Diffraction at CDF and at the LHC

Konstantin Goulianos
The Rockefeller University

LOW X MEETING:
HOTEL VILLA SORRISO, ISCHIA ISLAND, ITALY, September 8-13 2009
theme:
factorization breaking in diffraction

- pp and $\bar{p}p$ results
- $\gamma p$ and $\gamma^*p$ results
- renormalization: *the common thread*
- diffraction at the LHC
pp and $\bar{p}p$ results
\( \bar{p}p \) results from CDF

http://physics.rockefeller.edu/publications.html#diffraction
see also CDF talks in this conference by M. Albrow and J. Pinfold

Soft and hard diffractive processes studied at CDF

- SD: Single Diffraction dissociation
- DD: Double Diffraction dissociation
- DPE: Double Pomeron Exchange
- SDD: Single + Double Diffraction

Exclusive \( JJ, b, J/\psi, W \)

\( \bar{p} \rightarrow JJ...ee...\mu\mu...\gamma \rightarrow p \)
\[ \sigma_{SD}^{T} (pp \ & \ \bar{p}p) \]

\( \rightarrow \) suppressed relative to Regge prediction

\[ \sigma_{SD}^{T} \text{ mb} \]

\[ \sqrt{s} = 1800 \ (540) \text{ GeV} \]

Factor of \(~8 \ (\sim 5)\) suppression at \(\sqrt{s} = 1800 \ (540) \text{ GeV}\)

KG, PLB 358, 379 (1995)
$M^2$ scaling

$\Rightarrow \frac{d\sigma}{dM^2}$ independent of $s$ over 6 orders of magnitude!

\[ \frac{d\sigma}{dM^2} \propto \frac{S^{2\varepsilon}}{(M^2)^{1+\varepsilon}} \rightarrow 1 \]

\[ \Rightarrow \text{Independent of } s \text{ over 6 orders of magnitude in } M^2! \]

\[ \Rightarrow \text{factorization breaks down to ensure } M^2 \text{ scaling!} \]
Gap survival probability - $S$

\[ S = \frac{\phi}{\eta} \]

\[ S_{1\text{-gap/0\text{-gap}}}^{2\text{-gap/1\text{-gap}}}(1800 \text{ GeV}) \approx 0.23 \]

\[ S_{1\text{-gap/0\text{-gap}}}^{2\text{-gap/1\text{-gap}}}(630 \text{ GeV}) \approx 0.29 \]
\( \sigma_{\text{SD}} \) and dijets

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

**Shape of \( \beta \) distribution:** ZEUS, H1, and Tevatron - why different slopes?
Dijets - $E_T$ distributions

$E_T = (E_{T_{\text{jet1}}} + E_{T_{\text{jet2}}})/2$ (GeV)

- similar for SD and ND over 4 orders of magnitude

Kinematics
Dijets: diffractive structure function $x_{Bj}$ and $Q^2$ dependence

$E_T^{\text{jet}} \sim 100 \text{ GeV}$!

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

$\Rightarrow$ Pomeron evolves as the proton!
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 Q2 dependence in slope from inclusive to $Q^2 \sim 10^4$ GeV$^2$
- Same slope over entire region of $\sim 1 < Q^2 < 4,500$ GeV$^2$
Hard diffractive fractions

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

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

Run I

<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/ψ</td>
<td>1.45 +/- 0.25</td>
</tr>
</tbody>
</table>

All fractions \sim 1%
(differences due to kinematics)

- \sim uniform suppression
- \sim FACTORIZATION!

LOW X 2009, Ischia, September 8-13
Diffraction at CDF and at the LHC
K. Goulianos
Diffractive W/Z production - Run II

- Diffractive W production probes the quark content of the Pomeron
- Production by gluons is suppressed by a factor of $\alpha_S$

**DIFFRACTIVE FRACTIONS**

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

Run I: $R^W = 1.15 \pm 0.55 \%$ for $\xi < 0.1 \Rightarrow$ estimate $0.97 \pm 0.47 \%$ in $0.03 < \xi < 0.10$ & $|t|<1$

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

Fractions $R^W$ and $R^Z$ are equal within uncertainties
Multi-gap dijets - factorization restored!

The diffractive structure function measured on the proton side in events with a leading antiproton is NOT suppressed relative to predictions based on DDIS.
Exclusive dijet and Higgs production

Phys. Rev. D 77, 052004

ExHuME suppression factor ~ 50
Central gaps

The distribution of the gap fraction $R_{gap} = N_{gap} / N_{all}$ vs $\Delta \eta$ for MinBias ($CLC_p \cdot CLC_{p\bar{p}}$) and MiniPlug jet events ($MP_p \cdot MP_{p\bar{p}}$) of $E_T^{jet1,2} > 2$ GeV and $E_T^{jet1,2} > 4$ GeV.

The distributions are similar in shape within the uncertainties.
$\gamma p$ and $\gamma^* p$ results
Vector meson production
(Pierre Marage, HERA-LHC 2008)

- Why different $\sigma$ vs. $W$ slopes?
- Why smaller $b$-slope in $\gamma^* p$?!
Dijets in $\gamma p$ at HERA - 2007

[slide from summary of the HERA/LHC Workshop of March 14, 2007]

Dijets in $\gamma p$

- large violation of naive factorization observed
- factorization breaking occurs in direct and resolved processes

Matthias Mozer, HERA-LHC 2007

QCD factorisation not OK

Unexpected, not understood
Dijets in $\gamma p$ at HERA - 2008

- H1 Diffractive Dijet Production

- 20-50% rise (?) from $E_T^{5\rightarrow10 \text{ GeV}}$

- DIS 2008 talk by W. Slomiński,
Renormalization: *the common thread*

- works for pp, $\bar{p}p$, $\gamma p$ and $\gamma^* p$
- removes overlapping gaps!

*Process*

- Thread #1
- Thread #2

figure from http://en.wikipedia.org/wiki/Thread_(computer_science)
1 - x_L ≡ \xi = \frac{M^2}{s}

\left( \frac{d\sigma}{d\Delta\eta} \right)_{t=0} \approx \text{constant} \Rightarrow \frac{d\sigma}{d\xi} \propto \frac{1}{\xi} \Rightarrow \frac{d\sigma}{dM^2} \propto \frac{1}{M^2}
Multigap cross sections

\[ \frac{d^5 \sigma}{\prod_i dV_i} = C \times F_p^2(t_1) \prod_{i=1-2} \left\{ e^{(\varepsilon + \alpha' t_i) \Delta y_i} \right\}^2 \times \kappa^2 \left\{ \sigma_o e^{\varepsilon (\Delta y'_1 + \Delta y'_2)} \right\} \]

5 independent variables

\[ \Delta y_1, \Delta y'_1, \Delta y_2, \Delta y'_2 \]

\[ \Delta y = \Delta y_1 + \Delta y_2 \]

\[ t_1, t_2 \]

Gap probability

\[ \int_{\Delta y, t} \sim s^{2 \varepsilon} / \ln s \]

Sub-energy cross section (for regions with particles)

Same suppression as for single gap!

\[ \Delta y \]
Diffractive dijets @ Tevatron

\[ F^D(\xi, x, Q^2) \propto \frac{1}{\xi^{1+2\varepsilon}} \cdot F(x/\xi, Q^2) \]

\[ \text{reorganize} \]
\[ F^D_{JJ}(\xi, \beta, Q^2) = N_{\text{renorm}} \frac{1}{\xi^{1+2\epsilon}} \cdot \frac{C(Q^2)}{(x/\xi)^x} = \frac{2\epsilon}{(\beta s)^{2\epsilon}} \cdot \frac{1}{\xi^{1+2\epsilon}} \cdot \frac{C(Q^2)}{\beta^x} \]

\[ N_{\text{renorm}}^{-1} = \int_{\xi_{\text{min}}}^{1} \frac{d\xi}{\xi^{1+2\epsilon}} \quad \text{with} \quad \xi_{\text{min}} = \frac{x_{\text{min}}}{\beta} \approx \frac{1}{\beta s} \]

\[ R_{ND}^{SD}(x) = \frac{2\epsilon}{s^{2\epsilon}} \cdot \frac{1}{\xi^{1-\lambda(Q^2)}} \cdot x^{-(2\epsilon)} \]

\[ \epsilon_g = 0.2 \rightarrow x^{-0.4} \]
SD/ND dijet ratio vs. $x_{Bj}\@ CDF$

$$R(x) = \frac{F_{jj}^{SD}(x)}{F_{jj}^{ND}(x)}$$

CDF Run I

$0.035 < \xi < 0.095$

Flat $\xi$ dependence for $\beta < 0.5$

$$R(x) = x^{-0.45}$$
Diffractive DIS @ HERA

J. Collins: factorization holds (but under what conditions?)

Pomeron exchange

Contradicted by direct vs. resolved DIS

Color reorganization

\[ F_2^{D(3)}(\xi, x, Q^2) \propto \frac{1}{\xi^{1+\xi} \cdot F_2(x, Q^2)} \]

\[ F_2^{D(3)}(\xi, \beta, Q^2) \propto \frac{1}{\xi^{1+\xi}} \cdot \frac{C(Q^2)}{(\beta'\xi)^{\lambda(Q^2)}} \propto \frac{1}{\xi^{1+\xi+\lambda(Q)^2}} \cdot \frac{C}{\beta^\lambda} \]
Inclusive vs. diffractive DIS


\[ F_2 \sim x^{-\lambda} \]

\[ F_2^{D(3)}(\xi, \beta, Q^2) \propto \frac{1}{\xi^{1+\varepsilon}} \cdot \frac{C(Q^2)}{(\beta \xi)^{\lambda(Q^2)}} \propto \frac{1}{\xi^{1+\varepsilon} + \lambda(Q^2)} \cdot \frac{C}{\beta^\lambda(Q^2)} \]
Dijets in $\gamma p$ at HERA: the expectation

K. Goulianos, POS (DIFF2006) 055 (p. 8)

Factor of ~3 suppression expected at $W \sim 200$ GeV (just as in pp collisions) for both direct and resolved components.
Dijets in $\gamma p$ at HERA - 2007

Dijets in $\gamma p$

- See figure on right:
  - Same suppression for direct and resolved processes
  - Suppression at low $z^{jets}$ since larger $\Delta \eta$ available for particles
Vector meson production
(Pierre Marage, HERA-LHC 2008)

- suppression of 20-50% at high \( W \) ➞ more room for particles
- suppression at low \(|t|\) for high \( Q^2 \) ➞ same reason
Diffraction at the LHC
FROM EDS 2009, 39 Jun 2009, CERN --Discussion panel

"What can we learn/expect from the LHC experiments?“ K. Goulianos

- goal.............understand the QCD basis of diffraction & discover new physics
- TEV2LHC...confirm, extend, discover...
- Tools...........larger $\sqrt{s} \rightarrow$ larger $\sigma$, $\Delta\eta$ & $E_T$

TODO:

- Elastic, diffractive, and total cross sections
  - Important to study partial cross section components
    - need topology (multiplicity, $E_T$, …)
- Hard diffraction
  - diffractive structure function $\rightarrow$ dijets vs. $W$
  - Multigap configurations
  - jet-gap-jet $\rightarrow$ $d\sigma/d\Delta\eta$ vs. $E_T^{jet}$ $\rightarrow$ BFKL, Mueller-Navelet
Dark Energy

Non-diffractive interactions
Rapidity gaps are formed by multiplicity fluctuations:

\[ P(\Delta y) = e^{-\rho \Delta y}, \quad \rho = \frac{dN_{\text{particles}}}{dy} \]

\( P(\Delta y) \) is exponentially suppressed

Diffractive interactions
Rapidity gaps at \( t=0 \) grow with \( \Delta y \):

\[ \Delta y \approx -\ln \xi = \ln s - \ln M^2 \]

\[ P(\Delta y) \bigg|_{t=0} \sim e^{2\varepsilon \Delta y} \]

2\( \varepsilon \): negative particle density!

Gravitational repulsion?
SUMMARY

- Diffraction results from CDF were presented under the physics theme of factorization breaking in diffraction.
- Results from $\gamma p$ ($\gamma^*p$) interactions at HERA were also discussed focusing on factorization breaking aspects.
- Renormalization of the rapidity gap probability was proposed as the common thread in explaining factorization breaking by eliminating double-counting from overlapping rapidity gaps.
- Suggestions for diffractive studies at the LHC were offered,

thank you for your attendance
The CDF II detectors

RPS acceptance \(~80\%\) for \(0.03 < \xi < 0.1\) and \(|t| < 0.1\)
\( \xi \) & \( \beta \) dependence of \( F^D_{jj} \) – Run I

\[
F^D_{jj}(\beta, \xi) \sim \frac{1}{\beta} \cdot \frac{1}{\xi}
\]

Pomeron dominated

\[
F^D_{jj}(\beta, \xi) \propto \frac{1}{\beta^{1.0 \pm 0.1}} \cdot \frac{1}{\xi^{0.9 \pm 0.1}}
\]

\( E_{T,1,2} \geq 7 \) GeV
\( |t| \leq 1.0 \) GeV^2

Inclusive, 1/N_{incl} dN/d\xi

\( \frac{d\sigma_{incl}}{d\xi} \propto \text{constant} \)