Rapidity Gaps in $\bar{p}p$, $ep$ and $e^+e^-$ Collisions

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For the CDF, ZEUS, H1 and L3 Collaborations

☞ Rapidity gaps between jets at Tevatron and HERA
☞ Rapidity gaps in hadronic $Z$ decays at LEP
☞ Multigap diffraction at Tevatron
Rapidity Gaps between Jets

(Color Singlet Exchange – CSE)

At Tevatron ($\bar{p}p$ collider),

\[ \begin{align*}
\bar{p} & \quad \rightarrow \quad \text{jet} \\
p & \quad \rightarrow \quad \text{jet} \\
\end{align*} \]

\[ \Delta \eta \]

$\rightarrow$ PRL 72, 2332 (1994) : DØ
$\rightarrow$ PRL 74, 885 (1995) : CDF
$\rightarrow$ PRL 76, 734 (1996) : DØ
$\rightarrow$ PRL 80, 1156 (1998) : CDF
$\rightarrow$ PLB 440, 189 (1998) : DØ
$\rightarrow$ PRL 81, 5278 (1998) : CDF

At HERA ($e^+p$ collider),

\[ \begin{align*}
e & \quad \rightarrow \quad \gamma \\
\gamma & \quad \rightarrow \quad \text{jet} \\
\end{align*} \]

\[ \Delta \eta \]

$\rightarrow$ PLB 369, 55 (1996) : ZEUS
$\rightarrow$ hep-ex/0203011 (2002) : H1
$\rightarrow$ Preliminary results (2002) : ZEUS
Rapidity Gaps between Jets at Tevatron

CDF and DØ measured CSE fraction at $\sqrt{s} = 1800$ and 630 GeV

Ratio of CSE fraction

\[ R\left[\frac{630}{1800}\right] = 2.4 \pm 0.7 \pm 0.7 : \text{CDF} \]

\[ R\left[\frac{630}{1800}\right] = 3.4 \pm 1.2 : \text{DØ} \]

CSE fraction vs $E_T$ and $\Delta\eta$ at $\sqrt{s} = 1800$ GeV

- rising trend : DØ
- approx. flat : CDF
- Not inconsistent within errors

PLB 440, 189 (1998) : DØ
PRL 81, 5278 (1998) : CDF
Rapidity Gaps between Jets at HERA: H1

$E_T^{gap}$: total $E_T$ between the two highest $E_T$ jets

- Excess at $E_T^{gap} < 0.5$ GeV over PYTHIA and HERWIG
- Significant difference between PYTHIA and HERWIG (due to different hadronization models)

### Differential Cross Section vs $E_T^{gap}$

- H1 data
- PYTHIA
- HERWIG

$E_T^{jet1} > 6.0$ GeV, $E_T^{jet2} > 5.0$ GeV

$2.5 < \Delta \eta < 4.0$
Rapidity Gaps between Jets at HERA: H1

Gap event: $E_T^{\text{gap}} < E_T^{\text{cut}}$

Gap fraction: $f = \frac{N_{\text{gap}}}{N_{\text{incl}}}$

PYTHIA predictions fall exponentially with $\Delta \eta$

Data distributions are flat or rising: CSE

$E_T^{\text{jet1}} > 6.0$ GeV, $E_T^{\text{jet2}} > 5.0$ GeV

Gap Fraction vs $\Delta \eta$

for different gap definitions

H1 data

PYTHIA
HERWIG

$E_T^{\text{gap}} < 0.5$ GeV

$E_T^{\text{gap}} < 1.0$ GeV

$E_T^{\text{gap}} < 1.5$ GeV

$E_T^{\text{gap}} < 2.0$ GeV
Rapidity Gaps between Jets at HERA : H1

Color Singlet Models :

☞ HERWIG 6.1 + BFKL
☞ PYTHIA 5.7 high-\(t\) \(\gamma\) exchange \((\times 1200)\)

BFKL describes data normalization and shape reasonably well

Gap Fraction vs \(\Delta \eta\)

\[
\begin{align*}
E_T^{\text{jet}1} &> 6.0 \text{ GeV} , \\
E_T^{\text{jet}2} &> 5.0 \text{ GeV}
\end{align*}
\]
Rapidity Gaps between Jets at HERA: ZEUS

$x^{OBS}_\gamma$: momentum fraction of $\gamma$ participating in 2-jet production

- Gap fraction and cross section are larger at high $x^{OBS}_\gamma$
- At high $x^{OBS}_\gamma$, MC models do not describe data well especially at low $\Delta \eta$
- At low $x^{OBS}_\gamma$ where BFKL contribution is larger, data are better described by the model with BFKL

ZEUS

$E_T^{jet1} > 6.0 \text{ GeV}$
$E_T^{jet2} > 5.0 \text{ GeV}$
$2.0 < \Delta \eta < 4.0$

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Rapidity Gaps in Hadronic $Z$ Decays at LEP

At LEP ($e^+e^-$ collider),

Look for rapidity gaps in symmetric 3-jet events produced in $e^+e^-$ annihilations

- hep-ex/0205004 : L3
- [PRL 76, 4886 (1996) : SLD]

$S_{23} \approx S_{31} < S_{q\bar{q}(12)}$
$A^S_{23} \approx A^S_{31} > A^S_{q\bar{q}(12)}$

$S$ : Separation angle, $A^S$ : Asymmetry of $S$

$A^S_{12} = \frac{-S_{12} + S_{23} + S_{31}}{S_{12} + S_{23} + S_{31}}$

- CO simulated by JETSET
- CS simulated using the color flow of $q\bar{q}\gamma$
  - CS0 : $\gamma$ replaced by $q\bar{q}$, then parton shower
  - CS2 : $\gamma$ replaced by $g$, then parton shower
Rapidity Gaps in Hadronic $Z$ Decays at LEP: L3

Data are in good agreement with color octet exchange (JETSET) predictions

Fraction of CSE events, $R$:

$$R = 0.015 \pm 0.030 \ (\text{from fit to } A_{12}^S)$$

$$(\chi^2/d.o.f. = 4.5/11)$$

All estimates of $R$ are compatible with 0

Obtain 95% C.L. upper bound

$$R(95\% \ C.L.) < 6.7(9.0)\%$$

for CS0 (CS2)
Multigap Diffraction: Introduction

Events with one rapidity gap

Single Diffraction (SD)

Double Diffraction (DD)

Events with two rapidity gaps

Single + Double Diffraction (SDD)

Double Pomeron Exchange (DPE)

Regge theory based on factorization

CDF studied inclusive (soft) SD and DD events previously

SD: PRD 50, 5535 (1994)
DD: PRL 87, 141802 (2001)

\[
\alpha_p(t) = 1 + \epsilon + \alpha'_t(\epsilon = 0.104, \text{PLB 389,176})
\]

\[
d^2\sigma_{SD}/dt'd\sigma_{DD}/dt' = \frac{\beta^2(t)}{16\pi} \xi_1 - 2 \alpha_{PR}(t) \beta(0)(t)(s')^\epsilon f_{p/p}(\xi,t)
\]

\[
f_{p/p}(\xi,t) = \text{Pomeron flux factor}
\]

\[
f_p(\beta(t)) g(t) = \text{Pomeron trajectory}
\]

\[
f_{p-p} = \text{Pomeron-IP coupling}
\]

\[
f_{p-\pi^+} = \text{triple-IP coupling}
\]

\[
f_{\Delta p} = \text{fractional momentum loss of } p(p)
\]
Multigap Diffraction: Introduction

Regge theory formula in terms of rapidity gap width

\[ \kappa \equiv \frac{g(0)}{\beta(0)} = 0.17, \quad \xi = e^{-\Delta y}, \quad (s')^\varepsilon = e^{\varepsilon \Delta y'}. \quad \Delta y' = \ln s - \sum \Delta y_i \]

<table>
<thead>
<tr>
<th>Process</th>
<th>Gap Probability ((P_{gap}))</th>
<th>(\sigma_{tot}(\Delta y'))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD: (d^2\sigma_{SD}/dt d\Delta y) = [ \frac{\beta(t)}{4\sqrt{\pi}} e^{(\varepsilon + \alpha' t)\Delta y} ]² (\kappa[\beta^2(0) e^{\varepsilon \Delta y'}])</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DD: (d^3\sigma_{DD}/dt d\Delta y d y_c) = (\kappa \left[ \frac{\beta(0)}{4\sqrt{\pi}} e^{(\varepsilon + \alpha' t)\Delta y} \right]^2 \kappa[\beta^2(0) e^{\varepsilon \Delta y'}])</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DPE: (d^4\sigma_{DPE}/dt_d t_d d\Delta y_d d\Delta y_p) = [ \prod_{i=p,p} \frac{\beta(t_i)}{4\sqrt{\pi}} e^{(\varepsilon + \alpha' t_i)\Delta y_i} ]² (\kappa^2[\beta^2(0) e^{\varepsilon \Delta y'}])</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Regge formulae have unitarity problem, e.g. \(\sigma_{SD}/\sigma_{tot} \rightarrow 1\) at \(\sqrt{s} \sim 2\) TeV


Normalizing the integral of the gap probability \(P_{gap}\) to unity yields the correct \(\sqrt{s}\) dependence of \(\sigma_{SD}\) and \(\sigma_{DD}\). What about \(\sigma_{DPE}\) and \(\sigma_{SDD}\)?
For events triggered on a leading antiproton, plot the distribution of $\xi_p$ obtained by:

$$\xi_p = \frac{M^2}{s \xi_{\bar{p}}} \approx \sum_i \frac{E_{T,i} \exp(+\eta_i)}{\sqrt{s}}$$

- $\xi_p$ distribution $\propto 1/\xi^{1+\epsilon}$
  (The line is from single diffraction)
- The bump at $\xi_p \sim 10^{-3}$ is due to cab. noise

DPE fraction in leading-$\bar{p}$ triggered SD events

<table>
<thead>
<tr>
<th>Source</th>
<th>$R(1800 \text{ GeV})$</th>
<th>$R(630 \text{ GeV})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>$0.197 \pm 0.001 \pm 0.010$</td>
<td>$0.168 \pm 0.001^{+0.015}_{-0.020}$</td>
</tr>
<tr>
<td>Regge $\oplus$ Factorization</td>
<td>$0.36 \pm 0.04$</td>
<td>$0.25 \pm 0.03$</td>
</tr>
<tr>
<td>Renormalized $I^P$-flux (PLB 358,379(1995))</td>
<td>$0.041 \pm 0.004$</td>
<td>$0.041 \pm 0.004$</td>
</tr>
<tr>
<td>Renormalized $P_{gap}$ (hep-ph/0110240)</td>
<td>$0.21 \pm 0.02$</td>
<td>$0.17 \pm 0.02$</td>
</tr>
</tbody>
</table>
Single + Double Diffraction (SDD) Analysis : CDF

\[ \frac{d^5 \sigma_{SDD}}{dt_1 dt_2 d\Delta y_1 d\Delta y_2 dy_c} = P_{gap}(t_1, t_2, \Delta y_1, \Delta y_2, y_c) \times \kappa^2 \beta^2(0)(s')^\epsilon \]

\[
P_{gap} = \left[ \frac{\beta(t_1)}{4\sqrt{\pi}} e^{(\epsilon+\alpha't_1)\Delta y_1} \right]^2 \kappa \left[ \frac{\beta(0)}{4\sqrt{\pi}} e^{(\epsilon+\alpha't_2)\Delta y_2} \right]^2
\]

SDD fraction in leading-\( \bar{p} \) triggered SD events

\[ 0.06 < \xi_1 < 0.09, \ \Delta \eta_2 > 3 \]

<table>
<thead>
<tr>
<th>Source</th>
<th>( R(1800 \text{ GeV}) )</th>
<th>( R(630 \text{ GeV}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>0.252 ± 0.001 ± 0.045</td>
<td>0.192 ± 0.001 ± 0.046</td>
</tr>
<tr>
<td>Regge ⊕ Factorization</td>
<td>0.66 ± 0.07</td>
<td>0.40 ± 0.04</td>
</tr>
<tr>
<td>Renormalized ( P_{gap} )</td>
<td>0.26 ± 0.03</td>
<td>0.21 ± 0.02</td>
</tr>
</tbody>
</table>

(predictions have ±10% uncertainty due to error in \( \kappa \))
Summary of Soft Diffraction Results

Good agreement with renormalized gap predictions

\( SD \)
\[
\begin{array}{c}
\overline{p} \\
p \\
\text{IP} \\
p \\
p \\
\end{array}
\]

\( DD \)
\[
\begin{array}{c}
\overline{p} \\
p \\
\text{IP} \\
p \\
p \\
\end{array}
\]

\( DPE \)
\[
\begin{array}{c}
\overline{p} \\
p \\
\text{IP} \\
p \\
p \\
\end{array}
\]

\( SDD \)
\[
\begin{array}{c}
\overline{p} \\
p \\
\text{IP} \\
p \\
\text{IP} \\
\end{array}
\]

Total Single Diffraction Cross Section (mb)

- \( \sigma \) (mb)
- \( \sqrt{s} \) (GeV)

CDF Data: DPE/SD ratio (Preliminary)

- Regge + Factorization
- Gap Probability Renorm.
- Pomeron Flux Renom.

Good agreement with renormalized gap predictions

CDF Preliminary: two-gaps/one-gap

Regge prediction

Renorm-gap prediction

1-gap

2-gap

CDF: one-gap/no-gap

10^{10}

10^{10}

10^{3}

10^{3}

10^{2}

sub-energy \( \sqrt{s} \) (GeV)

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

Rapidity gaps between jets at Tevatron and HERA

- Evidence of an excess of events with a rapidity gap between jets at both Tevatron and HERA
- BFKL model gives reasonable description of data (H1) at low $x_{\gamma}^{OBS}$ (ZEUS)

Rapidity gaps in hadronic $Z$ decays at LEP

- Data are well explained by color octet exchange alone

Multigap diffraction at Tevatron

- Fractions of DPE and SDD events in SD events are measured at $\sqrt{s} = 1800$ and 630 GeV by CDF
- The measured DPE and SDD fractions are in agreement with renormalized gap predictions
**ZEUS Gaps between Jets**


- $Q^2 < 0.4 \text{ GeV}^2$, 
  $135 < W < 280 \text{ GeV}$

- **Jet**: cone algorithm, $R = 1.0$
  $p_T^{jet1,2} > 6 \text{ GeV}$, 
  $\eta^{jet1,2} < 2.5$, 
  $|\bar{\eta}| < 0.75$, $\Delta \eta > 2.0$

- **Gap**: no particle with $E_T > 300 \text{ MeV}$ between the jet edges
$x_{\gamma}^{jets}$: momentum fraction of $\gamma$ participating in 2-jet production

- Standard photoproduction largely at high $x_{\gamma}$
- Direct events more likely to produce gaps

$E_T^{jet1} > 6.0$ GeV, $E_T^{jet2} > 5.0$ GeV
$2.5 < \Delta \eta < 4.0$
Rapidity Gaps between Jets at HERA: H1

\[ x_p^{jets} \]: momentum fraction of \( p \) participating in 2-jet production

In principle, could distinguish between models coupling preferably to quarks/gluons

Currently, insufficient statistics

\[ E_T^{jet1} > 6.0 \text{ GeV}, \ E_T^{jet2} > 5.0 \text{ GeV} \]
\[ 2.5 < \Delta \eta < 4.0 \]
Rapidity Gaps in Hadronic $Z$ Decays at LEP : L3

Variables sensitive to gaps

Angle from the bisector in gap between jet1 and jet2: $B_{12} = \min(\phi_1, \phi_2)$

Angular Asymmetry for bisector angle:

$$A_{12}^B = \frac{-B_{12} + B_{23} + B_{31}}{B_{12} + B_{23} + B_{31}}$$

$A_{23}^B$ and $A_{31}^B$ are defined similarly

Maximum separation angle between adjacent particles $S_{ij}$

$A_{12}^S$, $A_{23}^S$, and $A_{31}^S$ are defined similarly

Identify quark/gluon jets by

- jet energy ordering (jet1 and jet2 are likely due to primary quarks)
- $B$-tagging ($B$-tag jet1 and jet2, anti-$B$-tag jet3)

Color Octet (CO) | Color Singlet (CS)
---|---
$\psi_{23} \approx \psi_{31} < \psi_{q\bar{q}(12)}$ | $\psi_{23} \approx \psi_{31} > \psi_{q\bar{q}(12)}$
$A_{23}^\psi \approx A_{31}^\psi > A_{q\bar{q}(12)}^\psi$ | $A_{23}^\psi \approx A_{31}^\psi < A_{q\bar{q}(12)}^\psi$
$(\psi = B$ or $S')$
Rapidity Gaps in Hadronic $Z$ Decays at LEP: L3

Rathsman model: PLB 452, 364
(based on Generalized Area Law)

Area of string between partons $i,j$:

$$A_{ij} = 2(p_ip_j - m_im_j)$$

Strong-reinteraction probability:

$$P = R_0[1 - \exp(-b \cdot \Delta A)]$$

The Rathsman model with the default color reconnection parameter ($R_0 = 0.1$) disfavored by data

Fits performed to find the best $R_0$ value

All estimates of $R_0$ compatible with 0

Obtain 95% C.L. upper bound on $R_0$

$$R_0(95\% \text{ C.L.}) < 0.0093$$
Double Pomeran Exchange (DPE) Analysis : UA8

UA8 studied SD and DPE events at CERN $S_{p\bar{p}}S$ collider at $\sqrt{s} = 630$ GeV

$$\frac{d^4\sigma_{\text{DPE}}}{d\xi_{\bar{p}} d\xi_p dt_{\bar{p}} dt_p} = F_{IP/\bar{p}}(\xi_{\bar{p}}, t_{\bar{p}}) \cdot F_{IP/p}(\xi_p, t_p) \cdot \sigma_{IP/\bar{IP}}^{\text{tot}}(s')$$

$f_{IP/p}(\xi, t)$ : Pomeran flux factor

UA8 extracted $\sigma_{IP/\bar{IP}}^{\text{tot}}$ using $F_{IP/p}(\xi, t)$ derived in the SD data analysis by Erhan and Schlein, PLB 481, 177 (2000)

The extracted $\sigma_{IP/\bar{IP}}^{\text{tot}}$ exceeds factorization expectations by an order-of-magnitude
Single Diffractive Cross Section

\[ \xi = \frac{\Delta p}{p} = \frac{M^2(= s')}{s} = e^{-\Delta y} \]

\[ \frac{d^2 \sigma_{SD}}{d \xi dt} = \frac{\beta^2(t)}{16\pi} \xi^2 (s') \left( 1 - 2 \alpha_{IP}(t) \right) \frac{\beta(0)g(t)}{s'} \left( \frac{s'}{s_0} \right) \]

\[ \sigma_{IP}^{tot}(s') = \frac{\alpha_{IP}(t)}{1 + \epsilon + \epsilon' \cdot t} \]

\[ \epsilon = \alpha_{IP}(0) - 1 \]

\[ \kappa = g(0)/\beta(0) \]

\[ (= 0.104 \text{ in PLB 389, 176(1996)}) \]

\[ f_{IP}(\xi, t) : \text{Pomeron flux factor} \]

\[ \alpha_{IP}(t) : \text{Pomeron trajectory} \]

\[ \beta(t) : \text{IP}-p(\bar{p}) \text{ coupling} \]

\[ g(t) : \text{triple-IP} \text{ coupling} \]

\[ \sigma_{SD}^{tot}(s) = \beta^2(0) \left( \frac{s}{s_0} \right) \alpha_{IP}(0) - 1 \]
The ratio reaches unity at $\sqrt{s} \sim 2$ TeV in data, $s^\varepsilon$ in $d\sigma_{SD}/dM^2 \rightarrow 1$.
Soft Single Diffraction Results

**KG&JM : PRD 59, 114017 (1999)**

\[ \frac{d\sigma}{dM^2} \]

- 14 GeV (0.01 < \( \xi \) < 0.03)
- 20 GeV (0.01 < \( \xi \) < 0.03)
- 546 GeV (0.005 < \( \xi \) < 0.03)
- 1800 GeV (0.003 < \( \xi \) < 0.03)

\[ \frac{1}{(M^2)^{1+\Delta}} \]

\( \Delta = 0.05 \)
\( \Delta = 0.15 \)

546 GeV std. flux prediction
1800 GeV std. flux prediction

\[ \frac{d\sigma_{SD}}{dM^2} \]

- Differential cross section shape agrees with Regge predictions (left)
- Normalization is suppressed by flux factor integral (right)

**KG : PLB 358, 379 (1995)**

\[ \sigma_{SD}^{tot} \text{ vs } \sqrt{s} \]

\[ \xi < 0.05 \]

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

Standard flux
Renormalized flux

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Renormalization

Single Diffraction

\[
\frac{d\sigma_{SD}}{d\xi} \propto \frac{1}{\xi^{1+2\epsilon}} \cdot (\xi s)^\epsilon \quad \xi = \frac{M^2}{s} \quad \frac{d\sigma_{SD}}{dM^2} \propto \frac{s^{2\epsilon}}{(M^2)^{1+\epsilon}}
\]

In data: \( s^{2\epsilon} \rightarrow 1 \)

Renormalization

Normalizing the integral of the flux factor/gap probability to unity yields the correct \( \sqrt{s} \) dependence of \( \sigma_{SD} \)

\[
1/N_{ren} = \int_{M_0^2/s}^{0.1} \frac{1}{\xi^{1+2\epsilon}} d\xi \propto s^{2\epsilon}
\]

\[
\frac{d\sigma_{SD}}{dM^2} \propto N_{ren} \times \frac{s^{2\epsilon}}{(M^2)^{1+\epsilon}} \propto \frac{1}{(M^2)^{1+\epsilon}}
\]
Soft Double Diffraction Results

\[
\frac{d^3\sigma_{DD}}{dt d\Delta y dy_c} = \kappa \left[ \beta(0) e^{(\epsilon+\alpha' t)\Delta y} \right]^2 \cdot \kappa [\beta^2(0) e^{\epsilon\Delta y'}]
\]

\[\Delta y' = \ln s' = \ln M_1^2 + \ln M_2^2\]

\[\Delta y \leftarrow \ln M_1^2 \leftrightarrow \Delta y \leftarrow \ln M_2^2\]

CDF: PRL 87, 141802 (2001)

Differential cross section shape agrees with Regge predictions (left)
Normalization is suppressed by flux factor integral (right)
Regge theory prediction based on factorization

\[
\frac{d^4 \sigma_{DPE}}{d \xi_{\bar{p}} d \xi_p dt_{\bar{p}} dt_p} = f_{IP/\bar{p}}(\xi_{\bar{p}}, t_{\bar{p}}) f_{IP/p}(\xi_p, t_p) \left( \kappa^2 \beta^2(0)(s')^\epsilon \right)
\]

\[
\frac{d^4 \sigma_{DPE}}{dt_{\bar{p}} dt_p d\Delta y_{\bar{p}} d\Delta y_p} = \left[ \prod_{i=\bar{p},p} \frac{\beta(t_i)}{4\sqrt{\pi}} e^{[\alpha_{\pi}(t_i) - 1] \Delta y_i} \right]^2 \left( \kappa^2 \beta^2(0)(s')^\epsilon \right)
\]

\[\frac{\sigma_{DPE}}{\sigma_{SD}} \approx 0.36 \ (0.25) \text{ at } 1800 \ (630) \text{ GeV}\]

Renormalized IP-flux model: both \( f_{IP/\bar{p}} \) and \( f_{IP/p} \) are renormalized independently (both gaps are suppressed)  K. Goulianos, PLB 353,379(1995)

\[\frac{\sigma_{DPE}}{\sigma_{SD}} \approx 0.041 \ (0.041) \text{ at } 1800 \ (630) \text{ GeV}\]

Renormalized gap probability model: the combined gap probability is renormalized (only one gap is suppressed)  K. Goulianos, hep-ph/0110240

\[\frac{\sigma_{DPE}}{\sigma_{SD}} \approx \kappa = 0.17 \ [0.21 \ (0.17) \text{ at } 1800 \ (630) \text{ GeV}]\]
$\xi^X$ Calibration at $\sqrt{s} = 1800$ GeV

$\xi^X$ distribution in every $\xi^{RP}$ bin is fitted to

$$f(\xi) = P3 \exp \left( -0.5 \left( \frac{\xi - P1}{P2} + \exp \left( -\frac{\xi - P1}{P2} \right) \right) \right)$$

$P1 : \text{Peak}, \ P2 : \text{Width}$

**CDF Preliminary**

![Graph of $f(\xi) = P3 \cdot \exp \left( -0.5 \left[ \frac{\xi - P1}{P2} + \exp \left( -\frac{\xi - P1}{P2} \right) \right] \right)$](image)

$\sqrt{s} = 1800$ GeV

$0.05 \leq \xi^{RP} < 0.06$

$P2/P1 = 0.606 \pm 0.001$

$P1 = (0.594 \pm 0.001) \times \xi^{RP}$

Use these correlations to
- calibrate $\xi^X$
- take into account $\xi^X$ resol. effect
\[ \xi^X \text{ Calibration at } \sqrt{s} = 630 \text{ GeV} \]

\( \xi^X \) distribution in every \( \xi^{RP} \) bin is fitted to

\[ f(\xi) = P3 \exp \left( -0.5 \left[ \frac{\xi - P1}{P2} + \exp \left( -\frac{\xi - P1}{P2} \right) \right] \right) \]

\( P1 : \) Peak, \( P2 : \) Width

\[ \begin{align*}
\sqrt{s} &= 630 \text{ GeV} \\
0.06 &\leq \xi^{RP} < 0.07
\end{align*} \]

\[ \frac{P2}{P1} = 0.622 \pm 0.003 \]

\[ P1 = (0.407 \pm 0.002) \times \xi^{RP} \]

Use these correlations to
- calibrate \( \xi^X \)
- take into account \( \xi^X \) resol. effect
$\xi_p^X$ distributions at $\sqrt{s} = 1800$ and 630 GeV

CDF Preliminary

$\sqrt{s} = 1800$ GeV
$0.035 < \xi_p < 0.095$
$|t_p| < 1.0$ GeV$

CDF Preliminary

$\sqrt{s} = 630$ GeV
$0.035 < \xi_p < 0.095$
$|t_p| < 0.2$ GeV$

$\xi_p^X$ distributions show $\sim 1/\xi^{1+\epsilon}$ dependence

The $\xi_p^X$-resolution has little effect on the $\xi_p^X$ distribution

The bump at $\xi_p^X \sim 10^{-3}(10^{-2})$ is due to calorimeter noise