

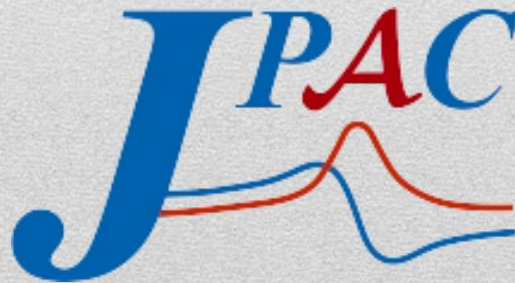
# Future prospects and XYZ

Alessandro Pilloni

JPAC review, November 17<sup>th</sup>, 2022



Università  
degli Studi di  
Messina



# Looking at the future

## Summary of Topical Group on Hadron Spectroscopy (RF07)

### Rare Processes and Precision Frontier of Snowmass 2021

Conveners: Richard F. Lebed<sup>1</sup>, Tomasz Skwarnicki<sup>2</sup>

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<sup>2</sup>Department of Physics, Syracuse University, Syracuse, NY 13244, USA

Contributing Authors: Liupan An<sup>3</sup>, Sean Dobbs<sup>4</sup>, Bryan Fulsom<sup>5</sup>, Feng-Kun Guo<sup>6,7</sup>,  
Marek Karliner<sup>8</sup>, Ryan E. Mitchell<sup>9</sup>, Alessandro Pilloni<sup>10,11</sup>, Alexis Pompili<sup>12,13</sup>,  
Sasa Prelovsek<sup>14,15</sup>, Elena Santopinto<sup>16</sup>, Justin Stevens<sup>17</sup>, Adam Szczepaniak<sup>18,19,20</sup>

## Amplitude analyses and (Light) Hadron Spectroscopy

2022 Town Hall Meeting

Arkaitz Rodas

arXiv:2207.14594

The physics of the next decade is being planned now!

The next Long Range Plan for Nuclear Science will appear in 2023

The DPF Snowmass process has just completed

arXiv:2203.08208

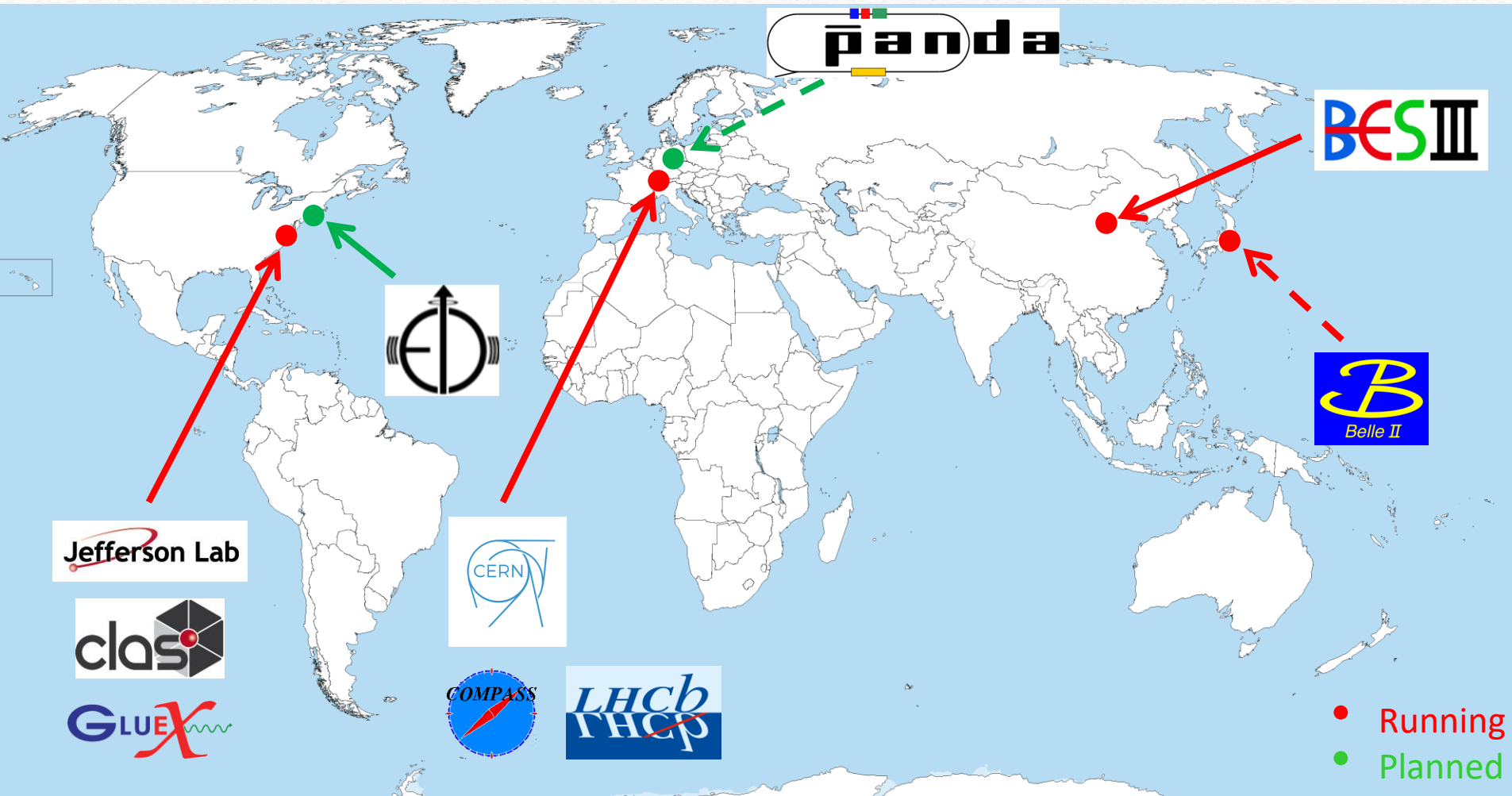
JPAC is investing in making the case for spectroscopy

### Need for amplitude analysis in the discovery of new hadrons





Miguel Albaladejo,<sup>1</sup> Marco Battaglieri,<sup>2</sup> Lukasz Bibrzycki,<sup>3</sup> Andrea Celentano,<sup>2</sup> Igor V. Danilkin,<sup>4</sup>  
Sebastian M. Dawid,<sup>5,6</sup> Michael Döring,<sup>7</sup> Cristiano Fanelli,<sup>8</sup> César Fernández-Ramírez,<sup>9,10,\*</sup>  
Sergi González-Solís,<sup>11</sup> Astrid N. Hiller Blin,<sup>12</sup> Andrew W. Jackura,<sup>13,14</sup> Vincent Mathieu,<sup>15,16</sup>  
Mikhail Mikhasenko,<sup>17,18</sup> Victor I. Mokeev,<sup>19</sup> Emilie Passemar,<sup>5,6,13</sup> Robert J. Perry,<sup>20</sup>  
Alessandro Pilloni,<sup>21,22,†</sup> Arkaitz Rodas,<sup>13,23,‡</sup> Matthew R. Shepherd,<sup>6</sup> Nathaniel Sherrill,<sup>24</sup>  
Jorge A. Silva-Castro,<sup>10</sup> Tomasz Skwarnicki,<sup>25</sup> Adam P. Szczepaniak,<sup>5,6,13,§</sup> and Daniel Winney<sup>5,6,26,27</sup>

(Joint Physics Analysis Center)

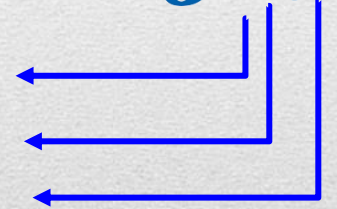
# JPAC interactions with experiments



# The programs of Hall-D at JLab

Activity, experiment running	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
	scheduled									
Run PRIMEX- $\eta$	■	■								
Run SRC		■								
Installation CPP		■								
Run CPP-NPP		■								
Run GlueX-II 			■							
Installation FCAL2			■							
Run GlueX-II+JEF 				■						
Installation KLF ( $K_L$ beam) 					■					
Commissioning, Run KLF 						■	■	■		
Back to photon beam								■		
Installation of GDH									■	
Commissioning, Run GDH										■

Support required for planning the experiment and/or for analyzing data



E. Chudakov

~8 years at ~30 weeks/year already planned

# JPAC and the JLab12 program

## Strange Hadron Spectroscopy with Secondary $K_L$ Beam in Hall D

### Theoretical Support:


Alexey Anisovich<sup>5,44</sup>, Alexei Bazavov<sup>38</sup>, Rene Bellwied<sup>21</sup>, Veronique Bernard<sup>42</sup>, Gilberto Colangelo<sup>3</sup>, Aleš Cieplý<sup>46</sup>, Michael Döring<sup>19</sup>, Ali Eskanderian<sup>19</sup>, Jose Goity<sup>20,49</sup>, Helmut Haberzettl<sup>19</sup>, Mirza Hadžimehmedović<sup>55</sup>, Robert Jaffe<sup>36</sup>, Boris Kopeliovich<sup>54</sup>, Heinrich Leutwyler<sup>3</sup>, Maxim Mai<sup>19</sup>, Terry Mart<sup>65</sup>, Maxim Matveev<sup>44</sup>, Ulf-G. Meißner<sup>5,29</sup>, Colin Morningstar<sup>9</sup>, Bachir Moussallam<sup>42</sup>, Kanzo Nakayama<sup>58</sup>, Wolfgang Ochs<sup>37</sup>, Youngseok Oh<sup>31</sup>, Rifat Omerovic<sup>55</sup>, Hedim Osmanović<sup>55</sup>, Eulogio Oset<sup>62</sup>, Antimo Palano<sup>64</sup>, Jose Peláez<sup>34</sup>, Alessandro Pilloni<sup>66,67</sup>, Maxim Polyakov<sup>48</sup>, David Richards<sup>49</sup>, Arkaitz Rodas<sup>49,56</sup>, Dan-Olof Riska<sup>12</sup>, Jacobo Ruiz de Elvira<sup>3</sup>, Hui-Young Ryu<sup>45</sup>, Elena Santopinto<sup>23</sup>, ...

## A Search for Hybrid Baryons in Hall B with CLAS12

Vincent Mathieu<sup>†</sup>, Vladyslav Pauk, Alessandro Pilloni, Adam Szczepaniak<sup>†</sup>  
*Theory Center, Jefferson Laboratory, Newport News, Virginia 23606, USA*  
(<sup>†</sup>Joint with Indiana University, Bloomington, Indiana 47405, USA)

## Backward-angle Exclusive $\pi^0$ Production above the Resonance Region

Wenliang Li (Spokesperson and contact person),\* Justin Stevens (Spokesperson), David Armstrong, Todd Averett, Andrew Hurley, Lydia Lorenti, Arkaitz Rodas, and Amy Schertz  
*College of William and Mary, Williamsburg, VA, USA*

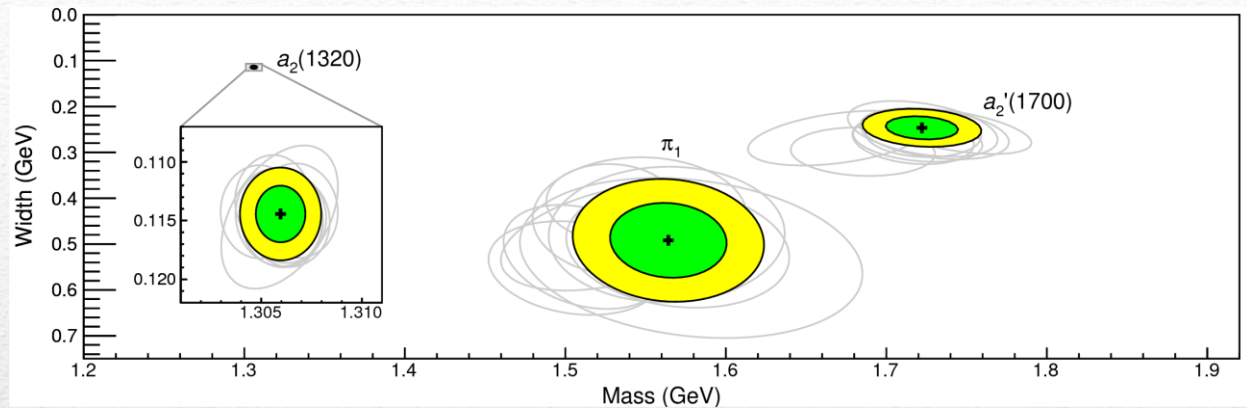
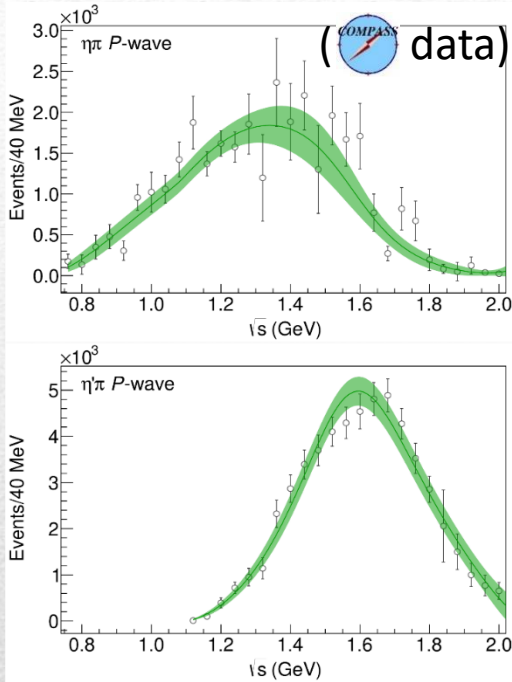
 support is requested by a number of proposals that enrich the 12 GeV program

## Measurement of the parameters of the LHCb pentaquark states through double polarization asymmetries with SBS in Hall A

C. Fanelli  
*MIT, Cambridge, MA 02139*

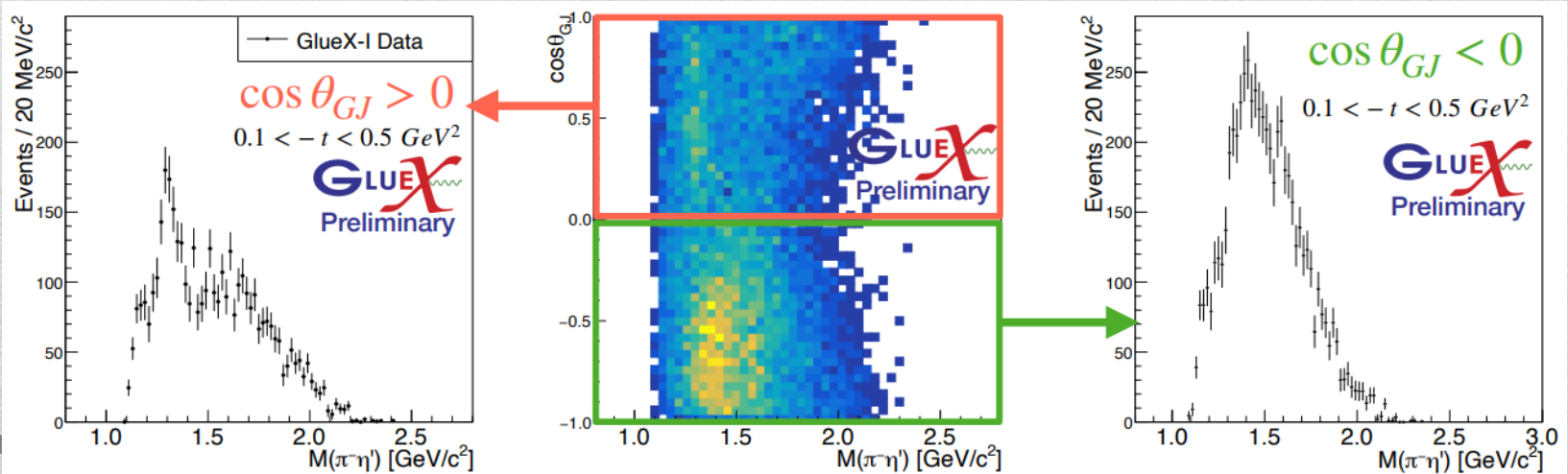
L. Pentchev, B. Wojtsekhowski  
*Thomas Jefferson National Accelerator Facility, Newport News, VA 23606*

# JPAC and the hybrid at GlueX

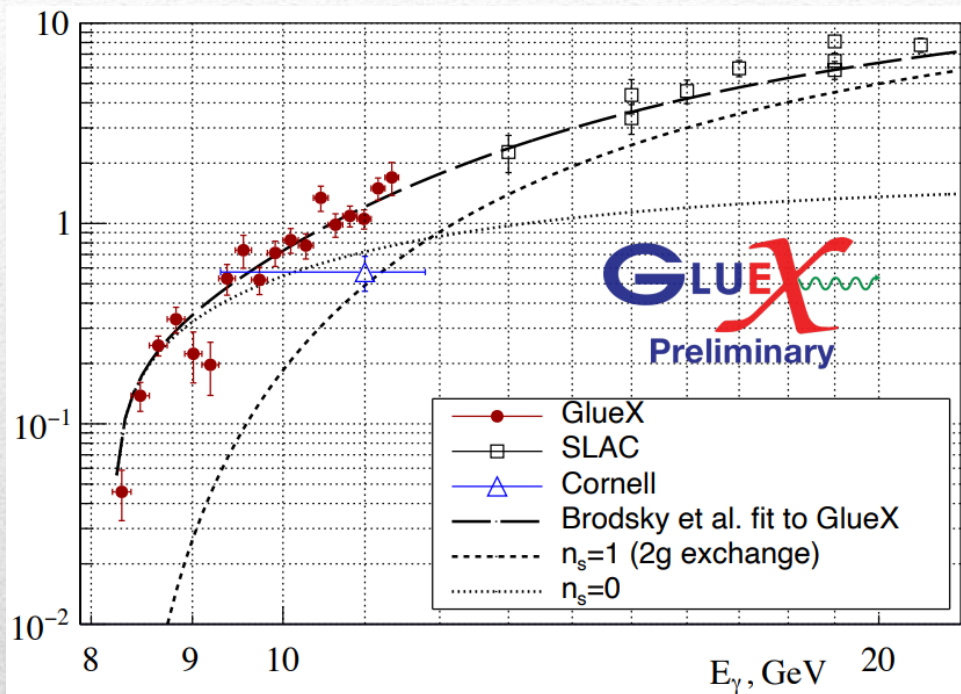


JPAC reconciled the  $\pi_1(1400)/\pi_1(1600)$  puzzle  
 Tools and methodology created for GlueX analysis

A. Rodas *et al.* (JPAC) PRL122, 042002  
 JPAC, PPNP 127, 103981



# Charmonia studies at GlueX



JLab12 has the right energy to study charmonium photoproduction in the near threshold region

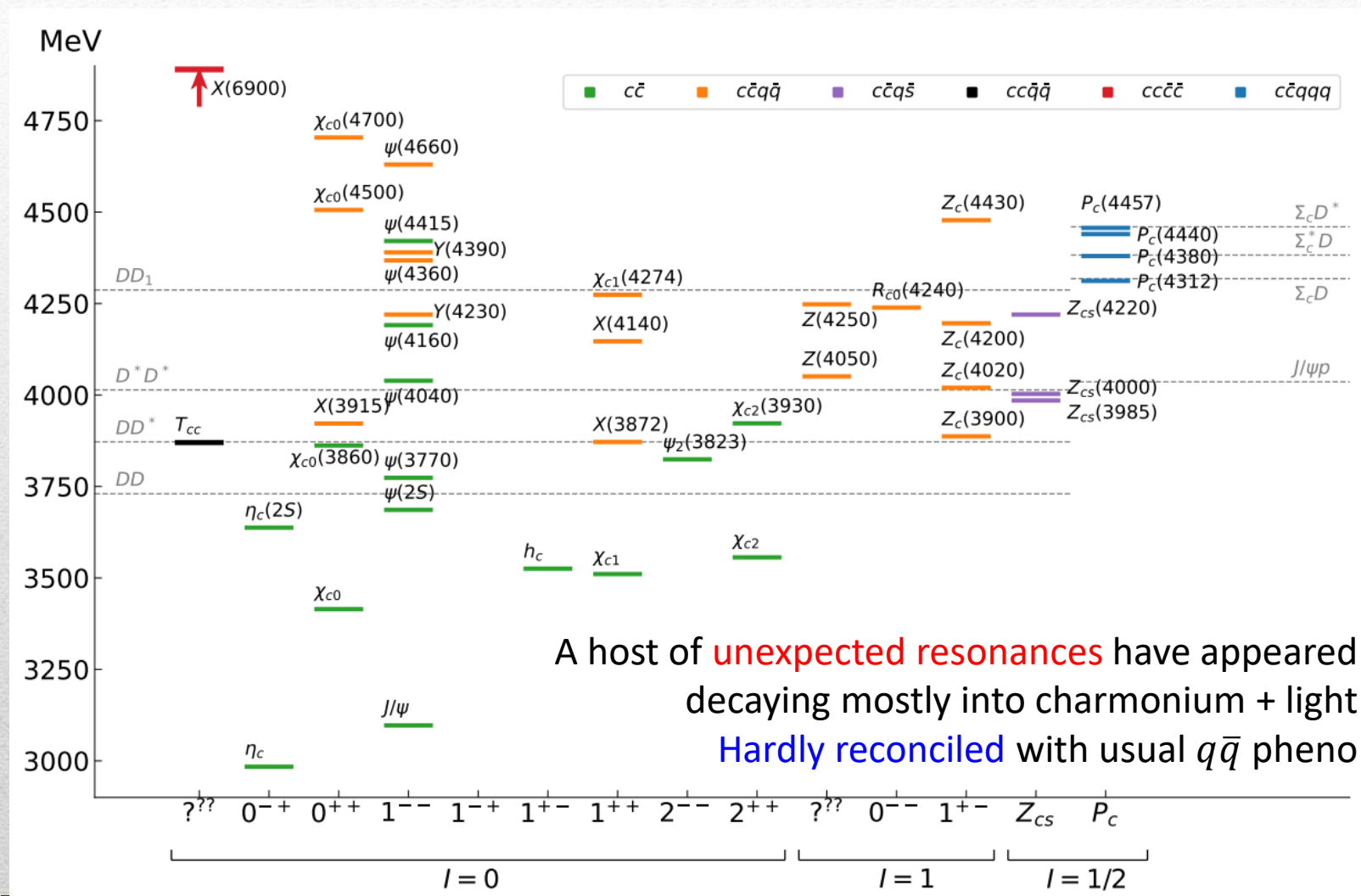
JPAC is helping in implementing models for  $J/\psi$  and other positive-parity charmonia

Diffractive model [JPAC, PRD 100 \(2019\) 3, 034019](#)

Low energy model [Du et al., EPJC 80, 1053 \(2020\)](#)

# Exotic landscape in $c\bar{c}$

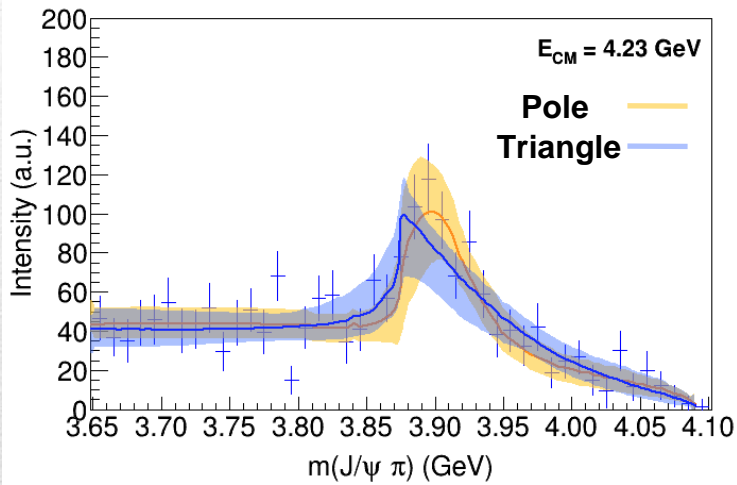
JPAC, PPNP 127 (2022), 103981



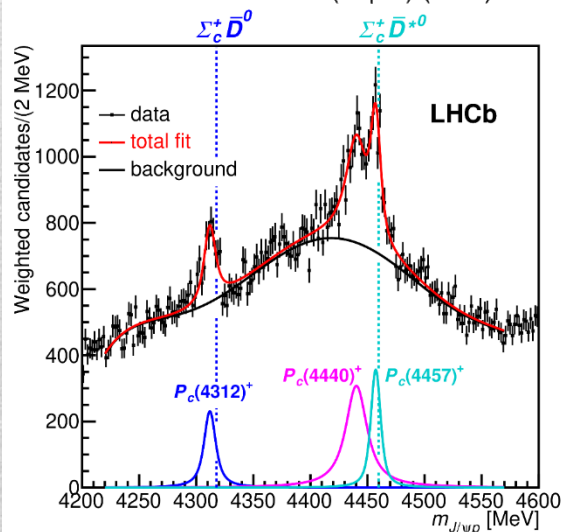


# XYZ at JPAC

This is the hottest topic in spectroscopy in the last two decades  
Big effort within JPAC to study this sector



- D. Winney *et al.*, PRD106 (2022) 094009
- L. Ng *et al.*, PRD 105 (2022) 9, L091501
- M. Albaladejo *et al.*, PRD102 (2020) 114010
- D. Winney *et al.*, PRD 100 (2019) 3, 034019
- C. Fernandez-Ramirez *et al.*, PRL 123 (2019) 9, 09200
- AP *et al.*, PLB 772 (2017) 200-209
- A. Hiller Blin *et al.*, PRD 94 (2016) 3, 034002



as well as contributing to experimental papers

- LHCb, arXiv:2210.10346
- LHCb, arXiv:2204.12597
- LHCb, Nature Commun. 13 (2022), 3351
- LHCb, Phys. Rev. Lett. 128 (2022), 062001
- LHCb, Phys. Rev. Lett. 122 (2019), 222001

# Exotic landscape

Broad mesons seen in  $b$  decay:  
 $X(4140)$ ,  $Z(4430)$ ,  $Z_{cS}(4000)$ ...

Scarce consistency between various  
production mechanisms

Narrow structures seen in  $b$  decay:  
 $X(3872)$ ,  $P_c$ ,  $(P_{cS})$

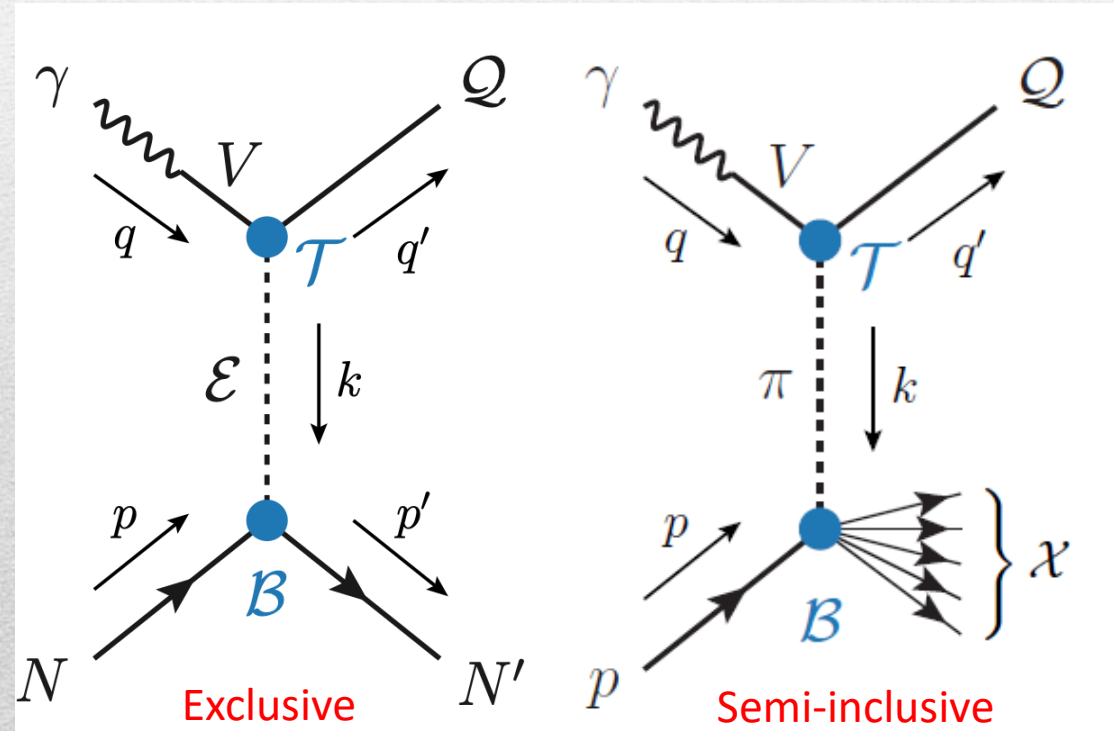
Narrow structures seen in  $e^+e^-$ :  
 $X(3872)$ ,  $Y(4260)$ ,  $Z_{c,b}^{(\prime)}$

# Why photoproduction?

- It's new: no XYZ state has been uncontroversially seen so far
- Dependence on beam energy can disentangle rescattering mechanisms that could mimic resonances in multibody decays
- The framework is (relatively) clean from a theory point of view
- Radiative decays offer another way of discerning the nature of the states

# The jpacPhoto library

- Couplings extracted from data as much as possible, not relying on the nature of XYZ
- Diffractive model, aiming at order-of-magnitude estimates



M. Albaladejo *et al.* [JPAC],  
PRD102 (2020) 114010  
D. Winney *et al.* [JPAC],  
PRD106 (2022) 094009

Code libraries available on GitHub

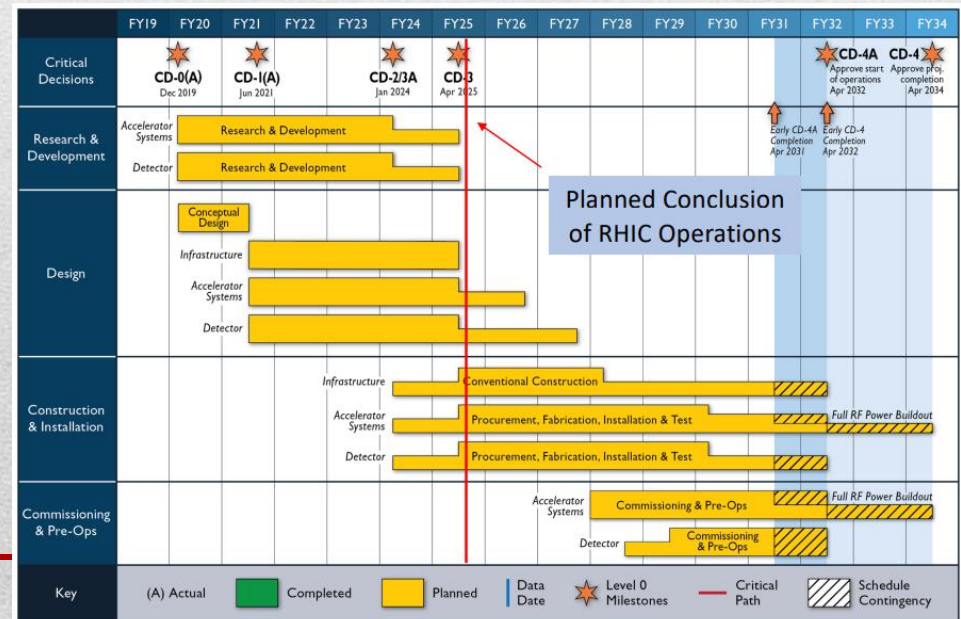
# XYZ at the Electron Ion Collider

SCIENCE REQUIREMENTS  
AND DETECTOR  
CONCEPTS FOR THE  
ELECTRON-ION COLLIDER  
EIC Yellow Report

Collaboration with D. Glazier and J. Stevens to perform feasibility studies for spectroscopy at the EIC

These have entered the EIC yellow report

arXiv:2103.05414v1 [physics.ins-det] 17 Mar 2021



# XYZ at Jefferson Lab

## XYZP spectroscopy at a charm photoproduction factory

M. Albaladejo,<sup>1</sup> M. Battaglieri,<sup>2,3</sup> A. Esposito,<sup>4</sup> C. Fernández-Ramírez,<sup>5</sup>  
 A. N. Hiller Blin,<sup>1</sup> V. Mathieu,<sup>6</sup> W. Melnitchouk,<sup>1</sup> M. Mikhasenko,<sup>7</sup> V. I. Mokeev,<sup>2</sup>  
 A. Pilloni,<sup>3,8,\*</sup> A. D. Polosa,<sup>9</sup> J.-W. Qiu,<sup>1</sup> A. P. Szczepaniak,<sup>1,10,11</sup> and D. Winney<sup>10,11</sup>

arXiv:2203.08290

LoI RF7\_RFO\_120

PPNP 127 (2022) 103985

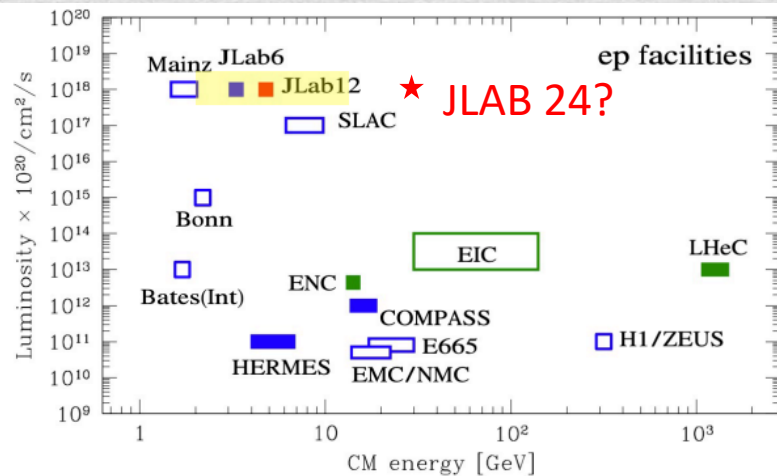
Submitted to the Proceedings of the US Community Study  
 on the Future of Particle Physics (Snowmass 2021)

## Hadron Spectroscopy in Photoproduction

Miguel Albaladejo<sup>1</sup>, Lukasz Bibrzycki<sup>2</sup>, Sean Dobbs<sup>3</sup>, César Fernández-Ramírez<sup>4,5</sup>,  
 Astrid N. Hiller Blin<sup>6</sup>, Vincent Mathieu<sup>7,8</sup>, Alessandro Pilloni<sup>9,10</sup>, Justin Stevens<sup>11</sup>,  
 Adam P. Szczepaniak<sup>12,13,14</sup>, and Daniel Winney<sup>13,14,15,16</sup>

## Physics with CEBAF at 12 GeV and Future Opportunities

J. Arrington<sup>1</sup>, M. Battaglieri<sup>2,15</sup>, A. Boehnlein<sup>2</sup>, S.A. Bogacz<sup>2</sup>, W.K. Brooks<sup>10</sup>, E. Chudakov<sup>2</sup>, I. Cloët<sup>3</sup>, R. Ent<sup>2</sup>,  
 H. Gao<sup>4</sup>, J. Grames<sup>2</sup>, L. Harwood<sup>2</sup>, X. Ji<sup>5,6</sup>, C. Keppel<sup>2</sup>, G. Krafft<sup>2</sup>, R. D. McKeown<sup>2,8,\*</sup>, J. Napolitano<sup>7</sup>, J.W. Qiu<sup>2,8</sup>,  
 P. Rossi<sup>2,14</sup>, M. Schram<sup>2</sup>, S. Stepanyan<sup>2</sup>, J. Stevens<sup>8</sup>, A.P. Szczepaniak<sup>12,13,2</sup>, N. Toro<sup>9</sup>, X. Zheng<sup>11</sup>



Explore the complementarity  
 w.r.t. the forthcoming Electron Ion Collider

# JPAC leads the upgrade efforts

Spectroscopy is one of the main physics cases to push for the energy upgrade

JPAC is leading this effort on the theory side  
Heavy involvement in workshop organization and white paper drafting



**J-FUTURE**

March 28, 2022 - March 30, 2022 • Messina, Italy

**TOPICS**

- Physics opportunities
- Hadron spectroscopy
- Nucleon structure
- Nuclear structure
- Detector developments
- Accelerator infrastructures

**ORGANIZERS**

M. Battaglieri (INFN Genova)  
G. Mandaglio (Messina U. and INFN Catania)  
A. Pilloni (Messina U. and INFN Catania)  
A. Szczepaniak (Indiana U. and JLab)  
E. Voutier (LPSG Grenoble)

**WORKSHOP SECRETARY**

M. T. Reggio (Messina U.)

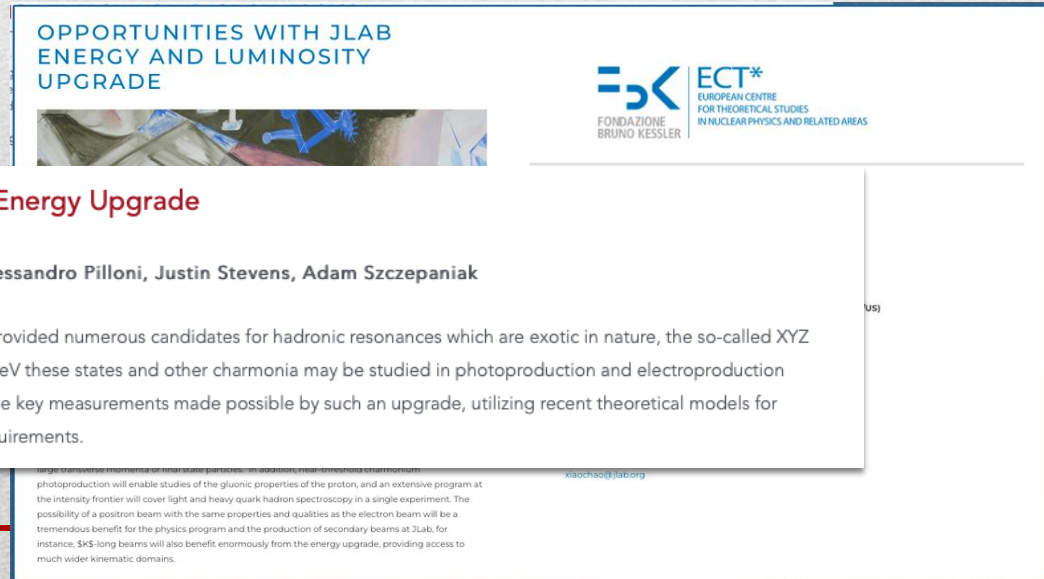
**CONTACT**

alessandro.pilloni@unime.it  
giuseppe.mandaglio@unime.it

**ABSTRACT**

While the JLab 12 GeV program is running, it is already time to plan the future developments for the facility.

A new round of upgrades to CEBAF are under technical development. One of these is a potential energy upgrade to 24 GeV using novel magnet designs in the existing recirculation arcs. Another is a potential for intense polarized beams of electrons or positrons, which would allow for new measurements in nucleon tomography, provide precision extraction of contributions from higher order electromagnetic currents, and allow new tests of the standard model. In addition, it is possible to open new research lines using secondary beams.



**OPPORTUNITIES WITH JLAB ENERGY AND LUMINOSITY UPGRADE**

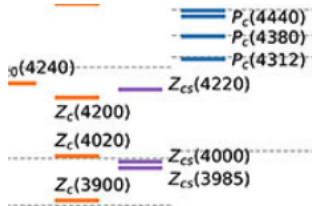
FONDAZIONE BRUNO KESSLER | ECT\* EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS

**Hadron Spectroscopy with a CEBAF Energy Upgrade**  
June 16 & 17  
Marco Battaglieri, Sean Dobbs, Derek Glazier, Alessandro Pilloni, Justin Stevens, Adam Szczepaniak

Recent observations in heavy-quark spectroscopy have provided numerous candidates for hadronic resonances which are exotic in nature, the so-called XYZ and Pc states. With a CEBAF energy upgrade to 20-24 GeV these states and other charmonia may be studied in photoproduction and electroproduction measurements at JLab. This workshop aims to identify the key measurements made possible by such an upgrade, utilizing recent theoretical models for production and evaluating the detector performance requirements.

large transverse momenta of final state particles. In addition, near-threshold charmonium photoproduction will enable studies of the gluonic properties of the proton, and an extensive program at the intensity frontier will cover light and heavy quark hadron spectroscopy in a single experiment. The possibility of a positron beam with the same properties and qualities as the electron beam will be a tremendous benefit for the physics program and the production of secondary beams at JLab, for instance, SRS-long beams will also benefit enormously from the energy upgrade, providing access to much wider kinematic domains.

xiaocha@jlab.org



# Conclusions

- JLab12 program has a full schedule well into the future  
several current and planned experiments  
require JPAC work for results to be delivered
- Close collaboration with GlueX in order to achieve the first  
observation of a hybrid meson in photoproduction
- Strong effort in creating a XYZP spectroscopy program  
at the EIC and at an upgraded JLab facility
- Involvement in other running and future experiments  
around the world to make the best of high statistics data

**Thank you!**



# BACKUP

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# Timescales

- BESIII plans to operate for up to 10 more years
- Upgrades planned for 2024
  - Increase center of mass energy up to 5.6 GeV → access new thresholds!
  - Increase luminosity by a factor of 3 → better statistics!
- Many more analyses in the works

