Diffractive Session
DIS-97
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Diffractive Parton Distribution Functions and Factorization Tests

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(with L. Alvero, J. Collins and J. Terron)

Outline:

1. Introduction - Motivation and Procedure
2. QCD Model
3. Partons in the pomeron from Fits to HERA DIS Data
4. Hard Diffractive Cross Sections at Tevatron and HERA
5. Conclusions

1. Introduction

Motivation

PL B307 (93) 161 NP B474 (96) 18 :

- Since it has been conjectured (Collins, Frankfurt, Strikman and Berera, Collins) that factorization of hard processes in diffractive scattering is not expected to hold: HENCE,
- It is important to test it experimentally

Procedure

- Assume a particular QCD-based Model - that of Ingelman and Schlein PL B152 (85) 256
- Make fits to the ZEUS diffractive DIS data (Full NLO QCD)
- Extract quark and gluon densities in the pomeron
- Calculate diffractive cross sections for W/Z bosons and dijet production at the Tevatron - WITH THE ASSUMPTION OF HARD SCATTERING FACTORIZATION
- Calculate diffractive photoproduction at HERA IN PROGRESS and charm production (SEE TERRON'S TALK)
- Compare with data

PAPERS

1. P. BRUNI, G. INGELMAN PL B311 (93) 317

   CALCULATED HERA AND W/Z @ TEVATRON

2. A. CAPELLA, A. KAIDALOV, C. MERINO, J. TRAN THANH VAN PL B343 (95) 403

   DESCRIBE HERA WITH ℙ pdf

3. J.C. COLLINS, J. HUSTON, J. PUMPLIN, H. WEERTS, J. WHITMORE PRD51 (95) 3182

   PROPOSED TO TEST FACTORIZATION, ℙ pdf IN A VARIETY OF HARD SCATTERING REACTIONS

4. K. GOLEC-BIERNAT, J. KWIECIŃSKI PL B353 (95) 329

   DESCRIBE HERA WITH ℙ pdf

5. T. GEHRMANN, W.J. STIRLING Z.f.P C70 (96) 89

   DESCRIBE HERA WITH ℙ pdf, CHARM

6. K. GOULIANOS PL B358 (95) 379

   RENORMALIZED ℙ FLUX, ℙ pdf, W, JETS IN MC, HERA

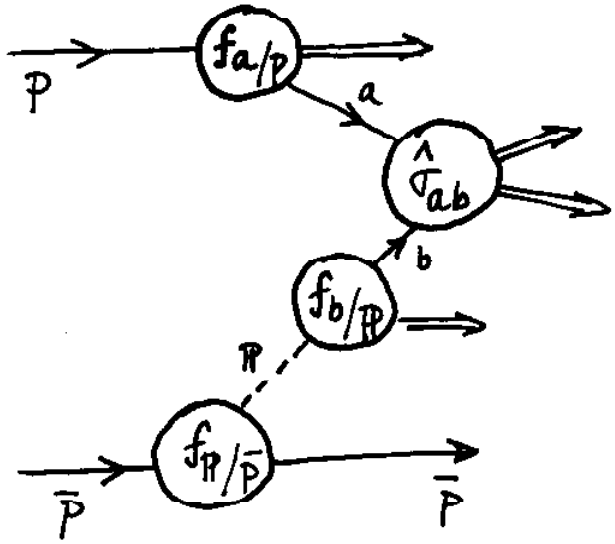
7. Z. KUNSZT, W.J. STIRLING hep-ph/9609245 DIS96

   HERA DATA => ℙ pdf

2. QCD Model

We assume I-S and Hard Scattering Factorization(eg for $\bar{p}p$:)

$$\sigma^{diff} = \sum_{a,b} f_{I\!P/\bar{p}}(x_{I\!P}, \mu) \otimes f_{a/p}(x_a, \mu) \otimes f_{b/I\!P}(x_b, \mu) \otimes \hat{\sigma}_{ab} \tag{1.1}$$



- The function $f_{I\!P/p}$ is the "flux of pomerons in the (anti)proton":

(DL) $$f^{DL}_{I\!P/p}(x_{I\!P}) = \int_{-\infty}^{0} dt\, \frac{9\beta_0^2}{4\pi^2} \left[\frac{4m_p^2 - 2.8t}{4m_p^2 - t} \left(\frac{1}{1 - t/0.7} \right)^2 \right]^2 x_{I\!P}^{1-2\alpha(t)}. \tag{1.2}$$

  where m_p is the proton mass, $\beta_0 \simeq 1.8\, GeV^{-1}$ is the pomeron-quark coupling and $\alpha(t) = 1.085 + 0.25t$ is the pomeron trajectory.

- $f_{a/p}(x_a)$ is the distributions of partons in the proton - we have used CTEQ3M

- $f_{b/I\!P}(x_b)$ is the distribution function of parton b in the pomeron (from a fit to the DIS diffractive data)

- $\hat{\sigma}_{ab}$ is the (LO) partonic hard scattering coefficient and μ is the factorization scale.

3. Partons in the pomeron

Diffractive structure functions are related to the differential cross section for the process $e + p \to e + p + X$:

$$\frac{d^4\sigma_{diff}}{d\beta dQ^2 dx_{I\!P} dt} = \frac{2\pi\alpha^2}{\beta Q^4}\left\{[1 + (1-y)^2] F_2^{D(4)} - y^2 F_L^{D(4)}\right\}. \tag{1.3}$$

where $\beta = x_{bj}/x_{I\!P}$, with x_{bj} being the usual Bjorken scaling variable of DIS.

The diffractive structure function $F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t)$ is assumed to obey Regge factorization, so that it is written as a pomeron flux factor times a pomeron structure function:

$$F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t) = f_{I\!P}(x_{I\!P}, t) F_2^{I\!P}(\beta, Q^2). \tag{1.4}$$

Generally, t is not measured so we integrate over t:

$$F_2^{D(3)}(\beta, Q^2, x_{I\!P}) = \int_{-\infty}^{0} dt F_2^{D(4)}(\beta, Q^2, x_{I\!P}, t). \tag{1.5}$$

The actual fits are to $\tilde{F}_2^D(\beta, Q^2)$, which is obtained by integrating $F_2^{D(3)}(\beta, Q^2, x_{I\!P})$ over the measured range of $x_{I\!P}$, $6.3 \cdot 10^{-4} < x_{I\!P} < 10^{-2}$, using the *fitted* $x_{I\!P}$ dependence.

Hard scattering factorization gives $F_2^{I\!P}$ in terms of parton densities and hard scattering coefficients in the usual fashion:

$$F_2^{I\!P}(\beta, Q^2) = \sum_a e_a^2 \beta f_{a/I\!P}(\beta) + \text{NLO corrections}. \tag{1.6}$$

No correction here for (15±10)% contribution from 'double-dissociation'.

3. Partons in the pomeron

- **We made 5 fits to the ZEUS data on $\tilde{F}_2^D(\beta, Q^2)$ with the following initial parton distributions at $Q_0^2 = 4$ GeV^2 with ($q = u, \overline{u}, d, \overline{d}$):**

A

$$\begin{aligned} \beta f^A_{q/I\!P}(\beta, Q_0^2) &= 0.585\, \beta(1-\beta), \\ \beta f^A_{g/I\!P}(\beta, Q_0^2) &= 0. \end{aligned} \tag{1.7}$$

B

$$\begin{aligned} \beta f^B_{q/I\!P}(\beta, Q_0^2) &= 0.516\, \beta(1-\beta), \\ \beta f^B_{g/I\!P}(\beta, Q_0^2) &= 12.28\, \beta(1-\beta). \end{aligned} \tag{1.8}$$

C

$$\begin{aligned} \beta f^C_{q/I\!P}(\beta, Q_0^2) &= 0.470\, \beta(1-\beta) + 0.080\,(1-\beta)^2, \\ \beta f^C_{g/I\!P}(\beta, Q_0^2) &= 0. \end{aligned} \tag{1.9}$$

D

$$\begin{aligned} \beta f^D_{q/I\!P}(\beta, Q_0^2) &= 0.512\, \beta(1-\beta) + 0.005\,(1-\beta)^2, \\ \beta f^D_{g/I\!P}(\beta, Q_0^2) &= 11.65\, \beta(1-\beta). \end{aligned} \tag{1.10}$$

SG

$$\begin{aligned} \beta f^{SG}_{q/I\!P}(\beta, Q_0^2) &= 0.354\, \beta(1-\beta), \\ \beta f^{SG}_{g/I\!P}(\beta, Q_0^2) &= 70.756\, \beta^8(1-\beta)^{0.3}. \end{aligned} \tag{1.11}$$

- **We did not impose a momentum sum rule constraint on the parton distributions.**
- **All fits were made with full NLO QCD with evolution ($n_f = 3$).**

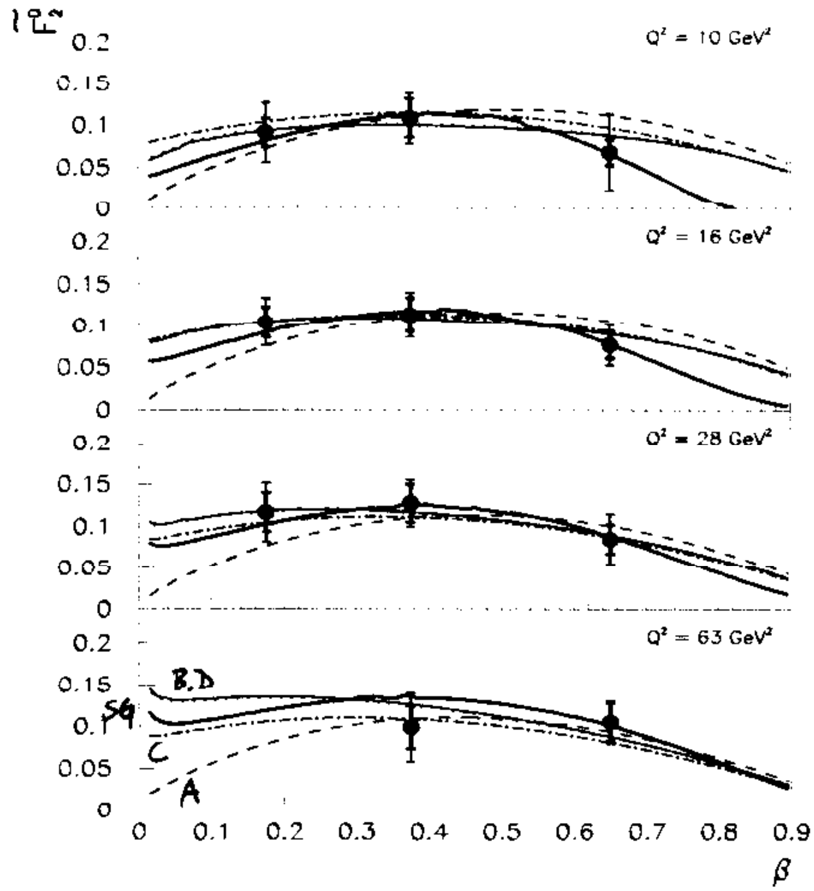


Figure 1.1: **The β dependence of the diffractive structure function $\tilde{F}_2^D$ measured by ZEUS, together with our fits. Fit A is represented by the dashed line, fit B by the thin solid line, fit C by the dot-dashed line, fit D by the dotted line, and fit SG by the thick solid line. Note that fits B and D are essentially indistinguishable.**

	Fit A	Fit B	Fit C	Fit D	Fit SG
χ^2/d.o.f	3.7/10	1.7/9	2.5/9	1.7/8	1.2/9
Statistical χ^2/d.o.f	18/10	3.8/9	6.0/9	3.8/8	3.1/9

(1.12)

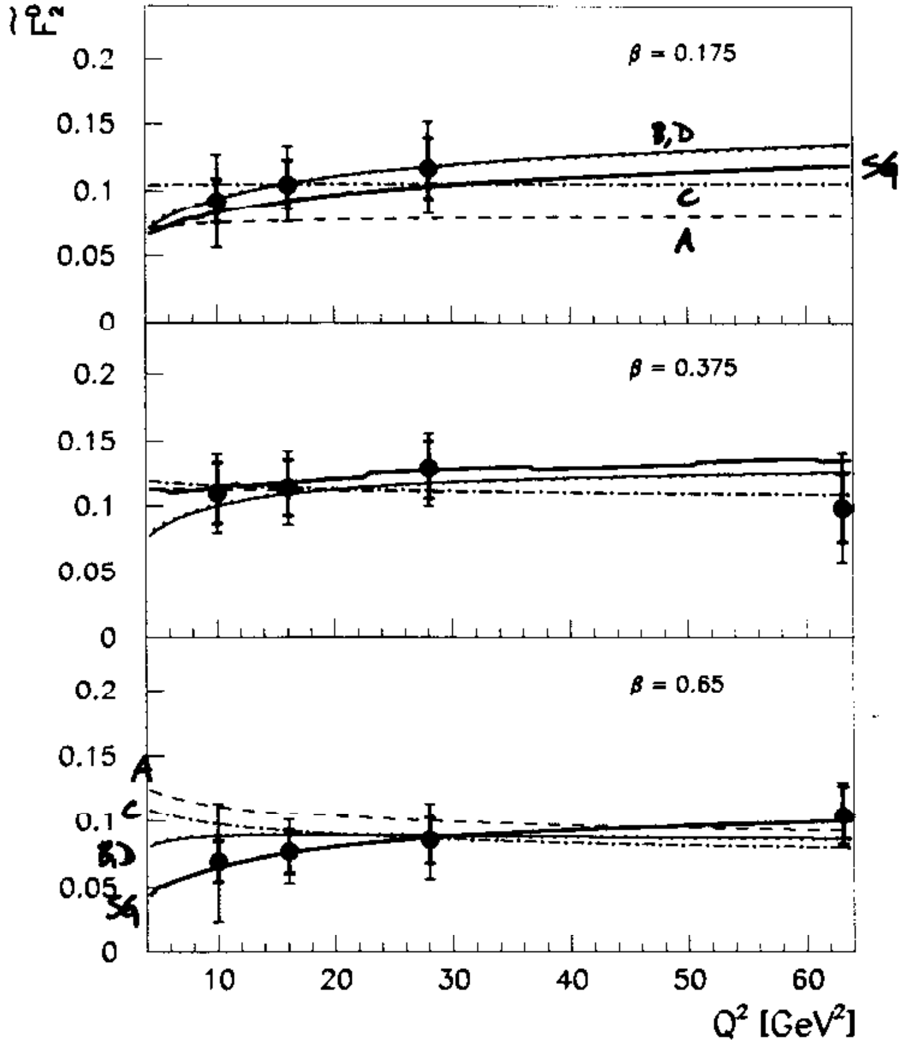


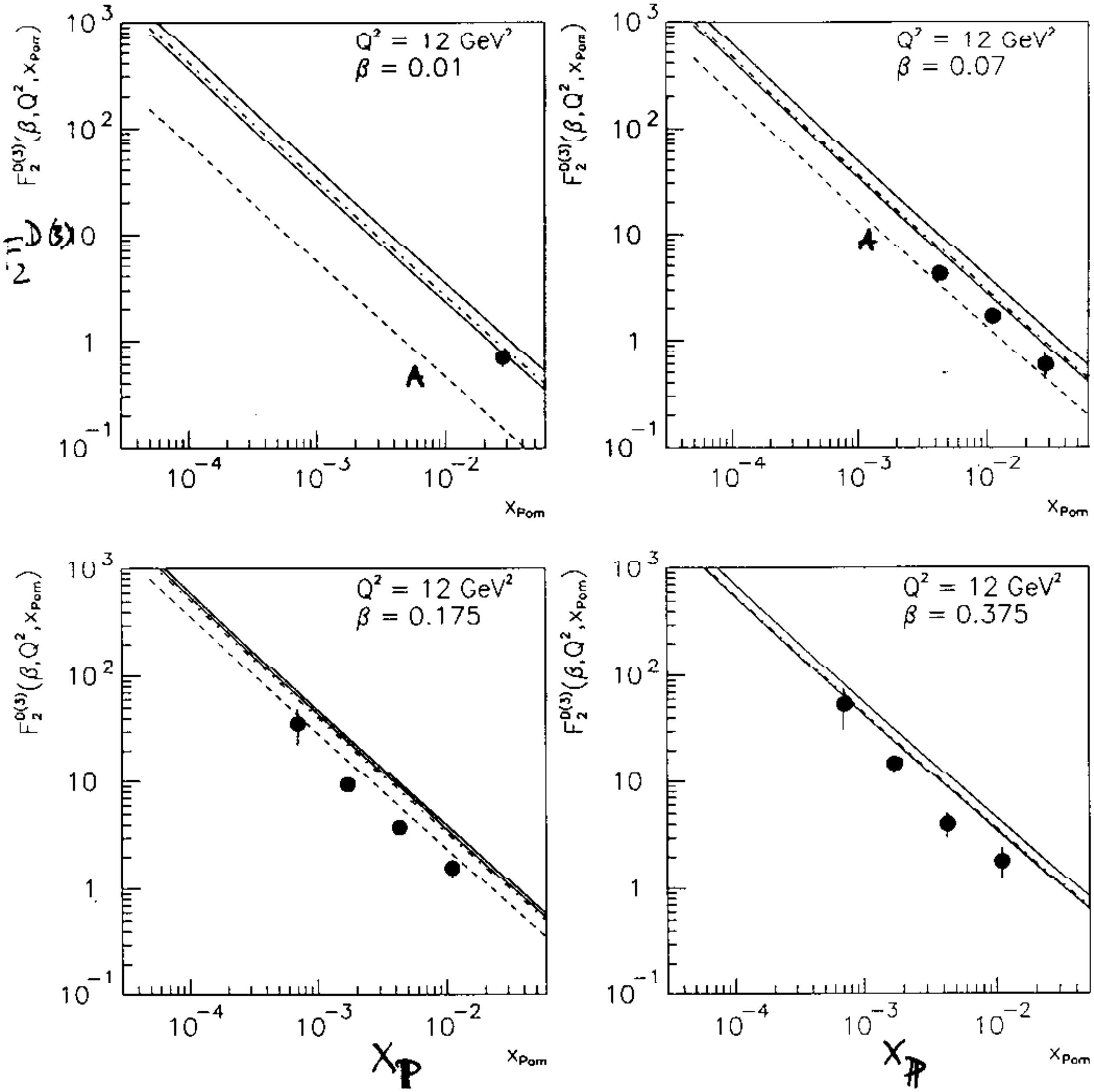
Figure 1.2: The Q^2 dependence of the diffractive structure function $\tilde{F}_2^D$ measured by ZEUS.

The momentum sums $\sum_a \int_0^1 d\beta\,\beta f_{a/I\!P}(\beta)$ are as follows:

	Fit A	Fit B	Fit C	Fit D	Fit SG
Quarks	0.39	0.34	0.42	0.35	0.24
Gluons	0	2.05	0	1.94	3.57
Total	0.39	2.39	0.42	2.29	3.81

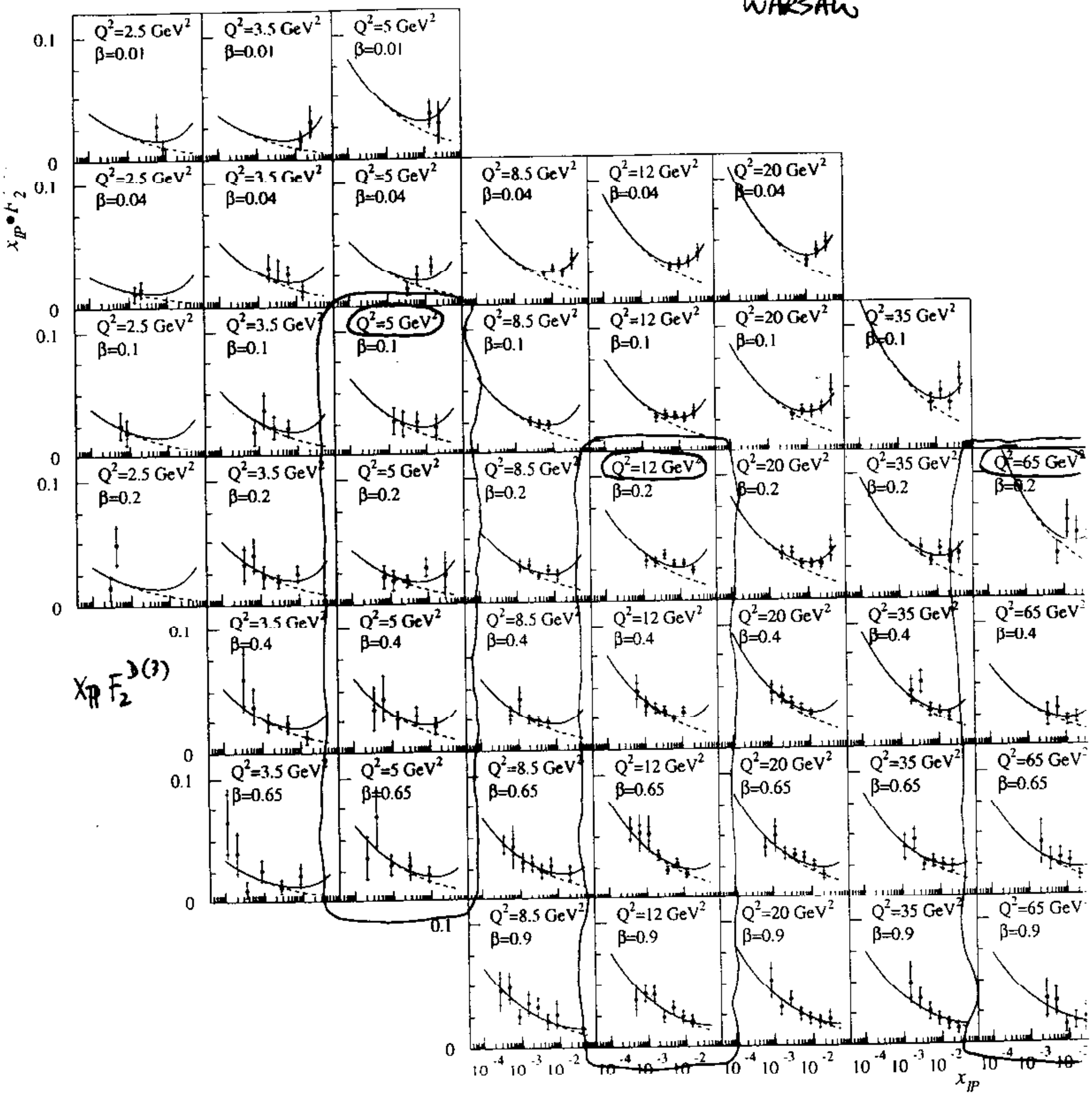
(1.13)

PRELIMINARY ZEUS - LPS (WARSAW)



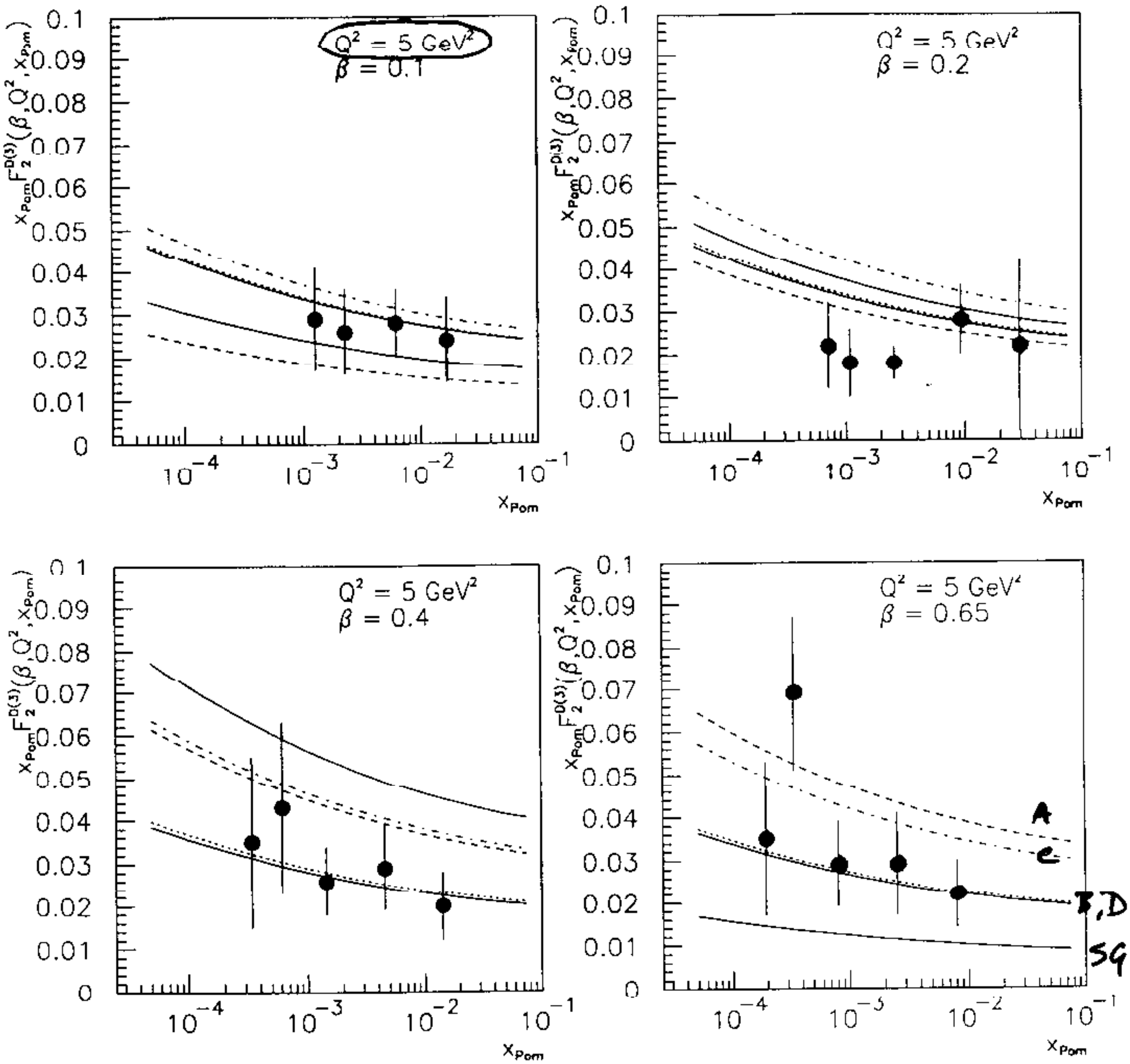
H1 Preliminary 1994

WARSAW

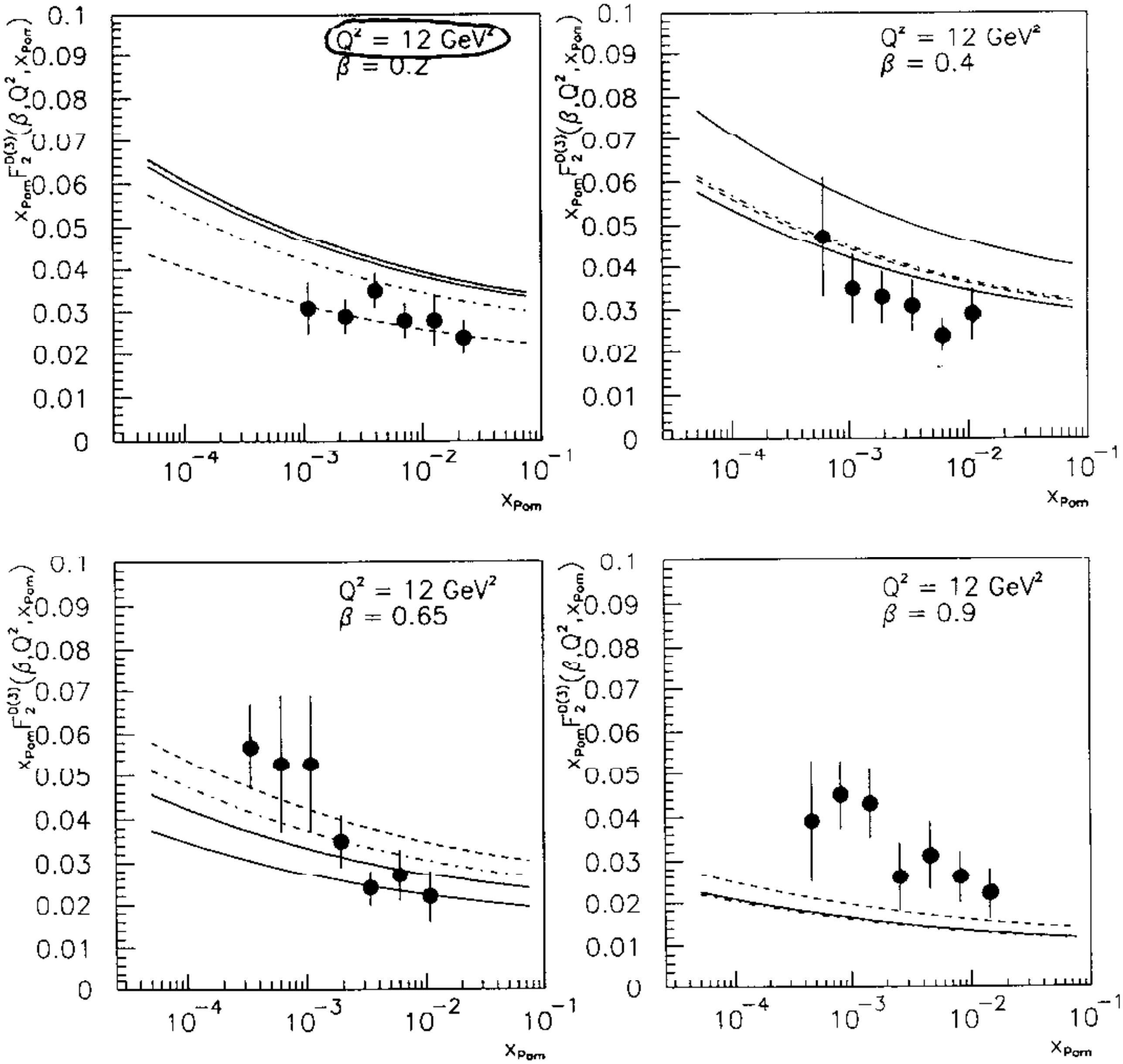


X_{IP}

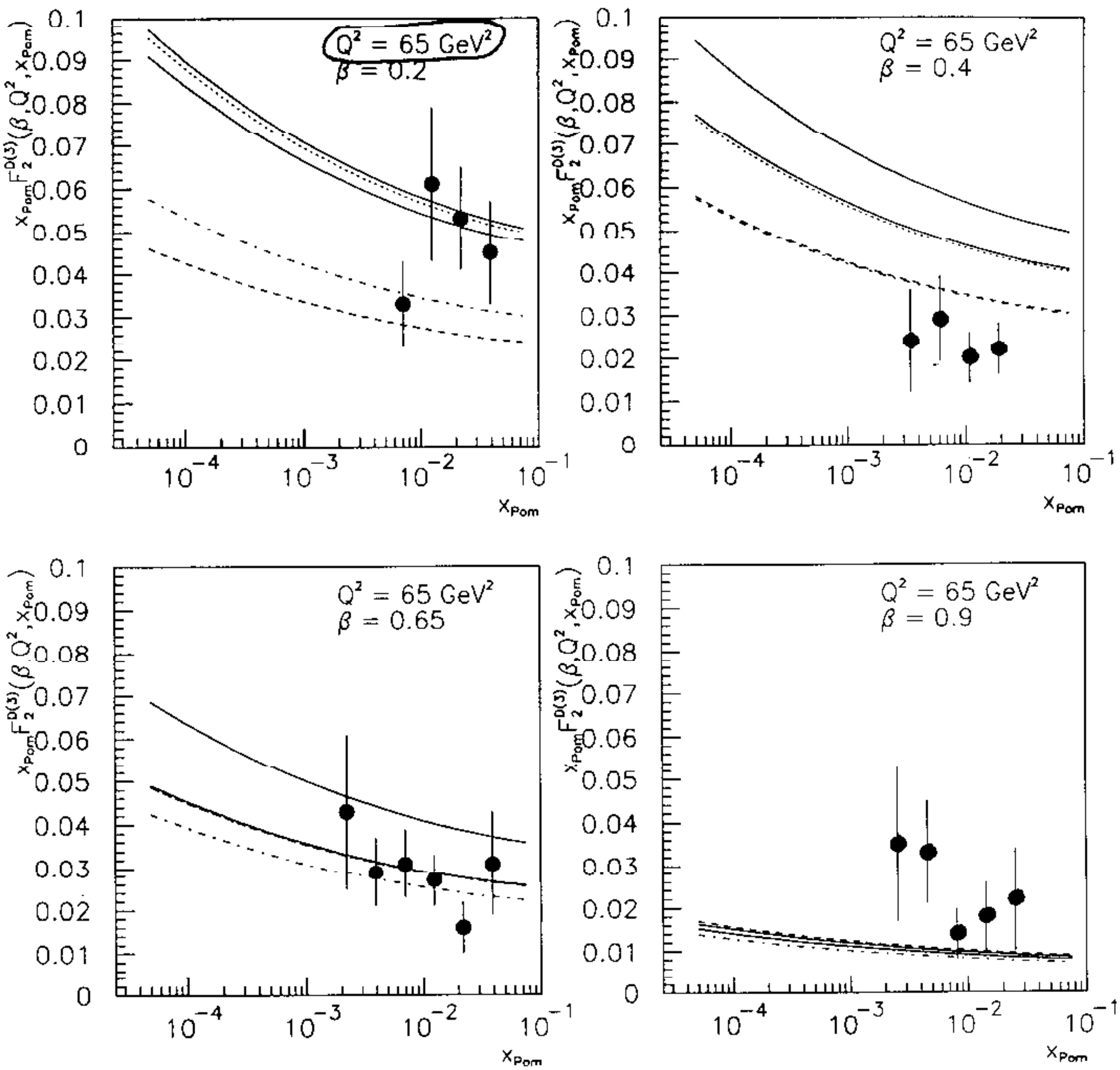
H1 PRELIMINARY (WARSAW)



H1 PRELIMINARY (WARSAW)



H1 PRELIMINARY (WARSAW)



4. Hard Diffractive Cross Sections at Tevatron

- Diffractive jet production

  The lowest order hard-scattering process is $2 \to 2$ at the parton level:

$$\frac{d\sigma^{jet}}{dy} = \sum_{a,b} \int_{E_T^{min}}^{E_T^{max}} dE_T\, 2E_T \int_{y'_{min}}^{y'_{max}} dy' \int_{x_{P}^{min}}^{x_{P}^{max}} dx_{I\!P}\, f_{I\!P/\bar{p}}(x_{I\!P}, \mu)\, f_{a/p}(x_a, \mu)\, f_{b/I\!P}(x_b, \mu) x_a x_b \frac{d\hat{\sigma}_{ab}^{jet}}{d\hat{t}} \tag{1.14}$$

  $(\mu = E_T^{jet})$

- Diffractive W and Z production

  The cross section for the diffractive production of weak vector bosons is given by:

$$\sigma^{W,Z} = \sum_{a,b} \int_{x_{P}^{min}}^{x_{P}^{max}} dx_{I\!P} \int_{x_b^{min}}^{1} dx_b f_{I\!P/\bar{p}}(x_{I\!P}) f_{b/I\!P}(x_b) f_{a/p}(x_a) \tilde{C}_{ab}^2 \frac{1}{s x_b x_{I\!P}} \left[\sqrt{2}\frac{\pi}{3} G_F M_{VB}^2\right], \tag{1.15}$$

  where $M_{VB} = M_W$ or M_Z is the vector boson mass, and G_F is the Fermi constant. For W bosons, $\tilde{C}_{ab}^W = V_{ab}$, the relevant Cabibbo-Kobayashi-Maskawa matrix element, while for the Z boson,

$$\tilde{C}_{ab}^Z = \delta_{\bar{a}b}\left[\frac{1}{2} - 2|e_b|\sin^2\theta_W + 4|e_b|^2\sin^4\theta_W\right], \tag{1.16}$$

  where e_b is the fractional charge of parton b and θ_W is the Weinberg or weak-mixing angle and $\mu = M_{VB}$.

- Define $R = \frac{\sigma^{diff}}{\sigma^{incl}}$
- We use the SAME (D-L) flux factor as in the fits to DIS data
- σ^{incl} is calculated in an analogous way without the diffractive requirement (ie using $f_{b/p}$, and no pomeron flux factor).

Comparison with Bruni and Ingelman

- Use the Ingelman-Schlein flux factor:

$$f_{\mathbb{P}/p}^{IS}(x_{\mathbb{P}}) = \int dt \frac{1}{2.3 x_{\mathbb{P}}} \left(6.38 e^{8t} + 0.424 e^{3t}\right). \tag{1.17}$$

- Use unevolved hard quark pdf:

$$\begin{aligned} \beta f_{q/\mathbb{P}}(\beta) &= \frac{6}{4}\beta(1-\beta), \\ \beta f_{g/\mathbb{P}}(\beta) &= 0. \end{aligned} \tag{1.18}$$

- Results

INCLUSIVE CROSS SECTION

	LO EHLQ1	EHLQ1	CTEQ3M
$W^+ + W^-$	14000	14332	18150
Z	4400	4407	5383

pb

Q_0^2

5 GeV^2 4 GeV^2

Pomeron: Proton:	BI unevolved EHLQ1	Our BI unevolved EHLQ1	BI evolved EHLQ1	Fit A evolved CTEQ3M	Fit D evolved CTEQ3M
$W^+ + W^-$	2800	2768	2025	518	844
Z	760	738	520	133	204

pb

$X_{\mathbb{P}}^{max} = 0.1$

DIFFRACTIVE CROSS SECTIONS

Pomeron: Proton:	BI (evolved) EHLQ1	Fit A (evolved) CTEQ3M	Fit D (evolved) CTEQ3M
$W^+ + W^-$	52.3	12.8	13.9
Z	6.6	1.6	1.6

pb

$X_{\mathbb{P}}^{max} = 0.01$

Comparison with Bruni and Ingelman

- Why are the fractions smaller than from BI?

  1. **A factor 0.8 because of the larger inclusive cross sections when one uses CTEQ3M instead of the obsolete EHLQ1 distributions in the proton.**
  2. **A factor 0.7 for the effect of the evolution of the parton densities in the pomeron.**
  3. **A factor 0.7 for the use of the Donnachie-Landshoff flux factor instead of the Ingelman-Schlein flux factor, when the momentum sum is kept fixed.**
  4. **A factor 0.5 because the data indicate that the quarks give a contribution to the momentum sum of 0.5 (with the DL normalization), instead of unity as assumed by Bruni and Ingelman.**

- The net effect is a factor of 5 smaller than B-I

Results

- Diffractive W and Z production at the Tevatron

	BI (unevolved) $x_{\mathbb{P}}^{max} = 0.1$	Fit A $x_{\mathbb{P}}^{max} = 0.1$	Fit D $x_{\mathbb{P}}^{max} = 0.1$	Fit A $x_{\mathbb{P}}^{max} = 0.01$	Fit D $x_{\mathbb{P}}^{max} = 0.01$
$W^+ + W^-$	19% 17%	2.9%	4.7%	0.07%	0.08%
Z	17% 15%	2.5%	3.8%	0.03%	0.03%

Table 1.1: Diffractive fractions

- Diffractive Jets at the Tevatron

$y_1 \cdot y_2 > 0 \quad E_T^{Jet} > 20\,\text{GeV} \quad |y| > 1.8$

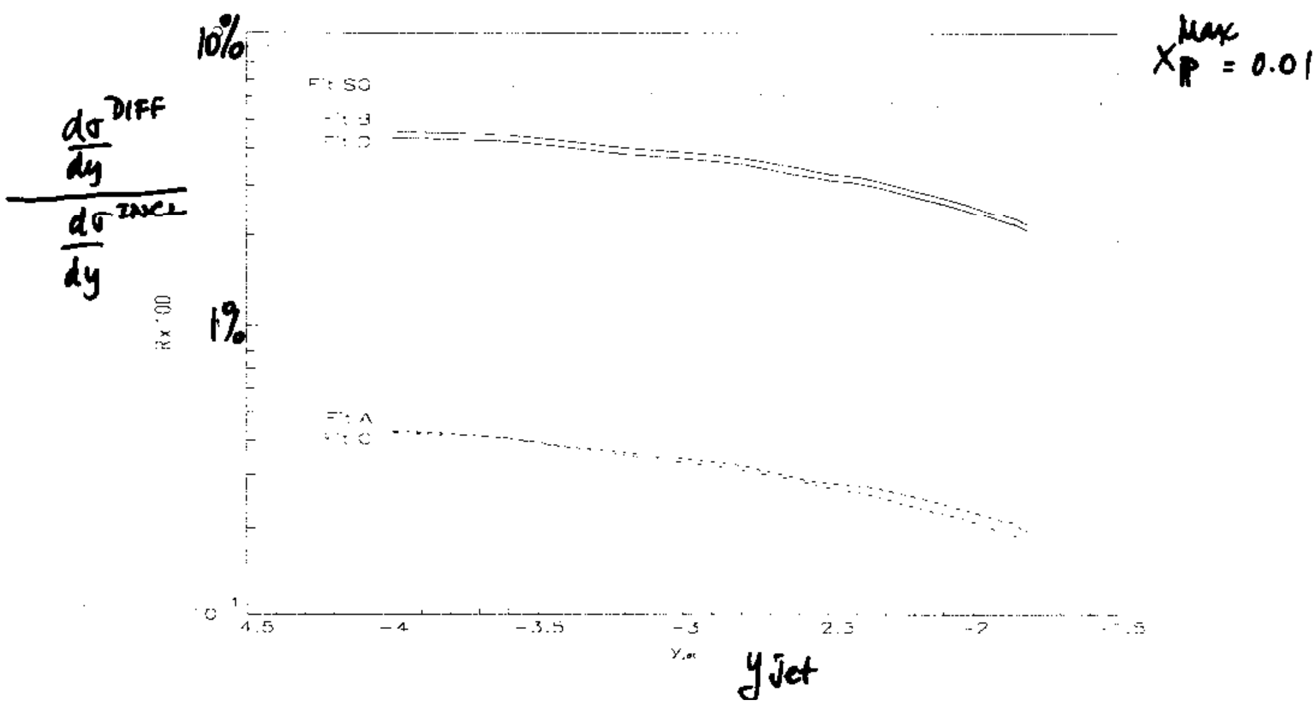


Figure 1.3: Diffractive Jet Production Rates.

Comparison with CDF and D0 data

- CDF Diffractive W production (hep-ex/9703010)

  $p\bar{p}$ **collisions at** $\sqrt{s} = 1.8\,TeV$ **and a rapidity gap** $2.4 < |\eta| < 4.2$.

  $R_W = [1.15 \pm 0.51(stat) \pm 0.23(syst)]\%.$ $= \dfrac{\text{DIFFRACTIVE}}{\text{NON-DIFFRACTIVE}}$

  They are computed with the diffracted hadron being allowed to be either the proton or the antiproton.

	Fit A	Fit B	Fit C	Fit D	$x_{\mathbb{P}}^{max}$
$W^+ + W^-$	0.56%	0.67%	0.50%	0.66%	0.017
$W^+ + W^-$	5.8%	9.5%	5.9%	9.4%	0.1

"From MC simulations, we estimate that the diffractive events are concentrated at ζ-values in the range 0.01-0.05".

$\zeta = x_{\mathbb{P}}$

Comparison with CDF and D0 data

- CDF Diffractive Dijet Data

  1. A rapidity gap (Fermilab-Pub-97/076-E):
     $2.4 < |\eta| < 4.2$, $E_T^{jet} > 20$ **GeV and** $1.8 < |\eta^{jet}| < 3.5$, **and** $\eta_1\eta_2 > 0$.
     $R_{JJ} = [0.75 \pm 0.05 \pm 0.09]\%$. **Our calculation assumes that either the**

	Fit A	Fit B	Fit C	Fit D	56	x_P^{max}
$\frac{\sigma^{jet,diff}}{\sigma^{jet,incl}}$	0.57%	5.5%	0.58%	5.2%		0.01
$\frac{\sigma^{jet,diff}}{\sigma^{jet,incl}}$	1.5%	16.4%	1.8%	15.6%	17.5%	0.1

     antiproton or the proton is diffracted.
     "The events are concentrated at $0.005 < \zeta < 0.015$." x_P

  2. Roman pot triggered sample
     $R_{JJ} = [0.109 \pm 0.003 \pm 0.016]\%$.
     For $x_{I\!P}$ **in the range** $0.05 < x_{I\!P} < 0.1$, **with** $E_T^{jet} > 10$ **GeV.**

	Fit A	Fit B	Fit C	Fit D
$\frac{\sigma^{jet,diff}}{\sigma^{jet,incl}}$	0.41%	4.2%	0.45%	4.0%

     Need to correct these down by $(15 \pm 10)\%$ **for unidentified proton dissociation. Our calculation assumes that only the antiproton is diffracted.**

- D0 diffractive dijet production

  $E_T > 12\,GeV$ **and** $|\eta^{jet}| > 1.6$.
  $R_{JJ} = [0.67 \pm 0.05]\%$.
  Our calculation assumes that either the antiproton or the proton is diffracted.

	Fit A	Fit B	Fit C	Fit D	x_P^{max}
$\frac{\sigma^{jet,diff}}{\sigma^{jet,incl}}$	0.96%	10.3%	1.1%	9.8%	0.1

5. Conclusions

- Diffractive DIS HERA data prefer fits with large initial gluon distribution in the pomeron
- It is difficult to directly compare the calculated diffractive contributions with the Tevatron data owing to the uncertainty in the $x_{I\!P}$ range from the rapidity gap data.
- Compared to diffractive W and dijet data from CDF and D0, the predictions with large gluon content are factors of 10 above the data.
- The fits with small gluon content are tens of % greater than the data.

This suggests a breakdown of hard scattering factorization

- The more recent H1 and ZEUS diffractive DIS data soon to be published as well as the direct photon contribution to the diffractive hard photoproduction data from ZEUS can be expected to further address the issue of hard scattering factorization in diffractive processes.