

The measurement of the Helicity-Selection-Rule (HSR) suppressed decay

$$\chi_{c2} \rightarrow VP$$

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Outline

- Motivation
- The analysis of $\chi_{c2} \rightarrow VP$
 - ✓ $\chi_{c2} \rightarrow K^* \bar{K} + C.C.$
 - ✓ $\chi_{c2} \rightarrow \rho^+ \pi^- + C.C.$
- Summary

[arXiv:1612.07398 \[hep-ex\]](https://arxiv.org/abs/1612.07398)

$\chi_{cJ} \rightarrow VV, VP$

- Helicity Selection Rule (HSR): $\sigma^{\text{initial}} = \sigma_1 \cdot \sigma_2$ ($, \sigma = P \cdot (-1)^J$)

	VV	VP
χ_{c0}	✓	Suppressed
χ_{c1}	Suppressed	✓
χ_{c2}	✓	Suppressed

- The helicity selection rule (HSR) is one of the most important consequences of pQCD at leading twist accuracy.
- $\chi_{c2} \rightarrow VP$ are ideal for testing the HSR and pinning down the mechanisms that may violate the leading pQCD approximation.

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- $\chi_{c2} \rightarrow VP$ are of great interest is that this process is ideal for probing the long-range interactions arising from intermediate D-meson loop transitions.

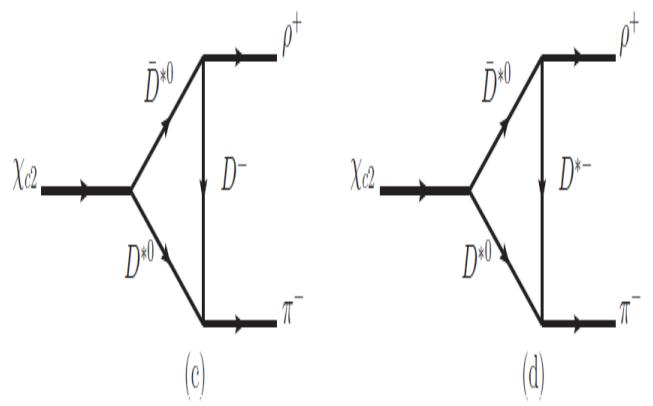
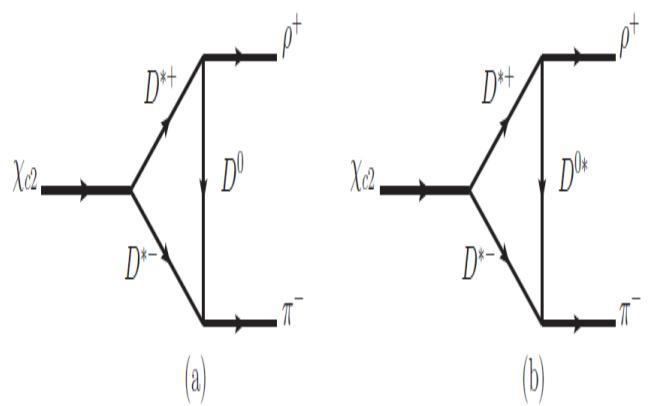


FIG. 2: Triangle loop diagrams that describe the long-distance contributions in $\chi_{c2} \rightarrow \rho^+ \pi^-$. The diagrams for $\chi_{c2} \rightarrow \rho^- \pi^+$ are implicated.

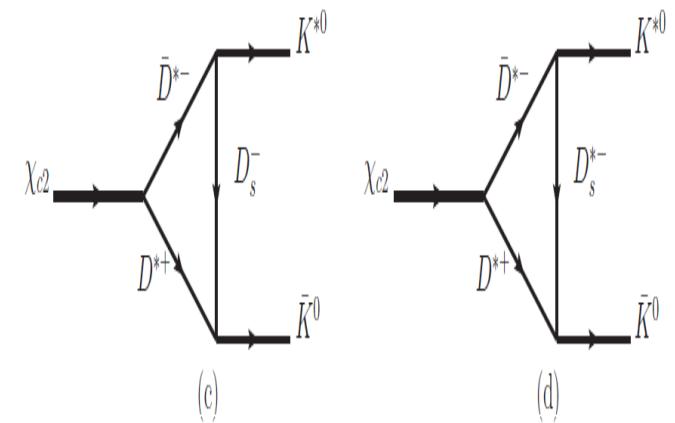
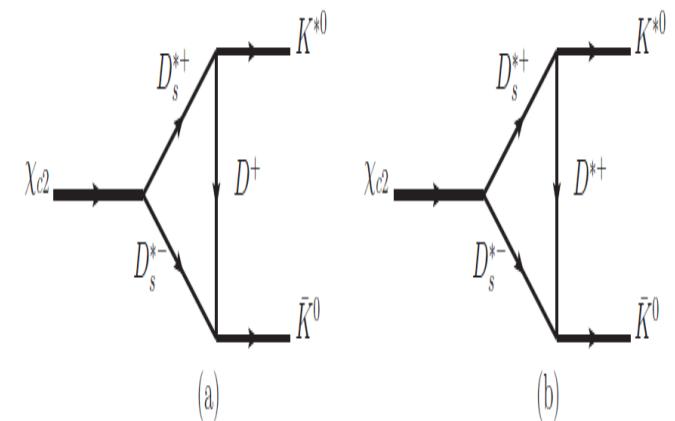


FIG. 3: Triangle loop diagrams that describe the long-distance contributions in $\chi_{c2} \rightarrow K^0 \bar{K}^0$. The diagrams for $\chi_{c2} \rightarrow \bar{K}^0 K^0$ are implicated.

- The approximate **G-parity or isospin conservation** would further **suppress** the non-strange intermediate **D-meson loop transitions** in the process of $\chi_{c2} \rightarrow \rho^\pm \pi^\mp$.
- **U-spin symmetry breaking** due to the relatively large mass **difference between u/d and s quarks** would lead to **significant contributions** from the intermediate charmed-strange **Ds-meson loops** in the decay of $\chi_{c2} \rightarrow K^*(892) \bar{K}$

- Therefore, a precise measurement of these decays is of great value for our understanding of the physics in the interplay between the pQCD and non-pQCD regimes
- The comparison between these two decays can provide a direct investigation into the role of the intermediate meson loops as a dominant mechanism for violating the HSR.

- **Intermediate meson loop prediction**

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BR($\times 10^{-5}$)	$K^{*0}\bar{K}^0 + c.c.$	$K^{*+}K^- + c.c.$	$\rho^+\pi^- + c.c.$
Meson loop	$4.0 \sim 6.7$	$4.0 \sim 6.7$	$(1.2 \sim 2.0) \times 10^{-2}$
Exp. data	—	—	—

$\chi_{c2} \rightarrow VP$

- $\chi_{c2} \rightarrow K^* \bar{K}$ $(K^{*+} K^- + c.c. , K^{*0} \bar{K}^0 + c.c.)$

✓ $\psi' \rightarrow \gamma \chi_{c2} \rightarrow \gamma K^+ K^- \pi^0$

✓ $\psi' \rightarrow \gamma \chi_{c2} \rightarrow \gamma K_S K^\pm \pi^\mp$

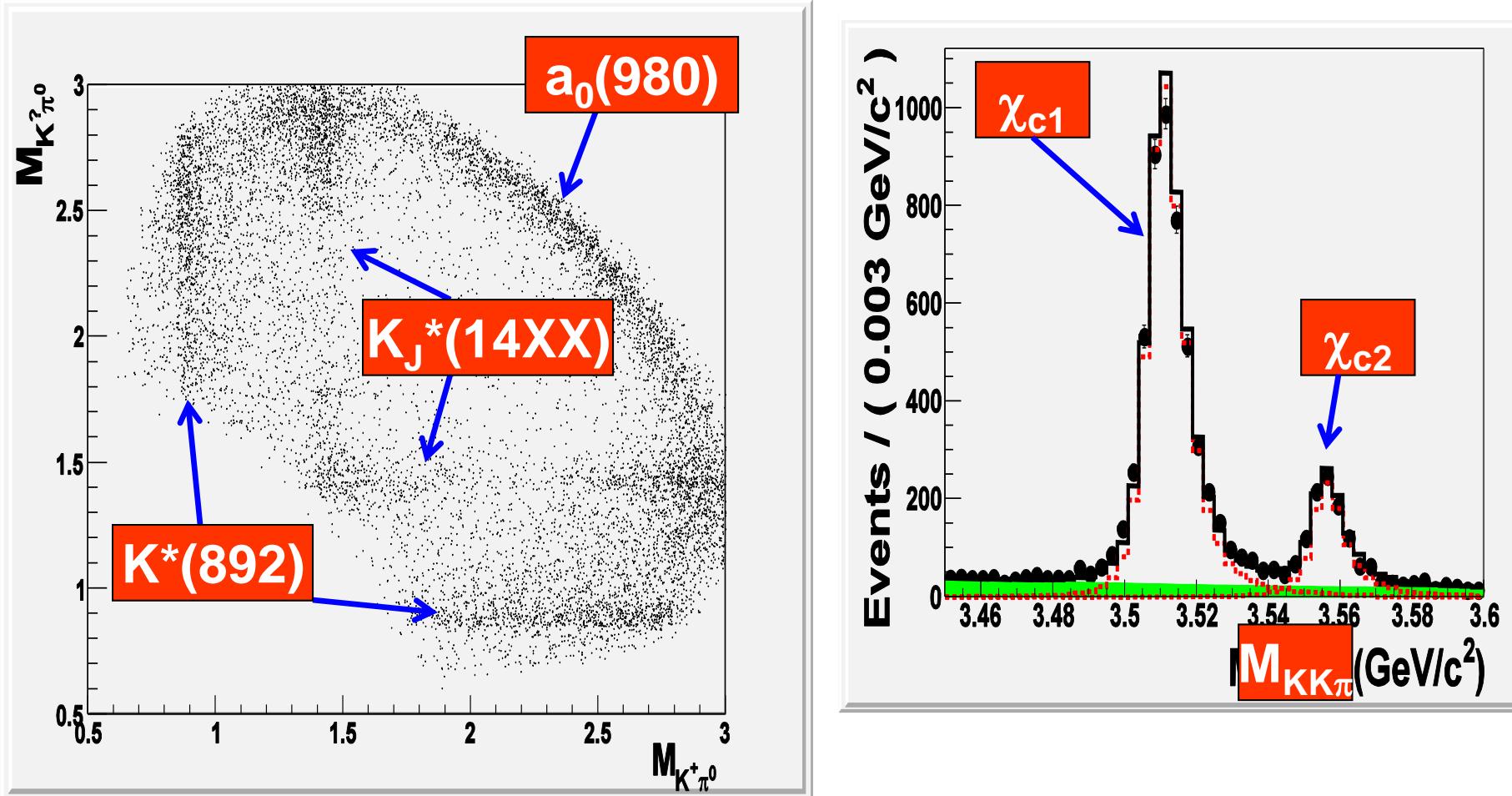
► $\psi' \rightarrow \gamma \chi_{c2} \rightarrow \gamma K_S K_S \pi^0$

- $\chi_{c2} \rightarrow \rho^+ \pi^- + c.c.$

Events selection for $\psi' \rightarrow \gamma K^{*\pm} K^{\mp}$

(Final states: $\gamma\gamma\gamma KK$)

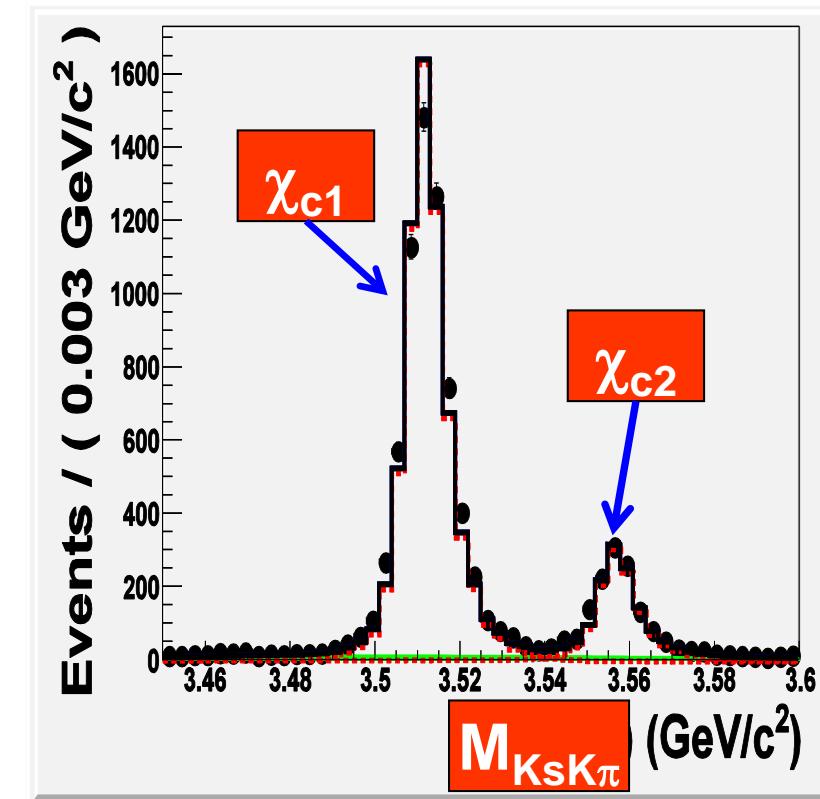
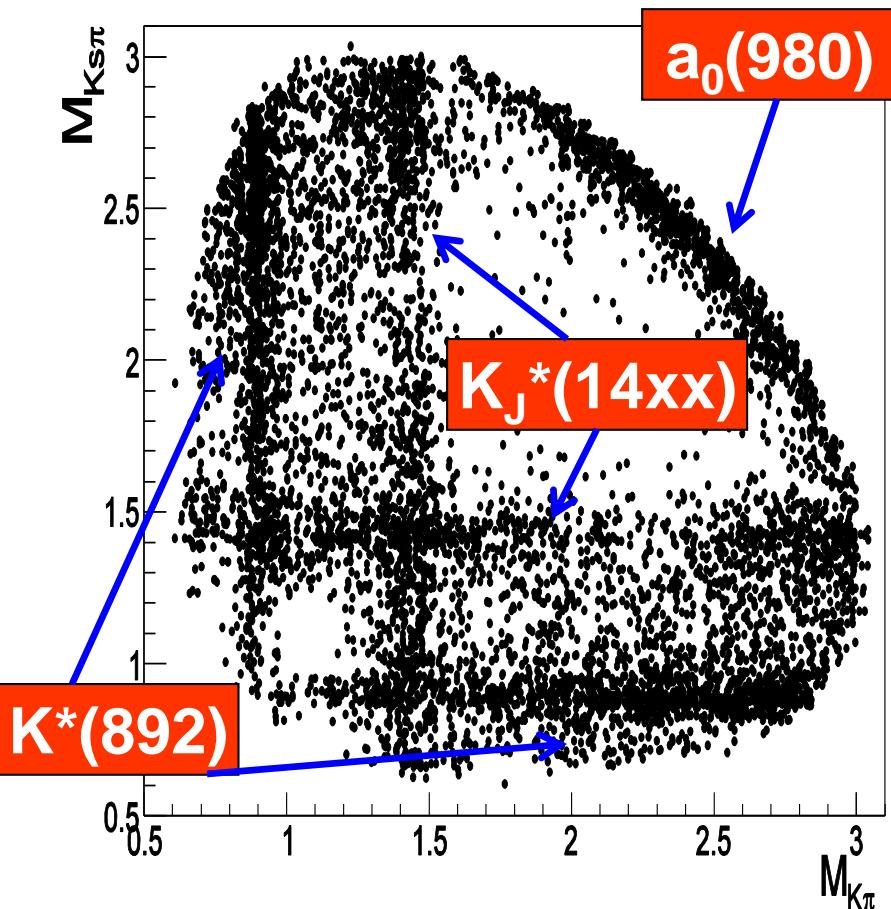
$\hookrightarrow K^\pm \pi^0$



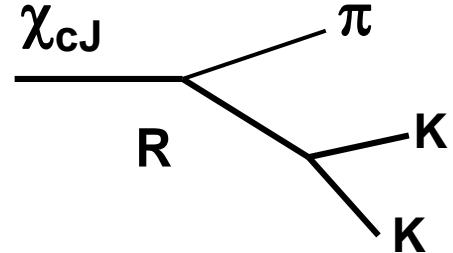
Events selection for $\psi' \rightarrow \gamma K^{*\pm} K^\mp$, $\gamma K^{*0} K^0$

(Final states: $\gamma K3\pi$)

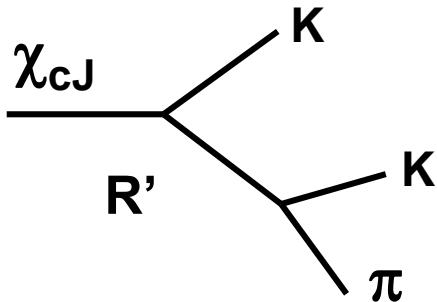
$\downarrow K^0 \pi^\pm$ $\downarrow K^\mp \pi^\pm$



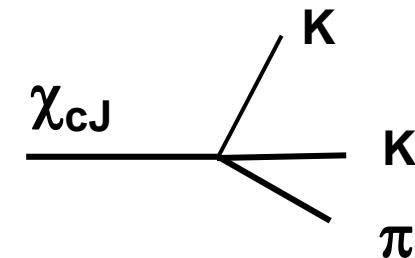
- Processes



a. $\chi_{cJ} \rightarrow \pi R, R \rightarrow KK$



b. $\chi_{cJ} \rightarrow KR', R' \rightarrow K\pi$



c. $\chi_{cJ} \rightarrow KK\pi$

Amplitude (Helicity-Covariant amplitude: **S.U.Chung, PRD57,431**)

a and b : quasi-two body decays

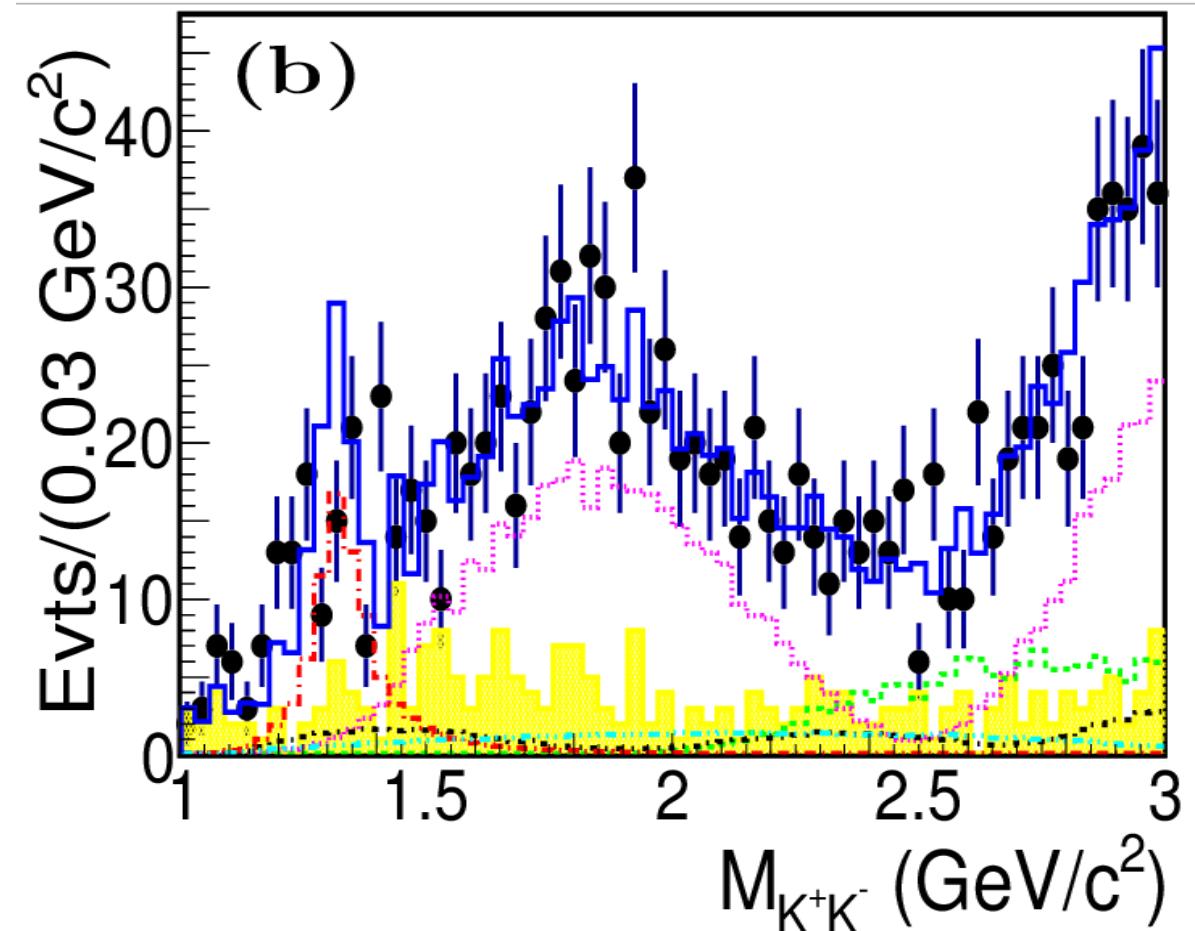
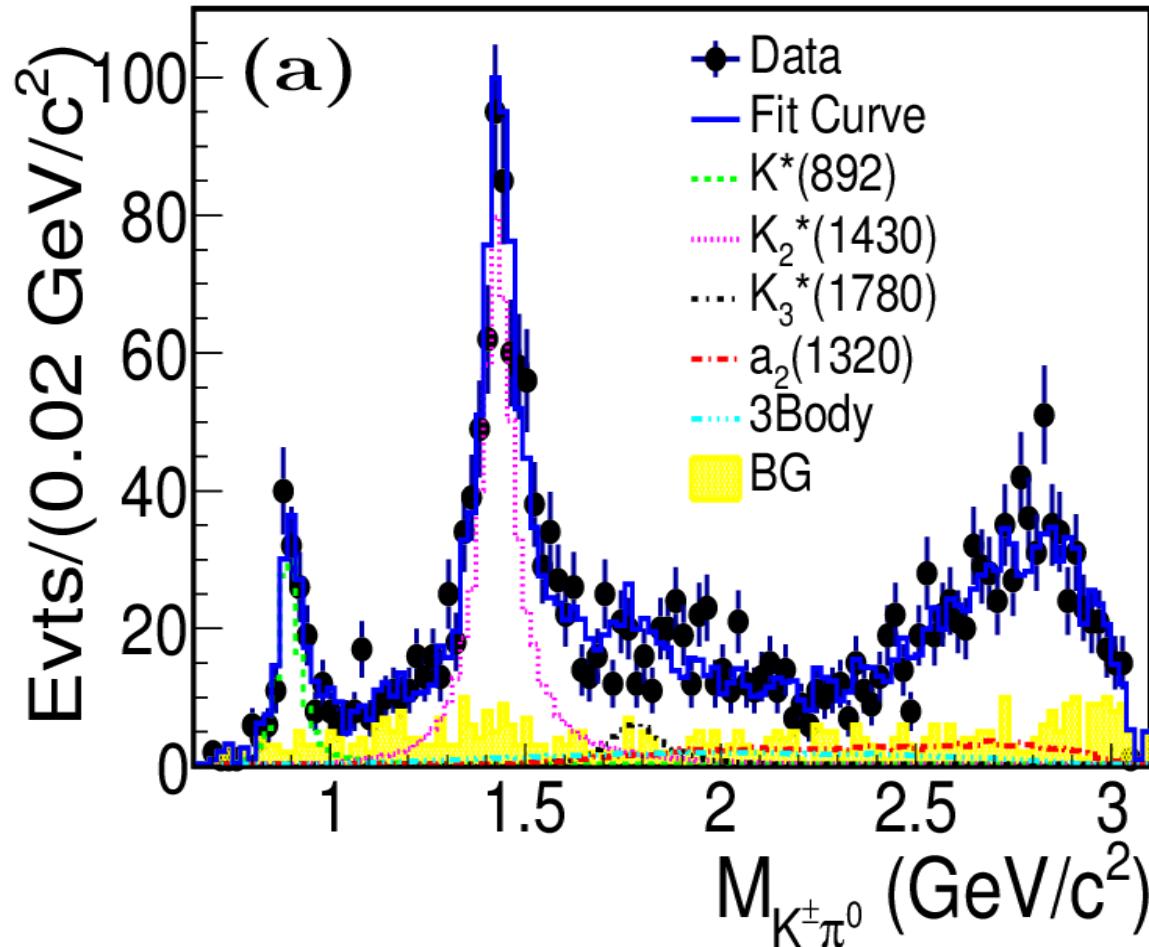
c : modeled with a non-resonance contribution of $K\pi$
or KK system with a certain spin-parity.

PWA of $\chi_{c2} \rightarrow K\bar{K}\pi$

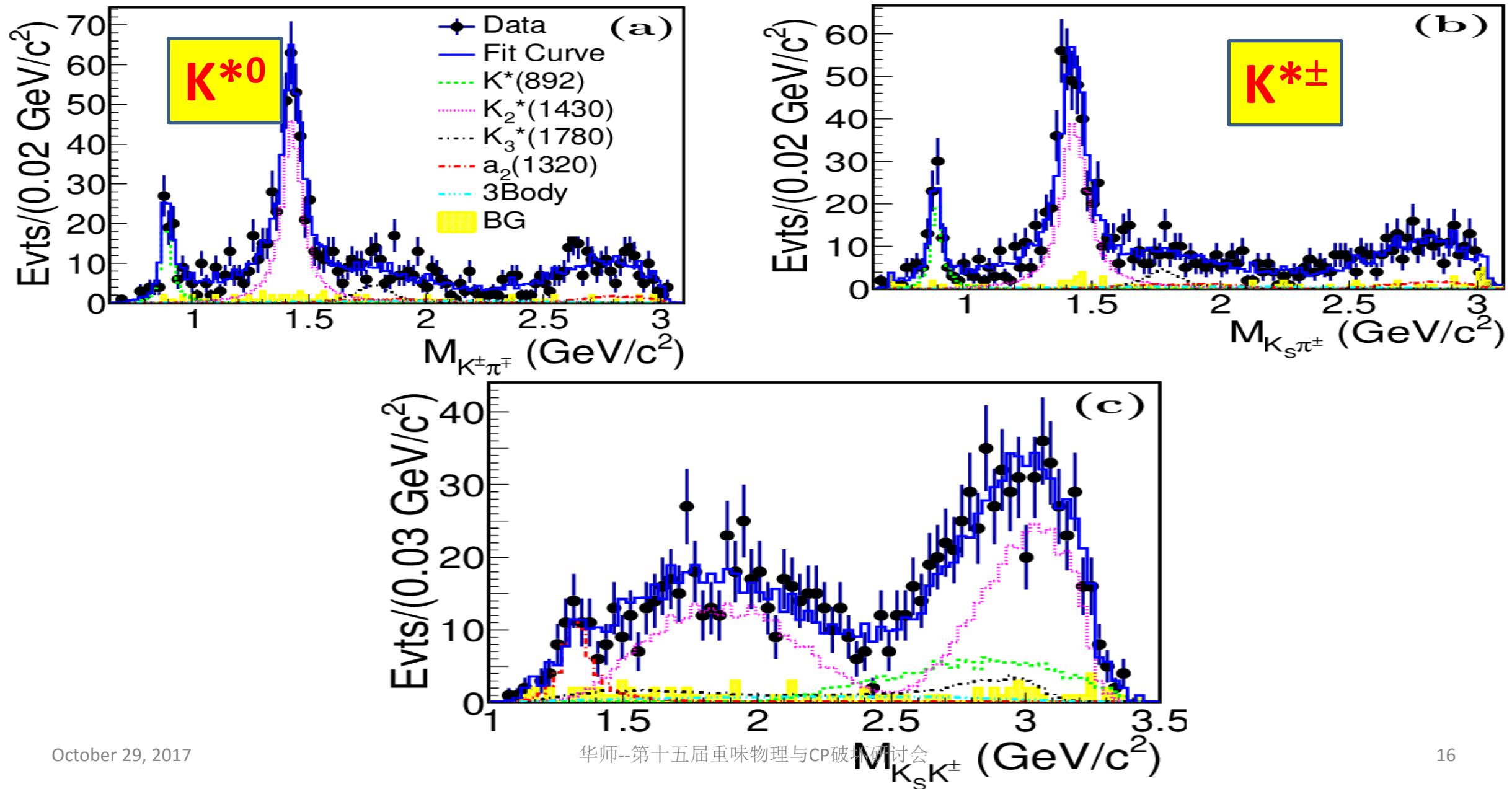
Baseline solution:

- **($K\pi$)-system :** $K^*(892)$, $K_2^*(1430)$
- **(KK)-system :** $a_2(1320)$
- $K_3^*(1780)$, $K^*(1410)$, $K^*(1680)$

Data ($\chi_{c2} \rightarrow K^+ K^- \pi^0$)



Data ($\chi_{c2} \rightarrow K_s K^\pm \pi^\mp$)



Branching Fractions: $\chi_{c2} \rightarrow (K\pi)\bar{K}, (K\bar{K})\pi,$

Mode	$K^+K^-\pi^0$	$K_SK^\pm\pi^\mp$	Combined
$K^*\pm K^\mp$	$1.8 \pm 0.2 \pm 0.2$	$1.4 \pm 0.2 \pm 0.2$	$1.5 \pm 0.1 \pm 0.2$
$K^{*0}\bar{K}^0$	—	$1.3 \pm 0.2 \pm 0.2$	—
$K_2^*\pm K^\mp$	$18.2 \pm 0.8 \pm 1.6$	$13.6 \pm 0.8 \pm 1.4$	$15.5 \pm 0.6 \pm 1.2$
$K_2^{*0}\bar{K}^0$	—	$13.0 \pm 1.0 \pm 1.5$	—
$K_3^*\pm K^\mp$	$5.3 \pm 0.5 \pm 0.9$	$5.9 \pm 1.1 \pm 1.5$	$5.4 \pm 0.5 \pm 0.7$
$K_3^{*0}\bar{K}^0$	—	$5.9 \pm 1.6 \pm 1.5$	—
$a_2^0\pi^0$	$13.5 \pm 1.6 \pm 3.2$	—	—
$a_2^\pm\pi^\mp$	—	$18.4 \pm 3.3 \pm 5.5$	—

The Ratio of Helicity Amplitude

pQCD leading twist accuracy:

$$Br_{J_c\bar{c}(\lambda) \rightarrow h_1(\lambda_1)h_2(\lambda_2)} \sim \left(\frac{\Lambda_{QCD}^2}{m_c^2} \right)^{|\lambda_1 + \lambda_2|+2}$$

$$(\Lambda_{QCD} \sim 0.2 \text{GeV}/c^2, m_c \sim 1.5 \text{GeV}/c^2)$$

The Ratio of Helicity Amplitude

TABLE II. The measured ratios of helicity amplitude squared $|F_{2,0}|^2/|F_{1,0}|^2$, where the uncertainties are statistical only.

	$K^+K^-\pi^0$	$K_SK^\pm\pi^\mp$	
	Charged K^*	Charged K^*	Neutral K^*
$K_2^*(1430)$	0.046 ± 0.001	0.042 ± 0.019	0.031 ± 0.018

Our result implies the $F_{1,0}$ is the dominance in the transition amplitudes.

The Ratio of Helicity Amplitude

- $\text{Br} \sim \begin{cases} \left(\frac{\Lambda_{QCD}}{m_c}\right)^6, & HSR \text{ Violation } (K^*\bar{K}) \\ \left(\frac{\Lambda_{QCD}}{m_c}\right)^4, & HSR \text{ Conservation } (VV) \end{cases}$
- $\frac{Br_{sup.}}{Br_{cons.}} \sim \left(\frac{\Lambda_{QCD}}{m_c}\right)^2 \sim 0.02$
 $(\Lambda_{QCD} \sim 0.2 \text{GeV}/c^2, m_c \sim 1.5 \text{GeV}/c^2)$

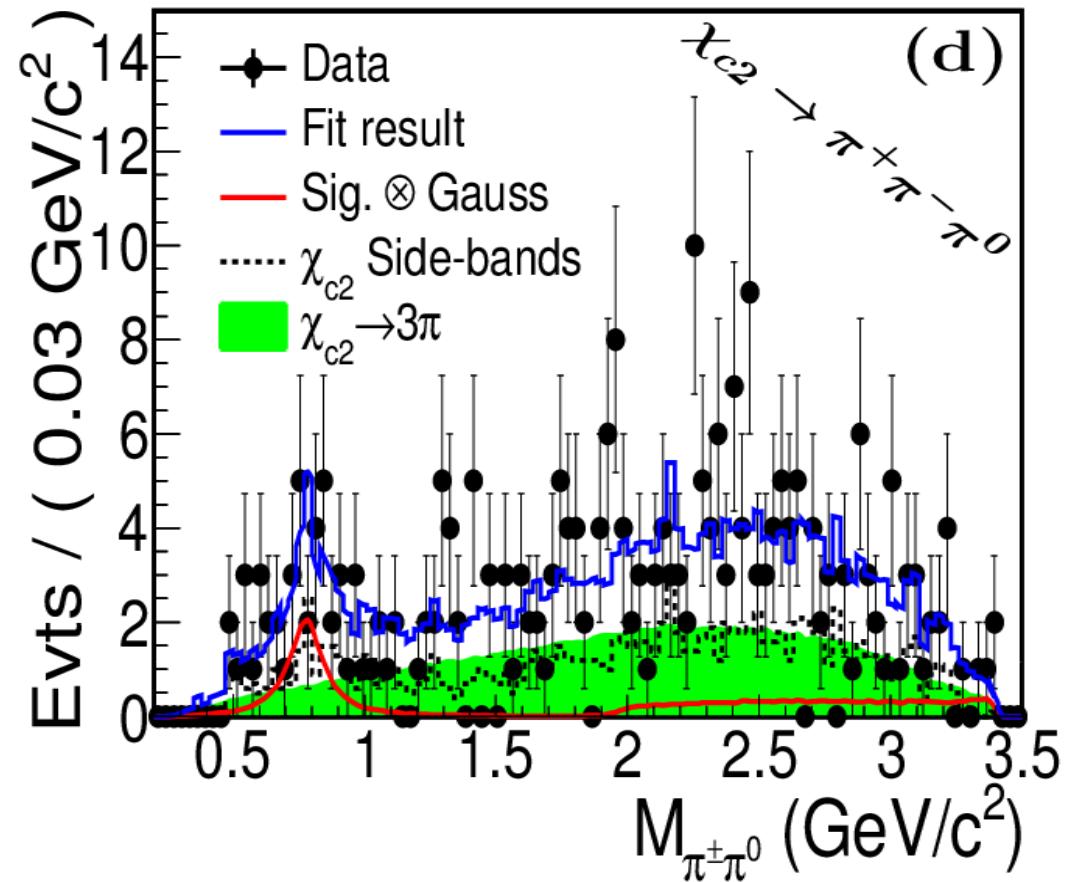
The Ratio of Helicity Amplitude

However, the measured Br of $\chi_{c2} \rightarrow K_2^* \bar{K}$
appears to be the same order of magnitude as that for
 $\chi_{c2} \rightarrow VV$

Fit results & Calculation of the $\text{Br}(\chi_{c2} \rightarrow \rho^\pm \pi^\mp)$

Binned Fit

- ρ : MC signal shape \otimes Gauss
- Background: $\chi_{c2} \rightarrow 3\pi$ MC shape
- $N\rho = 14.7 \pm 8.9$
- Significance of ρ : 2.8σ
- $N_{3\pi} = 63.6 \pm 13.0$



Fit results & Calculation of the $\text{Br}(\chi_{c2} \rightarrow \rho^\pm \pi^\mp)$

- $\text{Br}(\chi_{c2} \rightarrow \rho^+ \pi^- + \text{c.c.}) = \frac{N_\rho}{N_{\psi'} \cdot \varepsilon \cdot \text{Br}(\psi' \rightarrow \gamma \chi_{c2}) \cdot \text{Br}(\rho^\pm \rightarrow \pi^\pm \pi^0) \cdot \text{Br}(\pi^0 \rightarrow \gamma \gamma)}$
 $= (6.4 \pm 3.9 \pm 0.7) \times 10^{-6}$
 $< 1.1 \times 10^{-5}$
- $\varepsilon = 5.7\%$
- $N_{\psi'} = (448.1 \pm 2.9) \times 10^6$
- $\text{Br}(\psi' \rightarrow \gamma \chi_{c2}) = (9.11 \pm 0.31)\%$
- $\text{Br}(\rho \rightarrow \pi \pi) \sim 100\%$
- $\text{Br}(\pi^0 \rightarrow \gamma \gamma) = (98.823 \pm 0.034)\%$

Summary

Br (x10 ⁻⁵)	$\rho^+\pi^- + \text{C.C.}$	$K^*(892)^0 \bar{K}^0$	$K^*(892)^\pm K^\mp$
Meson Loop	(1.2~2.0)x10 ⁻²	4.0~6.7	4.0~6.7
BESIII	0.64±0.39±0.07 <1.1 (90% C.L.)	13±2±2	15±1±2

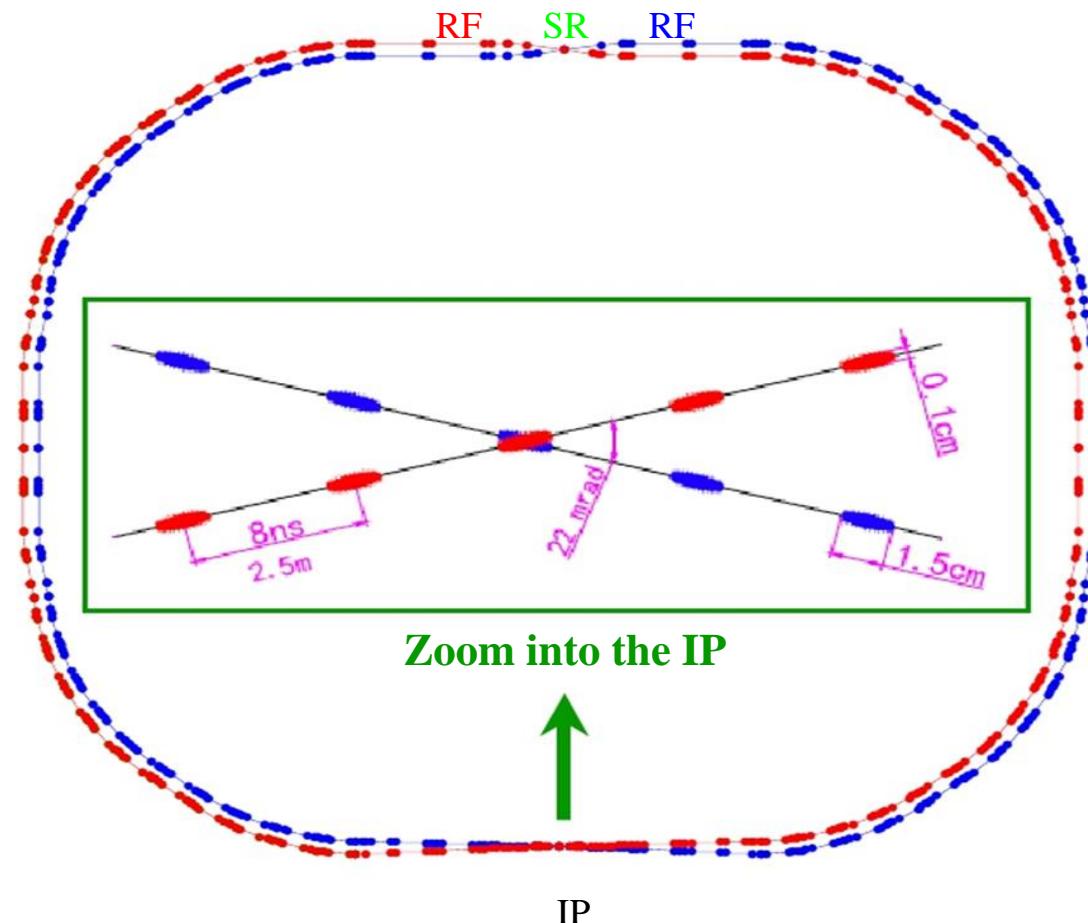
Summary

- $\text{Br}(\chi_{c2} \rightarrow K^*(892) \bar{K}) \sim 10^* \text{Br}(\chi_{c2} \rightarrow \rho^\pm \pi^\mp)$
- $\text{Br}(\chi_{c2} \rightarrow K^*(892) \bar{K})$ are rather sizeable with respect to those of the HSR conserving decay $\chi_{c2} \rightarrow VV$
- HSR violation in $\chi_{c2} \rightarrow K^*(892) \bar{K}$ occurs via the intermediate meson loops due to the large U-spin symmetry breaking, while that in $\chi_{c2} \rightarrow \rho^\pm \pi^\mp$ is due to isospin symmetry breaking
- Due to the large mass difference between s and u/d quarks, the U-spin symmetry is broken more severely in comparison with isospin symmetry

Thanks for your attention

BEPCII

Two-ring, large crossing angle, multi-bunch, high-current



- Design -

Beam energy:

1 - 2.3 GeV

Luminosity:

$1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1}$

Optimum energy:

1.89 GeV

Energy spread:

5.16×10^{-4}

No. of bunches:

93

Bunch length:

1.5 cm

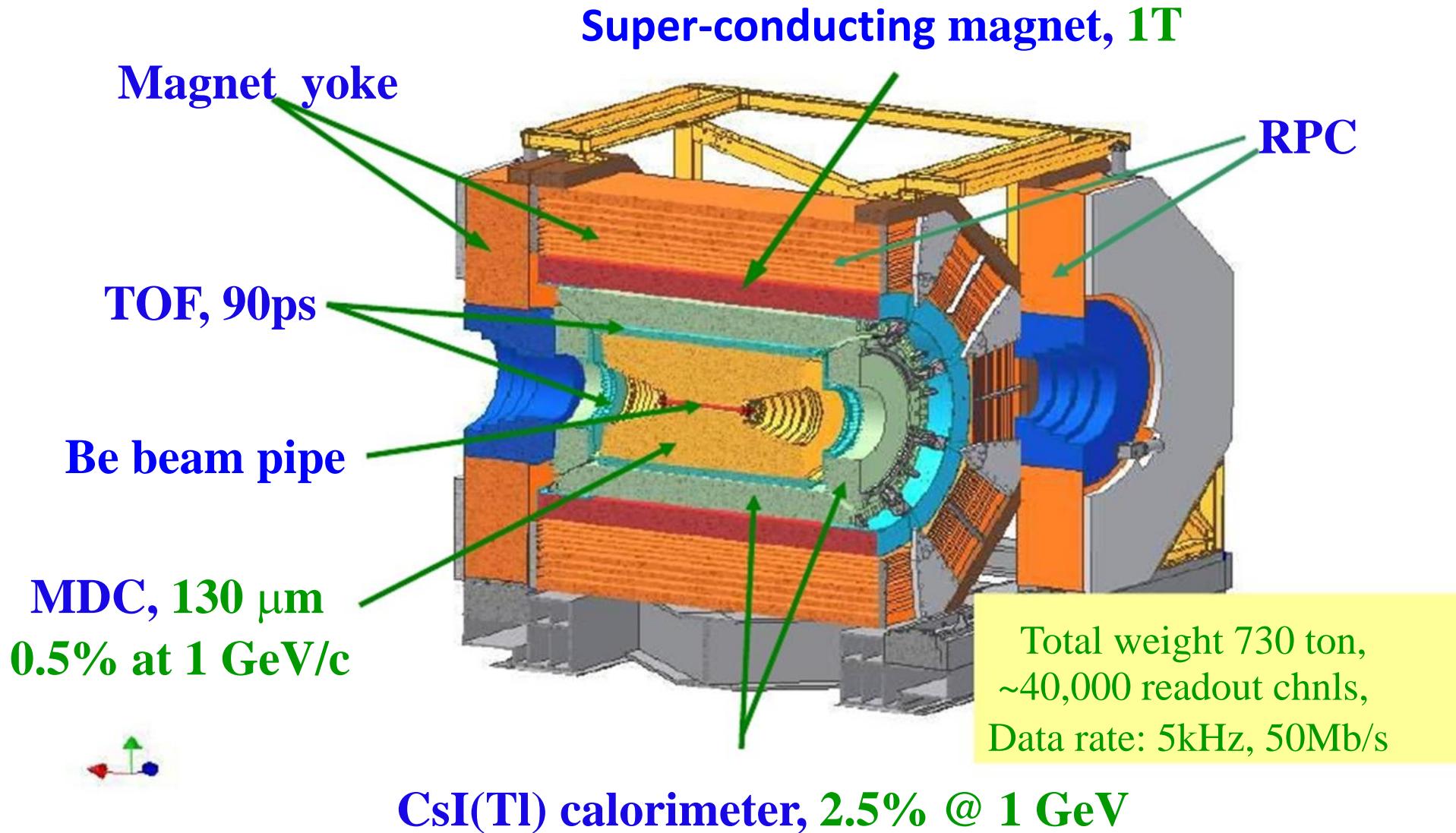
Total current:

0.91 A

SR mode:

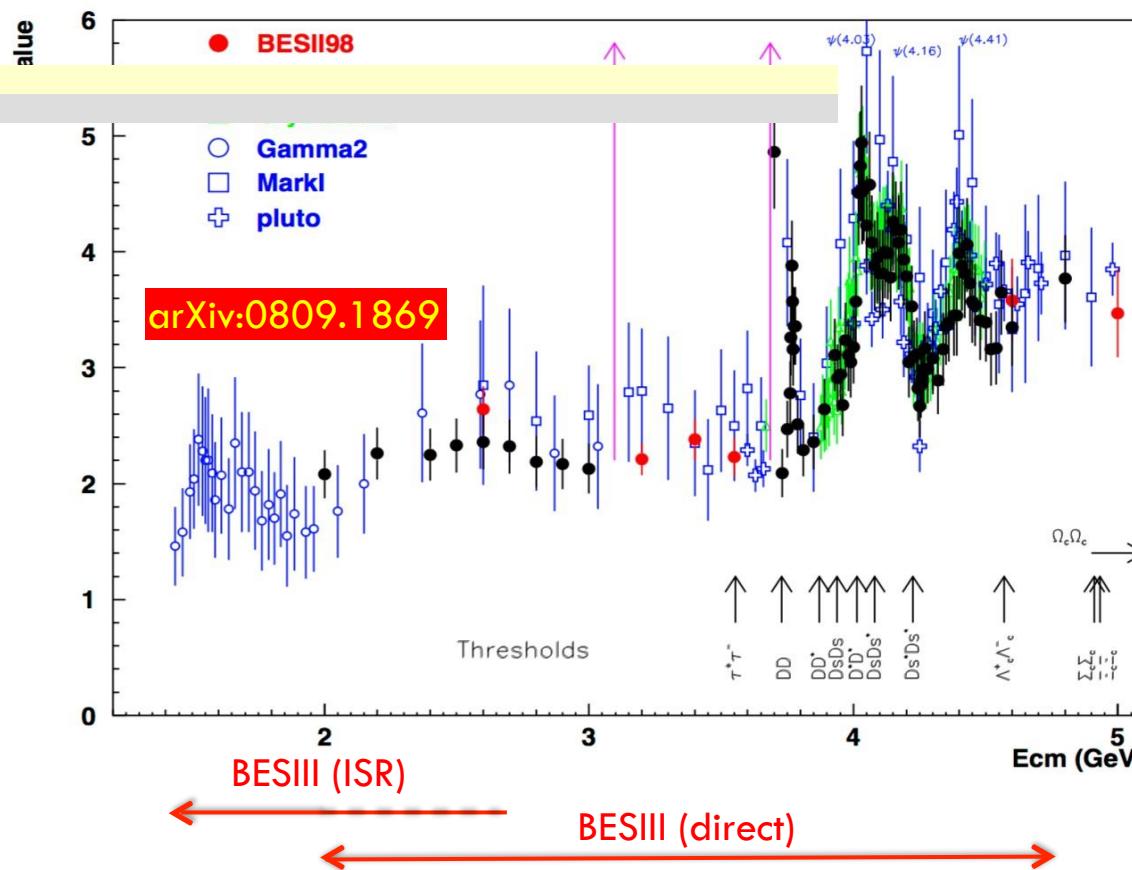
0.25A @ 2.5 GeV

BESIII Spectrometer



BESIII started data taking for physics since 2009

- ✓ $1.3 \times 10^9 J/\psi$
- ✓ $5 \times 10^8 \psi(2S)$
- ✓ 2.9 fb^{-1} @ ψ_{3770}
- ✓ 0.5 fb^{-1} @ ψ_{4040}
- ✓ 2.3 fb^{-1} @ $4230/4260 \text{ MeV}$
- ✓ 0.5 fb^{-1} @ 4360 MeV
- ✓ 0.5 fb^{-1} @ 4600 MeV
- ✓ 1 fb^{-1} @ ψ_{4415}
- ✓ 0.1 fb^{-1} @ $4470/4530 \text{ MeV}$
- ✓ 0.04 fb^{-1} around Λ_c threshold
- ✓ 1 fb^{-1} @ 4420 MeV
- ✓ R scan:
 - 2-3 GeV, 19 points, $\sim 0.5 \text{ fb}^{-1}$
 - 3.85-4.59 GeV, 104 points, $\sim 0.8 \text{ fb}^{-1}$
- ✓ 0.1 fb^{-1} data @ 2.125 GeV
- ✓ 3.1 fb^{-1} data at 4.18 GeV



MORE: Data Taking Plan

- 3554 MeV 24 pb^{-1} τ mass; 4100-4400 MeV 0.5 fb^{-1} coarse scan
- On-going data taking, χ_{c1} , $X(3872)$, ...