On study of small-angle pp scattering

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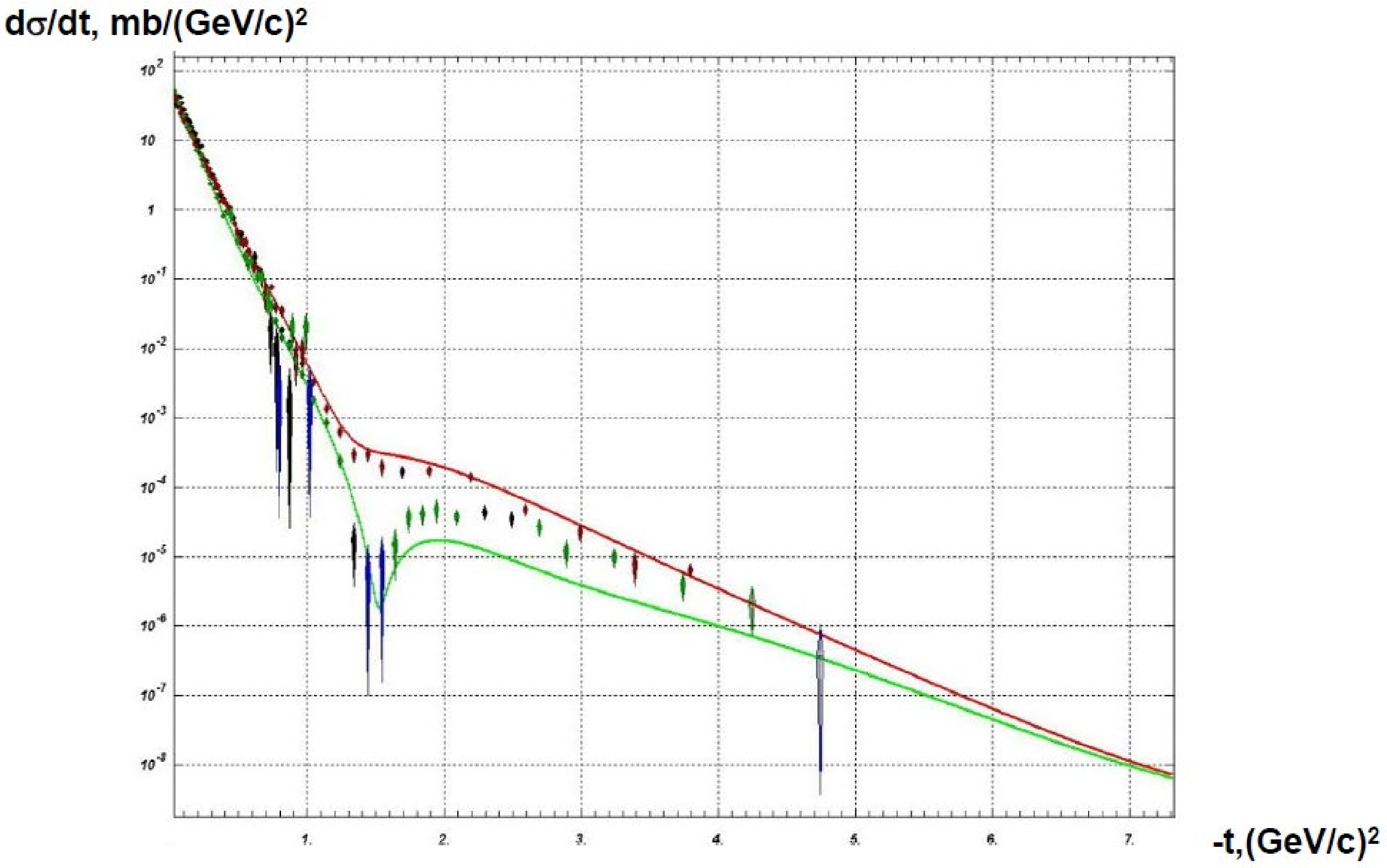
Motivation: what to measure and why ?

- Exp challenges (Protvino)
- Other exp data
- Regge phenomenology and uncertain vertex functions
- Space structure of the nucleon ?

Exp possibilities at the 1st stage of SPD (A. Terkulov)

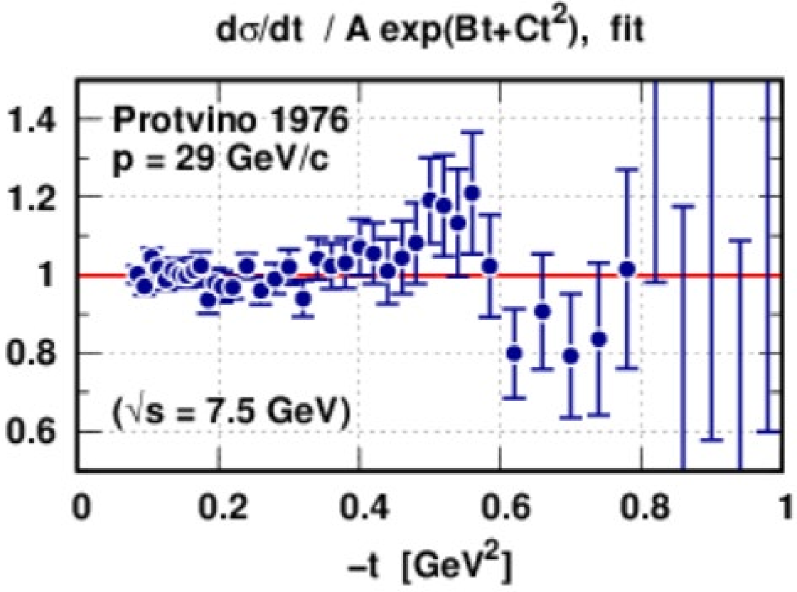


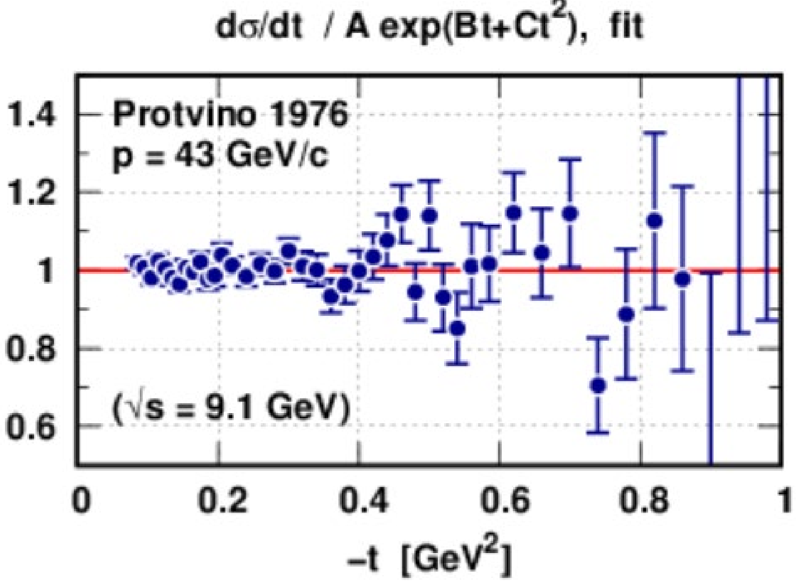
COMPAS:

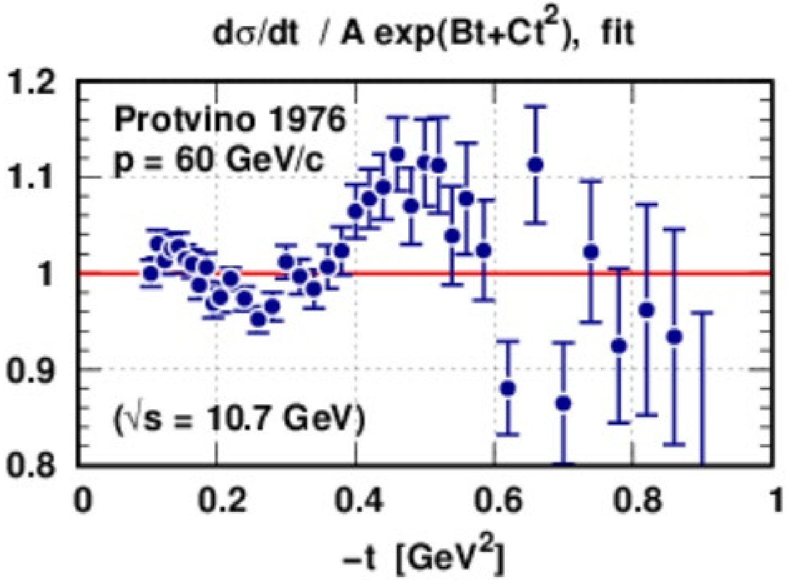
pp and anti-p p scattering

at p_lab = 50 GeV/c as example

Below 1 (GeV/c)^2 almost Ideal exponential decrease of dσ/dt with t







Data from Protvino 1976 on elastic pp scattering with 23, 41 and 104 $\times$ 10^3 events at 29, 43 and 60 GeV/c, resp. (preprint IHEP-76-95; Antipov et al. COMPAS)

Unusual oscillations at –t = 0.5 GeV^2 beyond common diffractive decrease $\propto$ exp(Bt).

Do they really exist? What do they mean?

IHEP project to continue with up to 10^9 events at 50 GeV/c: Denisov et al. Phys.At.Nucl. 79 (2016) 199

Regge phenomenology: high s, low t << s

<u>Cudell et al. 2006</u> PR D73 (2006) 034008, restricted to -t < 0.5 GeV^2

Selyugin

Ezhela, Tkachenko; COMPAS in PDG2016 (to describe very high energy region and odderon)

<u>Sibirtsev et al. 2010</u> (most comprehensive for moderate $\sqrt{s}$ ~ 3-10 GeV) EPJ A45 (2010) 357

ρ, ω, f_2, a_2, P simple Regge exchanges, gaussian vertices

Below is a brief layout of available exp data:

Sibirtsev et al. 2010

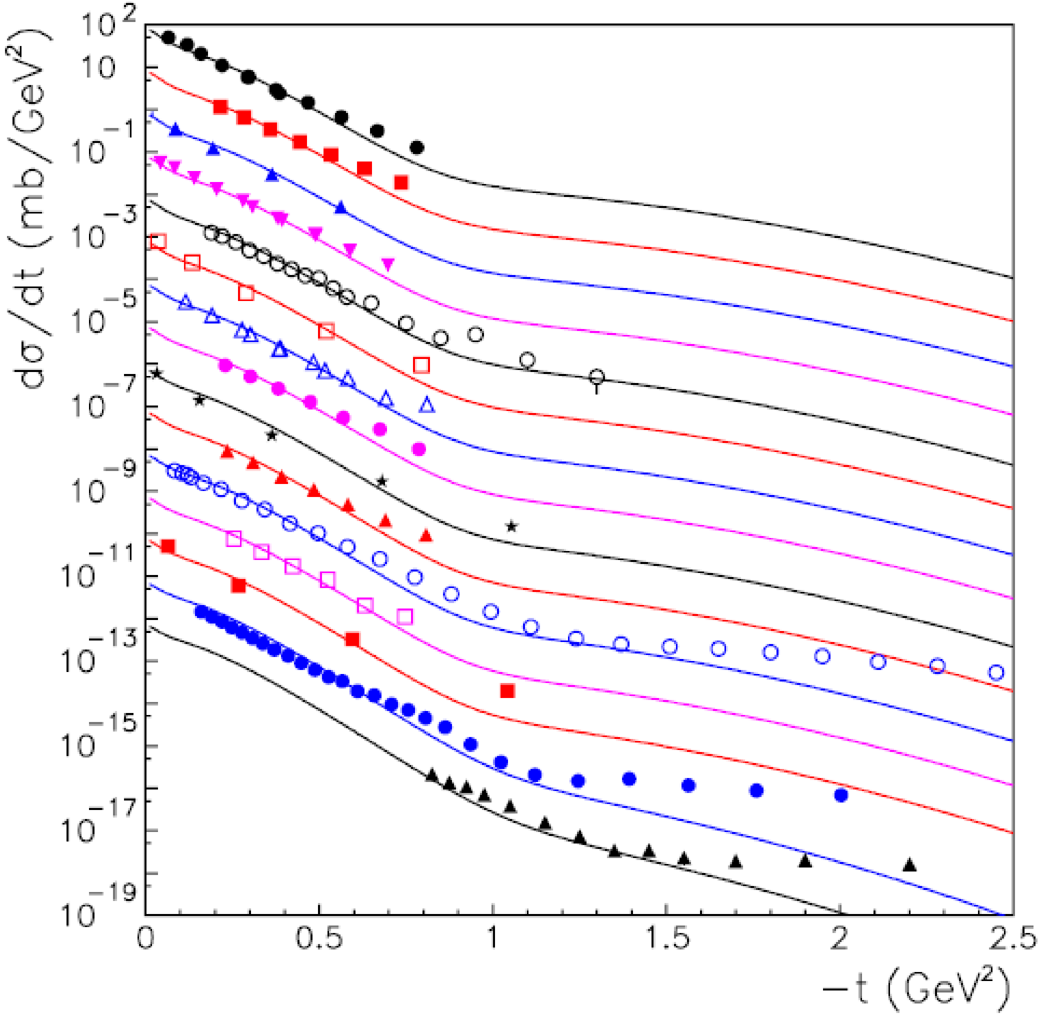
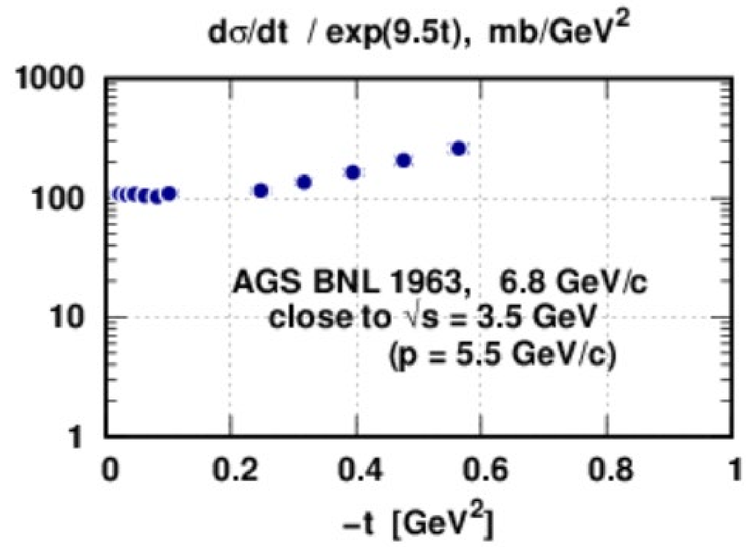
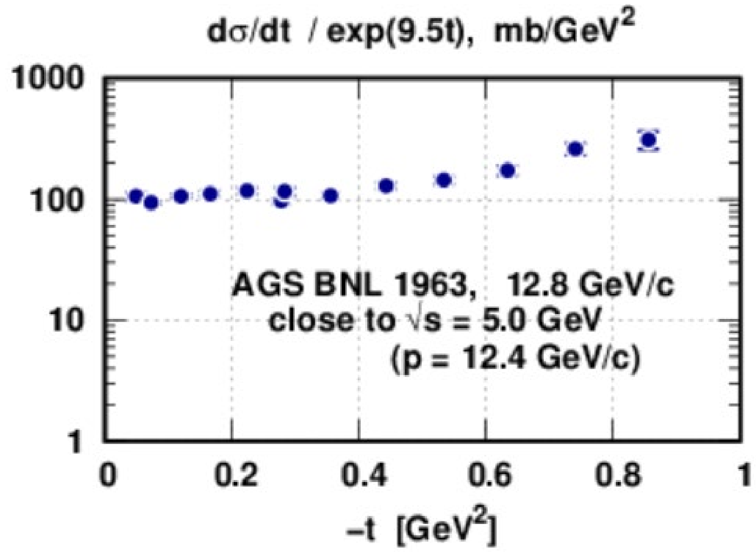
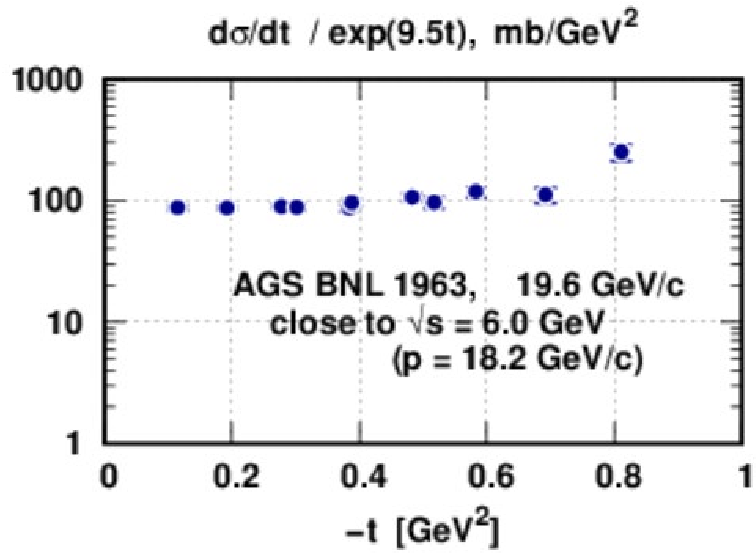


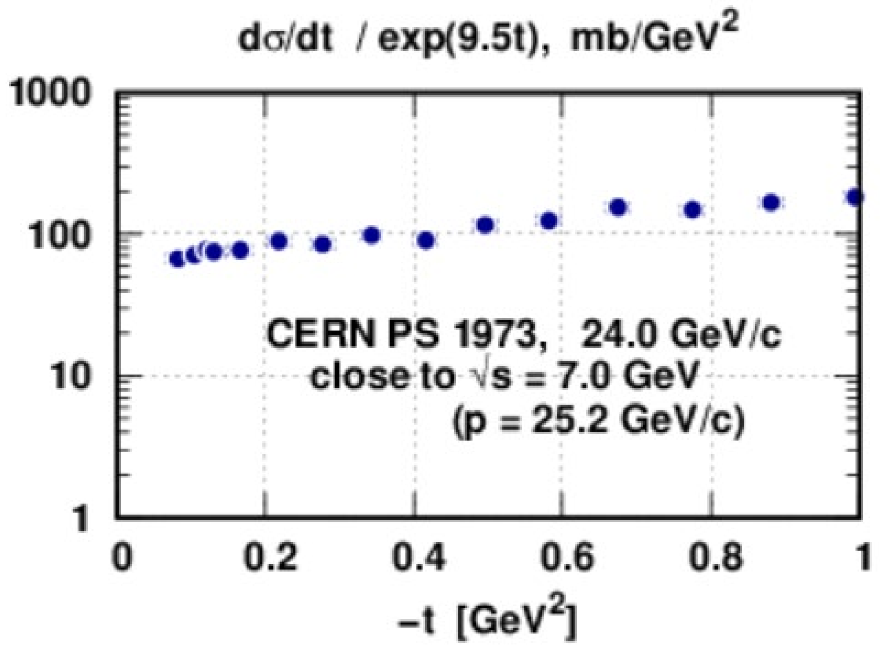
Fig. 6. Differential cross section for the pp elastic scattering as a function of the four-momentum transfer squared t. Results are shown for different beam momenta (from top to bottom: 14.8, 14.93, 15.5, 16.7, 18.4, 18.6, 19.6, 19.84, 21.4, 21.88, 24.0, 24.63, 26.2, 44.5, 50.0 GeV/c). The solid lines are our model results. The data points and the lines are scaled by factors of 10^0 (top) to 10^{-13} (bottom), consecutively. References to the data are given in tables 2 and 3.

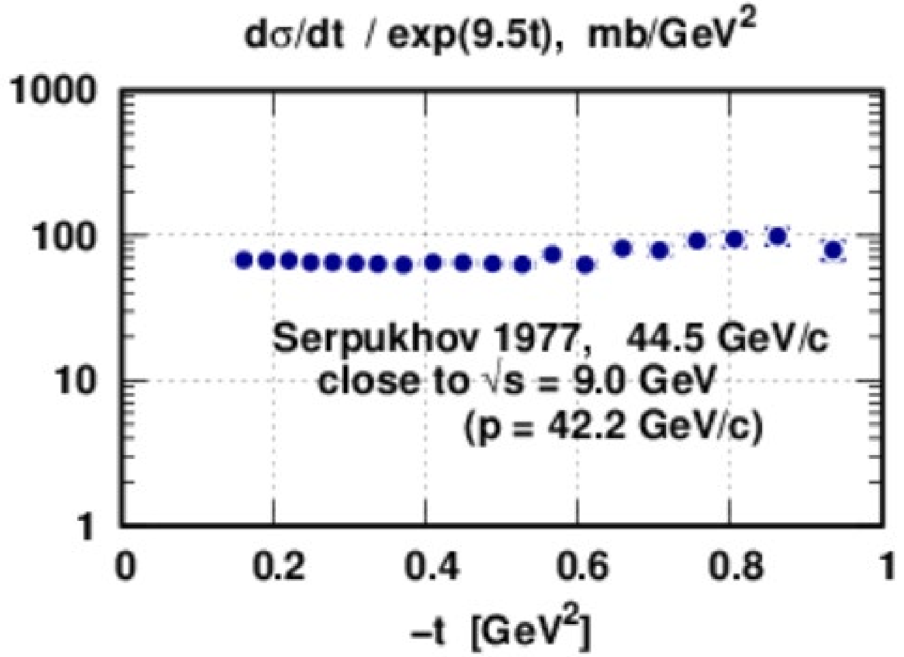
From the list of exp works included into the analysis of Sibirtsev et al. 2010:





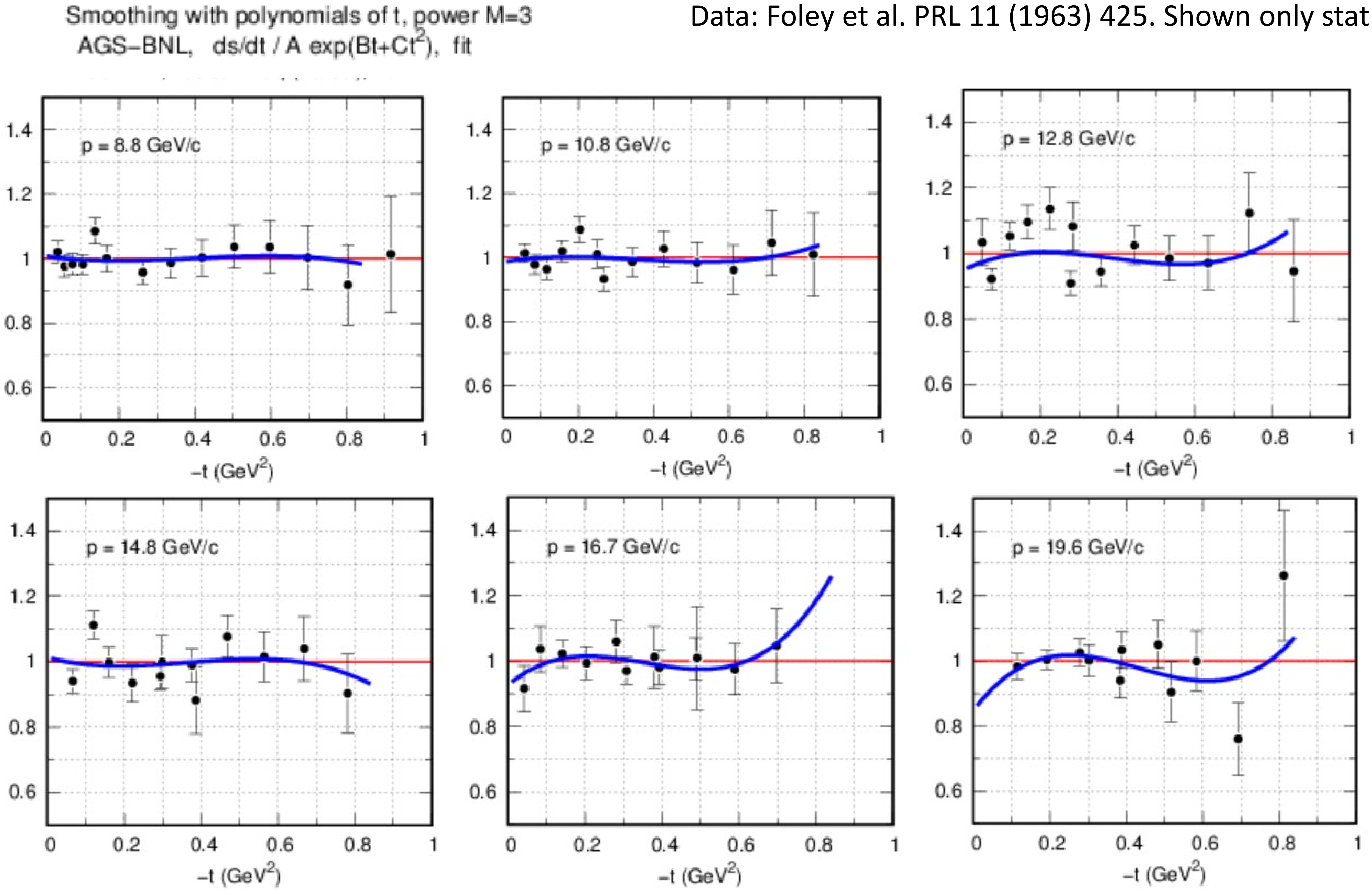






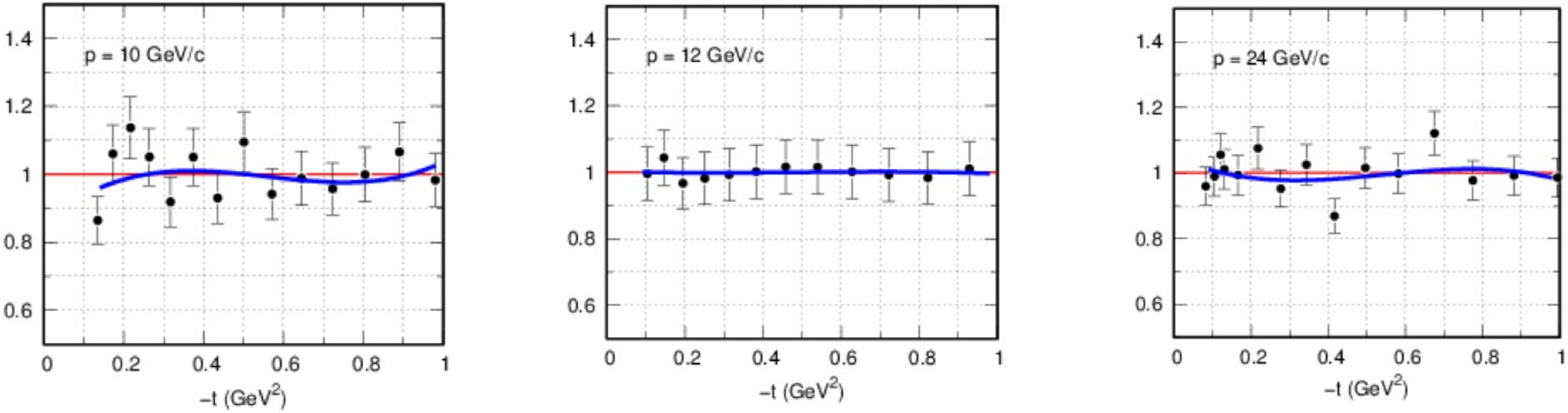
In more details:

Data: Foley et al. PRL 11 (1963) 425. Shown only stat errors



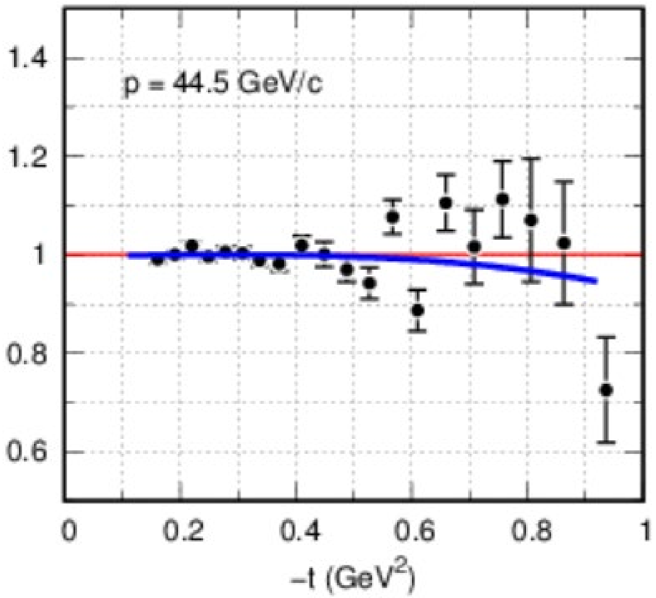
Smoothing with polynomials of t, power M=3
CERN−PS, ds/dt / A exp(Bt+Ct^2), fit

Data: Allaby et al. NP B52 (1973) 316



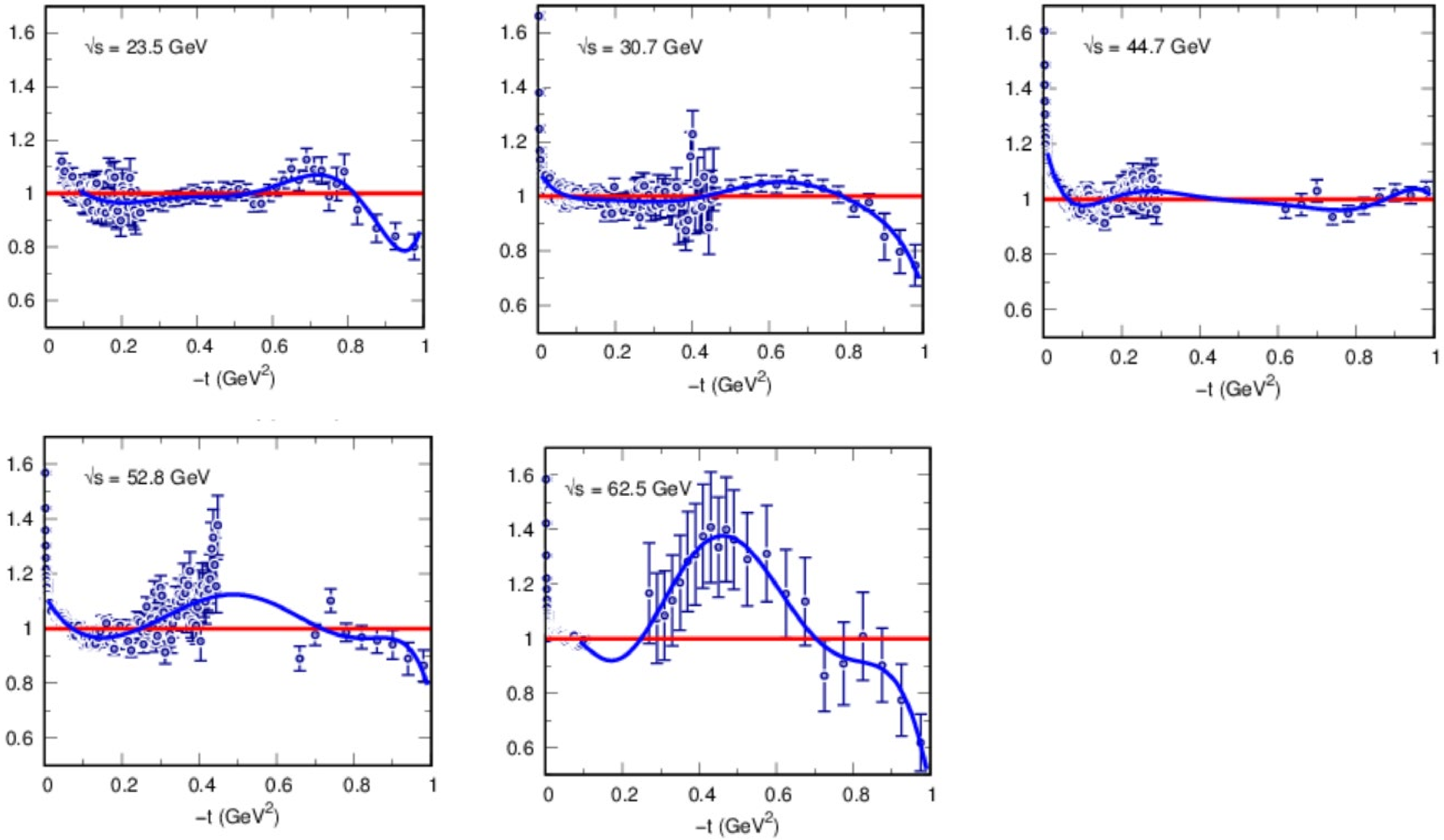
Smoothing with polynomials of t of the power M=3
IHEP−77, ds/dt / A exp(Bt+Ct^2), fit

Data: Bruneton et al. NP B124 (1977) 391



Smoothing with polynomials of t of the power M=7
ISR, ds/dt / A exp(Bt+Ct^2), fit

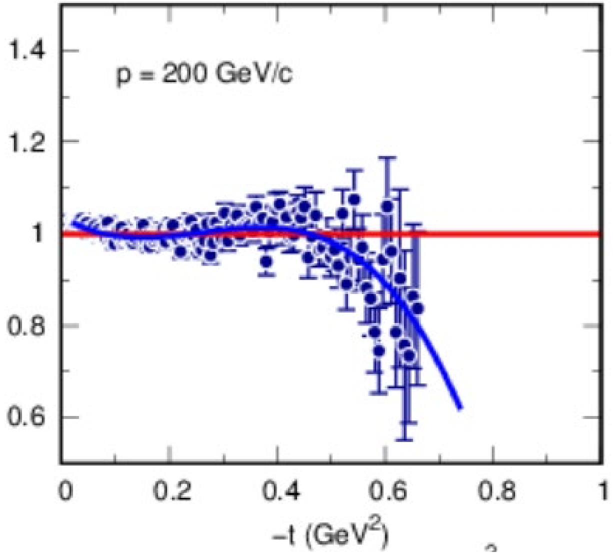
Data: Durham /HepData/8531



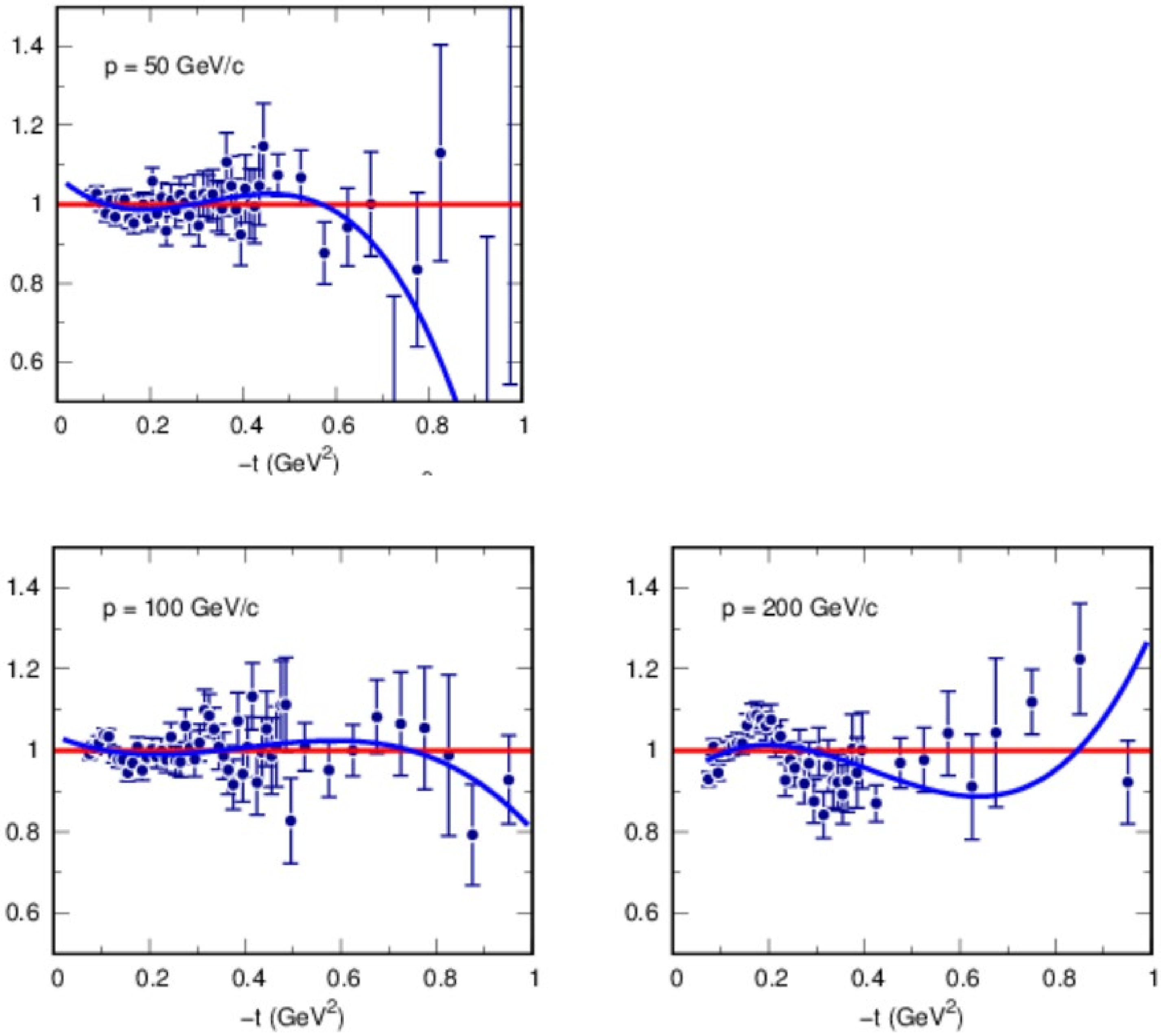
Smoothing with polynomials of t of the power M=3

FNAL–81 ds/dt / A exp(Bt+Ct^2), fit

Data: Schiz et al. PR D24 (1981) 26



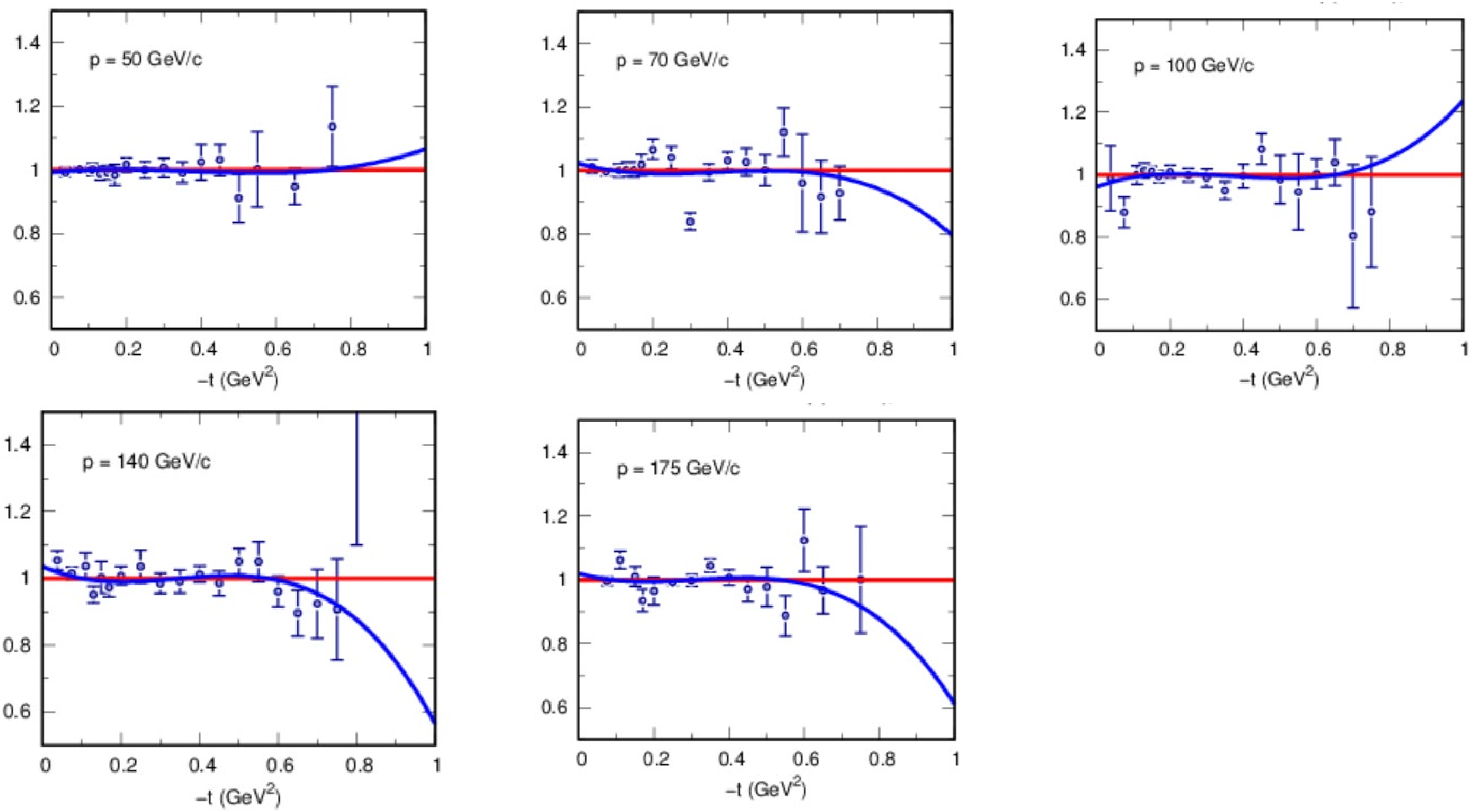
FNAL–76 Data: Akerlof et al. PR D14 (1976) 2864



Smoothing with polynomials of t of the power M=3

FNAL–77 ds/dt / A exp($Bt+Ct^2$), fit

Data: Ayres et al. PR D15 (1977) 3105



Instead of summary:

In the SPD range of $\sqrt{s}$ there is a lack of precise exp data on elastic pp-scattering at low and moderate t.

(concerning both energy dependence and t-dependence).

SPD experiment can essentially extend the data base,

and this should be one of its aims.

Vertices in Regge models. Very uncertain !!!

Sibirtsev

$$\phi_{ai}(s,t) = \pi\beta_{ai}(t)\frac{\zeta_i(s,t)}{\Gamma(\alpha(t))}$$

$$\zeta_i(t,s) = \frac{1+\mathcal{S}_i\,\exp\left[-i\,\pi\,\alpha_i(t)\right]}{\sin[\pi\,\alpha_i(t)]}\left[\frac{s}{s_0}\right]^{\alpha(t)}$$

$$\beta_{1i}(t) = c_{1i}\ \exp(b_{1i}t),$$

$$\beta_{2i}(t) = c_{2i}\ \exp(b_{2i}t)\,\frac{-t}{4m_N^2}\,,$$

Vertices in Regge models

Qudell

TABLE V. Parametrization of the form factors.

	p	π	K
S	$\frac{1}{1-t/t_S^{(1)}+(t/t_S^{(2)})^2}$	$\frac{1}{1-t/t^\pi}$	$\frac{1}{1-t/t^K}$
$C=+1$	$\frac{1}{(1-t/t_+)^2}$	$\frac{1}{1-t/t^\pi}$	$\frac{1}{1-t/t^K}$
$C=-1$	$\frac{1}{(1-t/t_-)^2}$	$\frac{1}{1-t/t^\pi}$	$\frac{1}{1-t/t^K}$
H	$\frac{1}{(1-t/t_H)^2}$	$\frac{1}{1-t/t^\pi}$	$\frac{1}{1-t/t^K}$

Selyugin - EM f-factor

Vertices in Regge models

Denisov 1976

$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=0} \exp(bt)$$

$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=0} \exp(bt + ct^2)$$

$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=0} \frac{\exp(bt) + \alpha^2 \exp(0{,}5\,bt)}{1 + \alpha^2}$$

$$\frac{d\alpha}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=0} \frac{\exp(bt) + \alpha^2 \exp(R\,bt)}{1 + \alpha^2}$$

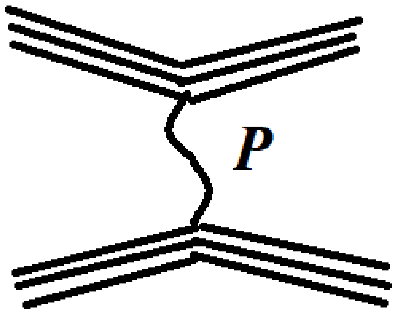
$$\frac{d\sigma}{dt} = \left(\frac{d\sigma}{dt}\right)_{t=0} \frac{\exp(bt) + \alpha^2 \exp(R\,bt) + 2\alpha \cos\varphi \exp[(R+1)bt/2]}{1 + \alpha^2 + 2\alpha\cos\varphi}$$

Uncertainties can be reduced with obtaining data in the wide range of energies and t

Some fantasy on the origin of oscillations (if any)

In hard collisions protons look like beams of partons (beams of current quarks and gluons) with intrinsic longitudinal and transverse movement.
In soft collisions such partons come collectively (coherently) as constituent quarks (as successful phenomenology suggests). This suggests a constituent f-factor of Reggeon (Pomeron) coupling to the nucleon.

Constituent quark model
Isgur, Karl 1978
Capstick, Isgur 1986 (relativized, with QCD-motivated forces)
Capstick, Roberts 2000



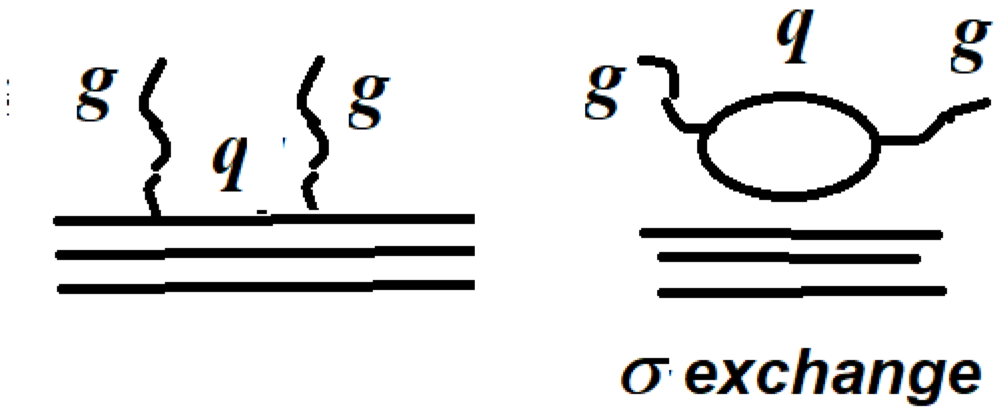
Zero approximation: oscillator interquark forces $\psi(r) \sim \exp(-\alpha^2 r^2/2)$.
F-factor exp(-r_E^2 /6 q^2) r_E^2 = 1 / (mω**) = 0.5 fm^2 if m=300 MeV,** ω **= 500 MeV.**
Contribution to the differential cross section of pp-scattering
~ exp(Bt), B = 2/3 r_E^2 = 4.4 GeV^-2 (approximately ½ of the total B; another ½ is due to Reggeon propagator).

In case of Coulomb-like attraction at small distances oscillator wave function acquires a non-gaussian piece $\psi(r) \sim \exp(-ar)$ **(like in the hydrogen atom) leading to non-gaussian part in the f-factor** $\sim 1/(1 + a^2 q^2)$
that enhances pure gaussian f-factor at high q and imitate oscillation (descrease of B).

For quantative estimates some further theoretical work is needed…

One more effect anticipated for constituent particles that ought to contribute to the Pomeron (two-gluon object) coupling to the nucleon. This is a loop effect of vacuum polarisation caused by decrease of constituent quark mass in the loop - in the vicinity of the baryon matter (this effect is described by sigma-particle exchange in the quark-level sigma-model between quarks in the loop and valence quarks in the nucleon; on a more fundamental level appearence of constituent masses was explained in works of M.Diakonov et al.

Similar effect contribute to the electric polarizability of the nucleon (contribution of constituent quark vacuum distorted by valence quarks of the nucleon). Numerically it gives about ½ of the electric polarizability of the nucleon (in chiral perturbation theory this contribution is buried among adjusted low-energy constants of unknown origin).



Quantitative evaluation of such contribution also need further theoretical work.

Observation in the SPD experiment, 1^{st} stage

(based of simulations done by Adel Terkulov using FTF indico.jinr.ru/event/4985).

One has to think how to normalise x-sections…

Perhaps, one needs to make only relative measurements of yields at different t…

- **Title**
- Small-angle elastic pp scattering
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- **Abstract**
- High luminosity of pp collisions expected at the 1st stage of the SPD experiment allows to accurately measure differential cross sections of elastic scattering $d\sigma/dt$ in the kinematical region of intermediate energies and momentum transfers poorly covered in series of experiments mostly performed in 1960-1970's at AGS BNL, CERN PS, Protvino. In particular, some fine properties of effective degrees of freedom, Reggeons in the regime of relatively low energies, remained unstudied. One of such properties is a preliminary observation at Protvino of a rapid oscillation of $d\sigma/dt$ (as a function of t) around a smooth exponent typical for diffractive processes.
- Some possibilities to perform new measurements in this direction are outlined here.
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- **General information**
- **Observables:** t-dependence of the differential cross section of elastic pp-scattering at $|t|$ up to about 1 GeV^2.
- **Physics being addressed:** effective degrees of freedom (Pomeron and others Reggeons, with their couplings) for reactions at energies close to the resonance region.
- **Theoretical motivation papers:** [1], [2], [3], [4]
- **Competitiveness:** low-energy collisions at SPD are a suitable tool for the proposed studies
- **Keywords**

- **Experimental requirements:**
- **Beam species:** pp
- **Involved SPD subsystems:** MCT, Straw end-cap, magnetic field
- **Collision energy sqrt(s):**
- a) 3.5 GeV, luminosity 2$\times$10^27, test measurements to check algorithms,
- 3 days to have 10^5 events up to 0.5 GeV^2
- b) 5.0 GeV, luminosity 5$\times$10^28, cf. with older measurements,
- 3 days to have 10^5 events up to 0.8 GeV^2
- c) 7.0 GeV, luminosity 5$\times$10^29, cf. with older measurements,
- 5 days to have 10^5 events up 1.0 GeV^2
- d) 8.0 GeV, luminosity 1$\times$10^30, cf. with older measurements,
- 5 days to have 10^5 events up 1.0 GeV^2
- e) 11.0 GeV, luminosity 6$\times$10^30, new measurements, without magnetic field,
- needs a further study for inelastic background separation,
- 5 days to have 10^5 events up 1.0 GeV^2
- [events can be collected in parallel with many other channels]
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- **Polarization:** useful but not necessary at this stage
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- **References**

- [1] J.V. Allaby et al. Proton-proton elastic scattering and nucleon resonance production at high energies. Nucl. Phys. B52 (1973) 316.
- [2] S. P. Denisov, A. V. Kozelov, and V. A. Petrov. On the Possibility for Precision measurements of Differential Cross Sections for Elastic Proton–Proton Scattering at the Protvino Accelerator. Phys. Atomic Nuclei, 79 (2016) 199.
- [3] A. Sibirtsev et al. Proton-proton scattering above 3 GeV/c. Eur. Phys. J. A 45, 357 (2010).
- [4] A.R. Terkulov. https://indico.jinr.ru/event/4985

THANK YOU FOR ATTENTION