CDF II RESULTS ON DIFFRACTION

CHRISTINA MESROPIAN
THE ROCKEFELLER UNIVERSITY

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  - Exclusive χ_c

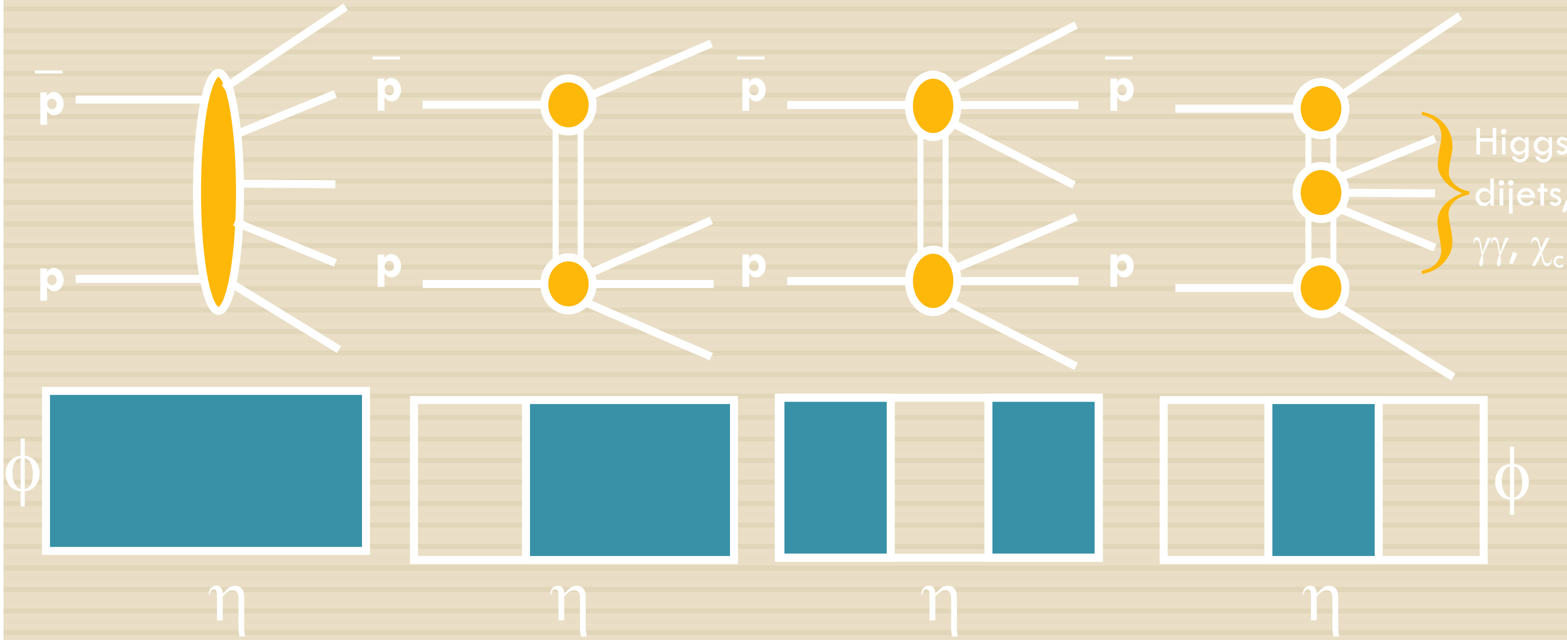
Introduction

Non- Diffractive (ND)

Single Diffraction (SD)

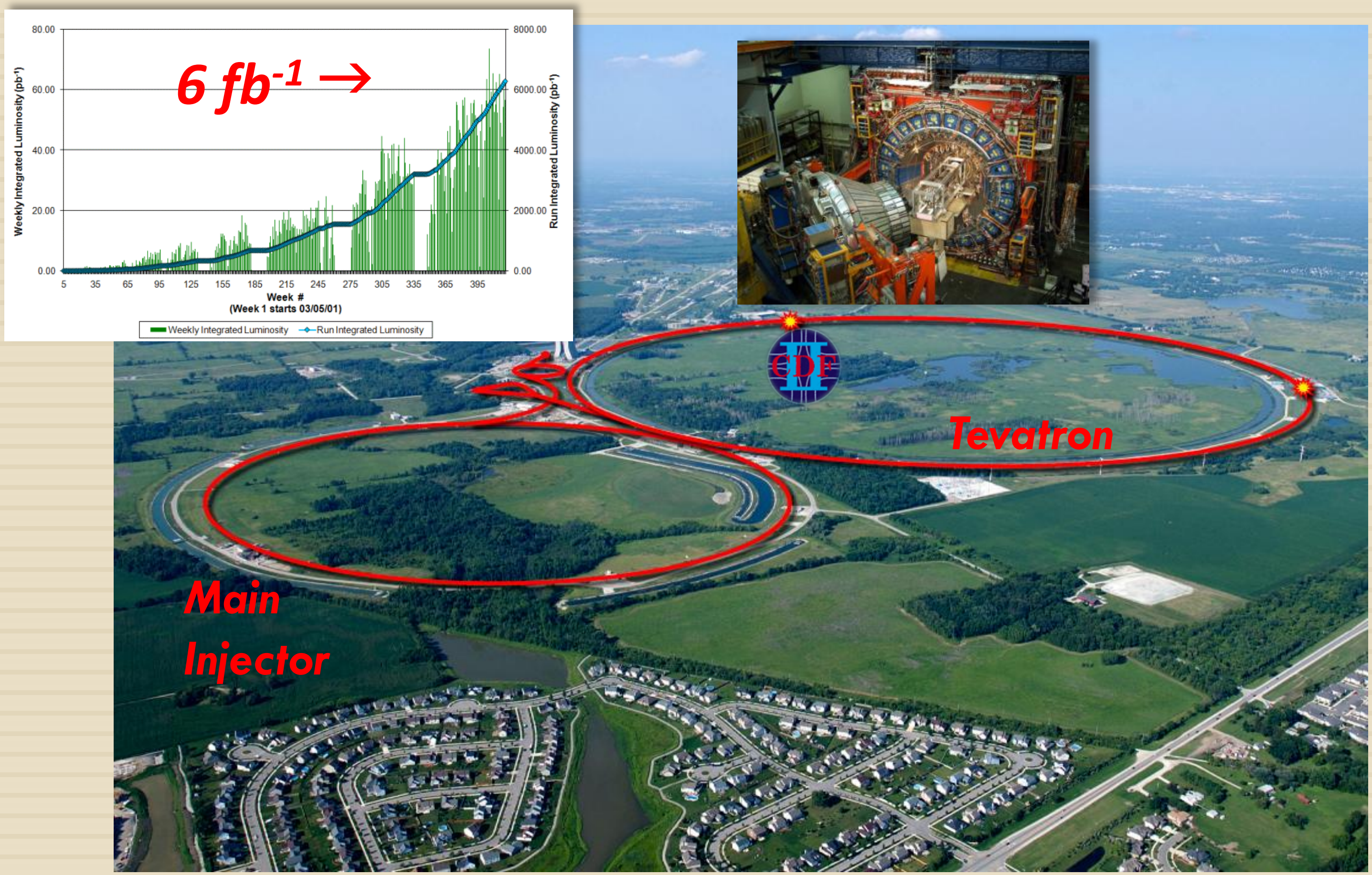
Double Diffraction (DD)

Double Pomeron Exchange (DPE)



Diffractive reactions at hadron colliders are defined as reactions in *which no quantum numbers* are exchanged between colliding particles

Collider Run II Integrated Luminosity

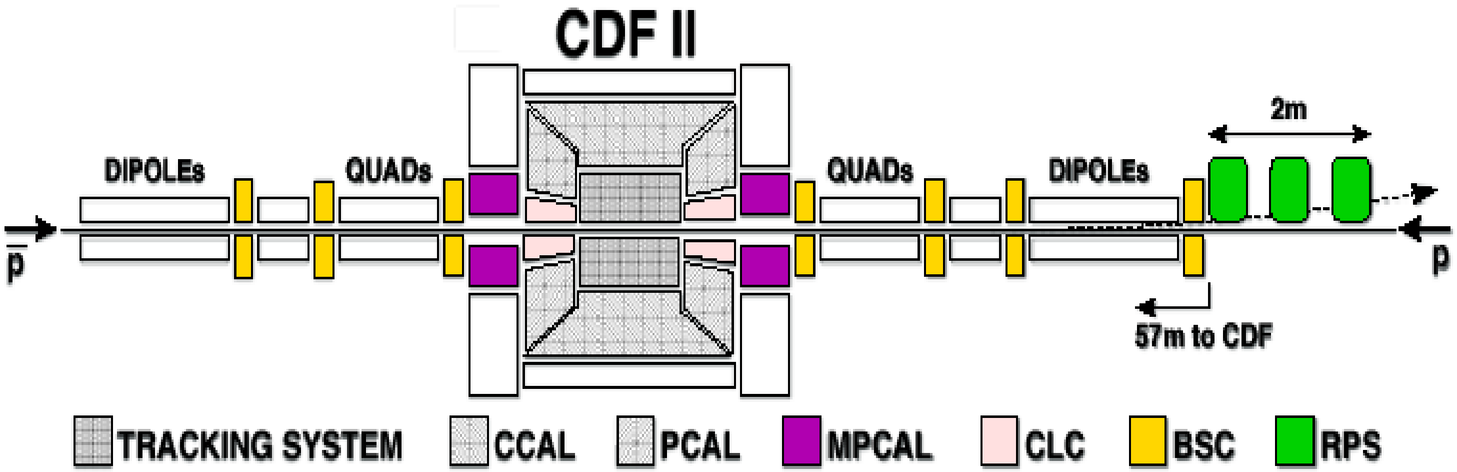


Tevatron *pp* Collider

Run I (1992-1996) √s=1.8 TeV (~120 pb^{-1})

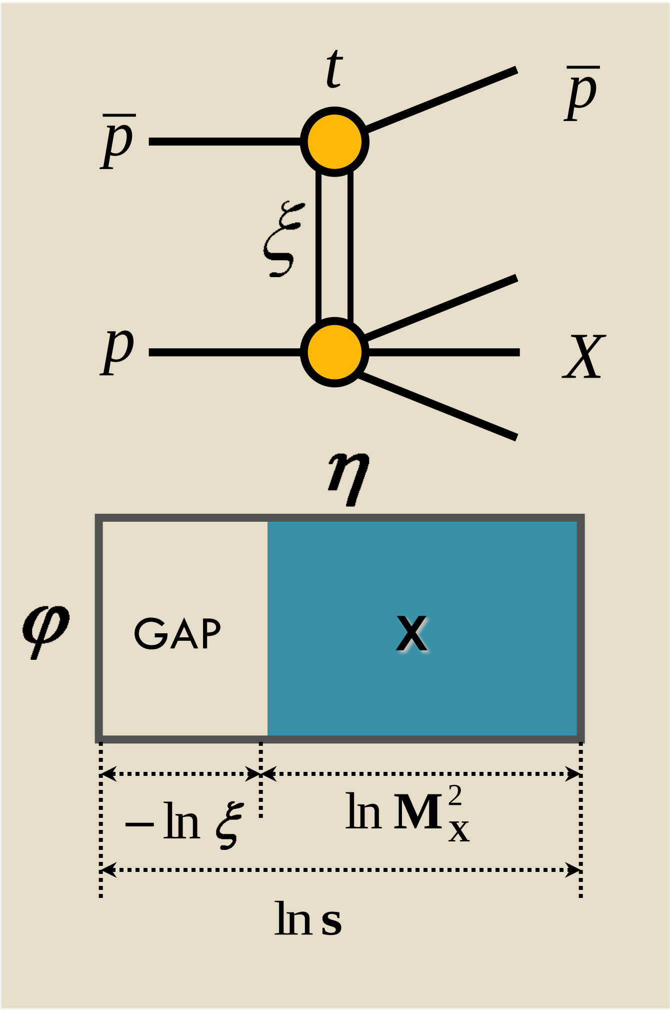
Run II (2001-) √ s= 1.96 TeV

CDF II Detectors



- 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 $3.5 < |\eta| < 5.1$

Kinematics of Diffractive Events



t - four-momentum transfer squared

ξ - fractional momentum loss of antiproton

M_X - mass of system X

$\xi = M_X^2/s$

Selection of Diffractive Events

- CDF Roman Pots acceptance ~80% for $0.03<\xi_{pbar}<0.10$, $|t_{pbar}|<1GeV^2$
- by presence of rapidity gap

Diffractive Structure Function

Diffractive dijet cross section

$$\sigma(\bar{p}p \rightarrow \bar{p}X) \approx F_{jj} \otimes F_{jj}^{D} \otimes \hat{\sigma}(ab \rightarrow jj)$$

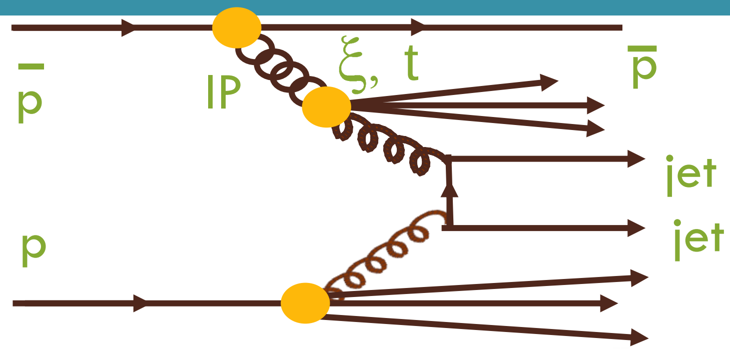
Study the diffractive structure function

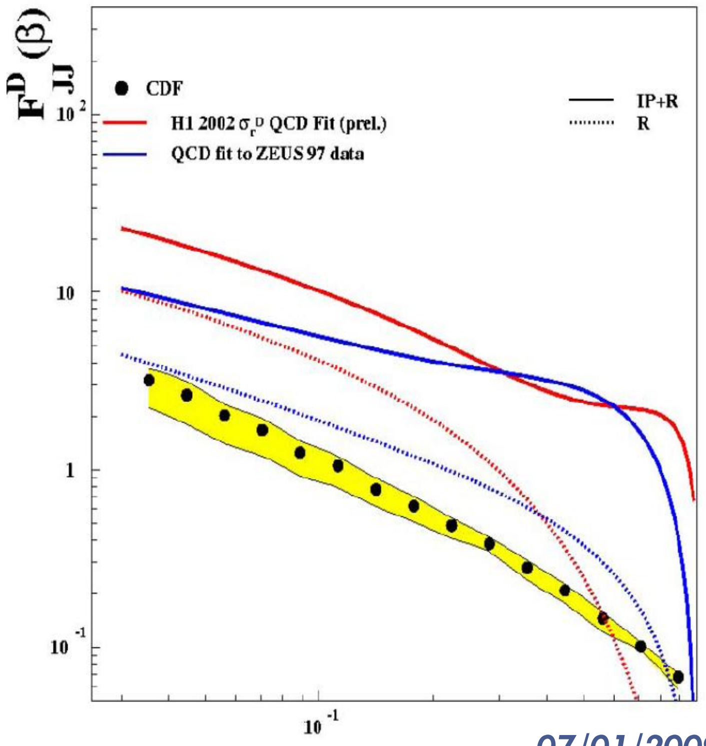
$$F_{jj}^{D} = F_{jj}^{D}(x, Q^{2}, t, \xi)$$

Experimentally determine diffractive structure function F_{jj}^{D}

$$R_{\frac{SD}{ND}}(x,\xi) = \frac{\sigma(SD_{jj})}{\sigma(ND_{jj})} = \frac{F_{jj}^{D}(x,Q^{2},\xi)}{F_{jj}(x,Q^{2})}$$

Data — known PDF

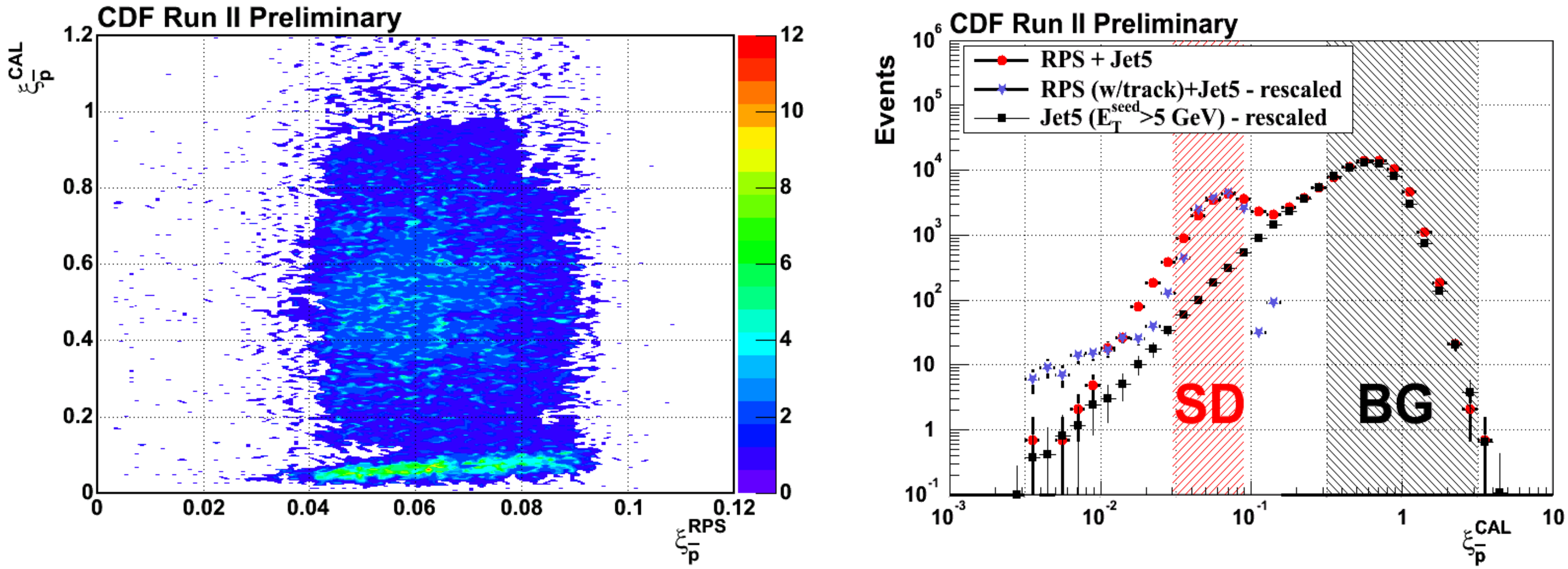




Methods and Challenges

- Determine ξ using Roman Pots tracking
- Also can determine ξ from E_T in calorimeters

important to have MiniPlugs ↗ $\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$



Main challenge: multiple interactions spoiling diffractive signatures

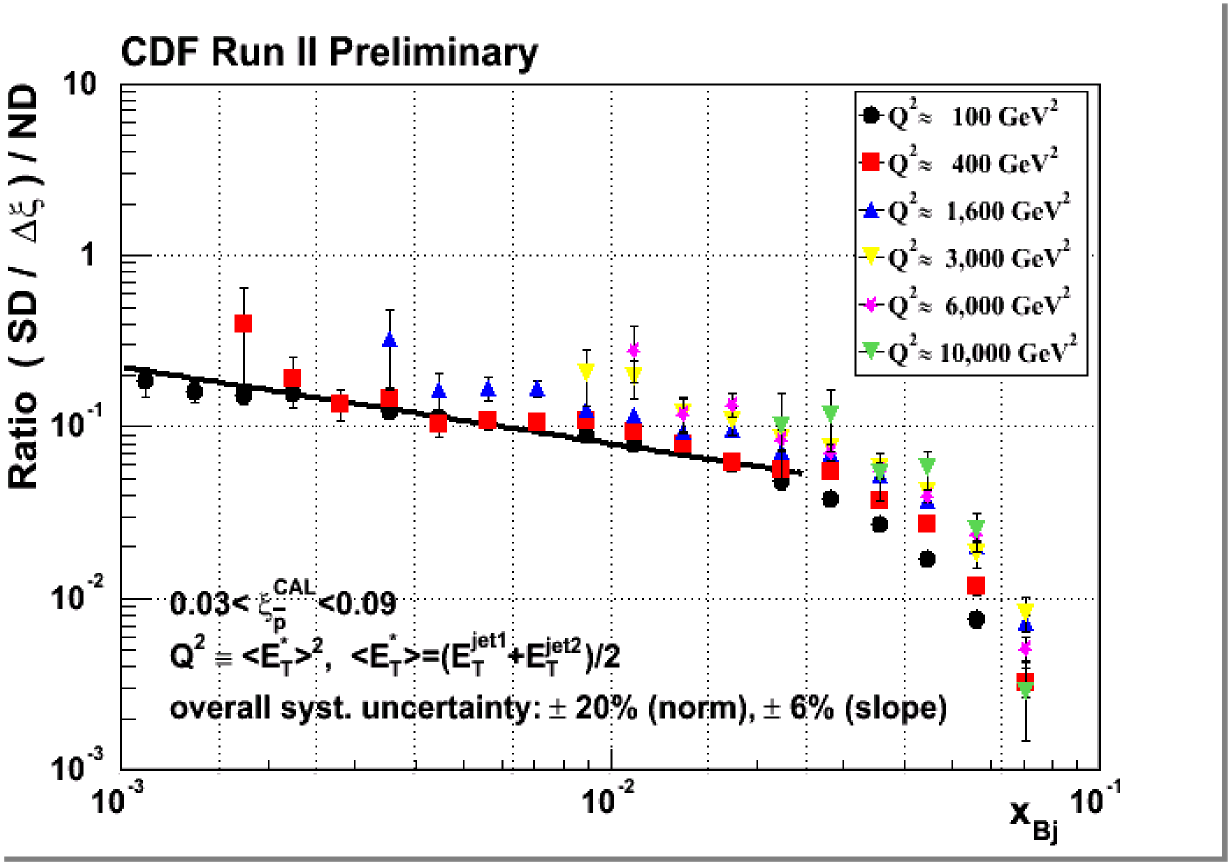
use $\xi^{cal} < 0.1$ to reject overlap events → non-diffractive contributions

Diffractive Structure Function

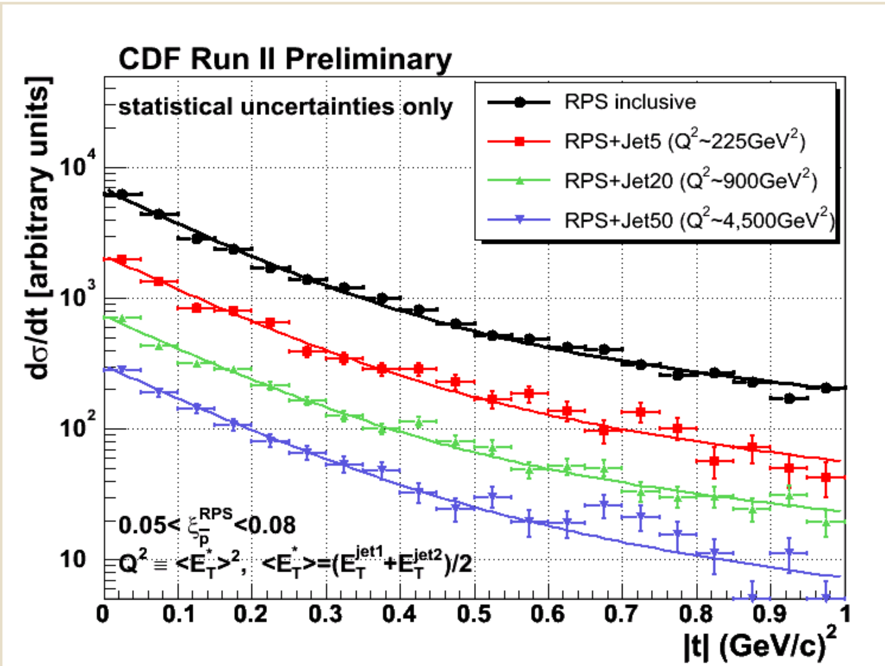
Confirms Run I Results

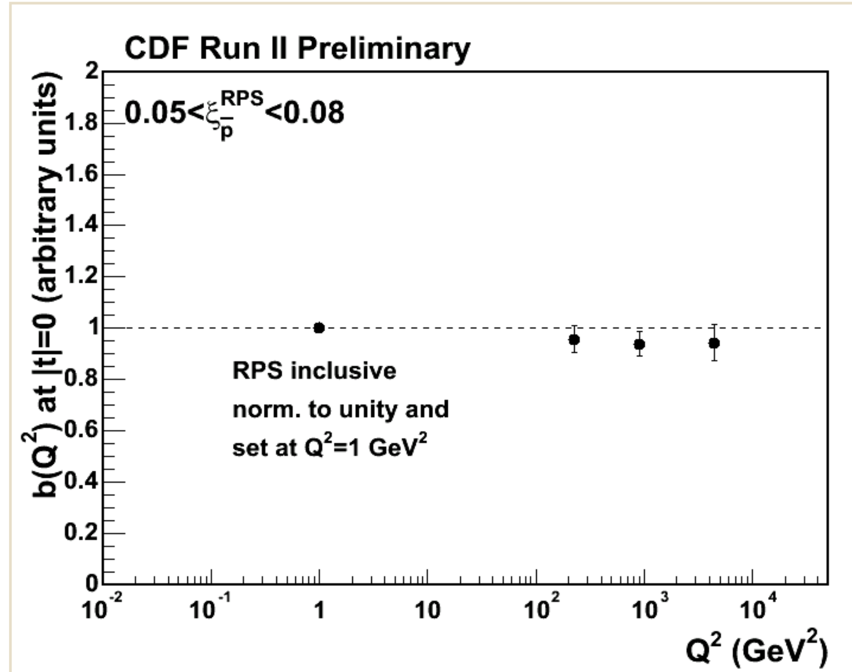
No significant Q^2 dependence for $10^2 < Q^2 < 10^4$ GeV^2

→ Pomeron evolves like proton



Diffractive *t* Distribution





Fit to double exponential function:

$d\sigma/dt \propto 0.9\, e^{b1\ t} + 0.1\, e^{b2\ t}$

- no diffractive dips
- no Q^2 dependence in slope from inclusive to $Q^2 \sim 10^4$ GeV^2

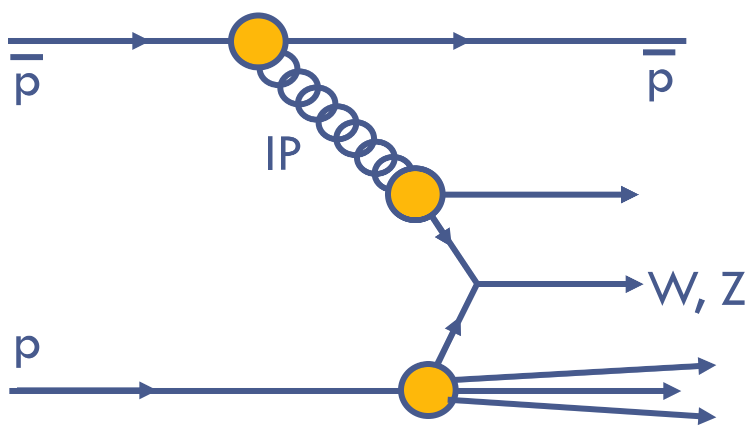
Work in progress:

- high |t| range
- absolute |t|-slope values

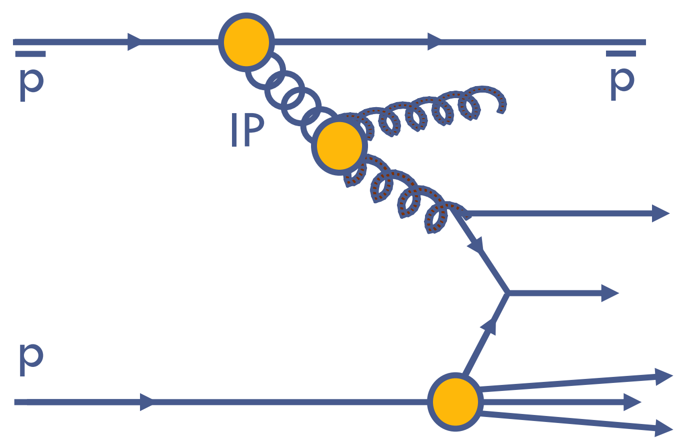
Diffractive W/Z Production

Diffractive W/Z production probes the quark content of the Pomeron

- to Leading Order
  the W/Z are produced
  by a **quark** in the Pomeron



- production by gluons is
  suppressed by a factor
  of α_s
  and can be distinguished by
  an associated jet



Diffractive W production – Run I

Run I studies used rapidity gaps instead of Roman-Pots

•CDF Phys Rev Lett **78, 2698 (1997)**

– Fraction of W events due to SD
[1.15±0.51(stat) ± 0.20(syst)]%

•DØ Phys Lett B **574, 169 (2003)**

– Fraction of events with rapidity gap (uncorrected for gap survival)

–W: [0.89+0.19-0.17]%

– Z: [1.44+0.61-0.52]%

Diffractive W Production – Run II

Identify diffractive events using Roman Pots:

- accurate event-by-event ξ measurement
- no gap acceptance correction needed
- can still calculate ξ^{cal}

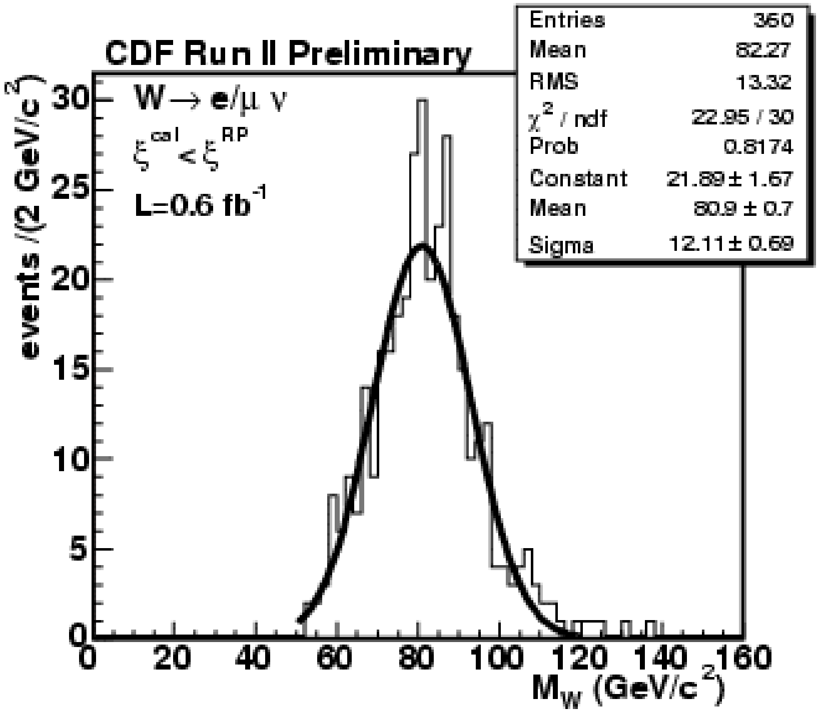
$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

In W production, the difference between ξ^{cal} and ξ^{RP} is related to missing E_T and η_ν

$$\xi^{RP} - \xi^{cal} = \frac{E_T}{\sqrt{s}} e^{-\eta_\nu}$$

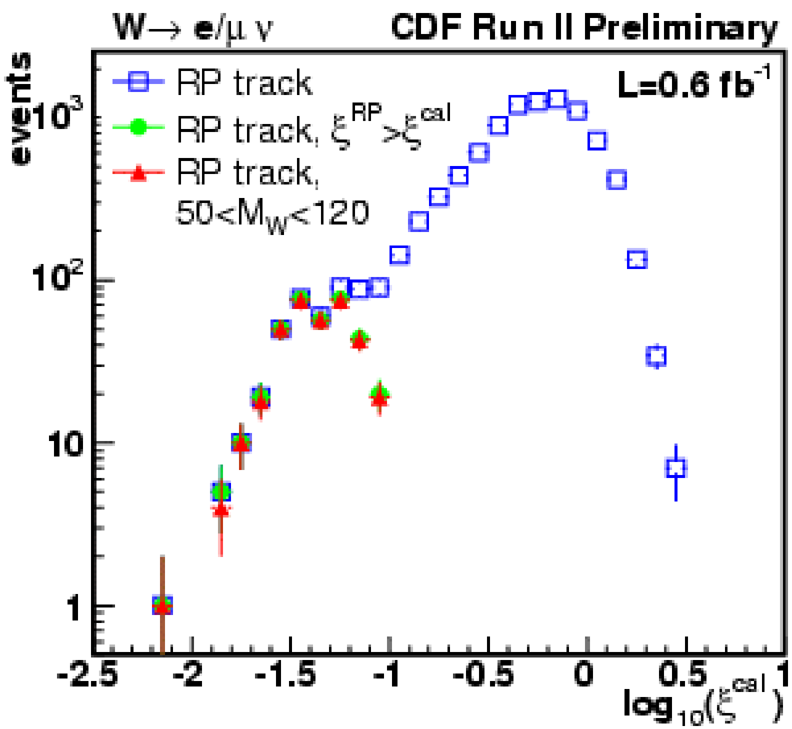
allows to determine:

- neutrino and W kinematics
- x_{bj}



reconstructed diffractive W mass

Diffractive W Production: measurement



- $\xi^{cal} < \xi^{RP}$ requirement removes most events with multiple pbar-p interactions
- $50 < M_W < 120\ GeV/c^2$ requirement on the reconstructed W mass cleans up possible mis-reconstructed events

Fraction of diffractive W

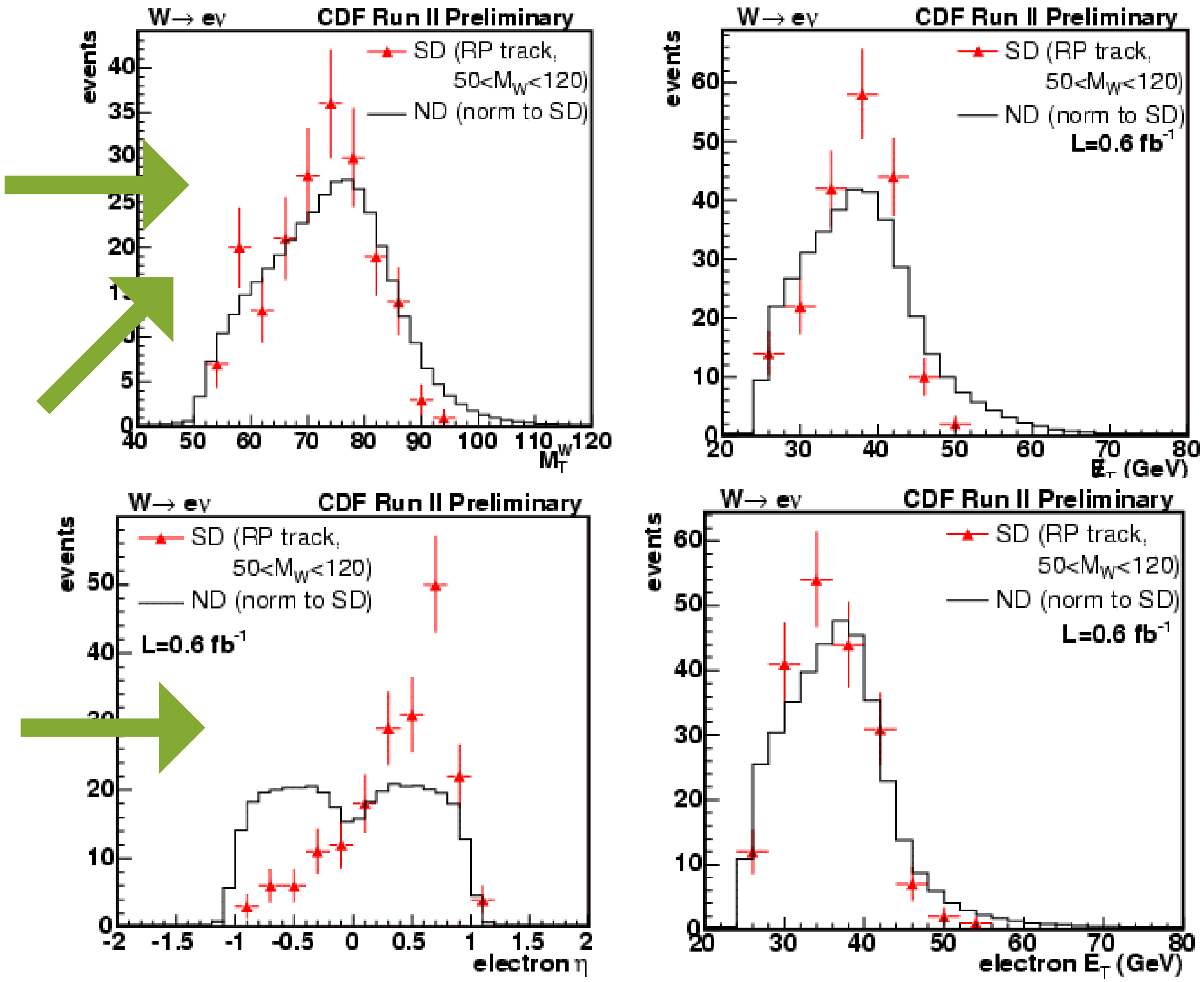
R_W (0.03<ξ<0.10, |t|<1)= [0.97 ±0.05(stat) ±0.11(syst)]%

consistent with Run I result, extrapolated to all ξ

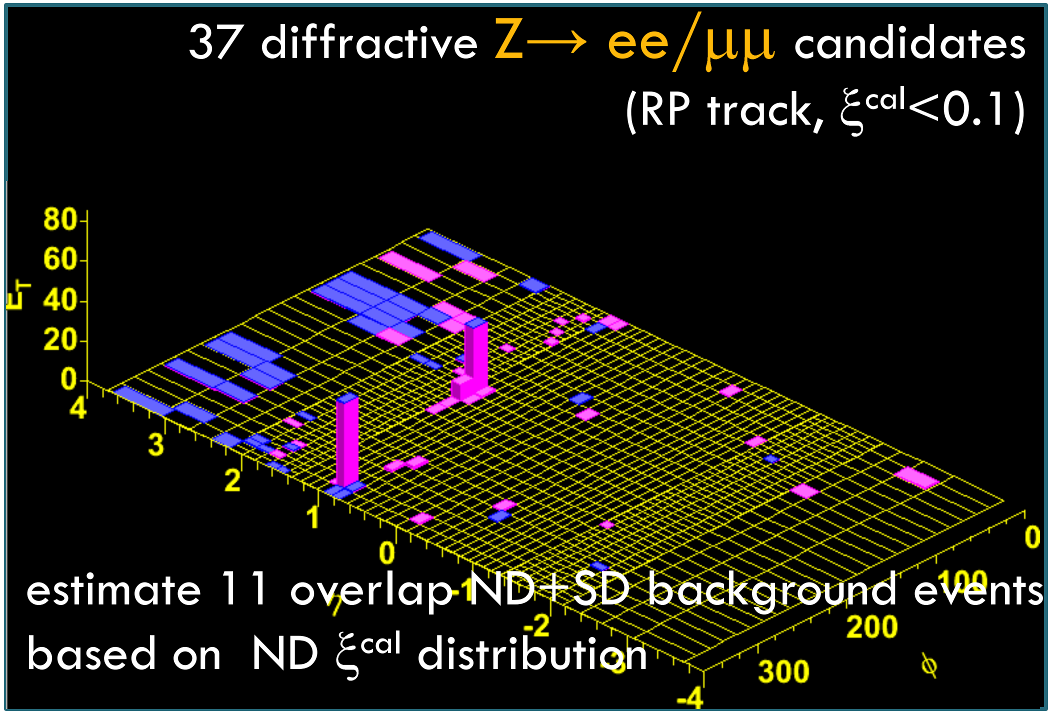
$W \rightarrow e\nu$ Kinematics

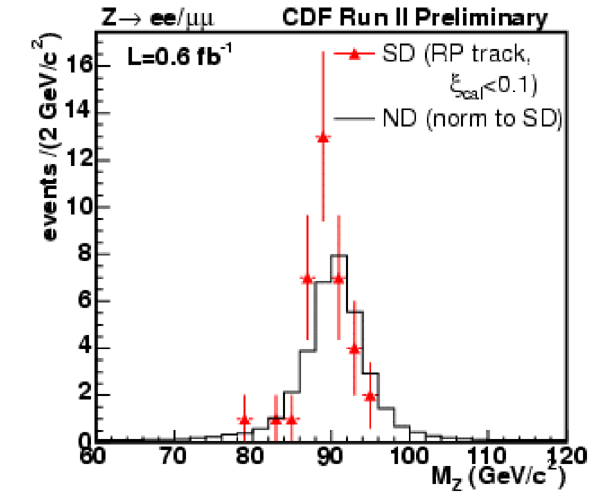
similar for SD and ND

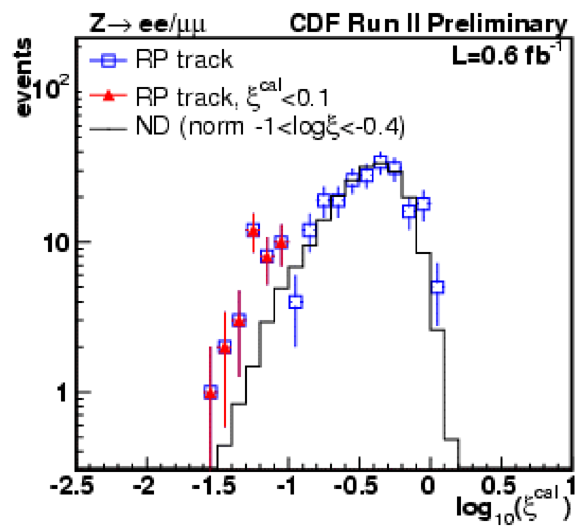
electrons are boosted away from anti-protons in diffractive sample



Diffractive Z Production





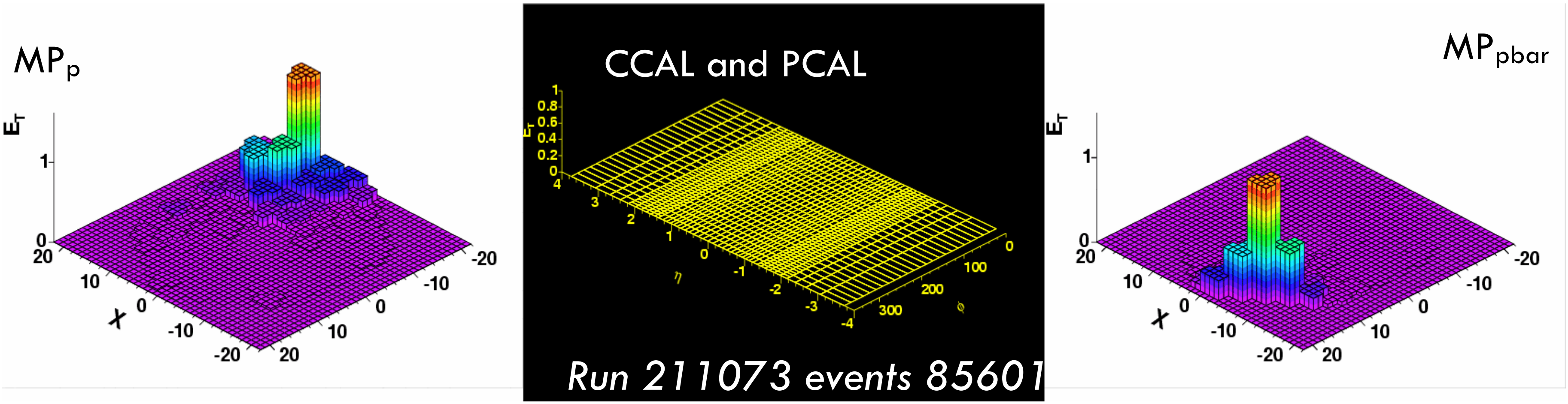


Fraction of diffractive Z

R_Z (0.03< ξ <0.10, |t|<1)=

[0.85±0.20(stat) ±0.11(syst)]%

Forward Jets and Rapidity Gaps



Goals:

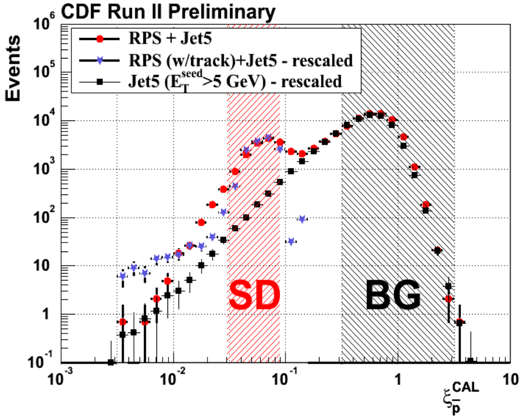
- characterize rapidity gap formation in forward jet events
  - fraction of events with rapidity gap
  - dependence on rapidity gap width
- study Mueller-Navelet jets

Forward Jets and Central Gaps

Nucl. Instrum. Meth. ***A**518 (2004) 42.*

Nucl. Instrum. Meth. ***A**496 (2003) 333.*

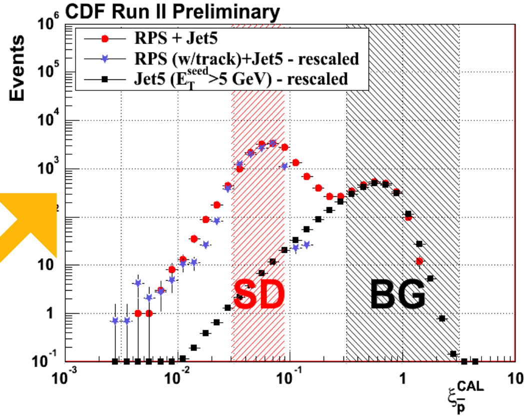
to detect forward jets $3.6 < |\eta| < 5.2$ we use **MiniPlug Calorimeters**



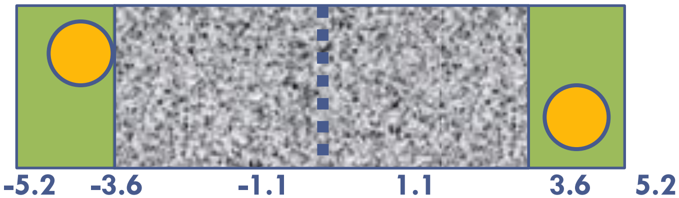
for gap studies need **low luminosity** run

average luminosity

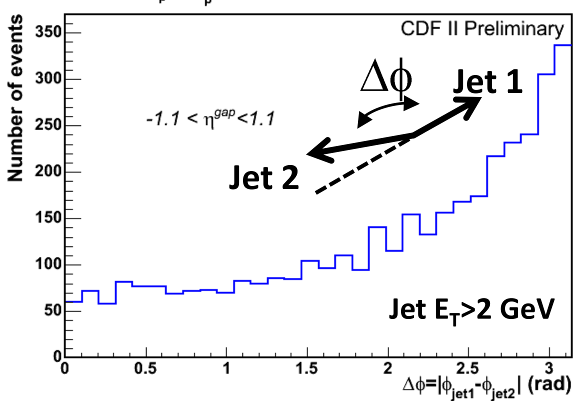
$\mathcal{L} \sim 1\mathrm{x}10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

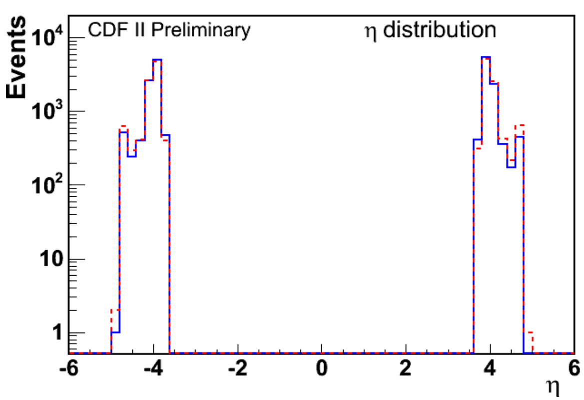


Jet Azimuthal Angle (De)correlation

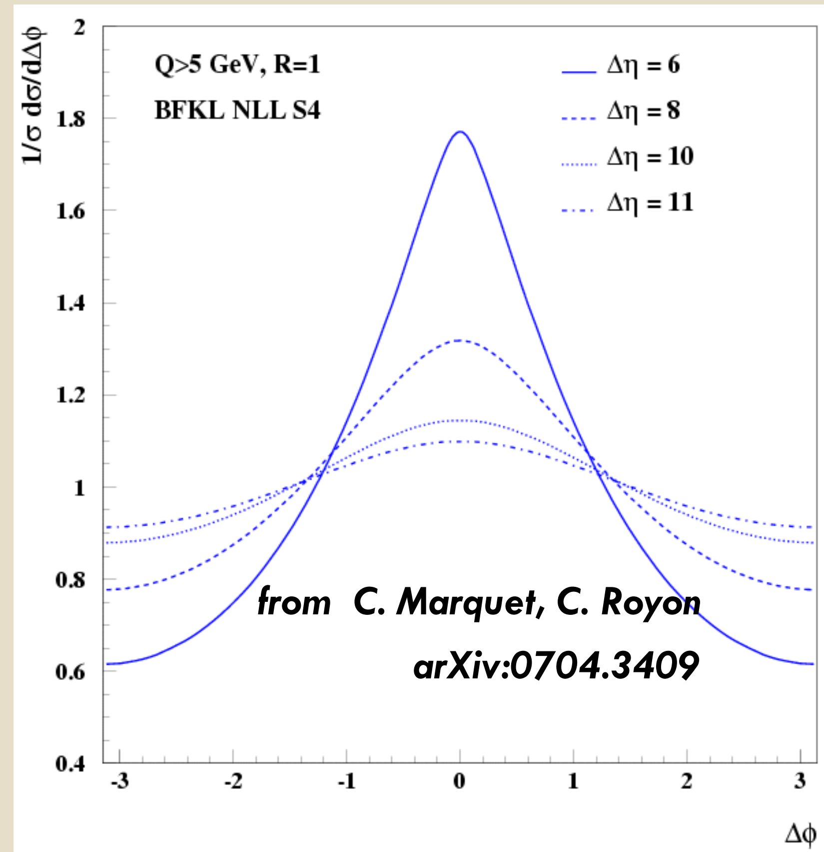


Δϕ for $MP_p \bullet MP_{\bar{p}}$ jets with CCAL gap





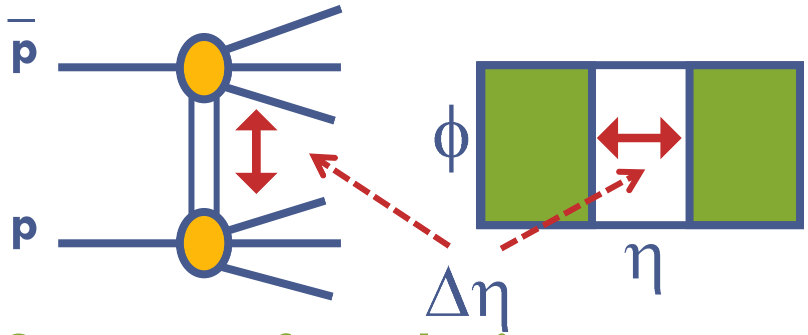
azimuthal decorrelation for CDF kinematics



work in progress…

Rapidity Gaps in Minbias Events

Soft Double-Diffraction (DD)



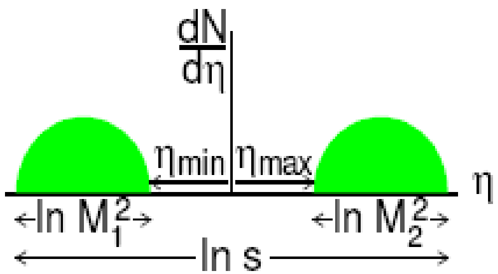
Strategy of analysis:

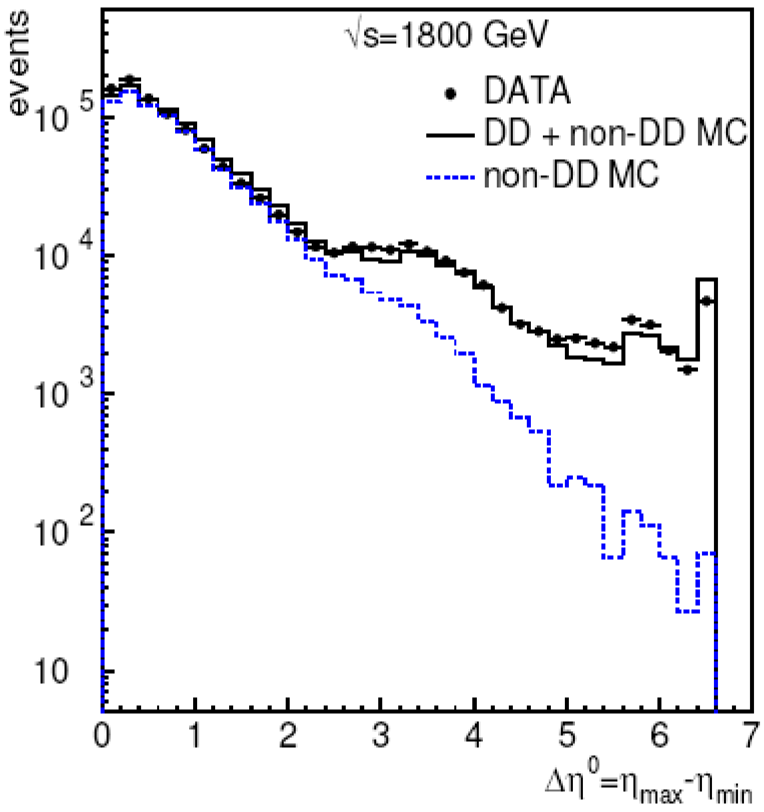
look for "experimental gaps" defined as

$\Delta\eta \equiv \eta_{max} - \eta_{min}$

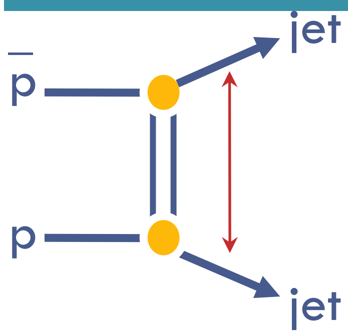
$\eta_{max}(\eta_{min})$- "particle" closest to $\eta=0$

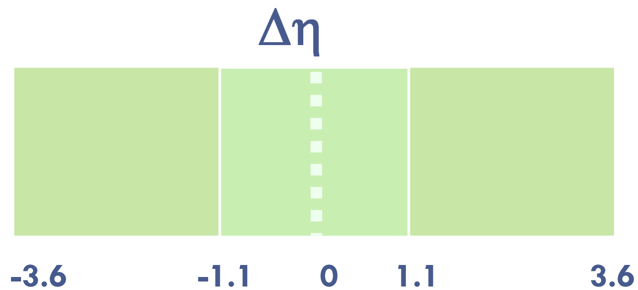
in the p(p) direction

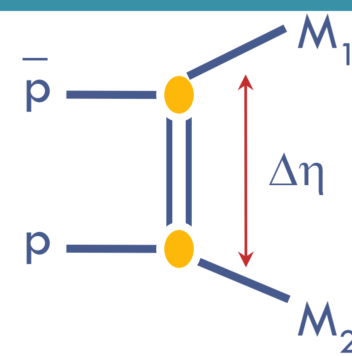




Central Gaps in Soft and Hard DD





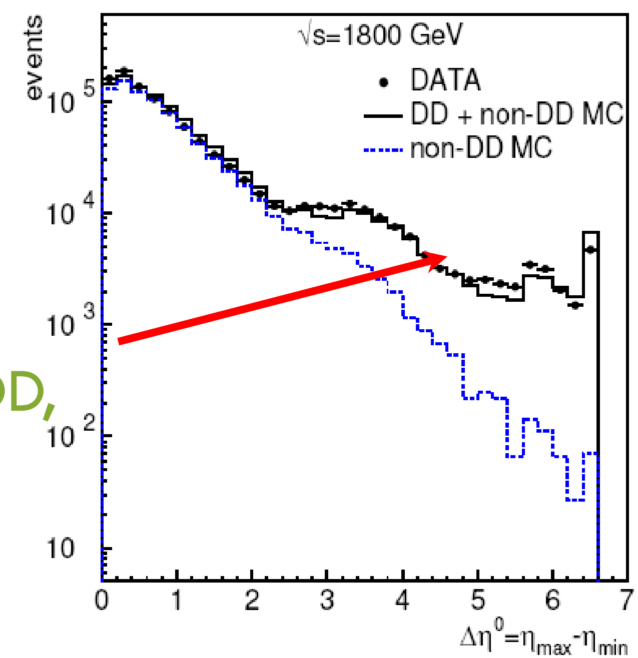


To **compare gap probability** in soft and hard DD dissociation:

reconstruct $\Delta\eta$ in both cases

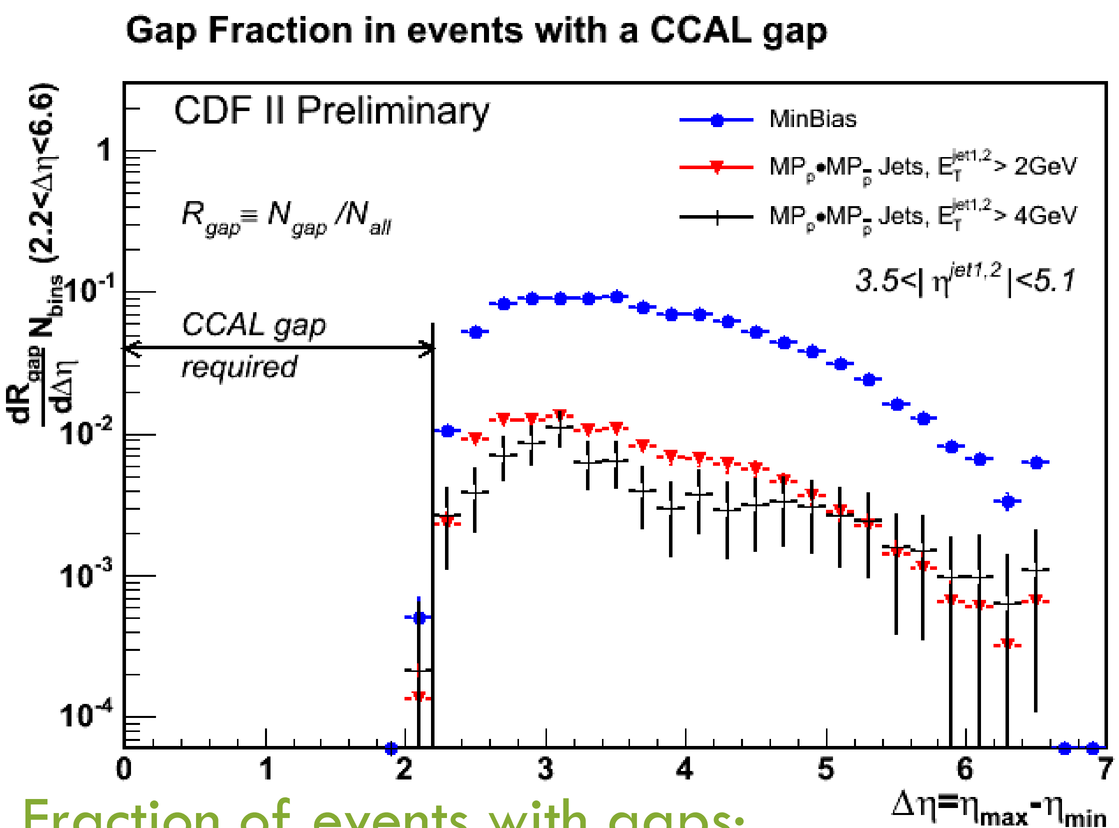
require events to have gap in CCAL $|\eta|<1.1 \Rightarrow \Delta\eta>2 \Rightarrow$ significant DD contribution

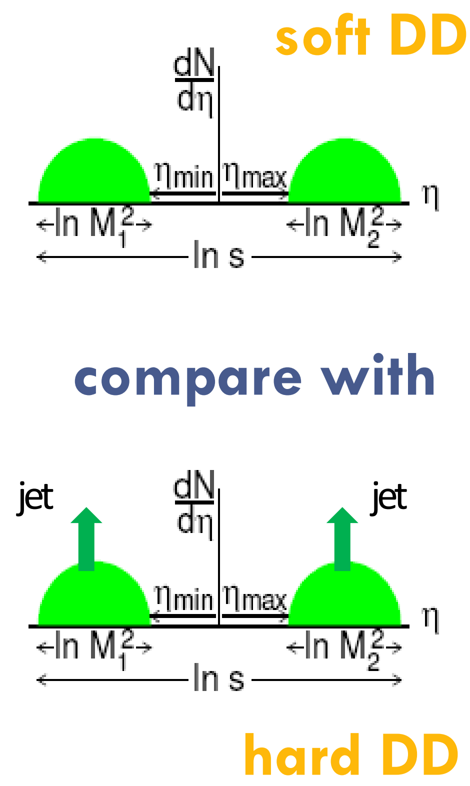
require opposite side MP jets for hard DD, with $E_T>2$ GeV



Direct comparison of the results is relatively free of systematic uncertainties.

Central Gaps in Soft and Hard DD





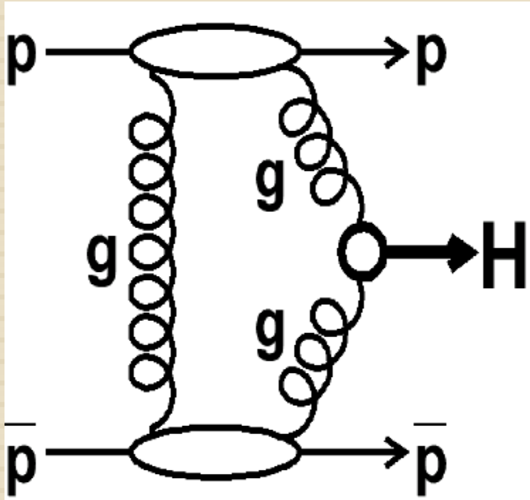
Fraction of events with gaps:

~10% in soft DD events and ~1% in jet events

The distributions are similar in shape within the uncertainties

Exclusive Production

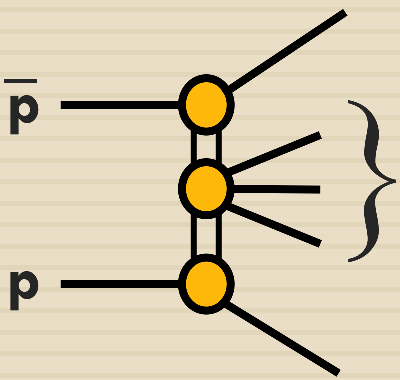
LHC



➔ suppression at LO of the background sub-processes (J_z=0 selection rule)

➔ "exclusive channel" ⟶ clean signal (no underlying event)

CDF



Dijets,

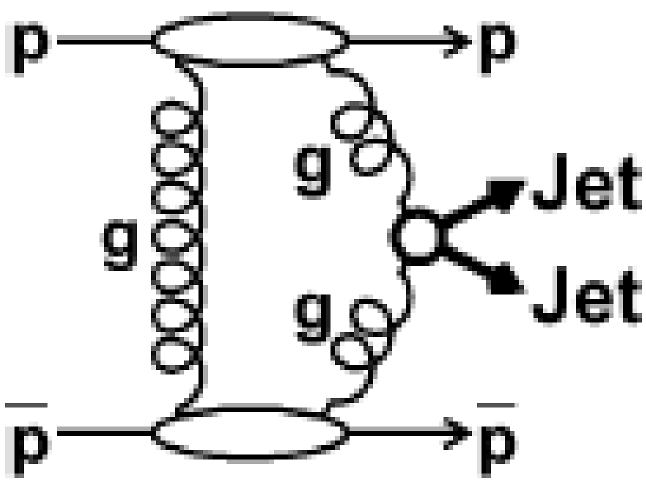
$\gamma\gamma$,

χ_c

At the Tevatron we use similar processes with larger cross sections to test and calibrate theor. predictions

Exclusive Dijet Production

Run I



CDF limit of

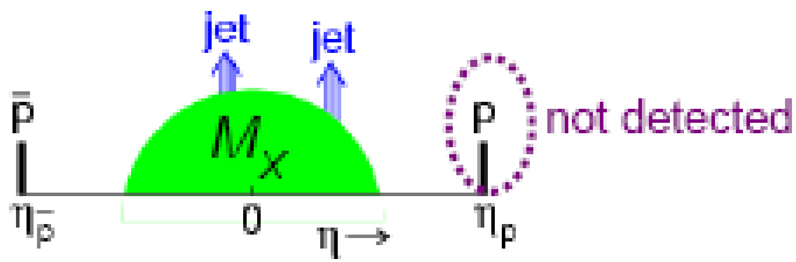
σ_{excl}<3.7 nb(95% CL)

Run II

Method:

Select inclusive diffractive dijet events produced by DPE

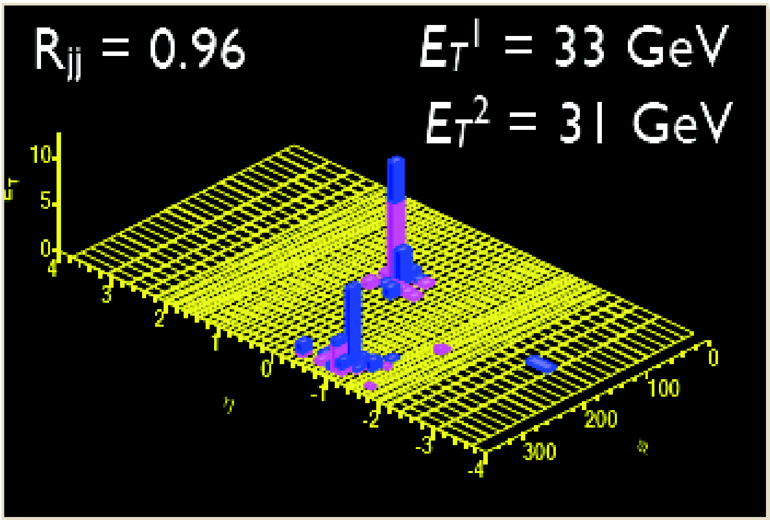
$p+\bar{p} \rightarrow I\!P + I\!P \rightarrow \bar{p} + X(\geq 2 \text{ jets}) + gap$

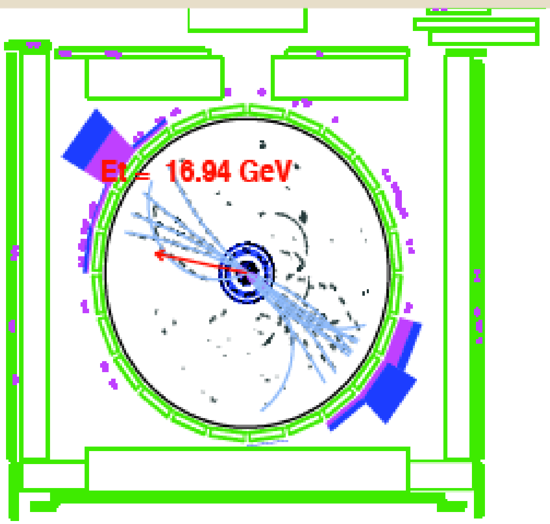


Reconstruct $R_{jj} = \frac{M_{jj}}{M_X}$, where

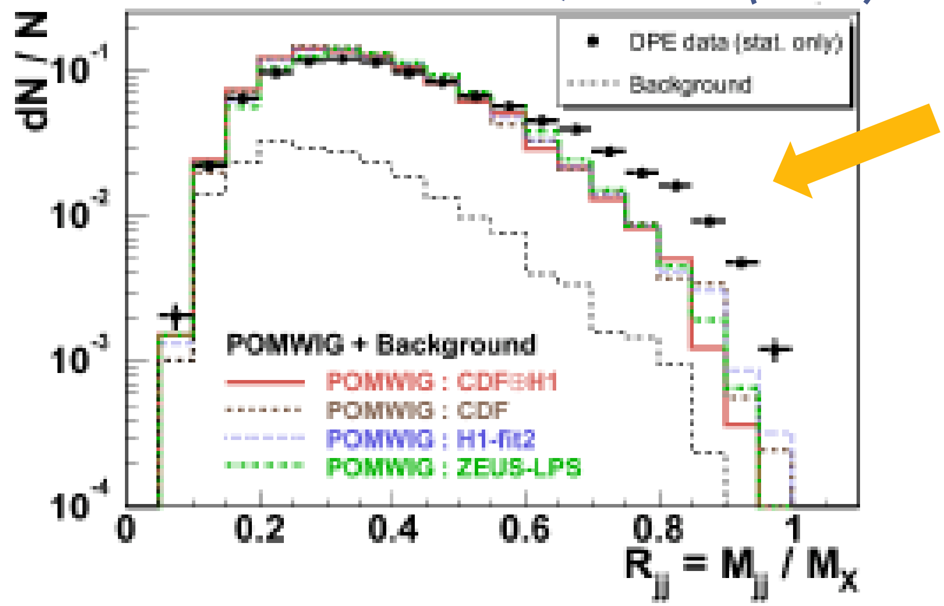
M_{jj} - dijet mass, M_X - mass of system X

Observation of Exclusive Dijet Production





PRD 77, 052004 (2008)



Observe excess over inclusive DPE dijet MC's at high dijet mass fraction

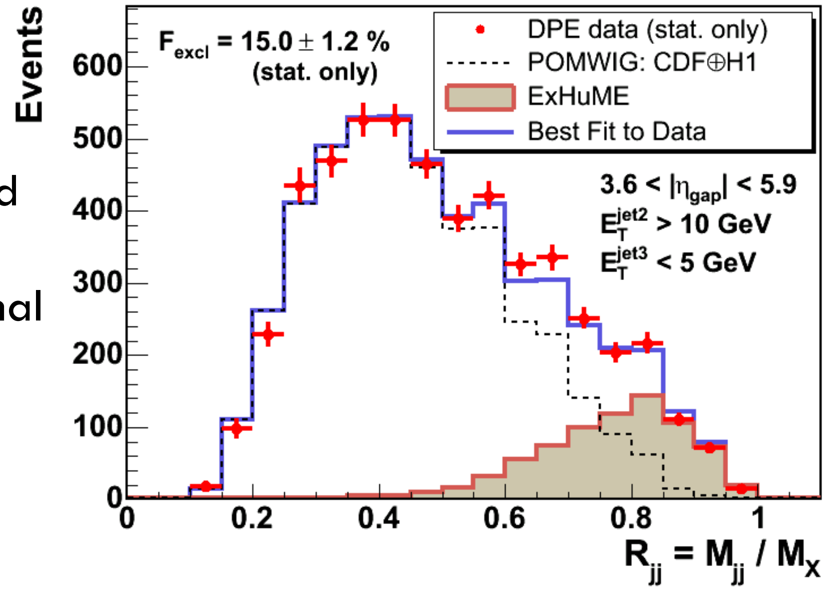
Signal at R_{jj}=1 is smeared due to shower/hadronization effects, NLO $gg \rightarrow ggg, q\bar{q}g$ contributions

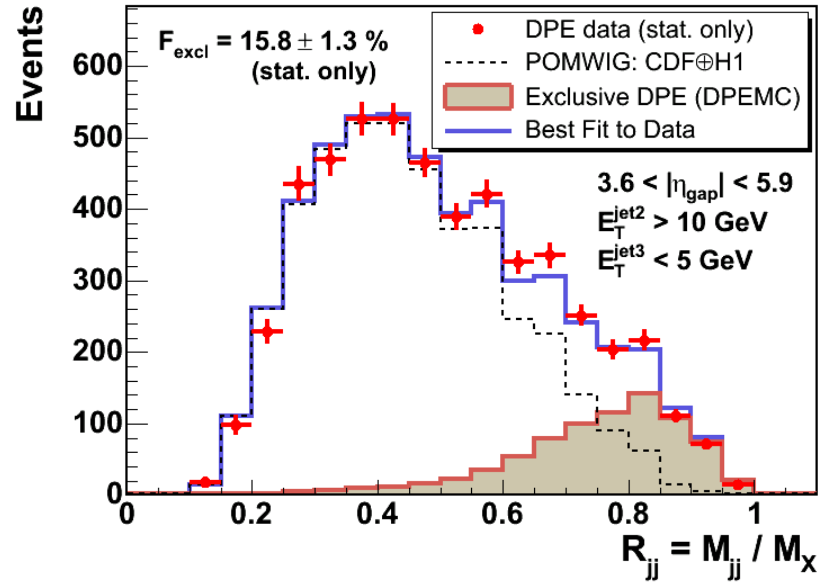
Exclusive Dijets

Signal MC ExHuME *CPC 175,232 (2006)*

Exclusive DPE as input to DPEMC *CPC 167,217 (2005)*

- data
- bkgd
- signal
- fit





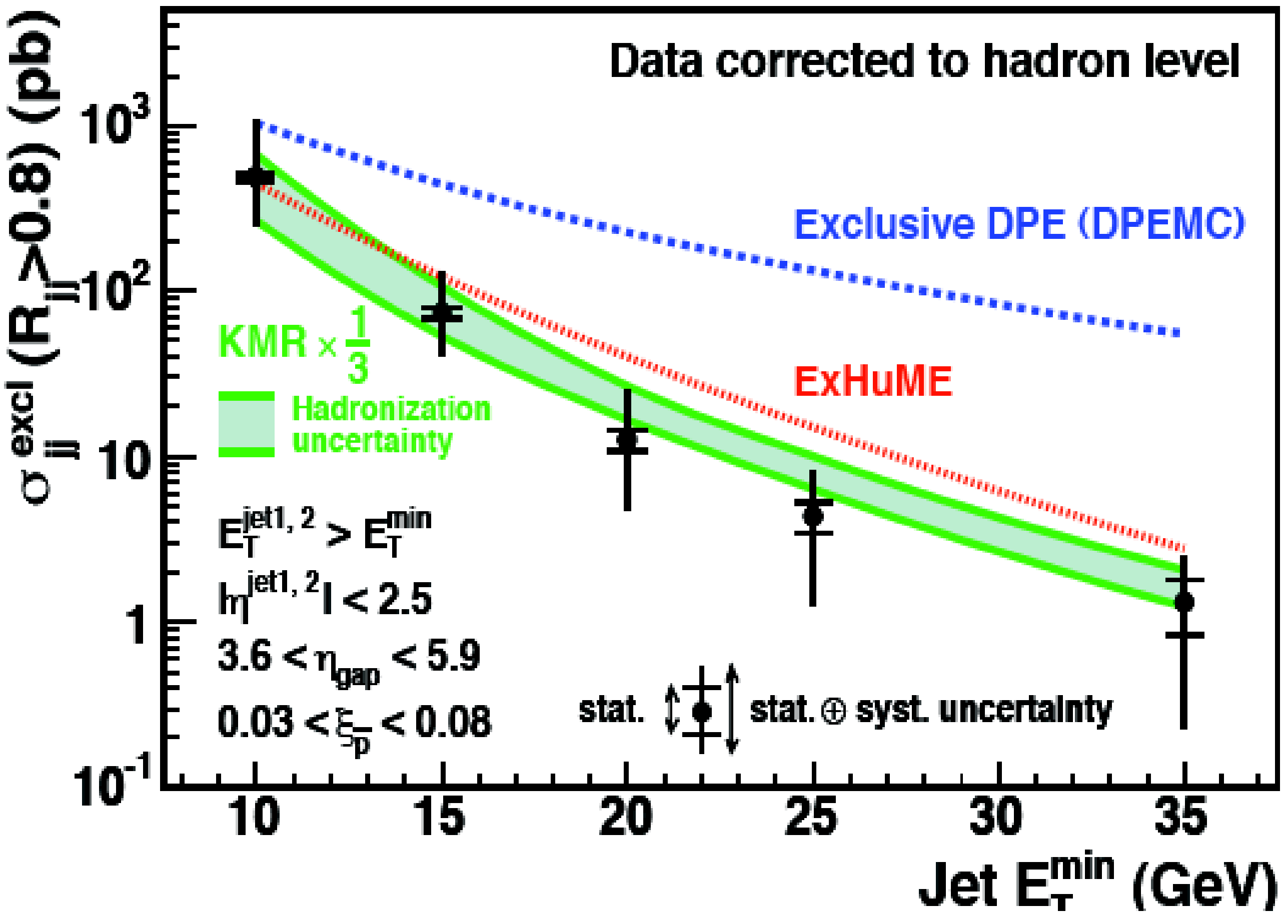
→ Shape of excess described by exclusive dijet MC based on two models (ExHuME, DPEMC), shows good agreement

Exclusive Dijet Cross Section

➔ Exclusive dijet cross section compared with MC based on two models : ExHuME, and excl. DPE DPEMC.

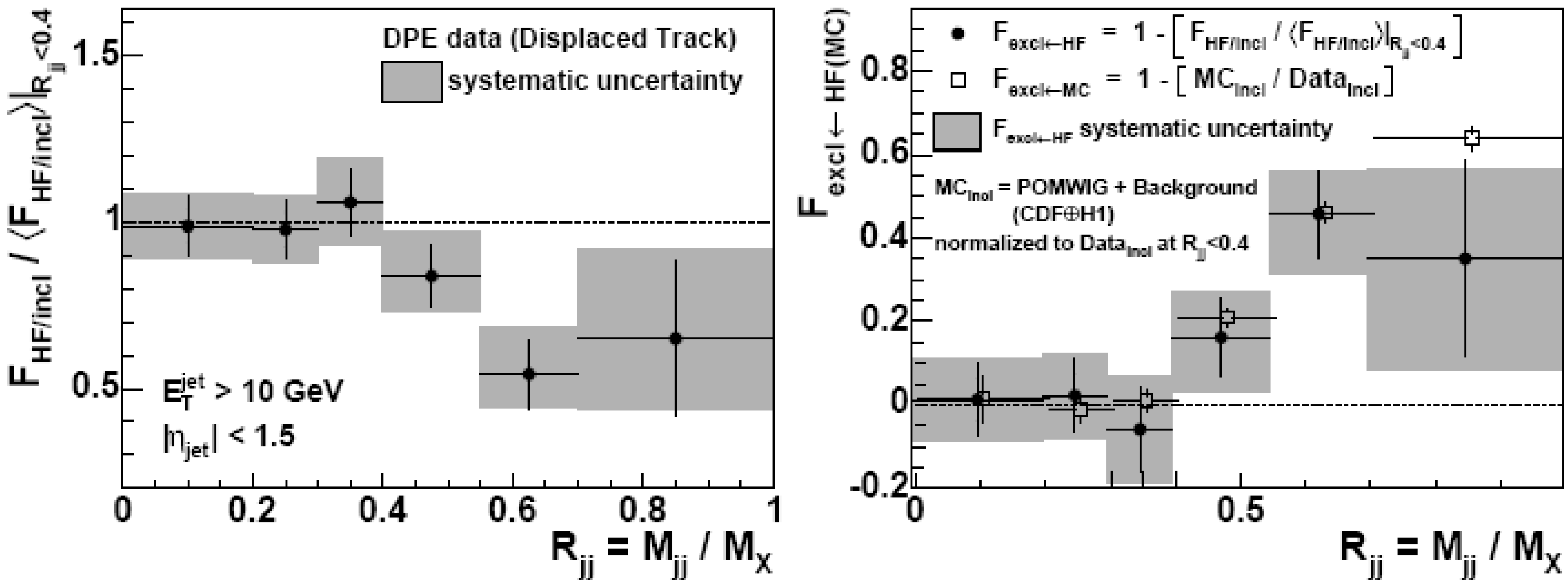
Cross section disfavors exclusive DPE model.

➔ Calculation by Khoze, Martin, and Ryskin consistent within its factor of 3 uncertainty. *Eur. Phys J C14, 525 (2000).*



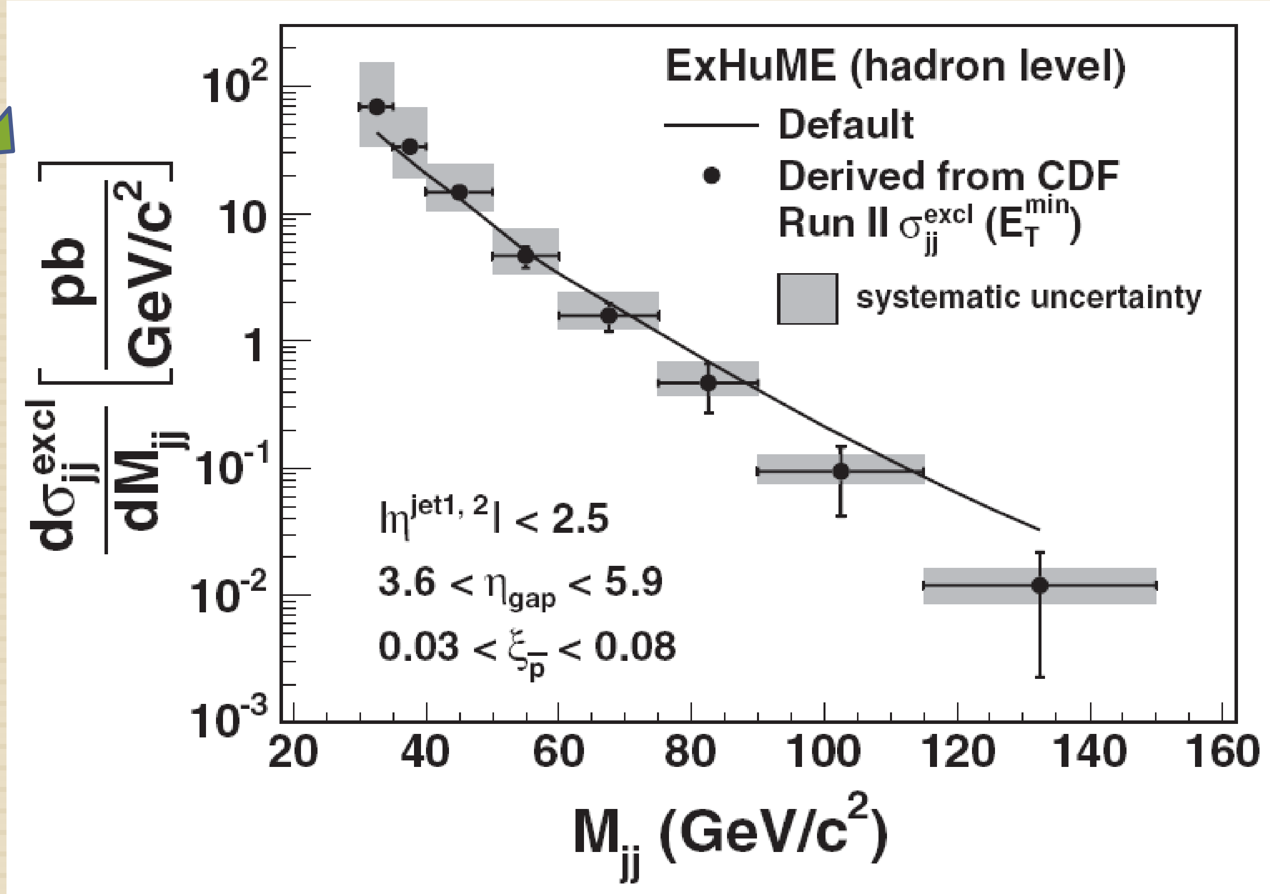
Heavy Flavor Suppression

- LO exclusive gg →qq suppressed (J_Z =0 rule)
- Look for **heavy flavor jet suppressio**n relative to inclusive dijets at high Rjj



Suppression of heavy flavor for R_{jj}> 0.4 is consistent in shape and magnitude with the results based on MC based extraction of exclusive dijet signal.

derived from CDF excl. dijet x-sections using ExHuME

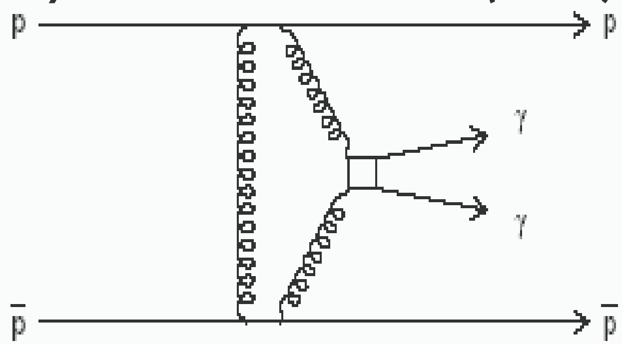


Excl. Cross Section vs Dijet Mass

Stat. and syst. errors are propagated from measured cross section uncertainties using M_{jj} distribution shapes of ExHuME generated data.

Exclusive $\gamma\gamma$ Production

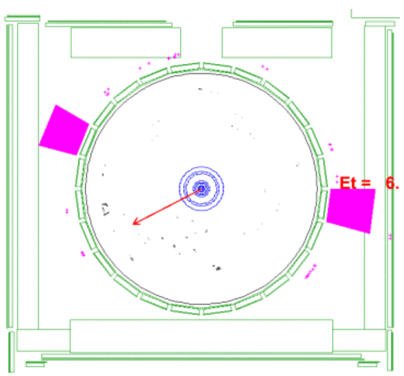
Phys.Rev.Lett. 99,242002 (2007)



3 candidates observed:

2 events are good $\gamma\gamma$ candidates

1 event is good $\pi^0\pi^0$ candidate



$E_T(\gamma) > 5$ GeV

$|\eta(\gamma)| < 1.0$

Theoretical Prediction:

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

σ (with our cuts) = (36 +72 – 24) fb

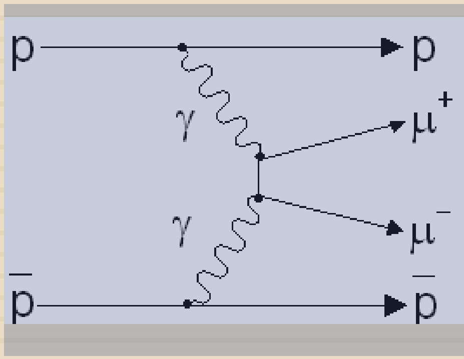
= 0.8 +1.6 –0.5 events.

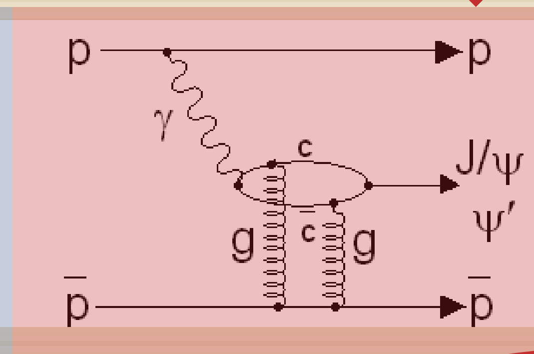
Cannot yet claim “discovery” as b/g study *a posteriori*,

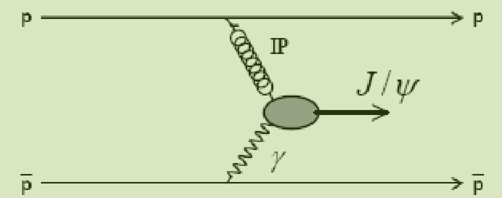
2 events correspond to $\sigma \sim 90$ fb, agreeing with Khoze *et al.*

$$\bar{p} + p \rightarrow \bar{p} + \mu^+ \mu^- + p \qquad 3\ \mathrm{GeV}/c^2 < M_{\mu\mu} < 4\ \mathrm{GeV}/c^2$$

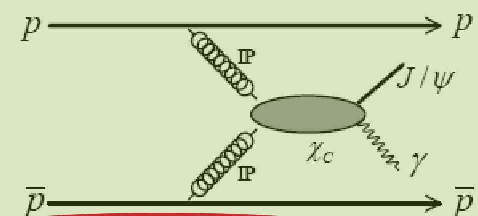
Many Physics Processes in this data:







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



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

exclusive χ_c in DPE

Exclusive Dimuon Production

Observation of exclusive χ_c PRL 242001 (2009)

More on exciting new results :
see talks by M. Albrow and J. Pinfold

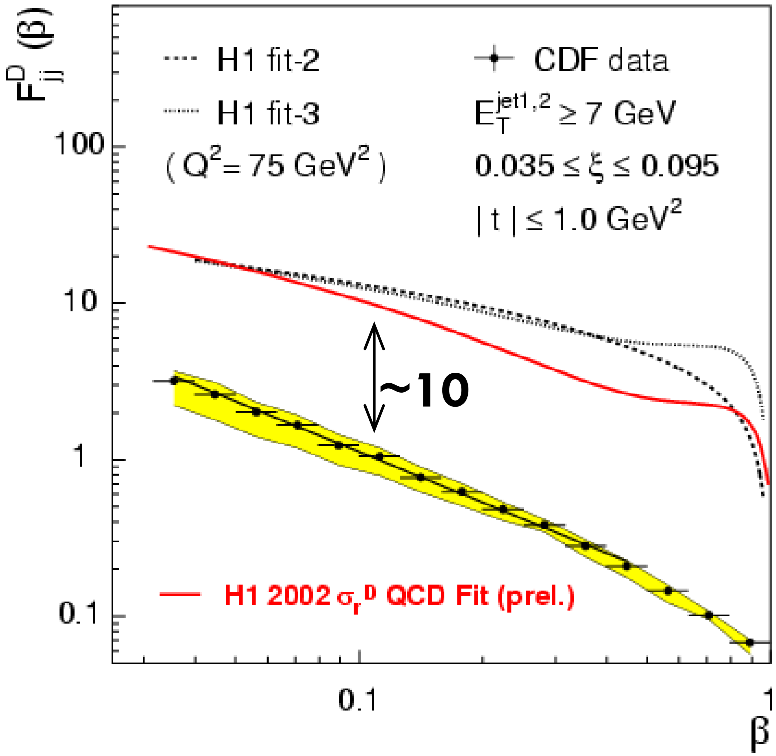
Conclusions

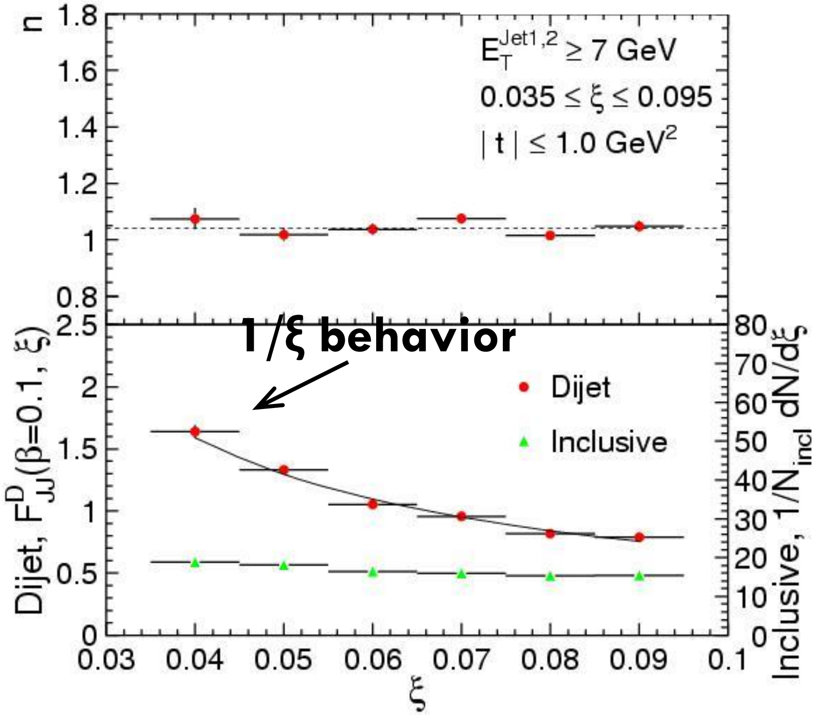
The long-standing diffractive program at CDF continues to improve our understanding of the diffractive processes.

- Diffractive dijets:
  - x_{BJ}, Q^2, t-dependence
- Diffractive W/Z measurement with RP:
  - W diffractive fraction confirms Run I rapidity gap result
- Central Rapidity Gaps:
  - Gap fraction dependence on width and η-position of gap for hard / soft triggers at $|\eta|>4$ - shapes are similar
- Exclusive Production
  - observation of the exclusive dijet production
  - search for exclusive $\gamma\gamma$ production (3 candidates)
  - observation of the excl.χ_{c0}, excl. photoproduction of J/ψ, $\psi(2s)$

Back up

The Diffractive Structure Function





discrepancy in normalization

↓

QCD factorization breakdown

$$F^D_{jj} = C\beta^{-n}\xi^{-m}$$

Regge factorization holds

pomeron exchange

for $\beta < 0.5$

$n = 1.0 \pm 0.1$

$m = 0.9 \pm 0.1$

W/Z Selection

$$E_T^e(p_T^\mu) > 25\,\mathrm{GeV}$$
$$\not{E}_T > 25\,\mathrm{GeV}$$
$$40 < M_T^W < 120\,\mathrm{GeV}$$
$$|Z_{vtx}| < 60\,\mathrm{cm}$$

$$E_T^{e1}(p_T^{\mu 1}) > 25\,\mathrm{GeV}$$
$$E_T^{e2}(p_T^{\mu 2}) > 25\,\mathrm{GeV}$$
$$66 < M^Z < 116\,\mathrm{GeV}$$
$$|Z_{vtx}| < 60\,\mathrm{cm}$$

- RPS trigger counters – require MIP
- RPS track - $0.03 < \xi < 0.10$, $|t| < 1\,\mathrm{GeV}^2$
- W → $\xi^{cal} < \xi^{RP}$, $50 < M_W(\xi^{RPS},\xi^{cal}) < 120\,\mathrm{GeV}^2$
- Z → $\xi^{cal} < 0.1$

W/Z Results

R^W (0.03 < ξ < 0.10, |t|<1)= [0.97 ± 0.05(stat) ± 0.11(syst)]%

Run I: R^W (ξ<0.1)=[1.15±0.55] % ➔ **0.97±0.47** % in **0.03 < ξ < 0.10 & |t|<1**

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

CDF/DØ Comparison – Run I (ξ < 0.1)

CDF PRL 78, 2698 (1997)

R^w=[1.15±0.51(stat)±0.20(syst)]%

gap acceptance A^{gap}=0.81

Uncorrected for A^{gap}

R^W=(0.93±0.44)%

DØ Phys Lett B **574**, 169 (2003)

R^w=[5.1±0.51(stat)±0.20(syst)]%

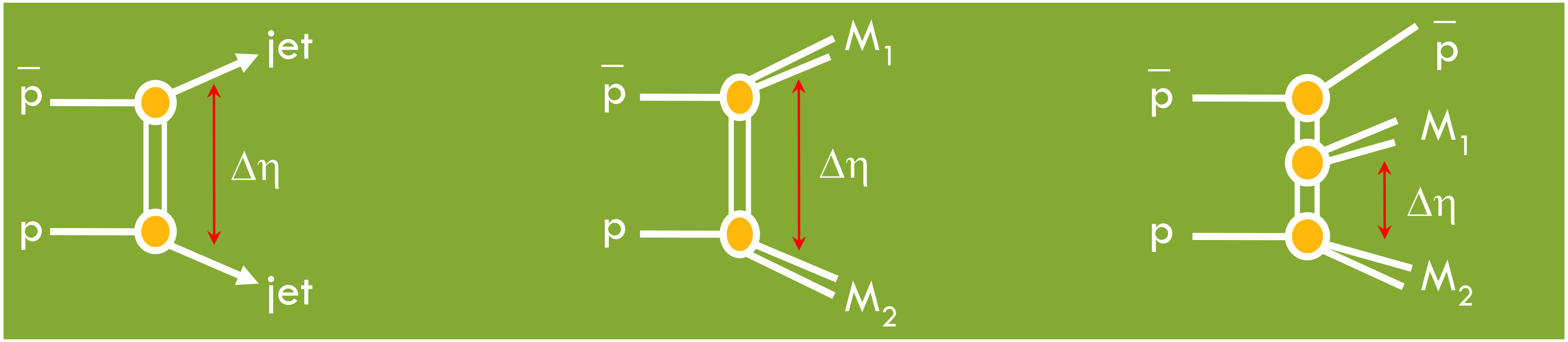
gap acceptance A^{gap}=(0.21±4)%

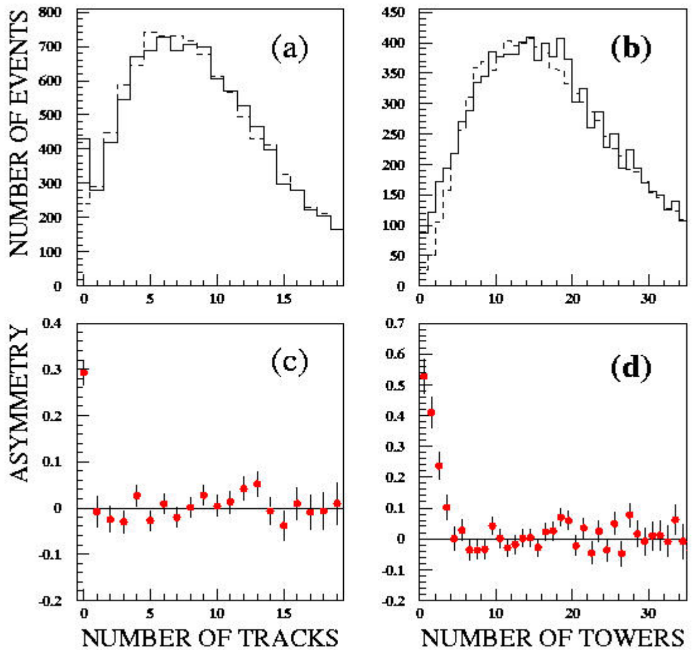
Uncorrected for A^{gap}

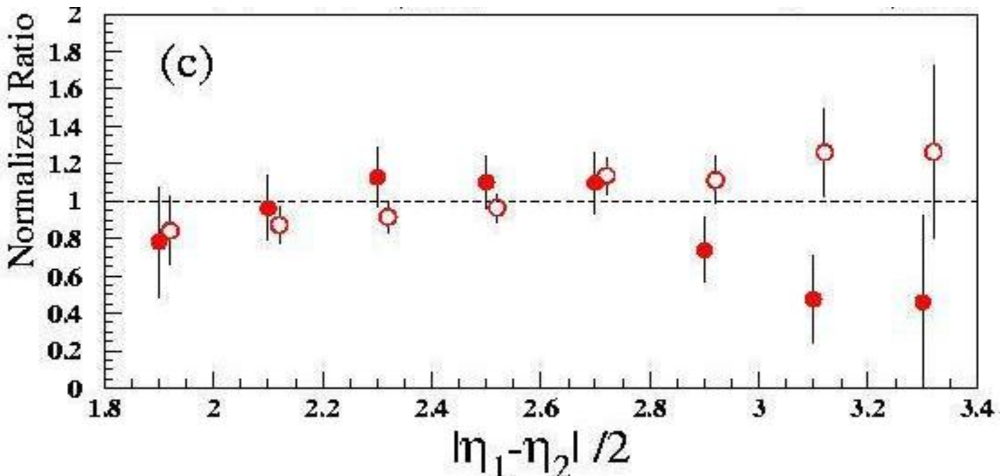
R^W=[0.89+0.19-0.17]%

R^Z=[1.44+0.61-0.52]%

Central Gaps in Run I



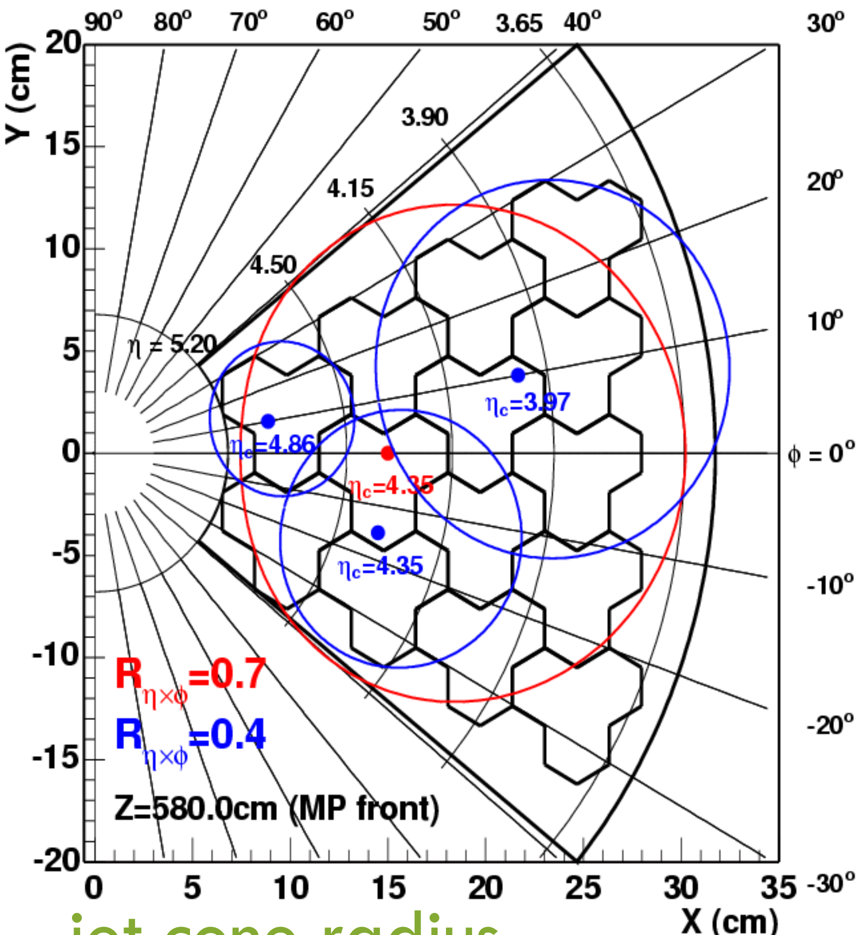




R=[1.13±0.12(stat) ±0.11(syst)]% at 1800 GeV

R=[2.7±0.7(stat) ±0.6(syst)]% at 630 GeV

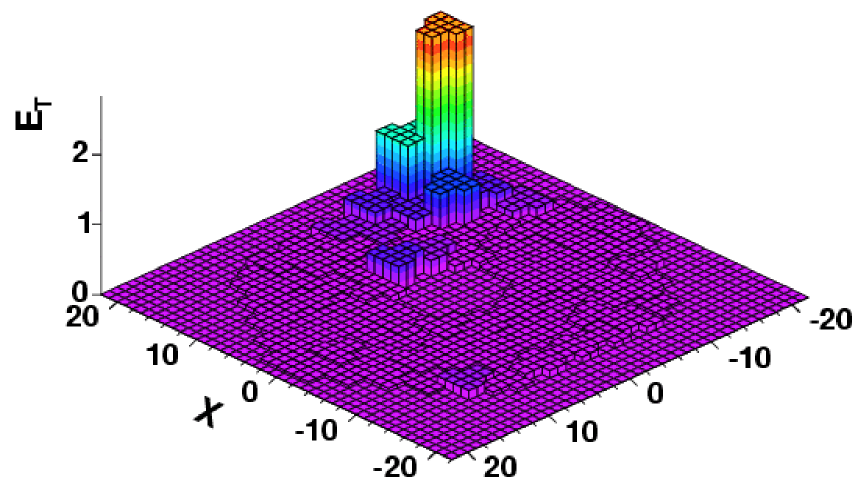
MiniPlug Jets



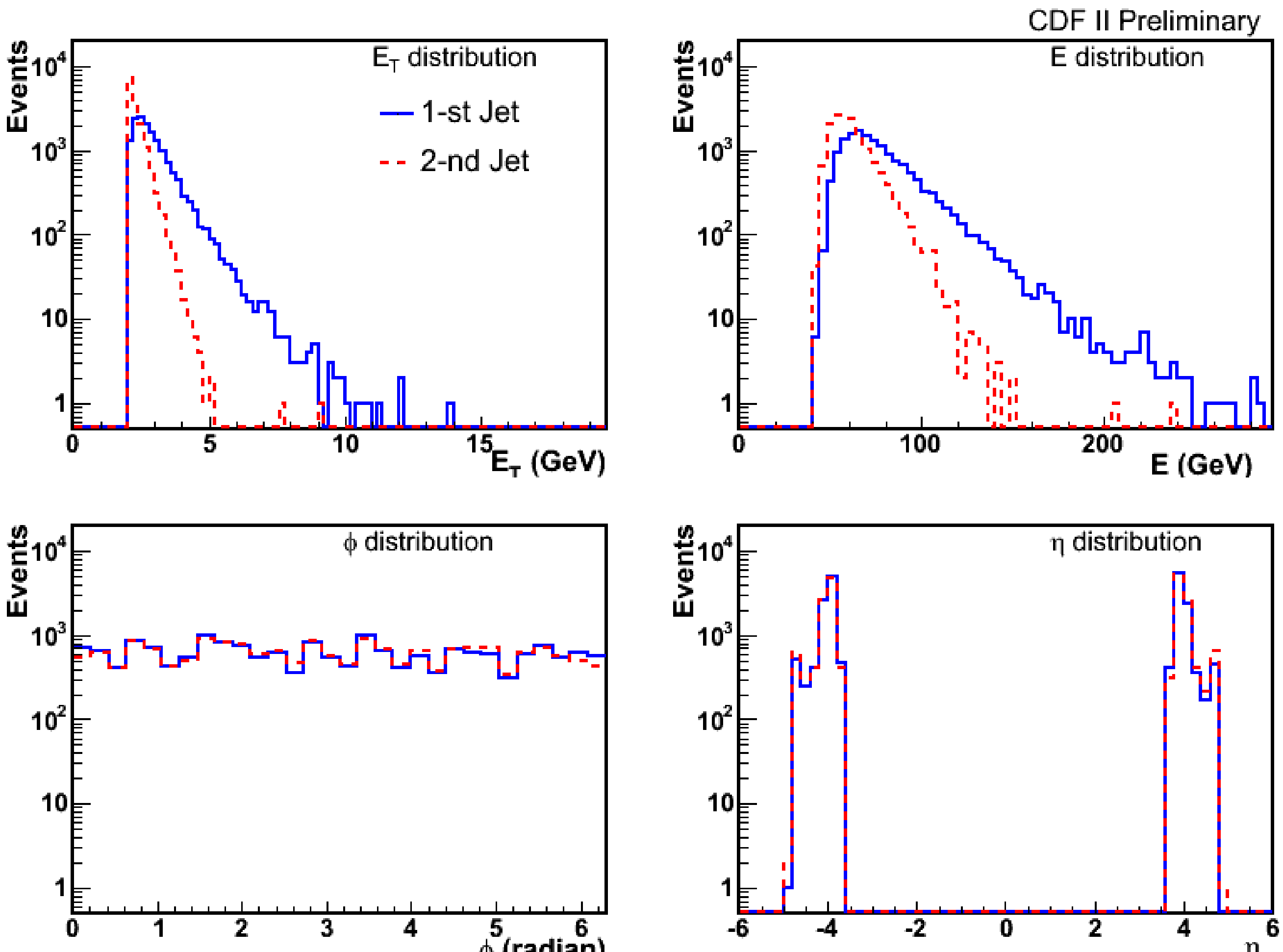
jet cone radius
R = 0.4 (0.7)

MP jet is defined as a vector pointing to a cluster with seed tower ($E_T > 400$ MeV) and 1 layer of surrounding towers

MP Jet energy = energy of the seed tower
+
energy of the towers in
the layer surrounding the seed



Kinematic Distributions for MP Jets



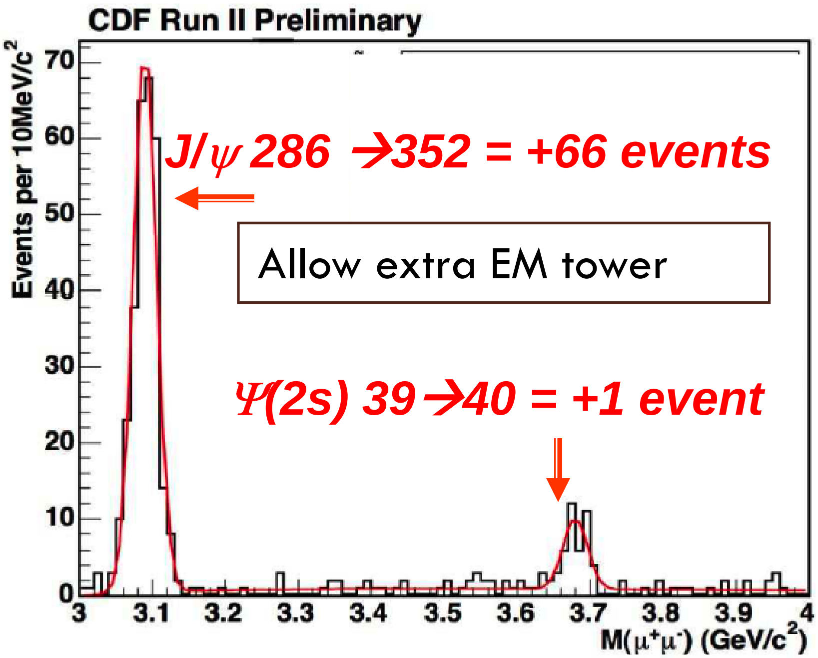
$E^{Jet1,2}_T > 2$ GeV

$3.5 < |\eta^{Jet1,2}| < 5.1$

$\eta^{Jet1} \cdot \eta^{Jet2} < 0$

Kinematic distributions for the two leading jets in the $MP_p \bullet MP_{pbar}$ sample

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



➔ Allowing EM towers (E_T >80MeV)

large increase in the J/ψ peak

minor change in the $\psi(2S)$ 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)