Search for new hadrons by the radiative decays into pseudo-scalar charmonium

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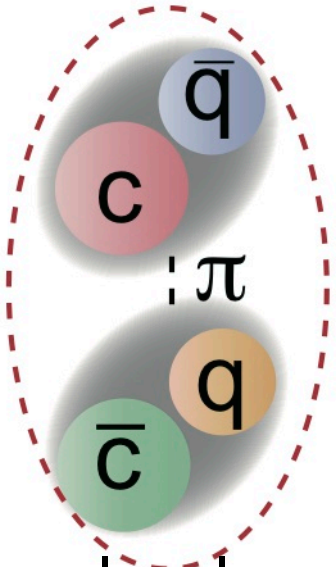
Outline

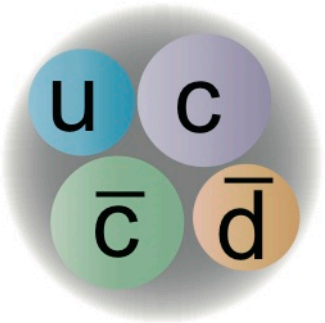
- Exotic hadrons, number of constituents > 3
- X(3872) and its partner states search
- Radiative decay $\gamma\ \eta_c$(1S or 2S) for $J^{PC}=1^{+-}$
- Belle data analysis status
- Summary

Exotic hadrons
number of constituents > 3

- No explicit forbidding rule to form unusual structure (not conventional $q\bar{q}$ or qqq) hadrons.



molecule

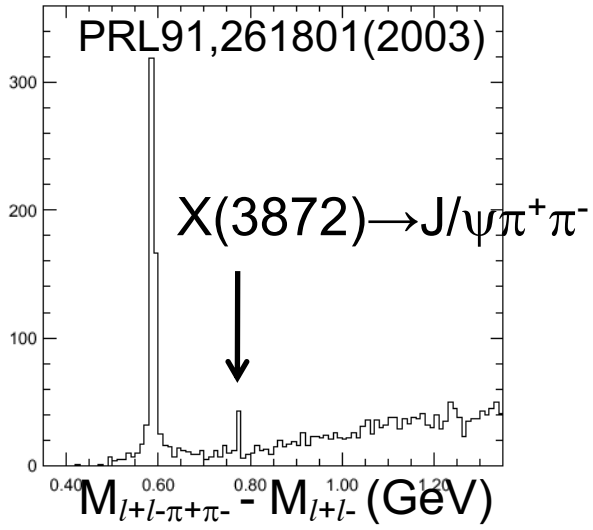


tetraquark

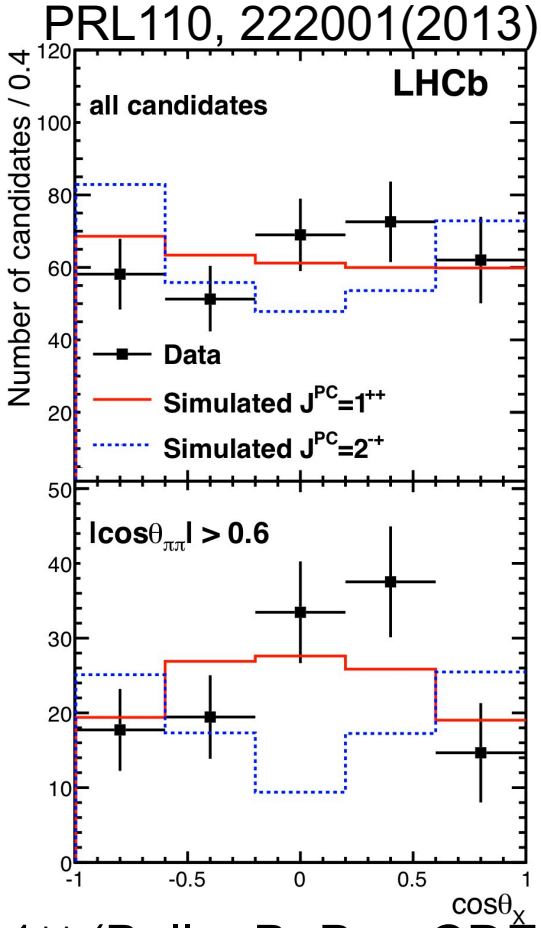
+glue ball,
pentaquark, …

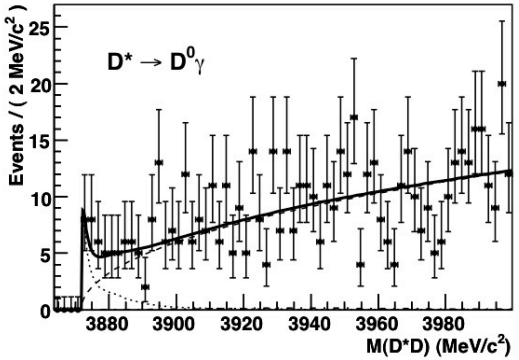
- But lack of experimental evidence for long time.
- Maybe a key to open unrevealed aspect of QCD.

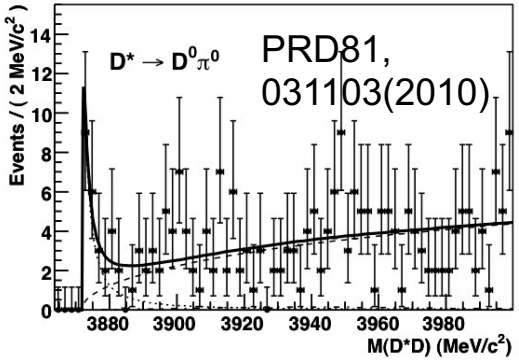
X(3872)



Including $c\bar{c}$, unusually narrow despite its mass above DD threshold.





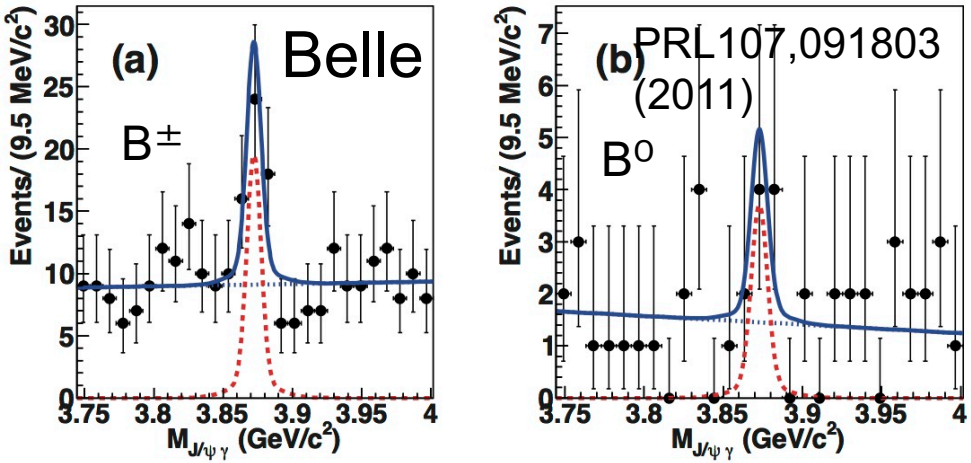


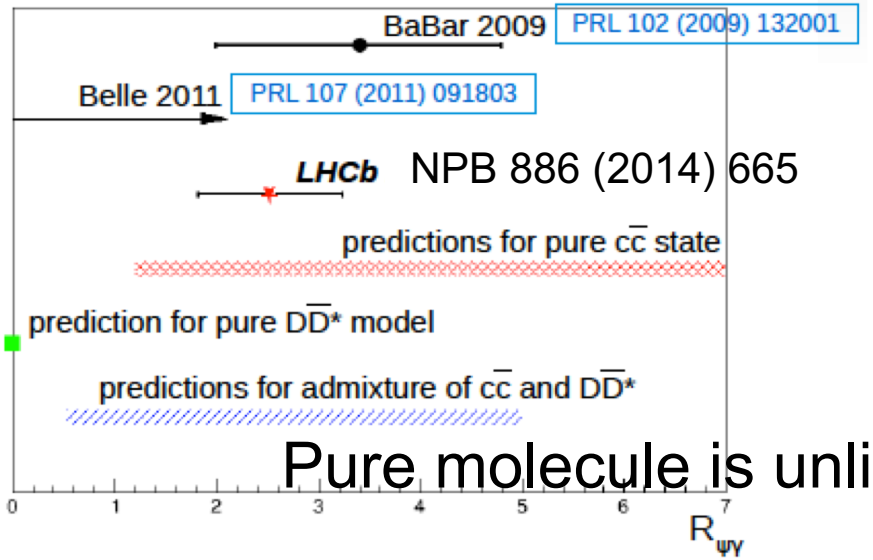
Br(X(3872)→$D^0\bar{D}^{*0}$) is about Br(X(3872)→J/ψ $\pi^+\pi^-$) × 10.

$J^{PC}=1^{++}$ (Belle, BaBar, CDF, LHCb) from J/ψ $\pi^+\pi^-$ angular distribution.

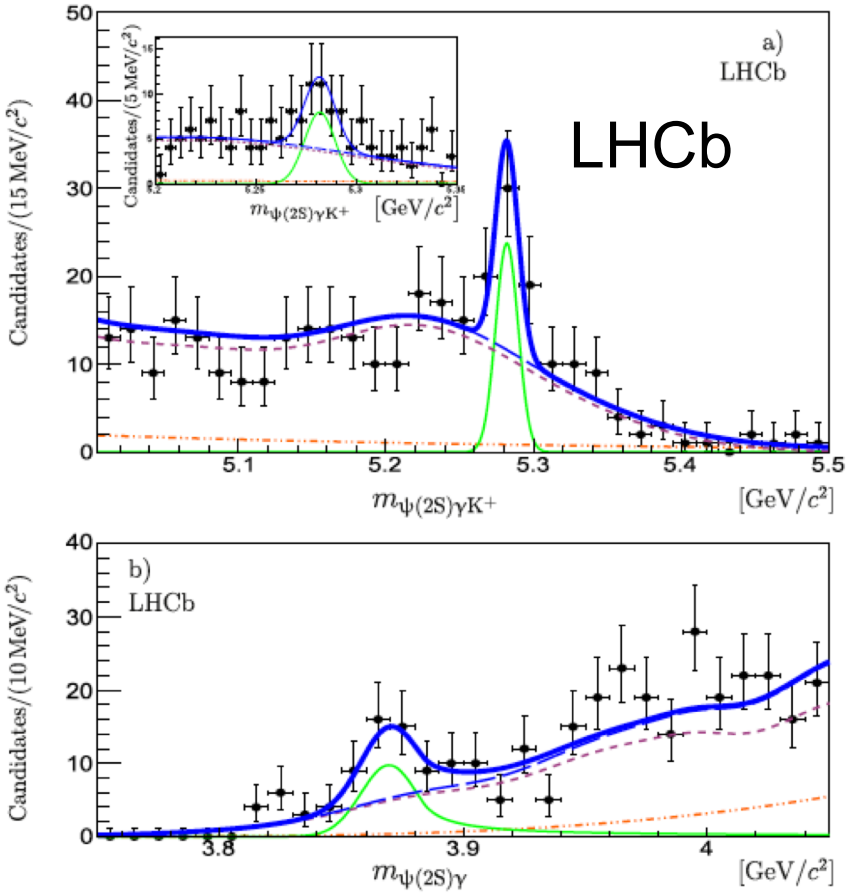
More about X(3872)

X(3872)→J/ψ γ; C=+1



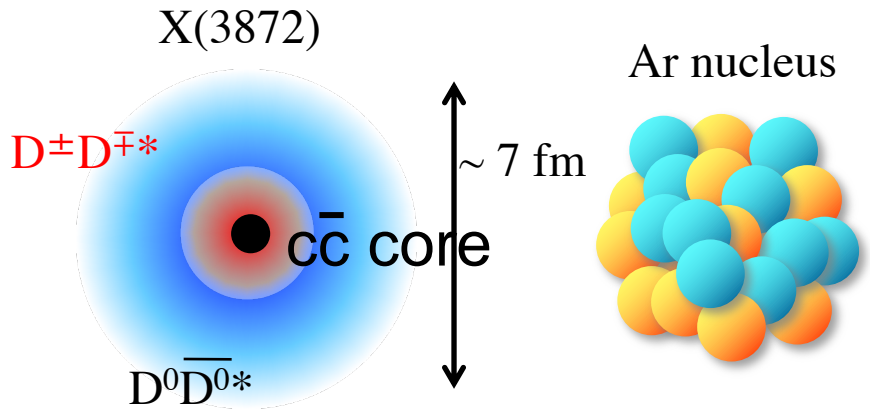


Pure molecule is unlikely ..



X(3872)→ψ(2S) γ found at LHCb.

Admixture : most plausible interpretation for X(3872)



E. J. Eichiten et al., PRD73,014014(2006); A. M. Badalian et al., PRD85,031103(2012), S.Takeuchi, K.Shimizu and M.Takizawa, PTEP2014(2014)123D01

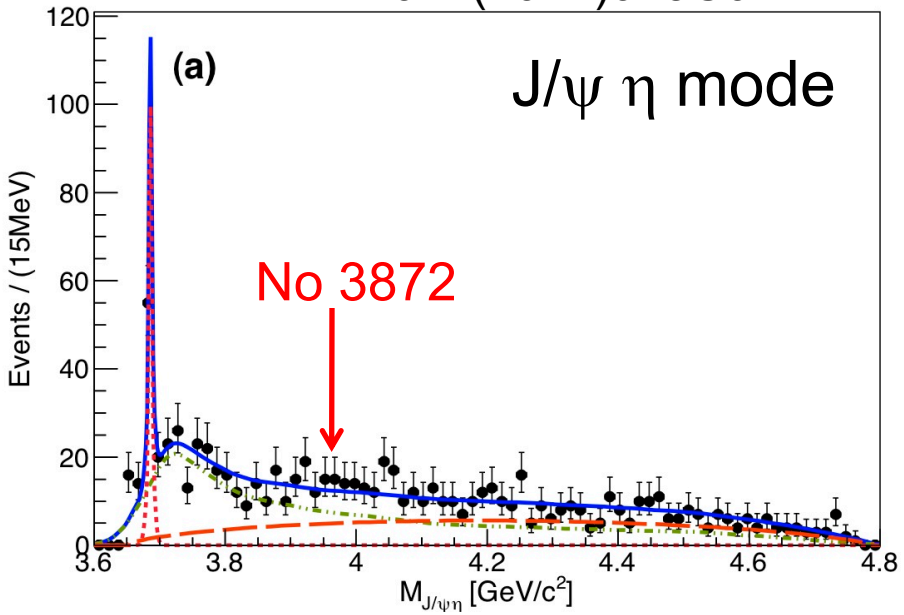
$D\bar{D}^*$ component is coupled with the same J^{PC} $c\bar{c}$, $\chi_{c1}(2P)$ (unseen).
→can explain $Br(X\rightarrow D^0\bar{D}^{*0})/Br(X\rightarrow J/\psi\ \pi^+\pi^-)$ is about 10.
→pure molecule is too fragile to be produced at Tevatron/LHC.
→another $\chi_{c1}(2P)$ dominant state would become broad.
Reaching such an interpretation is remarkable progress.

So far, no partner state found

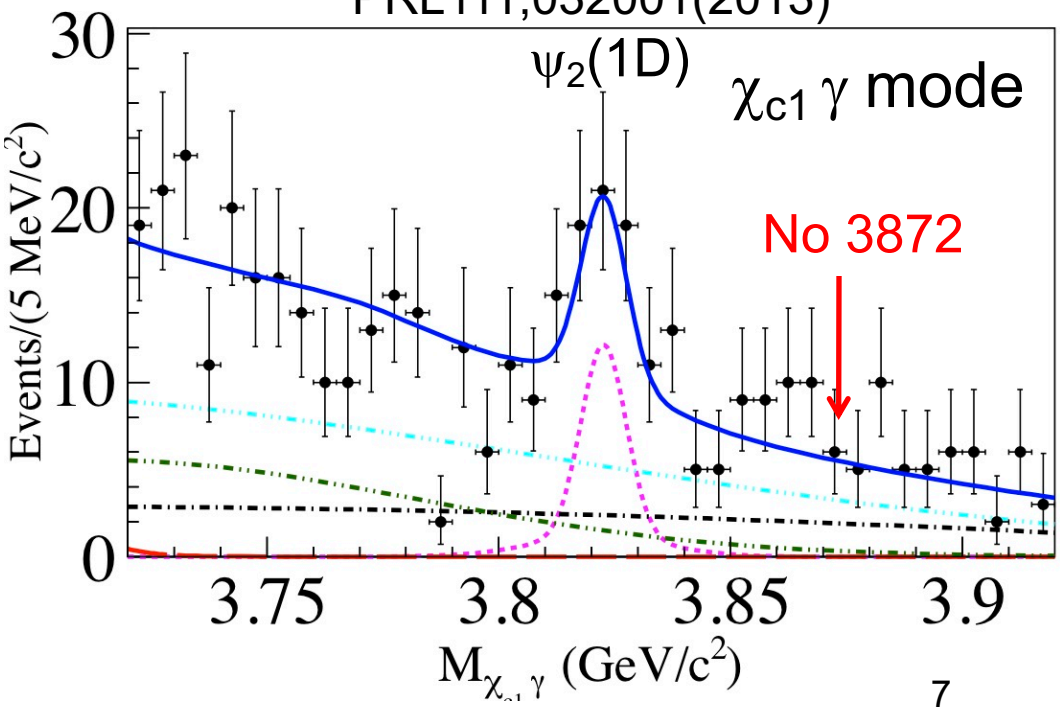
No signature for

- Charged partner in J/ψ $\pi^+\pi^0$. → most likely, isospin=0.
- C=-1 partner in J/ψ η and χ_{c1} γ. → disfavor tetraquark hypothesis.

PTEP2014(2014)043C01



PRL111,032001(2013)

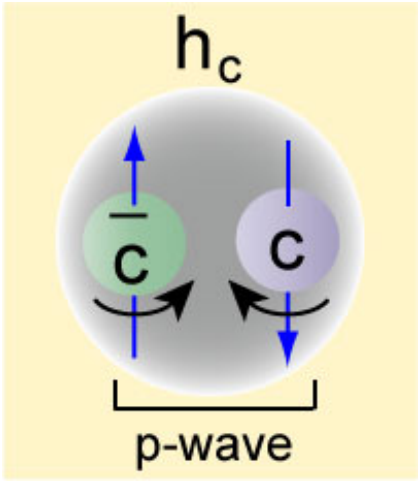


What does it mean?

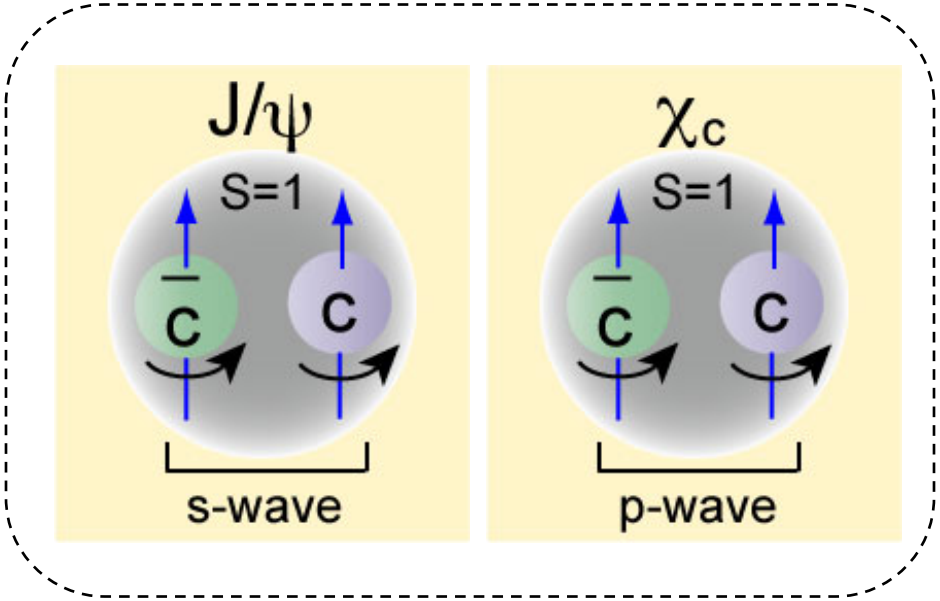
Assuming that X(3872) is admixture of molecule and $\chi_{c1}(2P)$, its C-odd partner, $J^{PC}=1^{+-}$ state, is also admixture of

$$| \text{molecule} > = \{ |D^0 D^{*0}> - |D^{*0} D^0> \}/\sqrt{2}$$

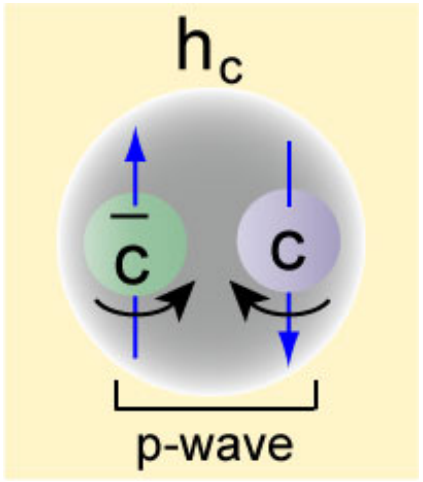
and



then not familiar with

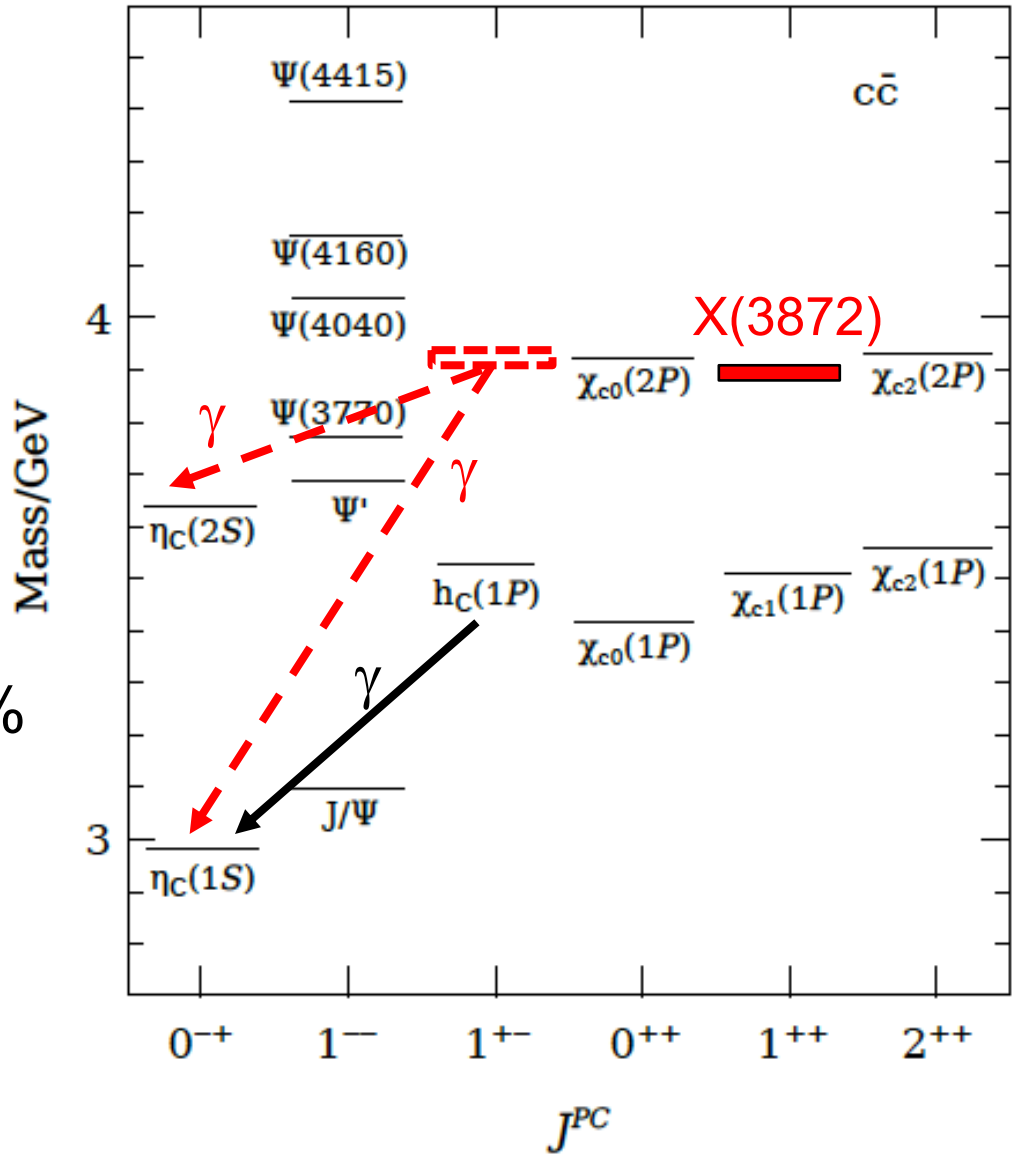


$J^{PC}=1^{+-}$ state possible decay

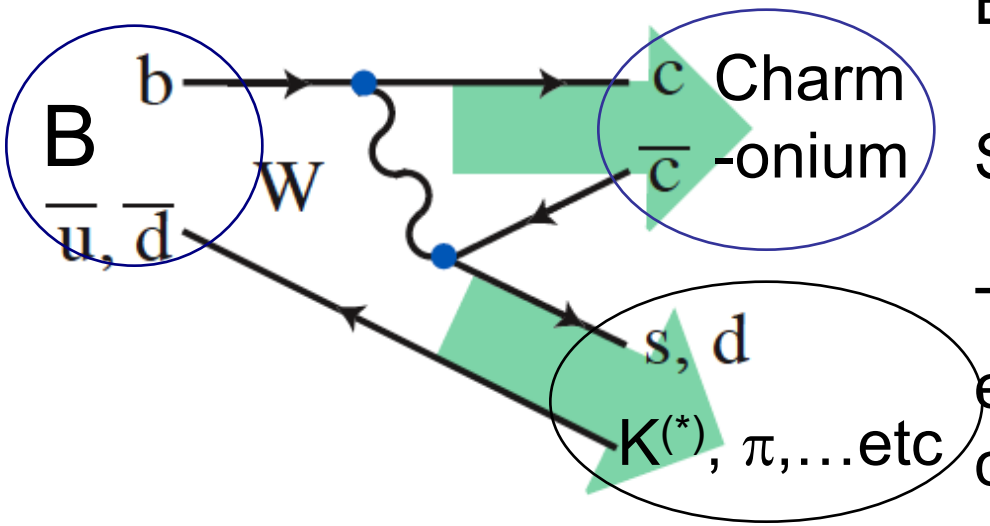


In PDG2019,
$h_c(1P)$ mass=3525 MeV
$Br(h_c(1P) \rightarrow \gamma\, \eta_c(1S))=51\%$

$\gamma\, \eta_c(1S)$ and $\gamma\, \eta_c(2S)$ are the pursuit of.



In B meson decays



B meson is heavy (m_B=5.28 GeV)

↓

Small final state interactions.

↓

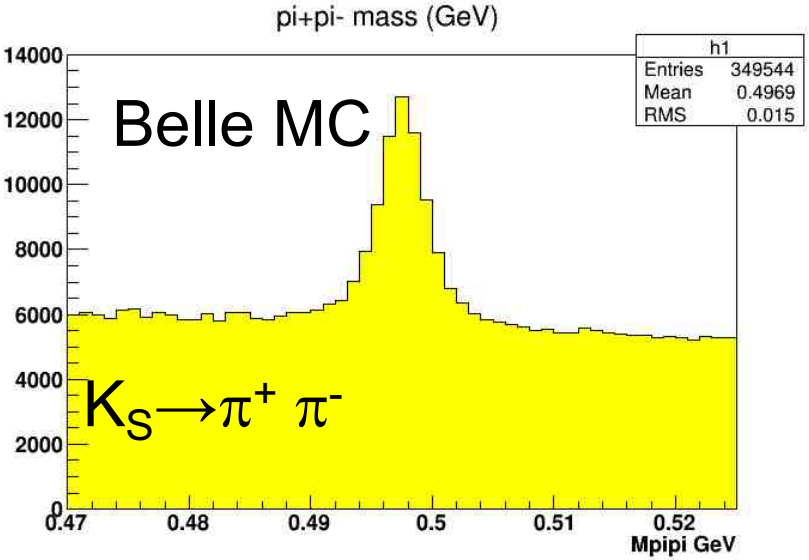
Two-body decay amplitude can be expressed as a product of two currents (into two daughters).
= Factorization hypothesis.

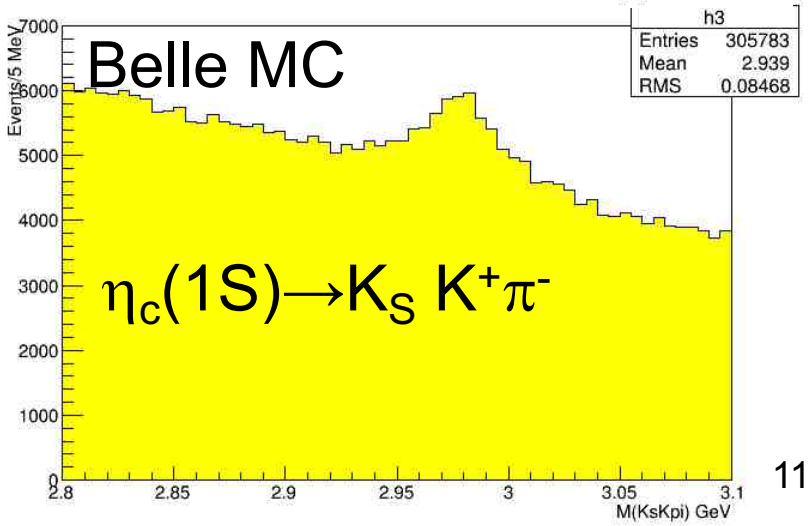
$J^{PC}=0^{-+}$, 1^{--}, 1^{++} charmonia favored, while 1^{+-}, 0^{++}, 2^{++} suppressed.
To be released from this restriction, try three-body decay.

$B^0 \rightarrow \gamma\ \eta_c\ K^-\ \pi^+$ to see $\gamma\ \eta_c$ invariant mass spectrum

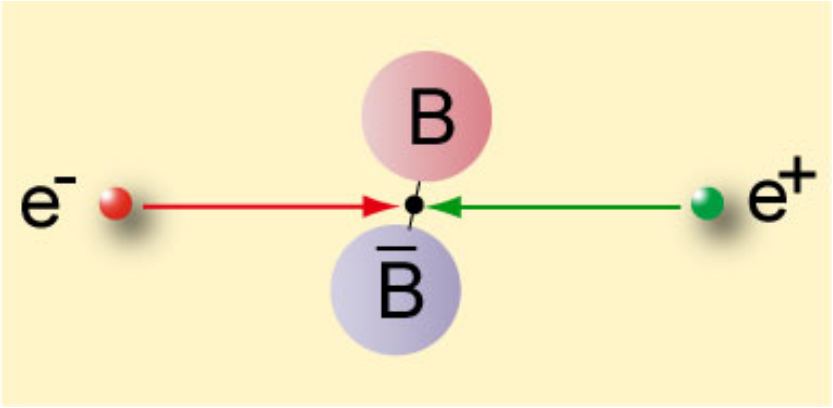
- Simulation under Belle analysis software environment.

- $B^0 \rightarrow h_c(1P)\ K^-\ \pi^+$, $h_c(1P) \rightarrow \gamma\ \eta_c(1S)$, $\eta_c(1S) \rightarrow K_S\ K^+\pi^-$.
- Other B generic decay.

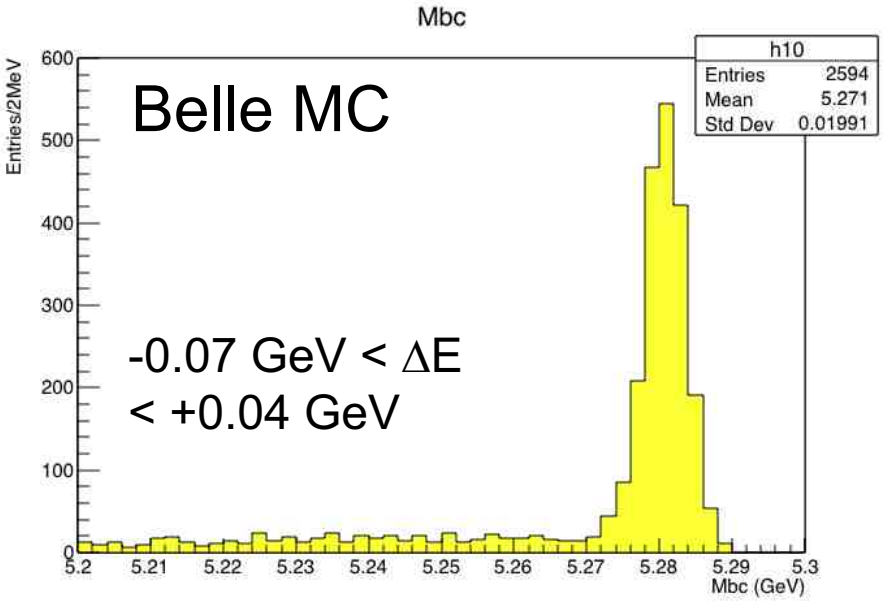




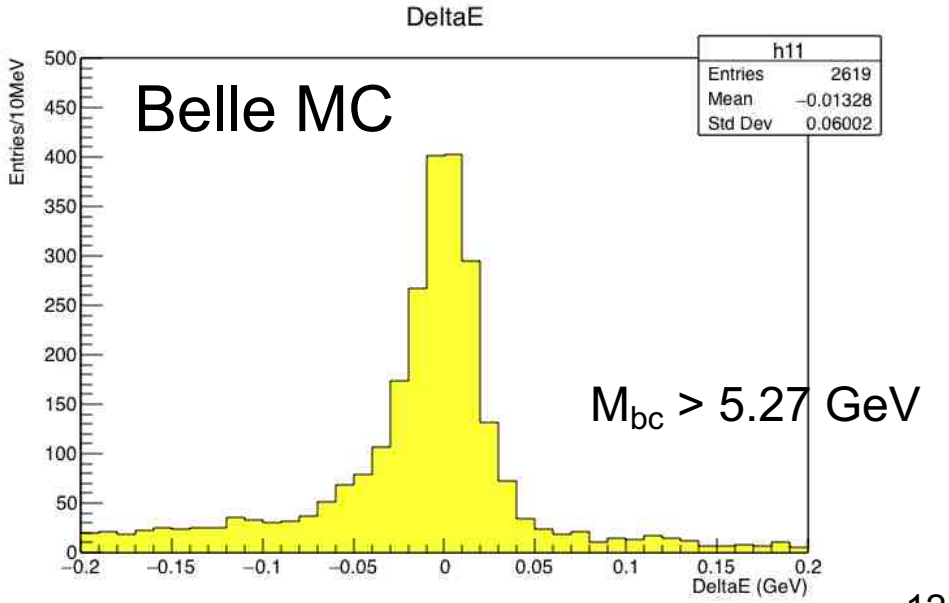
B decay candidate reconstruction



Exploit two-body kinematics.
$M_{bc}=\{(E_{CM}/2)^2-P^2\}^{1/2}$ peaks at 5.28GeV.
$\Delta E=E-(E_{CM}/2)$ peaks at zero.

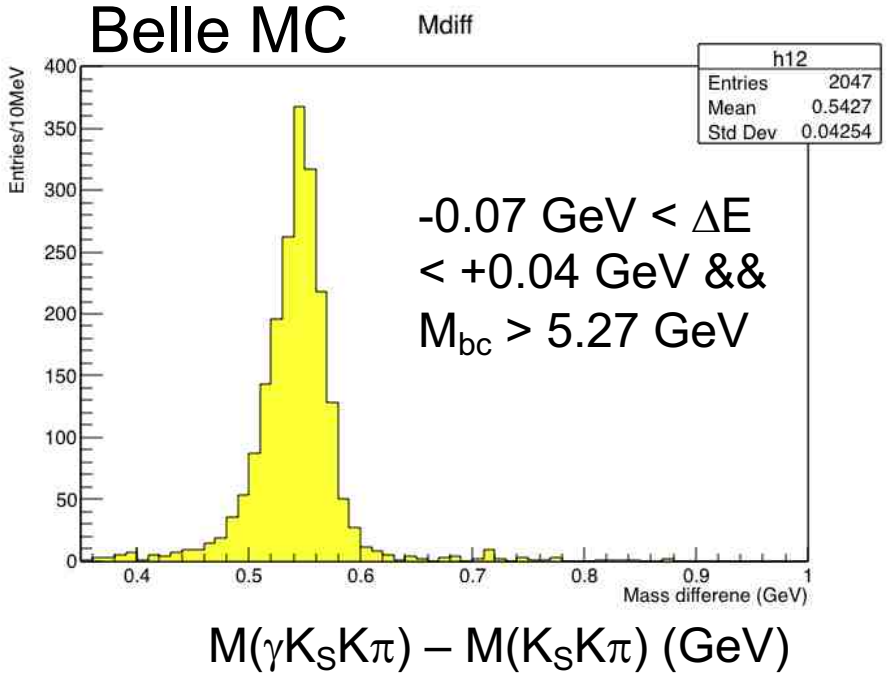


M_{bc} [GeV]



ΔE [GeV]

$\gamma\ \eta_c(1S)$ mass spectrum



In order to visit $\gamma K_S K\pi$ spectrum, mass difference of; $M(\gamma K_S K\pi) - M(K_S K\pi)$ is suitable to find a peak because $M(K_S K\pi)$ measurement error cancels out.

In the MC simulation, proper peak corresponding to $h_c(1P) \rightarrow \gamma\ \eta_c(1S)$ is confirmed.
→basic reconstruction routine works.

Reconstruction efficiency is 2.05 %. It looks reasonable because 4%~5% is quoted for B → hc K search, (PRD74,012007(2006)) and taking one additional pion into account.

Summary

- Molecule-charmonium admixture has become almost consensus for interpretation of X(3872).
- To search for the production of X(3872)'s C-odd partner($J^{PC}=1^{+-}$), $\gamma\ \eta_c(1S)$ and $\gamma\ \eta_c(2S)$ are suitable.
- In order to look for in B meson decays, to become free from the restriction by the factorization, three-body B decays ($\rightarrow$[$J^{PC}=1^{+-}$ state] $K^+\ \pi^-$) are pursuit of.
- Basic reconstruction routine has been composed.
- Background estimation and its reduction are next steps (maybe huge combinatorial background).