



J/ ψ Production at CLAS12

R. Tyson
JLUO Annual Meeting
23rd of June 2026



J/ψ Near-Threshold Photoproduction

We are interested in measuring the process:

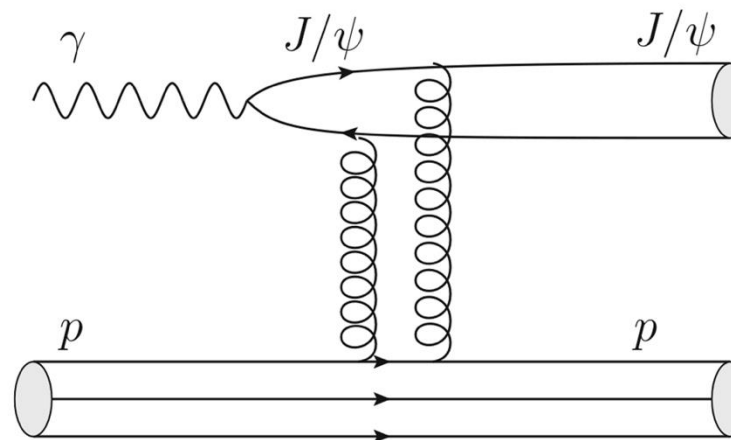
$$eN \rightarrow e'J/\psi N \rightarrow e'l^+l^-N$$

Close to the 8.2 GeV threshold, J/ψ photoproduction is predicted to be mediated by the exchange of two gluons.

Mechanical form factors encode mass, pressure and shear stress distributions of quarks and gluons in nucleon/nuclei.

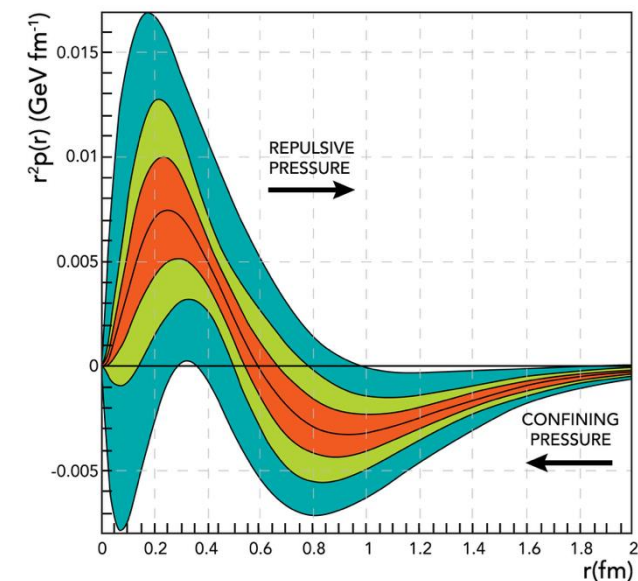
The quark mechanical form factors can be probed with DVCS, TCS, DDVCS.

J/ψ allows to probe the gluonic mechanical form factors.



Pressure
distribution of
quarks inside
the proton.

V. D. Burkert, L. Elouadrhiri, F. X. Girod, *Nature* **557**, 396–399 (2018).



J/ψ Photoproduction on the Free Proton

See talk by P. Chatagnon later today!

GlueX – Hall D

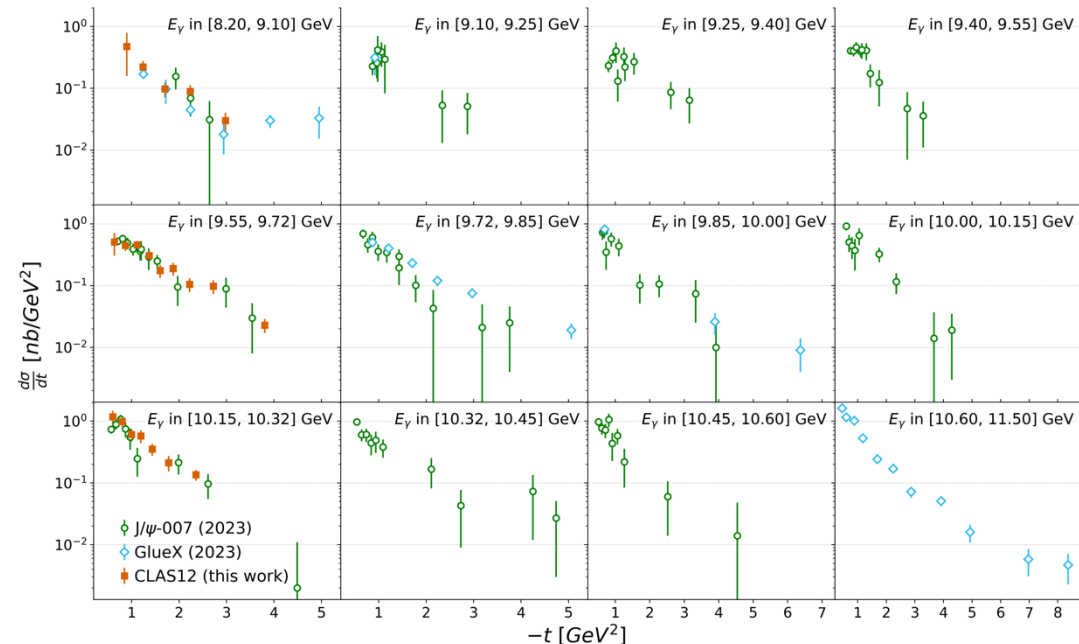
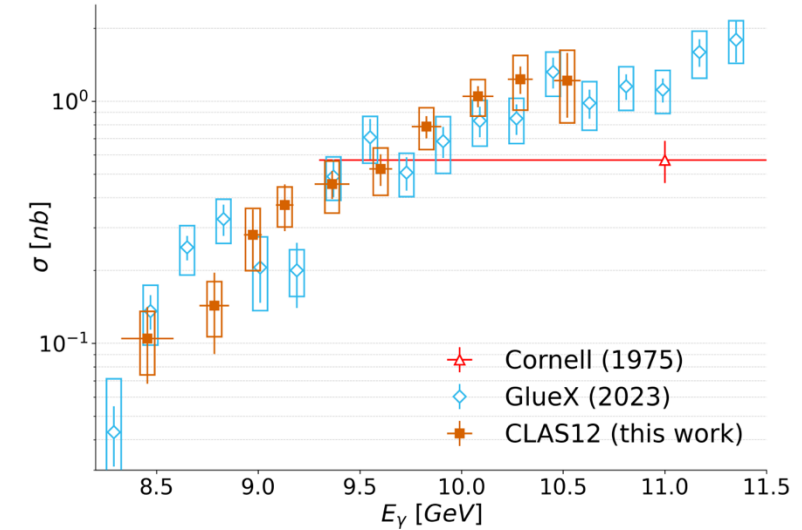
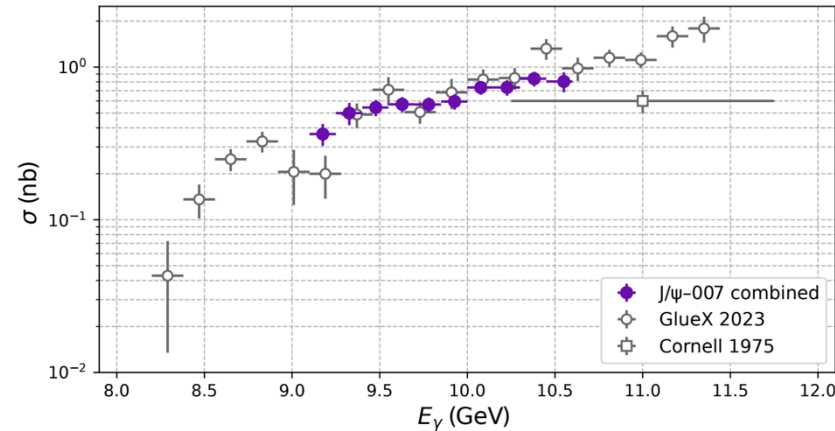
The GlueX Collaboration has made measurements of the total and differential cross section over the full near-threshold range.

J/ψ 007 – Hall C

The J/ψ – 007 Collaboration has made measurements of the total and differential cross section as a function of t in 10 bins of E_γ in e^+e^- and $\mu^+\mu^-$ channels

CLAS12 – Hall B

The CLAS12 Collaboration has made measurements of the total and differential cross section as a function of t in e^+e^- channel



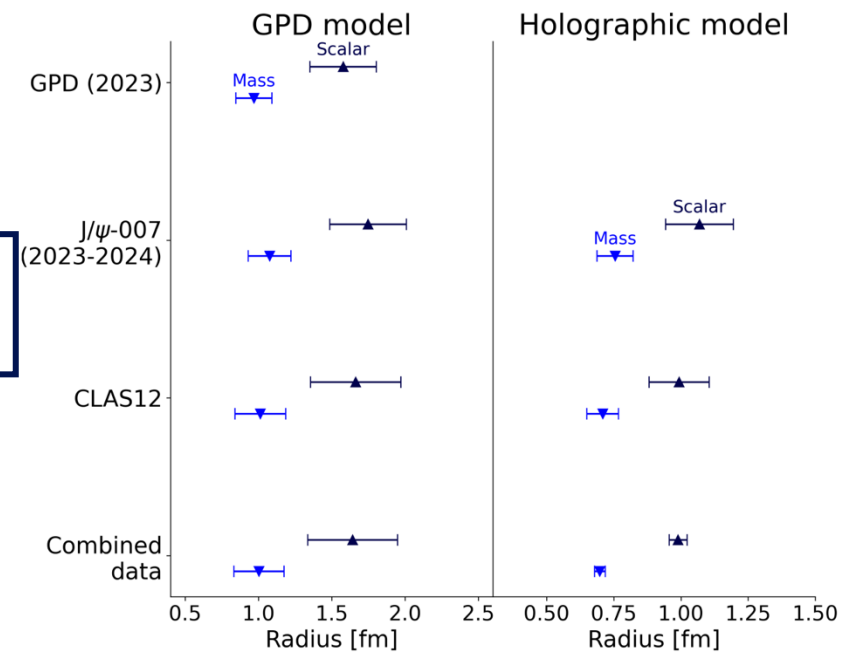
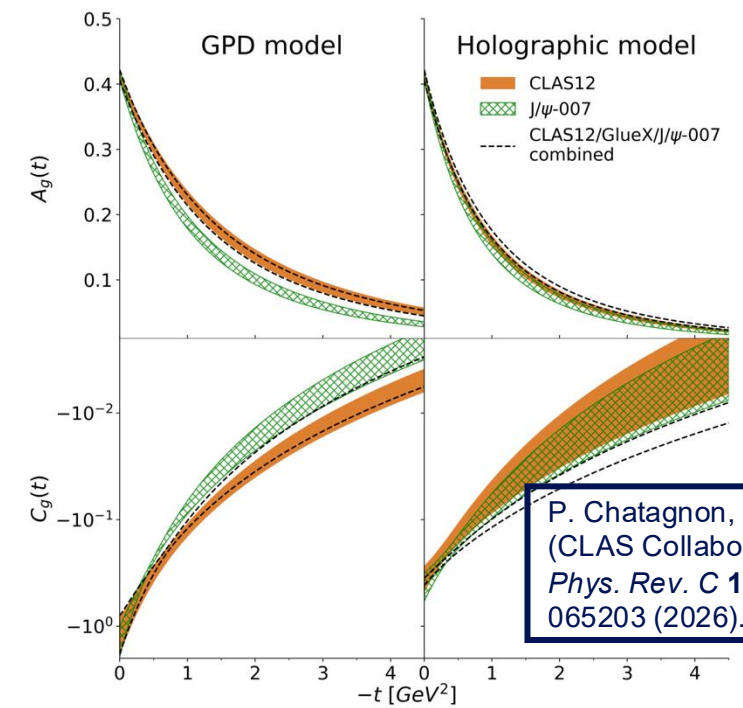
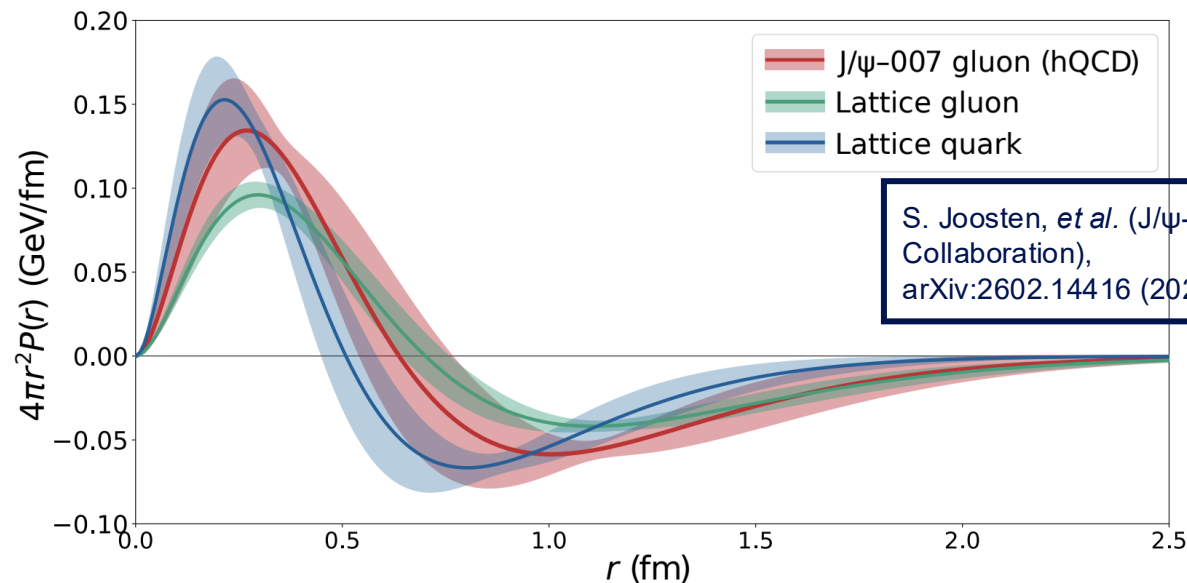
A. Ali, *et al.* (GlueX Collaboration), *Phys. Rev. Lett.* **123**, 072001 (2019).
 S. Adhikari *et al.* (GlueX Collaboration) *Phys. Rev. C* **108**, 025201 (2023).
 D. Duran, *et al.* (J/ψ-007 Collaboration), *Nature* **615** (2023).
 S. Joosten, *et al.* (J/ψ-007 Collaboration), arXiv:2602.14416 (2026).
 P. Chatagnon, *et al.* (CLAS Collaboration) *Phys. Rev. C* **113**, 065203 (2026).

Holographic QCD & GPDs

In holographic QCD a higher dimensional duality relates spin-2 fields to gravity. J/ψ is produced by the exchange of gravitons (tensor 2^{++} glueballs) and scalar (0^{++}) glueballs.

In the GPD framework, large skewness at threshold allows to relate the scattering amplitude to gluon GPDs. The mechanical form factors are extracted from the first moments of the GPDs.

Gluonic pressure distribution in the Breit frame in GeV/fm from $J/\psi - 007$ data



J/ ψ Production and Nuclear Structure

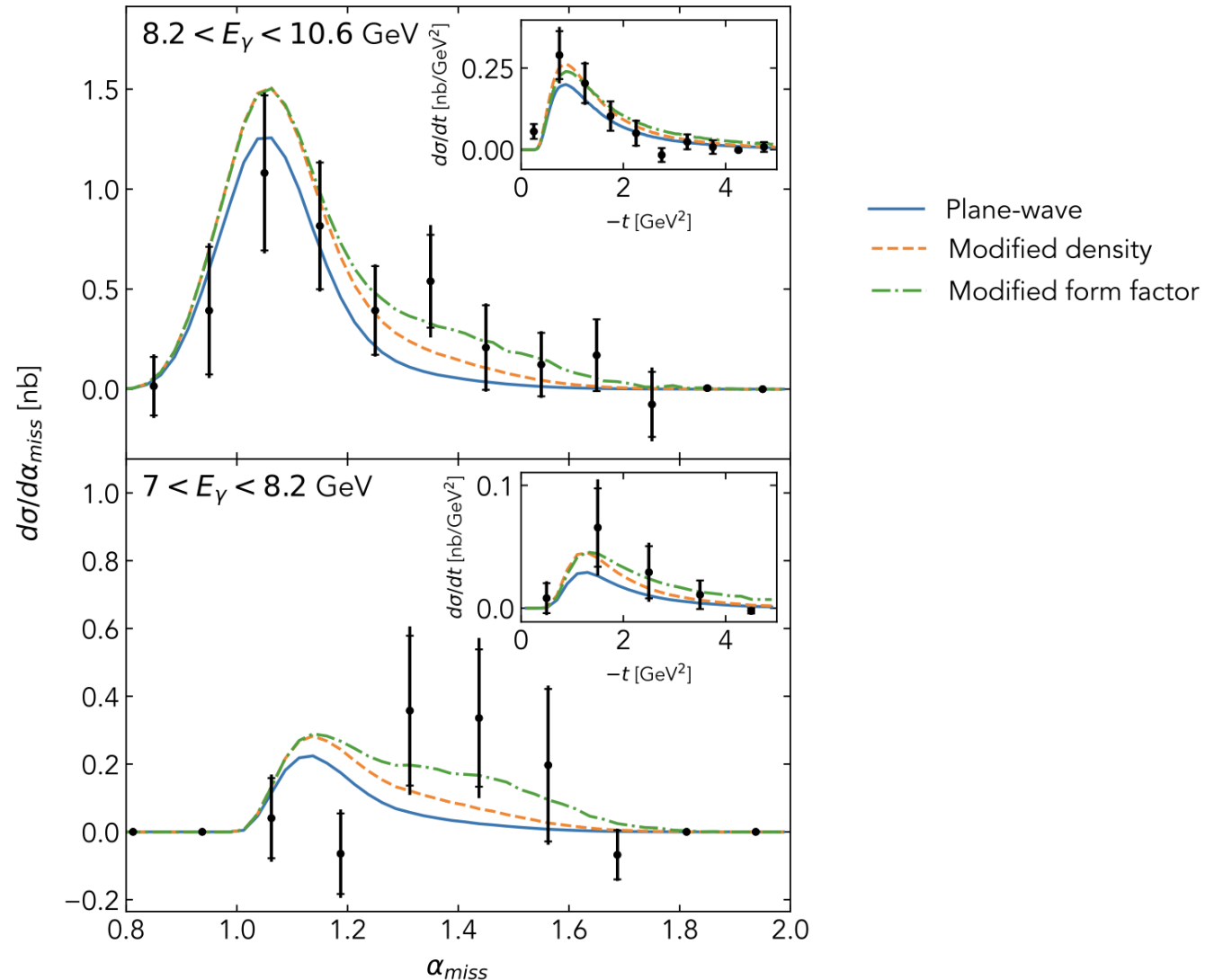
Comparing J/ ψ production on bound vs free proton could hint towards modification of gluon structure of the nucleon in nuclei.

It's been argued that subthreshold production can be a probe of nuclear and SRC structure.

First measurements from SRC-CT (Hall D) contain possible hints of increased subthreshold cross section. Point to:

- Increased gluon density
- Decreased gluon radius

Y. Hatta, *et al.*, *Phys. Lett. B*, **803**, 10 35321 (2020).
J. R. Pybus, *et al.* (SRC-CT Collaboration) *Phys Rev Lett* **134**, 201903 (2025)

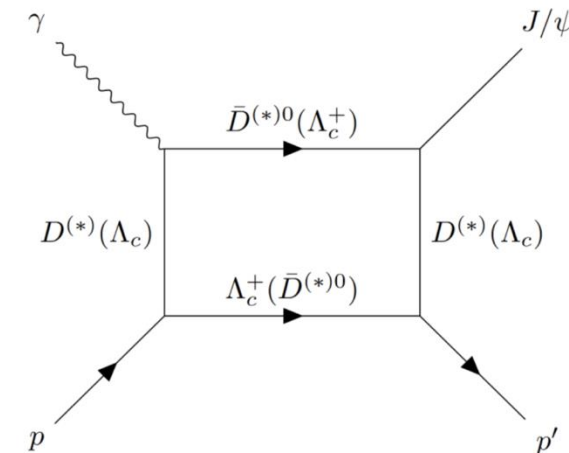
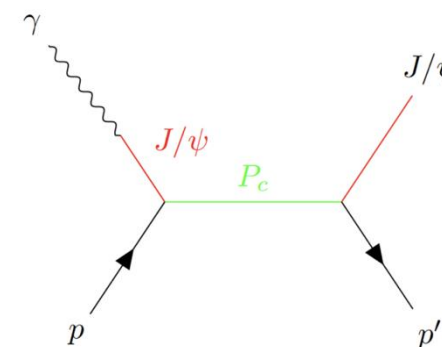
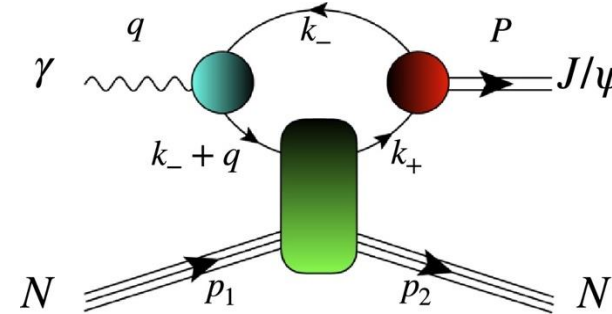
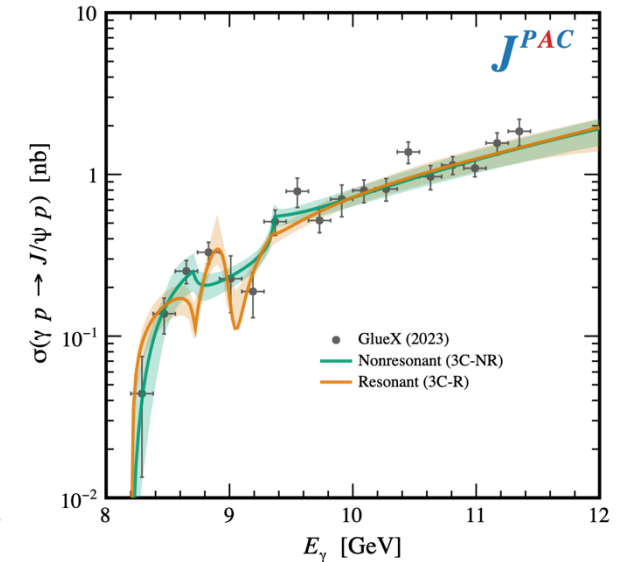
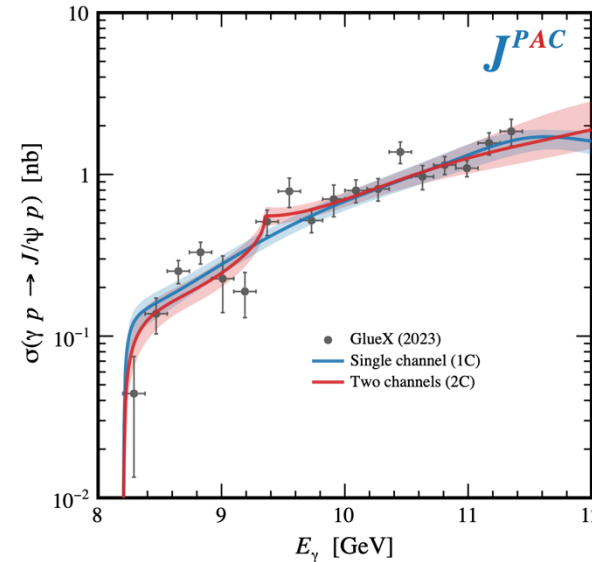


Production Mechanism

Several different proposed near-threshold production mechanisms:

- Two-gluon exchange
- Higher (lower) twist 3 (1) gluon exchange
- Open-Charm intermediate states
- Pomeron exchange
- Meson exchange
- 2015, 2019 LHCb pentaquarks

Need higher statistical precision and polarization observables to distinguish between production mechanisms.



M.-L. Du, *et al.*, *Eur. Phys. J. C* **80** 1053 (2020).
D. Winney, *et al.* (Joint Physics Analysis Center), *Phys. Rev. D* **108** 054018 (2023).
L.Tang, Y.-X. Yang, Z.-F. Cui, C. D. Roberts, *Phys. Lett. B* **856** 138904 (2024).
S.H. Kim, *Phys. Lett. B*, **868** 139725 (2025).
S.J. Brodsky, E. Chudakov, P. Hoyer, J.M. Laget, *Phys.Lett. B* **498** 23 (2001).

What More Can CLAS12 Offer?

CLAS12 has taken several datasets relevant to the points addressed in previous slides.

The RG-B experiment employed a deuterium target.

The RG-C experiment employed a longitudinally polarized NH₃ target

The RG-D and RG-E experiments employed a range of nuclear targets (D₂, C, Al, Cu, Sn, Pb)

We can look at various channels:

$$ep \rightarrow e' J/\psi p \rightarrow (e') e^+ e^- p \quad (\text{free proton})$$

$$e p_{\text{bound}} \rightarrow e' J/\psi p \rightarrow (e') e^+ e^- p \quad (\text{incoherent})$$

$$e n_{\text{bound}} \rightarrow e' J/\psi n \rightarrow (e') e^+ e^- n \quad (\text{incoherent})$$

See R. Paremuzyan talk on Thursday on μ CLAS12!

Experiment	Target(s)	Accumulated Charge (mC)	Data Status
RG-A	LH2	114 mC	~60% Available
RG-B	LD2	107 mC	~60% Available
RG-C	NH3 (long. pol.)	13 mC	~80% Available
RG-D	LD2, CuSn, CxC	32, 183, 33 mC	Available
RG-E	LD2+ C, LD2+Al, LD2+Cu, LD2+Sn, LD2+Pb,	24, 21, 22, 22, 27 mC	Available

Proposal to 2025 JLab PAC:

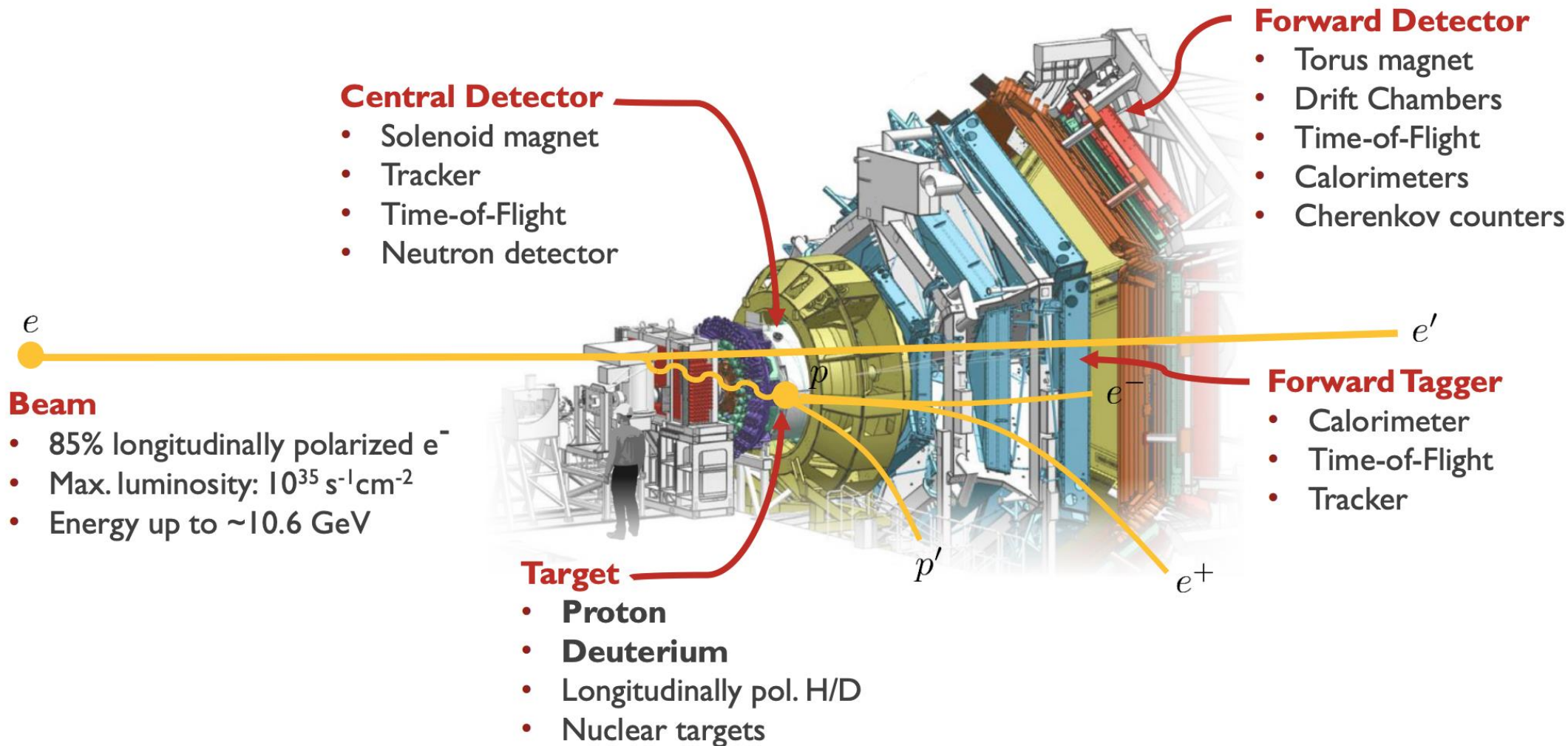
- A Measurement of the Coherent J/ψ Electroproduction Cross Section off ^4He – deferred until existing data is analysed
- Electro- and photo-production of muon pairs with μ CLAS12 - J/ψ , TCS and DDVCS at high luminosity, approved

Submissions to 2026 JLab PAC:

- Direct measurement of open charm photoproduction cross section (Open Charm at JLab with the sPHENIX MAPS Tracker - Proposal)
- J/ψ on carbon and tungsten targets (J/ψ production on Nuclear Targets - Letter of Intent)



CLAS12



Beam

- 85% longitudinally polarized e^-
- Max. luminosity: $10^{35} \text{ s}^{-1} \text{ cm}^{-2}$
- Energy up to $\sim 10.6 \text{ GeV}$

Target

- Proton
- Deuterium
- Longitudinally pol. H/D
- Nuclear targets

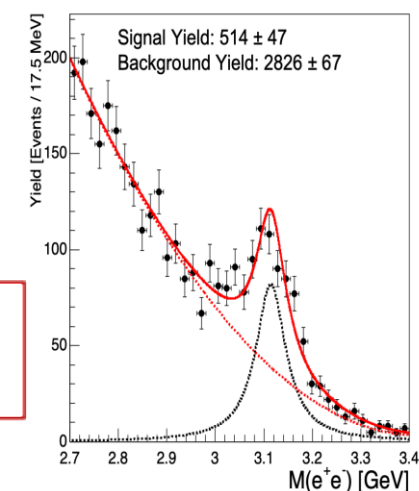
Cross Section Calculation

Total cross section as a function of quasi-real virtual photon energy

$$\sigma_0(E_\gamma)$$

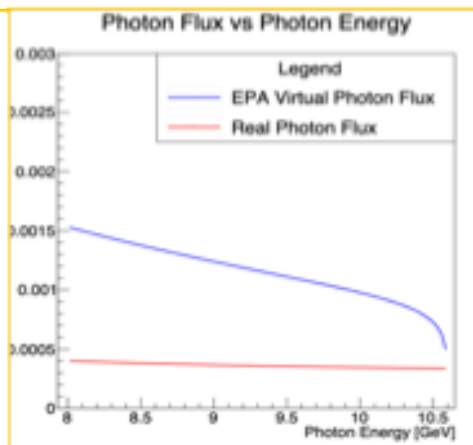
$$= \frac{N_{J/\psi}(E_\gamma)}{N_\gamma(E_\gamma) \cdot l_T \cdot \rho_T \cdot Br \cdot R_c(E_\gamma) \cdot \epsilon(E_\gamma) \cdot \omega_c}$$

Number of J/ψ from fit in E_γ bins



Luminosity:

N_γ is calculated from the photon flux
 l_T and ρ_T are the target length and density

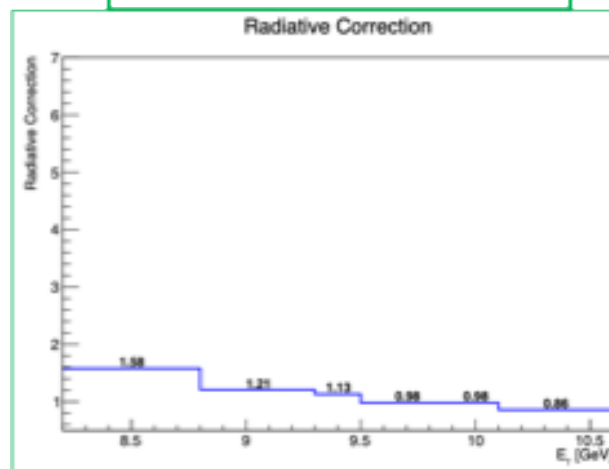


6 % Branching Ratio
($J/\psi \rightarrow e^+e^-$)

Efficiency in E_γ bins from MC

Normalisation to Bethe Heitler process

Radiative Corrections



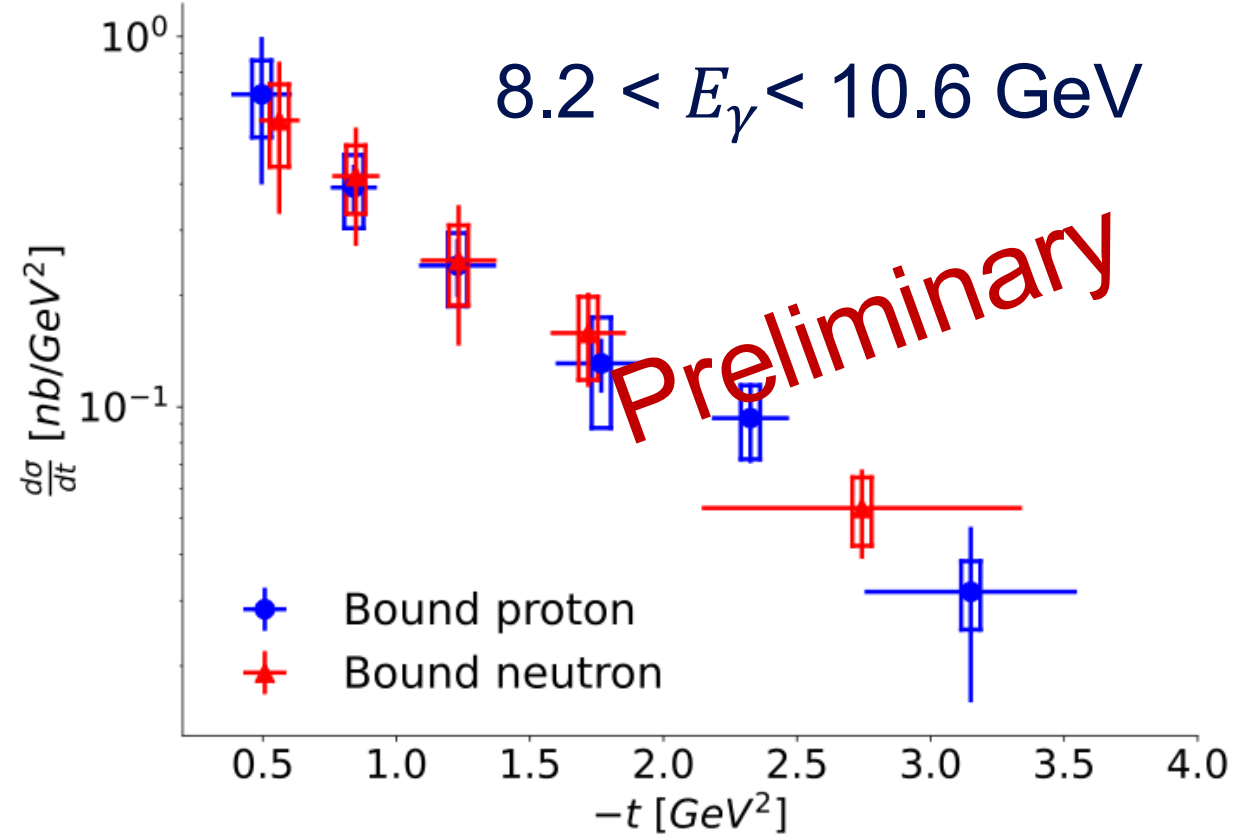
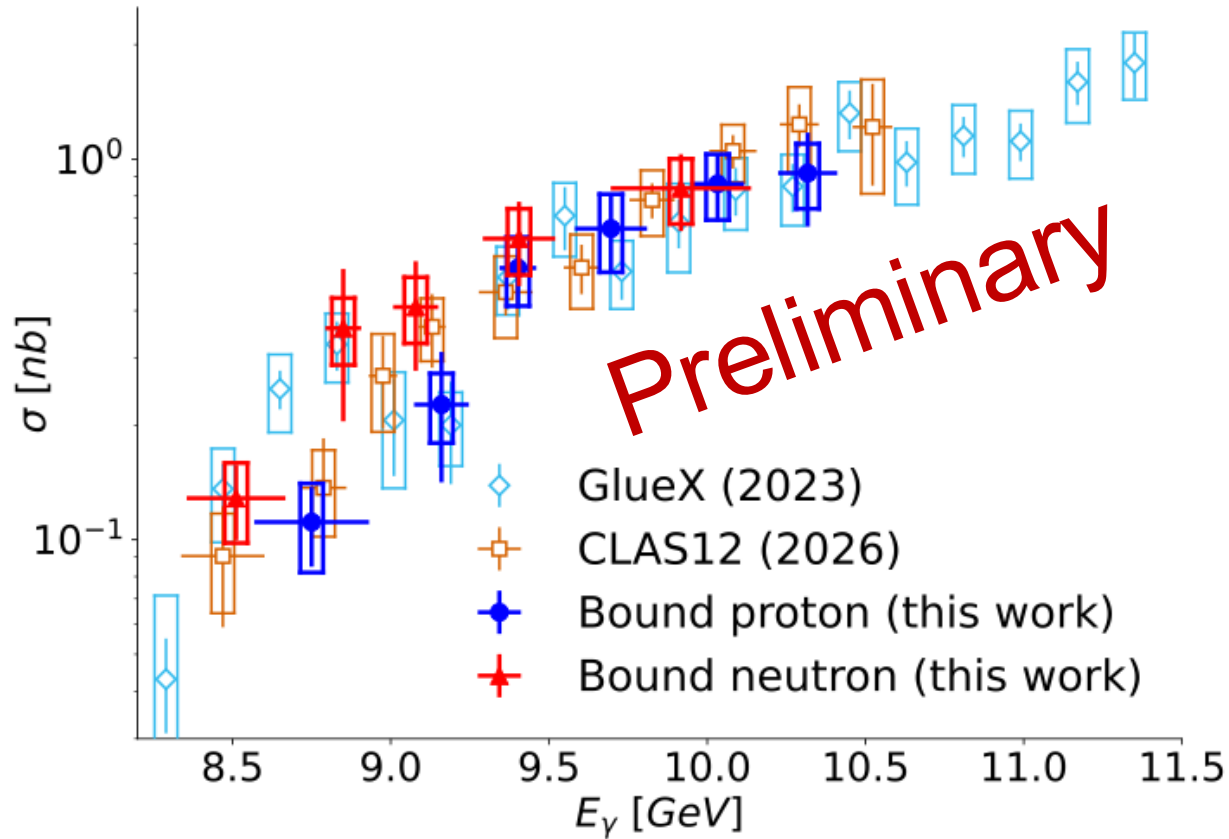
Could also call this a correction to the efficiency and flux calculations.



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Incoherent J/ψ Production in LD2

Further
constraints on
production
mechanism?



Analysis approved, article in
CLAS Collaboration review

Incoherent J/ ψ Production in LD2

Fit the **mechanical form factors** shown below to differential cross section:

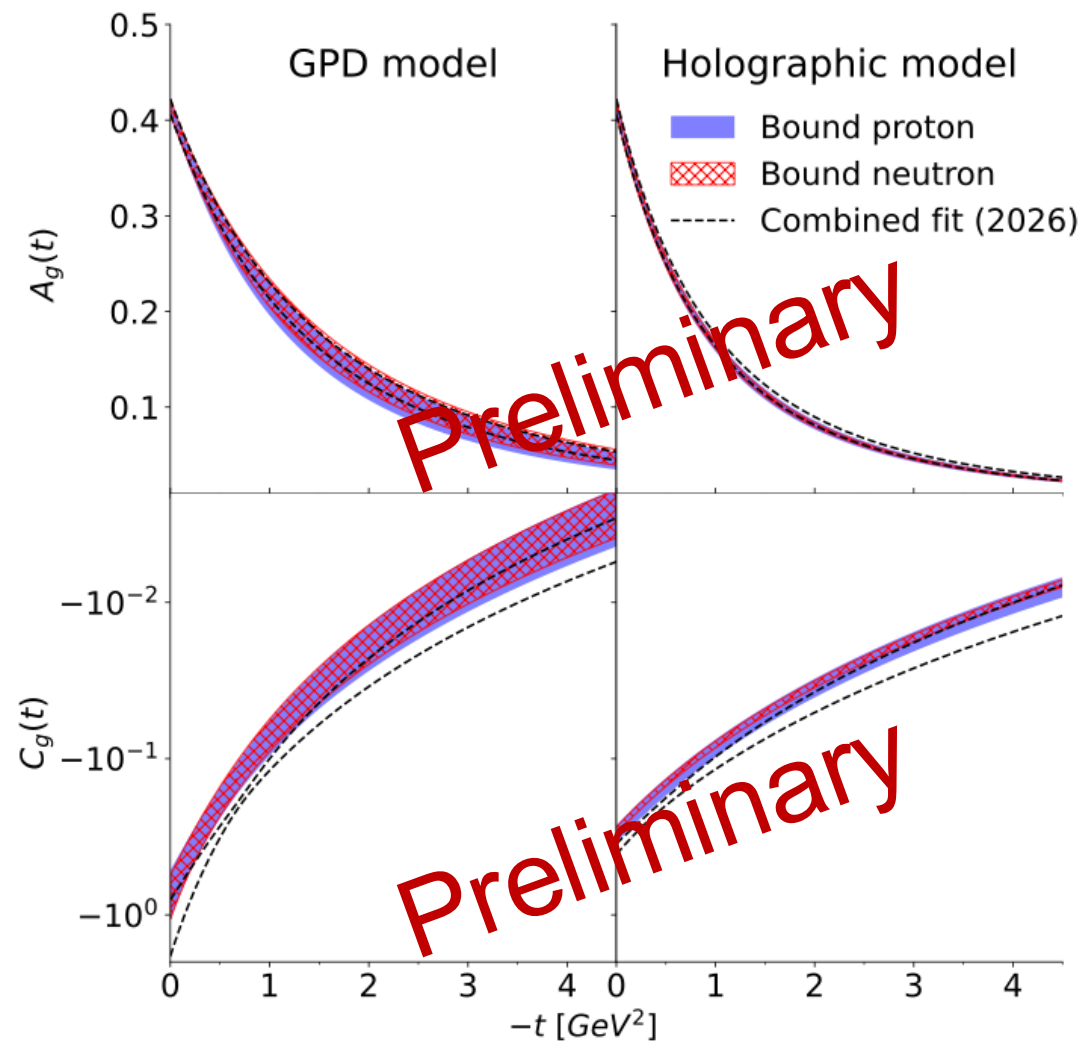
$$\langle N' | T_{q,g}^{\mu,\nu} | N \rangle = \bar{u}(N') \left(A_{q,g}(t) \gamma^{\mu\nu} + B_{q,g}(t) \frac{iP^{\mu\sigma\nu} \rho \Delta_\rho}{2M} + C_{q,g}(t) \frac{\Delta^\mu \Delta^\nu - g^{\mu\nu} \Delta^2}{M} + \bar{C}_{q,g}(t) M g^{\mu\nu} \right) u(N)$$

Some assumptions in fit:

- Assume dominant two-gluon production mechanism
- Assume FSI contribution to cross section much smaller than plane wave impulse approximation (A. Freese, M.M Sargsian, *Phys. Rev. C* **88**, 044604 (2013.))
- Neglect $B(t)$ and $\bar{C}(t)$.
- Assume tripole shape for mechanical form factors:

$$A_g(t) = \frac{A_g(0)}{\left(1 - \frac{t}{m_A}\right)^3}, C_g(t) = \frac{C_g(0)}{\left(1 - \frac{t}{m_C}\right)^3}$$

- Gaussian constrained with $A_{t=0}$ constrained to the average gluon PDF from CT18, m_C to free proton data.

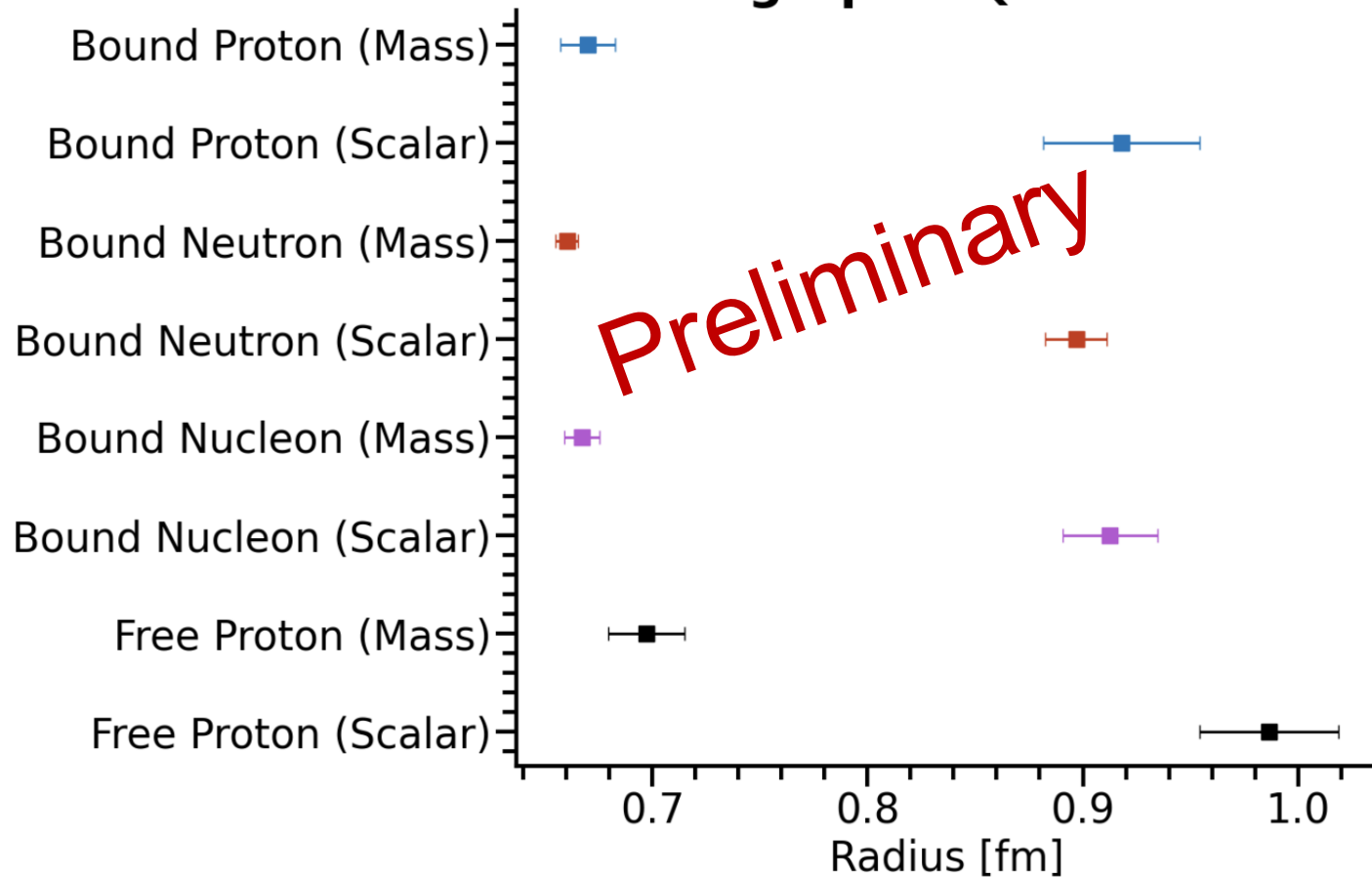




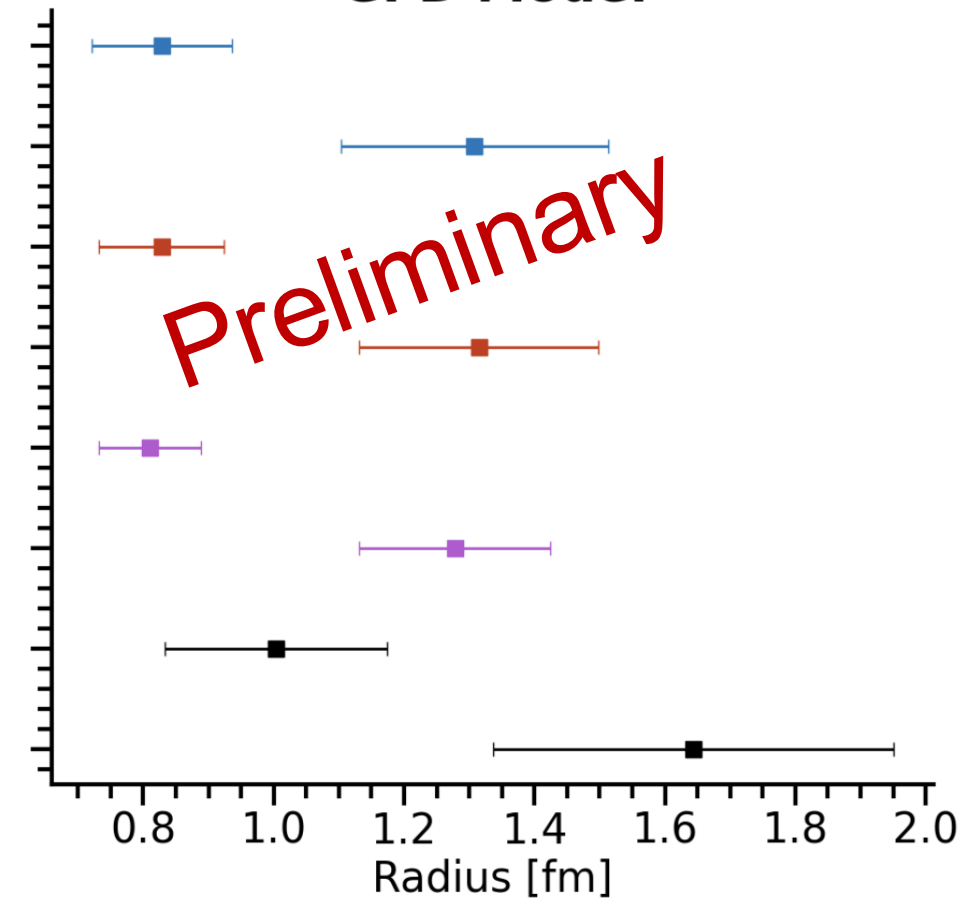
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Incoherent J/ψ Production in LD2

Holographic QCD Model



GPD Model



J/ψ Polarisation Observables

D. Winney, et al. (JPAC Collaboration), *Phys. Rev. D* **100**, 034019 (2019).

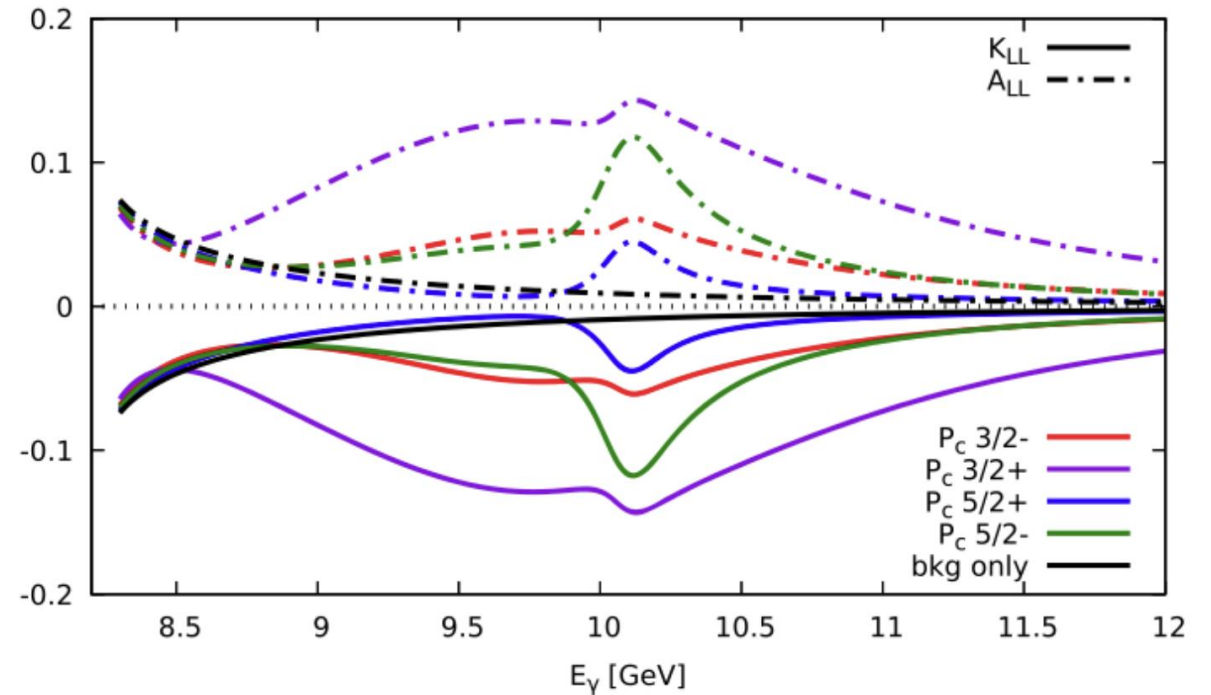
Predictions from JPAC on Double Spin Asymmetry for LHCb pentaquark production.

Possible further predictions for open-charm and gluon exchange production mechanism.

Aim is to measure:

- Unpolarised Spin Density Matrix Elements (SDMEs)
- Beam Spin Asymmetry (BSA)
- Target Spin Asymmetry (longitudinally polarised target)
- Double Spin Asymmetry (longitudinally polarised target)

Compare BSA and SDME measurements on longitudinally polarised and unpolarised targets.



$$\text{BSA; } A_{LU} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{P_b \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$\text{TSA; } A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{D_f \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$\text{DSA; } A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{P_B \cdot D_f (P_T^-(N^{++} + N^{-+}) + P_T^+(N^{+-} + N^{--}))}$$

J/ψ Polarisation Observables

NH3 (long. pol.)

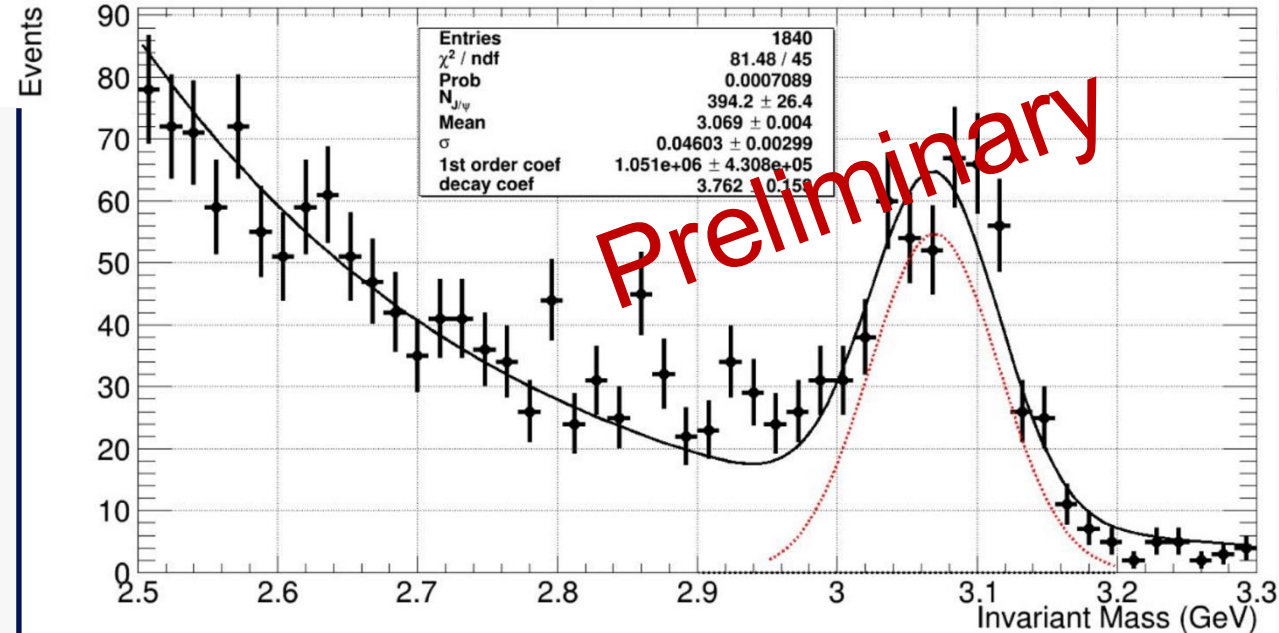
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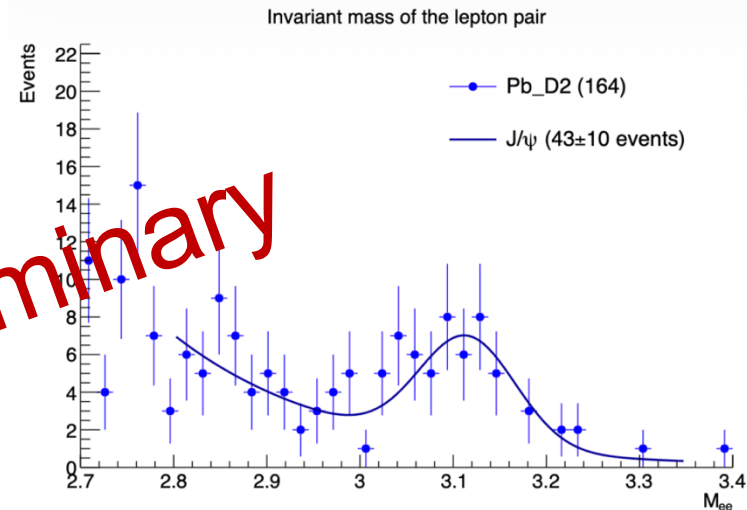
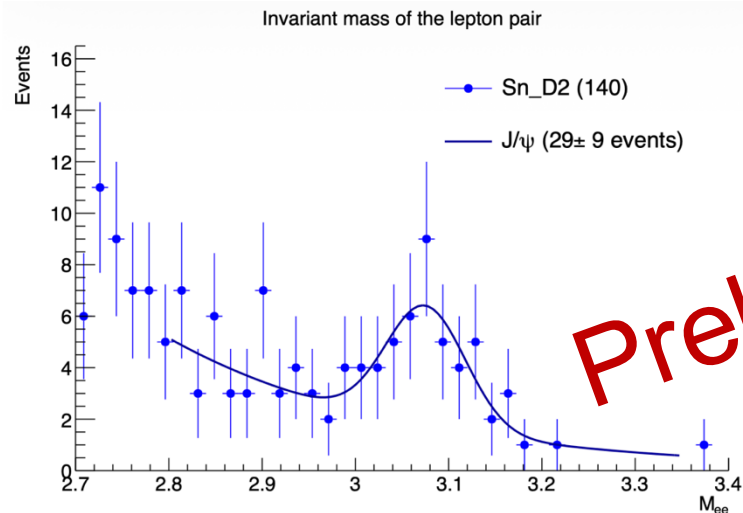
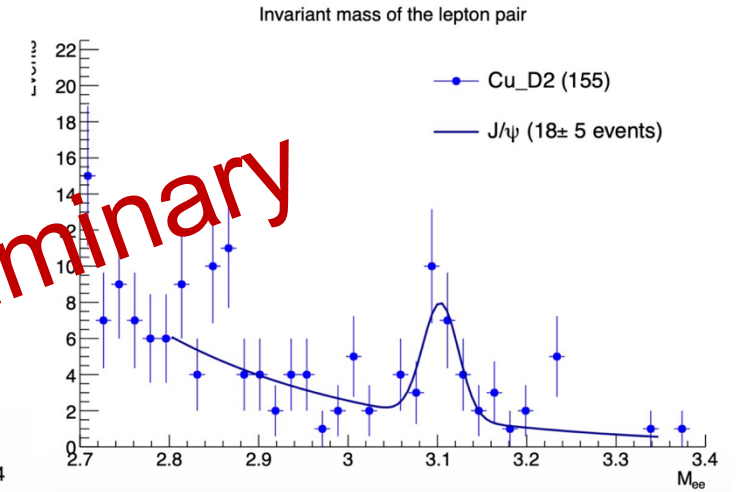
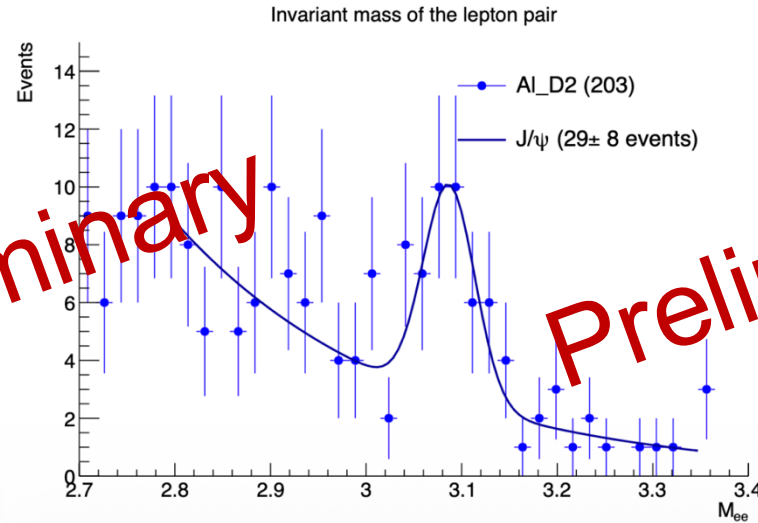
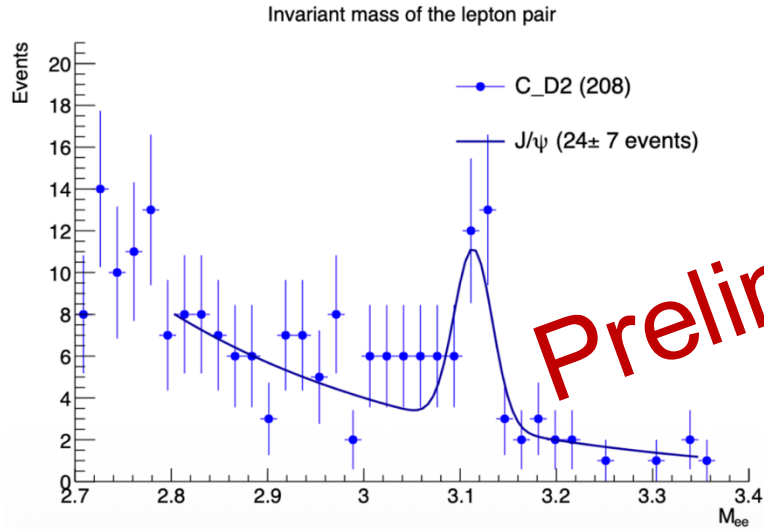
$$\text{BSA; } A_{LU} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{P_b \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$\text{TSA; } A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{D_f \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$\text{DSA; } A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{P_B \cdot D_f (P_T^-(N^{++} + N^{-+}) + P_T^+(N^{+-} + N^{--}))}$$



Incoherent J/ψ Yield Estimation with Nuclear Targets



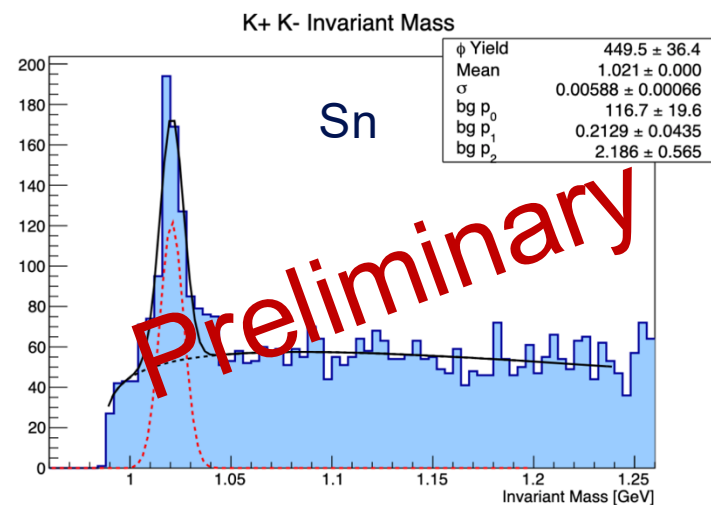
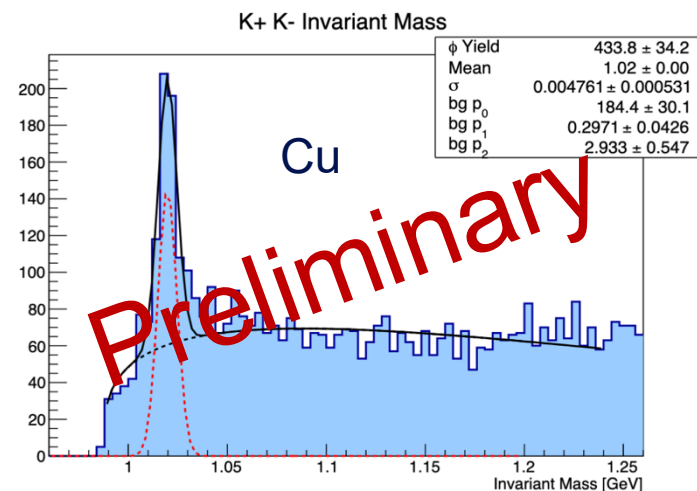
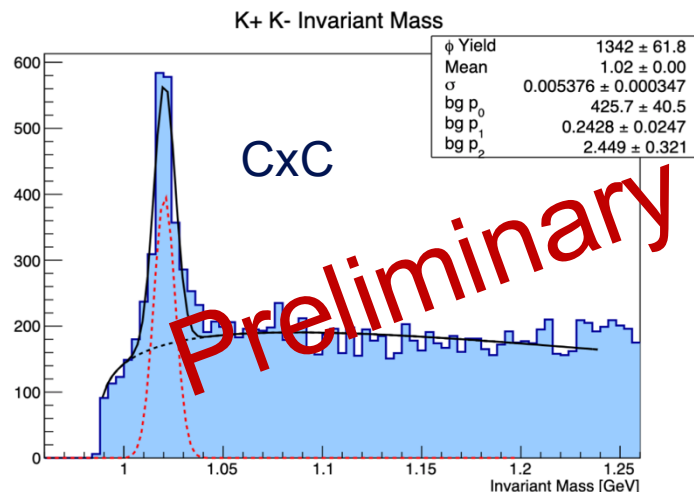
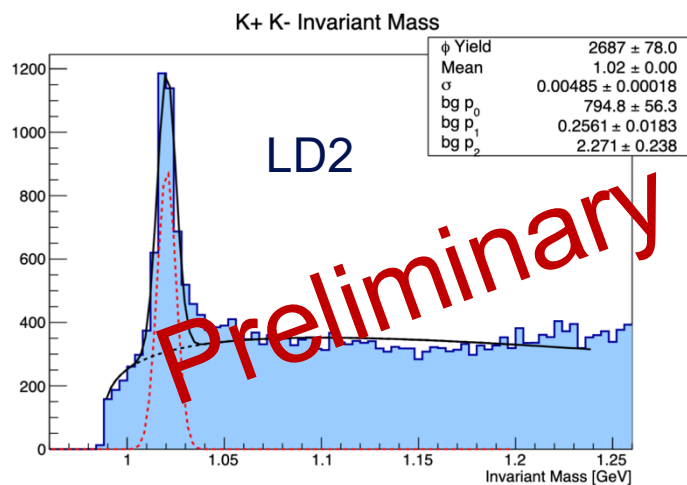
Letter of Intent submitted to PAC for J/ψ production on carbon and tungsten targets (P. Chatagnon, S. Paul, RT)

P. Chatagnon

SRC-CT published measurements:

- ~ 50 J/ψ on C
- ~ 45 J/ψ on He
- ~ 25 J/ψ on D

Incoherent ϕ Yield Estimation with Nuclear Targets



Two datasets RG-D, and RG-E, yield estimation with $\sim 10\%$ of RG-D.

Expected final yields on full RG-D dataset

- LD2: ~ 25000
- CxC: ~ 13000
- Cu: ~ 4500
- Sn: ~ 4500

Aim to probe:

- Cross section ratios (function of x)
- Q^2 dependence
- Model dependent FSI contribution
- Coherent production on d (Q^2 dependence)
- Coherent production via entanglement enabled intensity interferometry?

Conclusion

CLAS12 has released measurements of the total and differential cross section on the free proton.

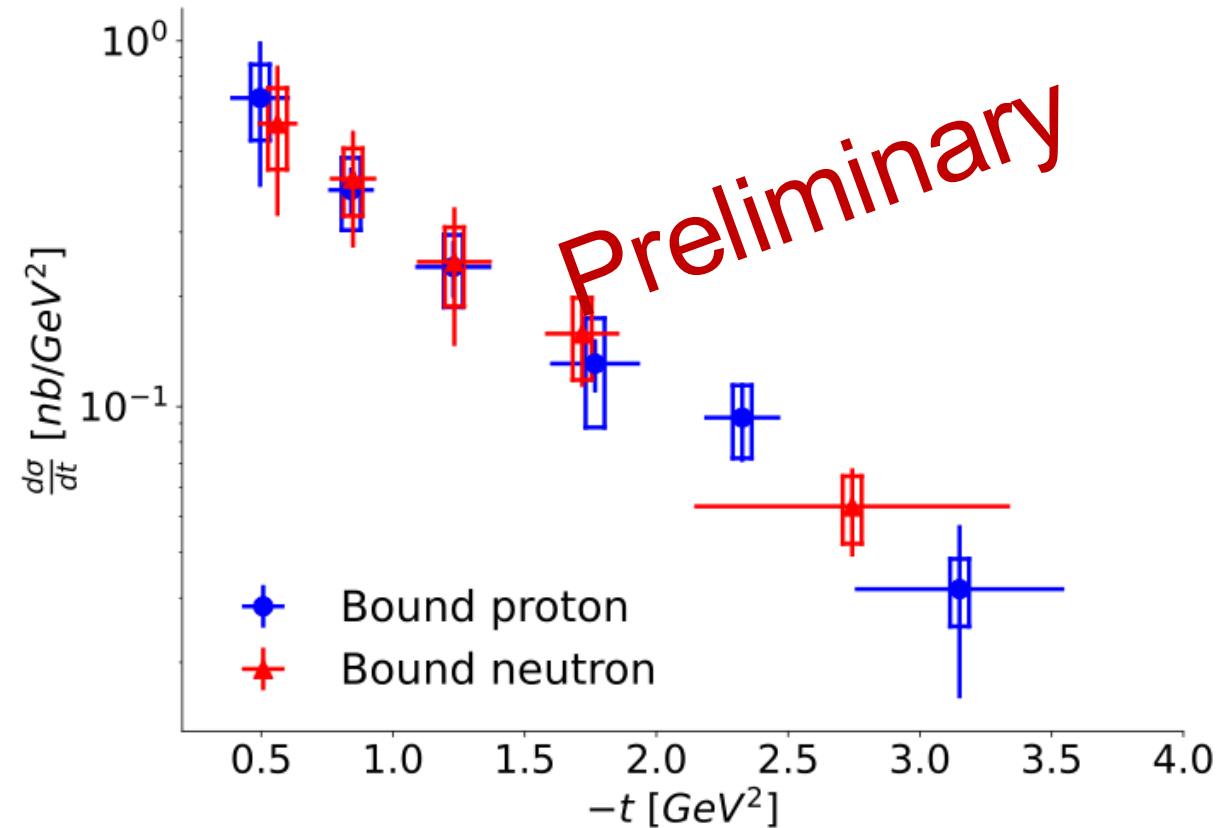
Plenty more interesting results to come:

- Measurements on the bound proton and neutron in deuterium (article in collaboration review)
- Measurements of polarization observables, including on longitudinally polarized targets (early stage)
- Measurements on nuclear targets (early stages)

Few things I didn't have time to discuss further:

- Coherent production on deuteron (N. Silva, Y. Ilieva)
- Direct measurement of open charm cross section (proposal to PAC by S. Paul *et al.*)
- Measurements on 4He (W.R. Armstrong, S. Lee)

Theory support and suggestions always welcome!!





Back-up Slides



General Analysis Steps

Particle & Event Selection

Momentum measured by drift chambers.

Time of Flight Detectors used for hadron PID.

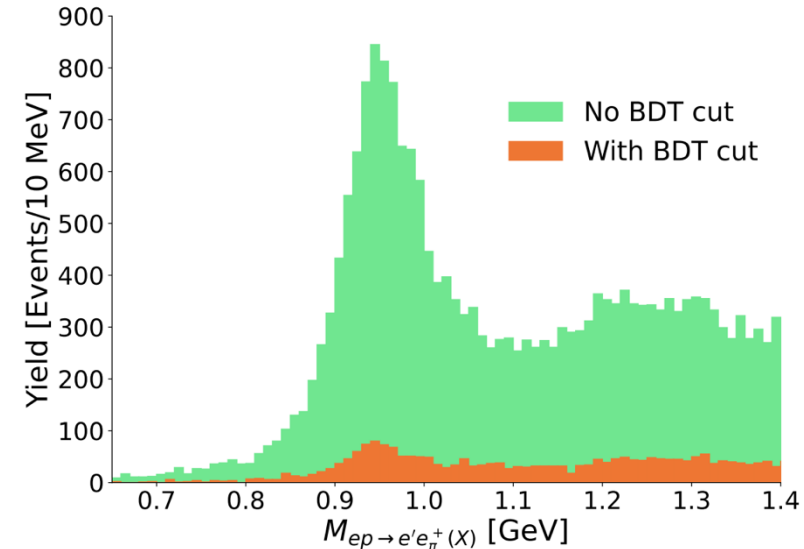
High Threshold Cherenkov Counters and electromagnetic calorimeters used to ID electrons,

Above 4.5 GeV, employ ML based PID.

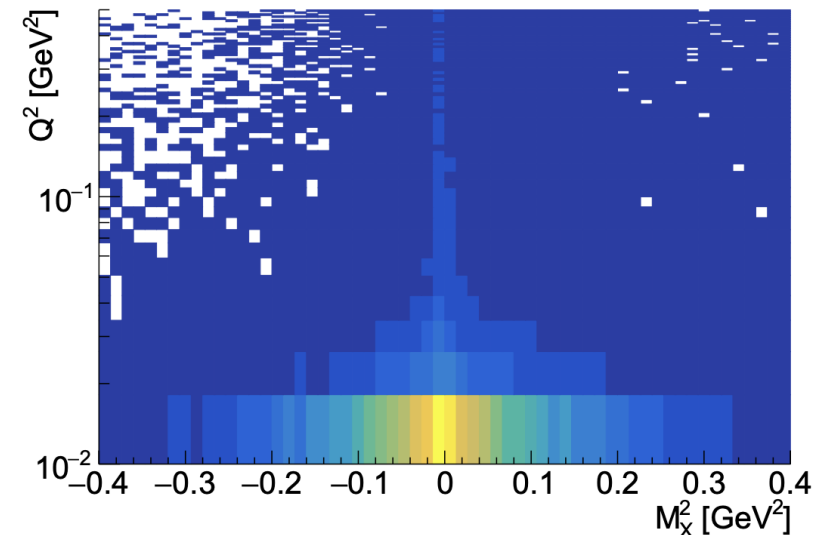
Use cuts on Q^2 and missing mass squared from:
 $eN \rightarrow e^+e^-N(X)$

-t measured using recoil nucleon. E_γ measured from final state e^+e^-N

Yield obtained by fitting e^+e^- invariant mass.



Suppressing π^+
IDed as e^+ .



Efficiency & Normalisation

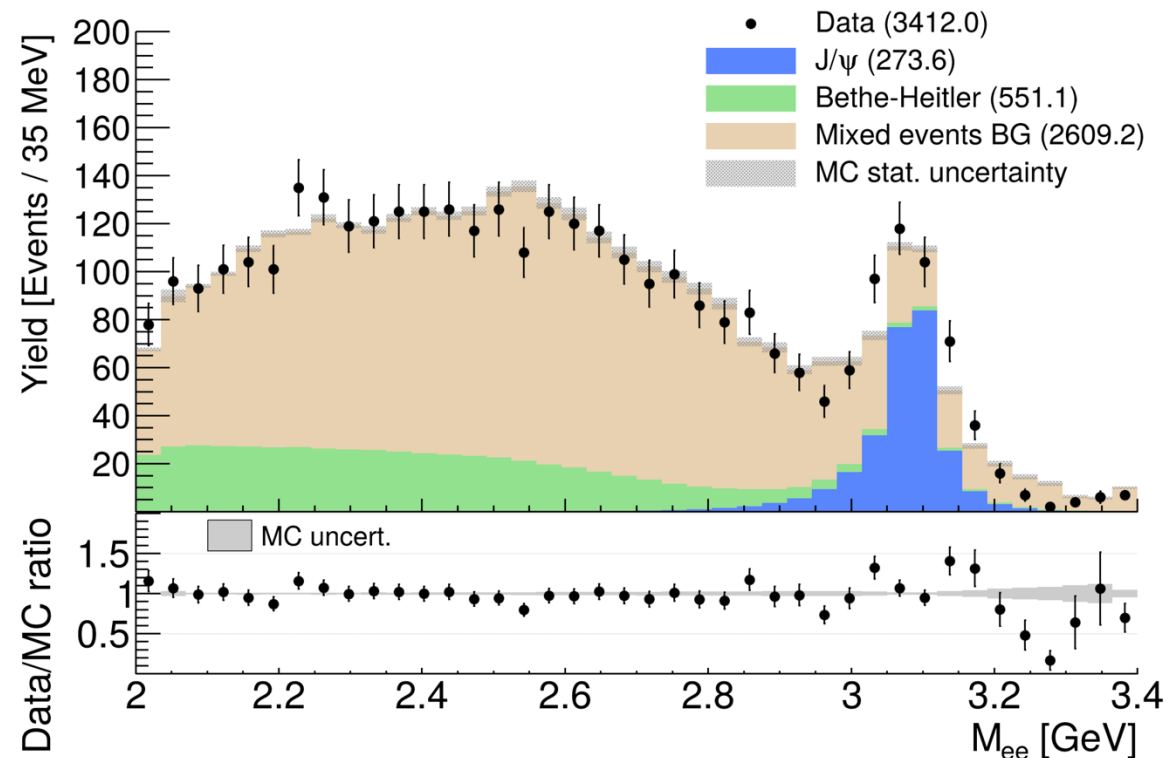
The efficiency calculation takes into account geometrical acceptance and detection efficiency effects on the measured J/ψ rate, generally obtained from MC.

Several corrections are applied to the MC:

- Smearing to reconstructed momentum and angles.
- Neutron detection efficiency.
- Reconstruction efficiency as a function of beam current.
- Efficiency ratios for e^+/e^- PID and exclusivity cuts.

Further compare the expected number of Bethe Heitler events in MC to that in CLAS12 data in the invariant mass region of 2.0 - 2.9 GeV. This accounts for errors in the efficiency and flux calculations.

Systematic uncertainty on the Bethe Heitler normalization 10 - 20 %.



Vector Meson Dominance Framework

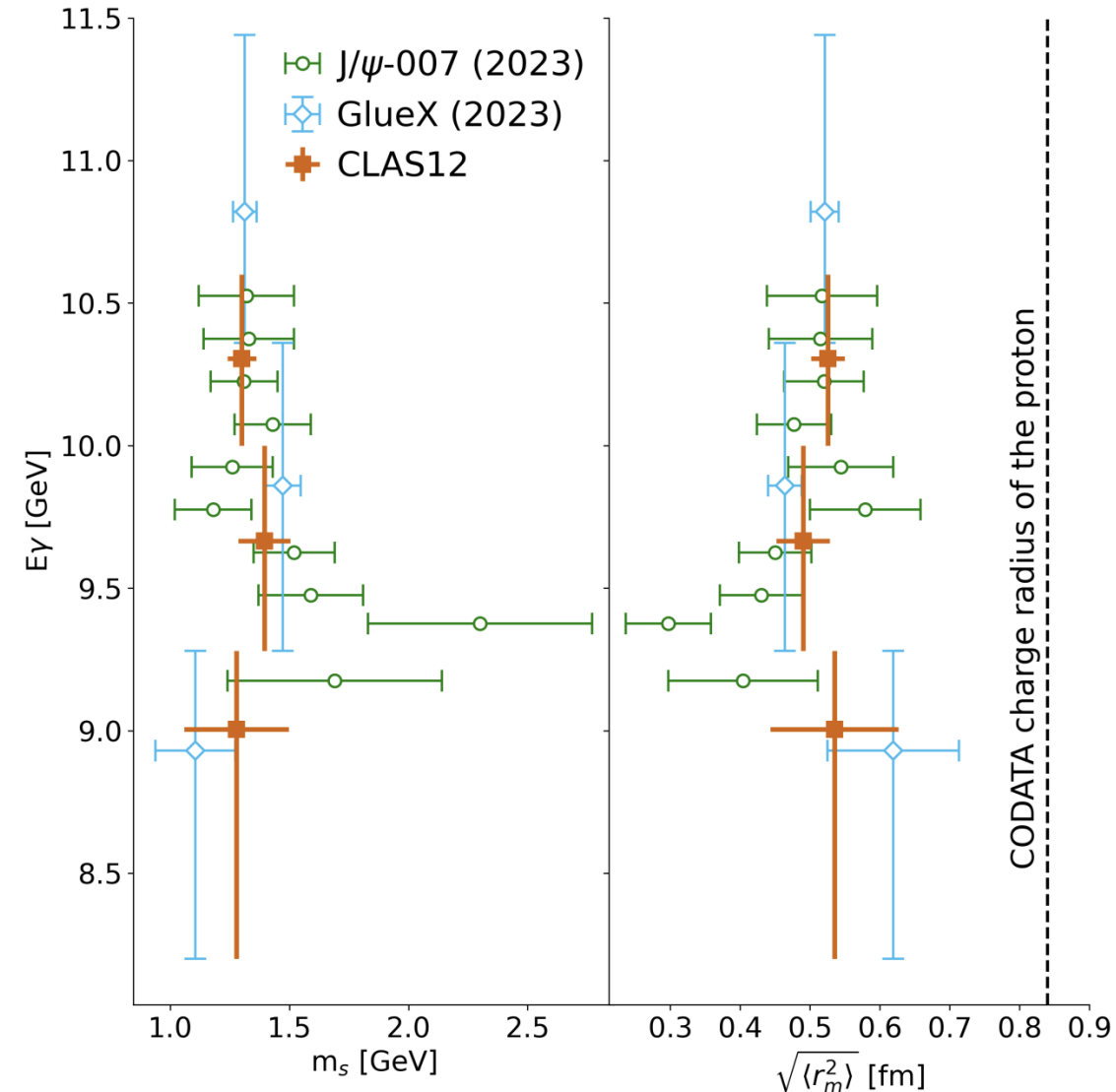
The nucleon mass can be decomposed into the contributions from the quark masses, the energy of quarks and gluons and the trace anomaly contribution .

A scalar gravitational form factor $G(t)$ gives access to the mass radius of the nucleon. Assuming a dipole form for $G(t)$:

$$\frac{d\sigma}{dt} = G(t)^2 = \left(\frac{M_p}{1 - \frac{t}{m_s^2}} \right)^2$$

The mass radius r_m is calculated from the free parameter m_s :

$$r_m = \frac{\sqrt{12}\hbar c}{m_s}$$





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