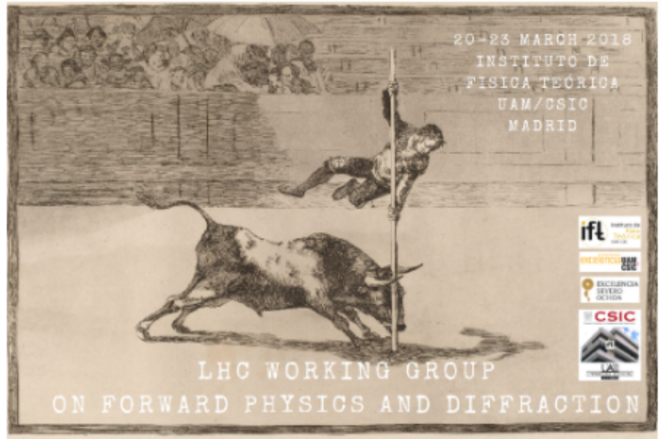



The LHC Working Group on Forward Physics and Diffraction is a forum for:

# Elastic proton-proton scattering at 13 TeV in the theoretical perspective

Valery Khoze (IPPP, Durham & PNPI, St.Petersburg.)

(in collaboration with Alan Martin and Misha Ryskin)

arXiv:1712.00325- **revisited**

## Elastic proton-proton scattering at 13 TeV

**Abstract**

The predictions of a model which was tuned in 2013 to describe the elastic and diffractive $pp$- and/or $p\bar{p}$-data at collider energies up to 7 TeV are compared with the new 13 TeV TOTEM results. The possibility of an odd-signature Odderon exchange contribution is discussed.

**Disclaimer:**

WORK IN PROGRESS

(Valentina's talk)

at $\sqrt{s}$=13 TeV of the $pp$ total cross section $\sigma_{\rm tot} = 110.6 \pm 3.4$ mb and of the ratio of the real-to-imaginary parts of the forward $pp$-amplitude[1], $\rho \equiv {\rm Re}A/{\rm Im}A = 0.10 \pm 0.01$ [1]. These striking 13 TeV data (in particular the indication of the possible strong decrease of $\rho$ with increasing collider energy) were advocated as a definitive confirmation of the experimental discovery of the Odderon in its maximal form. **(MO)**

[1]The value $\rho = 0.10 \pm 0.01$ is obtained from data in the interval $|t| < 0.15$ GeV$^2$. If data are used in a more restricted interval $|t| < 0.07$ GeV$^2$ (corresponding to the $|t|$ range of the UA4/2 data [2]) then $\rho = 0.09 \pm 0.01$

(Evgenij's talk)

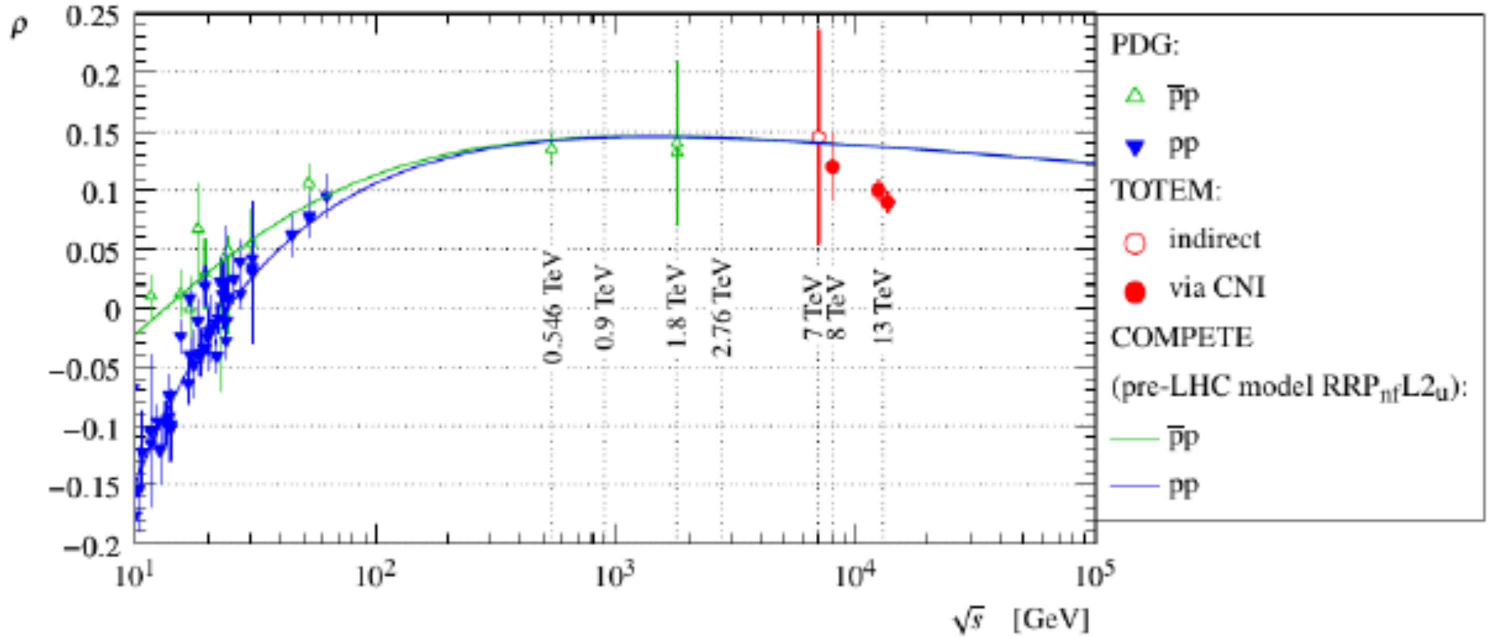
[arXiv:1711.03288](arXiv:1711.03288)

Evgenij Martynov[a], Basarab Nicolescu[b]

[a]*Bogolyubov Institute for Theoretical Physics, Metrologichna 14b, Kiev, 03680 Ukraine*
[b]*Faculty of European Studies, Babes-Bolyai University, Emmanuel de Martonne Street 1, 400090 Cluj-Napoca, Romania*

**Abstract**

The present study shows that, beyond any doubt, the new TOTEM datum $\rho^{pp} = 0.098 \pm 0.01$ can be considered as the first experimental discovery of the Odderon, namely in its maximal form.




TOTEM

CERN-EP-2017-321
CERN-EP-2017-335

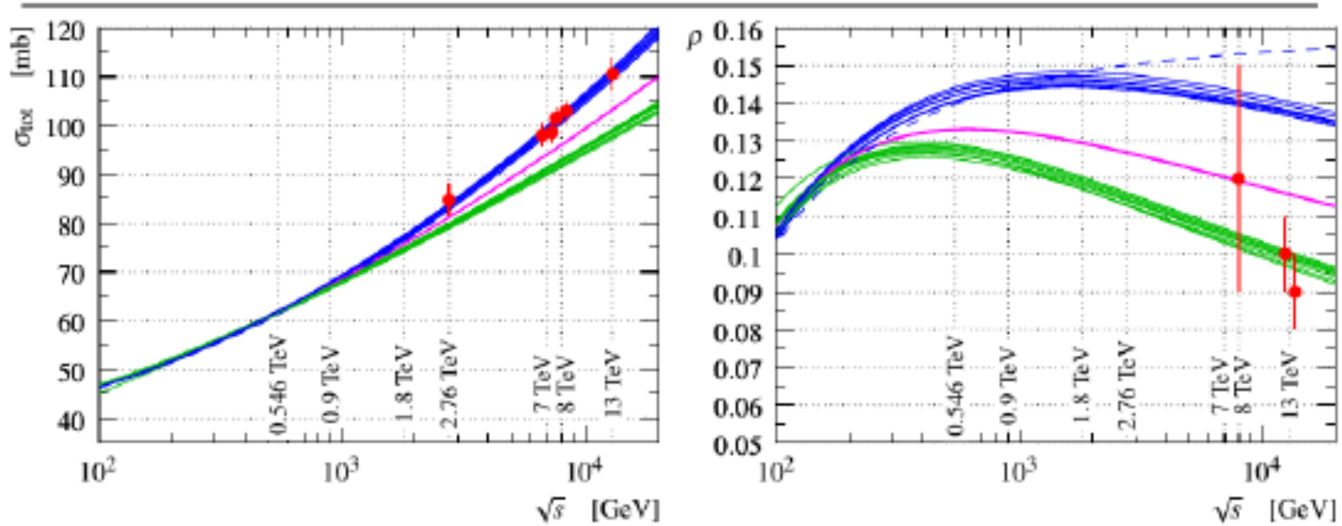



**Fig. 18:** Predictions of COMPETE models [32] for pp interactions. Each model is represented by one line

COMPETE uses a simplified parametrization motivated by Froissart asymptotics

$$\frac{1}{s}\mathrm{Im}A(s,t=0) \;=\; c\,\ln^2(s/s_0) \;+\; P \;+\; R(s) \qquad (1)$$

$\rho_{COMPETE} \simeq 0.135 \qquad \rho_{TOTEM} = (0.09 - 010) \pm 0.01$

$\sigma_{\mathrm{tot}}$ =110.6 mb

- Long-awaited Odderon would be very welcome news for the theoretical community

- our main aim is to try to evaluate whether the new TOTEM data could be accommodated within the existing 'conventional' multi-Pomeron framework

exemplified by the non-tuned KMR 2013-model arXiv:1306.2149

**(study within the framework of dynamical (QCD-based) models for both P&O)**

In the analysis of arXiv:1712.00325 we used a modified model 4, according to arXiv:1402.2778 aiming to accommodate all existing data on low-mass SD, in particular the central value 2.6 mb, measured by TOTEM at 7 TeV.

New CMS 13 TeV results: arXiv:1802.02613

**Tension in CMS-TOTEM data**

$$\sigma_T(s) \leq \frac{\pi}{m_\pi^2} \log^2\left(\frac{s}{s_0}\right)$$ Froissart–Martin theorem

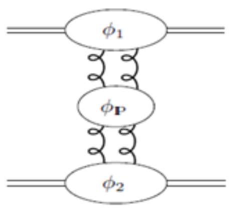
$\ln^2 s$ **Not a MUST !** (Per's talk)

$$\Delta\sigma = \sigma_T^{\bar{p}p} - \sigma_T^{pp} \underset{s\to\infty}{\longrightarrow} 0\,.$$ I. Ya. Pomeranchuk, JETP **7** (1958) 499.

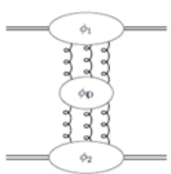
$$\frac{\sigma_T^{\bar{p}p}}{\sigma_T^{pp}} \underset{s\to\infty}{\longrightarrow} 1$$ general Pomeranchuk theorem. $|\Delta\sigma| \leq \text{const} \cdot \log s\,.$

Odderon in asymptotic theories , L .Lukaszuk , B.Nicolescu-1973

**QCD**



Pomeron- the total cross section section asymptotics- pQCD
a compound state of two reggeized gluons BFKL (1975—1978)
Regge theory-Gribov (1962).



Odderon-difference of particle and antiparticle cross sections-pQCD
a compound state of three reggeized gluons
BKP The Bartels-Kwieciński-Praszałowicz Equation (1980)

**Until very recently no firm experimental observation**

Low-mass dissociation is a consequence of the internal structure of proton. A constituent can scatter & destroy coherence of $|p\rangle$

**KMR-2013 Models (1-4)**

Good-Walker: $|p\rangle = \Sigma\, a_i\, |\varphi_i\rangle$ (1960)

where $\varphi_i$ diagonalize T -- have only “elastic-type” scatt

- Usually GW eigenstates assumed independent of t & s
  KMR (2013) parametrize form factor $F_i(t)$ for each $\varphi_{i=1,2}$

  - Allows for $B_{el} \sim 10\ \mathrm{GeV}^{-2}$ at CERN-ISR
    $B_{el} \sim 20\ \mathrm{GeV}^{-2}$ at LHC (7 TeV)
    as well as diff$^{ve}$ dip

- abs. corr$^{ns}$ between intermediate parton-parton inter$^{ns}$
  $\sigma_{abs} \sim 1/k_t^2$, suppress low $k_t$ → mean $k_t$ increases with s

$$k_{min}^2 \sim s^{\,0.28}$$

(enhanced multi-pom effects introduce dynamical infrared cutoff)

✶ Conventional RFT assumed all $k_t$ limited and small.

| | $\sqrt{s}$ TeV | $\sigma_{\rm tot}$ mb | $\sigma_{\rm el}$ mb | $B$ $\mathrm{GeV}^{-2}$ | $\sigma^{\rm SD}_{{\rm low}\,M}$ mb | $\sigma^{\rm DD}_{{\rm low}\,M}$ mb | $\sigma^{\rm D}_{{\rm low}\,M}$ mb | $S^2$ |
|---|---|---|---|---|---|---|---|---|
| model 1 | 0.0625 | 42.0 | 6.8 | 13.3 | **2.02** | 0.14 | 2.16 | 0.105 |
| | 0.546 | 63.1 | 12.5 | 16.2 | 3.14 | 0.22 | 3.36 | 0.041 |
| | 1.8 | 77.6 | 16.9 | 18.2 | 3.85 | 0.28 | 4.13 | 0.023 |
| | 7 | 97.0 | 23.2 | 20.7 | 4.72 | 0.37 | **5.09** | 0.011 |
| | 14 | 108 | 26.9 | 22.1 | 5.20 | 0.42 | 5.61 | 0.007 |
| | 100 | 144 | 39.6 | 26.7 | 6.64 | 0.57 | 7.21 | 0.002 |

V.A. Khoze, A.D. Martin, M.G. Ryskin arXiv:1306.2149

**Simplified Model for Odderon:**

M.G. Ryskin, Sov. J. Nucl. Phys. **46** (1987) 337.

E.M. Levin, M.G. Ryskin, Phys. Rept. 189 (1990) 267 (sect.7).

M.Fukugita,J.Kwieciński, **1979**

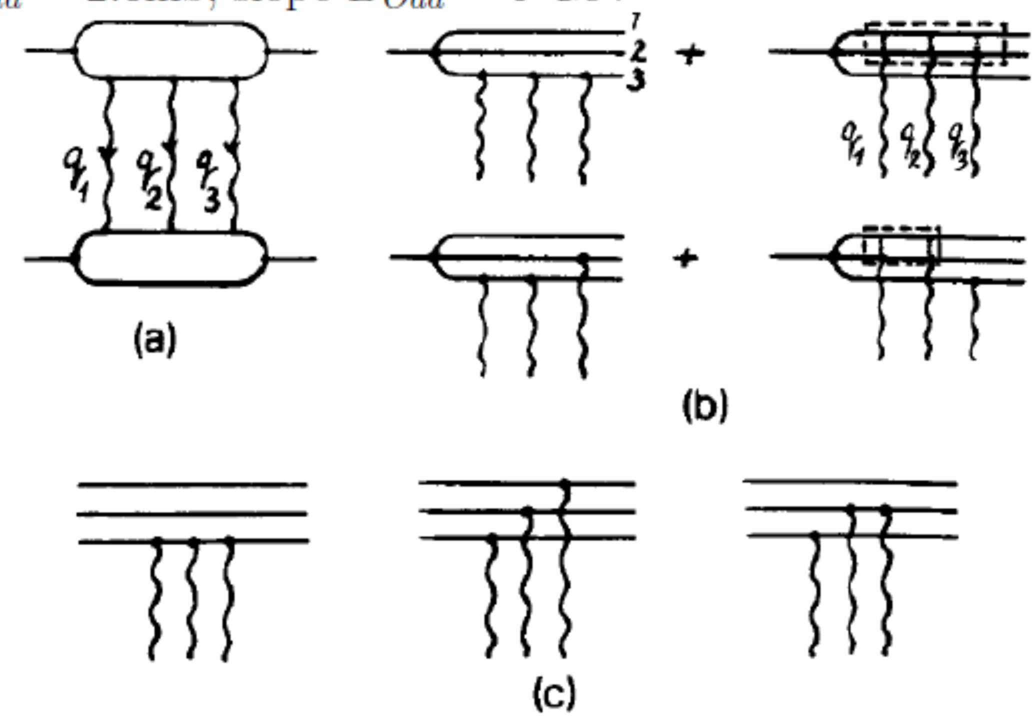
QCD Odderon included into $\Omega(b)$ with

general solution of unitarity equation

$$A(b) \;=\; i\left(1-e^{-\Omega(b)/2}\right),$$

Absorptive effects

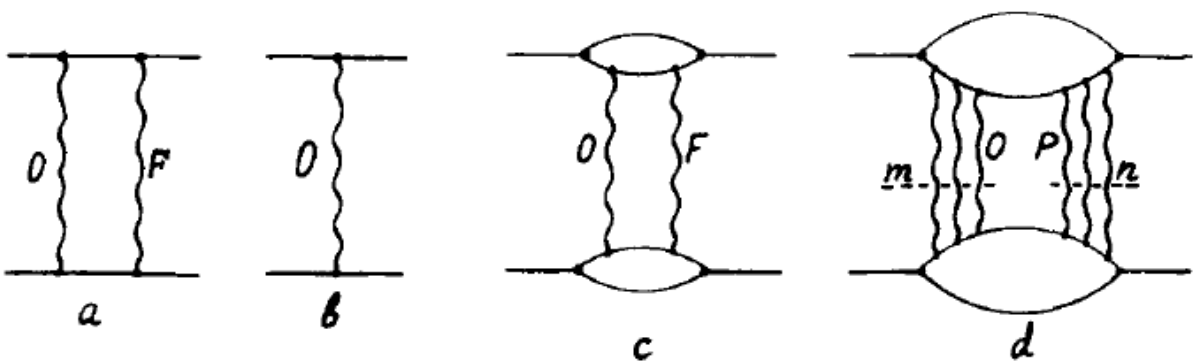
$\mathrm{Re}A_{Odd} = 2.8\mathrm{mb}$, slope $B_{Odd} = 6\ \mathrm{GeV}^{-2}$




. Odderon structure in the Born approximation of QCD (three gluon exchange).

- $(q_t \geq 1/r_{12})$ typical value $q_t \simeq 0.8$–$0.9$ GeV/$c$
- the non-relativistic quark model with oscillatory potential for a description of the nucleon.
- $M^{\mathrm{odd}}_{\mathrm{n.f.}}(0) \sim s\alpha_s^3 \cdot 20.6\,\mathrm{mb}$
- For large $Q^2$ $\qquad M^{\mathrm{odd}}_{\mathrm{n.f.}}(Q) \backsim 1/Q^6$
- As any amplitude, odderon exchange is accompanied by absorption corrections

→ Decreases the Odderon contribution




$$\frac{|M^{\mathrm{odd}}(t=0,s)|}{|M^{\mathrm{froissarton}}(t=0,s)|} \leqslant \frac{\pi}{m_\pi R(s)} \backsim 1/\ln s \to 0\,.$$

Asymptotically **Pomeron** → **black** absolutely absorptive disc

❑ the screening correction reveals itself in the most striking way at asymptotically high energy. At such energies the positive signature amplitude (froissarton) is a black, absolutely absorptive disc with radius $R = a \ln s$

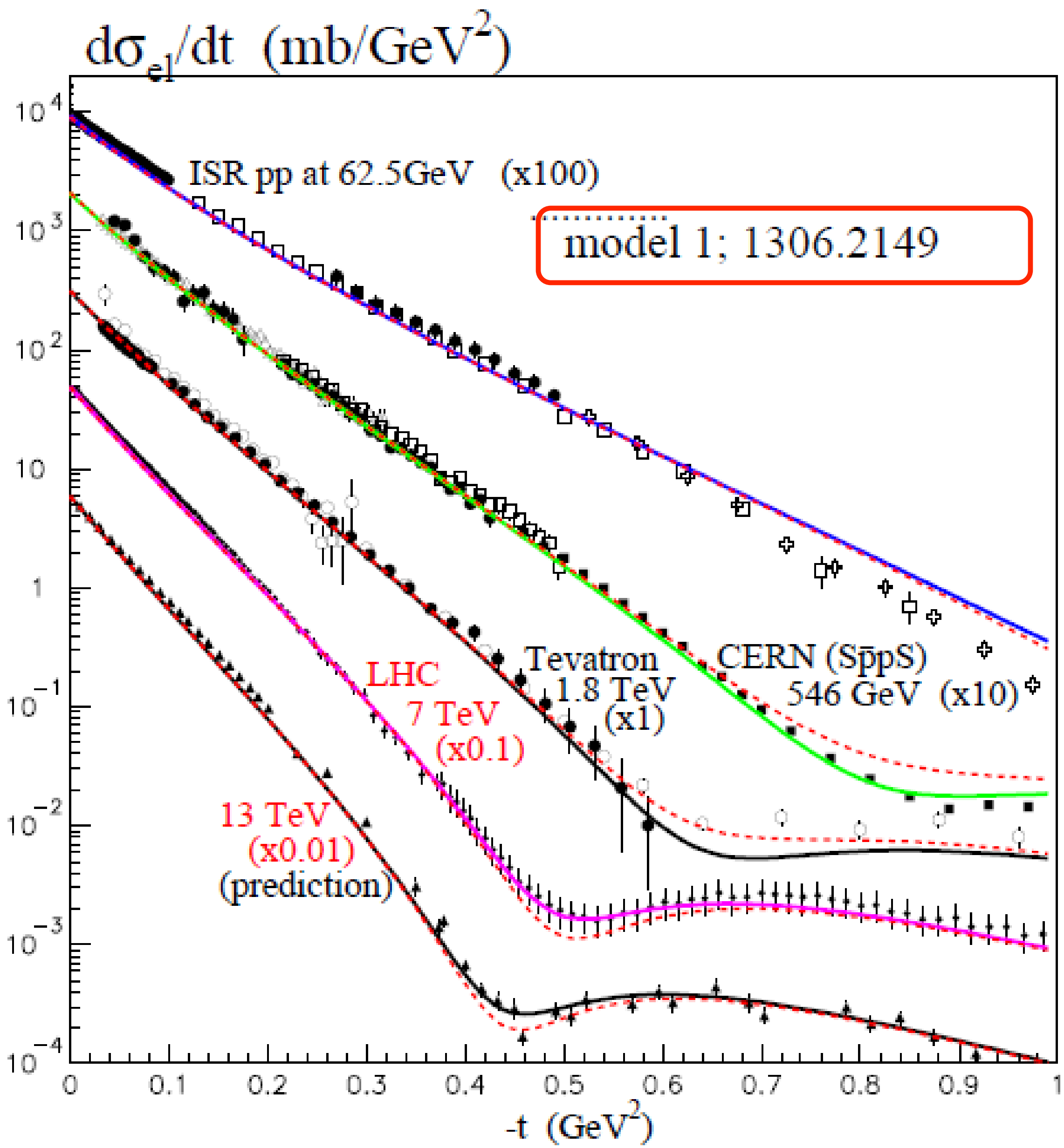
❑ the only way to describe the hadron interaction in the Froissart regime ($\sigma_t \backsim \ln^2 s$) is the full screening of any process that differs from froissarton exchange inside the disc. As an example, the sum of the diagrams in figs. 7.3b and c can be written in the form

$$M = M_a + M_b = M(b_t, s)[1 + if(b_t, s)] \to 0 \tag{7.4}$$

at high energy for any $b_t < R(s) = a \ln s$.

under the condition $R_{\text{odd}} = R(s)$. Thus the ratio of the odderon and pomeron contributions should be small at high energy, namely

$$\frac{|M^{\text{odd}}(t=0, s)|}{|M^{\text{froissarton}}(t=0, s)|} \leqslant \frac{\pi}{m_\pi R(s)} \backsim 1/\ln s \to 0\,.$$




KMR-Non-tuned 2013 predictions, model 1

TOTEM-2017 data

| $\sqrt{s}$ (TeV) | $\rho$ | $\sigma_{tot}$ (mb) | $\sigma_{el}$ (mb) | $B_{el}(0)$ ($GeV^{-2}$) | $B_{el}(\|t\| = 0.05 - 0.15 GeV^2)$ ($GeV^{-2}$) |
|---|---|---|---|---|---|
| 0.546 | 0.141 | 63.1 | 12.5 | 15.3 | 15.4 |
| 1.8 | 0.133 | 77.7 | 16.9 | 17.4 | 17.3 |
| 2.76 | 0.131 | 83.4 | 18.8 | 18.3 | 18.1 |
| 7. | 0.125 | 97.3 | 23.2 | 20.3 | 19.9 |
| 8. | 0.124 | 99.1 | 23.9 | 20.6 | 20.2 |
| **13.** | **0.121** | **106.9** | **26.5** | **21.8** | **21.3** |
| 100. | 0.110 | 144.0 | 39.6 | 27.5 | 27.3 |

Table 1: The values of the observables given by the model 1.

KMR, arXiv:1306.2149

TOTEM results

$\sigma_{tot} = (110.6 \pm 3.4)$ mb $\qquad \sigma_{el} = (31.0 \pm 1.7)$ mb

$\rho = 0.09 \pm 0.01$ and $\rho = 0.10 \pm 0.01$, depending on different physics assumptions

$\sigma_{SD}^{\mathrm{low}M_X}$ = $2.6 \pm 2.2$ mb at 7 TeV

Model 1- 4.72 mb at 7 TeV

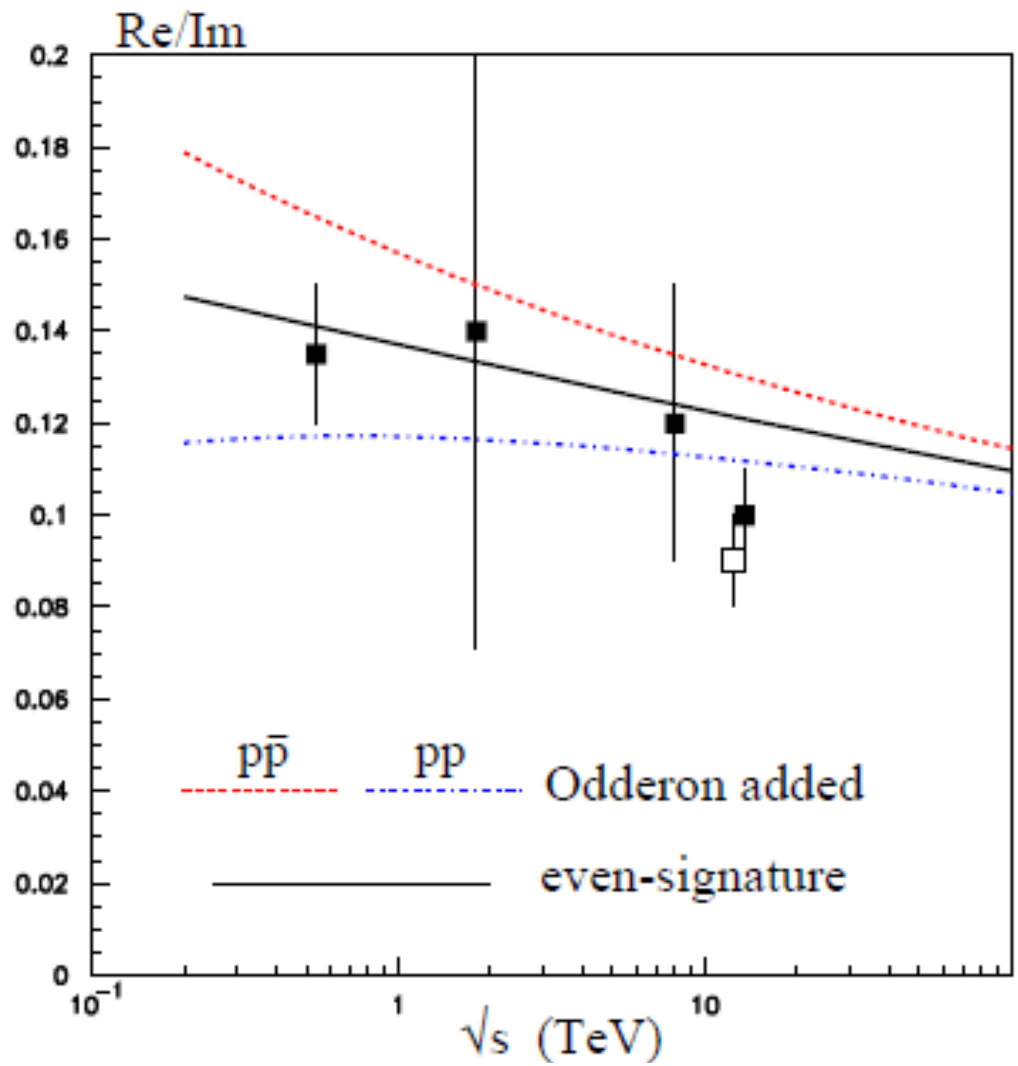



Figure 2: The energy dependence of the $\rho$ =Re$A$/Im$A$ ratio. The data are taken from [2, 18, 19, 1]; the first two data points correspond to $p\bar{p}$ scattering and the last points to $pp$ scattering. At 13 TeV we show also by the open square the value of $\rho$ obtained under the same conditions as that used by UA4/2 group (see footnote 1). The values of $\rho$ given by the model [7] are shown by the solid curve. The dashed curves include a *possible* QCD Odderon contribution calculated as described in the text.

ODDERON-1973 –asymptotic theorems

L. Lukazsuk, B. Nicolescu, Lett. Nuovo Cim. 8 (1973) 405

1975 D. Joynson, E. Leader, B. Nicolescu and C. Lopez, Nuovo Cim. A 30 (1975) 345

**MO**

$$F_{-}^{MO}(z) = (s-2m^2)[O_1 \ln^2(-iz)+O_2 \ln(-iz)+O_3]$$

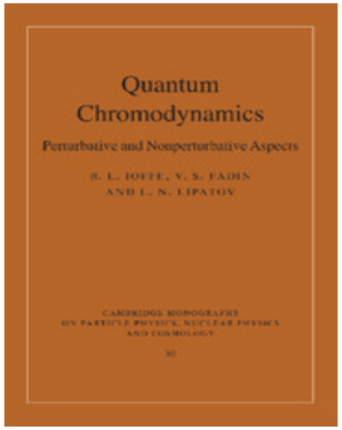
$$z= (s-2m^2)/2m^2.$$

**QCD** J. Bartels, Nucl. Phys. B 175 (1980) 36; J. Kwiecinski and M. Praszalowicz, Phys. Lett. B 94 (1980) 413
J. Bartels, L. N. Lipatov and G. P. Vacca, Phys. Lett. B, 477 (2000) 178

**Intensive theoretical discussions :**

**reviews** M. A. Braun, [hep-ph/9805394].

C. Ewerz, [hep-ph/0306137]; [hep-ph/0511196].



# Some comments on MO

- This procedure evidently preserves the relation between the real and imaginary partys of the amplitude and so does not formally violate the analitycity properties. However it does not look too consistent. It is a well-known fact that any contribution of one particle exchange in the $t$-channel is real and is a polinomial in $s$, so that it does not contain any singularities in $s$. However this does not justify its throwing away. As a rule, it will show up via unitarity in the two-particle exchange contribution in the form of a cut with a nonzero imaginary part. There is little doubt that the same will occur with the asymptotic odderon, should its authors consider its multiple appearance through the $s$-channel unitarity.

M. Braun, hep-ph/9805394

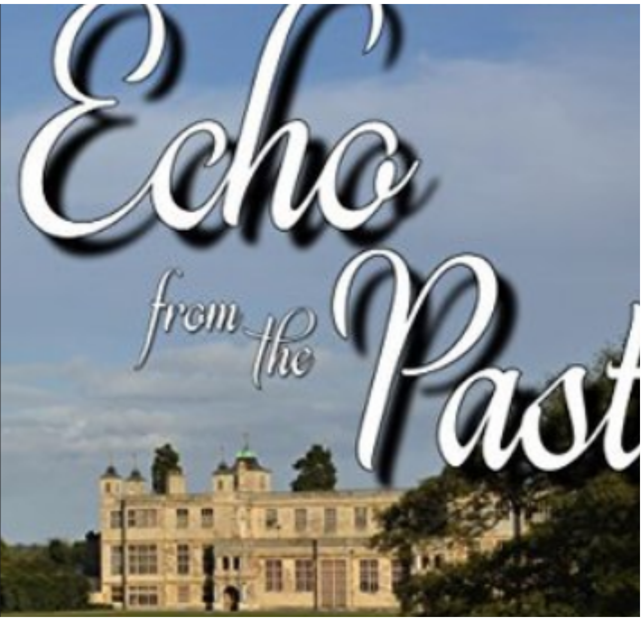
- In CGC models the odderon contribution is decreasing with energy due to saturation effects

  For example ; S. Jeon and R. Venugopalan, Phys. Rev. D 71, 125003 (2005) hep-ph/0503219
  Y. V. Kovchegov, L. Szymanowski, and S. Wallon, Phys. Lett. B 586, 267 (2004) hep-ph/0309281

- Problems with the multi-particle unitarity: KMR-17

## Forward scattering at collider energies and eikonal unitarization of the odderon

J.Finkelstein, H.M.Fried, K.Kang and C.I.Tan Phys.Lett. B232 (1989) 257-262




**Abstract**

The continuing increase of hadron total cross sections up to the highest energies currently available can most naturally be understood through an eikonal mechanism, leading to the saturation of the Froissart bound. This picture can be motivated in a nonperturbative treatment of QCD, e.g., in the large-*N* limit. It is then natural to ask whether this same mechanism would lead to the maximal allowed behavior for the difference of the particle-particle and antiparticle-particle cross section, i.e., the “maximal odderon”. We shall show in this paper that, using eikonals which are dynamically meaningful for high-energy hadron-hadron scattering at collider energies, this behavior is not possible.

KMR arXiv:1801.07065

**Black disk, maximal Odderon and unitarity**

## Abstract

We argue that the so-called maximal Odderon contribution breaks the 'black disk' behaviour of the asymptotic amplitude, since the cross section of the events with Large Rapidity Gaps grows faster than the total cross section. That is the 'maximal Odderon' is not consistent with the unitarity.

multi-Reggeon reactions,

$$pp \to p + X_1 + X_2 + \ldots + X_n + p$$

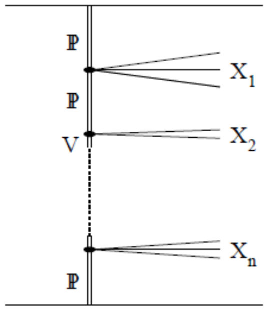



Figure 1: Multi-Reggeon production

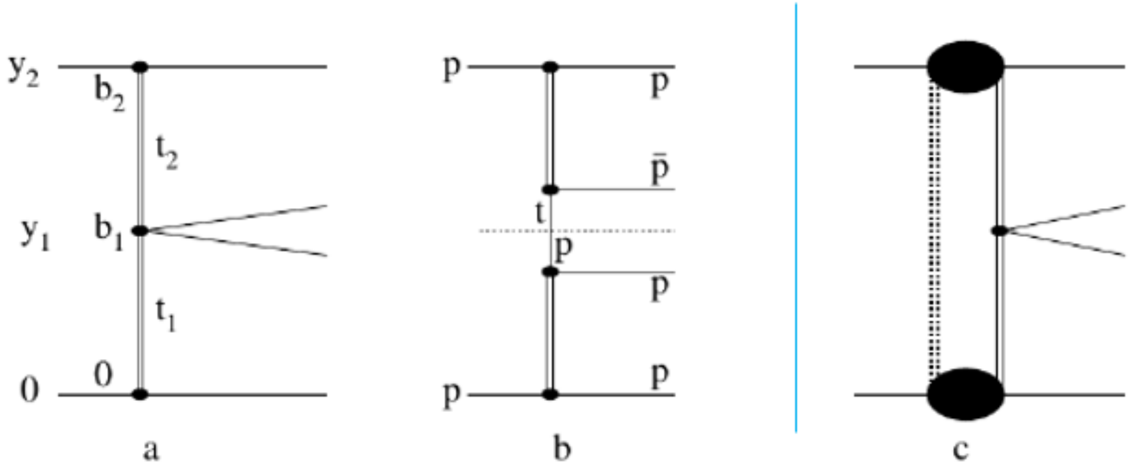
- cross section of such quasi-diffractive production increases faster than a power of $s$.

**Finkilstein-Kajantie disease**

] I.A. Verdiev, O.V. Kancheli, S.G. Matinyan, A.M. Popova and K.A. Ter-Martirosyan, Sov. Phys. JETP **19**, 1148 (1964).

] J. Finkelstein, K. Kajantie, Phys.Lett. **26B** (1968) 305-307.

# CEP




Central Exclusive Production.

$$A^{\rm CEP}(y_1,y_2,t_1,t_2) \;=\; A(y_1,t_1)\cdot V\cdot A(y_2-y_1,t_2)$$

$$\sigma^{\rm CEP} \;=\; N\int_0^Y dy_1 \int dt_1 dt_2 |A(y_1,t_1)\cdot V\cdot A(Y-y_1,t_2)|^2 \;,$$

$B\propto R^2$,, Froissart condition $R\le {\rm const}\cdot Y$

$$I=\int dt|A(Y,t)|^2\sim Y^2$$

leading to

$$\sigma^{\rm CEP} \;=\; N\int_0^Y dy|I(y)\cdot V^2\cdot I(Y-y)| \;\propto\; Y^5\;.$$

Thus in such a case, the CEP cross section would grow much faster than the total cross section $\sigma_{\rm tot}\sim\ln^2 s \;=\; Y^2$.

The sum of these $\ln s$ factors leads to the power behaviour.

# The solution of the FK problem


the absorptive correction to the original CEP process

$$|A_{\rm full}(b)|^2 \ = \ |A^a(b) - A^c(b)|^2 \ = \ S^2(b) \cdot |A^a(b)|^2$$

The solution of unitarity equation $A(b) = i(1 - e^{-\Omega(b)/2})$

The gap survival factor , $S^2(b) \ = \ 1 - G_{\rm inel}(b) \ = \ e^{-{\rm Re}\Omega(b)}$

In the case of *black disk* asymptotics[2] we get $S^2(b) \ \to \ 0$

$${\rm Re}\Omega(b) \to \infty \ \ \text{and} \ \ A(b) \to i, \ \ \text{for } b \ < \ R.$$

J. L. Cardy, Nucl. Phys. B **75** (1974) 413.
Giuseppe Marchesini, Eliezer Rabinovici. Nucl.Phys. **B120** (1977) 253

For **MO** ${\rm Re}A/{\rm Im}A \ \ \to \ \ \text{constant} \neq 0.$ $\quad S^2 \ = \ |1 + iA|^2 \ \geq \ |{\rm Re}A|^2 \ \neq \ 0$

We are loosing the possibility to compensate the growth of the multi-Pomeron cross sections by the survival factor.

**Lessons**

a) the maximal Odderon violates multiparticle $s$-channel unitarity

b) the Odderon contribution disappears in the black disk limit when ${\rm Re}\Omega \to \infty$.

# Preliminary conclusions

Per-nice pedagogical overview

- Either the total cross section above 13 TeV starts slowing down or there is a sizeable Odderon contribution at 13 TeV .
- The data at 540 GeV strongly restrict the Odderon contribution.


- New precise data on Re/Im at 7-8 TeV and especially at 0.9 TeV would be very useful.
  The possible Odderon contribution at 0.9 TeV could be quite significant.
- High statistics TOTEM data on elastic cross-section in the dip-bump region are very welcome.
- In order to resolve a tension between the Totem and CMS results on low mass SD more experimental studies are needed.
- the maximal Odderon violates multiparticle $s$-channel unitarity
  the Odderon contribution disappears in the black disk limit when $\mathrm{Re}\Omega \to \infty$.


If the bare pomeron lies above the bare odderon, then $\Delta\sigma_T(s)$ must fall like a power of $s$. However, this power could well turn out to be quite small, and so nothing in the argument we have presented prevents there from being important odd-signature effects at collider energies. It in fact does not exclude the possibility that phenomenology based on a maximal odderon could work for a range of energies, even though the maximal odderon would not be expected to survive asymptotically. However, a large part of the appeal of the maximal odderon hypothesis is that one could do phenomenology with an asymptotically-correct amplitude.

J.Finkelstein, H.M.Fried, K.Kang and C.I.Tan **Phys.Lett. B232 (1989) 257-262**


**But a dynamical model needed**


THANK
YOU