Experimental expectations for XYZs at GlueX

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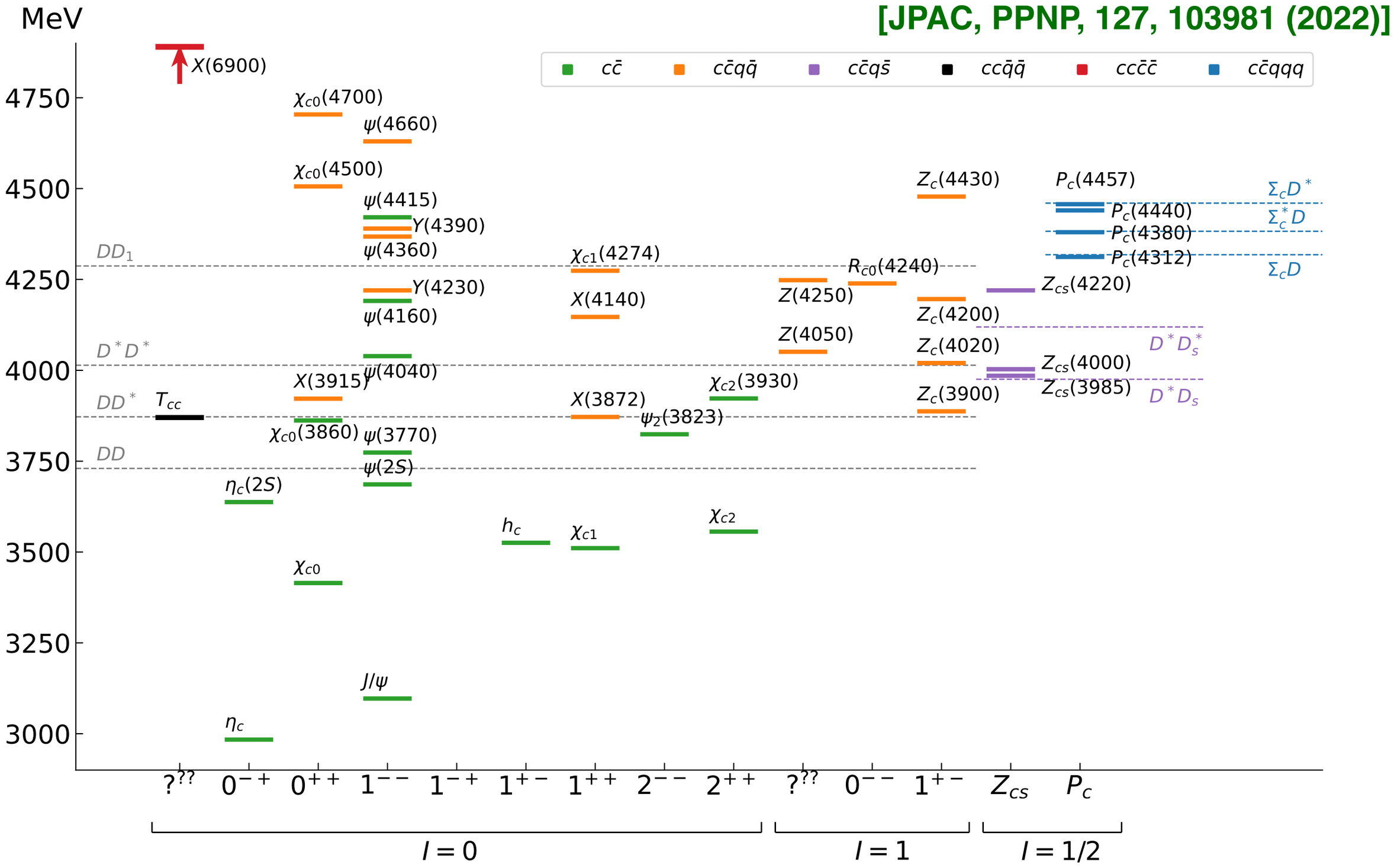
Science at the Luminosity Frontier: Jefferson Lab at 22 GeV

12 / 9 / 2024

Current State of Charmonium(-like) States



- Photoproduction can confirm non-$q\bar{q}$ candidate states
- “clean” theoretical framework, and free from rescattering mechanisms

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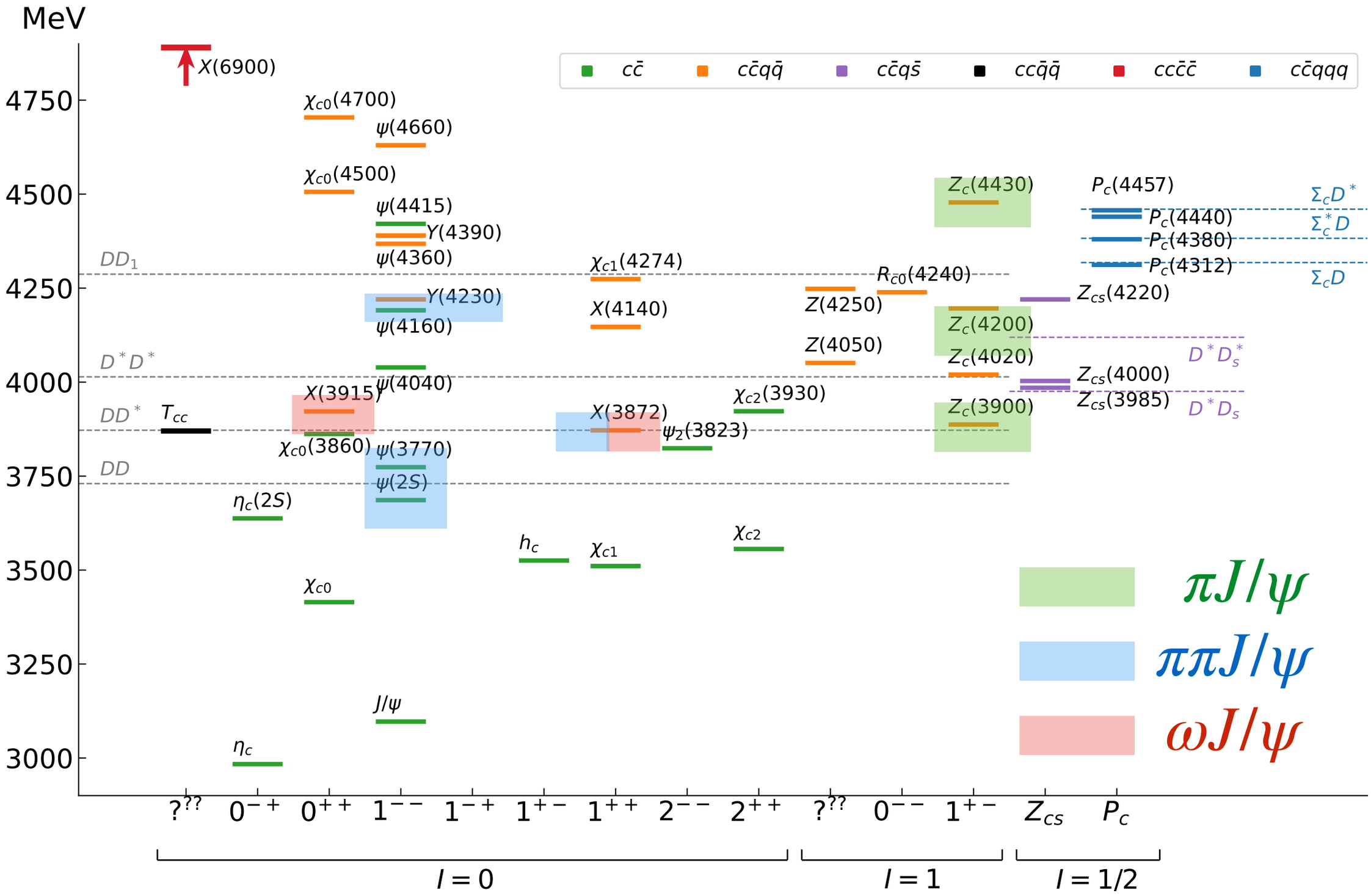

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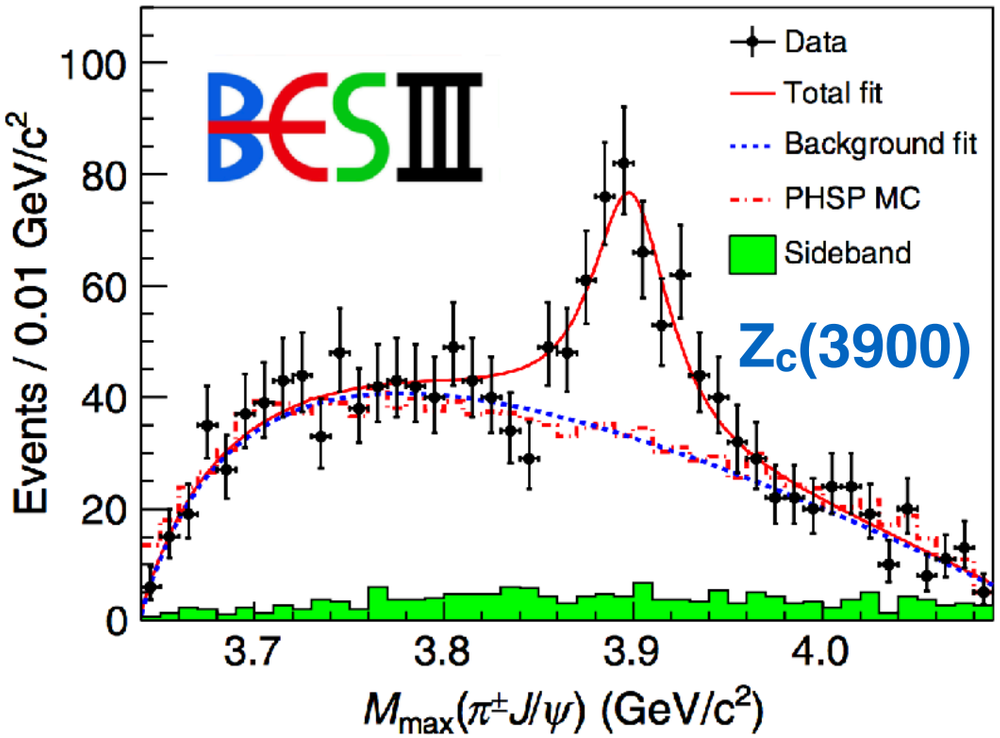
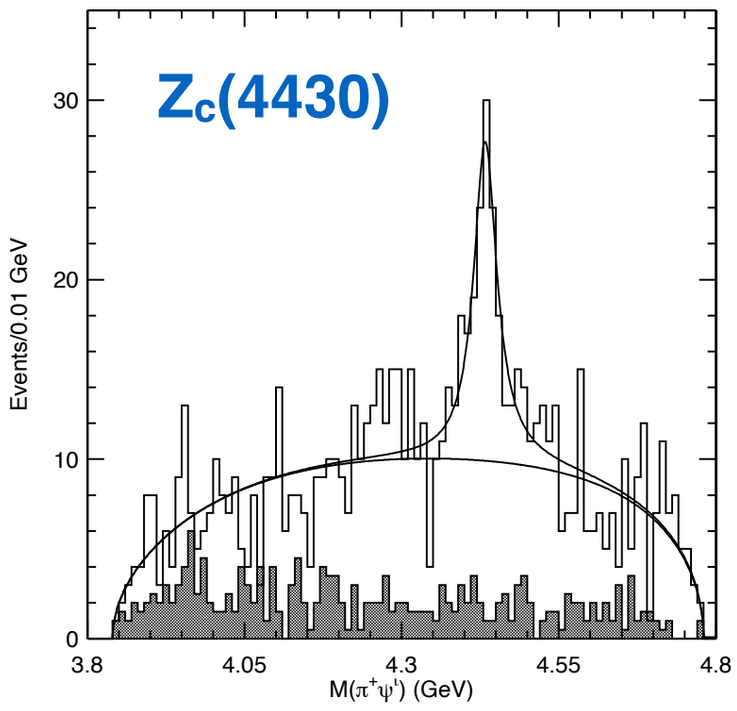
- “clean” theoretical framework, and free from rescattering mechanisms

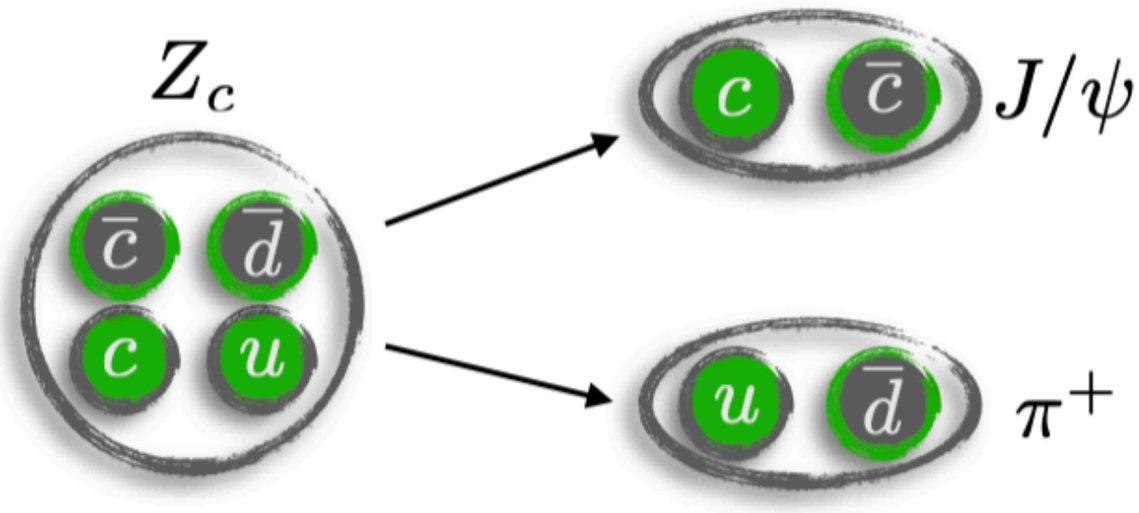
Discovery of the Zc(3900)

BESIII: PRL 110, 252001 (2013)



Belle: PRL 100, 142001(2008)

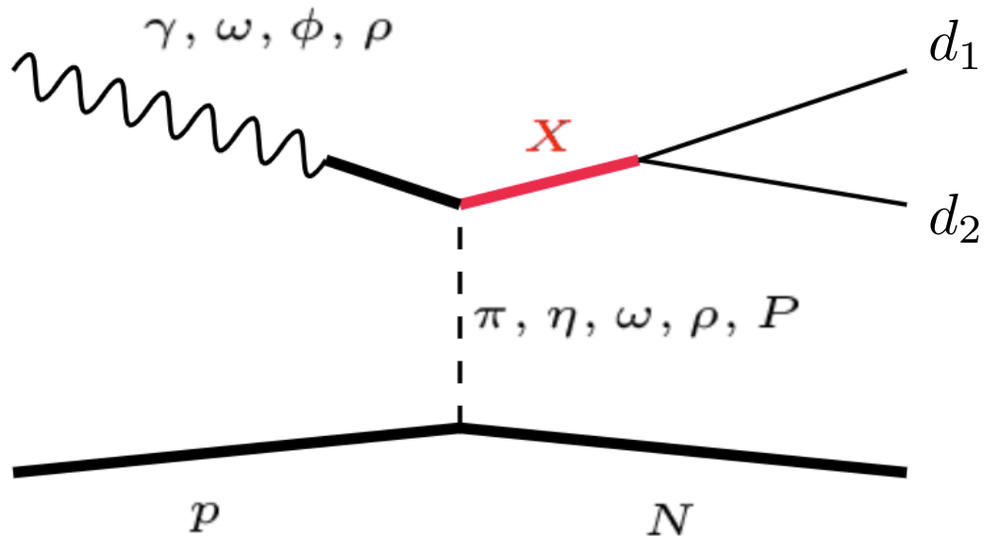


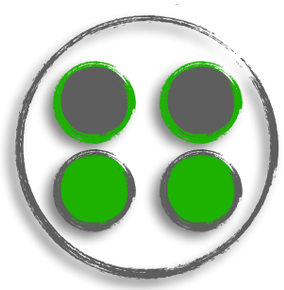


- Decays imply $c\bar{c}q\bar{q}$ quark content
- Spectrum of possible explanations: tetraquark, molecule, virtual state, triangle singularity, …
- Crucial to confirm these states in other production processes, establish multiplets

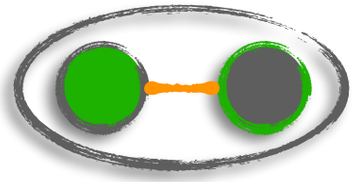
Spectroscopy using Photoproduction

- Versatile process:
  - Can produce mesons of any J^{PC}
    - Linear beam polarization filters naturality of exchanged particle
    - Allows insight into structure





Tetraquark



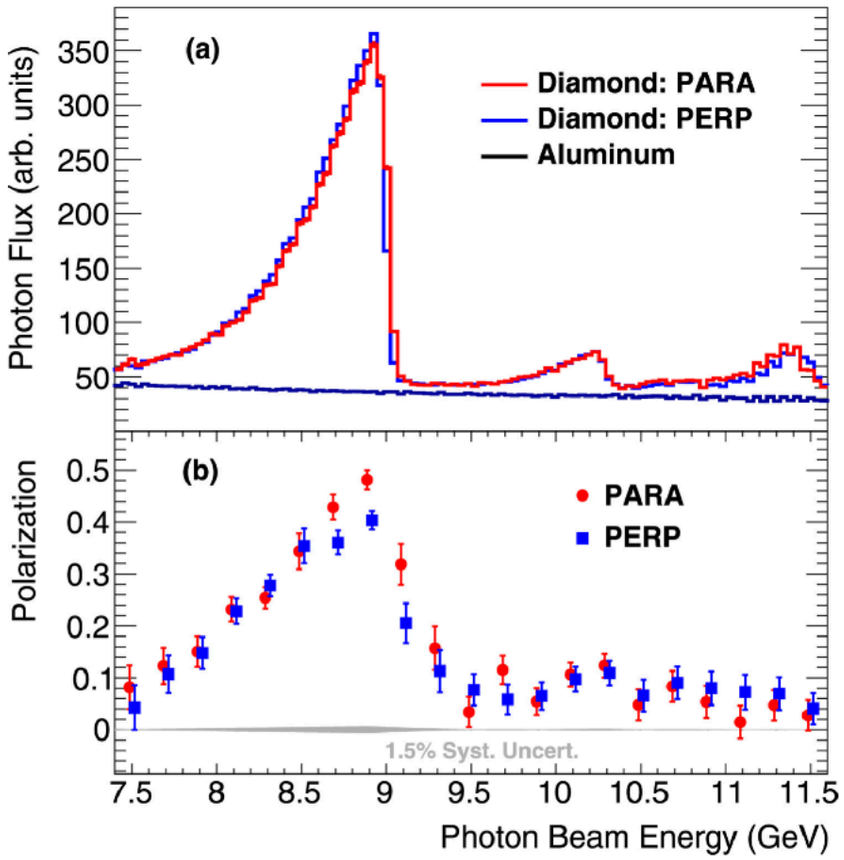
- Hybrids (mesons with excited gluonic degrees of freedom)

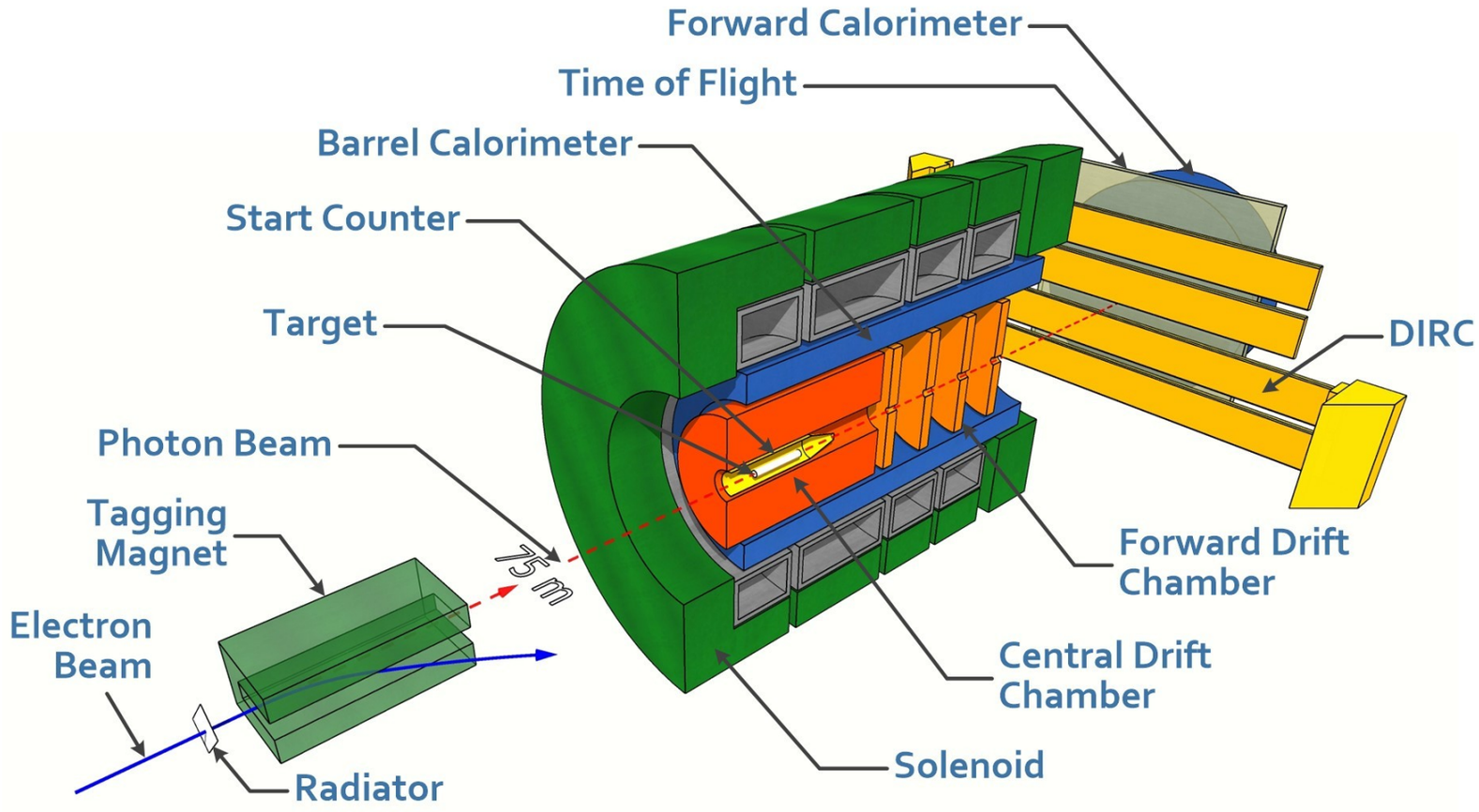
[see e.g. PRD 92, 014005; PRD90, 014044 , ...]

  - Production of mesonic resonances as well as target excitations
  - Ideal also for Baryon spectroscopy
    → background for meson production

- GlueX has excellent capability to search for XYZ states
  - Large acceptance for charged and neutral particles

The GlueX Experiment

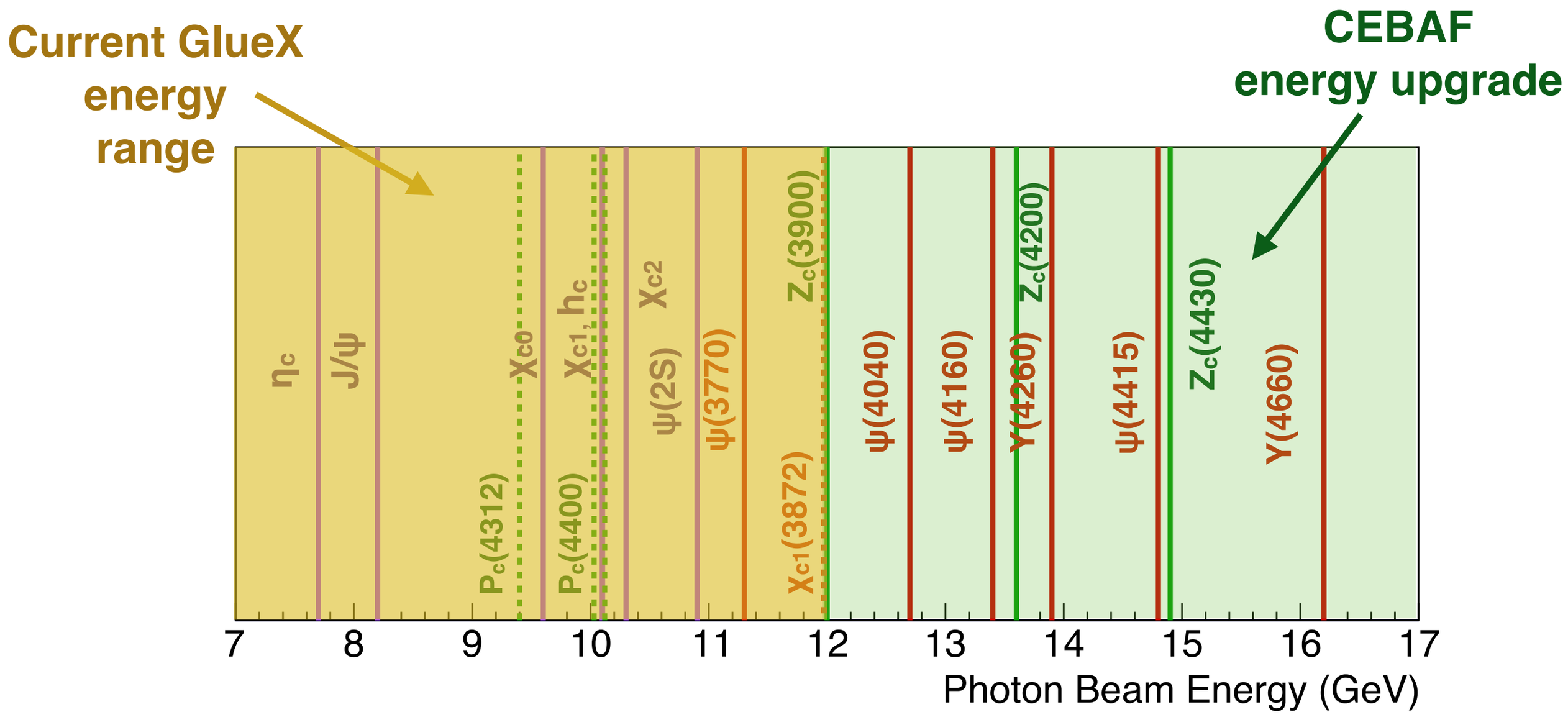




- Linearly polarized, tagged photon beam (P≈40%) impinging on Liquid Hydrogen Target
- Four polarization orientations, coherent peak: ~8.2-8.8 GeV
- Large acceptance for charged and neutral final state particles
- GlueX Phase I completed (2017-18, $\int L = 125\,\mathrm{pb}^{-1}$), Phase II ongoing (expect 3-4 times Phase I data), Phase III approved!

[(GlueX) NIMA **987** (2021) 164807]

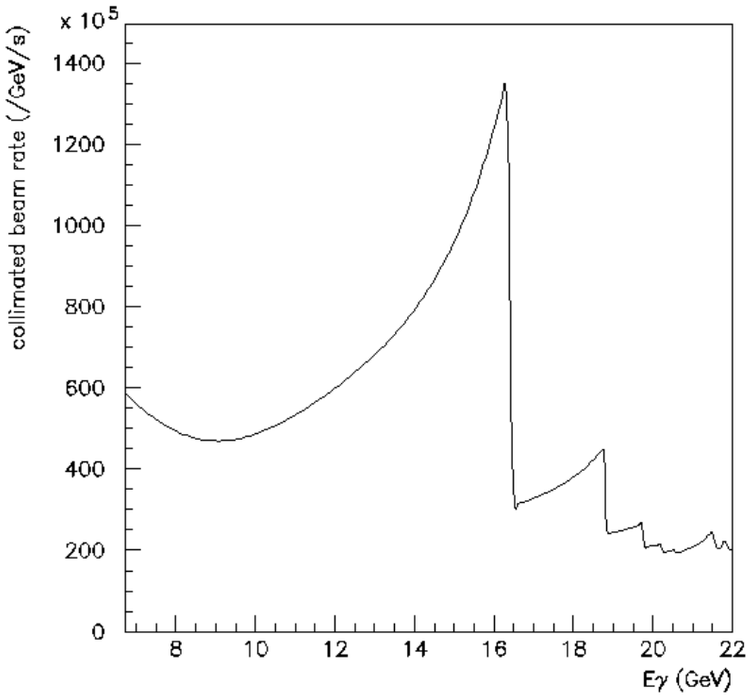
Production Thresholds



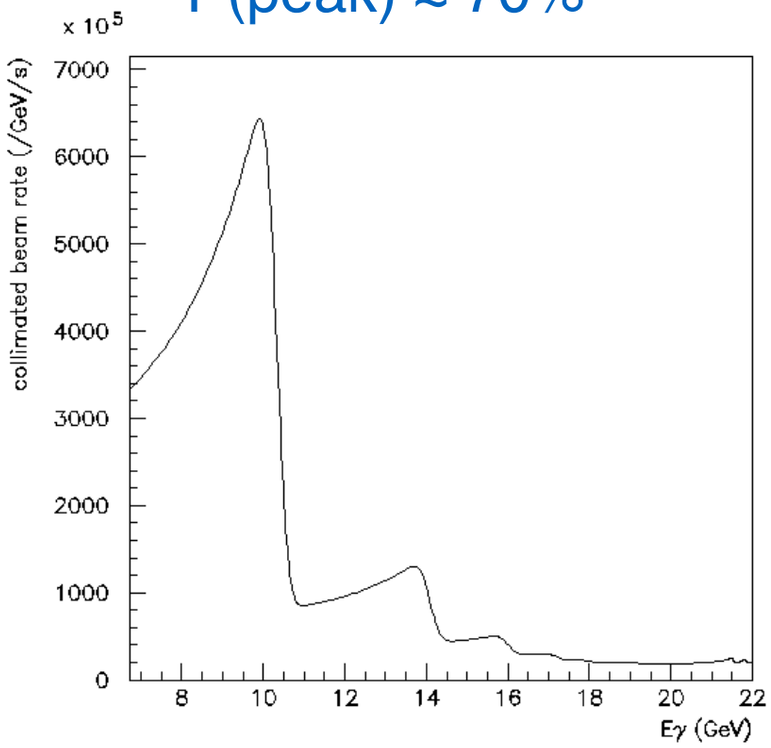
- Current max CEBAF energy allows study of bound $c\bar{c}$, P_c states
- 22 GeV e- gives access to most exotic states, good phasespace, linear polarization

Luminosity Expectations

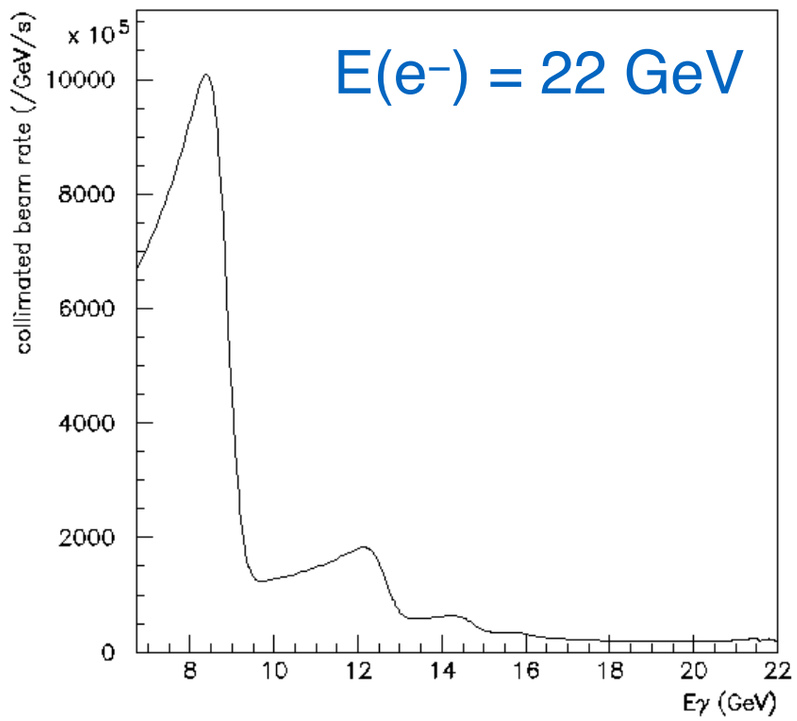
E(peak) = 16.5 GeV
P(peak) ≈ 35%



E(peak) = 10.5 GeV
P(peak) ≈ 70%



E(peak) = 9 GeV
P(peak) ≈ 80%



- "Old" baseline: "high-intensity" GlueX-II in 2020 @ 500 pb^{-1} / year ($E_\gamma > E_{e-} / 2$)
  - Based on measured tagged photon flux
- This is the **lower limit**, path to higher rates:
  - Simple tagger upgrades → factor 4 increase
  - Upgrades to forward tracking / TOF to reach highest rates

Updated Baseline: GlueX-III Luminosity

- Approved by PAC52: Proposal for GlueX-III data taking

PR12-24-006

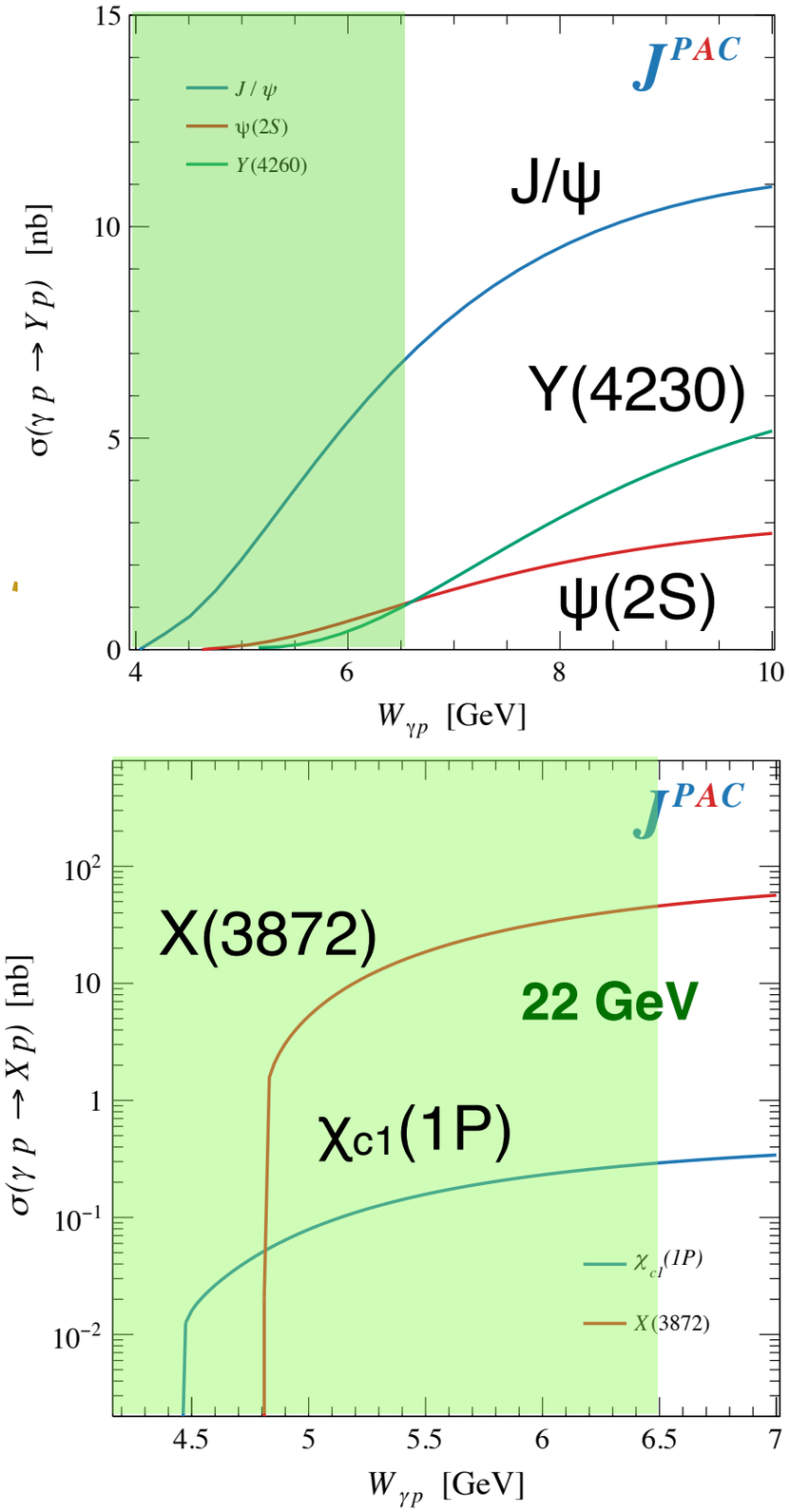
Scientific Rating: A

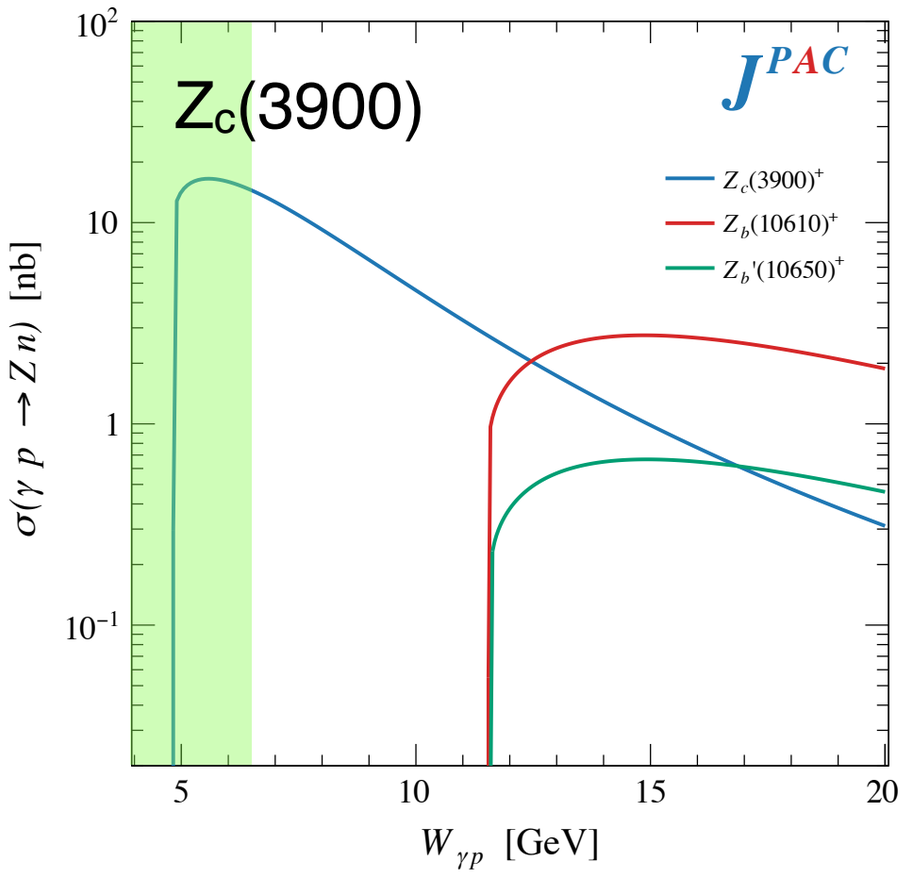
Recommendation: Approved for 200 PAC days in Hall D

Title: GlueX-III: a path to the Luminosity Frontier in Hall D

- Will serve as proof-of-principle for High-Rate-Running with mostly existing detector setup
  - Minimal modifications:
    - Tagger
    - Forward tracking (TRD, improves e/π separation by factor 10)
- **Estimation: 1000 pb^-1 per year running**

Cross Section Predictions



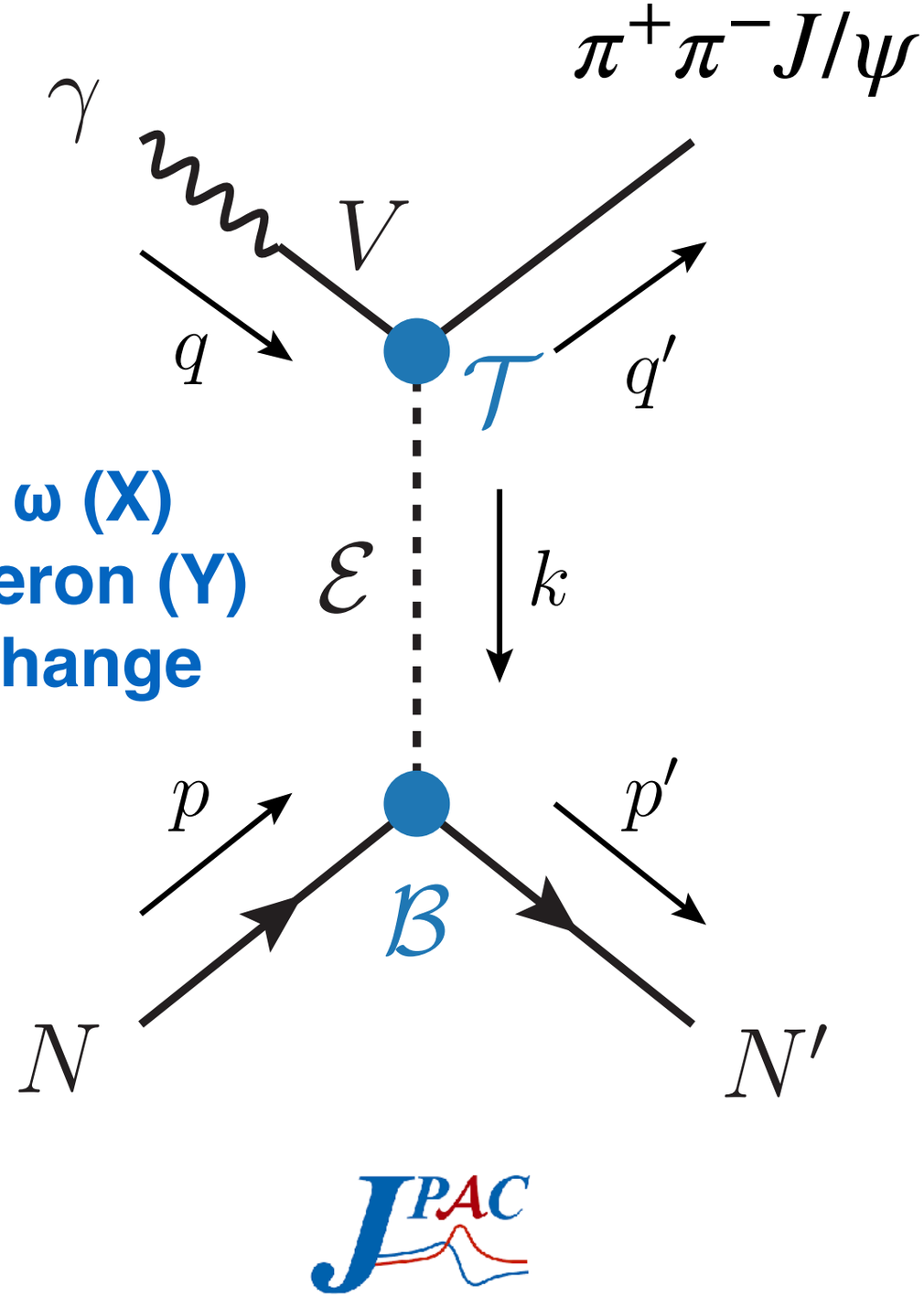


- JPAC predictions using fixed-spin exchanges near threshold
  - **PRD 102, 114010 (2020) arXiv:2209.05882**
- GlueX can test models by measuring $\chi_{c1}(1P)$, $\psi(2S)$ production

see talk by L. Pentchev

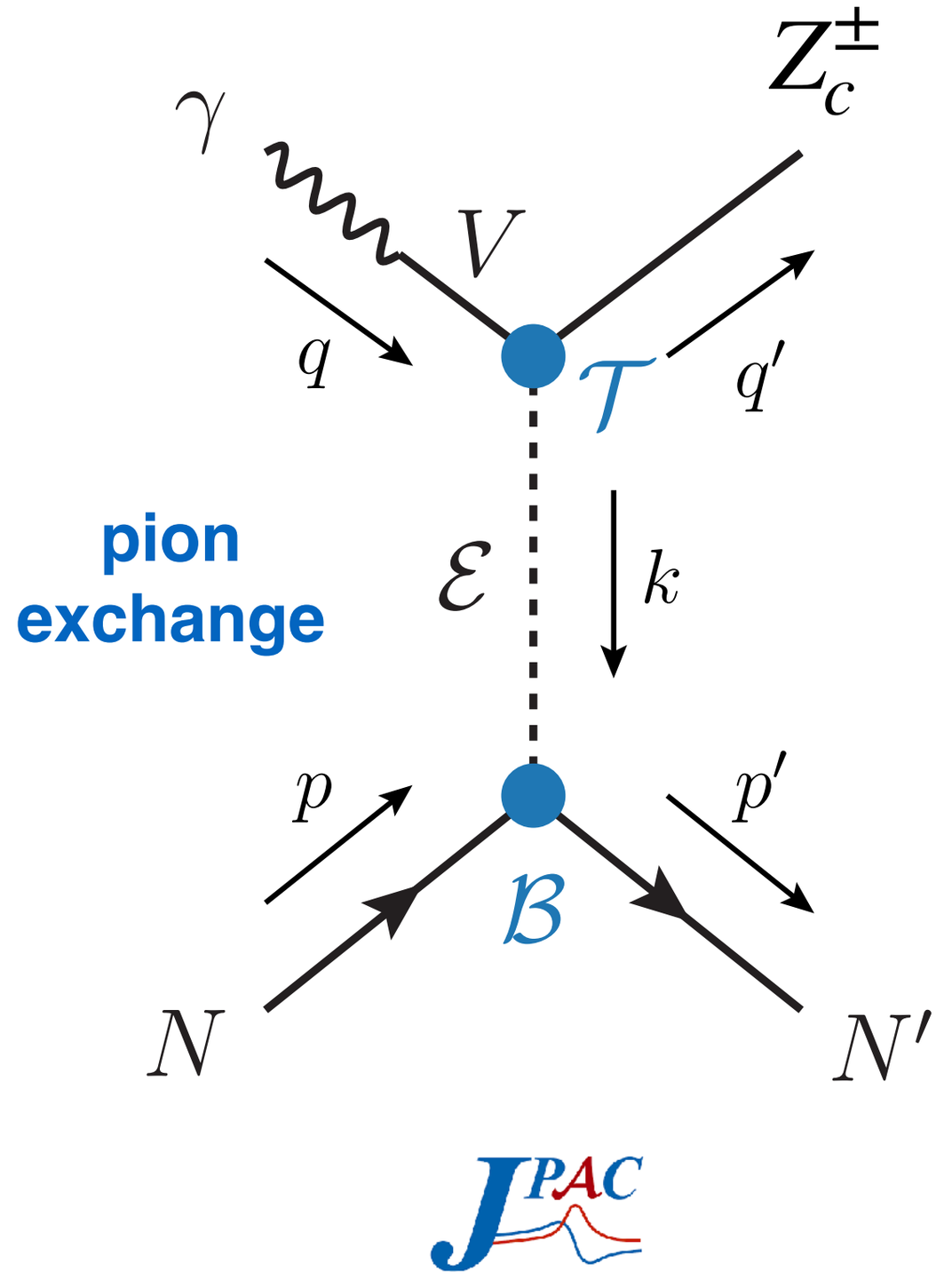
Photoproduction of X,Y States

- Benchmark: X(3872), Y(4320) production with $\pi\pi J/\psi$ decay
  - $\gamma p \to \pi^+\pi^- J/\psi p$
- Folded JPAC cross section model with expected coherent bremsstrahlung flux
- Run through full analysis chain
- Background estimation from PYTHIA
  - Note: uncertainty in background due to target excitations

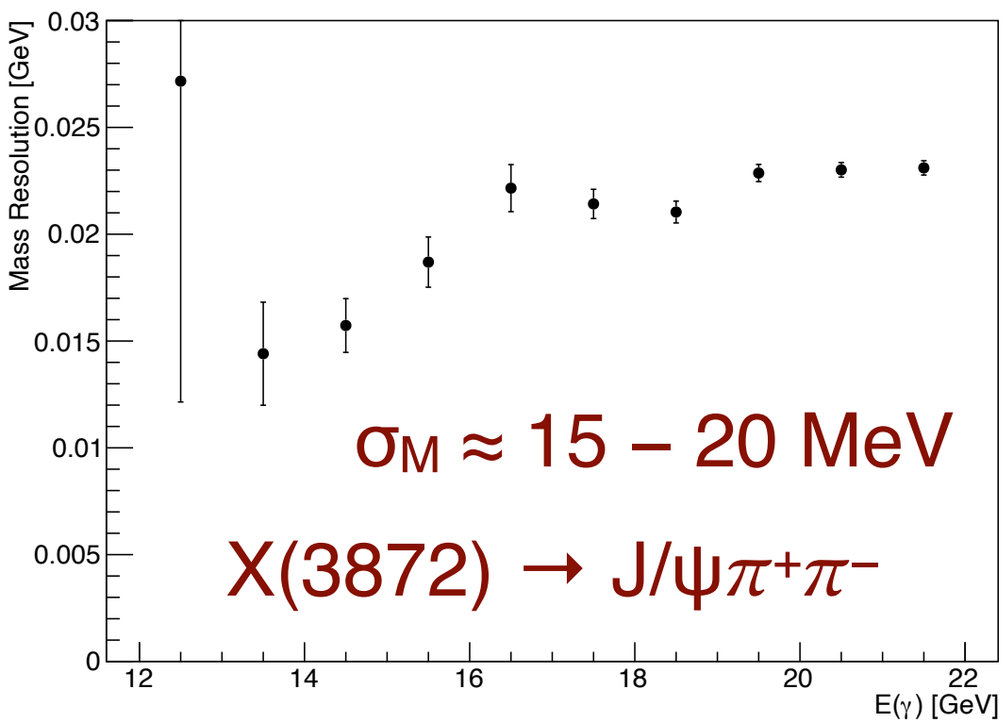


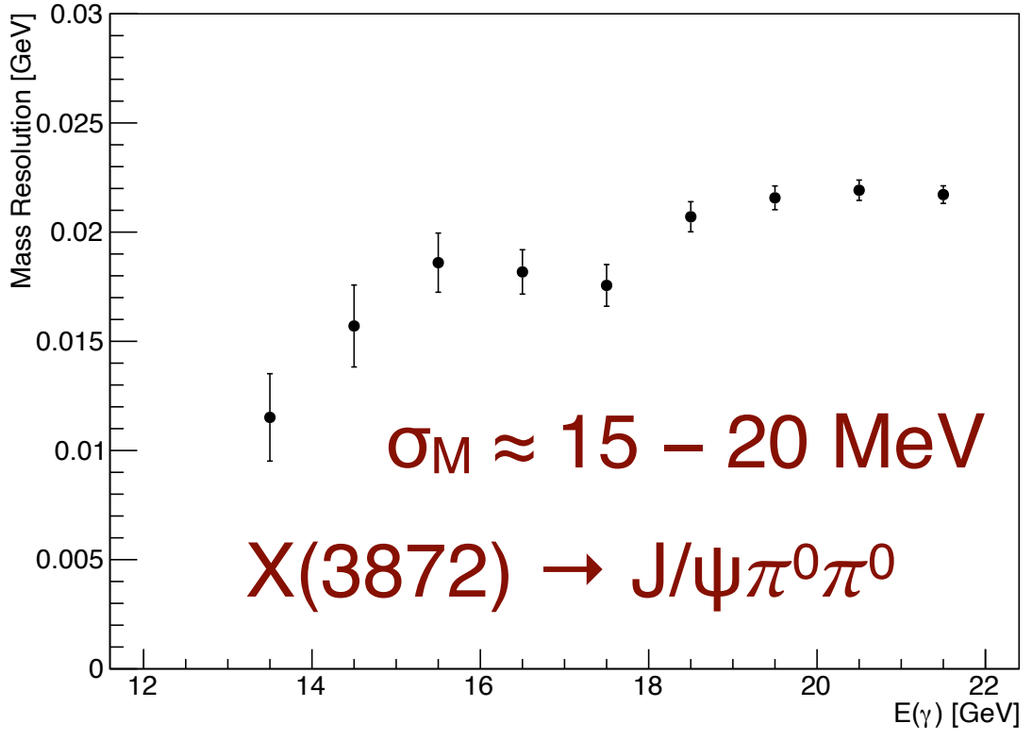
Photoproduction of Z states

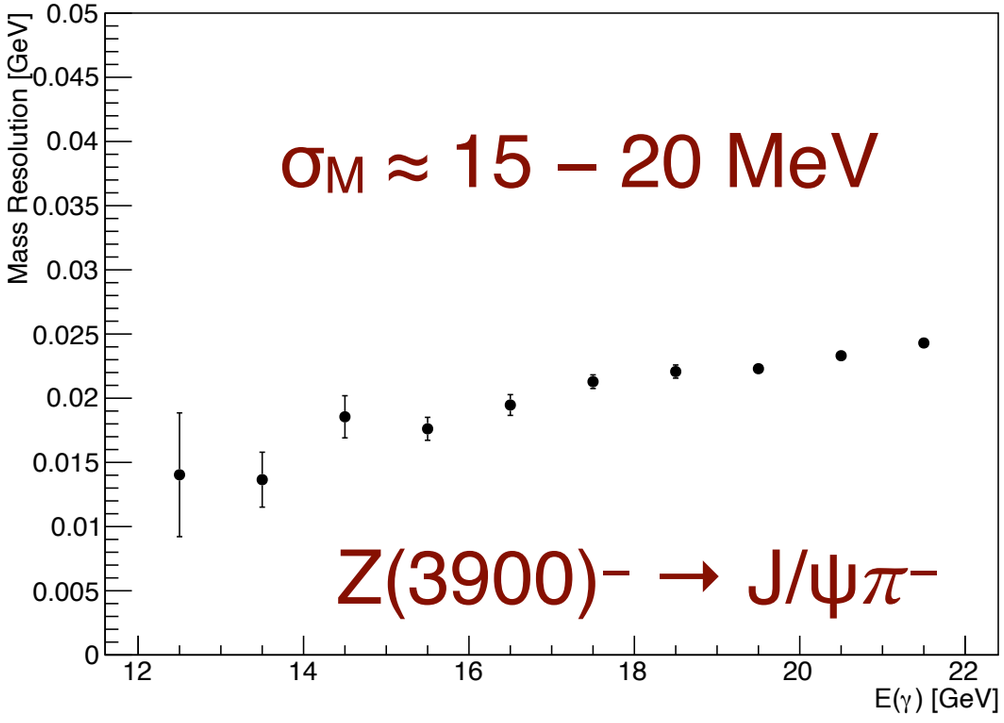
- Benchmark: $Z_c(3900)$ production with $\pi J/\psi$ decay
- Z_c has isopin=1, many ways to produce it:
  - $\gamma p \to Z_c^0 p$
  - $\gamma p \to Z_c^0 n$
  - $\gamma n \to Z_c^- p$
  - $\gamma p \to Z_c^- \Delta^{++}$
- Expected to have similar cross sections, all accessible at GlueX

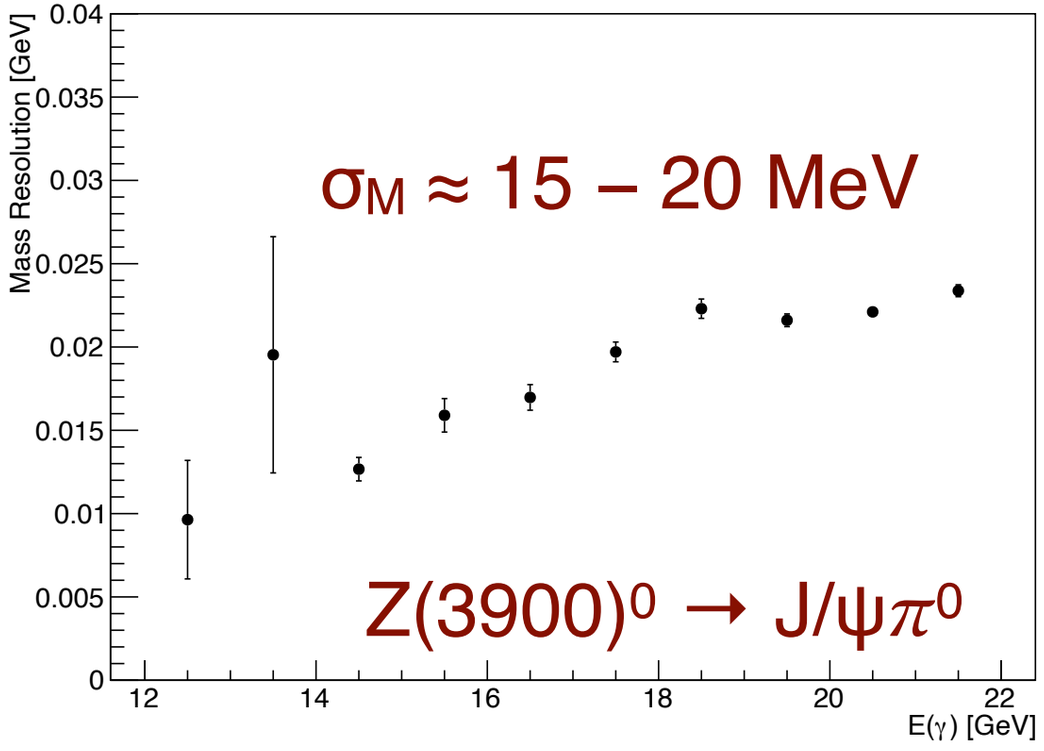


Projection: Expected Resolution

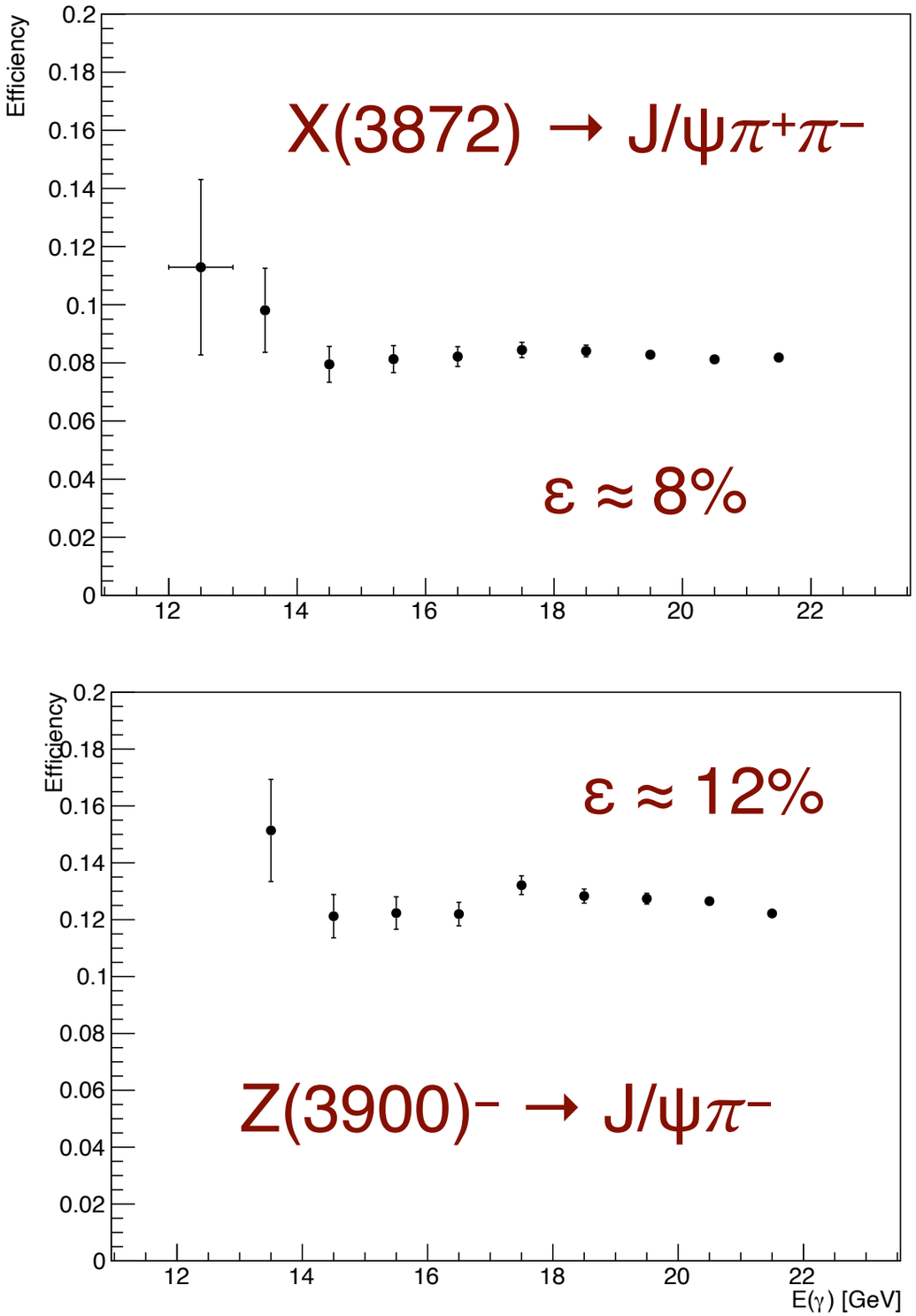


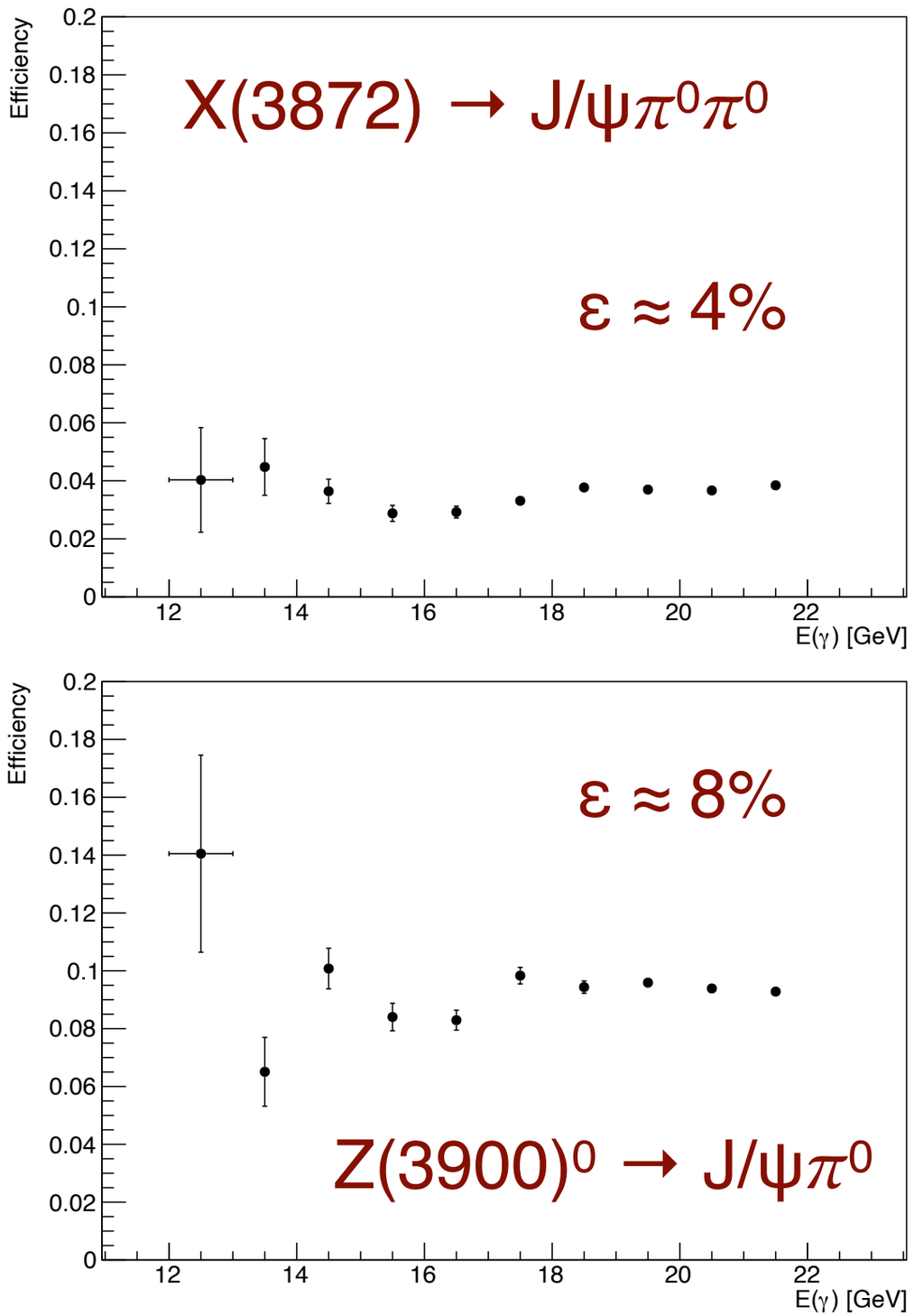






Projection: Efficiencies

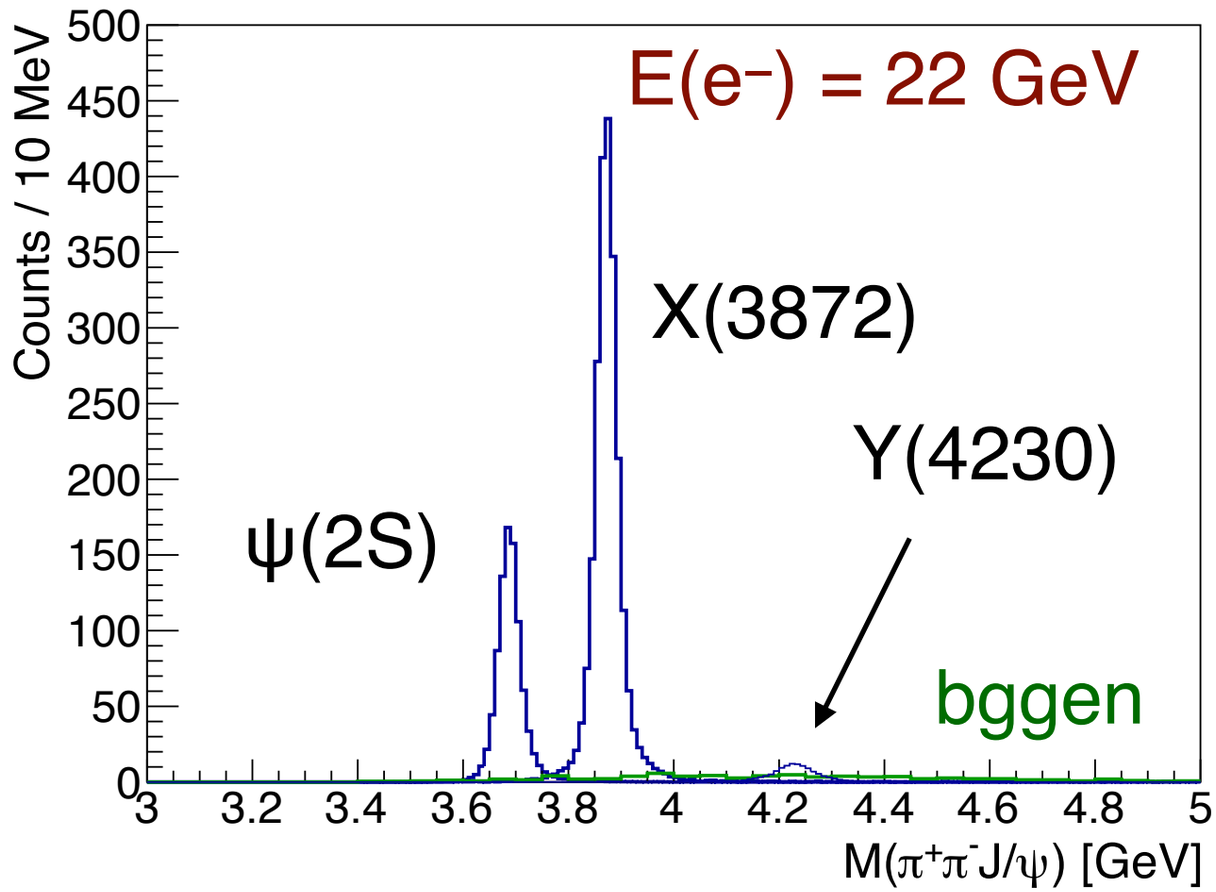




- n.b.: ε(J/ψ→e⁺e⁻) ≈ 15 – 20 %

Projections for $J/\psi\pi\pi$ Photoproduction

$\gamma p \rightarrow J/\psi\pi^+\pi^- p$, $J/\psi \rightarrow e^+e^-$



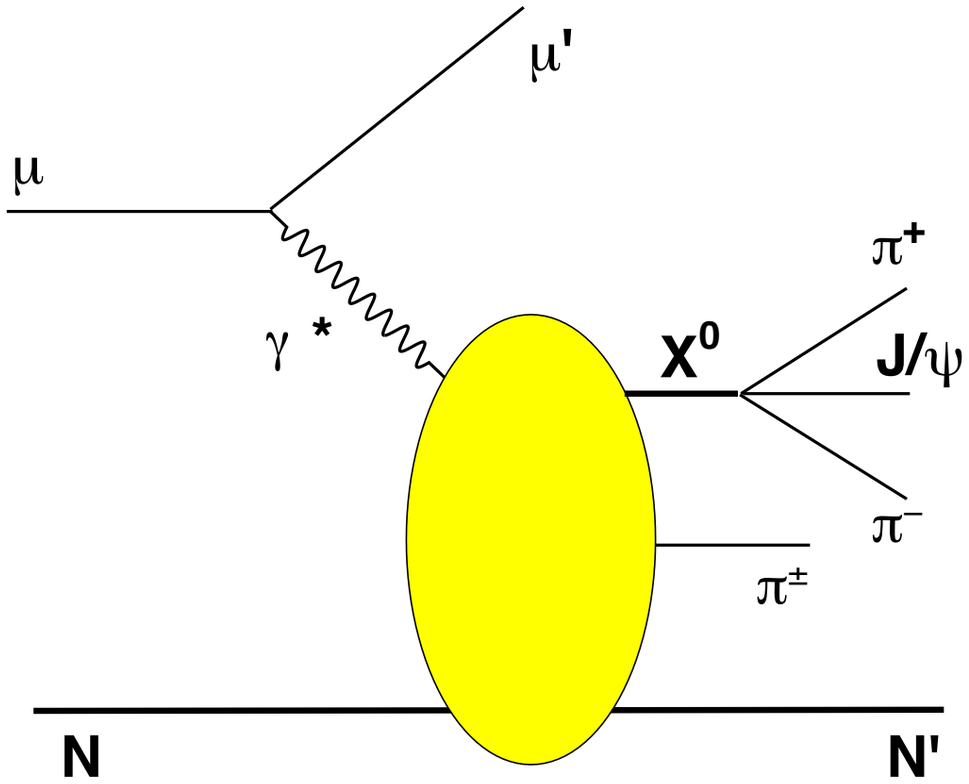
- Br(X,Y→ $\pi^+\pi^- J/\psi$) = 5%
- 1 year@500 pb^{-1} : N(ψ(2S)) = 900, N(X(3872)) = 2300, N(Y(4260)) = 120
- **With GlueX-III baseline (1 fb^{-1}/year): All numbers doubled**

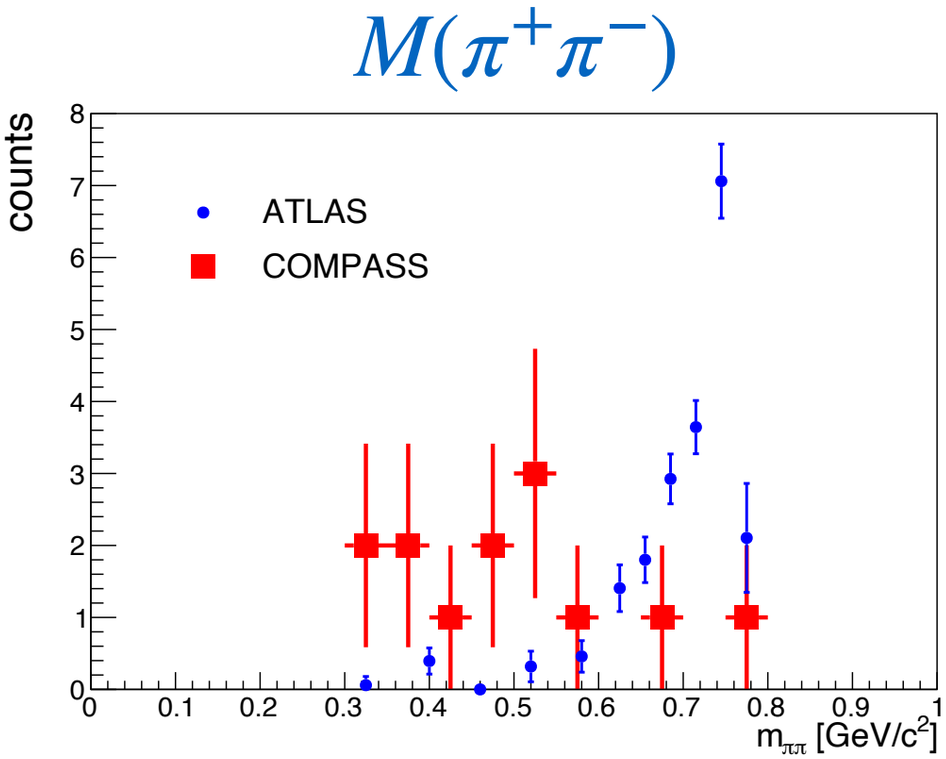
Background Estimation from COMPASS?

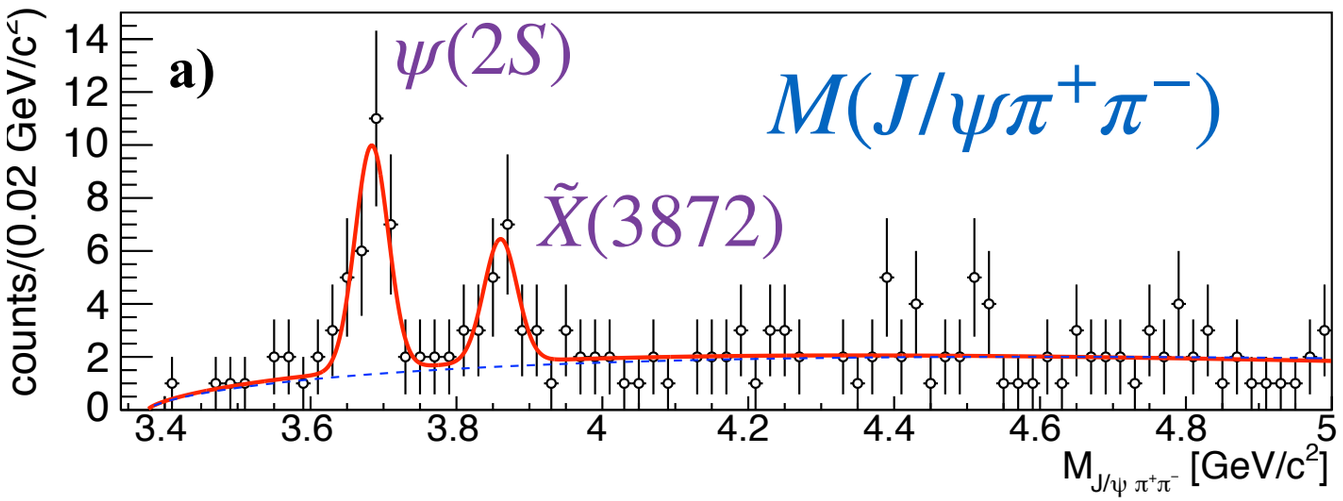
- Can we estimate backgrounds from other measurements?

$$\mu^+ N \to \mu^+ (J/\psi \pi^+ \pi^-) \pi^\pm N'$$

160/200 GeV/c μ^+ on ^{6}LiD or NH_3







COMPASS, PLB 783, 334 (2018)

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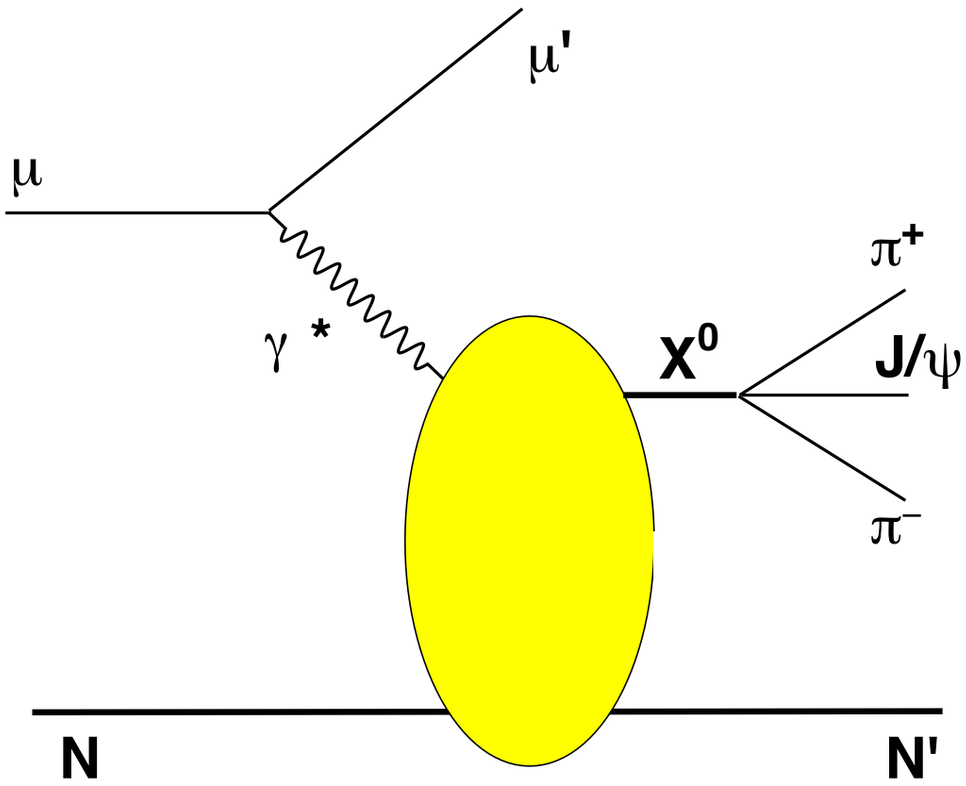
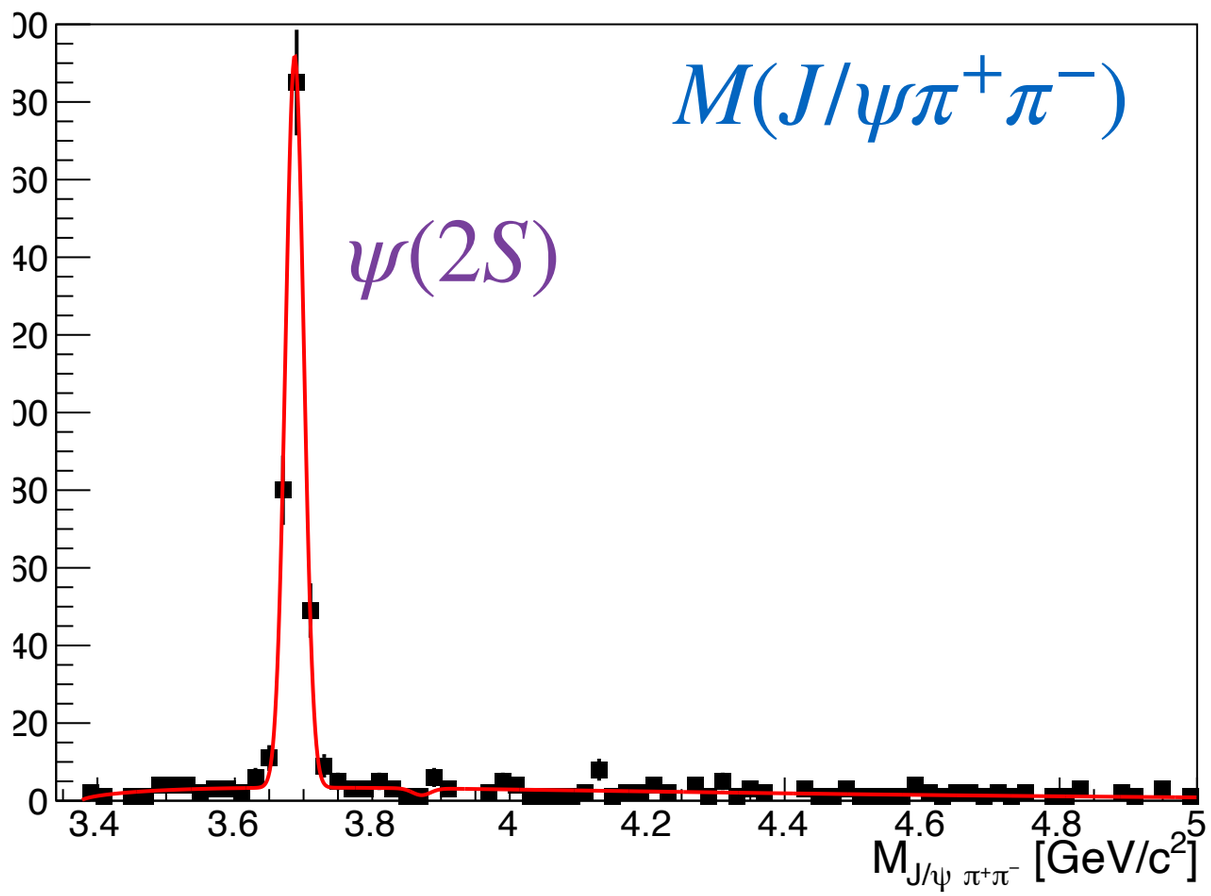




Source of background is unclear (physics / experimental?)

Contribution of double-reggeon exchange processes…?

—> **Need guidance from theory**

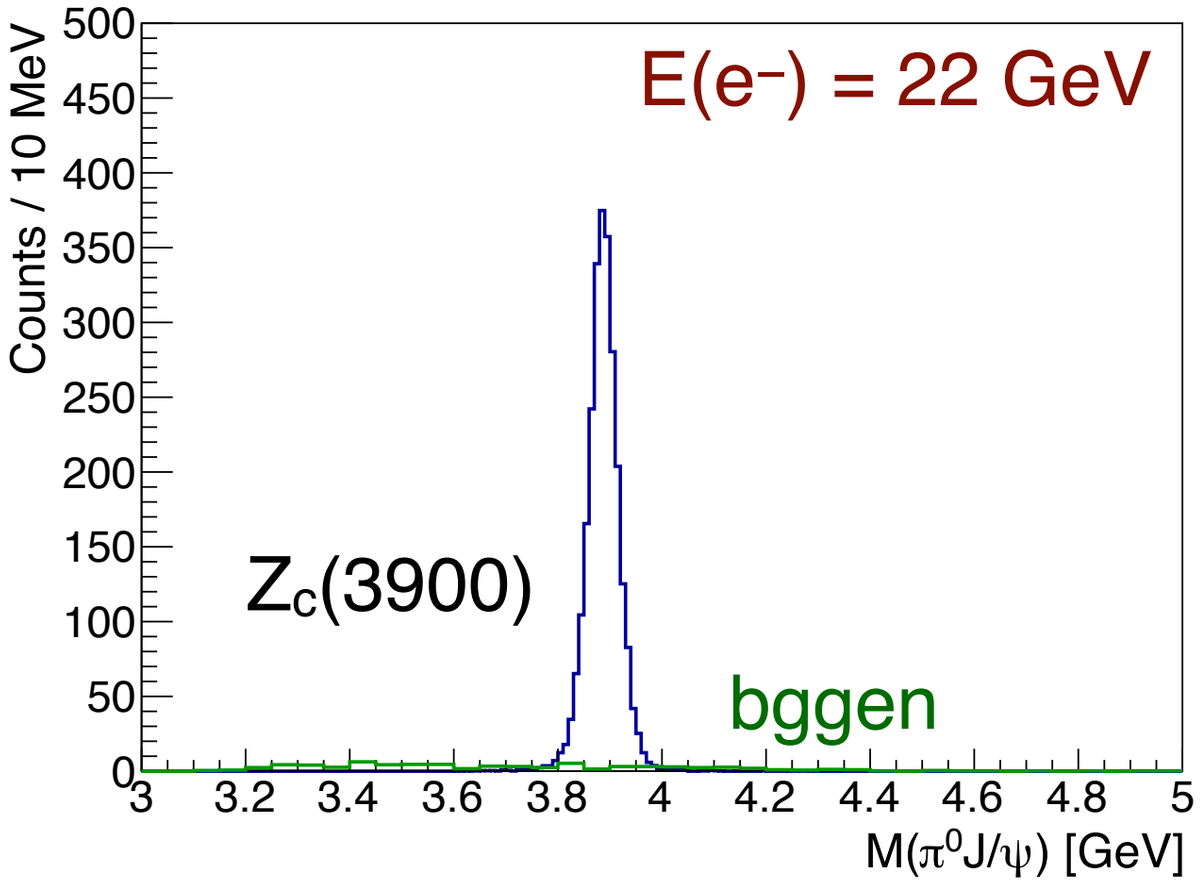
COMPASS, PLB 783, 334 (2018)

Open Charm Channels…?

- Example: $X(3872) \rightarrow D^0\overline{D}^0\pi^0$
  - Branching fraction: ~ 45%
  - Final state: $K^+K^-\pi^+\pi^-\pi^0 p$
  - Efficiency: ~8% (similar to $\pi^+\pi^- J/\psi$ channel)
- Projection taking into account Branching Fractions:
  - 1 year@500 pb^{-1} : N(X(3872)->DDpi) = 600
  - **With GlueX-III baseline (1 fb^{-1}/year): N = 1200**
- This seems feasible - background level to be addressed
- Simulations pending!

Projection for $J/\psi\pi^-$ Photoproduction

$\gamma p \rightarrow J/\psi\pi^0 p$, $J/\psi \rightarrow e^+e^-$



- Br($Z^0 \rightarrow \pi^0 J/\psi$) = 5%
- 1 year @ 500 pb^{-1}: N[$Z_c(3900)$, $J/\psi\pi^0$] = 2500
- **With GlueX-III baseline (1 fb^{-1}/year): All numbers doubled**
- Assume same cross section as $\gamma p \rightarrow Z_c^+ n$ as upper limit
  Can clearly extract signals an order of magnitude smaller

- **Simulations for $\gamma p \rightarrow Z_c^- \Delta^{++} \rightarrow (J/\psi\pi^-)(p\pi^+)$ underway, expecting similar rates!**

Summary

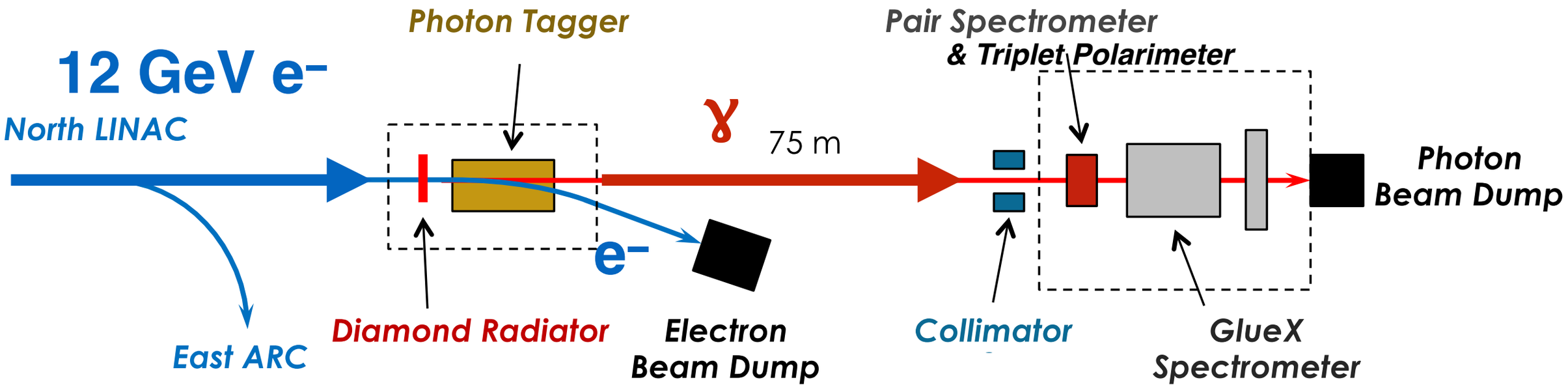
- Measuring XYZ states in photoproduction is a “new” - inherently interesting to study nature of these states
- Baseline GlueX detector can cleanly identify interesting samples of well-known XYZ states in decays containing J/ψ’s
  - Benchmark for lesser understood XYZ states, potential improvements for higher luminosity running
  - Expected detector upgrades: FCAL-II, forward GEM-TRD
- **Opens path to precision XYZ spectroscopy at GlueX**
  - Next steps include study of polarization observables to determine the microscopic structure of these states, alongside guidance from theory
  - Measurement of open-charm decay modes seem feasible

Backup

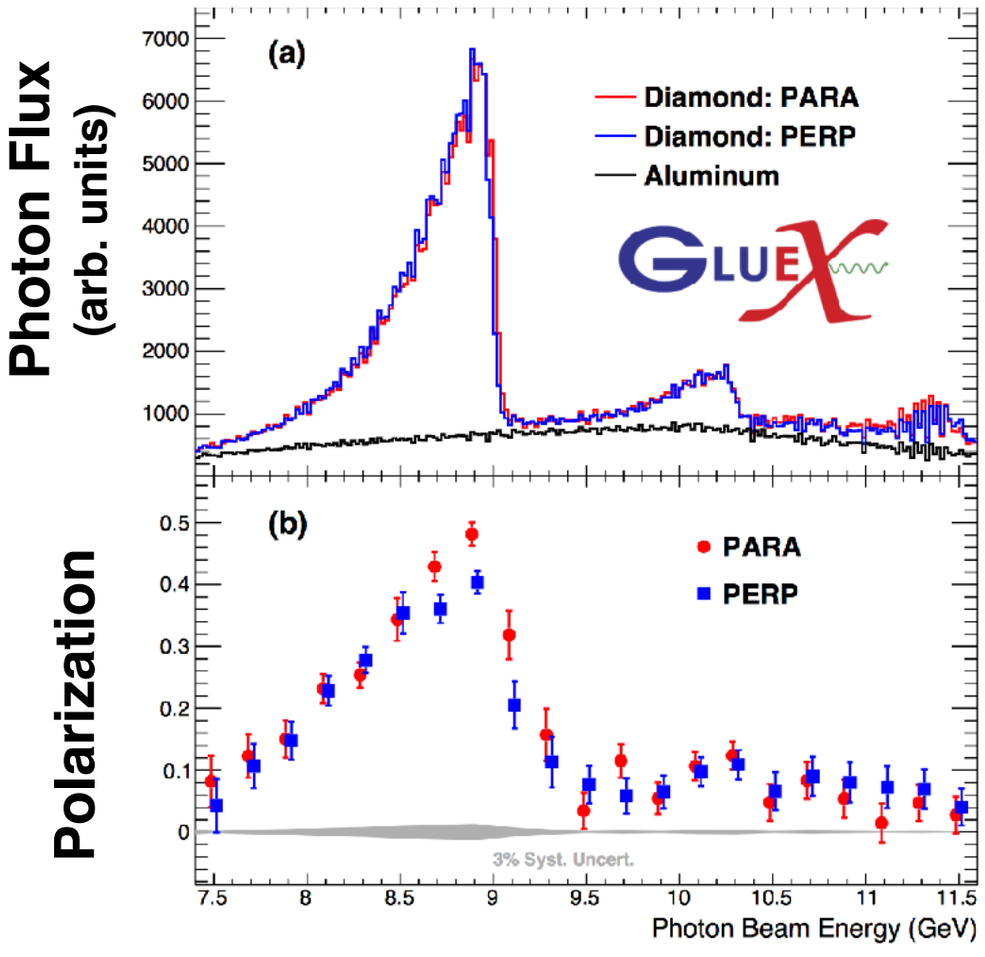
Light hadron spectroscopy at GlueX at higher energies

- At higher beam energies, GlueX can continue to support a rich program of light hadron spectroscopy
- Potential benefits:
  - Higher linear polarization (up to ~80%) leads to large increase in polarized FOM for PWA (P^2L)
  - Better kinematic separation between mesons / baryons, etc.
    - Kinematic fit works well to improve mass resolution
    - Can study beam energy dependence of hybrid xsecs, etc.
- Potential challenges:
  - Impact of larger momentum tracks needs to be evaluated
    - Effect on resolution and pion/kaon separation
  - Impact on efficiency

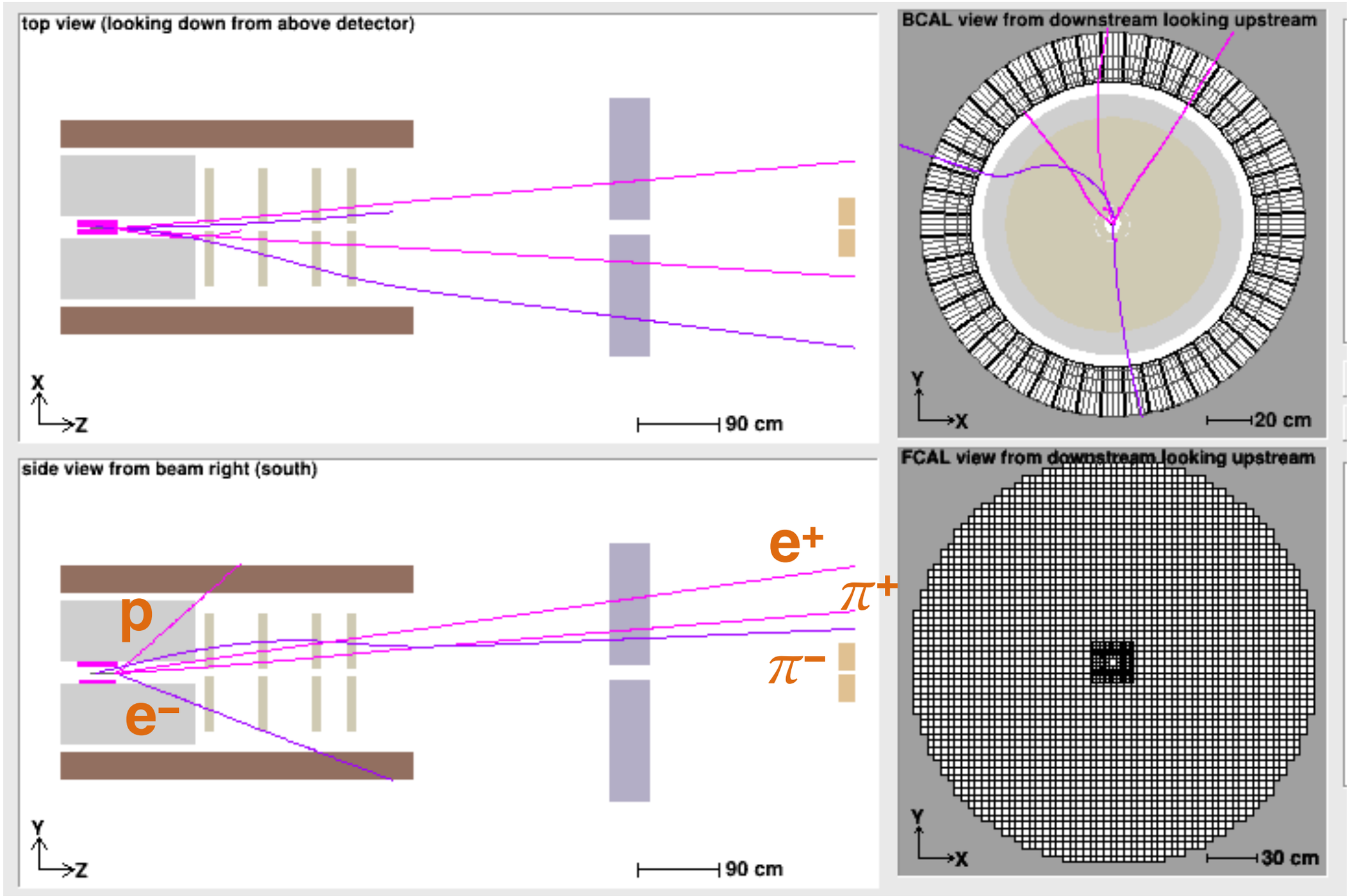
GlueX: Photon Beam



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



Example $\gamma p \rightarrow X(3872)p$, $X \rightarrow \pi^+\pi^- J/\psi$ event



- All reaction products well within GlueX acceptance