Results on total pp cross sections, and exclusive final states from ATLAS

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for the ATLAS collaboration

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


In print for the October 2015 volume.
Clean signature.
Precise QED calculation.
LHC a $\gamma \gamma$ collider!
Exclusive $\gamma\gamma \rightarrow e^+e^-$ Signature

- Leptons back-to-back in $\phi$
- No other activity in central detectors (in same pp interaction)
Exclusive $\gamma\gamma \rightarrow \mu^+\mu^-$ Signature

- Leptons back-to-back in $\phi$
- No other activity in central detectors (in same pp interaction)
Event selection

- **Exclusivity veto:**
  - No other track associated with dilepton vertex (above 400 MeV).
  - No track of vertices within 3 mm longitudinal distance
    → to suppress: $Z/\gamma^*$, multi-jet, $t\bar{t}$, diboson.

- **Z region removal**
  - Di lepton invariant mass not in $Z$ mass range.
    → Further rejection of: $Z/\gamma^*$

- $p_T^{ll} < 1.5$ GeV
  → to suppress: dissociative backgrounds.
Normalize signal and dominant background simulations.

- Maximum-Likelihood template-fit to acoplanarity distribution used to extract weighting factors.
- Subdominant backgrounds are not normalized. Taken from MC (pQCD)
Fiducial cross-sections in agreement with the theory (equivalent photon approximation EPA), provided proton absorptive effects are included. (≈ 20%)
Measurement of the total cross section from elastic scattering in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

Nuclear Physics, Section B (2014), pp. 486-548
Experimental setup: ALFA

- Main Detector: 10 double-sided modules with 64 scintillating fibers
- Spatial resolution $\approx 30 \mu m$
- 8 detectors housed in Roman Pot

ALFA is at $\approx 240$ m from the interaction point. 5 mm from the beam. $\beta^* = 90$ m. It measures proton scattering angle down to $10\mu rad$
- Measure the four-momentum transfer $-t \approx (p\theta^*)^2$
- $p = 3.5$ TeV, $\theta^* =$ scattering angle at interaction point.
- Unfolding is applied to measured $t$-distribution to correct for detector effects.
Differential elastic cross-section

\[
d\sigma/dt = \frac{1}{\Delta t} \frac{U^{-1}(S-B)}{A \epsilon_{\text{reco}} \epsilon_{\text{trig}} \epsilon_{\text{DAQ}} \mathcal{L}}
\]

Correct for:
- geometric acceptance
- reconstruction efficiency
- trigger efficiency
- deadtime correction
- integrated luminosity
Fit to $d\sigma_{el}/dt$ to extract $\sigma_{tot}$

$$d\sigma_{el}/dt = \sigma_{tot}^2 \frac{1+\rho^2}{16\pi} e^{Bt} + ...$$

- Nuclear term dominates ($\beta^* = 90$ m), Coulomb and Interference terms also included.
- $\rho = 0.14$ (from theory)
- Fit range $-t \in [0.01,0.1]$. (possible deviations from exponential form expected to be small)
- Result : $\sigma_{tot} = 95.4 \pm 1.4$ mb
- Uncertainty:
  - Vary upper limit to $-t = 0.15$
  - Vary $\rho \pm 0.008$
Total and elastic cross-sections

\[ \sigma_{tot} = 95.4 \pm 1.4 \text{ mb} \]
\[ \sigma_{el} = 24.0 \pm 0.6 \text{ mb} \]
Measurement of the Inelastic Proton-Proton Cross Section at 13 TeV with the ATLAS Detector at the LHC

ATLAS-CONF-2015-038

17 August 2015
Experimental Setup, Minimum Bias Trigger Scintillators

- Completely replaced for Run II
- 2 cm thick discs highly efficient polystyrene scintillator mounted in front of forward calorimeters.
- Acceptance: $2.07 < |\eta| < 3.86$

Trigger used in this analysis require signal in at least one MBTS counter

Event selection requires at least two of the 24 MBTS counters to collect a charge of at least 0.15 pC.

- $n_{\text{mbts}} \geq 2$. 
We have very high acceptance for non-diffractive events.

But we lose low-mass diffractive events.

- We do not measure $M_X$, but presence of MBTS hit gives a lower limit for it.
- Acceptance depends on $M_X$, we define a fiducial region such that $A(M_X) > 50\%$

$$\rightarrow M_X > 13 \text{ GeV}$$

or $\xi \equiv \frac{M_X^2}{s} > 10^{-6}$
Monte Carlo samples - comparison of $\xi$ distributions

For single and double diffractive events, the $\xi$ distributions vary quite a bit!

The impact of physics mismodeling is minimized within the fiducial range of the measurement by constraining the fraction of diffractive events in situ.
Constraining the fraction of diffractive events

We get a diffractive-enhanced sample by requiring hits in only one side of MBTS.

\[ R_{SS} \equiv \frac{\text{Corrected number events in single-sided sample}}{\text{Corrected number of events in inclusive sample}} \]

- \( R_{SS} \) depends on \( f_D \equiv \frac{\sigma_{SD} + \sigma_{DD}}{\sigma_{inel}} \)
- Measured in data = \( 10.4 \pm 0.5 \)
- For each MC, \( f_D \) is tuned to match \( R_{SS} \) measured in data.
Hit distribution, Sing-Sided sample

Models bracket the data

ATLAS Preliminary
\( \sqrt{s} = 13 \text{ TeV}, \int L \, dt = 63 \mu b^{-1} \)
Hit distribution, Inclusive Sample

Models bracket the data
Results: Fiducial cross-section

\[
\sigma(\xi > 10^{-6}) = \frac{(N - N_{BG})}{\epsilon_{\text{trig}} \times L} \times \frac{1 - f}{\epsilon_{\text{sel}}}
\]

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
<th>Rel. unc.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of selected events ((N))</td>
<td>4159074</td>
<td>−</td>
</tr>
<tr>
<td>Number of background events ((N_{BG}))</td>
<td>43512</td>
<td>±100 %</td>
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<tr>
<td>Luminosity ([\mu b^{-1}] (L))</td>
<td>62.9</td>
<td>±9 %</td>
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<tr>
<td>Trigger efficiency ((\epsilon_{\text{trig}}))</td>
<td>99.7%</td>
<td>±0.1 %</td>
</tr>
<tr>
<td>MC Correction factor (((1 - f_{\xi&lt;10^{-6}})/\epsilon_{\text{sel}}))</td>
<td>0.993</td>
<td>±0.5 %</td>
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</tbody>
</table>

\[
\sigma = 65.2 \pm 0.8(\text{exp.}) \pm 5.9(\text{lumi}) \text{ mb}
\]
Results: Fiducial cross-section

\[ \sigma = 65.2 \pm 0.8 (\text{exp.}) \pm 5.9 (\text{lumi}) \text{ mb} \]
Results: Total cross-section

\[ \sigma = 73.1 \pm 0.9(\text{exp.}) \pm 6.6(\text{lumi}) \pm 3.8(\text{extrapol.}) \text{ mb} \]
Results: Total cross-section

\[ \sigma = 73.1 \pm 0.9(\text{exp.}) \pm 6.6(\text{lumi}) \pm 3.8(\text{extrapol.}) \text{ mb} \]
Conclusions

- Exclusive $\gamma\gamma \rightarrow ll$ cross-section measurement are in agreement with the theory, provided proton absorptive effects are included.

- Total cross-section at 7 TeV measured with ALFA (Roman Pots). Via elastic cross-section measurement and optical theorem. $\rightarrow$ precise total cross-sections at LHC energies.

- Inelastic cross-section at 13 TeV measured with forward scintillators. Result within 1 sigma of expectations. $\rightarrow$ First measurement at 13 TeV, improvements in our understanding of luminosity scale will lead to a more precise measurement soon.
Backup Slides
## Uncertainties

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Uncertainty [%]</th>
<th>$\gamma\gamma \rightarrow e^+e^-$</th>
<th>$\gamma\gamma \rightarrow \mu^+\mu^-$</th>
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<tbody>
<tr>
<td>Electron reconstruction and identification efficiency</td>
<td>1.9</td>
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<tr>
<td>Electron energy scale and resolution</td>
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<td>Electron trigger efficiency</td>
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<tr>
<td>Muon reconstruction efficiency</td>
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<td>0.2</td>
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<tr>
<td>Muon momentum scale and resolution</td>
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<tr>
<td>Muon trigger efficiency</td>
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<tr>
<td>Backgrounds</td>
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<tr>
<td>Template shapes</td>
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<tr>
<td>Pile-up description</td>
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<td>Vertex isolation efficiency</td>
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<tr>
<td>LHC beam effects</td>
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<tr>
<td>QED FSR in DY $e^+e^-$</td>
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<tr>
<td>Luminosity</td>
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<tr>
<td>Total systematic uncertainty</td>
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<td>Data statistical uncertainty</td>
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<td>5.1</td>
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</table>
Event Selection

- Trigger, data quality
- Geometry acceptance
- Back-to-back topology
- Background rejection

800k elastic events were recorded, $80 \mu b^{-1}$