Measurement of exclusive  $\gamma \gamma \rightarrow \ell \ell$  production in proton-proton collisions at  $\sqrt{s} = 7$  TeV with the ATLAS detector

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(on behalf of the ATLAS Collaboration)







Vienna, Austria 22 - 29 July 2015

- ▶ Treating proton beams as sources of quasi real photons allows to study two-photon reactions at the LHC.
- ▶ The exclusive two-photon production of lepton pairs can be calculated in the framework of QED within uncertainties below 2% associated with the proton elastic form-factors.
- ▶ Exclusive di-lepton events have a clean signature leptons are produced back-to-back in azimuthal angle and there is no additional activity in the central detectors.
- $\blacktriangleright$  Use Equivalent Photon Approximation (EPA) to calculate the pp cross section

$$\sigma_{pp(\gamma\gamma)\to pp\ell^+\ell^-}^{\text{EPA}} = \iint P(x_1)P(x_2)\sigma_{\gamma\gamma\to\ell^+\ell^-}(m_{\ell^+\ell^-}^2)dx_1dx_2$$

where  $P(x_i)$  are equivalent photon spectra for protons and integration is over fractions of the protons energy carried away by the photons.  $m_{\ell^+\ell^-}$  is the invariant mass of the di-lepton pair.

▶ However, significant corrections are necessary due to hadronic interactions between elastically scattered protons.

# Dilepton exclusive production $\gamma \gamma \rightarrow \ell^+ \ell^-$

- ▶ Signal elastic scattering:  $pp \to pp(\gamma\gamma) \to pp\ell\ell$ 
  - simulation with Herwig++ (use of EPA formalism in pp collisions)
- ▶ single dissociative scattering:  $pp \rightarrow pX'(\gamma\gamma) \rightarrow pX'\ell\ell$ 
  - simulation with LPAIR (use Brasse and Suri-Yennie structure functions for proton dissociation)
- double dissociative scattering:  $pp \to X'X''(\gamma\gamma) \to X'X''\ell\ell$ 
  - simulation with Pythia 8 (use of NNPDF2.3QED parton distribution function)



Herwig++ and LPAIR do not include corrections for proton absorptive effects. In Pythia 8 absorptive effects are taken into account using multi-parton interactions model implemented in the generator.

M. Przybycień (AGH UST)

Exclusive  $\gamma \gamma \rightarrow \ell \ell$  production in pp

# The ATLAS detector

 $\begin{array}{l} \mbox{Detector coverage:} \\ \mbox{Inner Detector (ID):} & |\eta| < 2.5 \\ \mbox{Calorimeter (CAL):} & |\eta| < 3.2 (EM) \\ |\eta| < 4.9 (HAD) \\ 3.2 < |\eta| < 4.9 (HAD) \\ 3.2 < |\eta| < 4.9 (FCal) \\ \mbox{Muon Spectrometer (MS):} \\ |\eta| < 2.7 (2.4) \\ \mbox{MB Trig. Scint. (MBTS):} \\ 2.1 < |\eta| < 3.9 \\ \mbox{Magnetic fields:} \end{array}$ 

- 2T solenoid field in ID
- Toroidal field in MS

Muon reconstruction: combined measurements by silicon pixel detectors / silicon microstrip detectors / straw tube tracker (ID) and muon spectrometer. Electron reconstruction: combined measurements by ID and electromagnetic calorimeter.

p+p data (2011):  $\sqrt{s} = 7$  TeV, L = 4.6 fb<sup>-1</sup>,  $<\mu>= 6.3 - 11.6$ .



Toroid Magnets Solenoid Magnet SC

SCT Tracker Pixel Detector TRT Tracker



## Event selection

Select pp collisions with at least one vertex and two tracks with  $p_{\rm T} > 400$  MeV.

- Selection of the di-electron channel  $(\gamma \gamma \rightarrow e^+ e^-)$ :
- single  $(p_{\rm T}^e > 22 \text{ GeV})$  or double  $(p_{\rm T}^e > 12 \text{ GeV})$  electron trigger,
- two electron candidates with  $p_{\rm T}^e > 12$  GeV and  $|\eta^e| < 2.4$ ,
- electron candidates should meet standard "medium" ATLAS criteria based on shower shape and track quality,
- di-electron events should have two oppositely charged electron candidates with  $m_{e^+e^-} > 24$  GeV,
- 1.57 million di-electron events are left after this preselection.
- Selection of the di-muon channel  $(\gamma \gamma \rightarrow \mu^+ \mu^-)$ :
- single  $(p_{\rm T}^{\mu} > 18 \text{ GeV})$  or double  $(p_{\rm T}^{\mu} > 10 \text{ GeV})$  muon trigger,
- two muon candidates with  $p_{\rm T}^{\mu} > 10$  GeV and  $|\eta^{\mu}| < 2.4$ ,
- only isolated muons are selected (require that  $\sum_{p_{\rm T}>1{\rm GeV}} p_{\rm T} < 0.1 p_{\rm T}^{\mu}$  in the cone  $\Delta R = 0.2$  around the muon),
- di-muon events should have two oppositely charged muon candidates with  $m_{\mu^+\mu^-} > 20$  GeV,
- 2.42 million di-muon events are left after this preselection.

#### Electron reconstruction



M. Przybycień (AGH UST)

Exclusive  $\gamma \gamma \rightarrow \ell \ell$  production in pp

23 July 2015 5 / 13

# Exclusive event selection - muon pairs

- ▶ Main background sources:
- single- and double-proton dissociative events,
- $Z/\gamma^* \to \mu^+\mu^-, \tau^+\tau^-,$
- $\gamma\gamma \rightarrow t\bar{t}$ , multi-jet production.
- ▶ Selection of exclusive di-muon sample:
- exclusivity veto no additional tracks with  $p_{\rm T} > 400$  MeV associated with the di-muon vertex and no additional tracks or vertices within a 3 mm longitudinal isolation distance.



### Exclusive event selection - muon pairs

- contribution from the Drell–Yan processes can be further reduced by excluding events with di-lepton invariant mass in the Z-peak region  $(70 < m_{\mu^+\mu^-} < 105 \text{ GeV}).$
- to further suppress the proton dissociative background the lepton pair is required to have transverse momentum  $p_{\rm T}^{\mu^+\mu^-} < 1.5$  GeV.



After all selection criteria 2124 di-muon events left.

### Event selection - exclusive electron pairs



# Control distributions



• exclusive and single-dissociative yields scaled according to the fit results,

- use cut on acoplanarity  $(1 |\Delta \phi_{\ell^+ \ell^-}|/\pi < 0.008)$  instead of on total transverse momentum  $(p_T^{\ell^+ \ell^-} < 1.5 \text{ GeV}),$
- ▶ good description of data in both channels.

# Signal extraction

Numbers of selected events in data are below expectations from MC (80%).

• binned maximum-likelihood fit of the sum  $\frac{5}{2}$  250 of signal and single dissociative background 200 to the measured dilepton acoplanarity 150

 $(1-|\Delta\phi_{\ell^+\ell^-}|/\pi),$ 

• Drell–Yan and double-dissociative backgrounds are fixed to the MC predictions,

• determine scaling factors for data from the fit:

 $\begin{array}{l} R_{\gamma\gamma \to e^+e^-}^{\rm excl.} = 0.863 \pm 0.070 \\ R_{\gamma\gamma \to e^+e^-}^{\rm s-diss} = 0.759 \pm 0.080 \\ R_{\gamma\gamma \to \mu^+\mu^-}^{\rm excl.} = 0.791 \pm 0.041 \\ R_{\gamma\gamma \to \mu^+\mu^-}^{\rm s-diss} = 0.762 \pm 0.049 \end{array}$ 

• fitted scaling factors are strongly anti-correlated.



# Systematic uncertainties

- ▶ dominant sources of systematic uncertainty are from background modelling:
  - contribution from DY due to reweighting procedures of charged-particle multiplicity and  $p_{\rm T}^{\ell^+\ell^-}$  (20%),
  - $\bullet$  contribution from double proton dissociation due to uncertainties of the photon PDF (50%),
- modelling of vertex isolation and pile-up - uncertainty taken from discrepancy between data and simulation. ▶ lepton energy (momentum) scale and resolution - uncertainty obtained from comparison of Zinvariant mass distribution in data and simulation. luminosity measurement. Total systematic uncertainty

1.9	-
1.4	-
0.7	-
-	0.2
-	0.5
-	0.6
2.3	2.0
1.0	0.9
0.5	0.5
1.2	1.2
0.5	0.5
0.8	-
1.8	1.8
4.3	3.3
8.2	5.1
	1.9 1.4 0.7 - 2.3 1.0 0.5 1.2 0.5 0.8 1.8 4.3 8.2

below the statistical one.

Uncertainty [%]

# Measurement of the exclusive cross sections

Cross sections are restricted to the fiducial regions defined as:

Variable	Electron channel	Muon channel
$p_{\mathrm{T}}^{\ell}$	> 12  GeV	> 10  GeV
$ \eta^{\ell} $	< 2.4	< 2.4
$m_{\ell^+\ell^-}$	$> 24 { m ~GeV}$	$> 20 { m ~GeV}$

Cross sections are given by the product of the measured scale factors and the EPA calculations based on Herwig++ MC:

$$\sigma_{\gamma\gamma\to\ell^+\ell^-}^{\text{excl.}} = R_{\gamma\gamma\to\ell^+\ell^-}^{\text{excl.}} \cdot \sigma_{\gamma\gamma\to\ell^+\ell^-}^{\text{EPA}}$$

The measured cross sections are:

$$\sigma_{\gamma\gamma \to e^+e^-}^{\text{excl.}} = 0.428 \pm 0.035 \text{(stat)} \pm 0.018 \text{(sys) pb}$$

 $\sigma_{\gamma\gamma \to \mu^+\mu^-}^{\text{excl.}} = 0.628 \pm 0.032 \text{(stat)} \pm 0.021 \text{(sys) pb}$ 

The measured cross sections are in agreement with EPA calculations corrected for the proton absorptive effects calculated in Phys. Lett. B 741, 66 (2015). The measurements are also in agreement with CMS (JHEP 1201 (2012) 052).



# Summary

- ATLAS has measured cross sections for exclusive production of lepton pairs in two-photon collisions using 4.6 fb<sup>-1</sup> of pp data taken at  $\sqrt{s} = 7$  TeV.
- The cross sections have been measured in the fiducial regions defined as:  $p_{\rm T}^e > 12 \text{ GeV}, \ |\eta^e| < 2.4, \ m_{e^+e^-} > 24 \text{ GeV}$  for the electron channel and

 $p_{\rm T}^{\mu}>10~{\rm GeV},\, |\eta^{\mu}|<2.4,\,m_{\mu^+\mu^-}>20$  GeV for the muon channel.

- The observed cross sections are about 20% below the nominal EPA prediction, and consistent with the suppression expected due to proton absorption contributions.
- Good agreement with MC predictions of the shapes of dilepton kinematic distributions for exclusive signal and background dominated by the two-photon production of lepton pairs with single proton dissociation.
- Good agreement with previous CMS measurement.
- Most precise measurement of two-photon dilepton production.

More details in arXiv:1506:07098 [hep-ex] (to be published in Phys. Lett. B)

#### Thank you for your attention!

# Backup slides

#### Muon reconstruction



Run 183081, Event 94526500 Time 2011-06-05, 16:37 CEST

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# Fit results

68% and 95% confidence level (C.L.) contour plots for the signal vs. single-dissociative yield fractions in the fitted parameter plane for (a) the electron and (b) the muon channel. The contours represent the statistical uncertainties on the measurement and the points indicate the best-fit values. Prediction for signal yield fractions with absorptive corrections is also shown (red solid line).

