B decay reconstruction for the C-odd states with radiative decay

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Quantum Cluster workshop

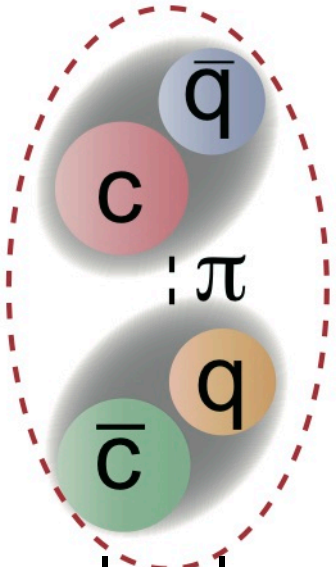
via zoom connection

Outline

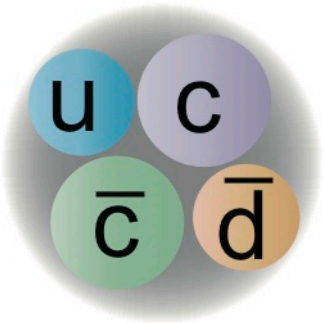
- Exotic hadrons
- X(3872) and its C-odd partner states search
- Radiative decay $\gamma\ \eta_c$(1S or 2S) for $J^{PC}=1^{+-}$
- Belle and Belle II data analysis status
- Summary

Exotic hadrons
number of constituents > 3

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



molecule

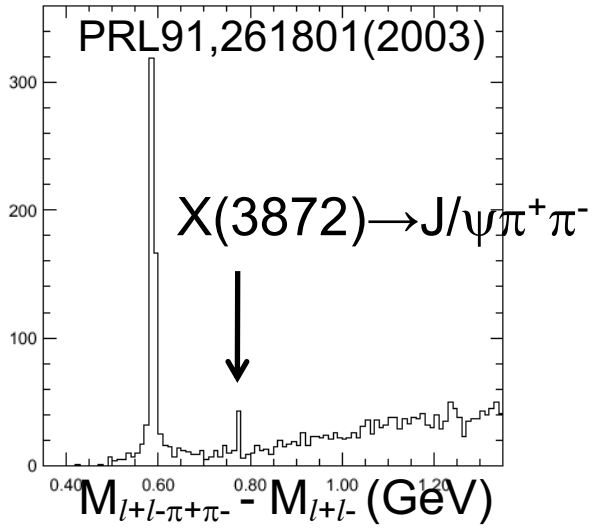


tetraquark

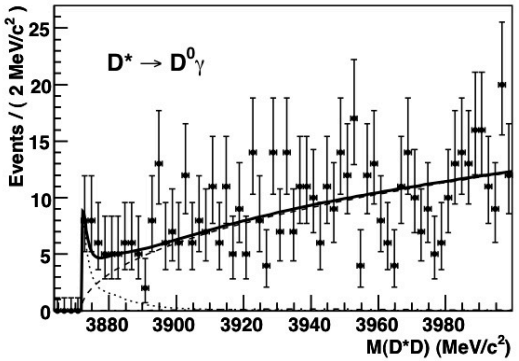
+glue ball,
pentaquark, …

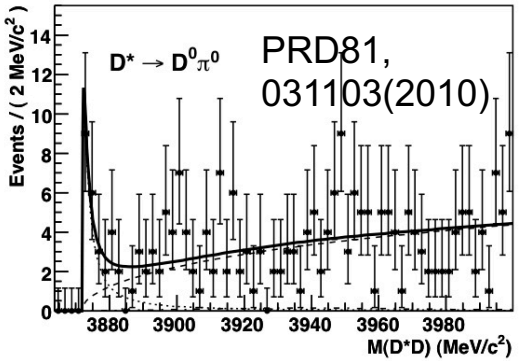
- But lack of experimental evidence for long time.
- Maybe a key to open unrevealed aspect of QCD.

X(3872)

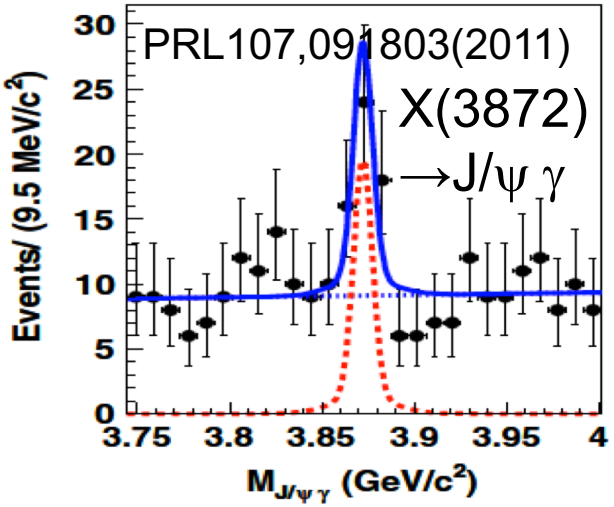


Including $c\bar{c}$, unusually narrow despite its mass above $D\bar{D}$ threshold(=3740MeV/c^2). It is contradicting with the ordinary cc mesons (conventional charmonia). Radiative decay to J/ψ γ, ψ(2S) γ seen, C=+1.



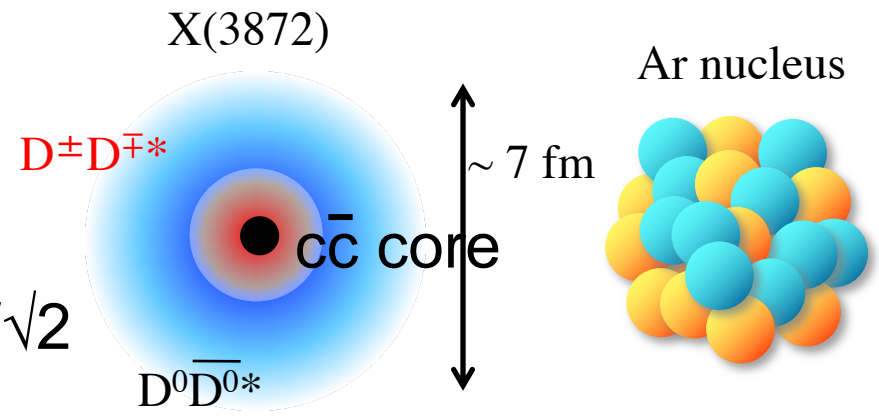


Br(X(3872)→$D^0\bar{D}^{*0}$) is about Br(X(3872)→J/ψ $\pi^+\pi^-$) × 10.



Admixture : most plausible interpretation for X(3872)

| molecule >
= { |$D\bar{D}^*$> + |$D^*\bar{D}$> }/√2



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

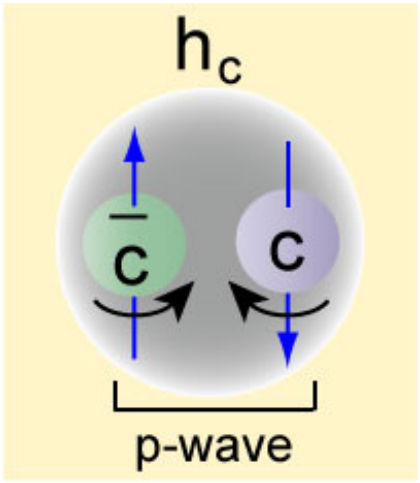
$D\bar{D}^*$ component is coupled with the same J^{PC} $c\bar{c}$, $\chi_{c1}(2P)$ (unseen).
→can explain $Br(X\to D^0\bar{D}^{*0})/Br(X\to J/\psi\,\pi^+\pi^-)$ is about 10.
→pure molecule is too fragile to be produced at Tevatron/LHC.
→another $\chi_{c1}(2P)$ dominant state would become broad.
Reaching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

Where C-odd partner looked for?

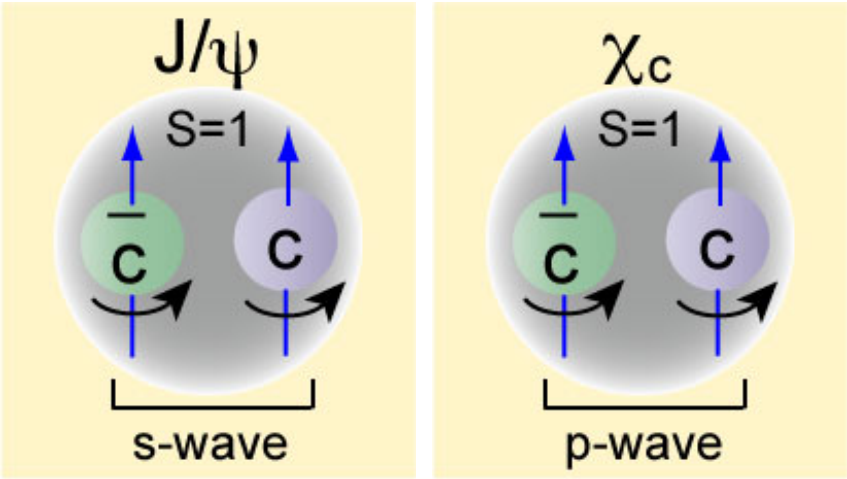
Assuming that X(3872) is admixture of molecule and $\chi_{c1}(2P)$, its C-odd partner, $J^{PC}=1^{+-}$ state, is also admixture of

$$| \text{molecule(C-odd)} > = \{ |D\bar{D}^{*}> - |D^{*}\bar{D}> \}/\sqrt{2}$$

and

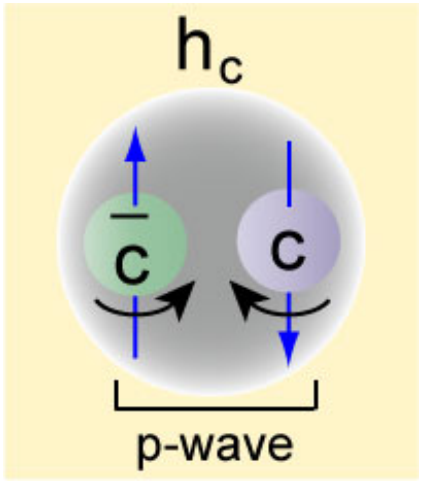


then not familiar with



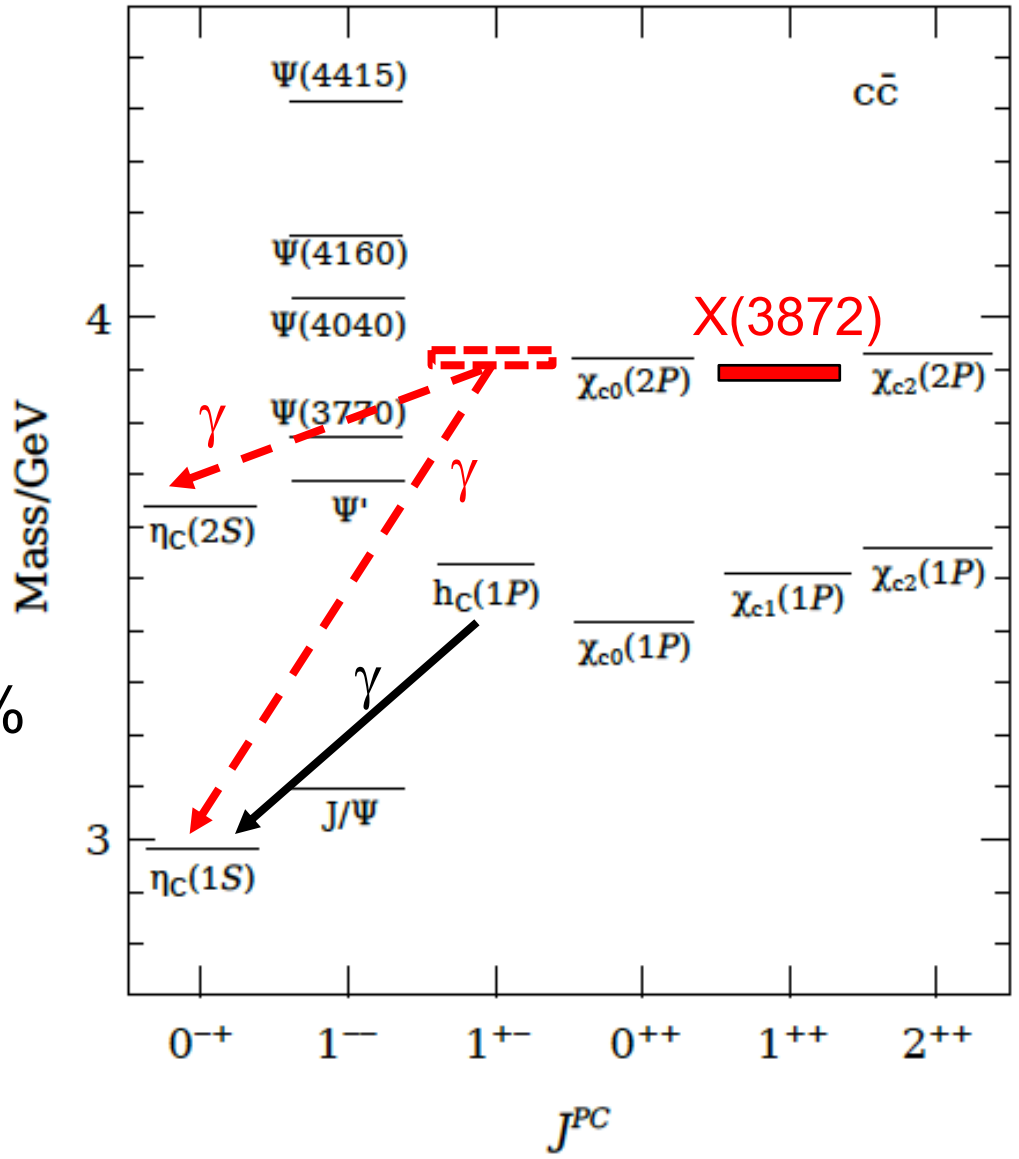
because heavy quark's spin-flip is suppressed.

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

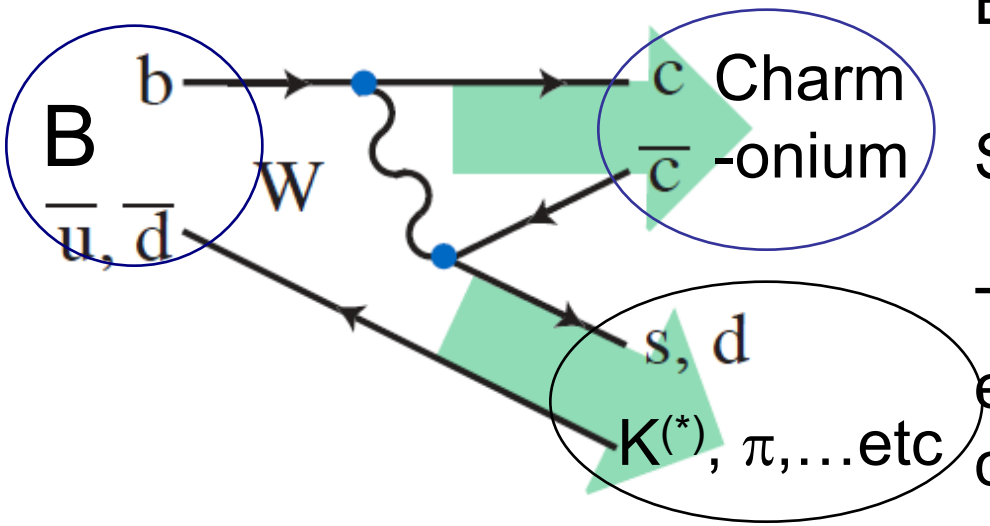


In PDG2019,
$h_c(1P)$ mass=3525 MeV
$Br(h_c(1P) \rightarrow \gamma\, \eta_c(1S))=51\%$

$\gamma\, \eta_c(1S)$ 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.

↓

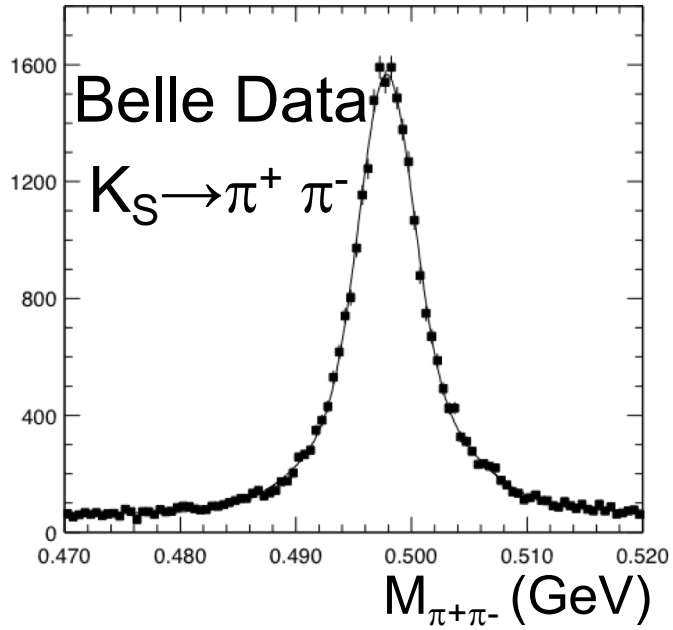
Two-body decay amplitude can be expressed as a product of two currents (into two daughters).
= Factorization hypothesis.

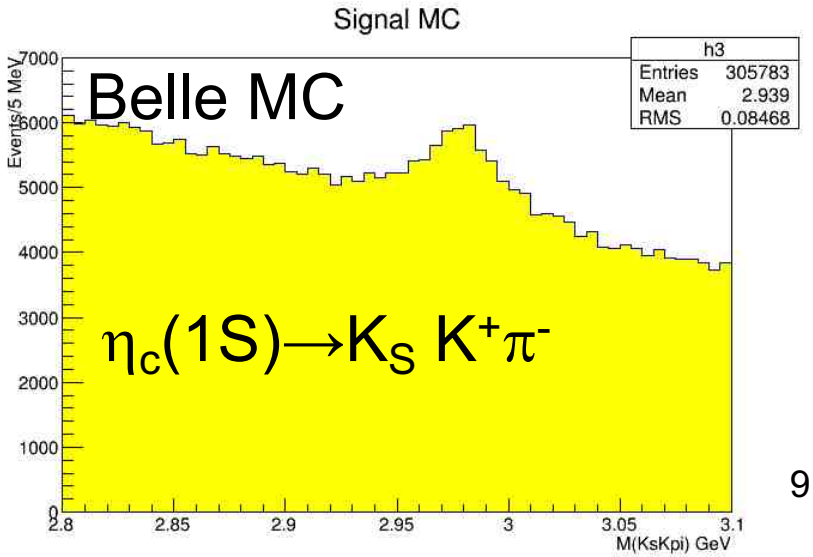
$J^{PC}=0^{-+}$, 1^{--}, 1^{++} charmonia favored, while 1^{+-}, 0^{++}, 2^{++} suppressed.
To be released from this restriction, try three-body decay.

$B^0 \rightarrow \gamma\ \eta_c\ K^-\ \pi^+$ reconstruction

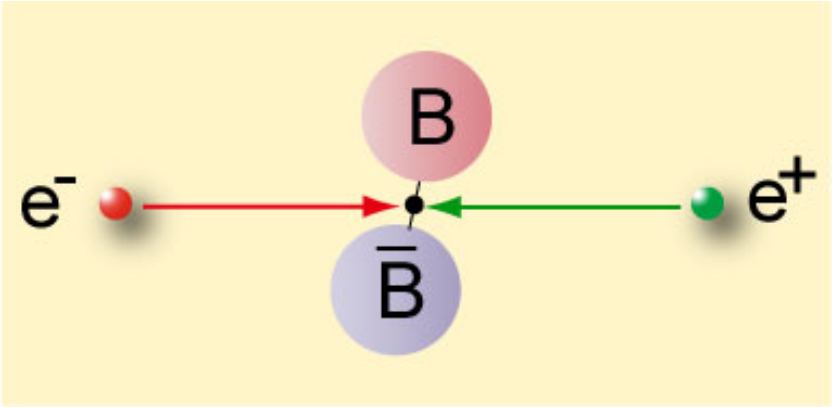
- Simulation under Belle analysis software environment done.

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

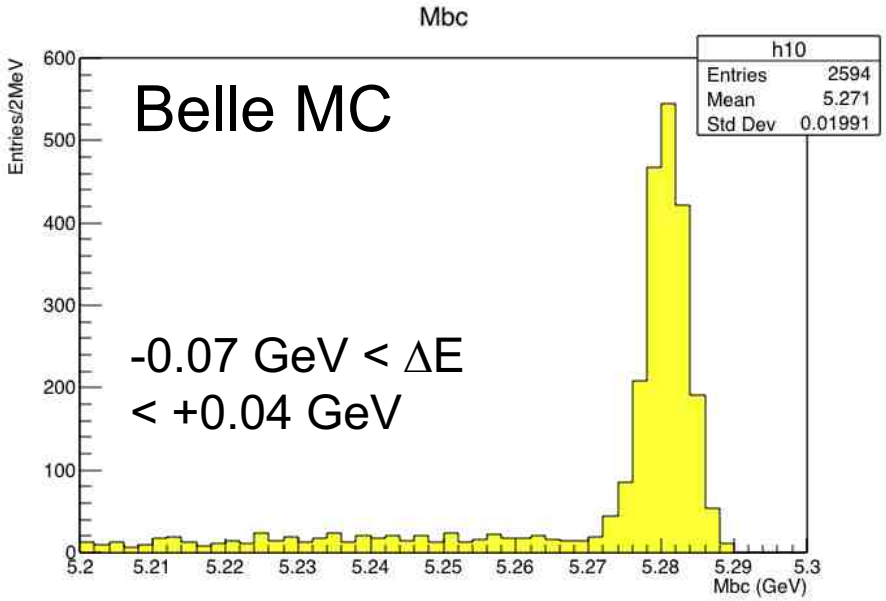




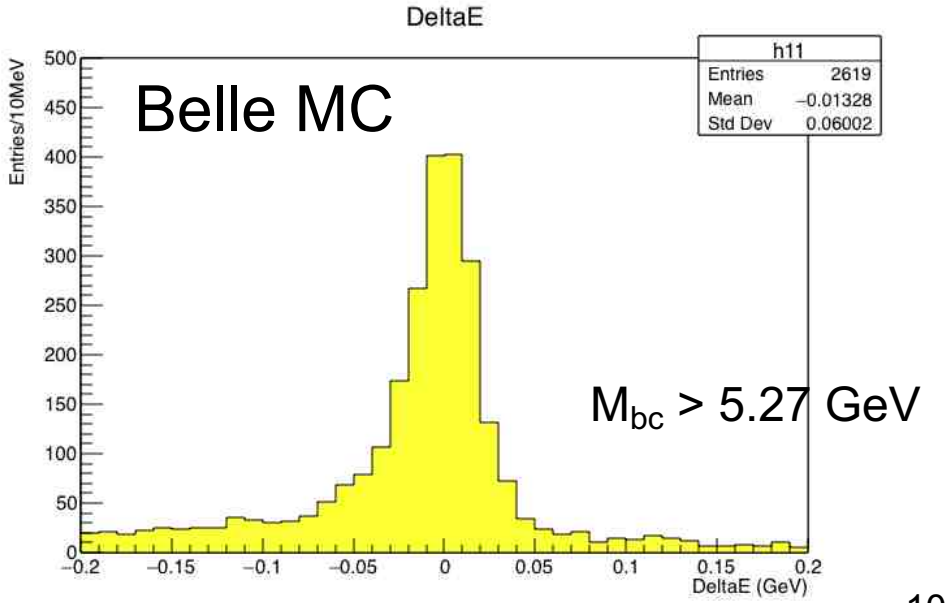
B decay candidate reconstruction



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.



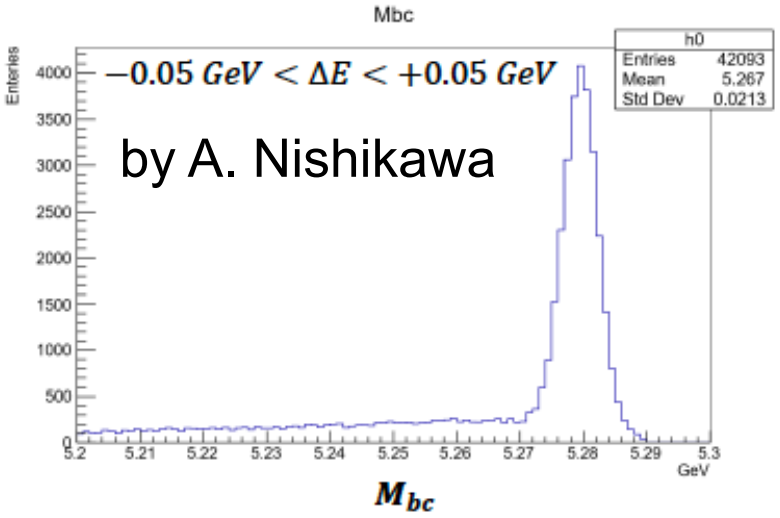
M_{bc} [GeV]



ΔE [GeV]

Adding $\eta_c \to p\bar{p}$ mode

A. Nishikawa (Nara master student) wrote Belle II analysis script to reconstruct $B \to \eta_c \gamma K^+ \pi^-$ (+ c.c.), $\eta_c \to p\bar{p}$ mode.

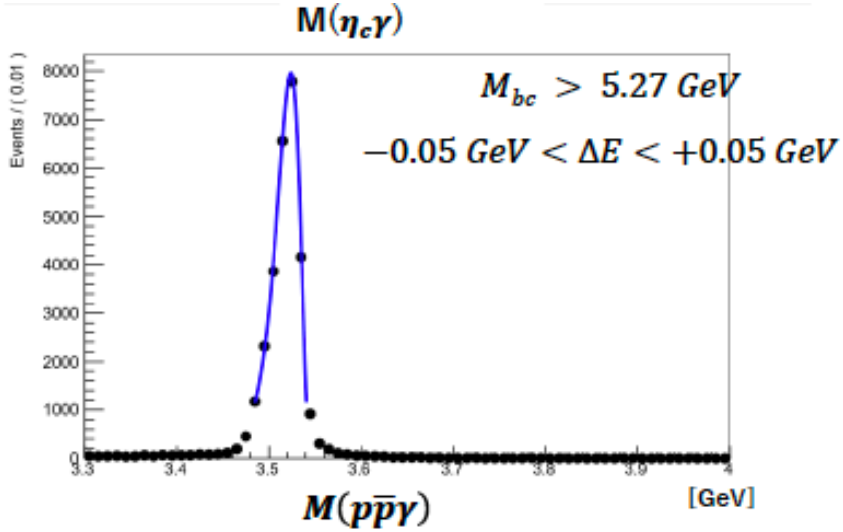


Multivariate analysis template is better prepared in Belle II software environment than Belle.
Belle mdst data is made readable in Belle II software by calling b2bii software(i.e. format converter).

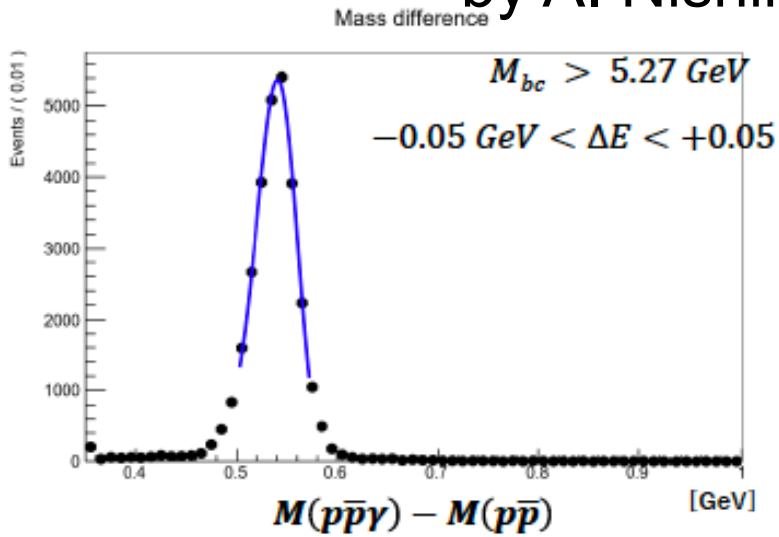
B decay reconstruction efficiencies
4.0% in $\eta_c \to K_S K^+ \pi^-$ (and c.c.) mode, 25% for $p\bar{p}$.
$Br(\eta_c \to K_S K^+ \pi^-) = 1.7\%$, $Br(\eta_c \to p\bar{p}) = 0.15\%$,
$\eta_c \to K_S K^+ \pi^-$ looks still larger yield.

Mass spectrum, different from other cases..

by A. Nishikawa



Mean [MeV]	Sigma [MeV]
3523.83 ± 0.18	13.29 ± 0.10



Mean [MeV]	Sigma [MeV]
540.8 ± 0.3	20.20 ± 0.18

χ_{c1}, $\chi_{c2} \rightarrow$ J/ψ γ radiative decays, the mass difference of M($l^+l^-\gamma$) – M(l^+l^-) shows narrower peak.

But since h_c is narrow(Γ =0.7MeV), η_c is slightly wide (Γ=32MeV), M($p\bar{p}\gamma$) peak is shaper than the mass difference.

Summary

- 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.
- Many-body decay, background amount is huge.
- In addition to $\eta_c \rightarrow K_S K^+\pi^-$, $p\bar{p}$ mode is to be added.
- $M(K_S K^+\pi^-\gamma)$ and $M(p\bar{p}\gamma)$ turned out to be visited.
- For background reduction, Multivariate Analysis is to be employed.