Diffractive x-sections and event final states at the LHC

Expanded talk presenter at DIFFRACTION DAY 7 May 2010 CERN



Konstantin Goulianos

The Rockefeller University

CDF ➔ PHENO ➔ CMS

http://physics.rockefeller.edu/



Forward physics @ LHC workshop

27-29 May 2010 Elba

OUTLINE

Describe a phenomenology based on pre-LHC results and use it to:

- make predictions for LHC
- suggest measurements to confirm / modify parameters
- suggest scheme to be implemented in MC simulations
- propose method to measure luminosity

Current MC generators: unreliable for extrapolations to LHC

- MC tuning ➔ based on multi-parameter tuning of ill-defined event topologies
- Solution: use nested x-sections

Contents

- define diffractive x-section event topologies
  ➔ nested diffractive gaps
- describe in terms of proton pdf''s and QCD color factors
- normalize to guarantee unitarity ➔ renormalization model

REMARKS

- **MC generators inadequate:**

  ➔ e.g. PYTHIA and PHOJET predictions of diffractive processes disagree with each other and with data.

- **Diffractive factorization at HERA? Breakdown observed in, e.g.**

  Vector mesons: σ vs. W, b-slopes of t-distributions

  Dijets: E_T^{jet} dependence, resolved vs. direct components, . ..

- **RENORM model: describes both p(pbar)-p and $\gamma(\gamma^*)$–p**

- **Luminosity measurement: requires a known x-section**

  ➔ suggest SD – well defined and slowly varying

p-p Interactions

Non-diffractive:

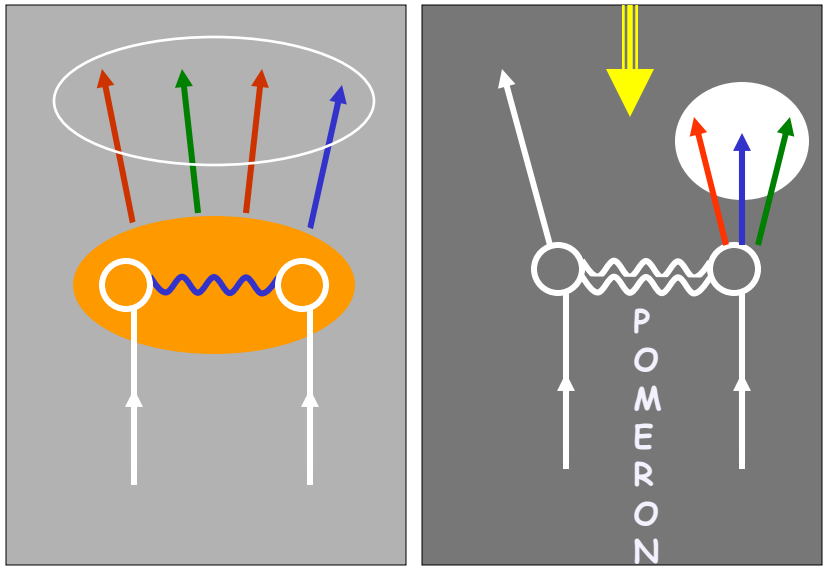
Color-exchange

Diffractive:

Colorless exchange carrying vacuum quantum numbers

rapidity gap

Incident hadrons acquire color and break apart



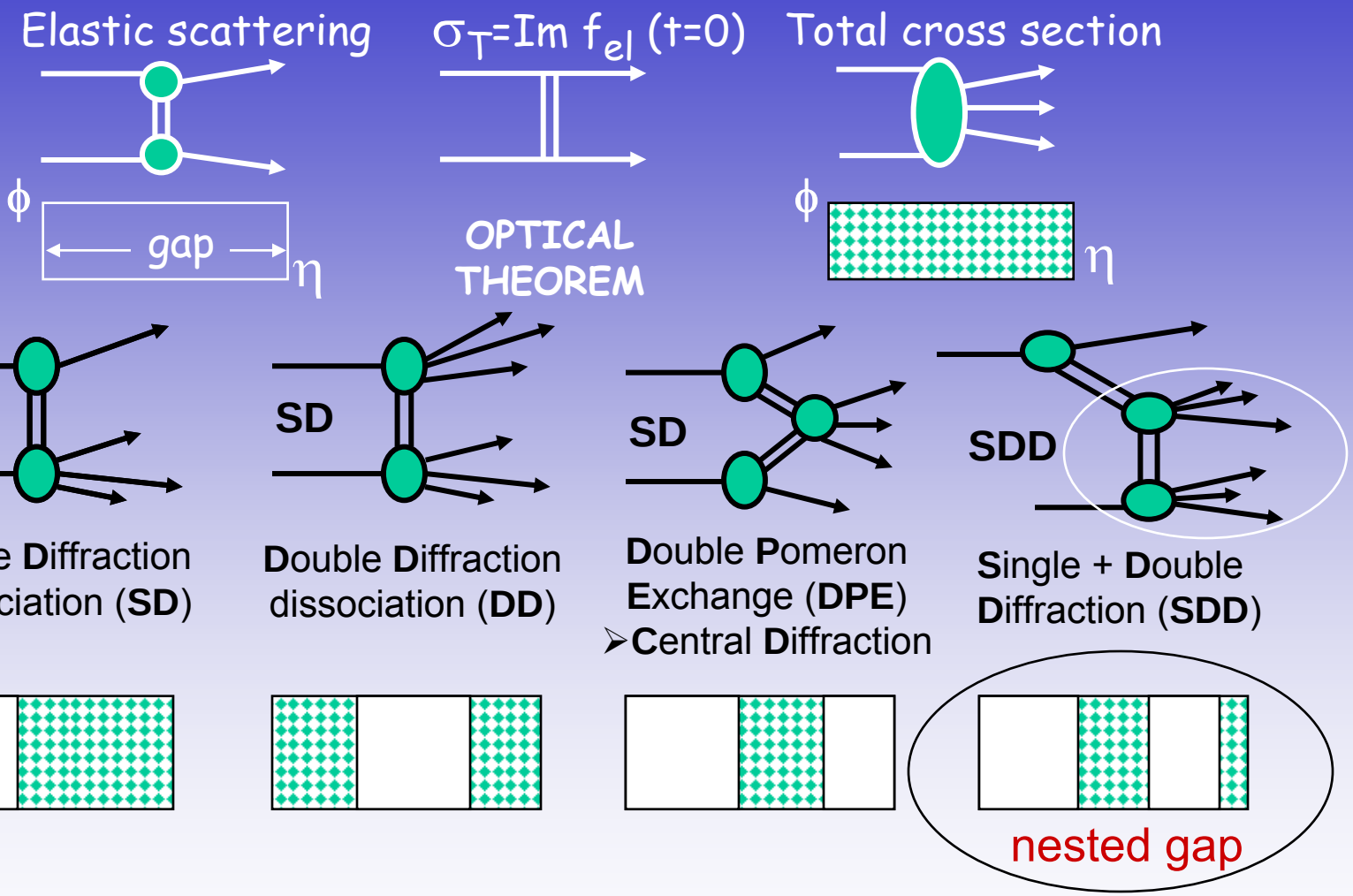
Incident hadrons retain their quantum numbers remaining colorless

CONFINEMENT

pseudo-DECONFINEMENT

Goal: understand the QCD nature of the diffractive exchange

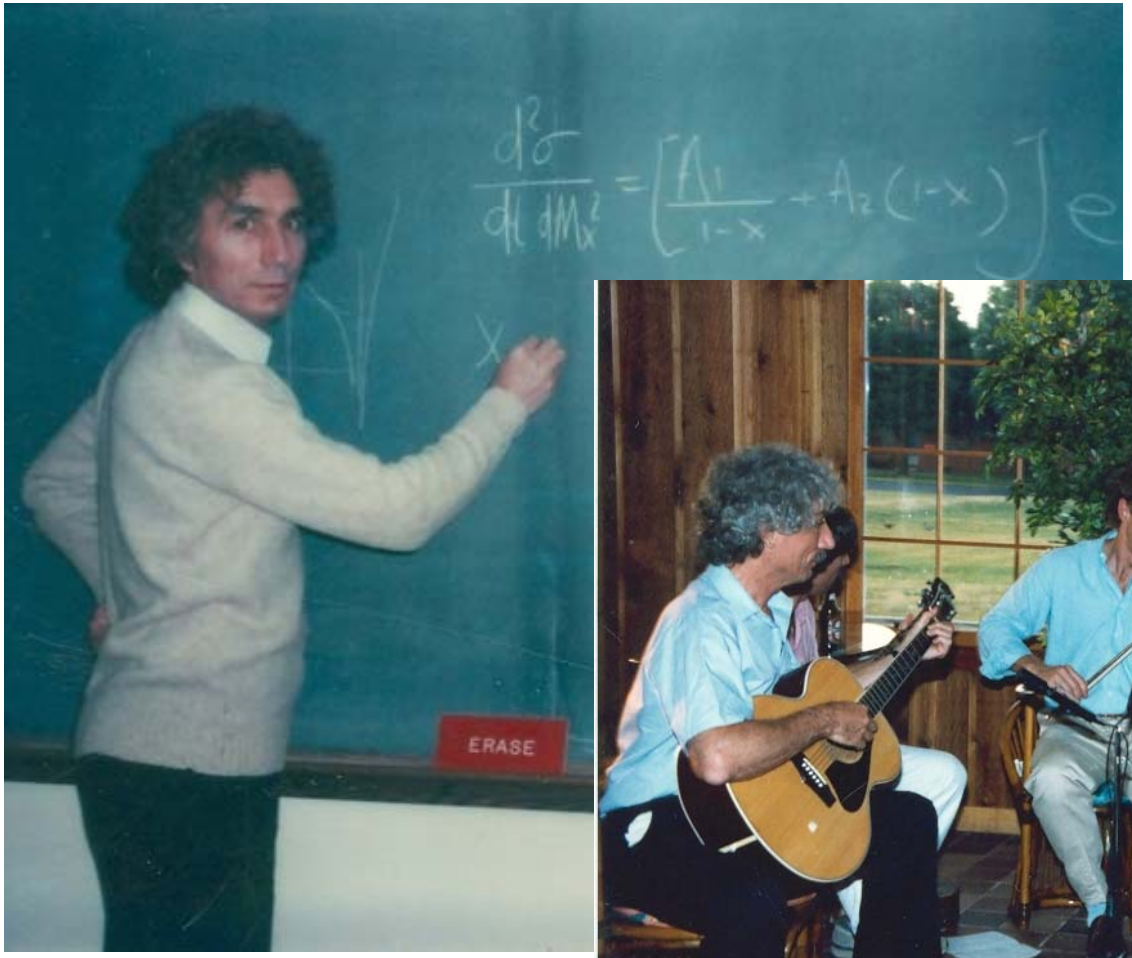
Diffractive pp($\bar{p}$p) processes @ CDF



Use nesting until no diffractive gap fits in $\sqrt{s'}$

A bit of history…

Diffraction in the70s ➔ the Pomeron unveiled!

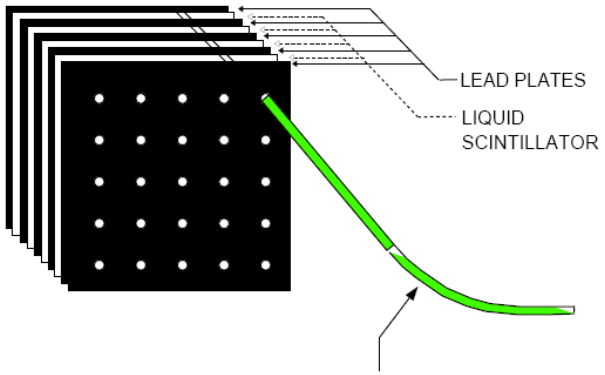


Opening night at Chez Leon - Fermilab (1989)



(right)➔Greg Snow on violin (Ph.D thesis: first observation of diffractive γ dissociation)

More history
Elba 2000



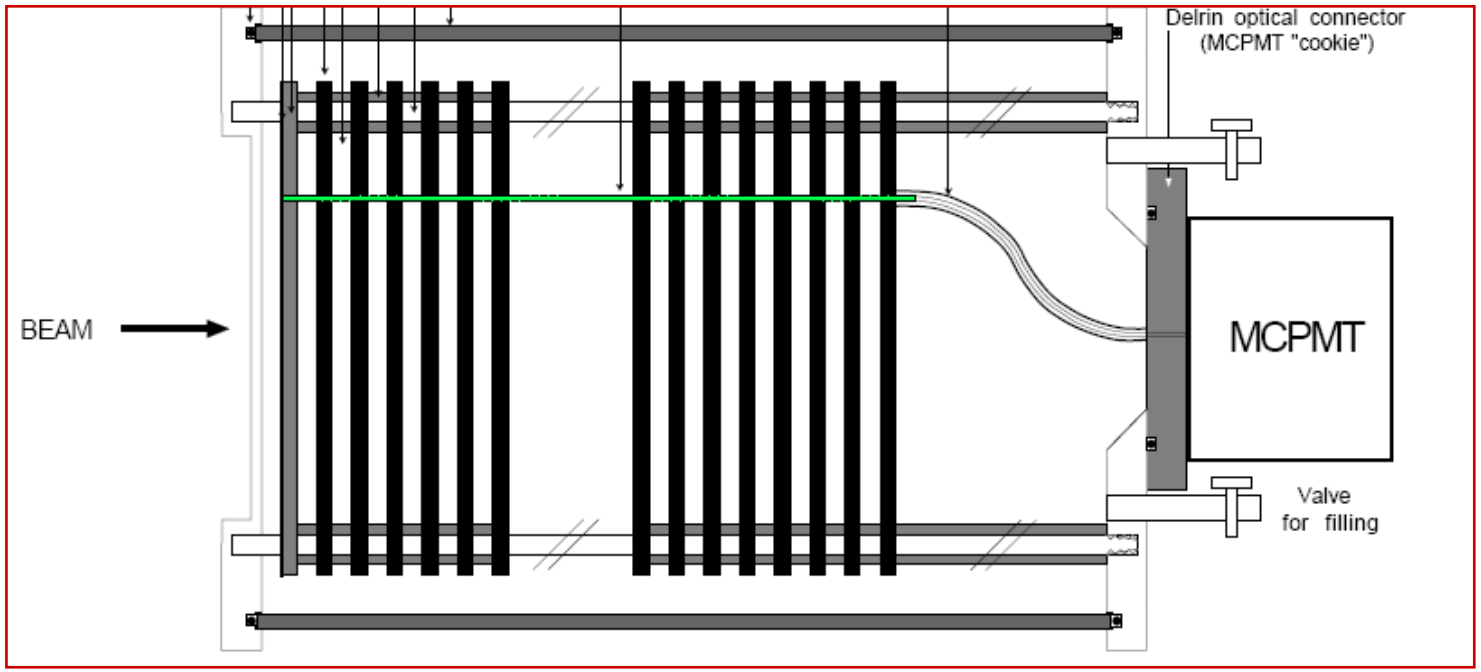
The CDF MiniPlugs

Proposed Forward Calorimeters for CDF-II

K. Goulianos [a], S. Lami [a]

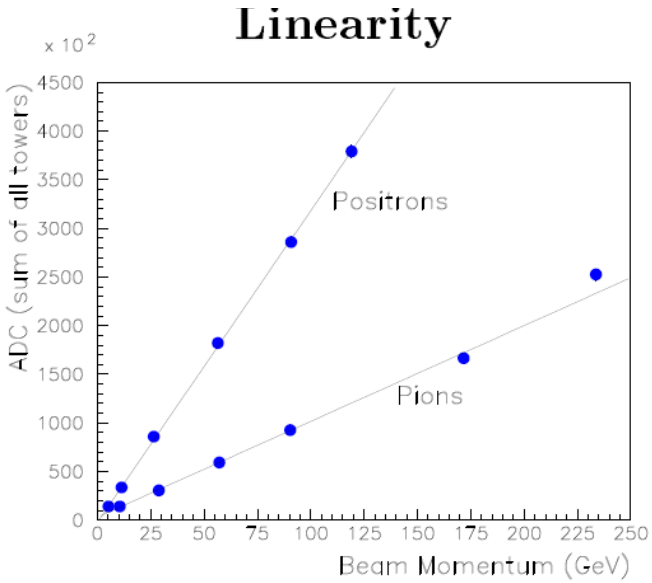
[a] *The Rockefeller University, New York, NY 10021, USA*

Presented by: K. Goulianos



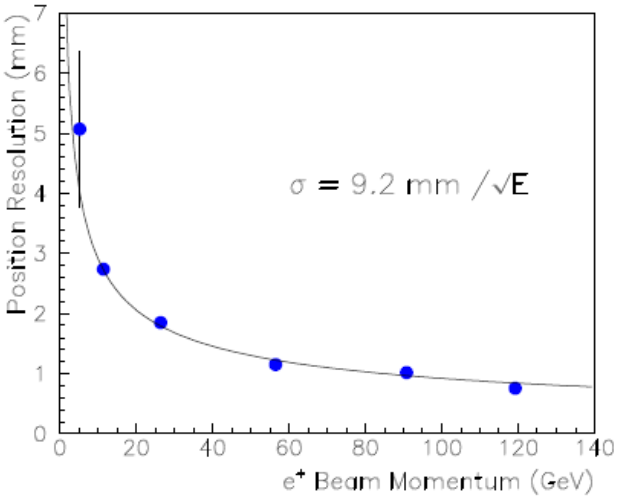
Elba 2000

The CDF MiniPlugs

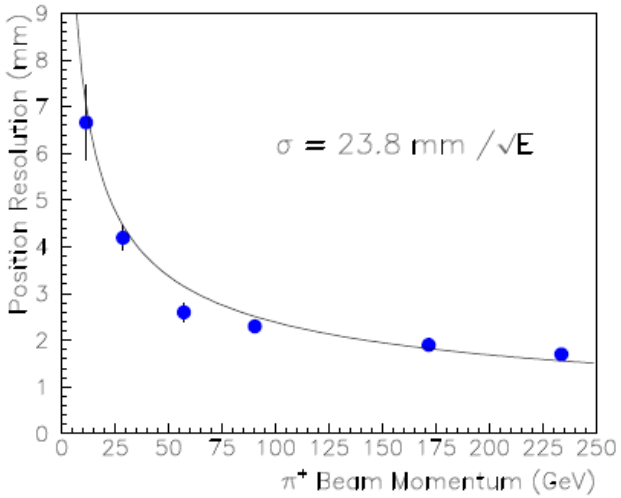


Position Resolution

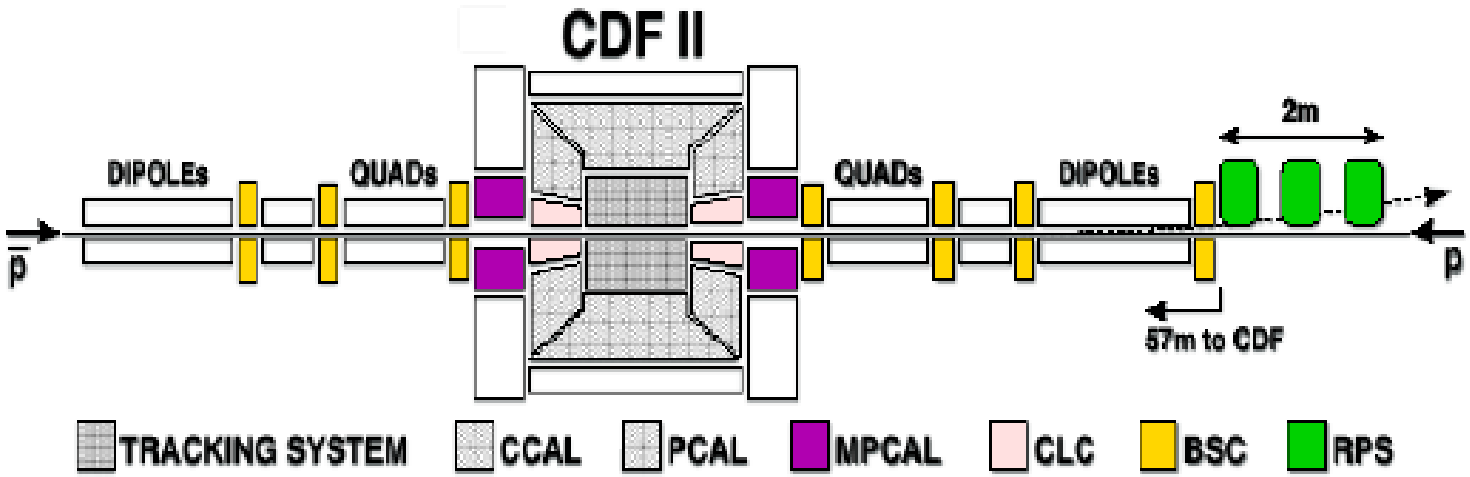
Electrons



Pions



The CDF II Detector



Tracking – Tracking Detectors $|\eta| < 2.0$

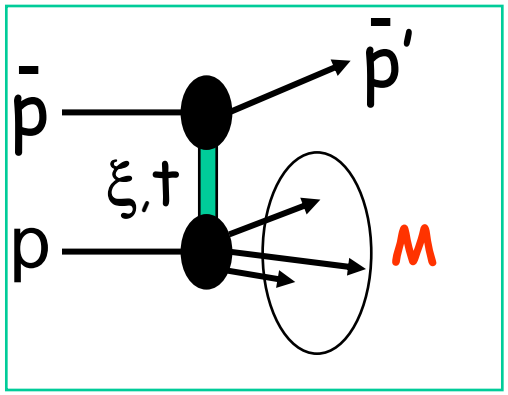
CCAL, PCAL – Calorimeters $|\eta| < 3.6$

RPS – Roman Pot Spectrometers $0.02 < \xi < 0.1$, $0 < |t| < 2\ \text{GeV}^2$

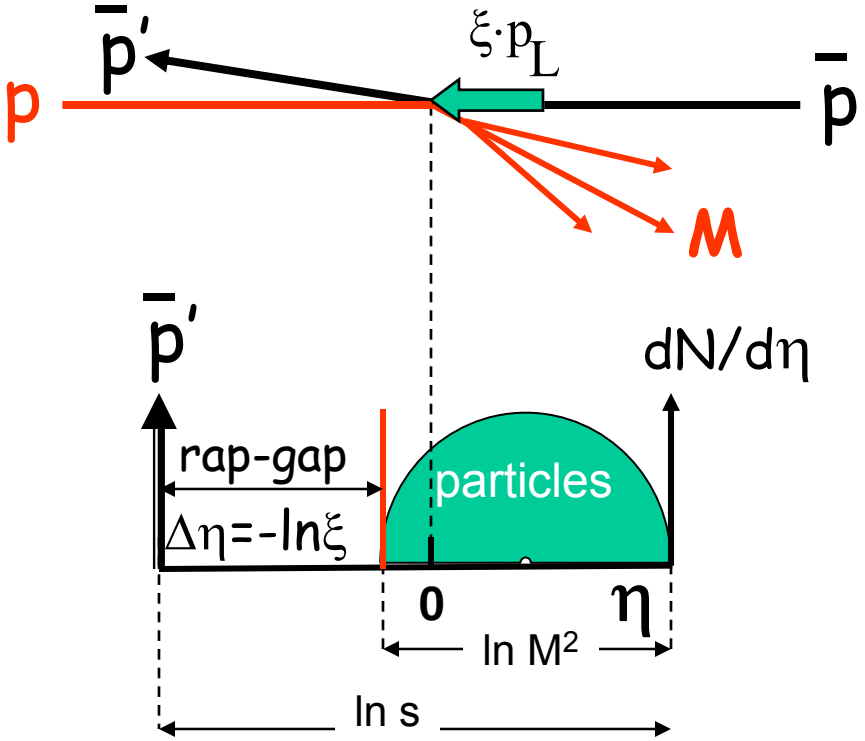
BSC – Beam Shower Counters $5.4 < |\eta| < 7.4$

MPCAL – MiniPlug Calorimeters $3.5 < |\eta| < 5.1$

Definitions



$$1 - x_L \equiv \xi = \frac{M^2}{s}$$



M² scaling: no price paid for increasing diffractive gap size

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

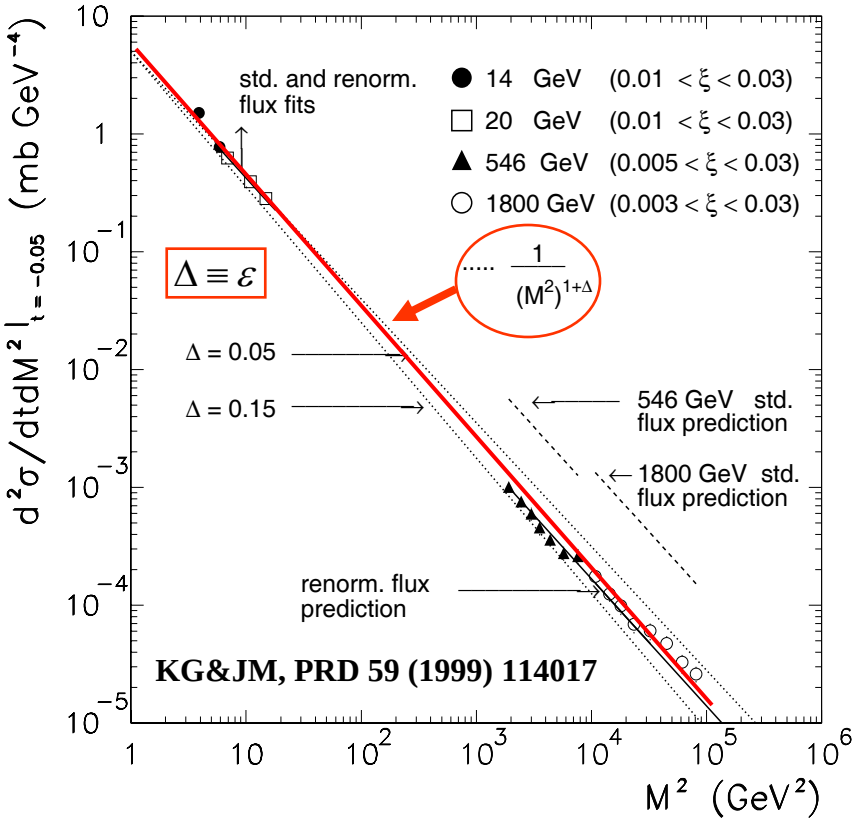
M^2 scaling

➔ $d\sigma/dM^2|_{t=-0.05}$ independent of s over 6 orders of magnitude!

Regge → data

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

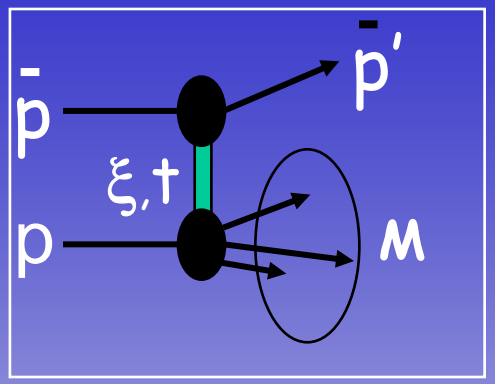
➔ Independent of s over 6 orders of magnitude in M^2 !



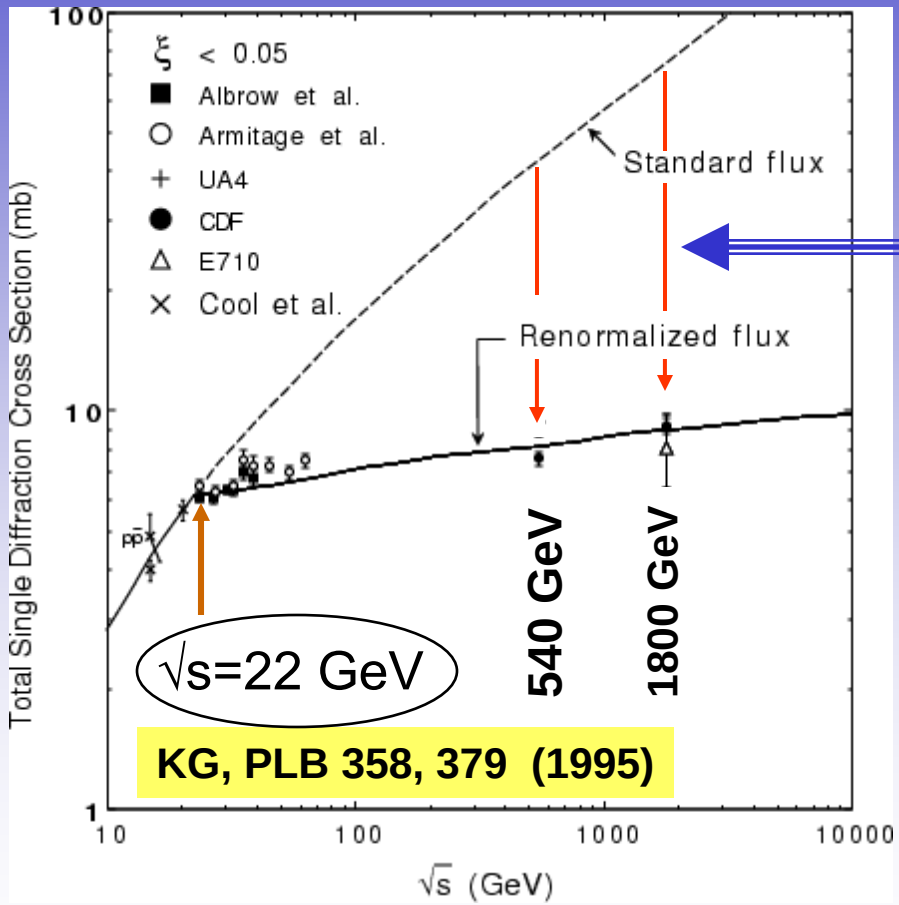
➔ factorization breaks down to ensure M^2 scaling - why?

σ^{T}_{SD} (pp & $\bar{p}p$)

➔ suppressed relative to Regge

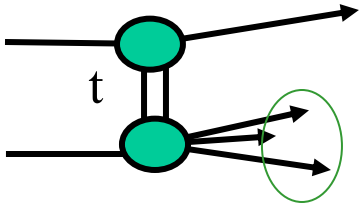


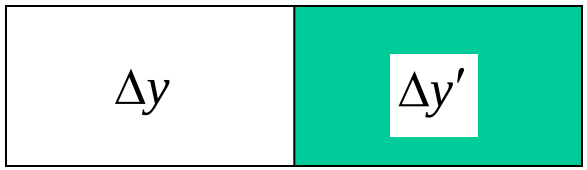
σ^{T}_{SD} mb



Factor of ~8 (~5) suppression at $\sqrt{s}$ = 1800 (540) GeV

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

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

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

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

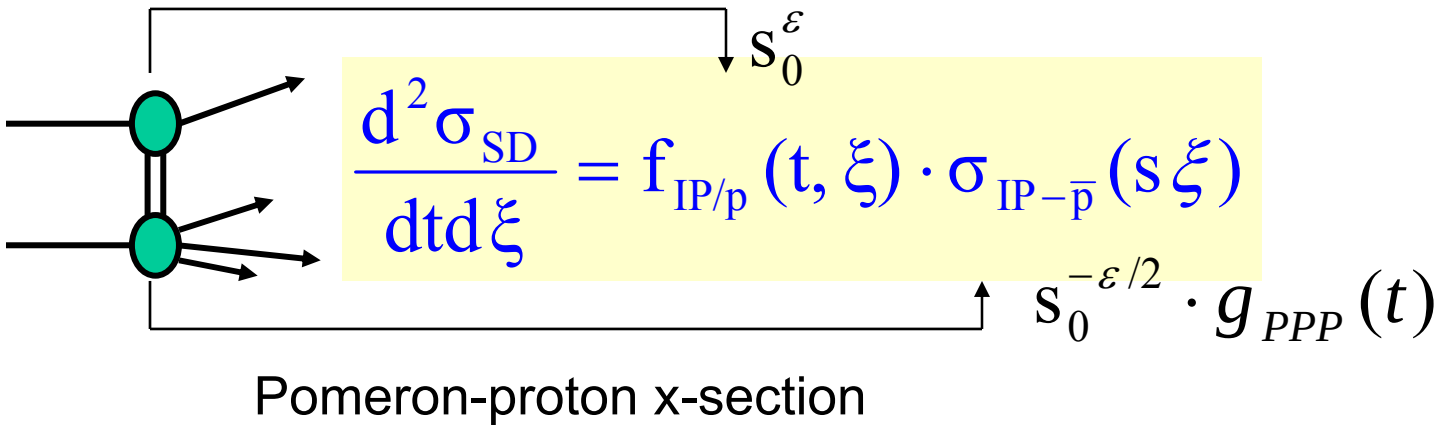
Grows slower than s^{ε}

→ Pumplin bound obeyed at all impact parameters

Unitarity and Renormalization

Pomeron flux ➔ gap probability

Set to unity – determines g_{PPP} and s_0 KG, PLB 358 (1995) 379

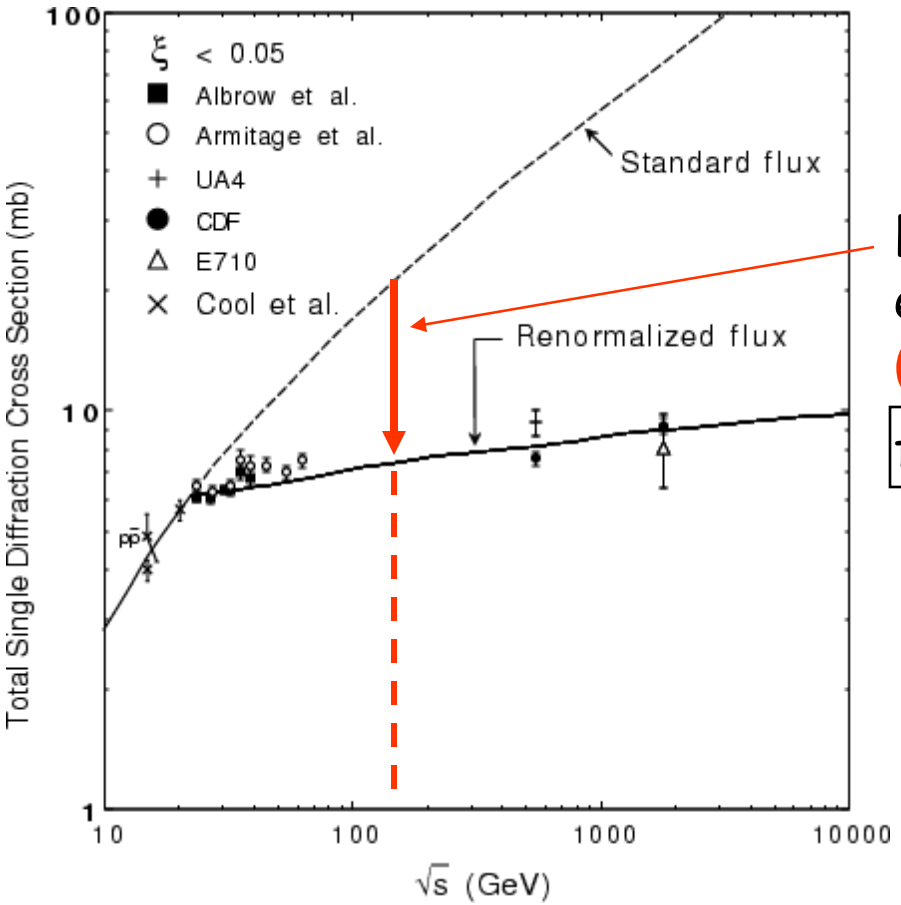


Pomeron-proton x-section

- Two free parameters: s_0 and g_{PPP}
- Obtain product $g_{PPP}\bullet s_0^{\varepsilon/2}$ from σ_{SD}
- Renormalized Pomeron flux determines s_0
- Get unique solution for g_{PPP}

Dijets in γp at HERA from RENORM

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

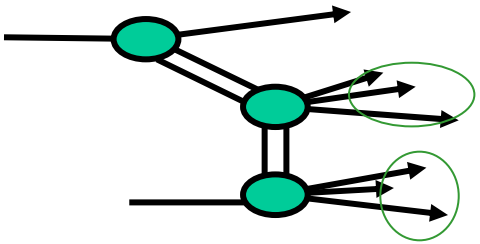


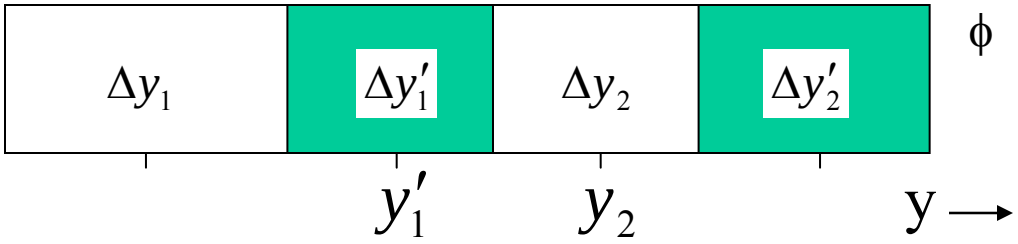
Factor of ~3 suppression expected at W~200 GeV (just as in pp collisions)

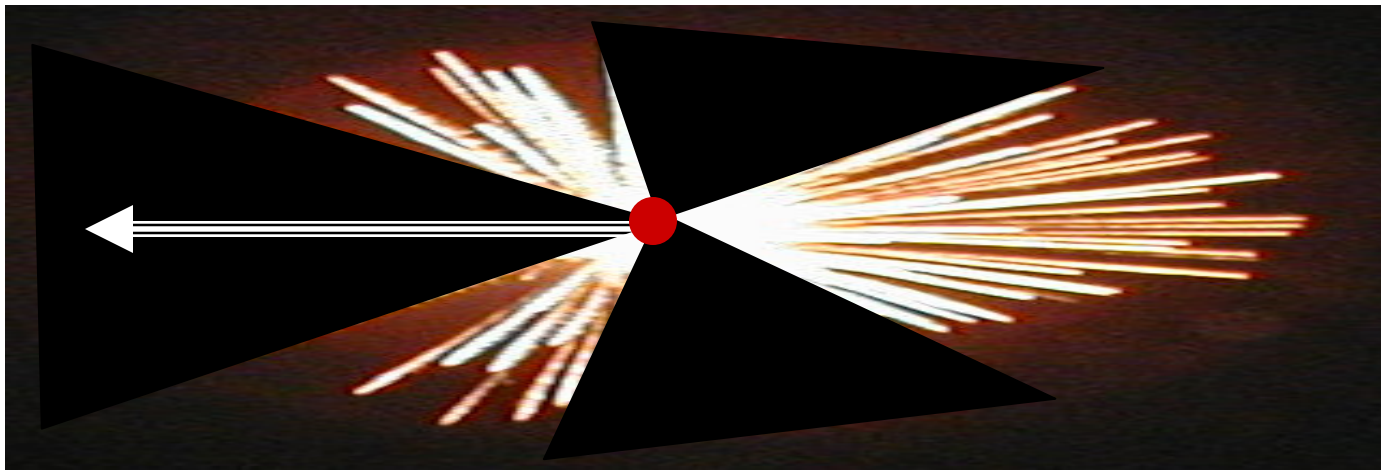
for both direct and resolved components

Multi-gap Diffraction

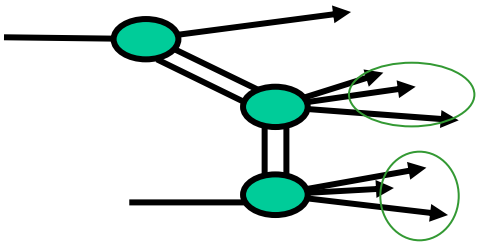
(KG, hep-ph/0205141)

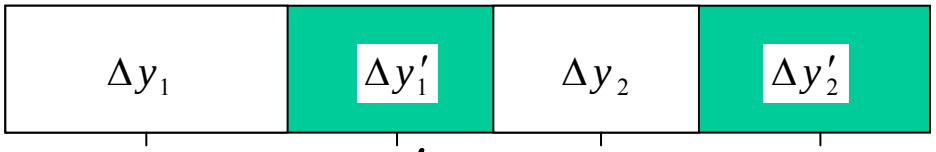






Multi-gap Cross Sections





5 independent variables $\{ t_1, \Delta y = \Delta y_1 + \Delta y_2, t_2 \}$ at y_1' and y_2

color factor

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

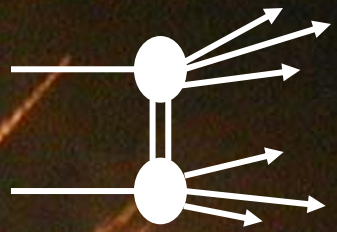
Gap probability

Sub-energy cross section (for regions with particles)

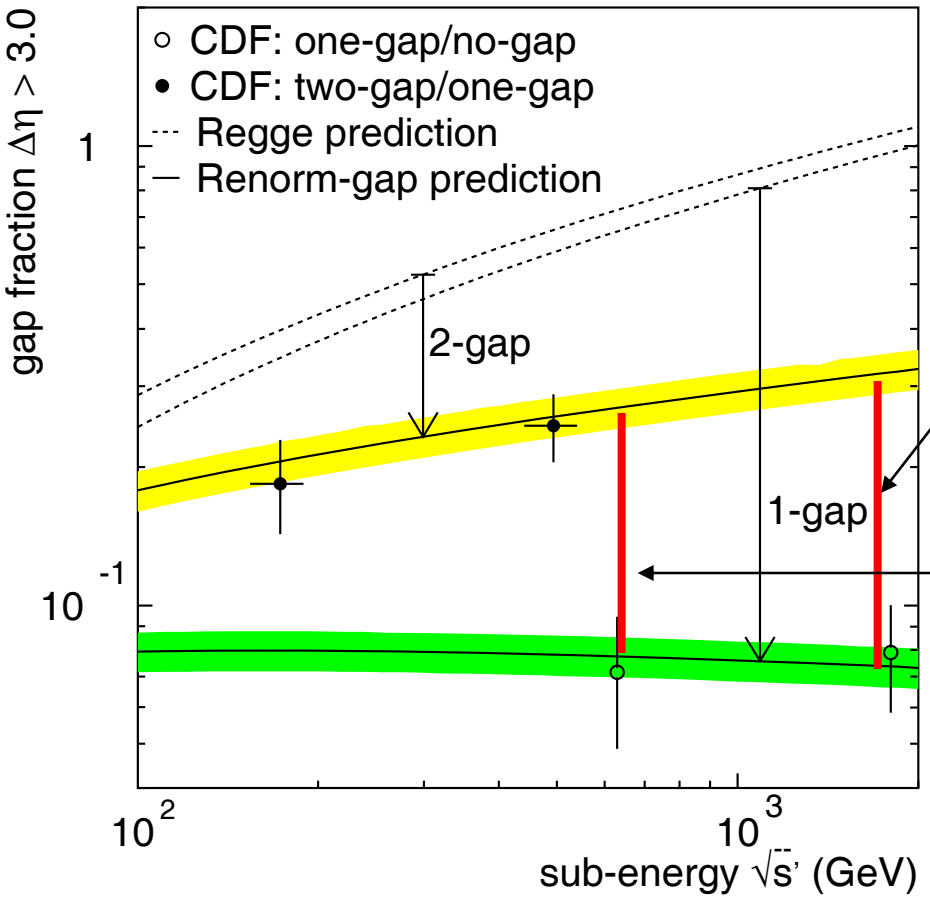
$$\int_{\Delta y, t} \sim s^{2\varepsilon} / \ln s$$

Same suppression as for single gap!

Rapidity Gaps in Fireworks



“Gap survival probability”



$$S = \frac{\phi\text{-}\eta \;/\; \phi\text{-}\eta}{\phi\text{-}\eta \;/\; \phi\text{-}\eta}$$

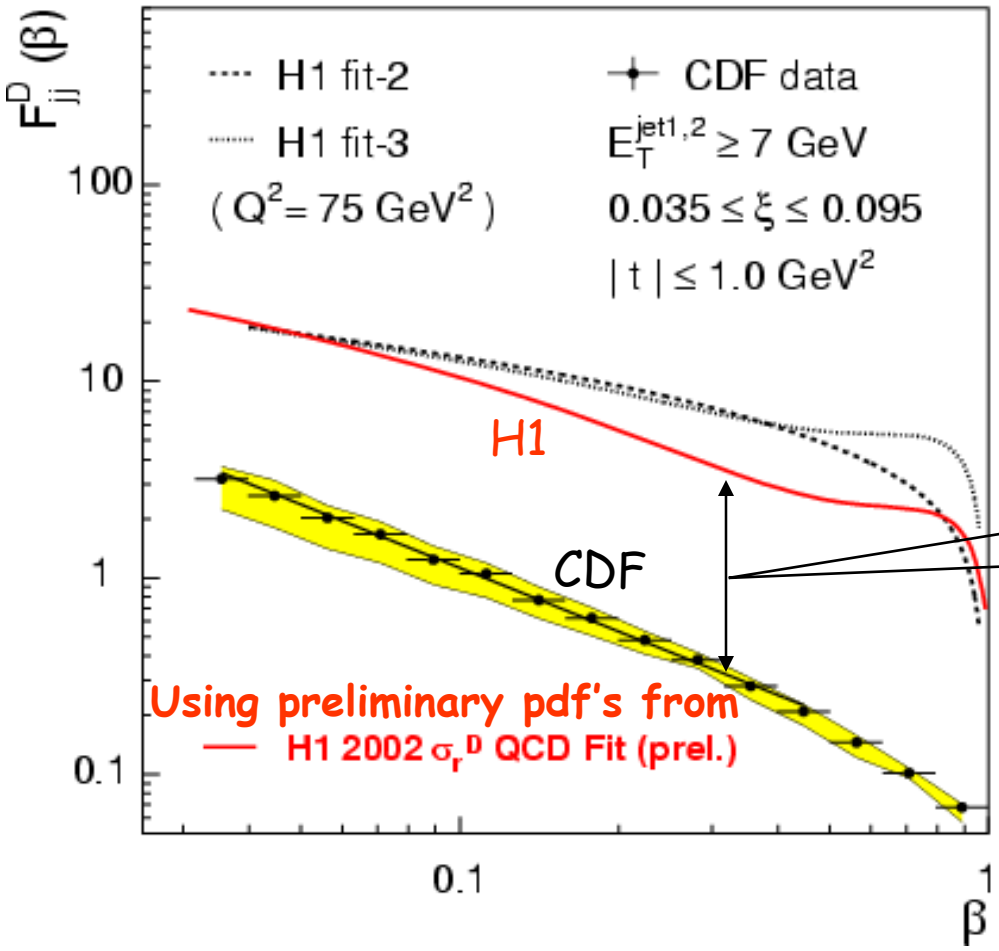
$$S^{1-\text{gap}/0-\text{gap}}_{2-\text{gap}/1-\text{gap}}(1800\ \text{GeV}) \approx 0.23$$

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

Diffractive Structure Function
➔ breakdown of QCD factorization !

Diffractive Structure Function

Breakdown of QCD factorization



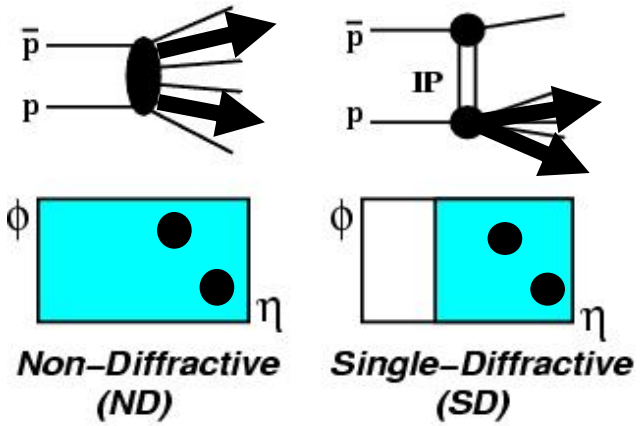
$$\bar{p}p \rightarrow \bar{p} + \text{dijet} + X$$

same suppression
as in soft diffraction – why?

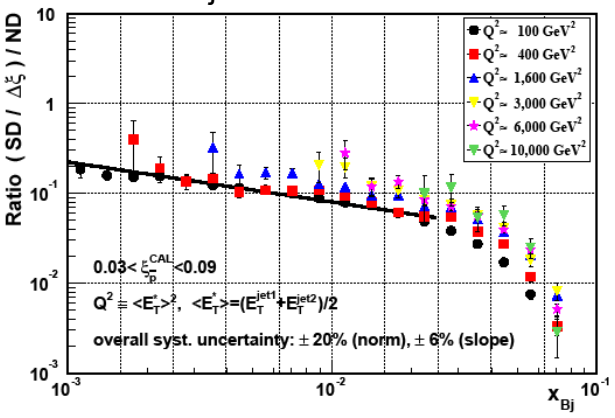
momentum fraction of parton
in "Pomeron" – note quotes

DSF from Dijets in Run II

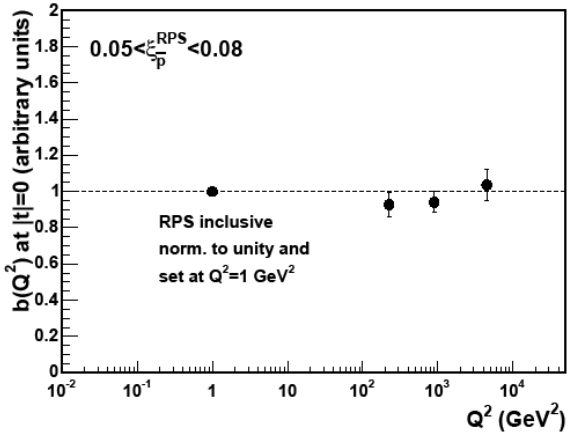
$$R(x_{Bj}) \equiv \frac{Rate_{jj}^{SD}(x_{Bj})}{Rate_{jj}^{ND}(x_{Bj})} \Rightarrow \frac{F_{jj}^{SD}(x_{Bj})}{F_{jj}^{ND}(x_{Bj})}$$



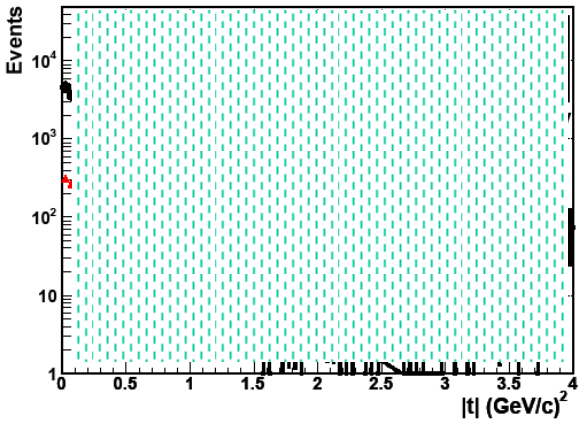
x_{Bj} - distribution



b - slope of t-distribution



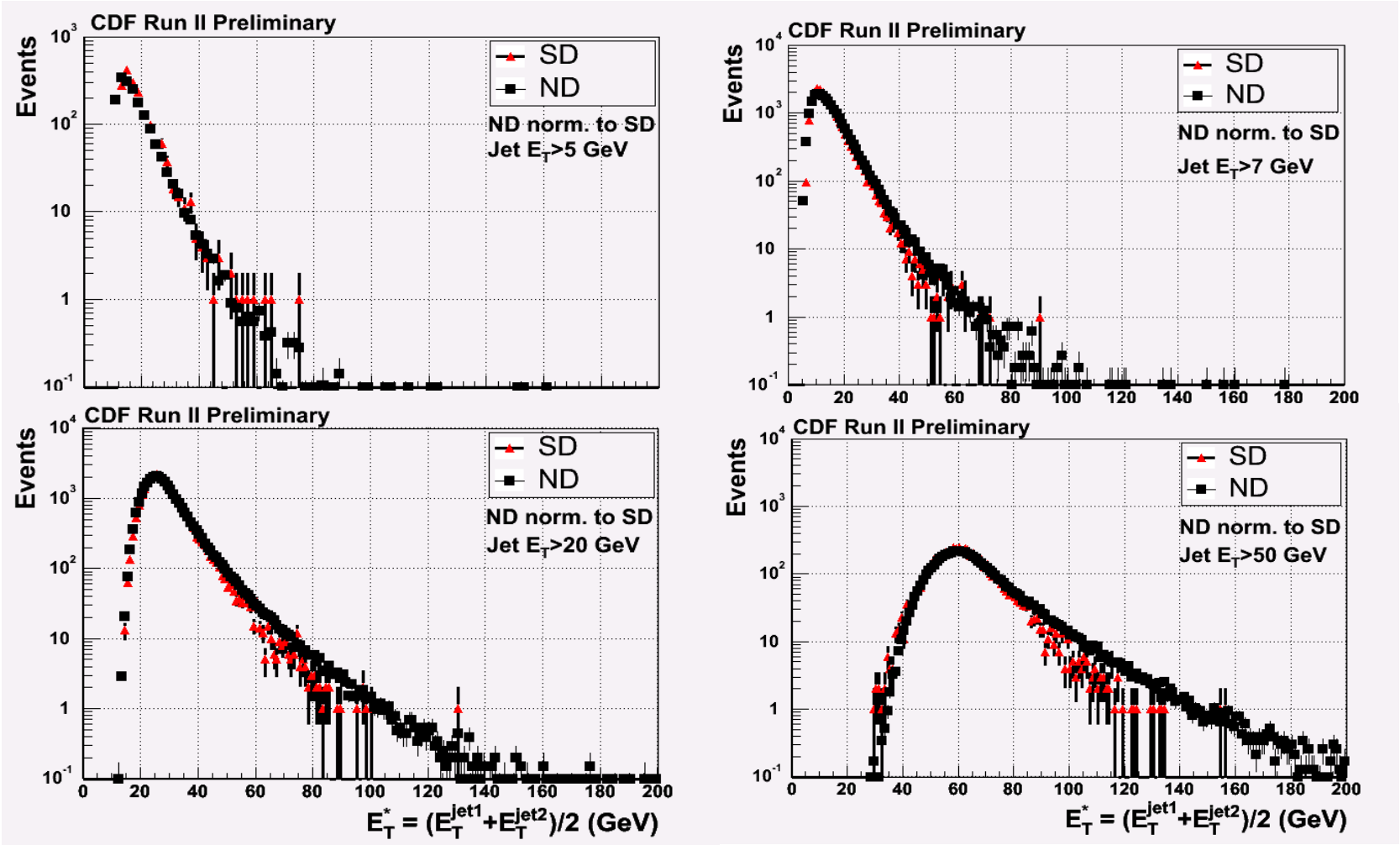
t - distribution



- The x_{Bj}-distribution of the SD/ND ratio has no strong Q^2 dependence
- the slope of the t-distribution is independent of Q^2
- the t-distribution ?????? diffraction minimum ??????

➢ all three results ➔ "first observation"

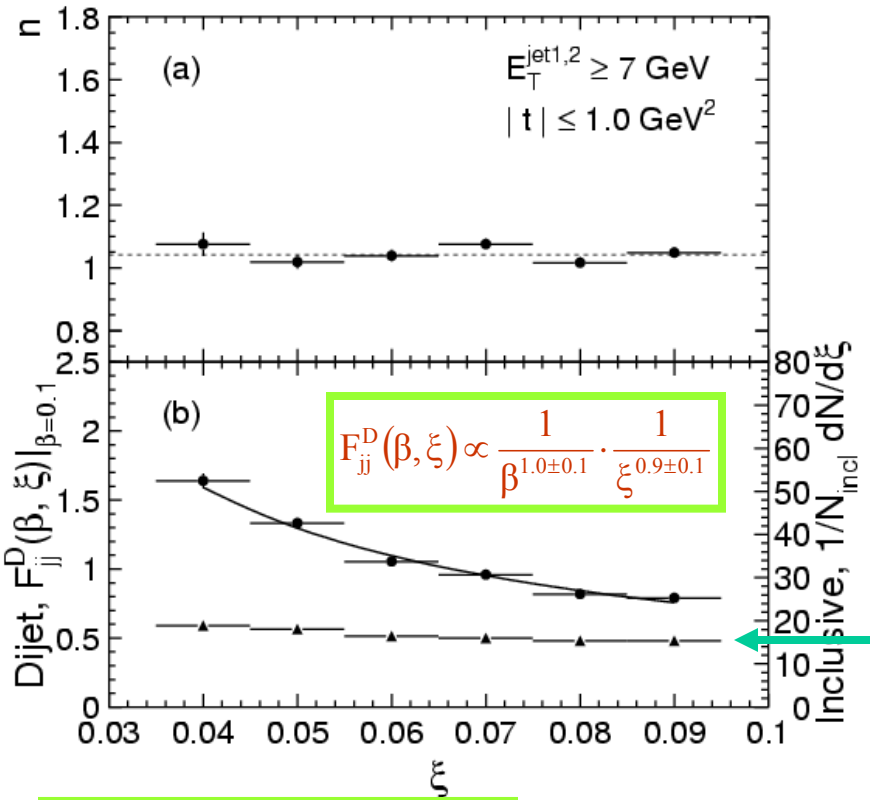
Dijet E_T distributions



➔ similar for SD and ND over 4 orders of magnitude

Kinematics

ξ & β dependence of F^D_{jj} – Run I



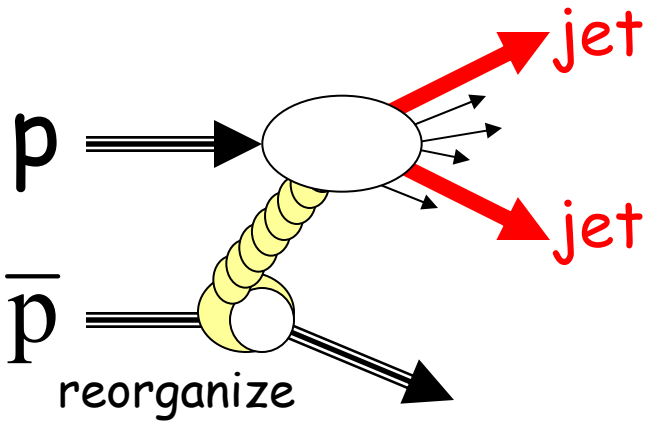
$$\frac{d\sigma_{incl}}{d\xi} \propto \text{constant}$$

$$F_{jj}^D(\beta,\xi) \sim \frac{1}{\beta} \cdot \frac{1}{\xi}$$

Pomeron dominated

hard diffraction phenomenology
➔ for your thought !

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

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

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

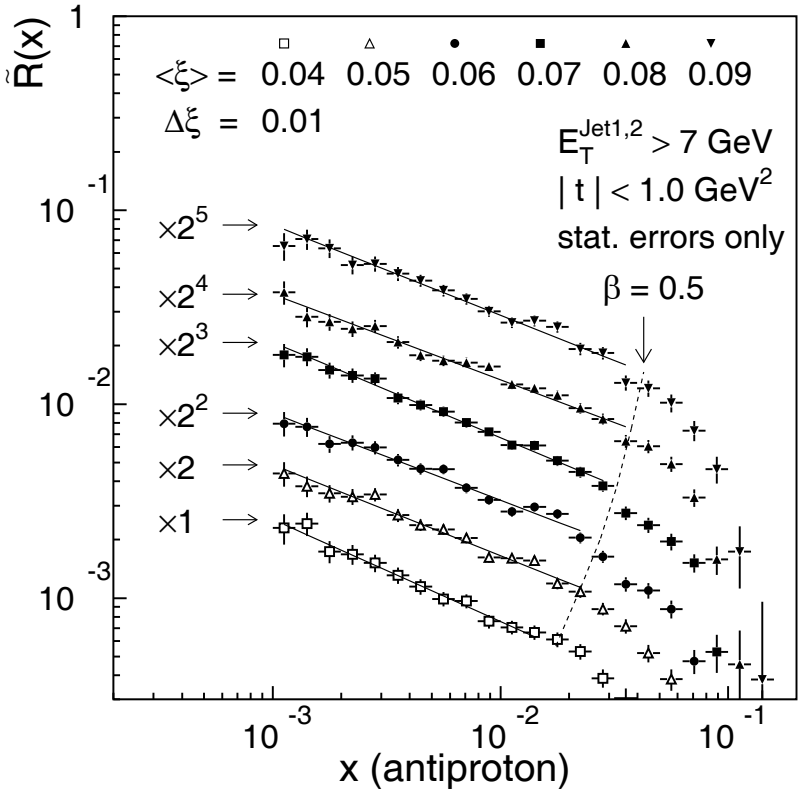
$$\text{RENORM} \Rightarrow R^{SD}_{ND}(x) = \frac{2\varepsilon}{s^{2\varepsilon}} \frac{1}{\xi^{1-\lambda(Q^2)}} \cdot x^{-(2\varepsilon)}$$

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

SD/ND dijet ratio vs. x_{Bj}@ CDF

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

CDF Run I



$0.035 < \xi < 0.095$

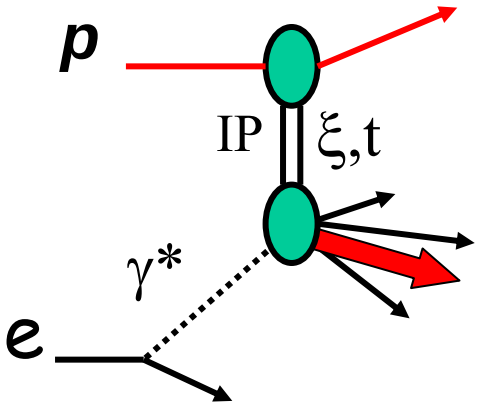
Flat ξ dependence for $\beta < 0.5$

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

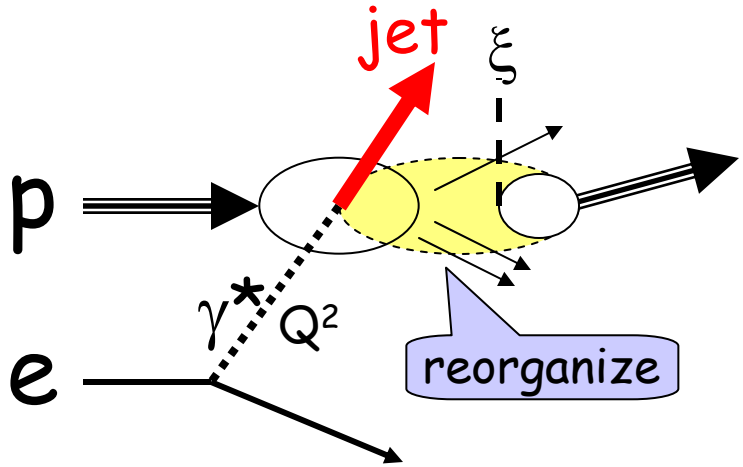
Diffractive DIS @ HERA

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

Pomeron exchange



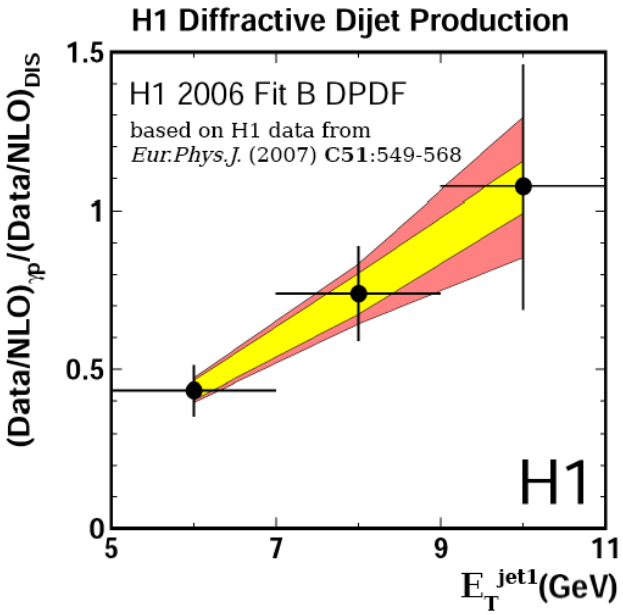
Color reorganization



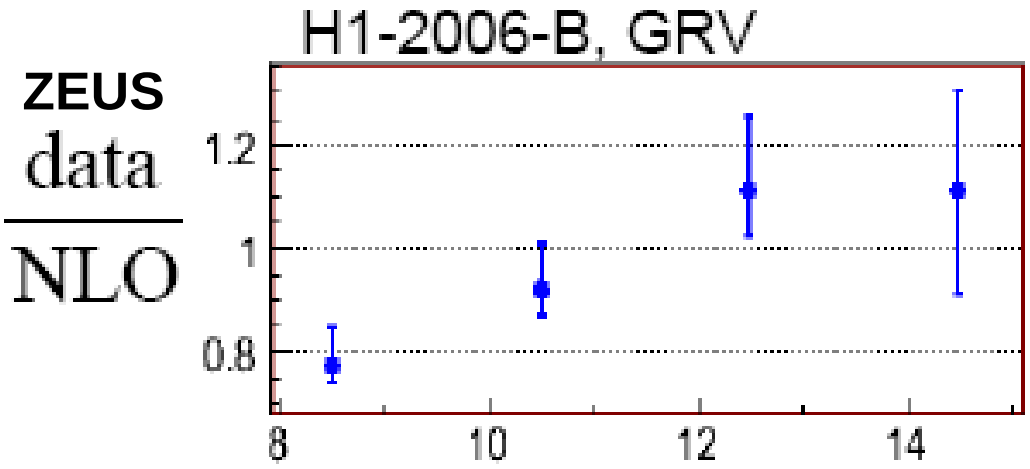
$$F_2^{D(3)}(\xi, x, Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F_2(x, Q^2)$$

Results favor color reorganization

Dijets in γp at HERA - 2008



DIS 2008 talk by W. Słomiński,

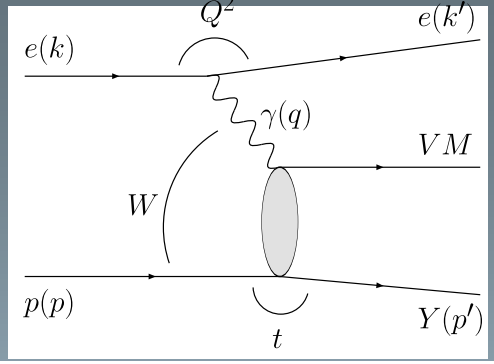


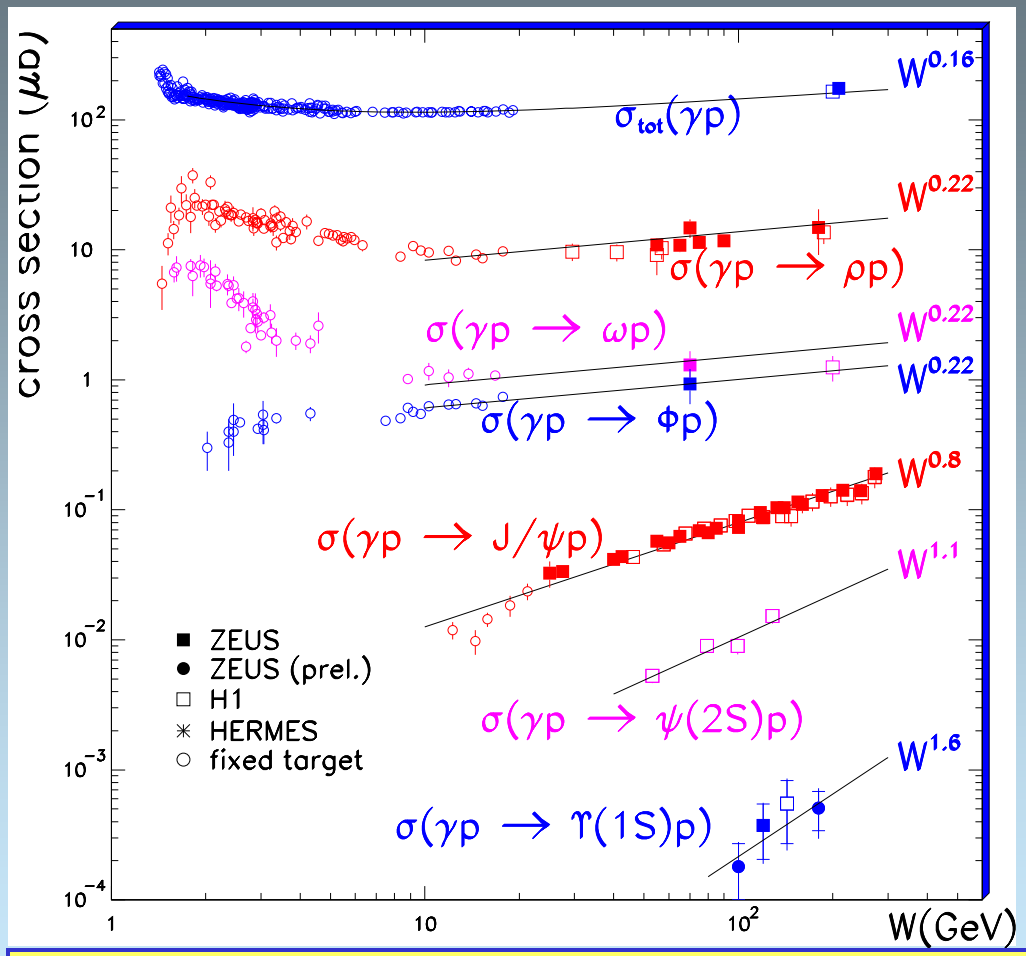
❑ 20-50 % apparent rise when E_T^{jet} 5→10 GeV

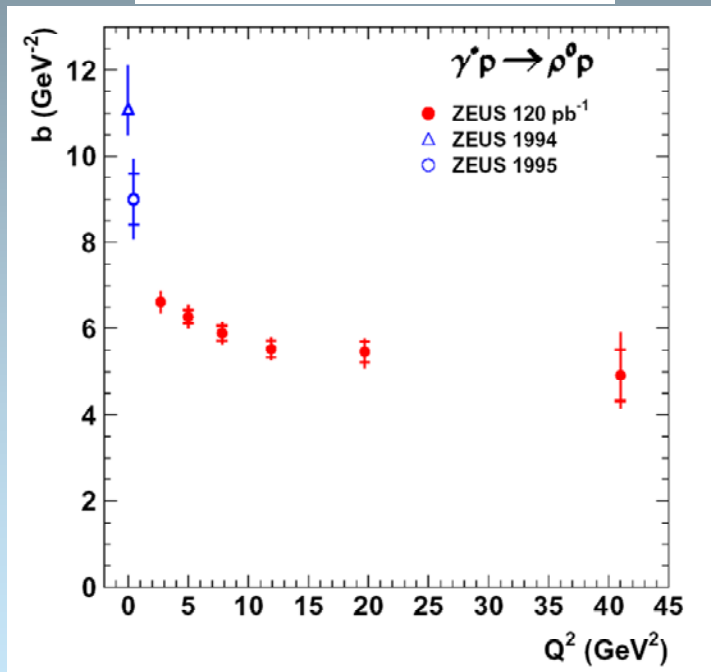
➔ due to suppression at low E_T^{jet} !!!

Vector meson production

(Pierre Marage, HERA-LHC 2008)





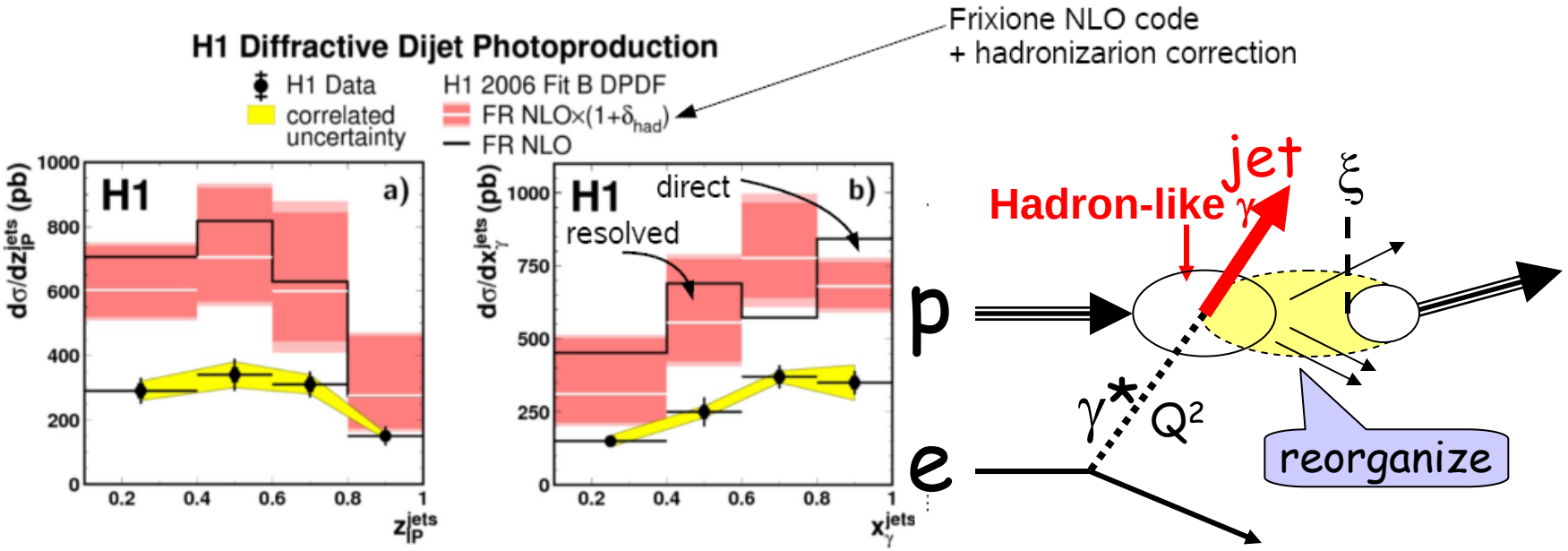


- *left* - why different σ vs. W slopes? ➔ more room for particles
- *right* - why smaller b-slope in γ*p? ➔ same reason

Dijets in γp at HERA – 2007

Dijets in γp

Direct vs. resolved



- the reorganization diagram predicts:
  - ➔ suppression at low Z_{IP}^{jets}, since larger $\Delta\eta$ is available for particles
  - ➔ same suppression for direct and resolved processes

more phenomenology

➔ for your thought, again!

σ^{SD} and ratio of α'/ε

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Pomeron intercept and slope: A QCD connection

Konstantin Goulianos

$$\frac{d^2\sigma_{sd}(s,M^2,t)}{dM^2dt} = \left[\frac{\sigma_\circ}{16\pi}\sigma_\circ^{\mathbb{P}p}\right]\frac{s^{2\epsilon}}{N(s)}\frac{1}{(M^2)^{1+\epsilon}}e^{bt}$$

$$\overset{s\to\infty}{\Rightarrow}\left[2\alpha' e^{(\epsilon b_0)/\alpha'}\sigma_\circ^{\mathbb{P}p}\right]\frac{\ln s^{2\epsilon}}{(M^2)^{1+\epsilon}}e^{bt}$$

$$\sigma^{\text{tot}}_{pp/\bar{p}p} = \sigma_\circ \cdot e^{\epsilon\Delta\eta}.$$

$$\sigma^{\infty}_{sd} = 2\sigma_\circ^{\mathbb{P}p}\exp\left[\frac{\epsilon b_\circ}{2\alpha'}\right] = \sigma_\circ^{pp}$$

$$\sigma_\circ^{\mathbb{P}p} = \beta_{\mathbb{P}pp}(0)\cdot g(t) = \kappa\sigma_\circ^{pp}$$

$$\kappa = \frac{f_g^\infty}{N_c^2-1} + \frac{f_q^\infty}{N_c}$$

$$b_\circ = R_p^2/2 = 1/(2m_\pi^2).$$

$$r = \frac{\alpha'}{\epsilon} = -[16m_\pi^2\ln(2\kappa)]^{-1}$$

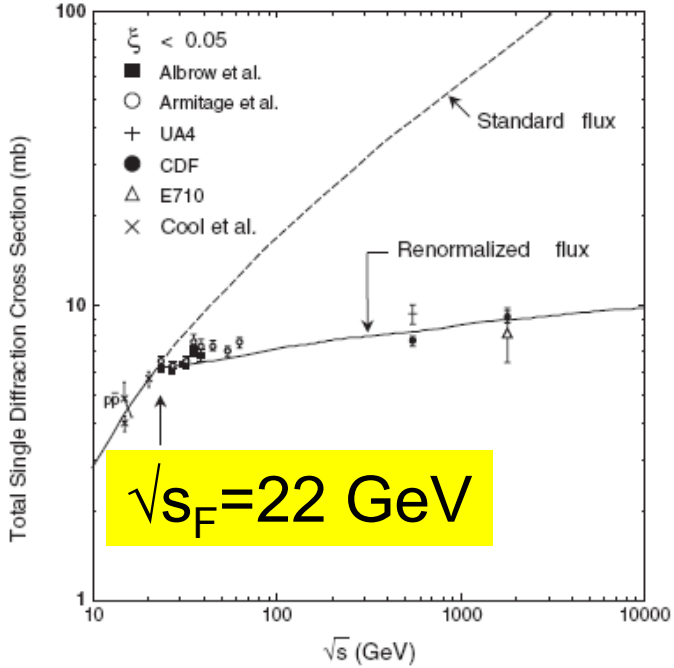
$$r_{\text{pheno}} = 3.2 \pm 0.4\ (\text{GeV}/c)^{-2}$$

$$r_{\text{exp}} = 0.25\ (\text{GeV}/c)^{-2}/0.08 = 3.13\ (\text{GeV}/c)^{-2}$$

Diffractive and Total pp Cross Sections at LHC

Konstantin Goulianos
The Rockefeller University

EDS '09



$\sqrt{s_F}$=22 GeV

- Use the Froissart formula as a *saturated* cross section

$$\sigma_t(s > s_F) = \sigma_t(s_F) + \frac{\pi}{m^2} \cdot \ln^2 \frac{s}{s_F}$$

- This formula should be valid above the *knee* in σ_{sd} vs. $\sqrt{s}$ at $\sqrt{s_F} = 22$ GeV (Fig. 1) and therefore valid at $\sqrt{s} = 1800$ GeV.

- Use $m^2 = s_o$ in the Froissart formula multiplied by $1/0.389$ to convert it to mb^{-1}.

- Note that contributions from Reggeon exchanges at $\sqrt{s} = 1800$ GeV are negligible, as can be verified from the global fit of Ref. [7].

- Obtain the total cross section at the LHC:

$$\sigma_t^{\text{LHC}} = \sigma_t^{\text{CDF}} + \frac{\pi}{s_o} \cdot \left(\ln^2 \frac{s^{\text{LHC}}}{s_F} - \ln^2 \frac{s^{\text{CDF}}}{s_F} \right)$$

SUPERBALL MODEL

$$\sigma^{LHC}_{14\,000\,\text{GeV}} = (80 \pm 3) + (29 \pm 12) = 109 \pm 12 \quad \text{mb}$$

Strategy and Conclusion

STRATEGY

- σ^T from SUPERBALL model
- optical theorem → Im $f_{el}(t=0)$
- dispersion relations → Re $f_{el}(t=0)$
- differential σ^{SD} from RENORM
- use nested pp final states for Pomeron-proton collisions at $\sqrt{s}$‘

σ_T

↕ **optical theorem**

Im $f_{el}(t=0)$

↕ **dispersion relations**

Re $f_{el}(t=0)$

For a phenomenological approach see: K. Goulianos, Phys. Lett. B 193 (1987) 151 pp

CONCUSION

more to come…

First CMS event



At the Gorge of Samaria (1980)





w/R. F. – a day of jokes!

