Pomeron Intercept and Slope: the QCD connection

12th International Conference on Elastic and Diffractive Scattering Forward Physics and QCD

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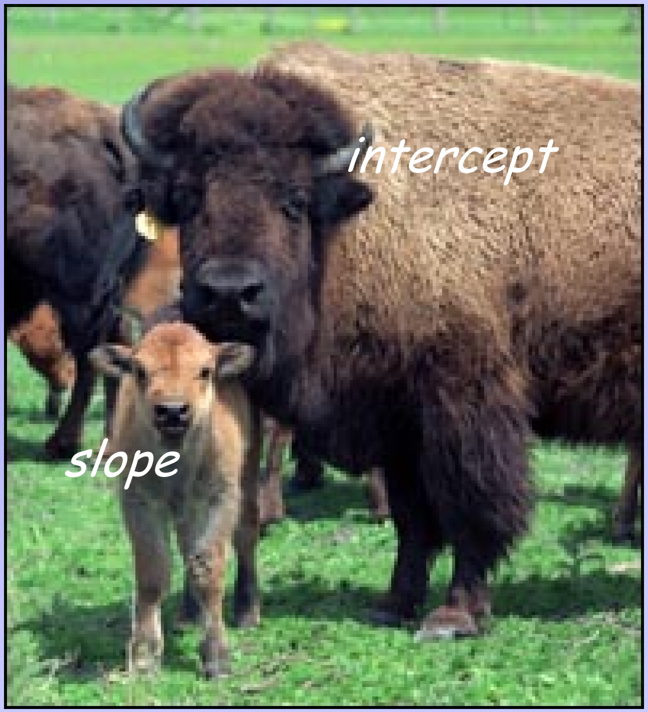
The Rockefeller University



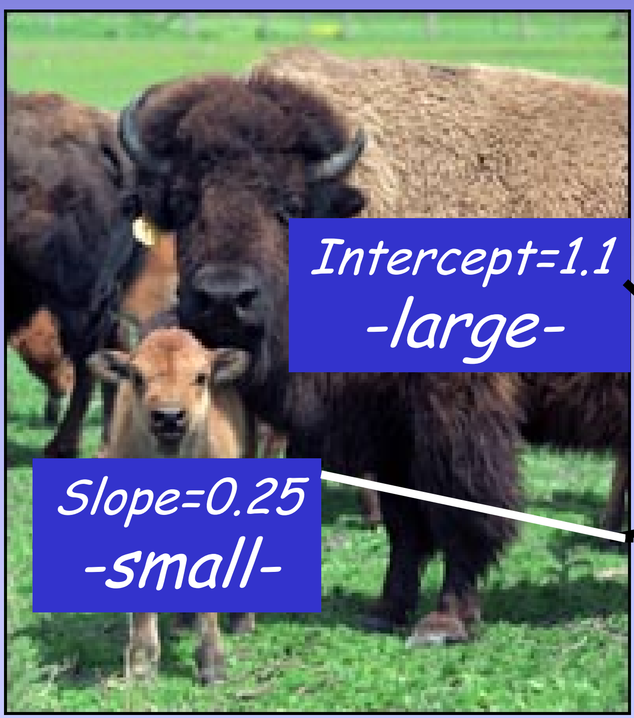
12th Blois Workshop, DESY, Hamburg, Germany 21-25 May2007

Contents

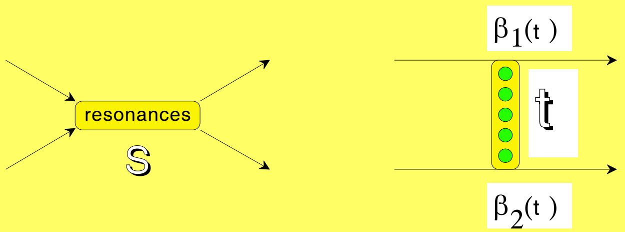
- Introduction
- Diffraction in QCD
- Pomeron intercept and slope
- Cross sections $^{\text{with}}$/no free parameters
- Conclusion

The Pomeron Trajectory

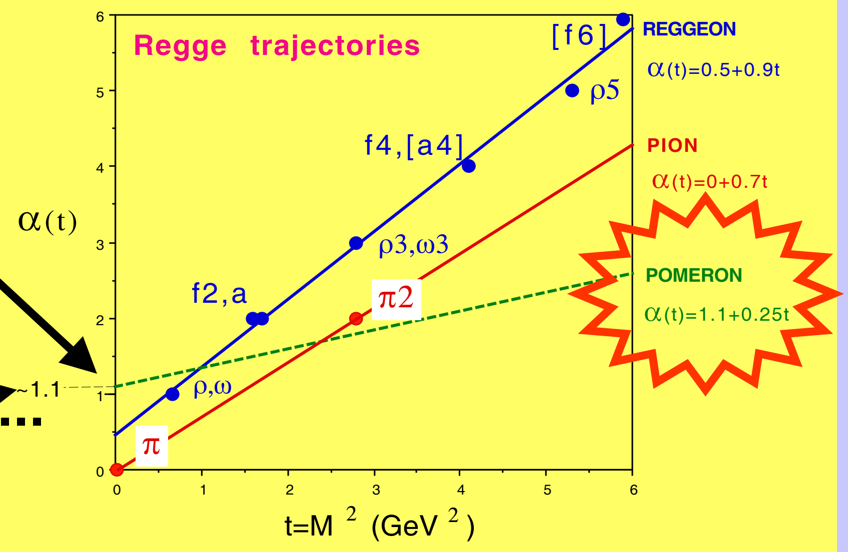
$$\alpha(t)=1.1+0.25\,t$$



REGGE THEORY

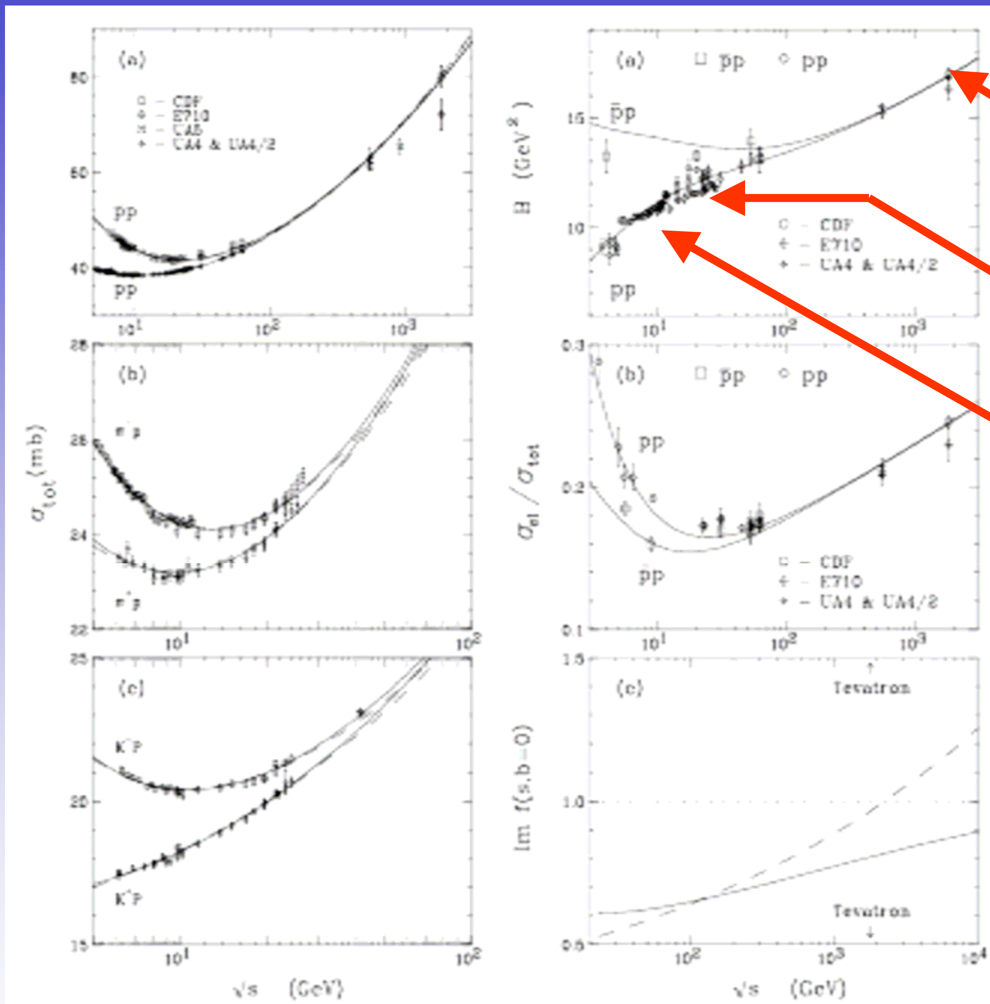


$$T(s,t) = \frac{1}{s}\beta_1(t)\,\beta_2(t)\,s^{\alpha(t)}\,\phi_{\_a(t)} \qquad \sigma_T = \beta^2(0)\,s^{\alpha(0)-1} \sim s^{\varepsilon}$$



A bit of history…

$$\alpha(t) = \alpha_0 + \alpha' \ t$$



Covolan, Montagna, and Goulianos
PLB 389 (1995) 176

time

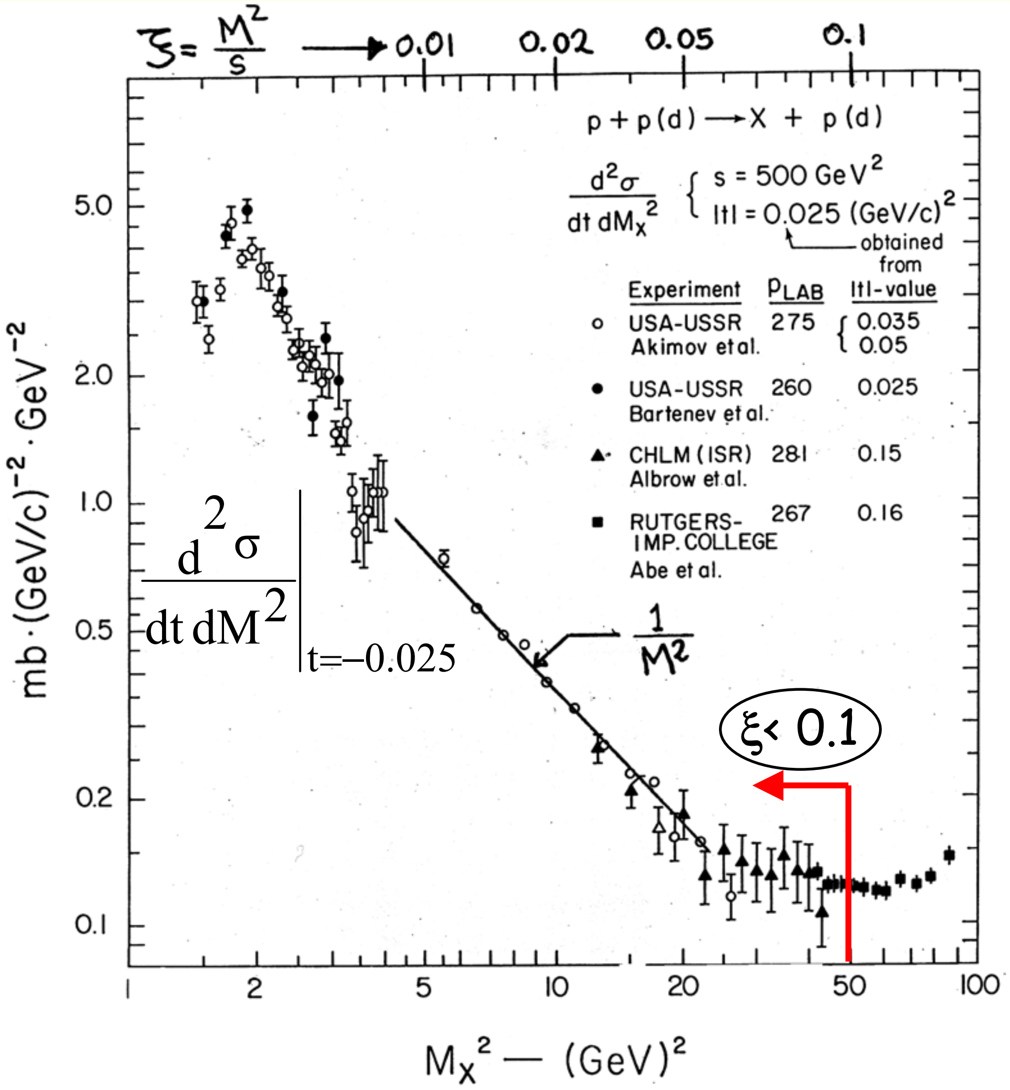
1995: α'=0.25, α_o=1.1

~1970: α'=0.5, α_o=1

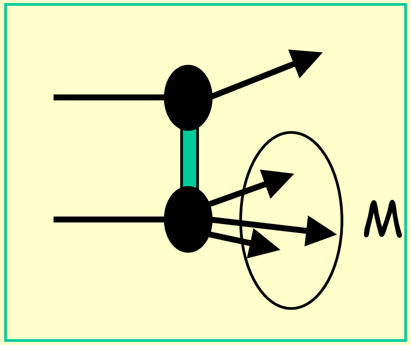
Pre-1970: guess a'~1
(as for other trajectories)

In this talk:
The QCD connection

A clue from Diffraction Dissociation



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



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

Why $1/M^2$?

$\bar{p}$-p Interactions

<u>Non-diffractive:</u>

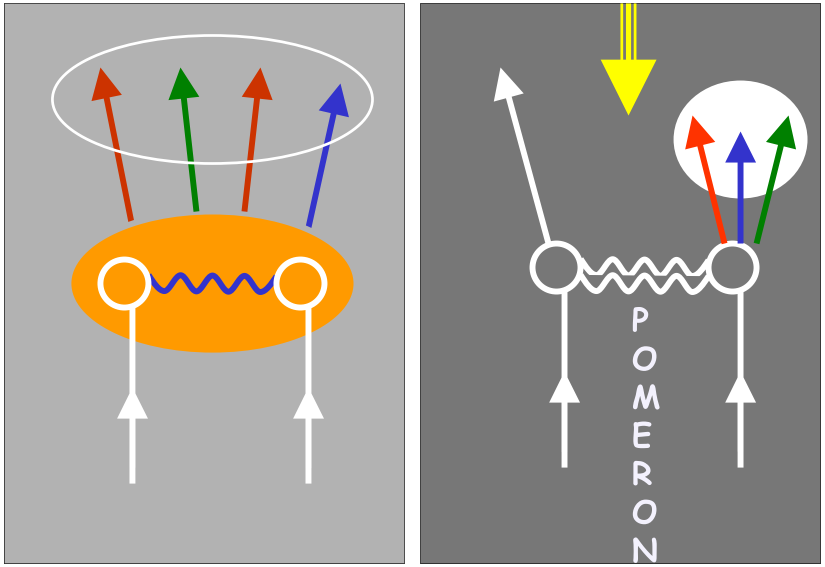
Color-exchange

<u>Diffractive:</u>

Colorless exchange with vacuum quantum numbers

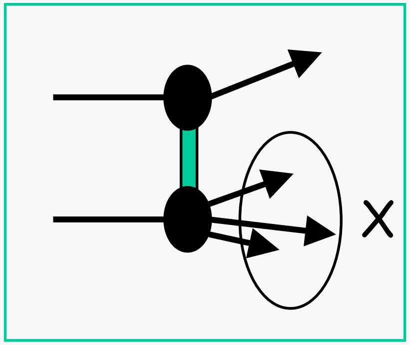
rapidity gap

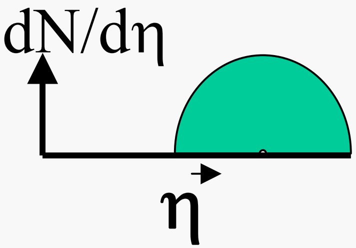
Incident hadrons acquire color and break apart

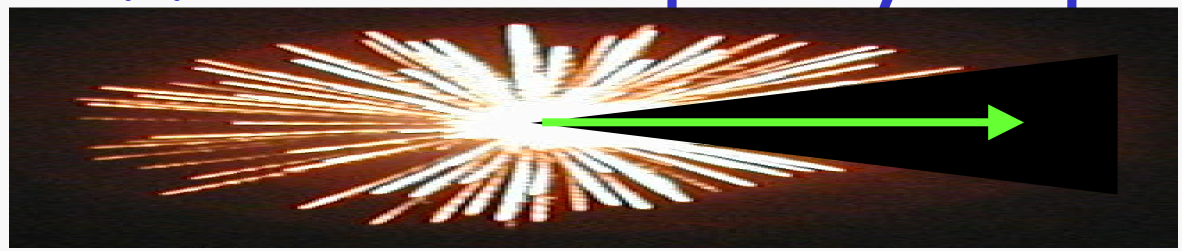


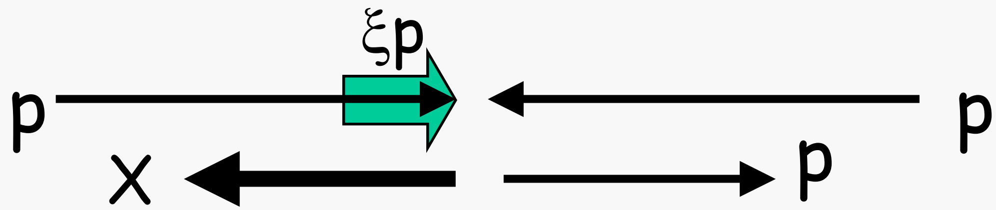
Incident hadrons retain their quantum numbers remaining colorless

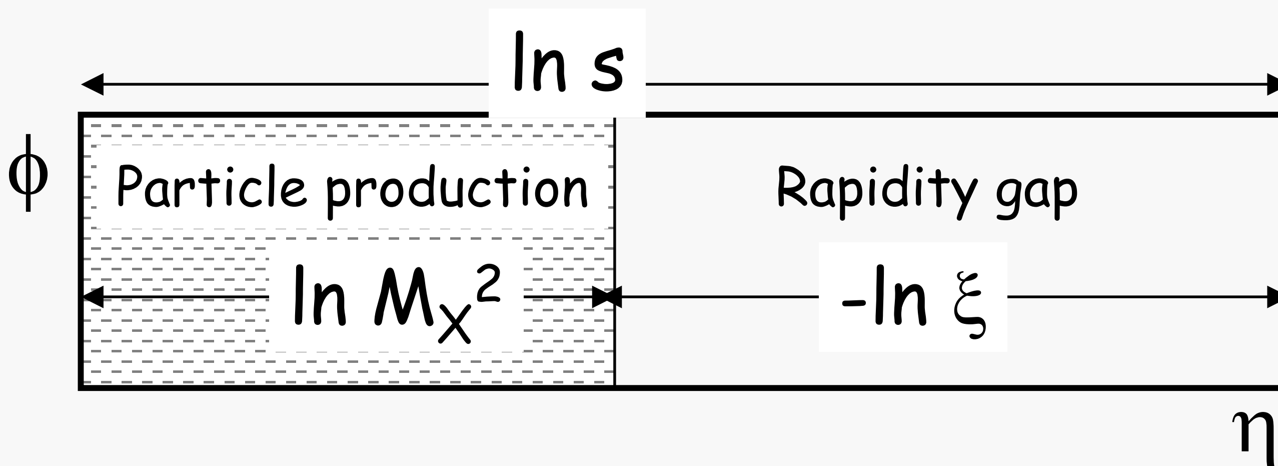
Diffractive Rapidity Gaps





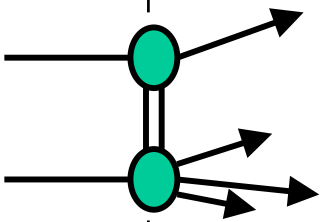






$$\left(\frac{d\sigma}{d\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{dM^2} \sim \frac{1}{M^2} \Rightarrow \frac{d\sigma}{d\xi} \sim \frac{1}{\xi}$$

Another clue: Diffraction and Unitarity



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

s^{ε}

s^{ε}

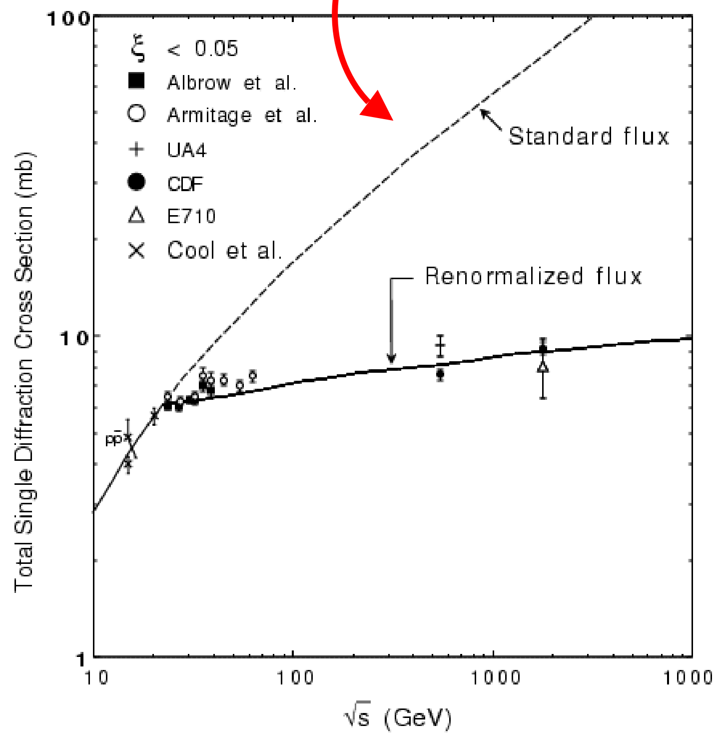
$\sigma_{SD} \sim s^{2\varepsilon}$

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

- **Renormalization:**
  Normalize Pomeron flux to unity
  to eliminate overlapping gaps

KG, PLB 358 (1995) 379

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



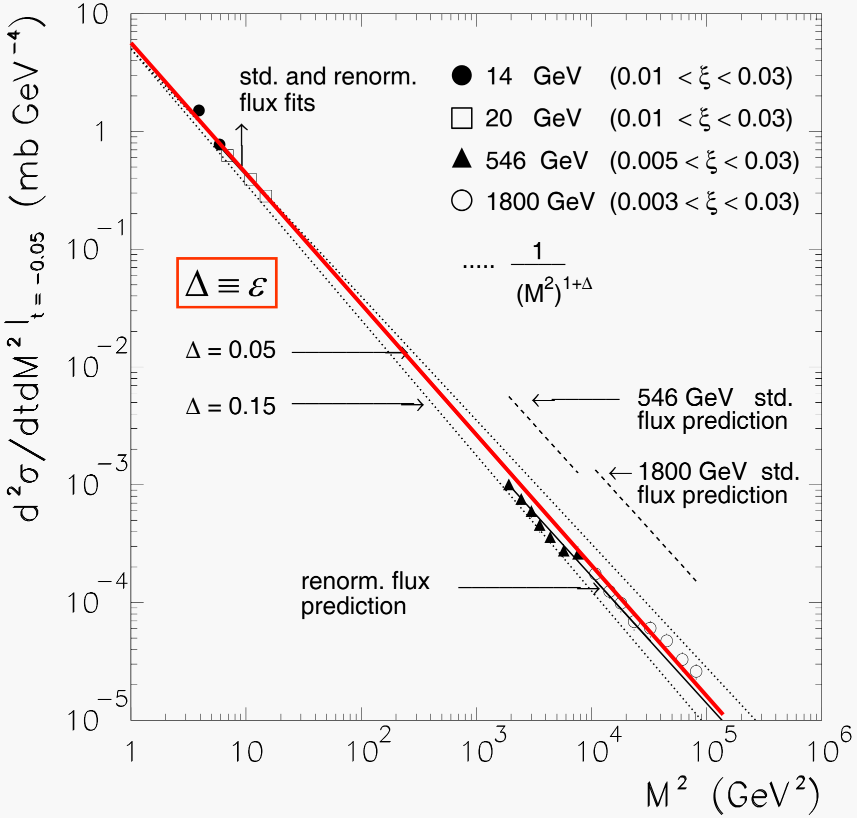
M^2-scaling

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

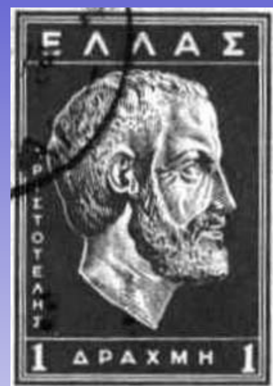


Factorization breaks down so as to ensure M^2-scaling!

PHENOMENOLOGY

Plato (427-347 B.C)

platonic love



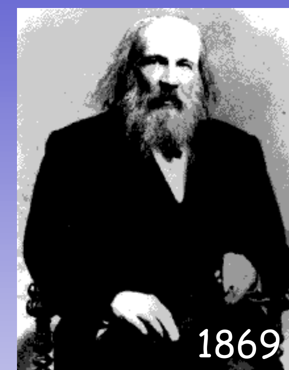
Aristotle

earth
water
air
fire

450 BC

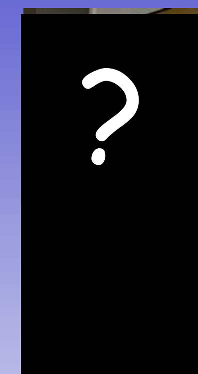
Demokritos

atom



Mendeleyev

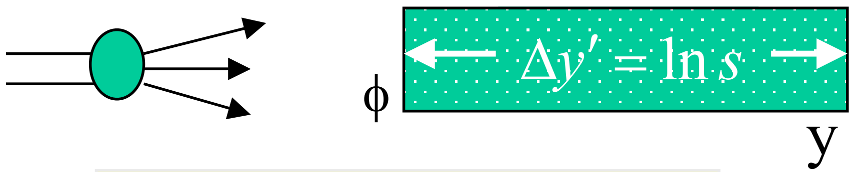
periodic table



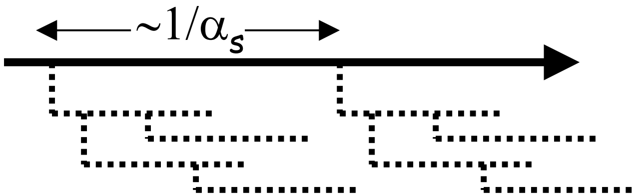
2007

candidates superimposed

The QCD Connection



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



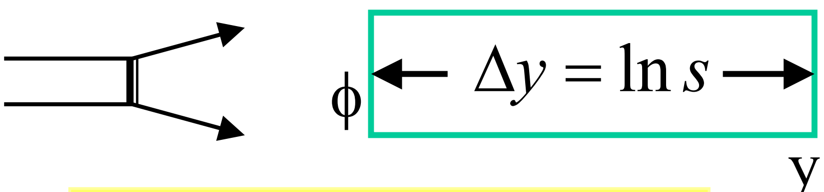
Emission spacing controlled by α-strong

➔ σ_T : power law rise with energy

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

α' reflects the size of the emitted cluster,

which is controlled by $1/\alpha_s$ and thereby is related to ε

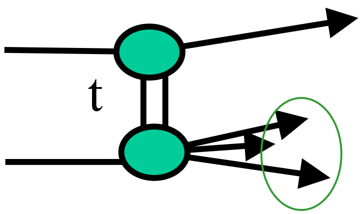


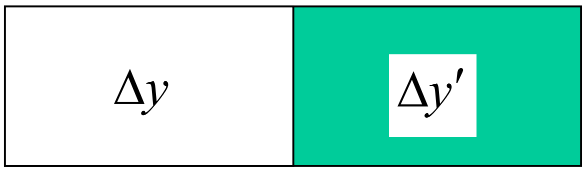
$$\mathrm{Im}\, f_{el}(s,t) \propto e^{(\varepsilon + \alpha' t)\Delta y}$$

← assume linear t-dependence

Forward elastic scattering amplitude

Single Diffraction in QCD





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

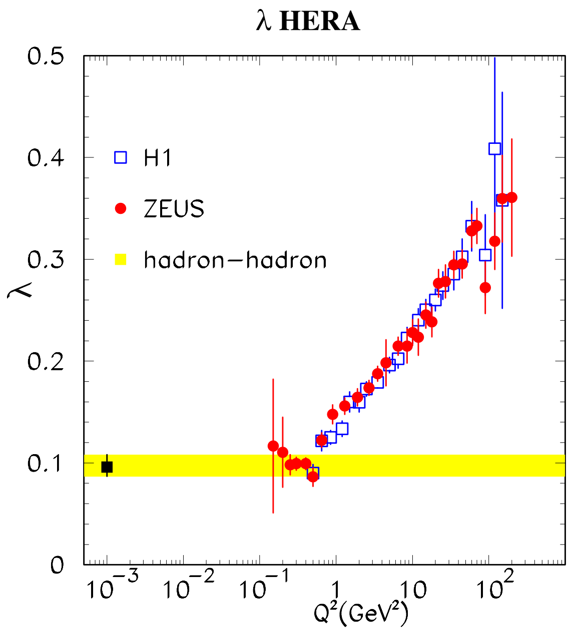
Experimentally:

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

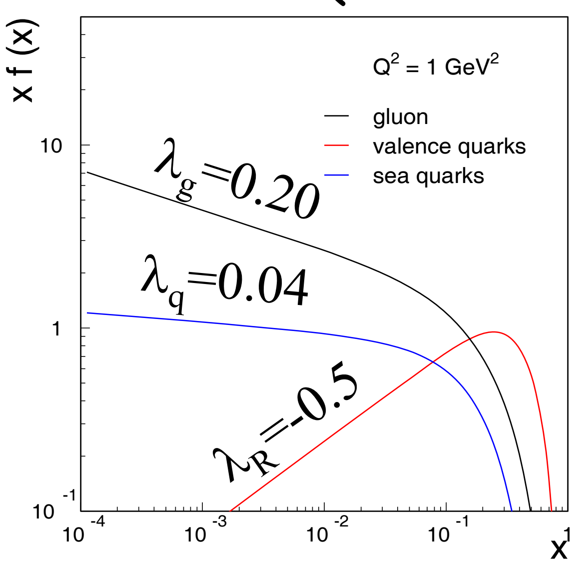


$$x \cdot f(x) = \frac{1}{x^{\lambda}}$$

f_g=gluon fraction
f_q=quark fraction

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

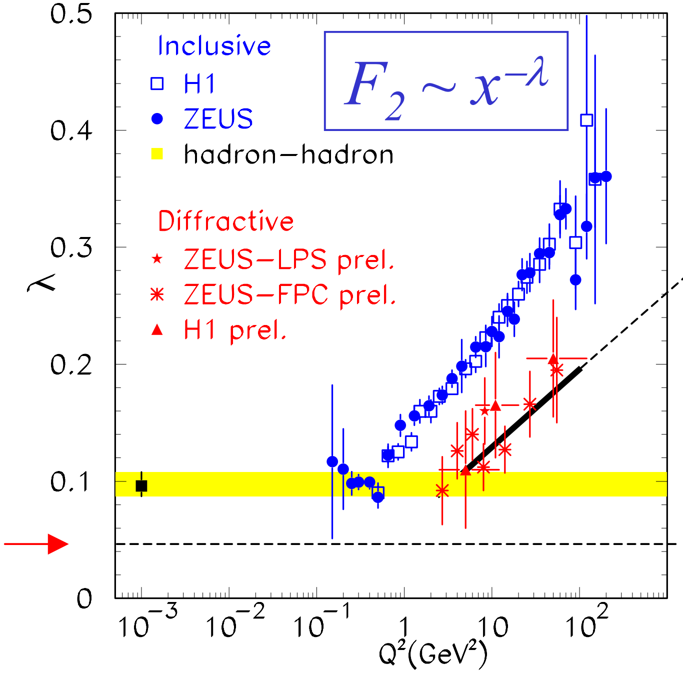
CTEQ5L



Inclusive vs Diffractive DIS

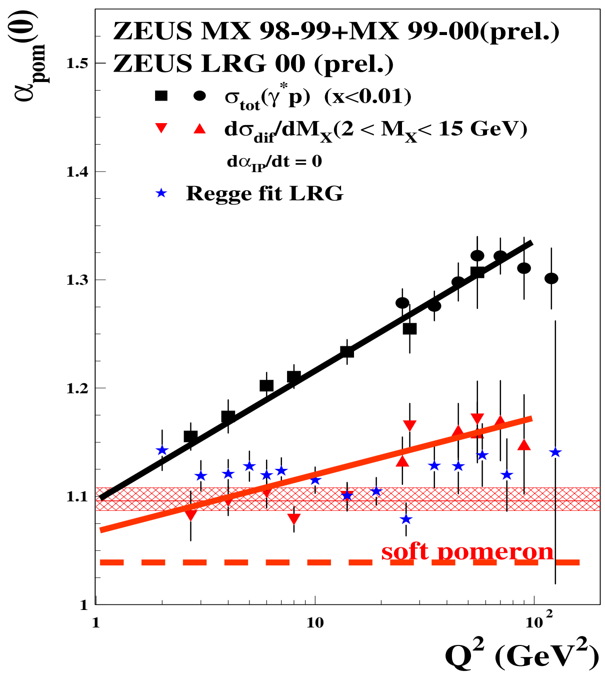
KG, "Diffraction: a New Approach," J.Phys.G26:716-720,2000 e-Print Archive: **hep-ph/0001092**

Brend Loehr@smallx-2007



$\alpha_P(0)$-1

$(\varepsilon_q+\lambda)/2$



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

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

Diffractive to ND ratio flat in x and Q2 for fixed ξ

α' versus ε

$$\frac{d^2\sigma(s,M^2,t)}{dM^2dt} = \left[\frac{\sigma_0^{pp}}{16\pi}\sigma_0^{\mathcal{P}p}\right]\frac{s^{2\epsilon}}{N(s)}\frac{1}{(M^2)^{1+\epsilon}}e^{bt} \overset{s\to\infty}{\longrightarrow} \left[2\alpha' e^{\frac{\epsilon b_0}{\alpha'}}\sigma_0^{\mathcal{P}p}\right]\underbrace{\frac{\ln s^{2\epsilon}}{(M^2)^{1+\epsilon}}e^{bt}}_{b=b_0+2\alpha'\ln\frac{s}{M^2}}$$

$$\sigma_{sd} \overset{s\to\infty}{\longrightarrow} \sigma_0^{\mathcal{P}p}\, e^{\frac{\epsilon}{2\alpha'}b_0}\, s^{\epsilon}\, \frac{\sum_{n=1}^{\infty}\frac{(\ln s^{\epsilon})^n}{n\, n!}}{\sum_{n=1}^{\infty}\frac{(\ln s^{2\epsilon})^n_{\alpha'}}{n\, n!}} = 2\sigma_0^{\mathcal{P}p}\, e^{\frac{\epsilon}{2\alpha'}b_0} \Rightarrow \sigma_0^{pp}$$

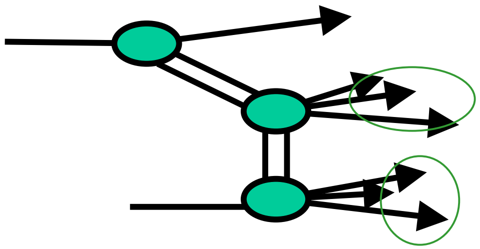
← Constant set to σ_o^{pp}

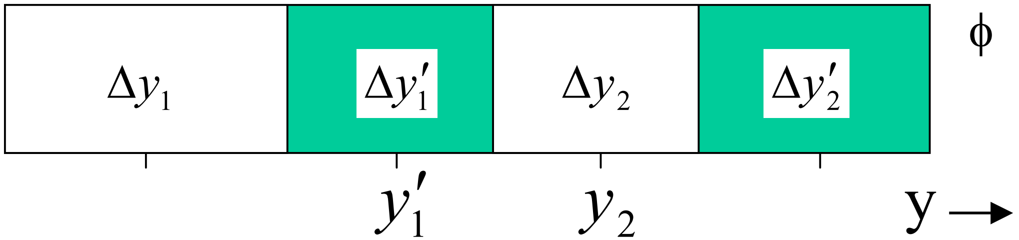
$$\sigma_0^{Pp} = \kappa\sigma_0^{pp} \Rightarrow 2\kappa\exp\left(\frac{\varepsilon b_o^{sd}}{2\alpha'}\right) = 1 \qquad b_o^{sd} = \frac{R_p^2}{2} = \frac{1}{2m_\pi^2}$$

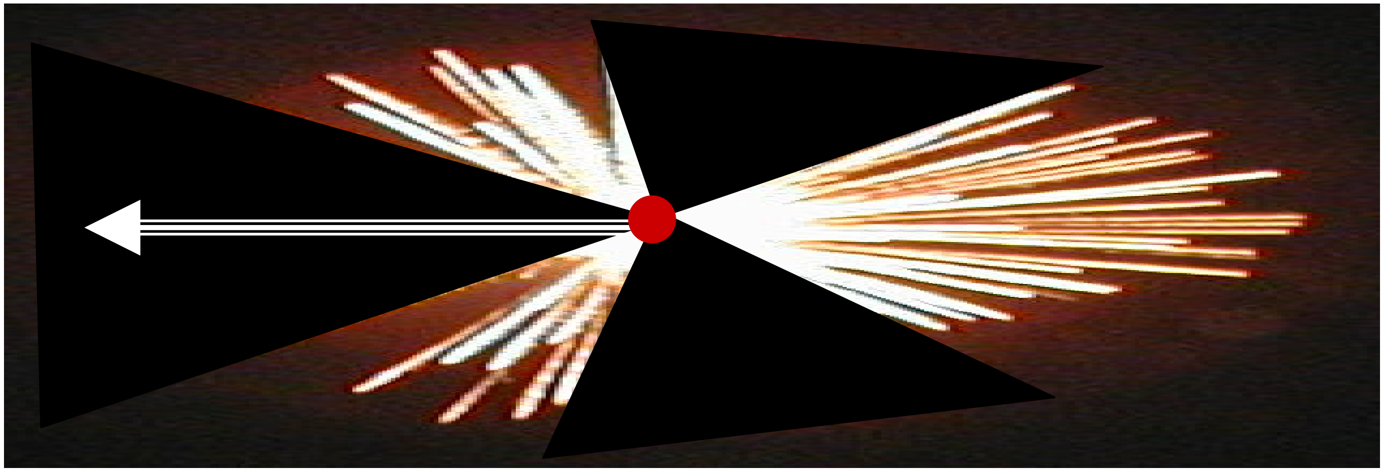
$$\alpha' = -\varepsilon\frac{1/4m_\pi^2}{4\ \ln(2\kappa)} = 0.25\ \text{GeV}^{-2}\ (\text{using } \varepsilon = 0.08) \Rightarrow \frac{\alpha'}{\varepsilon} = 3.14 = \pi\ !$$

Multigap Diffraction

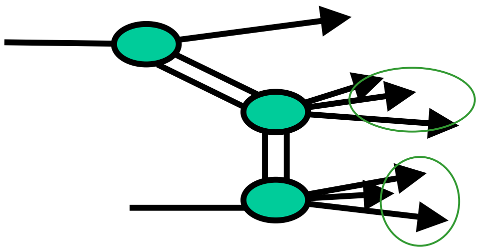
(KG, hep-ph/0205141)







Multigap Cross Sections



Δy_1	$\Delta y'_1$	Δy_2	$\Delta y'_2$

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

color factor

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

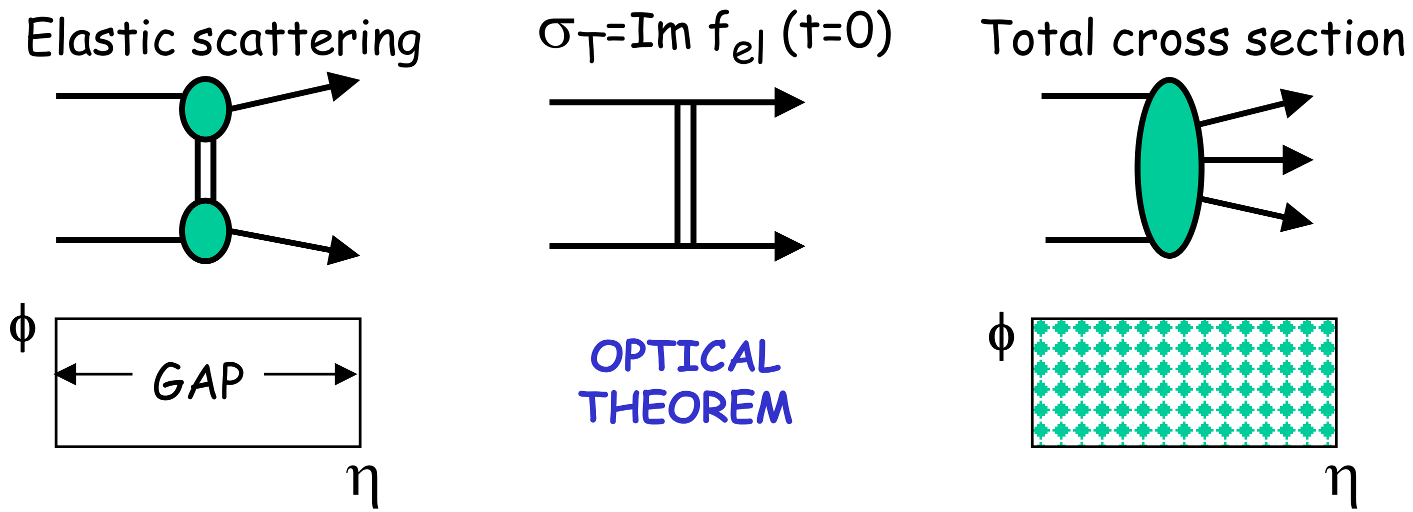
Gap probability

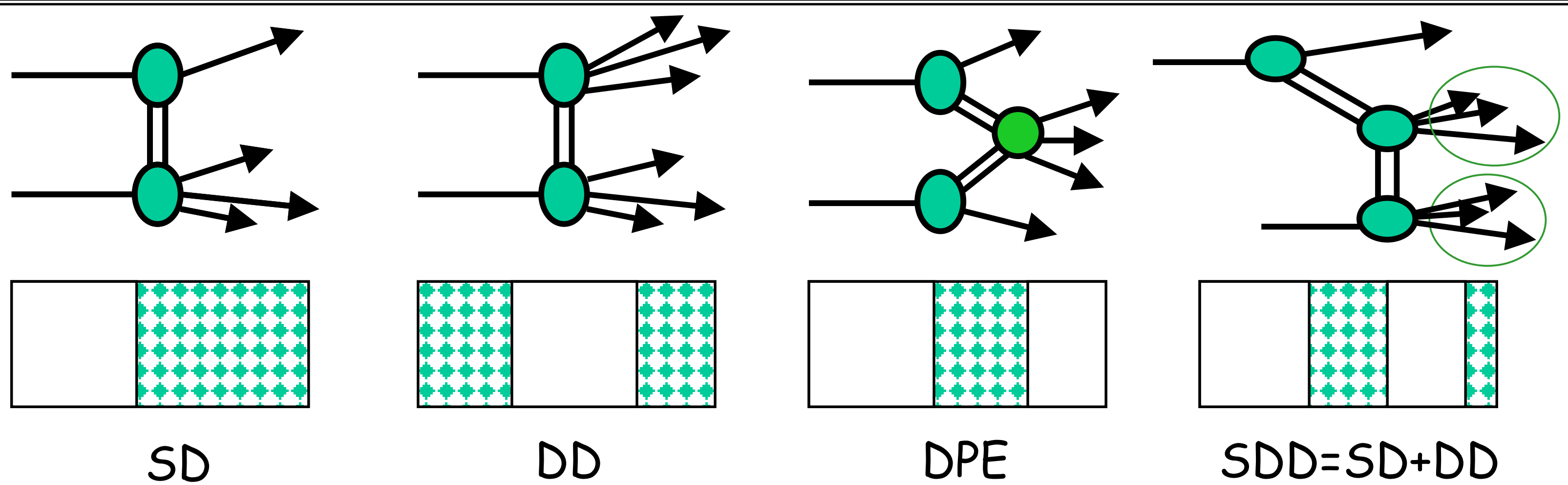
$$\int_{\Delta y, t} \sim s^{2\varepsilon} / \ln s$$

Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

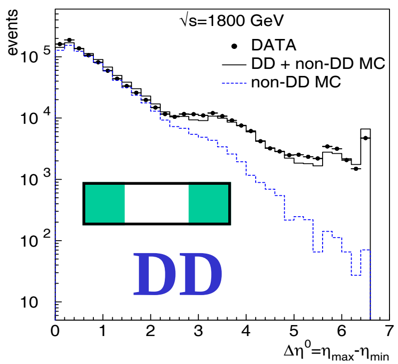
Diffractive Studies @ CDF

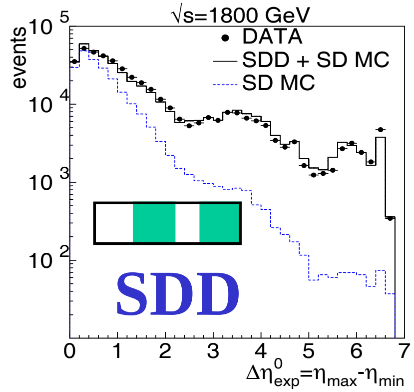


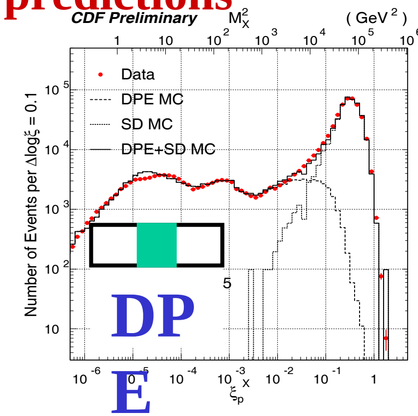


Central and Two-Gap CDF Results

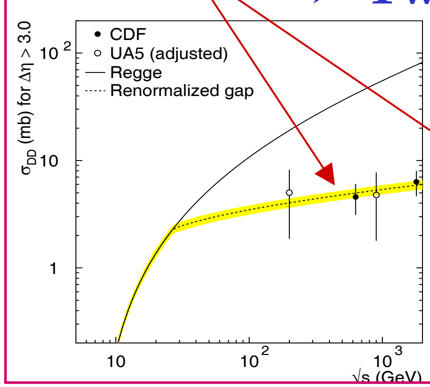
Agreement with renormalized Regge predictions

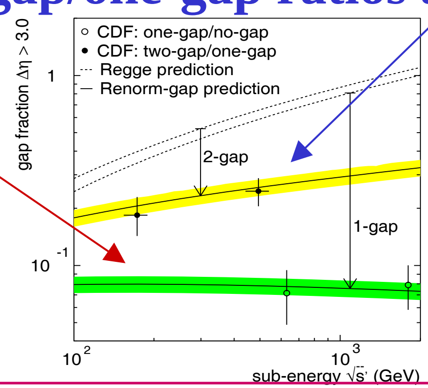


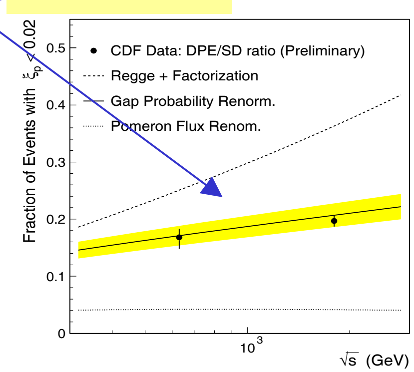




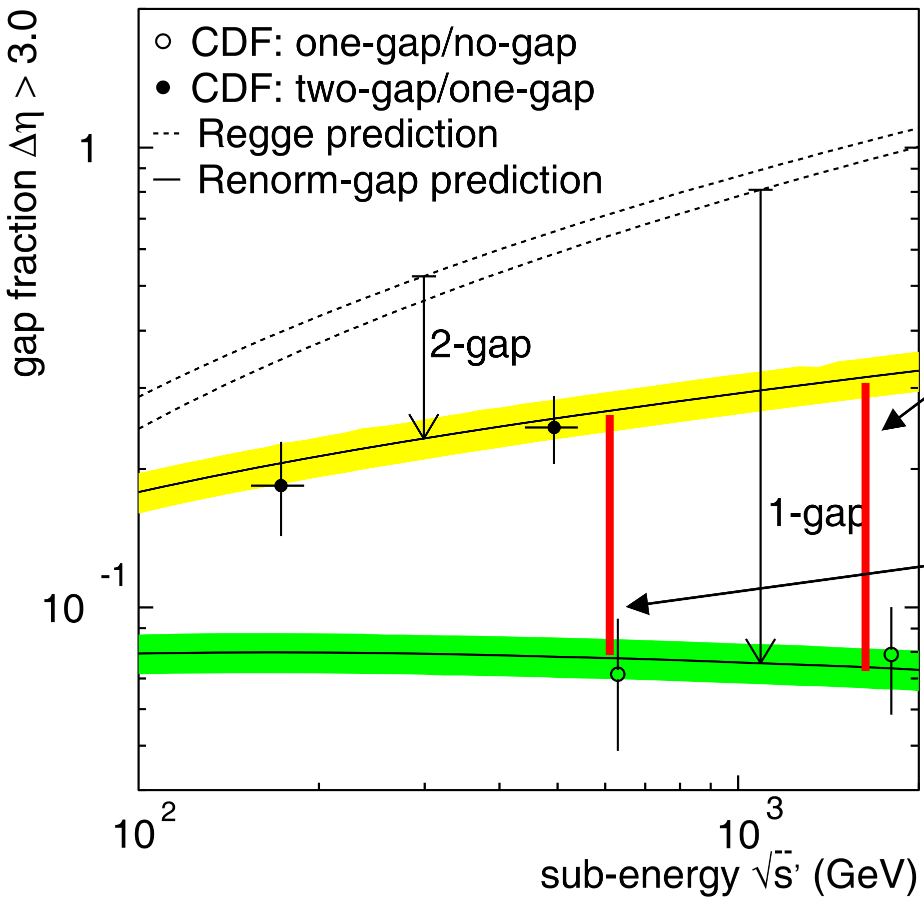
- **One-gap cross sections are suppressed**
- **Two-gap/one-gap ratios are $\approx \kappa = 0.17$**

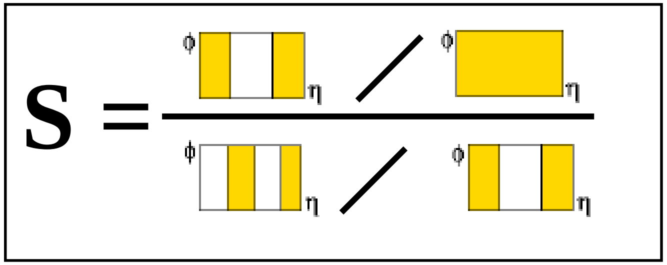






Gap Survival Probability





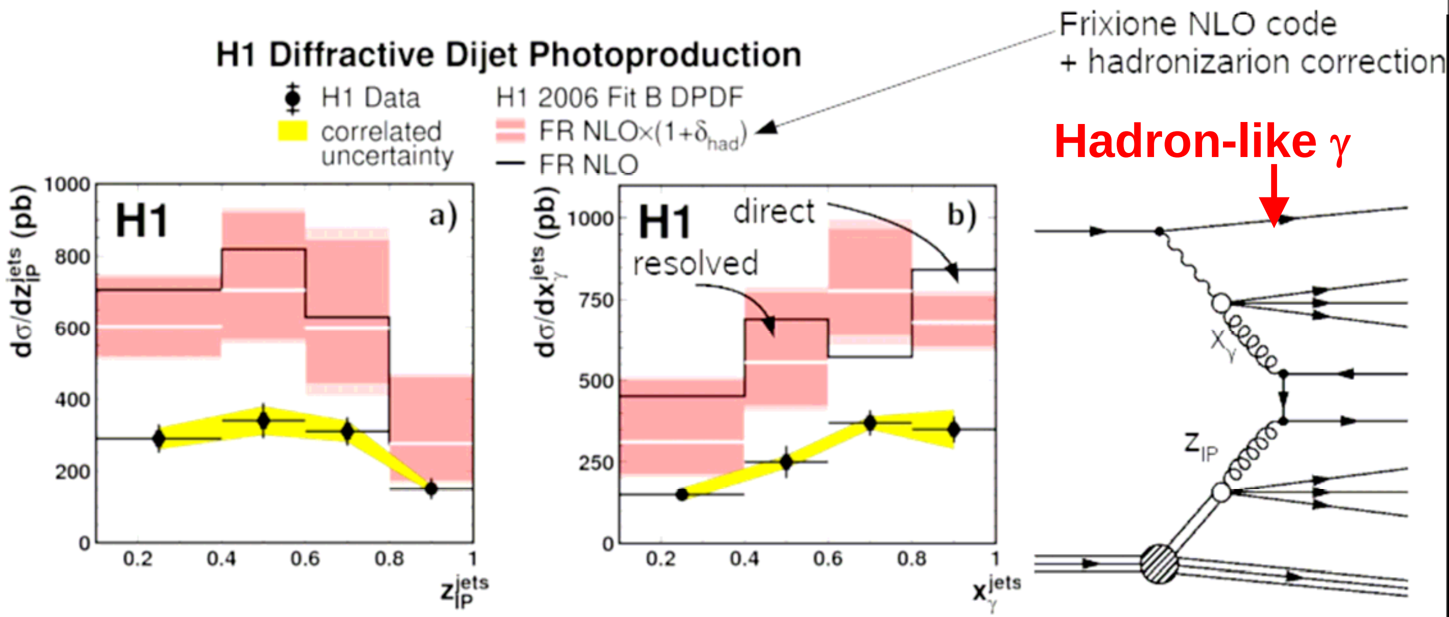
$$S^{1-\text{gap}/0-\text{gap}}_{2-\text{gap}/1-\text{gap}}(1800\ \text{GeV}) \approx 0.23$$

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

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

Dijets in γp at HERA: the puzzle (?)

slide imported from diffractive group experimental summary
of the HERA/LHC Workshop of March 14, 2007



- large violation of naive factorization observed
- factorization breaking occurs in direct and resolved processes

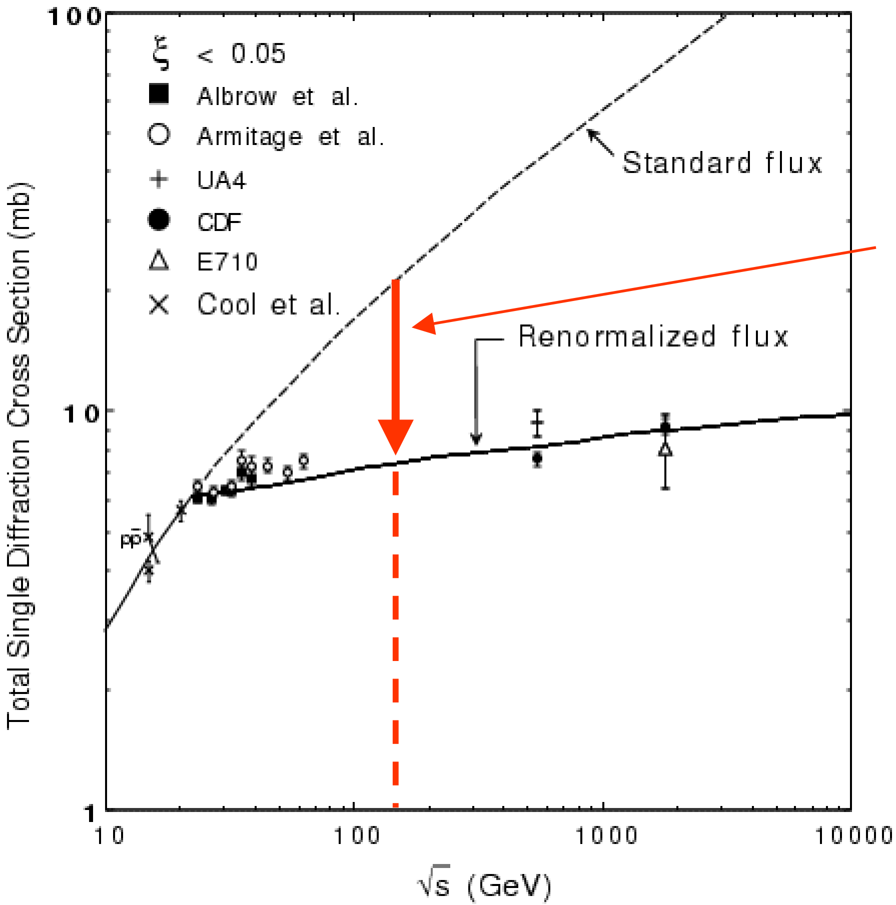
QCD factorisation not OK

Unexpected, not understood

Matthias Mozer, HERA-LHC 2007 12

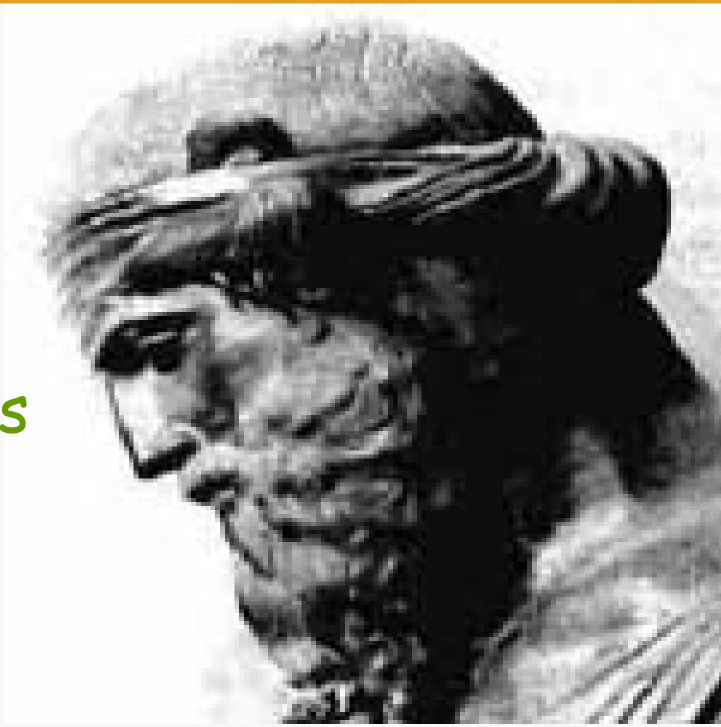
Dijets in γp at HERA: the expectation

K. Goulianos, POS (DIFF2006) 055 (p. 8)



Factor Of ~3 suppression
expected at W~200 GeV
(just as in pp collisions)
for both direct and resolved components

Conclusion



<u>Use:</u>

- M^2 - scaling
- Non-suppressed 2-gap to 1-gap ratios
- Renormalization

<u>Build:</u>

- QCD theory of diffraction