Diffraction from CDF2LHC

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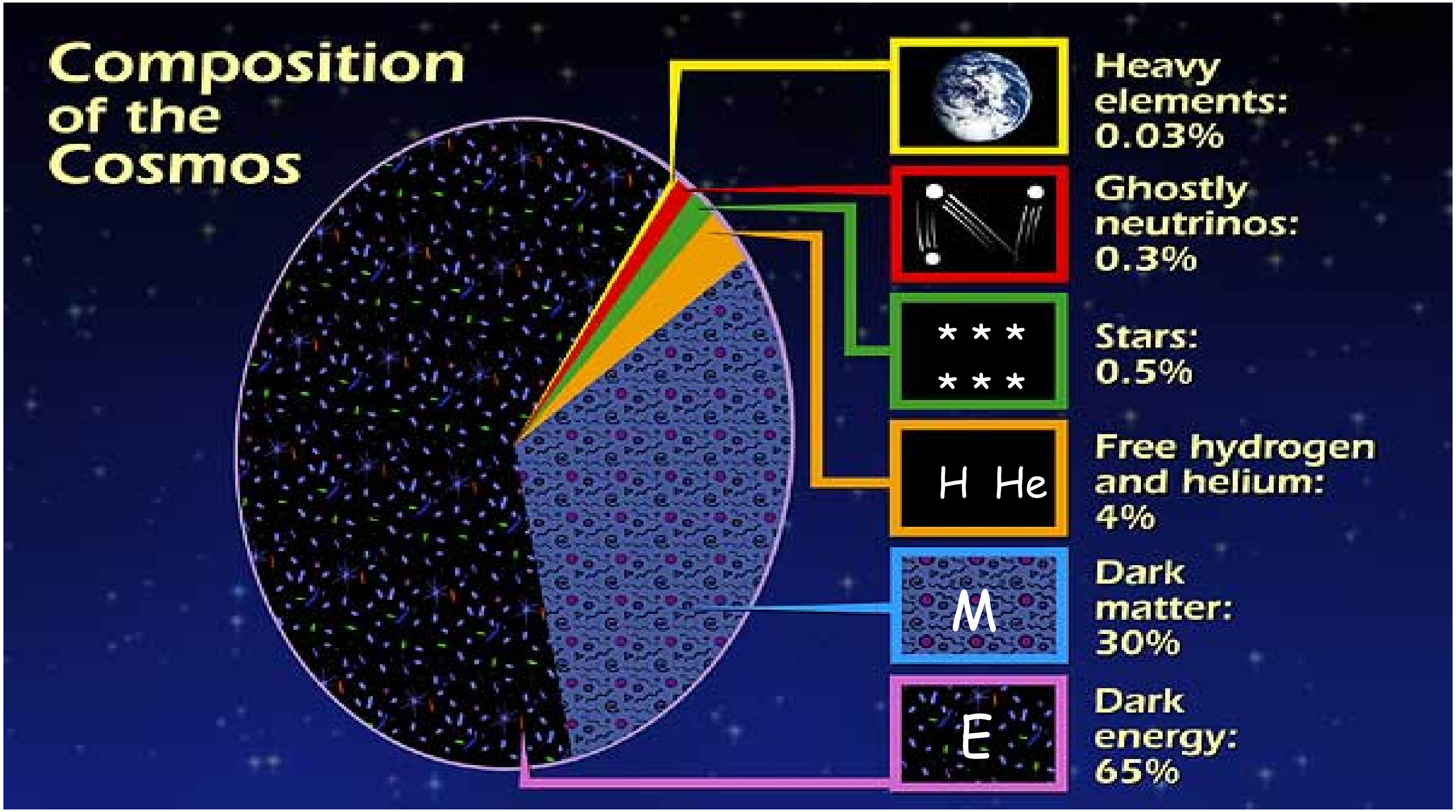
Tev4LHC
3-5 February 2005
Brookhaven National Laboratory

What is Dark Energy?



Rapidity Gaps

Bj, PRD 47 (1993) 101: regions of (pdeudo)rapidity devoid of particles

Non-diffractive interactions

Rapidity gaps are formed by multiplicity fluctuations.

From Poisson statistics:

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

(ρ=particle density in rapidity space)

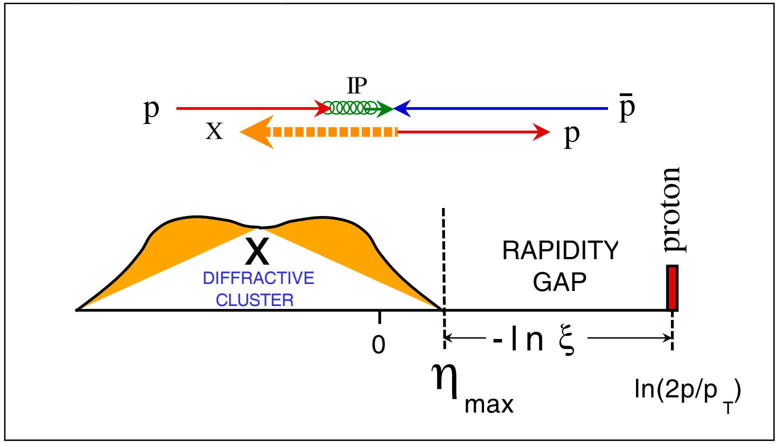
Gaps are exponentially suppressed

Diffractive interactions

Rapidity gaps at t=0 grow with Δy.

$$\xi \equiv \Delta p / p$$

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

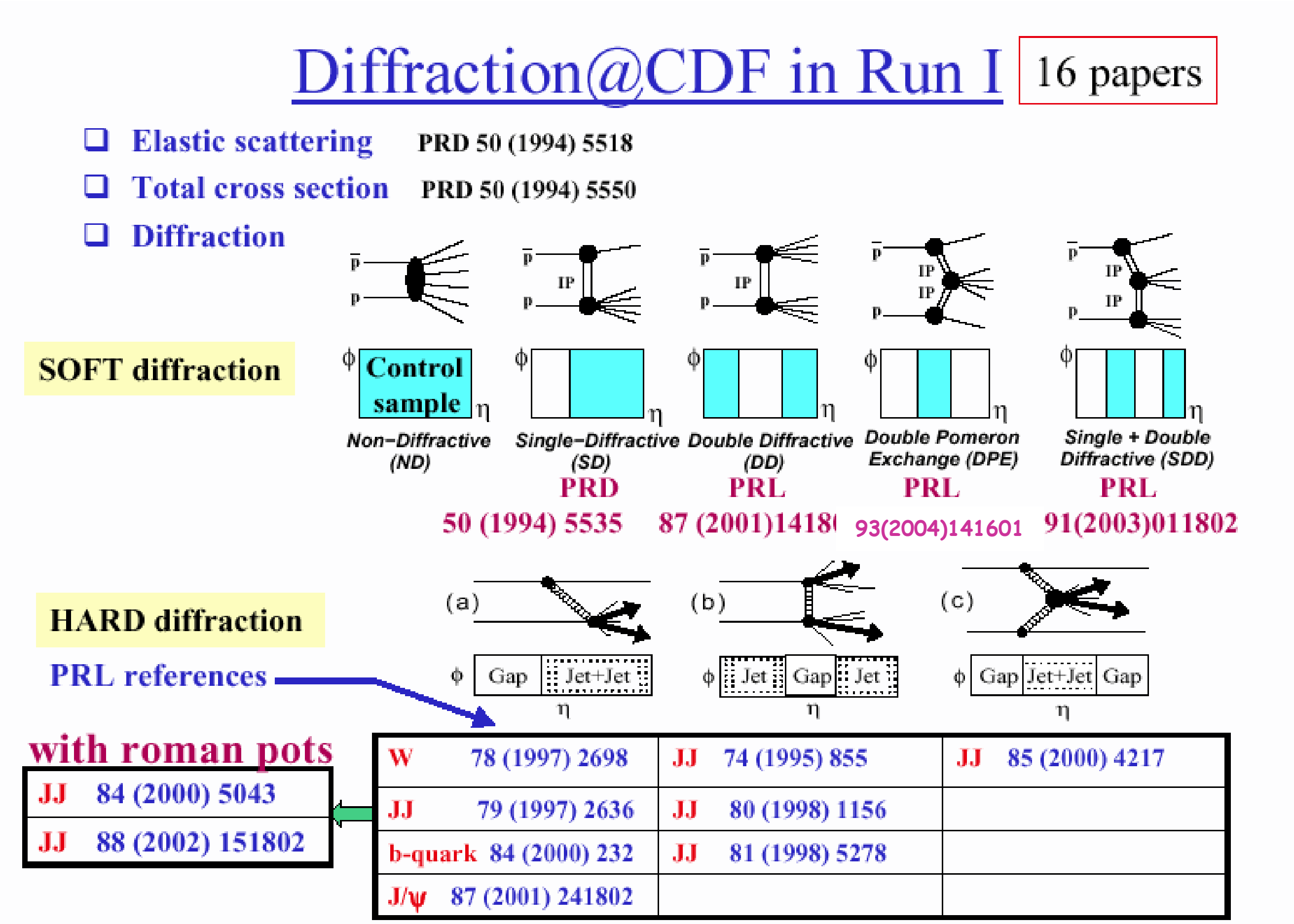


$$\left(\frac{d\sigma}{d\Delta y} \right)_{t=0} \sim e^{2\varepsilon \Delta y} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{\left(M^2\right)^{1+\varepsilon}}$$

2ε: negative particle density!

CDF Run I results

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



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)
Control sample	PRD	PRL	PRL	PRL
	50 (1994) 5535	87 (2001)1418	93(2004)141601	91(2003)011802

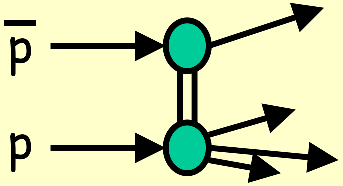
HARD diffraction

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		

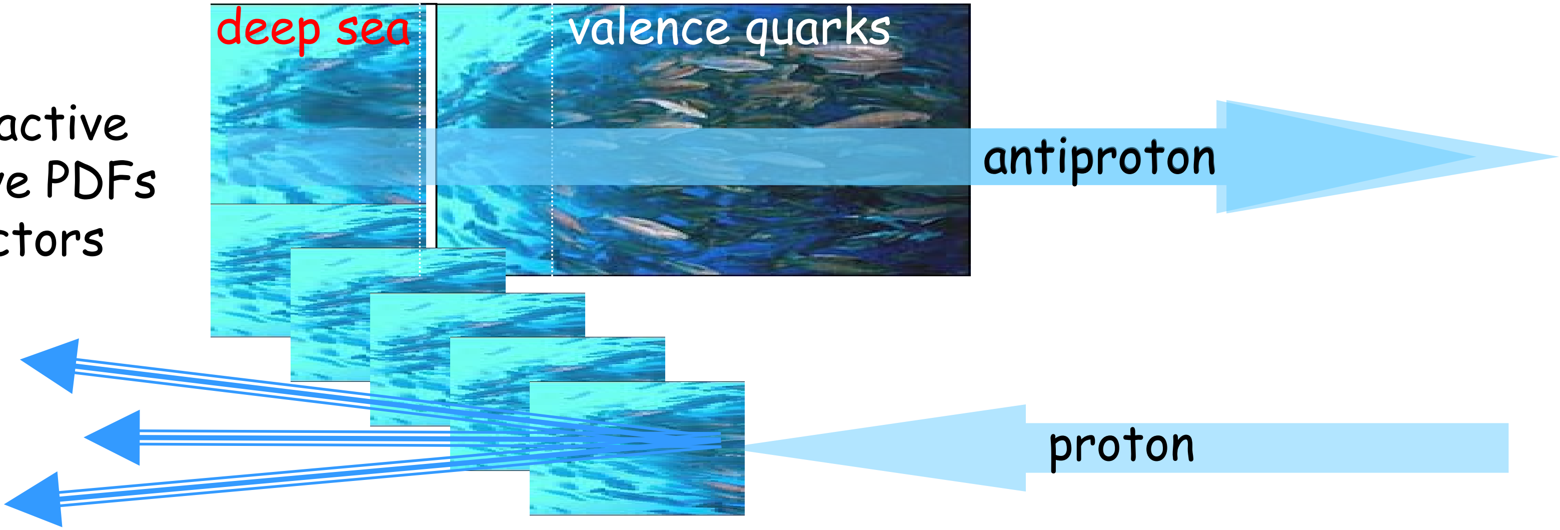
with roman pots

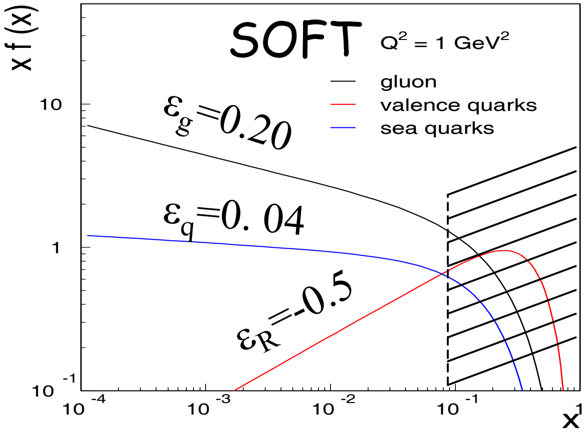
JJ	84 (2000) 5043
JJ	88 (2002) 151802



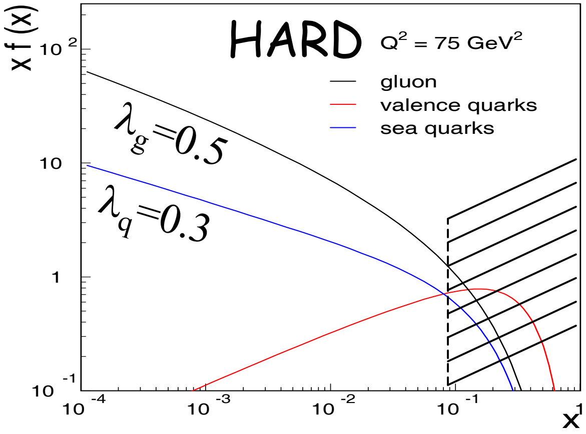
Single Diffraction

Derive diffractive from inclusive PDFs and color factors

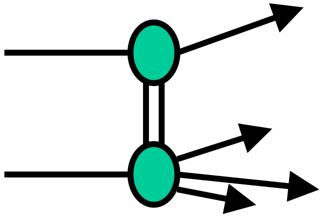




$$x\cdot f(x)=\frac{1}{x^{\varepsilon\,(\mathrm{or}\,\lambda)}}$$



Inclusive Single Diffraction



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

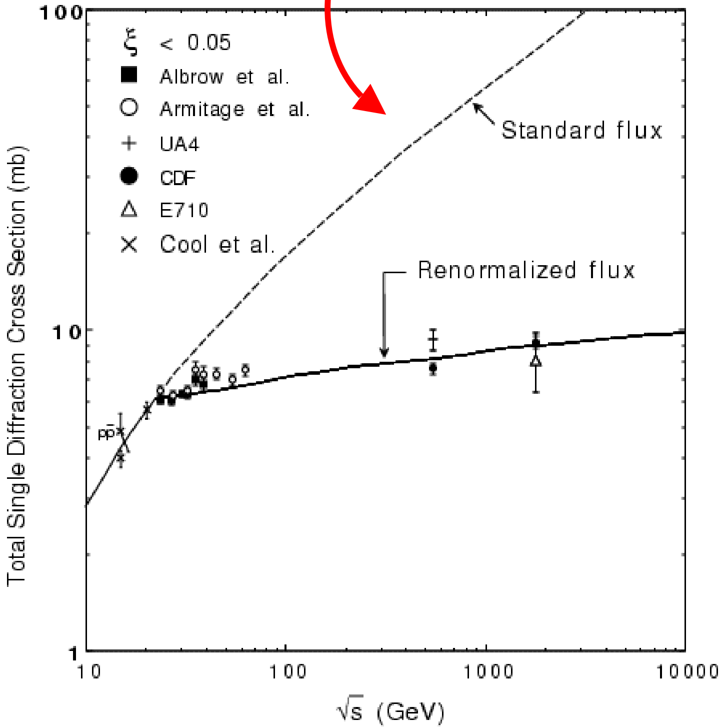
- **Unitarity problem:**
  Using factorization
  and std pomeron flux
  σ_{SD} exceeds σ_T at $\sqrt{s} \approx 2$ TeV.

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

KG, PLB 358 (1995) 379

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

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



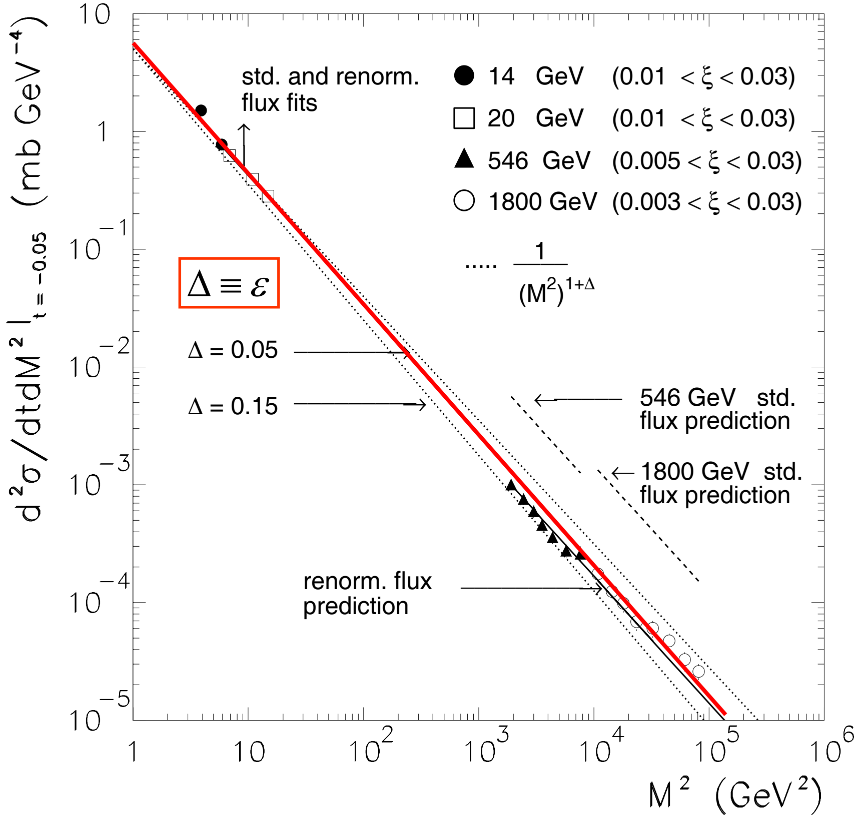
A Scaling Law in Diffraction

Factorization breaks down in favor of M^2-scaling

renormalization

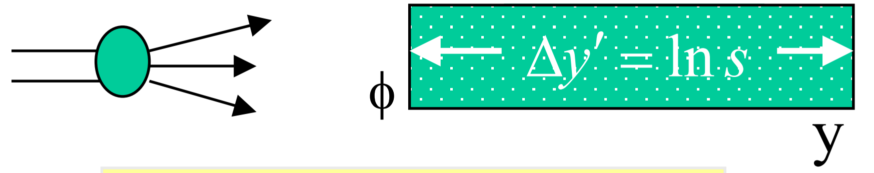
$$\frac{d\sigma}{dM^2}\propto\frac{s^{2\varepsilon}\rightarrow 1}{(M^2)^{1+\varepsilon}}$$

KG&JM, PRD 59 (1999) 114017



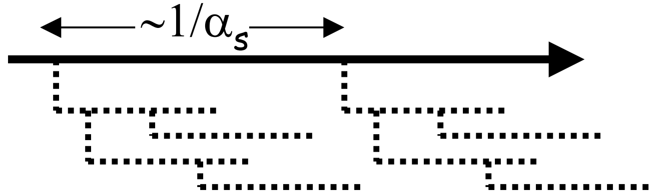
Elastic and Total Cross Sections

QCD expectations



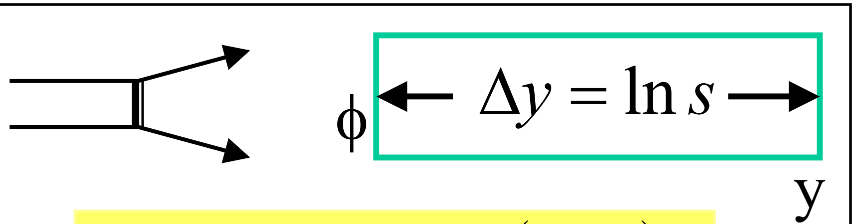
$$\sigma_T(s) = \sigma_o\, s^{\varepsilon} = \sigma_o\, e^{\varepsilon \Delta y'}$$

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)

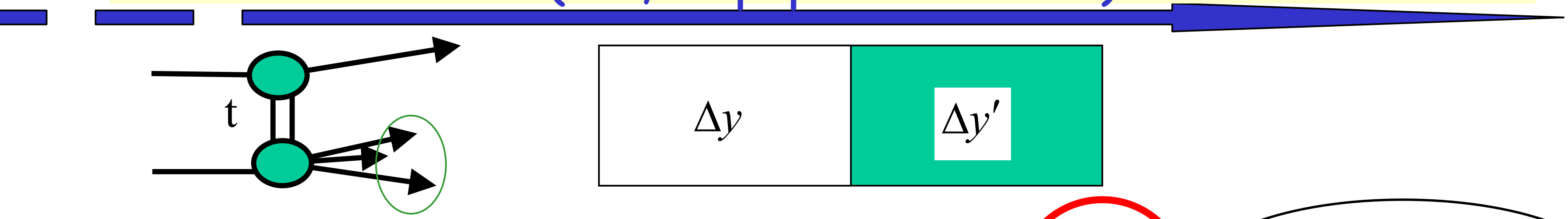


$$\text{Im}\, f_{el}(s,t) \propto e^{(\varepsilon + \alpha' t)\Delta y}$$

Elastic cross section:
forward scattering amplitude

Soft Diffraction

(KG, hep-ph/0205141)



2 independent variables: $t, \Delta y$

color factor

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

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

↓

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

Renormalization removes the s-dependence → SCALING

The Factors κ and ε

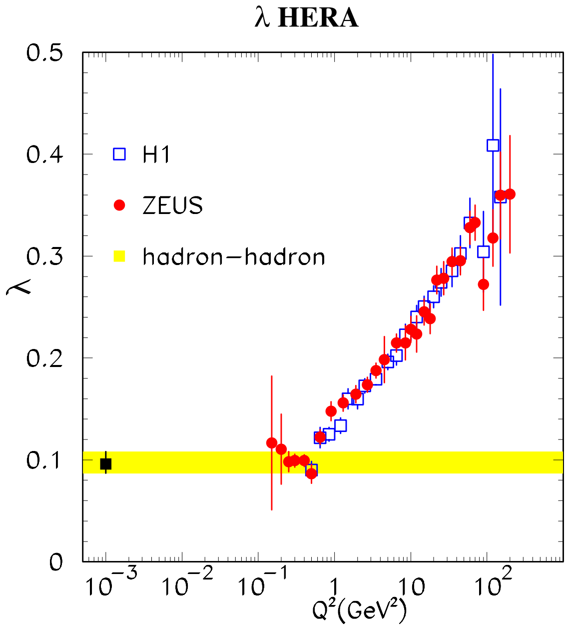
Experimentally:

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

KG&JM, PRD 59 (114017) 1999

Color factor: $\kappa = \mathrm{f}_g \times \frac{1}{N_c^2 - 1} + \mathrm{f}_q \times \frac{1}{N_c} \xrightarrow{Q^2 = 1} \approx 0.75 \times \frac{1}{8} + 0.25 \times \frac{1}{3} = \boxed{0.18}$

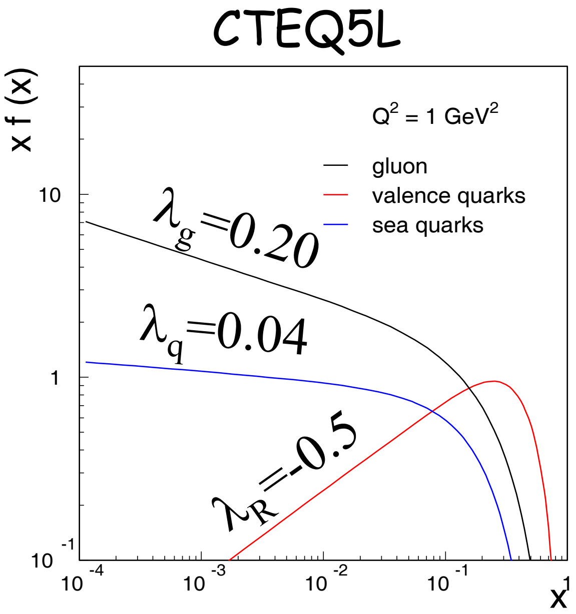
Pomeron intercept: $\varepsilon = \lambda_g \cdot \mathrm{w}_g + \lambda_q \cdot \mathrm{w}_q = \boxed{0.12}$



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

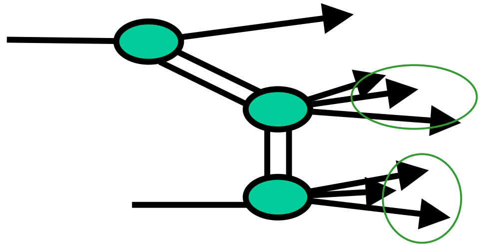
f_g=gluon fraction
f_q=quark fraction

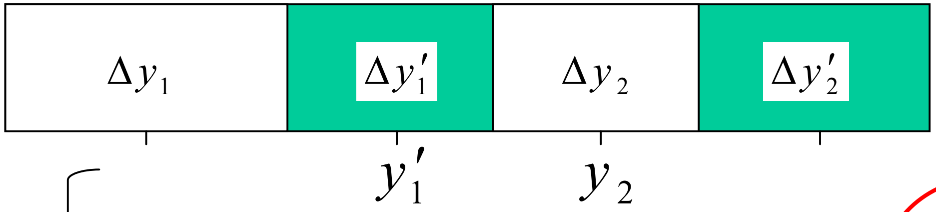
$$\boxed{\int_{x=1/s}^{1} f(x)\, dx \sim s^{\lambda}}$$



Multigap Diffraction

(KG, hep-ph/0205141)





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

color factors

$$\frac{d^5\sigma}{\prod_{i=1-5} dV_i} = \underbrace{C\times F_p^2(t_1)\prod_{i=1-2}\left\{e^{(\varepsilon+\alpha' t_i)\Delta y_i}\right\}^2}_{\text{Gap probability}} \times \kappa^2 \underbrace{\left\{\sigma_o\, e^{\varepsilon(\Delta y_1'+\Delta y_2')}\right\}}_{\text{Sub-energy cross section (for regions with particles)}}$$

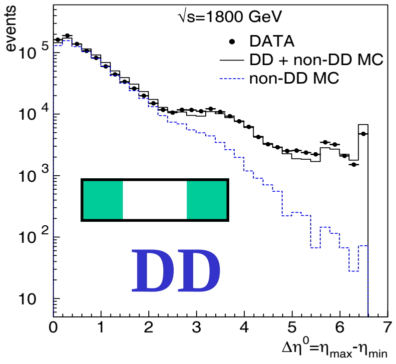
$$\sim e^{2\varepsilon\Delta y}$$

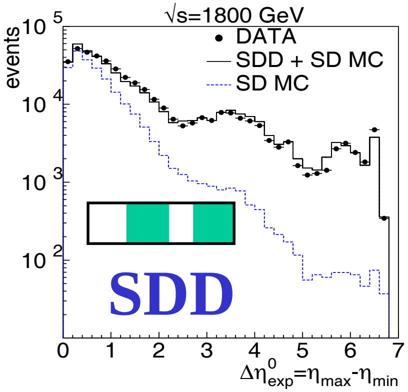
$$\boxed{\int_{\Delta y_{\min}}^{\Delta y=\ln s} s^{2\varepsilon\,\Delta y} \approx s^{2\varepsilon}}$$

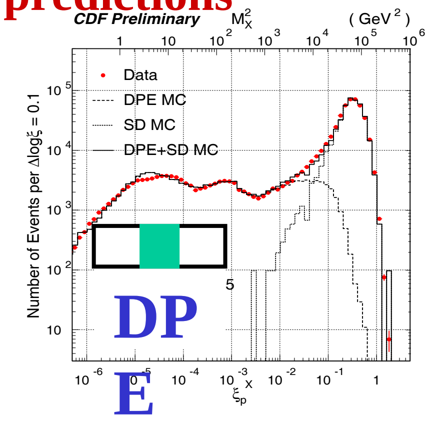
Same suppression as for single gap!

Central and Two-Gap CDF Results

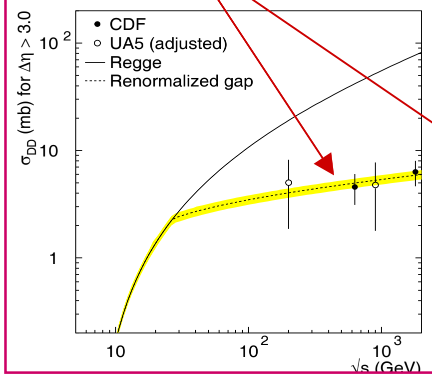
Differential shapes agree with Regge predictions

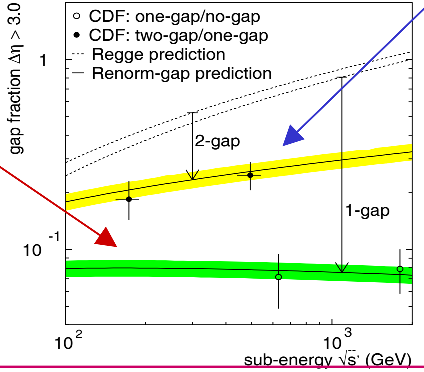


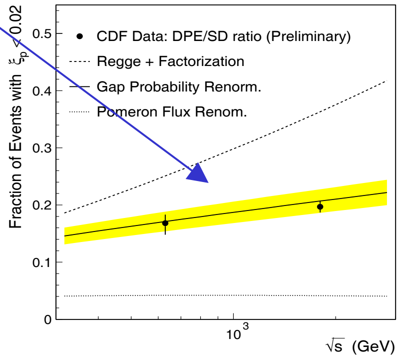




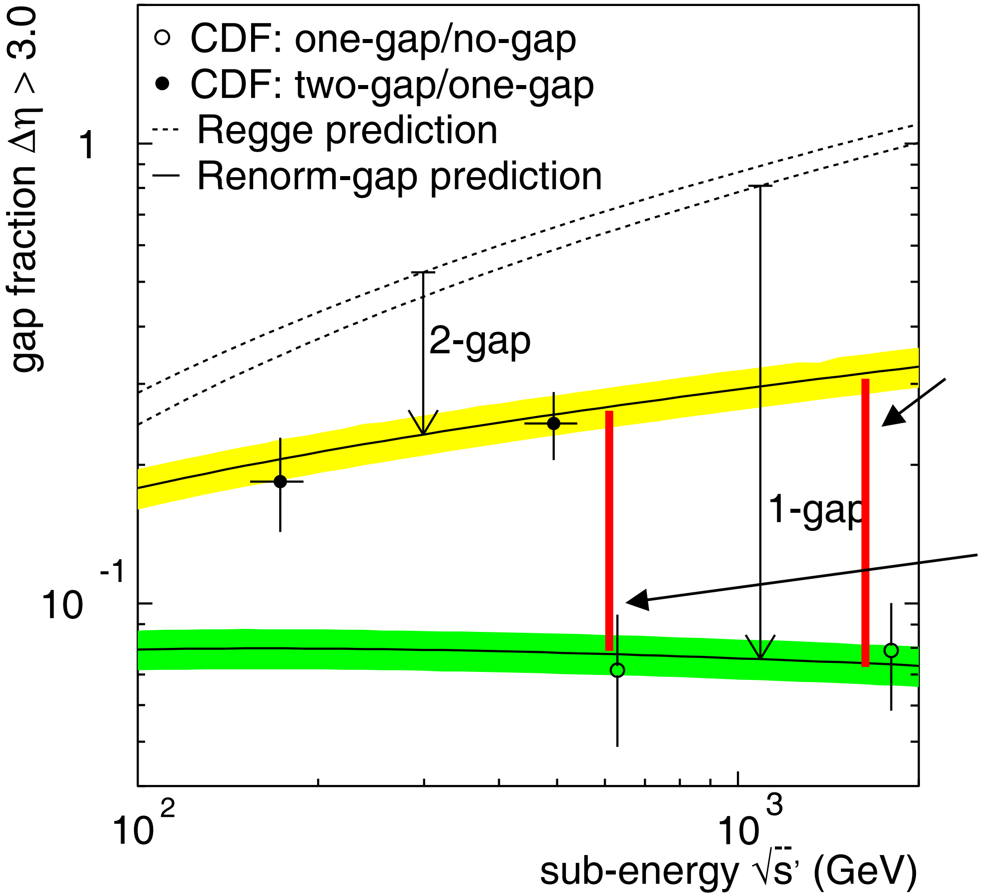
- One-gap cross sections are suppressed
- Two-gap/one-gap ratios are $\approx \kappa = 0.17$

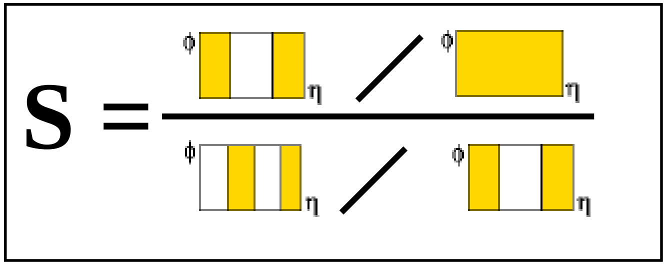






Gap Survival Probability





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

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

Results similar to predictions by:

Gotsman-Levin-Maor

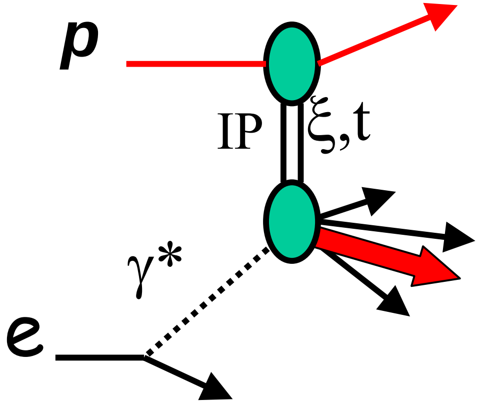
Kaidalov-Khoze-Martin-Ryskin

Soft color interactions

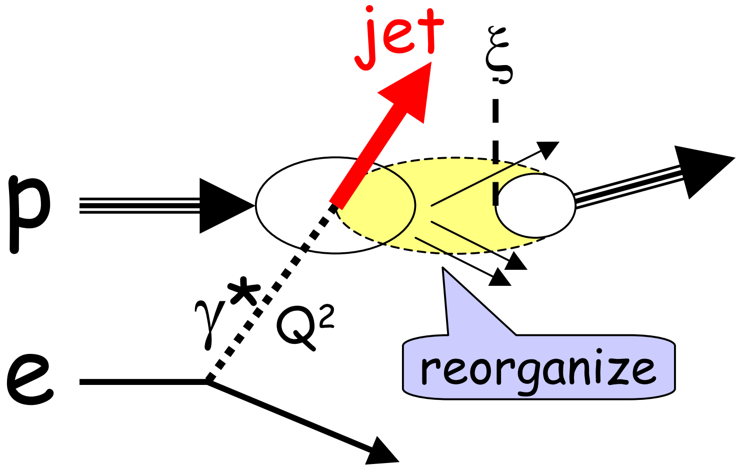
Diffractive DIS @ HERA

Factorization holds: J. Collins

Pomeron exchange



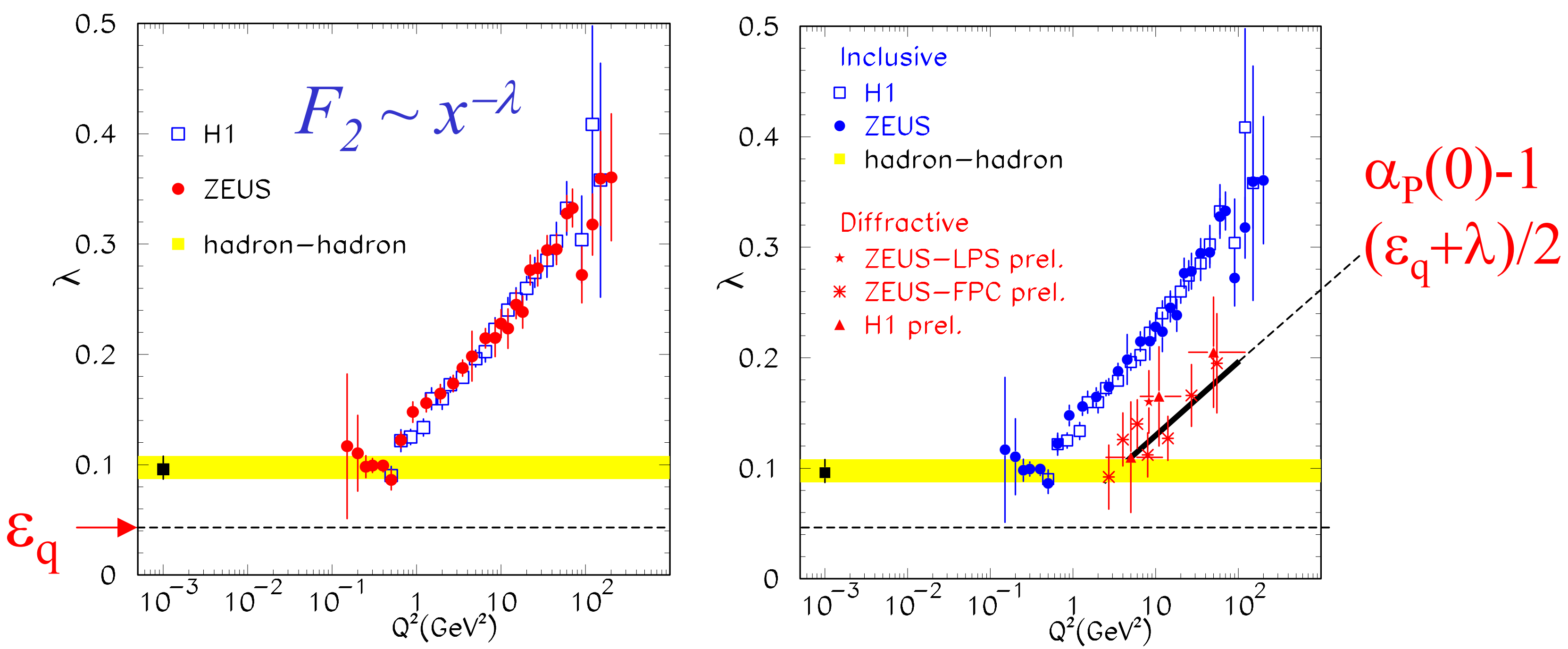
Color reorganization



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

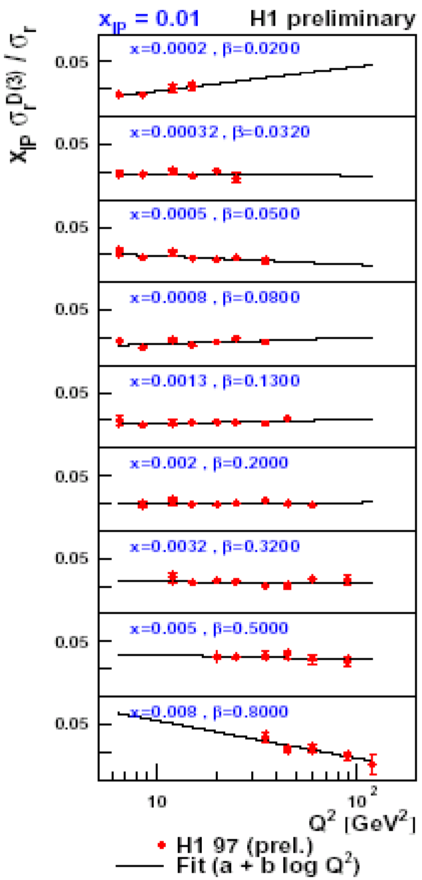
Inclusive vs Diffractive DIS

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



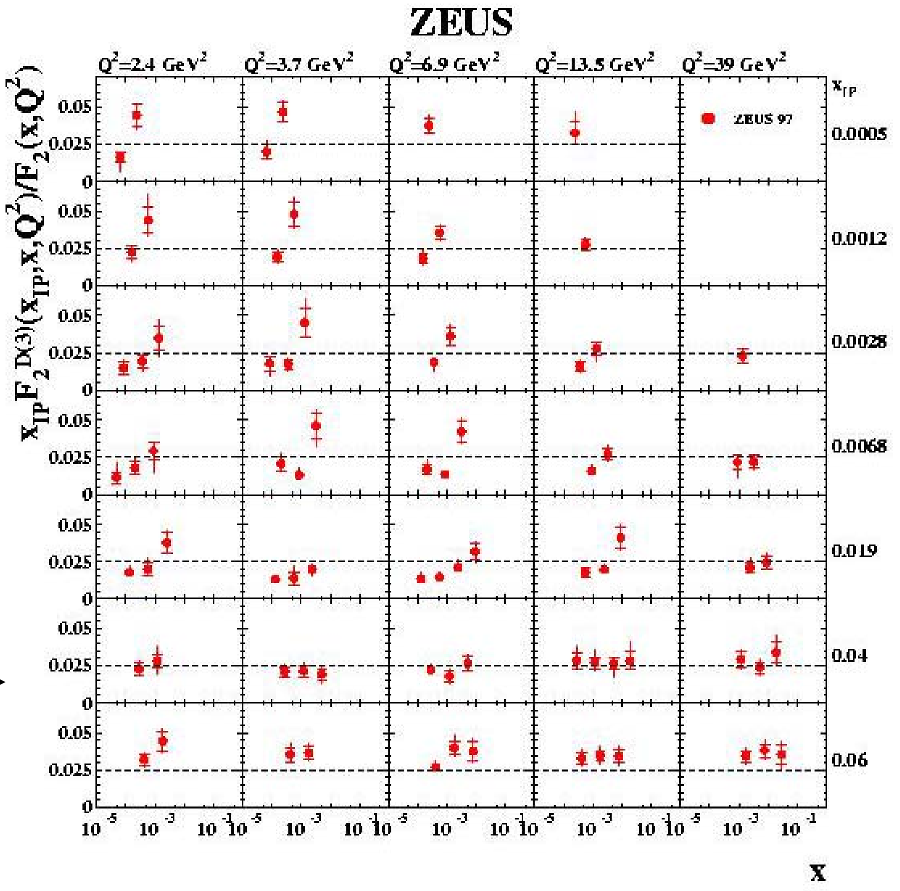
$$F_2^{D(3)}(\xi,\beta,Q^2) \propto \frac{1}{\xi^{1+\varepsilon}}\cdot\frac{C(Q^2)}{(\beta\xi)^{\lambda(Q^2)}} \propto \frac{1}{\xi^{1+\varepsilon+\lambda}}\cdot\frac{C}{\beta^{\lambda}}$$

$\sigma^{diff}/\sigma^{incl}$ DIS at HERA

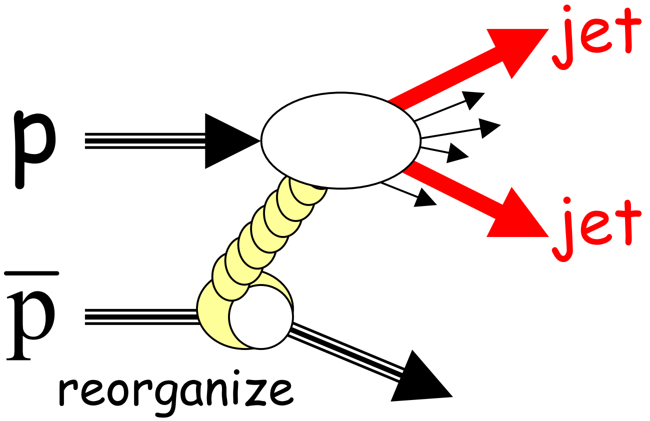


At fixed x:
flat Q^2-dependence

At fixed Q^2:
flat x-dependence



Diffractive Dijets @ Tevatron



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

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

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

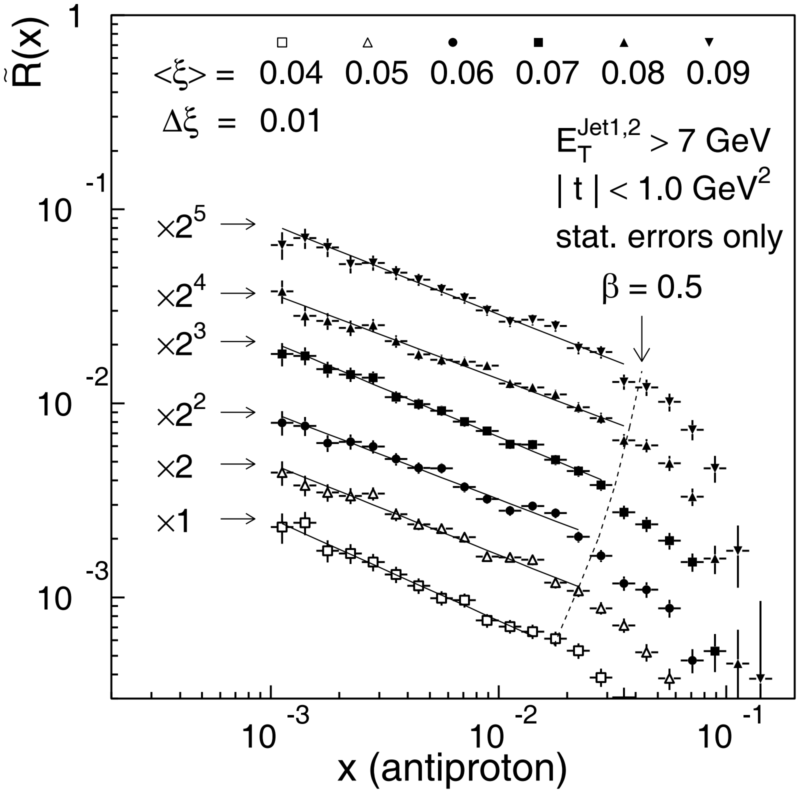
$$\mathrm{N}_{\text{renorm}}^{-1} = \int_{\xi_{\min}}^{1}\frac{d\xi}{\xi^{1+2\varepsilon}} \xrightarrow{\xi_{\min}=\frac{x_{\min}}{\beta}\sim\frac{1}{\beta\, s}} (\beta\, s)^{2\varepsilon}$$

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

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

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

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



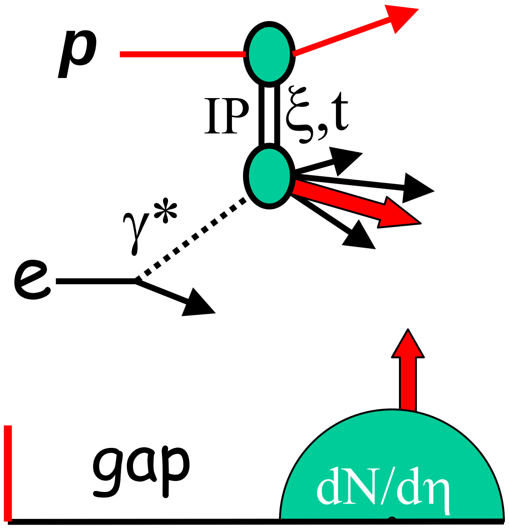
$0.035 < \xi < 0.095$

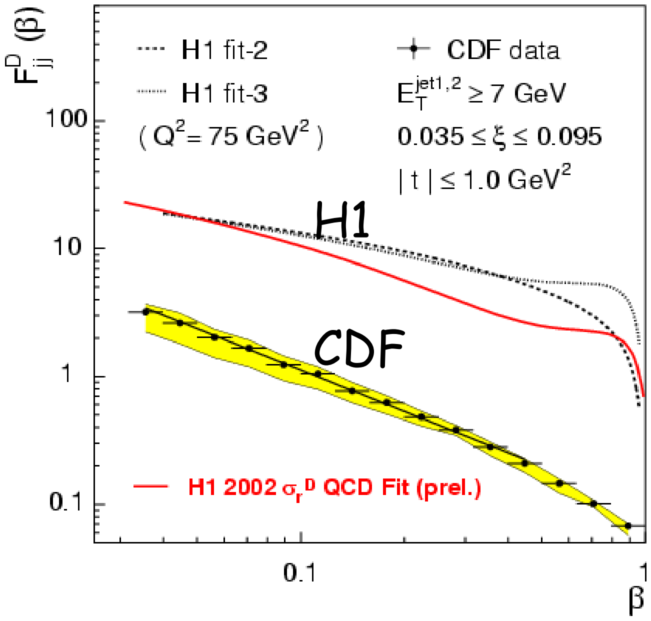
Flat ξ dependence

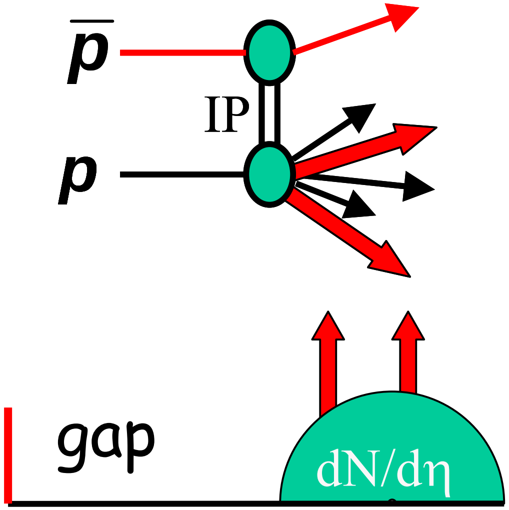
$$R(x) = x^{-0.45}$$

Tevatron vs HERA: Factorization Breakdown

Predicted in KG, PLB 358 (1995) 379

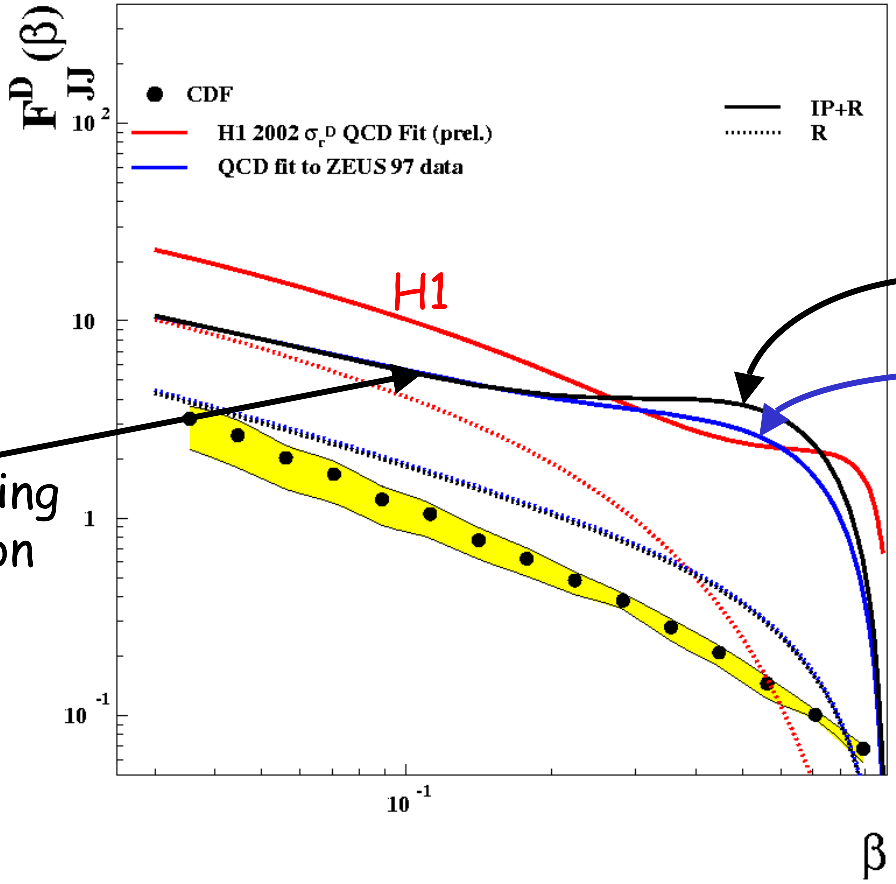






New: $F^D_{JJ}(\beta)$ from ZEUS-LPS Data

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

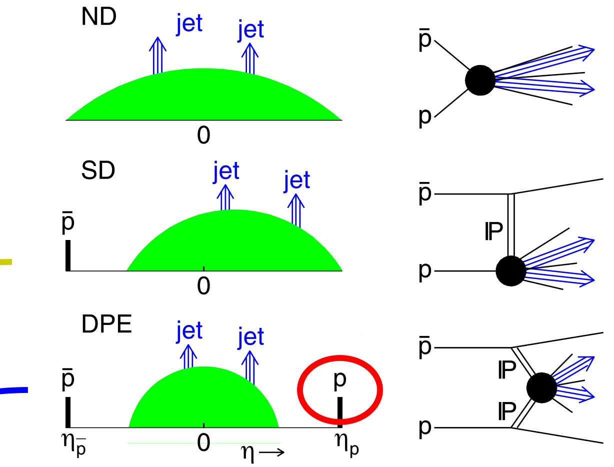


ZEUS
Fit including
charm data

Fit without
charm data

Flat after subtracting
Reggeon contribution

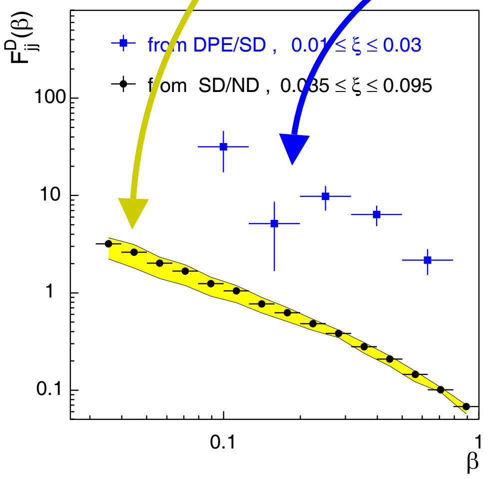
Restoring Factorization @ Tevatron

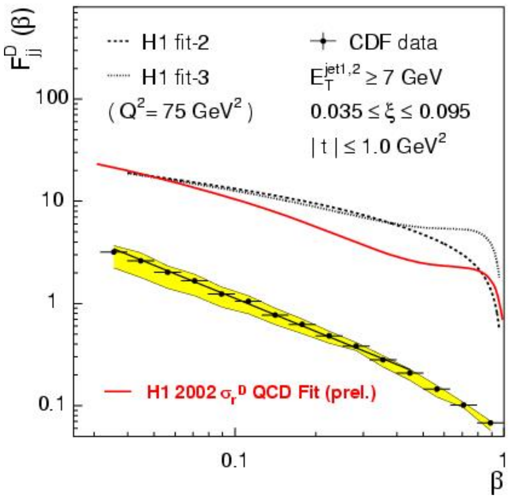


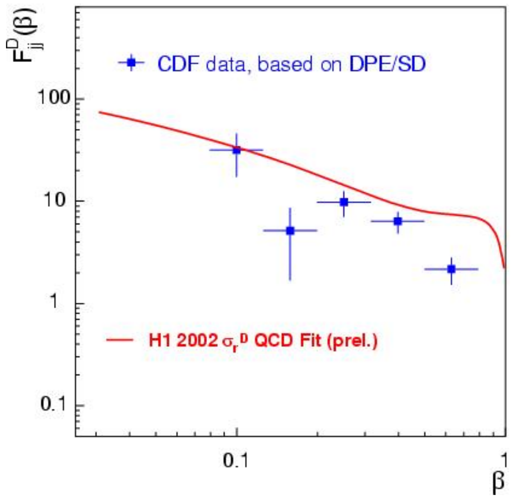
R(SD/ND)

R(DPE/SD)

DSF from two/one gap: factorization restored!

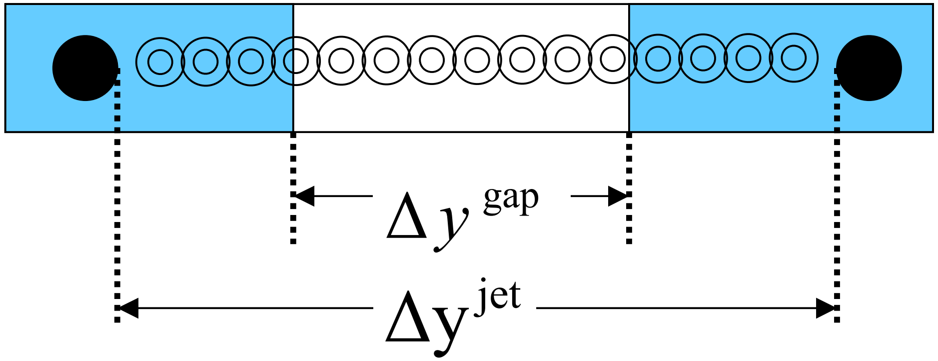






CDF2LHC

TOPIC	STATUS
➢ (Q^2, t) dependence of DSF	close to ready
➢ Exclusive χ_c production	close to ready
➢ Low mass states in DPE	need good trigger
➢ Exclusive b-bbar production in DPE	need b-trigger
➢ ξ -dependence of DSF	need low lum run
➢ Jet-gap-Jet w/jets in miniplugs	need low lum run



$$\Delta y^{gap} = \Delta y^{jet} \Rightarrow \text{BFKL}$$

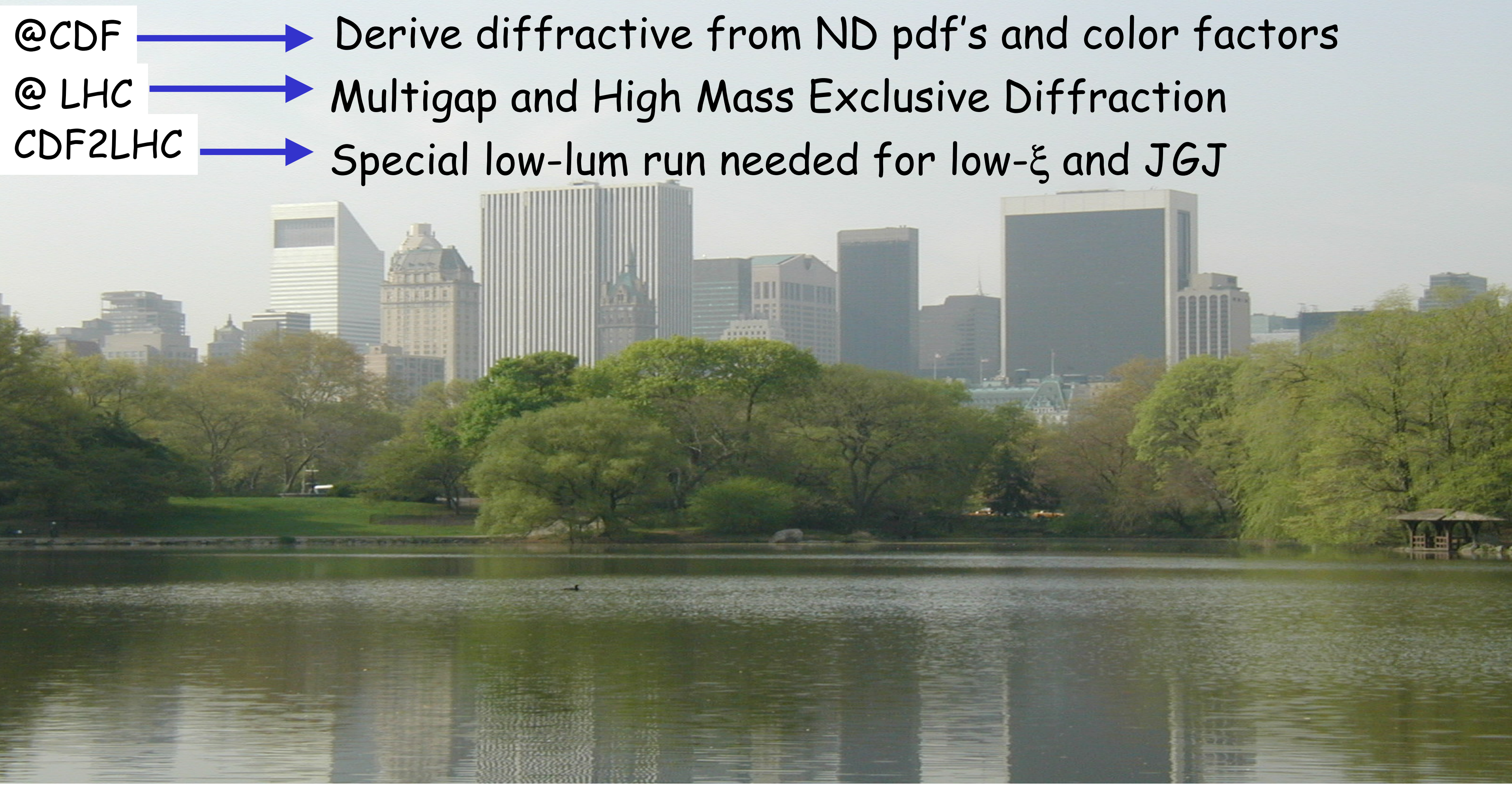
$$\Delta y^{gap} \neq \Delta y^{jet} \Rightarrow \text{composite}$$

Diffraction @ LHC

☐ Multigap diffraction

☐ Exclusive production of high mass states

Summary



@CDF → Derive diffractive from ND pdf's and color factors

@ LHC → Multigap and High Mass Exclusive Diffraction

CDF2LHC → Special low-lum run needed for low-ξ and JGJ