Diffraction at CDF

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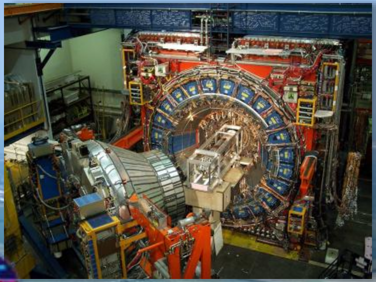
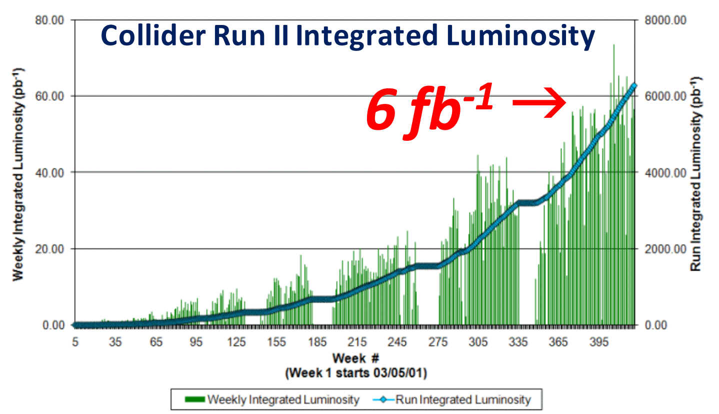
Fermilab Tevatron Collider

$p\bar{p}$ collider

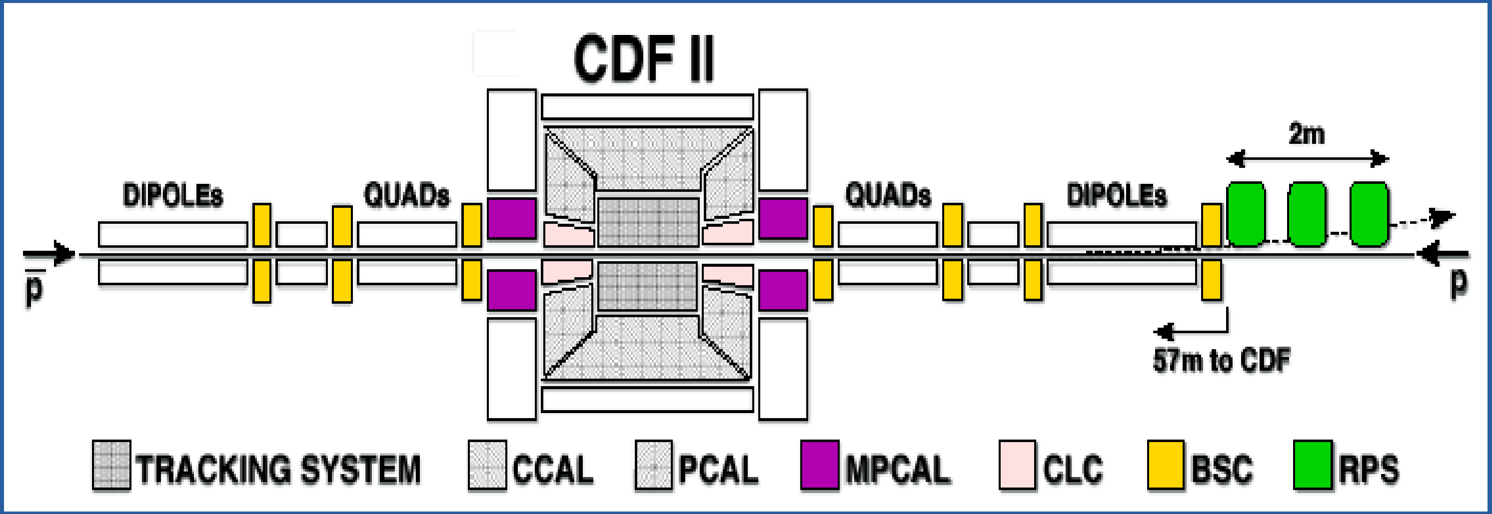


Run I (1992-1996)
√s=1.8 TeV (~120 pb^{-1})

Run II (2001-)
√ s= 1.96 TeV



CDF II Detectors

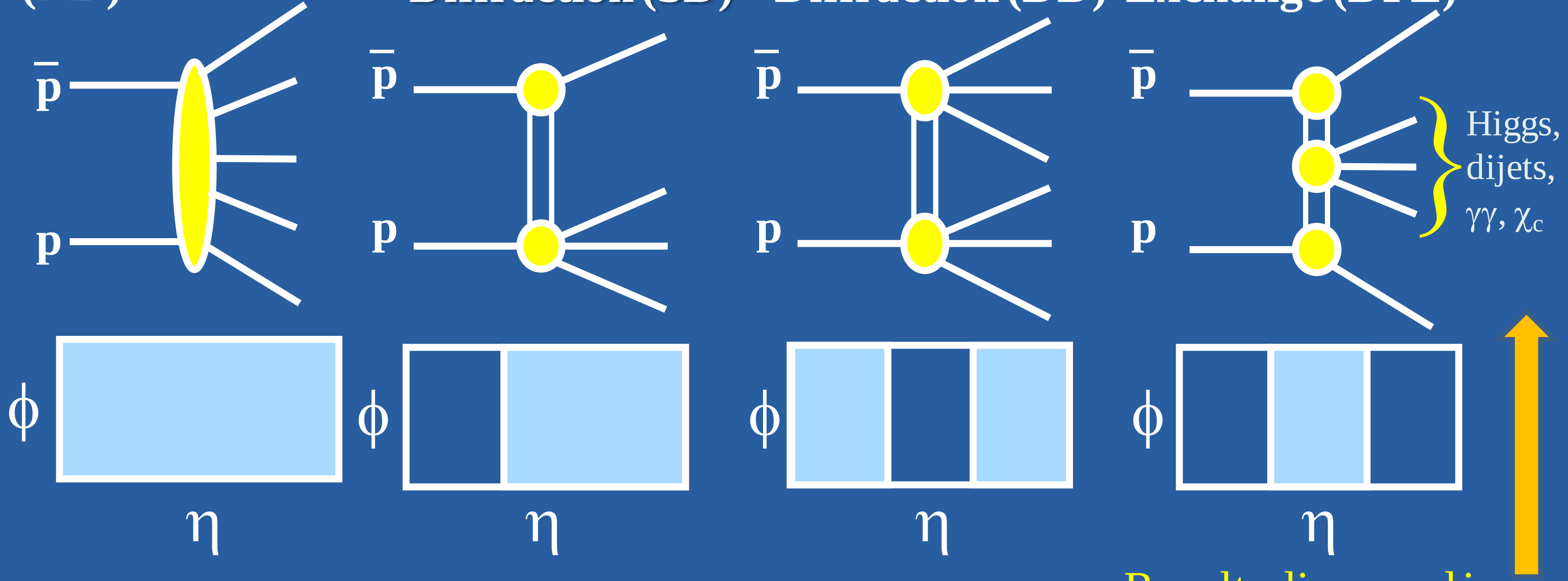


⬜	Tracking	– Tracking Detectors	$\lvert\eta\rvert < 2.0$
⬜	CCAL, PCAL	– Calorimeters	$\lvert\eta\rvert < 3.6$
🟩	RPS	– Roman Pot Spectrometers	$0.02 < \xi < 0.1$ $0 < \lvert t\rvert < 2$ GeV^2
🟨	BSC	– Beam Shower Counters	$5.4 < \lvert\eta\rvert < 7.4$
🟪	MPCAL	– MiniPlug Calorimeters	$3.5 < \lvert\eta\rvert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

Introduction

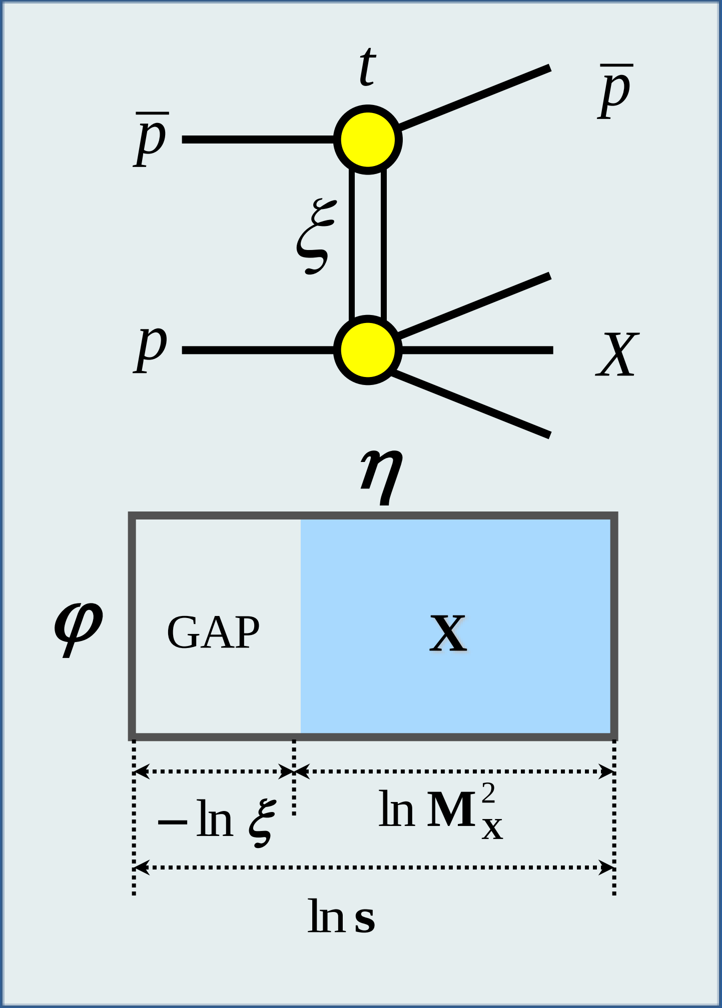
Diffractive reactions at hadron colliders are defined as reactions in *which* *no quantum numbers* are exchanged between colliding particles

Non-Diffractive (ND) **Single Diffraction (SD)** **Double Diffraction (DD)** **Double Pomeron Exchange (DPE)**



Results discussed in
"Exclusive Production with Rapidity Gaps at CDF"

Kinematics of Diffractive Events



t - four-momentum transfer squared

ξ - fractional momentum loss of antiproton

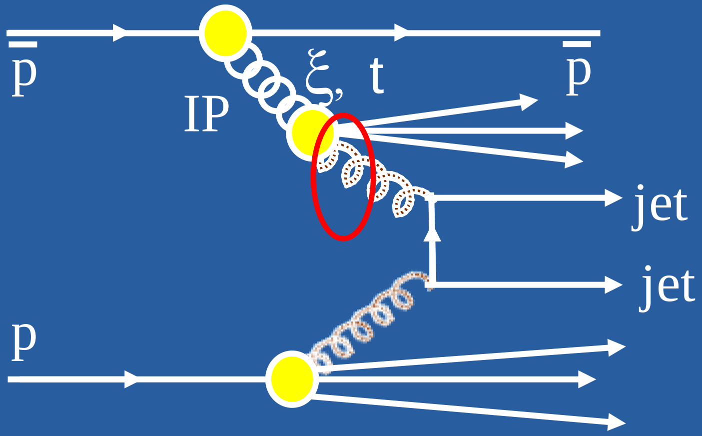
M_X - mass of system X

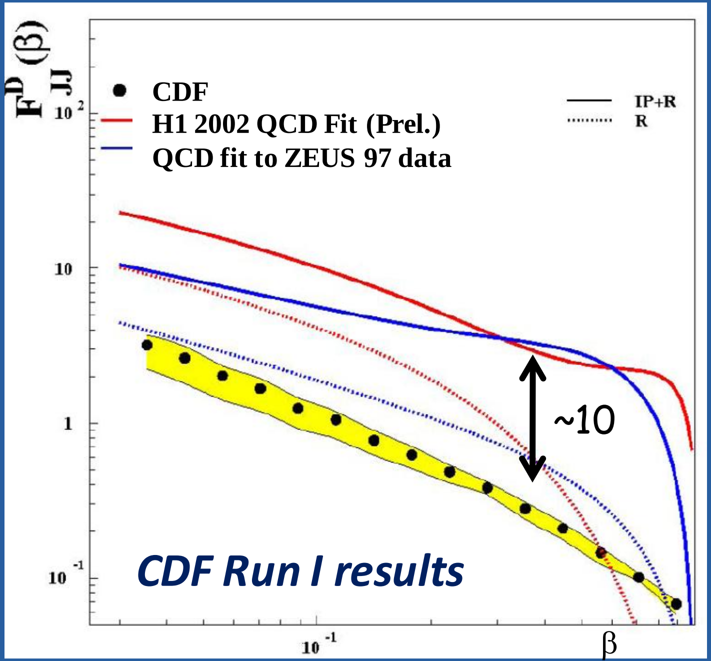
$$\xi = M_X^2/s$$

Selection of Diffractive Events

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

Diffractive Structure Function





Diffractive dijet cross section

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

Study the diffractive structure function

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

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

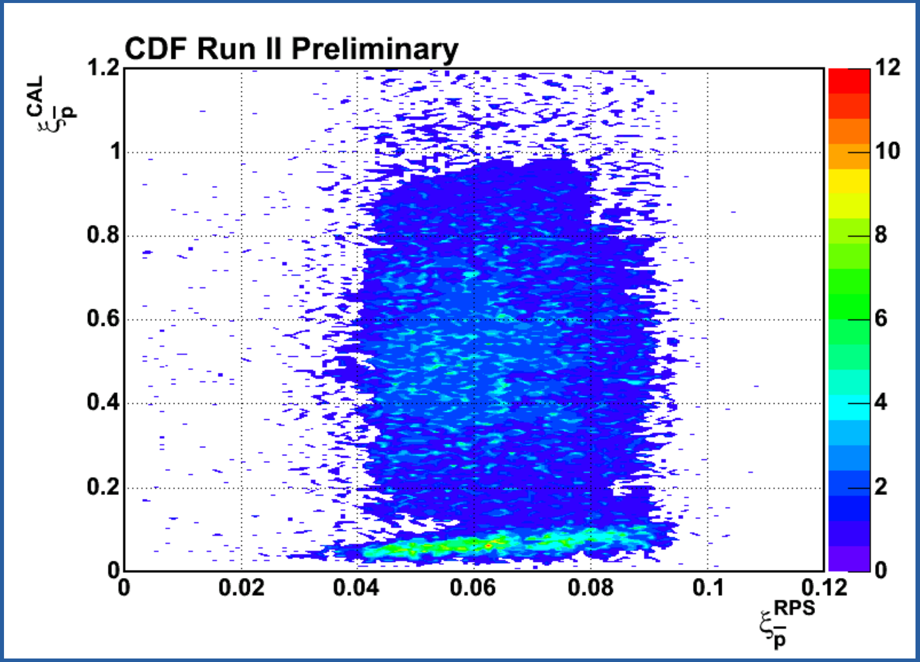
$$R_{\frac{SD}{ND}}(x,\xi) = \underset{\text{Data}}{\frac{\sigma(SD_{jj})}{\sigma(ND_{jj})}} = \frac{F_{jj}^{D}(x,Q^2,\xi)}{\underset{\text{known PDF}}{F_{jj}(x,Q^2)}}$$

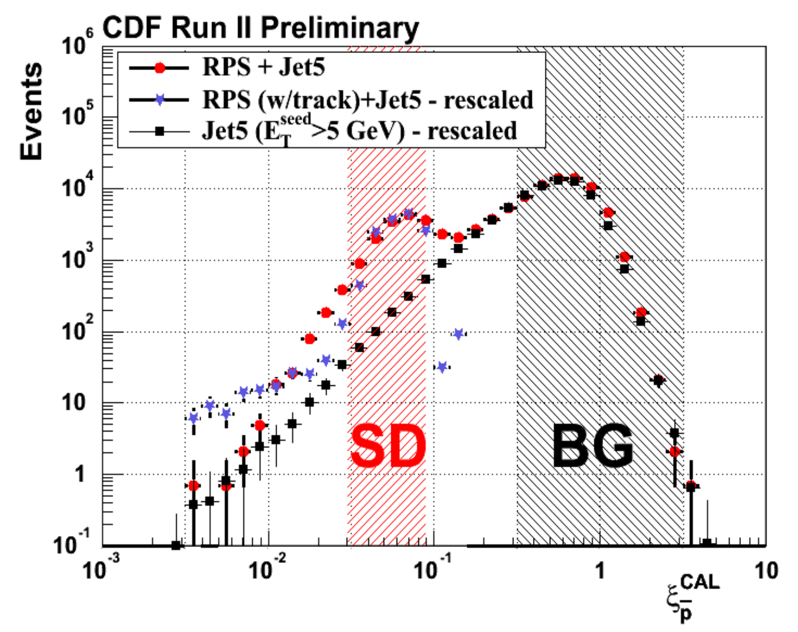
Methods and Challenges

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

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

important to have MiniPlugs →

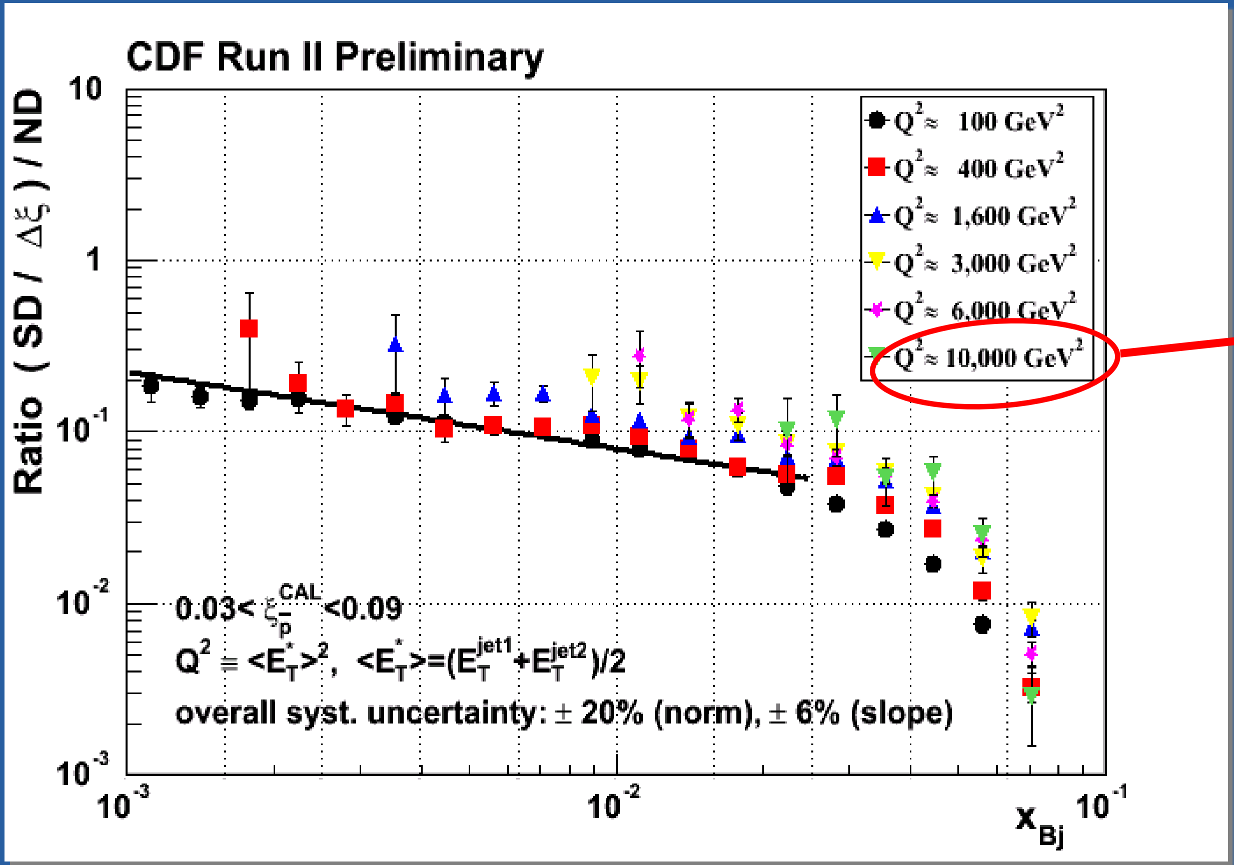




Main challenge: **multiple interactions spoiling diffractive signatures**

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

Diffractive Structure Function

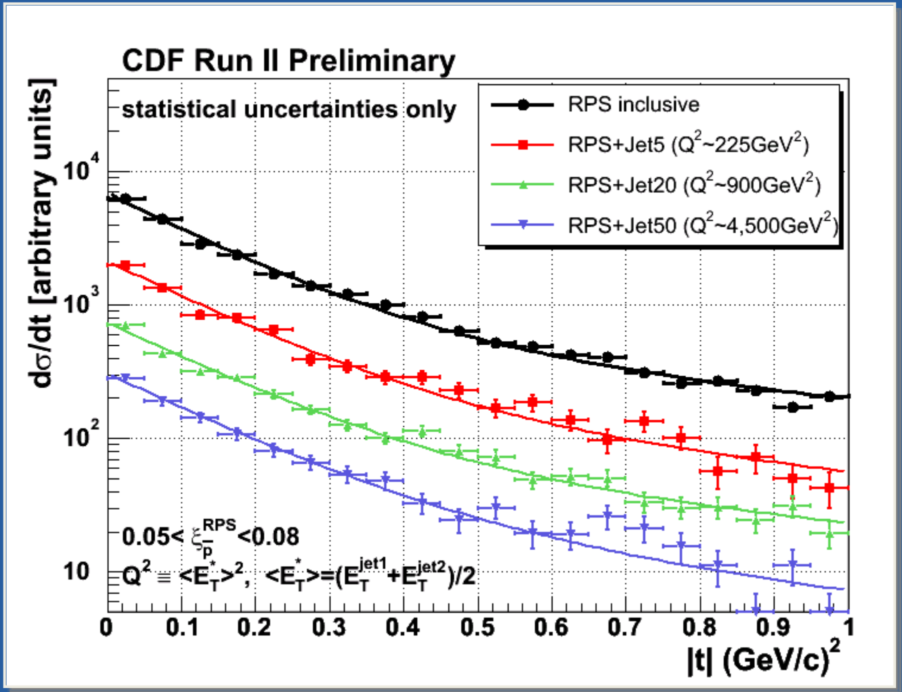


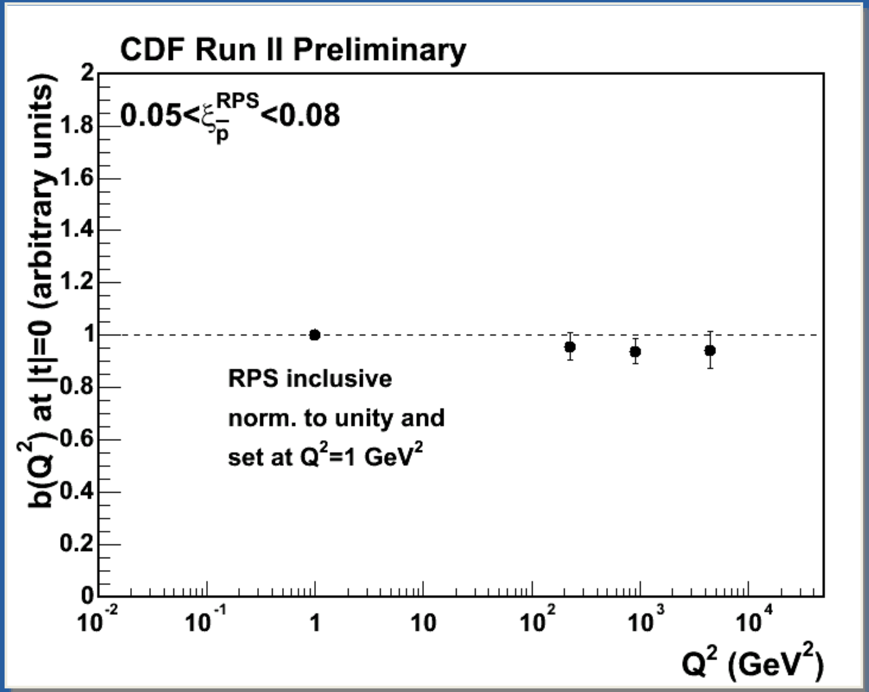
100 GeV jets

Confirms Run I results

No significant Q^2 dependence for $100 < Q^2 < 10000\ GeV^2$
→ 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:

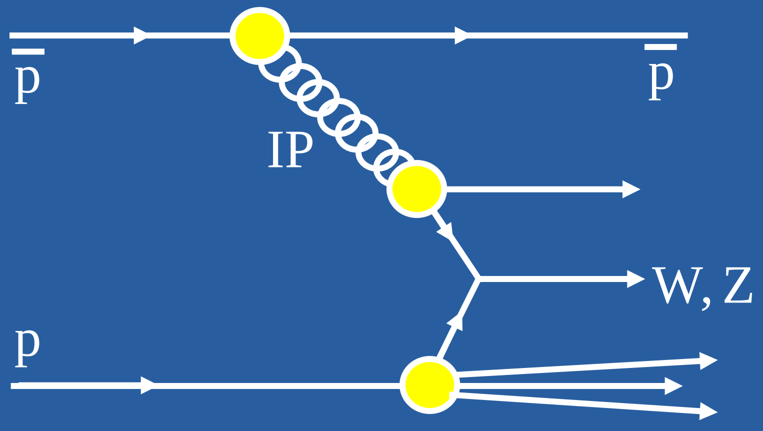
- high |t| range
- absolute |t|-slope values

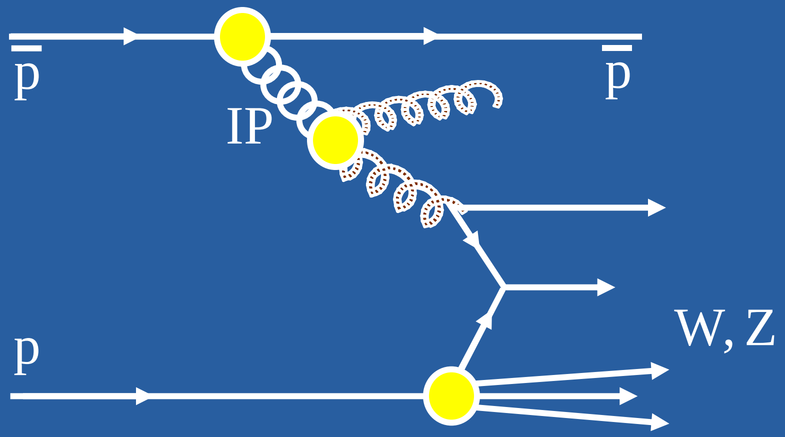
Diffractive W/Z Production

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}

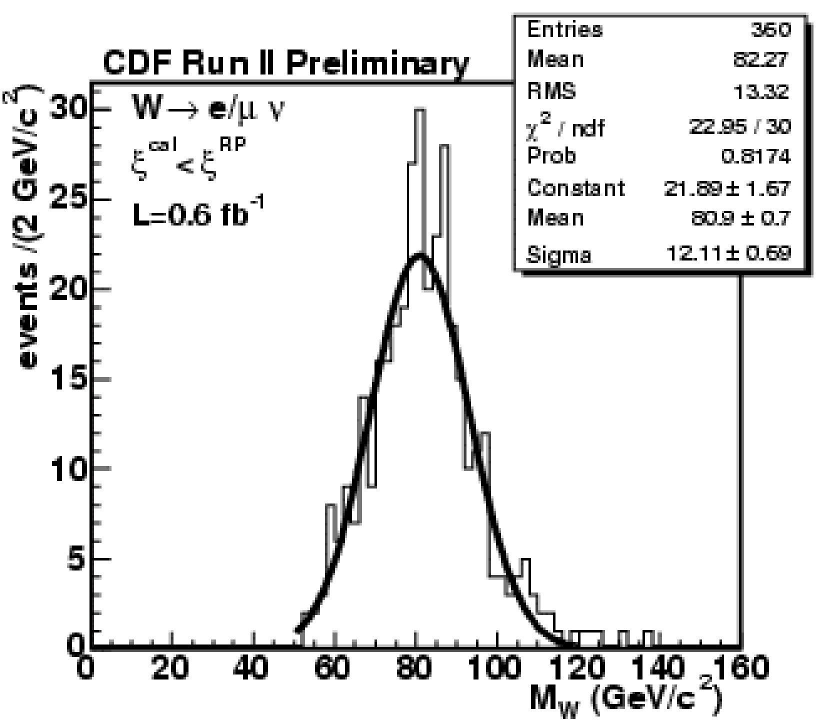
$$\xi^{cal} = \sum_{towers} \frac{E_T}{\sqrt{s}} e^{-\eta}$$

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

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

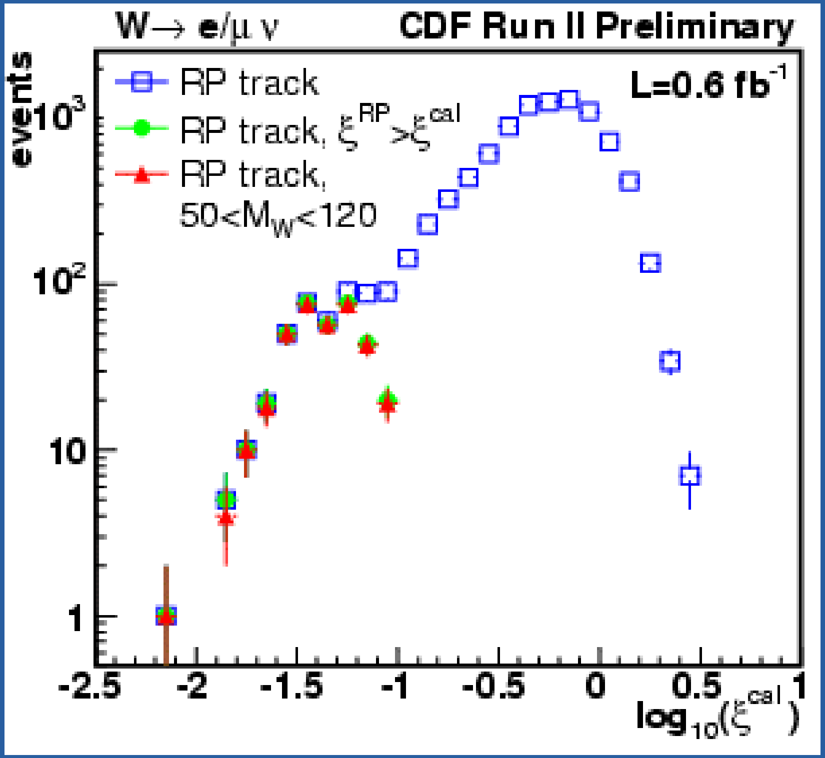
allows to determine:

neutrino and W kinematics
x_{bj}



reconstructed diffractive W mass

Diffractive W Production: measurement



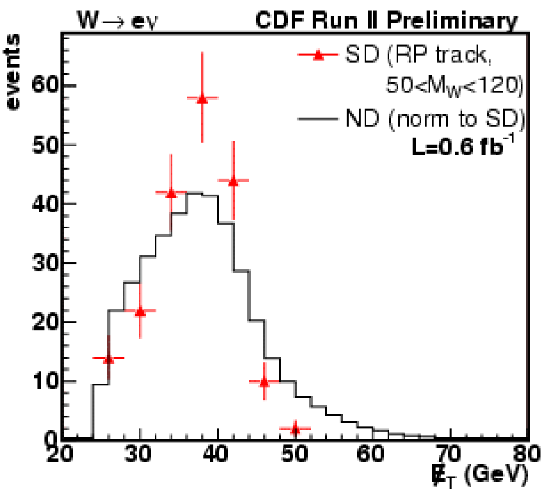
- $\xi^{cal} < \xi^{RP}$ requirement removes most events with multiple pbar-p interactions
- $50 < M_W < 120$ GeV/c^2 requirement on the reconstructed W mass cleans up possible mis-reconstructed events

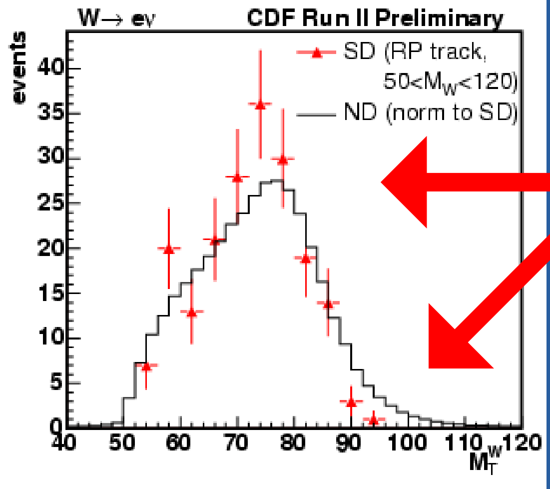
Fraction of diffractive W

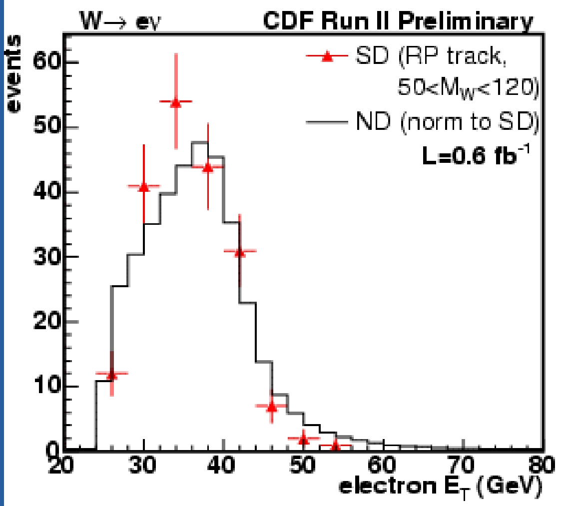
R_W (0.03<ξ<0.10, |t|<1)= [0.97 ±0.05(stat) ±0.11(syst)]%

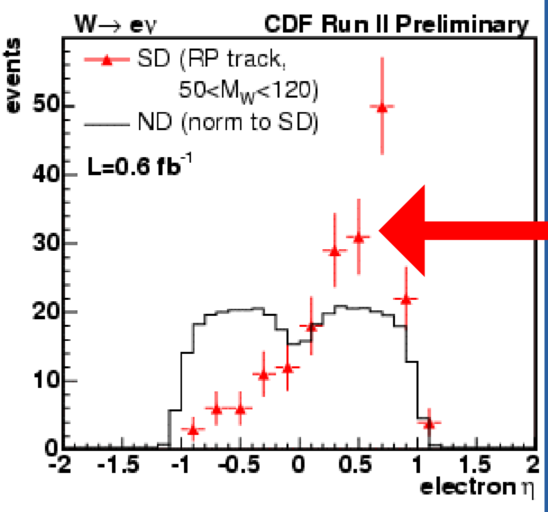
consistent with Run I result, extrapolated to all ξ

W→eν Kinematics







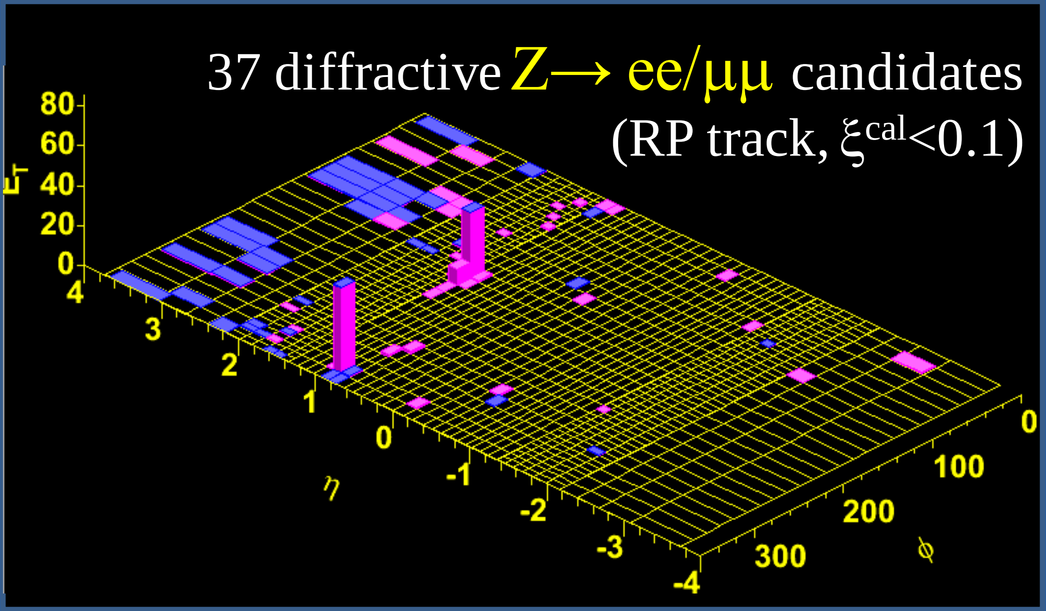


missing E_T,
M_T of W,
electron E_T

} similar for SD and ND

electrons are boosted away from anti-protons in diffractive sample

Diffractive Z Production



37 diffractive $Z \rightarrow ee/\mu\mu$ candidates

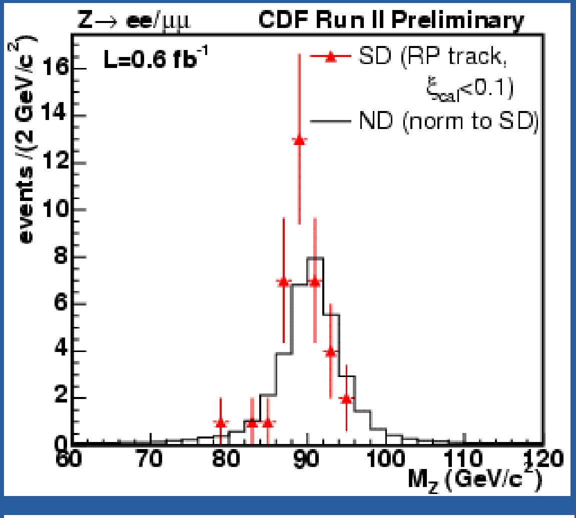
(RP track, $\xi^{cal}<0.1$)

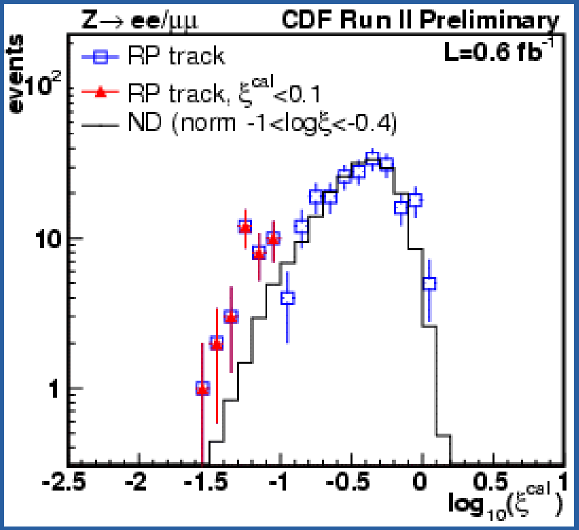
estimate 11 overlap ND+SD background events based on ND ξ^{cal} distribution

Fraction of diffractive Z

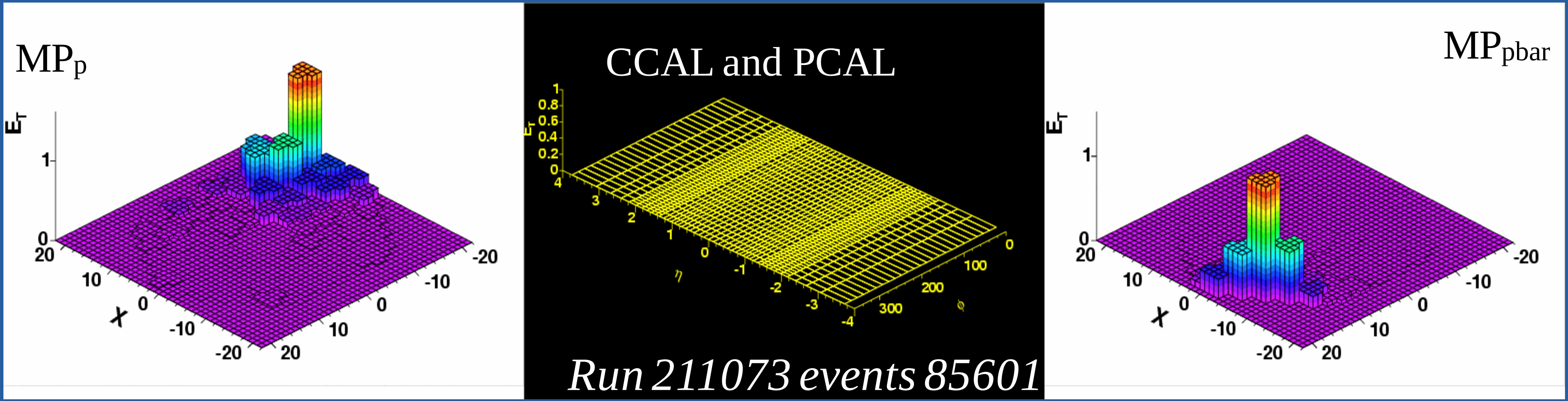
R_Z ($0.03< \xi <0.10$, $|t|<1$)=

[0.85±0.20(stat) ±0.11(syst)]%





Rapidity Gaps btwn Forward Jets



Run 211073 events 85601

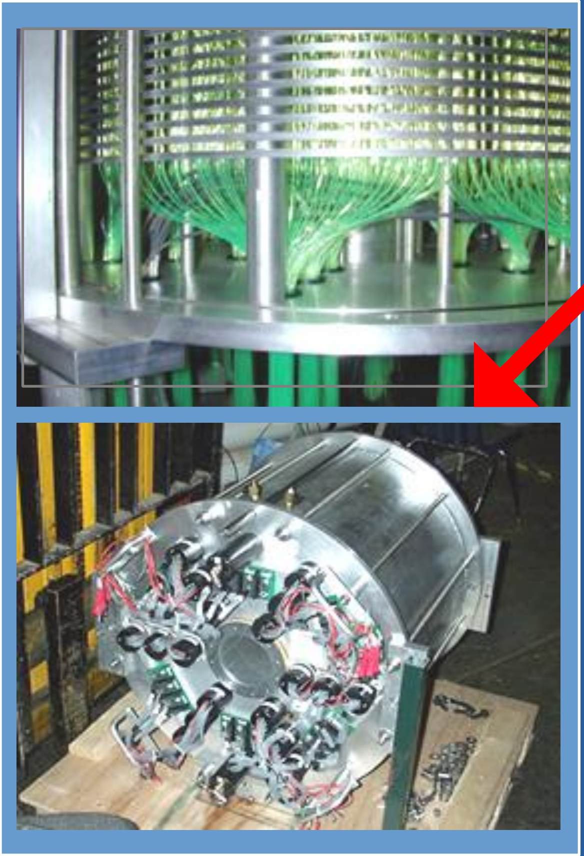
Goals:

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

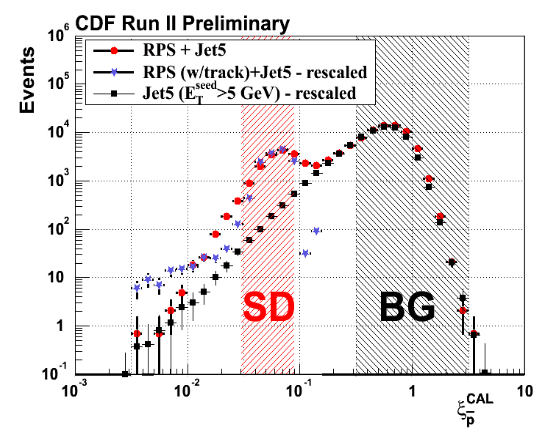
Forward Jets and Central Gaps

Nucl. Instrum. Meth. A518 (2004) 42.

Nucl. Instrum. Meth. A496 (2003) 333.

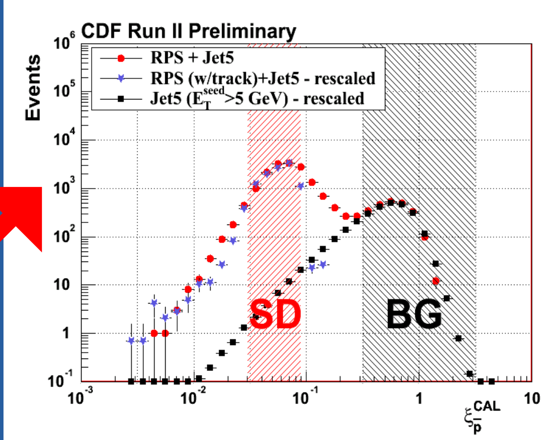


to detect forward jets $3.6<|\eta|<5.2$ we use **MiniPlug Calorimeters**

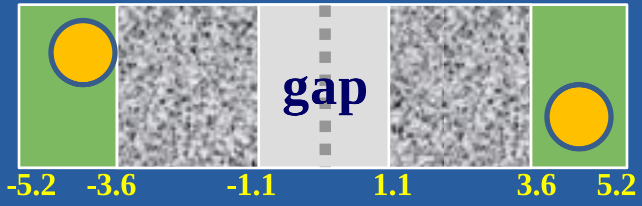


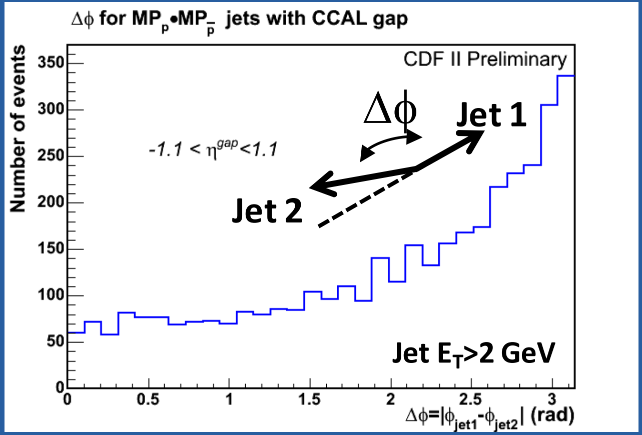
for gap studies
need **low luminosity** run

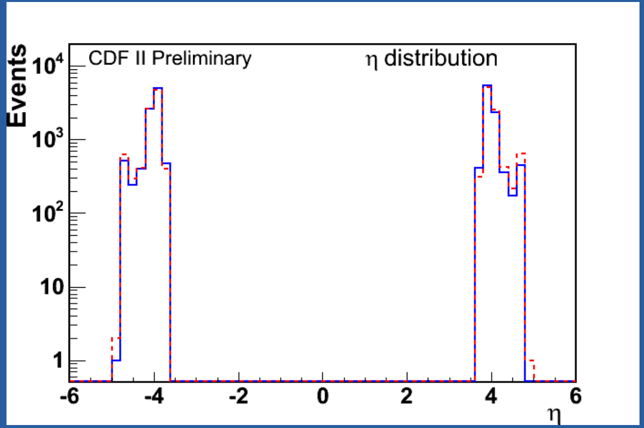
average luminosity
$\mathcal{L} \sim 1x10^{30}cm^{-2}s^{-1}$



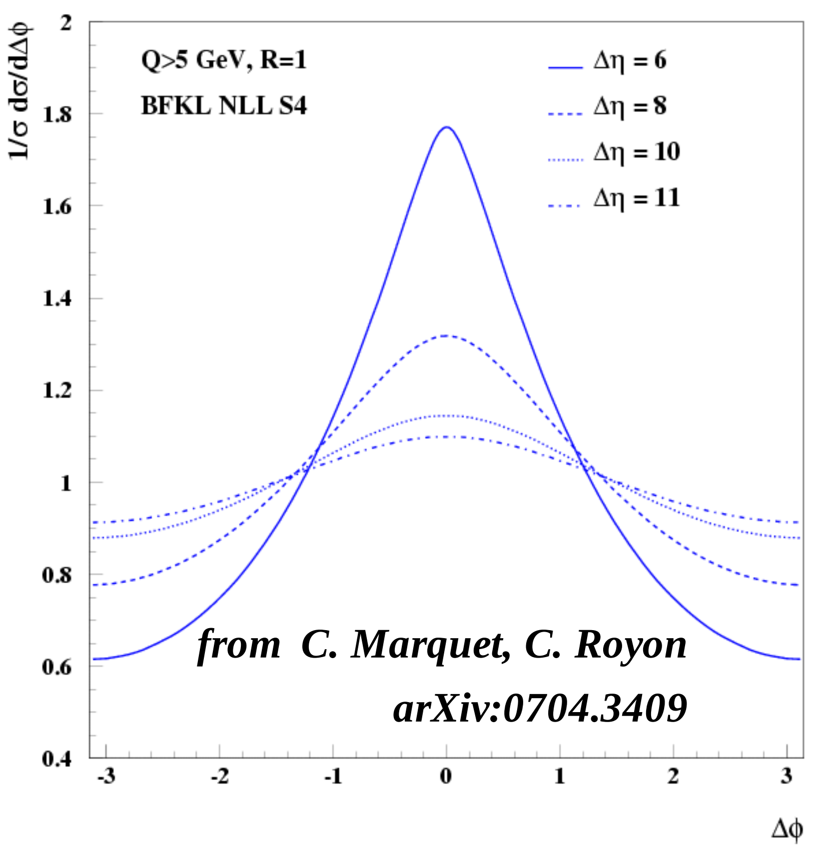
Jet Azimuthal Angle (De)correlation







azimuthal decorrelation for CDF kinematics



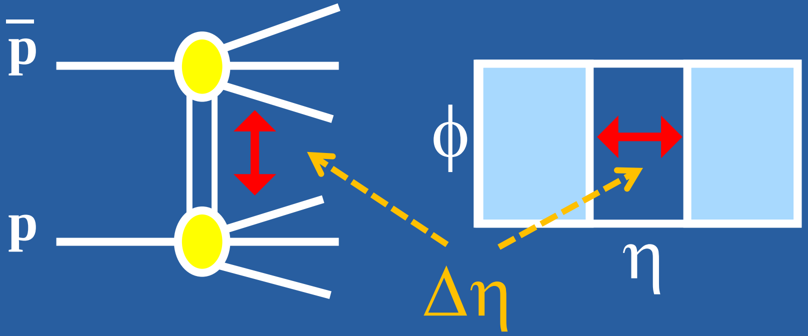
from C. Marquet, C. Royon

arXiv:0704.3409

work in progress...

Rapidity Gaps in Minbias Events

Soft Double-Diffraction (DD)



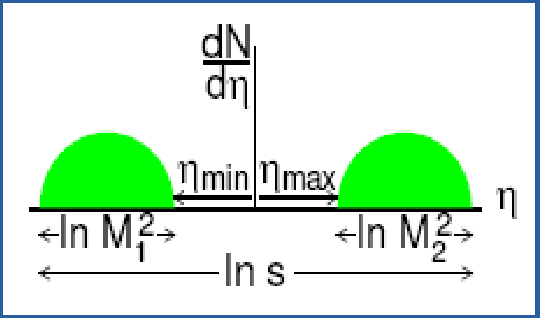
Strategy of analysis:

look for "experimental gaps" defined as

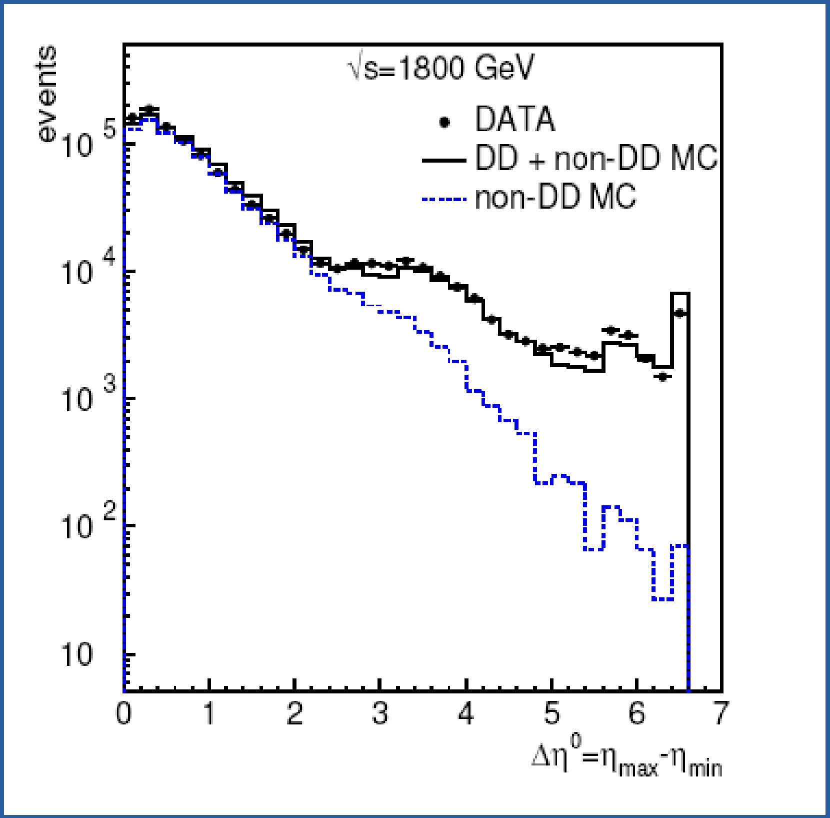
$\Delta\eta \equiv \eta_{max} - \eta_{min}$

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

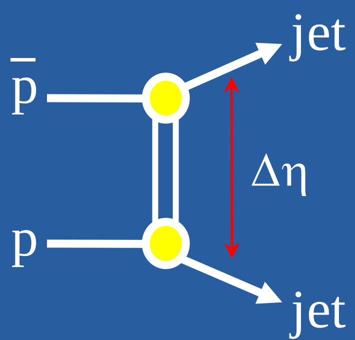
in the p(p) direction

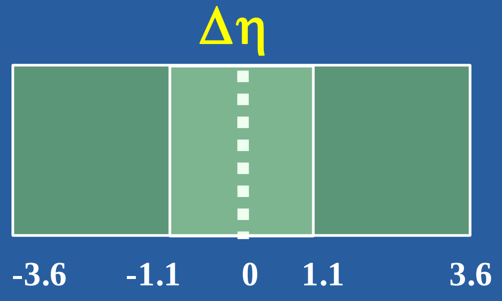


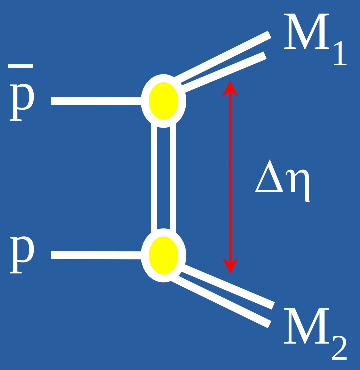
PRL ***87***, *(2001) 141803*



Central Gaps in Soft and Hard DD





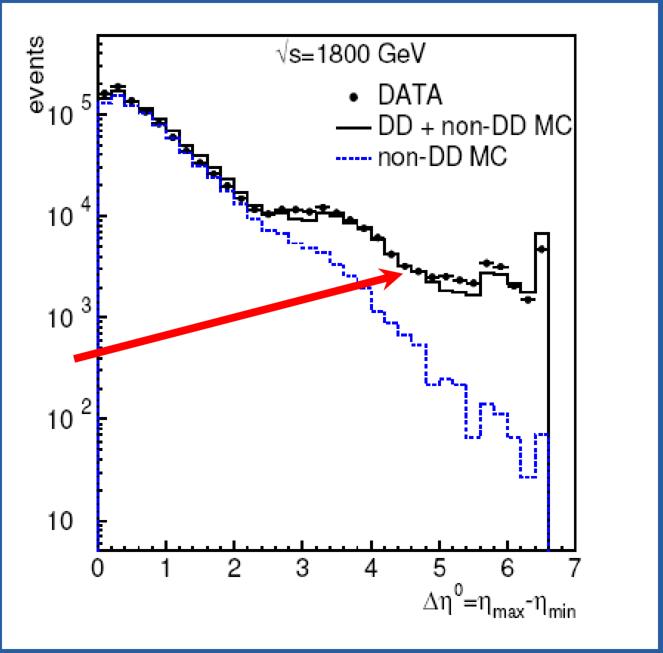


To **compare gap probability** in soft and hard DD dissociation:

reconstruct $\Delta\eta$ in both cases
require events to have gap in CCAL $|\eta|<1.1$
=> $\Delta\eta>2$ => significant DD contribution

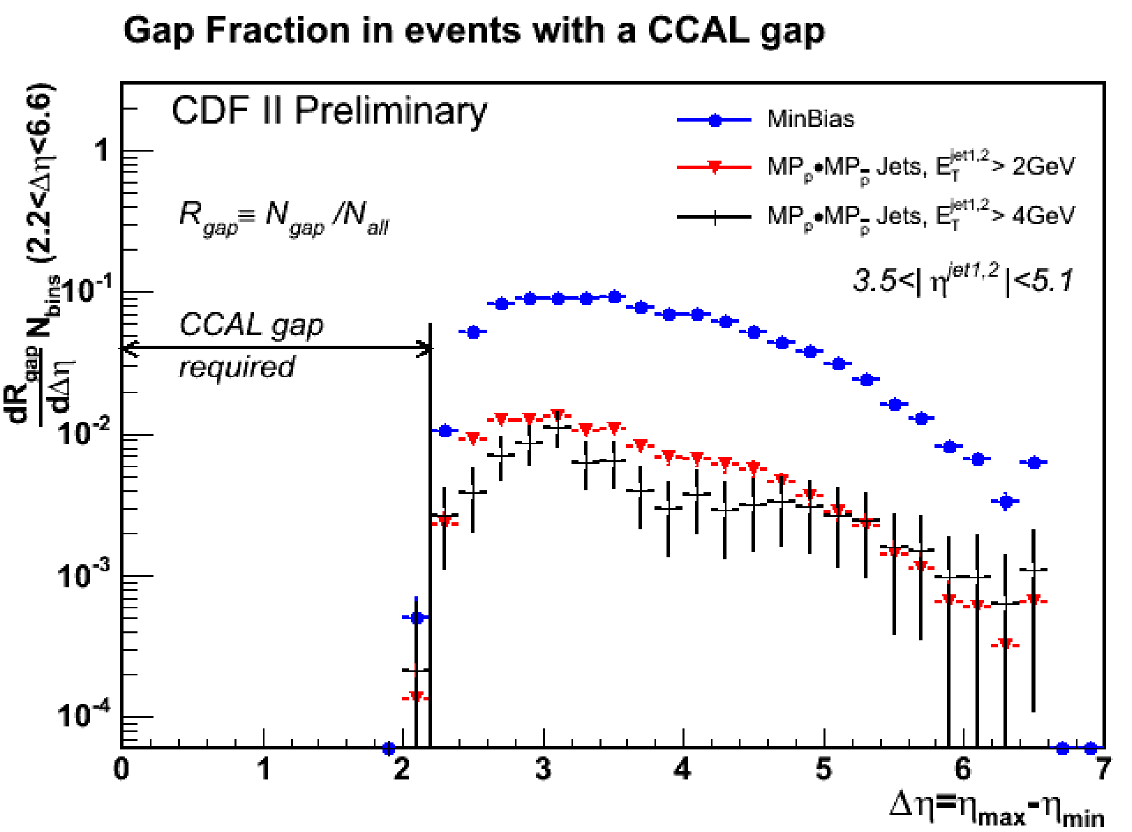
require opposite side MP jets for hard DD,
with $E_T>2$ GeV

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

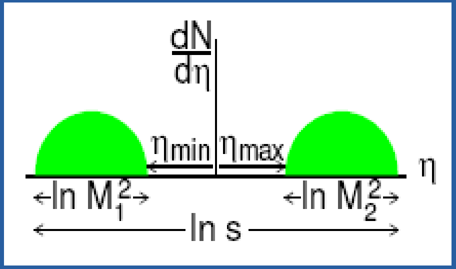


Central Gaps in Soft and Hard DD

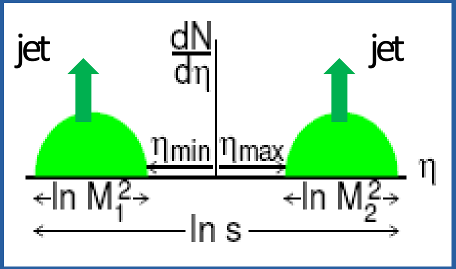
Gap Fraction in events with a CCAL gap



soft DD



compare with



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

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:

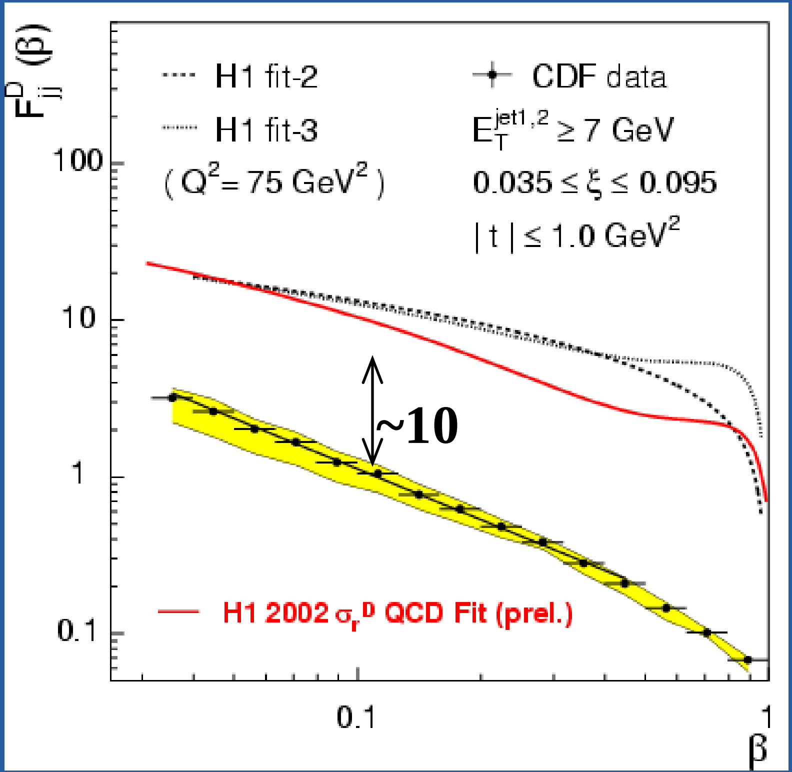
- W diffractive fraction confirms Run I rapidity gap result
- W and Z diffractive fractions are equal within error

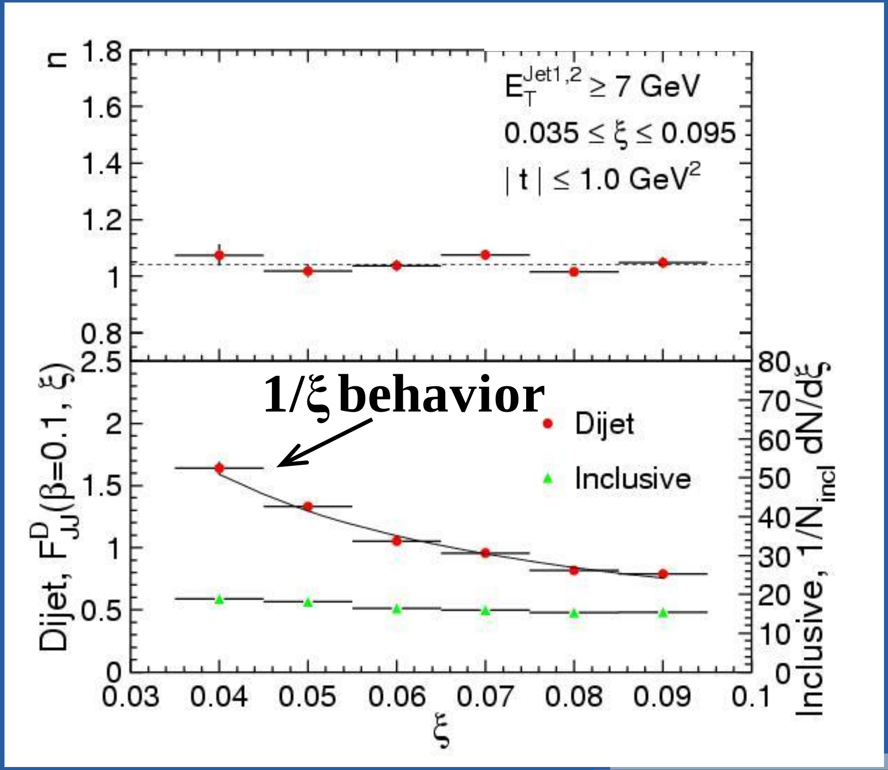
Central Rapidity Gaps:

- Gap fraction dependence on width and η-position of gap for hard / soft triggers at $|\eta|>4$
- distributions shapes similar for hard / soft triggers
- hard-scale fractions suppressed by factor of ~10

Extra Slides

The Diffractive Structure Function





discrepancy in normalization

⬇

QCD factorization breakdown

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

Regge factorization holds

$\boldsymbol{for\ \beta < 0.5}$
$\boldsymbol{n = 1.0 \pm 0.1}$
$\boldsymbol{m = 0.9 \pm 0.1}$

pomeron exchange

W/Z Selection

$$E_T^e(p_T^\mu) > 25\,\mathrm{GeV}$$

$$\not{E}_T > 25\,\mathrm{GeV}$$

$$40 < M_T^W < 120\,\mathrm{GeV}$$

$$|Z_{vtx}| < 60\,\mathrm{cm}$$

$$E_T^{e1}(p_T^{\mu 1}) > 25\,\mathrm{GeV}$$

$$E_T^{e2}(p_T^{\mu 2} > 25\,\mathrm{GeV}$$

$$66 < M^Z < 116\,\mathrm{GeV}$$

$$|Z_{vtx}| < 60\,\mathrm{cm}$$

Diffractive W/Z selection

- 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**

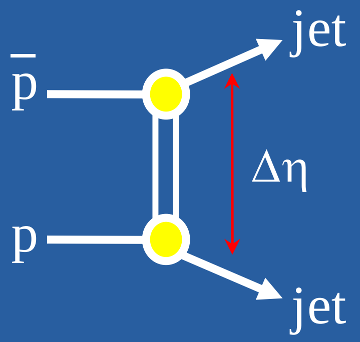
R^Z (0.03 < x < 0.10, |t|<1)= [0.85 ± 0.20(stat) ± 0.11(syst)]%

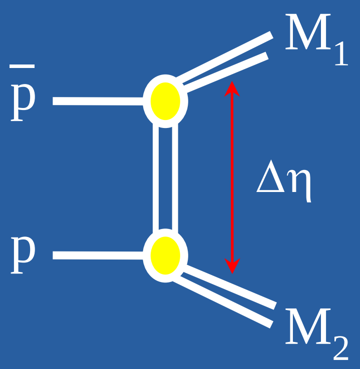
CDF/DØ Comparison – Run I (ξ < 0.1)

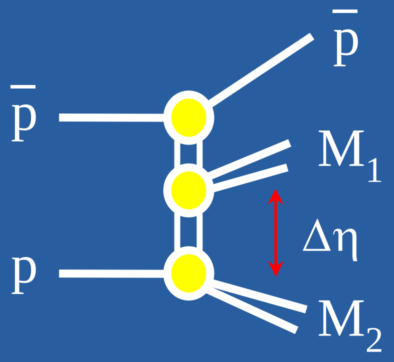
CDF PRL 78, 2698 (1997)
R^W=[1.15±0.51(stat)±0.20(syst)]%
gap acceptance A^{gap}=0.81
Uncorrected for A^{gap}
R^W=(0.93±0.44)%

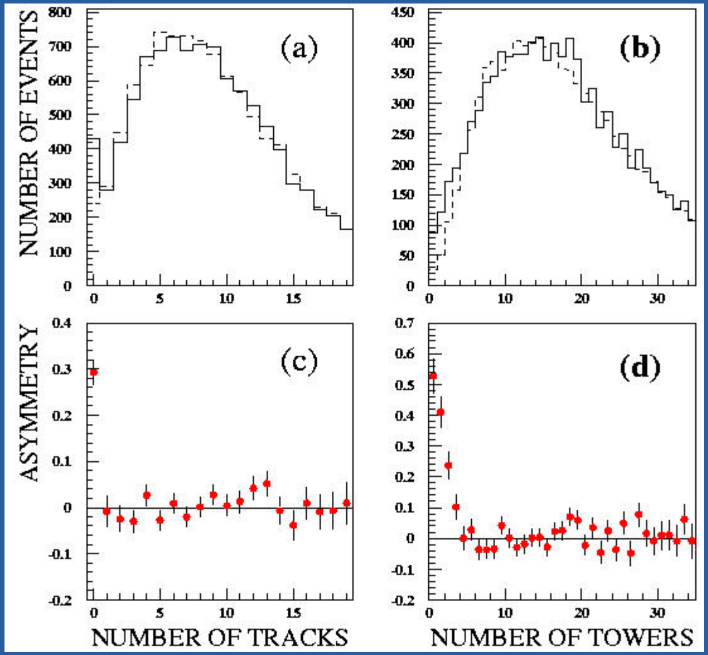
DØ Phys Lett B **574**, 169 (2003)
R^W=[5.1±0.51(stat)±0.20(syst)]%
gap acceptance A^{gap}=(0.21±4)%
Uncorrected for A^{gap}
R^W=[0.89+0.19-0.17]%
R^Z=[1.44+0.61-0.52]%

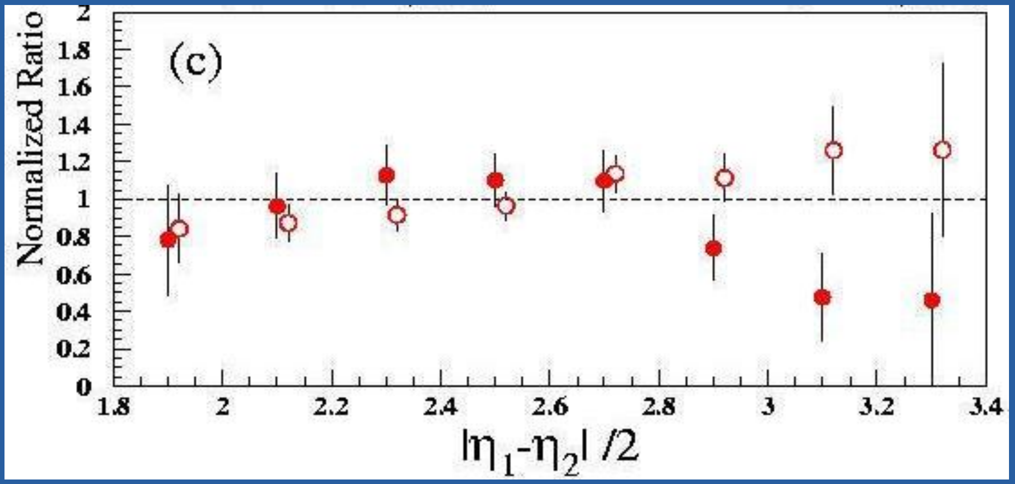
Central Gaps in Run I







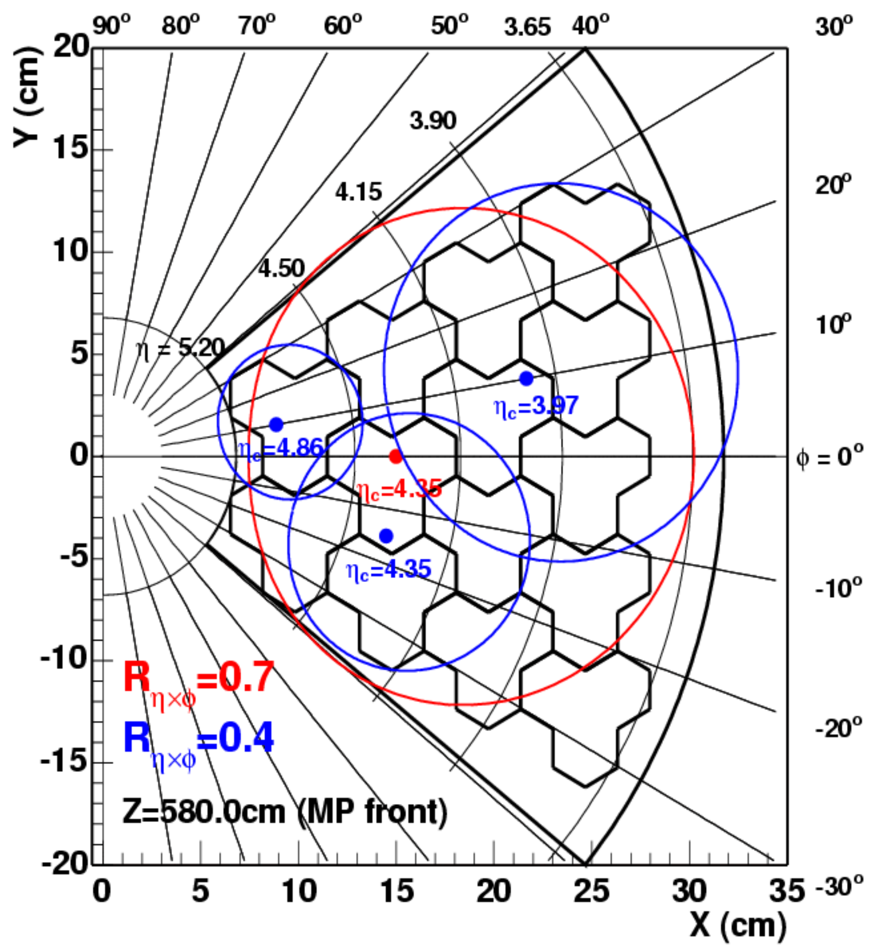




R=[1.13±0.12(stat) ±0.11(syst)]% at 1800 GeV

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

MiniPlug Jets

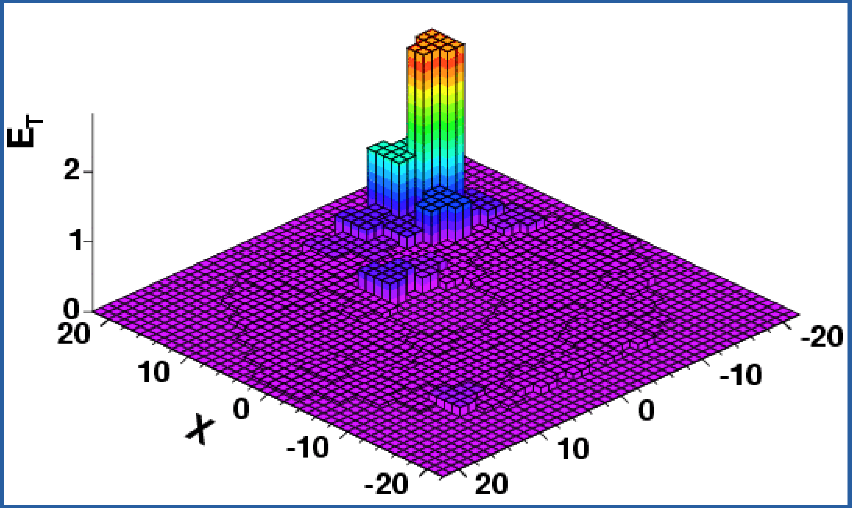


jet cone radius

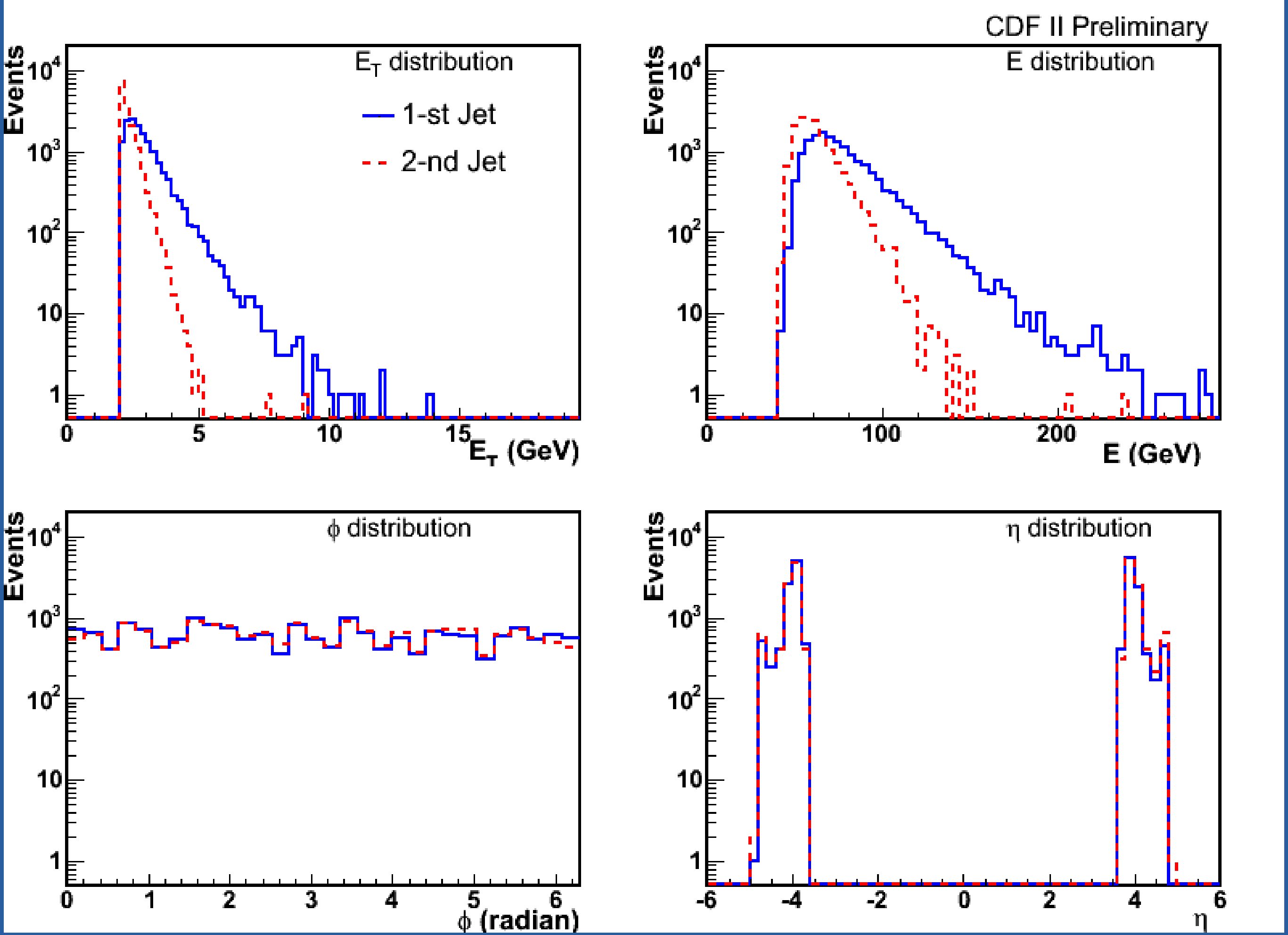
R = 0.4 (0.7)

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

Extra Slides