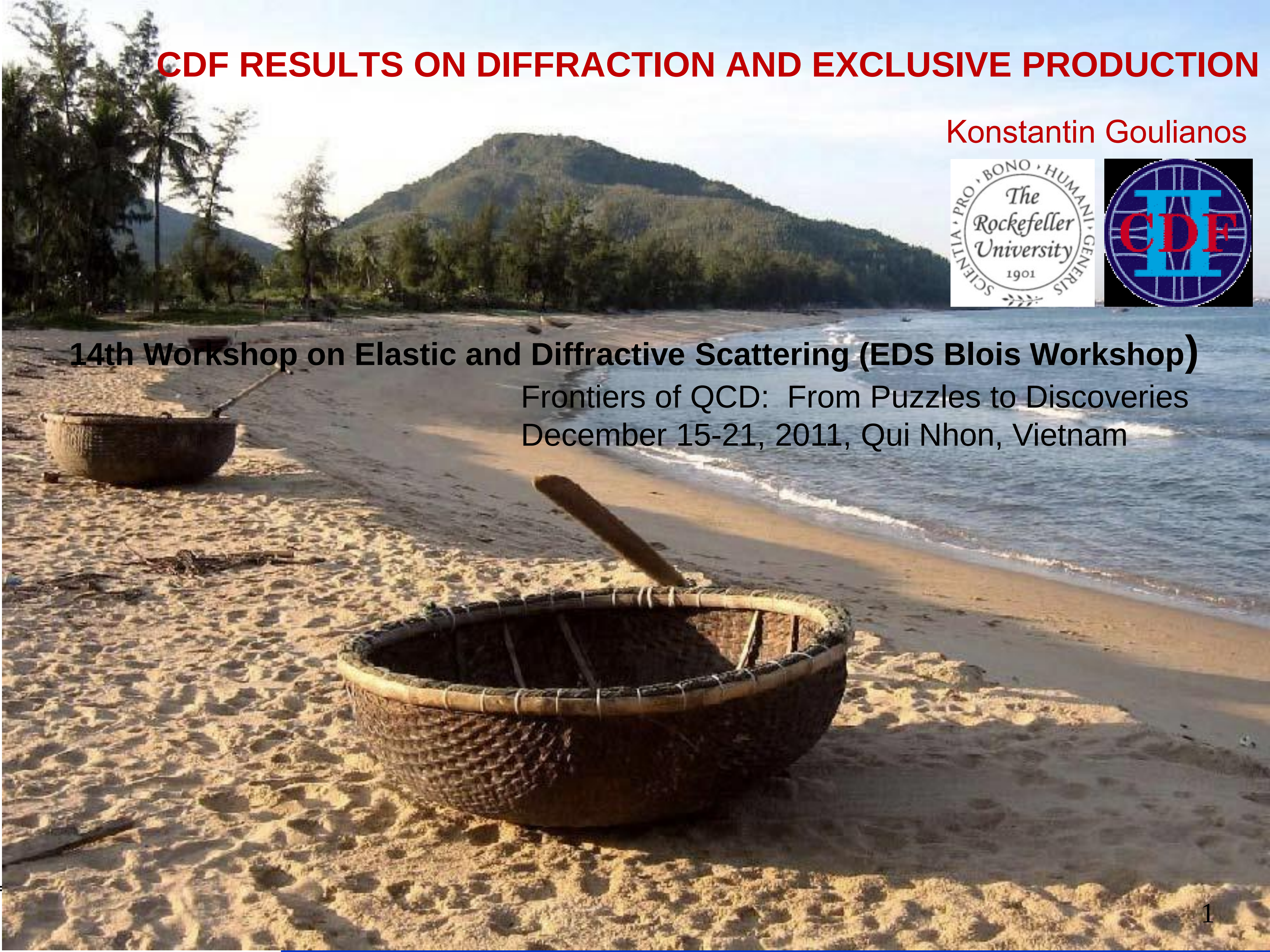
CDF RESULTS ON DIFFRACTION AND EXCLUSIVE PRODUCTION

Konstantin Goulianos

14th Workshop on Elastic and Diffractive Scattering (EDS Blois Workshop)

Frontiers of QCD: From Puzzles to Discoveries

December 15-21, 2011, Qui Nhon, Vietnam

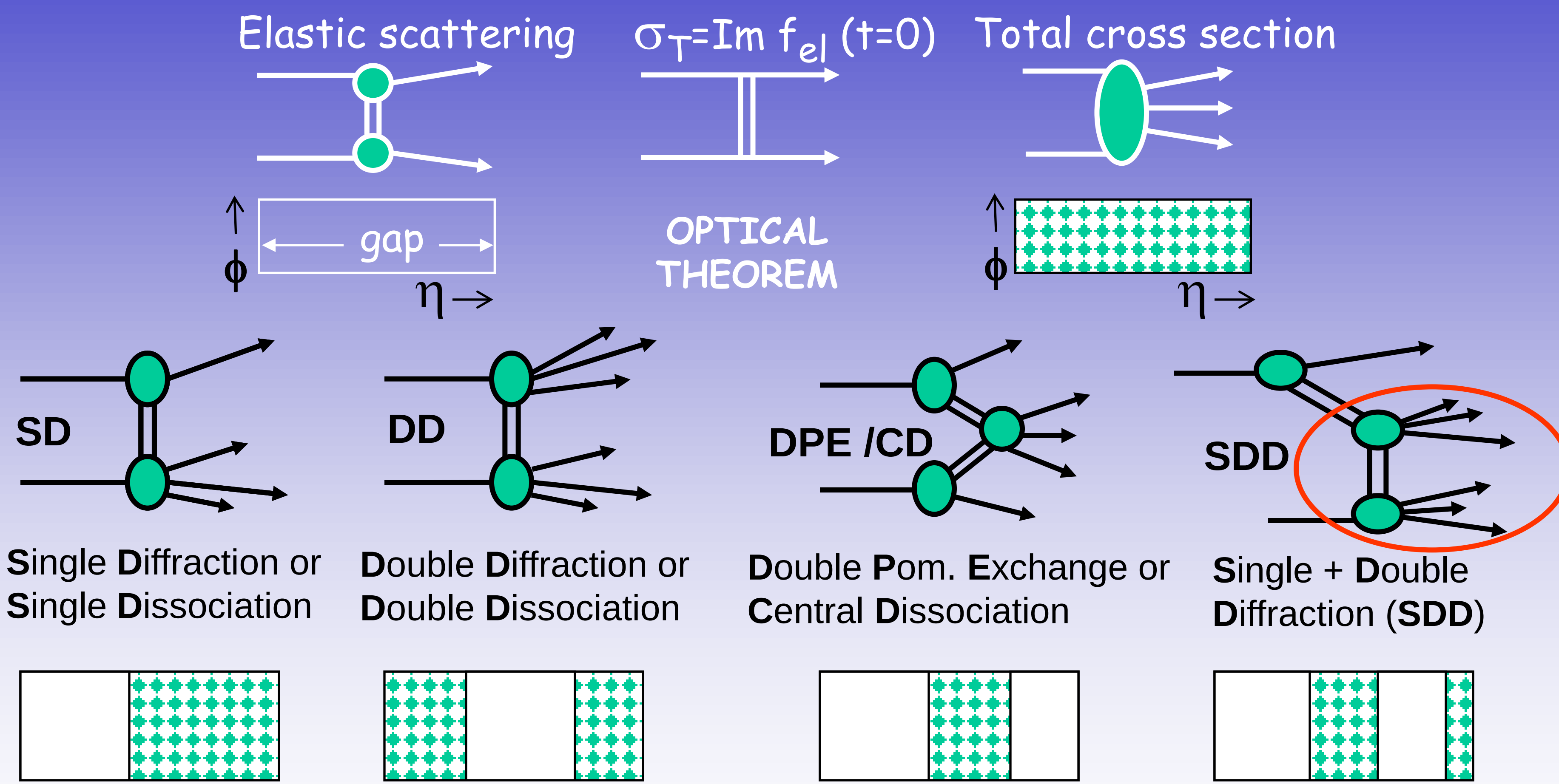


CONTENTS

- INTRODUCTION
- DIFFRACTION
  - ✓ Diffractive *W* and *Z* production – *published*
  - ✓ Diffractive structure function in dijet production – *update*
  - ✓ Rapidity gaps between jets - *update*
- EXCLUSIVE PRODUCTION
  - ✓ Exclusive $\gamma\gamma$ in *pp* collisions at 1.96 TeV – *new*!
- CONCLUSION

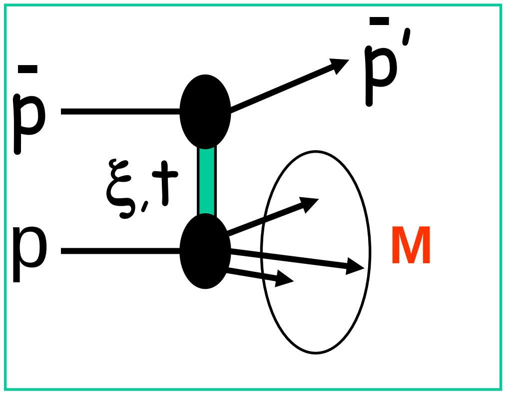
Diffraction at CDF in Run I

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

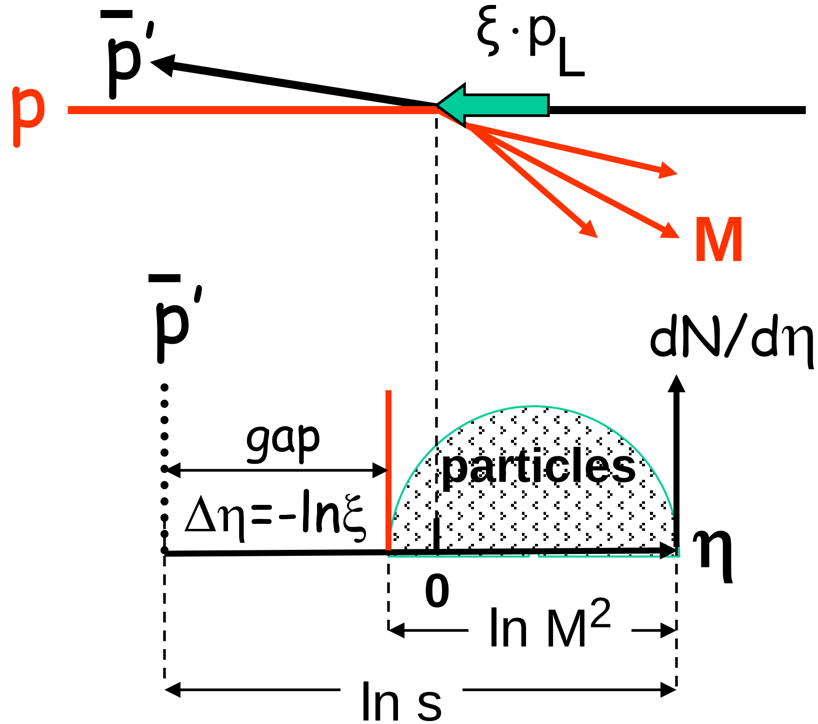


multi-gap **^{w}/ two gaps**
→ part of SD

Definitions



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



No radiation →
no price paid for increasing diffractive gap size

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

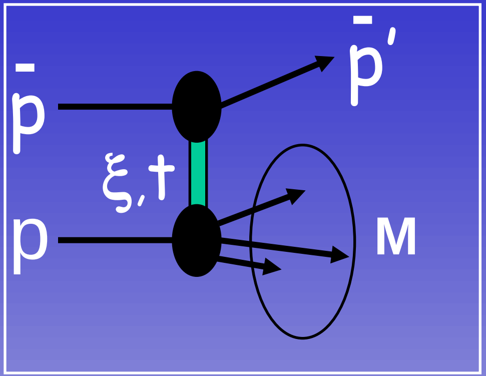
Run I

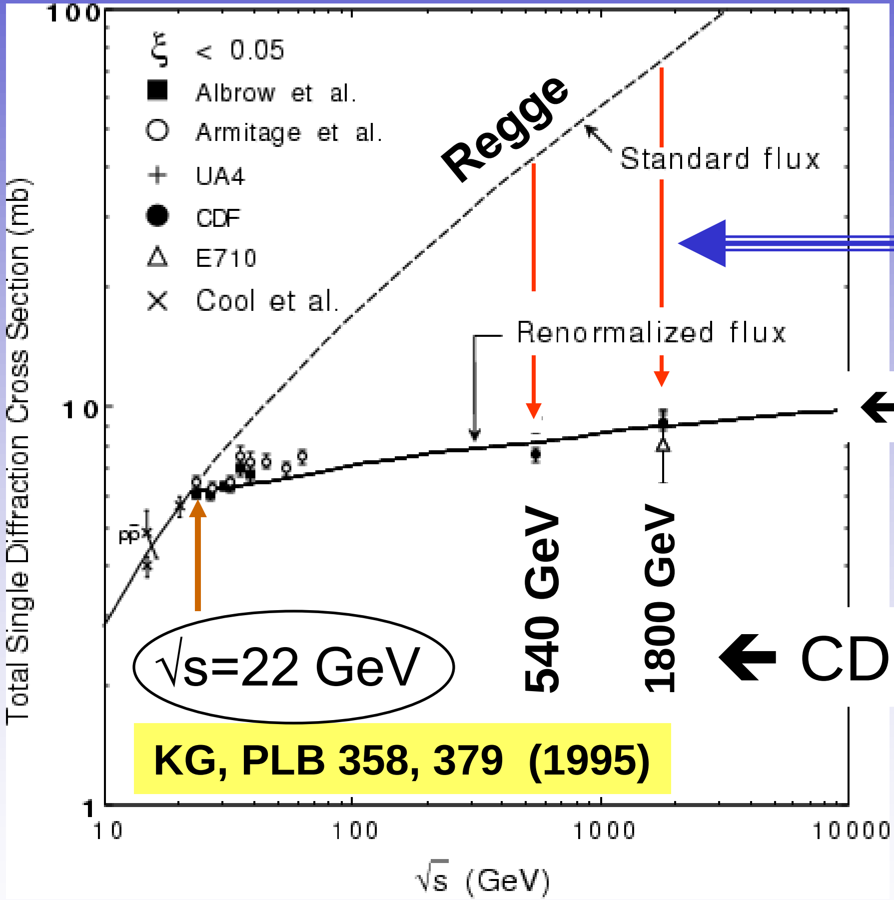
Highlights of Run I Results

The MBR (Minimum Bias Rockefeller) Monte Carlo was used in the forward physics program - see:
http://physics.rockefeller.edu/publications.html

Run I TOTAL SD x-SECTION

➔ suppressed relative to Regge



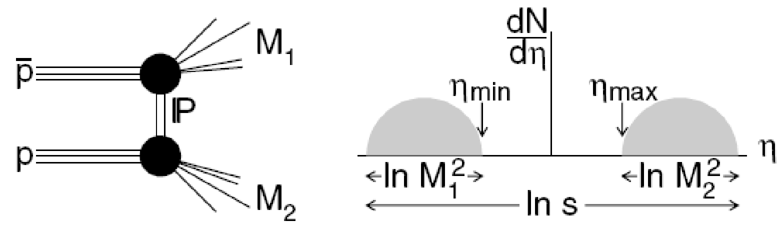


Factor of ~8 (~5) suppression at √s = 1800 (540) GeV

🡐 RENORMALIZATION

🡐 CDF results

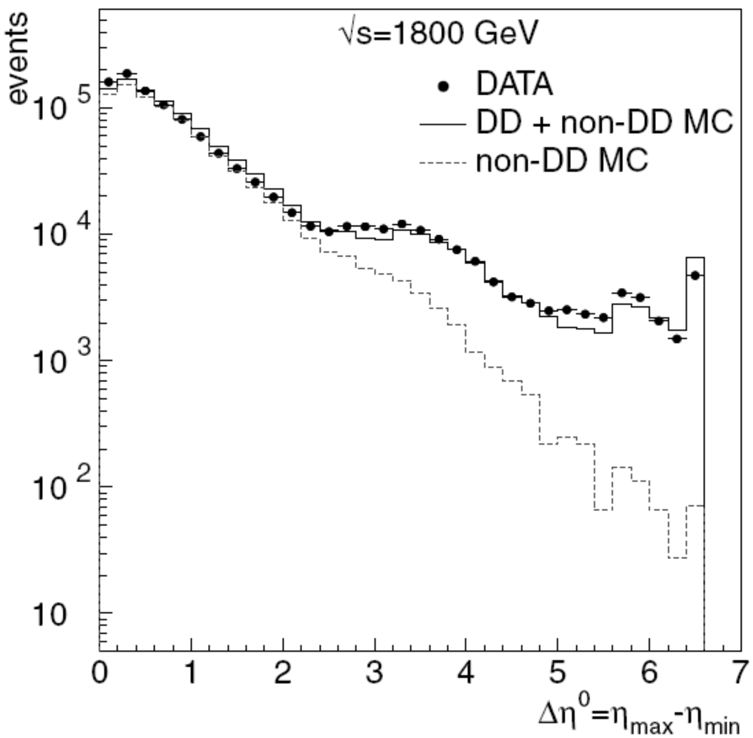
Run I DD at CDF

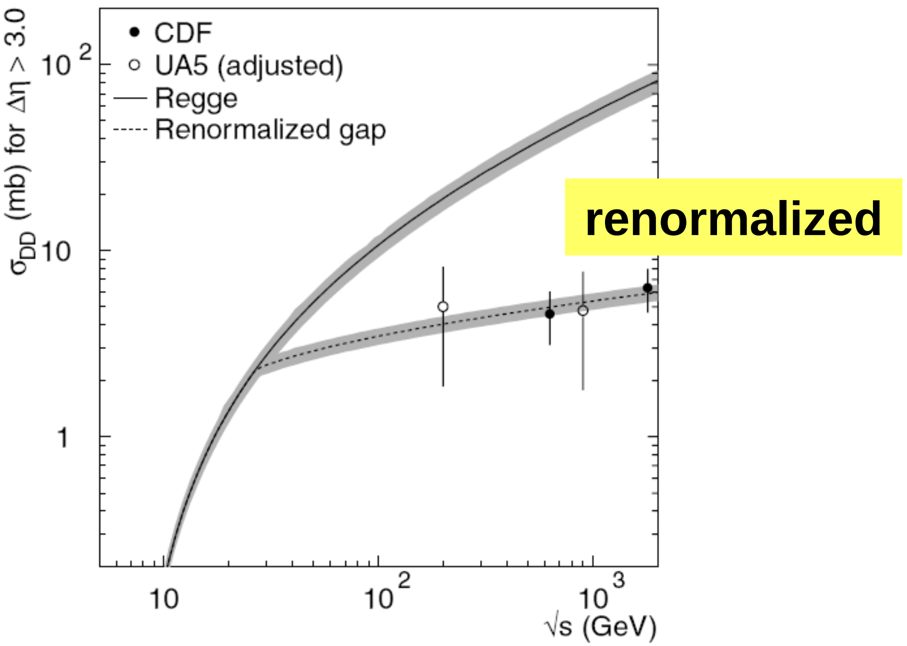


$$\frac{d^3\sigma_{DD}}{dt\,dM_1^2\,dM_2^2} = \frac{d^2\sigma_{SD}}{dt\,dM_1^2}\,\frac{d^2\sigma_{SD}}{dt\,dM_2^2} \Big/ \frac{d\sigma_{el}}{dt} = \frac{[\kappa\beta_1(0)\beta_2(0)]^2}{16\pi}\,\frac{s^{2\epsilon}e^{b_{DD}t}}{(M_1^2M_2^2)^{1+2\epsilon}}$$

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

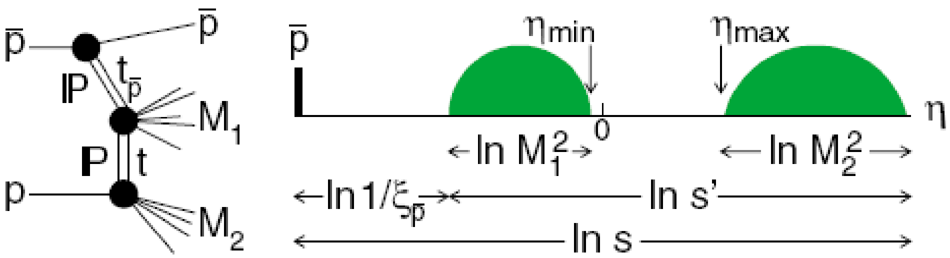
gap probability x-section

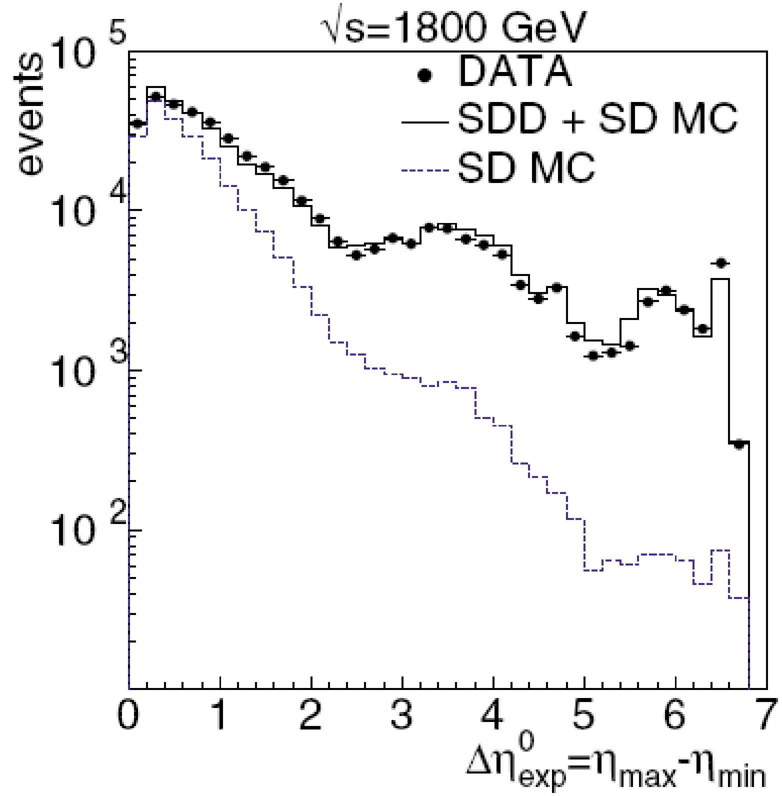




Run I

SDD at CDF



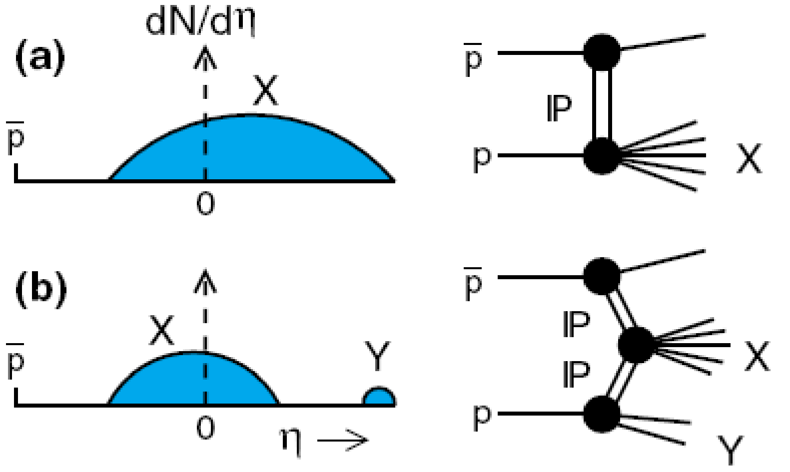


- Excellent agreement between data and MBR (MinBiasRockefeller) MC

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

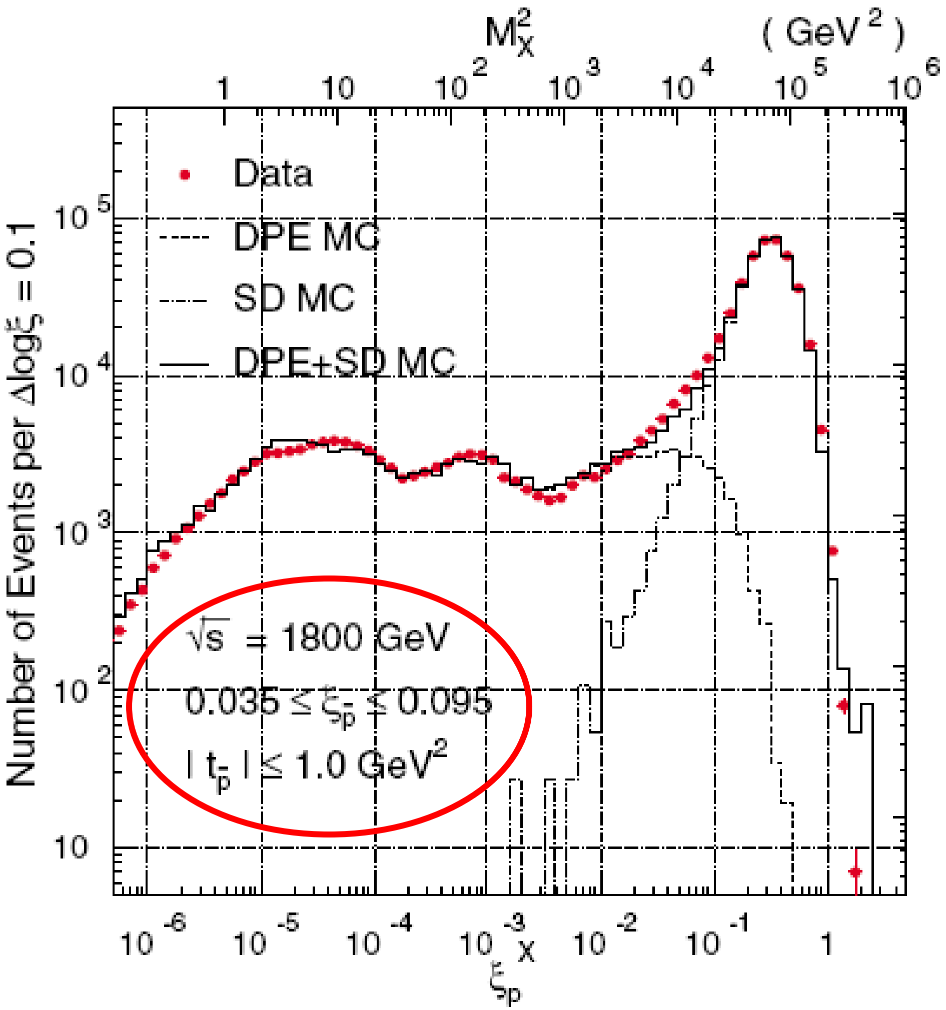
Run I

DPE / CD at CDF



- Excellent agreement between data and MBR

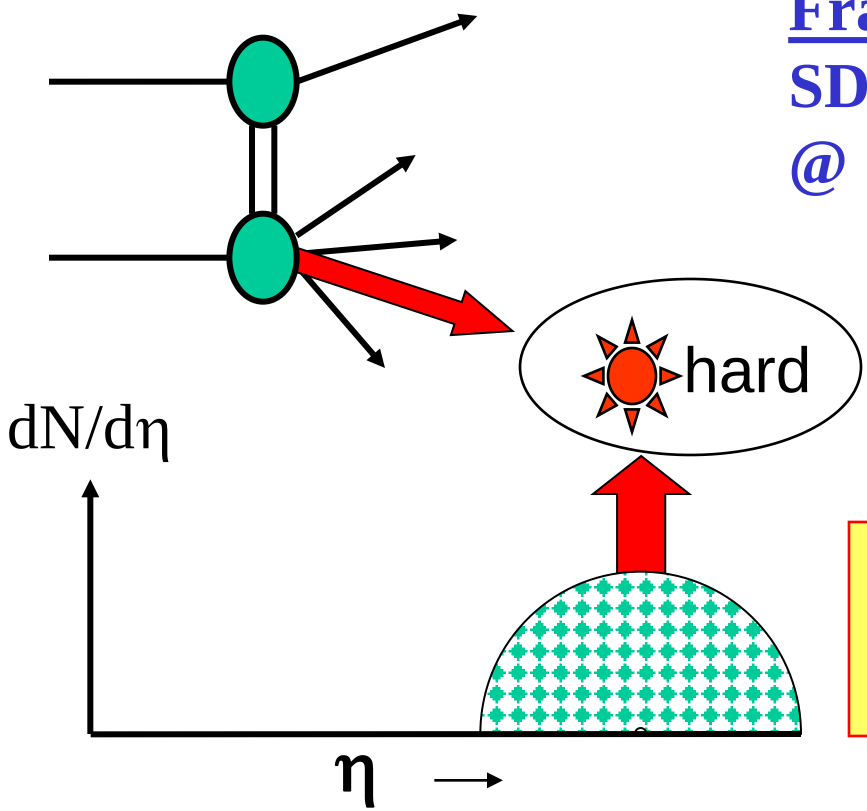
➔ low and high masses are correctly implemented



Run I

Hard diffraction

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



Fraction:
SD/ND ratio @ 1800 GeV

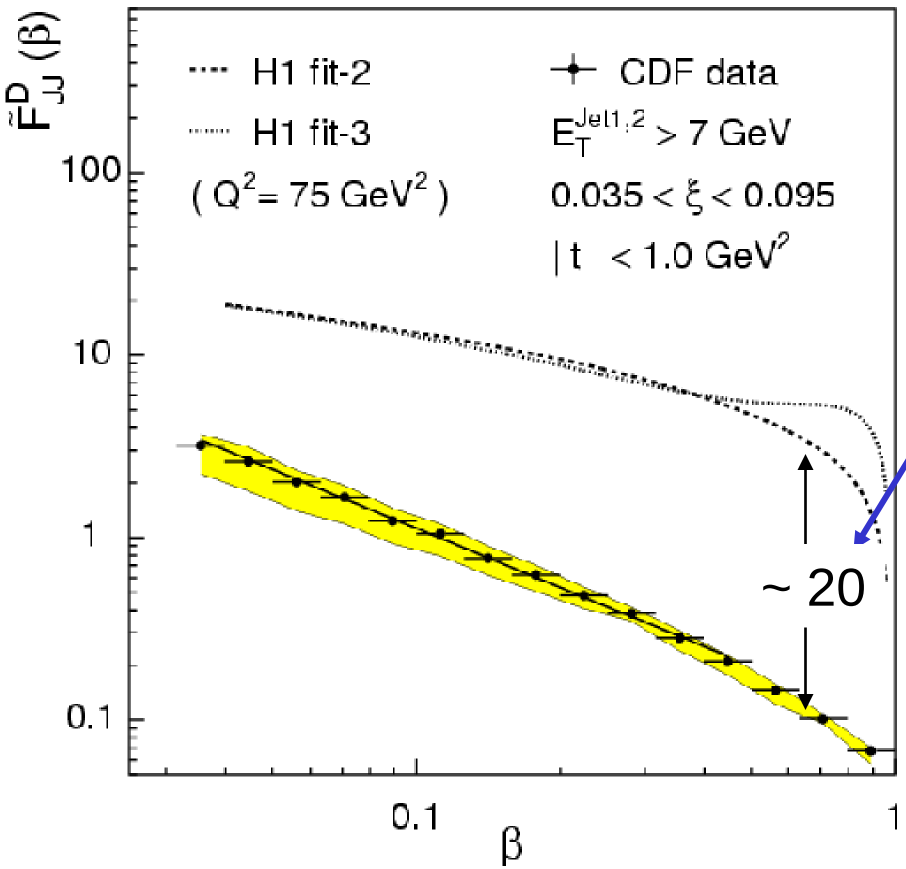
☼	Fraction %
JJ	0.75 +/- 0.10
W	1.15 +/- 0.55
b	0.62 +/- 0.25
J/ψ	1.45 +/- 0.25

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

Run I Diffrr. Structure Function - DSF

→ **breakdown of QCD factorization**

Run I **PRL 84, 5043 (2000)**



$\bar{p}+p \rightarrow \bar{p}+[JJ+X]$

- suppression factor is 2.5 times larger than in soft diffraction
- one of the main reasons for repeating measurement in Run II with an improved forward detector system

β → momentum fraction of parton in "Pomeron"

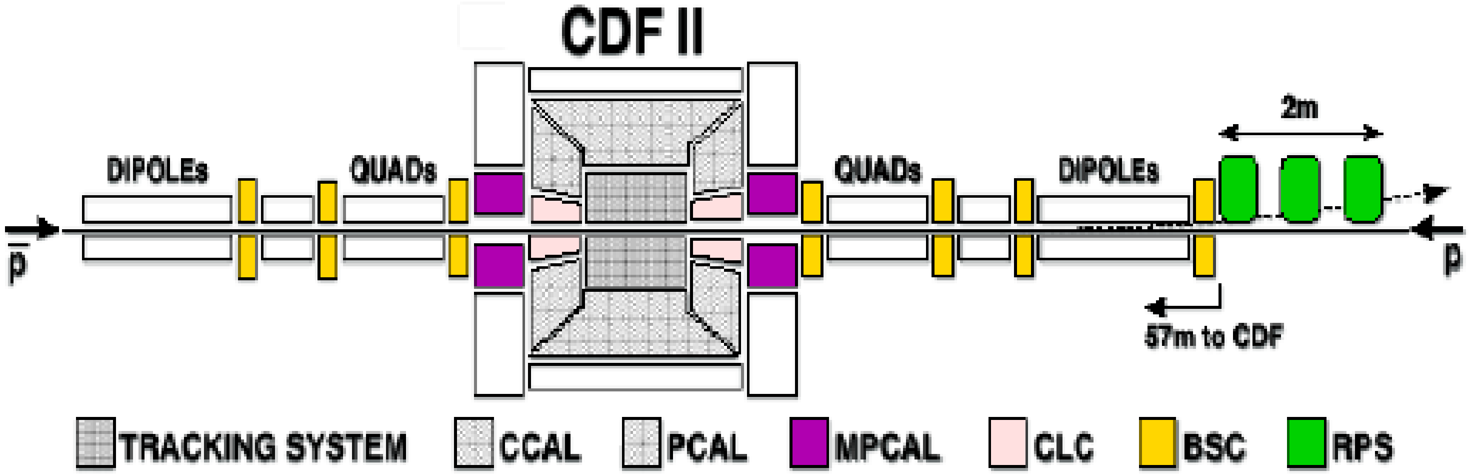
Run I

Puzzles from run I

- 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

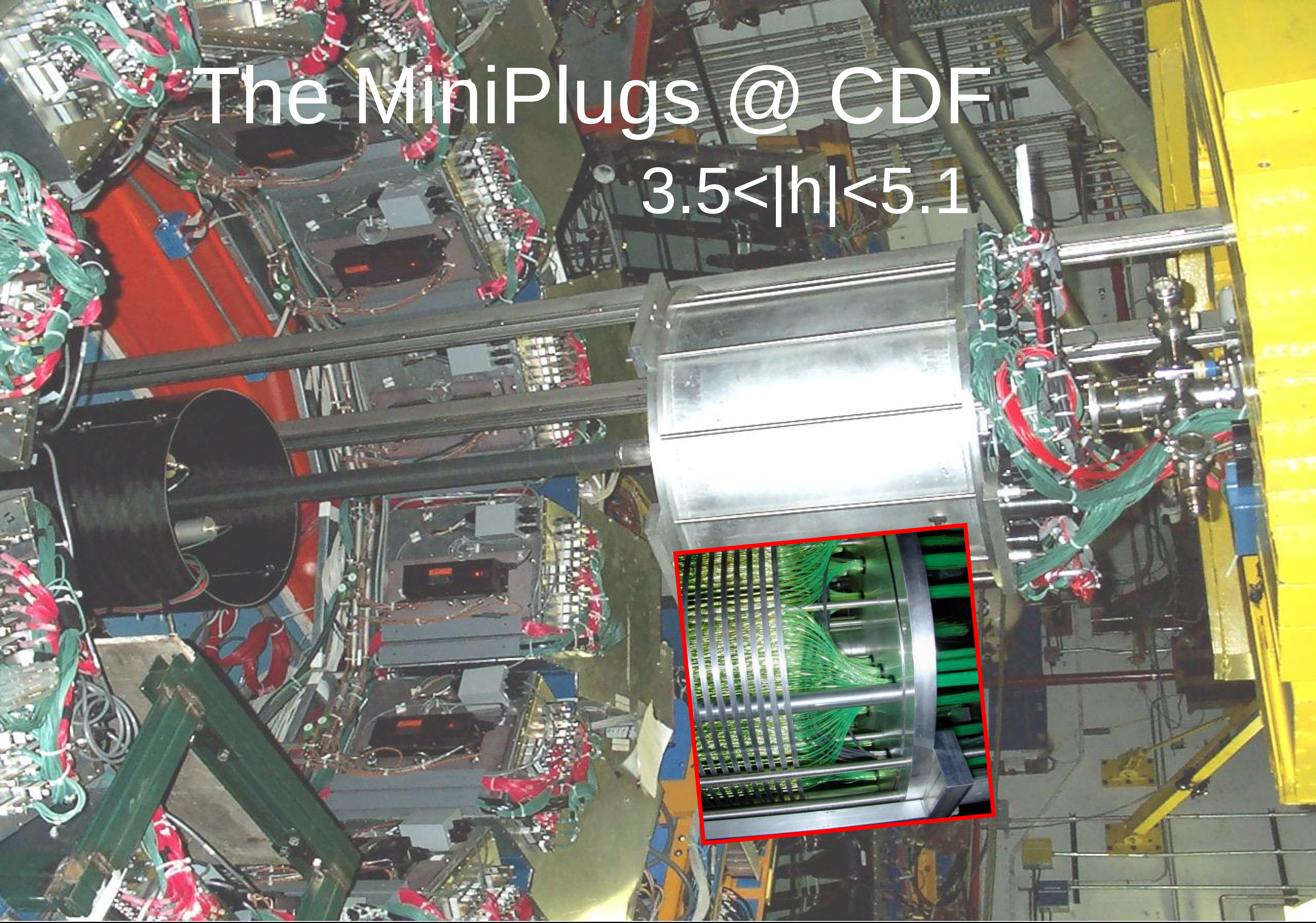
The CDF II Detector – plan view



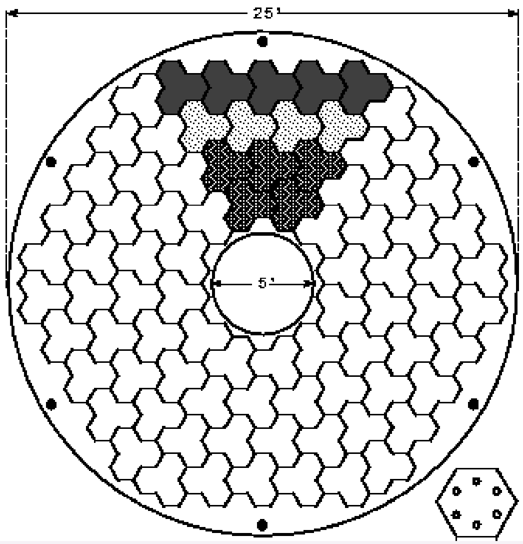
Tracking	–	Tracking Detectors	$\|\eta\| < 2.0$
CCAL, PCAL	–	Calorimeters	$\|\eta\| < 3.6$
RPS	–	Roman Pot Spectrometers	$0.02 < \xi < 0.1$ $0 < \|t\| < 2\ GeV^2$
BSC	–	Beam Shower Counters	$5.4 < \|\eta\| < 7.4$
MPCAL	–	MiniPlug Calorimeters	$3.5 < \|\eta\| < 5.1$

The MiniPlugs @ CDF

3.5<|h|<5.1



Measurements ^{w}/the MiniPlugs



MP TOWER STRUCTURE

MULTIPLICITY @ POSITION

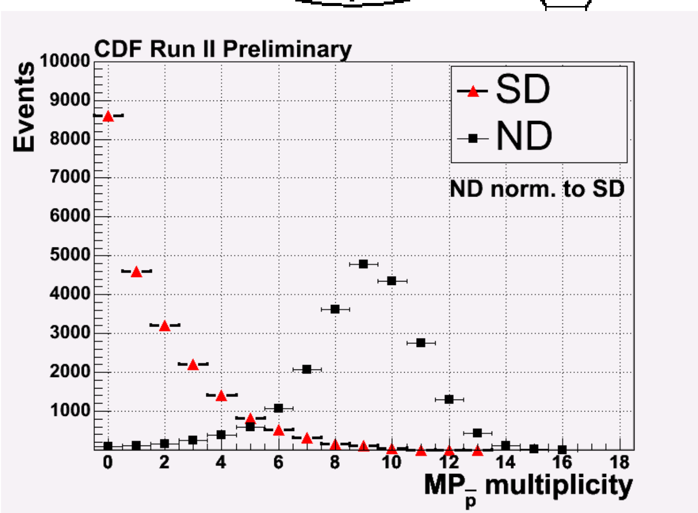
ENERGY

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

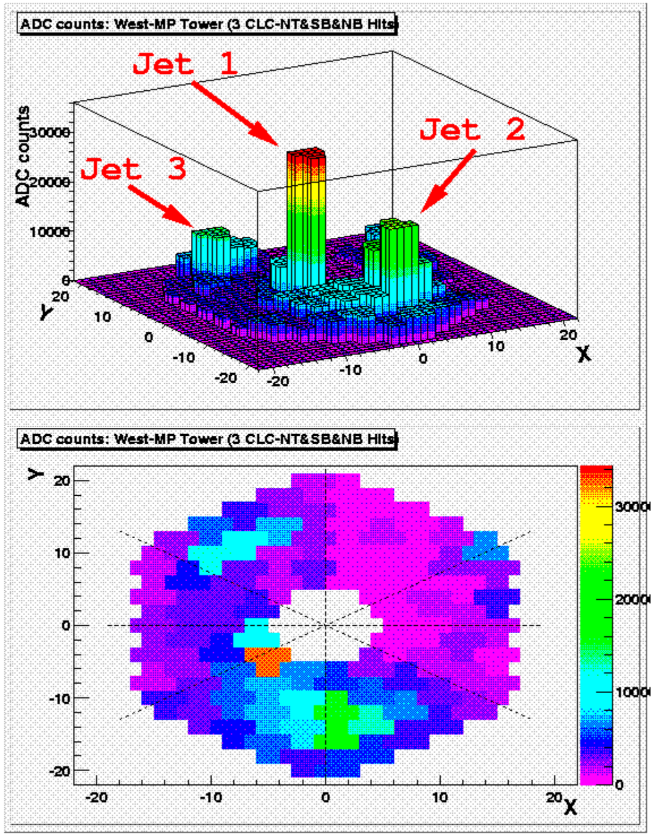
NIM A 430 (1999)

NIM A 496 (2003)

NIM A 518 (2004)



Multiplicity of SD and ND events

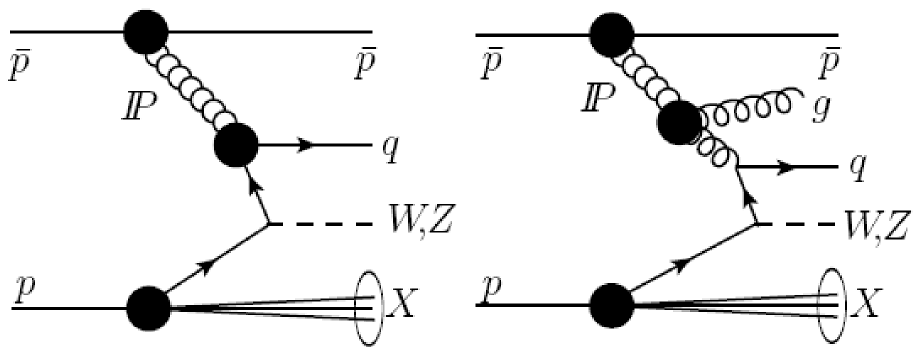


ADC counts in MiniPlug towers in a pbar-p event at 1960 GeV.

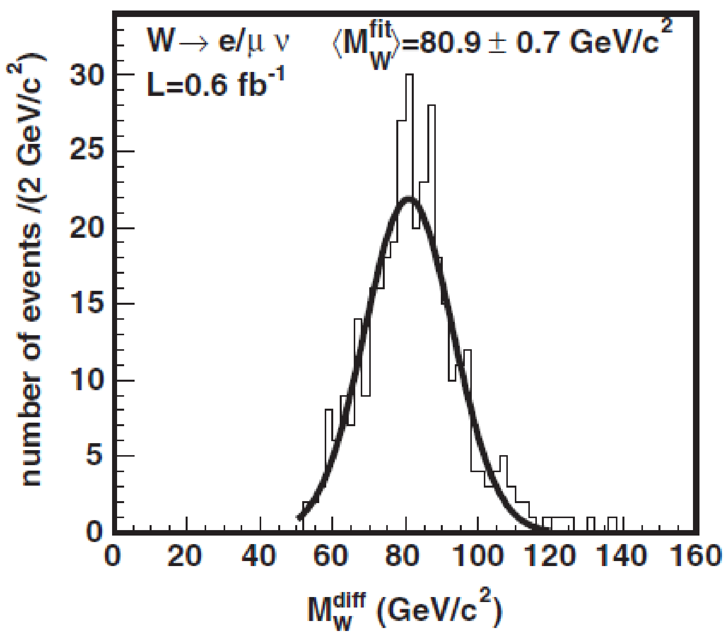
- "jet" indicates an energy cluster and may be just a hadron.
- **1000 counts ~ 1 GeV**

PHYSICAL REVIEW D **82**, 112004 (2010)

Diffractive *W* and *Z* production at the Fermilab Tevatron



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



$$\xi^{\mathrm{RPS}} - \xi^{\mathrm{cal}}_{\bar{p}} = \sum_{i=1}^{\text{all towers}} \frac{E_T^i}{\sqrt{s}} e^{-\eta^i}$$

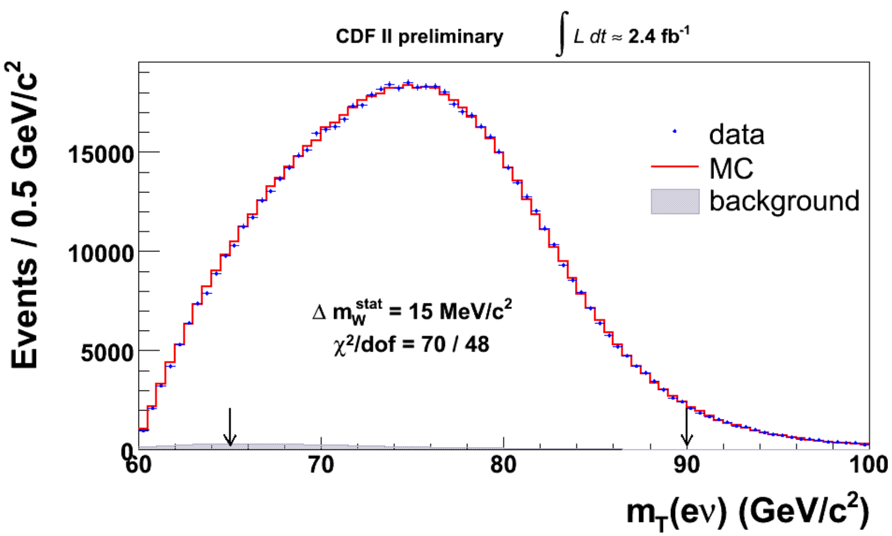
$$E^{\mathrm{w}} = E^e + \sqrt{E_T^2 + (p_z^\nu)^2}.$$

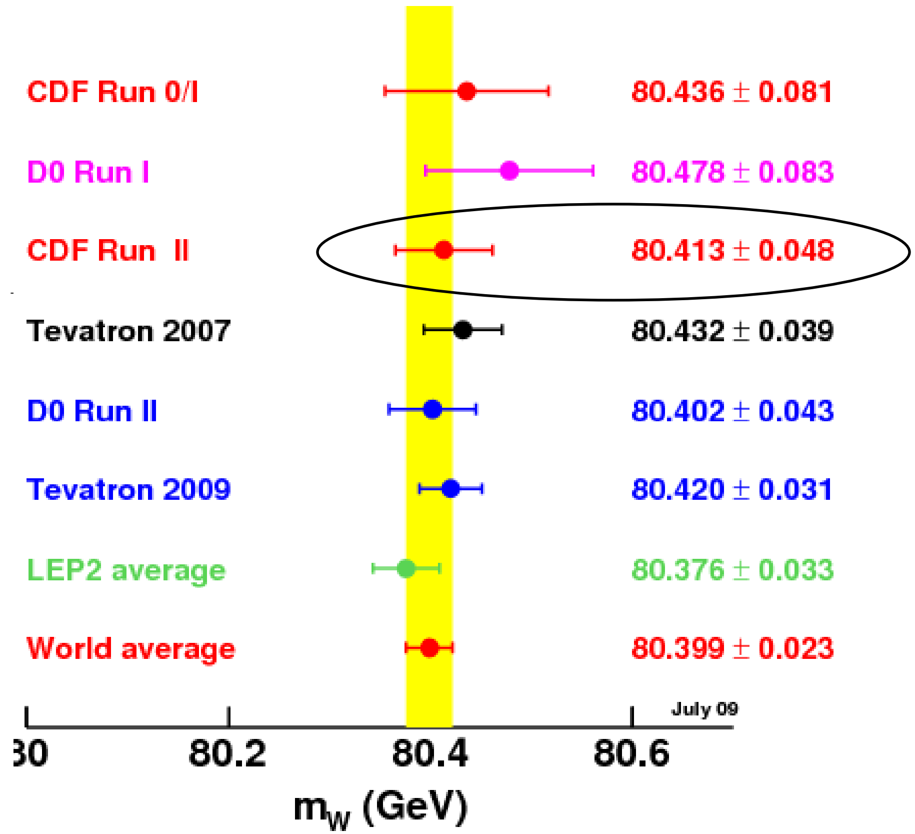
→ M_W

M_W from inclusive W→e/μ+ν

Method: compare transverse M^W data with MC

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





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

Data and event selection

0.6 fb-1 of integrated luminosity data

TABLE I: 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	← W
	$Z \to ee$	$Z \to \mu\mu$	$Z \to ll$	
RPS-trigger-counters	650	341	991	
RPS-track	494	253	747	
$\xi^{\rm cal} < 0.10$	24	12	36	← Z

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

Diffractive W/Z fractions

$$R_W(R_Z) = \frac{2 \cdot N^W_{SD}(N^Z_{SD})}{A_{\rm RPS} \cdot \epsilon_{\rm RPStrig} \cdot \epsilon_{\rm RPStrk} \cdot N^{1-{\rm int}}_{ND}}$$

~80%

68-80%

~87%%

f1-int =(25.6±1.2)%

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

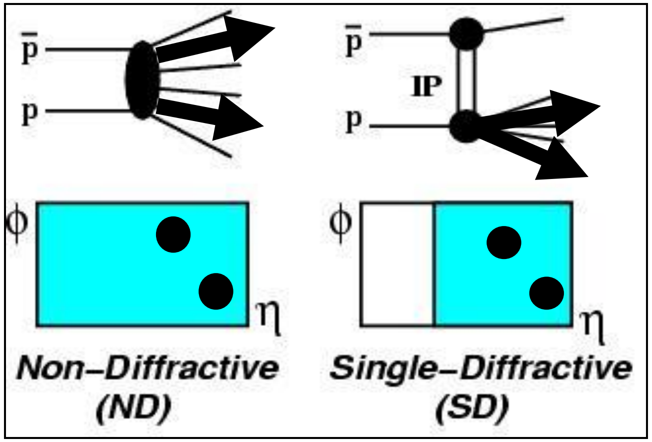
$$R_Z = [0.88 \pm 0.21({\rm stat}) \pm 0.08({\rm syst})]\%$$

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

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

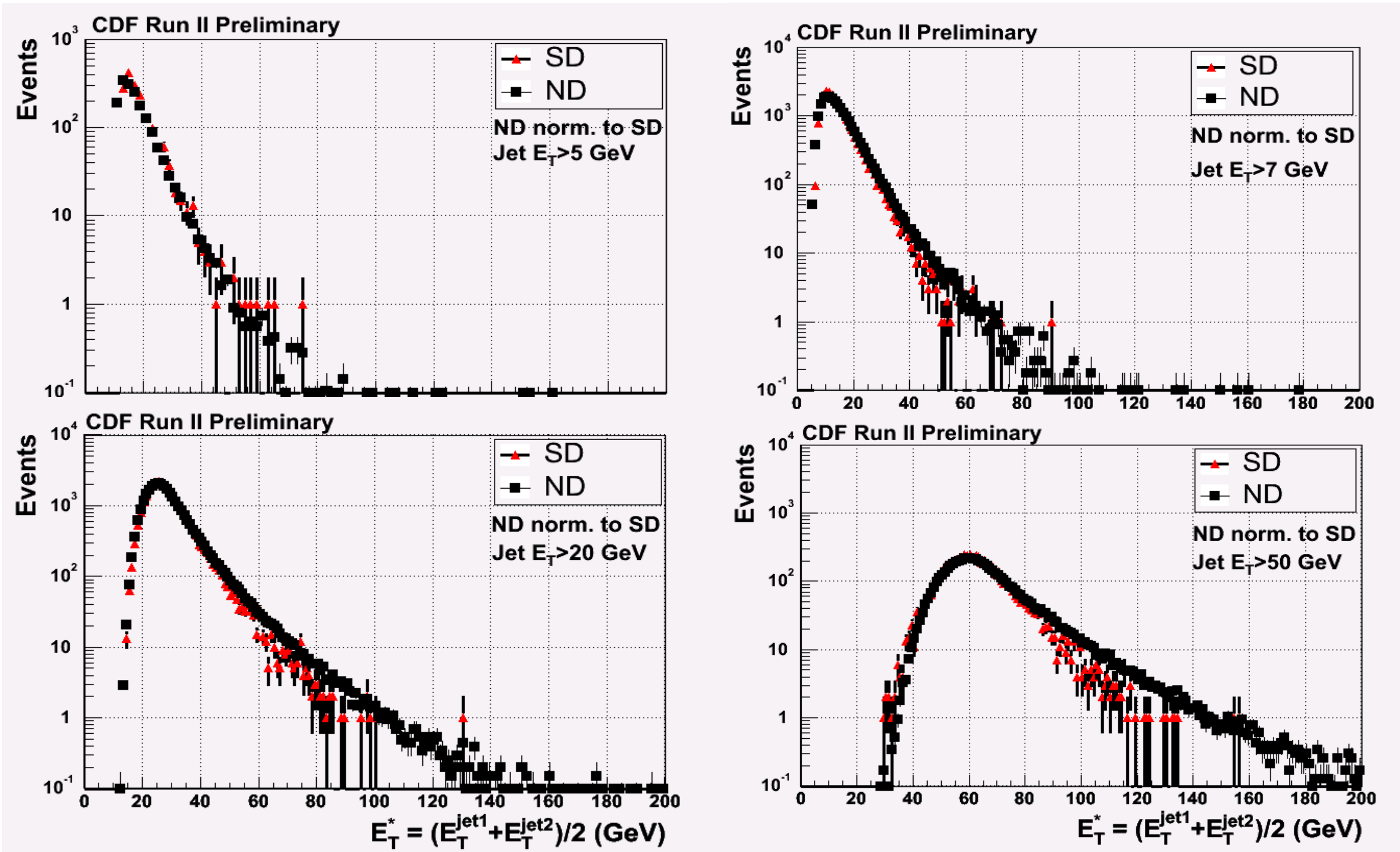
DSF from Dijets in Run II

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



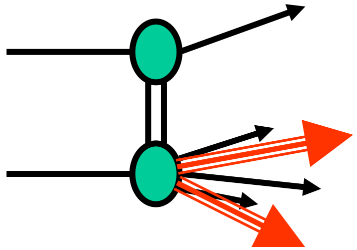
- x_{Bj}-distribution of SD/ND ratio has no strong Q^2 dependence
- slope of t-distribution is independent of Q^2 for $|t| < 1$ (GeV/*c*)^2
- **does the t-distribution have a diffraction minimum beyond |t|=1 GeV/*c*)^2??**
  - ➔ **stay tuned, release coming soon!**

Dijet E_T distributions

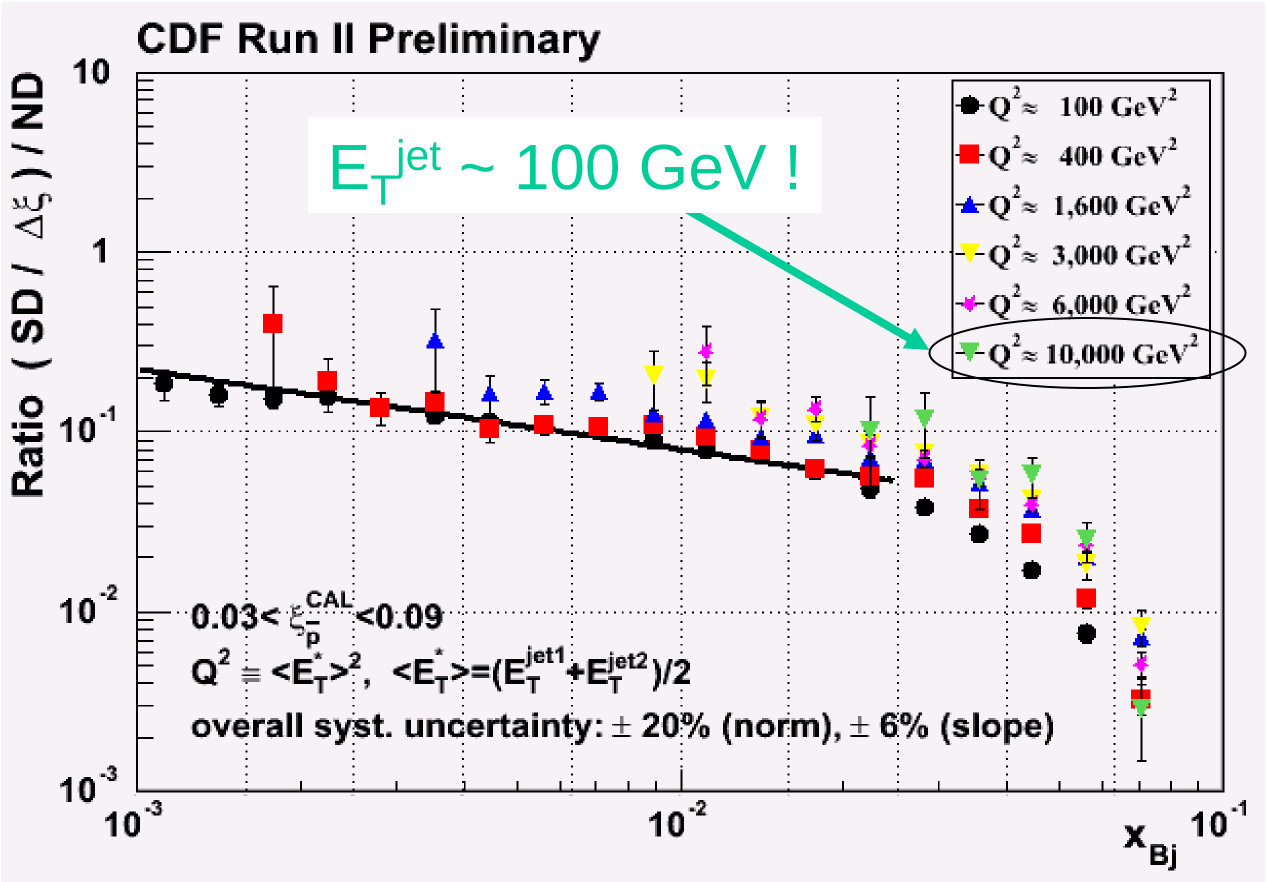


➔ similar for SD and ND over 4 orders of magnitude

Kinematics

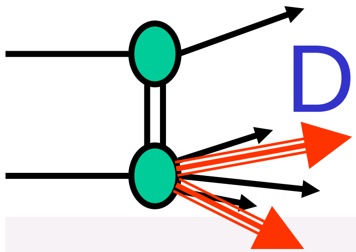


Q^2 dependence of DSF in dijets

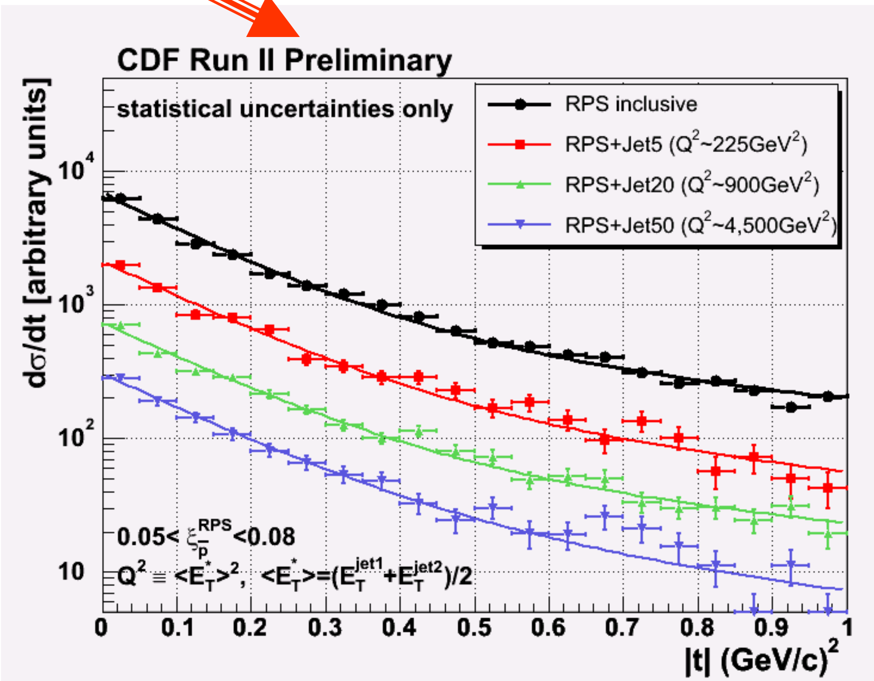


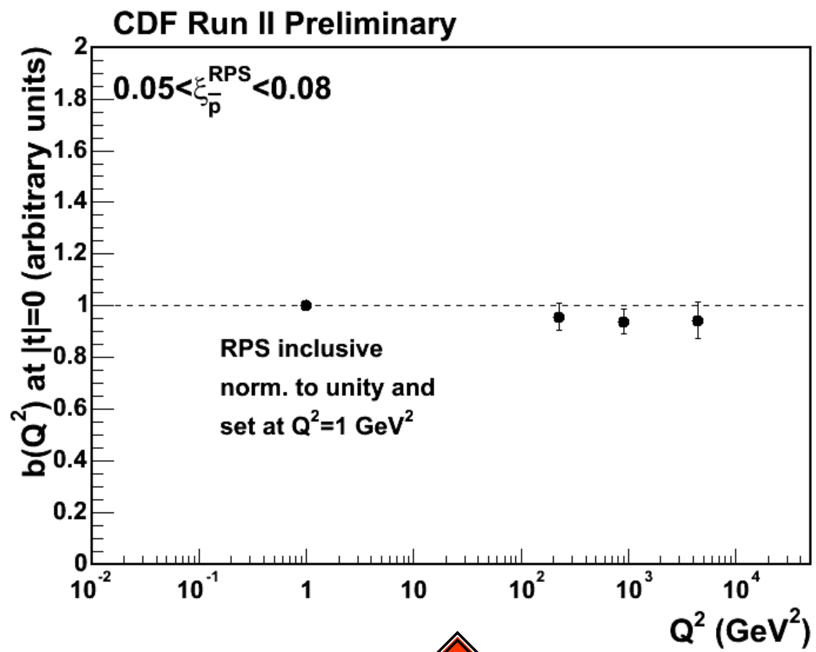
- **S**mall Q^2 dependence in region $100 < Q^2 < 10\,000$ GeV^2 where $d\sigma^{SD}/dE_T$ & $d\sigma^{ND}/dE_T$ vary by a factor of ~10^4 !

➔ The Pomeron evolves as the proton !



Diffractive structure function – Run II
t - dependence





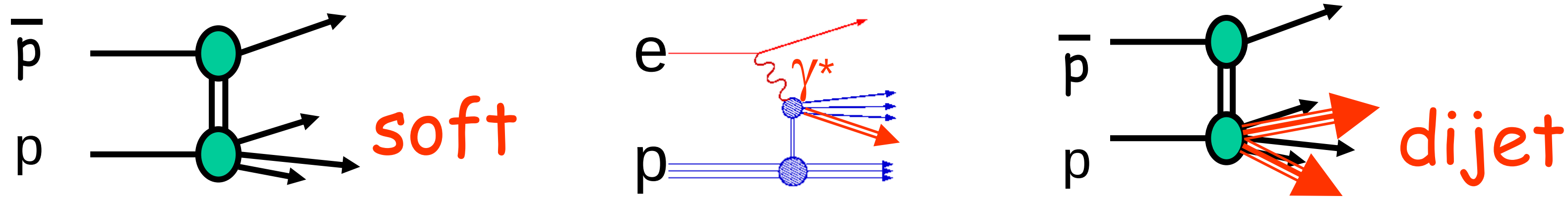
Fit dσ/dt to a double exponential:

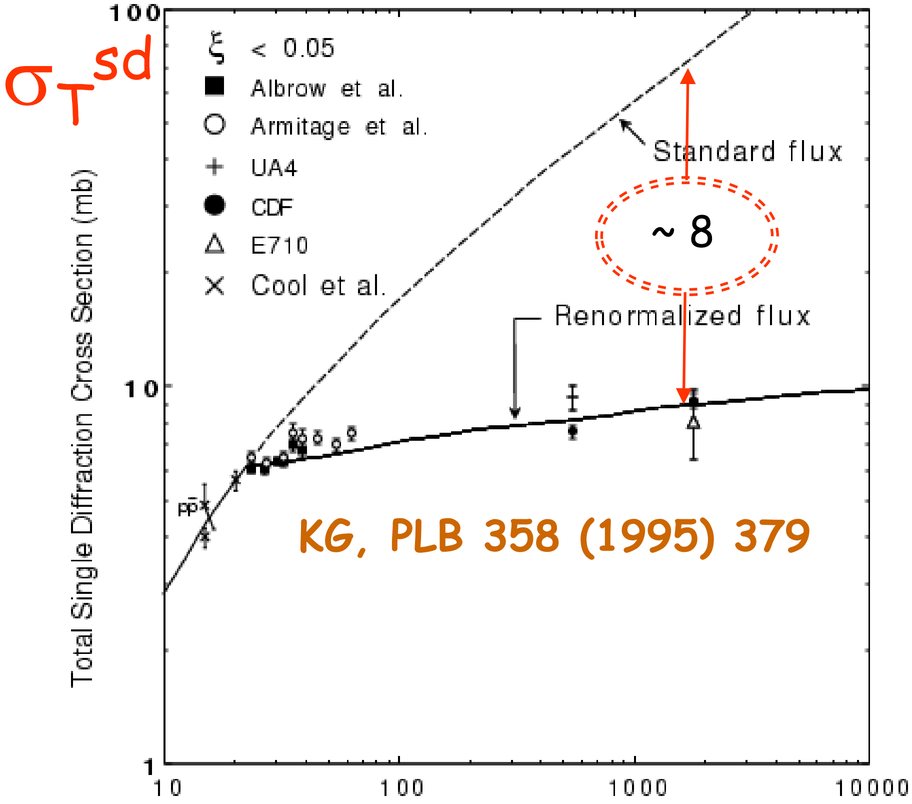
$$F = 0.9 \cdot e^{b_1 \cdot t} + 0.1 \cdot e^{b_2 \cdot t}$$

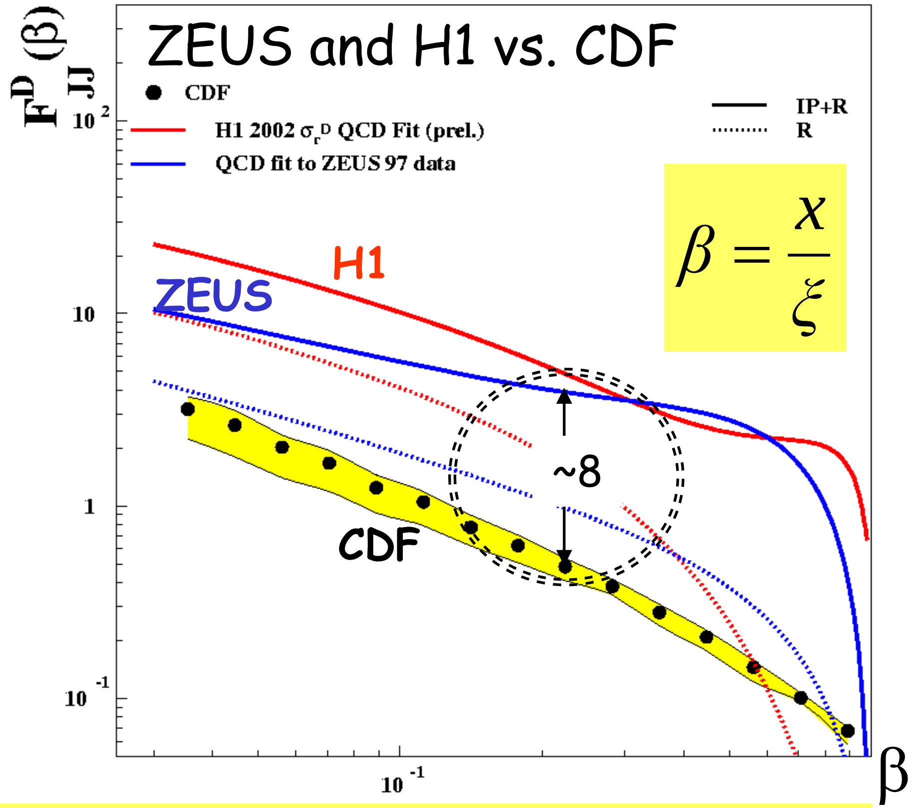
- No diffraction dips at |t| < 1 **GeV²**
- No Q2 dependence in slope from inclusive up to Q²~10⁴ **GeV²**

- Same slope over entire region of $0 < Q^2 < \sim 10\,000$ GeV²!

σ^{T}_{SD} and dijets



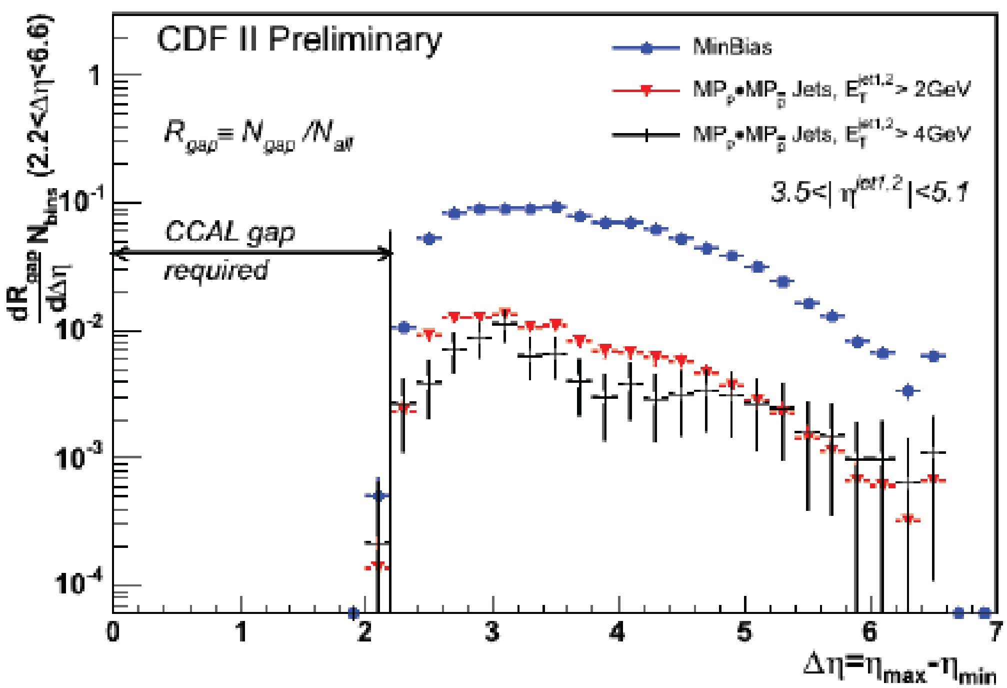


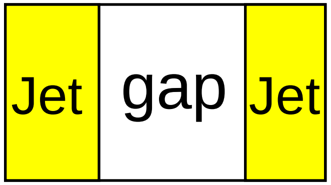


Magnitude: same suppression factor in soft and hard diffraction!
Shape of β distribution: ZEUS, H1, and Tevatron – why different slapes?

GAPS BETWEEN JETS

Gap Fraction in events with a CCAL gap



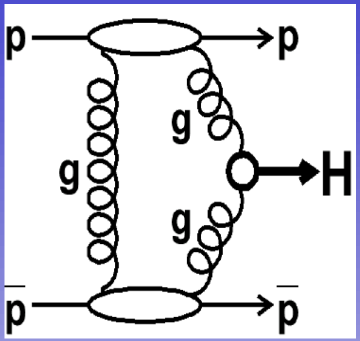


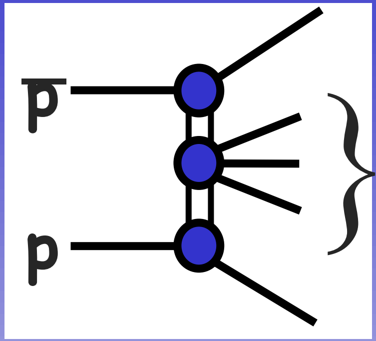
The distribution of the gap fraction $R_{gap}=N_{gap}/N_{all}$ vs $\Delta\eta$ for MinBias (CLC_p•CLC_{pbar}) and MiniPlug jet events (MP_p•MP_{pbar}) of $E_{T(jet1,2)}$>2 GeV and $E_{T(jet1,2)}$> 4 GeV.

The distributions are similar in shape within the uncertainties.

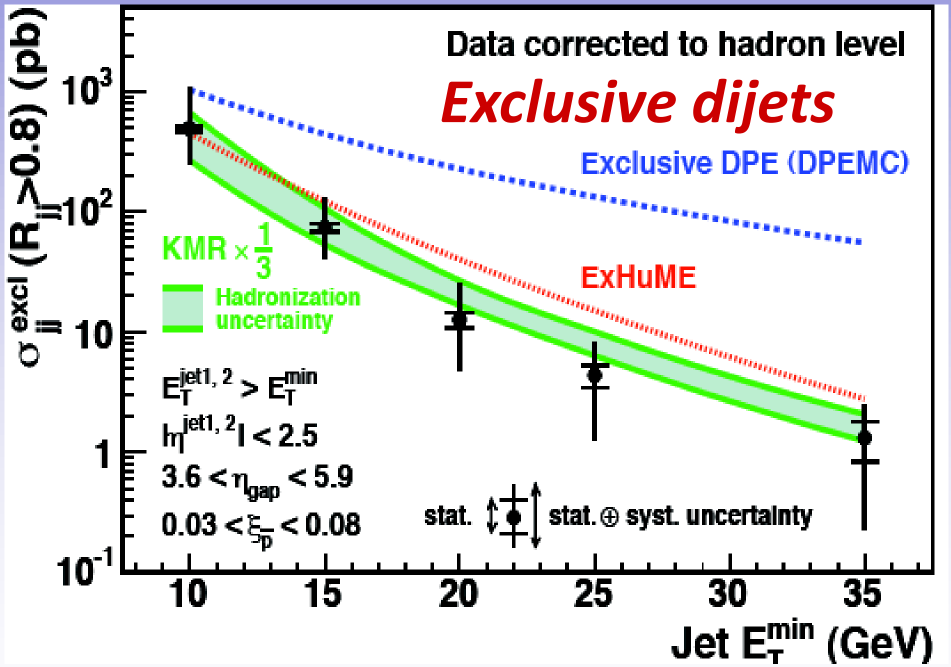
- ❑ analysis nears completion
- ❑ repeat at LHC at 7 TeV with higher E_T forward jets

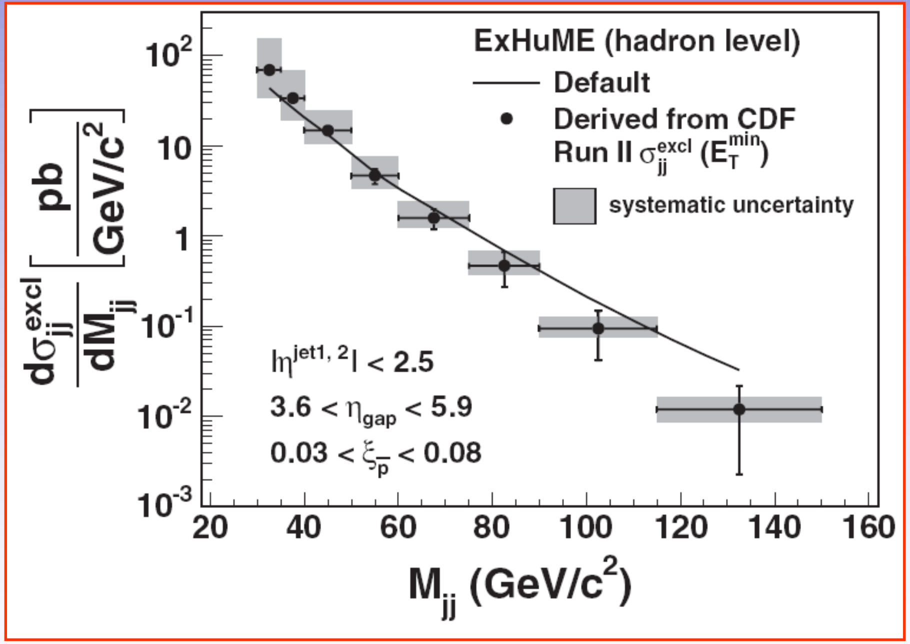
EXCLUSIVE Dijet→ Excl. Higgs *THEORY CALIBRATION*





JJ	***PRD 77, 052004 (2008)***
$\gamma\gamma$	***PRL 99, 242002 (2007)***
χ_c	***PRL 242001 (2007)***

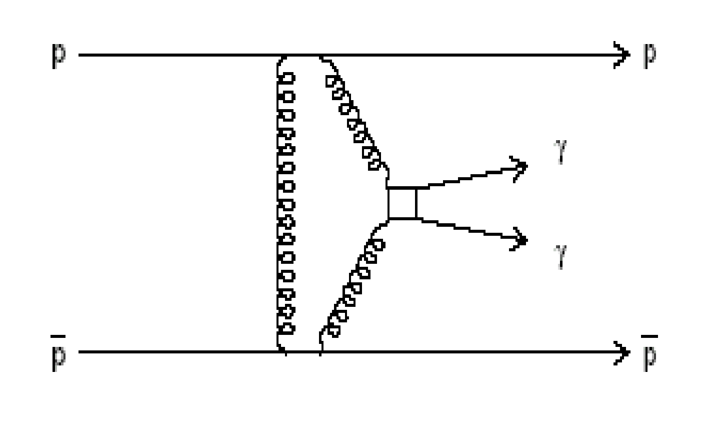




Exclusive $\gamma\gamma$ production

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):

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

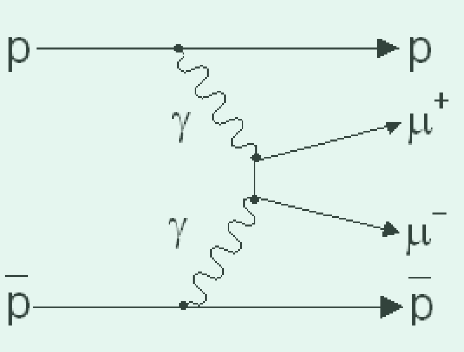
- 2 events ➔ σ ~ 90 fb, in agreement with theory
- cannot claim discovery as bgd study was made *a posteriori*

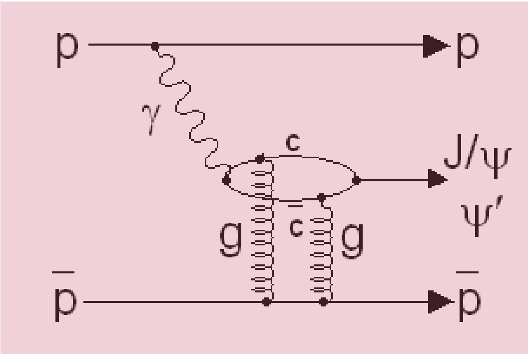
Exclusive Dimuon Production

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

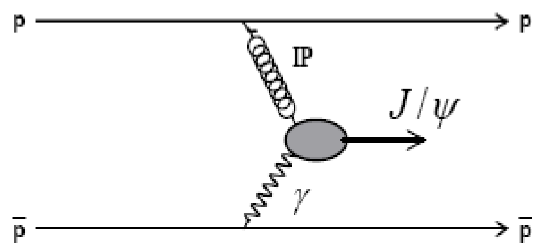
3 GeV/c² <$M_{\mu\mu}$<4 GeV/c²

- many physics processes in this data set:

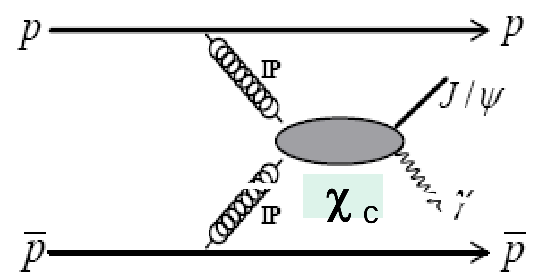




exclusive χ_c in DPE



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



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

Exclusive J/ψ and ψ(2s)

J/ψ production

243 ±21 events

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

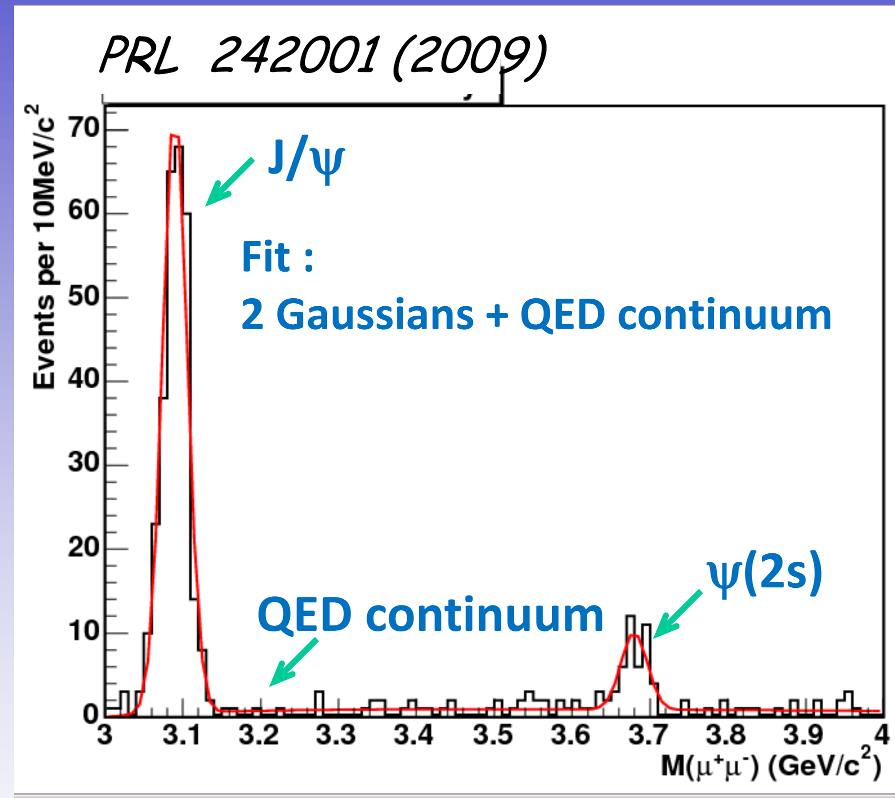
Theoretical Predictions

2.8 nb [Szczurek07,],

2.7 nb [Klein&Nystrand04],

3.0 nb [Conclaves&Machado05], and

3.4 nb [Motkya&Watt08].



Ψ(2s) production

34±7 events

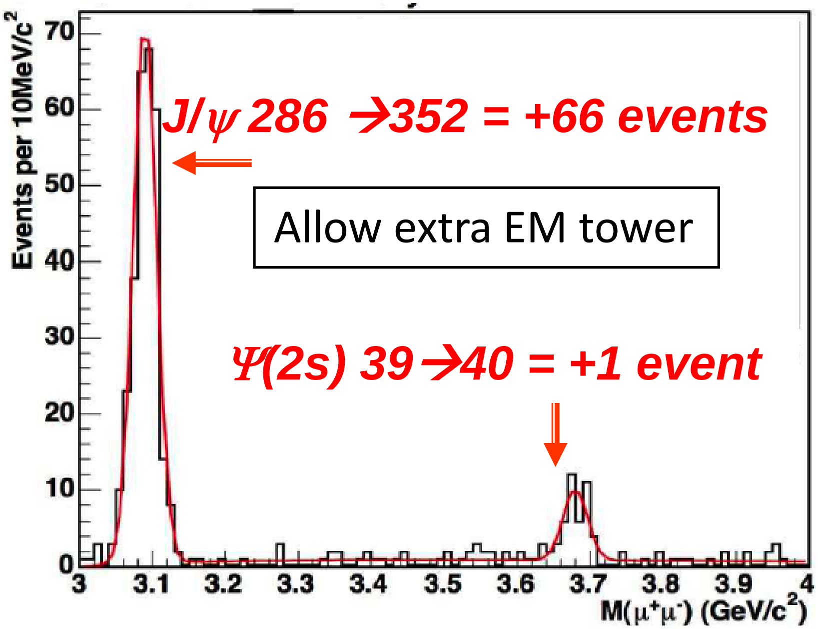
$\boldsymbol{d\sigma/dy|_{y=0} = 0.54 \pm 0.15}$ **nb**

R = ψ(2s)/J/ψ = 0.14 ± 0.05

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

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

PRL 242001 (2009)



- Allowing EM towers (E_T >80MeV)

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

➔ Evidence for:

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

$d\sigma/dy|_{y=0}$ = 75 ± 14 nb,

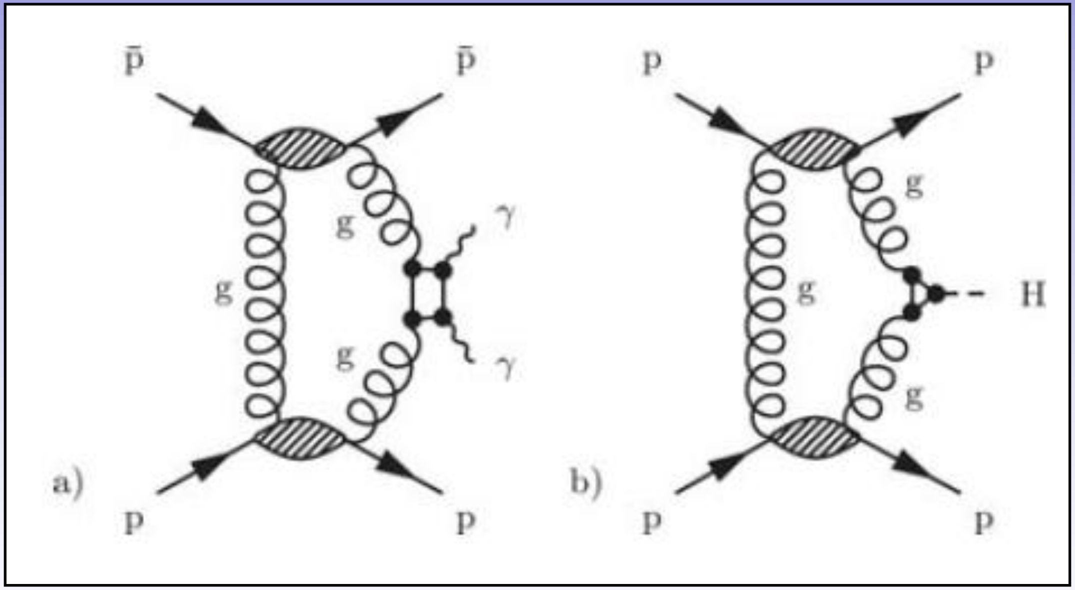
compatible with theoretical predictions

- 160 nb (Yuan 01)
- 90 nb (KMR01)

Exclusive γγ production – *new!*

(submitted to PRL: **arXiv:1112.0858**)

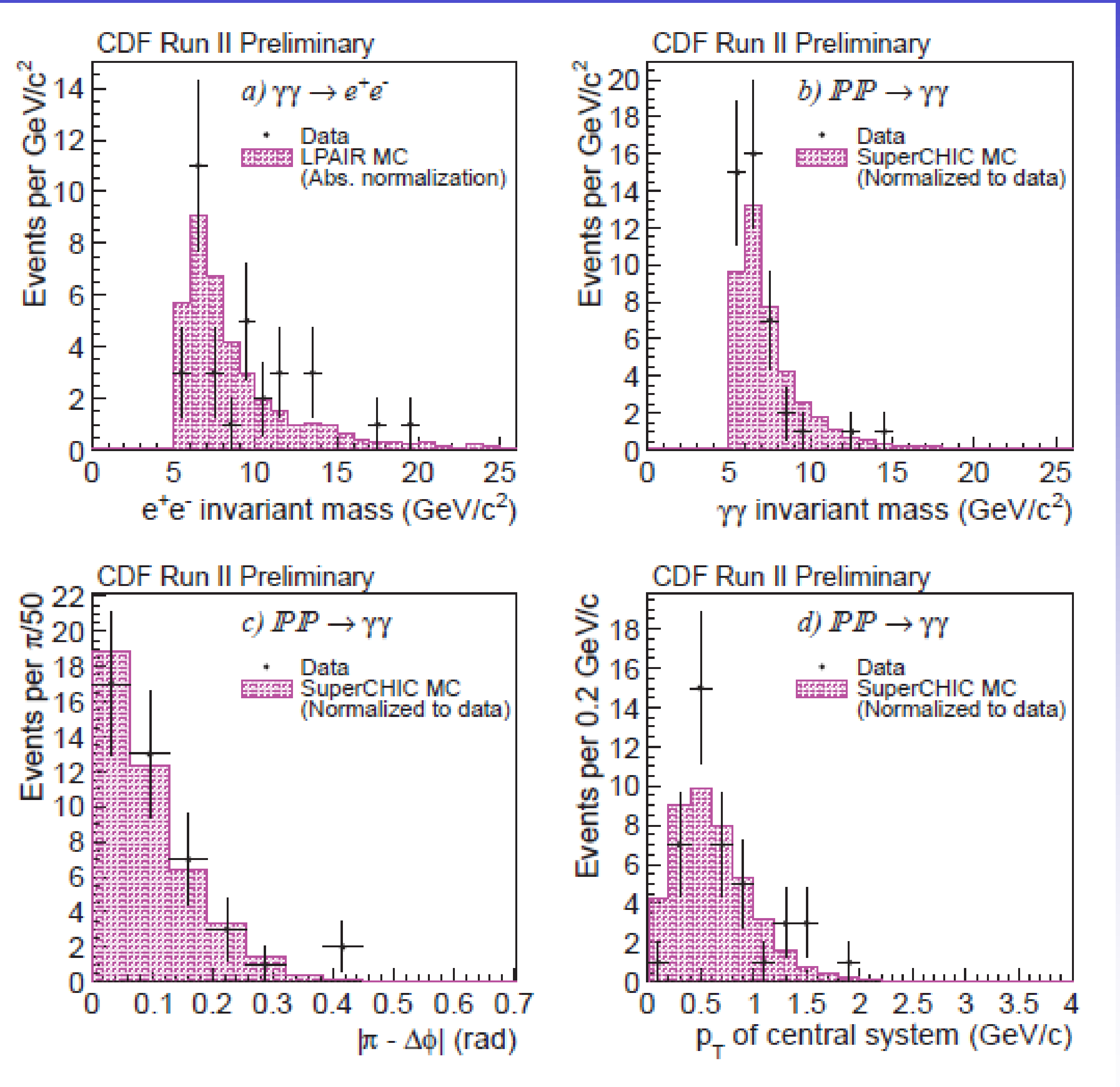
Observation of Exclusive $\gamma\gamma$ Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV



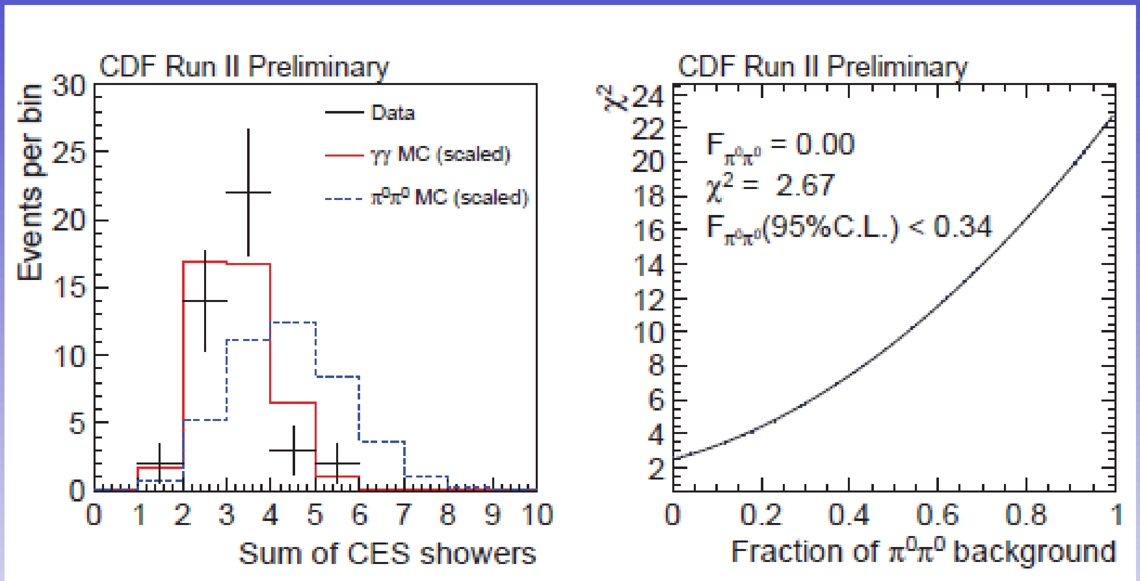
Exclusive $\gamma\gamma$ and e^+e^- events

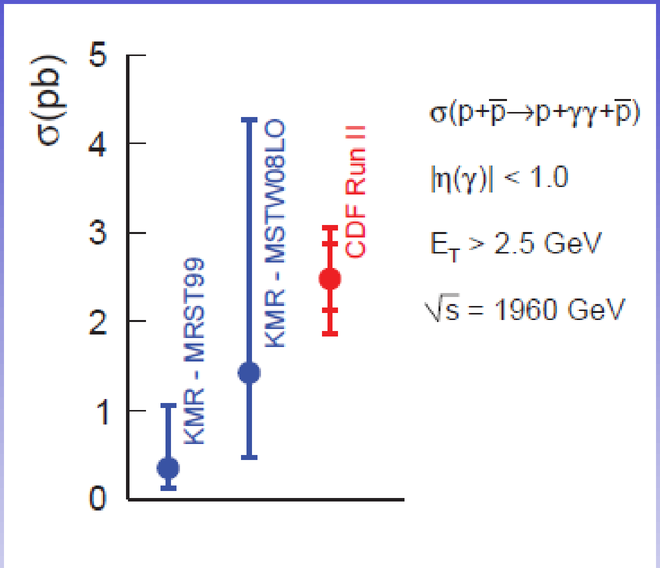
Integrated luminosity $\mathcal{L}_{\text{int}}$	1.11 ± 0.07 fb^{-1}
Exclusive efficiency	0.068 ± 0.004 (syst)
Exclusive $\gamma\gamma$	
Events	43
Photon pair efficiency	0.40 ± 0.02 (stat) ± 0.03 (syst)
Probability of no conversions	0.57 ± 0.06 (syst)
$\pi^0\pi^0$ b/g (events)	0.0, < 15 (95% C.L.)
Dissociation b/g (events)	0.14 ± 0.14 (syst)
Exclusive e^+e^-	
Events	34
Electron pair efficiency	0.33 ± 0.01 (stat) ± 0.02 (syst)
Probability of no radiation	0.42 ± 0.08 (syst)
Dissociation b/g (events)	3.8 ± 0.4 (stat) ± 0.9 (syst)

Exclusive γγ data vs. MC



Exclusive γγ cross section



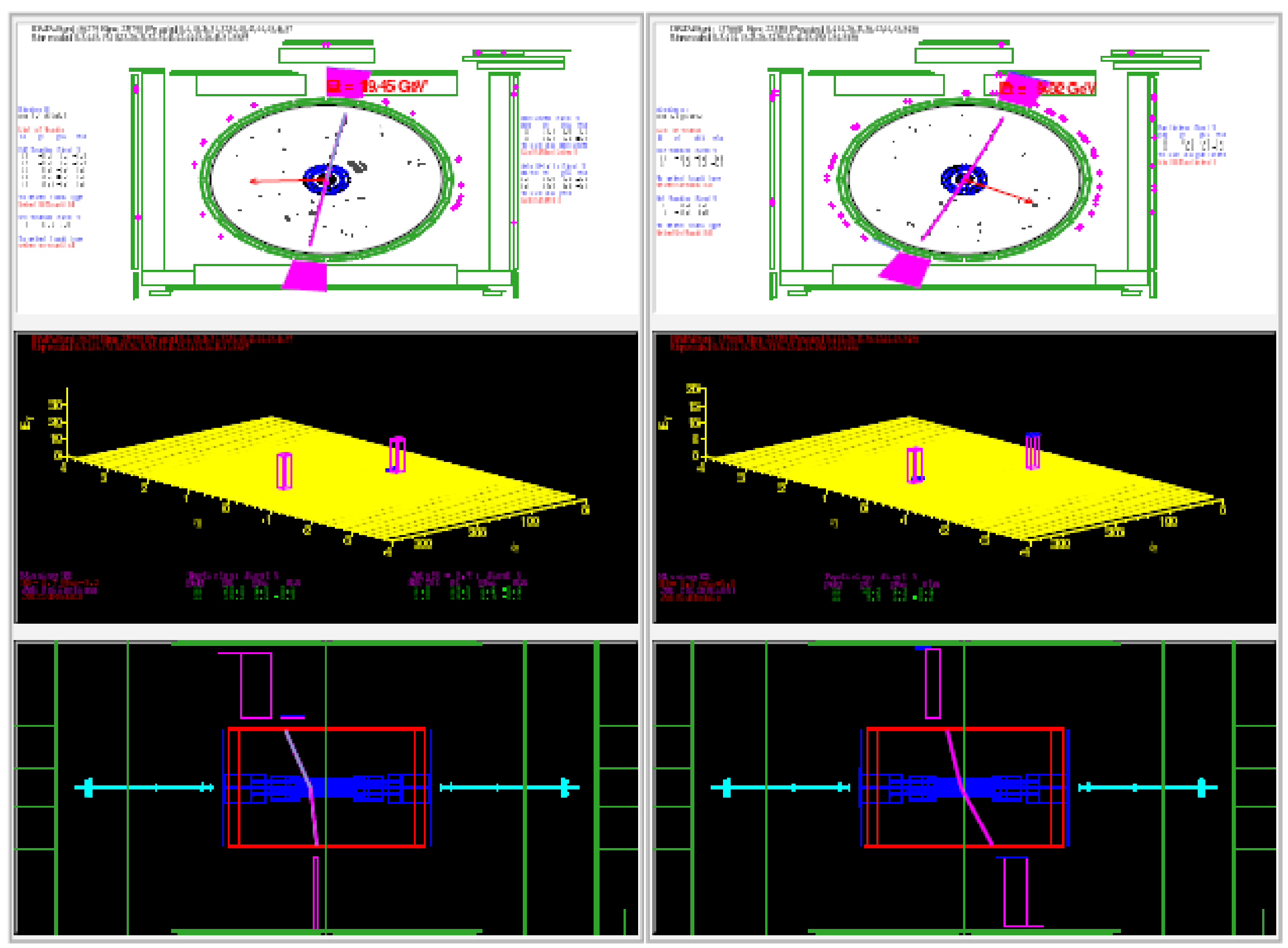


$$s_{\text{SuperCHIC}}^{|\eta|<1,\,E_T>5\text{GeV}} = 0.35^{\times 3}_{\div 3}\ \text{pb}\ (\text{MRST99})$$

$$s_{\text{SuperCHIC}}^{|\eta|<1,\,E_T>5\text{GeV}} = 1.42^{\times 3}_{\div 3}\ \text{pb}\ (\text{MSTW0SLO})$$

$$s_{\gamma\gamma\,\text{excl}}^{|\eta|<1,\,E_T>5\text{GeV}} = 2.48^{\times 3}_{\div 3} \pm 0.42(\text{stat}) \pm 0.41(\text{syst})\text{pb}$$

Exclusive γγ event candidate



Tevatron Low-s Energy Scan September 8-16 2011

- ❑ √s=300 & 900 GeV (CDF already studied √s=630 , 1800 &1960 GeV)
  - ➢ MinBias events (charged particle multiplicities, dN/dη, etc…
  - ➢ Underlying event for various processes
  - ➢ Gap-X-Gap events
- ❑ Tune MC generators
- ❑ Plan to have (some) results in summer conferences

√s CDF data	0-bias	Minbias	Gap-X-Gap	Jets	e,μ,ν	Total # events
300	1.89 M	12.1 M	9.2 M	8.3 K	352	23.2 M
900	8.0 M	54.3 M	21.8 M	550 K	16 K	84.7 M

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/or t dependence over a wide range
  - ✓ is there a diffraction dip in the t-distribution? ➔ coming soon

- 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

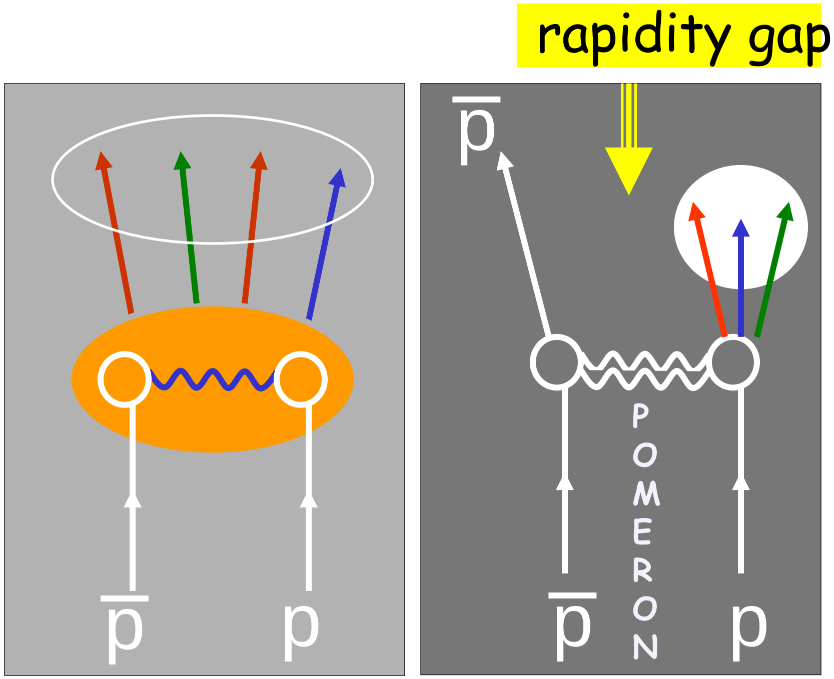
- Color-exchange

Diffractive → gaps

- Colorless exchange with vacuum quantum numbers

Incident hadrons acquire color and break apart

CONFINEMENT

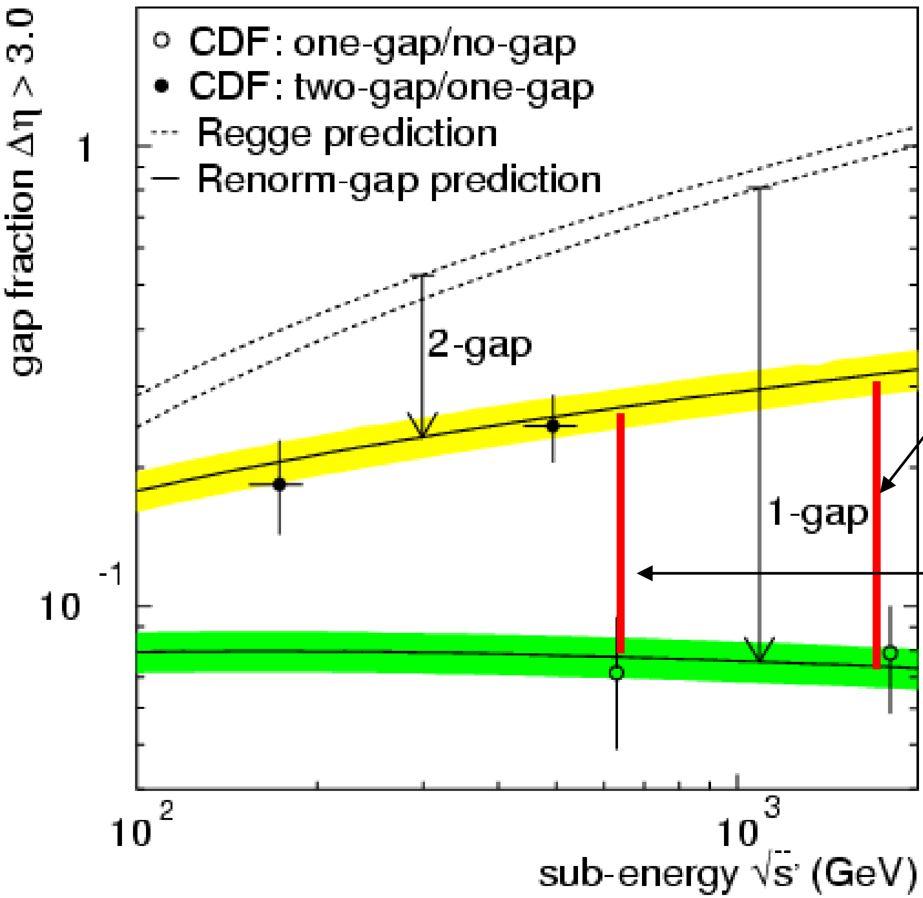


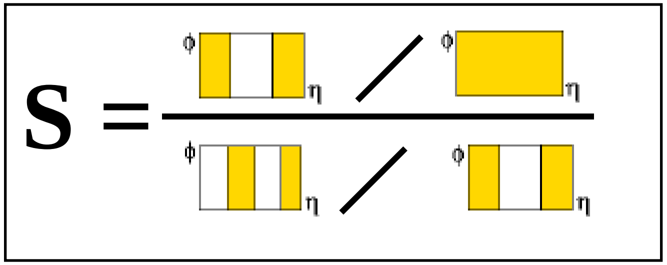
Incident hadrons retain their quantum numbers remaining colorless

pseudo-DECONFINEMENT

Goal: understand the QCD nature of the diffractive exchange

Gap survival probability



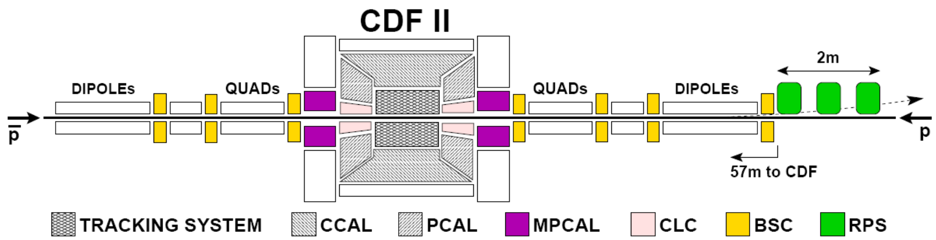


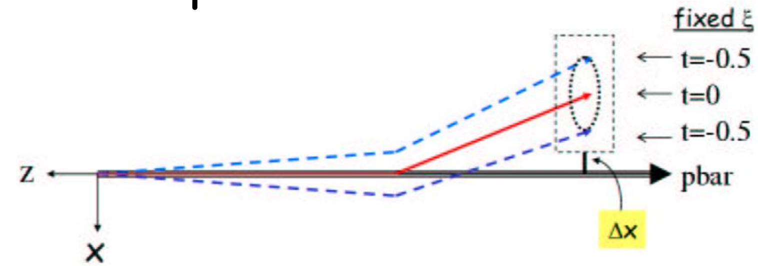
$$S^{1-gap/0-gap}_{2-gap/1-gap}(1800\ \text{GeV}) \approx 0.23$$

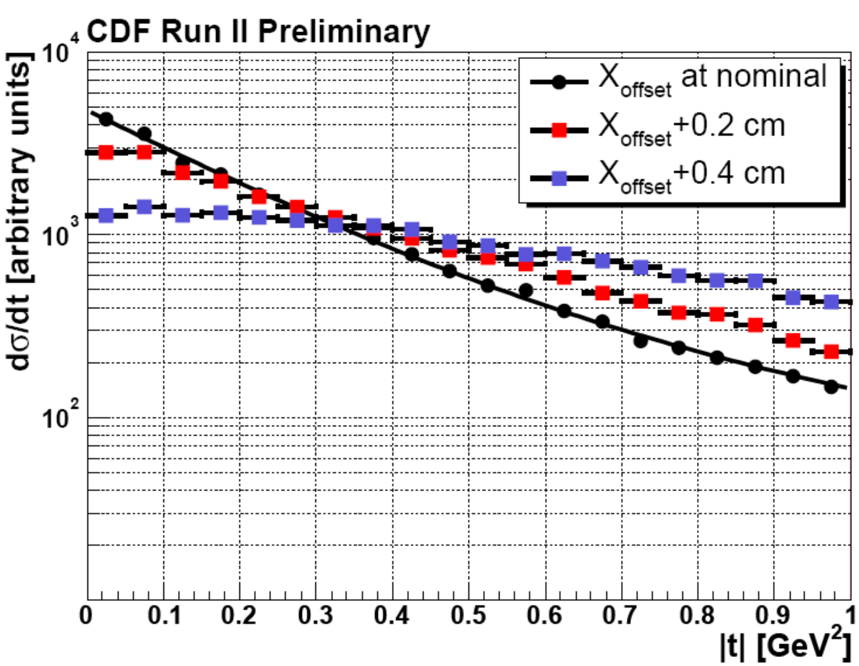
$$S^{1-gap/0-gap}_{2-gap/1-gap}(630\ \text{GeV}) \approx 0.29$$

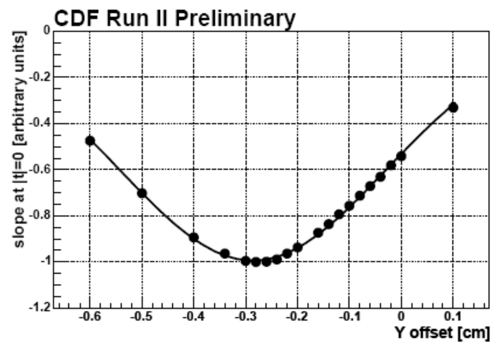
Dynamic Alignment of RPS Detectors

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



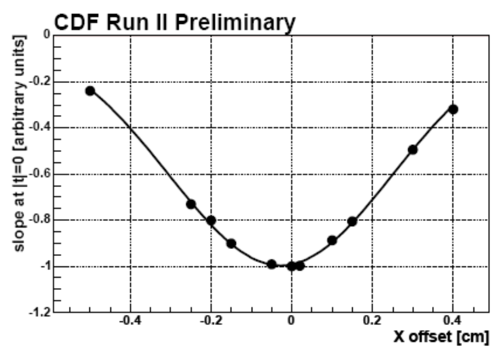






Limiting factors

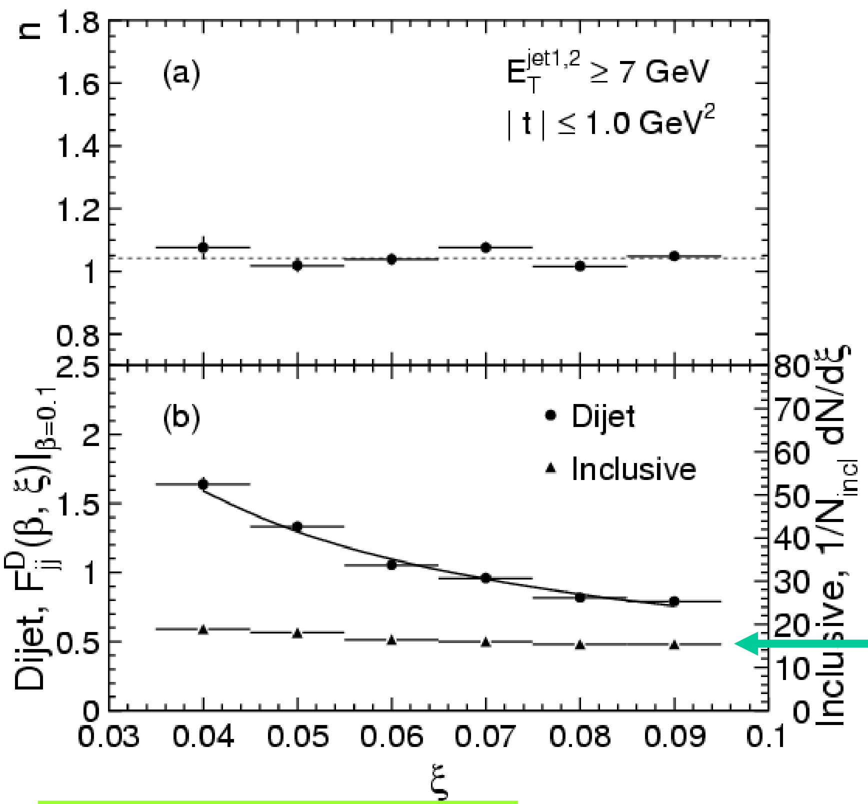
1-statistics
2-beam size
3-beam jitter



@ CDF
w/lowlum data

$\pm 30\ \mu m$

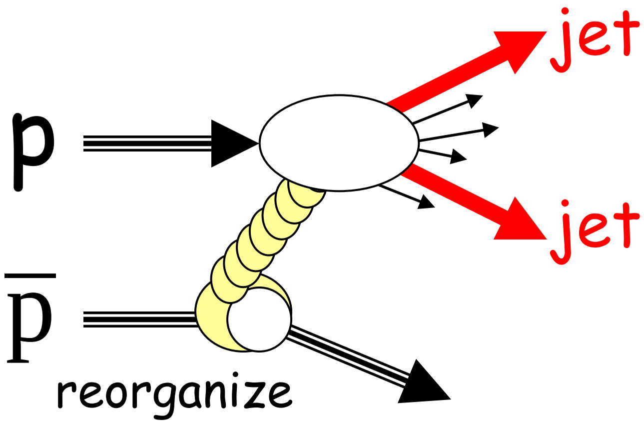
ξ & β dependence of F^D_{jj} – Run I



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

Pomeron dominated

Diffractive dijets @ Tevatron

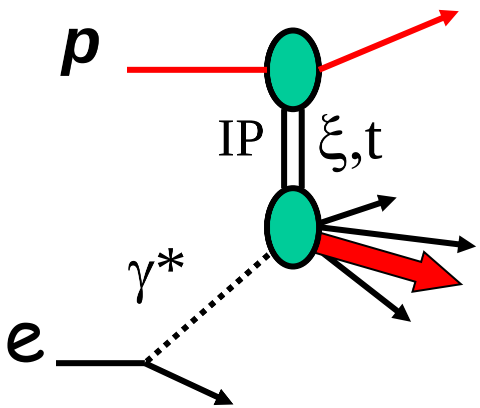


$$F^D(\xi, x, Q^2) \propto \frac{1}{\xi^{1+2\varepsilon}} \cdot F(x/\xi, Q^2)$$

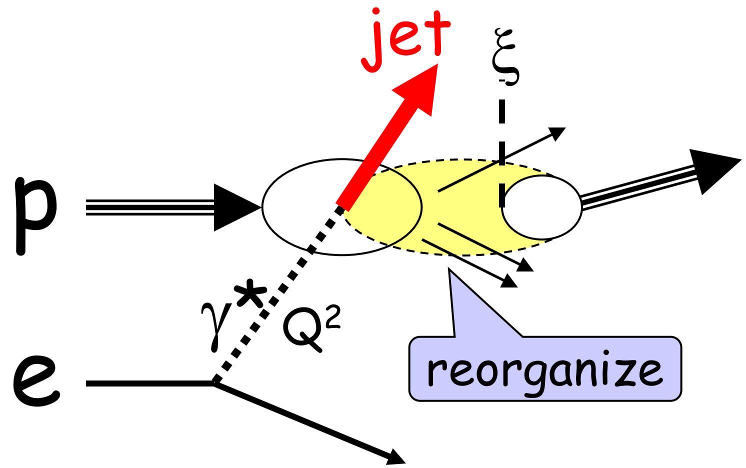
Diffractive DIS @ HERA

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