Confirmation of \( p\bar{p} \) Mass Threshold Enhancement and X(1835) at BESIII

Huang Yanping
For BESIII Collaboration

Institute of High Energy Physics (IHEP)

Hadron09, Tallahassee, Nov 30-Dec 04, 2009
Outline

- Introduction and Motivation
- $p\bar{p}$ mass threshold study in $J/\psi$ and $\psi(2S)$ radiative decays
- Confirmation of $X(1835)$ in $J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$
- Summary
Introduction

- Hadrons consist of 2 or 3 quarks:

  Naive Quark Model:
  
  Meson (q \bar{q})
  Baryon (q q q)

- New forms of hadrons (QCD):
  
  • Multi-quark states: Number of quarks \geq 4
  • Hybrids: qqqg, qqqqg ...
  • Glueballs: gg, ggg ...

How quarks/gluons form a hadron is far from being well understood.
Motivation

- Multi-quark states, glueballs and hybrids have been searched for experimentally for a very long time, but none is established.
- However, during the past three years, a lot of surprising experimental evidences showed the existence of hadrons that cannot (easily) be explained in the conventional quark model.
  - $pp$ threshold enhancement was observed in $J/\psi \rightarrow \gamma pp$
  - $X(1835)$ was observed in $J/\psi \rightarrow \gamma \pi^+\pi^-\eta'$

With $\sim110M \psi(2S)$ data and $\sim220M J/\psi$ data:
We have a good chance to confirm the existence of $pp$ threshold enhancement and $X(1835)$
**pp** mass threshold study in \(J/\psi\) and \(\psi(2S)\) radiative decays

- Review of previous experimental results

- **pp** mass threshold study
  - \(\psi(2S) \rightarrow \pi\pi J / \psi (J / \psi \rightarrow \gamma pp)\)
  - \(J / \psi \rightarrow \gamma pp\)
  - \(\psi(2S) \rightarrow \gamma pp\)
Observation of an anomalous enhancement near the threshold of $p\bar{p}$ mass spectrum

$J / \psi \rightarrow \gamma p\bar{p}$

**theoretical speculation:**
- $p\bar{p}$ bound state (baryonium)
- FSI effect
- ……
The narrow threshold enhancement is not observed in those channels.

No significant narrow strong enhancement near threshold (~2σ if fitted with X(1860))
Summary on the previous experimental results

- The strong and narrow $p\bar{p}$ mass threshold enhancement has only been observed in $J/\psi$ radiative decay, not in any other place so far.

- Any model trying to interpret the mass threshold enhancement should also answer why it is not observed in other places, especially in $\psi(2S)$ and $Y(1S)$ radiative decays as well as in $J/\psi \rightarrow \omega \ p\bar{p}$ process.
Event Selection for $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow \gamma p\bar{p}$

**Initial Selection Criteria:**

- $N_{\text{charged}} = 4$, $N_\gamma \geq 1$
- Particle ID: $n_p = 1$, $n_{\bar{p}} = 1$
- $\chi^2_{4C}(\gamma \pi^+ \pi^- p\bar{p}) < 100$

**Final Selection Criteria:**

- Reconstruction of $J/\Psi$: $\left| M_{\pi\pi_{\text{recoiling}}} - M_{J/\psi} \right| < 6\, \text{MeV}$
- $|U_{\text{miss}}| < 0.04$
- $P^2_{t\gamma} < 0.0005$
- $M_{\pi^+ \pi^- p\bar{p}} < M_{\psi} - 15\, \text{MeV}$
Mass Spectrum and Dalitz Plot

\[ \psi(2S) \rightarrow \pi^+ \pi^- J / \psi, J / \psi \rightarrow \gamma p\bar{p} \]

- Narrow threshold enhancement is evident in \( p\bar{p} \) mass spectrum.
- There is no obvious N* state.
Background study

- **$J/\psi$ sideband region**
  - ~2%

- **Inclusive MC sample**
  - $\psi(2S) \rightarrow \pi\pi J/\psi (J/\psi \rightarrow \pi^0 p\bar{p})$

- **Exclusive MC sample**
  - ~5%

- **Main background in data**
  - $\psi(2S) \rightarrow \pi^+\pi^- J/\psi (J/\psi \rightarrow \pi^0 p\bar{p})$

No threshold enhancement
Mass spectrum fitting method

- **Fit function:**
  - **signal:** acceptance weighted S-wave BW function: \( BW(M) \propto \frac{q^{(2l-1)}k^3}{(M^2 - M_0^2)^2 + M^2\Gamma^2} \)
  - \( q \): the proton momentum in cms of ppb
  - \( k \): the photon momentum
  - \( k \): the ppb orbital angular momentum
  - **background shape:** \( f_{bkg}(\delta) = \delta^{1/2} + a_1\delta^{3/2} + a_2\delta^{5/2} \)
    - \( a_1 \) and \( a_2 \) are obtained from uniform phase space MC sample
Mass spectrum fitting result

\( J / \psi \rightarrow \gamma p\bar{p} \)

\( \psi(2S) \rightarrow \pi^+ \pi^- J / \psi, J / \psi \rightarrow \gamma p\bar{p} \)

\[
M = 1859^{+3}_{-10} \quad 5^{+5}_{-25} \text{ MeV/c}^2 \\
\Gamma < 30 \text{ MeV/c}^2 \text{ (90\% CL)}
\]

\[
M = 1865 \pm 5 \text{ MeV/c}^2 \\
\Gamma < 33 \text{ MeV/c}^2 \text{ (90\% CL)}
\]

PRL 91 (2003) 022001
$p\bar{p}$ invariant mass spectrum and Dalitz plot

$J/\psi \rightarrow \gamma p\bar{p}$

Significant narrow threshold enhancement exists
Fit result:

Mass = 1861.6 ± 0.8 MeV / c^2

Γ < 8 MeV (90% CL)

M = 1859^{+3}_{-10}^{+5}_{-25} MeV/c^2

Γ < 30 MeV/c^2 (90% CL)
$p\bar{p}$ threshold mass spectrum in $\psi(2S)$ radiative decay

No significant narrow strong enhancement near threshold ($\sim 2\sigma$ if fitted with $X(1860)$)

FSI interpretation of the narrow and strong $p\bar{p}$ threshold enhancement is disfavored.
Analysis in $J / \psi \rightarrow \gamma \pi^+ \pi^- \eta'$

- Review of BESII results

- Analysis in $J / \psi \rightarrow \gamma \pi^+ \pi^- \eta' (\eta' \rightarrow \gamma \rho, \rho \rightarrow \pi^+ \pi^-)$

- Analysis in $J / \psi \rightarrow \gamma \pi^+ \pi^- \eta' (\eta' \rightarrow \pi^+ \pi^- \eta)$

- Combination of the two channels
Observation of X(1835) in $J/\psi \rightarrow \gamma \pi^+ \pi^- \eta'$ at BESII

Statistical Significance $\sim 6 \sigma$

Statistical Significance $\sim 5.1 \sigma$

PRL 95,262001(2005)
Motivation

- Confirmation of $X(1835)$ is necessary with high statistic data sample.

- LQCD predicts the glueball mass of $0^{-+}$ is $\sim 2.3\text{GeV}$.

- For $0^{-+}$ glueball, it may have similar property as $\eta_c$ (the main decay mode is $\pi\pi\eta'$).

- It is important and interesting for $J/\psi \rightarrow \gamma\pi^+\pi^-\eta'$ study.
Event selection for $J/\psi \rightarrow \gamma\pi^+\pi^-\eta'(\eta' \rightarrow \gamma\rho)$

**Initial selection criteria:**

- $N_{\text{charged}} = 4$, $N_\gamma \geq 2$
- $N_\pi > 2$
- Kinematic fit(4C):
  $$\chi^2_{4C}(\gamma\pi^+\pi^-\pi^+\pi^-) < 40$$
  $$\chi^2_{4C}(\gamma\pi^+\pi^-\pi^+\pi^-) < \chi^2_{4C}(\gamma\pi^+\pi^-\pi^+\pi^-)$$

**Final selection criteria:**

- Reduce background from $\pi^0\pi^+\pi^-\pi^+\pi^-$:
  $$|m_{\gamma\gamma} - m_\pi| < 0.04 GeV$$
  $$|m_{\gamma\gamma} - m_\eta| < 0.03 GeV$$
  $$0.72 GeV < m_{\gamma\gamma} < 0.82 GeV$$

Selection for $\rho$ and $\eta'$ signal:

- $|M_{\pi\pi} - m_\rho| < 0.2 GeV$
- $|M_{\gamma\rho} - m_{\eta'}| < 0.018 GeV$
Mass spectrum of $\pi^+ \pi^- \eta'$

- Significant peak at M~1835MeV
- Statistic significance of X(1835) is about 18 $\sigma$
Background study

- \( \eta' \) sideband:
  - No clear peak at \( M \approx 1835\text{MeV} \)

- Inclusive sample
  - main background channel:
    \[ J / \psi \rightarrow \rho \pi \eta' \]

- Analysis of \( J / \psi \rightarrow \pi^0 \pi^+ \pi^- \eta' \) in data
  - No enhancement at \( M \approx 1835\text{MeV} \)
Event selection for $J / \psi \rightarrow \gamma\pi^+\pi^-\eta'(\eta' \rightarrow \pi^+\pi^-\eta)$

- Initial selection criteria:
  - $N_{\text{charged}}=4, \ N_{\gamma} \geq 3$
  - $N_{\pi}>2$
  - Kinematic fit (4C,5C):
    - $\chi^2_{4C}(\gamma\gamma\pi^+\pi^-\pi^+\pi^-)<40$
    - $\chi^2_{5C}(\gamma\eta\pi^+\pi^-\pi^+\pi^-)<40$

- Final selection criteria:
  - selection for $\eta$ and $\eta'$ signal:
    - $|M_{\gamma\gamma} - m_\eta| < 0.03\text{GeV}$
    - $|M_{\pi\pi\eta} - m_{\eta'}| < 0.01\text{GeV}$
Mass spectrum of $\pi\pi\eta'$

- Significant peak at $M \sim 1835\text{MeV}$
- Statistic significance of $X(1835)$ is about 9 $\sigma$
Background study

- $\eta'$ sideband:
  - No clear peak at $M \sim 1835$ MeV

- Inclusive sample
  - Main background channel:
    \[ J / \psi \rightarrow \rho \pi \eta' \]

- Analysis of $J / \psi \rightarrow \pi^0 \pi^+ \pi^- \eta'$ in data

No enhancement at $M \sim 1835$ MeV
Combined mass spectrum of the two decay modes

The signal of $X(1835)$ is obvious

BESIII preliminary
Mass spectrum fitting

Whether there are two new resonances, further careful study is needed.

**Fit result (Statistic significance ~ 21σ):**

\[ M = 1842.4 \pm 2.8 \text{(stat)} \text{MeV} \]
\[ \Gamma = 99.2 \pm 9.2 \text{(stat)} \text{MeV} \]

**BESII result (Statistic significance ~ 7.7σ):**

\[ M = 1833.7 \pm 6.1 \text{(stat)} \pm 2.7 \text{(syst)} \text{MeV} \]
\[ \Gamma = 67.7 \pm 20.3 \text{(stat)} \pm 7.7 \text{(syst)} \text{MeV} \]
Summary

☆ The mass threshold enhancement of $p\bar{p}$ have been confirmed at both $\psi(2S) \rightarrow \pi\pi J / \psi (J / \psi \rightarrow \gamma p\bar{p})$ and $J / \psi \rightarrow \gamma p\bar{p}$

☆ The threshold enhancement from $\psi(2S)$ data: $M=1865 \pm 5\text{MeV}, \Gamma < 33\text{MeV}(90\%\text{CL})$

☆ There is no significant narrow enhancement in $\psi(2S) \rightarrow \gamma p\bar{p}$

☆ $X(1835)$ is confirmed in two decay modes of $\eta'$ for $J / \psi \rightarrow \gamma \pi^+\pi^-\eta'$

☆ Whether $X(1860)$ and $X(1835)$ are the same resonance, still needs further study.
Thank You
Event selection for
\( \mathcal{J} / \psi \rightarrow \gamma \pi^+ \pi^- \eta' (\eta' \rightarrow \gamma \rho, \rho \rightarrow \pi^+ \pi^-) \)

- **Initial selection criteria:**
  - \( N_{\text{charged}} = 4, \ N_\gamma \geq 2 \)
  - \( N_\pi > 2 \)
  - Kinematic fit(4C):
    \[ \chi^2_{4C}(\gamma\pi^+ \pi^- \pi^+ \pi^-) < 40 \]
    \[ \chi^2_{4C}(\gamma\pi^+ \pi^- \pi^+ \pi^-) < \chi^2_{4C}(\gamma\pi^+ \pi^- \pi^+ \pi^-) \]

- **Final selection criteria:**
  - Reduce background from \( \pi^0 \pi^+ \pi^- \pi^- \) :
    \[ |m_{\gamma\gamma} - m_\pi| < 0.04 GeV \]
    \[ |m_{\gamma\gamma} - m_\eta| < 0.03 GeV \]
    \( 0.72 GeV < m_{\gamma\gamma} < 0.82 GeV \)
  - Selection for \( \rho \) and \( \eta' \) signal:
    \[ |M_{\pi\pi} - m_\rho| < 0.2 GeV \]
    \[ |M_{\gamma\rho} - m_\eta'| < 0.018 GeV \]
Event selection for \( \psi \rightarrow \gamma\pi^+\pi^-\eta' (\eta' \rightarrow \pi^+\pi^-\eta) \)

- **Initial selection criteria:**
  - \( N_{\text{charged}} = 4, \ N_{\gamma} \geq 2 \)
  - \( N_{\pi} > 2 \)
  - Kinematic fit(4C,5C):
    \[
    \chi^2_{4C} (\gamma\gamma\pi^+\pi^-\pi^+\pi^-) < 40
    \]
    \[
    \chi^2_{5C} (\gamma\eta\pi^+\pi^-\pi^+\pi^-) < 40
    \]

- **Final selection criteria:**
  - selection for \( \eta \) and \( \eta' \) signal:
    \[
    | M_{\gamma\gamma} - m_\eta | < 0.03 \text{GeV}
    \]
    \[
    | M_{\pi\pi\eta} - m_{\eta'} | < 0.01 \text{GeV}
    \]
Efficiency study

- Since the generator we used to produce $\psi' \rightarrow \pi\pi J/\psi$ has correct $J/\psi$ angular distribution, so we can get correct efficiency dependence on invariant mass $p\bar{p}$.

- However, we need to check the DATA/MC consistency, and if there is any difference, we should correct mc efficiency.