Scaling Properties of Soft Diffraction and Predictions for Hard Diffraction

K. GOULIANOS
The Rockefeller University

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OUTLINE

- The soft Pomeron intercept
- Scaling in soft diffraction
  (with J. Montanha)
- Hard diffraction at $\bar{p}p$ colliders
- Hard diffraction at HERA

The soft pomeron intercept

Donnachie and Landshoff
(fit $p^{\pm}p$ cross sections not including CDF data)
Phys. Lett. B296 (1992) 227

$$\sigma_{tot}^{hp} = Xs^{\epsilon} + Ys^{-\eta} \tag{1}$$

$$\epsilon_{DL} = 0.08$$

CDF (total cross sections at $\sqrt{s}$=546 and 1800 GeV)
PRD 50 (1994) 5550

$$\epsilon_{CDF} = 0.112 \pm 0.013$$

Cudell, Kang and Kim
(fit $p^{\pm}p$ cross sections including CDF data)
hep-ph/9601336 (24 September 1996)

$$\epsilon_{CKK} = 0.096^{+0.012}_{-0.009}$$

Covolan, Montanha and Goulianos
(fit all $p^{\pm}p$, $\pi^{\pm}p$ and $K^{\pm}p$ cross sections and ρ-values)
Phys. Lett. B389 (1996) 176

$$\epsilon_{CMG} = 0.104 \pm 0.002$$

Diffractive Cross Section

$$\frac{d^2\sigma(s,\xi,t)}{d\xi dt} = \left[\frac{\beta^2_{\bar{p}I\!P}(t)}{16\pi}\,\xi^{1-2\alpha(t)}\right]\cdot\left[g(t)\beta_{pI\!P}(0)\left(\frac{\xi s}{s_0}\right)^{\epsilon}\right]$$

$$= f_{I\!P/\bar{p}}(\xi,t)\cdot\sigma^{I\!Pp}(s',t)$$

$$\xi = M_X^2/s$$
$$\alpha(t) = 1+\epsilon+\alpha' t$$
$$s' = \xi s = M_X^2$$

Pomeron Flux

$$f(\xi,t) = D\cdot f_{I\!P/\bar{p}}(\xi,t)$$

Standard flux D=1

Renormalized flux $\int_\xi\int_t D\cdot f_{I\!P/\bar{p}}(\xi,t)d\xi dt = 1$

Phys. Lett. B358 (1995) 379

Pomeron Structure

$$\beta G(\beta) = (f_g+f_q)[6\beta(1-\beta)]$$

Monte Carlo Simulations

POMPYT For diffractive production

PYTHIA For non-diffractive production

Triple-pomeron cross sections

Standard Regge theory

$$\sigma_{SD} \sim s^{2\epsilon}$$

$$\frac{d^2\sigma}{dt\,d\xi} = A(\xi, t)\ s^{\epsilon}$$

$$\frac{d^2\sigma}{dt\,dM^2}\Big|_{t=0} = \frac{C\ s^{2\epsilon}}{(M^2)^{1+\epsilon}}$$

Renormalized pomeron flux

$$\sigma_{SD} \sim constant$$

$$\frac{d^2\sigma}{dt\,d\xi} = B(\xi, t)\ \frac{1}{s^{\epsilon}}$$

$$\frac{d^2\sigma}{dt\,dM^2}\Big|_{t=0} = \frac{B}{(M^2)^{1+\epsilon}}$$

28 September 1995

PHYSICS LETTERS B

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Physics Letters B 358 (1995) 379–388

Renormalization of hadronic diffraction and the structure of the pomeron

K. Goulianos

The Rockefeller University, 1230 York Avenue, New York, NY 10021, USA

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Abstract

A phenomenological renormalization scheme for hadronic diffraction is proposed, which unitarizes the triple-pomeron Regge amplitude while preserving its M^2 and t dependence. Predictions for $pp/p\bar{p}$ single diffractive, double diffractive and double pomeron exchange cross sections are presented and compared with experimental results. A new interpretation of hard and deep inelastic diffractive data emerges in which the momentum sum rule is obeyed by the constituents of a pomeron described as a mixture of quark and gluon color singlets in a ratio dictated by asymptopia.

1. Introduction

It is well known that pomeron exchange in Regge theory accounts for the main features of high energy elastic, diffractive and total cross sections [1,2]. In particular, for proton-(anti)proton interactions, it accounts for the rise of the total cross section and the shrinking of the forward elastic peak with energy, and also describes correctly the M^2 and t dependence of single diffraction dissociation (SD). Furthermore, the concept of factorization provides relationships between cross sections that pass successfully the test of experimental observation [1].

The early success of the simple Regge-pole model has been, however, tempered by the more recent measurements of the $p\bar{p}$ single diffraction (SD) dissociation cross section at the $Sp\bar{p}S$ Collider [3] and at the Tevatron [4,5]. As seen in Fig. 1, the theoretical prediction for the SD cross section based on standard Regge theory (dashed curve) has a much steeper energy dependence than the data. Such a result was, of

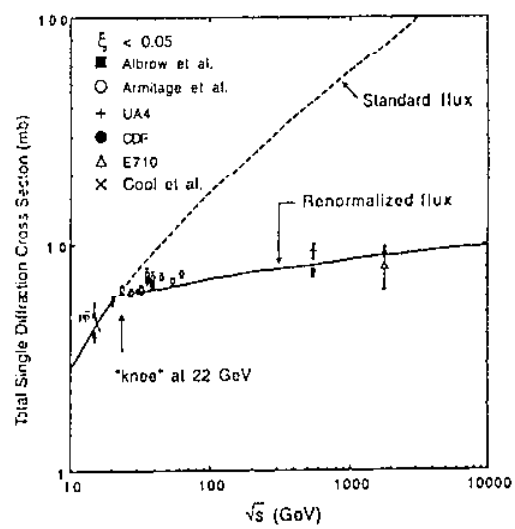

Fig. 1. Total $pp/p\bar{p}$ single diffraction cross section data (*both* sides) for $\xi < 0.05$ compared with predictions based on the standard and the renormalized pomeron flux.

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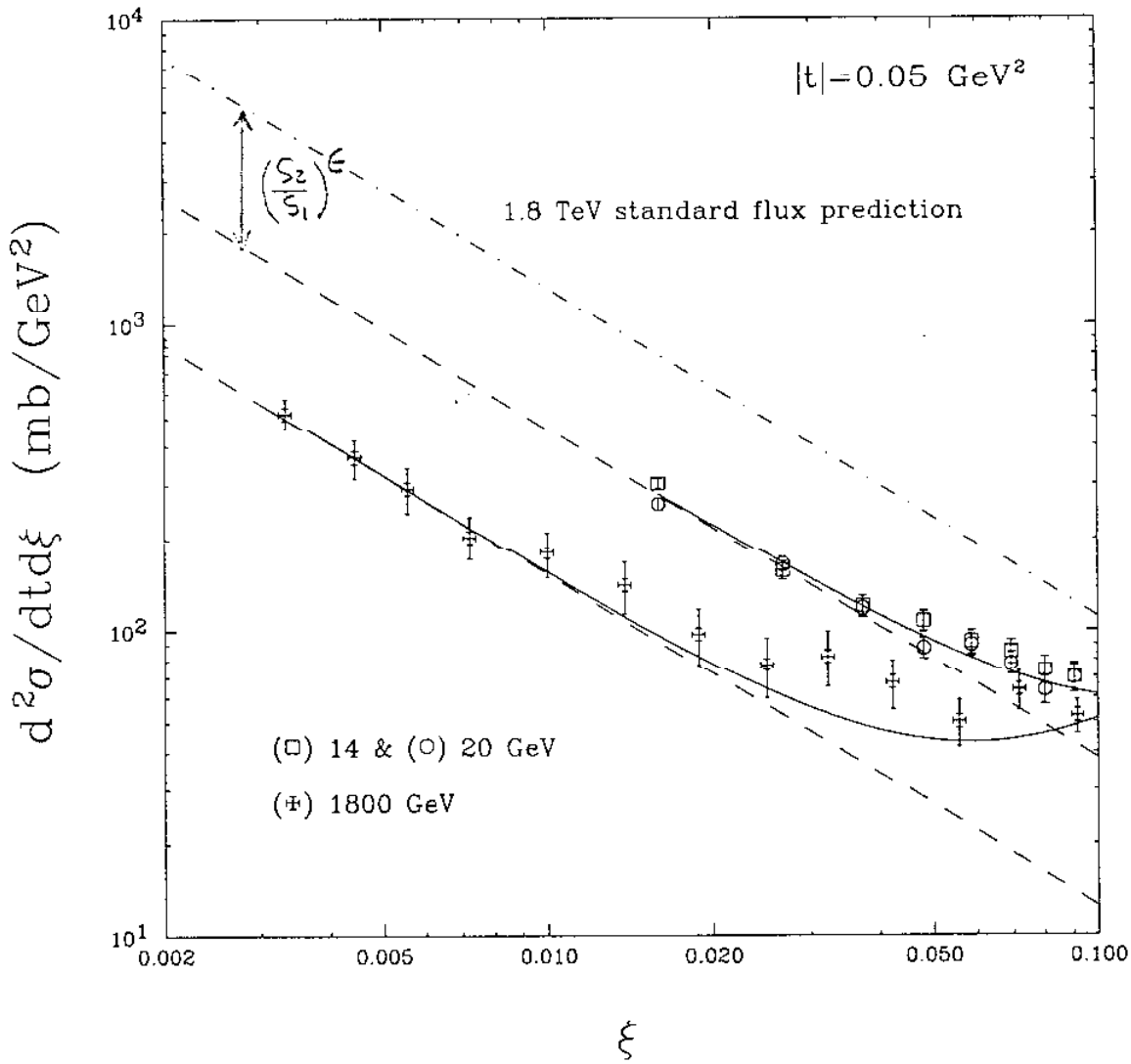
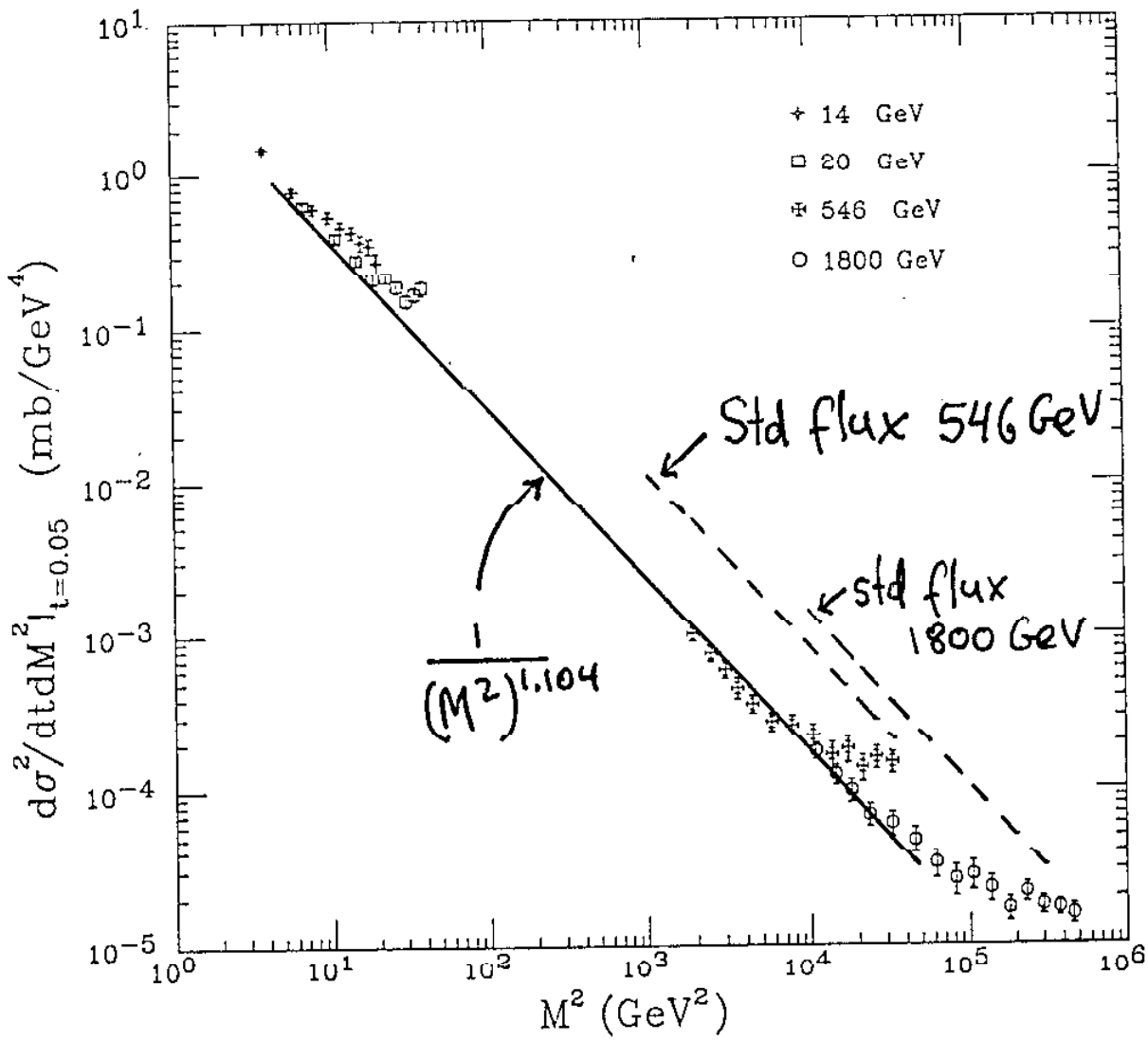
SSDI 0370-2693(95)01023-8

Diffractive cross section vesus ξ at $t = -0.05$
(Data: $p - p(\bar{p})$ fixed target and Tevatron)

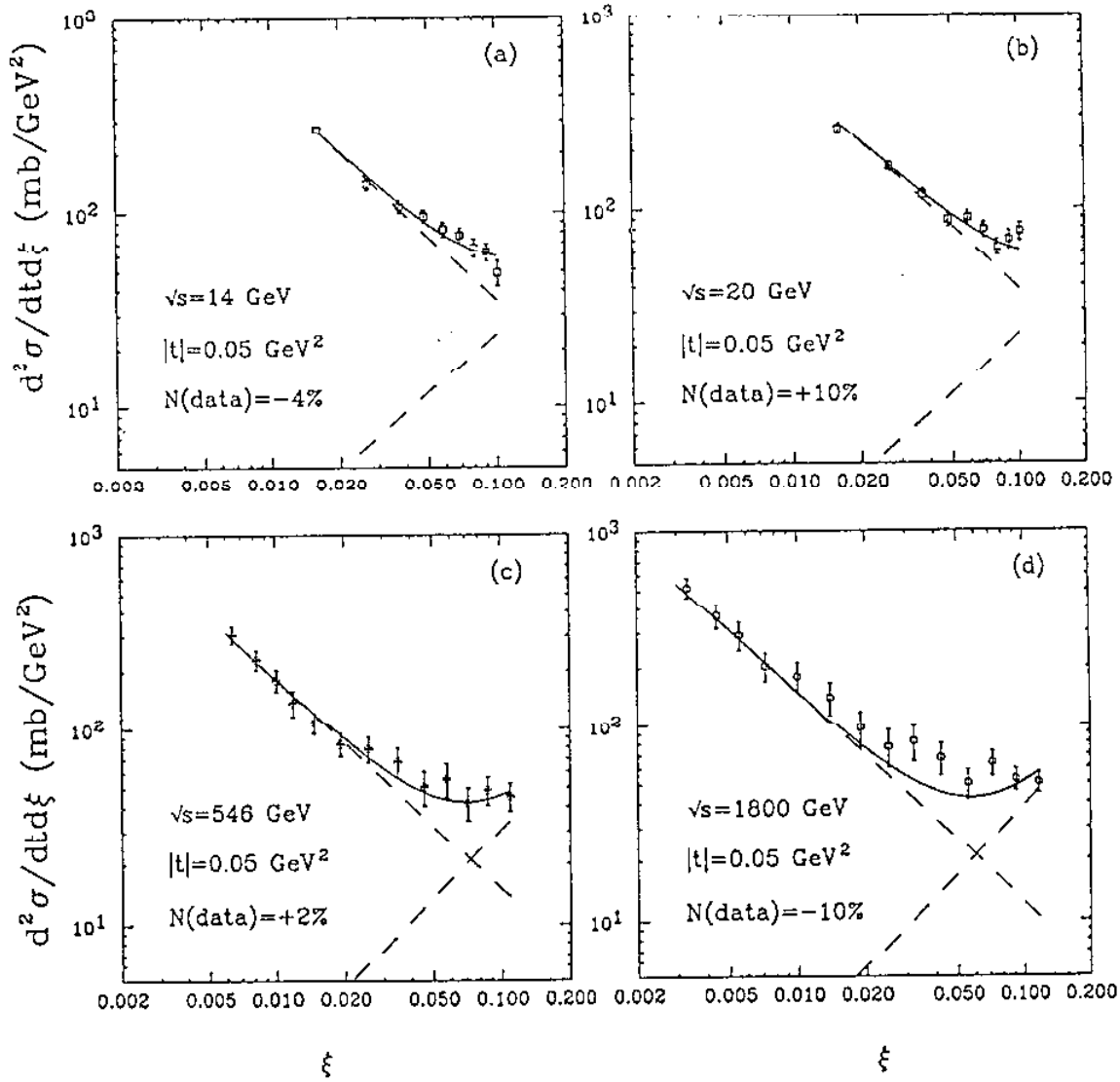


Cross section versus M^2 at $t = -0.05$ GeV^2
(Fixed target and CDF data)



Global fit to cross sections

(Fixed target and CDF data at $t = -0.05$ GeV^2)



Pion Exchange

$$\frac{d^2\sigma}{d\xi\, dt} = f_{\pi/p}(\xi, t) \cdot \sigma_{\pi p}(s\xi)$$

$$f_{\pi/p}(\xi, t) = \frac{1}{4\pi}\, \frac{g^2_{\pi Np}}{4\pi}\, F_{\pi Np}(t)\, \xi^{1-2\alpha_\pi}$$

$$2\alpha_\pi = 0 + \lambda t \quad (\lambda \approx 0.9)$$

$$F_{\pi Np}(t) = \frac{|t|}{(t-\mu^2)^2} G_1(t)$$

$$G_1(t) = e^{b_\pi(t-\mu^2)} \approx \frac{2.3-\mu^2}{2.3-t} \qquad (\mu = m_\pi)$$

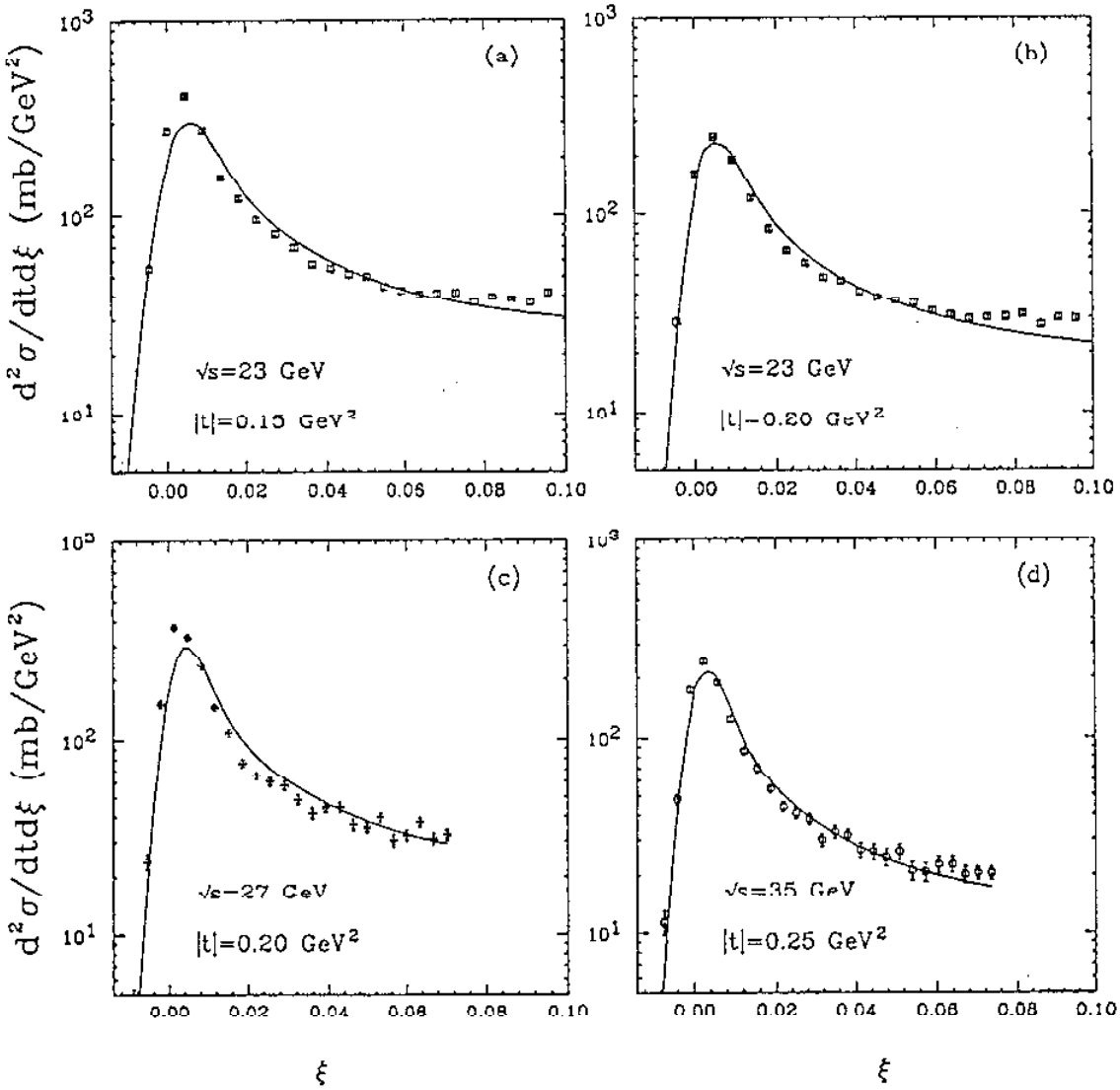
$$\frac{g^2_{\pi pp}}{4\pi} \approx 14.5; \quad g^2_{\pi np} = 2g^2_{\pi pp}$$

$$\sigma^{\pi^\circ p} = \frac{1}{2}(\sigma^{\pi^+ p} + \sigma^{\pi^- p})$$

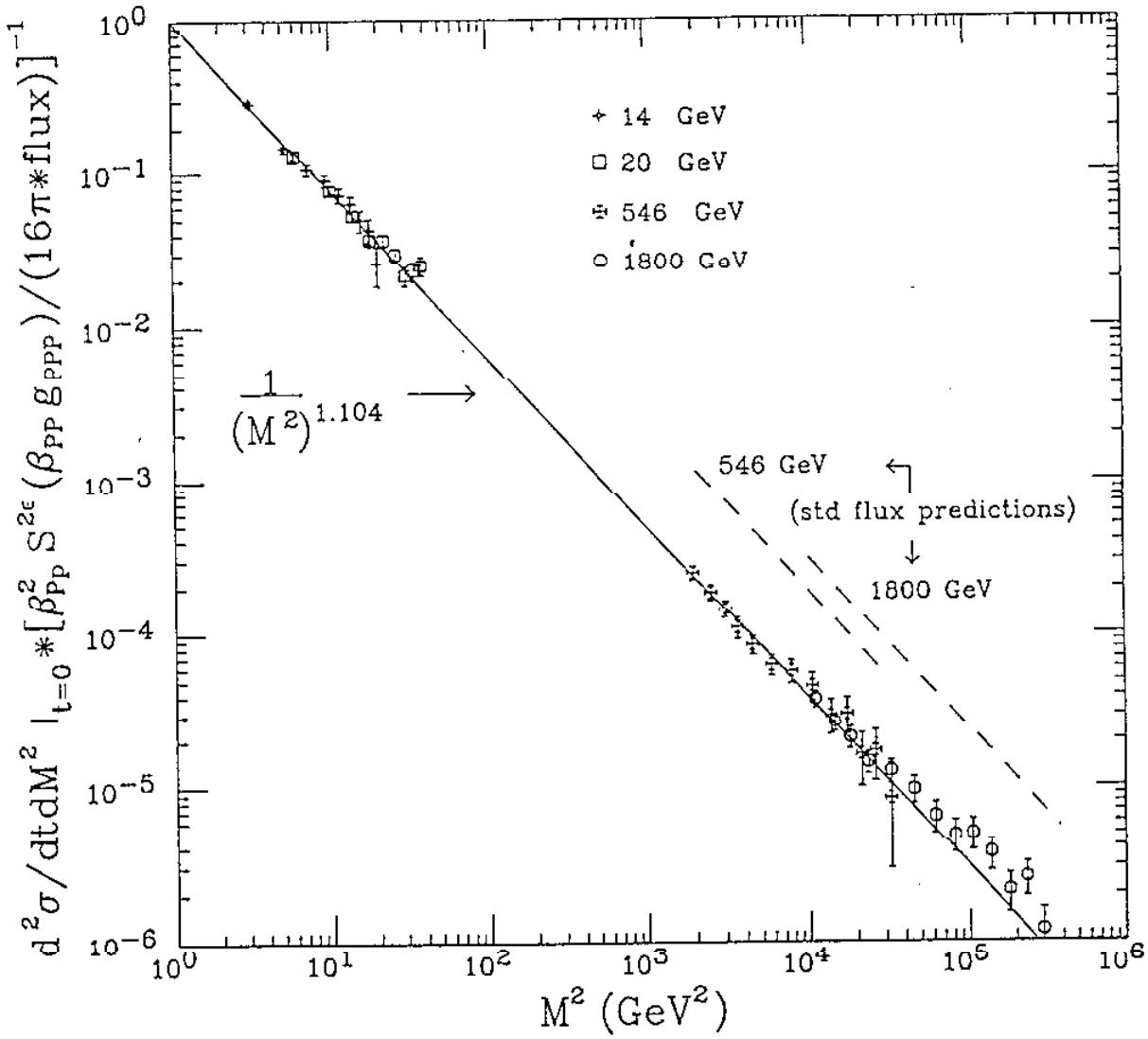
For $\gamma + p \to X + p$ use $\sigma^{\pi^\circ \gamma} = \frac{\sigma^{I\!P\gamma}}{\sigma^{I\!Pp}} \cdot \frac{2}{3}\sigma^{\pi^\circ p}$

Cross section vesus ξ at fixed t

(Data: ISR; Fit: Pomeron + Pion $\oplus$ Resolution)



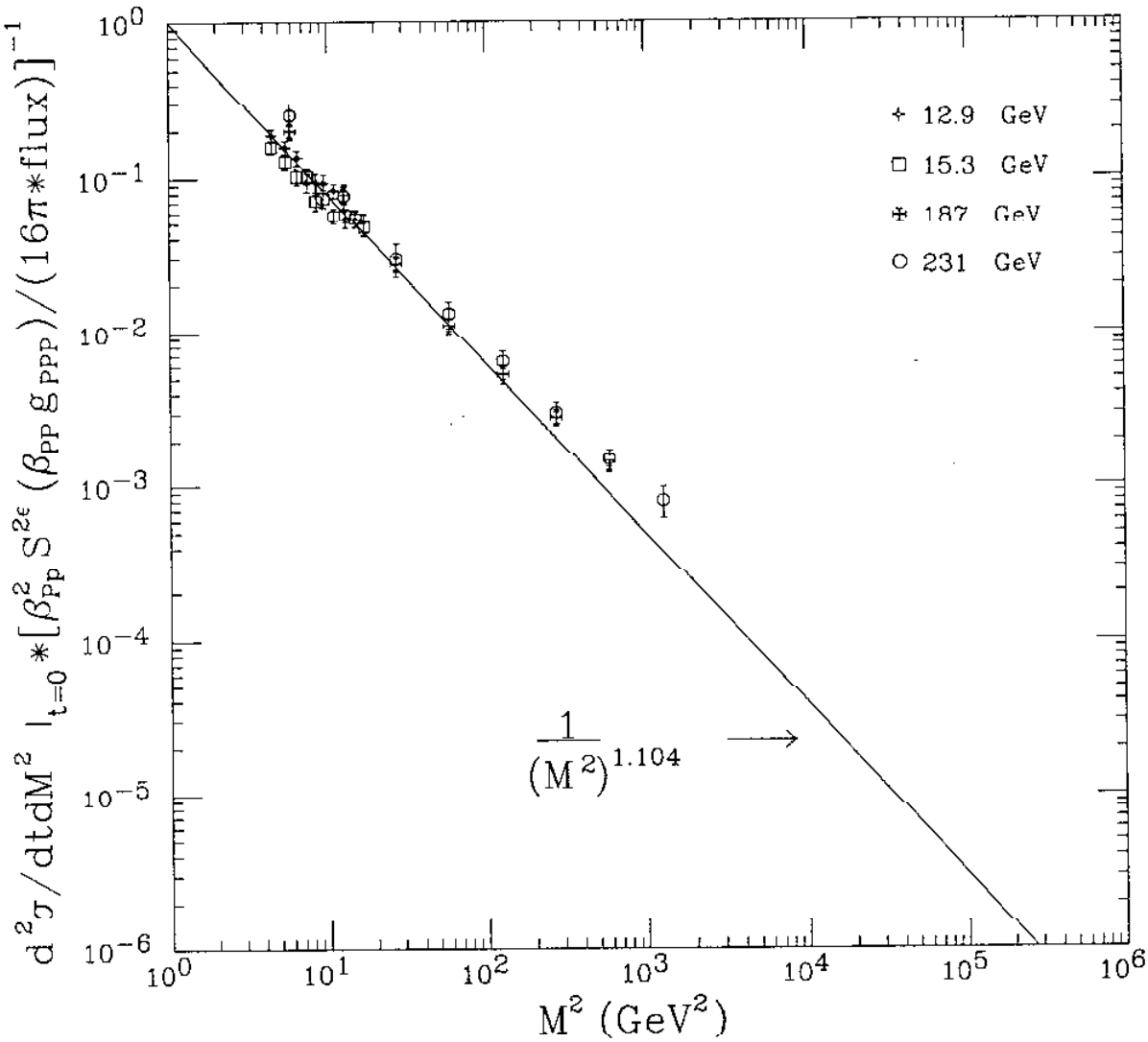
Cross section versus M^2at $t = 0$
(Normalized)



$\gamma + p \to X + p$ cross section vesus M^2 at $t = 0$

Data: Fixed target and HERA-H1

(normalized to pp data at $\sqrt{s} = W = 14$ GeV)



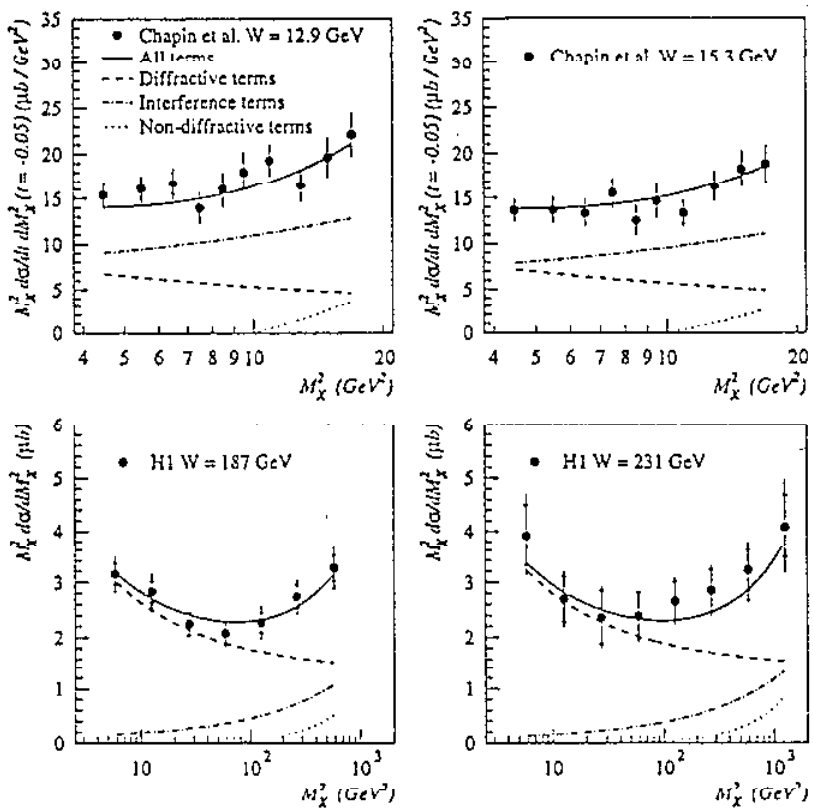


Figure 6: Measurements of the quantity $M_X^2\, d\sigma_{\gamma p \to XY}/dM_X^2$ with $M_Y < 1.6$ GeV and $|t| < 1.0$ GeV^2 by H1 and of $M_X^2\, d\sigma_{\gamma p \to Xp}/dM_X^2\, dt$ from [25]. For the H1 data the inner error bars are statistical and the outer error bars show statistical and systematic errors added in quadrature. Overall scale uncertainties of 13% at $\langle W \rangle = 12.9$ GeV and $\langle W \rangle = 15.3$ GeV, 5.2% at $\langle W \rangle = 187$ GeV and 6.9% at $\langle W \rangle = 231$ GeV are omitted from the errors. The triple-Regge fit (b) with maximal constructive interference and the resulting decomposition of the cross section is superimposed.

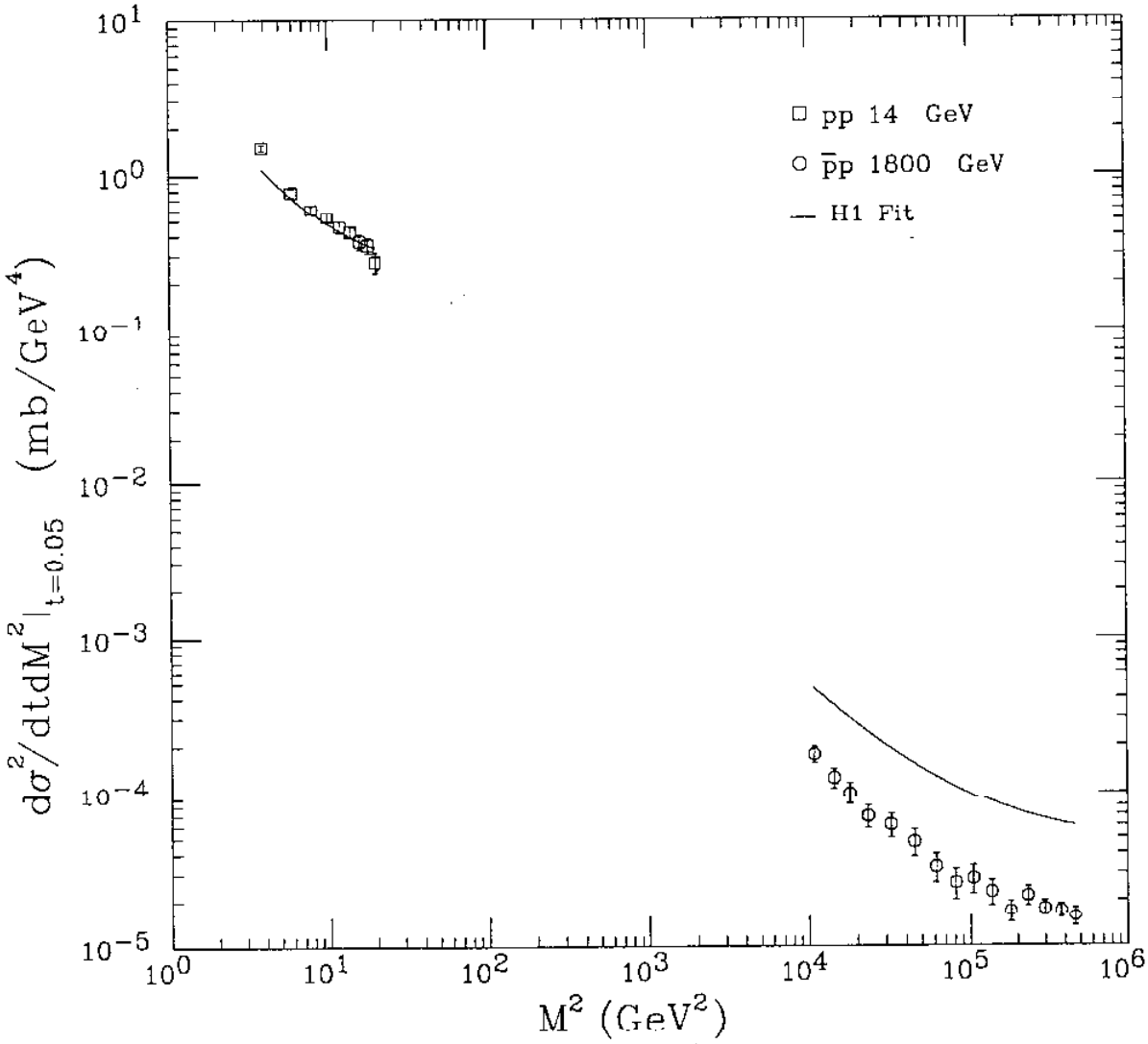
$k = \mathbb{P}$ and $k = \mathbb{R}$. Maximal coherence is assumed and, through equation (8), the interference couplings at $t = 0$ are parameterised as $G_{\{\mathbb{PR}\}\mathbb{P}}(0) = 2\sqrt{|G_{\mathbb{PPP}}(0)\, G_{\mathbb{RRP}}(0)|}$ and $G_{\{\mathbb{PR}\}\mathbb{R}}(0) = 2\sqrt{|G_{\mathbb{PPR}}(0)\, G_{\mathbb{RRR}}(0)|}$. This represents the scenario in which the f is the dominant subleading exchange and the f and the pomeron couple similarly to the proton [43,44]. The results are presented in table 4b and figure 6.

In fit (c) effects arising from isovector exchanges are investigated. The interference terms are not included, but the non-diffractive terms ($\mathbb{RRR}$ and $\mathbb{RRP}$) are allowed to be different in the H1 and the fixed target data. This accounts for possible additional contributions to the H1 data from the specific terms in table 2 that are marked with a star. A further free fit parameter $\mathcal{R}$ is therefore introduced, defined as the ratio of the sum of the couplings $G_{\mathbb{RRP}}(0)+G_{\mathbb{RRR}}(0)$ in the H1 data to that in the fixed target data. If there

$\frac{d^2\sigma}{dt\,dM^2}$ for $pp/\bar{p}p$ vesus M^2 at $t = -0.5GeV$

Data: pp at $\sqrt{s} = 14$ GeV and $\bar{p}p$ at $\sqrt{s} = 1800$ GeV

Solid line: H1 fit to $\gamma p \to Xp$ normalized to 14 GeV pp data

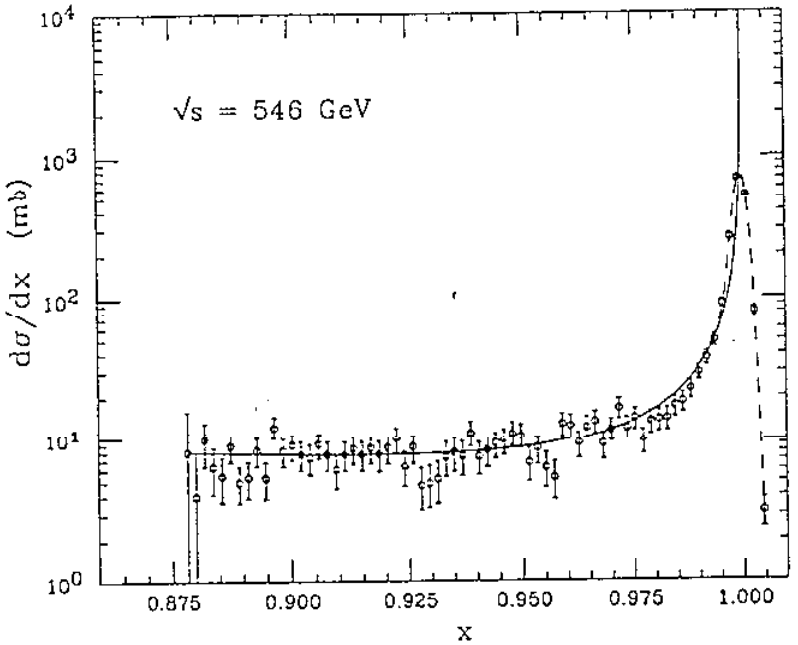


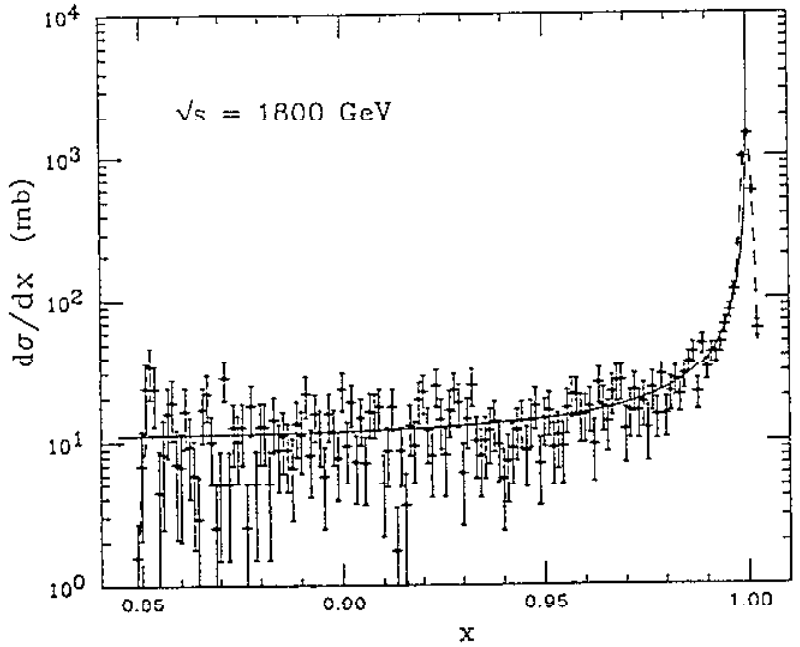
Triple-Regge Amplitudes

$$\alpha_{I\!P}(0) = 1+\epsilon \qquad \alpha_R(0) = 0.5 \qquad \alpha_\pi(0) = 0$$

Amplitude	$d\sigma/d\xi\|_{t=0}$	$d\sigma/dM^2\|_{t=0}$	σ
$(I\!P I\!P)I\!P$	$\frac{s^\epsilon}{\xi^{1+\epsilon}}$	$\frac{s^{2\epsilon}}{(M^2)^{1+\epsilon}}$	$s^{2\epsilon}$
$(I\!P R)R$	$\frac{1/\sqrt{s}}{\xi^{1+\epsilon}}$	$\frac{s^\epsilon/\sqrt{s}}{(M^2)^{1+\epsilon}}$	$s^\epsilon/\sqrt{s}$
$(I\!P I\!P)R$	$\frac{s^\epsilon/\sqrt{s}}{\xi^{1.5+\epsilon}}$	$\frac{s^{2\epsilon}}{(M^2)^{1.5+2\epsilon}}$	$s^{2\epsilon}$
$(I\!P R)I\!P$	$\frac{s^\epsilon}{\xi^{0.5}}$	$\frac{s^\epsilon\sqrt{s}}{(M^2)^{0.5}}$	$s^{1+\epsilon}$
$(RR)I\!P$	$s^\epsilon\xi^\epsilon$	$(1/s)(M^2)^\epsilon$	s^ϵ
$(RR)R$	$\frac{1/\sqrt{s}}{\xi^{0.5}}$	$\frac{1/s}{(M^2)^{0.5}}$	$1/\sqrt{s}$
Renormalized: $(I\!P I\!P)I\!P$	$\frac{1/s^\epsilon}{\xi^{1+\epsilon}}$	$\frac{1}{(M^2)^{1+\epsilon}}$	s^0
$(\pi\pi)I\!P$	$s^\epsilon\xi^{1+\epsilon}$	$\frac{s^\epsilon/s^2}{(M^2)^{1+\epsilon}}$	$s^{2\epsilon}$
$(\pi\pi)R$	$(1/\sqrt{s})\xi^{0.5}$	$\frac{1}{s^2}(M^2)^{0.5}$	$1/\sqrt{s}$

CDF Single Diffractive Cross Sections
(corrected for acceptance)





Conclusions for Soft Diffraction

STANDARD REGGE THEORY

- ξ and M^2 distributions do not scale with s.
- Unitarity is violated in σ_{SD}/σ_T.
- Flux integral depends on ξ_{min} and for $pp \to pX$ it is $\sim s^{2\epsilon}$.

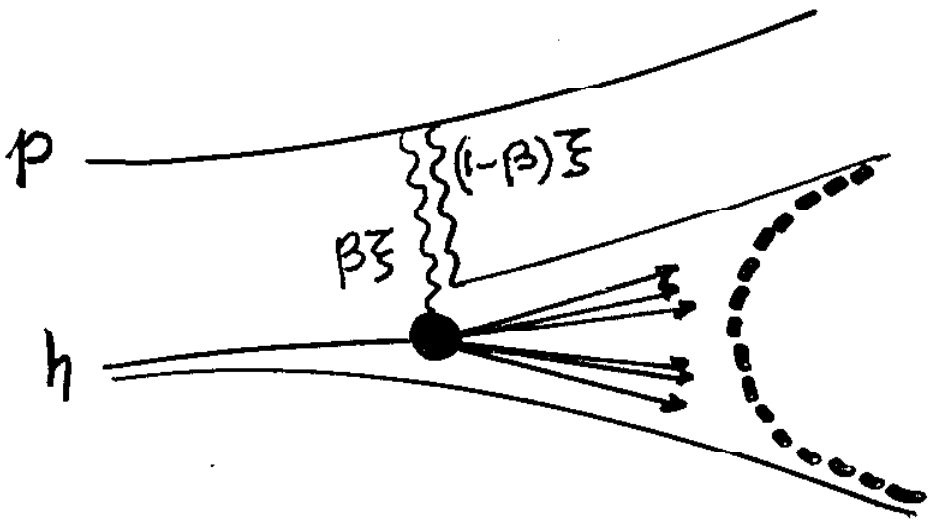
REALITY

- M^2 distribution at $t = 0$ scales (approximately) with s.
- Unitarity is, of course, obeyed!

RENORMALIZATION

- Flux integral $\Rightarrow 1$ **True scaling property!!!**
- $d\sigma/dM^2|_{t=0}$ scales (approximately) with s.
- Unitarity is obeyed in σ_{SD}/σ_T.

HARD DIFFRACTION



$$f_N(\xi, t) = D \cdot f_{I\!P/p}(\xi, t)$$

$$N \equiv \frac{1}{D} - \int_{\xi_{min}}^{0.1} \int_{t=0}^{\infty} f_{I\!P/p}(\xi, t)\, d\xi dt = 1$$

$$\xi_{min} = \xi_0 \quad N = 1 \quad \Rightarrow \qquad D = 1 \quad \xi_0 = 0.004$$

$$\xi_{min} \geq \xi_0 \quad N < 1 \quad \Rightarrow \qquad D = 1$$

$$\xi_{min} < \xi_0 \quad N \approx \left(\frac{\xi_0}{\xi_{min}}\right)^{2\epsilon} \quad \Rightarrow \quad D = 1/N$$

$$\beta \xi_{min} = \frac{M_o^2}{s}$$

- Soft diffraction
  $\xi_{min} = \frac{M_o^2}{s} \quad \Rightarrow \quad N \approx \left(\frac{\xi_0}{M_o^2}\right)^{2\epsilon} s^{2\epsilon} \quad (M_o^2 = 1.5 \text{ GeV}^2)$
- Hard diffraction
  $\beta \xi_{min} = \frac{M_o^2}{s} \Rightarrow N \approx \left(\frac{\xi_0}{M_o^2}\right)^{2\epsilon} (\beta s)^{2\epsilon} \approx 6$ (at 1.8 TeV)

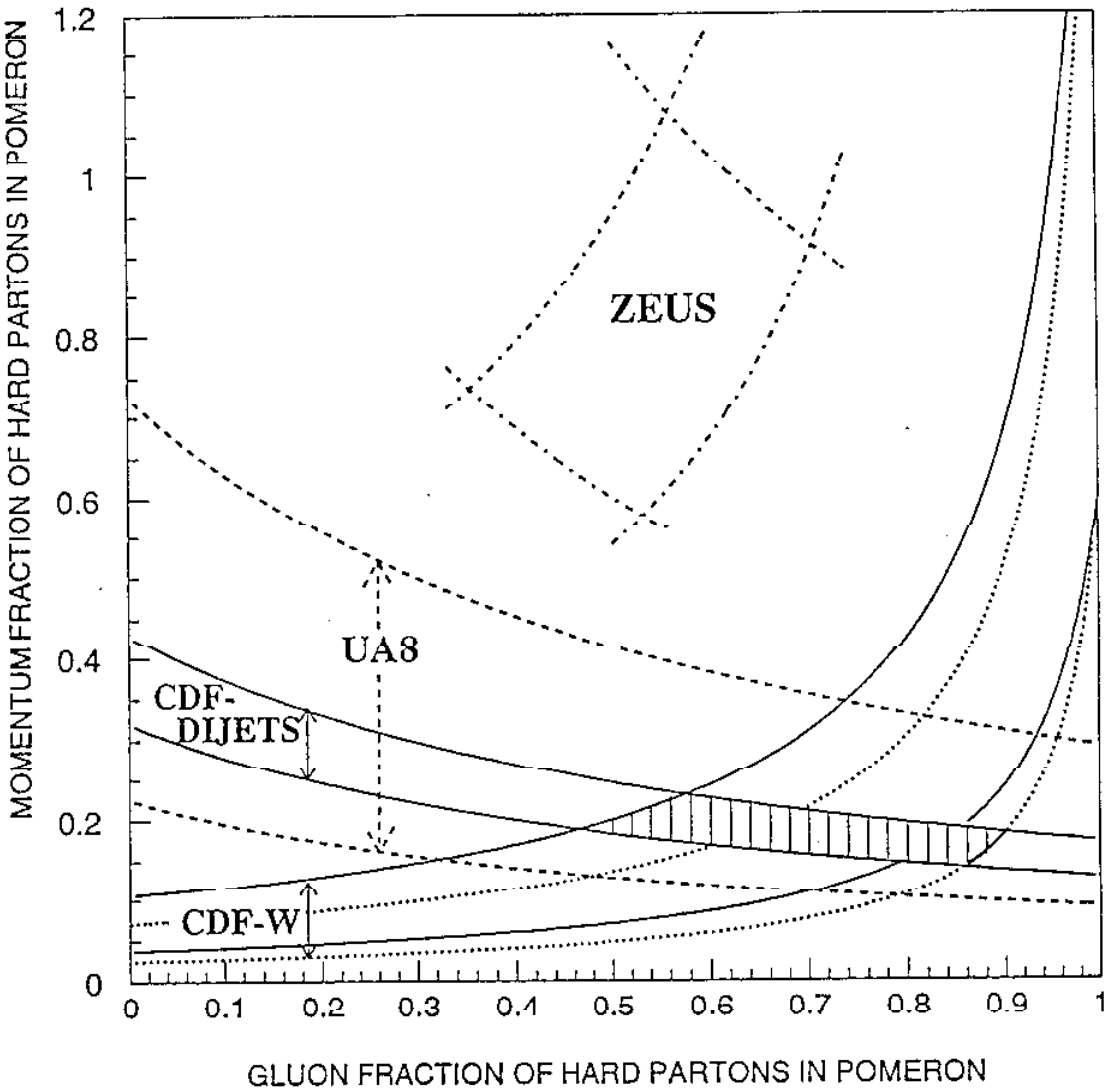
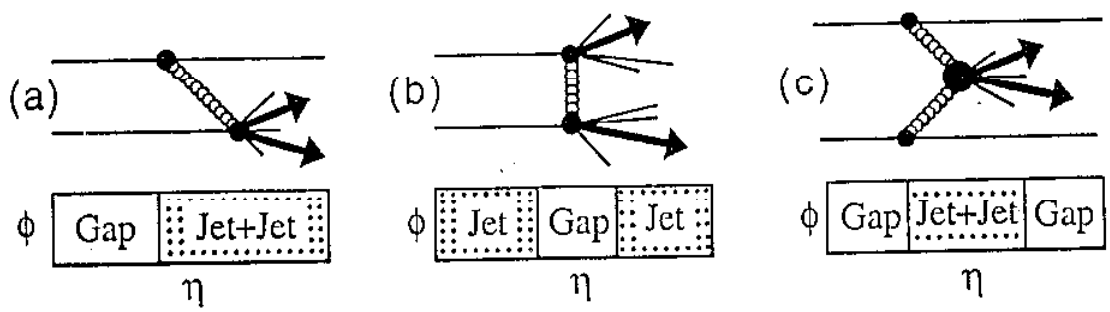


Figure 5: Momentum fraction versus gluon fraction of hard partons in the pomeron evaluated by comparing measured diffractive rates with Monte Carlo predictions based on the standard pomeron flux and assuming that only hard pomeron partons participate in the diffractive processes considered. Results are shown for ZEUS (dashed-dotted), UA8 (dashed) and the CDF-DIJET and CDF-W measurements. The CDF W result is shown for two (dotted) or three (solid) light quark flavors in the pomeron . The shaded region is used in the text to extract the quark to gluon fraction of the pomeron and the standard flux discrepancy factor.

Diffractive Production

- (a) Single Diffraction
- (b) Double Diffraction
- (c) Double Pomeron Exchange



The CDF Detector

BBC	$3.2 < \|\eta\| < 5.9$	Beam-Beam Counters	
CTC	$\eta\| < 1.8$	Central Tracking Chamber	
CAL	central: $\|\eta\| < 1.1$	plug: $1.1 < \|\eta\| < 2.4$	forward: $2.2 < \|\eta\| < 4.2$

"PARTICLE"

- a hit in a BBC
- a track with $P_T > 300$ MeV in the CTC
- a calorimeter tower with $E_T > 200$ MeV (corrected $E_T >\sim 300$ MeV); for $2.4 < |\eta| < 4.2$ we require a tower *energy* of $E > 1.5$ GeV.

HIGHLIGHTS OF HARD DIFFRACTION RESULTS

1. Diffractive W Production

$$R_W = (1.15 \pm 0.55)\%$$
$$(\xi < 0.1)$$

2. Diffractive Dijet Production

$$R_{GJJ} = (0.75 \pm 0.10)\%$$
$$(E_T^{jet} > 20 \text{ GeV},\ |\eta^{jet}| > 1.8,\ \eta_1\eta_2 > 1,\ \xi < 0.1)$$

3. Jet-Gap-Jet Events

$$R_{JGJ} = (1.13 \pm 0.16)\%$$
$$(E_T^{jet} > 20 \text{ GeV},\ |\eta^{jet}| > 1.8,\ \eta_1\eta_2 < 1,\ |\eta_{gap}| < 1)$$

4. Diffractive Heavy Quark Production

$$R < 0.9\% \ (90\% \text{ CL})$$
$$(0.05 < \xi < 0.1)$$

5. Dijets with $E_T^{jet} > 7$ GeV in:
Single Diffraction (SD): $0.05 < \xi < 0.1$
Double-Pomeron Exchange (DPE): $0.05 < \xi_1 < 0.1$, $\xi_2 \sim \xi_1$
Non-Diffractive events (ND)

DPE/SD	$[0.170 \pm 0.036(stat) \pm 0.024(syst)]\%$
SD/ND	$[0.160 \pm 0.002(stat) \pm 0.024(syst)]\%$
(DPE/SD)/(SD/ND)	1.1 ± 0.3
DPE/ND	$(2.7 \pm 0.7) \times 10^{-6}$

The Structure of the Pomeron

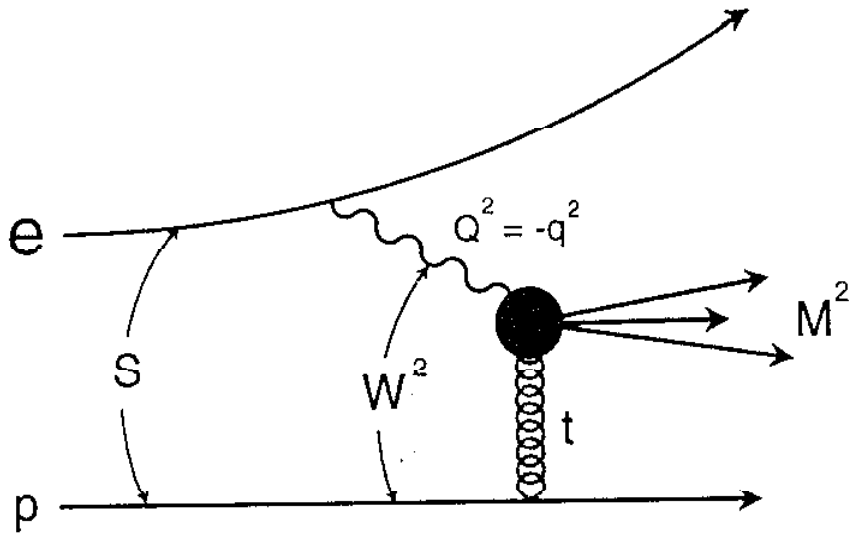
1. The low fraction of diffractive $W + Jet$ events observed indicates the presense of a **hard quark component** in the pomeron structure.

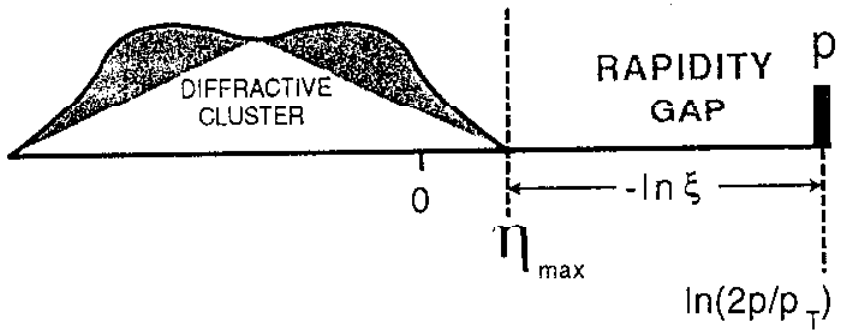
2. From R_W and R_{JJ}, the hard gluon content of the pomeron is determined to be **(independent of the pomeron flux normalization)**

$$f_g = 0.7 \pm 0.2$$

3. The Jet-Gap-Jet signal **decreases at large rapidity gaps.**

HERA


e
$Q^2 = -q^2$
M^2
s
W^2
t
p


DIFFRACTIVE
CLUSTER
RAPIDITY
GAP
p
0
$-\ln \xi$
η_{max}
$\ln(2p/p_T)$

DIS at HERA

$$x_{bj} = \beta\,\xi - \frac{Q^2}{W^2}$$

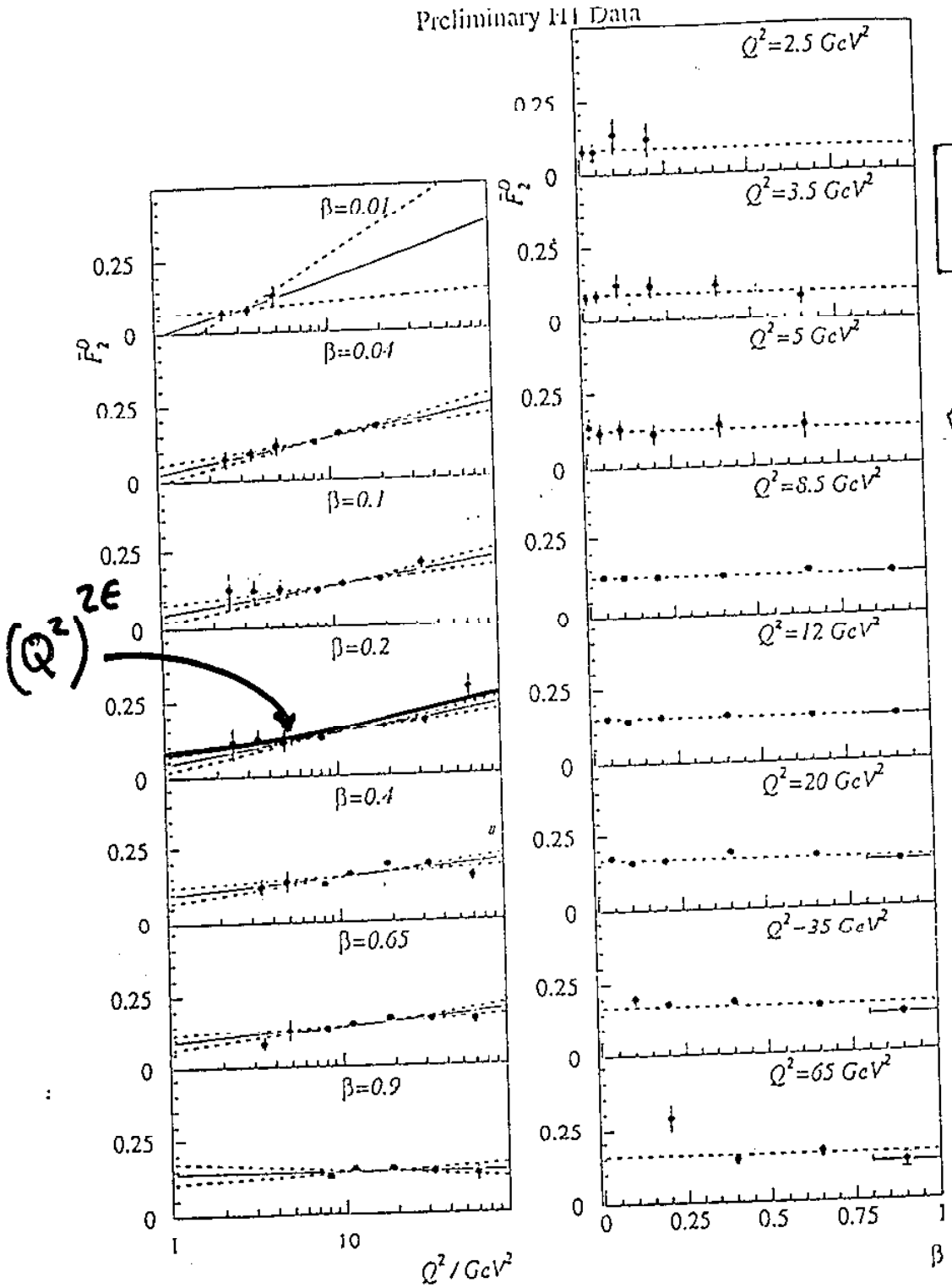
For fixed β and Q^2 the pomeron ξ varies as $\frac{1}{W^2}$ and becomes minimum at $W^2 = s$

$$\xi_{min} = \frac{Q^2}{\beta\ s}$$

$$N \approx \left(\frac{\xi_0}{\xi_{min}}\right)^{2\epsilon} \approx (\xi_0\ s)^{2\epsilon} \left(\frac{\beta}{Q^2}\right)^{2\epsilon}$$

$$D = \frac{1}{N} \approx \left(\frac{\xi_0}{\xi_{min}}\right)^{-2\epsilon} \approx (\xi_0\ s)^{-2\epsilon} \left(\frac{Q^2}{\beta}\right)^{2\epsilon}$$

$$\boxed{\tilde{F}_2^D(Q^2,\beta) \sim \left(\frac{Q^2}{\beta}\right)^{2\epsilon} \cdot F_2^{I\!P}(Q^2,\beta)}$$



$$\beta = \frac{Q^2}{Q^2+M_x^2}$$

$$\boxed{M_x^2 = \frac{Q^2}{\beta} - Q^2}$$

For the $\beta=0.9$ bin

$M_x^2 \sim 0.9\ GeV^2$

$M_x^2 \sim 1.3$

$M_x^2 \sim 2.2$

$M_x^2 \sim 3.9$

$M_x^2 \sim 7.2$

CONCLUSION

The **renormalized pomeron flux** hypothesis:

- Unitarizes the SD amplitude.
- Predicts the correct soft diffraction cross sections.
- Predicts the CDF rates for diffractive W and dijet production and the UA8 rate for diffractive dijet production.
- Predicts the double-pomeron/diffractive/non-diffractive scaling observed by CDF.
- Introduces a $(Q^2/\beta)^{2\epsilon}$ dependence in the diffractive structure function measured in DIS at HERA, which affectes the extracted pomeron structure function from these measurements:
  See Phys. Lett. B358 (1995) 379-388 and B363 (1995) 268.