Twenty Years of Diffraction at the Tevatron

K. Goulianos
The Rockefeller University

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http://physics.rockefeller.edu/dino/my.html

Forty Years of Diffraction
Twenty Years at the Tevatron

- 1960's BNL: first observation of pp -> pX
- 1970's Fermilab fixed target, ISR, SPS
  → Regge theory & factorization

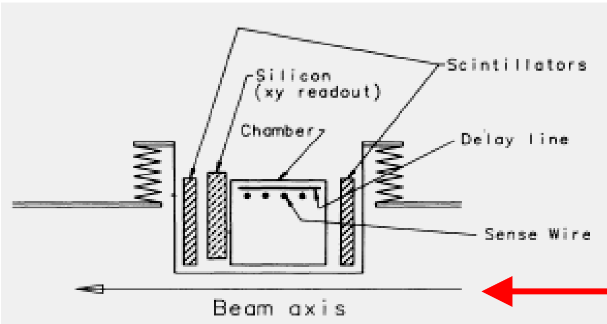
  Review: KG, Phys. Rep. 101 (1983) 169

- 1980's UA8: diffractive dijets ⇨ hard diffraction
- 1990's Tev Run-I: Regge factorization breakdown
  Tev vs HERA: QCD factorization breakdown
- 21st C Multigap diffraction: restoration of factorization
  Ideal for diffractive studies @ LHC

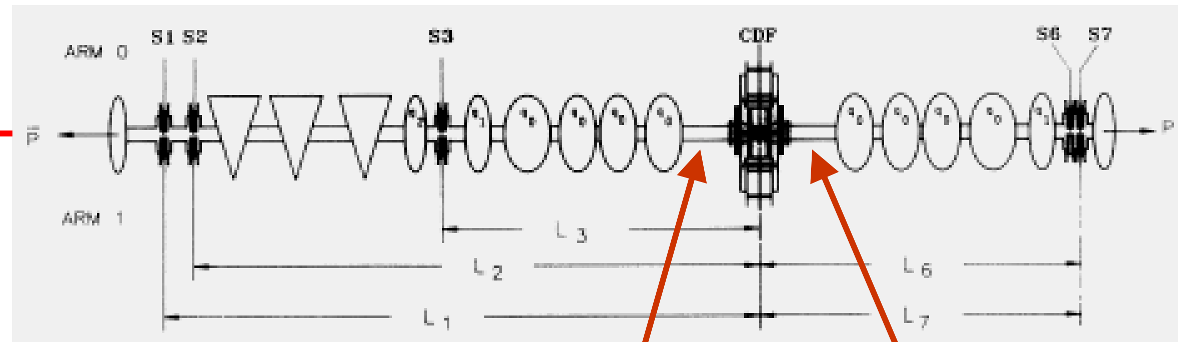
CDF Run 1-0 (1988-89)

Elastic, single diffractive, and total cross sections

@ 546 and 1800 GeV



Roman Pot Spectrometers



Roman Pot Detectors

- Scintillation trigger counters
- Wire chamber
- Double-sided silicon strip detector

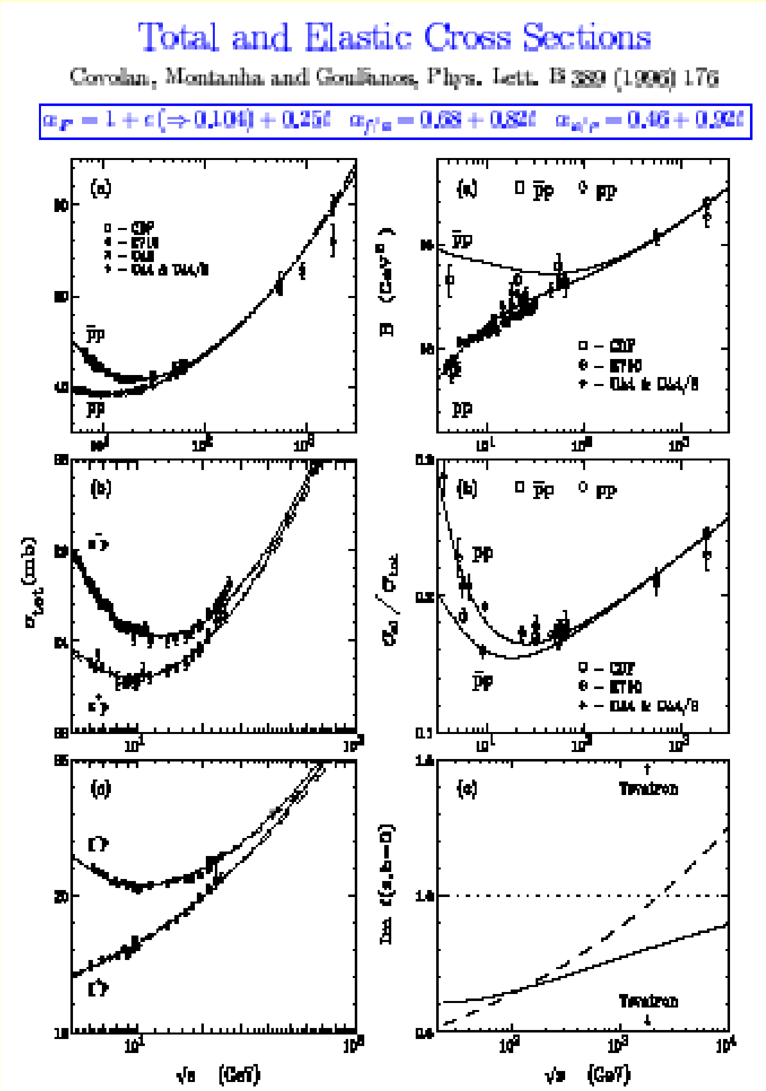
Additional Detectors

Trackers up to $|\eta| = 7$

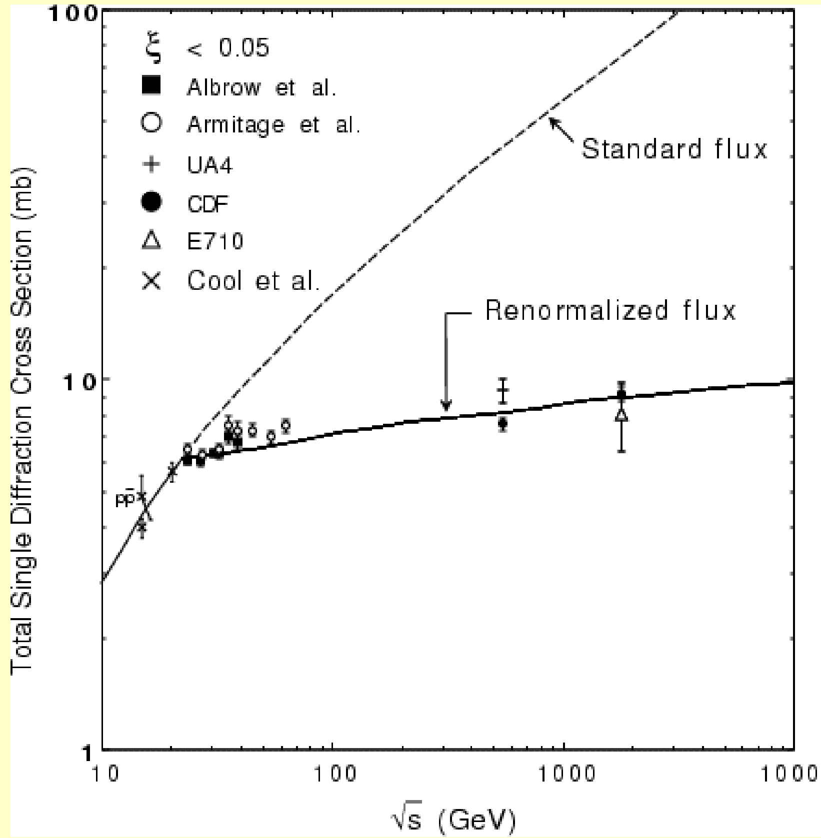
Results

- Total cross section $\sigma^{tot} \sim s^{\varepsilon}$
- Elastic cross section $d\sigma/dt \sim \exp[2\alpha' \ln s]$ → shrinking forward peak
- Single diffraction **Breakdown of Regge factorization**

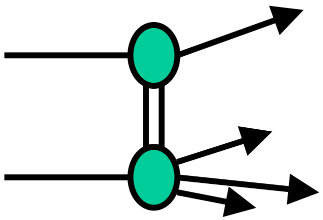
Run 1-0 results in perspective



KG, PLB 358 (1995) 379



Total Single Diffractive x-Section



$$\frac{d^2\sigma_{SD}}{dt\,d\xi} = f_{IP/p}(t,\xi)\cdot\sigma_{IP-\bar{p}}(s\xi)$$

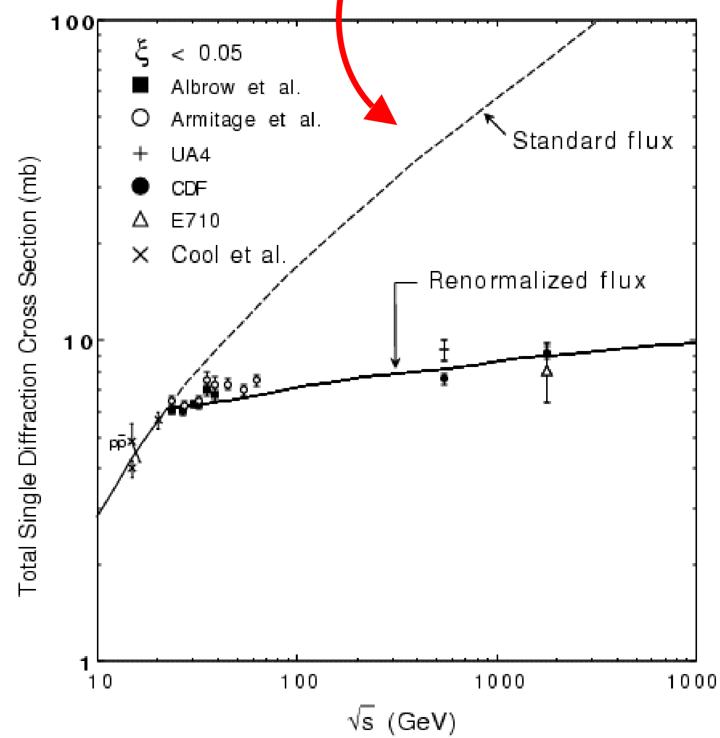
$\sigma_{SD} \sim s^{2\varepsilon}$

- **Unitarity problem:**
  Using factorization and std pomeron flux σ_{SD} exceeds σ_T at $\sqrt{s} \approx 2$ TeV.

- **Renormalization:**
  Normalize the Pomeron flux to unity

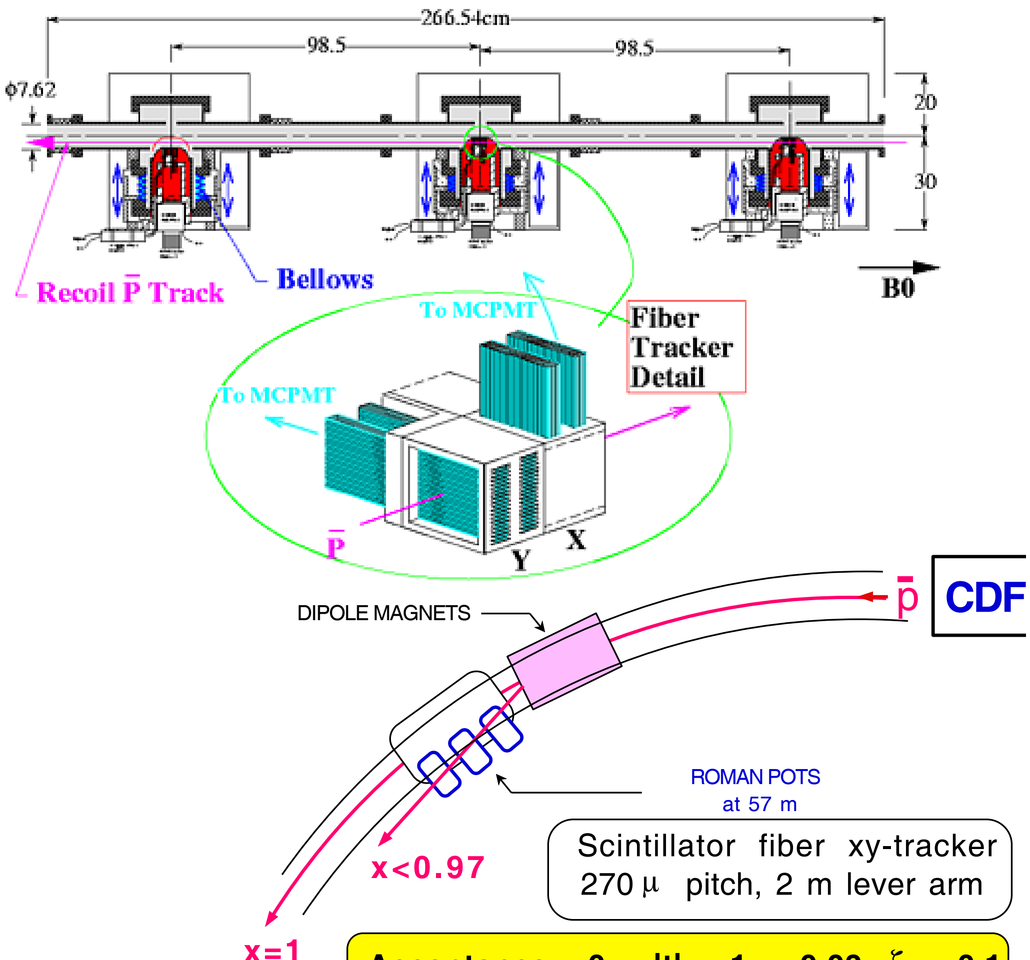
KG, PLB 358 (1995) 379

$$\int_{\xi_{min}}^{0.1}\int_{t=-\infty}^{0} f_{IP/p}(t,\xi)\,d\xi\,dt = 1$$



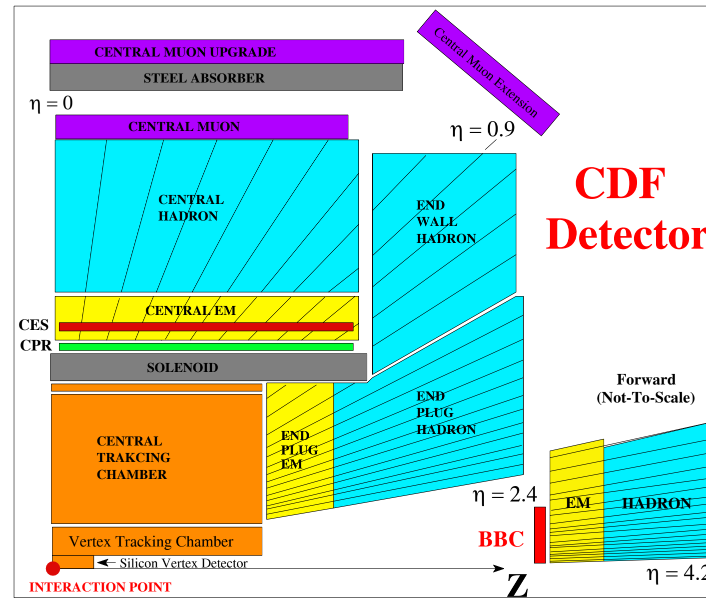
CDF Run 1 (1992-1995)

Run-IC



Acceptance: 0 < |t| < 1, 0.03< ξ < 0.1

Run-IA,B



Forward Detectors

BBC 3.2<η<5.9

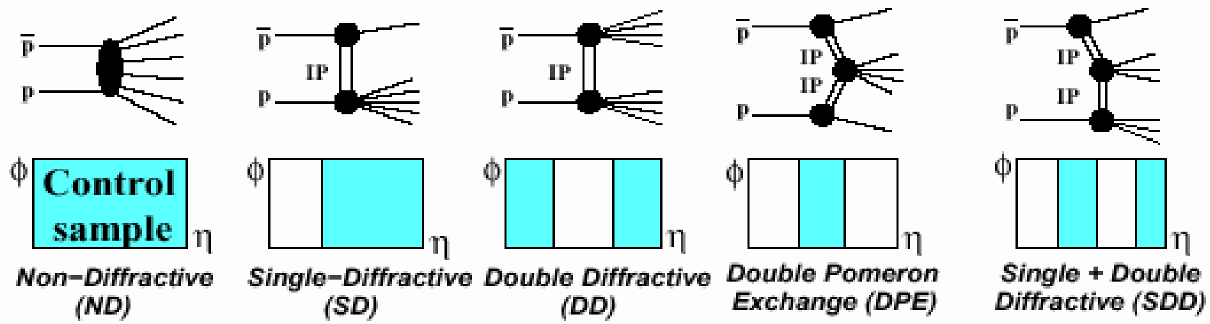
FCAL 2.4<η<4.2

Diffraction@CDF in Run I

16 papers

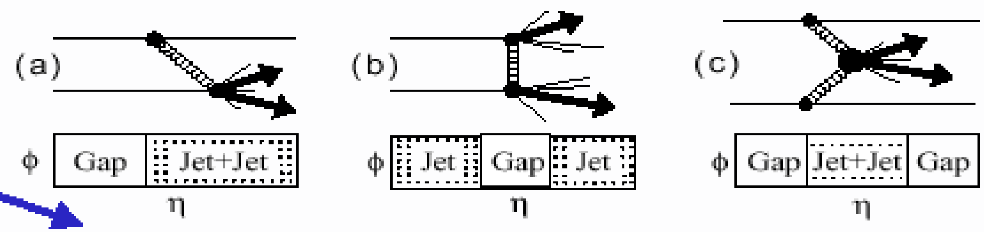
- Elastic scattering PRD 50 (1994) 5518
- Total cross section PRD 50 (1994) 5550
- Diffraction

SOFT diffraction



Single−Diffractive (SD)	Double Diffractive (DD)	Double Pomeron Exchange (DPE)	Single + Double Diffractive (SDD)
PRD 50 (1994) 5535	PRL 87 (2001)141802	PRL 93(2004)141601	PRL 91(2003)011802

HARD diffraction



PRL references

W 78 (1997) 2698	JJ 74 (1995) 855	JJ 85 (2000) 4217
JJ 79 (1997) 2636	JJ 80 (1998) 1156	
b-quark 84 (2000) 232	JJ 81 (1998) 5278	
J/ψ 87 (2001) 241802		

with roman pots

JJ	84 (2000) 5043
JJ	88 (2002) 151802

Diffractive Fractions @ CDF

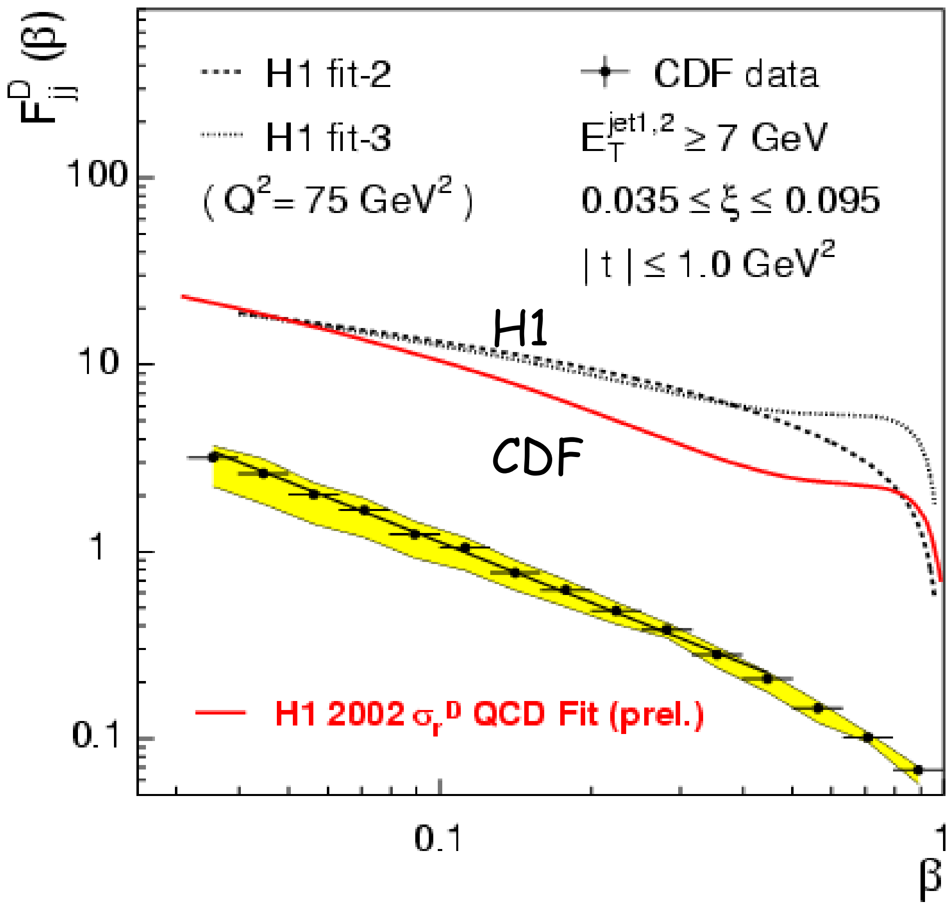
$$\bar{p}p \rightarrow (Hd + X) + \text{gap}$$

Fraction:
SD/ND ratio at 1800 GeV

Hd	Fraction(%)
W	1.15 (0.55)
JJ	0.75 (0.10)
b	0.62 (0.25)
J/ψ	1.45 (0.25)

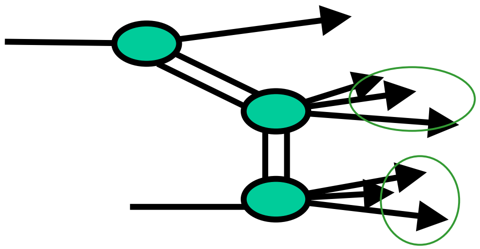
All ratios ~ 1%
➔ ~ uniform suppression
~ FACTORIZATION

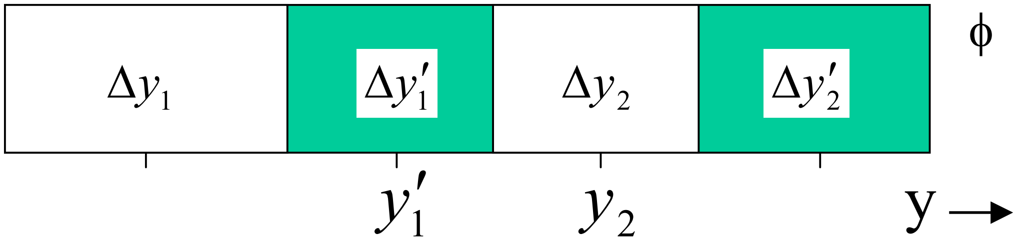
Tevatron vs HERA: Breakdown of QCD Factorization

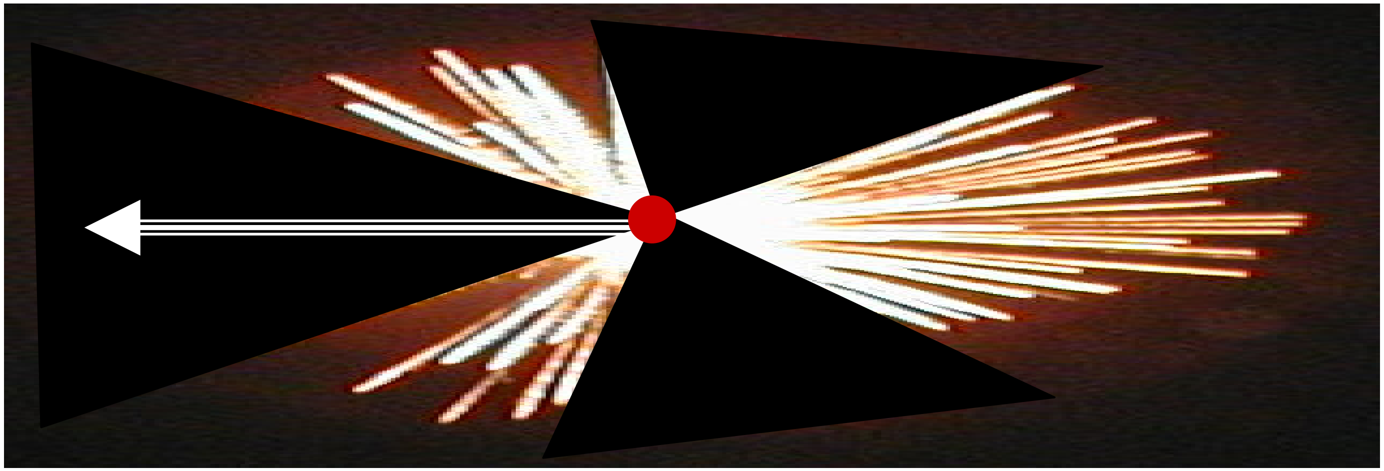


Multigap Diffraction

(KG, hep-ph/0205141)

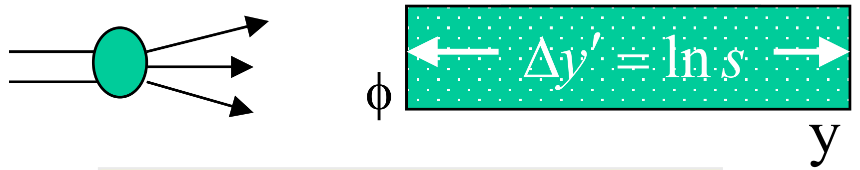






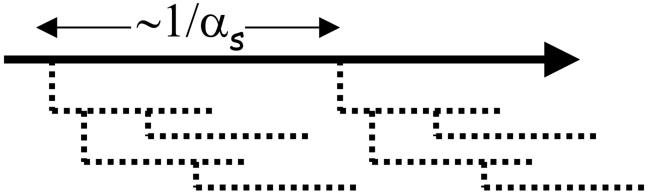
Elastic and Total Cross Sections

QCD expectations



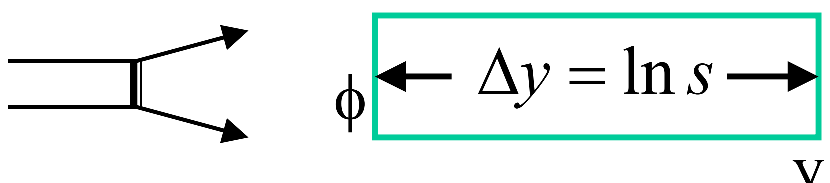
$$\sigma_T(s) = \sigma_o\, s^{\varepsilon} = \sigma_o\, e^{\varepsilon \Delta y'}$$

Total cross section:
power law rise with energy



The exponential rise of $\sigma_T(\Delta y')$ is due to the increase of wee partons with $\Delta y'$

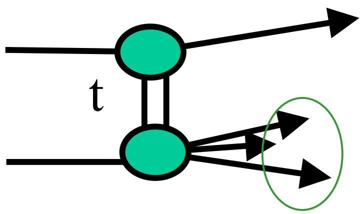
(see E. Levin, An Introduction to Pomerons,Preprint DESY 98-120)

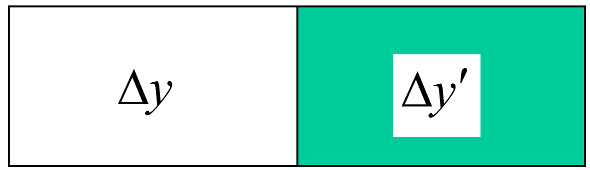


$$\mathrm{Im}\, f_{el}(s,t) \propto e^{(\varepsilon + \alpha' t)\Delta y}$$

Elastic cross section:
forward scattering amplitude

Single Diffraction





2 independent variables: $t, \Delta y$

color factor

$$\kappa = \frac{g_{IP-IP-IP}(t)}{\beta_{IP-p-p}(0)} \approx 0.17$$

$$\frac{d^2\sigma}{dt\, d\Delta y} = \underbrace{C \cdot F_p^2(t) \cdot \left\{ e^{(\varepsilon+\alpha' t)\Delta y} \right\}^2}_{\text{gap probability}} \cdot \kappa \cdot \underbrace{\left\{ \sigma_o\, e^{\varepsilon\, \Delta y'} \right\}}_{\text{sub-energy x-section}}$$

Gap probability MUST be normalized to unity!

The Factors κ and ε

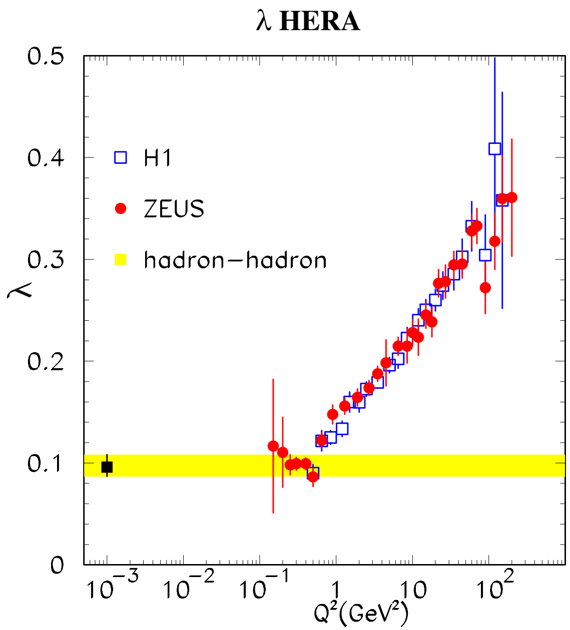
Experimentally:

$$\kappa = \frac{g_{IP-IP-IP}}{\beta_{IP-p}} = 0.17 \pm 0.02, \quad \varepsilon = 0.104$$

KG&JM, PRD 59 (114017) 1999

Color factor: $\kappa = f_g \times \frac{1}{N_c^2 - 1} + f_q \times \frac{1}{N_c} \xrightarrow{Q^2 = 1} \approx 0.75 \times \frac{1}{8} + 0.25 \times \frac{1}{3} = 0.18$

Pomeron intercept: $\varepsilon = \lambda_g \cdot w_g + \lambda_q \cdot w_q = 0.12$

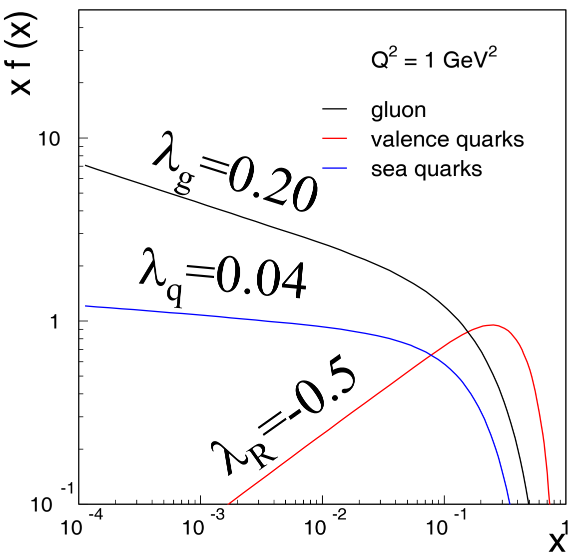


$$x \cdot f(x) = \frac{1}{x^{\lambda}}$$

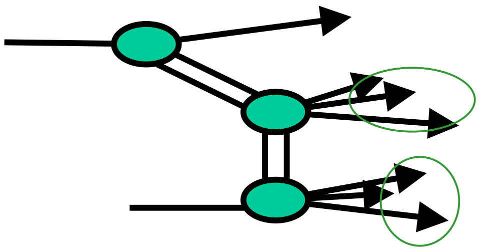
f_g=gluon fraction
f_q=quark fraction

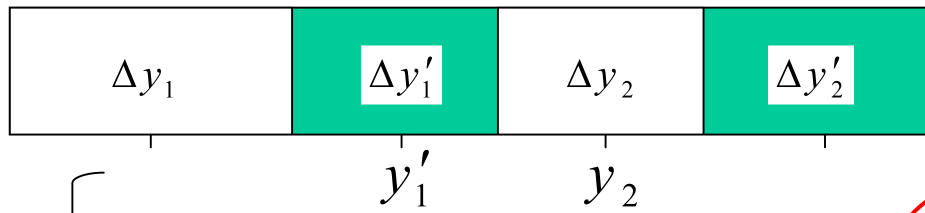
$$\int_{x=1/s}^{1} f(x)\,dx \sim s^{\lambda}$$

CTEQ5L



Multigap Cross Sections





5 independent variables: t_1, $\Delta y = \Delta y_1 + \Delta y_2$, t_2, y'_1, y_2

color factors

$$\frac{d^5\sigma}{\prod_{i=1-5} dV_i} = C \times F_p^2(t_1) \prod_{i=1-2} \left\{ e^{(\varepsilon+\alpha' t_i)\Delta y_i} \right\}^2 \times \kappa^2 \left\{ \sigma_o \, e^{\varepsilon(\Delta y'_1 + \Delta y'_2)} \right\}$$

Gap probability

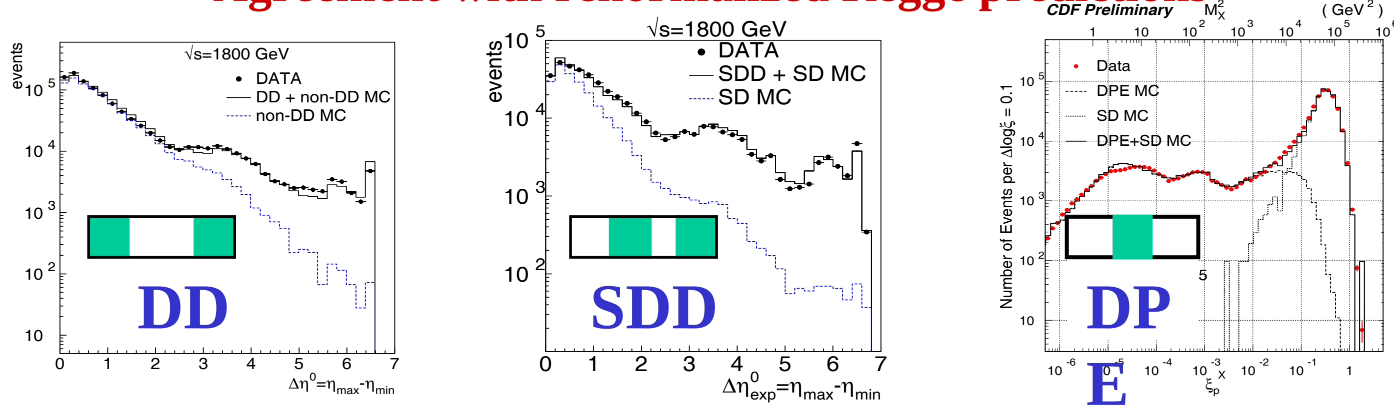
$$\int_{\Delta y, t} \sim s^{2\varepsilon}$$

Sub-energy cross section (for regions with particles)

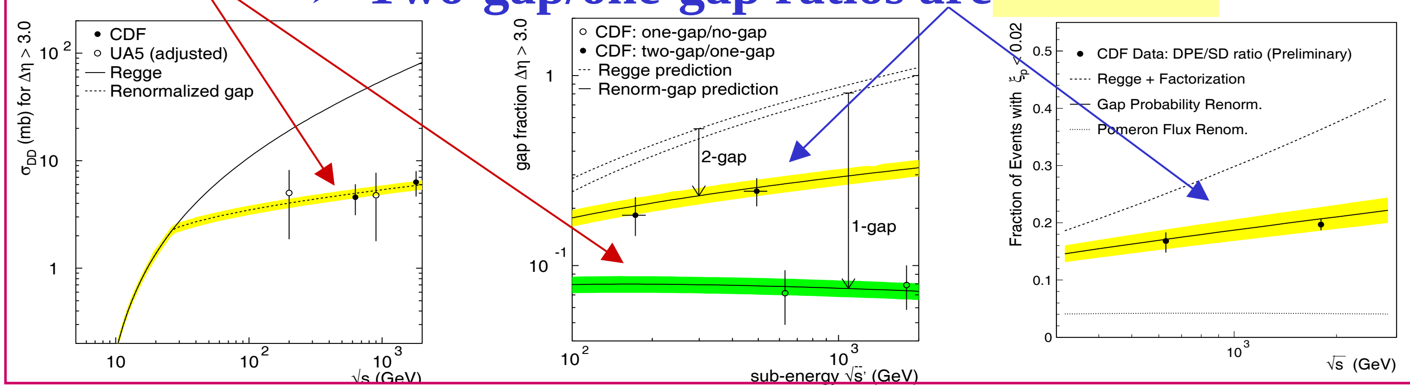
Same suppression as for single gap!

Central and Two-Gap CDF Results

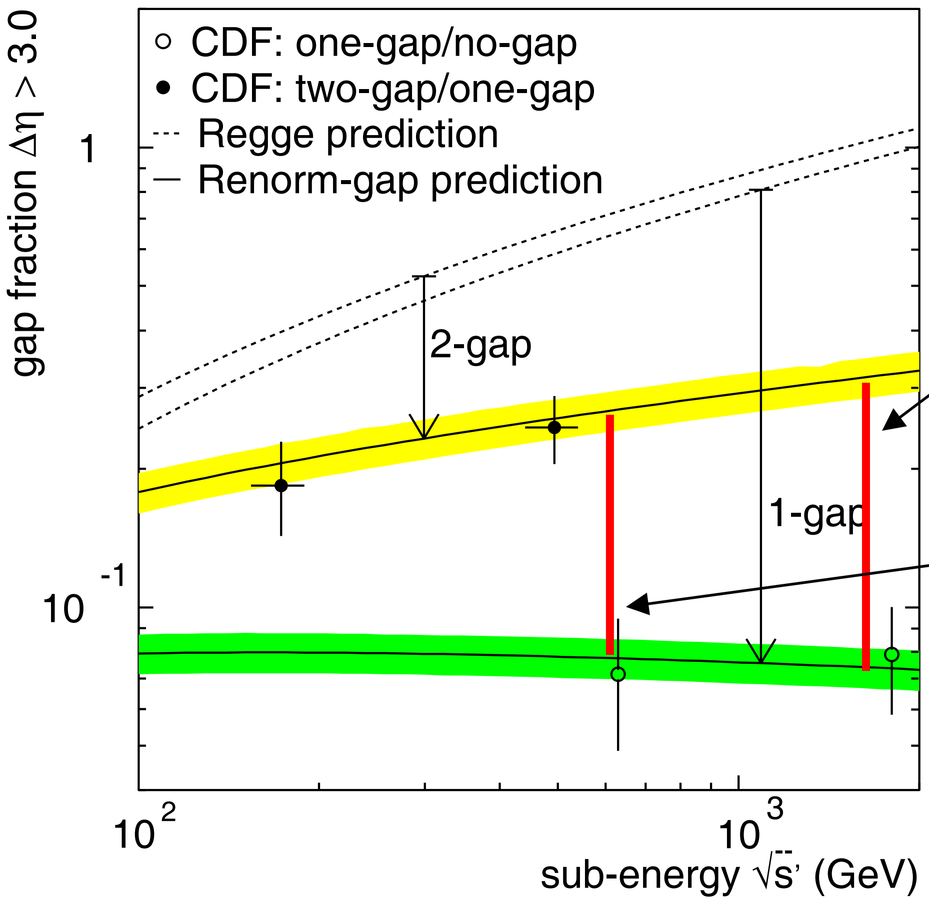
Agreement with renormalized Regge predictions

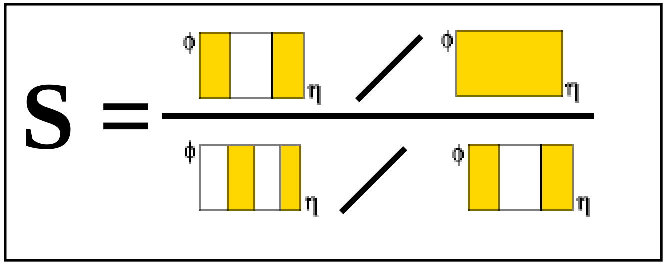


- One-gap cross sections are suppressed
- Two-gap/one-gap ratios are $\approx \kappa = 0.17$



Gap Survival Probability





$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \text{GeV}) \approx 0.23$$

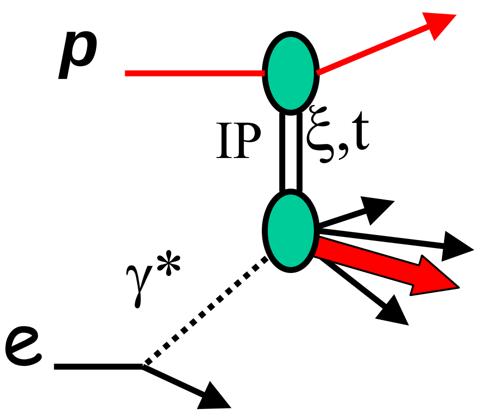
$$S^{1-gap/0-gap}_{2-gap/1-gap}(630\ \text{GeV}) \approx 0.29$$

Results similar to predictions by:
Gotsman-Levin-Maor
Kaidalov-Khoze-Martin-Ryskin
Soft color interactions

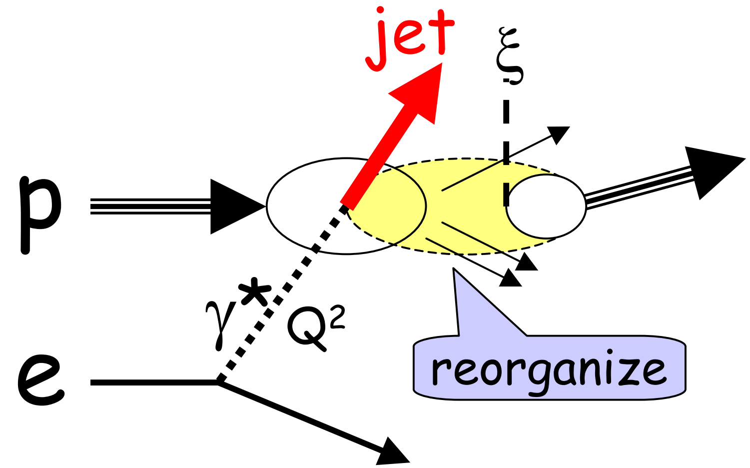
Diffractive DIS @ HERA

Factorization holds: J. Collins

Pomeron exchange



Color reorganization

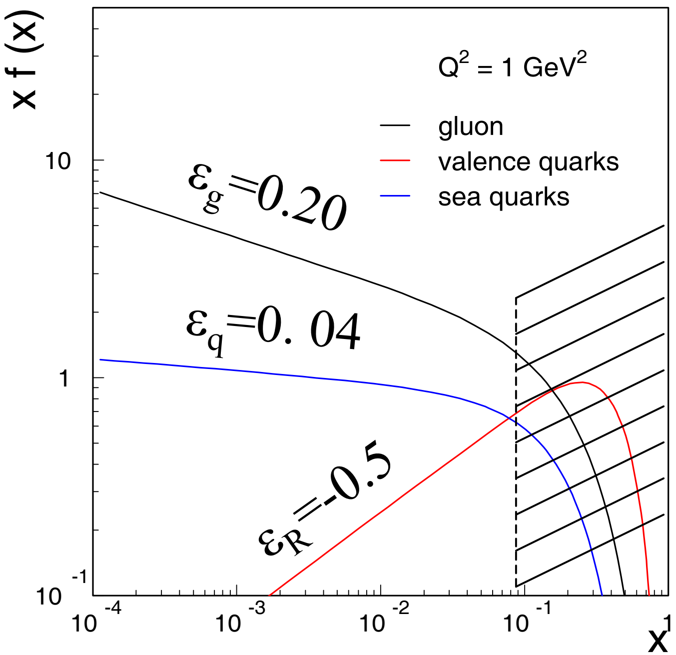


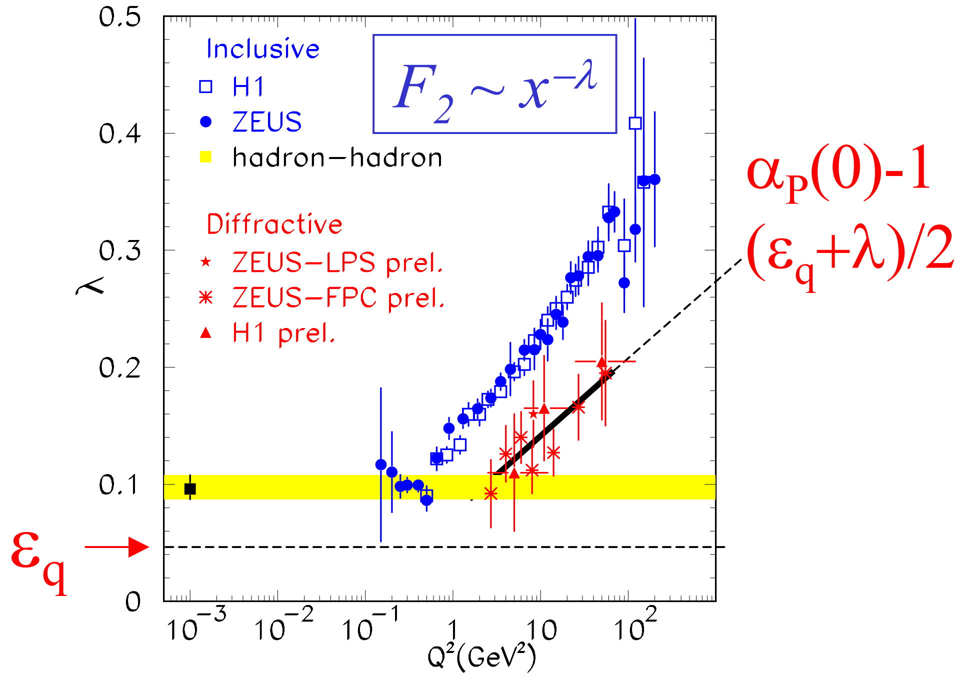
$$F_2^{D(3)}(\xi, x, Q^2) \propto f_q(\xi, Q^2 = m^2_{hadron}) \cdot F_2(x, Q^2)$$

Brodsky et al. rescattering?

Inclusive vs Diffractive DIS

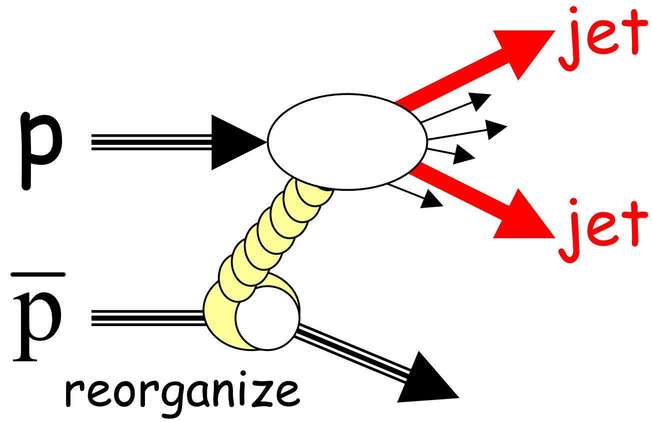
KG, "Diffraction: a New Approach," J.Phys.G26:716-720,2000 e-Print Archive: **hep-ph/0001092**





$$F_2^{D(3)}(\xi,\beta,Q^2) \xrightarrow{\xi\le 0.05} \sum_{q,R} \frac{1}{\xi^{1+\varepsilon_{q,R}}} \cdot \frac{C_{Q^2}}{(\beta\xi)^{\lambda_{Q^2}}} \propto \sum_{q,R} \frac{1}{\xi^{1+\varepsilon_{q,R}+\lambda_{Q^2}}} \cdot \frac{C_{Q^2}}{\beta^{\lambda_{Q^2}}}$$

Diffractive Dijets @ Tevatron



$$F^D(\xi, x, Q^2) \propto \frac{1}{\xi^{1+2\varepsilon_{soft}}} \cdot F(x/\xi, Q^2)$$

$F^D_{JJ}(\xi,\beta,Q^2)$ @ Tevatron

$$F^D(\xi,\beta,Q^2) = \mathrm{N}_{\mathrm{renorm}} \frac{1}{\xi^{1+2\varepsilon}} \cdot \frac{C(Q^2)}{(x/\xi)^{\lambda(Q^2)}} = \frac{2\varepsilon}{(\beta\, s)^{2\varepsilon}} \cdot \frac{1}{\xi^{1+2\varepsilon}} \cdot \frac{C(Q^2)}{\beta^{\lambda(Q^2)}}$$

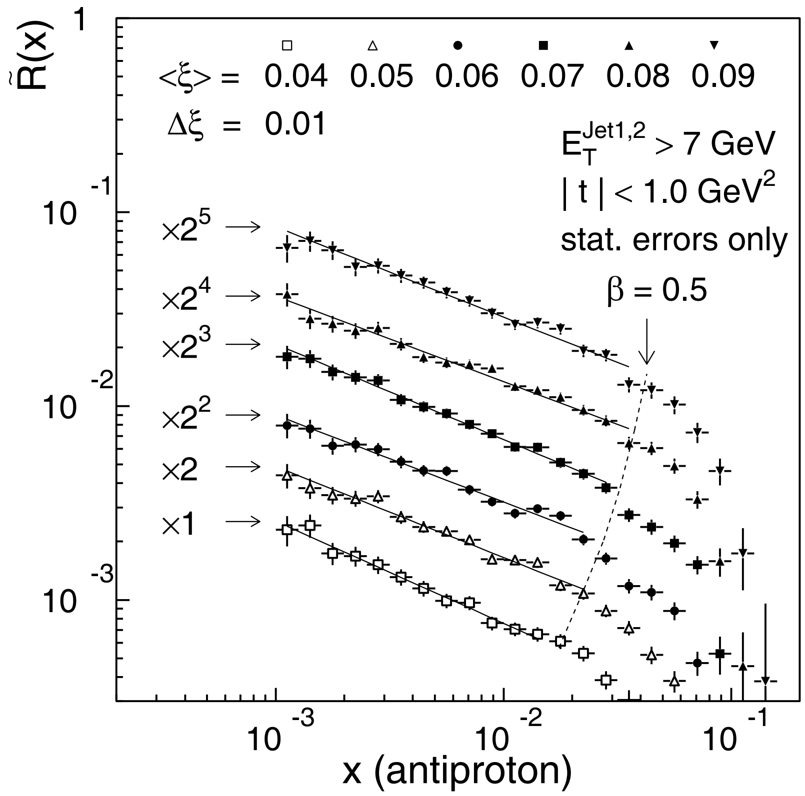
$$\mathrm{N}^{-1}_{\mathrm{renorm}} = \int_{\xi_{\min}}^{1} \frac{d\xi}{\xi^{1+2\varepsilon}} \xrightarrow{\xi_{\min} = \frac{x_{\min}}{\beta} \approx \frac{1}{\beta\, s}} \frac{(\beta\, s)^{2\varepsilon}}{2\varepsilon}$$

$$\text{RENORM} \quad \Rightarrow \quad \mathrm{R}\,\frac{SD}{ND}(x) = \frac{2\varepsilon}{s^{2\varepsilon}} \frac{1}{\xi^{1-\lambda(Q^2)}} \cdot x^{-(2\varepsilon)}$$

$$\varepsilon_g = 0.2 \rightarrow x^{-0.4}$$

SD/ND Dijet Ratio vs x_{Bj}@ CDF

$$R(x) = \frac{F_{jj}^{SD}(x)}{F_{jj}^{ND}(x)}$$

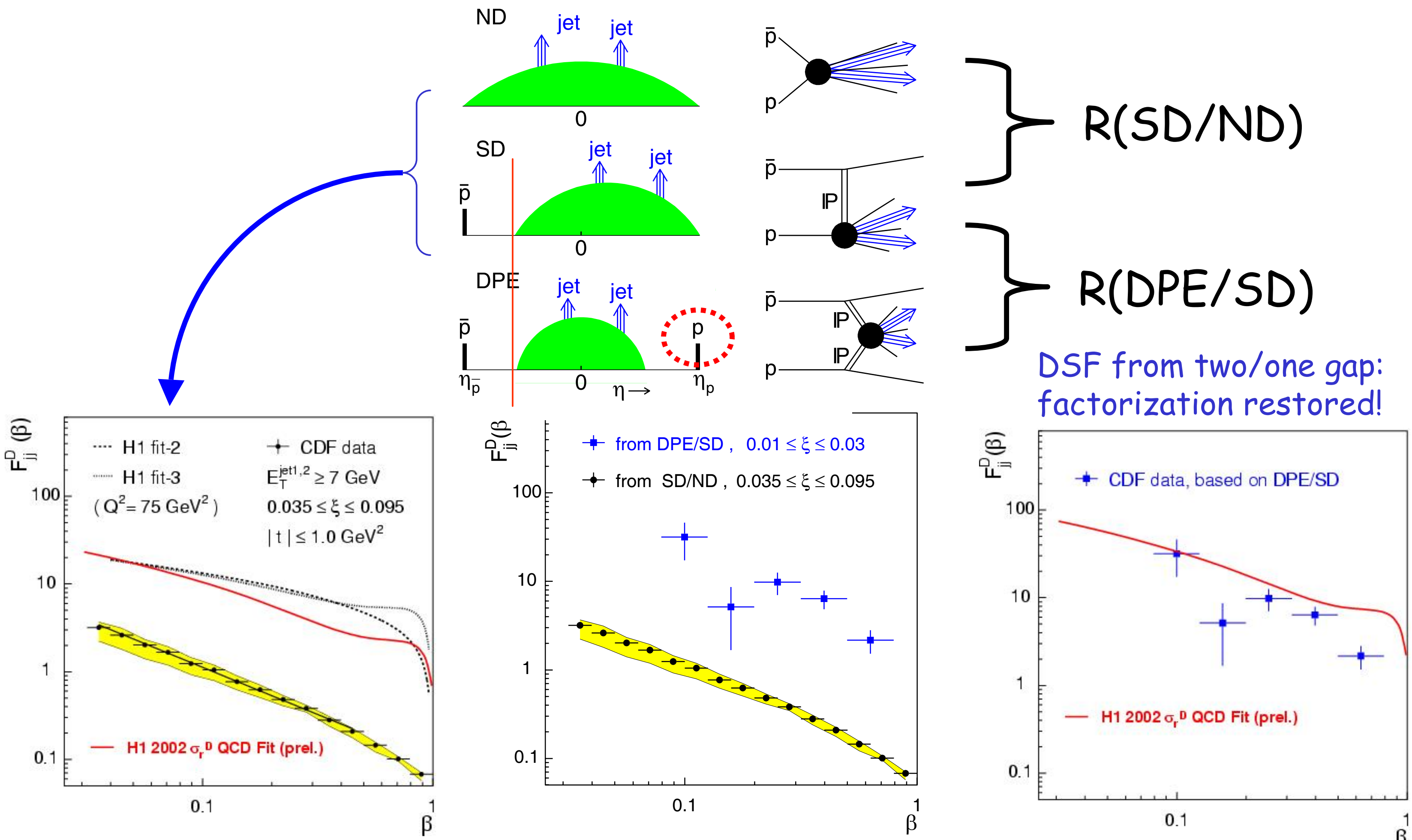


0.035 < ξ < 0.095

Flat ξ dependence

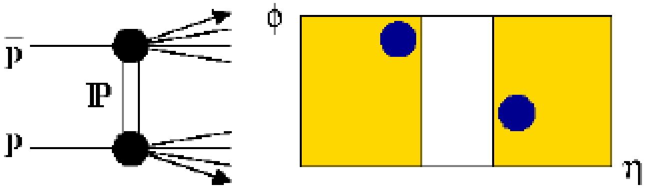
$$R(x) = x^{-0.45}$$

Restoring Factorization @ Tevatron

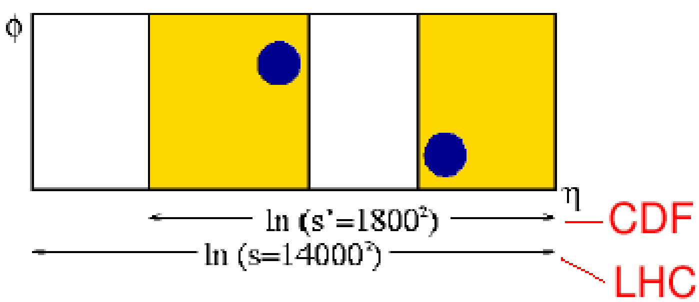


Gap Between Jets

$\bar{p} + p \to \text{Jet} + \text{Gap} + \text{Jet}$



$$R^{J-G-J}_{TEV}(s') \approx 1\%/$$

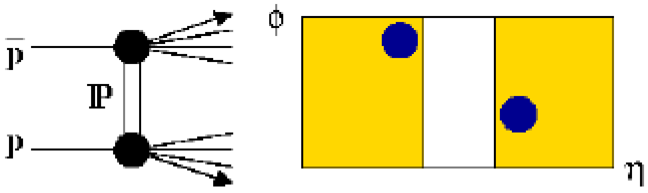


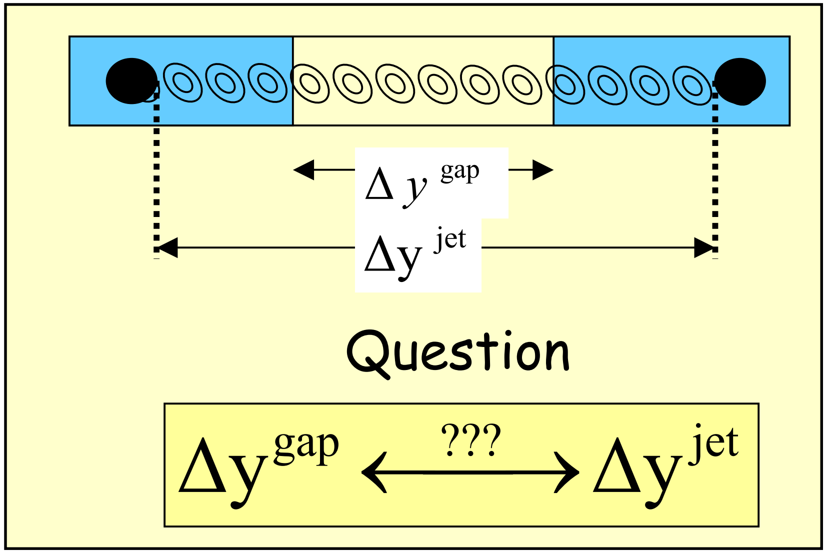
$$R^{J-G-J}_{LHC}(s') = \frac{R^{J-G-J}_{TEV}}{S} \approx \frac{1\%}{0.2} \approx 5\%$$

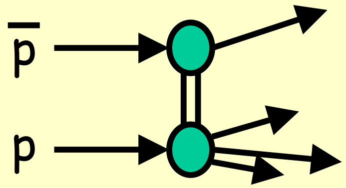
Gap Between Jets

Is the diffractive exchange BFKL-like
or simply a color rearrangement?

$$\bar{p} + p \rightarrow \text{Jet} + \text{Gap} + \text{Jet}$$

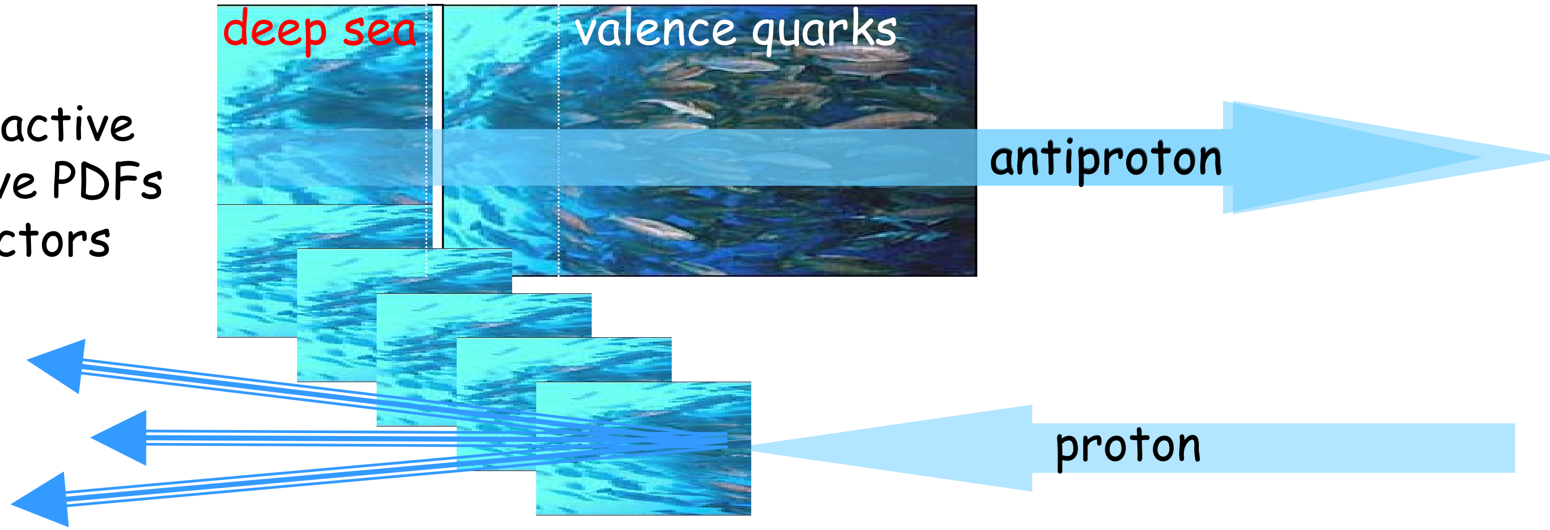


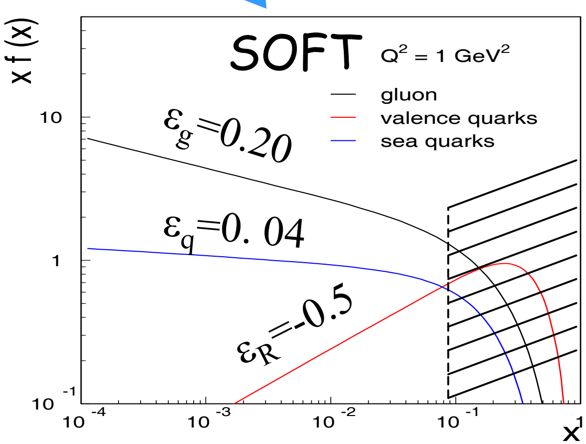




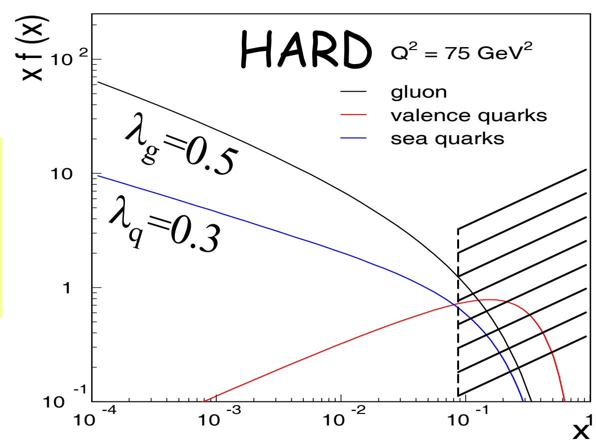
Low-x and Diffraction

Derive diffractive from inclusive PDFs and color factors





$$x \cdot f(x) = \frac{1}{x^{\varepsilon\,(\mathrm{or}\,\lambda)}}$$



Run 2 CDF Diffractive Program

- Single Diffraction
  - ξ and Q^2 dependence of F_{jj}^D
  - Process dependence of F^D $(W, J/\psi)$
- Double Diffraction
  - Jet-Gap-Jet: $\Delta\eta^{gap}$ for fixed large $\Delta\eta^{jet}$
- Double Pomeron Exchange
  - F_{jj}^D on p-side vs ξ-pbar

Also:

Exclusive central production

- Dijets, χ_c

Other

- Tev4LHC issues

Summary

- Diffraction is a low-x QCD phenomenon subject to color constraints.
- Multigap processes offer the opportunity to study diffraction without complications arising from rapidity gap survival issues.
- Regularities observed in Run 1 at the Tevatron and in results obtained at HERA paint a picture of the Pomeron as a composite object constructed from the underlying inclusive pdf's of the (anti)proton. This picture could be further clarified and advanced to a theory by studies at the LHC.