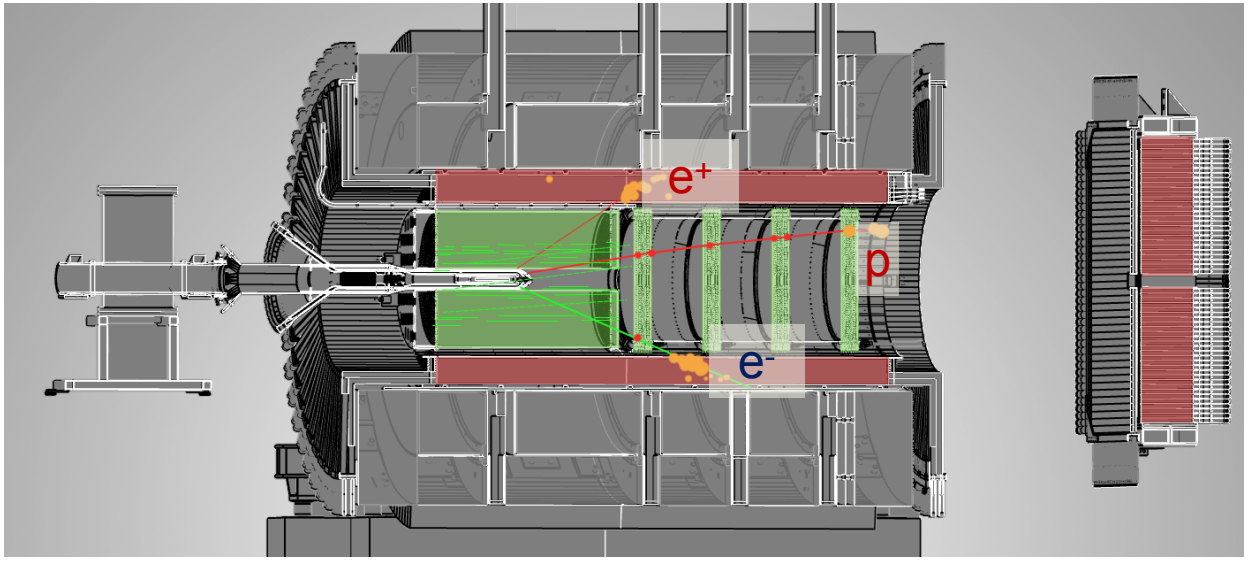
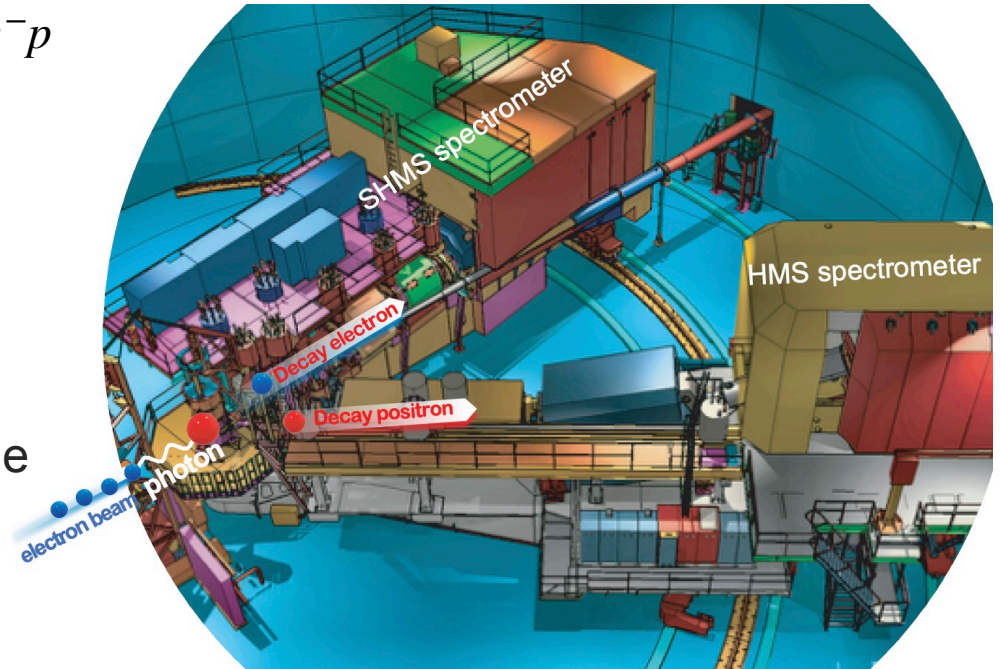
Recent (and future) JLab results on threshold charmonium photoproduction

Lubomir Pentchev
(GlueX Collaboration)



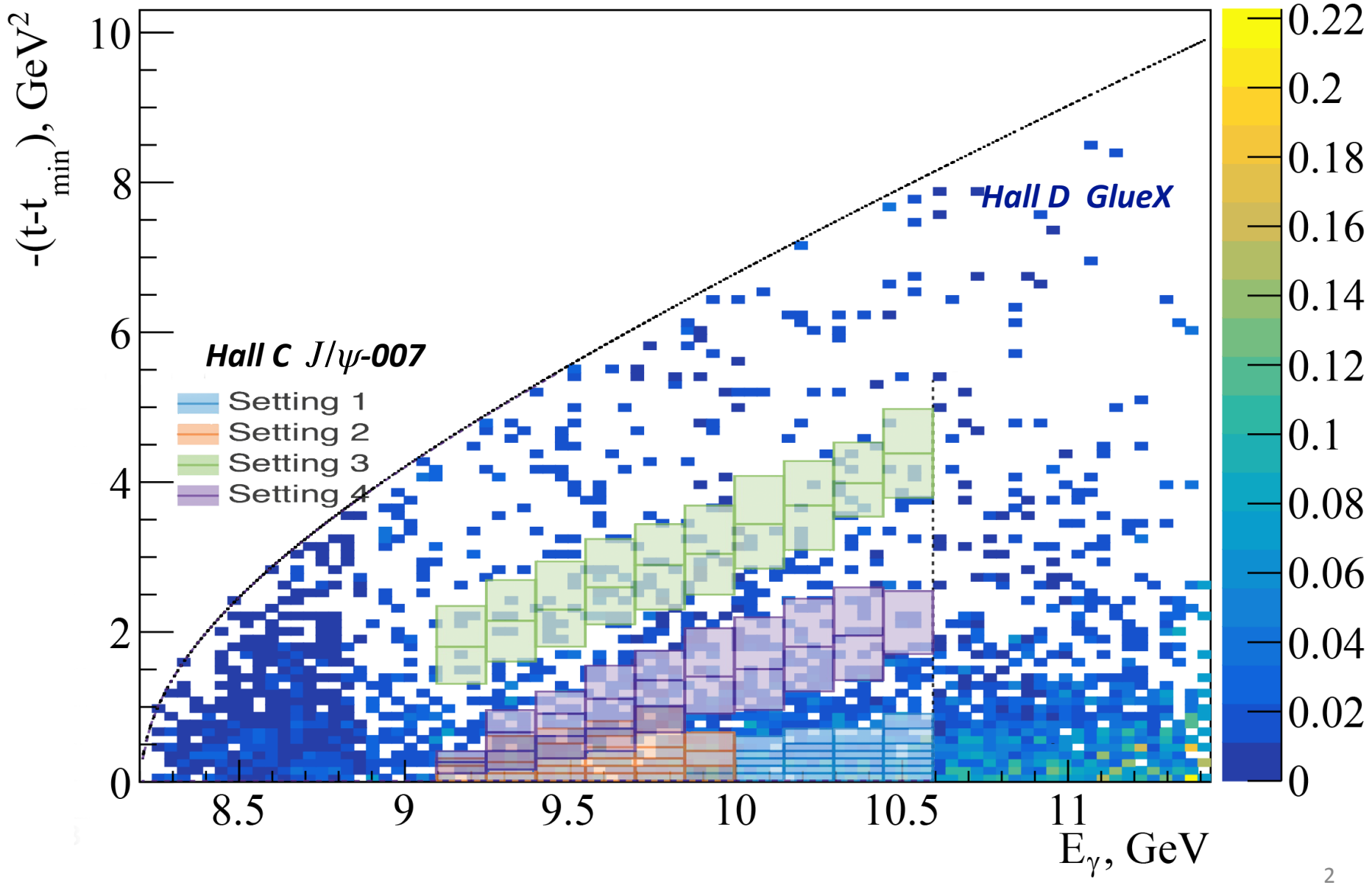
Hall D GlueX $\gamma p \to J/\psi p \to e^+e^-p$

Hall C J/ψ-007
$(\gamma)p \to J/\psi(p) \to e^+e^-(p)$

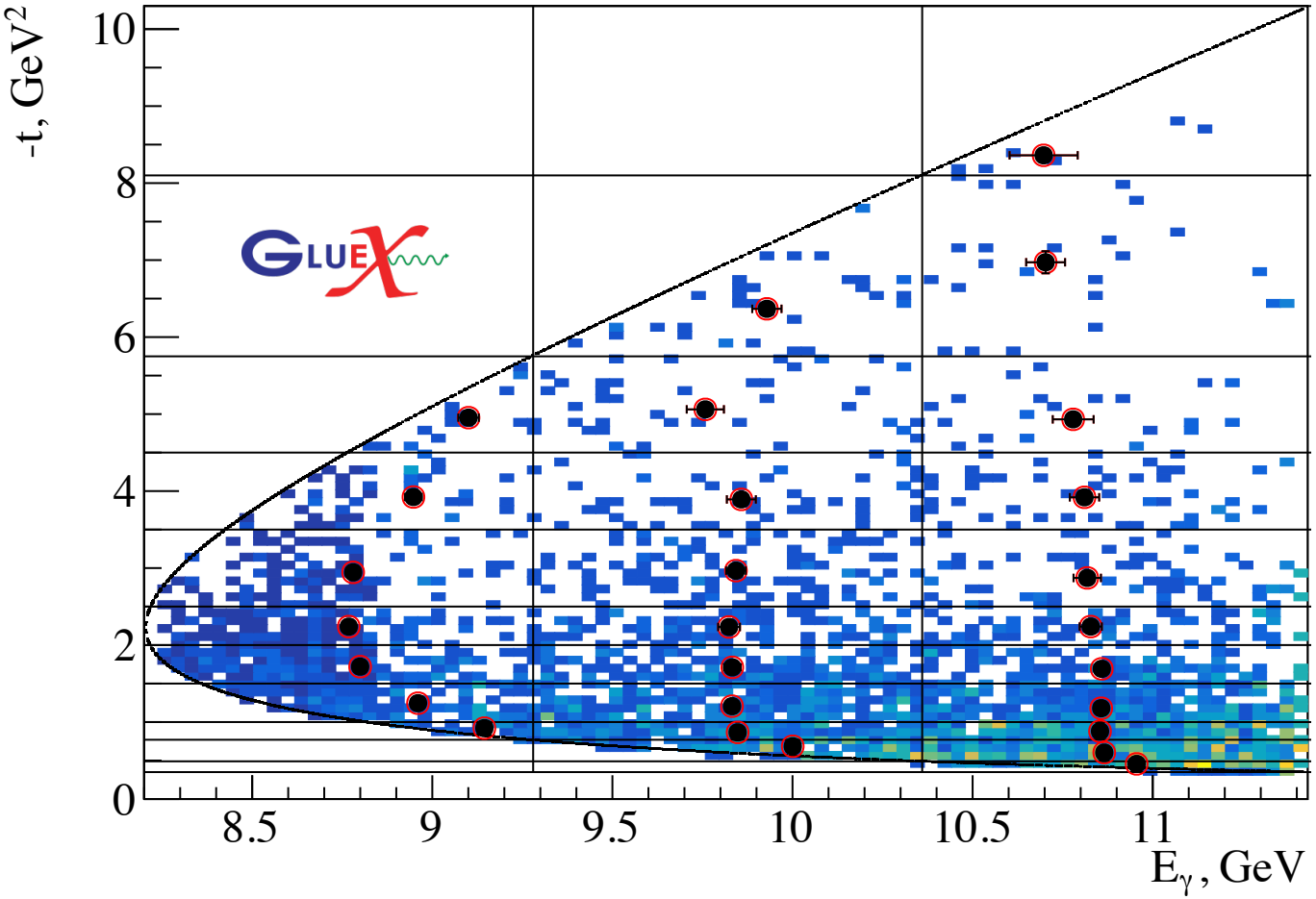


- Recent J/ψ results from Hall C & D
- … and their interpretation
- Higher-mass charmonium states and prospects with CEBAF energy upgrade using GlueX detector

J/ψ threshold region coverage

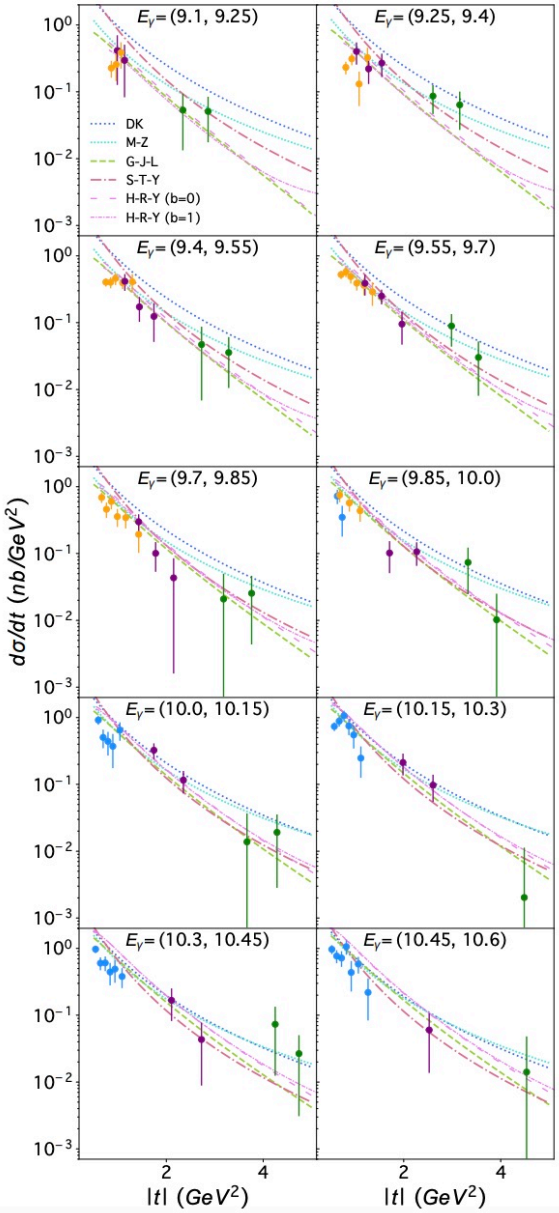


J/ψ threshold region coverage

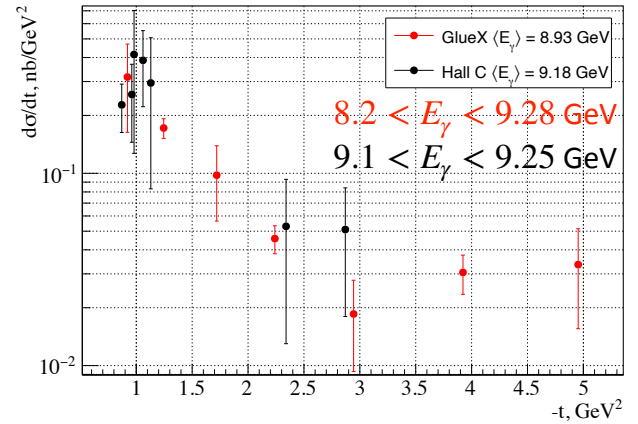


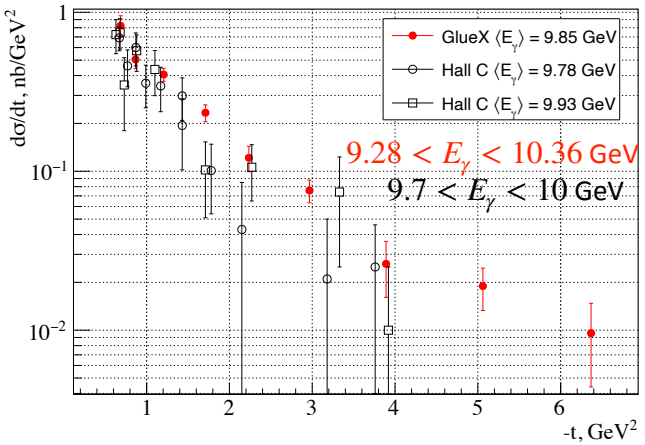
- Event-by-event weighting by luminosity
- Dots - mean energy and t-value for the corresponding bin
- Results reported at mean energy for corresponding slice
- Deviations due to bin averaging included in the systematic errors

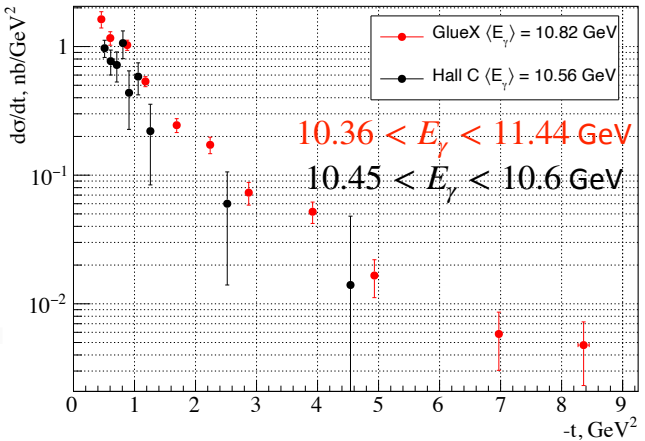
Differential cross sections from J/ψ-007 and GlueX



B. Duran et al. (J/ψ-007), Nature 615 (2023)



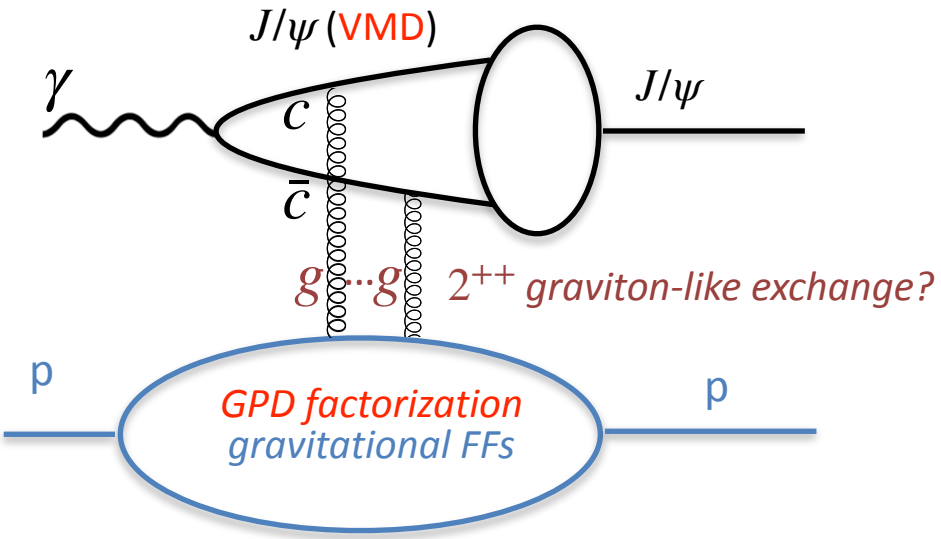


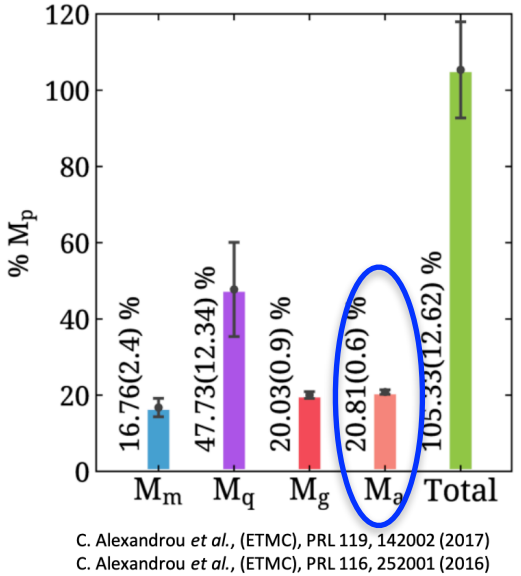


- 10 energy bins in J/ψ-007
- Results for the three **GlueX energy bins** compared to closest **Hall C (J/ψ-007) energies**
- Scale uncertainties: 20% in GlueX and 4% in Hall C results
- Good agreement within the errors; note also differences in average energies

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

Uniqueness of exclusive threshold charmonium photoproduction - relation to gluonic properties of proton



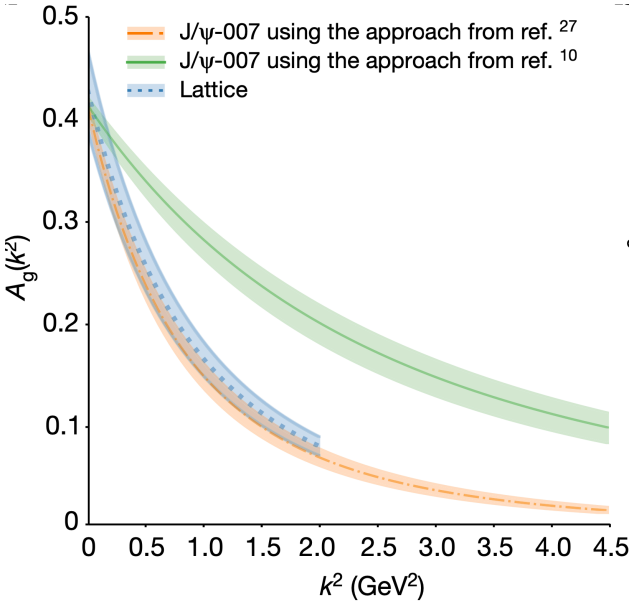


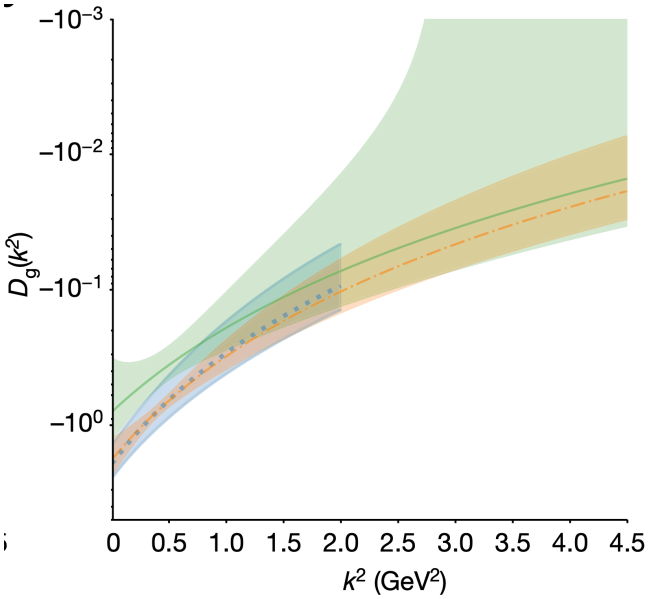
C. Alexandrou *et al.*, (ETMC), PRL 119, 142002 (2017)
C. Alexandrou *et al.*, (ETMC), PRL 116, 252001 (2016)

- J/ψ-nucleon interaction at threshold dominated by gluon exchange (*Brodsky Miller, Phys. Lett. B412 1997*) - considering light-meson and even open-charm exchange!
- VMD reduces $\gamma p \to J/\psi p$ to $J/\psi p \to J/\psi p$
- If $m_c \to \infty$ interaction via gluon exchange, at threshold sensitive to trace of EMT (*Kharzeev, Satz, Syamtomov, Zinovjev 1996-1999*) and its contribution to proton mass (*Ji 1995*)
- GPD factorization valid for $m_c \to \infty$ at threshold (*Gun, Ji, Liu 2021, Hatta, Strikman 2021*)
- t-dependance of the amplitudes related to gluon gravitational form factors, $A_g(t), B_g(t), C_g(t), \bar{C}_g(t)$ $\to$ mass radius of the proton, D-term (*Hatta, Kharzeev, Ji et al. 2018-2021*)

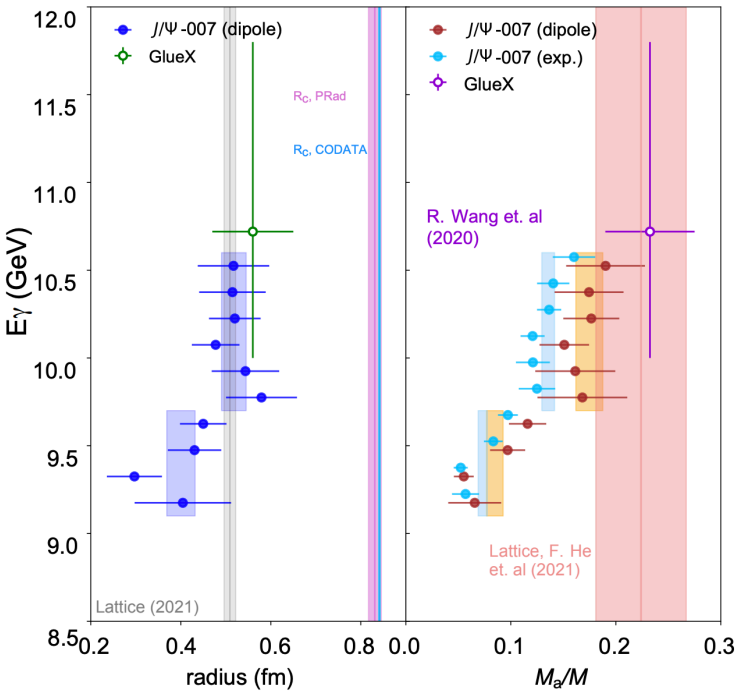
Such ambitious program requires detailed studies of the reaction mechanism to justify these assumptions.

Extracted Gravitational Form Factors - J/ψ-007





B. Duran et al. (J/ψ-007), Nature 615 (2023)



Global fit of all Hall C $d\sigma/dt$ data with 3 parameters, m_A, m_C, $C(0)$:

$$A_g(t) = \frac{A_g(0)}{(1 - t/m_A{}^2)^3}\,,\quad C_g(t) = \frac{C_g(0)}{(1 - t/m_C{}^2)^3},\quad D_g(t) = 4C_g(t)$$

($A_g(0)$ fixed from global DIS analysis) using two theoretical models:

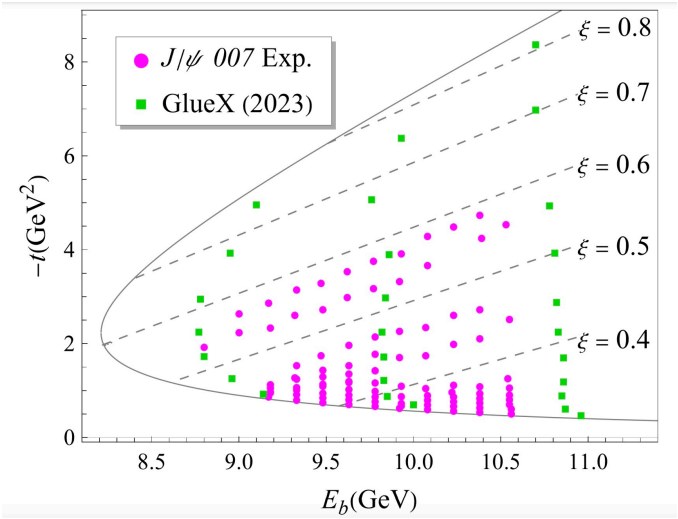
1) Guo, Ji, Liu PRD103 (2021), using GPD factorization in $m_c \to \infty$ limit, $\xi \to 1$ expansion (*Hatta, Strikman PLB817, 2021)*

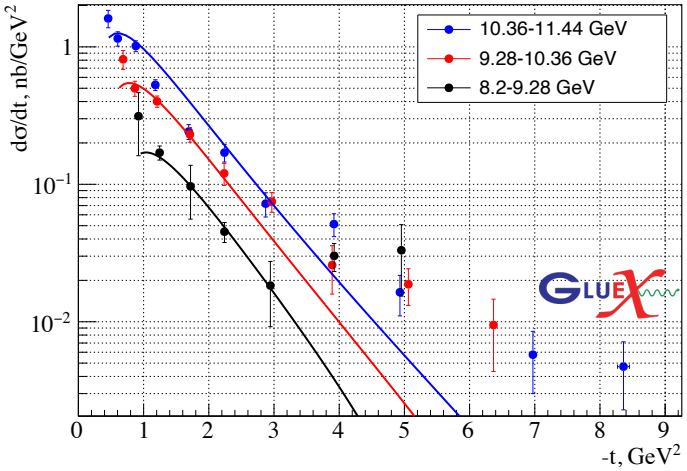
2) Mamo, Zahed PRD101 (2020), holographic QCD, $d\sigma/dt(t)$ directly related to GFF

Lattice calculations of GFF: Pefkou, Hackett, Shanahan PRD105 (2022)

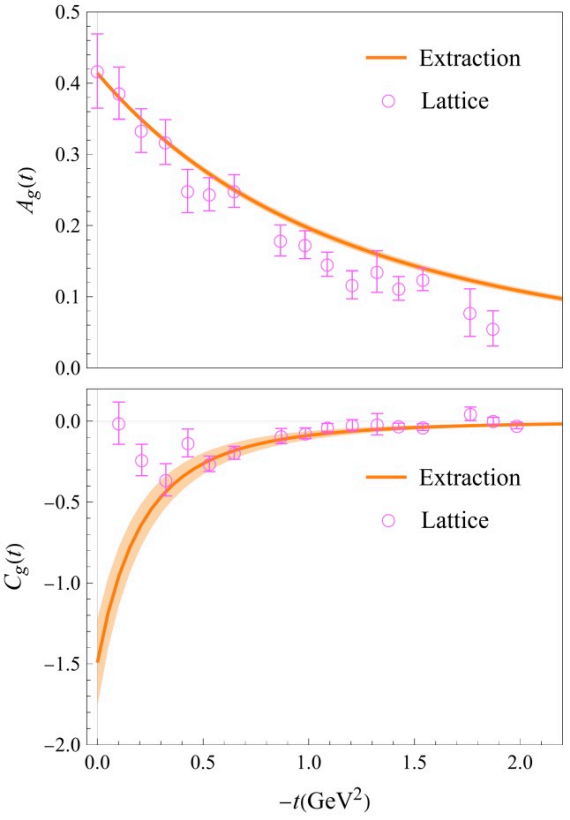
Extracted Gravitational Form Factors - J/ψ-007 & GlueX

Revised GPD analysis by Guo, Ji, Liu, Yan
arXiv:2305.06992 (2023), ξ expansion *valid for high* ξ
global fit of both Hall C & D $d\sigma/dt(t)$*:*

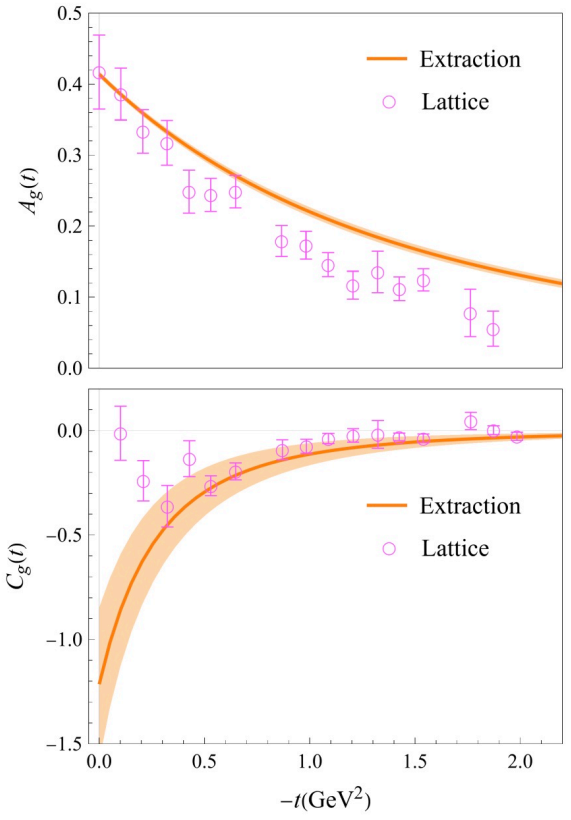




Fits to GlueX $d\sigma/dt(t)$ for all ξ values



all ξ

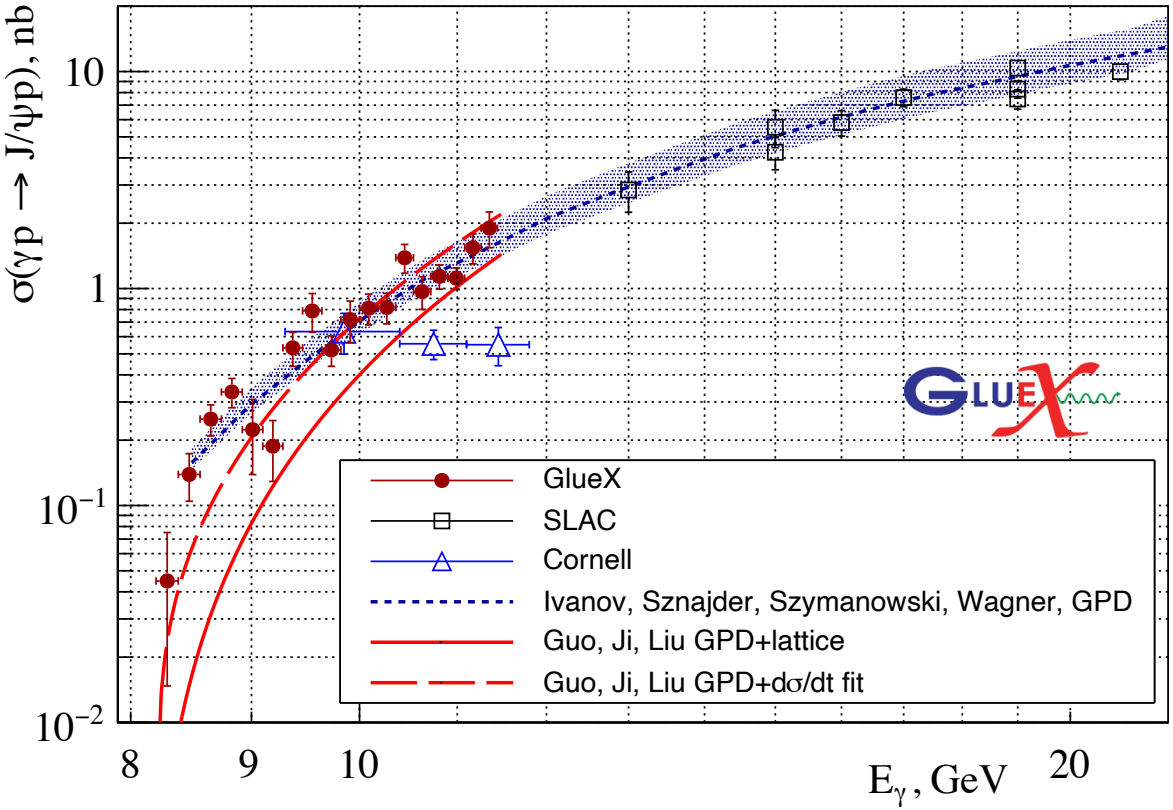


$\xi > 0.4$

$$D_g(0) = 4C_g(0) \approx -4.8$$

$$D_{u+d}(0) = -1.64 \pm 0.48$$ *(Hall B DVCS, Burkert arXiv:2303.08347)*

GPD factorization models

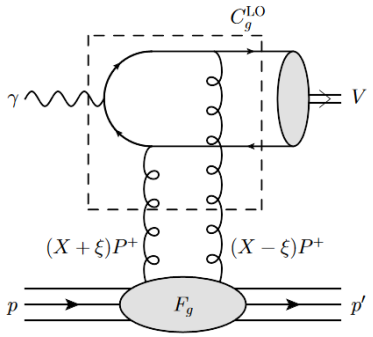


Ivanov, Sznajder, Szymanowski, Wagner (2022)

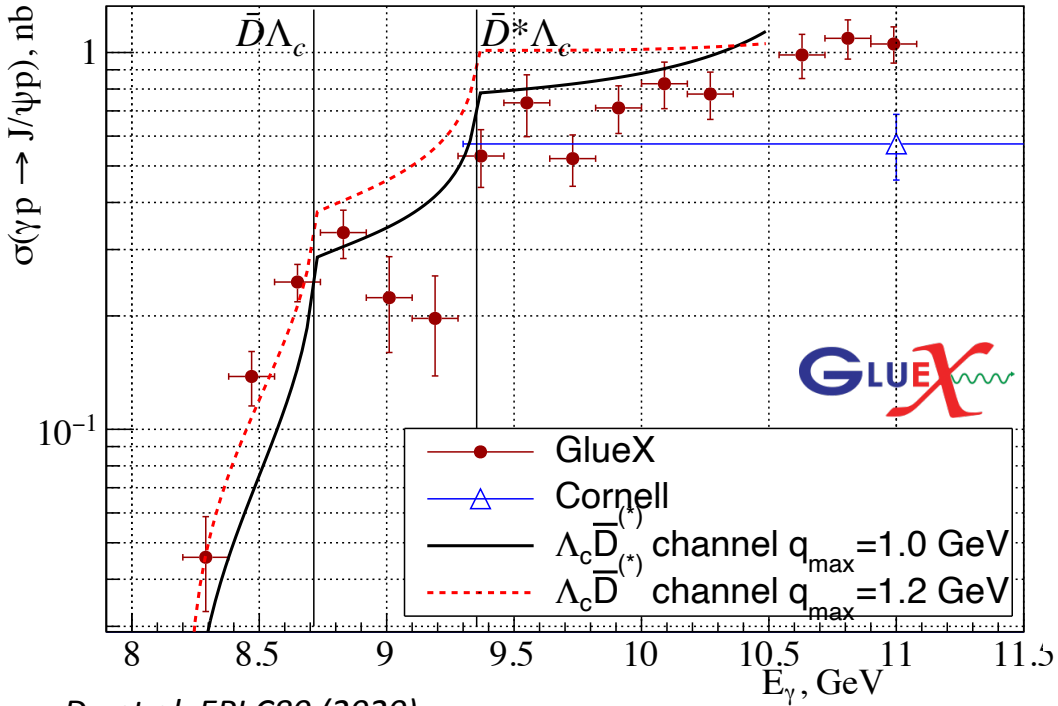
- GPD LO calculations
- Big uncertainties in NLO, data can help to constrain gluon GPDs

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

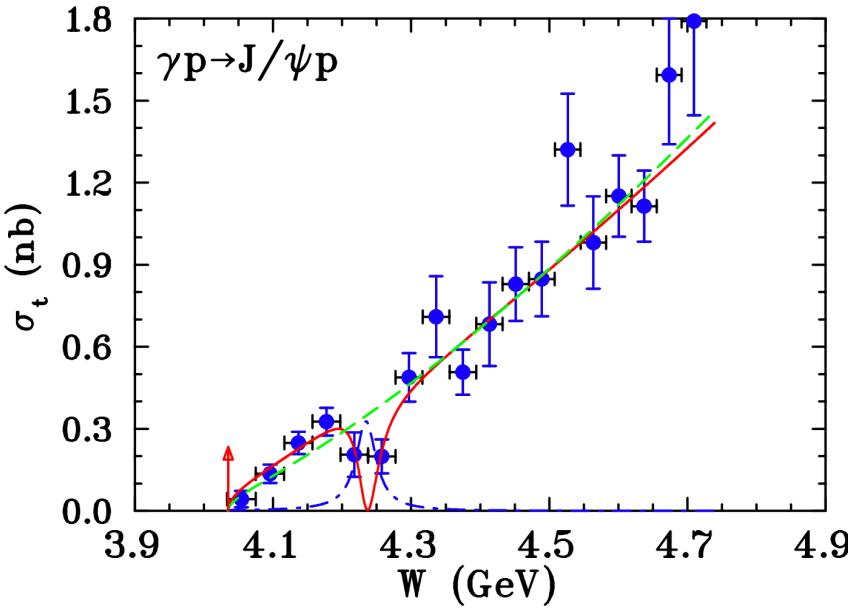
- factorization valid near threshold
- connection to gravitational FFs



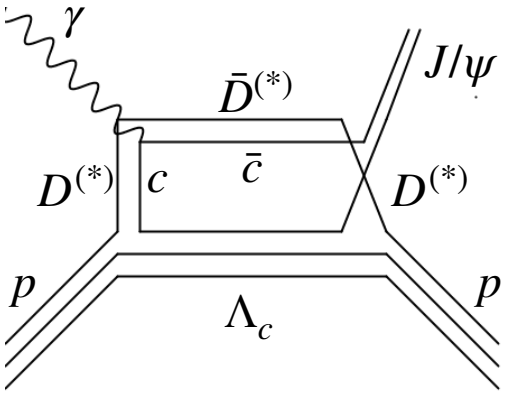
Other reaction mechanisms: open-charm, 5q exchange

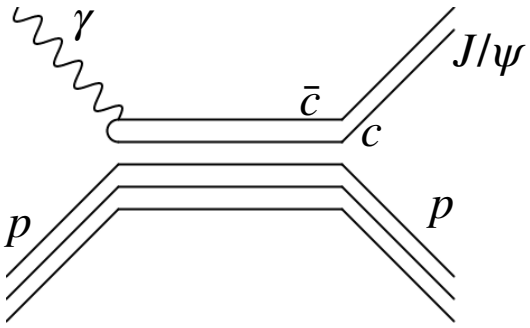


Du et al. EPJ C80 (2020)

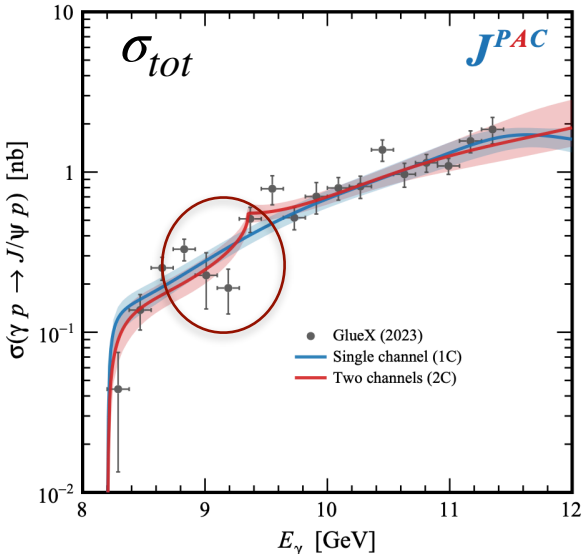


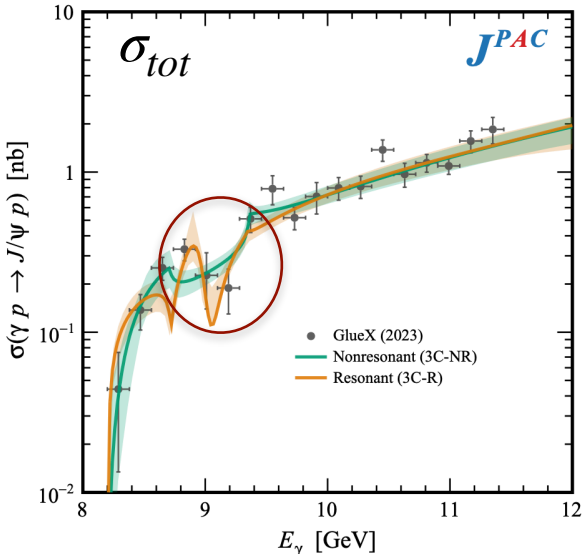
Strakovsky et al. PRC 108 (2023)

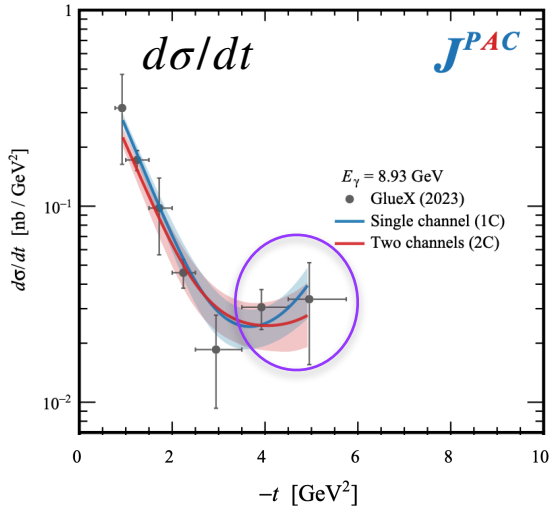


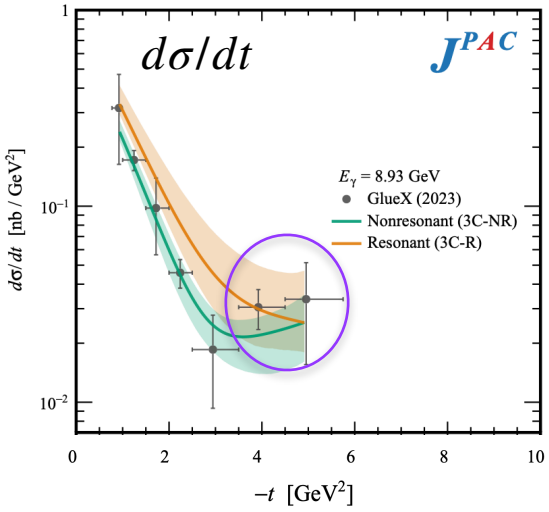


Gluon or charm exchange: JPAC interpretation









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 $\bar{D}^*\Lambda_C$
- (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 s-channel contribution: due to proximity to threshold or open-charm exchange

Threshold J/ψ photoproduction - summary

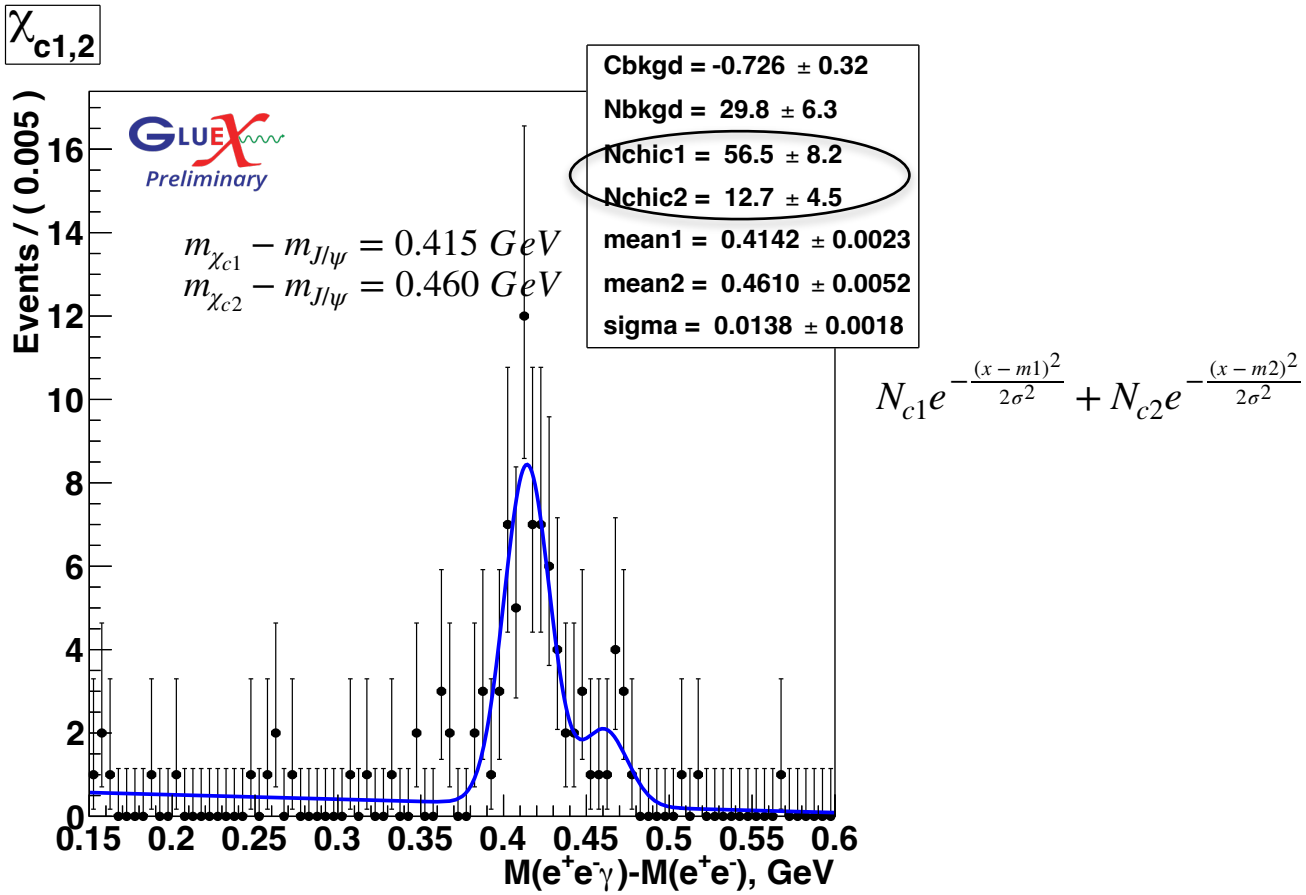
- Differential cross sections for $|t| < 3\ GeV^2$ generally consistent with gluon exchange, however enhancement at higher $|t|$ indicates contribution beyond t-channel
- Total cross section is consistent with some GPD models assuming factorization, however the structure at 9 GeV, if statistically significant, 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:
  - has on tape and started already analysis with x2 more statistics
  - assuming same running conditions expect another x2 for the rest of phase-II
  - test running with x3 higher intensity, submitted LOI (requires tagger modification)
- Hall B: projections with existing data show similar statistics as with GlueX-I, expect much more assuming CLAS12 luminosity upgrade
- SoLID: the ultimate J/ψ factory, including electroproduction (2π acceptance, may not have full near-threshold coverage with all final state particles detected, limited by 11GeV beam energy).

C-event charmonium states at threshold with GlueX

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

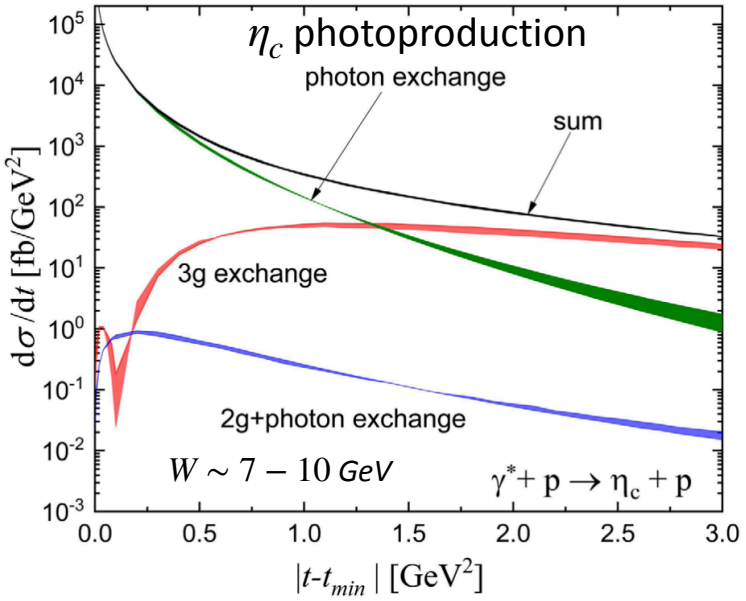


- $\chi_{c1}(3511)$ and $\chi_{c2}(3556)$, 1^{++} and 2^{++} $(1P)$, $E_\gamma^{thr} = 10.1$ GeV

First ever evidence for photoproduction of C-even charmonium

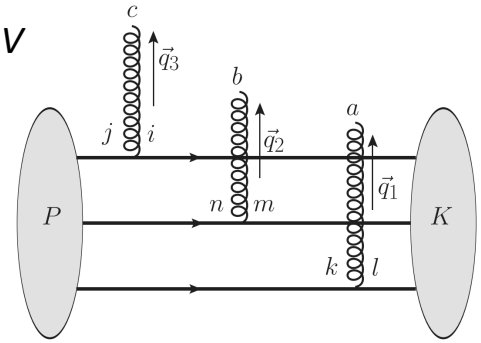
C-even charmonium states with GlueX

C-odd (J/ψ, ψ') vs C-even (η_c, χ_c) production

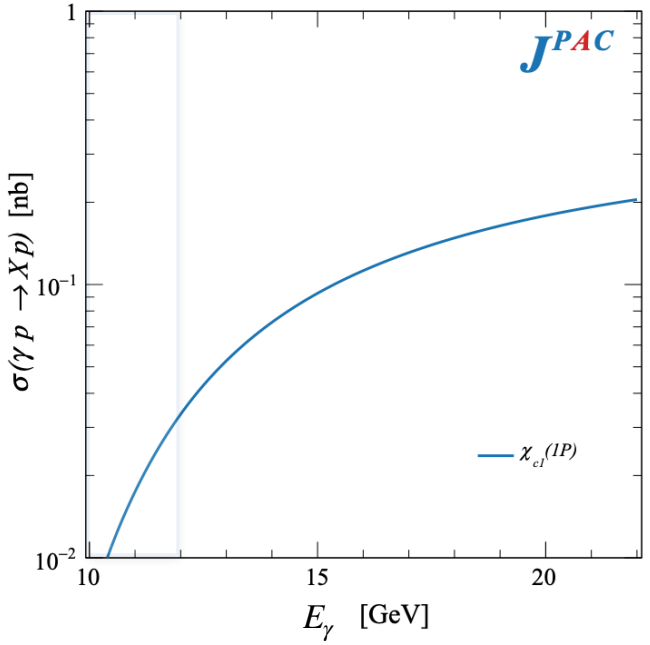


Dumitru, Skokov, Stebel, PRD 101 (2020), Dumitru, Stebel, PRD 99 (2019)

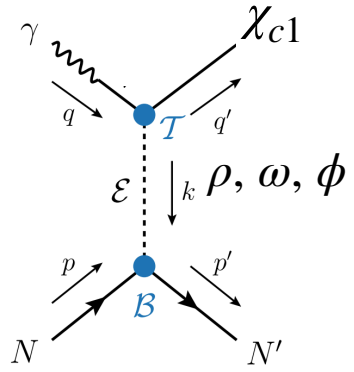
$W \sim 7 - 10$ GeV



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



JPAC, PRD 102 (2020)

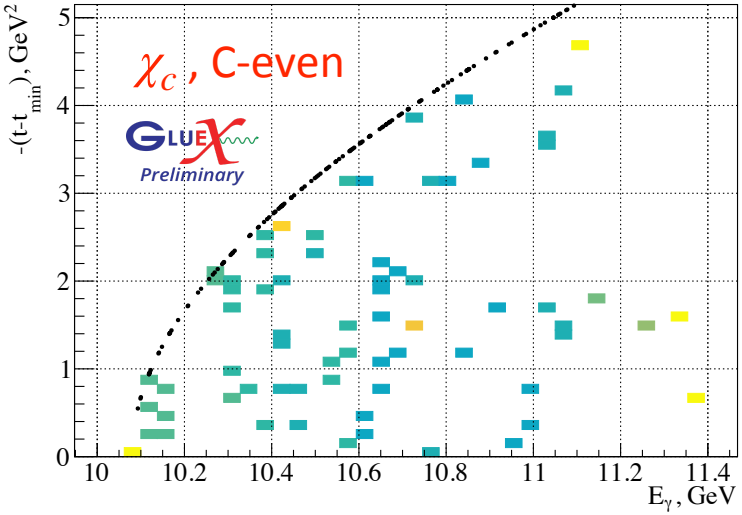


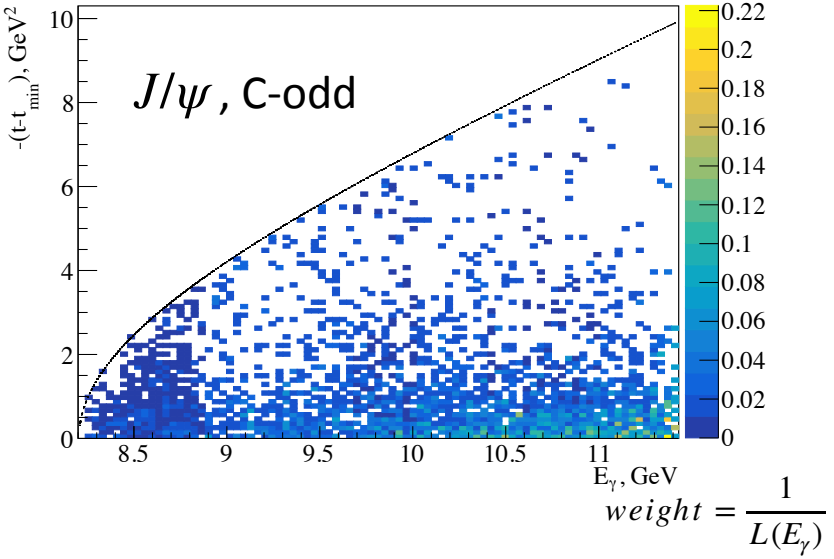
- Low energies - non-perturbative approach, vector meson exchange

C-even charmonium states with GlueX

C-odd (J/ψ, ψ') vs C-even (η_c, χ_c) production

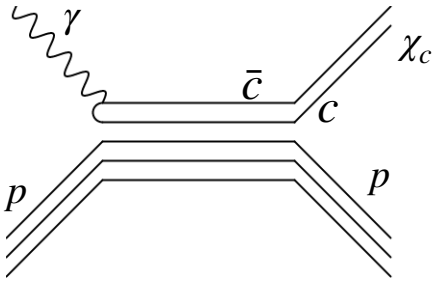
- Dramatic difference: χ_c distribution in (E_γ, t) w.r.t. J/ψ



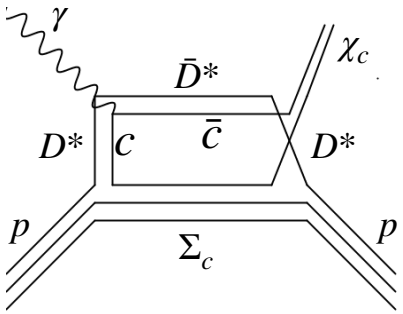


- At threshold other possible mechanisms may dominate:

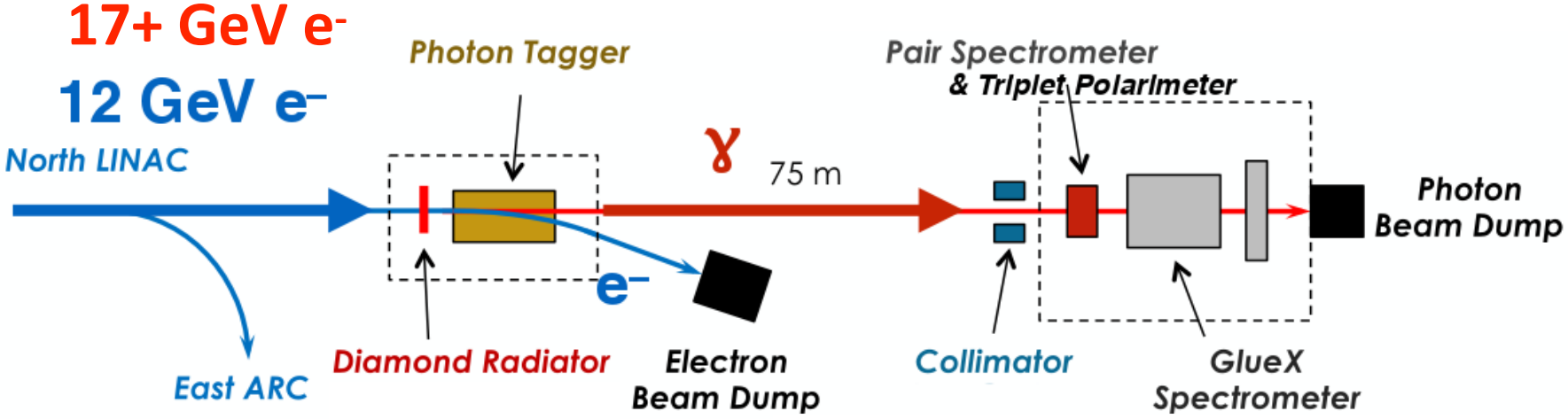
S-channel exchange of 5q

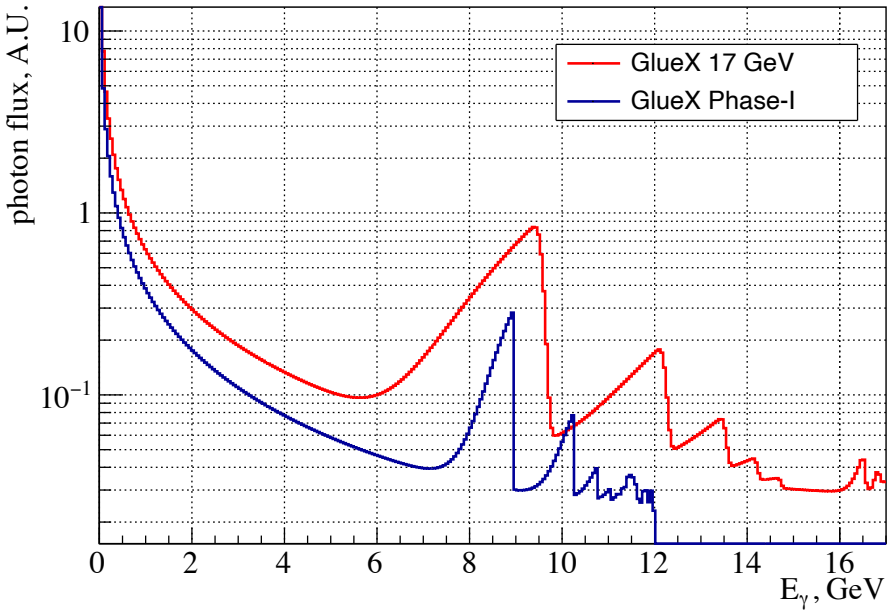


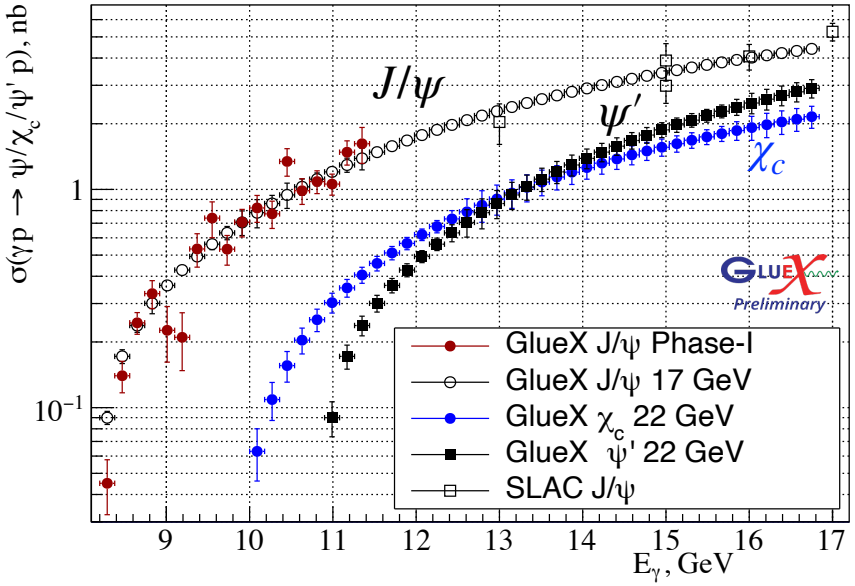
Open-charm exchange



Hall D Apparatus with 17+ GeV electron beam

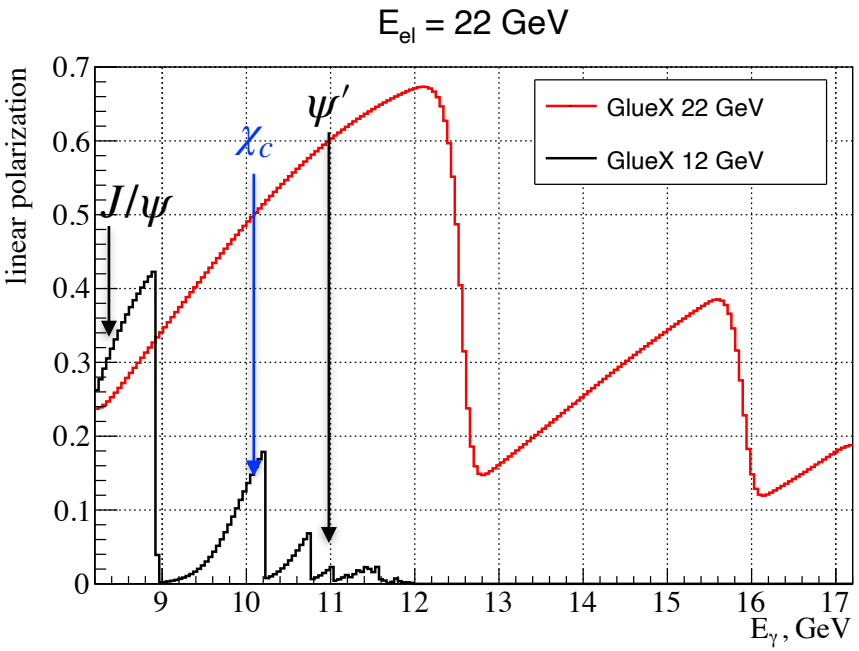




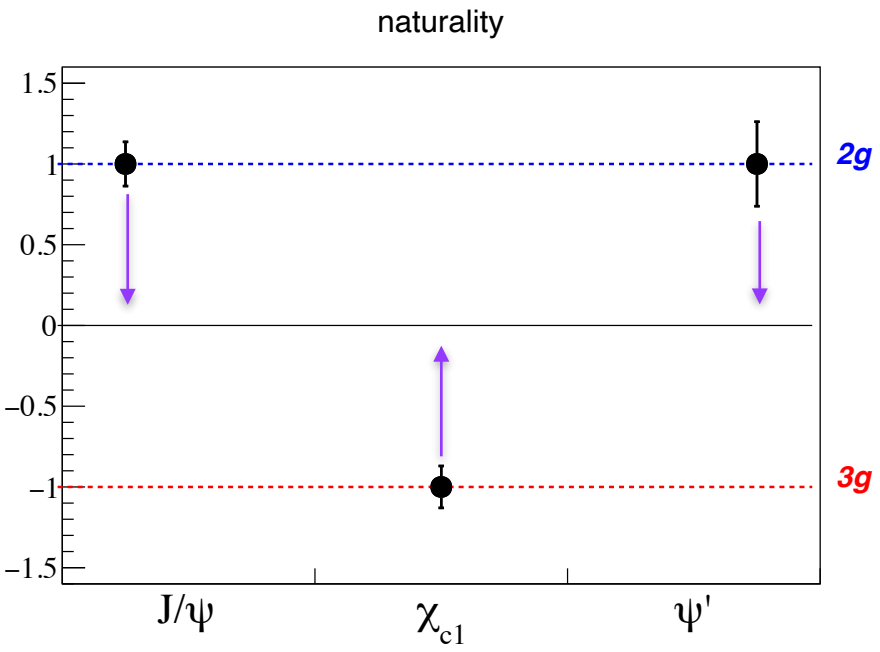


- Moving end point from 12 GeV to 17+ GeV:
  - higher flux (and polarization) toward higher energies, while low energies less affected (no load on detectors)

Charmonium polarization measurements at 22 GeV



$$naturality \times (-1)^J = P$$



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