X(3872) Result at BESIII

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内容提要

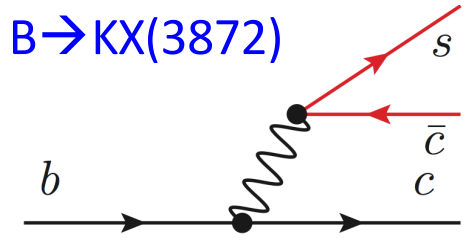
一. X(3872)的发现和基本性质

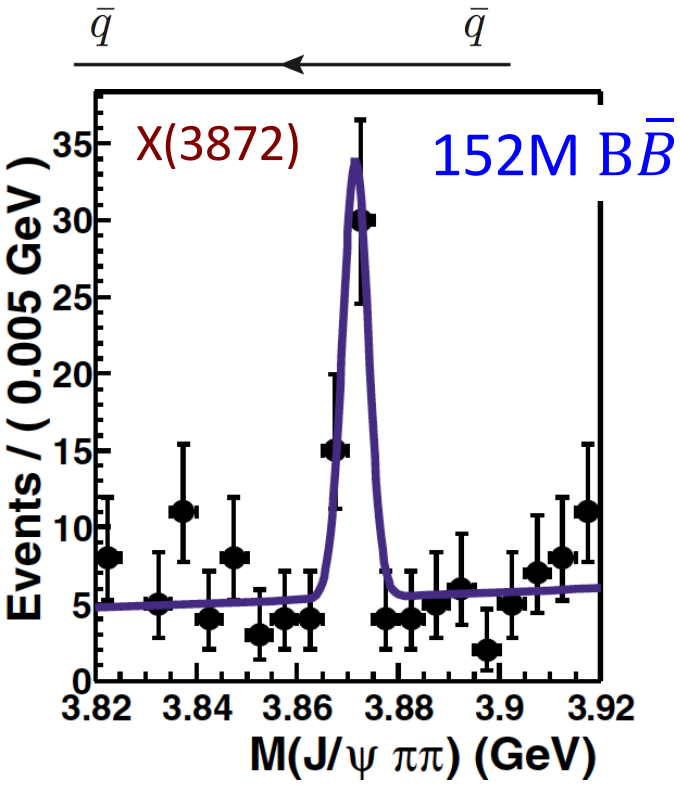
二. X(3872)的模型解释

三. X(3872)的最新研究进展

四. 总结

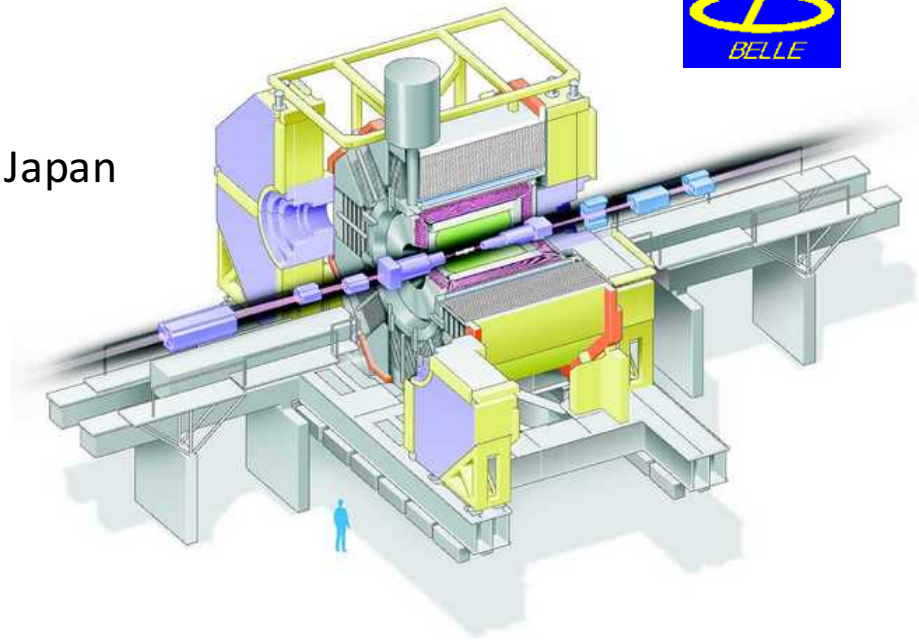
X(3872)的发现





Confirmed by 7 independent experiments (BABAR, LHCb, CDF, D0, CMS, ATLAS, BESIII)

Solid signal !



KEK, Japan

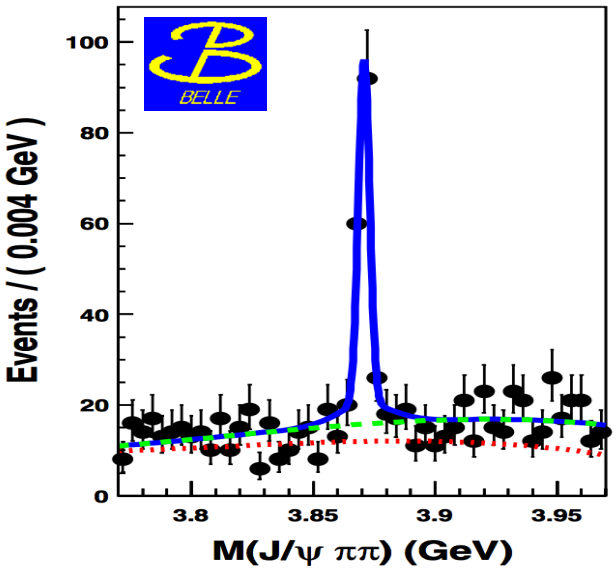
PRL 91, 262001 (2003)

X(3872)的质量

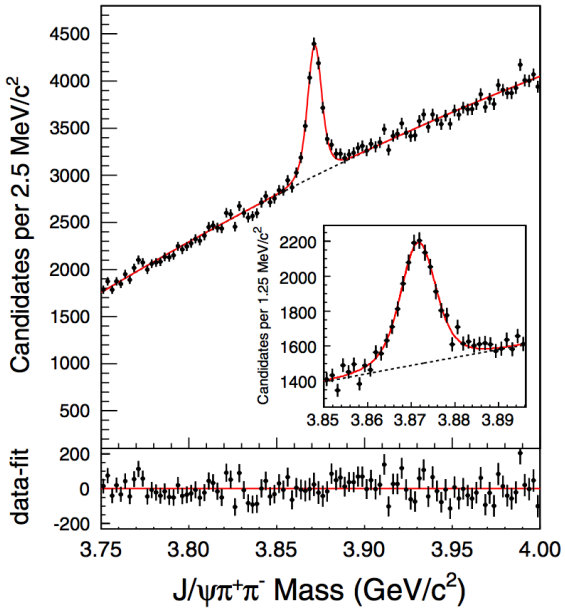
- Belle (2003): M= 3872.0 ±0.6±0.5 MeV → where its name come from
- Belle (2011): M= 3871.85±0.27±0.19 MeV (updated with 772M $B\bar{B}$)

- CDF (2009): M= 3871.61±0.16±0.19 MeV → most precise measurement by far!
- BaBar & LHCb (±0.6; ±0.48); BESIII (aiming for ±0.3(?) MeV level)

PRD 84, 052004 (2011)
173±16 events



PRL 103, 152001 (2009)
~6000 events



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$\chi_{c1}(3872)$ PDG

3871.69± 0.17 OUR AVERAGE

$\Gamma_{X(3872)} < 1.2$ MeV [Belle (2011)]

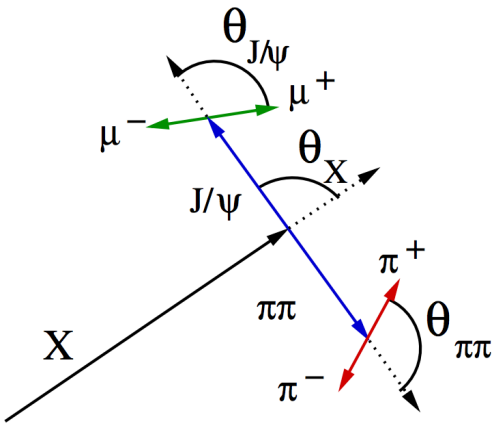
$\Delta E = m[X(3872)]-(m[D^0]+m[\overline{D^{*0}}]) = (0.01 \pm 0.19)$ MeV

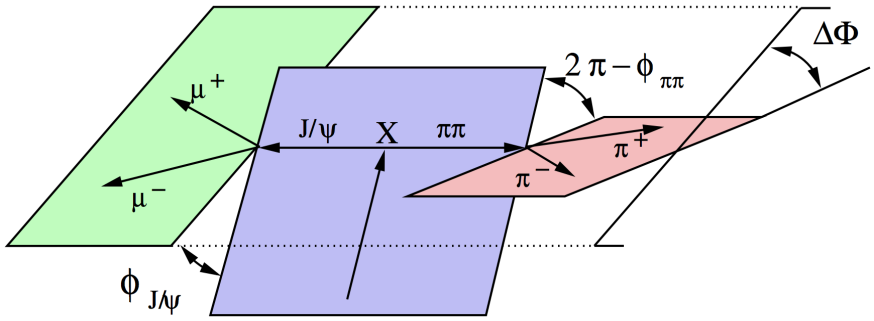
δ[m(D^0)]~50 keV, δ[m(D^{*0})]~14 keV (???)

X(3872)的J^{PC}量子数

- Observation of X(3872)→γJ/ψ by BaBar (2006) & Belle (2011) → C-even state

- CDF prompt production (2007) → 1^{++} or 2^{-+}
- Belle B→KX(3872) decay (2011) → 1^{++} or 2^{-+}
- BaBar X(3872)→ωJ/ψ (2010) P-wave → favor 2^{-} assignment





CDF PRL 98, 132002 (2007)

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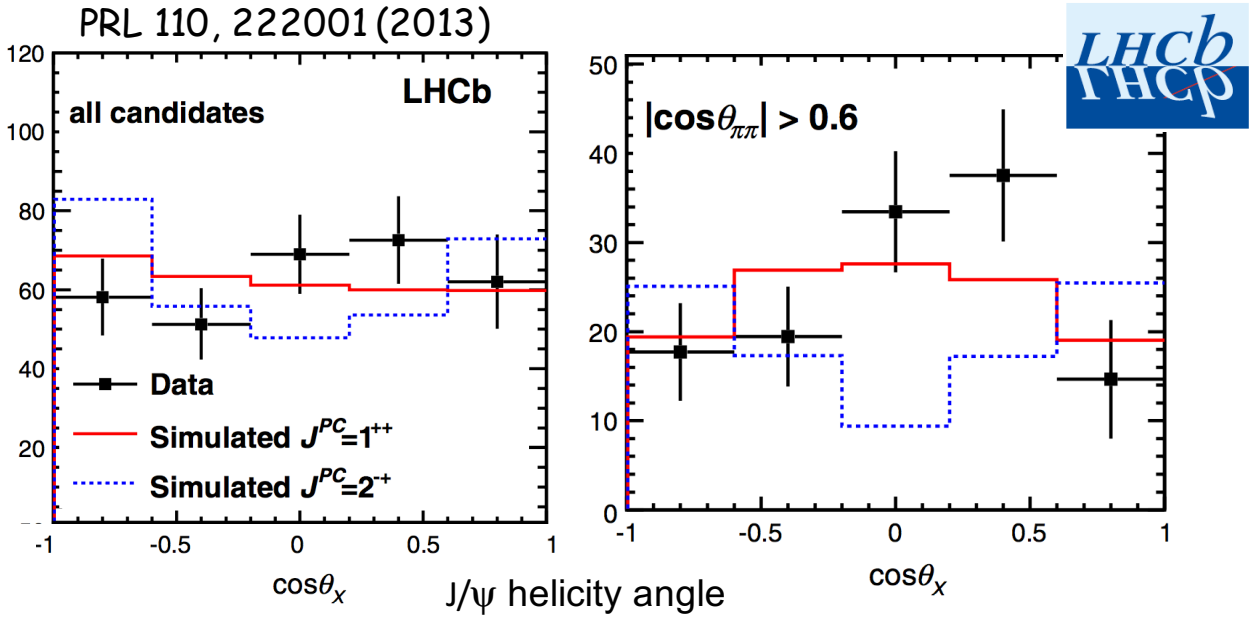
- LHCb B→KX(3872)→$K\pi^+\pi^-J/\psi$→$K\pi^+\pi^-\mu^+\mu^-$ (2013), by analyzing angular distribution

PRL 110, 222001 (2013)



$J^{PC}=1^{++}$

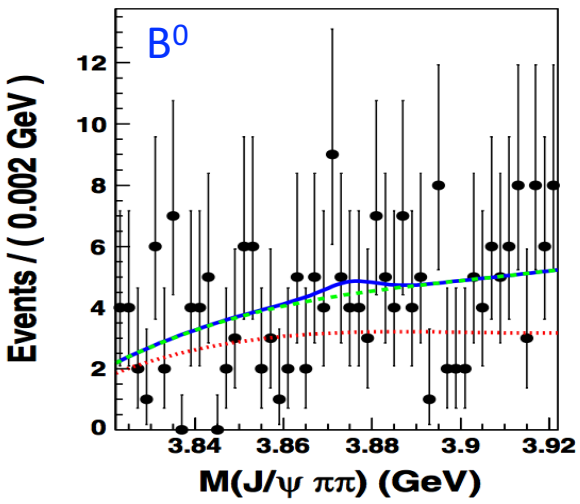
2-+ was ruled out by more than 8σ

X(3872)的同位旋量子数

PRD 84, 052004 (2011)

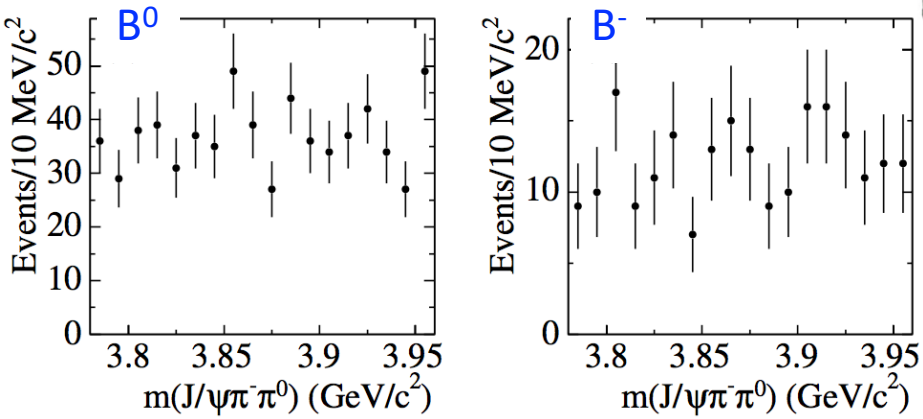
772M $B\bar{B}$

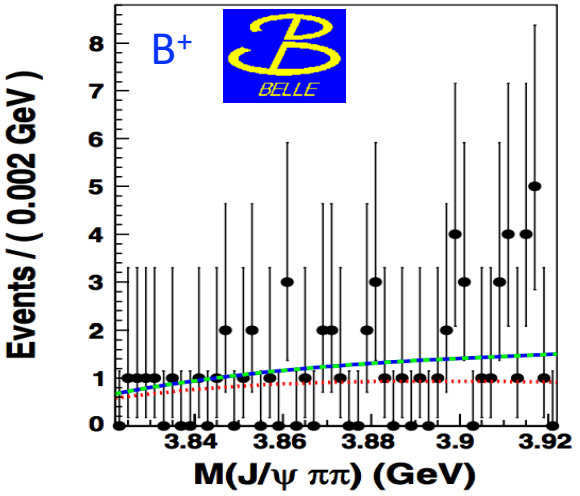
$X^+ \to \rho^+ J/\psi$



234M $B\bar{B}$

PRD 71, 031501 (2005)





No charged partner observed by far, suggest X(3872) is an iso-spin singlet (I=0).

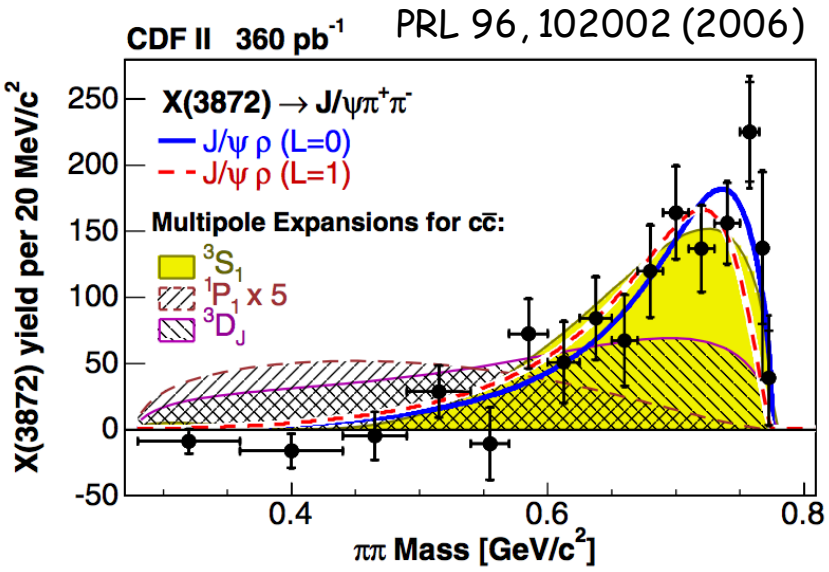
BaBar

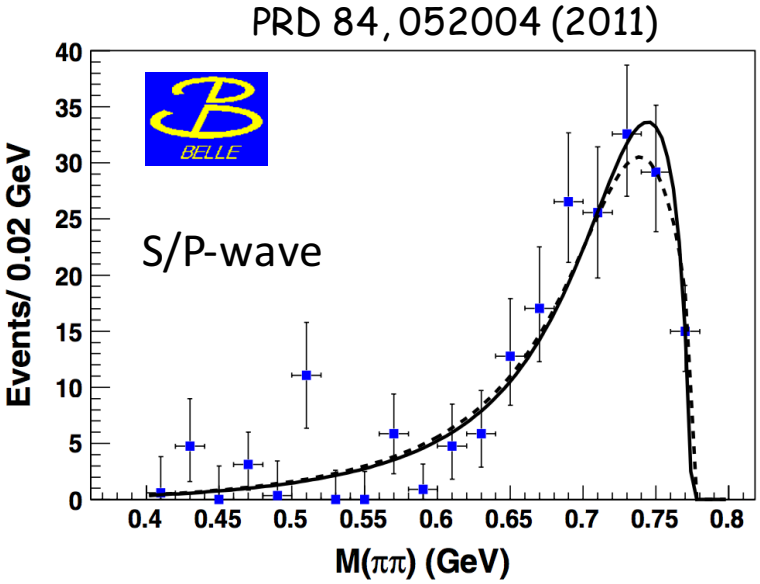
$$\mathcal{B}(\bar{B}^0 \to K^- X^+) \times \mathcal{B}(X^+ \to \rho^+ J/\psi) < 5.4 \times 10^{-6}$$
$$\mathcal{B}(B^+ \to K^0 X^+) \times \mathcal{B}(X^+ \to \rho^+ J/\psi) < 22 \times 10^{-6}$$

Belle

$$\mathcal{B}(\bar{B}^0 \to K^- X^+) \times \mathcal{B}(X^+ \to \rho^+ J/\psi) < 4.2 \times 10^{-6}$$
$$\mathcal{B}(B^+ \to K^0 X^+) \times \mathcal{B}(X^+ \to \rho^+ J/\psi) < 6.1 \times 10^{-6}$$

同位旋破坏效应



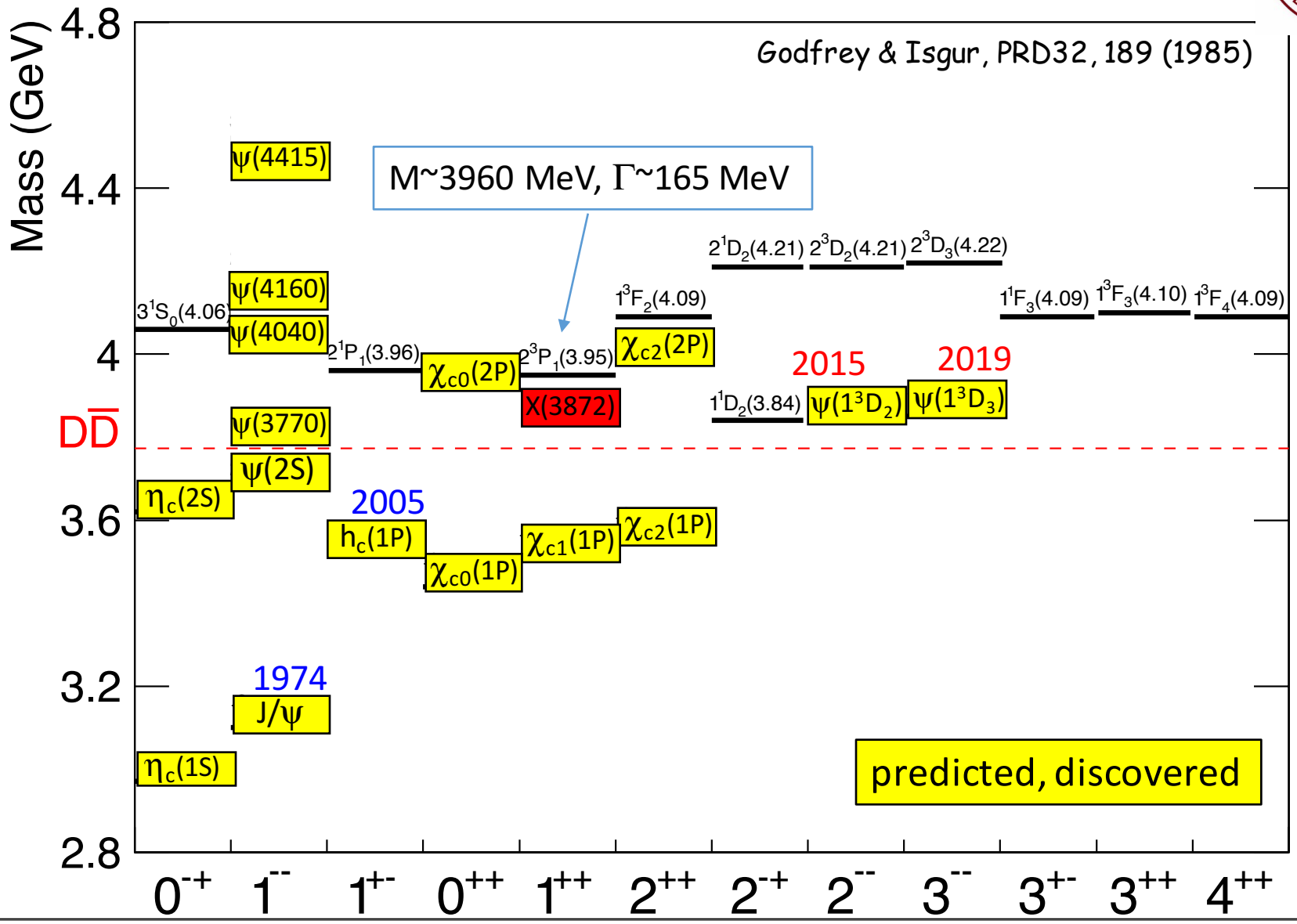


- X(3872)→$\pi^+\pi^-$J/ψ, CDF & Belle fit the $\pi^+\pi^-$ system with a ρ^0 candidate (ρ-ω mixing)
- Iso-spin violation decay: X(3872)→ρ^0J/ψ, branching ratio ~ (4-5)%
- A typical charmonium ψ(2S)→π^0J/ψ, branching ratio ~0.1%

性质十分奇特!

X(3872)的模型解释

Charmonium Spectrum



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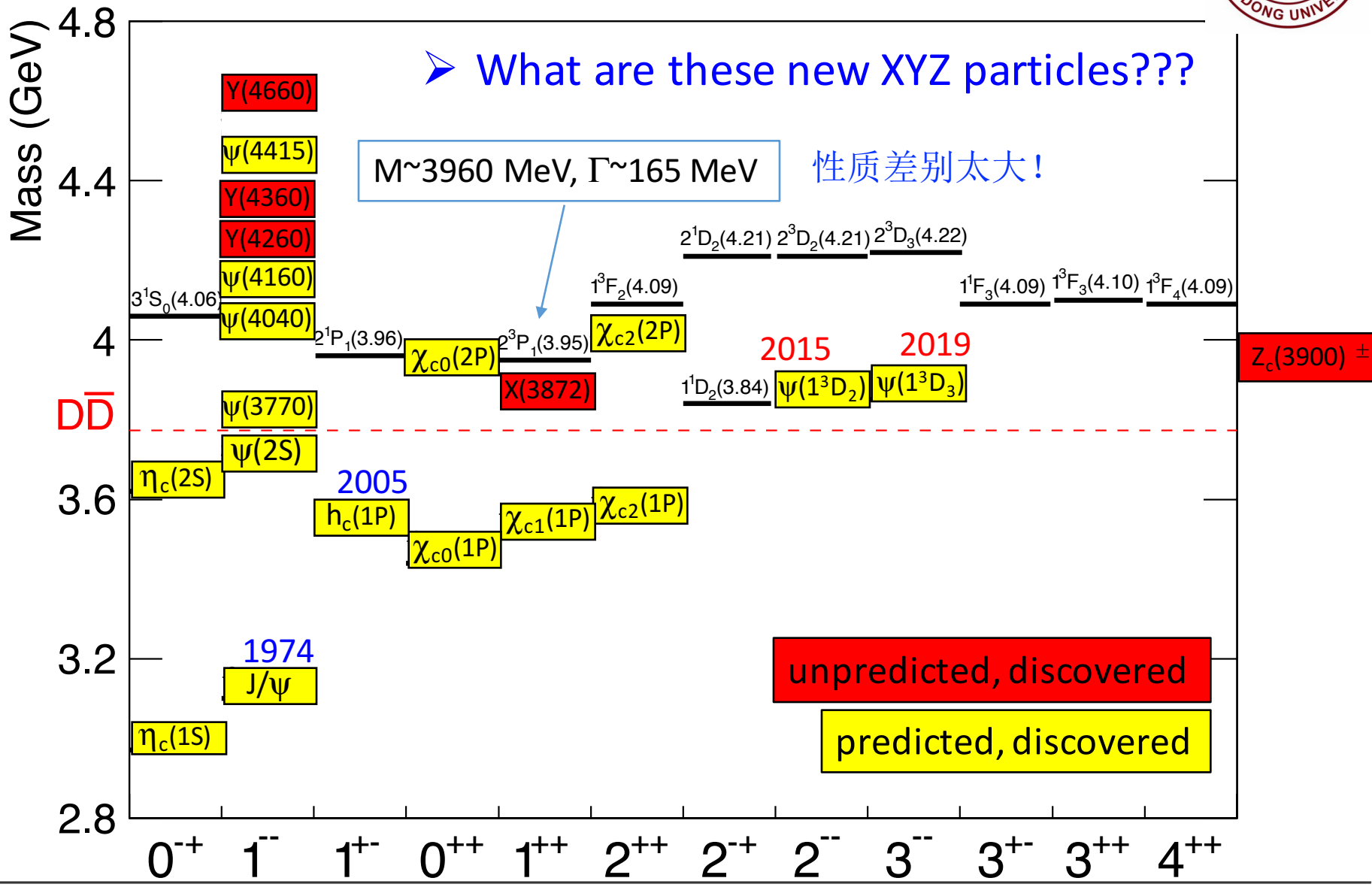

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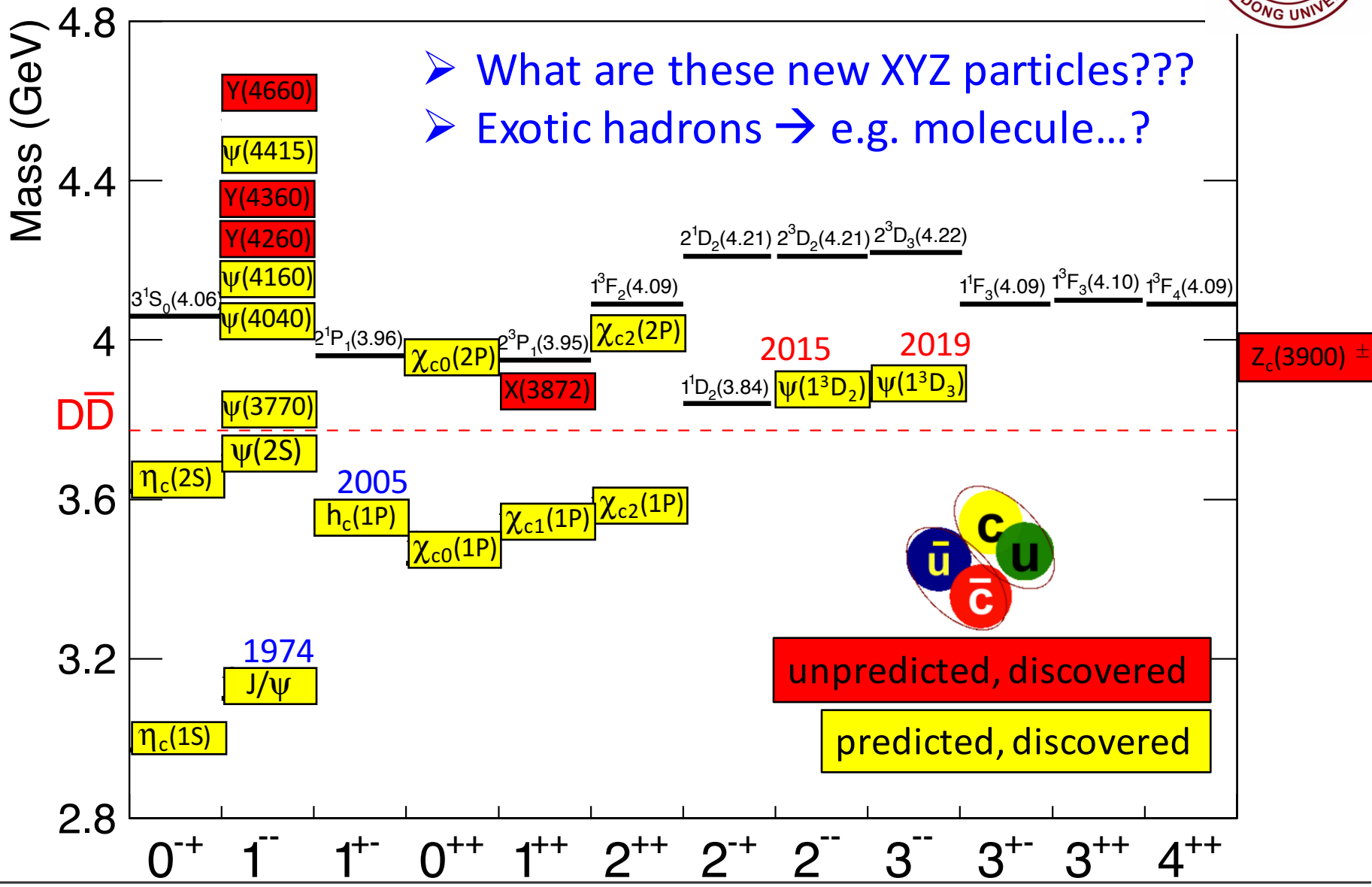
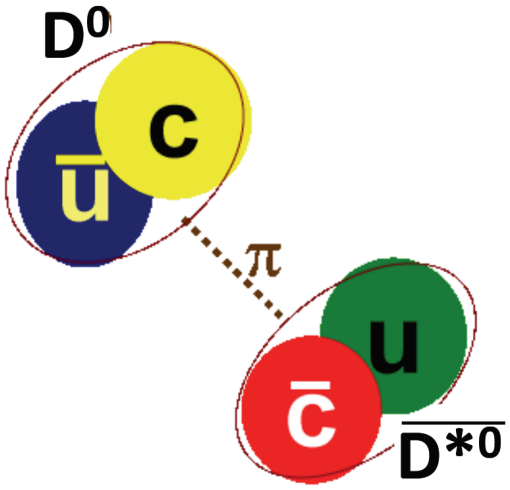


- What are these new XYZ particles???
- Exotic hadrons → e.g. molecule…?

强子分子态



$D^0 - \overline{D^{*0}}$ "molecule"

Rev. Mod. Phys. 90, 015004 (2018)

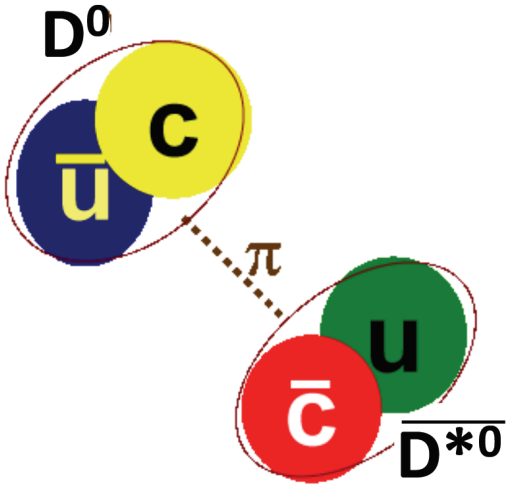
"Hadronic molecules are analogs of light nuclei, most notably the deuteron（氘）. They can be treated to a good approximation as composite systems made of two or more hadrons which are bound together via the strong interactions."

- Long-range (π, σ…) exchange nuclear force
- 氘核 (p,n) bound state: ΔE = -2.22 MeV, r ~(1-2) fm

$\Delta E = m[X(3872)]-(m[D^0]+m[\overline{D^{*0}}]) = (0.01 \pm 0.19)$ MeV, r ~(8-10) fm

Loosely bounded !

强子分子态



$D^0 - \overline{D^{*0}}$ "molecule"

解释疑难：

- Decay branching ratio: $D^0\overline{D^{*0}}$ (~30%-50%)
- Iso-spin violation

问题：

- Production rate in $p\bar{p}$ collision @ 1.96 TeV
- Suppressed by MC studies [PRL 103, 162001 (2009)]
- CDF [~20% of ψ(2S)]; ATLAS [~10% of ψ(2S)/high pt]

$$\text{Mixture: } 5\%|c\bar{c}> + 95\%|D^0\overline{D^{*0}}>$$

PTEP(2013),093D01

wave fcn overlap is too tiny, $<10^{-3}$

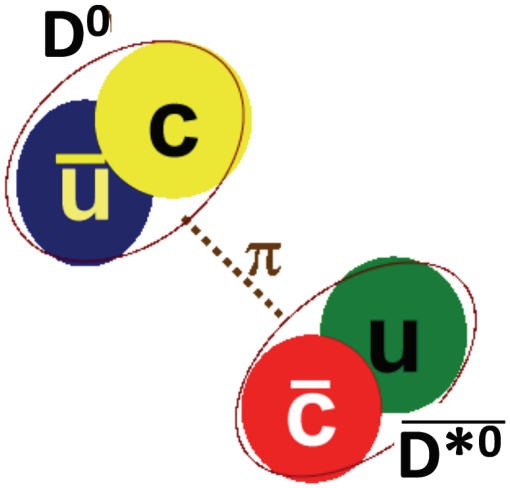
Polosa: "Multiquark Hadrons," pg 56
Achasov: MPLA 30, 1550181 (2015)

Vol ~ $(8\ \text{fm})^3$

Vol ~ $(0.5\ \text{fm})^3$

From Steve Olsen in Hadron2019

强子分子态



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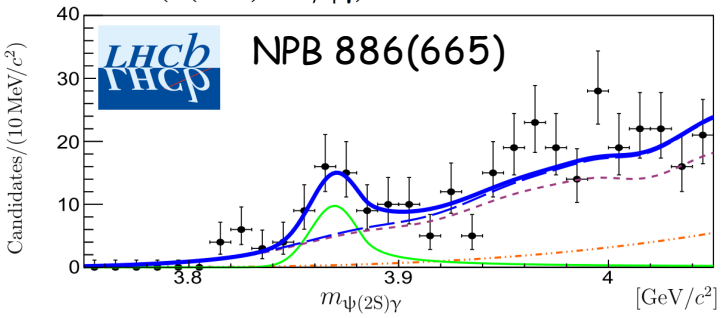
问题：

- Relative decay between X(3872)→γψ(2S)/γJ/ψ
  - Swanson's calculation is suppressed
  - Hanhart's calculation is OK

$$\frac{\mathcal{B}(X(3872) \to \psi(2S)\gamma)}{\mathcal{B}(X(3872) \to J/\psi\gamma)} = 2.46 \pm 0.64 \pm 0.29,$$



465M $B\bar{B}$

PRL 102, 132001 (2009)

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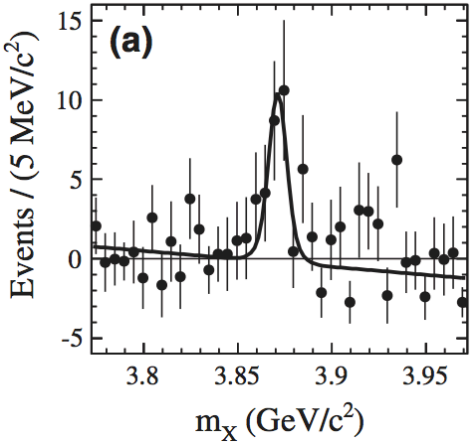

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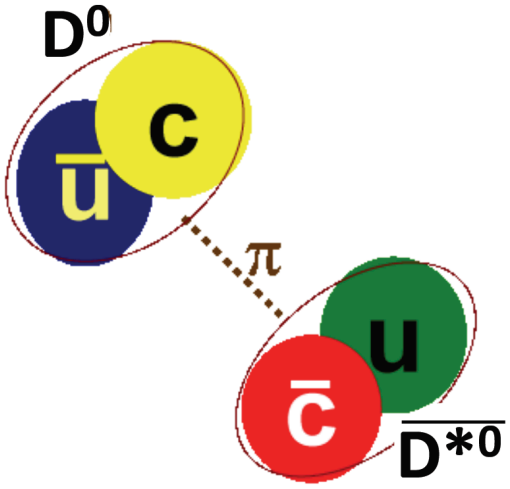

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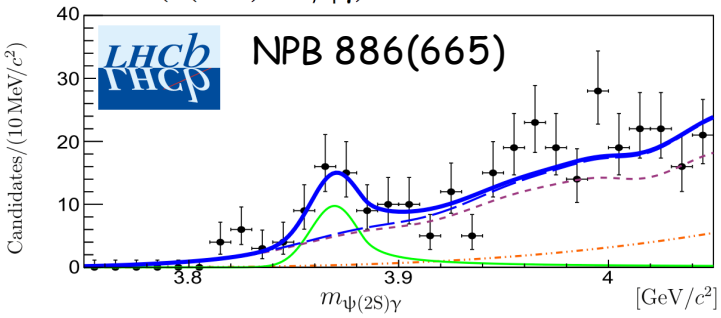
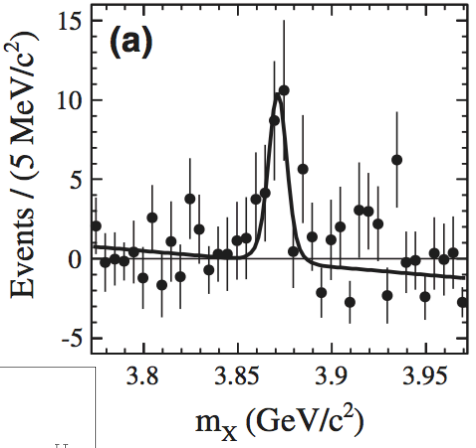
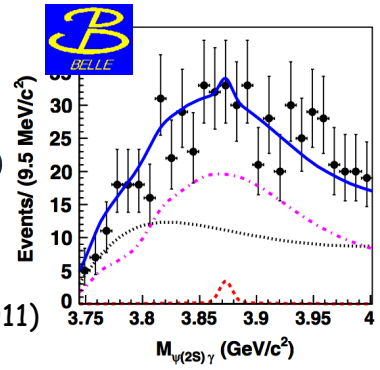
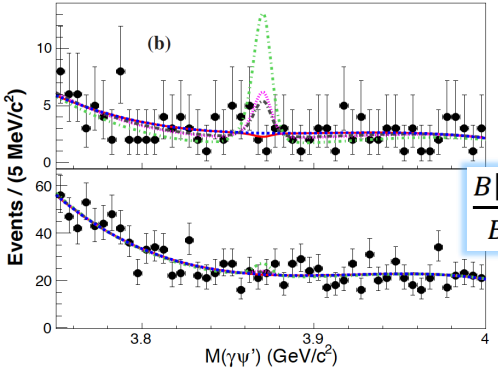




$$\frac{\mathcal{B}(X(3872)\to\psi'\gamma)}{\mathcal{B}(X(3872)\to J/\psi\gamma)} < 2.1 \ \text{(at 90\% C.L.)}$$

772M $B\bar{B}$
PRL 107, 091803 (2011)



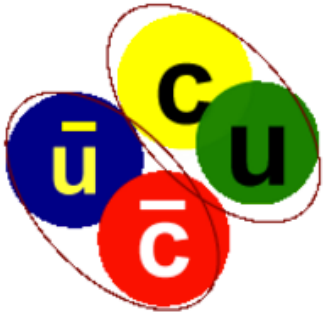


arXiv:2001.01156

$$\frac{B[X(3872)\to\gamma\psi(2S)]}{B[X(3872)\to\gamma J/\psi]} < 0.59$$

BESIII

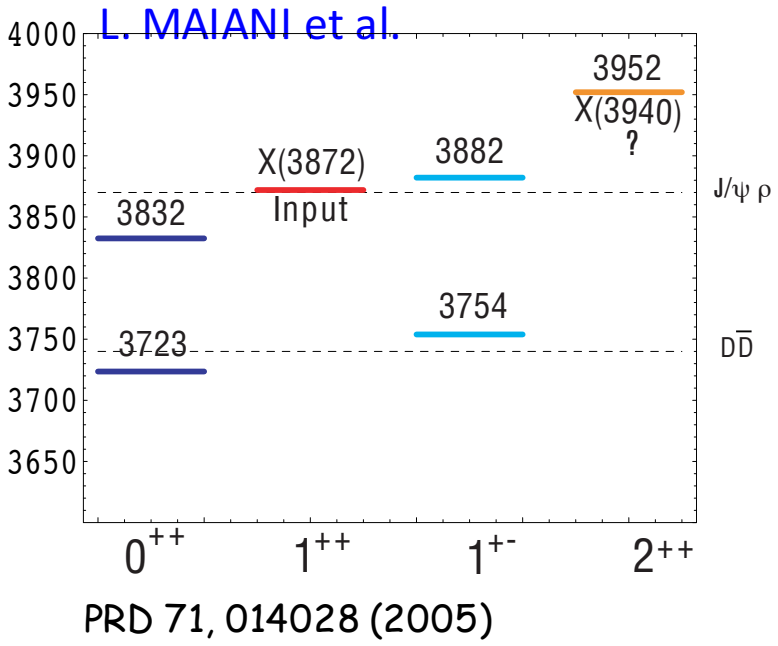
四夸克态



diquark - diantiquark

Tetraquark - compact state

- Four quarks confined in a “bag”
- Diquark & diantiquark can be colored
- Explains: iso-spin violation …
- Prediction: partner particles



PRD 71, 014028 (2005)

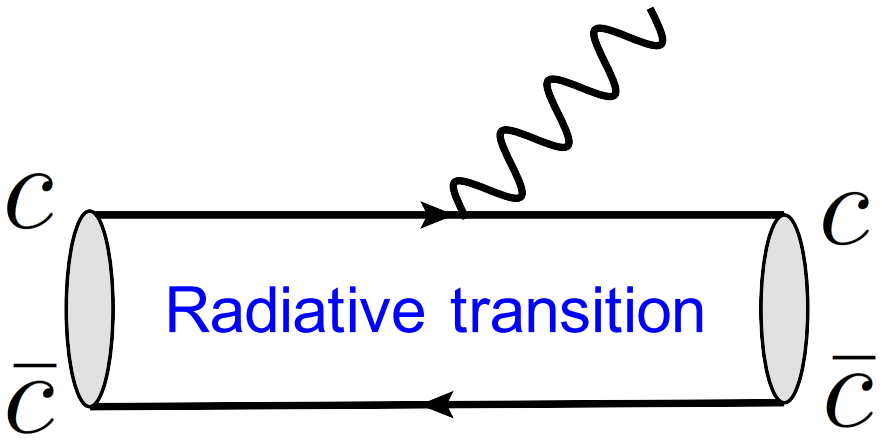
Partners not well established!

$$H = \sum_i m_i + \sum_{i<j} 2\kappa_{ij}(S_i \cdot S_j)$$

Phenomenological model (CMI)

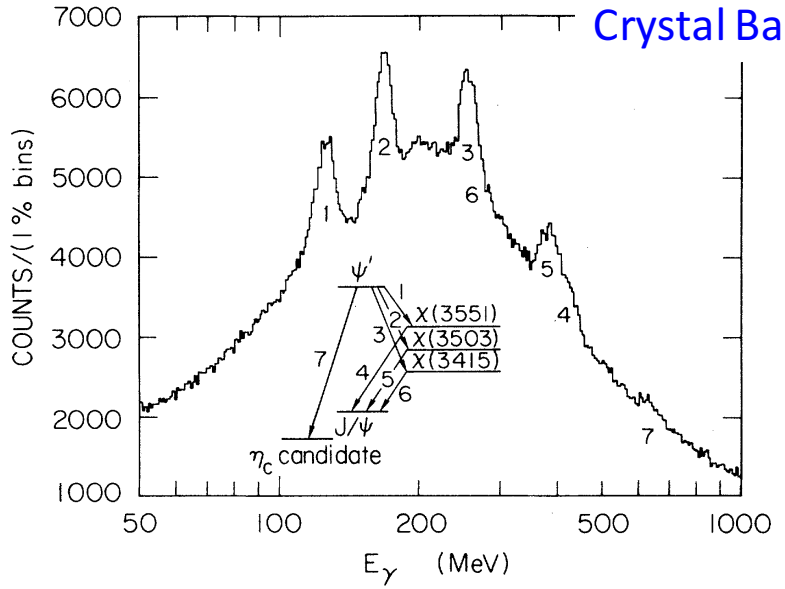
X(3872)的最新进展

Y(4260)→γX(3872)



Charmonium

Excited state → Ground state

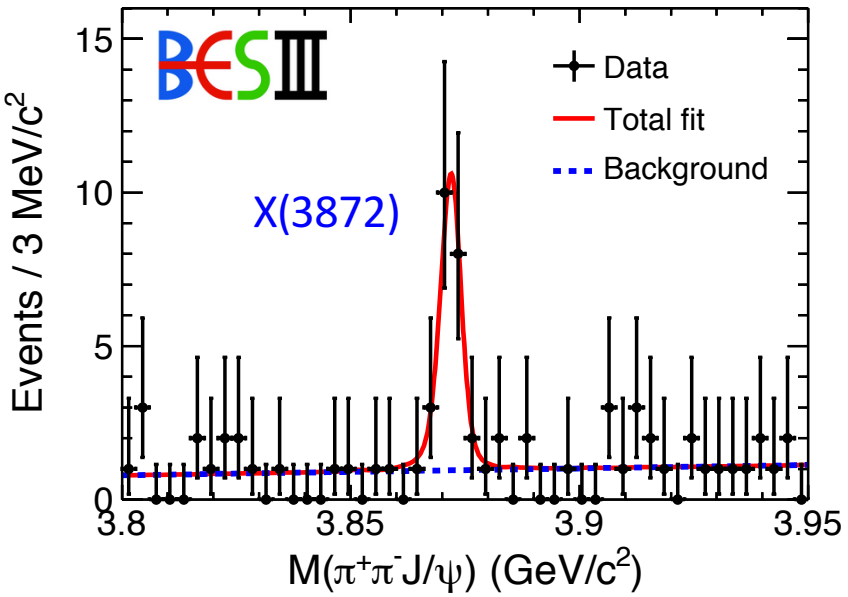


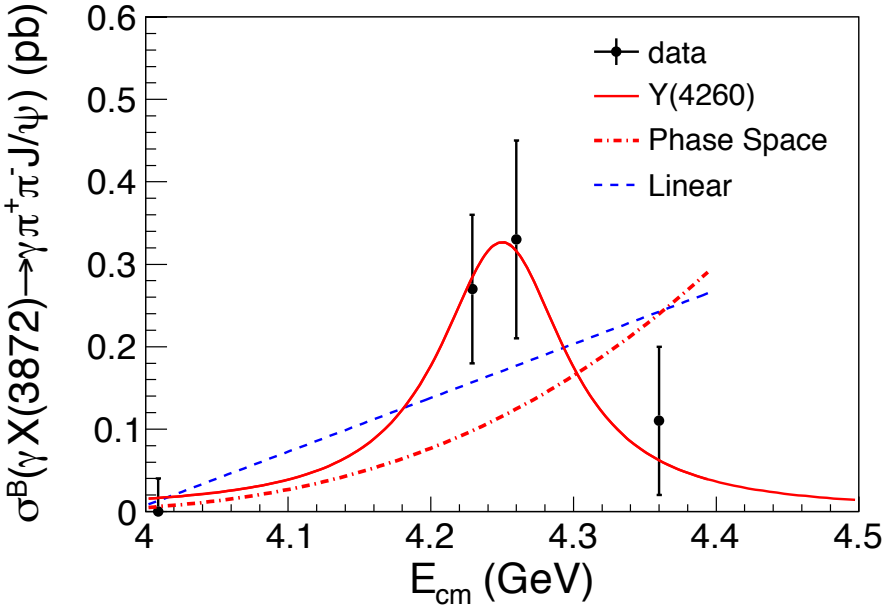
$\psi(2S) \rightarrow \gamma\chi_{c0,c1,c2}/\gamma\eta_c$

$\chi_{c0,c1,c2} \rightarrow \gamma J/\psi$

Y(4260)→γX(3872)

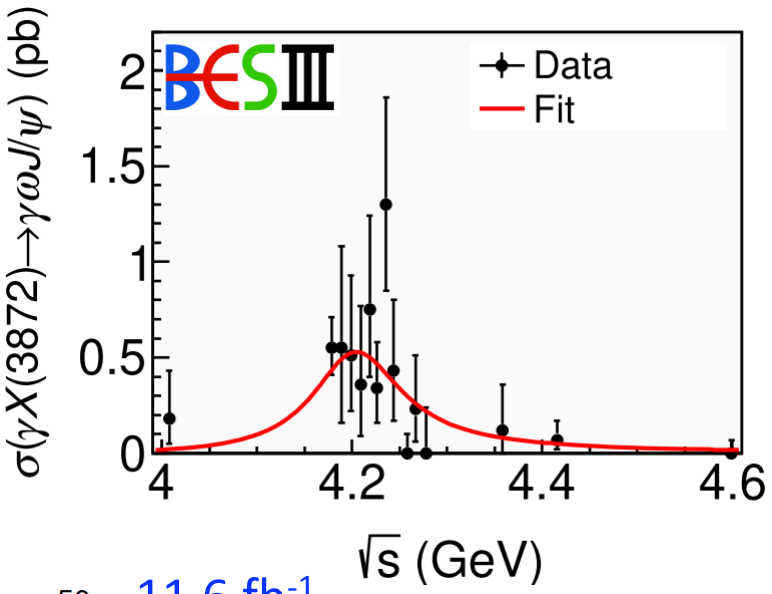
PRL 112, 092001 (2014)

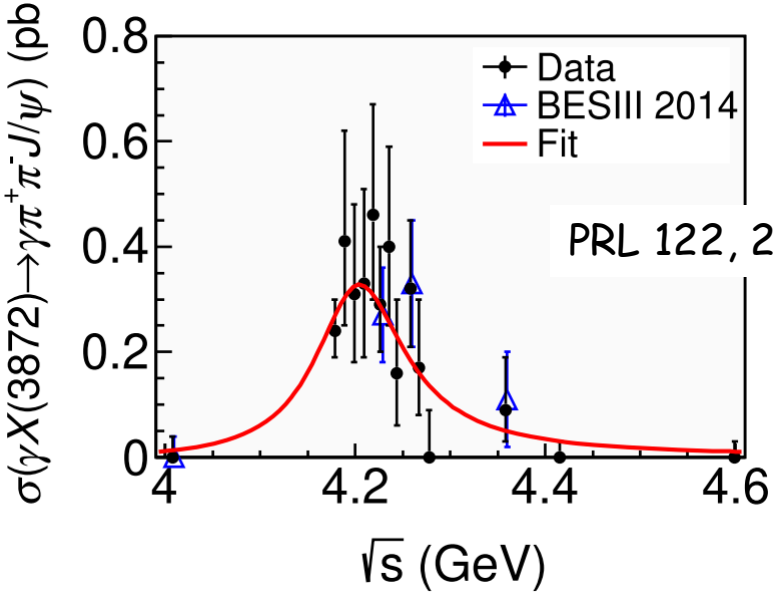




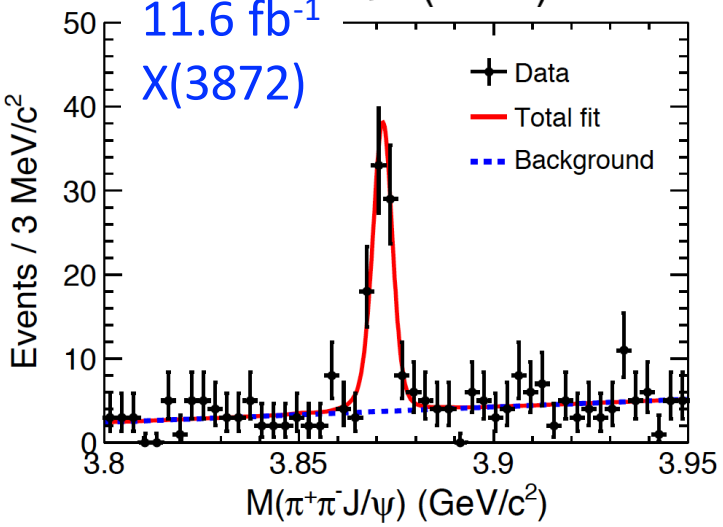
- e^+e^-→γX(3872) by BESIII [X(3872) $J^{PC}=1^{++}$]
- Cross section shows a peak near 4.26 GeV
- Strongly suggest Y(4260)→γX(3872) transition

Y(4260)→γX(3872)





PRL 122, 232002 (2019)

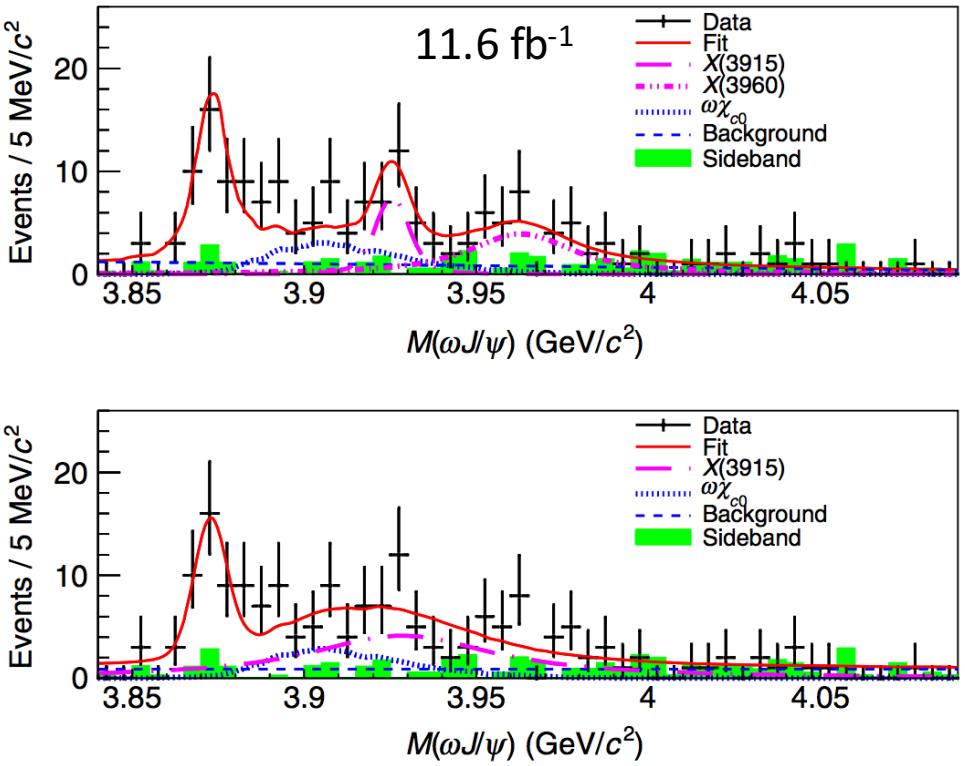


- e^+e^-→γX(3872) cross section by BESIII
- $M=4200.6^{+7.9}_{-13.3}\pm3.0$ MeV, $\Gamma=115^{+38}_{-26}\pm12$ MeV
- Agree with the Y(4260) resonance

Commonality between Y & X?

X(3872)→ωJ/ψ

BESIII PRL 122, 232002 (2019)



- $e^+e^-\to\gamma X(3872)\to\gamma\omega J/\psi$ at BESIII
- Observed $X(3872)\to\omega J/\psi$ signal with >5σ significance (first time)

$B[X\to\omega J/\psi]/B[X\to\rho J/\psi]=1.6^{+0.4}_{-0.3}\pm0.2$

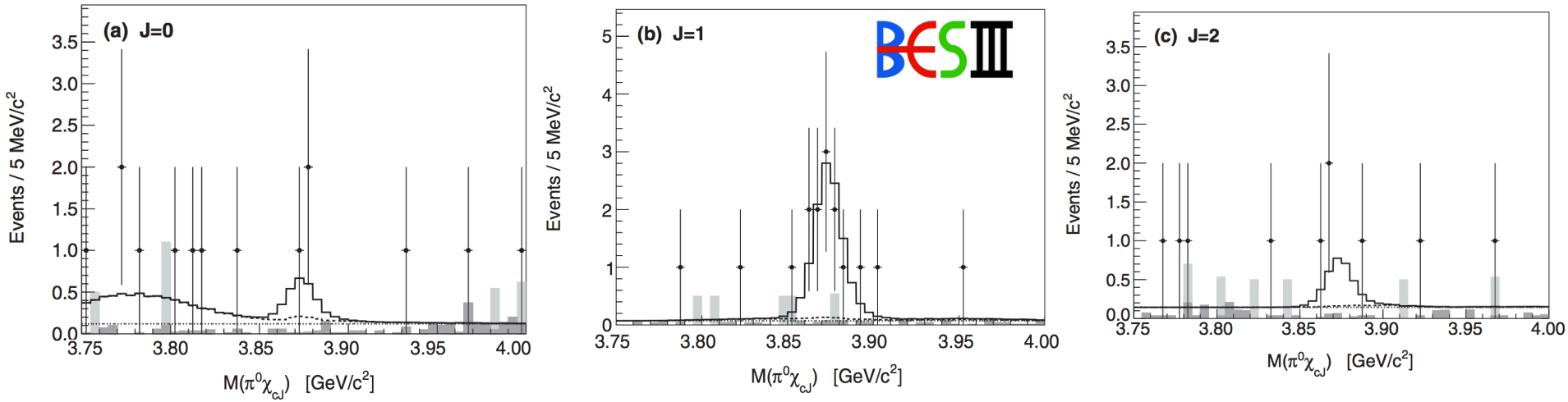
$$R_{X(3872)}=\left|\frac{A(\rho J/\psi)}{A(\omega J/\psi)}\right| \sim 0.2\text{-}0.3$$

$$R_{\psi(2S)}=\frac{g_{\pi^0 J/\psi}}{g_{\eta J/\psi}}\approx 0.03$$

PRD 85, 011501(R) (2012)

$X(3872)\rightarrow\pi^0\chi_{c1}$

PRL 122, 202001 (2019)



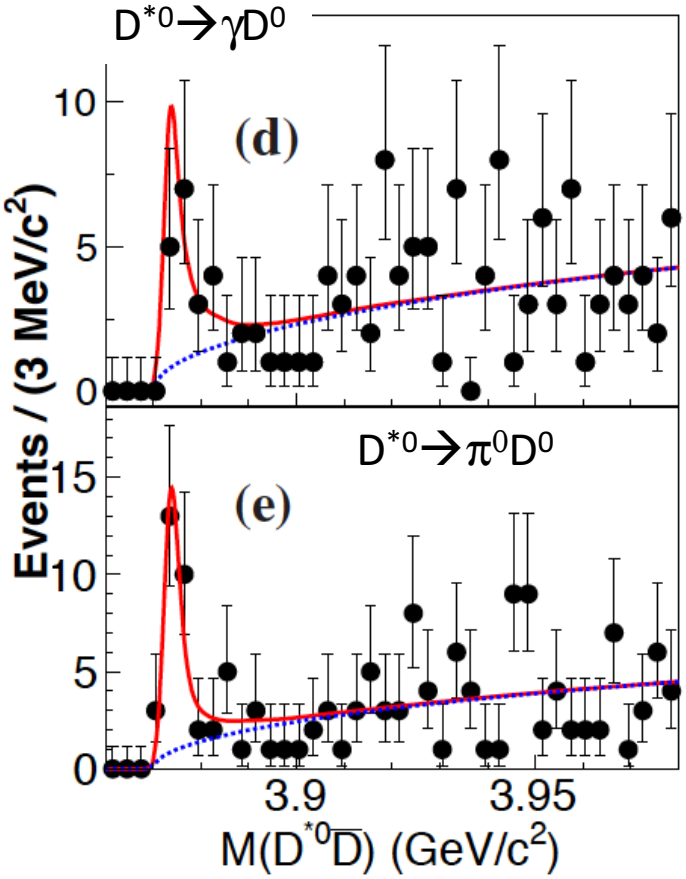
- Observed the $X(3872)\rightarrow\pi^0\chi_{c1}$ decay for the first time with >5σ significance
- Iso-spin violation, comparable decay rate with $\rho^0 J/\psi$ → disfavor $\chi_{c1}(2P)$ assignment

$B[X(3872)\rightarrow \pi^0\chi_{c0}]/B[X(3872)\rightarrow \rho J/\psi] < 19$ @ 90% C.L.

$B[X(3872)\rightarrow \pi^0\chi_{c1}]/B[X(3872)\rightarrow \rho J/\psi] = 0.88^{+0.33}_{-0.27} \pm 0.10$

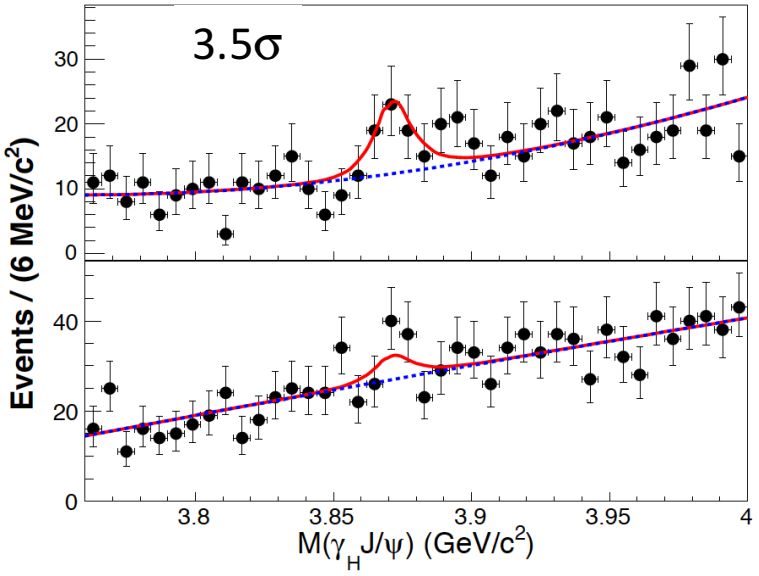
$B[X(3872)\rightarrow \pi^0\chi_{c2}]/B[X(3872)\rightarrow \rho J/\psi] < 1.1$ @ 90% C.L.

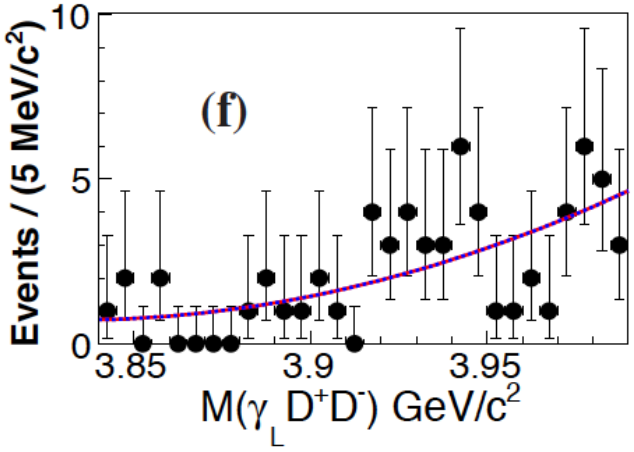
X(3872)→$D^0\overline{D^{*0}}$/γJ/ψ/γD⁺D⁻



arXiv:2001.01156

BESIII





Do not observe
X(3872)→$D^0\overline{D^0}\pi^0$

B[X(3872)→$D^0\overline{D^{*0}}$]/B[X(3872)→ρJ/ψ]=11.8±3.1
B[X(3872)→γJ/ψ]/B[X(3872)→ρJ/ψ]=0.79±0.28

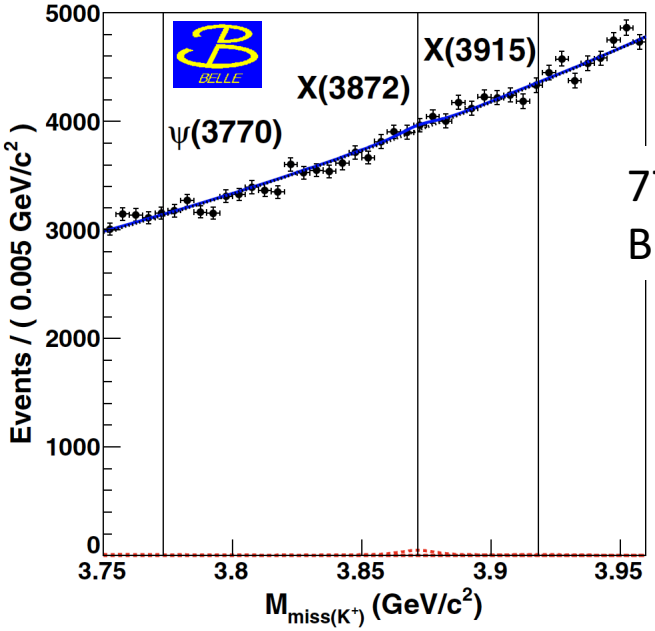
Summary

- 17 years stories of X(3872) since its discovery…
- Lots of progresses both from experiment and theory
- Still do not fully understand it, maybe a molecule…
- Mass (more precise?), width (?), absolute branching ratio (?), production (?)…

Thanks for your attention!

Absolute branching fraction

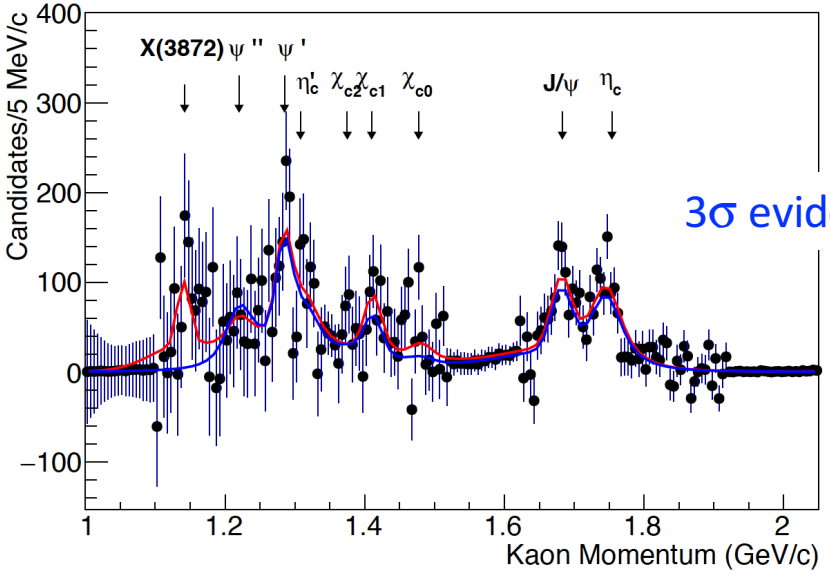
PRD 97, 012005 (2018)



772M $B\bar{B}$

B→K+anything

arXiv:1911.11740 465M $B\bar{B}$



3σ evidence

B[X(3872)→$\pi^+\pi^-$J/ψ]>3% @ 90% C.L.

B[X(3872)→$\pi^+\pi^-$J/ψ]=(4.1±1.3)%

Li & Yuan, PRD 100, 094003 (2019)

Global fit (average):

B[X(3872)→$\pi^+\pi^-$J/ψ]=$(4.1^{+1.9}_{-1.1})$%; B[X(3872)→$D^0\overline{D^{*0}}$]=$(52.4^{+25.3}_{-14.3})$%