Production of exotic states at EICs and UPCs

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Outline

- Background
- Production of pentaquark states in EICs
- Production of pentaquark states in UPCs
- Production of XYZ states at EICs
- Summary

Motivation

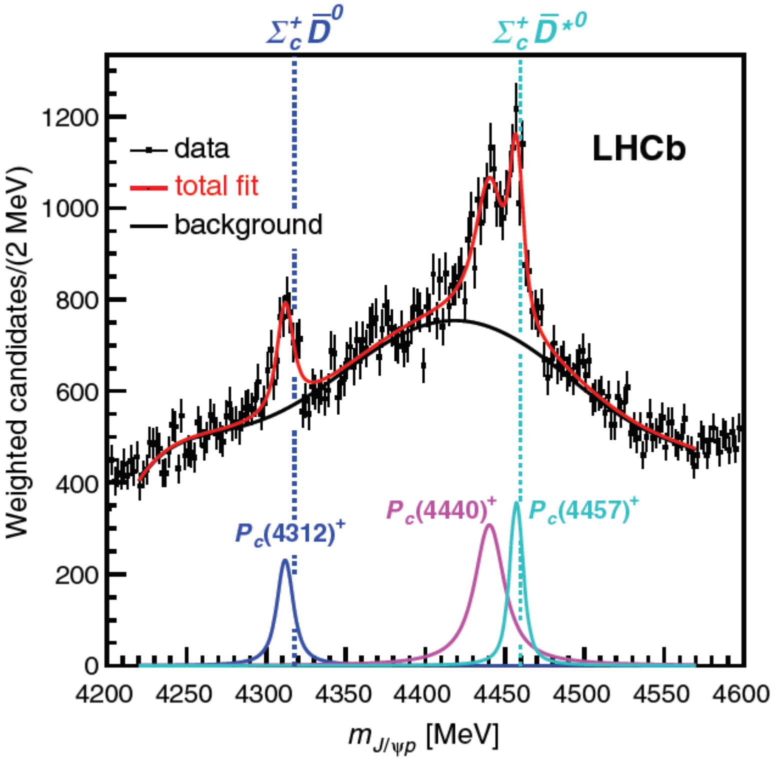
- Photoproduction of exotic states is an important field in particle physics. It can help us to investigate the structure of the exotic states and their nature.
- Electron Ions Collider is an important platform to study the structure of nucleons and exotic states
- Ultraperipheral collisions are very important to study photoproduction of vector mesons and exotic states

Discovery of pentaquark states

Three resonance states were discovered at LHCb (arXiv:1904.03947, PRL-122-222001)

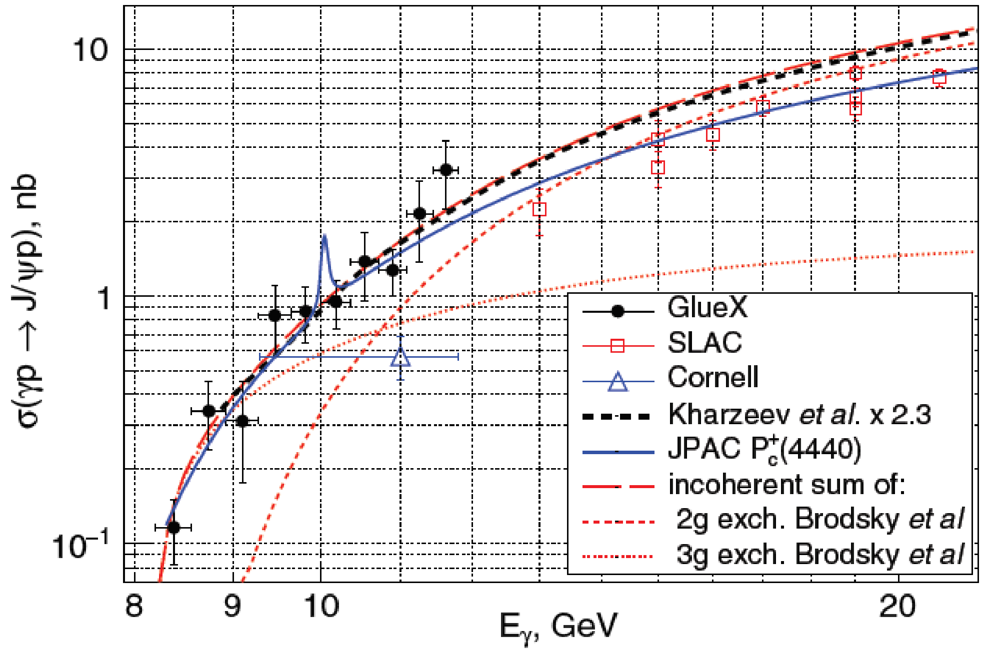
$$\Lambda_b^0 \to J/\psi + p + K^-$$

State	M [MeV]	Γ [MeV]
$P_c(4312)^+$	$4311.9 \pm 0.7^{+6.8}_{-0.6}$	$9.8 \pm 2.7^{+\ 3.7}_{-\ 4.5}$
$P_c(4440)^+$	$4440.3 \pm 1.3^{+4.1}_{-4.7}$	$20.6 \pm 4.9^{+\ 8.7}_{-10.1}$
$P_c(4457)^+$	$4457.3 \pm 0.6^{+4.1}_{-1.7}$	$6.4 \pm 2.0^{+\ 5.7}_{-\ 1.9}$



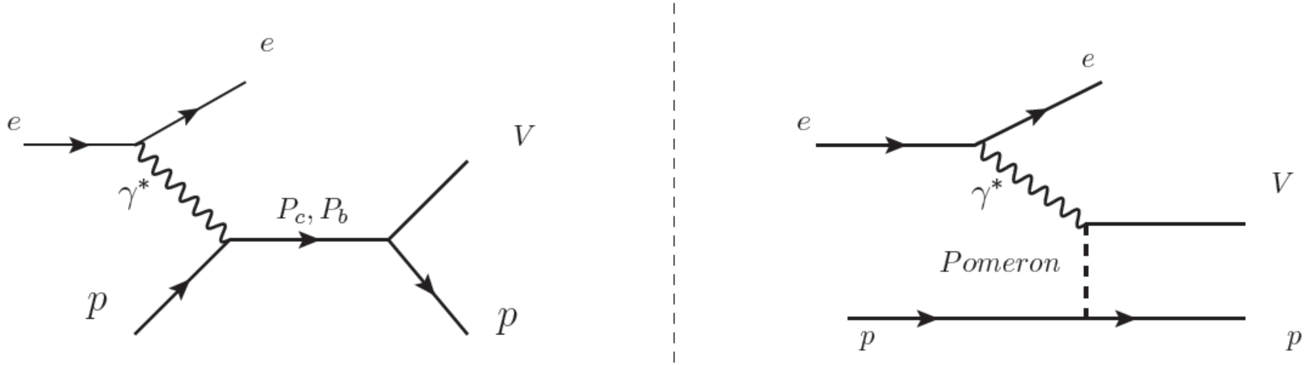
GlueX cross section

The cross sections of J/ψ were measured at GlueX, There is no evidence of Pc in the GlueX results (arXiv:1905.10811,PRL-123-072201)



Photoproduction of VM in two channels

Photoproduction of pentaquark states in electron-proton scattering

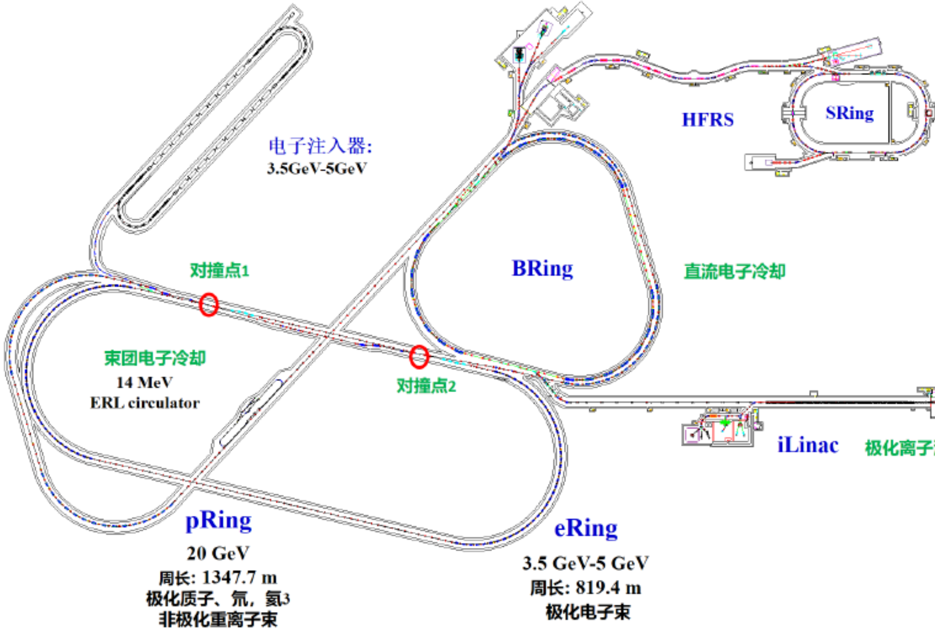


$s - channel$ $t - channel$

Introduction to EICs

EIC is platform to study Nucleon structure in the future

	EicC	EIC-US
E of e	3.5 GeV	18 GeV
E of proton	20 GeV	275 GeV



Photoproduction of pentaquark states

The cross section of VM in electron-proton scattering can be obtained as (arXiv:1803.06420, PRC-99-015203)

$$\sigma(ep \to eVp) = \int dk dQ^2 \frac{dN^2(k,Q^2)}{dk dQ^2} \sigma_{\gamma^* p \to Vp}(W,Q^2)$$

The photon flux is given as

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

The cross section of vector meson is given as

$$\sigma(\gamma + p \to V + p) = \sigma_p \cdot \left[1 - \frac{(m_p + m_V)^2}{W_{\gamma p}^2}\right]^2 \cdot W_{\gamma p}^{\epsilon}.$$

Photorpdoction of pentaquark states

Cross section of pentaquark states in photon-proton scattering (arXiv:1904.06015, PRD-100-054033)

$$\sigma^{P_X}_{\gamma p \to V p}(W) = \frac{2J+1}{2(2s_2+1)} \frac{4\pi}{k_{in}^2} \frac{\Gamma_{P_X}^2}{4} \frac{\mathcal{B}(P_X \to \gamma p)\mathcal{B}(P_X \to V p)}{(W - M_{P_X})^2 + \Gamma_{P_X}^2/4}.$$

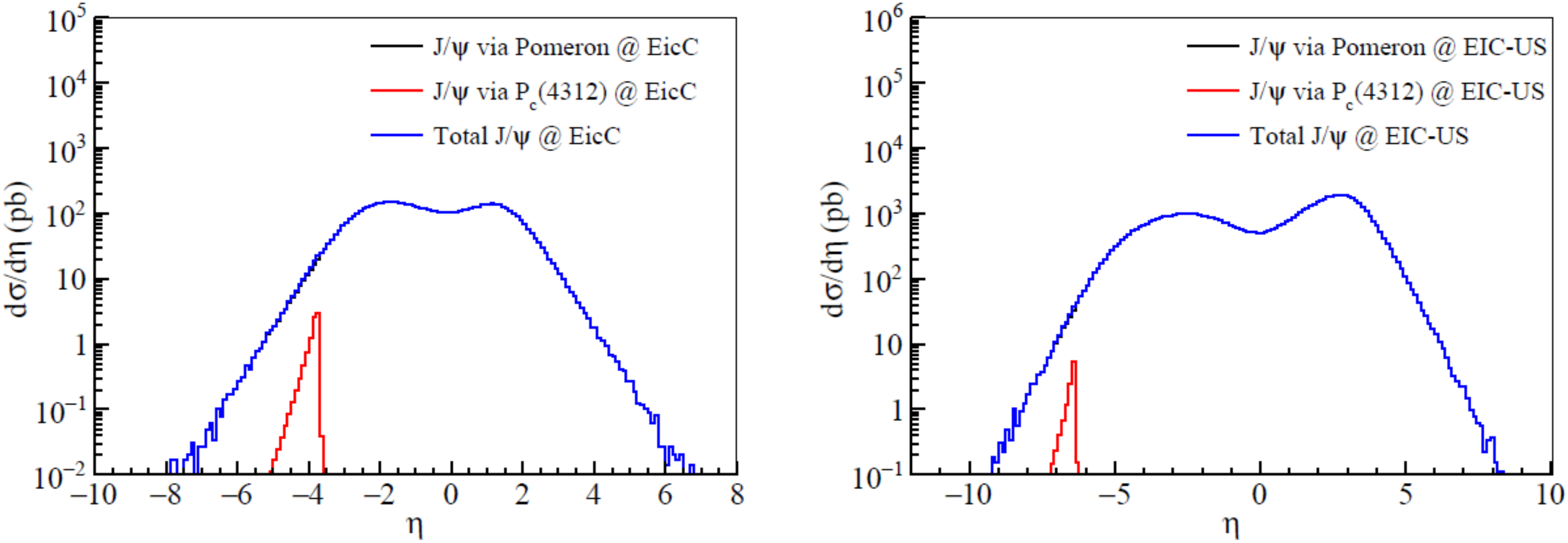
where

$$\mathcal{B}(P_X \to \gamma p) = \frac{3\Gamma(V \to e^+ e^-)}{\alpha M_V} \left(\frac{k_{in}}{k_{out}}\right)^{2L+1} \mathcal{B}(P_X \to V p).$$

Production of VM in EICs

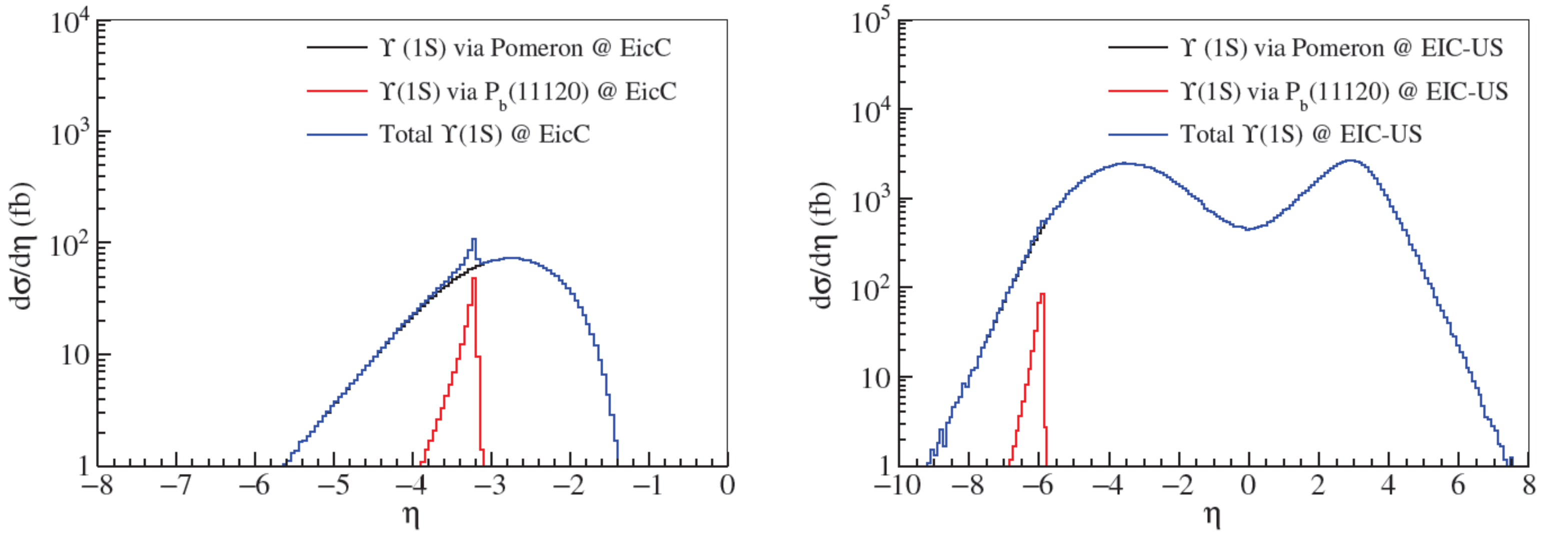
Using the MC simulation program, we can obtain the four momentum of the final states, We can get the pseudo-rapidity distributions

$$y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}, \qquad \eta = \frac{1}{2}\ln\frac{p+p_z}{p-p_z}, \qquad \eta = -\ln\tan\frac{\theta}{2}$$



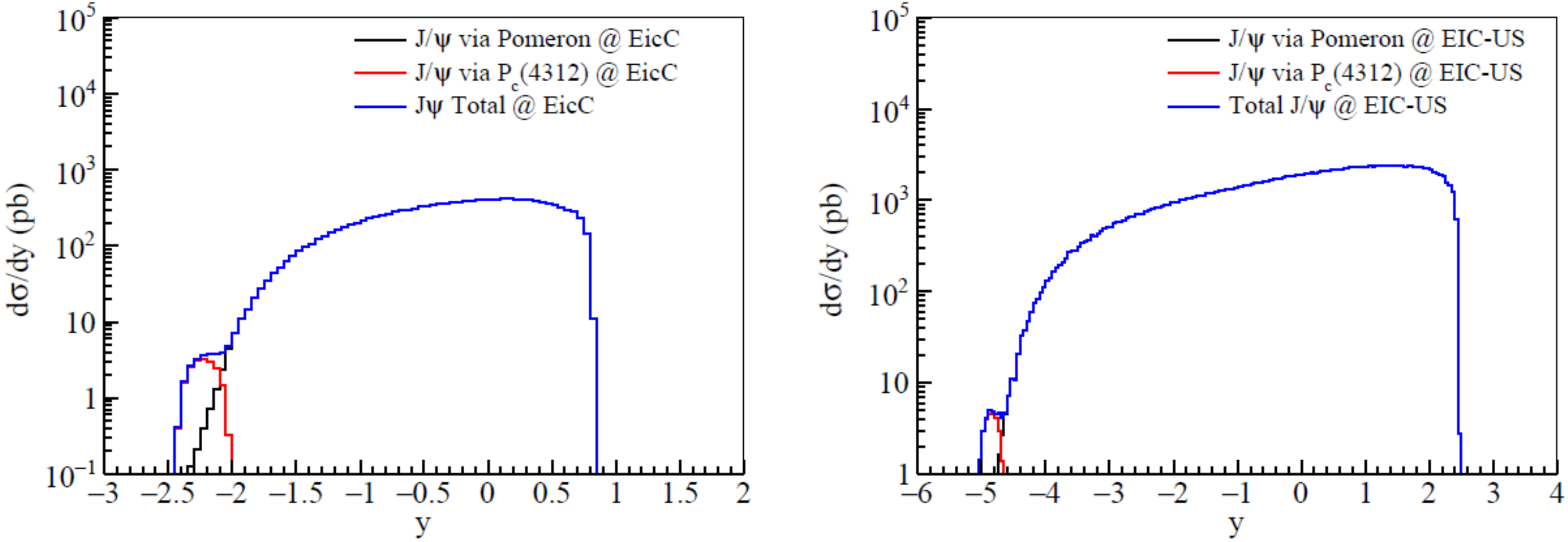
Production of VM in EICs

Pseudo-rapidity distributions of VM in EICs



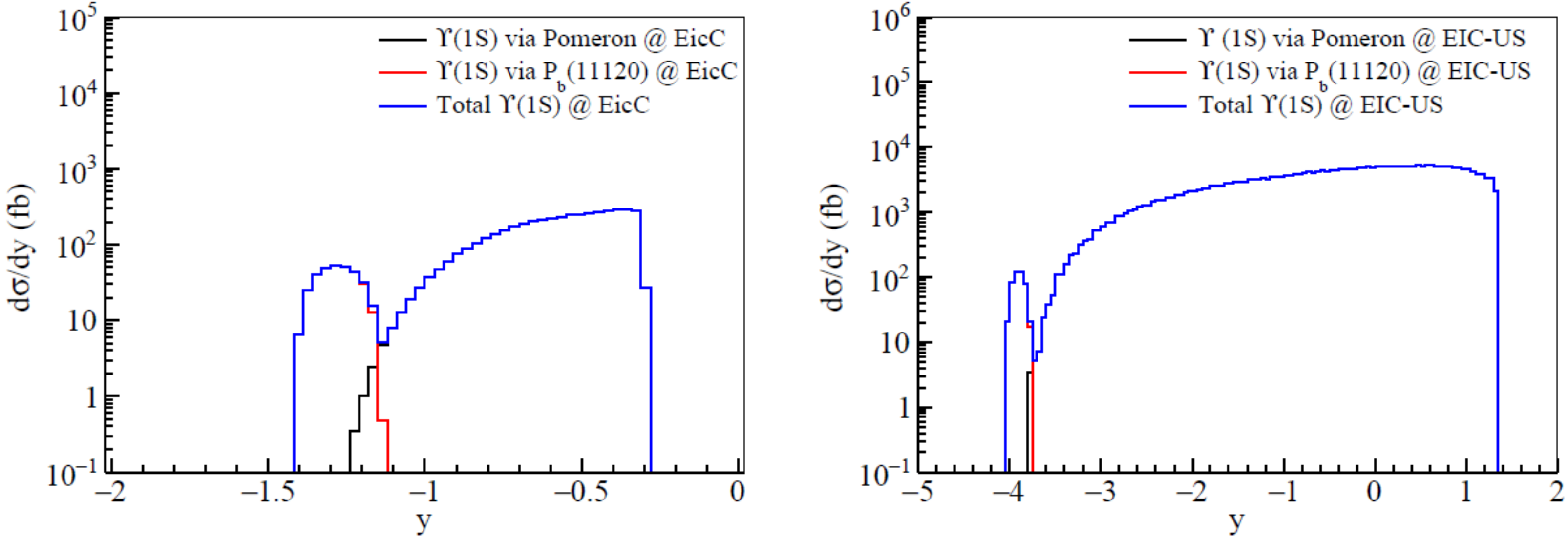
Production of VM in EICs

Rapidity distributions of VM in two channels



Production of VM in EICs

Rapidity distributions of vector meson in two channels



Cross section of pentaquark in EicC and EIC-US

The total cross sections of vector mesons in two channels are also calculated

States		Properties	Collider	EicC	EIC-US
			Energy (e.vs. p)	3.5 GeV vs 20 GeV	18 GeV vs 275 GeV
$P_c(4312)$	Mass	$4.311 \pm 0.7^{+6.8}_{-0.6}$ GeV	$\sigma_t(ep \to J/\psi p)$	0.69 nb	9.1 nb
	Width	$9.8 \pm 2.7^{+3.7}_{-4.5}$ MeV	$\sigma_s(ep \to J/\psi p)$	0.89 pb	1.3 pb
$P_b(11120)$	Mass	11.120 GeV	$\sigma_t(ep \to \Upsilon p)$	0.13 pb	15 pb
	Width	30 – 300 MeV	$\sigma_s(ep \to \Upsilon p)$	9.3 – 82 fb	0.022 –0.19 pb

- The background of Pc(4312) is large
- The background of Pb(11120) is small

Production of VM in UPCs

Cross section of vector meson in p-A UPCs

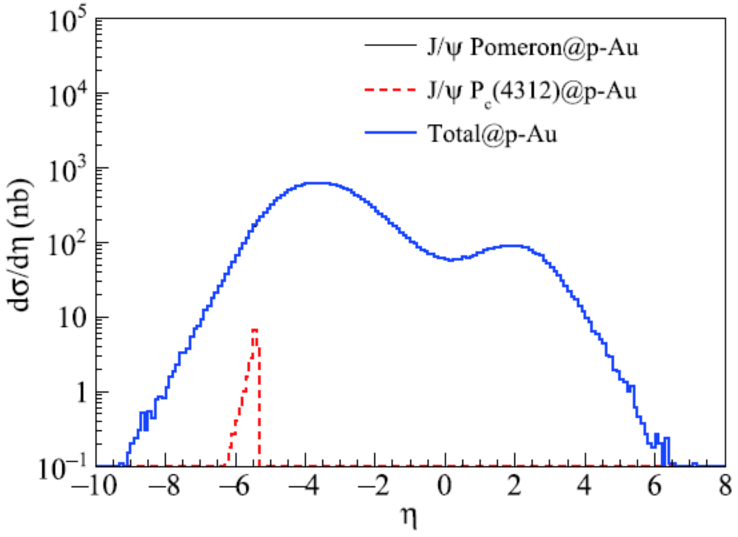
$$\sigma(pA \rightarrow pAV) = \int \mathrm{d}k \frac{\mathrm{d}N_\gamma(k)}{\mathrm{d}k} \sigma_{\gamma p \rightarrow pV}(W)$$

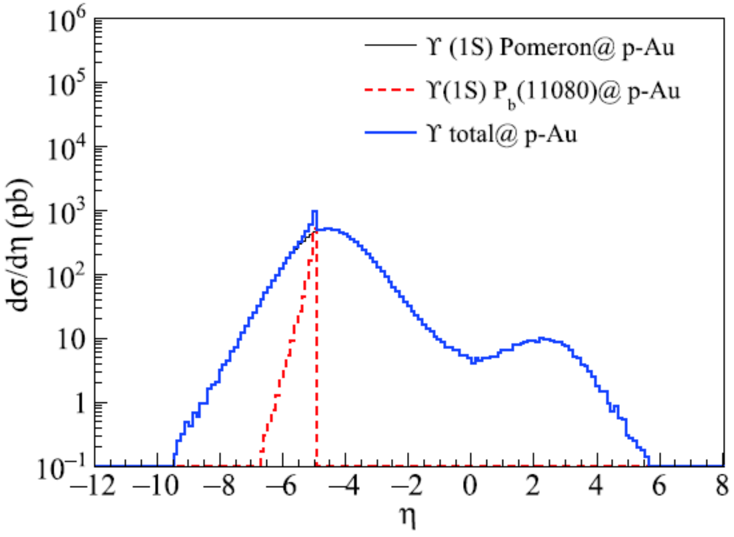
The photon flux is given as

$$\frac{\mathrm{d}N_\gamma(k)}{\mathrm{d}k} = \frac{2Z^2\alpha}{\pi k}(XK_0(X)K_1(X) - \frac{X^2}{2}[K_1^2(X) - K_0^2(X)])$$

Production of VM in UPCs

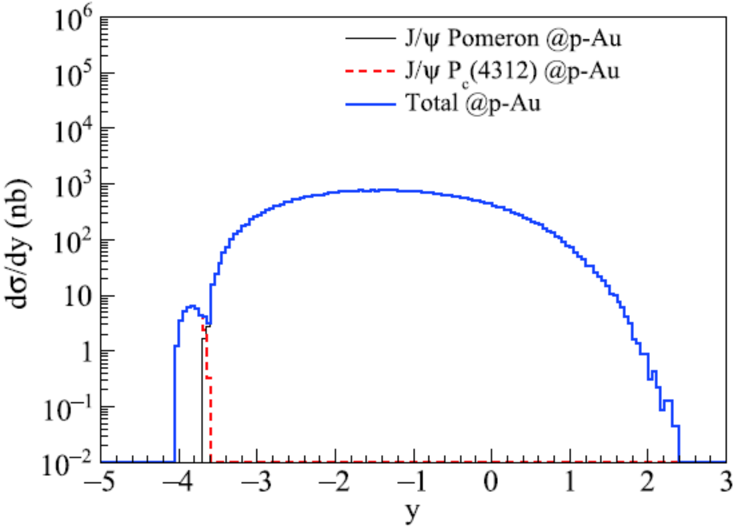
Pseudo-rapidity distributions of vector mesons in p-Au UPCs

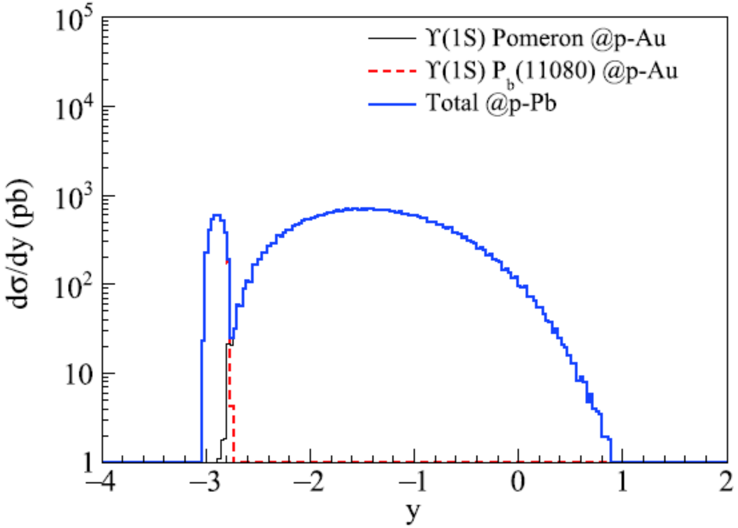




Production of VM in UPCs

Rapidity distributions of vector meson in UPCs





Production of VM in UPCs

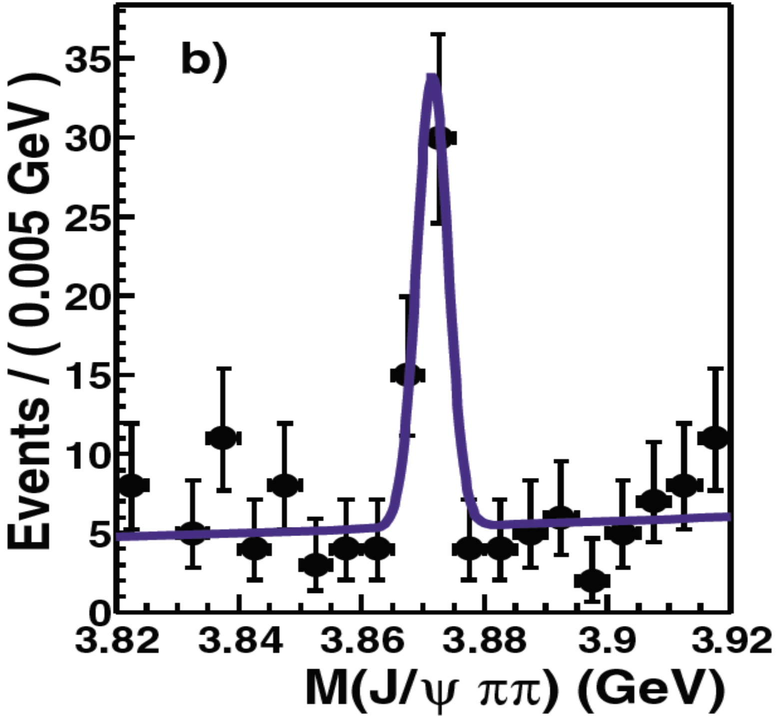
Cross sections of vector mesons in two channels in p-Au UPCs

resonance		properties [8, 29]		s-channel	t-channel
$P_c(4312)$	mass	$4311.9 \pm 0.7^{+6.8}_{-0.6}$ MeV	J/ψ cross section	1.8 nb	2.2 μb
	decay width	$9.8 \pm 2.7^{+3.7}_{-4.5}$ MeV	event number	8.1 K	9.9 M
$P_b(11080)$	mass	11080 MeV	$\Upsilon(1S)$ cross section	0.10 nb	1.2 nb
	decay width	1.58 MeV	event number	0.45 K	5.4 K

Discovery of XYZ states

X(3872) was the first exotic state discovered (arXiv:hep-ex 0309032, PRL-91-262001)

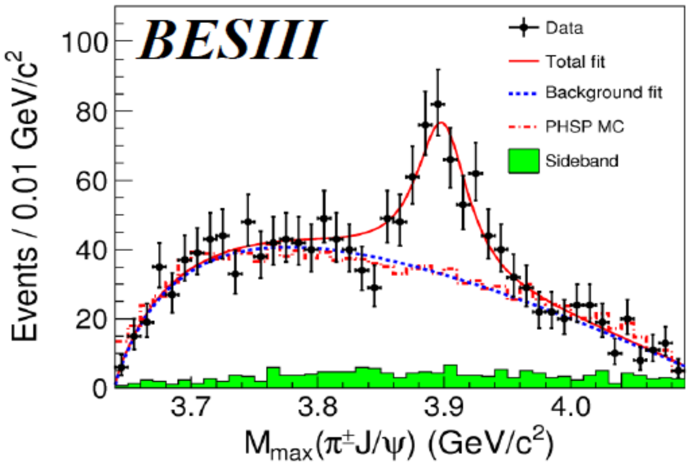
$B^+ \to X(3872)K^+ \to J/\psi\pi^+\pi^-K^+$
At Belle 2003
M = $(3871.69 \pm 0.7 \pm 0.2)$ MeV
$\Gamma <$ 1.2 MeV

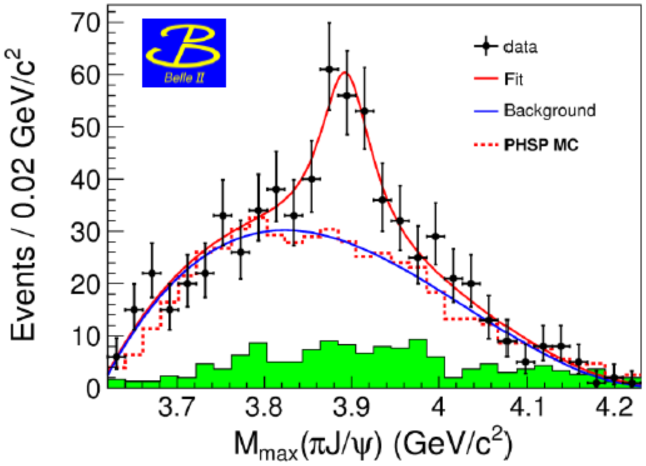


Discovery of XYZ states

Zc(3900) was observed at 2013 (arXiv:1303.0949 ,PRL-110-252001,arXiv:1304.0121,PRL-110-252002)

Zc(3900) was discovered in $Y(4260) \rightarrow Z_c^{\pm}\pi^{\mp} \rightarrow J/\psi\pi^{\pm}\pi^{\mp}$ at BESIII and Belle





M = (3899.0±3.6 ±4.9) MeV

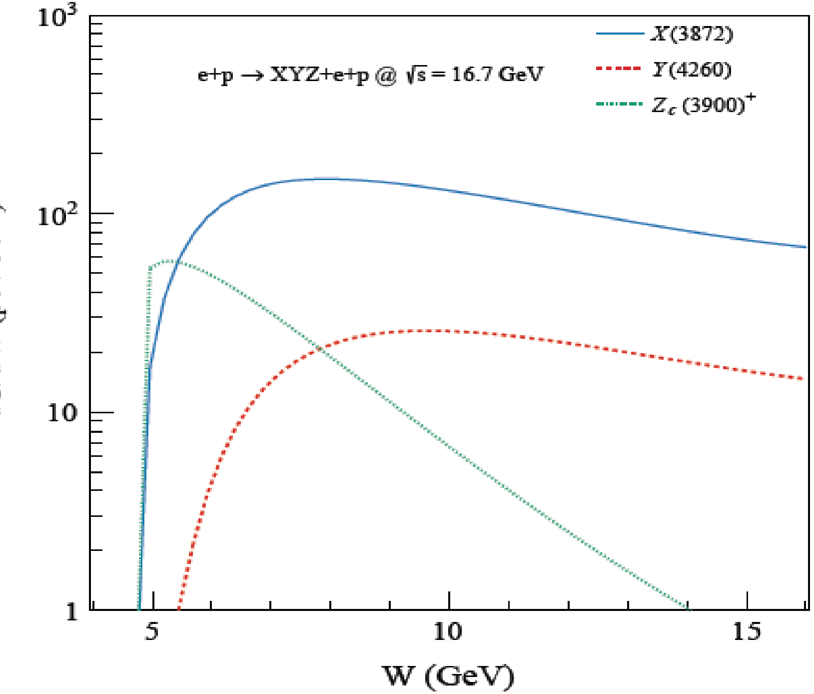
$\Gamma = (46 \pm 10 \pm 20)$ MeV

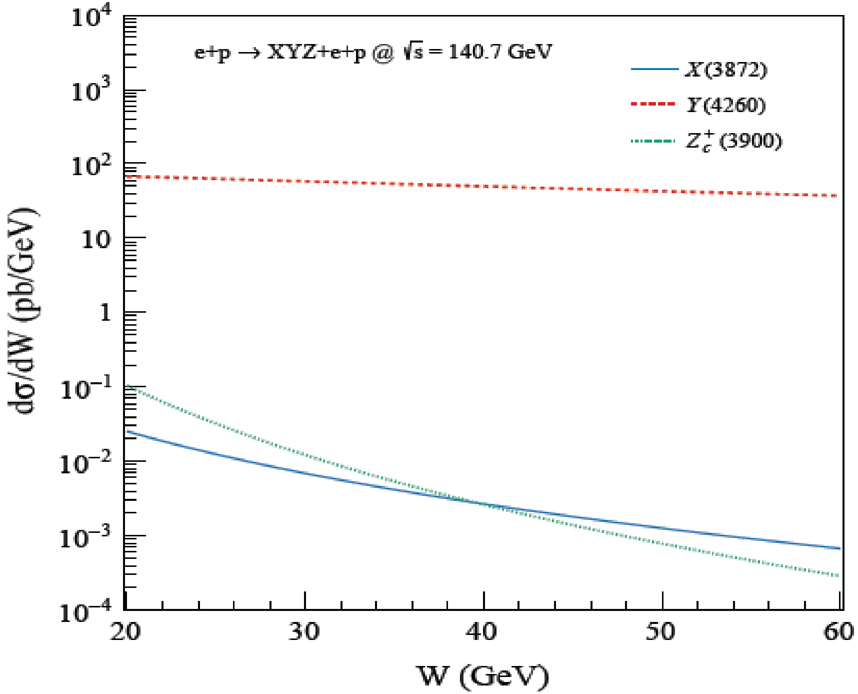
M = (3894.5±6.6 ±4.5) MeV

$\Gamma = (63 \pm 24 \pm 26)$ MeV

Production of XYZ at EICs

XYZ production in electron-proton scattering in future EICs (using the photoproduction of XYZ in arXiv:2008.01001, PRL-102-114010)





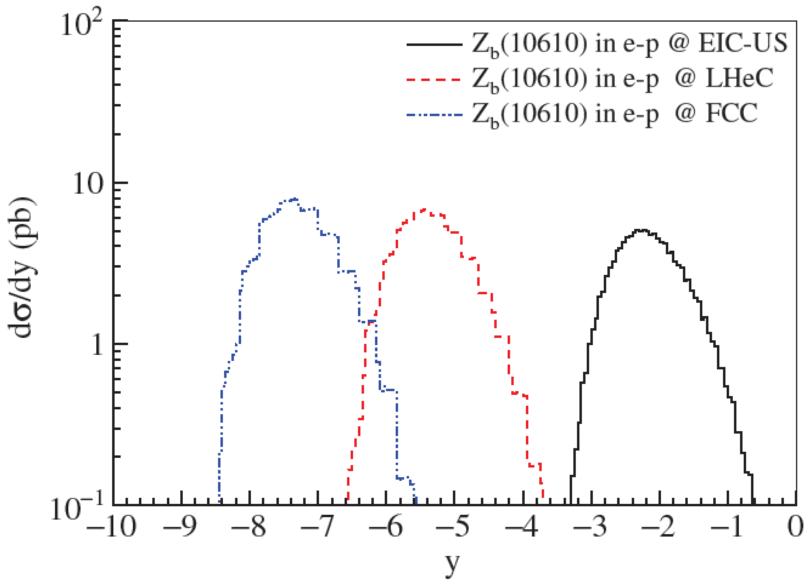
Cross sections of XYZ states in EicC and EIC-US

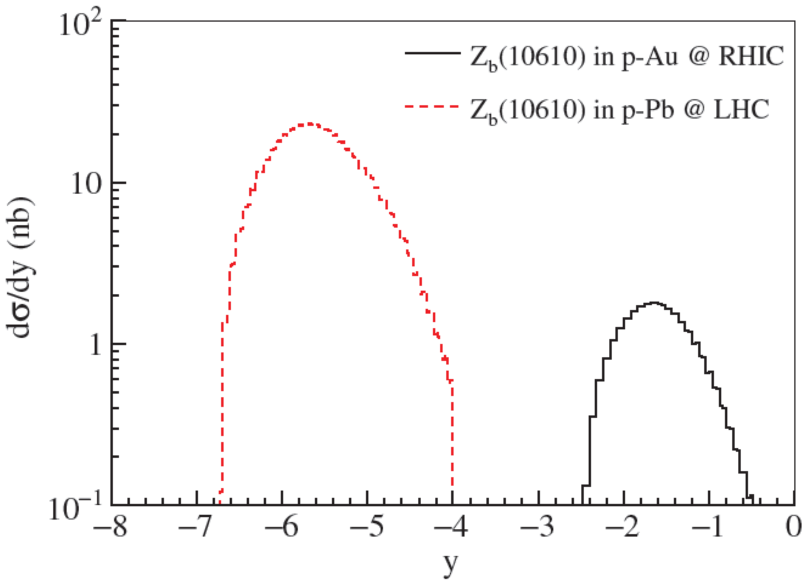
Three kinds of exotic states cross sections are presented as

	EicC	EIC-US
Collide energy	$\sqrt{s} = 16.7$ GeV	$\sqrt{s} = 140.7$ GeV
W region	W $<$ 16 GeV	20 GeV $<$ W $<$ 60 GeV
$X(3872)$	1.2 nb	0.21 pb
$Y(4260)$	0.20 nb	2.0 nb
$Z_c^+(3900)$	0.16 nb	0.48 pb

Production of Zb(10610) at EICs and UPCs

Rapiditiy distributions of Zb(10610) at EICs and UPCs





Cross sections of Zb(10610) states at EICs and UPCs

cross sections of Zb(10610) at EICs and UPCs

	e-p EIC-US	e-p LHeC	e-p FCC	p-Au RHIC	p-Pb LHC
Beam energy, GeV	18 (e) vs. 275 (p)	60 (e) vs. 7×10^3 (p)	60 (e) vs. 50×10^3 (p)	100 (p) vs. 100 (Au)	7×10^3 (p) vs. 2.778×10^3 (Pb)
Integrated luminosity	10 fb^{-1}	10 fb^{-1}	150 fb^{-1}	4.5 pb^{-1}	2 pb^{-1}
Z_b(10610) Cross sections	6.2 pb	8.5 pb	9.8 pb	2.0 nb	30 nb
Expected statistics, 10^6 events	0.062	0.085	1.5	0.0090	0.060

Summary

Our calculations indicate that:

- In EICs, the Pc(4312) is not easy to be identified because of the large background
- In EICs, the Pb can be identify as the small background
- The cross sections of pentaquark states and XYZ states at EICs and UPCs are calculated for experiments

Thank you very much !