Small-angle diffractive pp scattering @ NICA-SPD

(V.A. Baskov, O.D. Dalkarov, A.I. L’vov, V.V. Poliansky)
(Lebedev Physical Institute)

1) Motivation:
   Fine structure of the diffraction peak in pp scattering. Anomalies.
   Available data (U-70, ISR, FNAL, LHC). Open questions.

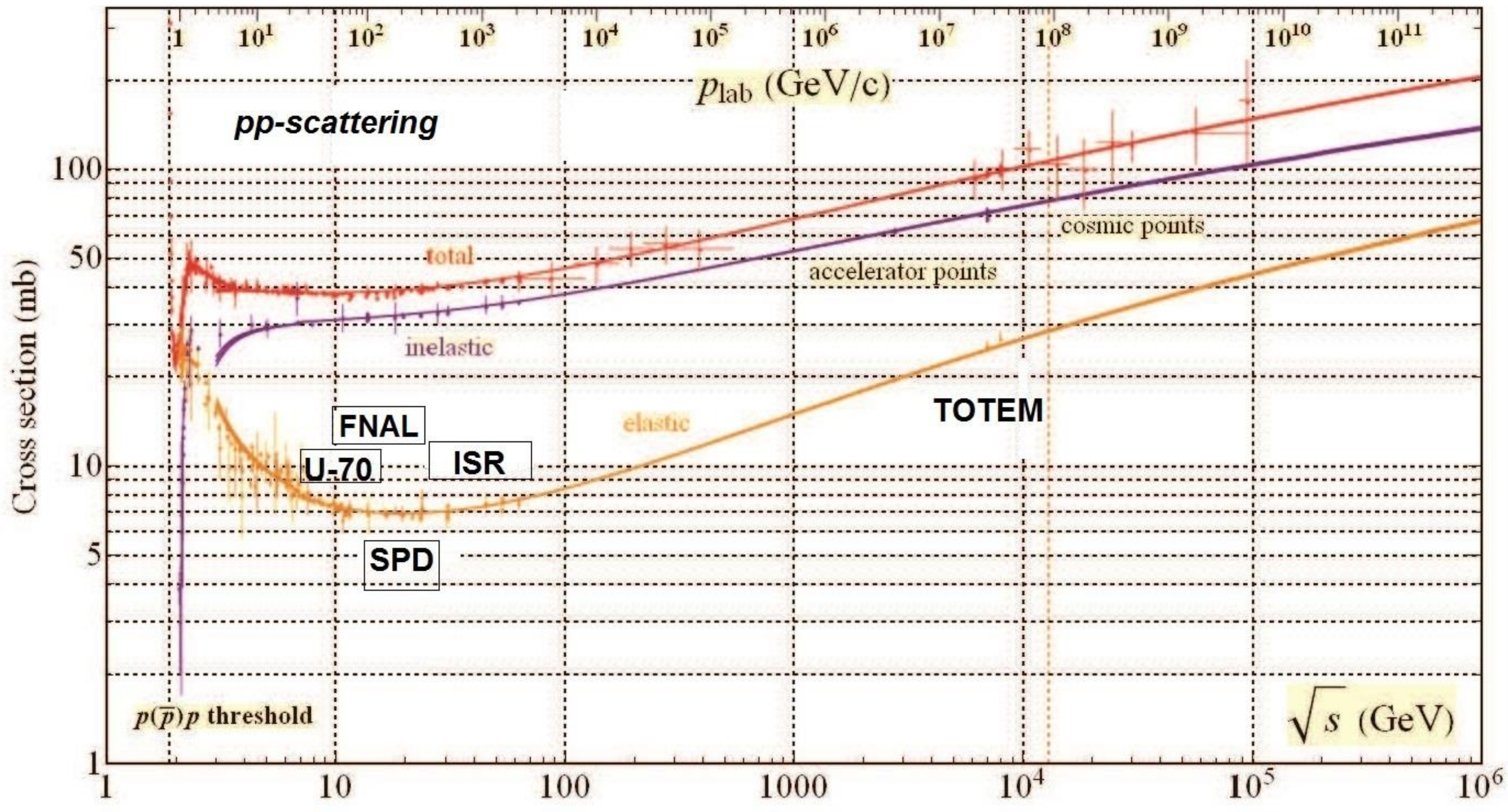
2) Possibilities of the NICA-SPD experiment.
   Luminosity, Yields, Uncertainties.

3) Measurement of Luminosity.

Data on the total cross section of high-energy pp interaction

- **Energy region of SPD is in between that of U-70 (Protvino) and ISR (CERN)**
- **Registration of pp pairs in SPD can serve as a luminosity monitor of collisions**

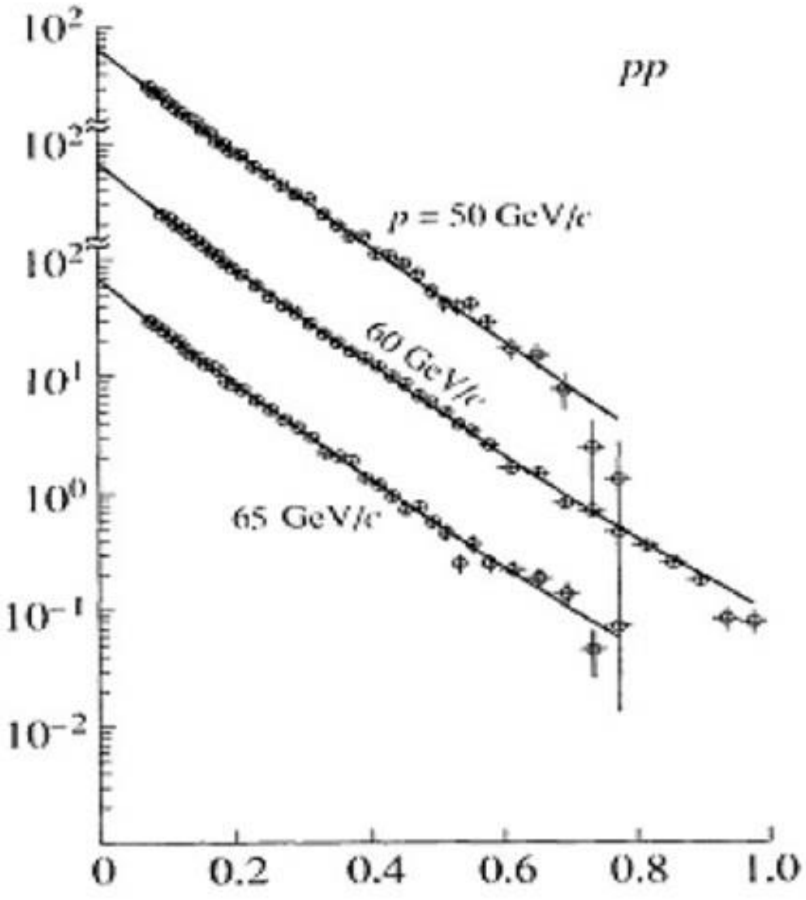
In the region of SPD, the most precise data are from U-70 (pp), ISR (p-anti-p) and FNAL (pp).



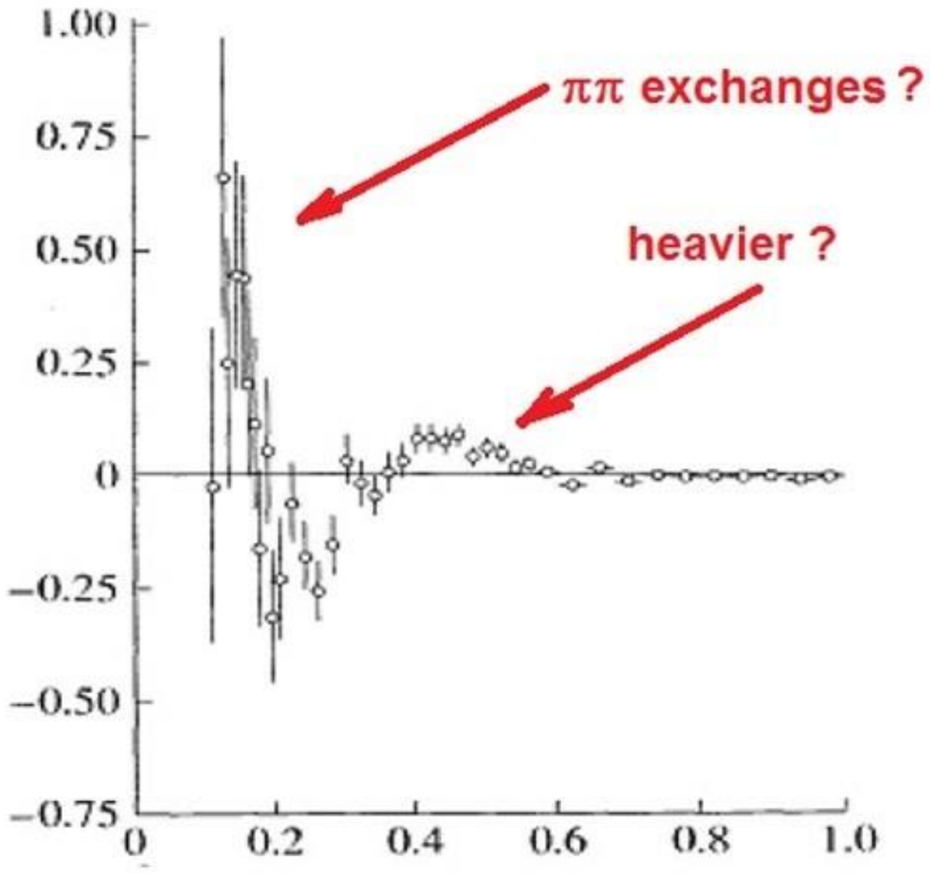
Differential cross sections of pp scattering (Protvino)

- **Diff. cross sections and deviations from the reference exponential form *exp(Bt + Ct²) at √s ~ 11 GeV.***
- **Such deviations were observed on repeated occasions at various machines and energies.**
- **Diff. cross sections fitted with a squared exponential (left) and the difference between the 60 GeV data and their fitted values (right)**

$d\sigma/dt$, mb/(GeV/c)^2



$(d\sigma/dt) - (d\sigma/dt)_{fit}$, mb/(GeV/c)^2



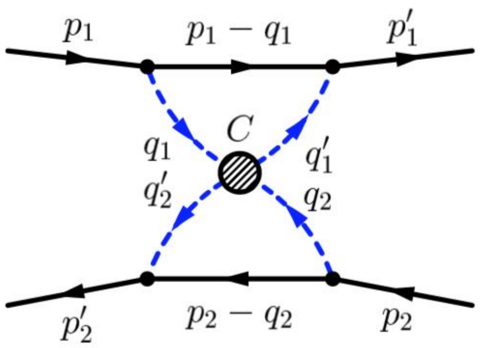
$|t|$, (GeV/c)^2

Antipov et al. preprint 1976.
Denisov et al. Yad.Fiz. 79 (2016) 121.

Two-pion effect at low t

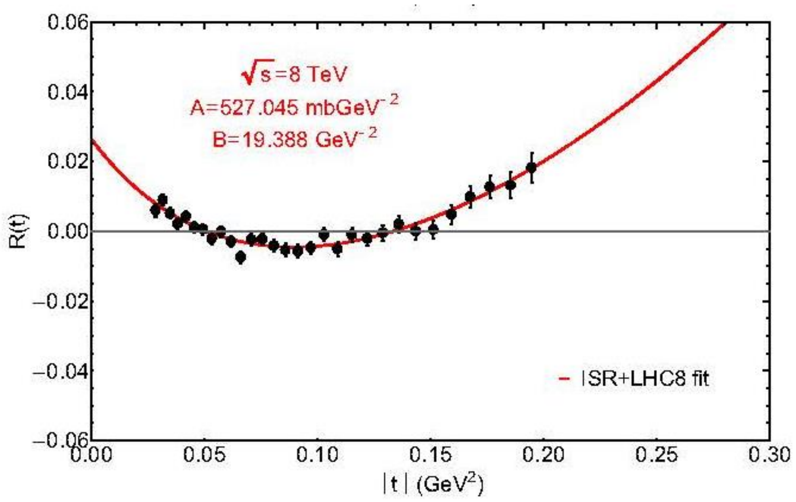
Large impact distances suggest that exchanges with light particles (pions) are responsible for irregularities in the differential cross section at small t.

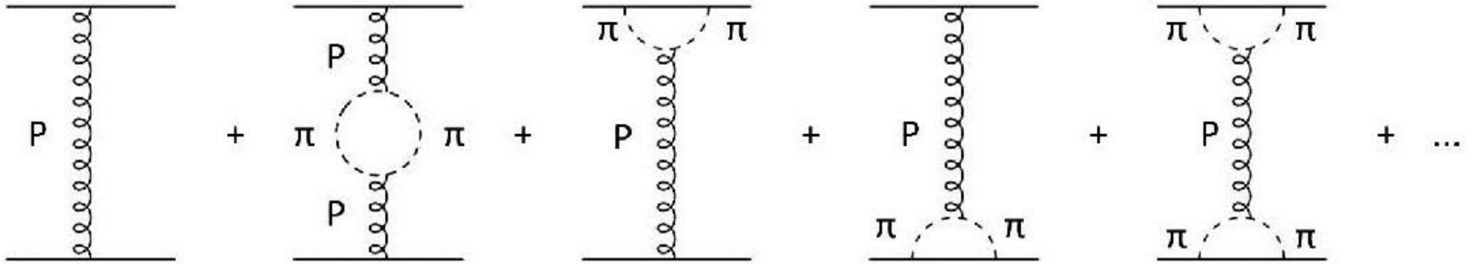
Jenkovszky: Two-pion exchanges explain irregularities in diffractive high-energy data up to LHC energies.



A. Anselm, V. Gribov. "Zero pion mass limit in interaction at very high energies". Phys. Lett. 40B (1972) 487.

L. Jenkovszky et al. "Shape of proton and the pion cloud". Eur. Phys. J A (2018) 54.





TOTEM

However, this concerns only very low -t ~ 0.1 GeV^2

Impact parameter interpretation of the second peak ?
(just an estimate)

In the impact parameter space

$$\frac{d\sigma}{dt} = |f(s,t)|^2 \approx \frac{\sigma_t^2}{16\pi} e^{Bt}, \qquad \mathrm{Im}\, f(s,0) = \frac{\sigma_t}{\sqrt{16\pi}},$$

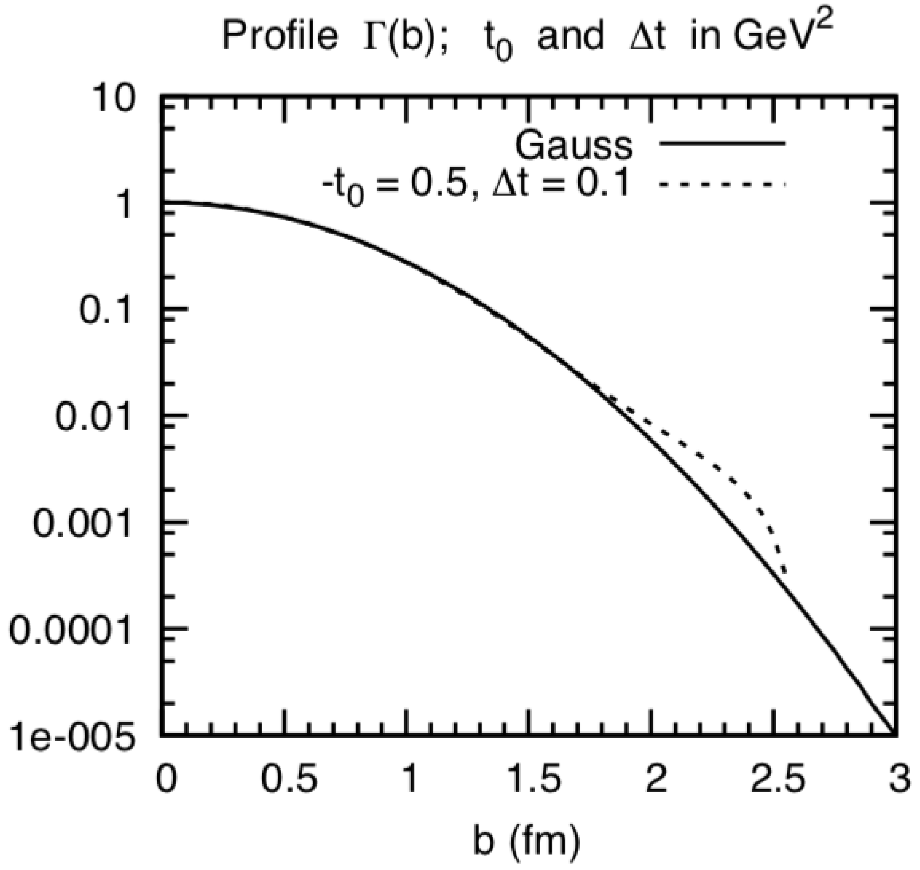
$$\Gamma(s,b) = \frac{1}{2i\sqrt{\pi}} \int_0^\infty f(s,t) J_0(b\sqrt{|t|})\, d|t|.$$

Let's assume $f(t) \propto ie^{Bt/2}$, therefore the corresponding $\Gamma(b) \propto \exp(-b^2/2B)$

If we add the local amplitude $f(t)$ enhancement at the point $t = t_0 = -0.5\ GeV^2$

$$f(t) \to ie^{Bt/2}\Big[1 + \epsilon\ \exp\Big(-\frac{(t-t_0)^2}{2\Delta t^2}\Big)\Big]$$

we'll see some enhancement in the corresponding $\Gamma(b)$ in the impact parameter region $b \sim 2\ fm$ $(\epsilon = 0.1)$

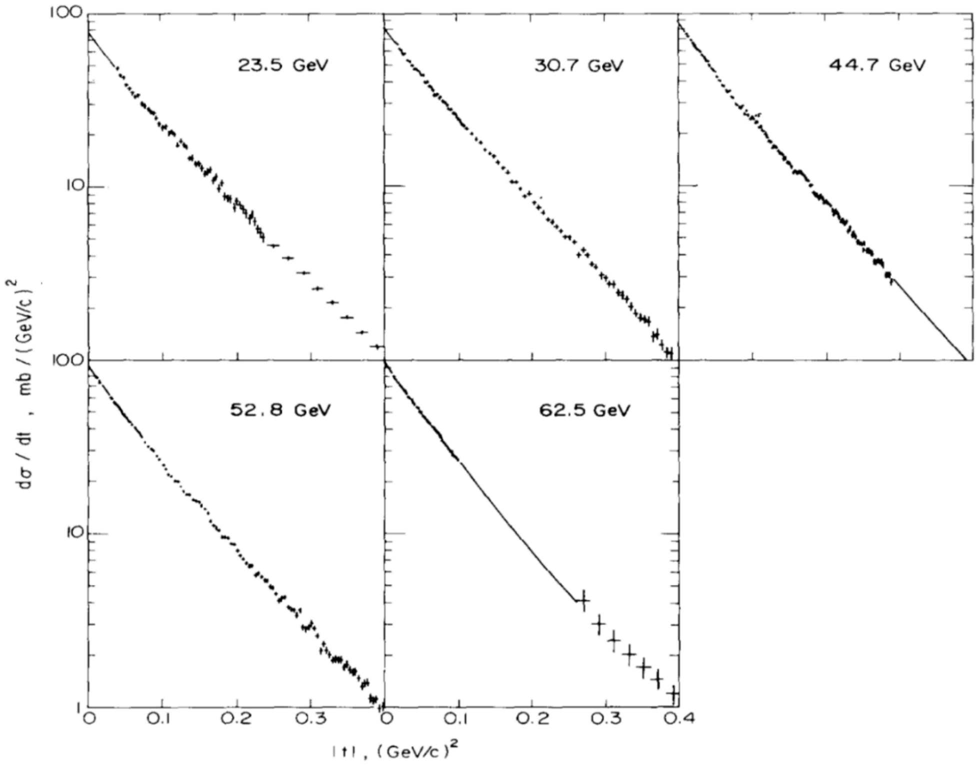


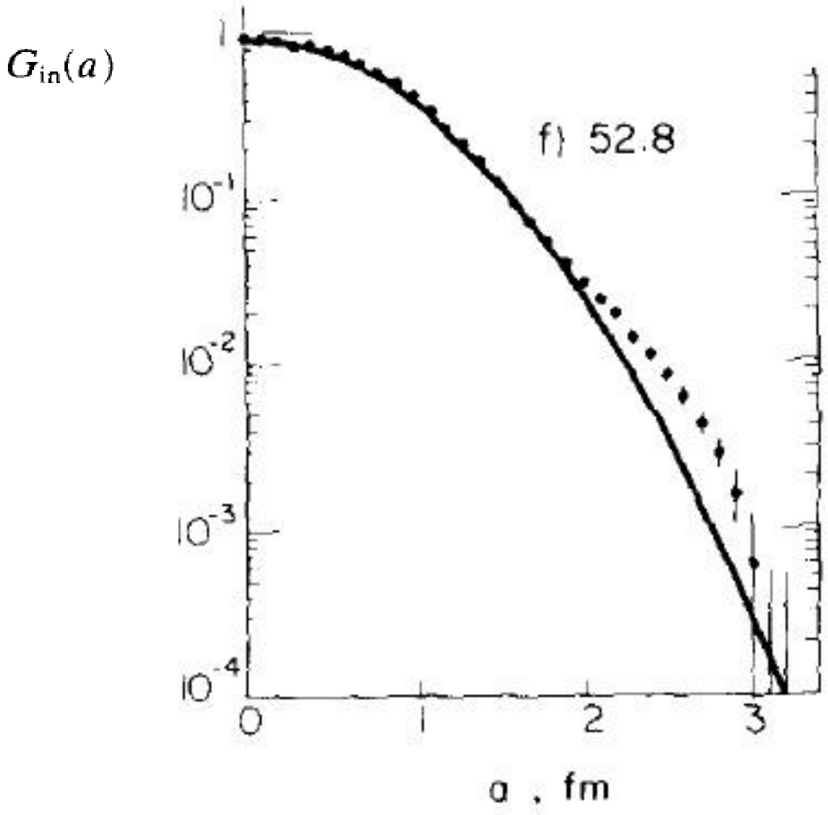
Impact parameter interpretation of the second peak ?
(just an estimate)

Data from U-70 indicate that another anomaly in the differential cross section exists at $-t = 0.4 - 0.5$ GeV^2 ($\gg 4m_\pi^2$).
Perhaps it is relatied with heavier than pion exchanges existing in the proton structure (σ-meson??).

Physics of this phenomenon is a very good task for SPD experiment. In the range of $-t \sim 0.4 - 0.5$ GeV^2 there is almost no data on the diffractive pp-scattering: the accuracy decreases when $-t$ increases from $0.1 - 0.2$ GeV^2 to $0.4 - 0.5$ GeV^2.

ISR data (p-anti-p collisions)





In the notations of the review paper of ref. [26], the unitarity condition is

$$2 \,\mathrm{Re}\, \Gamma(a) = |\Gamma(a)|^2 + G_{in}(a)\,, \qquad (6)$$

where $\Gamma(a)$ is the elastic "profile function" defined as

$$\Gamma(a) = \frac{1}{i\hbar c\sqrt{\pi}} \int_0^\infty \mathrm{d}q q f(q) J_0(qa/\hbar c)\,, \qquad (7)$$

and $G_{in}(a)$ is the (real) inelastic overlap integral in impact parameter space; J_0 is the

U. Amaldi, K.R. Schubert. "Impact parameter interpretation of proton-proton scattering from a critical review of all ISR data ". Nucl. Ohys. B166 (1980) 301.

ISR data (p-anti-p collisions)

U. Amaldi, K. R. Schubert / Review of all ISR data 317

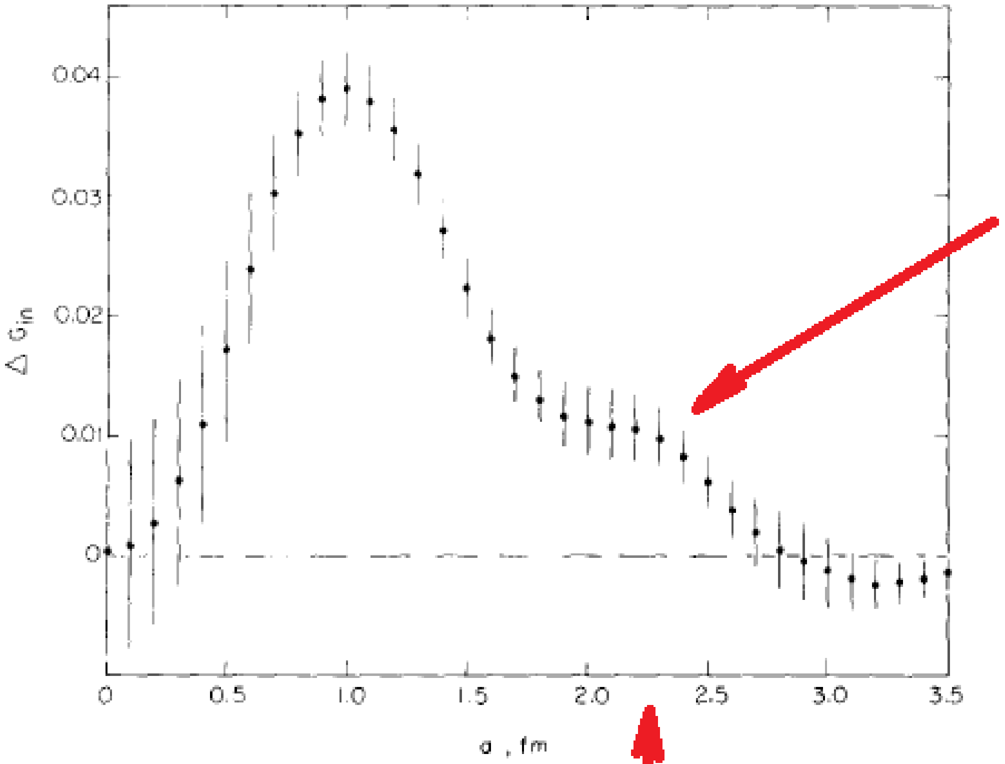
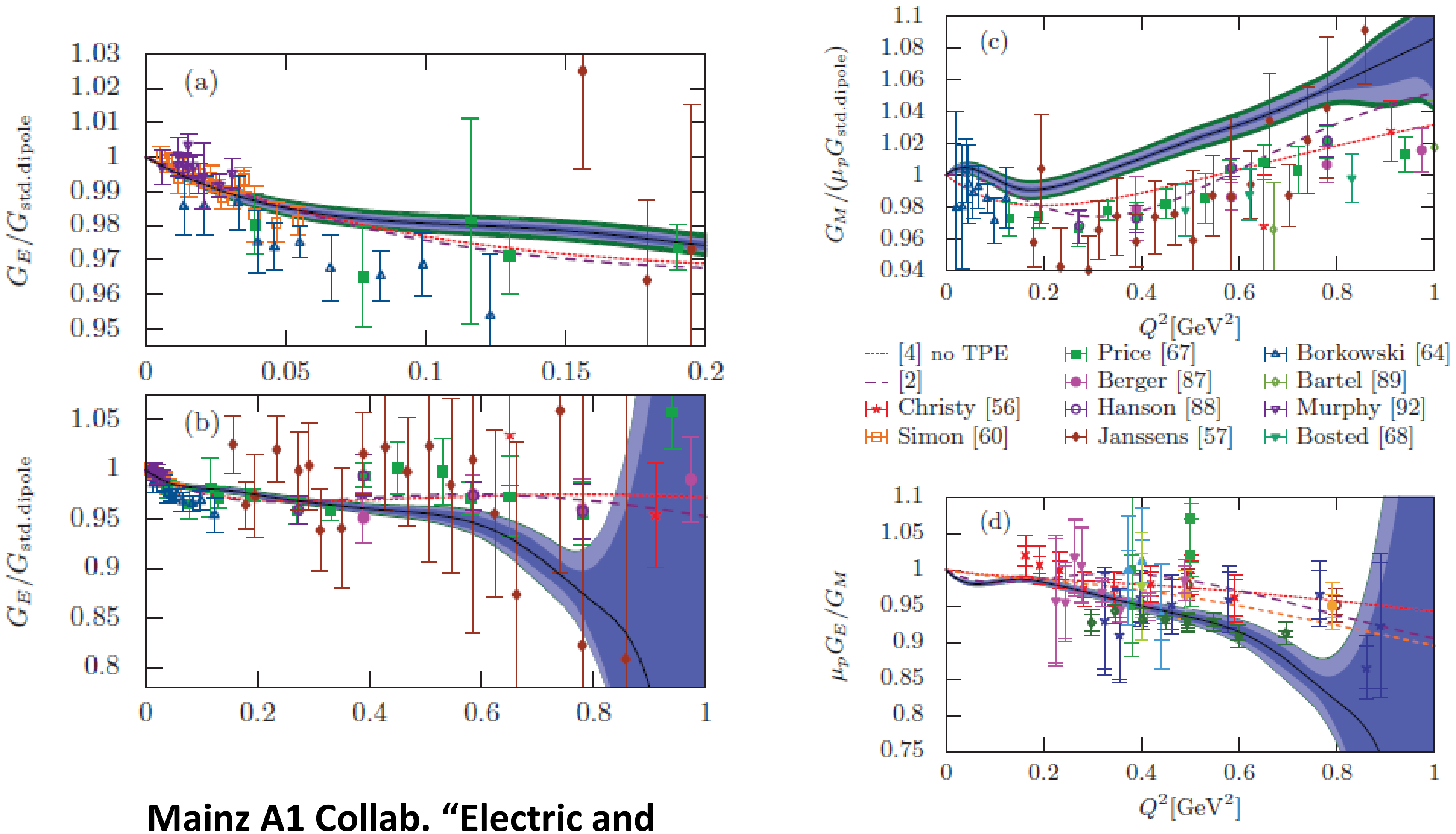


Fig. 8. Increase ΔG_{in} of the inelastic overlap function over the ISR energy range as a function of the impact parameter; ΔG_{in} is obtained by using eq. (14) and the results at all five energies.

U. Amaldi, K.R. Schubert.
"Impact parameter interpretation of proton-proton scattering from a critical review of all ISR data ".
Nucl. Ohys. B166 (1980) 301.

Cf. EM form factors of the proton



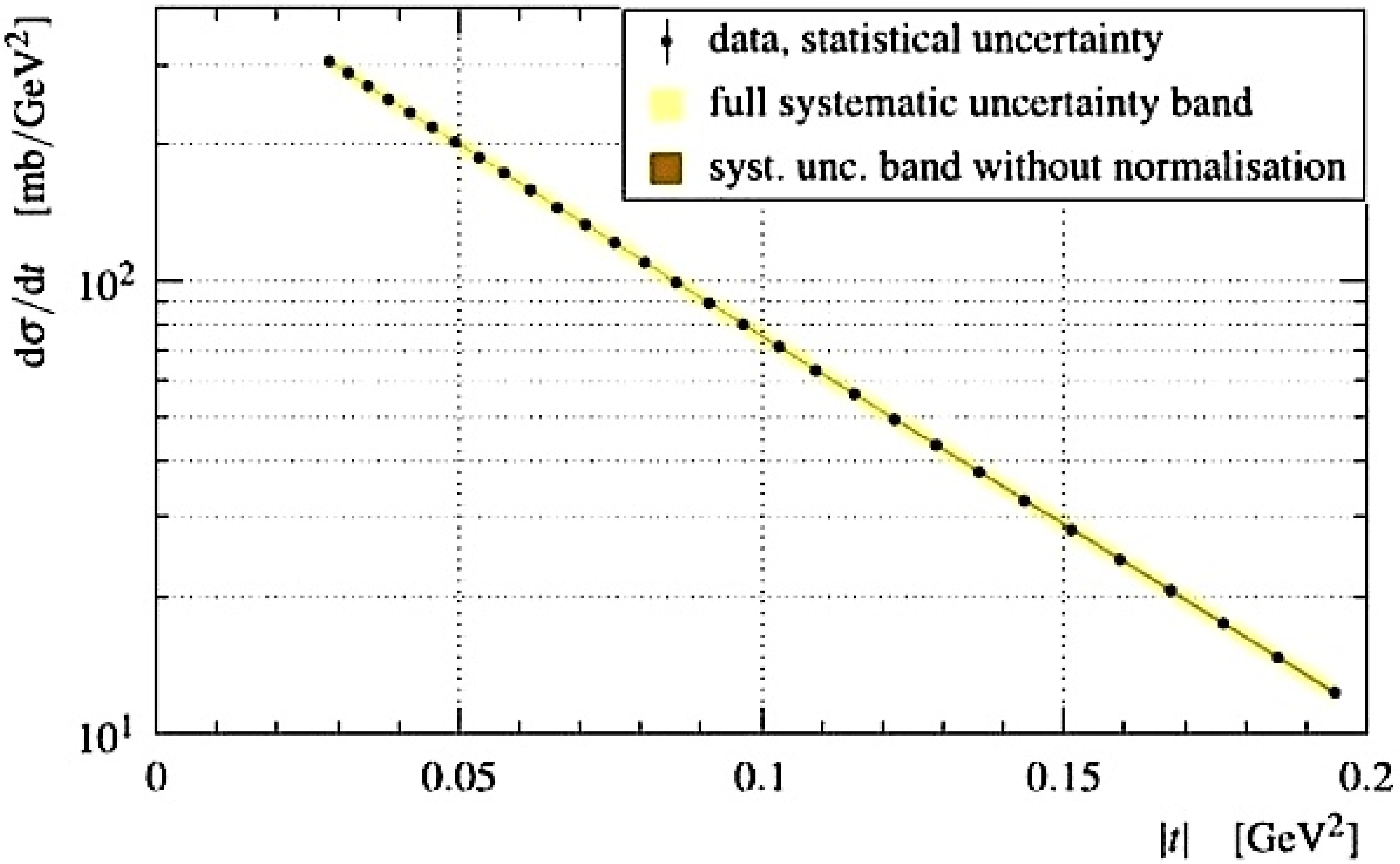
At the scale of a few per cent, EM formafactors of the proton show irregularities at medium Q^2 below 1 GeV^2 (deviations from a simple dipole Ansatz).

Mainz A1 Collab. "Electric and magnetic form factors of the proton". Phys. Rev. C90 (2014) 015206.

pp-scattering at very high energies

TOTEM data are very precise, however they are still restricted by -t < 0.2 GeV^2

Ref:
TOTEM Collab. (LHC), 2015 “Evidence for non-exponential elastic proton–proton differential cross-section at low |t | and √s = 8 TeV by TOTEM Collaboration”. Nucl. Phys. B 899 (2015) 527.



Preliminary conclusion

Deviations from the Gaussian diffraction behavior of the differential cross section of elastic pp scatterimg are firmly established at very low $-t \sim 0.1$ GeV^2 ($\approx 4m_\pi^2$), both at medium and very high energies $\sqrt{s}$.
They are probably related with collisions of two pion clouds of the colliding protons.

At $-t \sim 0.4$-0.5 GeV^2 some smaller deviation are seen at medium energies in two experiments (p = 60 GeV/c at Protvino, $\sqrt{s}$ = 58.5 GeV at ISR). Meanwhile they are not found in Fermilab measurements at p = 200 GeV/c reaching statistical accuracy compatible with that of U-70 and ISR.

Anyway, diffractive pp scattering at low t is an interesting subject, and it certainly deserves a detailed study at NICA SPD which is quite suitable for that (see below).

Diffractive pp-scattering @ SPD

Brief sketch:

- Bunch sizes
- Luminosity
- Number of pp collisions
- Idealized kinematics
- Simulations
  - initital particles
  - final particles
  - errors
- Some results

File tech-notes.pdf