Diffractive and Exclusive Dijets and W/Z at CDF

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Introduction

Soft and hard diffraction @ CDF

SD, DD, DPE, SDD = SD + DD

$p p \rightarrow JJ, \ b, \ J/\psi, \ W, \ \bar{p}$

exclusive $\rightarrow JJ, \ ee, \ \mu\mu, \ \gamma\gamma$

$p$
SD kinematics

\[ \xi, t \]

\[ \Delta \eta = -\ln \xi \]

\[ L_p \cdot \xi \]

\[ dN/d\eta \]
Breakdown of factorization - Run I

\[ \Omega \sim 0.05 \]

Run I

\[ \xi \times \beta = \text{H1ZEUS} \]

\[ \text{CDF} \]

\[ \int \int dt d\xi (\xi, \beta) \to 8 \]

\[ \sigma_{T,\text{sd}} \]

\[ \text{KG, PLB 358 (1995) 379} \]

**Magnitude:** same suppression factor in soft and hard diffraction!

**Shape of \( \beta \) distribution:** ZEUS, H1, and Tevatron - why different shapes?
Hard diffractive fractions - Run I

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

**Fraction:**
SD/ND ratio @ 1800 GeV

<table>
<thead>
<tr>
<th></th>
<th>Fraction %</th>
</tr>
</thead>
<tbody>
<tr>
<td>JJ</td>
<td>0.75 +/- 0.10</td>
</tr>
<tr>
<td>W</td>
<td>0.115 +/- 0.55</td>
</tr>
<tr>
<td>b</td>
<td>0.62 +/- 0.25</td>
</tr>
<tr>
<td>J/\psi</td>
<td>1.45 +/- 0.25</td>
</tr>
</tbody>
</table>

All fractions \( \sim 1\% \)
(differences due to kinematics)
- \( \sim \) uniform suppression
- \( \sim \) FACTORIZATION!

\( dN/d\eta \)
Multi-gap diffraction - Run I

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.
\[ F_{jj}^D (\beta, \xi) \sim \frac{1}{\beta} \cdot \frac{1}{\xi} \]

\[ d\sigma_{\text{incl}} \propto \text{constant} \]

\[ E_T^{1,2} \geq 7 \text{ GeV} \]
\[ \left| t \right| \leq 1.0 \text{ GeV}^2 \]
Diffractive structure function – Run II

$Q^2$ - dependence

CDF Run II Preliminary

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

Small $Q^2$ dependence in region $100 < Q^2 < 10000$ GeV$^2$
where each $d\sigma^{\text{ND}}/dE_T$ differ by a factor of $\sim 10^4$

The Pomeron evolves as the proton!
Diffractive structure function - Run II
\( t \) - 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 \( Q^2 \approx 10^4 \) GeV\(^2\)

- Same slope over entire region of \( 0 < Q^2 < \sim 10000 \) GeV\(^2\) across soft and hard diffraction!
Looks like…

... the underlying diffractive PDF on a hard scale is similar to the proton PDF except for small differences - presumably due to the requirement of combining with the soft PDF to form a spin 1 color singlet with vacuum quantum numbers.
Diffractive W/Z production

- Diffractive W production probes the quark content of the Pomeron
  - To leading order, the W is produced by a quark in the Pomeron
- Production by gluons is suppressed by a factor of $\alpha_s$, and can be distinguished from quark production by an associated jet
Diffractive W/Z - motivation

- **In Run I**, by combining diffractive dijet production with diffractive W production we determined the quark/gluon content of the Pomeron

- **In Run II** we aim at determining the diffractive structure function for a more direct comparison with HERA.

- To accomplish this we use:
  - **New forward detectors**
  - **New methodology**
  - **More data**

Phys Rev Lett 78, 2698 (1997)
Fraction of W events due to SD
\[ R^w = [1.15 \pm 0.51 \text{(stat)} \pm 0.20 \text{(syst)} ] \% \]
for \( \xi < 0.1 \) integrated over \( t \)
The DF II detectors

RPS acceptance ~80% for 0.03 < x < 0.1 and |t| < 0.1
**Diffractive W/Z analysis**

Using RPS information:

- No background from gaps due to multiplicity fluctuations
- No gap survival probability systematics
- The RPS provides accurate event-by-event $\xi$ measurement
- Determine the full kinematics of diffractive W production by obtaining $\eta_v$ using the equation:

$$\xi_{\text{RPS}} - \xi_{\text{cal}} = \frac{E_T}{\sqrt{s}} e^{-\eta_v}$$

where

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

This allows the determination of:

- W mass
- $x_{Bj}$
- Diffractive structure function
**W/Z selection requirements**

### Standard W/Z selection

\[
\begin{align*}
E_T^e (p_T^\mu) &> 25 \text{ GeV} \\
M_T &> 25 \text{ GeV} \\
40 < M_T^W &< 120 \text{ GeV} \\
|Z_{vtx}| &< 60 \text{ cm}
\end{align*}
\]

### Diffractive W/Z selection

- RPS trigger counters - MIP
- RPS track - 0.03 < \(\xi\) < 0.10, |t| < 1
- \(W \rightarrow 50 < M_W(\xi^{RPS}, \xi^{cal}) < 120\)
- \(Z \rightarrow \xi^{cal} < 0.1\)
Reconstructed diffractive $W$ mass
Rejection of multiple interaction events

ND dijet w/soft SD overlap
Diffractive 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: \( R^W =1.15\pm0.55 \% \) for \( \xi<0.1 \) \( \Rightarrow \) estimate \( 0.97\pm0.47 \% \) 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 (\( \xi < 0.1 \))

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>( R^w=[1.15\pm0.51\text{(stat)}\pm0.20\text{(syst)}] % )</td>
<td>( R^w=[5.1\pm0.51\text{(stat)}\pm0.20\text{(syst)}] % )</td>
</tr>
<tr>
<td>gap acceptance ( A^{\text{gap}}=0.81 ) uncorrected for ( A^{\text{gap}} )</td>
<td>gap acceptance ( A^{\text{gap}}=(0.21\pm4) % ) uncorrected for ( A^{\text{gap}} )</td>
</tr>
</tbody>
</table>
| \( R^w=(0.93\pm0.44) \% \) (\( A^{\text{gap}} \) calculated from MC) | \( R^w=[0.89+0.19-0.17 ] \% \)
| \( R^Z=1.44+0.61-0.52 \% \) | \( R^Z=[1.44+0.61-0.52 \% \) |

Stay connected for results on \( F^D_{w/z} \)
EXCLUSIVE JJ & HIGGS BOSONS

\[ p p' p (p M \Delta M \approx (1-2) \text{ GeV}) \]

Determine spin of $H$
Exclusive dijet and Higg production

URL: http://link.aps.org/abstract/PRD/v77/e052004 DOI: 10.1103/PhysRevD.77.052004

ExHuME

DPEMC
The DPE data sample

\[ \xi_{\overline{p}p} = \sum_{\text{towers}} \frac{E_{T}}{\sqrt{S}} e^{-\eta} \]
Kinematic distributions

\[ E_T^* = \frac{(E_T^{jet1} + E_T^{jet2})}{2} \text{ (GeV)} \]

\[ \eta^* = \frac{(\eta_{jet1} + \eta_{jet2})}{2} \]

\[ \Delta \phi = |\phi_{jet1} - \phi_{jet2}| \text{ (radian)} \]
Exclusive dijet signal

Excess observed over POMWIG MC prediction at large \( R_{jj} \)

Exclusive b-jets are suppressed as expected (\( J_z = 0 \) selection rule)
Underlying event
Jet1 vs. Jet2: signal and background regions

DATA

A: signal region
B: background region

POMWIG
Background region

(a) $E_T^* = \frac{E_T^{\text{jet}_1} + E_T^{\text{jet}_2}}{2}$

(b) $M_{jj}$ (GeV)

(c) $\eta^* = \frac{\eta^{\text{jet}_1} + \eta^{\text{jet}_2}}{2}$

(d) $M_X$ (GeV)
**Inclusive DPE W/LRG-p data vs. MC**

*ExHuME* ↔ *exclusive MC models* ↔ *DPEMC*

**ExHuME (KMR):** $gg \rightarrow gg$ process (based on LO pQCD)

**DPEMC:** exclusive DPE MC based on Regge theory

Shape of excess of events at high $R_{jj}$ is well described by both ExHuME & DPEMC
HF suppression vs. inclusive signal

HF suppression

HF vs. incl

Invert HF vertically and compare with 1-MC/DATA

⇒ good agreement observed
ExHuME vs. DPEMC and vs. data

- Measured x-sections favor ExHuME

- KMR $\times 1/3$ agrees with data
  - Within theoretical uncertainty of +/- factor of 3

- $\sigma_{jj}^{\text{excl}}/\sigma_{jj}^{\text{incl}}$ approx. independent of $E_T^{\text{min}}$
  - WHY?
Exclusive dijet x-section vs. $M_{jj}$

**Graph:**
- **ExHuME (hadron level):**
  - Default
  - Derived from CDF Run II $\sigma_{jj}^{\text{excl}} (E_T^{\text{min}})$
- **Systematic uncertainty**

**Legend:**
- $|\eta^{\text{jet1,2}}| < 2.5$
- $3.6 < \eta_{\text{gap}} < 5.9$
- $0.03 < \zeta_p < 0.08$

**Curve:** ExHuME hadron-level exclusive dijet cross sections vs. dijet mass

**Points:** Derived from CDF excl. dijet x-sections using ExHuME

Stat. and syst. errors are propagated from measured cross section uncertainties using $M_{jj}$ distribution shapes of ExHuME generated data.
Introduction
- diffractive PDF looks like proton PDF

Diffractive W/Z – RPS data
- W diffractive fraction in agreement with Run I
- W/Z diffractive fractions equal within error
- New techniques developed to enable extracting the diffractive structure function in W production

Exclusive dijet/(Higgs?) production
- Results favor ExHuME over DPEMC
BACKUP

Measurements w/the MiniPlugs
Dynamic Alignment of RPS Detectors
$E_T^{\text{jet}}$ Calibration
Measurements with the MiniPlugs

ADC counts in MiniPlug towers in a pbar-p event at 1960 GeV.
- “jet” indicates an energy cluster and may be just a hadron.
- 1000 counts ~ 1 GeV

Energy

Multiplicity

@ Position

MP Tower Structure

NIM A 430 (1999)
NIM A 496 (2003)
NIM A 518 (2004)

Multiplicty of SD and ND events
Dynamic Alignment of RPS Detectors

Method: iteratively adjust the RPS X and Y offsets from the nominal beam axis until a maximum in the b-slope is obtained @ t=0.

Limiting factors:
1. statistics
2. beam size
3. beam jitter

@ CDF
w/lowlum data
± 30 μm
**$E_T^{jet}$ Calibration**

use RPS information to check jet energy corrections

CDF Run II Data

- $E_T^{jet,2} > 10$ GeV
- $E_T^{jet,3} < 5$ GeV
- $0.035 \leq \xi_{RPS} \leq 0.095$
- $3.6 < |\eta_{gap}| < 5.9$
- $R_{jj} > 0.8$

Raw Jets (dotted)

- Entries: 160
- Mean: 0.02438
- RMS: 0.01115

L5 Corrected Jets (dashed)

- Entries: 293
- Mean: 0.004665
- RMS: 0.01315

L7 Corrected Jets (shaded)

- Entries: 360
- Mean: 0.00269
- RMS: 0.01364

Calibrate $E_T^{jet}$ or $\xi$, as you wish!

$\Delta \xi = \xi_{RPS} - \xi_{jj}^X$
thank you