J/ψ Near-Threshold Photoproduction on the Proton and Neutron at CLAS12

Richard Tyson, Thomas Jefferson National Accelerator Facility

GHP2025

16th of March 2025

J/ψ Near-Threshold Photoproduction

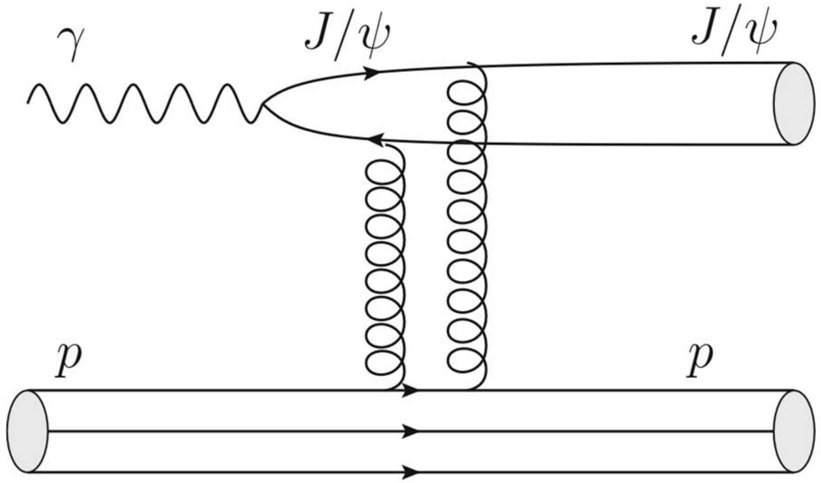
We are interested in measuring the process:

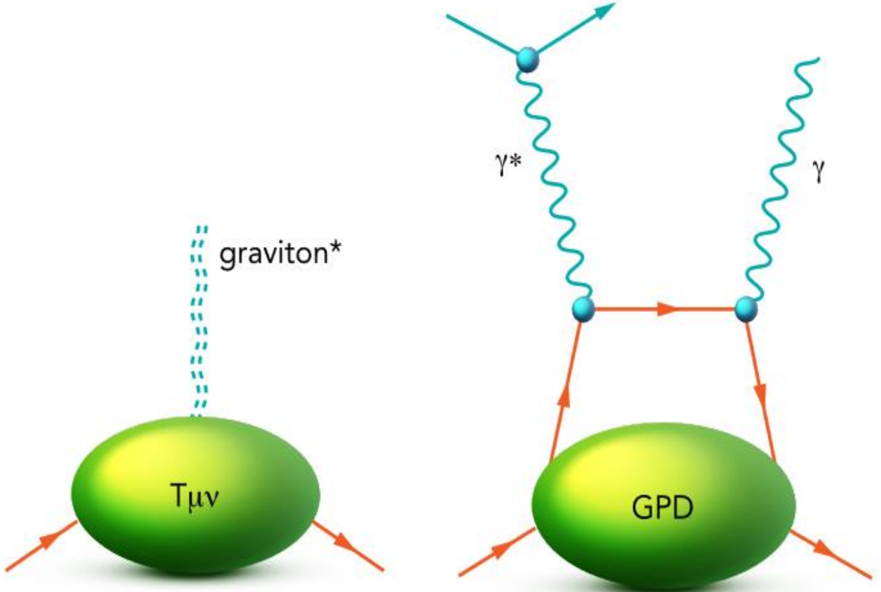
$$eN \rightarrow e'J/\psi N \rightarrow e'l^{+}l^{-}N$$

Close to the 8.2 GeV threshold, J/ψ photoproduction is mediated by the exchange of two gluons [1,2,3,4].

Any spin-2 field couples to the EMT and gives rise to a force indistinguishable from gravity, allows to probe the nucleon gravitational form factors (GFFs) [4,6].

The quark GFFs have already been investigated in the context of DVCS [7,8]. J/ψ allows to probe the gluonic GFFs.





Thomas Jefferson National Accelerator Facility (JLab)

JLab is located in Newport News, Virginia.

The Continuous Electron Beam Accelerator Facility (CEBAF) produces a 12 GeV electron beam.

Upcoming Solenoidal Large Intensity Device (SoLID) will be located in Hall A.

The CEBAF Large Acceptance Spectrometer (CLAS12) is located in Hall B.

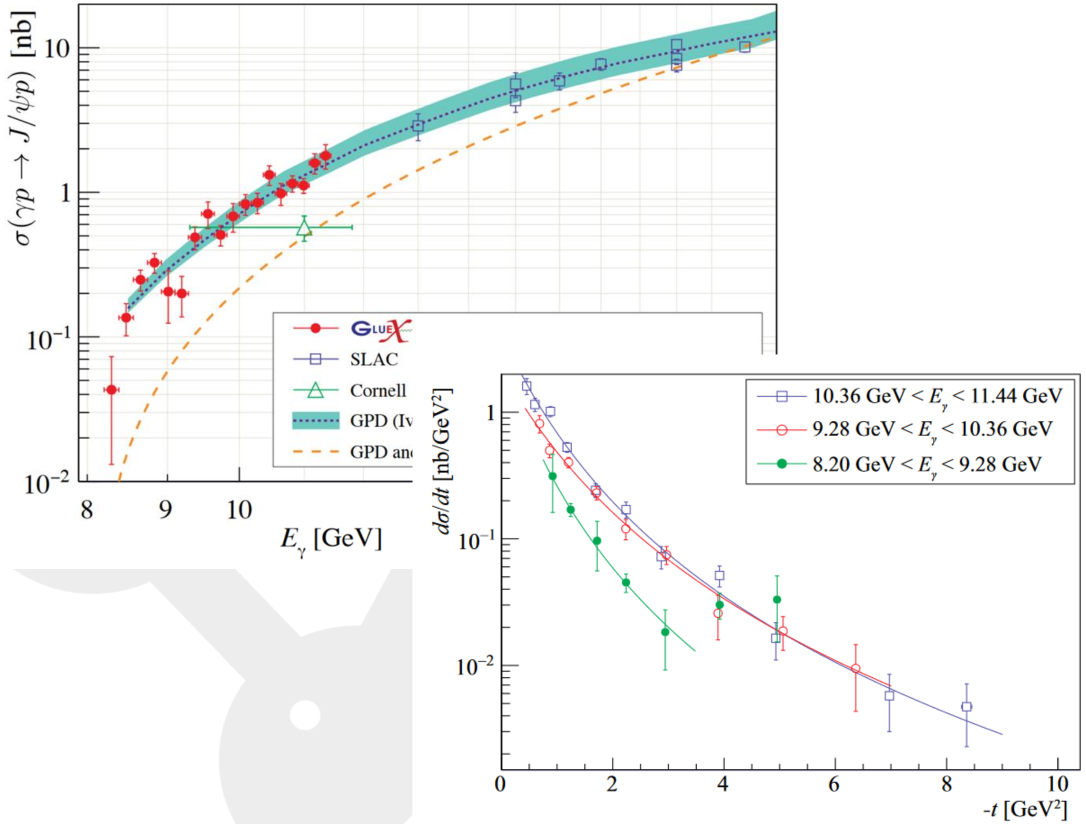
The J/ψ – 007 Collaboration located in Hall C [9].

The Gluonic Excitation Experiment (GlueX) is located in Hall D [10,11].

Previous Measurements at JLab

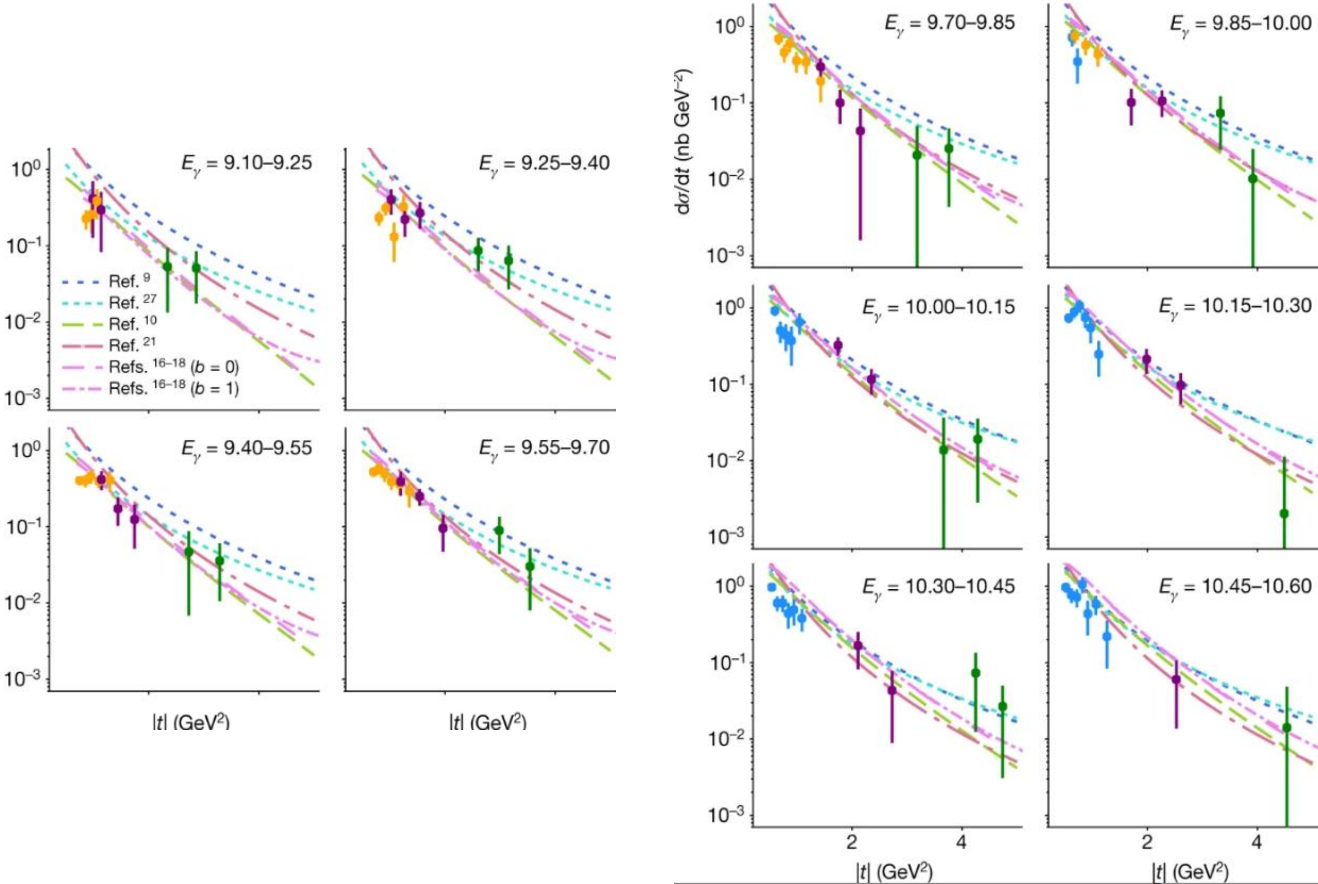
GlueX – Hall D

The GlueX Collaboration has made measurements of the total and differential cross section over the full near-threshold range [10,11].



J/ψ 007 – Hall C

The J/ψ – 007 Collaboration has made high precision measurements of the differential cross section as a function of t in 10 bins of E_γ [9].

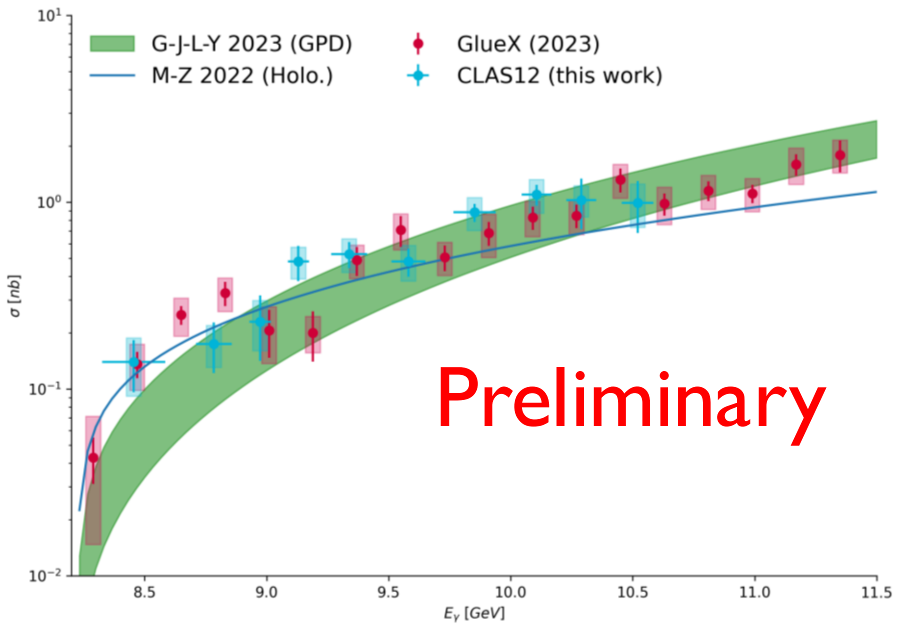


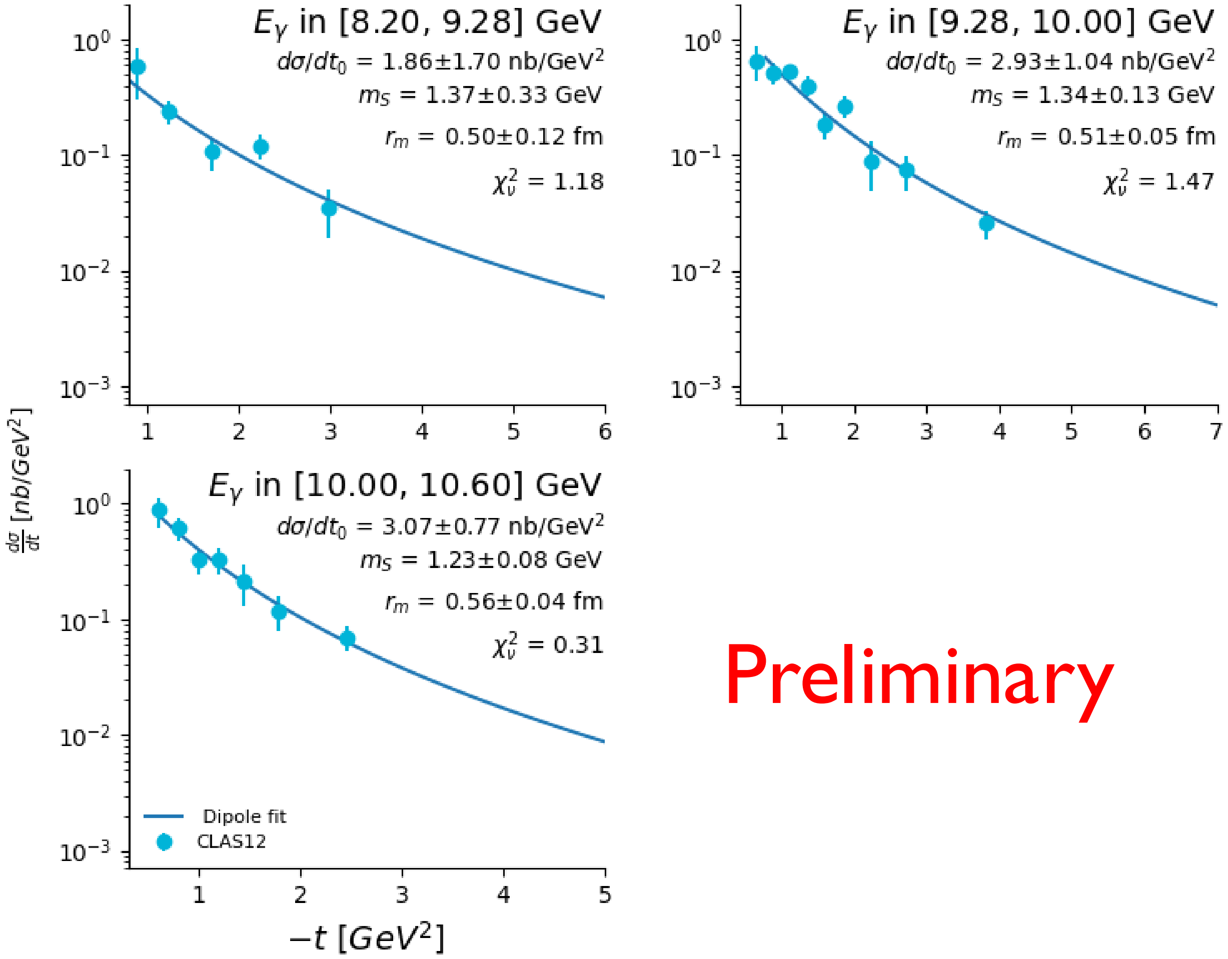
Measurements at CLAS12 – *P. Chatagnon*

Measurements of the total and differential cross section produced on the free proton are currently undergoing internal CLAS collaboration review.

Good agreement with the GlueX and Hall C results.

Stay Tuned!

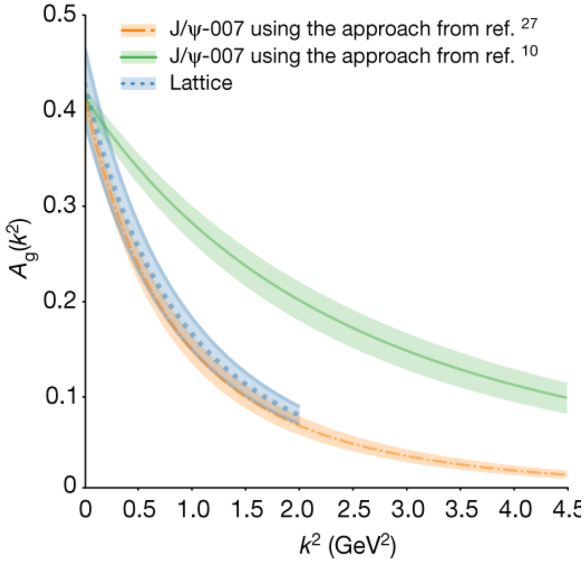




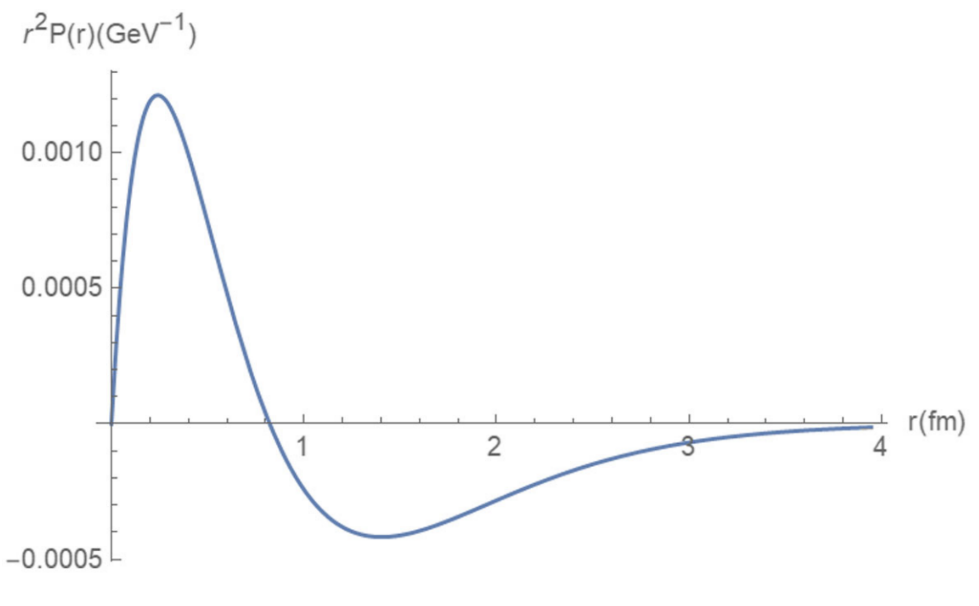
GPDs & Holographic QCD

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 [2,12].

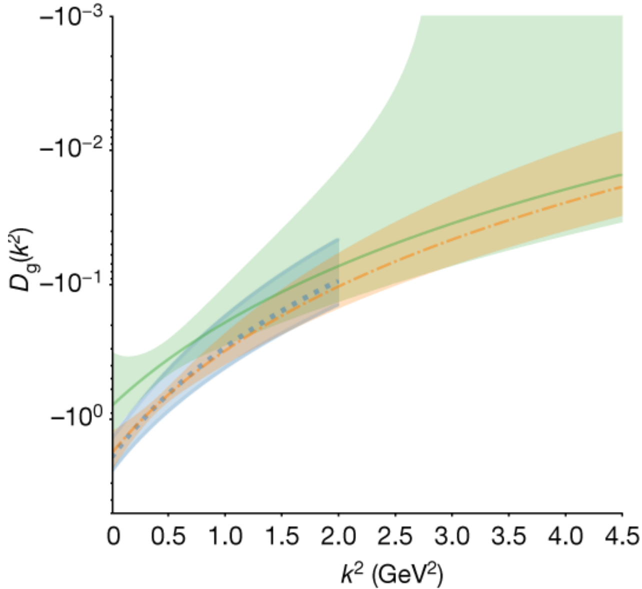
In the GPD framework, large skewness at threshold allows to relate the scattering amplitude to gluon GPDs. The GFFs are extracted from the first moments of the GPDs [3,13,14].



The $A_g(t)$ and $D_g(t)$ GFFs [9] estimated using holographic QCD [12] (orange) and GPD [3] (green) models compared to lattice QCD predictions [15] (blue). ($k^2 \equiv |t|$)



The gluon contribution to the pressure distribution inside the proton from a GPD based model fit to lattice and J/ψ photoproduction data [3].



Vector Meson Dominance Framework

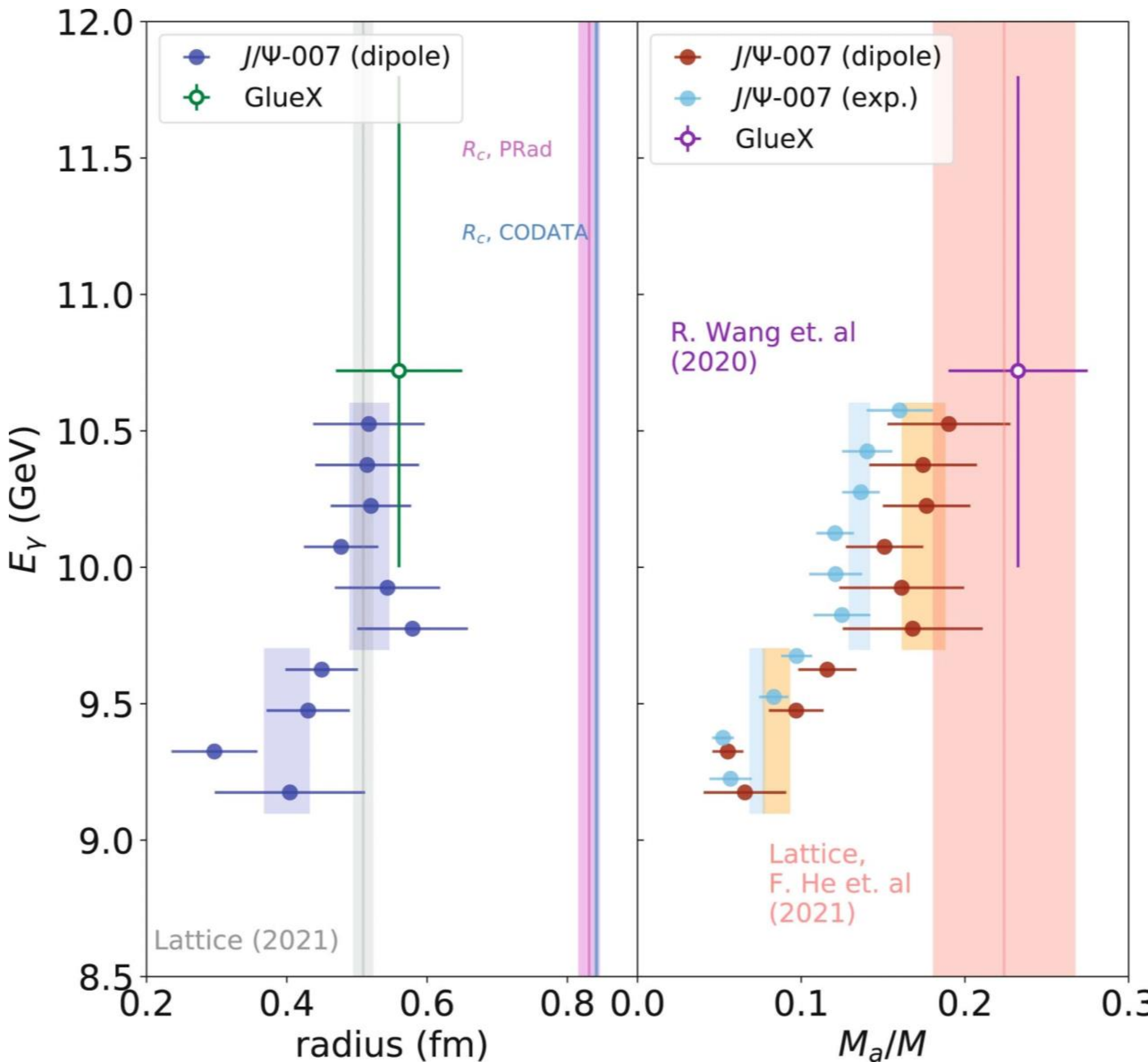
The nucleon mass can be decomposed into the contributions from the quark masses, the energy of quarks and gluons and the trace anomaly contribution [16].

A scalar gravitational form factor $G(t)$ gives access to the mass radius of the nucleon. Assuming a dipole form for $G(t)$ [17]:

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

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

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

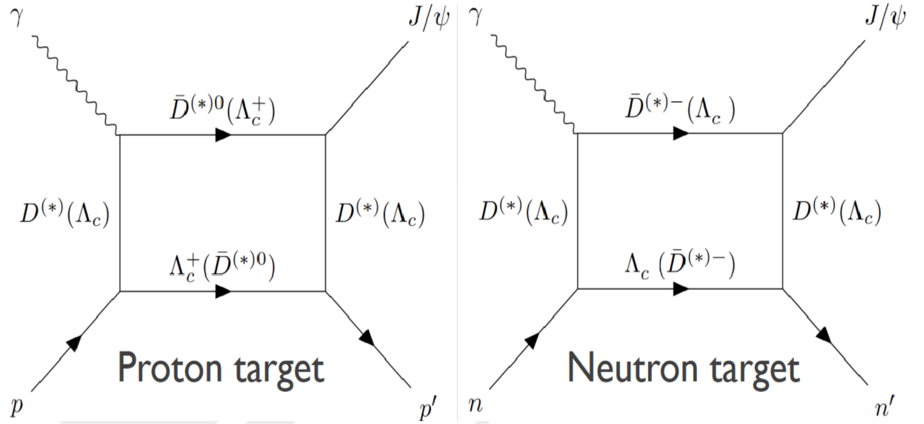


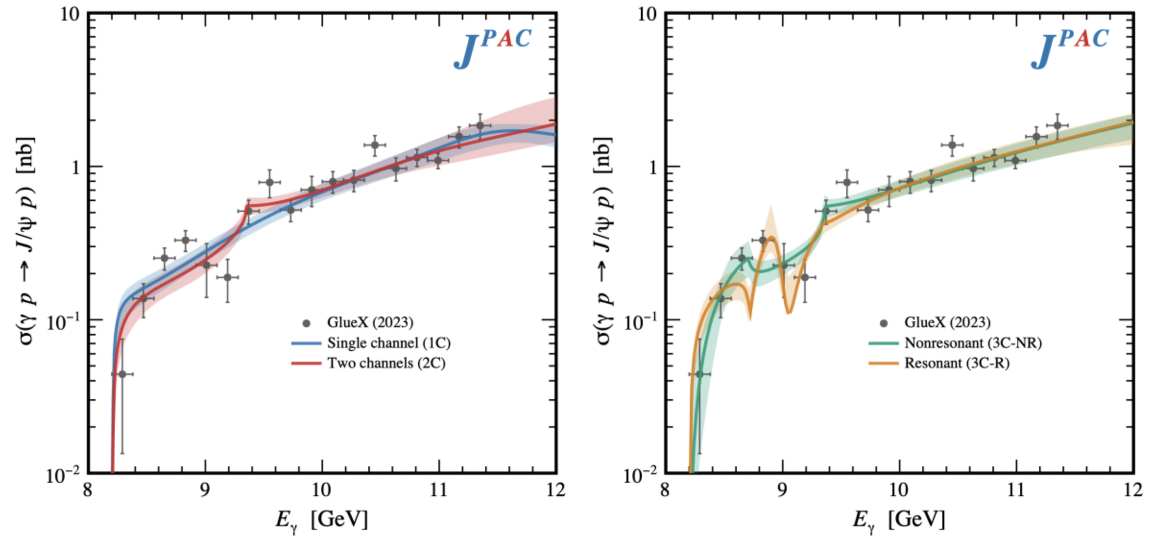
J/ψ Photoproduction On the Neutron

CLAS12 can make a first measurement of the near-threshold cross section on the bound neutron (and proton) in deuteron.

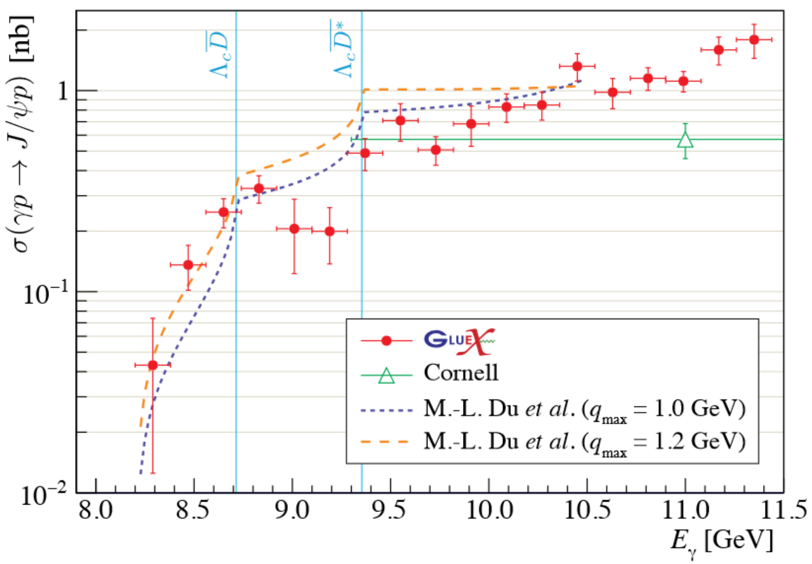
Measuring photoproduction on both proton and neutron will bring new constraints on open-charm contributions to the cross section.

Comparing the cross section on proton and neutron allows to test the isospin invariance of the production mechanism.





Estimating the contribution to the J/ψ cross section from intermediate open charm production [19, 20].



CEBAF Large Acceptance Spectrometer @ 12 GeV (CLAS12)

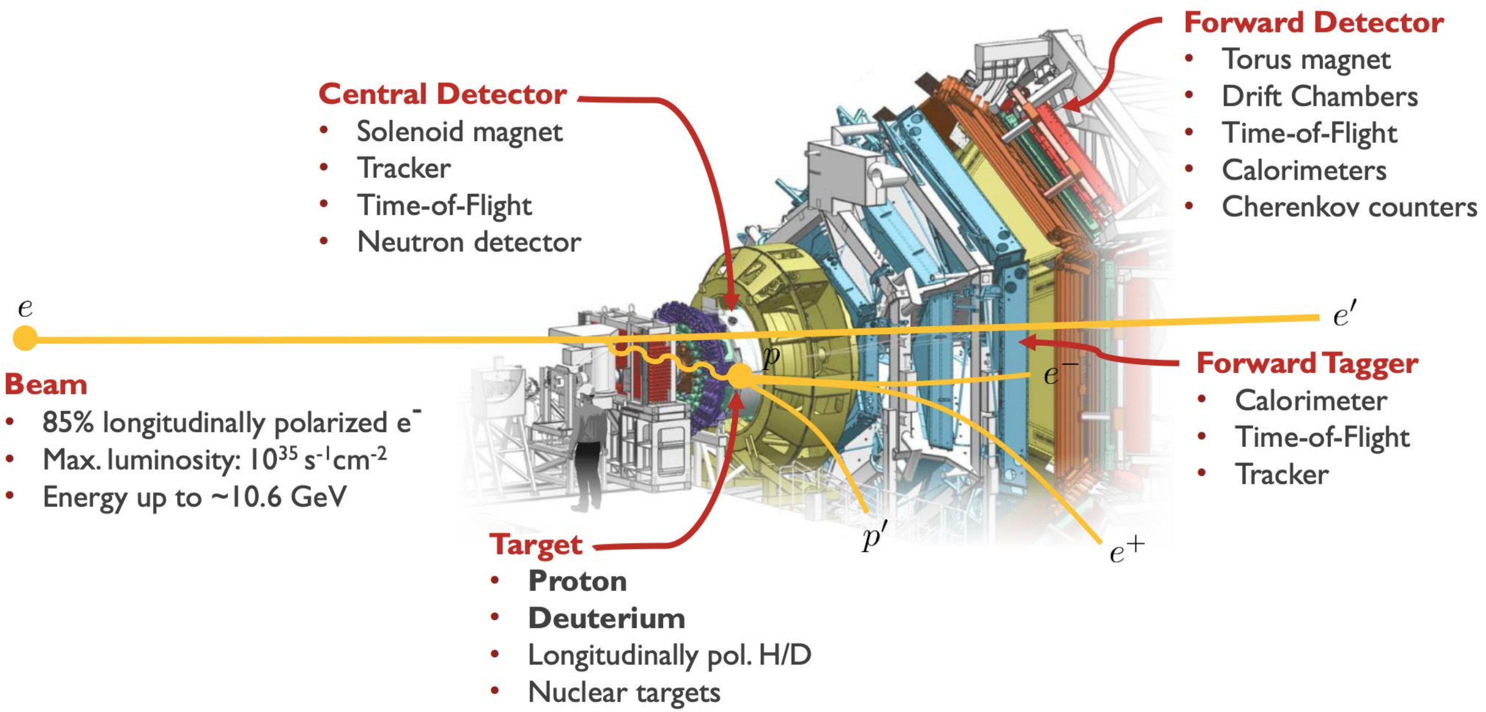
Beam energies up to 11 GeV are delivered to Hall B.

The Forward Detector has polar angle coverage of 5 to 35 degrees.

The Central Detector has polar angle coverage of 35 to 125 degrees.

CLAS12 took data with both a proton and a deuterium target:

$$e\,p \rightarrow \mathrm{e'J/\psi\;p} \rightarrow (\mathrm{e'})e^+e^-\mathrm{p} \qquad (LH_2\ \text{target})$$
$$e\,p_{bound} \rightarrow \mathrm{e'J/\psi\;p} \rightarrow (\mathrm{e'})e^+e^-\mathrm{p} \qquad (LD_2\ \text{target})$$
$$e\,n_{bound} \rightarrow \mathrm{e'J/\psi\;n} \rightarrow (\mathrm{e'})e^+e^-\mathrm{n} \qquad (LD_2\ \text{target})$$



Jefferson Lab clas

Particle Selection

Leptons

e^+/e^- identified using High Threshold Cherenkov Counters and energy deposition in calorimeters.

Refine the lepton identification with ML.

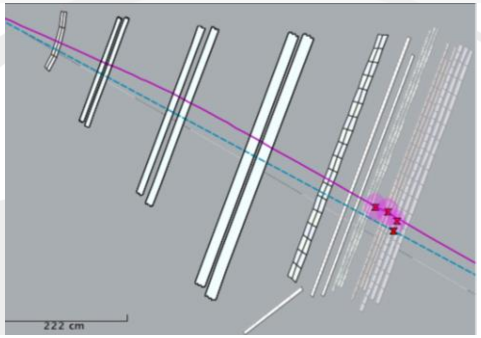
Apply some corrections to momentum.

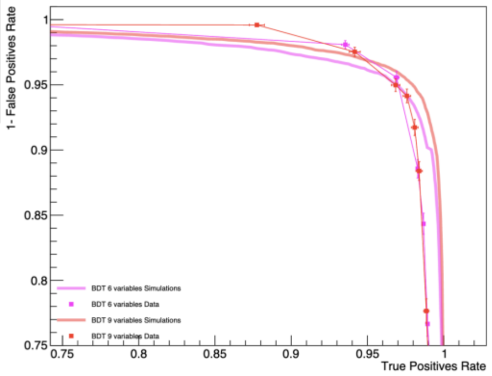
Protons/Neutron

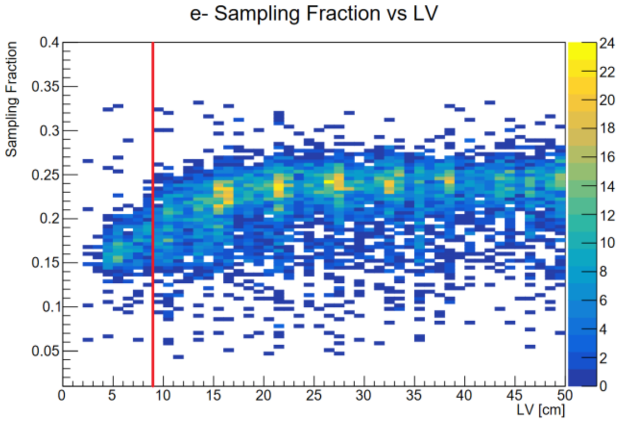
Protons identified from time of flight technique.

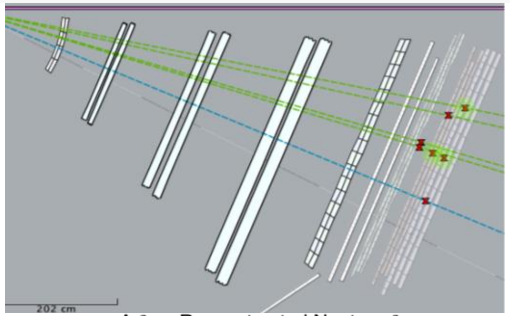
Neutrons detected in calorimeters.

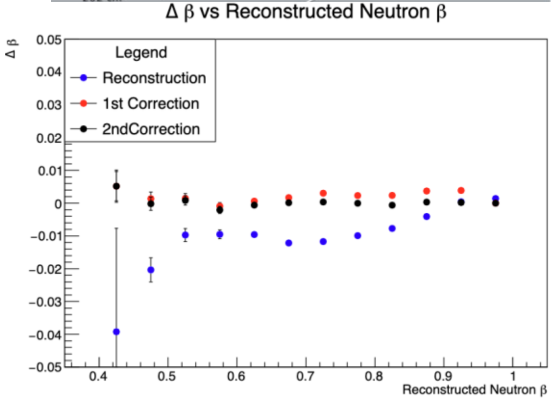
Apply some corrections to momentum.

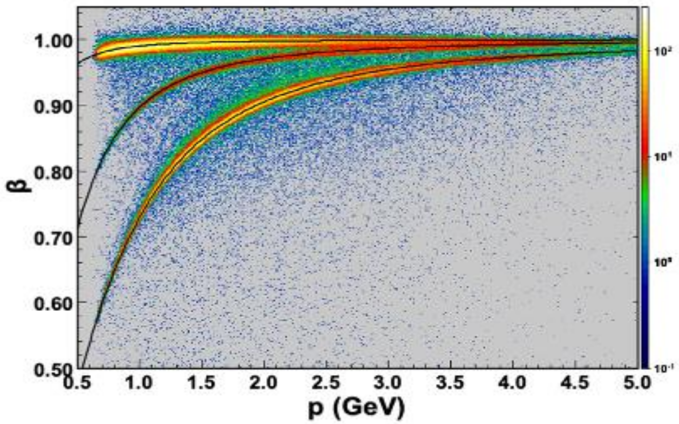












Jefferson Lab clas

Event Selection

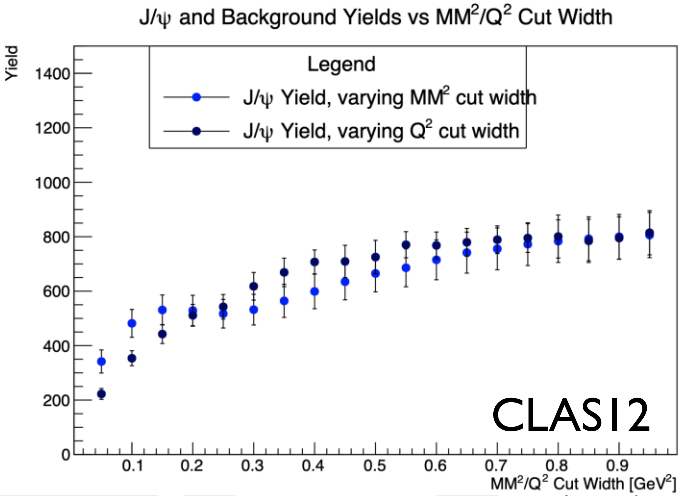
Exclusivity

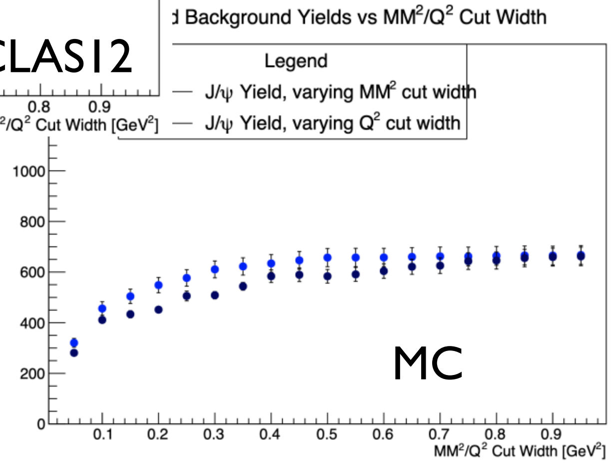
Cut on the missing mass of $eN \rightarrow (e')e^+e^-N$

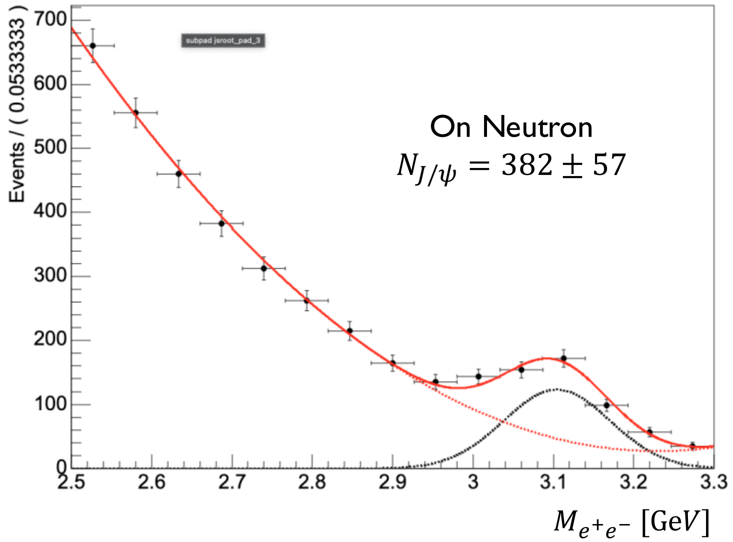
Work in the quasi-real photoproduction regime ie Q^2 should be close to zero.

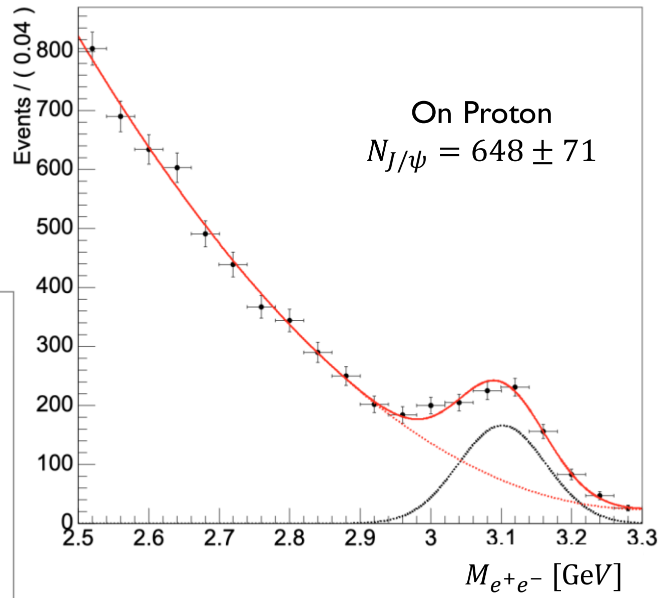
Counting J/ψs

Fit the e^+e^- invariant mass close to the J/ψ mass to find the number of J/ψ.









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

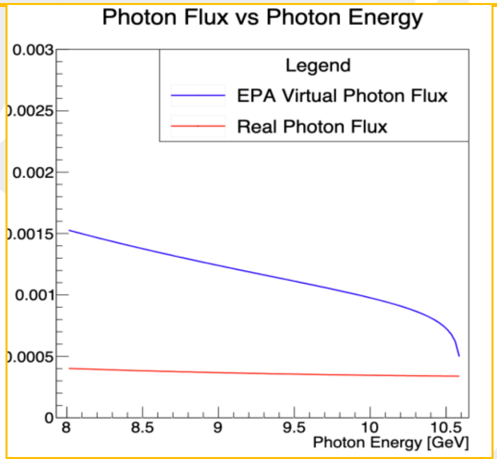
Luminosity:
N_γ is calculated from the photon flux
l_T and ρ_T are the target length and density

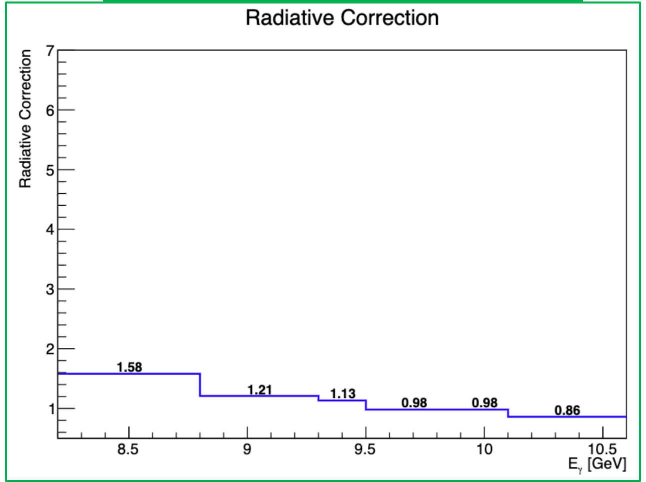
6 % Branching Ratio($J/\psi \rightarrow e^+e^-$)

Radiative Corrections

Efficiency in E_γ bins from MC

Normalisation to Bethe Heitler process





Efficiency Calculation

The efficiency calculation takes into account geometrical acceptance and detection efficiency effects on the measured J/ψ rate.

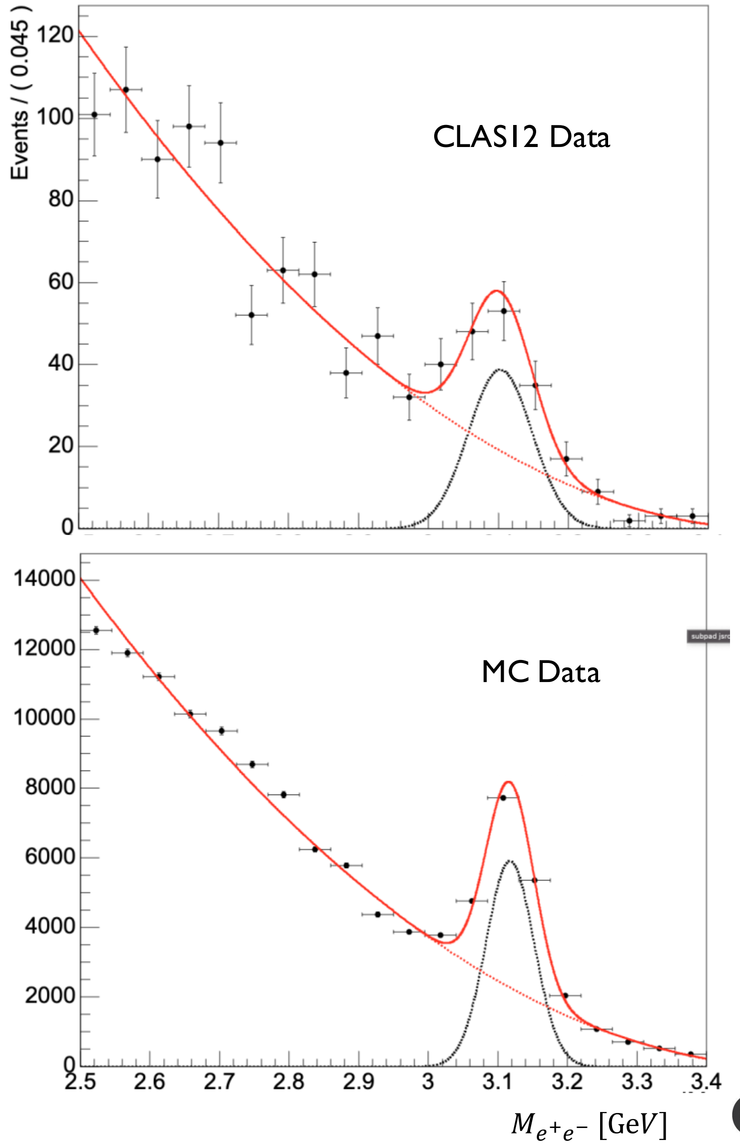
This is obtained by looking at the ratio of generated to reconstructed events.

Several corrections are applied to the efficiency in MC:

- Neutron detection efficiency.
- Reconstruction efficiency as a function of beam current.
- Fiducial cuts.
- Efficiency ratios for e+/e- PID.

MC smearing and momentum corrections are meant to decrease impact of different resolution on cuts and fitting.

Mixed event background is added to the MC and the e^+e^- is fitted as the data to account for fit systematics in obtaining the number of J/ψ in E_γ,t bins



Bethe Heitler Normalisation

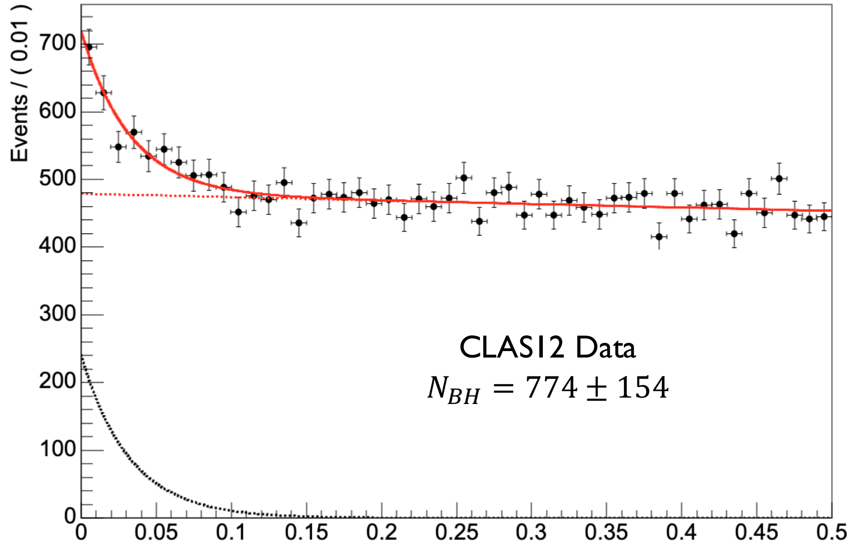
The Bethe Heitler cross section is calculable from QED.

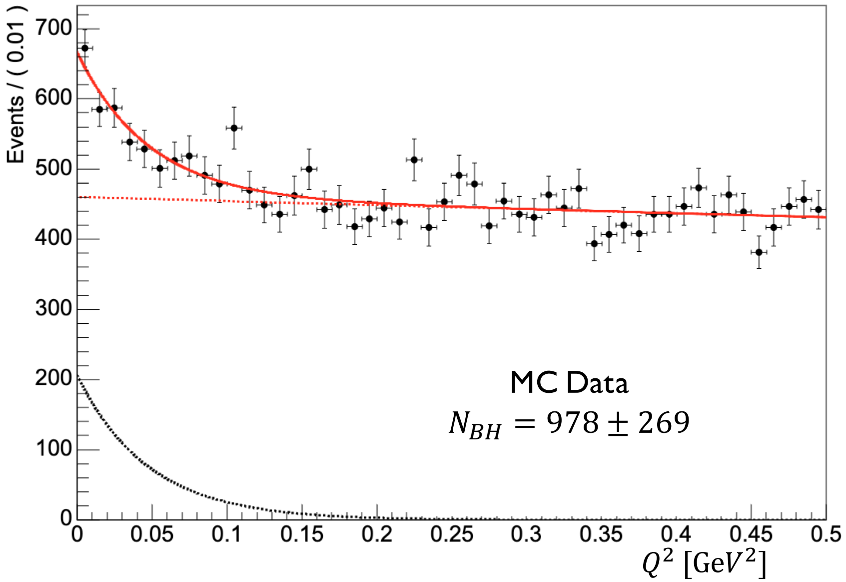
We can compare the expected number of Bethe Heitler events in MC to that in CLAS12 data, the ratio of the two gives us our normalization.

This accounts for errors in the efficiency and flux calculations.

Fit Q^2 in e^+e^- invariant mass region of 2.0 - 2.9 GeV. Only photoproduction events in this region are from Bethe Heitler.

Here the normalization is $\omega = 0.79 \pm 0.27$
⇒ source of systematic uncertainty.





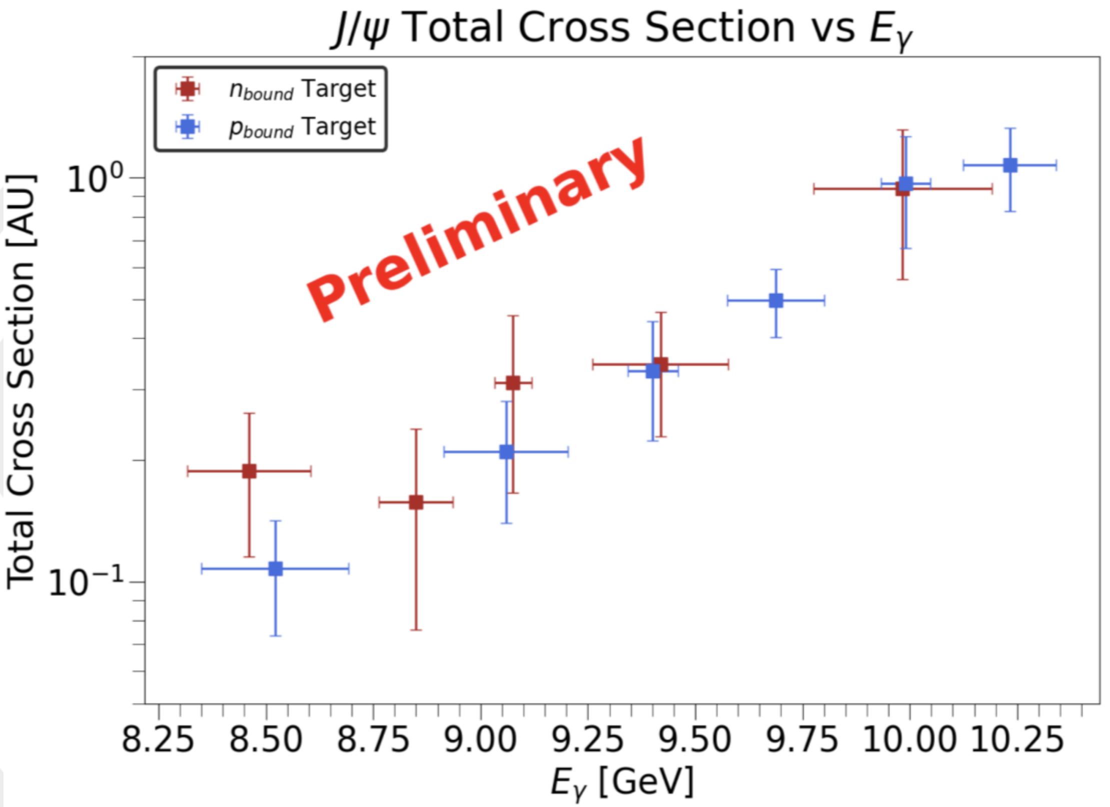
Cross Section

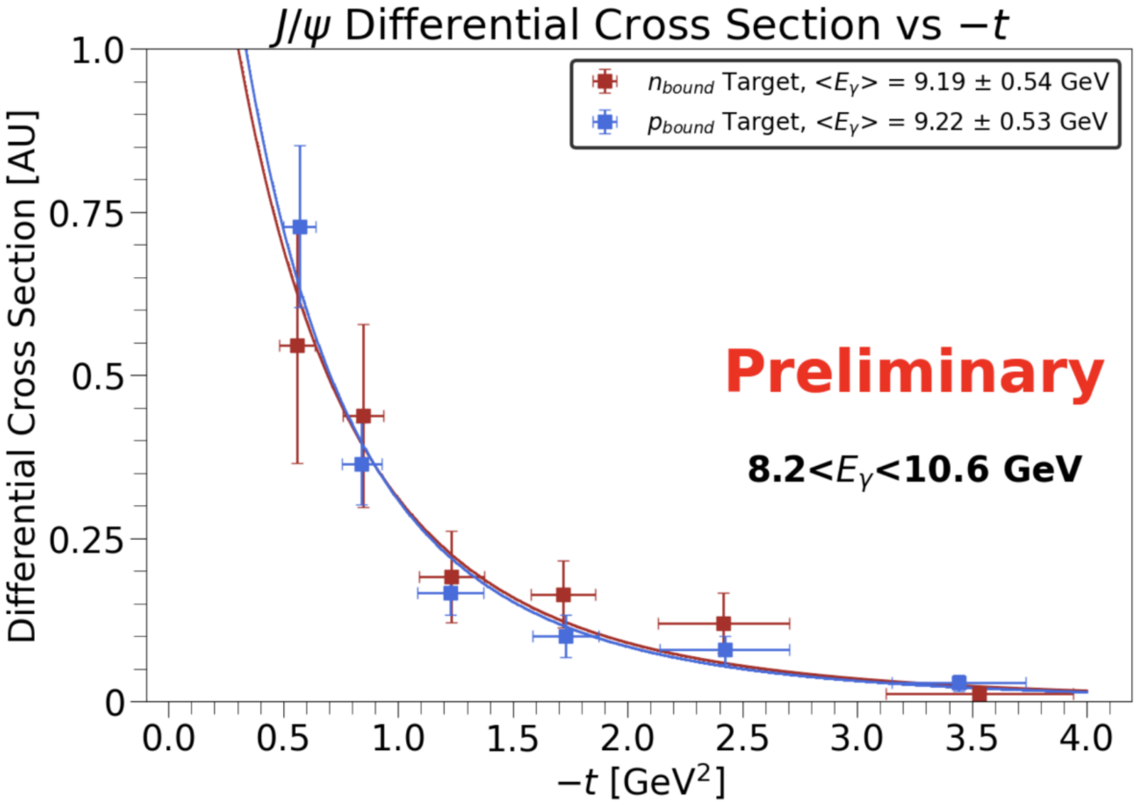
Total Cross Section

Good agreement between cross section on proton and neutron suggests isospin invariant production mechanism (or isospin breaking less than statistical uncertainty).

Differential Cross Section

Don't have the statistical precision to estimate neutron GFFs but we can extract the VMD expectation of the neutron mass radius (and expect similar GFFs to proton).





Conclusion

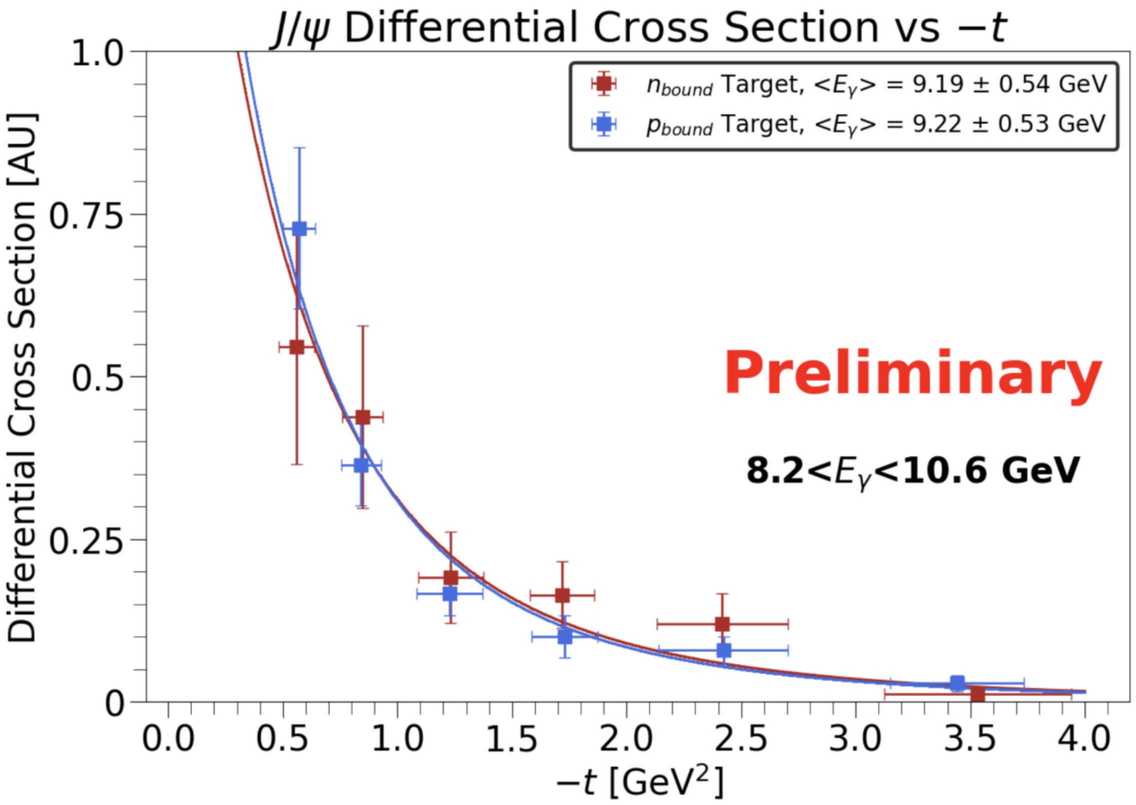
J/ψ near threshold photoproduction has received a lot of interest in recent times due to its predicted ability to probe the nucleon gluonic GFFs.

CLAS12 is aiming for a first measurement of the cross section of J/ψ near threshold photoproduction on the neutron.

Preliminary results have been obtained demonstrating good agreement between the cross section measurements on the neutron and proton in the deuteron.

The analysis will soon go under internal CLAS collaboration review.

More data on the deuteron will be taken which should improve the statistical precision of these measurements in the future.



Jefferson Lab clas

References

[1] D. Kharzeev, H. Satz, A. Syamtomov, and G. Zinovev, *Nucl.Phys. A* **661** 568 (1999).

[2] Y. Hatta, D.-L. Yang, *Phys. Rev. D* **98** 074003 (2018).

[3] Y. Guo, X. Ji, Y. Liu, *Phys. Rev. D* **103**, 096010 (2021).

[4] S.J. Brodsky, E. Chudakov, P. Hoyer, J.M. Laget, *Phys.Lett. B* **498** 23 (2001).

[5] H. Pagels, *Phys. Rev.* **144** (1966).

[6] C.W. Misner, K.S. Thorne, J.A Wheeler, W. H. Freeman 1973 Box 18.1.

[7] V.D. Burkert, L. Elouadrhiri, F.X. Girod , *Nature* **557** 7705 (2018).

[8] V.D. Burkert, L. Elouadrhiri, F.Girod, arXiv:2104.02031 (2021).

[9] D. Duran, et al. (J/ψ-007 Collaboration), *Nature* **615** (2023).

[10] A. Ali, *et. al.* (GlueX Collaboration), *Phys. Rev. Lett.* **123,** 072001 (2019).

[11] S. Adhikari et al. (GlueX Collaboration) *Phys. Rev. C* **108**, 025201 (2023).

[12] K.A. Mamo and I. Zahed *Phys. Rev. D* **106**, 086004 (2022).

[13] Y. Guo, X. Ji, Y. Liu, J. Yang, *Phys. Rev. D* **108**, 034003 (2023).

[14] Y. Guo, X. Ji, F. Yuan, *Phys. Rev. D* **109** 014014 (2024).

[15] D.A. Pefkou, D. C. Hackett, P. E. Shanahan, *Phys. Rev. D* **105** 054509 (2022).

[16] R. Wang, X. Chen, J. Evslin, *Eur. Phys. J. C* **80** 507 (2020).

[17] D. Kharzeev, *Phys. Rev. D* 104 054015 (2021).

[19] M.-L. Du, V. Baru, F.-K. Guo, C. Hanhart, U.-G. Meißner, A. Nefediev, I.Strakovsky, *Eur. Phys. J. C* 80 1053 (2020).

[20] D. Winney, *et. al.* (Joint Physics Analysis Center), *Phys. Rev. D* **108**, 054018 (2023).