PROCEEDINGS OF SCIENCE

Measurement of the Total Cross Section and ρ-parameter from Elastic Scattering at $\sqrt{s} = 13$ TeV

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The study of elastic scattering in hadron colliders provides valuable insights into non-perturbative dynamics that are inaccessible to analytic calculations. The ALFA detector, a subsystem of the ATLAS detector, consists of four Roman Pot stations set at both sides of the ATLAS interaction point. Roman Pot technology allows the detectors to be placed at very small distances from the beam and thus measure the very low scattering angles associated with elastic scattering. We present the results of the study of a data-taking campaign that collected an integrated luminosity of 340 μb^{-1} at $\sqrt{s} = 13$ TeV. The key observables are the total hadronic cross section $\sigma_{tot}(pp \to X)$ and the ρ-parameter. The results give a σ_{tot} of 104.68 ± 1.08 mb and a ρ-parameter of 0.0978 ± 0.0085. The main uncertainties in these measurements arise from luminosity and alignment. A 2.2 σ tension with TOTEM's collaboration result for σ_{tot} is found, attributed to differences in absolute normalization methods.

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1. Introduction

Experimental measurements of elastic scattering at hadron colliders provide valuable insights into non-perturbative dynamics, inaccessible by analytic calculations. Of particular importance are observables as the total hadronic cross section, denoted as σ_{tot}, and the ratio of the real part to the imaginary part of the elastic scattering amplitude, f_{el}, known as the ρ-parameter.

$$\rho = \left. \frac{Re\left[f_{el}(t)\right]}{Im\left[f_{el}(t)\right]} \right|_{t \to 0} \tag{1}$$

This parameter serves as a valuable probe into Coulomb–Nuclear Interference (CNI). Since at low enough values of $|t|$ the differential elastic cross-section:

$$\frac{d\sigma}{dt} = \frac{1}{16\pi} \left| f_C(t) e^{i\alpha\phi(t)} + f_N(t) \right|^2 \tag{2}$$

is sensitive to both the Coulomb $f_C(t)$ and the strong $f_N(t)$ amplitudes, and since the phase of the Coulomb amplitude is known one can infer the value of ρ. The ρ-parameter is introduced here as a part of the nuclear term of Eq. 2.

$$f_N(t) = (\rho + i) \frac{\sigma_{\text{tot}}}{\hbar c} e^{\frac{-B|t| - C|t^2| - D|t^3|}{2}} \tag{3}$$

2. Experimental Set-up

Due to the low scattering angle of the protons in the elastic events, the detectors need to be able to reach a very close distance to the beam. In our case, distances of the order of 1 mm are required. The ALFA (Absolute Luminosity For ATLAS) detector [1] consist of a set of four Roman Pot stations installed on both sides[1] of the ATLAS [2] collision point. Each station consists of two Roman Pots, one above and one below the beam, situated at 237 m and 245 m from the interaction point, as can be seen in Fig. 1 (left).

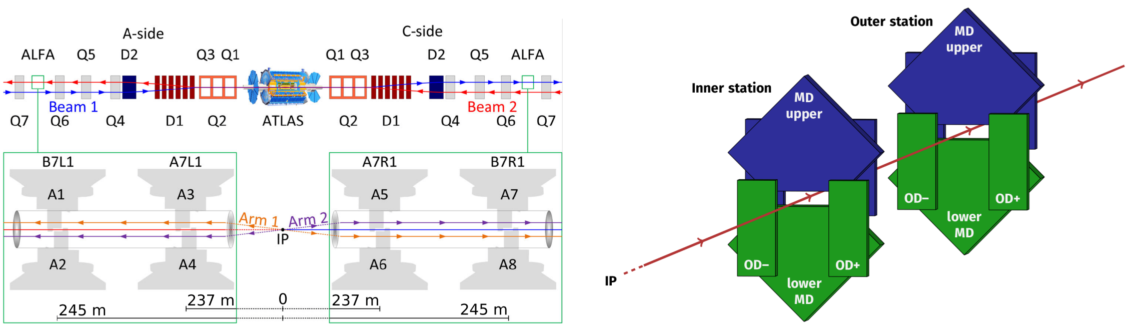

Figure 1: Left: schematic of ALFA location around ATLAS. Q1-Q7 stands for the LHC quadrupole magnets, whereas D1 and D2 are dipoles. **Right:** layout of ALFA on one side of ATLAS.

Each Roman Pot is equipped with main tracking detectors (MDs) and overlap detectors (ODs). Each MD has 10 modules with 2×64 scintillating fibres arranged orthogonally for precise trajectory

[1] ATLAS sides are named A (towards the LHCb experiment) and C (towards the ALICE experiment).

measurements, providing a spatial resolution of about 32 μm [1]. The ODs, placed on the sides of MDs, use three layers of 0.5 mm fibres to measure the vertical distance between upper and lower MDs. Trigger counters made of 3 mm scintillator tiles complement the detectors. A schematic of this detector can be found in Fig. 1 (right).

3. Data Analysis

The data was taken at $\sqrt{s}$ = 13 TeV using special, β^* = 2.5 km, optics [3]. An integrated luminosity of 340 μb^{-1}, which includes 6.9 millions elastic candidates in a range of 2.5·10^{-4} < -t < 0.46 GeV^2, was collected. The full analysis is described in Ref. [4], whereas here only a few key aspects are highlighted.

The event selection was based upon selections of geometrical nature, exploiting the back-to-back symmetry of the elastic events. The event was required to have a distance between the A and C side of less than 3.5σ in the horizontal plane and 2 mm in the y-plane, see Fig. 2 (left).

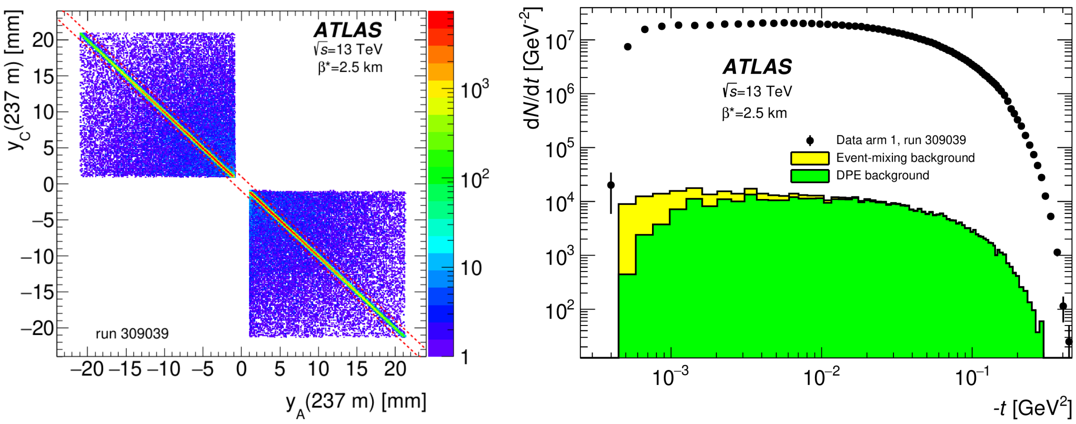

Figure 2: Left: correlations in the vertical plane between the inner stations of both side A and C. **Right:** counting rate dN/dt in arm 1 as a function of t, compared to background coming from accidental coincidences and double Pomeron exchange process. Both figures extracted from Ref. [4].

A small fraction of the background is expected within the phase space volume defined by the event selection cuts. Two types of background are considered: non-elastic scattering processes and accidental coincidences. A data-driven method is used for accidental coincidences, creating a background template by mixing uncorrelated single-sided events. For the non-elastic processes, a Monte Carlo simulation based on the MBR model [5] is employed. The resulting background estimate, dominated by the double-Pomeron exchange, is shown in Fig. 2 (right). The expected background contribution is 0.75 ‰ of the signal, with a 10.4 - 14.8 % uncertainty.

4. Final Results

The total cross-section σ_{tot} and ρ-parameter are found to be 104.68 ± 1.08 mb and 0.0978 ± 0.0085, respectively, with the main uncertainties arising from the luminosity and alignment. This measurement differs from the TOTEM Collaboration's measurement of σ_{tot} [6], indicating a

2.2σ tension. The disagreement is traced back to the differences in absolute normalization. While ATLAS compares the results of different detectors and algorithms to provide a luminosity estimation, TOTEM performs the normalization by luminosity-independent methods. However, the ATLAS and TOTEM measurements of the ρ-parameter are in agreement with each other.

A comparison with the collected data suggests tension with the COMPETE model prediction of the ρ-parameter [7], while it has good agreement in σ_{tot}. There are two main modelizations that could explain this difference. One is the possibility that σ_{tot} asymptotically grows slightly slower than the $ln^2 s$ evolution assumed by COMPETE, specifically by $\frac{\ln^2 s}{1+\alpha \ln^2 s}$. This does not follow from any particular physics model, but limits the growth of the σ_{tot}. The best agreement with ALFA data can be found with $\alpha = 0.0014$, as can be seen in the dotted blue line of Fig. 3.

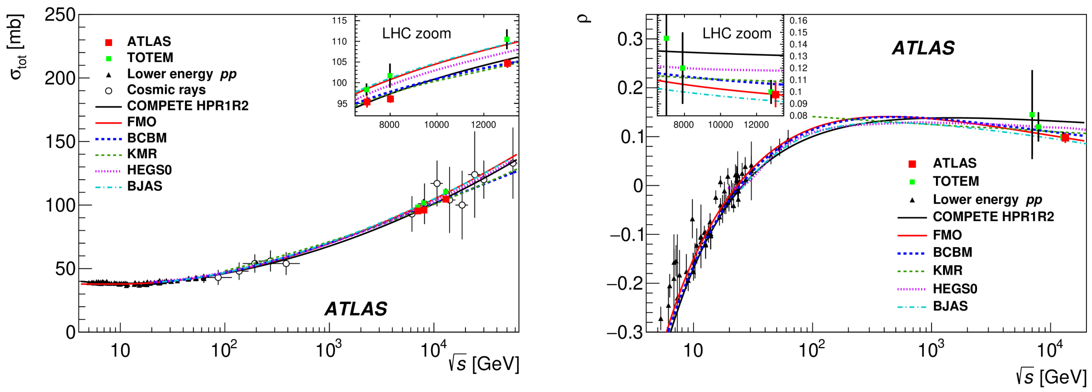

Figure 3: Evolution of σ_{total} (**left**) and ρ (**right**) with $\sqrt{s}$. Taken from [4].

Another possibility is the intervention in the process of a crossing-odd amplitude, which is identified with a three-gluon state, the Odderon, in contrast with the crossing-even amplitude with a two-gluon state, the Pomeron. Several models of this kind are included in Fig. 3. For example, the Froissaron Maximal Odderon (FMO) [8] assumes that the strong force is as strong as allowed within the constraints of axiomatic field theory, provides the best description of TOTEM data, for which it was tuned, but the worst for ALFA.

In conclusion, it is impossible to distinguish the effects of damped energy evolution of σ_{tot} from additional Odderon contributions within the currently available data.

Acknowledgements

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