Measurements of the elastic, inelastic and total cross sections in pp collisions with ATLAS subdetectors

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On behalf of the ATLAS collaboration

EPS EUROPEAN PHYSICAL SOCIETY HEP2015

Introduction

- This presentation summarizes the ATLAS results at 7 TeV on σ_{tot}, σ_{el} and σ_{inel} using the Roman Pot technique

  ATLAS Collab., *Nucl. Phys. B* **889**, 486 (2014).

- The results are compared with results from other experiments

- The results are also discussed in relation to previous ATLAS measurements based upon " minimum bias" data

- Unfortunately no data from 13 TeV is available at this point

The quantities σ_{tot}, σ_{el} and σ_{inel} can all be determined from a single measurement of the differential elastic cross section

- The σ_{tot}, is extracted using the optical theorem:

$$\sigma_{tot} \propto 4\pi \cdot \mathrm{Im}(f_{el})_{t\to 0}$$

- The σ_{el} is obtained by integration

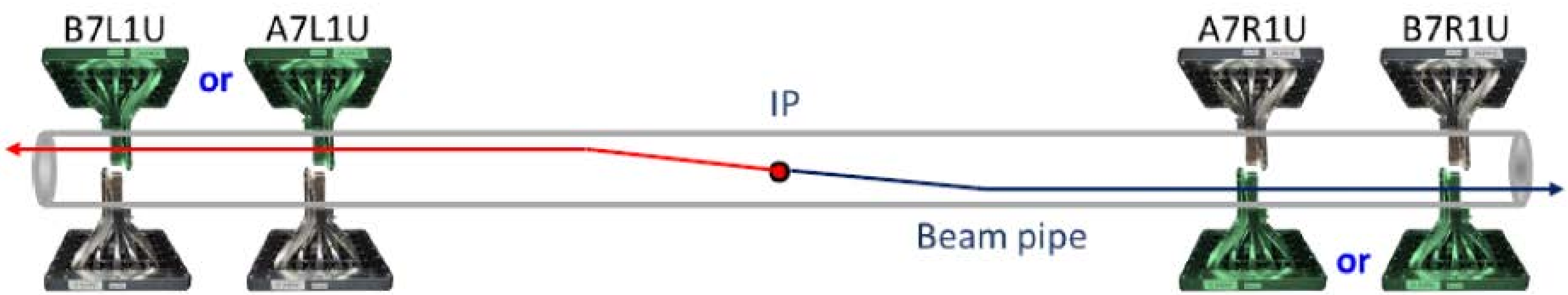
$$\sigma_{el} = \int d\sigma_{el}/dt$$

- The σ_{inel} is derived by a simple subtraction

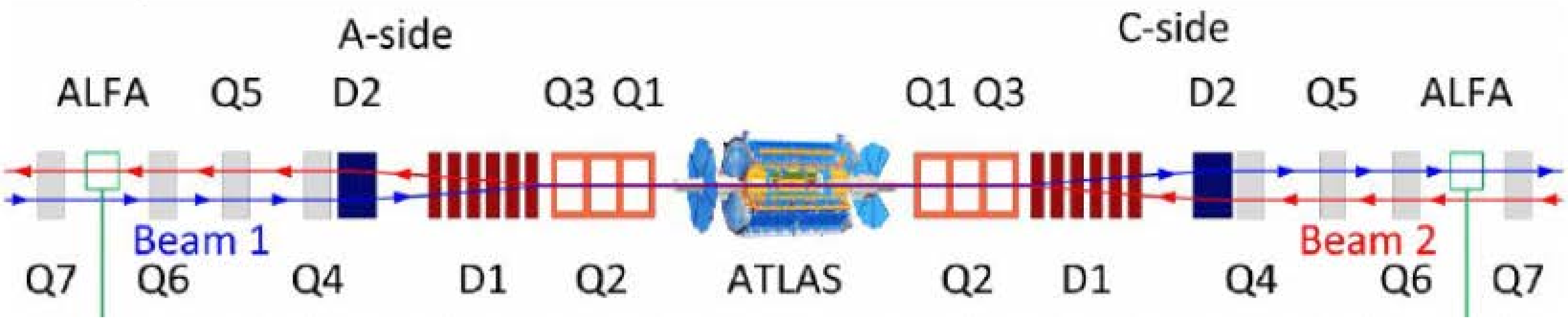
$$\sigma_{inel} = \sigma_{tot} - \sigma_{el}$$

Elastic scattering using the ATLAS Roman Pots(ALFA)

Elastic scattering is measured in a dedicated run of the LHC with special high β*=90m optics with the ALFA Roman Pot sub-detector.



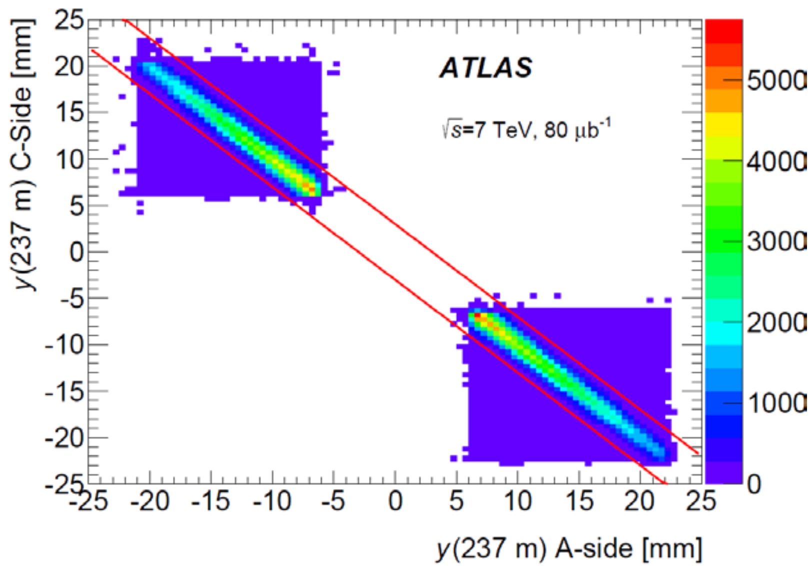
The ALFA detector is at 240m from the IP, the detector was placed at ~5mm from the beam, 800k elastic events were recorded.



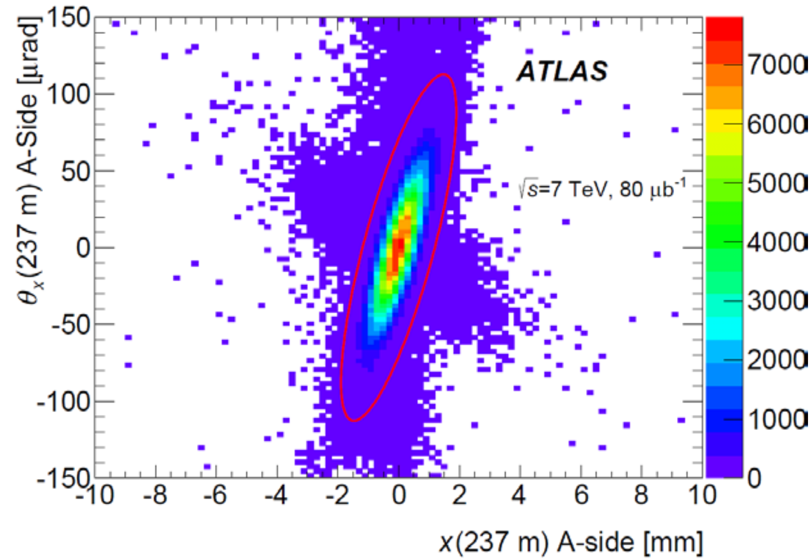
Event Selection

- first level elastic trigger
- data quality cuts
- apply geometrical acceptance cuts
- apply elastic selection based on back-to-back topology and background selection cut

Elastic selection

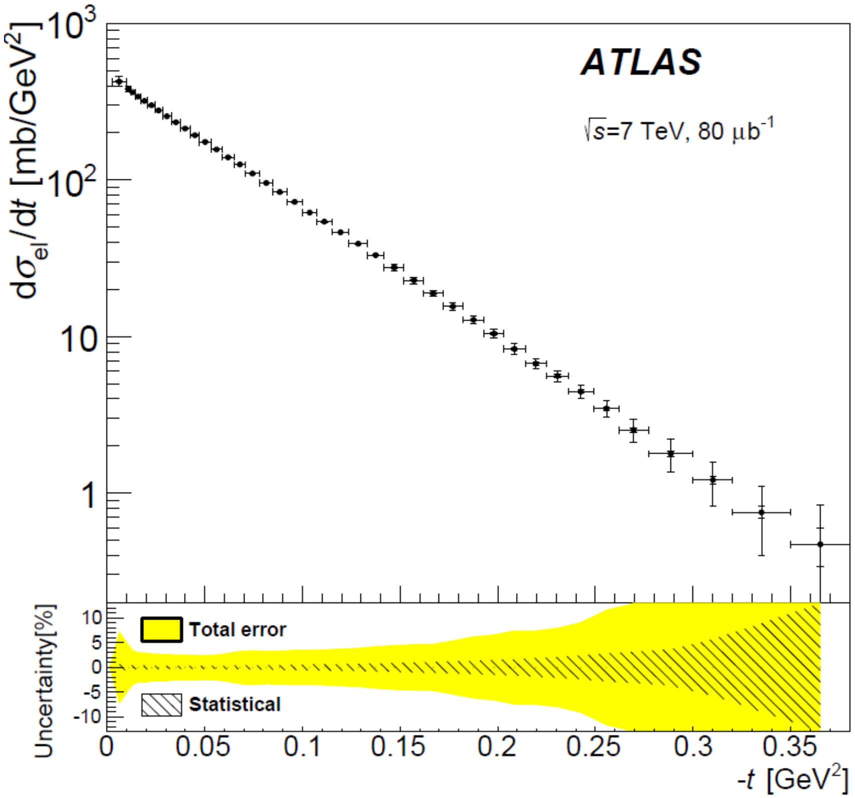


Background rejection



The differential elastic cross section

Corrected t-spectrum in the two arms are combined and divided by luminosity



$$\left(\frac{d\sigma}{dt}\right)_i = \frac{1}{t_i} \cdot \frac{\mathrm{M}^{-1}[N_i - B_i]}{A_i \cdot \varepsilon^{reco} \cdot \varepsilon^{trig} \cdot \varepsilon^{DAQ} \cdot \mathrm{L}_{\mathrm{int}}}$$

A: acceptance(t)

M: unfolding procedure (symbolic)

N: selected events

B: estimated background

ε^{reco}: reconstruction efficiency

ε^{trig}: trigger efficiency

ε^{DAQ}: dead-time correction

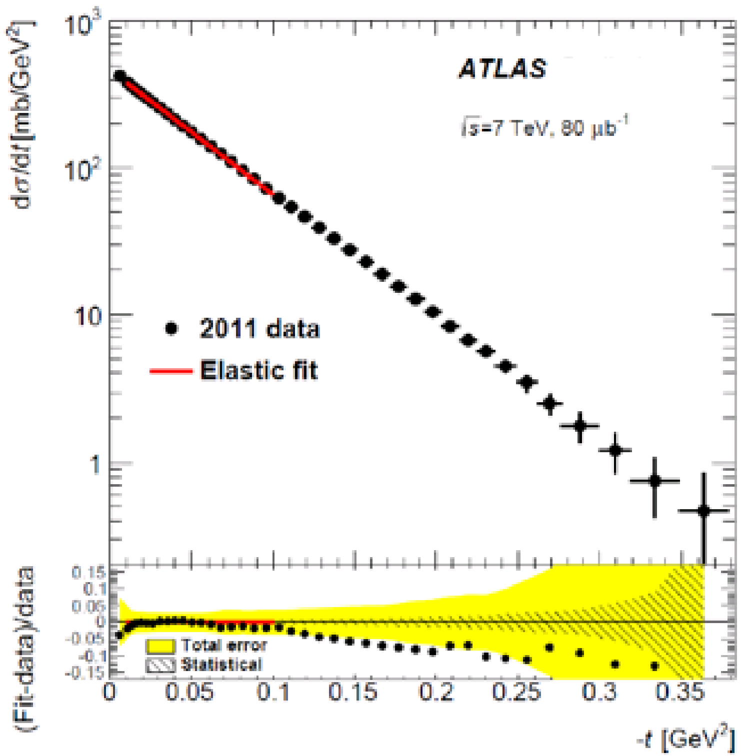
L_{int}: luminosity

Main systematic uncertainties

- luminosity
- nominal beam energy

Extracting σ_{tot} and B

$$\sigma_{tot} \propto 4\pi \cdot \mathrm{Im}(f_{el})_{t\to 0}$$



$$\sigma_{tot} = 95.4 \pm 1.3\,\mathrm{mb}$$
$$B = 19.73 \pm 0.24\,\mathrm{GeV}^{-2}$$

exp.+stat.

The fit includes experimental systematic uncertainties in the χ.

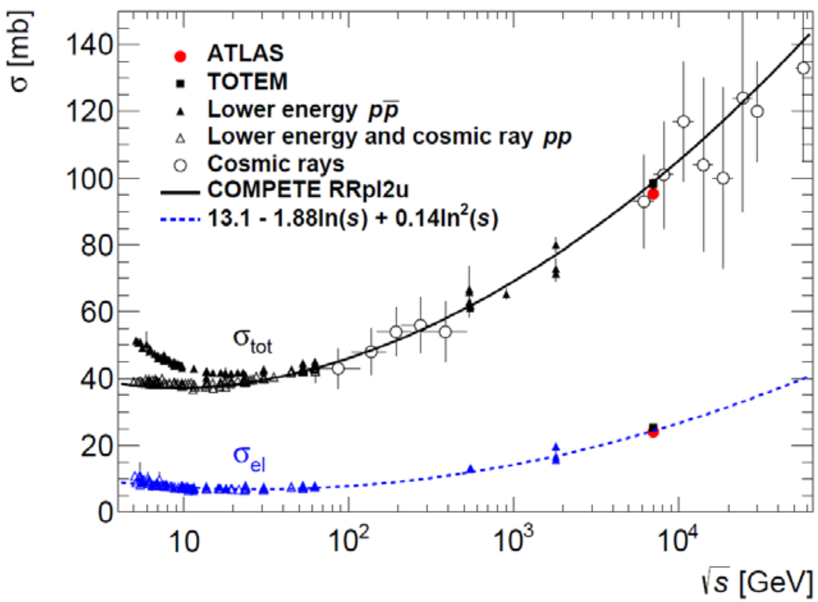
The fit quality is good: χ^2/Ndof=7.4/16.

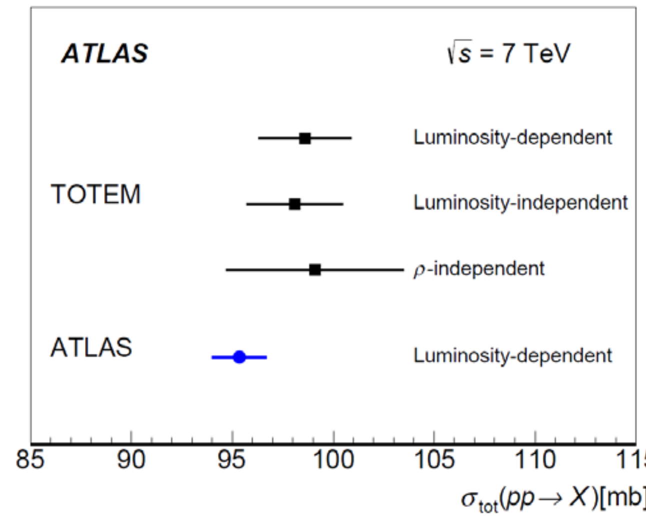
The fit range is set to –t[0.01,0.1] GeV^2, where possible deviations from exponential form are small.

Further uncertainty arise from the extrapolation t→0, probed by a variation of the fit range from 0.1 to 0.15 resp. to 0.058.
Extrapolation error $\Delta\sigma_{tot}$= ±0.4mb, ΔB= ±0.17 GeV^2

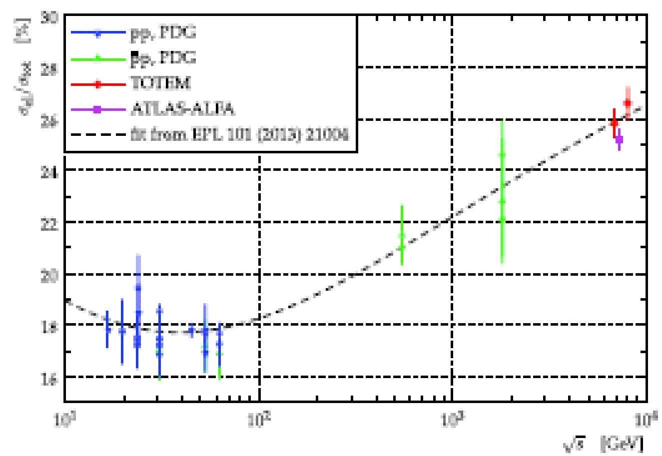
The total cross section and the elastic cross section

From the fit ; σ_{tot}= 95.4± 1.4 mb





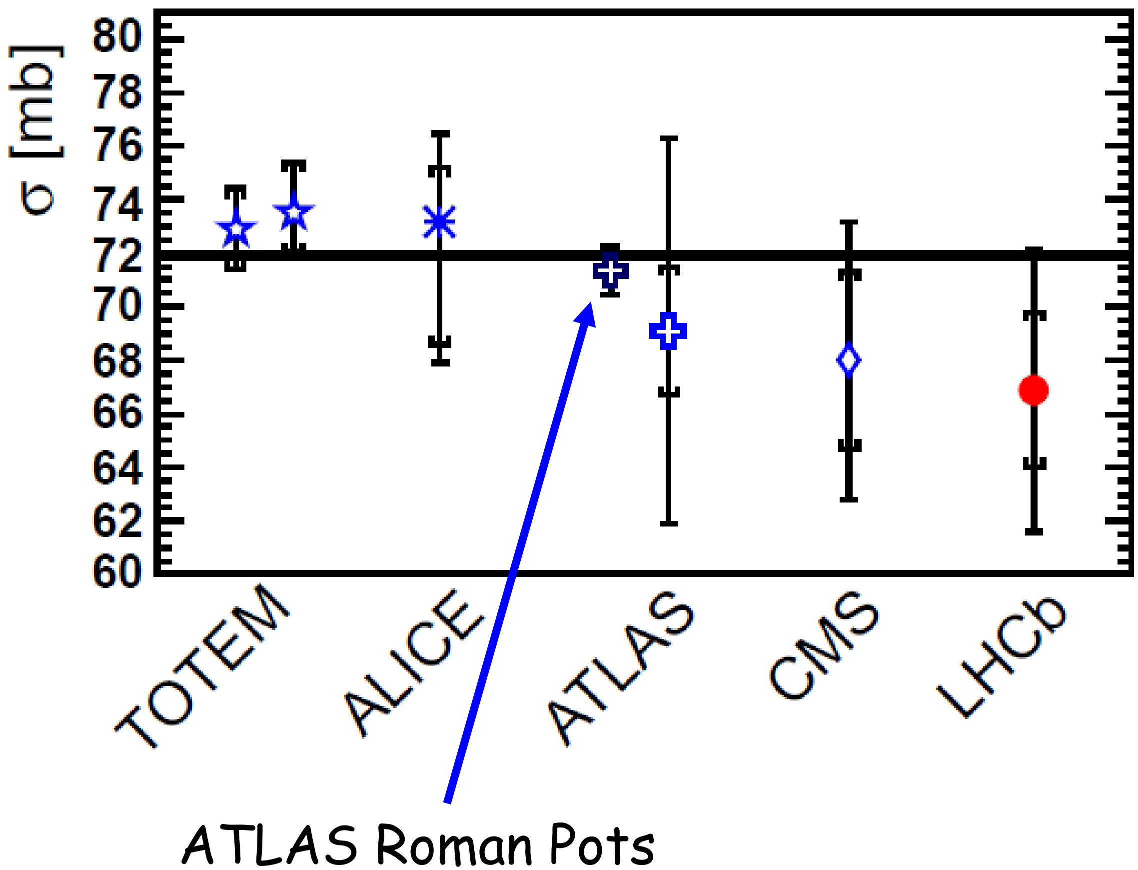
From the integral $\int d\sigma_{el}/dt$;
σ_{el} = 24.0 ±0.6 mb



Plot from TOTEM

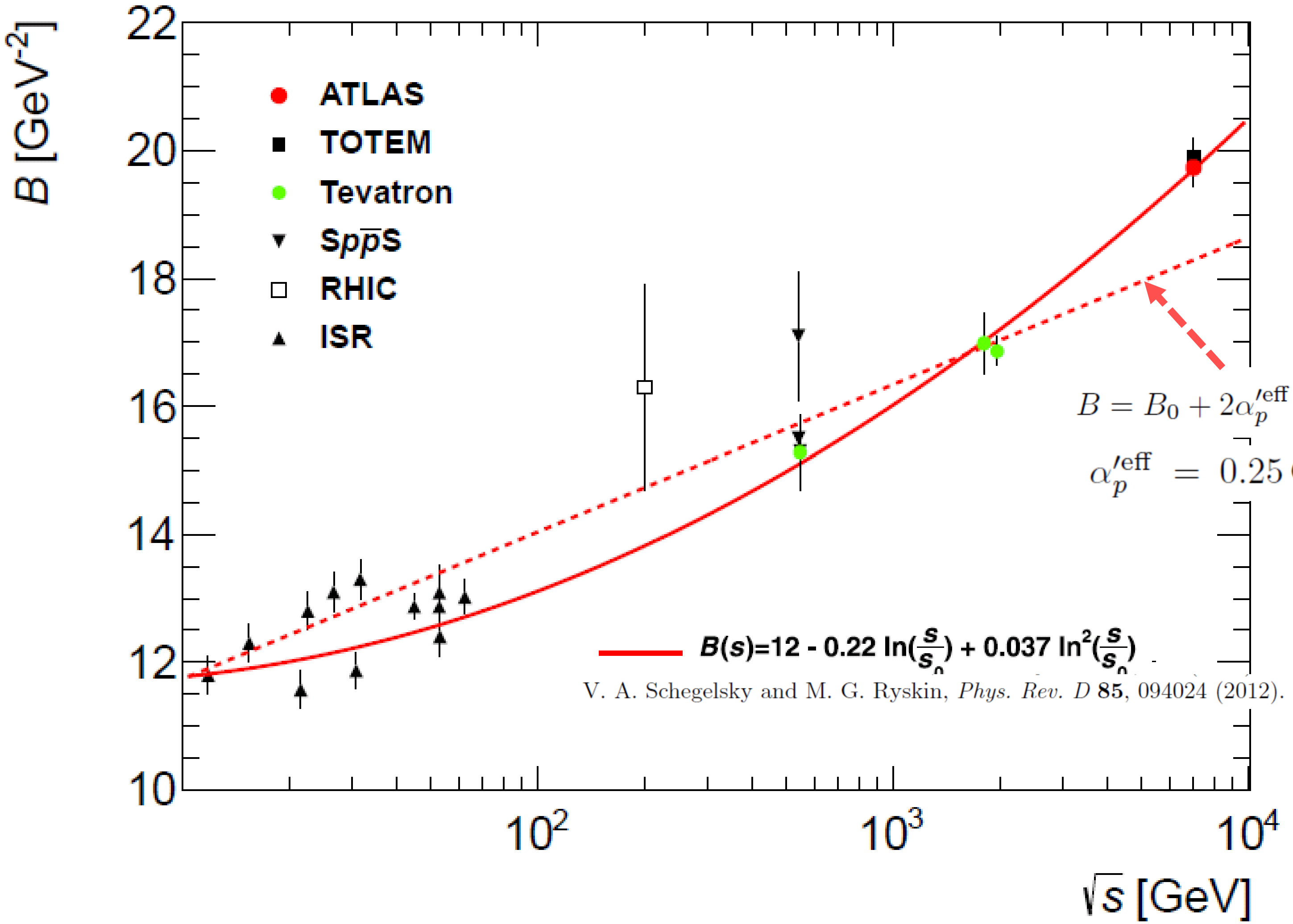
The inelastic cross section

$\sigma_{inel}=\sigma_{tot}-\sigma_{el}$ = 71.3± 0.9 mb



Recent compilation from LHCb

The slope parameter



$B = B_0 + 2\alpha_p'^{\text{eff}} \ln(s/s_0)$

$\alpha_p'^{\text{eff}} = 0.25\,\text{GeV}^{-2}$

V. A. Schegelsky and M. G. Ryskin, *Phys. Rev. D* **85**, 094024 (2012).

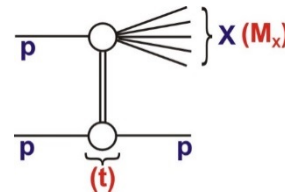
Previous ATLAS measurement of σ_{inel}

ATLAS Collab., *Nat. Commun.* **2**, 463 (2011).

Used " minimum bias" sample to extract σ_{inel}

Limited acceptance for diffractive events in terms of the mass of the dissociated system

$\xi \geq 5 \times 10^{-6} \Longrightarrow M_X \geq 15$ GeV



$$\xi = \frac{M_X^2}{s} = 1 - \frac{E_p^{/}}{E_p}$$

Commonly used variables

σ_{inel} = 60.3 ±2.1 mb in the fiducial region

σ_{inel} = 71.3. ±0.9 mb from Roman Pot measurement

$\Longrightarrow$

σ_{inel} = 11.0. ±2.3 mb for M_X < 15 GeV

Pythia and Phojet predicts: 3-6 mb

e.g models of Khoze Martin and Ryskin (KMR) better description: 11-14 mb

Conclusions

- σ_{tot}, σ_{el} and σ_{inel} have been measured using the Roman Pot technique. Results are in agreement with TOTEM measurements but with slightly better precision. Concerning σ_{inel} the results are in agreement with all other LHC experiments but again with the better precision.

- Comparing σ_{inel} with a previous minimum biased based measurement from ATLAS yield a cross section of 11 ± 2.3 mb for diffractive masses below 15 GeV.

- The slope parameter B increases with s faster than the " standard" $2\,\alpha'_p \ln(s/s_0)$ behavior normally assumed.

- Looking forward to 13 TeV data

BACK-UP

The measurement principle

Measure elastic track positions at ALFA to get the scattering angle and thereby the t-spectrum dσ/dt

$$t = -(p\theta^*)^2$$

p=beam momentum, θ*=scattering angle

To calculate the scattering angle from the measured tracks we need the *beam optics*, i.e. the transport matrix elements.

$$\begin{pmatrix} y \\ \theta_y \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} y^* \\ \theta_y^* \end{pmatrix}$$

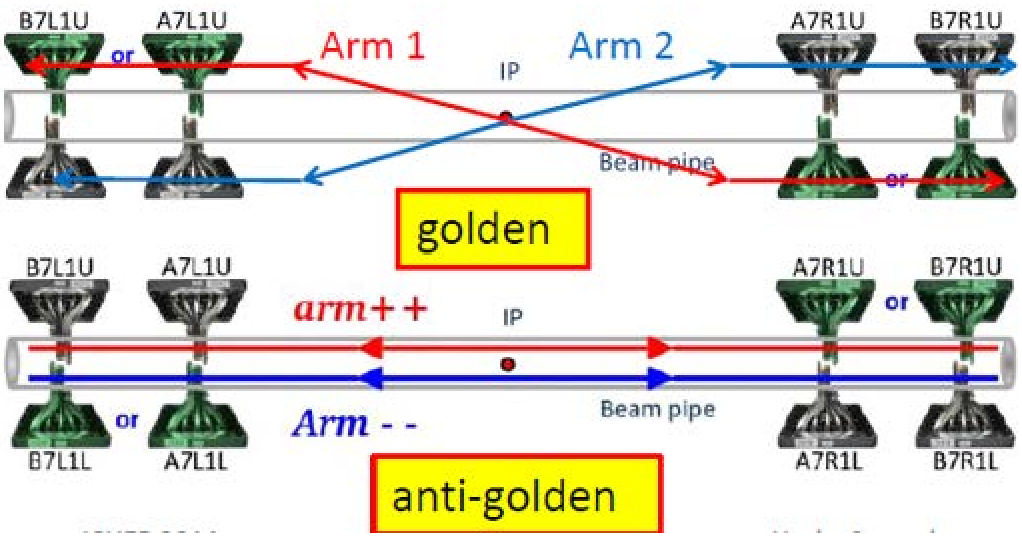
In the simplest case (high β*, phase advance 90°, parallel-to-point focusing)

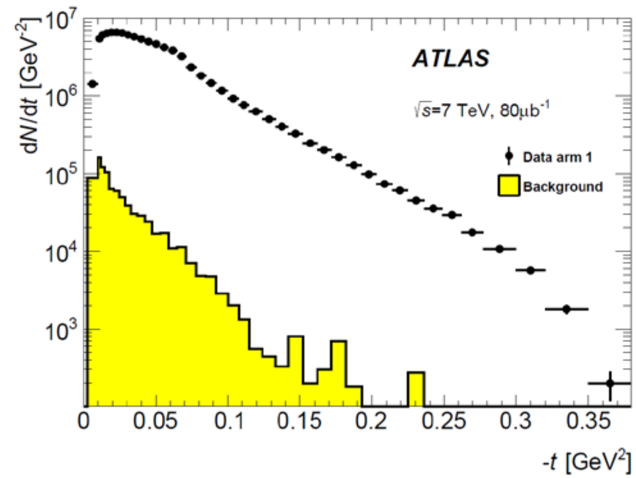
$$\theta_y^* = \frac{y}{M_{12}}$$

Background

Two ways to estimate the background

- Use «anti-golden « configuration
- Reconstruct the vertex distribution in x

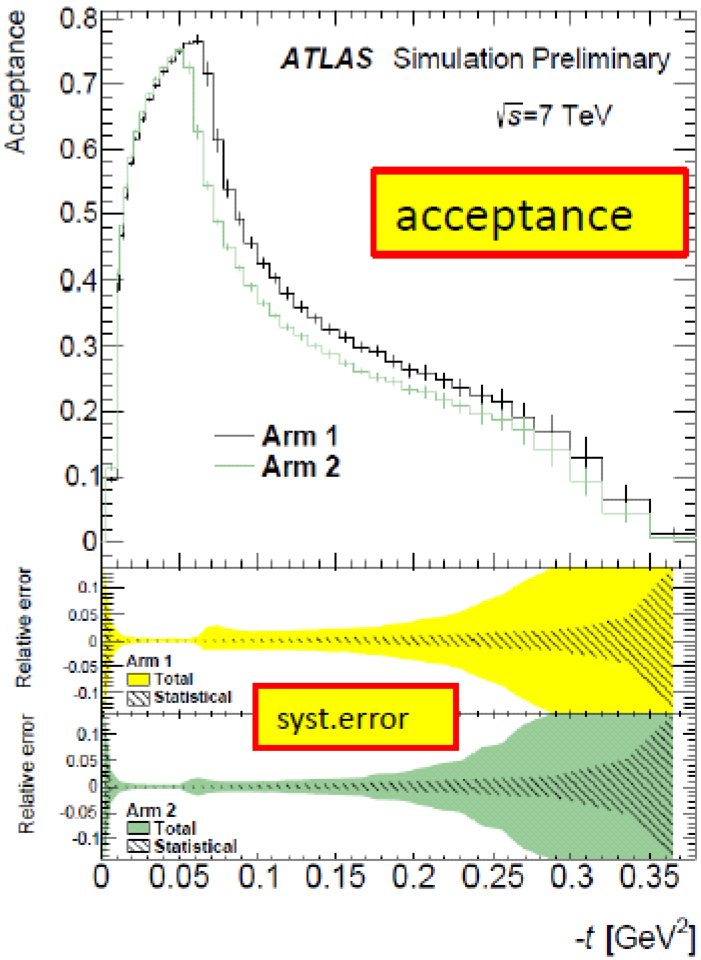


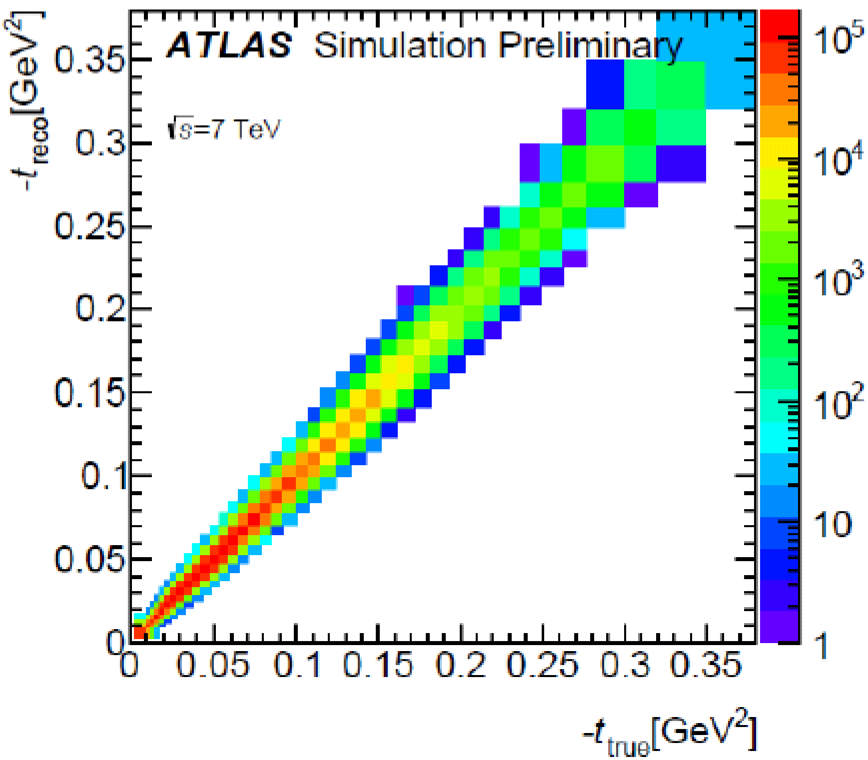


Background fraction ~0.5 %
dominated by halo protons

Simulation: acceptance & unfolding

- Using PYTHIA8 as elastic scattering generator
- Beam transport IP→RP (matrix transport / MadX PTC)
- Fast detector response parameterization tuned to data

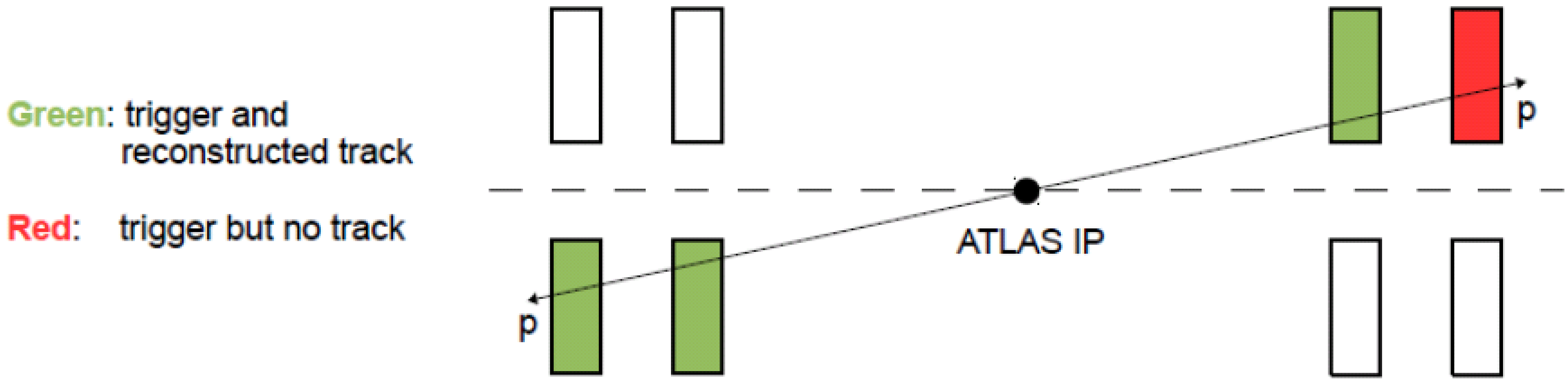




Transition matrix used as input for IDS unfolding.

Reconstruction efficiency

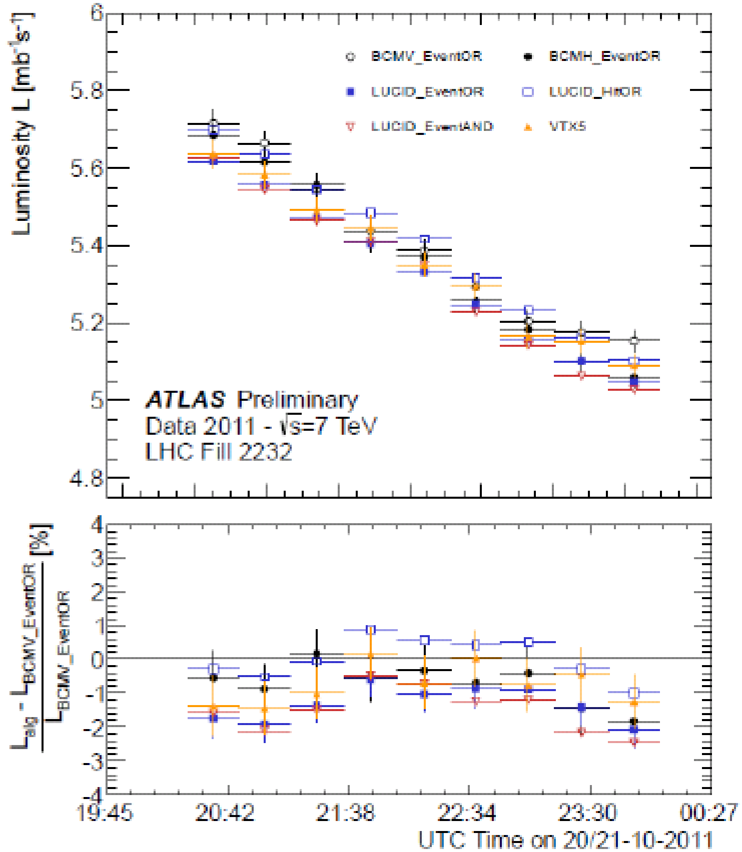
Fully data-driven method, using a tag-and-probe approach exploiting elastic back-to-back topology and high trigger efficiency.



	Arm 1	Arm 2
Efficiency ε_{rec}	0.898	0.880
Uncertainty	±0.006	±0.009

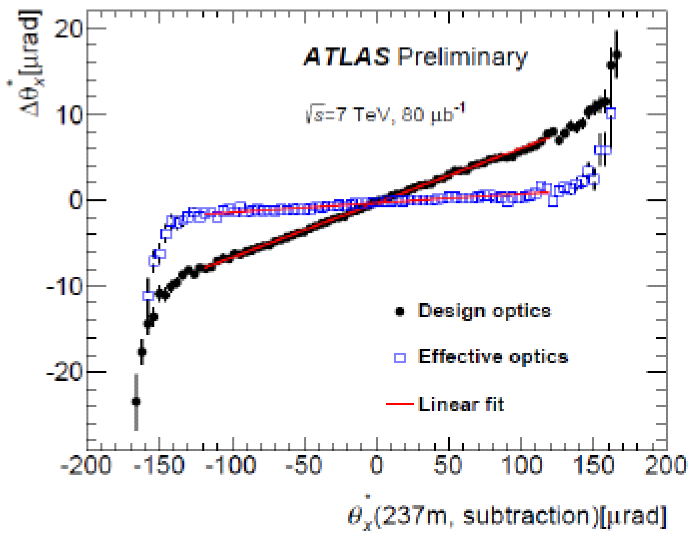
Slightly different efficiency in the two arms → material budget is different.

Luminosity and beam optics

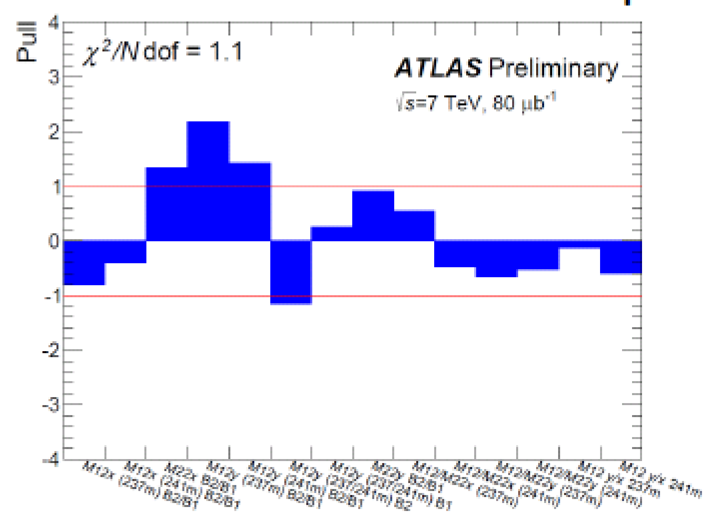


L=78.7±1.9 μb^{-1}

Luminosity uncertainty 2.3%



Constraints on beam optics



Small correction to optics model, 3‰ to inner triplet magnet strength.

Theoretical prediction

The theoretical prediction used to fit the elastic data consists of the Coulomb term, the Coulomb-Nuclear-Interference term and the dominant Nuclear term.

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2(\hbar c)^2}{|t|^2} \cdot G^4(t)$$ Coulomb

CNI $$- \sigma_{\text{tot}} \cdot \frac{\alpha G^2(t)}{|t|} [\sin(\alpha\phi(t)) + \rho\cos(\alpha\phi(t))] \cdot \exp\frac{-B|t|}{2}$$

Nuc. $$+ \sigma_{\text{tot}}^2 \frac{1+\rho^2}{16\pi(\hbar c)^2} \cdot \exp(-B|t|) \ .$$

ρ	0.14
Λ	0.71 GeV^2
ϕ_C	0.577

$$G(t) = \left(\frac{\Lambda}{\Lambda+|t|}\right)^2 ,$$ Proton dipole form factor

$$\phi(t) = -\ln\frac{B|t|}{2} - \phi_C ,$$ Coulomb phase