New ATLAS results on photon-pomeron interference in elastic pp scattering

2207.12246 [hep-ex]

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on behalf of the ATLAS Collaboration

New Vistas in Photon Physics in Heavy-Ion Collisions
Cracow, 19 – 22 September 2022

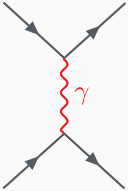
* Supported in part by Polish National Science Centre NCN project no 2021/42/E/ST2/00350

Elastic *pp* scattering

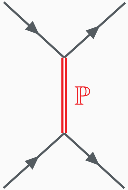
- Energy and momentum conservation
- 2 kinematic degrees of freedom: φ, θ
- φ – trivial (uniform)
- $t \approx -p^2\theta^2 = p_T^2$
- small $|t|$ – large distance, large high $|t|$ – small distance

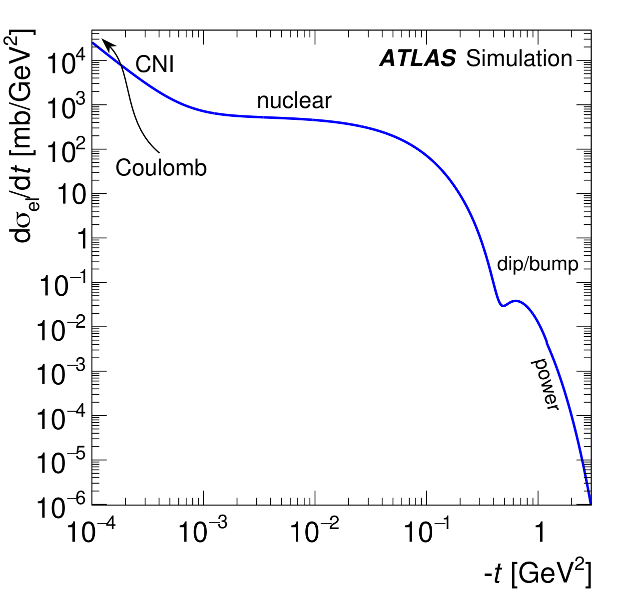
Mechanisms

Coulomb (electromagnetic)



Nuclear (strong)





Optical theorem

Optical theorem

$$\sigma_{\textbf{tot}} = 4\pi \,\textbf{Im}\, f_{\textbf{el}}(t = 0)$$

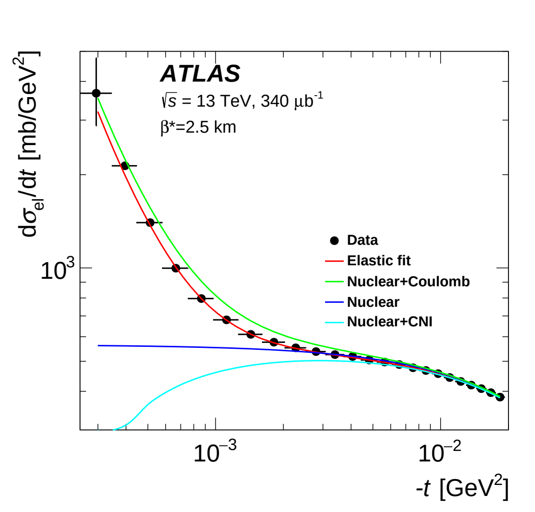
Differential elastic cross section

- Assuming a simplistic t dependence: $f_{\text{el}}(t) \propto \exp(-B|t|/2)$
- Introducing $\rho = \text{Re}\, f_{\text{el}} / \text{Im}\, f_{\text{el}}|_{t=0}$

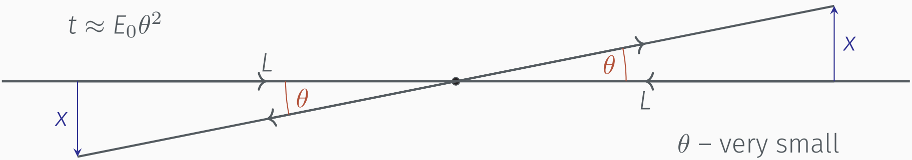
$$\frac{\mathrm{d}\sigma_{\textbf{el}}}{\mathrm{d}t} = \sigma_{\textbf{tot}}^2 \frac{1+\rho^2}{16\pi} \exp\left(-|B|t\right)$$

Phase of the nuclear amplitude

$$\frac{d\sigma_{\mathbf{el}}}{dt} \propto |f_{\mathbf{N}}(t) + f_{\mathbf{C}}(t)|^2$$



Measurement principle



No magnetic fields:

$$x = L\theta \qquad \theta_{\text{local}} = \theta$$

With magnetic fields

$$x = L_{\text{eff}}\theta \qquad \theta_{\text{local}} \propto \theta$$

Finite beam size:

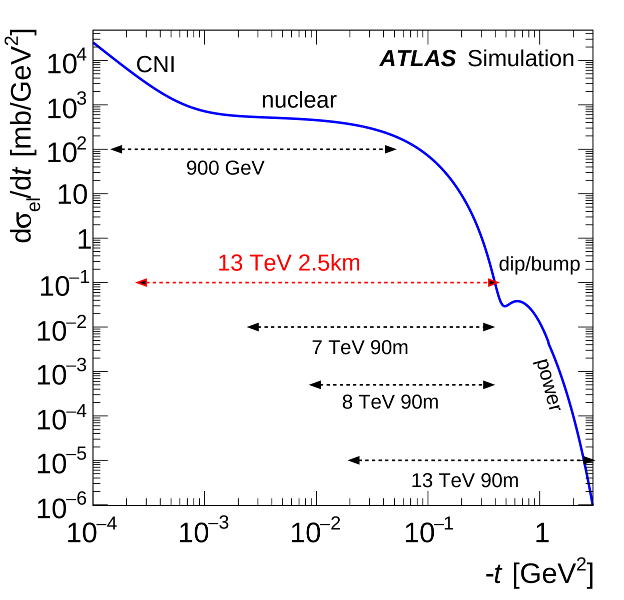
$$\begin{pmatrix} x \\ \theta_{\text{local}} \end{pmatrix} = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} \begin{pmatrix} x_0 \\ \theta \end{pmatrix}$$

$$(\theta, \varphi) \leftrightarrow (\theta_x, \theta_y)$$

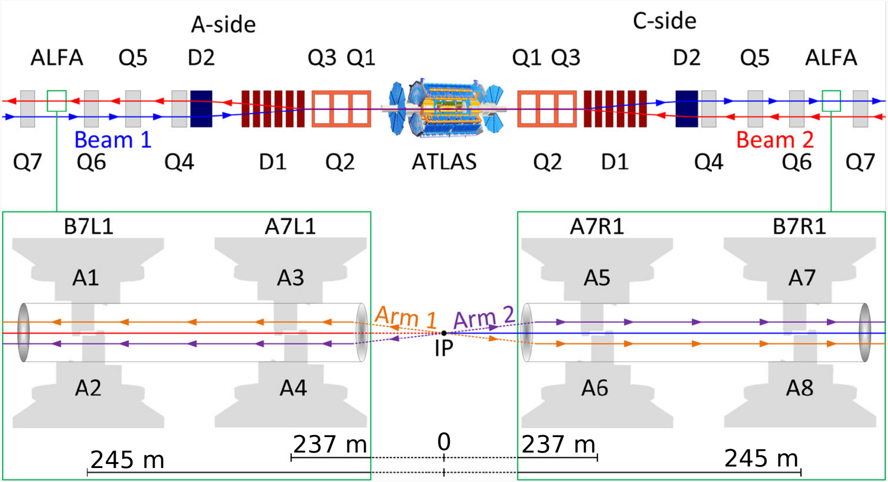
$$\begin{pmatrix} x \\ \theta_{x,\text{local}} \end{pmatrix} = \begin{pmatrix} M^x_{11} & M^x_{12} \\ M^x_{21} & M^x_{22} \end{pmatrix} \begin{pmatrix} x_0 \\ \theta \end{pmatrix}$$

$$\begin{pmatrix} y \\ \theta_{y,\text{local}} \end{pmatrix} = \begin{pmatrix} M^y_{11} & M^y_{12} \\ M^y_{21} & M^y_{22} \end{pmatrix} \begin{pmatrix} y_0 \\ \theta \end{pmatrix}$$

Experimental reach



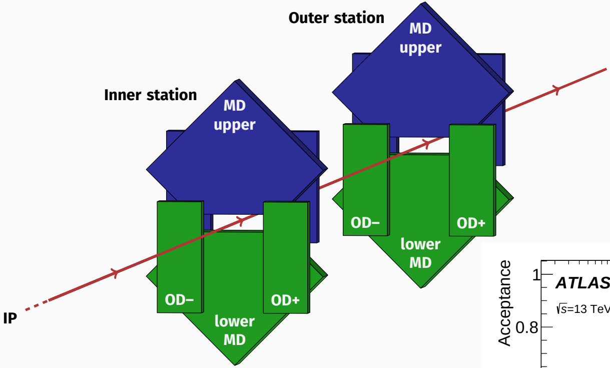
ALFA detectors



2 Roman pot stations on each side of IP

2 tracking detectors in each station

ALFA detectors

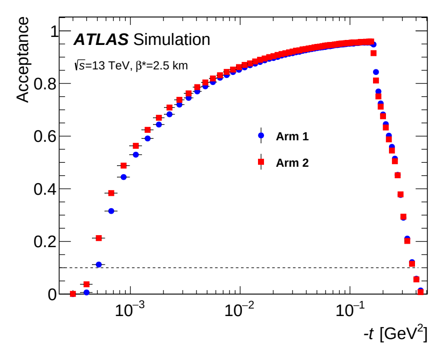


Main detectors (MDs)
for physics

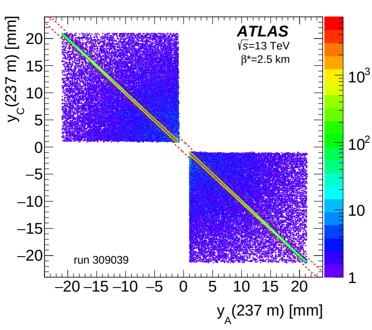
Overlap detectors (ODs)
for alignment

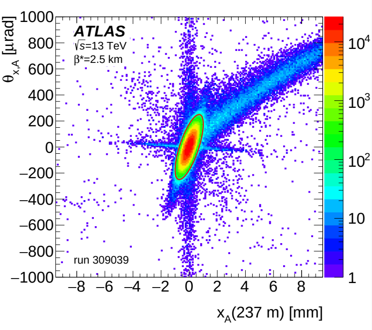
Detectors operate very closely to the beam (few millimetres)

Distance to the beam determines the lowest t



Event selection and background estimation



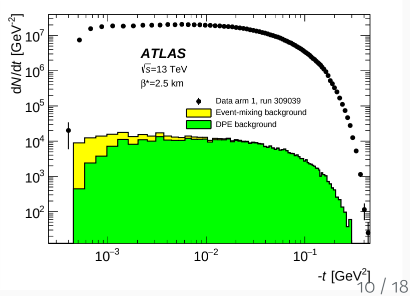


Event selection based on strong correlations present in elastic events

Background (normalized in control regions):

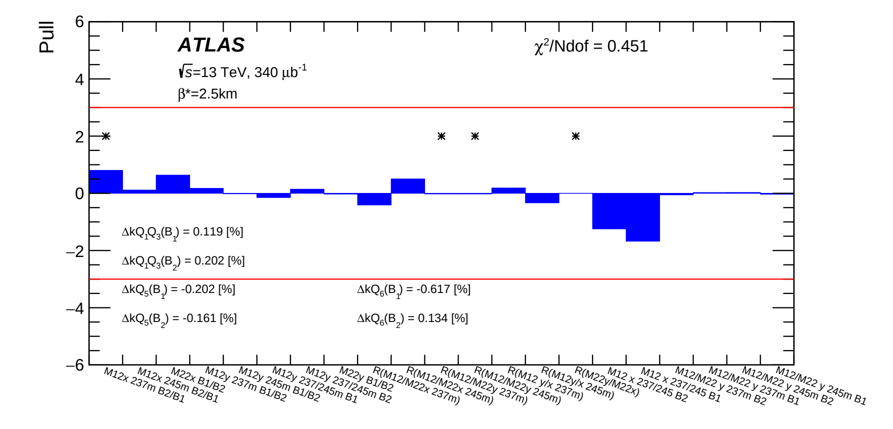
- accidental halo+halo and halo+SD coincidences (data-driven templates)
- central diffraction (MC simulation)

Relative uncertainty of 10 – 15%.

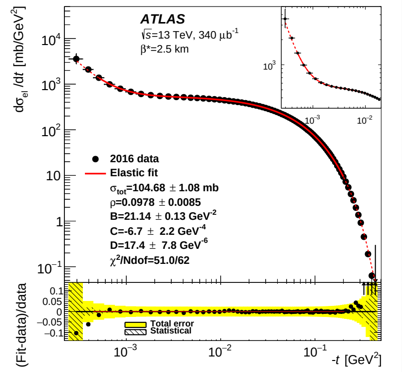


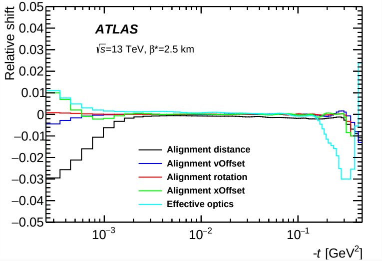
Data-driven methods

Many ingredients of the analysis are based on data exploiting strongly constrained elastic events: alignment, reconstruction efficiency, optics



Differential cross section





Systematic uncertainties evaluated as function of t

Main sources: alignment, luminosity, reconstruction efficiency

Fitted function:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}t} = \frac{1}{16\pi}\left|f_\mathrm{N}(t) + f_\mathrm{C}(t)\mathrm{e}^{\mathrm{i}\alpha\phi(t)}\right|^2$$

$$f_\mathrm{C}(t) = -8\pi\alpha\hbar c\frac{G^2(t)}{|t|}$$

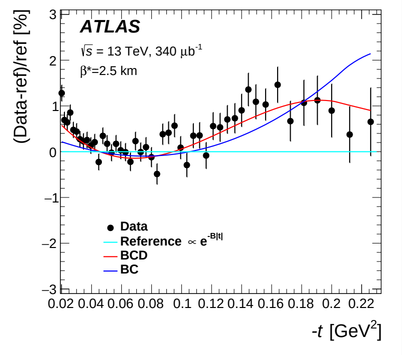
$$f_\mathrm{N}(t) = (\rho + \mathrm{i})\,\frac{\sigma_\mathrm{tot}}{\hbar c}\,\mathrm{e}^{(-B|t|-C|t|^2-D|t|^3)/2}$$

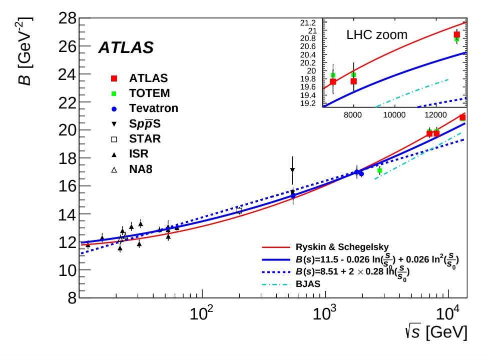
$$\rho = \frac{\mathrm{Re}\, f_\mathrm{N}(0)}{\mathrm{Im}\, f_\mathrm{N}(0)}$$

Results in nuclear region

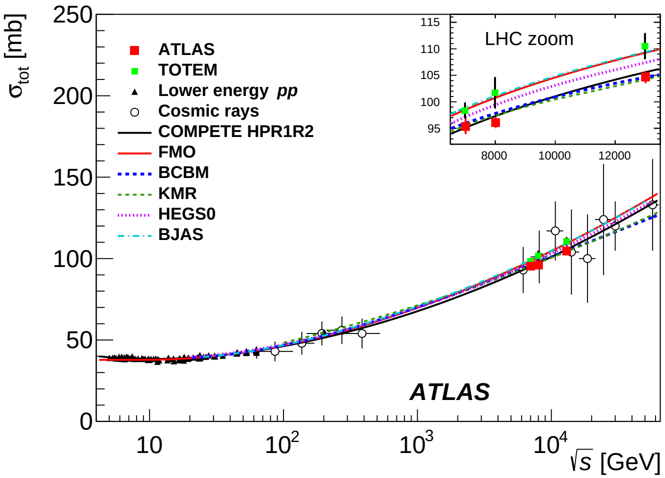
- Non-exponential shape of $d\sigma/dt$
- B–slope measurement

$$B = 21.14 \pm 0.07(\text{stat.}) \pm 0.11(\text{exp.}) \pm 0.01(\text{th.})\text{GeV}^{-2}$$





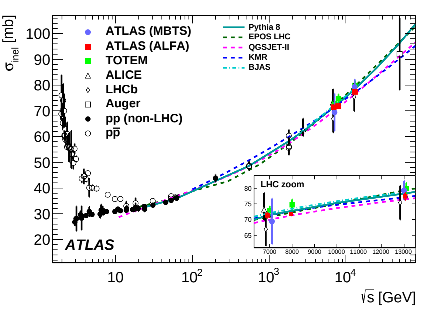
Results in nuclear region



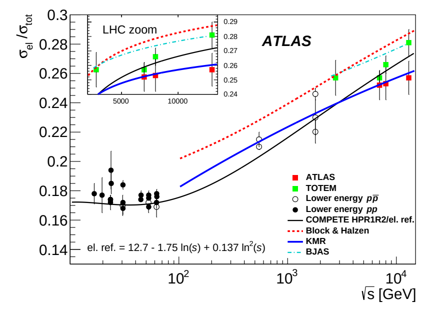
$$\sigma_{\text{tot}} = 104.68 \pm 0.22(\text{stat.}) \pm 1.06(\text{exp.}) \pm 0.12(\text{th.}) \text{ mb}$$

Most precise σ_{tot} measurement. 2.2σ) tension with TOTEM σ_{tot} result.

Derived quantities

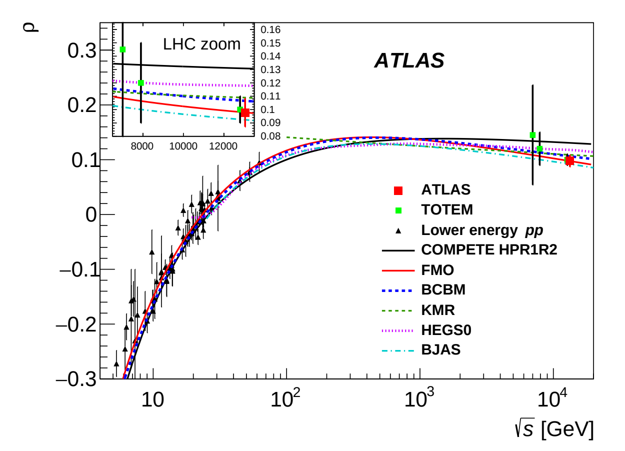


Total inelastic cross section in agreement with previous ATLAS measurements using MBTS detectors



Ratio of elastic to total cross section in tension with TOTEM’s results

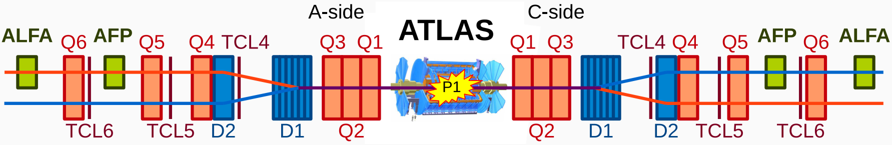
Results in interference region

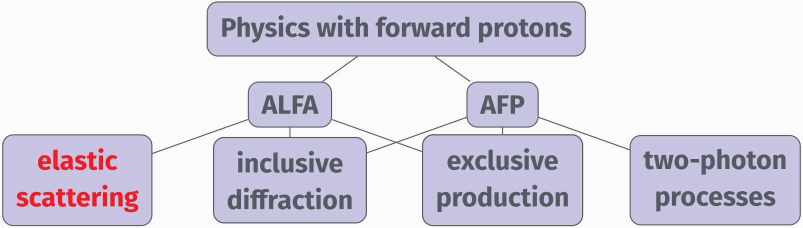


$$\rho = 0.0978 \pm 0.0043(\text{stat.}) \pm 0.0073(\text{exp.}) \pm 0.0064(\text{th.})$$

Result incompatible with COMPETE (community-standard semi-empirical fits) indicating Odderon exchange or a slowdown of σ_{tot} rise at high $\sqrt{s}$.

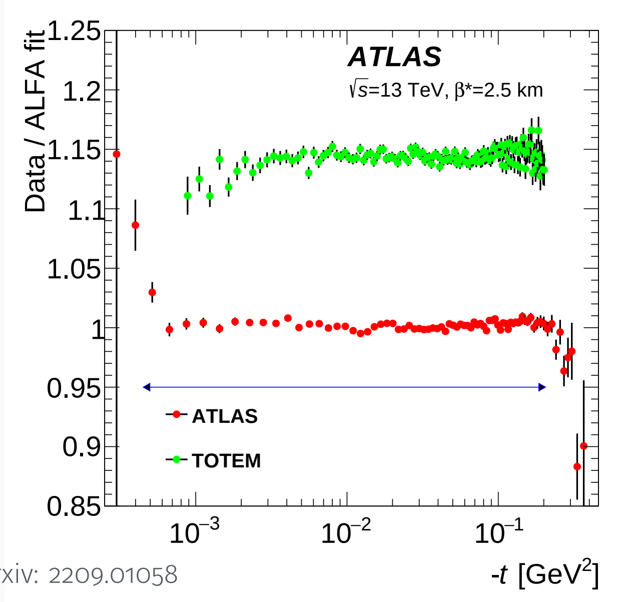
Outlook: physics with forward detectors in ATLAS





BACKUP

ATLAS vs TOTEM



See also arxiv: 2209.01058