Searching for $e^+e^- \to \psi' + c\bar{c}$ at $\sqrt{s}$ = 10.58 GeV in Belle and BelleII

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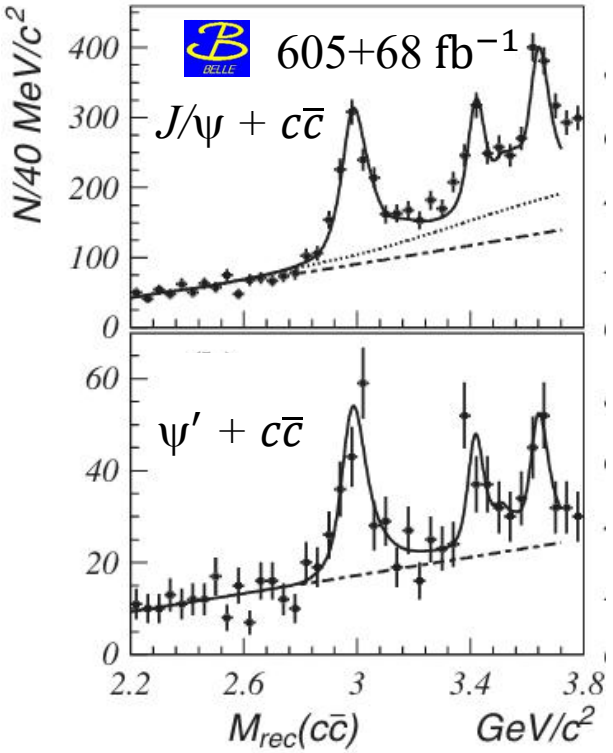
Outline

Motivation

- The production of double charmonium is one of the simplest exclusive processes in perturbative QCD calculations. Measuring its cross section helps us test the predictions of non-relativistic QCD (NRQCD).

- In 2007 and 2009, the Belle experiment measured the cross section of the process $e^+e^- \to J/\psi + c\bar{c}$. However, no cross section measurement has yet been reported for the $e^+e^- \to \psi' + c\bar{c}$.

- Our work aims to provide a precise measurement of $e^+ e^- \to \psi' + c\bar{c}$ by utilizing the larger data sample from Belle and the new data from Belle II.



This work only provides the number of events for $e^+e^- \to \psi' + c\bar{c}$

Analysis Method

1、Measure the cross section when the $c\bar{c}$ forms charmonium state.

According to previous studies, the $c\bar{c}$ forms the following charmonium state:

$$\begin{cases} e^+e^- \to \psi' + \eta_c \\ e^+e^- \to \psi' + \chi_{c0} \\ e^+e^- \to \psi' + \eta_c(2S) \end{cases}$$

We will use more decay modes if there is anything new!

1.1 Fully reconstruct the ψ'

1.2 Search the charmonium state on the recoil mass spectrum.

$$\mathrm{M_{rec}}(\psi') = \sqrt{(\mathrm{E_{C.M.}} - \mathrm{E}_{\psi'})^2 - (\vec{\mathrm{P}}_{\mathrm{C.M.}} - \vec{\mathrm{P}}_{\psi'})^2} \Rightarrow c\bar{c}$$

2、Require the production of a *D* meson and search for the accompanying *D* recoiling against the $\psi' D$ system.

MC and Data samples$_{Belle}$

- **Belle**
- **MC simulations Events**
- signal MC(used Phokara and EvtGen to generate signal)

1、$e^+e^- \to \psi' + \eta_c$(HELAMP 1 0 0 0 -1 0), 5 * 10^5 events

2、$e^+e^- \to \psi' + \chi_{c0}$ (PHSP), 5 * 10^5 events

3、$e^+e^- \to \psi' + \eta_c(2S)$ (HELAMP 1 0 0 0 -1 0), 5 * 10^5 events

- Generic MC (6 times as real data samples) at $\sqrt{s}$ = 10.58 GeV.

- **Data samples**
- Use HadronB(J) data samples at $\sqrt{s}$ = 10.58 GeV(711 fb^{-1}) and $\sqrt{s}$ = 10.52 GeV(100 fb^{-1})

MC and Data samples $_{Belle\ II}$

- **Belle II**
- **MC simulations Events**
- signal MC(used Phokara and EvtGen to generate signal)

1、$e^+e^- \to \psi' + \eta_c$(HELAMP 1 0 0 0 -1 0), 1 * 10^5 events

2、$e^+e^- \to \psi' + \chi_{c0}$ (PHSP), 1 * 10^5 events

3、$e^+e^- \to \psi' + \eta_c(2S)$ (HELAMP 1 0 0 0 -1 0), 1 * 10^5 events

- Generic MC (MC15_rundependent) at $\sqrt{s}$ = 10.58 GeV .

- **Data samples**
- Use CharmoniumPsi data samples $\sqrt{s}$ = 10.58 GeV(361.65 fb^{-1})

Decay modes

- ψ' candidate are reconstructed via the decay to $J/\psi\ \pi^+\ \pi^-$
- J/ψ candidates are reconstructed via the l^+l^-

$$e^+\ e^- \longrightarrow \psi' + c\bar{c}\ (\eta_c/\chi_{c0}/\eta_c(2S))$$
$$\hookrightarrow J/\psi\ \pi^+\ \pi^-$$
$$\hookrightarrow e^+\ e^-$$
$$\hookrightarrow \mu^+\ \mu^-$$

- Whether to include the process of ψ' decaying into lepton pairs will be considered later based on the number of the background.

Selection in Belle and BelleII

For e, μ, π candidates

1、Pions: $\frac{\mathcal{L}(K)}{\mathcal{L}(K)+\mathcal{L}(\pi)} < 0.4$

2、dr<2 cm and |dz|<4.0 cm.

3、PID Selection

3.1、eIDBelle > 0.01 and muIDBelle > 0.1 in Belle

3.2、electronID_noSVD_noTOP > 0.01 and muonID_noSVD > 0.1 in Belle II.

4、CorrectBrems, angleThreshold = 0.05.

For ψ′, J/ψ candidates

1、TreeFit and Mass Constraint for ψ', J/ψ , Update the momentum of the daughter particles, all candidates are retained.

Events

1、ChargeTracks (dr<2 cm and |dz|<4.0 cm and charge = 1) > 4

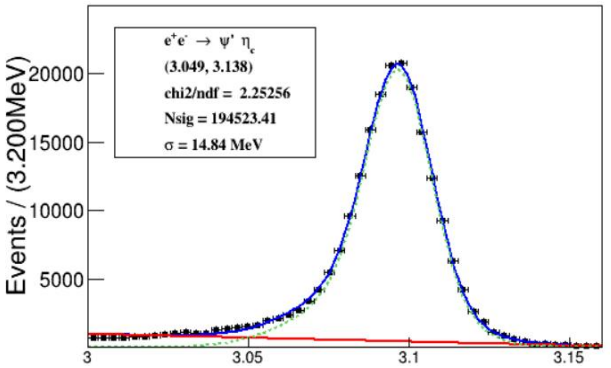
Best Candidate

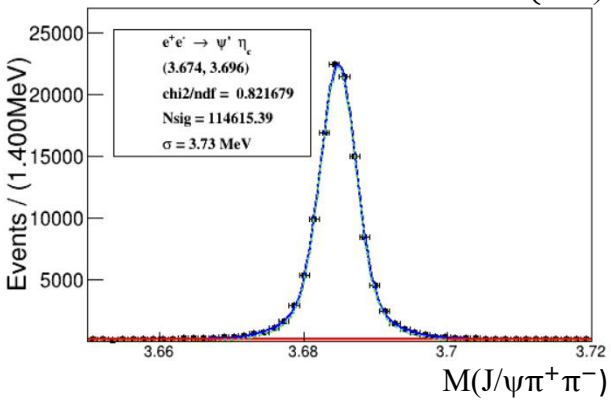
1、Select ψ' candidates with the invariant mass closest to 3.686 GeV/c²

J/ψ, ψ' distribution in Belle

Fit Signal MC to get the signal region

Double Gaussian function as Signal
Second Order polynomials as Background
about $\pm 3\sigma$ signal region
The J/ψ, ψ' distribution is same for different $c\bar{c}$



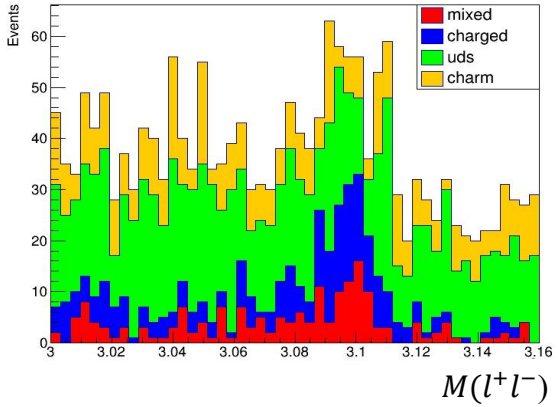


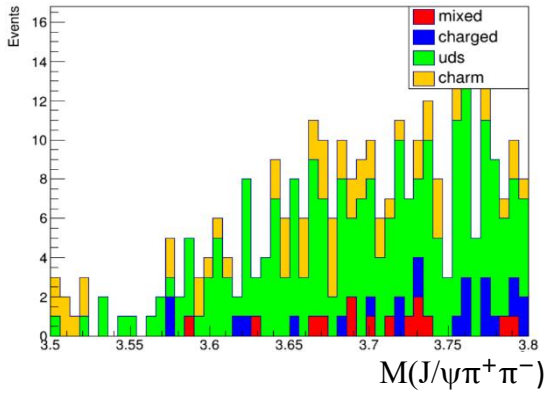
$|M_{l^+l^-} - M_{J/\psi}| < 50\ \mathrm{MeV/c^2}$

$|M_{J/\psi\pi^+\pi^-} - M_{\psi'}| < 10\ \mathrm{MeV/c^2}$

The distribution of ψ' has subtracted the resolution of J/ψ.

Generic MC





The main background comes from $q\bar{q}$

No peaking in $M(J/\psi\pi^+\pi^-)$ distribution !

J/ψ, ψ' distribution in Belle II

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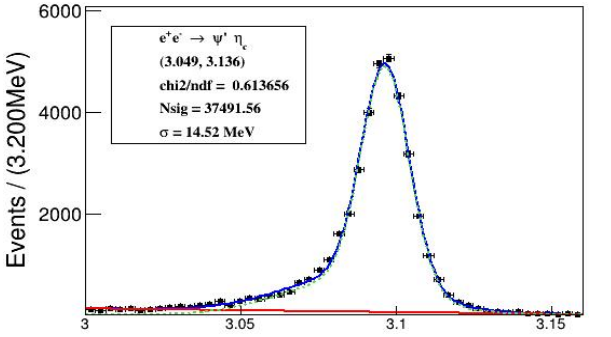

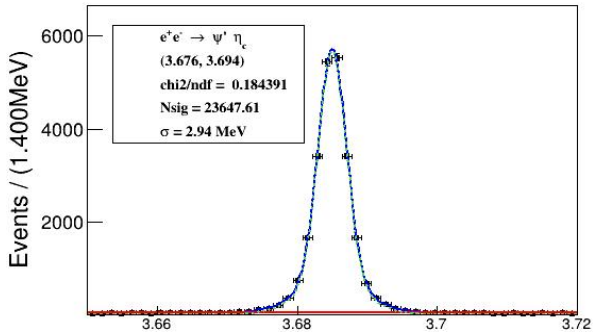

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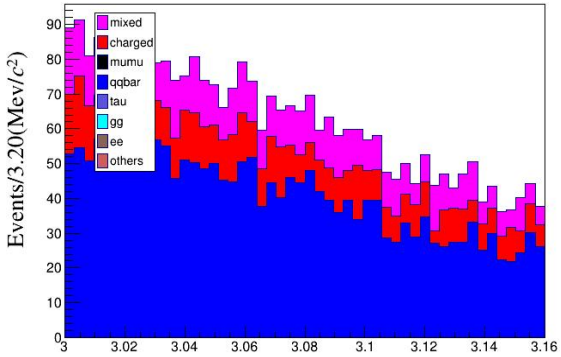

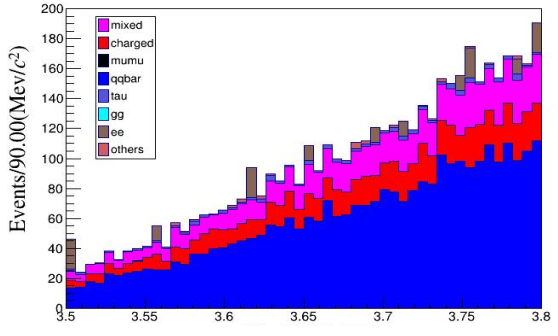

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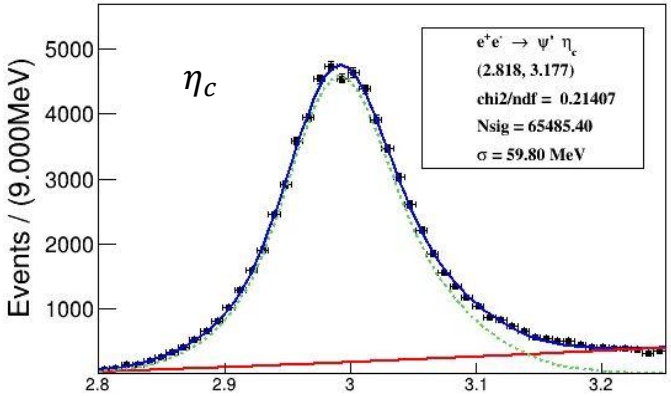
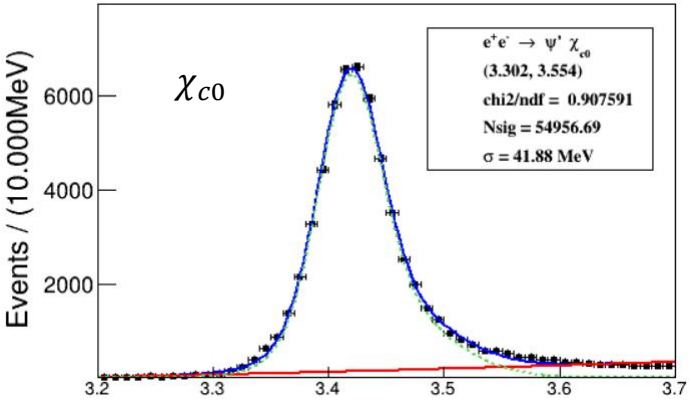
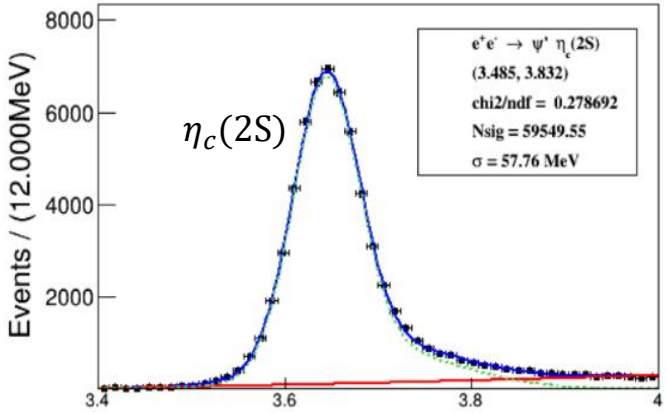
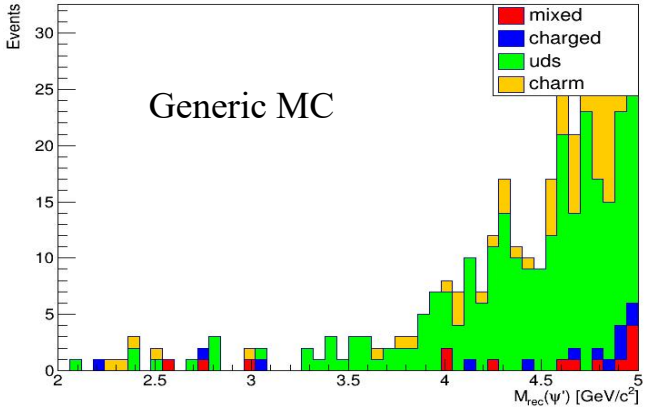
Recoil Mass Spectrum in Belle



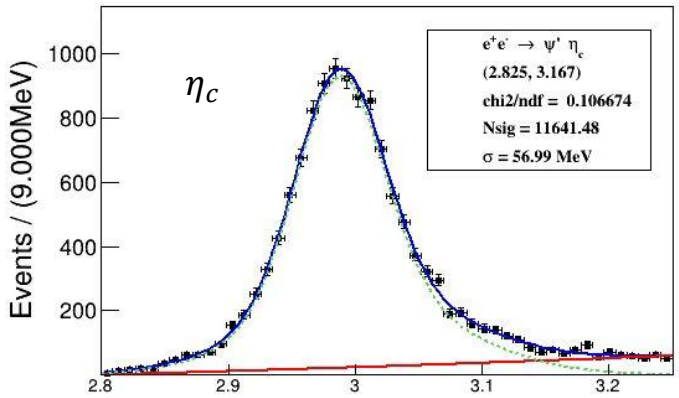


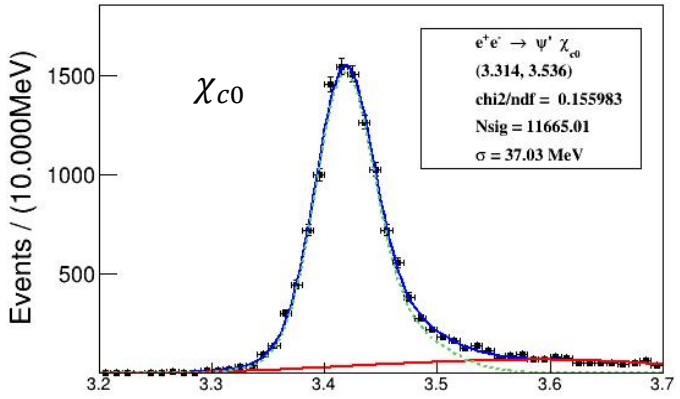


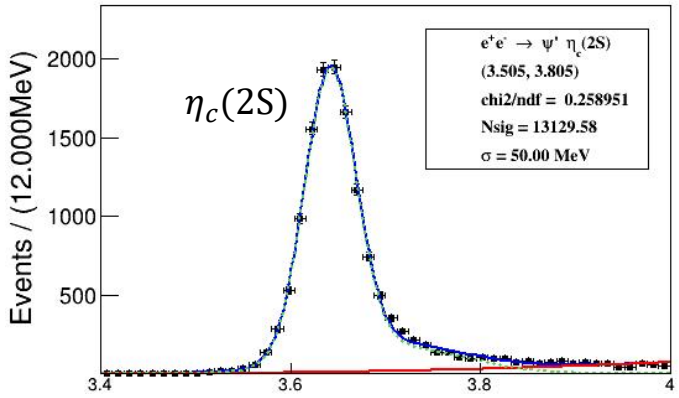


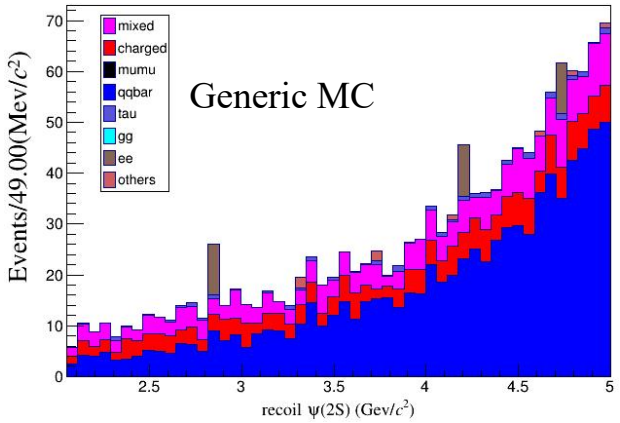
No peaking

Recoil Mass Spectrum in Belle II







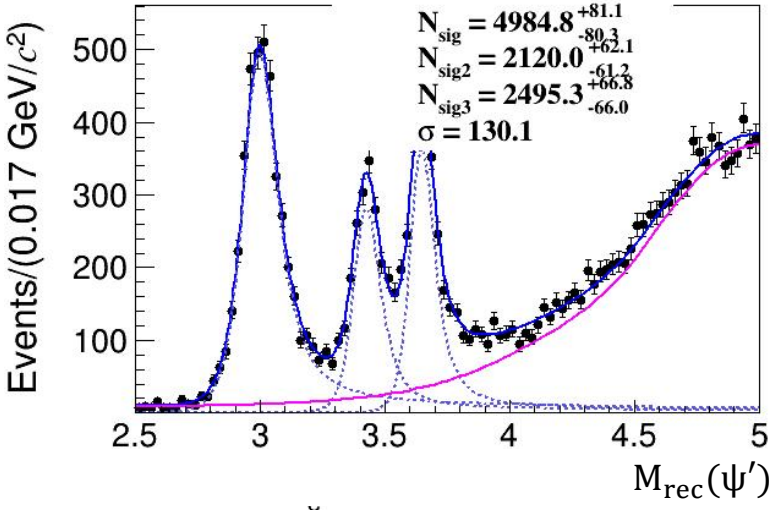


Decay Modes	Efficiency(Belle)	Efficiency(BelleII)
$e^+e^- \to \psi' + \eta_c$	14.02%	12.18%
$e^+e^- \to \psi' + \chi_{c0}$	13.72%	12.20%
$e^+e^- \to \psi' + \eta_c(2S)$	13.11%	13.73%

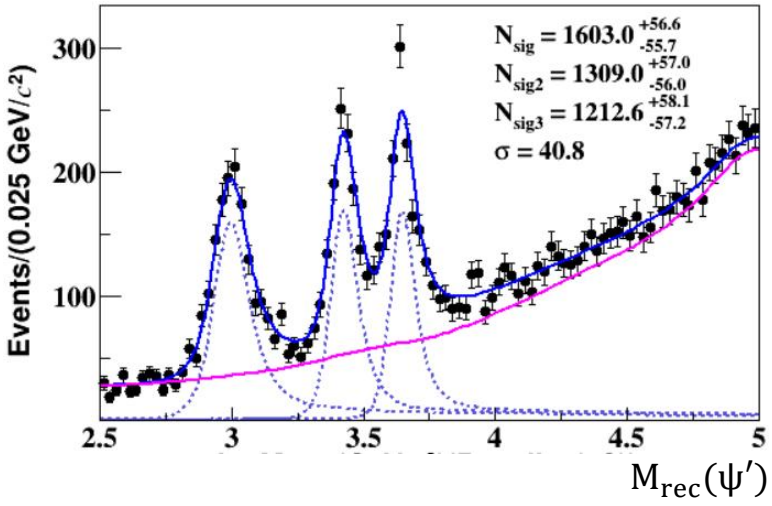
ToyMC

Use PDF to generate the ToyMC and do I/O check

Belle



BelleII



Generate ToyMC(Just one example)

Sig : Signal MC
Bkg : Generic MC
Belle Input : η_c: 5000 χ_{c0}: 2000 $\eta_c(2S)$: 2600
BelleII Input : η_c: 1614 χ_{c0}: 1262 $\eta_c(2S)$: 1183

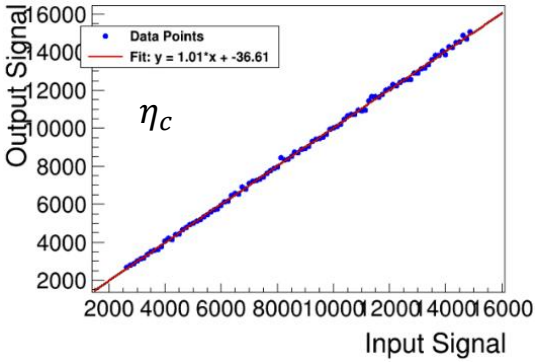
Fitting

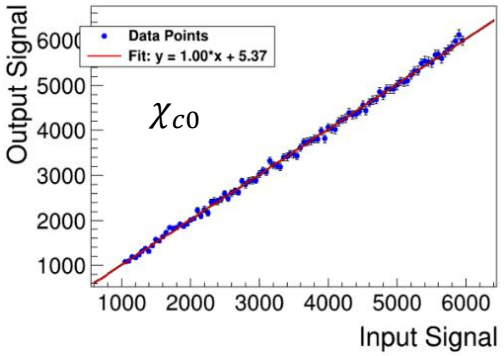
Sig : Signal MC shape
Bkg : Generic MC shape

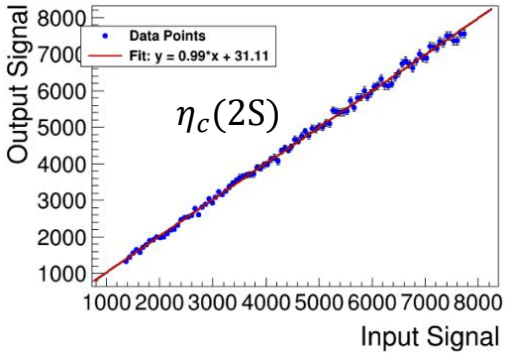
I/O check

x-axis represents the number of input events
y-axis represents the number of fitted events

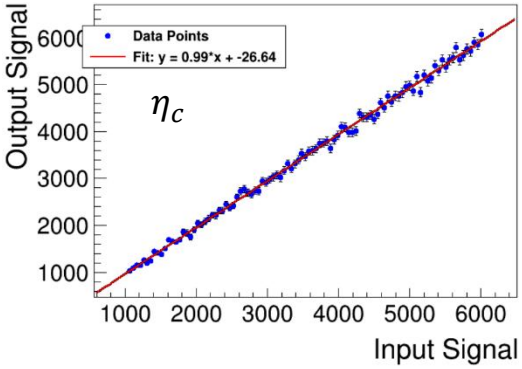
Belle

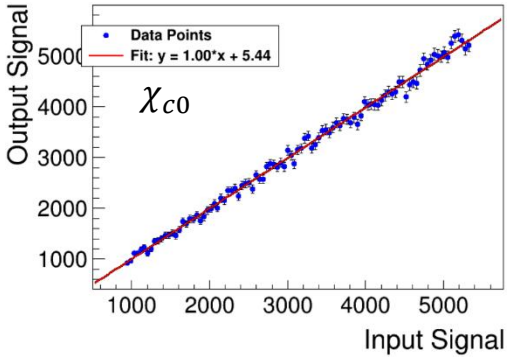


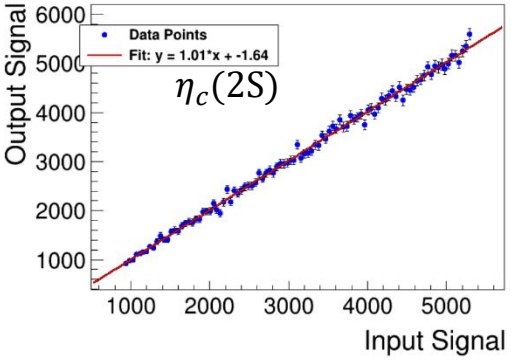




BelleII







The input and output can be matched!

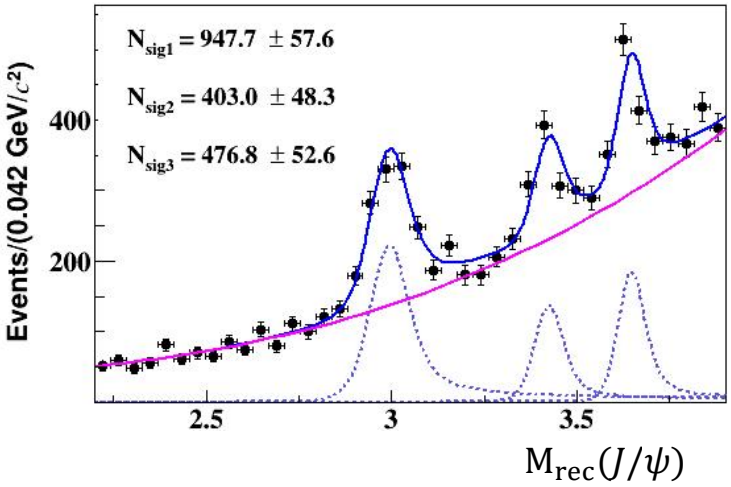
Data

To verify the correctness of the work:

1、Under unchanged selection criteria, a preliminary measurement of the signal event yield in the $e^+e^- \to J/\psi + c\bar{c}$ process was conducted.

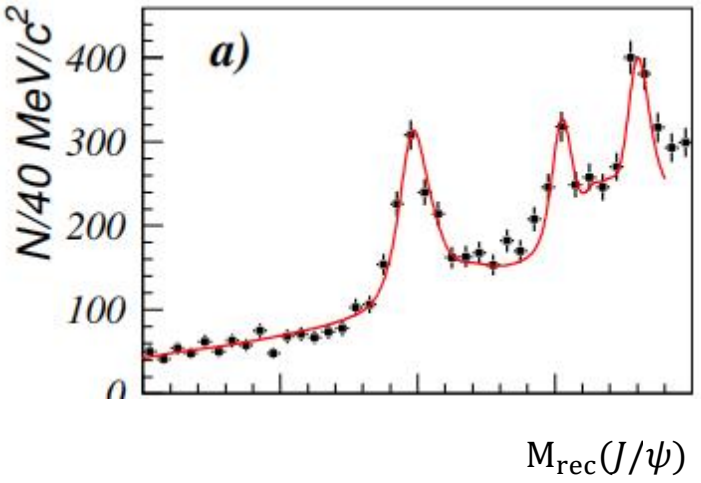
2、The results were directly compared with those reported in prior work (in Belle).

Fitting result for our work



Use Belle $\Upsilon(4S)$ Data ($711 fb^{-1}$)

Published work



Use Belle $\Upsilon(4S)$ and continuum Data ($673 fb^{-1}$)

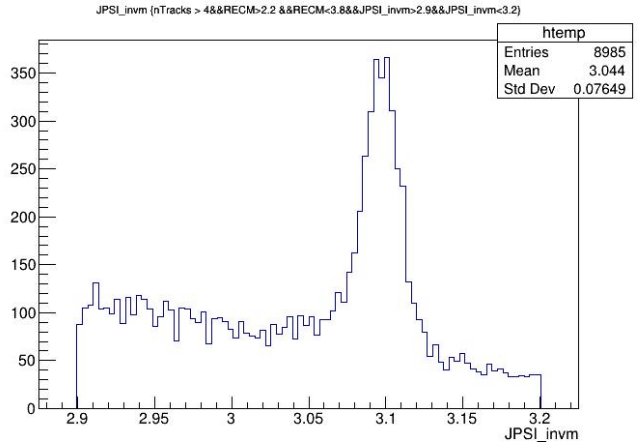
Decay modes	η_c	χ_{c0}	$\eta_c(2S)$
Our work	947 ± 58	403 ± 48	477 ± 53
Published work	1032 ± 62	525 ± 54	679 ± 63

The event yields are in close agreement

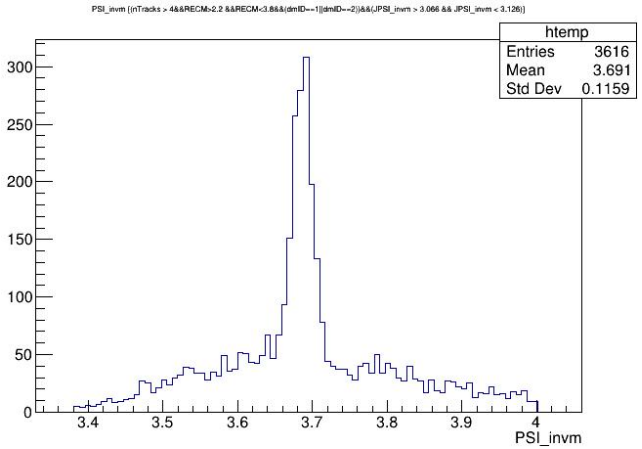
Data

Belle $\Upsilon(4S)$ Data : 711[fb^{-1}]
Belle II $\Upsilon(4S)$ Data : 361.65 [fb^{-1}]

Belle

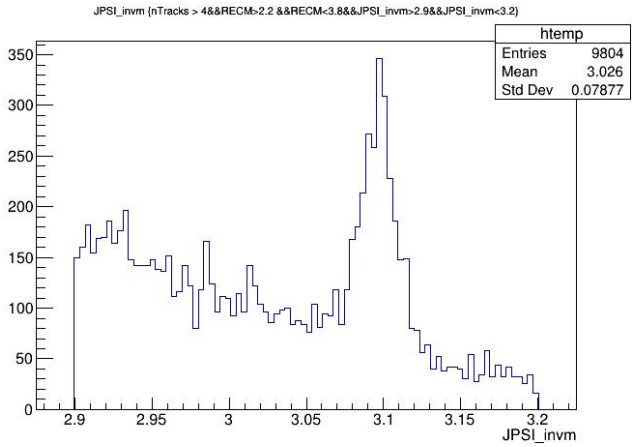


$M(l^+l^-)$



$M(\mathrm{J}/\psi\pi^+\pi^-)$

BelleII



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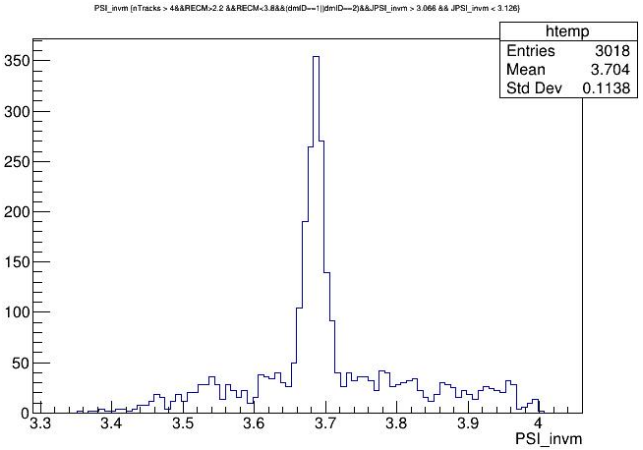
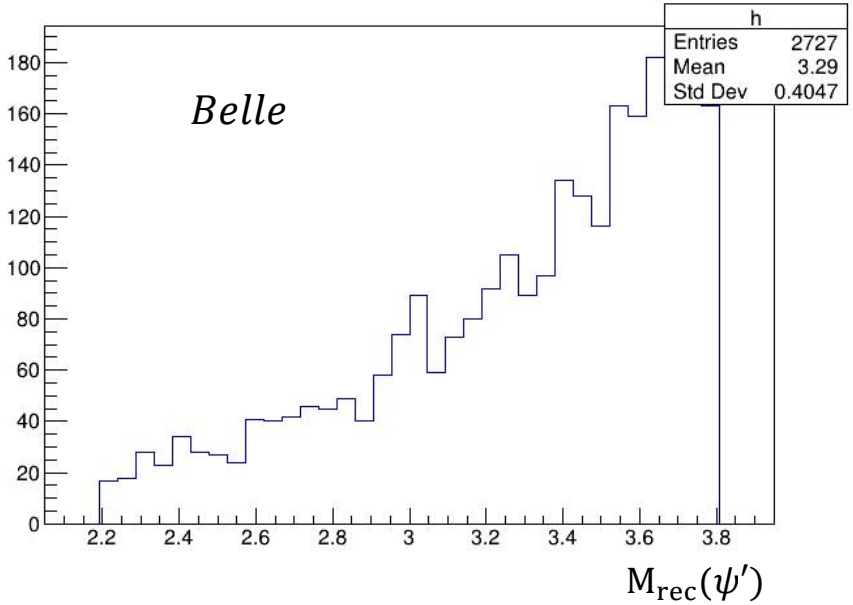


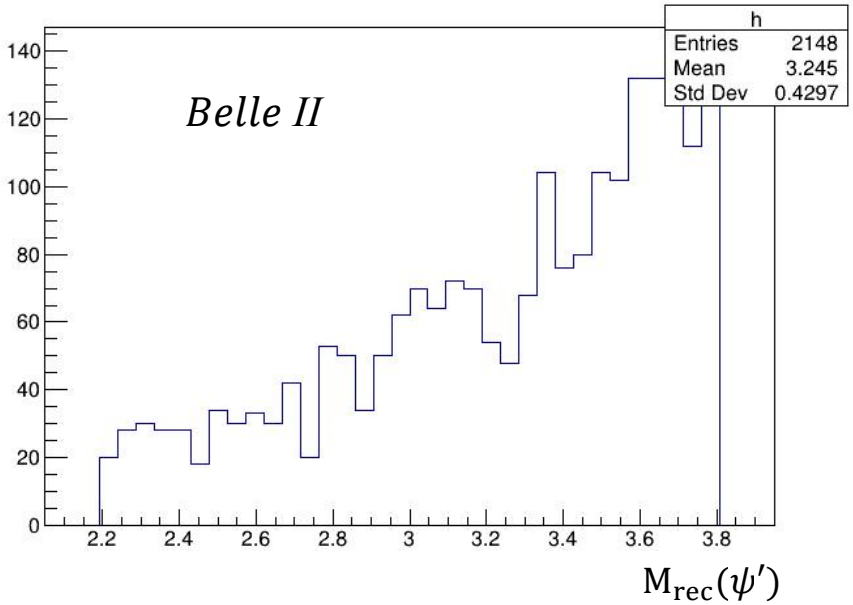
$M(\mathrm{J}/\psi\pi^+\pi^-)$

Sideband

Belle $\Upsilon(4S)$ Data : $711[\mathrm{fb}^{-1}]$
Belle II $\Upsilon(4S)$ Data : $361.65\ [\mathrm{fb}^{-1}]$

$\mathrm{M}_{\mathrm{rec}}(\psi')$ in $M(\psi')$ sideband
$M(\psi') < 3.58$ or $M(\psi') > 3.78$





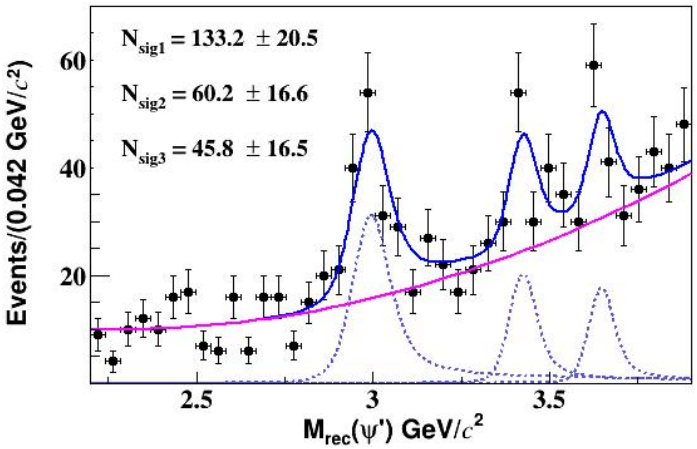
No peaking !

Data

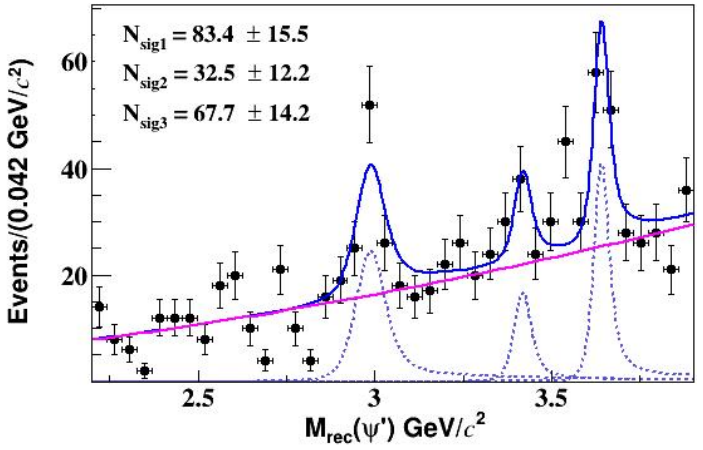
Belle $\Upsilon(4S)$ Data : $711[\text{fb}^{-1}]$
Belle II $\Upsilon(4S)$ Data : $361.65\ [\text{fb}^{-1}]$

MC Shape as signal function
Second Order polynomials as Background
Fitting range: [2.2,3.9]

Belle Data



Belle II Data

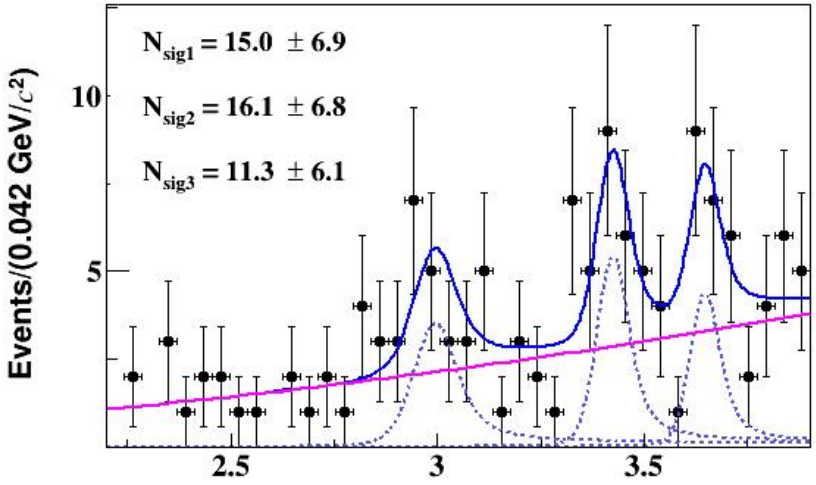


Decay modes	η_c	χ_{c0}	$\eta_c(2S)$
Belle σ（fb）	39.0 ± 6.0	16.5 ± 4.6	11.8 ± 4.2
Belle II σ（fb）	55.2 ± 10.1	17.5 ± 6.9	38.6 ± 8.4

Data

Belle *continuum* Data ：$\approx 100[\mathrm{fb}^{-1}]$

MC Shape as signal function
Second Order polynomials as Background
Fitting range: [2.2,3.9]



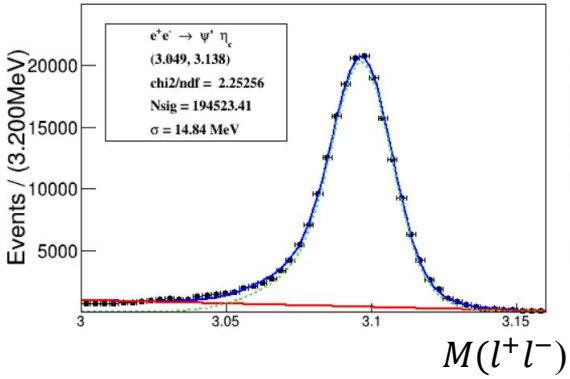
Decay modes	η_c	χ_{c0}	$\eta_c(2S)$
Belle σ（fb）	31.3 ± 14.4	31.4 ± 10.3	20.7 ± 11.2

Thank you !

Signal MC in Belle

Fit to get the signal region

Double Gaussian function as Signal
Second Order polynomials as Background
about ±3σ signal region



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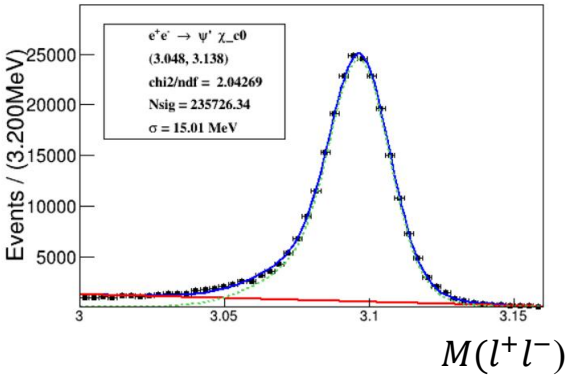

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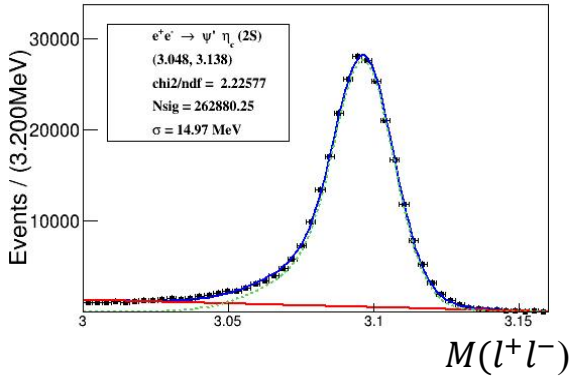

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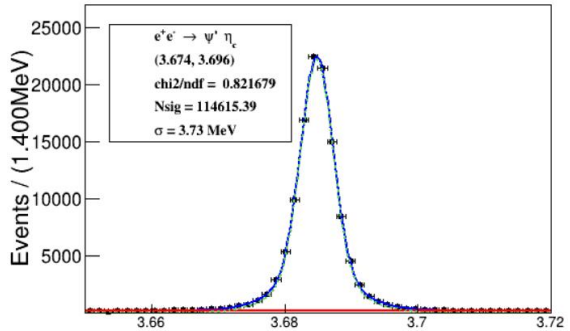
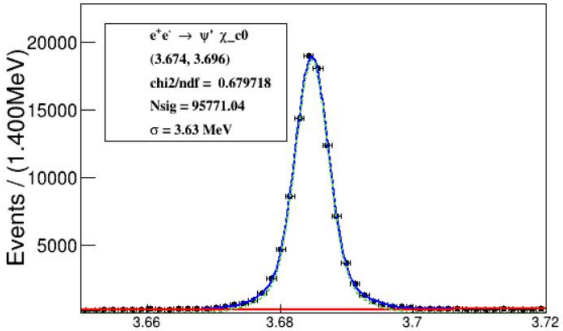
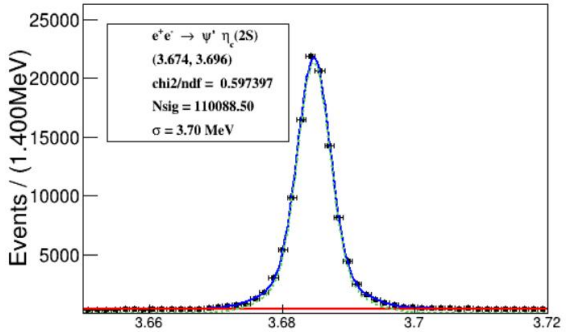


$M(J/\psi\pi^+\pi^-)$



$M(J/\psi\pi^+\pi^-)$



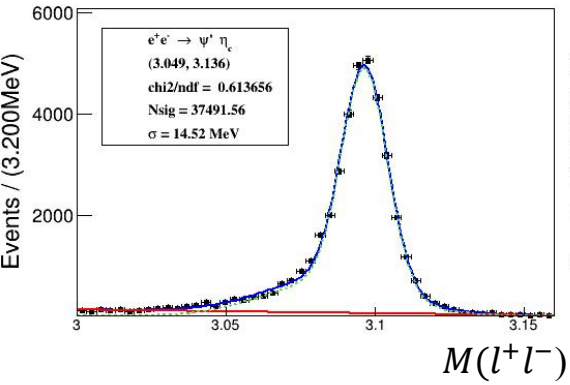
$M(J/\psi\pi^+\pi^-)$

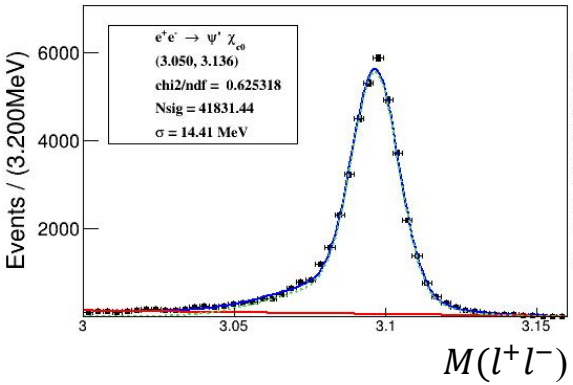
$$|M_{J/\psi\pi^+\pi^-} - M_{J/\psi}| < 50\ \mathrm{MeV/c^2}$$
$$|M_{l^+l^-} - M_{\psi'}| < 10\ \mathrm{MeV/c^2}$$

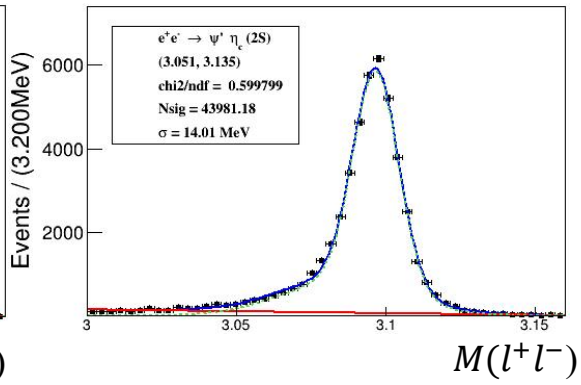
The distribution of ψ' has subtracted the resolution of J/ψ.

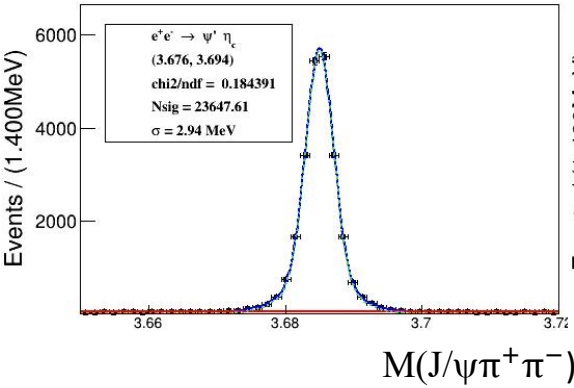
Signal MC in BelleII

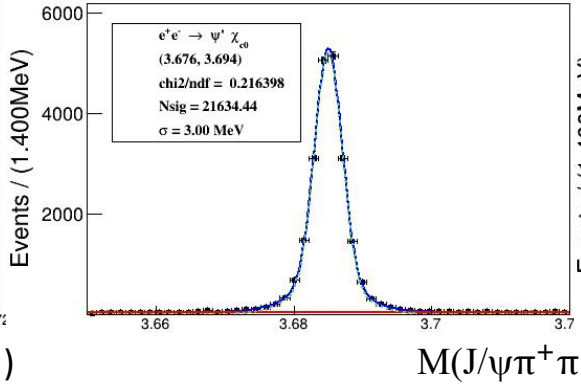
Double Gaussian function as Signal
Second Order polynomials as Background
$\pm 3\sigma$ signal region

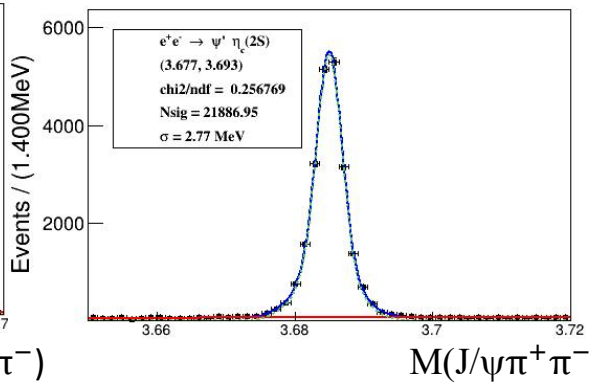










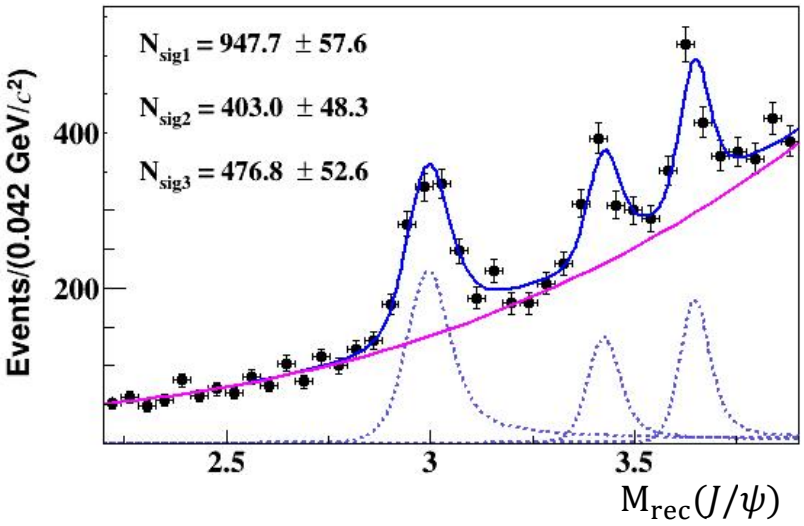


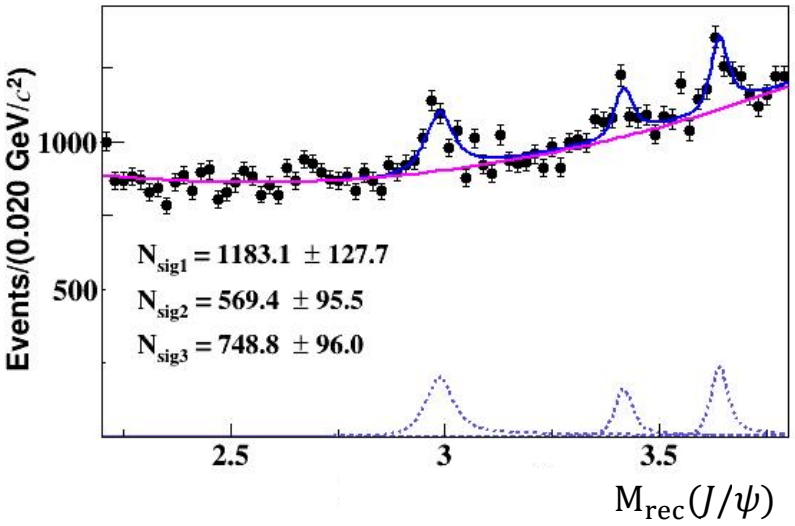
$$|\mathrm{M}_{J/\psi\pi^+\pi^-} - M_{J/\psi}| < 50\ \mathrm{MeV/c^2}$$
$$|\mathrm{M}_{l^+l^-} - M_{\psi'}| < 10\ \mathrm{MeV/c^2}$$

The distribution of ψ' has subtracted the resolution of J/ψ.

Sideband

$e^+e^- \to J/\psi + c\bar{c}$ for Belle and Belle II

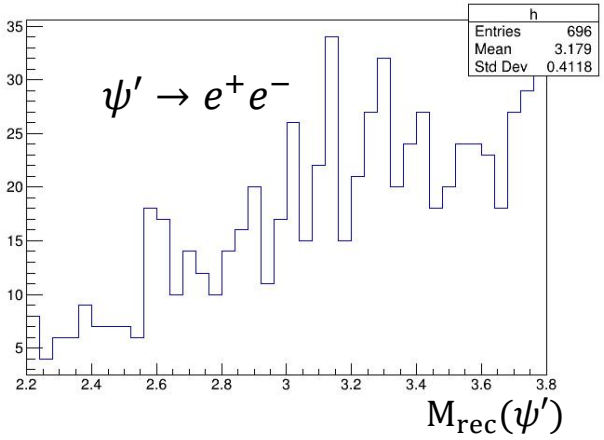


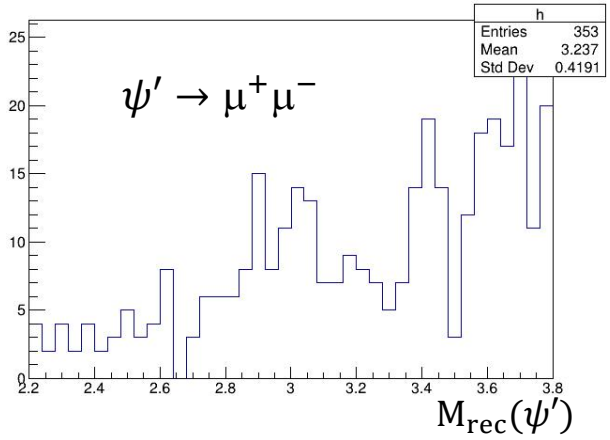


The Belle II data exhibit a substantially high background level, while the signal yield obtained from the fitting is also unusually large. The cause of this phenomenon is currently under investigation.

Data

$e^+e^- \to \psi'(\to l^+l^-) + \ c\bar{c}$ in Belle





The background is low
incorporating this dataset could be considered to enhance the signal significance