Central Exclusive $\pi^+\pi^-$ Production in $p\bar{p}$ Collisions at $\sqrt{s} = 0.9$ and 1.96 TeV in CDF

CDF = Collider Detector at Fermilab

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PHYSICS MOTIVATION

1) Pomeron: Strongly interacting color singlet exchange
Carrier of 4-momentum (t-channel) in elastic scattering
and other diffractive – large rapidity gap – interactions.

Non-perturbative QCD: models required for calculations.
At leading order gluon pair \{gg\} in color singlet.
Vacuum quantum numbers I PC = 0 ++
s-channel continuation would be a glueball \{gg\}

2) Double Pomeron Exchange (DPE): P + P → X
Excellent channel for meson spectroscopy I^{GJ_{PC}} = 0^{+}\text{even}^{++}
Especially for scalar and tensor (J=2) glueballs
Uniquely produced in isolation (or an isolated pair)
Introduction

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

In this study \( X = \pi^+\pi^- \) and central: \(|y(\pi^+\pi^-)| < 1.0\)

\( + \): Rapidity gaps \( \Delta\eta > 4.6 \) with no detected particles.

Allowed t-channel exchanges only \( \gamma \) or \( P \)(dominant)

Quantum numbers of state \( X \) have to be \( Q = S = B = 0 \)

Isospin \( I = 0 \), Parity = +1, C-parity = +1, spin \( J = 0 \) or 2

Established states (PDG): \( f_0(500, 980, 1370, 1500, 1710) \)
\( f_2(1270, 1525, 1950, 2010, 2300, 2340) \)
\( \chi_{c0}(1P), \chi_{c2}(1P), \chi_{c0}(2P), \chi_{c2}(2P) \)
\( \chi_{b0}(1P), \chi_{b2}(1P), \chi_{b0}(2P), \chi_{b2}(2P) \)

\& \ Higgs(125) ! (@ LHC?)
\[ \sqrt{s} = 1960 \text{ GeV} \quad p-p\bar{p} \]
\[ & \quad \sqrt{s} = 900 \text{ GeV} \]
(special run for this & … )

Outgoing protons not detected –
Dissociation e.g. \( p\pi\pi \)
allowed if all \( |\eta| > 5.9 \)

Level 1 Trigger:
2 Calo towers \( |\eta| < 1.3 \) with \( E_T > 0.5 \) GeV
& all these in VETO:

\begin{itemize}
  \item BSC = Beam Shower Counters \( |\eta| = 5.4 - 5.9 \)
  \item CLC = Cherenkov Lumi Counters \( |\eta| = 3.75-4.75 \)
  \item Plug Calorimeter \( |\eta| = 2.11 - 3.64 \)
\end{itemize}
Only single, no pile-up, interactions usable
Data mostly at end of stores when pile-up is low.

Off-line select exactly two tracks on a common vertex
& excluding cones of $R = 0.3$ in calo around extrapolated tracks,
full detector $-5.9 < \eta < +5.9$ “empty” = consistent with noise.

\[
R = \sqrt{\Delta \phi^2 + \Delta \eta^2}
\]

**Determining noise levels (exclusivity cuts)**
Zero bias (bunch crossing) triggers, same periods
Make two distinct classes:
A) “No Interaction” = no tracks, no CLC hits, no muon stubs
B) “Interaction” = All other events

Plot distributions of A and B for $\Sigma E$, $\Sigma$ADC counts, hottest PMT
for each subdetector
Examples of determining noise levels = exclusivity cuts

Good noise-hits separation
Red under noise = genuine gaps

Shift cuts for systematics

These are for the “west” side.  East side plots ~ identical
Applying all exclusivity cuts to zero-bias data →
Probability empty detector fn $L_{\text{bunch}}$ $\varepsilon(\text{excl})$ vs $L_{\text{bunch}}$
-- 36 x 36 bunches not all equal
Intercept = 1.0 (no beams no noise!)
P(0) is exponential
Slope → detected inelastic cross section

| $\sigma_{\text{obs}}(|\eta|<5.9)$ | 1960 GeV | 900 GeV |
|--------------------------------|---------|--------|
| 55.9(4) mb                    | 65.8(4) mb |
| $L_{\text{eff}}$              | 1.15/pb | 0.059/pb |

Higher M(diss.) allowed at 1960 GeV
Provides the effective no-pileup luminosity, convoluting $L_{\text{bunch}}$ distribution of data
Further analysis:
Exactly two tracks, opposite charge (|Q| = 2 kept for B/G control) on a common vertex in interaction region.
Track quality (χ²) cuts, and p_T(track) > 0.4 GeV/c, |η(track)| < 1.3
|y(π+π-)| < 1.0
Additional noise cut on hottest EM tower (E_T < 90 MeV) outside track cones.

Cosmic ray background = 0 after cuts

Final sample:
127,340 events at √s =1960 GeV
6,240 events at √s = 900 GeV
Invariant mass distribution, not corrected for acceptance

Acceptance very low for $M_{\pi\pi} < 1$ GeV/c^2 ($p_T$ cut)
But no significant $\rho$ (forbidden in DPE)
f0(980)/cusp at KK threshold
Strong f2(1270) with f0(1300) shoulder
Structures at higher masses

Need to correct for acceptance!
Components to acceptance x efficiency:

Trigger efficiency ($p_T$, $\eta$, $\phi$)
Single track acceptance ($p_T$, $\eta$, $\phi$)
Two track acceptance ($M_{\pi\pi}$, $p_{T\pi\pi}$, $y_{\pi\pi}$)

… we assume isotropic decay (S-wave): the only model dependence Will be checked by comparing with data … compatible with isotropic?

---

Single track acceptance ($p_T$, $\eta$, $\phi$)

Probability of triggering exactly 1 tower

> At high $p_T$ 2 or more towers trigger
Acceptance x efficiency for $\pi\pi$, function of $M_{\pi\pi}$ and $p_{T\pi\pi}$

Avoid (low M, low $p_T$) hole and edges: select two regions

CDF Run II Preliminary

$p_T > 1 \text{ GeV/c all } M$

$M > 1 \text{ GeV/c}^2 \text{ all } p_T$
Data, corrected for acceptance and efficiencies in $M$, $p_T$ and effective luminosity:

Cross sections, integrated over $p_T$ in two regions (1960 GeV)

Broad continuum below 1 GeV/$c^2$

“Cusp” at KK threshold/f0(980)

Resonance(s) up to 1500 MeV/$c^2$
dominated by f2(1270)

…asymmetric: probable f0(1300)

Change (~dip) at 1500 MeV/$c^2$

Possible higher mass structures
$M_{\pi\pi} > 1600$ MeV/c$^2$ structures?
Fit 1600 – 3600 MeV/c$^2$ to 4$^{th}$ order polynomial

Cannot say more now:
other channels
e.g. KK, KK$\pi\pi$, $\phi\phi$ etc very desirable.
(LHC Low pile-up running?)
Peak at 3100 MeV/c$^2$ is
consistent with photoproduced $J/\psi \to e^+e^-$ (muon stubs were veto’d)
$\sqrt{s}$ dependence 0.9 TeV and 1.96 TeV

\[ R(0.9:1.96) \text{ from } 1000 - 2000 \text{ MeV}/c^2 = 1.284 \pm 0.039 \]
Consistent with $R \sim 1.3$ from Regge phenomenology, $\sigma(p+X+p) \sim 1/\ln(s)$ [but $p^*$ included]

\[ R(0.9:1.96) \text{ from } 2000 < M < 3000 \text{ MeV}/c^2 = 1.560 \pm 0.056. \textbf{Why higher?} \]
Backgrounds
I: Same sign sample (non-exclusive)

- Remove $Q(\pi\pi) = 0$ requirement. Same charge pairs are
- $6.1\%$ (900 GeV) and $7.1\%$ (1960 GeV)
- Some non-exclusive background with 2 or more undetected charged particles. Can be:
  → very low $p_T$ (with no reconstructed track and calorimeter $E/E_T$ below the noise level or in a crack)
  → very forward $|\eta| = 4.75 - 5.40$ or $|\eta| > 5.9$

The $M(\pi\pi)$ distribution for $++/\mp\mp$ pairs is featureless
→ But is indication of a similar background from $\pi^+\pi^-\pi^+\pi^-$ (e.g.) events in $\pi^+\pi^-$ sample
→ We do not subtract.
II: Non-$\pi^+\pi^-$ background

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

For $|\eta|<1.3$: 67% of the pairs have both particles identified.
Of those 89% are $\pi^+\pi^-$ pairs

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

We do not subtract non-$\pi^+\pi^-$ backgrounds; systematics would be large.

Assigning pion masses
Mean $p_T(\pi^+\pi^-)$ as a function of $M_{\pi^+\pi^-}$

Decrease above 1 GeV/c² can be acceptance effect
Sharp jump at 1.5 GeV/c² cannot be. **Interesting region**
Angular distributions (not a full partial wave analysis)

In $\pi^+\pi^-$ frame, cos $\theta$ distribution of $\pi^+$ w.r.t. X direction.
Flat for $J = 0$ S-wave if $4\pi$ coverage, sculpted by central acceptance.
Black points are data, red histogram is S-wave Monte Carlo with acceptance.
Four mass bands: 0.8 < $M$ < 1.5 GeV isotropic (even through f2(1270) peak)
Above 1.5 GeV Forward-Backward peaking.
Conclusions

- We have measured $\pi^+\pi^-$ pairs between large rapidity gaps $\Delta\eta > 4.6$ in CDF at the Tevatron, which should be dominated by double pomeron exchange.
- Contribution of non-$\pi^+\pi^-$ pairs background and non-exclusive backgrounds 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.

Glueballs remain elusive, but this is a promising channel (LHC!)
Thank you
Back Ups
Trigger Efficiency
1500 MeV/c² region? \( f_0(1500) \) as dip in \( \pi\pi \), peak in KK, \( \sigma\sigma \)?

AFS Collaboration (ISR, \( \sqrt{s} = 63 \) GeV)

E690 (FNAL) 800 GeV/c \( \sqrt{s} = 27.4 \) GeV
\( p + K^0 S K^0_S + p \)  Gaps \( \Delta y > 1.2 \& > 3.7 \)

WA102 (Omega) \( \sqrt{s} = 29 \) GeV


\[
|f_0(1710)\rangle = 0.42|\check{G}\rangle + 0.89|\check{S}\rangle + 0.17|\check{N}\rangle,
|f_0(1500)\rangle = -0.61|\check{G}\rangle + 0.37|\check{S}\rangle - 0.69|\check{N}\rangle,
|f_0(1370)\rangle = 0.65|\check{G}\rangle - 0.15|\check{S}\rangle - 0.73|\check{N}\rangle.
\]