Properties of the X(3872) State

Isaac Hall

University of Oklahoma

Representing the DØ Collaboration
Overview

• First observed by Belle. Confirmed by CDF, DØ, BaBar.
• The quark makeup of X(3872) unknown
• Theories include:
  – Another charmonium state
  – D D* molecular state
• Since the X(3872) lies close in mass to the ψ(2S) charmonium state, and has a common decay mode (X → J/ψ π⁺ π⁻), we compare production and decay properties of these two states through this decay mode.
Belle & Babar

Belle, PRL 91 (2003) 262001
Mass $3872.0 \pm 0.6 \pm 0.5$ MeV

~35 candidates

BaBar: hep-ex/0406022
Probing different production mechanisms in hadronic collisions

Belle & Babar

Tevatron: D0 and CDF

Via B decays

and/or

"Prompt"

D0: hep-ex/0405044 (sub.)
CDF: hep-ex/0312021 (acc.)
Comparison channel: $\psi(2S)$

At DØ

Via $B$ decays

~20%

and

Resolution

"Prompt"

~80%

Isolation

"Prompt"

Tevatron: DØ and CDF

Via $B$ decays

and/or
Data and Analysis

- Used ~225 pb\(^{-1}\) data collected by the DØ detector between April 2002 and January 2004.
  - selected events that passed any dimuon trigger
- Reconstruct a J/ψ from 2 well identified muons
  - Add 2 tracks, assuming each track is a charged pion.
  - Look for signal in ΔM, \(M(\mu^+\mu^-\pi^+\pi^-) - M(\mu^+\mu^-)\) to improve resolution.
  - large backgrounds
Cuts

• Cuts designed to reduce background while keeping a reasonable signal of $\psi(2S)$
  – At least two of the $\mu^+ \mu^- \pi^+ \pi^-$ tracks must have at least one silicon hit.
  – Require a good vertex.
    • $(\mu^+ \mu^- \pi^+ \pi^-)$ Vertex $\chi^2 < 16$ for 5 degrees of freedom
  – There must be less than 100 tracks in the event.
  – Dimuon invariant mass must be between 2.8 and 3.4 GeV/c$^2$
  – $P_T(J/\psi) > 5$ GeV/c
  – $P_T(\pi) > 0.7$ GeV/c
  – Spatial separation cut to keep pions near the $X$ candidate
    • $\Delta R$, the spatial separation ($\sqrt{\Delta \eta^2 + \Delta \phi^2}$) of each pion with respect to the $J/\psi \pi \pi$ system must be $< 0.4$
  – $M(\pi\pi) > 0.52$ GeV/c$^2$
X(3872) at DØ

• After applying all cuts, we arrive at the following:
  – mass spectrum in
  \[ \Delta M = M_{\mu\mu\pi\pi} - M_{\mu\mu} \]
  to improve resolution
    • effectively \( M_X - M_{J/\psi} \)
  – Systematic from uncertainty in momentum scale.

\[ \Delta M = 0.7749 \pm 0.0031 \text{(stat)} \pm 0.0030 \text{(syst)} \text{ GeV}/c^2 \]

522 ± 100 events
Comparison to $\psi(2S)$

- Compared production and decay ratios of $X(3872)$ and $\psi(2S)$ in production and decay variables
- For each variable, split into two subsamples, a and b and form ratio:
  \[ \frac{N_a}{(N_a + N_b)} \]
- **Production Variables:**
  - $P_T (J/\psi \pi \pi)$
    - a: <15 GeV
    - b: >15 GeV
  - Rapidity ($|y|$)
    - a: <1
    - b: >1
  - x-y decay length (dl)
    - a: <100 microns
    - b: > 100 microns
    - gives an idea of prompt vs from B-decay
Comparison to $\psi(2S)$

- Decay variables:
  - Isolation
    - $a: =1$
    - $b: <1$
      » Isolation is defined as the ratio of the $X(3872)$ momentum to the sum of the $X(3872)$ momentum and the momentum of all other particles in a cone of 0.5
  - $\cos(\theta_\pi)$
    - $a: <0.4$
    - $b: >0.4$
      » $\cos(\theta)$ is found by boosting the $X(3872)$ and one of the pions (or muons) into the dipion (or dimuon) rest frame and measuring the angle between these two particles
      » Helicity of dipion (or dimuon) system can be inferred from this angle
  - $\cos(\theta_\mu)$
    - $a: <0.4$
    - $b: >0.4$
Comparison to $\psi(2S)$

- After splitting data into 2 subsamples, fit the mass spectrum to obtain the number of $\psi(2S)$ and $X(3872)$ in each region.
- Example: rapidity →
Comparison

• Observe no significant differences between $\psi(2S)$ and $X$

• This comparison will be more useful once we have models of the production and decay of, e.g., meson molecules that predict the observables used in the comparison.
  – such as Braaten, hep-ph/0408230
Conclusions and plans

- DØ confirms the existence of $X(3872)$ and measures the mass difference
  - $\Delta M = M_{X(3872)} - M_{J/\psi} = 0.7749 \pm 0.0031 \text{ (stat)} \pm 0.0030 \text{ (syst)} \text{ GeV}$

- Further, in the production and decay properties examined, the $X(3872)$ is consistent with $\psi(2S)$ charmonium state.

- Future
  - Measure prompt fraction. [e.g. using decay length, isolation]
  - Search for radiative decays
  - Search for charge conjugate of the $X$ in $X^+ \rightarrow J/\psi \pi^+\pi^0$
    - reconstruction of neutrals is difficult, but progress has been made
  - $m(\pi^+\pi^-)$ spectrum
Backup slides
Systematic Error

- Linear scaling of mass difference between $\Psi(2S)$ and $J/\Psi$ for DØ and the same quantity as accepted by PDG.