Hadronic Diffraction

Where do we stand?

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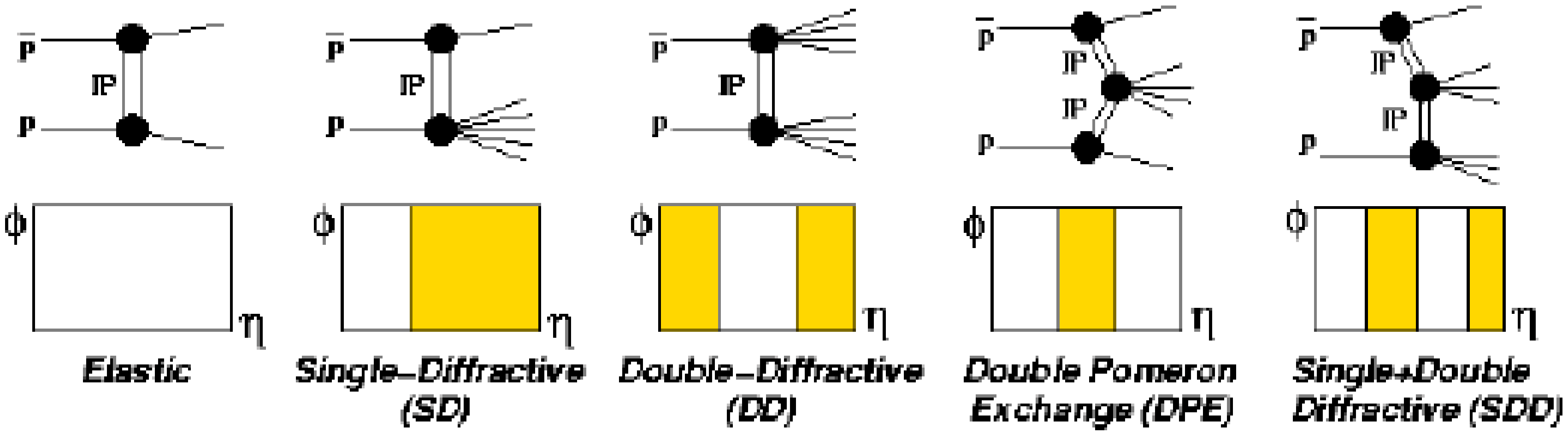
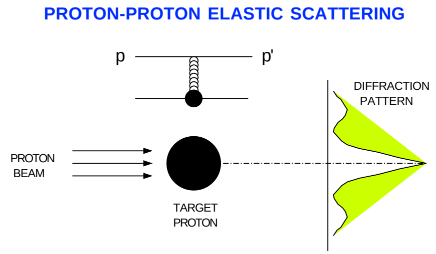
LaThuile 2004

Diffracive signatures

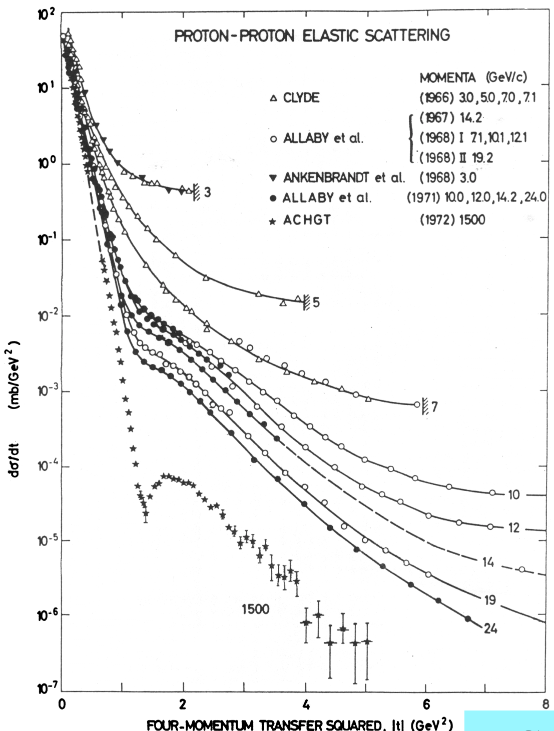
- Leading hadron(s)
- Rapidity gap(s)



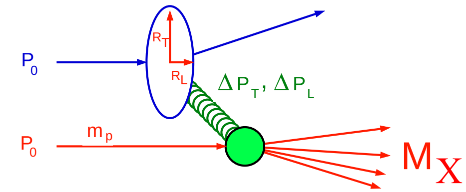
Leading hadrons



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



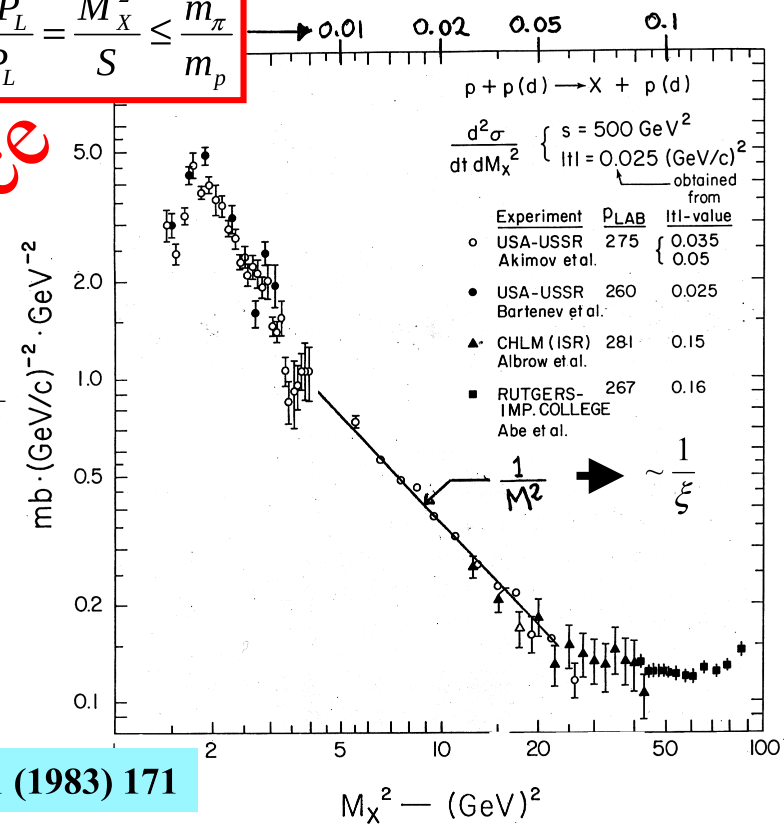
Diffraction dissociation



$$\xi = \frac{\Delta P_L}{P_L} = \frac{M_X^2}{S} \le \frac{m_\pi}{m_p}$$

coherence

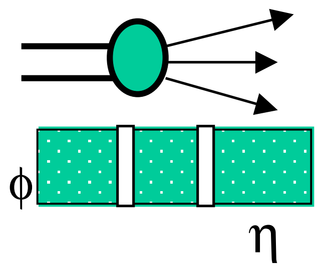
$\frac{d^2\sigma}{dt\,dM^2}$



KG, Phys. Rep. 101 (1983) 171

Rapidity gaps

❖ Minimum bias

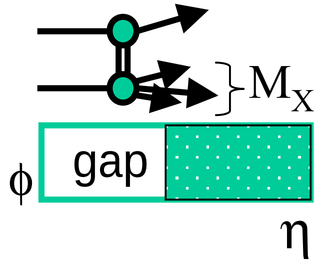


From Poisson statistics:

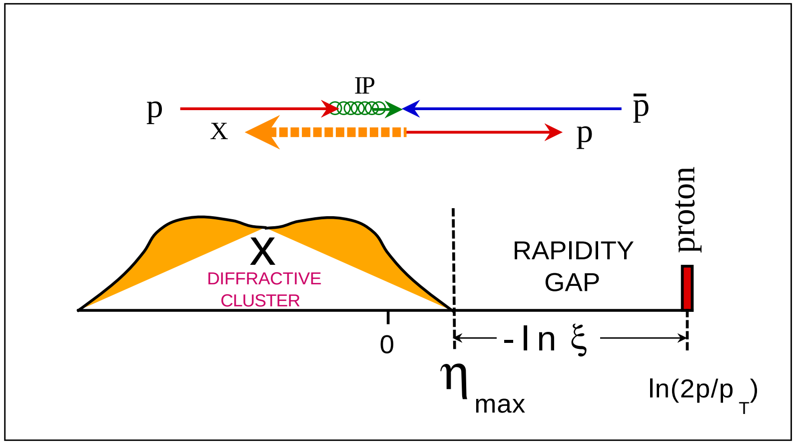
$$P(\Delta y) = e^{-\rho \Delta y} \quad \left(\rho = \frac{dn}{dy} \right)$$

Gaps exponentially suppressed

❖ Diffraction dissociation

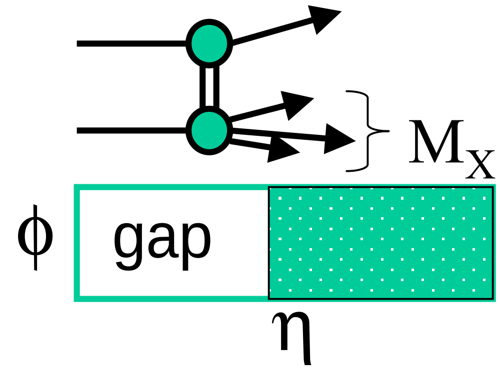


$$\Delta y \approx -\ln \xi = \ln s - \ln M^2$$



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

QCD aspects of diffraction



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

  POMERON

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

  the exchange is COLOR-SINGLET with vacuum quantum numbers

- **Rapidity gap formation:**

  NON-PERTURBATIVE

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

  ?

  POMERON ⟷ CONFINEMENT

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

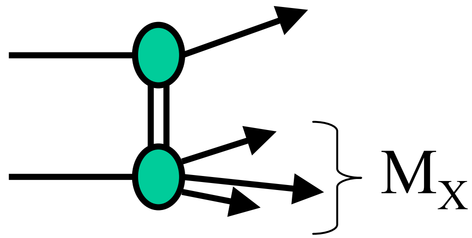
History of Diffraction

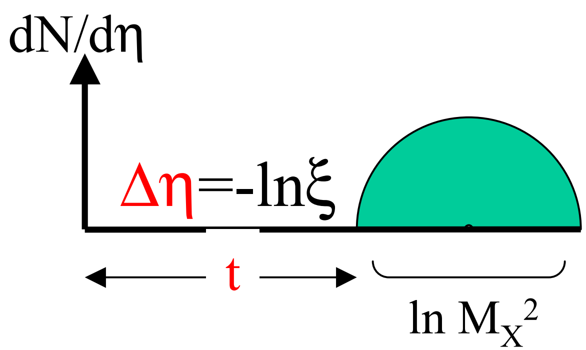
40 years of diffraction

1960	Good and Walker
1960's	BNL: first observation
1970's	Fermilab fixed target, ISR, SPS
1883	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



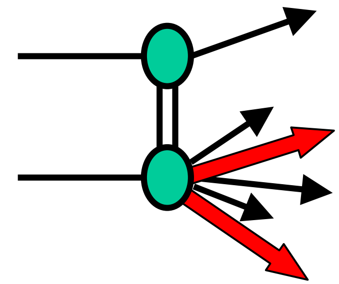


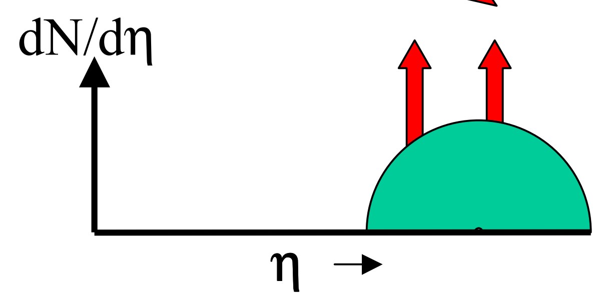
$\xi = \Delta P_L / P_L$

fractional momentum loss
of scattered (anti)proton

Variables: (ξ, t) or (Δη, t)

- HARD DIFFRACTION





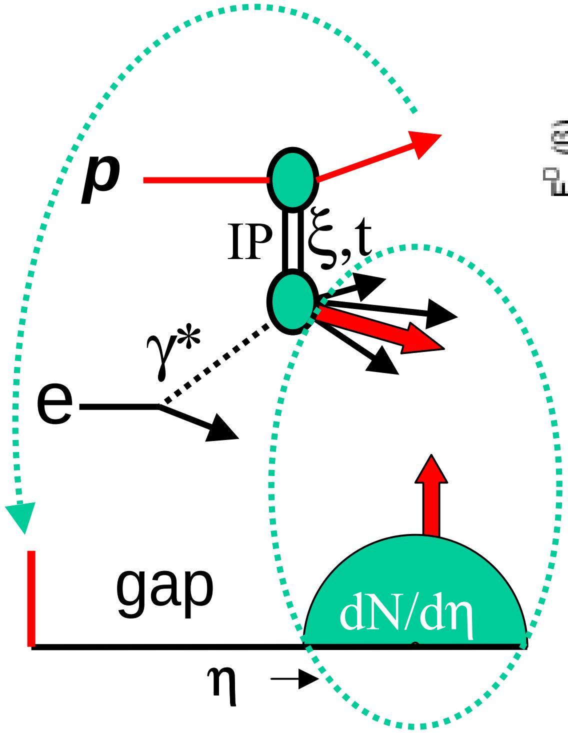
Hard scatter variables: (***x***, Q^2)

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

$$x = \beta\, \xi \leq \xi$$

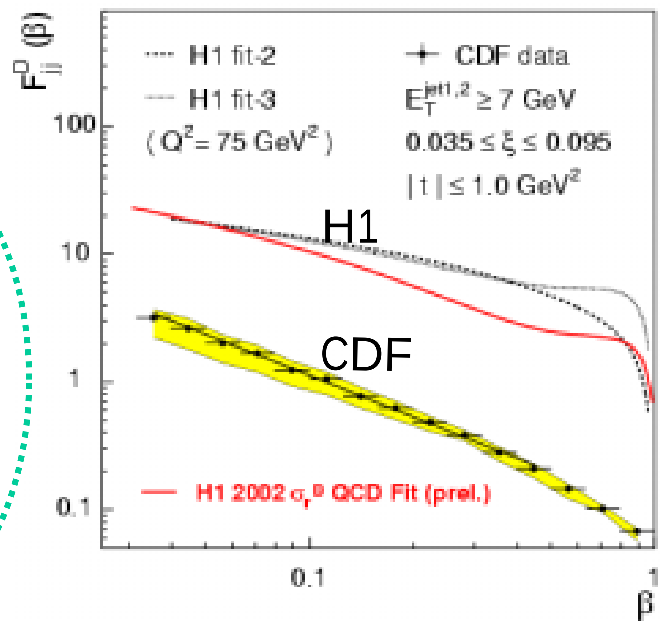
Breakdown of QCD factorization

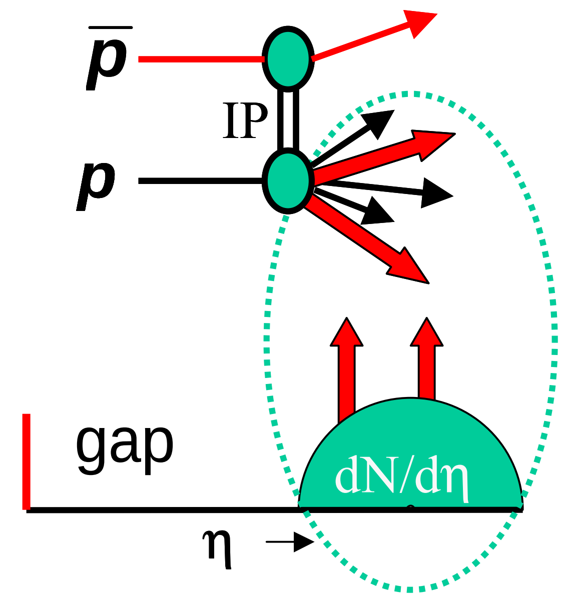
HERA → TEVATRON



$$F_2(Q^2, x)$$

$$F_2^D(Q^2, \beta, \xi, t)$$

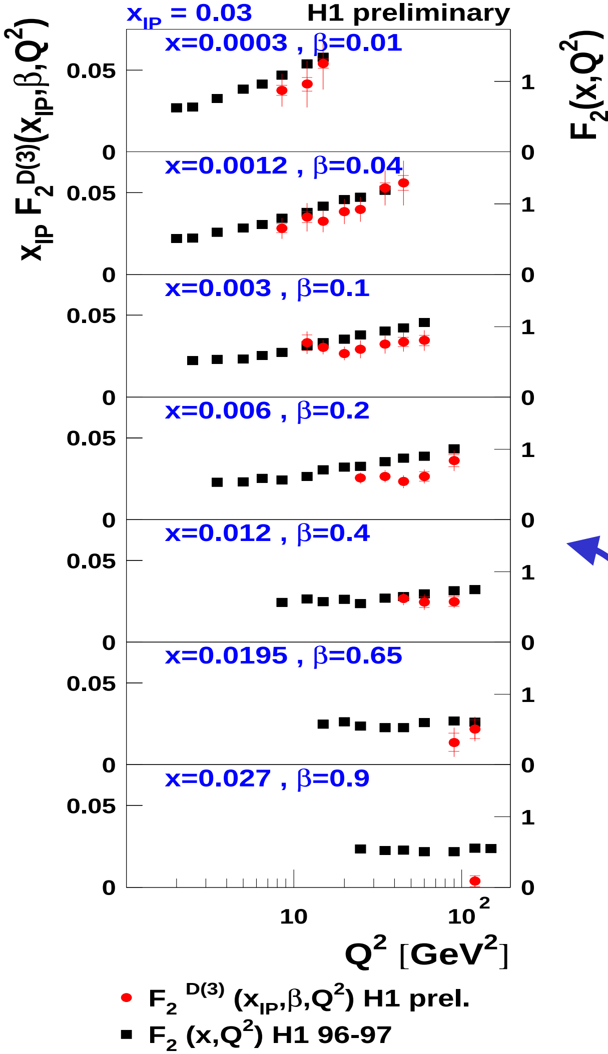


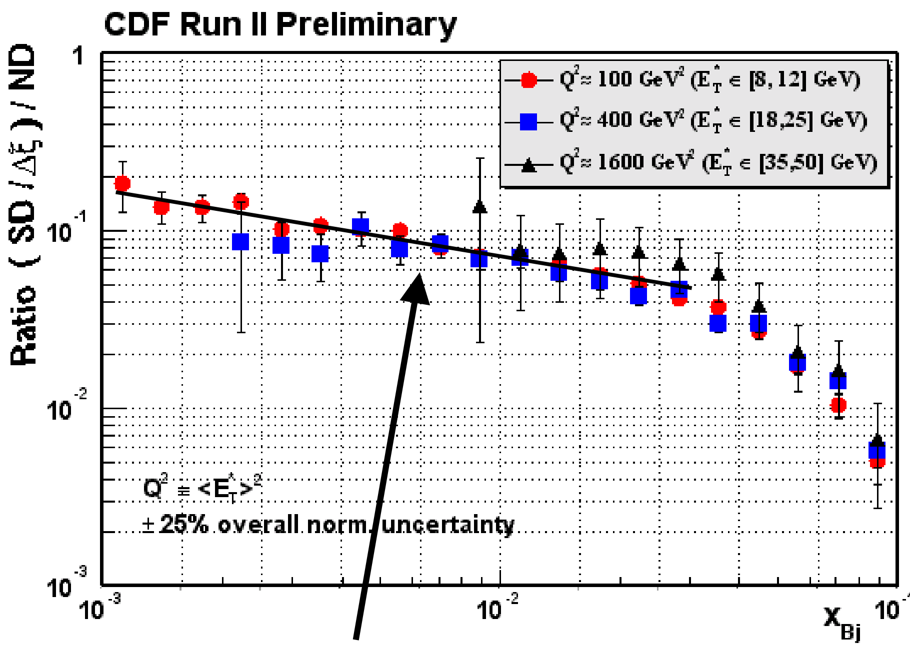


$$F_{JJ}(E_T^{Jet}, x)$$

$$F_{JJ}^D(E_T^{Jet}, \beta, \xi, t)$$

Diffractive vs inclusive structure fn's



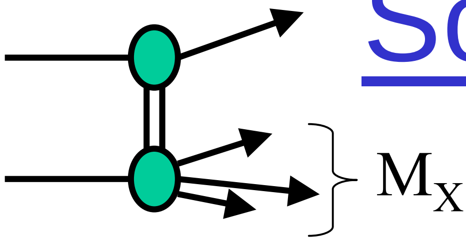


$F^D_{JJ}(x,Q^2)\ /F(x,Q^2)$

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

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

Soft Diffraction



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

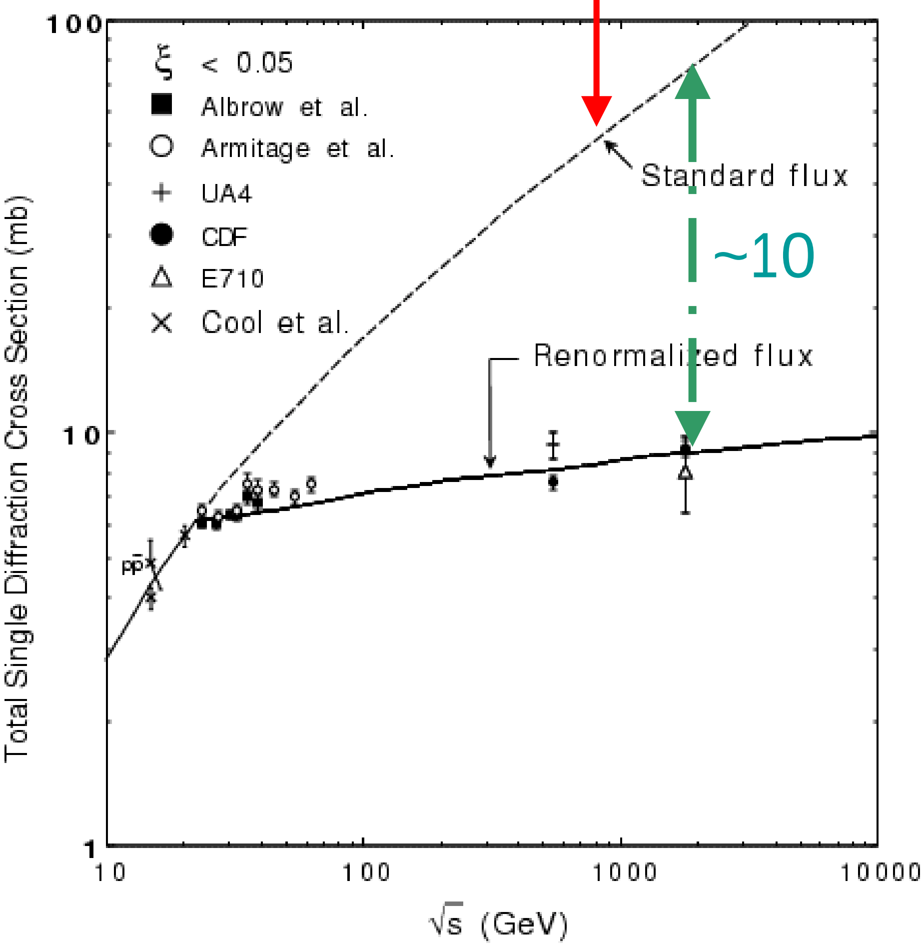
$$\sigma_{SD} \sim s^{2\varepsilon}$$

❖ **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

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



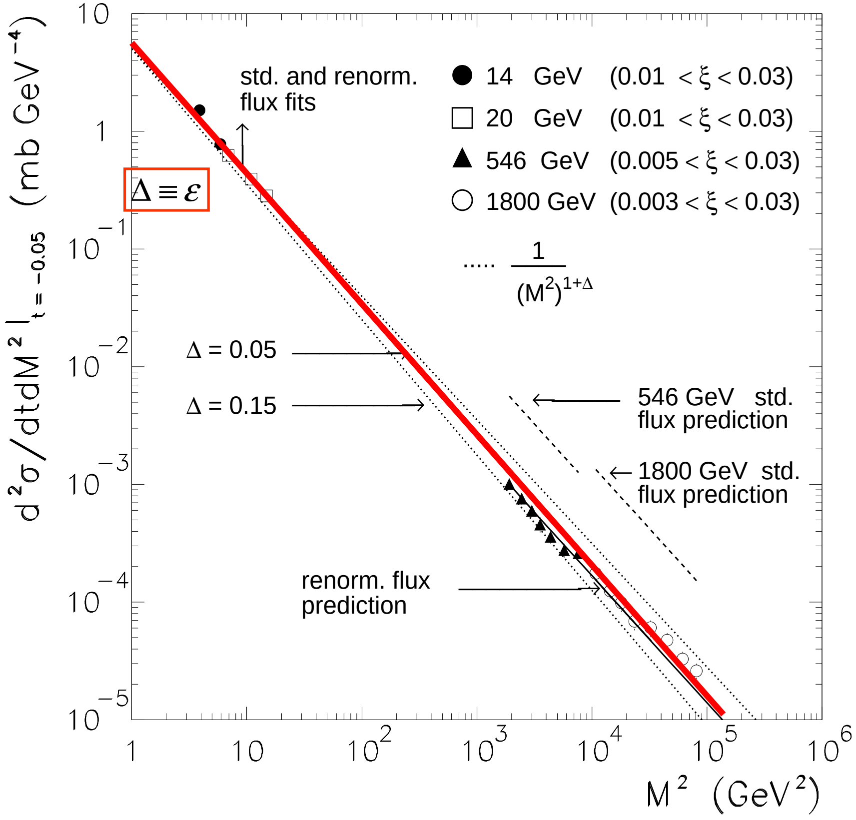
A Scaling Law in Diffraction

Factorization breaks down in favor of a scaling behavior.

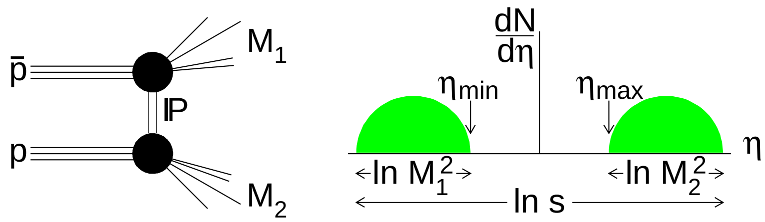
renormalization

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

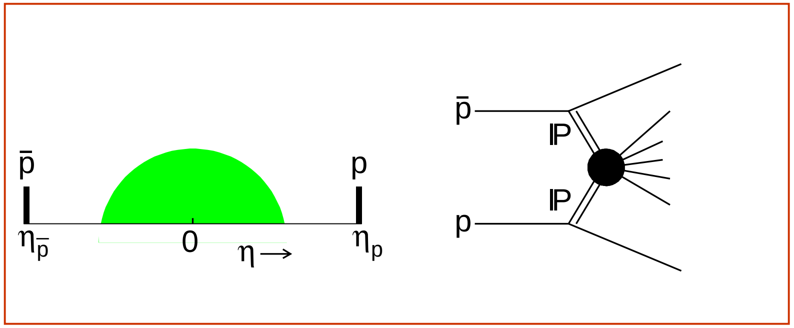
KG&JM, PRD 59 (1999) 114017



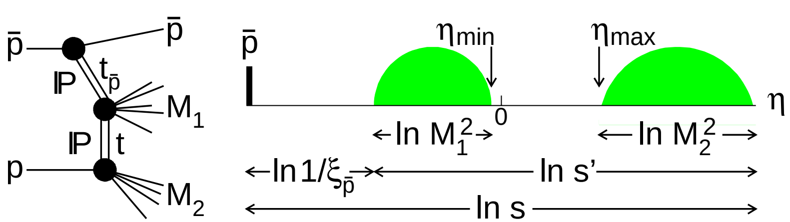
Central and Double Gaps



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



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



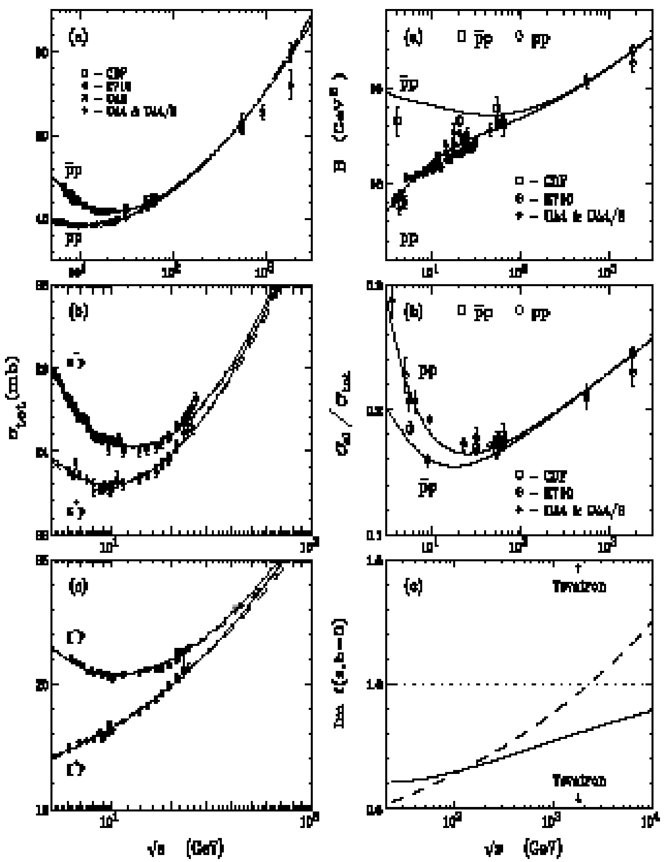
- **SDD: Single+Double Diffraction**
  - Forward + central gaps

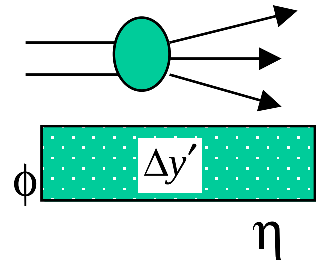
Elastic & total σ

Total and Elastic Cross Sections

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

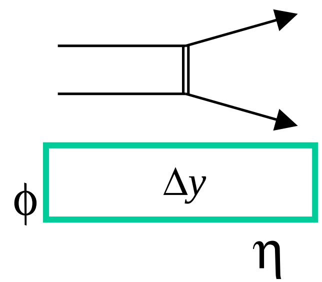
$\alpha_{I\!P} = 1 + \epsilon (\Rightarrow 0.104) + 0.25t \quad \alpha_{f/a} = 0.68 + 0.82t \quad \alpha_{\omega/\rho} = 0.46 + 0.92t$





$$\Delta y' = \ln s$$

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

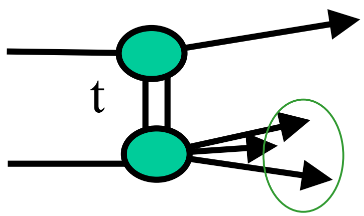


$$\Delta y = \ln s$$

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

Generalized renormalization

(KG, hep-ph/0205141)



Δy	$\Delta y'$

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

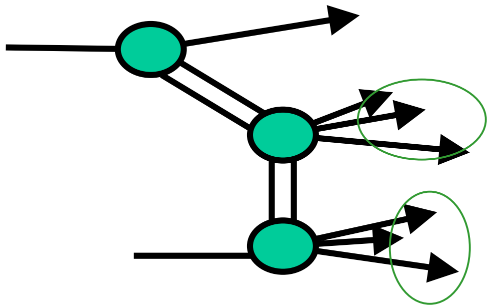
$$\sim e^{2\varepsilon \Delta y}$$

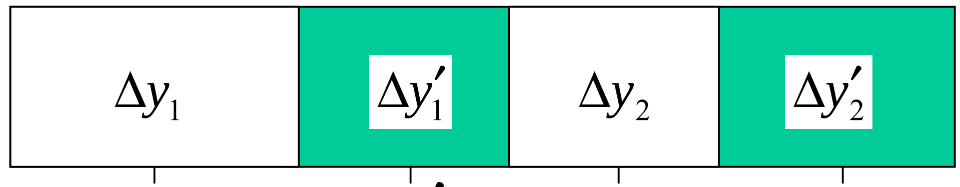
→ Integral $\sim s^{2\varepsilon}$

Renormalization removes the s-dependence → SCALING

Two-Gap Diffraction

(KG, hep-ph/0205141)





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

color factor

$$\frac{d^5\sigma}{\prod_{i=1-5} dV_i} = C \times F_p^2(t_1) \prod_{\mathrm{i=1-2}} \left\{ e^{(\varepsilon+\alpha' t_i)\Delta y_i} \right\}^2 \times \kappa^2 \left\{ \sigma_o \, e^{\varepsilon(\Delta y_1' + \Delta y_2')} \right\}$$

Gap probability

Sub-energy cross section (for regions with particles)

Integral $\sim s^{2\varepsilon}$ ← $\sim e^{2\varepsilon \Delta y}$

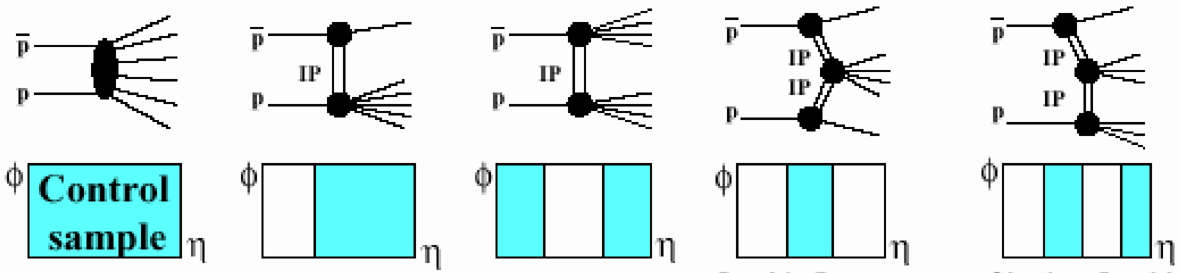
Renormalization removes the s-dependence → SCALING

Diffraction@CDF in Run I

16 papers

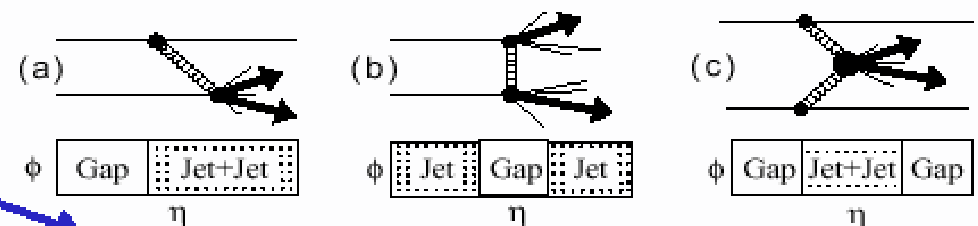
- Elastic scattering   PRD 50 (1994) 5518
- Total cross section   PRD 50 (1994) 5550
- Diffraction

SOFT diffraction



Non-Diffractive (ND)	Single-Diffractive (SD)	Double Diffractive (DD)	Double Pomeron Exchange (DPE)	Single + Double Diffractive (SDD)
	PRD 50 (1994) 5535	PRL 87 (2001)141802	PRL submitted	PRL 91(2003)011802

HARD diffraction



PRL references

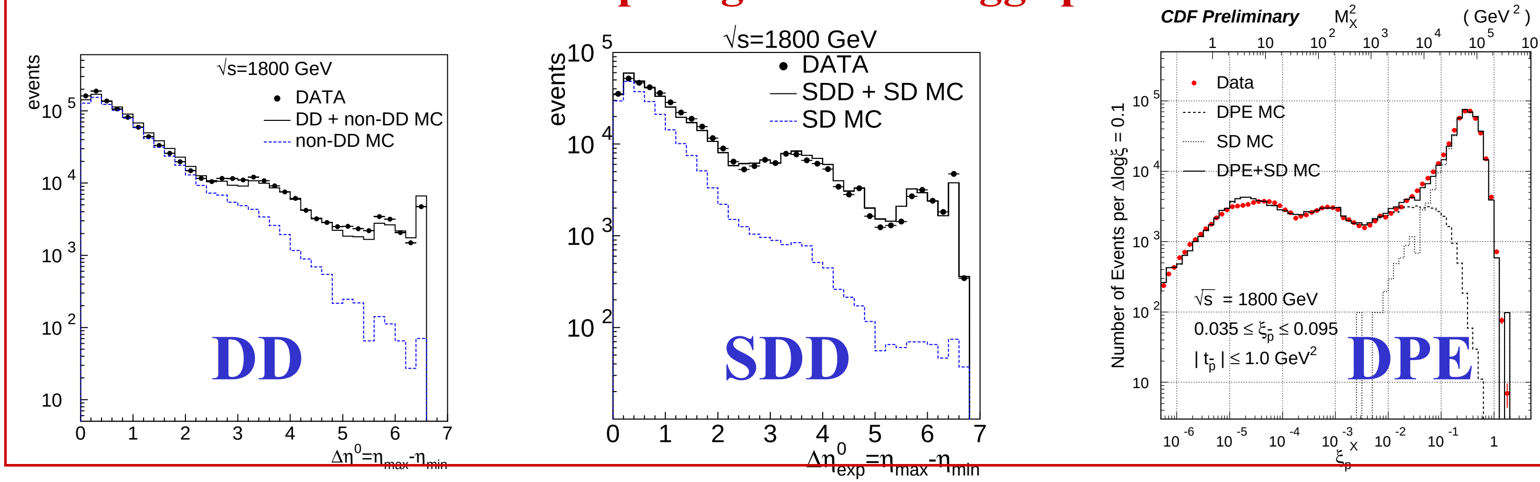
W	78 (1997) 2698	JJ	74 (1995) 855	JJ	85 (2000) 4217
JJ	79 (1997) 2636	JJ	80 (1998) 1156		
b-quark	84 (2000) 232	JJ	81 (1998) 5278		
J/ψ	87 (2001) 241802				

with roman pots

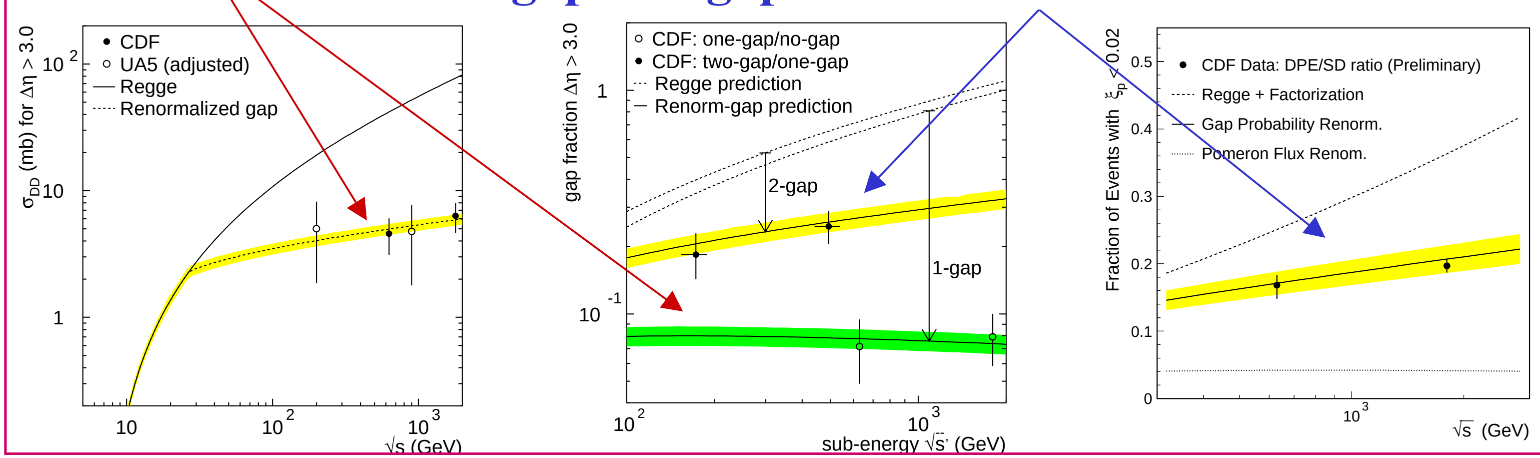
JJ	84 (2000) 5043
JJ	88 (2002) 151802

Central & Double-Gap Results

Differential shapes agree with Regge predictions



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



Hard Diffraction & QCD

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

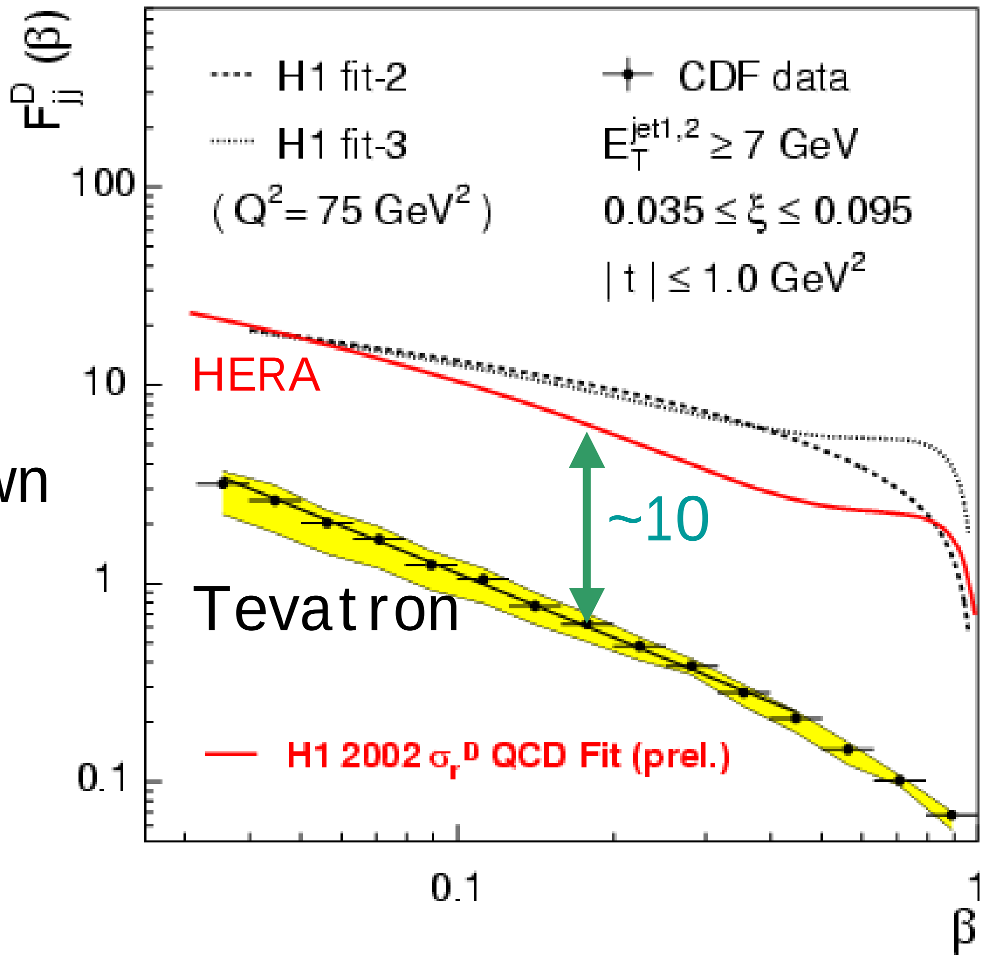
- The diffractive structure function measured using SD dijets at the Tevatron is suppressed by about an order of magnitude relative to predictions based on diffractive DIS at HERA

⇓

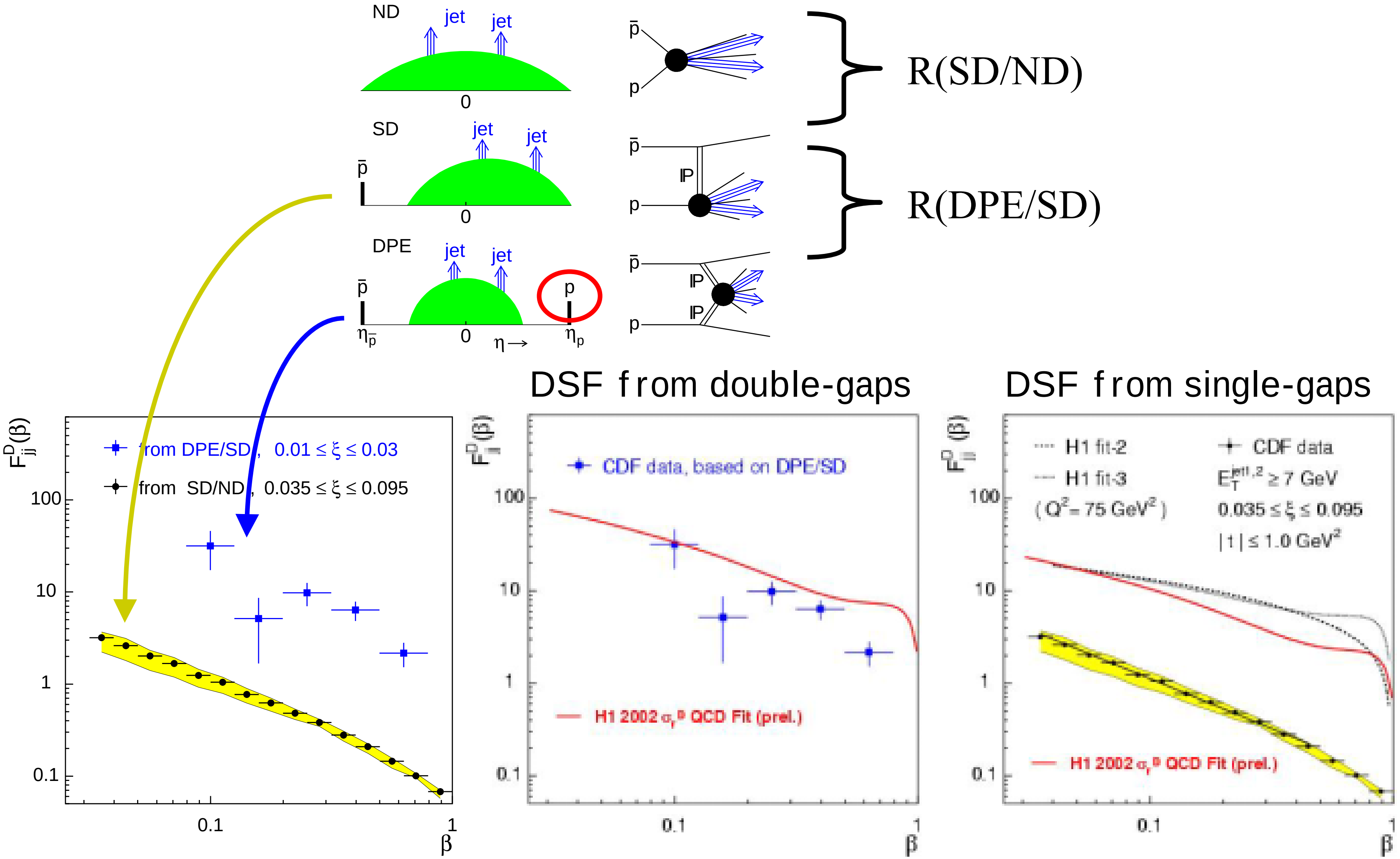
Factorization Breakdown

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

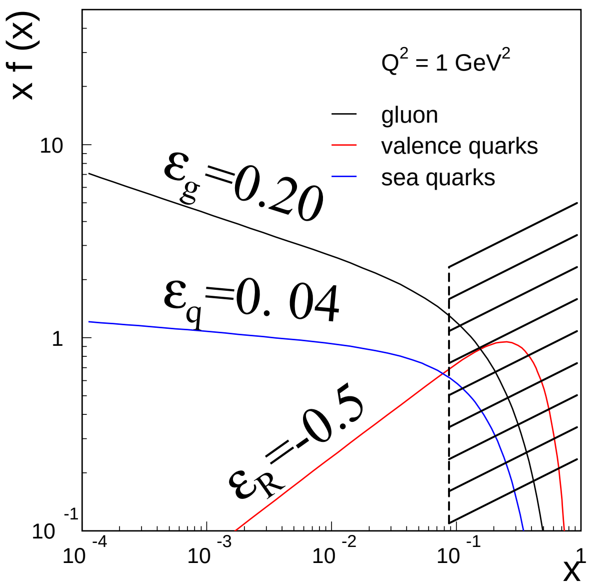
Diffractive structure function



Double-Gap Hard Diffraction @TEV vs HERA



Diffractive structure functions from inclusive pdf's (KG)



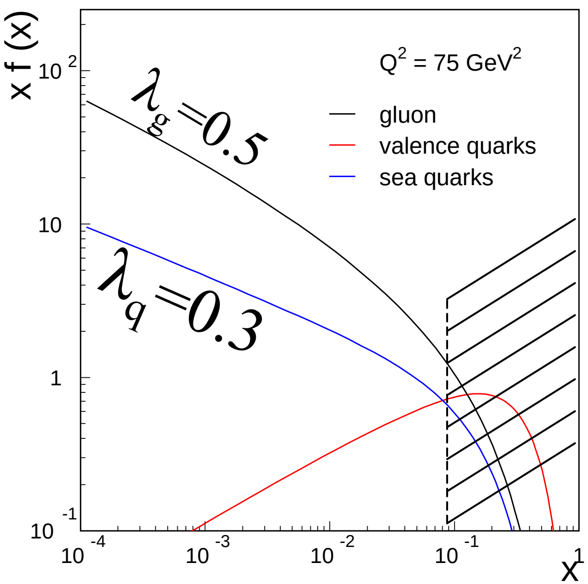
$$x \cdot f(x) = \frac{1}{x^{\varepsilon}}$$

Power-law region

$\xi_{max} = 0.1$

$x_{max} = 0.1$

$\beta < 0.05\xi$

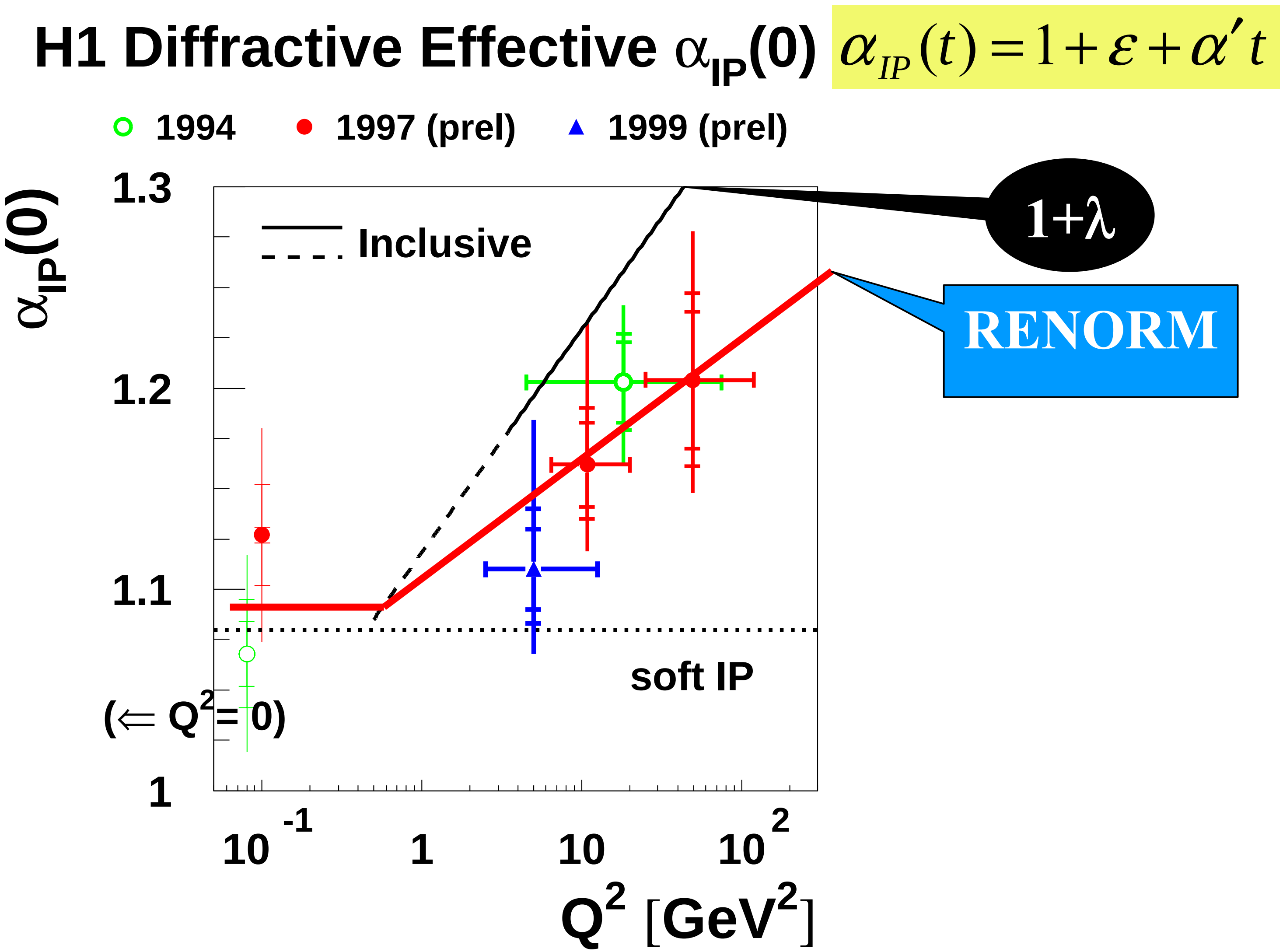


$$F^{D}(Q^2, x, \xi) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F(Q^2, x) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot \frac{C(Q^2)}{(\beta\xi)^{\lambda(Q^2)}} \Rightarrow \frac{A_{NORM}}{\xi^{1+\varepsilon+\lambda}} \cdot \kappa \cdot \frac{C}{\beta^{\lambda}}$$

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

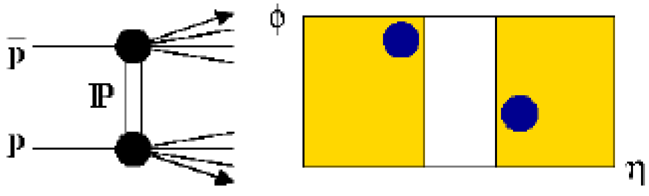
TEVATRON (RENORM): $R_{JJ}\left(\frac{SD}{ND}\right) \propto x^{-(\varepsilon+\lambda)}$

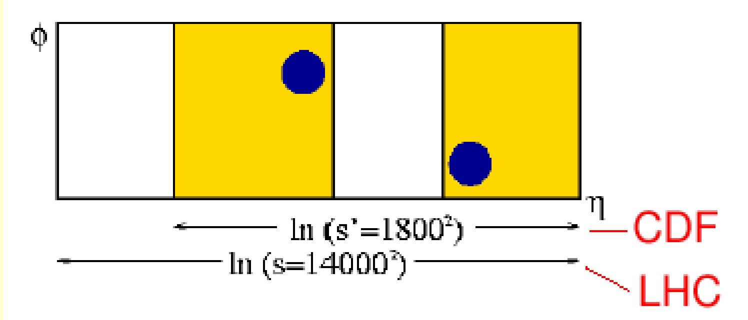
Pomeron Intercept in DDIS



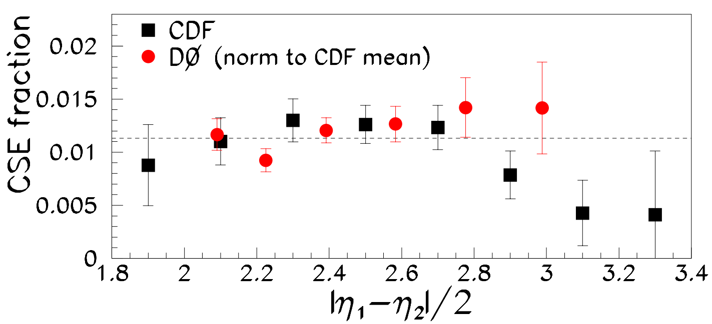
Gap between jets

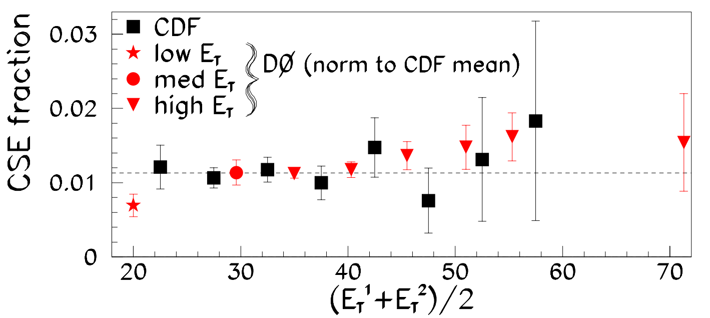
$\bar{p} + p \rightarrow Jet + Gap + Jet$

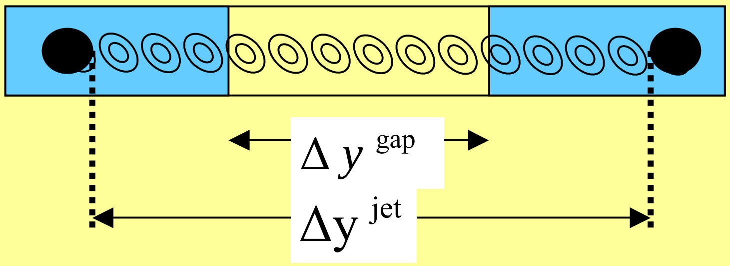




$R^{J-G-J}_{LHC}(s') = R^{J-G-J}_{TEV}/S \approx 1\%/0.2 \approx 5\%$







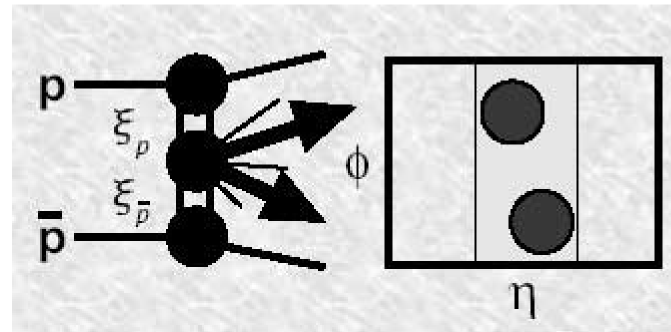
Question

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

Exclusive Dijets in DPE

Interest in diffractive Higgs production

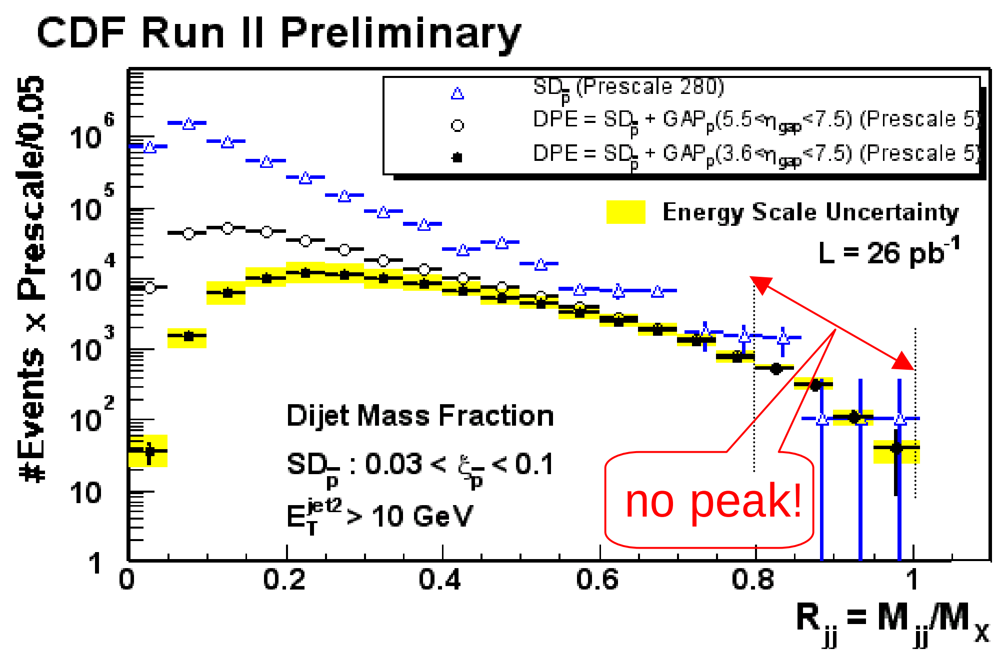
Calibrate on exclusive dijets



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



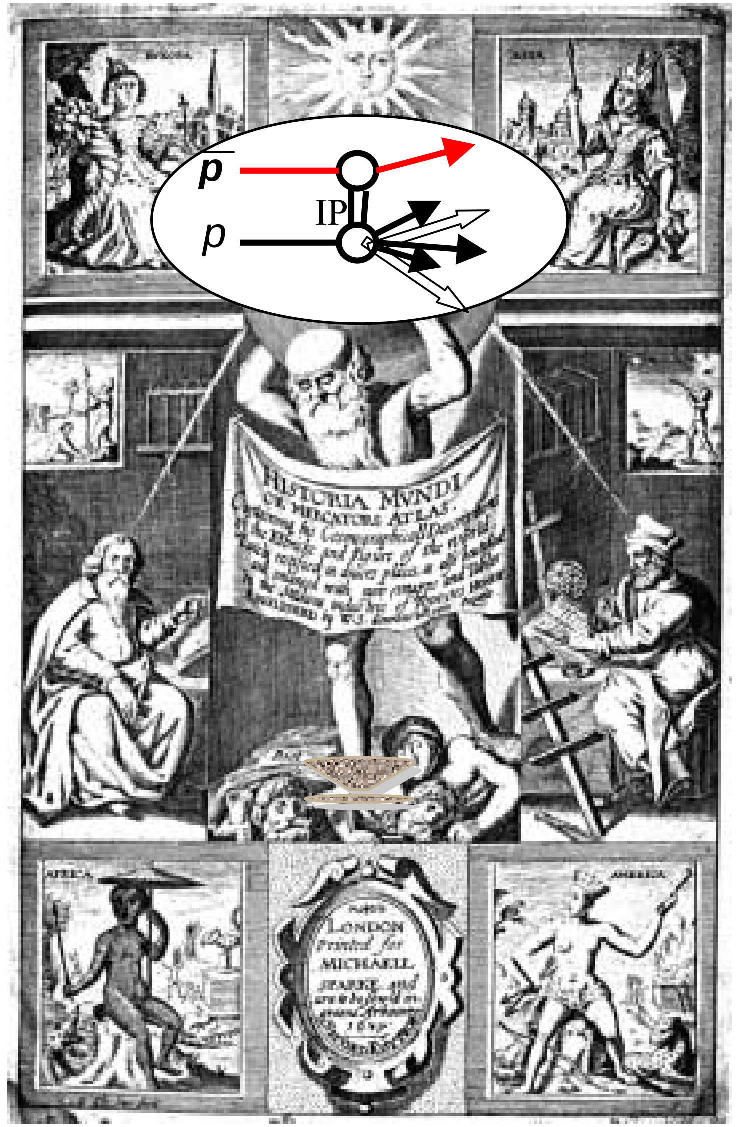
Upper limit for excl DPE-jj consistent with theory

Summary

- Scaling behavior of soft diffractive M^2 - distributions
- Flavor-independent hard diffractive production
- Universality of rapidity gap formation across soft and hard diffraction
- Non-suppressed double-gap to single-gap ratios
- Limit on exclusive dijet production in double-Pomeron exchange

La Thuile

Diffraction



Soft & Hard