Diffraction at CDF and Universality of Diffractive Factorization Breaking

Low x 2010, 23-27 June 2010 Kavala (Greece)

Konstantin Goulianos
The Rockefeller University
http://physics.rockefeller.edu/dino/my.html/

CONTENTS

- Introduction
- Diffraction at CDF: latest results
  - Dijets
  - *W* and *Z*
  - Jet-Gap-Jet
- Universality of Diffractive Factorization Breaking

INTERACTIONS

Non-diffractive:

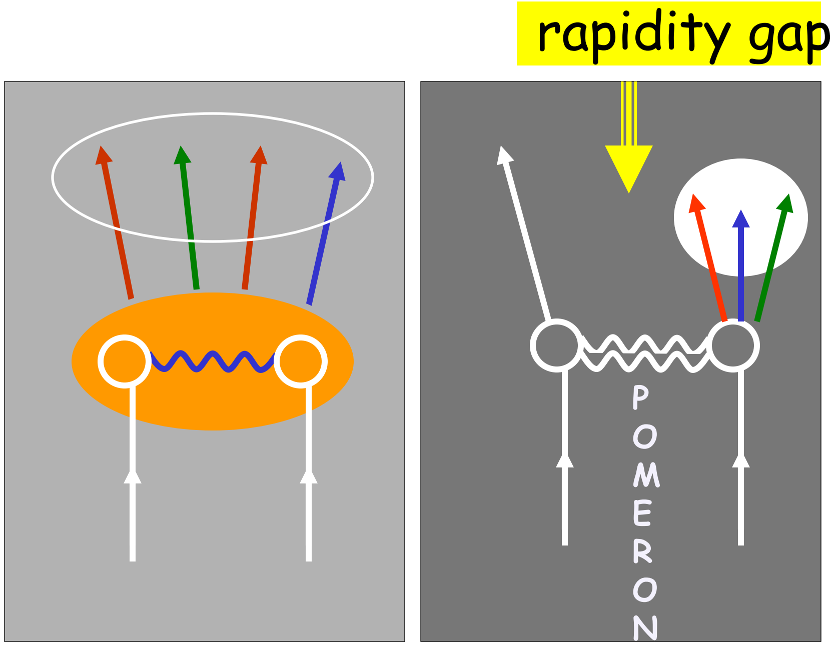
Color-exchange

Diffractive:

Colorless exchange carrying vacuum quantum numbers

Incident hadrons acquire color and break apart

CONFINEMENT

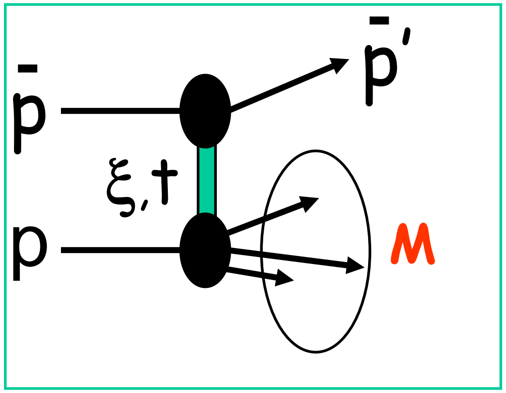


Incident hadrons retain their quantum numbers remaining colorless

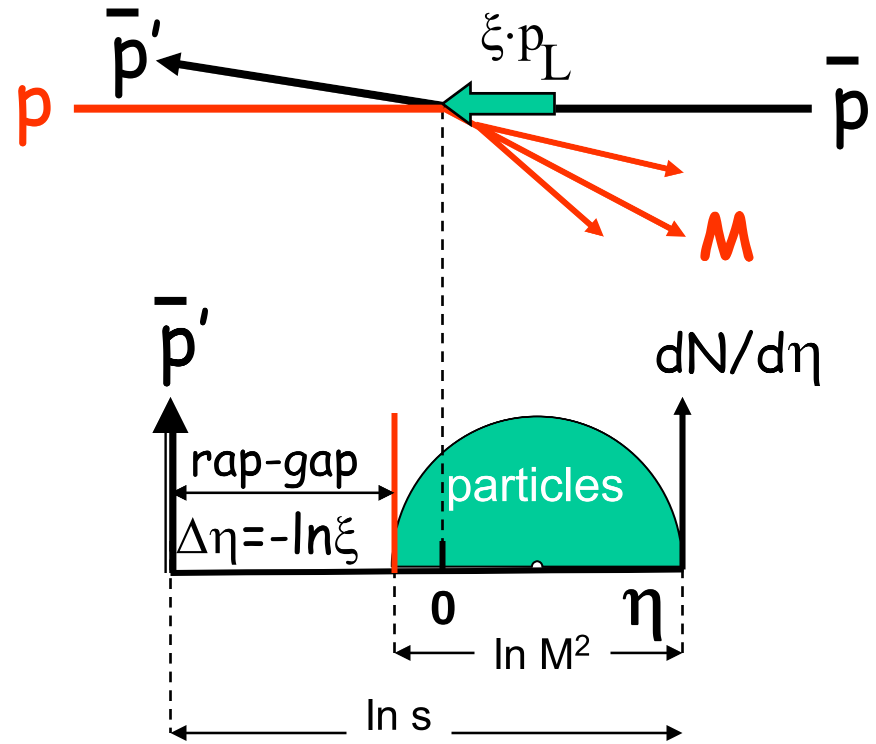
pseudo-DECONFINEMENT

Goal: understand the QCD nature of the diffractive exchange

Definitions



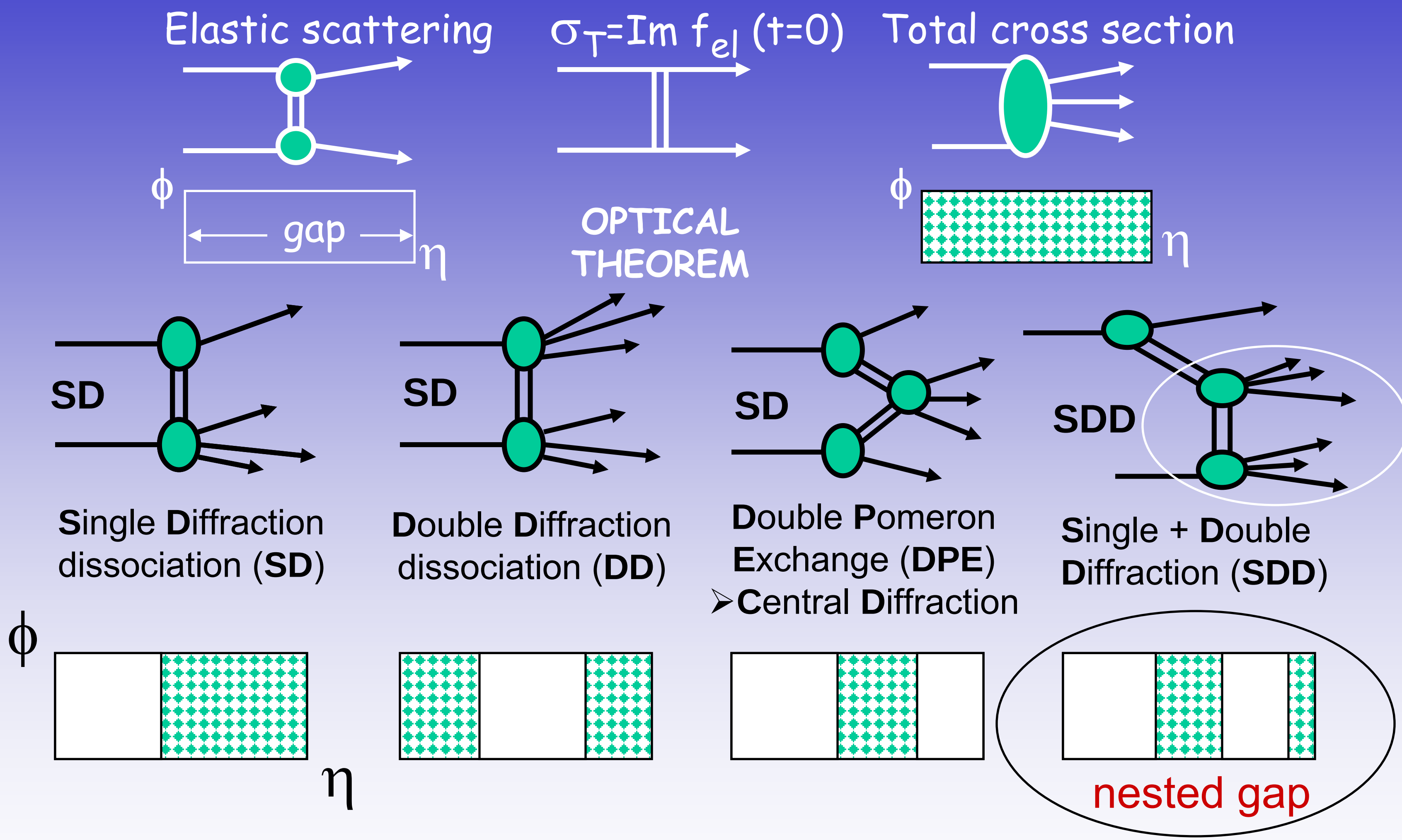
$$1 - x_L \equiv \xi = \frac{M^2}{s}$$



M² scaling: no price paid for increasing diffractive gap size

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

Diffractive pp(p̄p) processes @ CDF



use gap nesting until no diffractive gap fits in √s'

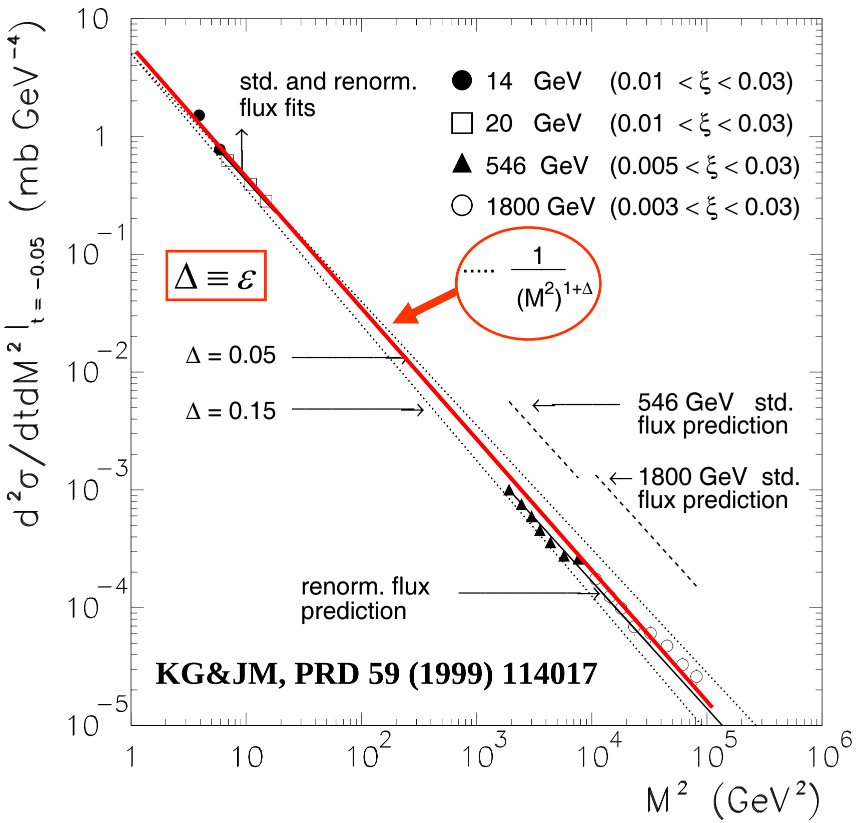
M^2 scaling

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

Regge → data

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

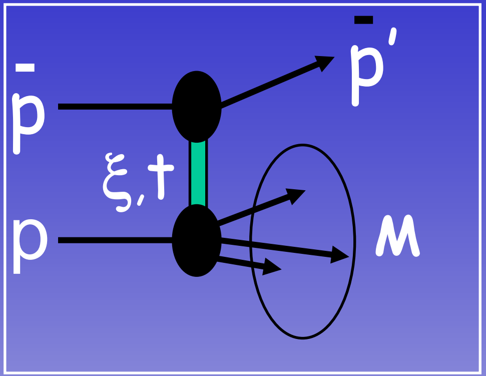
➔ Independent of s over 6 orders of magnitude in M^2!



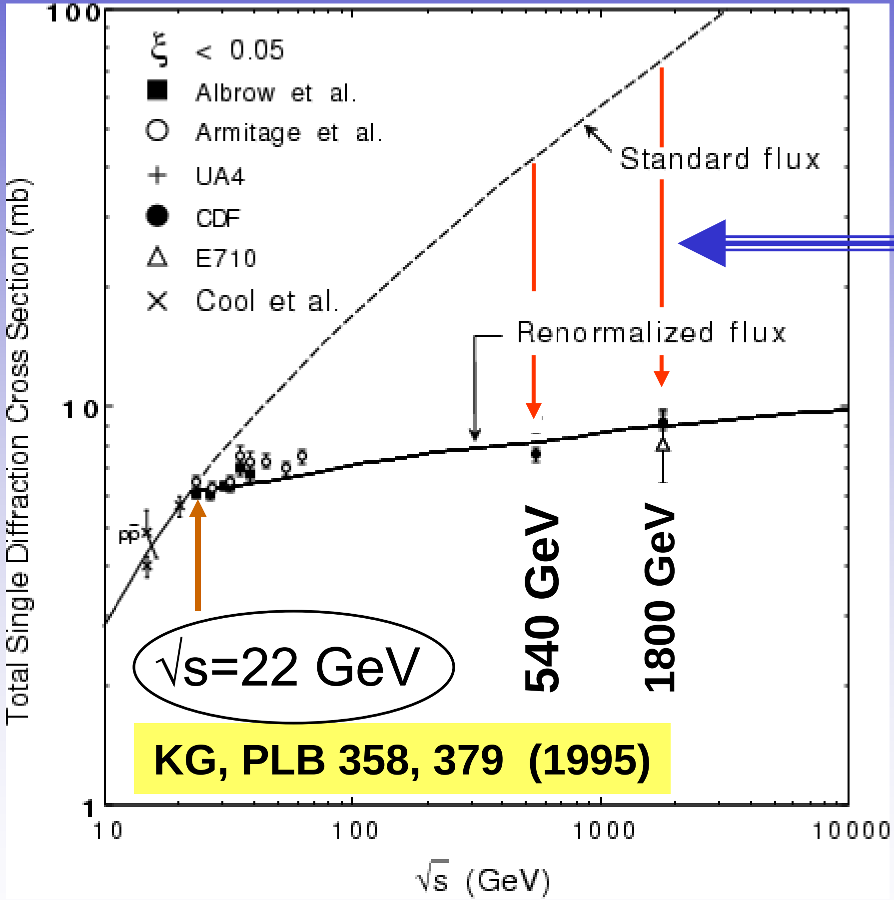
➔ factorization breaks down to ensure M^2 scaling - why?

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

REMARKS

- **MC generators for diffractive studies:**

  ➔ **PYTHIA & PHOJET disagree with each other and with data.**

- **Diffractive factorization breaking at HERA:**

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

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

- **Renormalization (RENORM) model: describes both p ($\bar{p}$) - p and** γ (γ*) **– p**

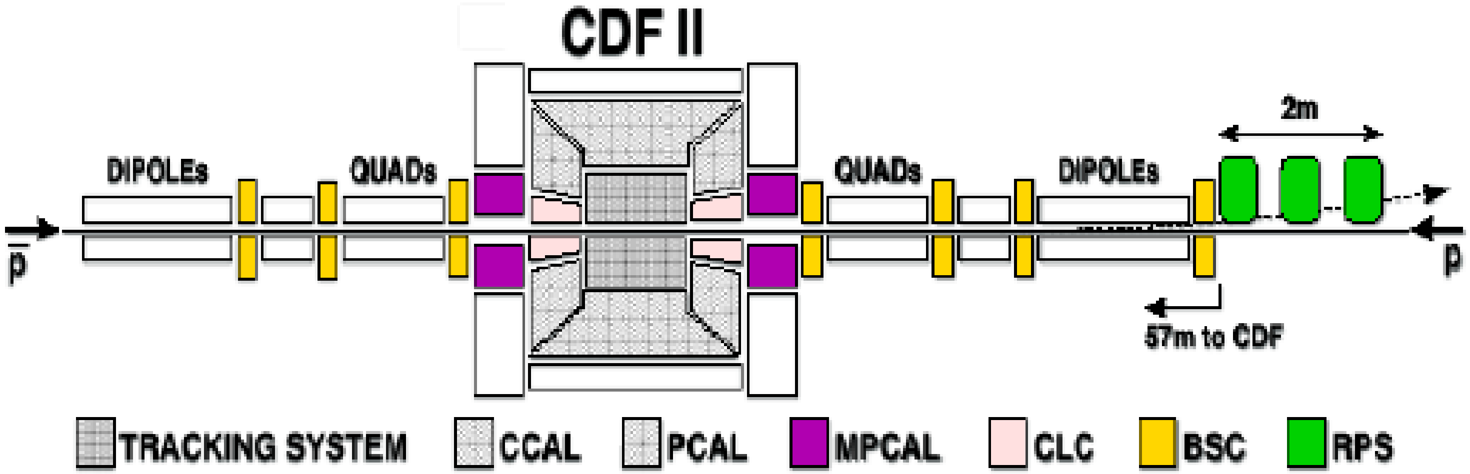
  ➔ **MC based on RENORM model:**

  MBR (Minimum Bias Rockefeller) used at CDF.

- **Luminosity measurement: requires a known x-section and MC predicted acceptance of a detector component.**

  ➔ **suggest SD: well defined and slowly varying x-section**

The CDF II Detector



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

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

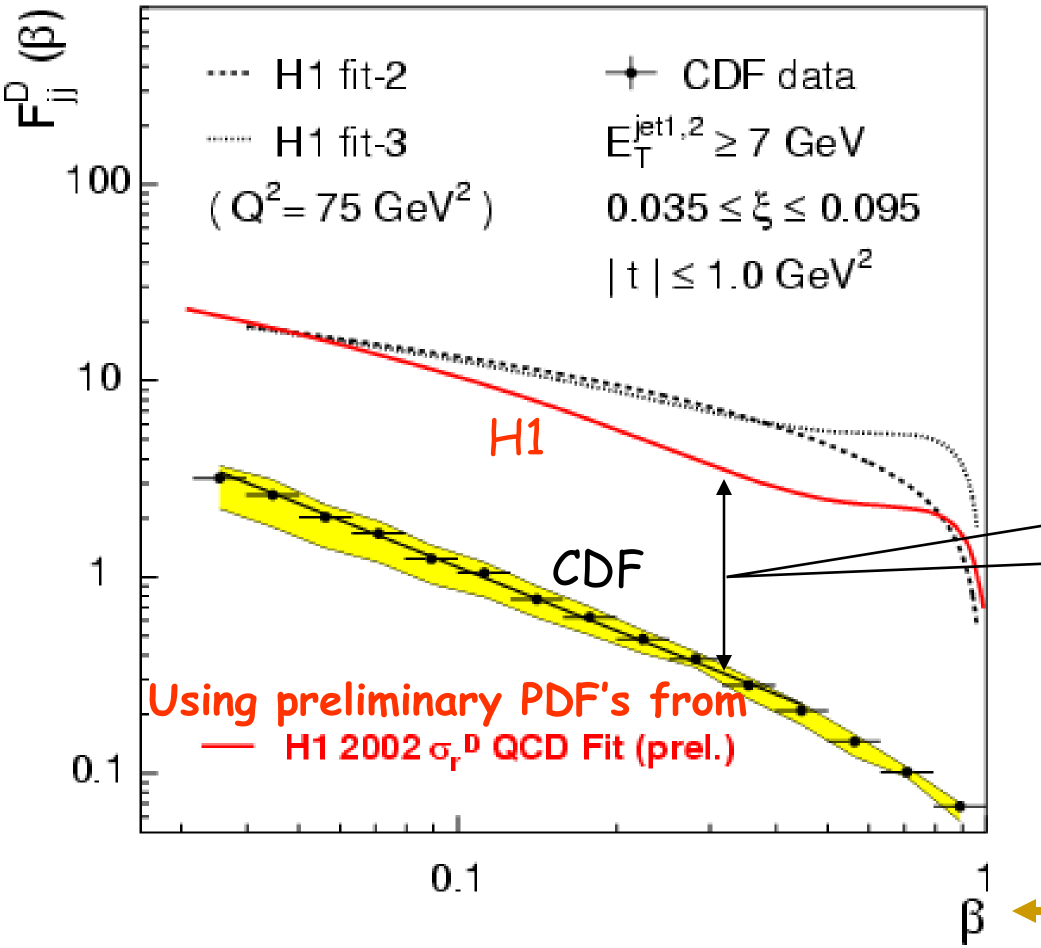
RPS – Roman Pot Spectrometers $0.02 < \xi < 0.1$
$0 < |t| < 2\ GeV^2$

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

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

Diffractive Structure Function
→ breakdown of QCD factorization !

Diffractive Structure Function

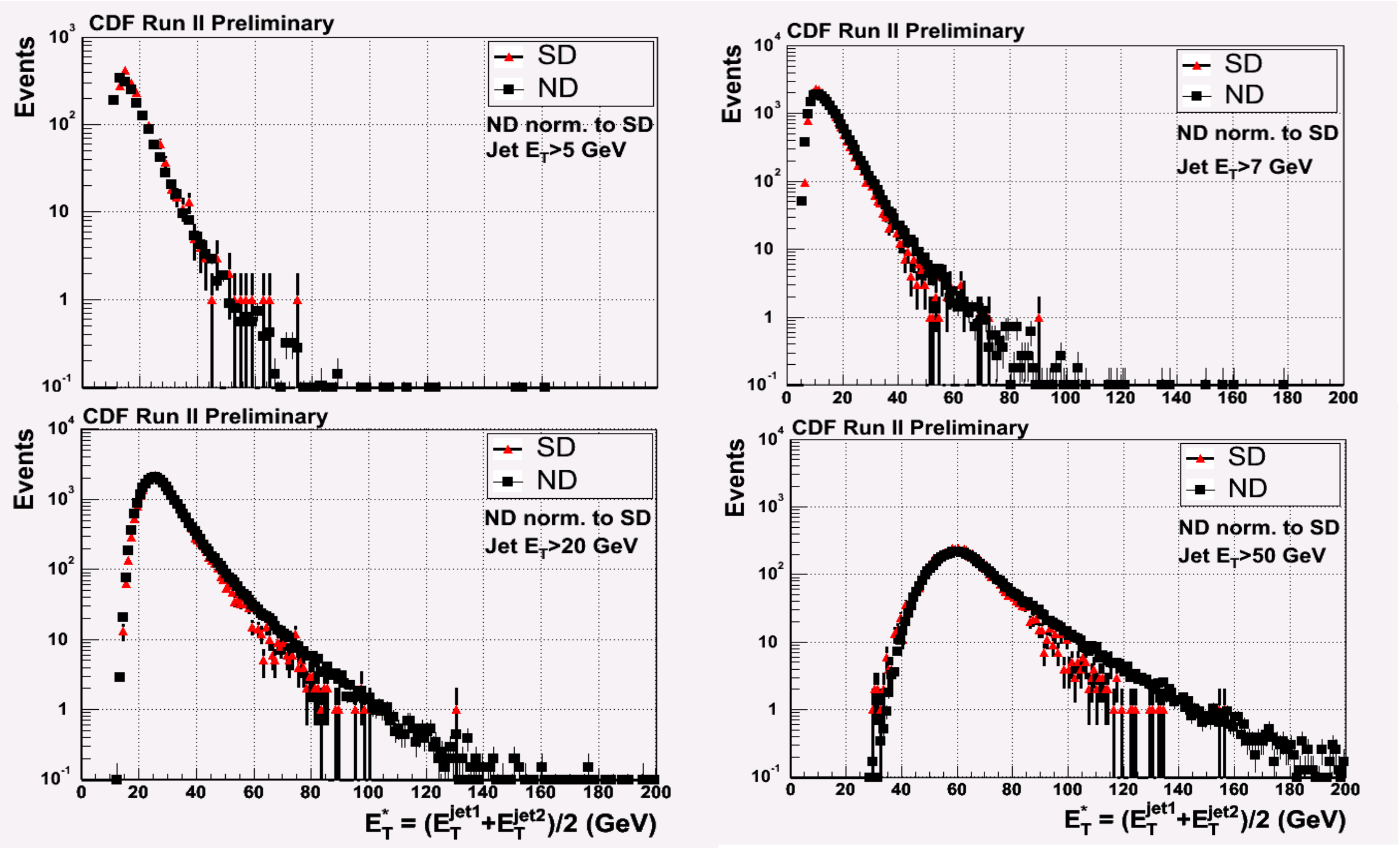


$$\bar{p}p \rightarrow \bar{p} + \text{dijet} + X$$

same suppression as in soft diffraction – why?

momentum fraction of parton in "Pomeron" – note quotes

Dijet E_T distributions

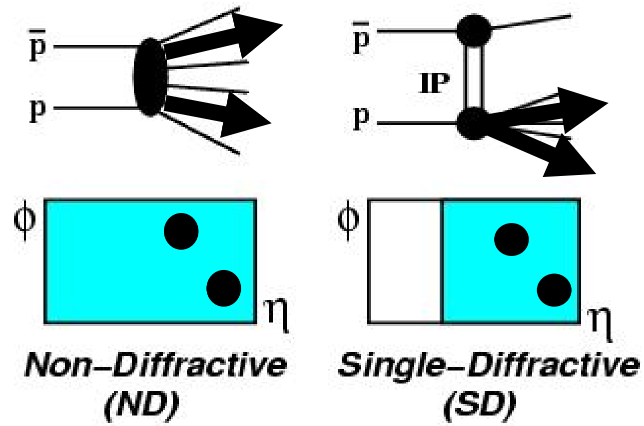


➔ similar for SD and ND over 4 orders of magnitude

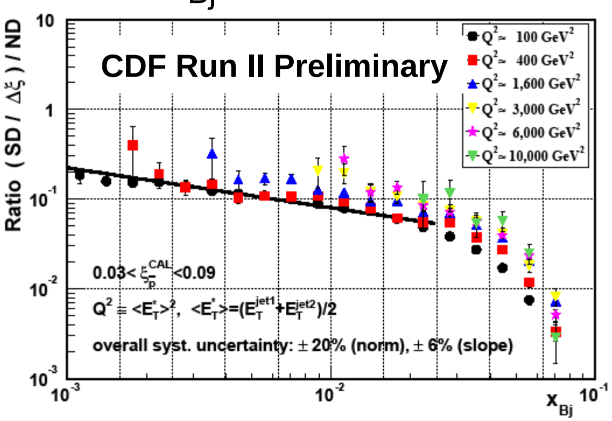
Kinematics

DSF from Dijets in Run II

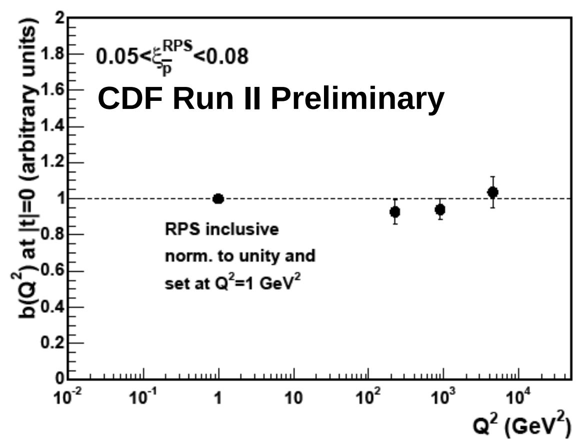
$$R(x_{Bj}) \equiv \frac{\mathrm{Rate}_{jj}^{SD}(x_{Bj})}{\mathrm{Rate}_{jj}^{ND}(x_{Bj})} \Rightarrow \frac{F_{jj}^{SD}(x_{Bj})}{F_{jj}^{ND}(x_{Bj})}$$



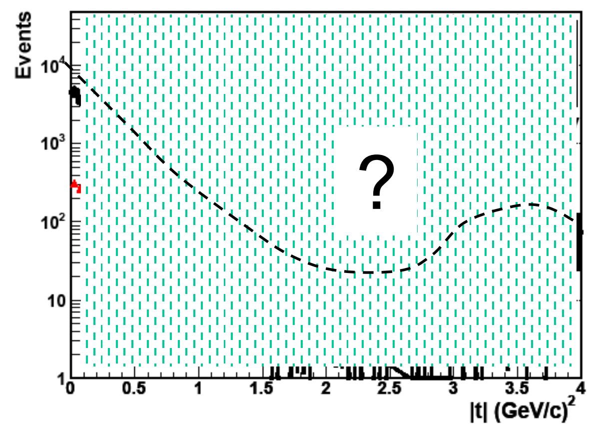
x_{Bj} - distribution



b - slope of t-distribution



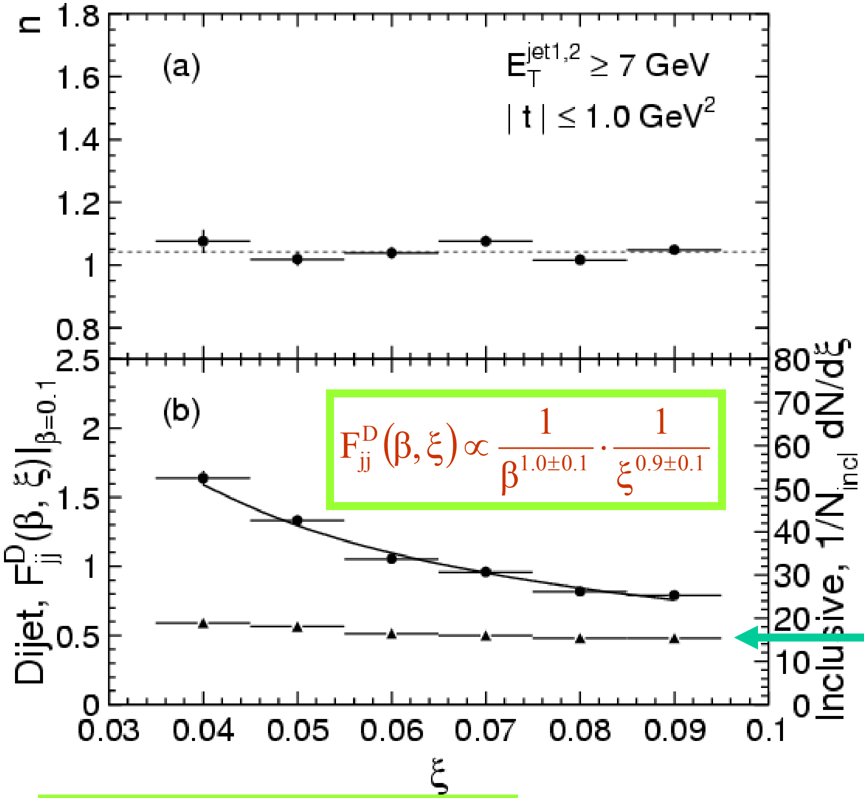
t - distribution



- 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”

ξ & β dependence of F^D_{jj} – Run I

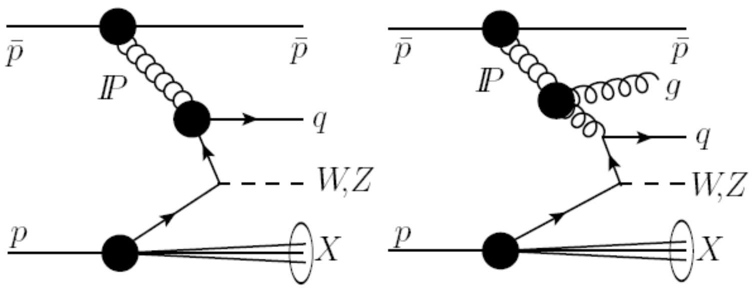


$$\frac{d\sigma_{incl}}{d\xi} \propto \text{constant}$$

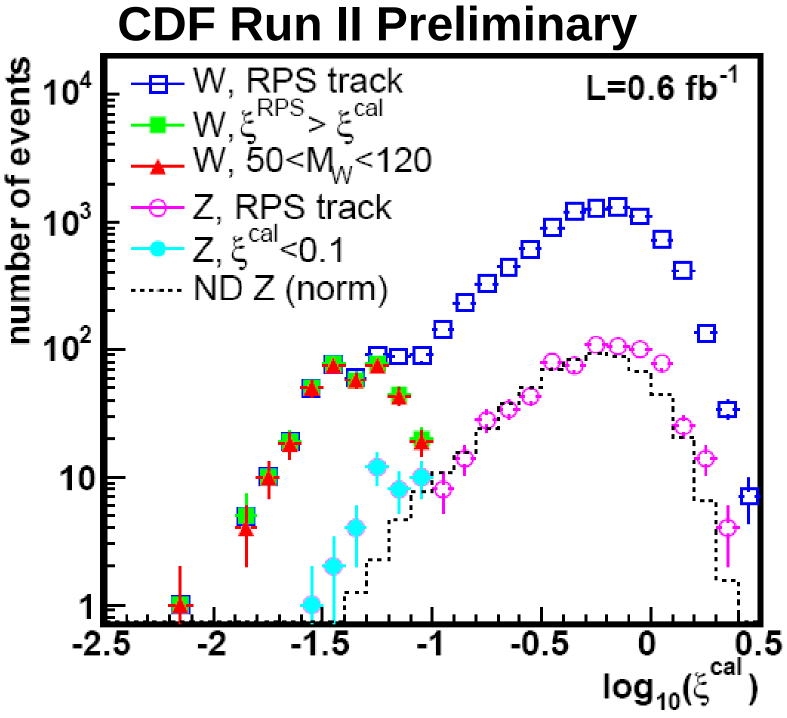
$$F^D_{jj}(\beta,\xi) \sim \frac{1}{\beta} \cdot \frac{1}{\xi}$$

Pomeron dominated

Diffractive *W* / Z - analysis



$$\xi^{\mathrm{cal}}_{\bar{p}} = \sum_{i=1}^{N_{\mathrm{towers}}} \frac{E_{\mathrm{T}}^{i}}{\sqrt{s}} e^{-\eta^{i}}$$



$$\xi^{\mathrm{RPS}} - \xi^{\mathrm{cal}} = \sum_{i=1}^{\text{all towers}} \frac{\not{E}_T^{i}}{\sqrt{s}} e^{-\eta^{\nu}},$$

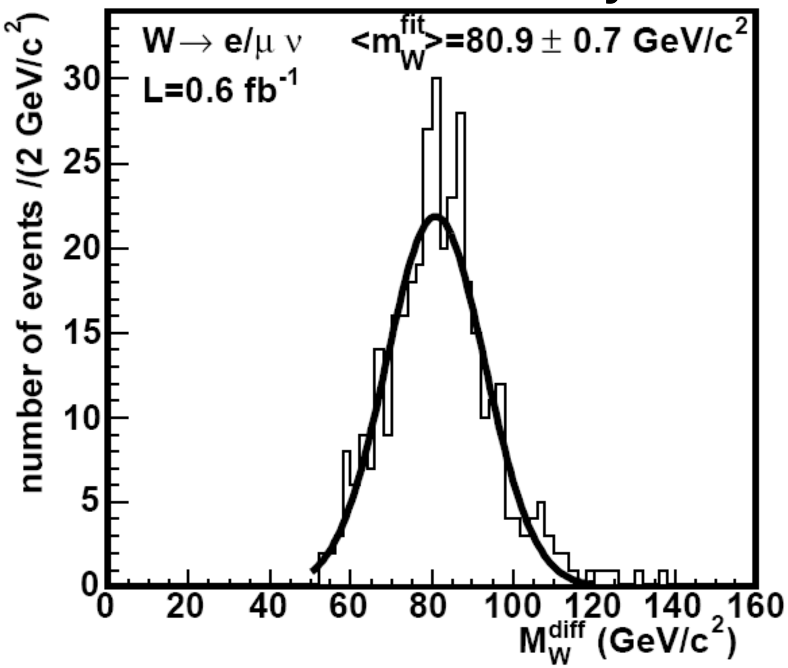
$$p_z^{\nu} = \not{E}_T / \tan\left[2\tan^{-1}\left(e^{-\eta^{\nu}}\right)\right],$$

$$M_{\mathrm{w}}^2 = 2[E_e\sqrt{\not{E}_T^2 + p_z^{\nu\,2}} - p_x^e p_x^{\nu} - p_y^e p_y^{\nu} - p_z^e p_z^{\nu}],$$

$$p_z^{\mathrm{w}} = p_z^e + p_z^{\nu},\;\; E^{\mathrm{w}} = E^e + \sqrt{\not{E}_T^2 + p_z^{\nu\,2}},$$

Diffractive W / Z - results

CDF Run II Preliminary



$$M_W^{PDG} = 80.398 \pm 0.025 \text{ GeV}/c^2$$

Table 1: W and Z events passing successive selection requirements.

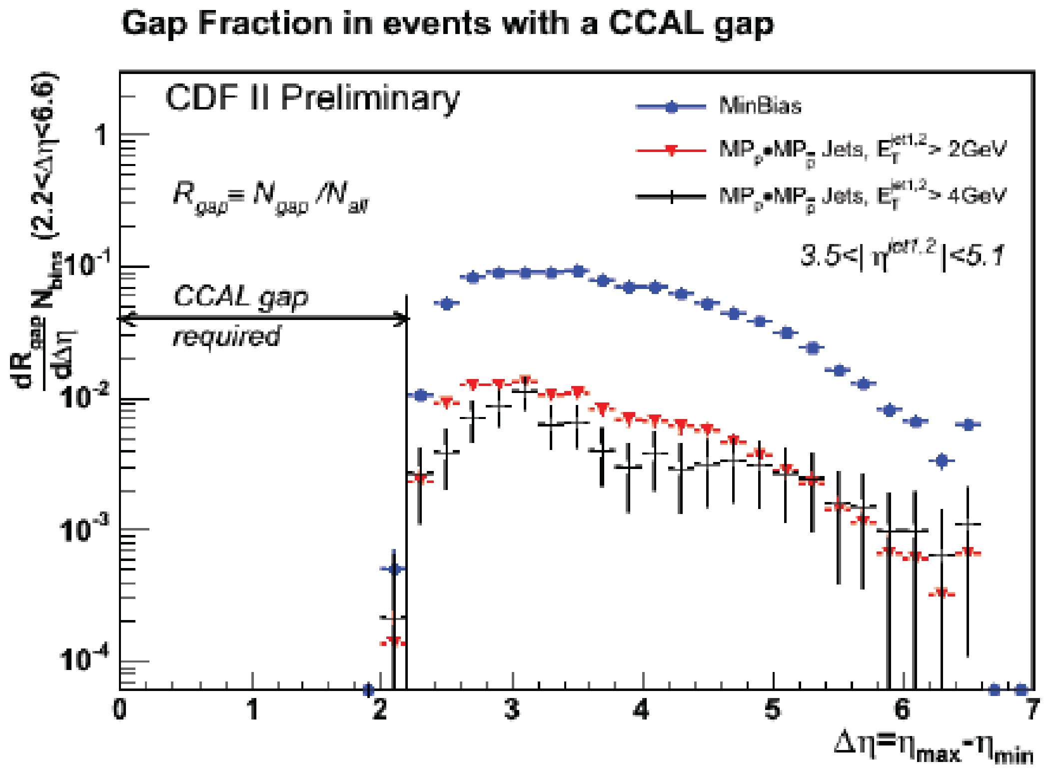
	$W \to e\nu$	$W \to \mu\nu$	$W \to l(e/\mu)\nu$
RPS-trigger-counters	6663	5657	12 320
RPS-track	5124	4201	9325
$50 < M_W < 120$	192	160	352
	$Z \to ee$	$Z \to \mu\mu$	$Z \to ll$
RPS-trigger-counters	650	341	991
RPS-track	494	253	747
$\xi^{cal} < 0.10$	24	12	36

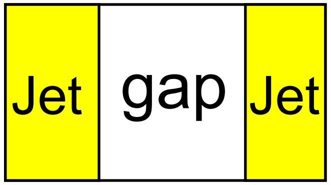
$$R_W(R_Z) = \frac{2 \cdot N_{SD}^W (N_{SD}^Z)}{R_{RPS} \cdot \epsilon_{\text{RPStrig}} \cdot \epsilon_{\text{RPStrk}} \cdot N_{ND}^{1-\text{int}}}$$

$$R_{\text{W}} = [0.97 \pm 0.05\,(\text{stat.}) \pm 0.10(\text{ syst.})]\%$$

$$R_{\text{Z}} = [0.85 \pm 0.20(\text{ stat.}) \pm 0.08(\text{ syst.})]\%$$

CENTRAL GAPS



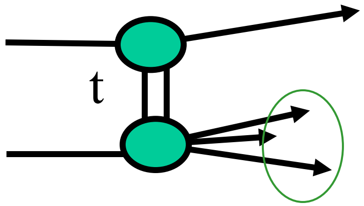


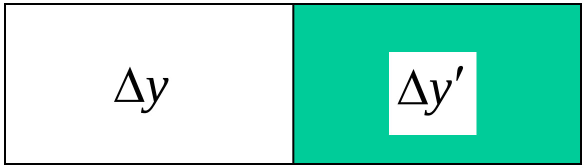
The distribution of the gap fraction $R_{gap}=N_{gap}/N_{all}$ vs $\Delta\eta$ for MinBias ($CLC_p \cdot CLC_{pbar}$) and MiniPlug jet events ($MP_p \cdot MP_{pbar}$) of $E_{T(jet1,2)}>2$ GeV and $E_{T(jet1,2)}>4$ GeV.

The distributions are similar in shape within the uncertainties.

DIFFRACTION PHENOMENOLOGY

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

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

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

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

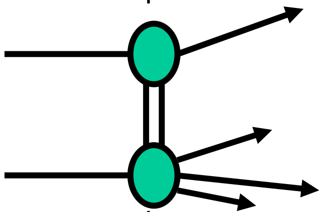
Grows slower than s^{ε}

→ 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



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

s_0^{ε}

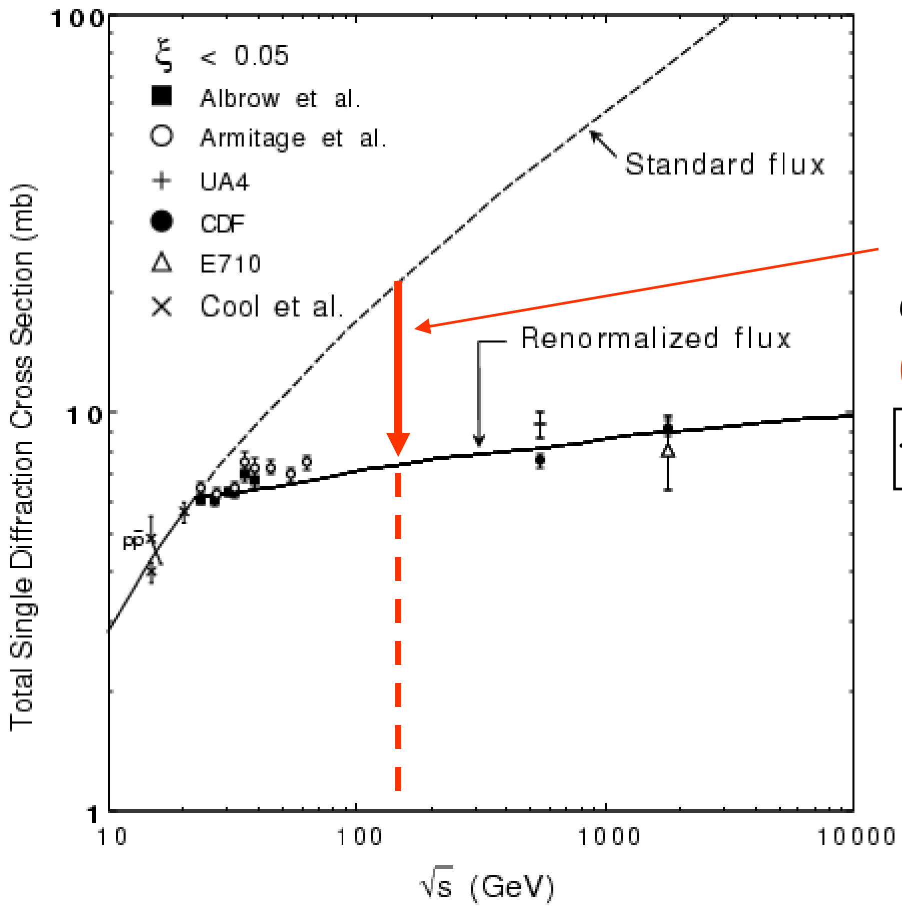
$s_0^{-\varepsilon/2}\cdot g_{PPP}(t)$

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)

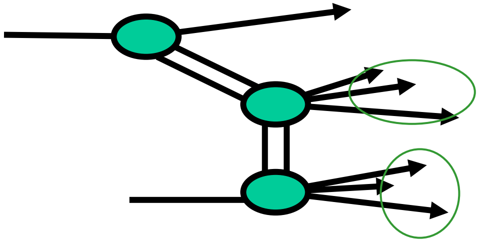


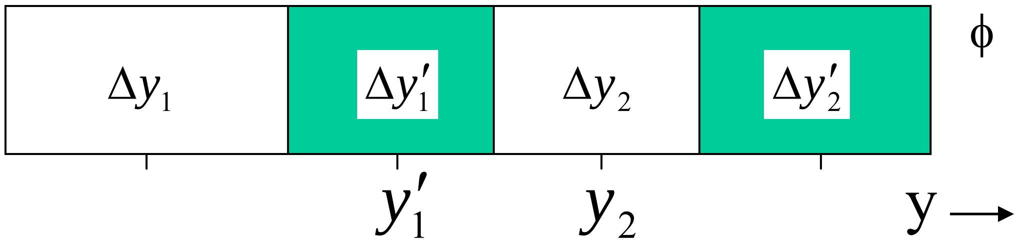
Factor of ~3 suppression expected at W~200 GeV
(just as in pp collisions)

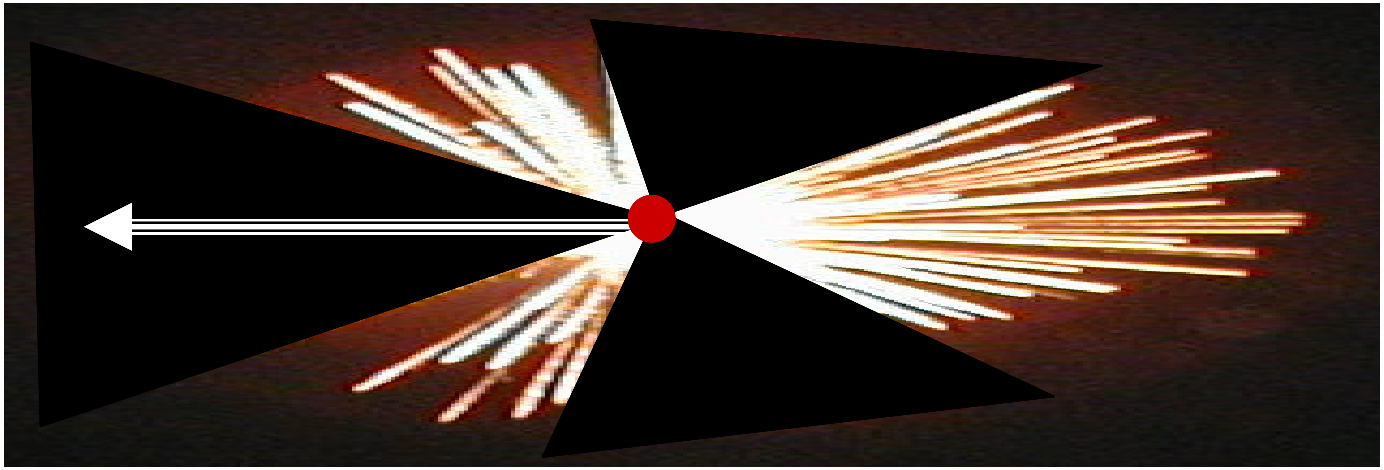
for both direct and resolved components

Multi-gap Diffraction

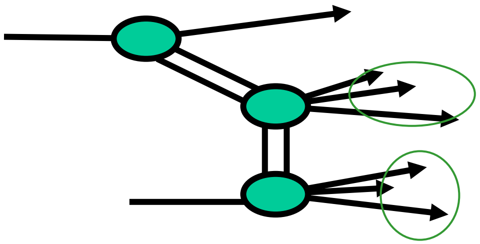
(KG, hep-ph/0205141)

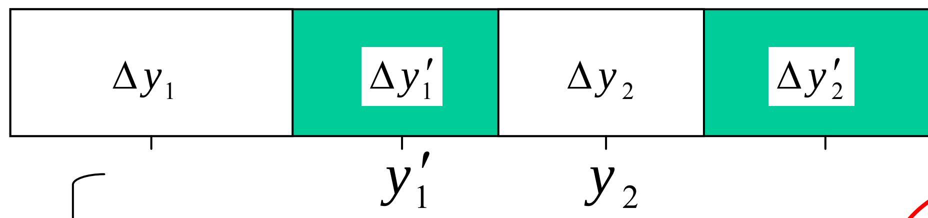






Multi-gap Cross Sections





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

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

color factor (κ^2)

Gap probability

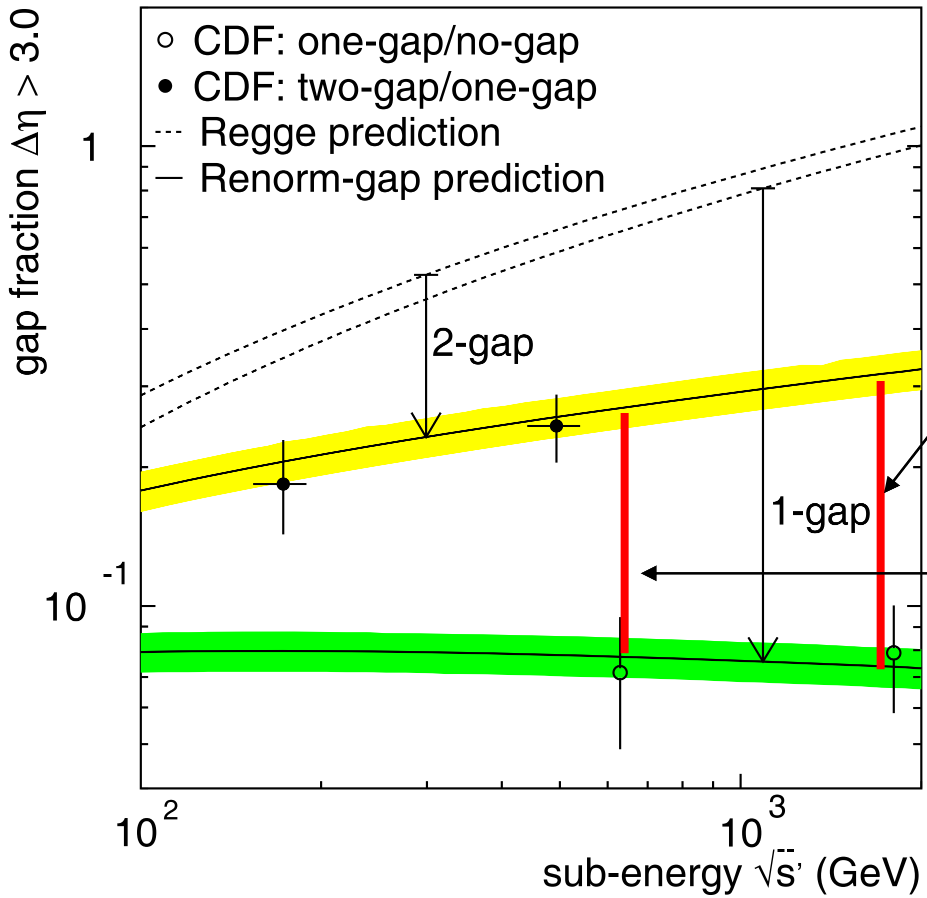
$$\int_{\Delta y, t} \sim s^{2\varepsilon} / \ln s$$

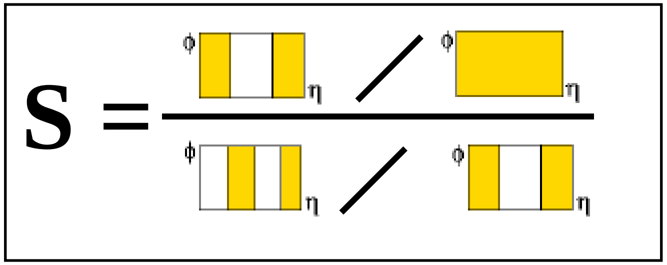
Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

Rapidity Gaps in Fireworks

“Gap survival probability”



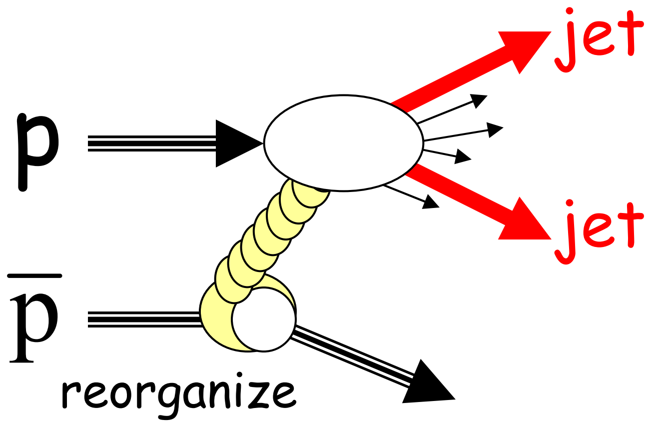


$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \text{GeV}) \approx 0.23$$

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

Hard Diffraction Phenomenology

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

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

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

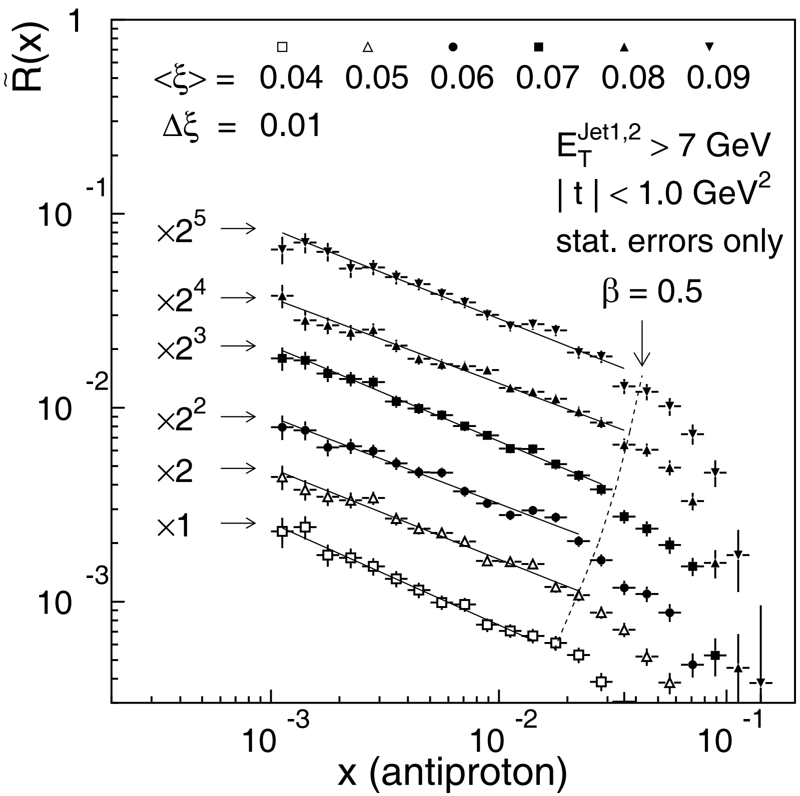
$$\text{RENORM} \quad \Rightarrow \quad R^{SD}_{ND}(x) = \frac{2\varepsilon}{s^{2\varepsilon}}\frac{1}{\xi^{1-\lambda(Q^2)}}\cdot x^{-(2\varepsilon)}$$

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

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

CDF Run I

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



0.035 < ξ < 0.095

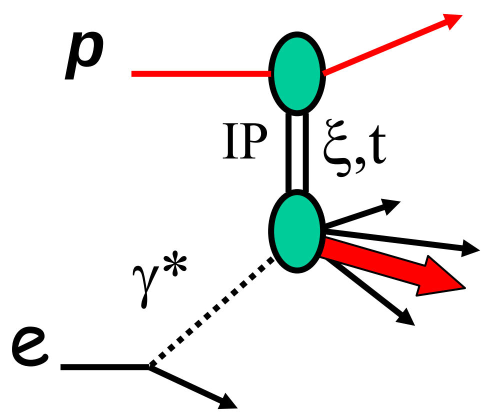
Flat ξ dependence for β < 0.5

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

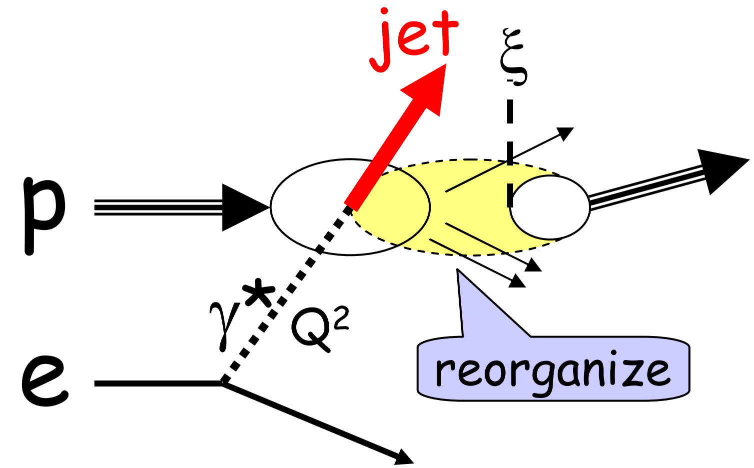
Diffractive DIS @ HERA

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

Pomeron exchange



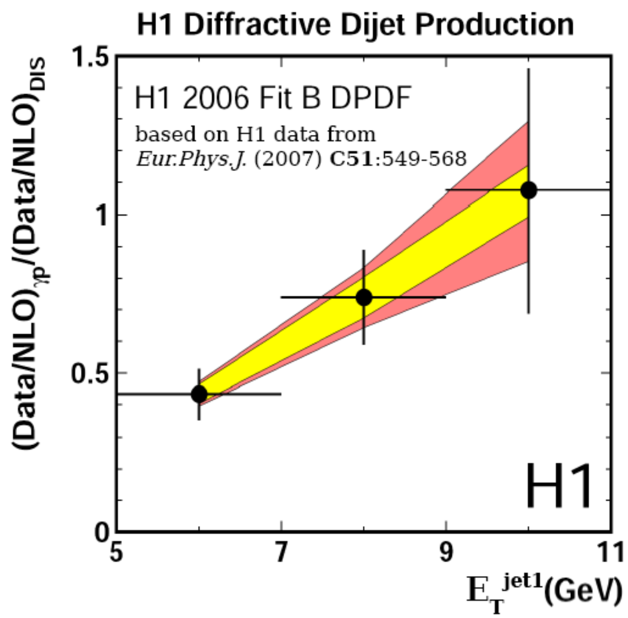
Color reorganization



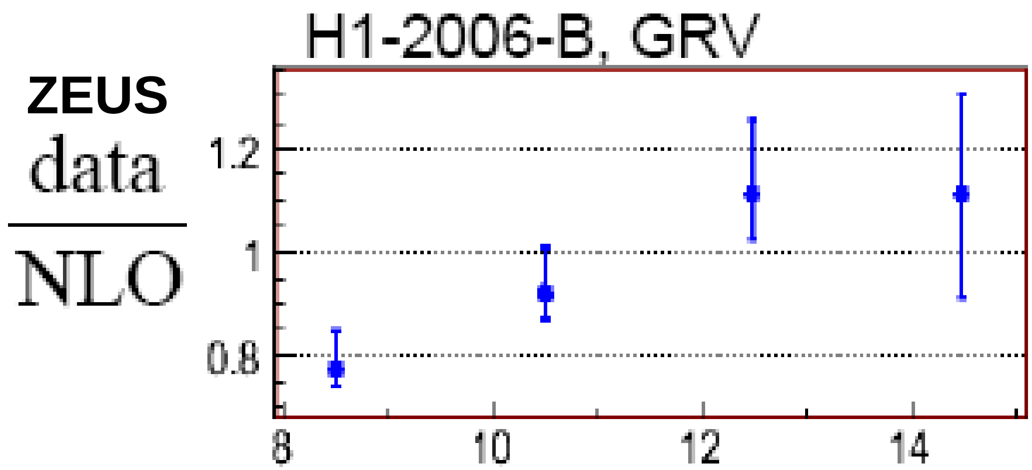
$$F_2^{D(3)}(\xi, x, Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F_2(x, Q^2)$$

Results favor color reorganization

Dijets in γp at HERA - 2008



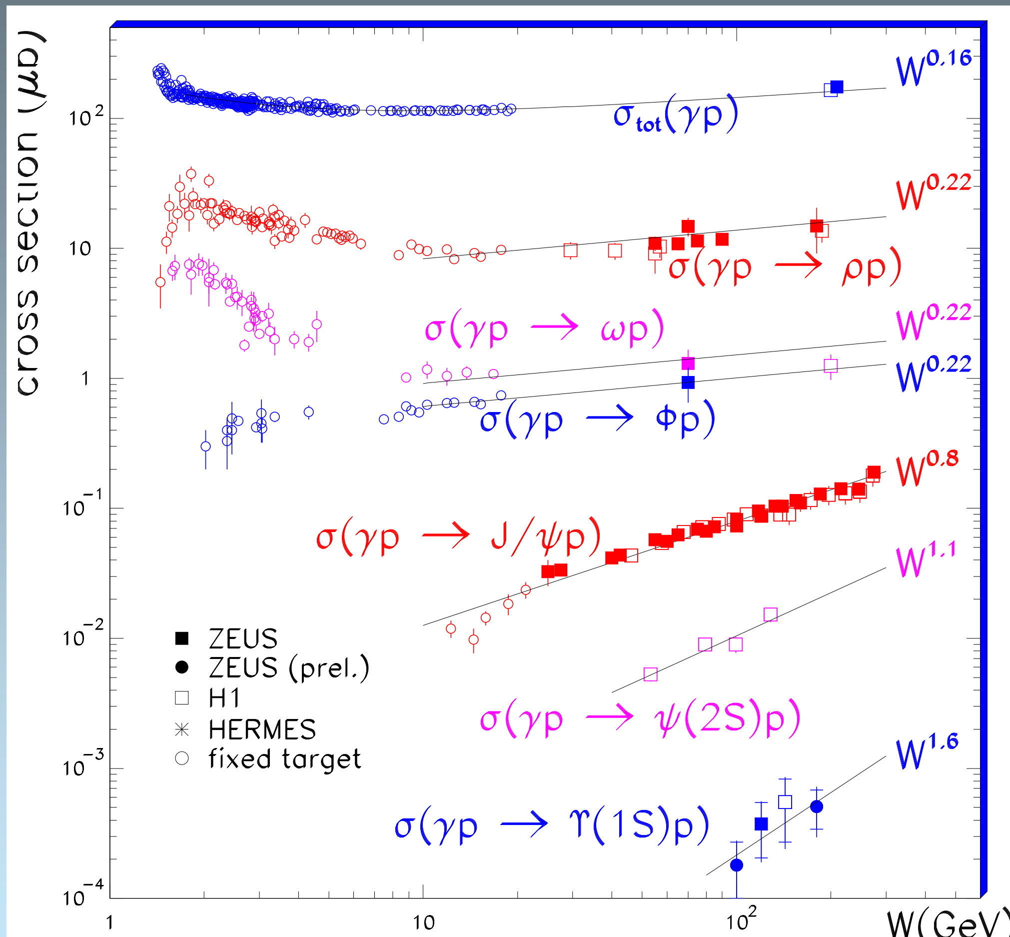
DIS 2008 talk by W. Słomiński,

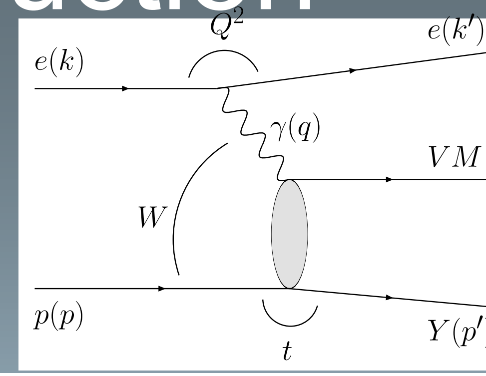


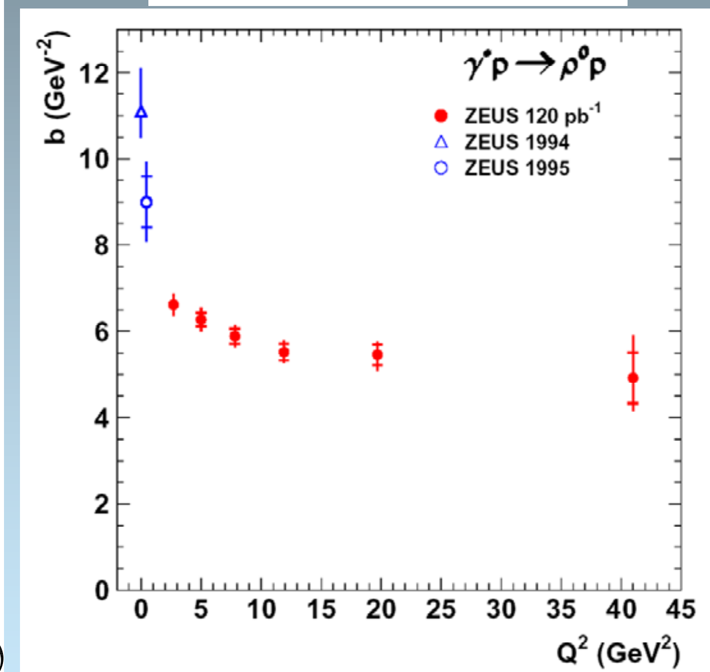
- ❑ 20-50 % apparent rise when E_T^{jet} 5→10 GeV
- ➔ due to suppression at low E_T^{jet} !!!

Vector meson production

(Pierre Marage, HERA-LHC 2008)





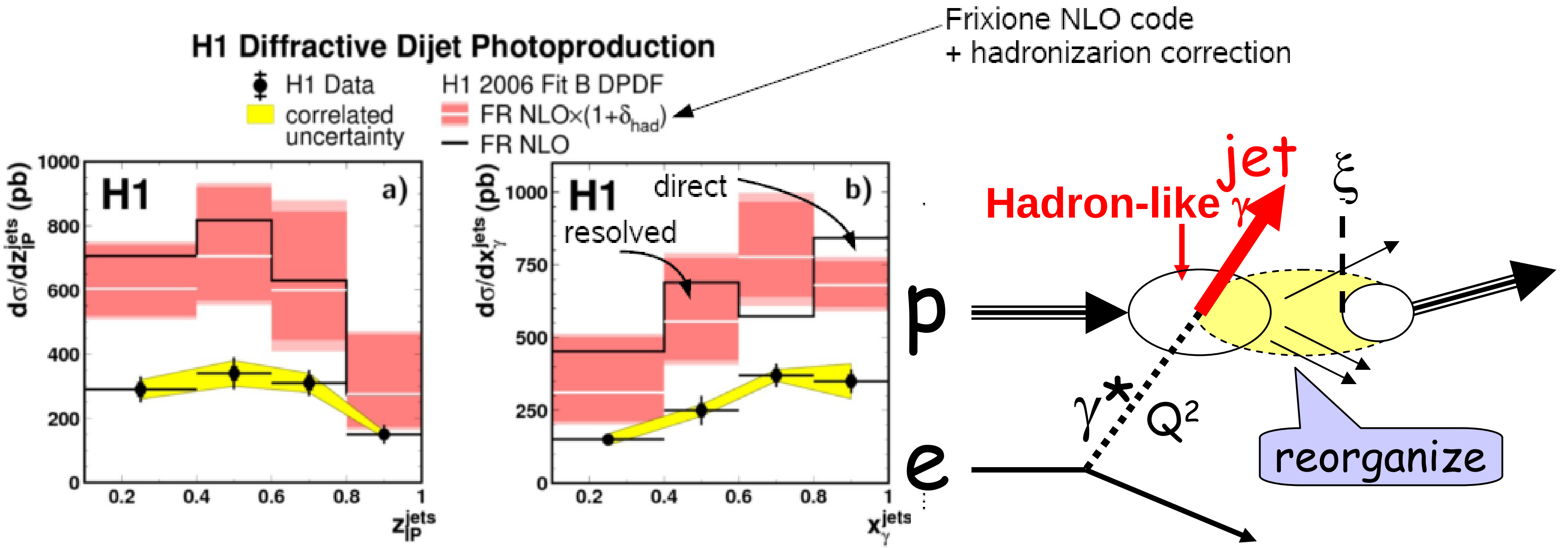


- *left* - why different σ vs. W slopes? ➔ more room for particles
- *right* - why smaller b-slope in γ*p? ➔ same reason

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

Pomeron α'/ε and σ_t in a QCD inspired parton model approach

σ^{SD} and ratio of α'/ε

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

Pomeron intercept and slope: A QCD connection

Konstantin Goulianos

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

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

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

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

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

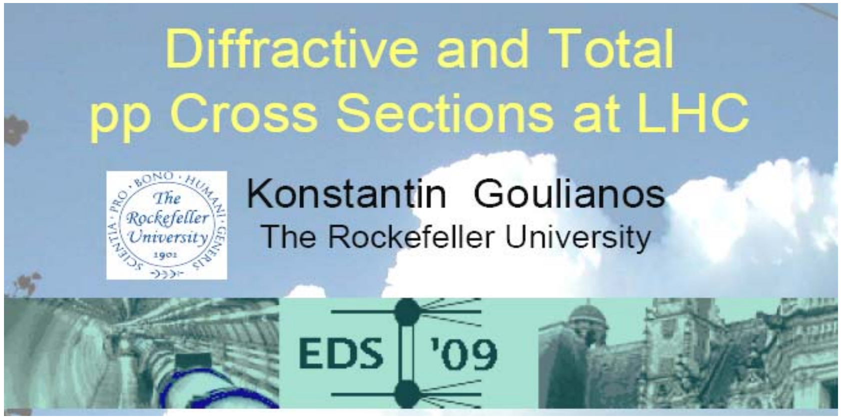
$$\kappa = \frac{f_g^\infty}{N_c^2-1} + \frac{f_q^\infty}{N_c}$$

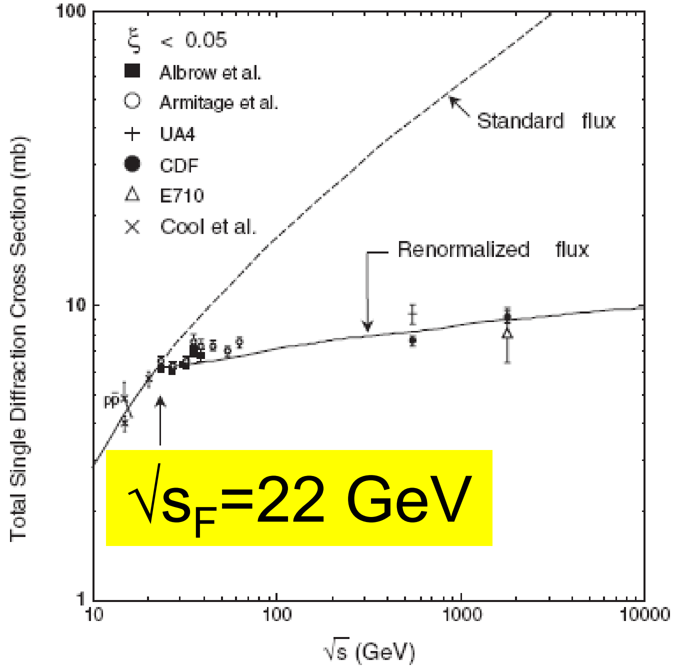
$$b_\circ = R_p^2/2 = 1/(2m_\pi^2).$$

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

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

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





- 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

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

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

Monte Carlo Strategy for the LHC

MONTE CARLO 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 pp collisions at the IP - p sub-energy √s'

σ_T
↕ **optical theorem**
Im $f_{el}(t=0)$
↕ **dispersion relations**
Re $f_{el}(t=0)$

See K. Goulianos, Phys. Lett. B 193 (1987) 151 pp
"A new statistical description of hardonic and e+e− multiplicity distributions "

CONCUSION

stay tuned …

The first CMS event