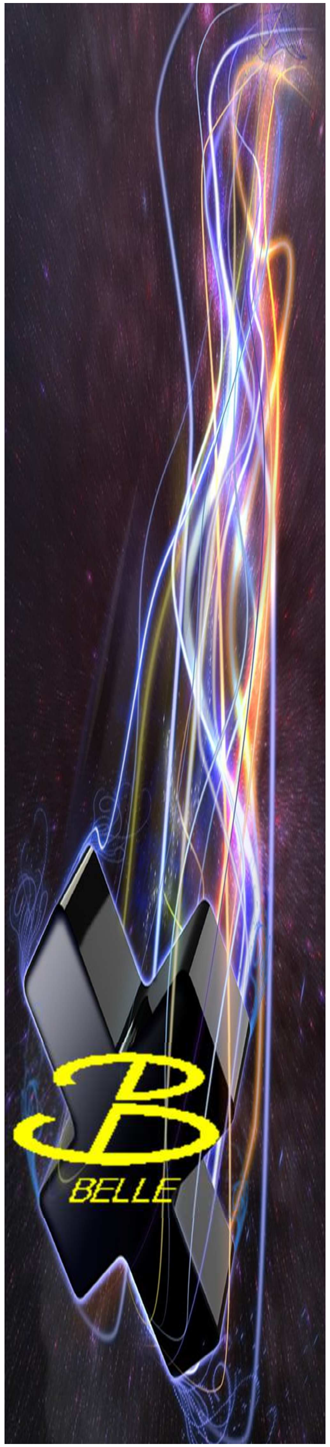
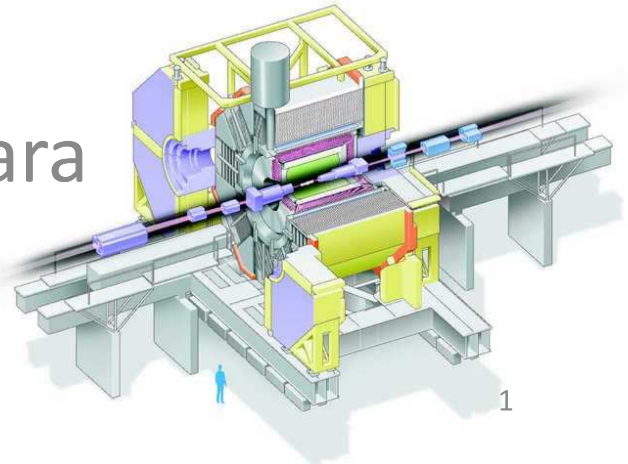
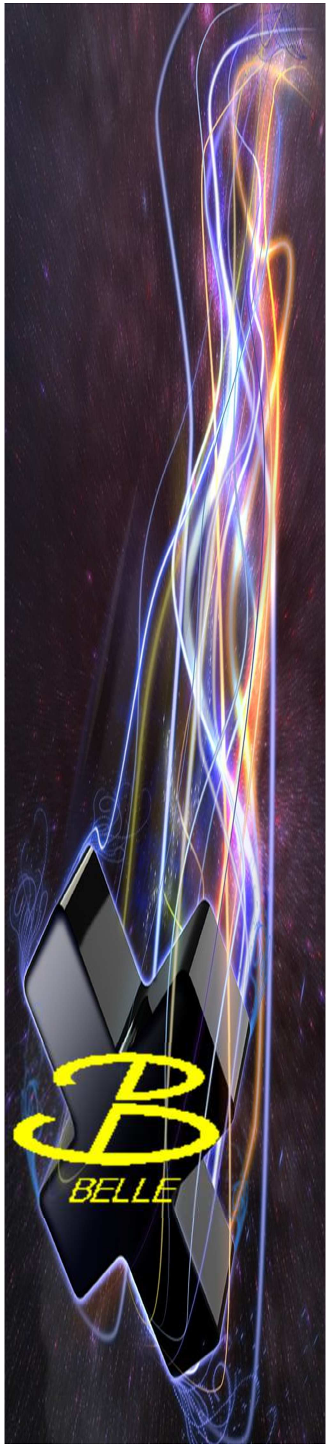


Studies of radiative X(3872) decays at Belle

Charm 2012

Vishal Bhardwaj, Nara
(on behalf of Belle)

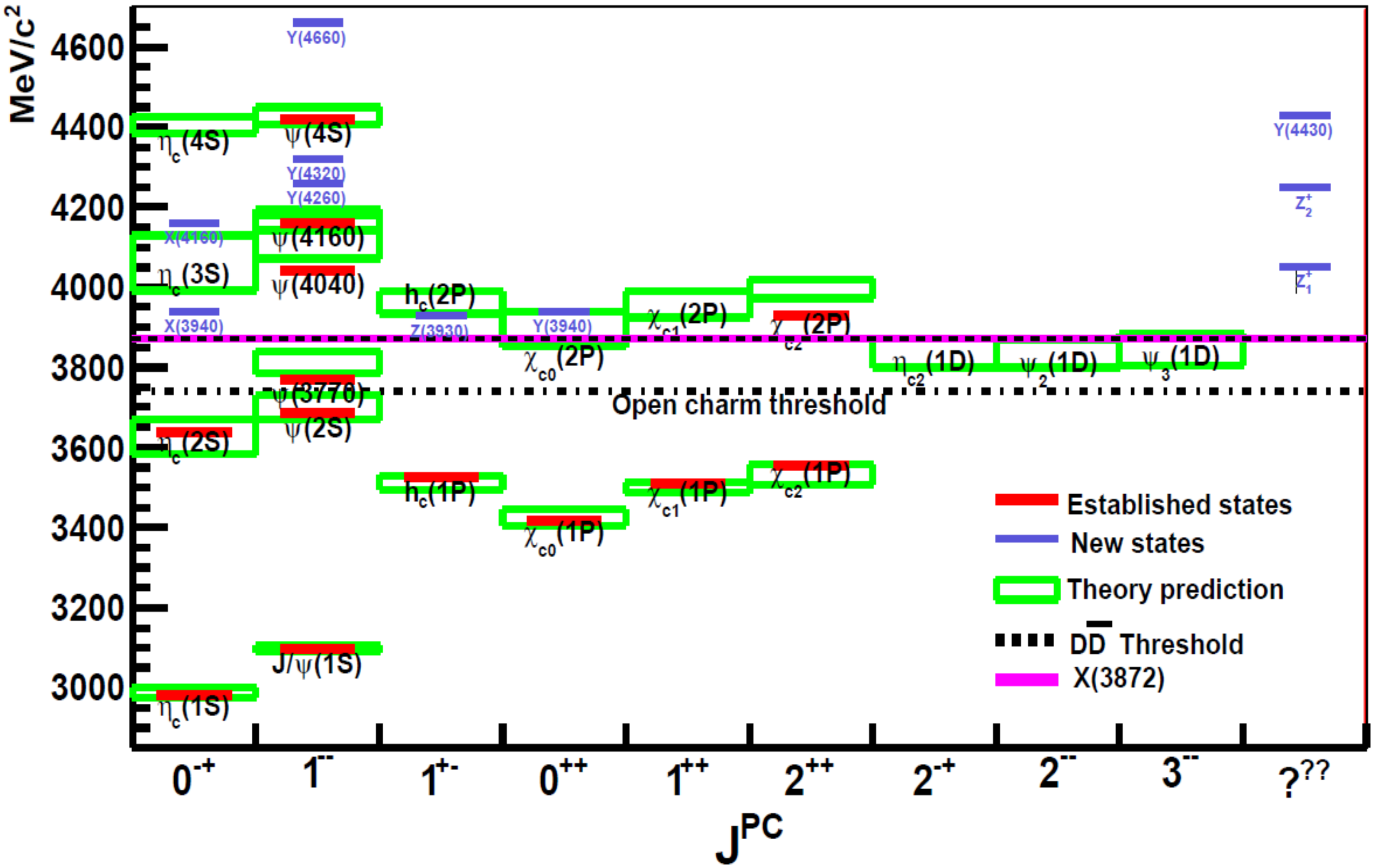




Outline

- Charmonium at Belle
- Radiative decays of X(3872).
- Search for $X(3872)^{C-}$ in $\chi_{c1,c2}\gamma$
- First evidence of Ψ_2
- Result and Conclusion

Charmonium spectrum



Contribution to new states:

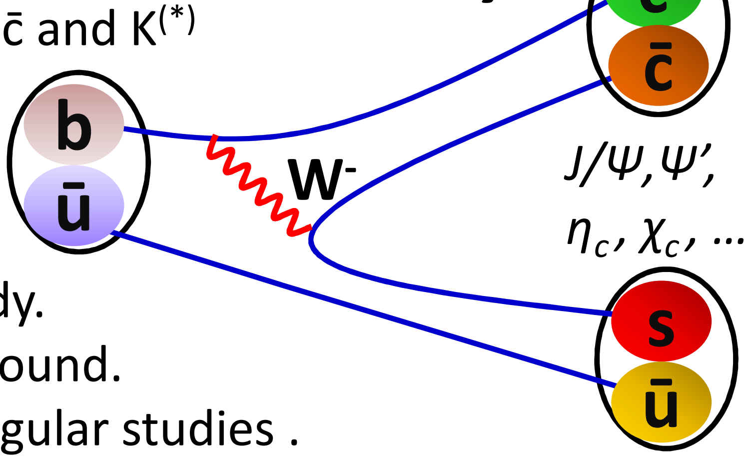
$\eta_c(2S)$, Ψ_2, X(3872), X(3915), Z(3930), X(3940), Y(3940), $Z_1(4050)^+$, $Z_2(4250)^+$, Y(4260), $Z(4430)^+$, Y(4660), ...

In this talk

Production of cc̄ (-like) in B-*factory*

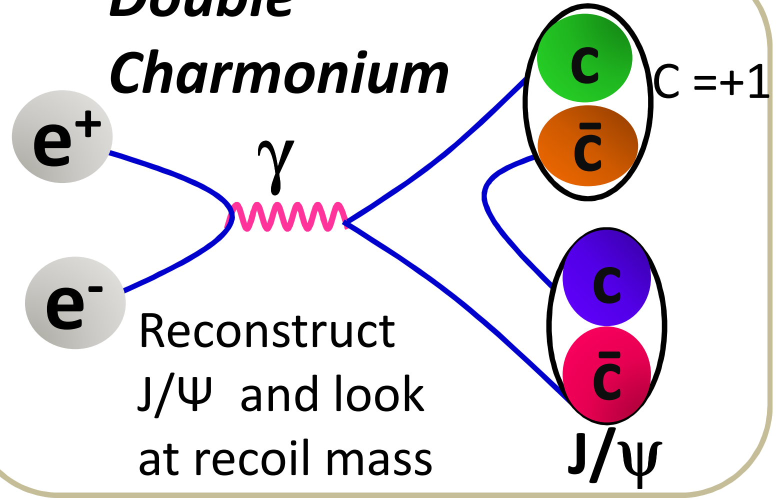
B-decays

A few % of B mesons decay into cc̄ and K(*)



Easy to study.
Low background.
J^{PC} using angular studies .

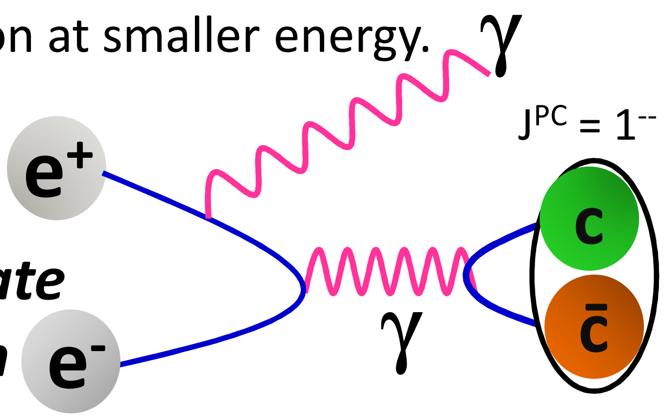
Double Charmonium



Reconstruct J/Ψ and look at recoil mass

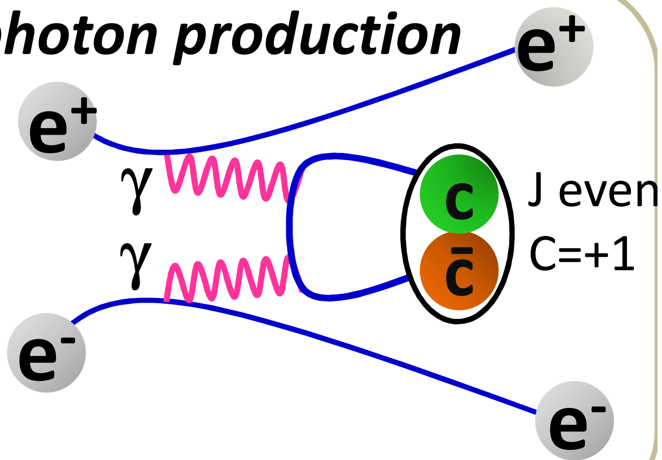
Initial state radiation

Annihilation at smaller energy.



Two photon production

cc̄ states produced without additional hadrons.



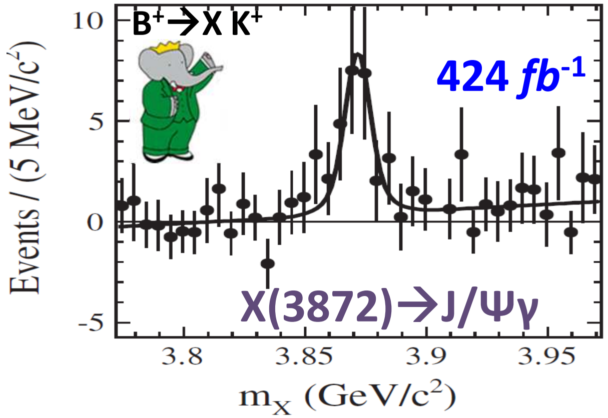
Clean and ideal place to carry charmonium spectroscopy related business.

Radiative decays of X(3872)

Belle found evidence for $X(3872) \to J/\psi\gamma$ in $B^+ \to X(3872)\, K^+$

+ve C parity

Belle, arXiv:0505037

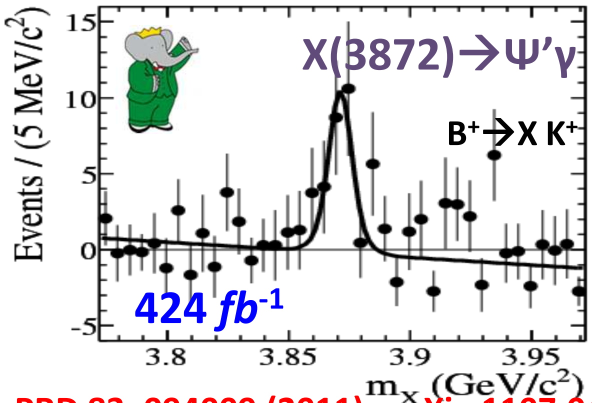


Also seen by BaBar

$\mathcal{BR}(B^+ \to XK^+) \,.\, \mathcal{BR}(X \to J/\psi\gamma) = (2.8 \pm 0.8 \pm 0.1) \times 10^{-6}$

BaBar, PRL 102, 132001 (2009)

BaBar find signal in $X(3872) \to \Psi'\gamma$



$\mathcal{BR}(X(3872) \to \psi'\gamma) / \mathcal{BR}(X(3872) \to J/\psi\gamma) = 3.5 \pm 1.4$

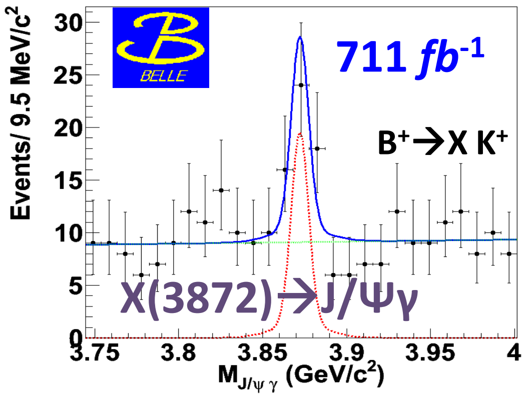
If pure molecular (model dependent) :- **Phys.Rept. 429,243(2006)**

$\mathcal{BR}(X(3872) \to \psi'\gamma) < \mathcal{BR}(X(3872) \to J/\psi\gamma)$

PRD 83, 094009 (2011) , arXiv:1107.0443v3
PLB 697,3, 233-237 (2011)

Update from Belle, established $X(3872) \to J/\Psi\gamma$ with 5.5σ observation*

Belle, PRL 107, 091803 (2011)

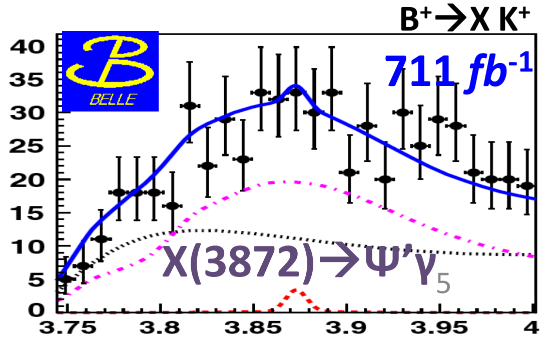


$\mathcal{BR}(B^+ \to XK^+) \times \mathcal{BR}(X \to J/\psi\gamma) = (1.78 \pm 0.46 \pm 0.12) \times 10^{-6}$

However, Belle didn't see any signal in $X(3872) \to \Psi'\gamma$

$$\frac{BR(X \to \psi'\gamma)}{BR(X \to J/\psi\gamma)} < 2.1\ (@90\%\ CL)$$

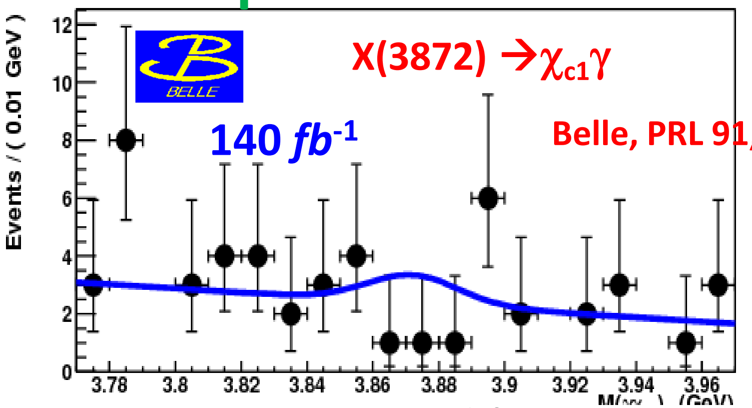
No Belle evidence for $X(3872) \to \Psi'\gamma$



* combining $B^+ \to X K^+$ & $B^0 \to XK^0$

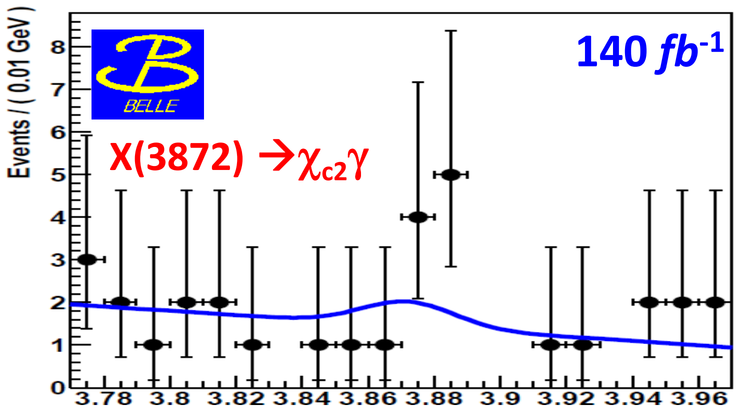
Search for X(3872)$^{c-}$ in $\chi_{c1,c2}\gamma$

- **Earlier search for tetraquark partner (charged X(3872)), no signal was seen.** Belle, PRD 85,052004 (2011)
- **However, many tetraquark models predict X(3872)$^{+}$ to be broad and non-observed yet due to low statistics (?).** K. Terasaki, Prog. Theor. Phys. 127, 577-582 (2012)
- **X(3872) C-even parity prohibit it to decay into $\chi_{c1,c2}\gamma$.**
- **If X(3872) is tetraquark than its' C-odd partner can decay into $\chi_{c1,c2}\gamma$.**
- **In Belle previous searches (with less data), no signal was seen and UL was provided.**



Belle, PRL 91,262001(2003)

$M_{\chi c1\gamma}$ (GeV/c^2)



Belle, arXiv:0408116 $M_{\chi c2\gamma}$ (GeV/c^2)

$$\frac{\Gamma(X3872\rightarrow\chi_{c1}\gamma)}{\Gamma(X3872\rightarrow J/\Psi\pi\pi)}<0.9$$

$$\frac{\Gamma(X3872\rightarrow\chi_{c2}\gamma)}{\Gamma(X3872\rightarrow J/\Psi\pi\pi)}<1.1$$

With 5 x more data either we can observe or provide much tighter constraint to C-odd partner of X(3872)

Search for $c\bar{c}$ (-like) states

- Many conventional states still awaiting confirmation and B decays provide a gateway to study them.
- Theory predicts $^3D_2$ $c\bar{c}$ state to lie around ~3810-3840 MeV/c^2 mass and should be narrow.

  Partial width, $\Gamma(\psi_2 \rightarrow \chi_{c1}\gamma)$ = 260 keV.
- Along with this, there should be $^3D_3$ $c\bar{c}$ state lying around ~ 3830-3880 MeV/c^2 mass and will decay into $\chi_{c2}\gamma$.

  Partial width, $\Gamma(\psi_3 \rightarrow \chi_{c2}\gamma)$ = 286 keV.

S. Godfrey & N. Isgur, PRD 32, 189 (1985)
E. Eichten et al., PRL 89,162002 (2002), PRD 69, 094019 (2004)

✓ With current statistics, we expect to find some hint of Ψ_2 and Ψ_3.

✓ Along with this, we may also find some other C-odd $c\bar{c}$ - like resonance.

Search for new exotic state in $\chi_{c1}\gamma$ and $\chi_{c2}\gamma$ by scanning $M_{\chi c1,c2\gamma}$ (mass distribution) for narrow peak.

Analysis procedure

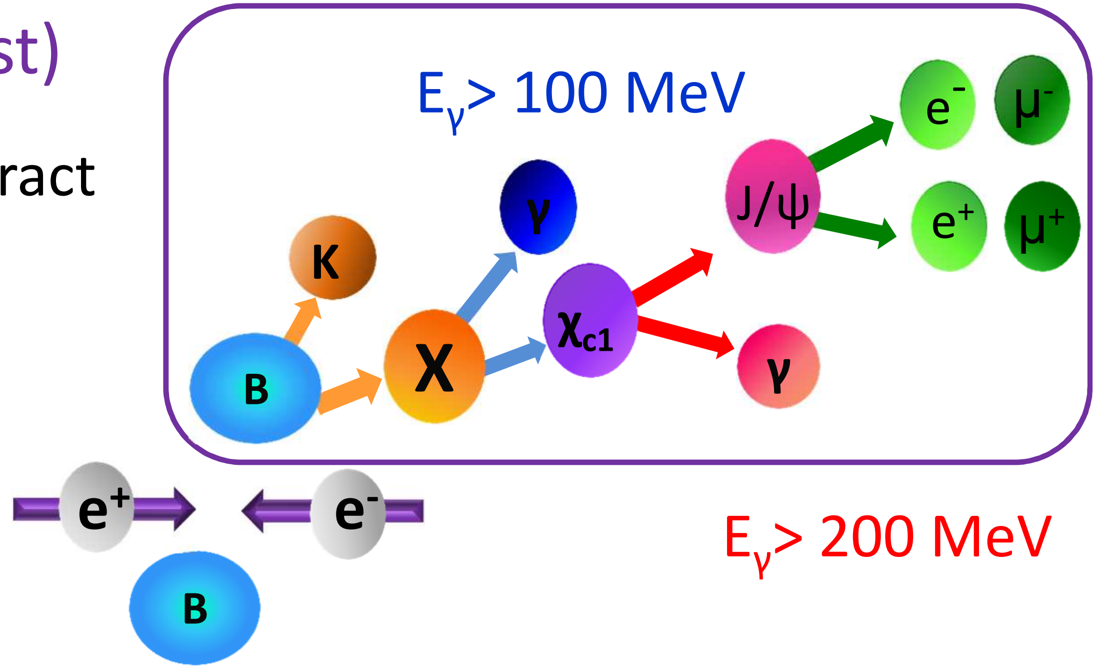
Reconstruct $B^{\pm}$ (of interest)

Variable used in analysis to extract signal

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$$

$$\Delta E = E_B - E_{beam}$$

$$M_{\chi c1\gamma} \quad \text{or} \quad M_{\chi c2\gamma}$$



To identify background, large sample of B→J/Ψ X (final state, here X can be anything) MC is used.

$B^{\pm} \rightarrow \chi_{c1}\gamma K^{\pm}$

Analysis procedure

Reconstruct $B^{\pm}$ (of interest)

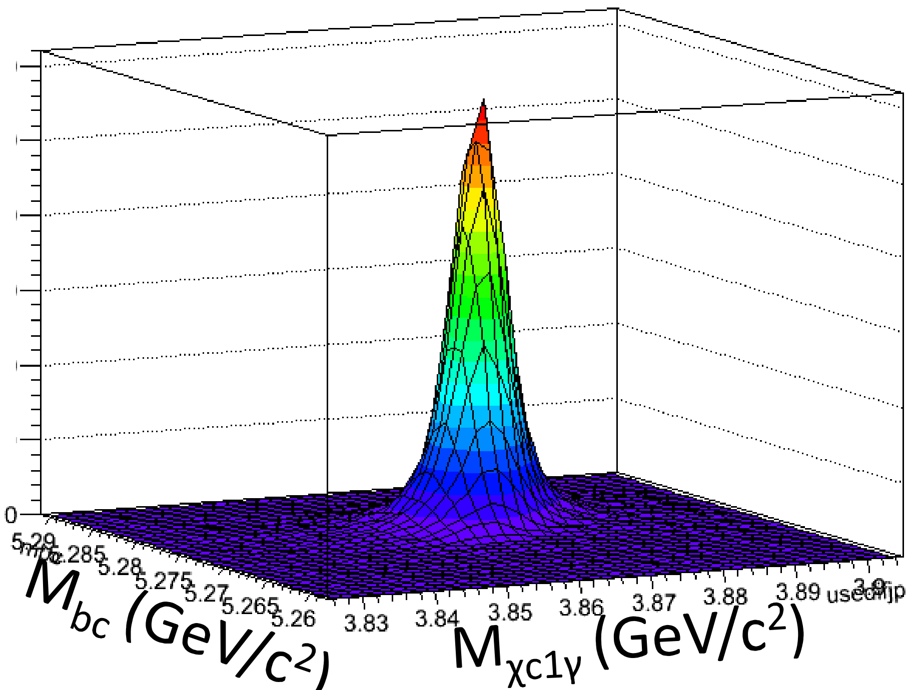
To reduce background

- π^0 veto
- $\chi_{c1,c2}'\ \gamma$ veto

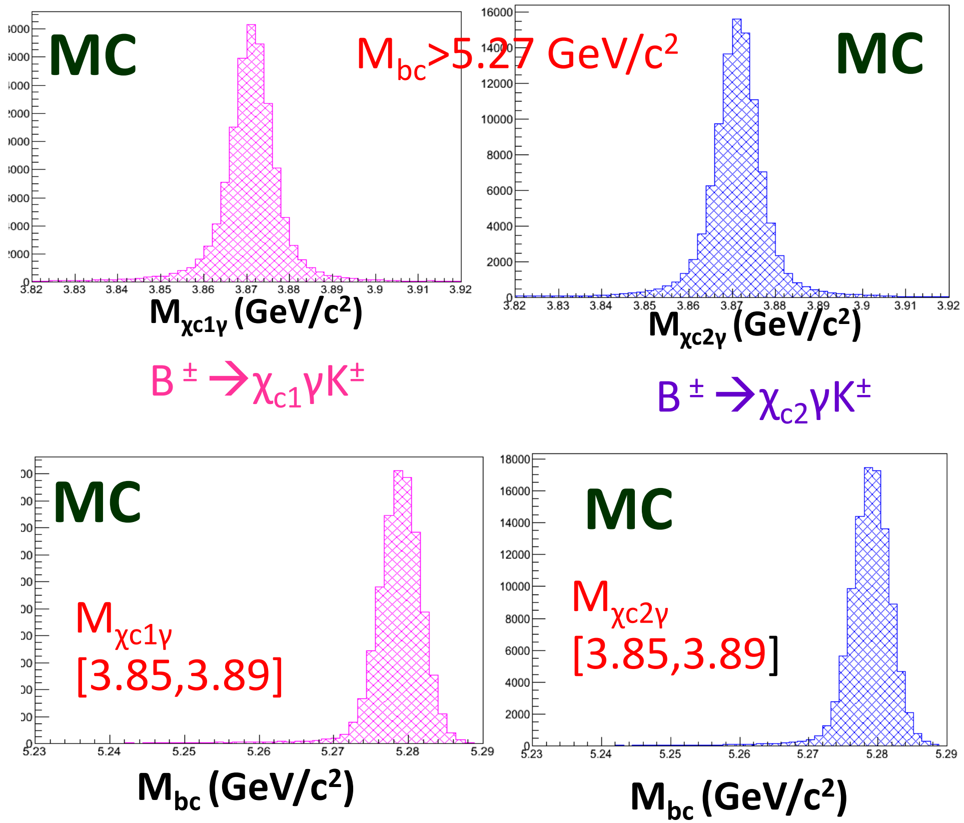
-28 MeV < ΔE < 30 MeV

E_γ scaled (ΔE=0) to improve the resolution of $M_{\chi c1,c2\gamma}$

- 2D UML fit to $M_{\chi c1,c2\gamma}$ & M_{bc} extract signal yield
- If some new resonance, it will become visible in $M_{\chi c1,c2\gamma}$, in M_{bc} signal region.



MC for illustration purpose



Projection in signal region

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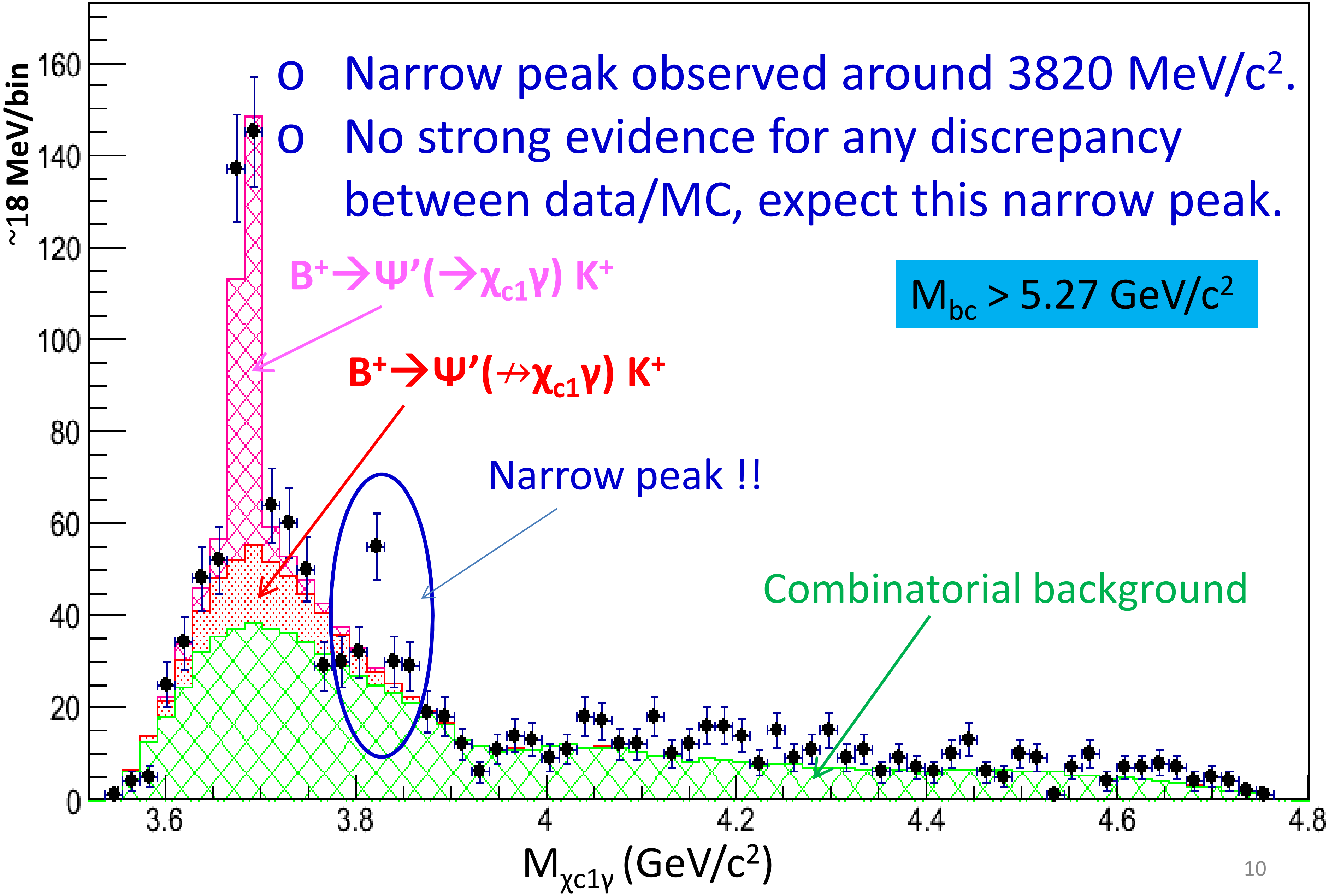
$M_{\chi c1\gamma}$ distribution

$B^{\pm} \rightarrow \chi_{c1}\gamma K^{\pm}$

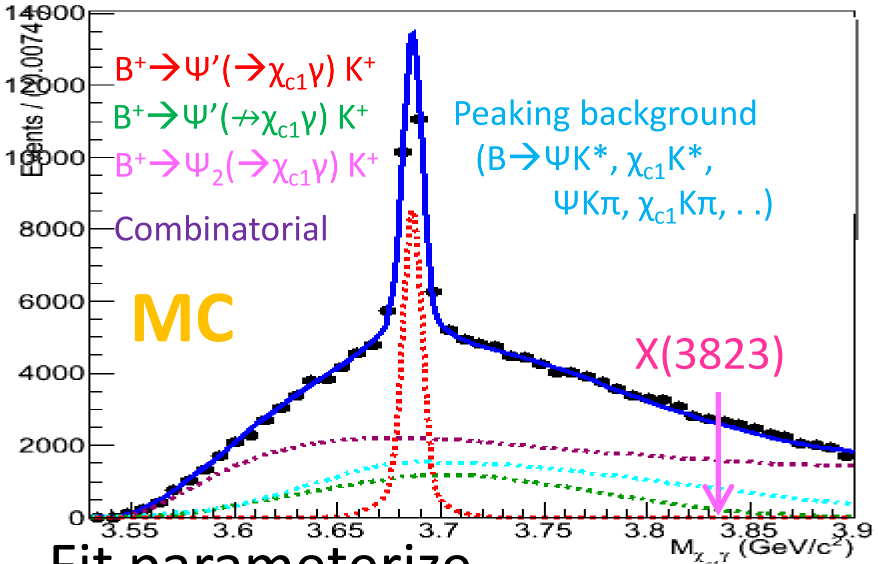


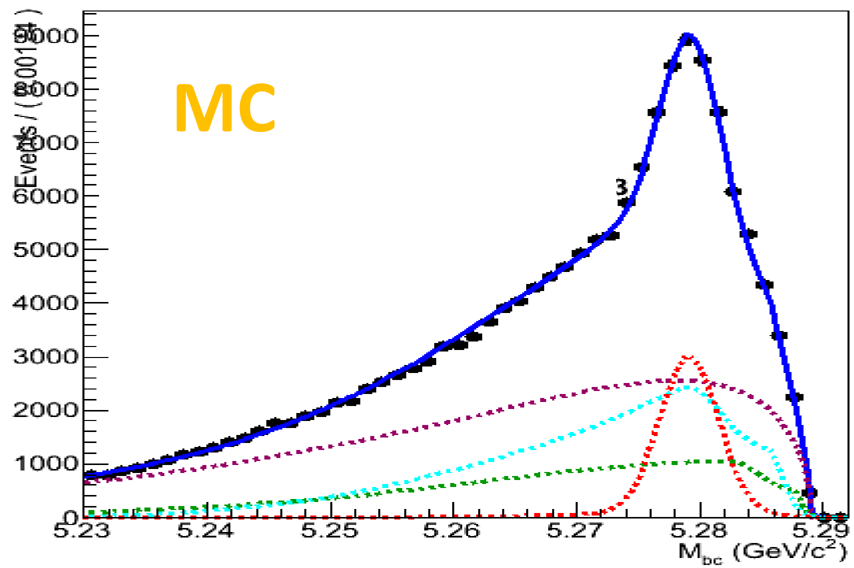
$B^{\pm} \rightarrow \chi_{c1}\gamma K^{\pm}$

Signal extraction in $M_{\chi c1\gamma}$

2D UML fit

Background parameterize using large $B \rightarrow J/\Psi$ X MC sample





Fit parameterize

- Sum of two Gaussian (convoluted with Breit-Wigner)* is used to fit Ψ_2 (from MC).
- Tail part Gaussian same as Ψ' (tested on MC study).
- M_{bc} PDF same as Ψ' (from MC study).
- Ψ_2 width is fix to zero, resolution is estimated from Ψ' peak (and scaled from MC*).

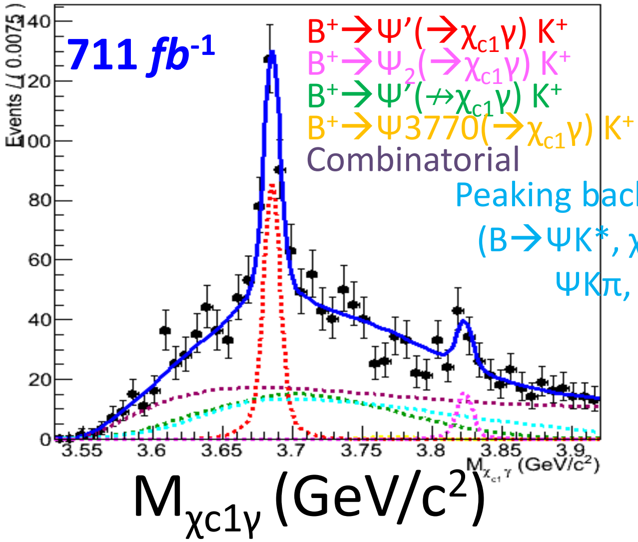
For fit bias, 2000 toys and no significant bias is observed.

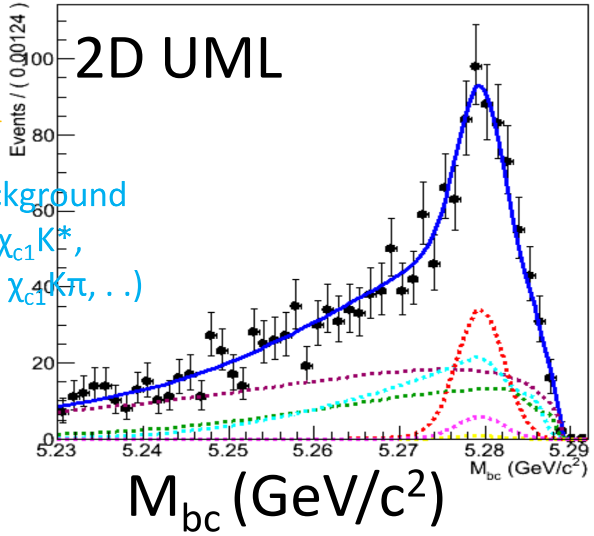
Maximum bias of 2% estimated and included in the systematics.

*Estimated from signal MC (for different width) *preliminary*

Mass of new peak

$B^{\pm} \to \chi_{c1}\gamma K^{\pm}$





Peak at
3823.5 ± 2.8 MeV/c^2

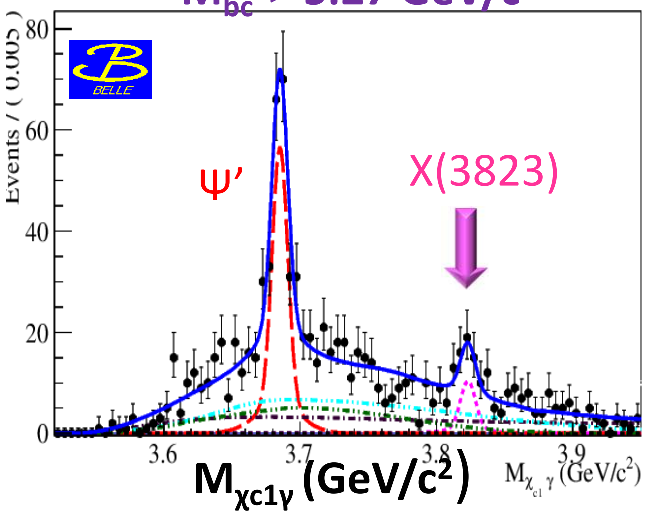
Yield: 4.2σ (syst. Included)
33.2 ± 9.1

Clear evidence of signal at 3823 MeV/c^2

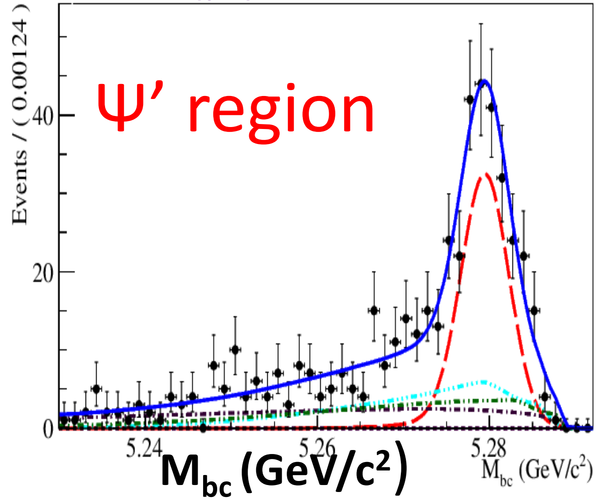
$\Gamma = 4 \pm 6$ MeV if fitted, poor sensitivity

Projection in signal region

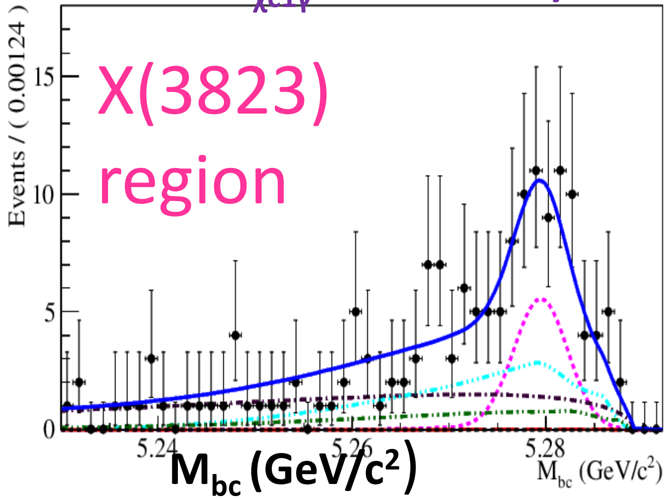
$M_{bc} > 5.27$ GeV/c^2



$3.66 < M_{\chi c1\gamma} < 3.708$ GeV/c^2



$3.805 < M_{\chi c1\gamma} < 3.845$ GeV/c^2



What is this peak?

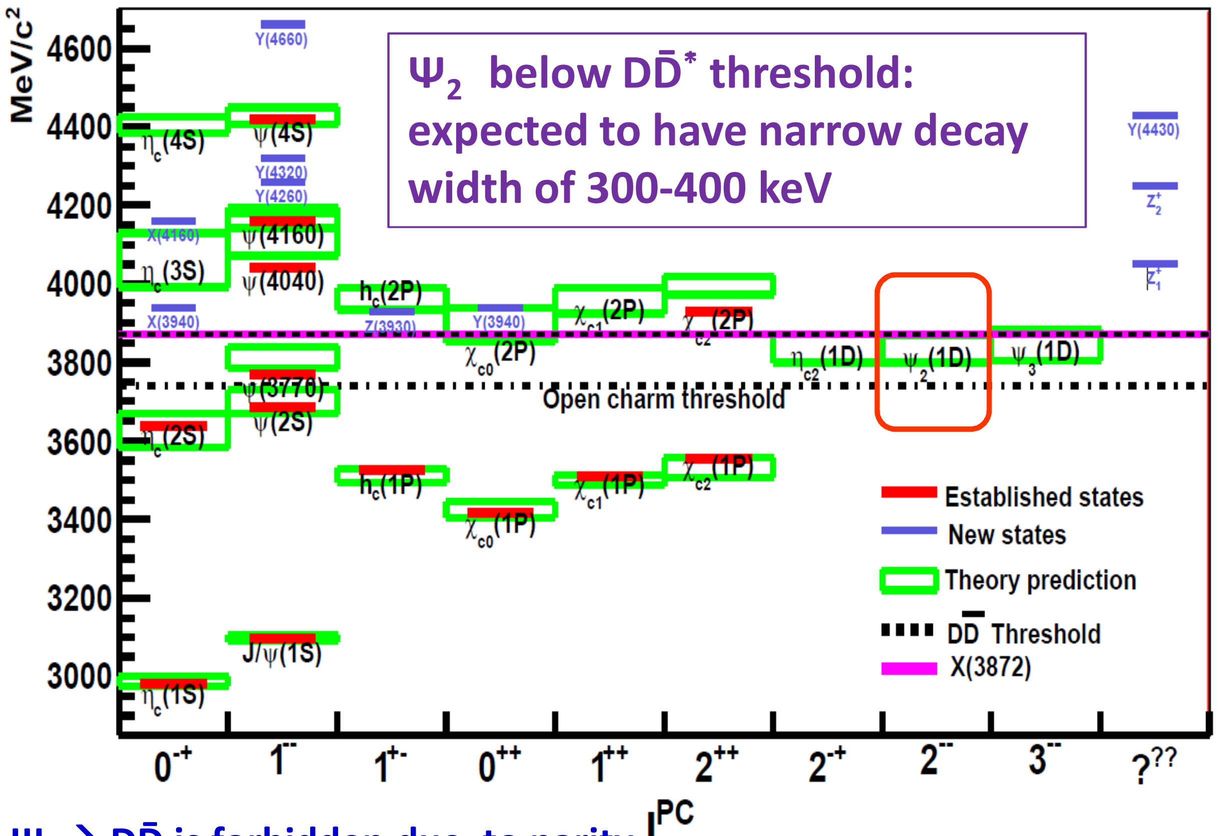


TABLE III: Charmonium spectrum, including the influence of open-charm channels. All masses are in MeV. The penultimate column holds an estimate of the spin splitting due to tensor and spin-orbit forces in a single-channel potential model. The last column gives the spin splitting induced by communication with open-charm states, for an initially unsplit multiplet.

State	Mass	Centroid	Splitting (Potential)	Splitting (Induced)
1^1S_0	2 979.9[a]	3 067.6[b]	−90.5	+2.8
1^3S_1	3 096.9[a]		+30.2	−0.9
1^3P_0	3 415.3[a]	3 525.3[c]	−114.9[e]	+5.9
1^3P_1	3 510.5[a]		−11.6[e]	−2.0
1^1P_1	3 525.3		+1.5[e]	+0.5
1^3P_2	3 556.2[a]		−31.9[e]	−0.3
2^1S_0	3 637.7[a]	3 673.9[b]	−50.4	+15.7
2^3S_1	3 686.0[a]		+16.8	−5.2
1^3D_1	3 769.9[ab]		−40	−39.9
1^3D_2	3 830.6	(3 815)[d]	0	−2.7
1^1D_2	3 838.0		0	+4.2
1^3D_3	3 868.3		+20	+19.0
2^3P_0	3 931.9	3 968[d]	−90	+10
2^3P_1	4 007.5		−8	+28.4
2^1P_1	3 968.0		0	−11.9
2^3P_2	3 966.5		+25	−33.1

[a]Observed mass, from *Review of Particle Physics*, Ref. [13].
[b]Inputs to potential determination.
[c]Observed 1^3P_J centroid.
[d]Computed.
[e]Required to reproduce observed masses.

$^3D_3$ doesn't have E1 transition to $\chi_{c1}\gamma$

$\Psi_2 \to D\bar{D}$ is forbidden due to parity
Mostly decaying into $\chi_{c1}\gamma$.

$^3D_2$ mass is quite near and the observed peak has not been seen in $D\bar{D}$ ($^3D_2 \nrightarrow D\bar{D}$ is expected).

S. Godfrey & N. Isgur, PRD 32, 189 (1985)
E. Eichten et al., PRL 89,162002 (2002), PRD 69, 094019 (2004)

X(3823) seems to be the missing Ψ_2 from the charmonium spectrum .

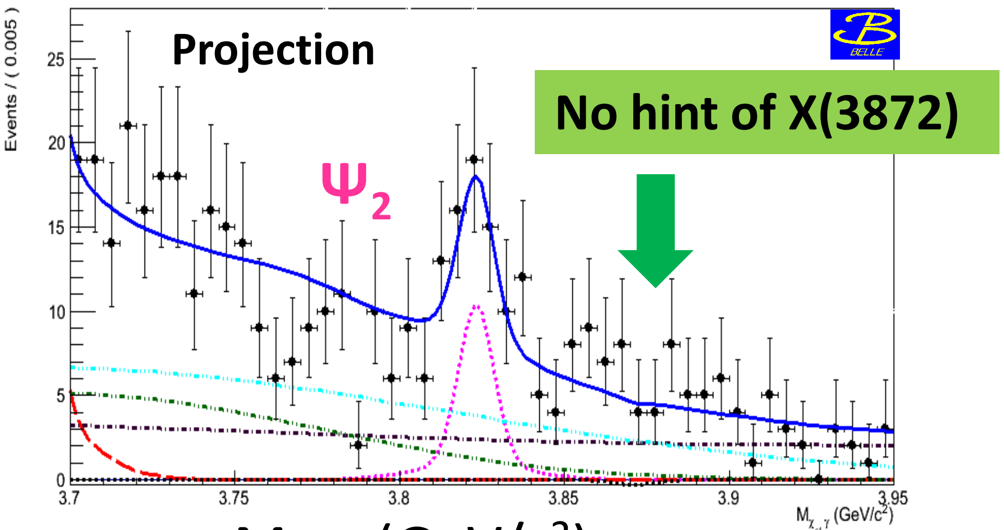
$B^{\pm} \rightarrow \chi_{c1}\gamma K^{\pm}$

$X(3872)^{C-}$

711 fb^{-1}

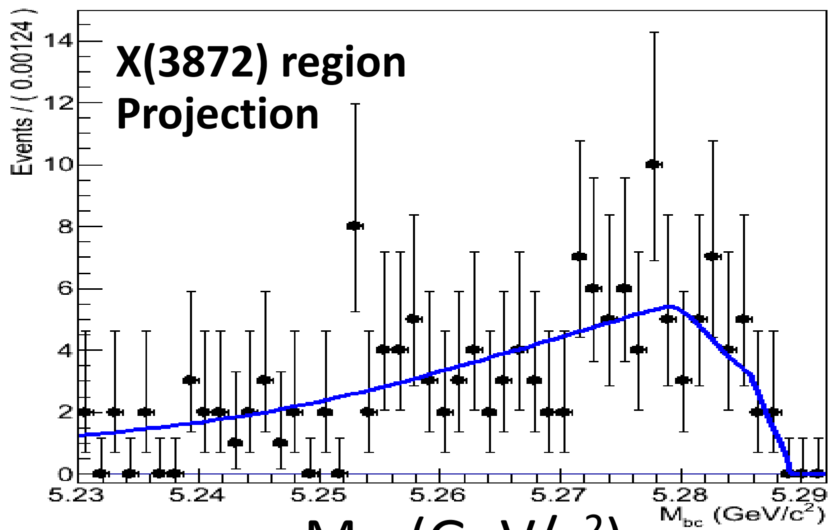
preliminary

X(3872) yield : -0.9±5.1 events



$M_{\chi c1\gamma}$ (GeV/c^2)

$M_{bc} > 5.27$ GeV/c^2



M_{bc} (GeV/c^2)

$3.84 < M_{\chi c1\gamma} < 3.9$ GeV/c^2

No signal is observed in the X(3872) region.

B.R.($B^{\pm} \rightarrow X(3872)K^{\pm}$) x B.R.($X(3872) \rightarrow \chi_{c1}\gamma$) < 2.0 x 10^{-6} (@90% CL)

$$\frac{\Gamma(X3872 \rightarrow \chi_{c1}\gamma)}{\Gamma(X3872 \rightarrow J/\Psi\pi\pi)} < 0.26$$

Belle, PRD 85,052004 (R) (2011)

* Recent Belle result used for BR(B→X3872K)*BR(X3872→J/Ψ$\pi^+\pi^-$).

711 fb^{-1}

Fit results *preliminary*

$B^{\pm} \to \chi_{c1}\gamma K^{\pm}$

$B^{\pm} \to \chi_{c1}\gamma K^{\pm}$	Yield	$\mathcal{BR}$ (10^{-4})	
		Belle	World Average
$\Psi' \to \chi_{c1}\gamma$	193±19	$7.74^{+0.77}_{-0.74}(stat)^{+0.87}_{-0.83}(syst)$	6.39 ± 0.33

$\mathcal{BR}(B^{+} \to \Psi' K^{+})$ consistent with world average

$B^{\pm} \to \chi_{c1}\gamma K^{\pm}$	Yield	$\mathcal{BR}(B^{+} \to X K^{+}) . \mathcal{BR}(X \to \chi_{c1}\gamma)$ (10^{-6})
$\Psi_2 \to \chi_{c1}\gamma$	33.2±9.1	$9.70^{+2.84}_{-2.51}(stat)^{+1.06}_{-1.03}(syst)$
$X(3872) \to \chi_{c1}\gamma$	-0.9±5.1	< 2.0(@90% CL)

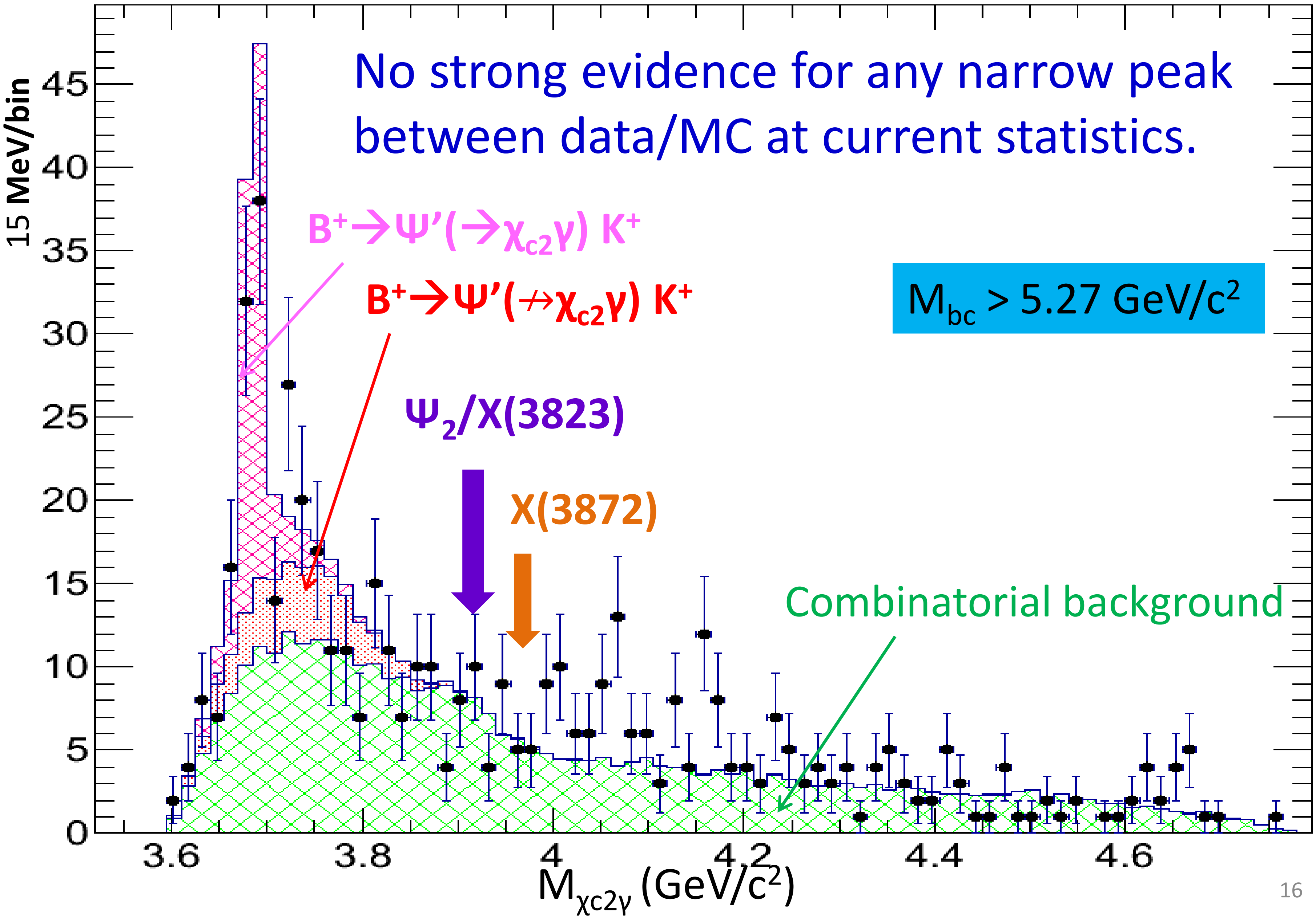
First evidence of Ψ_2 with 4.2 σ significance by Belle.

$$\frac{\Gamma(X3872 \to \chi_{c1}\gamma)}{\Gamma(X3872 \to J/\Psi\pi\pi)} < 0.26$$

711 *fb*$^{-1}$

$M_{\chi c2\gamma}$ distribution

$B^{\pm} \to \chi_{c2}\gamma K^{\pm}$

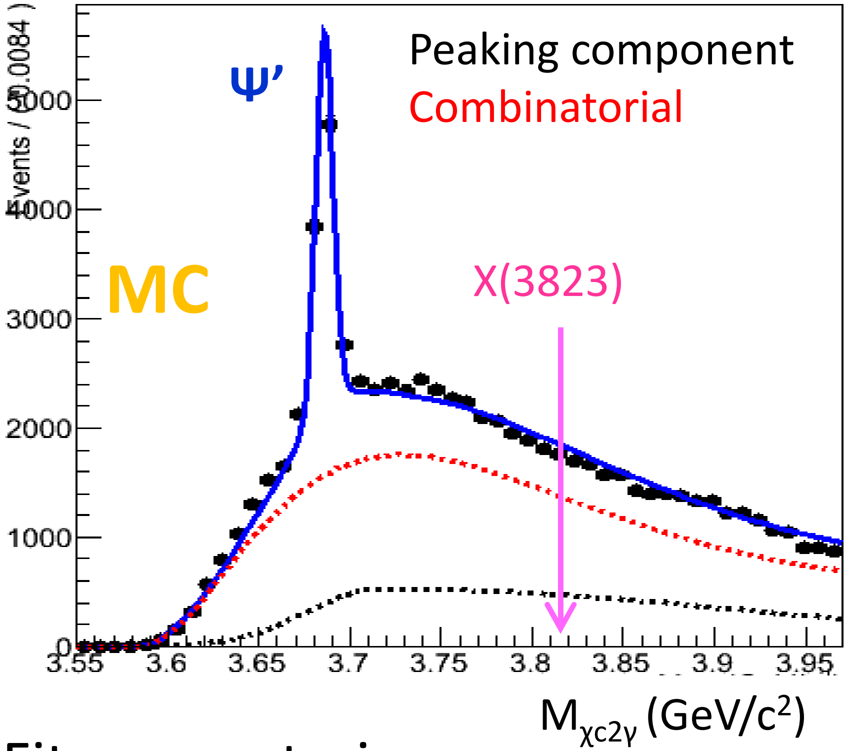


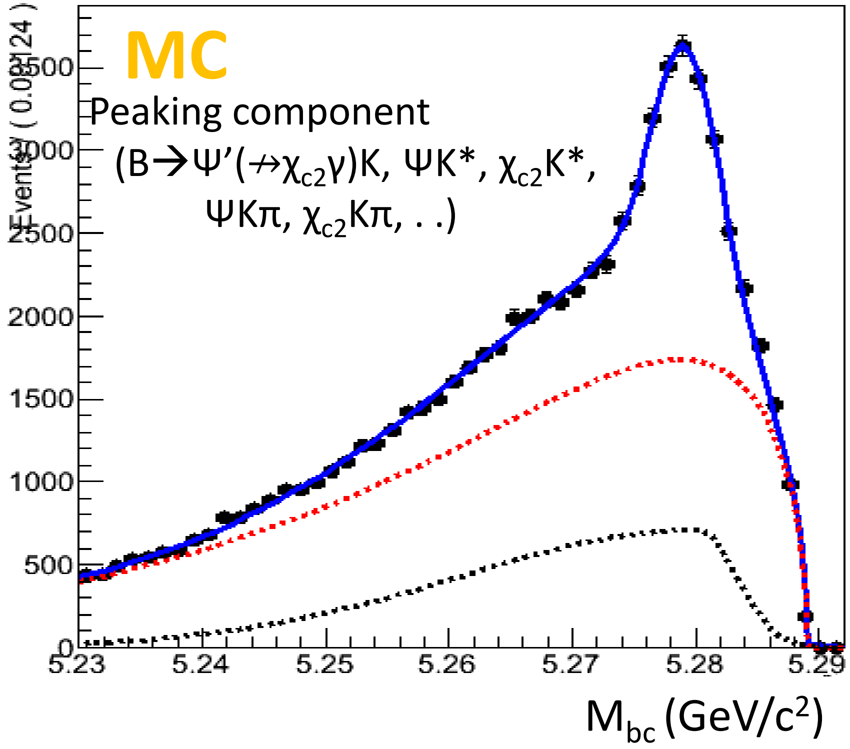
$B^{\pm} \rightarrow \chi_{c2}\gamma K^{\pm}$

Signal extraction in $M_{\chi c2\gamma}$

2D UML fit

Background parameterize using large $B \rightarrow J/\Psi$ X MC sample





Fit parameterize

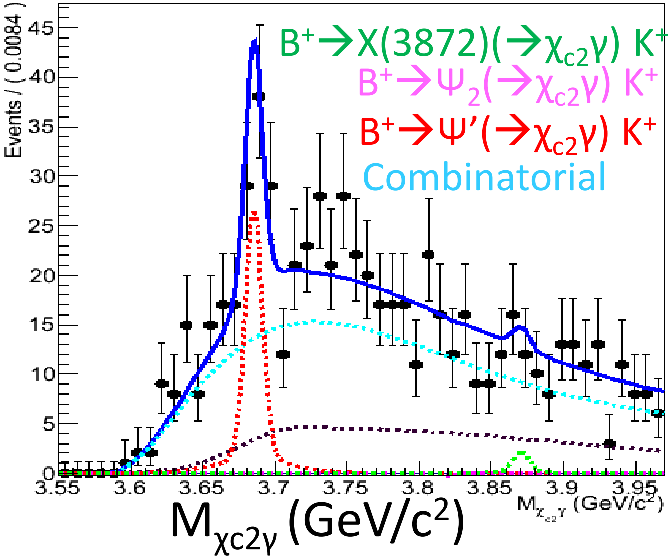
- Sum of two Gaussian is used to fit Ψ' and Ψ_2 shape estimated (from MC).
- Data/MC correction estimated from $B^{\pm} \rightarrow \Psi'(\rightarrow \chi_{c1}\gamma)K^{\pm}$.
- 2000 toys were used to test fitter and no significant bias is observed.

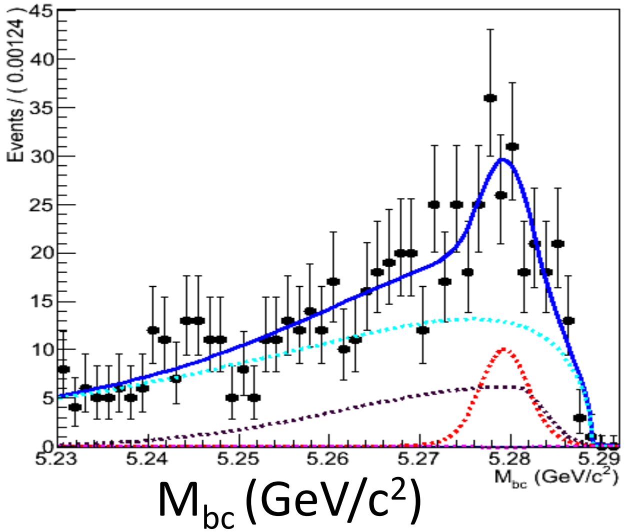
711 fb^{-1}

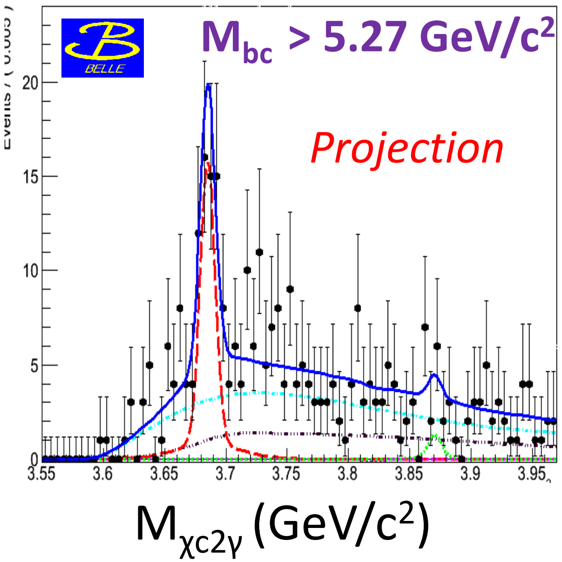
Results

preliminary

2D UML







$B^{\pm}\to\chi_{c2}\gamma K^{\pm}$	Yield	BR (10^{-4})	
		$\chi_{c2}\gamma$	$\chi_{c1}\gamma$
$\Psi'\to\chi_{c2}\gamma$	56.6±9.3	5.82±0.95(*stat*)±0.61(*syst*)	$7.74^{+0.77}_{-0.74}(stat)^{+0.87}_{-0.83}(syst)$
		BR($B^+\to X K^+$). **BR**($X\to\chi_{cx}\gamma$) (10^{-6})	
$\Psi_2\to\chi_{c2}\gamma$	-0.4±3.4	< 3.4	$9.70^{+2.84}_{-2.51}(stat)^{+1.06}_{-1.03}(syst)$
$X(3872)\to\chi_{c2}\gamma$	3.9±3.9	< 6.0	< 2.0

$$\frac{\Gamma(\Psi_2\to\chi_{c2}\gamma)}{\Gamma(\Psi_2\to\chi_{c1}\gamma)} < 0.48$$, **Expected ~ 0.2 (model dependent)**

E. J. Eichten *et al*, PRL 89, 162002 (2002)

U.L. (@ 90% CL)

Result & conclusion

First evidence of narrow state at 3823 MeV in $\chi_{c1}\gamma$.

- Most probable the missing $\Psi_2(c\bar{c})$ state.
- Useful for quarkonium model.
- Also, useful in understanding other resonances.

No narrow state evident in $\chi_{c2}\gamma$, at current statistics.

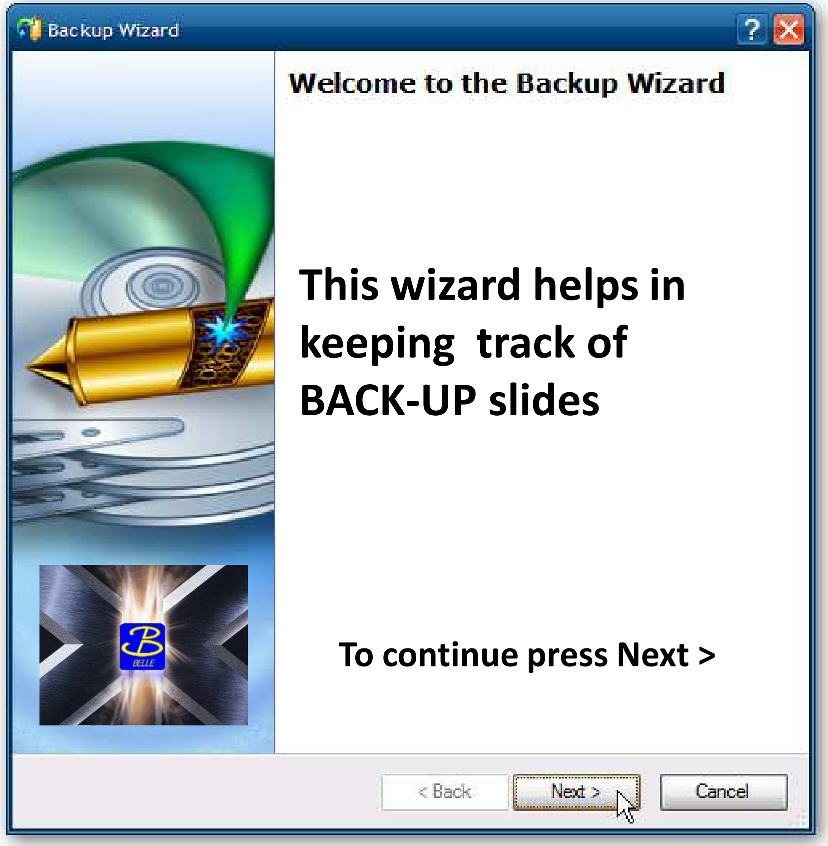
$\Psi_2 \rightarrow \chi_{c2}\gamma$ UL consistent with the expectation.

X(3872) as tetraquark

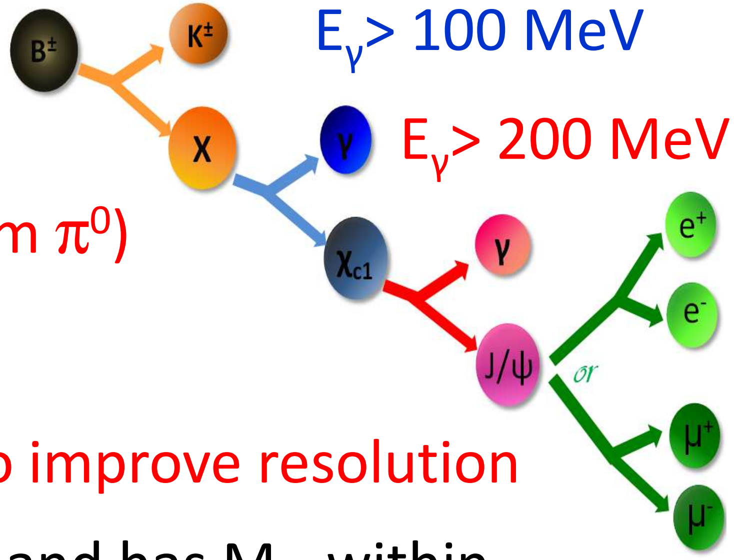
- No signal is seen in C-odd partner of X(3872) (tetraquark interpretation) in $\chi_{c1}\gamma$ and $\chi_{c2}\gamma$.
- More stringent upper limits are provided.

Confirmation of Ψ_2 at other experiments.
Interesting to compare it with predicted $\mathcal{BR}(\Psi_2 \rightarrow J/\Psi\pi\pi)$, can be measured at LHC.

Thank you


Backup Wizard
Welcome to the Backup Wizard
This wizard helps in keeping track of BACK-UP slides
To continue press Next >
< Back
Next >
Cancel

Reconstruction



E_γ> 100 MeV

E_γ> 200 MeV

$\chi_{c1,c2}$ reconstruct from $J/\psi\gamma$

- $p_{J/\psi} < 2.0$ GeV/c
- Koppenberg's π^0 veto < 0.6 (to reject γ from π^0)
- 3.47 GeV/c^2 < $M_{J/\psi\gamma}$ < 3.54 GeV/c^2 for χ_{c1}
- 3.54 GeV/c^2 < $M_{J/\psi\gamma}$ < 3.58 GeV/c^2 for χ_{c2}
- Mass constrained and vertex fit in order to improve resolution

γ is rejected if it is combined with another γ and has $M_{\gamma\gamma}$ within [117,153] MeV/c^2 (π^0 veto)

γ is veto, if it is making best $\chi_{c1,c2}$ in that event.

R_K> 0.6

-28 MeV < ΔE < 30 MeV as ΔE window

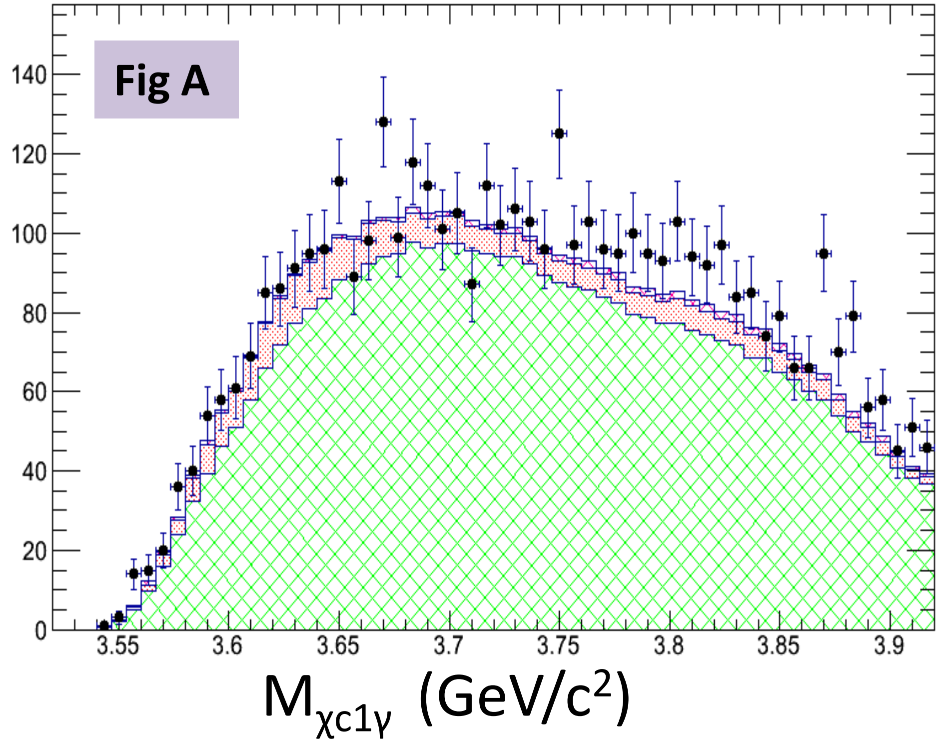
For multiple candidate, ΔE closest to 0.

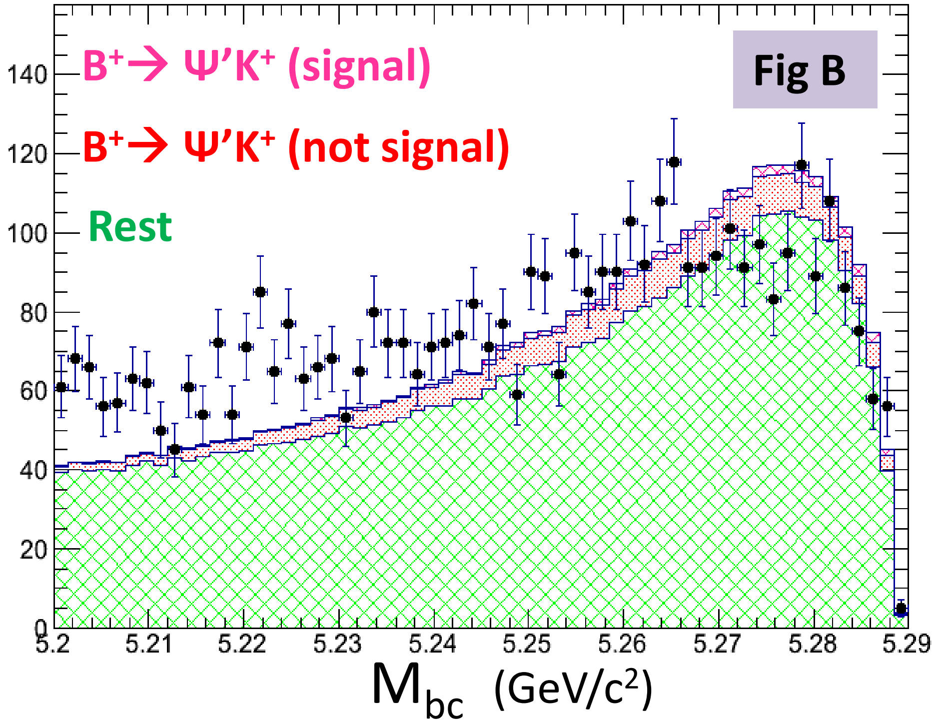
- **E_γ is scaled in order to improve the resolution of $M_{\chi c1\gamma}$ (ΔE=0).**
- **Extract signal yield using fit to $M_{\chi c1\gamma}$ & M_{bc} (2D UML fit).**

-198 < ΔE < -140 MeV
100 < ΔE < 158 MeV

ΔE sideband

2 x signal region



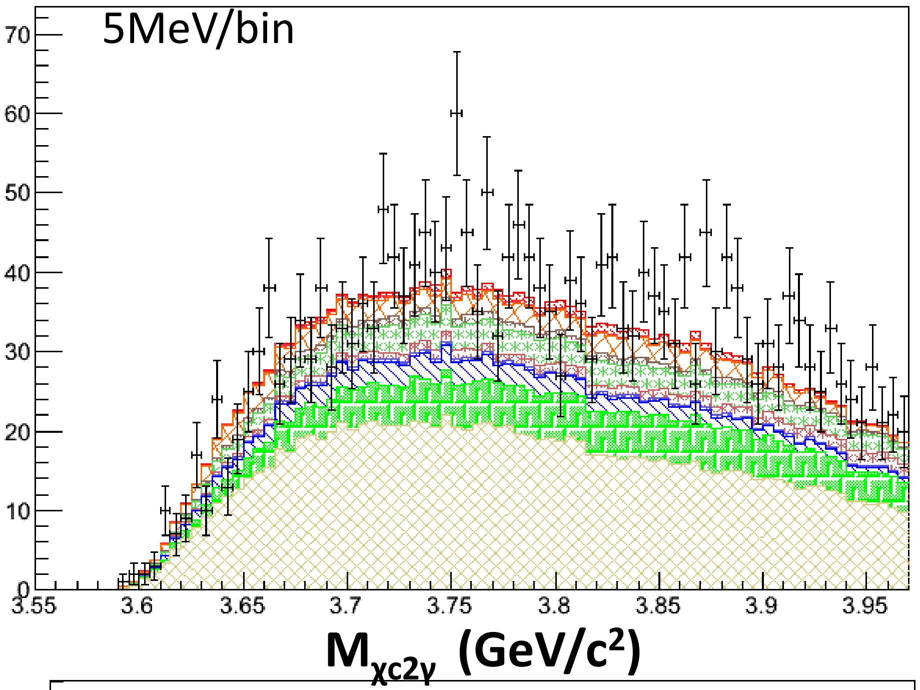


- No unexpected peaking background is seen.
- B→J/ψ X MC agrees quite well with data.

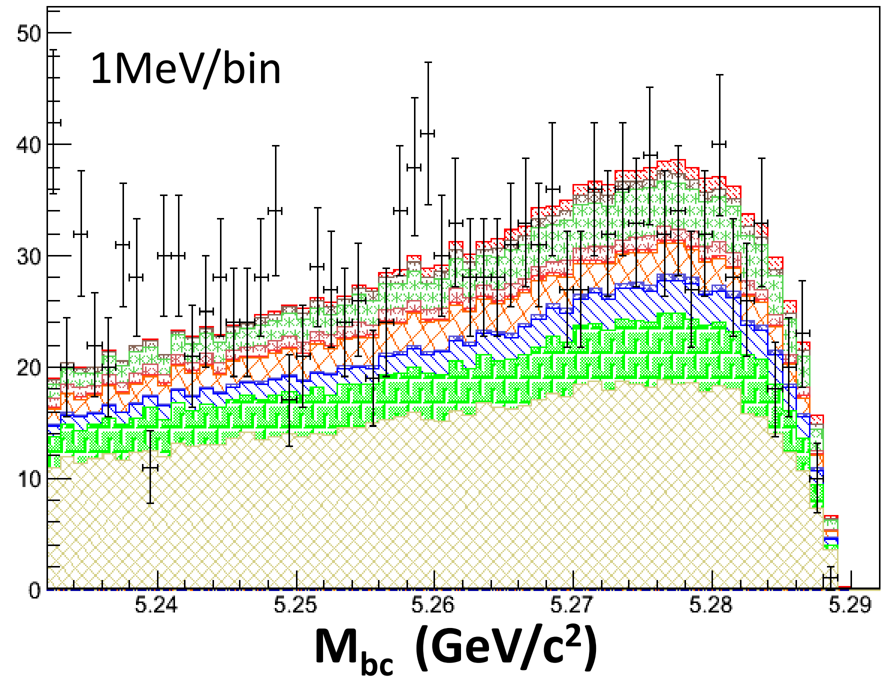
$-198 < \Delta E < -140$ MeV
$100 < \Delta E < 158$ MeV

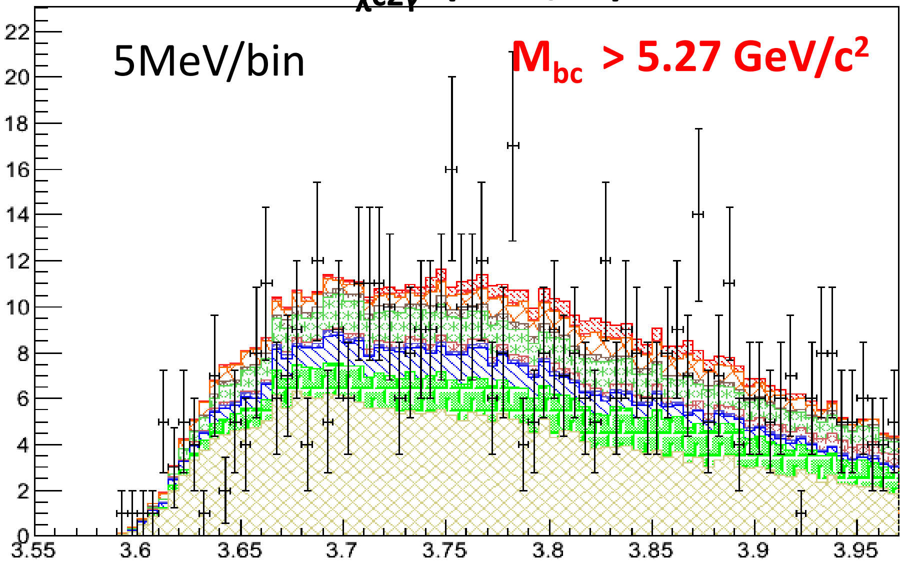
ΔE sideband

2 x signal region



$M_{\chi c2\gamma} < 3.97$ GeV/c^2

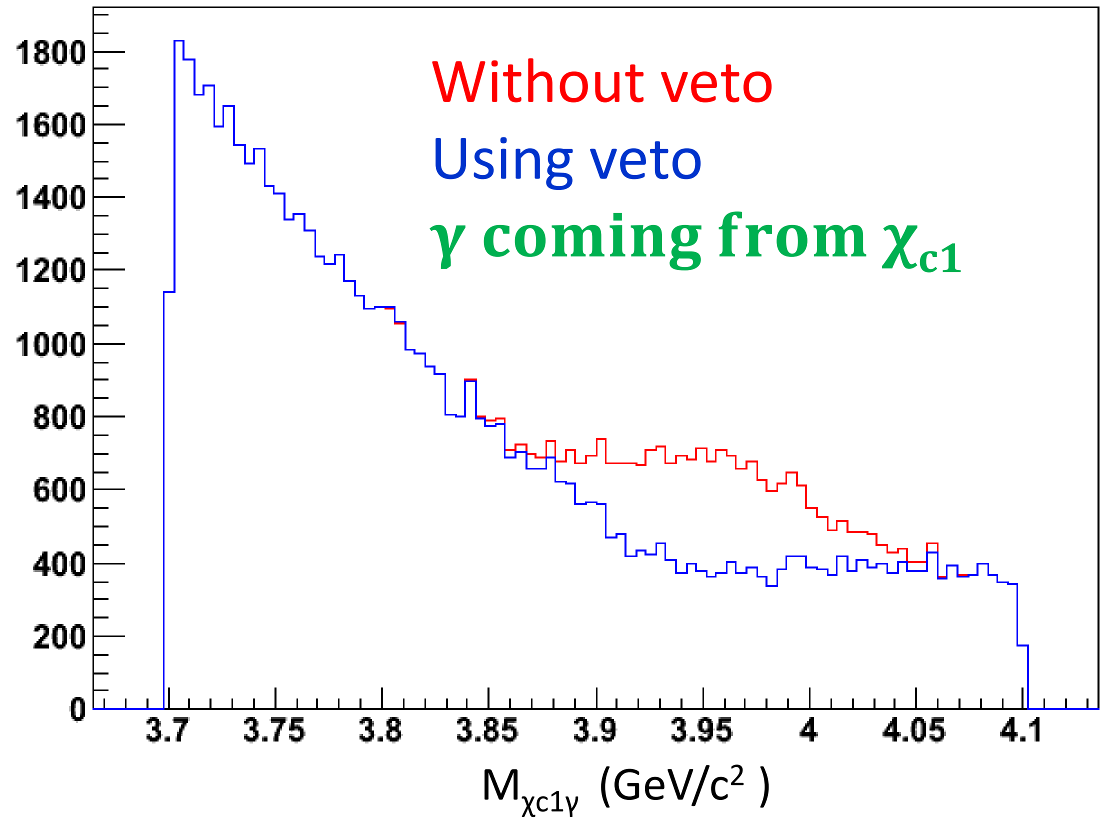




- No unexpected peaking background is seen.
- B→J/ψ X MC agrees quite well with data.

MC

χ_{c1}'s γ veto



There is a small bump around 3950 MeV/c^2 due to γ of χ_{c1} combining with fake χ_{c1}.

In order to remove this bump, we need to use χ_{c1}' γ veto.

χ_{c1}	J/ψ	J/ψ
$\gamma 1$		
$\gamma 2$		
$\gamma 3$		
$\gamma 4$		
...		

True candidates

γ to be vetoed

$B^+ \rightarrow \chi_{c1}(\rightarrow J/\psi \gamma_a)\gamma_b K^+$

but

$B^+ \rightarrow \chi_{c1}(\rightarrow J/\psi \gamma_{random})\gamma_a K^+$

Avoid this situation by removing γ_a from list of γ_b

TABLE I: Thresholds for decay into open charm.

Channel	Threshold Energy (MeV)
$D^0\bar{D}^0$	3729.4
D^+D^-	3738.8
$D^0\bar{D}^{*0}$ or $D^{*0}\bar{D}^0$	3871.5
$D^{\pm}D^{*\mp}$	3879.5
$D_s^+D_s^-$	3936.2
$D^{*0}\bar{D}^{*0}$	4013.6
$D^{*+}D^{*-}$	4020.2
$D_s^+\bar{D}_s^{*-}$ or $D_s^{*+}\bar{D}_s^-$	4080.0
$D_s^{*+}D_s^{*-}$	4223.8

TABLE V: Calculated and observed rates for E1 radiative transitions among charmonium levels. *Values in italics* result if the influence of open-charm channels is not included.

Transition (γ energy in MeV)	Partial width (keV) Computed	Measured
$1^3D_1(3770) \to \chi_{c2}\gamma(208)$	*3.2* → 3.9	
$1^3D_1(3770) \to \chi_{c1}\gamma(251)$	*183* → 59	
$1^3D_1(3770) \to \chi_{c0}\gamma(338)$	*254* → 225	
$1^3D_1(3815) \to \chi_{c2}\gamma(250)$	*5.5* → 6.8	
$1^3D_1(3815) \to \chi_{c1}\gamma(293)$	*128* → 120	
$1^3D_1(3815) \to \chi_{c0}\gamma(379)$	*344* → 371	
$1^3D_2(3815) \to \chi_{c2}\gamma(251)$	*50* → 40	
$1^3D_2(3815) \to \chi_{c1}\gamma(293)$	*230* → 191	
$1^3D_2(3831) \to \chi_{c2}\gamma(266)$	*59* → 45	
$1^3D_2(3831) \to \chi_{c1}\gamma(308)$	*264* → 212	
$1^3D_2(3872) \to \chi_{c2}\gamma(303)$	*85* → 45	
$1^3D_2(3872) \to \chi_{c1}\gamma(344)$	*362* → 207	
$1^3D_3(3815) \to \chi_{c2}\gamma(251)$	*199* → 179	
$1^3D_3(3868) \to \chi_{c2}\gamma(303)$	*329* → 286	
$1^3D_3(3872) \to \chi_{c2}\gamma(304)$	*341* → 299	

TABLE III: Charmonium spectrum, including the influence of open-charm channels. All masses are in MeV. The penultimate column holds an estimate of the spin splitting due to tensor and spin-orbit forces in a single-channel potential model. The last column gives the spin splitting induced by communication with open-charm states, for an initially unsplit multiplet.

State	Mass	Centroid	Splitting (Potential)	Splitting (Induced)
1^1S_0	2 979.9[a]	3 067.6[b]	−90.5	+2.8
1^3S_1	3 096.9[a]		+30.2	−0.9
1^3P_0	3 415.3[a]	3 525.3[c]	−114.9[e]	+5.9
1^3P_1	3 510.5[a]		−11.6[e]	−2.0
1^1P_1	3 525.3		+1.5[e]	+0.5
1^3P_2	3 556.2[a]		−31.9[e]	−0.3
2^1S_0	3 637.7[a]	3 673.9[b]	−50.4	+15.7
2^3S_1	3 686.0[a]		+16.8	−5.2
1^3D_1	3 769.9[ab]	(3 815)[d]	−40	−39.9
1^3D_2	3 830.6		0	−2.7
1^1D_2	3 838.0		0	+4.2
1^3D_3	3 868.3		+20	+19.0
2^3P_0	3 931.9	3 968[d]	−90	+10
2^3P_1	4 007.5		−8	+28.4
2^1P_1	3 968.0		0	−11.9
2^3P_2	3 966.5		+25	−33.1

S. Godfrey & N. Isgur, PRD 32, 189 (1985)
E. Eichten et al., PRL 89,162002 (2002), PRD 69, 094019 (2004)

E705 Collaboration

Belle Mass
3.823 GeV/c²

Looking at ψ’, here 3.836 peaks looks prominent ???

A search has been made in 300 GeV/c $\pi^{\pm}$- and proton-Li interactions for production of states that decay into J/ψ or ψ' plus one or two pions. A 2.5σ enhancement in the $J/\psi\,\pi^0$ spectrum, possibly the recently reported $^1P_1$ state of charmonium, is observed at a mass of 3.527 GeV/c^2. In the J/ψ plus two pion mass spectrum, we report, together with the expected $\psi' \to J/\psi\,\pi^+\pi^-$, the tentative observation of a structure at a mass of 3.836 GeV/c^2. No enhancements are seen in the $J/\psi\,\pi^{\pm}\pi^{\pm}$, $J/\psi\,\pi^{\pm}\pi^0$, $J/\psi\,\pi^{\pm}$, or $\psi'\,\pi^{\pm}$ mass spectra.

PhysRevD.50.4258

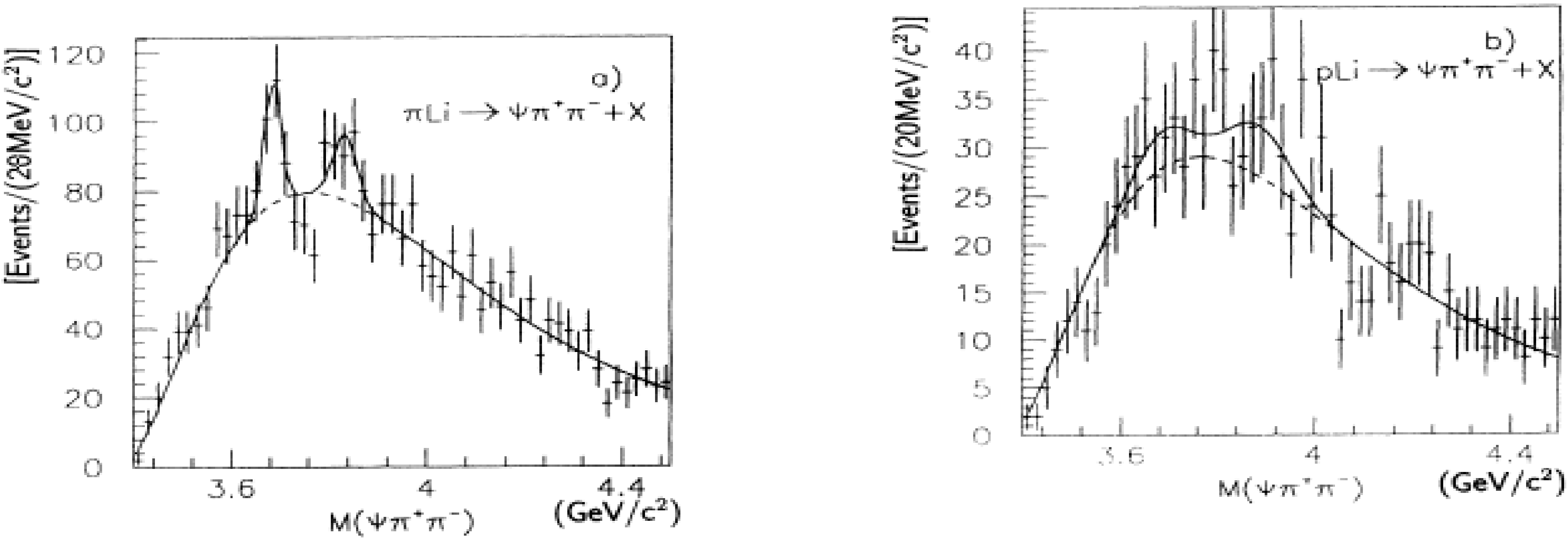
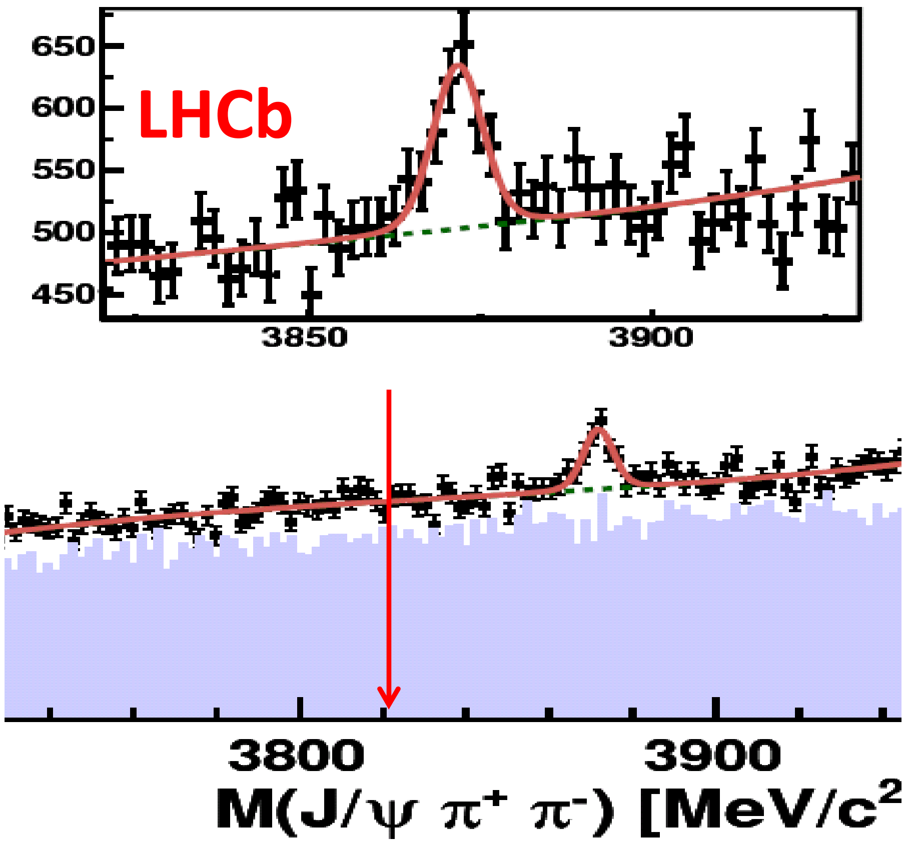
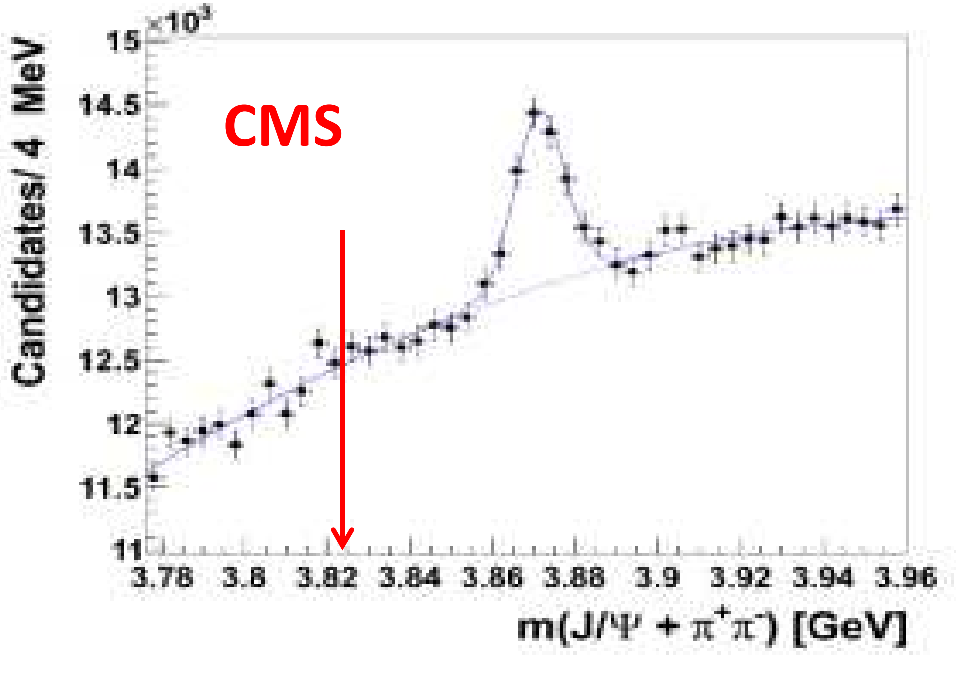
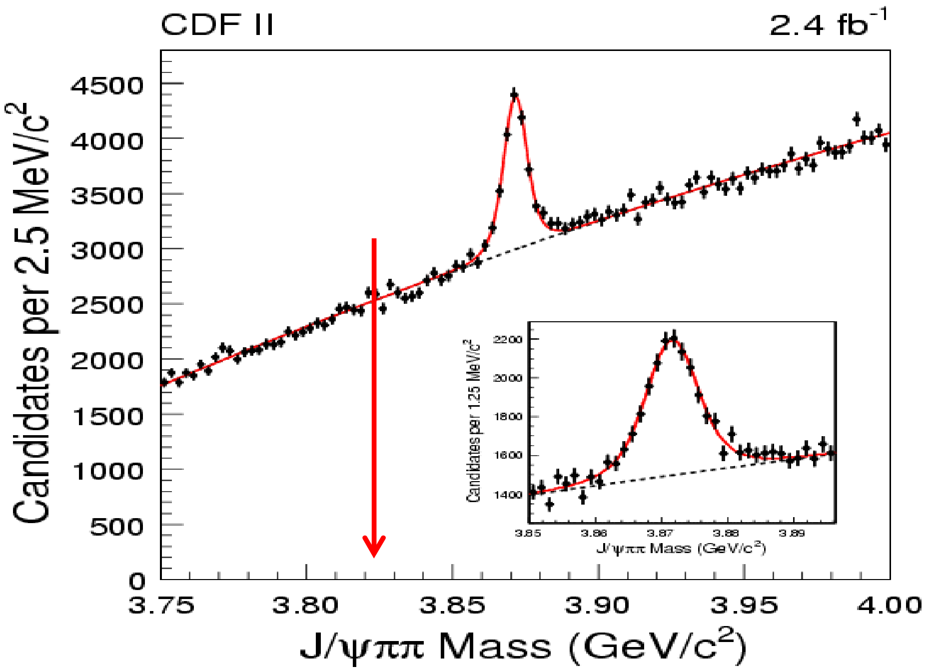


FIG. 6. $J/\psi\,\pi^+\pi^-$ mass spectra from 300 GeV/$c\pi^{\pm}$Li interactions; (b) $J/\psi\,\pi^+\pi^-$ mass spectrum from 300 GeV/c proton Li interactions.



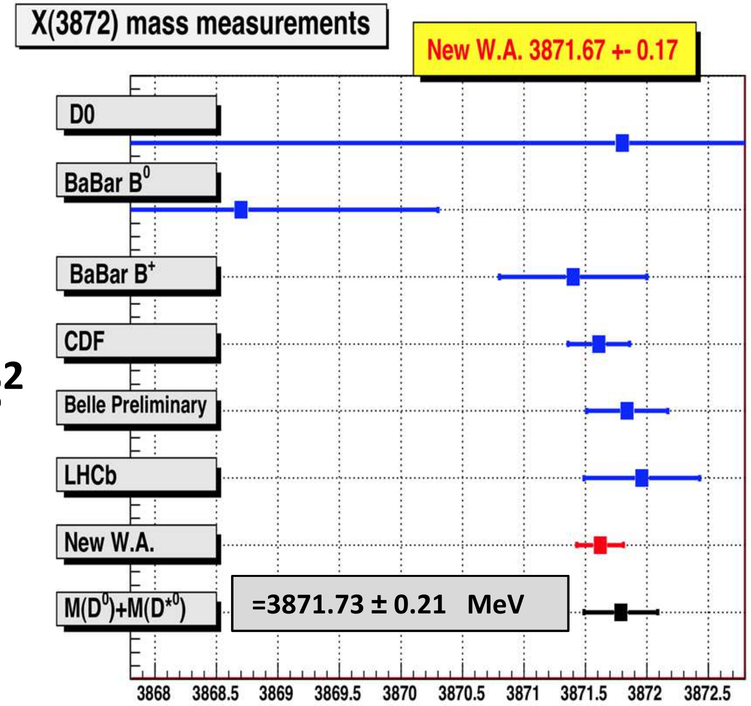




Interestingly Ψ_2 is not seen in J/Ψππ in other experiments.

Some properties of X(3872)

X(3872) found in $J/\psi\pi\pi$,
similar to ψ'
Another charmonium ?



World average mass → 3871.6 ± 0.2 MeV/c^2
$X(3872)\to J/\psi\pi\pi$

CDF II $3871.61\pm0.16\pm0.19$
PRL, 103, 152001 (2009)

Belle $3871.84\pm0.27\pm0.19$

Belle, PRD 85,052004 (2011)

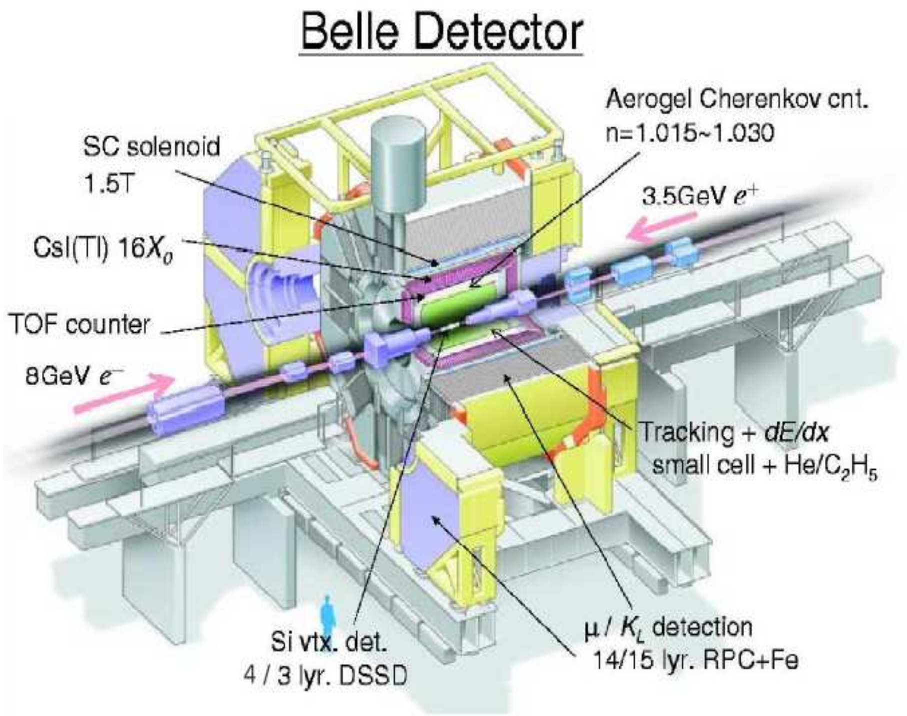
Mass near D^0 and $\bar{D}^{*0}$ threshold → 3871.73 ± 0.21 MeV/c^2 PDG

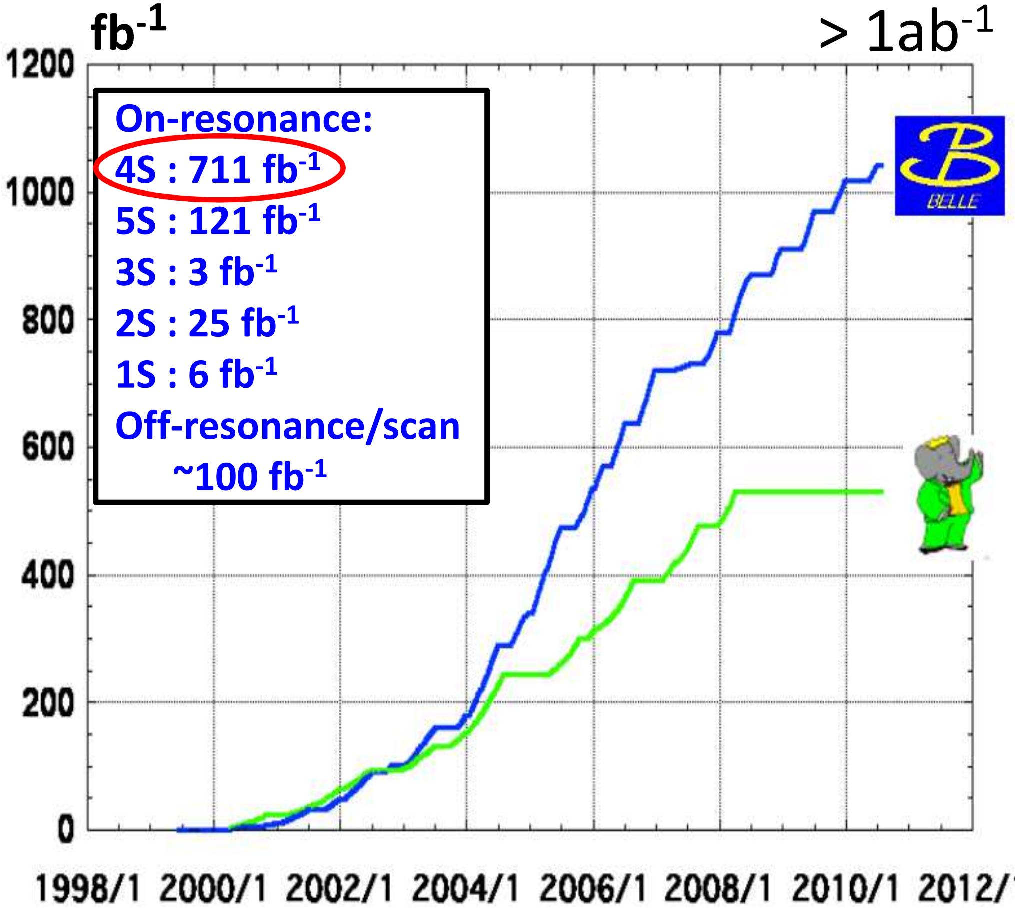
How is it related to $D^0\bar{D}^{*0}$? $D^0\bar{D}^{*0}$ molecule or something else ?

X(3872) much narrower width ($\Gamma < 1.2$MeV @ 90% CL) than other charmonium states above $D\bar{D}$ threshold.
arXiv:1107.0163

Observed in $D^0\bar{D}^{*0}$ mode. PRL 97,162002 (2006), PRD 77,011102 (2008) and PRD 81, 031103 (2010)

$c\bar{c}$ (-like) states at Belle





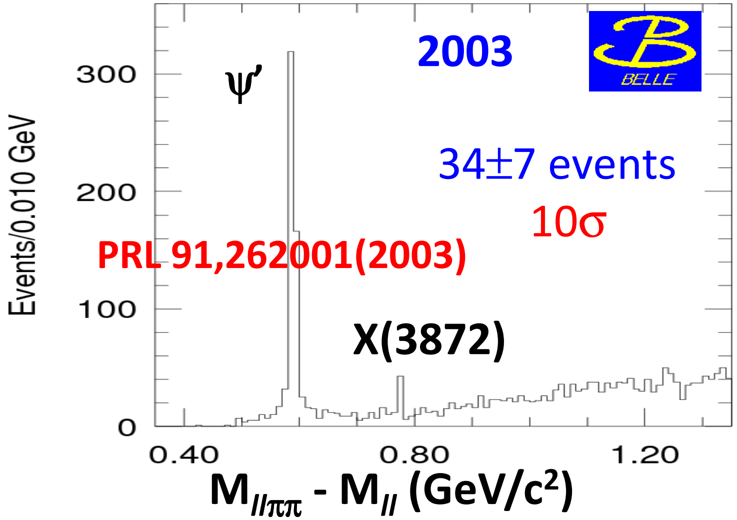
General purpose detector, build to test Standard Model mechanism for CP violation in B decays to charmonium ($B^0 \rightarrow J/\Psi, \Psi', \chi_{c1}\ K^0$). arXiv:1201.4643v1 accepted in PRL

Contribution to charmonium (-like) states:

$\eta_c(2S)$, X(3872), Y(3940), Z(3930), X(3940), X(3915), Y(4260), Y(4660), $Z(4430)^+$, $Z_1(4050)^+$, $Z_2(4250)^+$ …

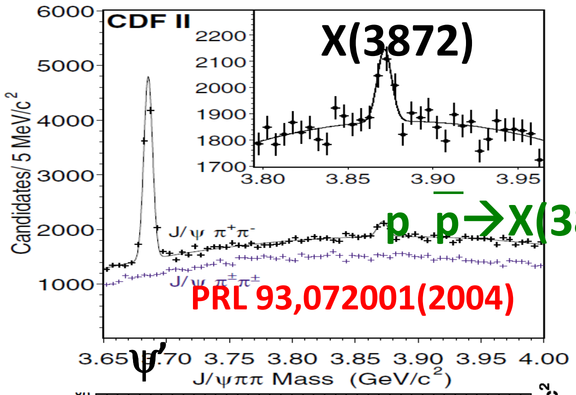
X(3872) Most famous $c\bar{c}$ (-like) state

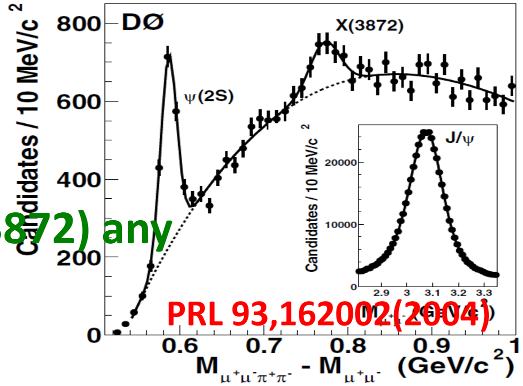
Discovered by Belle in $J/\psi\pi\pi$ decay mode

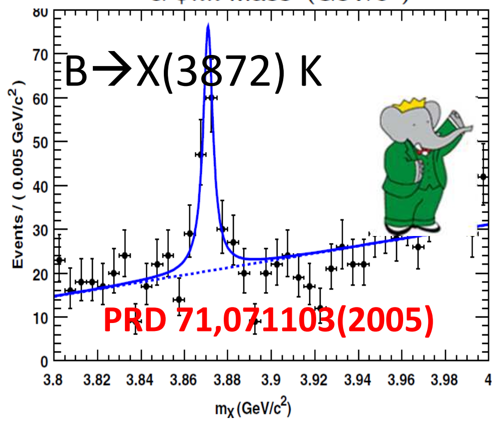


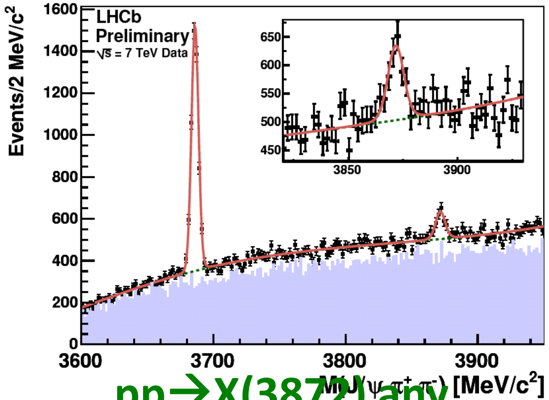
$B^+ \rightarrow X(3872)\ K^+$,
$X(3872) \rightarrow J/\psi\pi^+\pi^-$

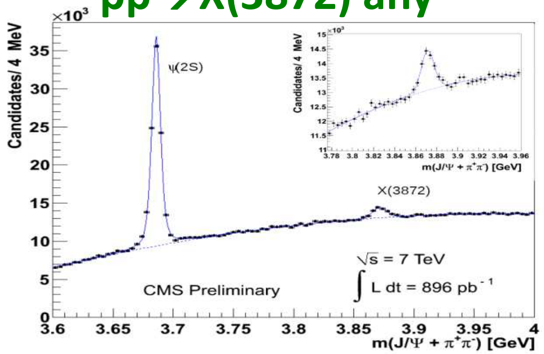
$\Gamma < 2.5$ MeV (90%CL)











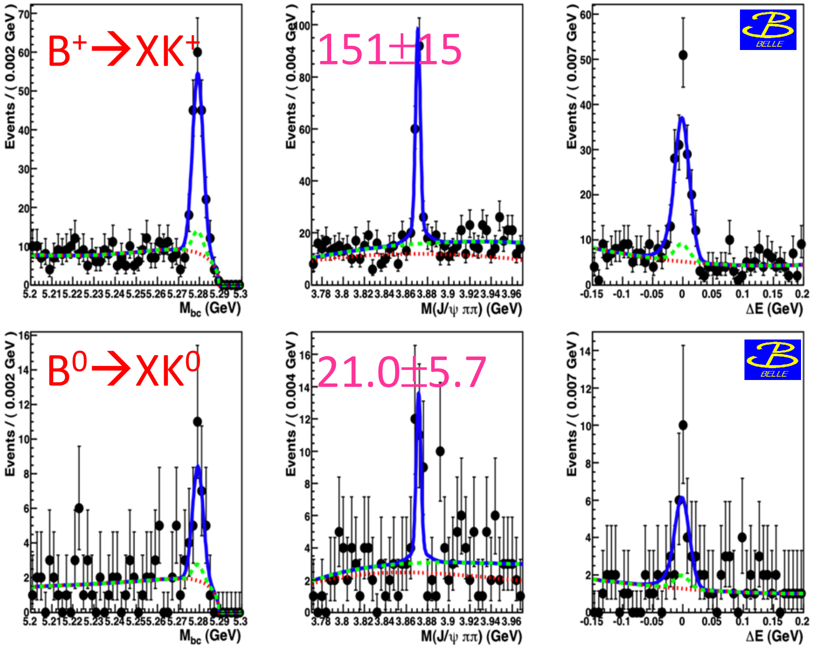
Difficult to assign to a conventional charmonium state.

Confirmed by CDF, DO, BaBar, CMS and LHCb.

With full data sample

Update on properties of X(3872)

Belle, PRD 85,052004 (2011)



$\mathcal{BR}(B^+ \to X(3872)K^+) \times \mathcal{BR}(X(3872) \to J/\psi\pi\pi) = (8.61 \pm 0.82 \pm 0.52) \times 10^{-6}$

$M_{X(3872)} = (3871.84 \pm 0.27 \pm 0.19)$ MeV

$\Gamma_{X(3872)} < 1.2$ MeV (90% C.L.)

W.A. $M_{X(3872)}^{(J/\Psi\pi\pi)}$: 3871.67±0.17 MeV/c^2

W.A. $M_{D^0} + M_{\bar{D}^{*0}}$: 3871.73±0.21 MeV/c^2

Mass diff. b/w charged and neutral B decay is

$\Delta M_{X(3872)} = (-0.69 \pm 0.97 \pm 0.19)$ MeV

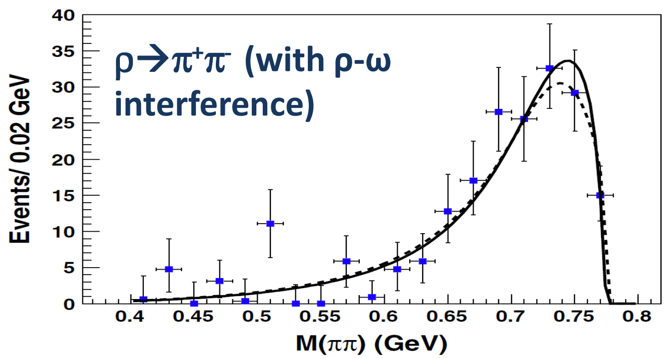
Maiani *et al.*, PRD71, 014028(2005)

Prediction: $\Delta M(M_x(B^+) - M_x(B^0)) = (8 \pm 3)$ MeV

$X(3872) \to J/\Psi\rho(\to \pi^-\pi^+)$

J^{PC} through angular analysis

- 1^{++}
- 2^{-+} a free complex parameter; one value gives an acceptable fit



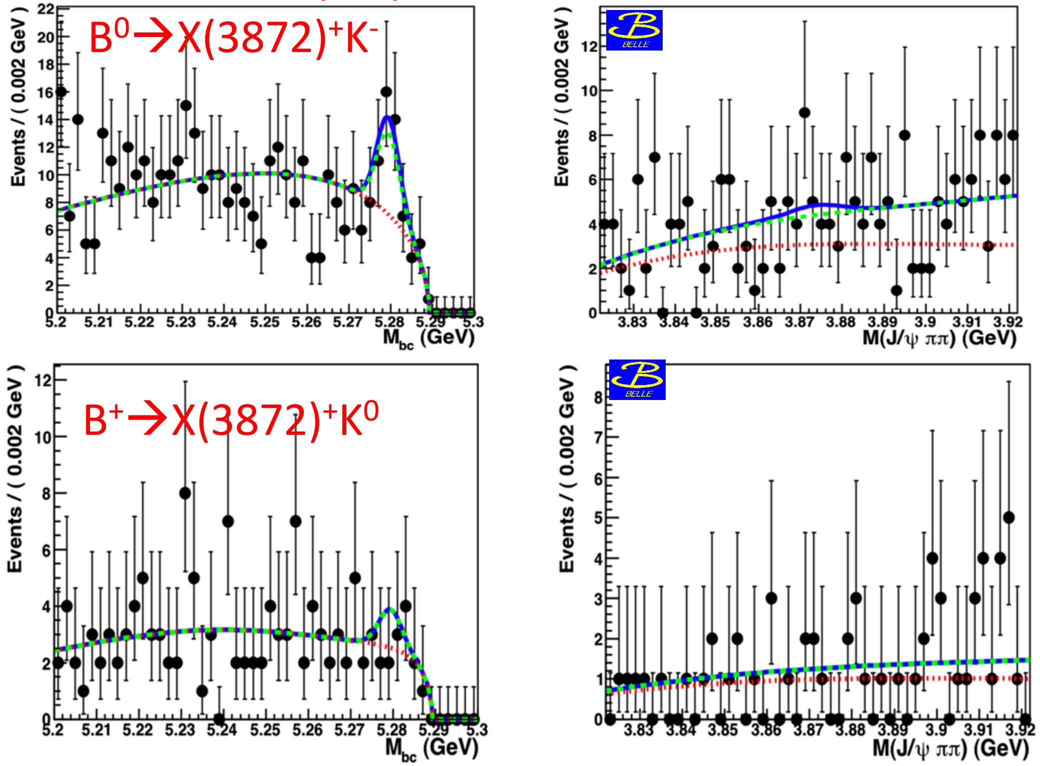
With full data sample

$X(3872)^+$ existence ?

Tetraquark model predicts the existence of isospin triplet : $X(3872)^+$

Belle, PRD 85,052004 (2011)

Maiani *et al.*, PRD71, 014028(2005)



$\mathcal{BR}(B^+ \rightarrow X(3872)^+K^0) = 2 \times \mathcal{BR}(B^0 \rightarrow X(3872)K^0)$

- Reconstruct $X(3872)^+ \rightarrow J/\Psi\pi^+\pi^0$
- No signal is seen
- UL (@90% CL) is provided

$\mathcal{BR}(B^0 \rightarrow X^+K^-) \times \mathcal{BR}(X^+ \rightarrow \pi^+\pi^0 J/\psi) < 3.9\times10^{-6}$

No charged partner

$\mathcal{BR}(B^+ \rightarrow X^+K^0) \times \mathcal{BR}(X^+ \rightarrow \pi^+\pi^0 J/\psi) < 4.5\times10^{-6}$

Rule out isospin triplet model ?

Few tetraquark models predict $X(3872)^+$ to be broad, non-observed yet because of low statistics (?).

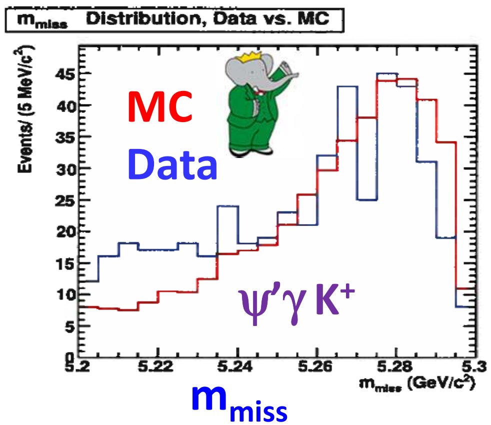
K. Terasaki, arxiV : 1107.5868v2

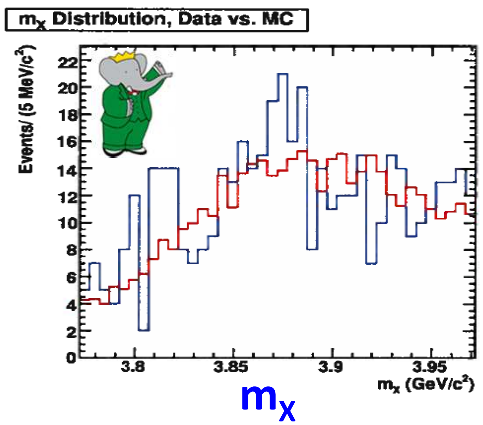
If X(3872) is tetraquark, than X(3872) has C-odd partner which can dominantly decay into

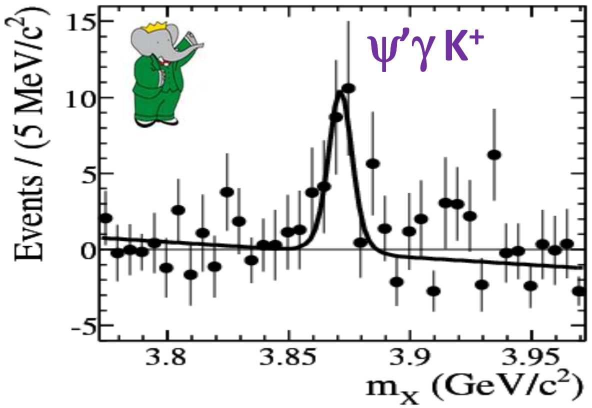
✓ $X(3872)^{C-} \rightarrow \chi_{c1}\gamma$

Belle Babar comparison

- BaBar used 1d UML fit to m_{miss} and use $_s$Plot to project signal in m_X
- We use 1d UML fit to $M_{\psi'\gamma}$ to extract yield

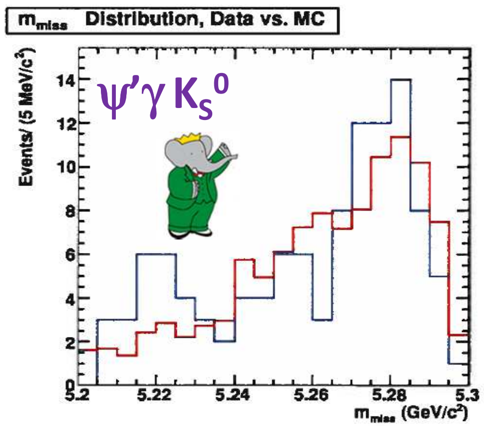


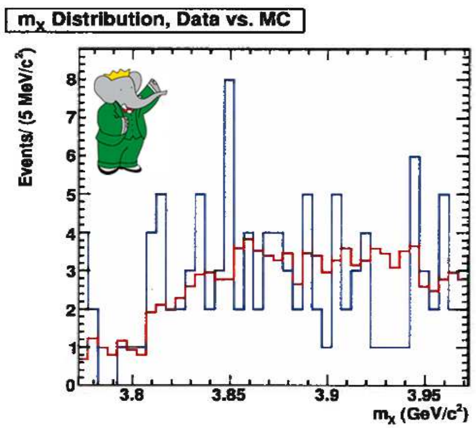


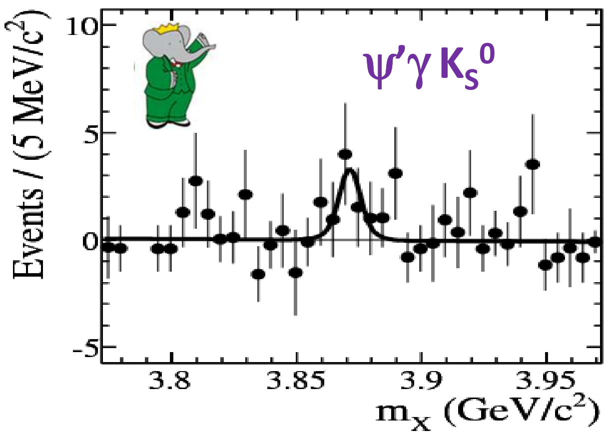


Raw distribution from Fulsom's thesis

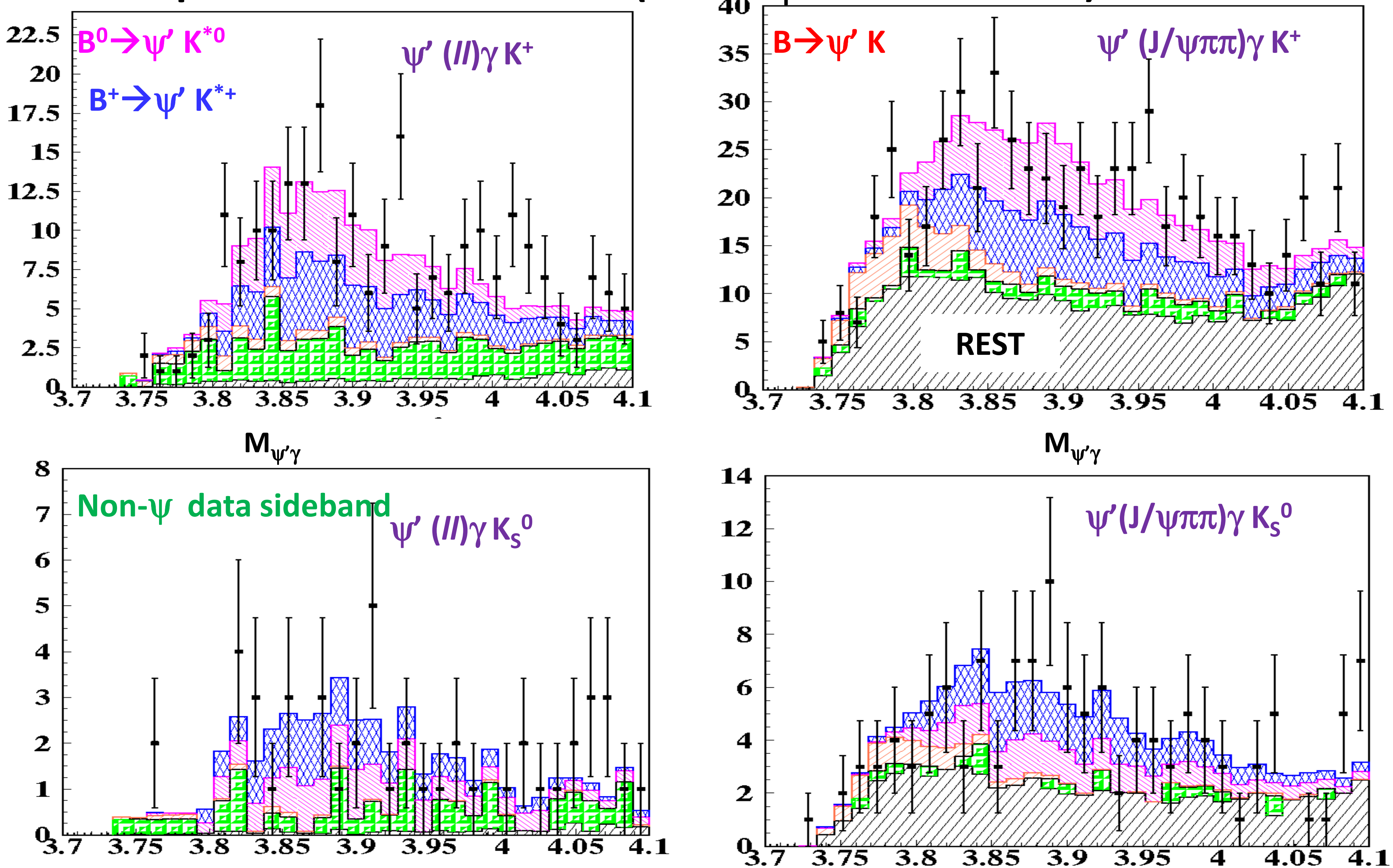
$_s$Plot projection in m_X bins







Comparison of inclusive MC (+ non-ψ data sideband) with DATA



MC agrees quite well with Data.. No sign of signal……

X(3872) other radiative decay

Angular analysis carried by Belle Belle, PRD 85,052004 (2011) and CDF PRL98, 132002 (2007) suggest , X(3872)'s J^{PC} to be 1^{++} or 2^{-+}.

PRD 83, 094009 (2011) , arXiv:1107.0443v3

$J^{PC} = 2^{-+}$ hypothesis:

- $\mathcal{BR}$(X(3872)→ψ′γ) is expected to be suppressed (consistent with our U.L.).
- Disagrees with the BaBar's measured $\mathcal{BR}$(X(3872)→ψ′γ)

$J^{PC} = 1^{++}$ hypothesis: PLB 697,3, 233-237 (2011)

- Our result can be explained using molecular or using $c\bar{c}$ admixture (less in our case).
- In BaBar's case, sizeable admixture of $c\bar{c}$ is necessary in order to explain large $\mathcal{BR}$(X(3872)→ψ′γ)