The Present Situation of the Odderon Intercept - Experiment, Theory and Phenomenology

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I will not make make an historical review.
I already presented such reviews in the past:
EDS 1991, Vancouver 1998, EDS 1999

Just a reference:

Basarab Nicolescu, « The Odderon - past, Present and Future », *Nucl. Phys.* (Proc. Suppl.) **25B** (1992) 142

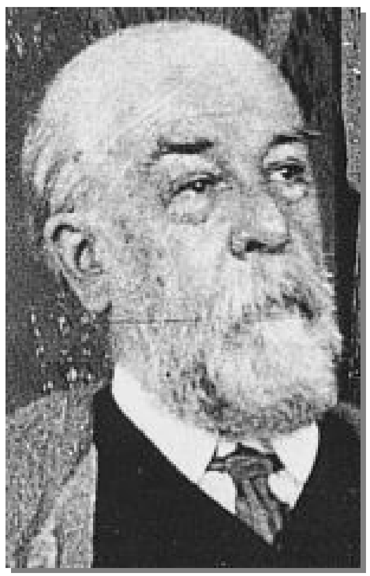
« Future » for me, in 1992, was RHIC and LHC.

RHIC is now « the present », while LHC is still « the future ».

Here : a review on the odderon intercept, a crucially important information for RHIC experiments.

In fact, the situation of the Odderon was already nicely summarized in 1881 by Odilon Redon (Kazunori Itakura, private communication, 2005)

My own contribution: « Odderon » is just an anagram of « Od. Redon ».



(1840 - 1916)

General definition of the Odderon: a J-plane singularity **near** J=1 in the odd-under-crossing amplitude $F_-(s,t)$, i.e. $\alpha_{\mathrm{Odd}}(0) \approx 1$, or more precisely, $\alpha_{\mathrm{Odd}}(0) \leq 1$ (1 is the unitarity limit)

Question: how many analytic forms of the Odderon are allowed by the general principles - analyticity, unitarity and positivity ?

Answer: an infinite number, but in a restricted class of functions

The most pedagogical way of visualising the restrictions introduced by general principles is, I think, to consider the following toy model for the even-under-crossing amplitude $F_+(s,t)$ and for the odd-under-crossing amplitude $F_-(s,t)$, valid at t = 0 and high s:

$$(1/s)F_+(s) \to iC_+\left[\ln\left(se^{-i\pi/2}\right)\right]^{\beta_+}$$

and

$$(1/s)F_-(s) \to -C_-\left[\ln\left(se^{-i\pi/2}\right)\right]^{\beta_-}$$

(an overall scale factor is, of course, assumed)

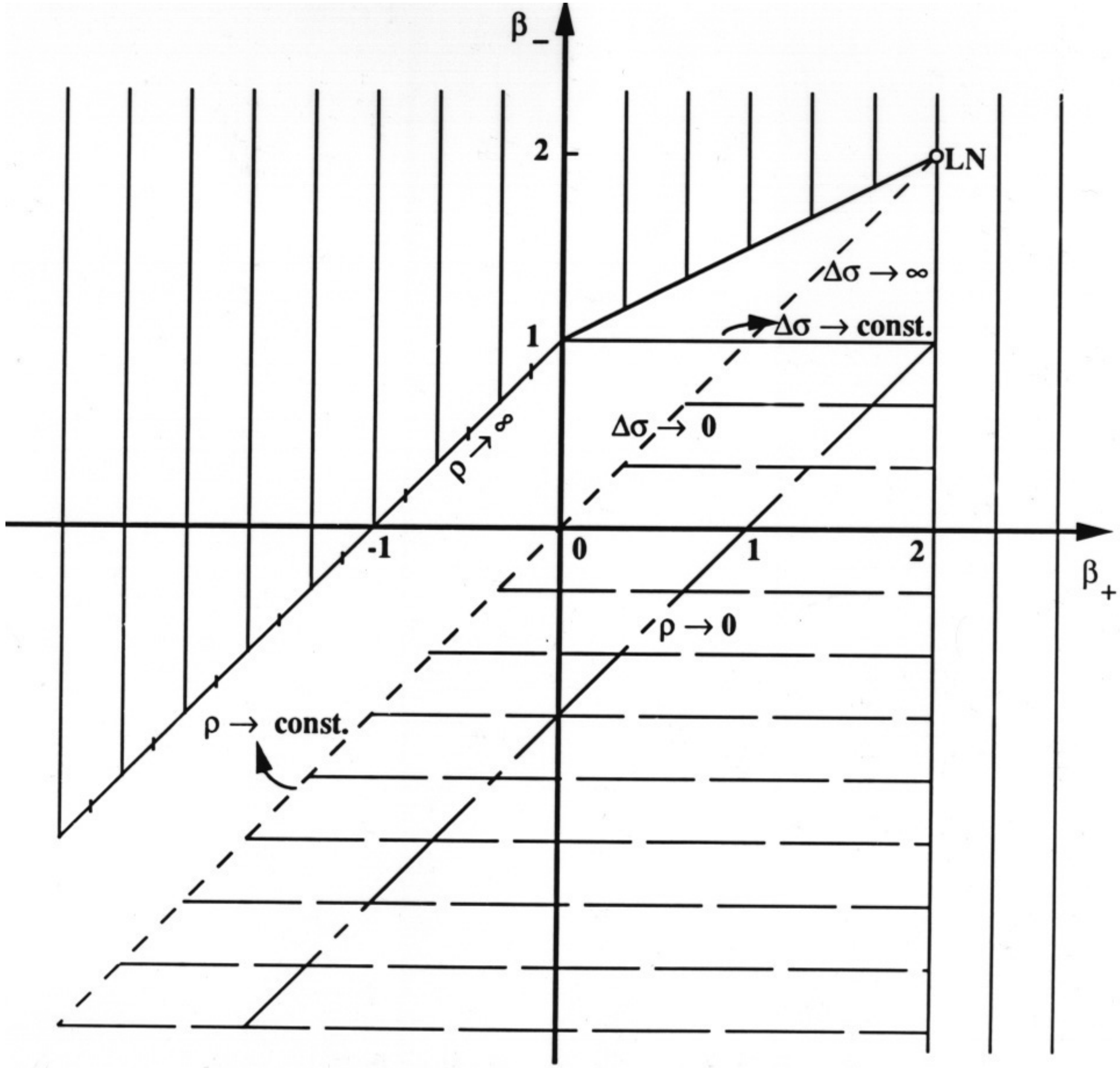
Cornille showed in 1973 that analyticity, unitarity and positivity of the total cross-sections imply

$$\beta_+ \leq 2$$

$$\beta_- \leq \frac{1}{2}\beta_+ + 1$$

$$\beta_- \leq \beta_+ + 1$$

The restrictions induced by the general principles are visualized in the Cornille plot (β_+, β_-)


β_
2
1
LN
Δσ → ∞
Δσ → const.
Δσ → 0
ρ → ∞
-1
0
1
2
β+
ρ → 0
ρ → const.

Interesting particular cases:

1. Odderon as simple Regge pole

$$\beta_+ = 0,\ \beta_- = 0$$
$$\mathrm{Re}\, F_- \propto s$$
$$(\text{and}\ \mathrm{Im}\, F_+ \propto s)$$

2. The minimal Odderon

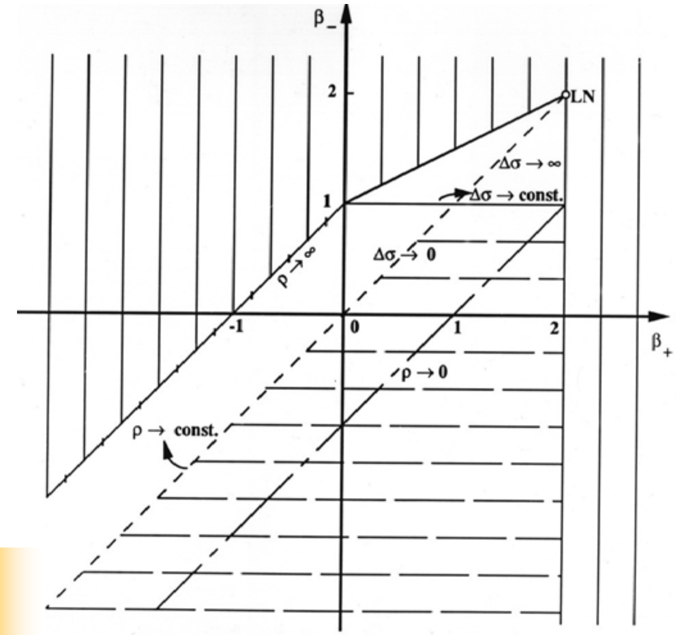
$$\beta_+ = 0,\ \beta_- = 1$$
$$\mathrm{Re}\, F_- \propto s \ln s$$
$$(\text{and}\ \mathrm{Im}\, F_+ \propto s)$$

3. The maximal Odderon

$$\beta_+ = 2,\ \beta_- = 2$$

IT IS NOT a simple Regge pole but a dipole at J=1

$$\mathrm{Re}\, F_- \propto s \ln^2 s$$
$$(\text{and}\ \mathrm{Im}\, F_+ \propto s \ln^2 s)$$



N.B.

1. β_+=2 is the « Heisenberg line » $\rightarrow \sigma_T \propto \ln^2 s$ (1951)
2. The line —+—+—+— is excluded as involving the violation of the generalized Pomeranchuk theorem

$$(\sigma_T)_{\bar{H}H} / (\sigma_T)_{HH} \rightarrow 1 \text{ at } s \rightarrow \infty$$

I love, of course, the LN point ($b_+ = 2$, $b_- = 2$) and I hope that Leszek, Elliot and maybe Lev also love this point in the graph.

My preference is, first of all, based on esthetics:

1. The maximal Odderon embodies the old maximality principle of strong interactions:

   strong interactions are as strong as possible

2. The maximal Odderon corresponds to a nice symmetry of the analytic behaviour of F_+ and F_-

$$\mathrm{Re}\,F_+ \sim \mathrm{Im}\,F_-, \;\; \mathrm{Im}\,F_+ \sim \mathrm{Re}\,F_-$$

3. The maximal Odderon is in agreement with a nice philosophical theorem of Leibniz (Hans Guenter Dosch, private communication, 2003)

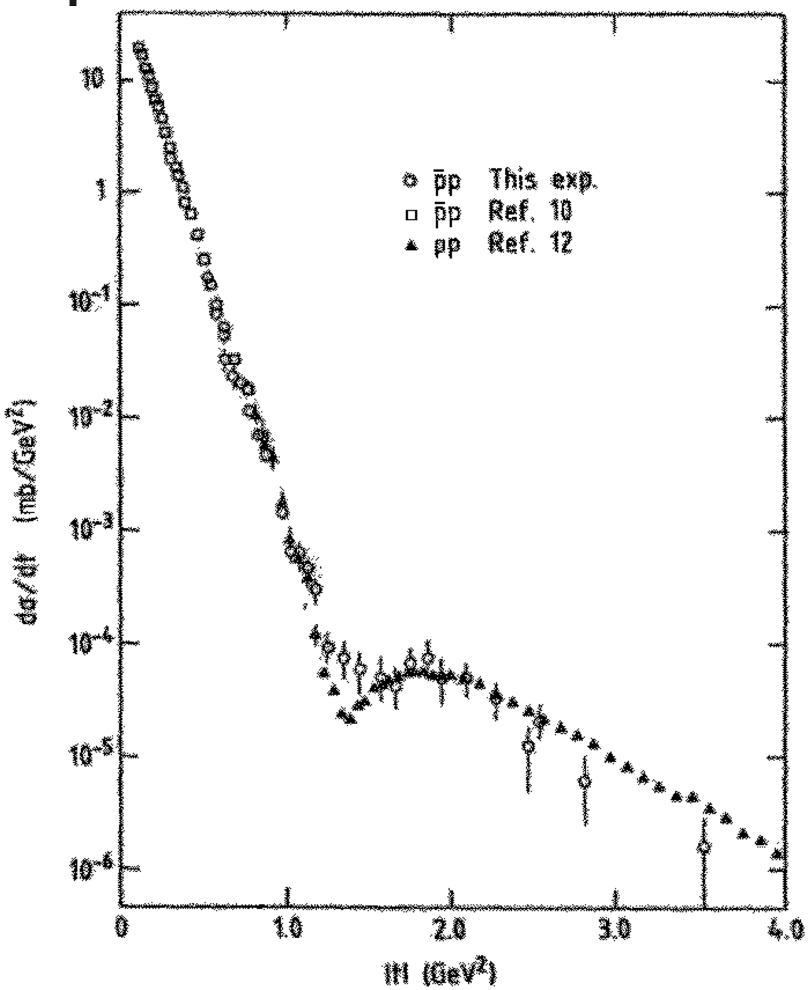
« I have reasons to believe that any arbitrary event will not be embodied in the great Universe… But I am convinced that any event, compatible with the perfect harmony of the Universe, will be embodied. »

Leibniz, New Essays 3, IV,12

So, I keep being convinced, from 32 years now, that experimentalists will find the maximal Odderon. But I will be not totally unhappy if they will find another type of Odderon.

EXPERIMENTAL EVIDENCE FOR THE ODDERON

a. Strong evidence for the non-perturbative Odderon



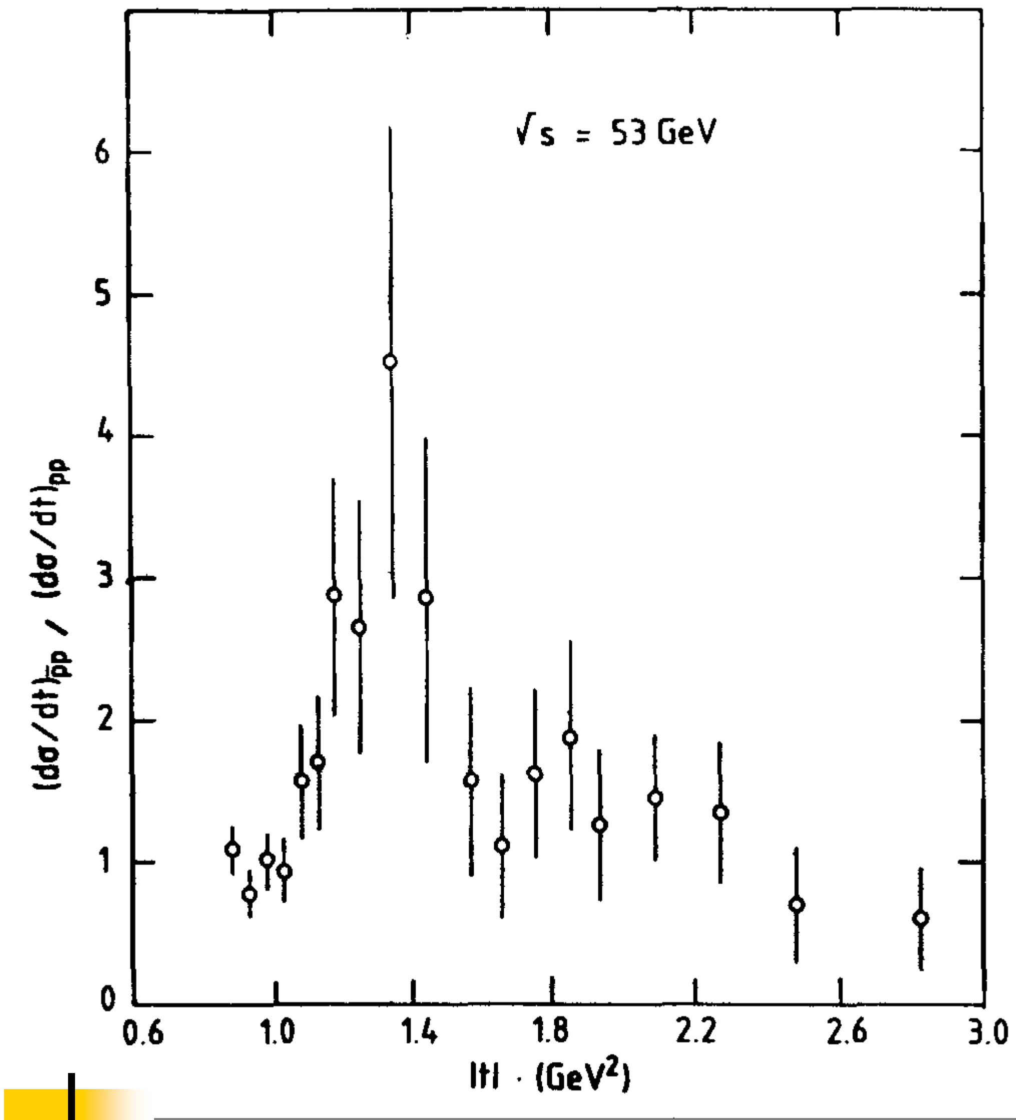
1985: Experimental discovery at ISR of a difference between

$$\left(\frac{d\sigma}{dt}\right)^{\bar{p}p} \text{ and } \left(\frac{d\sigma}{dt}\right)^{pp}$$

in the dip-shoulder region

$$|t| = 1.3 \text{ GeV}^2, \ \sqrt{s} = 52.8 \text{ GeV}$$

A. Breakstone et al., *Phys. Rev. Lett.* **54** (1985) 2180.
S. Erhan et al., *Phys. Lett.* **B152** (1985) 131.
Data obtained in one week, just before ISR was closed.



$$R = \frac{(d\sigma / dt)_{\bar{p}p}}{(d\sigma / dt)_{pp}}$$

in the region

1.1 < | t | < 1.5 GeV^2

If $R = 1 \;\Rightarrow \chi^2 / dof = 4.2$

99.9 % confidence level

for this Odderon effect

Phenomenology:

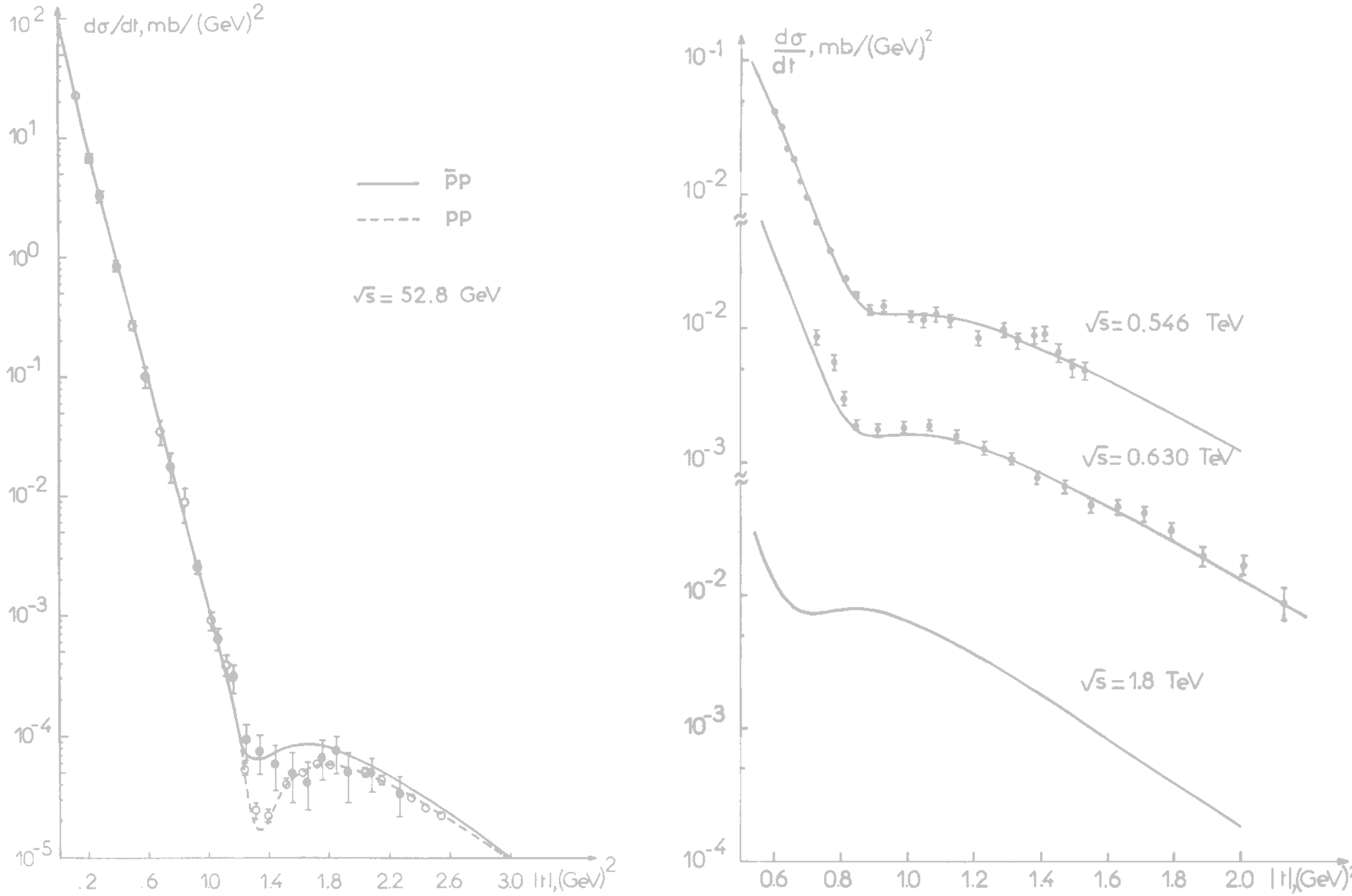
1. P. Gauron, E. Leader and B. Nicolescu, *Phys. Lett.* **B238** (1990) 406 ; *Nucl. Phys.* **B299** (1988) 640

GLN model:

$$\begin{cases} F_+ = \text{Froissaron } \left(\operatorname{Im} F_+ \propto \ln^2 s\right) + \text{ Pomeron pole + secondary Regge poles + cuts} \\ F_- = \text{Maximal Odderon } \left(\operatorname{Im} F_- \propto \ln s\right) + \text{ Odderon pole + secondary Regge poles + cuts} \end{cases}$$

Result: very good fit of all existing $\bar{p}p$ and pp data $\left(\sigma_T, \rho, \text{ b}, d\sigma/dt\right)$ for $4 \leq \sqrt{s} \leq 630$ GeV gives

$$\beta_+ = 2 \pm 0.005, \ \beta_- = 2 \pm 0.05$$



N.B.: The region in t where the Odderon effect appears → t quite small → Regge approach is valid

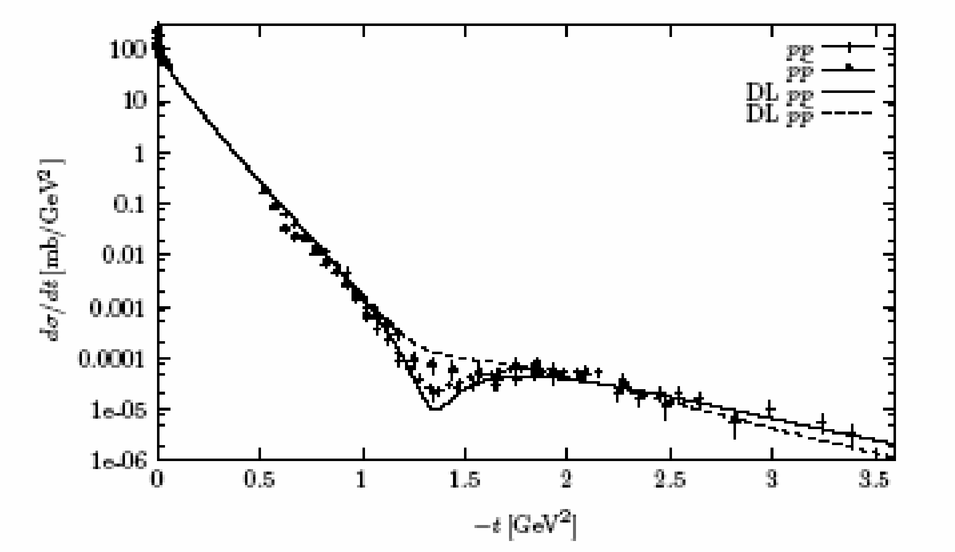
This is evidence for the non-perturbative Odderon

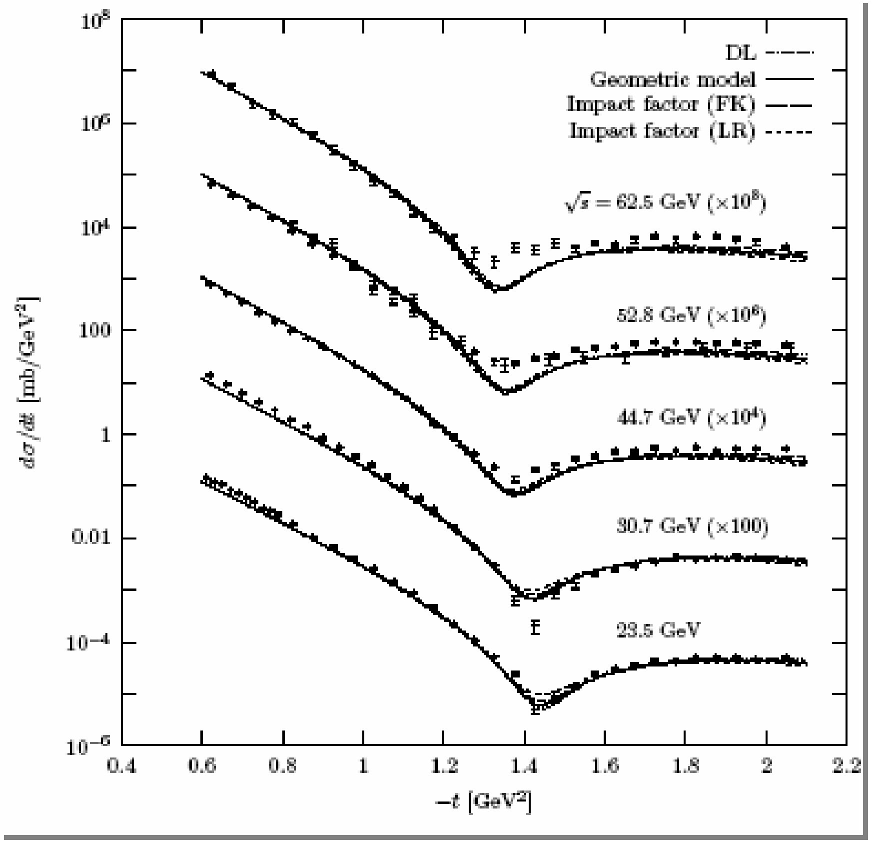
2. A. Donnachie and P.V. Landshoff, *Nucl. Phys.* **B244** (1984) 322

→prediction based upon a perturbative 3-gluon Odderon (non-reggeized gluons) → however not a very good description of the data (the dip in *pp* is too deep and $(d\sigma/dt)_{\bar{p}p}$ is higher than the data - see Carlo Ewerz, hep-ph/0306137.

N.B. : The slope of the Odderon trajectory is very small : near 0 !

The evolution of *(dσ/dt)* with *s* favours the maximal Odderon.





b. Moderate evidence for the non-perturbative Odderon

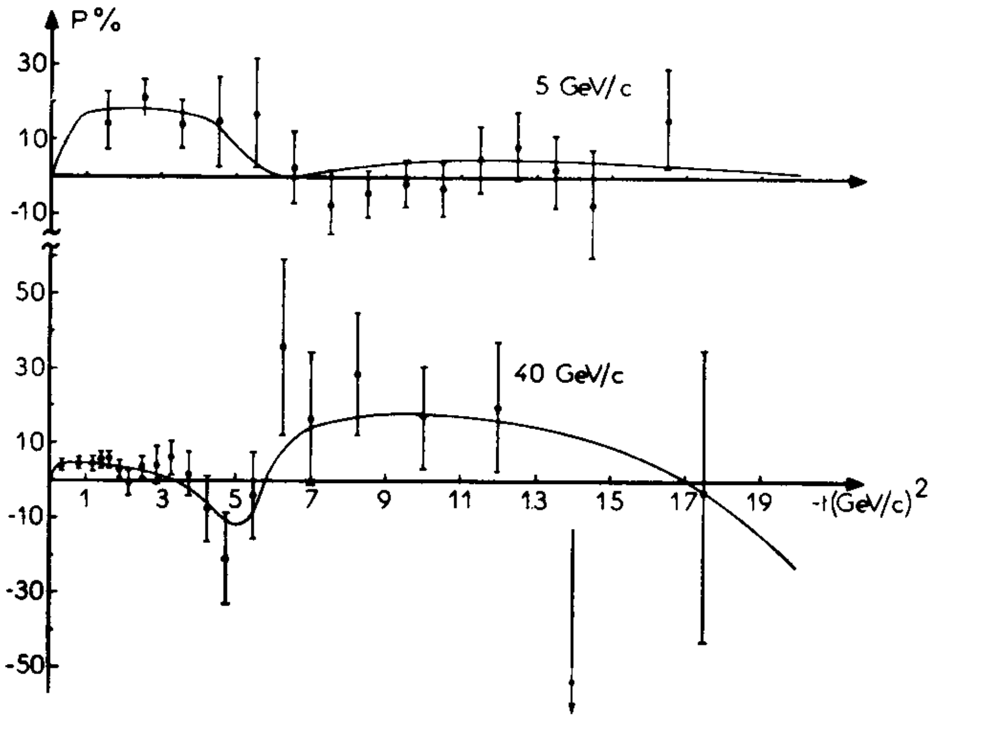
Experimentally, one sees a dramatic change of shape in the polarization in $\pi^- p \to \pi^0 n$, in going from p_L = 5 GeV/c

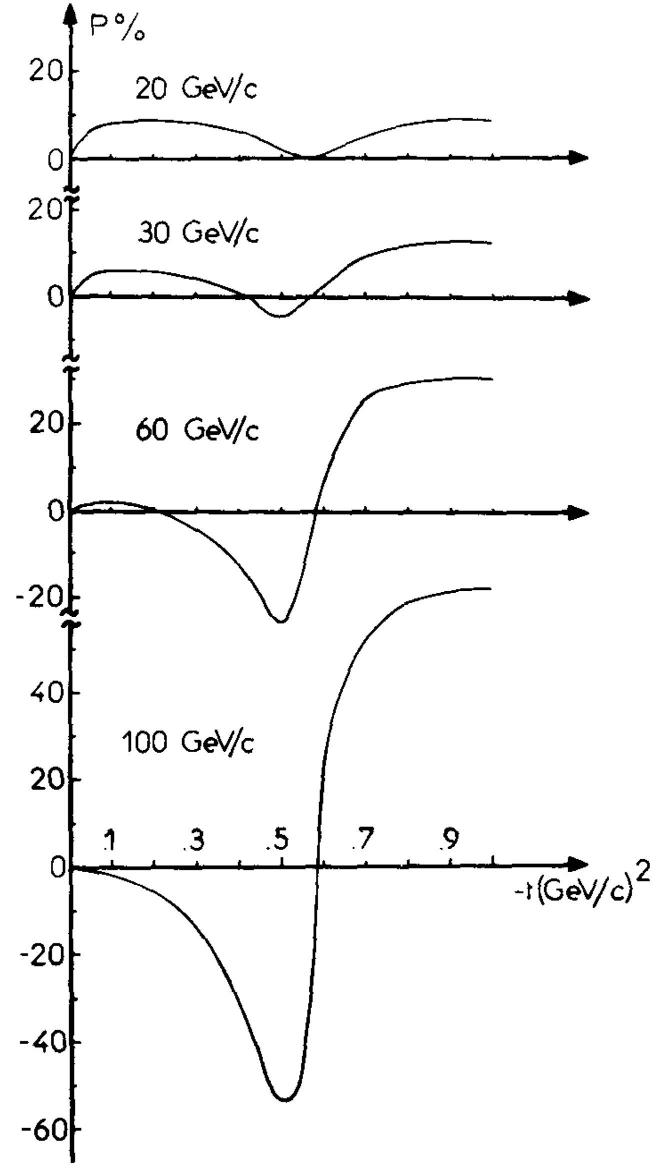
D. Hill et al., Phys. *Rev. Lett.* **30** (1973) 239
P. Bonamy et al., *Nucl. Phys.* **52B** (1973) 392

to p_L = 40 GeV/c

D. Apokin et al., *Z. Phys.* **C15** (1982) 293

Namely, the polarization goes from positive values at small t ($0 < |t| < 0.5$ GeV^2) at $p_L = 5$ GeV/c to negative values at $p_L = 40$ GeV/c (a **new zero** appears in the polarization. This is compatible with the maximal Odderon.





D. Joynson, E. Leader, C. Lopez and B. Nicolescu, *Nuovo Cimento Lett.* **15** (1976) 397
P. Gauron, E. Leader and B. Nicolescu, *Phys. Rev. Lett.* **52** (1984) 1952

Remarks:

- the phase of the maximal Odderon is radically different from those of Regge poles $\rightarrow$ strong interference effects
- $\rho + \rho'$ can not explain the change in shape of the polarization
- new dynamical zero: cancellation between $\rho \otimes \rho'$ and $\rho \otimes$ Odderon terms
- the position of this zero moves towards $t = 0$ when energy increases and the polarization becomes more and more negative (dominance of $\rho \otimes$ Odderon term).
- This Odderon **is not** the perturbative QCD Odderon, whose quantum numbers are those of the vacuum (except C)

This Odderon has the ρ quantum numbers $I^G(J^{PC})=1^+(1^{--})$

c. Weak evidence for the non-perturbative Odderon

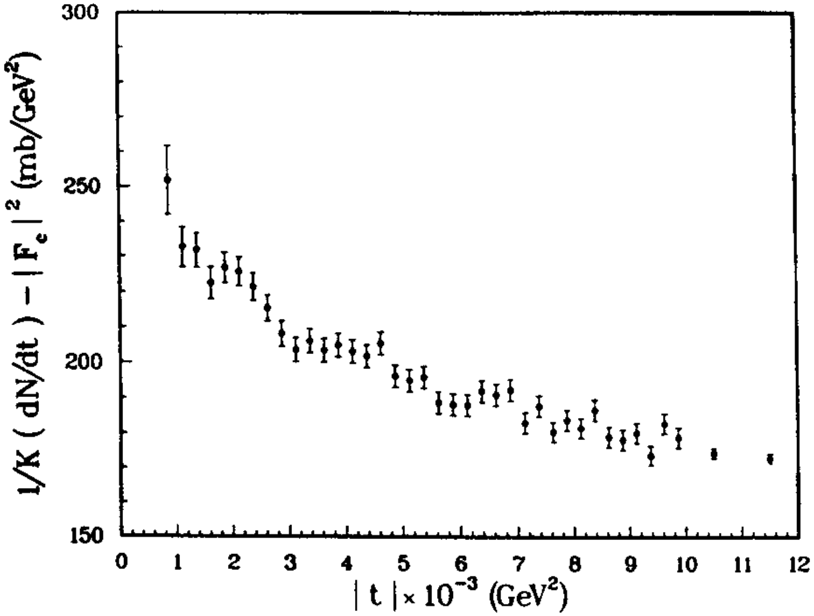
A strange effect is seen in the UA4/2 *dN/dt* data at $\sqrt{s}$ = 541 GeV, namely **bump** at $|t| = 2 \cdot 10^{-3}$ GeV^2.

UA4/2 Coll. C. Augier et al., *Phys. Lett.* **B316** (1993) 448

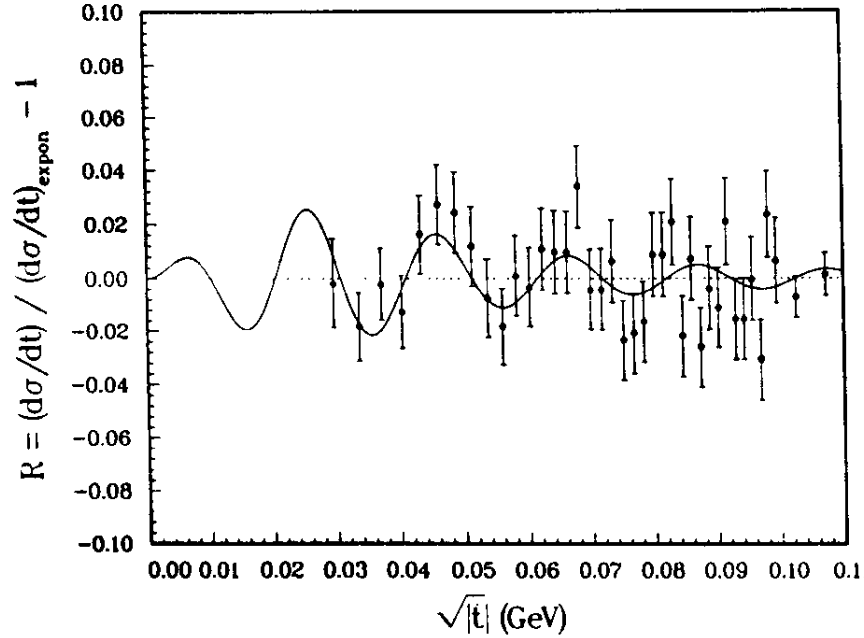
Maurice Haguenauer agrees that this bump is significantly present in the data (private communication, 1997).

Strangely enough, nobody remarked this strange effect, except us (P. Gauron, B. Nicolescu and O. Selyugin).

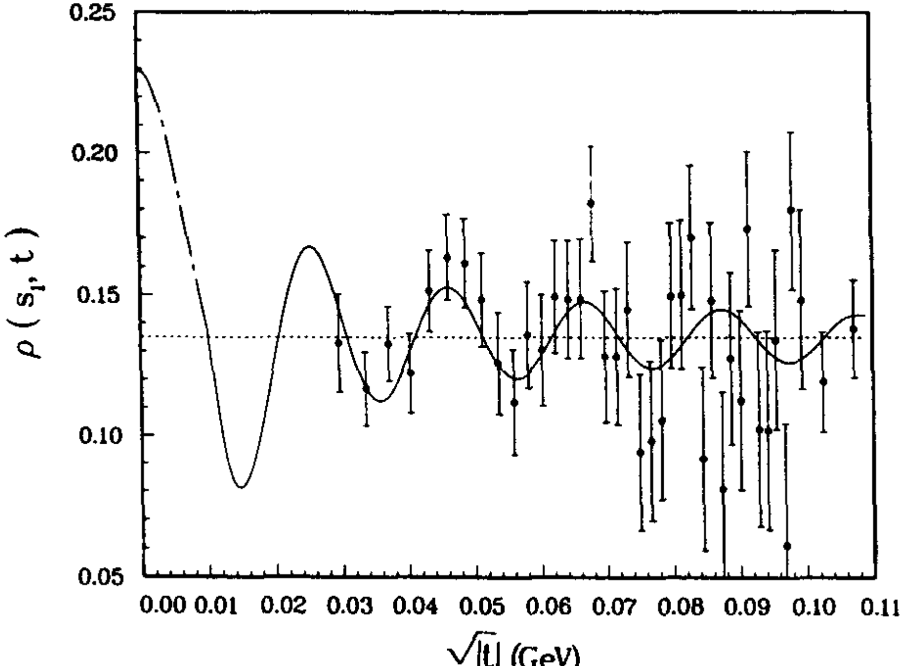
The bump at $|t| = 2 \cdot 10^{-3}$ GeV^2



Zoom in the small-t region of the UA4/2 dN/dt data.



The ratio R vs. $\sqrt{|t|}$.



The function $\rho(s_1, t)$ vs. $\sqrt{|t|}$ at $\sqrt{s_1}$ = 541 GeV. The dashed line corresponds to $\rho(s_1, t)$ = const. = 0.135.

Theoretical interpretation of the « bump »:

P. Gauron, B. Nicolescu and O. Selyugin, Phys. Lett. **B397** (1997) 305

Oscillations of a very small period due to the Auberson-Kinoshita-Martin (AKM) theorem (for the F_+ amplitude) :

G. Auberson, T. Kinoshita and A. Martin, *Phys*. *Rev*. **D3** (1971) 3185

Generalization for the F_- amplitude:

P. Gauron, E. Leader and B. Nicolescu, *Nucl*. *Phys*. **B299** (1988) 640

$$\frac{1}{s} F_-(s,t) \;\propto\; \ln^2 \tilde{s}\; \frac{\sin(R_-\tilde{\tau})}{R_-\tilde{\tau}}$$

$$\tilde{s} = (s/s_0) e^{-i\pi/2} \;,\; s_0 = 1 \text{ GeV}^2$$

$$\tilde{\tau} = (-t/t_0)^{1/2} \ln \tilde{s} \;,\; \mathrm{t}_0 = 1 \text{ GeV}^2$$

d. Negative evidence for the Heidelberg Odderon

Heidelberg BDBN Odderon:

E. R. Berger, A. Donnachie, H. G. Dosch and O. Nachtmann, *Eur. Phys. J.* **C14** (2000) 673
A. Donnachie, H. G. Dosch and O. Nachtmann, hep-ph/0508196

in the Stochastic Vacuum Model (SVM) of Dosch and Simonov.
Search for photoproduction of C = + mesons (π^0, f_2, a_2)

Reaction	Prediction (nb)	Experiment (H1 data HERA), in nb
$\gamma p \to \pi^0 N^*$	294 ± 150	< 49
$\gamma p \to f_2 N^*$	21 ± 10	< 16
$\gamma p \to a_2 N^*$	190 ± 10	< 96

Data : H1 Coll., C. Adloff et al., Phys. Lett. **B544** (2002) 35

N.B. : The Heidelberg Odderon is a simple Regge pole

From a very detailed analysis of all pp and $\bar{p}p$ data in a huge range of energies, we concluded, longtime ago, that the **Odderon pole is highly suppressed**:

GLN, *Phys. Lett.* **B238** (1990) 406

The reason of this suppression is trivial: ρ - data for $4 < \sqrt{s} < 1.8$ TeV can be perfectly described by Froissaron + Pomeron pole + Maximal Odderon + secondary Reggeons

$\rightarrow$ The coupling of the Odderon pole is compatible with 0. Why ? Contribution only to Re F $\rightarrow$ shifts ρ - values by a constant amount from the best fit.

Conclusion of this section on **experiment vs. phenomenology**

- only few experimental evidences for the non-perturbative Odderon: this is not a paradox, because experimentalists looked till now only in channels where the Odderon is hidden by the huge Pomeron contribution
- no (yet) experimental evidence for the perturbative Odderon, which nevertheless has a much firmer - perturba-tive QCD - status ! This situation is quite paradoxical, but it will certainly change in the future
- many proposals already made for looking for both non-perturbative and perturbative Odderon in the appropriate channels. In this context, the RHIC polarization will certainly bring major (good) surprises.

THEORY

Odderon - major object of QCD.

It was (theoretically) rediscovered both in QCD and in CGC (Color Glass Condensate).

So, it has to be found.

If not, QCD might be wrong:

Odderon is a crucial test of QCD.

There are two Odderon solutions found in QCD (two different classes of functions):

1. R. A. Janik and J. Wosiek, *Phys. Rev. Lett.* **82** (1999) 1092

The Odderon intercept is

$$\alpha_{\mathrm{Odd}}(0) = 1 - \left(9\alpha_s / 2\pi\right)\varepsilon$$

where

ε (the Odderon energy) = 0.16478

By taking $\alpha_s = 0.19$ one gets

$$\alpha_{\mathrm{Odd}}(0) = 0.94$$

The same solution found, in a different formalism by

M. A. Braun, P. Gauron and B. Nicolescu, *Nucl. Phys.* **B542** (1999) 329

$\varepsilon = 0.22269 \rightarrow$ $\alpha_{\mathrm{Odd}}(0) = 0.96$

N.B. The Janik-Wosiek solution corresponds to an intercept smaller than 1. But it is very near 1. Therefore, it has important phenomenological consequences:
this intercept is much higger than the intercept of the leading secondary Reggeons with $\alpha_R(0) = 0.5$.

2. J. Bartels, L. N. Lipatov and G. P. Vacca, *Phys. Lett.* **B477** (2000) 178.

Solution corresponding to an intercept exactly equal to 1

$$\alpha_{\mathrm{Odd}}(0) = 1$$

BLV solution is, of course, more spectacular, because it persists at very high energies, while the JW solution vanishes at very high energies.

However, the JW and BLV Odderons are coupled in a different way to external particles - e.g. BLV couples to the impact factor $\gamma^* \to \eta_c$, while JW does not couple.

N.B. Both JW and BLV Odderons ARE NOT simple poles: cuts in the complex angular momentum plane. « Intercept » means here the beginning of the cut.

THE ODDERON INTERCEPT FROM SPECTROSCOPY

There are several calculations, all indicating a **low** intercept.

However, the way in which this intercept is identified in lattice calculations is questionable.

H. B. Meyer and M. J. Teper, *Phys. Lett.* **B605** (2005) 344

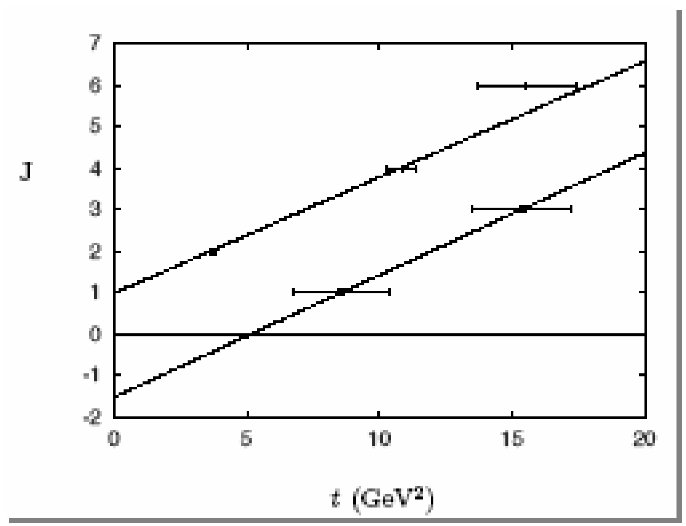
H. B. Meyer, PhD thesis at Oxford, hep-lat/0508002

The authors get a 1^{--} state with mass

$$m_1 = 3.24 \text{ GeV}$$

and a 3^{--} state with mass

$$m_3 = 4.33 \text{ GeV}$$



By drawing a straight line

$$\alpha(t) = \alpha(0) + \alpha' t$$

through these states, they get

$$\alpha_{Odd}(0) = -1.54$$

and

$$\alpha'_{Odd} = 0.24 \text{ (GeV)}^{-2}$$

(near the value of α'_{Pom})

However, the problem is the following: if $\alpha_{\text{Odd}} = 1$, then obviously the state 1^{--} **can not** belong to the leading trajectory - the first state is 3^{--}

In this case

$$\alpha_{\text{Odd}} = 1 \qquad \alpha' = 0.11$$

and therefore, the 1^{--} state belongs to a trajectory with intercept **-0.12** $\rightarrow$ i.e. it is on the first **daughter** trajectory.

Check of all this: calculation of the mass of 5^{--} (not yet done)

$$\alpha_{\text{Odd}} = -1.54, \quad \alpha'_{\text{Odd}} = 0.24 \quad \rightarrow \quad m_5 = 5.22 \text{ GeV}$$

$$\alpha_{\text{Odd}} = 1, \quad \alpha'_{\text{Odd}} = 0.11 \quad \rightarrow \quad m_5 = 6.03 \text{ GeV}$$

TWO REMARKS :

1. I do not see why the slope of the Odderon trajectory has to be the same as the slope of the Pomeron trajectory : **string tension is different**, in principle, in the 2 constituent-gluons case (Pomeron) as compared with the 3 constituent-gluons case (Odderon). The argument of Kaidalov and Simonov (2000) - analogy between diquarks and digluons - does not seem convincing.

2. One intriguing theoretical possibility:

   If the maximal Odderon is the final answer, the problem of high or low intercept of the oddball trajectory is **irrelevant** : the maximal Odderon is anyway dominant at high energies.

THE ODDERON

The Odderon, the Odderon,
one has heard of it.
It likes to be shy,
when one wants to detect it.
Nebulous are all signs,
a kink in σ must suffice.
But that data bend here
Can not convince everybody.
An η, diffractively appearing
would most lovely serve us.
Yet, the search remains very simple,
one simply does not find it.
And even if we hope so much,
in the end as always things are open.

Carlo Ewerz
(translation from the original in German)

CONCLUSION

OMNE POSSIBILE EXISTERE EXIGIT

RHIC is our hope