Diffraction at the Tevatron: CDF Results

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presented on behalf of the CDF Collaboration

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Contents

- Run-I diffraction @ CDF
- Run II results
  - Diffractive structure function
    - $x_{Bj}$, $Q^2$, and $t$ dependence
  - Exclusive production
    - dijet & diphoton
Run-I Diffraction @ CDF

Elastic scattering

$\sigma_T = \text{Im} f_{el}(t=0)$

Total cross section

$GAP$

$OPTICAL\ THEOREM$

$\phi$

$SD$

$DD$

$DPE$

$SDD = SD + DD$
Run I-0 (1988-89)
Elastic, single diffractive, and total cross sections
@ 546 and 1800 GeV

Roman Pot Spectrometers

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

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

Additional Detectors
Trackers up to \( |\eta| = 7 \)
Breakdown of Regge factorization

\[ \frac{d^2\sigma_{SD}}{dt d\xi} = f_{IP/p}(t, \xi) \cdot \sigma_{IP-p}(M^2_X) \]

Pomeron flux

\[ \sigma_{SD} \sim S^{2\varepsilon} \]

\[ \xi < 0.05 \]

- Albro et al.
- Armitage et al.
- UA4
- CDF
- E710
- Cool et al.

Total Single Diffraction Cross Section (mb)

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

KG, PLB 358 (1995) 379
Diffraction at the Tevatron: CDF results

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Central and Double Gaps @ CDF

- **Double Diffraction Dissociation**
  - One central gap

- **Double Pomeron Exchange**
  - Two forward gaps

- **SDD: Single+Double Diffraction**
  - One forward + one central gap

Results: DD, like SD, is suppressed
The formation of the second gap in two-gap events is not suppressed!
Hard Diffractive Fractions @ CDF

$\bar{p}p \rightarrow (\bullet + X) + \text{gap}$

### Fraction:
SD/ND ratio at 1800 GeV

<table>
<thead>
<tr>
<th>% Fraction (+/-)</th>
<th>W</th>
<th>JJ</th>
<th>b</th>
<th>J/ψ</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.15 (0.55)</td>
<td>0.75 (0.10)</td>
<td>0.62 (0.25)</td>
<td>1.45 (0.25)</td>
<td></td>
</tr>
</tbody>
</table>

- All ratios $\sim 1\%$
- $\rightarrow$ uniform suppression
- $\sim$ FACTORIZATION!
Diffractive Structure Function:
Breakdown of QCD Factorization

$\beta = \text{momentum fraction of parton in Pomeron}$

The diffractive structure function at the Tevatron is suppressed by a factor of $\sim 10$ relative to expectation from pdf’s measured by H1 at HERA.

Using preliminary pdf’s from
- H1 2002 $\sigma_r^D$ QCD Fit (prel.)
- CDF data

$E_T^{\text{jet}1,2} \geq 7 \text{ GeV}$
$0.035 \leq \xi \leq 0.095$
$|t| \leq 1.0 \text{ GeV}^2$

Similar suppression factor as in soft diffraction relative to Regge expectations!
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 II Results

- Diffractive structure function
  
  NEW:
  
  - $Q^2$ - dependence
  - $t$ - dependence

- Exclusive production
  
  - dijet
  - diphoton
CDF in Run-II

ROMAN POT DETECTORS

BEAM SHOWER COUNTERS:
Used to reject ND events

MINIPLUG CALORIMETER
DIFRACTIVE STRUCTURE FUNCTION

Systematic uncertainties due to energy scale and resolution cancel out in the ratio

$$R(x_{Bj}) \equiv \frac{\text{Rate}^{SD}_{jj}(x_{Bj})}{\text{Rate}^{ND}_{jj}(x_{Bj})} \Rightarrow \frac{F^{SD}_{jj}(x_{Bj})}{F^{ND}_{jj}(x_{Bj})}$$
Diffractive Dijet Signal

- Bulk of data taken with RPS trigger but no RPS tracking
- Extract $\xi$ from calorimetric information
- Calibrate calorimetric $\xi$ using limited sample of RPS tracking data
- Subtract overlap background using a rescaled dijet event sample
- Verify diffractive $\xi$ range by comparing $\xi^{RPS}$ with $\xi^{CAL}$

Overlapped events: mainly ND dijets plus SD low $\xi$ RPS trigger
Alignment of RPS using Data

maximize the $|t|$-slope
⇒ determine X and Y offsets

CDF Run II Preliminary

<table>
<thead>
<tr>
<th>Y offset [cm]</th>
<th>-0.6</th>
<th>-0.5</th>
<th>-0.4</th>
<th>-0.3</th>
<th>-0.2</th>
<th>-0.1</th>
<th>0</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>slope at $</td>
<td>t</td>
<td>=0$ [arbitrary units]</td>
<td>-1.2</td>
<td>-1.0</td>
<td>-0.8</td>
<td>-0.6</td>
<td>-0.4</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>X offset [cm]</th>
<th>-0.4</th>
<th>-0.2</th>
<th>0</th>
<th>0.2</th>
<th>0.4</th>
</tr>
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\( \xi_{\text{CAL}} \) Calibration

- \( \xi_{\text{CAL}} \) distribution for slice of \( \xi_{\text{RPS}} \)
- \( \sigma / \text{mean} \approx 30\% \)

\( \xi_{\text{CAL}} = (0.97 \pm 0.04) \xi_{\text{RPS}} \)
Dijet Properties

\[ \eta^+ = \frac{\eta^{\text{jet1}} + \eta^{\text{jet2}}}{2} \]

\[ \Delta \phi = |\phi^{\text{jet1}} - \phi^{\text{jet2}}| \text{ (radians)} \]

[CDF Run II Preliminary graphs showing data for SD and ND with boosted event opposite to pbar]
$E_T$ distributions

CDF Run II Preliminary

- SD
- ND

ND norm. to SD
Jet $E_T > 5$ GeV

CDF Run II Preliminary

- SD
- ND

ND norm. to SD
Jet $E_T > 7$ GeV

CDF Run II Preliminary

- SD
- ND

ND norm. to SD
Jet $E_T > 20$ GeV

CDF Run II Preliminary

- SD
- ND

ND norm. to SD
Jet $E_T > 50$ GeV

$E_T^* = (E_{T1} + E_{T2})/2$ (GeV)

120 GeV
Diffractive Structure Function: 
$Q^2$ dependence

CDF Run II Preliminary

$E_{T}^{\text{jet}} \sim 100 \text{ GeV}$!

Small $Q^2$ dependence in region $100 < Q^2 < 10,000 \text{ GeV}^2$

$\Rightarrow$ Pomeron evolves as the proton!
Diffractive Structure Function: 
$t$- dependence

Fit $d\sigma/dt$ to a double exponential:

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

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

- Same slope over entire region of $0 < Q^2 < 4,500$ GeV$^2$
across soft and hard diffraction!
Diffractive dijets: $\Delta \phi = \phi_{p\bar{p}} - \phi_{dijet}$

CDF Run II Preliminary

- $\Delta \Phi(J_1+J_2,p\bar{p})$
- $\Delta \Phi(J_1,p\bar{p})$

Events vs $\Delta \Phi$
EXCLUSIVE PRODUCTION

Measure exclusive jj & γγ ➔ ➔ ➔ Calibrate predictions for H production rates @ LHC

Search for exclusive dijets:
Measure dijet mass fraction

\[ R_{jj} = \frac{M_{jj}}{M_X(\text{all calorimeters})} \]

Look for signal as \( M_{jj} \rightarrow 1 \)

Search for exclusive γγ

Search for events with two high \( E_T \) gammas and no other activity in the calorimeters or BSCs

Clean discovery channel

C. Royon, hep-ph/0308283
B. Cox, A. Pilkington, PRD 72, 094024 (2005)

KMR: \( \sigma_H(\text{LHC}) \sim 3 \text{ fb} \)
S/B \sim 1 \text{ if } \Delta M \sim 1 \text{ GeV}
Exclusive Dijet Signal

Dijet fraction - all jets

CDF Run II Preliminary

CDF+H1

Excess over MC predictions at large dijet mass fraction

b-tagged dijet fraction

CDF Run II Preliminary

DPE data (SVT)

Systematic Uncertainty

Excessive b-jets are suppressed by $J_Z=0$ selection rule

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**R_{JJ}(excl): Data vs MC**

**CDF Run II Preliminary**

- **ExHuME (KMR):** \( gg \rightarrow gg \) process
  - \( \Rightarrow \) uses LO pQCD

- **Exclusive DPE (DPEMC):**
  - \( \Rightarrow \) non-pQCD based on Regge theory

**Shape of excess of events at high \( R_{jj} \)
is well described by both models**
**COMPARISON**

Inclusive data vs MC @ b/c-jet data vs inclusive
$J J_{\text{excl}}$ : $x$-section vs $E_T^{\text{min}}$

Comparison with hadron level predictions

ExHuME (red)

Exclusive DPE in DPEMC (blue)
$JJ_{\text{excl}}$: cross section predictions

ExHuME Hadron-Level Differential Exclusive Dijet Cross Section vs Dijet Mass
(dotted/red): Default ExHuME prediction
(points): Derived from CDF Run II Preliminary excl. dijet cross sections

Statistical and systematic errors are propagated from measured cross section uncertainties using ExHuME $M_{jj}$ distribution shapes.


**J J_{excl} : R(excl/incl) vs E T_{min}**

CDF Run II Preliminary

Data corrected to the hadron level

\[ E_T^{jet1, 2} > E_T^{min} \]
\[ |\eta^{jet1, 2}| < 2.5 \]
\[ 3.6 < \eta_{gap} < 5.9 \]
\[ 0.03 < \xi_p < 0.08 \]
Exclusive $\gamma\gamma/ee$ Search

$pp \to p + \gamma\gamma + \bar{p}$

$\gamma\gamma$ cross-check to exclusive $\gamma\gamma$

- (anti)proton not detected
- require 2 EM showers ($E_T > 5$ GeV, $|h| < 2$)
- veto on all BSCs and cal towers except for those of the 2 EM showers
- $L \sim 530$ pb$^{-1}$ delivered $\Rightarrow L_{\text{effective}} = 46$ pb$^{-1}$

$\Rightarrow 19$ events with 2 EM showers + "nothing" [above threshold]
Exclusive ee Search

16 candidate events found
background $2.1^{+0.7}_{-0.3}$ events

$\sigma_{\text{measured}} = 1.6^{+0.5}_{-0.3} \text{ (stat)} \pm 0.3 \text{ (sys)}$ pb

good agreement with LPAIR:

$\sigma_{\text{LPAIR}} = 1.711 \pm 0.008$ pb
Exclusive $\gamma\gamma$ Search

3 events are found.
$1^{st}$ events are predicted from ExHuME MC

Background estimate is not yet complete

$E_T^1 = 6.8 \text{ GeV/c}$
$E_T^2 = 5.9 \text{ GeV/c}$
Summary

Run I

- Suppression of single gap diffraction
- $M^2$ - scaling: $d\sigma/dM^2$ independent of $s$
- Non-suppressed double-gap to single-gap ratios

Run II

- Diffractive structure function vs $x_{Bj}$, $Q^2$, and $t$
  - Composite Pomeron
    made up from proton pdf's?
- Exclusive production; dijet and diphoton
  - Diffractive Higgs @ LHC under control
BACKUP
p-p Interactions

**Non-diffractive:**
Color-exchange

**Diffractive:**
Colorless exchange
w/vacuum quantum numbers

Incident hadrons retain their quantum numbers remaining colorless

**Goal:** understand the QCD nature of the diffractive exchange
$\mathcal{M}^2$ - scaling

renormalization

\[ \frac{d\sigma}{dM^2} \propto \left( \frac{\mathcal{S}^2}{M^2} \right)^{1+\epsilon} \]

\( \Rightarrow \) Independent of \( \mathcal{S} \) over a range of six orders of magnitude in \( \mathcal{M}^2 \! \)!

Factorization breaks down so as to ensure \( \mathcal{M}^2 \)-scaling!
\[ \frac{d\sigma_{\text{incl}}}{d\xi} \propto \text{constant} \]

\[ F_{jj}^D (\beta, \xi) \propto \frac{1}{\beta^n} \cdot \frac{1}{\xi^m} \quad (n = 1.0 \pm 0.1, \quad m = 0.9 \pm 0.1) \]

Pomeron dominated
The MiniPlug Calorimeters

About 1500 wavelength shifting fibers of 1 mm dia. are 'strung' through holes drilled in $36 \times \frac{1}{4}''$ lead plates sandwiched between reflective Al sheets and guided into bunches to be viewed individually by multi-channel photomultipliers.