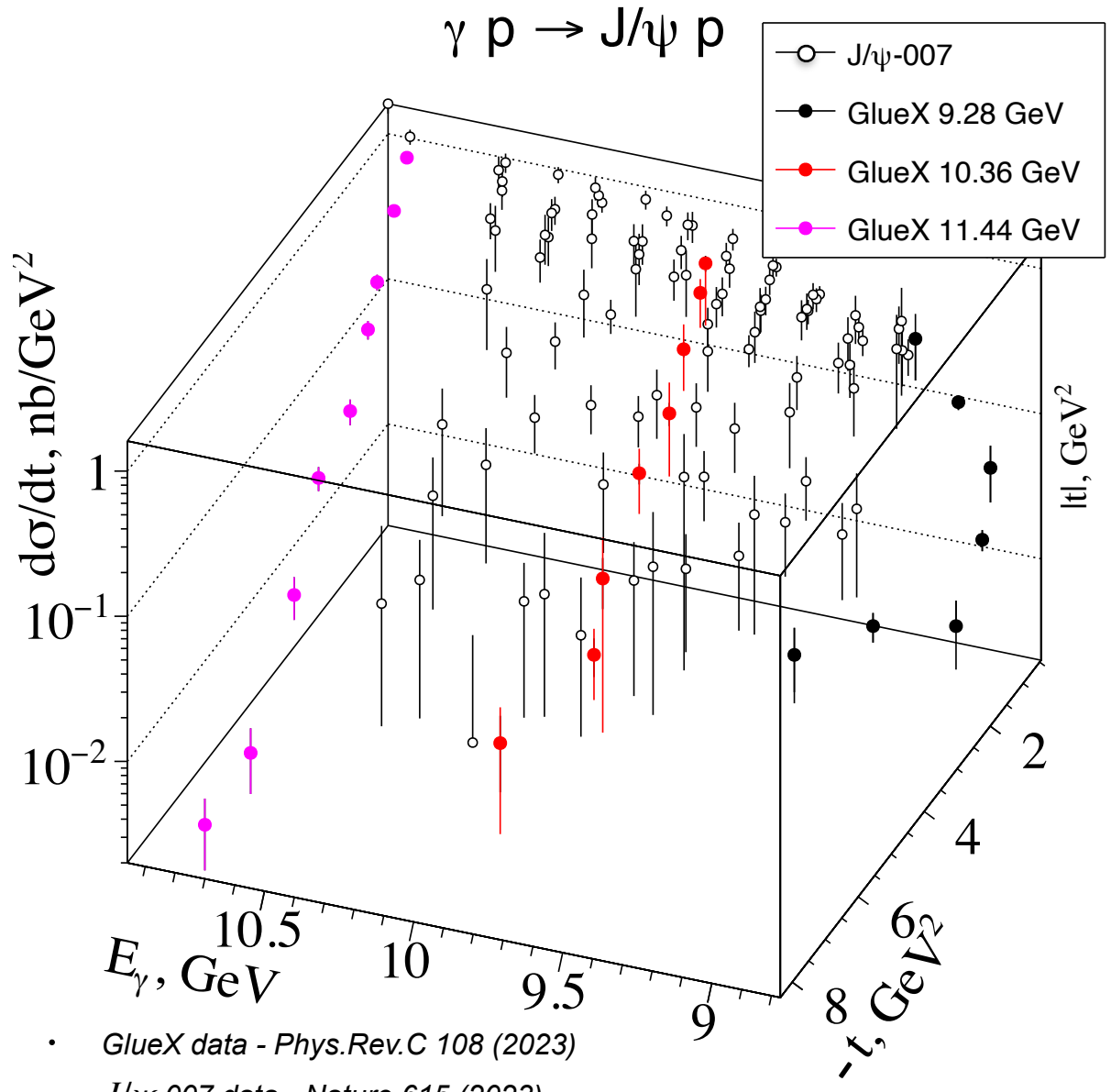
χ_c measurements with Gluex

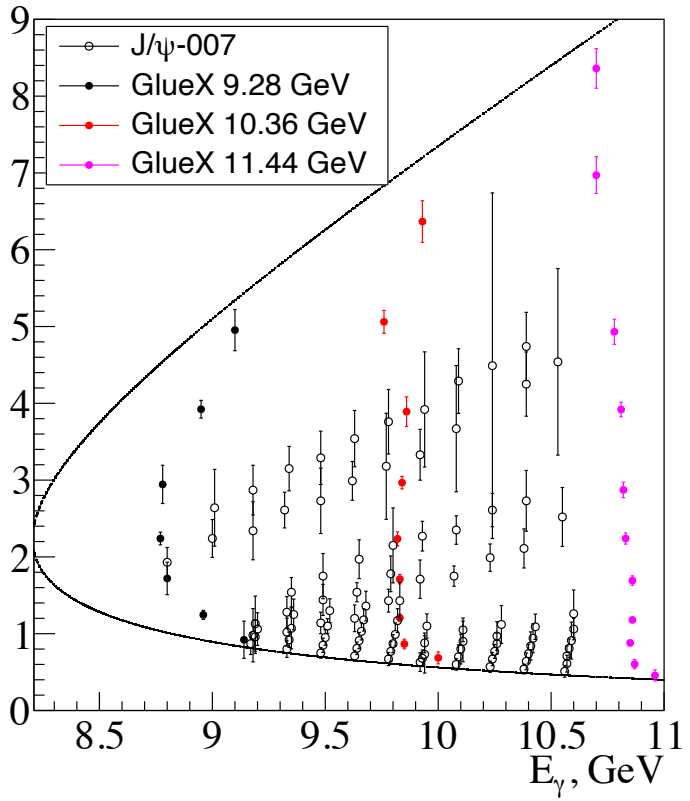
C-even charmonium photoproduction at threshold

Lubomir Pentchev

- Some open questions in J/ψ photoproduction
- Observation of $\chi_{c1,2}$ photoproduction with GlueX
- Photoproduction of charmonia with opposite-to-photon parity
  - what does it mean?
  - complementarity to C-odd charmonium (J/ψ) photoproduction

Threshold J/ψ photoproduction - the data

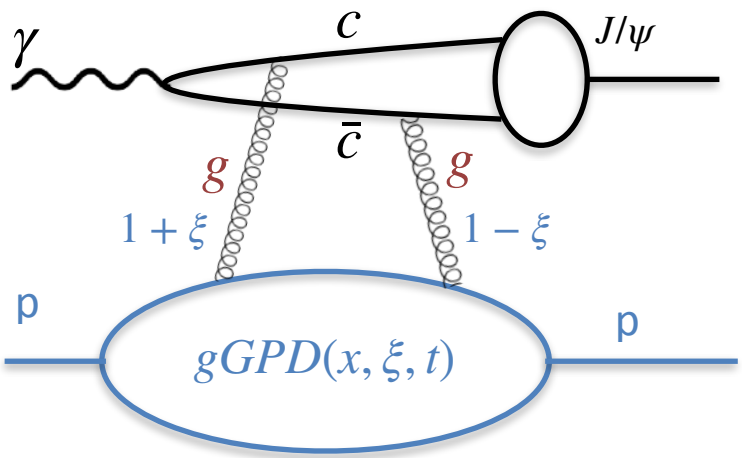




- *GlueX data - Phys.Rev.C 108 (2023)*

  J/ψ-007 data - Nature 615 (2023)

Example: Rosenbluth separation of J/ψ photoproduction data



GPD analysis by Guo, Ji, Yuan PRD 109 (2024)

$$\left(\frac{d\sigma}{dt}\right)_{\gamma p\to J/\psi p} = F(E_\gamma)\xi^{-4}[G_0(t)+\xi^2 G_2(t)]+\dots$$

$$G_0(t) = \left(\mathcal{A}_g^{(2)}(t)\right)^2 - \frac{t}{4m^2}\left(\mathcal{B}_g^{(2)}(t)\right)^2$$

$$G_2(t) = 2\mathcal{A}_g^{(2)}(t)\mathcal{C}_g(t)+2\frac{t}{4m^2}\mathcal{B}_g^{(2)}(t)\mathcal{C}_g(t)-\left(\mathcal{A}_g^{(2)}(t)+\mathcal{B}_g^{(2)}(t)\right)^2$$

for high ξ values

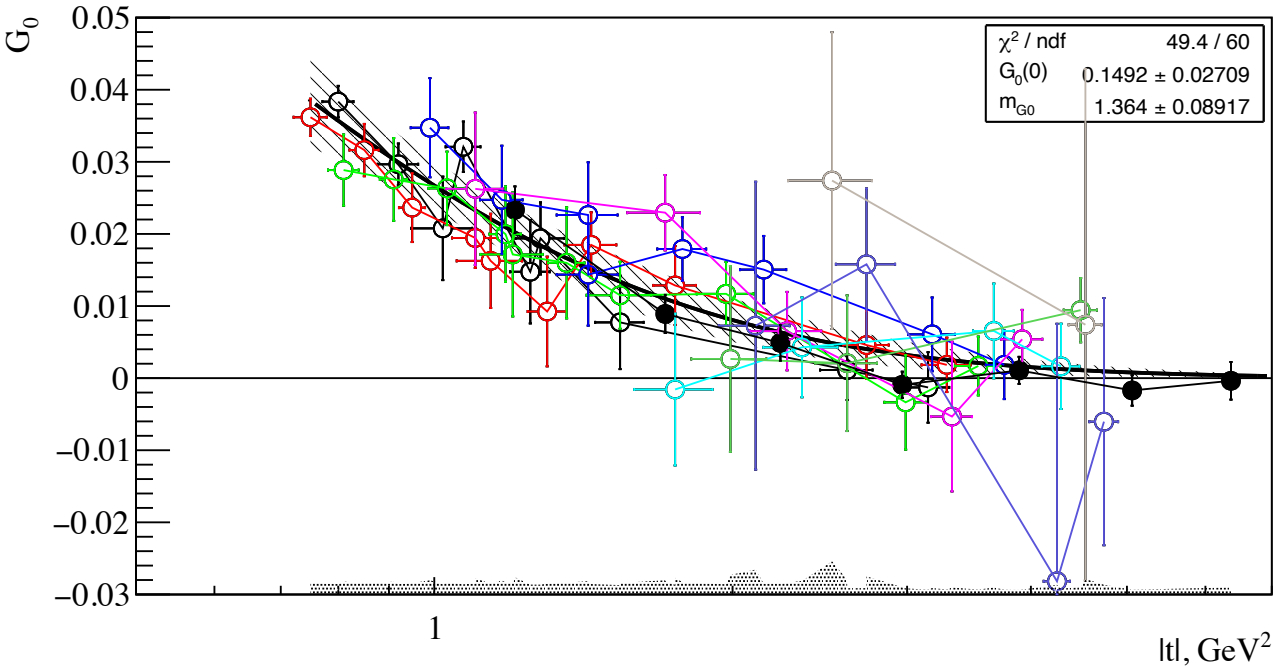
$$\mathcal{A}_g^{(2)}(t) = A_g(t)$$

$$\mathcal{B}_g^{(2)}(t) = B_g(t)$$

$$\mathcal{C}_g(t) = 4C_g(t)$$

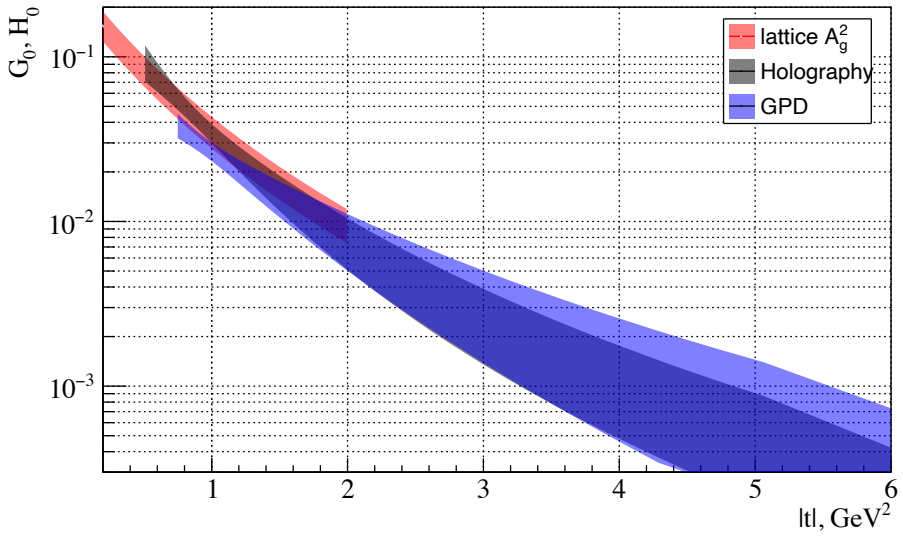
leading moments

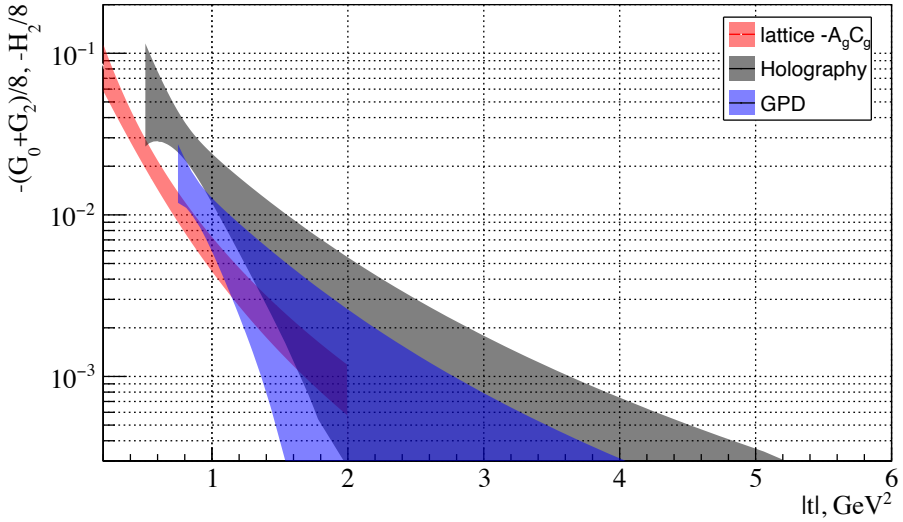
$$\xi = \frac{M_{J/\psi}^2 - t}{2(s-m^2) - M_{J/\psi}^2 + t}$$



LP and E.Chudakov
Phys. Rev. D **112**, 052009 (2025)

Relation to Gluon Gravitational Form Factors





Features in data consistent with the GFF models:

- $d\sigma/dt(E_\gamma, t \to fixed)$ increases with energy
- $G(t)$ and $H(t)$ form factor functions are energy independent (within the experimental errors)

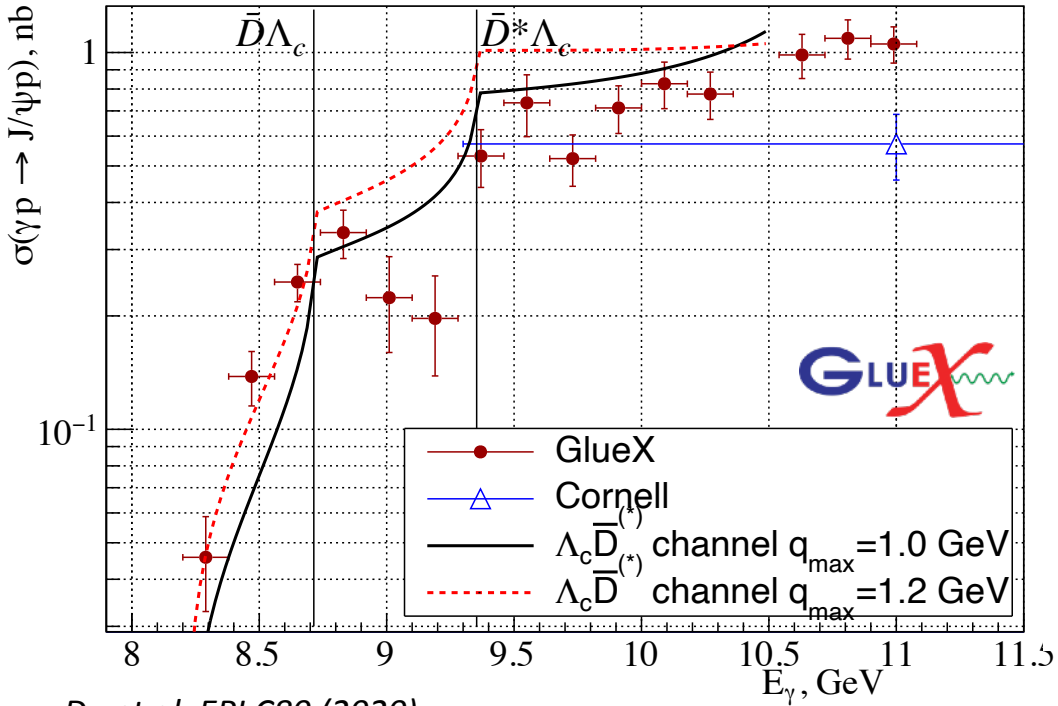
- In leading-term approximation (and neglecting B_g):

  $G_0(t) = H_0(t) = A_g^2(t)$ and

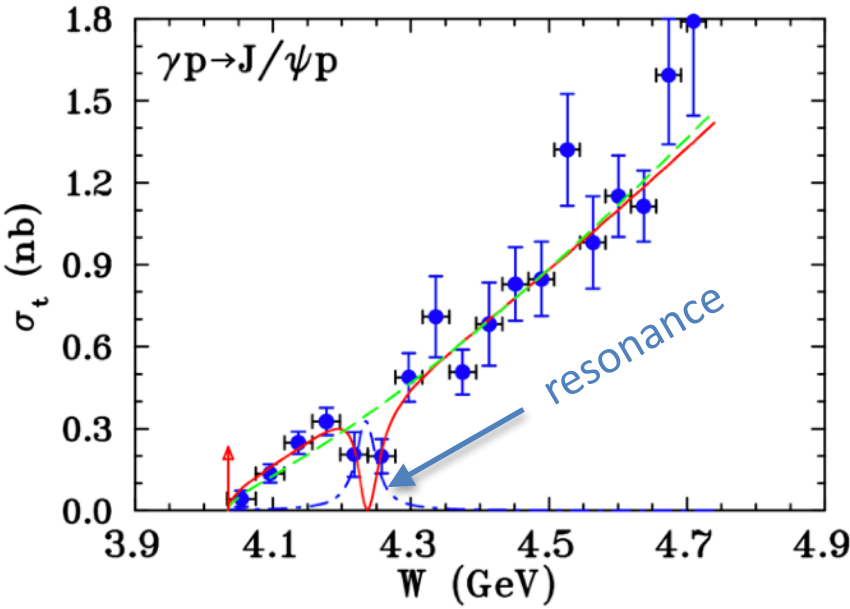
  $G_0(t) + G_2(t) = H_2(t) = 8C_g(t)A_g(t)$

  General agreement b/n extracted FFs using two diametric theories
- agreement with lattice
- possible conclusion: the model corrections are not dominant

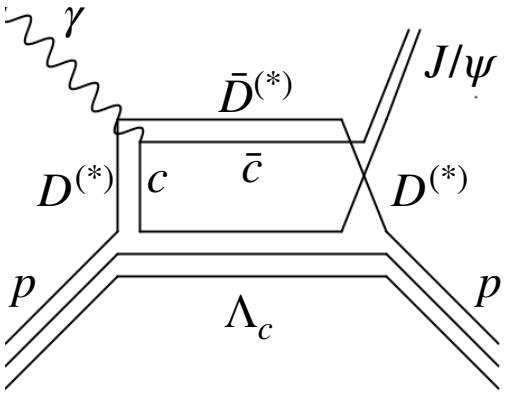
Other reaction mechanisms: open-charm, resonance

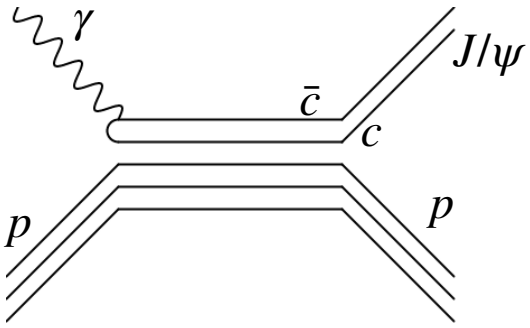


Du et al. EPJ C80 (2020)

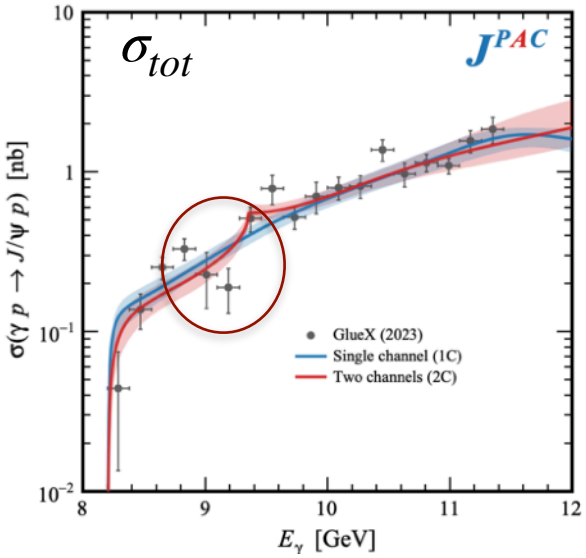


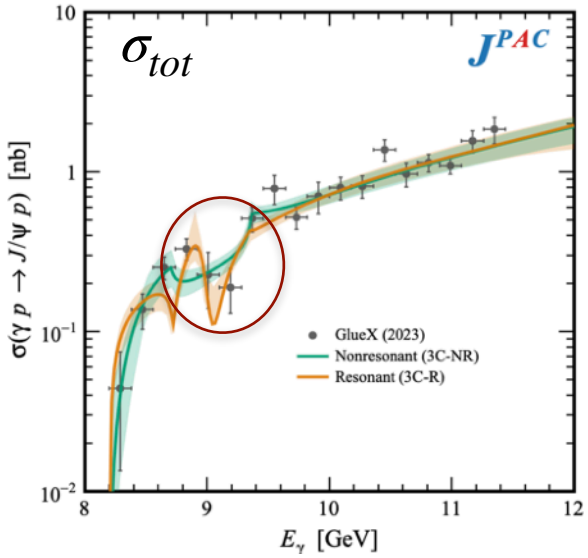
Strakovsky et al. PRC 108 (2023)

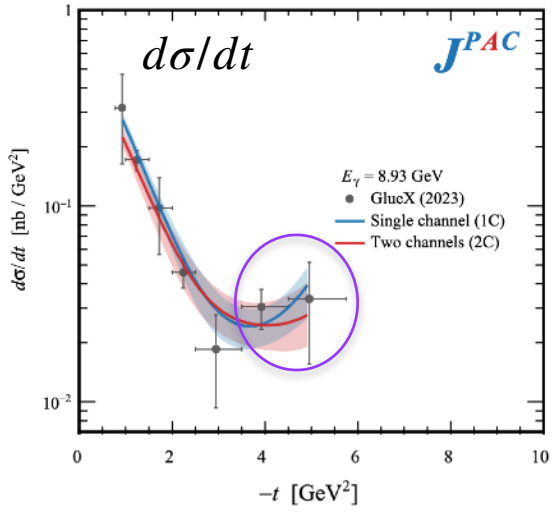


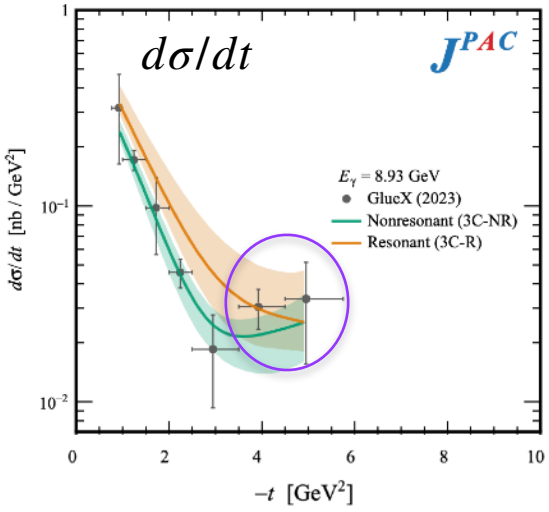


Phenomenological approach: JPAC results









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)

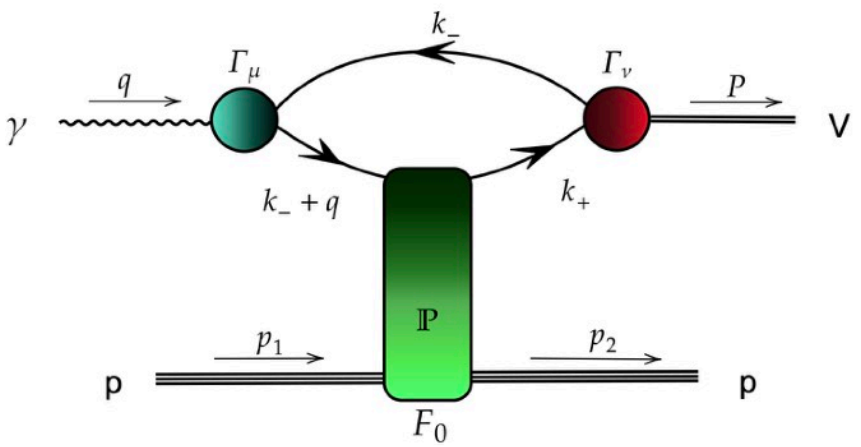
No stat. significant preference:

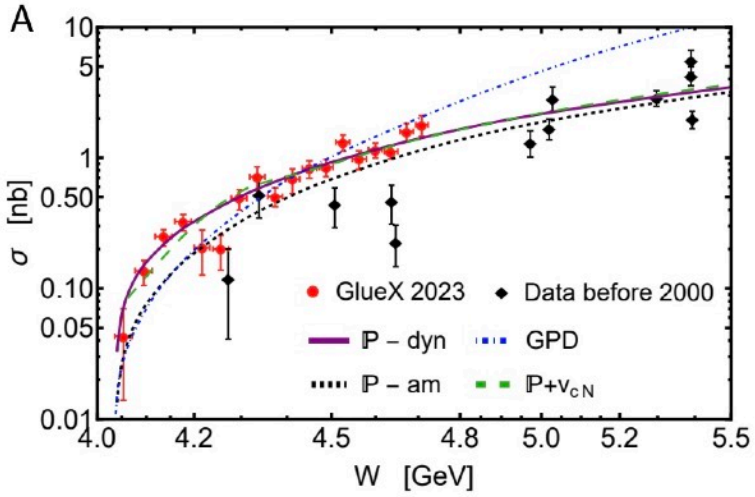
- 9 GeV structure requires sizable contribution from open charm
- Severe violation of VMD and factorization not excluded
- s-channel resonance not excluded
- t-enhancement indicates s-channel contribution: due to proximity to threshold or open-charm exchange

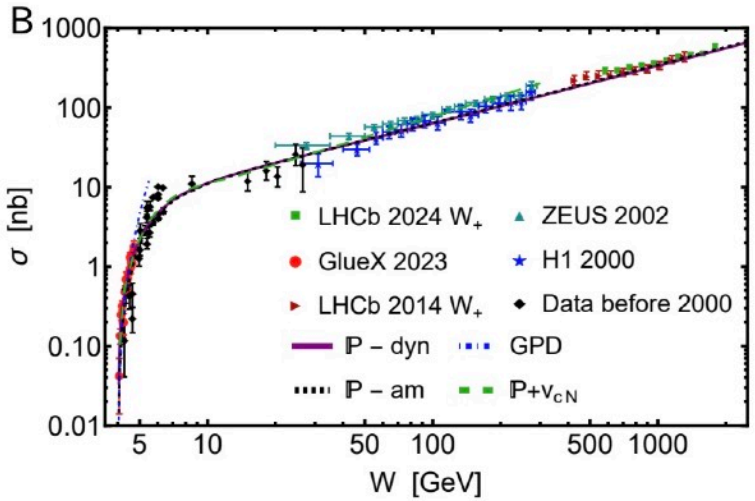
JPAC Phys.Rev.D 108 (2023)

Global fit of both Hall C & D $d\sigma/dt(t)$ and Hall D $\sigma_{tot}(E_\gamma)$

Non-perturbative BS + Pomeron model





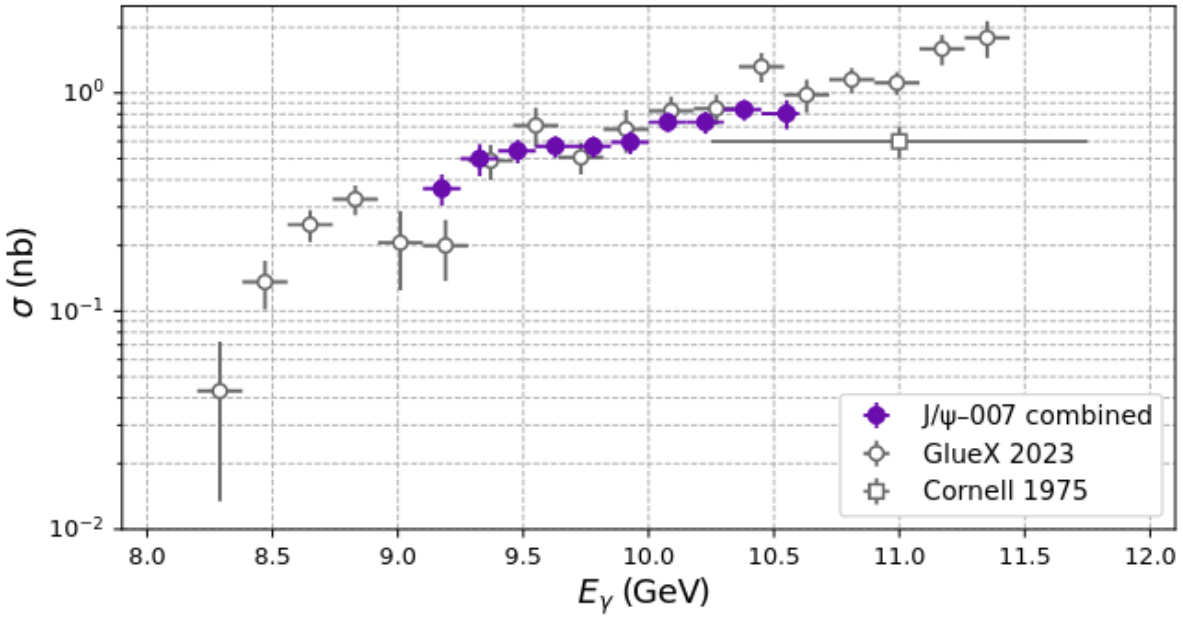


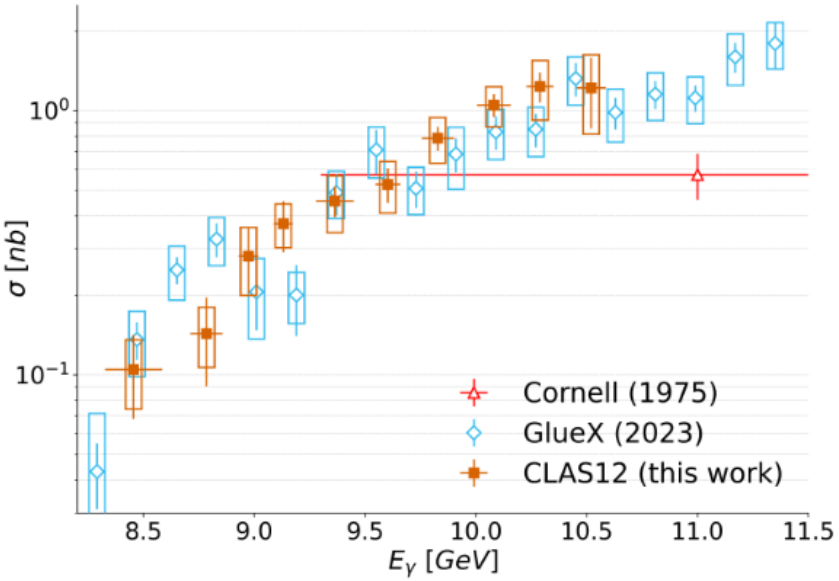
L.Tang et al., "*Exclusive photoproduction of light and heavy vector mesons: thresholds to very high energies", Eur. Phys. J. C (2026)*

- Key for threshold production: realistic non-perturbative description of $\gamma \to V$ transition using BS equation
- Pomeron exchange model - "*unrelated to in-proton glue*"

Craig Roberts: "*This work thus demonstrates that, at present and despite the "desire" of many practitioners to draw far-reaching conclusions from their measurement, any attempt to constrain in-proton glue distributions from near-threshold $\gamma + p \to V + p$ photoproduction data is unjustified.*"

Recent results from CLAS12 and J/ψ-007

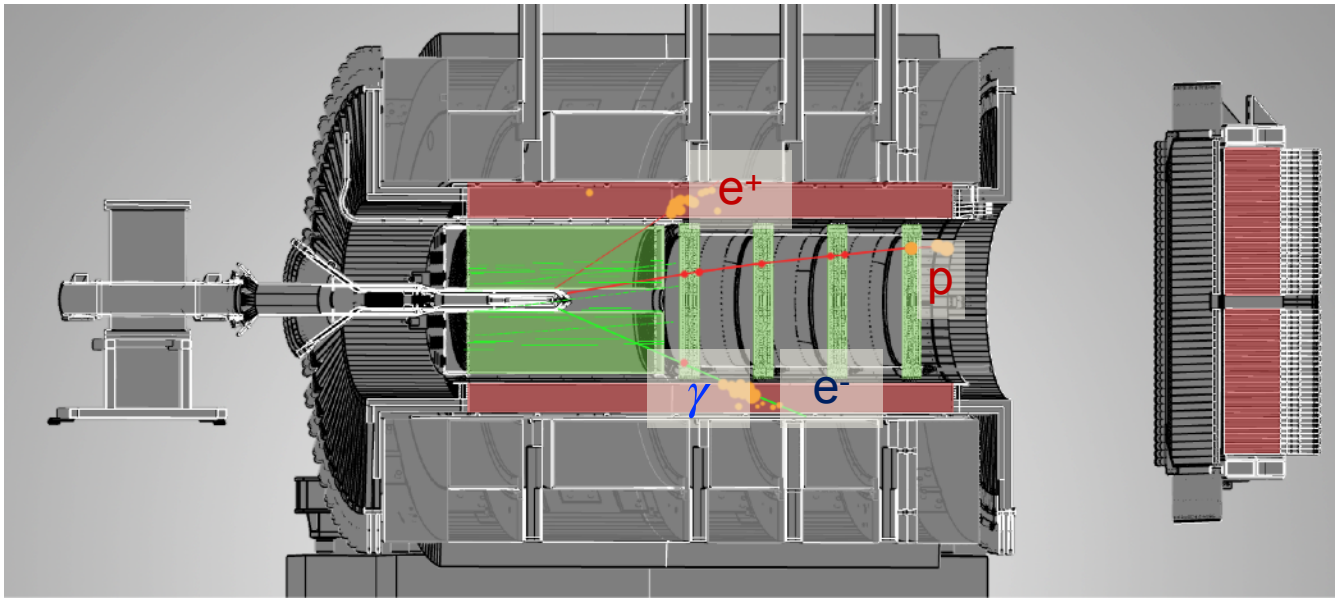


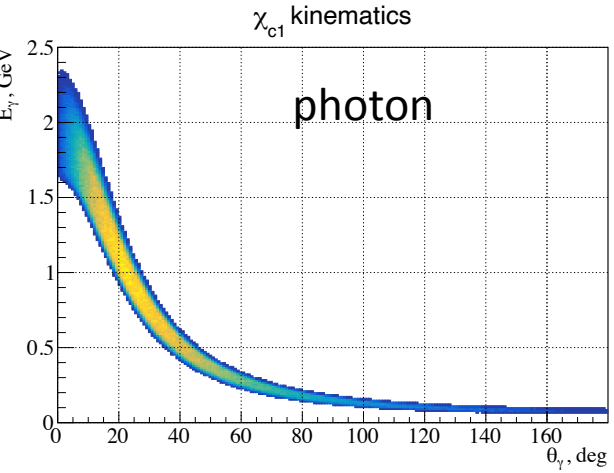


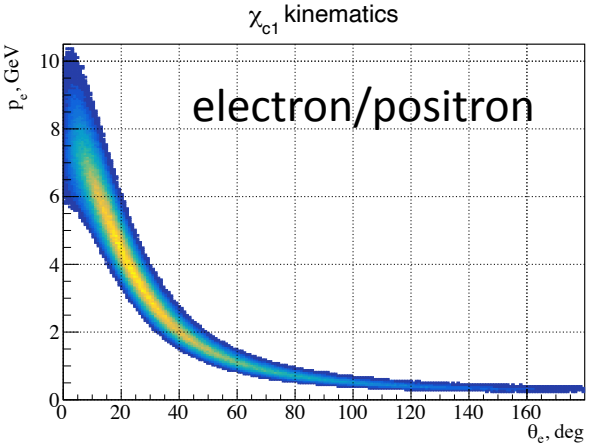
- No obvious dip seen in recent CLAS12 and J/ψ-007 (including muon channel) data
- Still, statistically compatible with GlueX results

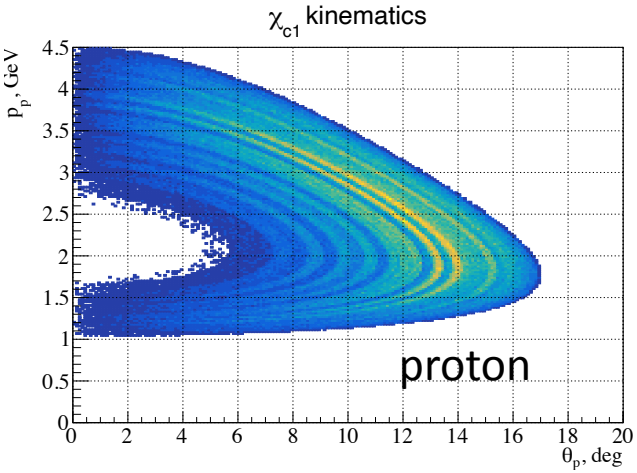
χ_c detection with GlueX

$$\gamma p \rightarrow \chi_c p \rightarrow J/\psi\gamma\, p \rightarrow e^+e^-\gamma\, p \quad \textit{exclusive}$$





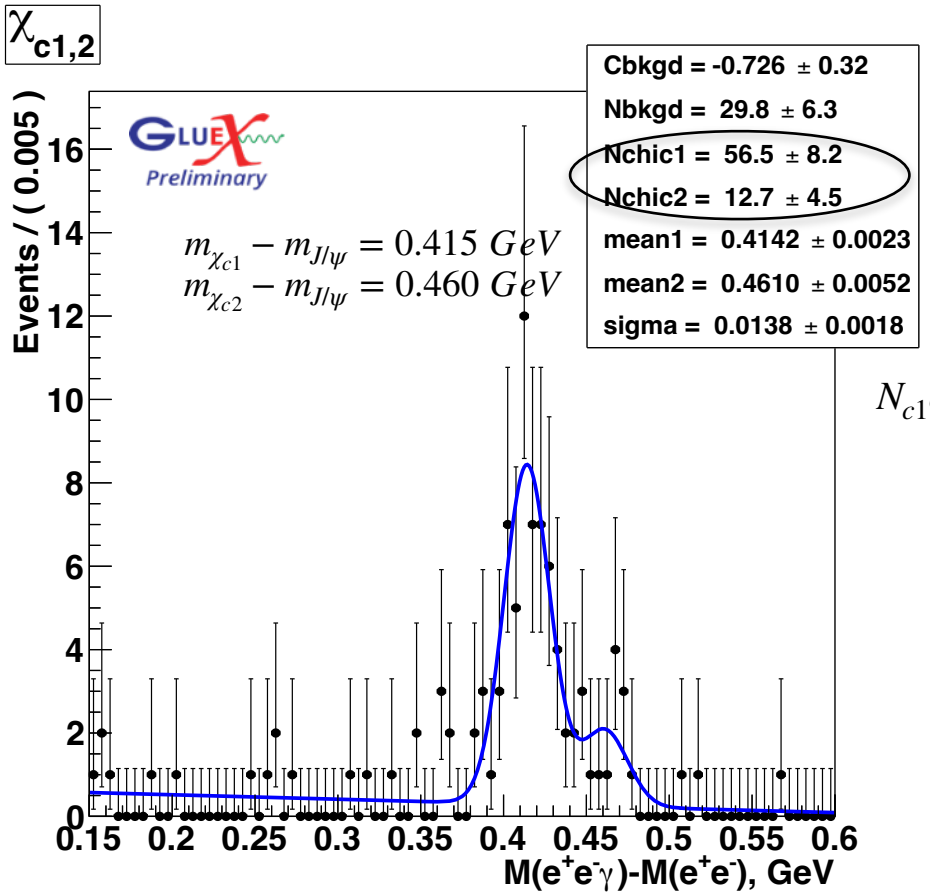




MC simulations

C-event charmonium states at threshold with GlueX

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



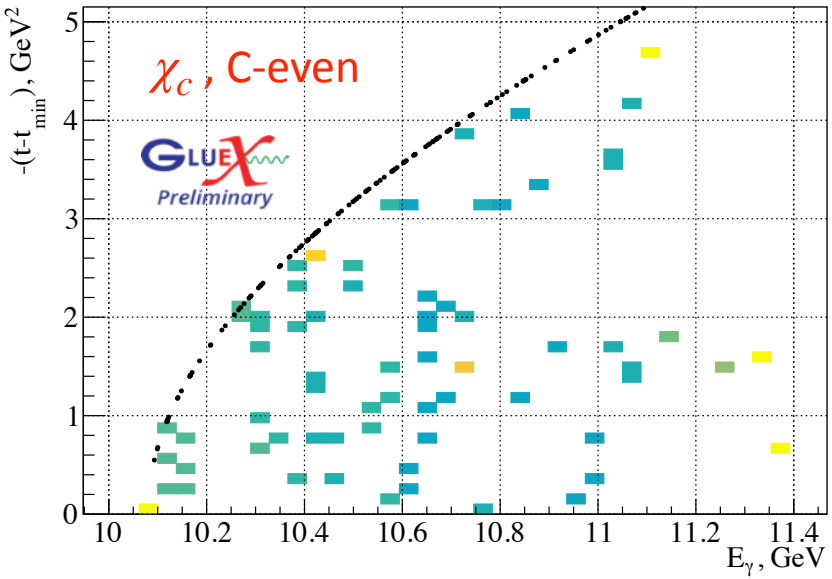
$$N_{c1}e^{-\frac{(x-m1)^2}{2\sigma^2}} + N_{c2}e^{-\frac{(x-m2)^2}{2\sigma^2}}$$

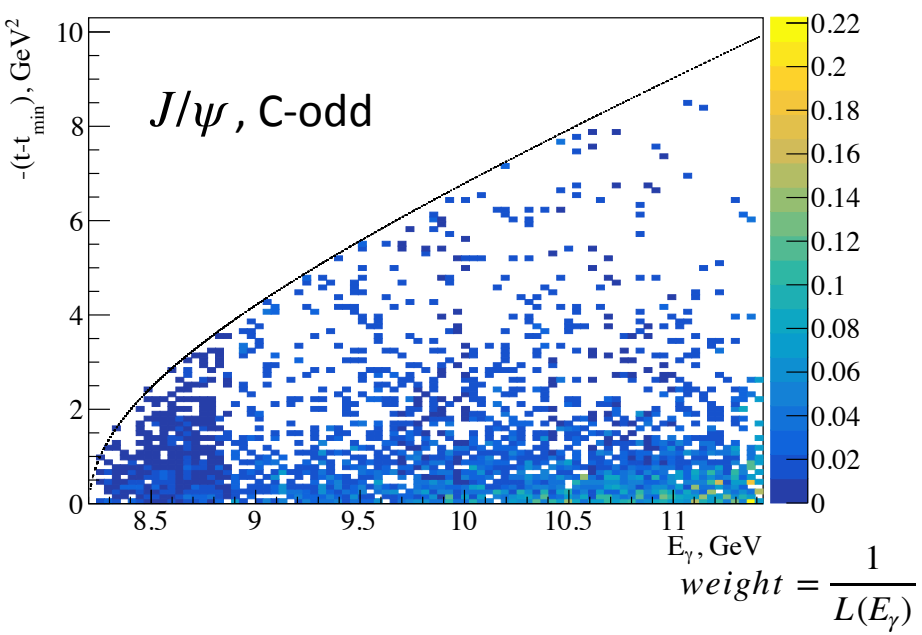
- $\chi_{c1}(3511)$ and $\chi_{c2}(3556)$, 1^{++} and 2^{++} $(1P)$, $E_\gamma^{thr} = 10.1$ GeV

First ever evidence for photoproduction of C-even charmonium

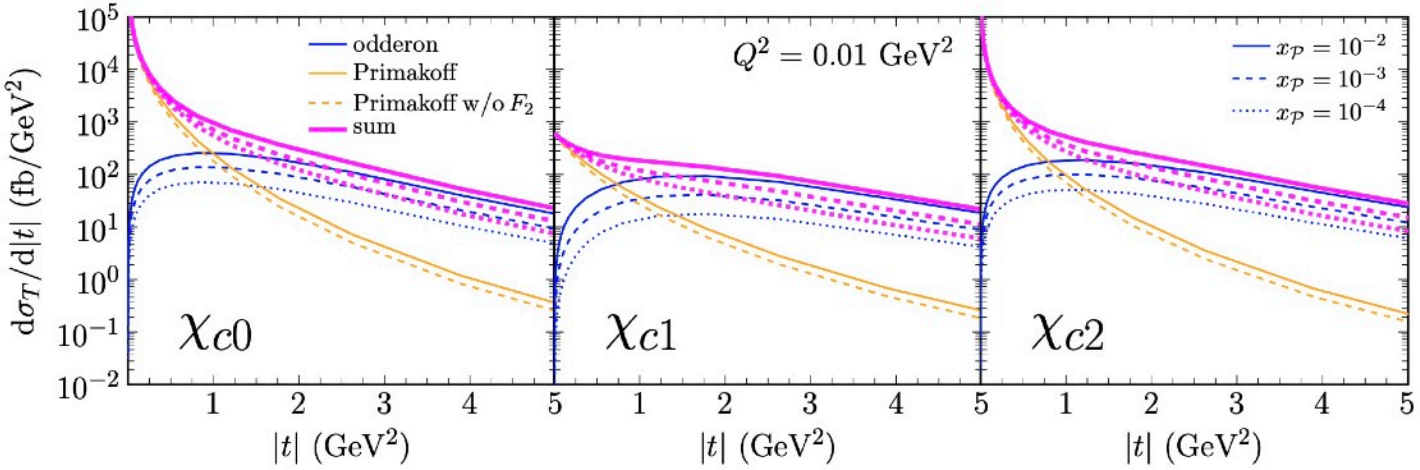
C-event charmonium states at threshold with GlueX

- Dramatic difference: χ_c distribution in (E_γ, t) vs J/ψ

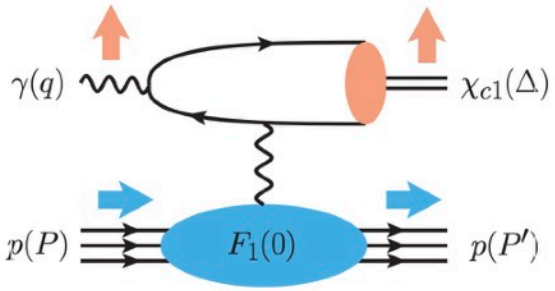




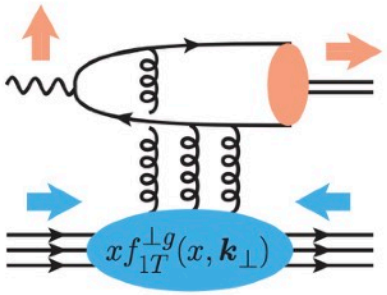
t-channel production - perturbative calculations



Benic, Dumitru, Kaushik, Motyka, Stebel, PRD 110 (2024) -
perturbative calculations (high energies)

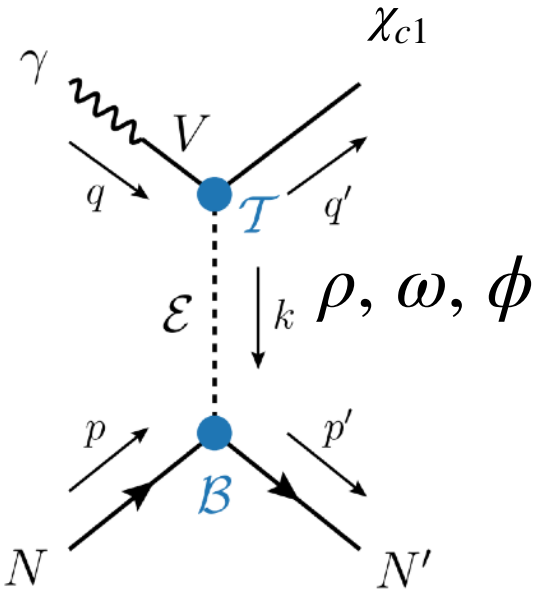


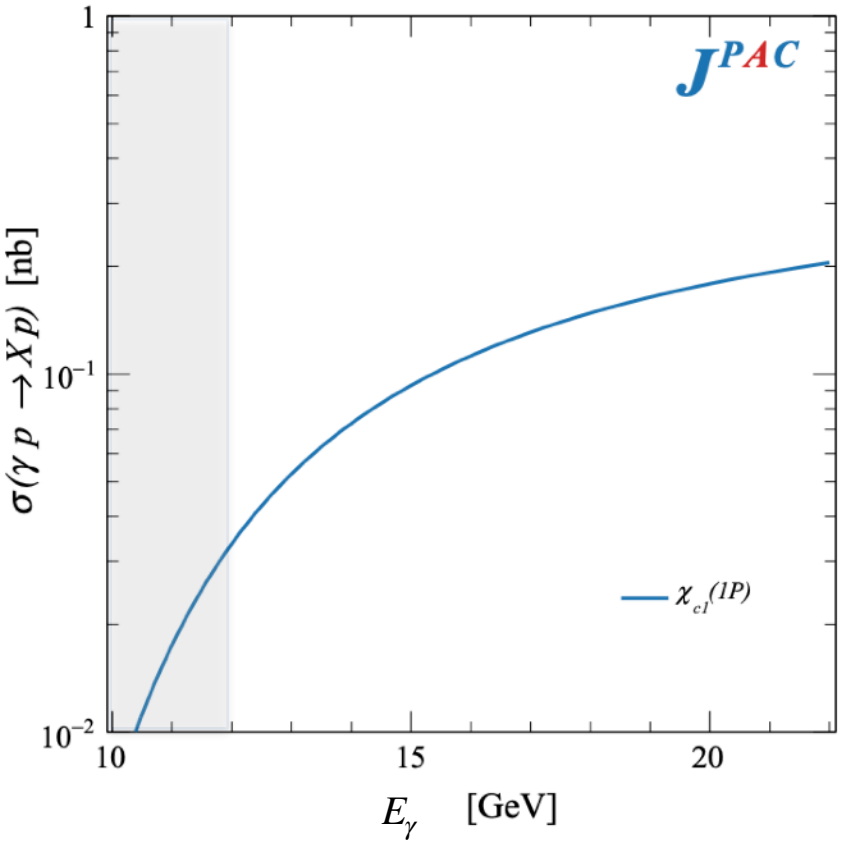
- Primakoff - suppressed for χ_{c1} due to Landau-Yang theorem:
  $\chi_{c1}(J=1) \to \gamma\gamma$ suppressed for $t \to 0$



- Odderon (odd-parity Pomeron) 3g exchange - suppressed by $1/\alpha_s^6$ still dominates at higher $|t|$ due to $n_s = 0$ ($n_s = 2$ for Primakoff)

t-channel production - VM exchange





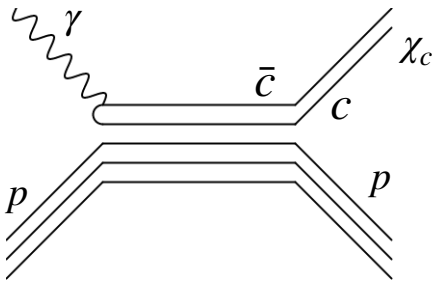
JPAC, PRD 102 (2020)

- Low energies - non-perturbative approach, vector meson exchange
- $\chi_c \to \gamma V(\rho, \omega, \phi)$ is suppressed

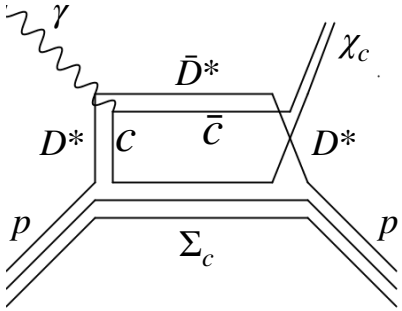
s-channel mechanisms

- *t*-channel is suppressed (requires C-odd exchange), allows us to study other possible mechanisms that may dominate:

S-channel exchange of 5q



Open-charm exchange



Conclusions

- Studying gluon structure of the proton with J/ψ photoproduction requires better understanding of reaction mechanism
- First-time observation of charmonium photoproduction with opposite-to-photon parities; expect more events with GlueX-III (~400 total)
- Photoproduction of χ_c in t-channels is suppressed due to C-parity flip. This allows us to study s-channel reaction mechanisms that would help understanding their contributions in J/ψ photoproduction
- Threshold production of higher-mass charmonia (with different J^{PC}) adds a new dimension in understanding gluonic content of the proton