DIFFRACTION RESULTS FROM CDF

Konstantin Goulianos
The Rockefeller University
Representing the CDF Collaboration

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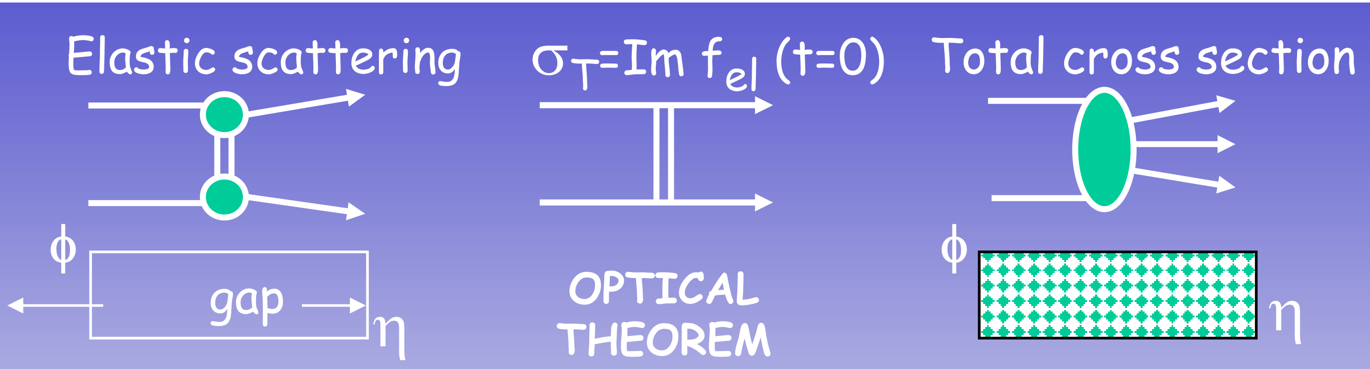
Diffraction at CDF in Run I

Find references in http://physics.rockefeller.edu/publications.html

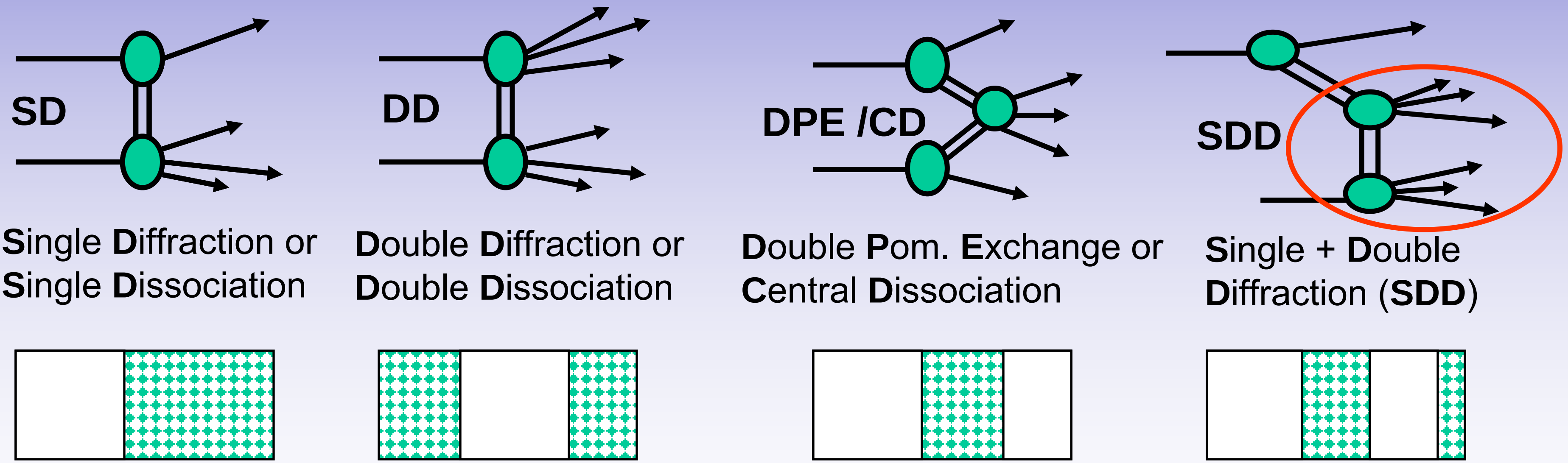


Elastic scattering

$\sigma_T = \text{Im}\, f_{el}\,(t=0)$

OPTICAL THEOREM

Total cross section



Single **D**iffraction or **S**ingle **D**issociation

Double **D**iffraction or **D**ouble **D**issociation

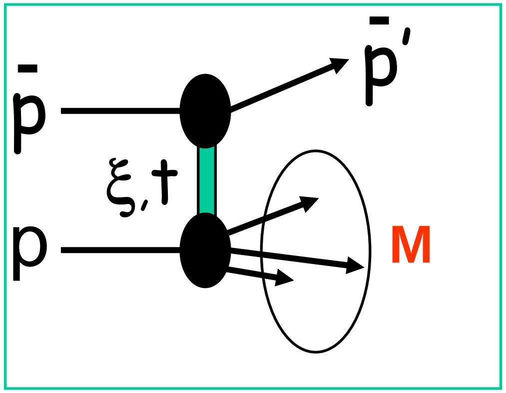
Double **P**om. **E**xchange or **C**entral **D**issociation

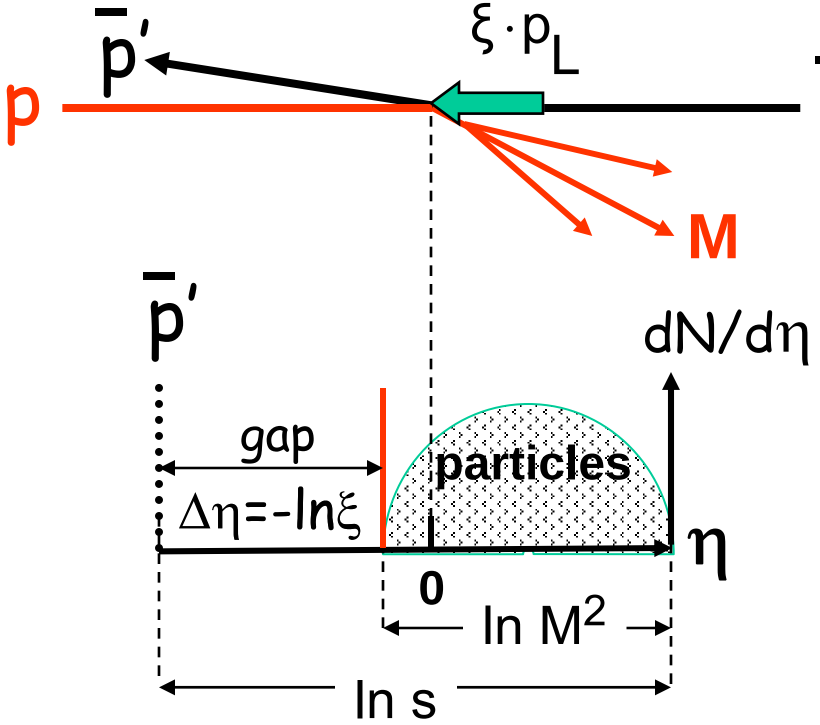
Single + **D**ouble **D**iffraction (**SDD**)

multigap **^{w}/two gaps**

→ part of SD

Definitions





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

No radiation →
no price paid for increasing diffractive gap size

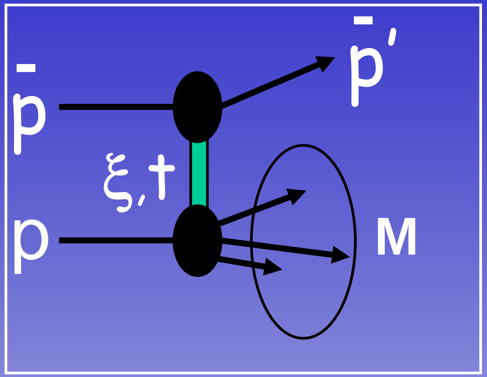
$$\left(\frac{d\sigma}{d\,\Delta\eta}\right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \quad \Rightarrow \quad \frac{d\sigma}{dM^2} \propto \frac{1}{M^2}$$

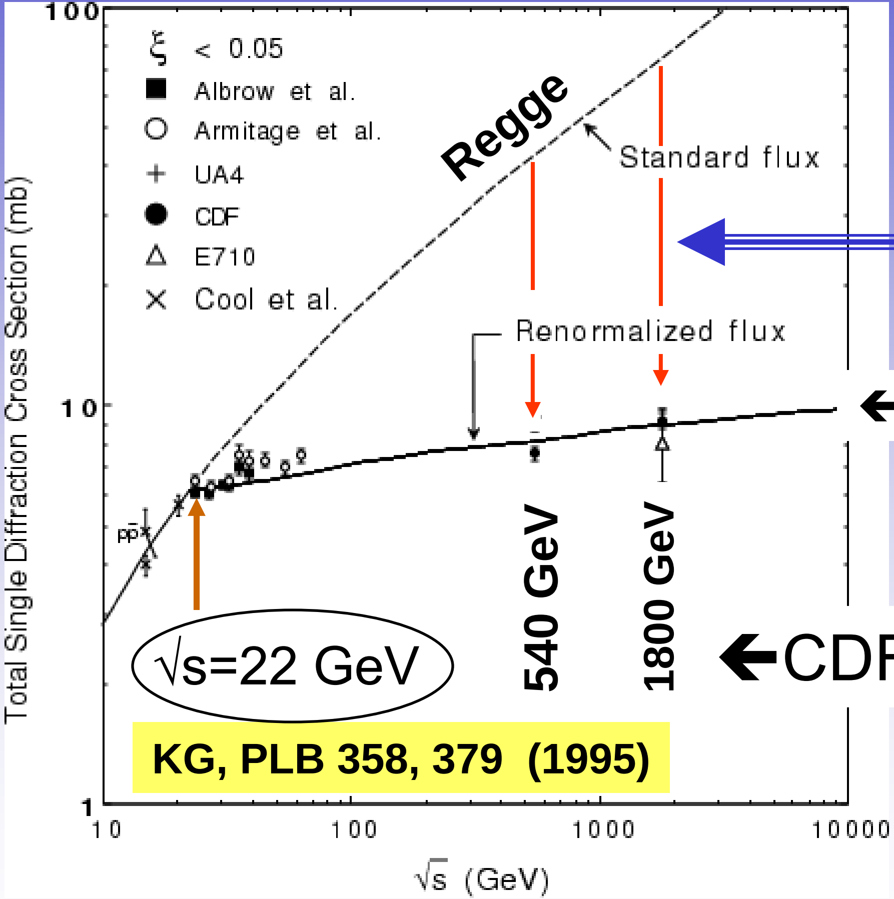
Highlights of Run I Results

Use MBR (Minimum Bias Rockefeller) MC for forward physics

TOTAL SD X-SECTION

➔ suppressed relative to Regge





√s=22 GeV

540 GeV

1800 GeV

KG, PLB 358, 379 (1995)

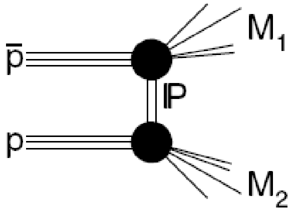
Factor of ~8 (~5) suppression at √s = 1800 (540) GeV

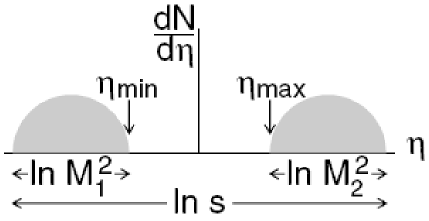
🡐 RENORMALIZATION MODEL

🡐CDF results

DD at CDF

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



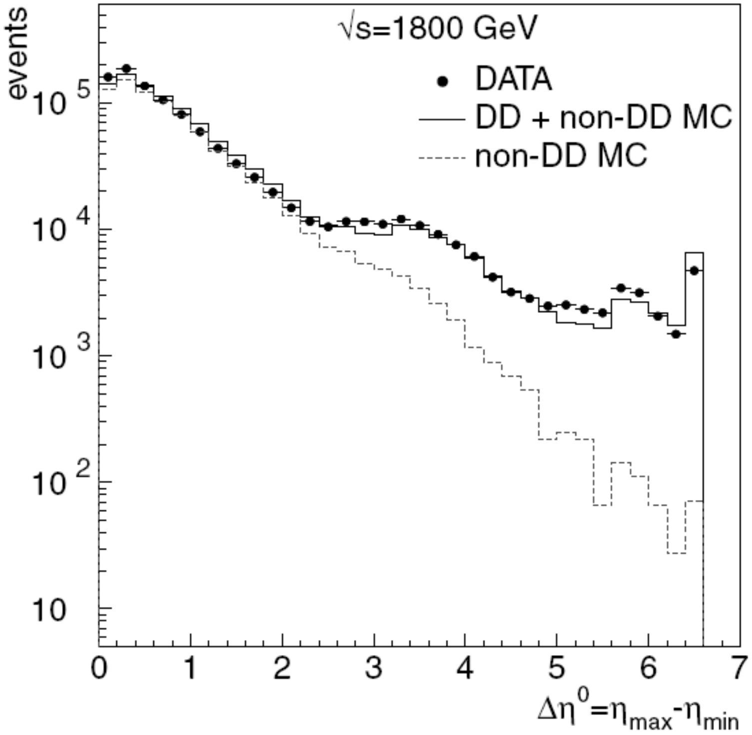


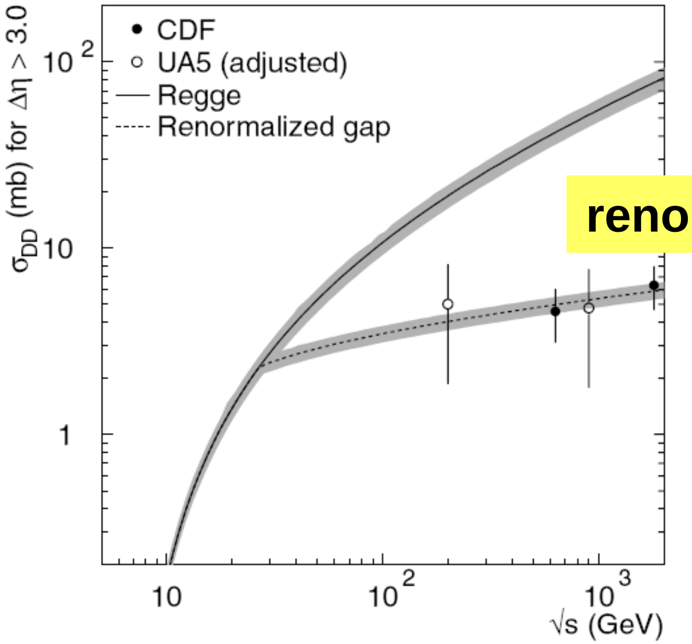
$$\frac{d^3\sigma_{\rm DD}}{dt\,dM_1^2\,dM_2^2} = \frac{d^2\sigma_{\rm SD}}{dt\,dM_1^2}\,\frac{d^2\sigma_{\rm SD}}{dt\,dM_2^2}\Big/\frac{d\sigma_{el}}{dt}$$

$$= \frac{[\kappa\beta_1(0)\beta_2(0)]^2}{16\pi}\,\frac{s^{2\epsilon}e^{b_{\rm DD}t}}{(M_1^2M_2^2)^{1+2\epsilon}}$$

$$\frac{d^3\sigma_{\rm DD}}{dt\,d\Delta\eta\,d\eta_c} = \left[\frac{\kappa\beta^2(0)}{16\pi}\,e^{2[\alpha(t)-1]\Delta\eta}\right]\left[\kappa\beta^2(0)\left(\frac{s'}{s_0}\right)^{\epsilon}\right]$$

gap probability x-section

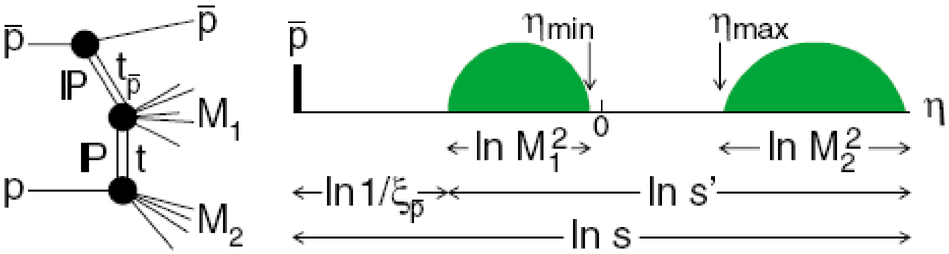


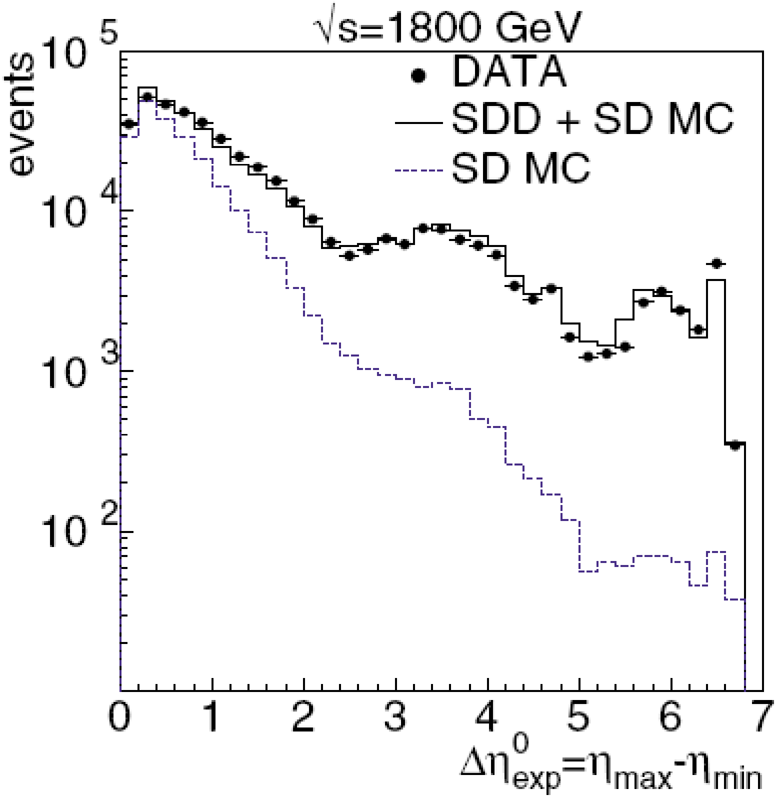


renormalized

SDD at CDF

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



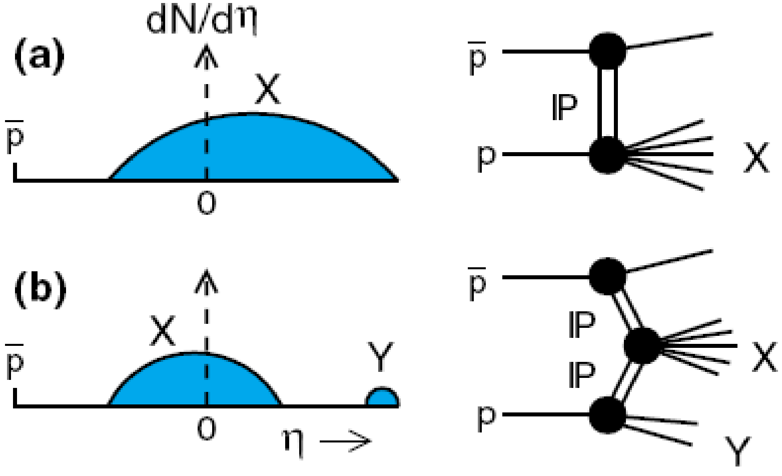


- Excellent agreement between data and MBR (MinBiasRockefeller) MC

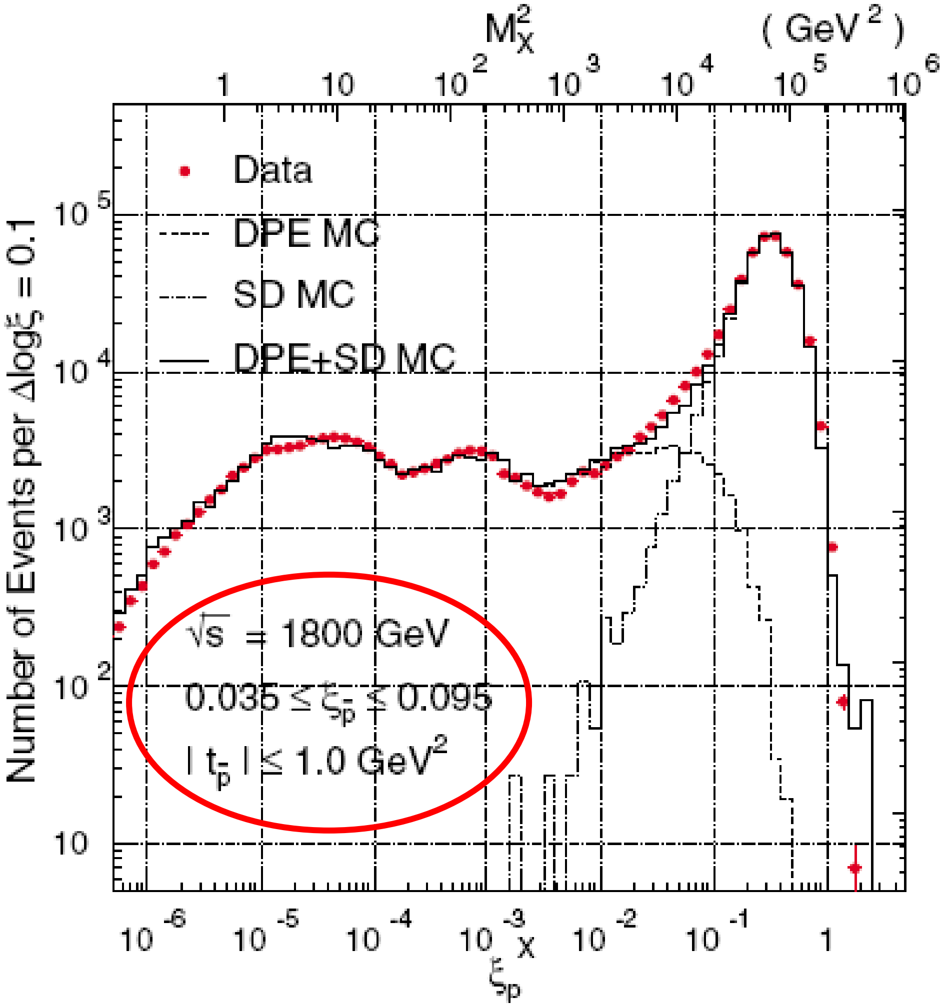
$$\frac{d^5\sigma}{dt_{\bar{p}}\,dt\,d\xi_{\bar{p}}\,d\Delta\eta\,d\eta_c}=\left[\frac{\beta(t)}{4\sqrt{\pi}}\,e^{[\alpha(t_{\bar{p}})-1]\ln(1/\xi)}\right]^2\times\kappa\left\{\kappa\left[\frac{\beta(0)}{4\sqrt{\pi}}\,e^{[\alpha(t)-1]\Delta\eta}\right]^2\kappa\left[\beta^2(0)\left(\frac{s''}{s_\circ}\right)^{\epsilon}\right]\right\}$$

DPE / CD at CDF

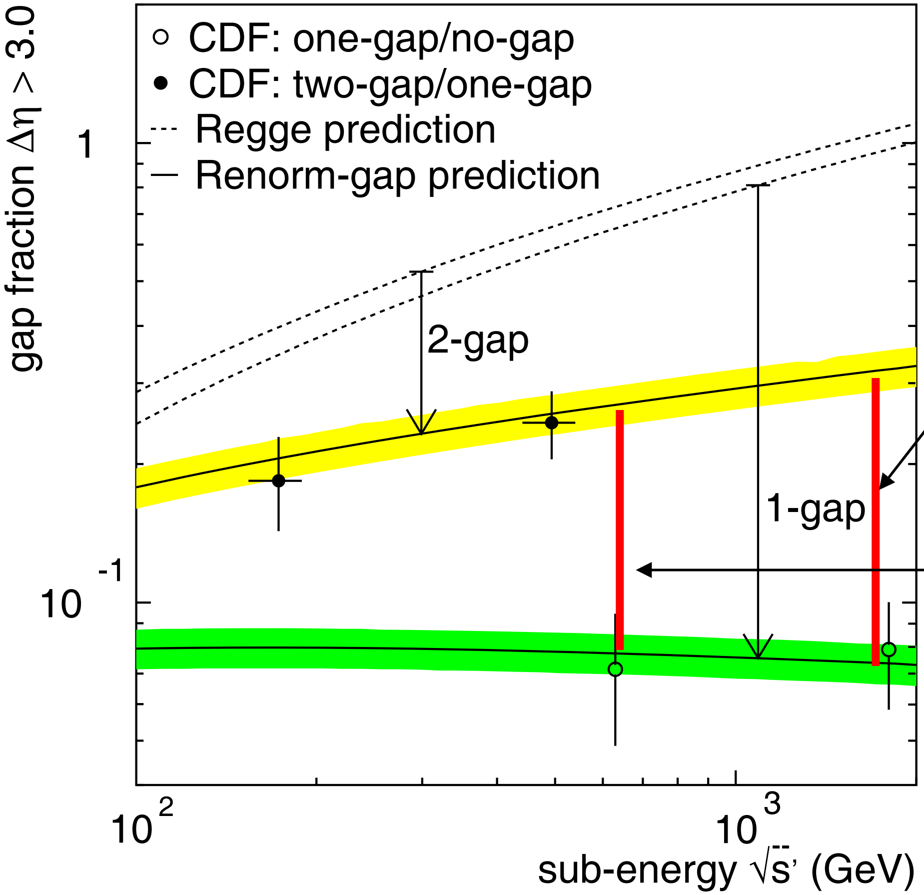
http://physics.rockefeller.edu/publications.html

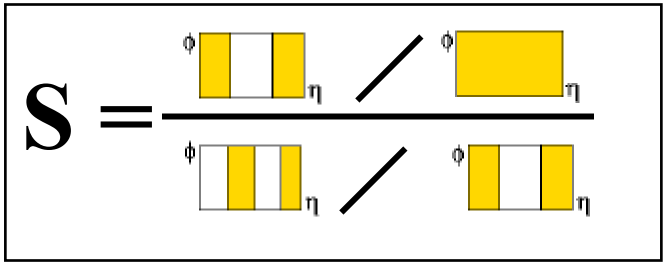


- Excellent agreement between data and MBR
➔ low and high masses are correctly implemented



Gap survival probability



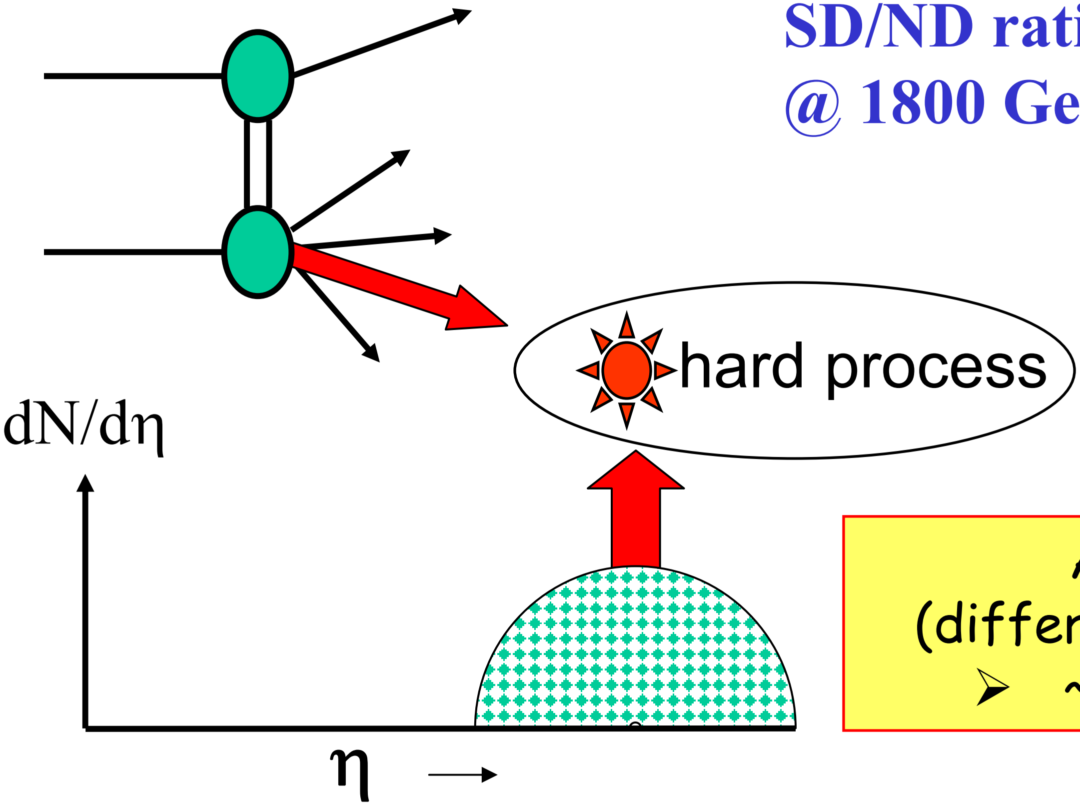


$$S^{1-\text{gap}/0-\text{gap}}_{2-\text{gap}/1-\text{gap}}(1800\text{ GeV}) \approx 0.23$$

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

Run I Hard diffractive fractions

$$\bar{p}p \rightarrow (\text{✹} + X) + \text{gap}_{p} \text{ or } \text{gap}_{\text{pbar}}$$



Fraction:
SD/ND ratio @ 1800 GeV

✹	Fraction %
JJ	0.75 +/- 0.10
W	1.15 +/- 0.55
b	0.62 +/- 0.25
J/ψ	1.45 +/- 0.25

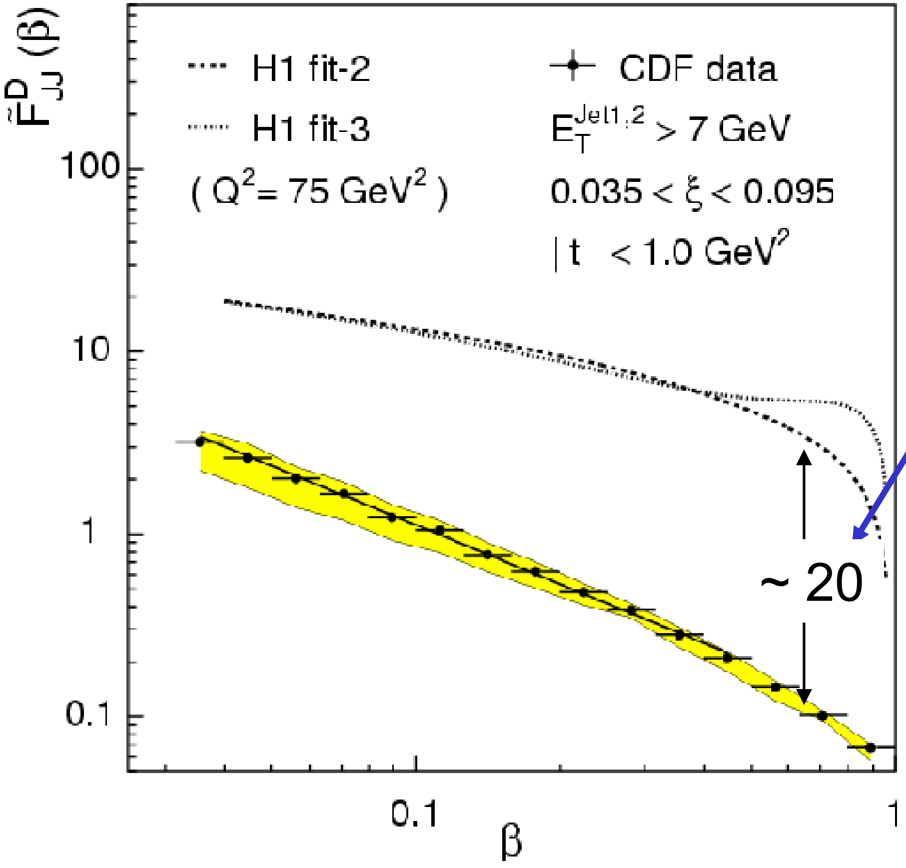
All fractions ~ 1%
(differences due to kinematics)
➢ ~ FACTORIZATION !

Diffractive Structure Function (DSF)

→ breakdown of QCD factorization

Run I

PRL 84, 5043 (2000)



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

suppression factor is 2.5 times larger than in soft diffraction

This contradicted the RENORM prediction of suppression factor ~ 8 → as in soft diffraction

β → momentum fraction of parton in "Pomeron"

Puzzles from run I results

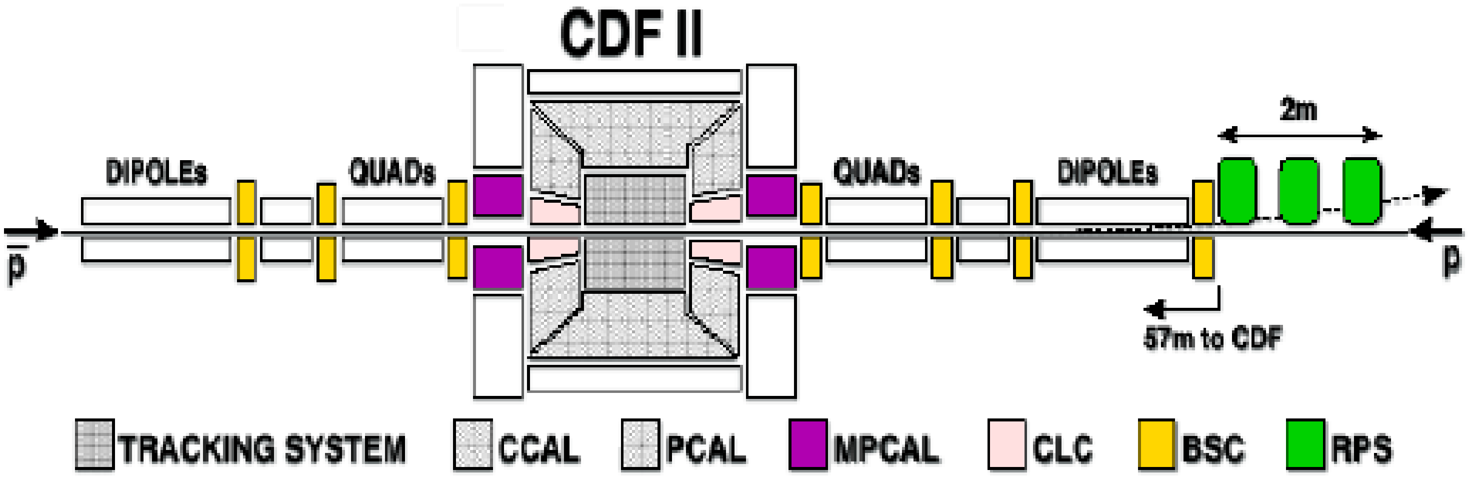
☐ gap fractions are suppressed relative to theory predictions, both for soft (Regge) and hard diffraction
…but
factorization holds among processes at the same energy, just like at HERA

☐ DSF at √s=1800 GeV suppressed by factor ~ 20 while Regge by factor ~8 → contradicts RENORM prediction,
but…see further down in the talk

Diffraction at CDF in Run II - why?

- Resolve question on soft vs. hard diffraction suppression – are they really different?
- Make precise measurement of the DSF in dijets
  - – sensitive to gluon pdf's
- Measure diffractive *W/Z* production
  - – sensitive to quark pdf's
- Central gaps in soft and hard diffraction
  - – BFKL, Mueller-Navelet, other
- Observe and measure exclusive dijet production
  - – important for diffractive Higgs searches

The CDF II Detector – plan view



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

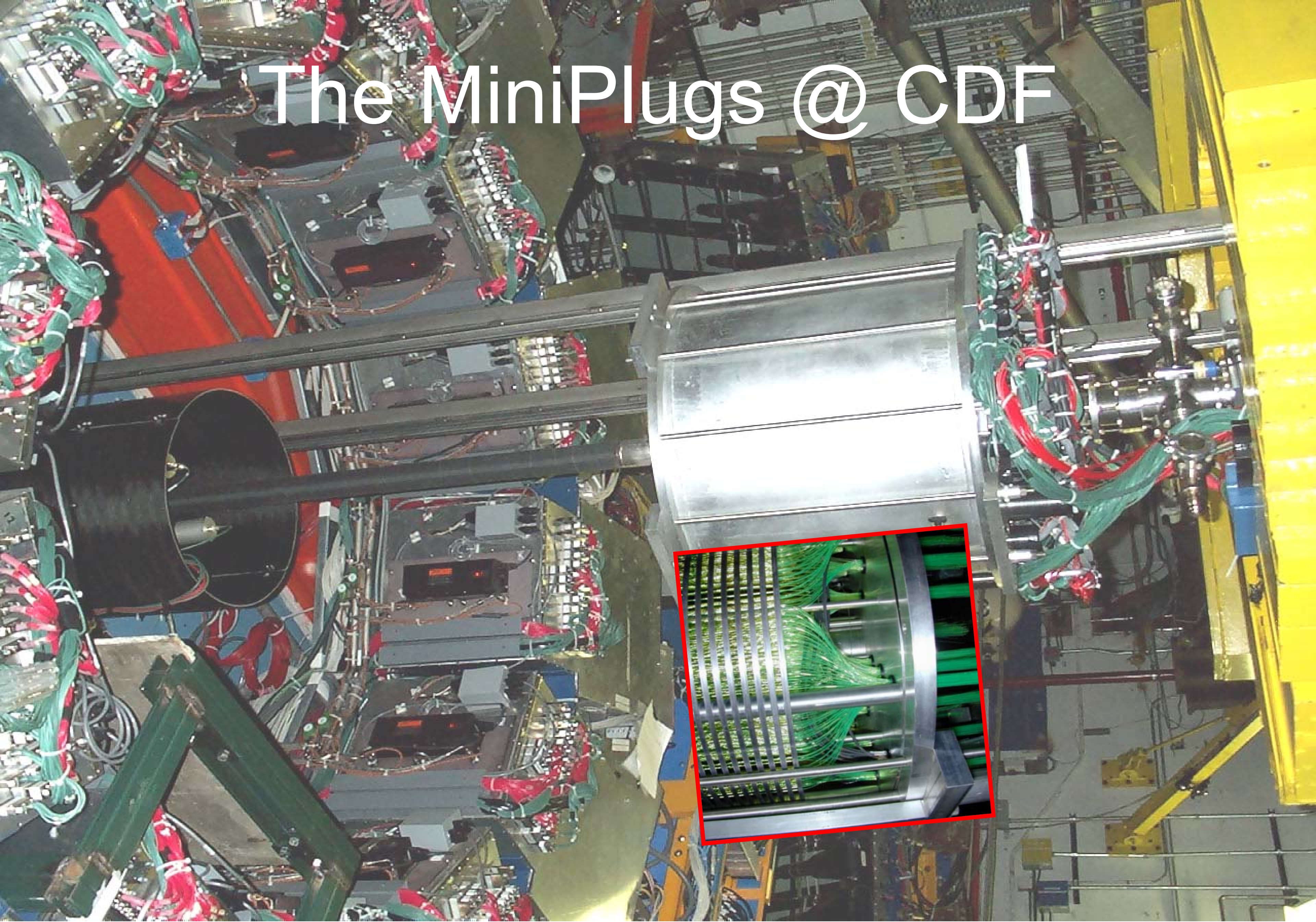
▨ CCAL, PCAL – Calorimeters $|\eta| < 3.6$

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

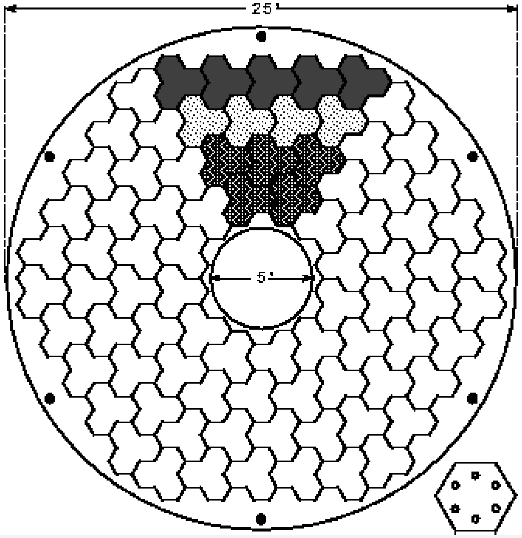
🟨 BSC – Beam Shower Counters $5.4 < |\eta| < 7.4$

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

The MiniPlugs @ CDF



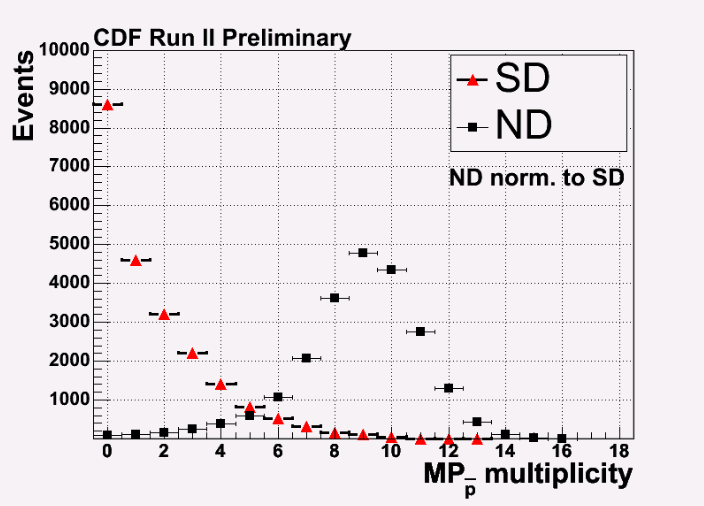
Measurements ^{w}/the MiniPlugs



MP TOWER STRUCTURE

MULTIPLICITY @ POSITION

ENERGY



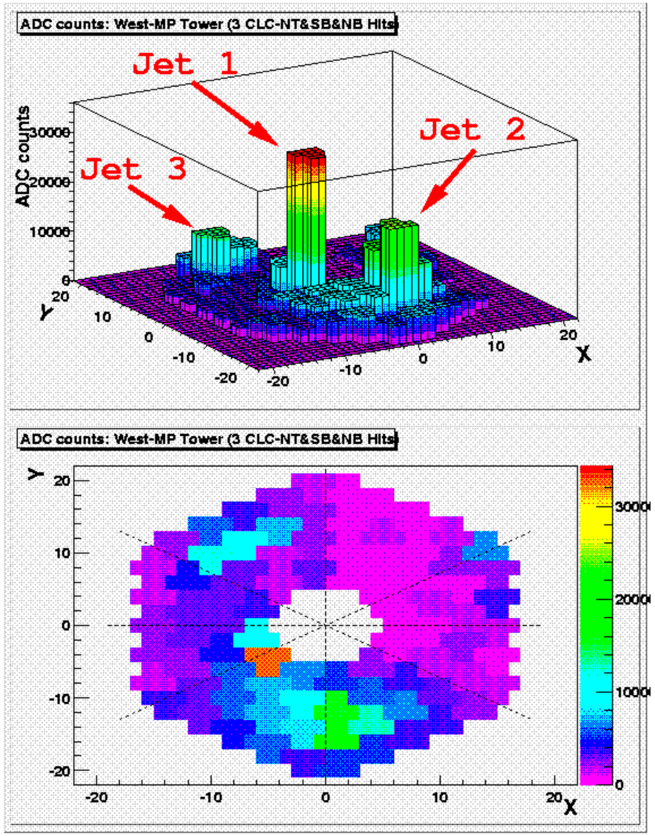
Multiplicity of SD and ND events

$$\xi^{CAL} = \frac{\Sigma_i E_T^i e^{-\eta_i}}{\sqrt{s}}$$

NIM A 430 (1999)

NIM A 496 (2003)

NIM A 518 (2004)

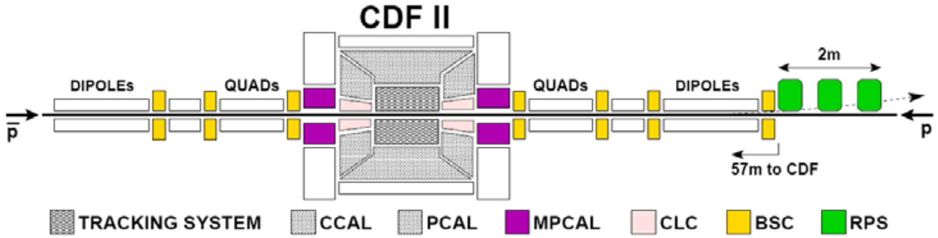


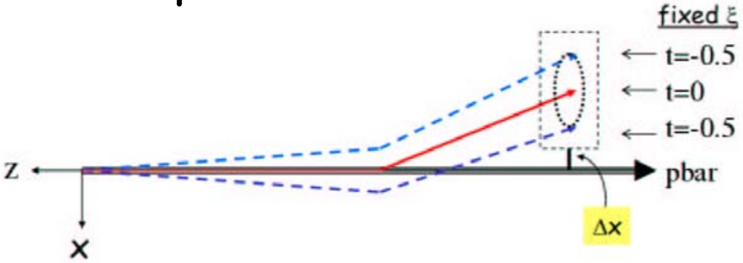
ADC counts in MiniPlug towers in a pbar-p event at 1960 GeV.

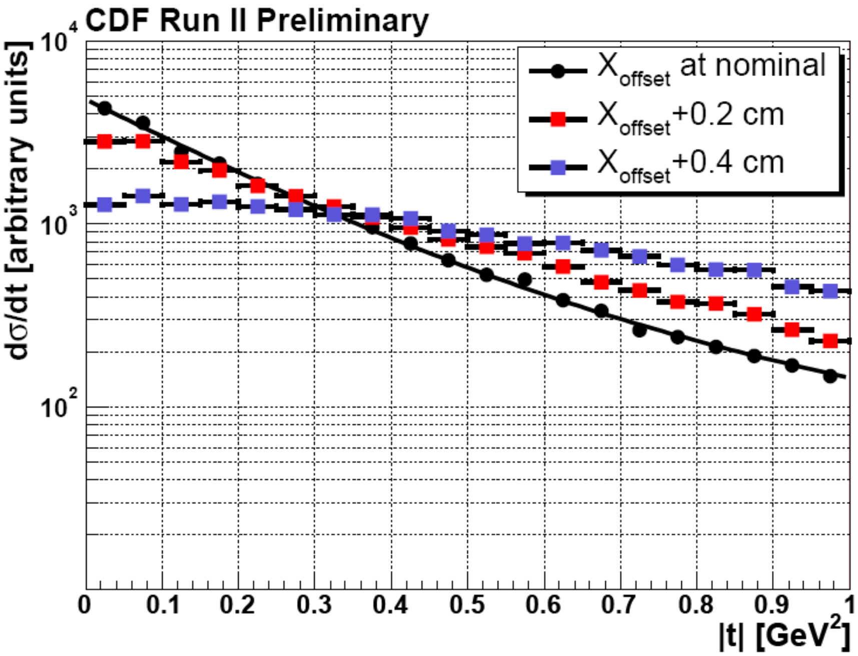
- “jet” indicates an energy cluster and may be just a hadron.
- 1000 counts ~ 1 GeV

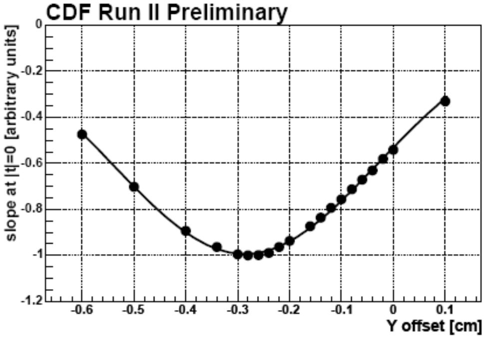
Dynamic Alignment of RPS Detectors

<u>Method:</u> iteratively adjust the RPS X and Y offsets from the nominal beam axis until a maximum in the b-slope is obtained @ t=0.



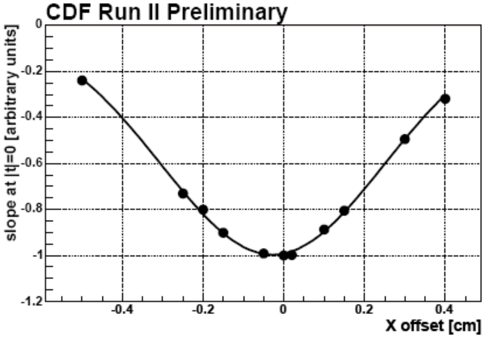






Limiting factors

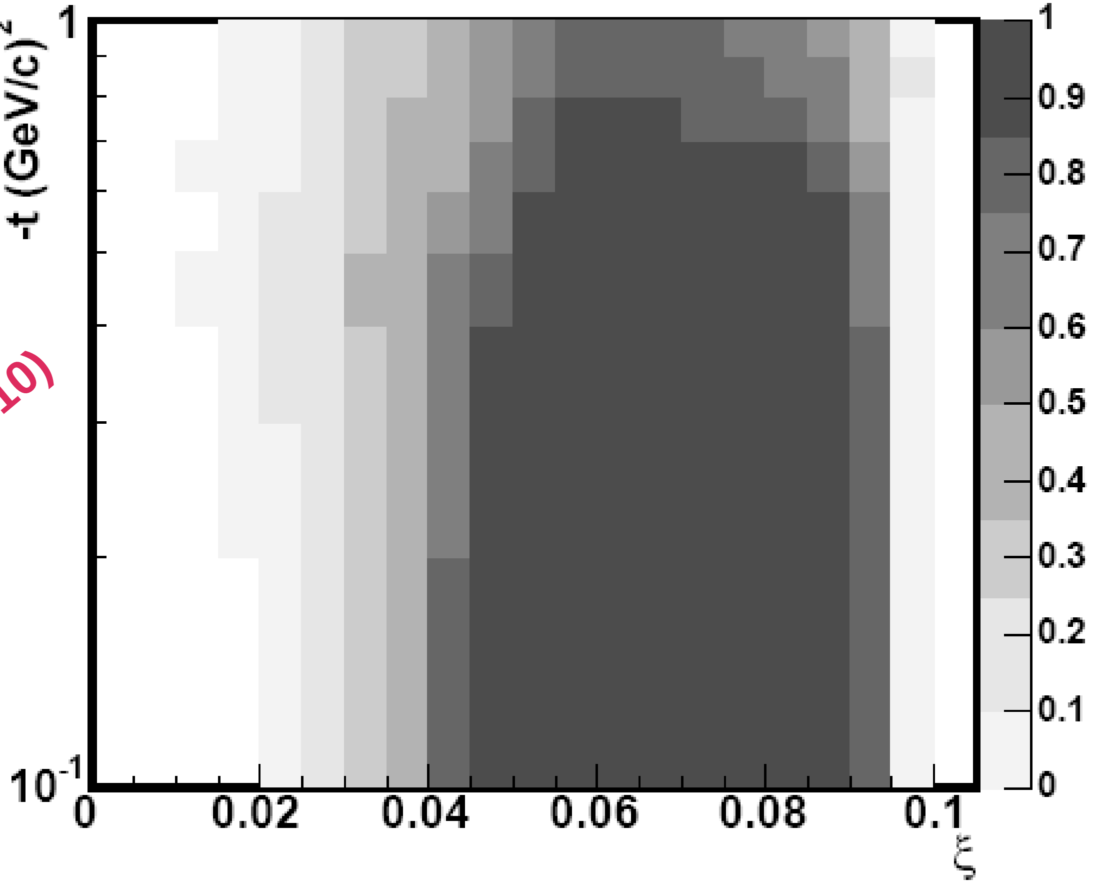
1-statistics
2-beam size
3-beam jitter



@ CDF
^{w}/lowlum data

±30 μm

RPS acceptance

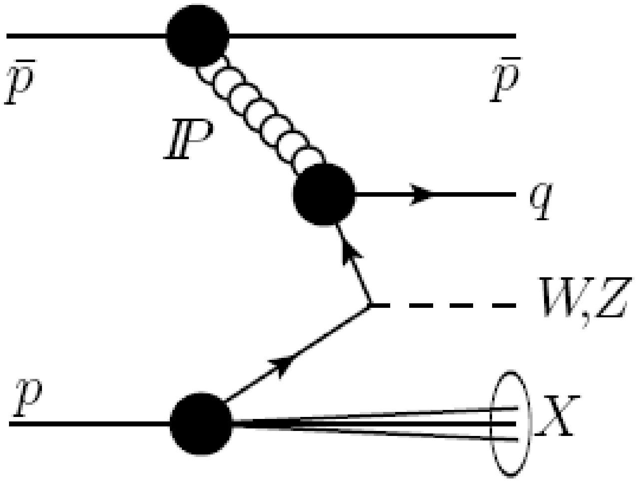


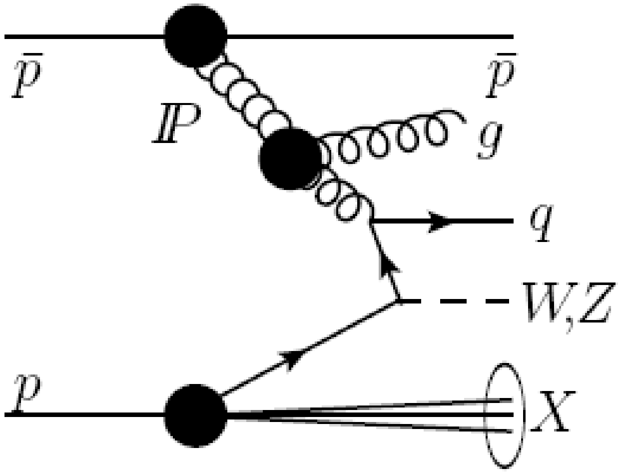
PRD 82, 112004 (2010)

FIG. 3: RPS acceptance as a function of ξ and t obtained from simulation using the transport parameters between the nominal interaction point and the Roman pots.

Diffractive W/Z production

PRD 82, 112004 (2010)





- In LO QCD *W* probes the quark content of diffractive exchange
- Production by gluons is suppressed by a factor of α_S, and can be distinguished from quark production by an associated jet

Data and event selection

0.6 fb-1 of integrated luminosity data

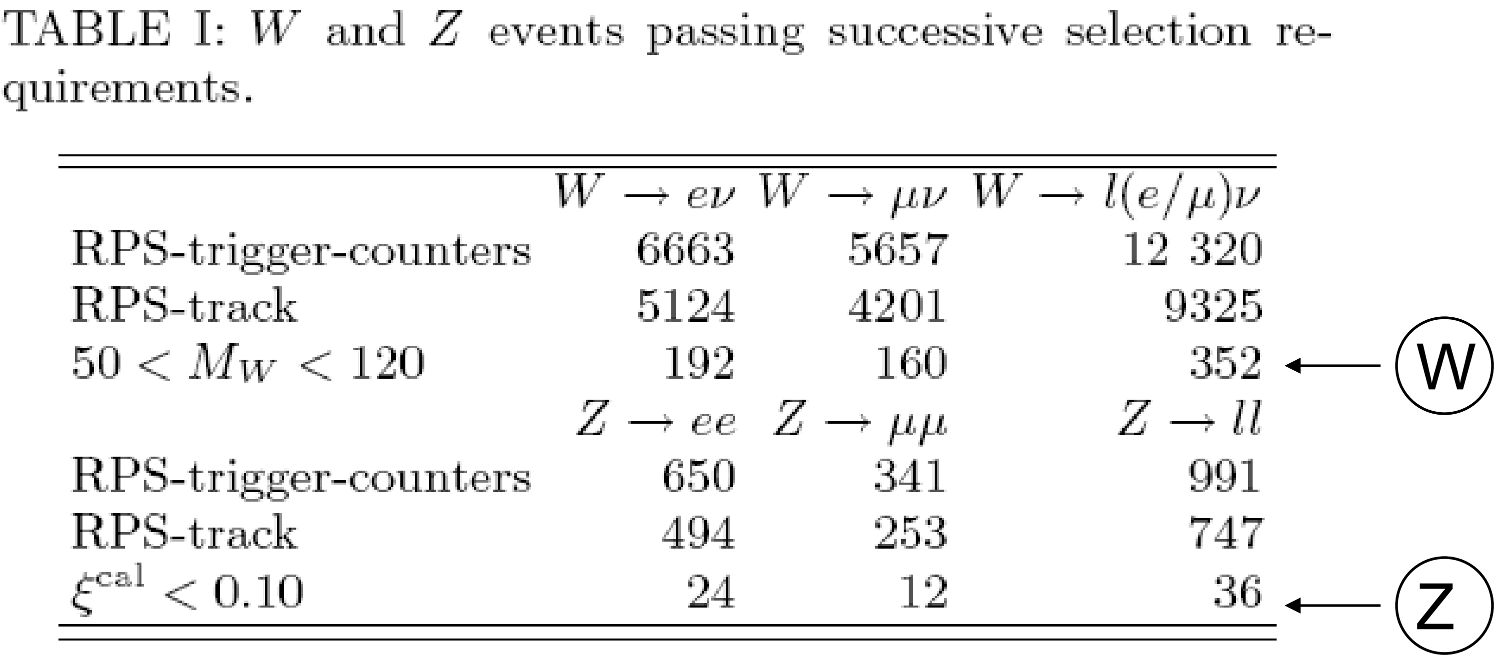


TABLE I: W and Z events passing successive selection requirements.

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

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

Diffractive W/Z analysis

Using RPS information:

- No background from gaps due to multiplicity fluctuations
- No gap survival probability problem
- The RPS provides accurate event-by-event ξ measurement
- Determine the full kinematics of diffractive W production by obtaining η_ν using the equation:

$$\boxed{\xi^{\mathrm{RPS}} - \xi^{\mathrm{cal}} = \frac{\not{E}_T}{\sqrt{s}} e^{-\eta_\nu}}$$

where

$$\xi^{\mathrm{cal}} = \sum_{\mathrm{towers}} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

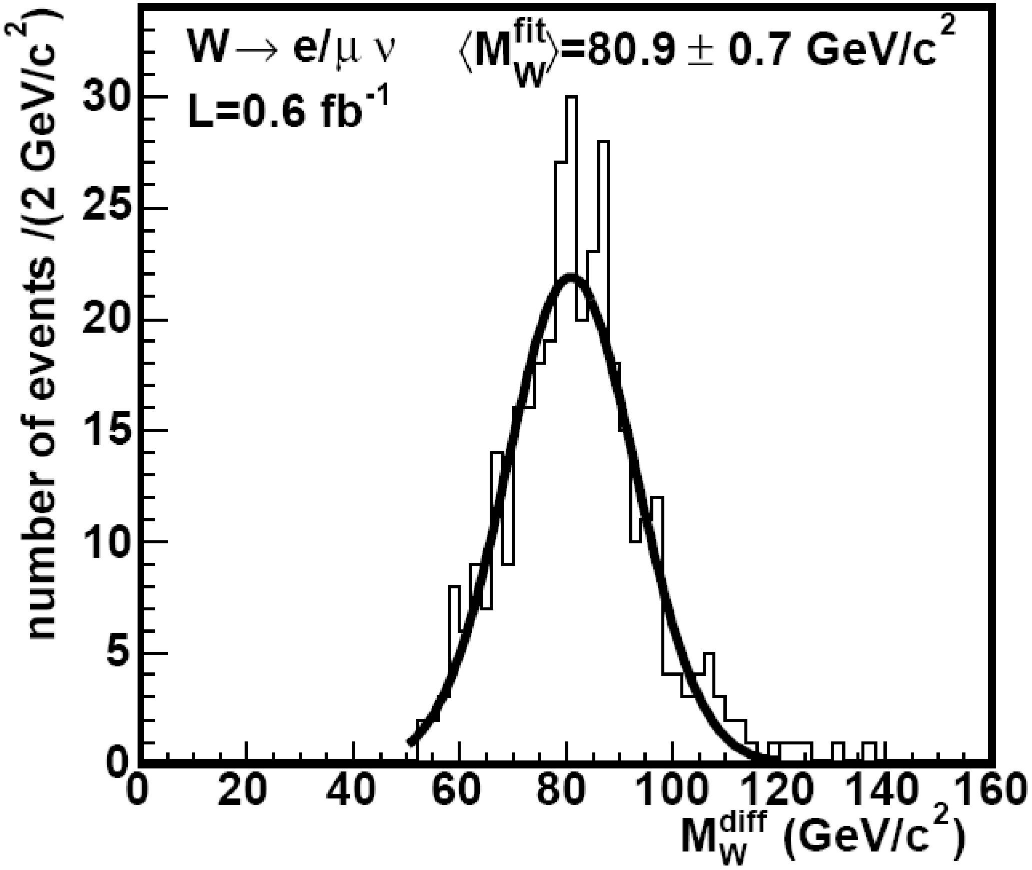
This allows determination of:

- W mass

  and potentially (not enough range in present case)

  - x_{Bj} distribution
  - Diffractive structure function

Reconstructed M_W^{diff}

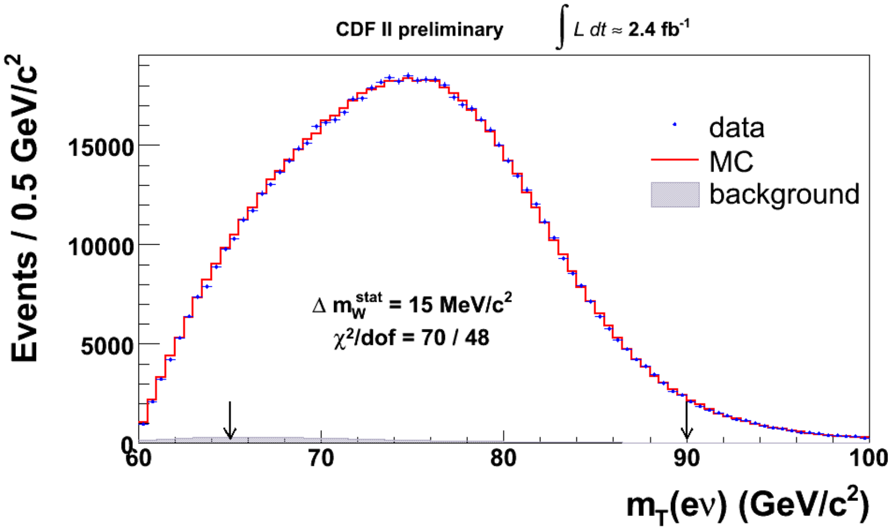


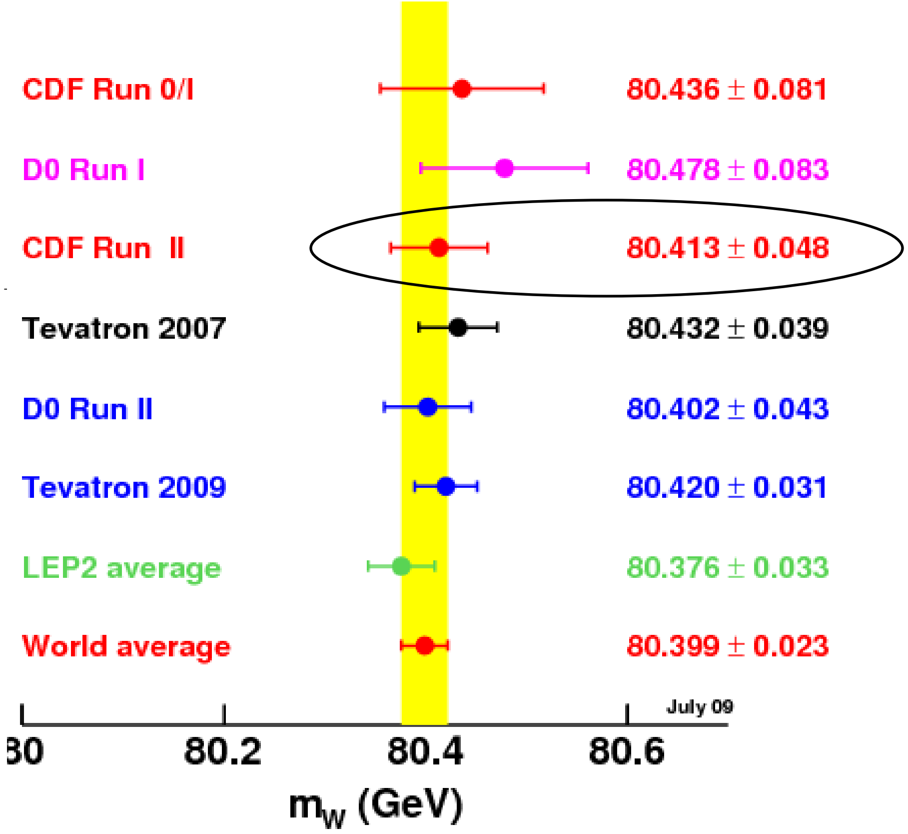
- ❑Reconstructed W mass using the 352 diffractive events fitted with a Gaussian.

M_W from inclusive $W \to e/\mu + \nu$

Method: compare transverse M^W data with MC

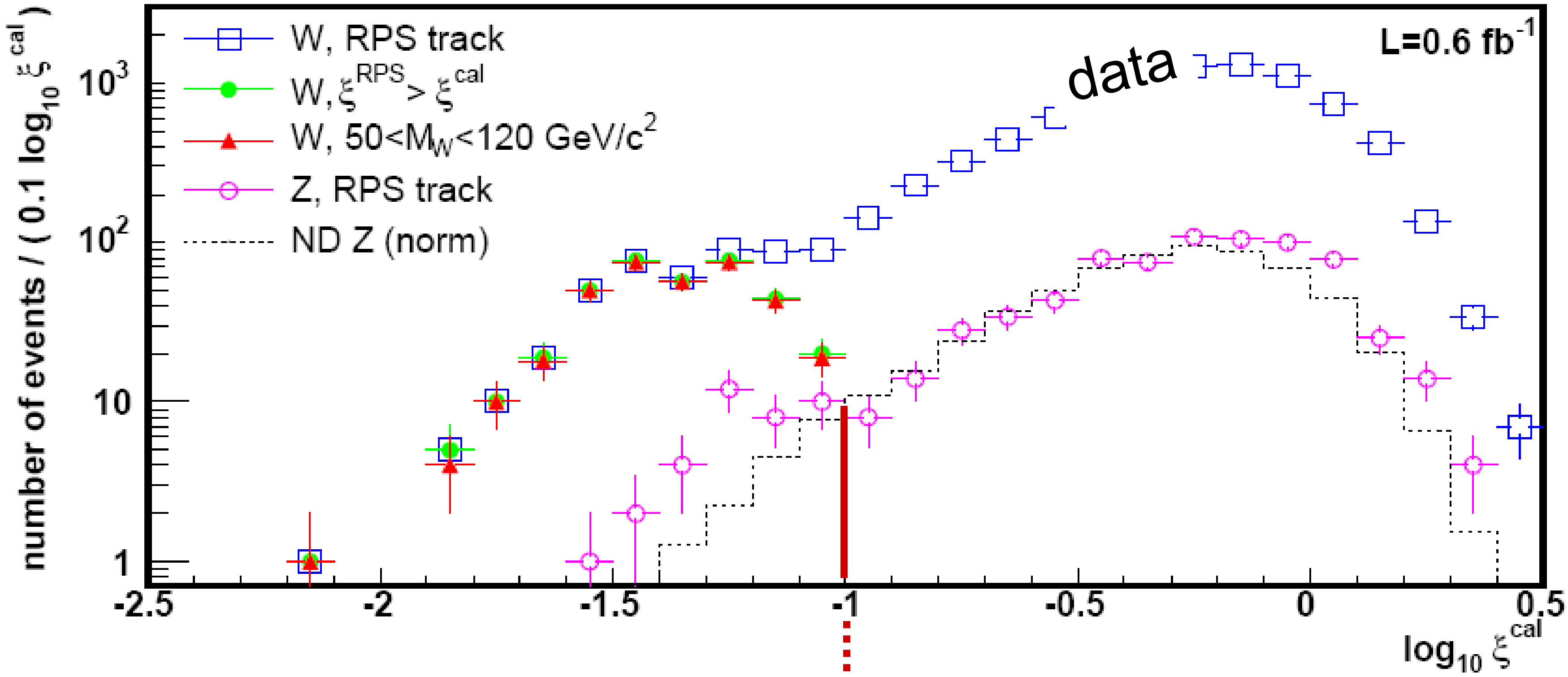
$$M_T^W = \sqrt{2(p_T^l p_T^\nu - \overrightarrow{p}_T^l \cdot \overrightarrow{p}_T^\nu)}/c$$





$$M_W^{diff} = 80.9 \pm 0.7\ \text{GeV}/c^2$$

ξ^{cal} distribution



diffractive event
enhanced region

nondiffractive event
region and overlaps

Diffractive W/Z fractions

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

~80%

~87%%

68-80%

f1-int =(25.6±1.2)%

$$R_W = [1.00 \pm 0.05(\mathrm{stat}) \pm 0.10(\mathrm{syst})]\%$$

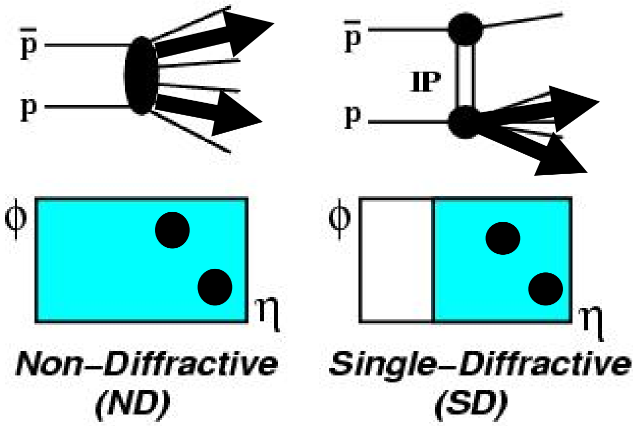
$$R_Z = [0.88 \pm 0.21(\mathrm{stat}) \pm 0.08(\mathrm{syst})]\%$$

Run I: R^W =1.15±0.55 % for $\xi_{min} < \xi < 0.1$

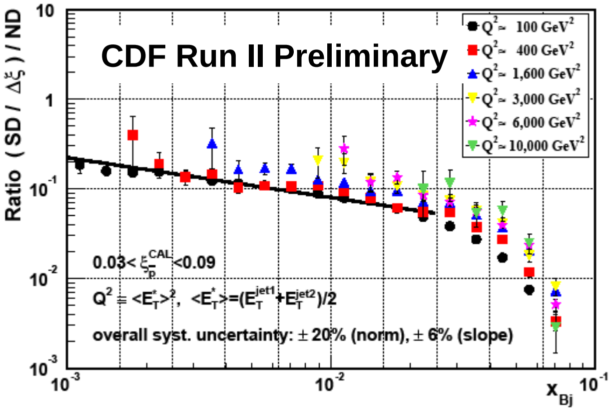
➔ [0.88±0.21 (stat)% within $0.03 < \xi < 0.10$ & $|t|<1$

DSF from Dijets in Run II

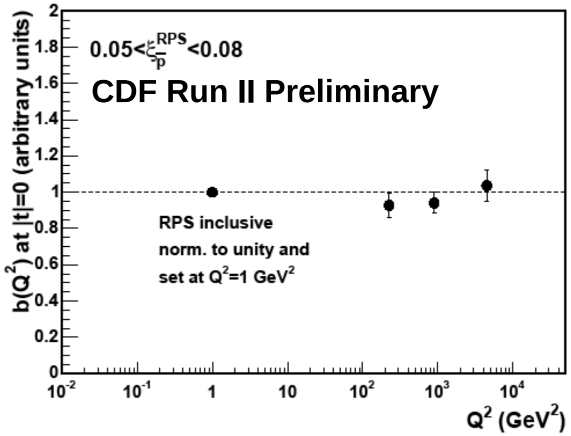
$$R(x_{Bj}) \equiv \frac{\mathrm{Rate}_{jj}^{SD}(x_{Bj})}{\mathrm{Rate}_{jj}^{ND}(x_{Bj})} \Rightarrow \frac{F_{jj}^{SD}(x_{Bj})}{F_{jj}^{ND}(x_{Bj})}$$



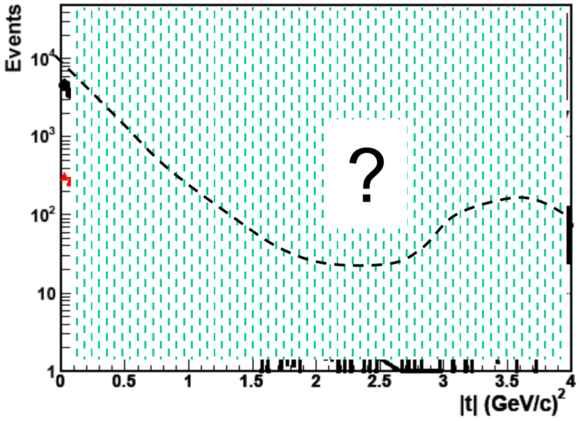
x_{Bj} - distribution



b - slope of t-distribution



t - distribution

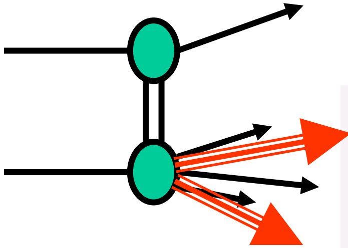


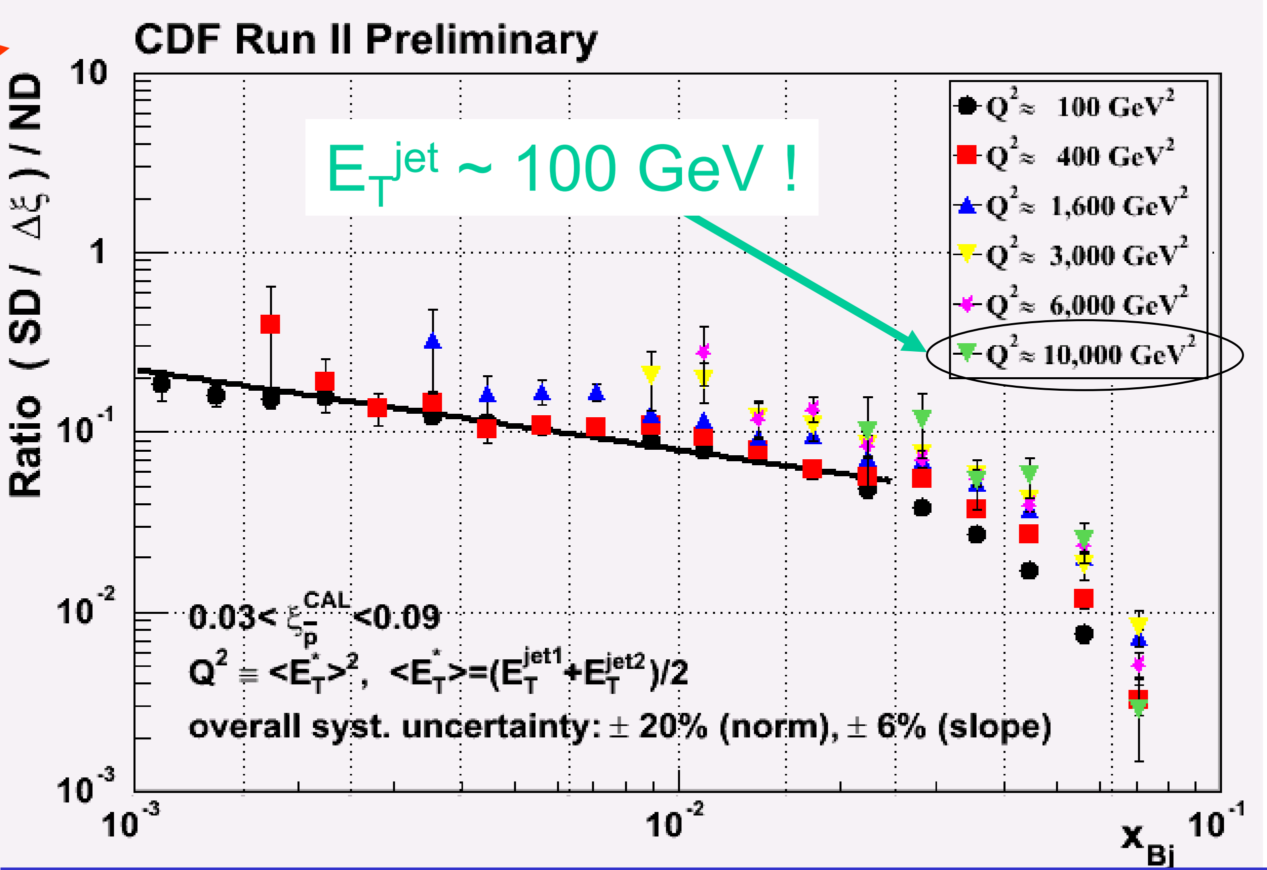
- The x_{Bj}-distribution of the SD/ND ratio has no strong Q^2 dependence
- the slope of the t-distribution is independent of Q^2 for $|t| < 1$ (GeV/*c*)^2
- does the t-distribution have a diffraction minimum at $|t| \sim 2.5$ (GeV/c)^2 (?)

➢ all three results are / would be ➔ "first observation"

Diffractive structure function – Run II

Q^2 - dependence

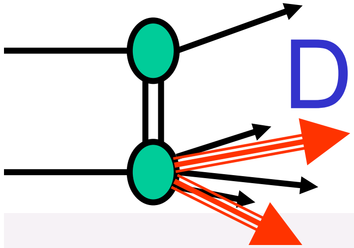




$E_T^{jet} \sim 100$ GeV !

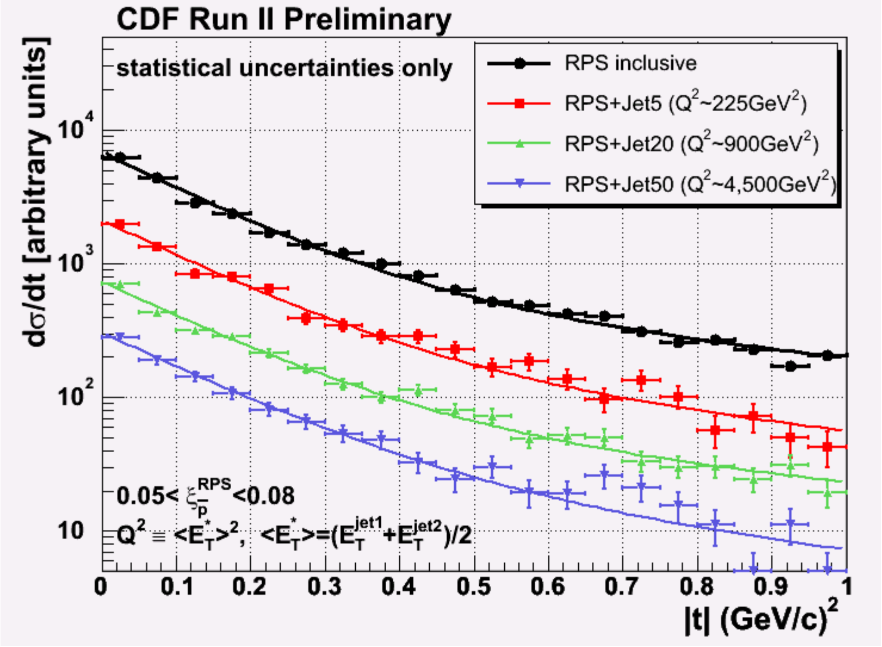
- Small Q^2 dependence in region $100 < Q^2 < 10\,000$ GeV^2 where $d\sigma^{SD}/dE_T$ & $d\sigma^{ND}/dE_T$ vary by a factor of $\sim 10^4$

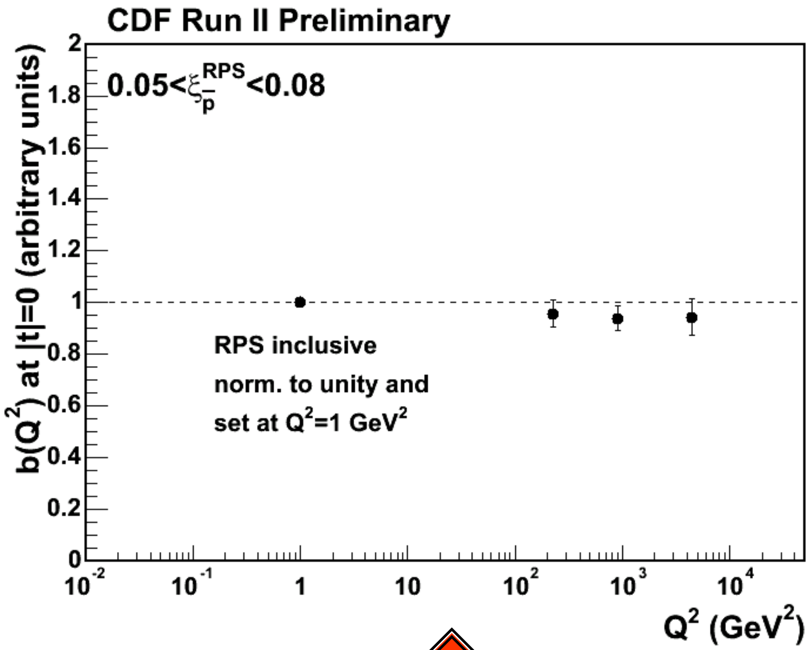
➔ The Pomeron evolves as the proton !



Diffractive structure function – Run II

t - dependence





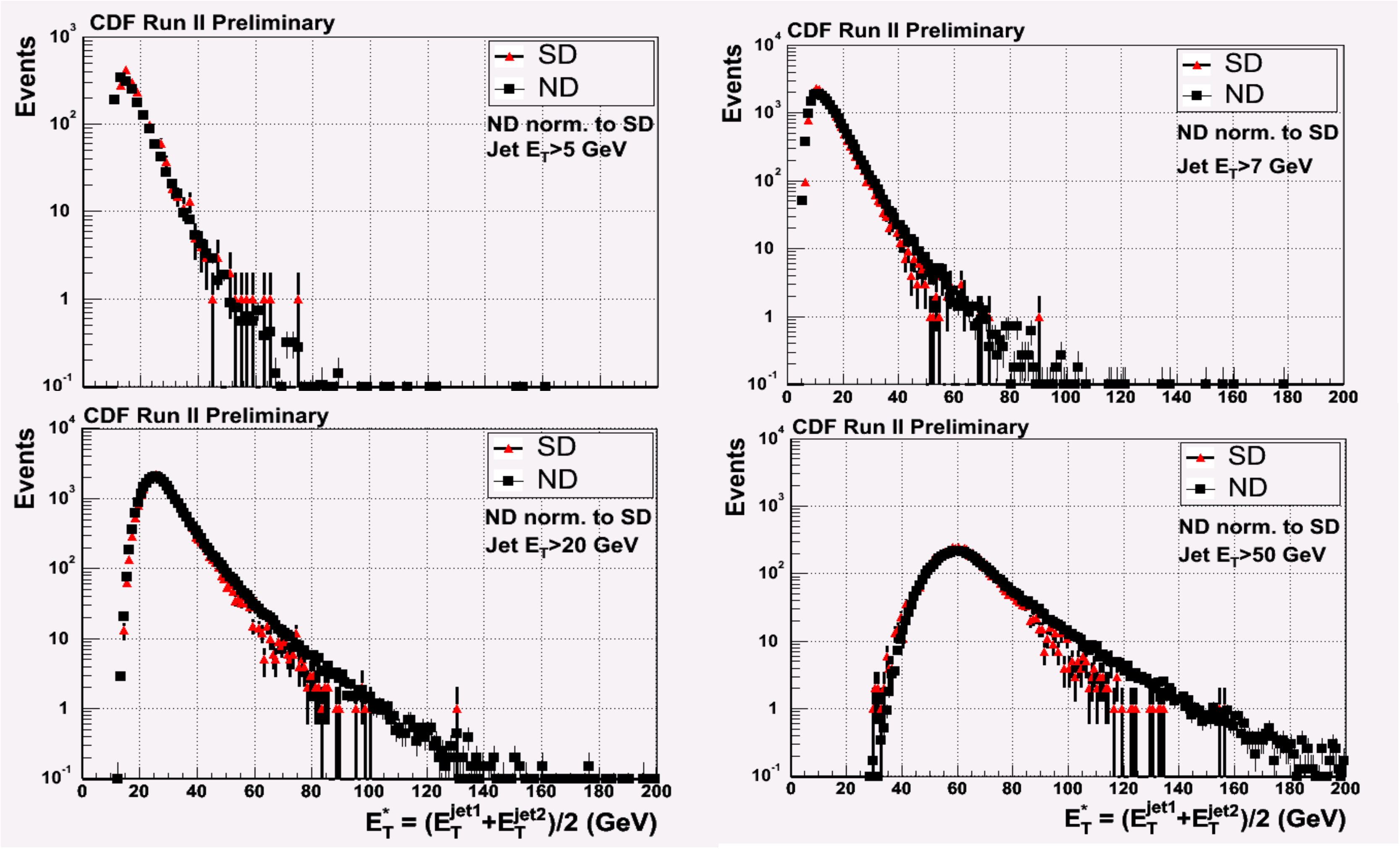
Fit dσ/dt to a double exponential:

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

- No diffraction dips at |t| < 1 **GeV^2**
- No Q2 dependence in slope from inclusive up to Q^2~10^4 **GeV^2**

- Same slope over entire region of 0 < Q^2 < ~ 10 000 GeV^2!

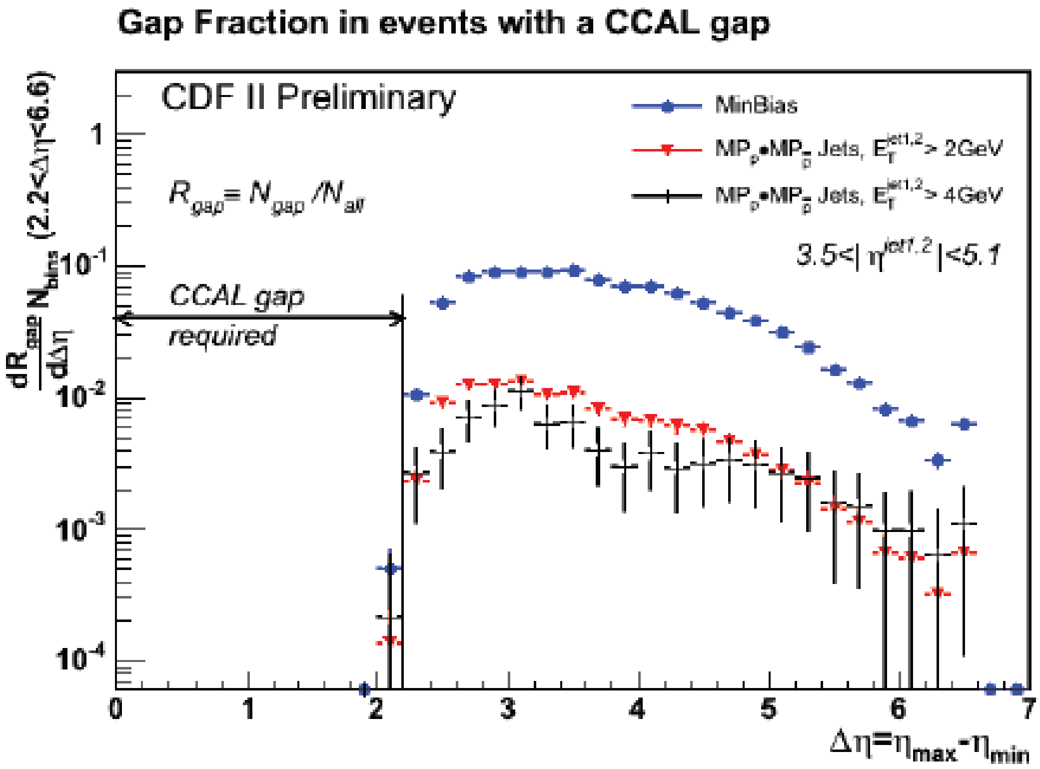
Dijet E_T distributions

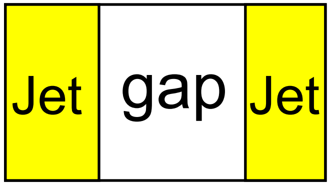


➔ similar for SD and ND over 4 orders of magnitude

Kinematics

CENTRAL GAPS

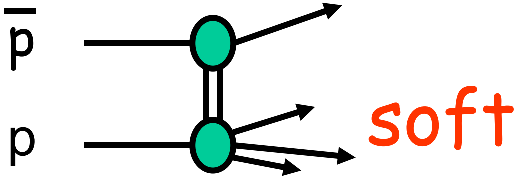


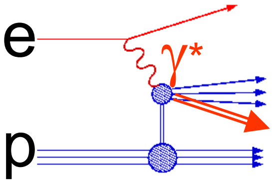


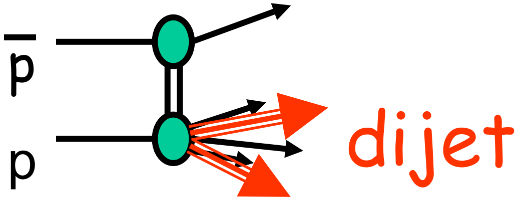
The distribution of the gap fraction $R_{gap}=N_{gap}/N_{all}$ vs $\Delta\eta$ for MinBias ($CLC_p \bullet CLC_{pbar}$) and MiniPlug jet events ($MP_p \bullet MP_{pbar}$) of $E_{T(jet1,2)}>2$ GeV and $E_{T(jet1,2)}> 4$ GeV.

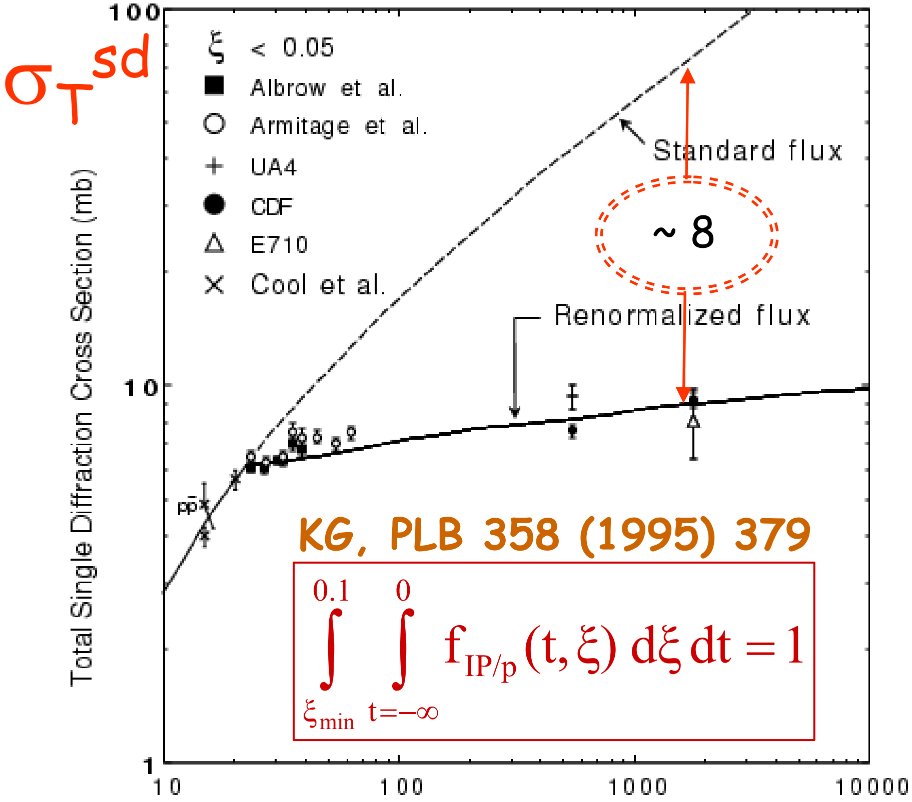
The distributions are similar in shape within the uncertainties.

σ^{T}_{SD} and dijets



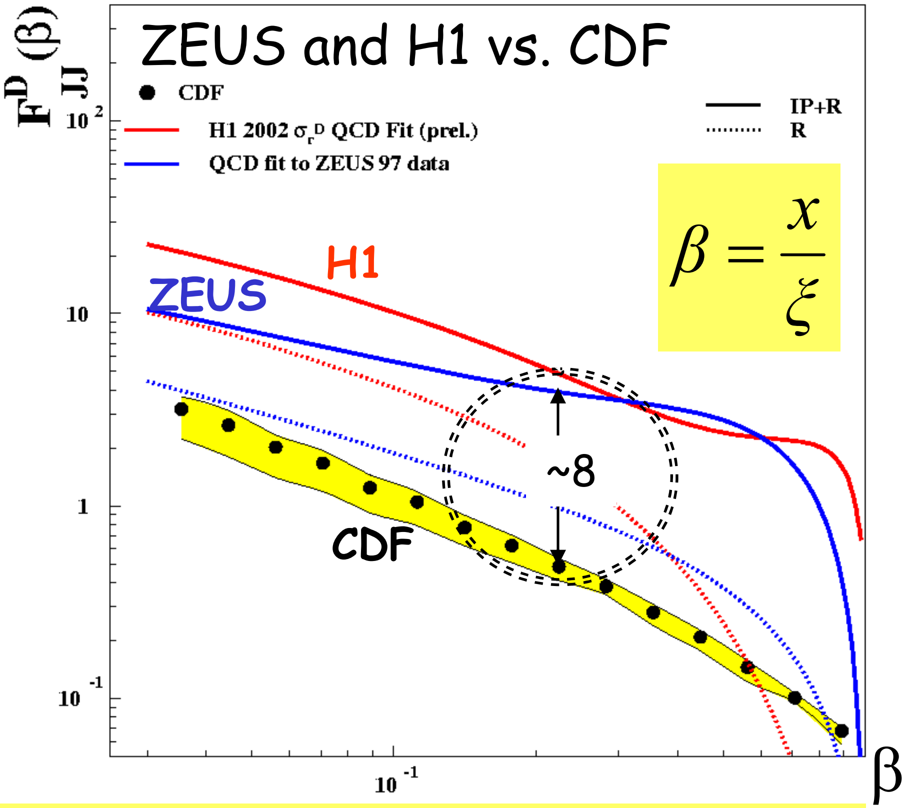






KG, PLB 358 (1995) 379

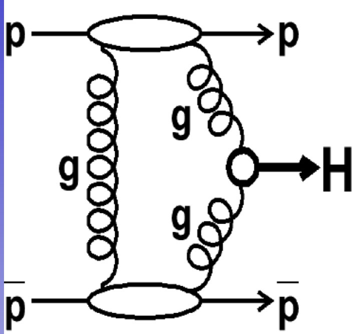
$$\int_{\xi_{min}}^{0.1}\int_{t=-\infty}^{0} f_{IP/p}(t,\xi)\, d\xi\, dt = 1$$

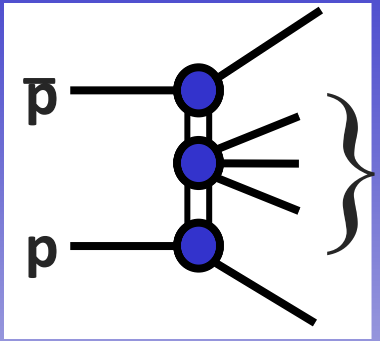


$$\beta = \frac{x}{\xi}$$

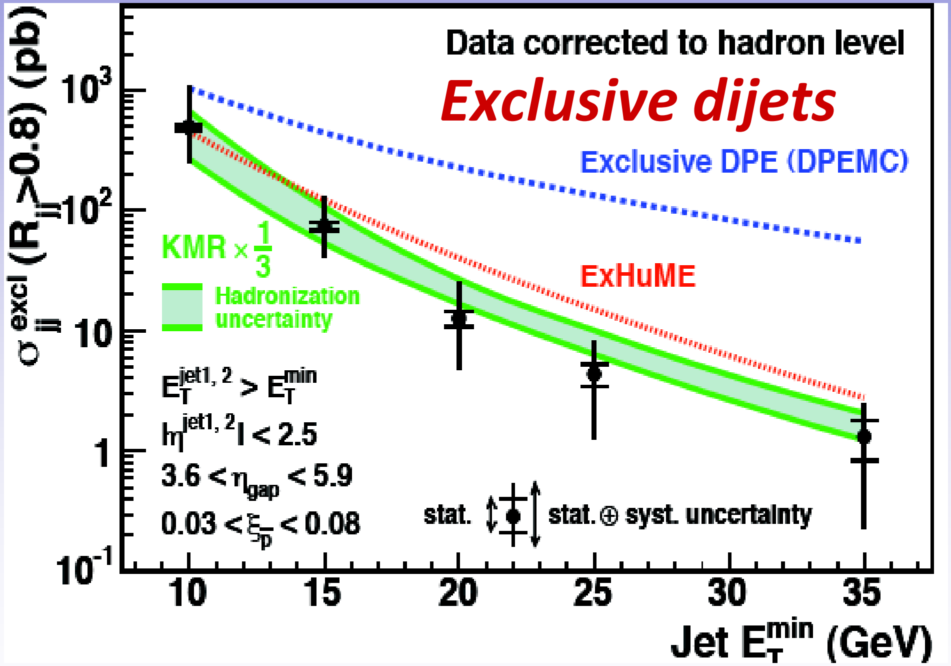
Magnitude: same suppression factor in soft and hard diffraction!
Shape of β distribution: ZEUS, H1, and Tevatron – why different slapes?

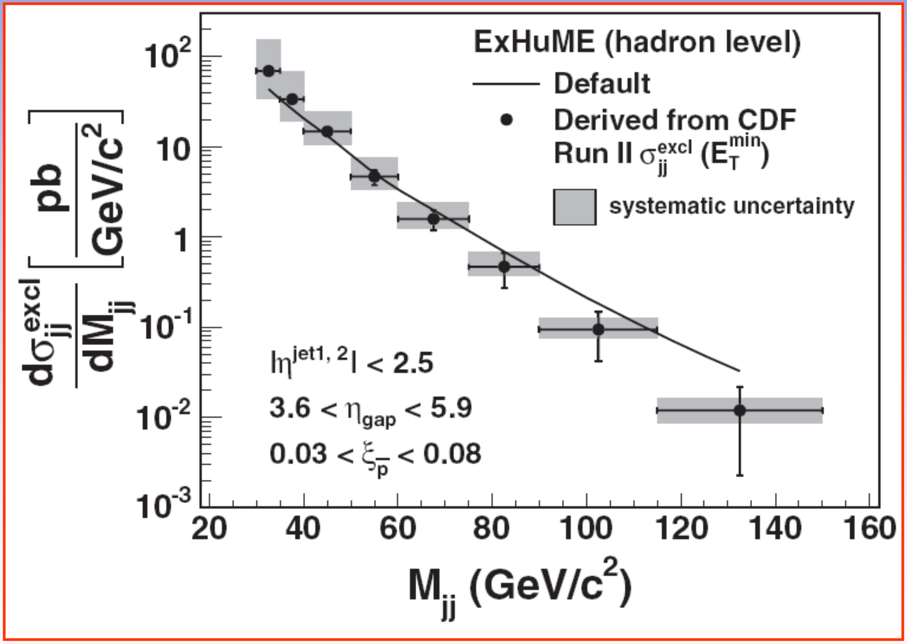
EXCLUSIVE Dijet→ Excl. Higgs *THEORY CALIBRATION*





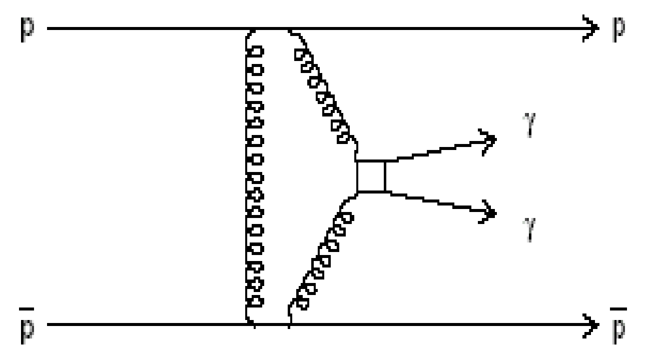
JJ	*PRD 77, 052004 (2008)*
γγ	*PRL 99, 242002 (2007)*
χ_c	*PRL 242001 (2007)*





Exclusive γγ production

Phys.Rev.Lett. 99,242002 (2007)



$E_T(\gamma) > 5$ GeV
$|\eta(\gamma)| < 1.0$

- 3 $\gamma\gamma$ / $\pi^o\pi^o$ evts observed
  - 2 $\gamma\gamma$ candidates
  - 1 $\pi^0\pi^0$ candidate

V.A.Khoze et al. Eur. Phys. J C38, 475 (2005):

$$\boxed{\sigma\,(\text{with CDF cuts}) = 56^{+72}_{-24}\ \text{fb}\ \Rightarrow 0.8^{+1.6}_{-0.5}\ \text{events}}$$

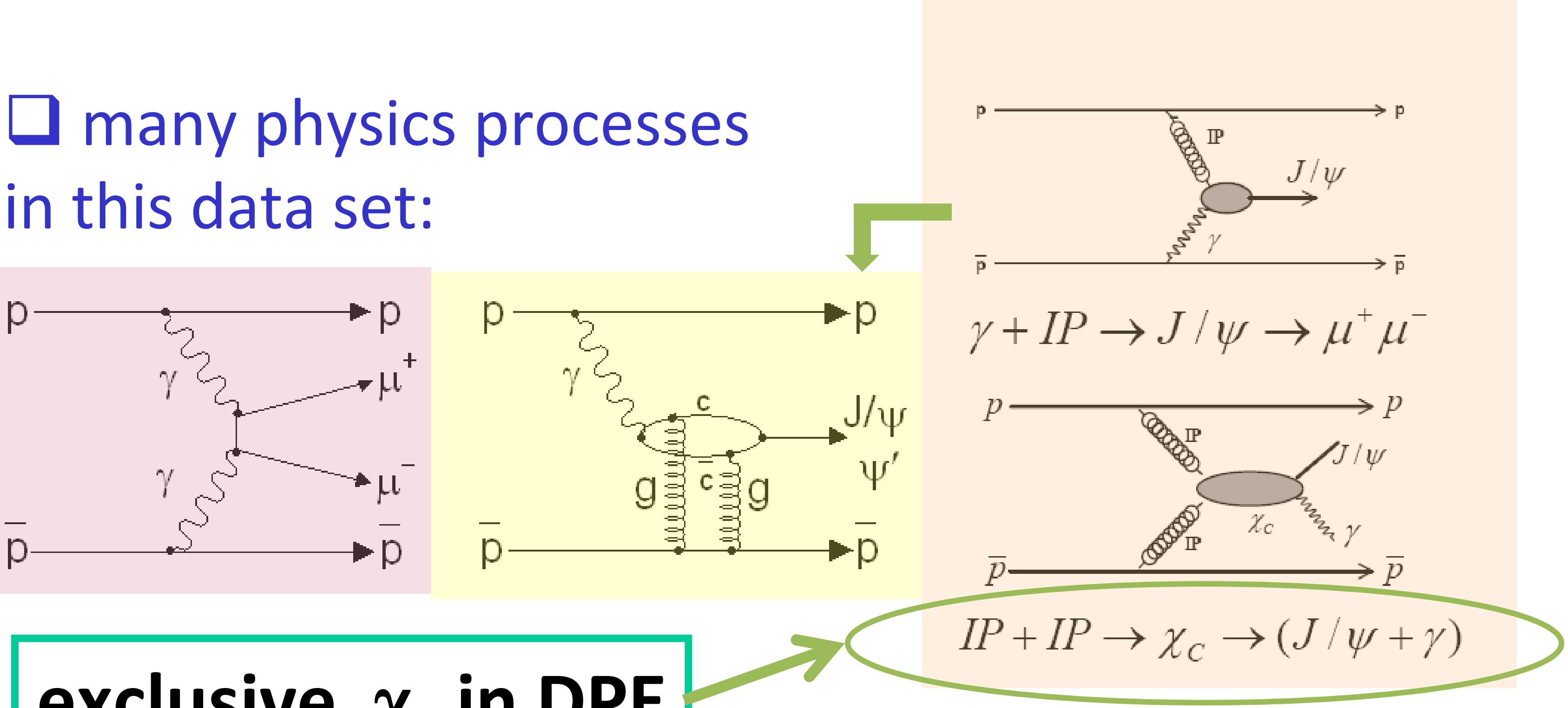
- 2 events ➔ σ ~ 90 fb, in agreement with theory
- cannot claim discovery as bgd study was made *a posteriori*

Exclusive Dimuon Production

$p+\bar{p} \rightarrow p+\mu^+\mu^-+\bar{p}$

$3 \text{ GeV}/c^2 < M_{\mu\mu} < 4 \text{ GeV}/c^2$

- ❑ many physics processes in this data set:



$\gamma + IP \rightarrow J/\psi \rightarrow \mu^+\mu^-$

$IP + IP \rightarrow \chi_C \rightarrow (J/\psi + \gamma)$

exclusive χ_c in DPE

Exclusive J/ψ and ψ(2s)

J/ψ production

243 ±21 events

$d\sigma/dy|_{y=0} = 3.92 \pm 0.62$ nb

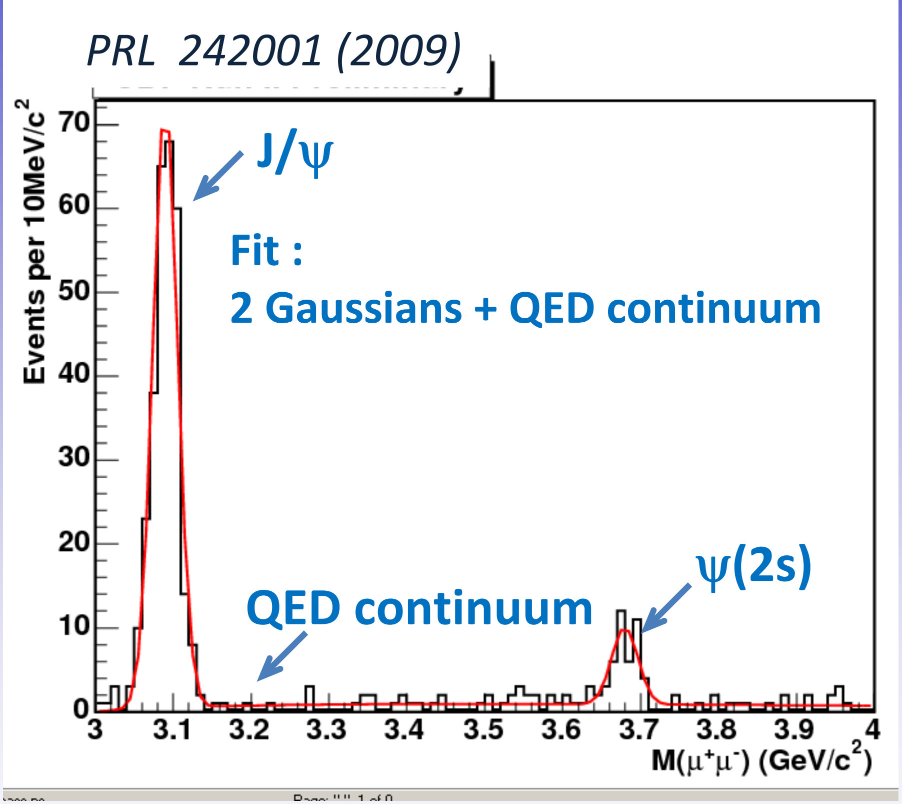
Theoretical Predictions

2.8 nb [Szczurek07,],

2.7 nb [Klein&Nystrand04],

3.0 nb [Conclaves&Machado05], and

3.4 nb [Motkya&Watt08].



PRL 242001 (2009)

J/ψ

Fit :

2 Gaussians + QED continuum

QED continuum

ψ(2s)

Ψ(2s) production

34±7 events

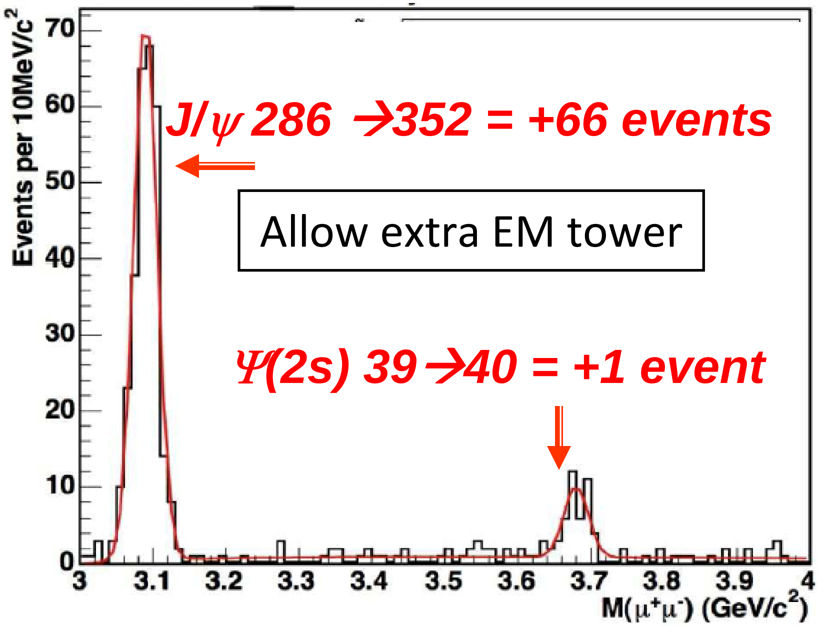
$d\sigma/dy|_{y=0} = 0.54 \pm 0.15$ nb

R = ψ(2s)/J/ψ = 0.14 ± 0.05

In agreement with HERA: R = 0.166 ± 0.012 in a similar kinematic region

Exclusive $\chi_c \to J/\psi(\to \mu^+\mu^-)+\gamma$

PRL 242001 (2009)



J/ψ 286 →352 = +66 events

Allow extra EM tower

Ψ(2s) 39→40 = +1 event

- ☐ Allowing EM towers (E_T >80MeV)

  →large increase in the J/ψ peak & minor change in the ψ(2s) peak

➔ Evidence for:

$\chi_c \to J/\psi+\gamma$ production

$d\sigma/dy|_{y=0}$ = 75 ± 14 nb,

compatible with theoretical predictions

▪160 nb (Yuan 01)

90 nb (KMR01)

SUMMARY

- ☐ **Diffractive W and Z fractions: final results based on Run II CDF data using a Roman Pot Spectrometer (RPS) to measure the recoil pbar momentum**
- ☐ **The W fraction is in good agreement with the fraction measured in Run I based on a rapidity gap analysis**
- ☐ **The Z fraction is about 10% smaller than the W fraction, just as in non-diffractive events**

- ☐ **Diffractive structure function in dijet production:**
  - ➔ **no strong Q2 and t dependence over a wide range**

- ☐ **Central rapidity gaps in min-bias and very forward dijet events:**
  - ➔ **same dependence on $\Delta\eta=\eta_{max}-\eta_{min}$**

- ☐ **exclusive production observed/measured for several processes**

thank you

for your attendance

BACKUP

DIFFRACTIVE AND NON-DIFFRACTIVE INTERACTIONS

Non-diffractive → no "large" gaps

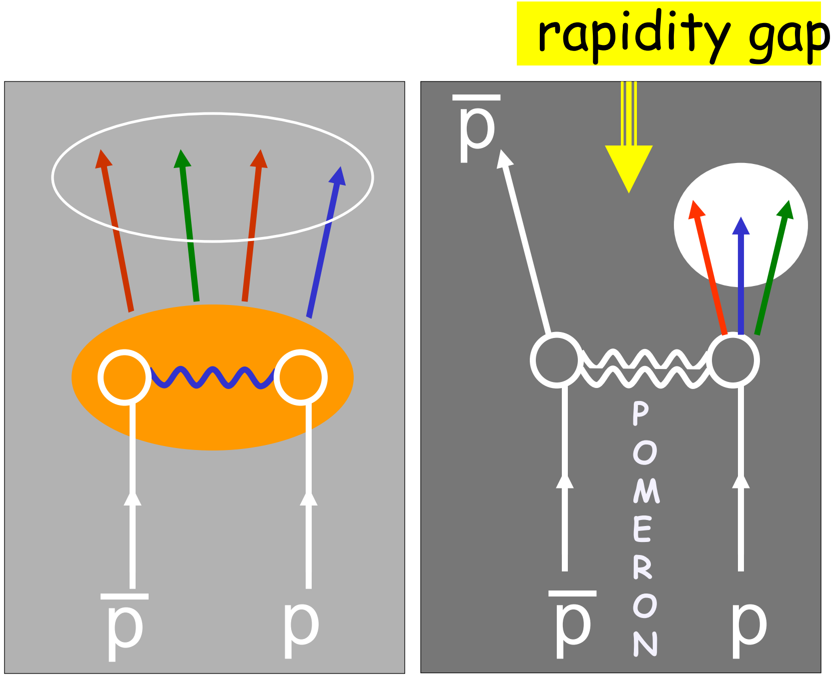
- Color-exchange

Diffractive → gaps

- Colorless exchange with vacuum quantum numbers

Incident hadrons acquire color and break apart

CONFINEMENT

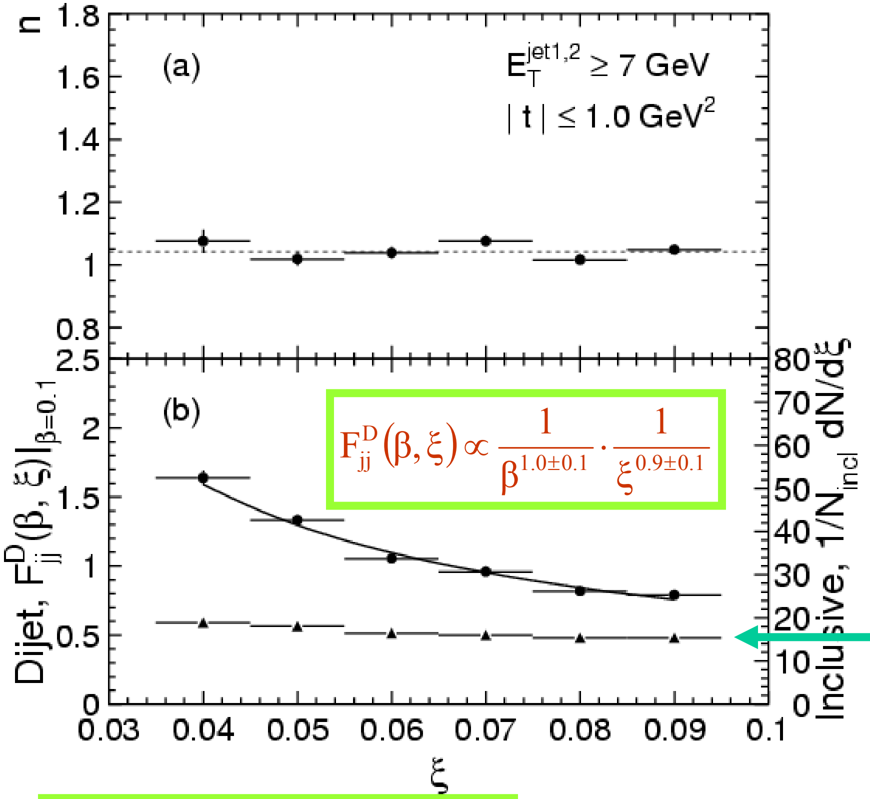


Incident hadrons retain their quantum numbers remaining colorless

pseudo-DECONFINEMENT

Goal: understand the QCD nature of the diffractive exchange

ξ & β dependence of F^D_{jj} – Run I

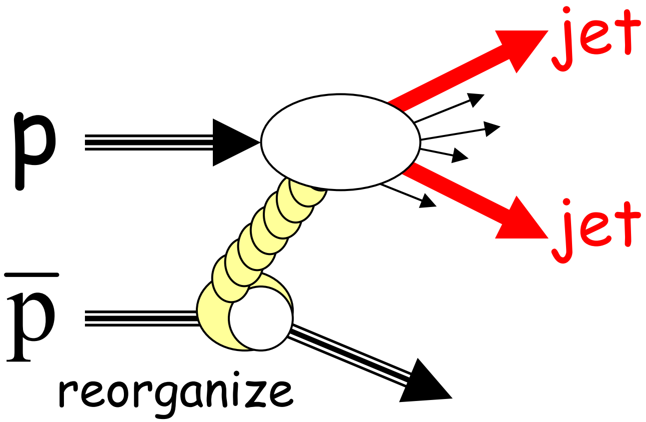


$$\frac{d\sigma_{incl}}{d\xi} \propto \text{constant}$$

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

Pomeron dominated

Diffractive dijets @ Tevatron

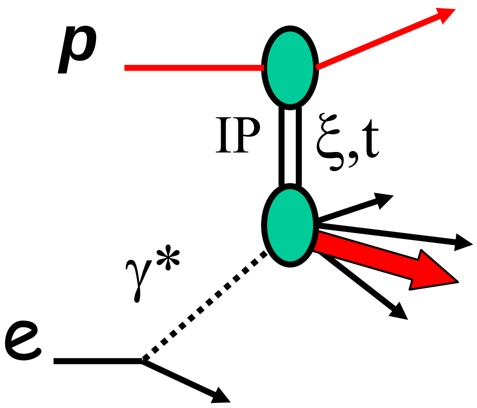


$$F^D(\xi, x, Q^2) \propto \frac{1}{\xi^{1+2\varepsilon}} \cdot F(x/\xi, Q^2)$$

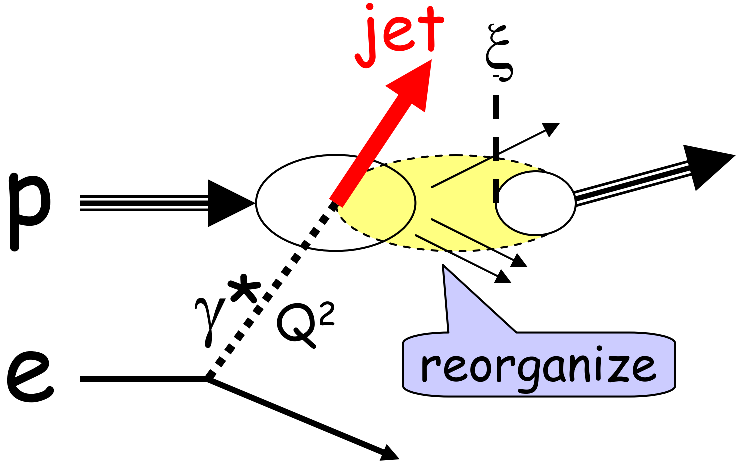
Diffractive DIS @ HERA

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