

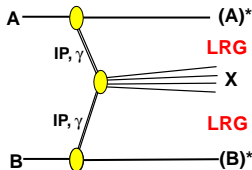
Measurements of exclusive production with the ATLAS detector

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On behalf of ATLAS Collaboration

June 28, 2017

Central Exclusive Measurements with ATLAS



Central Exclusive Production (CEP):

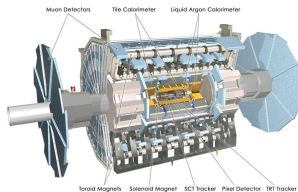
$$A + B \rightarrow (A)^* \text{ gap } X \text{ gap } (B)^*$$

where X is a simple centrally produced system.

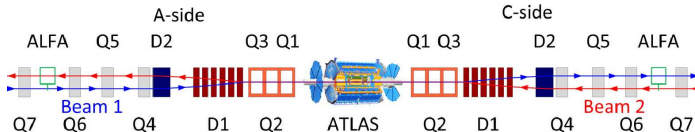
- $pp(\gamma\gamma) \rightarrow p + l^+l^- + p$ at $\sqrt{7}$ TeV, 4.6 fb^{-1}
 - provides direct access to the elastic photon distributions in proton
 - non-negligible background to Drell-Yan like reactions
- $pp(\gamma\gamma) \rightarrow p + W^+W^- + p$ at $\sqrt{8}$ TeV, 20.2 fb^{-1}
 - tests of SM $\gamma\gamma WW$ quartic gauge coupling
 - can probe physics beyond the electroweak scale and set limits on anomalous quartic gauge couplings (aQGCs)
- $pp(gg) \rightarrow p + \text{Higgs} + p \rightarrow p + W^+W^- + p$ at $\sqrt{8}$ TeV, 20.2 fb^{-1}
 - can be used for Higgs properties studies
- $Pb + Pb \rightarrow Pb + X + Pb$ (M. Guzik's talk)
- $p + p \rightarrow p + X + p$ with forward proton detectors (analysis in progress)

ATLAS detector

- Inner Detector ($|\eta| < 2.5$)
- Calorimeters ($|\eta| < 4.9$)



- Muon spectrometer ($|\eta| < 2.7$)
- Minimum Bias Trigger Scintillator ($2.1 < |\eta| < 3.9$)



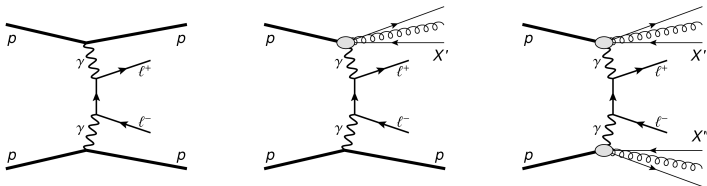
Forward proton detectors:

- ALFA : vertical RPs
 - located ≈ 240 m from IP1
 - optimized for elastic scattering
 - suitable for processes with relatively high cross. sect. (low mass CEP)
- AFP : horizontal RPs
 - located ≈ 210 m from IP1
 - optimized for hard diffraction
 - suitable for high mass CEP

Selection of exclusive production of state X :

- no additional activity in Inner Detector associated with the production vertex of state X
- without forward proton detectors:
 - search for kinematic variable with power to suppress non-exclusive (proton dissociation) production of state X
- with forward proton detectors (ALFA/AFP) at low pile-up select events with single primary vertex:
 - direct proof of exclusive production
 - event kinematics fully reconstructed (make use of correlation between central and forward regions)
 - no additional activity in MBTS.
- with AFP forward proton detectors (high pile-up):
 - Time Of Flight measurement required to associate forward protons with production vertex (I. Lopez's talk)

- Signal modeling using the Equivalent Photon Approximation (EPA) + QED with non-negligible absorptive corrections
- Cross-section dominated by so-called single- and double-proton dissociative reactions
- Elastic process is characterized by the production of back-to-back leptons, $p_T^l \approx 0$, providing a way to separate the elastic from the dissociative production



Phys. Lett. B 749 (2015) 242-261 (arXiv:1506.07098)

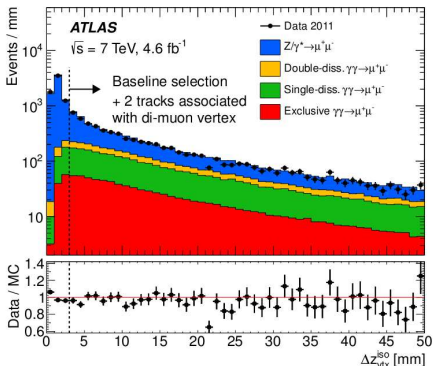
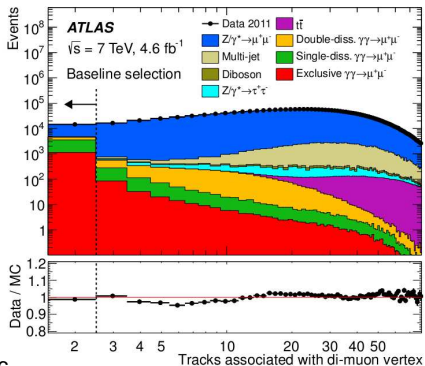
4.6 fb^{-1} at $\sqrt{7} \text{ TeV}$,

- Preselection:

- $p_T^\mu > 10$ GeV, $|\eta_\mu| < 2.4$, $M_{\mu\mu} > 20$ GeV
- $p_T^e > 12$ GeV, $|\eta_e| < 2.4$, $M_{ee} > 24$ GeV

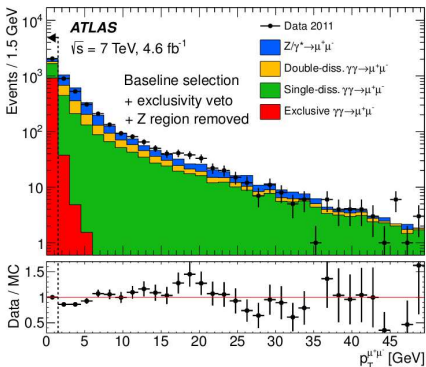
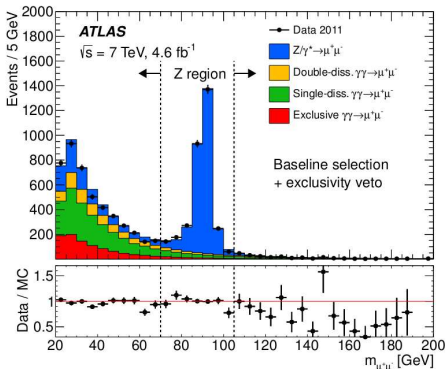
- Selecting dilepton vertex:

- Dilepton vertex has exactly two charged-particle tracks ($p_T > 0.4$ GeV)
- 3 mm dilepton-vertex longitudinal isolation (no additional tracks/vertices)



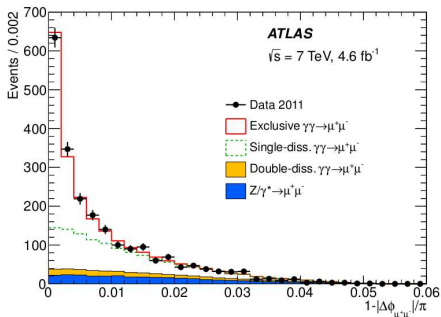
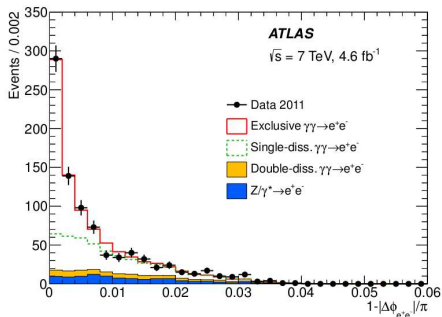
Selecting exclusive events

- Remove Z-boson mass region $70 \text{ GeV} < M_{ll} < 105 \text{ GeV}$
- Select $p_T^{ll} < 1.5 \text{ GeV}$ to suppress the dissociative background



Cross section measurement:

- Binned maximum-likelihood fit of the exclusive and single-dissociative contributions to the measured dilepton acoplanarity distribution
- Double-dissociative and Drell-Yan background are fixed to the MC predictions



Fiducial cross-sections:

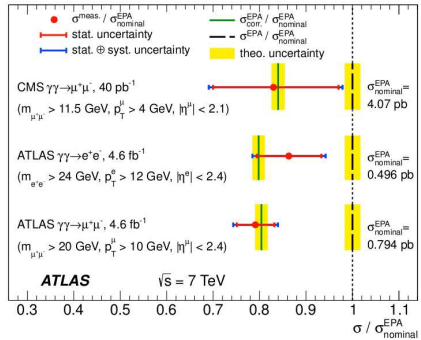
$$\sigma_{\gamma\gamma \rightarrow ee}^{excl.} = 0.428 \pm 0.035(stat.) \pm 0.018(syst.) \text{ pb}$$

$$\sigma_{\gamma\gamma \rightarrow \mu\mu}^{excl.} = 0.628 \pm 0.032(stat.) \pm 0.021(syst.) \text{ pb}$$

Theory predictions (QED-EPA)
with absorptive corrections(20 % effect) from PLB 741 (2015) 66-70

$$\sigma_{\gamma\gamma \rightarrow ee}^{EPAcorr.} = 0.398 \pm 0.007(\text{theo.}) \text{ pb}$$

$$\sigma_{\gamma\gamma \rightarrow \mu\mu}^{EPAcorr.} = 0.638 \pm 0.011(\text{theo.}) \text{ pb}$$



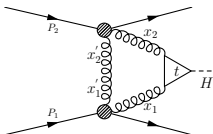
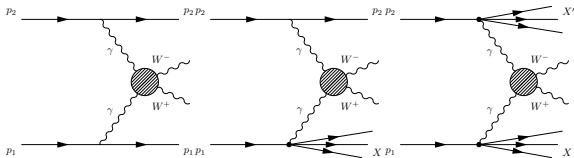
- Measured cross-sections are in agreement with the predicted values corrected for proton absorptive effects
- They are also consistent with the CMS measurement JHEP 1201 (2012) 052

Exclusive $\gamma\gamma \rightarrow l^+l^-$ production: ongoing analysis

Analysis of dimuon production in progress using data collected at $\sqrt{s} = 13$ TeV in 2015 with similar integrated luminosity:

- Optimized trigger allows reduction of the muon transverse momentum threshold and extension of the measurement into region of smaller dimuon masses.
- Measurement of the differential cross section as a function of dimuon mass to study expected dependence of the absorptive corrections on dimuon mass
- Compare results with more models of absorptive corrections

- Signal modeling: the Equivalent Photon Approximation (EPA) + QED
- Consider both elastic and dissociative (SD/DD) production as signal
- Test of SM $\gamma\gamma WW$ quartic gauge coupling
- Probe of anomalous quartic gauge couplings (aQGCs)



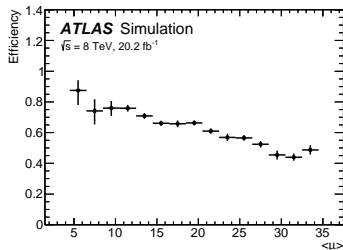
- Similar final state as in exclusive $\gamma\gamma \rightarrow W^+W^-$ measurement
- Can be used for Higgs properties studies

PRD 94 (2016) 032011 (arXiv:1607.03745)

- 20.1 fb^{-1} at $\sqrt{8}$ TeV,
- $WW \rightarrow e\nu\mu\nu$ final states are considered

Selecting dilepton vertex

- Distance between the two leptons be $|z_0^{l1} - z_0^{l2}| < 1$ mm
- 1 mm dilepton-vertex longitudinal isolation (no additional tracks)



Full event selection criteria:

	W^+W^- selection	Higgs boson selection
	Oppositely charged $e\mu$ final states	
Preselection	$p_T^{e1} > 25$ GeV and $p_T^{e2} > 20$ GeV	$p_T^{e1} > 25$ GeV and $p_T^{e2} > 15$ GeV
	$m_{e\mu} > 20$ GeV	$m_{e\mu} > 10$ GeV
	$p_T^{e\mu} > 30$ GeV	
	Exclusivity selection, Δz_0^{iso}	
aQGC signal	$p_T^{e\mu} > 120$ GeV	-
Spin-0 Higgs boson	-	$m_{e\mu} < 55$ GeV
	-	$\Delta\phi_{e\mu} < 1.8$
	-	$m_T < 140$ GeV

p_T^2 and $m_{e\mu}$ thresholds are lowered for the Higgs Boson search because one W is on-shell and the other is off-shell



exclusive $\gamma\gamma \rightarrow W^+W^-$ production search for exclusive $gg \rightarrow H \rightarrow W^+W^-$

Validation using $\gamma\gamma \rightarrow l^+l^-$ production

- Ratio of observed elastic $\gamma\gamma \rightarrow l^+l^-$ to EPA prediction:

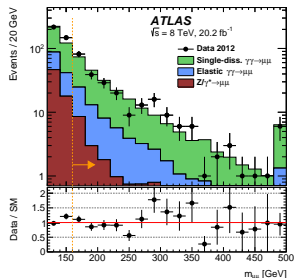
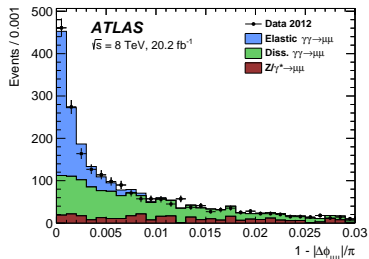
$$0.76 \pm 0.04(\text{stat.}) \pm 0.10(\text{sys.})$$

- Suppression is stronger due to larger invariant mass being probed

No simulation available for SD and DD

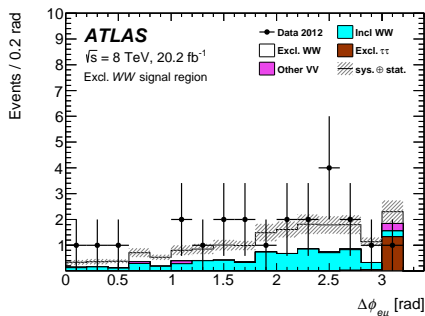
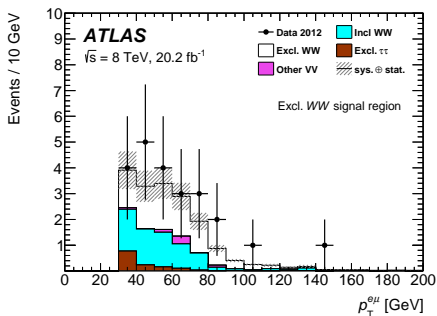
$\gamma\gamma \rightarrow W^+W^-$ (and EL+SD+DD are indistinguishable due to W decays): a correction factor is applied using $\gamma\gamma \rightarrow l^+l^-$ for $m_{ll} > 160$ GeV:

$$\frac{N_{\text{Data}} - N_{\text{Back.}}}{N_{\text{Elast.}}} = 3.3 \pm 0.22(\text{stat.}) \pm 0.06(\text{sys.})$$



Results for exclusive SM: $\gamma\gamma \rightarrow W^+W^-$

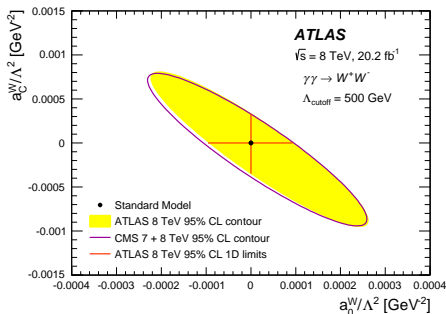
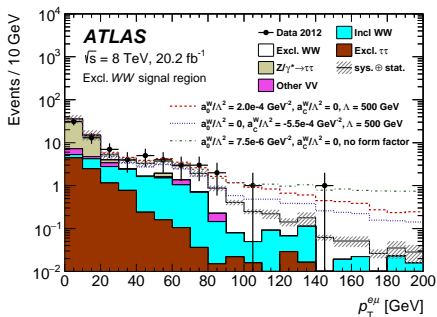
- Exclusive W^+W^- event yields: Data = 23, Background = 8.3 ± 2.6 , Signal = 9.3 ± 1.2
 - Measurement significance of 3σ



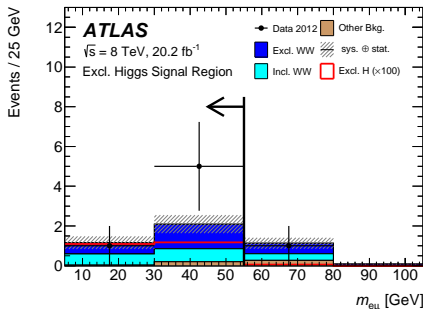
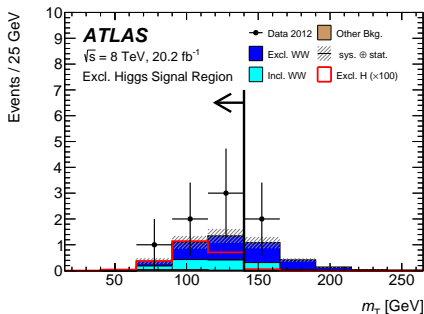
exclusive $\gamma\gamma \rightarrow W^+W^-$ production search for exclusive $gg \rightarrow H \rightarrow W^+W^-$

Results for aQGCs

- aQGC event yields for $p_T^{\ell\mu} > 120$ GeV: Data = 1, Background = 0.37 ± 0.13 , SM Signal = 0.37 ± 0.04
- new aQGC limits are set



- Exclusive Higgs event yields: Data = 6, Background = 3.0 ± 0.8 , SM Signal = 0.023 ± 0.003
 - Observed and expected limits:
 - $\sigma < 1.2$ pb @ 95% CL (Observed)
 - $\sigma < 0.7$ pb @ 95% CL (Expected)



Exclusive production with forward proton detectors: ongoing measurements.

Ongoing exclusive measurements using data collected in special high $\beta^* = 90$ m optics runs with ALFA detector:

- Analysis of exclusive dipion production $p + p \rightarrow p + \pi^+ \pi^- + p$
@ $\sqrt{s} = 7, 8, 13$ TeV.
Due to the ALFA geometrical acceptance range process dominated by Double Pomeron Exchange (DPE): $IPIP \rightarrow \pi^+ \pi^-$
- @ $\sqrt{s} = 13$ TeV also candidates for exclusive production of $KK, pp, \pi\pi\pi\pi$ final states as well as $\gamma IP \rightarrow \pi^+ + \pi^-$ are observed

Summary

- Cross sections of the exclusive $\gamma\gamma \rightarrow l^+l^-$ production have been measured @ $\sqrt{s} = 7$ TeV
 - Observation is consistent with the suppression (20%) expected due to proton absorption contributions
 - Ongoing analysis @ $\sqrt{s} = 13$ TeV including single differential cross section as a function of dimuon invariant mass.
- Evidence of SM exclusive $\gamma\gamma \rightarrow W^+W^-$ production (significance of 3σ)
 - No evidence for an excess in the kinematic region targeting aQGC
- Limits on exclusive Higgs production $gg \rightarrow H \rightarrow W^+W^-$ cross section are also set
- Ongoing measurements of low mass (DPE) exclusive processes using data collected in special high $\beta^* = 90$ m optics runs with protons measured in ALFA

Backup slide

Control regions:

- Same selection criteria as the exclusive WW region, except the exclusivity selection requires 1 to 4 extra tracks associated with dilepton-vertex
- $p_T^{\ell\ell} > 30$ GeV : inclusive WW control region
- $p_T^{\ell\ell} < 30$ GeV : Drell-Yan $\tau\tau$ control region

