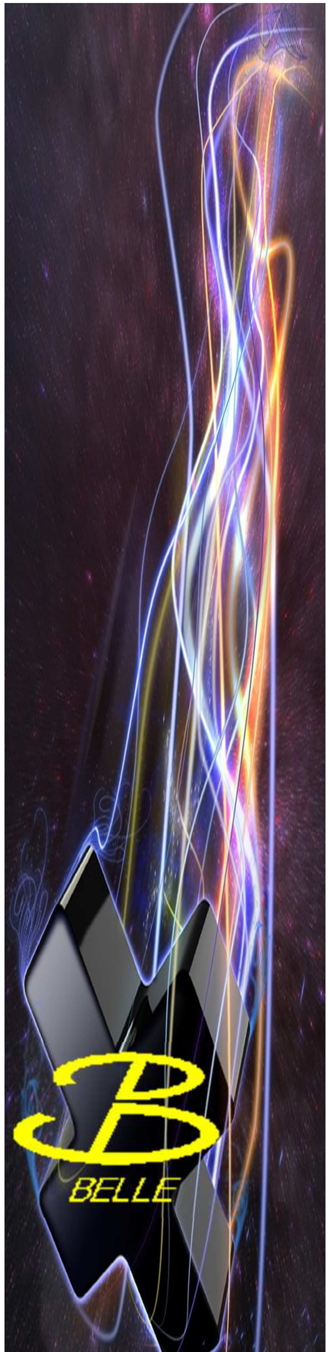


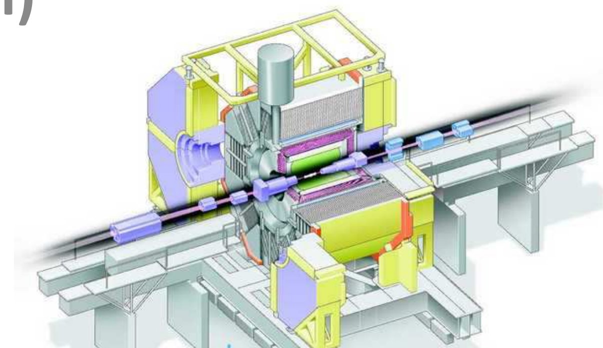
Study of $B \rightarrow \chi_{cJ}$ X at Belle (J=1,2)

Vishal Bhardwaj

University of South Carolina

(for Belle Collaboration)

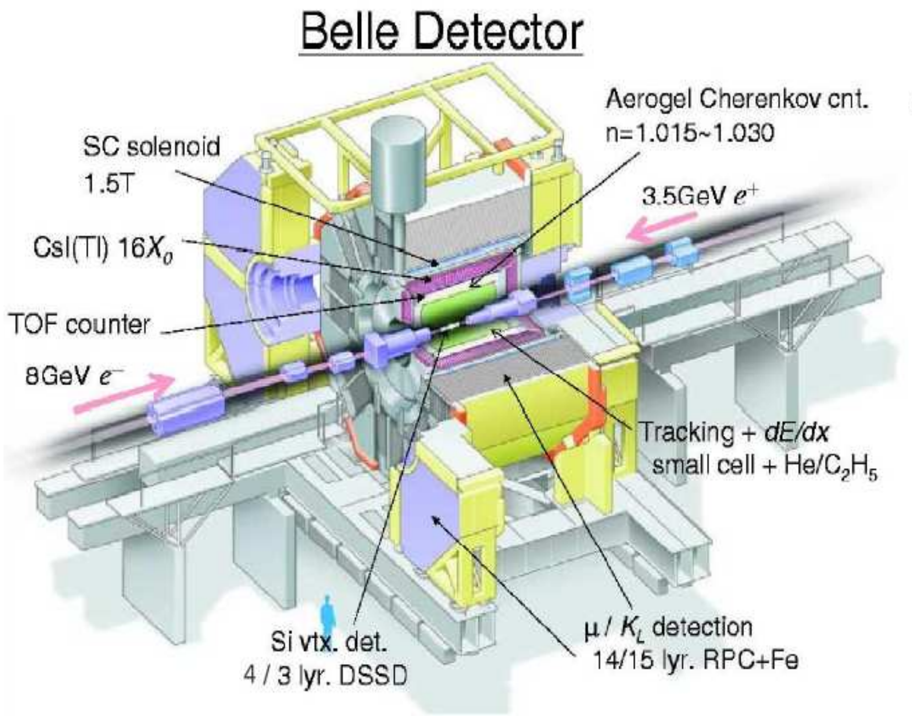
18-23 May 2015

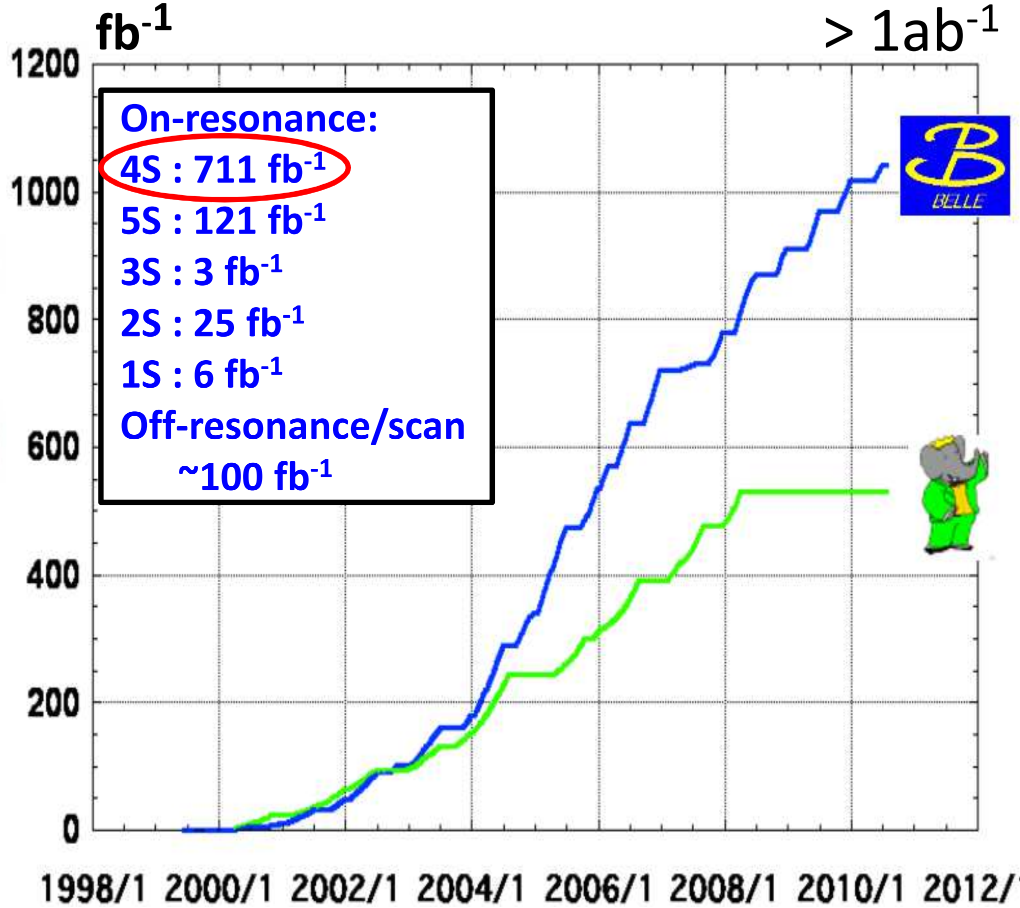


Outline

- *Measurement of $\mathcal{B}(B \rightarrow \chi_{cJ} X)$*
- *Differential branching fraction in bins of $p^*_{\chi_{cJ}}$*
- *Exclusive reconstruction of χ_{cJ} in B decays*
- *Search for exotics in exclusive decays.*

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





General purpose detector, built to test Standard Model mechanism for CP violation in B decays to charmonium ($B^0 \to [J/\Psi, \Psi', \chi_{c1}]K^0$).

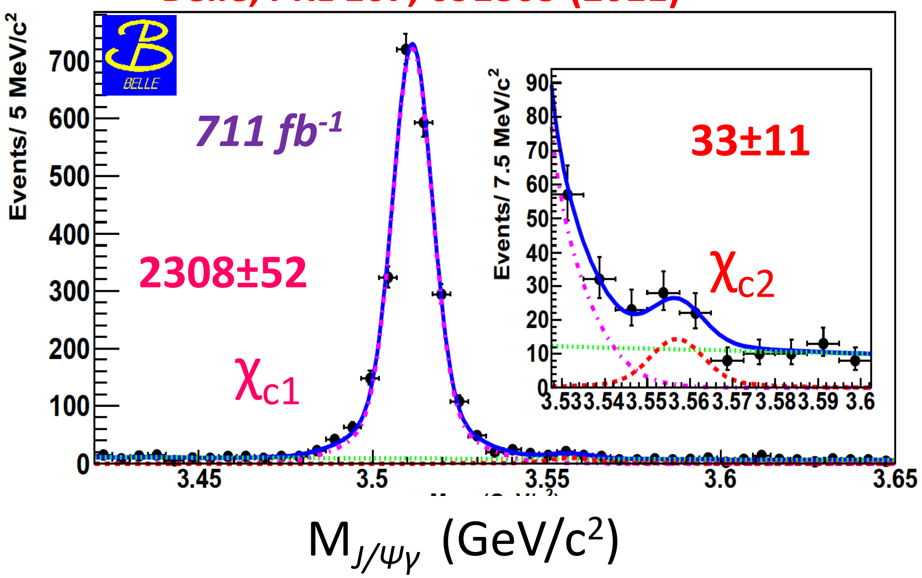
Contribution to charmonium (-like) states: Belle,PRL 108, 171802 (2012)

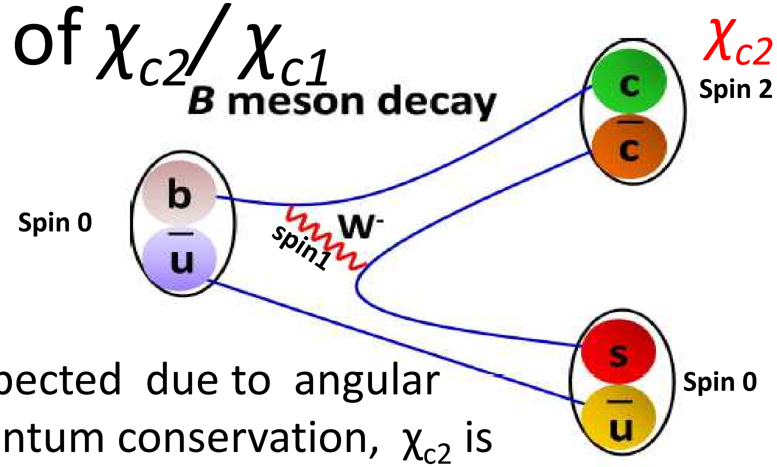
$\eta_c(2S)$, X(3823), X(3872), $Z(3895)^+$, X(3915), Y(3940), Z(3930), X(3940), Y(4260),X(4350), X(4630), Y(4660), $Z(4430)^+$, $Z_1(4050)^+$, $Z_2(4250)^+$ …

Inclusive production of χ_{c2}/χ_{c1}

$B^{\pm} \rightarrow \chi_{c1,c2} K^{\pm}$

Belle, PRL 107, 091803 (2011)





As, expected due to angular momentum conservation, χ_{c2} is suppressed in two body decay ($B \rightarrow \chi_{c2} K$)

$$\frac{N\, K^{\pm}\chi_{c2}}{N\, K^{\pm}\chi_{c1}} = \frac{33 \pm 11}{2308 \pm 52} = 1.4 \pm 0.4\ \%$$

Naïve expectation: χ_{c2} yield similar in inclusive decay mode ?

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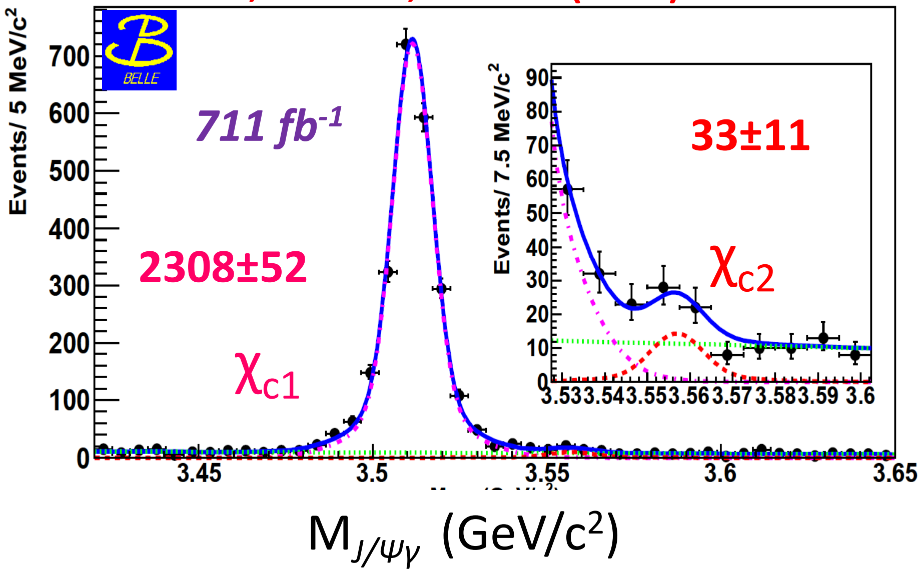
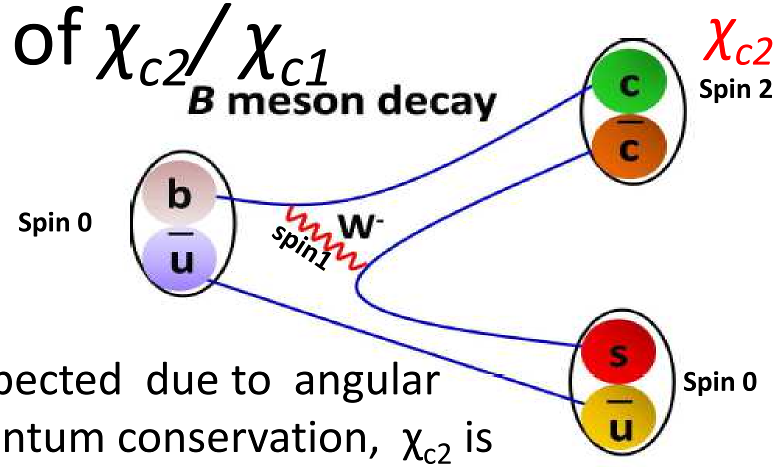
Belle, PRL 107, 091803 (2011)





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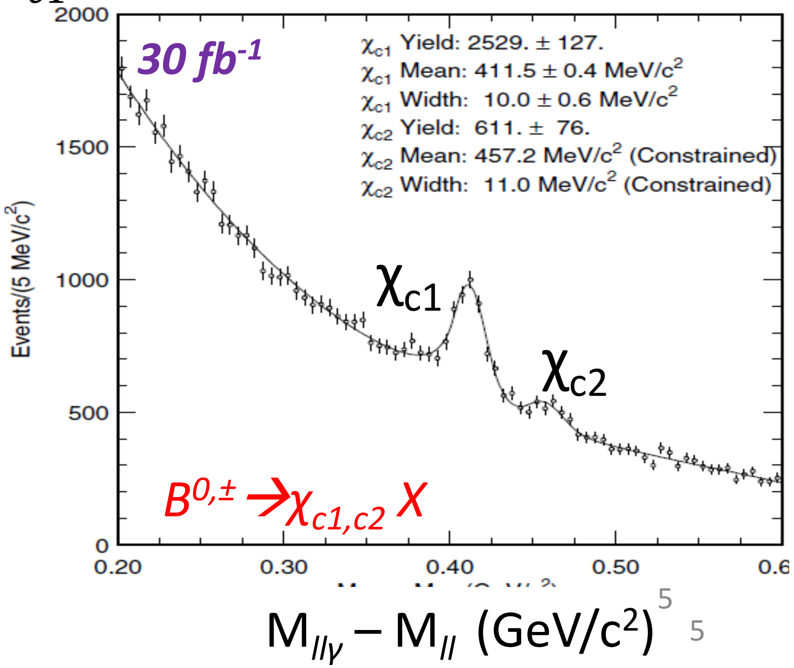
Naïve expectation: χ_{c2} yield similar in inclusive decay mode ?

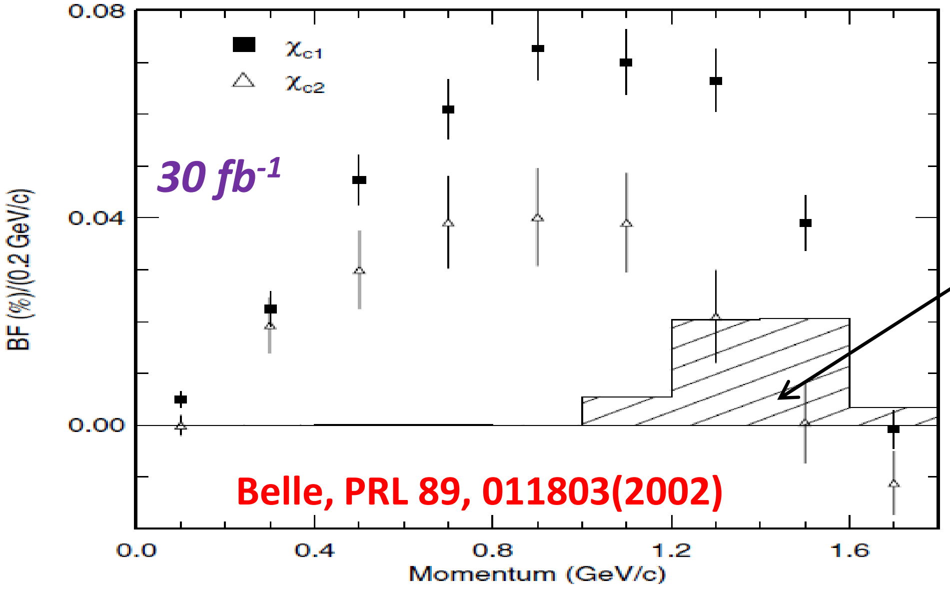
Despite the fact that $B \rightarrow \chi_{c2} K$ is suppressed, relatively large inclusive production

Belle, PRL 89, 011803(2002)

$$\frac{N\chi_{c2}}{N\chi_{c1}} = \frac{611 \pm 76}{2529 \pm 127} = 24 \pm 3\ \%$$



χ_{c2}/χ_{c1} for inclusive decays much larger than for two-body decays !



Branching fraction as a function of $p^*_{\chi_{cJ}}$ (momentum, GeV/c)

$p^*_{\chi_{cJ}}$ of $B^{\pm} \rightarrow \chi_{c2} K^{\pm}$

χ_{c2} appears to come from 3-4 body processes and there may be some exotic mechanism behind this decay.

- Exotic mechanism means : some intermediate state (normal charmonium or charmonium-like state).

$B \rightarrow$ (unknown) $K^{(*)}$

$\quad \hookrightarrow \chi_{c2}\pi$, $\chi_{c2}\pi\pi$, χ_{c2}?? Multibody or some resonance ?

- One can further try to study difference in production mechanism of χ_{c2} and χ_{c1} in B decays.
- Worth revisiting inclusive $J/\Psi\gamma$ with 25 times more data. *711 fb^{-1}*

Reconstruction

$\chi_{c1,c2}$ reconstructed in $J/\psi\gamma$ mode

  $|dz| < 3.5$cm& $|dr| < 1.0$ cm

  $R_2 < 0.5$

  J/Ψ reconstruction

   $3.07(3.05) < M_{\mu\mu}\ (M_{ee\gamma}) < 3.13$ GeV/c^2

   γs added within 0.5 mrad to J/Ψ→e^+e^- mode

$E_\gamma > 100$ MeV

  π^0 veto to reject γ from π^0; new veto leads to simpler background.

$M_{J/\psi\ \gamma}$ to identify χ_{c1} and χ_{c2}.

Mass-constrained fit to J/Ψ and χ_{cJ} candidates to improve resolution

---

Exclusive reconstruction

Combine with K and πs to reconstruct the decay mode of interest

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

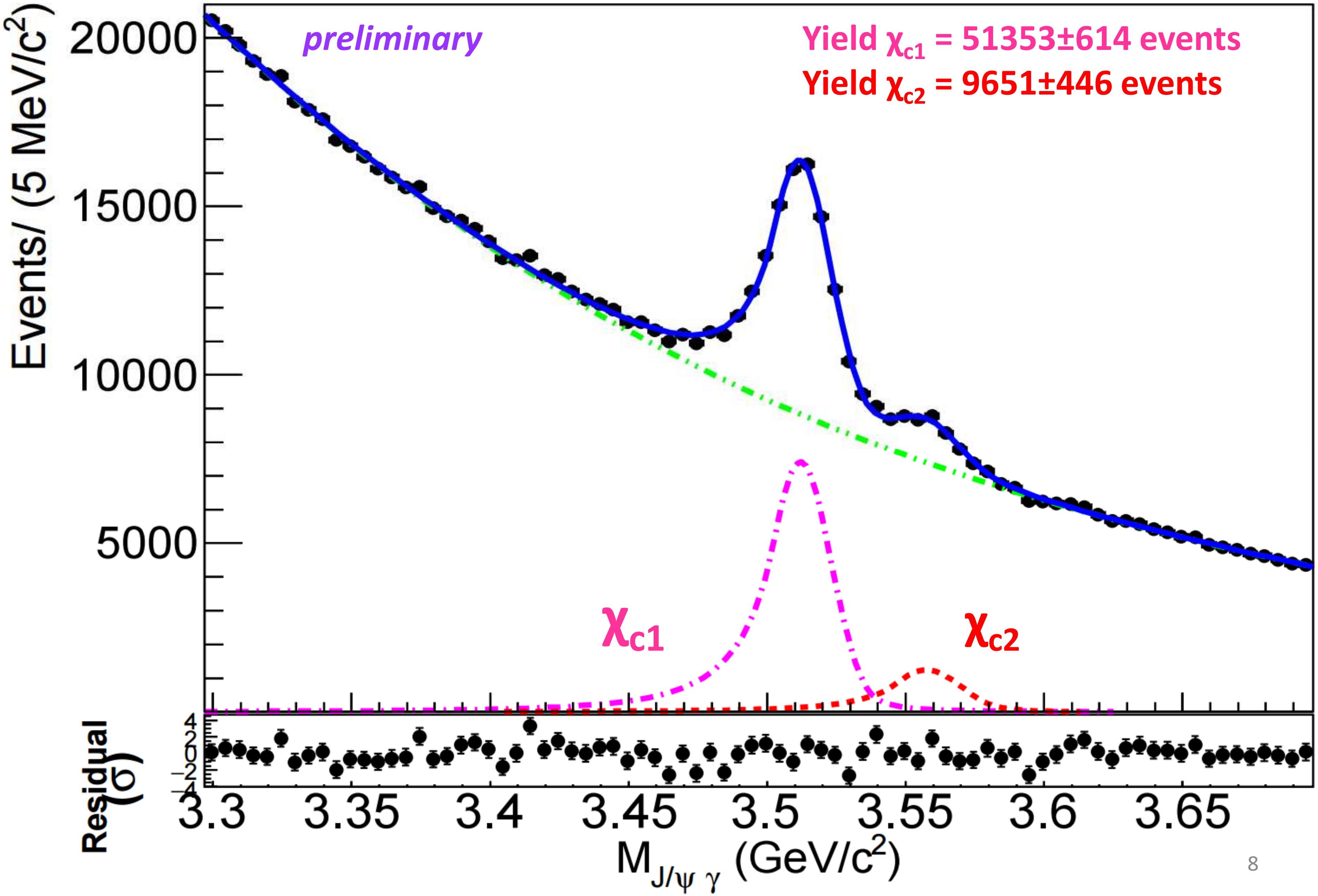
$$\Delta E = E_B - E_{beam}$$

To identify the signal

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

772×10^6 $N_{B\bar{B}}$

J/Ψγ inclusive spectrum



preliminary

Measured $\mathcal{B}(B \to \chi_{cJ}\ X)$

$772 \times 10^6\ N_{B\bar{B}}$

	$B \to \chi_{c1} X$		$B \to \chi_{c2} X$	
	Yield	$\mathcal{B}$, 10^{-3}	**Yield**	**$\mathcal{B}$, 10^{-3}**
Fit	51353±614		**9651±446**	
Continuum subtraction	50261±623	3.33±0.04	**8928±458**	**0.98±0.05**
$\Psi' \to \chi_{cJ}\gamma$ feed down subtraction	-	3.03±0.04	**-**	**0.70±0.05**

$\mathcal{B}(B \to \chi_{c1}\ X) = [3.03 \pm 0.04(\text{stat.}) \pm 0.21(\text{syst.})] \times 10^{-3}$
$\mathcal{B}(B \to \chi_{c2}\ X) = [0.70 \pm 0.05(\text{stat.}) \pm 0.07(\text{syst.})] \times 10^{-3}$

Major systematics : Efficiency, $\mathcal{B}_{\text{secondary}}$, $PDF_{for\,\chi_{c2}}$

$\mathcal{B}(B \to \chi_{c1}\ X) = (2.60 \pm 0.17 \pm 0.23) \times 10^{-3}$
$\mathcal{B}(B \to \chi_{c2}\ X) = (0.97^{+0.16}_{-0.19} \pm 0.13) \times 10^{-3}$

Belle, PRL 89, 011803(2002)
(Belle previous result after scaling)

- Nice agreement with previous Belle measurement.
- $\mathcal{B}(B \to \chi_{c2} X)$ lower than expected.

Scaling refers to secondary branching ratios
Equal production of B^+ and B^0 at $\Upsilon(4S)$

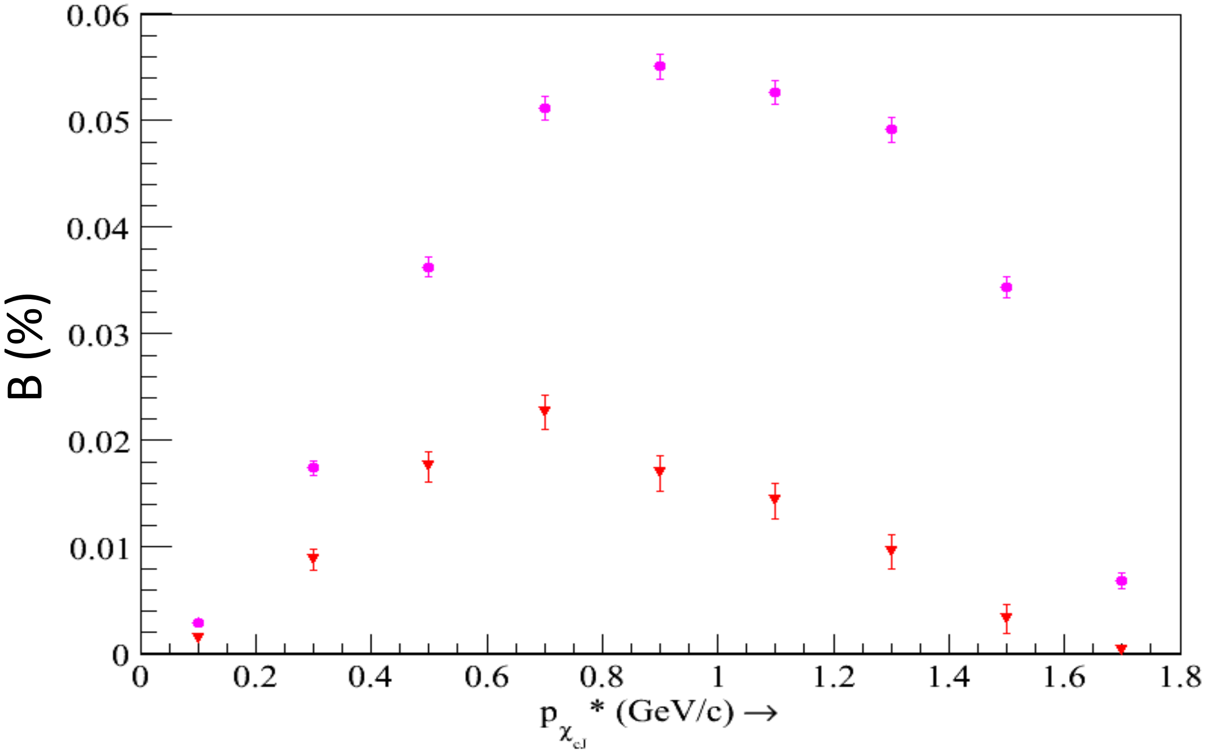
***compare $\mathcal{B}(B \to \chi_{cJ}$ + anything)**

$\mathcal{B}$ as function of $p^*_{\chi_{cJ}}$

772 x 10^6 $N_{B\bar{B}}$

χ_{c1} ●

χ_{c2} ▼



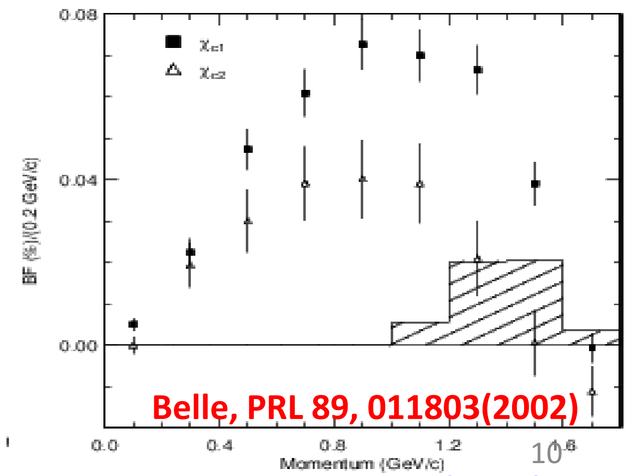
preliminary

Reduction in the uncertainty !

Possible χ_{c2} production mechanisms:

a) Multi body *B* decays.

b) Some intermediate exotic state.



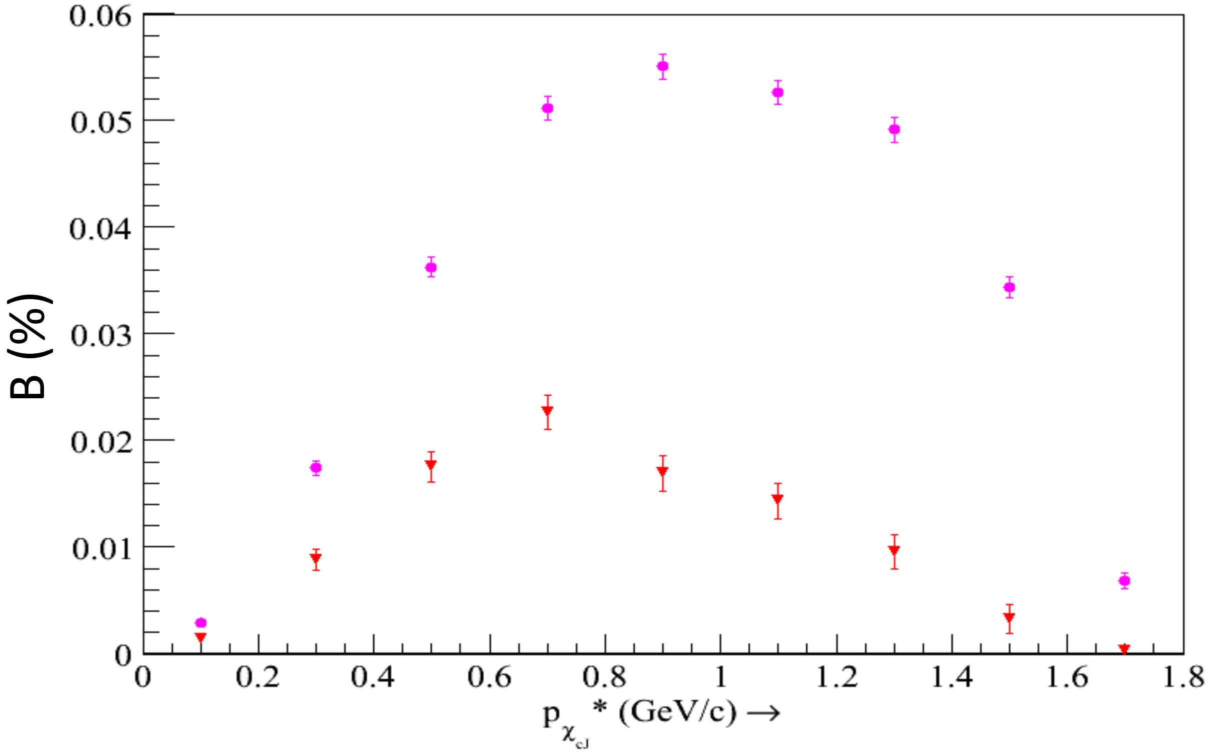
Previous reported study

χ_{c1} ●
χ_{c2} ▼

$\mathcal{B}$ as function of $p^*_{\chi_{cJ}}$

772 x 10^6 $N_{B\bar{B}}$

preliminary



Reduction in the uncertainty !

Possible χ_{c2} production mechanisms:

a) Multi body *B* decays.

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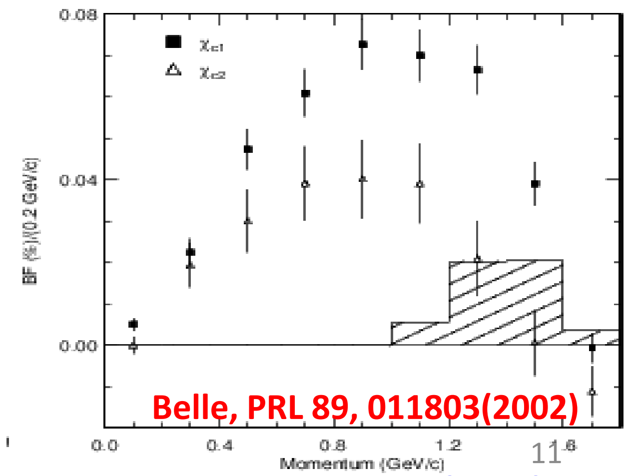
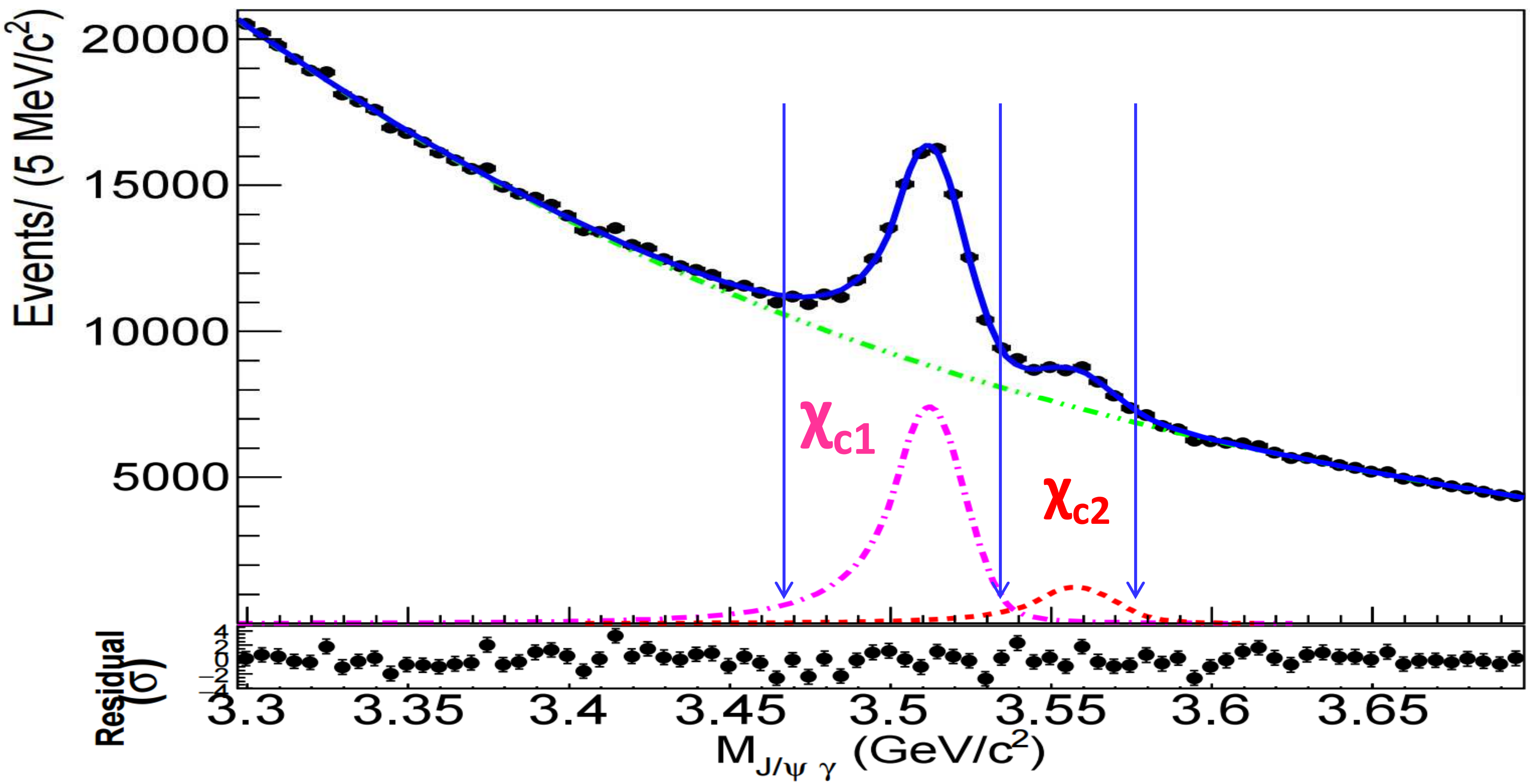
Portal to search for exotic states



Previous reported study

Exclusive reconstruction



After χ_{c1} (χ_{c2}) is identified as 3.467 GeV < $M_{J/\psi\gamma}$ < 3.535 GeV (3.535 GeV < $M_{J/\psi\gamma}$ < 3.579 GeV), mass is constrained to improve the resolution; then χ_{c1} and χ_{c2} are combined with π and K, in the six following 3-body decays and 4-body decays :

$B^0 \to \chi_{c1}\pi^- K^+$, $B^0 \to \chi_{c2}\pi^- K^+$, $B^+ \to \chi_{c1}\pi^+ K_S^0$, $B^+ \to \chi_{c2}\pi^+ K_S^0$, $B^+ \to \chi_{c1}\pi^0 K^+$ and $B^+ \to \chi_{c2}\pi^0 K^+$

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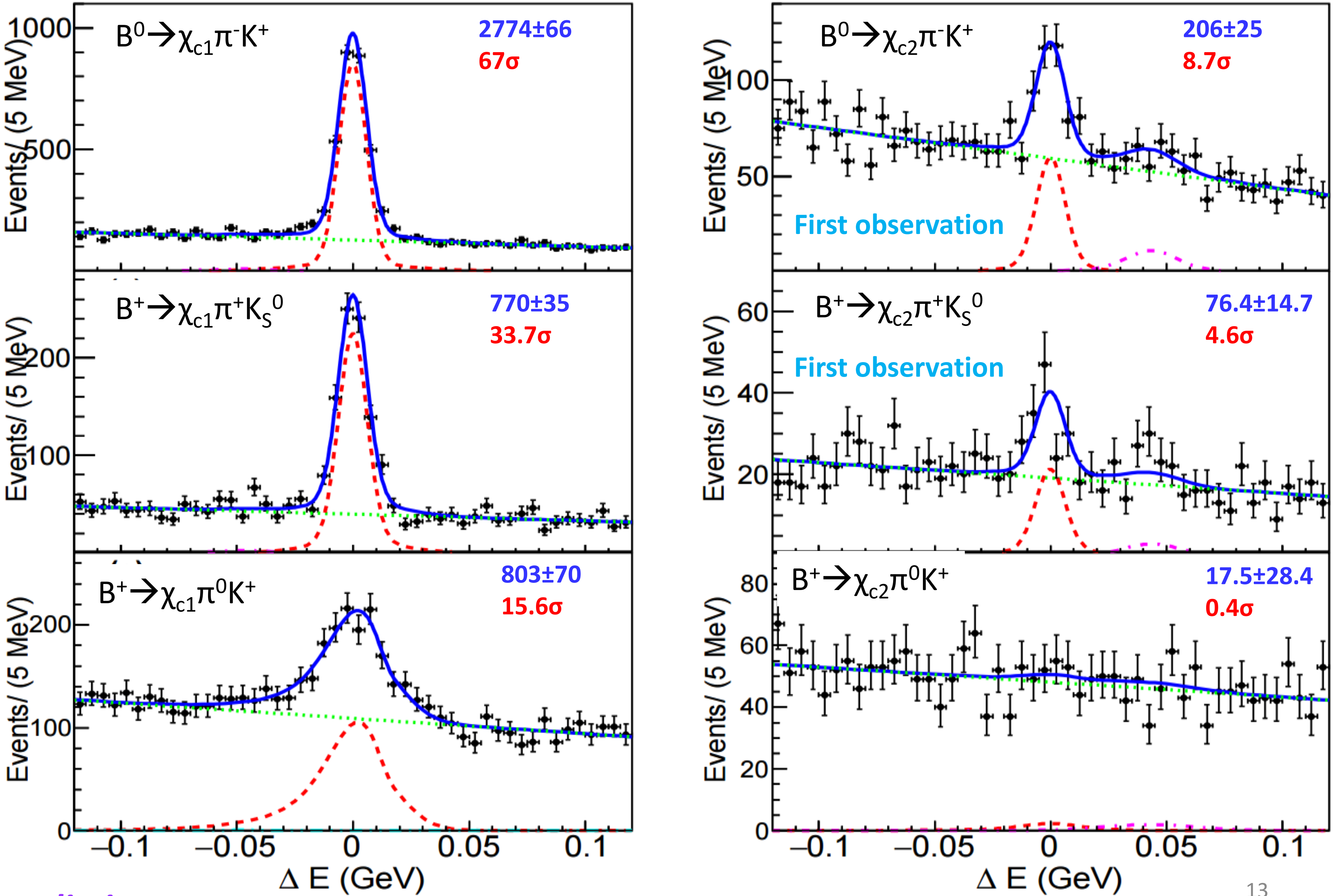
3-body decays

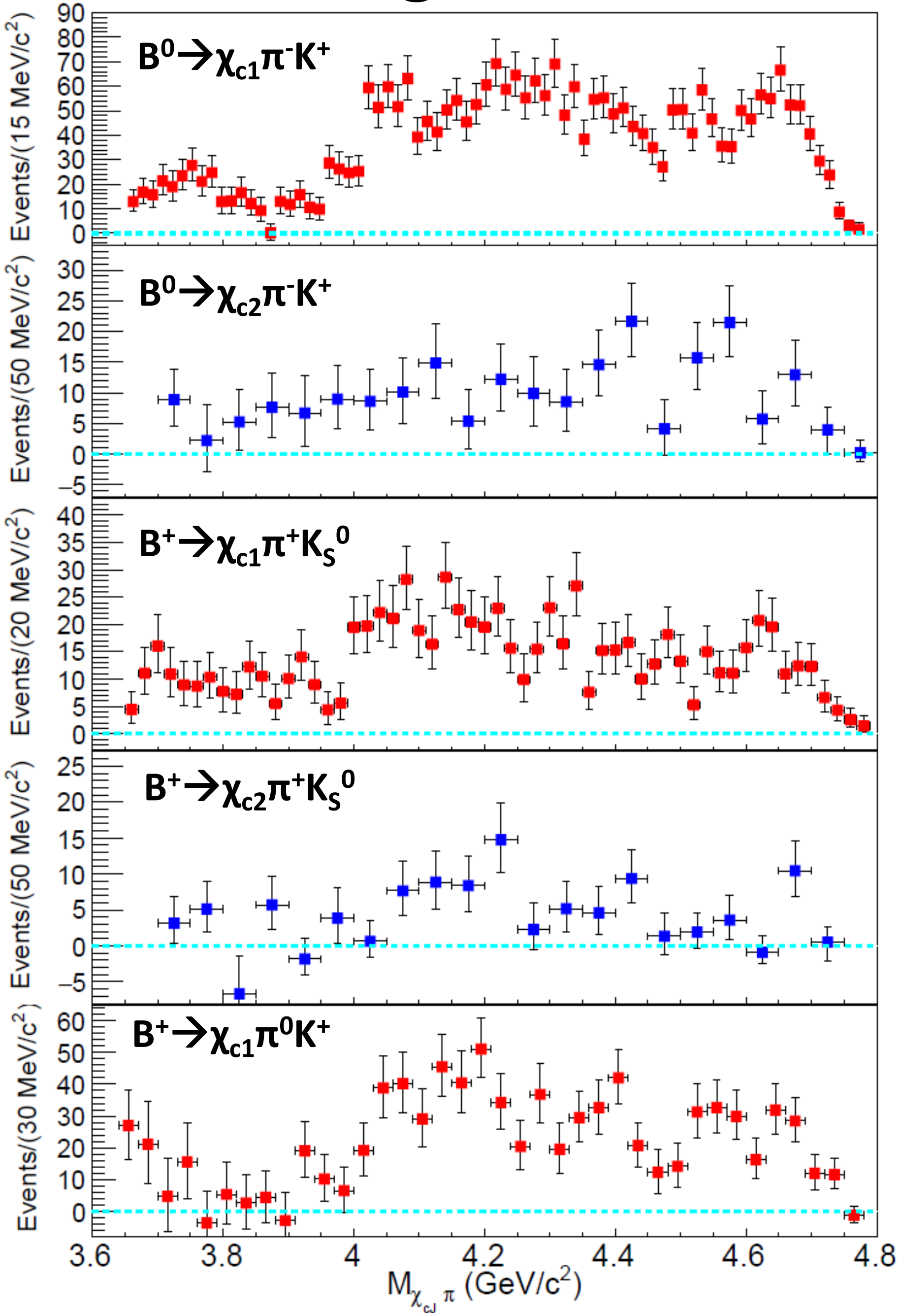
Fit to ΔE distribution

$772 \times 10^6\ N_{B\bar{B}}$



preliminary

Background subtracted $M(\chi_{cJ}\pi)$ distribution



preliminary

- To search for narrow resonance and to study the production dynamics.
  - Fit ΔE in the bins of $M(\chi_{cJ}\pi)$ to get background subtracted distribution.

- All $B \to \chi_{c1}\pi K$ decay modes show similar $M(\chi_{c1}\pi)$ distribution.
  - $B^0 \to \chi_{c1}\pi^- K^+$ results consistent with the two charged Z states from a previous Belle study.

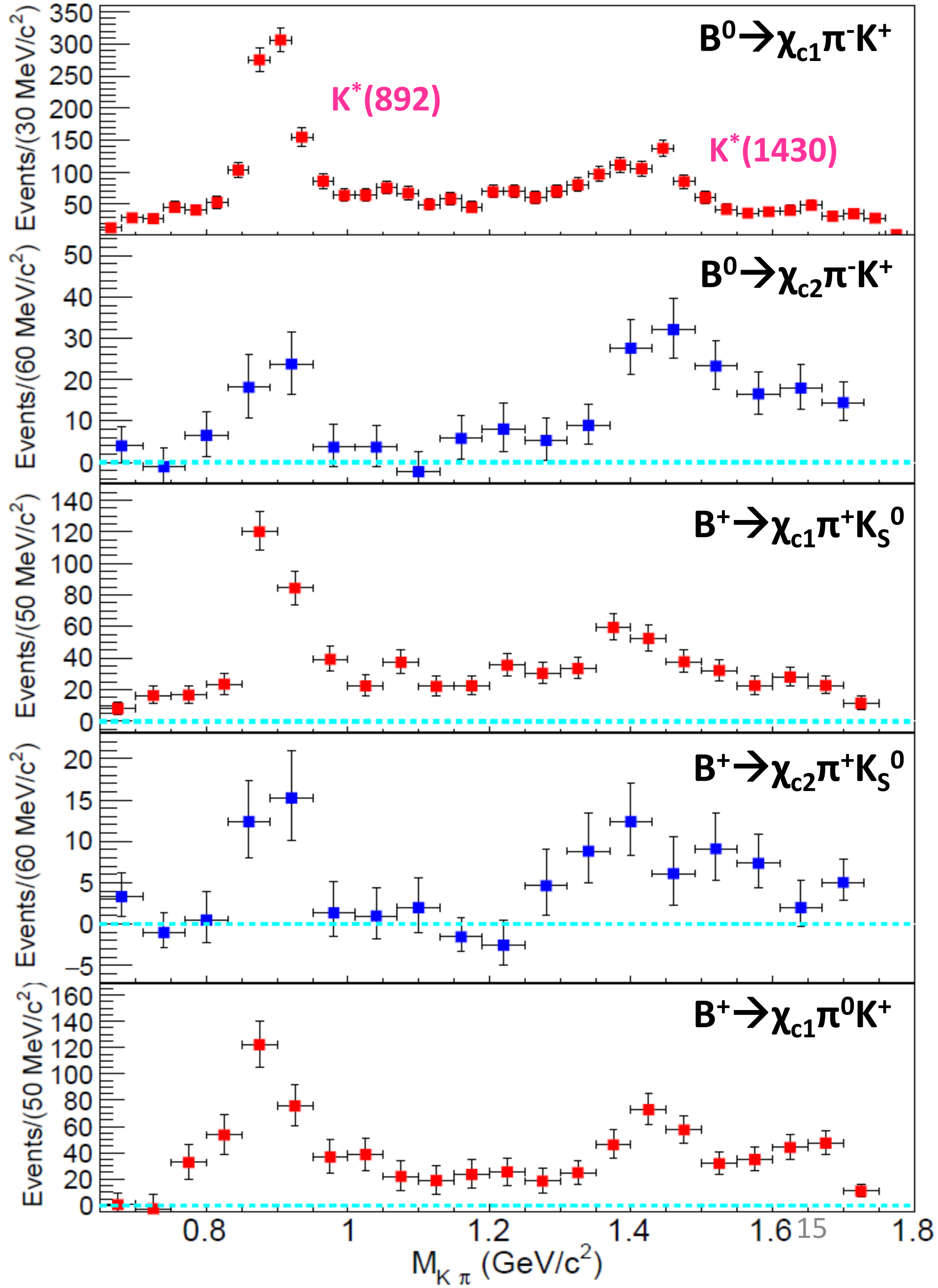
PRD78, 072004 (2008)

- The $M(\chi_{c2}\pi)$ distribution appears to be different in $B \to \chi_{c2}\pi^+ K$ decays.
  - No narrow resonance is seen.

Background subtracted $M_{K\pi}$ distribution

preliminary

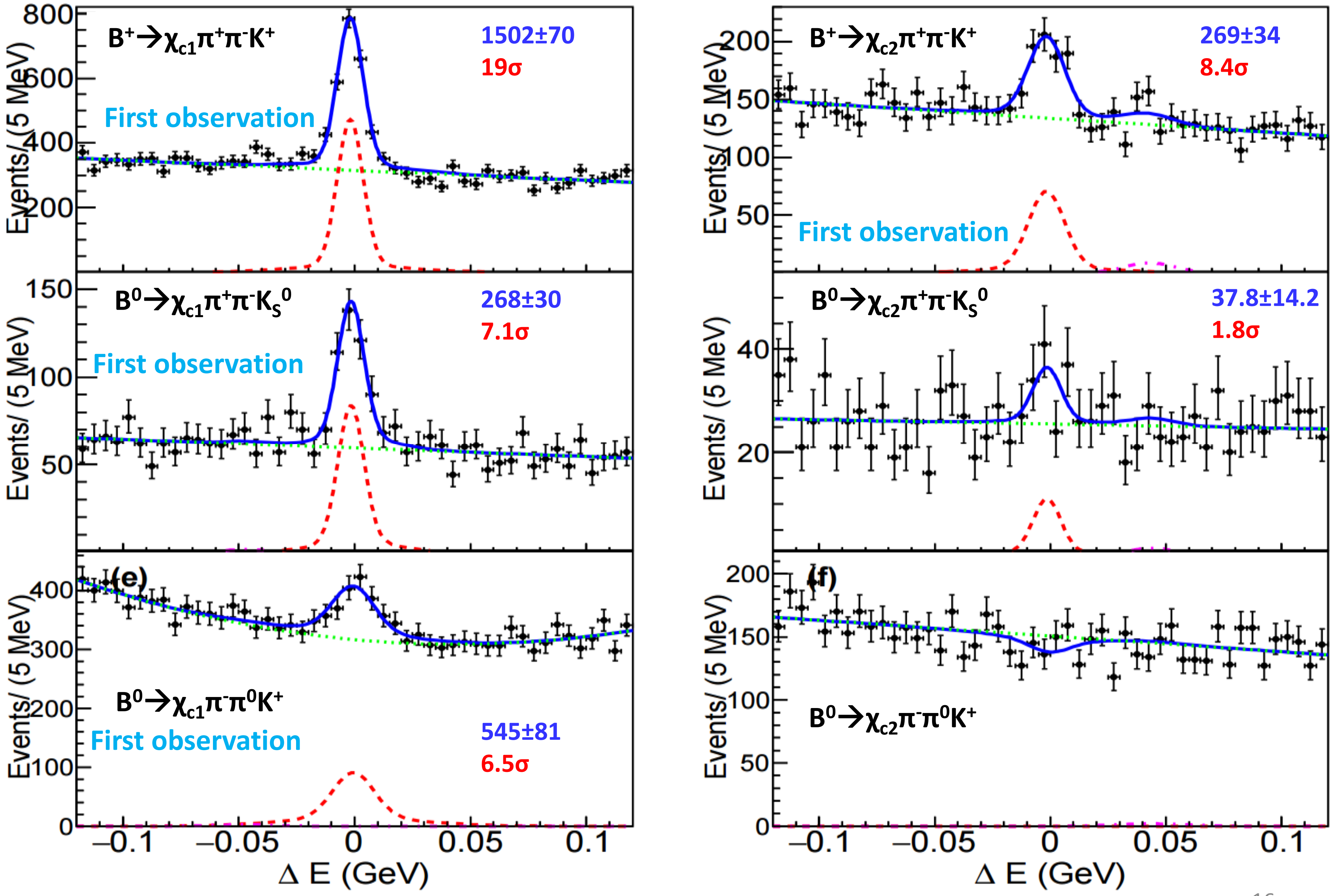
- Similarly, fit ΔE in the bins of $M_{K\pi}$ to get background subtracted distribution.
- K*(892) and higher resonance K*(1430) can be seen in the decay modes
- $B \rightarrow \chi_{c2}\pi K$ decay modes show clearly different behavior in comparison to $B \rightarrow \chi_{c1}\pi K$ decay modes
  - Most of the χ_{c2} comes from higher resonances, which is in contrast to χ_{c1} decays.
  - All previous studies of $B \rightarrow \chi_{c2}K^*$ limited themselves to $K^*(892)^0$.
  - χ_{c2} seems to be produced more often with higher mass K*'s.



4-body decays

Fit to ΔE distribution

preliminary

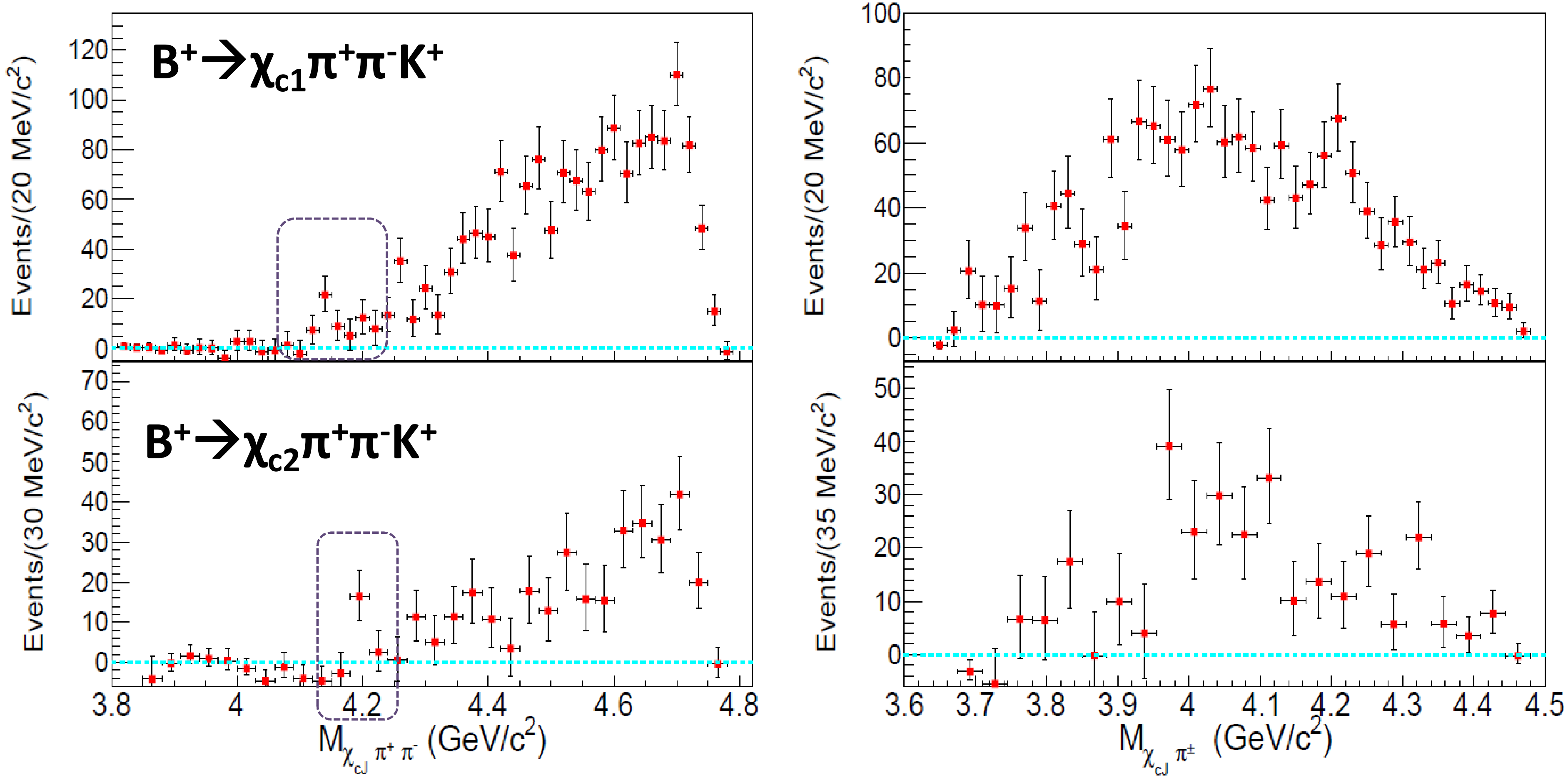


$M(\chi_{cJ} n\pi)$ distribution

Background subtracted

preliminary

Fit ΔE in each bin



No narrow resonance is seen with current statistics !

Reflection coming from $B \rightarrow K\pi\Psi'(\rightarrow \chi_{cJ}\gamma)$ decay mode
Same effect also seen in MC background study

preliminary

Search for X(3872) / χ_{c1}' *in $B^+ \to \chi_{c1}\pi^+\pi^- K^+$*

Recent measurements of the X(3872) definitively identify J^{PC} as 1^{++} .

Interpretation :

- Admixture of DD* molecule with $c\bar{c}$ state, if so then χ_{c1}'
- If χ_{c1}' is not X(3872), then one can expect to observe it decaying into $\chi_{c1}\pi^+\pi^-$

$\chi_{c1}' \to \chi_{c1}\pi^+\pi^-$ similar to $\Psi' \to J/\Psi\pi^+\pi^-$

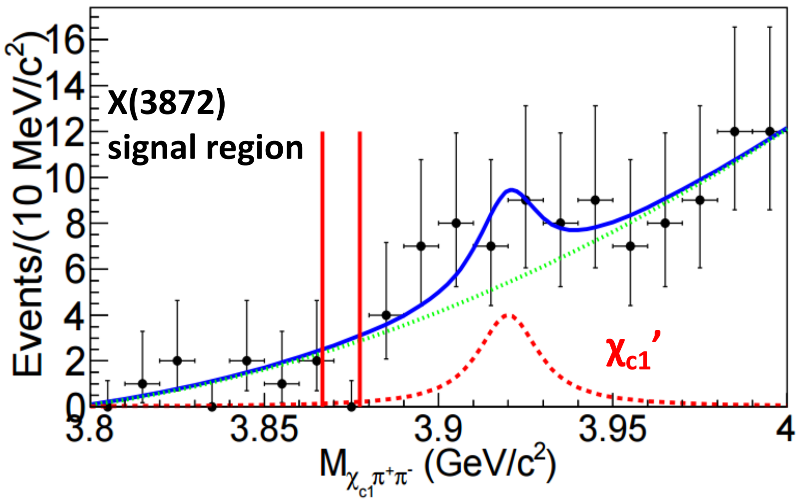
Mass prediction ~ 3920 MeV/c^2

In both scenarios, X(3872) $\to \chi_{c1}\pi^+\pi^-$

Not forbidden !

Observation of signal will help in understanding $c\bar{c}$ and exotic state [mainly X(3872)]

M_{bc}> 5.27 GeV/c^2 -20 MeV <ΔE > 20 MeV



No signal with current data set

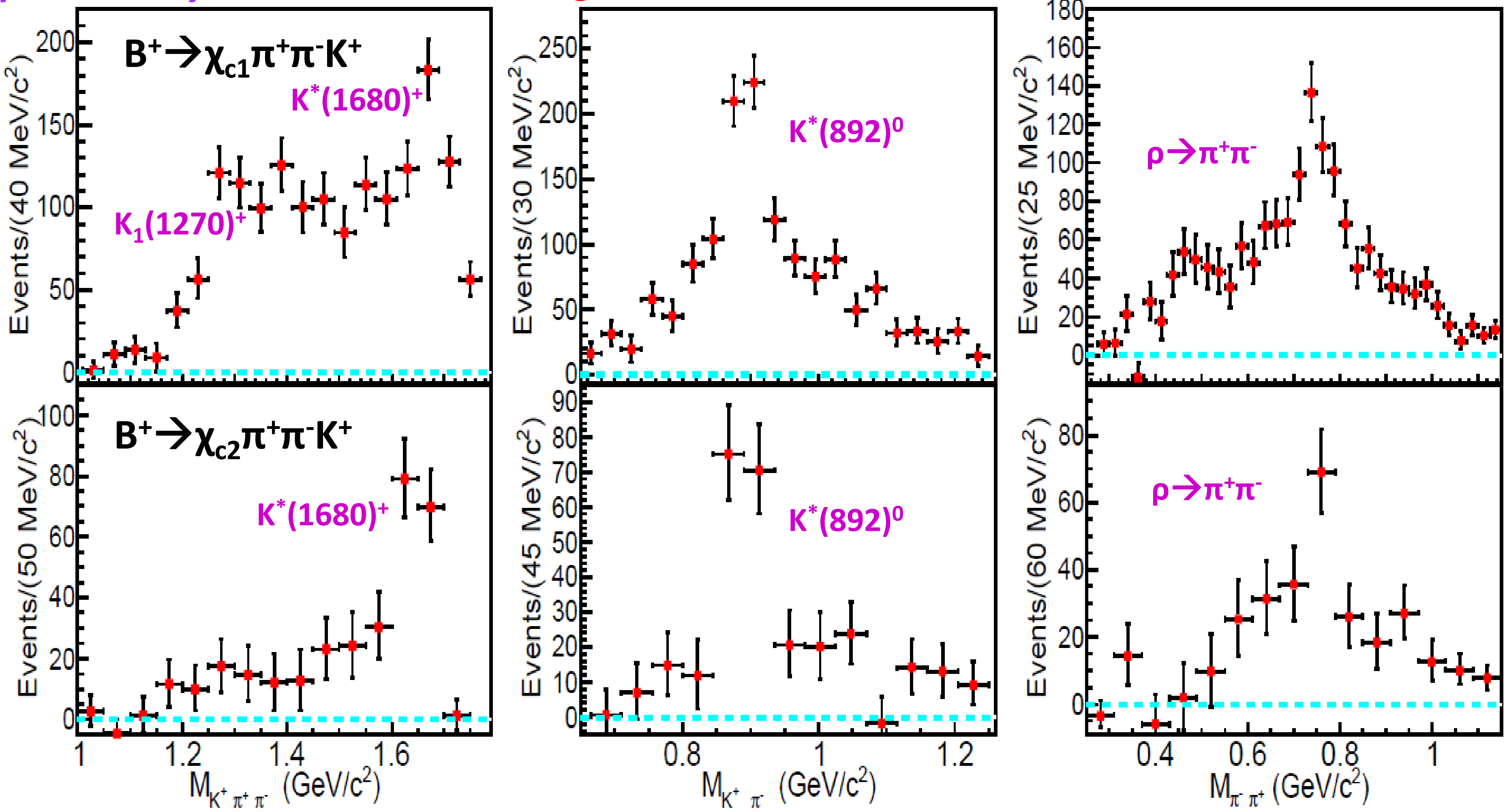
Mode	Yield$^{U.L.}$	ε(%)	$\mathcal{B}^{U.L.}$(x 10^{-6})
X(3872)	< 2.6	5.6	<1.4
χ_{c1}'	< 30.3	8.9	<1.0

PRD 69, 074005 (2004)
PRD 77, 094013(2008)

X(3872) as admixture state of $D\bar{D}$* molecule and χ_{c1}' more plausible*

$M_{\pi(\pi K)}$ distribution for 4 body decays

preliminary Background subtracted Fit ΔE in each bin



$K^*(1680)^+ \to K^*(892)\pi,\ K^+\rho$

χ_{c2} production is different in comparison to χ_{c1}

- Prefers to decay with higher K* !

preliminary

Branching fraction measurements

Decay	Yield (Y)	$\mathcal{S}(\sigma)$	$\epsilon(\%)$	$\mathcal{B}$ (10^{-4})	$\mathcal{R}_{\mathcal{B}}$
$B^0 \to \chi_{cJ}\pi^- K^+$					0.14 ± 0.02
χ_{c1}	2774 ± 66	66.7	18.0	$4.93 \pm 0.12 \pm 0.27$	
χ_{c2}	206 ± 25	8.7	16.3	$0.72 \pm 0.09 \pm 0.05$	
$B^+ \to \chi_{cJ}\pi^+ K^0$					0.20 ± 0.04
χ_{c1}	770 ± 35	33.7	8.7	$5.68 \pm 0.26 \pm 0.31$	
χ_{c2}	76.4 ± 14.7	4.6	7.5	$1.16 \pm 0.22 \pm 0.12$	
$B^+ \to \chi_{cJ}\pi^0 K^+$					< 0.21
χ_{c1}	803 ± 70	15.6	8.0	$3.24 \pm 0.28 \pm 0.19$	
χ_{c2}	17.5 ± 28.4	0.4	7.0	< 0.62	
$B^+ \to \chi_{cJ}\pi^+\pi^- K^+$					0.36 ± 0.05
χ_{c1}	1502 ± 70	19.2	13.0	$3.72 \pm 0.17 \pm 0.24$	
χ_{c2}	269 ± 34	8.4	11.5	$1.32 \pm 0.17 \pm 0.08$	
$B^0 \to \chi_{cJ}\pi^+\pi^- K^0$					< 0.61
χ_{c1}	268 ± 30	7.1	5.5	$3.11 \pm 0.34 \pm 0.31$	
χ_{c2}	37.8 ± 14.2	1.8	4.8	< 1.70	
$B^0 \to \chi_{cJ}\pi^0\pi^- K^+$					< 0.25
χ_{c1}	545 ± 81	6.5	5.0	$3.51 \pm 0.52 \pm 0.24$	
χ_{c2}	-76.7 ± 42.0	-	4.3	< 0.74	

$$\mathcal{R}_{\mathcal{B}} = \frac{\mathcal{B}(B\to\chi_{c2}X)}{\mathcal{B}(B\to\chi_{c1}X)}$$

increases

Using these measurements†, we are able to saturate the inclusive $\mathcal{B}$ measurement by (57±5)% and (34±5)% for $B\to\chi_{c1} X$ and $B\to \chi_{c2} X$, respectively.

†Assume $\mathcal{B}(B^+\to\chi_{cJ}nX) = \mathcal{B}(B^0\to\chi_{cJ}nX)$,

Summary

Inclusive $B \to \chi_{cJ}$ + anything

$\mathcal{B}(B \to \chi_{cJ} X)$ is measured in bins of $p^*_{\chi_{cJ}}$
Shows suppression in higher momentum bin.

$B \to \chi_{cJ} K\pi$ study

- First observation of $B \to \chi_{c2} K^+ \pi^-$
- First evidence of $B \to \chi_{c2} K_S^0 \pi^+$
- No structure found in $M(\chi_{c2}\pi^+)$
- $M(\chi_{c1}\pi^+)$ distribution consistent with two charged Z states from a previous Belle study

$B \to \chi_{cJ} K\pi\pi$ study

- First observation of $B \to \chi_{c1}\pi^+\pi^- K^+$, $B \to \chi_{c2}\pi^+\pi^- K^+$, $B \to \chi_{c1}\pi^+\pi^- K_S^0$, $B \to \chi_{c1}\pi^+\pi^0 K^+$
- No narrow resonance is found.
- No hint of $X(3872)/\chi_{c1}'$ in $M(\chi_{c1}\pi\pi)$
  - *X(3872) as admixture state of $D\bar{D}^*$ molecule and χ_{c1}' more plausible**

$B \to \chi_{c2} K$ is barely seen due to suppression of tensor in B decay.
Able to saturate inclusive $\mathcal{B}(B \to \chi_{c1} X)$ by (57±5)% and $\mathcal{B}(B \to \chi_{c2} X)$ by (34±5)%

Thank you