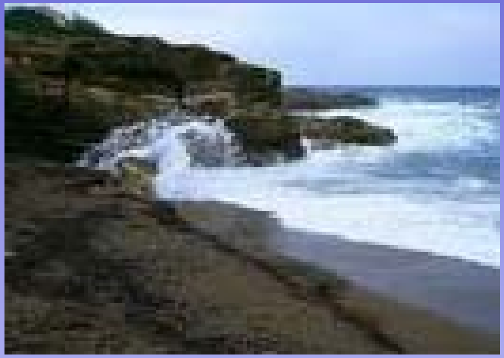
Diffractive x-sections and event final states at the LHC

Expanded talk presenter at DIFFRACTION DAY 7 May 2010 CERN



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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

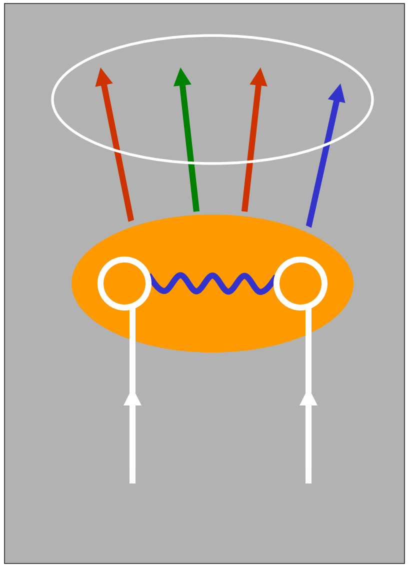
Diffractive:

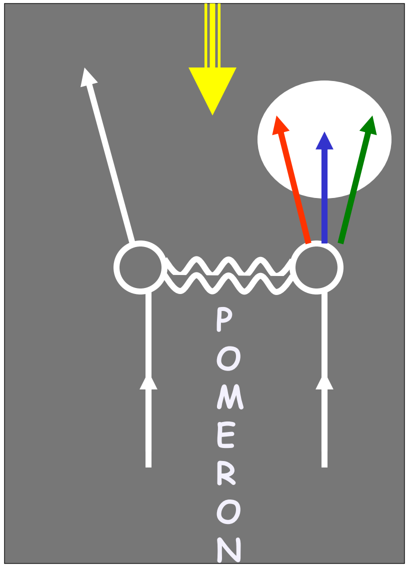
Colorless exchange carrying vacuum quantum numbers

rapidity gap

Incident hadrons acquire color and break apart

CONFINEMENT



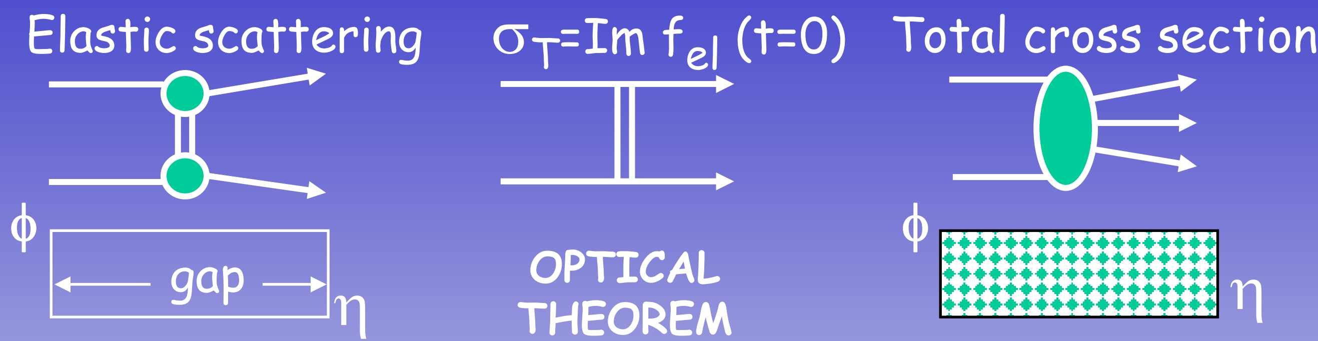


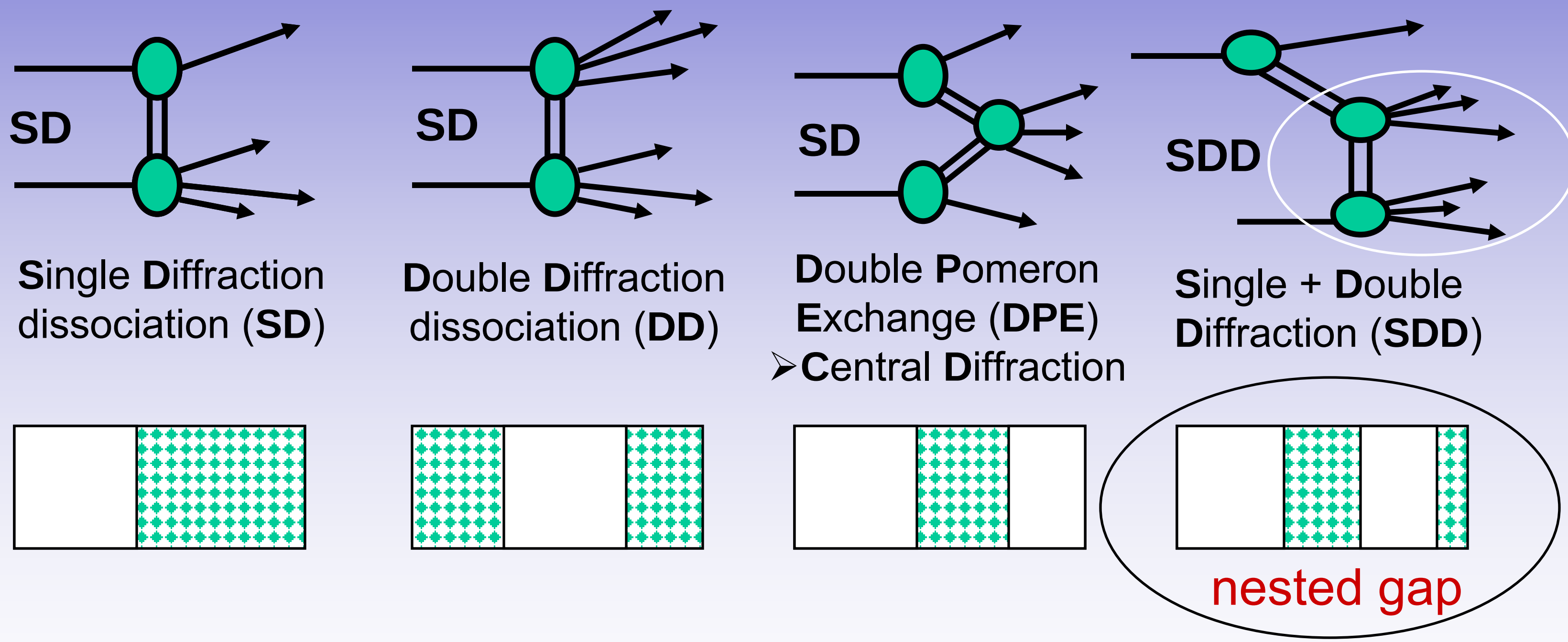
Incident hadrons retain their quantum numbers remaining colorless

pseudo-DECONFINEMENT

Goal: understand the QCD nature of the diffractive exchange

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

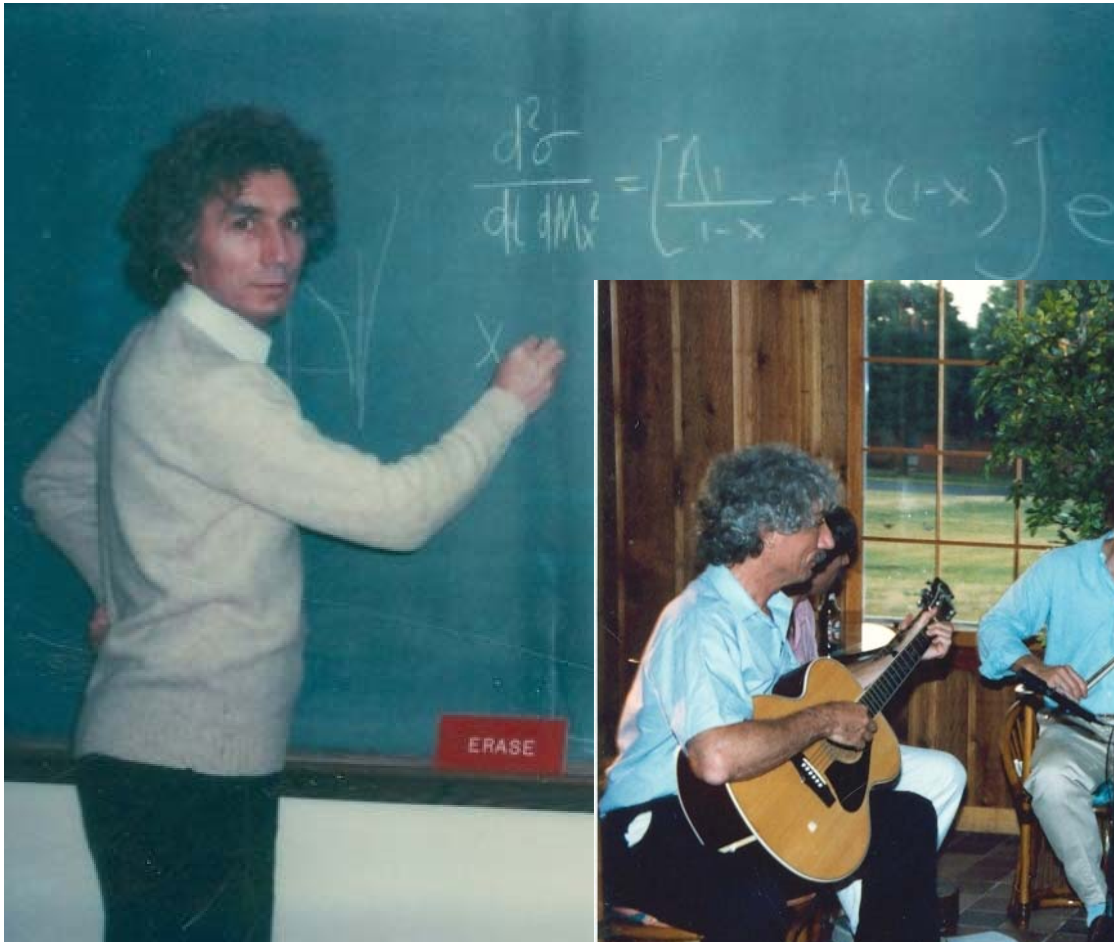




Use nesting until no diffractive gap fits in √s'

A bit of history…

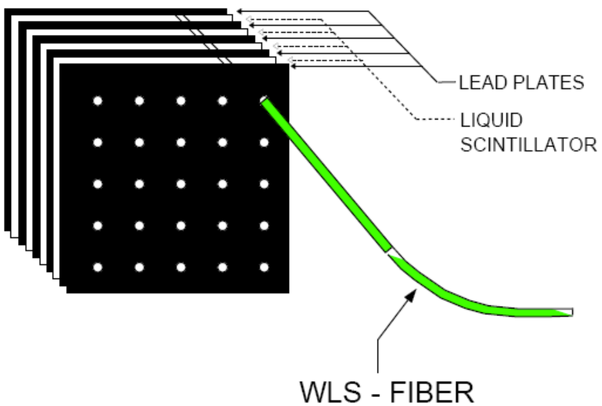
Diffraction in the70s ➔ the Pomeron unveiled!



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

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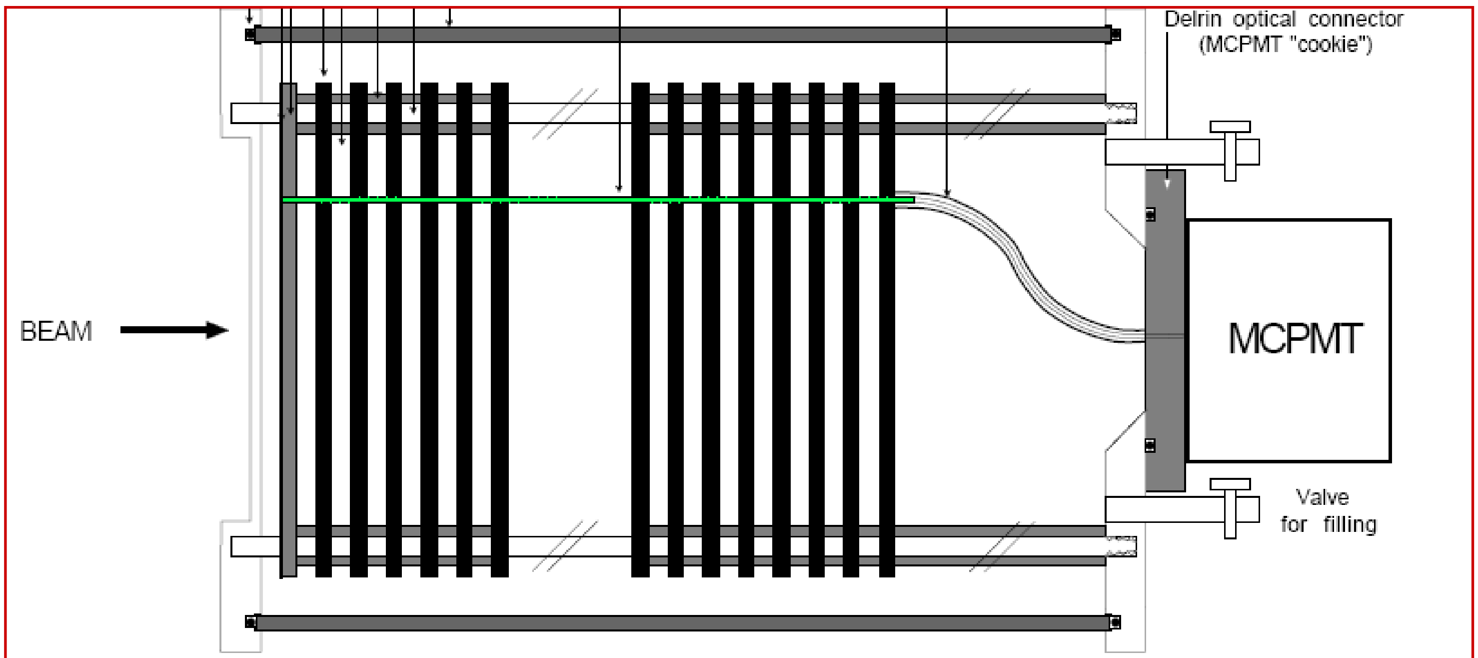
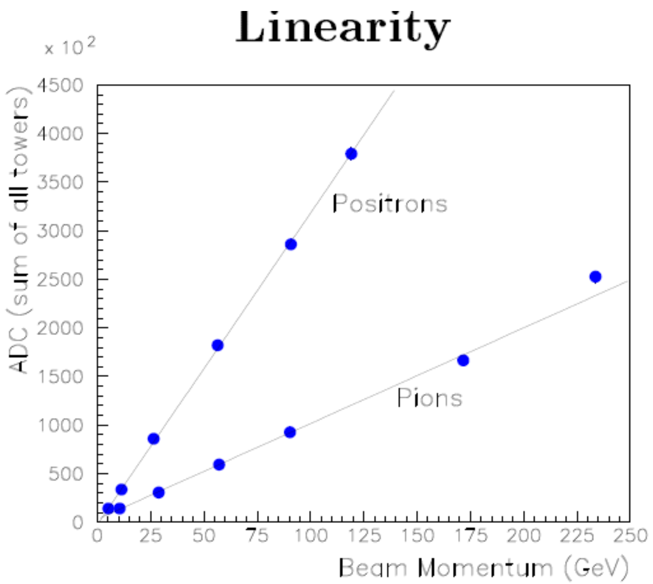
Presented by: K. Goulianos



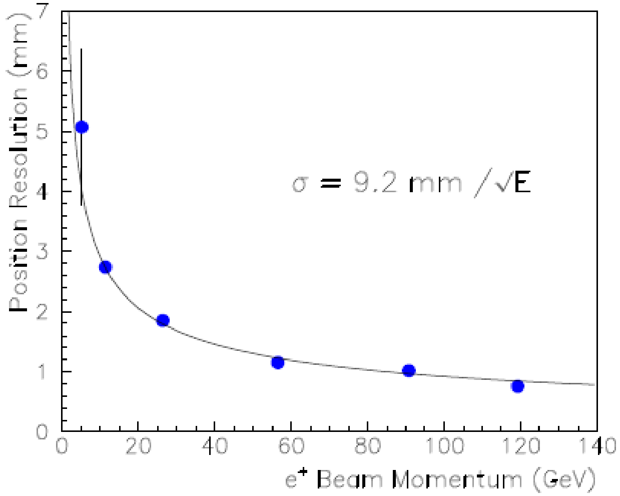
Elba 2000

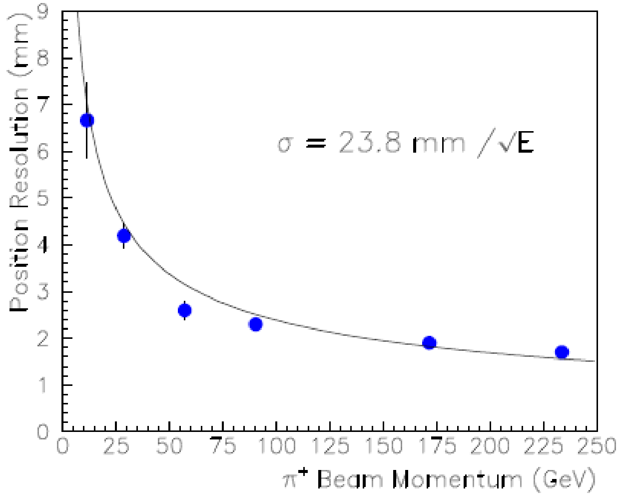
The CDF MiniPlugs



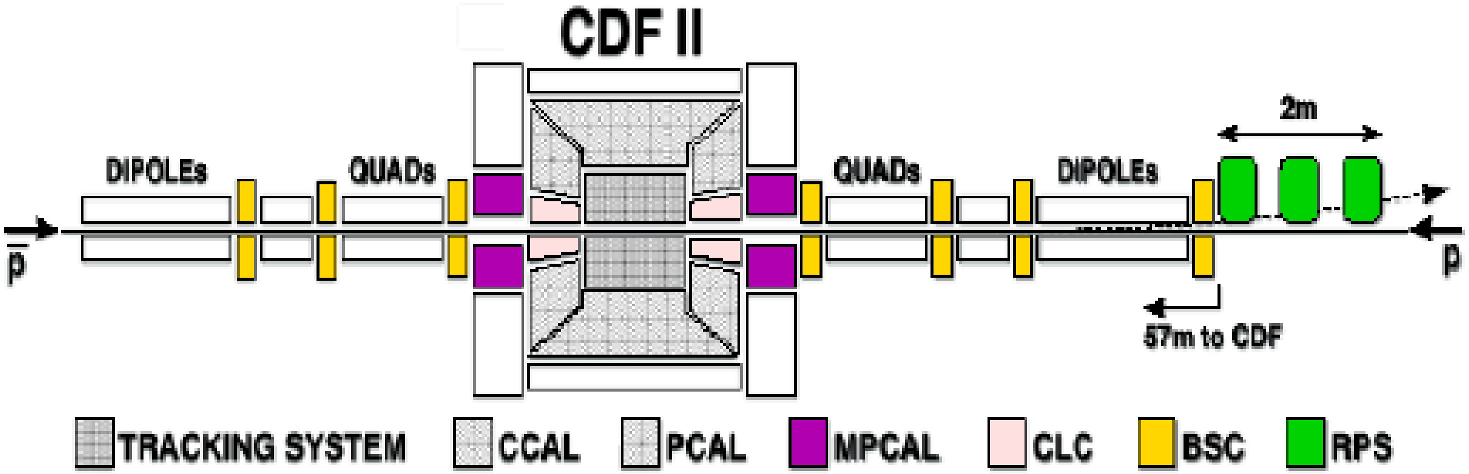
Position Resolution

Electrons **Pions**



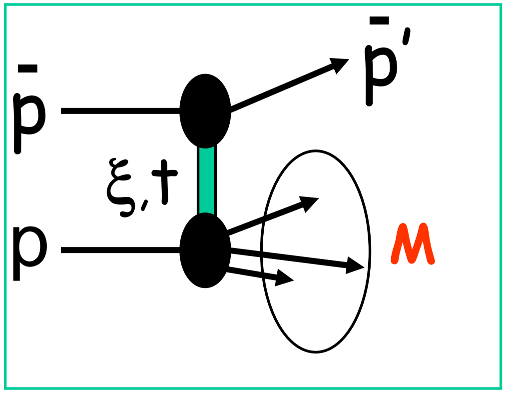


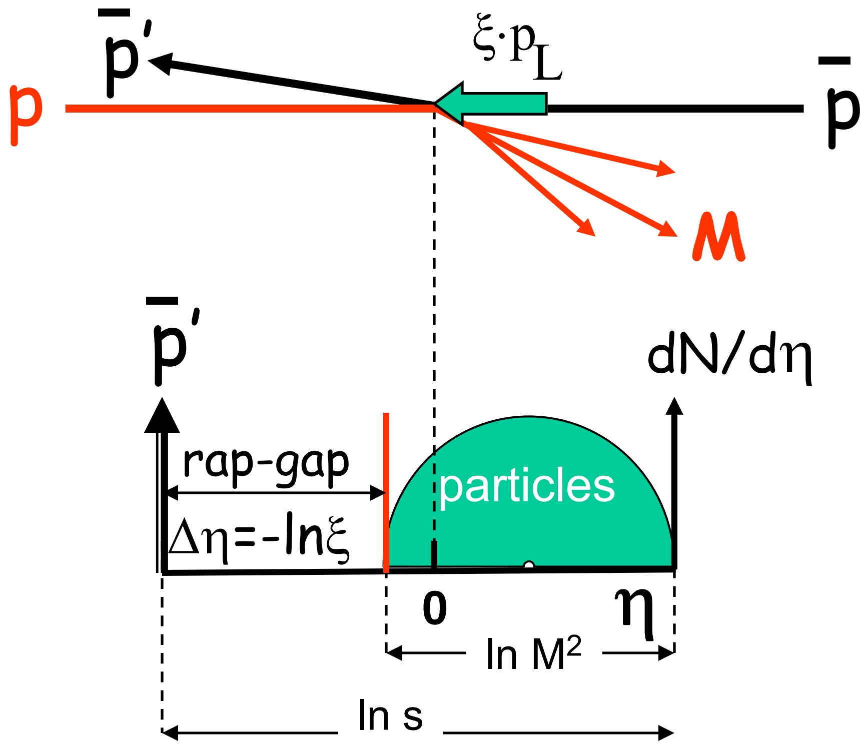
The CDF II Detector



- 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

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

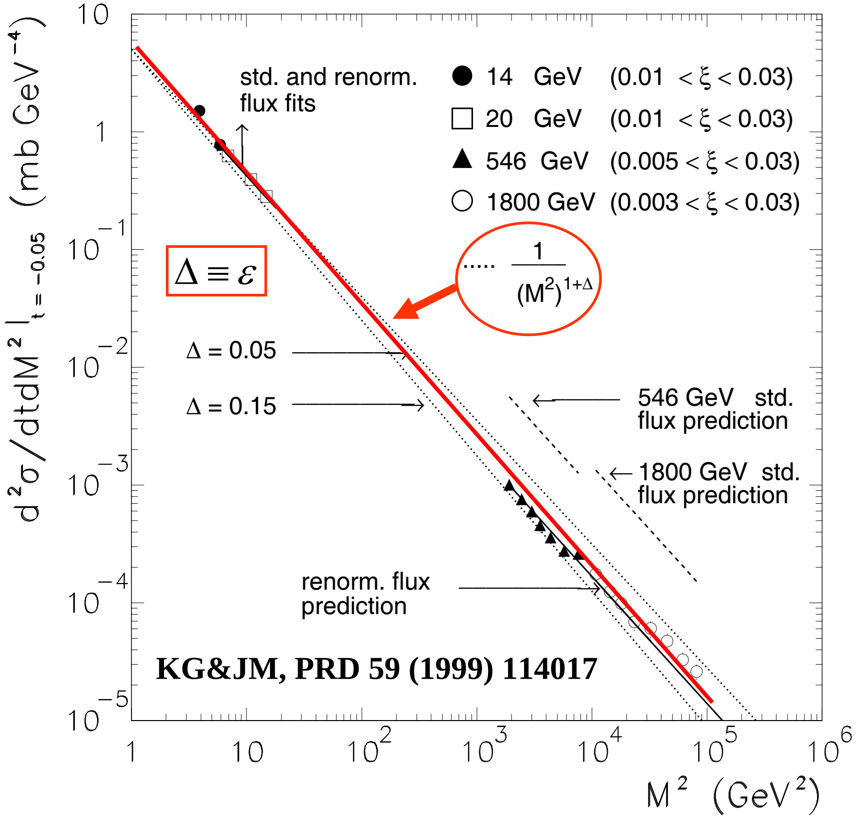
M^2 scaling

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

Regge ➔ $s^{2\varepsilon}$; data ➔ 1

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

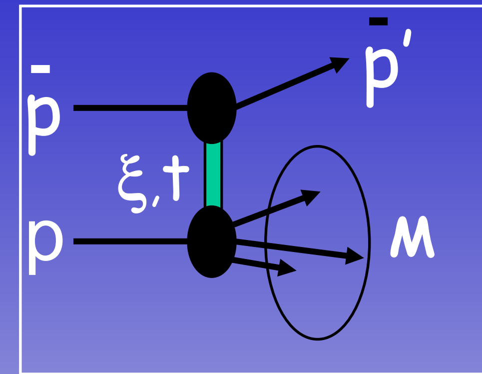
➔ Independent of s over 6 orders of magnitude in M^2!



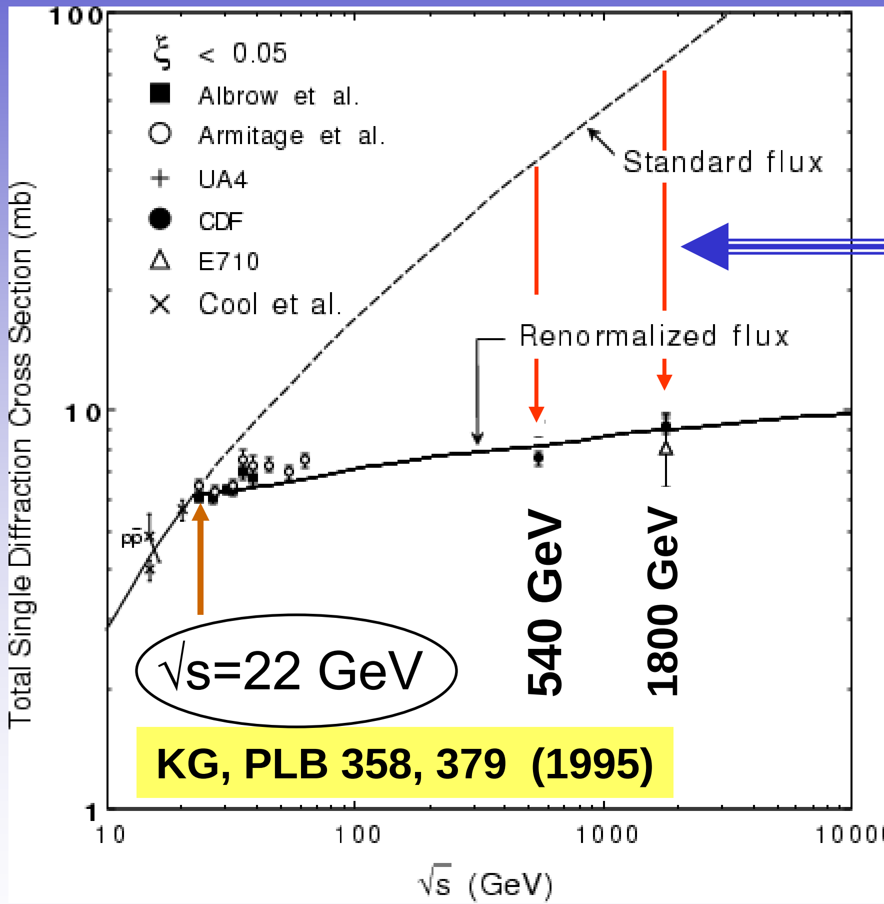
➔ factorization breaks down to ensure M^2 scaling - why?

σ^T_{SD} (pp & $\bar{p}$p)

➔ suppressed relative to Regge

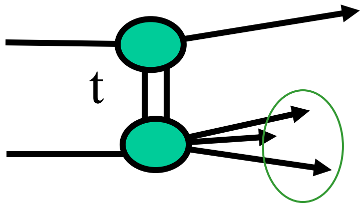


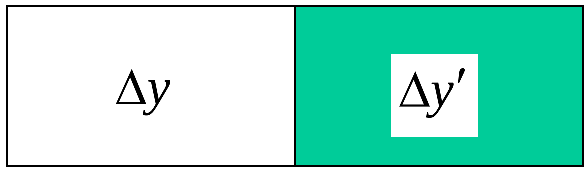
σ^T_{SD} mb



Factor of ~8 (~5) suppression at √s = 1800 (540) GeV

Single Diffraction





2 independent variables: $t, \Delta y$

color factor

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

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

Gap probability MUST be normalized to unity!

Single diffraction (re)normalized

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

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

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

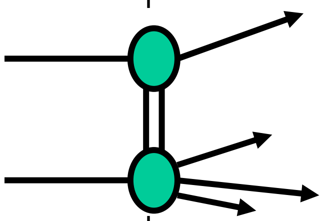
Grows slower than s^{ε}

→ 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



$$\frac{d^2\sigma_{SD}}{dt\,d\xi} = \underbrace{f_{IP/p}(t,\xi)}_{\cdot\, s_0^{\varepsilon}} \cdot \sigma_{IP-\bar{p}}(s\xi)$$

s_0^{ε}

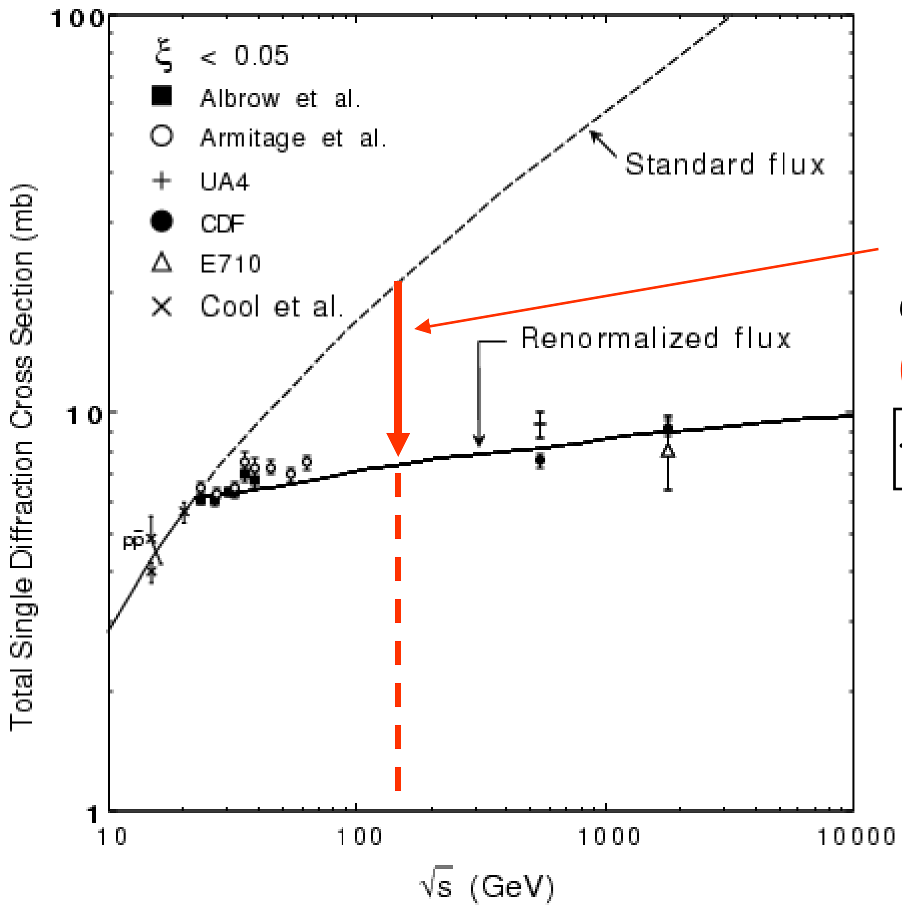
$s_0^{-\varepsilon/2} \cdot g_{PPP}(t)$

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)

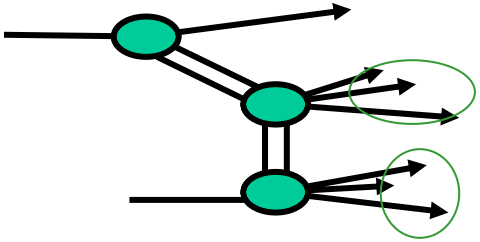


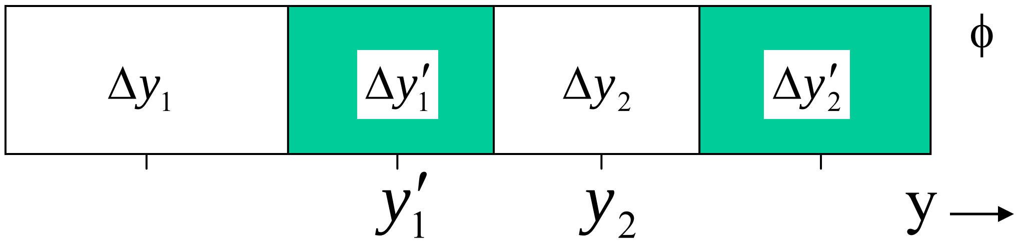
Factor of ~3 suppression expected at W~200 GeV (just as in pp collisions)

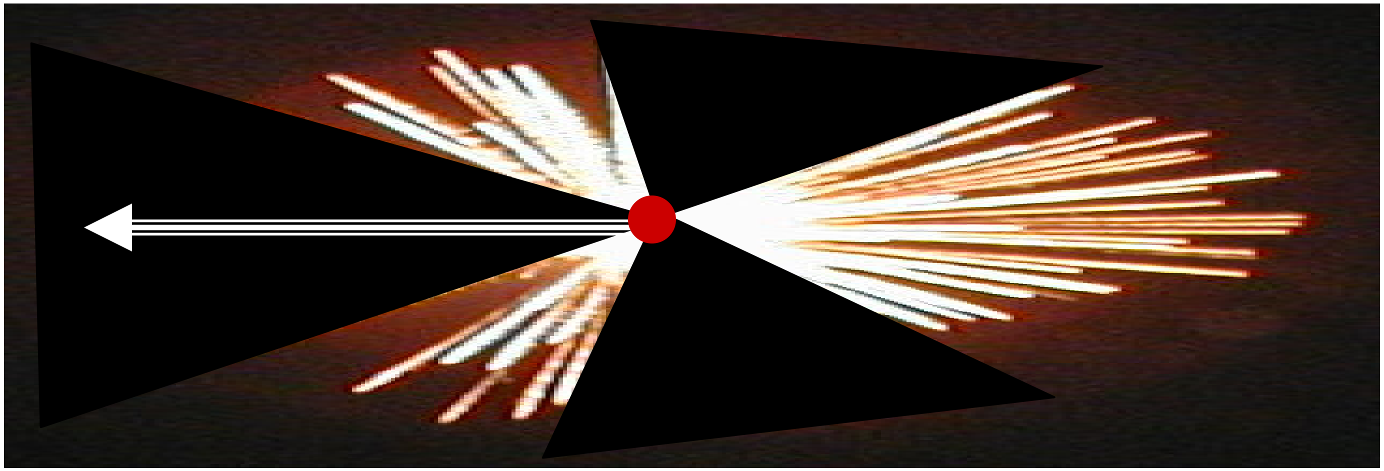
for both direct and resolved components

Multi-gap Diffraction

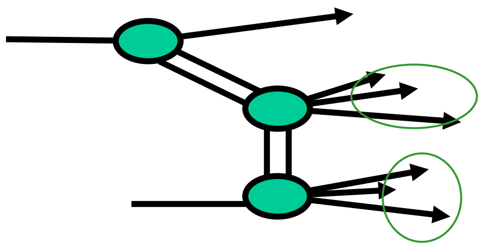
(KG, hep-ph/0205141)

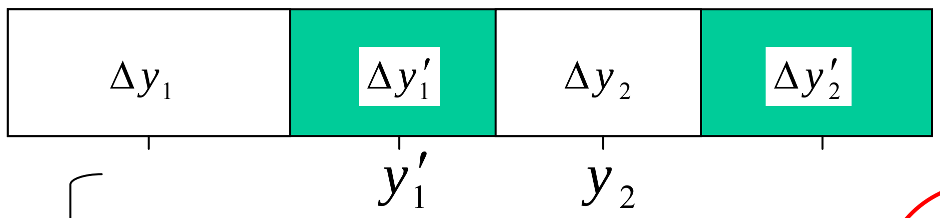






Multi-gap Cross Sections





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

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

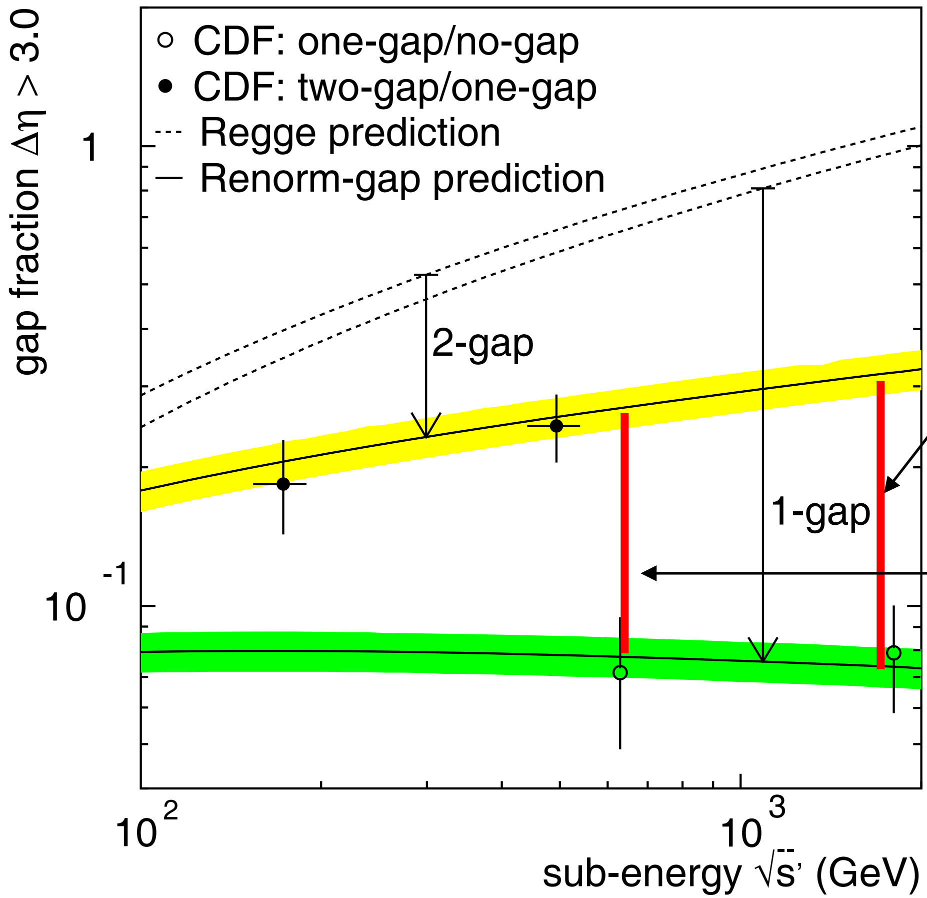
$$\int_{\Delta y, t} \sim s^{2\varepsilon} / \ln s$$

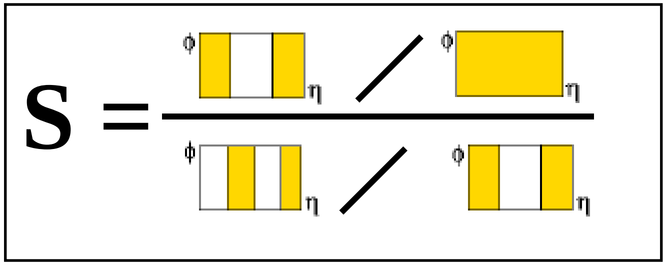
Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

Rapidity Gaps in Fireworks

"Gap survival probability"





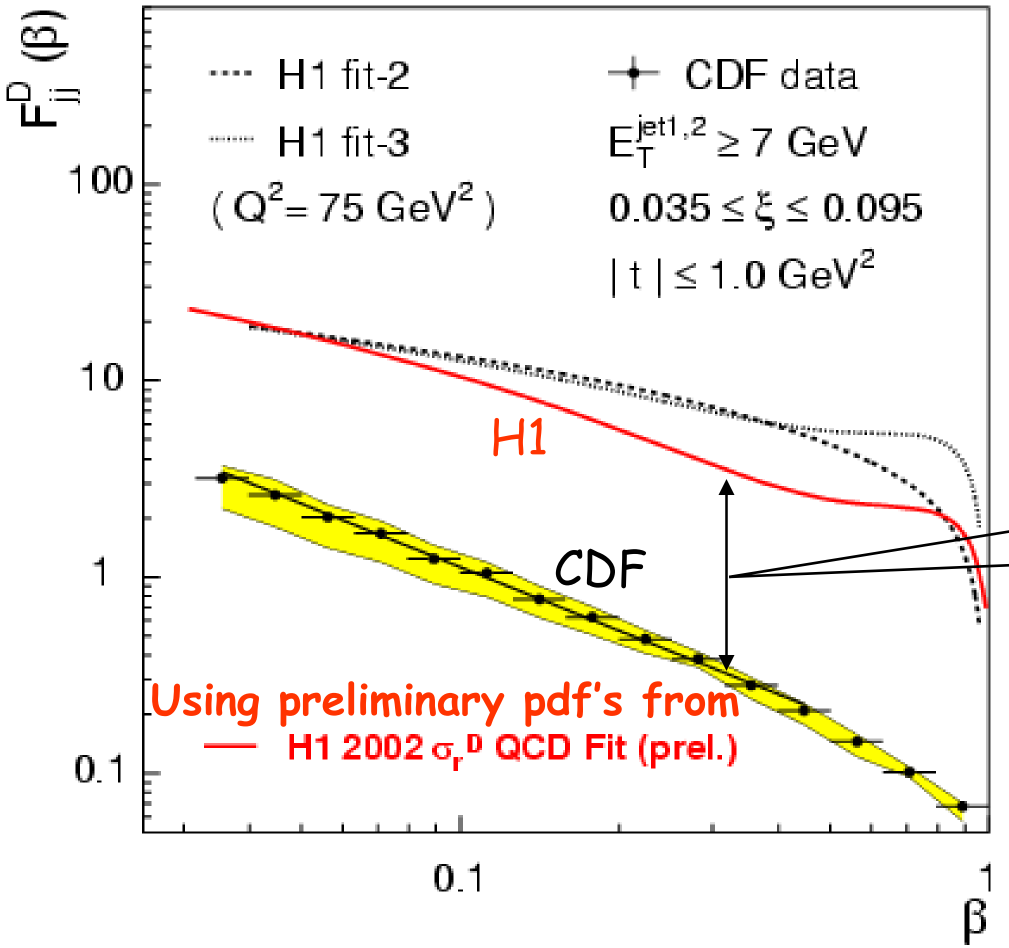
$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \mathrm{GeV}) \approx 0.23$$

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

Diffractive Structure Function
➔ breakdown of QCD factorization !

Diffractive Structure Function

Breakdown of QCD factorization



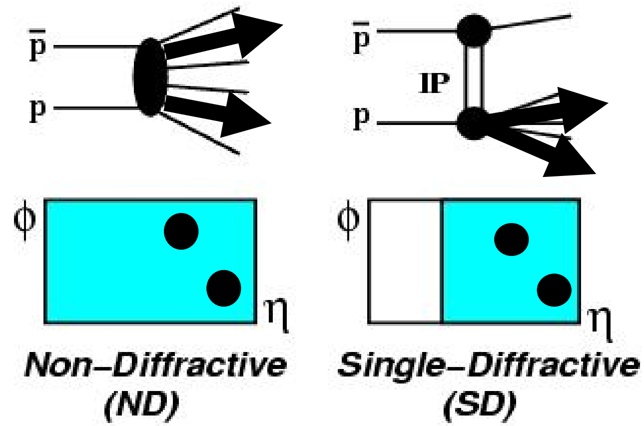
$\bar{p}p \rightarrow \bar{p} + \text{dijet} + X$

same suppression
as in soft diffraction – why?

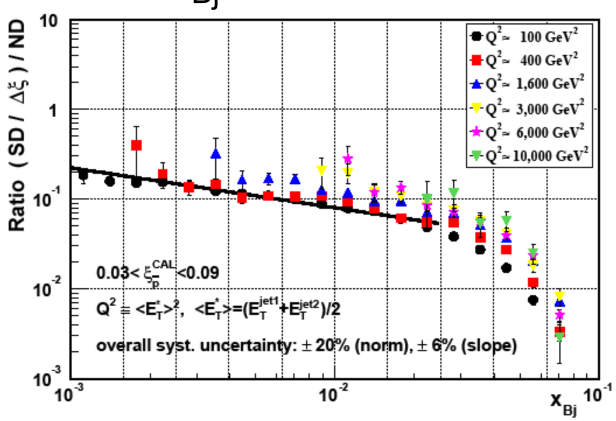
momentum fraction of parton
in "Pomeron" – note quotes

DSF from Dijets in Run II

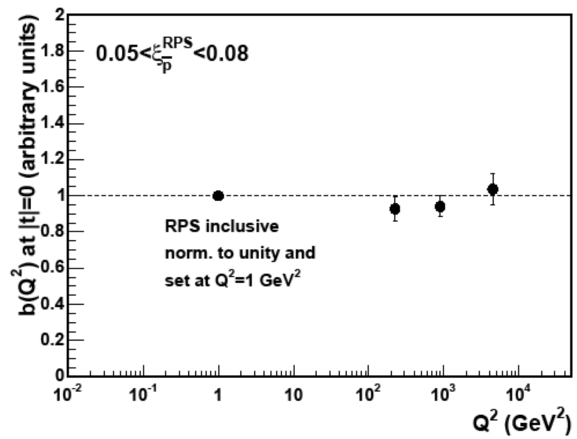
$$R(x_{Bj}) \equiv \frac{\mathrm{Rate}_{jj}^{SD}(x_{Bj})}{\mathrm{Rate}_{jj}^{ND}(x_{Bj})} \Rightarrow \frac{F_{jj}^{SD}(x_{Bj})}{F_{jj}^{ND}(x_{Bj})}$$



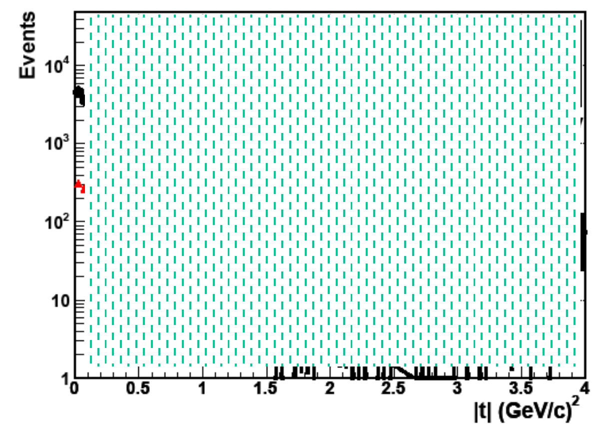
x_{Bj} - distribution



b - slope of t-distribution



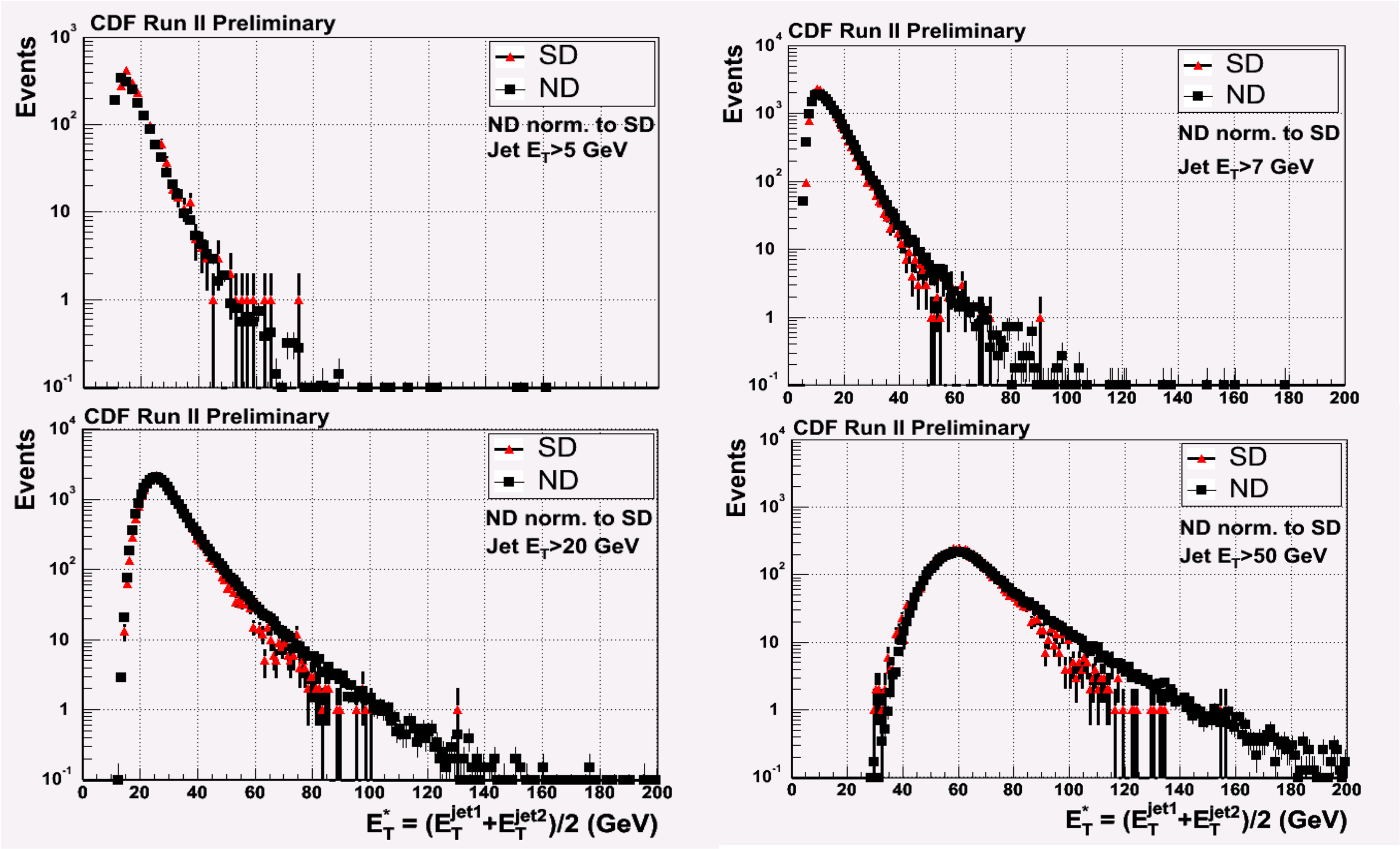
t - distribution



- 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"

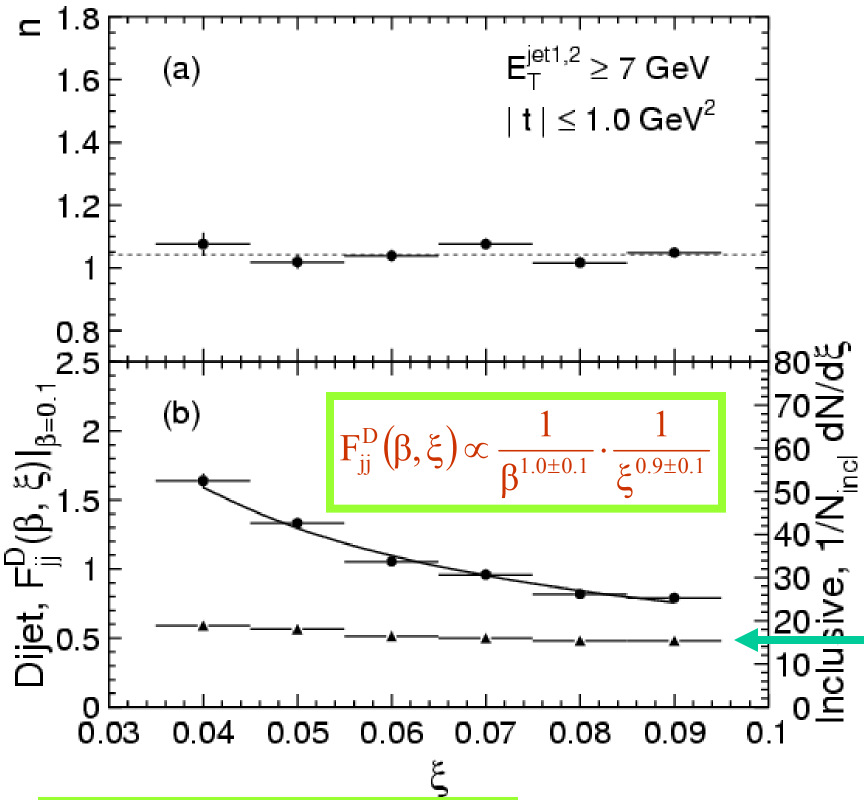
Dijet E_T distributions



➔ similar for SD and ND over 4 orders of magnitude

Kinematics

ξ & β dependence of F^D_{jj} – Run I



$$F^D_{jj}(\beta,\xi) \propto \frac{1}{\beta^{1.0\pm0.1}} \cdot \frac{1}{\xi^{0.9\pm0.1}}$$

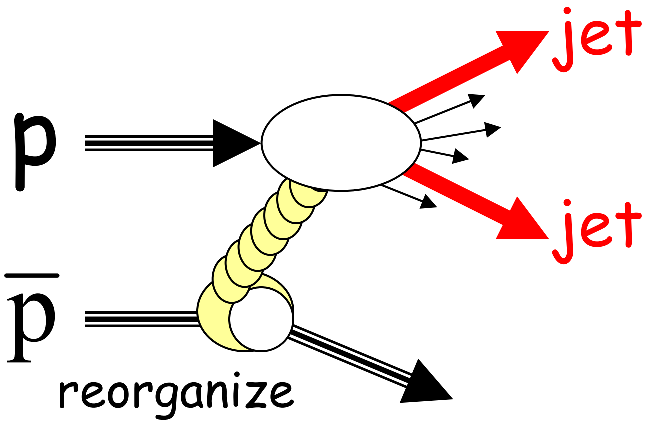
$$\frac{d\sigma_{incl}}{d\xi} \propto \text{constant}$$

$$F^D_{jj}(\beta,\xi) \sim \frac{1}{\beta} \cdot \frac{1}{\xi}$$

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

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

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

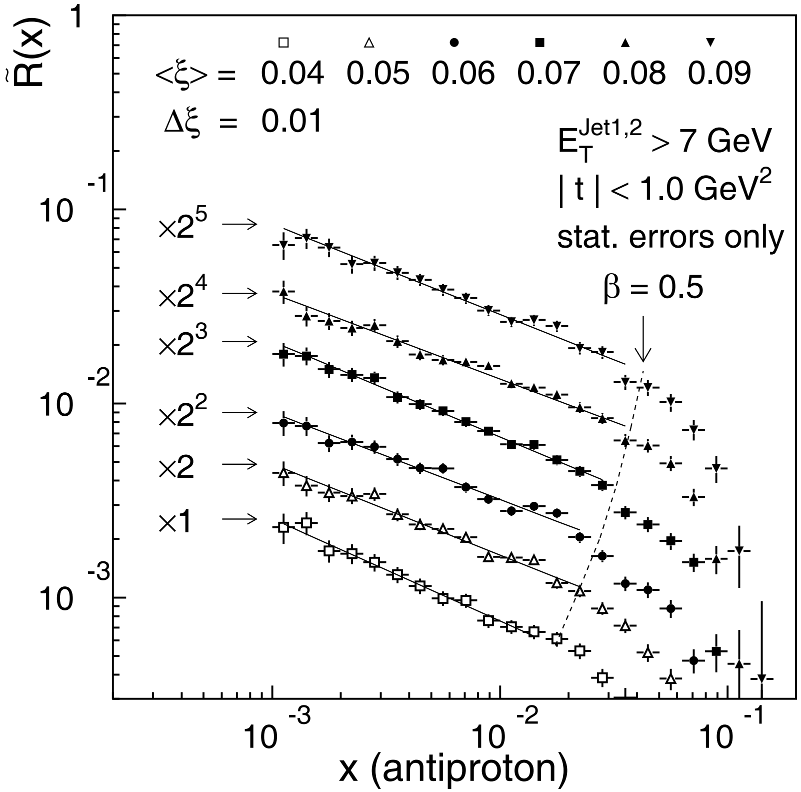
RENORM $\Rightarrow$ $R^{SD}_{ND}(x) = \frac{2\varepsilon}{s^{2\varepsilon}}\frac{1}{\xi^{1-\lambda(Q^2)}}\cdot x^{-(2\varepsilon)}$

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

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

CDF Run I

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



$0.035 < \xi < 0.095$

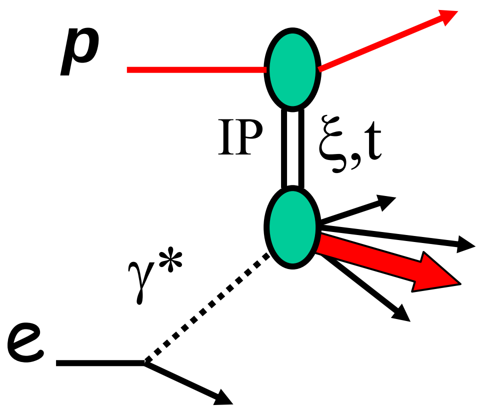
Flat ξ dependence for $\beta < 0.5$

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

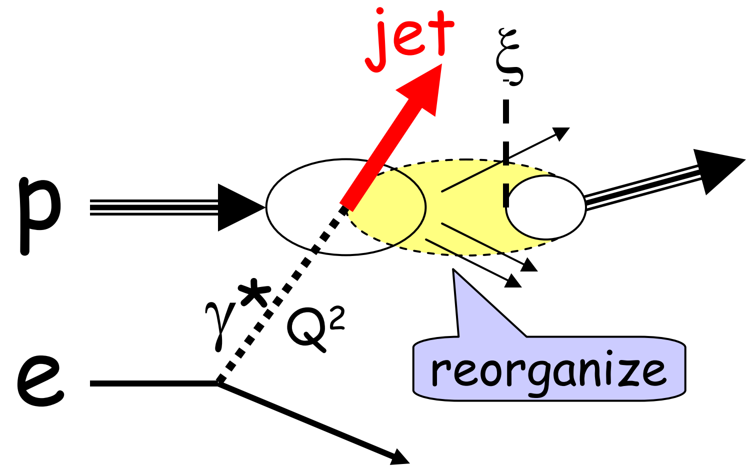
Diffractive DIS @ HERA

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

Pomeron exchange



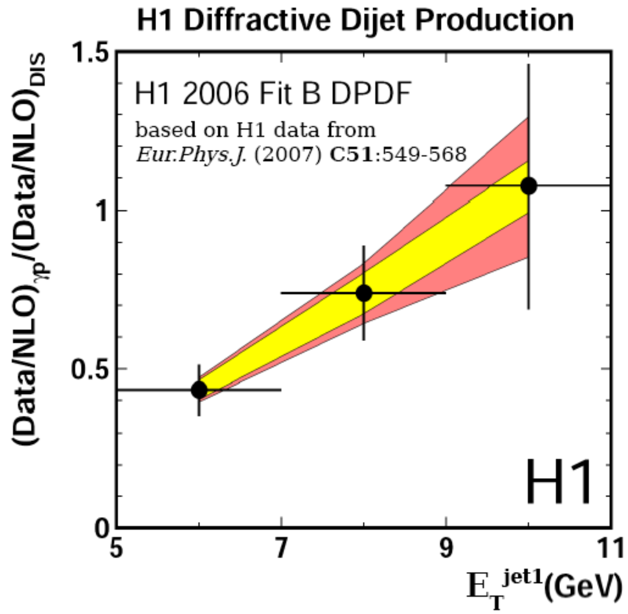
Color reorganization



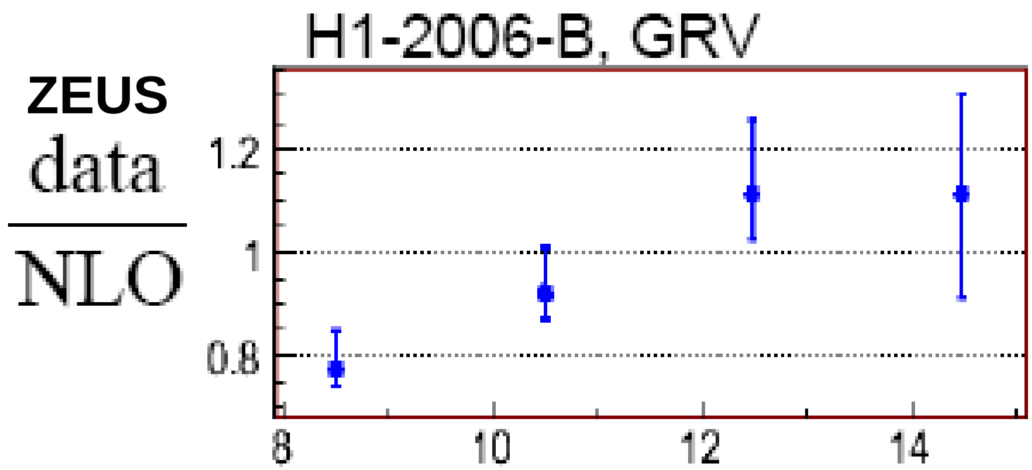
$$F_2^{D(3)}(\xi, x, Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F_2(x, Q^2)$$

Results favor color reorganization

Dijets in γp at HERA - 2008



DIS 2008 talk by W. Slomiński,

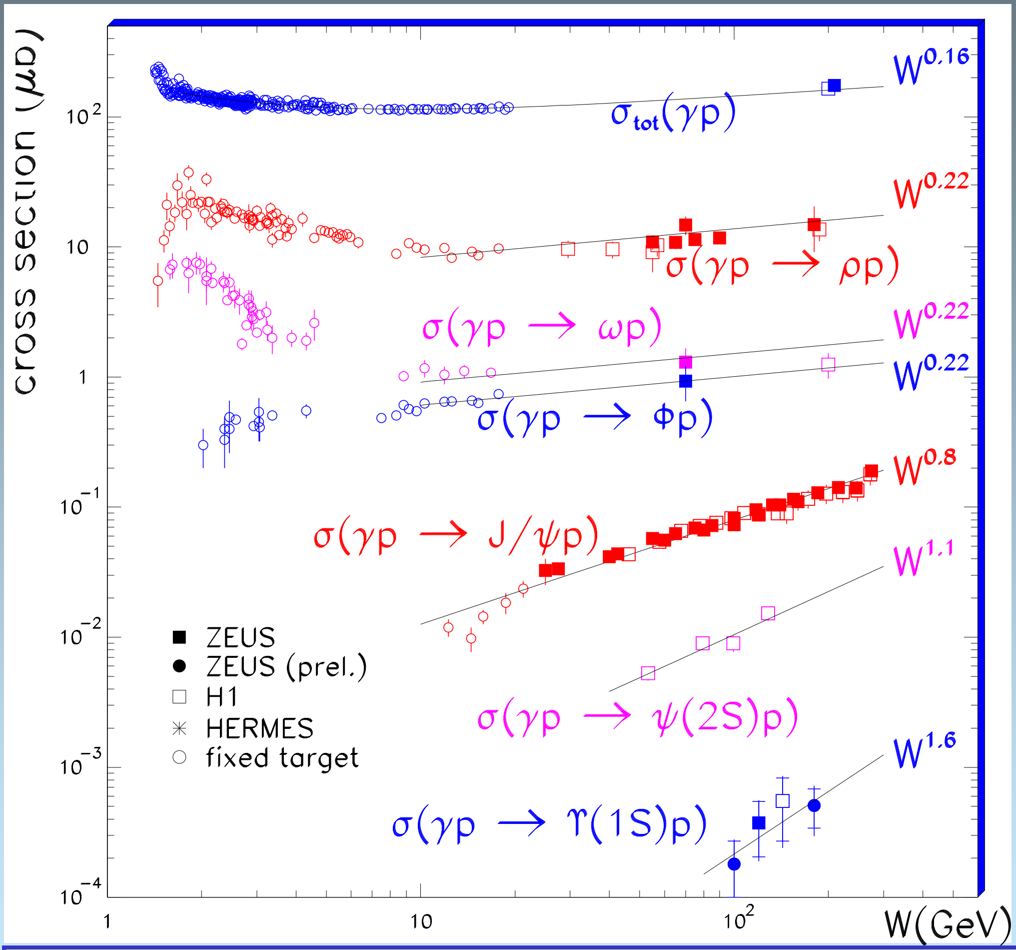


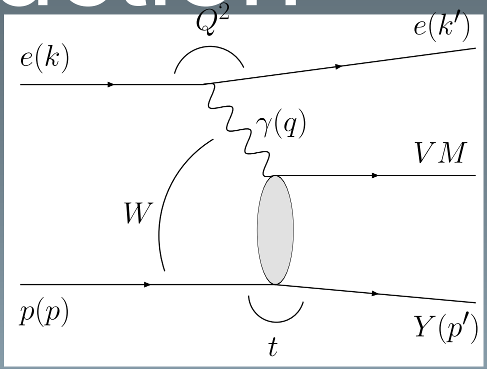
- 20-50 % apparent rise when E_T^{jet} 5→10 GeV

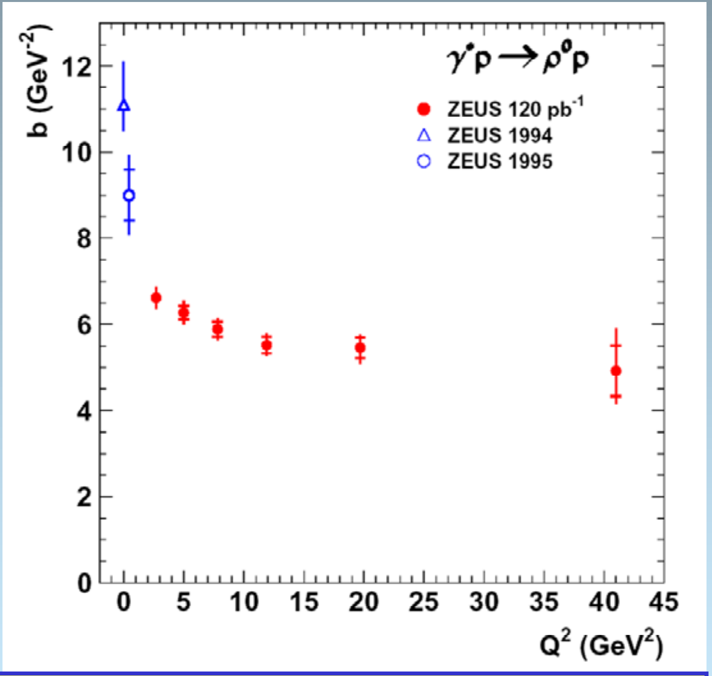
➔ **due to suppression at low E_T^{jet} !!!**

Vector meson production

(Pierre Marage, HERA-LHC 2008)





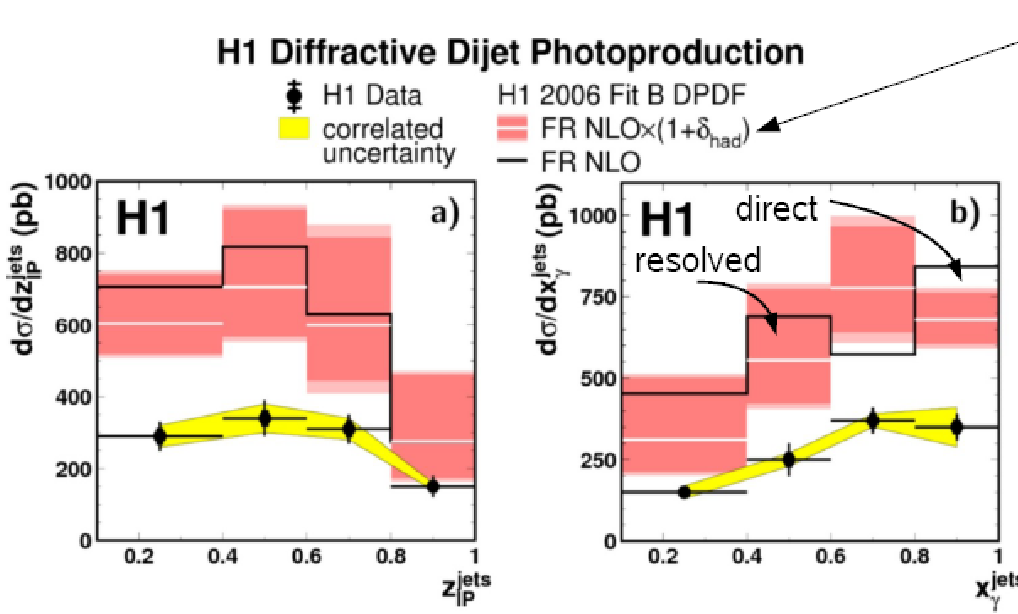


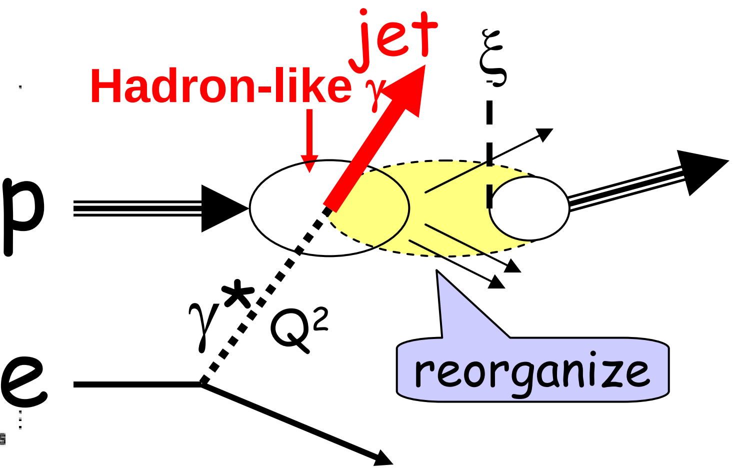
- *left* - why different σ vs. W slopes? ➔ more room for particles
- *right* - why smaller b-slope in $\gamma^* p$? ➔ same reason

Dijets in γp at HERA – 2007

Direct vs. resolved

Dijets in γp





- 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

PHYSICAL REVIEW D **80**, 111901(R) (2009)

Pomeron intercept and slope: A QCD connection

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

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

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

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

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

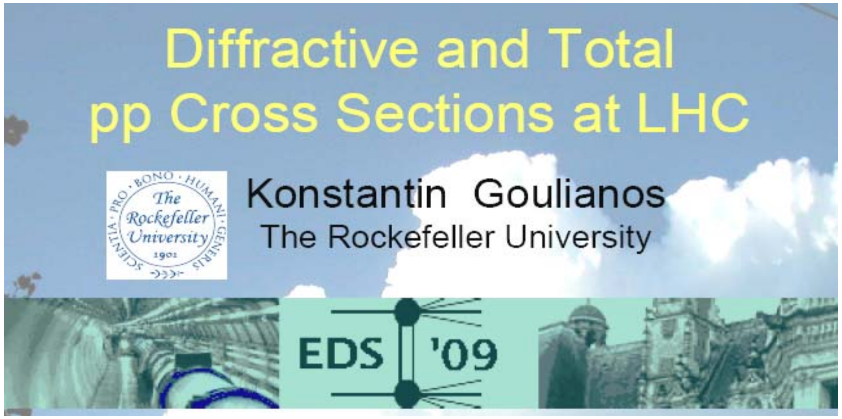
$$\kappa = \frac{f_g^\infty}{N_c^2-1} + \frac{f_q^\infty}{N_c}$$

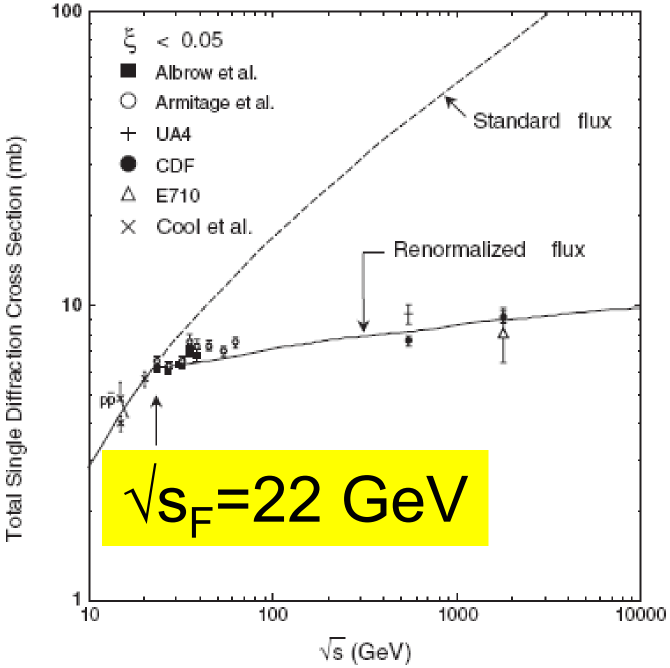
$$b_\circ = R_p^2/2 = 1/(2m_\pi^2).$$

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

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

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





- 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:

SUPERBALL MODEL

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

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

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