University of Glasgow

CLAS Collaboration, *First Measurement of Near-Threshold J/ψ Photoproduction on the Neutron*, arXiv 2609.03579

J/ψ Near-threshold Photoproduction at CLAS12

R. Tyson

CLAS Collaboration Meeting

17th of November 2026

CEBAF Large Acceptance Spectrometer

J/ψ Near-Threshold Photoproduction

We are interested in measuring the process:

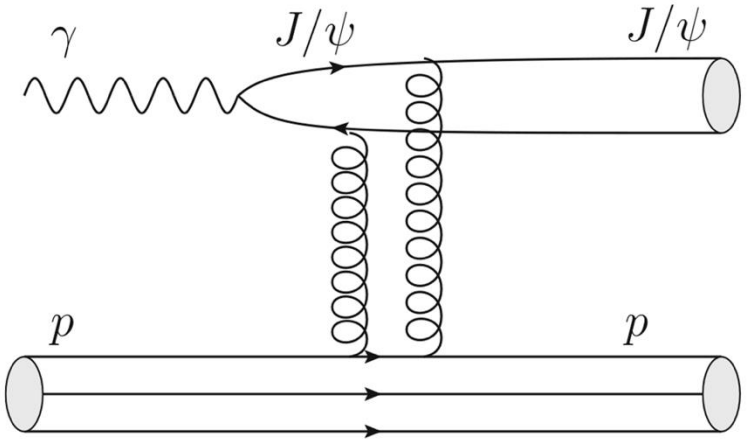
$$eN \rightarrow e'J/\psi N \rightarrow e'l^+l^-N$$

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

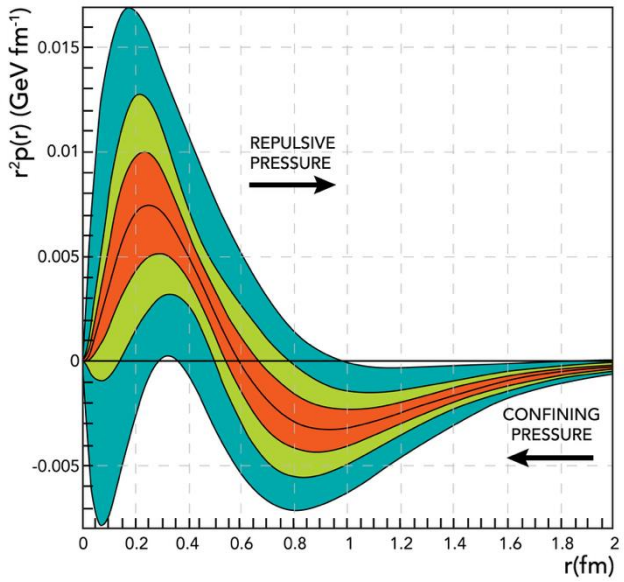
Mechanical form factors encode mass, pressure and sheer stress distributions of quarks and gluons in nucleon/nuclei.

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.

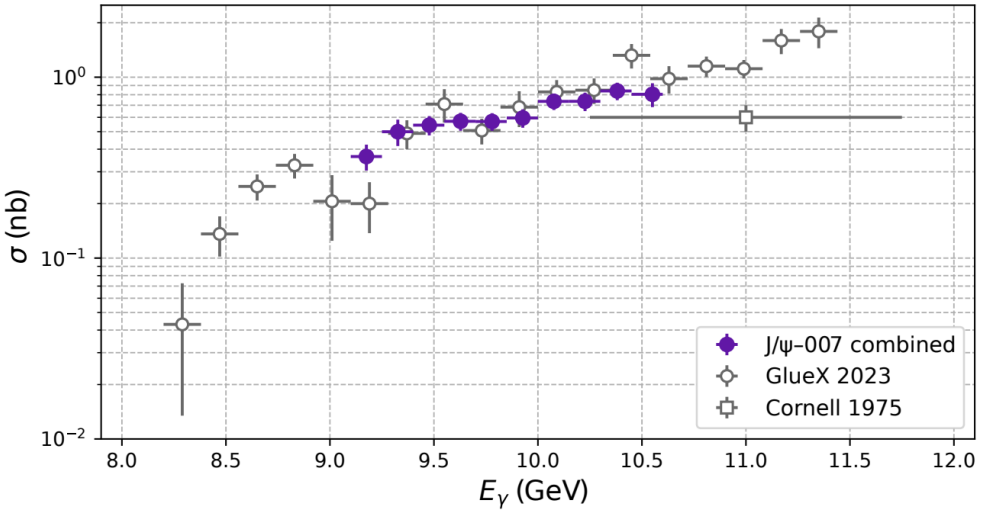


V. D. Burkert, L. Elouadrhiri, F. X. Girod, *Nature* **557,** 396–399 (2018).

Recent Measurements (Free Proton)

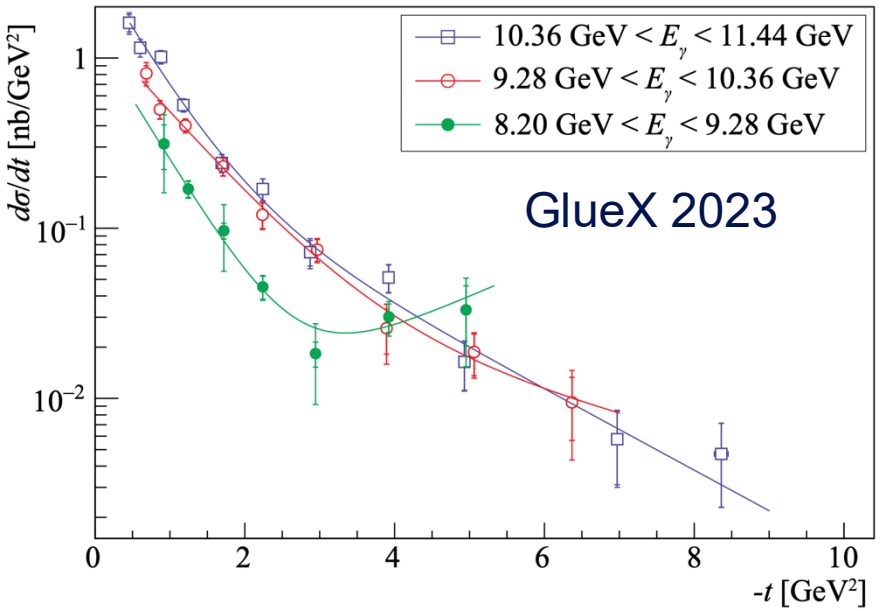
J/ψ 007 – Hall C

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



GlueX – Hall D

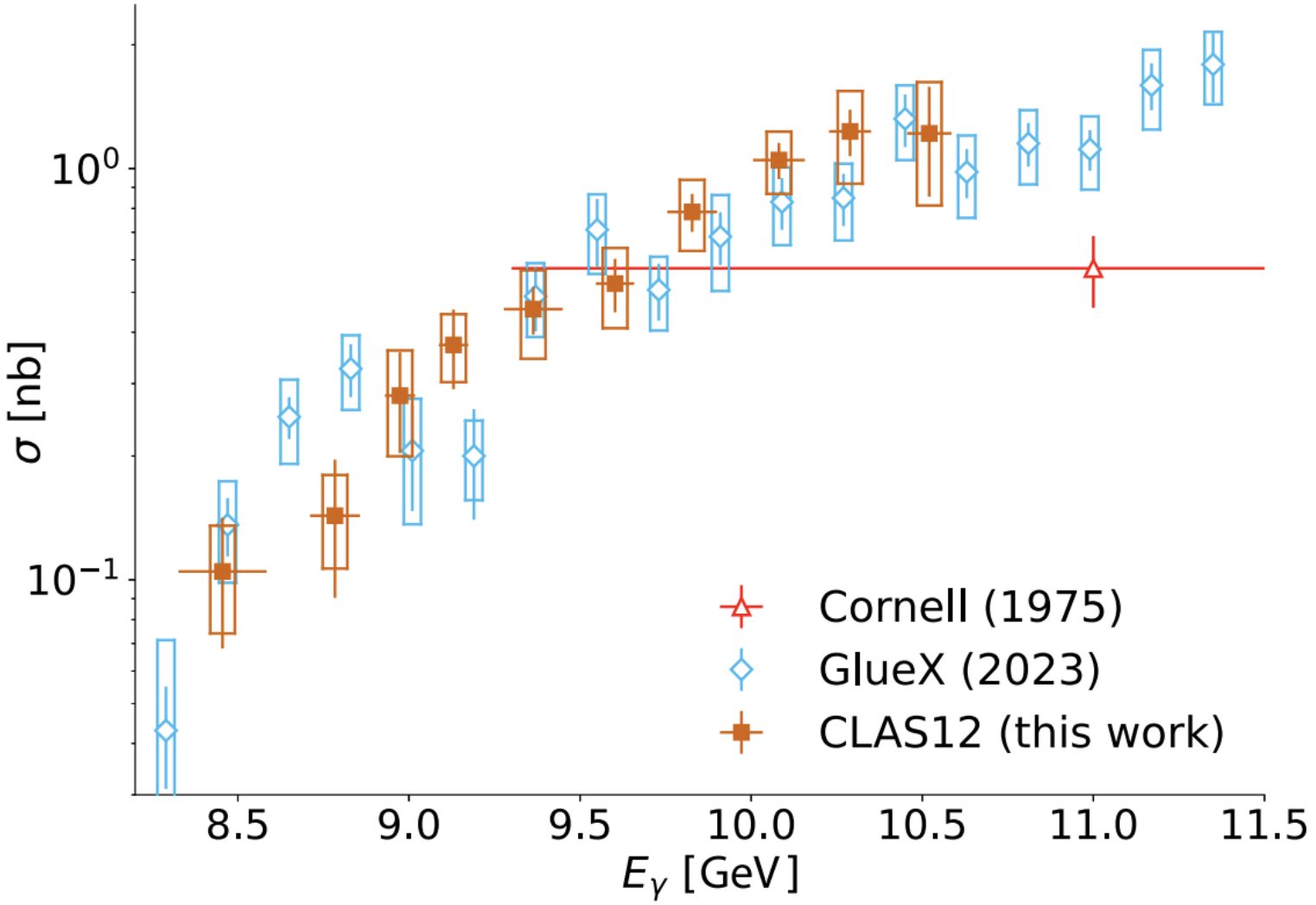
The GlueX Collaboration has made measurements of the total and differential cross section over the full near-threshold range.



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).

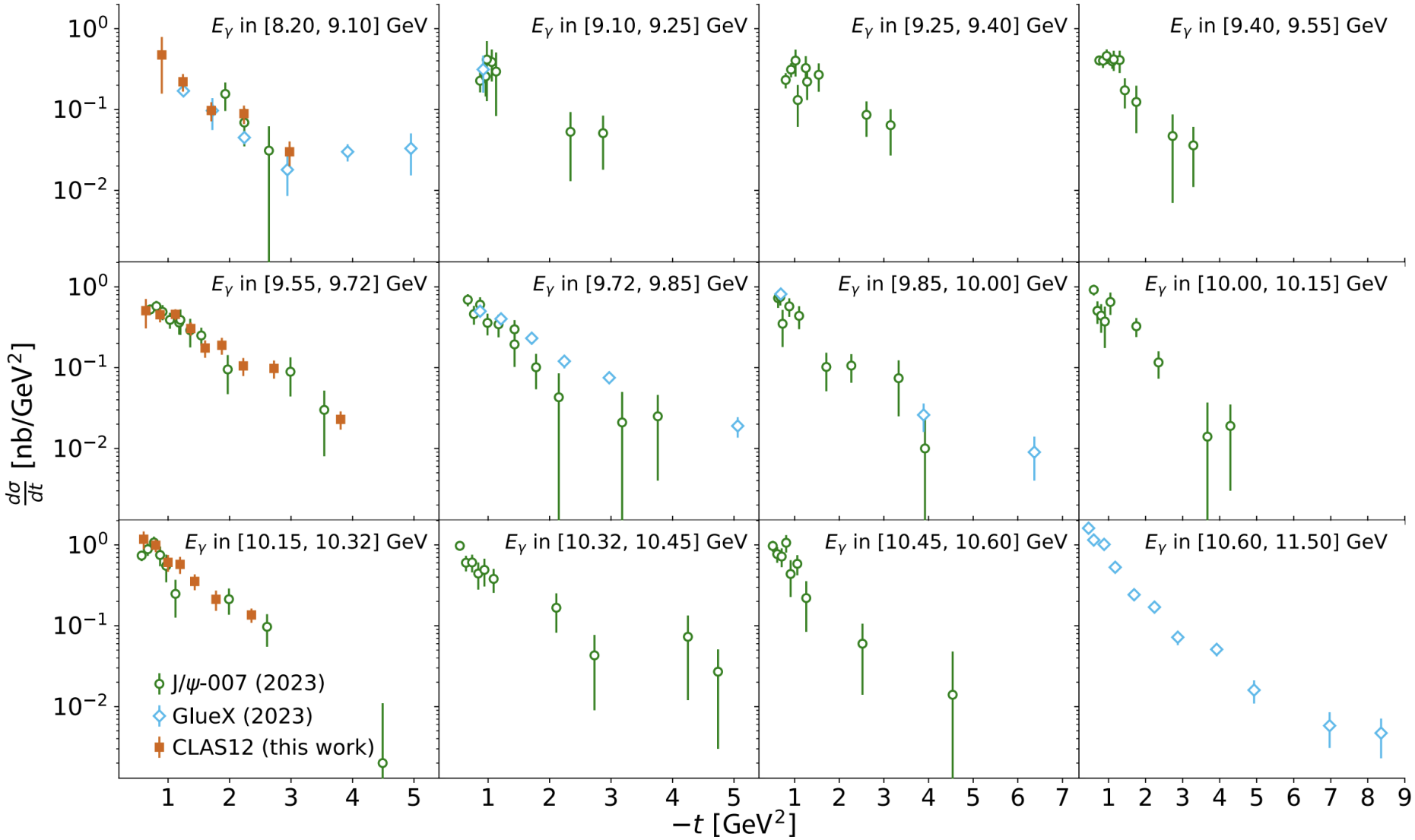
CLAS12 Measurements: Free Proton

P. Chatagnon, *et al.* (CLAS Collaboration) *Phys. Rev. C* **113**, 065203 (2026).



CLAS12 Measurements: Free Proton

P. Chatagnon, *et al.* (CLAS Collaboration) *Phys. Rev. C* **113**, 065203 (2026).



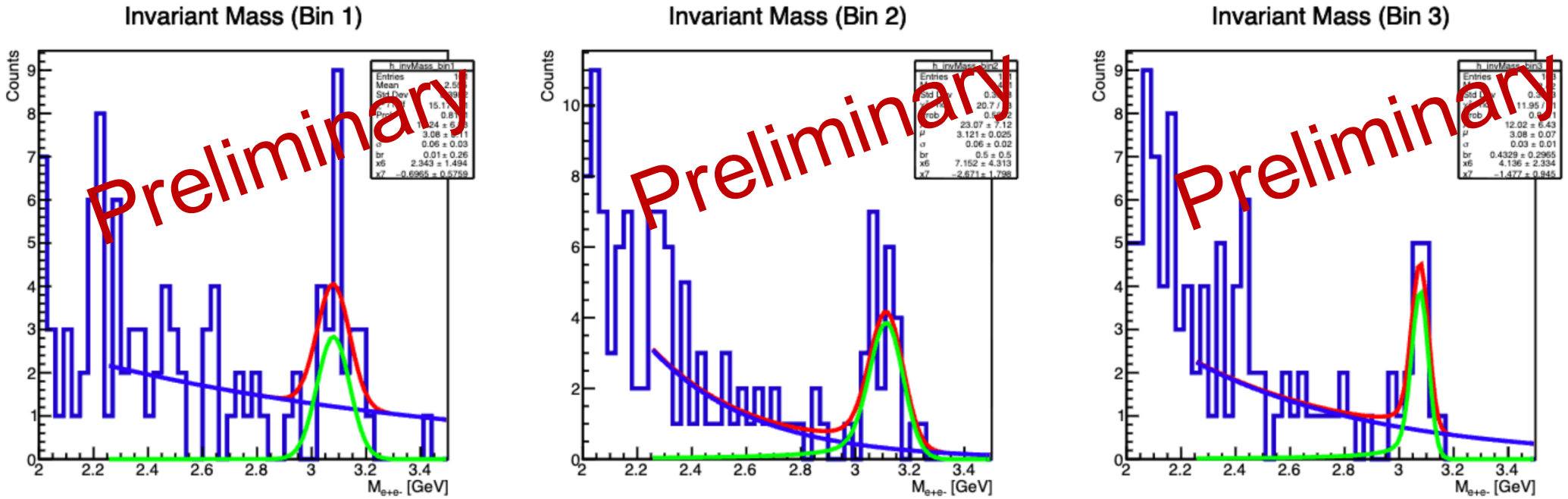
Electroproduction on the Free Proton at CLAS12

M. Tenorio-Pita
Analysis in progress
Thesis: DOI: 10.25777/bc2f-st95

We can detect the scattered electron in FT, at the cost of a decreased photon flux & acceptance.

Can probe electroproduction roughly from $0.01 < Q^2 < 0.15\ \mathrm{GeV}^2$.

Place some initial constraints on the Q^2 dependence.



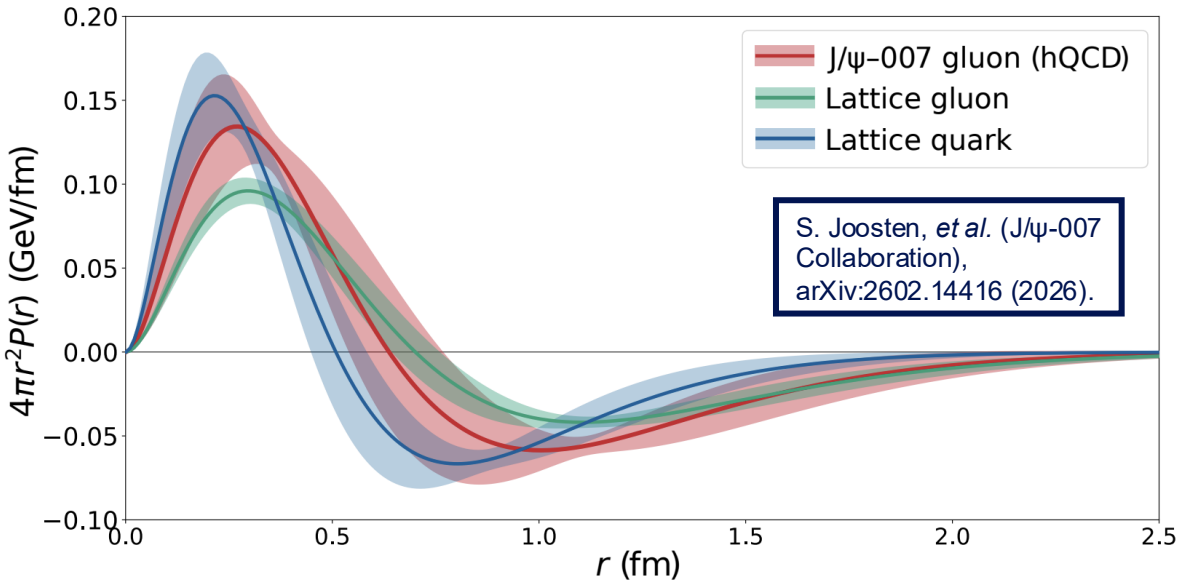
Holographic QCD & GPDs

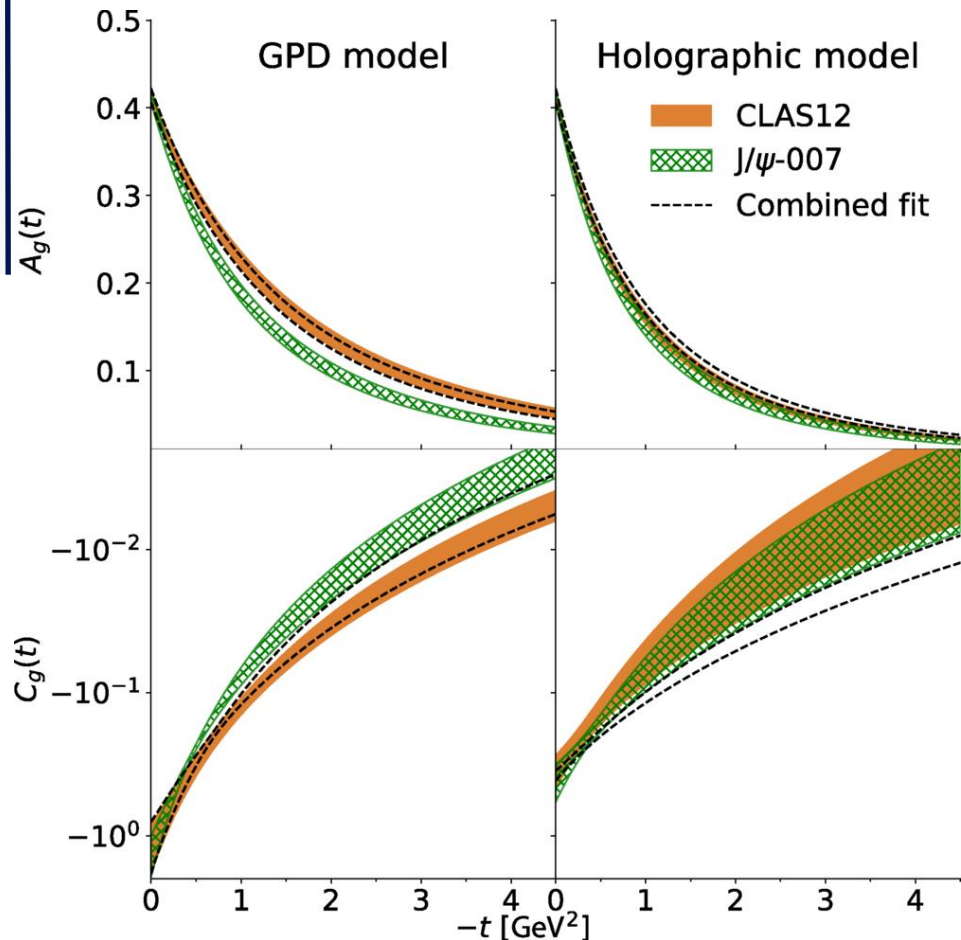
K. A. Mamo, *et al.*, *Phys. Rev. D,* **106**, 8, 086004 (2022).
Y. Guo, *et al.*, *Phys. Rev. D,* **108**, 3, 034003 (2023).
Z.E. Meziani, *POS,* **SPIN2023** 168 (2024).
P. Chatagnon, *et al.* (CLAS Collaboration) *Phys. Rev. C* **113**, 065203 (2026).

In holographic QCD a higher dimensional duality relates spin-2 fields to gravity. J/ψ is produced by the exchange of gravitons (tensor glueballs) and scalar glueballs, enables access to mechanical form factors.

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





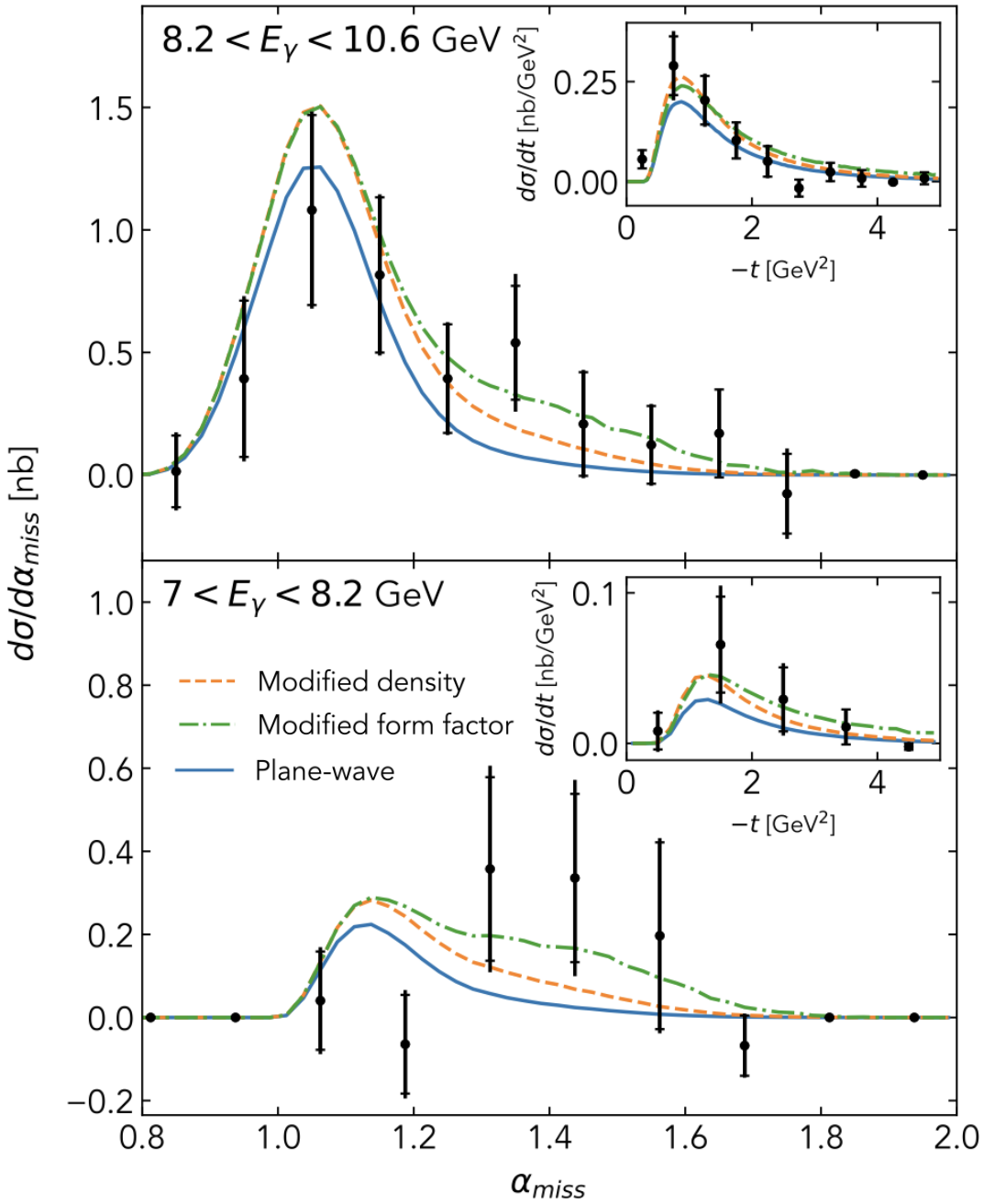
J/ψ Production and Nuclear Structure

Subthreshold production may be a probe of nuclear and SRC structure.

Bound vs free proton comparison could hint towards modifications of gluon structure of the nucleon in nuclei.

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

- Increased gluon density
- Decreased gluon radius



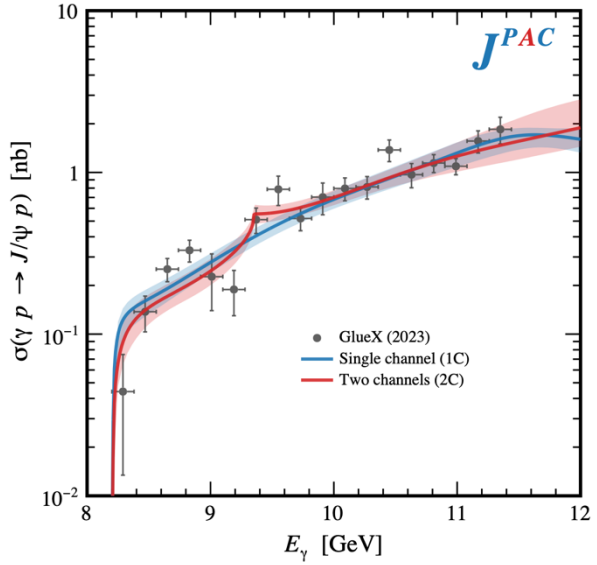
Y. Hatta, *et al.*, *Phys. Lett. B,* **803**, 10 35321 (2020).
J. R. Pybus, *et al.* (SRC-CT Collaboration) *Phys Rev Lett* **134**, 201903 (2025)

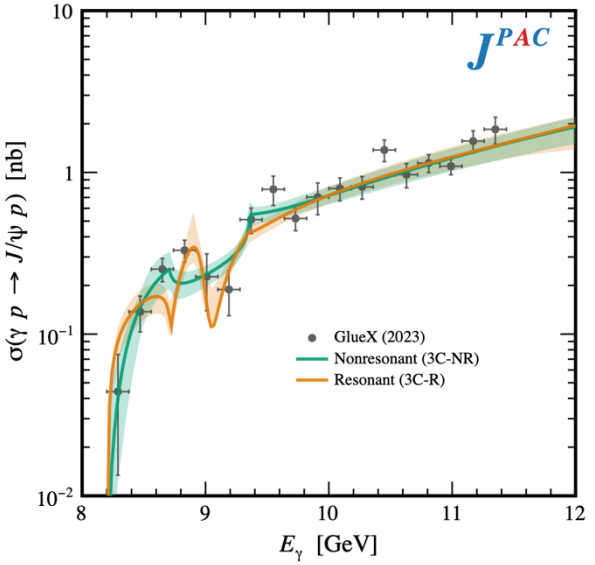
Production Mechanism

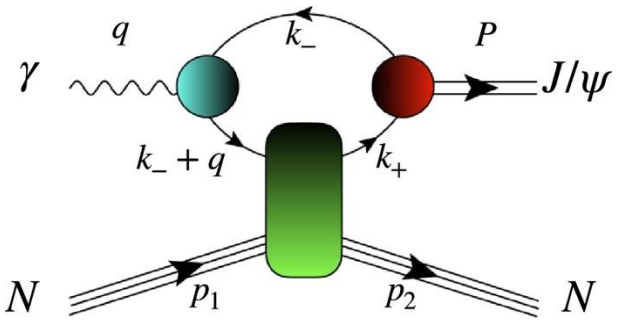
Several different proposed near-threshold production mechanisms:

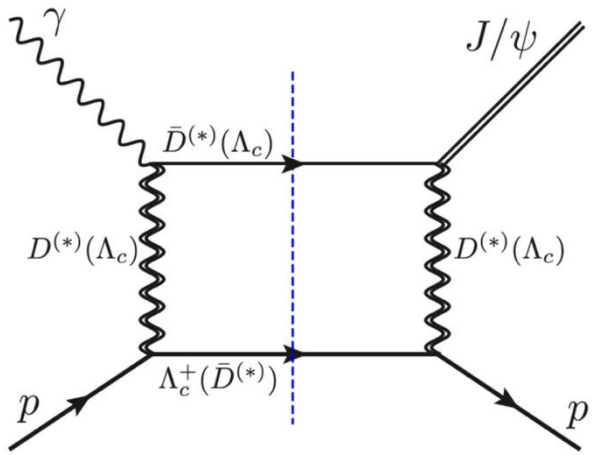
- Tensor (two-gluon) exchange
- Higher (lower) twist 3 (1) gluon exchange
- Open-Charm intermediate states
- Pomeron exchange
- Meson exchange
- 2015, 2019 LHCb P_c^+ pentaquarks
- …

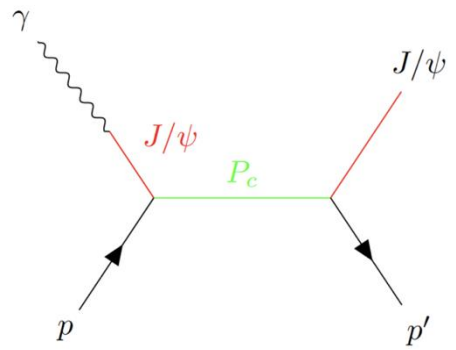
Need higher statistical precision and **polarization observables** to distinguish between production mechanisms.











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?

The RG-B experiment employed a deuterium target.

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

The RG-C experiment employed a longitudinally polarized NH3 target

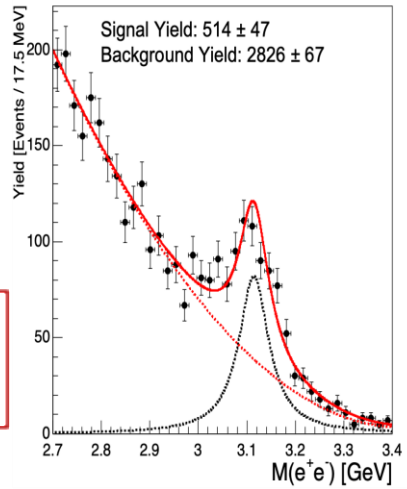
μCLAS12 and mini μCLAS12 for high lumi data taking

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 (Mostly?)

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 μCLAS12 - J/ψ, TCS and DDVCS at high luminosity, approved

Submissions to 2026 JLab PAC:
- Open Charm at JLab with the sPHENIX MAPS Tracker - Proposal deferred
- J/ψ on carbon and tungsten targets (J/ψ production on Nuclear Targets - Letter of Intent, depends on open charm proposal)

Cross Section Calculation

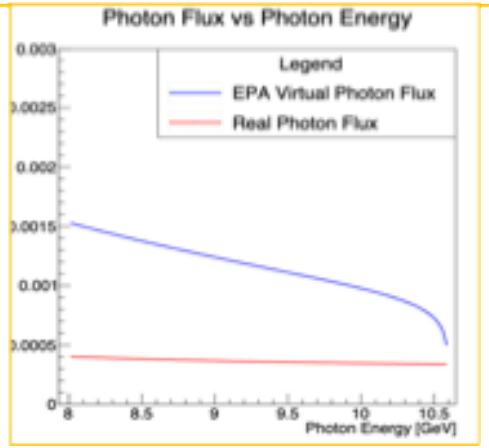


Total cross section as a function of quasi-real virtual photon energy

Number of J/ψ from fit in E_γ bins

$$\sigma_0(E_\gamma) = \frac{N_{J/\psi}(E_\gamma)}{N_\gamma(E_\gamma) \cdot l_T \cdot \rho_T \cdot Br \cdot R_c(E_\gamma) \cdot \epsilon(E_\gamma) \cdot \omega_c}$$

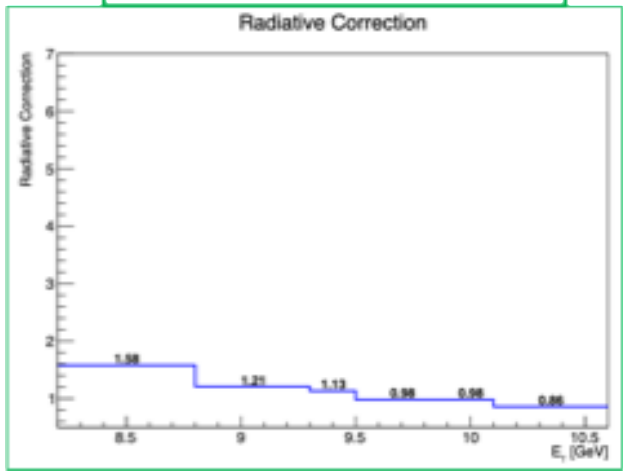
Luminosity:
N_γ is calculated from the photon flux
l_T and ρ_T are the target length and density



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

Efficiency in E_γ bins from MC

Radiative Corrections



Normalisation to Bethe Heitler process

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

Bethe Heitler Normalisation

See Workfest 1 on Wednesday!

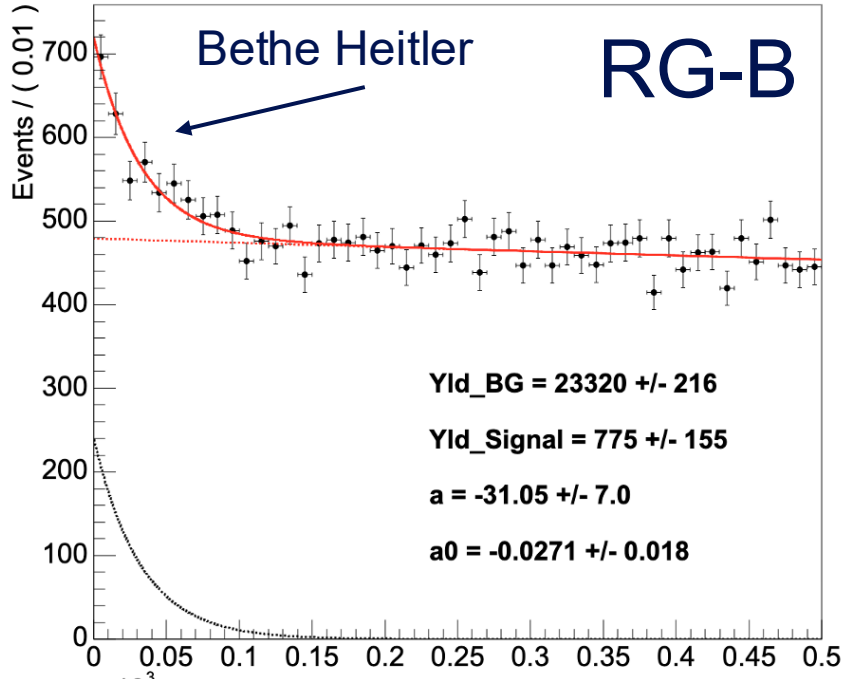
Calculate ratio Bethe Heitler events in RG-B over that in MC as predicted by QED + GEMC: 0.70 ± 0.14

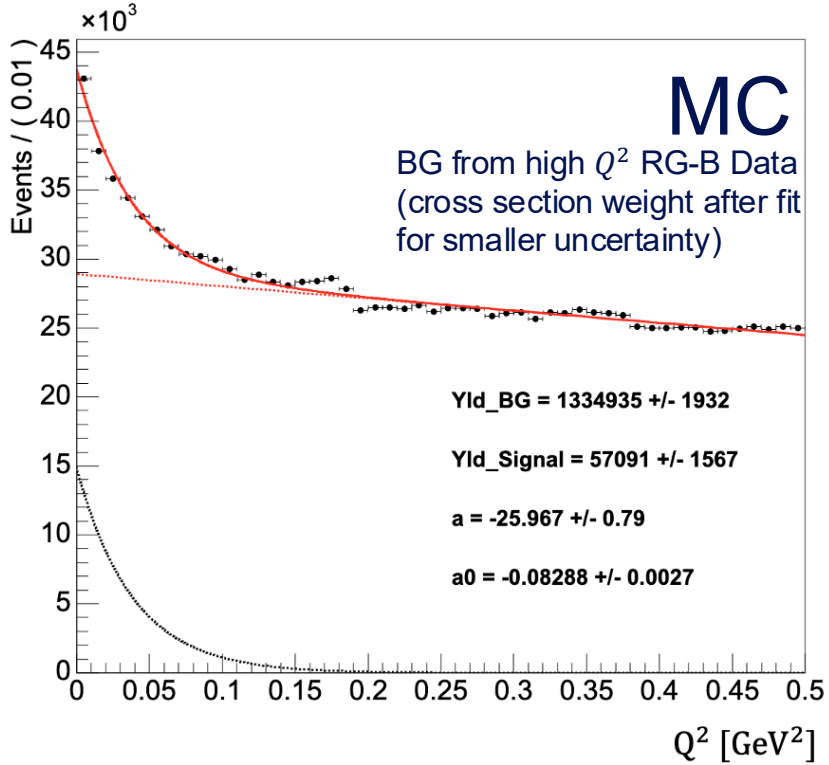
Use this ratio to correct J/ψ cross section:

- Same final state e^+e^-N
- Similar kinematics ($M(e^+e^-)$ > 2.0 GeV for BH, $M(e^+e^-)$ = 3.097 GeV for J/ψ)

We can bring ratio to 0.95 ± 0.19 using a variety of corrections comparing data and MC:

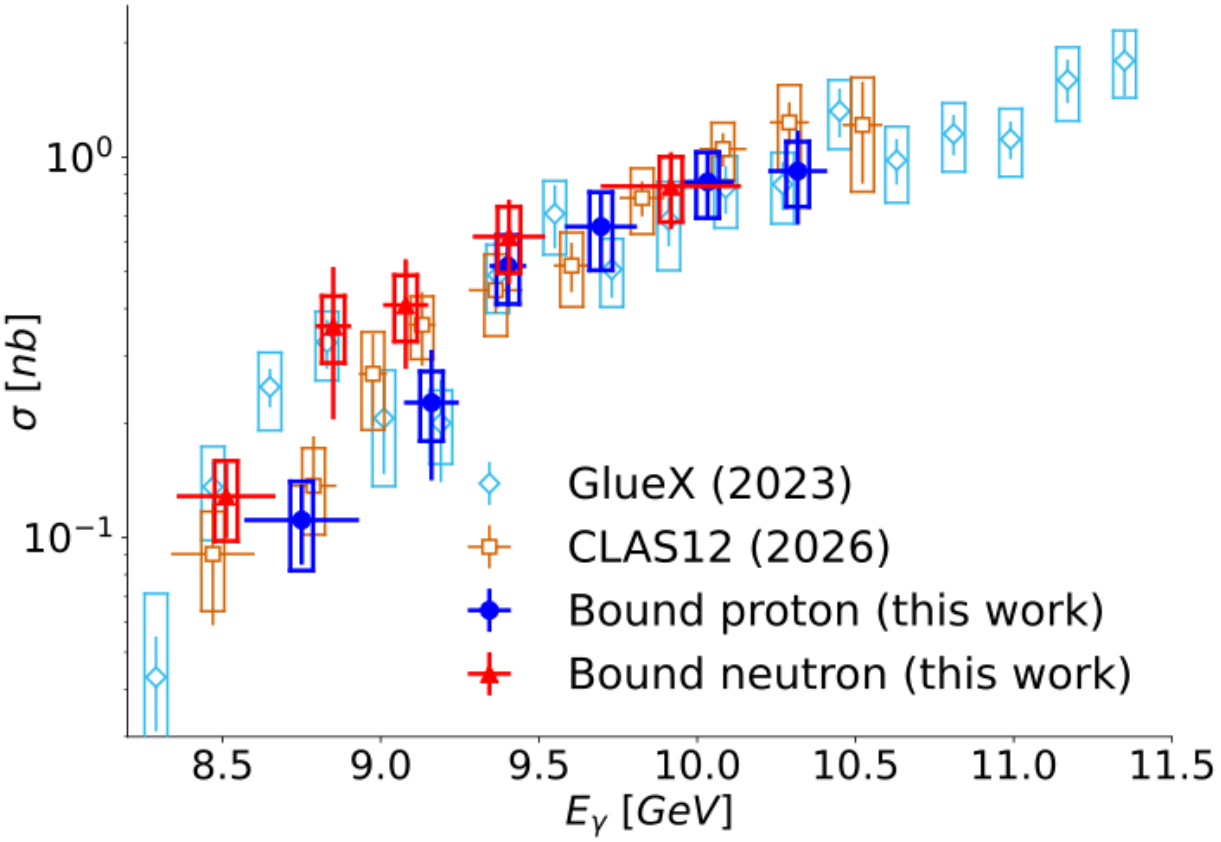
- Neutron detection efficiency from $ep \rightarrow e'\pi^+n$
- Rate of change of tracking efficiency vs beam current
- Electron & positron PID efficiency from $e^{\pm} \rightarrow e^{\pm}\gamma$ (see event builder PID & ML PID)
- Rate of change of number of J/ψ vs cut widths on exclusivity variables

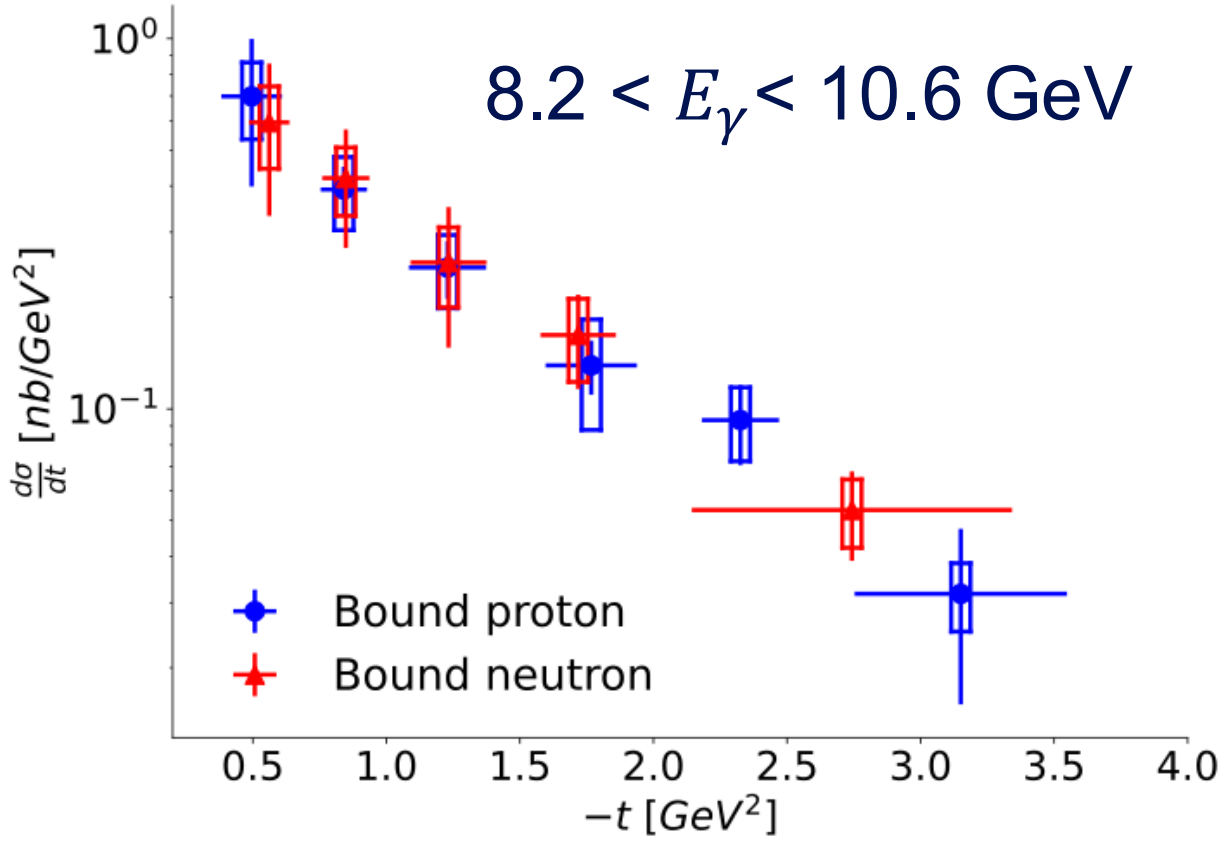




Incoherent J/ψ Production in LD2

Further constraints on production mechanism?





Fitting the Mechanical Form Factors

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

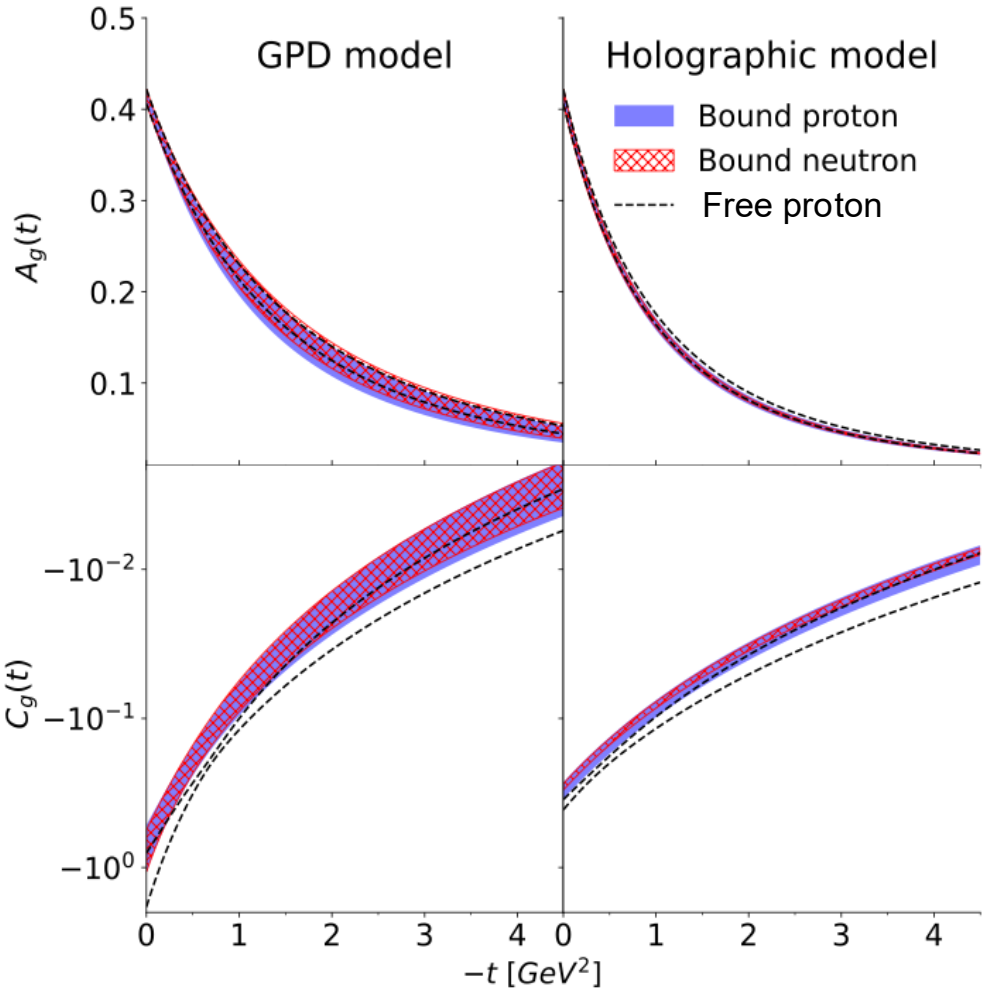
Fit mechanical form factors $A_g(t)$ and $C_g(t)$ to differential cross section

Some assumptions in fit:

- Convenient production mechanism
- Neglect $B(t)$ and $\bar{C}(t)$.
- Assume tripole shape for mechanical form factors:

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

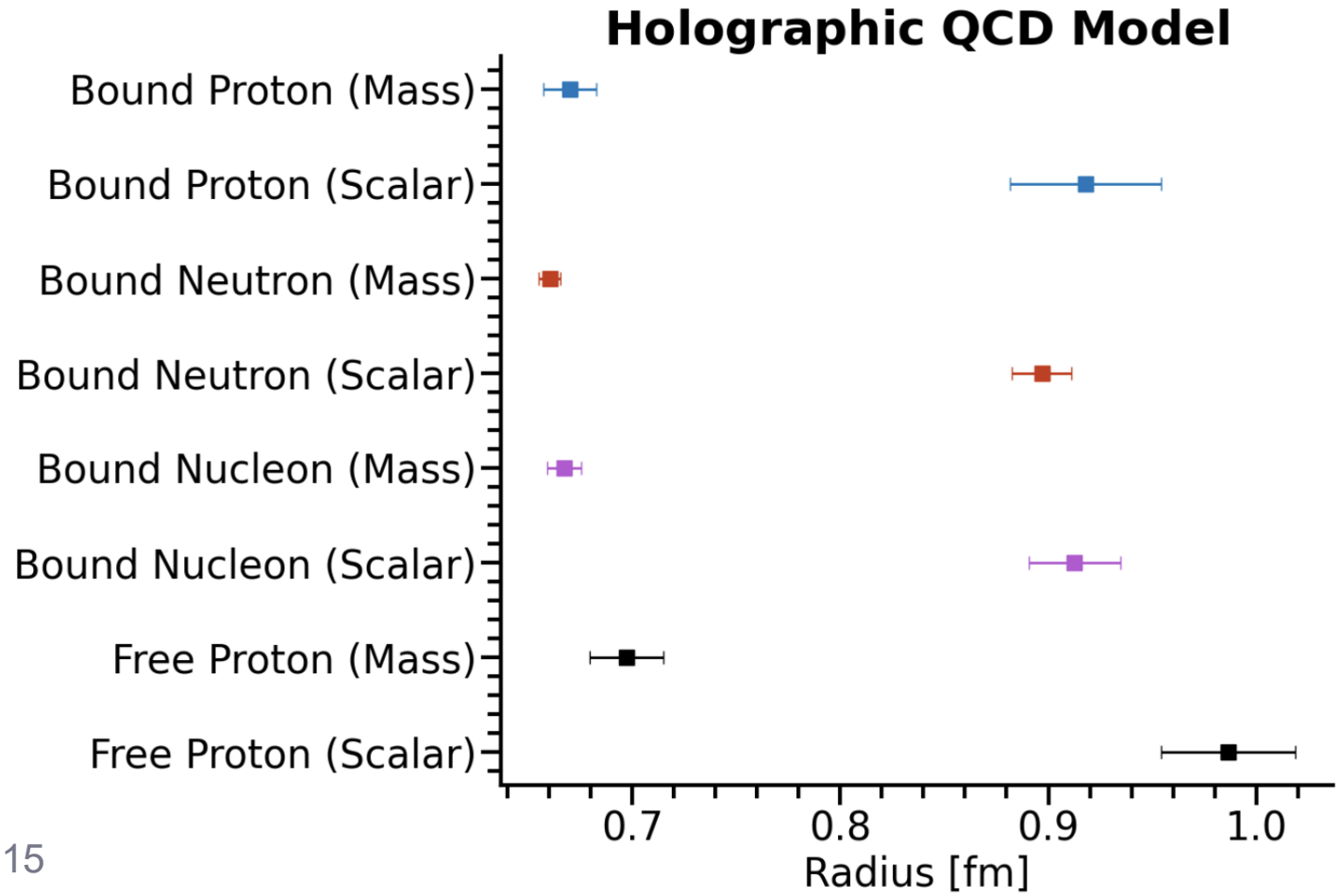
- Gaussian constrained with $A_{t=0}$ constrained to the average gluon PDF from CT18, m_C constrained to free proton data
- Assume FSI contribution to cross section much smaller than plane wave impulse approximation (*Phys. Rev. C* **88**, 044604 (2013))

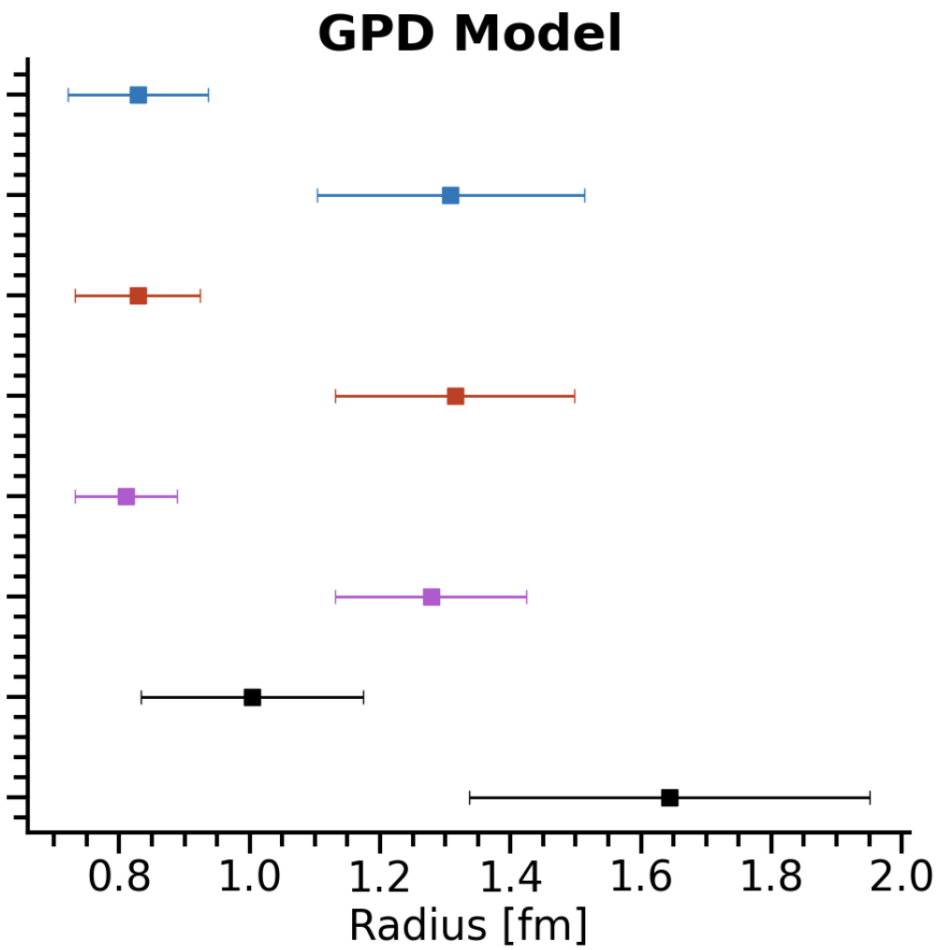


Mass and Scalar Radii

$$\langle r_m^2 \rangle_g = 6 \frac{1}{A_g(0)} \frac{dA_g(t)}{dt}\bigg|_{t=0} - 6 \frac{1}{A_g(0)} \frac{C_g(0)}{m_p^2}$$
$$= \frac{18}{m_A^2} - 6 \frac{1}{A_g(0)} \frac{C_g(0)}{m_p^2},$$

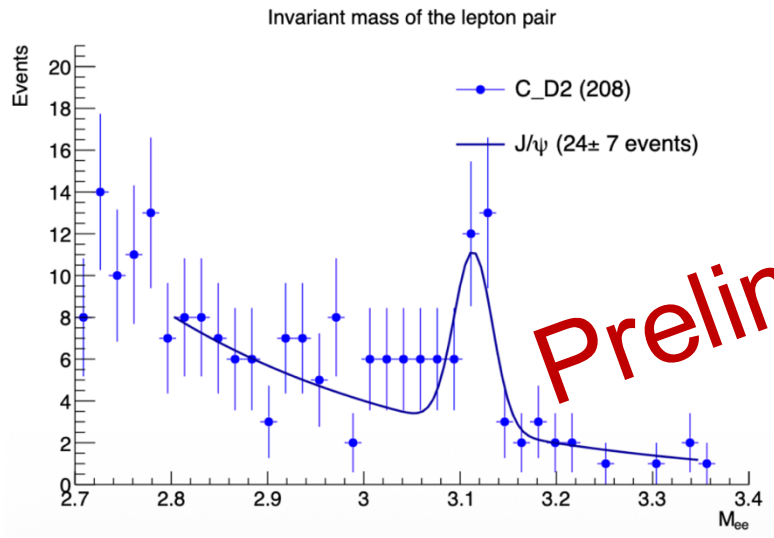
$$\langle r_s^2 \rangle_g = 6 \frac{1}{A_g(0)} \frac{dA_g(t)}{dt}\bigg|_{t=0} - 18 \frac{1}{A_g(0)} \frac{C_g(0)}{m_p^2}$$
$$= \frac{18}{m_A^2} - 18 \frac{1}{A_g(0)} \frac{C_g(0)}{m_p^2},$$

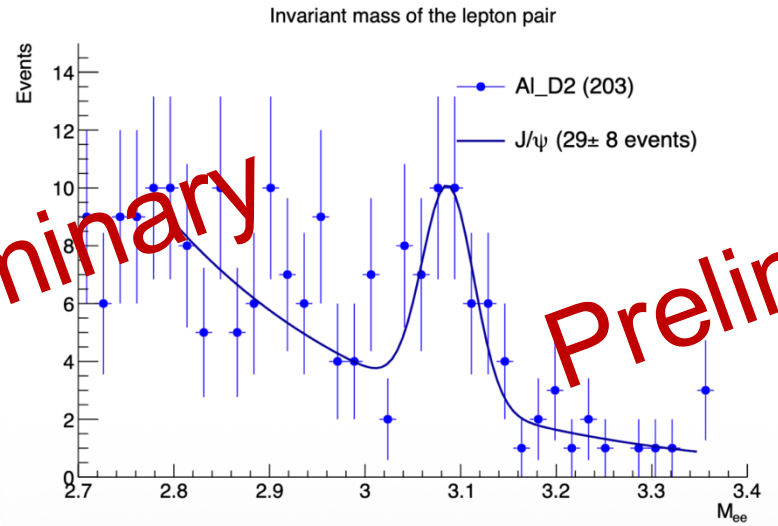


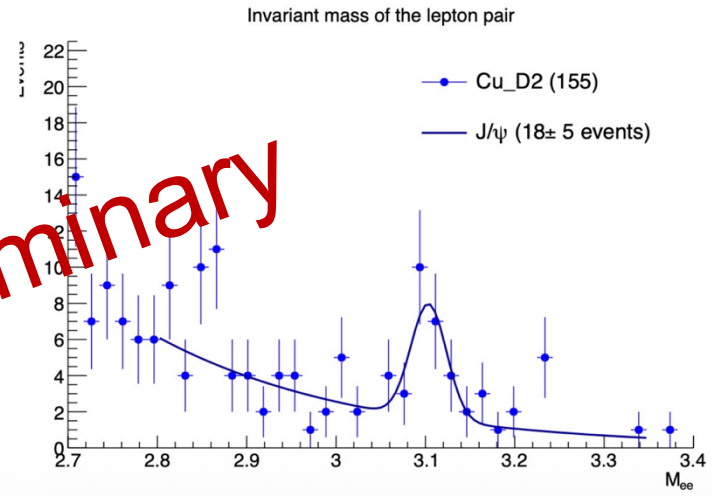


Incoherent J/ψ Yield Estimation with Nuclear Targets

P. Chatagnon
Data taken 2024
Analysis in progress



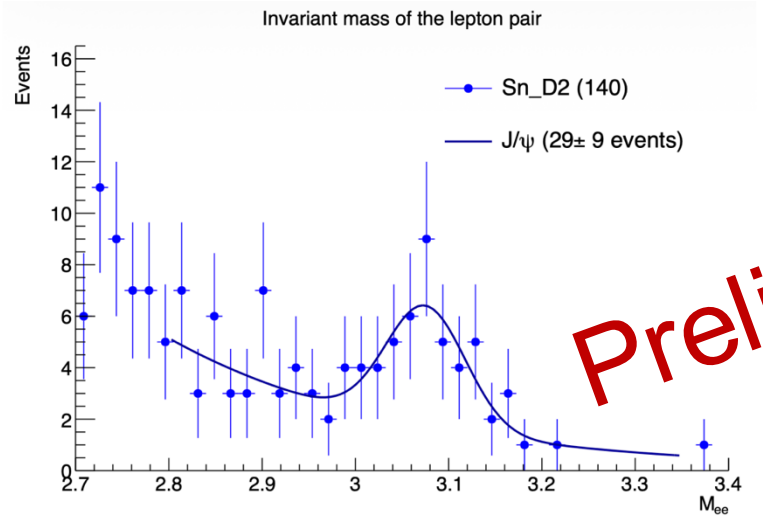


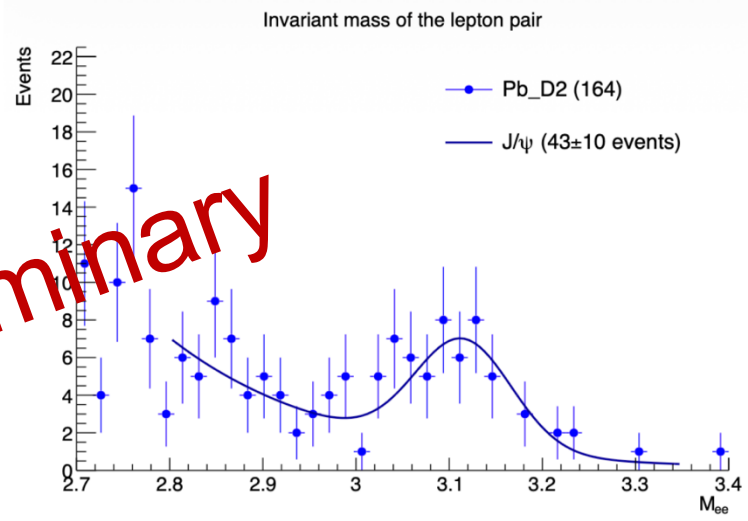


Preliminary

Preliminary

Complement by measuring **ϕ** electroproduction (several orders of magnitude more events)





Preliminary

SRC-CT published measurements:

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

J/ψ Polarisation Observables

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

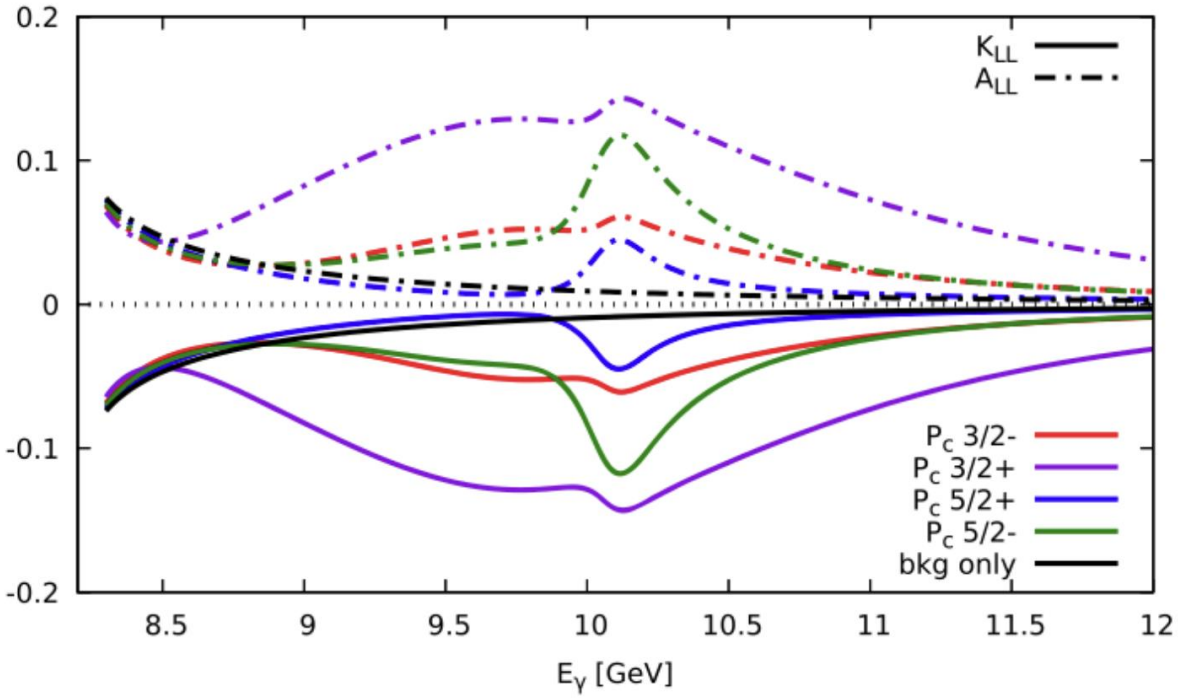
Predictions from JPAC on Double Spin Asymmetry for LHCb pentaquark production.
Possible further predictions for variety of observables for open-charm and gluon exchange production mechanism.

JPAC colleagues have told us that any measurements, even statistically limited, would be very valuable

K. Gates will present CAA aiming to use RG-A and RG-C data to probe polarization observables:

- (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.



See K. Gates talk on Friday!

mini μCLAS12 (High Lumi Stage 2)

mini μCLAS12 detector configuration with shielding up to 15 degrees added to normal CLAS12 set-up

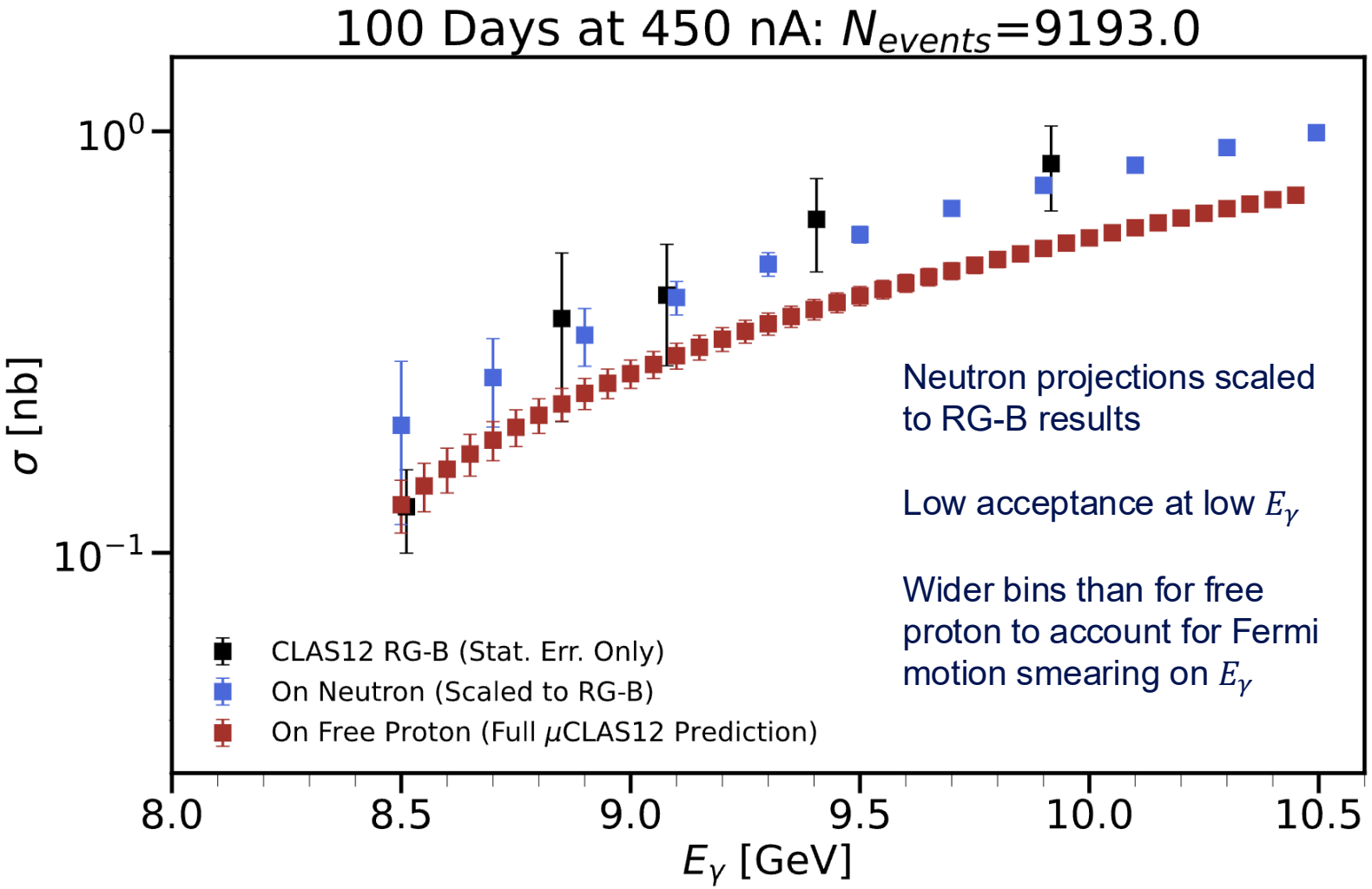
Make predictions for $en_{bound} \rightarrow (e')\mu^+\mu^-n$ on 5 cm LD2 target (same as RG-B)

Events weighted using Holographic QCD model scaled to RG-B measurements

Assume a 90% tracking efficiency per charged particle at 450nA

Cross section predictions for coherent production on deuteron:
Expect ~400 J/ψ produced

Projections by Pierre in progress for heavier nuclear targets



Conclusion

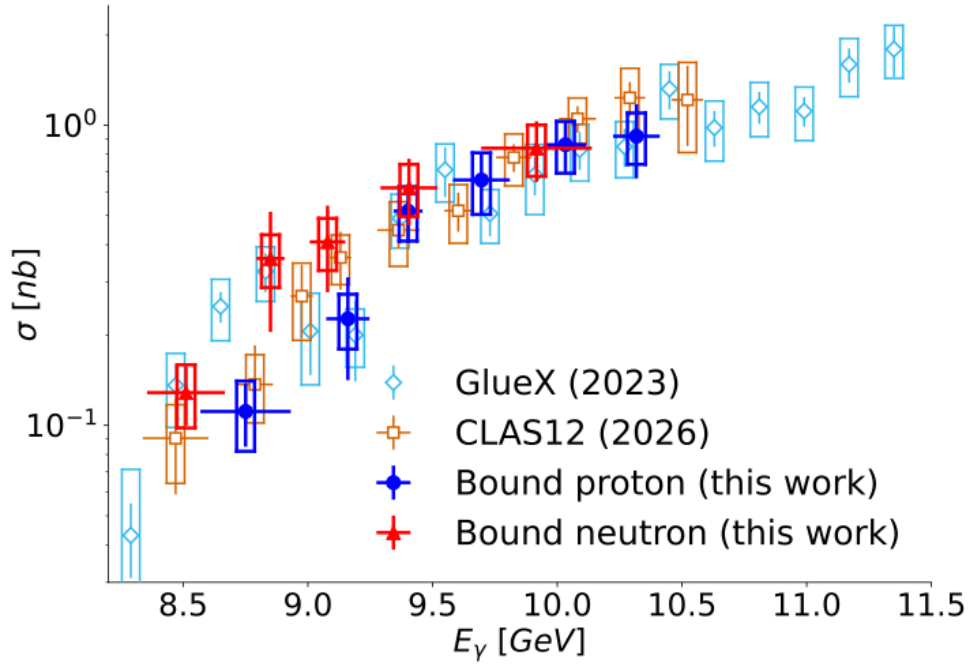
CLAS12 has released measurements of the total and differential cross section on the free proton and on the bound proton and neutron in deuterium

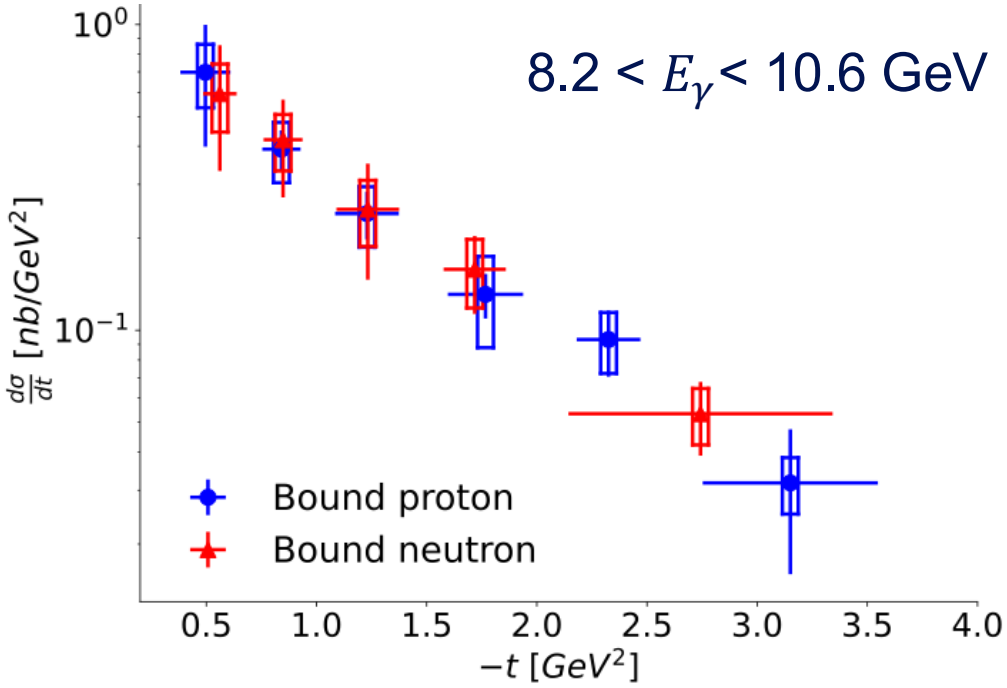
Plenty more interesting results to come:

- Measurements of Q^2 dependence (later stages)
- Measurements of polarization observables, including on longitudinally polarized targets (early stage)
- Measurements on nuclear targets (early stages)
- High statistics with (mini) μCLAS12 (2030s)

Few things I didn't have time to discuss:

- 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)







Back-up Slides



General Analysis Steps

P. Chatagnon, *et al.* (CLAS Collaboration) *Phys. Rev. C* **113**, 065203 (2026).

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,

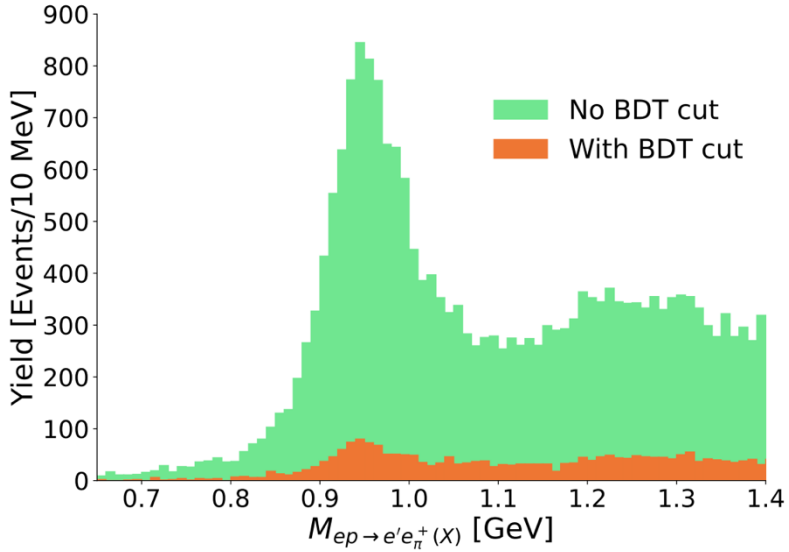
Above 4.5 GeV, employ ML based PID.

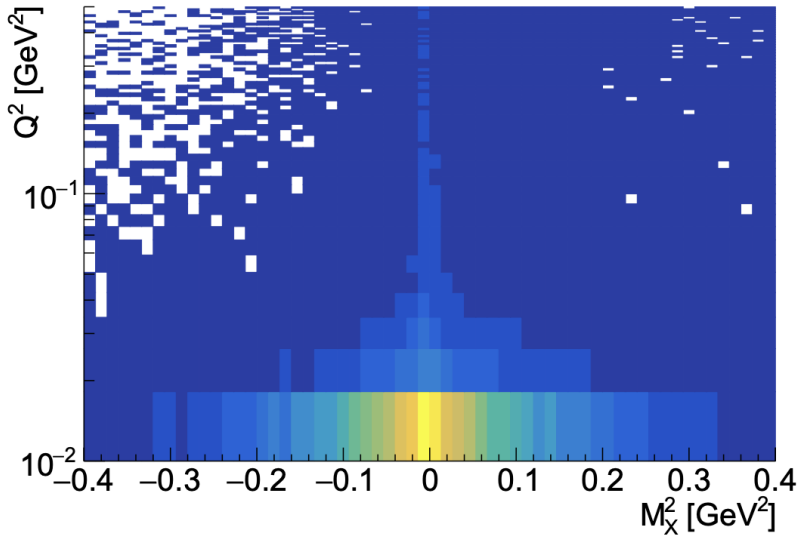
Use cuts on Q^2 and missing mass squared from:

$$eN \rightarrow e^+e^-N(X)$$

-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^+.

Vector Meson Dominance Framework

P. Chatagnon, *et al.* (CLAS Collaboration) *Phys. Rev. C* **113**, 065203 (2026).

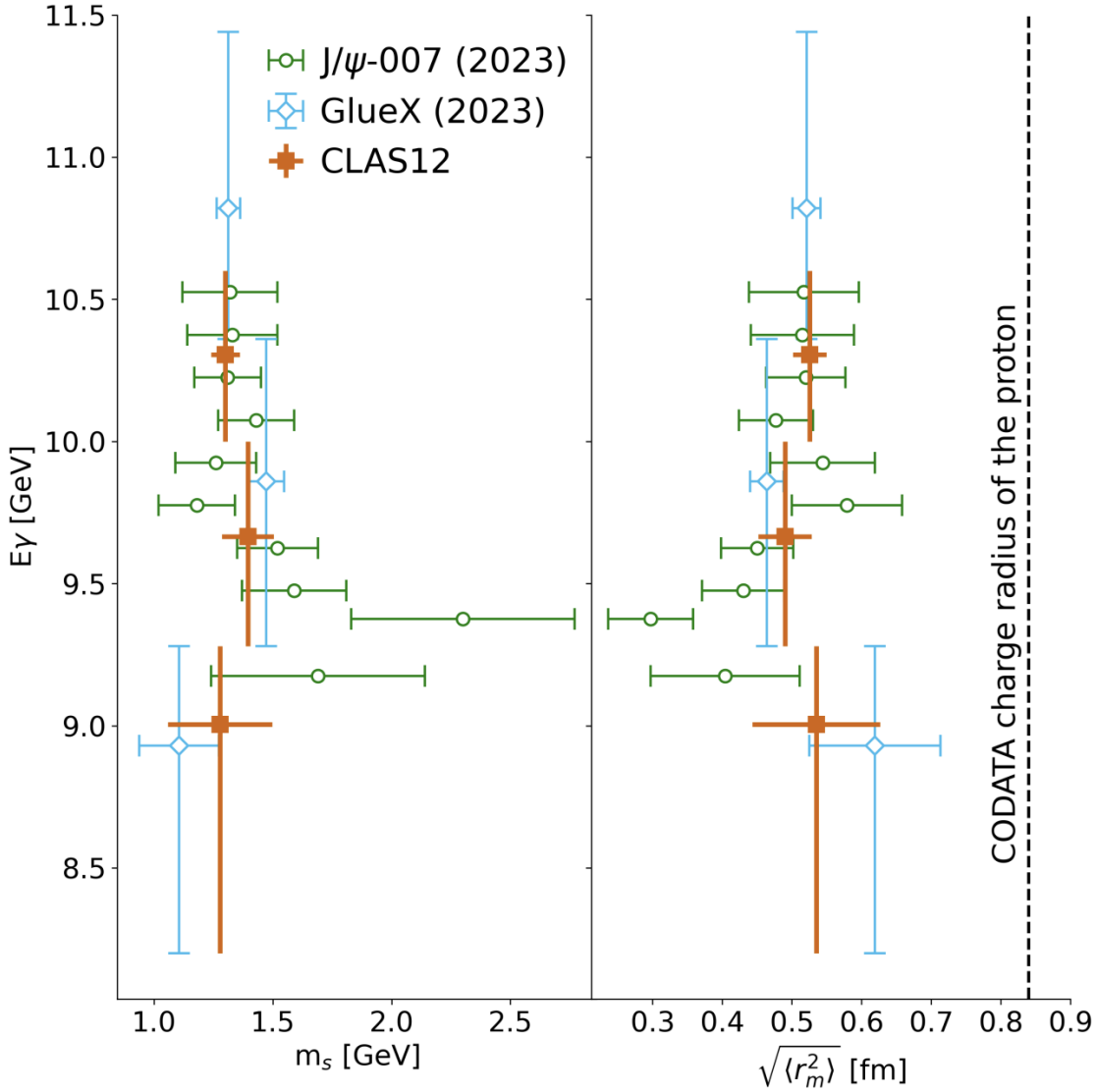
The nucleon mass can be decomposed into the contributions from the quark masses, the energy of quarks and gluons and the trace anomaly contribution .

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

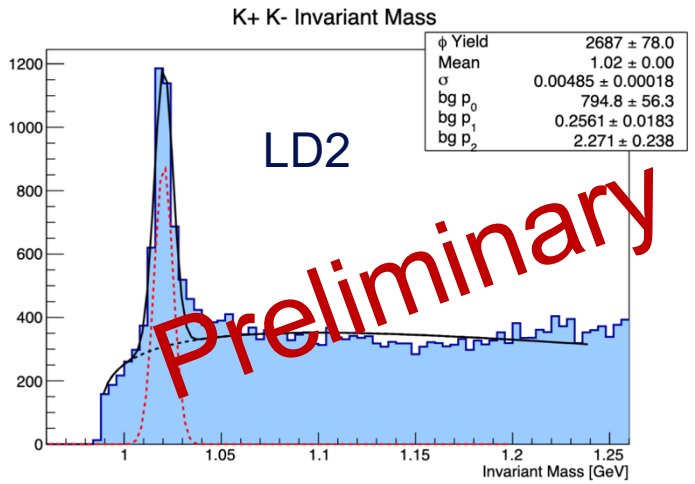
$$\frac{d\sigma}{dt} = G(t)^2 = \left(\frac{M_p}{(1-\frac{t}{m_s^2})^2}\right)^2$$

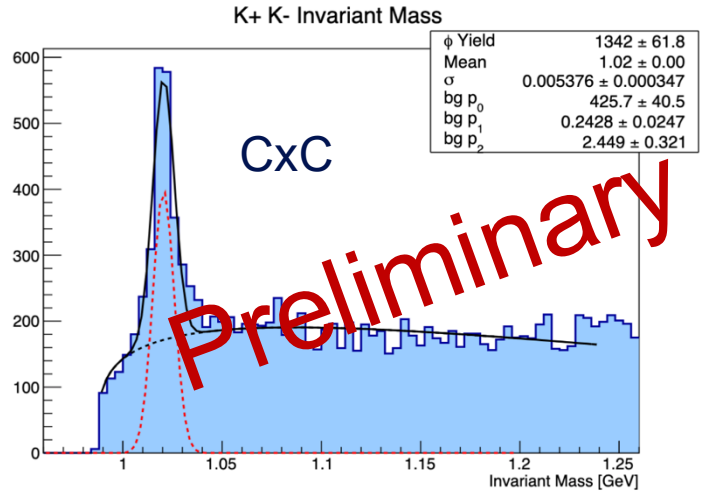
The mass radius r_m is calculated from the free parameter m_s:

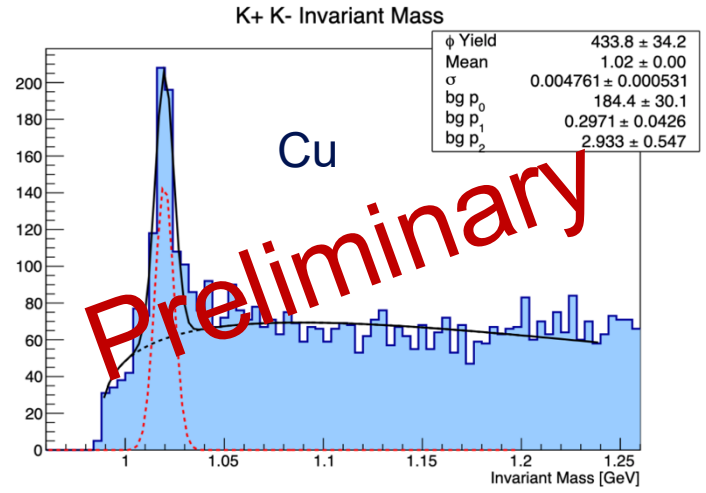
$$r_m = \frac{\sqrt{12}\hbar c}{m_s}$$

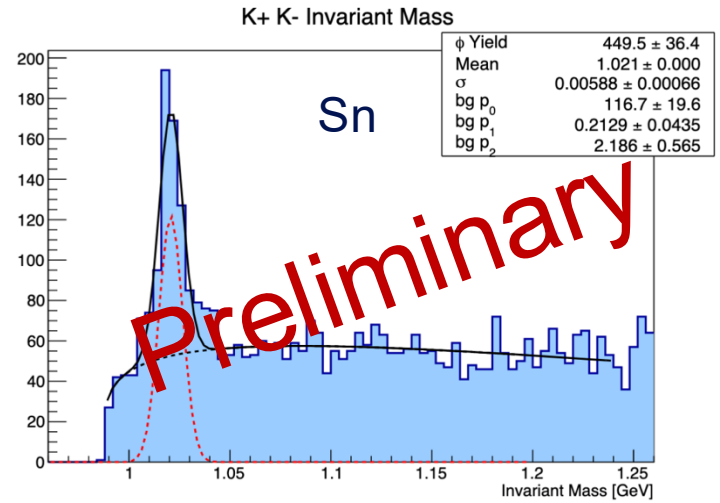


Incoherent ϕ Yield Estimation with Nuclear Targets









Two datasets RG-D, and RG-E, yield estimation with ~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?

ExEx

Ex

Exs

Ex

- Ex