Impact picture for near-forward elastic scattering up to LHC energies

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Collaboration with Claude Bourrely and Tai Tsun Wu

More than 20 papers published on the so-called BSW model since 1979

Most recent
CERN-PH-TH-2014-077
(arXiv:1405.6698, Special Issue of IJMPA, vol.30, 1542006, 2015)

Main features of 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 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.
This last term generates the phase of the amplitude, which is built in.

Main features of the BSW model

The choice one makes for $F(\mathbf{b}^2)$ is crucial 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,

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

We define
the ratio of the real to imaginary parts of the forward amplitude $\rho(s) = \frac{Re\ a(s,t=0)}{Im\ a(s,t=0)}$,
the total cross section $\sigma_{tot}(s) = (4\pi/s) Im\ a(s,t=0)$,
the differential cross section $d\sigma(s,t)/dt = \frac{\pi}{s^2}|a(s,t)|^2$,
and the integrated elastic cross section $\sigma_{el}(s) = \int dt \frac{d\sigma(s,t)}{dt}$.

Schematic representation of expanding protons

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

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

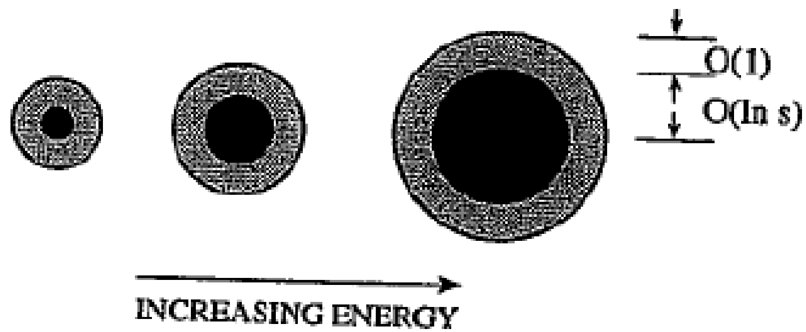


FIG. 4: Schematic representation of the appearance of a high-energy particle [$s = E^2$

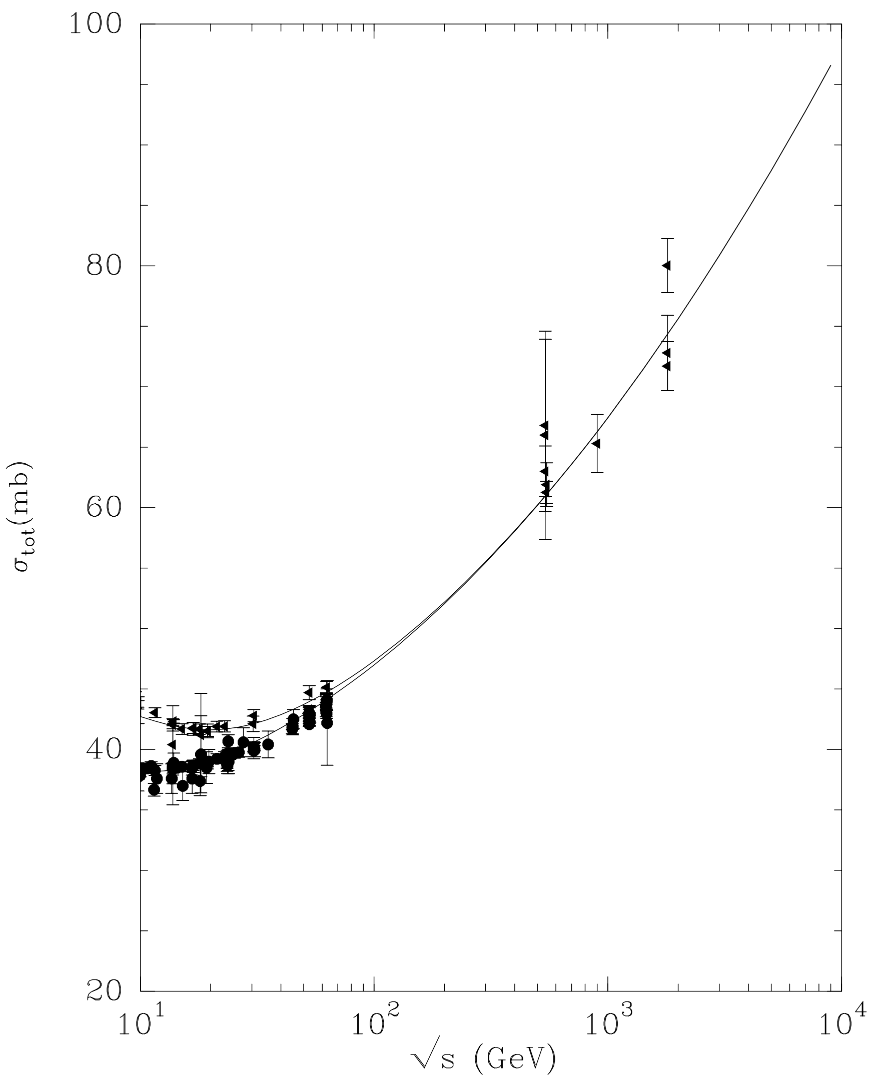
The BSW model parameters

At high energies the Regge Background is irrelevant and the model depends only on SIX parameters

Year	1979	1984
c	0.151	0.167
c'	0.756	0.748
m_1	0.619	0.586
m_2	1.587	1.704
f	8.125	7.115
a	2.257	1.953

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 $c' = 3/4$.

Total Cross sections below LHC



Cross sections at LHC

The BSW approach predicts at 7 TeV

$$\sigma_{tot} = 93.6 \pm 1\text{mb}$$
$$\sigma_{el} = 24.8 \pm 0.3\text{mb}$$

TOTEM has measured at 7 TeV

$$\sigma_{tot} = 98.0 \pm 2.5\text{mb}$$
$$\sigma_{el} = 24.8 \pm 1.2\text{mb}$$

ATLAS-ALFA (arXiv: 1408.5778) has measured at 7 TeV

$$\sigma_{tot} = 95.35 \pm 1.30\text{mb}$$
$$\sigma_{el} = 24.0 \pm 0.60\text{mb}$$

ATLAS-ALFA is more accurate than TOTEM

BSW agrees very well on both results for σ_{el}

but it is below both results on σ_{tot}, although closer to ATLAS-ALFA

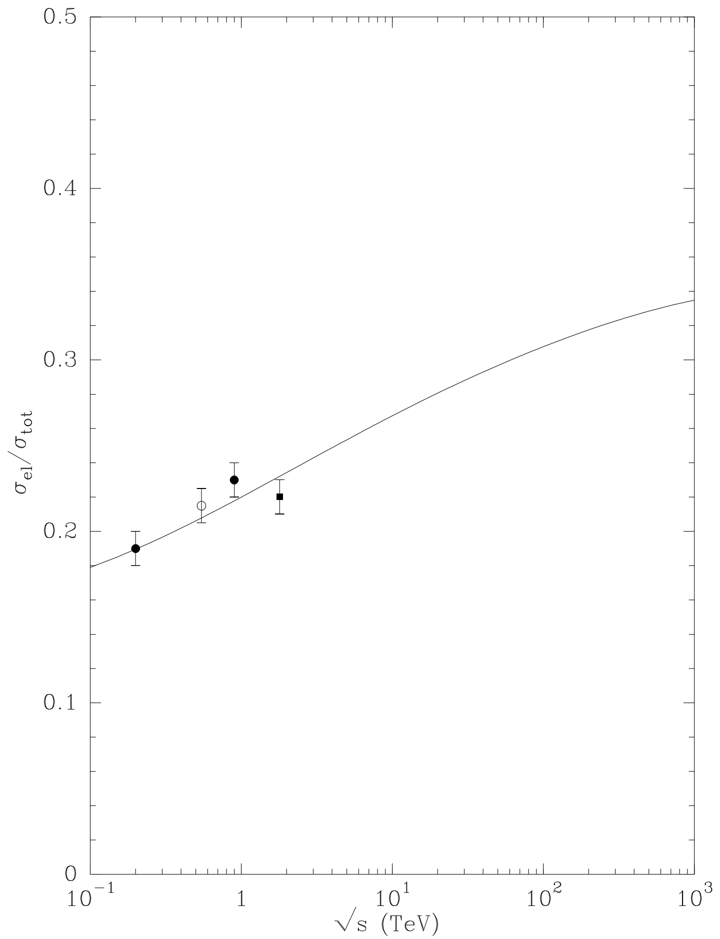
Two-scale hadronic structure model (B. Kopeliovich et al. PRD86, 051502 (2012)) predicts $\sigma_{tot} = 98$ mb and $\sigma_{el} = 25.63$ mb, in perfect agreement with TOTEM

BSW ratio σ_{el}/σ_{tot}

Find $\simeq 0.27$ at 7 TeV and $\simeq 0.30$ at 57 TeV

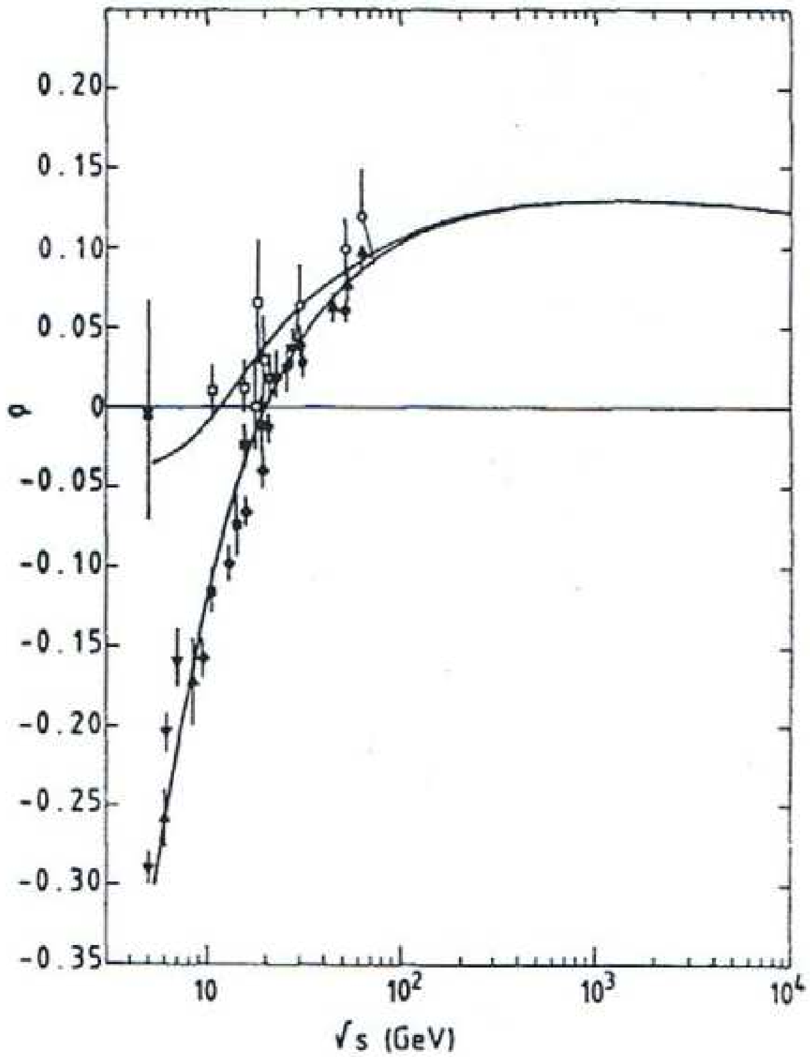
It is predicted to rise with increasing energy up to 1/2, the black disk limit

Important question : Which are the other production processes contributing to this rise?



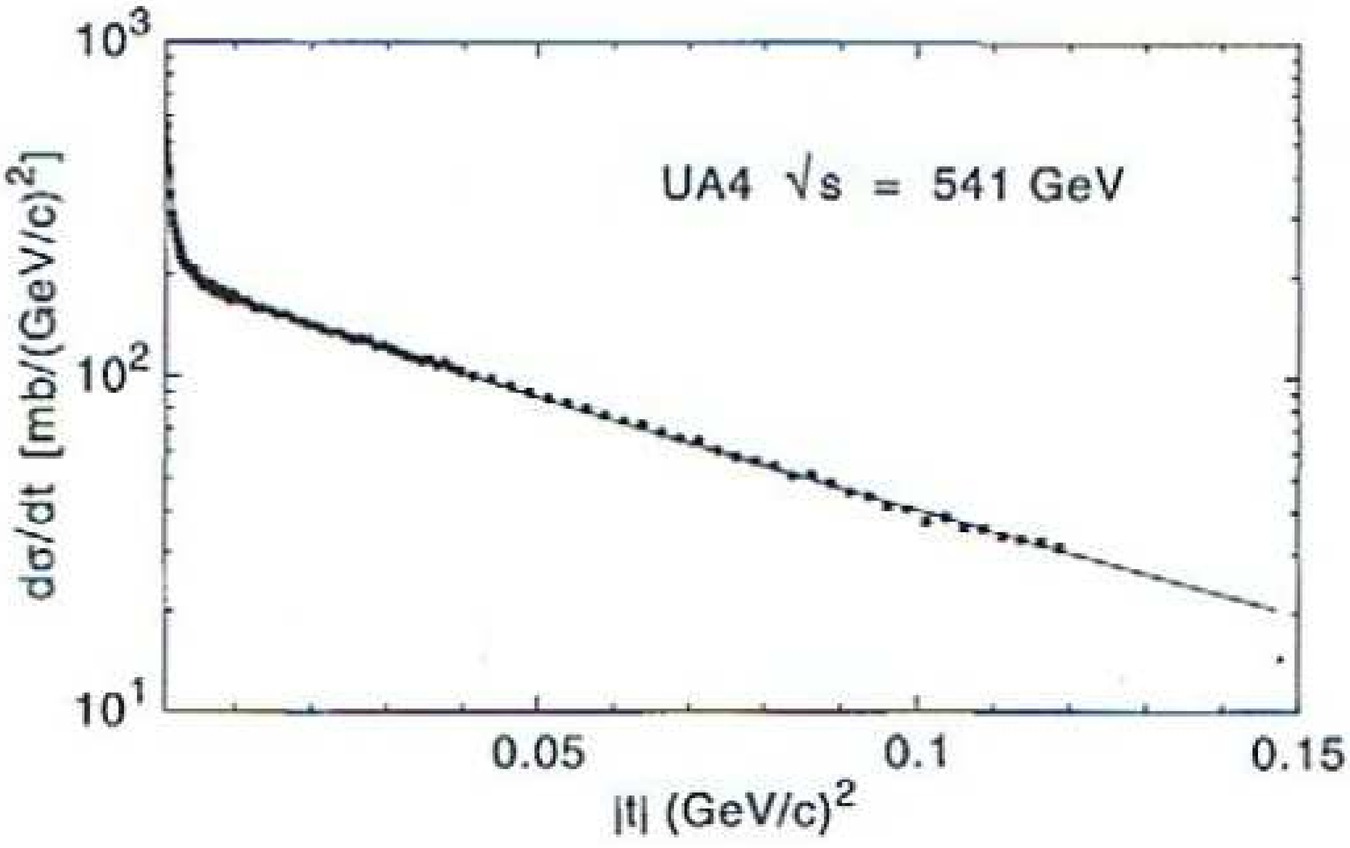
The ratio $\rho(s)$ for pp and $\bar{p}p$

We expect $\rho(s) \to 0$ for $s \to \infty$



CNI region from UA4 at CERN 1992

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



Why should ρ be measured at the LHC ?

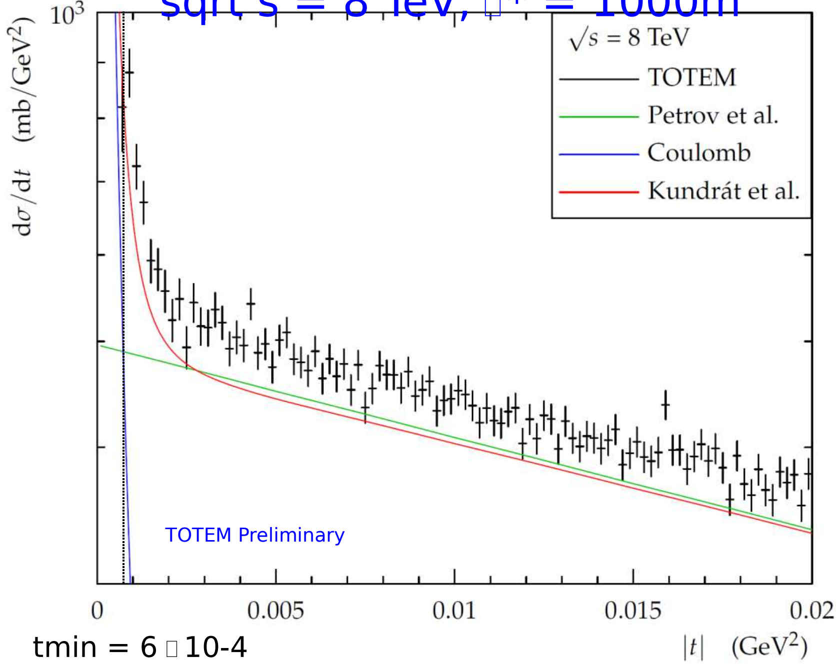
C. Bourrely, N.N. Khuri, A. Martin, J.S. and T.T. Wu (Blois 2005)

- 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 14 TeV
- According to BSW, which satisfies dispersion relations, one should find instead $\rho = 0.122$
- Dispersion relations could be also violated if σ_{tot} beyond the the LHC energy behaves very differently, due to possible new physics
- The highest energy where one has a reliable value of ρ is $\sqrt{s}$ = 541 GeV, $\rho = 0.35 \pm 0.007$, since the Tevatron value $\rho = 0.140 \pm 0.069$ is very inaccurate
- **For all these reasons one needs an accurate value of ρ at LHC**

First attempt to reach the CNI region at LHC

First Coulomb interference region measurement

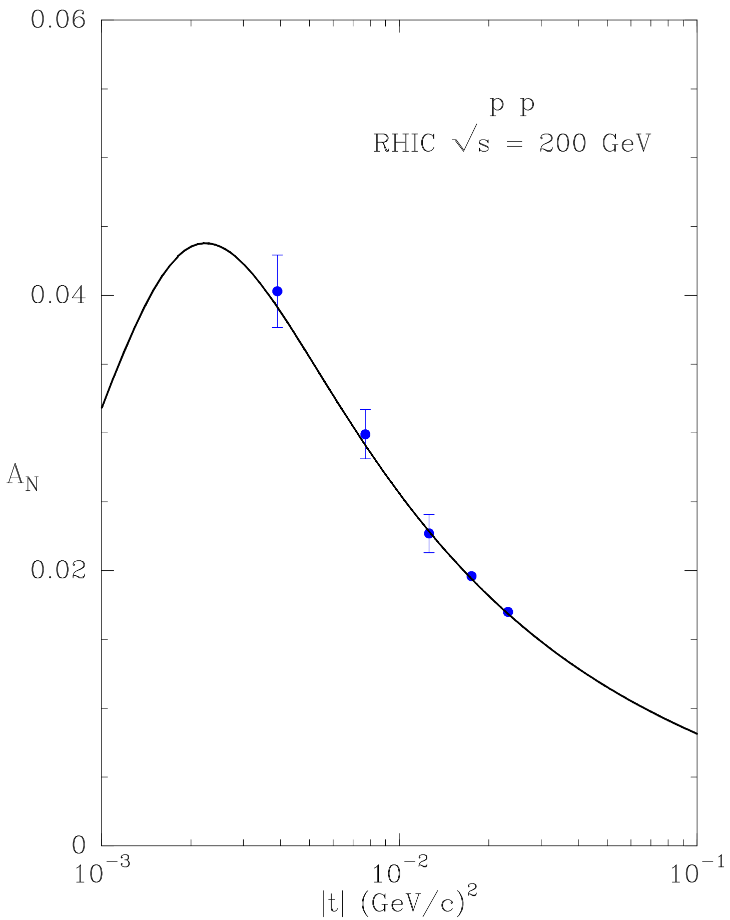
sqrt s = 8 TeV, □* = 1000m



tmin = 6 □10-4 GeV2

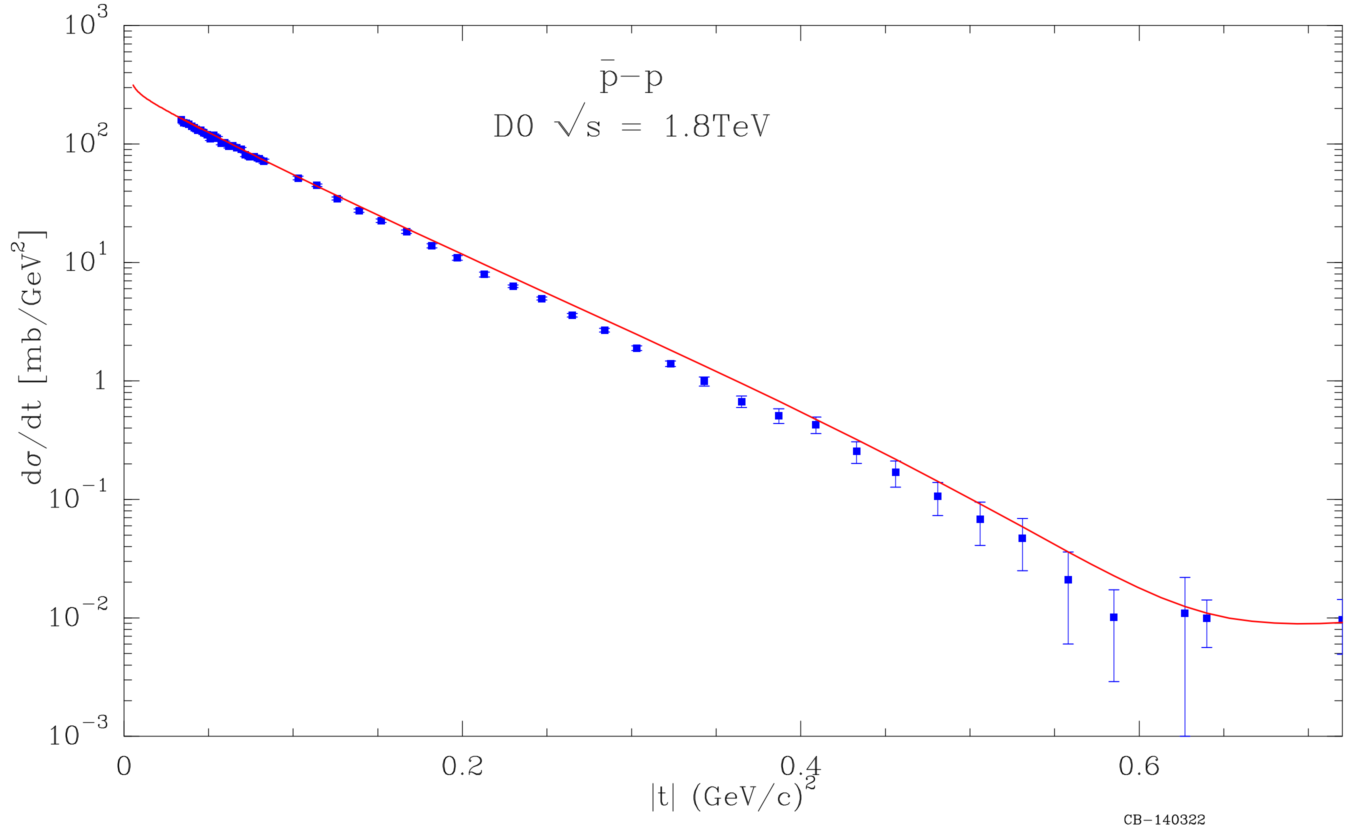
Single spin asymmetry A_N in the CNI region at RHIC by STAR

The good agreement confirms the absence of single-flip hadronic amplitude and the right determination of $Ima(s,t)$ in the CNI region



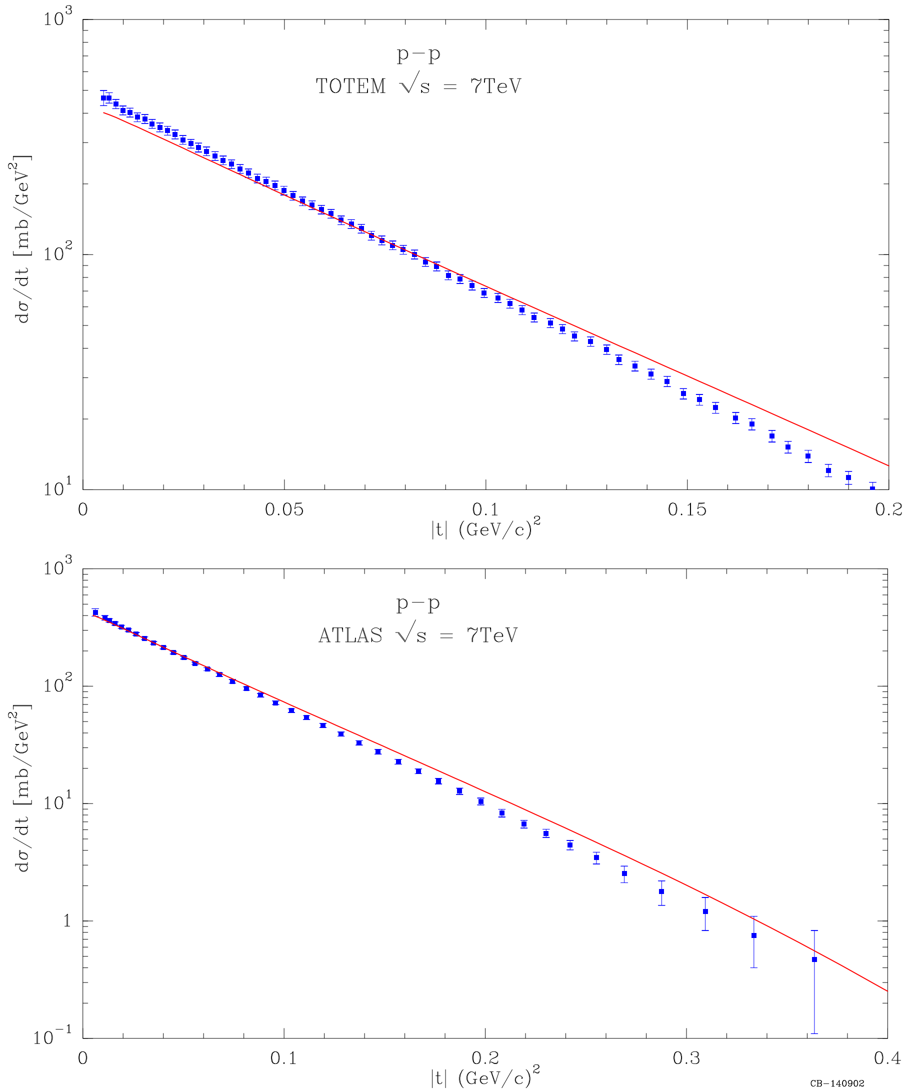
Comparison of $d\sigma/dt$ BSW prediction with D0 at FNAL

▲



There is a reasonable agreement

Comparison of $d\sigma/dt$ BSW prediction with TOTEM and ATLAS-ALFA



Comparison of $d\sigma/dt$ BSW prediction with TOTEM and ATLAS-ALFA

BSW disagrees with TOTEM both near the optical point and above $|t| = 0.1$GeV^2

However BSW is not in such disagreement with ATLAS-ALFA

The two-scale hadronic structure, which is in excellent agreement with TOTEM, must fail a very good description of ATLAS-ALFA near the optical point

What about the near-forward slope?

This was recently questioned by TOTEM

Evidence for non-exponential elastic pp cross section at low $|t|$ and $\sqrt{s} = 8$TeV

arXiv:1503.08111v2

A simple method to extract the near-forward elastic slope from the data (BSW, EPJ C71, 1601 (2011))

Let us write the real and imaginary parts of the amplitude

$$
\begin{aligned}
Re\ a(t) &= c_1(t_1+t)e^{d_1 t}\,, \\
Im\ a(t) &= c_2(t_2+t)e^{d_2 t}\,, \\
\frac{d\sigma(t)}{dt} &= (Re\ a(t))^2 + (Im\ a(t))^2
\end{aligned}
$$

and the slope defined as

$$
B(t) = \frac{d}{dt}\log\left(\frac{d\sigma}{dt}\right)\,.
$$

is given by

$$
B(t) = \frac{2c_1^2(t_1+t)(1+d_1(t_1+t))e^{2d_1 t} + 2c_2^2(t_2+t)(1+d_2(t_2+t))e^{2d_2 t}}{d\sigma(t)/dt}\,.
$$

Results for ATLAS-ALFA

The fit of the differential cross section gives a $\chi^2 = 1.96$ for 40 points and the parameters (with suitable units) are:

$$c_1 = 6.772 \quad t_1 = 0.401 \quad d_1 = 0.808$$

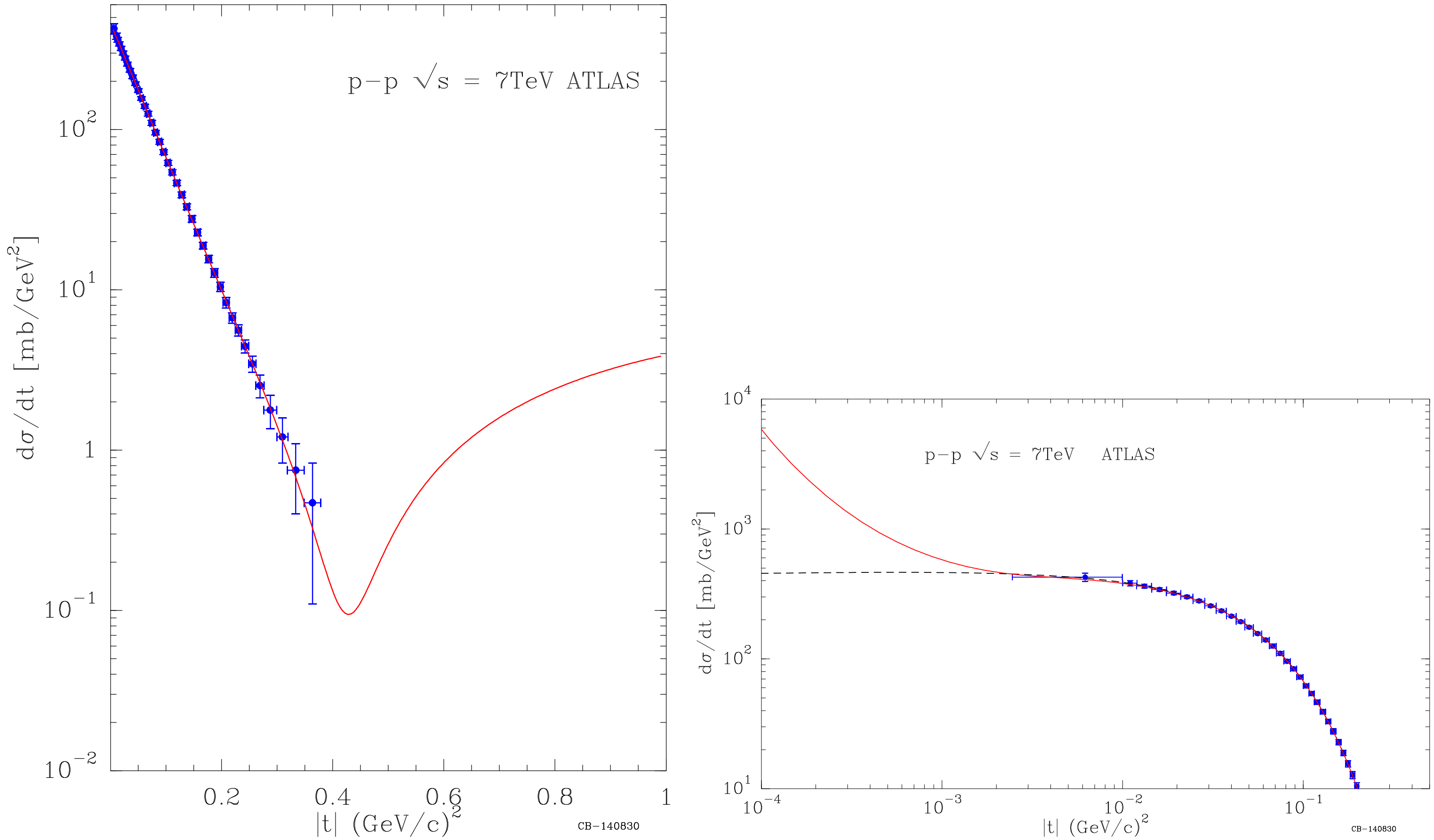
$$c_2 = 20.028 \quad t_2 = 0.9716. \quad d_2 = 8.876$$

Our results are:

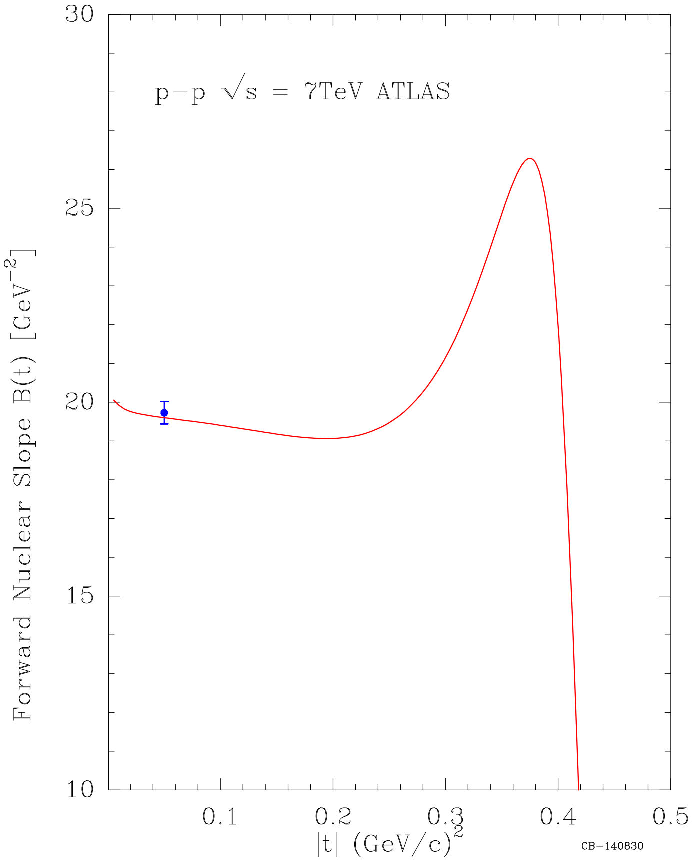
$$\rho = 0.1398, \quad d\sigma/dt(t=0) = 472.35 \text{mbGeV}^{-2}, \quad \sigma_{tot} = 95.22 \text{mb},$$

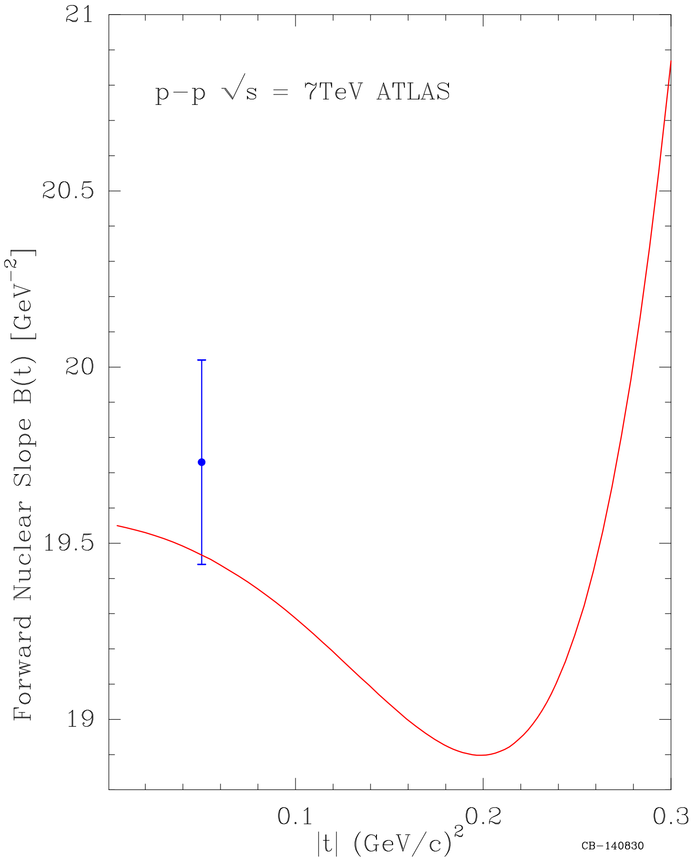
they are in good agreement with the ATLAS results.

Results for ATLAS-ALFA



Results for ATLAS-ALFA





Results for TOTEM

The fit of the differential cross section gives a $\chi^2/pt = 0.14$ for 40 points and the parameters (with suitable units) are:

$$c_1 = 2.85 \quad t_1 = 1.0 \quad d_1 = 5.14$$

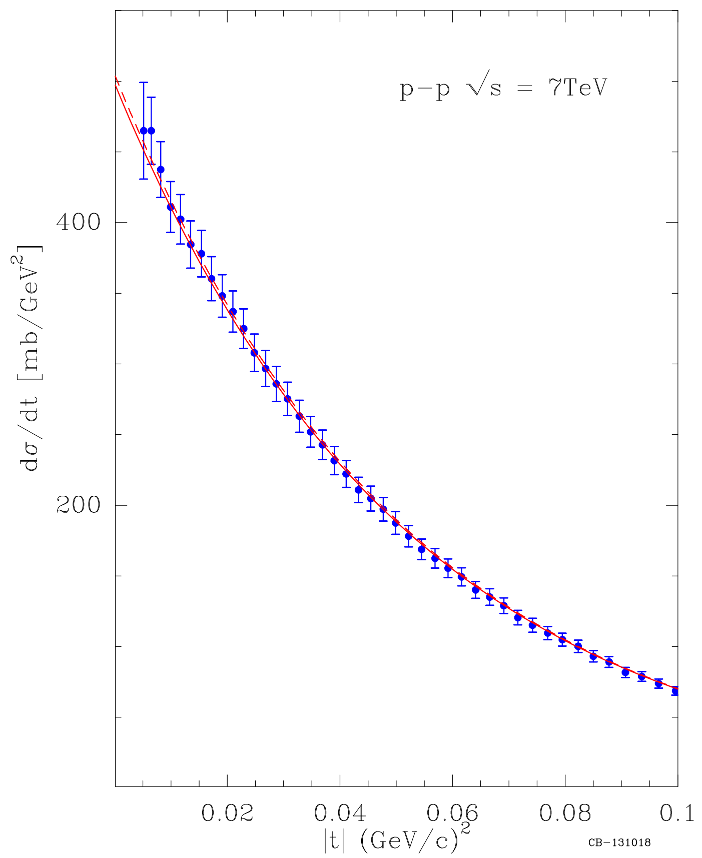
$$c_2 = 37.34 \quad t_2 = 0.53. \quad d_2 = 7.85$$

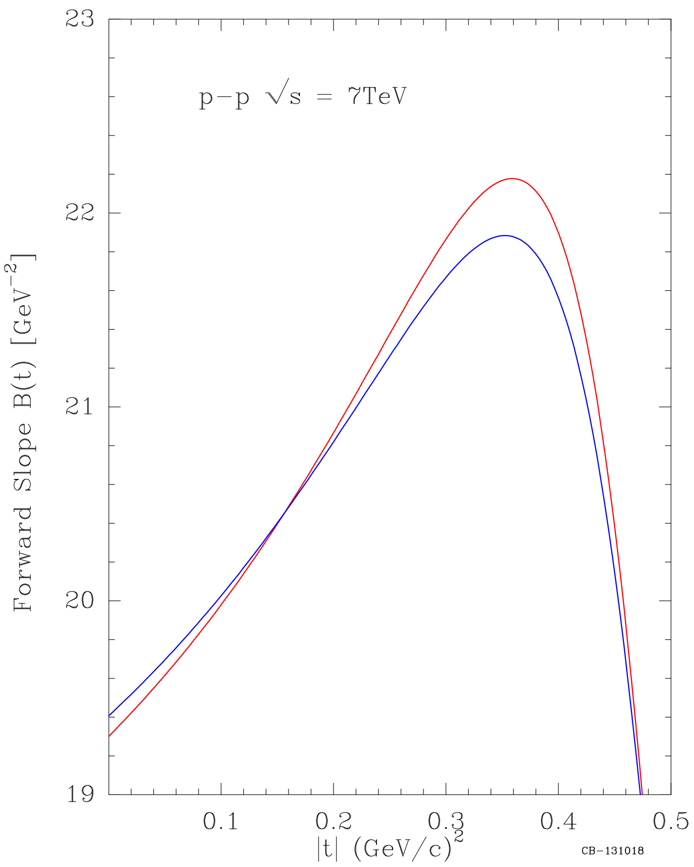
Our results are:

$$\rho = 0.144, \quad d\sigma/dt(t=0) = 498.14\text{mbGeV}^{-2}, \quad \sigma_{tot} = 97.73\text{mb},$$

they are in good agreement with the TOTEM results.

Results for TOTEM





Conclusions

- Elastic scattering at LHC energies has still more to teach us
- BSW model had an extremely good predictive power for pre LHC energy region, but the 7 TeV LHC energy seems to create some unexpected problems
- An accurate measurement of ρ has to come
- Future LHC results at 13 TeV will be of particular interest