Update on CDF Results on Diffraction

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The Rockefeller University
(Representing the CDF Collaboration)

DIS 2005
27 April - 1 May
Madison, Wisconsin
**p-p Interactions**

**Diffractive:**
- Vacuum exchange
- Protons retain their quantum numbers

**Non-diffractive:**
- Color exchange
- Protons acquire color and break apart

**Goal:** understand the nature of the colorless exchange
CDF Run 1-0 (1988-89)
Elastic, single diffractive, and total cross sections
@ 546 and 1800 GeV

Roman Pot Spectrometers
- Scintillation trigger counters
- Wire chamber
- Double-sided silicon strip detector

Results
- Total cross section \( \sigma^{tot} \sim S^E \)
- Elastic cross section \( d\sigma/dt \sim \exp[2\alpha' \ln s] \rightarrow \) shrinking forward peak
- Single diffraction Breakdown of Regge factorization
Run 1-0 results in perspective

Total and Elastic Cross Sections

\[ \sigma_{el} = 1 + \varepsilon (0.10) + 0.25 \] 

\[ \sigma_{el} = 0.03 + 0.02 \] 

\[ \sigma_{el} = 0.46 + 0.20 \] 

KG, PLB 358 (1995) 379

\( \gamma < 0.05 \)
- Albrow et al.
- Armitage et al.
- UA4
- CDF
- E710
- Cool et al.

Standard flux
Renormalized flux

Total Single Diffraction Cross Section (mb)

\( \sqrt{s} \) (GeV)

Run-IC

Run-IA, B

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New CDF Results on Diffraction

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Acceptance: 0 < |t| < 1, 0.03 < ξ < 0.1
Diffraction @ CDF in Run I

16 papers

- Elastic scattering  PRD 50 (1994) 5518
- Total cross section  PRD 50 (1994) 5550
- Diffraction

SOFT diffraction

Non-Diffractive (ND)

Single-Diffractive (SD)

Double Diffractive (DD)

Double Pomeron Exchange (DPE)

Single + Double Diffractive (SDD)

PRL 50 (1994) 5535
PRL 87 (2001) 141802
PRL 93 (2004) 141601
PRL 91 (2003) 011802

HARD diffraction

PRL references

with roman pots

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<tr>
<td>JJ</td>
<td>88 (2002) 151802</td>
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<tr>
<td>J/ψ</td>
<td>87 (2001) 241802</td>
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Diffractive Fractions @ CDF

\[ \bar{p}p \rightarrow (Hd + X) + \text{gap} \]

Fraction:
SD/ND ratio at 1800 GeV

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Value</th>
<th>Error</th>
</tr>
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<tbody>
<tr>
<td>Hd</td>
<td>1.15</td>
<td>0.55</td>
</tr>
<tr>
<td>W</td>
<td>1.15</td>
<td>0.55</td>
</tr>
<tr>
<td>JJ</td>
<td>0.75</td>
<td>0.10</td>
</tr>
<tr>
<td>b</td>
<td>0.62</td>
<td>0.25</td>
</tr>
<tr>
<td>J/ψ</td>
<td>1.45</td>
<td>0.25</td>
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All ratios ~ 1%

⇒ uniform suppression
⇒ FACTORIZATION
\[ R(x) = \frac{F_{jj}^{SD}(x)}{F_{jj}^{ND}(x)} \]

\[ R(x) \propto x^{-0.45} \]

0.035 < \xi < 0.095

Flat \( \xi \) dependence
Tevatron vs HERA: Breakdown of QCD Factorization

\[ F_{jj}^D (\beta) \]

- H1 fit-2
- H1 fit-3
- CDF data

\( Q^2 = 75 \text{ GeV}^2 \)
\( E_T^{jet 1,2} \geq 7 \text{ GeV} \)
\( 0.035 \leq \xi \leq 0.095 \)
\( |t| \leq 1.0 \text{ GeV}^2 \)

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New CDF Results on Diffraction
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Restoring Factorization

The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS.
Run 2 Diffractive Program

- **Single Diffraction**
  - $\xi$ and $Q^2$ dependence of $F_{jj}^D$
  - Process dependence of $F^D(W, J/\psi)$

- **Double Diffraction**
  - Jet-Gap-Jet: $\Delta \eta^{\text{gap}}$ for fixed large $\Delta \eta^{\text{jet}}$

- **Double Pomeron Exchange**
  - $F_{jj}^D$ on p-side vs $\xi$-pbar

**Also:**

**Exclusive central production**
  - Dijets, $\chi_c$

**Other**
  - Tev4LHC issues
**SD and ND collisions**

SD: $\bar{p}p \rightarrow \bar{p} + \text{gap} + X$

ND: $\bar{p}p \rightarrow X$

Particle density  

Energy flow
CDF-II

ROMAN POT DETECTORS

BEAM SHOWER COUNTERS:
Used to reject ND events

MINIPLUG CALORIMETER
Artist’s View of MiniPlug

- 84 towers
- 25 in
- 5.5 in
MiniPlug Run II Data

Multiplicity distribution in 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.
Diffractive Structure Function

\[ R(x_{Bj}) \equiv \frac{\text{Rate}^{SD}_{jj}(x_{Bj})}{\text{Rate}^{ND}_{jj}(x_{Bj})} \]

\[ \Rightarrow \frac{F^{SD}_{jj}(x_{Bj})}{F^{ND}_{jj}(x_{Bj})} \]
Diffractive Dijet Sample

\[ \xi = \sum_{\text{all towers}} \frac{E_T e^{-\eta}}{\sqrt{s}} \]

\[ \frac{d\sigma}{d\xi} \sim \frac{1}{\xi} \Rightarrow \frac{d\sigma}{d\log\xi} \sim \text{constant} \]
$\xi_{RP}$ vs $\xi_{cal}$

$\xi_{cal} = (0.94 \pm 0.03) \xi_{RP}$

Overlap events
Signal region
$\xi_{cal}$ distribution for slice of $\xi_{RP}$

\(\sigma/\text{mean} \sim 30\%\)
Ratio of SD/ND dijet event rates
- agreement with Run 1 result
- no $\xi$ dependence in $0.03 < \xi < 0.1$
- confirms Run I results

No appreciable $Q^2$ dependence
in region $100 < Q^2 < 1,600 \text{ GeV}^2$
- Pomeron evolves as proton

MORE DATA CURRENTLY AT HAND
Measure $\xi$-dependence of $F_{jj}(\xi,\beta,t)$ down to $\xi\sim0.001$ using gap trigger.

**STATUS:**
Data at hand
Analysis in progress
Diffractive $W$ production

Probes the quark content of the Pomeron

$\rightarrow$ More direct comparison with HERA

Run I: 8,246 $W$(ev) events - PRL 78 (1997), 2698

$R_W \ (SD/ND) = 1.15 \pm 0.51(stat) \pm 0.20(syst) \%$

![Diagram of hard-quark dominated Pomeron](left)

![Diagram of hard-gluon dominated Pomeron](right)

hard-quark dominated Pomeron

hard-gluon dominated Pomeron

(rate lower by $\alpha_s$)

Status: data at hand, analysis in progress
**Gap Between Jets**

Is the diffractive exchange BFKL-like or simply a color rearrangement?

\[ \bar{p} + p \rightarrow \text{Jet} + \text{Gap} + \text{Jet} \]

**Question**

\[ \Delta y_{\text{gap}} \leftrightarrow ??? \rightarrow \Delta y_{\text{jet}} \]

**Work in progress: low luminosity run needed**

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New CDF Results on Diffraction

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Exclusive Dijet Production

Use dijet rate to calibrate Higgs production calculations

Boonekamp, Peschanski, Royon: PRL 87, 251806(2001)
Exclusive Dijets in Run 1

PRL 85 (2000) 4215

Exclusive dijet limit:
\( \sigma_{jj} \) (excl.) < 3.7 nb (95% CL)

Theoretical expectation (KMR) ~1 nb

Dijet Mass fraction

\( R_{jj} = \frac{M_{jj}}{M_X} \)
Run 2 dijet mass fraction

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

\[ \bar{p}p \rightarrow \bar{p} + JJ + \text{gap}_{5.5<\eta<7.5} \]

\[ \bar{p}p \rightarrow \bar{p} + JJ + \text{gap}_p^{3.6<\eta<7.5} \]

**Minimum \( E_T(Jet1) \)**

<table>
<thead>
<tr>
<th>( E_T(Jet1) )</th>
<th>Cross section ( (R_{jj}&gt;0.8) )</th>
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<tr>
<td>10 GeV</td>
<td>( 1.1 \pm 0.1 \text{(stat)} \pm 0.5 \text{(syst)} ) nb</td>
</tr>
<tr>
<td>25 GeV</td>
<td>( 25 \pm 3 \text{(stat)} \pm 10 \text{(syst)} ) pb</td>
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Exclusive Dijet Events?

$R_{jj} = 0.36$

$E_{T^{\text{jet1(2)}}} = 33(31) \text{ GeV}$

$E_{T^{\text{jet1(2)}}} = 36(33) \text{ GeV}$
Limits on Exclusive production

CDF Run II Preliminary

\[ DPE = SD_p + GAP_p \]

- \( SD_p : 0.03 < \zeta_p < 0.1 \)
- \( GAP_p : 3.6 < |\eta_{gap}| < 7.5 \)
- \( |\eta_{jet1,2}| < 2.5 \)

Martin, Kaidalov, Khoze, Ryskin, Stirling
Heavy flavor exclusive dijets

Theory:
- $J_z = 0$ spin selection rule
- $gg \to gg$ dominant contribution at LO
- $gg \to q\bar{q}$ suppressed when $M_{jj} \gg m_q$

Experimental method:
- Normalize $R_{jj}(q\bar{q})$ to $R_{jj}(all\, jets)$
- Look for suppression at large $R_{jj}$

Pros:
- Many systematics cancel out
- Good HF quark id
- Small $g$ mistag $O(1\%)$

Cons:
- Heavy quark mass:
  - Suppression is not complete
Heavy flavor tagged dijet fraction

CDF Run II Preliminary

DPE = SD_p + GAP_p

Systematic Uncertainty

exclusive production?
need:
• to compare with MC
• more data!

\[ R_{btag}(R_{jj} > 0.7)/R_{btag}(R_{jj} < 0.4) = 0.59 \pm 0.33 \text{ (stat)} \pm 0.23 \text{ (syst)} \]
Exclusive $\chi_c$

\[
p\bar{p} \rightarrow p\chi_c\bar{p} \quad \rightarrow J/\psi \gamma \rightarrow \mu\mu \gamma
\]

From inclusive $J/\psi$ data:

Cross section upper limit: $\sigma_{\text{excl}}(J/\psi + \gamma) = 49 \pm 18(\text{stat}) \pm 39(\text{syst})$ pb


STATUS: data from new $\text{gap} + J/\psi + \text{gap}$ trigger are being analyzed
CONCLUSION

Run 2

- CDF has a comprehensive Run 2 diffractive program
- Data at hand are being analyzed
- More data are being collected
- Proposal for low luminosity ($\sim 10^{30}$) run under study

Beyond Run 2

- Tev4LHC studies