Forward physics and diffraction results of the ATLAS experiment

Rafał Staszews

Diffractive processes Soft diffractio

Diffractive dijets

processes

Exclusive lepton pai in ppExclusive muon paii

Exclusive WW and HNEW: Light-by-light scattering in PbPb

Summary

Forward physics and diffraction results of the ATLAS experiment

Rafał Staszewski

(on behalf of the ATLAS Collaboration)

Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN Cracow)



QCD at LHC: forward physics and UPC collisions of heavy ions 26 – 30 September 2016, ETC*, Trento, Italy

Forward physics and diffraction results of the ATLAS experiment

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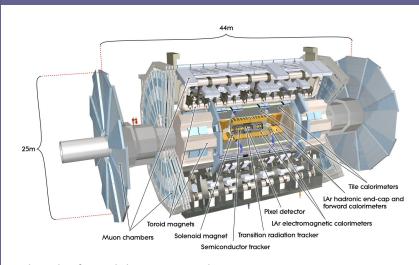
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Exclusive lepton pair ppExclusive muon pair PbPbExclusive WW

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...but also forward detectors providing measurements of forward intact protons: **ALFA** and **AFP**

ALFA (Absolute Luminosity For ATLAS) detectors

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Two-photon processes

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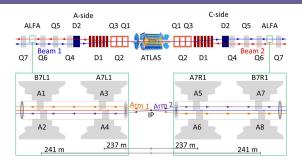
200 Lower energy pp

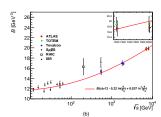
1 Lower energy pp

2 Committed Type

150 Comm

(a)





More in Per's talk later today

AFP (ATLAS Forward Proton) detectors

Forward physics and diffraction results of the ATLAS experiment

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Exclusive lepton in ppExclusive muon in pp

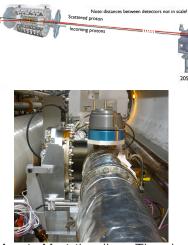
in PbPb

Exclusive WW

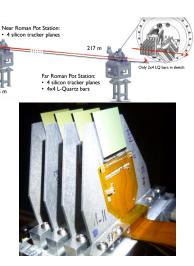
and H

NEW: Light-by-ligh scattering in PbPb

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More in Maciej's talk on Thursday



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Italai Staszew:

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Raiai Staszew:

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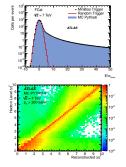
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Early measurements – soft diffraction

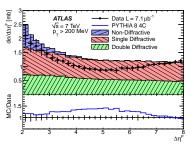
Forward physics and diffraction results of the ATLAS experiment



non-diffractive elastic single central double diffraction a diffraction a diffraction b b b X b b b b



 Calorimeter used to measure rapidity gaps



- Separation of diffractive processes from non-diffractive processes
- Full separation of single and double diffraction not possible

Forward physics and diffraction results of the ATLAS experiment

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Exclusive lepton |
in pp

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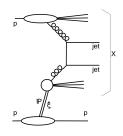
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Forward physics and diffraction results of the ATLAS experiment

- Low pile-up data sample from 2010 $(\sqrt{s} = 7 \text{ TeV})$
- Integrated luminosity: 6.8 nb
- Anti-kT algorithm
 - pT > 20 GeV
 - $|\eta| < 4.4$
 - R = 0.4, 0.6
- Rapidity gap based on
 - tracks ($|\eta|$ < 2.5, pT > 200 MeV)
 - calorimeter cells ($|\eta| < 4.8$)



Reconstruction of diffractive proton kinematics

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Diffractive processes

Diffractive dijets

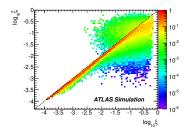
Two-photon processes P_{ab} in P_{ab} Exclusive muon pairs in P_{b} Exclusive P_{b} Exclusive P_{b} Exclusive P_{b} Exclusive P_{b} Exclusive P_{b} Exclusive P_{b} P_{b} P_{b} P_{b} P_{b}

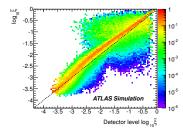
Proton energy loss and diffractive mass

$$\xi = M_X^2/s$$

■ Reconstruction:

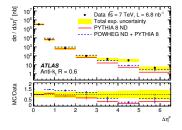
$$\tilde{\xi} = \frac{\sum p_T e^{\pm \eta}}{\sqrt{s}}$$

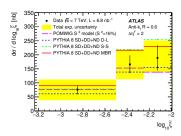




Results

Forward physics and diffraction results of the ATLAS experiment





- Evidence of diffractive component
- Good description by Pythia8
- Gap survival probability: 0.16 ± 0.04 (stat) ± 0.08 (exp. syst.)

Forward physics and diffraction results of the ATLAS experiment

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Diffractive processes
Soft diffraction

Two-photon

Exclusive lepton pairs in pp Exclusive muon pairs in PbPb Exclusive WW and H NEW: Light-by-light scattering in

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■ Soft diffraction

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3 Two-photon processes

 \blacksquare Exclusive lepton pairs in pp

lacktriangle Exclusive muon pairs in PbPb

lacktriangle Exclusive WW and H

■ **NEW:** Light-by-light scattering in PbPb

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Motivation

Forward physics and diffraction results of the ATLAS experiment

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Diffractive processes Soft diffraction Diffractive dije

Two-photon processes

in ppExclusive muon pairs in PbPbExclusive WW and HNEW: Light-by-light scattering in PbPb

- Two-photon processes can be computed within QED
- Absorptive corrections (gap survival probability)
- Exclusive $\gamma\gamma \rightarrow ll$
 - Standard candle for photon-induced physics
 - Non-negligible background to Drell-Yan like reactions
- Test of SM γWW and $\gamma \gamma WW$ couplings
- Searches for new physics

Forward physics and diffraction results of the ATLAS

- - Soft diffraction
 - Diffractive dijets
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 - Exclusive lepton pairs in pp
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$\gamma\gamma \to \mu\mu$ event

and diffraction results of the ATLAS experiment

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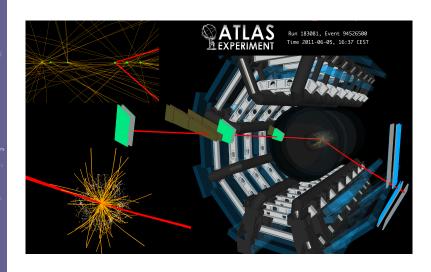
Two-photon processes

in pp

in PbPbExclusive WW

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Event selection

Forward physics and diffraction results of the ATLAS

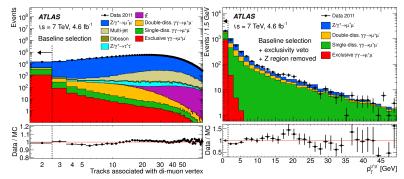
of the ATLAS experiment Rafał Staszewsk

iffractive rocesses oft diffraction Diffractive dijets wo-photon rocesses

Exclusive lepton pair in ppExclusive muon pair in PbPbExclusive WW and HNEW: Light-by-light

■ Preselection:

- lacktriangleright muons: $p_T > 10$ GeV, $|\eta| < 2.4$, $M_{\mu\mu} > 20$ GeV
- lacktriangle electrons: $p_T > 11$ GeV, $|\eta| < 2.4$, $M_{ee} > 24$ GeV
- Exclusive selection:
 - 3 mm vertex longitudinal isolation (efficiency = 74%)
 - lacksquare p_T of the pair below 1.5 GeV



Results

Forward physics and diffraction results of the ATLAS experiment

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Diffractive
rocesses
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wo-photon
rocesses

Exclusive lepton pairs in pp

Exclusive muon pairs in PbPbExclusive WW and HNEW: Light-by-light scattering in

250 Events / 0.002 ATLAS stat. uncertainty 300 — stat. ⊕ svst. uncertainty vs = 7 TeV, 4.6 fb-1 theo, uncertainty CMS γγ→μ*μ*, 40 pb*1 4.07 pb $(m_{_{\rm crit}} > 11.5~{\rm GeV},\, p_{_{\rm T}}^{\mu} > 4~{\rm GeV},\, |\eta^{\mu}| < 2.1)$ - Data 2011 Exclusive γy→e+e-200 Single-diss. γy→e+e ATLAS γy→e⁺e⁻, 4.6 fb⁻¹ 0.496 pb 150 Double-diss. γγ→e+e (m_, > 24 GeV, p, > 12 GeV, |ηe| < 2.4) $Z/\gamma^* \rightarrow e^+e^-$ 100 ATLAS $\gamma\gamma \rightarrow \mu^{+}\mu^{-}$, 4.6 fb⁻¹ σ^{EPA} $(m_{_{\rm crit}} > 20~{\rm GeV},\,p_{_{\rm P}}^{\mu} > 10~{\rm GeV},\,|\eta^{\mu}| < 2.4)$ 0.794 pb 50 ATLAS $\sqrt{s} = 7 \text{ TeV}$ 0.01 σ / σ^{EPA} nominal 1-|Δφ_-|/π

- Agreement with calculations
 (absorptive corrections are important)
- Agreement with CMS measurement

Forward physics and diffraction results of the ATLAS experiment

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in ppExclusive muon pairs

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Diffractive processes

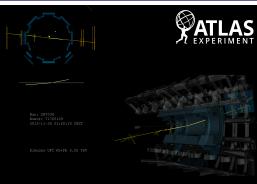
Soft diffraction
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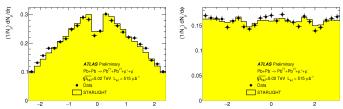
in ppExclusive muon pairs in PbPb

Exclusive WW and HNEW: Light-by-light scattering in PbPb

 $p_T > 5 \text{ GeV}$ $|\eta| < 2.4$ (both muons)

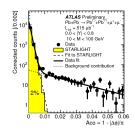
- $M_{\mu\mu} > 10 \text{ GeV}$
- Muons form a vertex
- No other tracks
- 12069 events after selection

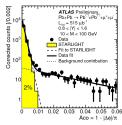


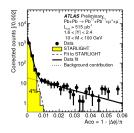


Acoplanarity

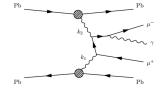
Forward physics and diffraction results of the ATLAS experiment







- No QED radiative corrections in MC (Starlight)
- Two variants assumed:
 - tail is background
 - tail is due to FSR



- The background fraction with acoplanarity < 0.08 is 2 4%.
- The result is average of the two possibilities
- Difference is taken as systematic uncertainty

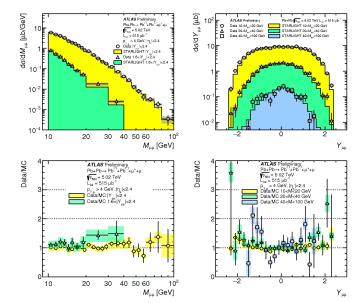
Results

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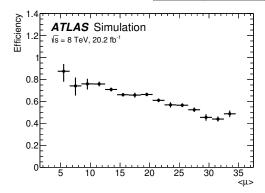
Event selection

Forward physics and diffraction

	$\gamma\gamma$	\rightarrow	WW	\rightarrow	$e\nu\mu\nu$
--	----------------	---------------	----	---------------	--------------

- lacktriangledown exclusive $H o WW o e
 u \mu
 u$
- exclusive selection: 1 mm vertex longitudinal isolation

Variable	Excl W ⁺ W ⁻	Excl Higgs	
p_T^{lep}	> 25, 20 GeV	> 25, 15 GeV	
$m_{e\mu}$	$> 20 \mathrm{GeV}$	$> 10 \mathrm{GeV}$	
$p_T^{e\mu}$	> 30 GeV	$> 30 \mathrm{GeV}$	
Δz_0^{iso}	1mm	1mm	
$p_T^{e\mu}$ (aQGC)	$> 120~{ m GeV}$	-	
$m_{e\mu}$	-	$< 55 \; \mathrm{GeV}$	
$\Delta \phi_{e\mu}$	-	< 1.8	
m _T	-	$< 140 \; \mathrm{GeV}$	



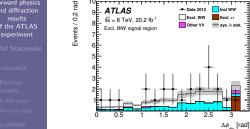
Results for $\gamma\gamma \to WW$

Other VV

sys. ⊕ stat.

Forward physics and diffraction results of the ATLAS

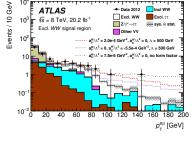


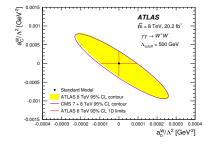


ATLAS

√s = 8 TeV, 20,2 fb⁻¹

Excl. WW signal region





- Standard Model signal
 - \blacksquare 3σ significance
- New physics searches
 - $p_T^{e\mu} > 120 \text{ GeV}$
 - Data: 1
 - Background: 0.37 ± 0.13
 - SM Signal: 0.37 ± 0.04
 - limits on anomalous $\gamma\gamma WW$ couplings

Results on exclusive Higgs searches

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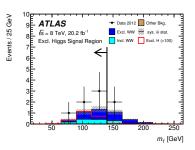
Exclusive muon pain PbPbExclusive WWand HNEW: Light-by-lightscattering in

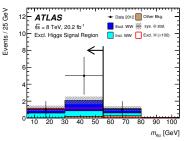
lacksquare Backgrounds: exclusive and inclusive WW

■ Exclusive Higgs event yields: data: 6, background: 3.0 ± 0.8 , signal: 0.023 ± 0.003

• Observed and expected limits: $\sigma < 1.2$ pb @ 95% CL (Observed) $\sigma < 0.7$ pb @ 95% CL (Expected)

■ Upper limit: 400 times expected cross section for elastic process





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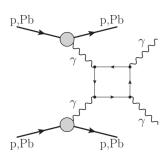
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Light-by-light scattering in PbPb

Forward physics and diffraction results

- NEW: Light-by-light

- Elastic scattering of two photons
- Quantum effect: not present in classical theory
- Very small cross section
- No direct observation so far
- Possible channel to study new physics



Event selection

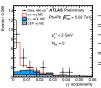
Forward physics and diffraction results of the ATLAS experiment

Dedicated trigger: photons + clean event

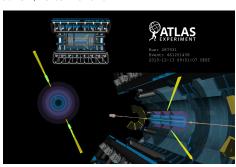
Selection:

- Two photons, $E_T > 3$ GeV
- $M_{\gamma\gamma} > 6 \text{ GeV}$
- Exclusivity: no tracks
- $p_T^{\gamma\gamma} < 6 \text{ GeV}$
- Acoplanarity:

$$(1 - \Delta\Phi_{\gamma\gamma}/\pi) < 0.01$$



Selection	Data	Signal	$\gamma \gamma \rightarrow e^+e^-$	CEP $gg \rightarrow \gamma \gamma$	Hadronic fakes	Other fakes
Preselection	105	9.1	74	4.7	6	19
$N_{\text{trk}} = 0$	39	8.7	4.0	4.5	6	19
$p_{\rm T}^{\gamma\gamma} < 2~{ m GeV}$	21	8.5	3.5	4.4	3	1.3
Aco < 0.01	13	7.3	1.3	0.9	0.3	0.1
Uncertainty		1.5	0.3	0.5	0.3	0.1



processes

Soft diffraction

Diffractive dijets

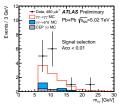
Two-photon

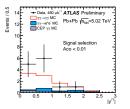
processes

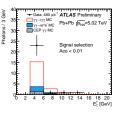
Exclusive lepton pairs in ppExclusive muon pairs in PbPbExclusive WWand HNEW: Light-by-light

- First direct observation of the light-by-light signal
- Excess in the data consistent with predictions
 (M. Kłusek-Gawenda et al., Phys.Rev. C93 (2016) no.4, 044907)

$$\sigma_{
m fid}^{
m meas} = 70 \pm 20 ({
m stat}) \pm 17 ({
m syst}) \; {
m nb} \qquad \sigma_{
m fid}^{
m th} = 49 \pm 10 \; {
m nb}$$







- Observed significance: 4.4σ (expected: 3.8σ)
- Signal strength: $\mu = 1.6 \pm 0.6$

Forward physics and diffraction results of the ATLAS experiment

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Exclusive $W\,W$ and H

scattering in PbPb

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Forward physics and diffraction results of the ATLAS experiment

Summary

- Measurements of diffraction with rapidity-gap method exploiting ATLAS calorimetry
 - soft diffraction
 - diffractive jets
- Measurements of elastic scattering and prospects for new measurements with proton taggers:
 - ALFA (Per's talk)
 - AFP (Maciej's talk)
- Two-photon physics
 - \blacksquare In pp and PbPb
 - Understanding of absorptive corrections
 - Searches for new physics
 - Observation of light-by-light scattering