Measurement of the total proton-proton cross section at $\sqrt{s} = 7$ TeV with the ATLAS detector at the LHC

Joanna Knapik

Institute of Nuclear Physics Polish Academy of Sciences, Krakow
on behalf of the ATLAS Collaboration

Reference to original article:

Nuclear Physics B 889 (2014) 486-548

<http://www.sciencedirect.com/science/article/pii/S0550321314003253>

<http://cds.cern.ch/record/1751527?ln=en>

Total cross section & elastic scattering

- Total hadronic cross section – important parameter of strong interactions, giving an information about the size of the interaction region at a given energy.
- Calculation of the total hadronic cross section from first principles (QCD) is currently not possible...
- ... but it can be measured at hadron colliders via elastic scattering using optical theorem.
- Optical theorem: $\sigma_{tot} \propto \text{Im}[f_{el}(t \rightarrow 0)]$, where $f_{el}(t \rightarrow 0)$ is the elastic scattering amplitude extrapolated to the forward direction and t is four-momentum transfer.
- Measurement of elastic scattering in the very forward direction gives information on the total cross section.
- An independent measurement of the luminosity is required. Elastic cross section can be normalized when luminosity is known.

Theoretical input

Elastic scattering is related to the total cross section through the optical theorem.
Differential elastic cross section is obtained from the scattering amplitudes:

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

where $f_N(t)$ is nuclear amplitude, $f_C(t)$ is Coulomb amplitude.

$$\frac{d\sigma}{dt} = \frac{4\pi\alpha^2(\hbar c)^2}{|t|^2} \times G^4(t) - \sigma_{tot} \times \frac{\alpha G^2(t)}{|t|} [\sin(\alpha\phi(t)) + \rho \cos(\alpha\phi(t))] \times e^{\frac{-B|t|}{2}} + \sigma_{tot}^2 \frac{1 + \rho^2}{16\pi(\hbar c)^2} \times e^{-B|t|}$$

An extrapolation of the differential cross section to $|t| \rightarrow 0$ gives the total cross section value through the formula:

$$\sigma_{tot}^2 = \frac{16\pi(\hbar c)^2}{1 + \rho^2} \left. \frac{d\sigma_{el}}{dt} \right|_{t \rightarrow 0}$$

Variable t is Mandelstam four - momentum transfer

Measurement method

In elastic scattering at high energies the four-momentum transfer t is calculated from θ^* as:

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

where p is nominal beam momentum (3.5TeV) and θ^* is calculated from the proton trajectories measured in $\sqrt{s}$ detector.

θ^* is the angle between y or x coordinate and z at the interaction point.

Important: special beam optics characterized by a β^* of 90m at the interaction point resulting in a small divergence and providing parallel-to-point focusing in the vertical plane.

Four-momentum t is calculated from the scattering angles as follows:

$$-t = \left((\theta_x^*)^2 + (\theta_y^*)^2 \right) p^2$$

Experimental setup – ALFA detector

ALFA (**A**bsolute **L**uminosity **F**or **A**TLAS) – the most forward ATLAS detector, covers pseudorapidity range $|\eta| > 8.5$ (small angle proton scattering)

Data taking

- Run specification: dedicated low-luminosity run using beam optics with β^* of 90m.
- For elastic scattering events main pair of colliding bunches was used, containing around 7×10^{10} protons per bunch.
- Triggers required a coincidence of the main detector trigger scintillators between either of two upper/lower detectors on side A and either the two lower/upper detector on side C.

The correlation of the y coordinate measured at the A- and C-side. Elastic scattering candidates are shown.

Results – differential cross section

Δt_i - bin width
 $\mathcal{M}^{-1}$ - unfolding procedure applied to the background-subtracted number of events N_i – B_i
 ϵ^{reco} - event reconstruction efficiency
 ϵ^{trig} - trigger efficiency
 ϵ^{DAQ} - dead-time correction
 L_{int} - integrated luminosity used for analysis

Fully corrected t – spectra:

$$\frac{d\sigma}{dt_i} = \frac{1}{\Delta t_i} \times \frac{\mathcal{M}^{-1}[N_i - B_i]}{A_i \times \epsilon^{reco} \times \epsilon^{trig} \times \epsilon^{DAQ} \times L_{int}}$$

Results – total cross section

The σ_{tot} and slope parameter B are obtained from a fit of theoretical spectrum to the measured differential cross section, including the Coulomb-nuclear interference term

Fit range from $t = -0.01 \text{ GeV}^2$ to $t = -0.1 \text{ GeV}^2$.

The fit yields:

$$\sigma_{tot} = 95.35 \pm 1.30 \text{ mb}$$

$$B = 19.73 \pm 0.24 \text{ GeV}^{-2}$$

Function to fit:

$$\frac{d\sigma}{dt} \approx \sigma_{tot}^2 \frac{1 + \rho^2}{16\pi(\hbar c)^2} \times e^{-B|t|}$$

Conclusion & Summary

From a fit to the differential elastic cross section, using the optical theorem, the total cross section is determined to be:

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

Comparison of total and elastic cross section measurements measured by ALFA with other published measurements.

Model predictions as function of the centre-of-mass energy is also shown.

ALFA result agrees with value measured by TOTEM ($\sigma_{tot} = 98.6 \pm 2.2 mb$).

Thank you for your attention!

My PhD studies are supported by Krakowskie Konsorcjum Naukowe "Materia-Energia-Przyszłość" (KNOW)