Diffraction at CDF and at the LHC

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LOW X MEETING:

HOTEL VILLA SORRISO, ISCHIA ISLAND, ITALY, September 8-13 2009

theme:

factorization breaking in diffraction

- pp and $\bar{p}$p results
- γp and γ^*p results
- renormalization: *the common thread*
- diffraction at the LHC

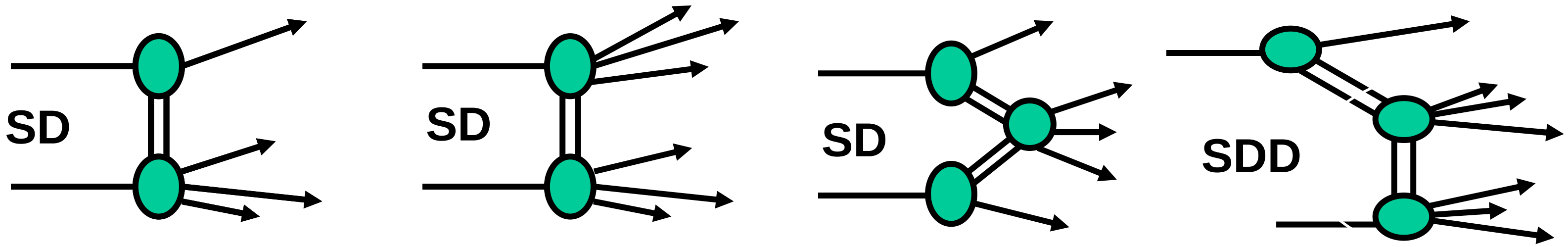
pp and $\bar{p}p$ results

$\bar{p}p$ results from CDF

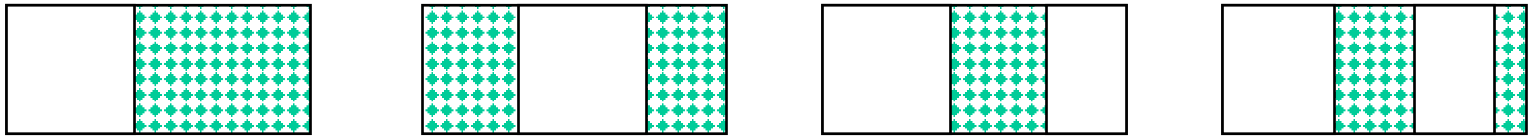
http://physics.rockefeller.edu/publications.html#diffraction

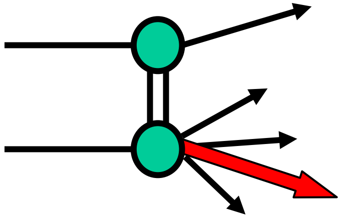
see also CDF talks in this conference by M. Albrow and J. Pinfold

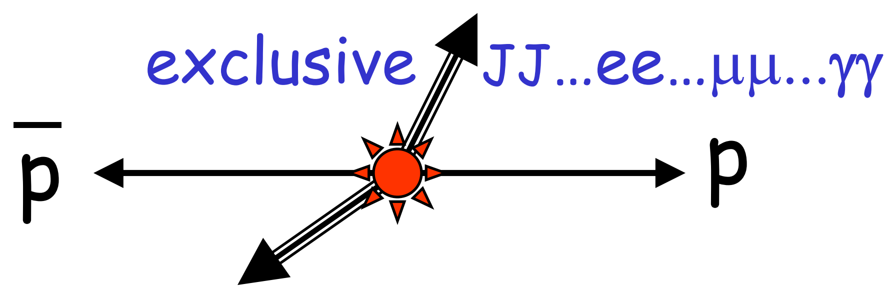
soft and hard diffractive processes studied at CDF



Single **D**iffraction dissociation (**SD**) | **D**ouble **D**iffraction dissociation (**DD**) | **D**ouble **P**omeron **E**xchange (**DPE**) | **S**ingle + **D**ouble **D**iffraction (**SDD**)

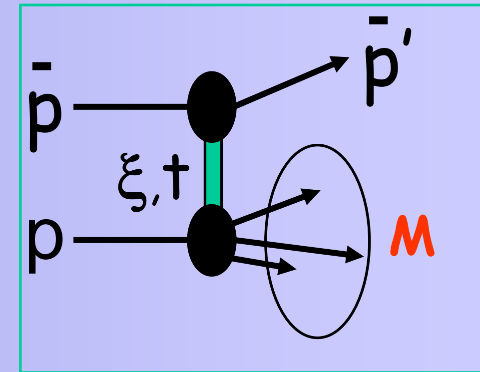




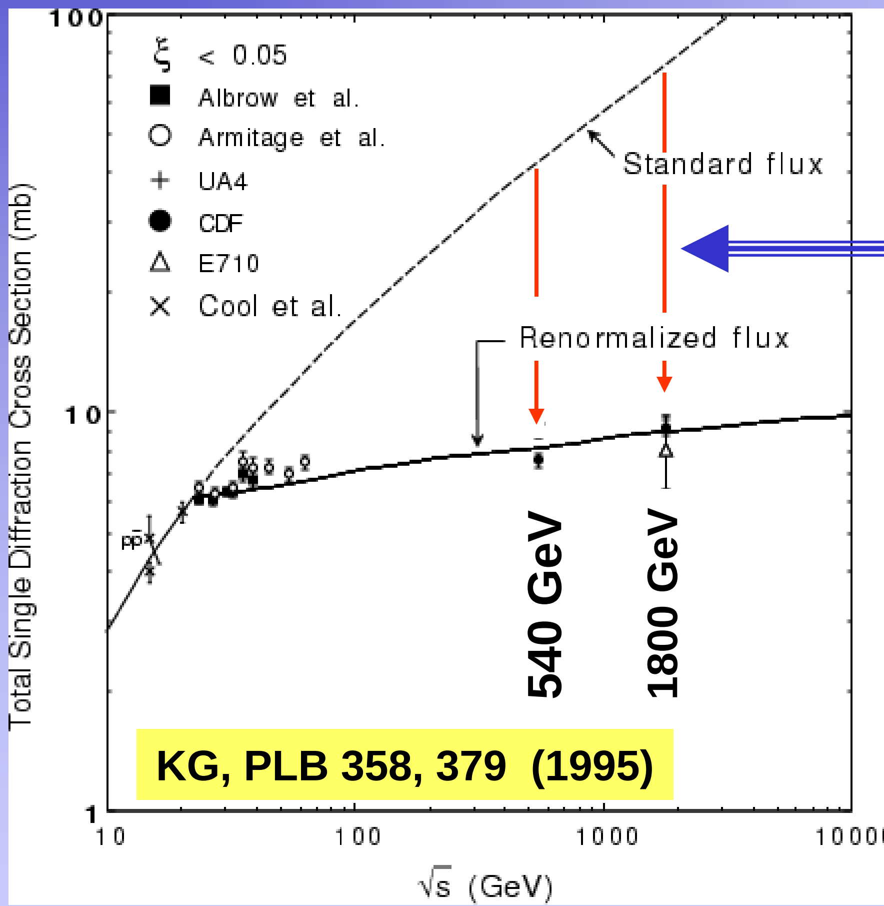


σ^T_{SD} (pp & $\bar{p}$p)

➔ suppressed relative to Regge prediction



σ^T_{SD} mb



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

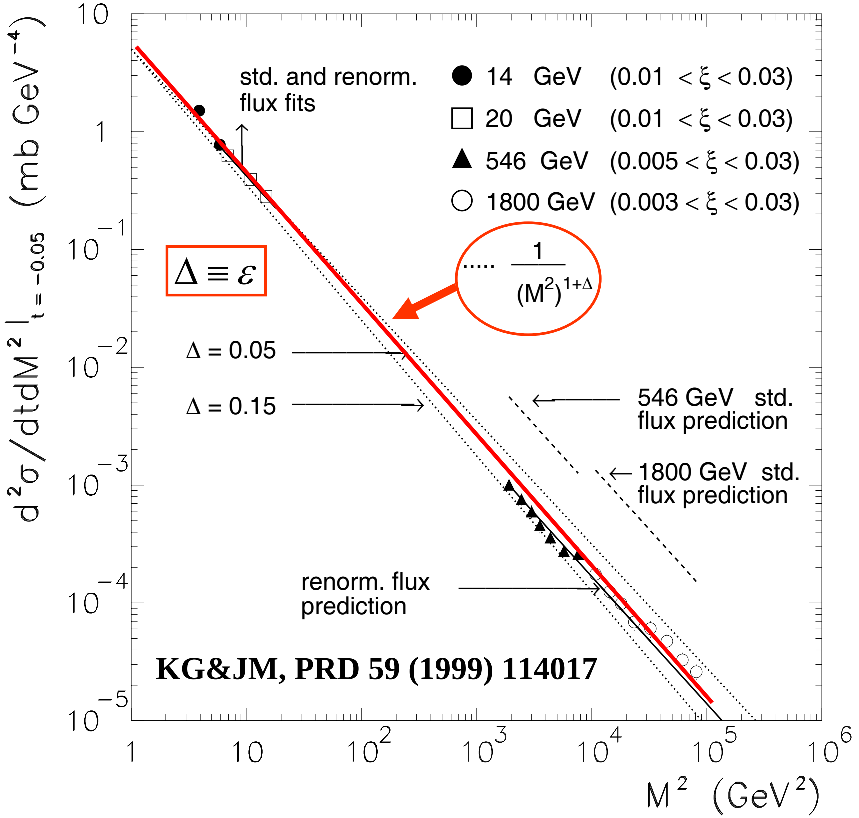
M^2 scaling

➔ $d\sigma/dM^2$ independent of s over 6 orders of magnitude!

renormalization

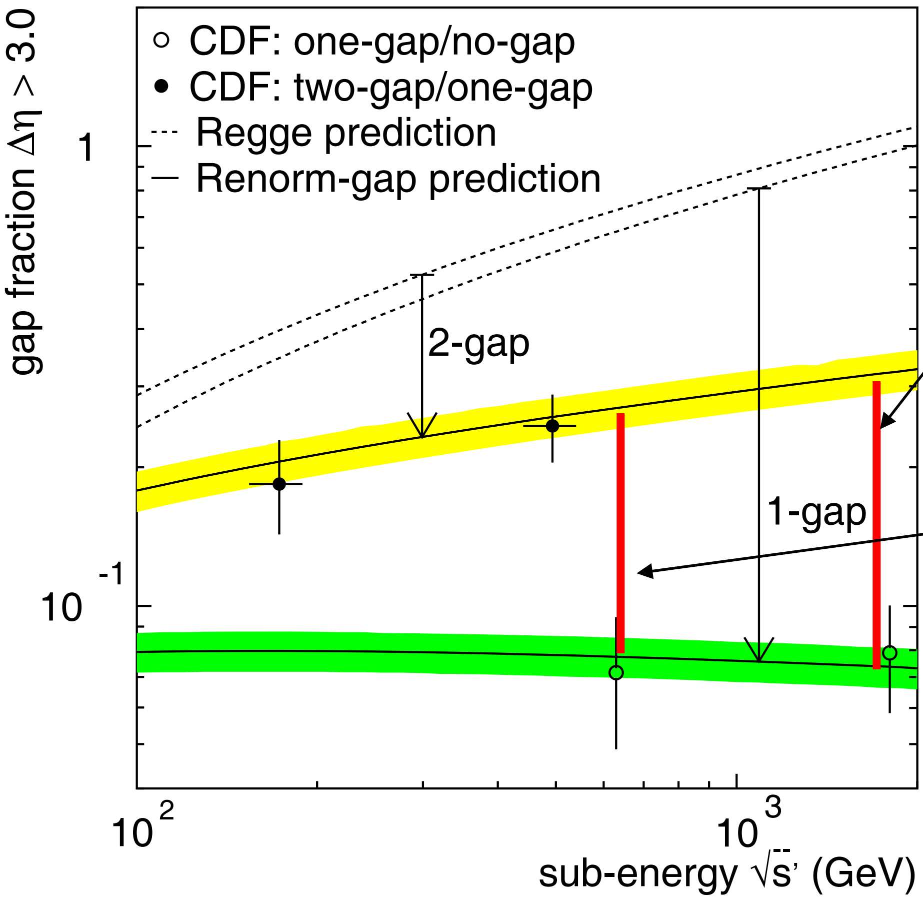
$$\frac{d\sigma}{dM^2} \propto \frac{s^{2\varepsilon} \rightarrow 1}{(M^2)^{1+\varepsilon}}$$

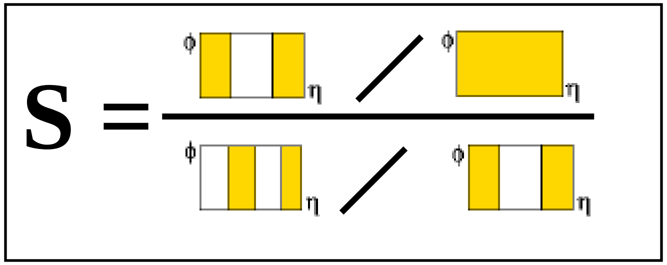
➔ Independent of s over 6 orders of magnitude in M^2!



➔ factorization breaks down to ensure M^2 scaling!

Gap survival probability - S

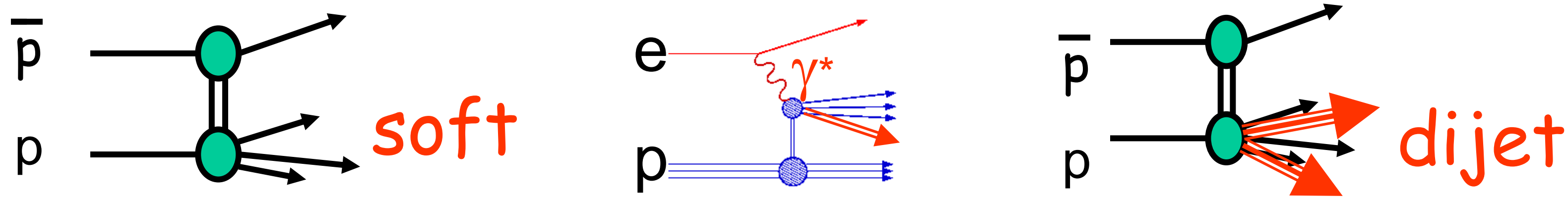


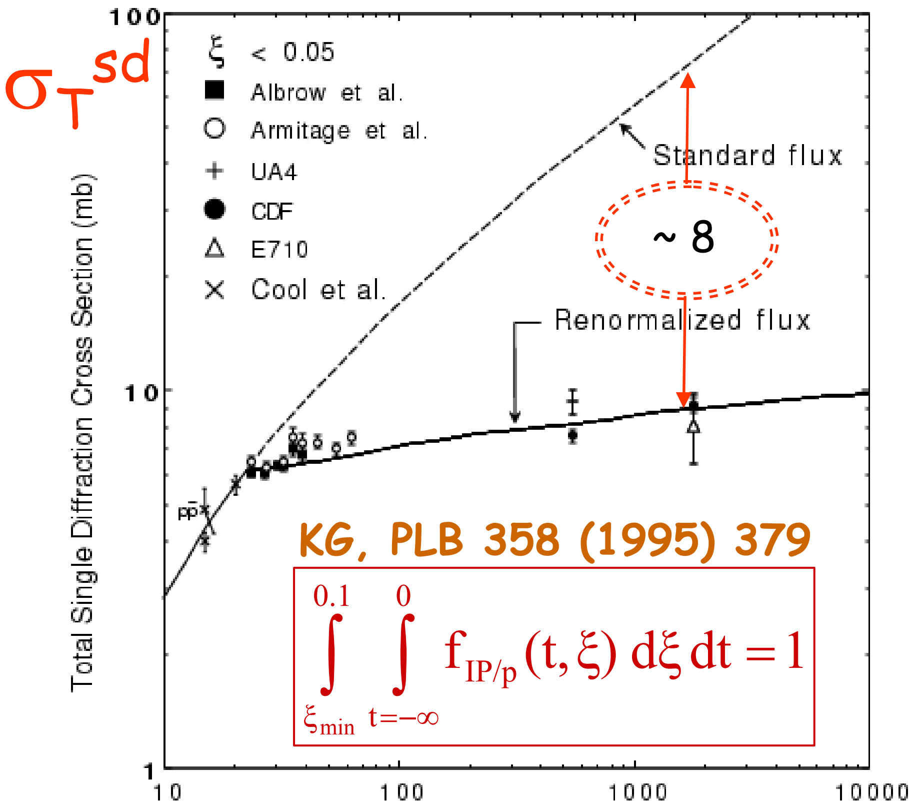


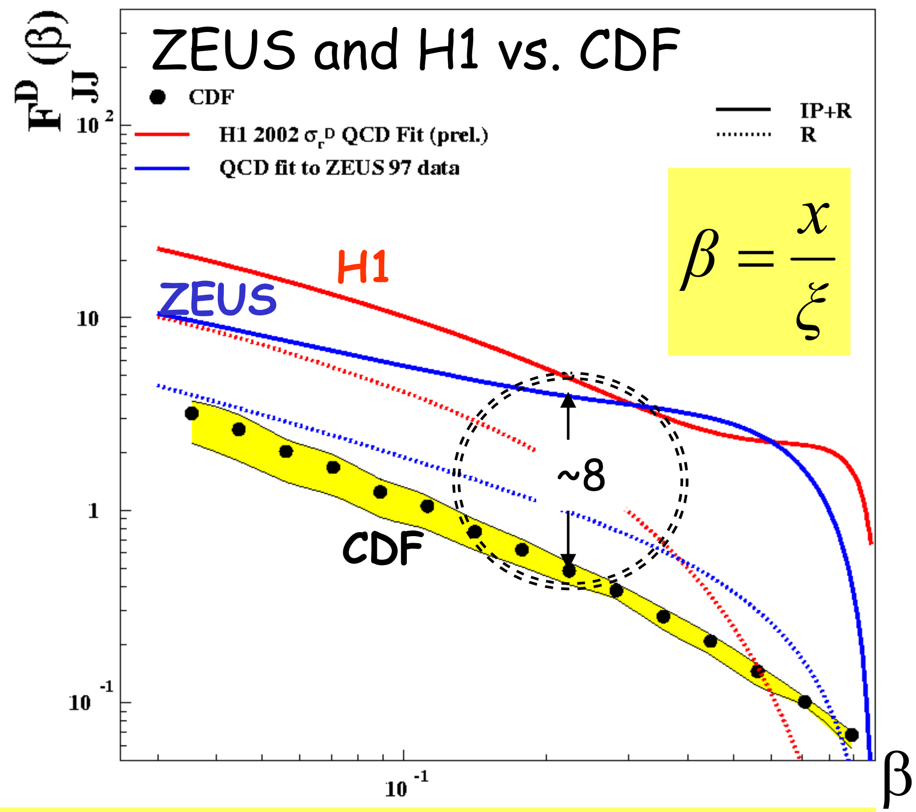
$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \mathrm{GeV}) \approx 0.23$$

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

σ^T_{SD} and dijets

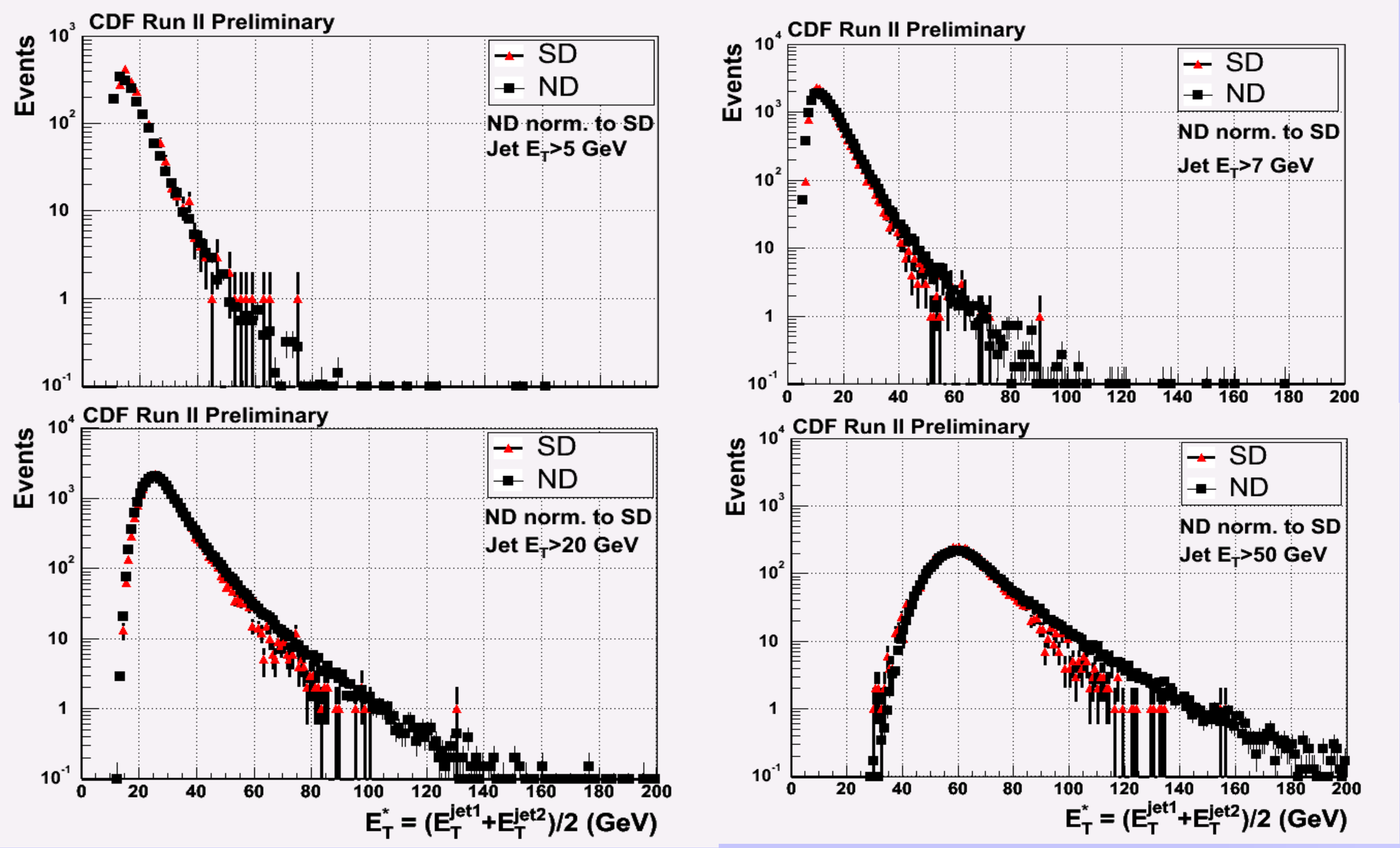






Magnitude: same suppression factor in soft and hard diffraction!
Shape of β distribution: ZEUS, H1, and Tevatron – why different slapes?

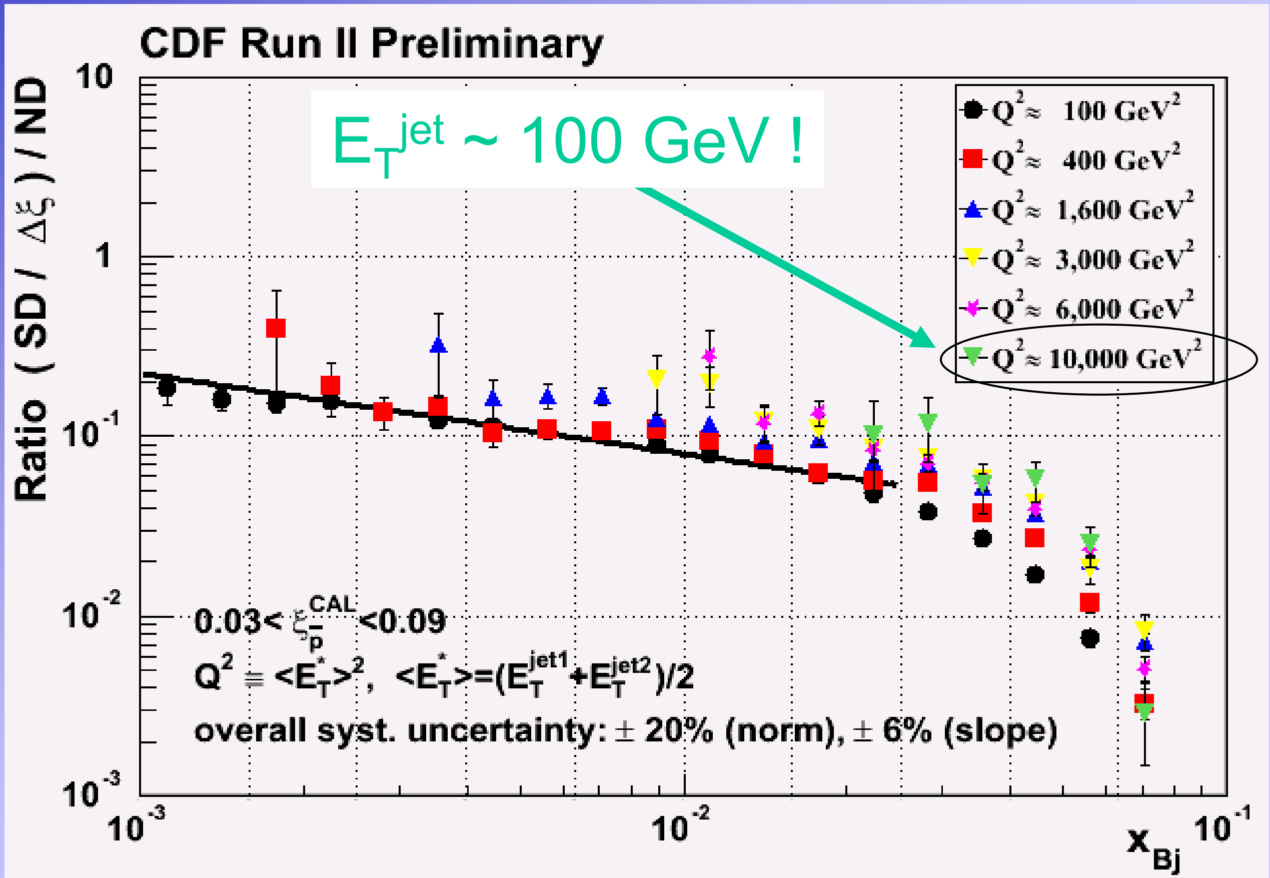
Dijets - E_T distributions



→ similar for SD and ND over 4 orders of magnitude

Kinematics

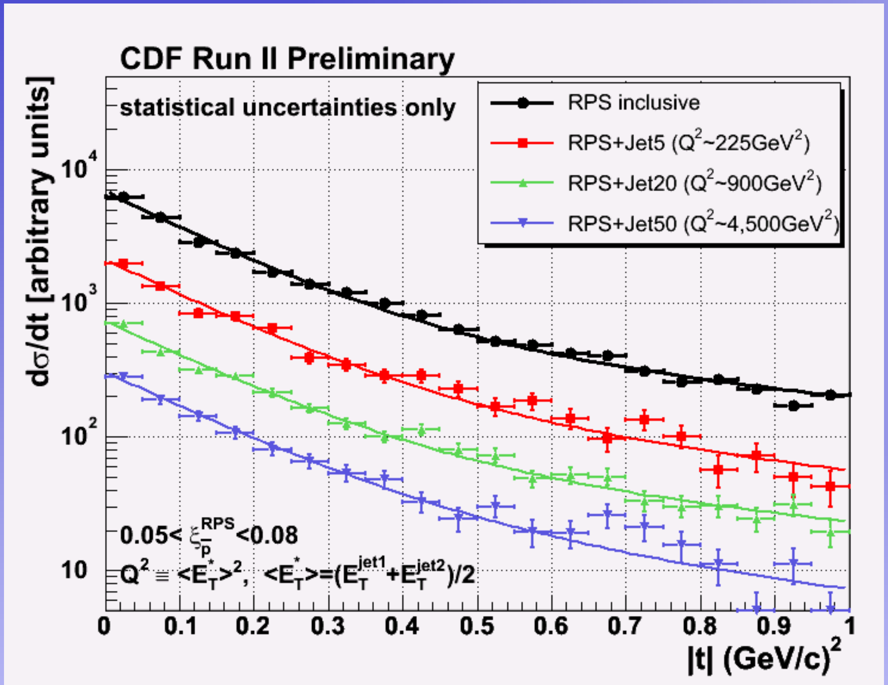
Dijets: diffractive structure function x_{Bj} and Q^2 dependence

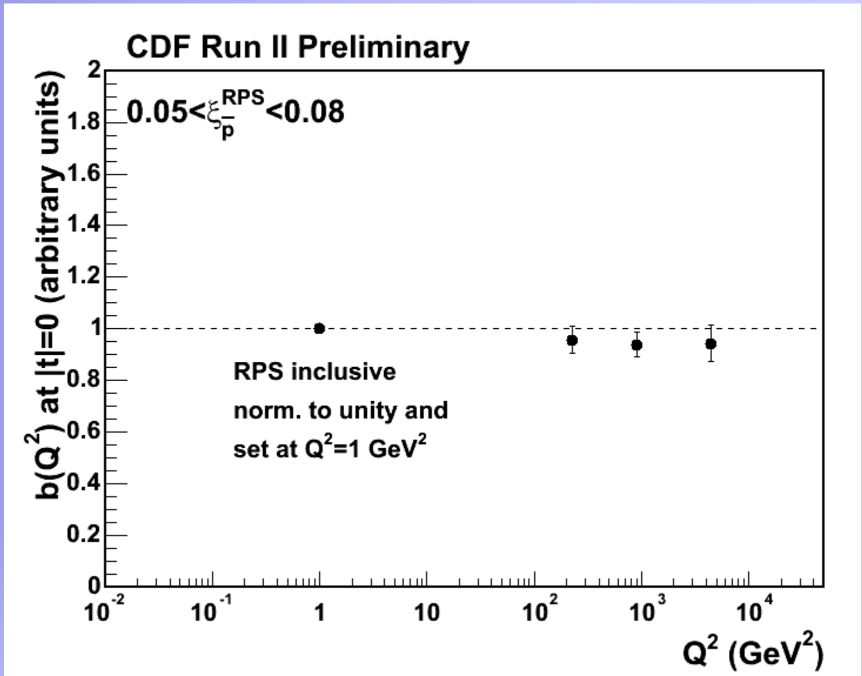


Small Q^2 dependence in region $100 < Q^2 < 10{,}000$ GeV^2

⇨ Pomeron evolves as the proton!

Dijets - diffractive structure function
t- dependence





Fit dσ/dt to a double exponential

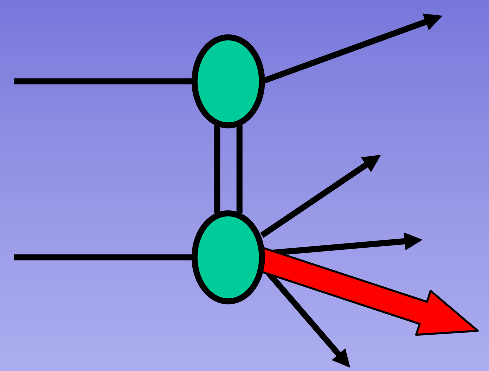
$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

- No Q2 dependence in slope from inclusive to Q^2~10^4 GeV^2

- Same slope over entire region of ~1< Q^2 < 4,500 GeV^2

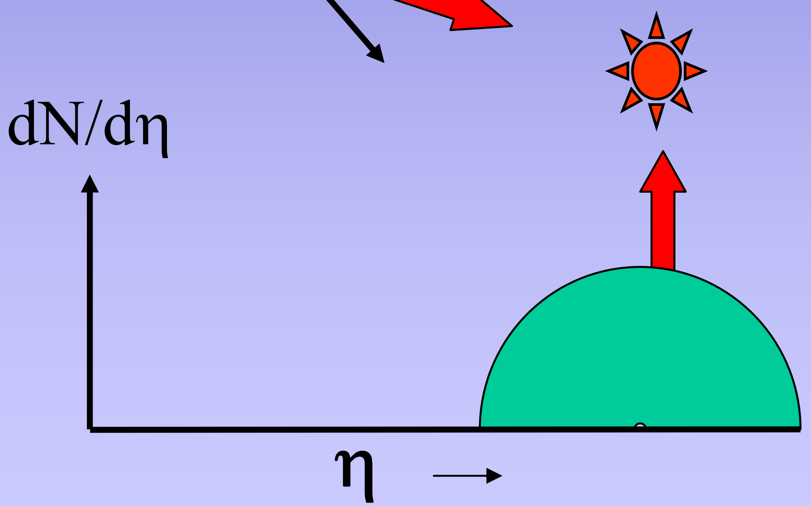
Hard diffractive fractions

$$\bar{p}p \to (☼ + X) + \text{gap}$$



<u>Fraction: SD/ND</u>
@ 1800 GeV

Run I

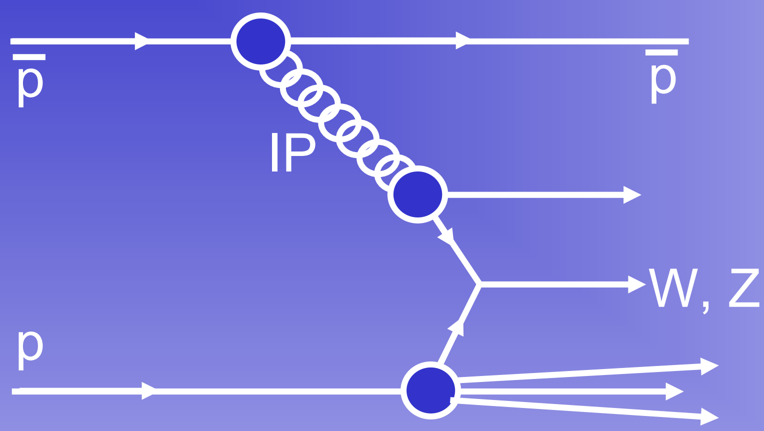


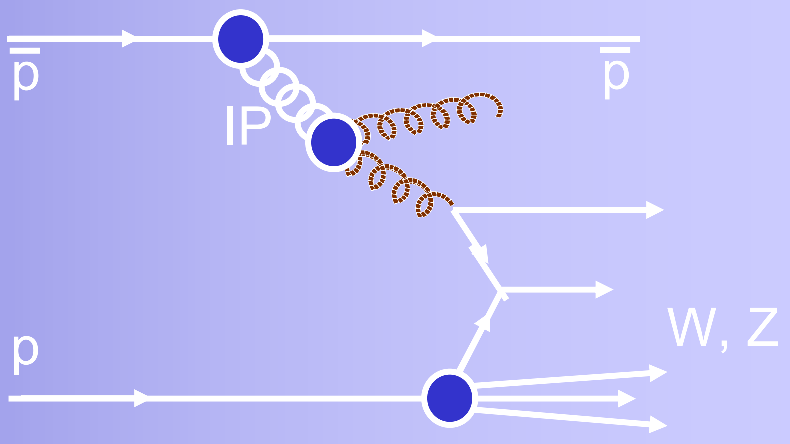
	Fraction (%)
JJ	0.75 +/- 0.10
W	0.115 +/- 0.55
b	0.62 +/- 0.25
J/ψ	1.45 +/- 0.25

All fractions ~ 1%
(differences due to kinematics)

- ~ uniform suppression
- ~ FACTORIZATION !

Diffractive W/Z production - Run II





- Diffractive W production probes the quark content of the Pomeron
- Production by gluons is suppressed by a factor of α_S

DIFFRACTIVE FRACTIONS

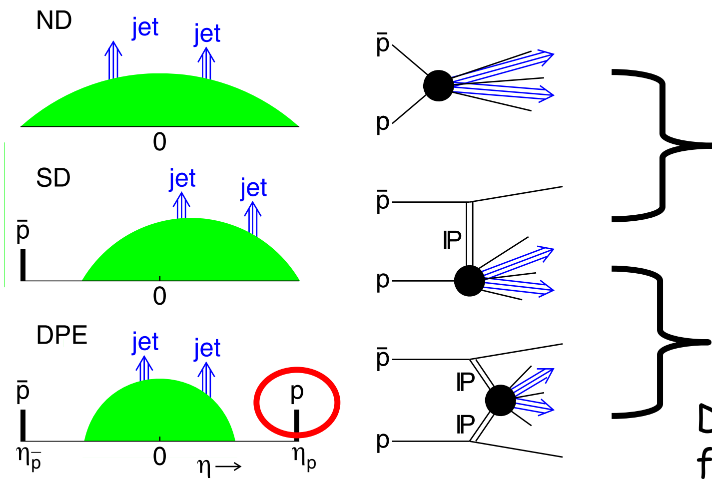
R^W $(0.03 < \xi < 0.10, |t|<1)= [0.97 \pm 0.05(stat) \pm 0.11(syst)]\%$

Run I: R^W =1.15±0.55 % for $\xi<0.1$ ➔ estimate **0.97±0.47 %** in **$0.03 < \xi < 0.10$ & $|t|<1$)**

R^Z $(0.03 < x < 0.10, |t|<1)= [0.85 \pm 0.20(stat) \pm 0.11(syst)]\%$

➔ Fractions R^W and R^Z are equal within uncertainties

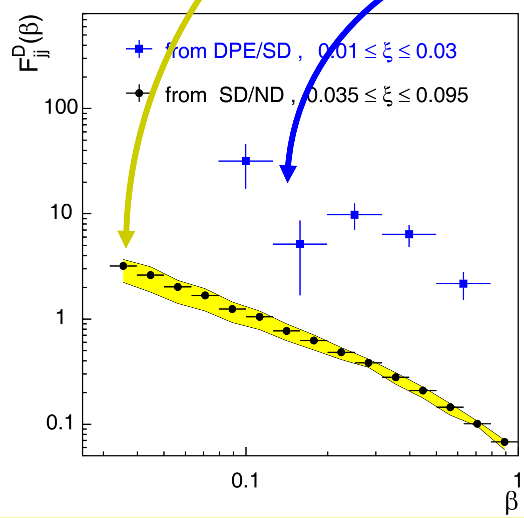
Multi-gap dijets - factorization restored!

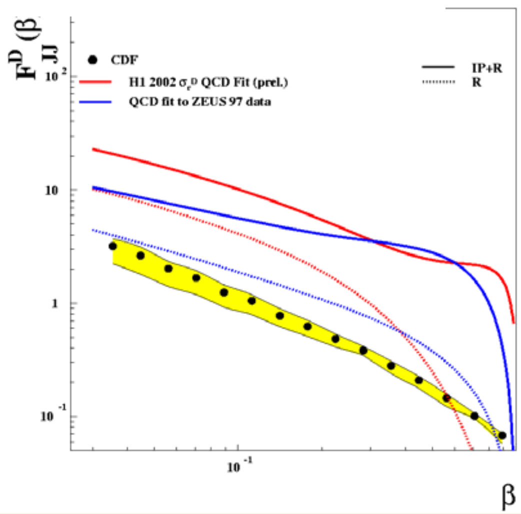


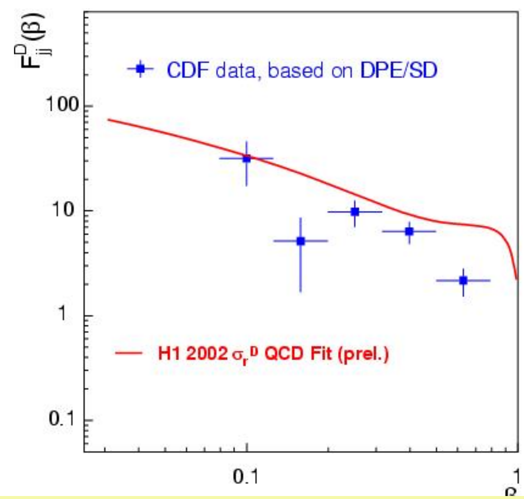
R(SD/ND)

R(DPE/SD)

DSF from ratio of two/one gap: factorization restored!



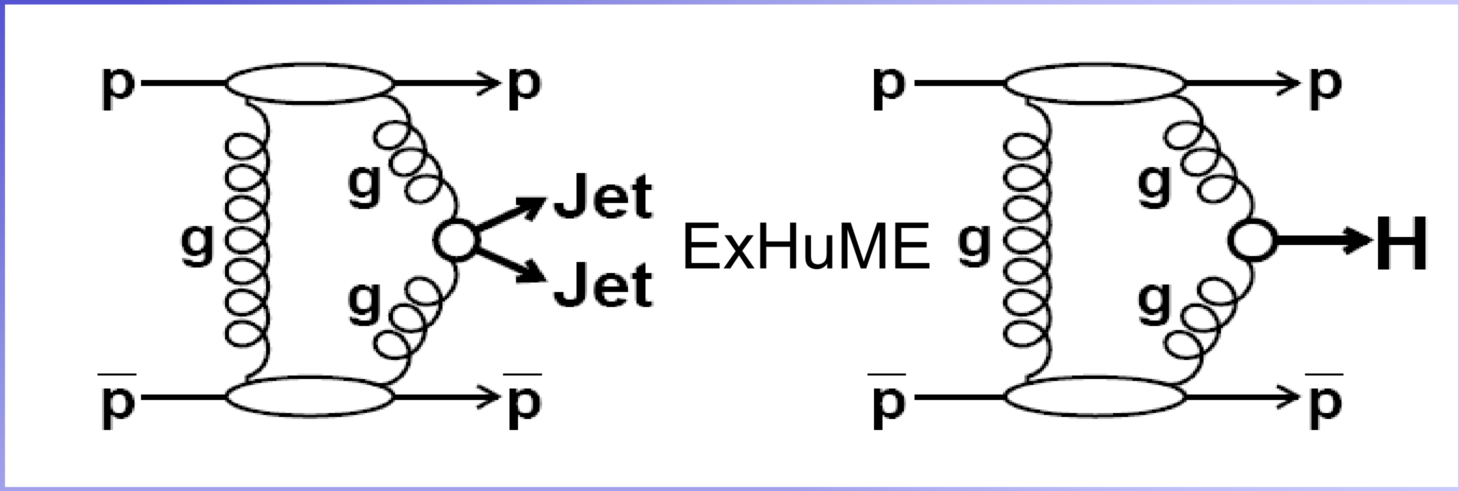


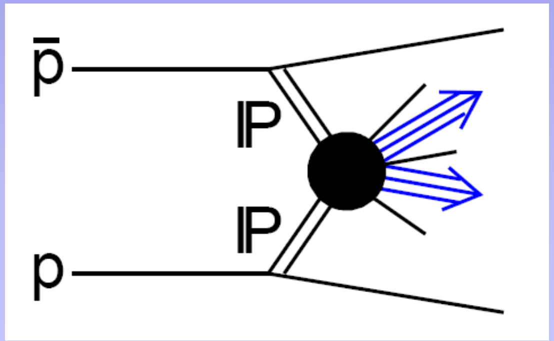


The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS

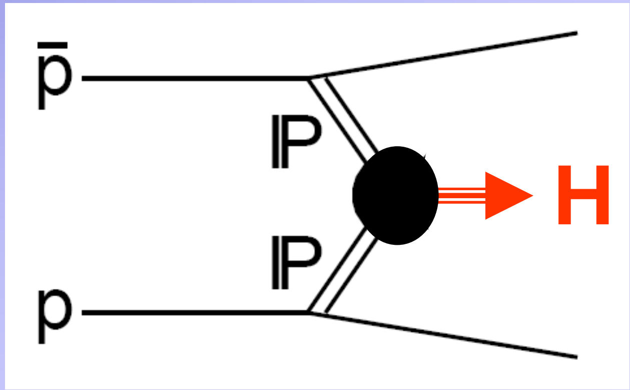
Exclusive dijet and Higgs production

Phys. Rev. D 77, 052004



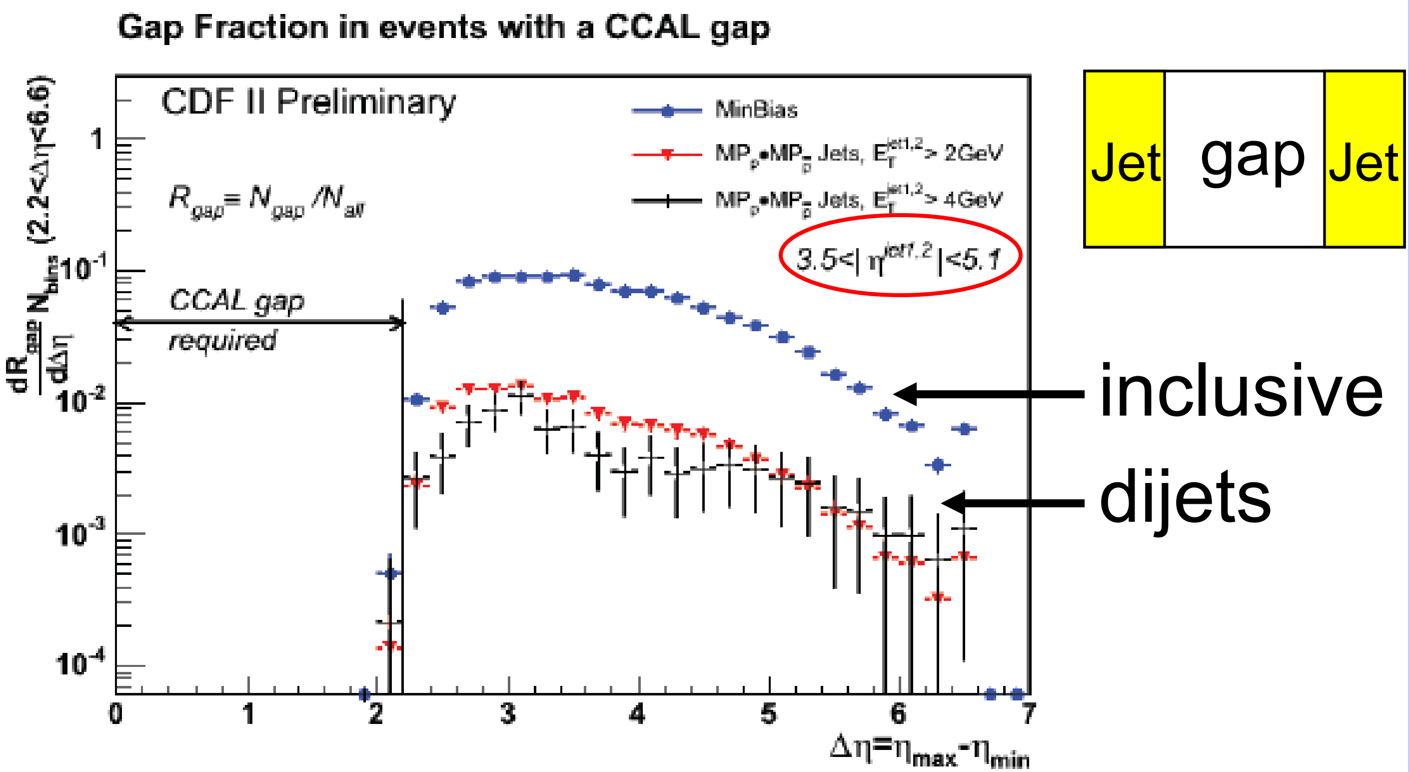


DPEMC



suppression factor ~ 50

Central gaps



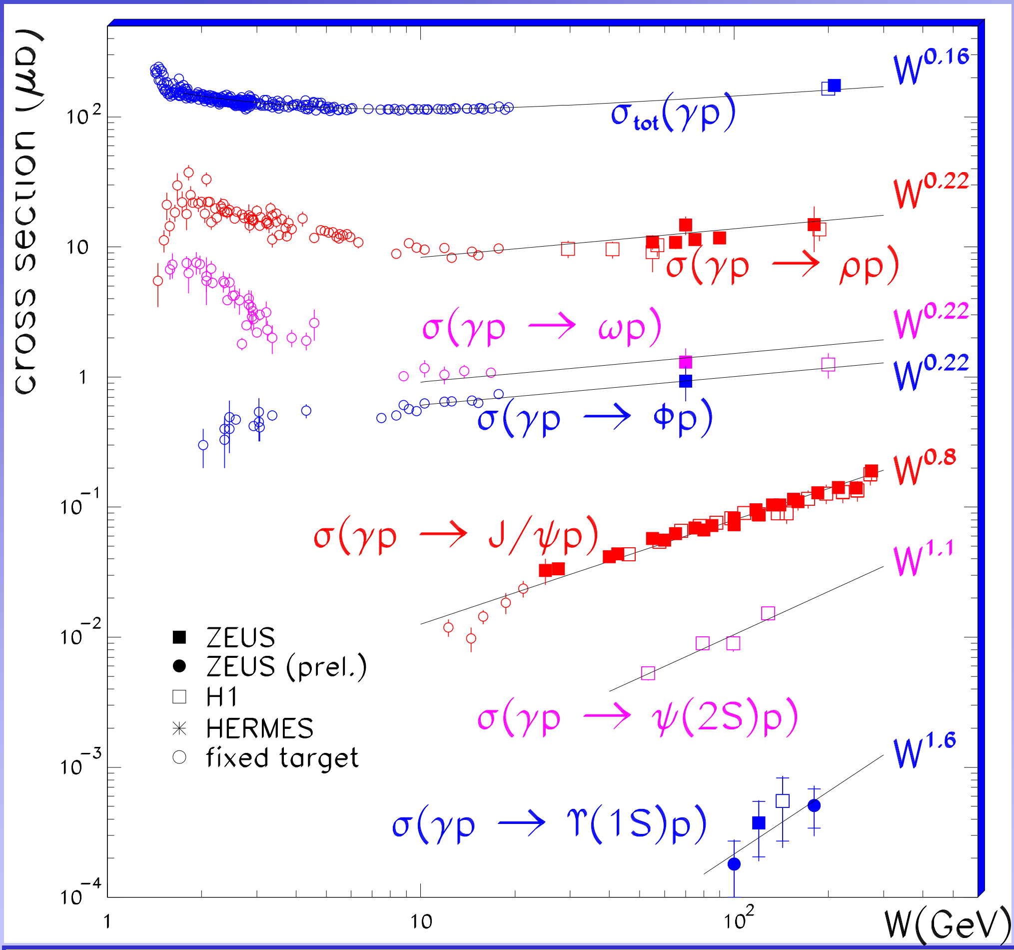
The distribution of the gap fraction $R_{gap}=N_{gap}/N_{all}$ vs $\Delta\eta$ for MinBias ($CLC_p \bullet CLC_{pbar}$) and MiniPlug jet events ($MP_p \bullet MP_{pbar}$) of $E_{T(jet1,2)}$>2 GeV and $E_{T(jet1,2)}$> 4 GeV.

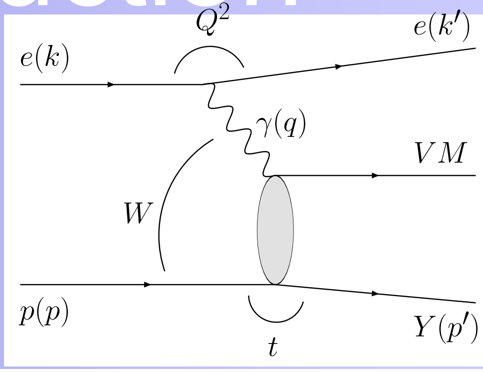
The distributions are similar in shape within the uncertainties.

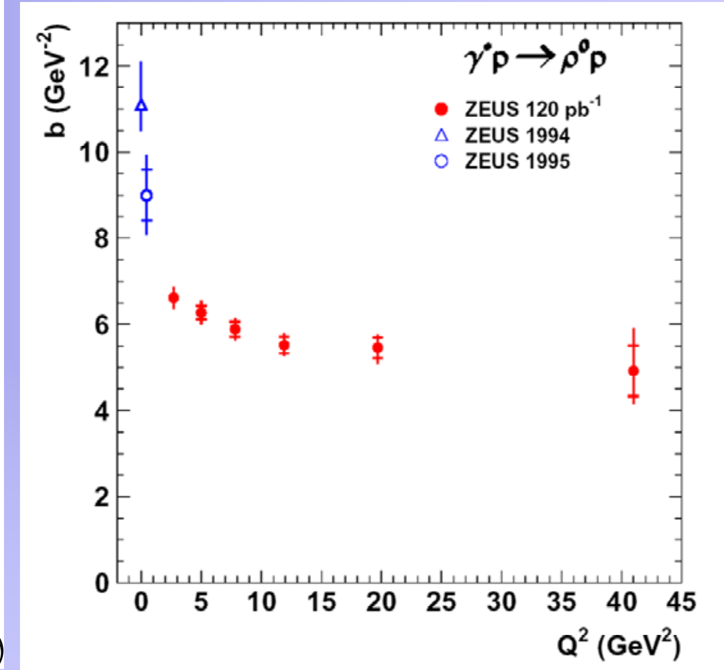
γp and γ*p results

Vector meson production

(Pierre Marage, HERA-LHC 2008)







- *left* - why different σ vs. W slopes?
- *right* - why smaller b-slope in γ^*p?!

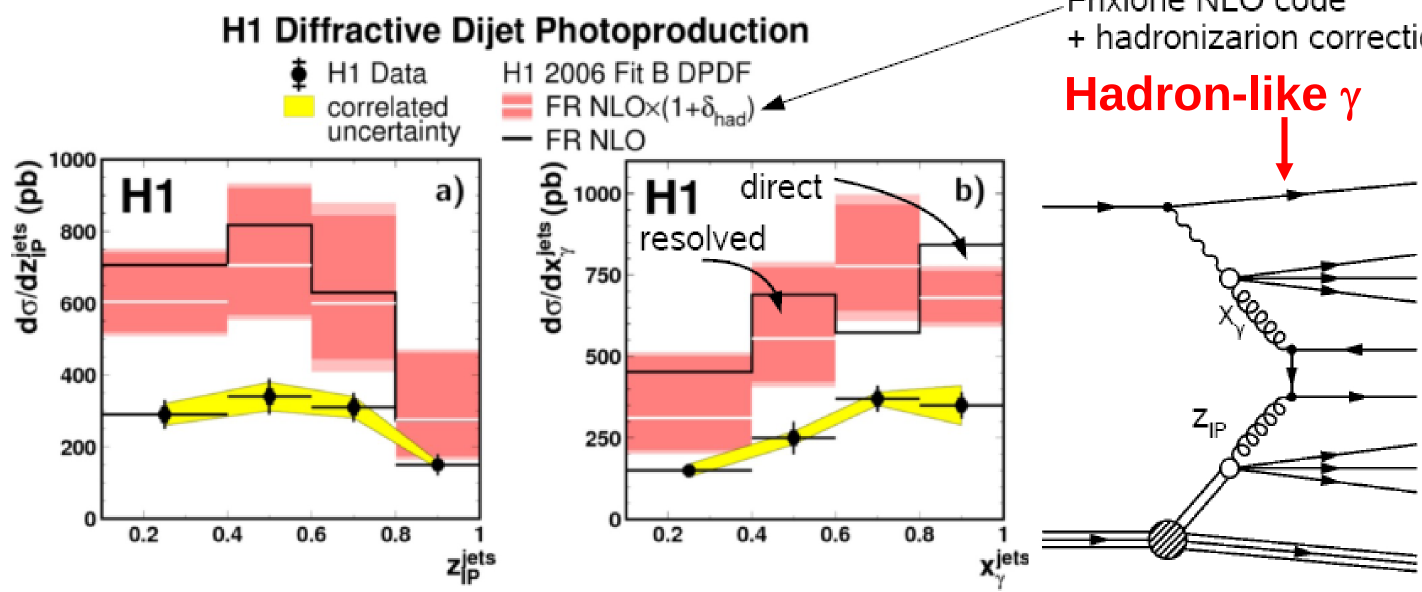
Dijets in γp at HERA - 2007

[slide from summary of the HERA/LHC Workshop of March 14, 2007]

Dijets in γp

Frixione NLO code
+ hadronizarion correction

Hadron-like γ



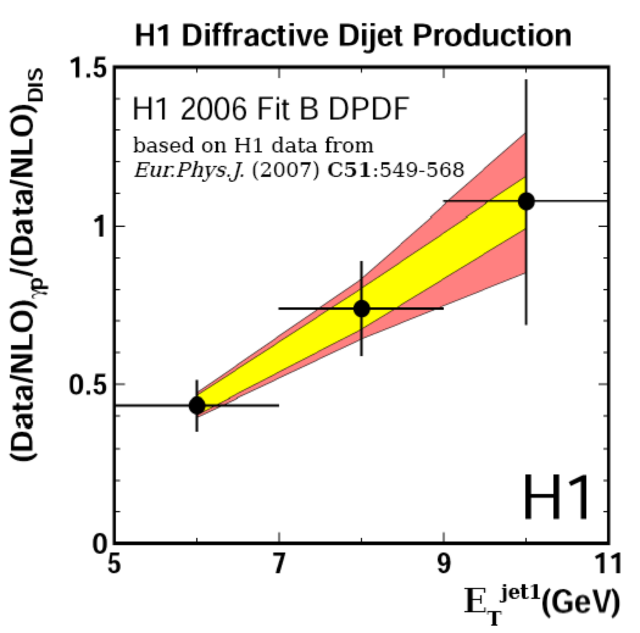
- large violation of naive factorization observed
- factorization breaking occurs in direct and resolved processes

QCD factorisation not OK

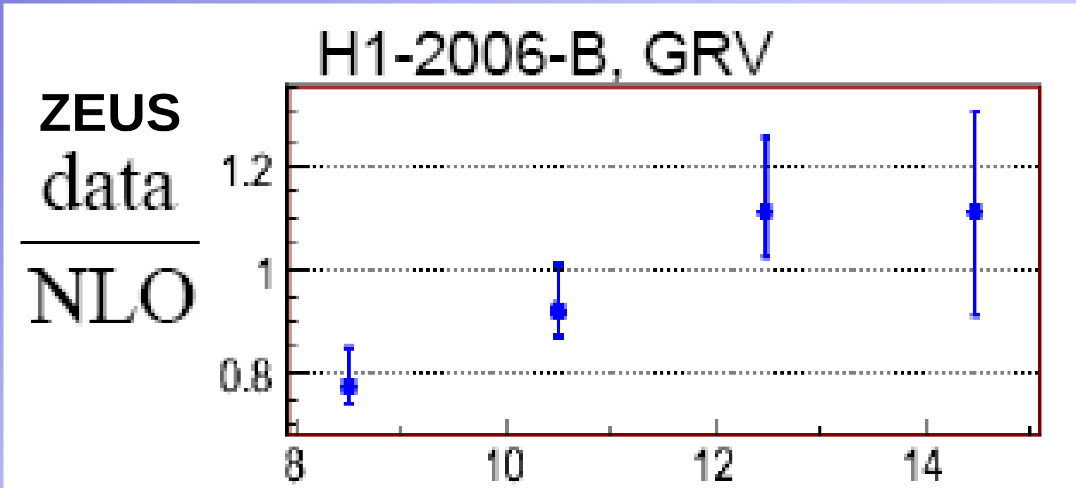
Unexpected, not understood

Matthias Mozer, HERA-LHC 2007 12

Dijets in γp at HERA - 2008



DIS 2008 talk by W. Slomiński,



❑ 20-50 % rise (?) from E^T 5→10 GeV

Renormalization: *the common thread*

➔ works for pp, $\bar{p}$p, γp and γ^*p

➔ removes overlapping gaps!

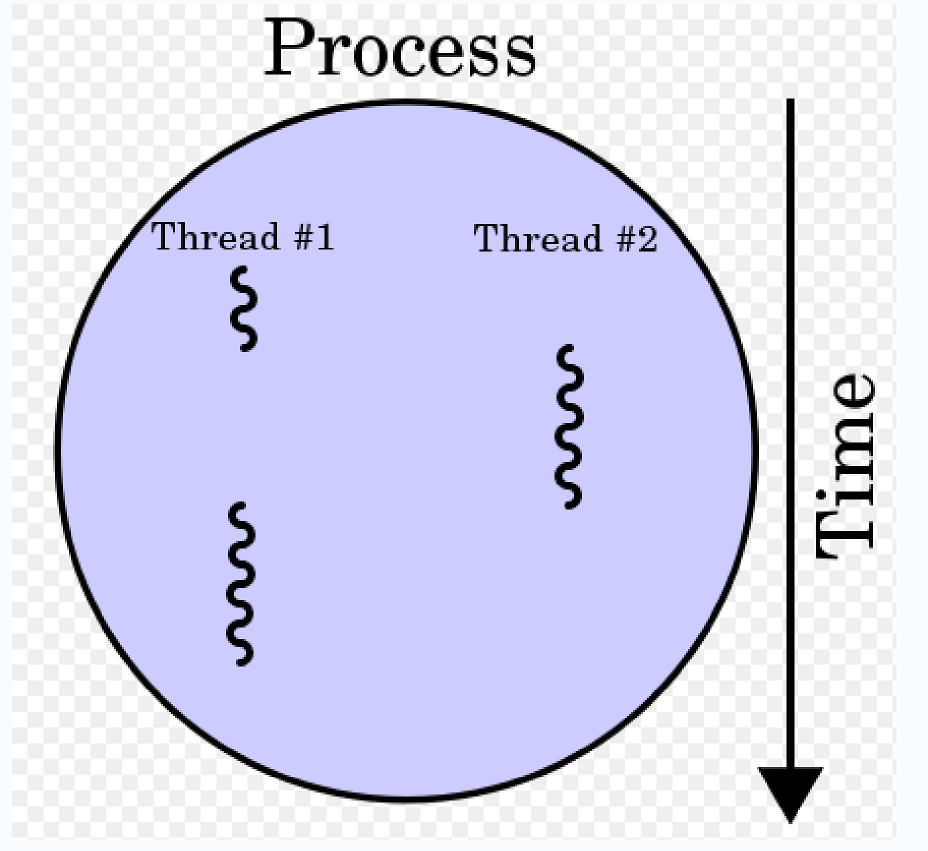
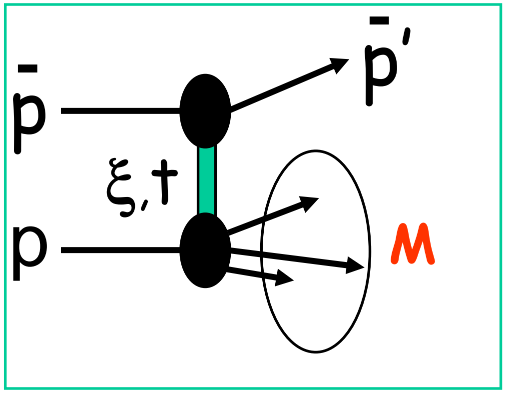
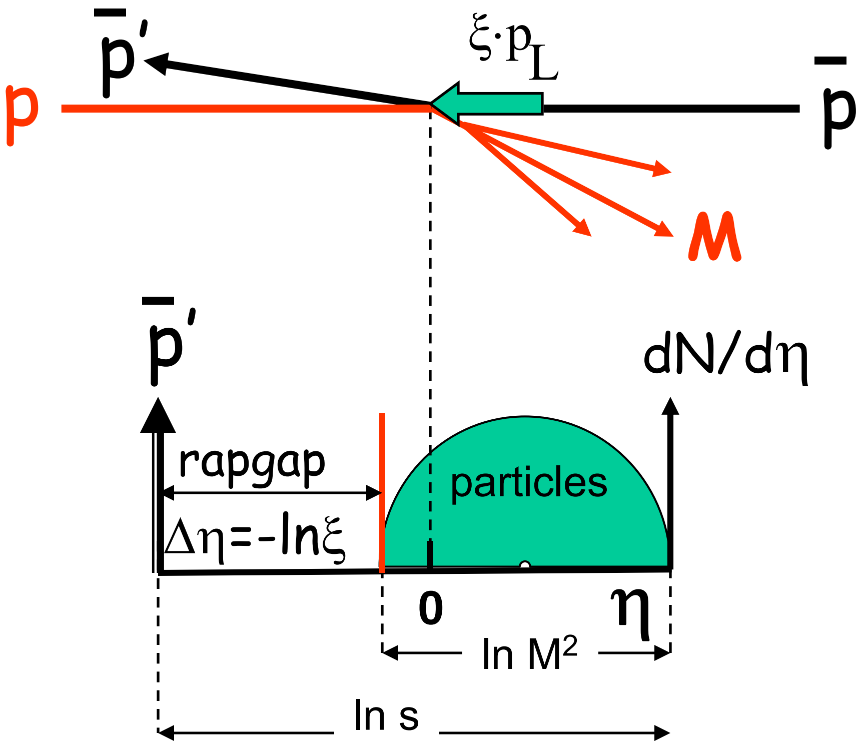


figure from http://en.wikipedia.org/wiki/Thread_(computer_science)



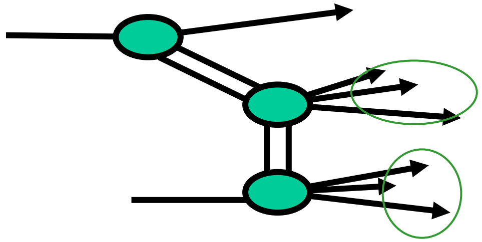


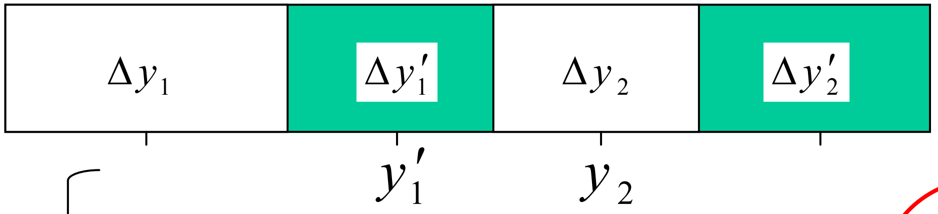
$$1 - x_L \equiv \xi = \frac{M^2}{s}$$

vacuum exchange ⇒

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

Multigap cross sections





5 independent variables $\left\{ \begin{array}{l} y_1' \quad y_2 \\ t_1 \quad \Delta y = \Delta y_1 + \Delta y_2 \quad t_2 \end{array} \right.$

color factor

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

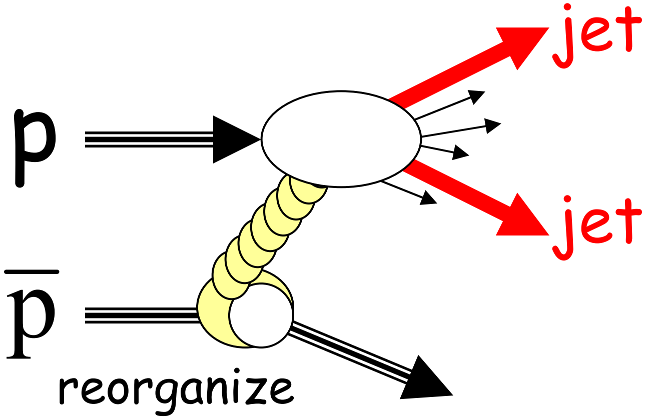
Gap probability

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

Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

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

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

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

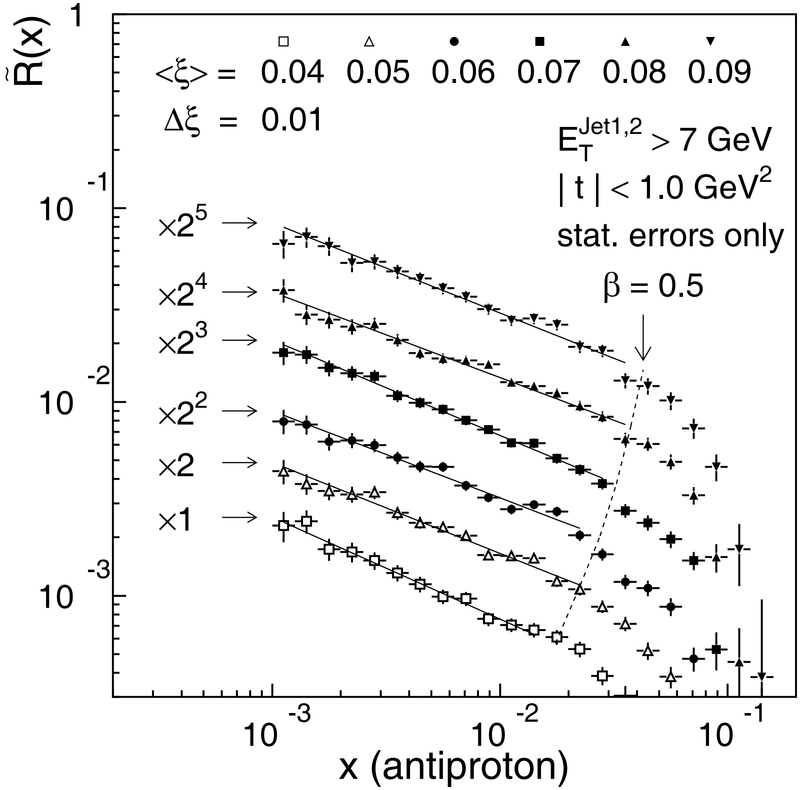
RENORM $\Rightarrow$ $R^{SD}_{ND}(x) = \frac{2\varepsilon}{s^{2\varepsilon}} \frac{1}{\xi^{1-\lambda(Q^2)}} \cdot x^{-(2\varepsilon)}$

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

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

CDF Run I

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



$0.035 < \xi < 0.095$

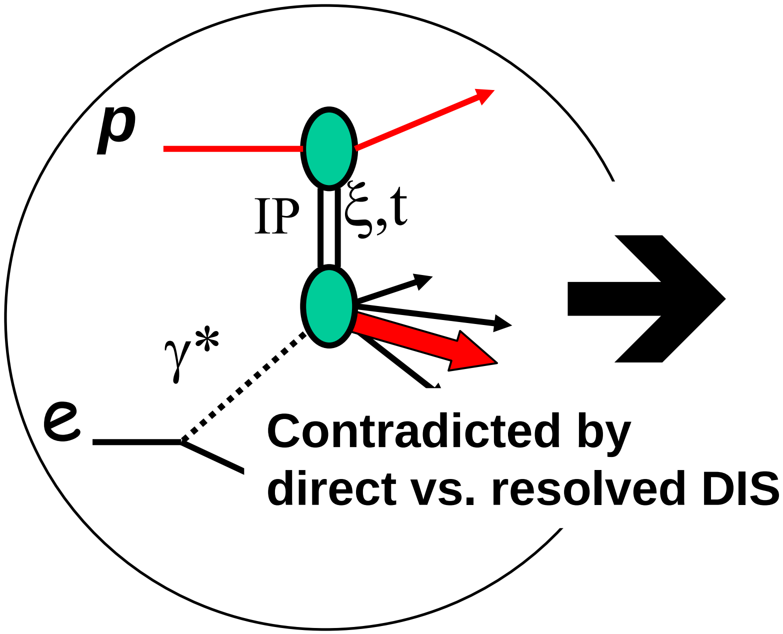
Flat ξ dependence for $\beta < 0.5$

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

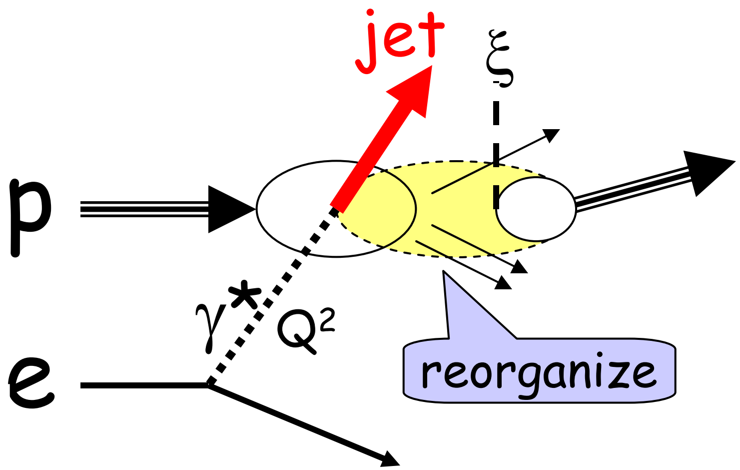
Diffractive DIS @ HERA

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

Pomeron exchange



Color reorganization

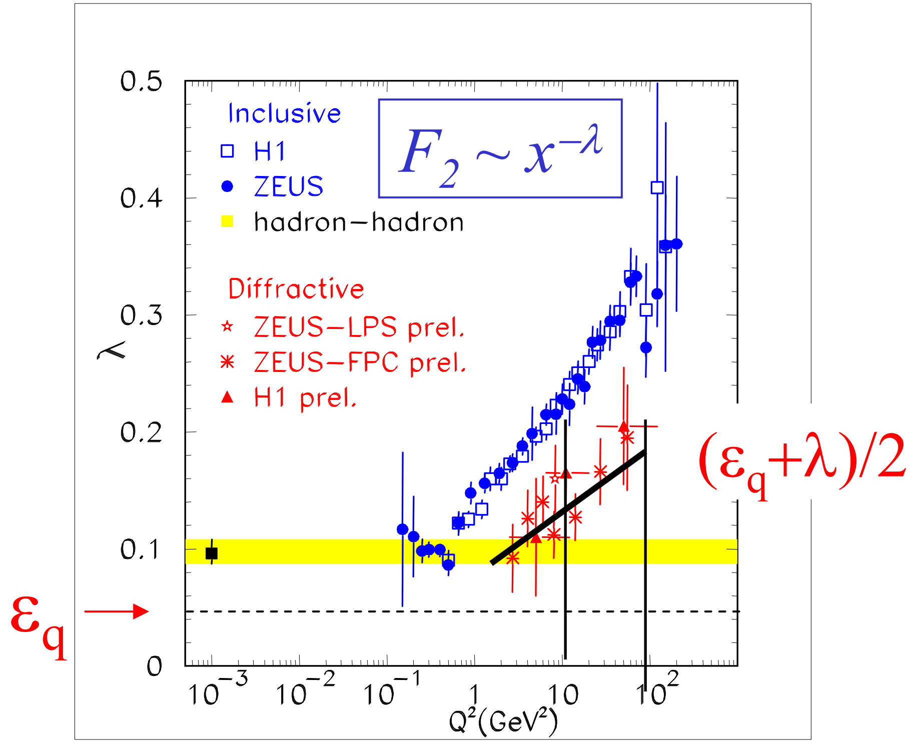


$$F_2^{D(3)}(\xi, x, Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot F_2(x, Q^2)$$

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

Inclusive vs. diffractive DIS

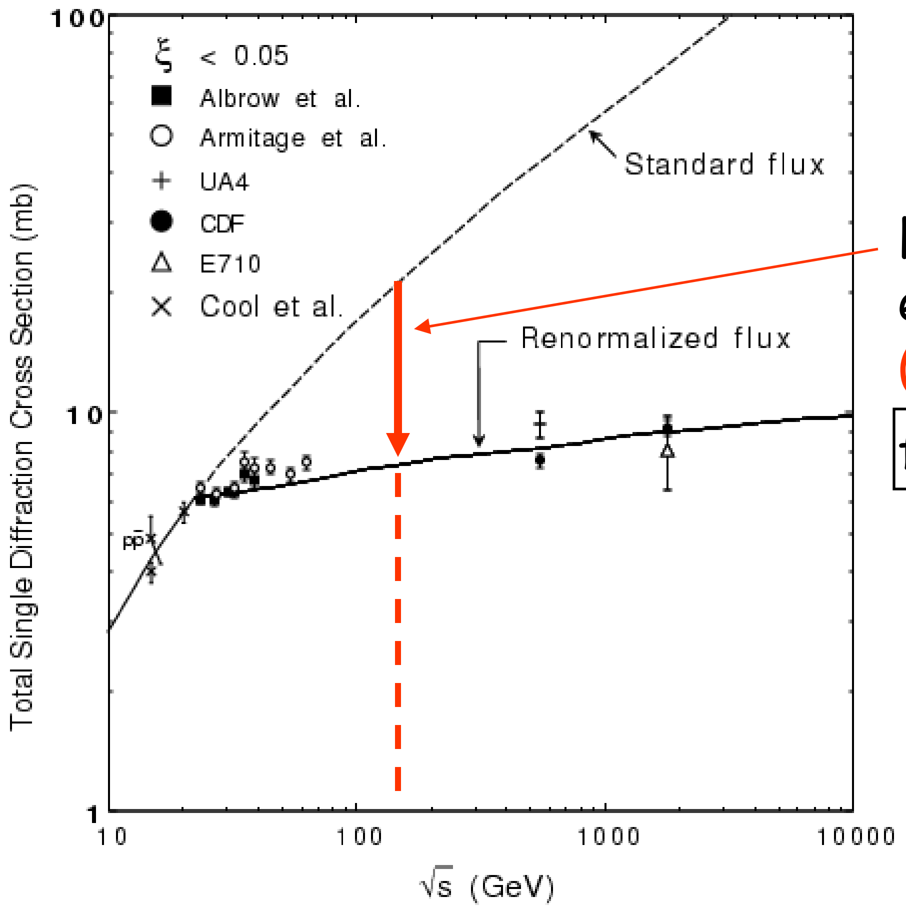
KG, "Diffraction: a New Approach," J.Phys.G26:716-720,2000 e-Print Archive: **hep-ph/0001092**



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

Dijets in γp at HERA: the expectation

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

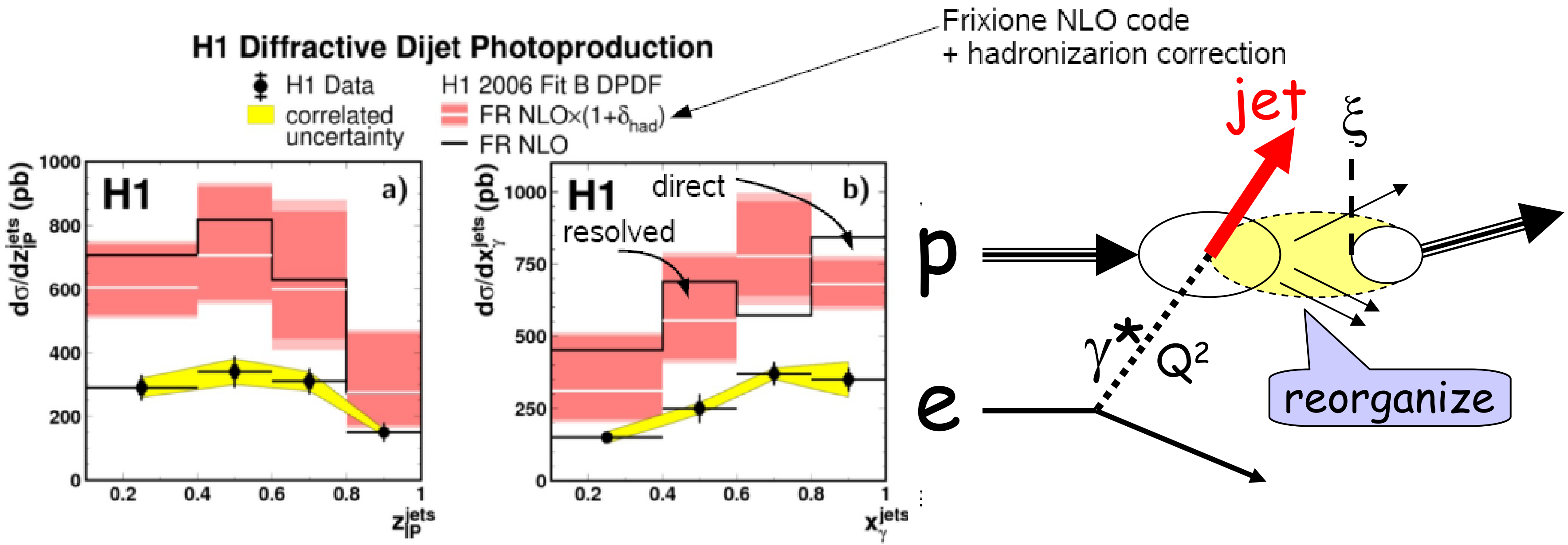


Factor of ~3 suppression expected at W~200 GeV
(just as in pp collisions)

for both direct and resolved components

Dijets in γp at HERA - 2007

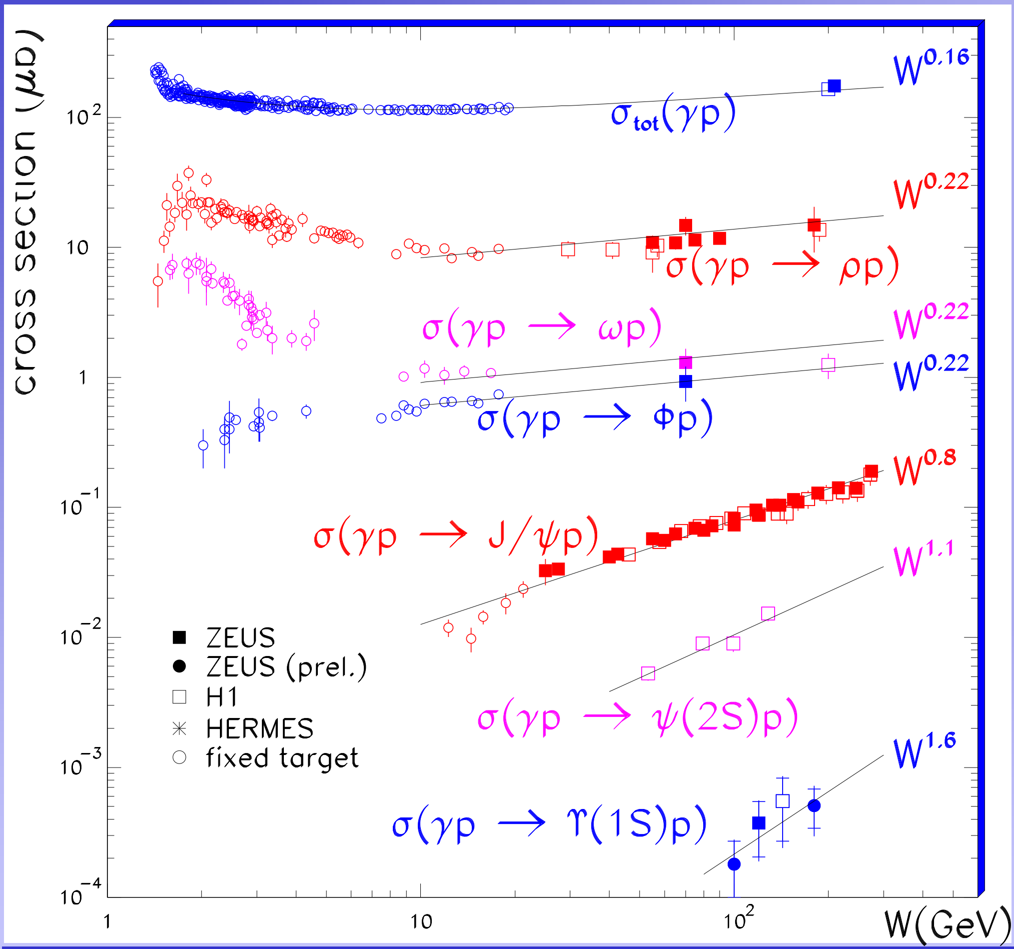
Dijets in γp

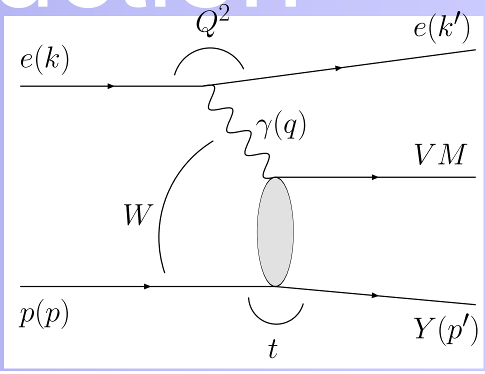


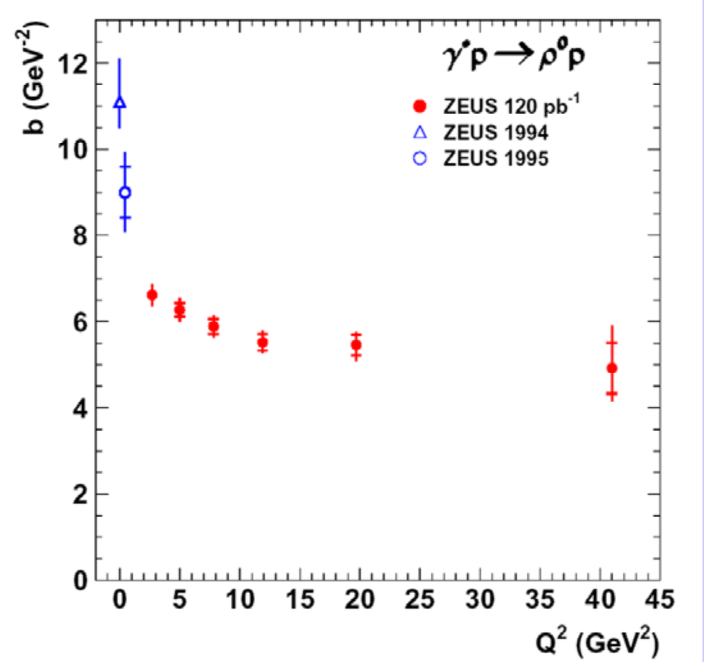
- ❑ see figure on right:
- ❑ ➔ same suppression for direct and resolved processes
- ❑ ➔ suppression at low z^{jets} since larger $\Delta\eta$ available for particles

Vector meson production

(Pierre Marage, HERA-LHC 2008)







- *left* - suppression of 20-50% at high W ➔ more room for particles
- *right* - suppression at low |t| for high Q^2 ➔ same reason

Diffraction at the LHC

FROM EDS 2009, 39 Jun 2009, CERN --Discussion panel

"What can we learn/expect from the LHC experiments?" K. Goulianos

- goal…..........understand the QCD basis of diffraction & discover new physics
- TEV2LHC…confirm, extend, discover…
- Tools………larger $\sqrt{s} \rightarrow$ larger σ, $\Delta\eta$ & E_T

TODO:

- Elastic, diffractive, and total cross sections
  - Important to study partial cross section components
    - ➔ need topology (multiplicity, E_T, …)
- Hard diffraction
  - diffractive structure function ➔dijets vs. W
  - Multigap configurations
  - jet-gap-jet ➔ $d\sigma/d\Delta\eta$ vs. E_T^{jet}➔ BFKL, Mueller-Navelet

Dark Energy

Non-diffractive interactions

Rapidity gaps are formed by multiplicity fluctuations:

$$P(\Delta y) = e^{-\rho\,\Delta y}, \quad \rho = \frac{dN_{particles}}{dy}$$

P(Δy) is exponentially suppressed

Diffractive interactions

Rapidity gaps at t=0 grow with Δy:

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

$$P(\Delta y)\big|_{t=0} \sim e^{2\varepsilon\Delta y}$$

2ε: negative particle density!

⇓

Gravitational repulsion?

SUMMARY

- Diffraction results from CDF were presented under the physics theme of factorization breaking in diffraction.
- Results from γp ($\gamma^* p$) interactions at HERA were also discussed focusing on factorization breaking aspects.
- **Renormalization** of the rapidity gap probability was proposed as *the* ***common thread*** in explaining factorization breaking by eliminating double-counting from overlapping rapidity gaps.
- Suggestions for diffractive studies at the LHC were offered,

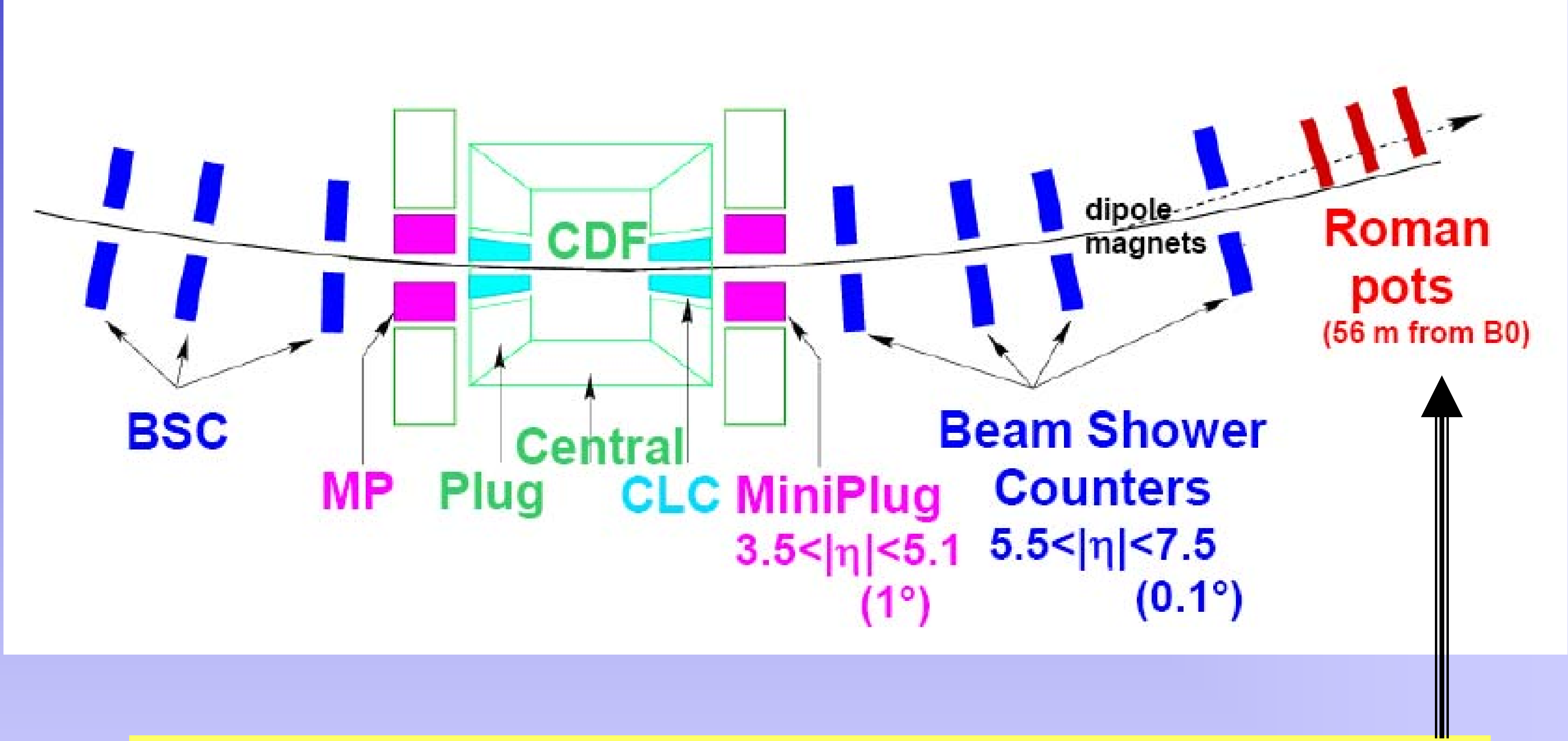
thank you

for your attendance

QUESTIONS?

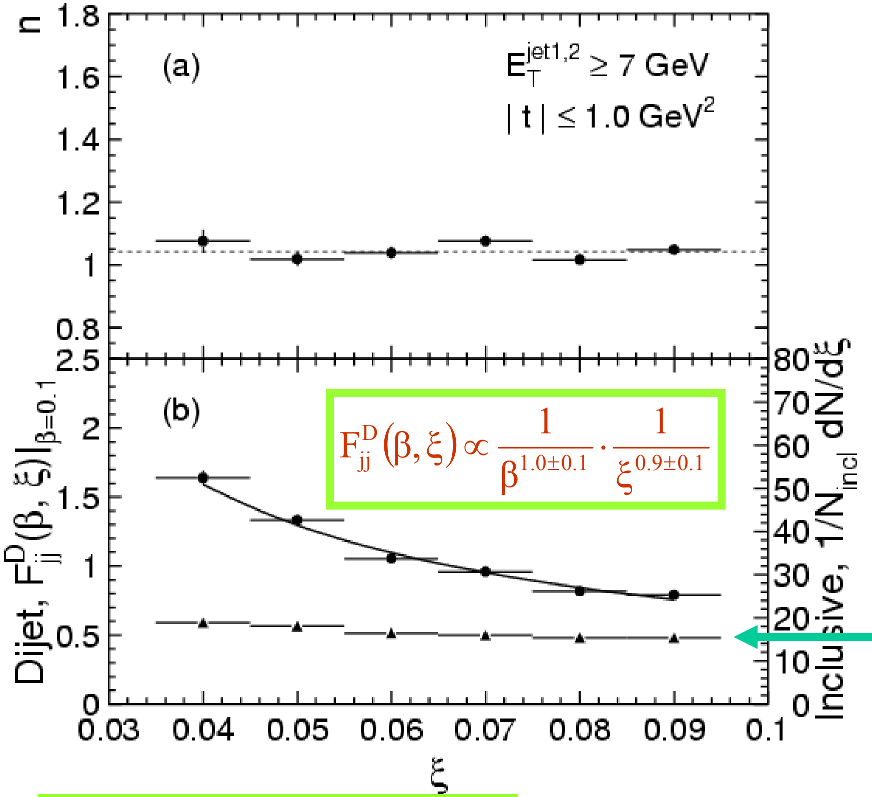
BACKUP

The CDF II detectors



RPS acceptance ~80% for 0.03 < ξ < 0.1 and |t| < 0.1

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