TOTEM experiment - results

V. Kundrát, Institute of Physics, AS CR, v.v.i.

Bari-KFKI Budapest-Case Western Reserve Univ.-CERN-Genoa-Helsinki-Pisa/Siena-Prague-Tallinn (~ 80 physicists)

1. Introduction – experimental set-up.
2. Elastic pp scattering at LHC energies – results, problems.

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 ~ 1fm= 10^{-15} m) moving in opposite direction with velocity of light

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

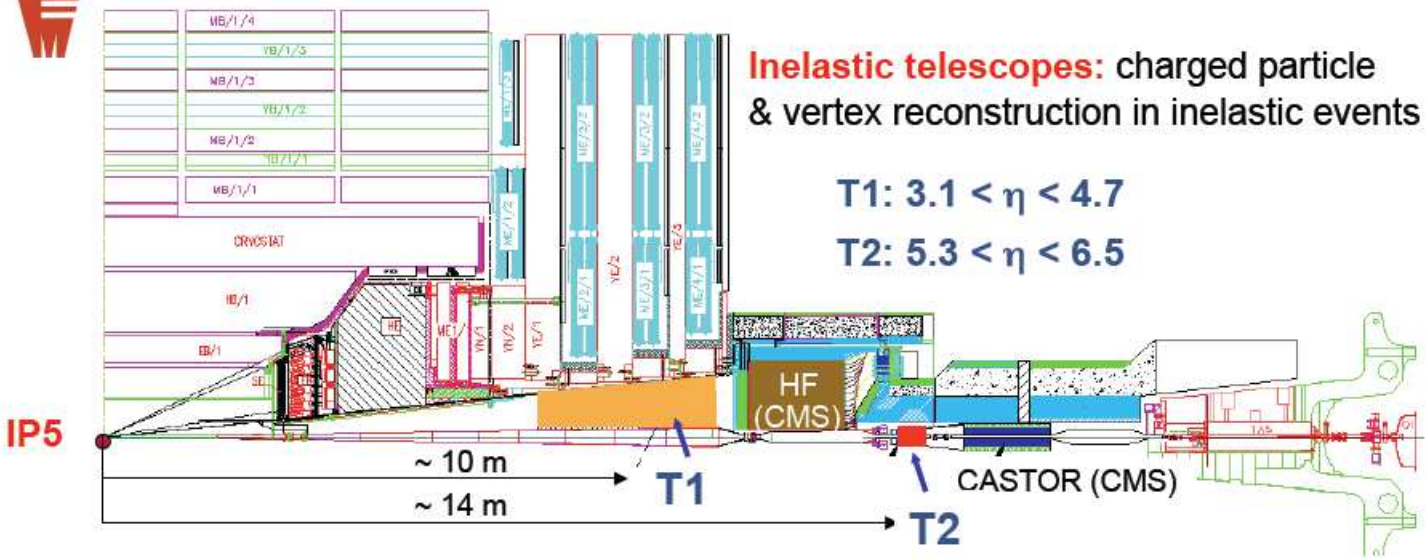
experiment TOTEM

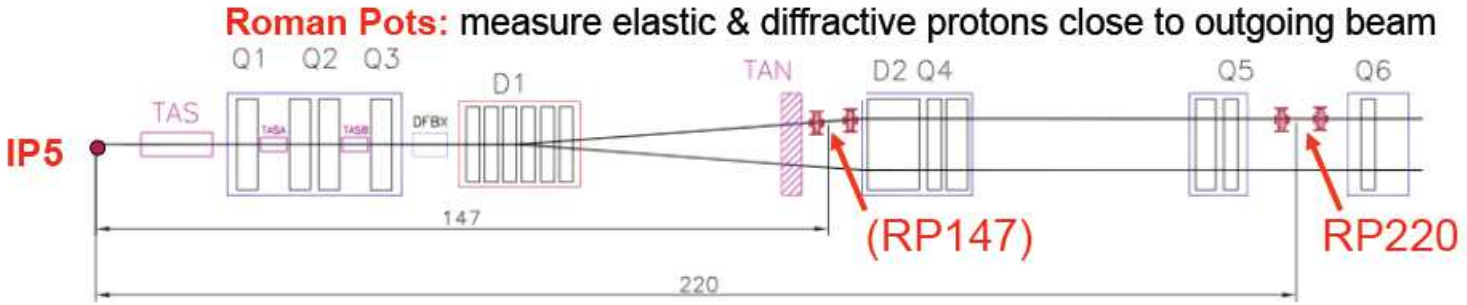
- measurement of particles scattered in forward direction (scattered particles remain inside tubes of LHC) → detectors: Roman pots
- scattering processes (diffractive processes):

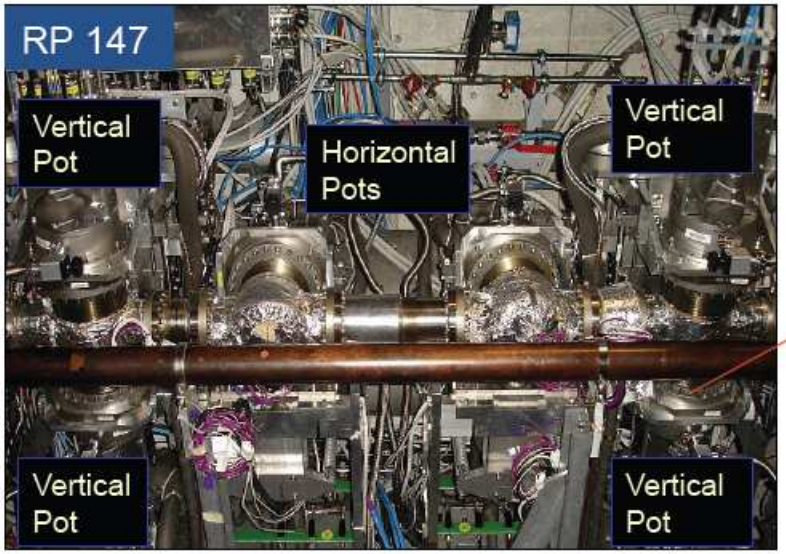
  (i) elastic scattering ($pp \rightarrow pp$)

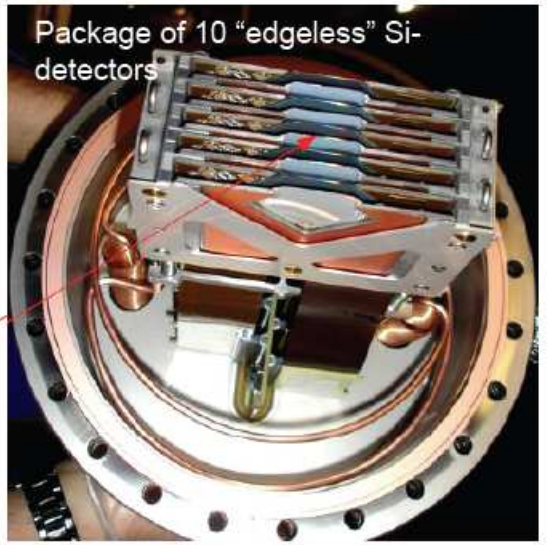
  (ii) diffractive production processes: $pp \rightarrow pn\pi^+$, $pp \rightarrow (p\pi^+ \pi^-)(p\pi^+ \pi^-)$,…
- dynamical characteristics: small value of momentum transfers t , weak energy dependence
- requirements on the LHC: special optics (high value of betatron function β^* , low luminosity, small number of bunches, …)

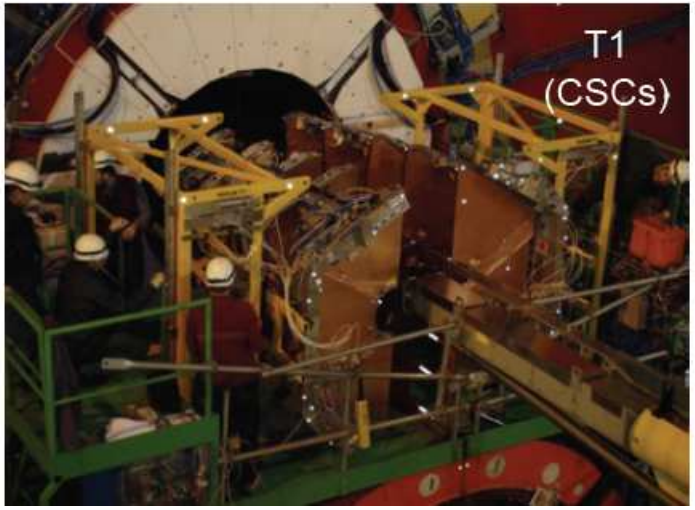
Totem experimental setup

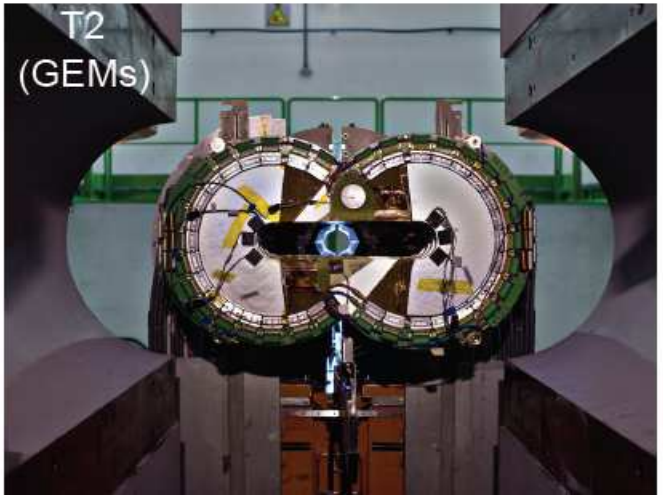





RP 147
Vertical Pot
Horizontal Pots
Vertical Pot
Vertical Pot
Vertical Pot


Package of 10 “edgeless” Si-detectors


T1
(CSCs)


T2
(GEMs)

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 Δt
- 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) → complete amplitude $F^{C+N}(s,t)$

$$\frac{d\sigma}{dt} = \frac{\pi}{sp^2}\left|F^{C+N}(s,t)\right|^2$$

s … energy squared

t … momentum transfer squared

p … momentum value

pp at plab = 24 ÷ 2900 GeV/c

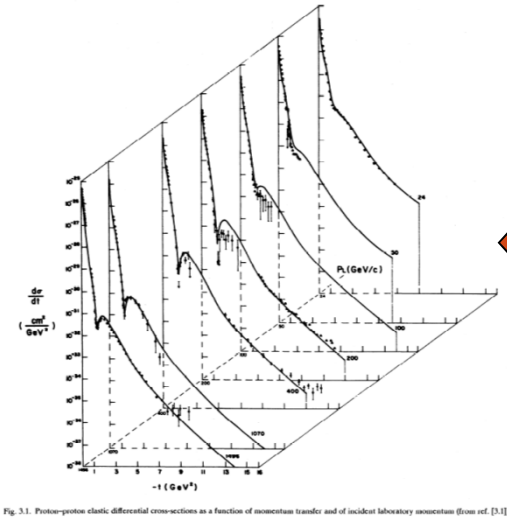
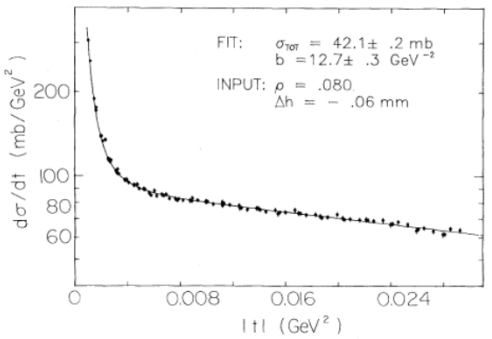


Fig. 3.1. Proton–proton elastic differential cross-sections as a function of momentum transfer and of incident laboratory momentum (from ref. [3.1]).

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 σ_{tot} , diffractive slope B , ρ … 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 σ_{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

$$F^{C+N}(s,t) = \pm\frac{\alpha s}{t} f_1(t) f_2(t) + F^N(s,t)\left[1 \mp i\alpha G(s,t)\right]$$
$$G(s,t) = \int_{t_{min}}^{0} dt' \left\{ \ln\left(\frac{t'}{t}\right) \frac{d}{dt'}\left[f_1(t') f_2(t')\right] + \frac{1}{2\pi}\left[\frac{F^N(s,t')}{F^N(s,t)} - 1\right] I(t,t') \right\}$$
$$I(t,t') = \int_0^{2\pi} d\Phi'' \frac{f_1(t'') f_2(t'')}{t''} \qquad t_{min} = -s + 4m^2$$
$$t'' = t + t' + 2\sqrt{tt'}\cos\Phi''$$

$$\sigma_{tot} = \frac{4\pi}{p\sqrt{s}} |F^N(s,0)| \quad \rho(s,t) \equiv \frac{\Re F^N(s,t)}{\Im F^N(s,t)}$$
$$B(s,t) = \frac{d}{dt}\left[\ln\frac{d\sigma^N}{dt}\right] = \frac{2}{|F^N(s,t)|}\frac{d}{dt}|F^N(s,t)|$$

$B(s,t)$ & $\rho(s,t)$ … model dependent quantities (separation of Coulomb and hadronic scattering)

Publications (mainly elastic pp scattering)

[1] G. Antchev,..., J. Kašpar, J. Kopal, V. Kundrát, ..., M. Lokajíček, ..., J. Procházka,…, V. Vacek, M. Vitek, …,et al: Proton-proton elastic scattering at the LHC energy of $\sqrt{s}$ = 7 TeV; EPL 95 (2011) 41001.

[2] G. Antchev,..., J. Kašpar, J. Kopal, V. Kundrát, ..., M. Lokajíček, ..., J. Procházka,…, V. Vacek, M. Vitek, …, et al: First measurement of the total proton-proton cross-section at the LHC energy of $\sqrt{s}$ = 7 TeV; EPL 96 (2011) 21002.

[3] G. Antchev,..., J. Kašpar, J. Kopal, V. Kundrát, ..., M. Lokajíček, ..., J. Procházka,…, V. Vacek, M. Vitek, …, et al: Measurements of the forward charged particle pseudorapitidy desity in pp collisions at $\sqrt{s}$ = 7 TeV with the TOTEM experiment; EPL 98 (2012) 31002.

[4] G. Antchev,..., J. Kašpar, J. Kopal, V. Kundrát, ..., M. Lokajíček, ..., J. Procházka,…, V. Vacek, M. Vitek, …, et al; Measurement of proton-proton elastic scattering and total cross section at $\sqrt{s}$ = 7 TeV; EPL 101 (2013) 21002.

[5] G. Antchev,..., J. Kašpar, J. Kopal, V. Kundrát, ..., M. Lokajíček, ..., J. Procházka,…, V. Vacek, M. Vitek, …, et al; Measurement of proton-proton inelastic scattering cross section at $\sqrt{s}$ = 7 TeV; EPL 101 (2013) 21003.

[6] G. Antchev,..., J. Kašpar, J. Kopal, V. Kundrát, ..., M. Lokajíček, ..., J. Procházka,…, V. Vacek, M. Vitek, …, et al; Luminosity-independent measurements of total, elastic and inelastic cross section at $\sqrt{s}$ = 7 TeV; EPL 101 (2013) 21004.

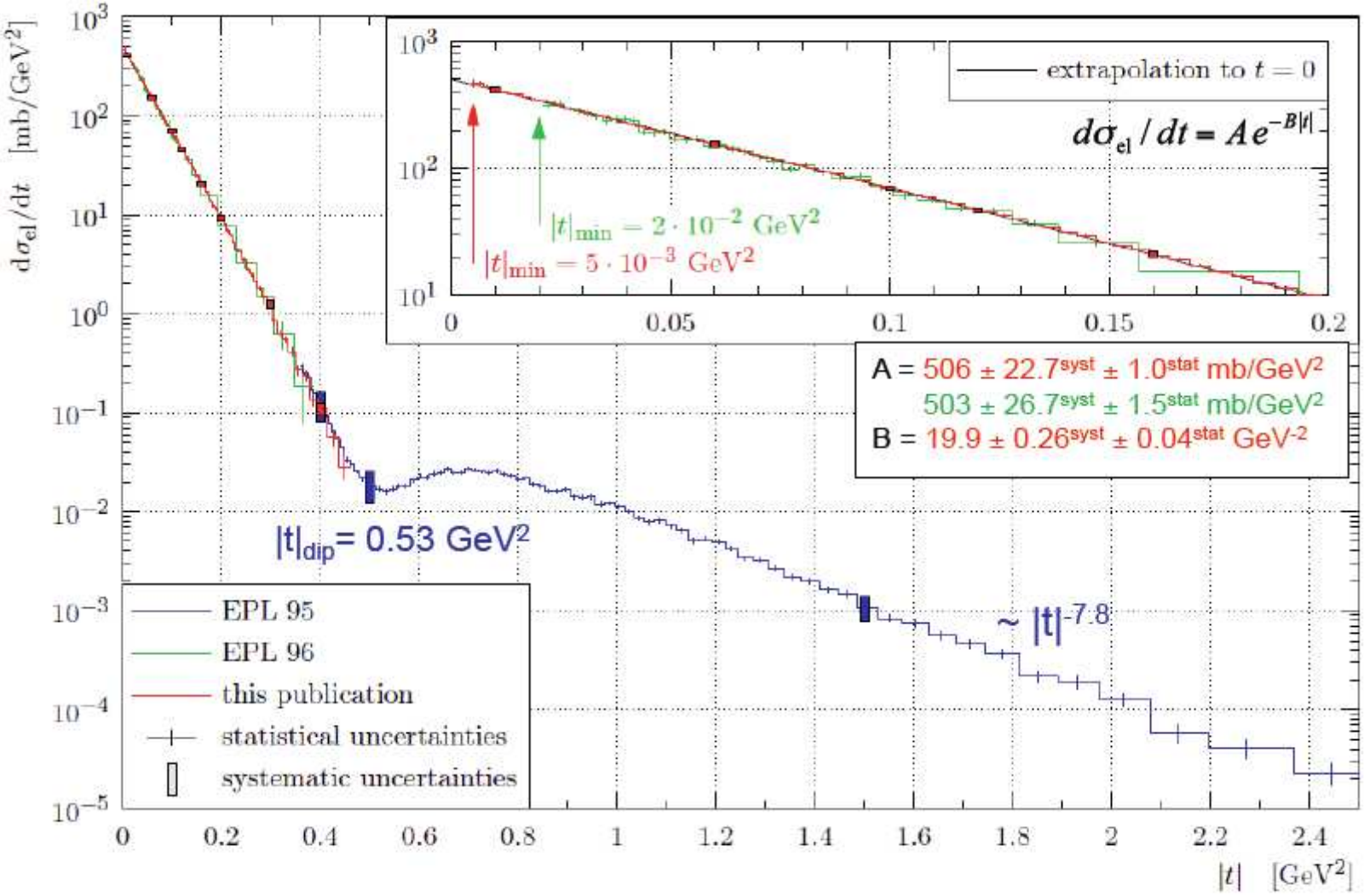
[7] G. Antchev,..., J. Kašpar, J. Kopal, V. Kundrát, ..., M. Lokajíček, ..., J. Procházka,…, V. Vacek, M. Vitek, …, et al; A luminosity-independent measurement of the proton-proton total cross section at $\sqrt{s}$ = 8 TeV; to be published in Phys. Rev. Lett.

[8] J. Kašpar, V. Kundrát, M. Lokajíček, J. Procházka: Phenomenological models of elastic nucleon scattering and predictions for LHC; Nucl. Phys. B 843 (2011) 84.

Report:

V. Kundrát, M. Lokajíček, 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



$\sigma_{tot} = (98.6 \pm 2.2)$ *mb* … elastic observables only

$\sigma_{tot} = (98.6 \pm 2.2)$ *mb* … ρ independent

$\sigma_{tot} = (98.0 \pm 2.5)$ *mb* …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 β^*, …)
- the smallest distance of edgeless detectors housed in the RP's to the beam (~ 4 σ_{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