Significant issues related to elastic scattering at very high energies

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Outline

1 - A short review of the BSW model

2 - Some issues related to Real and Imaginary parts

3 - Earlier success for $\sqrt{s} < 1TeV$

4 - New data for $\sqrt{s} > 1TeV$

5 - Concluding remarks

BSW since 1979

Collaboration with Claude Bourrely and Tai Tsun Wu

About 20 papers on the subject

Also with N.N. Khuri and André Martin on the importance of the real part at LHC. (See XIth Blois Workshop EDS-2005)

The BSW model

In the impact picture approach we define the scattering amplitude as

$$a(s,t) = \frac{is}{2\pi} \int e^{-i\mathbf{q}\cdot\mathbf{b}} (1 - e^{-\Omega_0(s,\mathbf{b})}) d\mathbf{b} \ ,$$

where $\mathbf{q}$ is the momentum transfer ($t = -\mathbf{q}^2$) and $\Omega_0(s,\mathbf{b})$ is the opaqueness at impact parameter $\mathbf{b}$ and at a given energy s. We take

$$\Omega_0(s,\mathbf{b}) = S_0(s)F(\mathbf{b}^2) + R_0(s,\mathbf{b}) \ ,$$

the first term is associated with the "Pomeron" exchange, which generates the diffractive component of the scattering and the second term is the Regge background which is negligible at high energy. The Pomeron energy dependence is given by the complex crossing symmetric expression

$$S_0(s) = \frac{s^c}{(\ln s)^{c'}} + \frac{u^c}{(\ln u)^{c'}} \ ,$$

where u is the third Mandelstam variable.

The BSW model

The c and c' are two constants given below. For the asymptotic behavior at high energy and small momentum transfer, we have to a good approximation $\ln u = \ln s - i\pi$, so that

$$S_0(s) = \frac{s^c}{(\ln s)^{c'}} + \frac{s^c e^{-i\pi c}}{(\ln s - i\pi)^{c'}}.$$

The choice one makes for $F(\mathbf{b}^2)$ is essential and we take the Bessel transform of

$$\tilde{F}(t) = f[G(t)]^2 \frac{a^2 + t}{a^2 - t},$$

where $G(t)$ stands for the proton "nuclear form factor", parametrized like the electromagnetic form factor, as having two poles,

$$G(t) = \frac{1}{(1 - t/m_1^2)(1 - t/m_2^2)}.$$

Schematic representation of expanding protons

- Diffractive scattering goes like lns (gray region)
- Elastic scattering goes like $(lns)^2$ (black region)

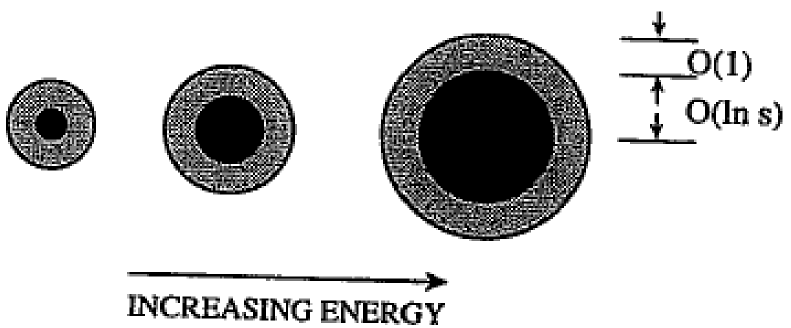


FIG. 4: Schematic representation of the appearance of a high-energy particle [$s = E^2$

When $\sqrt{s}$ increases the proton becomes larger and darker

The BSW model parameters

At high energies the Regge background is irrelevant and the model depends only on six parameters

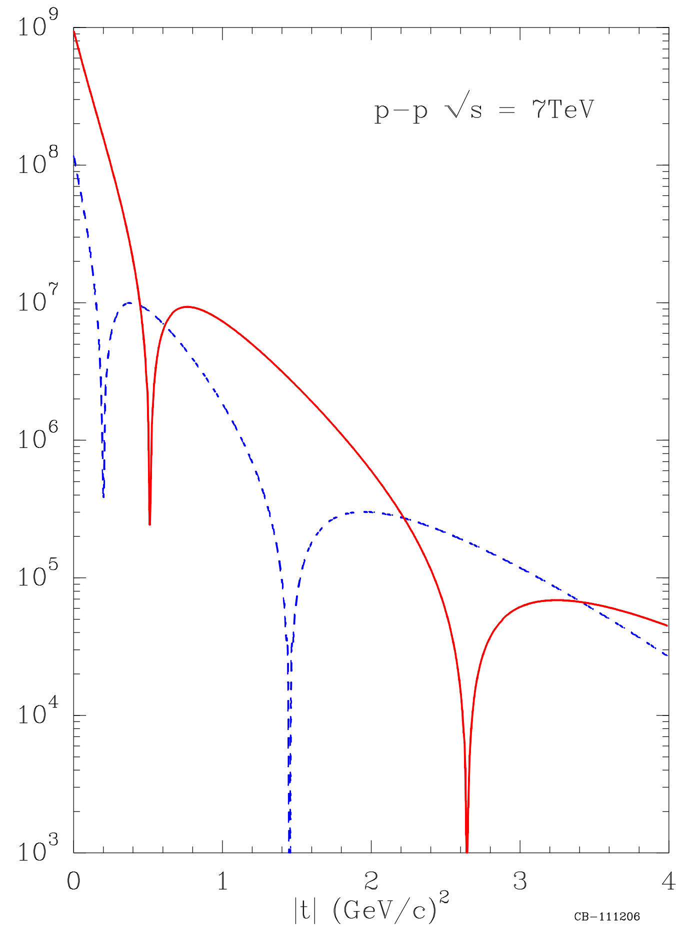
$$\begin{array}{rclrcl} c &=& 0.167, & c' &=& 0.748 \\ m_1 &=& 0.5779\ \text{GeV}, & m_2 &=& 1.7240\ \text{GeV} \\ a &=& 1.9312\ \text{GeV}, & f &=& 7.0932\ \text{GeV}^{-2} \end{array}$$

NOTE

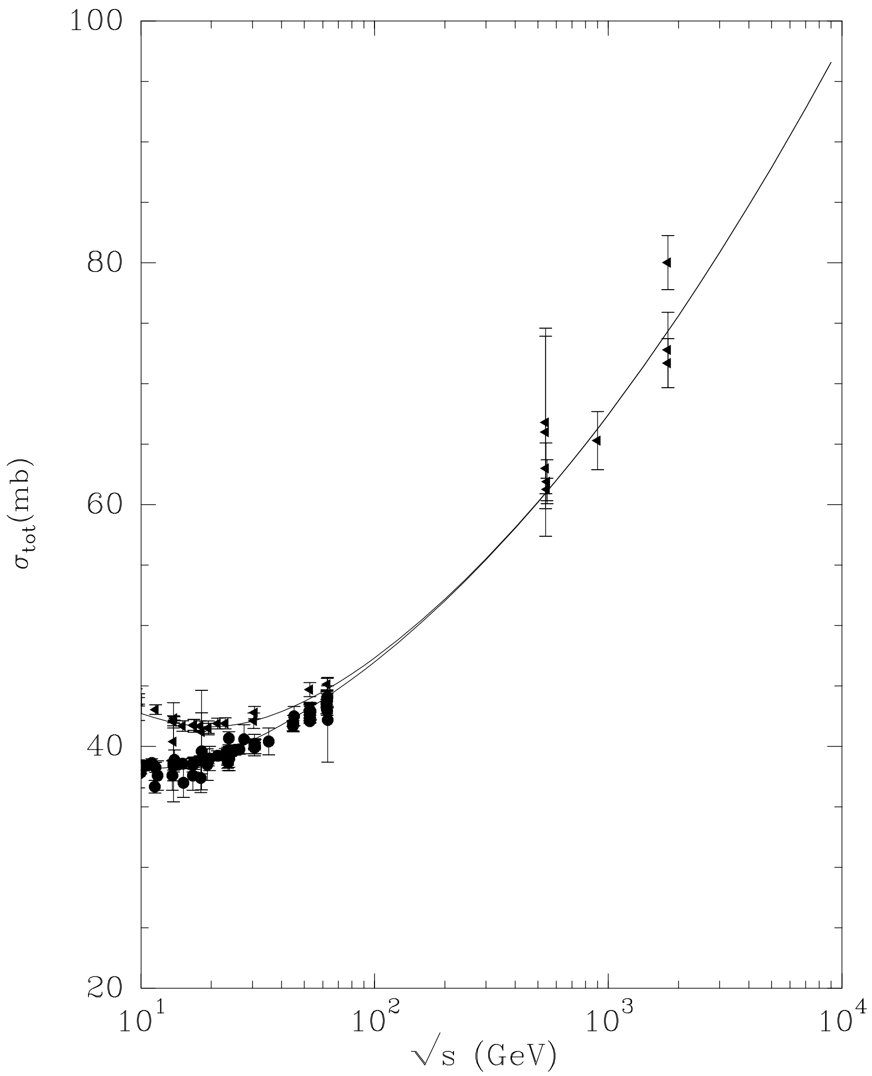
In the Abelian case one finds $c' = 3/2$ and it was conjectured that in Yang-Mills non-Abelian gauge theory one would get $c' = 3/4$

Real and Imaginary parts of the amplitude

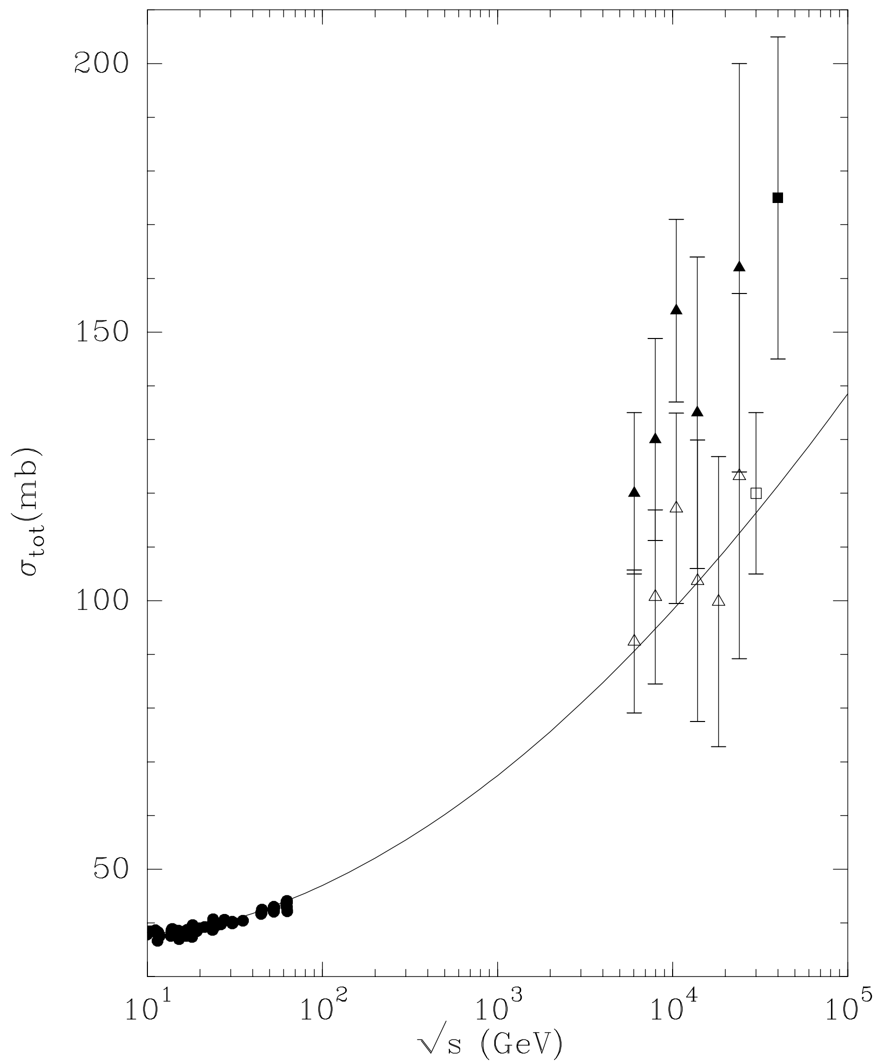
- The phase is built in. They cannot be independent
- They have both some zeroes but at different t values



Total cross section before LHC

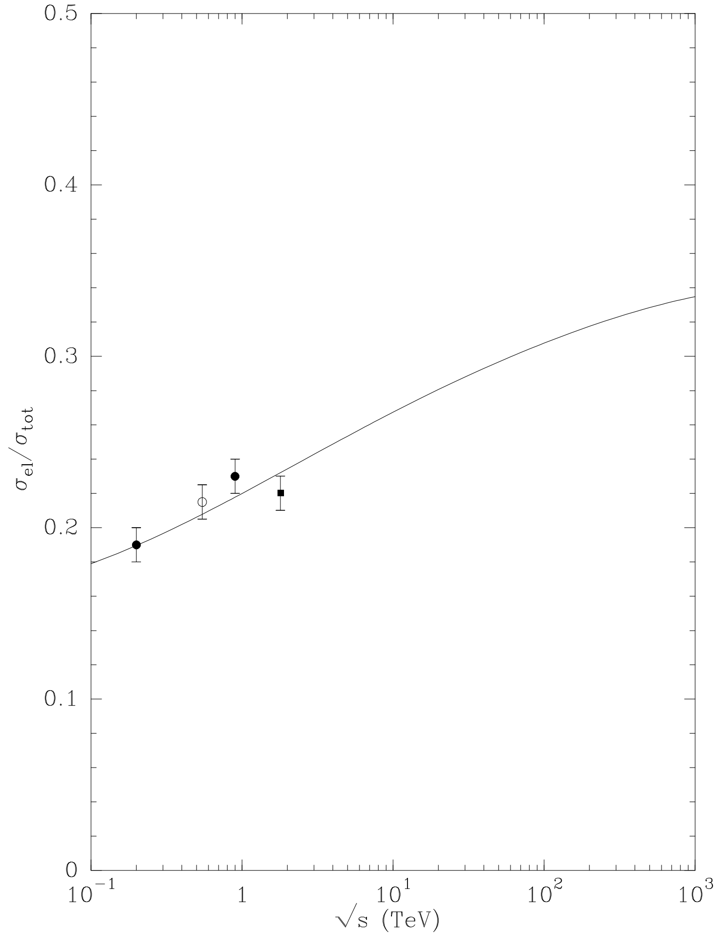


Total cross section up to cosmic rays region



Ratio σ_{el}/σ_{tot}

It is predicted to rise with increasing $\sqrt{s}$ up to 1/2, the black disk limit



Cross sections at LHC

The BSW approach predicts at 7 TeV

$\sigma_{tot} = 93.6mb$,

$\sigma_{el} = 24.8mb$,

$\sigma_{inel} = 68.8mb$

To be compared with TOTEM

$\sigma_{tot} = 98.3 \pm 0.2(stat) \pm 2.7(syst)mb$,

$\sigma_{el} = 24.8 \pm 0.2(stat) \pm 1.2(syst)mb$,

$\sigma_{inel} = 73.5 \pm 0.6(stat) + 1.8(-1.3)(syst)mb$,

ATLAS

$\sigma_{inel} = 69.4 \pm 2.4(expt) \pm 6.9(extra)mb$,

CMS

$\sigma_{inel} = 68 \pm 2(syst) \pm 2.4(lum) \pm 4(extra)mb$,

To be compared with the predictions of K. Goulianos arXiv:1105.4916

$\sigma_{tot} = 98 \pm 8mb$,

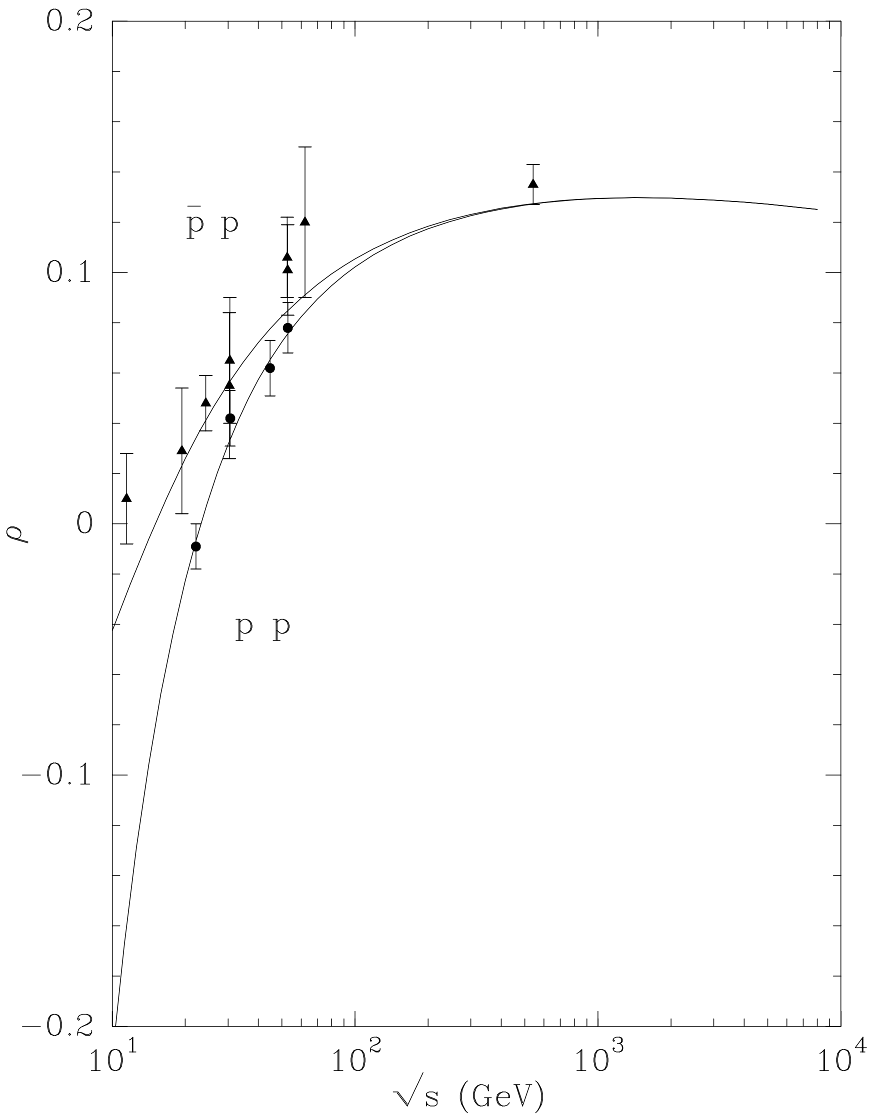
$\sigma_{el} = 27 \pm 2mb$,

$\sigma_{inel} = 71 \pm 6mb$

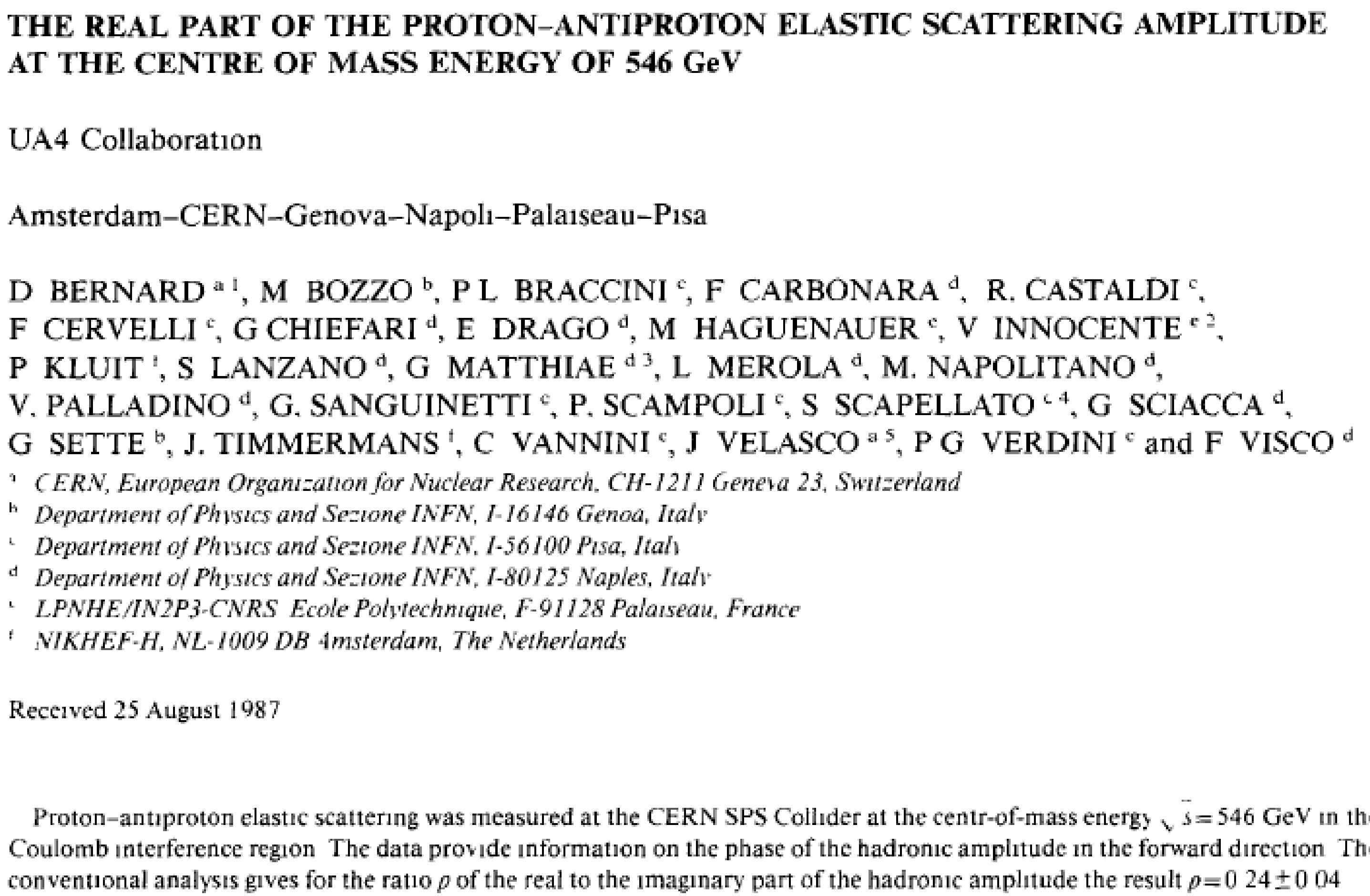
The uncertainties are related to that of s_0.

Real part of the forward amplitude

$$\rho(s) = \textbf{Re}\ a(s, t=0)/\textbf{Im}\ a(s, t=0)$$



CNI region from UA4 data 1987


THE REAL PART OF THE PROTON–ANTIPROTON ELASTIC SCATTERING AMPLITUDE AT THE CENTRE OF MASS ENERGY OF 546 GeV

UA4 Collaboration

Amsterdam–CERN–Genova–Napoli–Palaiseau–Pisa

D BERNARD [a,1], M BOZZO [b], P L BRACCINI [c], F CARBONARA [d], R. CASTALDI [c], F CERVELLI [c], G CHIEFARI [d], E DRAGO [d], M HAGUENAUER [e], V INNOCENTE [e,2], P KLUIT [f], S LANZANO [d], G MATTHIAE [d,3], L MEROLA [d], M. NAPOLITANO [d], V. PALLADINO [d], G. SANGUINETTI [c], P. SCAMPOLI [c], S SCAPELLATO [c,4], G SCIACCA [d], G SETTE [b], J. TIMMERMANS [f], C VANNINI [c], J VELASCO [a,5], P G VERDINI [c] and F VISCO [d]

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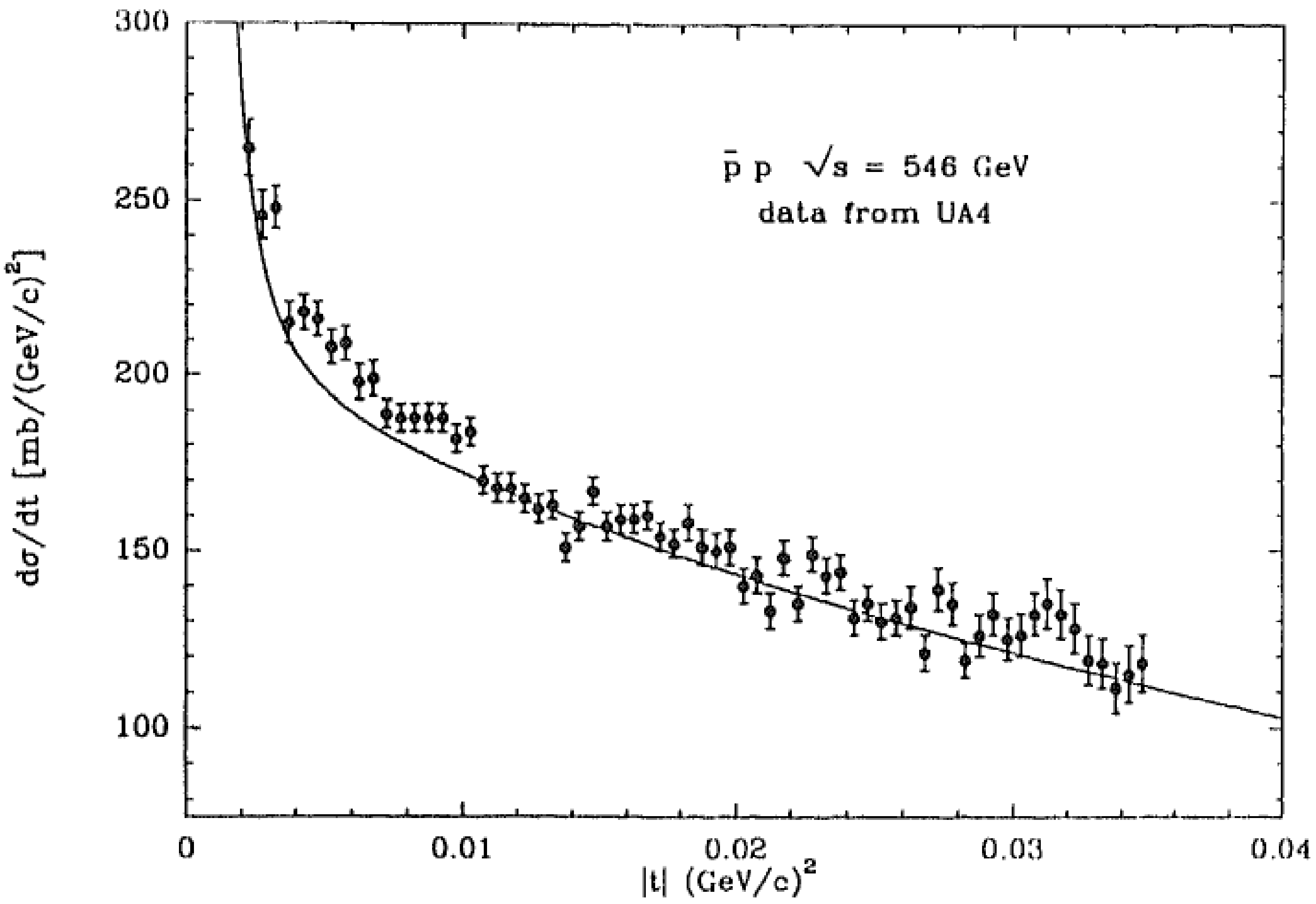
Proton–antiproton elastic scattering was measured at the CERN SPS Collider at the centr-of-mass energy $\sqrt{s}=546$ GeV in the Coulomb interference region The data provide information on the phase of the hadronic amplitude in the forward direction The conventional analysis gives for the ratio ρ of the real to the imaginary part of the hadronic amplitude the result $\rho=0\ 24\pm0\ 04$

CNI region from UA4 data 1987

Comparison with BSW prediction and $\rho = 0.13$



CNI region from UA4 1992

Excellent agreement with BSW prediction and $\rho = 0.13$

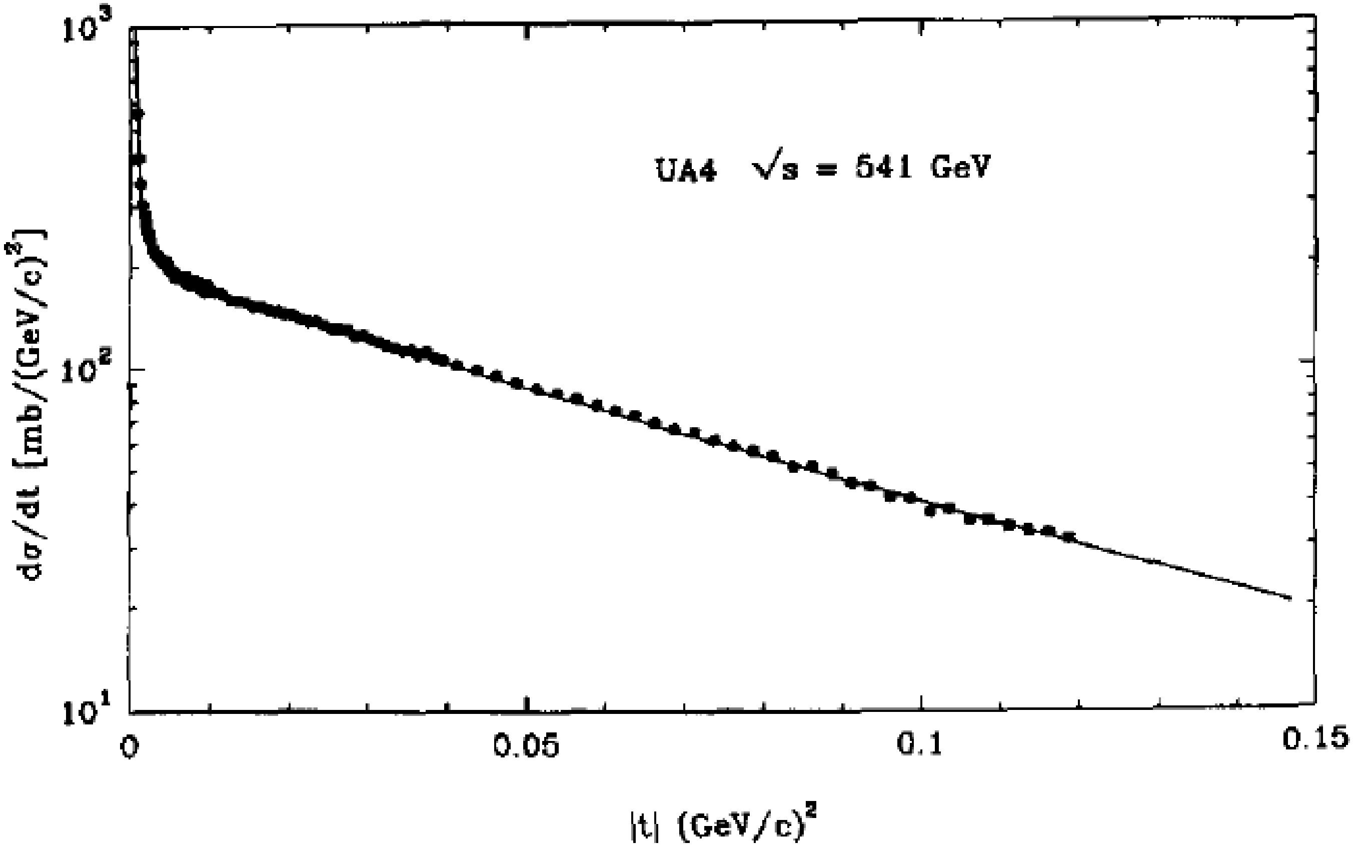
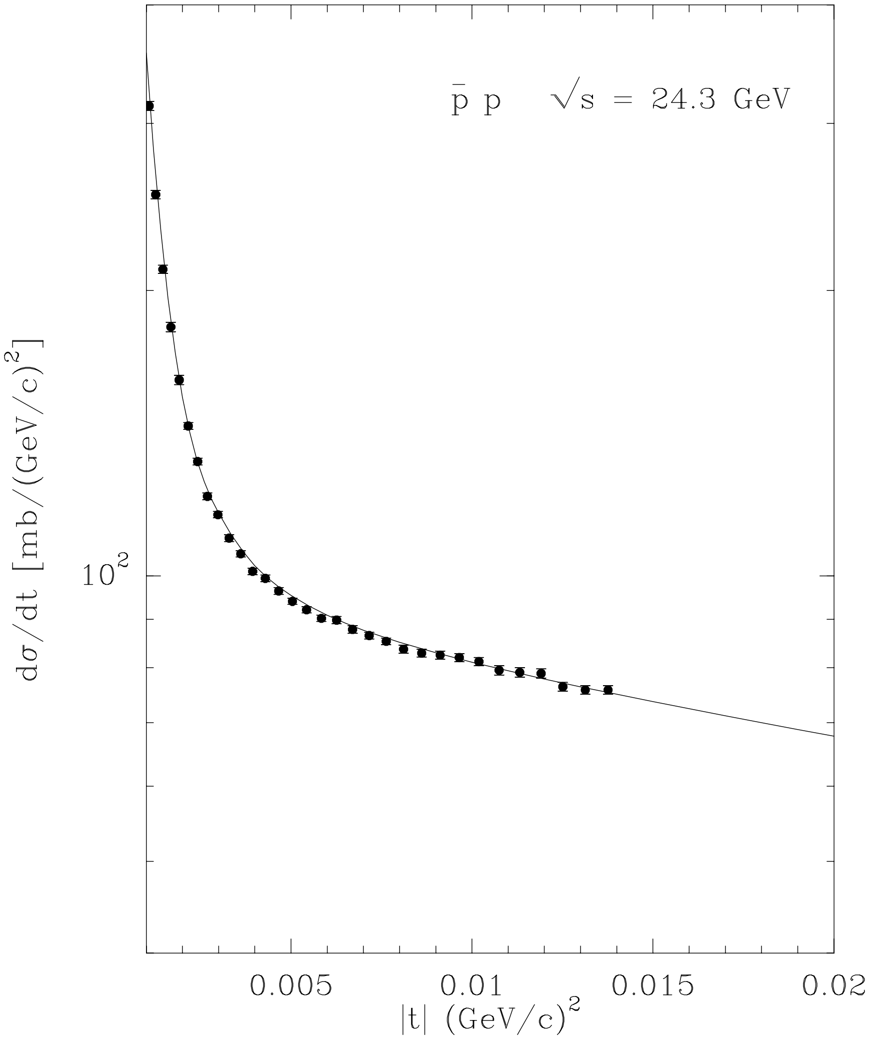


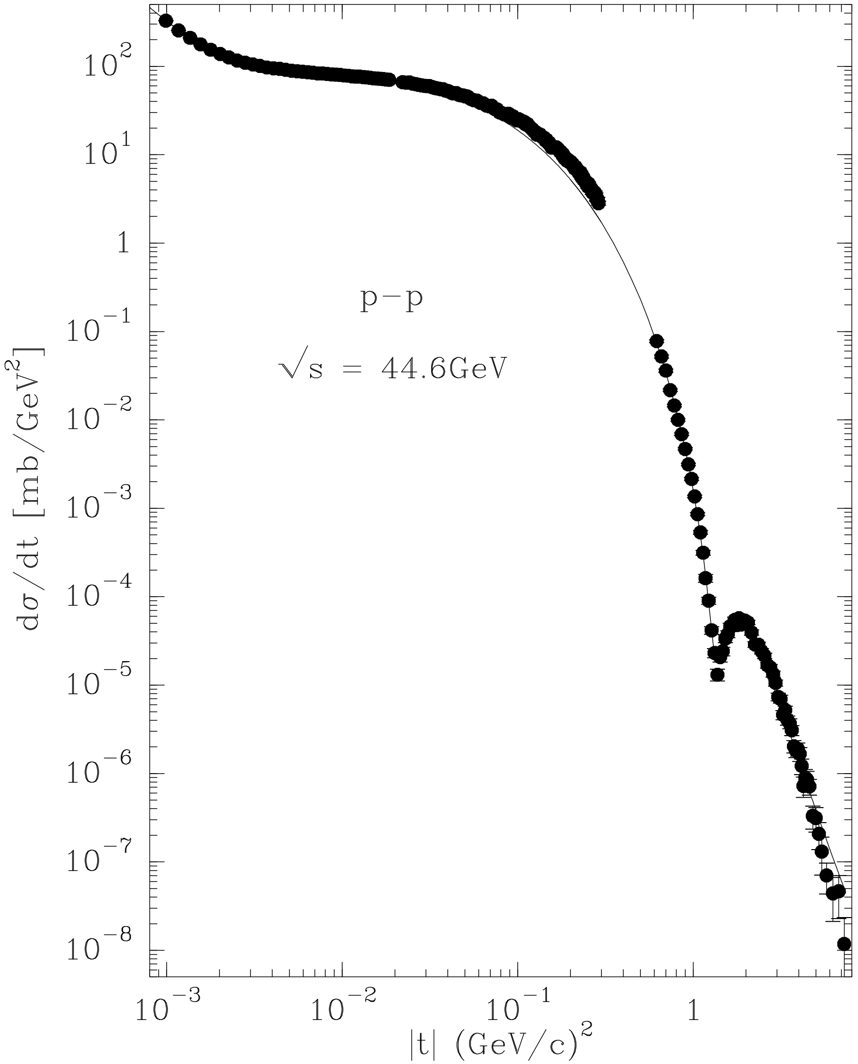
Fig. 1. Comparison of the theoretical prediction of ref. [4] and the new experimental measurement by UA4 [11] at $\sqrt{s} = 541$ GeV in the small t-region.

Elastic cross section in the CNI region

UA6 CERN data agree perfectly with BSW prediction

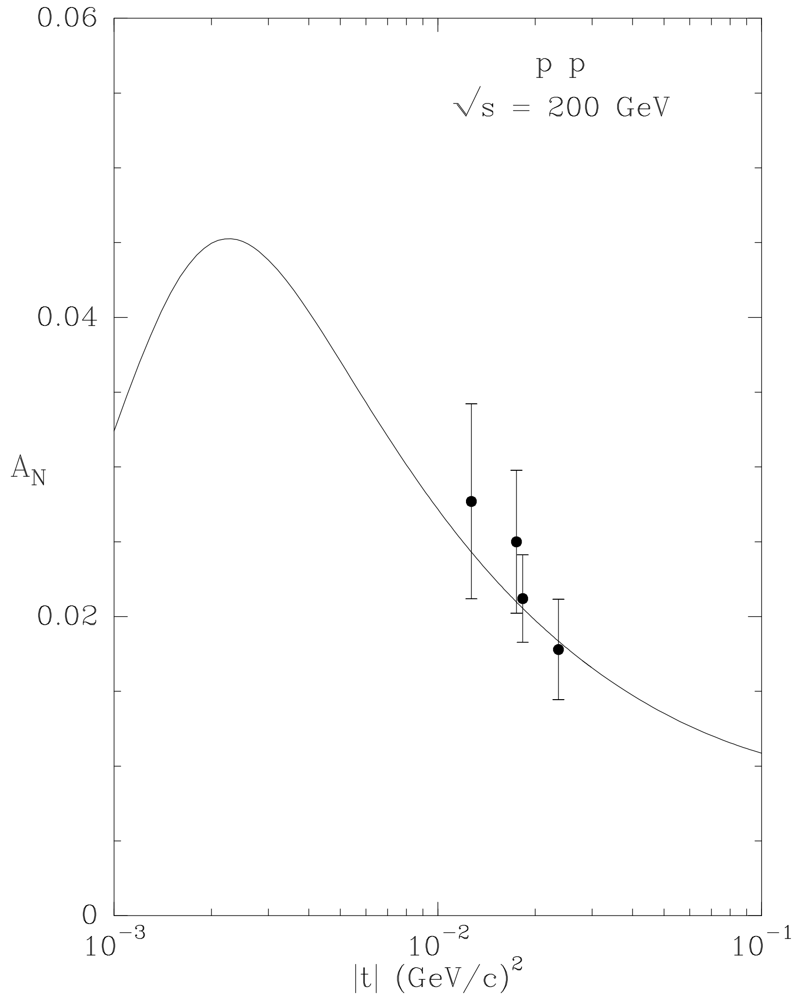


Elastic cross section including the CNI region at ISR



Single spin asymmetry in the CNI region at RHIC

Sensitive to an eventual hadronic flip amplitude (See new STAR results)

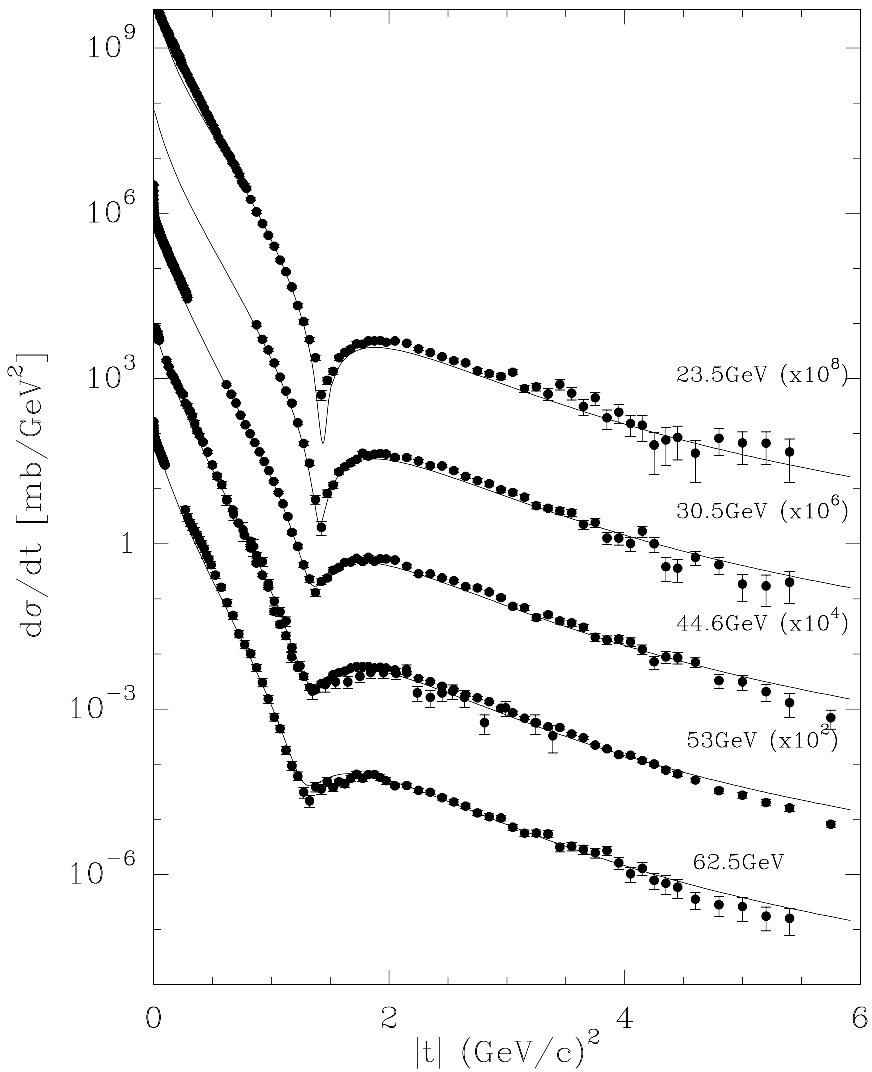


Why should ρ be measured at the LHC ?

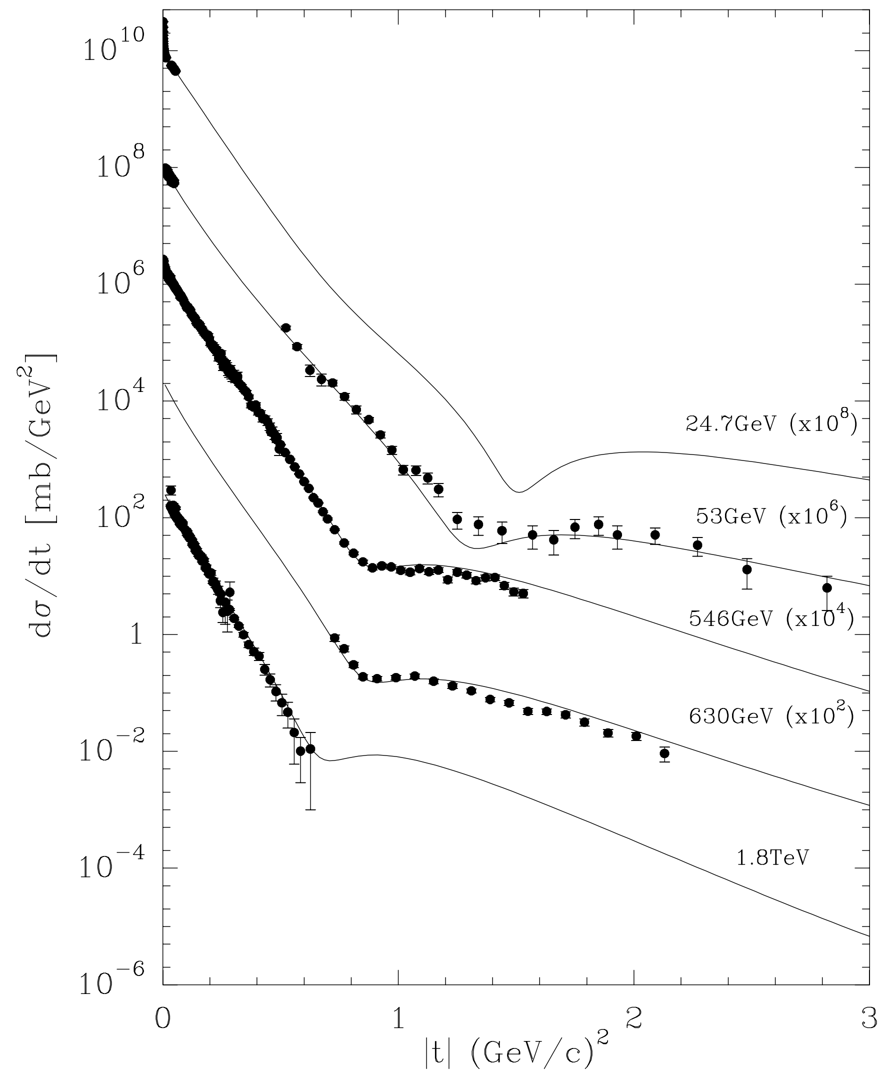
- Real and Imaginary parts of the scattering amplitude must obey dispersion relations according to local quantum field theory
- In string theory extra dimensions could generate observable non-local effects and therefore a violation of dispersion relations
- Can make a simple model to break polynomial boundness in some regions of the analyticity domain, leading for example to $\rho = 0.21$ at 14TeV
- According to BSW, which satisfy dispersion relations, one should find instead $\rho = 0.122$
- Dispersion relations could be also violated if σ_{tot} beyond the LHC energy, behaves very differently, due to some new physics.
- The highest energy where one has a reliable value of ρ is at $\sqrt{s} = 546$GeV, $\rho = 0.135 \pm 0.007$, since the Tevatron value $\rho = 0.140 \pm 0.069$ is useless

- **For all these reasons one needs an accurate value of ρ at LHC**

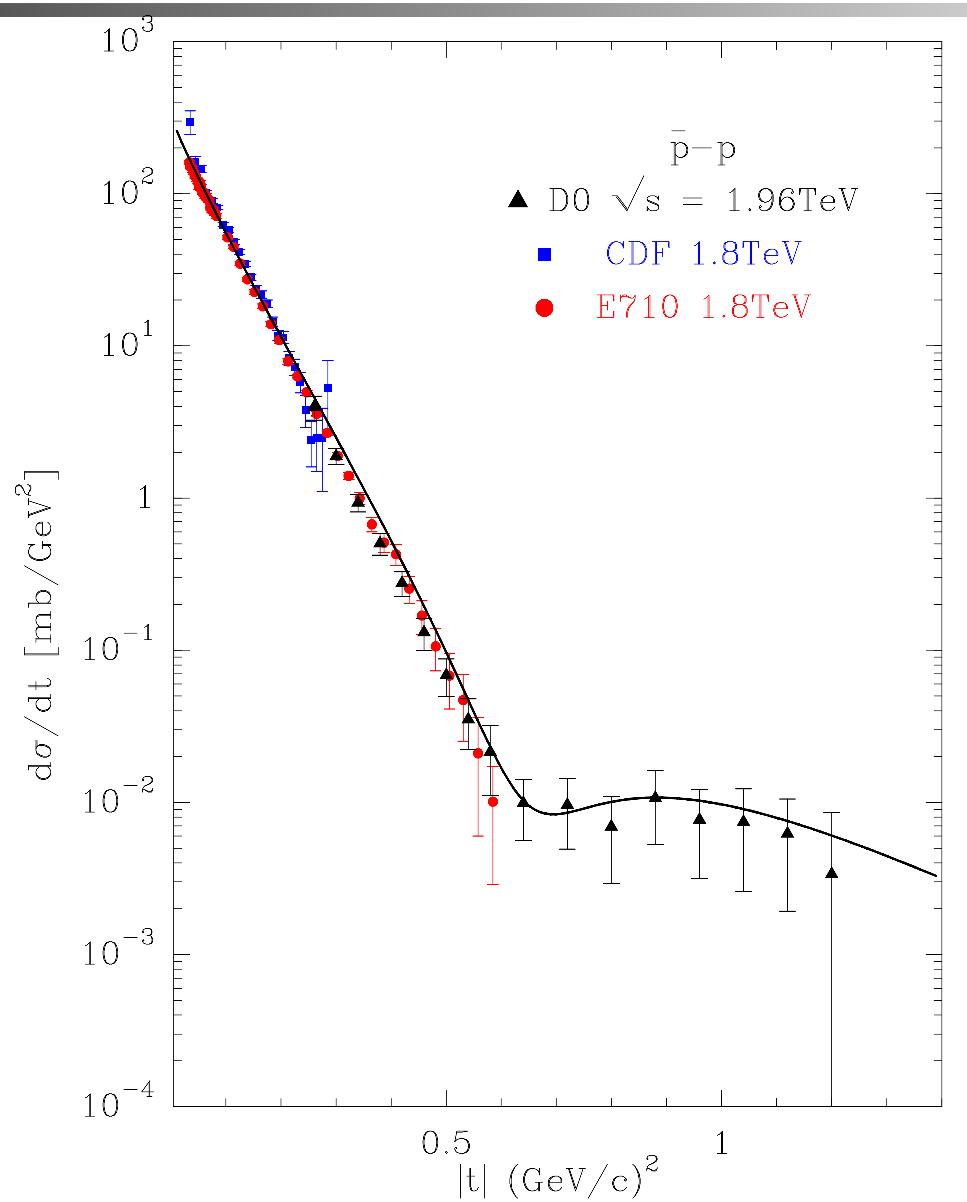
Differential elastic cross sections at ISR



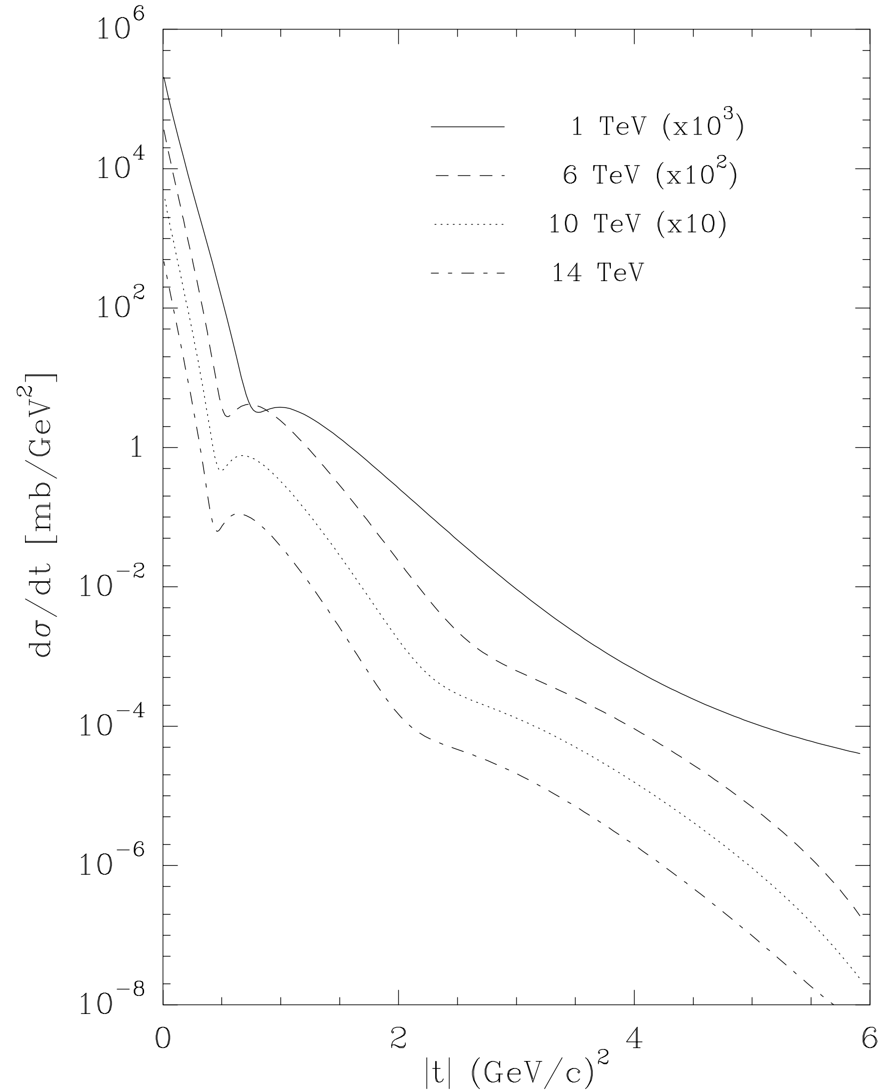
Differential elastic cross section



Differential elastic cross section at Tevatron



Differential elastic cross section up to LHC



New TOTEM data

The TOTEM Collaboration (G. Antchev *et al.*)

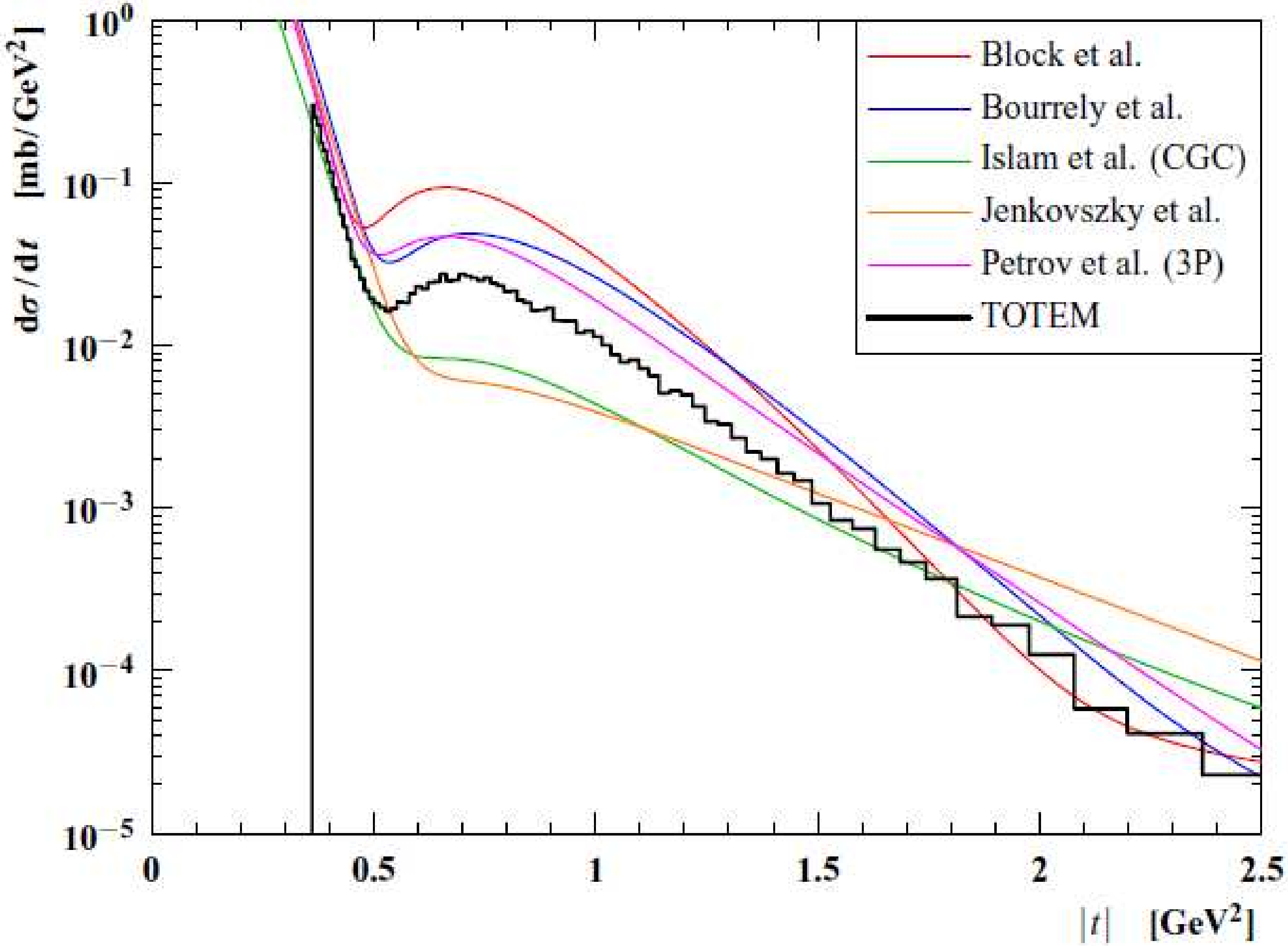


Fig. 4: The measured $d\sigma/dt$ compared to the predictions of several models (see table 4).

New TOTEM data

TOTEM vs Models comparison

	B (t=-0.4 GeV^2) [GeV^{-2}]	t_{DIP} [GeV^2]	t^{-N} [1.5–2.0 GeV^2] [N]
Islam	19.9	0.65	5.0
Jenkovsky	20.1	0.72	4.2
Petrov	22.7	0.52	7.0
Bourrely	21.7	0.54	8.4
Block	24.4	0.48	10.4
TOTEM	23.6 ± 0.5 ± 0.4	0.53 ± 0.01 ± 0.01	7.8 ± 0.3 ± 0.1

Concluding remarks

- LHC is opening up a new area for pp elastic scattering
- TOTEM has confirmed the following basic features expected at LHC
  - σ_{tot} increases
  - σ_{el}/σ_{tot} increases
  - shrinkage of the diffraction peak
  - moving in of the dip position
  - moving up of the second maximum
- So far only partial quantitative agreement with BSW

More data are needed and don't forget ρ at LHC


Thank you !