Diffractive Gap Probability

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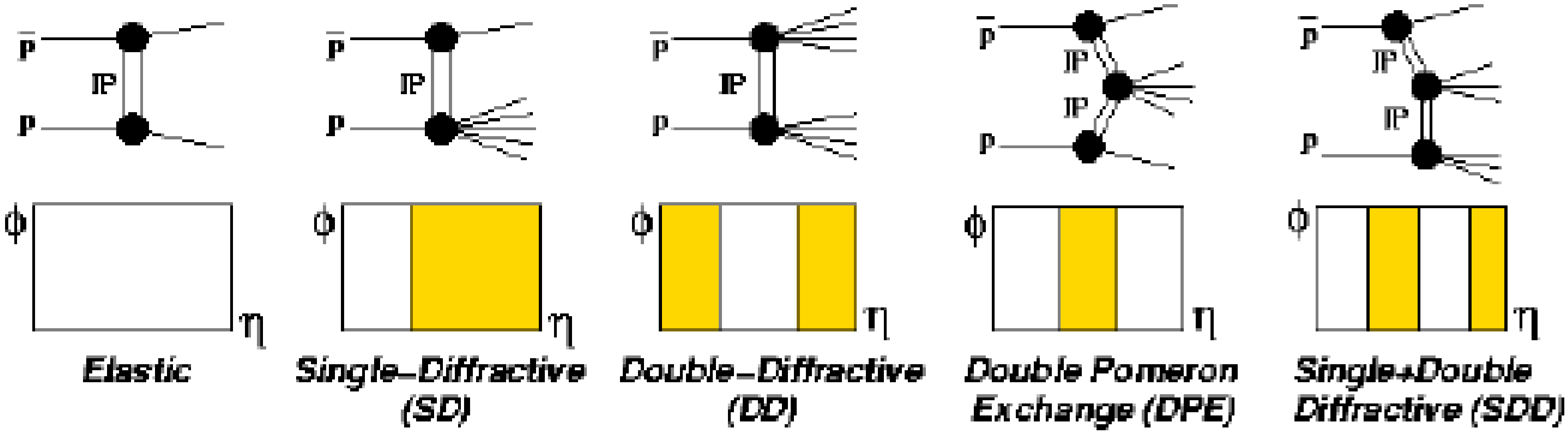
CERN 26-27 March 2004

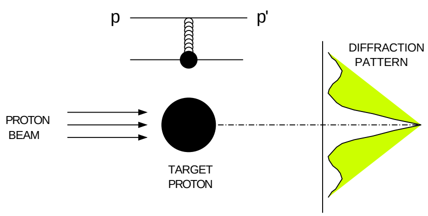
Diffractive signatures

- Leading hadron(s)
- Rapidity gap(s)

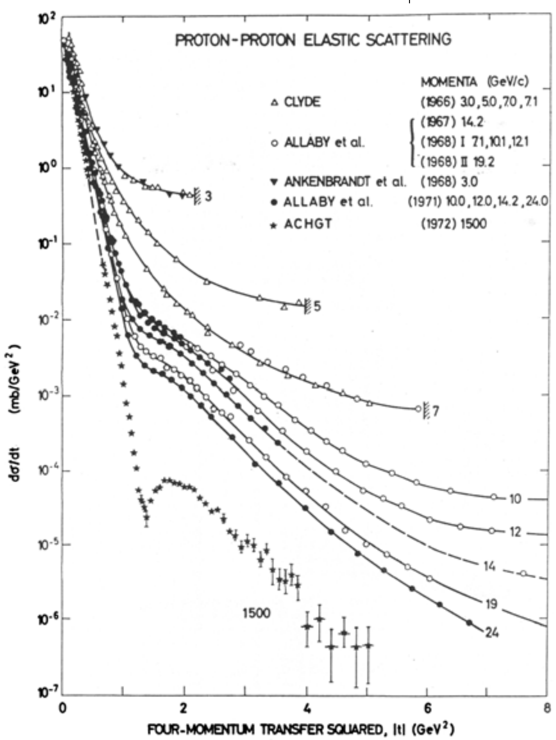


Leading hadrons

PROTON-PROTON ELASTIC SCATTERING

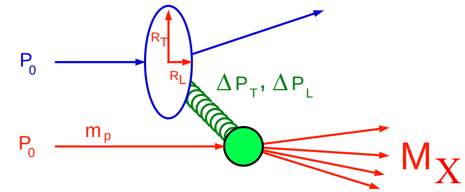


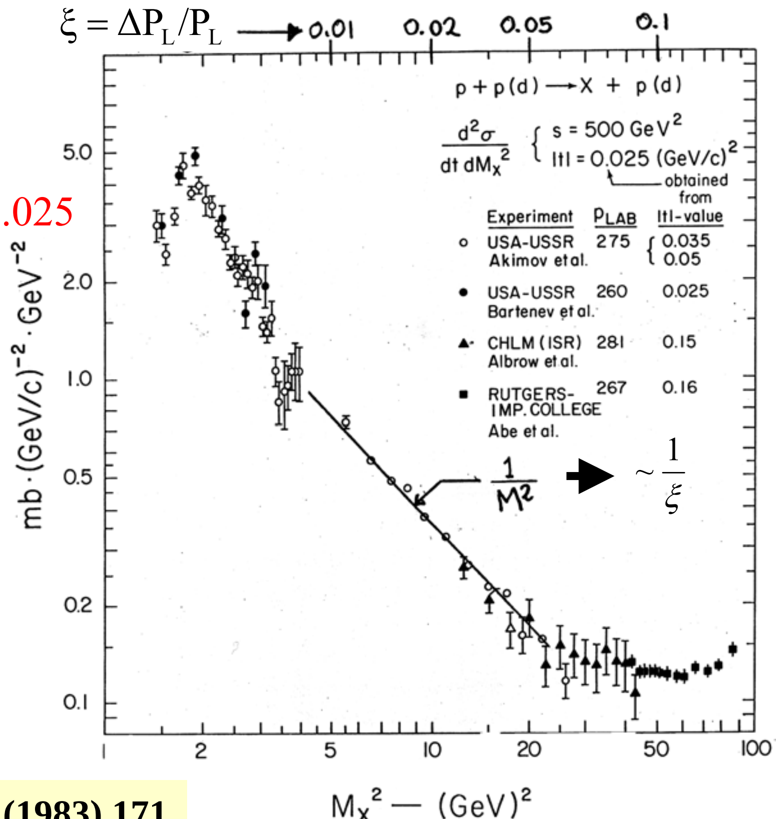
$$\frac{d\sigma}{dt}$$



$$\frac{d^2\sigma}{dt\, dM^2}\Bigg|_{t=0.025}$$

Diffraction dissociation

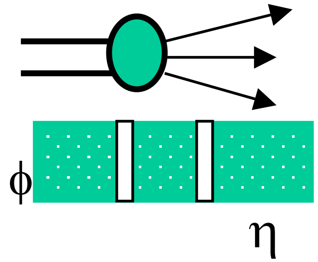




KG, Phys. Rep. 101 (1983) 171

Rapidity gaps

❖ Minimum bias

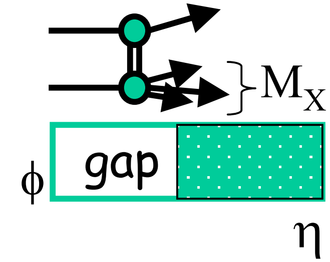


From Poisson statistics:

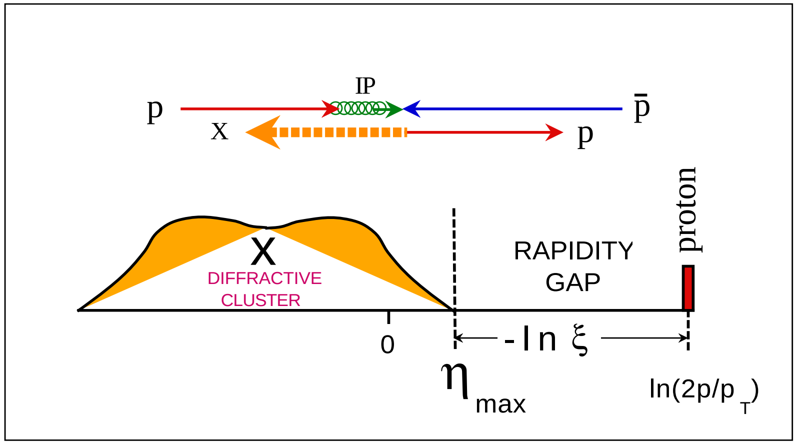
$$P(\Delta y) = e^{-\rho \Delta y} \quad \left(\rho = \frac{dn}{dy} \right)$$

Gaps exponentially suppressed

❖ Diffraction dissociation

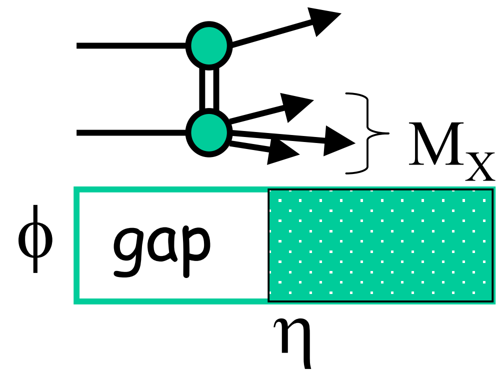


$$\Delta y \approx -\ln \xi = \ln s - \ln M^2$$



$$\frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \quad \leftrightarrow \quad \frac{d\sigma}{dy} \propto \text{constant}$$

QCD aspects of diffraction



- **Quark/gluon exchange across a rapidity gap:**

  POMERON

- **No particles radiated in the gap:**

  the exchange is COLOR-SINGLET <u>with vacuum quantum numbers</u>

- **Rapidity gap formation:**

  NON-PERTURBATIVE

- **Diffraction probes the large distance aspects of QCD:**

  POMERON ? CONFINEMENT

  - **PARTONIC STRUCTURE**
  - **FACTORIZATION PROPERTIES**

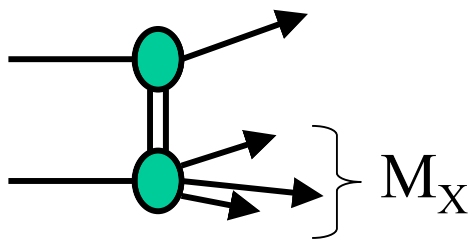
History of Diffraction

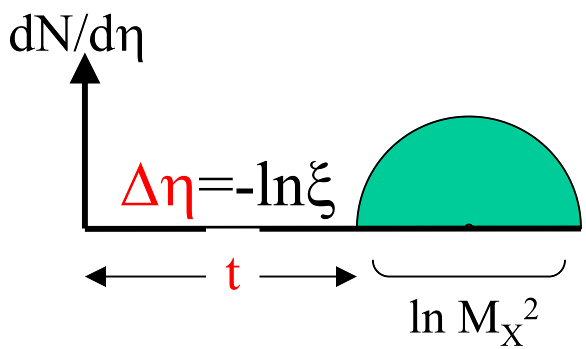
40 years of diffraction

1960	Good and Walker
1960's	BNL: first observation
1970's	Fermilab fixed target, ISR, SPS
1983	KG, Phys. Rep. 101, 169 (1983)
1992	UA8: diffractive dijets ⇨ hard diff
1993-2003	Golden decade: HERA, Tevatron, RHIC

Soft and Hard Diffraction

- SOFT DIFFRACTION



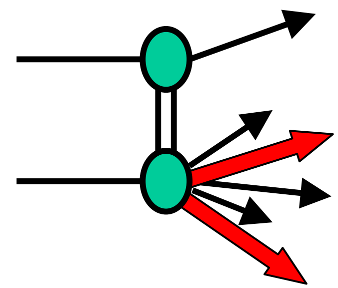


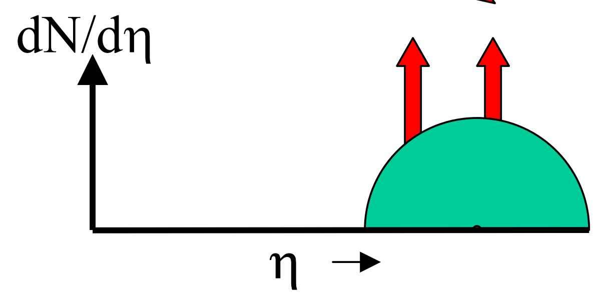
$\xi = \Delta P_L / P_L$

ξ=fractional momentum loss of scattered (anti)proton

Variables: (ξ, t) or (Δη, t)

- HARD DIFFRACTION





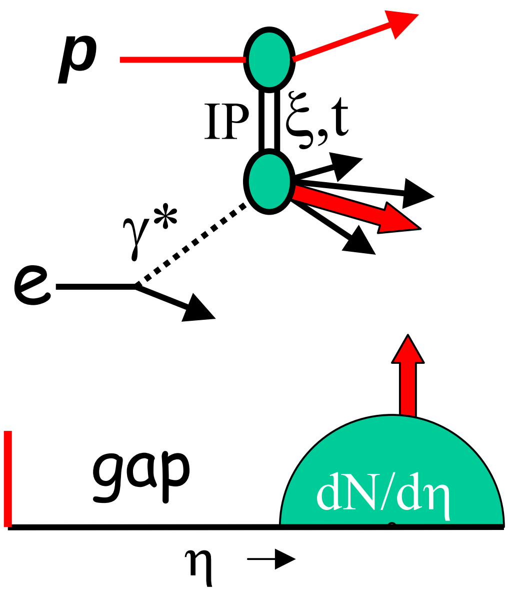
Additional variables: ($\boldsymbol{x}$, Q^2)

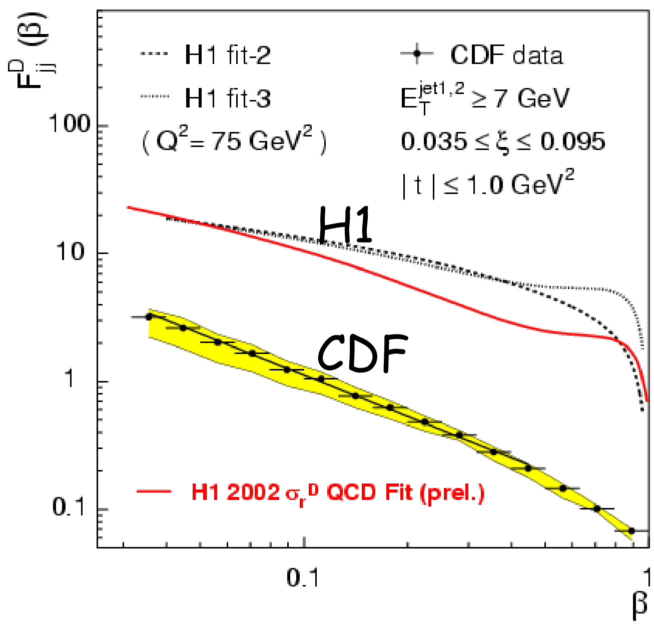
$$x_{Bj} = \sum E_T^{jet} e^{-\eta^{jet}} / \sqrt{s}$$

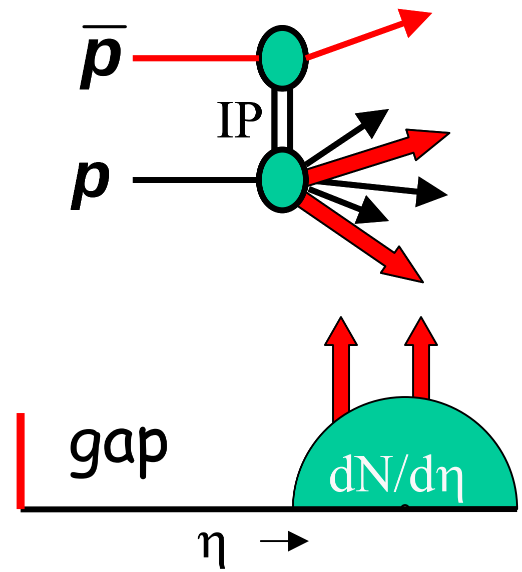
$$x = \beta\, \xi, \quad Q^2 = (E_T^{jet})^2$$

Breakdown of QCD factorization

HERA ⟶ TEVATRON



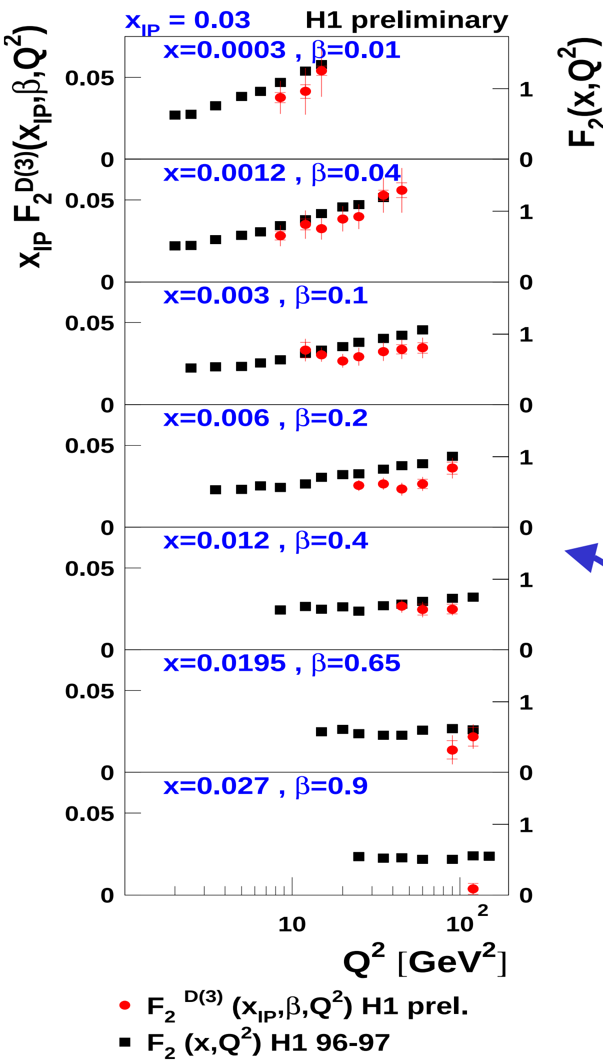


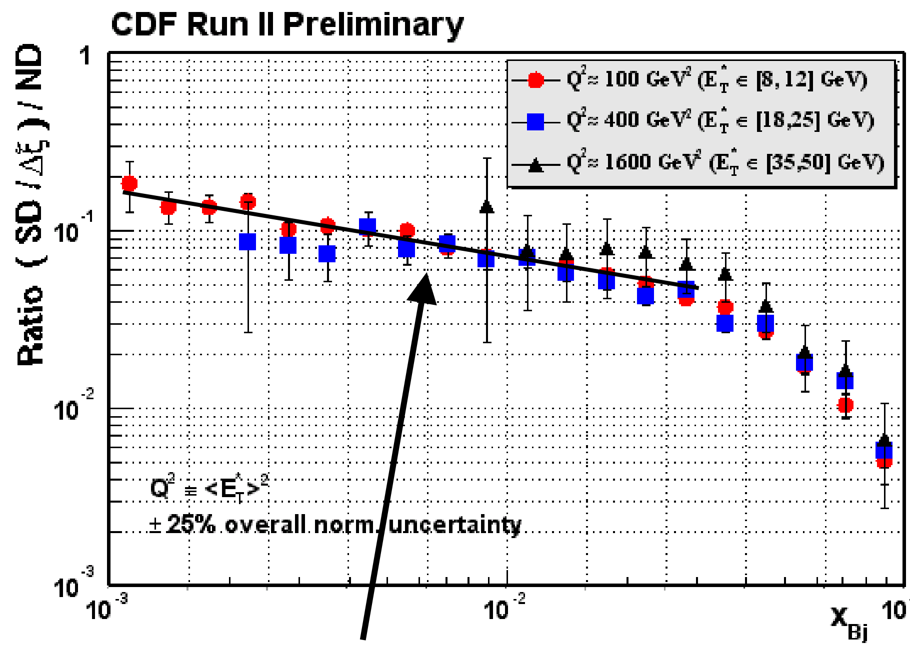


$F_2(Q^2, x)$ ⟶ $F_{JJ}(E_T^{Jet}, x)$

$F_2^D(Q^2, \beta, \xi, t)$ —— XXX ⟶ $F_{JJ}^D(E_T^{Jet}, \beta, \xi, t)$

Diffractive vs inclusive structure fn's





$F^D_{JJ}(x,Q^2)\ /F(x,Q^2)$

$F_2^D(x,Q^2)\ /F_2(x,Q^2)$

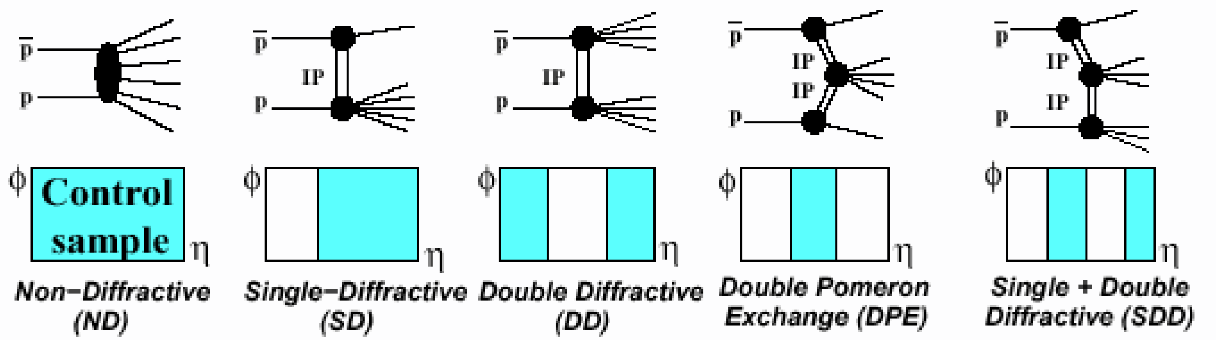
$$R\left(\frac{F^D(Q^2,x,\xi)}{F(Q^2,x)}\right) \Rightarrow \begin{cases} \sim \text{no } Q^2 \text{ dependence} \\ \sim \text{flat at HERA} \\ \sim 1/x^{0.5} \text{ at Tevatron} \end{cases}$$

Diffraction@CDF in Run I

16 papers

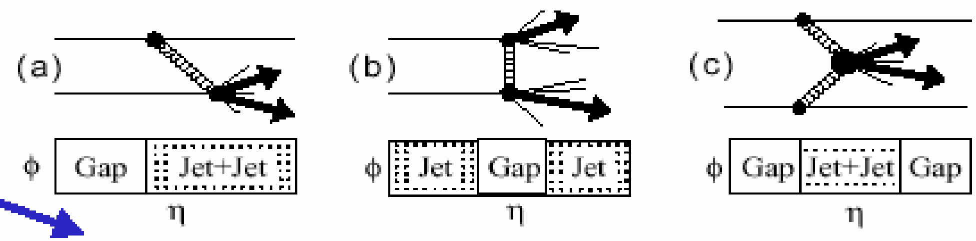
- Elastic scattering — PRD 50 (1994) 5518
- Total cross section — PRD 50 (1994) 5550
- Diffraction

SOFT diffraction



	PRD	PRL	PRL	PRL
	50 (1994) 5535	87 (2001)141802	submitted	91(2003)011802

HARD diffraction



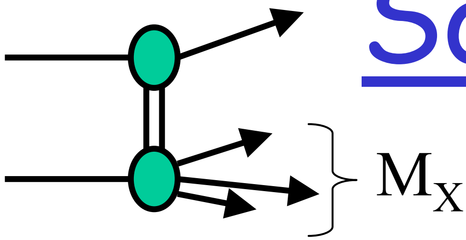
PRL references

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

Soft Diffraction



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

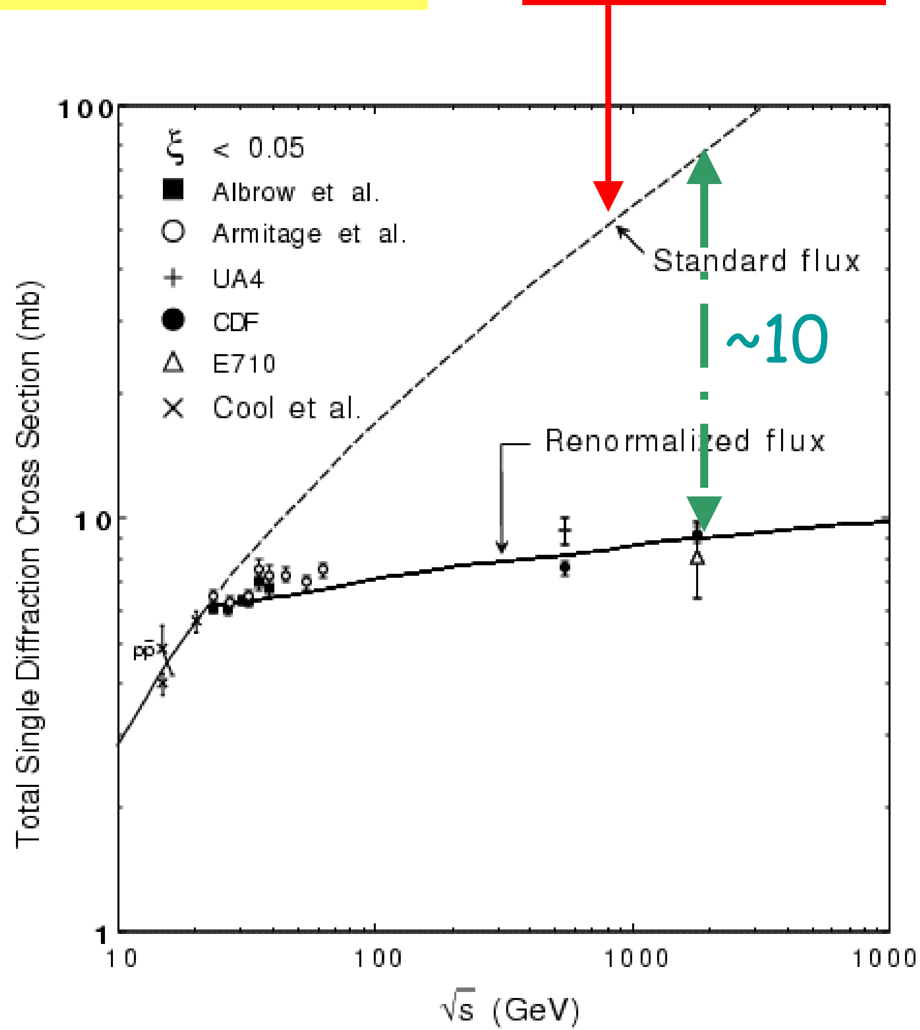
$$\sigma_{SD} \sim s^{2\varepsilon}$$

- **Unitarity problem:**
  With 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

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



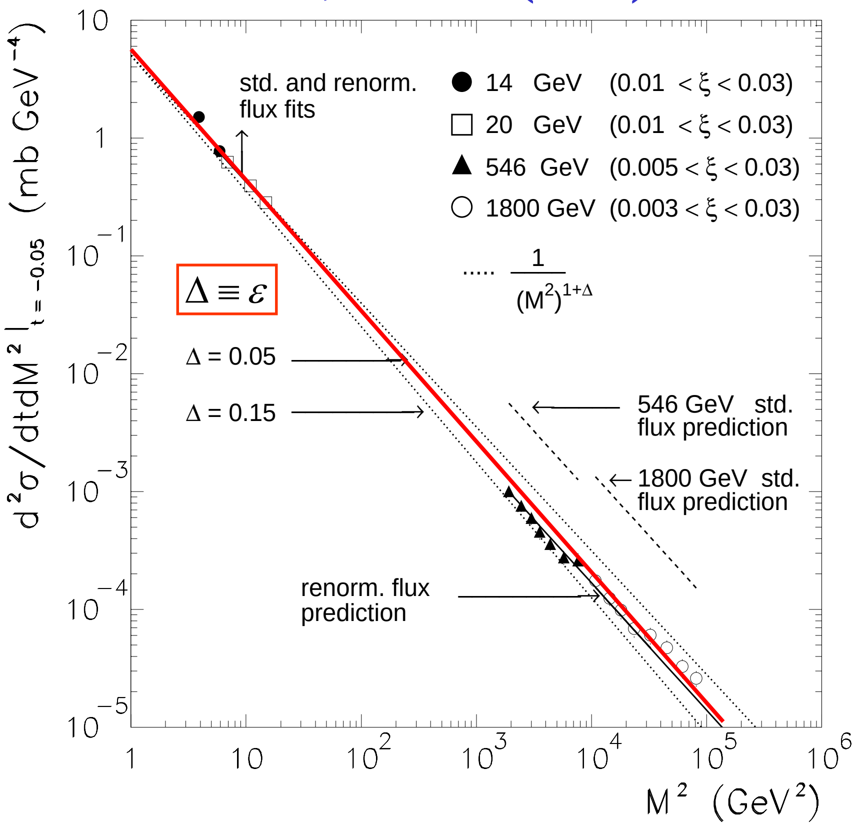
A Scaling Law in Diffraction

Factorization breaks down in favor of M^2-scaling

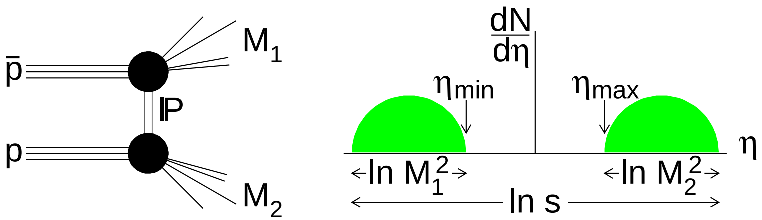
renormalization

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

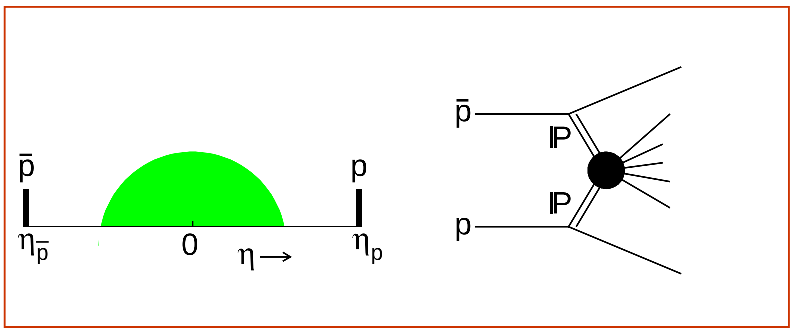
KG&JM, PRD 59 (1999) 114017



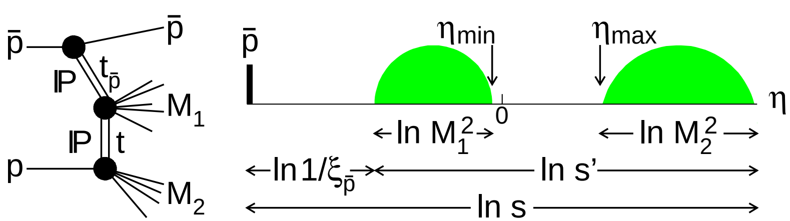
Central and Double Gaps



- **Double Diffraction Dissociation**
  - **One central gap**

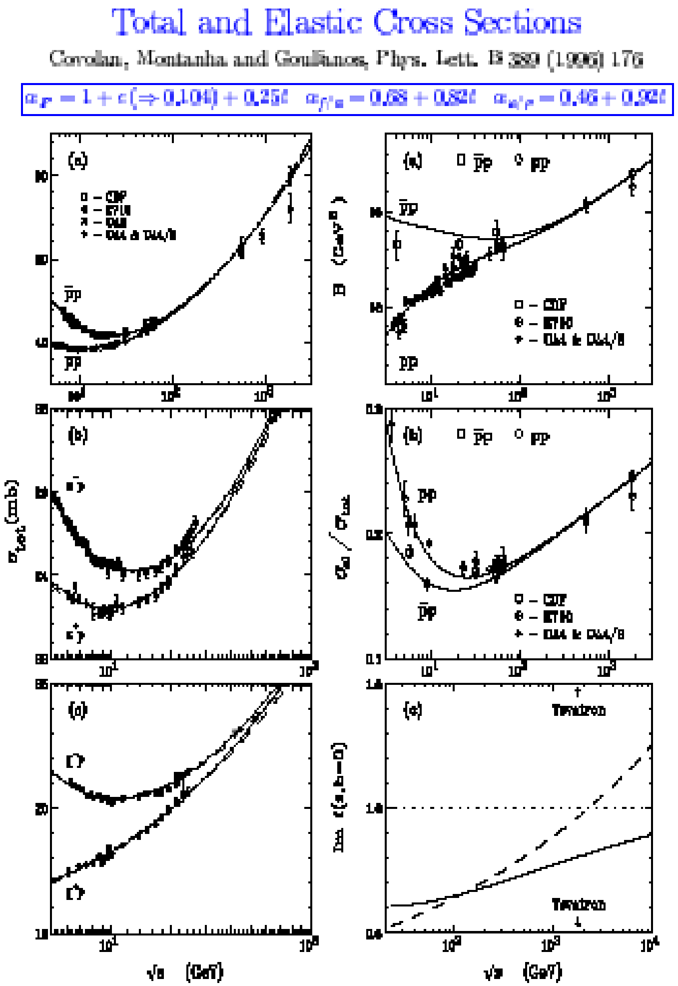


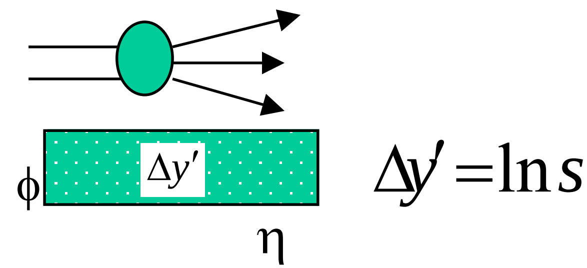
- **Double Pomeron Exchange**
  - **Two forward gaps**



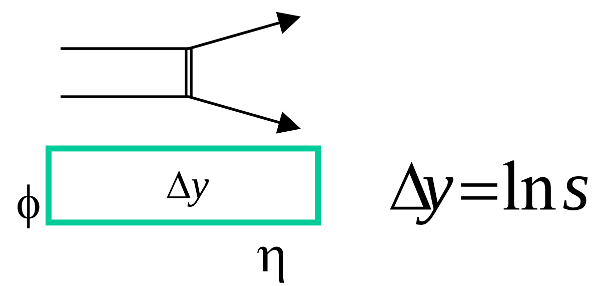
- **SDD: Single+Double Diffraction**
  - **Forward + central gaps**

Elastic & total σ





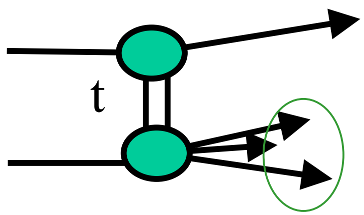
$$\sigma_T(s) = \sigma_o\, s^{\varepsilon} = \sigma_o\, e^{\varepsilon \Delta y'}$$

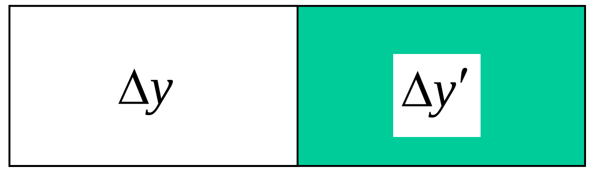


$$\sigma_{el}(s,t) \propto \left(e^{(\varepsilon+\alpha' t)\Delta y}\right)^2$$

Generalized renormalization

(KG, hep-ph/0205141)





2 independent variables: $t, \Delta y$

color factor

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

$$\frac{d^2\sigma}{dt\, d\Delta y} = \underbrace{C \bullet F_p^2(t_1) \bullet \left\{ e^{(\varepsilon+\alpha' t)\Delta y} \right\}^2}_{\text{Gap probability}} \bullet \kappa \bullet \underbrace{\left\{ \sigma_o\, e^{\varepsilon\, \Delta y'} \right\}}$$

Gap probability

$$\sim e^{2\varepsilon \Delta y} \longrightarrow \int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon\, \Delta y} \approx s^{2\varepsilon}$$

Renormalization removes the s-dependence → SCALING

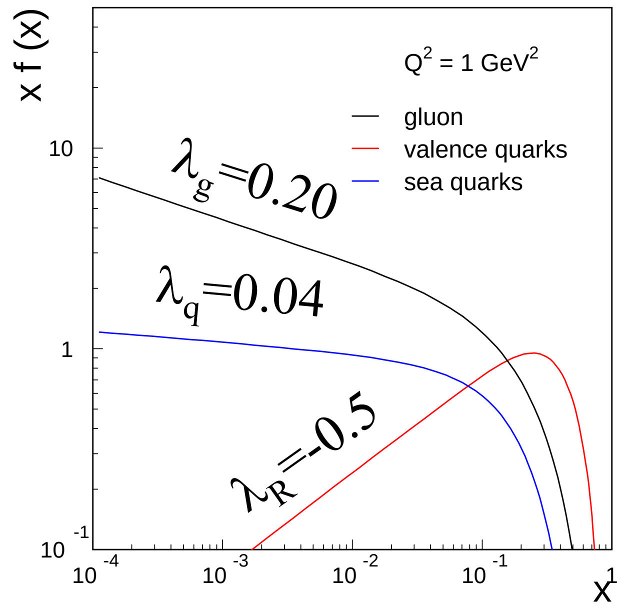
The factors κ and ε

Experimentally: $\kappa = \dfrac{g_{IP-IP-IP}}{\beta_{IP-p}} = 0.17 \pm 0.02$ $\leftarrow$ KG&JM, PRD 59 (114017) 1999

Color factor: $\kappa = f_g \times \dfrac{1}{N_c^2 - 1} + f_q \times \dfrac{1}{N_c} \xrightarrow{Q^2 \to 0} \approx 0.75 \times \dfrac{1}{8} + 0.25 \times \dfrac{1}{3} = 0.18$

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

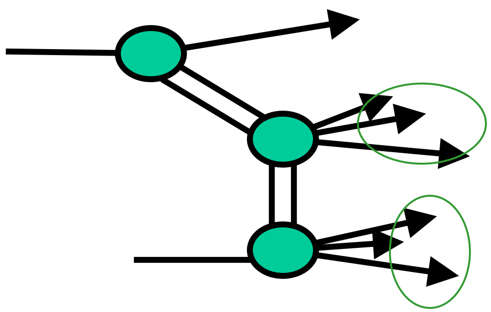
$$x \cdot f(x) = \frac{1}{x^{\lambda}}$$

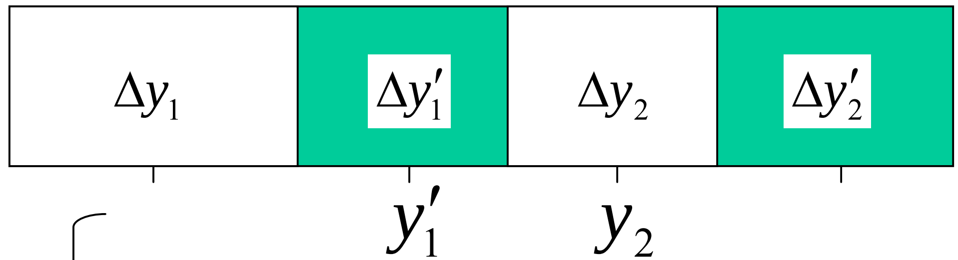


f_g=gluon fraction
f_q=quark fraction

Two-Gap Diffraction

(KG, hep-ph/0205141)





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

color factor

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

Gap probability $\sim e^{2\varepsilon \Delta y}$

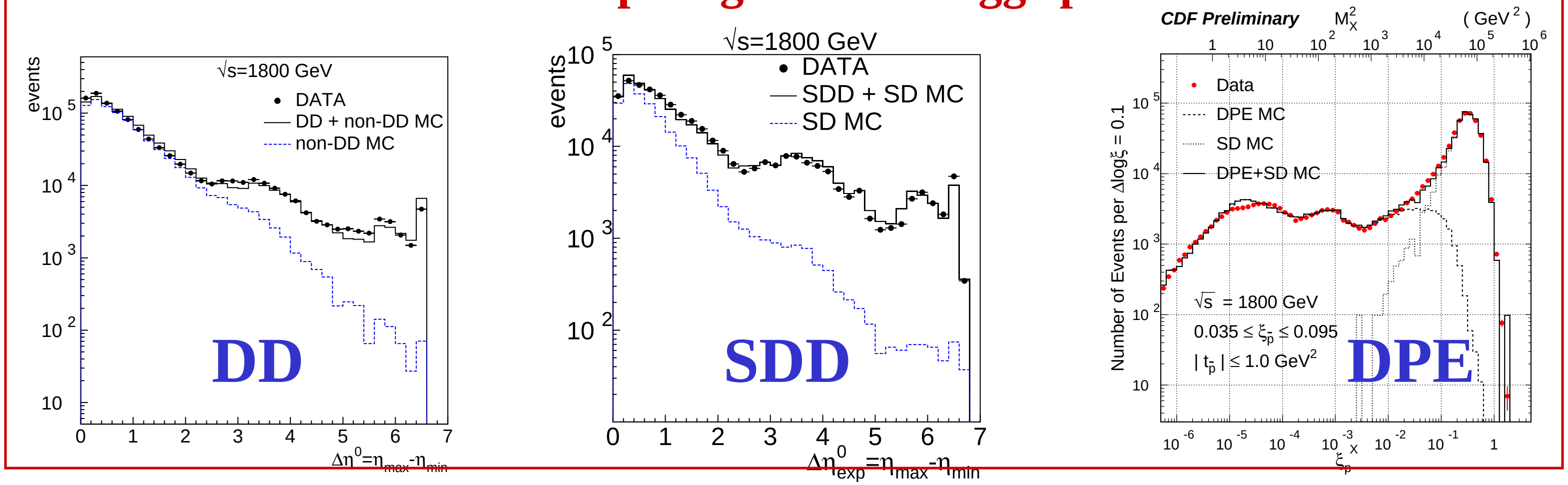
Sub-energy cross section (for regions with particles)

$$\int_{\Delta y_{\min}}^{\Delta y = \ln s} s^{2\varepsilon\,\Delta y} \approx s^{2\varepsilon}$$

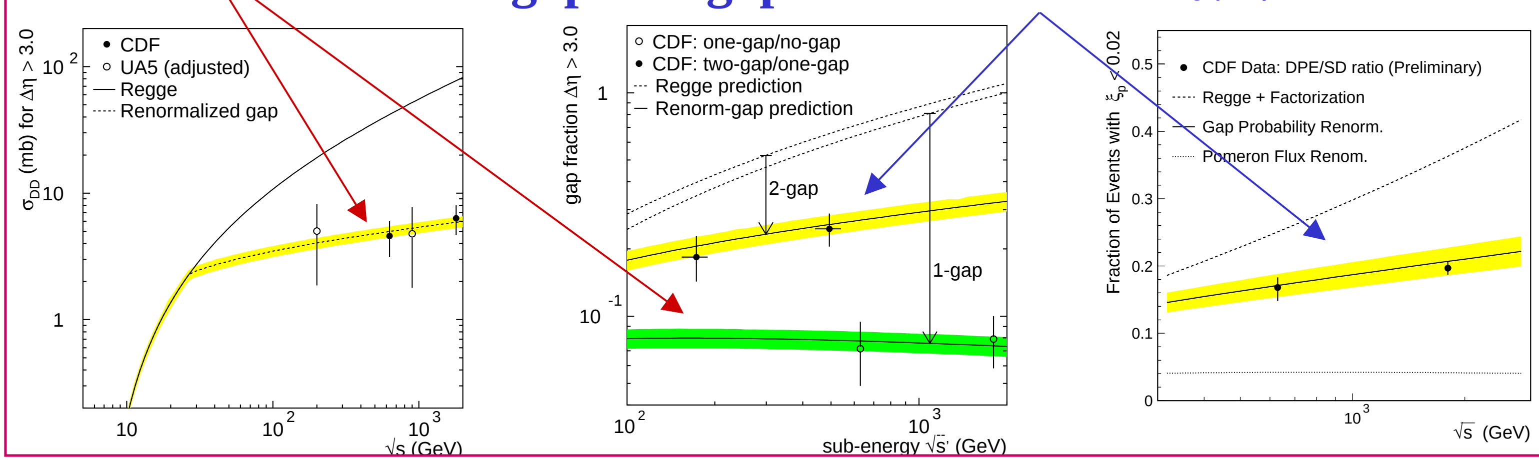
Same suppression as for single gap!

Central & Double-Gap Results

Differential shapes agree with Regge predictions



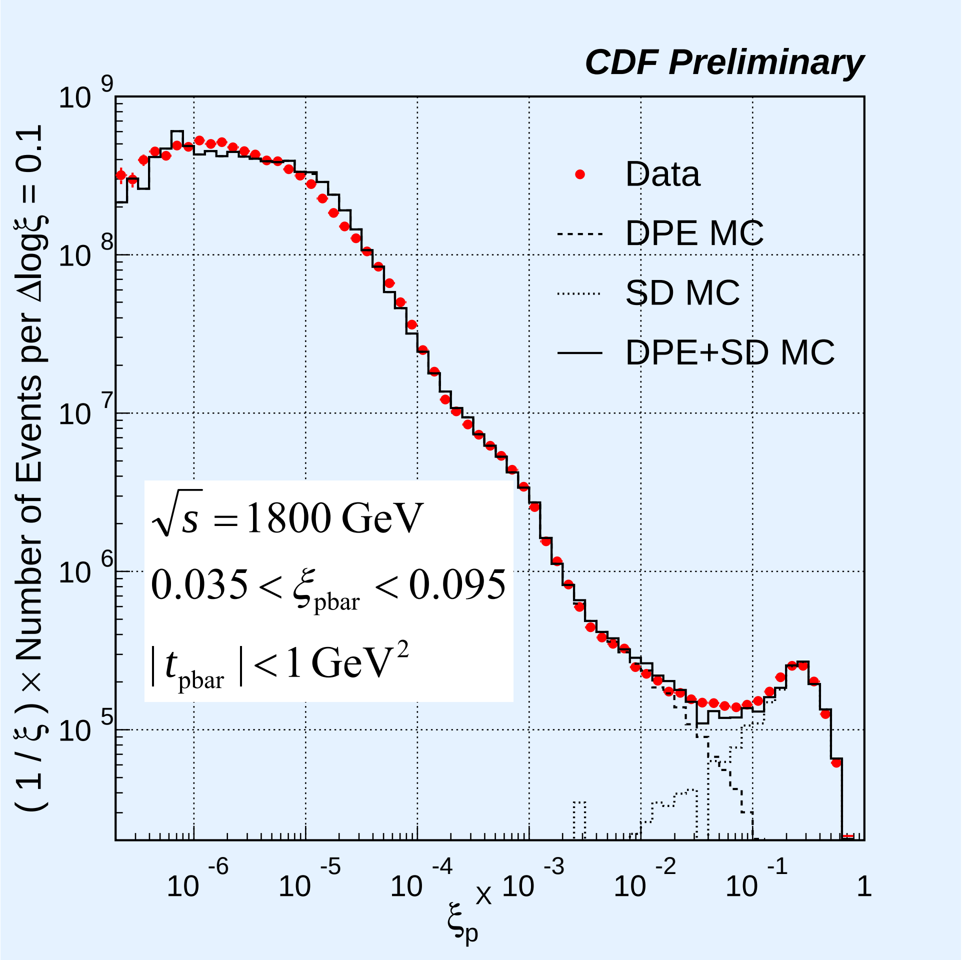
- **One-gap cross sections are suppressed**
- **Two-gap/one-gap ratios are** $\approx \kappa = 0.17$



Soft Double Pomeron Exchange

- Roman Pot triggered events
- $0.035 < \xi\text{-pbar} < 0.095$
  $|t\text{-pbar}| < 1\ \text{GeV}^2$
- ξ-proton measured using

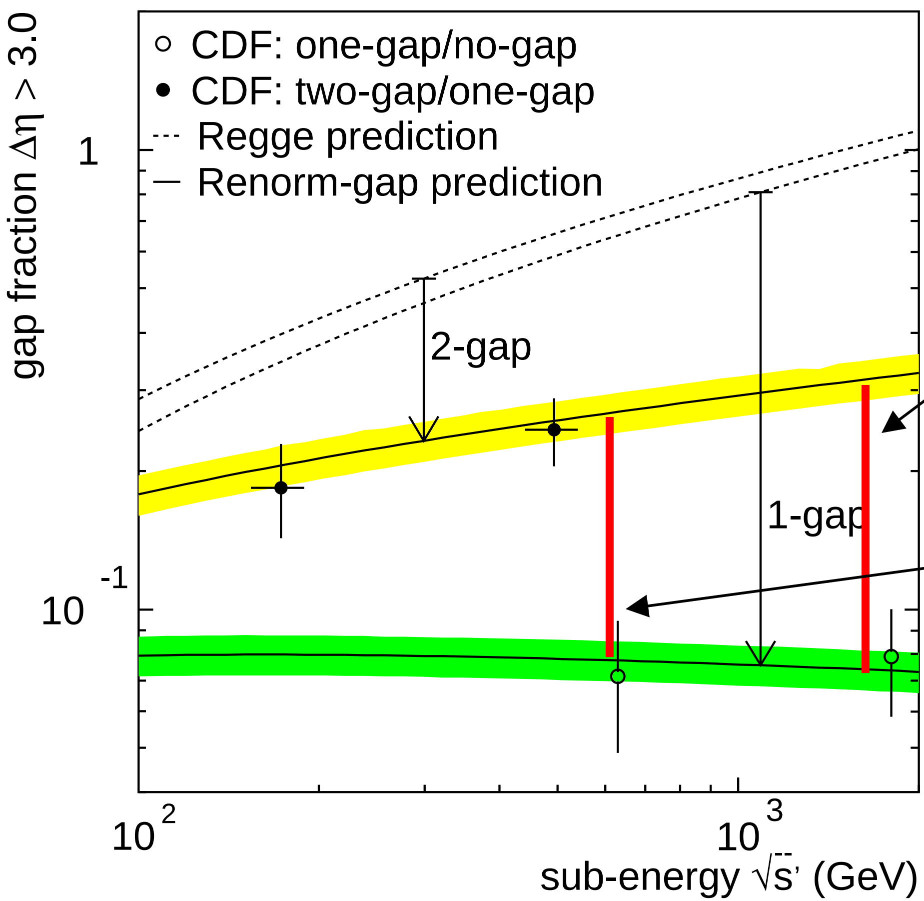
$$\xi_p = \frac{1}{\sqrt{s}} \sum_{\text{all particles}} E_T^i \cdot e^{\eta_i}$$

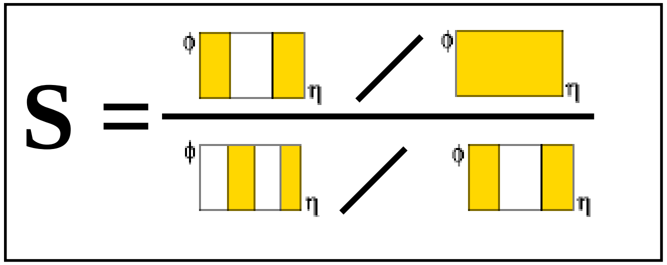


- Data compared to MC based on Pomeron exchange with
- ➔ Pomeron intercept $\varepsilon = 0.1$

- Good agreement over 4 orders of magnitude!

Soft gap survival probability





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

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

Hard Diffraction & QCD

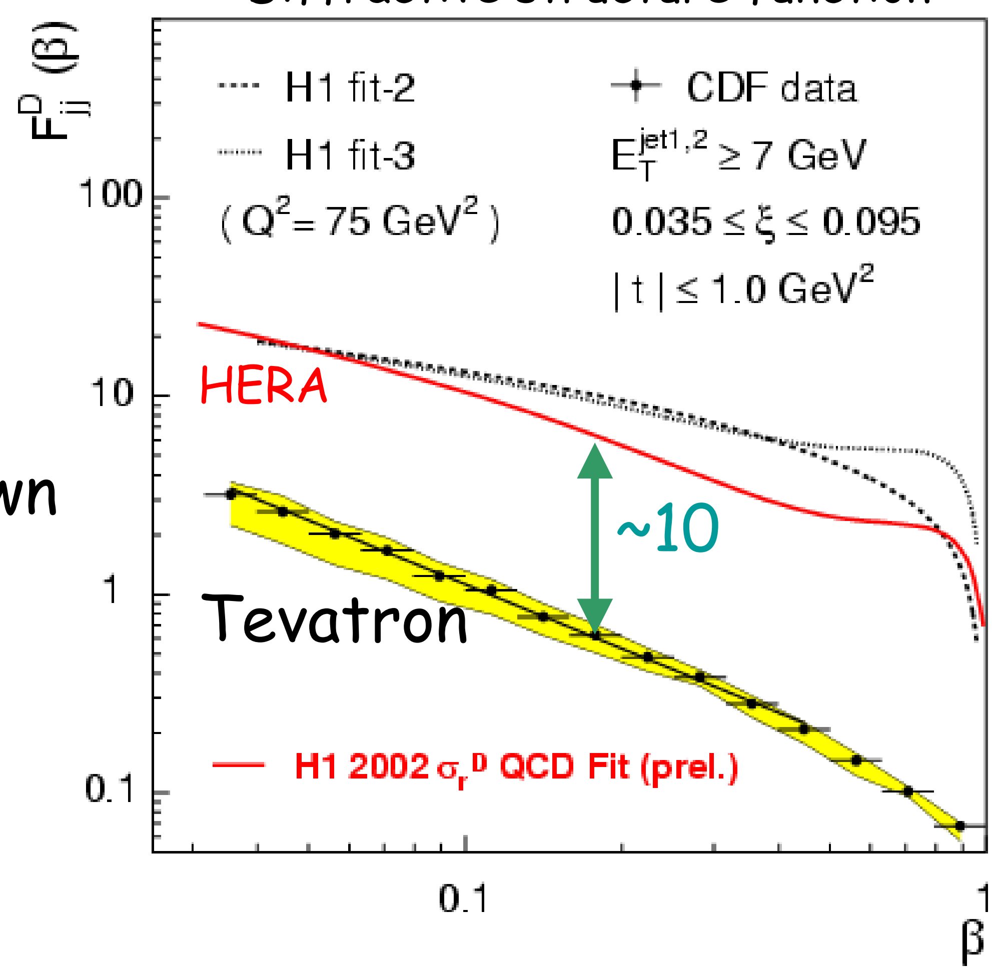
$$\overline{p} + p \rightarrow \overline{p} + Jet + Jet + X$$

- The diffractive structure function measured using SD dijets at the Tevatron is suppressed by about an order of magnitude relative to predictions based on diffractive DIS at HERA

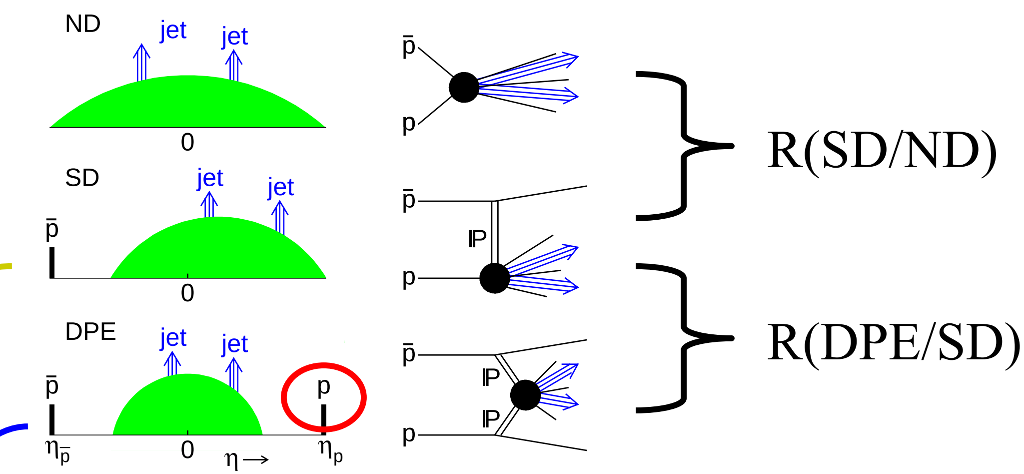
Factorization Breakdown

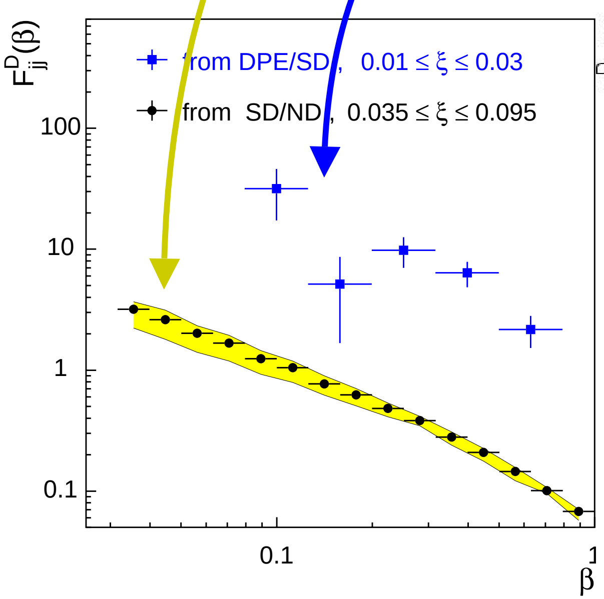
- The discrepancy is generally attributed to additional color exchanges which spoil the diffractive rapidity gap.

Diffractive structure function

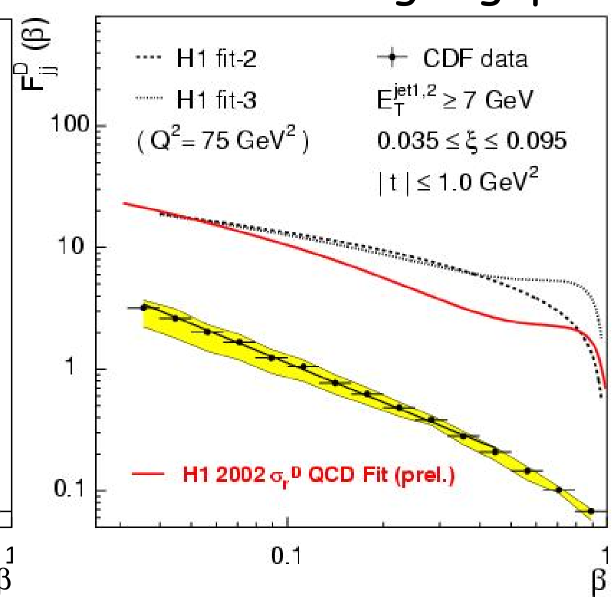


Double-Gap Hard Diffraction @TEV vs HERA

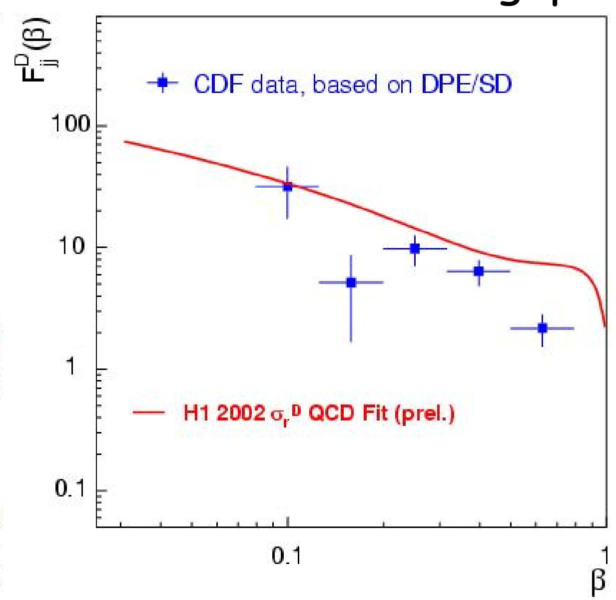




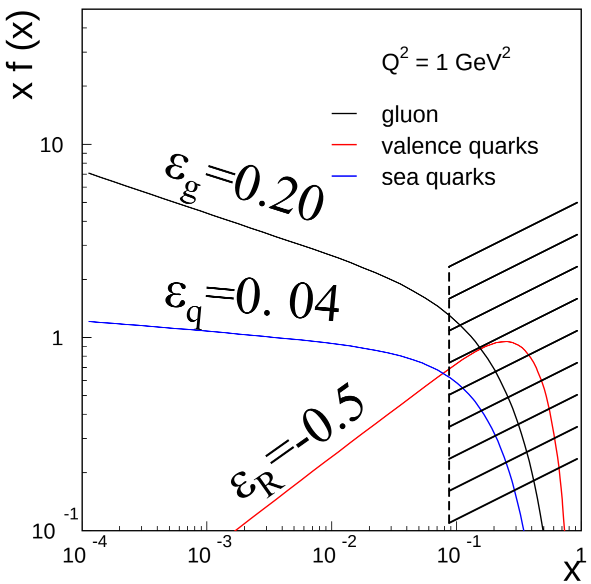
DSF from single-gaps



DSF from double-gaps



Diffractive structure function from inclusive pdf's (KG)



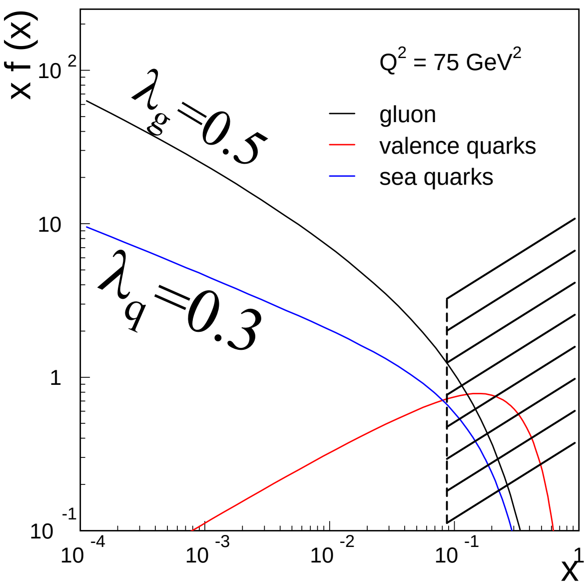
$$x \cdot f(x) = \frac{1}{x^{\varepsilon}}$$

Power-law region

$\xi_{max} = 0.1$

$x_{max} = 0.1$

$\beta < 0.05\xi$

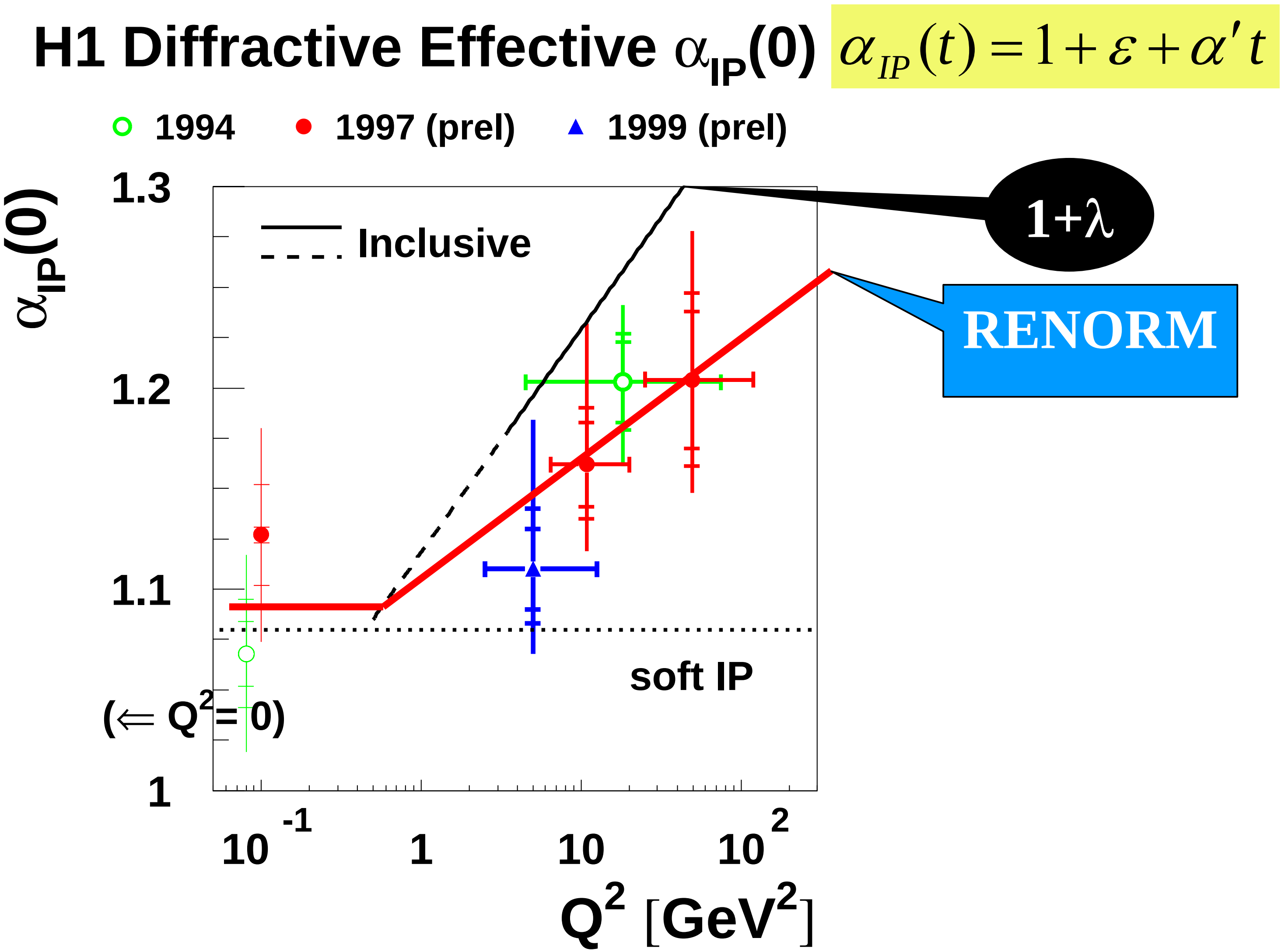


$$F^D(Q^2,x,\xi) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F(Q^2,x) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot \frac{C(Q^2)}{(\beta\xi)^{\lambda(Q^2)}} \Rightarrow \frac{A_{NORM}}{\xi^{1+\varepsilon+\lambda}} \cdot \kappa \cdot \frac{C}{\beta^{\lambda}}$$

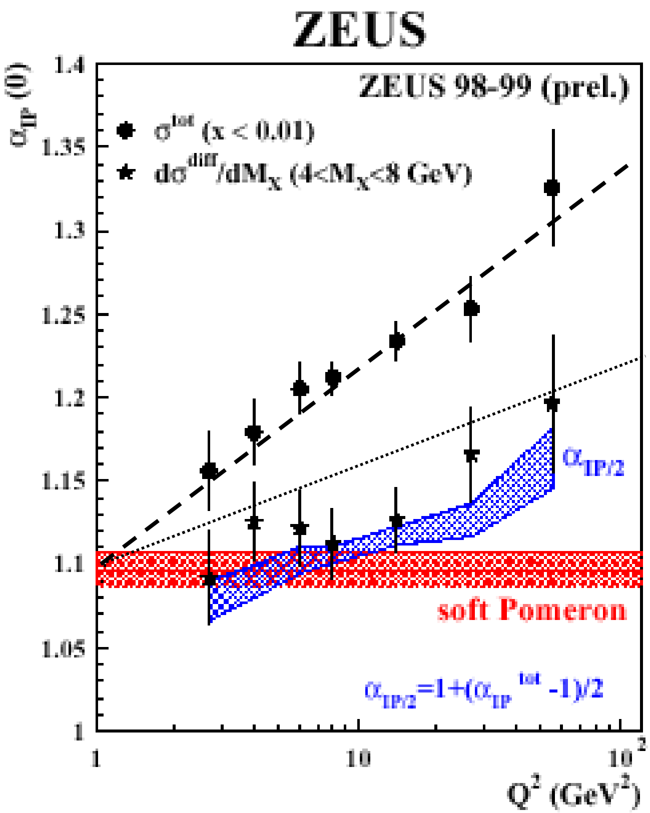
HERA(no RENORM) : $R^{DDIS}_{DIS} \xrightarrow{\text{fixed } \xi}$ constant, $2\varepsilon^{D}_{DIS} = \varepsilon + \lambda(Q^2)$

TEVATRON (RENORM) : $R_{JJ}\left(\frac{SD}{ND}\right) \propto x^{-(\varepsilon+\lambda)}$

Pomeron Intercept from H1



Pomeron intercept from ZEUS



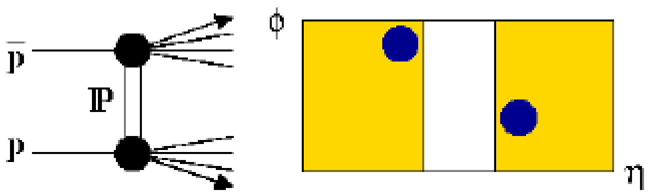
Submitted to the
International Europhysics Conference on High Energy Physics
July 17 - 23, 2003, Aachen, Germany

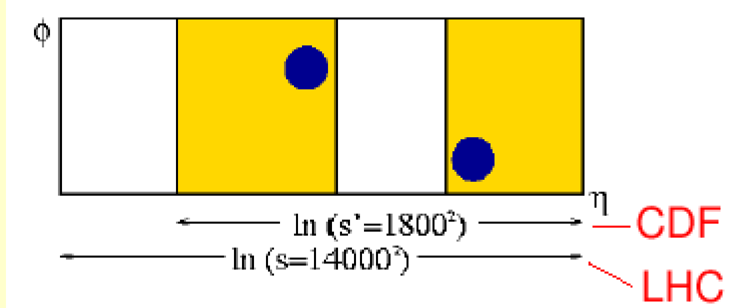
Abstract: 538 Session: HP

Deep inelastic diffractive scattering measured with the ZEUS Forward Plug Calorimeter

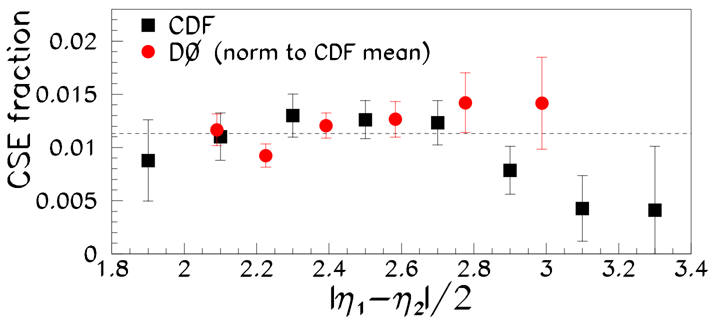
Gap between jets

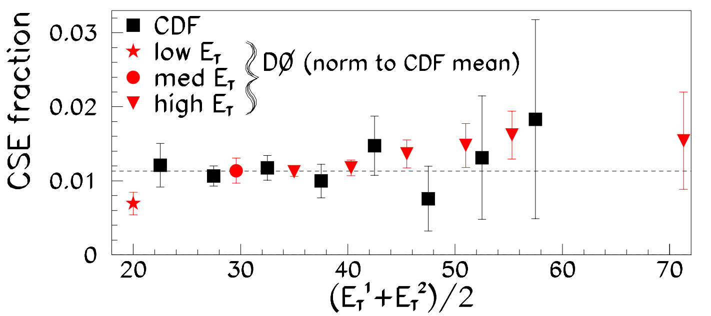
$$\bar{p} + p \rightarrow \text{Jet} + \text{Gap} + \text{Jet}$$

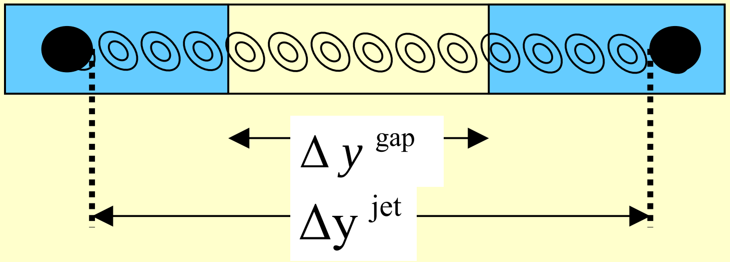




$$R_{LHC}^{J-G-J}(s') = R_{TEV}^{J-G-J}/S \approx 1\%/0.2 \approx 5\%$$





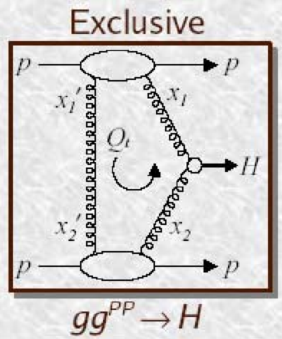


Question

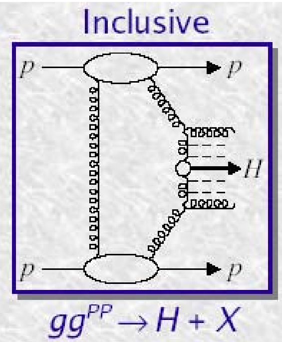
$$\Delta y^{gap} \overset{???}{\longleftrightarrow} \Delta y^{jet}$$

Exclusive Dijets in DPE

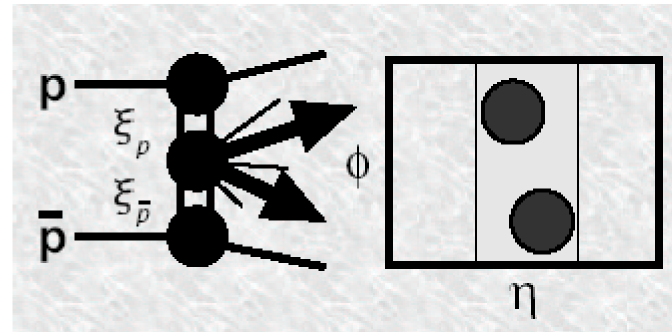
Interest in diffractive Higgs production



Khoze, Martin, Ryskin
Eur. Phys. J.
C23, 311 (2001),
C26, 229 (2002)

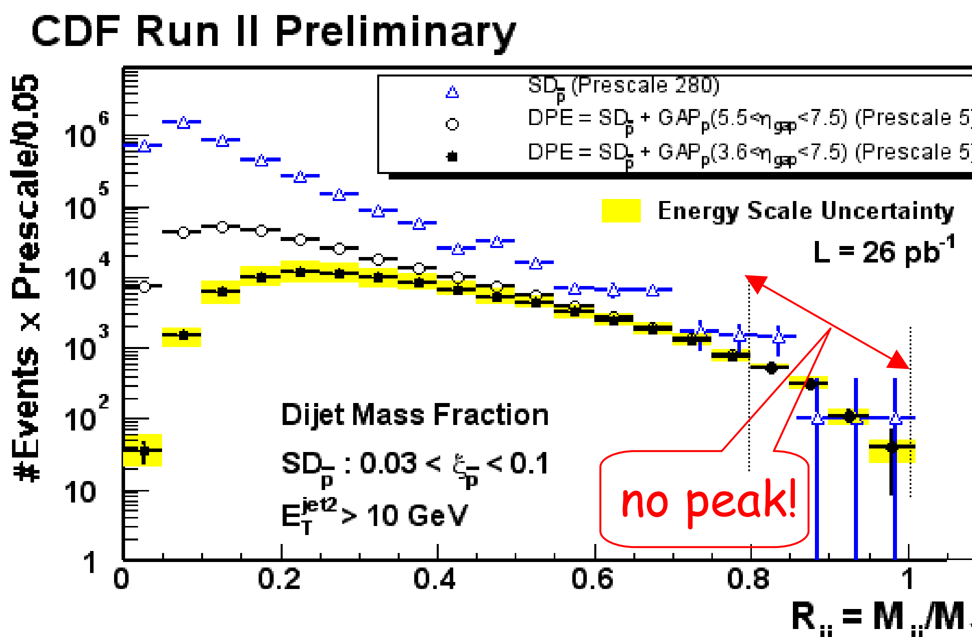


Calibrate on exclusive dijets



Dijet mass fraction

$$R_{jj} = \frac{M_{jj}^{cone}}{M_X}$$



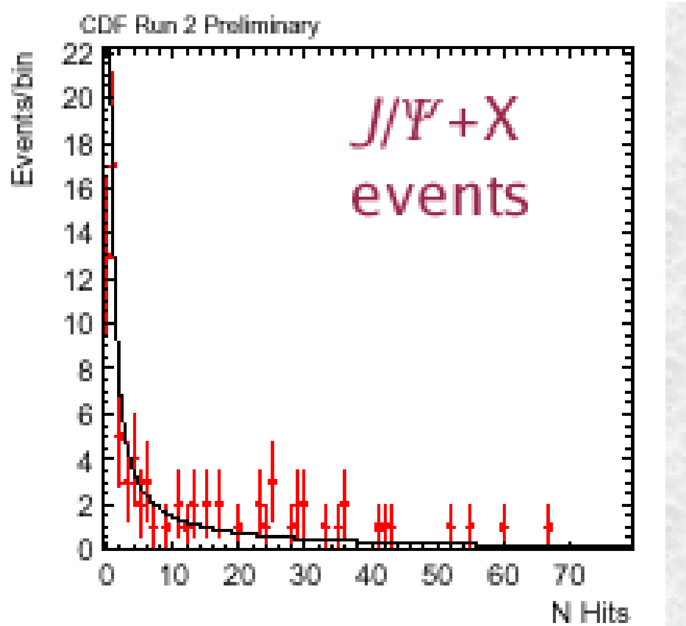
E_T^{jet}	$\sigma_{DPE}^{excl\ jj}(R_{jj} > 0.8)$
10 GeV	$970 \pm 65 \pm 272$ pb
25 GeV	$34 \pm 5 \pm 10$ pb

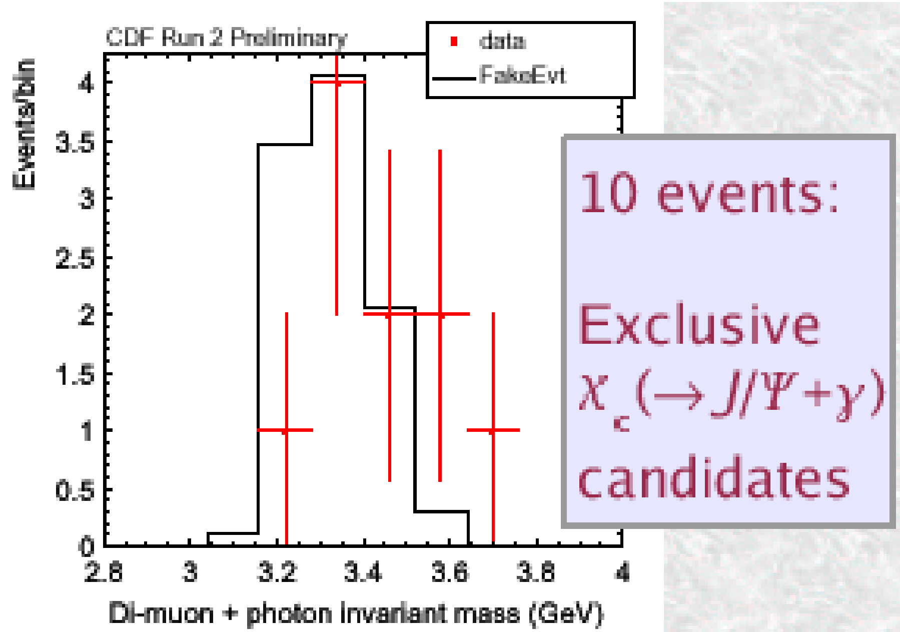
Upper limit for excl DPE-jj consistent with theory

Exclusive χ_c Production in DPE

$$\bar{p} + p \rightarrow \bar{p} + \chi_c(\rightarrow J/\psi + \gamma) + p$$

- Events are triggered on by a di-muon trigger
- Muons have P_t> 1.5 GeV, $|\eta| < 0.6$
- Reject cosmic rays with time of flight info.
- Select events in J/ψ mass window.





Cross section upper limit comparable to KMR prediction

Summary

SOFT DIFFRACTION

- M^2 - scaling
- Non-suppressed double-gap to single-gap ratios

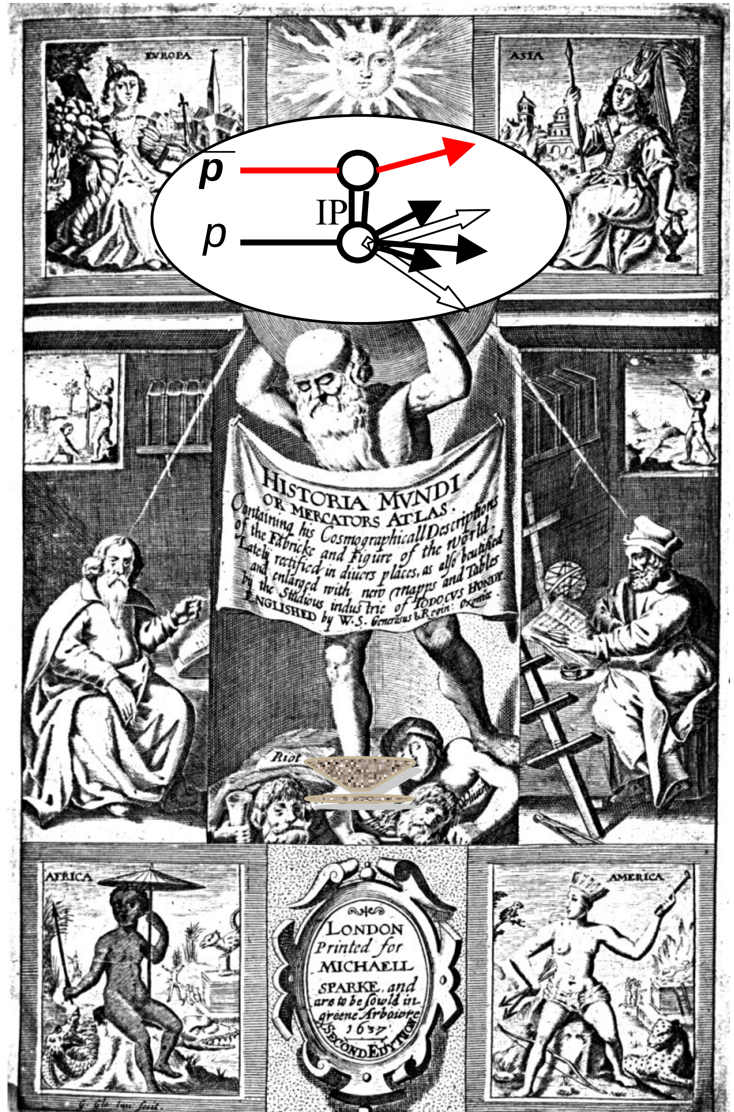
HARD DIFFRACTION

- Flavor-independence SD/ND ratio
- Get diffractive from non-diffractive pdf's

Universality of gap prob. across soft and hard diffraction

HERA &Tevatron->LHC

Diffraction



Soft & Hard