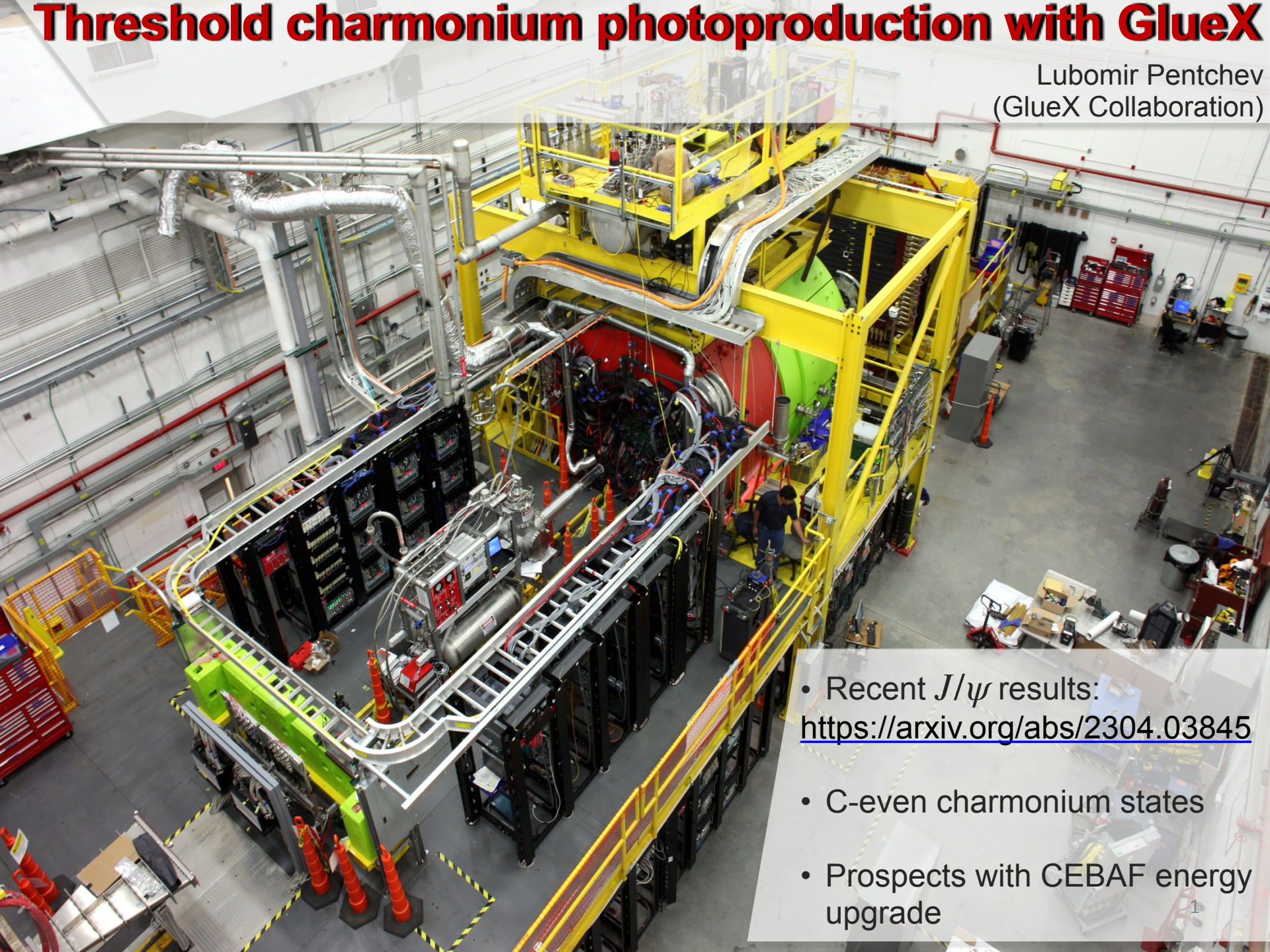


# Threshold charmonium photoproduction with GlueX

Lubomir Pentchev  
(GlueX Collaboration)

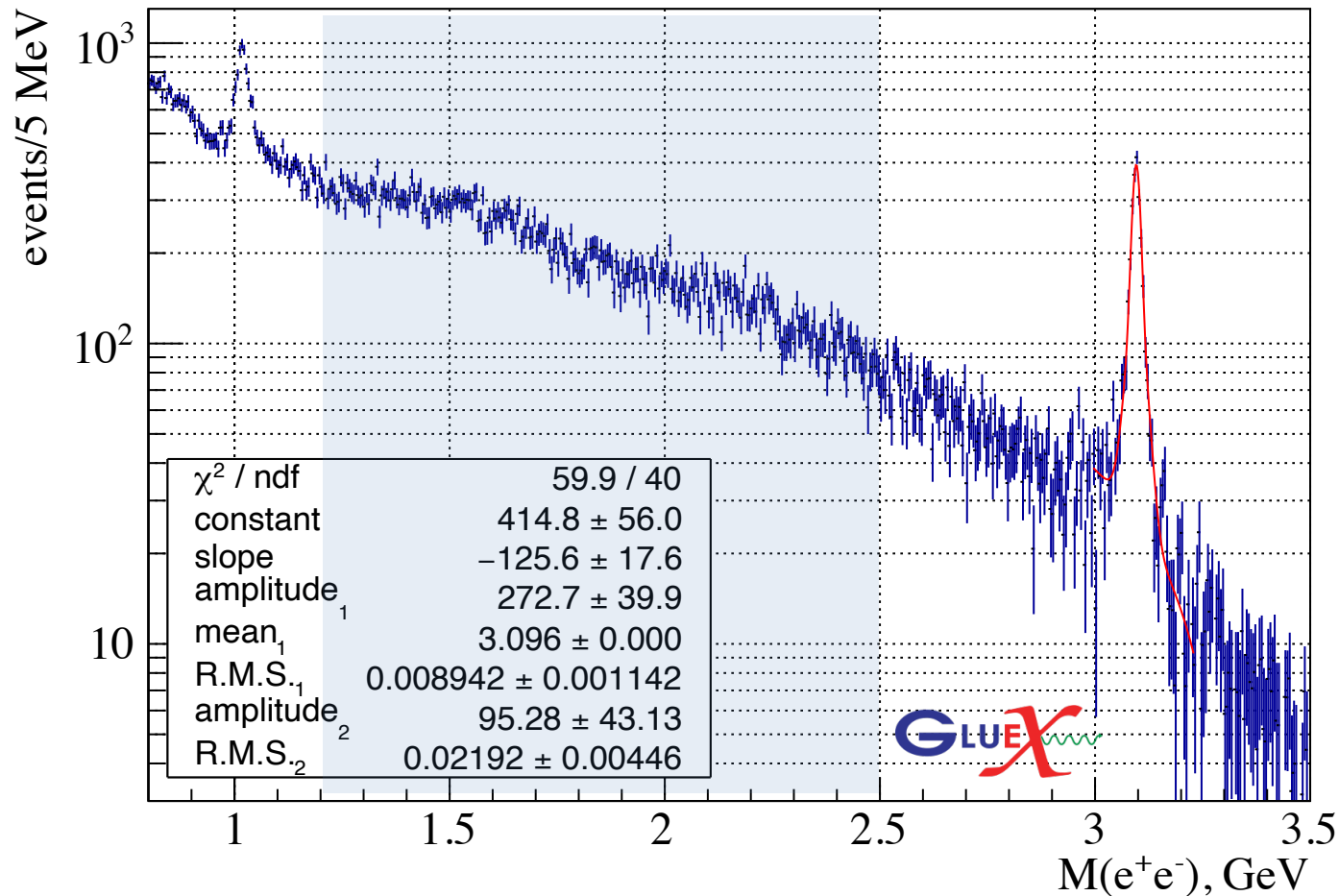


- Recent  $J/\psi$  results:  
<https://arxiv.org/abs/2304.03845>

- C-even charmonium states

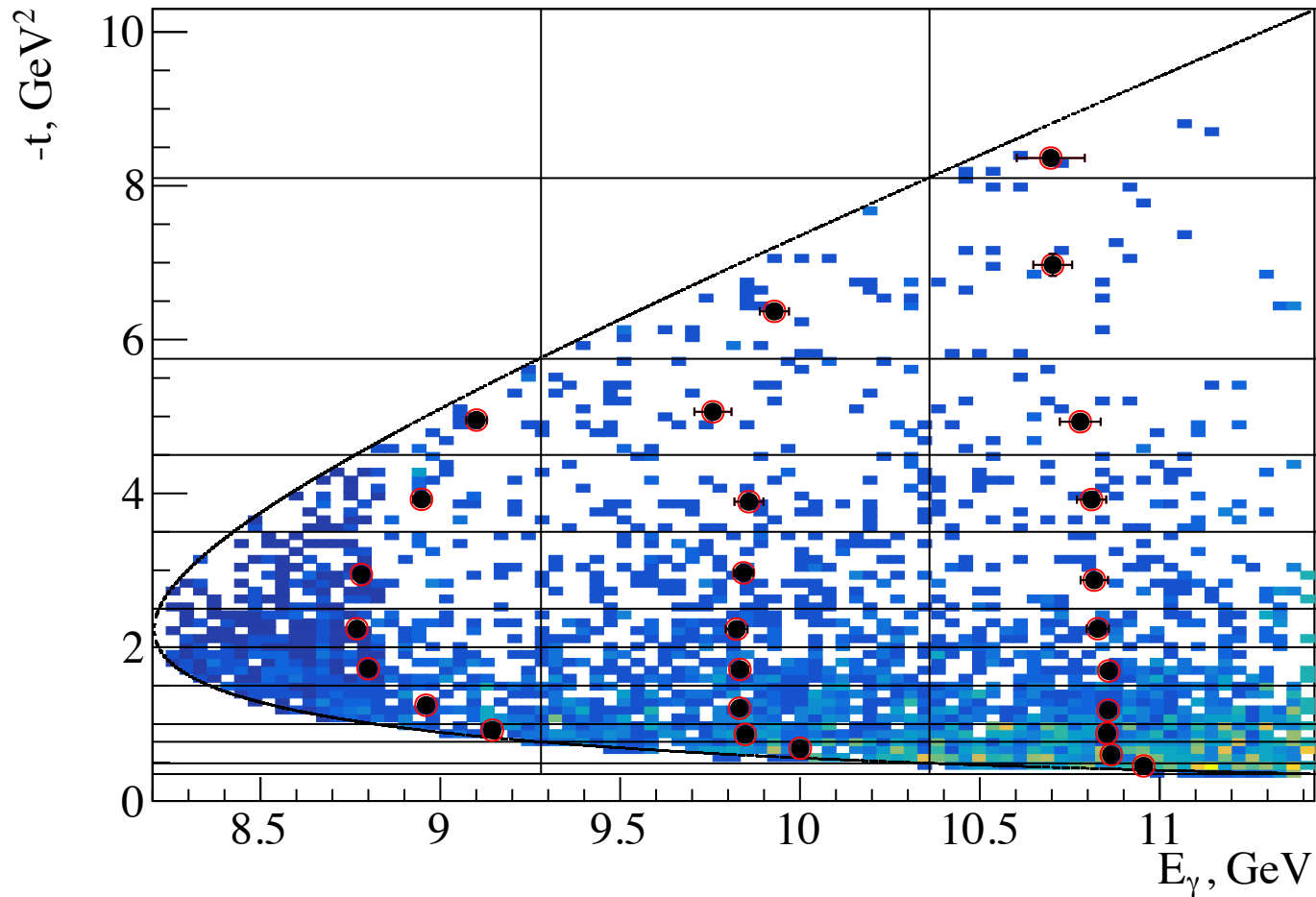
- Prospects with CEBAF energy upgrade

# Exclusive reaction $\gamma p \rightarrow J/\psi p \rightarrow e^+ e^- p$



- GlueX uses tagged polarized photon beam (0.2% energy resolution) from coherent Bremsstrahlung (of 12 GeV electron beam) off thin diamond
- +**exclusivity of the reaction: kinematic fit** 13 MeV mass resolution;
- $J/\psi$  yields extracted from fits of  $M(e^+e^-)$  distributions
- BH(1.2 – 2.5 GeV) used for normalization

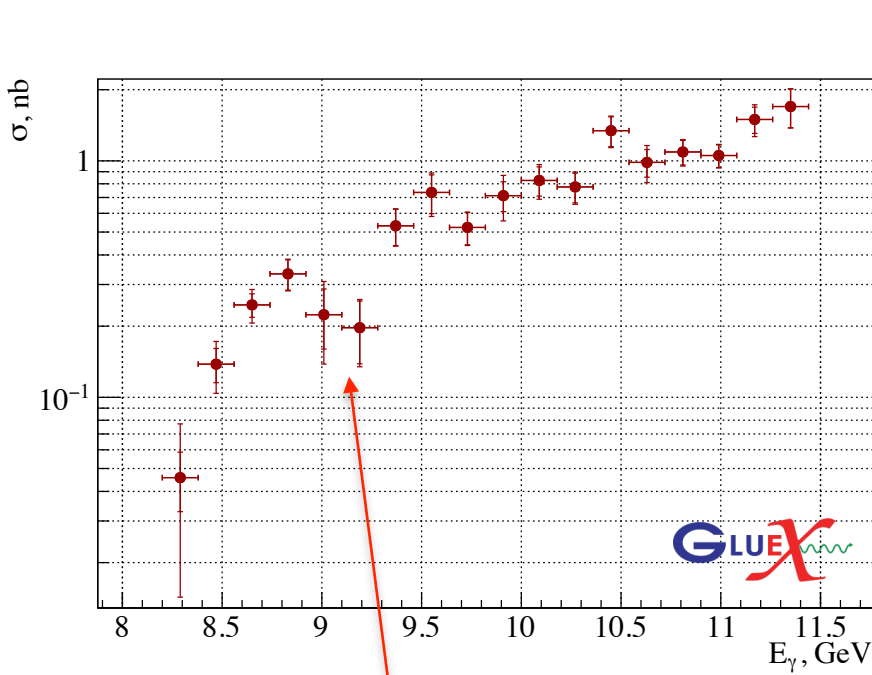
# Threshold region coverage



- 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

# GlueX results: total and differential cross-sections

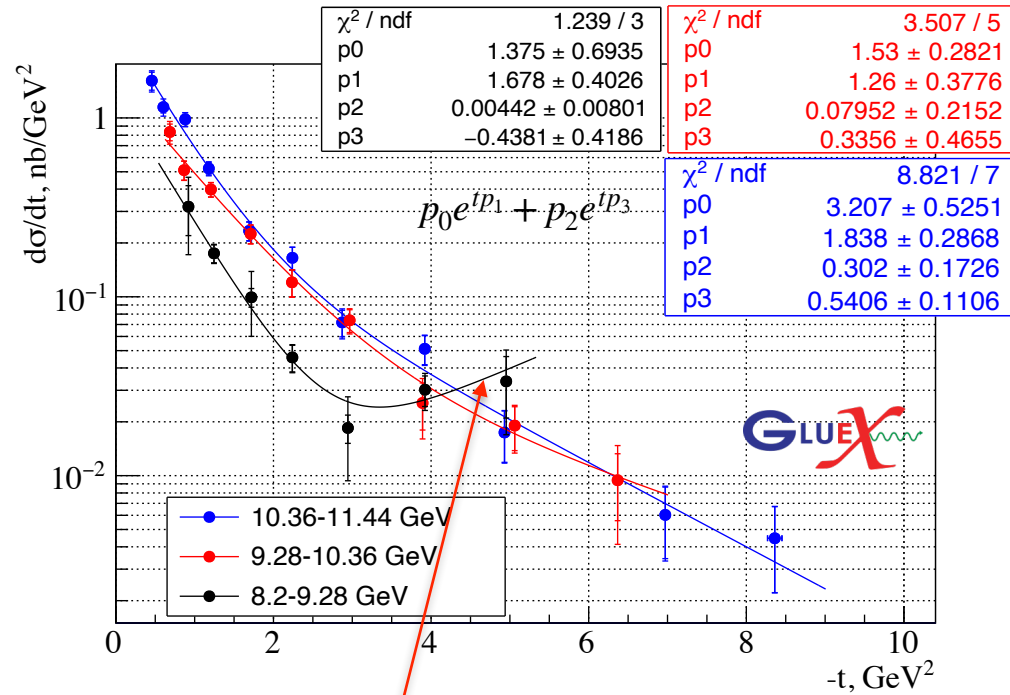
$$\gamma p \rightarrow J/\psi p \rightarrow e^+ e^- p$$



- $\sigma_{tot}$  increasing with energy approximately following the phase space

however:

- Possible structure in  $\sigma(8.6 - 9.6\text{GeV})$ , the statistical significance of the two “dip” points is  $2.6\sigma$ ; if include look-elsewhere effect -  $1.3\sigma$

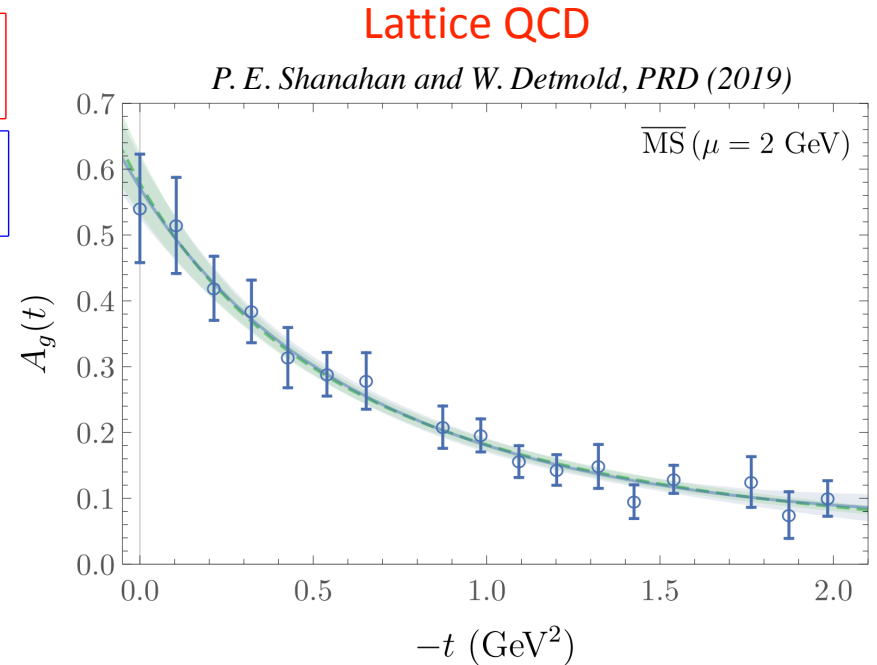
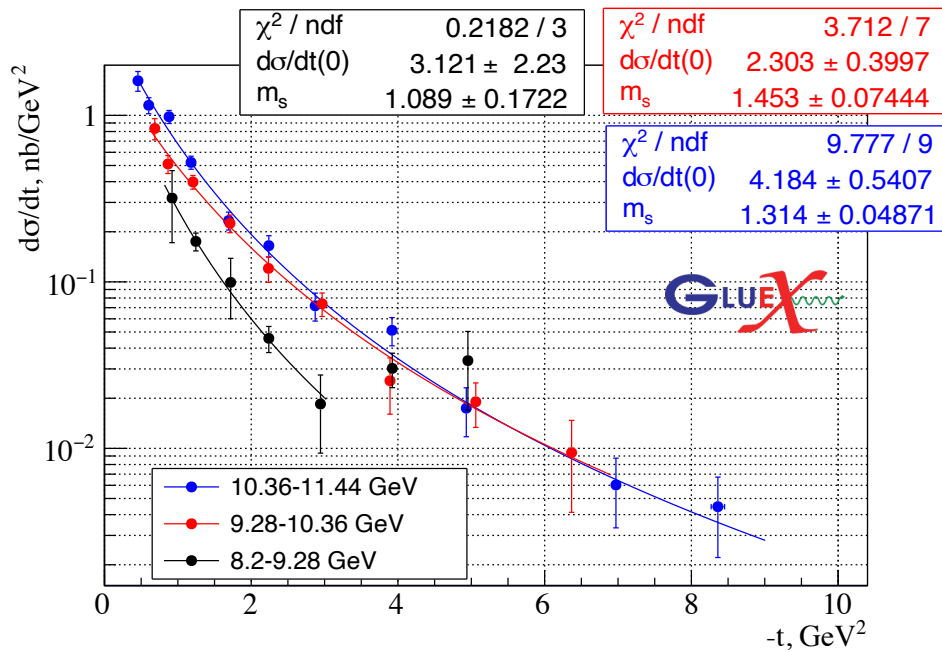


- Exponentially falling  $t$ -dependence

however:

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

# Differential cross-sections vs Lattice QCD



Dipole fits:  $\frac{d\sigma/dt(0)}{(1 - t/m_s^2)^4}$

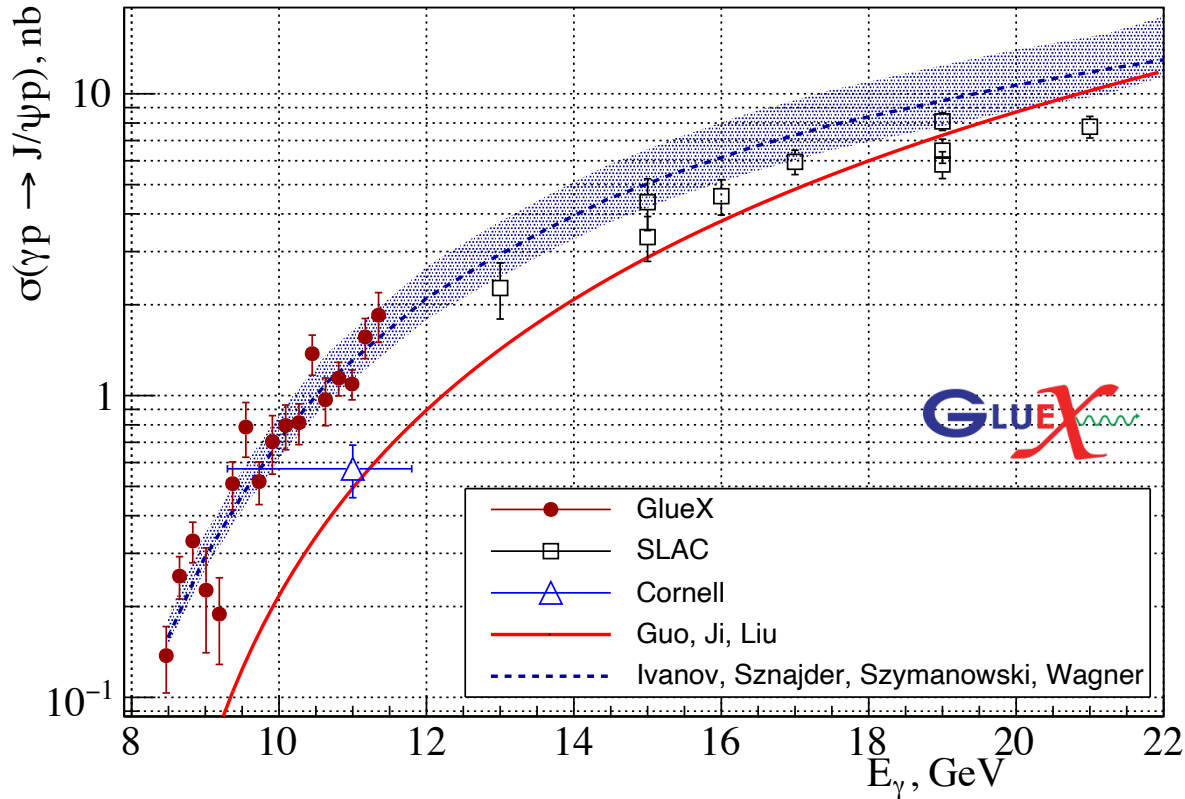
$q_{c.m.}, GeV$ ( $J/\psi$ c.m.)	0.499	0.767	0.978
$d\sigma/dt(0), nb/GeV^2$	$3.121 \pm 2.23$	$2.303 \pm 0.400$	$4.184 \pm 0.541$
$m_s, GeV$	$1.089 \pm 0.172$	$1.453 \pm 0.074$	$1.314 \pm 0.049$

$m_s$  of  $A_g(t)$ ,  $GeV$  Lattice QCD  $1.13 \pm 0.06$

$d\sigma/dt(t)$  generally consistent with gluon exchange mechanism

More detailed analysis in Shivangi Prasad's talk from Hall C ( $J/\psi$ -007) data

# GPD factorization models



Ivanov, Sznajder, Szymanowski, Wagner (2022)

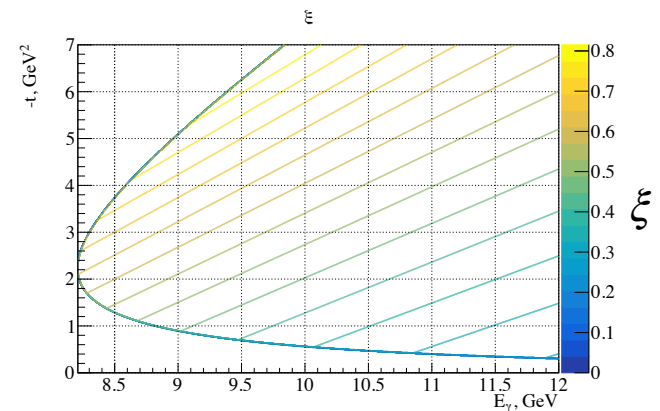
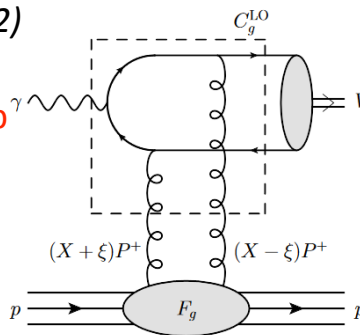
- GPD LO calculations
- Big uncertainties in NLO, **data can help to constrain gluon GPDs**

Guo, Ji, Liu PRD103 (2021),

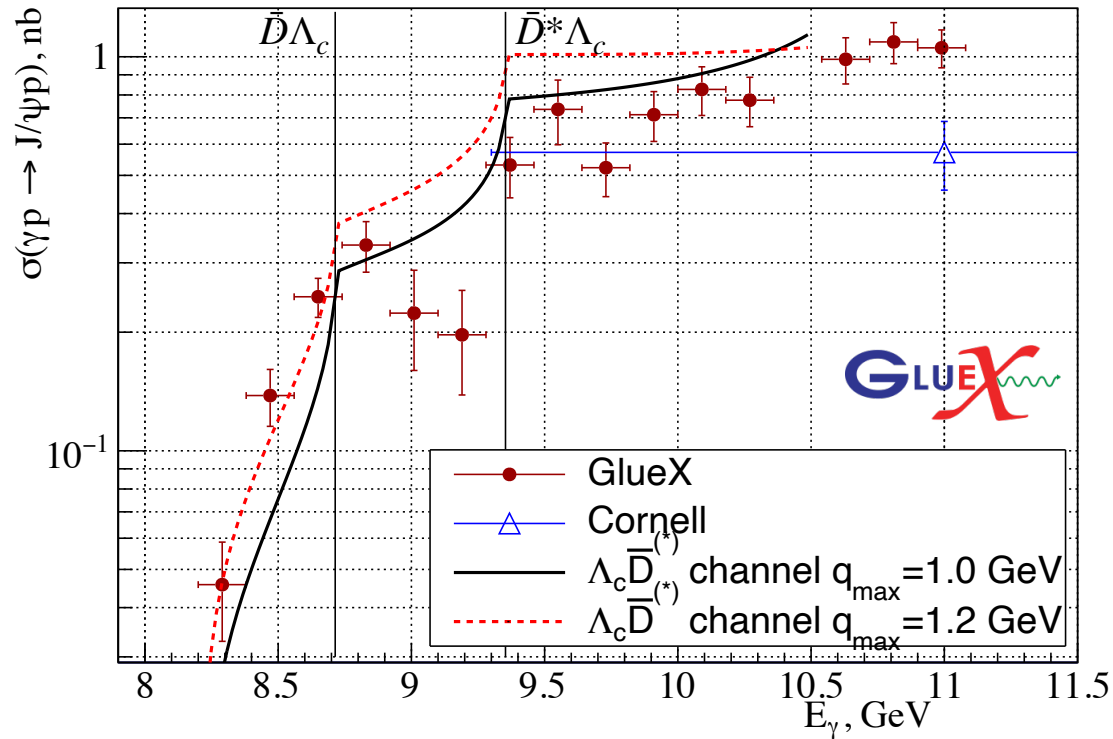
in  $m_c \rightarrow \infty$  limit,  $\xi \rightarrow 1$  expansion

(Hatta, Strikman 2021):

- factorization valid near threshold
- connection to gravitational FFs



# Open-charm exchange



Du, Baru, Guo, Hanhart,  
 Meissner, Nefediev,  
 Strakovsky EPJ C80 (2020)

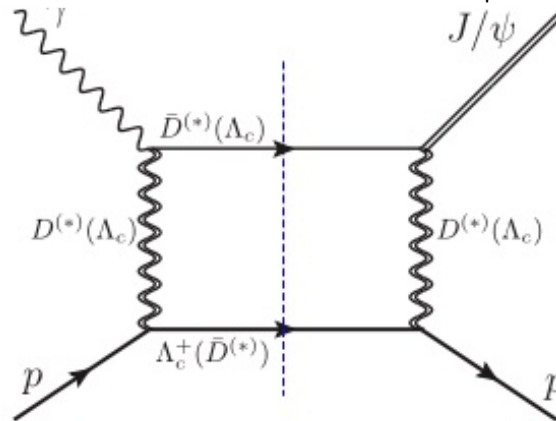
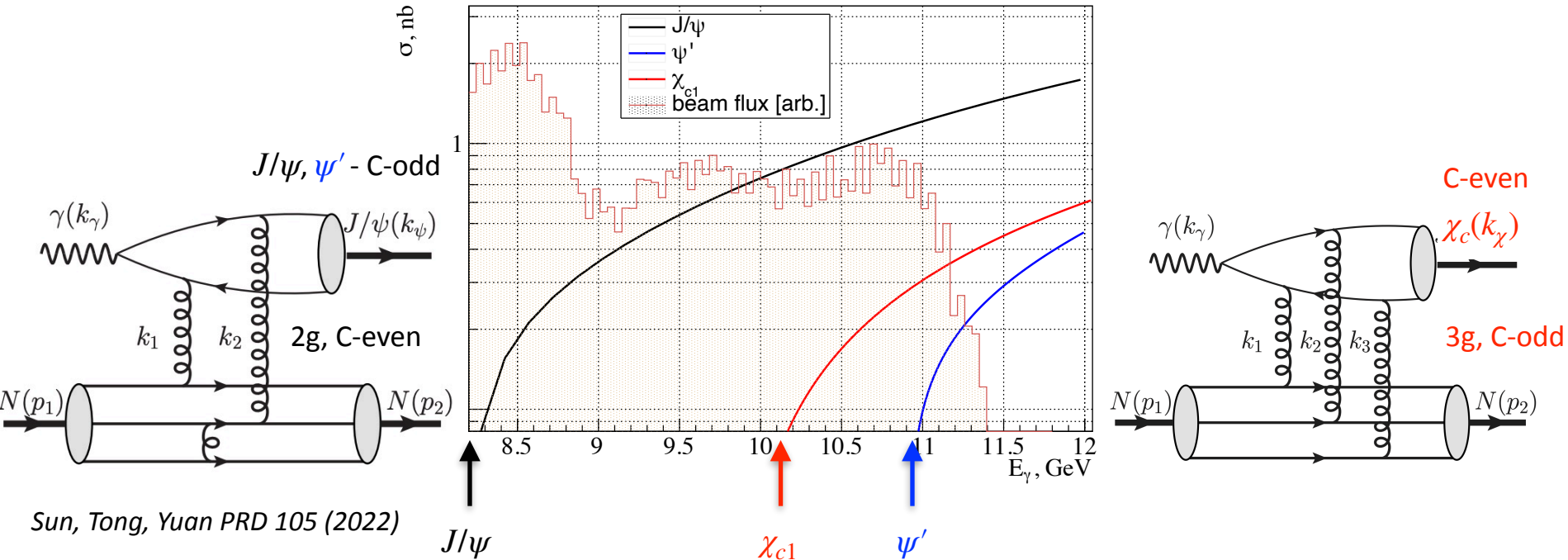


FIG. 3. Feynman diagram for the proposed CC mechanism. The dashed blue line pinpoints the open-charm intermediate state.

# C-event charmonium states at threshold with GlueX

C-odd ( $J/\psi, \psi'$ ) vs C-even ( $\chi_c$ ) production



Sun, Tong, Yuan PRD 105 (2022)

- $\chi_{c1}(3511)$  and  $\chi_{c2}(3556)$ ,  $1^{++}$  and  $2^{++}$  ( $1P$ ),  $E_\gamma^{thr} = 10.1$  GeV
- C-even charmonium states require 3g-exchange

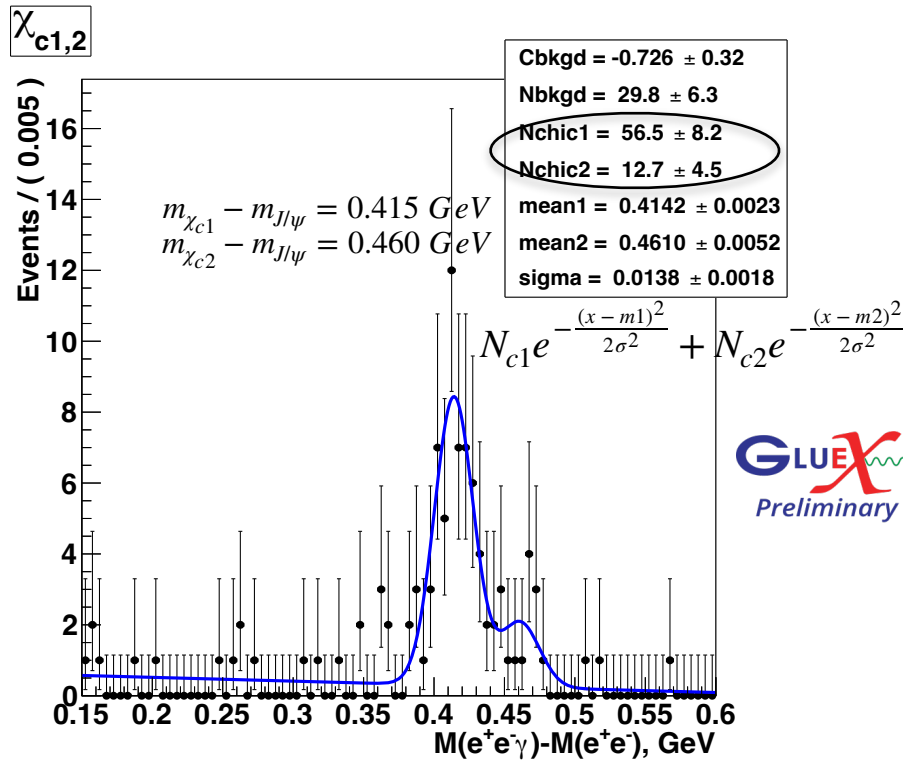
- GlueX has observed also a small number of  $\psi'(3686)$  ( $2S$ ) states in  $\gamma p \rightarrow \psi' p \rightarrow (e^+e^-)p$ ,  $E_\gamma^{thr} = 10.9$  GeV



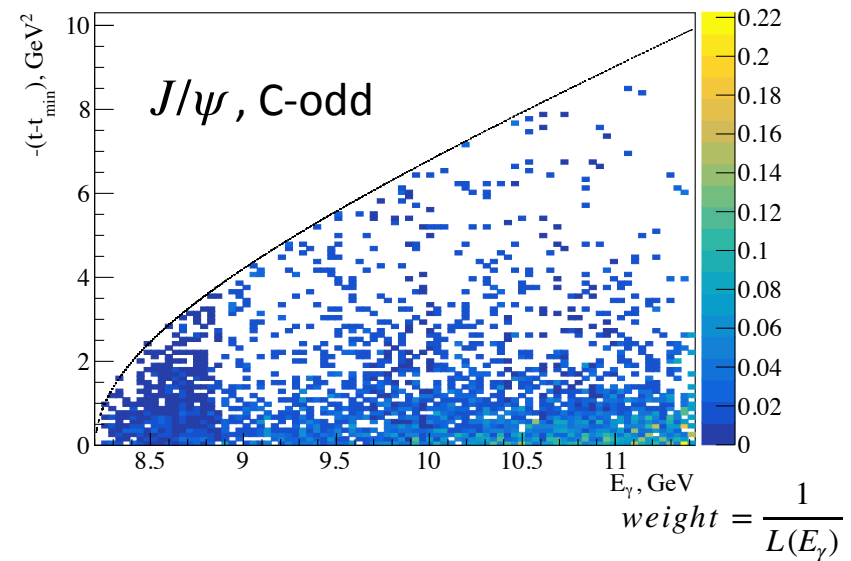
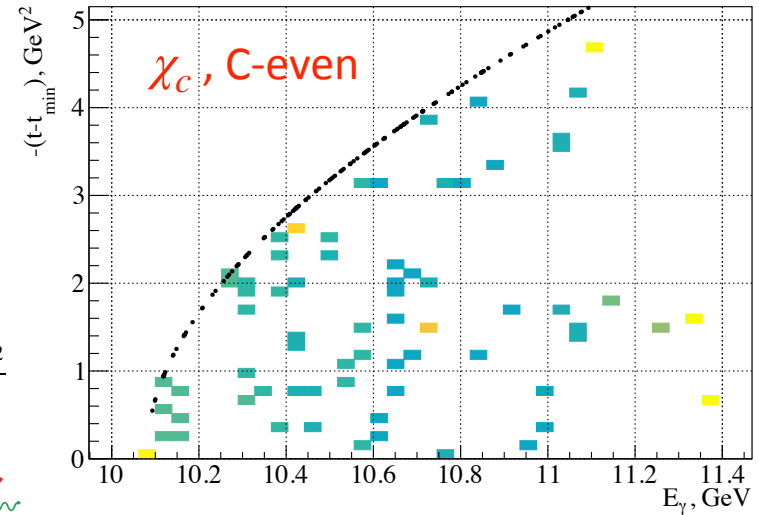
# C-event charmonium states at threshold with GlueX

C-odd ( $J/\psi, \psi'$ ) vs C-even ( $\chi_c$ ) production

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



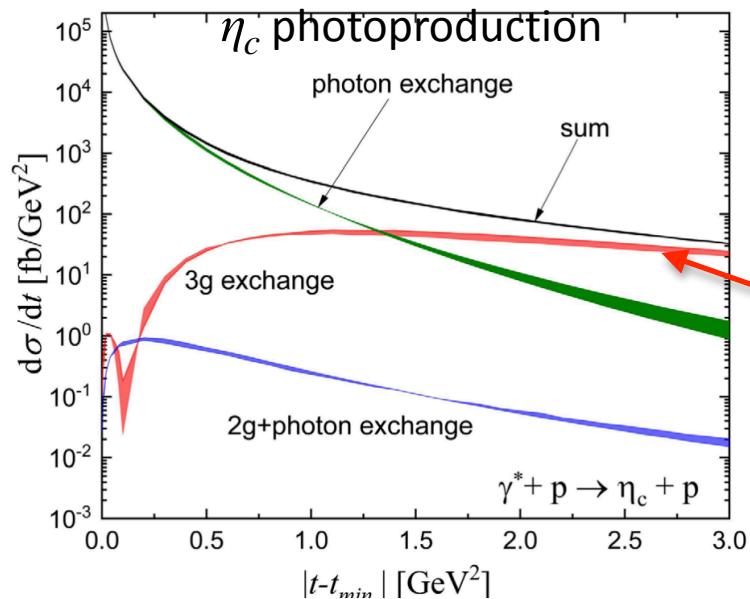
- $\chi_{c1}(3511)$  and  $\chi_{c2}(3556)$ ,  $1^{++}$  and  $2^{++}$  ( $1P$ ),  
 $E_\gamma^{thr} = 10.1$  GeV
- C-even charmonium states require 3g-exchange
- Dramatic difference in  $(E_\gamma, t)$  distribution w.r.t  $J/\psi$



First ever (?) evidence for photoproduction of C-even charmonium

# C-even charmonium states with GlueX

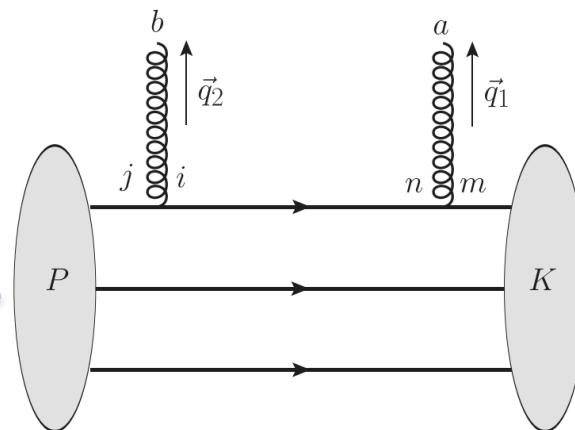
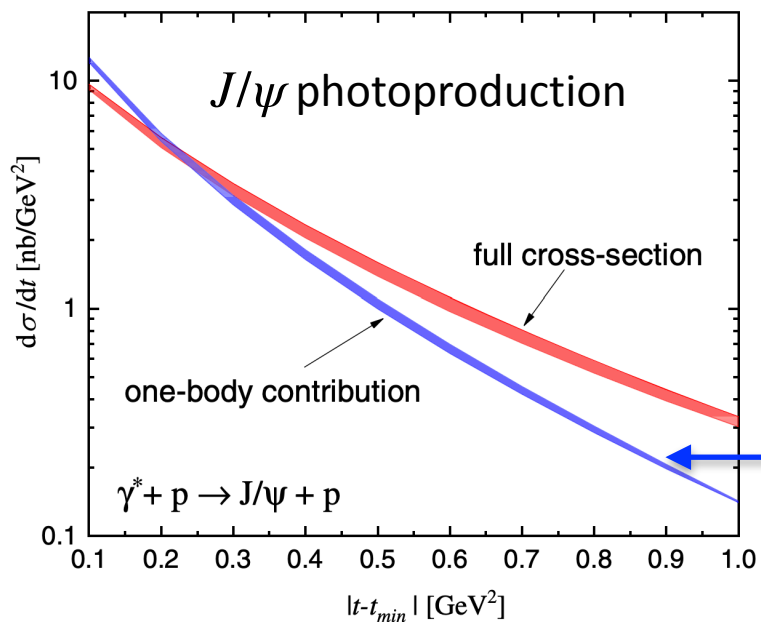
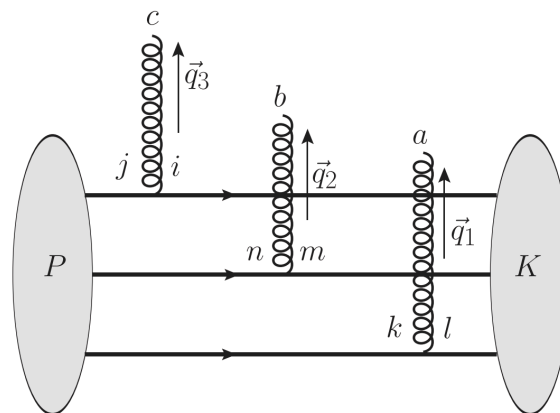
C-odd ( $J/\psi, \psi'$ ) vs C-even ( $\eta_c, \chi_c$ ) production



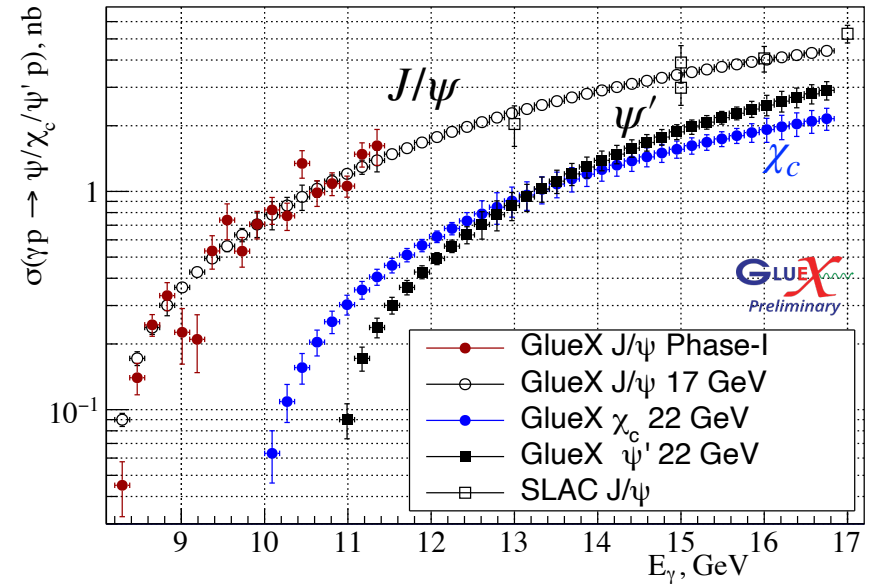
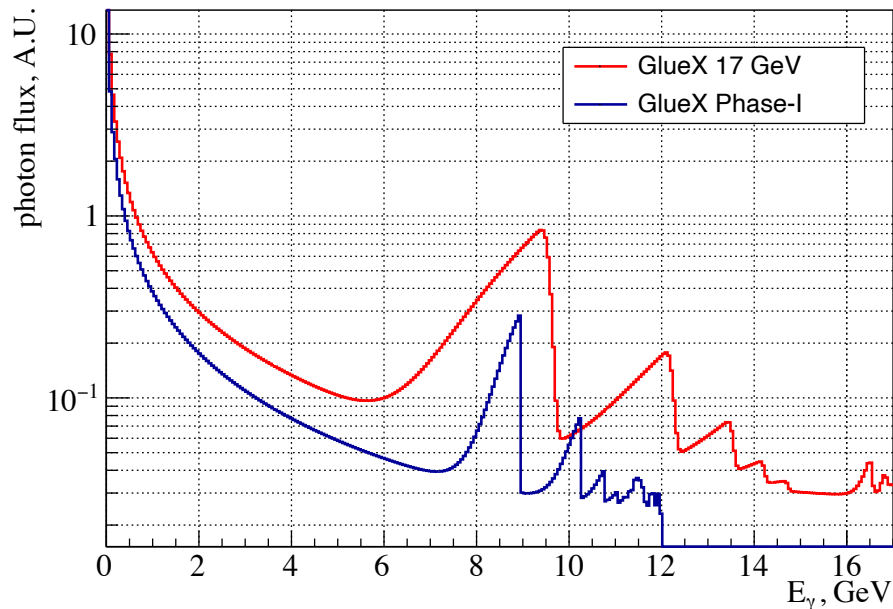
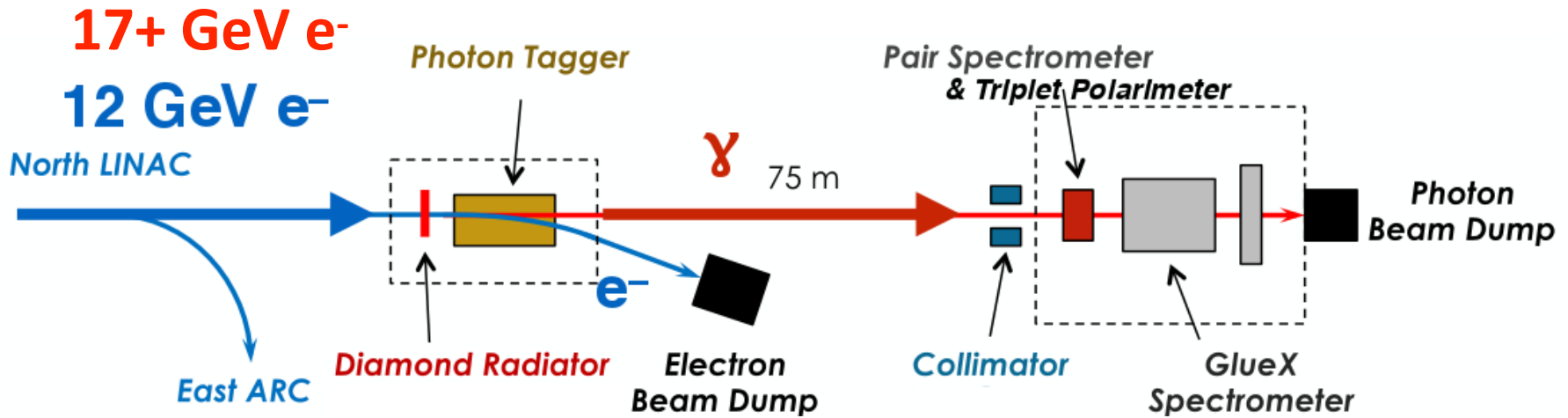
*Dumitru, Skokov, Stebel, PRD 101 (2020)*

*Dumitru, Stebel, PRD 99 (2019)*

$W \sim 7 - 10$  GeV



# Hall D Apparatus with 17+ GeV electron beam

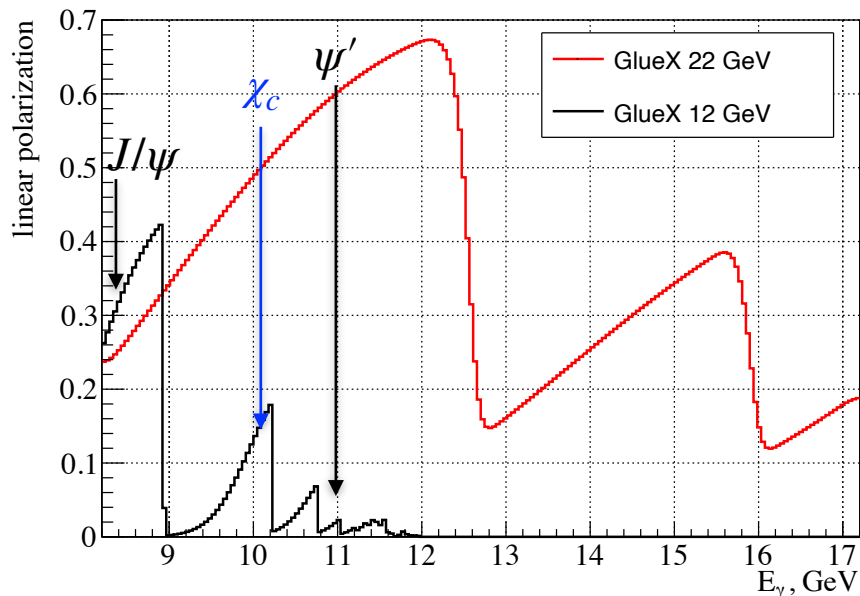


- Moving end point from 12 GeV to 17+ GeV:  
- higher flux (and polarization) toward higher energies, while low energies less affected (no load on detectors)

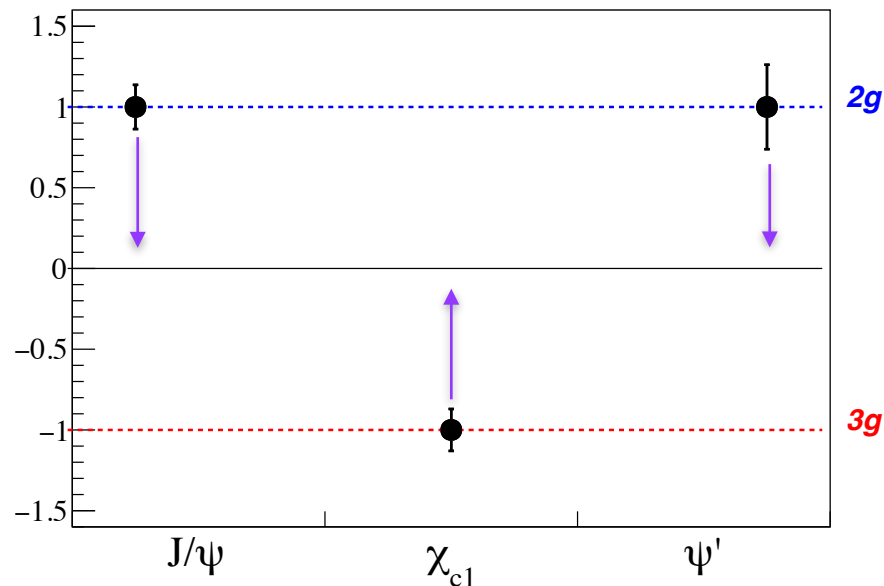
# Charmonium polarization measurements at 22 GeV

$$\text{naturalness} \times (-1)^{J=P}$$

$E_{el} = 22 \text{ GeV}$



naturalness



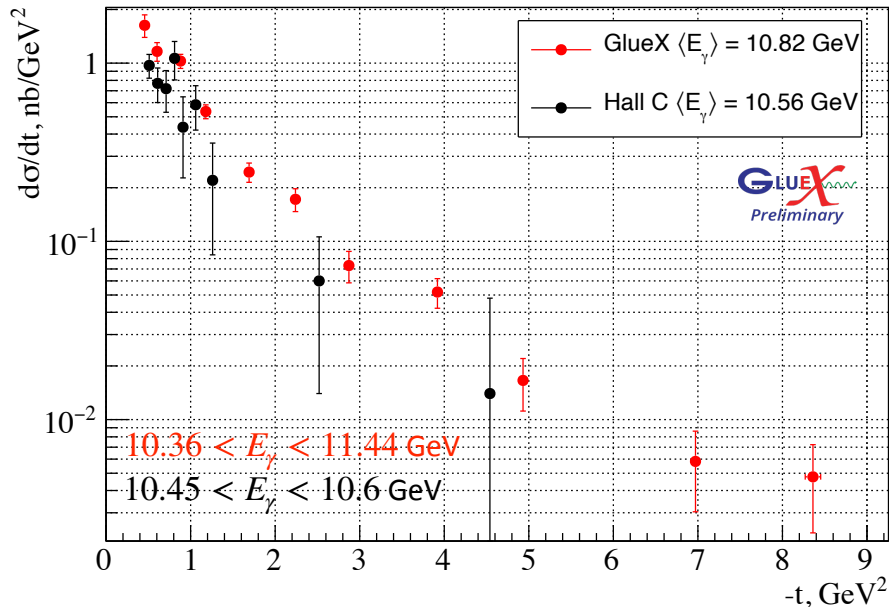
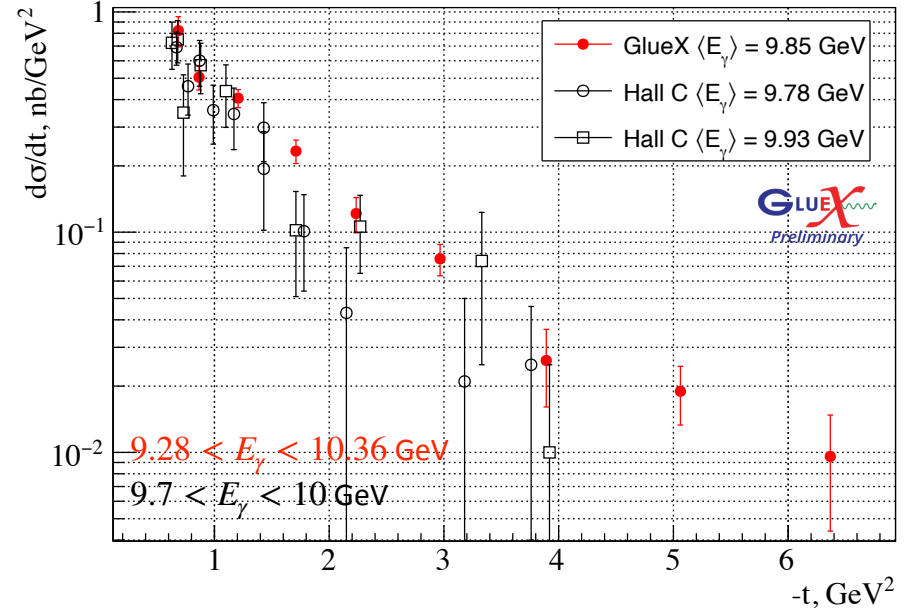
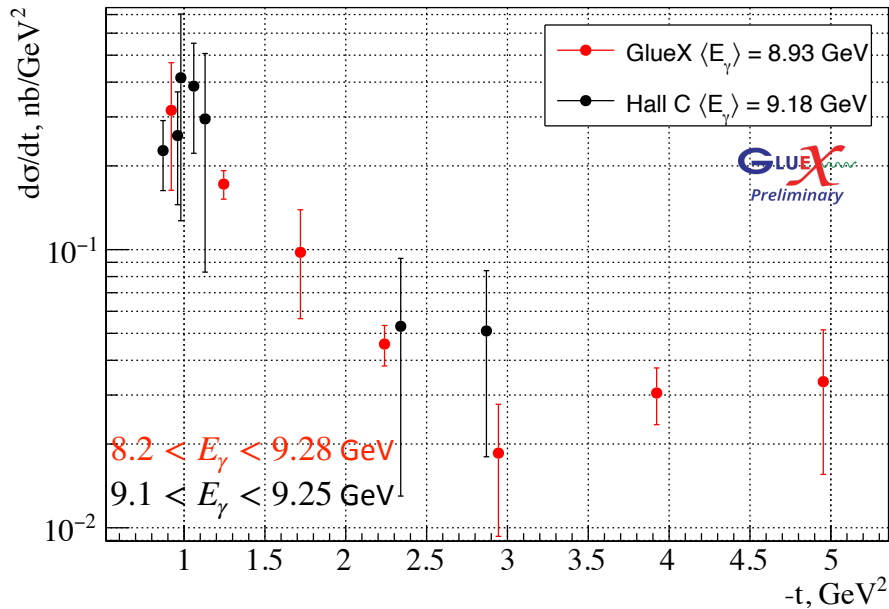
Any deviation from the expected naturalness indicates contribution of mechanism different from what is needed to study mass properties of the proton

# Conclusions

- The reported total and differential cross sections of  $J/\psi$  photoproduction near threshold are generally consistent with gluon exchange (t-slope, GPD factorization), except some features consistent with open charm exchange.
- 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 gravitational form factors and study mass properties of proton.
- First ever (?) evidence for C-even charmonium photoproduction - important tool to understand C-odd exchange mechanism (3gluon - odderon?)
- 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

# Back-ups

# GlueX results: comparison to Hall C (J/ $\psi$ -007)



- Three GlueX energies compared to closest Hall C (J/ $\psi$ -007) energies
- Shown only 4 out of 10 energies for Hall C - common fit of all 10 used to disentangle contributions from  $A_g(t)$  and  $C_g(t)$  (B.Duran <https://arxiv.org/abs/2207.05212>)
- Scale uncertainties: 20% in GlueX and 4% in Hall C results
- **Good agreement within the errors**; note also differences in average energies