Renormalized Diffractive Parton Densities and Exclusive Production

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Diffraction 2006
Milos island, Greece, 5-10 September 2006

Contents

- Introduction
- Phenomenology
- Experiment confronts phenomenology
- Exclusive Production

$\bar{p}$-p Interactions

<u>Non-diffractive:</u>

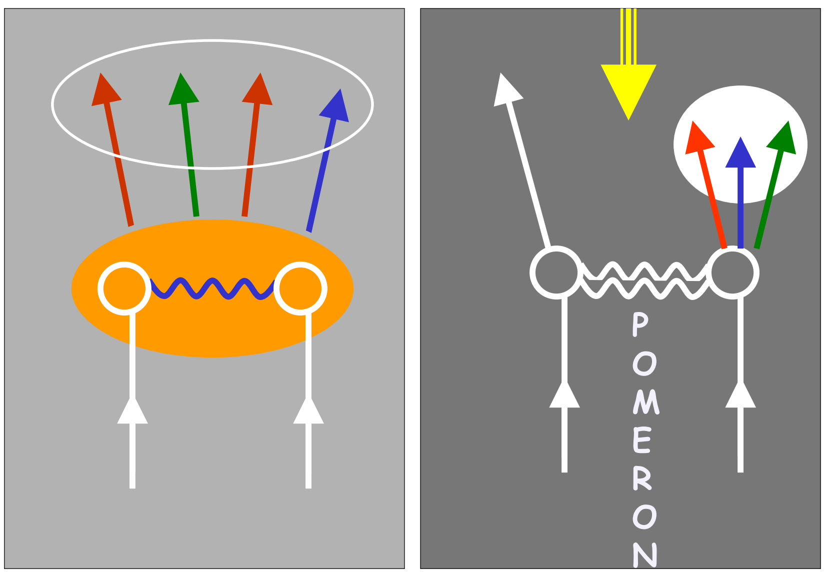
Color-exchange

<u>Diffractive:</u>

Colorless exchange with vacuum quantum numbers

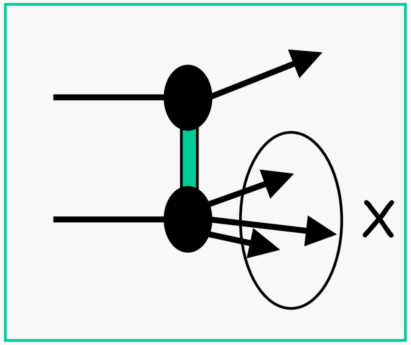
rapidity gap

Incident hadrons acquire color and break apart

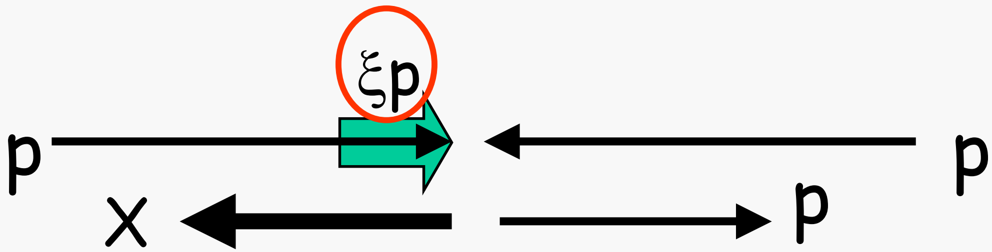


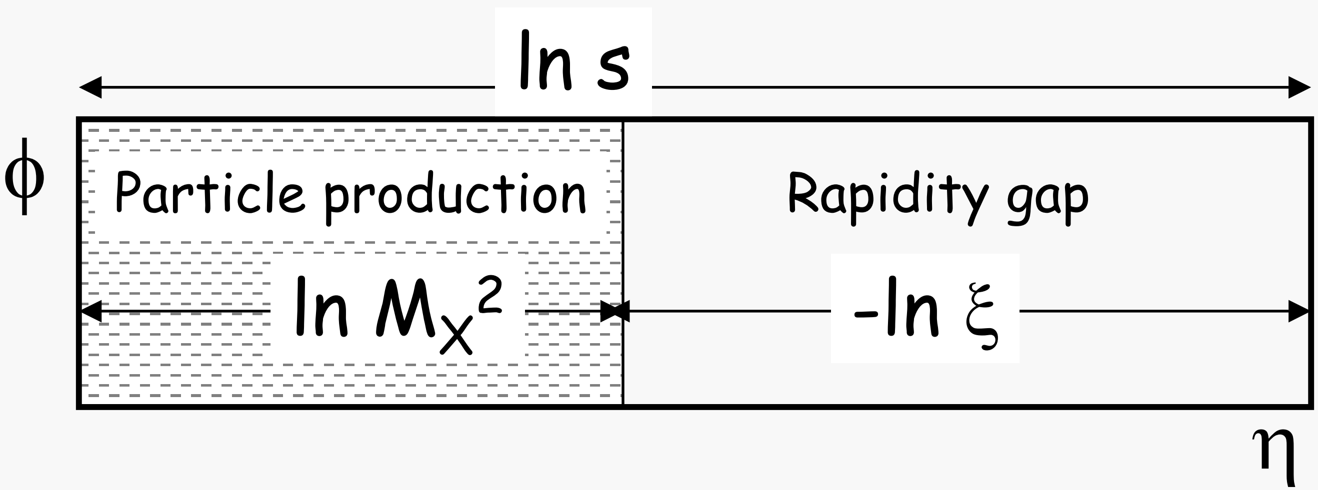
Incident hadrons retain their quantum numbers remaining colorless

<u>Goal:</u> develop a QCD based phenomenology for diffraction



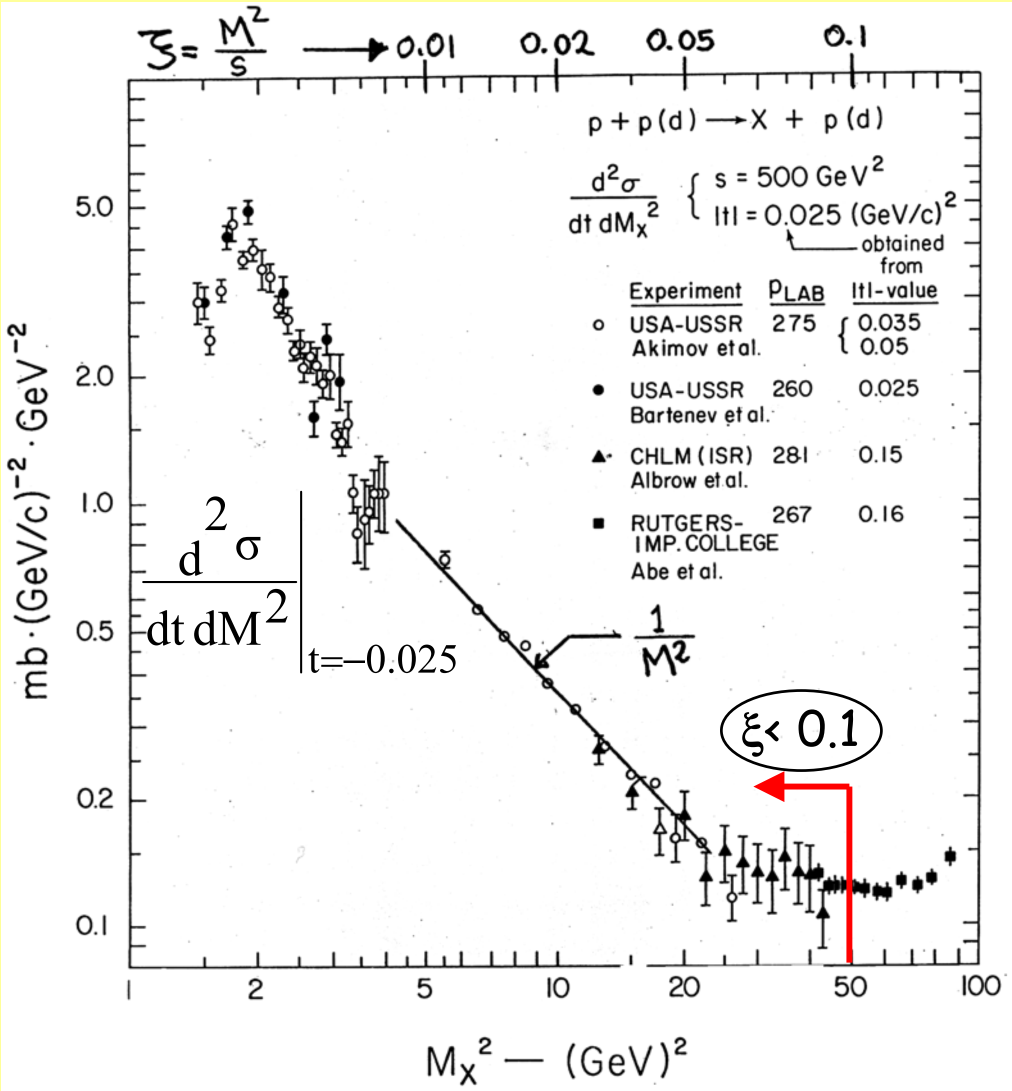
Diffractive Rapidity Gaps





$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \quad \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

Diffraction Dissociation

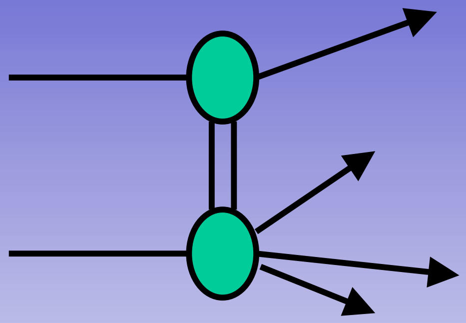


$$\left.\frac{d^2\sigma}{dt\,dM^2}\right|_{t=-0.025}$$

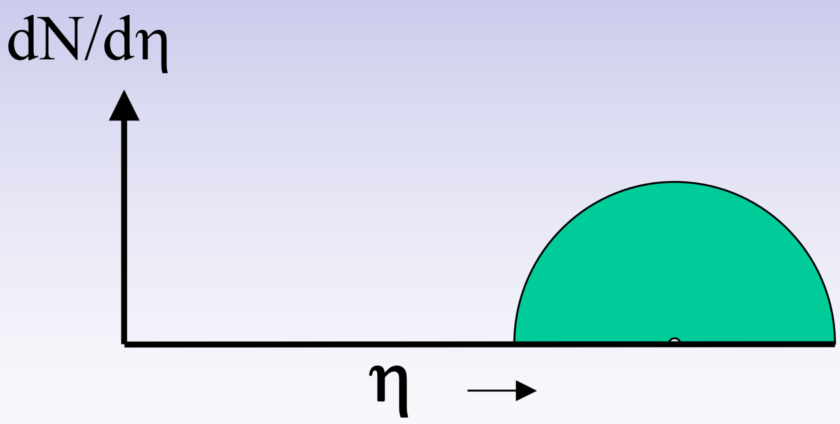
KG, Phys. Rep. 101, 169 (1983)

$$\frac{d\sigma}{dM^2} \sim \frac{1}{dM^2} \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

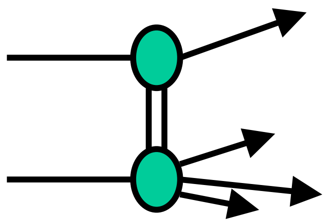
Factorization and scaling in soft single diffraction



- Total SD cross section
  ➔ factorization breakdown
- M^2-scaling
  ➔ controls level of breakdown



Total Single Diffractive Cross Section



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

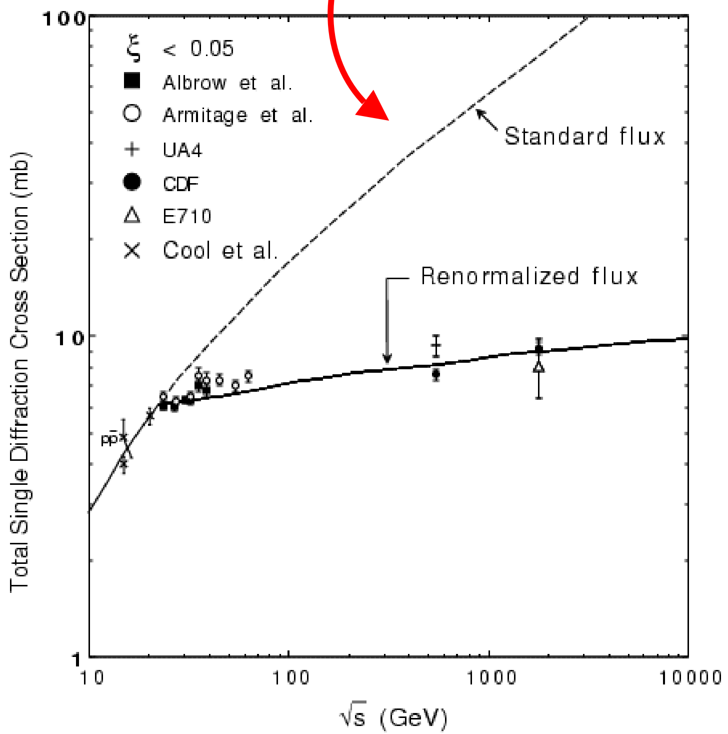
- **Unitarity problem:**
  Using factorization
  and std pomeron flux
  σ_{SD} exceeds σ_T at $\sqrt{s} \approx 2$ TeV.

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

KG, PLB 358 (1995) 379

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

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



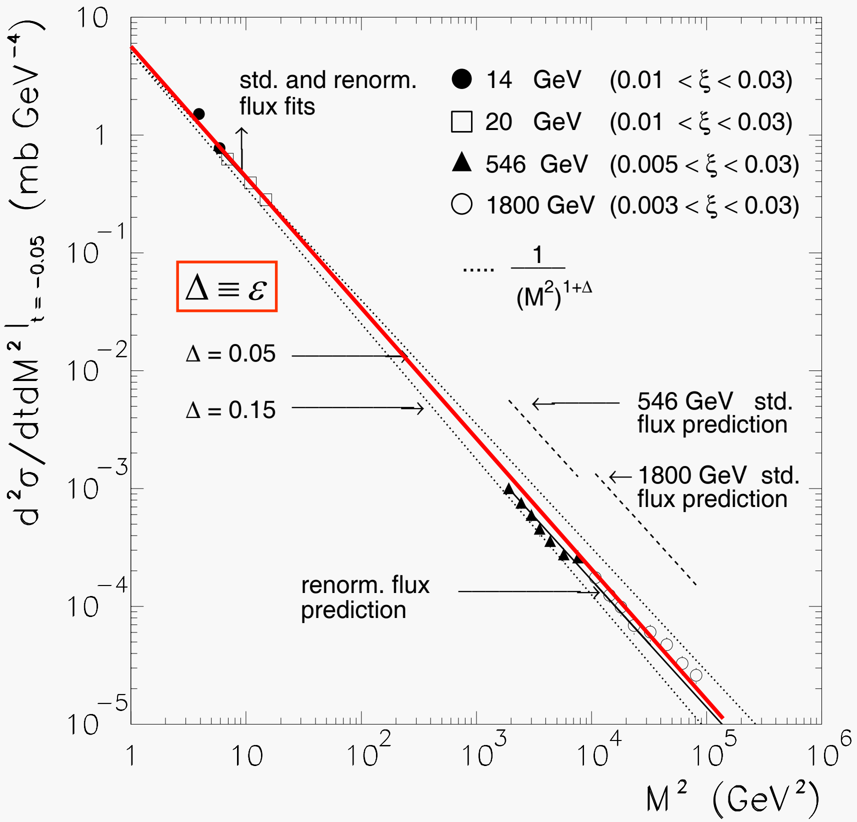
M^2-scaling

renormalization

$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon} \rightarrow 1}{(M^2)^{1+\varepsilon}}$$

➔ Independent of S over 6 orders of magnitude in M^2!

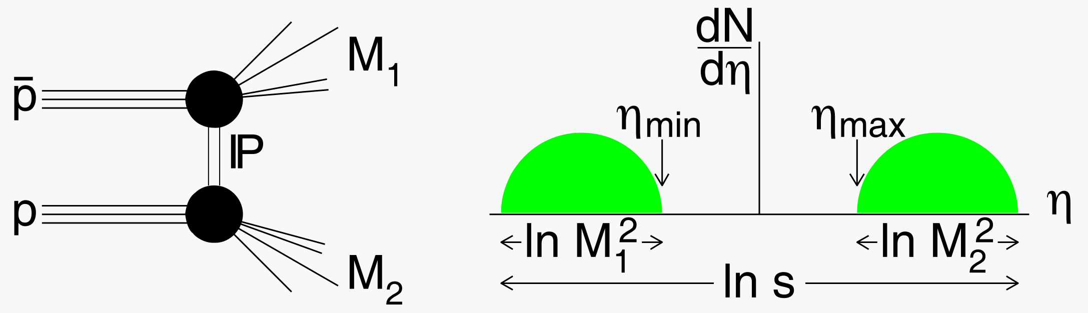
KG&JM, PRD 59 (1999) 114017



Factorization breaks down so as to ensure M^2-scaling!

Double Diffraction Dissociation

➔ entral rapidity gaps ⟵

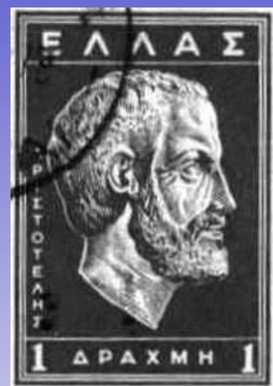


How does one apply Pomeron flux renormalization in this case?
➔ Need generalized renormalization!

PHENOMENOLOGY

Plato (427-347 B.C)

platonic love



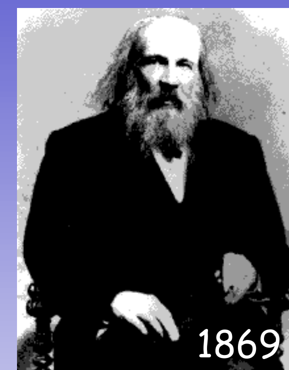
Aristotle

earth
water
air
fire

450 BC

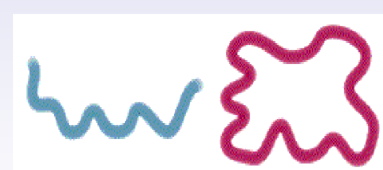
Demokritos

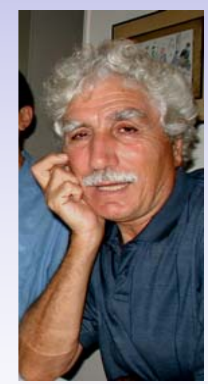
atom



Mendeleyev

periodic table

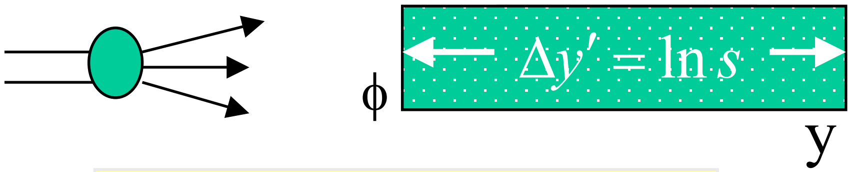




2006

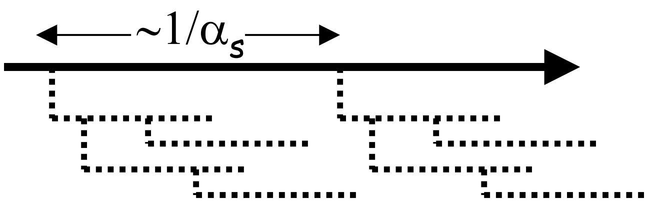
Elastic and Total Cross Sections

QCD expectations



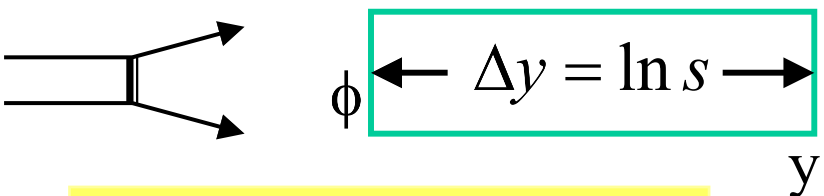
$$\sigma_T(s) = \sigma_o\, s^{\varepsilon} = \sigma_o\, e^{\varepsilon \Delta y'}$$

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 $\Delta y'$

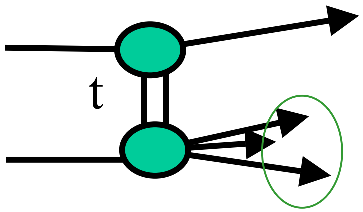
(see E. Levin, An Introduction to Pomerons,Preprint DESY 98-120)

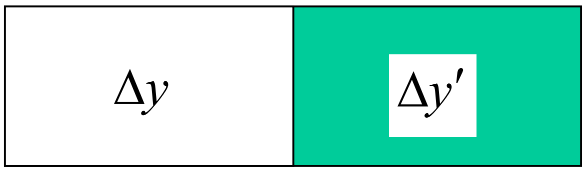


$$\mathrm{Im}\, f_{el}(s,t) \propto e^{(\varepsilon+\alpha' t)\Delta y}$$

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!

Single diffraction (re)normalized

$$\frac{d^2\sigma}{dt\, d\Delta y} = N_{gap} \cdot \underbrace{C \cdot F_p^2(t) \cdot \left\{e^{(\varepsilon+\alpha' t)\Delta y}\right\}^2}_{P_{gap}(\Delta y, t)} \cdot \kappa \cdot \left\{\sigma_o\, e^{\varepsilon\, \Delta y'}\right\}$$

$$N_{gap}^{-1}(s) = \int_{\Delta y, t} P_{gap}(\Delta y, t)\, d\Delta y\, dt \xrightarrow{s\to\infty} C' \cdot \frac{s^{2\varepsilon}}{\ln s}$$

$$\frac{d^2\sigma}{dt\, d\Delta y} = C'' \left[e^{\varepsilon(\Delta y - \ln s)} \cdot \ln s\right] e^{(b_0 + 2\alpha' \Delta y)t}$$

Grows slower than s^{ε}

→ The Pumplin bound is obeyed at all impact parameters

The Factors κ and ε

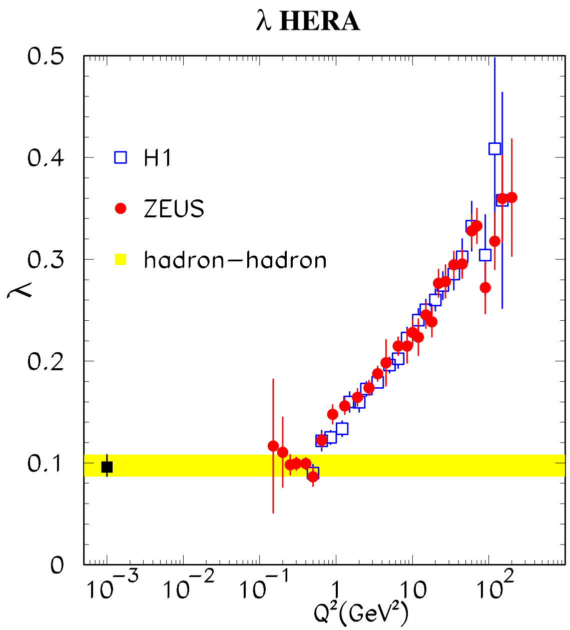
Experimentally:

KG&JM, PRD 59 (114017) 1999

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

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

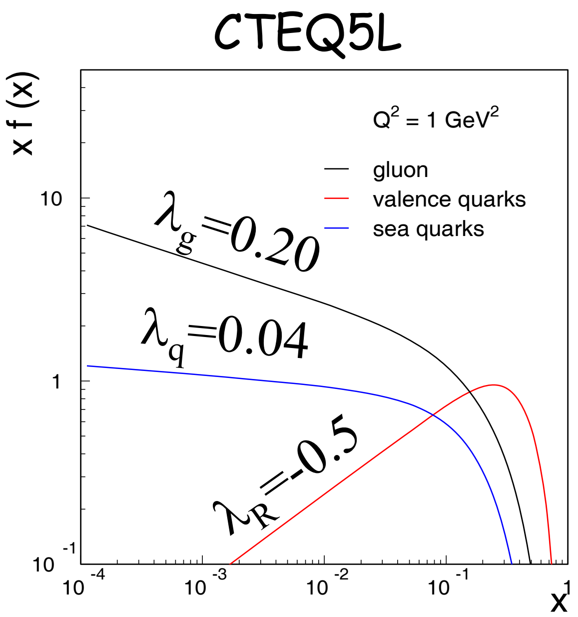
Pomeron intercept: $\varepsilon = \lambda_g \cdot w_g + \lambda_q \cdot w_q = 0.12$



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

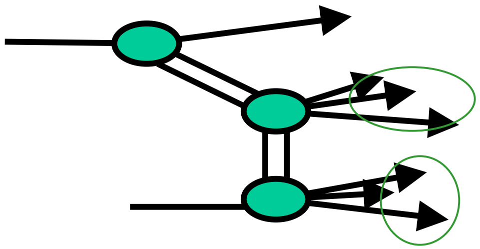
f_g=gluon fraction
f_q=quark fraction

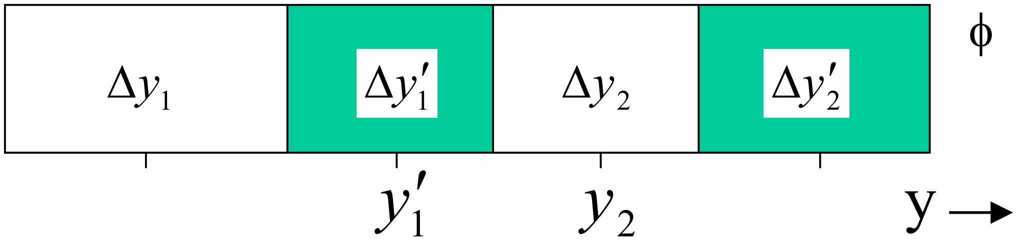
$$\int_{x=1/s}^{1} f(x)\,dx \sim s^{\lambda}$$

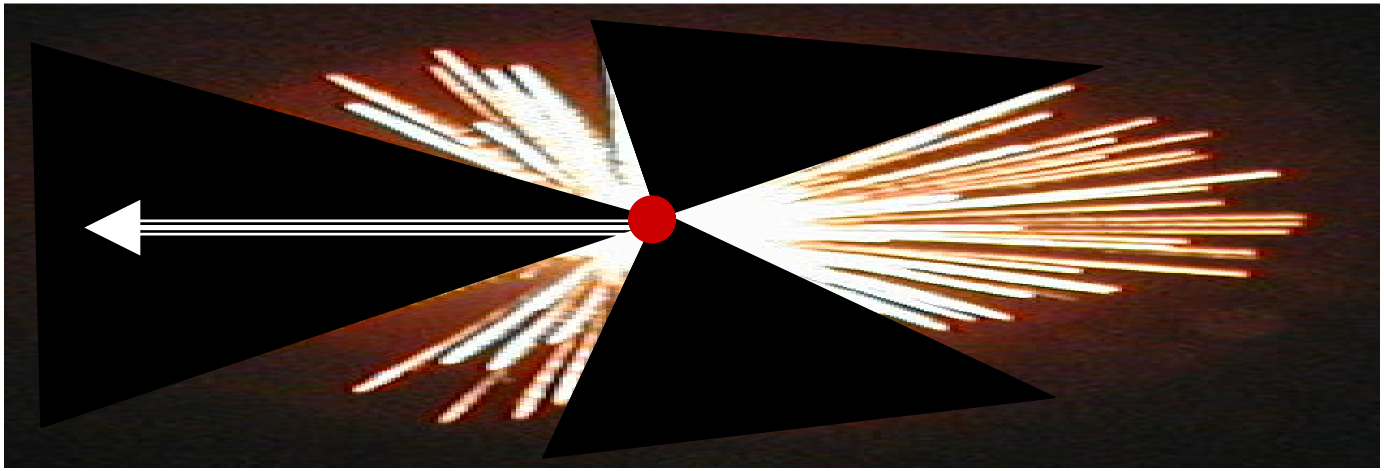


Multigap Diffraction

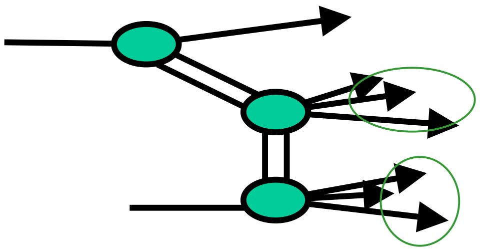
(KG, hep-ph/0205141)

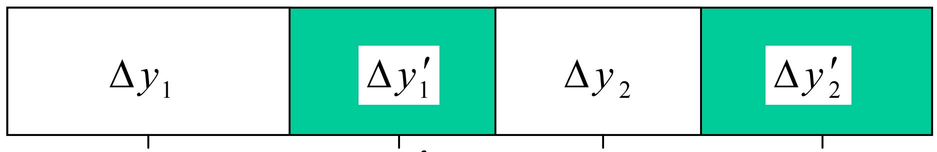






Multigap Cross Sections





y'_1 y_2

5 independent variables $\left\{ t_1 \quad \Delta y = \Delta y_1 + \Delta y_2 \quad t_2 \right.$

color factor

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

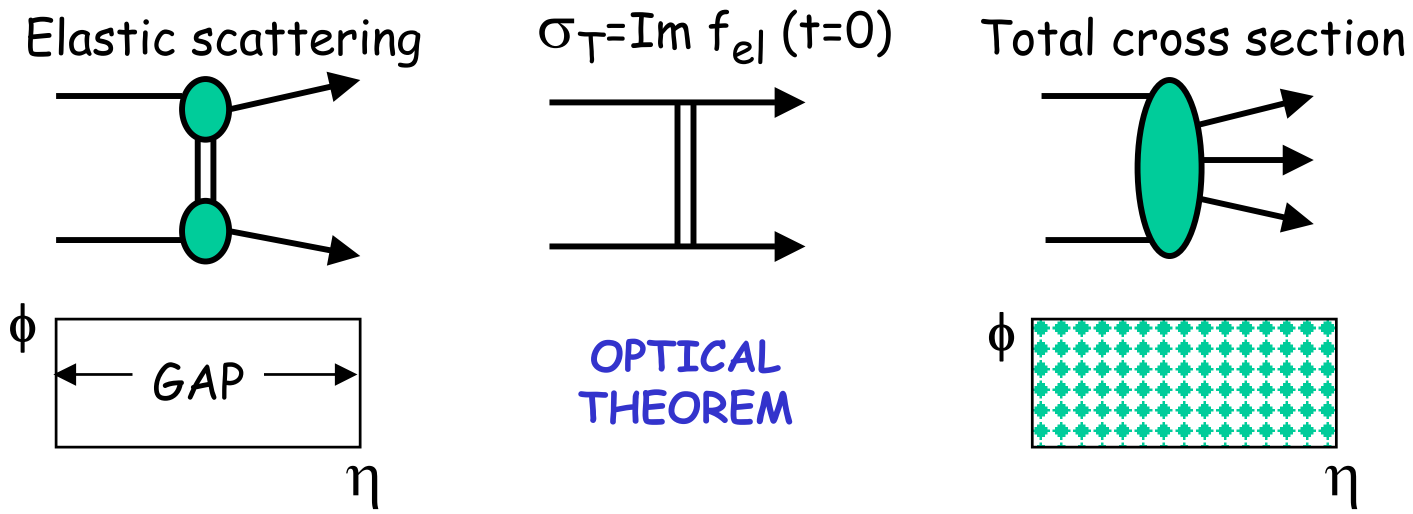
Gap probability

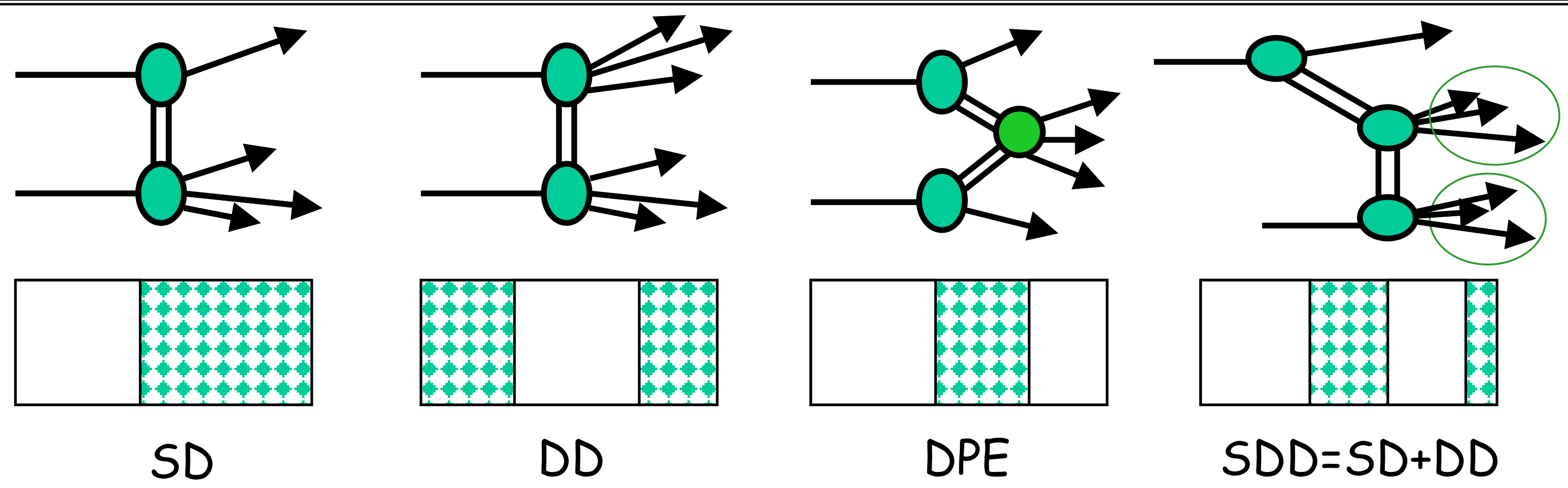
$$\int_{\Delta y, t} \sim s^{2\varepsilon} / \ln s$$

Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

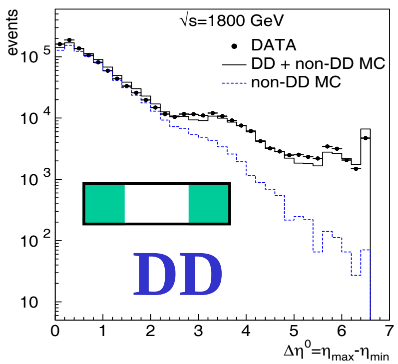
Diffractive Studies @ CDF

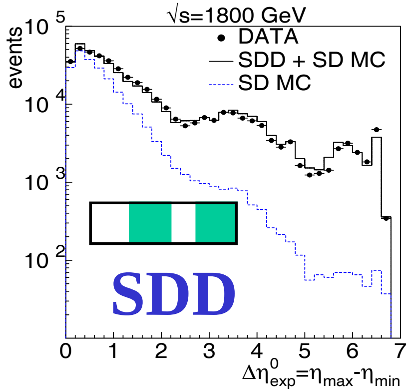


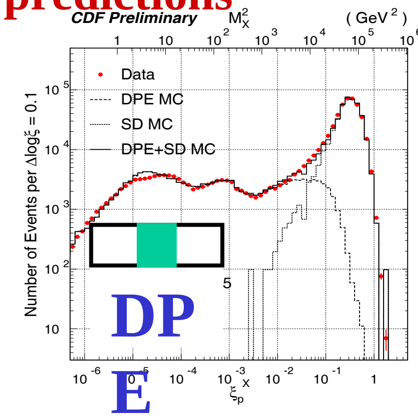


Central and Two-Gap CDF Results

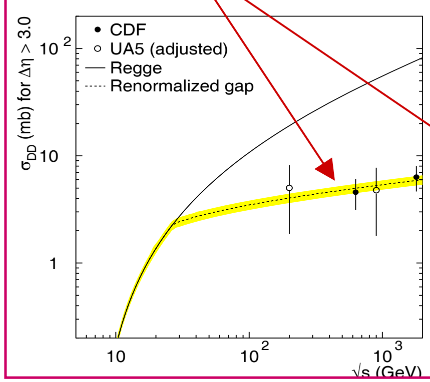
Agreement with renormalized Regge predictions

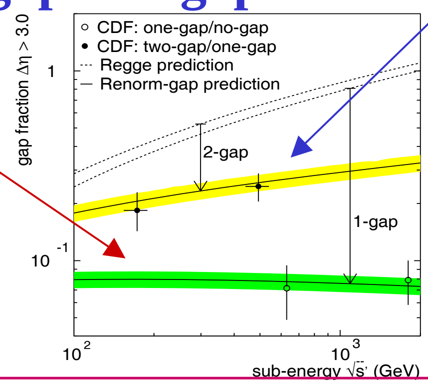


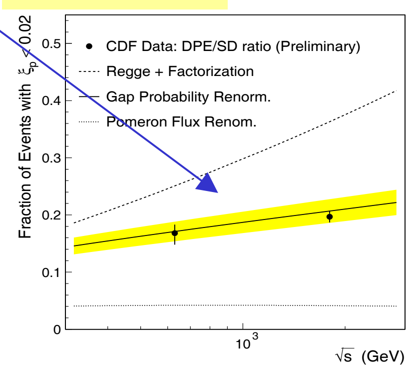




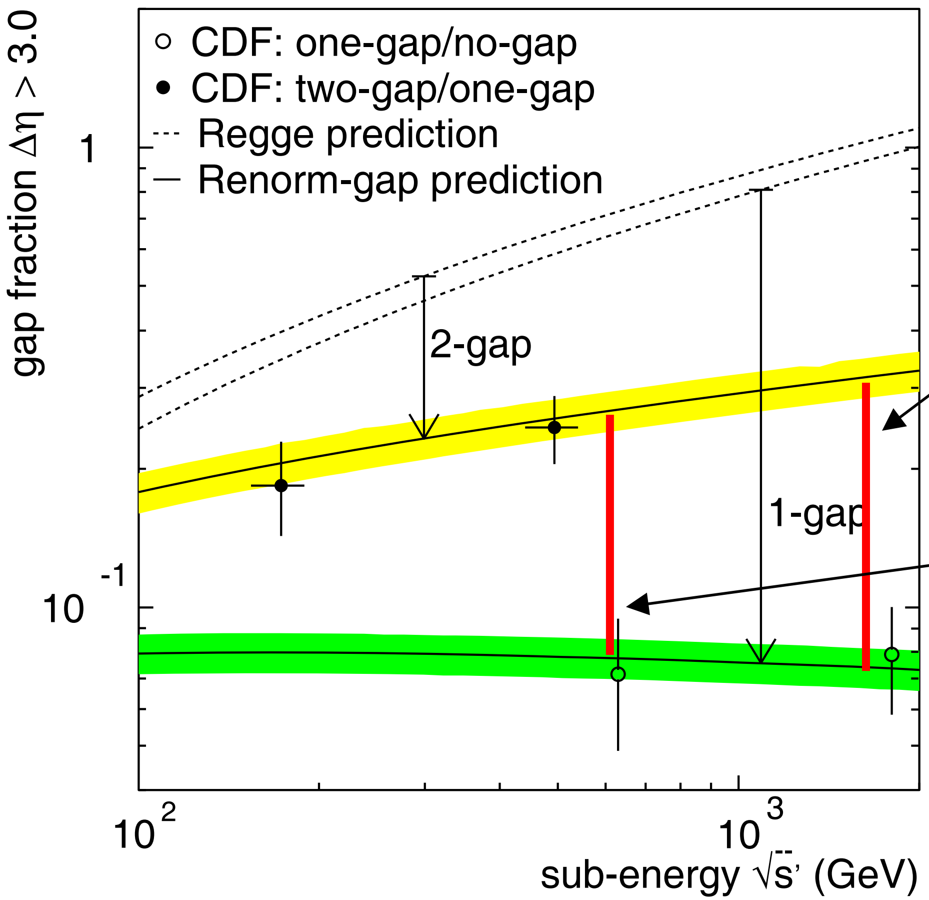
- **One-gap cross sections are suppressed**
- **Two-gap/one-gap ratios are $\approx \kappa = 0.17$**

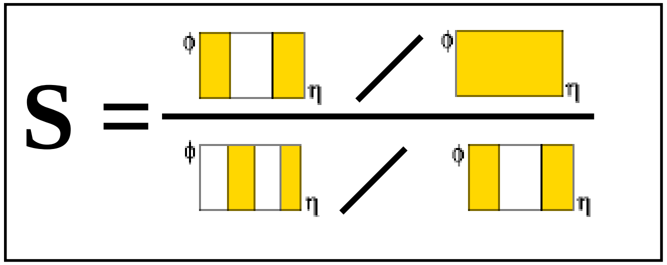






Gap Survival Probability





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

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

Results similar to predictions by:

Gotsman-Levin-Maor

Kaidalov-Khoze-Martin-Ryskin

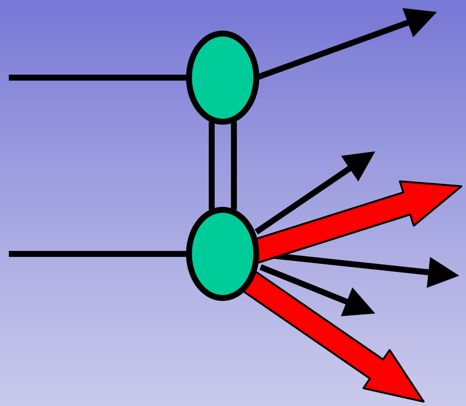
Soft color interactions

Lessons from Soft Diffraction

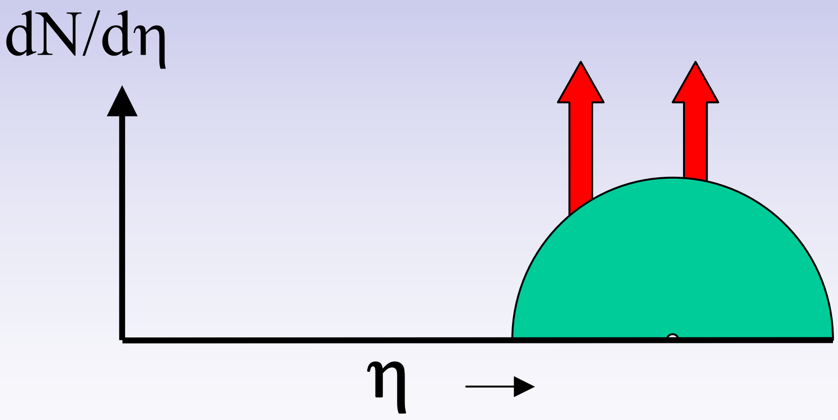
- M^2 - scaling ➔ renormalization
- Non-suppressed 2-gap to 1-gap ratios

➔ Pomeron: composite object made up from underlying proton pdf's subject to QCD color constraints

HARD DIFFRACTION



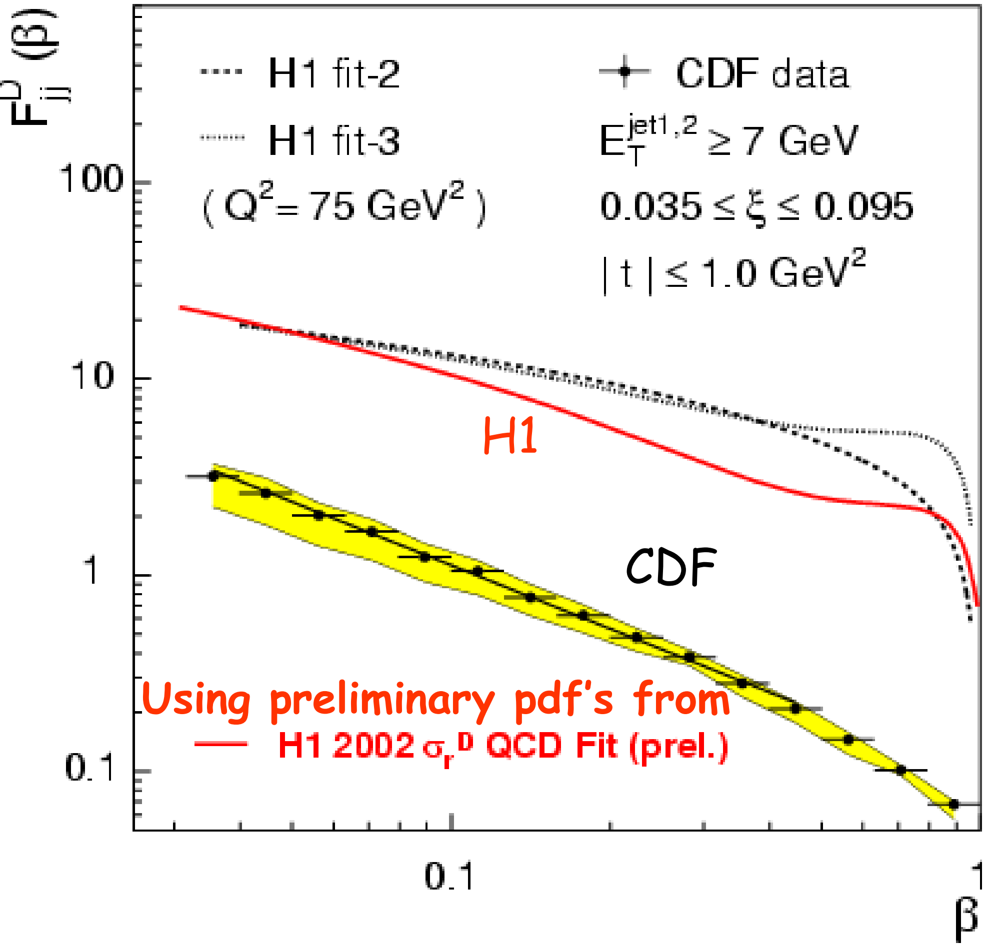
- Diffractive structure function
  - ➔ factorization breakdown - how?
- Restoring factorization
- Diffractive fractions



JJ, W, b, J/ψ

Diffractive Structure Function:

Breakdown of QCD Factorization

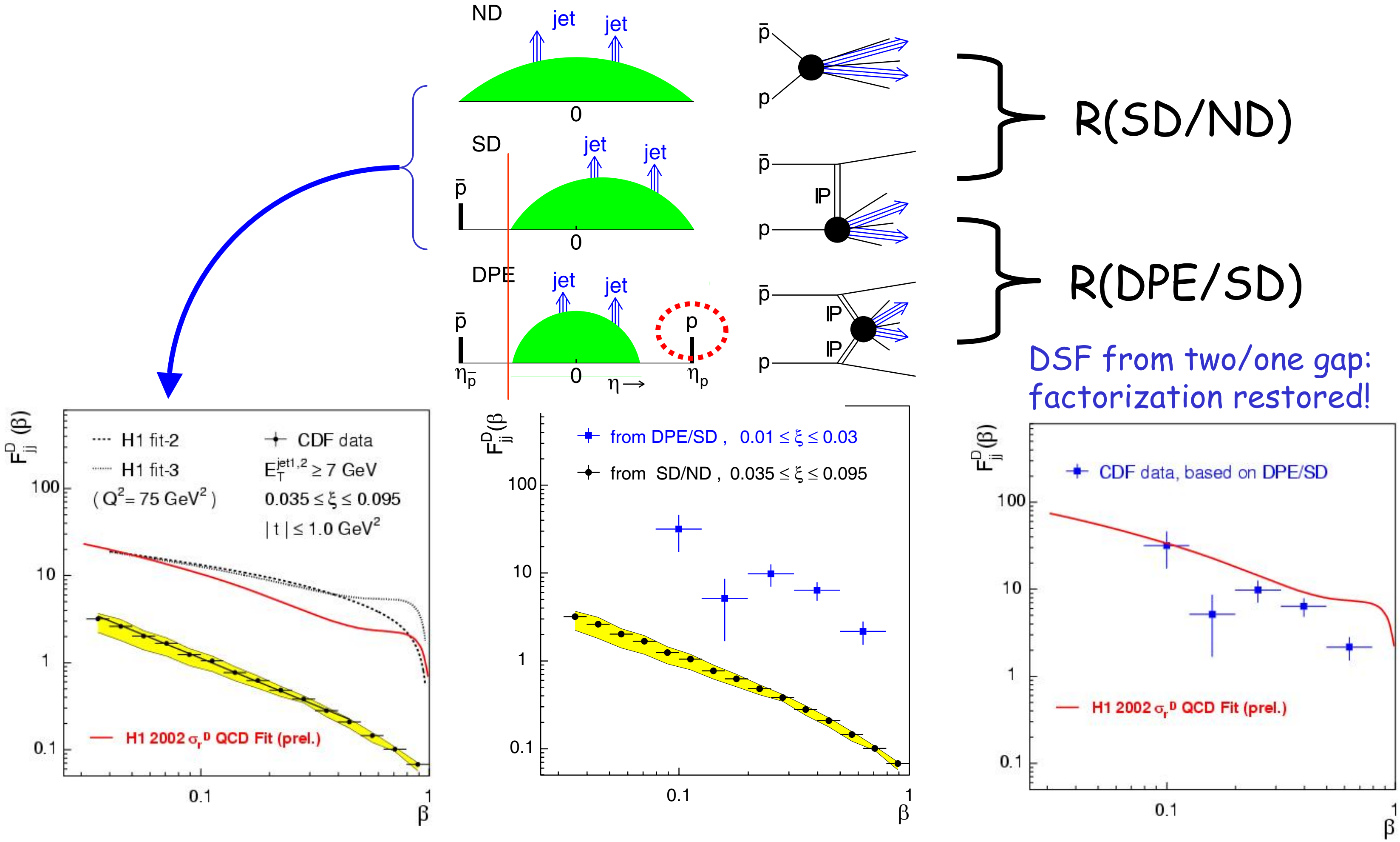


β = momentum fraction of parton in Pomeron

The diffractive structure function at the Tevatron is suppressed by a factor of ~10 relative to expectation from pdf's measured by H1 at HERA

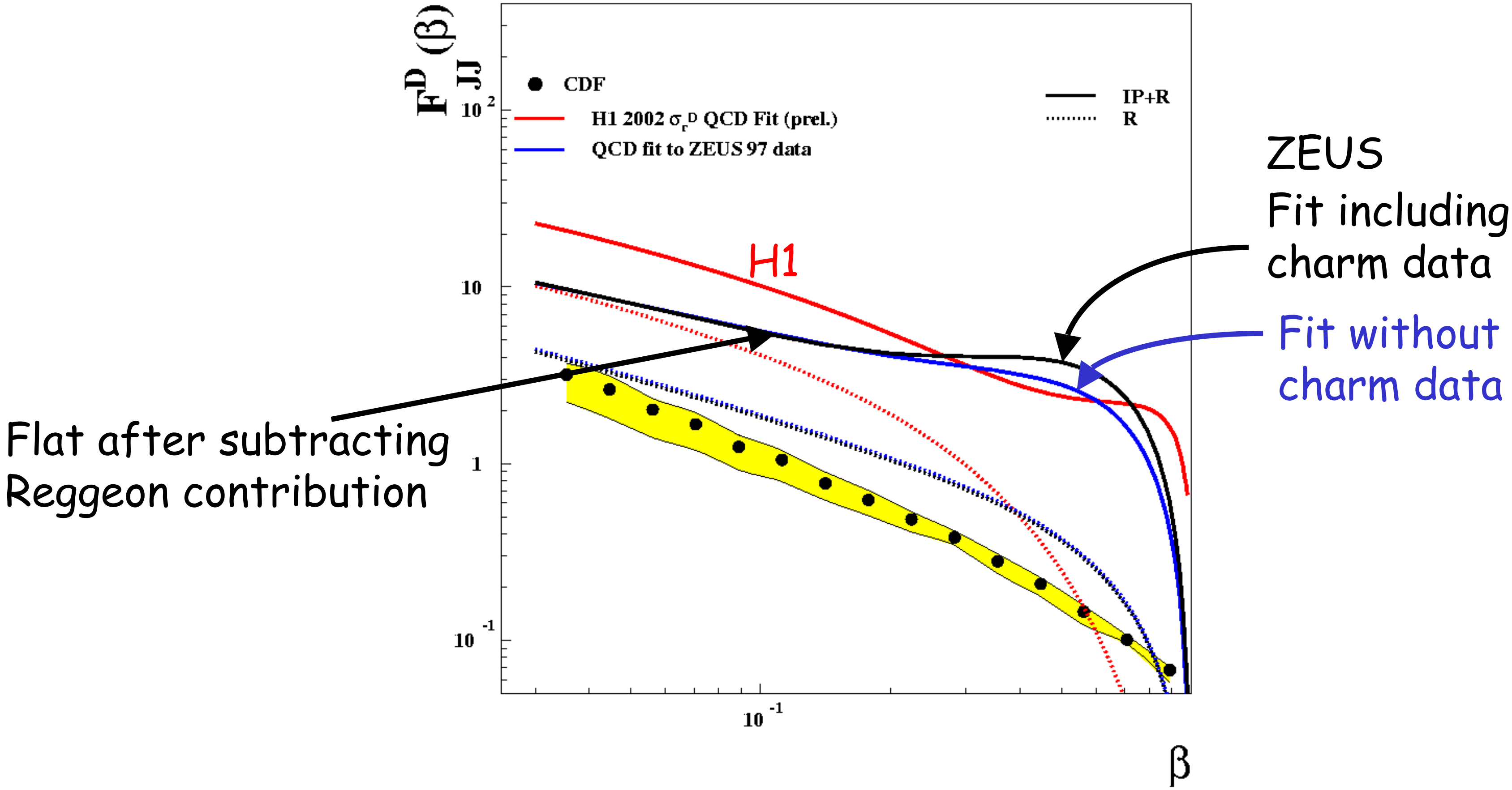
Similar suppression factor as in soft diffraction relative to expectations from Regge theory and factorization!

Restoring Factorization @ Tevatron

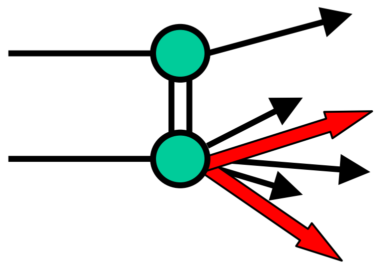


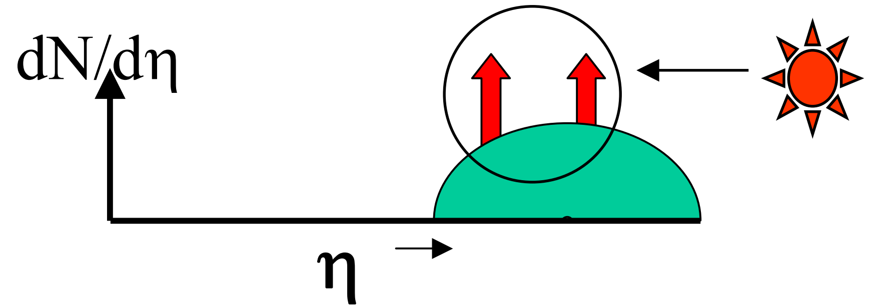
$F^D_{JJ}(\beta)$ from ZEUS-LPS Data

From: M. Arneodo, HERA/LHC workshop, CERN, 11-13 Oct 2004



Hard Diffractive Fractions @ CDF





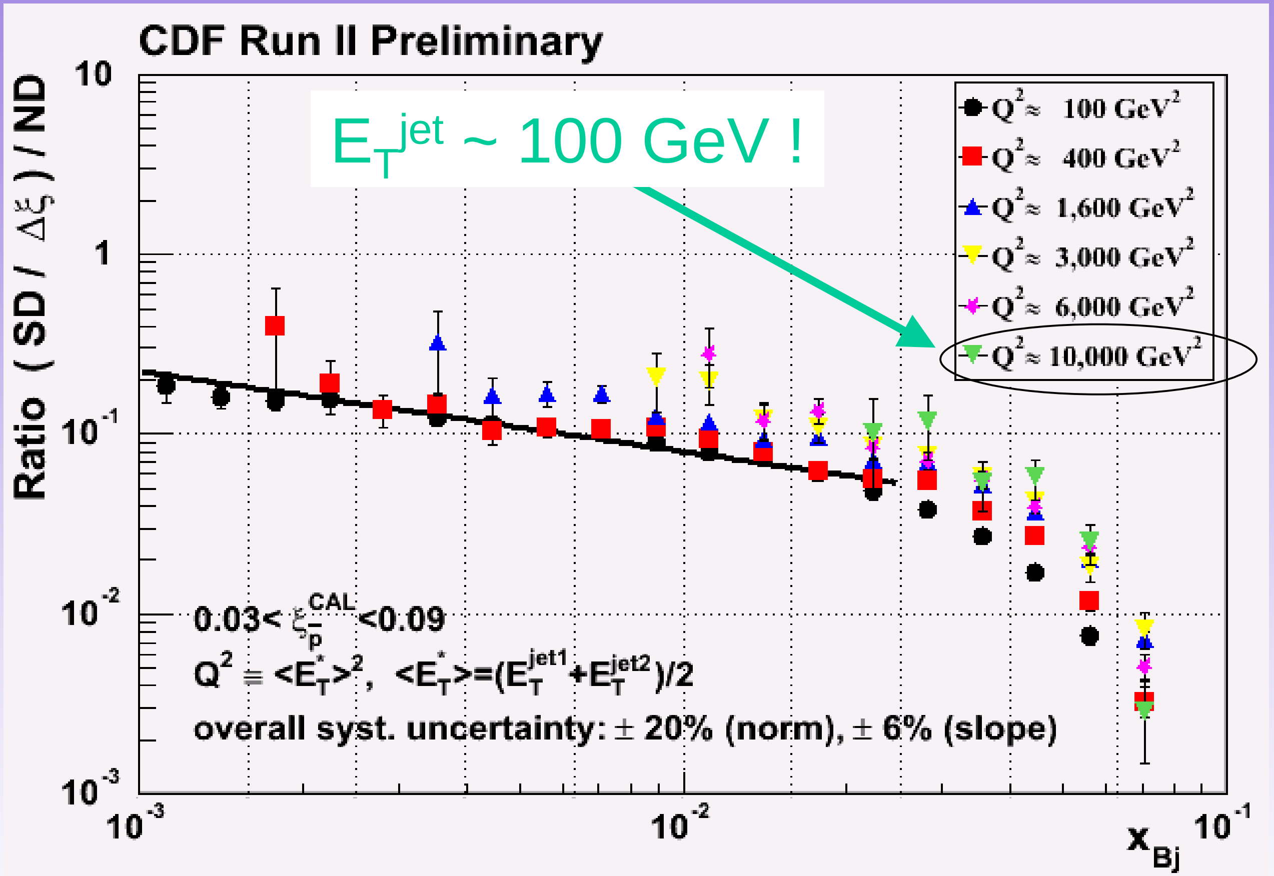
$$\bar{p}p \to (\text{☼} + X) + \text{gap}$$

Fraction:
SD/ND ratio at 1800 GeV

☼	% 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 !

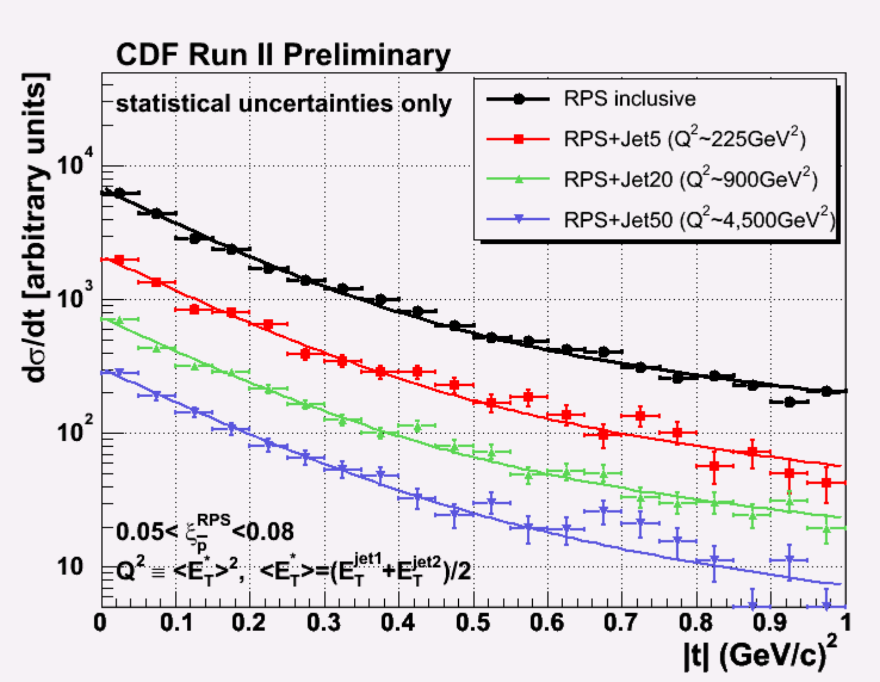
Diffractive Structure Function:
Q^2 dependence

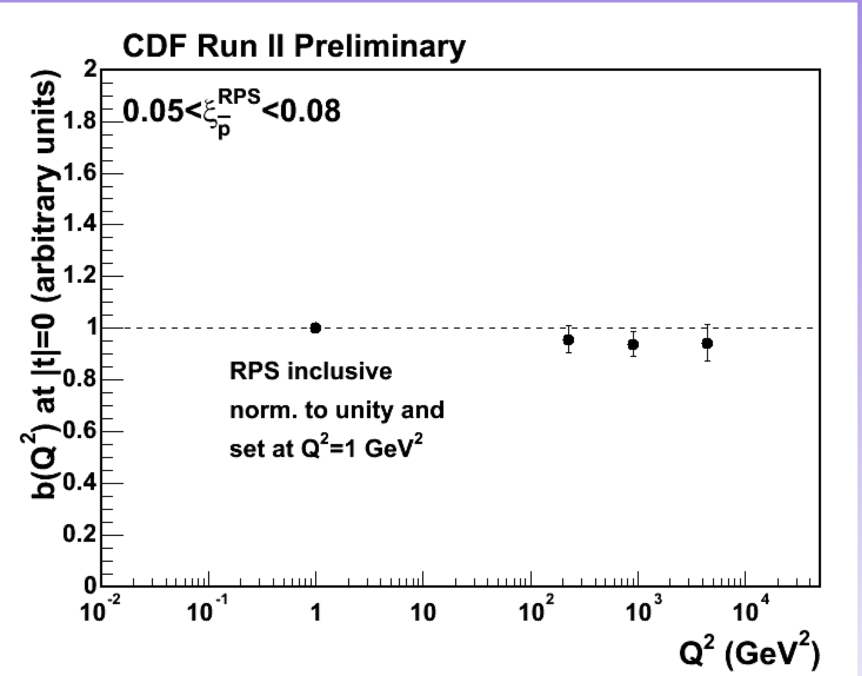


Small Q^2 dependence in region $100 < Q^2 < 10{,}000$ GeV²

⇨ Pomeron evolves as the proton!

Diffractive Structure Function:
t- dependence





Fit dσ/dt to a double exponential:

$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

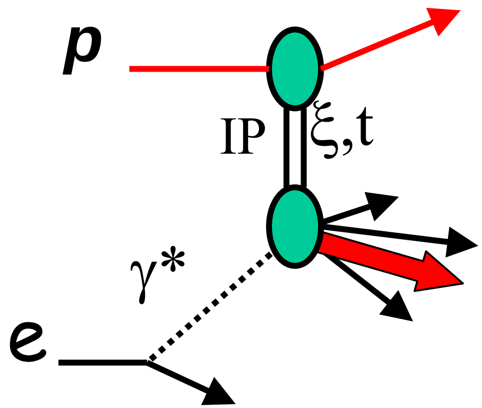
- No diffraction dips
- No Q2 dependence in slope from inclusive to $Q^2 \sim 10^4$ GeV^2

- Same slope over entire region of $0 < Q^2 < 4{,}500$ GeV^2 across soft and hard diffraction!

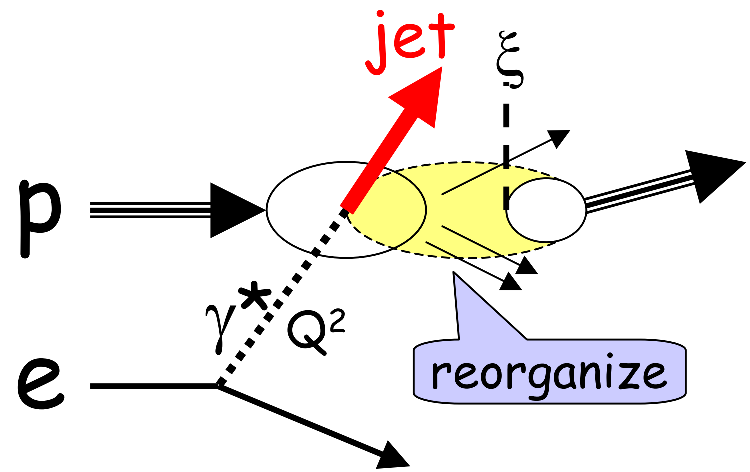
Diffractive DIS @ HERA

J. Collins: factorization holds (but under what contitions?)

Pomeron exchange



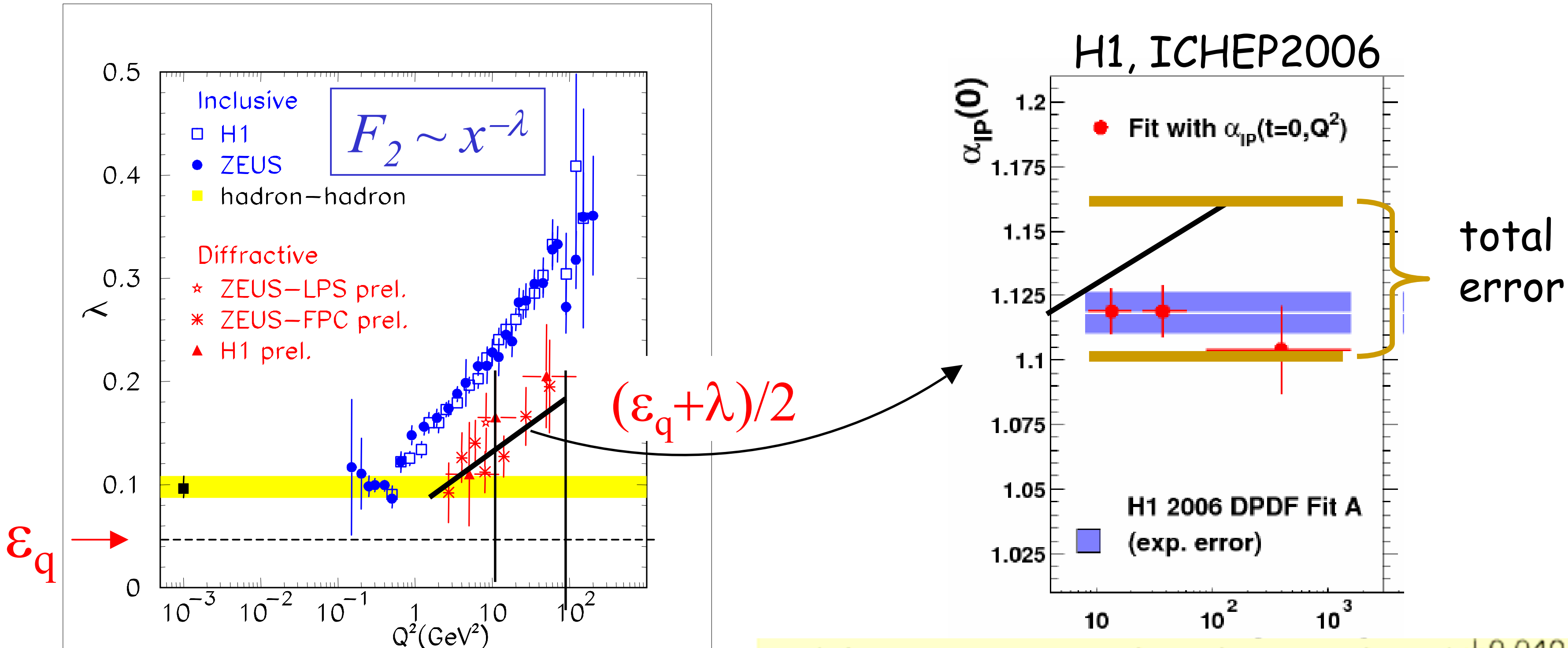
Color reorganization



$$F_2^{D(3)}(\xi, x, Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F_2(x, Q^2)$$

Inclusive vs Diffractive DIS

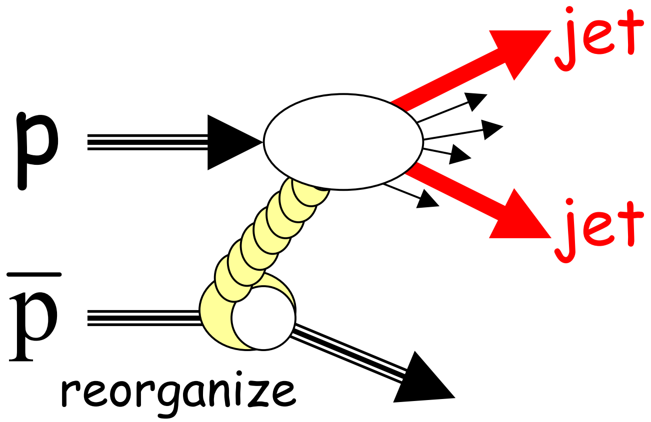
KG, "Diffraction: a New Approach," J.Phys.G26:716-720,2000 e-Print Archive: **hep-ph/0001092**



$\alpha_{I\!P}(0) = 1.114 \pm 0.018(\text{stat.}) \pm 0.012(\text{syst.})^{+0.040}_{-0.020}(\text{th.})$

$$F_2^{D(3)}(\xi,\beta,Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot \frac{C(Q^2)}{(\beta\xi)^{\lambda(Q^2)}} \propto \frac{1}{\xi^{1+\varepsilon+\lambda}} \cdot \frac{C}{\beta^{\lambda}}$$

Diffractive Dijets @ Tevatron



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

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

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

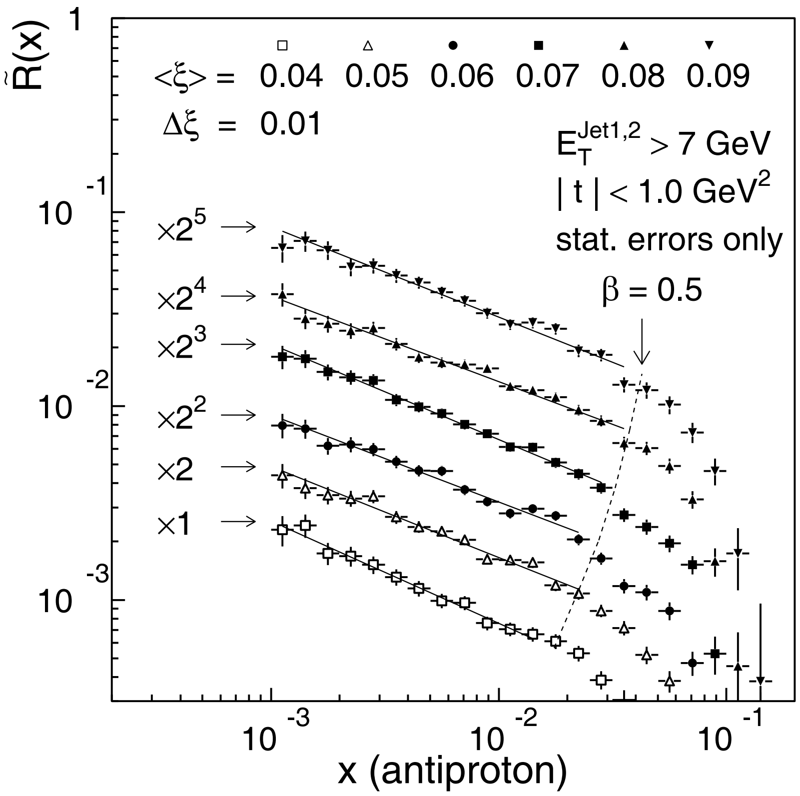
$$\mathrm{N}^{-1}_{\text{renorm}} = \int_{\xi_{\min}}^{1} \frac{d\xi}{\xi^{1+2\varepsilon}} \xrightarrow{\xi_{\min} = \frac{x_{\min}}{\beta} \approx \frac{1}{\beta s}} \frac{(\beta s)^{2\varepsilon}}{2\varepsilon}$$

RENORM $\Rightarrow$ $R^{SD}_{ND}(x) = \dfrac{2\varepsilon}{s^{2\varepsilon}} \dfrac{1}{\xi^{1-\lambda(Q^2)}} \cdot x^{-(2\varepsilon)}$

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

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

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



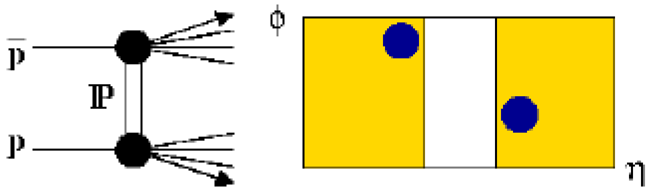
0.035 < ξ < 0.095

Flat ξ dependence

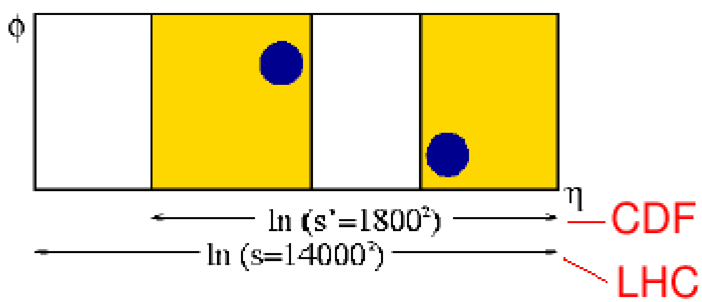
$$R(x) = x^{-0.45}$$

Gap Between Jets

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

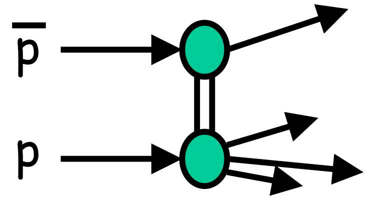


$$R^{J-G-J}_{TEV}(s') \approx 1\%/$$

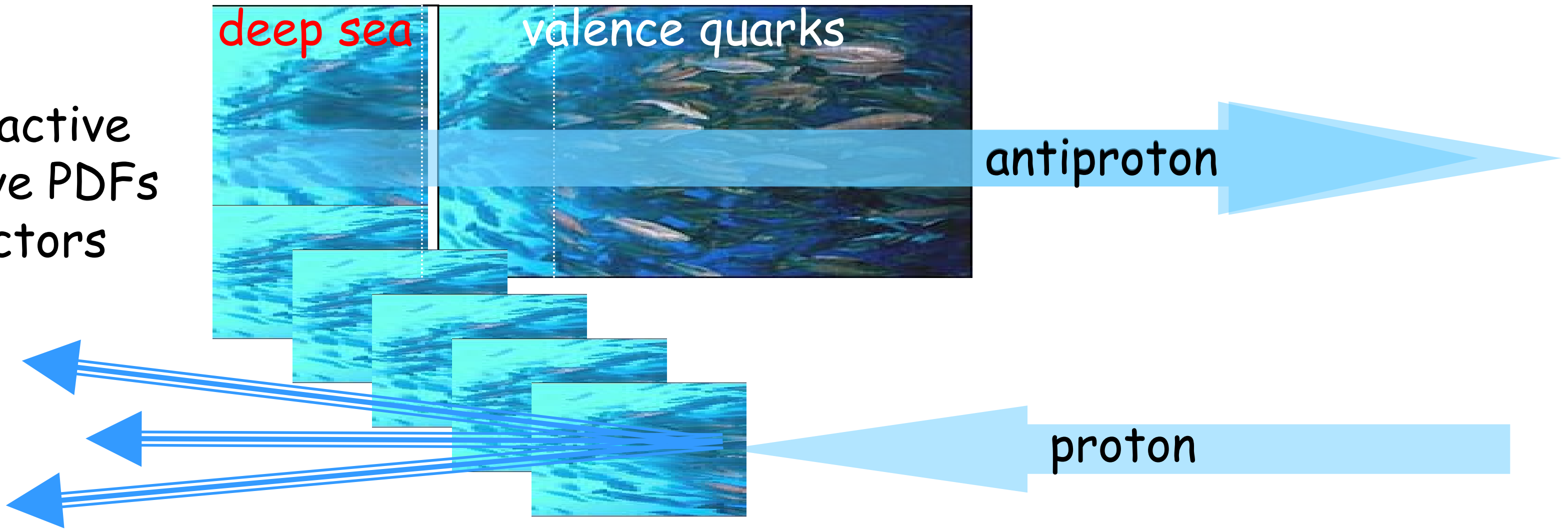


$$R^{J-G-J}_{LHC}(s') = \frac{R^{J-G-J}_{TEV}}{S} \approx \frac{1\%}{0.2} \approx 5\%$$

Hard Diffraction in QCD

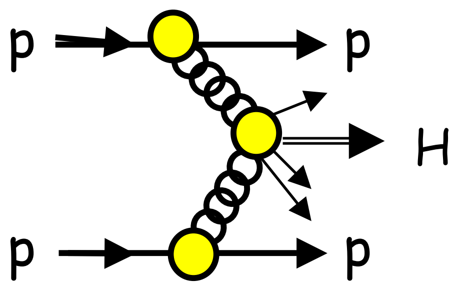


Derive diffractive
from inclusive PDFs
and color factors



Diffractive Higgs @ LHC

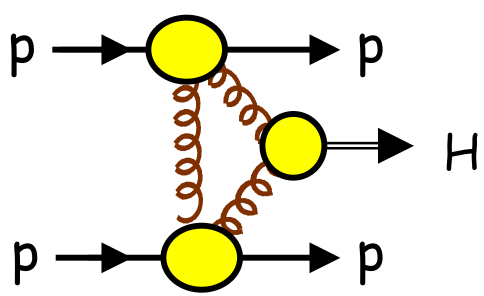
Back of the envelope calculation



Inclusive production

$$\ln s'_{LHC} \approx \ln s_{Tevatron}$$

σ^{D}(LHC) ~ P(gap) x σ^{ND} (Tevatron)
~ 0.1 x 1 pb = 100 fb



Exclusive production

σ^{excl} ~ σ^{incl} x 0.02~ 2 fb

Fraction of 2/all particle multiplicity

OTHER THEORETICAL PREDICTIONS

Exclusive DPE Higgs production pp→p H p : 3-10 fb (KMR)
Inclusive DPE Higgs production pp→p+X+H+Y+p : 50-200 fb (others)

SUMMARY

Diffraction is an interaction between low-x partons subject to color constraints