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1. Introduction – experimental set-up.
1. Goal of TOTEM experiment in LHC at CERN

**LHC collider:** huge intersecting storage rings: enabling pp collision at a given place (i.e. particles of small dimensions \(\sim 1\text{fm} = 10^{-15}\text{m}\)) moving in opposite direction with velocity of light

- realization: “collision” of bunches containing large number of particles (protons)

**experiment TOTEM**

- measurement of particles scattered in forward direction (scattered particles remain inside tubes of LHC) → detectors: Roman pots
- scattering processes (diffractive processes):
  - (i) elastic scattering \((pp \rightarrow pp)\)
  - (ii) diffractive production processes: \(pp \rightarrow p\pi^\pi^+, pp \rightarrow (p\pi^\pi^-)(p\pi^\pi^-),…\)
- dynamical characteristics: small value of momentum transfers \(t\), weak energy dependence
- requirements on the LHC: special optics (high value of betatron function \(\beta^*\), low luminosity, small number of bunches, …)
Totem experimental setup

**Inelastic telescopes:** charged particle & vertex reconstruction in inelastic events

- **T1:** $3.1 < \eta < 4.7$
- **T2:** $5.3 < \eta < 6.5$

**Roman Pots:** measure elastic & diffractive protons close to outgoing beam
2. Elastic pp scattering at LHC energies – problems

- hadronic interactions at all \( t \), Coulomb scattering mainly at small \(|t|\);
- measured: \( \Delta N(t) \) number of elastic pp events corresponding to \( \Delta t \);
- theory needs: differential cross section \( \frac{d\sigma}{dt} \)

\[
\Delta N(t) = \mathcal{L} \frac{d\sigma}{dt}
\]

\( \mathcal{L} \) luminosity

- influence of both interactions (spins neglected) \(\rightarrow\) complete amplitude \( F_{C+N}(s,t) \)

\[
\frac{d\sigma}{dt} = \frac{\pi}{s p^2} |F_{C+N}(s,t)|^2
\]

\( s \) ... energy squared
\( t \) ... momentum transfer squared
\( p \) ... momentum value

pp at plab = 24 ÷ 2900 GeV/c

first observation of diffractive structure
• how to specify complete amplitude $F_{C+N}(s,t)$?

• Bethe, West-Yennie (simplified formula, used at $|t| \leq 10^{-2}$ GeV$^2$)

$$F_{C+N}(s,t) = \pm \frac{\alpha s}{t} f_1(t) f_2(t) e^{i\alpha \Phi} + \frac{\sigma_{tot}}{4\pi p \sqrt{s}} (\rho + i)e^{Bt/2}$$

$$\alpha \Phi = \mp \alpha (\ln(-Bt/2) + \gamma)$$

• total cross section $\sigma_{tot}$, diffractive slope $B$, $\rho$ ... ratio of real to imag. parts in forward direction (constant); $f_j(t)$ form factors; at larger $|t|$ Coulomb scattering neglected!

• more precise form of complete amplitude for determination of $\sigma_{tot}$, $B(t)$, $\rho(t)$

(V. K., M. Lokajíček, Z. Phys. C63 (1994) 619) ... modulus and the phase of complex hadronic amplitude $F_{C+N}(s,t)$ should be conveniently parameterized

$$F_{C+N}(s,t) = \pm \frac{\alpha s}{t} f_1(t) f_2(t) + F_N(s,t) \left[ 1 \mp i\alpha G(s,t) \right]$$

$$G(s,t) = \int_{t_{min}}^{0} dt' \left\{ \ln \left( \frac{t'}{t} \right) \frac{d}{dt'} \left[ f_1(t') f_2(t') \right] + \frac{1}{2\pi} \left[ \frac{F_N(s,t')}{F_N(s,t)} - 1 \right] I(t,t') \right\}$$

$$I(t,t') = \int_{0}^{2\pi} d\Phi'' \frac{f_1(t'') f_2(t''')}{t'''}$$

$$t_{min} = -s + 4m^2$$

$$t''' = t + t' + 2\sqrt{tt'} \cos \Phi'''$$

$$\sigma_{tot} = \frac{4\pi}{p \sqrt{s}} |F_N(s,0)| \quad \rho(s,t) \equiv \frac{\Re F_N(s,t)}{3 |F_N(s,t)|}$$

$$B(s,t) = \frac{d}{dt} \left[ \ln \left( \frac{d\sigma_N}{dt} \right) \right] = \frac{2}{|F_N(s,t)|} \frac{d}{dt} |F_N(s,t)|$$

$B(s,t)$ & $\rho(s,t)$ ... model dependent quantities (separation of Coulomb and hadronic scattering)
Publications (mainly elastic pp scattering)


Report:

V. Kundrát, M. Lokajiček, J. Kašpar, J. Procházka: Form factors and elastic scattering of protons at high energies; talk presented at the March TOTEM collaboration meeting in Kirchberg, Austria; available at https://indico.cern.ch/getFile.py/access?contribId=37&resId=0&materialId=slides&confId=121894
pp elastic scattering at 7 TeV

\[ \sigma_{\text{tot}} = (98.6 \pm 2.2) \text{ mb} \quad \text{... elastic observables only} \]

\[ \sigma_{\text{tot}} = (98.6 \pm 2.2) \text{ mb} \quad \text{... } \rho \text{ independent} \]

\[ \sigma_{\text{tot}} = (98.0 \pm 2.5) \text{ mb} \quad \text{... luminosity independent} \]

Separation of Coulomb and hadronic scattering could not be performed!
• reliable separation of Coulomb and hadronic scattering requires to have data in the broadest interval of $t$, especially at very small $|t|$; from the data only $t$ dependence of the modulus can be specified; $t$ dependence of the hadronic phase should be specified by other physical requirements, i.e., by shape of distribution of elastic hadron scattering in the impact parameter space

• separation: always model-dependent

• slightly different and more precise values of cross sections (total, integrated elastic and inelastic ones – unitarity equation,…)

• diffractive structure in elastic differential cross sections – more diffractive minima (?)

• parton structure of proton

• this can be achieved if: convenient conditions at the LHC (optics, high $\beta^*$, …)

• the smallest distance of edgeless detectors housed in the RP’s to the beam ($\sim 4\sigma_{beam}$)

• hints for theoretical description - no reliable theory up to now

• elastic scattering still very mysterious scattering process

Next measurements – at each studied energy:

(i) elastic scattering of pp

(ii) diffractive production processes: either TOTEM alone or in collaboration with CMS