# Recent Gue Results and Prospects on Charmonia and Hybrids

## Sean Dobbs

Florida State U.

Experimental and theoretical status of and perspectives for XYZ states April 14, 2021







#### **Hadron Spectroscopy and Photoproduction**

 Photoproduction is an interesting process to search for exotic hadrons





- Photons couple to proton through exchanged QNs, can produce mesons of any J<sup>PC</sup>
- Photon polarization provides constraints on production processes, probe of hadron properties

#### **Hybrid Mesons**



HadSpec: PRD 88, 094505 (2013)

 Long history of search for "hybrid" mesons with gluonic excitations

- Best evidence is for  $\pi_1(1600)$  in COMPASS pion-production data
- Establishing the light quark hybrid spectrum → insight to the heavy quark hybrid spectrum

JPAC: PRL 122, 042002 (2019)

a2'(1700)

 $\pi^- p \rightarrow \eta^{(\prime)} \pi^- p$ 

#### **GlueX: High Statistics Photoproduction Data**



- GlueX has collected orders of magnitude more data than previous experiments at E<sub>x</sub> ≈ 9 GeV
  - > 5 times more η(')π than COMPASS
    amplitude analysis underway
- Hybrid search range allows searching for strange XYZ partners
  - φ(2170), Z<sub>s</sub>, ...



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- Near-threshold production is ideal for studying the cc+N interaction
  - Probes the distribution of gluons in the proton and the nature of the proton mass
  - Can look for s-channel production of resonant states



leading-twist





- GlueX energy range:  $E_{\gamma} < 12 \text{ GeV}$
- Large hadronic xsec, focus on decays containing J/ $\psi \rightarrow e^+e^-$
- Decays to light hadrons ( $\eta_{c}, \chi_{c0}$ ) parallel to hybrid searches



 Thresholds for states above the DD threshold extend to higher energies



Also have access to production of P<sub>c</sub>'s

## **The GlueX Experiment**



GlueX-I (2017–2018): E<sub>γ</sub> > 8 GeV, L = 330 pb<sup>-1</sup>

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GlueX-II (2020–): expect 3-4x GlueX-I

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10

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#### J/ψ Photoproduction at GlueX: Mass Spectrum



- Reconstruct  $p \gamma \rightarrow p + J/\psi$ ,  $J/\psi \rightarrow e^+e^-$
- · Calculate J/ $\psi$  cross sections normalized by non-resonant e+e-

## Published GlueX J/ψ Photoproduction Results



- Used portion of GlueX-I data [469 J/ψ] to measure cross sections
- 27% normalization uncertainty
- Model-dependent limits set on P<sub>c</sub> production



#### Interpretations of GlueX J/ψ Photoproduction Results

1.4

1.2

1.0

0.8

0.6

0.4

0.2

0.0

8500

[dn] (qψ\L↔qγ)

#### Kharzeev, arXiv:2102.00110 (2021)

#### Du et al., EPJC 80, 1053 (2020)

 $q_{\text{max}}=1.0 \text{ GeV}$ 

q<sub>max</sub>=1.2 GeV

9000



mass radius:  $R_m = 0.55 \pm 0.03$  fm charge radius:  $R_c = 0.8409 \pm 0.0004$  fm More data closer to the threshold is needed

Calculated cross section energy dependence including open charm loops Higher precision data is needed

 $E_V$  [MeV]

9500

10000

Lots of interest in these measurements—selected results shown above

## **Projected GlueX-I J/ψ Photoproduction Results**



dependence from published results and dipole t-dependence

- Full GlueX-I run has  $2k J/\psi$ , expect updated results soon! •
- Measurement of cross section t-dependence benefits from additional data

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## **X**c1(1<sup>3</sup>P1) Photoproduction at GlueX



- $\chi_{c1}(1^{++})$  photoproduction: probe of different parity, P<sub>c</sub> search
- JPAC model estimate using known  $\chi_{c1} \rightarrow \gamma(\rho, \omega, \phi, J/\psi)$  couplings
- GlueX-I expectation:  $N(\chi_{c1} \rightarrow \gamma J/\psi, J/\psi \rightarrow e^+e^-) = O(50)$

## ψ(2<sup>3</sup>S<sub>1</sub>) Photoproduction at GlueX



- $\psi(2S)$  photoproduction: probe of wave function dependence
- JPAC model estimates using known $\Gamma_{\chi gg}(\psi(2S)) / \Gamma_{\chi gg}(J/\psi)$
- GlueX-I expectation:  $N(\psi(2S) \rightarrow \pi^+\pi^- J/\psi, J/\psi \rightarrow e^+e^-) < 10$

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#### **Open Charm Production Near Threshold**

- Hadron (cc̄) molecules like to decay to open-charm final states, so can we see them?
- Open charm photoproduction cross section measured at SLAC for Eγ ≈ 20 GeV based on ~50 events
  - Roughly 5-10 larger than J/ψ cross section
  - Exclusive reconstruction of e.g.  $D^{(*)0} \Lambda_{c^+}$  is a factor  $\approx 25$  lower due to b.f.s
- Likely need full GlueX-II statistics with improved π/K separation

#### PRL 51, 156 (1983)



FIG. 2. An example of a charm event.

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#### **Summary and Prospects**

- GlueX has made the first measurement of the energy dependence of the  $J/\psi$  cross section near threshold
  - Expect an update soon with the full  $2k J/\psi$  from GlueX-I
  - The ongoing GlueX-II run allows us to measure  $d\sigma$  / dt dE
- Other measurements of bound charmonia are possible with the growing GlueX data set
  - $\chi_{c1}$  and  $\psi(2S)$  appear feasible
  - Other ideas: production off  $\Delta$ 's, deuteron/nuclear targets, ...
  - Open charm: exciting possibility but very difficult due to small b.f.'s, large background levels, GlueX-II DIRC will help...
- Exploring near-threshold photoproduction of other charmonia requires a higher-energy machine or an EIC

#### **Backup Slides**

#### **Zc Photoproduction at GlueX**

#### JPAC: PRD 102, 114010 (2020)

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 Zc(3900) production threshold just above energies accessible at GlueX—need CEBAF energy upgrade or EIC

#### J/ψ @ GlueX: Background Rejection



#### J/ψ @ GlueX: t-slope



#### Measurements near threshold

- Cornell at ~11 GeV 1.25 ± 0.20 GeV<sup>-2</sup>
- GlueX at 10–11.8 GeV 1.49 ± 0.33 GeV<sup>-2</sup>

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SLAC at 19 GeV
2.9 ± 0.3 GeV<sup>-2</sup>

## **The GlueX Experiment: Photon Beam**

![](_page_24_Figure_1.jpeg)

- Photon beam generated via coherent bremsstrahlung off thin diamond radiator
- Photon energies tagged by scattered electrons
  - Energy measurement precision < 25 MeV</li>
- Photon linear polarization  $P_{\gamma} \sim 40\%$  in peak
- Intensity of ~1–5  $\times$  10<sup>7</sup> g/s in peak

![](_page_24_Figure_7.jpeg)

#### Searching for "Charming" Hybrids

![](_page_25_Figure_1.jpeg)

- Hybrid mesons should have charmquark counterparts
  - Candidates exist
  - (Polarized) photons give clean probe
  - Vector mesons should be well produced via VMD
  - Other QN mesons can be produced as well
- EIC gives required CM energy (and luminosity?) to search for these

## The GlueX Experiment in Hall D @ JLab

- The GlueX experiment is located in Hall D, newly constructed as part of the Jefferson Lab 12 GeV upgrade.
  - Large acceptance solenoidal spectrometer
  - Linearly polarized photon beam peaking at 9 GeV
  - Detects all decay products from full hadronic photoproduction rate
- 100+ Collaborators from 26 institutions

![](_page_26_Picture_6.jpeg)