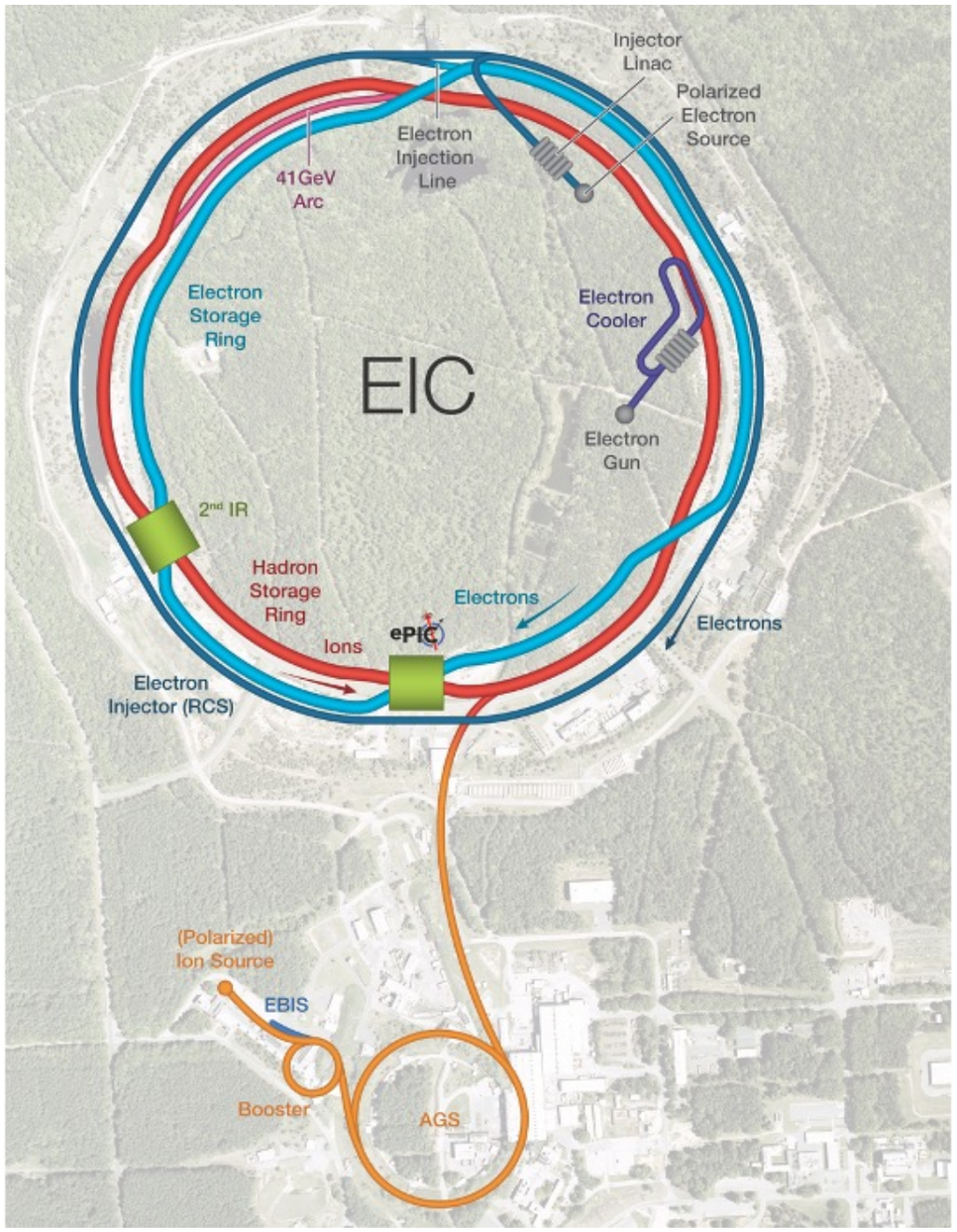
Hadron Spectroscopy at the EIC

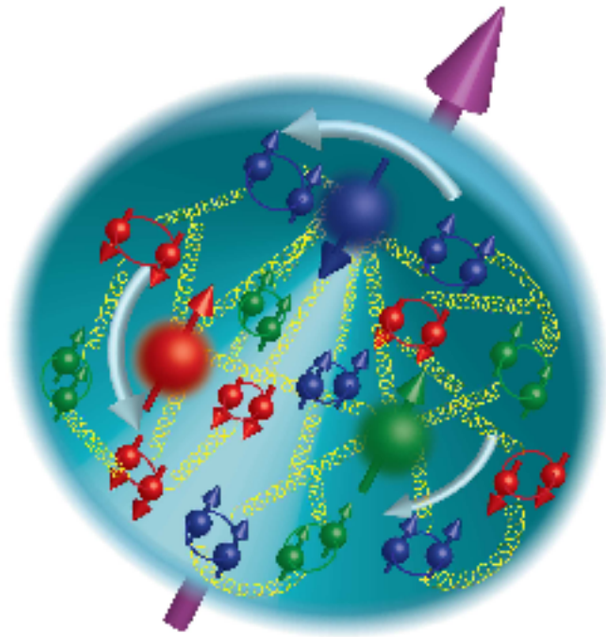
Justin Stevens

WILLIAM & MARY
CHARTERED 1693

Electron Ion Collider (EIC)



- Versatile high-luminosity, polarized e+p and e+A collider, recently launched DOE project
  - Nucleon spin and 3D structure
  - High gluon density and saturation

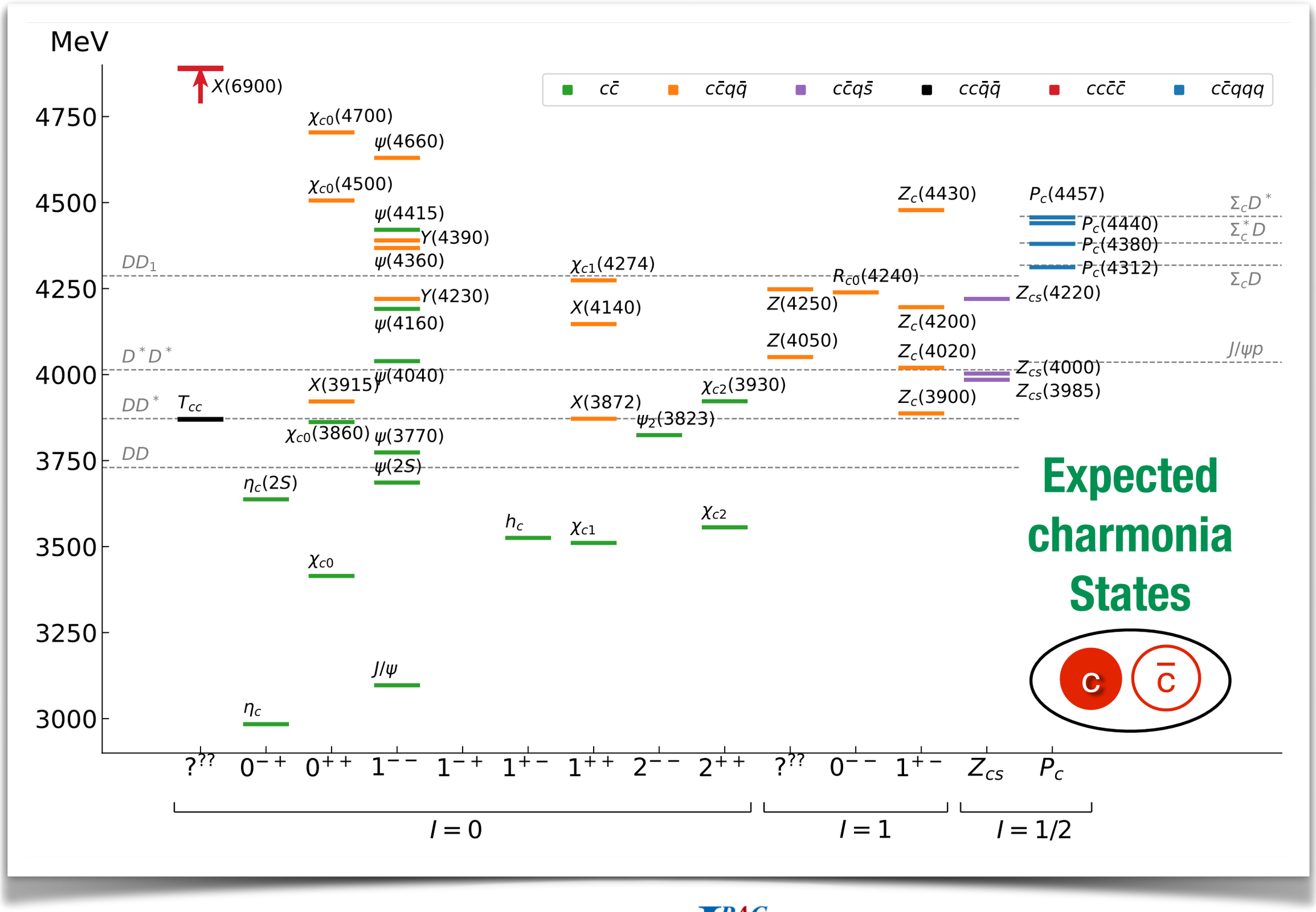


$$\sqrt{s} = 29 - 140\ GeV$$

$$\mathscr{L}_{ep} = 10^{33} - 10^{34}\ cm^{-2}s^{-1}$$

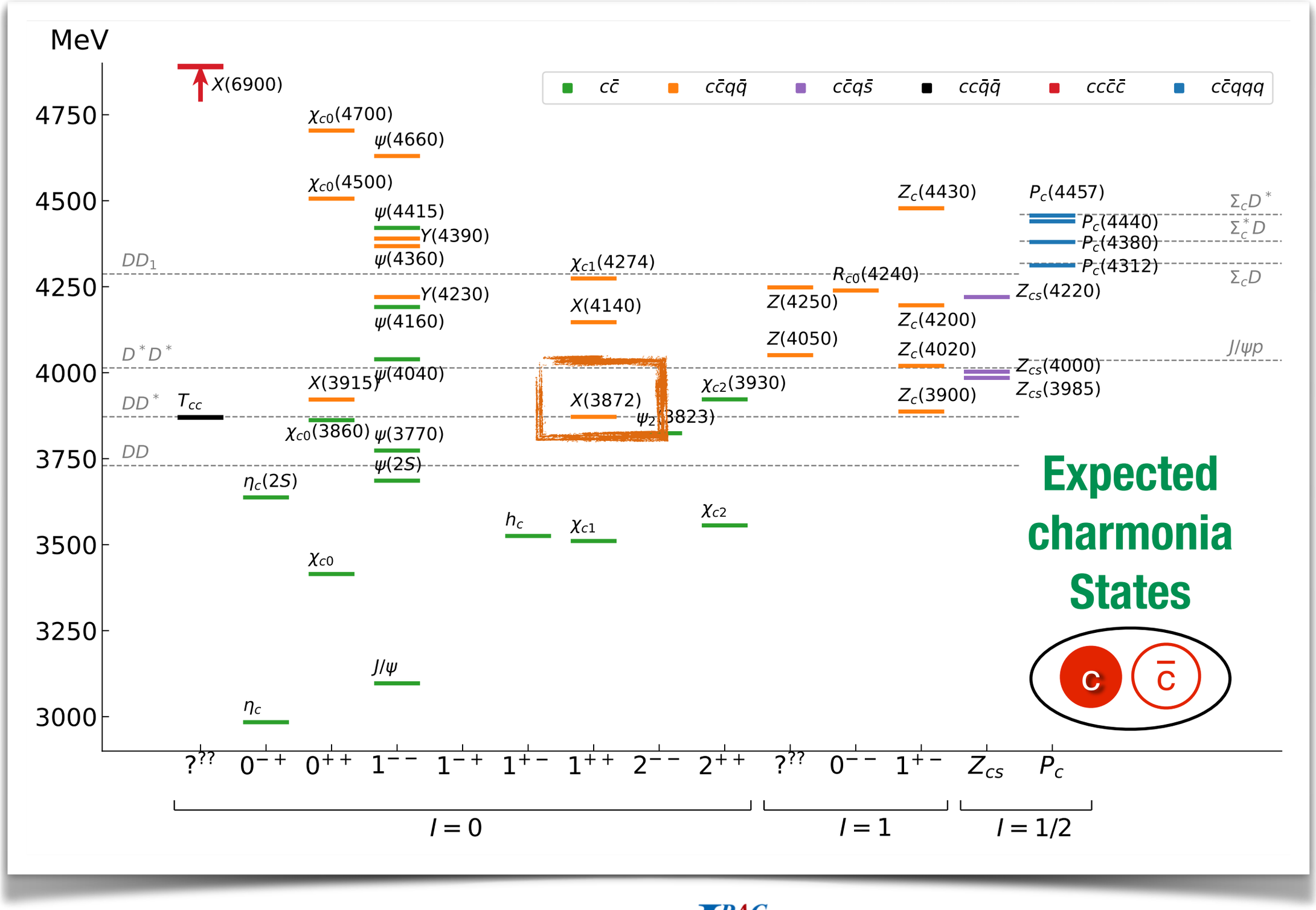
- **Today: what can we learn about the spectrum of hadrons with the EIC?**

Reminder of $XYZP_c$ states



Recent review: JPAC **Prog. Part. Nucl. Phys. 127 (2022) 103981**

$XYZP_c$ reminder: $X(3872)$ or $\chi_{c1}(3872)$



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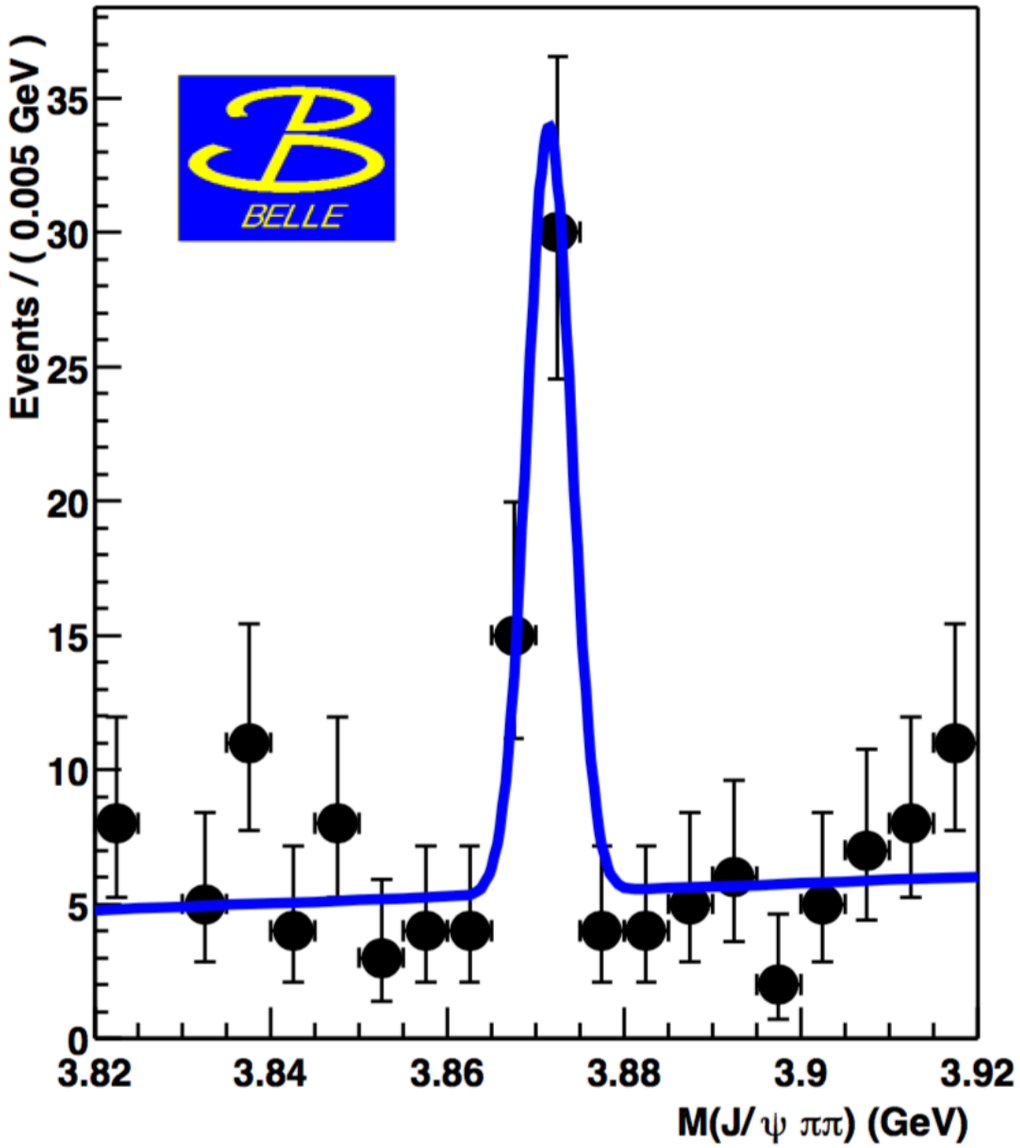
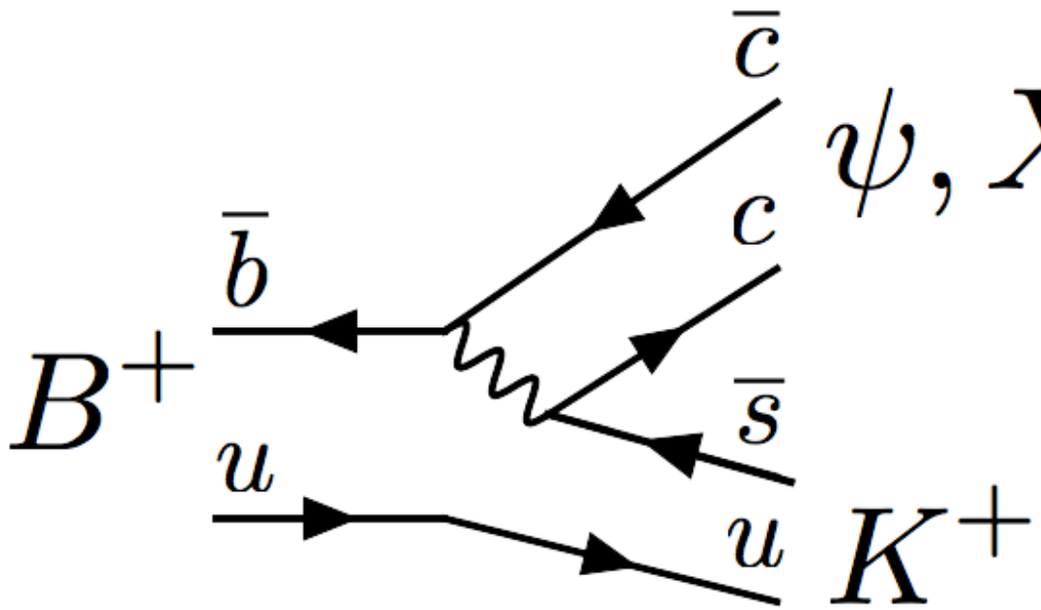
A charming surprise: $X(3872)$ or $\chi_{c1}(3872)$

$$X \to \pi^+\pi^- J/\psi$$





PRL 91, 262001 (2003)

A charming surprise: $\chi_{c1}(3872)$

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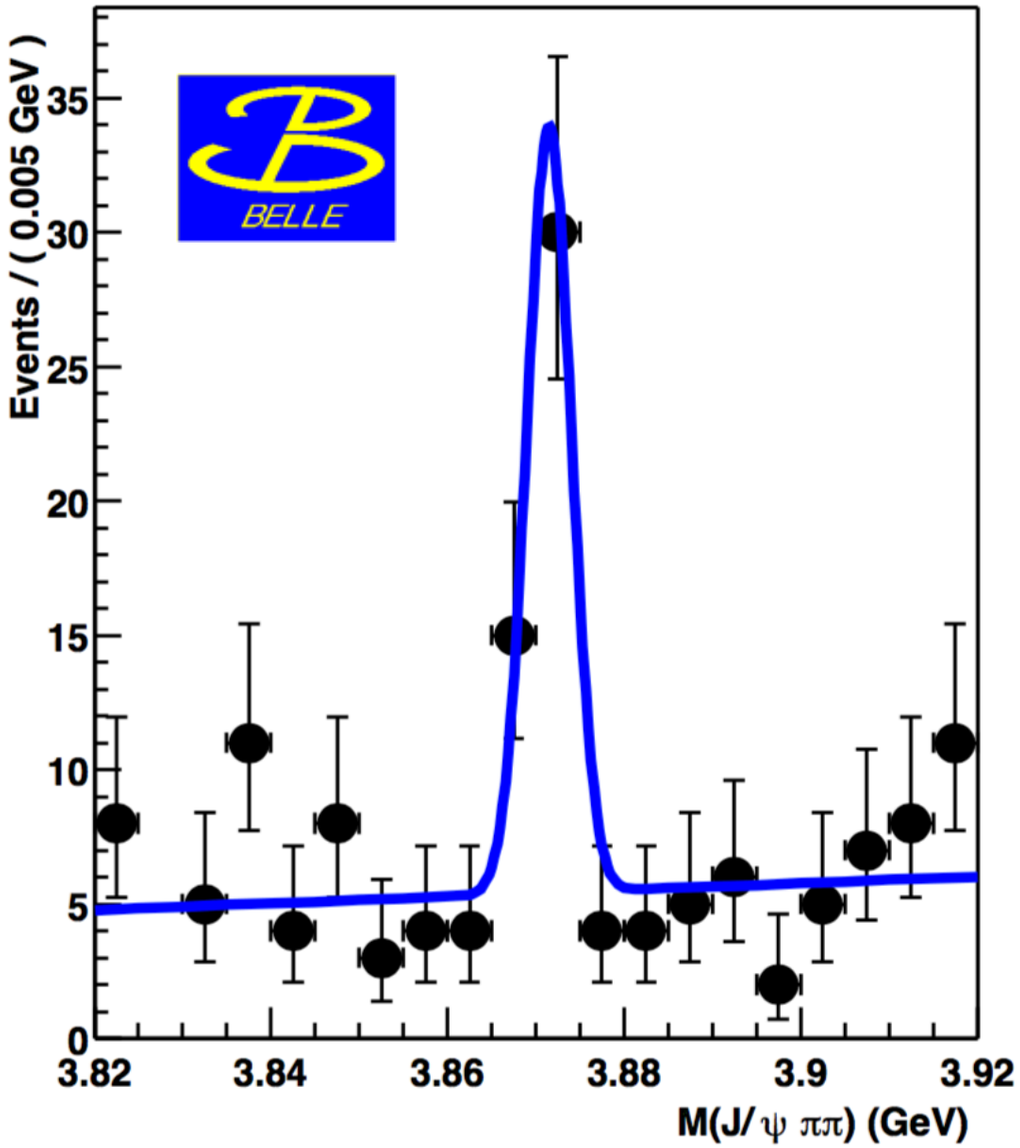
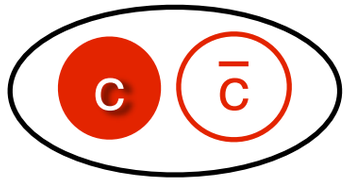


PRL 91, 262001 (2003)

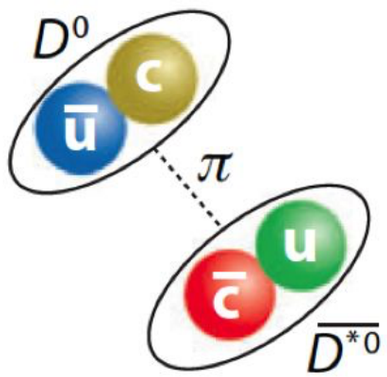
Quantum Numbers: $J^{PC} = 1^{++}$

Interpretation?

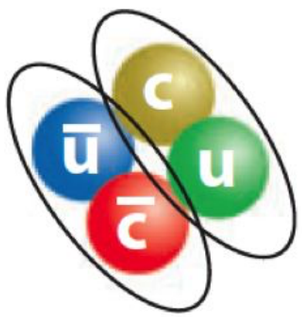
Conventional



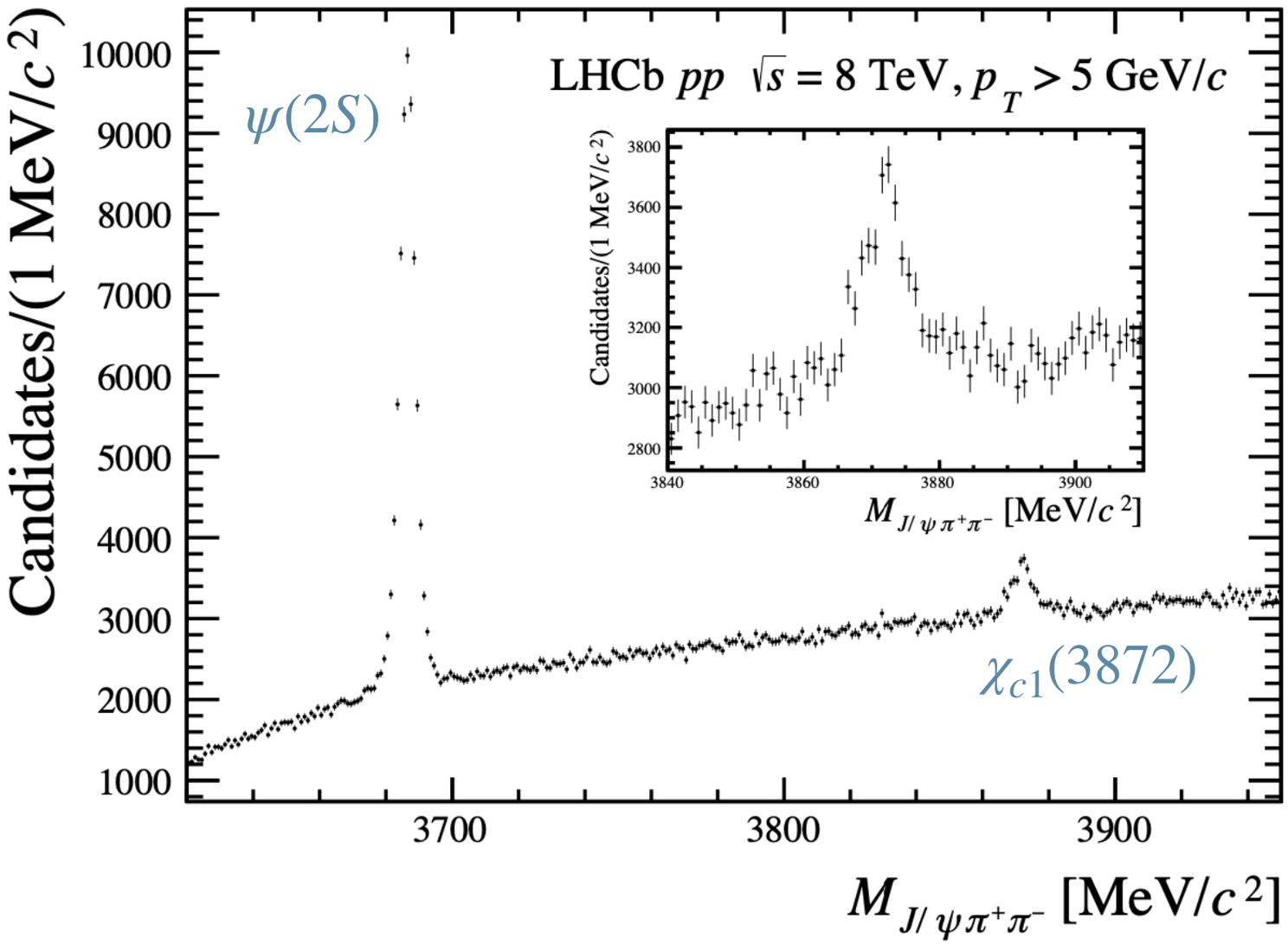
Molecule



Compact Tetraquark



$\chi_{c1}(3872)$ compared to $\psi(2S)$



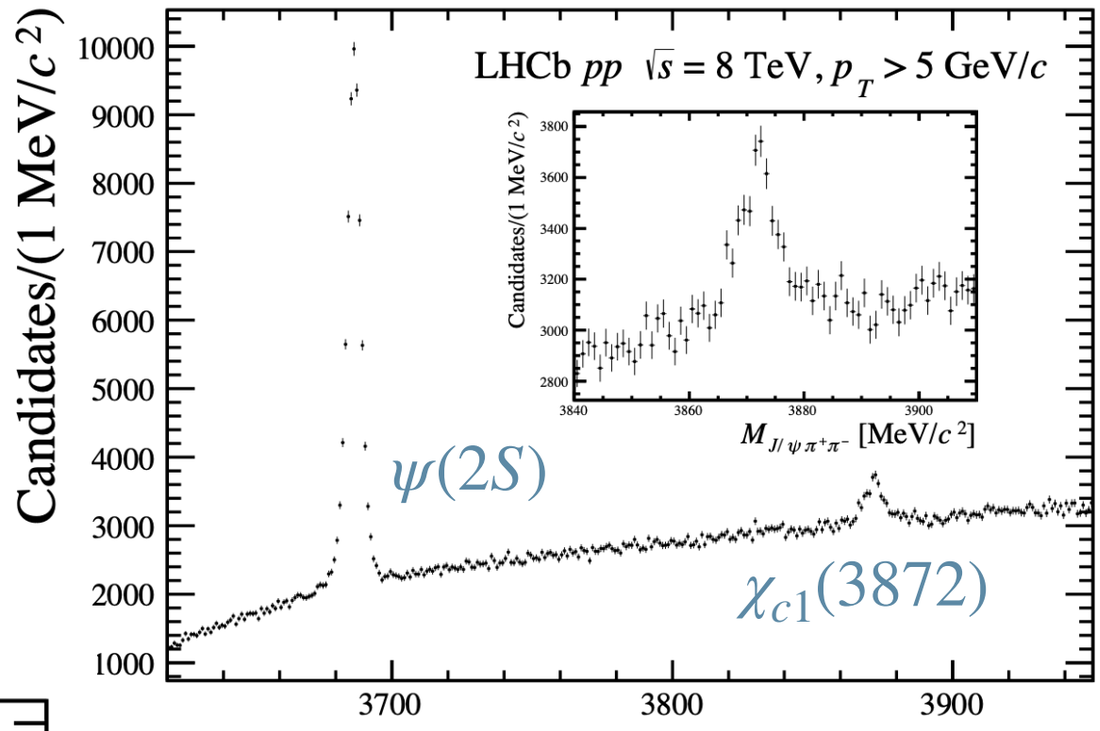
- LHCb results on "prompt" $\chi_{c1}(3872)$ production demonstrate robust signal, not just from B-decays

LHCb: PRL 126 (2021) 9, 092001

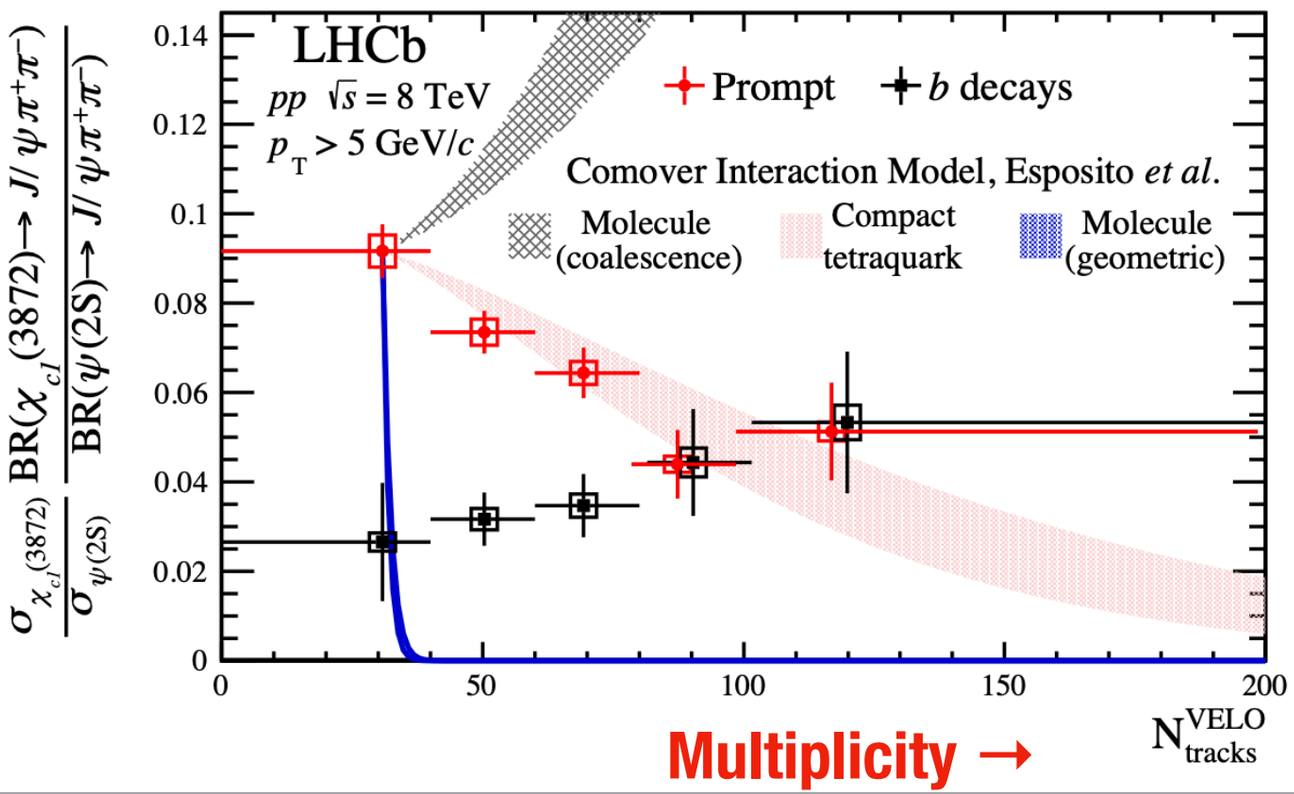
$\chi_{c1}(3872)$ compared to $\psi(2S)$

- Recent LHCb results in pp show prompt $\chi_{c1}(3872)$ decreases with multiplicity

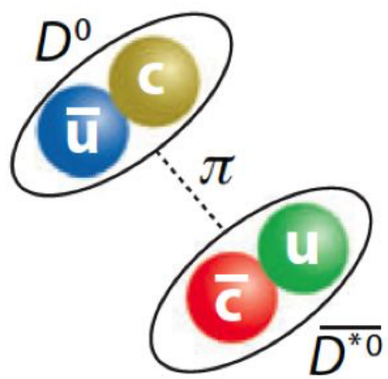
$$\frac{\sigma_{\chi_{c1}(3872)}}{\sigma_{\psi(2S)}} \frac{\mathrm{BR}(\chi_{c1}(3872) \to J/\psi\pi^+\pi^-)}{\mathrm{BR}(\psi(2S) \to J/\psi\pi^+\pi^-)}$$



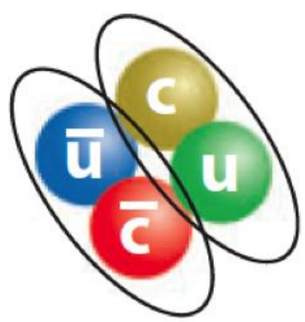
LHCb: PRL 126 (2021) 9, 092001



Molecule



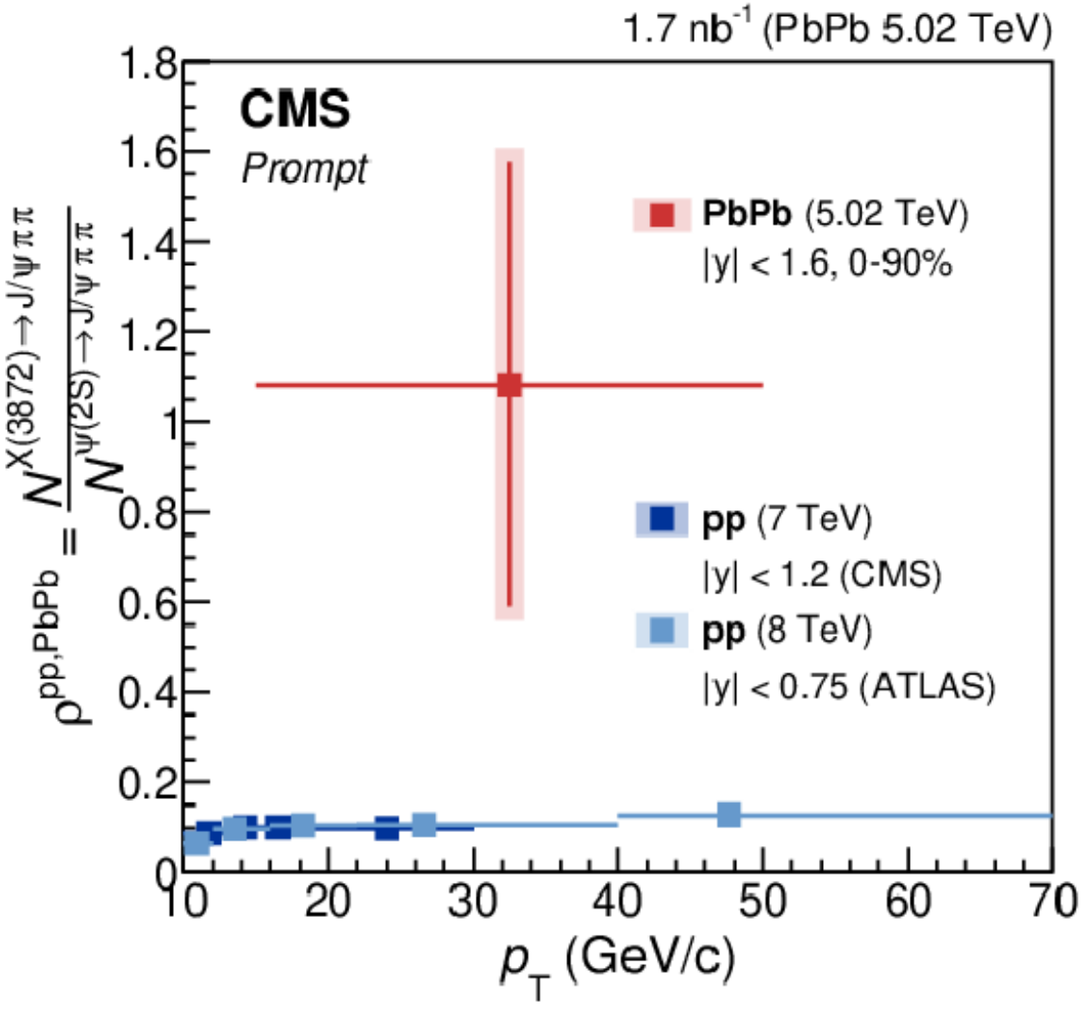
Compact Tetraquark



$\chi_{c1}(3872)$ in heavy ion collisions

- Recent LHCb results in pp show prompt $\chi_{c1}(3872)$ decreases with multiplicity
- First observation of prompt $\chi_{c1}(3872)$ in PbPb at CMS not suppressed relative to $\psi(2S)$

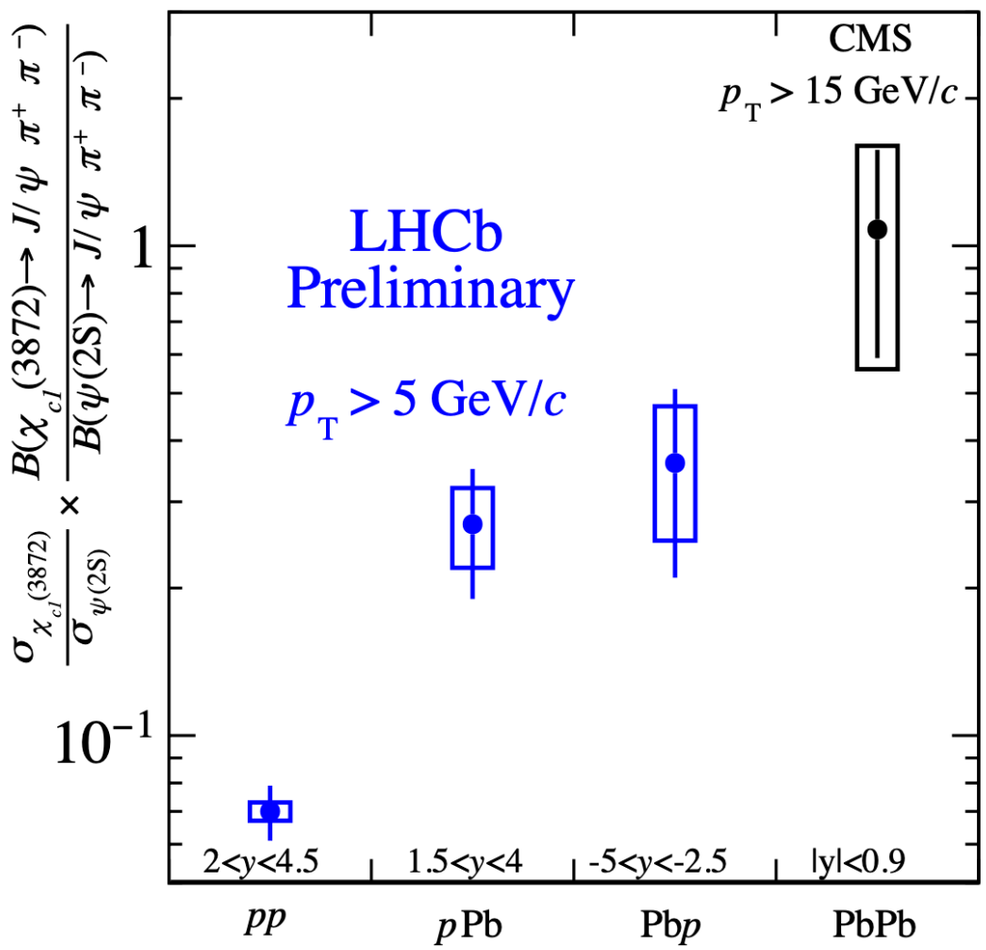
$$\frac{\sigma_{\chi_{c1}(3872)}}{\sigma_{\psi(2S)}} \frac{\mathrm{BR}(\chi_{c1}(3872) \to J/\psi \pi^+\pi^-)}{\mathrm{BR}(\psi(2S) \to J/\psi \pi^+\pi^-)}$$

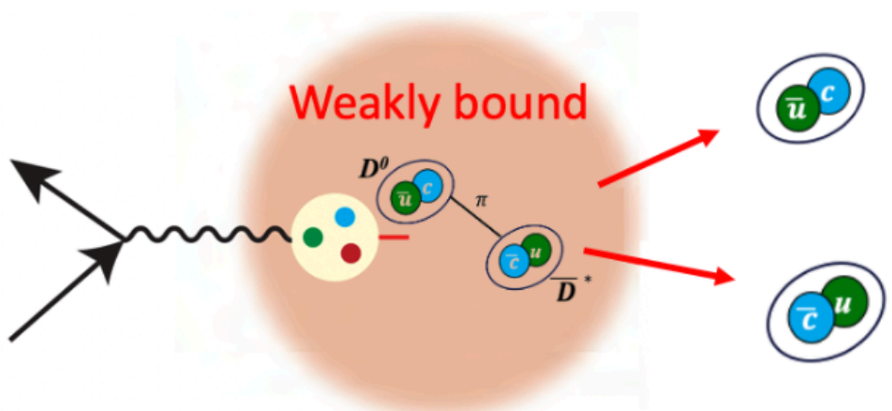


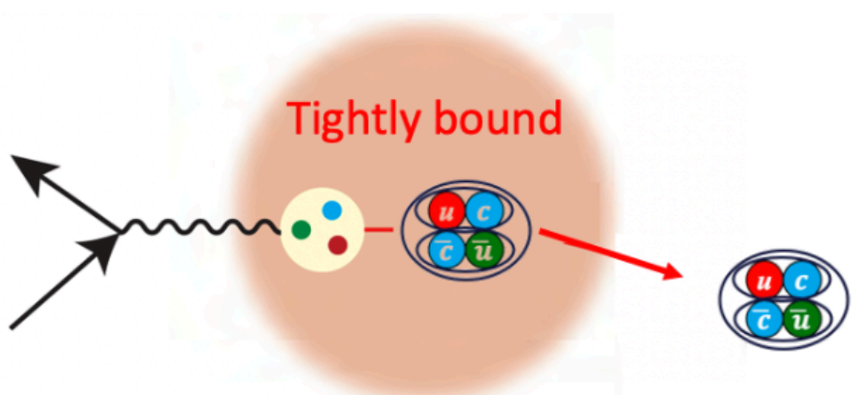
CMS: PRL 128 (2022) 3, 032001

$\chi_{c1}(3872)$ in heavy ion collisions

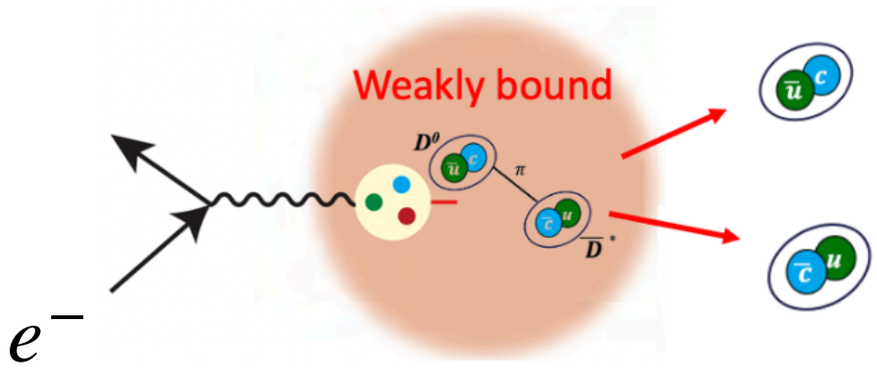
- Recent LHCb results in pp show prompt $\chi_{c1}(3872)$ decreases with multiplicity
- First observation of prompt $\chi_{c1}(3872)$ in PbPb at CMS not suppressed relative to $\psi(2S)$
- Enhancement in pPb relative to pp, increase with system size



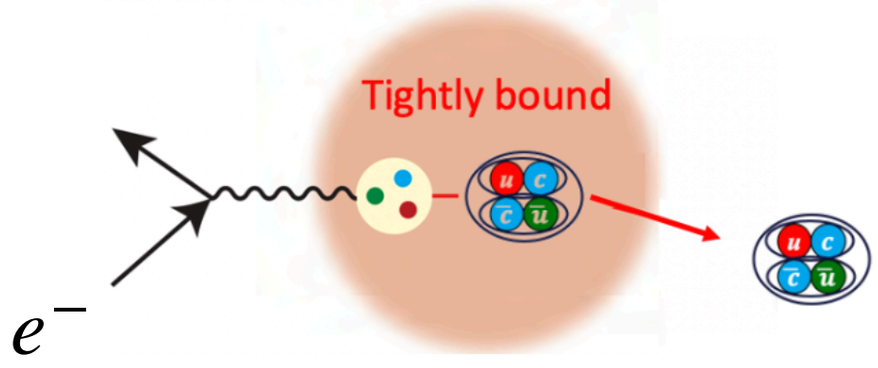




Electroproduction of $X(3872)$ in eA



Nucleus: A



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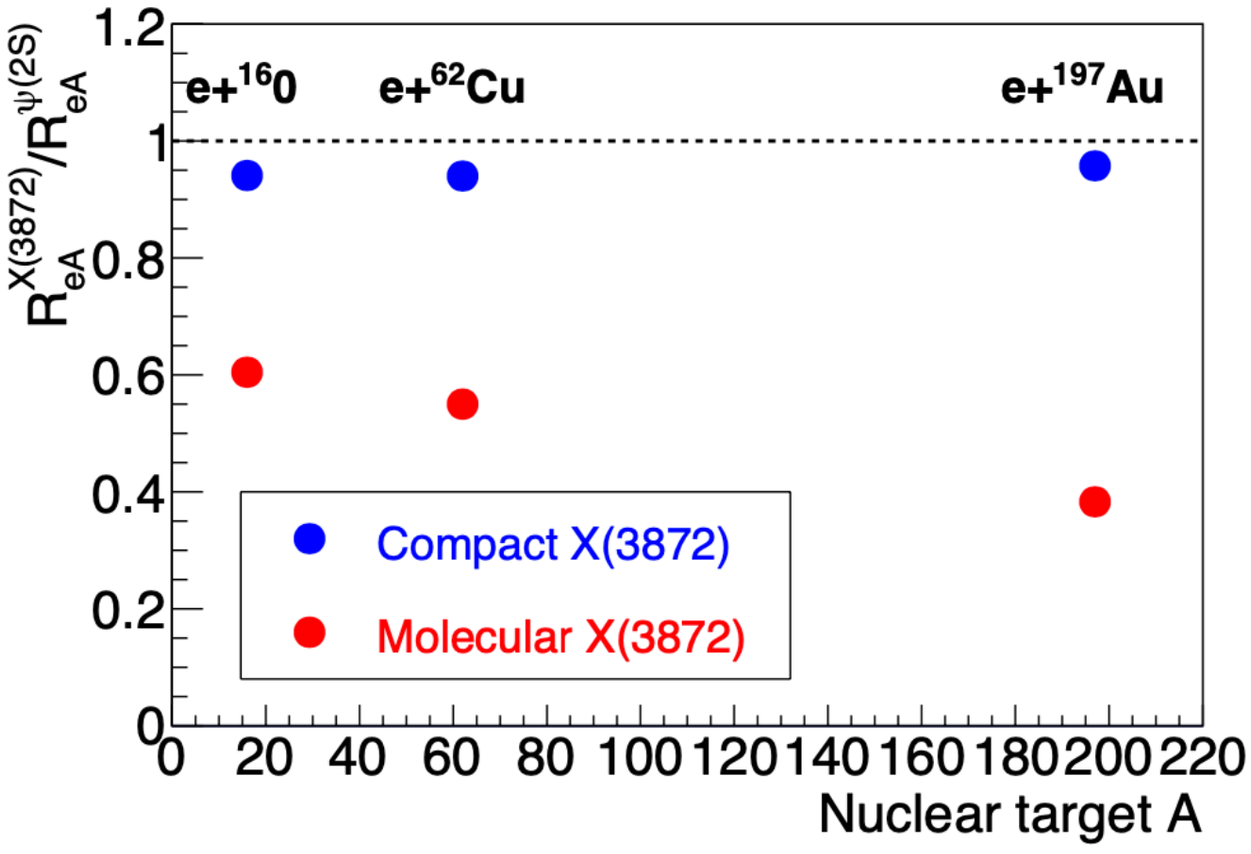
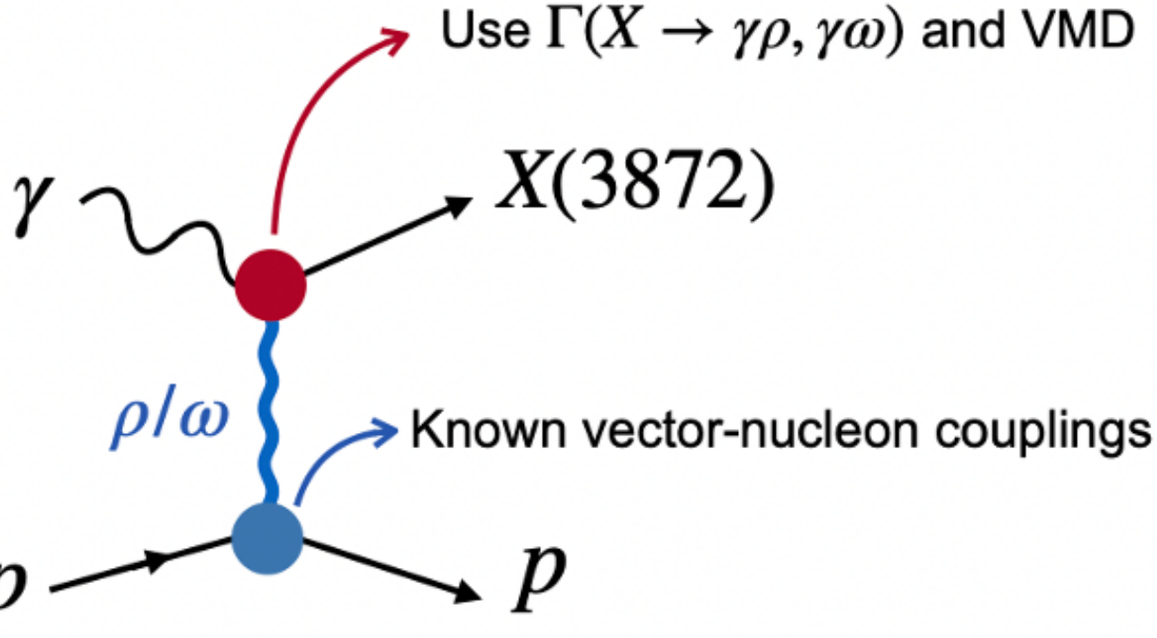
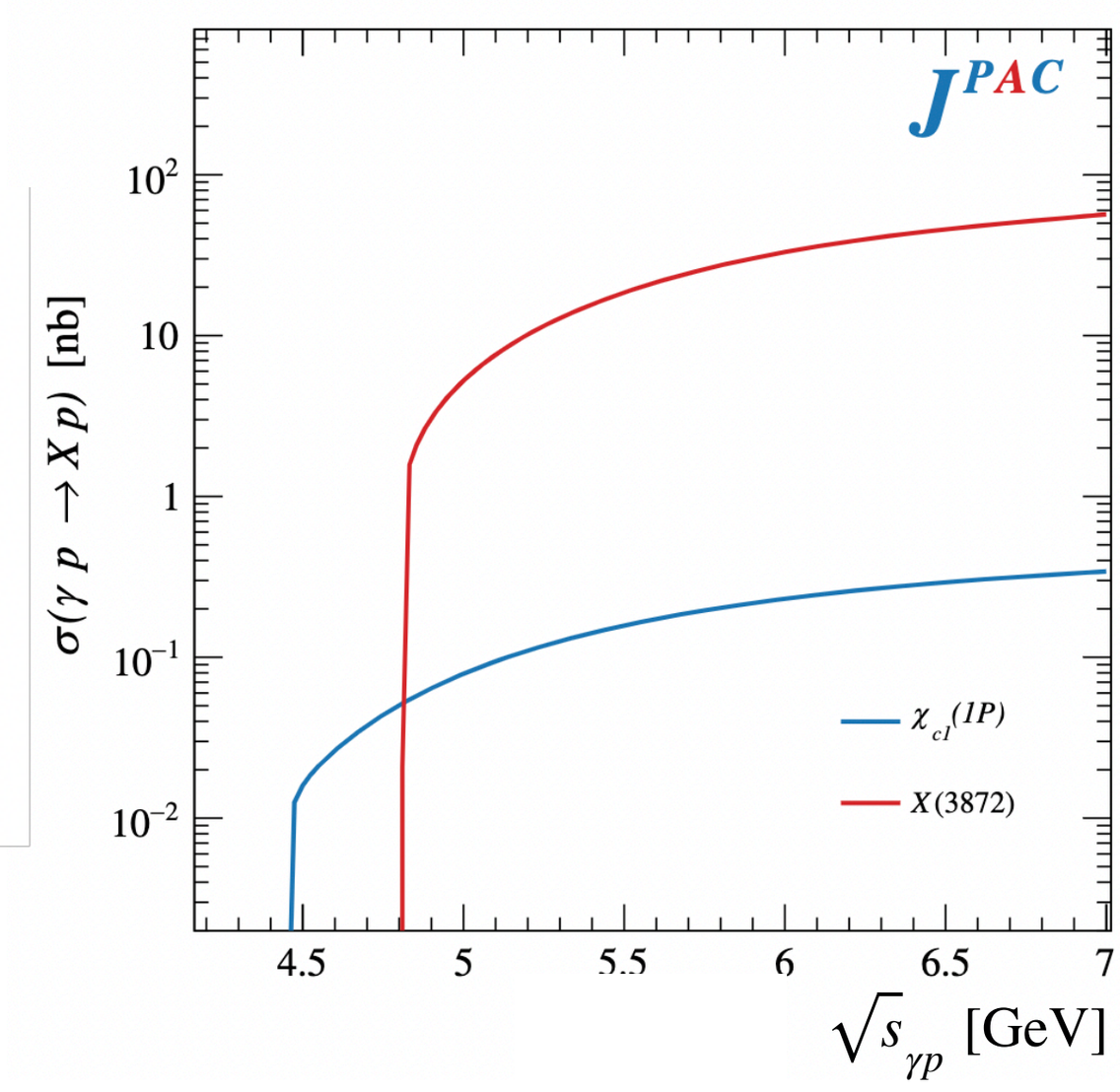


- Dependence on breakup of X(3872) in nuclei?
- Little suppression expected for compact tetraquark configuration
- Expect suppression of molecular (large size) configuration

Photoproduction of $X(3872)$

JPAC : PRD 102, 114010 (2020)

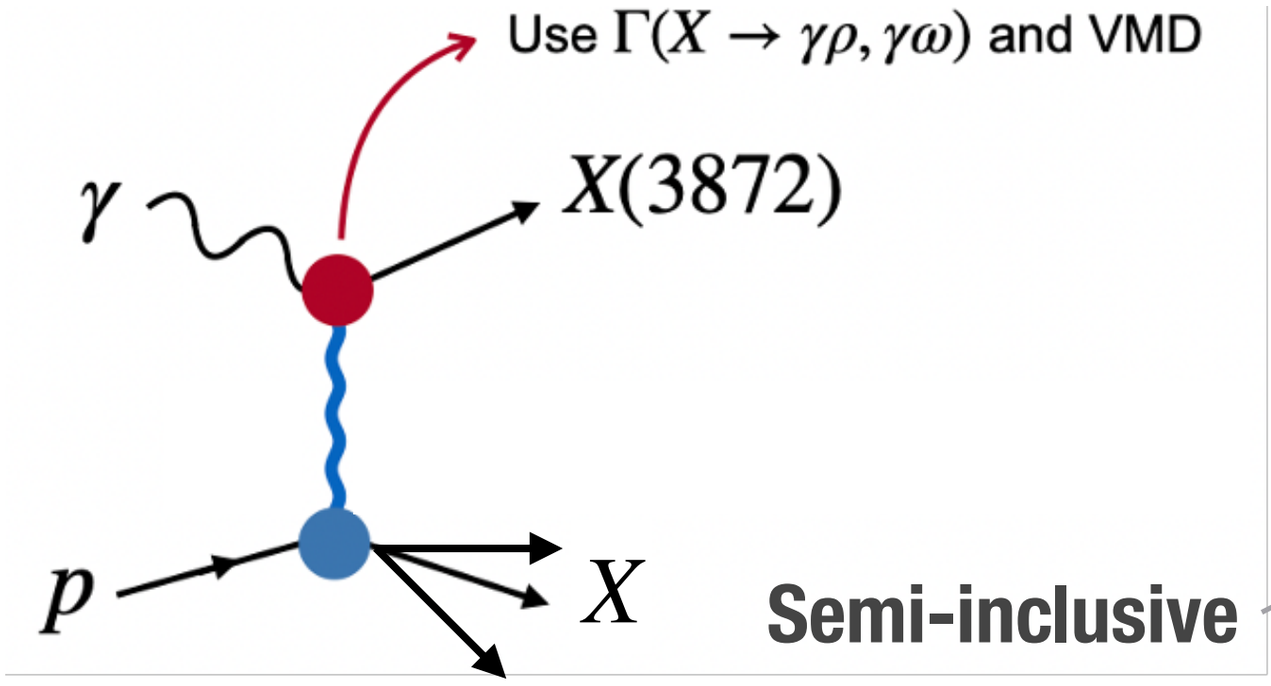




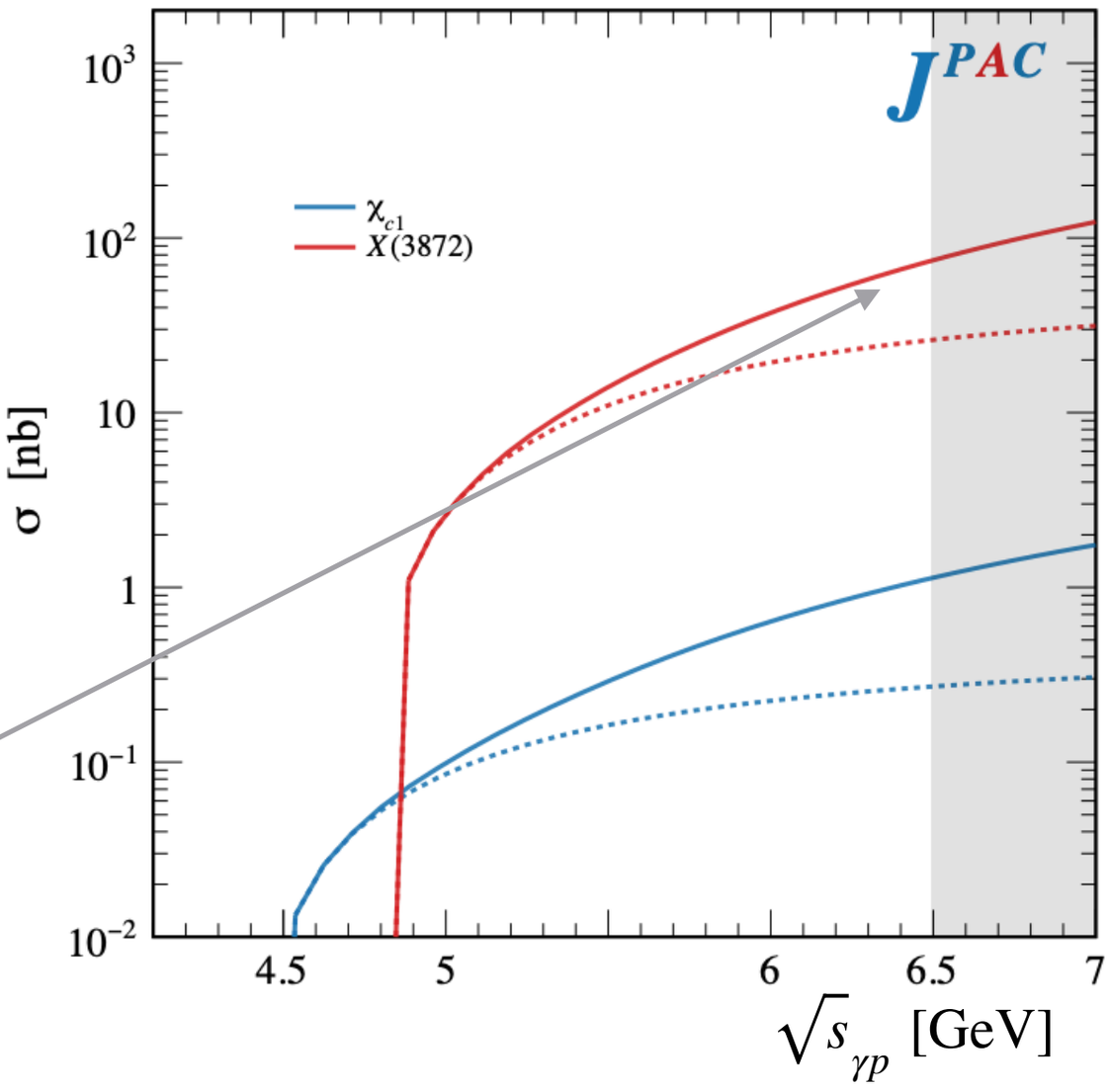
- Alternative production mechanism: free of rescattering effects and sensitive to photo couplings

Photoproduction of $X(3872)$

JPAC: PRD 102, 114010 (2020) and arXiv: 2404.05326

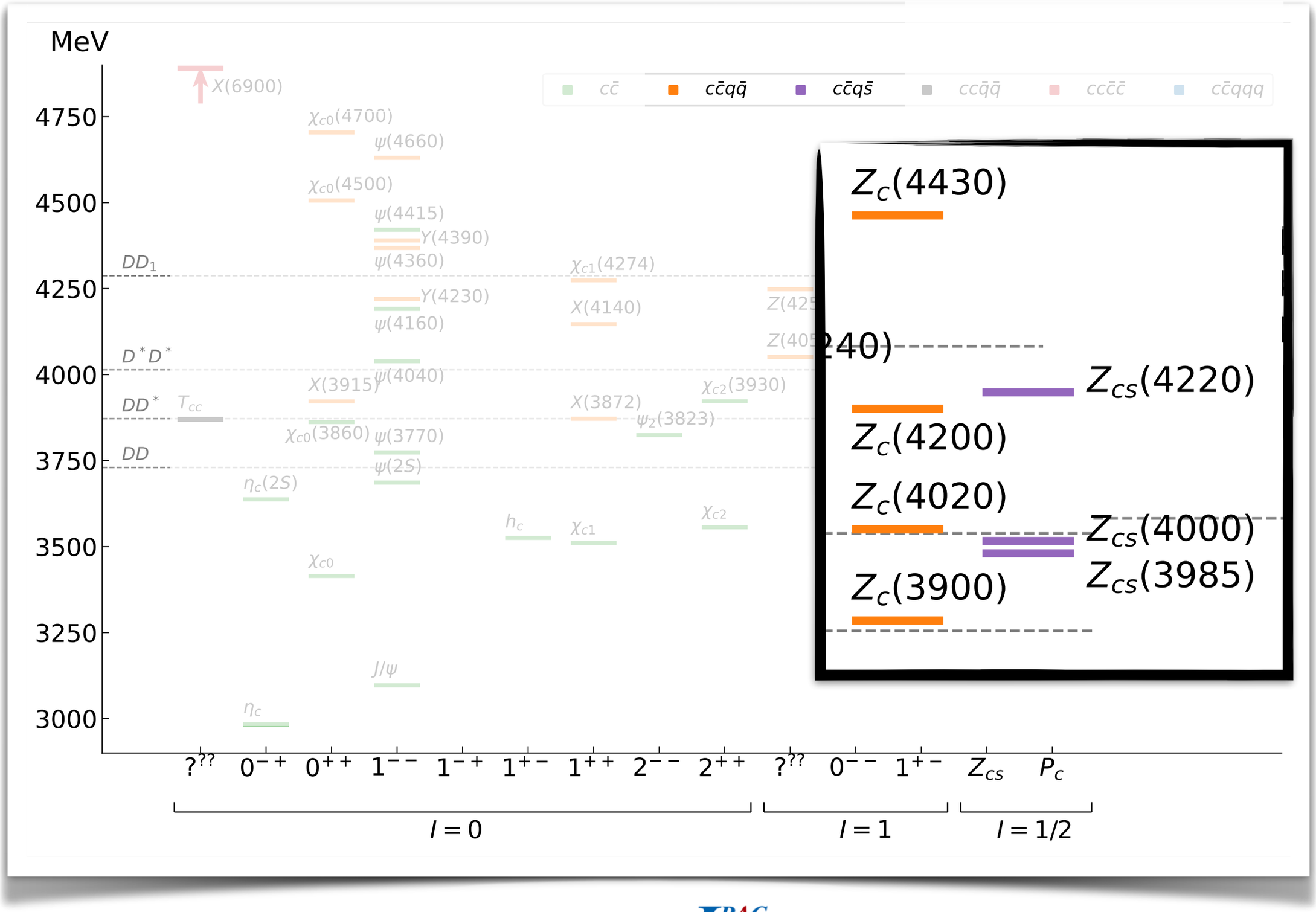


Semi-inclusive



- Alternative production mechanism: free of rescattering effects and sensitive to photo couplings

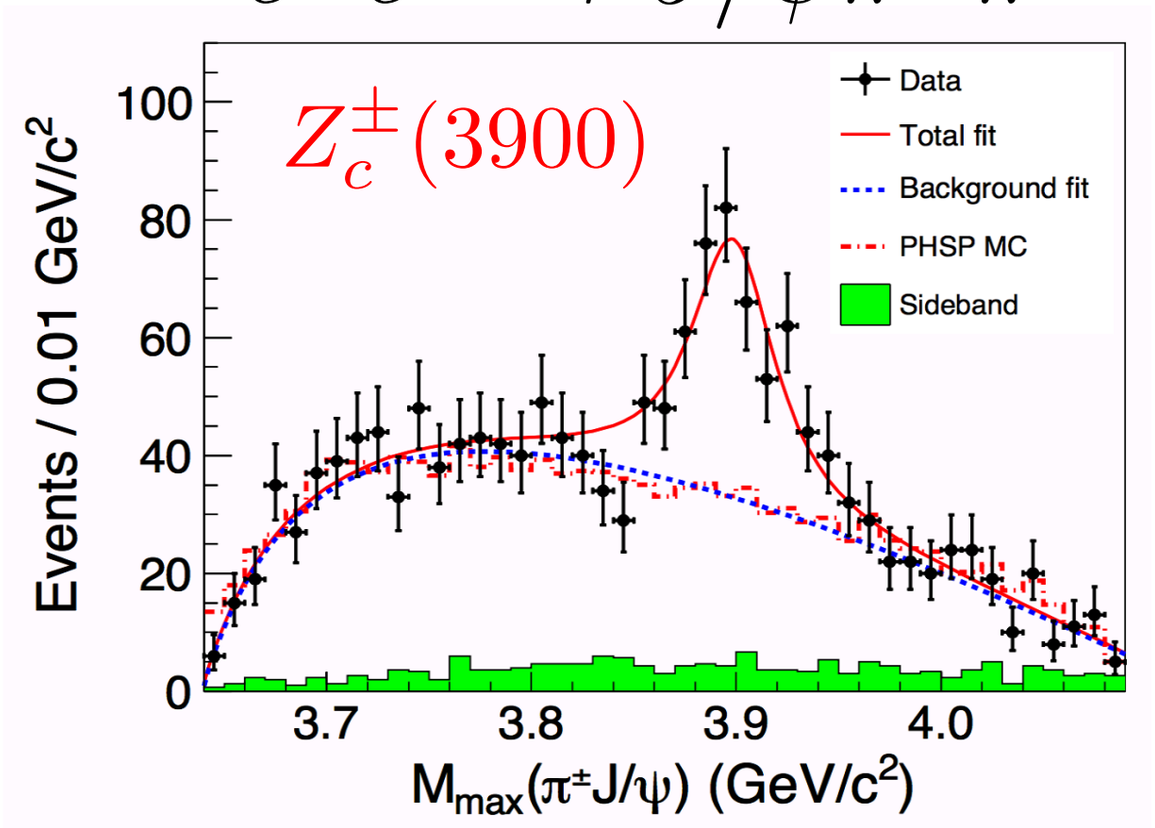
Charged tetraquark candidates: Z_c



Recent review: JPAC Prog. Part. Nucl. Phys. 127 (2022) 103981

Charged tetraquark candidates: Z_c

$$e^+e^- \to J/\psi\pi^+\pi^-$$



PRL 110, 252001 (2013) BESIII

PRL 110, 252002 (2013) BELLE

Charged tetraquark candidates: Z_c

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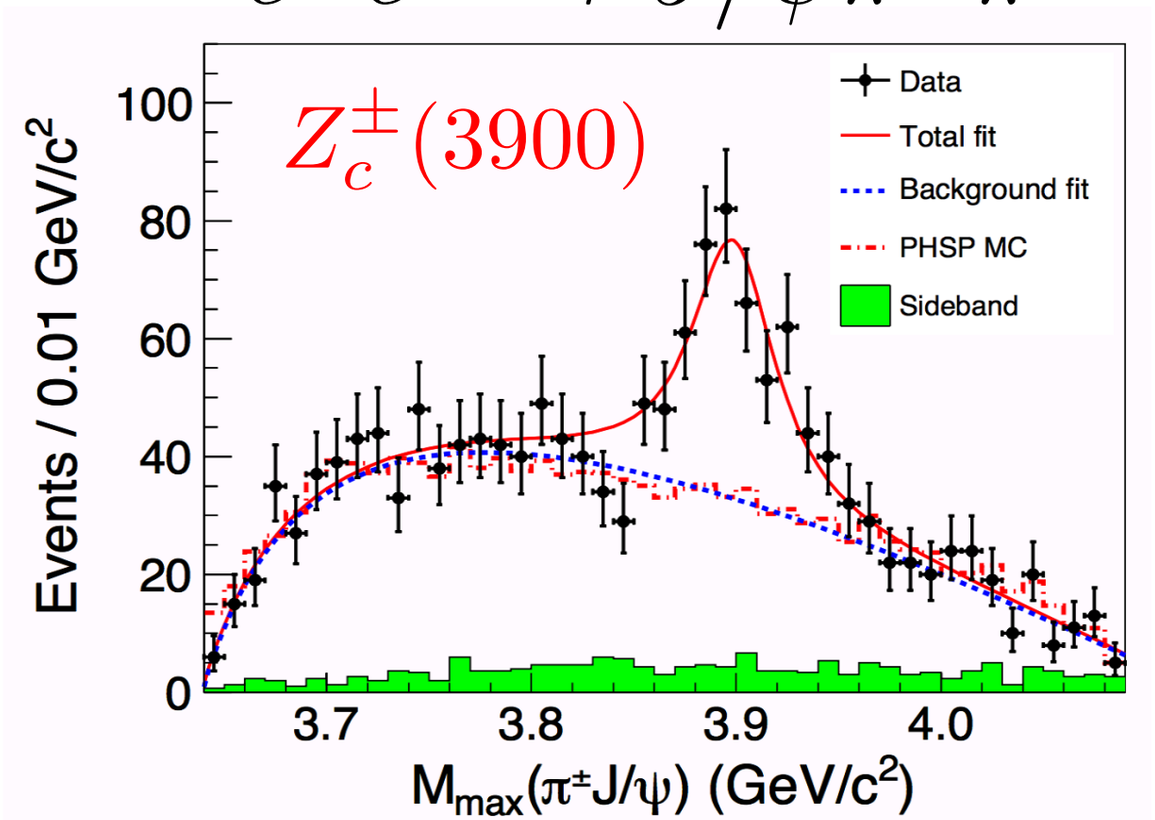
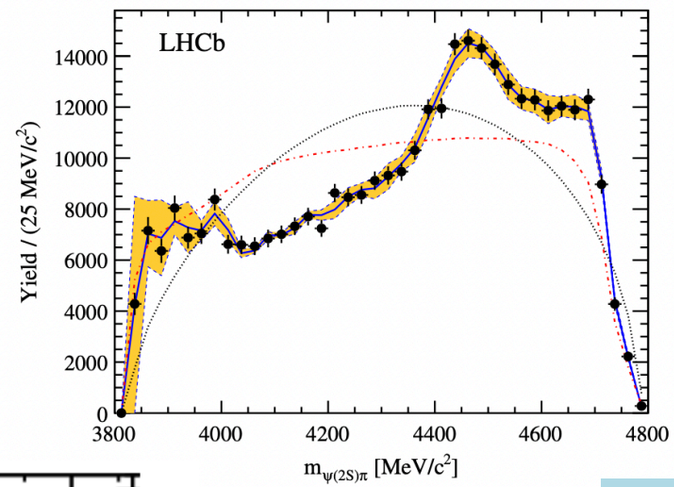


PRL 110, 252001 (2013) BESIII

PRL 110, 252002 (2013) BELLE

$Z_c^-(4430)$

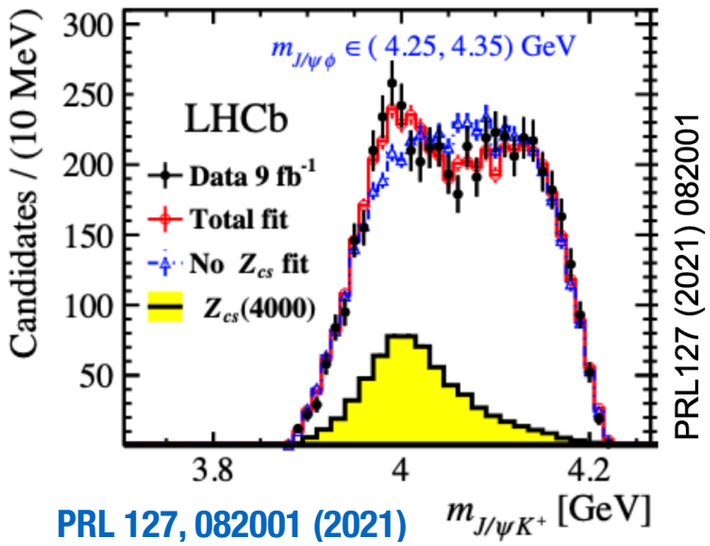
$$B^0 \to \psi(2S)K^+\pi^-$$



PRD 92, 112009 (2015) LHCb

$Z_{cs}^+(4000)$

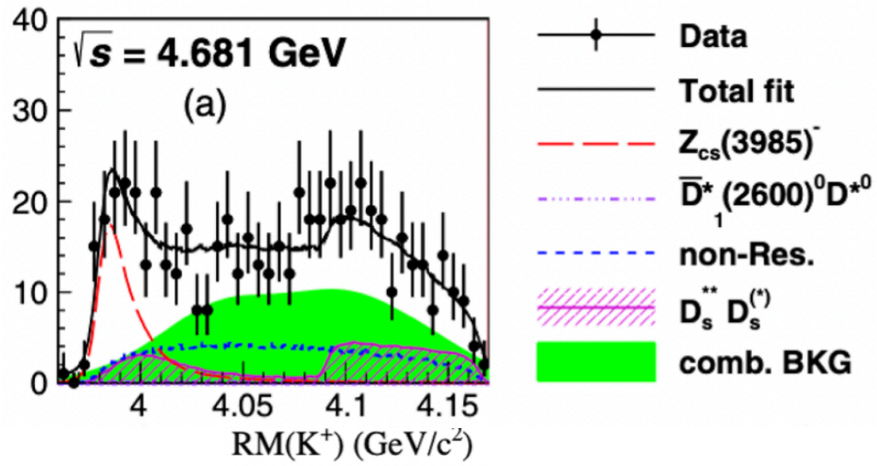
$$B^+ \to J/\psi\phi K^+$$



PRL 127, 082001 (2021)

$Z_{cs}^+(3985)$

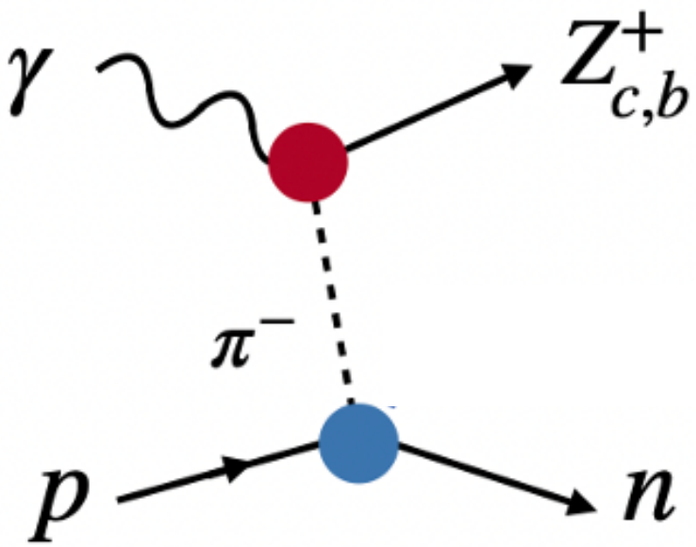
$$e^+e^- \to K^+D_s^-X$$

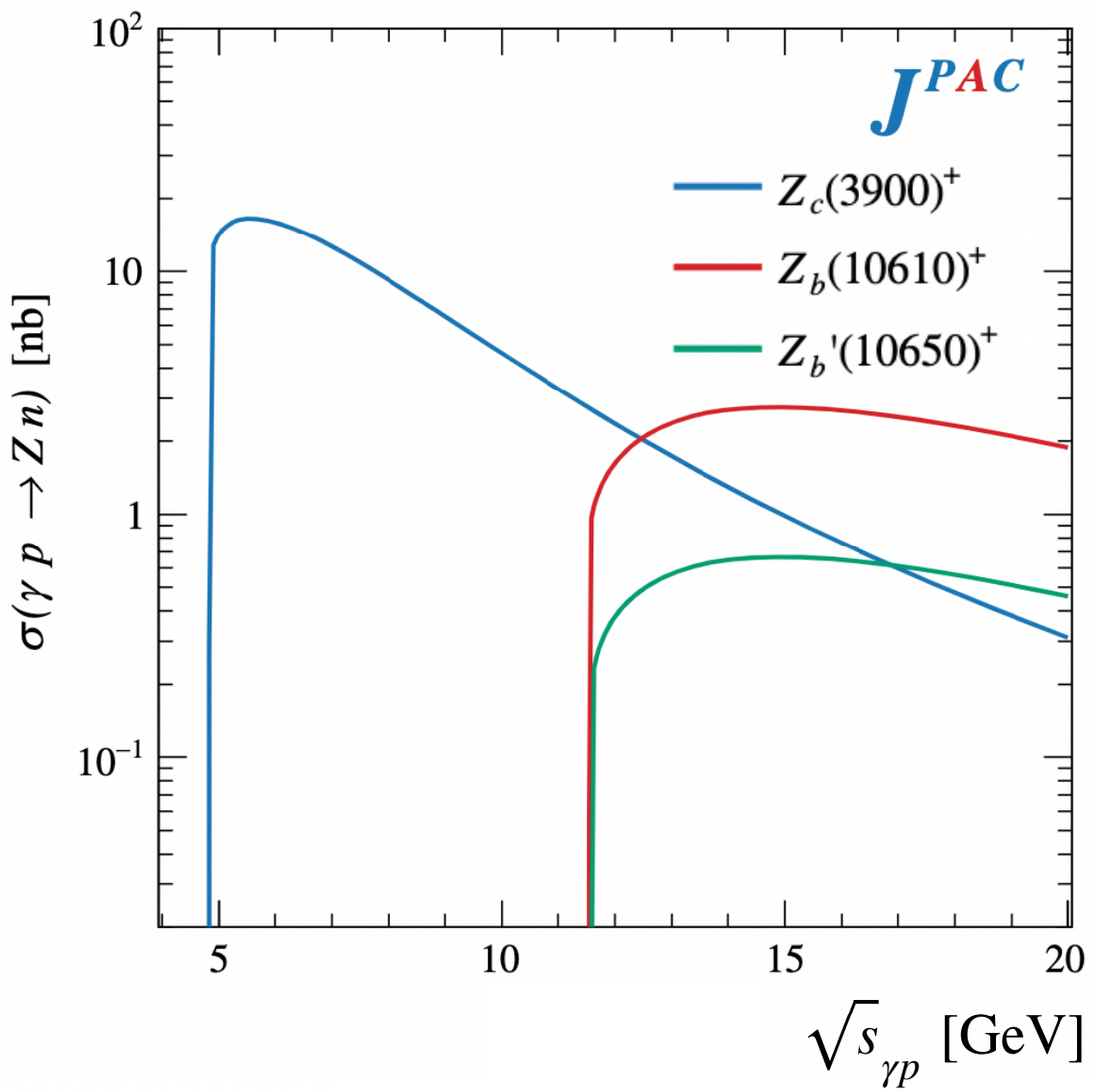


- Many observations of charged Z_c $(c\bar{c}q\bar{q})$ and Z_{cs} $(c\bar{c}s\bar{q})$
- Production mechanism dependent masses and widths (e^+e^- vs B decay)

Photoproduction of $Z_c^+(3900)$

- Alternative production mechanism: free of rescattering effects and sensitive to photo couplings
- Same production mechanism near threshold (π exchange) studied with light quarks in GlueX and CLAS12





JPAC : PRD 102, 114010 (2020)

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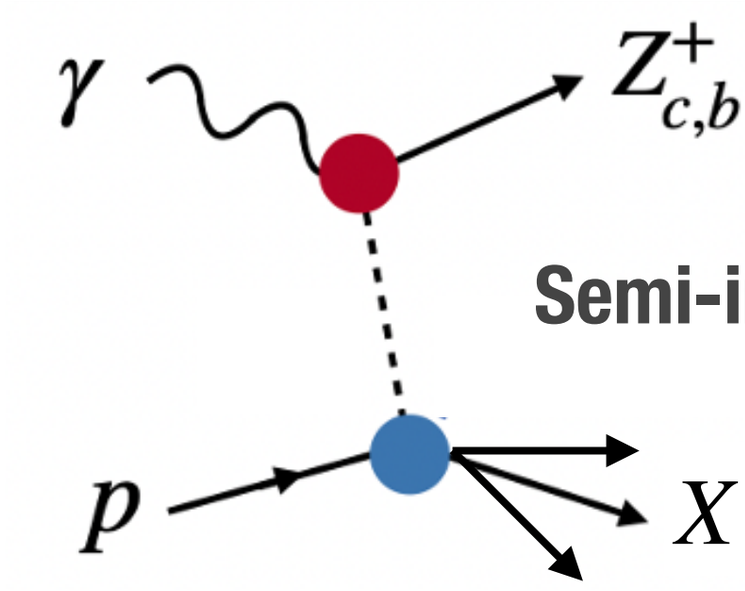
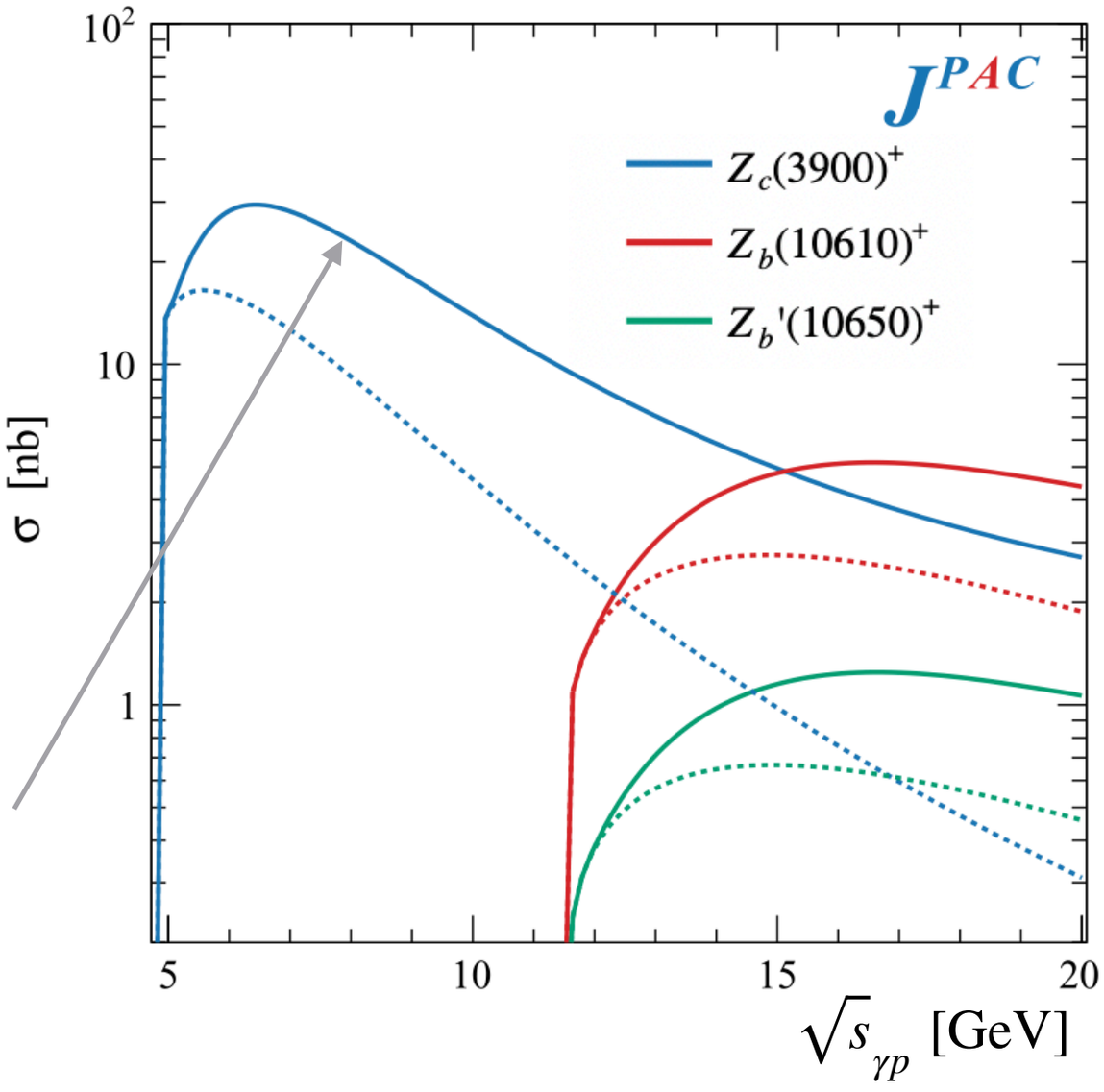
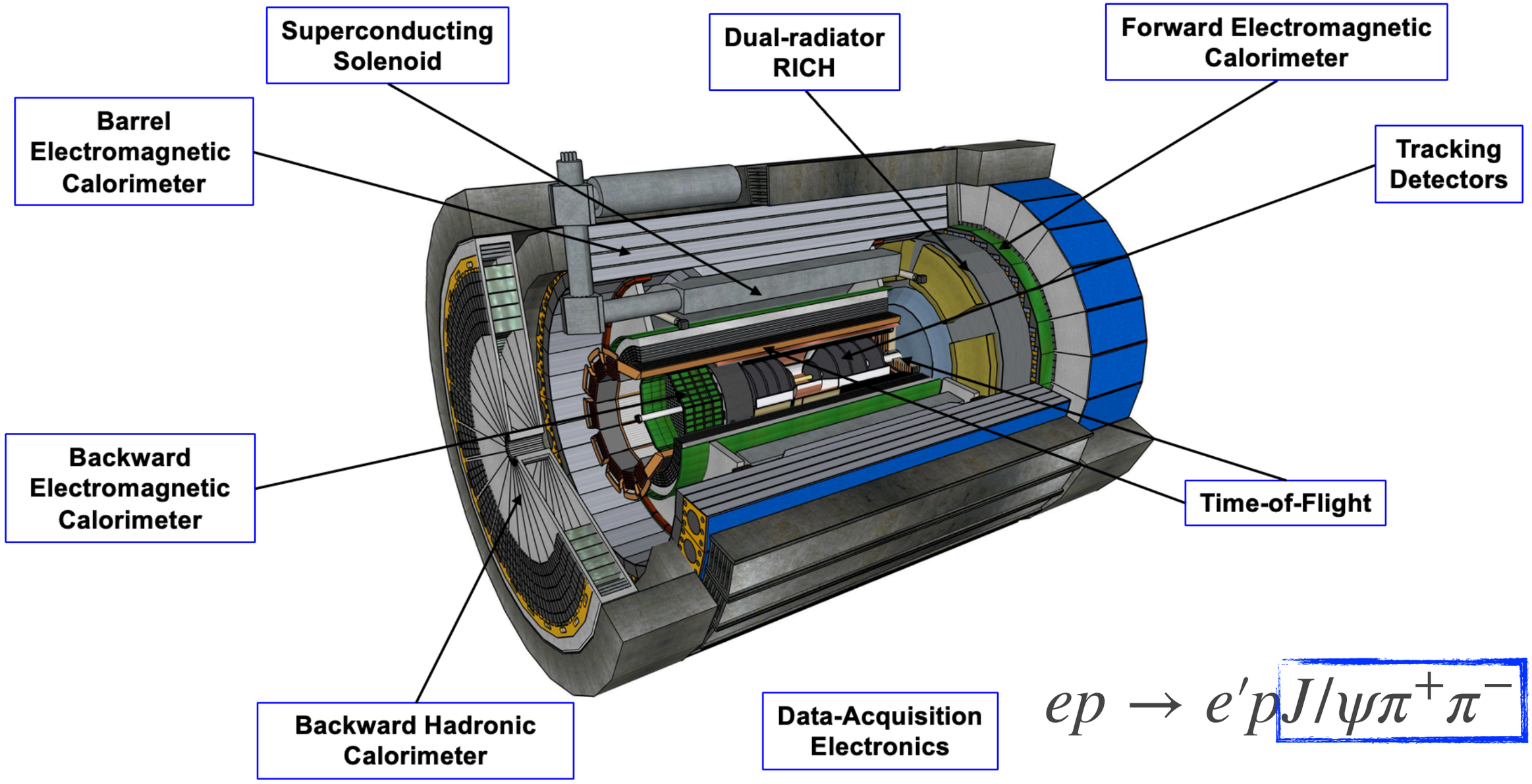


Semi-inclusive



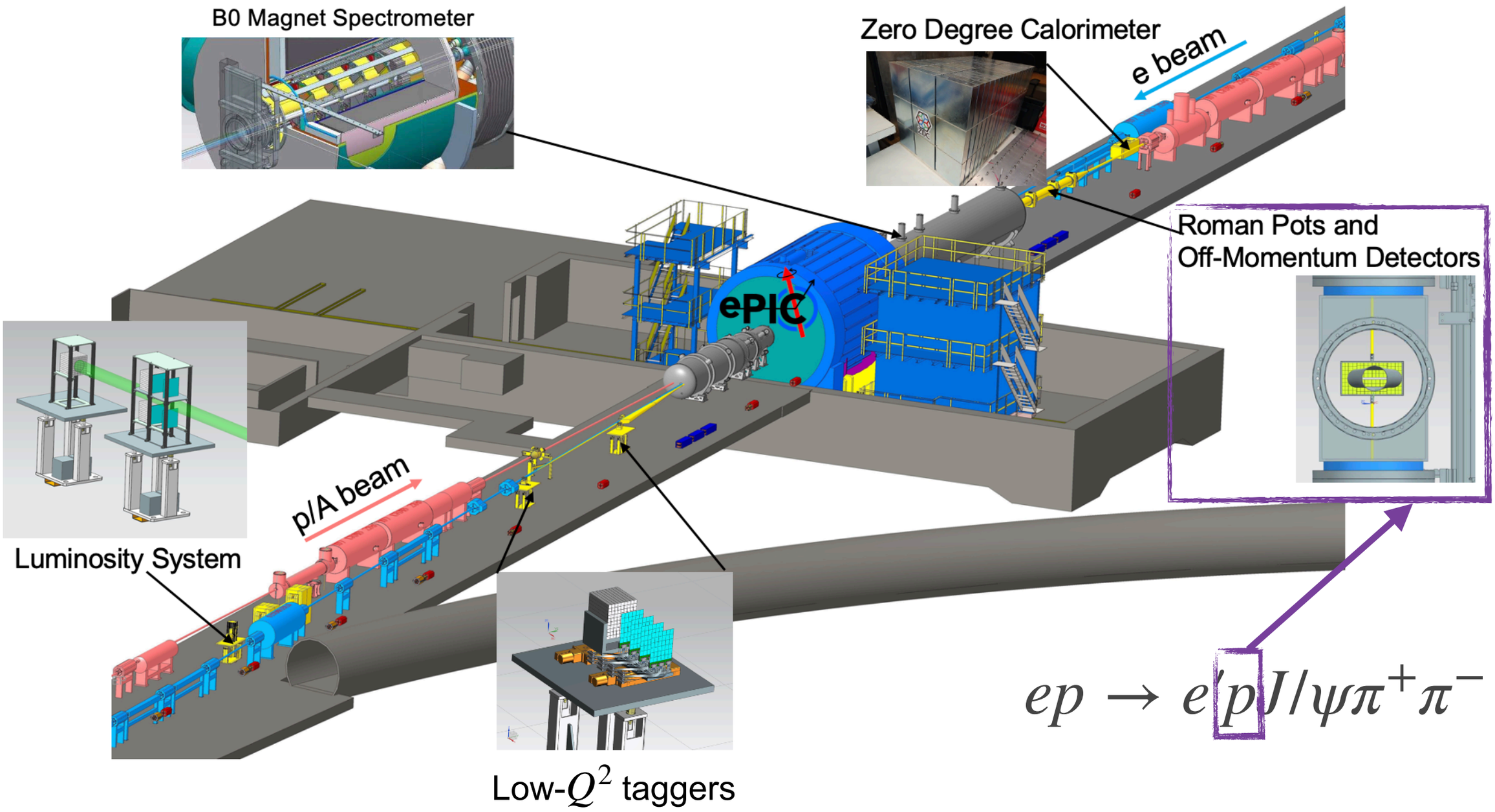
PRD 102, 114010 (2020)
PRD 106, 094009 (2022)

ePIC experiment



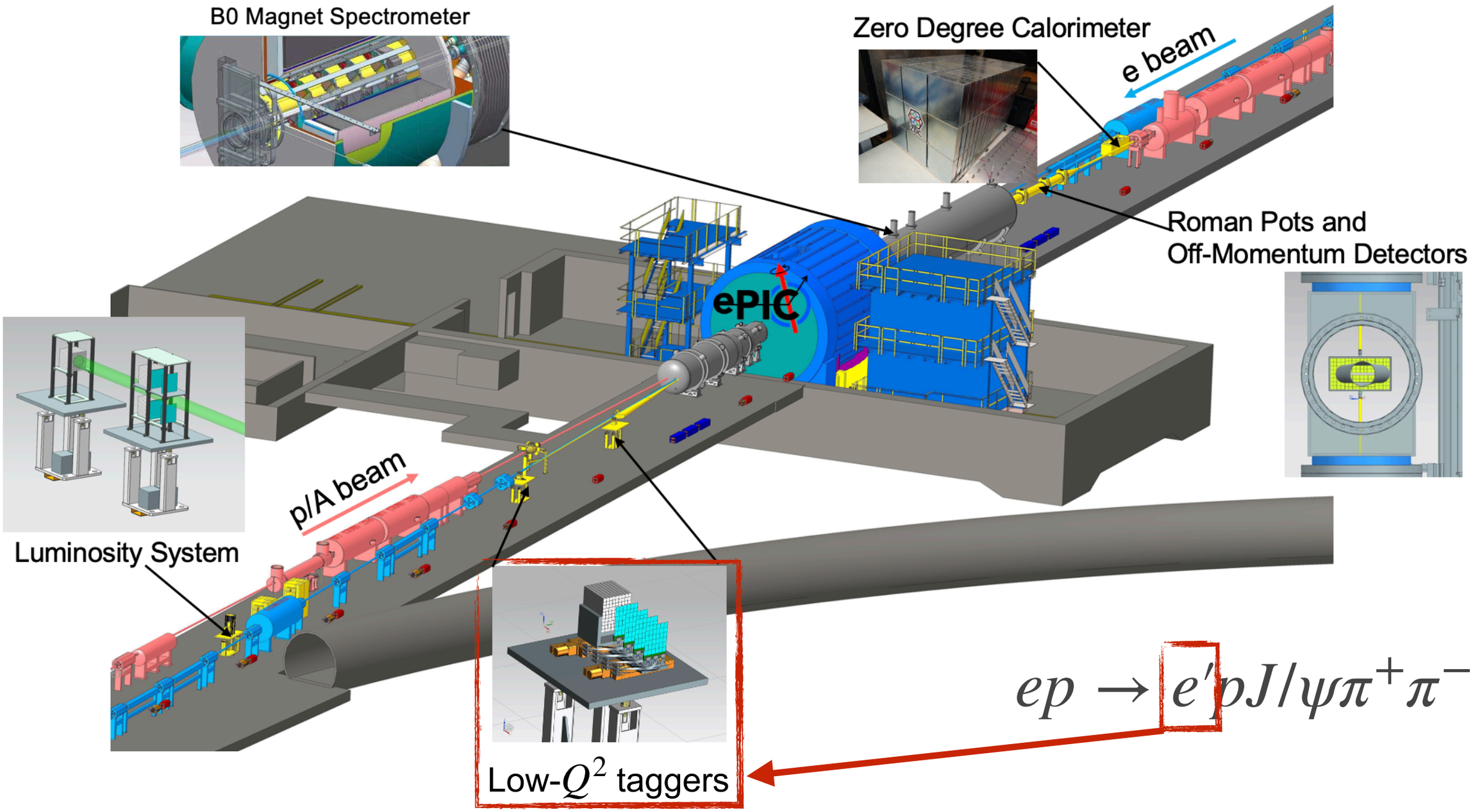
Asymmetric central detector concepts due to asymmetric beam energies: "complete" coverage for $|\eta| < 3.5$

ePIC experiment



Complete detectors are ~100 m with far-forward and backward regions

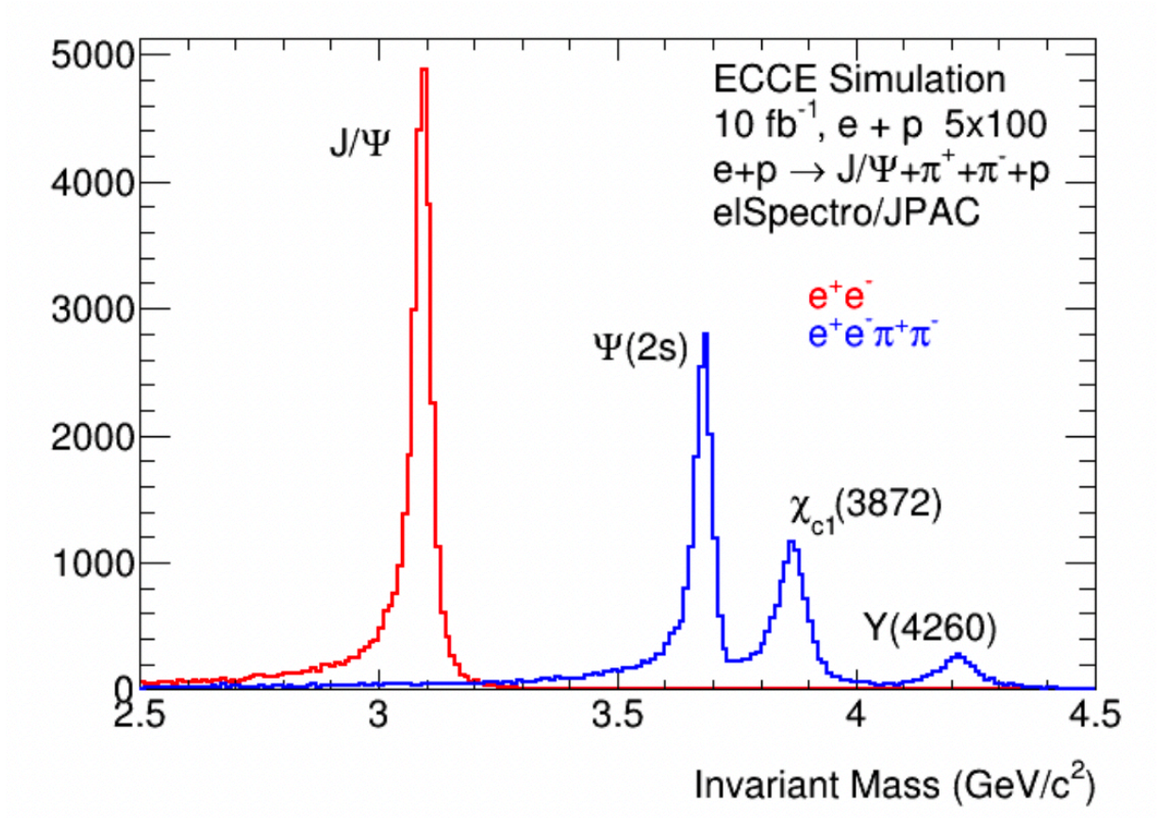
ePIC experiment

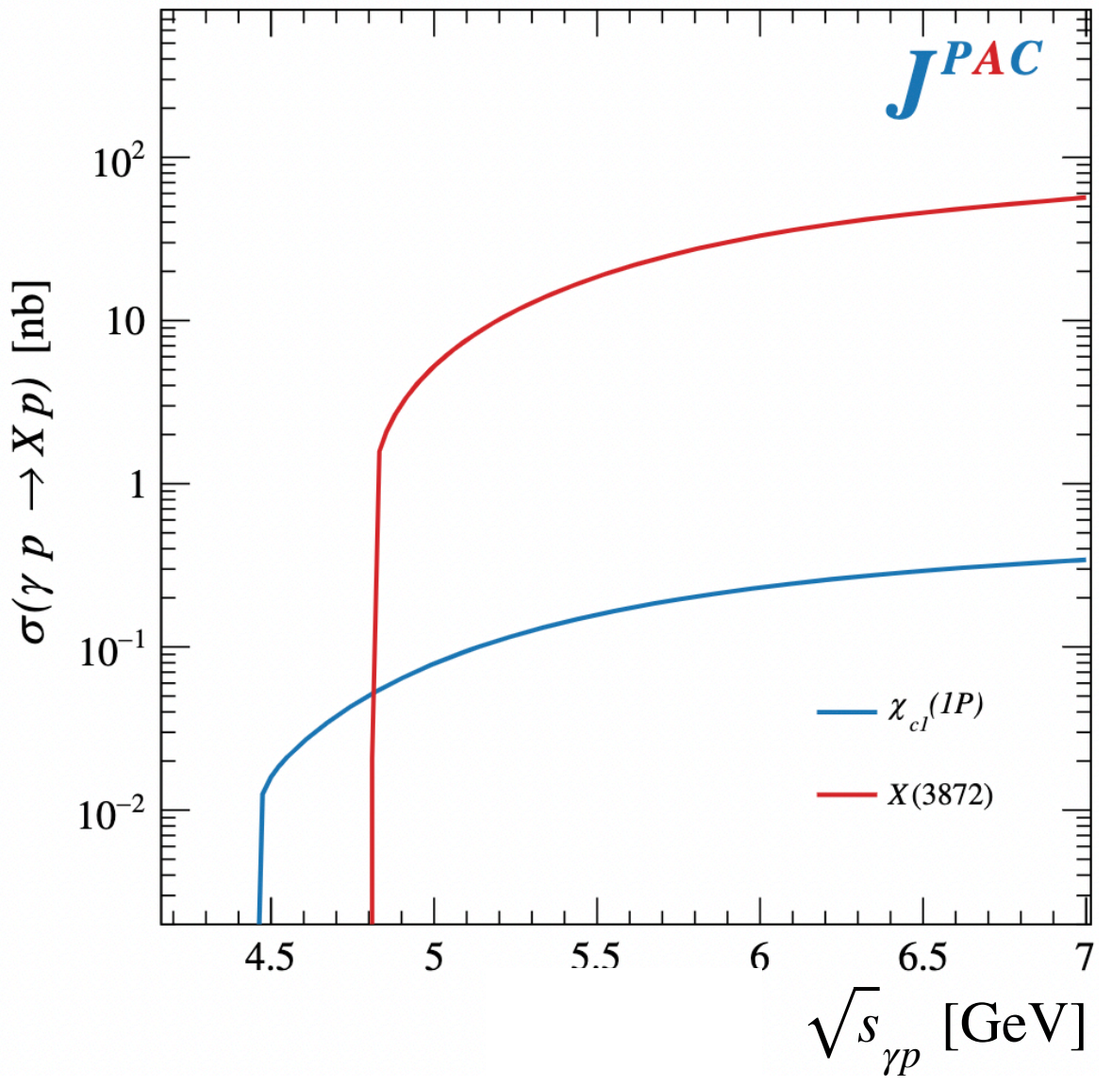


Complete detectors are ~100 m with far-forward and backward regions

Simulation of $X(3872)$

EIC: $\gamma p \to p J/\psi \pi^+ \pi^-$

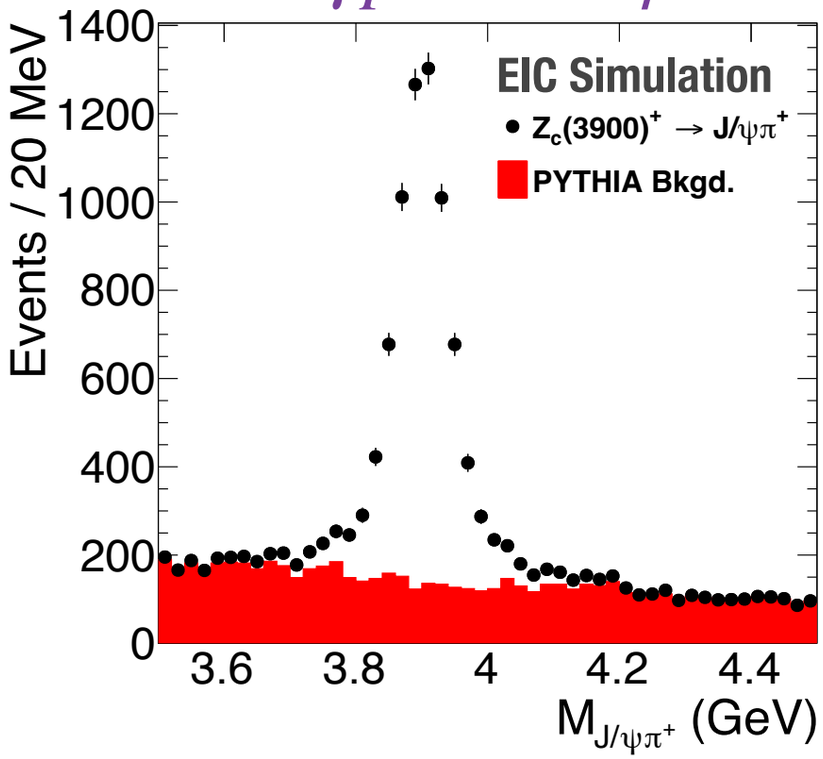




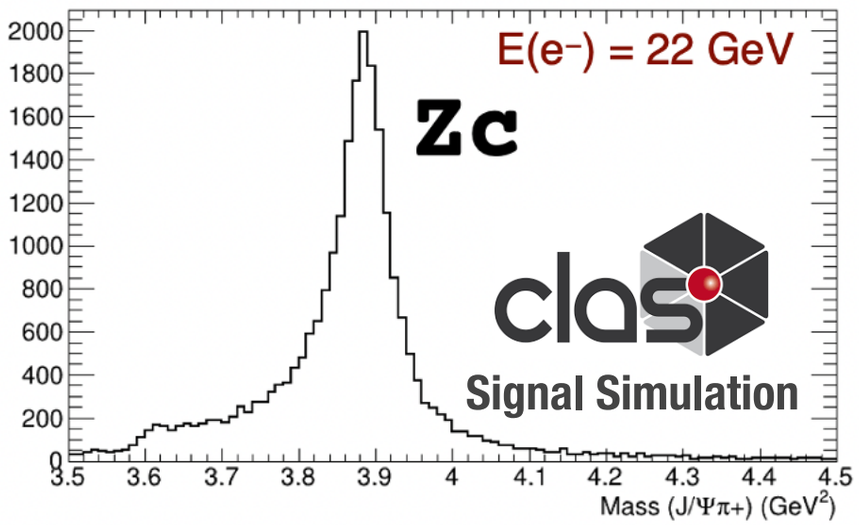
- Demonstrated reconstruction of exclusive final state, will uniquely test production mechanism

Photoproduction of $Z_c^+(3900)$

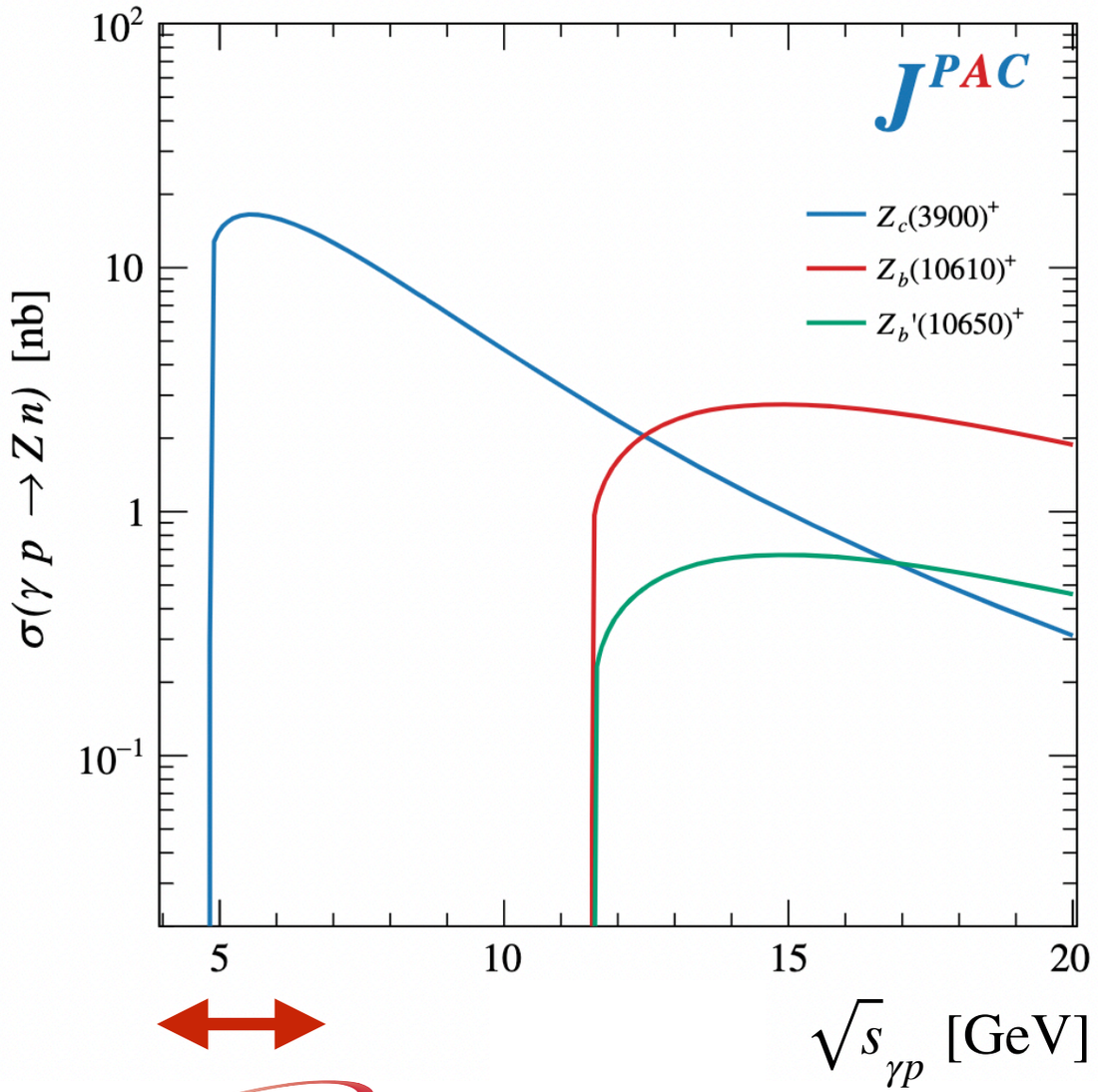
EIC: $\gamma p \to nJ/\psi\pi^+$



JLab 22 GeV: $\gamma p \to nJ/\psi\pi^+$



EIC broad energy coverage



Jefferson Lab 22 GeV

High luminosity near-threshold

Photoproduction of XYZ states

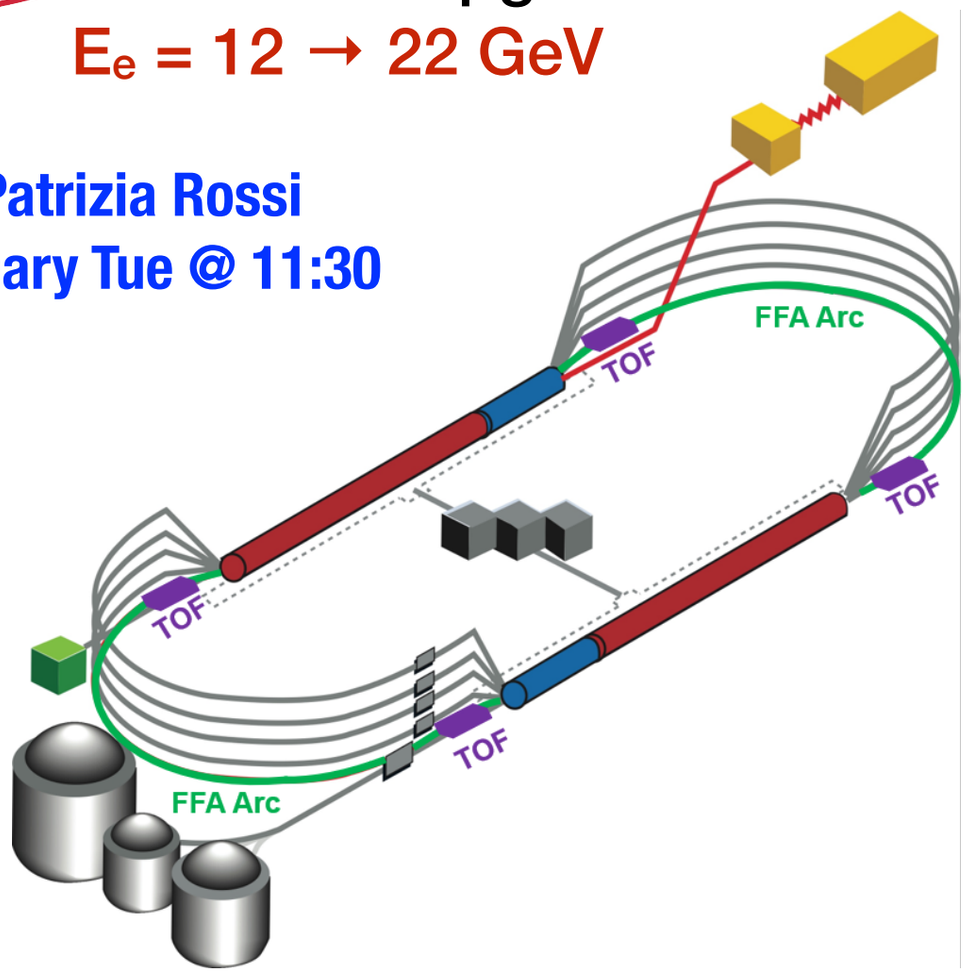
Complementary access to charmonium photoproduction with higher energy facilities

Jefferson Lab upgrade:

$E_e = 12 \rightarrow 22$ GeV

Patrizia Rossi

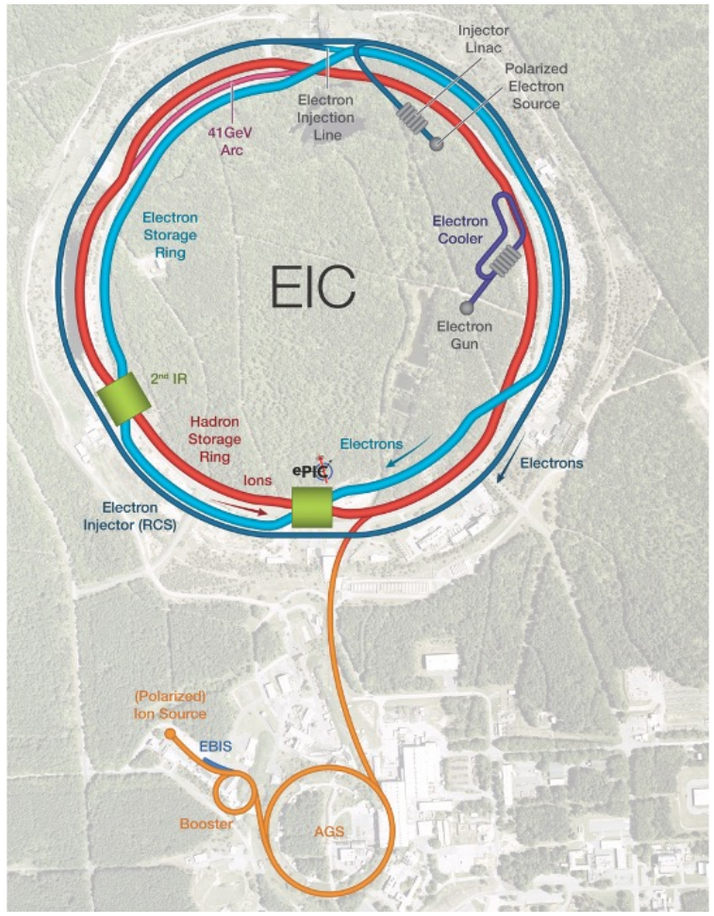
Plenary Tue @ 11:30



$$\sqrt{s_{\gamma p}} = 1.5 - 6.5 \text{ GeV}$$

$$\mathscr{L}_{ep} = 10^{35} - 10^{37}\ cm^{-2}s^{-1}$$

Electron Ion Collider (EIC)

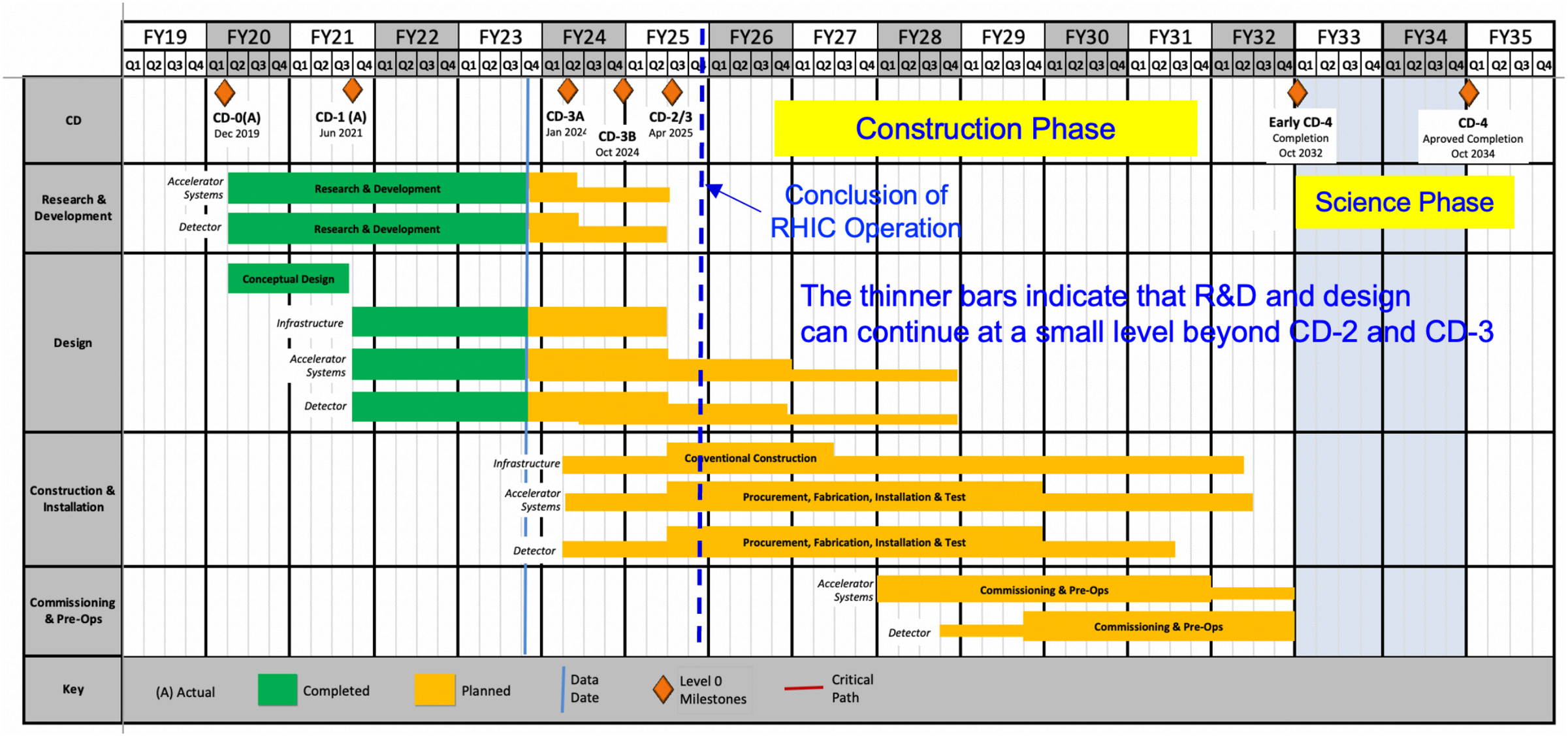


$$\sqrt{s_{\gamma p}} = 5 - 141 \text{ GeV}$$

$$\mathscr{L}_{ep} = 10^{34}\ cm^{-2}s^{-1}$$

EIC Project Schedule

- EIC project passed CD-3A review
- International ePIC collaboration developing detector



Rolf Ent's slides with "best guess" schedule from JLab User Organization meeting last week

Summary

- Considerable evidence for many exotic hadron candidates
  - ☑ Extra (supernumerary) states: **X and Y**
  - ☑ Charged states with hidden heavy quarks: **Z and P_c**
- Theoretical developments to understand these observations:
  - **Less exotic:** hadronic molecules, final-state rescattering, etc.
  - **More exotic:** tightly bound multi-quark states, gluonic field excitations, etc.
- EIC: alternative production mechanism to probe exotic hadrons,
- Continued theory/experiment collaboration and high statistics experiments promise to provide an exciting (exotic) future

JRS supported by DE-SC0023978 U.S. DEPARTMENT OF ENERGY | Office of Science

Backup

Realizing the EIC and JLab 22 GeV

Patrizia Rossi
Plenary Tue @ 11:30

- EIC project passed CD-3A review
  - International ePIC collaboration developing detector
- Jefferson Lab 12 GeV and positron program through 2030s
  - Broad 22 GeV program defined in White Paper [arXiv:2306.09360]

David Dean's slides with "Notional" plan from JLab User Organization meeting last week

Activities	Fiscal Year																	
	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42
Moller (MIE, 413.3B, CD-2/3)																			
SoLID (LRP, Rec 4)																			
Positron Source (R&D)																			
CEBAF Upgrade preCDR/preplan																			
Positron Project (potential)																			
Transport e+																			
22 GeV Development (R&D)																			
22 GeV Project (potential)																			
EIC Project (V4.2, CD-1, CD-3A)																			
CEBAF Up																			