

# Measurements of Total, Elastic, Inelastic and Diffractive Cross Sections with the ATLAS Detector

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on behalf of  
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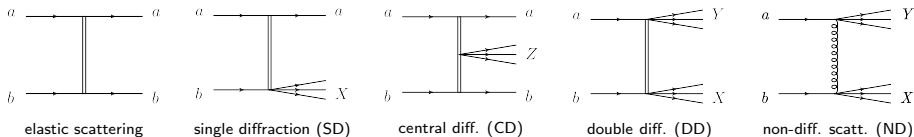


**24<sup>th</sup> International Workshop on Deep-Inelastic Scattering  
and Related Subjects**

**14<sup>th</sup> April 2016**

**Diffractive signature:** large rapidity gap due to colourless exchange

Exchange type: **electromagnetic (photon)** or **strong (Pomeron)**



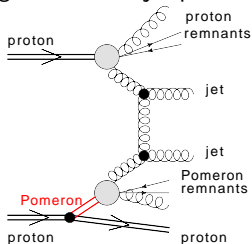
**Elastic cross-section:** elastic scattering measurement

**Inelastic cross-section:** single + double + central diff. + non-diffr. scattering

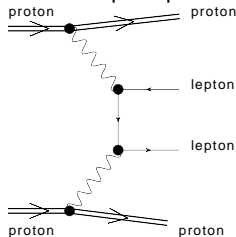
**Total cross-section:** inferred from the elastic measurement via the optical theorem

**Measurements of:**

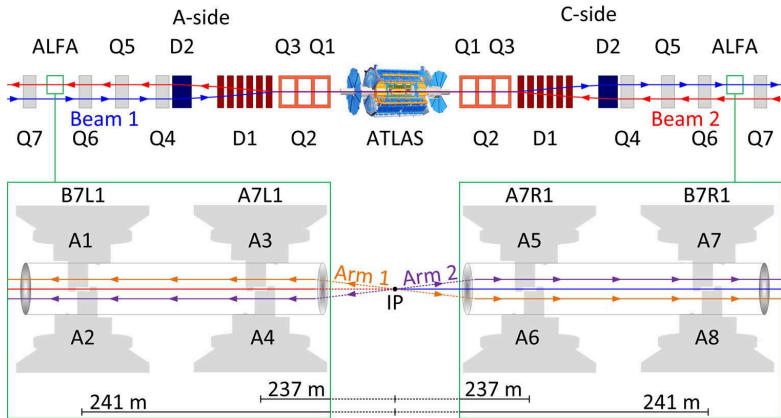
single diffractive jet production



exclusive di-lepton production

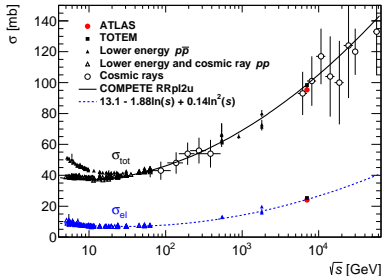


# Total and Elastic Cross-Section: Measurement Idea

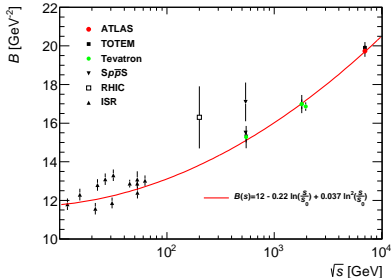


- elastic signature: two protons (scattered at small angle)
- dedicated detectors needed: **Absolute Luminosity For ATLAS**
- several LHC magnets on the way (**Dipoles and Quadrupoles**)
- LHC run conditions: special magnet settings (so-called  $\beta^* = 90$  m optics) needed to enhance detector acceptance
- data sample:  $80 \mu\text{b}^{-1}$  of integrated luminosity at  $\sqrt{s} = 7$  TeV

## total and elastic cross-section



## nuclear slope



- **elastic cross-section:**

$$\sigma_{el} = 24.00 \pm 0.19 \text{ (stat.)} \pm 0.57 \text{ (syst.) mb}$$

- **nuclear slope:**

$$B = 19.73 \pm 0.14 \text{ (stat.)} \pm 0.26 \text{ (syst.) GeV}^{-2}$$

- **total cross-section** obtained using optical theorem ( $\sigma_{tot} \sim \Im[f_{el}(t \rightarrow 0)]$ ):

$$\sigma_{tot}(pp \rightarrow X) = 95.35 \pm 0.38 \text{ (stat.)} \pm 1.25 \text{ (exp.)} \pm 0.37 \text{ (extr.) mb}$$

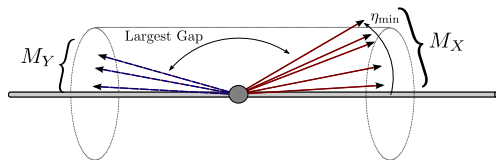
- **inelastic cross-section** (derived):

$$\sigma_{inel} = 71.34 \pm 0.36 \text{ (stat.)} \pm 0.83 \text{ (syst.) mb}$$

- details in: **Nuclear Physics, Section B 889 (2014), pp. 486-548**

# Inelastic Cross-Section: Measurement Idea

Use events (single + double + central diffraction + non-diffractive scattering) triggered by ATLAS **M**inimum **B**ias **T**rigger **S**cintillators



$M_X$  – larger of invariant masses of the two proton dissociated systems,  $M_X^2 = \sqrt{s} \sum p_T e^{\pm\eta}$   
 $\xi = M_X^2/s$  – energy lost by proton

c.m. energy	7 TeV	13 TeV
integrated luminosity	$20.3 \pm 0.7 \mu\text{b}^{-1}$	$63 \pm 6 \mu\text{b}^{-1}$
mean number of int. per bunch crossing	0.01	0.0023
MBTS coverage	$2.09 <  \eta  < 3.84$	$2.07 <  \eta  < 3.86$
minimal invariant mass	$M_X > 15.7 \text{ GeV}$	$M_X > 13 \text{ GeV}$
MC generators	PYTHIA6, PYTHIA8, PHOJET	PYTHIA 8 (various tunes), EPOS, QGSJET-II

Backgrounds: collisions of the beam with gas particles in the beam-pipe or with material upstream from the detector, and slowly-decaying, collision-induced radiation (*afterglow*).

## Results for 7 TeV:

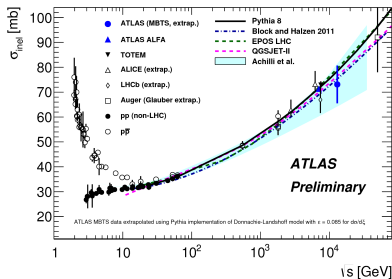
$\sigma(\xi > 5 \times 10^{-6})$ [mb]	
ATLAS Data 2010	$60.33 \pm 2.10(\text{exp.})$
Schuler and Sjöstrand	66.4
PHOJET	74.2
Ryskin <i>et al.</i>	51.8 – 56.2
$\sigma(\xi > m_p^2/s)$ [mb]	
ATLAS Data 2010	$69.4 \pm 2.4(\text{exp.}) \pm 6.9(\text{extr.})$
Schuler and Sjöstrand	71.5
PHOJET	77.3
Block and Halzen	69
Ryskin <i>et al.</i>	65.2 – 67.1
Gotsman <i>et al.</i>	68
Achilli <i>et al.</i>	60 – 75

## Results for 13 TeV:

Source	Value
This measurement	$65.2 \pm 0.8 (\text{exp.}) \pm 5.9 (\text{lum.})$ mb
Pythia8 DL, $\epsilon = 0.06$	71.0 mb
Pythia8 DL, $\epsilon = 0.085$	69.1 mb
Pythia8 DL, $\epsilon = 0.1$	68.1 mb
Pythia8 A2	74.4 mb
EPOS LHC	71.2 mb
QGSJET-II	72.7 mb

Extrapolated cross-section:

$73.1 \pm 0.9 (\text{exp.}) \pm 6.6 (\text{lum.}) \pm 3.8 (\text{extr.})$  mb

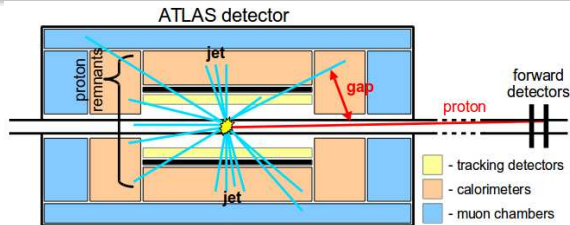


Results agree within the error with MC and general predicted trend.

## More details in:

- 7 TeV analysis:  
**Nature Commun. 2 (2011) 463**
- 13 TeV analysis:  
**ATLAS-CONF-2015-038**

Signature: at least two jets with  $p_T > 20$  GeV  
+ presence of gap in rapidity.



## Data sample:

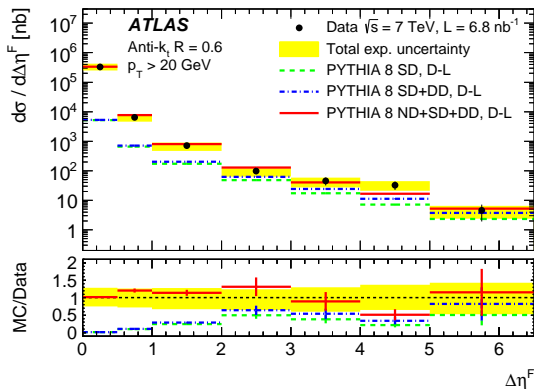
- c.m. energy: 7 TeV
- total integrated luminosity:  $6.8 \text{ nb}^{-1}$
- average number of collisions per bunch crossing: 0.12

## Jets:

- $p_T > 20$  GeV,  $|\eta| < 4.4$
- anti- $k_T$  algorithms ( $R=0.4$  and  $R=0.6$ )

Rapidity gap  $\Delta\eta^F$  – larger of the two empty pseudorapidity regions between detector edge and first reconstructed object:

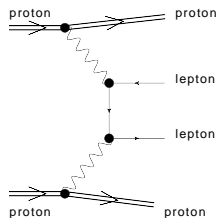
- $|\eta| < 2.5$ : track with  $p_T > 200$  MeV or
- $|\eta| < 4.8$ : calorimeter cell with signal greater than  $5\sigma$  above noise



- diffractive component is required for more complete description of data
- PYTHIA8 gives a good description of shape and normalisation
- rapidity gap survival factor – probability of non-emission by other soft processes (e.g. underlying event) into the gap:  
 $S^2 = 0.16 \pm 0.04$  (stat.)  $\pm 0.08$  (exp. syst.)
- more details in: **Physics Letters B 754 (2016) 214-234**



**Signal signature:** two scattered protons (not measured) + two leptons + nothing else!



## Data sample:

- c.m. energy: 7 TeV
- total integrated luminosity:  $4.6 \text{ fb}^{-1}$

## Electron channel:

- electron and positron originating from the same vertex,
- each with  $p_T^e > 12 \text{ GeV}$  and  $|\eta^e| < 2.4$
- invariant mass:  $m_{e^+e^-} > 24 \text{ GeV}$

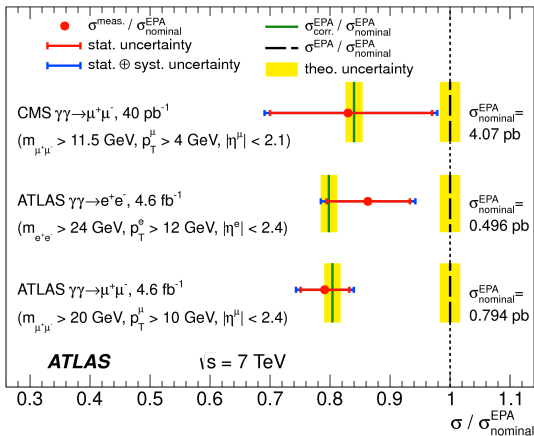
## Muon channel:

- $\mu^+$  and  $\mu^-$  originating from the same vertex,
- each with  $p_T^\mu > 10 \text{ GeV}$  and  $|\eta^\mu| < 2.4$
- invariant mass:  $m_{\mu^+\mu^-} > 20 \text{ GeV}$

## Exclusivity criteria:

- no additional charged particle with  $p_T > 400 \text{ MeV}$  from di-lepton vertex
- no additional track or vertex within 3 mm from di-lepton one
- remove Z-peak mass region:  $70 < m_{l^+l^-} < 105 \text{ GeV}$
- transverse momentum of lepton pair:  $p_T^{l^+l^-} < 1.5 \text{ GeV}$

# Exclusive Lepton Pair Production: Results



- result consistent with the recent CMS measurement
- suppression (20%) with respect to the Equivalent Photon Approximation prediction
- suppression expected due to the contribution of re-scattering effects
- more details in: **Physics Letters B 749 (2015) 242-261**

- **ATLAS measured:**
  - **elastic cross-section:**  
 $\sigma_{el}^{ALFA}(7\text{TeV}) = 24.00 \pm 0.19 \text{ (stat.)} \pm 0.57 \text{ (syst.) mb}$
  - **nuclear slope:**  
 $B^{ALFA}(7\text{TeV}) = 19.73 \pm 0.14 \text{ (stat.)} \pm 0.26 \text{ (syst.) GeV}^{-2}$
  - **total cross-section:**  
 $\sigma_{tot}^{ALFA}(7\text{TeV}) = 95.35 \pm 0.38 \text{ (stat.)} \pm 1.25 \text{ (exp.)} \pm 0.37 \text{ (extr.) mb}$
  - **inelastic cross-section:**  
 $\sigma_{inel}^{ALFA}(7\text{TeV}) = 71.34 \pm 0.36 \text{ (stat.)} \pm 0.83 \text{ (syst.) mb}$   
 $\sigma_{inel}^{MBTS}(7\text{TeV}) = 69.4 \pm 2.4 \text{ (exp.)} \pm 6.9 \text{ (extr.) mb}$   
 $\sigma_{inel}^{MBTS}(13\text{TeV}) = 73.1 \pm 0.9 \text{ (exp.)} \pm 6.6 \text{ (lum.)} \pm 3.8 \text{ (extr.) mb}$
- **Obtained values are in agreement with each other, MC predictions and expected global trend.**
- **Measurement of jets with a gap indicates that diffractive component is needed to describe the data.**
- **Rapidity gap survival was found to be of:**  
 $S^2 = 0.16 \pm 0.04 \text{ (stat.)} \pm 0.08 \text{ (exp. syst.)}$ .
- **Exclusive di-lepton production was measured by ATLAS in electron and muon channel with a good precision.**
- **Results in agreement with theoretical predictions and the ones obtained by the CMS experiment.**

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