Diffractive W and Z Production at Tevatron

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- Diffractive W / Z
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Diffraction and Exclusive Production at CDF

soft and hard topologies studied

Single Diffraction dissociation (SD)
Double Diffraction dissociation (DD)
Double Pomeron Exchange (DPE)
Single + Double Diffraction (SDD)

exclusive

JJ, b, J/ψ, W

p
p
Diffractive signature

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

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

\[ dN/d\eta \]

Recoil \( \bar{p} \) or rap-gap

\[ \bar{p}', \xi \cdot \bar{p} \]

\[ M_x \]
Breakdown of factorization

\[ \int \int f_{IP/p}(t, \xi) \, d\xi \, dt = 1 \]

same suppression factor in soft and hard diffraction

\[ \beta = \frac{x_{Bj}}{\xi} \]

\[ \sim 8 \]

\[ \sigma_{T_{sd}} \]

\[ \xi < 0.05 \]

Albrow et al.

Armitage et al.

UA4

CDF

E710

Cool et al.

KG, PLB 358 (1995) 379

standard flux

renormalized flux

\[ \sim 8 \]

same suppression factor in soft and hard diffraction

\[ \Rightarrow \text{gap survival responsible for suppression} \]
CDF hard diffraction fractions

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

Fraction:
R ≡ SD/ND ratio
@ 1800 GeV

<table>
<thead>
<tr>
<th></th>
<th>Fraction (R) %</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/ψ</td>
<td>1.45 +/- 0.25</td>
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</tbody>
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All fractions ~ 1%
(differences due to kinematics)

- ~ uniform suppression
- ~ FACTORIZATION!

→ suppression due to gap survival
DIFFRACTIVE W / Z PRODUCTION

- LO diagrams
- Motivation
- CDF II detectors
  - miniplugs
  - measurements with miniplugs
  - dynamic alignment
- Analysis
  - selection requirements
  - reconstructed diffractive W mass
  - rejection of multiple interactions
- Diffractive W / Z results
Diffractive LO W/Z diagrams

- 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, combining diffractive dijet production with diffractive W production was used to determine 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 CDF II detectors

RPS acceptance \(~80\%\) for \(0.03 < \xi < 0.1\) and \(|t| < 0.1\)
The MiniPlugs @ CDF
Measurements w/the MiniPlugs

**Multiplicities of 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.
  - 1000 counts ~ 1 GeV

- Multiplicity w/the MiniPlugs
  - ADC counts in MiniPlug towers
  - "jet" indicates an energy cluster and may be just a hadron.
  - 1000 counts ~ 1 GeV

**Energy**

**Energy**

\[ \xi_{\text{CAL}} = \frac{\sum_i E_T^i e^{-\eta_i}}{\sqrt{s}} \]

**Multiplicities**

- NIM A 430 (1999)
- NIM A 496 (2003)
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
Diffractive W/Z analysis

Using RPS information:

- No background from gaps due to multiplicity fluctuations
- No gap survival probability problem
- 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 determination of:

- W mass
- $\chi_{\text{Bj}}$
- Diffractive structure function
W/Z selection requirements

Standard W/Z selection

- $E_T^e (p_T^\mu) > 25$ GeV
- $E_T > 25$ GeV
- $40 < M_T^W < 120$ GeV
- $|Z_{vtx}| < 60$ cm

Diffractive W/Z selection

- RPS trigger counters - MIP
- RPS track - $0.03 < \xi < 0.10, |t| < 1$
- $W \rightarrow 50 < M_W(\xi^{\text{RPS}}, \xi^{\text{cal}}) < 120$
- $Z \rightarrow \xi^{\text{cal}} < 0.1$
Reconstructed Diffractive W-Mass

CDF W mass (press release 2007): 80,413 +/- 48 MeV/c^2
Rejection of Multiple Interactions

\( W \rightarrow e\nu \) or \( \mu\nu \)

\( Z \rightarrow ee \) or \( \mu\mu \)

- ND \( W \) w/soft SD overlap
- ND \( Z \) w/soft SD overlap

- \( \zeta_{\text{RPS}} > \zeta_{\text{CAL}} \) effective in rejecting overlaps in \( W \) case
- cannot be applied in \( Z \) case (no missing \( \nu \))
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: \( R^W = 1.15 \pm 0.55 \% \) for \( \xi < 0.1 \) → estimate \( 0.97 \pm 0.47 \% \) in \( 0.03 < \xi < 0.10 \) & \( |t|<1 \)

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

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

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>( R^w = [1.15 \pm 0.51 \text{(stat)} \pm 0.20 \text{(syst)}] % )</td>
<td>( R^w = [5.1 \pm 0.51 \text{(stat)} \pm 0.20 \text{(syst)}] % )</td>
</tr>
<tr>
<td>w/gap acceptance ( A_{\text{gap}} = 81 % ) (from MBR/PYTHIA Monte Carlo)</td>
<td>w/gap acceptance ( A_{\text{gap}} = (21 \pm 4) % ) (model dependent)</td>
</tr>
<tr>
<td>➢ uncorrected for ( A_{\text{gap}} ):</td>
<td>➢ uncorrected for ( A_{\text{gap}} ):</td>
</tr>
<tr>
<td>( R^w = (0.93 \pm 0.44) % )</td>
<td>( R^w = [0.89 + 0.19 - 0.17] % )</td>
</tr>
<tr>
<td>( R^Z = ? ) (not measured in Run I)</td>
<td>( R^Z = [1.44 + 0.61 - 0.52] % )</td>
</tr>
</tbody>
</table>

stay tuned for results on \( F^D_{w/z} \)
Thursday, March 12 2009

In diffractive scattering, on the other hand, one ball, we'll call the cue ball, remains the same and continues with almost its original momentum, while the other, we'll call the eight ball, breaks up into pieces. Since the cue ball keeps its properties, we can think of the object exchanged as the same one as in elastic scattering.

Diffractive scattering can occur at the Tevatron collider. Because the exchanged object doesn't carry any properties of the particles, theory predicts that an empty gap with no particles will be present in the event between the diffractive antiproton, the cue ball, and the particles produced when the proton, the eight ball, breaks up.

Previously, diffractive W-boson production, where one piece of the broken eight ball is a W boson, was measured by looking for these gaps. Recently, CDF scientists have improved upon the study of diffractive scattering by using special apparatus called Roman pots, which allow detectors to be located inside the beam pipe. These detectors measure the diffractive antiproton.

Scientists look for W bosons, which decay into an electron or muon plus a neutrino, using standard methods, including inferring the missing transverse energy from the neutrino, which doesn't interact in the detector. In addition, they combine the information from the antiproton measurement with energy measurements in the rest of the detector to determine the neutrino's longitudinal momentum. This technique is the only way to fully reconstruct the W kinematics with leptons at a hadron collider.

With this new result on diffractive W-boson production, CDF scientists removed ambiguities from other methods that rely on identifying particle-free gaps in the events. CDF scientists found that at the Tevatron, about 1 percent of W and Z bosons are produced diffractively.

— edited by Craig Gough

Mary Convery, of Fermilab, and Dino Goulianos, of Rockefeller University, have been collaborating on diffractive physics since 1997.
Exclusive $Z / \gamma\gamma \rightarrow ll$ studies*

Exclusive $Z$ SM cross section:
- 0.3 fb [Motyka & Watt]$^1$
- 1.3 fb [Goncalves & Machado]$^2$
Expect $\sim$0.6 - 2.6 events in 2 fb$^{-1}$
(not including 3.37% leptonic BF).
\rightarrow Search for BSM physics,
e.g. color sextet quark model$^3$: much enhanced cross section expected.

$^3$ Phys. Rev. D72, 036007

Exclusive di-lepton cross section:
- Background to exclusive $Z$
- Can be used to calibrate forward proton detectors:
\[ \xi = s^{-1/2} \sum p_T l e^{-\eta l} \]

* see Emily Nurse http://www.fp420.com/conference/dec2008/index.html
Exclusive di-leptons

\[ \sigma (p p \to p \ell \ell p) = 0.24^{+0.13}_{-0.10} \text{ pb} \]

\[ M_{\ell\ell} > 40 \text{ GeV}, |\eta| < 4.0 \]

[LPAIR prediction: \( \sigma = 0.256 \text{ pb} \)]

Exclusive Z

\[ \sigma(Z_{\text{excl}}) < 0.96 \text{ pb @ 95\% C.L.} \]

[SM: 0.3 fb [Motyka & Watt]

1.3 fb [Goncalves & Machado]]
SUMMARY

- Overview of diffraction at CDF
  - Breakdown of factorization – HERA vs. Tevatron
  - CDF hard diffraction fractions ~1 % – factorization?
  - Gap survival responsible for suppression

- Diffractive W/Z with Roman Pot Spectrometer tagging
  - W diffractive fraction in agreement with Run I
    
    \[ R^W (0.03 < \xi < 0.10, |t|<1) = [0.97 \pm 0.05\text{(stat)} \pm 0.11\text{(syst)}] \%
    \]
  - W and Z diffractive fractions are equal within error
    
    \[ R^Z (0.03 < \xi < 0.10, |t|<1) = [0.85 \pm 0.20\text{(stat)} \pm 0.11\text{(syst)}] \%
    \]

- Exclusive Z production – \[ \sigma(Z^{\text{excl}}) < 0.96 \text{ pb @ 95\% C.L.} \]
  - (~ 1 fb expected in the SM)
thank you