



质子偶素：理论与实验

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Experiment: News from BESIII

PHYSICAL REVIEW LETTERS **132**, 151901 (2024)

Editors' Suggestion

Featured in Physics

Observation of the Anomalous Shape of $X(1840)$ in $J/\psi \rightarrow \gamma 3(\pi^+ \pi^-)$ Indicating a Second Resonance Near $p\bar{p}$ Threshold

M. Ablikim *et al.*^{*}
(BESIII Collaboration)

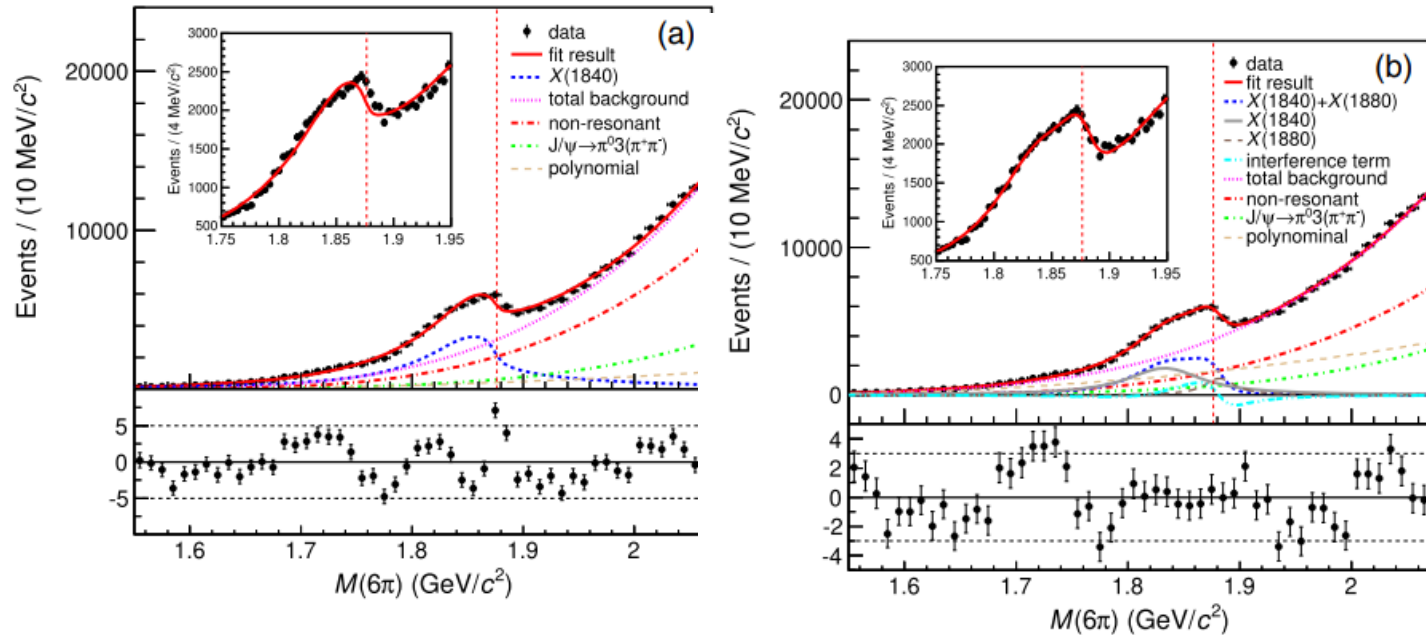


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利用100亿J/psi事例，分析 $J/\psi \rightarrow \gamma 3(\pi^+ \pi^-)$ 衰变道

Observation of $p+p\bar{p}$ state?

Experiment: X(1840)+X(1880)



Supports the existence of $p+\bar{p}$ states

Theoretical prediction of baryonium

PHYSICAL REVIEW D **72**, 034027 (2005)

Baryonium with a phenomenological Skyrmion-type potential

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In this paper, we investigate the nucleon-antinucleon static energies in the Skyrme model with the product *Ansatz*. The calculation shows that, in the ungroomed $S\bar{S}$ (Skyrmion and anti-Skyrmion) channel which leads to rapid annihilation, there exists a quasistable bound state which may give a natural explanation for the near-threshold enhancement in the proton-antiproton ($p\bar{p}$) mass spectrum reported by the BES Collaboration and the Belle Collaboration. Similar to the phenomenological well potential of the deuteron, we construct a phenomenological Skyrmion-type potential to study this narrow $p\bar{p}$ -resonance in $J/\psi \rightarrow \gamma p\bar{p}$. By this potential model, a $p\bar{p}$ baryonium with small binding energies is suggested and the decay width of this state is calculated by WKB approximation. In this picture the decay is attributed to quantum tunneling and $p\bar{p}$ annihilation. Prediction on the decay mode from the baryonium annihilation at rest is also pointed out.

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M.-L. Yan, S. Li, B. Wu, B.-Q. Ma, PRD 72 (2005) 034027, hep-ph/0405087

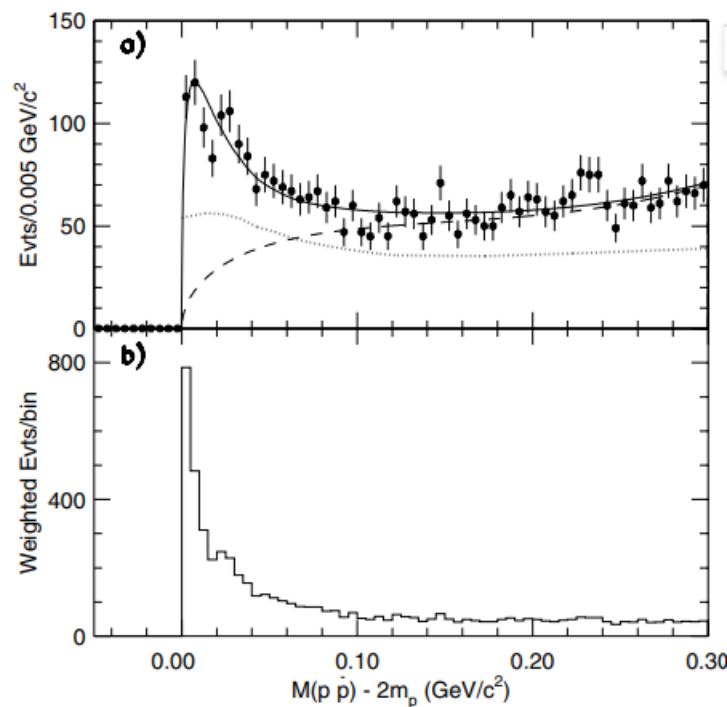
An earlier BES experiment

VOLUME 91, NUMBER 2

PHYSICAL REVIEW LETTERS

week ending
11 JULY 2003

Observation of a Near-Threshold Enhancement in the $p\bar{p}$ Mass Spectrum from Radiative $J/\psi \rightarrow \gamma p\bar{p}$ Decays



利用5800万J/psi事例，分析 $\gamma + p + pbar$ 衰变道

Observation of a new state X(1859)?

Different interpretations

- **Baryonium $p+pbar$ state**

A. Datta and P.J. O'Donnell, Phys. Lett. B 567 (2003) 273

M.-L. Yan, S. Li, B. Wu, B.-Q. Ma, PRD 72 (2005) 034027, hep-ph/0405087

- **Flavorless gluon state**

J. L. Rosner, Phys. Rev. D 68 (2003) 014004

- **Final state interaction**

B. S. Zou and H.C. Chiang, Phys. Rev. D 69 (2004) 034004

B. Kerbikov, A. Stavinsky, and V. Fedotov, Phys. Rev. C 69 (2004) 055205

- **Quark fragmentation process**

J. L. Rosner, Phys. Rev. D 68 (2003) 014004

Baryonium from a Skyrmion-type potential model

- Skyrmion: Skyrme proposed that solitons from the $SU(2)$ chiral fields can describe nucleon static properties from the theory.
- The soliton picture of baryons is consistent with QCD in the large N_c limit, as shown by Witten.
- We treat the skyrmion and anti-skyrmion system and find a solution of bound state near the $2m_p$.
- Then we construct a Skyrmion-type potential model for proton-anti-proton with the existence of a protonium.

The skyrmion and anti-skyrmion system

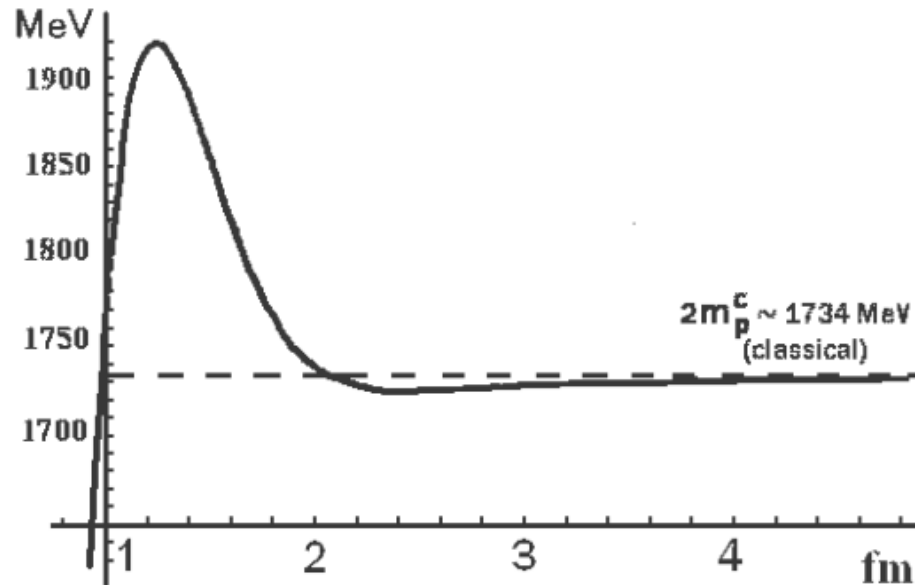


FIG. 1. The static energy of the Skyrmion–anti-Skyrmion system, where m_p^c is the classical single Skyrmion mass without quantum correction.

M.-L. Yan, S. Li, B. Wu, B.-Q. Ma, PRD 72 (2005) 034027, hep-ph/0405087

A phenomenological model with skyrmion-type potential

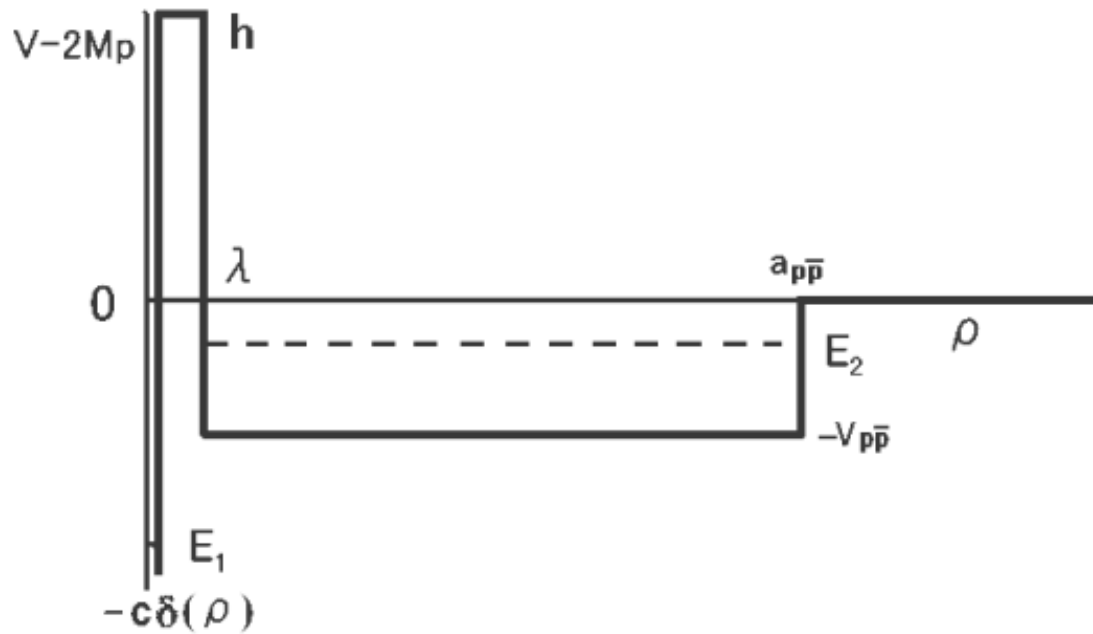


FIG. 2. The Skyrmon-type potential of the $p\bar{p}$ -system.

M.-L. Yan, S. Li, B. Wu, B.-Q. Ma, PRD 72 (2005) 034027, hep-ph/0405087

A Skyrmion-type potential model

- We conclude that the near-threshold narrow enhancement in the $p\bar{p}$ invariant mass spectrum from J/ψ to $\gamma p + p\bar{p}$ might be interpreted as a state of protonium.
- We predict new decay mode: the baryonium hadronic decay should also mostly favor processes with 4 to 7 pseudoscalar mesons in the final states over those with two or three mesons.
- This prediction is nontrivial and has been confirmed by EBS experiments.

**Observation of the Anomalous Shape of $X(1840)$ in $J/\psi \rightarrow \gamma 3(\pi^+ \pi^-)$
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(BESIII Collaboration)

Prediction of a new baryonium decay mode

M.-L. Yan, S. Li, B. Wu, B.-Q. Ma, PRD 72 (2005) 034027, hep-ph/0405087

two or three pions [23]. Considering that the binding energy of the nucleon (or antinucleon) is rather small (compared with the mass of nucleon), the annihilation of the baryonium occurs nearly at rest. Therefore, we would predict that the baryonium hadronic decay should also mostly favor processes with 4 to 7 pseudoscalar mesons in the final states over those with two or three mesons, even though the phase spaces for the latter are larger than the former. This prediction is nontrivial and needs to be tested by experiments.

**Observation of the Anomalous Shape of $X(1840)$ in $J/\psi \rightarrow \gamma 3(\pi^+ \pi^-)$
Indicating a Second Resonance Near $p\bar{p}$ Threshold**

M. Ablikim *et al.*^{*}
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Earlier suggestions to attribute pion as protonium

- E. Fermi and C.N. Yang, Phys. Rev. 76, 1739 (1949).
- Y. Nambu and G. Jona-Lasinio, Phys. Rev. 122, 345 (1961); 124, 246 (1961).

Such ideas have been superseded by the creation of the quark model

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- Tao Huang, Shi-Lin Zhu, X(1835): A Natural candidate of eta-prime's second radial excitation, Phys.Rev.D 73 (2006) 014023

More detailed BES analyses

CPC(HEP & NP), 2010, **34**(4): 421–426

Chinese Physics C

Vol. 34, No. 4, Apr., 2010

Observation of a $p\bar{p}$ mass threshold enhancement in $\psi' \rightarrow \pi^+\pi^- J/\psi (J/\psi \rightarrow \gamma p\bar{p})$ decay*

PRL **108**, 112003 (2012)

PHYSICAL REVIEW LETTERS

week ending
16 MARCH 2012

Spin-Parity Analysis of $p\bar{p}$ Mass Threshold Structure in J/ψ and $\psi(3686)$ Radiative Decays

A partial wave analysis of the $p\bar{p}$ mass-threshold enhancement in the reaction $J/\psi \rightarrow \gamma p\bar{p}$ is used to determine its J^{PC} quantum numbers to be 0^{-+} , its peak mass to be below threshold at $M = 1832_{-5}^{+19}(\text{stat})_{-17}^{+18}(\text{syst}) \pm 19(\text{model}) \text{ MeV}/c^2$, and its total width to be $\Gamma < 76 \text{ MeV}/c^2$ at the 90% C.L. The product of branching ratios is measured to be $\text{BR}[J/\psi \rightarrow \gamma X(p\bar{p})]\text{BR}[X(p\bar{p}) \rightarrow p\bar{p}] =$

With the inclusion of Julich-FSI effects, the mass is measured to be $M=1832 \text{ MeV}/c^2$.

More theoretical works on baryoniums

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Theoretical works on heavy baryoniums

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One explanation for the exotic state $Y(4260)$
- C.-F. Qiao, J.Phys.G 35 (2008)
A Uniform description of the states recently observed at B-factories
- Y.D. Chen & C.-F. Qiao, Phys.Rev.D 85 (2012) 034034
Baryonium Study in Heavy Baryon Chiral Perturbation Theory
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This talk is based on a review

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质子偶素：实验发现及理论预言  CrossMark 

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科学通报 (2004)

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arXiv:2406.19180

Protonium: 质子偶素的理论预言及BES实验发现

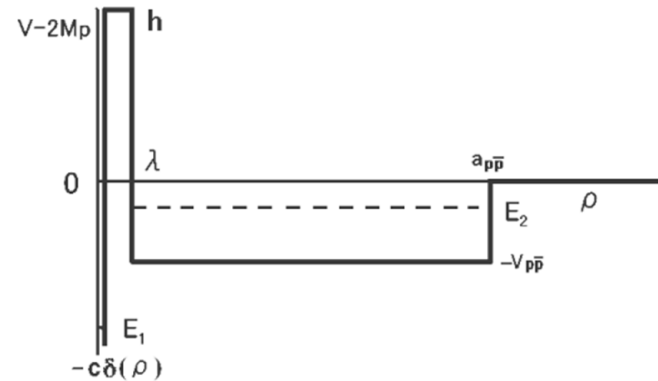
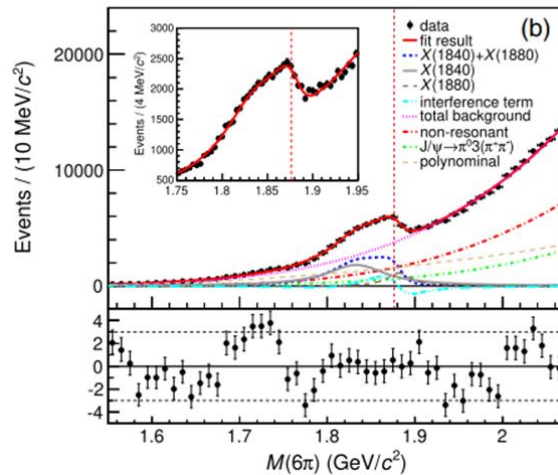
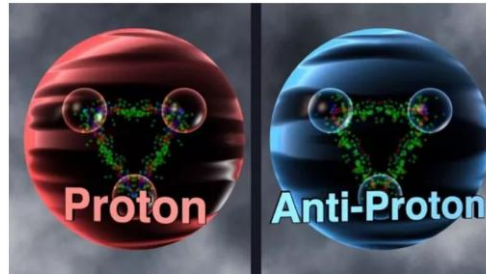


FIG. 2. The Skyrmin-type potential of the $p\bar{p}$ -system.

M.Yan, S.Li, B.Wu, B.-Q. Ma, Phys.Rev.D 72 (2005) 034027

Conclusions

- BES earlier observation of near-threshold enhance of J/ψ to $\gamma + p + \bar{p}$ could be interpreted as the existence of $p + \bar{p}$ bound state.
- A skyrmion-type potential model was established to explain such state.
- A new decay channel was predicted to test such $p + \bar{p}$ bound state: decay to 4 to 7 mesons.
- The new BESIII experiment of J/ψ to $\gamma + 3$ ($\pi^+ + \pi^-$) aligns with such prediction.
- More theoretical and experimental investigations are still needed to confirm the existence of protonium or baryoniums.