Recent (and future) GlueX results on threshold charmonium photoproduction Lubomir Pentchev (GlueX Collaboration)



 $\gamma p \rightarrow J/\psi p \rightarrow e^+e^-p$ using linearly polarized photon beam in Hall D at JLab

- Recent J/ψ results and the gluonic properties of proton experimental view
- Higher-mass charmonium states: C-even charmonium photo production
- Prospects with CEBAF energy upgrade using GlueX detector

Uniqueness of exclusive threshold charmonium photoproduction - relation to gluonic properties of proton (see Z.-E. Meziani's talk



To access proton gluonic properties (gluon Gravitational Form Factors (gGFF), D-term, mass radius of proton) assume:

- J/ψ -nucleon interaction at threshold dominated by gluon exchange
- Factorization
- Amplitudes are related to gGFF

Such program requires detailed studies of the reaction mechanism to justify these assumptions - experimental view

GlueX results: total and differential cross-sections $\gamma p \rightarrow J/\psi p \rightarrow e^+e^-p$



- σ_{tot} increasing with energy approximately following the phase space

except:

• Possible structure in $\sigma(8.6 - 9.6 GeV)$, the statistical significance of the two "dip" points is 2.6σ ; if include look-elsewhere effect - 1.3σ • Exponentially/falling *t*-dependence Except:

• Enhancement of $d\sigma/dt$ at high t (for the lowest energy slice), indicates contribution beyond gluon exchange

Gravitational Form Factors - J/ψ -007 & GlueX

GPD analysis by Guo, Ji, Liu, Yan arXiv:2305.06992, Guo, Ji, Liu, Yan arXiv:2305.06992 In high- ξ region: leading GPD moments related to gluon GFF global fit of both Hall C & D $d\sigma/dt(t)$:



GPD factorization models



Ivanov, Sznajder, Szymanowski, Wagner (2022)

- GPD LO calculations
- Big uncertainties in NLO, data can help to constrain gluon GPDs

Guo, Ji, Liu, Yang arxiv:2305.06992 (2023), in $m_c \rightarrow \infty$ limit, $\xi \rightarrow 1$ expansion (Hatta,Strikman 2021)



Other reaction mechanisms: open-charm, 5q exchange







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Phenomenological approach: JPAC results



JPAC arxiv:2305.01449 (2023) Global fit of both Hall C & D $d\sigma/dt(t)$ and Hall D $\sigma_{tot}(E_{\gamma})$ Phenomenological model based on s-channel PW expansion ($l \leq 3$):

- (1C) $J/\psi p$ interaction
- (2C) $J/\psi p$ and $ar{D}^*\Lambda_C$
- (3C-NR) $J/\psi p$, $\bar{D}\Lambda_C$, $\bar{D}^*\Lambda_C$ (non-resonant solution)
- (3C-NR) $J/\psi p$, $\bar{D}\Lambda_C$, $\bar{D}^*\Lambda_C$ (resonant solution)

No stat. significant preference:

- 9 GeV structure requires sizable contribution from open charm
- Severe violation of VMD and factorization not excluded
- s-channel resonance not excluded
- t-enhancement indicates schannel contribution: due to proximity to threshold or opencharm exchange

Threshold J/ψ photoproduction - summary

- Differential cross sections for $|t| < 3 \ GeV^2$ generally consistent with gluon exchange; enhancement at higher |t| indicates contribution beyond t-channel
- Total cross section is consistent with some GPD models assuming factorization; the structure at 9 GeV, if statistically significant, require sizable contribution from open-charm exchange (or s-channel resonance), that will obscure the relation to the proton gluonic properties.

Precise measurements are critically important to disentangle the reaction mechanisms and study mass properties of proton:

- GlueX (4π acceptance; full coverage of near-threshold region)
 - expect x4 in phase-II if running with the same intensity
 - test running with x3 higher intensity, submitted LOI
- Hall B: projections with existing data show similar statistics as with GlueX-phase-I (see P. Chatagnon's talk on Monday)
- SoLID: the ultimate J/ψ factory, including electroproduction (2π acceptance, may not have full near-threshold coverage, limited by 11GeV beam energy)
- JLab energy upgrade last part of this talk
- EIC (see Z.-E. Meziani's talk on Monday)

C-event charmonium states at threshold with GlueX

 $\gamma p \rightarrow \chi_c p \rightarrow (J/\psi \gamma) p \rightarrow (e^+ e^- \gamma) p$



First ever evidence for photoproduction of C-even charmonium

C-even charmonium states with GlueX C-odd $(J/\psi, \psi')$ vs C-even (η_c, χ_c) production



Dumitru, Skokov, Stebel, PRD 101 (2020), Dumitru, Stebel, PRD 99 (2019)



 High energies - perturbative calculation - Odderon (odd-parity Pomeron) 3g exchange



• Low energies - non-perturbative approach, vector meson exchange

C-even charmonium states with GlueX C-odd $(J/\psi, \psi')$ vs C-even (η_c, χ_c) production

• Dramatic difference: χ_c distribution in (E_{γ}, t) w.r.t. J/ψ



At threshold other possible mechanisms may dominate:

S-channel exchange of 5q



Open-charm exchange



Hall D Apparatus with 17+ GeV electron beam



Moving end point from 12 GeV to 17+ GeV:
 - higher flux (and polarization) toward higher energies, while low energies less affected (no load on detectors)

Charmonium polarization measurements at 22 GeV







Any deviation from the expected (via gluon exchange) naturality indicates contribution of mechanism different from what is needed to study mass properties of the proton

Conclusions

- The recent JLab total and differential cross sections of J/ψ photoproduction near threshold are generally consistent with gluon exchange (t-slope, GPD factorization), except some features consistent with open charm exchange or other s-channel contribution.
- It is important to separate between the gluon exchange, open-charm exchange, or any other contribution (resonances (P_c 's), u-channel) and possibly find a kinematic region that can be used to constrain gGPDs, extract proton GFFs and study mass properties of proton. Need precise data!
- First ever evidence for C-even charmonium photoproduction important tool to understand reaction mechanism, complementary to J/ψ (C-odd charmonium) studies
- JLab energy increase would be critical in understanding the charmonium photoproduction near threshold and justify this reaction as a method to study mass properties of the proton



Differential cross sections from J/ψ -007 and GlueX



- 10 energy bins in J/ψ -007
- Results for the three
 GlueX energy bins
 compared to closest Hall C
 (J/ψ-007) energies
- Scale uncertainties: 20% in GlueX and 4% in Hall C results
- Good agreement within the errors; note also differences in average energies

S.Adhikari et al. (GlueX), Phys. Rev. C 108, 025201

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