Exclusive Central $\pi^+\pi^-$ Production in Proton Antiproton Collisions at the CDF

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on behalf of the CDF Collaboration

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Physics Motivation
Double Pomeron Exchange (DPE)

Pomeron:
- Carrier of 4-momentum between protons
- Strongly interacting color singlet combination of gluons and quarks
- Quantum numbers of vacuum
- LO: $P = gg$
Analysis

GXG reaction

\[ \bar{p} + p \rightarrow \bar{p} (*) + GAP + X + GAP + p (*) \]

- \( X \) (in this study):
- hadron pair mostly \( \pi^+ \pi^- \)
- central \( |y(\pi^+ \pi^-)| < 1.0 \)
- between rapidity gaps \( \Delta \eta > 4.6 \)
- \( Q = S = 0, \ C = +1, \ J = 0 \) or \( 2, \ l=0 \)

Expected to be dominated by DPE in the t-channel!
Collider Detector at Fermilab

\[ \sqrt{s} = 1960 \text{ GeV} \]
\[ \sqrt{s} = 900 \text{ GeV} \]
Collider Detector at Fermilab

We do not detect outgoing protons
Forward detectors in veto

We require all detectors, $|\eta| < 5.9$, to be empty except for two tracks

- BSC – Beam Shower Counters
- CLC – Cherenkov Luminosity Counters
- PCAL – Plug Calorimeter
Central Hadronic State Analysis
Candidates selection

Trigger requirements:

- 2 central ($|\eta|<1.3$) towers with $E_t > 0.5$ GeV
- PCAL (2.11<$|\eta|<3.64$) in veto
- CLC (3.75<$|\eta|<4.75$) in veto
- BSC1 (5.4<$|\eta|<5.9$) in veto

Gap cuts:

To determine noise levels in subdetectors we divide zero-bias sample from same periods into two sub-samples:

<table>
<thead>
<tr>
<th>No Interaction:</th>
<th>Interaction:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• No tracks</td>
<td>At least one</td>
</tr>
<tr>
<td>• No CLC hits</td>
<td>• Track</td>
</tr>
<tr>
<td>• No muon stubs</td>
<td>•.CL C hit</td>
</tr>
<tr>
<td></td>
<td>• Muon stub</td>
</tr>
</tbody>
</table>
Exclusivity cuts
Central Hadronic State Analysis
Candidates selection

Exclusive 2 tracks:

→ Similar technique in region of central calorimeter

→ excluding cones of $R=0.3$ around each track extrapolation.

$$R = \sqrt{(\Delta \eta)^2 + (\Delta \varphi)^2}$$

Additional cuts:

• quality of tracks
• cosmic ray rejection

• 2 oppositely charged tracks

The “hottest” EM tower must be less than 90 MeV
Effective exclusive luminosity

- Determination of efficiency of having no-pileup using zero-bias sample.

  We measure ratio of empty events (all detectors on noise level) to all events.

- Exponential drop with bunch luminosity.

- Slope corresponds to total detected inelastic cross section.

<table>
<thead>
<tr>
<th></th>
<th>1960 GeV</th>
<th>900 GeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{obs}} (</td>
<td>\eta</td>
<td>&lt;5.9)$</td>
</tr>
<tr>
<td>$L_{\text{eff}}$</td>
<td>1.15/pb</td>
<td>0.059/pb</td>
</tr>
</tbody>
</table>

$L$ renormalization factor based on $\sigma_{\text{inel}}^{\text{inel}}$ for 900 GeV: 0.72

Higher dissociation masses allowed at 1960 GeV
Central Hadronic State Analysis
Acceptance and cut efficiency

Model independent analysis

Kinematic cuts:
- $P_t(\pi)>0.4$ GeV/c
- $|\eta(\pi)|<1.3$
- $|y(\pi^+ \pi^-)|<1.0$

3 components:
- Trigger efficiency
- Single track acceptance
- 2 tracks acceptance
Central Hadronic State Analysis

$M(\pi^+\pi^-)$ vs $P_t(X)$ for 1960 GeV

CDF Run II Preliminary

Data, \( \sqrt{s} = 1960 \) GeV

- $P_t(\pi) > 0.4$ GeV/c
- $|\eta(\pi)| < 1.3$
- $|y(X)| < 1.0$

$\frac{d\sigma}{dP_t dM}$ [\( \mu b/(GeV^2/c^3) \)]
Central Hadronic State Analysis

\(M(\pi^+\pi^-) \) vs \(P_t(X)\) for 1960 GeV

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Central Hadronic State Analysis

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CDF Run II Preliminary

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$P_t(\pi) > 0.4$ GeV/c

$|\eta(\pi)| < 1.3$

$|y(X)| < 1.0$

$\frac{d\sigma}{dP_t dM} [\mu b/(GeV^2/c^3)]$
Central Hadronic State Analysis

\(M(\pi^+\pi^-)\) for 1960 GeV

\[ p_T(\pi) > 1.0 \text{ GeV/c} \]
\[ |\eta(\pi)| < 1.3 \]
\[ |y(\pi\pi)| < 1.0 \]

→ Broad continuum below 1 GeV/c\(^2\)
→ Cusp at 1 GeV/c\(^2\)
→ Resonant enhancement around 1.0 – 1.5 GeV/c\(^2\)
dominated by \(f_2(1270)\)
Central Hadronic State Analysis

$M(\pi^+\pi^-)$ for 1960 GeV and 900 GeV

Indications of structure up to 2.4 GeV/c^2
Non-exclusive background

Same sign sample

- The events with two same charge tracks: 6.1% (900 GeV) and 7.1% (1960 GeV)
- Sign of non-exclusive background with 2 or more undetected charged particles:
  → very low pT (no reconstructed track and calorimetric E above the noise level)
  → very forward

The M(π^+π^-) distribution for ++/- - pairs is featureless
→ But! indication of a similar background from π^+π^-π^+π^- events in π^+π^- sample
→ No subtraction
Non-$\pi^+\pi^-$ background

ToF counter information used (coverage in $|\eta|<0.9$)

For $|\eta|<1.3$: 67% of the pairs have both particles identified  
→ $\pi^+\pi^-$ pairs – 89%

For $|\eta|<0.7$: 90% of the pairs have both particles identified  
→ No significant change in the composition

No non-$\pi^+\pi^-$ background subtraction
Conclusions

- We have measured $\pi^+\pi^-$ pairs between large rapidity gaps at the Tevatron, which should be dominated by double pomeron exchange.
- Contribution of non-$\pi^+\pi^-$ pairs background and non-exclusive background is small.
- The mass spectra show several structures:
  - Broad continuum below 1 GeV/c$^2$,
  - Sharp drop at 1 GeV/c$^2$
  - Resonant enhancement around 1.0 – 1.5 GeV/c$^2$.
- This is the only measurement from the Tevatron, and has much higher statistics than preliminary data from the LHC experiments.
MIND THE GAP
Backup slides
Acceptance calculation

Model independent analysis

Kinematics cuts:
- $P_t(\pi)>0.4$ GeV/c
- $|\eta(\pi)|<1.3$
- $|y(X)|<1.0$

3 components:
- Trigger efficiency
- Single track acceptance
- 2 tracks acceptance
Trigger efficiency

1. Sample of min-bias data, good quality isolated (no other tracks in cone with R=0.4) tracks.

2. Checking how often they fired 0, 1, 2 or more trigger towers (>= 4 bits) in 3x3 box around track extrapolation.

3. Trigger efficiency composed from those 3 probability distributions (which are functions of $P_t$ and $\eta$)
Trigger efficiency

Probability of triggering 2 or more towers in the central detector by two independent tracks „a” and „b”:

\[ \varepsilon = P_2(a) + P_1(a) \times [P_1(b) + P_2(b)] + P_0(a) \times P_2(b) \]

- \( P_0 \) – probability of triggering no towers
- \( P_1 \) – probability of triggering one tower
- \( P_2 \) – probability of triggering two or more towers

<table>
<thead>
<tr>
<th></th>
<th>( P_2b )</th>
<th>( P_1b )</th>
<th>( P_0b )</th>
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</thead>
<tbody>
<tr>
<td>( P_2a )</td>
<td>( \times )</td>
<td>( \times )</td>
<td>( \times )</td>
</tr>
<tr>
<td>( P_1a )</td>
<td>( \times )</td>
<td>( \times )</td>
<td></td>
</tr>
<tr>
<td>( P_0a )</td>
<td>( \times )</td>
<td></td>
<td></td>
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</table>
Single track acceptance

1. Single pion generation, flat in phi

2. Acceptance as a function of Pt(track) and eta

- Probability that track will be reconstructed at all
- Probability that track will pass all single track quality cuts
2 tracks cuts acceptance

Cuts:

- 3D opening angle
- $y$ of central state
- Separation
- $\Delta Z_0$

Based on J=0 phase space model

All previous cuts applied before
Invariant mass distribution

CDF Run II Preliminary

Statistical uncertainties only
Not corrected for acceptance

$\sqrt{s} = 1960$ GeV
Partial wave analysis

CDF Run II Preliminary \( P_t(\pi) > 0.4 \text{ GeV/c}, |\eta(\pi)| < 1.3, |y(X)| < 1.0 \)
Partial wave analysis

CDF Run II Preliminary

- $|\eta(\pi)| < 1.3$
- $|y(X)| < 1.0$
- $P_{t}\pi > 0.4$ GeV/c
- $0.8$ GeV < $M_{\pi\pi}$ < $1.5$ GeV

- Data, $\sqrt{s} = 1960$ GeV
- Syst. uncertainties

CDF Run II Preliminary

- $|\eta(\pi)| < 1.3$
- $|y(X)| < 1.0$
- $P_{t}\pi > 0.4$ GeV/c
- $1.5$ GeV < $M_{\pi\pi}$ < $2.0$ GeV

- Data, $\sqrt{s} = 1960$ GeV
- Syst. uncertainties

CDF Run II Preliminary

- $|\eta(\pi)| < 1.3$
- $|y(X)| < 1.0$
- $P_{t}\pi > 0.4$ GeV/c
- $2.0$ GeV < $M_{\pi\pi}$ < $3.0$ GeV

- Data, $\sqrt{s} = 1960$ GeV
- Syst. uncertainties

CDF Run II Preliminary

- $|\eta(\pi)| < 1.3$
- $|y(X)| < 1.0$
- $P_{t}\pi > 0.4$ GeV/c
- $3.0$ GeV < $M_{\pi\pi}$ < $5.0$ GeV

- Data, $\sqrt{s} = 1960$ GeV
- Syst. uncertainties
Partial wave analysis
Partial wave analysis

Comparison of data/MC s-wave $\cos(\theta)$ distributions

$H_0: \cos(\theta)$ distribuants for data and s-wave MC are the same (in mass bins)

- $H_1: \text{not } H_0$.
- Test type: Smirnow
- Test statistics: $\lambda$ Kolmogorov
Partial wave analysis

If p-value is smaller than 0.05 we reject the $H_0$ ($s = 0$) in favour of $H_1$ on the 95% CL.
If p-value is greater than 0.05 we cannot reject the null hypothesis $H_0$ ($s = 0$) on the 95% CL.