Exotic hadron on Electron-Ion Collider

吴佳俊 (中国科学院大学)

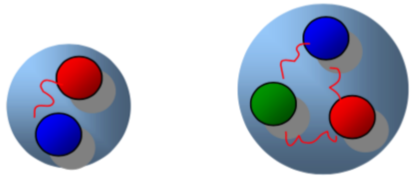
第一届中国电子离子对撞机相关物理年会 2026.04.20 青岛·山东大学

目录

- Background
- For P_c / P_{cs}
- For XYZ
- Summary and Outlook

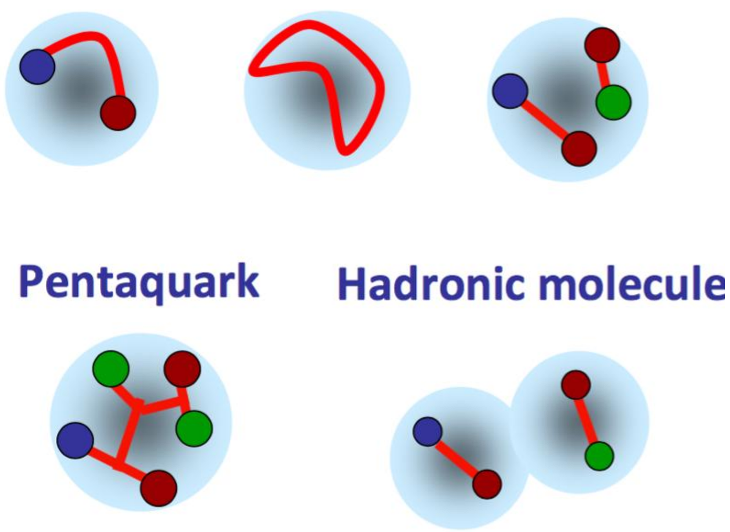
Background

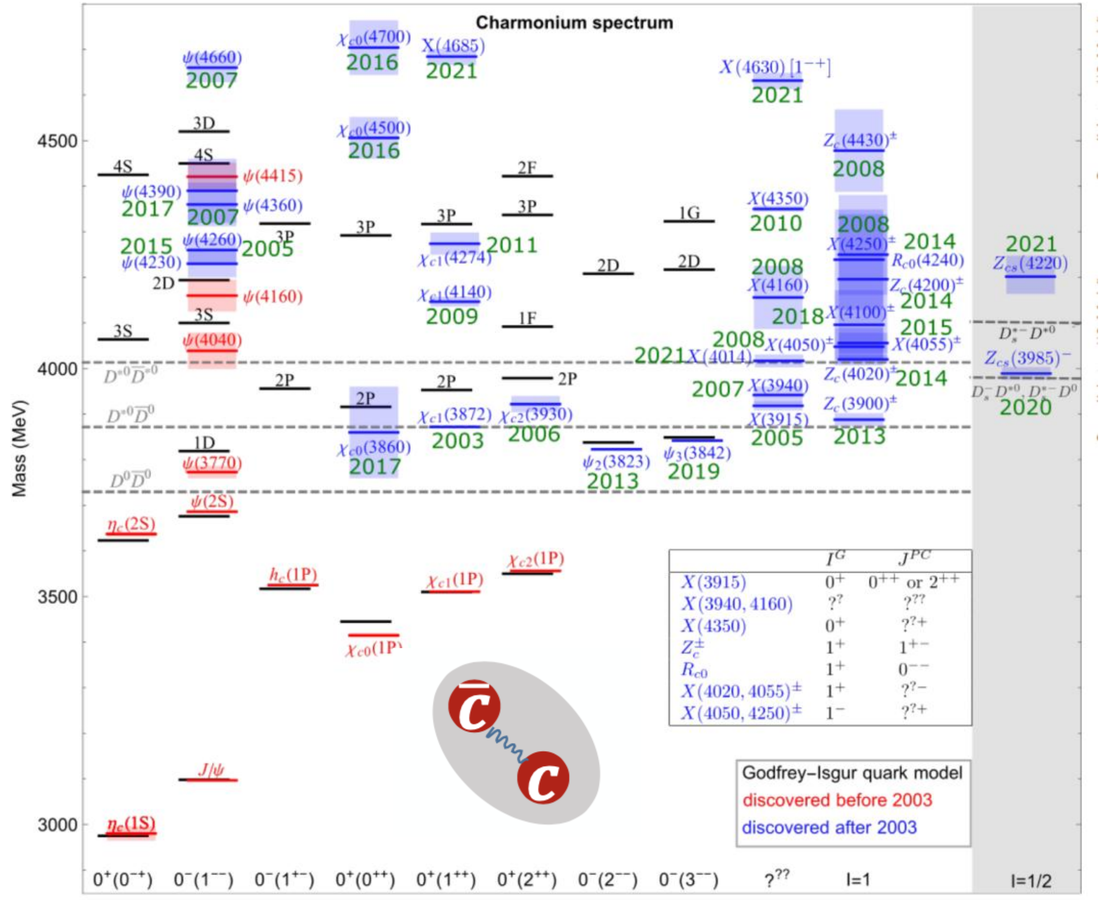
convential hadron



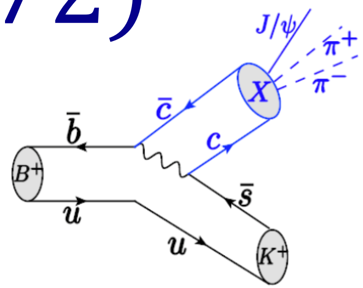
(q $\bar{q}$)   (qqq)

Exotic





Background Observation of $X(3872)$



Observation of a narrow charmonium-like state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays

#8

Belle Collaboration • S.K. Choi (Gyeongsang Natl. U.) et al. (Sep, 2003)

Published in: Phys.Rev.Lett. 91 (2003) 262001 • e-Print: hep-ex/0309032 [hep-ex]

pdf links DOI cite claim reference search 2,944 citations

- $J^{PC} = 1^{++}$.
- Close to $\overline{D^{*0}}D^0$ / $\overline{D^0}D^{*0}$ thresholds

PDG $J/\psi X$ mode : 3871.64 ± 0.06 MeV

$D\bar{D}\pi$ mode:

$3873.71^{+0.56}_{-0.50} \pm 0.13$			[1] HIRATA	23	BELL
$3872.9\ ^{+0.6}_{-0.4}\ ^{+0.4}_{-0.5}$	50		[2,3] AUSHEV	10	BELL
$3875.1\ ^{+0.7}_{-0.5} \pm 0.5$	33 ± 6		[3] AUBERT	08B	BABR
$3875.2 \pm 0.7\ ^{+0.9}_{-1.8}$	24 ± 6		[3,4] GOKHROO	06	BELL

$m_{\psi(2S)} = 3686.097$MeV

$\Delta m = 185.598 \pm 0.067 \pm 0.068$ MeV,
$\Gamma_{BW} = 1.39 \pm 0.24 \pm 0.10$ MeV,

inspired model, the mod

mode$=3871.69^{+0.00+0.05}_{-0.04-0.13}$ MeV,
FWHM$=0.22^{+0.07+0.11}_{-0.06-0.13}$ MeV.

Ar

$m_{D^0} = 1864.84 \pm 0.05$ MeV

$m_{D^{*0}} = 2006.85 \pm 0.05$ MeV

$m_{D^0} + m_{D^{*0}} = 3871.69 \pm 0.07$ MeV

- Close to $c\bar{c}(2^3P_1)$: m=3953.5 MeV

$\delta m = m_{\chi_{c1}(2P)} - m_{X(3872)} = 81.35$ MeV

Phys. Rev. D 32, 189 (1985).

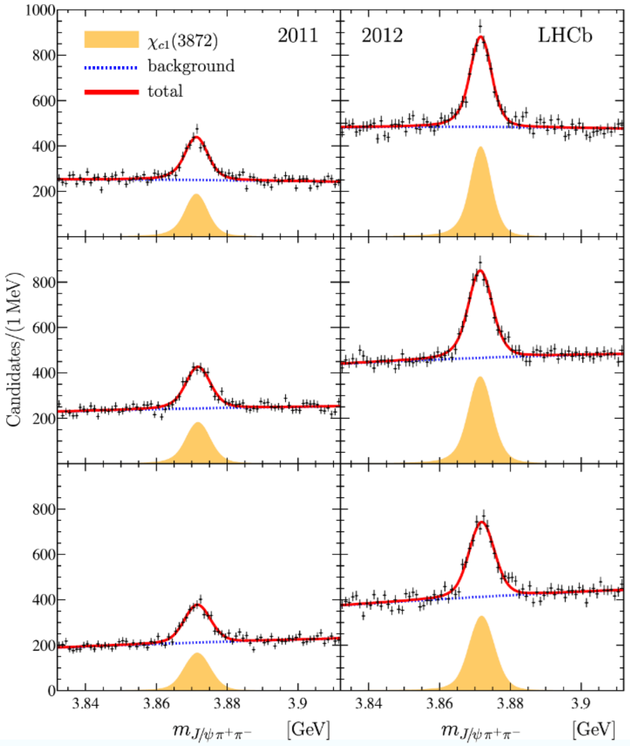


FIG. 2. Mass distributions for $J/\psi\pi^+\pi^-$ candidates in the $\chi_{c1}(3872)$ region for (top) the low, (middle) mid and (bottom) high $p_{\pi^+\pi^-}$ bins. The left- (right-) hand plot is for 2011 (2012) data. The projection of the fit described in the text is superimposed.

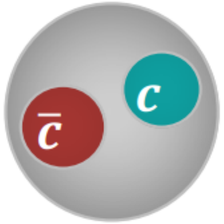
LHCb PRD 102, 092005 (2020)

- ***Complicated coupled-channel effect: $\bar{c}c$ & $\overline{D^*}D$ / $\overline{D}D^*$***

Background

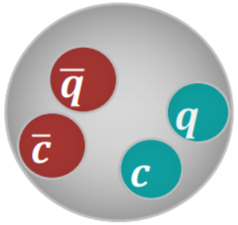
Conventional $\bar{c}c$: $\chi_{c1}(2P)$.

Eichten ,Lane, Quigg, Suzuki, Barnes, Godfrey,...



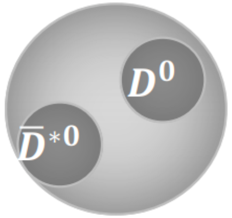
Compact tetraquark state.

Close, Maiani, Piccinini, Polosa, Riquer,...



The $\overline{D^*}D$ $/\overline{D}D^*$ molecular state.

Swanson, Wong, Guo, liu,....



the $\bar{c}c$ core + $\overline{D^*}D$ $/\overline{D}D^*$

Chao, H. Q. Zheng, Yu. S. Kalashnikova, P. G. Ortega...

Parameter index	Decay mode	Branching fraction
1	$X(3872) \to \pi^+\pi^- J/\psi$	$(4.1^{+1.9}_{-1.1})\%$
2	$X(3872) \to D^{*0}\bar{D}^0 + \text{c.c.}$	$(52.4^{+25.3}_{-14.3})\%$
3	$X(3872) \to \gamma J/\psi$	$(1.1^{+0.6}_{-0.3})\%$
4	$X(3872) \to \gamma\psi(3686)$	$(2.4^{+1.3}_{-0.8})\%$
5	$X(3872) \to \pi^0\chi_{c1}$	$(3.6^{+2.2}_{-1.6})\%$
6	$X(3872) \to \omega J/\psi$	$(4.4^{+2.3}_{-1.3})\%$
7	$B^+ \to X(3872)K^+$	$(1.9 \pm 0.6) \times 10^{-4}$
8	$B^0 \to X(3872)K^0$	$(1.1^{+0.5}_{-0.4}) \times 10^{-4}$
	$X(3872) \to \text{unknown}$	$(31.9^{+18.1}_{-31.5})\%$

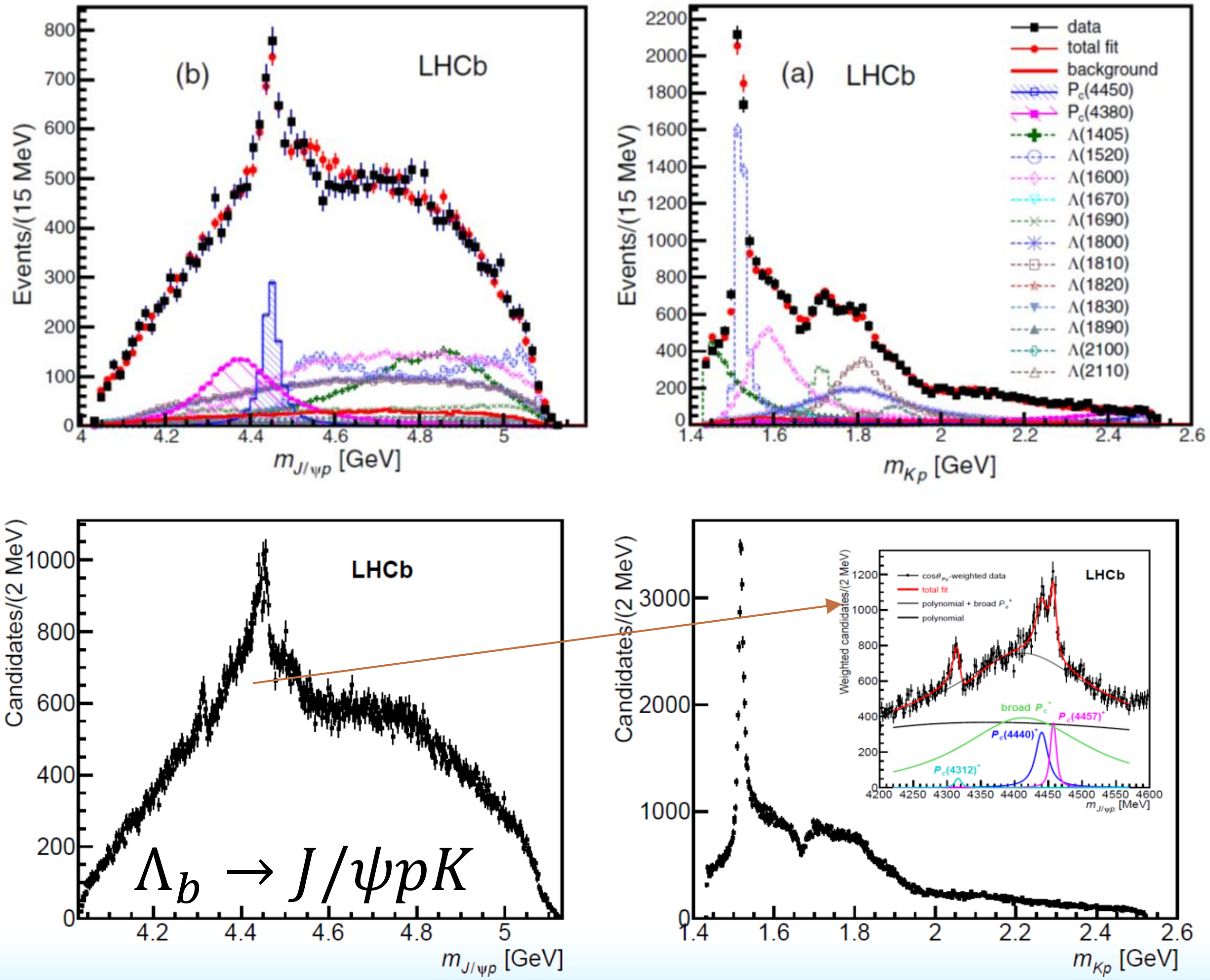
C. H. Li, C. Z. Yuan, Phys. Rev. D 100, 094003

G.-J. Wang, Z. Yang, J.-J Wu, M. Oka, S.-L. Zhu
***Sci.Bull.* 69 (2024) 3036-3041**

Large uncertainties of parameters: may describe a specific state

Various theoretical models but lack of experimental data & Lattice data.

Background Observation of P_c and P_{cs}



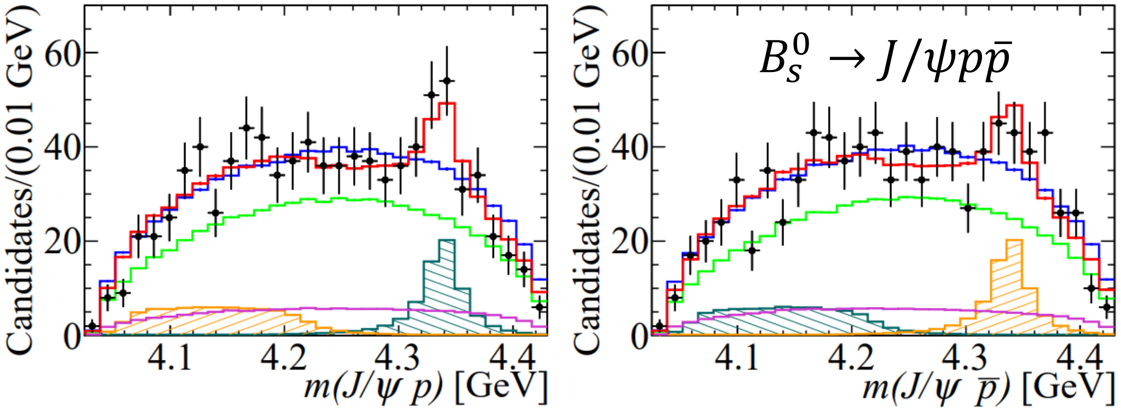
Pc(4312)	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+3.7}_{-4.5}$
Pc(4440)	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+8.7}_{-10.5}$
Pc(4457)	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+5.7}_{-1.9}$

LHCb

PRL 115 (2015) 072001 **citation 2137**

PRL 122 (2019) 222001 **citation 1030**

PRL 128 (2022) 6, 062001 **citation 175**



$$M_{P_c} = 4337\ ^{+7}_{-4}\ ^{+2}_{-2}\ \text{MeV},$$

$$\Gamma_{P_c} = 29\ ^{+26}_{-12}\ ^{+14}_{-14}\ \text{MeV},$$

Background Observation of P_c and P_{cs}

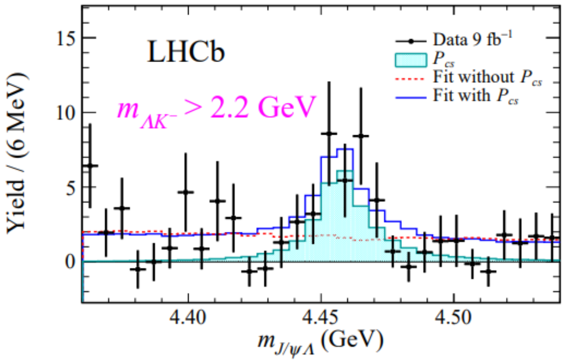
$P_{cs}(4459)$ $\Xi_b^- \to J/\psi\Lambda K^-$

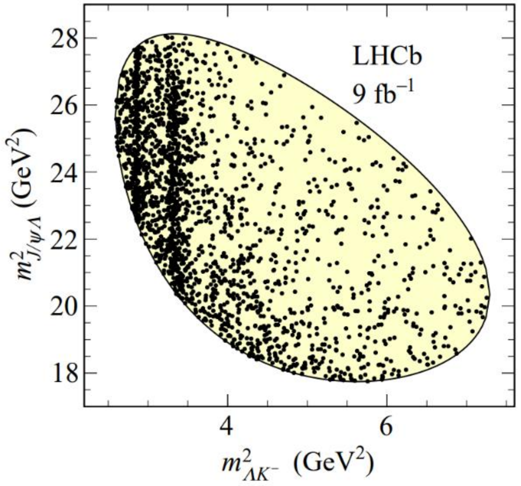
Sci.Bull. 66 (2021) 1278-1287

$4458.8 \pm 2.9^{+4.7}_{-1.1}$ MeV

$17.3 \pm 6.5^{+8.0}_{-5.7}$ MeV

P $\sim 3\sigma$





$P_{cs}(4338)$ $B^- \to J/\psi\Lambda\bar{p}$

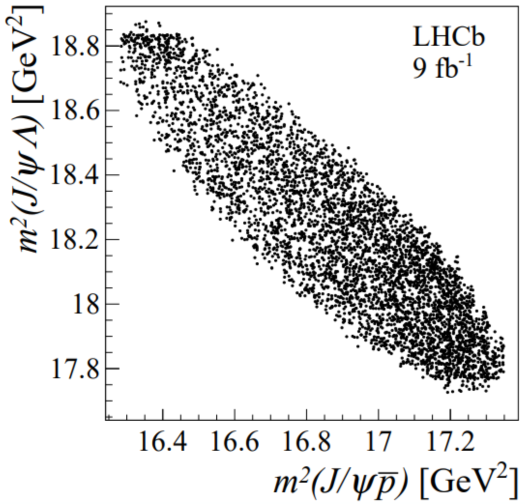
arXiv:2210.10346

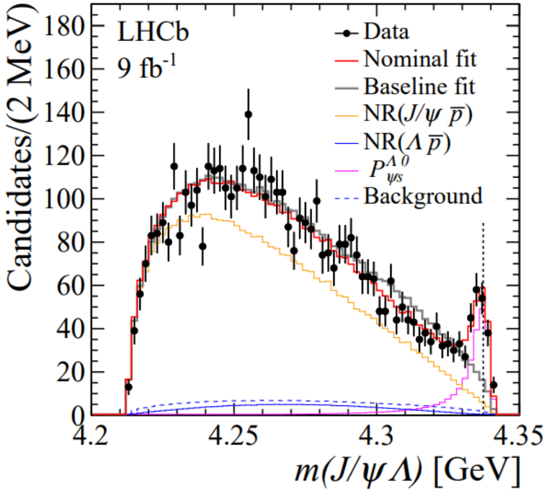
$4338.2 \pm 0.7 \pm 0.4$MeV

$7.0 \pm 1.2 \pm 1.3$MeV

P $> 15\sigma$

$J^P = \frac{1}{2}^-$





P_c & P_{cs}

ONLY LHCb??

University of Chinese Academy of Sciences

Background Observation of P_c and P_{cs}

Search for a pentaquark state decaying into pJ/ψ in Υ(1, 2S) inclusive decays at Belle #1

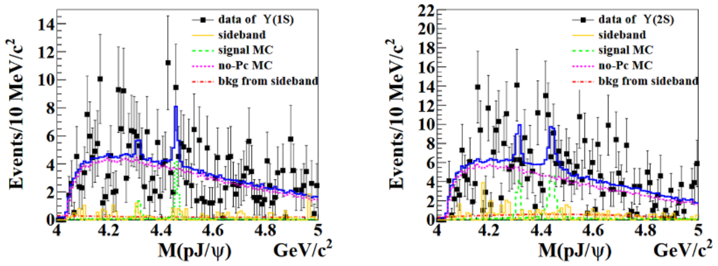
Belle Collaboration • X. Dong et al. (Mar 7, 2024)

Published in: *JHEP* 09 (2025) 048 • e-Print: 2403.04340 [hep-ex]

pdf DOI cite claim reference search 12 citations

P_c & P_{cs} ONLY LHCb??

BELLE data $\Upsilon(1S,2S)$ decays to pJ/ψ



No pentaquarks are found – only very slight excesses in the place of the LHCb results

$B(\Upsilon(1S) \to pJ/\psi + X) = (4.27 \pm 0.16 \pm 0.20) \times 10^{-5}$

$B(\Upsilon(2S) \to pJ/\psi + X) = (3.59 \pm 0.14 \pm 0.16) \times 10^{-5}$

$\sigma(pJ/\psi + X) = (57.5 \pm 2.1 \pm 2.5)$ fb at 10.52 GeV

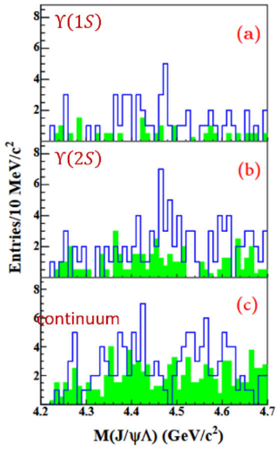
X. Dong et al, arXiv:2403.04340

$$\mathcal{B}[\Upsilon(1S) \to P_c(4312)^+ + anything] \cdot \mathcal{B}[P_c(4312)^+ \to pJ/\psi] < 3.9 \times 10^{-6},$$
$$\mathcal{B}[\Upsilon(1S) \to P_c(4440)^+ + anything] \cdot \mathcal{B}[P_c(4440)^+ \to pJ/\psi] < 6.2 \times 10^{-6},$$
$$\mathcal{B}[\Upsilon(1S) \to P_c(4457)^+ + anything] \cdot \mathcal{B}[P_c(4457)^+ \to pJ/\psi] < 5.5 \times 10^{-6},$$
$$\mathcal{B}[\Upsilon(2S) \to P_c(4312)^+ + anything] \cdot \mathcal{B}[P_c(4312)^+ \to pJ/\psi] < 4.7 \times 10^{-6},$$
$$\mathcal{B}[\Upsilon(2S) \to P_c(4440)^+ + anything] \cdot \mathcal{B}[P_c(4440)^+ \to pJ/\psi] < 7.2 \times 10^{-6},$$
$$\mathcal{B}[\Upsilon(2S) \to P_c(4457)^+ + anything] \cdot \mathcal{B}[P_c(4457)^+ \to pJ/\psi] < 2.6 \times 10^{-6},$$

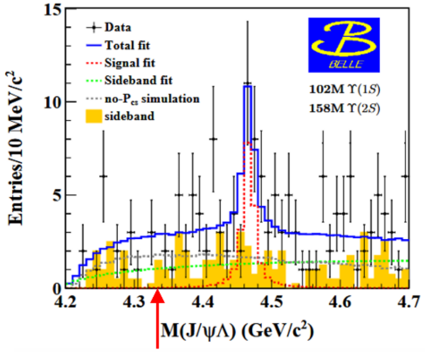
10

BELLE data $\Upsilon(1S,2S)$ decays to $\Lambda J/\psi$

PRELIMINARY



Green – sidebands Blue - signal



Peak observed in the region of the $P_{c\bar{c}s}(4459)^0$

Assuming it to be the same particle, the significance is 3.3 σ

Assuming it is NOT the same particle, Belle finds 3.8 σ

$M = 4471.7 \pm 4.8 \pm 0.6$ MeV/c²

$\Gamma = 21.9 \pm 13.1 \pm 2.7$ MeV

note that LHCb found

$M = 4458.8 \pm 2.9^{+4.7}_{-1.1}\ MeV/c^2$

$\Gamma = 17.3 \pm 6.5^{+8.0}_{-4.7}\ MeV$

No sign of the 4338

The data shows the first observation of $\Upsilon(1S)$, $\Upsilon(2S)$ decays into $\Lambda J/\psi$ final states and makes measurements of their branching fractions

arXiv:2502.09951

11

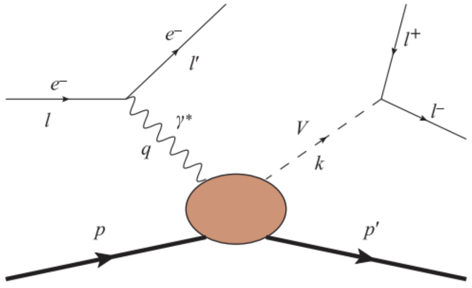
HADRON2025, John Yelton's talk

Searching Exotic in EicC

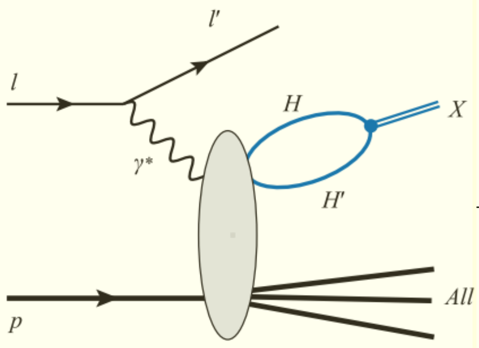
Table 2.3 Estimated event numbers that can be collected at EicC assuming an integrated luminosity of 50 fb^{-1}. The lepton pairs l^+l^- denote both $\mu^+\mu^-$ and e^+e^-. The event numbers are estimated using the assumed detection efficiencies listed in the third column, which are expected to be higher in the middle rapidity than that in the forward region.

Exotic states	Production/decay processes	Detection efficiency	Expected events
$P_c(4312)$	$ep \to eP_c(4312)$ $P_c(4312) \to pJ/\psi$ $J/\psi \to l^+l^-$	$\sim$30%	15−1450
$P_c(4440)$	$ep \to eP_c(4440)$ $P_c(4440) \to pJ/\psi$ $J/\psi \to l^+l^-$	$\sim$30%	20−2200
$P_c(4457)$	$ep \to eP_c(4457)$ $P_c(4457) \to pJ/\psi$ $J/\psi \to l^+l^-$	$\sim$30%	10−650
P_b(narrow)	$ep \to eP_b$(narrow) P_b(narrow) $\to p\Upsilon$ $\Upsilon \to l^+l^-$	$\sim$30%	0−20
P_b(wide)	$ep \to eP_b$(wide) P_b(wide) $\to p\Upsilon$ $\Upsilon \to l^+l^-$	$\sim$30%	0−200
$\chi_{c1}(3872)$	$ep \to e\chi_{c1}(3872)p$ $\chi_{c1}(3872) \to \pi^+\pi^- J/\psi$ $J/\psi \to l^+l^-$	$\sim$50%	0−90
$Z_c(3900)^+$	$ep \to eZ_c(3900)^+n$ $Z_c^+(3900) \to \pi^+ J/\psi$ $J/\psi \to l^+l^-$	$\sim$60%	90−9300

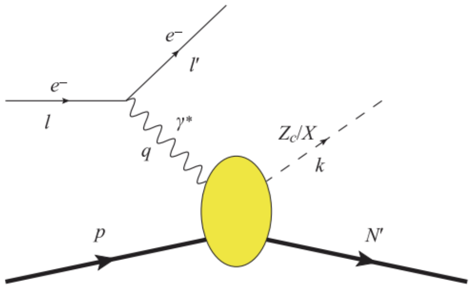
Front. Phys. 16(6), 64701 (2021)



$$ep \to e[P_c] \to e[Vp'] \to e[l^+l^-p']$$



$$ep \to e[X]\text{All}$$



$$ep \to e[X]N'$$

	Constituents	$IJ^{P(C)}$	EicC
$X(3872)$	$D\bar{D}^*$	01^{++}	21(89)
$Z_c(3900)^0$	$D\bar{D}^*$	11^{+-}	$0.4\times10^3(1.3\times10^3)$
$Z_c(3900)^+$	$D^{*+}\bar{D}^0$	11^+	$0.3\times10^3(1.0\times10^3)$
$Z_c(4020)^0$	$D^*\bar{D}^*$	11^{+-}	$0.2\times10^3(0.6\times10^3)$
Z_{cs}^-	$D^{*0}D_s^-$	$\frac{1}{2}1^+$	19(69)
Z_{cs}^{*-}	$D^{*0}D_s^{*-}$	$\frac{1}{2}1^+$	14(51)
$P_c(4312)$	$\Sigma_c\bar{D}$	$\frac{1}{2}\frac{1}{2}^-$	0.8(4.1)
$P_c(4440)$	$\Sigma_c\bar{D}^*$	$\frac{1}{2}\frac{3}{2}^-$	0.7(4.7)
$P_c(4457)$	$\Sigma_c\bar{D}^*$	$\frac{1}{2}\frac{1}{2}^-$	0.6(2.2)
$P_c(4380)$	$\Sigma_c^*\bar{D}$	$\frac{1}{2}\frac{3}{2}^-$	1.6(8.4)
$P_c(4524)$	$\Sigma_c^*\bar{D}^*$	$\frac{1}{2}\frac{1}{2}^-$	0.8(3.9)
$P_c(4518)$	$\Sigma_c^*\bar{D}^*$	$\frac{1}{2}\frac{3}{2}^-$	1.2(6.9)
$P_c(4498)$	$\Sigma_c^*\bar{D}^*$	$\frac{1}{2}\frac{5}{2}^-$	1.2(9.8)
P_{cs}	$\Xi_c\bar{D}$	$0\frac{1}{2}^-$	0.1 (1.6)
P_{cs}	$\Xi_c\bar{D}^*$	$0\frac{1}{2}^-$	0.1 (0.5)
P_{cs}	$\Xi_c\bar{D}^*$	$0\frac{3}{2}^-$	0.1 (0.9)
	$\Lambda_c\bar{\Lambda}_c$	00^{-+}	0.3 (3.0)
	$\Lambda_c\bar{\Sigma}_c$	10^-	0.01 (0.12)
	$\Lambda_c\bar{\Xi}_c$	$\frac{1}{2}0^-$	0.01 (0.14)

Table 1.8: Integrated cross sections (in units of pb) for $e^- + p \to X$ + all, where X = $X(3872)$, $Z_c(3900)^{0/+}$, $Z_c(4020)$, P_c states, P_{cs} states, and dibaryons. The listed quantum numbers for these states are those in the considered hadronic molecular model. Results outside (inside) brackets are obtained using cutoff Λ = 0.5 GeV (1 GeV), respectively.

$\gamma p \to J/\psi p$ or Υp for searching Pc

[1] Y. Huang, J. He, H.-F. Zhang, and X.-R. Chen, JPG 41, 115004 (2014).
[2] Q. Wang, X.-H. Liu, and Q. Zhao, PRD92, 034022 (2015).
[3] V. Kubarovsky and M. B. Voloshin, PRD92, 031502 (2015).
[4] M. Karliner and J. L. Rosner, PLB752, 329 (2016).
[5] Hiller Blin, Fernandez-Ramirez, Jackura, Mathieu, Mokeev, Pilloni,and Szczepaniak, PRD 94, 034002 (2016).
[6] E. Ya. Paryev and Yu. T. Kiselev, NPA978, 201 (2018).
[7] X.-Y. Wang, X.-R. Chen, J. He, PRD 99,114007 (2019)
[8] Xu Cao and Jian-ping Dai, PRD 100, 054033 (2019)
[9] J.-J. Wu, T.-S.H. Lee, B.-S. Zou PRC 100, 035206 (2019)
[10] Zhi Yang, Xu Cao, Yu-Tie Liang, Jia-Jun Wu CPC 44, No. 8 (2020) 084102
[11] ML Du, V Baru, FK Guo, C Hanhart, U-G Meißner, A Nefediev, and I Strakovsky, EPJC 80, 1053 (2020)
[12] X. Wang, X. Cao, A.-q. Guo, L. Gong, X.-S. Kang, Y.-T. Liang, J.-J. Wu, and Y.-P. Xie arXiv:2311.07008
[13] T. S. H. Lee, S. Sakinah, and Y. Oh, Eur. Phys. J. A 58, 252 (2022).
[14] Ming-Xiao Duan, Chang Gong, Lin Qiu, Qiang Zhao, 2409.10364
[16] L. Tang, Y.-X. Yang, Z.-F. Cui, C.D. Roberts, PLB 856, 138904 (2024)
[17] Xu Zhang, Eur.Phys.J.C 85 (2025) 10, 1120
[18] Sang-Ho Kim, PLB 868 (2025) 139725
[19] Lin Tang, Hui-Yu Xing, Minghui Ding, Craig D. Roberts EPJC 86 (2026) 3, 284
……

4.4 估计能够寻找超重核子激发态的实验截面

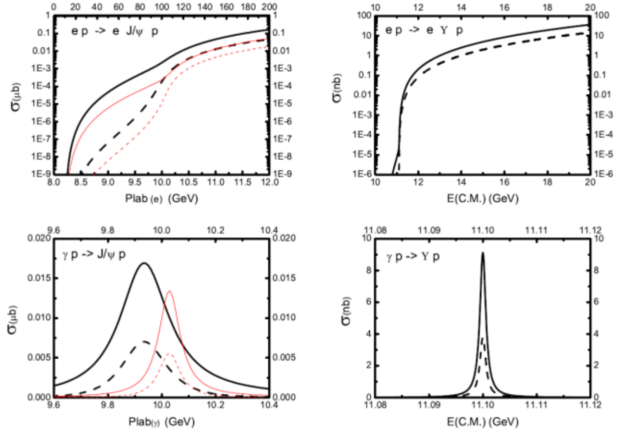
在前文中，我们已经预言了 $N^*_{c\bar{c}}$ 和 $N^*_{b\bar{b}}$ 的质量和宽度，下面我们在 pp，$p\bar{p}$，ep 和 γp 四类反应中估计 N^* 的产额，为实验寻找这些奇异的超重核子与超子激发态提供依据。针对即将在Fair进行的 $\bar{P}ANDA$ 实验，$\bar{P}$ 束流的动能高达 15 GeV；以及在美国Jefferson国家实验室电子动能高达 12 GeV的 ep 散射。特地估计了以下四类反应：

1) $pp \to pp\eta_c$，$p\bar{p} \to p\bar{p}\eta_c$，$pp \to pp\eta_b$，$p\bar{p} \to p\bar{p}\eta_b$；

2) $pp \to ppJ/\psi$，$p\bar{p} \to p\bar{p}J/\psi$，$pp \to pp\Upsilon$，$p\bar{p} \to p\bar{p}\Upsilon$；

3) $ep \to epJ/\psi$，$ep \to ep\Upsilon$；

4) $\gamma p \to pJ/\psi$，$\gamma p \to p\Upsilon$。



1. Resonances? or Kinematics effects (Threshold & TS)?

No Threshold & TS effect because two bodies final state.

2. If Resonances confirmed, what is the internal structure ?

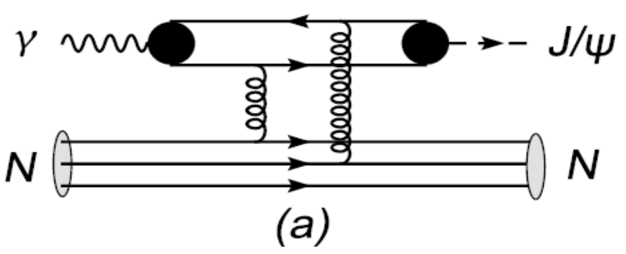
Meson-Baryon molecule or 5 quark configuration state ?

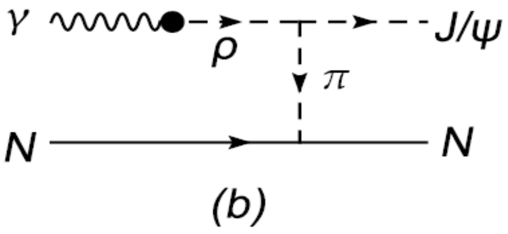
Decay width of channels

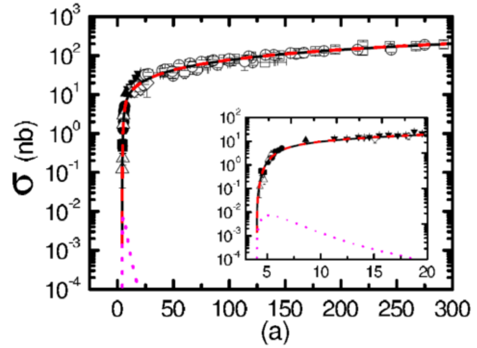
3. What the spin and parity (J^p) ?

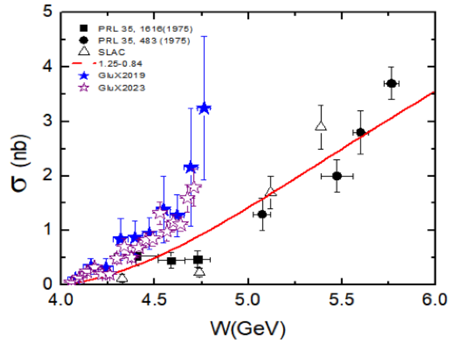
Angular differential cross section, Two body vs Three body

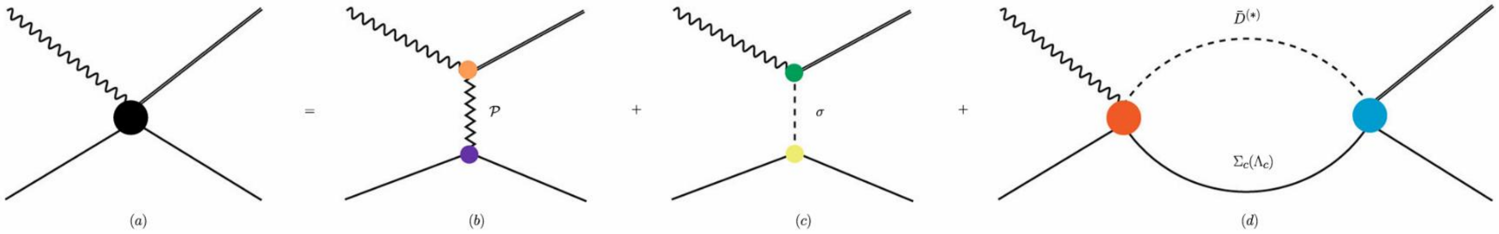
The background of $\gamma p \to J/\psi p$

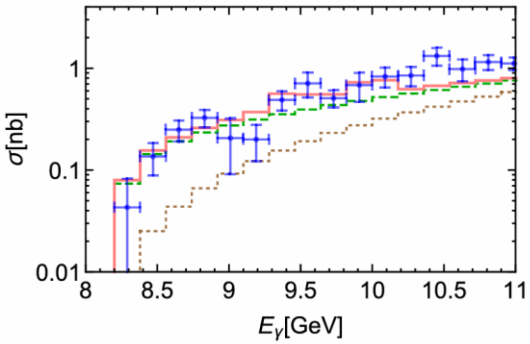


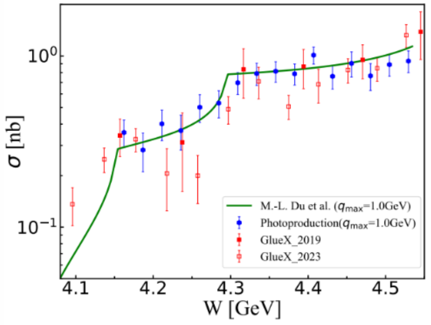








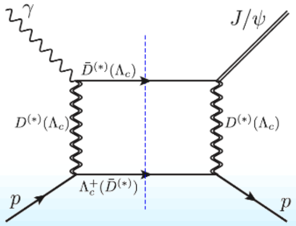




J.-J Wu, T.-S.H. Lee, B.-S. Zou, PRC 100, 035206 (2019)
Lin Tang, Hui-Yu Xing, Minghui Ding, Craig D. Roberts EPJC 86 (2026) 3, 284
L. Tang, Y.-X. Yang, Z.-F. Cui, C.D. Roberts, PLB 856, 138904 (2024)

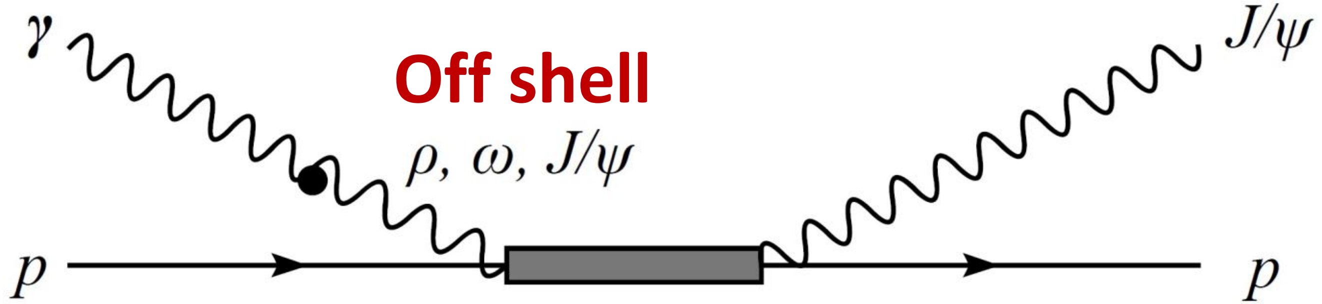
Xu Zhang, Eur.Phys.J.C 85 (2025) 10, 1120

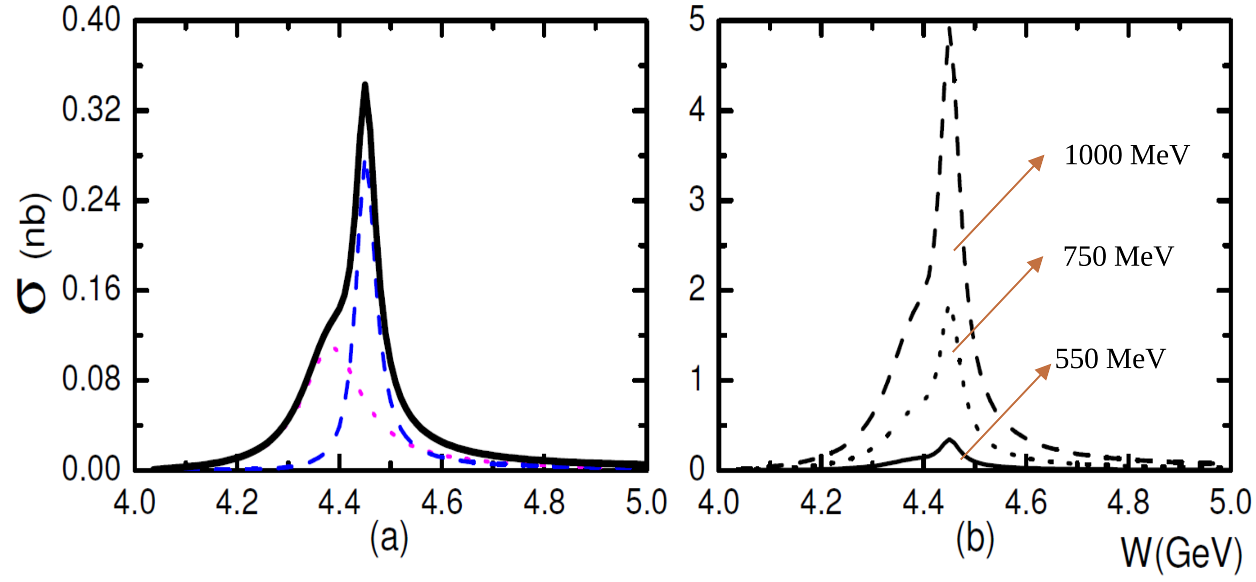
T.-S.H. Lee, S. Sakinah, Yongseok Oh EPJA 58 (2022) 12, 252

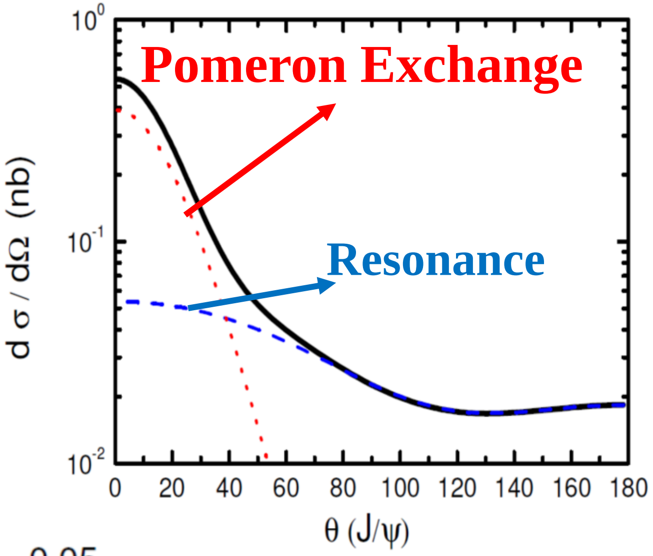


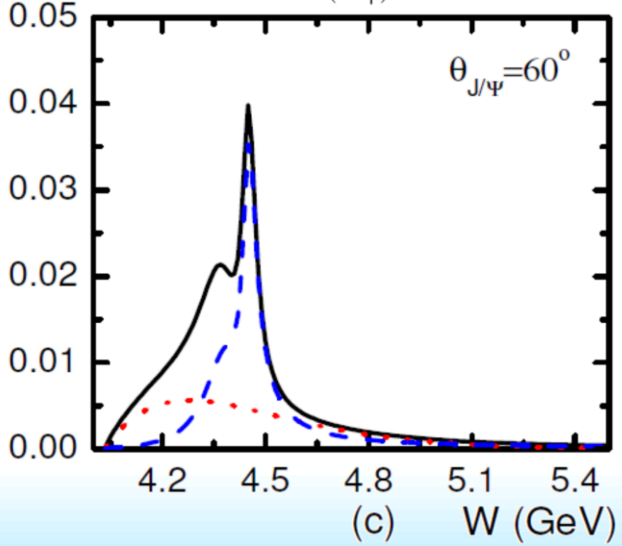
ML Du, V Baru, FK Guo, C Hanhart, U-G Meißner, A Nefediev, and I Strakovsky, EPJC 80, 1053 (2020)

The pentaquark state for $\gamma p \to J/\psi p$



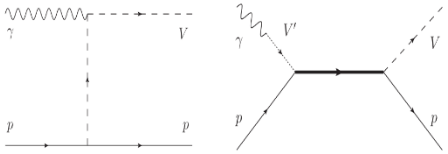






J.-J Wu, T.-S.H. Lee, B.-S. Zou, PRC 100, 035206 (2019)

$\gamma p \to P_b \to \Upsilon p$



- P_b

Physics Letters B 709 (2012) 70–76

Contents lists available at SciVerse ScienceDirect

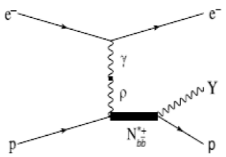
Physics Letters B

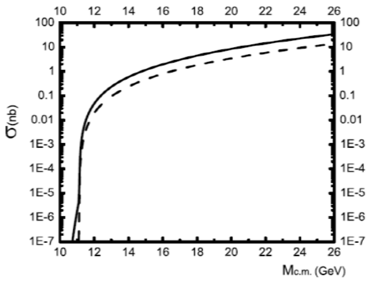
www.elsevier.com/locate/physletb

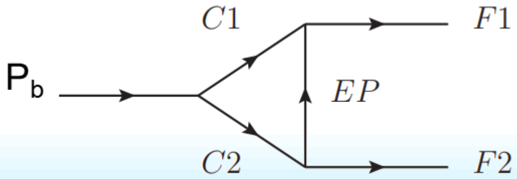
Prediction of super-heavy N^* and Λ^* resonances with hidden beauty

Jia-Jun Wu[a,*], Lu Zhao[a], B.S. Zou[a,b]

M (MeV)	Γ (MeV)	Γ_i (MeV)					
		πN	ηN	$\eta' N$	$K\Sigma$	$\eta_b N$	
11052	1.38	0.10	0.21	0.11	0.42	0.52	$1/2^-$
		ρN	ωN	$K^*\Sigma$	ΥN		
11100	1.33	0.09	0.30	0.39	0.51		$1/2^-$, $3/2^-$

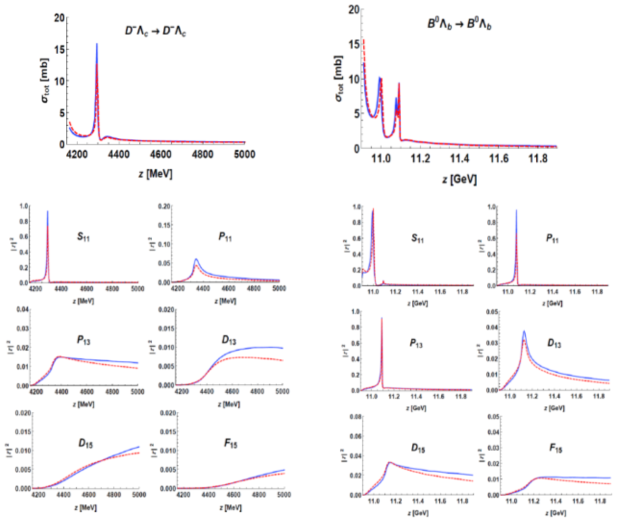






$\bar{D}\Lambda_c - \bar{D}\Sigma_c$ and $B\Lambda_b - B\Sigma_b$ dynamical coupled channel study

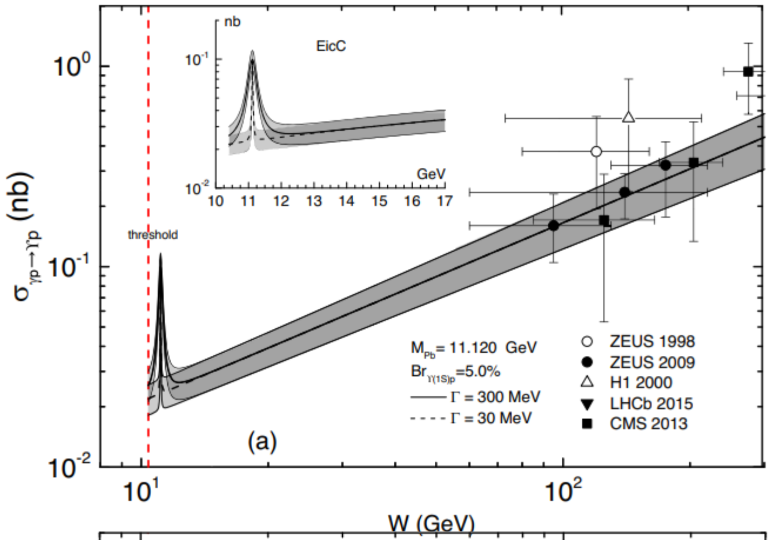
C.W.Shen, Roechen, Meissner, Zou, CPC42(2018) 023106

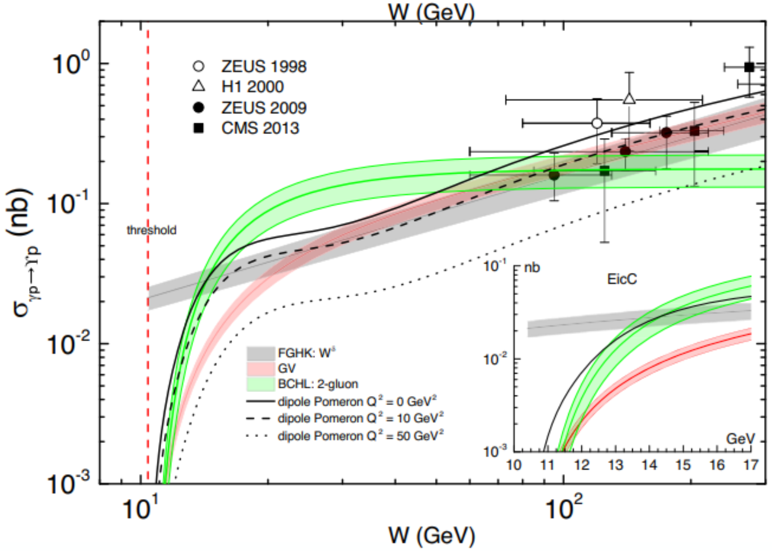


More pentaquarks with hidden beauty than with hidden charm

Mode	Widths (MeV)		
	$J^P = 3/2^-$		$J^P = 1/2^-$
	$B\Sigma_b^*$	$B^*\Sigma_b$	$B^*\Sigma_b$
$B^*\Lambda_b$	271.1	19.9	167.0
Υp	0.3	0.04	0.1
ρN	5.5	0.02	0.1
ωp	20.9	0.07	0.4
$B\Lambda_b$	-	7.3	135.9
$B\Sigma_b$	-	-	-
$\eta_b p$	0.02	0.0001	0.0009
$\chi_{b0} p$	1.4	0.0008	0.2
πN	0.7	0.005	0.003
$B\Sigma_b^*$	-	-	-
Total	299.9	27.4	303.8

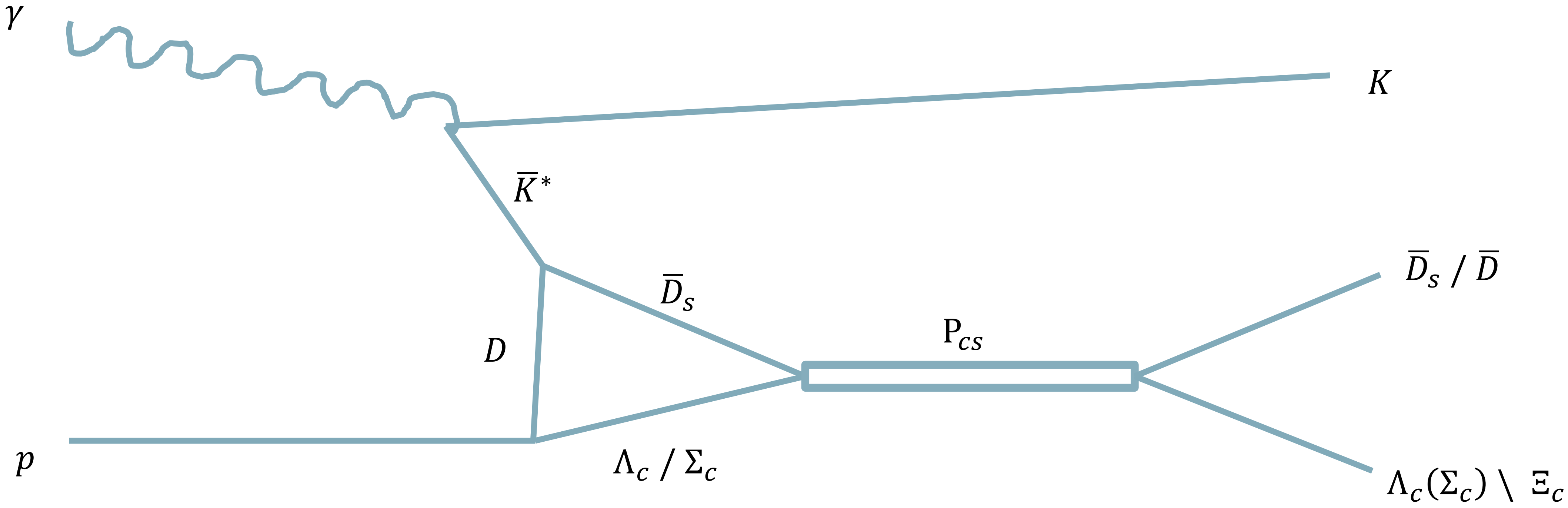
Y. H. Lin, C.W. Shen, B.S. Zou NPA 980 21 (2018)



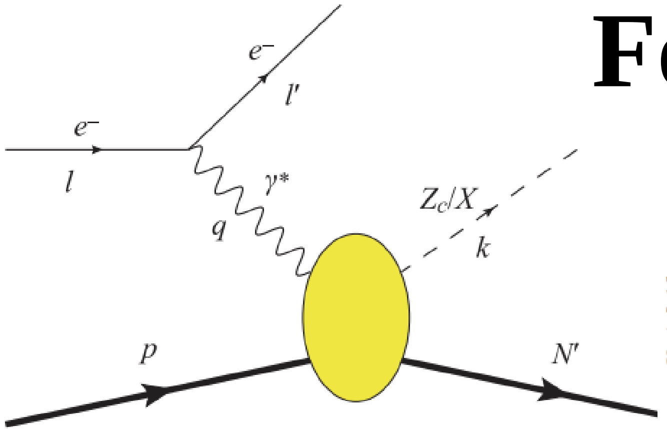


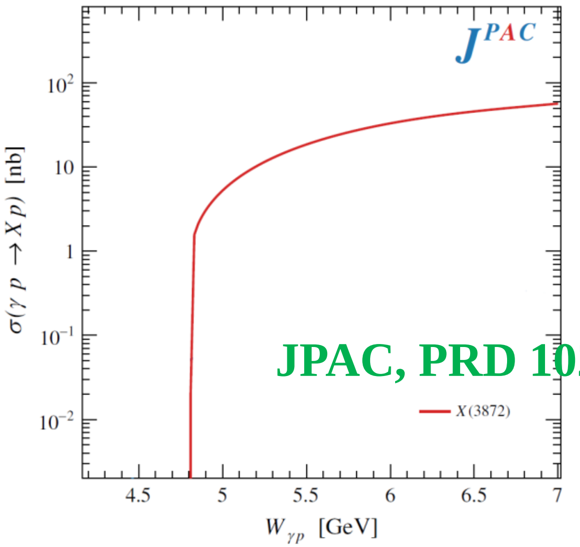
X. Cao, F.-K. Guo, Y.-T. Liang, J.-J. Wu, J.-J. Xie, Y.-P. Xie, Z. Yang, and B.-S. Zou PRD 101 (2020) 7, 074010

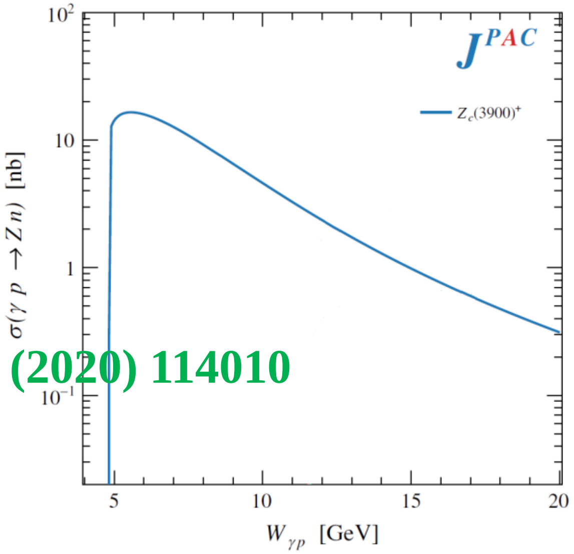
$\gamma p \to K P_{cs} \to K\ \Xi_c \bar{D} / \Lambda_c \bar{D}_s$



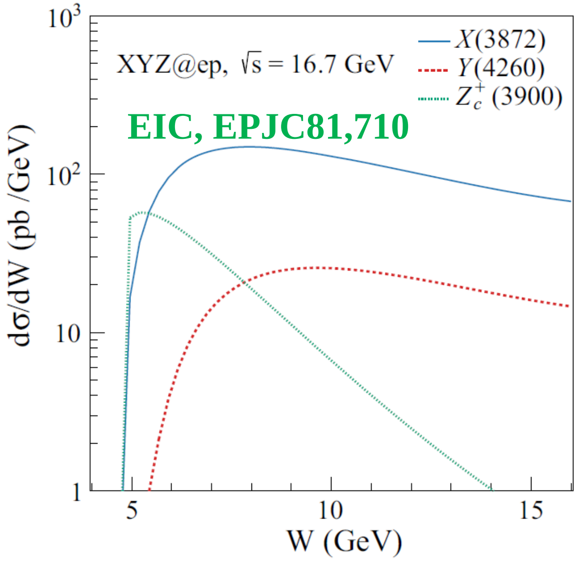
For X(3872) and Zc(3900)





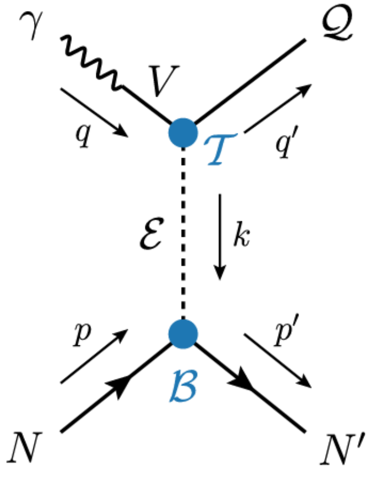


JPAC, PRD 102 (2020) 114010

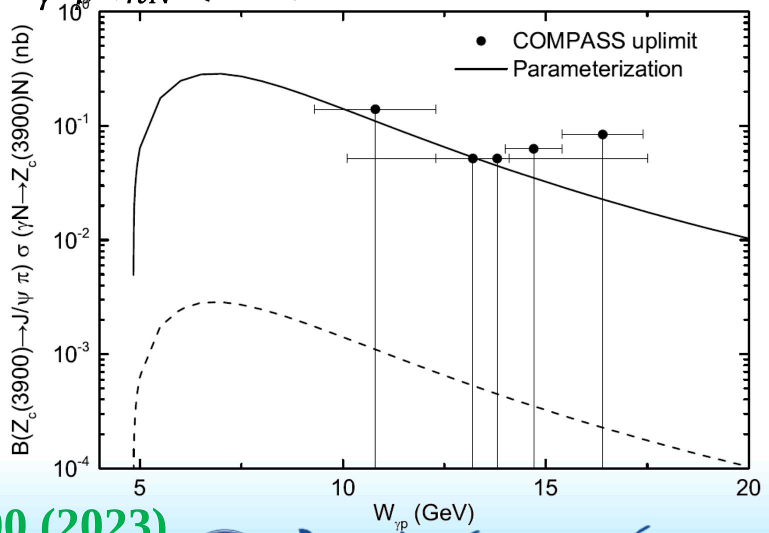


EIC, EPJC81,710

$$ep \to eX(3872)p$$
$$ep \to eZ_c(3900)n$$



$\sigma_{\gamma^* p\to hN'}(W,Q^2)$ is the cross section of exotics photon-production



$$\sigma_{\gamma N\to X(3872)N'}\mathcal{B}_{X(3872)\to J/\psi\pi\pi} < 2.9 \text{ pb}$$
$$(\text{CL} = 90\%) \quad \sqrt{s_{\gamma N}} = 13.7 \text{ GeV}$$

COMPASS, PLB 783, 334 (2018)

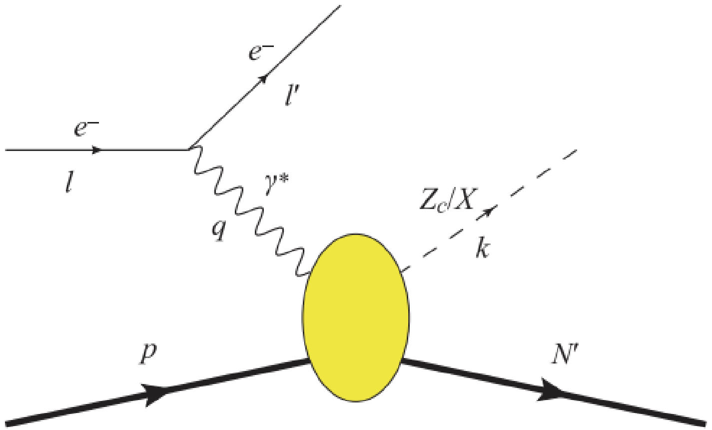
Upper limits for $Z_c^{\pm}(3900)$ production rate for intervals of $\sqrt{s_{\gamma N}}$.

Interval	$\langle\sqrt{s_{\gamma N}}\rangle$, GeV	$BR(J/\psi\pi)\times\sigma_{Z_c}/\sigma_{J/\psi}$, 10^{-3}
Full	13.8	3.7
$\sqrt{s_{\gamma N}}$ < 12.3 GeV	10.8	10
12.3 GeV < $\sqrt{s_{\gamma N}}$ < 14.1 GeV	13.2	3.7
14.1 GeV < $\sqrt{s_{\gamma N}}$ < 15.4 GeV	14.7	4.5
15.4 GeV < $\sqrt{s_{\gamma N}}$	16.4	6.0

Xu Cao Front. Phys. 18(4), 44600 (2023)

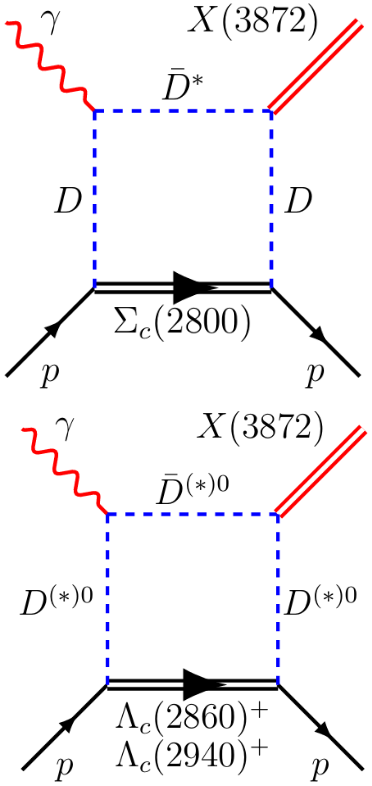
COMPASS, PLB 742, 330 (2015)

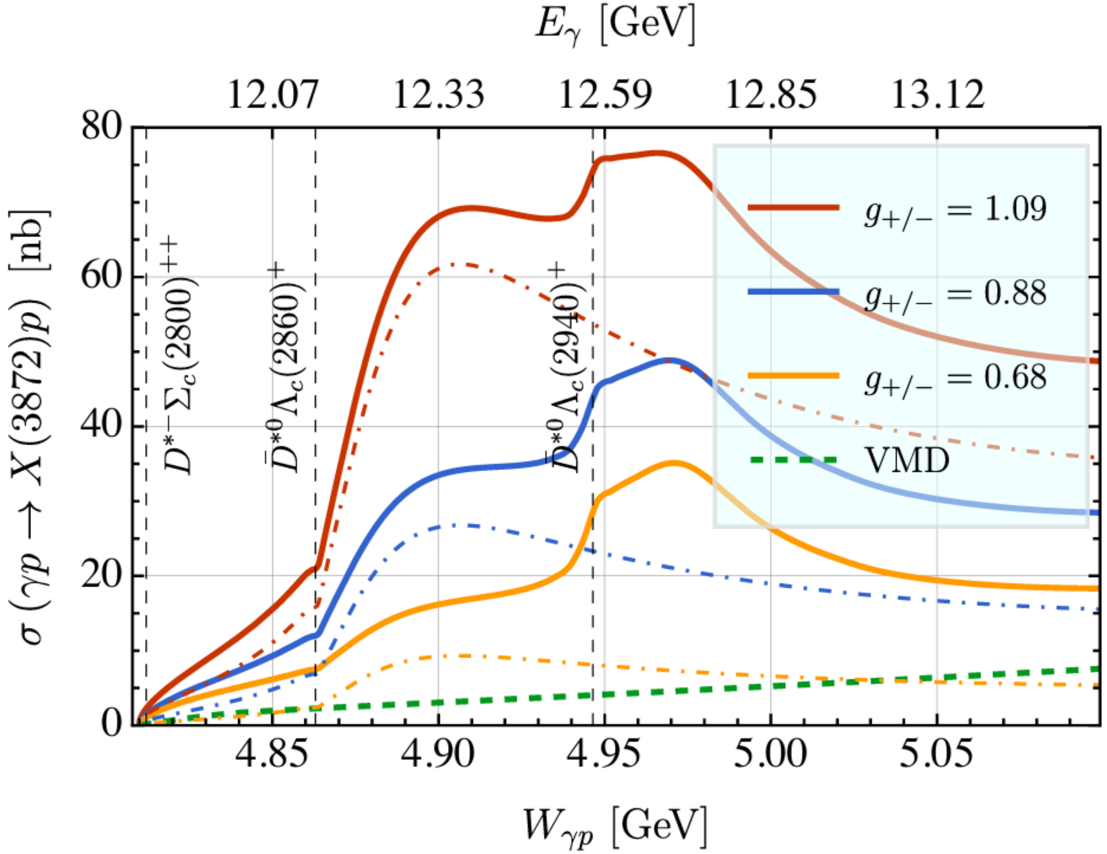
For X(3872) and Zc(3900)



$$ep \to eX(3872)p$$

$$ep \to eZ_c(3900)n$$

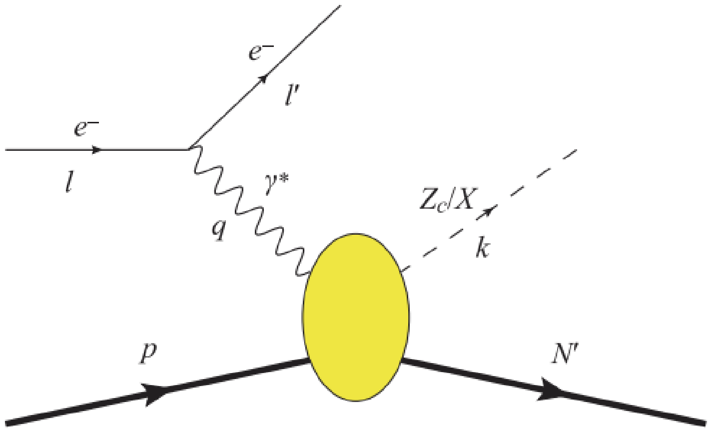




Xiong-Hui Cao, Meng-Lin Du, and Feng-Kun Guo. JPG, 51(10):105002, 2024.

JPAC, PRD 102, 114010 (2020)

Simulation



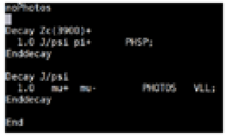
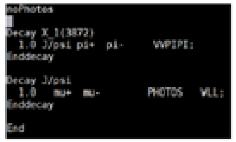
$$ep \rightarrow eX(3872)p$$

$$ep \rightarrow eZ_c(3900)n$$

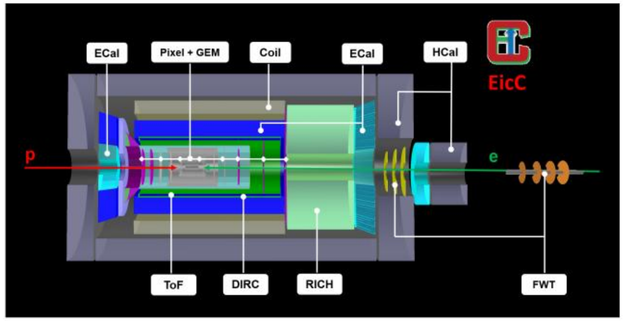
$$\sigma(ep \rightarrow ehN') = \int dkdQ^2 \frac{d^2N(k,Q^2)}{dkdQ^2}\sigma_{\gamma^* p\rightarrow hN'}(W,Q^2)$$

$$\frac{\mathrm{d}^2N(k,Q^2)}{\mathrm{d}k\mathrm{d}Q^2} = \frac{\alpha}{\pi k Q^2}\left[1-\frac{k}{E_e}+\frac{k^2}{2E_e^2}-\left(1-\frac{k}{E_e}\right)\left|\frac{Q^2_{\min}}{Q^2}\right|\right],$$ is the photon flux

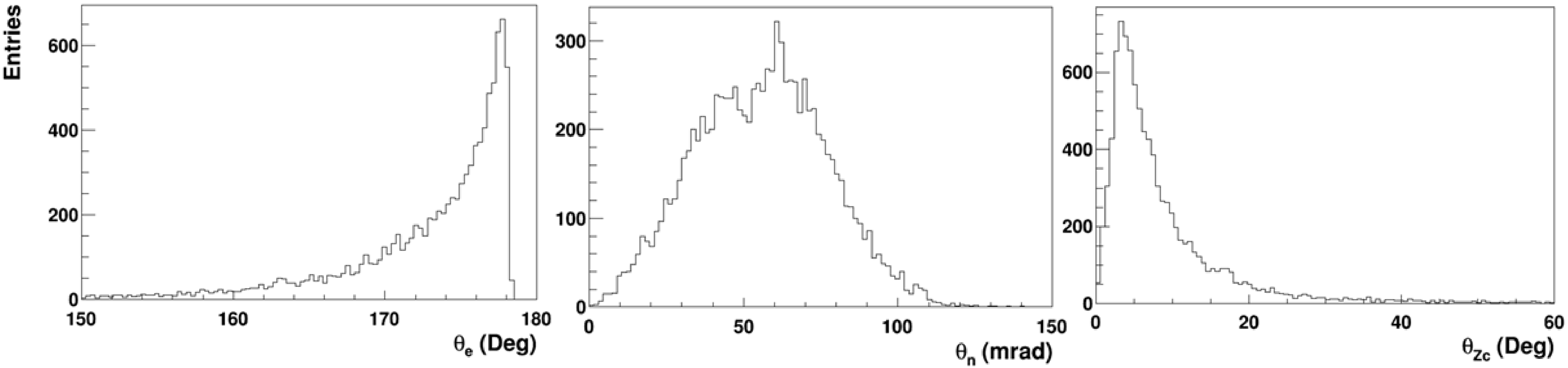
$\sigma_{\gamma^* p\rightarrow hN'}(W,Q^2)$ is the cross section of exotics photon-production

Step 1: Zc(3900), X(3872) eSTARLight Pc: eSTARLight/LAger			Yaping Xie	√
Step 2: Zc(3900), X(3872), Pc decay Using EiccEvtGen**Hybrid**		Aiqiang Guo	 Yutie Liang	√
Step 3: Implement the detector impact	Resolution + Efficiency table Update the physics output		Aiqiang Guo	√

Simulation of $Z_c(3900)$



Simulation of $e\,p \to e\,n\,Z_c$, proton direction = z

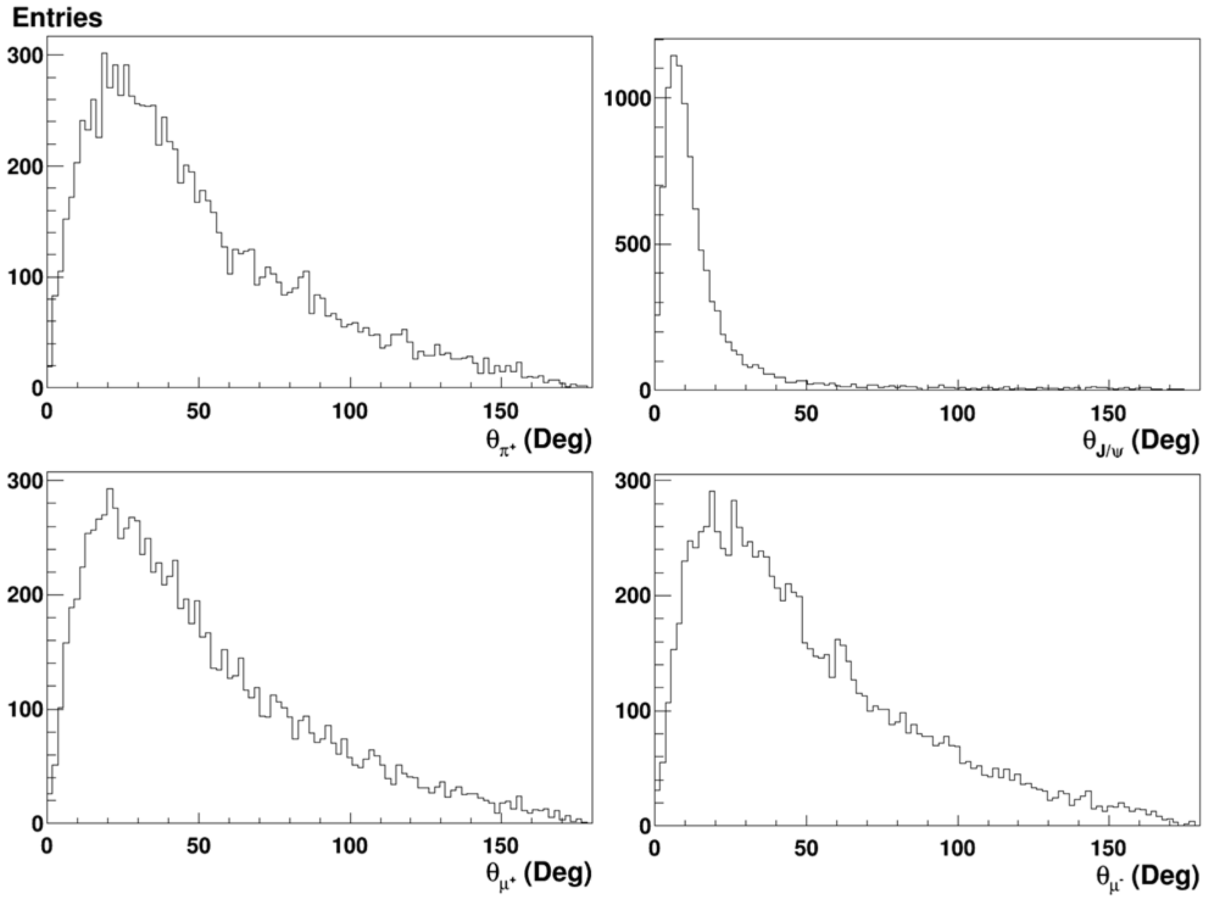


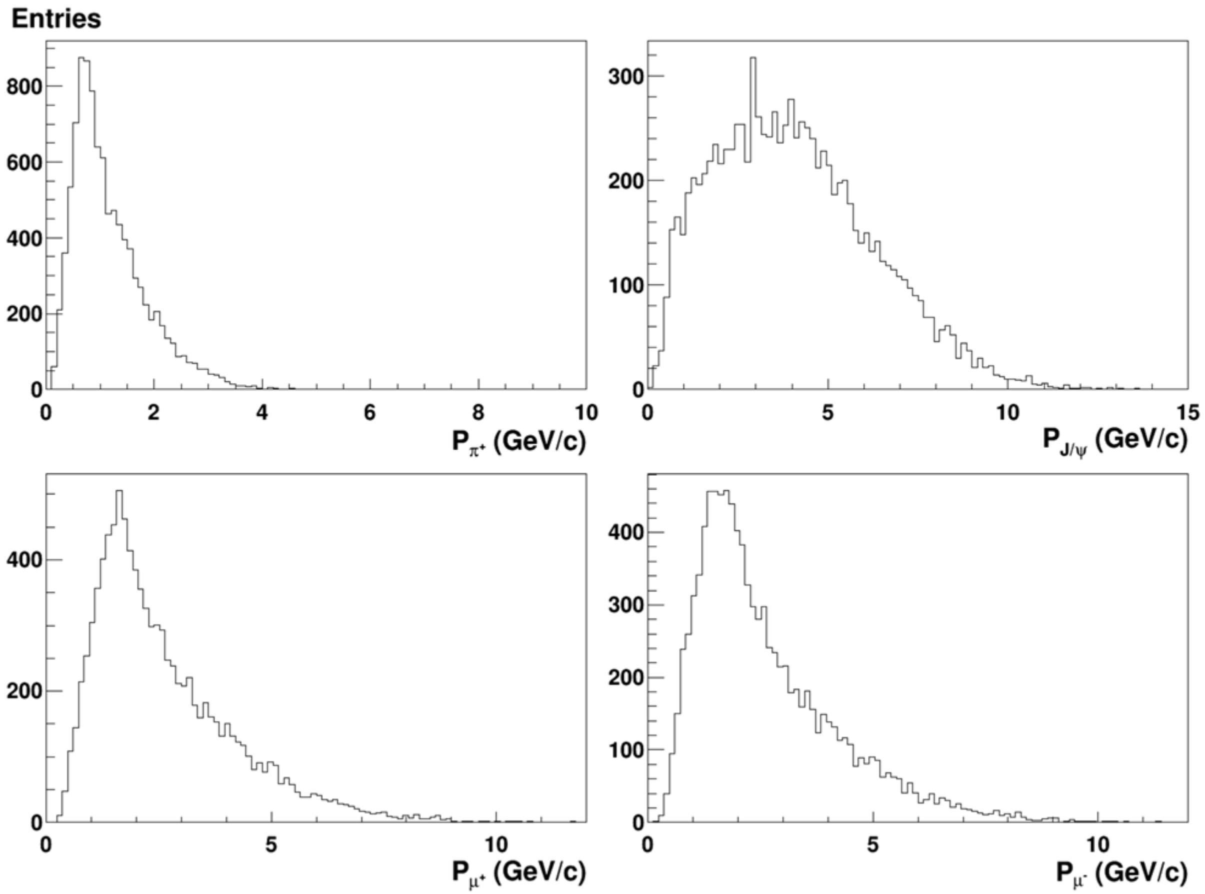
The scattering angle of electron is large

The scattering angle of neutron is along the direction of incoming proton

Simulation of $Z_c(3900)$

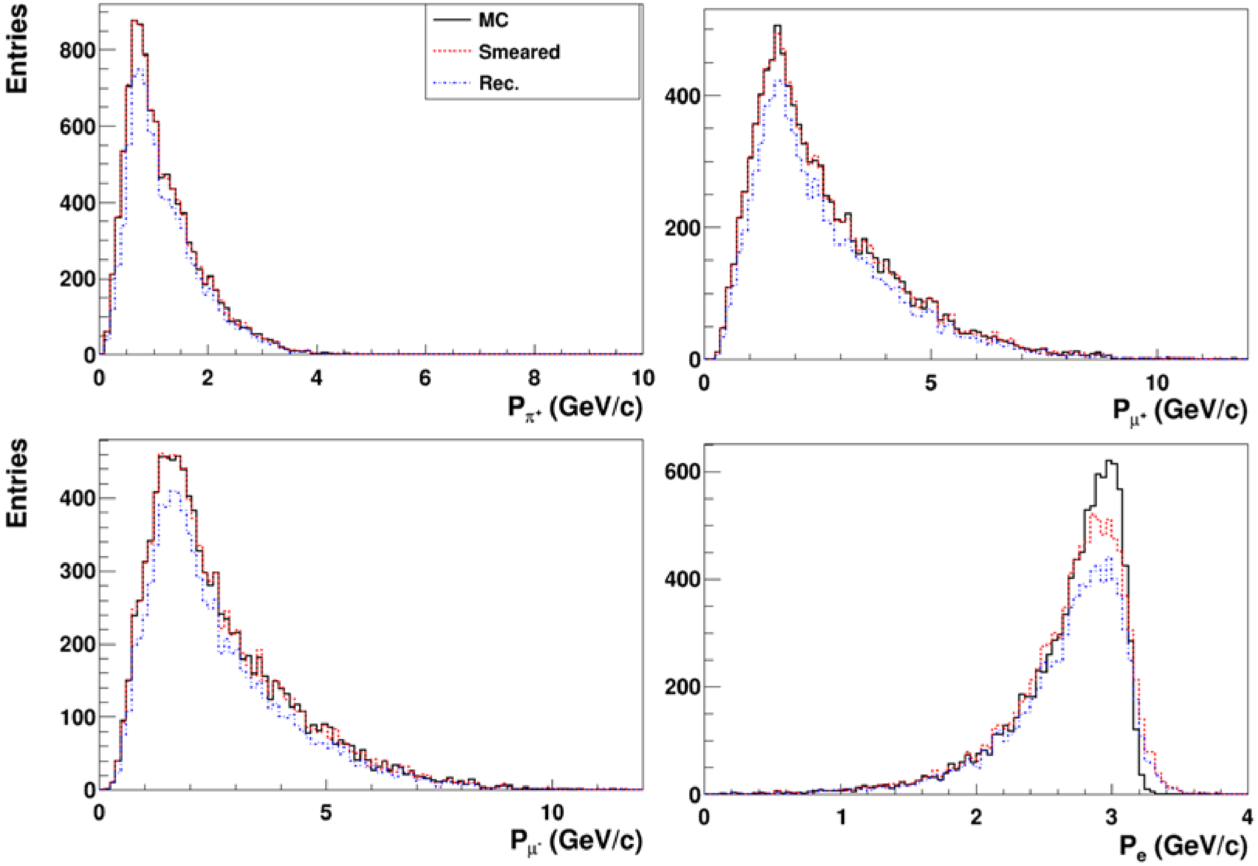
Decay of $Zc(3900) \rightarrow \pi^+ J/\psi \rightarrow \pi^+ l^+ l^-$

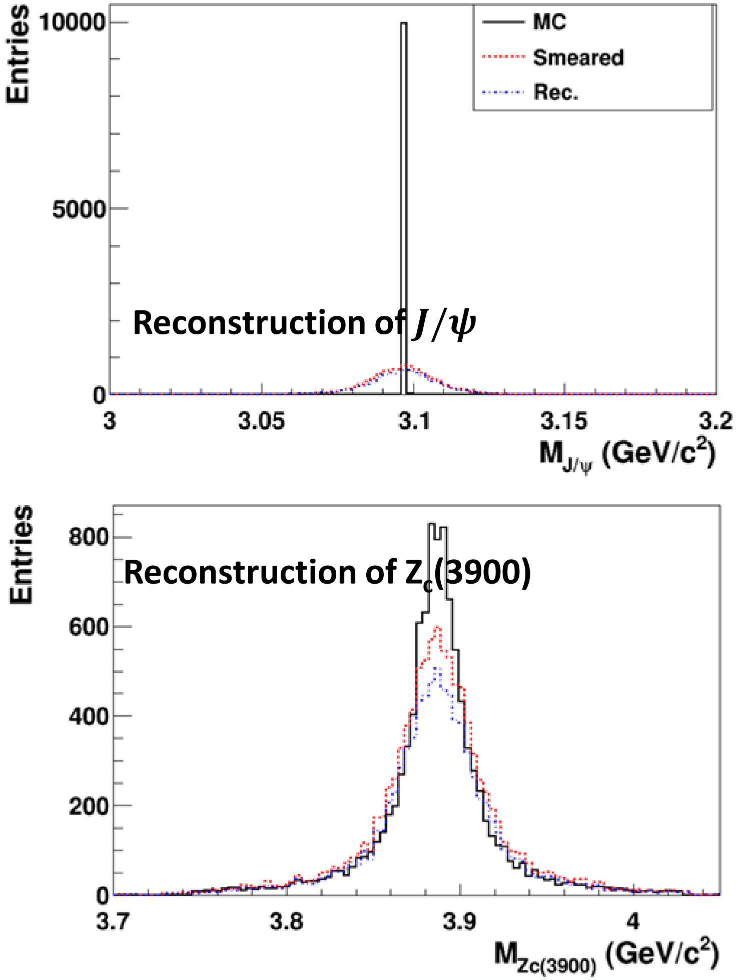




Simulation of $Z_c(3900)$

Detection of final state particles

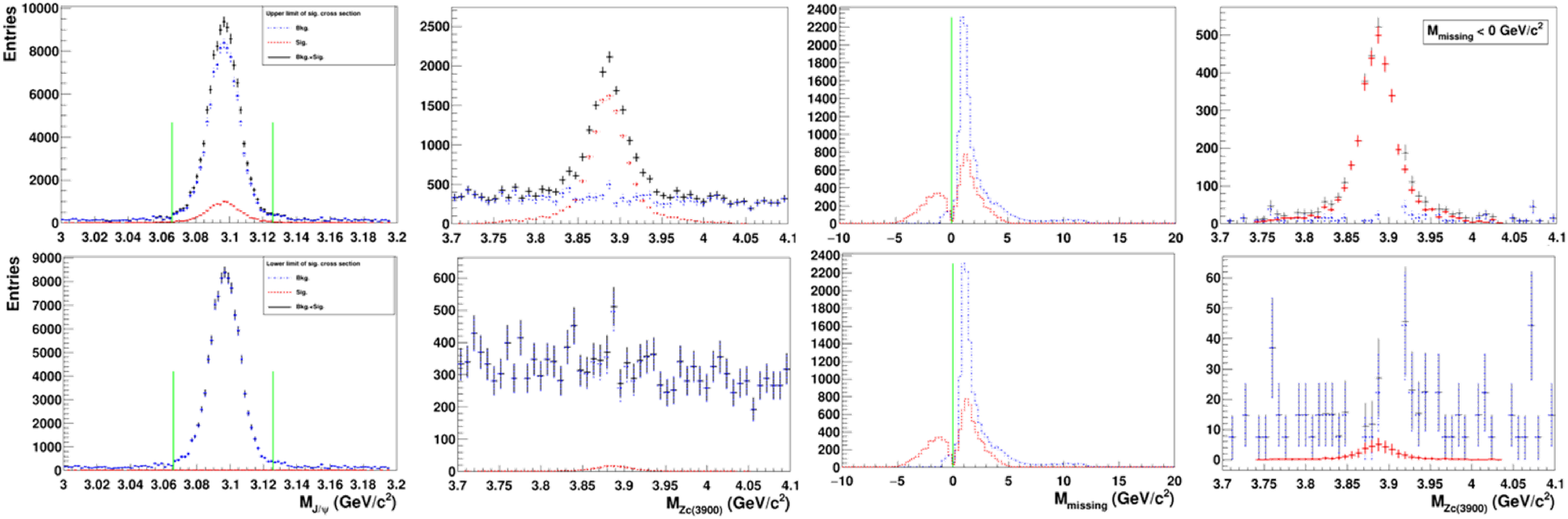




Simulation of $Z_c(3900)$

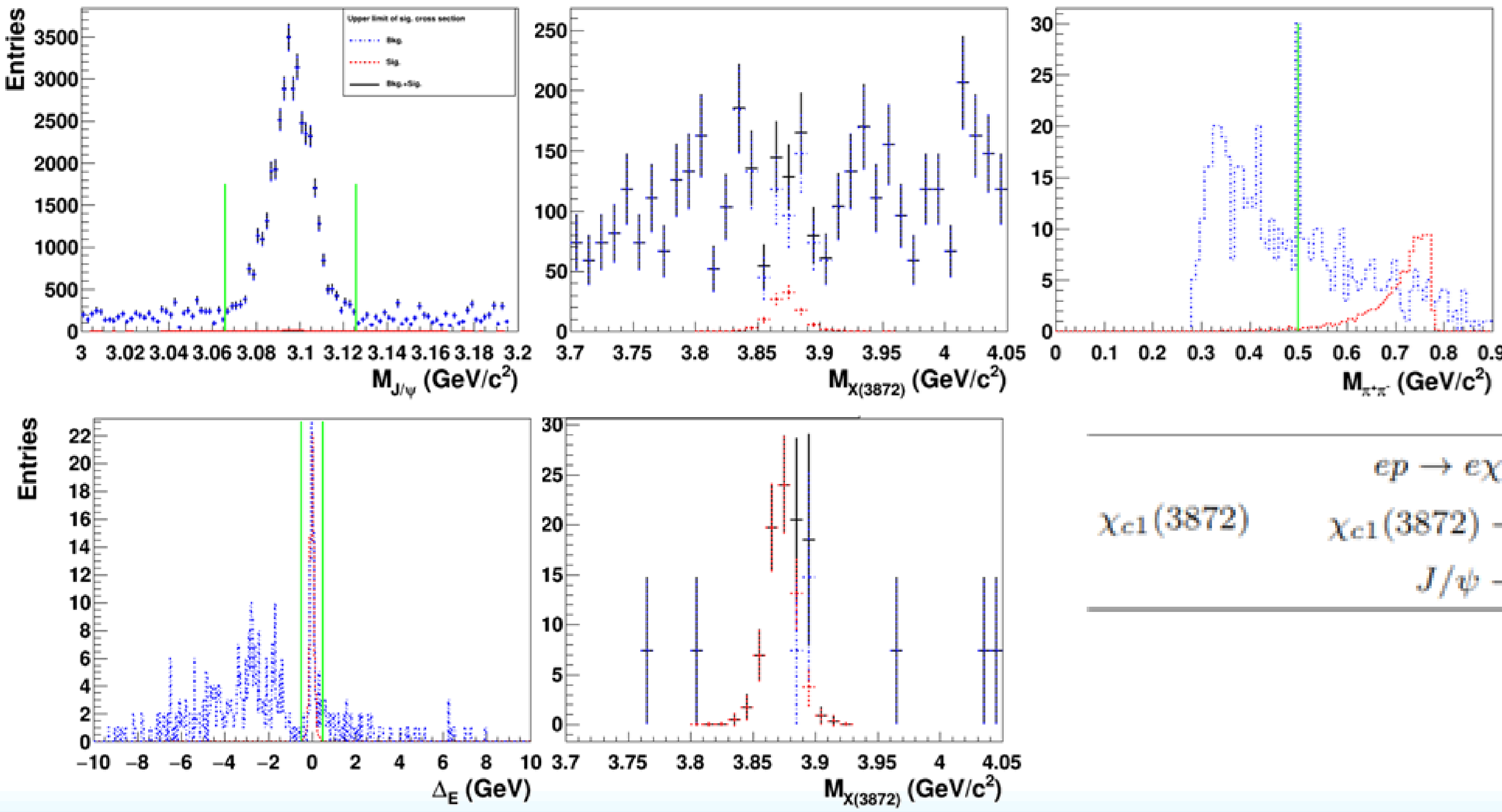
$Z_c(3900)^+$	$ep \to eZ_c(3900)^+ n$ $Z_c^+(3900) \to \pi^+ J/\psi$ $J/\psi \to l^+ l^-$	~60%	90–9300

Zc(3900) analysis with background mixing, L = 50 fb^{-1}, Efficiency = 79.7% πμμ 23.2% eπμμ



Simulation of X(3872)

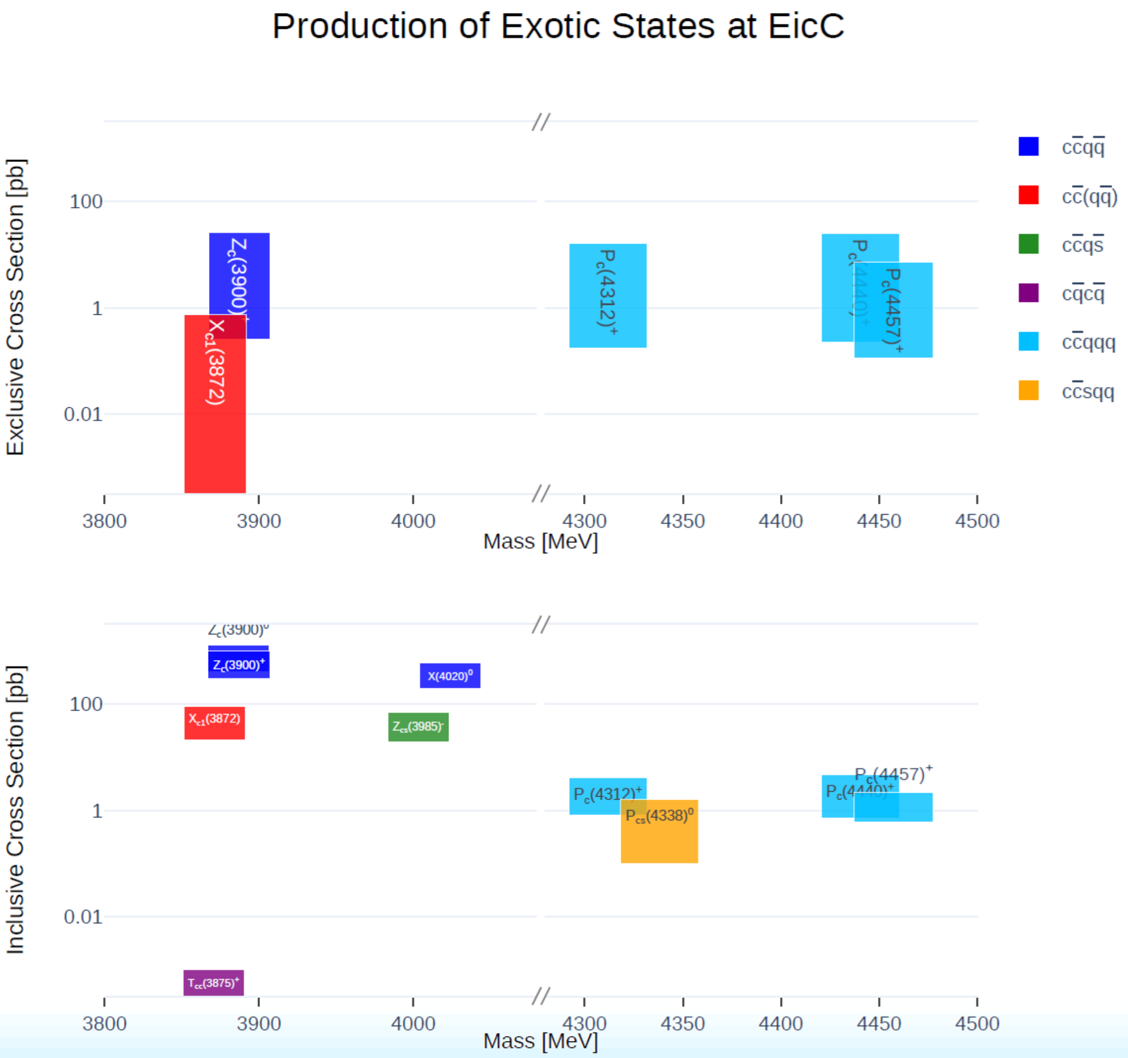
X(3872) analysis with background mixing,



L = 50 fb^{-1}
Efficiency =
53.9% $\pi\pi\mu\mu$
39.5% $ep\pi\pi\mu\mu$

$\chi_{c1}(3872)$	$ep \to e\chi_{c1}(3872)p$ $\chi_{c1}(3872) \to \pi^+\pi^- J/\psi$ $J/\psi \to l^+l^-$	~50%	0–90

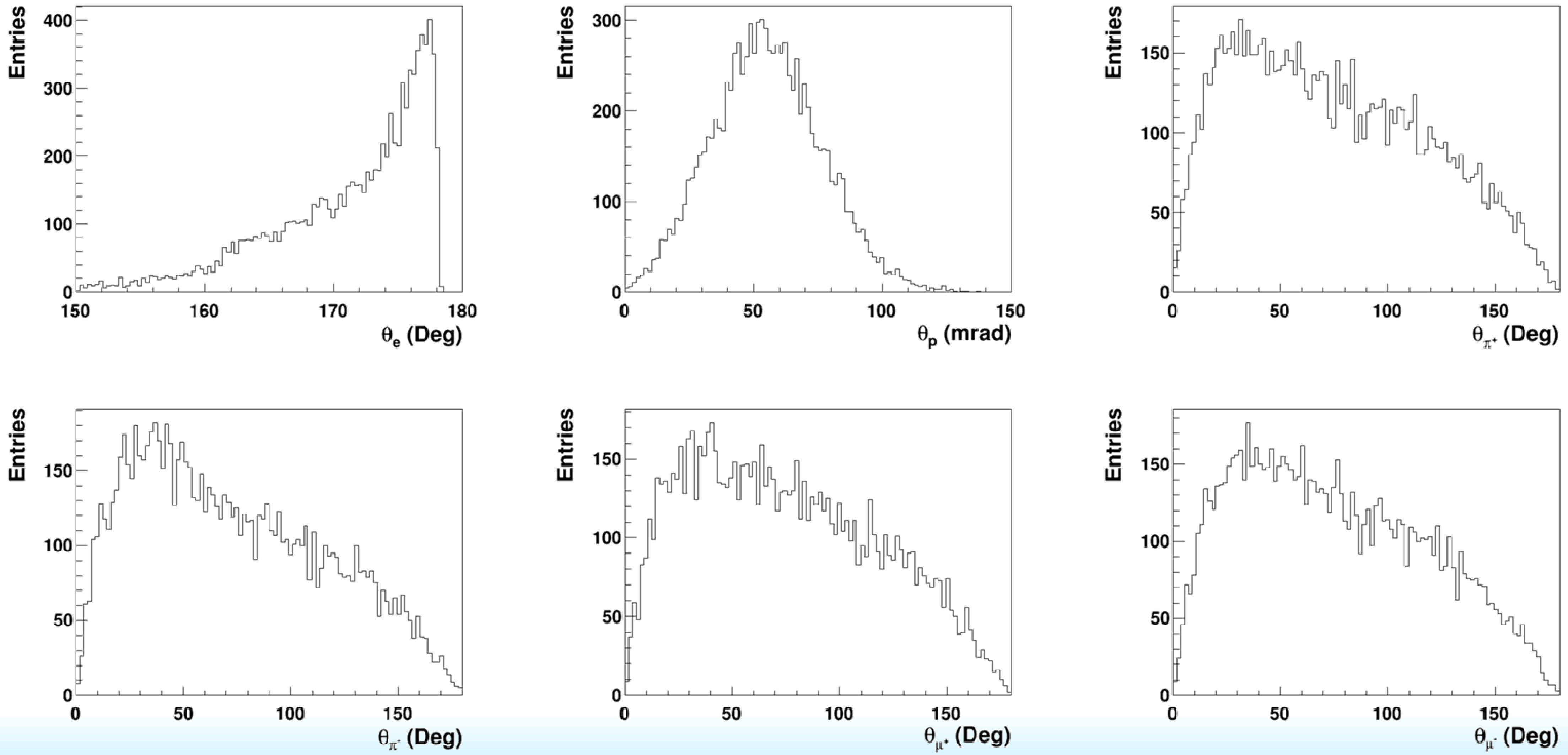
Summary and Outlook



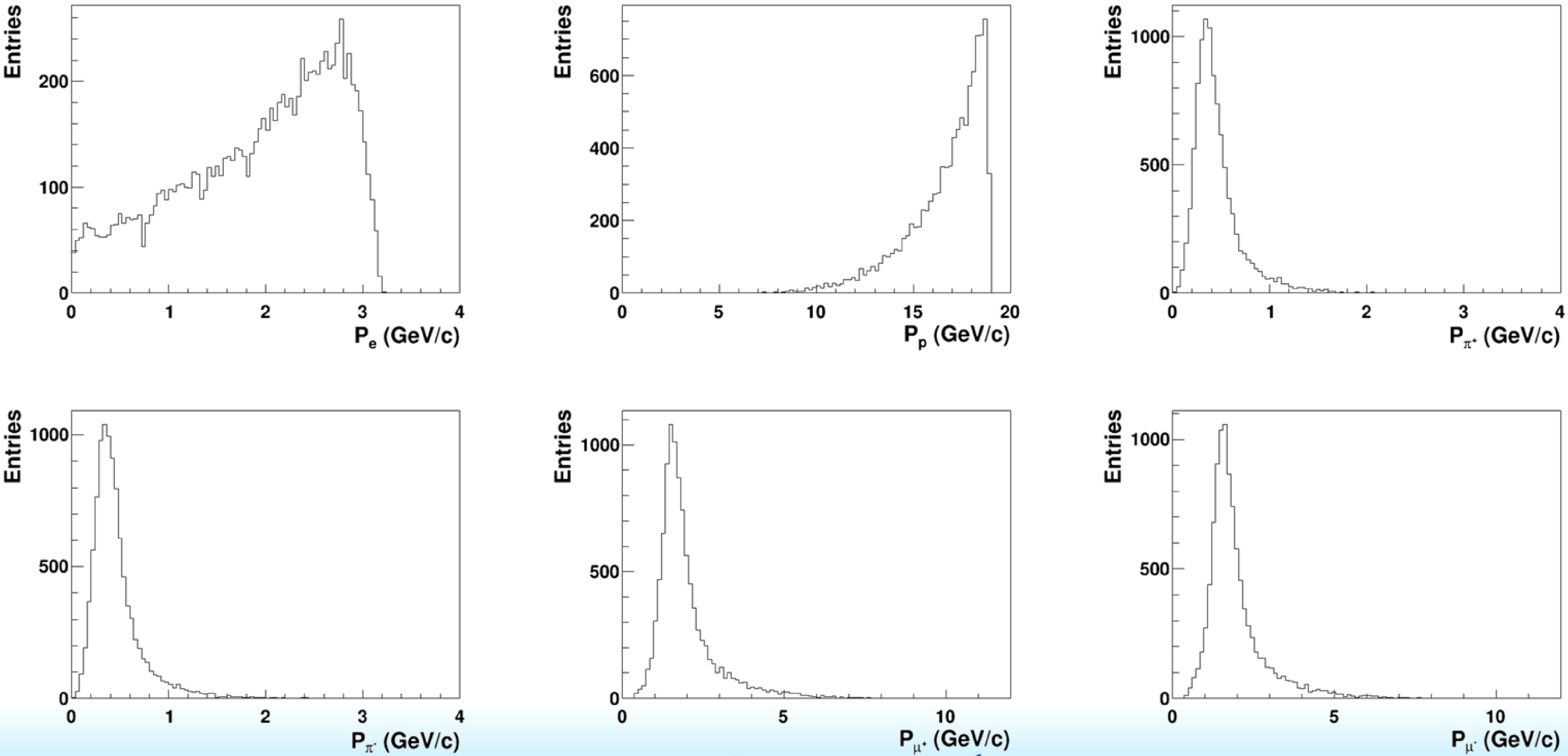
Thanks for attention!

Backup

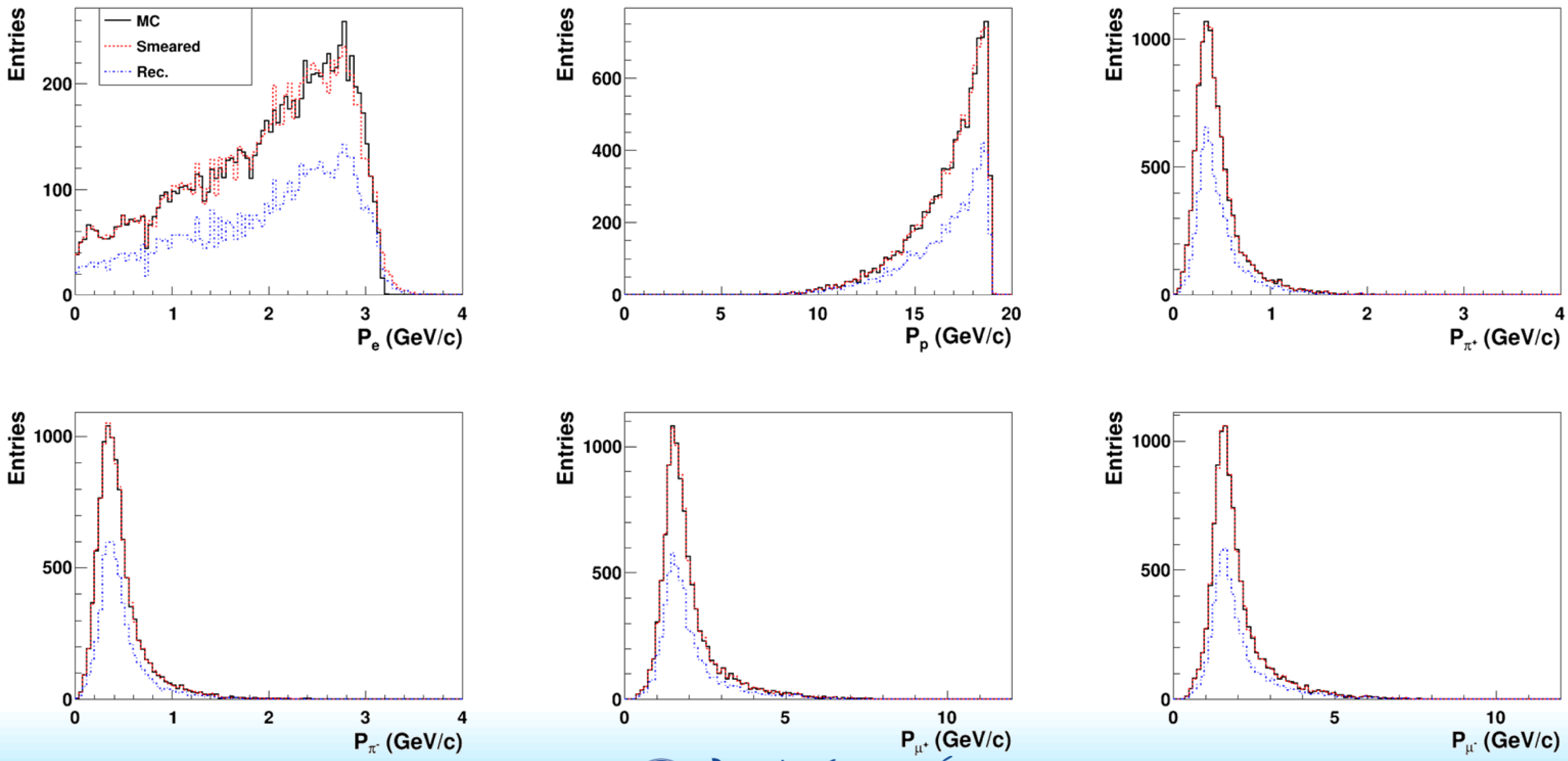
Simulation of ep→ epX(3872)→epππμμ



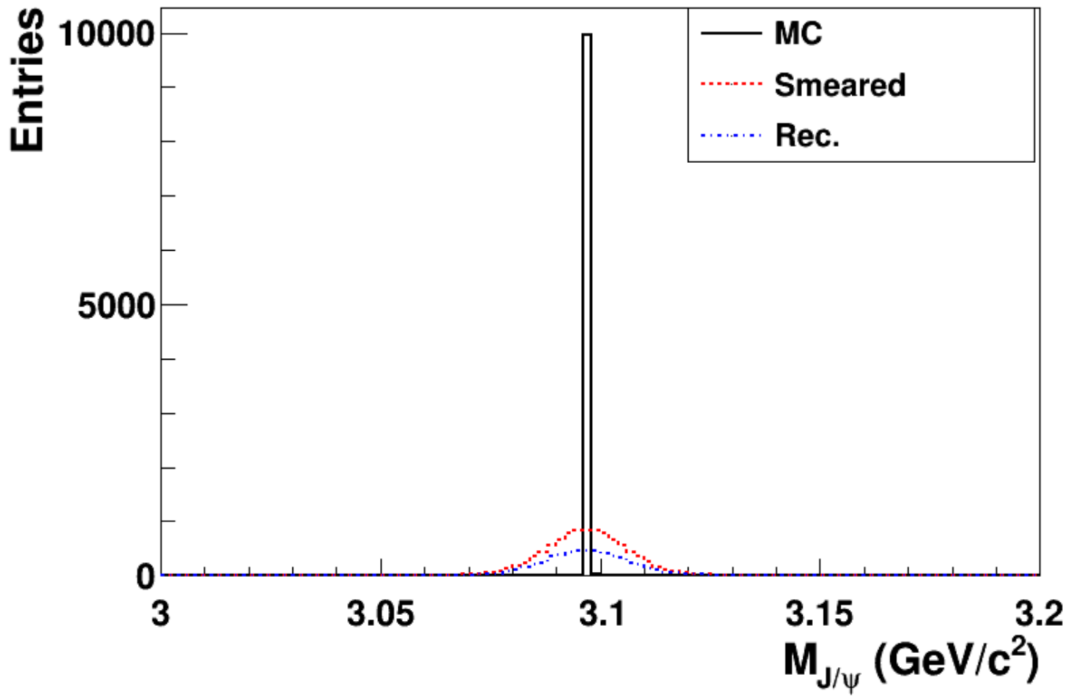
Simulation of ep→ epX(3872)→epππμμ

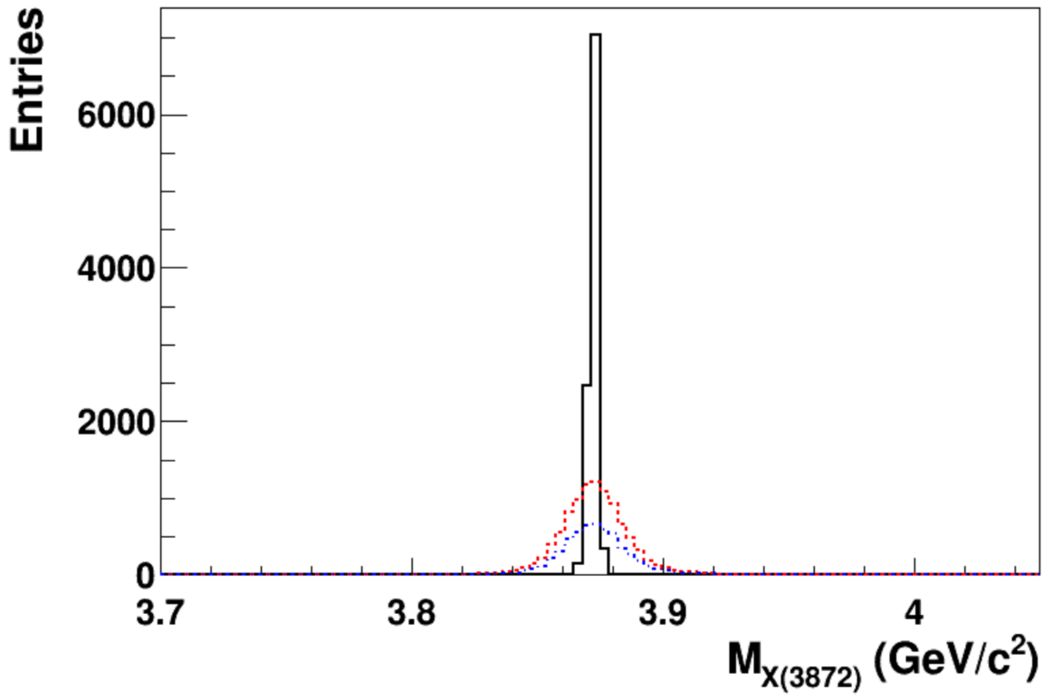


Detection of final state particles



Reconstruction of J/ψ and Zc(3900)





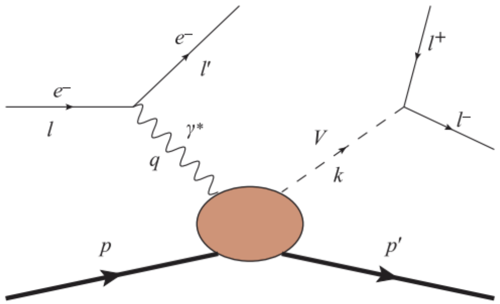
Important !

Searching Exotic in EicC

Table 2.3 Estimated event numbers that can be collected at EicC assuming an integrated luminosity of 50 fb^{-1}. The lepton pairs l^+l^- denote both $\mu^+\mu^-$ and e^+e^-. The event numbers are estimated using the assumed detection efficiencies listed in the third column, which are expected to be higher in the middle rapidity than that in the forward region.

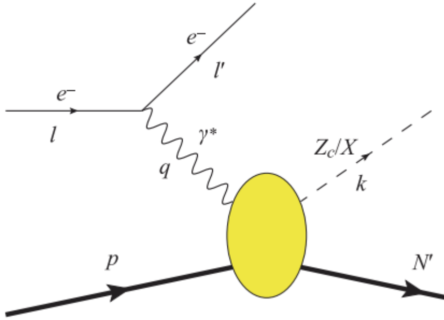
Exotic states	Production/decay processes	Detection efficiency	Expected events
$P_c(4312)$	$ep \to eP_c(4312)$ $P_c(4312) \to pJ/\psi$ $J/\psi \to l^+l^-$	$\sim$30%	15−1450
	$ep \to eP_c(4440)$	)%	20−2200
		)%	10−650
		)%	0−20
		)%	0−200
		)%	0−90
		)%	90−9300

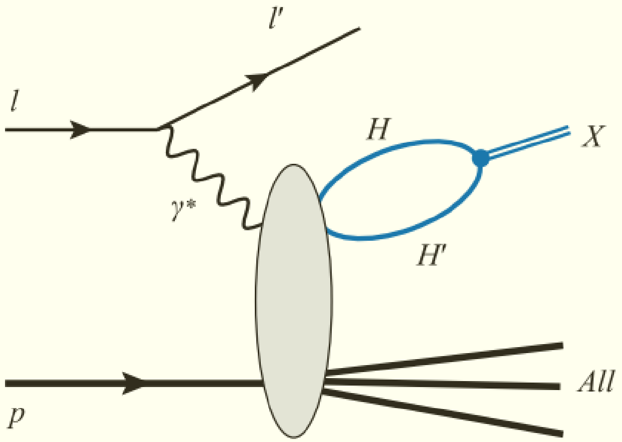
Front. Phys. 16(6), 64701 (2021)



$ep \to e[P_c]$
$\to e[Vp']$
$\to e[l^+l^-p']$

$ep \to e[X]N'$





$ep \to e[X]\text{All}$

	Constituents	$IJ^{P(C)}$	EicC
$X(3872)$	$D\bar{D}^*$	01^{++}	21(89)
$Z_c(3900)^0$	$D\bar{D}^*$	11^{+-}	$0.4\times10^3(1.3\times10^3)$
$Z_c(3900)^+$	$D^{*+}\bar{D}^0$	11^+	$0.3\times10^3(1.0\times10^3)$
$Z_c(4020)^0$	$D^*\bar{D}^*$	11^{+-}	$0.2\times10^3(0.6\times10^3)$
Z_{cs}^-	$D^{*0}D_s^-$	$\frac{1}{2}1^+$	19(69)
Z_{cs}^{*-}	$D^{*0}D_s^{*-}$	$\frac{1}{2}1^+$	14(51)
$P_c(4312)$	$\Sigma_c\bar{D}$	$\frac{1}{2}\frac{1}{2}^-$	0.8(4.1)
$P_c(4440)$	$\Sigma_c\bar{D}^*$	$\frac{1}{2}\frac{3}{2}^-$	0.7(4.7)
$P_c(4457)$	$\Sigma_c\bar{D}^*$	$\frac{1}{2}\frac{1}{2}^-$	0.6(2.2)
$P_c(4380)$	$\Sigma_c^*\bar{D}$	$\frac{1}{2}\frac{3}{2}^-$	1.6(8.4)
$P_c(4524)$	$\Sigma_c^*\bar{D}^*$	$\frac{1}{2}\frac{1}{2}^-$	0.8(3.9)
$P_c(4518)$	$\Sigma_c^*\bar{D}^*$	$\frac{1}{2}\frac{3}{2}^-$	1.2(6.9)
$P_c(4498)$	$\Sigma_c^*\bar{D}^*$	$\frac{1}{2}\frac{5}{2}^-$	1.2(9.8)
P_{cs}	$\Xi_c\bar{D}$	$0\frac{1}{2}^-$	0.1 (1.6)
P_{cs}	$\Xi_c\bar{D}^*$	$0\frac{1}{2}^-$	0.1 (0.5)
P_{cs}	$\Xi_c\bar{D}^*$	$0\frac{3}{2}^-$	0.1 (0.9)
	$\Lambda_c\bar{\Lambda}_c$	00^{-+}	0.3 (3.0)
	$\Lambda_c\bar{\Sigma}_c$	10^-	0.01 (0.12)
	$\Lambda_c\bar{\Xi}_c$	$\frac{1}{2}0^-$	0.01 (0.14)