Regge poles fight back

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II. Historical Interlude

- **In the Sixties** (operating the proton accelerators at Berkeley and CERN at $p_\ell \sim 30$ GeV and Serpukhov at $p_\ell \sim 50$ GeV), a blend of:
- i) Rigorous theorems by Froissart, Martin, Khuri, Bessis, Auberson, Kinoshita, Cornille, Pomeranchuk and Russian school.
- ii) Approximations and empirism

- iii) S-Matrix theory, Dispersion relations (analyticity), crossing and unitarity,
- iv) Complex angular momenta (WSR representation)
- v) Eikonal approximation
- vi) Mandelstam representation
- vii) Veneziano model

Clean and clever mathematics, muddy physics, growing multiplicities and increasing complication of exclusive reactions (3n-4 variables for n-body final states)

- **In the Seventies** (ISR, FNAL, CERN) attention turns to inclusive reactions

$$A + B \rightarrow C + X$$

- where X denotes a bunch of unresolved particles
- (3 variables instead of 3n-4).
- This can be diffractive according to the general prescription that no quantum numbers be exchanged

- i) Mueller generalized optical theorem
- ii) Decline of interest in standard diffractive physics
- iii) Rise of interest in DIS (Bjorken)
- iv) First proposal od QCD

- **In the Eighties** (CERN S$\underline{p}$pS, HERA, Tevatron planned)
- Begins the resurgence of interest in diffractive physics
- Perturbative picture of the Pomeron as made of gluon ladders (Lipatov, Fadin etc.)
- Ingelman & Schlein suggest that seminclusive ep physics (at HERA) is relevant for diffraction

- **In the Nineties** (HERA, Tevatron, LEP, LHC planned)
- Full come back of diffraction through small x physics (rise of $F_2(x, Q^2)$ at low x values)
- Pomeron (BFKL etc. in agreement with the data)
- **Donnachie & Landshoff**

$$\sigma_{tot} \sim A\, s^{\varepsilon+1} + O(s),$$

in principle violates Froissart's theorem not in practice and very economical.

BFKL corrections

- **In the first decade of the third millennium** (RHIC, Tevatron and great expectations waiting for LHC)
- Today's diffractive physics (take a look at the program of the school)

III. Regge poles resurrected

- **1. Diffraction in Deep Inelastic Scattering**

Regge theory has made a full come back. Together with DL somewhat unexpectedly, this comes from a brilliant twist in a topic, DIS (Deep Inelastic Scattering) that had received little attention from the point of view of diffraction since it had been devoted mostly to unravel the structure of the hadrons

- Classical DIS is the inclusive production in lepton proton (see figure …)

(1.1) $\ell(k) + h(p) \rightarrow \ell'(k') + X$

where, as already mentioned, X is a system of particles which are left unresolved ("summed over").

This process was very popular since it provided conclusive evidence that hadrons are made of seemingly pointlike constituents called quarks (or partons) and it became extremely interesting since it provided a direct clue to measuring the so-called *structure functions* of the proton.

- It was, however, observed by Ingelman and Schlein that, if we look at the semi inclusive reaction (see figure …)

(1,2) $\ell(k)+N(p) \rightarrow \ell'(k')+N'(p')+ X(J^{PC}=1^{--})$

- in which the two hadrons in the initial and final state are the same (i.e. have the same quantum numbers), in accord with our general definition of a diffractive process, this is one and Pomeron dominance is therefore expected.

- A somewhat different semi inclusive diffractive reactions could also be chosen like vector production

(1.3) $\ell(k) \; + \; N(p) \; \rightarrow \ell'(k') \; + \; V(1^{--}) \; + X$

- or quasi-elastic

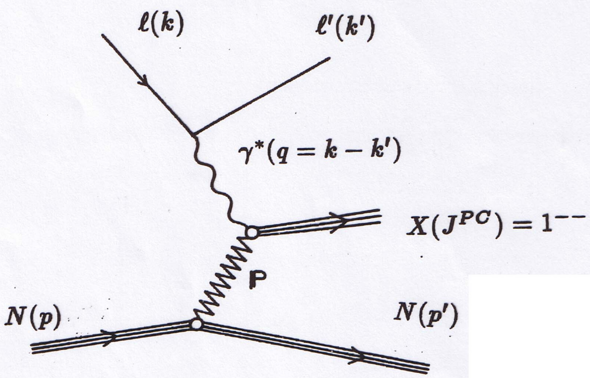
(1.4) $\ell(k) + N(p) \; \rightarrow \ell'(k') + N'(p') + V(1^{--})$

- All these reactions have been studied using a different diffractive signature tool proposed by Bjorken i.e., as we have already commented) *large rapidity gaps.*

$Q^2 = -(k-k')^2 > 0$

$\nu = p \cdot q / M_N$, DIS $\nu \gg |Q| \gg 0$

$x = Q^2 / 2p \cdot q$



$s = (p+k)^2$

$W^2 = (p+q)^2 = M_N^2 + Q^2\left(\frac{1}{x} - 1\right)$

$t = (p-p')^2$

$x = \frac{Q^2}{Q^2 + W^2 - M_N^2} \approx \frac{Q^2}{Q^2 + W^2}$

Fig. 21

$x_{\mathbb{P}} = \frac{q \cdot (p-p')}{q \cdot p} \approx \frac{Q^2 + M_X^2}{Q^2 + W^2}$ [$\Rightarrow$ POMERON MOMENTUM]

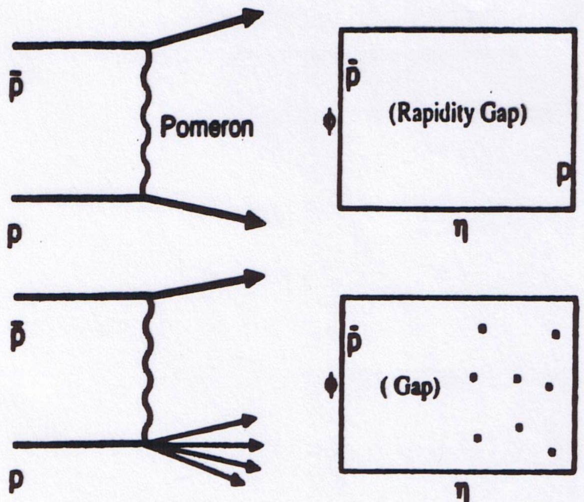
$\beta = \frac{Q^2}{2q \cdot (p-p')} \Rightarrow x = \beta x_{\mathbb{P}}$ [STRUCK QUARK MOMENTUM]

$x_F = 1 - x_{\mathbb{P}}$

$M_X^2 = \frac{1-\beta}{\beta} Q^2$

Rapidity Gaps

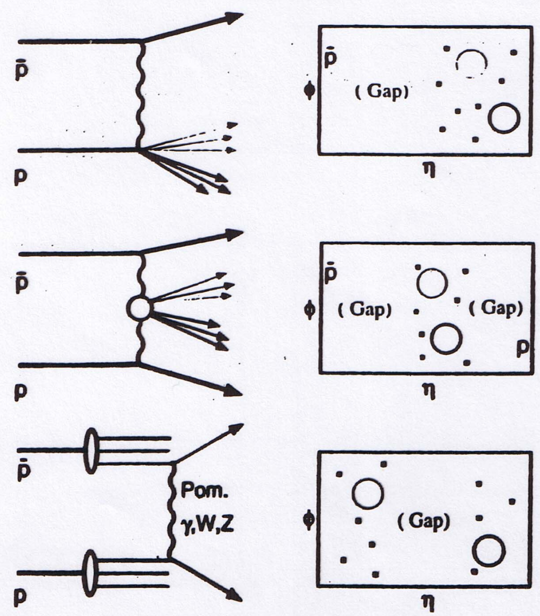
Soft Processes:



Elastic Scattering

Single Diffraction

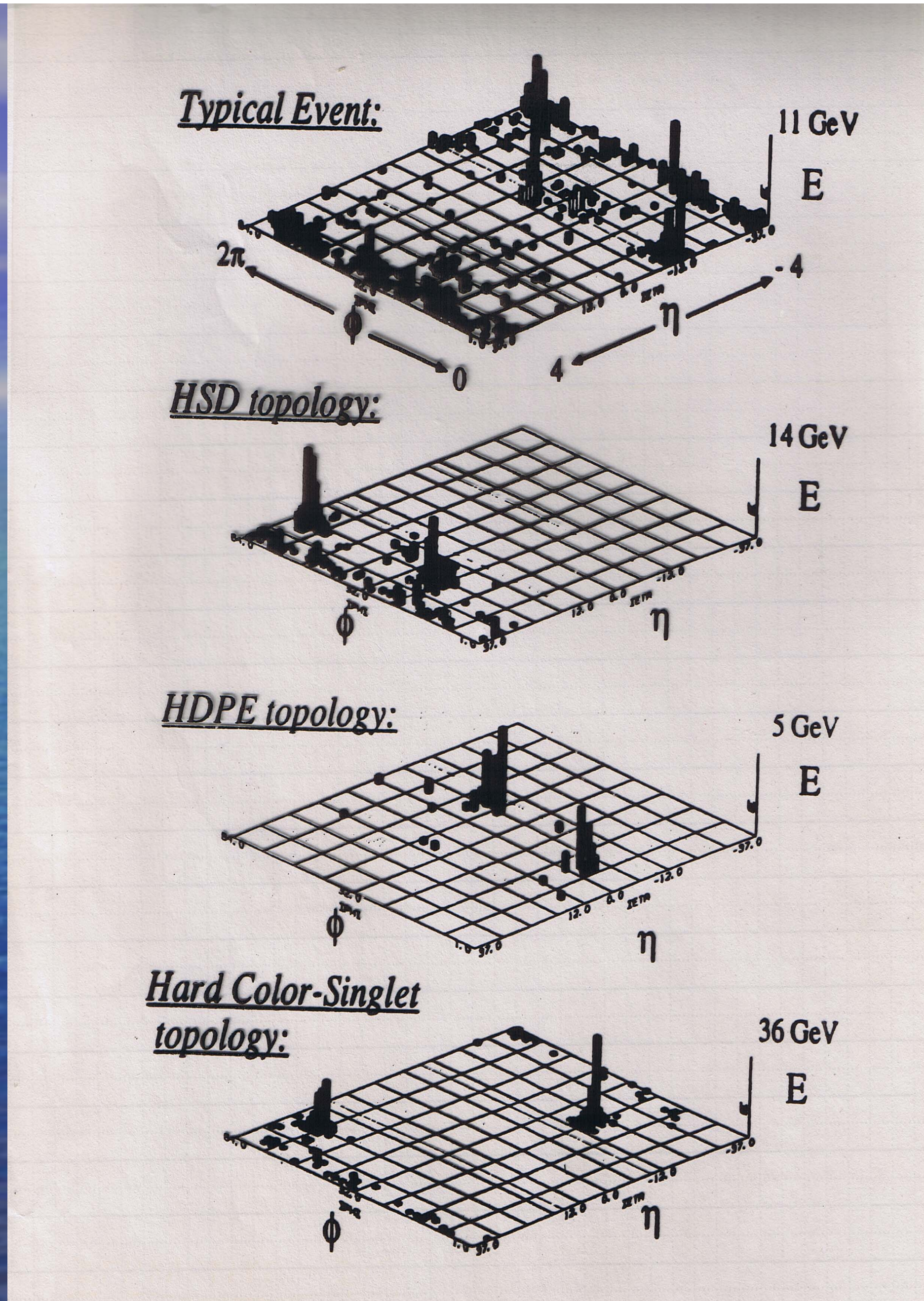
Hard Processes (jet production):



Hard Single Diffraction

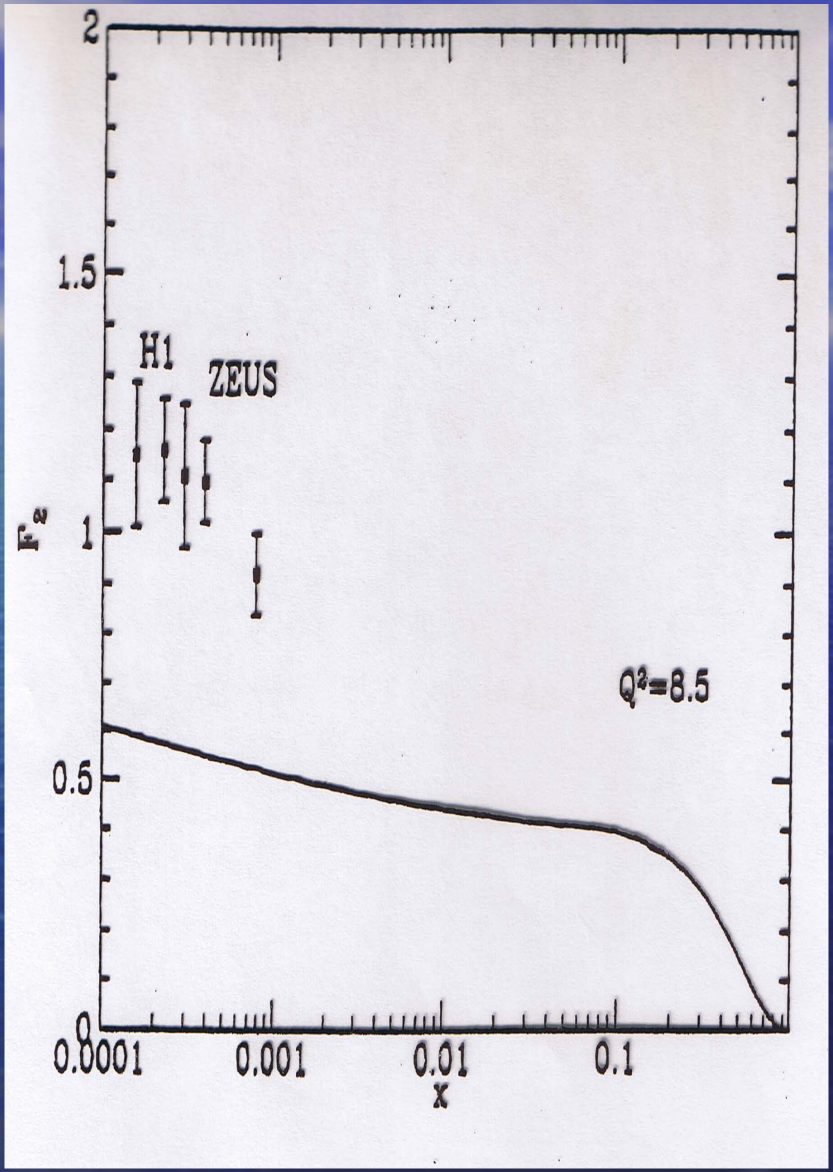
Hard Double Pomeron

Hard Color-Singlet



Typical Event:
11 GeV
E
2π
φ
0
4
η
- 4
HSD topology:
14 GeV
E
φ
η
HDPE topology:
5 GeV
E
φ
η
Hard Color-Singlet
topology:
36 GeV
E
φ
η

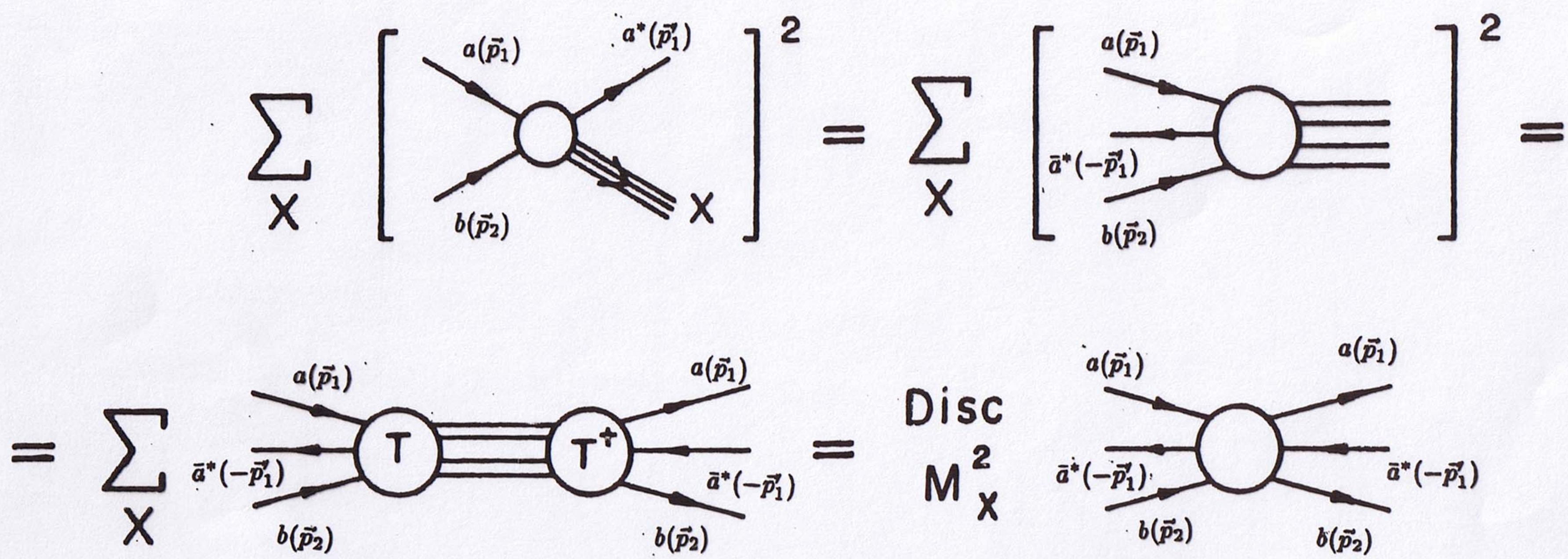
- We will not dig further on this topic which has been widely covered in previous lectures and seminars. Perhaps, it is just worth recalling how one of the shocking "discoveries" of HERA related to this huge chapter, came from the comparison of the "new" low-x data with the then prediction of the models (see figure). Of this shocking discovery (which had been anticipated by some authors) we are still under the spell today, as we have heard.


2
1.5
1
0.5
0
F_2
H1
ZEUS
Q^2=8.5
0.0001
0.001
0.01
0.1
x

4. Hard diffraction (just few words)

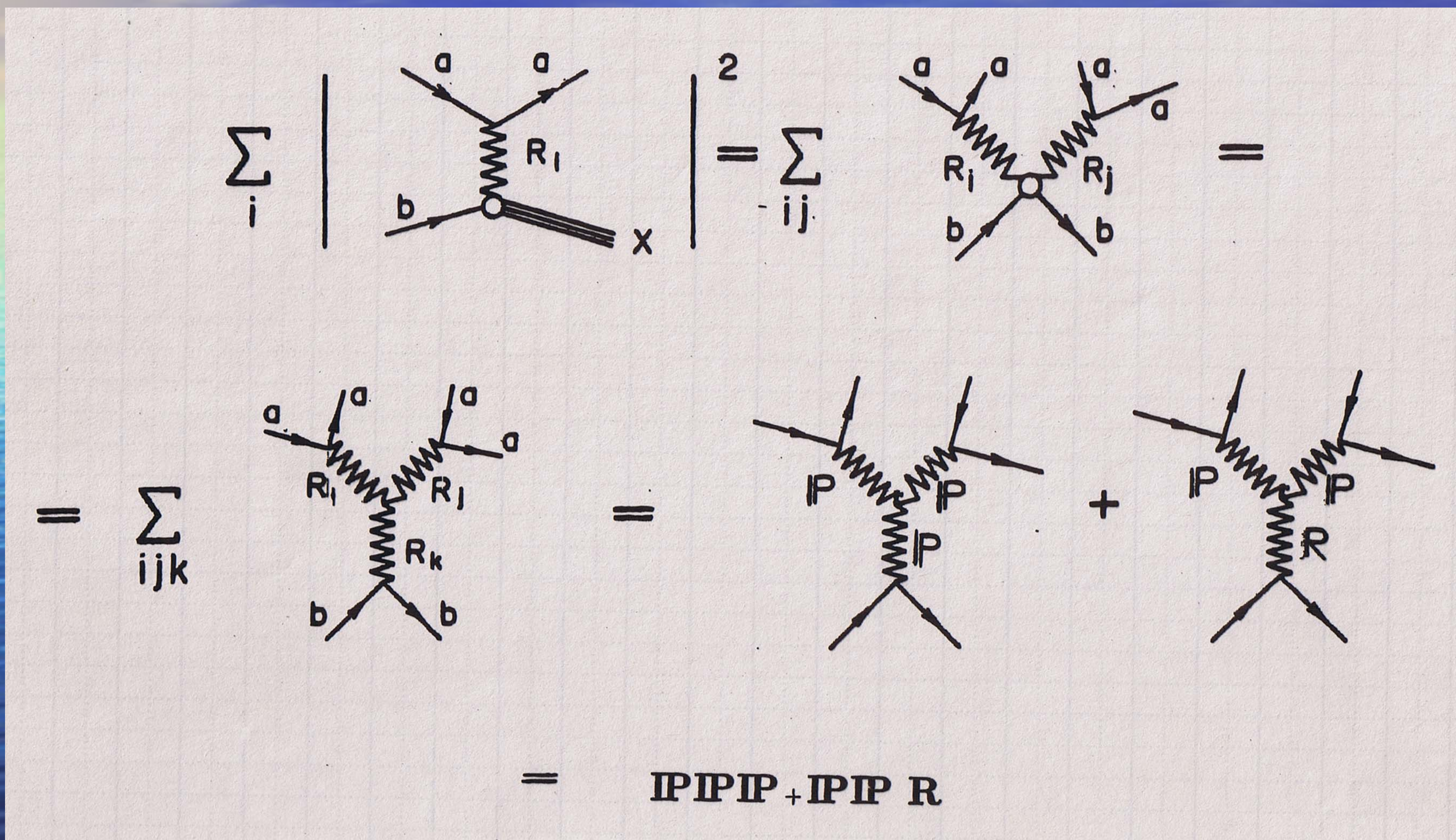
- Hard diffraction has been the queen of the school so that it would be senseless for me to spend more than few worlds on it. Let me just remind a key ingredient which has received little asttention (probably for its being too well known to everybody). This is Mueller generalized optical theorem which, graphically

Mueller generalized optical theorem

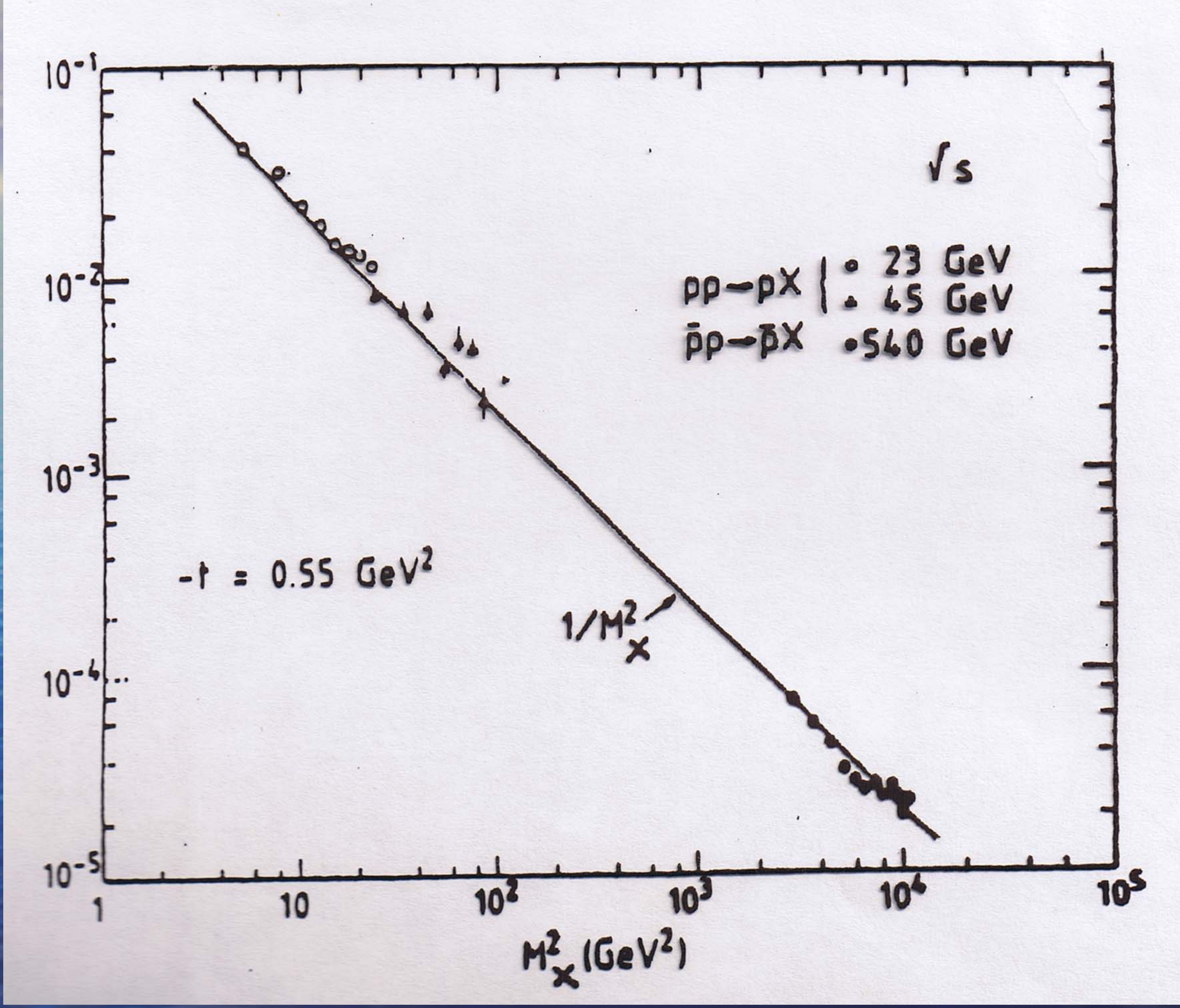


- One of the reasons to mention Mueller theorem is the role it has had in promoting the understanding of one of the key ingredients in the resurrection of Regge poles, the so called triple Regge coupling which, again, in graphical terms, reads

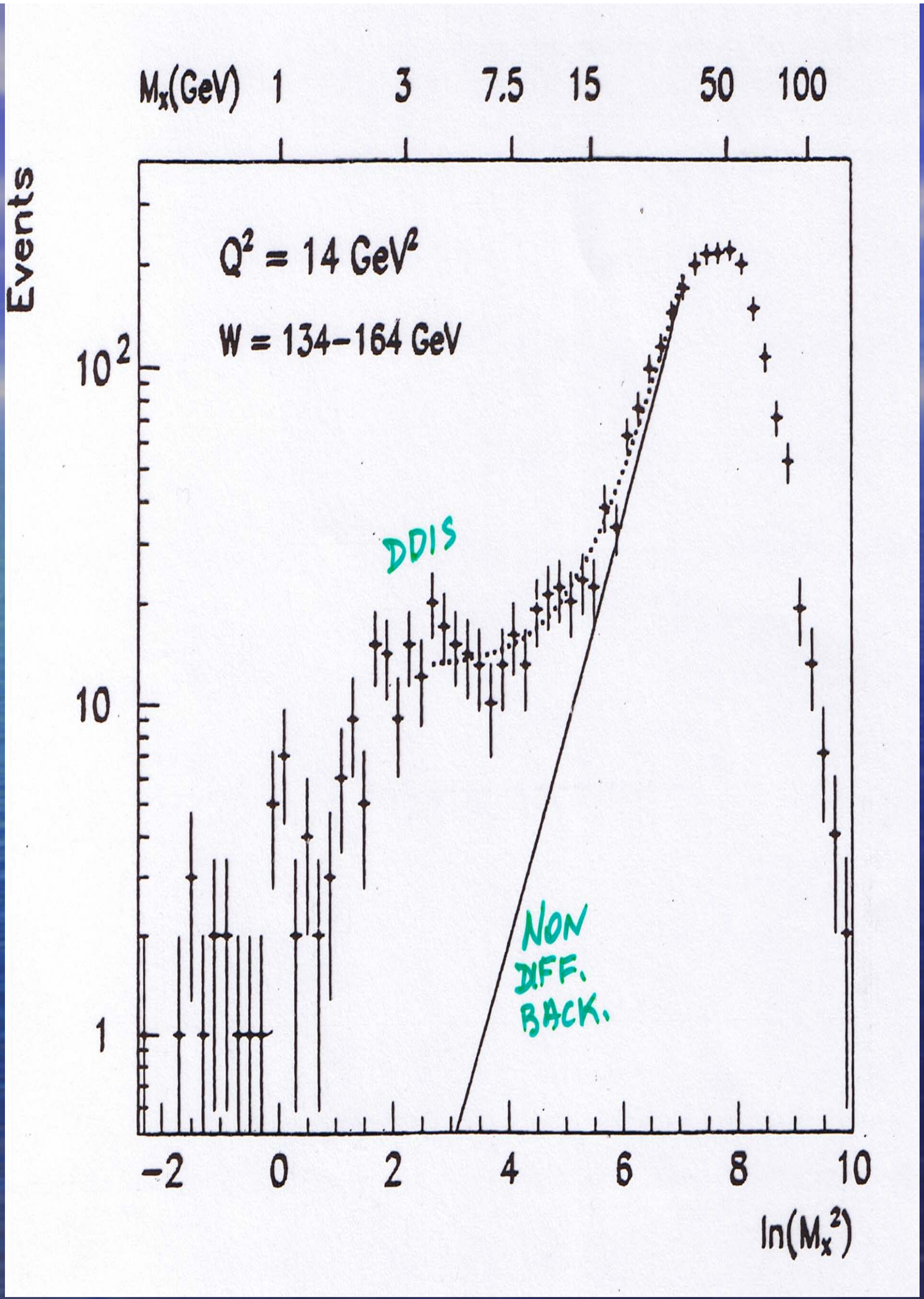
Triple Regge Couplings



- It' s easy to show using the full machinery recalled in these days, that the inclusive M^2 dependence predicted from triple pomeron for the inclusive cross section behaves like $1/M^2$ and, once again, this prediction is met by the data (see figure) but, once more, we will not elaborate on this point which would require more time and a much larger digression than we can give it



$\sqrt{s}$
pp→pX | ∘ 23 GeV
▴ 45 GeV
p̄p→p̄X •540 GeV
-t = 0.55 GeV²
$1/M_X^2$
M_X^2 (GeV²)



M_x(GeV) 1 3 7.5 15 50 100
Events
Q^2 = 14 GeV^2
W = 134–164 GeV
10^2
10
1
DDIS
NON
DIFF.
BACK.
-2 0 2 4 6 8 10
ln(M_x^2)

- For a comprehensive and self contained account of all the major developments that have occurred in the field of hadronic diffraction, let me refer once more to

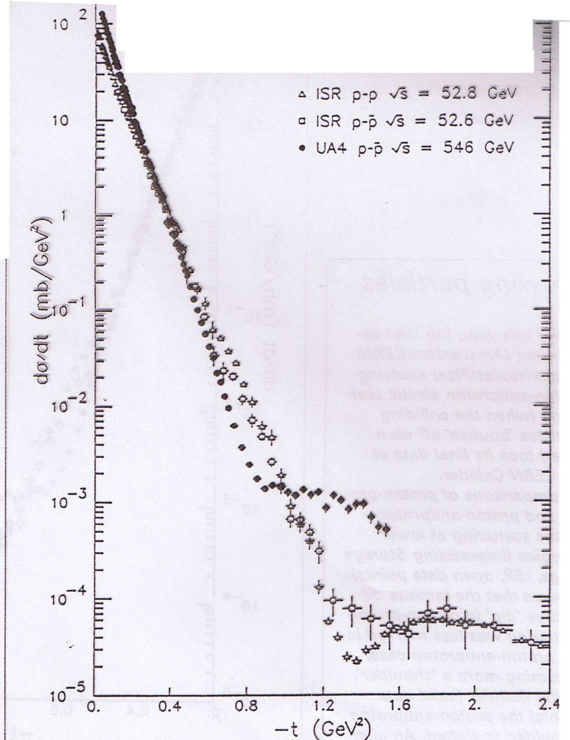
- **V. BARONE and E. PREDAZZI** *High energy particle diffraction* (Springer Texts and monographs in physics) ISBN 3-540-42107-6 (2002)

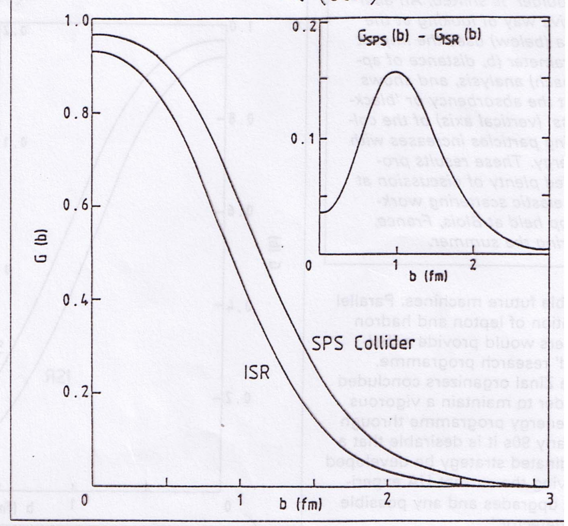
5. b-Unitarity

- Again jus a few words on an issue which is seldom taken up by some people who claim that power law increase of cross sections are a long way from leading to the violation of unitarity. This is true when comparing the energy growth in the usual energy variable but the situation is entirely different when we translate this in the language of the impact parameter repr.

Growing particles

Earlier this year, the UA4 experiment (Amsterdam/CERN/Genoa/Naples/Pisa) studying proton-antiproton elastic scattering (when the colliding particles 'bounce' off each other) took its final data at the CERN Collider.
Comparisons of proton-proton and proton-antiproton elastic scattering at lower energies (Intersecting Storage Rings, ISR, open data points) showed that the famous diffractive 'dip' in proton-proton scattering was less marked in the proton-antiproton case, becoming more a 'shoulder'. At the Collider (solid data points) the proton-antiproton 'shoulder' is shifted. An alternative way of looking at the data (below) uses the impact parameter (b, distance of approach) analysis, and shows that the absorbency or 'blackness' (vertical axis) of the colliding particles increases with energy. These results provided plenty of discussion at an elastic scattering workshop held at Blois, France, during the summer.





...sible future machines. Parallel ...ration of lepton and hadron ...ders would provide a 'bal...ed' research programme.
...he Zinal organizers concluded ...rder to maintain a vigorous ...energy programme through ...early 90s it is desirable that a ...dinated strategy be developed ...lving the current UA experi...nt upgrades and any possible ...detector.'

6. Conclusions…

- No clonclusions for such a lively, exciting and ever selfrenovating field.
- See you to the next school.