Exclusive $\gamma\gamma \to WW$ measurement with the ATLAS experiment at the LHC

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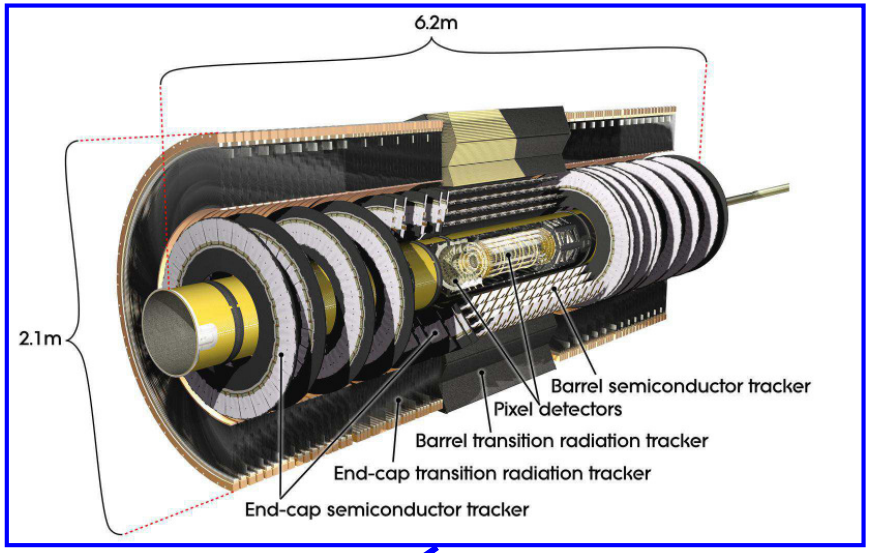
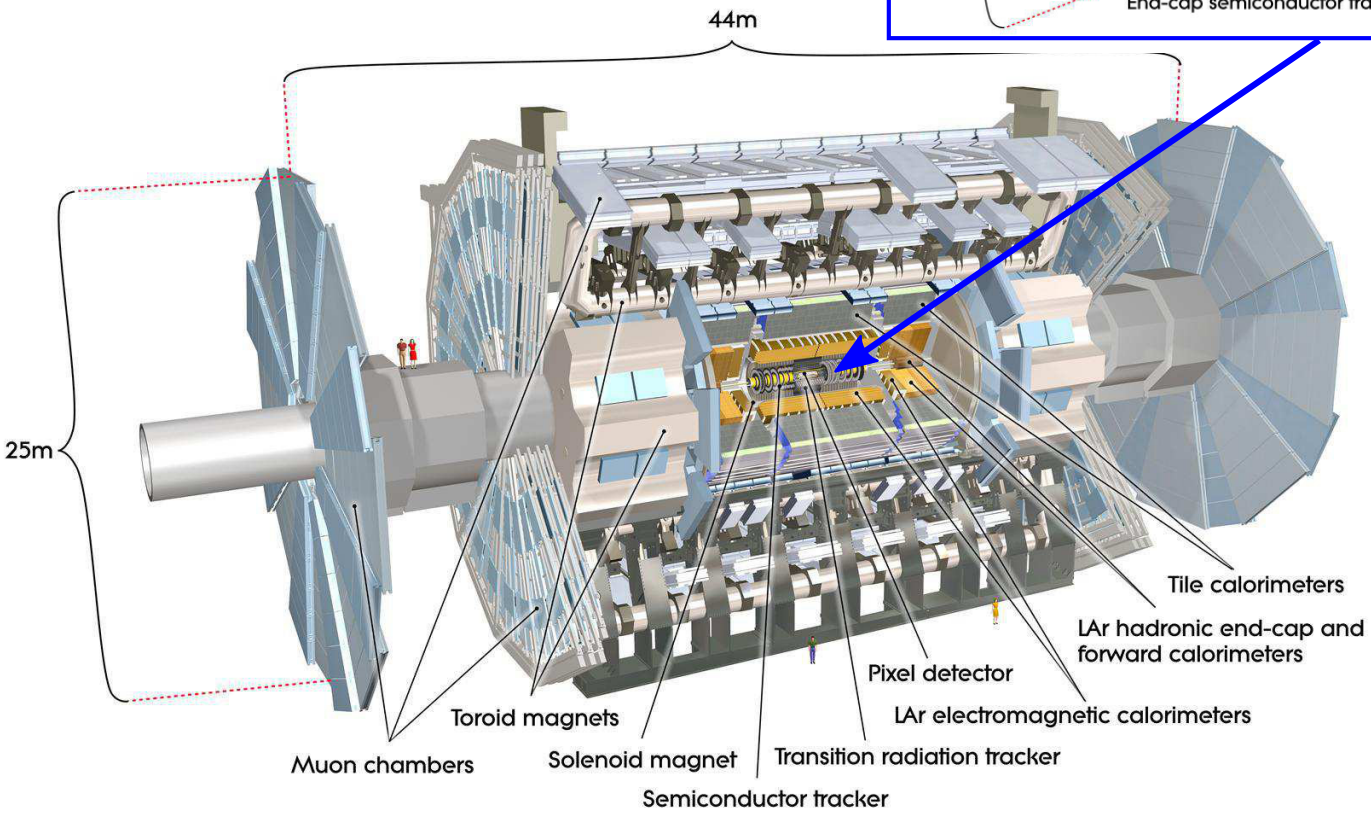
Outline

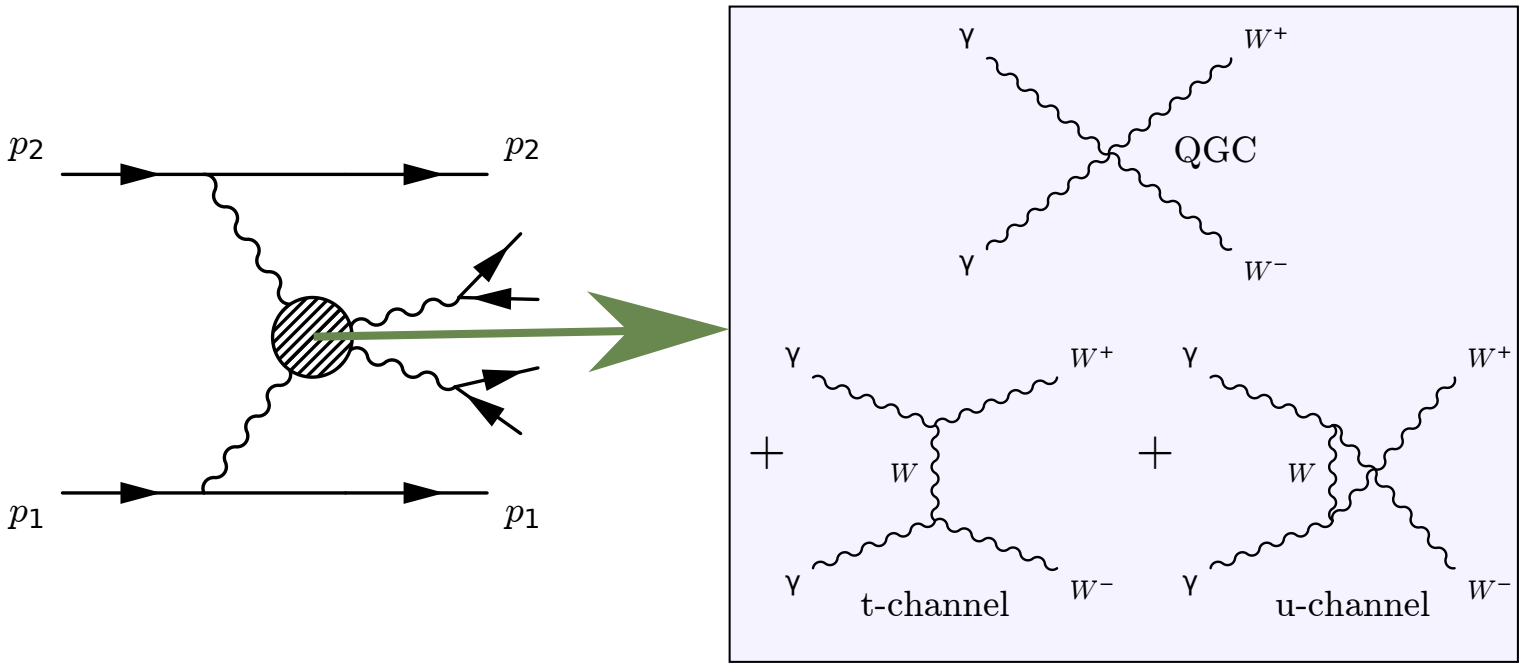
- Physics motivation
- Analysis strategy
- Monte Carlo normalization
- Preliminary results
- Summary





Physics motivation

- Sensitive to anomalous quartic gauge couplings (aQGC)
- Main goals of the analysis:
  - Measure the $p\gamma\gamma p \to pWWp$ cross-section
  - Search for evidence of new physics



Anomalous quartic gauge couplings

- We could extend the Standard Model as follows: $\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_6^0 + \mathcal{L}_6^C$

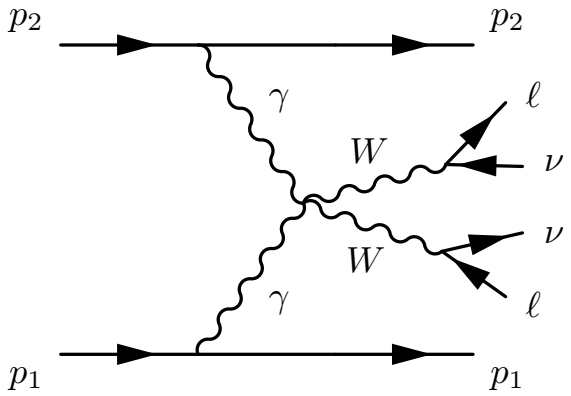
$$\mathcal{L}_6^0 = \frac{e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu}F^{\mu\nu} W^{+\alpha} W^-_\alpha - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2} F_{\mu\nu}F^{\mu\nu} Z^\alpha Z_\alpha$$

$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha}F^{\mu\alpha}(W^{+\alpha} W^-_\beta + W^{-\alpha} W^+_\beta) - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2} F_{\mu\beta}F^{\mu\beta} Z^\alpha Z_\beta$$

- $\mathcal{L}_6^0$ and $\mathcal{L}_6^C$ conserve local U(1), global SU(2), charge conjugation and parity
- Searches for the anomalous couplings a_0^W/Λ^2 and a_C^W/Λ^2 have been performed at LEP, Tevatron and CMS (7 TeV data)
- Also consider models with dimension-8 operators

Exclusive $p\gamma\gamma p \to pWWp$ production

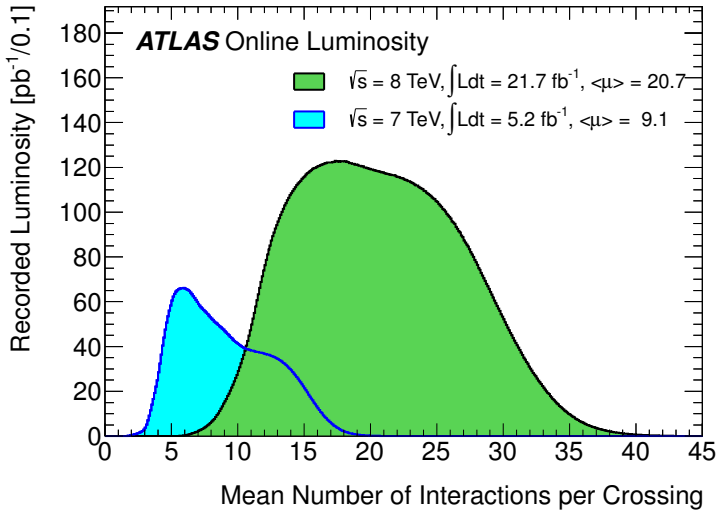
- Exclusive $p\gamma\gamma p \to pWWp \to pe\nu\mu\nu p$ production
  - Fully leptonic decay mode has a very clean signature
  - Incoming protons escape the interaction intact
  - Two lepton tracks coming from the event vertex

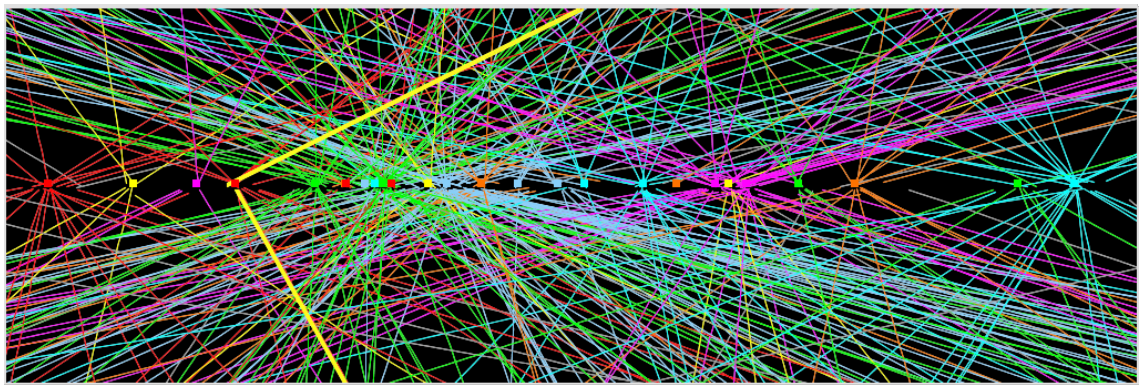


- Opposite flavour channel has 10 times less background than ee or $\mu\mu$ channel
- Main background are inclusive production of WW, $p\gamma\gamma p \to p\tau\tau p$
- Use the data taken at $\sqrt{s} = 8$ TeV by the ATLAS experiment in 2012

Event pile-up

- Many interactions occur during every LHC bunch crossing (called pile-up)
- Average pile-up during the 2012 operation was about 20, two times more than 2011
- Distinguishing the signal process from these underlying interactions is more challenging
- Strategy: Look for vertices having exactly two tracks that are isolated from other objects



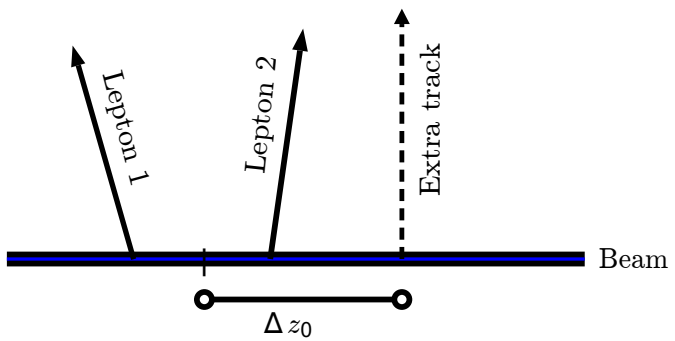


Event display showing a Z boson candidate (bold yellow tracks) with 25 reconstructed vertices

Strategy for selecting exclusive events

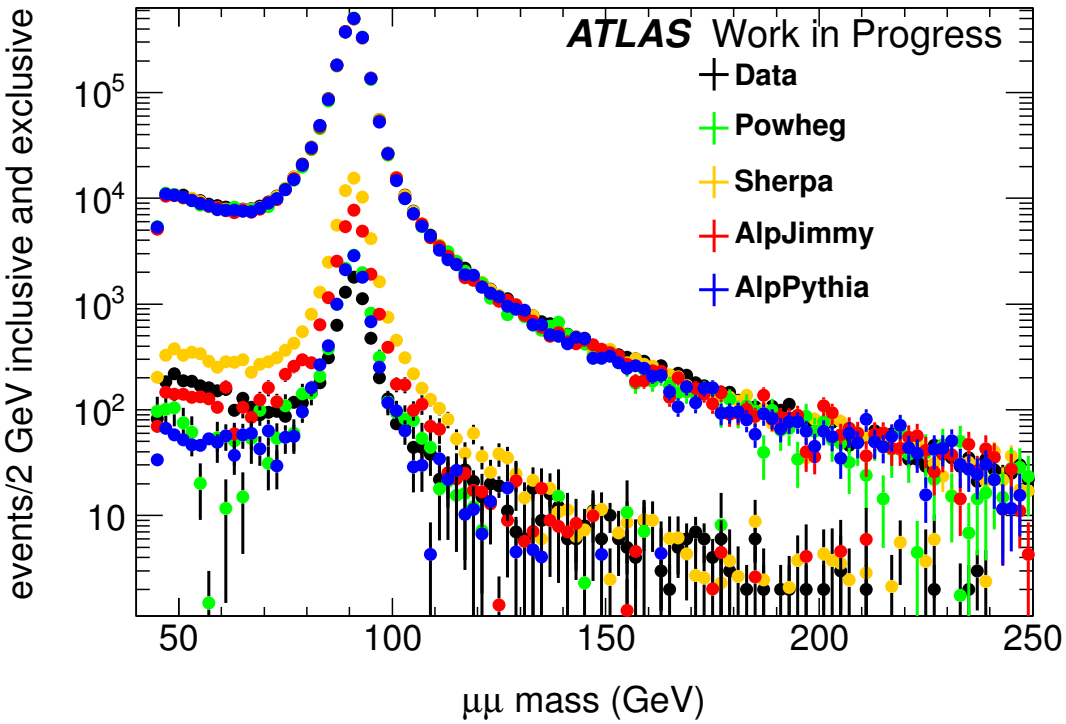
- **Track selection:**
  - Must leave some hits in the inner tracking system, to ensure good reconstruction
  - Must have $p_{\mathrm{T}} > 0.4$ GeV
- **Lepton selection:**
  - Have to be well identified electrons or muons
  - Must be reconstructed in the region covered by the inner tracking system ($|\eta| < 2.5$)
  - Must have $p_{\mathrm{T}} > 20$ GeV
- **Exclusivity selection:**
  - Select the two highest p_{T} leptons that also satisfy $m_{\ell\ell} > 20$ GeV
  - Require that the distance between the two lepton longitudinal impact parameter be $\Delta z_0(\ell, \ell) < 1$ mm
  - Reject events having tracks unmatched to the selected leptons within 1.5 mm of the event vertex
    - Track matched to a lepton if $\Delta R(\mathrm{track}, \ell) < 0.01$ and $\Delta z_0(\mathrm{track}, \ell) < 1$ mm

$$\text{Event vertex} \equiv (z_0^{\ell 1} + z_0^{\ell 2})/2$$



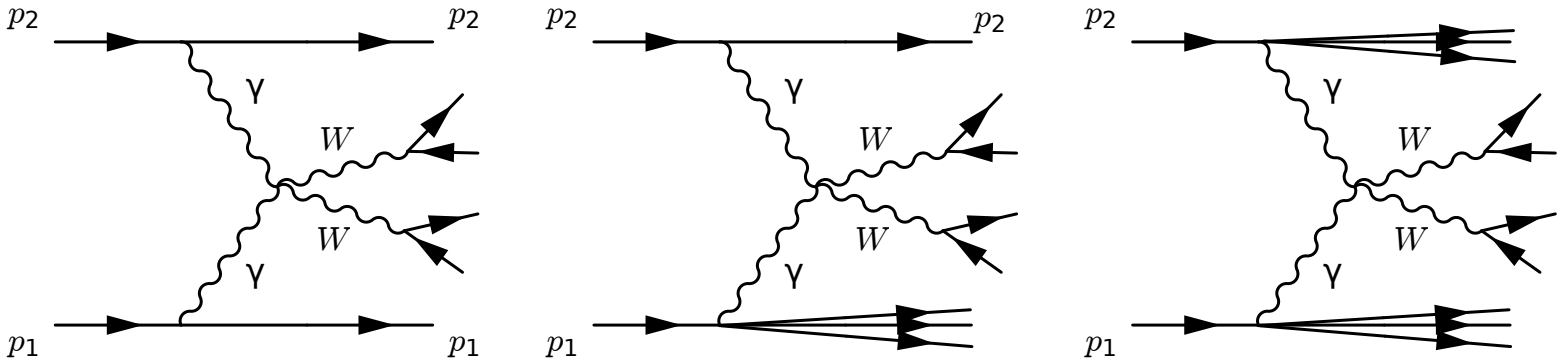
Background modelling

- MC generators don't model the track multiplicities well
- The exclusivity selection in simulation is not as efficient as in data
- We calibrate the exclusivity efficiencies using $Z \to \mu\mu$ events



Contribution from dissociative processes

- Observed $p\gamma\gamma p \to pWWp$ events come from:



Elastic | Single-dissociative (SD) | Double-dissociative (DD)

- SD and DD processes are not modelled well by MC generators
- Can estimate the SD and DD contribution from data

Strategy:

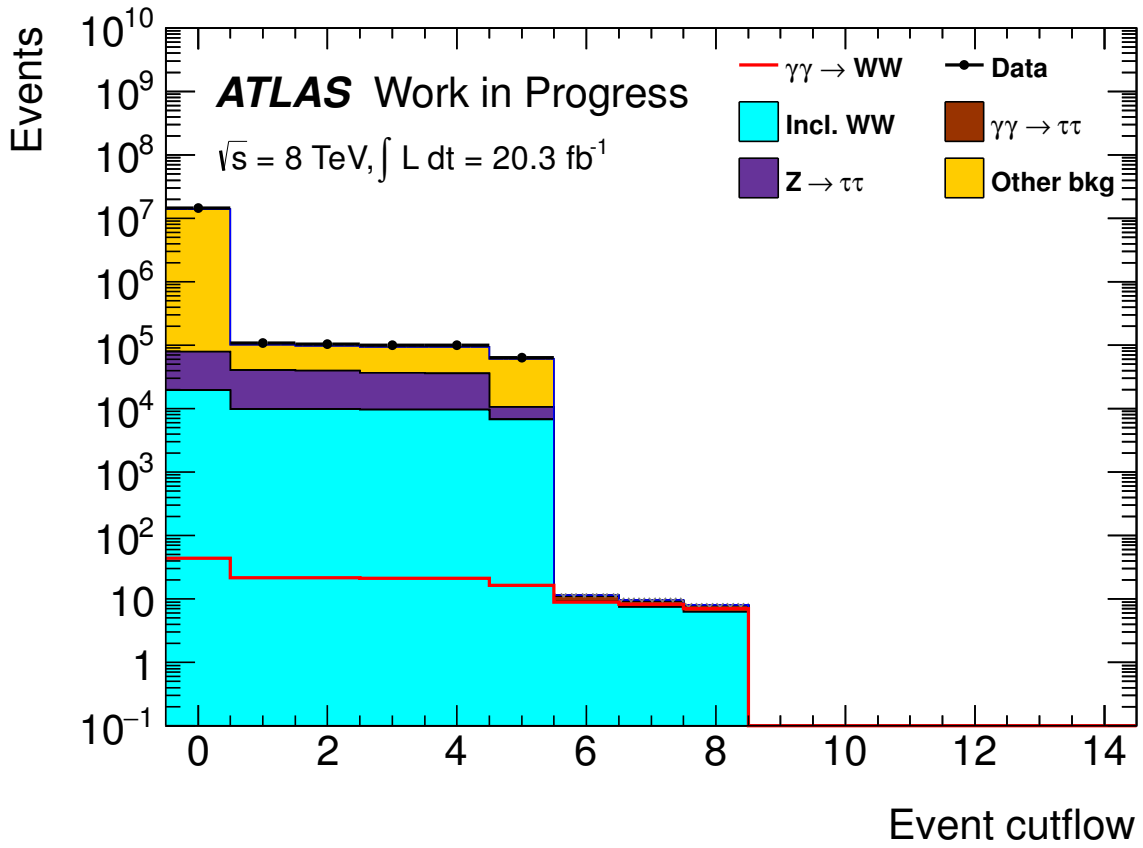
- Look at the $\mu\mu$ channel above $m_{\mu\mu} = 160$ GeV
- Compute the total $\gamma\gamma \to \mu\mu$ events (elastic + SD + DD) from data
- Count the number of elastic events from simulation
- Determine the ratio given by:

$$\frac{N_{observed} - N_{background}}{N_{elastic}}$$

- For the exclusivity selection of 1.5 mm, the ratio is 2.76 $\pm$ 0.21

Event cutflow

	Pre-selection
Cut 0	Exactly two good leptons
	Lepton $p_{\mathrm{T}} > 20$ GeV/c
	Dilepton $m_{\ell\ell} > 20$ GeV
	Signal region
Cut 1	$e\mu$ channel
Cut 2	Oppositely charged leptons
Cut 3	Leading $p_{\mathrm{T}}^{\ell} > 25$ GeV/c
Cut 4	$\Delta z_0(\ell, \ell) < 1$ mm
Cut 5	Dilepton $p_{\mathrm{T}}^{\ell\ell} > 30$ GeV/c
Cut 6	Exclusivity > 1.00 mm
Cut 7	Exclusivity > 1.25 mm
Cut 8	Exclusivity > 1.50 mm



- In the plot, the data is not shown after the exclusivity, because we are performing a blind analysis
- We are optimizing the criteria defining the aQGC signal region
- We will look at the data soon

Expected event yields

- Expected event yield with statistical uncertainties:

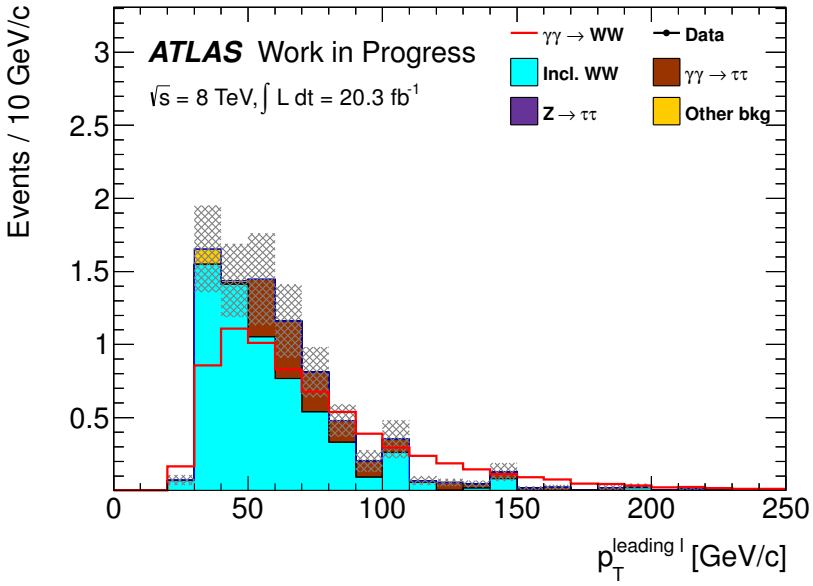
	$\gamma\gamma \to WW$	Total Bkg	Incl WW	$\gamma\gamma \to \tau\tau$	$Z \to \tau\tau$	other bkg
Exclusivity $>$ 1.5 mm	7.01 $\pm$ 0.06	8.0 $\pm$ 0.6	6.2 $\pm$ 0.5	1.7 $\pm$ 0.3	0 $\pm$ 0	0.1 $\pm$ 0.1

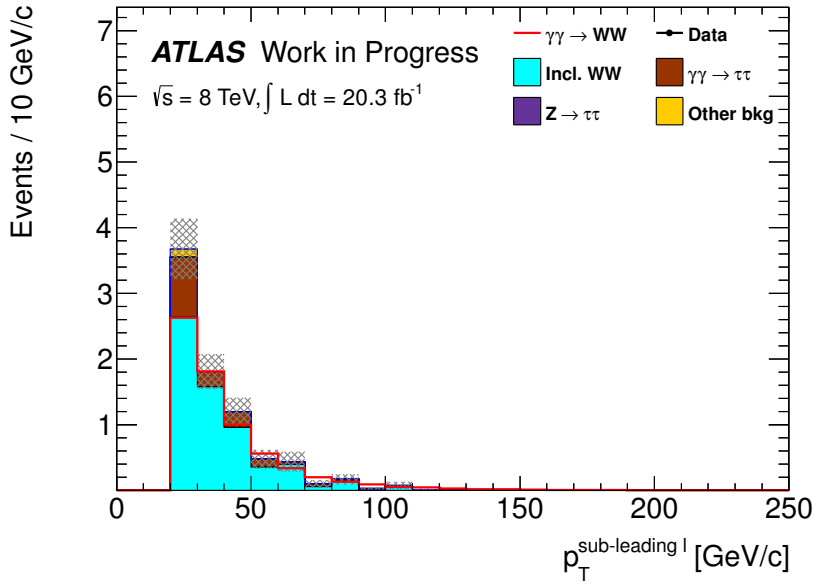
- Main background is inclusive WW production and exclusive $\gamma\gamma \to \tau\tau$.
- The QCD processes such as Z+jets, W+jets and $t\bar{t}$ are highly suppressed by the exclusivity selection
- The expected significance is

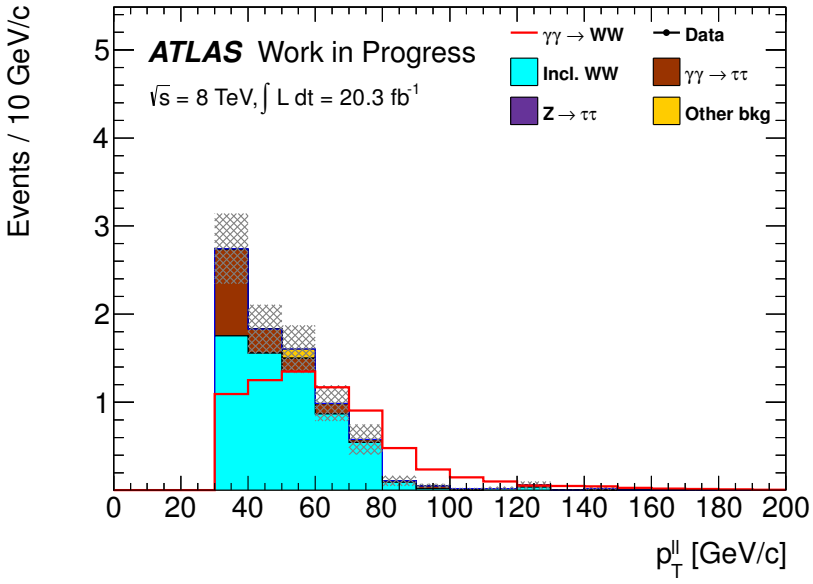
$$\frac{\text{signal}}{\sqrt{\text{signal} + \text{background}}} \approx 2$$

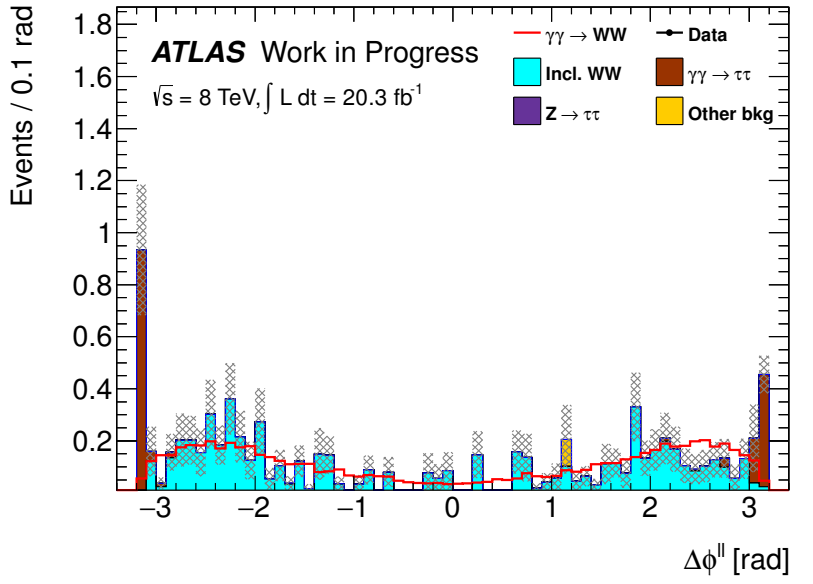
- Plan to complete the analysis and publish by the end of the year

Kinematic distributions after exclusivity of 1.5 mm



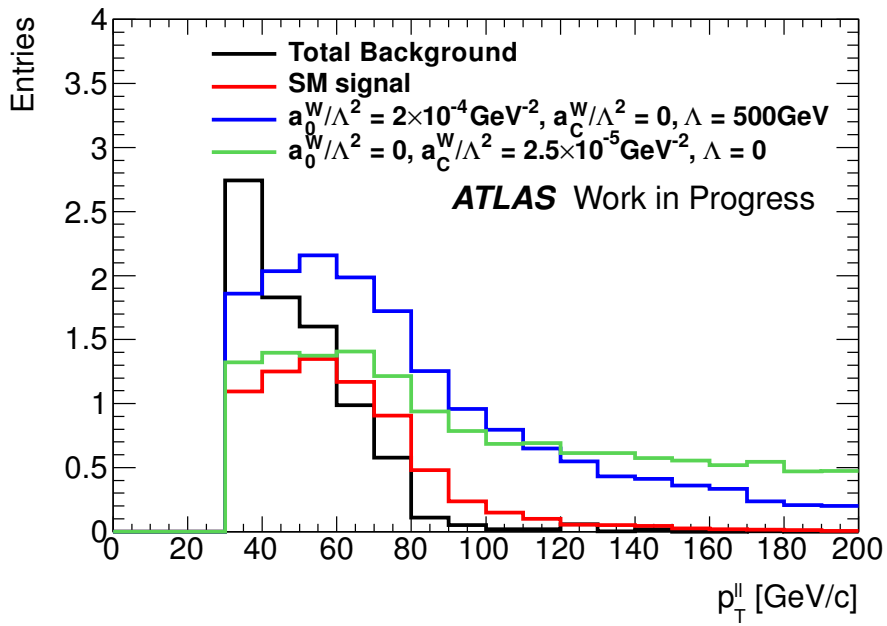


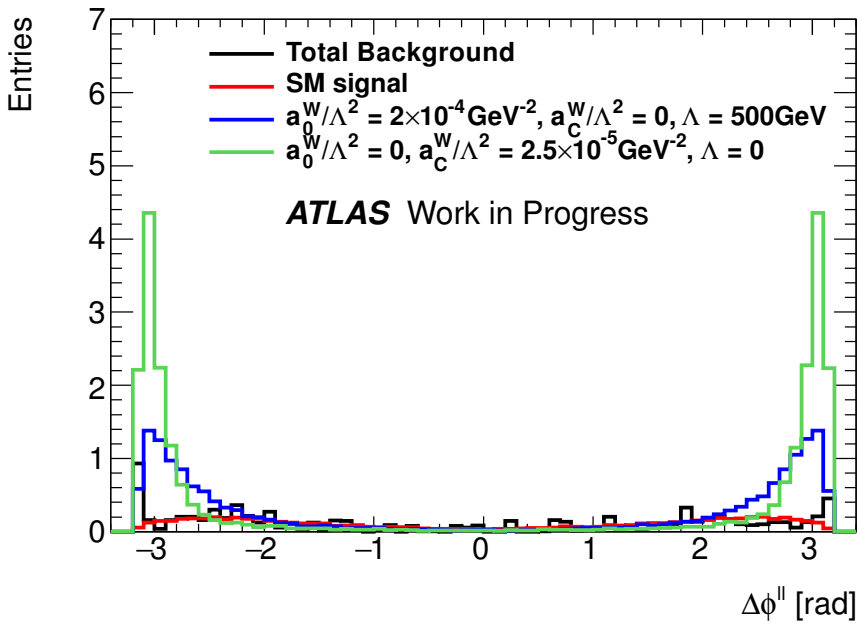




Predicted aQGC contribution

- Comparison of Standard model prediction to 2 example cases where:
  1) $a_0^W/\Lambda^2 = 2 \times 10^{-4}\ \mathrm{GeV}^{-2}$, $a_C^W/\Lambda^2 = 0$, $\Lambda_{\mathrm{cutoff}} = 500$ GeV
  2) $a_0^W/\Lambda^2 = 0$, $a_C^W/\Lambda^2 = 2.5 \times 10^{-5}\ \mathrm{GeV}^{-2}$, $\Lambda_{\mathrm{cutoff}} = 0$
- Searches for new physics can be performed in the high $p_{\mathrm{T}}^{\ell\ell}$ region, e.g. above 130 GeV, where the SM contribution is very small
- Anomalous quartic gauge couplings would increase the number of events near $\Delta\phi^{\ell\ell} = \pi$ and $-\pi$, hence no cut on this variable





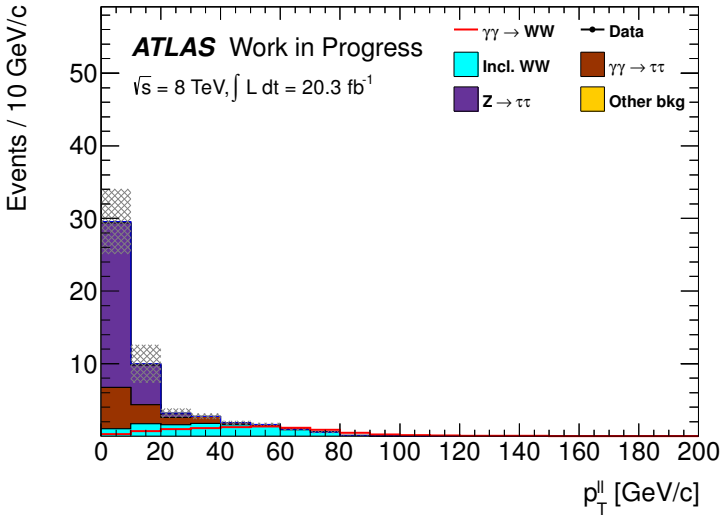
Summary

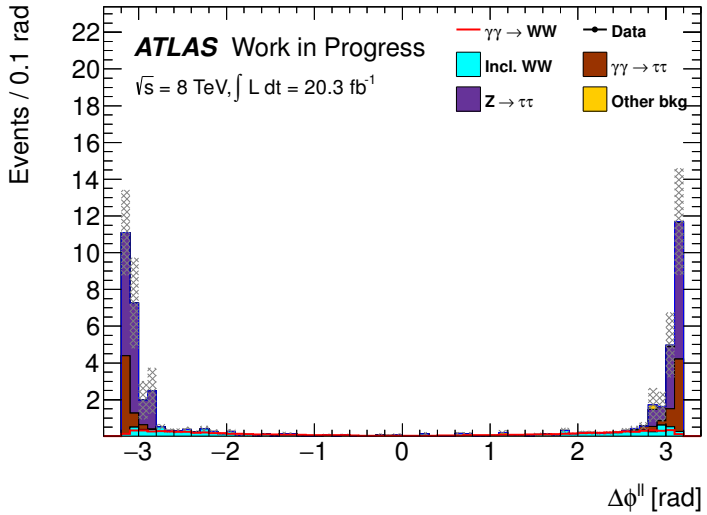
- Exclusive $p\gamma\gamma p \to pWWp$ production has a very clean signature
- This process probes the $WW\gamma\gamma$ coupling, possibly enhanced by physics beyond the Standard Model
- Preliminary studies predict 7 signal candidates over a total background of 8 events, resulting in a significance of about 2
- Plan to unblind the data soon and publish a paper by the end of the year

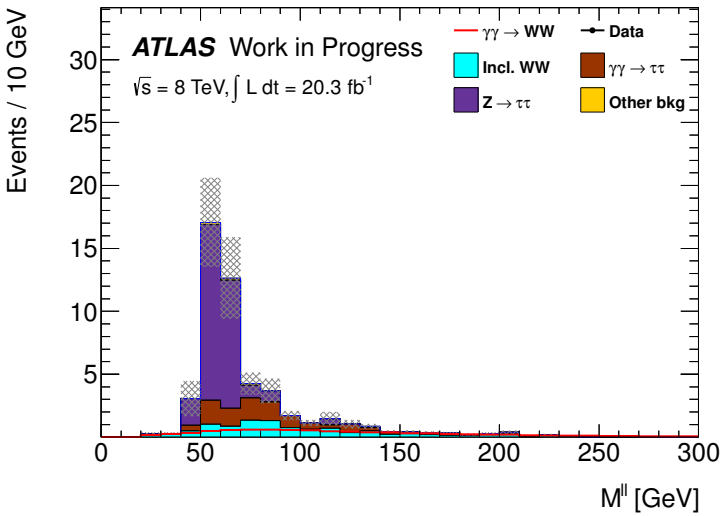
Additional materials

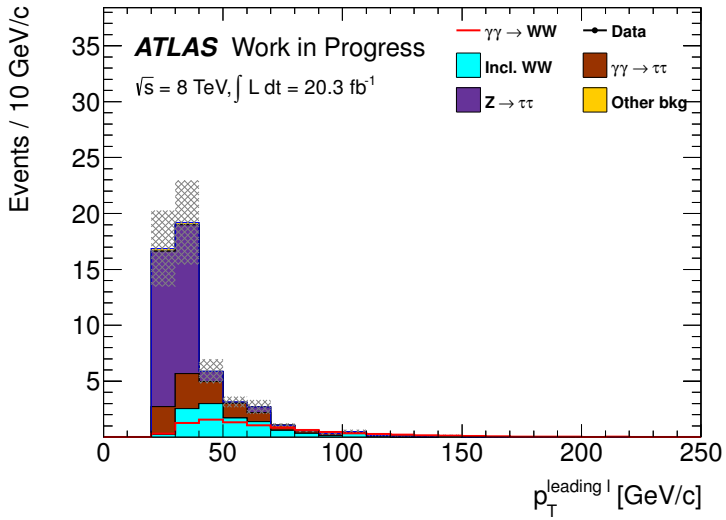
Rejection power of $p_{\mathrm{T}}^{\ell\ell}$

- Plots were produced after applying the nominal selection, except the $p_{\mathrm{T}}^{\ell\ell}$ cut
- $Z \to \tau\tau$ and $p\gamma\gamma p \to p\tau\tau p$ dominate the region $p_{\mathrm{T}}^{\ell\ell} < 30$ GeV
  - All $Z \to \tau\tau$ events are rejected by the $p_{\mathrm{T}}^{\ell\ell}$ cut, see the table in slide 11



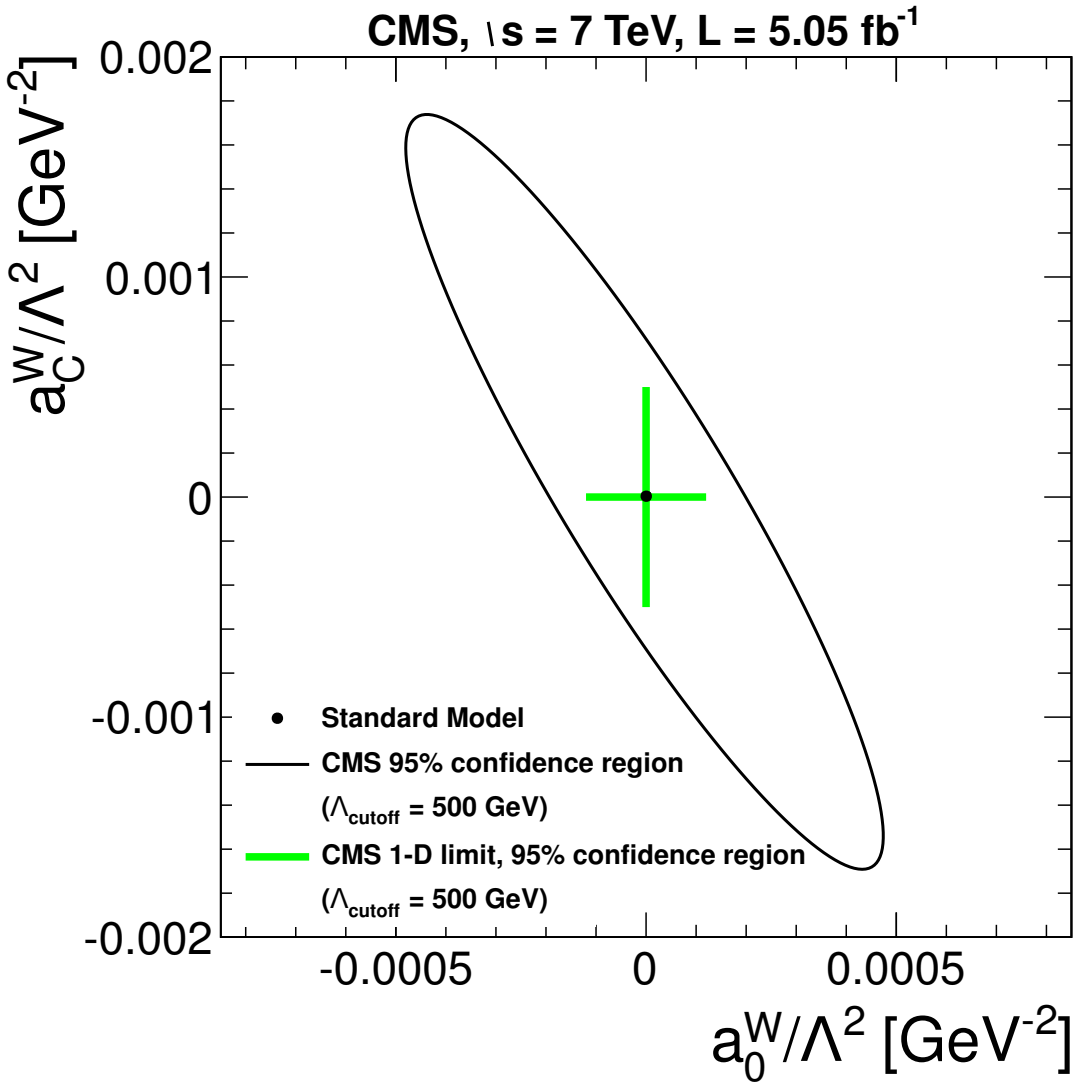






CMS limits

- Were obtained using the 2011 data, JHEP 07 (2013) 116
- Are the current most stringent experimental limits on a_0^W/Λ^2 and a_C^W/Λ^2



Unitarity constraint

- New terms $\mathcal{L}_6^0$ and $\mathcal{L}_6^C$, introduced in slide 4 can lead to unitarity violation at high energy
- One solution is to modify the parameter a_0^W and a_C^W as follow

$$a_0^W \to \frac{a_0^W}{\left(1 + \frac{s}{\Lambda_{\text{cutoff}}^2}\right)^p}$$

$$a_C^W \to \frac{a_C^W}{\left(1 + \frac{s}{\Lambda_{\text{cutoff}}^2}\right)^p}$$

- The parameter s is the $\gamma\gamma$ center-of-mass energy
- Previous studies, done at LEP and CMS, set Λ_{cutoff} to 500 GeV and p to two