PHENOMENOLOGY OF DIFFRACTIVE PARTON DENSITIES

POMERON: BEYOND THE STANDARD APPROACH
(hep-ph/9911210 2Nov 1999)

Konstantin Goulianos

The Rockefeller University
New York, NY 10021, U.S.A.

Physics at Run II Workshop
Diffraction and Color Coherence
Working Group VI

FERMILAB
4-6 November 1999

- Introduction
- **Lessons from experiment:**

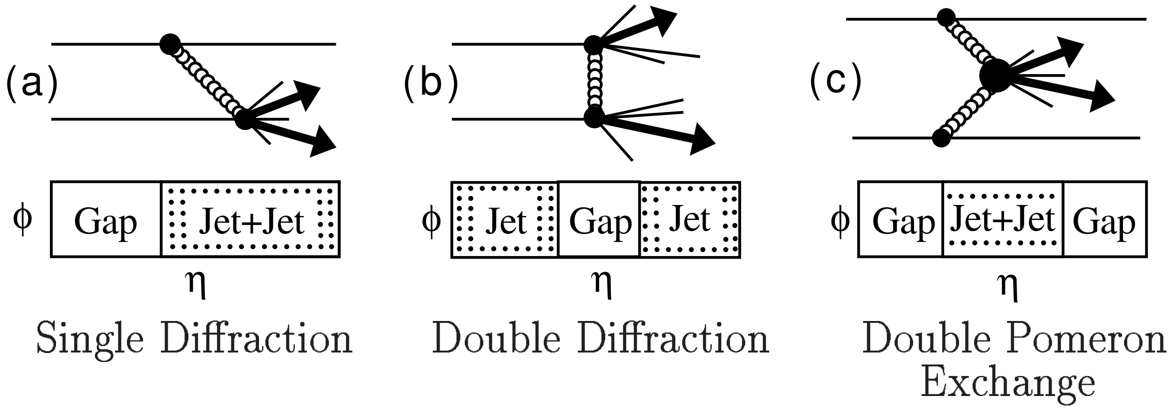
  1. SOFT DIFFRACTION

  2. HARD DIFFRACTION

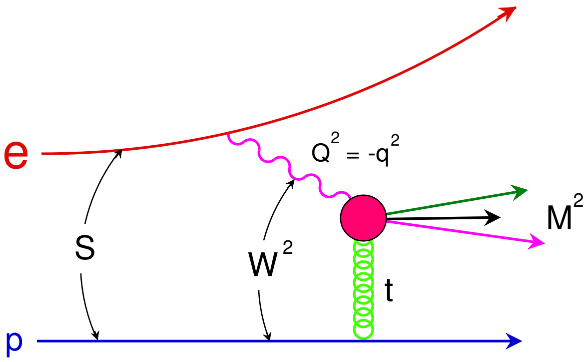
- **A new approach to Diffraction**

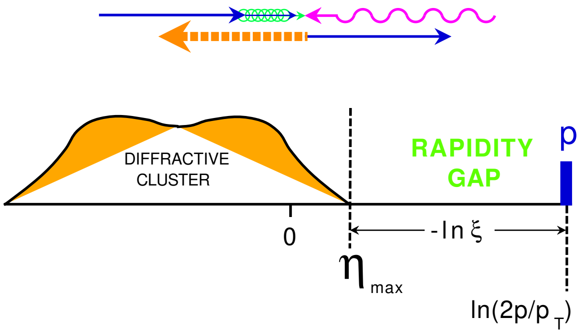
HARD DIFFRACTION

TEVATRON



HERA





$$\xi = \frac{(p - p')\cdot q}{p \cdot q} \approx \frac{\Delta p}{p}$$

$$\beta = \frac{x}{\xi}$$

$$\xi = \frac{M^2}{s} = \frac{1}{\sqrt{s}} \sum_i E_{T,i} e^{-y_i}$$

$$\Delta Y \approx \ln \frac{1}{\xi}$$

$$\boxed{F_2(\xi, t, x, Q^2)}$$

CDF RAPIDITY GAP RESULTS

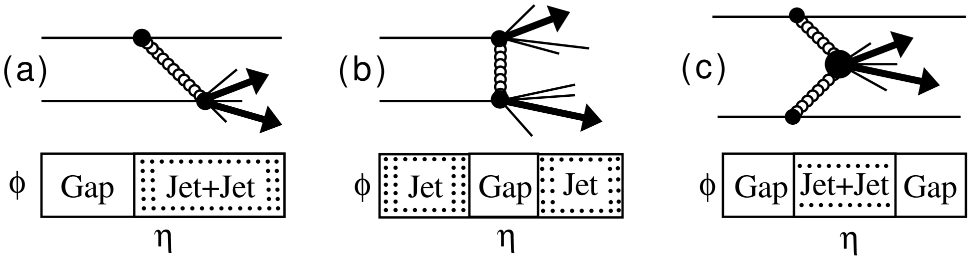


Fig. 1: Event topology of dijet production in (a) SD, (b) DD and (c) DPE.

Hard process	$\sqrt{s}$ (GeV)	$R = \frac{\text{DIFF}}{\text{TOTAL}}$ (%)	Comments	Ref
$\boxed{\text{SD}}$				
$W(\rightarrow e\nu)$+G	1800	1.15 ± 0.55	E_T^e, $\not{E}_T > 20$ GeV	1
Jet+Jet+G	1800	0.75 ± 0.1	$E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$	2
$b(\rightarrow e + X)$+G	1800	0.62 ± 0.25	$\|\eta^e\| < 1.1$, $p_T^e > 9.5$ GeV	3
$J/\psi(\rightarrow \mu\mu)$+G	1800	$(0.27 \pm 0.05)/\mathcal{A}^{\dagger}$	$\|\eta^\mu\| < 0.6$, $p_T^\mu > 2$ GeV	*
$\boxed{\text{DD}}$				
Jet-G-Jet	1800	1.13 ± 0.16	$E_T^{jet} > 20$ GeV, $\eta^{jet} > 1.8$	4
Jet-G-Jet	630	2.7 ± 0.9	$E_T^{jet} > 8$ GeV, $\eta^{jet} > 1.8$	5
$\boxed{\text{DPE}}$				
$\bar{p}$-(Jet+Jet)-G	1800	$\sim 10^{-5}/\mathcal{A}_{DPE}{}^{\ddagger}$	$E_T^{jet} > 7$ GeV, $0.04 < \xi_{\bar{p}} < 0.1$	*

* Preliminary

† $\mathcal{A}\sim 0.4$ (estimated rapidity gap acceptance)

‡ $\mathcal{A}_{DPE}\sim 0.2$ (estimated **double**-gap acceptance for DPE)

References

1. F. Abe *et al.*, CDF Collaboration, Phys. Rev. Lett. **78**, 2698 (1997).
2. F. Abe *et al.*, CDF Collaboration, Phys. Rev. Lett. **79**, 2636 (1997).
3. T. Affolder *et al.*, CDF Collaboration, submitted to PRL (August 1999).
4. F. Abe *et al.*, CDF Collaboration, Phys. Rev. Lett. **80**, 1156 (1998).
5. F. Abe *et al.*, CDF Collaboration, Phys. Rev. Lett. **81**, 5278 (1998).

Diffractive Parton Densities
Extracted from DIS at HERA
by the H1 Collaboration

$$\frac{d^3\sigma}{d\xi\, d\beta\, dQ^2} \sim A \cdot f_{I\!P}(\xi) \cdot F_2^{I\!P}(\beta, Q^2) + B \cdot f_{I\!R}(\xi) \cdot F_2^{I\!R}(\beta, Q^2)$$

Assumptions and fit parameters

- Assume: $f_{I\!P,I\!R}(\xi) = 1/\xi^{1+2\epsilon+2\alpha'\langle t\rangle}$
- $\epsilon_{I\!P}$ and $\epsilon_{I\!R}$ are free parameters;
  $\epsilon_{I\!P}$ turns out to be ~ 0.2 (instead of 0.1) $\boxed{\text{Why?}}$
- Assume $\alpha'_{I\!P} = 0.25$, the same as for soft diffraction
- **Normalization:** A and B are free parameters
- **Initial conditions:** Assume $g_{I\!P}(\beta, Q^2)$ at low Q^2
- Assume pion pdf's for reggeon exchange

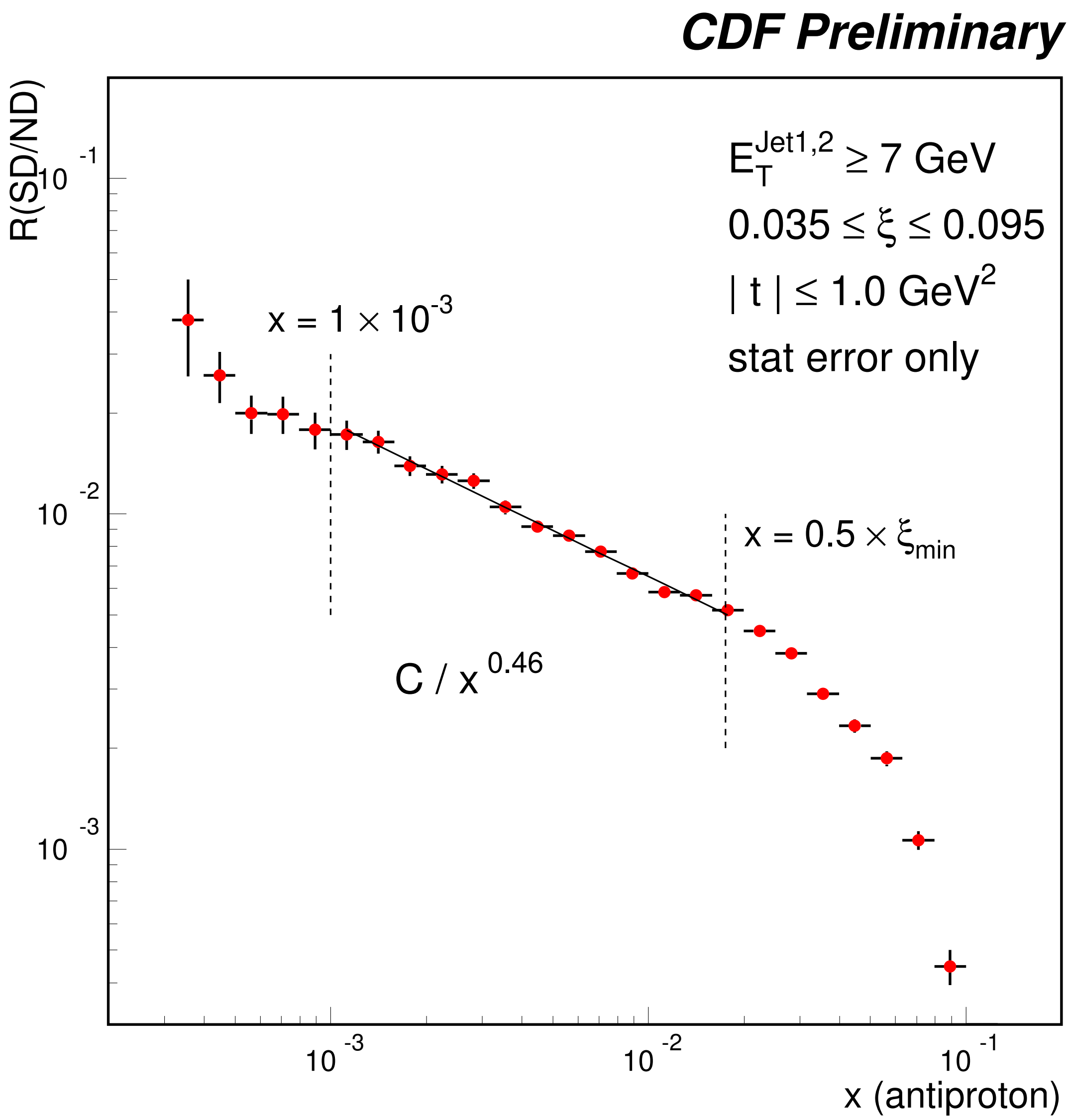
RESULTS

- Two solutions that differ at high β
- Extrapolation of the fit to low β does not work!

RATIO OF SD TO ND DIJET PRODUCTION RATES

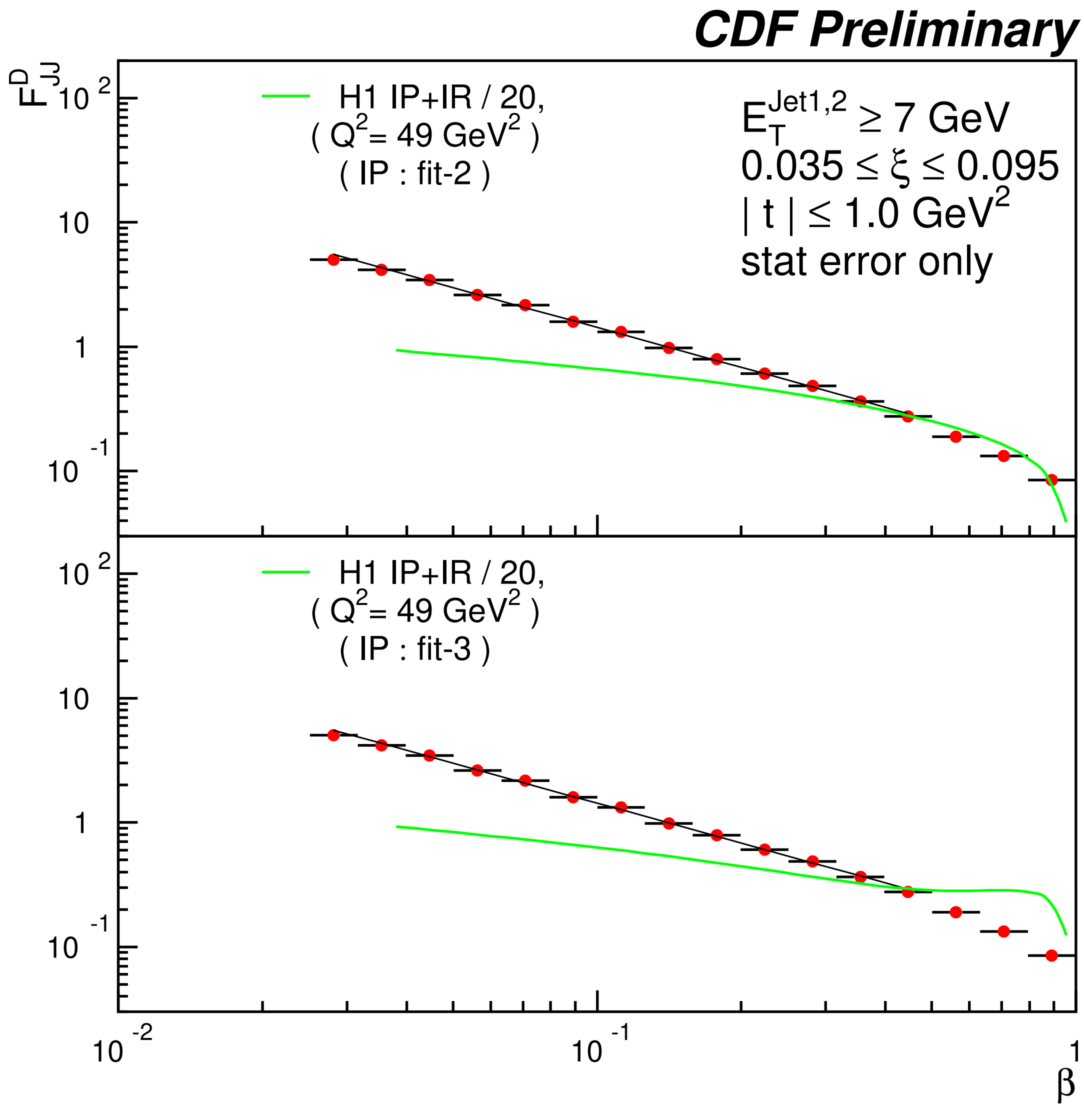
$$R_{\frac{SD}{ND}}(x_{\bar{p}}) = \frac{F^D_{JJ}(x_{\bar{p}})}{F_{JJ}(x_{\bar{p}})} \qquad \boxed{x_{\bar{p}} = \Sigma_i \frac{E^i_T\, e^{-y_i}}{\sqrt{s}}}$$

$$F^D_{JJ}(x_{\bar{p}}) = x_{\bar{p}}\left[g^{(D)}(x_{\bar{p}}) + \tfrac{4}{9}\Sigma_i\left\{q_i^{(D)}(x_{\bar{p}}) + \bar{q}_i^{(D)}(x_{\bar{p}})\right\}\right]$$



CDF versus HERA

$$\boxed{\beta = x_{\bar{p}}/\xi}$$



1 Fermilab Fixed Target Experiments

1.1 Internal Gas-Jet Target Experiments

$p-p$ **and** $p-d$ elastic scattering and diffraction dissociation:

- Shrinking of elastic peak with s: measure α'
- ρ-value $\Rightarrow$ rising total cross section
- $1/M_X^2$ behaviour
- Factorization (pp vs pd)
- Finite mass sum rule

1.2 Hadron Dissociation: $h+p \rightarrow X+p$ (h=$\pi^{\pm}$, $K^{\pm}$, $p^{\pm}$)

- Factorization
- Diffractive charged particle multiplicities $\Rightarrow$ **universality**

1.3 Photon Dissociation: $\gamma+p \rightarrow X+p$

- $1/M_X^2$ behaviour
- Comparison with $\pi^-+p \rightarrow X+p$

2 CERN: Experiment UA6

Precision measurement of pp and $\bar{p}p$ ρ-values at $\sqrt{s}=24.3$ GeV.

3 Collider Detector at Fermilab - CDF

- Measurement of elastic, diffractive and total cross sections at $\sqrt{s}=1800$ and 546 GeV
- Measurement of the double diffraction dissociation cross section
- Hard double diffraction at $\sqrt{s}=1800$ and 630 GeV: **Jet-Gap-Jet events**
- Hard single diffraction at $\sqrt{s}=1800$: W, **JJ**, b **and** J/ψ production
- Diffractive structure function of the antiproton

Regge Theory Predictions

- Total cross section

$$\sigma^{tot} \sim \left(\frac{s}{s_\circ}\right)^{\epsilon}$$

- Elastic scattering

$$b = b_\circ + 2\alpha' \ln \frac{s}{s_\circ}$$

- Single diffraction

$$\frac{d\sigma}{d\xi} \sim \frac{1}{\xi^{1+2\epsilon}} \cdot (\xi s)^{\epsilon}$$

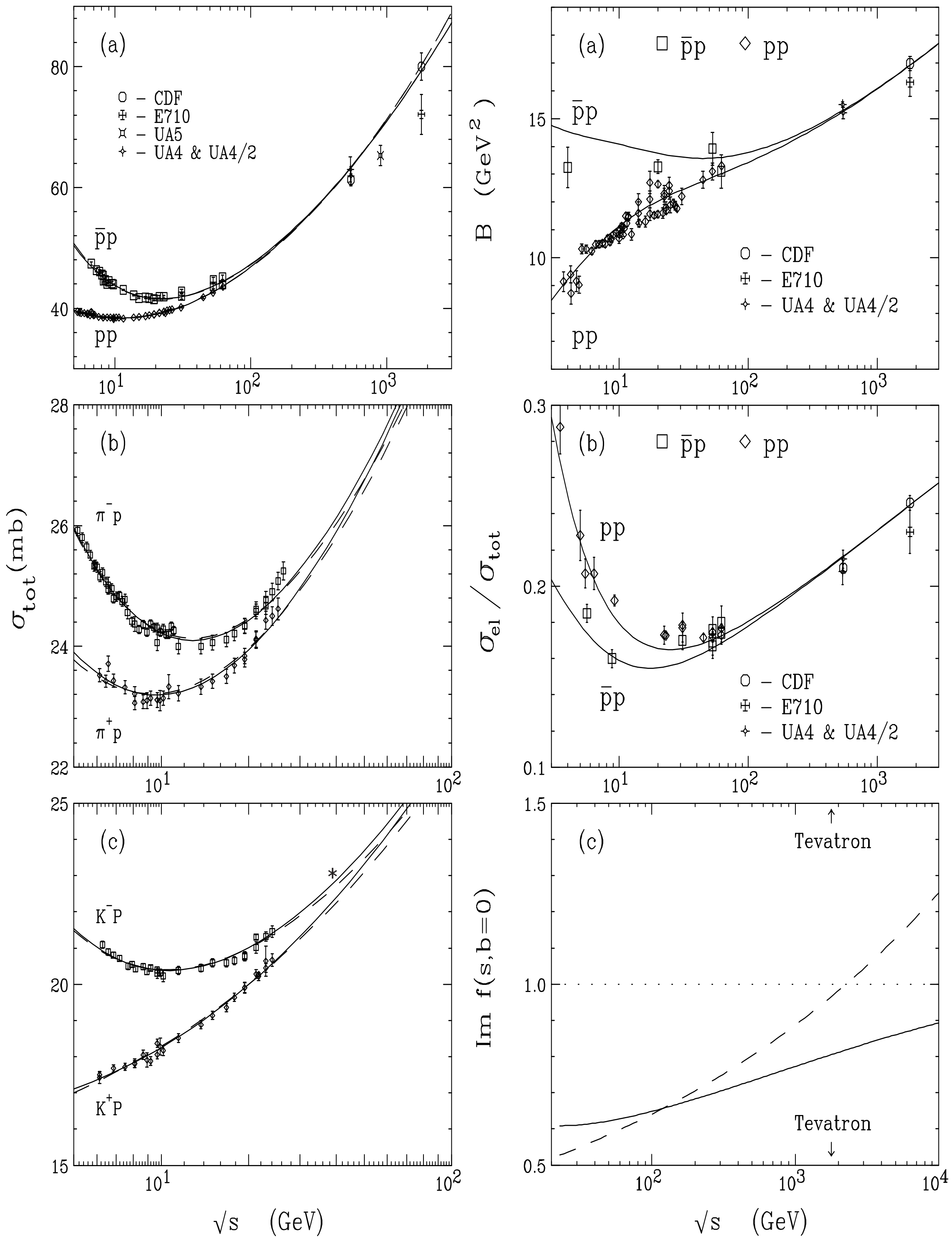
$$\boxed{\xi = \frac{M^2}{s}}$$

$$\frac{d\sigma}{dM^2} \sim \frac{s^{2\epsilon}}{(M^2)^{1+\epsilon}}$$

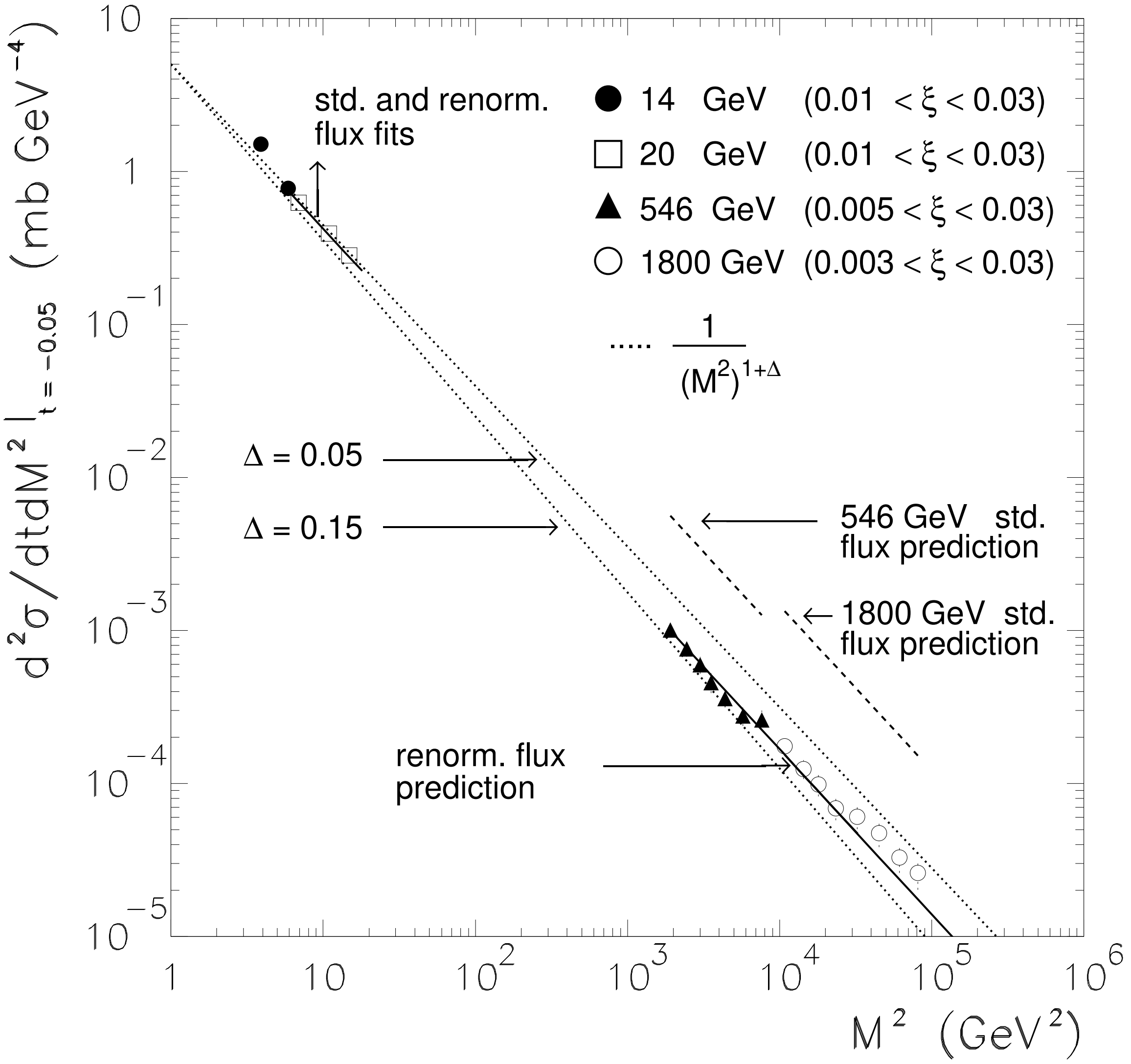
Total and Elastic Cross Sections

Covolan, Montanha and Goulianos, Phys. Lett. B 389 (1996) 176

$$\boxed{\alpha_{I\!P} = 1 + \epsilon\,(\Rightarrow 0.104) + 0.25t \quad \alpha_{f/a} = 0.68 + 0.82t \quad \alpha_{\omega/\rho} = 0.46 + 0.92t}$$



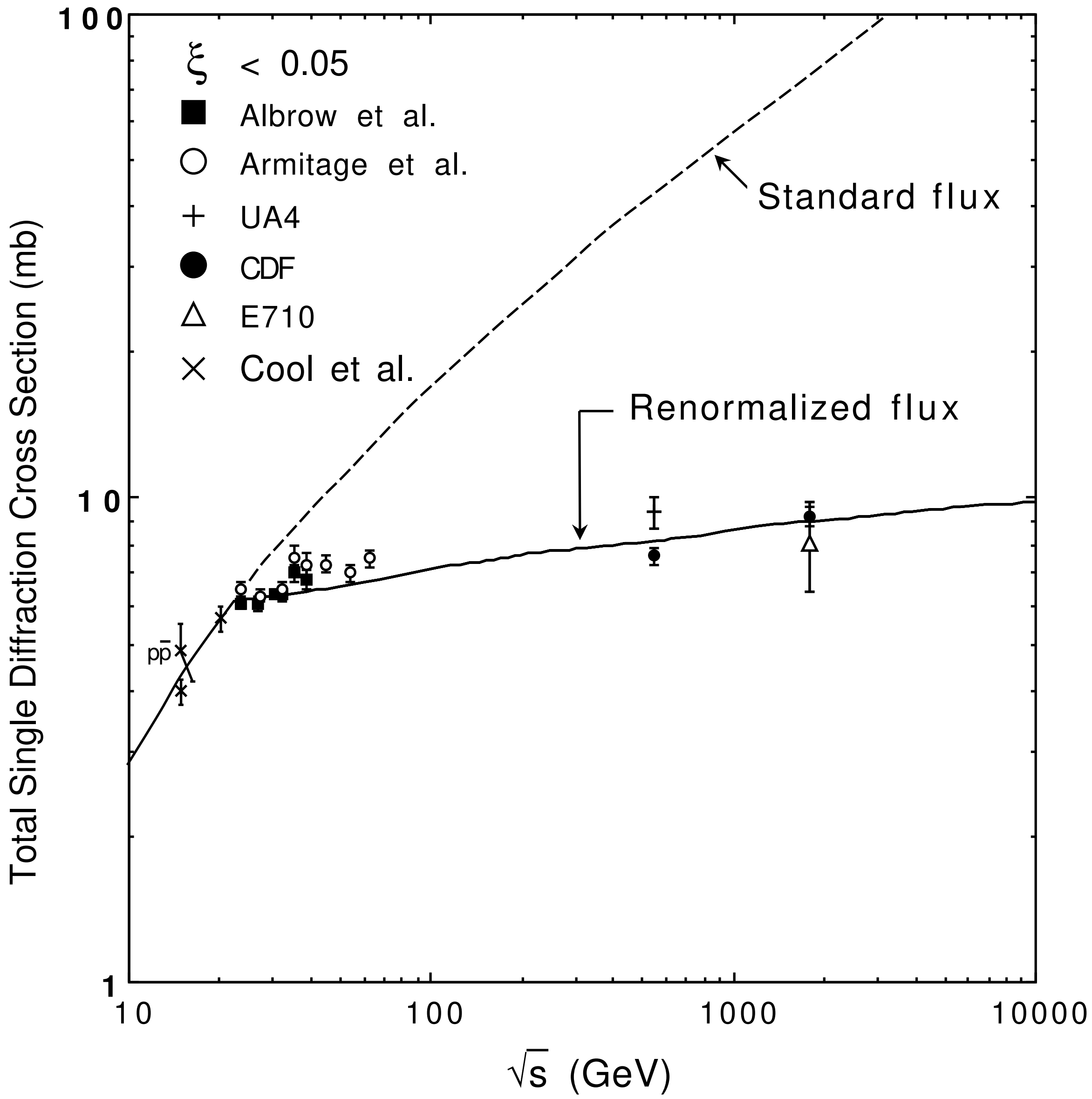
K. Goulianos and J. Montanha, Phys. Rev. **D 59**, 114017 (1999).



Cross sections $d^2\sigma_{sd}/dM^2dt$ for $p+p(\bar{p}) \rightarrow p(\bar{p})+X$ at $t=-0.05$ GeV^2 and $\sqrt{s}=14$, 20, 546 and 1800 GeV. At $\sqrt{s}$=14 and 20 GeV, the fits using the standard and renormalized fluxes coincide; at the higher energies, the standard (renormalized) flux predictions are shown by the dashed (solid) lines.

Single Diffraction Total Cross Sections

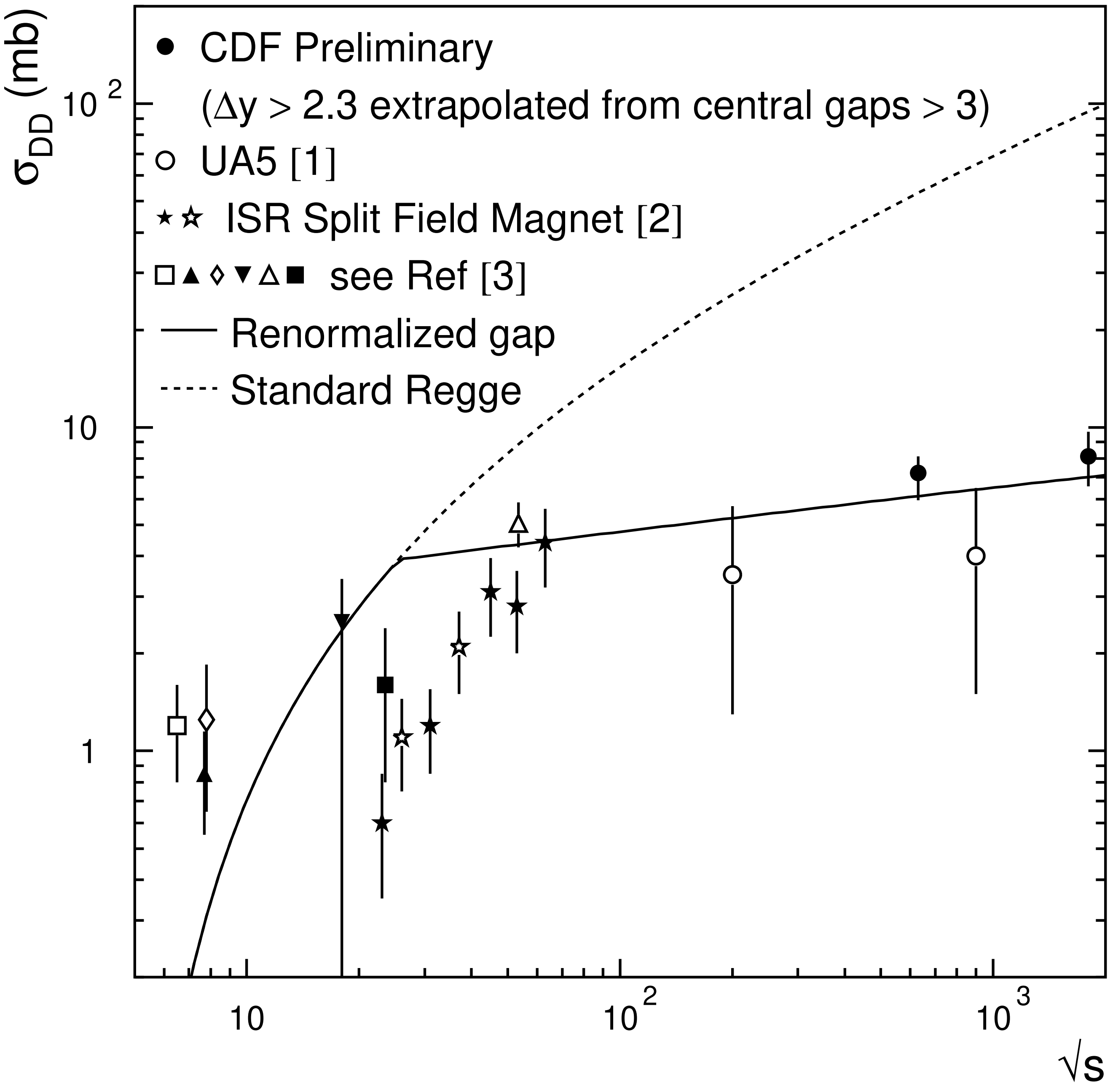
KG, Phys. Lett. B 358 (1995) 379



Double Diffraction Total Cross Sections

$$\frac{d^3\sigma^{DD}}{dt\,d\Delta y\,dy_\circ} =$$

$$\underbrace{\frac{\kappa\,\beta^2(0)}{16\pi} e^{2\epsilon\Delta y} e^{2\alpha'\Delta y t}}_{\text{GAP PROBABILITY}} \times \underbrace{\kappa\,\beta^2(0)(s'/s_\circ)^\epsilon}_{\text{SUB}-\text{ENERGY }\sigma^T}$$



$\boxed{\text{SMALL } x}$

- $\boxed{\sigma_T \sim \left(\frac{s}{s_\circ}\right)^\epsilon}$

$$\int_{(s_\circ/s)}^1 \frac{dx}{x^{1+\epsilon}} \sim \left(\frac{s}{s_\circ}\right)^\epsilon$$

- $\boxed{\frac{d\sigma^{el}}{dt} \sim e^{(b_\circ + 2\alpha' \ln s)t}} \Rightarrow \sim e^{(b_\circ + cs^\epsilon)t}$

Note: $(1800/20)^{2*0.104} = 2.55; \quad \ln(1800^2)/\ln(20)^2 = 2.50$

- $\boxed{\frac{d\sigma^{sd}}{dM^2} \sim \frac{1}{(M^2)^{1+\epsilon}}}$

$$\xi = \frac{M^2}{s} \qquad \Rightarrow \qquad \frac{d\sigma^{sd}}{d\xi} \sim \frac{1}{s^\epsilon} \frac{1}{\xi^{1+\epsilon}}$$

$$\boxed{\frac{d\sigma^{sd}}{d\xi} \sim \frac{1}{s^{2\epsilon}} \frac{1}{\xi^{1+2\epsilon}} \times (\xi s)^\epsilon}$$

Note: $\int_{(s_\circ/s)}^1 \frac{1}{s^{2\epsilon}} \frac{d\xi}{\xi^{1+2\epsilon}} = \text{constant}$

- DIS

$$\frac{d^2\sigma}{dx dQ^2} \sim \frac{F_2^h(x,Q^2)}{x}$$

- Diffractive DIS

$$\frac{d^3\sigma}{d\xi dx dQ^2} \sim \frac{F_2^h(x,Q^2)}{x} \times \frac{F_2^s(\xi)}{\xi} \otimes \xi\text{-norm}$$

$$\boxed{x \equiv \beta\xi}$$

$$\frac{d^3\sigma}{d\xi d\beta dQ^2} \sim \frac{F_2^h(\beta\xi,Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi} \otimes \xi\text{-norm}$$

$$\frac{d^3\sigma}{d\xi d\beta dQ^2} \sim \frac{\frac{F_2^h(\beta\xi,Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi}}{\int_{\xi_{min}=Q^2/\beta s}^{1} \frac{F_2^h(\beta\xi,Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi} d\xi} \times f_q \times \frac{F_2^h(\beta,Q^2)}{\beta}$$

$$\boxed{F_2^{D(3)}(\xi,\beta,Q^2) = \frac{\frac{F_2^h(\beta\xi,Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi}}{\int_{\xi_{min}=Q^2/\beta s}^{1} \frac{F_2^h(\beta\xi,Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi} d\xi} \times f_q \times F_2^h(\beta,Q^2)}$$

$$\boxed{R\left[\frac{\text{diff}}{\text{non}-\text{diff}}\right](\xi,x,Q^2) = f_q \times \frac{\frac{F_2^h(\beta,Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi}}{\int_{\xi_{min}}^{1} \frac{F_2^h(\beta\xi,Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi} d\xi}}$$

Note: In $\bar{p}p$ collisions $\xi_{min} = \frac{M_\circ^2}{s}$, where $M_\circ^2 \approx 1.5$ GeV^2

Diffractive DIS: Example calculation

$$F_2^h(x, Q^2) = \frac{A^h}{x^{\epsilon^h}}$$

$$F_2^s(x, \mu) = \frac{A^s}{x^{\epsilon^s}} \qquad (\mu = < p_T^s >^2)$$

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

$$\Rightarrow \int_{\xi_{min}}^{1} \frac{F_2^h(\beta\xi, Q^2)}{\beta} \times \frac{F_2^s(\xi)}{\xi} d\xi = \frac{A^h}{\beta^{\epsilon^h}} \, \frac{A^s}{\epsilon^h + \epsilon^s} \, \left(\frac{\beta s}{Q^2}\right)^{\epsilon^h + \epsilon^s}$$

$$F_2^{D(3)}(\xi, \beta, Q^2) = \frac{A^h}{\beta^{\epsilon^h}} \, \frac{f_q}{\xi^{1+\epsilon^h+\epsilon^s}} \, (\epsilon^h + \epsilon^s) \, \left(\frac{Q^2}{\beta s}\right)^{\epsilon^h + \epsilon^s}$$

$$\boxed{F_2^{D(3)}(\xi, \beta, Q^2) = \frac{A^h \cdot f_q \cdot (\epsilon^s + \epsilon^h) \cdot (Q^2/s)^{\epsilon^s + \epsilon^h}}{\xi^{1+\epsilon^h+\epsilon^s} \cdot \beta^{\epsilon^s + 2\epsilon^h}}}$$

$$\boxed{R\left[\frac{\text{diff}}{\text{non}-\text{diff}}\right](\xi, x, Q^2) \sim \frac{1}{x^{(\epsilon^h + \epsilon^s)}}}$$

Comparison with H1 data

$$\boxed{F_2^{D(3)}(\xi,\beta,Q^2) = \frac{A^h \cdot f_q \cdot (\epsilon^s + \epsilon^h) \cdot (Q^2/s)^{\epsilon^s+\epsilon^h}}{\xi^{1+\epsilon^h+\epsilon^s} \cdot \beta^{\epsilon^s+2\epsilon^h}}}$$

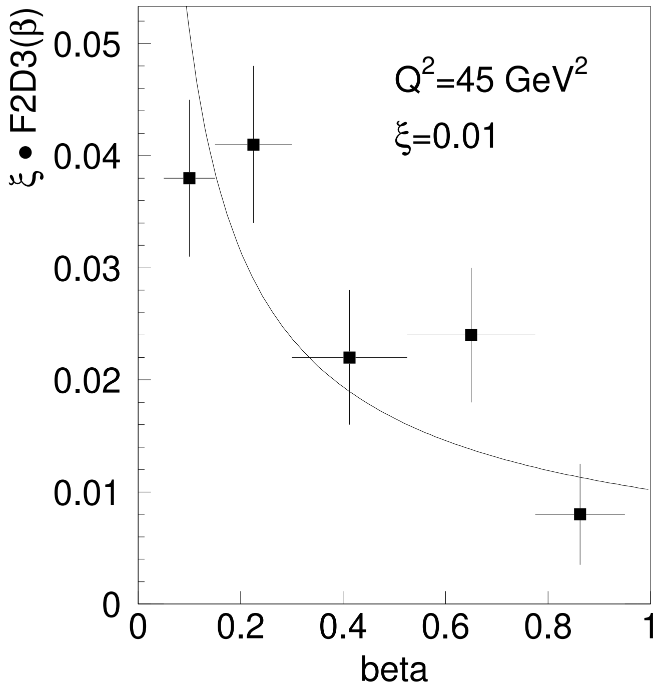
$$\sqrt{s} = 280 \text{ GeV}$$

$$\boxed{Q^2 = 45; \quad \epsilon^h = 0.3}$$

$$\boxed{\xi \approx 0.01; \quad \epsilon^s = 0.1}$$

$F_2(Q^2 = 50, x = 0.00133) = 1.46 = \frac{A^h}{x^{0.3}} \Rightarrow \quad A^h = 0.2$

$f_q = 0.4$



$\boxed{\textbf{Summary}}$

"BOUNDARY CONDITIONS" for diffractive DIS:

- $\sigma^D = f_{color} \times P_{gap} \times \sigma^T(\mathrm{sub} - \mathrm{energy})$
- $P_{gap} \Rightarrow$ Nornalized gap probability
- $P_{gap}(\xi) \sim$ parton density at $x = \xi$

$\boxed{\text{Apply to Jet-Gap-jet and Gap-JJ-Gap}}$