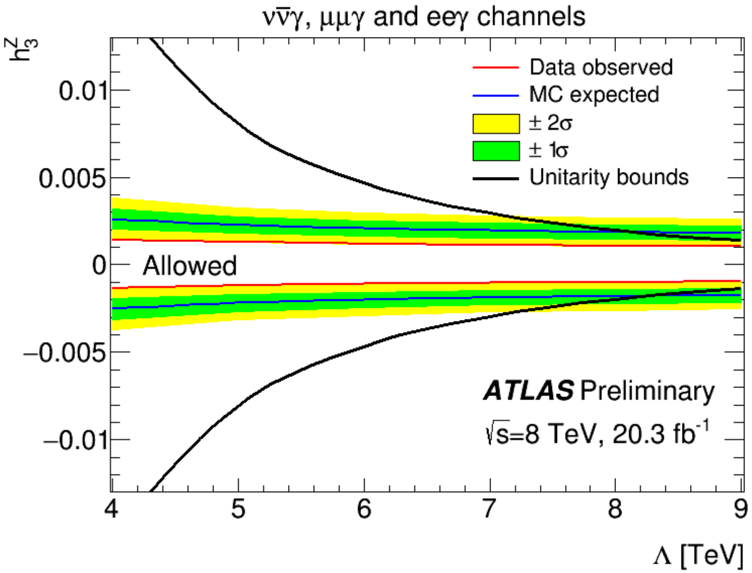
No sign of deviation from SM predictions

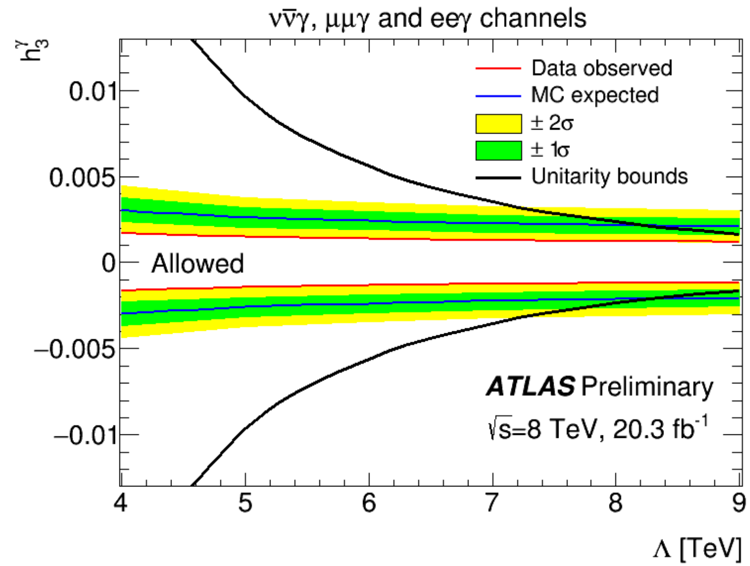
Limits on Anomalous Triple Gauge Couplings

ATGC limits dependencies vs. Λ scale



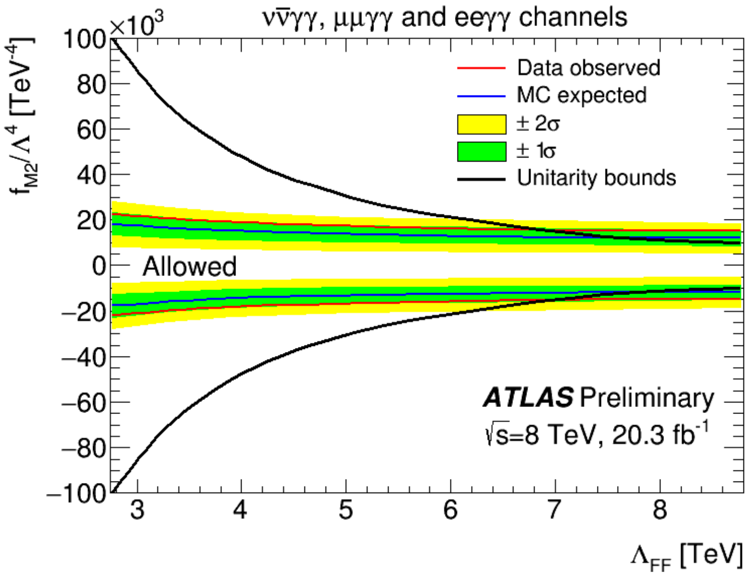


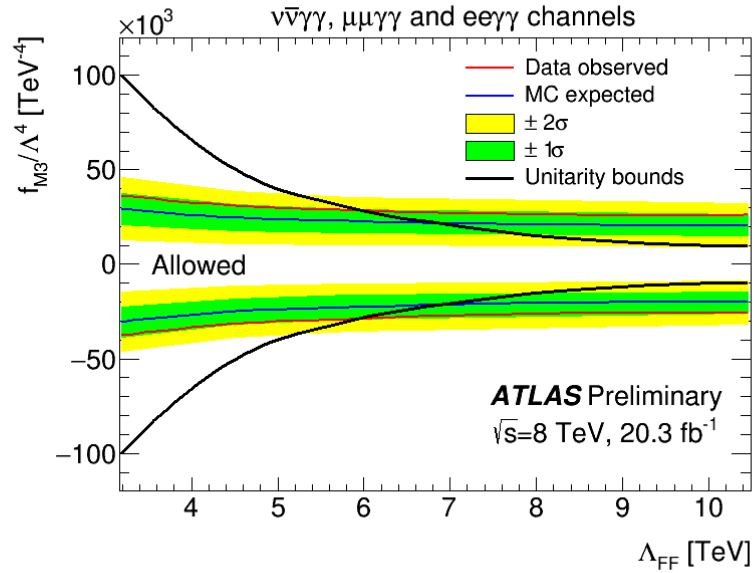


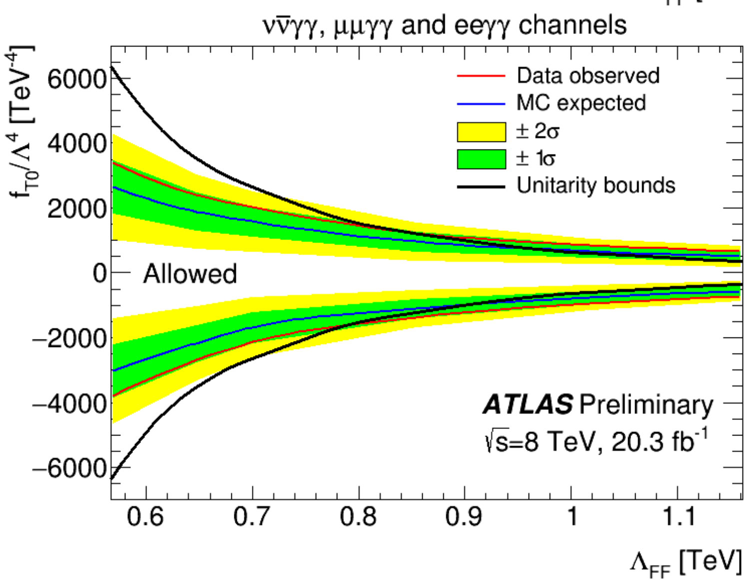


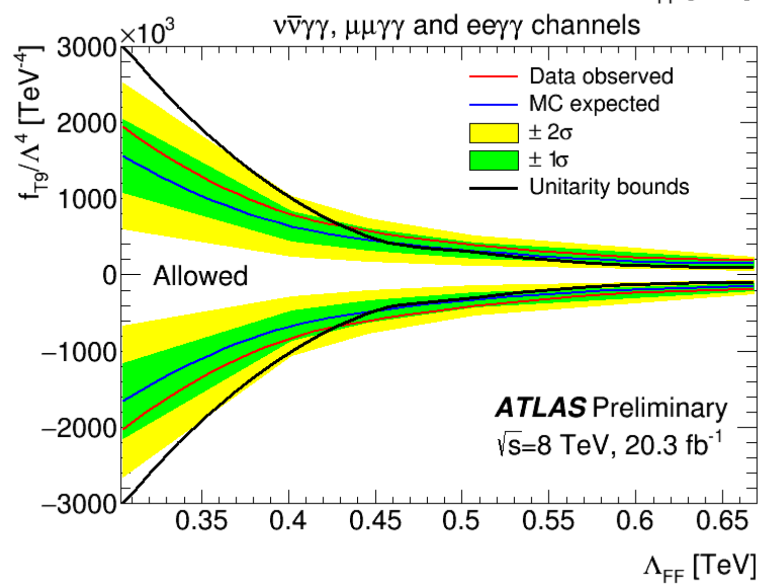
Limits on Anomalous Quartic Gauge Couplings

AQGC limits dependencies vs. Λ scale









Events signatures