Study of di-charmonium and $J/\psi p\bar{p}$ at STCF

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On behalf of STCF-Confinement physics group

2025.11.27

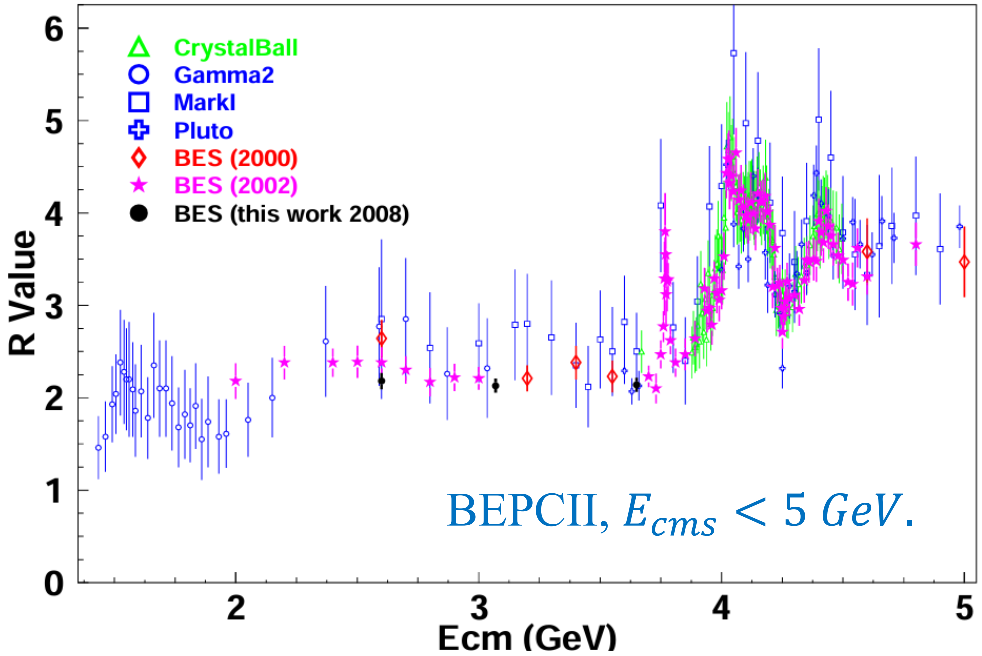
Outline

- 01 Purpose of this work
- 02 Study of $J/\psi p\bar{p}$
- 03 Study of di-charmonium

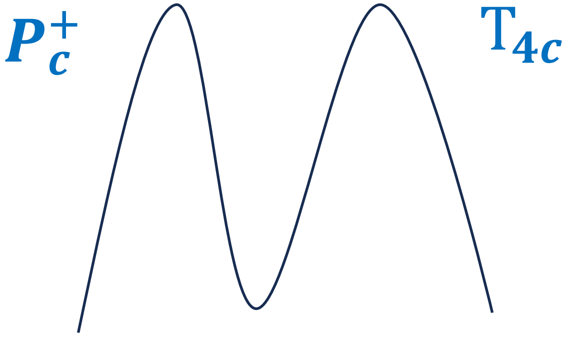
Purpose of this work

The primary objective of this work is to search for **multiquark states** in the 5–7 GeV.

BESIII



STCF



5–7 GeV

Outline

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Pentaquark State P_c^+

- The theoretical prediction of pentaquark states can be traced back to the quark model proposed by Murray Gell-Mann in 1964. In 1979, Daniel Stauffer constructed a four-quark plus one antiquark model, and in 1997, the team of Markov and Polyakov predicted the existence of a particle called Θ^+ with a mass of 1530 MeV. In 2003, the Japan LEPS experiment detected a resonance signal at 1540 MeV. After 2015, the LHCb experiment validated its existence through high-statistics data.

- In July 2015, the **LHCb collaboration** at CERN observed this type of particle for the first time in the decay of bottom lambda (Λ) baryons. Subsequent experiments have discovered multiple pentaquark states, including $P_c(4312)^+$, $P_c(4440)^+$, and $P_c(4457)^+$.

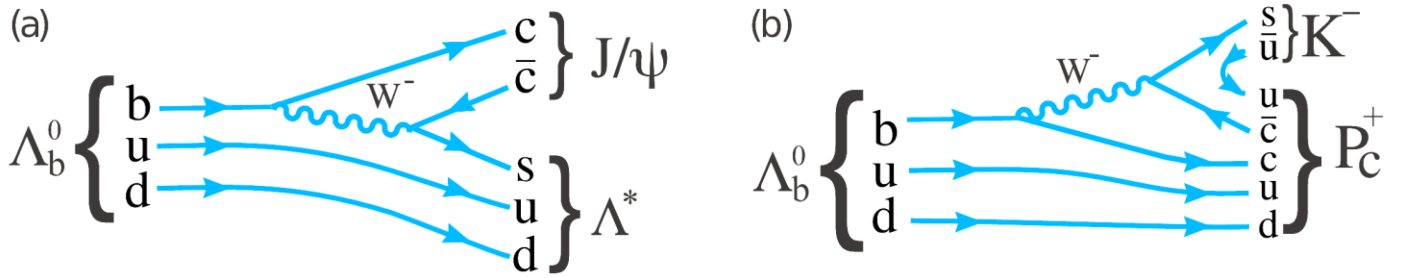


Figure 1: Feynman diagrams for (a) $\Lambda_b^0 \to J/\psi\,\Lambda^*$ and (b) $\Lambda_b^0 \to P_c^+ K^-$ decay.

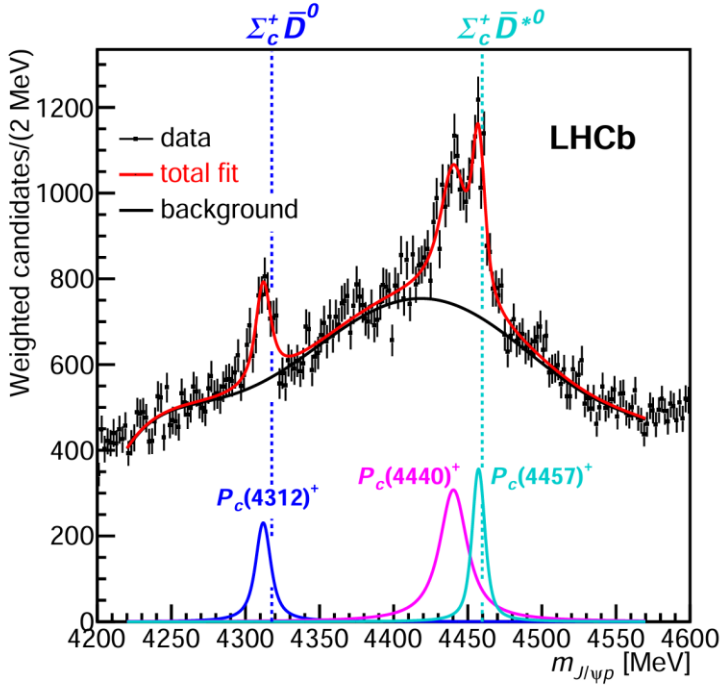


Figure 6: Fit to the $\cos\theta_{P_c}$-weighted $m_{J/\psi p}$ distribution with three BW amplitudes and a sixth-order polynomial background. This fit is used to determine the central values of the masses and widths of the P_c^+ states. The mass thresholds for the $\Sigma_c^+ \bar{D}^0$ and $\Sigma_c^+ \bar{D}^{*0}$ final states are superimposed.

MC Simulation

Study Process: $e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p} \to e^+e^-(\mu^+\mu^-)p\bar{p}$

Threshold: 4.457+0.938=5.395GeV

Sample1: Signal. MC samples for $e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p}$ were generated at an energy point of $\sqrt{s} = 6.5$ GeV, with a total of 200,000 events.

Sample2: Background. We generated 200,000 events background sample for the process $e^+e^- \to J/\psi p\bar{p}$ (without pentaquark state) at $\sqrt{s} = 6.5$ GeV.

Continuum background is the main background!

Type	Process	Amount	Generator
Signal MC	$e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p}$, $J/\psi \to e^+e^-(\mu^+\mu^-)$	200,000	ConExc,PHSP
Background MC	$e^+e^- \to J/\psi p\bar{p}$, $J/\psi \to e^+e^-(\mu^+\mu^-)$	200,000	ConExc,PHSP

OSCAR 2.6.2

Event Selection

Study Process: $e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p}$

Good charged tracks:

- $|V_{xy}| \leq 1cm$, $|V_z| \leq 10cm$

PID:

- p:prob(p)>prob(e, π, K, μ)
- e:prob(e)>prob(p, π, K, μ)
- μ:prob(μ)>prob(p, π, K, e)

Other selections:

- Number of $p = 1$ and $\bar{p} = 1$
- Number of $\mu^+ = \mu^- = 1$ or $e^+ = e^- = 1$

Vertex Fit:

- $p, \bar{p}$ and two lepton(e or μ) come from the same point.

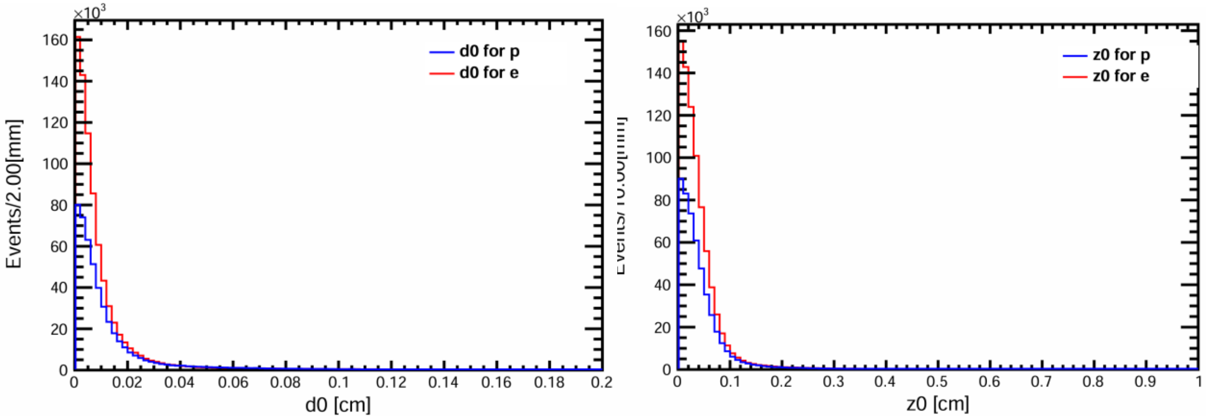
Kmfit Fit:

- $\mathrm{p}, \bar{\mathrm{p}}$ and two lepton(e or μ) restrain to center-of-mass.

Mass Requirement:

- We require $M_{J/\psi} \in [3.05, 3.15]$ GeV

$d_0(V_{xy})$ and $\mathrm{z_0(V_z)}$ distribution



The distribution of $M(J/\psi p)$

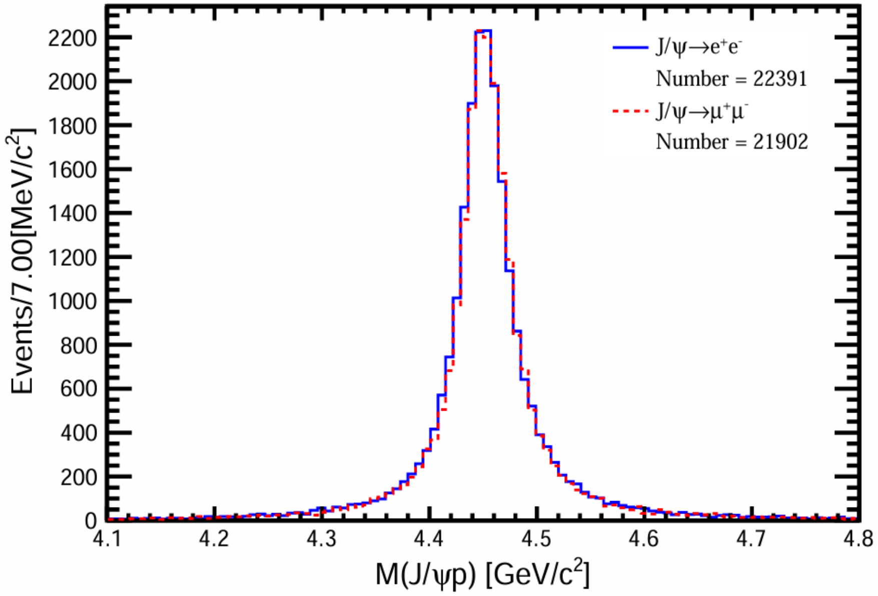
Use $P_c(4450)^+$ state as an example at $\sqrt{s} = 6.5GeV$!

$P_c(4450)^+$ is consist of two state $P_c(4440)^+$ and $P_c(4457)^+$

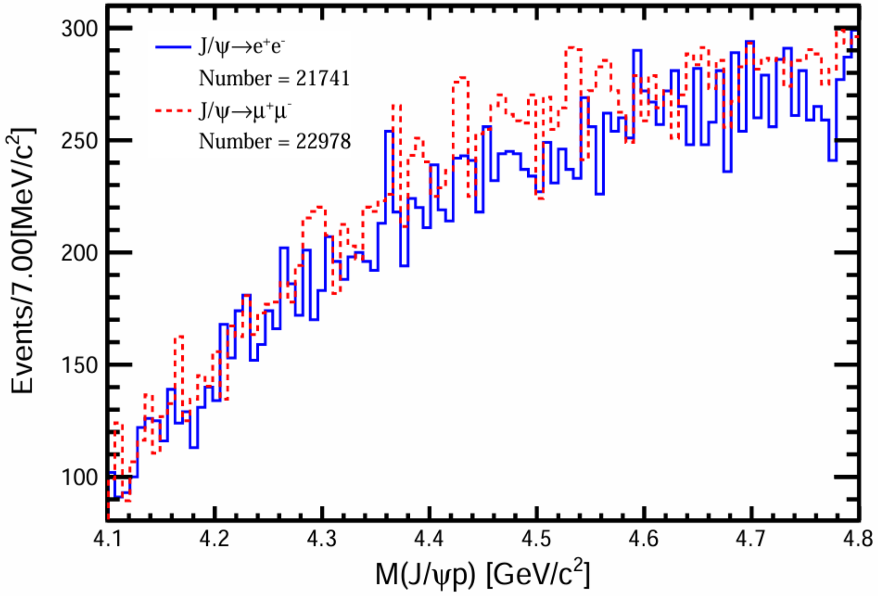
Continuum background is the main background!

Other background is very low.

Signal: $e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p}$



Background: $e^+e^- \to J/\psi p\bar{p}$

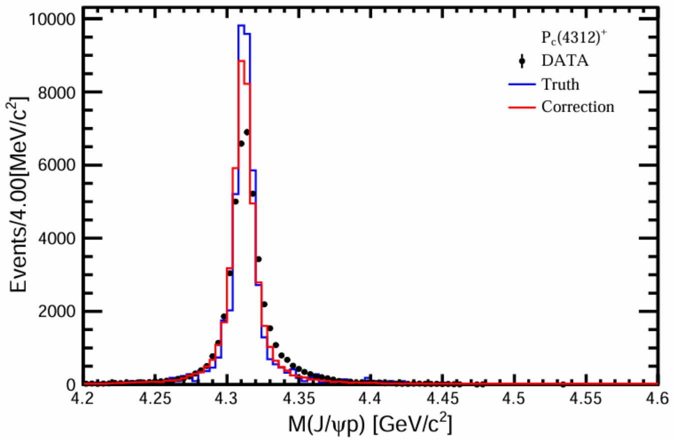


Resolution Correction

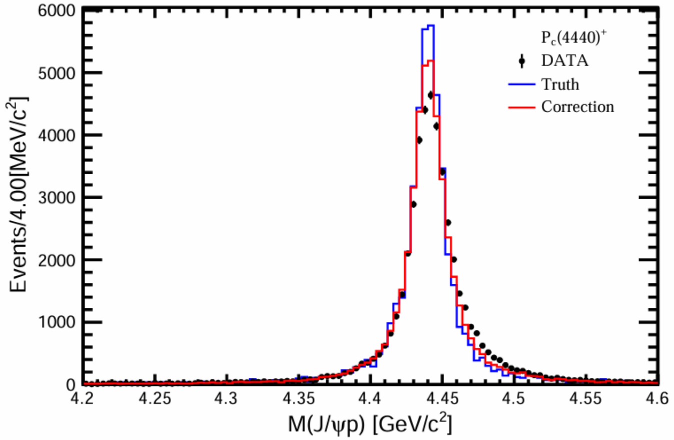
In order to improve the mass resolution, we correct the mass

Mass Resolution Correction: $M_{J/\psi p}^{corr} = M_{J/\psi p} - M_{e^+e^-/\mu^+\mu^-} + M_{J/\psi}^{PDG}$

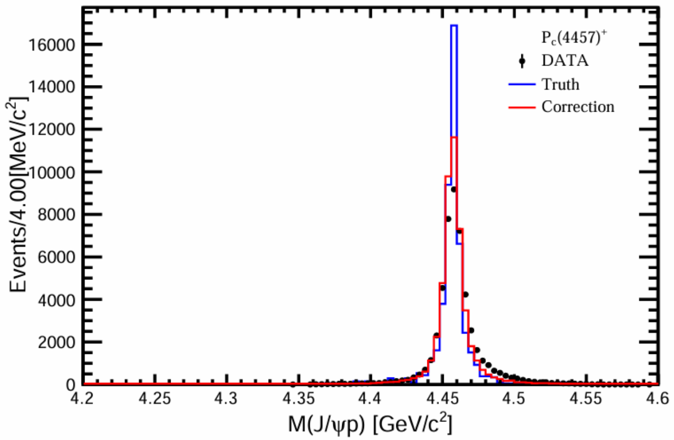
$P_c(4312)^+$



$P_c(4440)^+$



$P_c(4457)^+$



Integral to the data number.

Study of one P_c^+ State

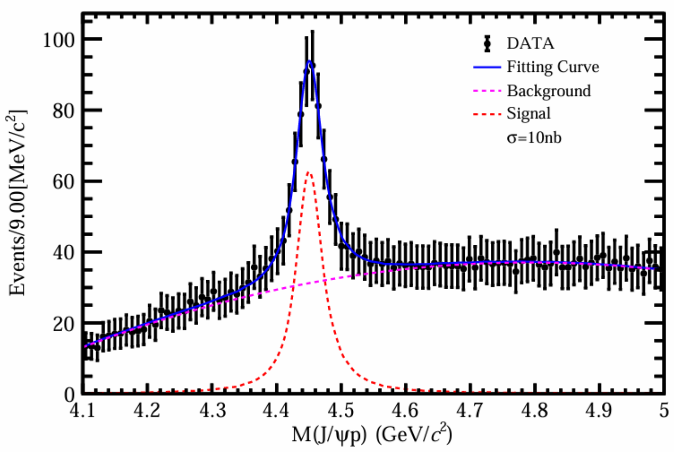
The design integral luminosity of STCF is 100 fb^{-1}. Consider the detect efficiency of $P_c(4450)^+$ is 47.2%

Signal Number: $N_{obs} = \mathcal{L}_{int} \cdot \sigma_{sig} \cdot \varepsilon$

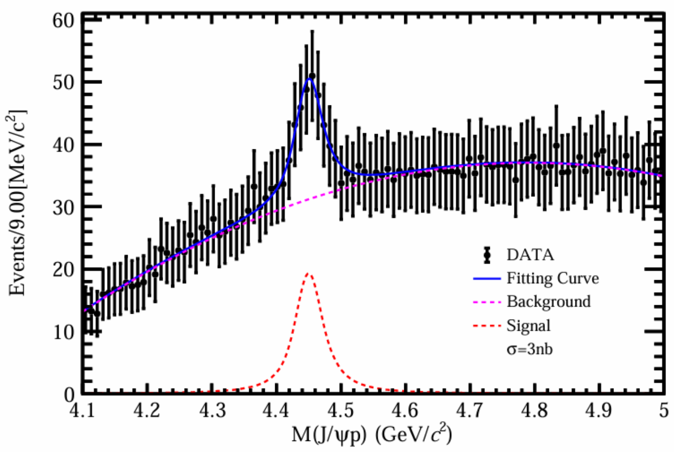
(background)

Assuming that $\sigma(e^+e^- \to J/\psi p\bar{p}) = 0.1pb$, the distribution of $M_{J/\psi}$ are displayed:

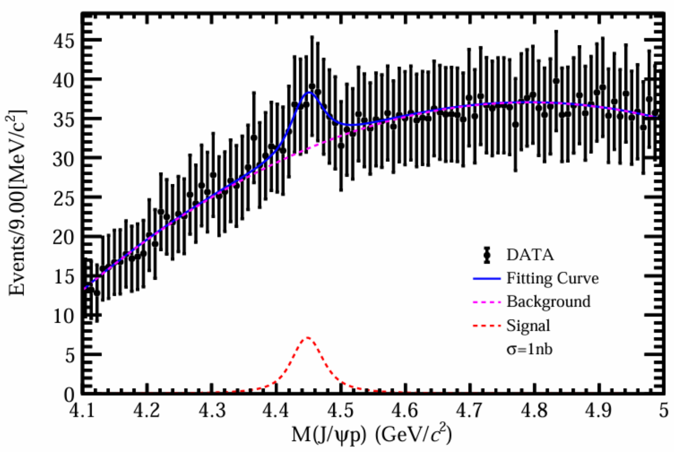
$\sigma_{sig} = 10fb$



$\sigma_{sig} = 3fb$



$\sigma_{sig} = 1fb$



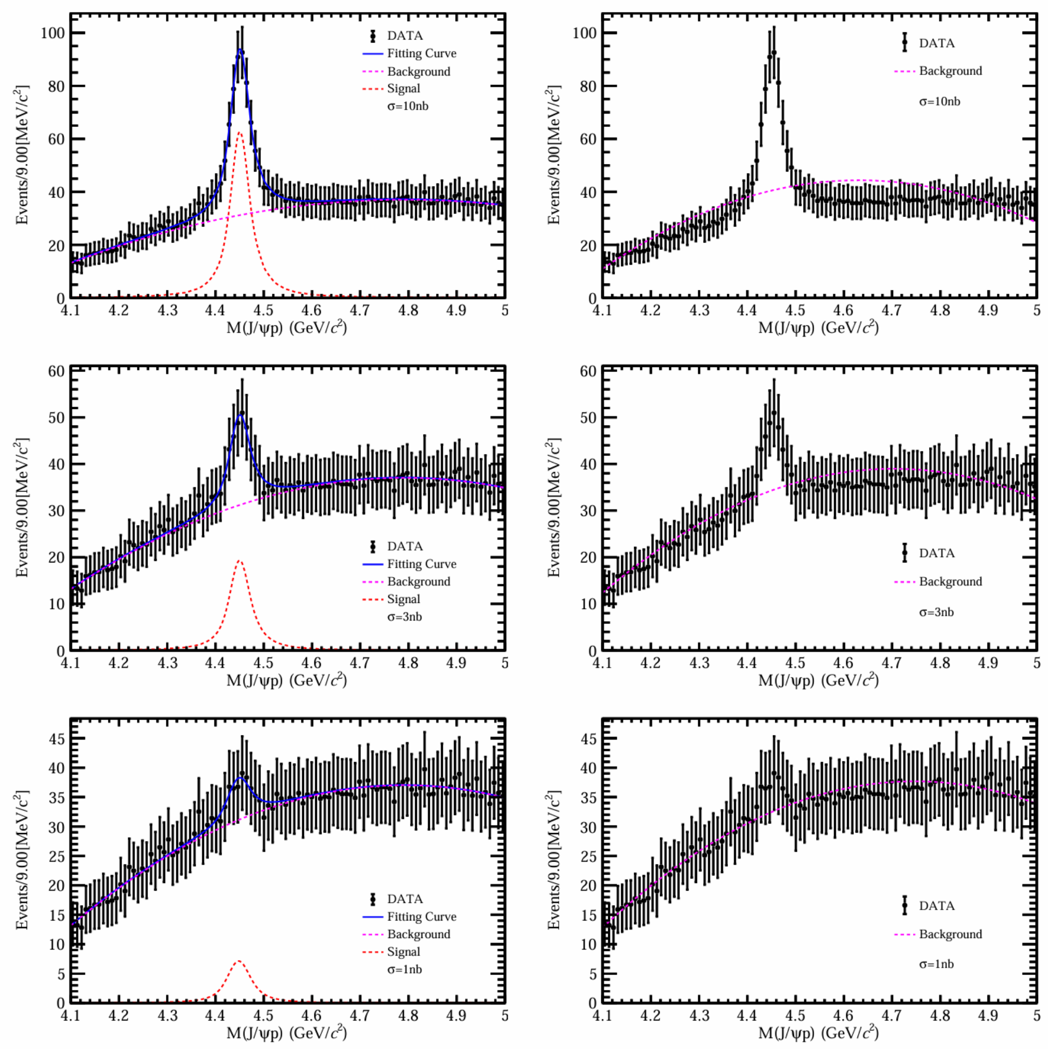
Significance of $P_c(4450)^+$ State

Signal Hypothesis **Background Hypothesis**

$10fb$

$3fb$

$1fb$

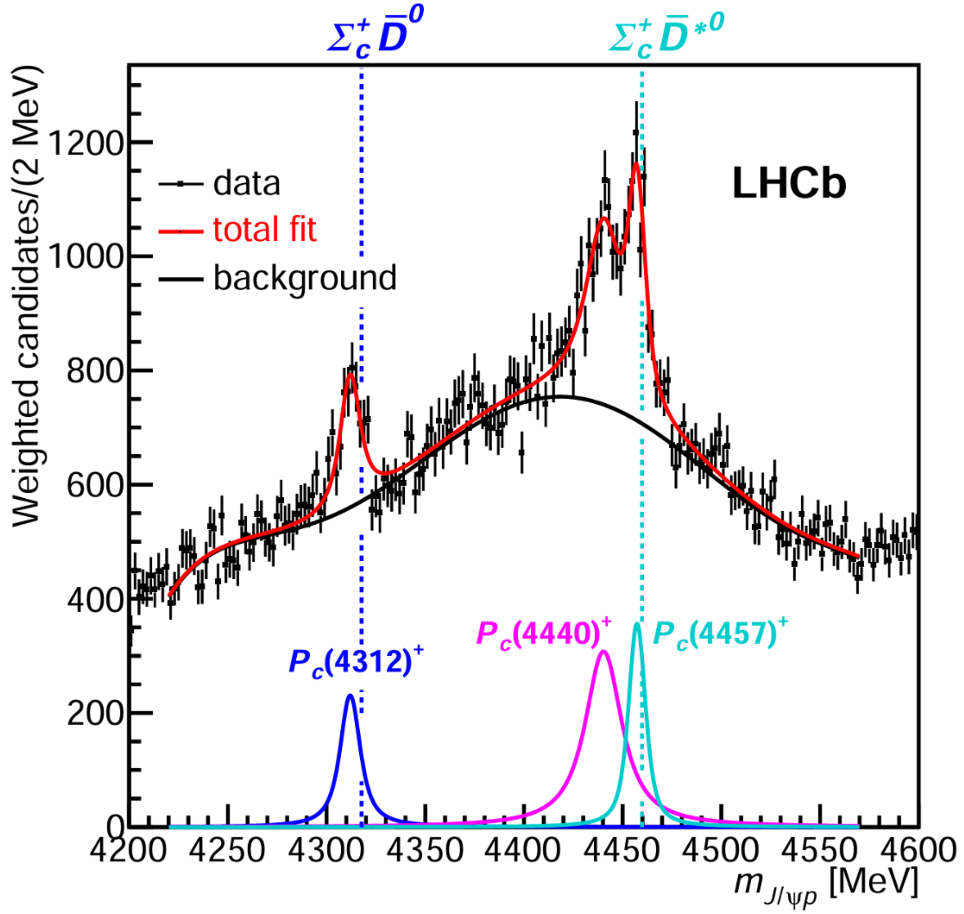


$$Significance = \sqrt{2(NLL_1 - NLL_2)}$$

$\sigma(e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p})$	10fb	4fb	3fb	2fb	1fb
Signal NLL	-11498.9	-9162.7	-8783.1	-8406.8	-8034.3
Bkg NLL	-11400.6	-9142.4	-8771.0	-8401.1	-8032.8
Significance	14.02σ	6.38σ	4.92σ	3.39σ	1.77σ

We find that when $\sigma(e^+e^- \to J/\psi p\bar{p}) =$ **0.1pb**, the cross section for the P_c^+ state should more than **$3fb$** that the significance can exceed 5σ (STCF can see the resonacne)

Compare with LHCb results



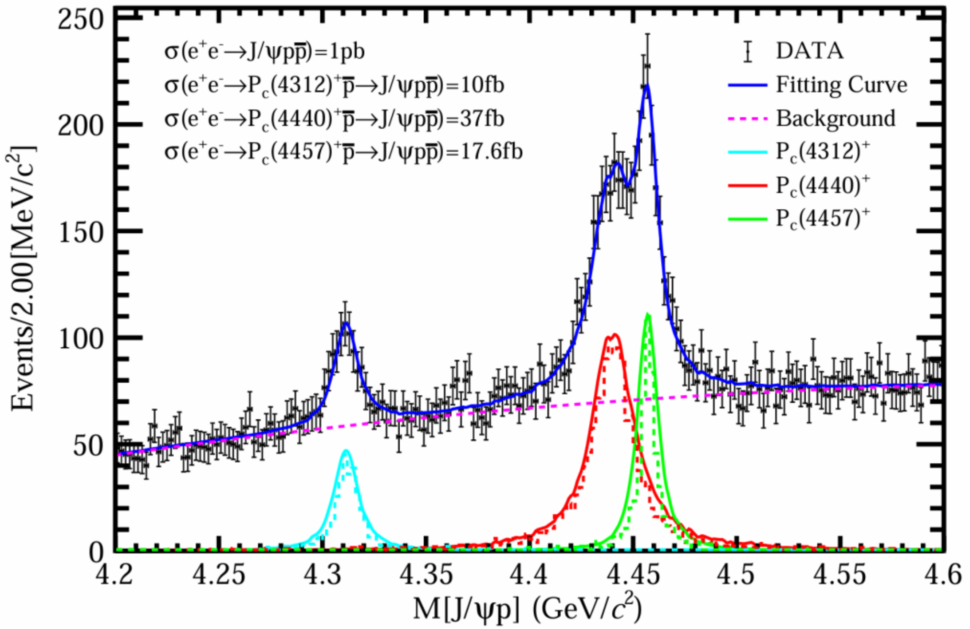
State	M [MeV]	Γ [MeV]	(95% CL)	$\mathcal{R}$ [%]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$	(< 27)	$0.30 \pm 0.07^{+0.34}_{-0.09}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$	(< 49)	$1.11 \pm 0.33^{+0.22}_{-0.10}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$	(< 20)	$0.53 \pm 0.16^{+0.15}_{-0.13}$

We can adopt the same relative contributions of the P_c^+ states as measured by LHCb to make prediction.

Assume that $\sigma(e^+e^- \to J/\psi p\bar{p}) = 1pb$

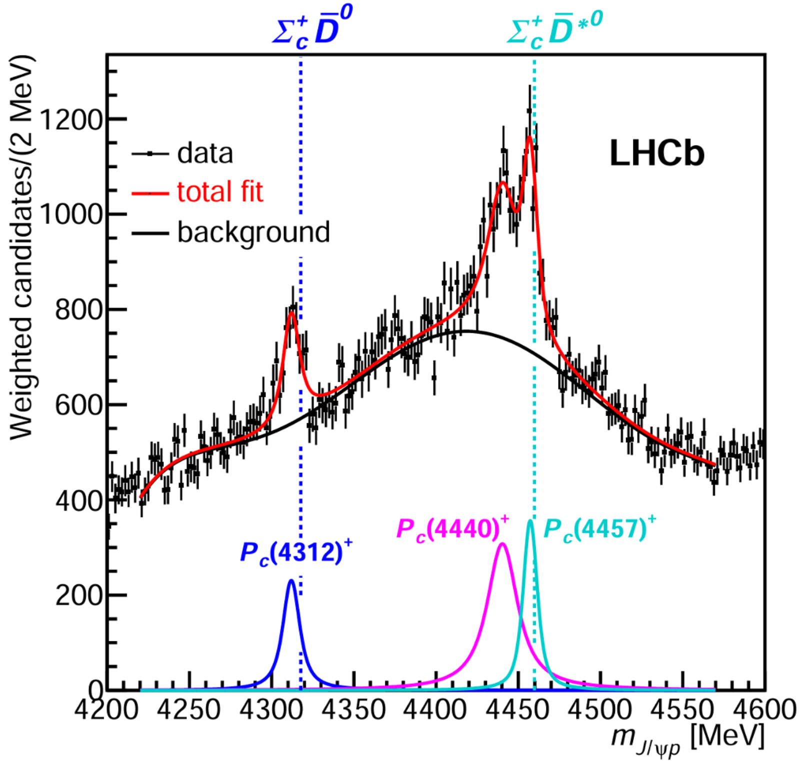
(We adopt the same 200 binning scheme as LHCb)

(High Cross Section Assumption)

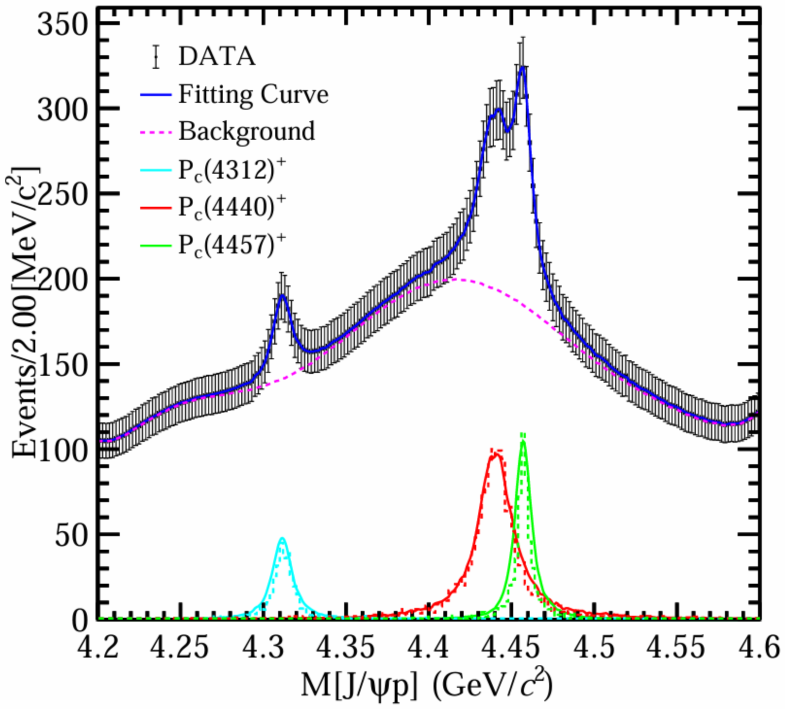


Compare with LHCb results

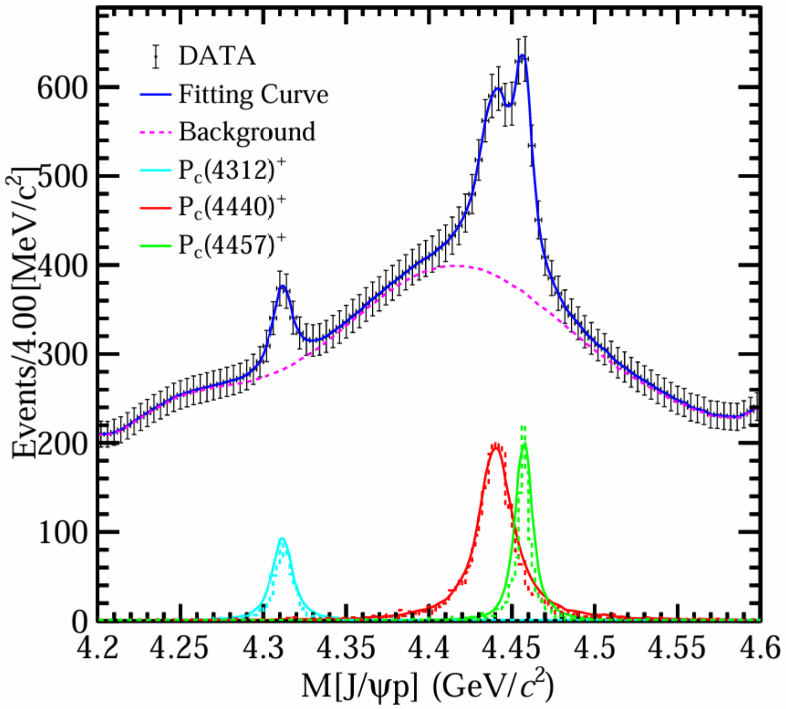
To better compare the resolution differences between the two experiments, we replace the background with the **sixth-order polynomial** used in the LHCb experiment for comparison.



Bin=200



Bin=100



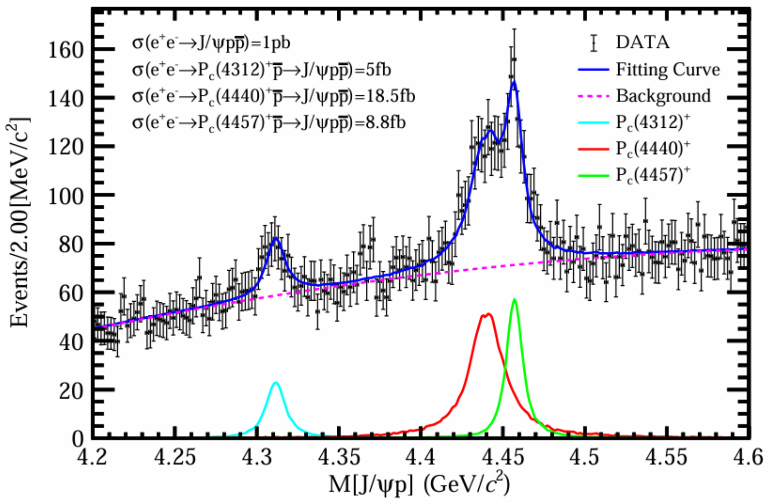
The mass resolution is sufficient to clearly resolve the $P_c(4440)^+$ and $P_c(4457)^+$ as distinct states.

Significance

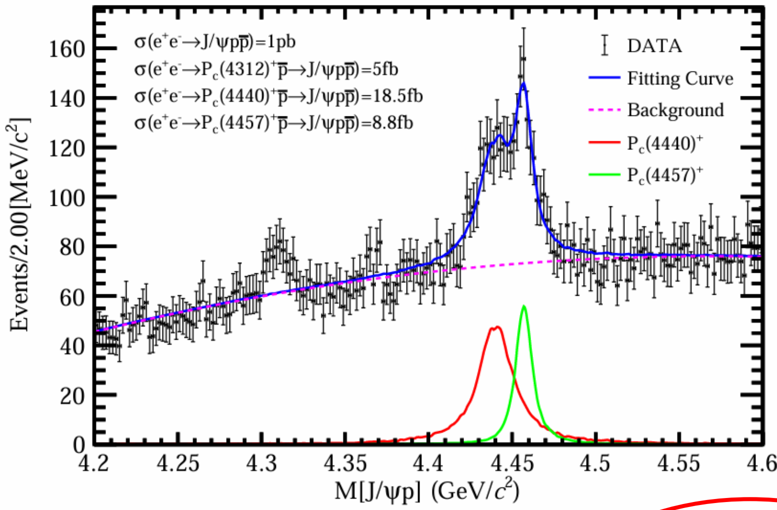
Significance1: Exist $P_c(4312)^+$ state. **VS** There is no $P_c(4312)^+$ state.

Significance2: $P_c(4440)^+$ and $P_c(4457)^+$ are two different state. **VS** They are the same state $P_c(4450)^+$.

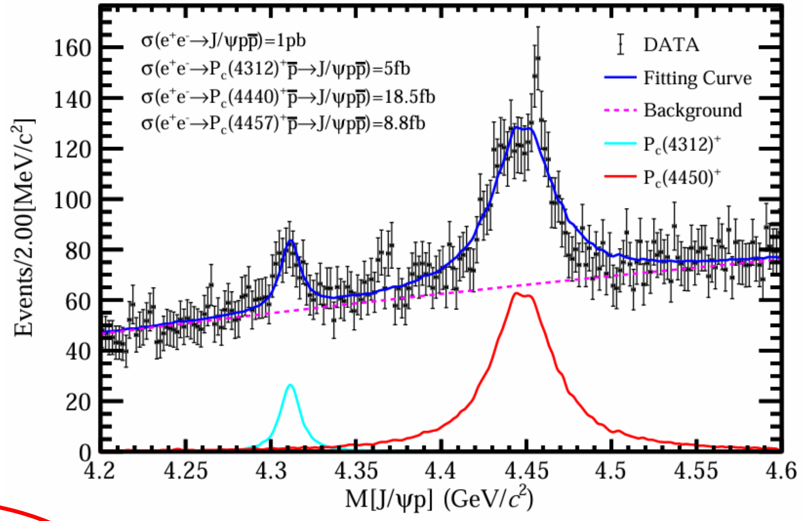
Origin



Hypothesis 1



Hypothesis 2



Background Cross Section
$\sigma(e^+e^- \to J/\psi p\bar{p}) = 1\text{pb}$

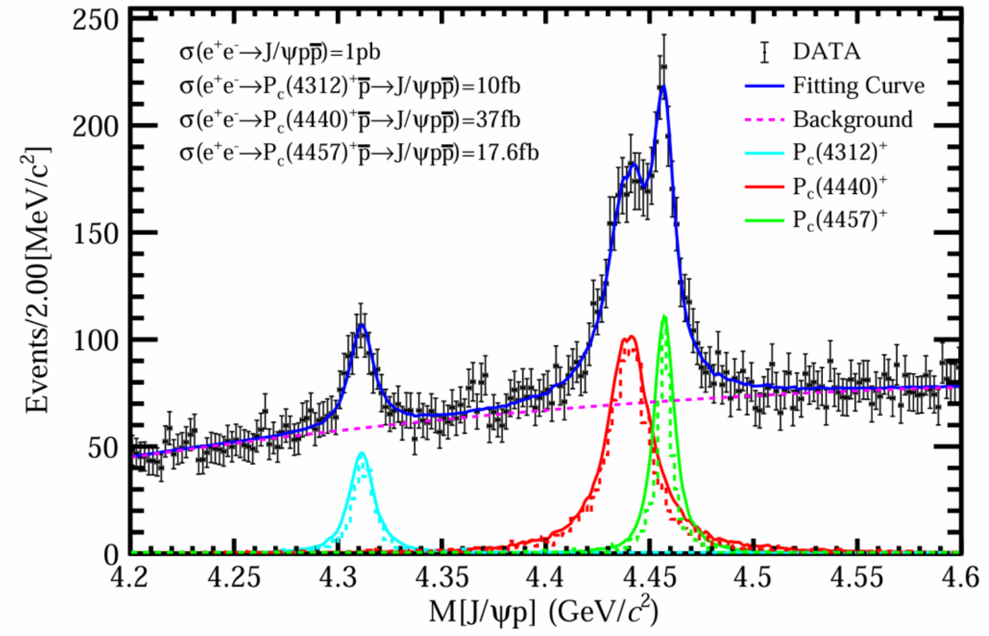
	$\sigma_1,\sigma_2,\sigma_3$ = 10, 37, 17.6fb		$\sigma_1,\sigma_2,\sigma_3$ = 5, 18.5, 8.8fb		$\sigma_1,\sigma_2,\sigma_3$ = 12.5, 9.25, 4.4fb	
Hypothesis	Significance1	Significance2	Significance1	Significance2	Significance1	Significance2
Signal NLL	-20992.9	-70808.3	-18583.6	-56783.3	-17394.8	-49927.7
Bkg NLL	-20936.2	-70769	-18568.7	-56770.5	-17391.3	-49923.6
Significance	10.65σ	8.87σ	5.46σ	5.06σ	2.65σ	2.86σ

Cross Section Measurement

The cross section for each P_c^+ state can be calculated by the follows equation:

This process is like IO-check

$$\sigma(e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p}) = \frac{N_{obs}}{\varepsilon \times \mathcal{L}}$$



Cross Section Results $\mathcal{L}_{\mathrm{int}} = 100\mathrm{fb}^{-1}$

	$P_c(4312)^+$	$P_c(4440)^+$	$P_c(4457)^+$
N_{obs}	464.3	1826.7	882.2
ε	47.46%	48.78%	48.65%
$\sigma(e^+e^- \to P_c^+\bar{p} \to J/\psi p\bar{p})$	9.78fb	37.45fb	18.13fb
Error	9.67%	4.83%	6.47%
Difference	2.17%	1.21%	3.03%

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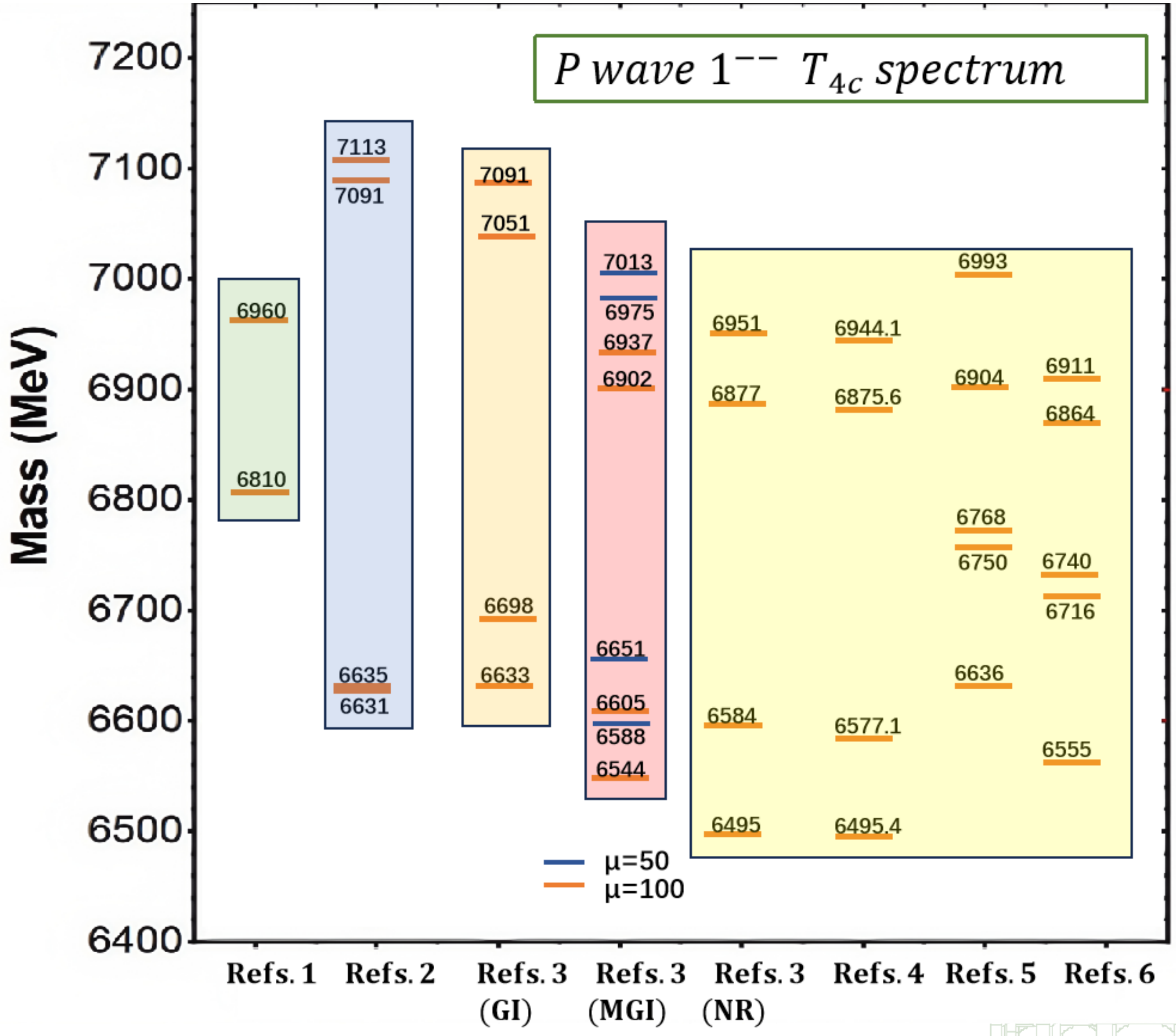
Current Status of Double Charmonium Theory and Experiments

- a survey of theoretical studies in the five models that are currently related to fully charmed tetraquark states



- QCD Sum Rules
- Relativistic Quark Model
- Godfrey-Isgur relativized diquark model
- The modified Godfrey-Isgur relativized diquark model with the color screening effects
- Nonrelativistic Quark Model

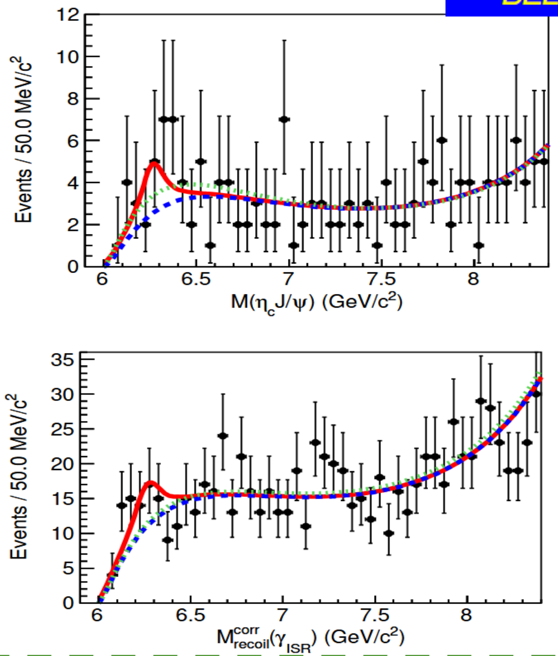
- For fully charmed tetraquark states with quantum numbers $J^{PC} = 1^{--}$,the theoretically predicted mass range is **6.495–7.113 GeV**

➢ Search for the double-charmonium state with $\eta_c J/\psi$ @ Belle

- Production process： $e^+e^- \rightarrow (\gamma_{ISR})\eta_c J/\psi$
- Energy： $10.52 GeV$
- **Decay Mode：**

  J/ψ: $e^+e^-, \mu^+\mu^-$

  η_c: $p\bar{p}, p\bar{p}\pi^0, K_0^S K^\pm\pi^\mp, K^+K^-\pi^0, K^+K^-K^+K^-, 2(\pi^+\pi^-\pi^0)$
- Integrated luminosity： $980\ fb^{-1}$
- Mass： $6267 \pm 43\ MeV/c^2$
- Width： $121 \pm 72\ MeV$
- Significance： 2.1σ （near threshold）

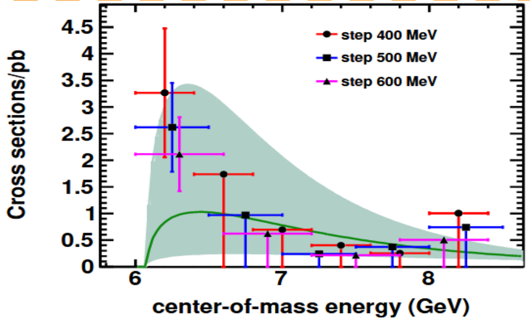


图A

- ηcJ/ψ mass region： $[6.0, 6.6]\ GeV/c^2$
- Cross-section result： 2.1 ± 0.7 ± 0.2 pb
- Continuum production cross-section fitting function

$$\Delta M = \sqrt{s} - m(\eta_c) - m(J/\psi)$$

$$\sigma = A\frac{\sqrt{2\mu\Delta M}}{(s/s_0)^n}$$



图B

Double tag J/ψ and η_c

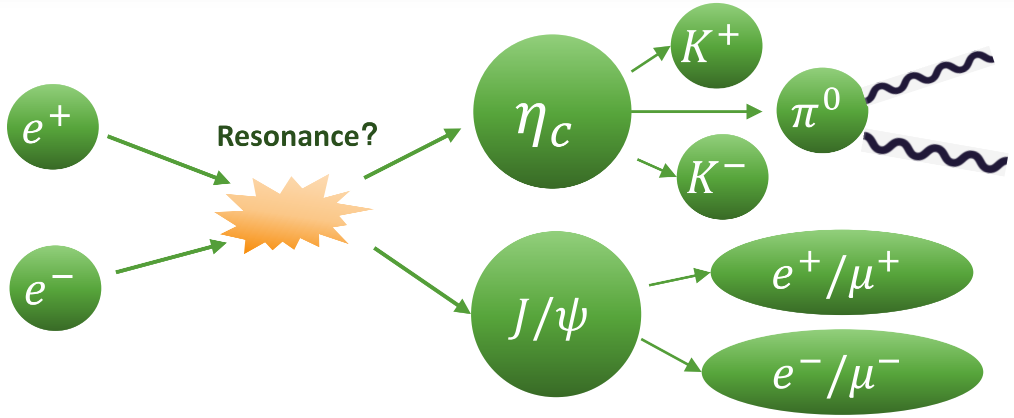
Exclusive MC production under OSCAR 2.6.2

Generator： ConExc

Event Number: 100,000

Signal Channel： $e^+e^- \to T_{4c} \to \eta_c J/\psi$,

- $\eta_c \to K^+K^-\pi^0$, $\pi^0 \to \gamma\gamma$
- $J/\psi \to \mu^+\mu^-$ or e^+e^-



- Using the Breit-Wigner formula to generate the input cross-section distribution for simulating resonances.

Breit-Wigner Formula :

$$\sigma(e^+e^- \to T_{4c}) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to \eta_c J/\psi}\frac{12\pi\Gamma_0^2}{\left(s - m_{T_{4c}}^2\right)^2 + m_{T_{4c}}^2\Gamma_0^2}$$

$M_{T_{4c}} = 6.75GeV$

6.72000	1.74915	0.0
6.72500	2.48728	0.0
6.73000	3.80113	0.0
6.73500	6.45682	0.0
6.74000	12.90311	0.0
6.74500	32.23149	0.0
6.75000	64.43911	0.0
6.75500	32.20762	0.0
6.76000	12.87256	0.0
6.76500	6.43104	0.0
6.77000	3.77999	0.0
6.77500	2.46962	0.0
6.78000	1.73409	0.0
6.78500	1.28226	0.0
6.79000	0.98561	0.0

Event Selection

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Charged-track selection:

- $|d_0| \leq 1.0cm$, $|d_z| \leq 10.0cm$;

Photon selection:

- Barrel: $|cos\theta| \leq 0.8325$, $E_{ecal} \geq 25MeV$,
- Endcap: $0.8325 \leq |cos\theta| \leq 0.9445, E_{ecal} \geq 50\ MeV$;
- Time of flight： $0 \leq |T_0| \leq 10\ ns$

Kaon selection：

- Global PID： $prob(K) \geq prob(\pi)\&\&prob(K) \geq prob(\mu)\&\&prob(K) \geq prob(e)$

Muon selection：

- $0.1 \leq E_{ecal} \leq 0.3$ ， $|p_\mu| \geq 0.9\ GeV$

Electron selection：

- $0.8 \leq \frac{E_e}{p_e} \leq 1.2$ ， $|p_e| \geq 0.9\ GeV$

π^0 reconstruction：

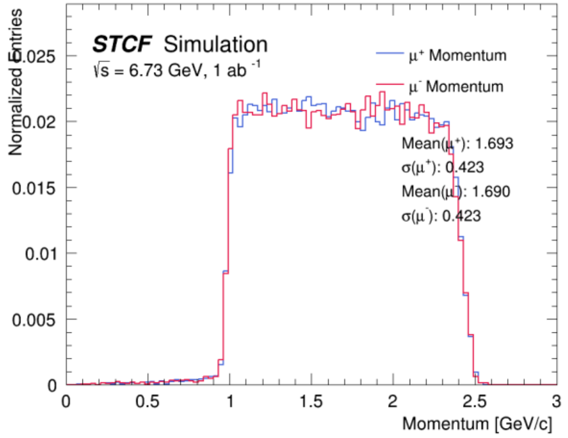
- $0.12GeV \leq M_{\gamma\gamma} \leq 0.15GeV$
- $1C\ kmfit\ \chi^2 \leq 60$

η_c reconstruction：

- $2.78GeV \leq M_{K^+K^-\pi^0} \leq 3.08GeV$

J/ψ reconstruction：

- Vertex fit: $\chi^2 \leq 60$
- $3.05GeV \leq M_{\mu^+\mu^-} \leq 3.15GeV$
- $3.05GeV \leq M_{e^+e^-} \leq 3.15GeV$



Double tag J/ψ and η_c

- $\sqrt{S} = 6.73$ GeV

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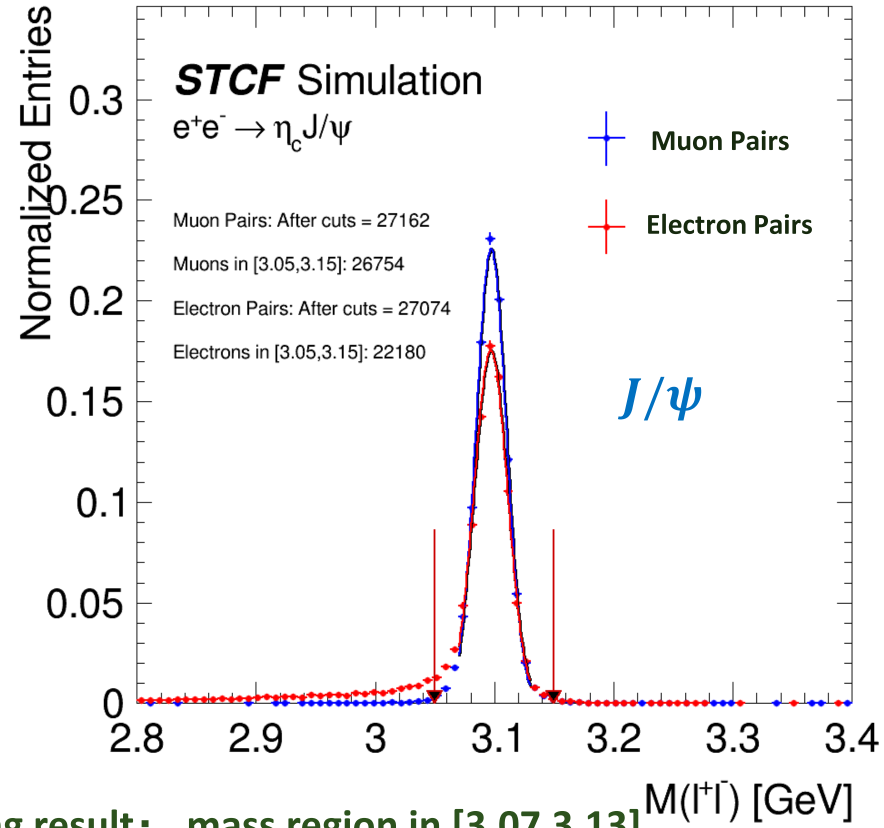
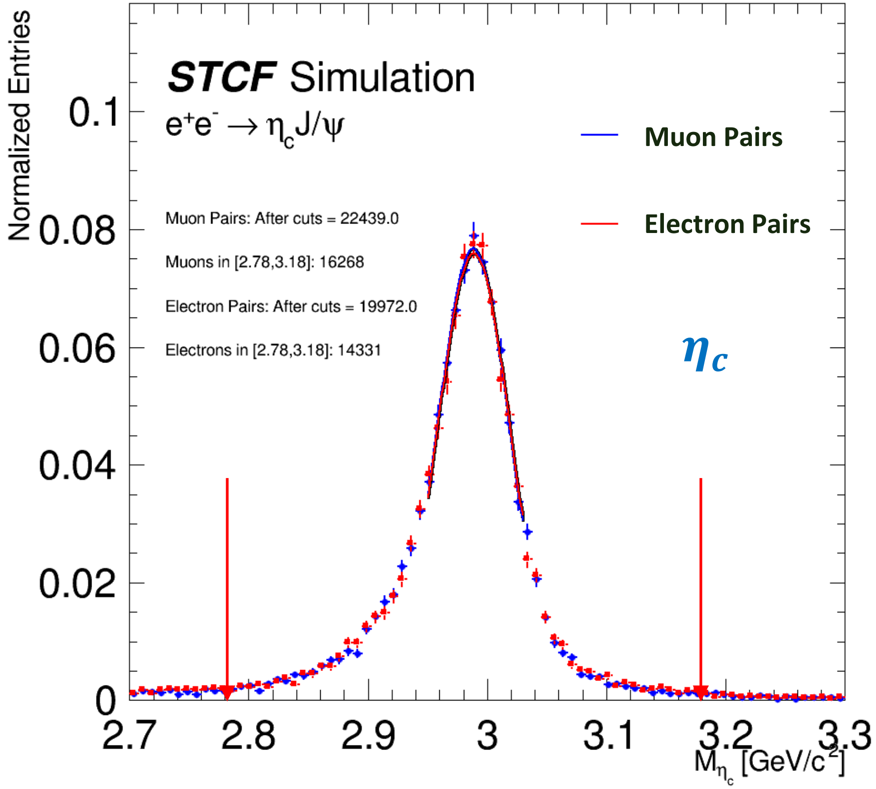
➢ Comparsion of $J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$

J/ψ *Mass cut*: $3.05GeV < M_{Le^+Le^-} < 3.15GeV$

η_c *Mass cut*: $2.78GeV < M_{K^+K^-\pi^0} < 3.18GeV$





Fitting result: mass region in [3.07,3.13]

- $\mu: \sigma = 12.79 \pm 0.07 MeV, mean = 3.097 \pm 0.001$
- $e: \sigma = 14.05 \pm 0.10 MeV, mean = 3.096 \pm 0.001$

Fitting result: mass region in [2.95,3.03]

- $\mu: \sigma = 30.31 \pm 0.6 MeV, mean = 2.988 \pm 0.001$
- $e: \sigma = 30.67 \pm 0.7 MeV, mean = 2.989 \pm 0.001$

Double tag J/ψ and η_c

$\sqrt{S} = 6.73$ GeV

Cut Flow(J/ψ->$\mu\mu$)	N_{obs}	relative ε	Cut Flow($J/\psi\rightarrow ee$)	N_{obs}	relative ε
$total\ number$:	50000	100.00%	$total\ number$:	50000	100.00%
$nGood\mathrm{m} \geq 2\&nGood\mathrm{p} \geq 2$:	34432	68.86%	$nGood\mathrm{m} \geq 2\&nGood\mathrm{p} \geq 2$:	33918	67.84%
$nGood\gamma \geq 2$:	29762	86.44%	$nGood\gamma \geq 2$:	29832	87.95%
$n\mu_p \geq 1\ and\ n\mu_m \geq 1$:	26712	89.75%	$ne_p \geq 1\ and\ ne_m \geq 1$:	26677	89.42%
$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	26321	98.54%	$J/\psi\ mass\ cut\ \&\ vtx\_\chi^2 \leq 60$:	21956	82.30%
$nK_m \geq 1\ and\ nK_p \geq 1$:	23150	87.95%	$nK_m \geq 1\ and\ nK_p \geq 1$:	19503	88.83%
$\pi^0 mass\ cut\ \&\ km\_\chi^2 < 60$:	20436	88.28%	$\pi^0 mass\ cut\ \&\ km\_\chi^2 < 60$:	17061	87.48%
$\eta_c$mass cut	17363	84.96%	$\eta_c$mass cut	14378	84.27%
$total\ cut$:	32.48%		$total\ cut$:	28.76%	

Single Tag J/ψ

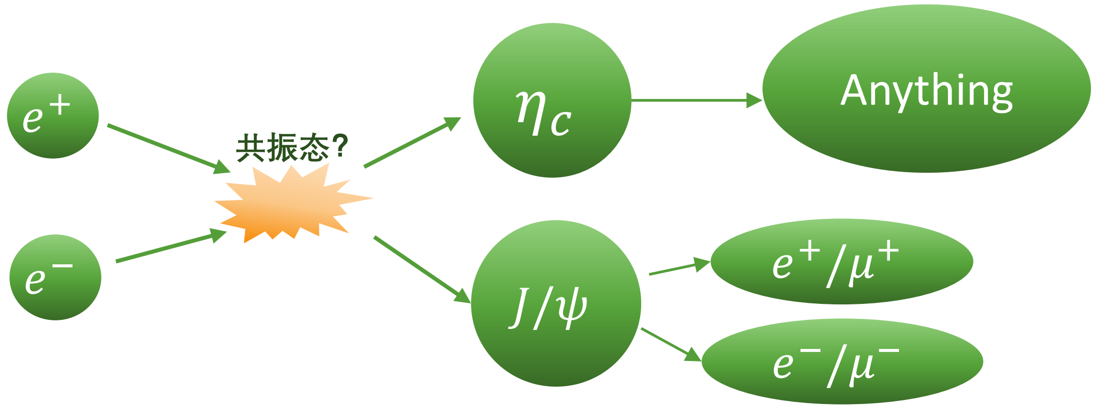
Exclusive MC production under OSCAR 2.6.2

Generator： ConExc

Event Number: 100000

Signal Channel： $e^+e^- \to T_{4c} \to \eta_c J/\psi$,

- $\eta_c \to anything$
- $J/\psi \to \mu^+\mu^-$ *and* e^+e^-



- **Decay Card**

```
noPhotos
Particle vpho 6.7300 0.0
Decay vpho
1.0000  gamma   gamma* ConExc -2  443  441;
Enddecay
#
Decay gamma*
1.0000    eta_c  J/psi       PHSP;
Enddecay
#
Decay J/psi
0.0594    e+   e-                PHOTOS  VLL;
Enddecay
#
Decay eta_c
0.027     eta' pi+ pi-                    PHSP;
0.014     eta' pi0 pi0                    PHSP;
0.006     rho0 rho0                       HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.012     rho+ rho-                       HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0100    K*0 K- pi+                      PHSP;
0.0100    anti-K*0 K+ pi-                 PHSP;
0.0034    K*+ K*-                         HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0034    K*0 anti-K*0                    HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0 ;
0.011     K*0 anti-K*0  pi+ pi-           PHSP;
0.0029    phi K+ K-                       PHSP;
0.00194   phi phi                         HELAMP 1.0 0.0 0.0 0.0 -1.0 0.0;
0.0288    K+ anti-K0  pi-                 PHSP;
0.0288    K- K0 pi+                       PHSP;
0.0144    K0 anti-K0 pi0                  PHSP;
0.0117    pi0  K+  K-                     PHSP;
0.0326    eta pi+ pi-                     PHSP;
0.0163    eta pi0 pi0                     PHSP;
```

- Using the Breit-Wigner formula to generate the input cross-section distribution for simulating resonances.

Breit-Wigner Formula :

$$\sigma(e^+e^- \to T_{4c}) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to\eta_c J/\psi}\frac{12\pi\Gamma_0^2}{\left(s - m_{T_{4c}}^2\right)^2 + m_{T_{4c}}^2\Gamma_0^2}$$

Single Tag J/ψ

$\sqrt{s} = 6.73$ GeV

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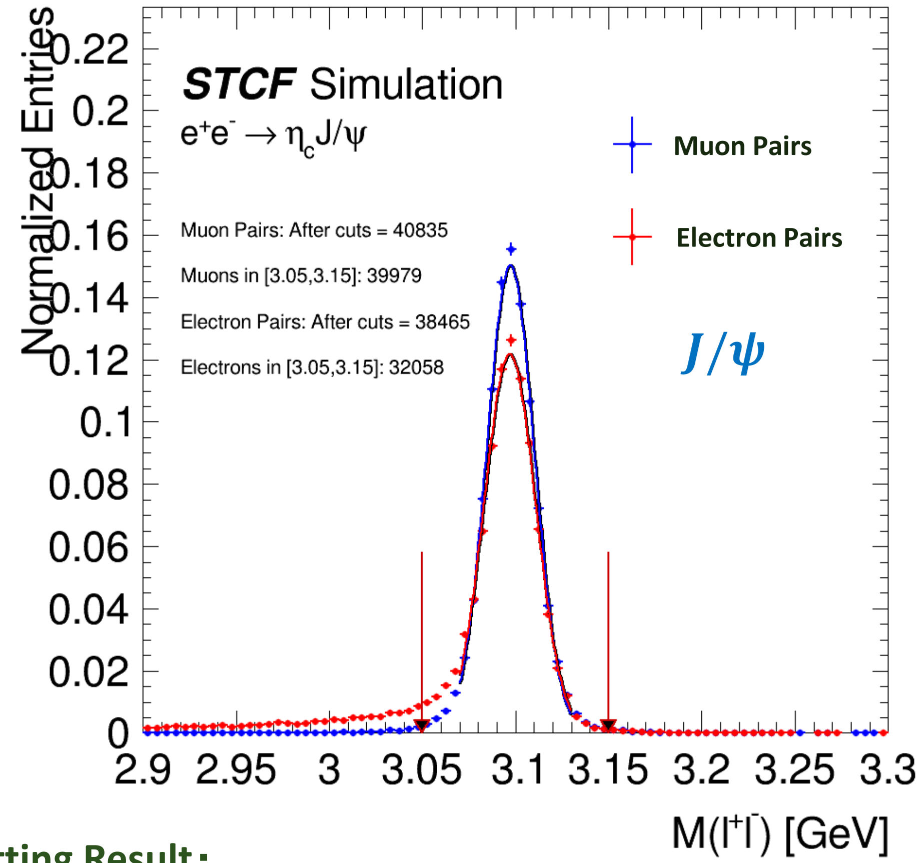
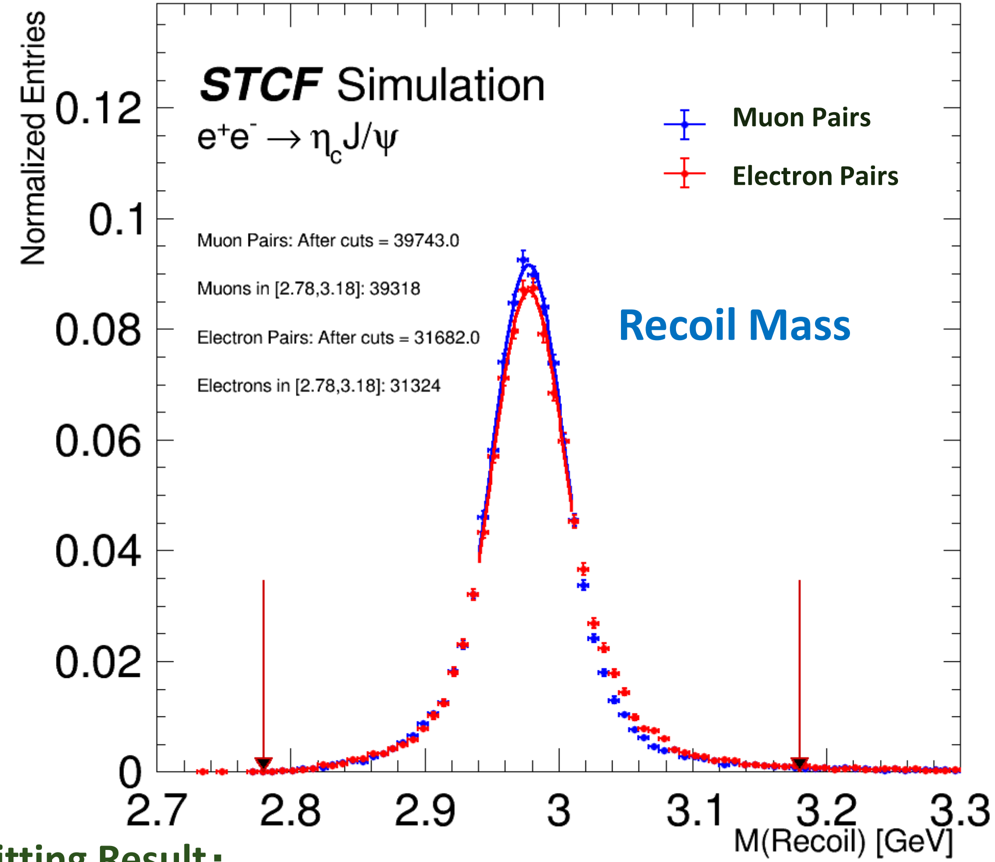
➢ Comparsion of $J/\psi \to \mu^+\mu^-$ and $J/\psi \to e^+e^-$

$$M_{\text{recoil}}(J/\psi) \equiv \sqrt{|p_{e^+e^-} - p_{J/\psi}|^2}/c$$

J/ψ ***Mass cut***: $3.05GeV < M_{le^+le^-} < 3.15GeV$

Recoil ***Mass cut***: $2.78GeV < M_{\text{recoil}} < 3.18GeV$





Fitting Result:

- $\mu: \sigma = 13.40 \pm 0.06 MeV, mean = 3.097 \pm 0.007$
- $e: \sigma = 15.05 \pm 0.08 MeV, mean = 3.096 \pm 0.009$

Fitting Result:

- $\mu: \sigma = 28.38 \pm 0.46 MeV, mean = 2.977 \pm 0.001$
- $e: \sigma = 28.93 \pm 0.56 MeV, mean = 2.978 \pm 0.001$

Single Tag J/ψ

Cut Flow(J/ψ->$\mu\mu$)	N_{obs}	relative ε	Cut Flow($J/\psi \to ee$)	N_{obs}	relative ε
$total\ number$:	50000	100.00%	$total\ number$:	50000	100.00%
$nGood\mathrm{m} \geq 1\&\&nGood\mathrm{p} \geq 1$:	49582	99.16%	$nGood\mathrm{m} \geq 1\&\&nGood\mathrm{p} \geq 1$:	49522	99.04%
$n\mu_p \geq 1\ and\ n\mu_m \geq 1$:	40436	81.55%	$ne_p \geq 1\ and\ ne_m \geq 1$:	39242	79.24%
$J/\psi\ vtxfit\_\chi^2 \leq 60$:	40404	99.99%	$J/\psi\ vtxfit\_\chi^2 \leq 60$:	39225	99.96%
$J/\psi\ mass\ cut$:	39743	98.36%	$J/\psi\ mass\ cut$:	32452	82.73%
Recoil mass cut	39099	98.38%	Recoil mass cut	31886	98.26%
$total\ cut$:	78.20%		$total\ cut$:	63.77%	

Background Analysis

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- Continuum cross section：

$$\sigma = A\frac{\sqrt{2\mu\Delta M}}{(s/s_0)^n}$$

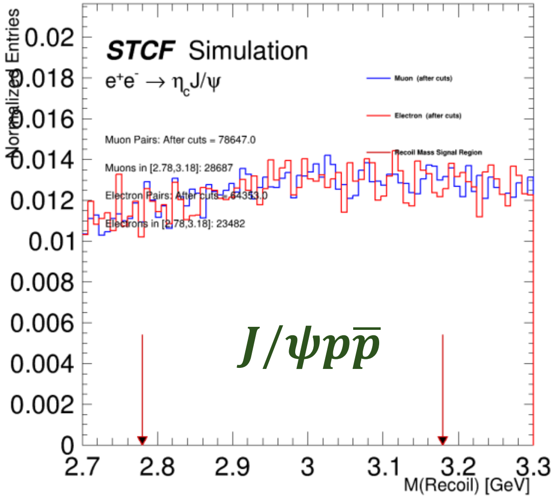
(From Belle)

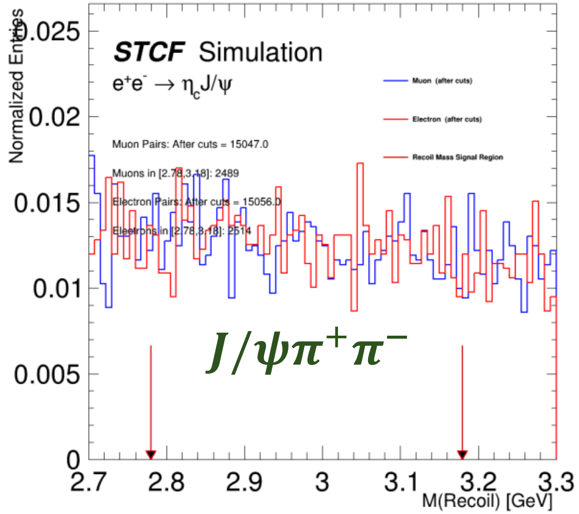
$\sqrt{s}$=6.75GeV	Double Tag efficiency	Double Tag σ(fb)	Double Tag Num	Single Tag efficiency	Single Tag σ(fb)	Single Tag Num
Signal	31.00%	64.43	3	70.50%	64.43	548
Continuum	31.00%	819.26	35	70.50%	819.26	6886
$J/\psi p\bar{p}$	1.38%	20	0	11.40%	20	27
$J/\psi\pi^+\pi^-$	0.42%	30	0	4.88%	30	18
$J/\psi K^+K^-$	1.41%	30	0	14.23%	30	51

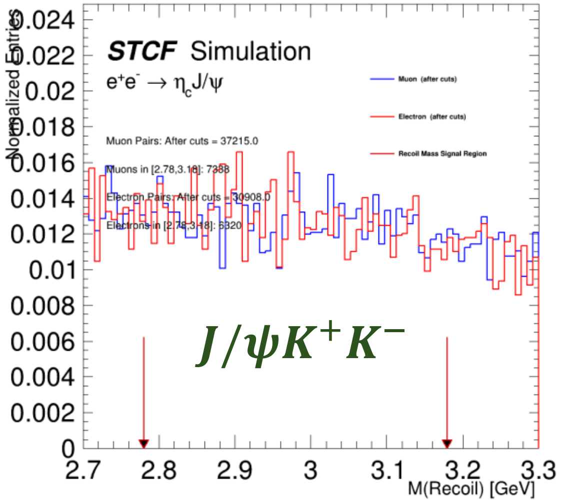
The cross-section estimates for $J/\psi p\bar{p}$、 $J/\psi\pi^+\pi^-$ and $J/\psi K^+K^-$ background at $\sqrt{s}$ =6.75 GeV are obtained by scaling their current measured values below 5 GeV down by a factor of 100.

Number of the bkg

5×10^5







Estimate Cross Section and Signal Number

- $\Gamma_{T_{4c}}^{ee} = 20eV,$
- $\Gamma_{T_{4c}} = 10MeV$
- $\Gamma_{\eta_c J/\psi} = 1MeV$
- $\mathcal{B}_{T_{4c}\to e^+e^-} \approx 2 * 10^{-6}$, $\mathcal{B}_{T_{4c}\to\eta_c J/\psi} = \frac{1}{10} \approx 0.1$

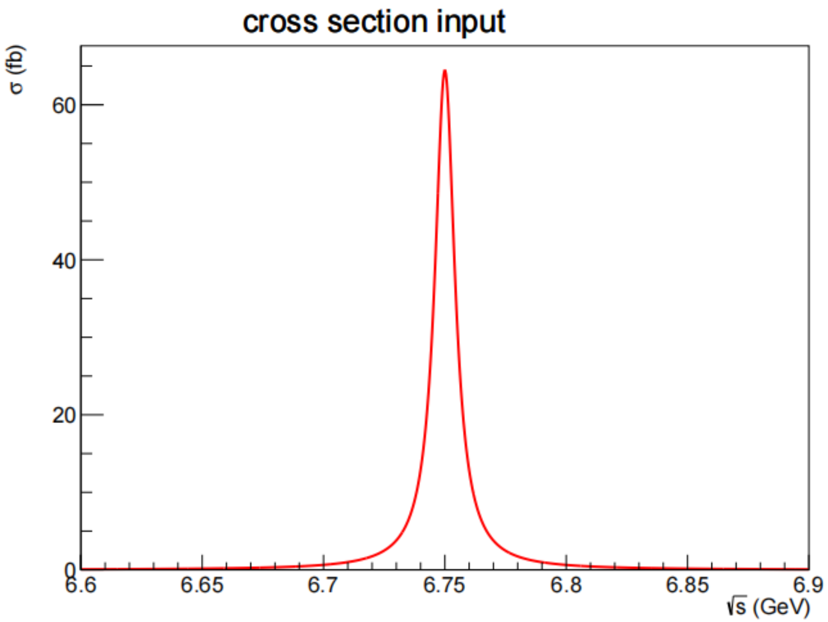
(peaking)

$$\boldsymbol{\sigma(e^+e^- \to T_{4c} \to \eta_c J/\psi) = \mathcal{B}_{T_{4c}\to e^+e^-}\mathcal{B}_{T_{4c}\to\eta_c J/\psi} \frac{12\pi\Gamma_{T4c}^2}{\left(s-m_{T_{4c}}^2\right)^2 + m_{T_{4c}}^2\Gamma_{T4c}^2}} \cong 64.43\text{fb}$$

- $L = 100\ fb^{-1}$
- $\mathcal{B}(J/\psi \to e^+e^-, \mu^+\mu^-)$ =0. 11932=11.932%
- $\mathcal{B}(\eta_c \to K^+K^-\pi^0)$ =0. 0115=1.15%

$$\boldsymbol{N_{obs} = \sigma\varepsilon L\mathcal{B}(J/\psi \to e^+e^-, \mu^+\mu^-)\mathcal{B}(\eta_c \to K^+K^-\pi^0)} \cong \boldsymbol{3(peak)}$$

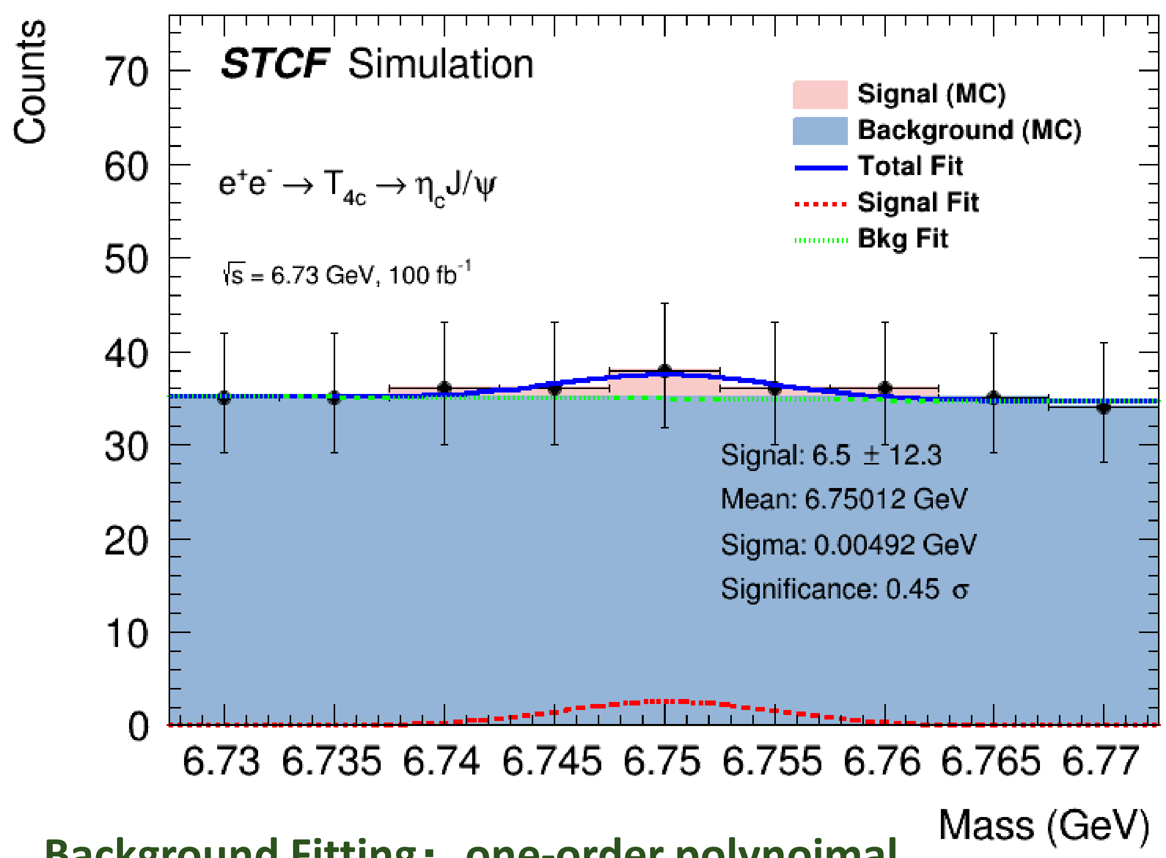
- STCF can generate $\boldsymbol{1 * 10^5\ T_{4c}}$（$\boldsymbol{N_{obs} = \sigma L}$）



A. Badalian, B. Ioffe and A. V. Smilga, Nucl. Phys. B281 (1987) 85

Fitting of Signal and Background

Double Tag $\sqrt{S}$: 6.73GeV~6.77GeV Step size:5MeV 8 steps



- **Background Fitting： one-order polynoimal**
- **Signal Fitting： Gaussian**

- **Significance：**

$$S = [2(\boxed{lnL_m(s+b)} - \boxed{lnL_m(b)})]^{1/2}.$$

log likelihood value from the fit w/o signal

log likelihood value from the fit

- $L = 100\, fb^{-1}$
- $significance = 0.45\sigma$

Fitting Result：

- $N_{sig} = 6.5 \pm 12.3$
- $N_{back} = 314.4 \pm 24.6$
- $Mean = 6.75 \pm 0.01\ GeV$
- $\sigma = 4.92 \pm 1.82\ MeV$

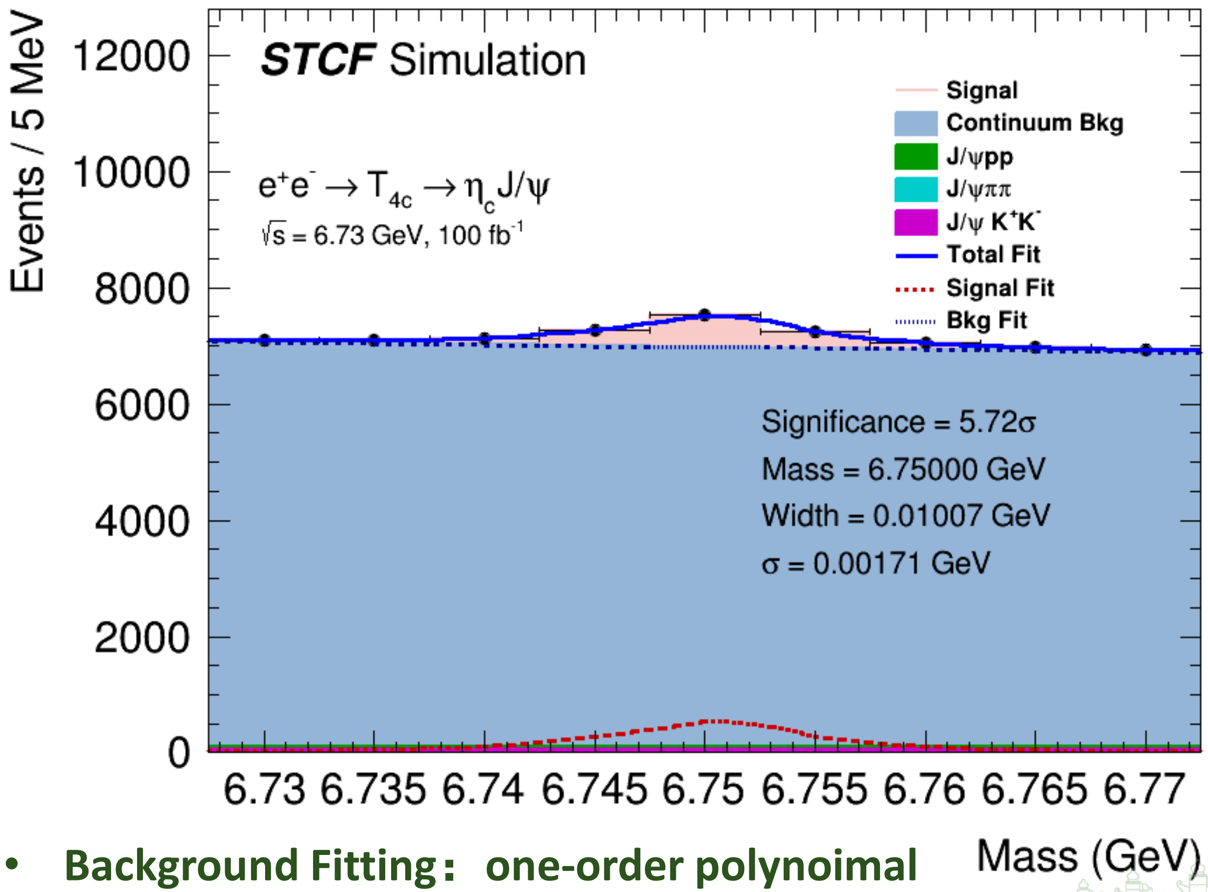
Calculated Reuslt：

- $N_{sig} = 8$
- $N_{back} = 313$

Fitting of Signal and Background

Single Tag J/ψ

$\sqrt{s}$: 6.73GeV~6.77GeV Step size:5MeV 8 steps



- Background Fitting: one-order polynoimal
- Signal Fitting: Gaussian convolution BW function

- **Significance:**

$$S = [2(\boxed{lnL_m(s+b)} - \boxed{lnL_m(b)})]^{1/2}.$$

log likelihood value from the fit w/o signal

log likelihood value from the fit

- $L = 100\, fb^{-1}$
- $significance = 5.72\sigma$

Fitting Result:

- $N_{sig} = 1530.3 \pm 473.4$
- $N_{back} = 62791.7 \pm 299.6$
- $Mean = 6.75 \pm 0.001\ GeV$
- $\sigma = 1.7 \pm 2.0\ MeV$

Calculated Reuslt:

- $N_{sig} = 1487$
- $N_{back} = 62377$

Results under different Cross Section Assumption

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	能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77	significance
Double Tag	input截面(fb)	3.8	6.5	12.9	32.2	64.4	32.2	12.9	6.4	3.8	0.45σ
	N_{obs}(信号)	0	0	1	1	3	1	1	0	0	
5 times	input截面(fb)	19.0	32.3	64.5	161.2	322.2	161.0	64.4	32.2	18.9	1.97σ
	N_{obs}(信号)	1	1	3	7	14	7	3	1	1	
10 times	input截面(fb)	38.0	64.6	129.0	322.3	644.4	322.1	128.7	64.3	37.8	3.58σ
	N_{obs}(信号)	2	3	6	14	28	14	6	3	2	

	能量点/GeV	6.73	6.735	6.74	6.745	6.75	6.755	6.76	6.765	6.77	significance
Single Tag	input截面(fb)	3.8	6.5	12.9	32.2	64.4	32.2	12.9	6.4	3.8	5.72σ
	N_{obs}(信号)	32	55	109	274	548	273	109	55	32	
5 times	input截面(fb)	19.0	32.3	64.5	161.2	322.2	161.0	64.4	32.2	18.9	26.76σ
	N_{obs}(信号)	161	274	547	1370	2738	1366	547	273	160	
10 times	input截面(fb)	38.0	64.6	129.0	322.3	644.4	322.1	128.7	64.3	37.8	57.66σ
	N_{obs}(信号)	323	548	1094	2740	5476	2732	1094	546	320	

Summary

- **For the P_c^+ states:** Our investigation involved simulating the distributions of various P_c^+ states at 6.5 GeV. A comparison with LHCb data was performed, and the significance was evaluated under different cross-section hypotheses, laying the groundwork for future studies.

- **For the di-charmonium:** Based on theoretical cross-section predictions, we simulated the expected signal and background distributions. The calculated significance led to the conclusion that the single-tag method is more viable than the double-tag method for detection.

Reference

1. Yin J H, Li Y B, Won E, et al. Search for the double-charmonium state with ηcJ/ψ at Belle[J]. Journal of High Energy Physics, 2023, 2023(8): 1-21.
2. Chen Z Z, Chen X L, Yang P F, et al. P-wave fully charm and fully bottom tetraquark states[J]. Physical Review D, 2024, 109(9): 094011.
3. Faustov R N, Galkin V O, Savchenko E M. Fully heavy tetraquark spectroscopy in the relativistic quark model[J]. Symmetry, 2022, 14(12): 2504.
4. Dong W C, Wang Z G. Going in quest of potential tetraquark interpretations for the newly observed T ψ ψ states in light of the diquark-antidiquark scenarios[J]. Physical Review D, 2023, 107(7): 074010.
5. Debastiani V R, Navarra F S. A non-relativistic model for the tetraquark[J]. Chinese Physics C, 2019, 43(1): 013105.
6. Liu M S, Liu F X, Zhong X H, et al. Fully heavy tetraquark states and their evidences in LHC observations[J]. Physical Review D, 2024, 109(7): 076017.
7. Wang G J, Meng L, Oka M, et al. Higher fully charmed tetraquarks: Radial excitations and P-wave states[J]. Physical Review D, 2021, 104(3): 036016.

Thank you!

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On behalf of STCF-Confinement physics group

2025.11.27