CDF II RESULTS ON DIFFRACTION

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Diffractive reactions at hadron colliders are defined as reactions in which no quantum numbers are exchanged between colliding particles.
Run I (1992-1996) $\sqrt{s} = 1.8$ TeV ($\sim 120$ pb$^{-1}$)

Run II (2001- ) $\sqrt{s} = 1.96$ TeV

Tevatron $pp$ Collider

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CDF II Detectors

- Tracking: Tracking Detectors $|\eta| < 2.0$
- CCAL, PCAL: Calorimeters $|\eta| < 3.6$
- RPS: Roman Pot Spectrometers $0.02 < \xi < 0.1$, $0 < |t| < 2 \text{ GeV}^2$
- BSC: Beam Shower Counters $5.4 < |\eta| < 7.4$
- MPCAL: MiniPlug Calorimeters $3.5 < |\eta| < 5.1$
Kinematics of Diffractive Events

\[ t \quad \text{four-momentum transfer squared} \]
\[ \xi \quad \text{fractional momentum loss of antiproton} \]
\[ M_X \quad \text{mass of system } X \]

\[ \xi = \frac{M_X^2}{s} \]

Selection of Diffractive Events

- CDF Roman Pots
  - acceptance \( \sim 80\% \) for
  \[ 0.03 < \xi_{\bar{p}p} < 0.10, \quad |t_{\bar{p}p}| < 1 \text{GeV}^2 \]
- by presence of rapidity gap

\[ \phi \quad \text{GAP} \]
\[ -\ln \xi \quad \ln M_X^2 \]
\[ \ln s \]
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 $$F_{jj}^D$$

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

Data

known PDF
Determine $\xi$ using Roman Pots tracking

Also can determine $\xi$ 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 $10^2 < Q^2 < 10^4 \text{ GeV}^2$

$\rightarrow$ Pomeron evolves like proton

CDF Run II Preliminary

$Q^2 = \langle E_T^{\text{jet1}} \rangle^2$, $\langle E_T \rangle = (E_T^{\text{jet1}} + E_T^{\text{jet2}})/2$

overall syst. uncertainty: $\pm 20\%$ (norm), $\pm 6\%$ (slope)
Fit to double exponential function:
\[ \frac{d\sigma}{dt} \propto 0.9 e^{b_1 t} + 0.1 e^{b_2 t} \]
- no diffractive dips
- no \( Q^2 \) dependence in slope from inclusive to \( Q^2 \sim 10^4 \text{ GeV}^2 \)

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 $\alpha_s$
  and can be distinguished by an associated jet
Run I studies used rapidity gaps instead of Roman-Pots

  - Fraction of W events due to SD
    \[ [1.15 \pm 0.51 \text{(stat)} \pm 0.20 \text{(syst)} ] \% \]

  - Fraction of events with rapidity gap
    (uncorrected for gap survival)
    - W: [0.89+0.19-0.17]%
    - Z: [1.44+0.61-0.52]%

07/01/2009
Identify diffractive events using Roman Pots:

- Accurate event-by-event $\xi$ measurement
- No gap acceptance correction needed
- Can still calculate $\xi^{\text{cal}}$

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

In $W$ production, the difference between $\xi^{\text{cal}}$ and $\xi^{\text{RP}}$ is related to missing $E_T$ and $\eta_{\nu}$

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

Allows to determine:
- Neutrino and $W$ kinematics
- $x_{bj}$
Diffractive W Production: measurement

\[ R_W (0.03 < \xi < 0.10, \ |t| < 1) = [0.97 \pm 0.05\text{(stat)} \pm 0.11\text{(syst)}] \% \]

Fraction of diffractive W consistent with Run I result, extrapolated to all \( \xi \)

\( \xi_{\text{cal}} < \xi_{RP} \) 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

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$W \rightarrow e \nu$ Kinematics

similar for SD and ND

electrons are boosted away from anti-protons in diffractive sample
Diffractive Z Production

37 diffractive \( Z \rightarrow e\bar{e}/\mu\bar{\mu} \) candidates
(RP track, \( \xi_{\text{cal}} < 0.1 \))

estimate 11 overlap ND+SD background events based on ND \( \xi_{\text{cal}} \) distribution

Fraction of diffractive Z
\[
R_Z (0.03 < \xi < 0.10, |t| < 1) = [0.85 \pm 0.20(\text{stat}) \pm 0.11(\text{syst})] \%
\]
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


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

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for gap studies need low luminosity run

average luminosity \( \mathcal{L} \sim 1 \times 10^{30} \text{cm}^{-2}\text{s}^{-1} \)
Jet Azimuthal Angle (De)correlation

azimuthal decorrelation for CDF kinematics

Q>5 GeV, R=1
BFKL NLL S4

from C. Marquet, C. Royon
arXiv:0704.3409

work in progress...

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Rapidity Gaps in Minbias Events

Strategy of analysis:
look for “experimental gaps” defined as
\( \Delta \eta \equiv \eta_{\text{max}} - \eta_{\text{min}} \)
\( \eta_{\text{max}}(\eta_{\text{min}}) \)- “particle” closest to \( \eta=0 \)
in the \( p(p) \) direction

Soft Double-Diffraction (DD)
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:

\[ \sim 10\% \text{ in soft DD events and } \sim 1\% \text{ in jet events} \]

The distributions are similar in shape within the uncertainties.
At the Tevatron we use similar processes with larger cross sections to test and calibrate theoretical predictions.
Exclusive Dijet Production

Run I

![Diagram](image1)

CDF limit of

\[ \sigma_{\text{excl}} < 3.7 \text{ nb}(95\% \text{ CL}) \]

Run II

**Method:**

Select inclusive diffractive dijet events produced by DPE

\[ p + \bar{p} \rightarrow IP + IP \rightarrow \bar{p} + X(\geq 2 \text{ jets}) + \text{gap} \]

**Reconstruct**

\[ R_{jj} = \frac{M_{jj}}{M_X} \]

where

- \( M_{jj} \) - dijet mass,
- \( M_X \) - mass of system X
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 $gg \rightarrow ggg, qqg$ contributions.
Shape of excess described by exclusive dijet MC based on two models (ExHuME, DPEMC), shows good agreement
Exclusive dijet cross section compared with MC based on two models: ExHuME, and excl. DPE DPEMC.

Cross section disfavors exclusive DPE model.

Heavy Flavor Suppression

- LO exclusive $gg \rightarrow qq$ suppressed ($J_Z = 0$ rule)
- Look for heavy flavor jet suppression relative to inclusive dijets at high $R_{jj}$

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.
Stat. and syst. errors are propagated from measured cross section uncertainties using $M_{jj}$ distribution shapes of ExHuME generated data.
3 candidates observed:
2 events are good $\gamma\gamma$ candidates
1 event is good $\pi^0\pi^0$ candidate

Theoretical Prediction:


$\sigma$ (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.
Observation of exclusive $\chi_c$ PRL 242001 (2009)

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

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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 $\eta$-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.$\chi_{c0}$, excl. photoproduction of $J/\psi$, $\psi(2s)$
Back up
discrepancy in normalization
QCD factorization breakdown

\[ F_{jj}^D = C \beta^{-n} \xi^{-m} \]
for \( \beta < 0.5 \)

\( n = 1.0 \pm 0.1 \)
\( m = 0.9 \pm 0.1 \)
W/Z Selection

\[ E_T^e(p_T^\mu) > 25 \text{ GeV} \]
\[ \not{p}_T > 25 \text{ GeV} \]
\[ 40 < M_T^W < 120 \text{ GeV} \]
\[ |Z_{vtx}| < 60 \text{ cm} \]

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

\[ E_T^{e1}(p_T^{\mu1}) > 25 \text{ GeV} \]
\[ E_T^{e2}(p_T^{\mu2}) > 25 \text{ GeV} \]
\[ 66 < M^Z < 116 \text{ GeV} \]
\[ |Z_{vtx}| < 60 \text{ cm} \]
W/Z Results

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

Run I: $R^W (\xi<0.1 )=[1.15\pm0.55] \% \Rightarrow 0.97\pm0.47 \%$ in $0.03 < \xi < 0.10 \& |t|<1$

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

CDF/DØ Comparison – Run I ($\xi < 0.1$)

CDF PRL 78, 2698 (1997)
$R^w=[1.15\pm0.51\text{(stat)}\pm0.20\text{(syst)}]\%$

gap acceptance $A^{gap}=0.81$

Uncorrected for $A^{gap}$
$R^w=(0.93\pm0.44)\%$

$R^w=[5.1\pm0.51\text{(stat)}\pm0.20\text{(syst)}]\%$

gap acceptance $A^{gap}=(0.21\pm4)\%$

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

\[ R = [1.13 \pm 0.12 \text{(stat)} \pm 0.11 \text{(syst)}] \% \text{ at } 1800 \text{ GeV} \]

\[ R = [2.7 \pm 0.7 \text{(stat)} \pm 0.6 \text{(syst)}] \% \text{ at } 630 \text{ GeV} \]
MiniPlug Jets

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.

jet cone radius $R = 0.4 (0.7)$
Kinematic distributions for the two leading jets in the $\text{MP}_p \cdot \text{MP}_\text{pbar}$ sample

\begin{align*}
E_{\text{Jet}1,2} & > 2 \text{ GeV} \\
3.5 & < |\eta_{\text{Jet}1,2}| < 5.1 \\
\eta_{\text{Jet}1} \cdot \eta_{\text{Jet}2} & < 0
\end{align*}
Exclusive $\chi_c \rightarrow J/\psi + \mu^+ \mu^- + \gamma$

Allowing EM towers ($E_T > 80$ MeV)

large increase in the $J/\psi$ peak

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

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

$d\sigma/dy \mid_{y=0} = 75 \pm 14$ nb,
compatible with theoretical predictions

160 nb (Yuan 01)

90 nb (KMR01)