Perspectives on charmonium(-like) states at the EicC

Feng-Kun Guo

Institute of Theoretical Physics, CAS

On behalf of the EicC working group

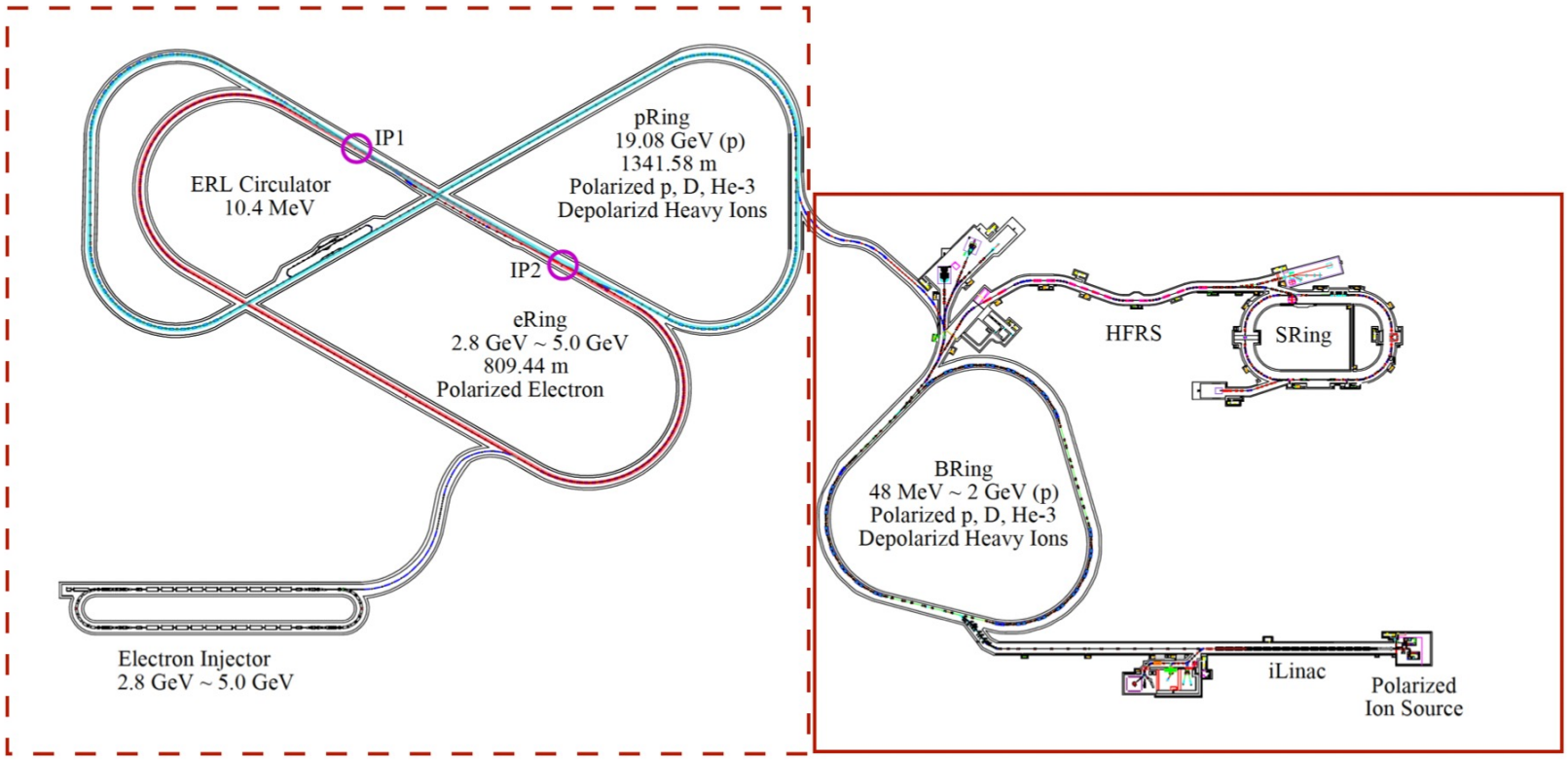
Polarized Electron-Ion Collider in China

Based on High-Intensity Heavy Ion Accelerator Facility (HIAF). About HIAF:

- Funded 2.5 billion RMB, under construction
- Multidisciplinary research facility (atomic, nuclear, biology, materials etc.)
- Upgrade to EicC taken into consideration during the design stage

Polarized Electron-Ion Collider in China

Layout of EicC

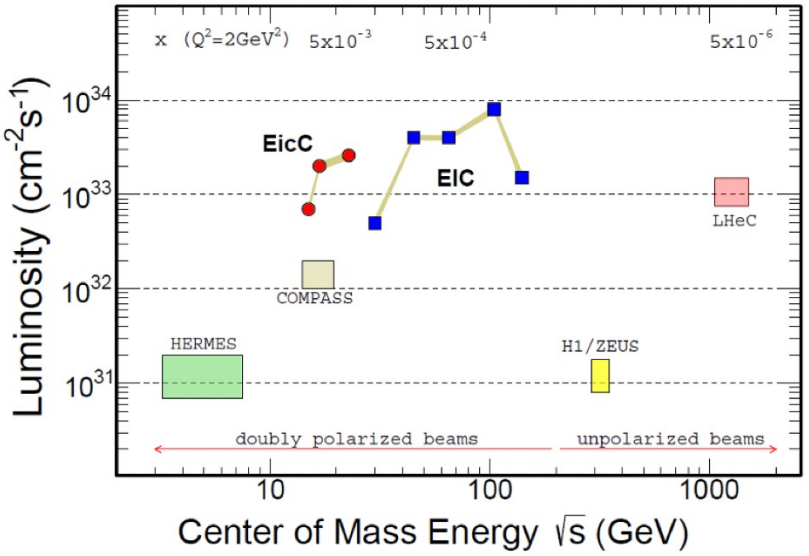


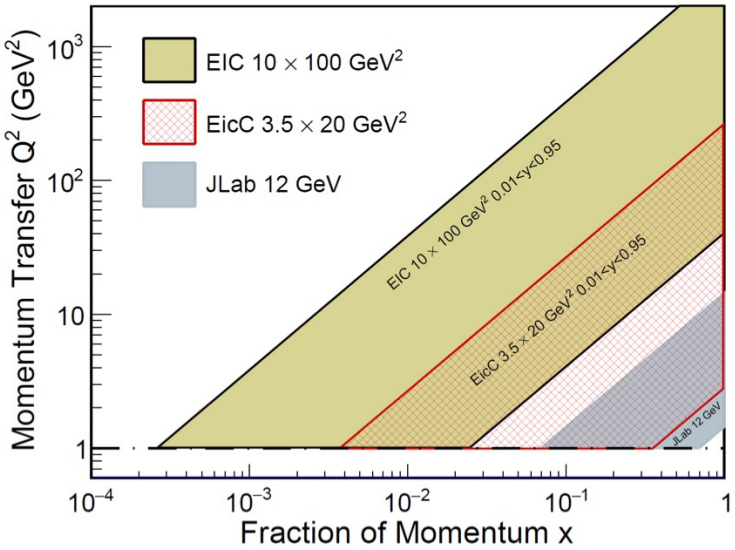
Need to be built for the EicC

HIAF under construction

- Polarized electron injector + racetrack eRing + Figure 8 pRing
- 2 interaction regions

Polarized Electron-Ion Collider in China

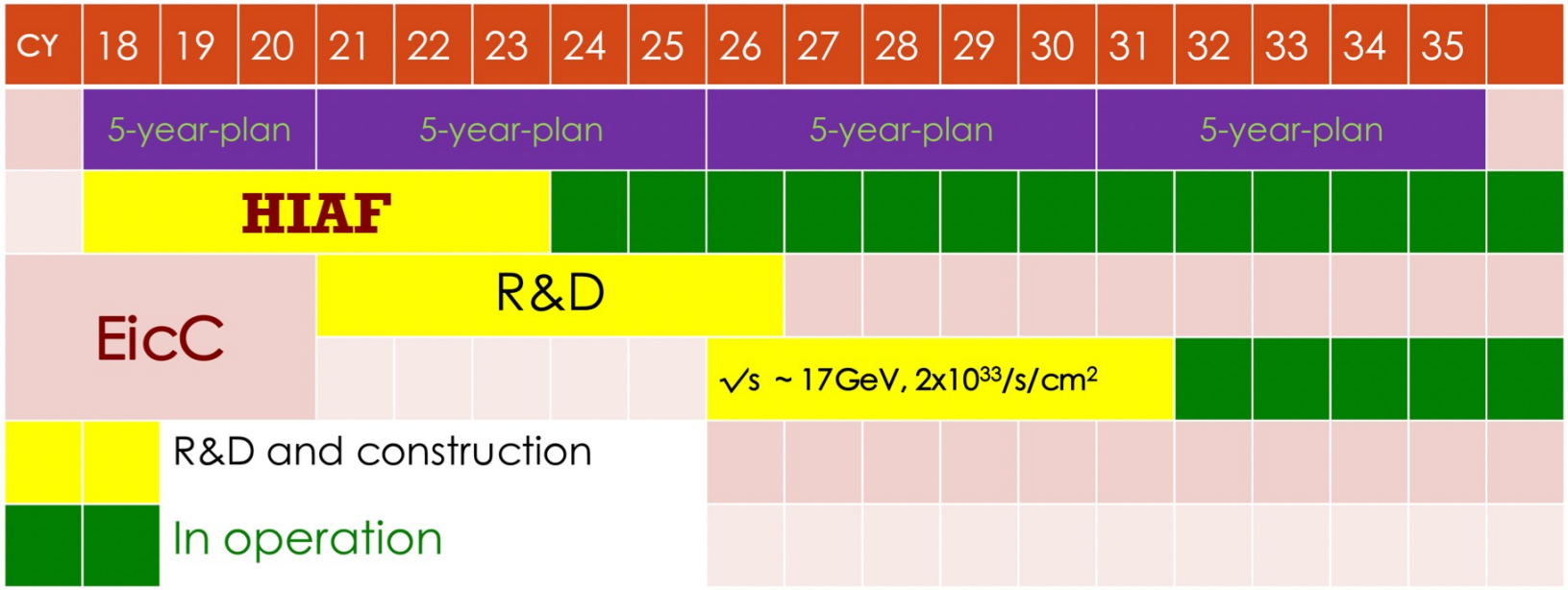




Facility	c.m. energy	lum./10^{33} $\mathrm{cm^{-2}\,s^{-1}}$	Ions	Polarization
EicC	$15-20$	$2-3$	$p \to \mathrm{U}$	e^-, p, and light nuclei
EIC-US	$30-140$	$2-15$	$p \to \mathrm{U}$	$e^-, p,\ ^3\mathrm{He}, \mathrm{Li}$

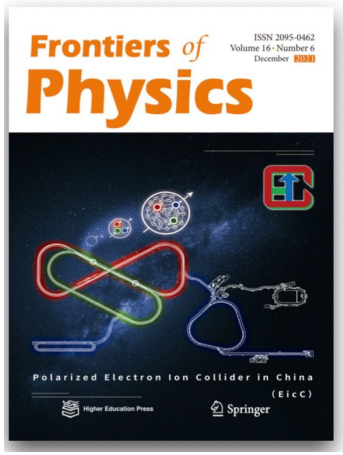
- EicC covers the kinematic region between experiments at JLab and EIC-US.
- moderate x and sea-quark for spin physics, exotic hadrons and nuclear modification.
- Υ near-threshold production

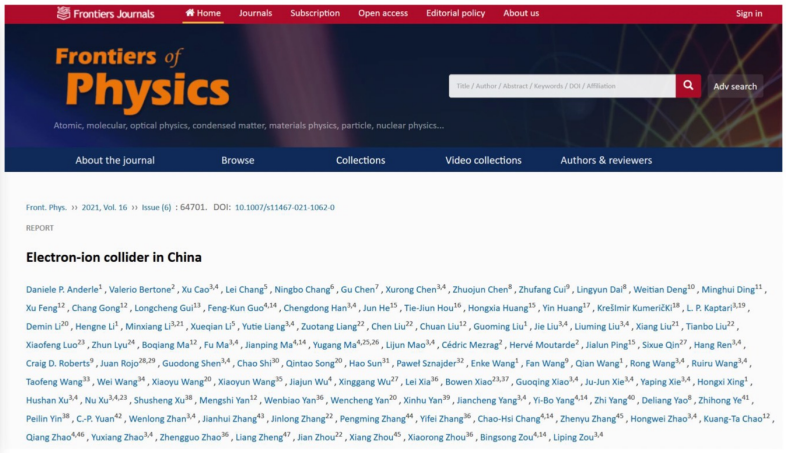
Polarized Electron-Ion Collider in China



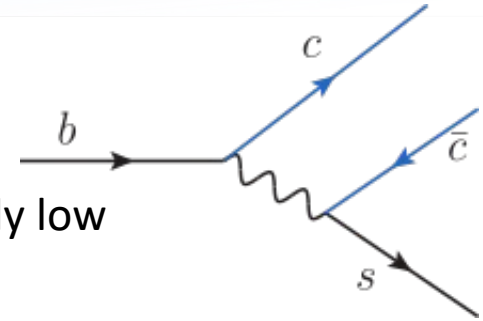
Hope to get support in the next 5-year-plan

EicC white paper:
Front. Phys. 16 (2021) 64701
[arXiv:2102.09222]

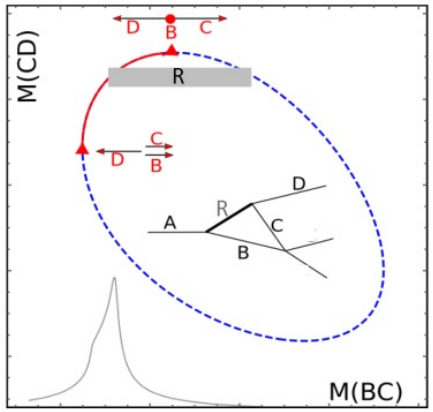




Current experiments for the hidden-charm particles



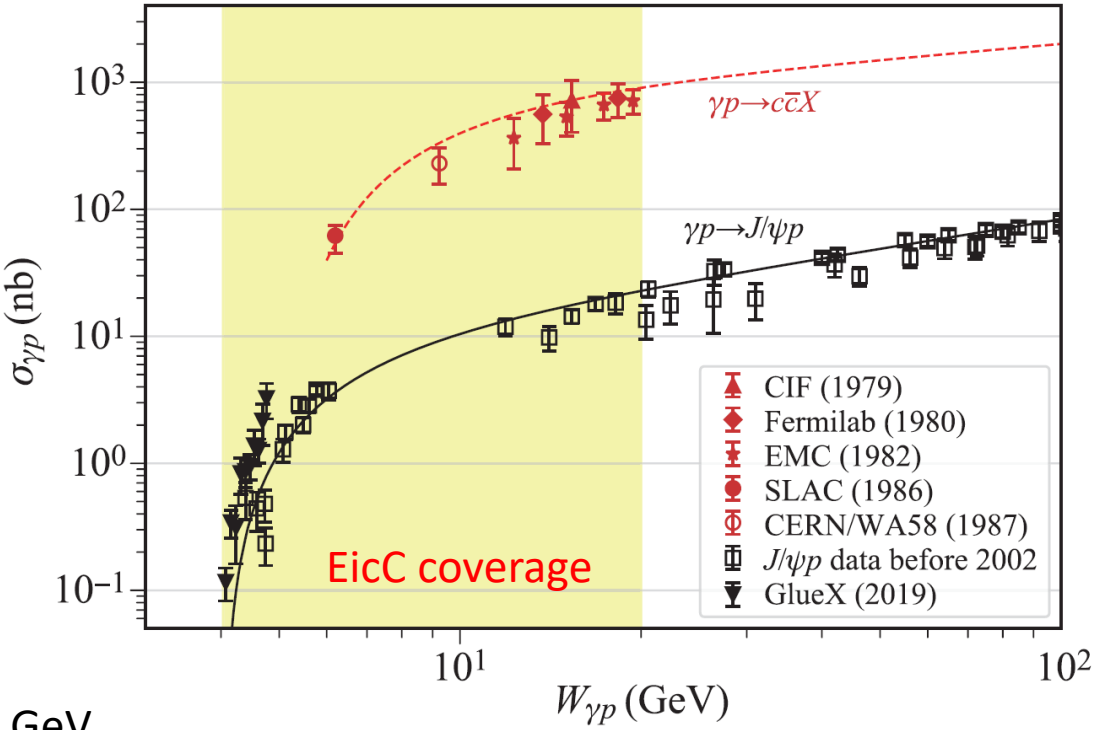
- B-factories
  - From ISR processes
    - Cross sections and selection efficiency are relatively low
  - From B decays with $b \to sc\bar{c}$
    - Energy region limited: $< m_B - m_K \approx 4.8$ GeV
    - Final states with 3 or more hadrons: $B \to K\psi\phi, K\psi\omega, K\psi\pi\pi, \ldots$
      Often difficult due to multi-hadron final states to get unambiguous properties of broad resonances
- Hadron colliders
  - From Λ_b decays with $b \to sc\bar{c}$
    - Energy region limited: $< m_{\Lambda_b} - m_\Lambda \approx 4.8$ GeV
    - Final states with 3 or more hadrons
  - Prompt productions: high background



- BESIII
  - Energy so far $\lesssim 4.96$ GeV, to be upgraded to 5.6 GeV
  - Low production rates (radiative transition) for $C = +$ states
  - Luminosity: less than 1×10^{33} cm^{-2} s^{-1} above 4 GeV

Photoproduction: charm

Figure from D. P. Anderle et al., Front.Phys. 16 (2021) 64701

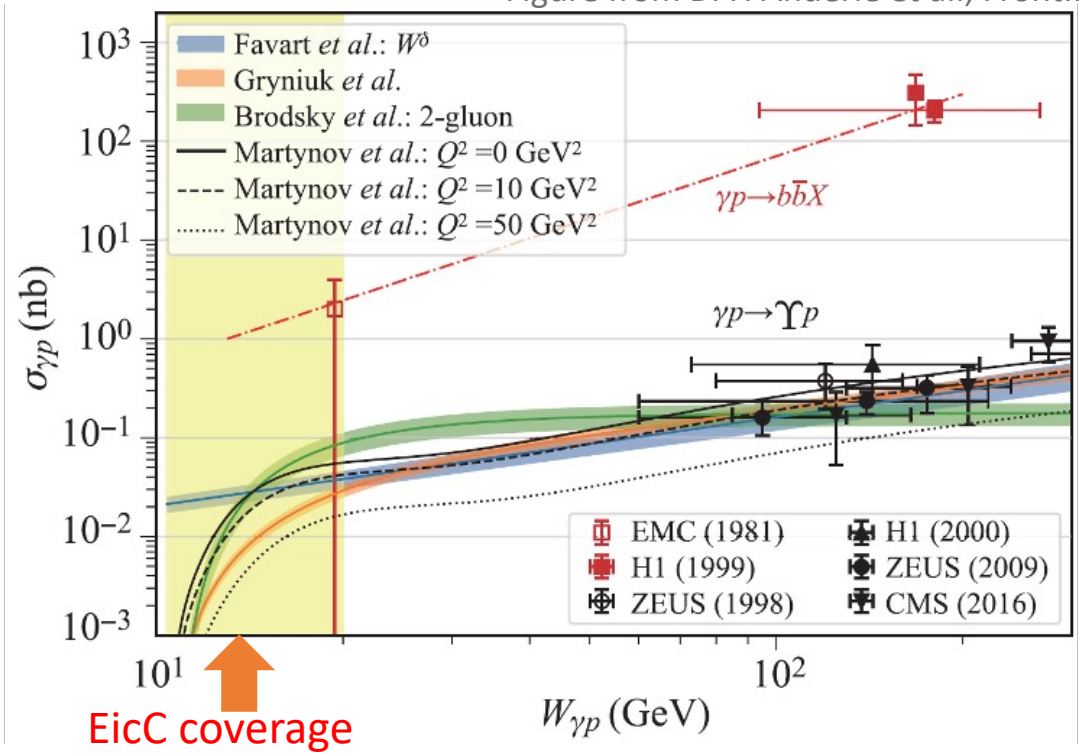


For W=10-20 GeV,

- Photoproduction: $\sigma(\gamma p \to J/\psi p) \sim O(10\ \text{nb})$, (no resonant enhancement considered), $\sigma(\gamma p \to c\bar{c}X) \sim 50\sigma(\gamma p \to J/\psi p)$
- Leptoproduction: cross sections are roughly two orders of magnitude (α) smaller
- For an integrated luminosity of 50 fb^{-1}, no. of J/ψ is $\sim O(10^7 - 10^8)$; many more open-charm hadrons D and Λ_c

Photoproduction: bottom

Figure from D. P. Anderle et al., Front.Phys. 16 (2021) 64701



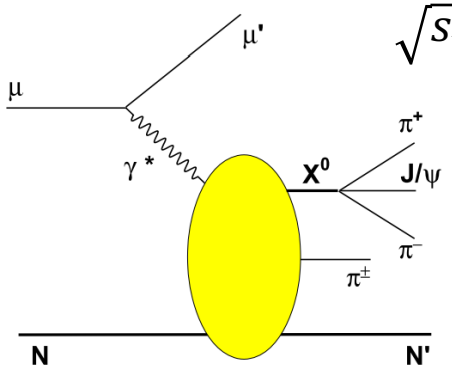
For W=15-20 GeV,

- Photoproduction: $\sigma(\gamma p \to \Upsilon p) \sim O(10\ \mathrm{pb})$ (no resonant enhancement considered), $\sigma(\gamma p \to b\bar{b}X)$ is about two orders higher
- Electroproduction: roughly two orders of magnitude (α) smaller, $\sim O(0.1\ p\mathrm{b})$
- For an integrated luminosity of 50 fb^{-1}, no. of Υ is $\sim O(10^4)$

Hidden-charm exotics at COMPASS

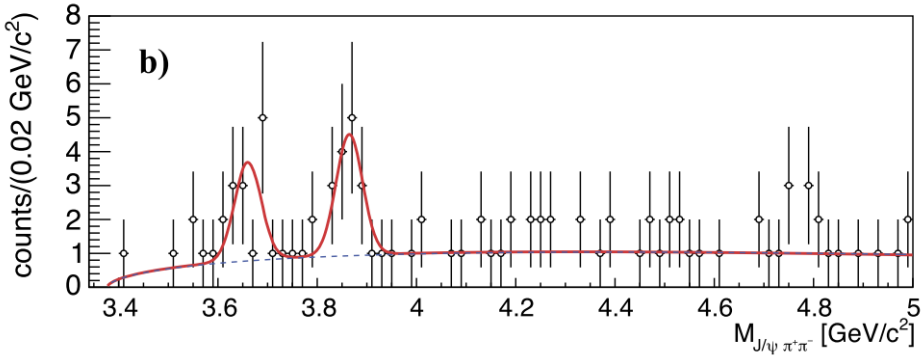
- Observation of $\tilde{X}(3872)$ in $\gamma^* N \to X^0 \pi^\pm N'$ with 4.1σ

COMPASS, PLB783(2018)334

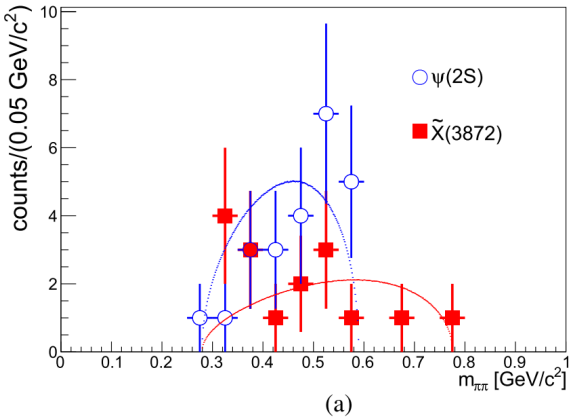


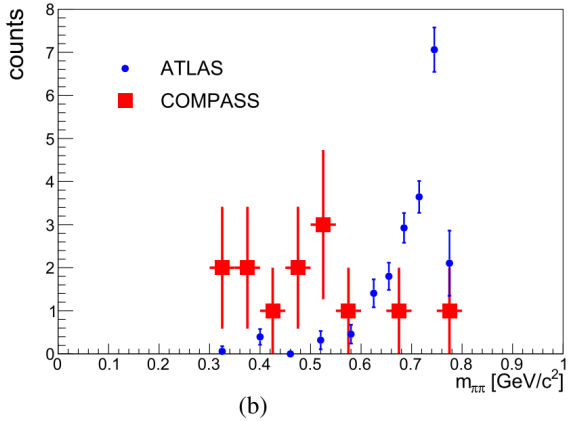
$\sqrt{s_{\gamma N}} \in [8, 18]$ GeV

$M_{\tilde{X}} = (3860.4 \pm 10.0)$ MeV



- The $\pi\pi$ invariant mass suggests $C(\tilde{X}) = -1$





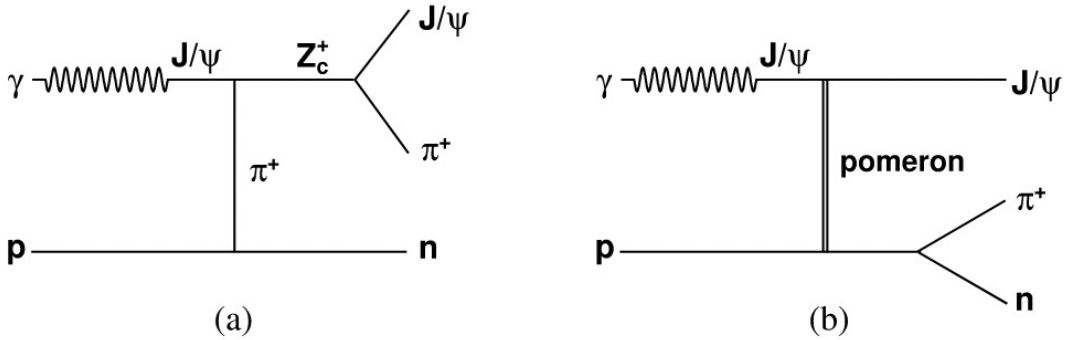
- Cross sections: $\sigma(\gamma N \to \tilde{X}\pi N') \times \mathcal{B}(\tilde{X} \to J/\psi\pi^+\pi^-) = (71 \pm 28 \pm 39)$ pb

$\sigma(\gamma N \to X(3872)N') \times \mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) < 2.9$ pb (CL = 90%)

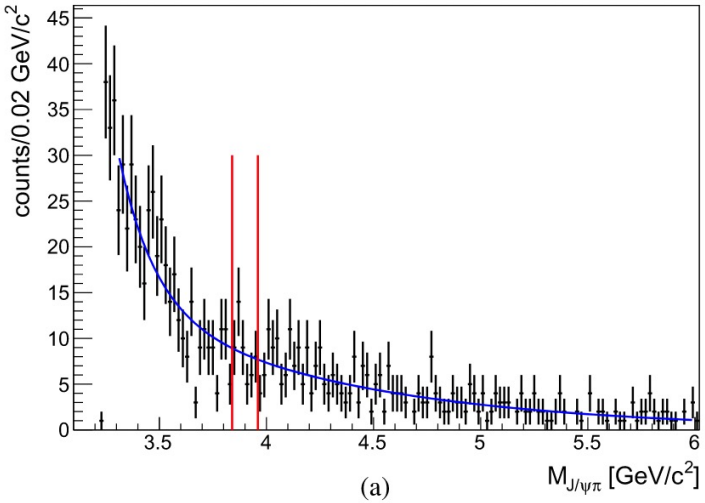
Hidden-charm exotics at COMPASS

- No evidence of $Z_c(3900)$ seen

COMPASS, PLB742(2015)330



$$\mu^+ N \to \mu^+ Z_c^{\pm}(3900) N \to \mu^+ J/\psi\, \pi^{\pm} N \to \mu^+\mu^+\mu^-\pi^{\pm} N \qquad \sqrt{s_{\gamma N}} \in [7, 19]\ \text{GeV}$$



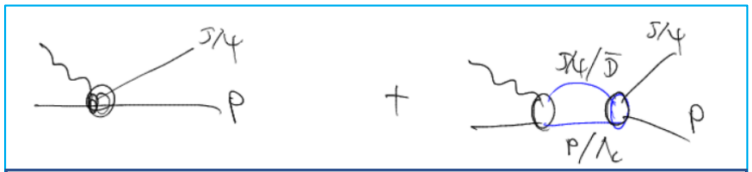
- Cross sections:

$$BR\left(Z_c^{\pm}(3900) \to J/\psi\pi^{\pm}\right) \times \sigma_{\gamma N \to Z_c^{\pm}(3900)N}\Big|_{\left\langle\sqrt{s_{\gamma N}}\right\rangle = 13.8\ \text{GeV}} < 52\ \text{pb}$$

Coupled-channel effects

- Open-charm channels easier to be produced than $J/\psi p$; thresholds nearby

M.-L. Du, V. Baru, FKG, C. Hanhart, U.-G. Meißner, A. Nefediev, I. Strakovsky, EPJC80(2020)1053

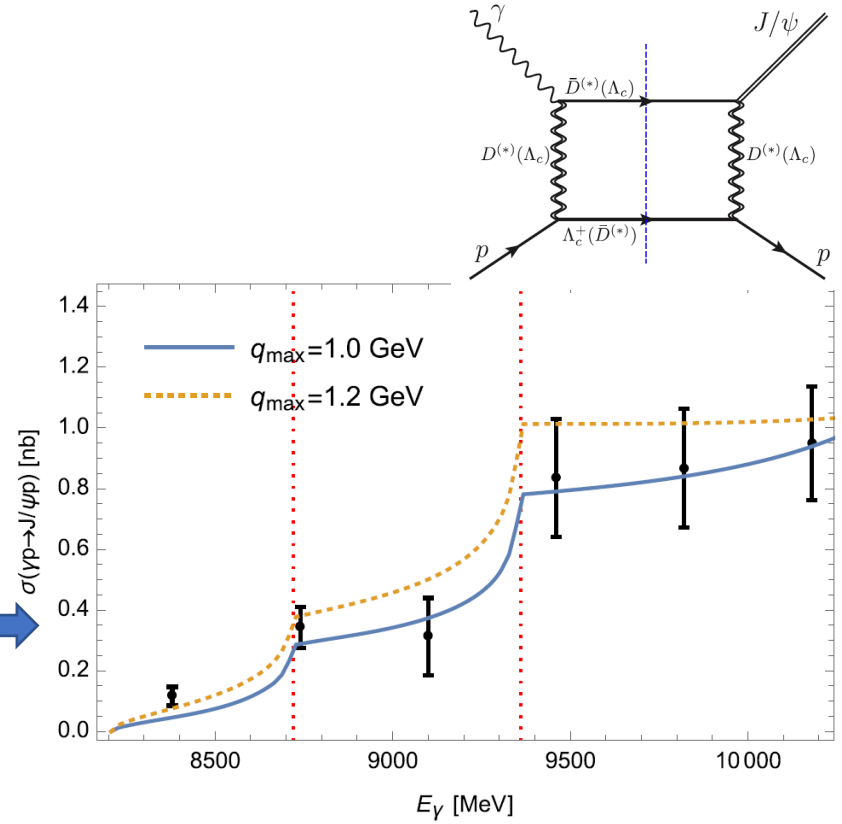


Unitarity: $J/\psi p \to J/\psi p$ enters w/o VMD, but cannot be singled out

$\Lambda_c^+ + \bar{D}$: 2286 + 1865 = 4151 MeV

$J/\psi + p$: 3097 + 938 = 4035 MeV

- Estimated cross section w/ couplings taken from literature
- Unique prediction: cusps at $\Lambda_c \bar{D}^{(*)}$ thresholds



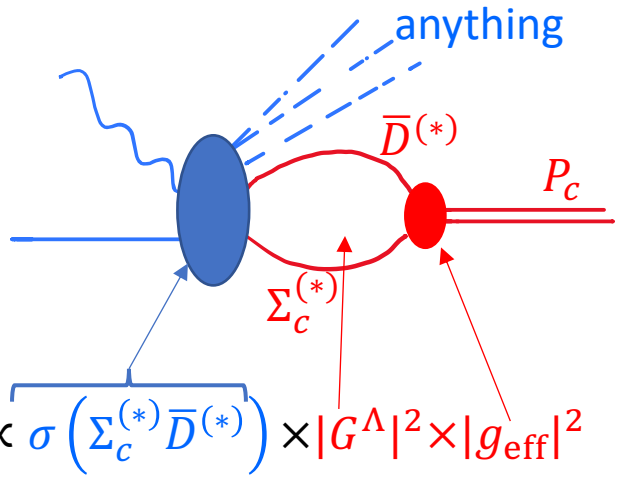
- The same mechanism for $J/\psi p \to J/\psi p$ leads to small scattering length; need to compare with the scattering length from gluon exchanges (ongoing):

$$\left|a^{J=1/2}\right| = 0.2 \ldots 3.1 \text{ mfm}, \quad \left|a^{J=3/2}\right| = 0.2 \ldots 3.0 \text{ mfm},$$

Cross section estimates

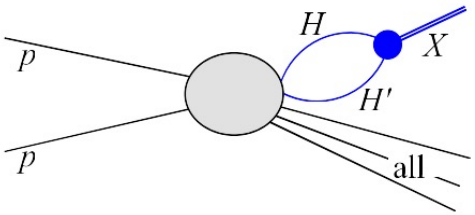
- Order-of-magnitude estimates of inclusive lepto-production of near-threshold hadronic molecules
- The cross section can be estimated as

  e.g., for P_c states



- The method has been used to estimate the X(3872) production at hadron colliders; despite the debates regarding the X(3872) structure, correct order of magnitude was reproduced

Artoisenet, Braaten, PRD83(2011)014019; FKG, Meißner, W. Wang, Z. Yang, EPJC74(2014)3063



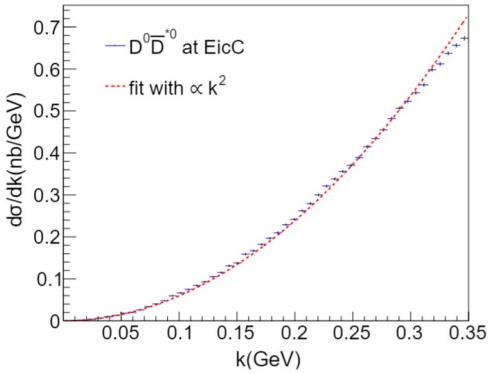
$\sigma(pp/\bar{p}\to X)$ [nb] Exp.		Λ=0.5 GeV	Λ=1.0 GeV
Tevatron	37-115	7 (5)	29 (20)
LHC-7	13-39	13 (4)	55 (15)

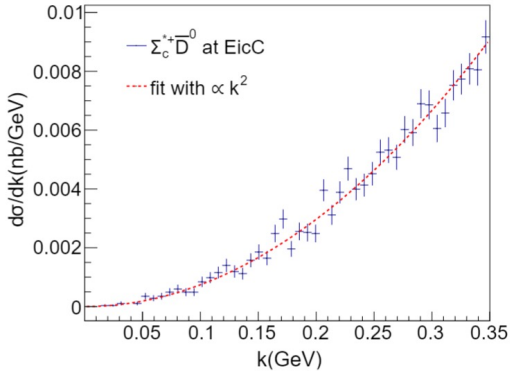
Albaladejo, FKG, Hanhart et al., CPC41(2017)121001

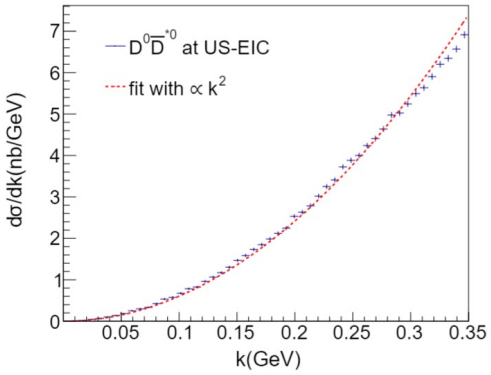
Cross section estimates

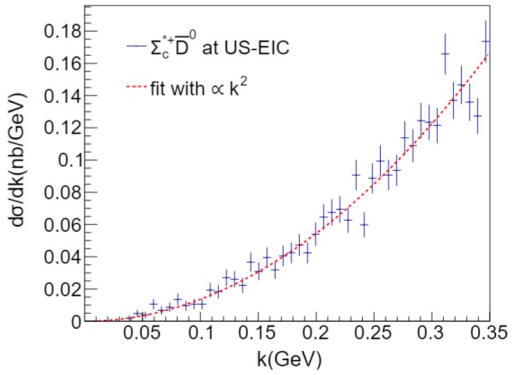
Z. Yang, FKG, CPC 45 (2021) 123101

- Charm hadron pairs generated using Pythia6.4









- Considered machine configurations

	EicC	EIC
e^- **energy** (GeV)	3.5	20
proton energy (GeV)	20	250
luminosity ($\mathrm{cm^{-2}\ s^{-1}}$)	2×10^{33}	10^{34}

Cross section estimates

Z. Yang, FKG, CPC 45 (2021) 123101; P.-P. Shi, FKG, Z. Yang, arXiv:2208.02639

- Order-of-magnitude estimates of the semi-inclusive electro-production of hidden/double-charm hadronic molecules (in units of pb)

	Constituents	$I, J^{P(C)}$	EicC	EIC
$X(3872)$	$D\bar{D}^*$	$0, 1^{++}$	21(89)	220(900)
$Z_c(3900)^0$	$D\bar{D}^*$	$1, 1^{+-}$	$0.4\times10^3(1.3\times10^3)$	$3.8\times10^3(14\times10^3)$
Z_{cs}^-	$D^{*0}D_s^-$	$1/2, 1^+$	19(69)	250(900)
$P_c(4312)$	$\Sigma_c\bar{D}$	$1/2, 1/2^-$	0.8(4.1)	15(73)
$P_{cs}(4338)$	$\Xi_c\bar{D}$	$0, 1/2^-$	0.1(1.6)	1.8 (30)
Predicted	$\Lambda_c\bar{\Lambda}_c$	$0, 0^{-+}$	0.3 (3.0)	10 (110)
Predicted	$\Lambda_c\bar{\Sigma}_c$	$1, 0^-$	0.01 (0.12)	0.5 (5.5)
T_{cc}^+	DD^*	$0, 1^+$	0.3×10^{-3} (1.2×10^{-3})	0.1 (0.5)

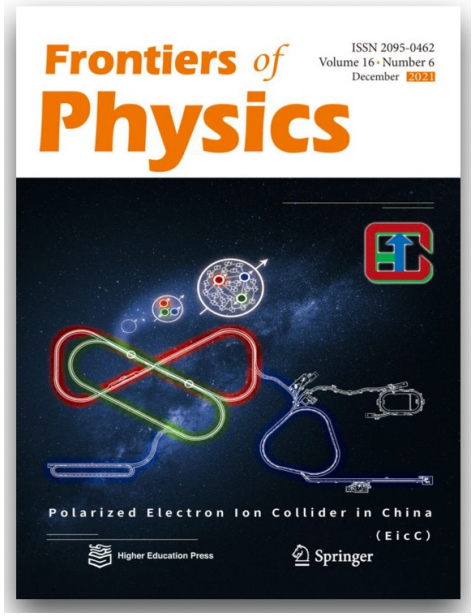
Results for more systems can be found in the above refs.

Estimated events

- Not in conflict with all previously reported photoproduction upper limits
- From our estimate, at GlueX $\sigma(\gamma p \to P_c)\times\mathcal{B}(P_c^+ \to J/\psi p)$ would be at most a few pb, difficult to detect
- At EicC, considering luminosity $50\ \mathrm{fb}^{-1}$
  - taking $\sigma(e^- p \to X(3872) + \text{anything}) \approx 40\ \text{pb}$, then $\sim 2\times10^6$ events; taking $\mathcal{B}(X(3872) \to J/\psi\pi^+\pi^-) = (3.8 \pm 1.2)\%, \mathcal{B}(J/\psi \to \ell^+\ell^-) = 12\%$, then $\sim 10^4$ events
  - taking $\sigma(e^- p \to Z_c(3900)^+ + \text{anything}) \approx 400\ \text{pb}$, $\sim 2\times10^7$ events; assuming $\mathcal{B}(Z_c \to J/\psi\pi)\times\mathcal{B}(J/\psi \to \ell^+\ell^-) = \mathcal{O}(1\%)$, then $\sim 2\times10^5$ events
  - taking $\sigma(e^- p \to P_c + \text{anything}) \approx 2\ \text{pb}$, then $\sim 10^5$ events; assuming $\mathcal{B}(P_c \to J/\psi p)\times\mathcal{B}(J/\psi \to \ell^+\ell^-) = \mathcal{O}(0.1\%)$, then $\sim 10^2$ events
  - …
  - Open charm final states can have much larger branching fractions

Outlook

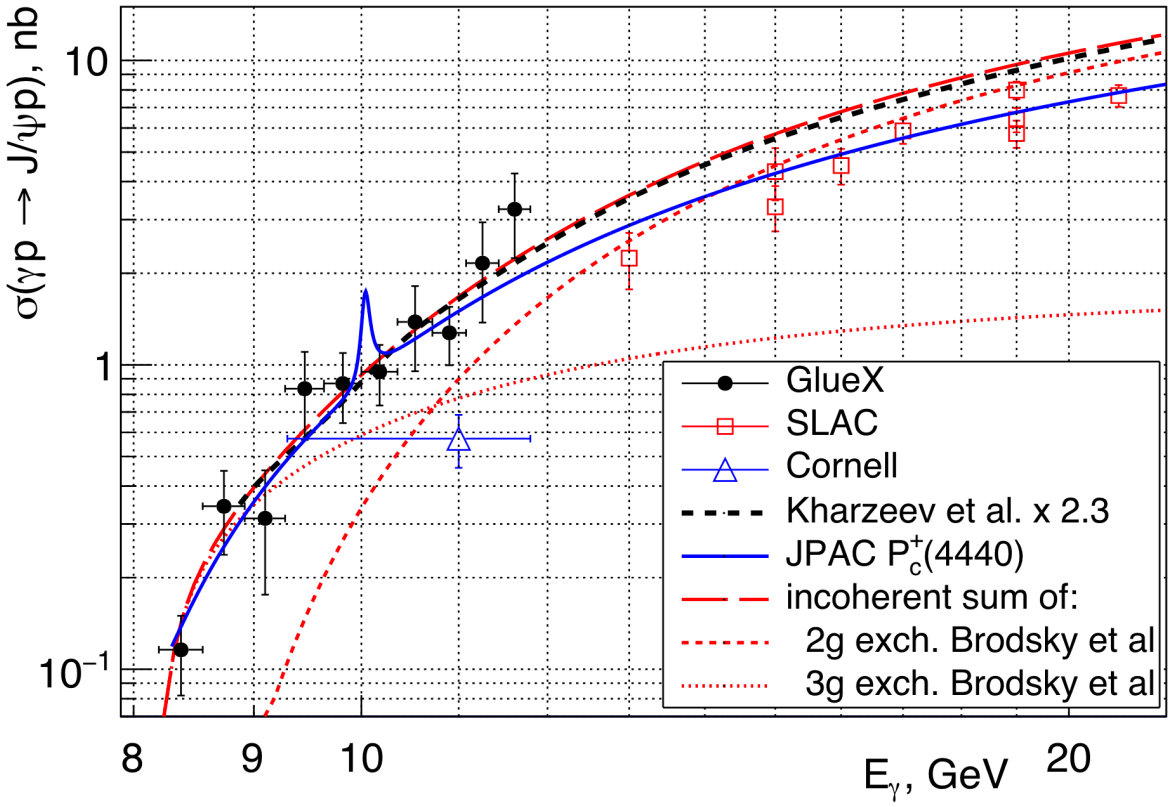
- EicC: Polarized Electron-ion collider in China
- Conceptual Design Report by 2023
- Future electron-proton machines will be able to contribute a lot to hadron spectroscopy



Thank you for your attention!

Near-threshold J/ψ production at GlueX

No evidence of P_c in the J/ψ photoproduction at GlueX

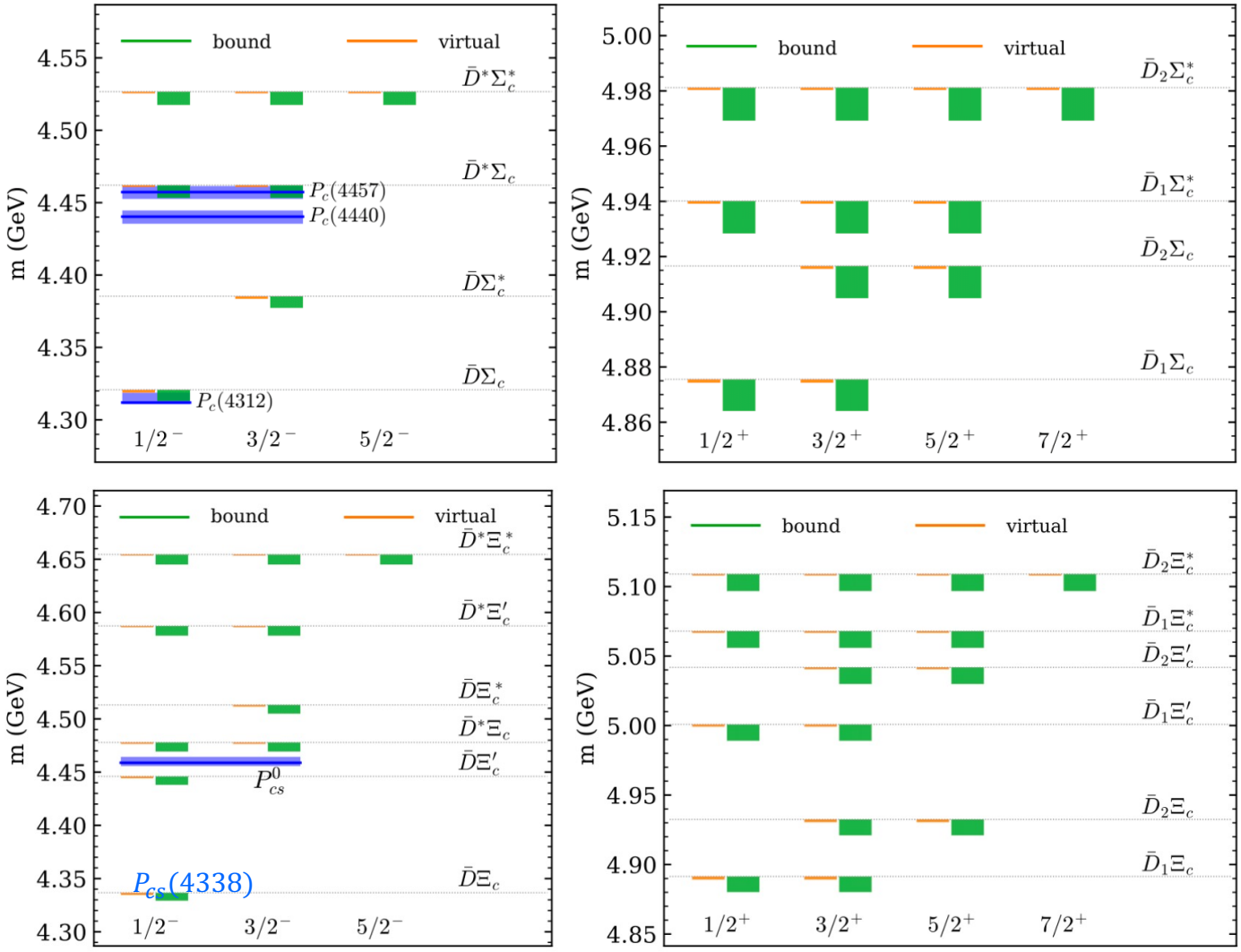


GlueX, PRL 122 (2019) 222001

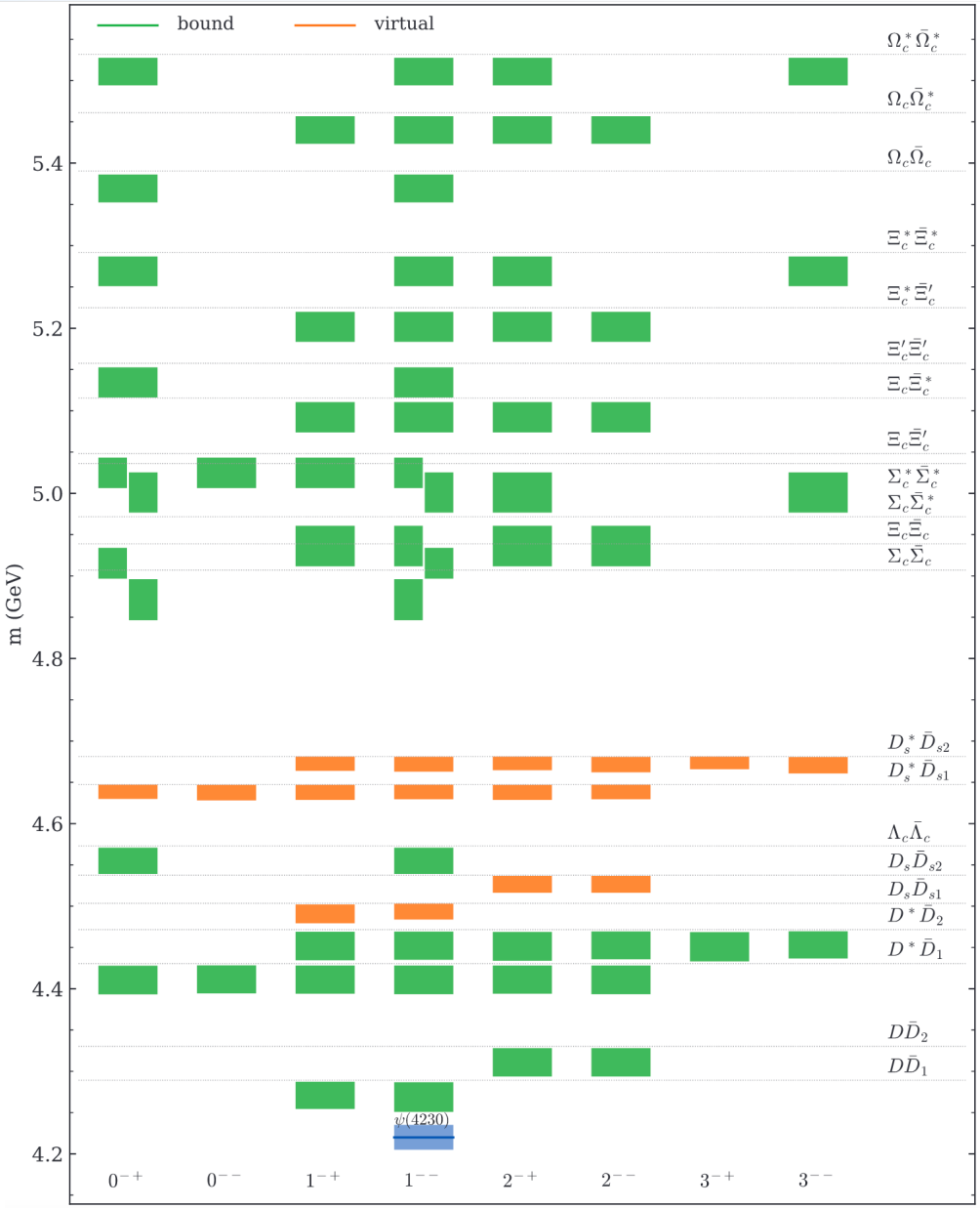
More hadronic molecules are expected

- Survey of hadronic molecular spectrum with a simple vector-exchange model
- Hidden-charm hadronic molecules

X.-K. Dong, FKG, B.-S. Zou, Progr.Phys.41 (2021) 65



More hadronic molecules are expected

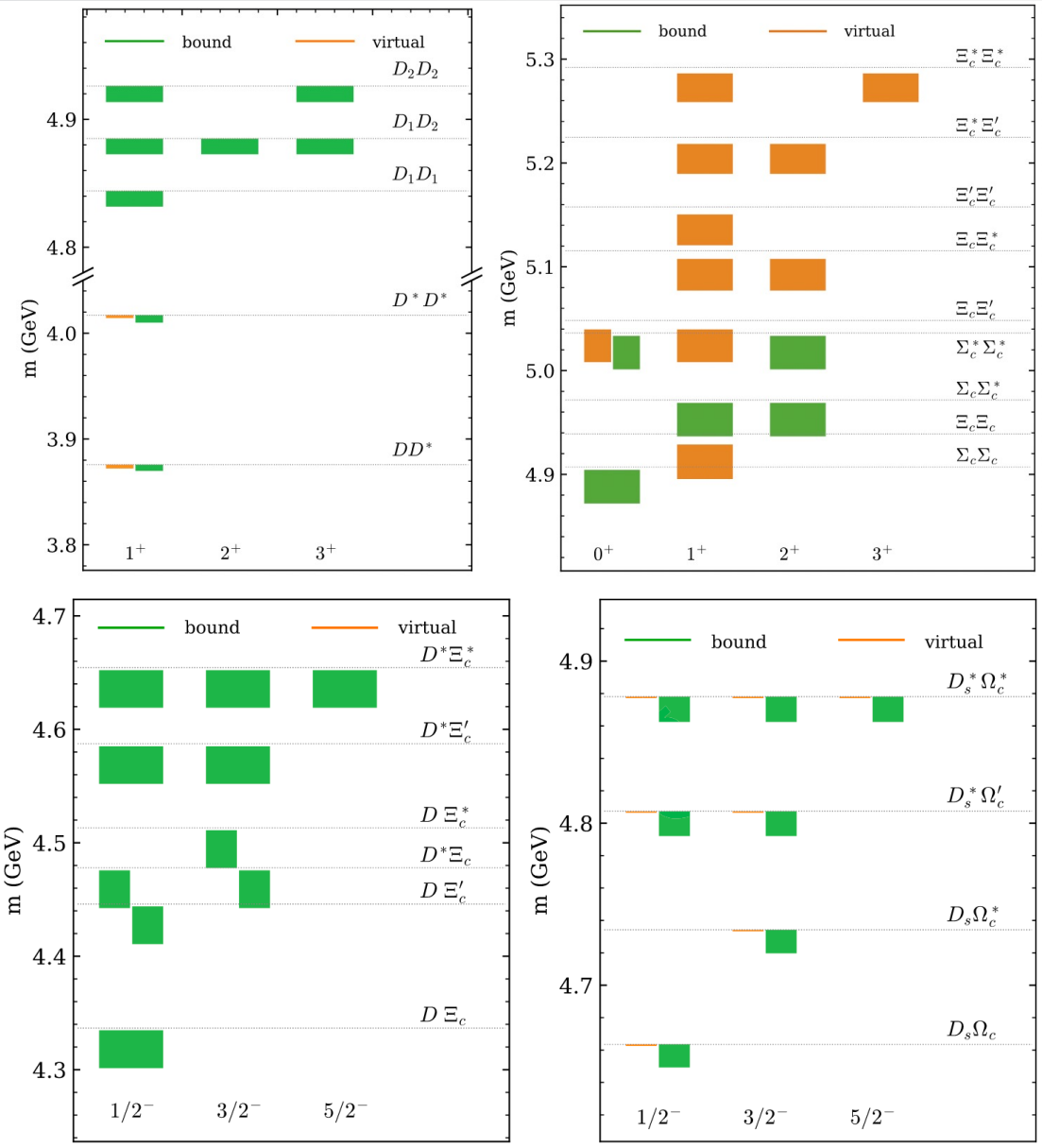


- Hidden-charm hadronic molecules

  X.-K. Dong, FKG, B.-S. Zou, Progr.Phys.41 (2021) 65

➢ High-luminosity experiments covering the energy range above 5 GeV are needed

More hadronic molecules are expected



- Double-charm hadronic molecules

  X.-K. Dong, FKG, B.-S. Zou, CTP73 (2021) 125201