A Deuterium Target at μCLAS12

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μCLAS12 workshop

9th of March 2026

μCLAS12

μCLAS12 was approved for 200 days with a 7.5 μA beam and a 5 cm LH2 target

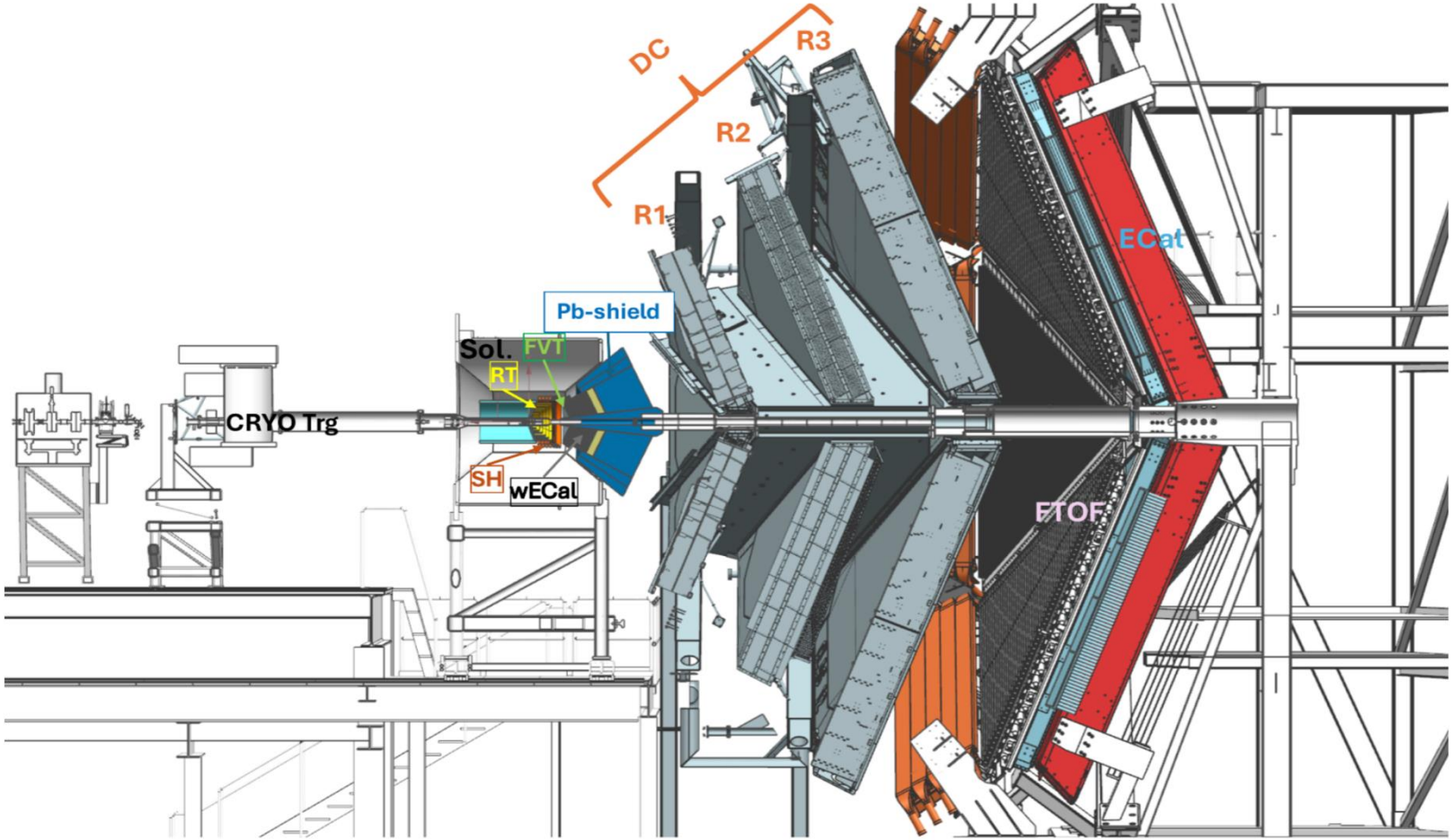
μCLAS12 will be a key facility to study proton GPDs via:

- J/ψ electroproduction
- DDVCS
- TCS

Key detector set-up:

- Forward muon detection (CLAS12 FD and Pb-shield)
- Forward electron detection (wECAL & FVT)
- Recoil Detection (RT & SH)

Can we exploit this set-up to study neutron and deuteron GPDs?



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J/ψ

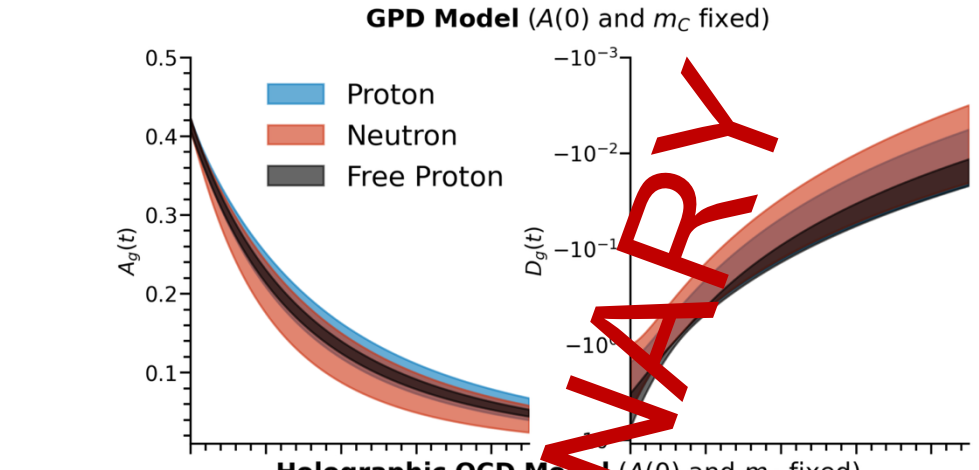
Incoherent Production

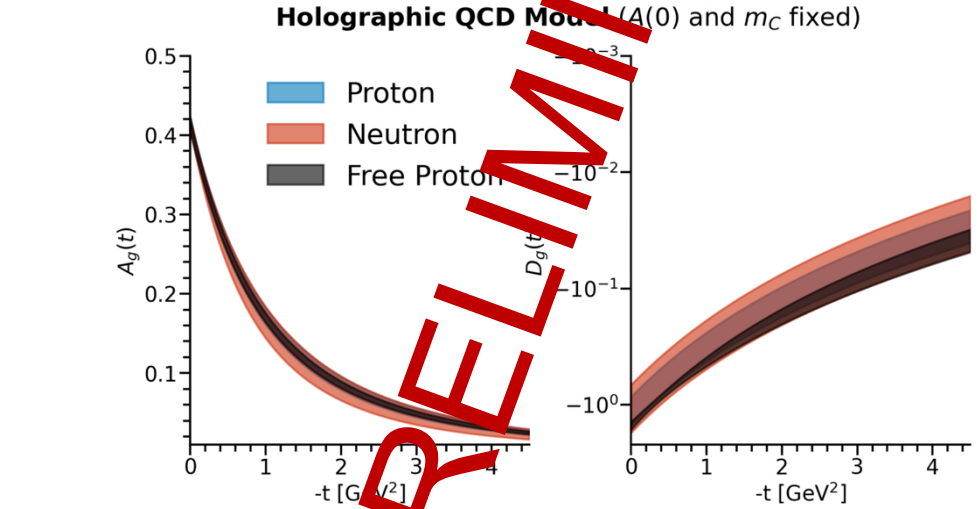
Aim for higher statistics incoherent J/ψ production on the bound proton and neutron than available with CLAS12.

Opportunity to study gluon content of the nucleon (under the assumption of low contributions from FSI interactions, see next slide).

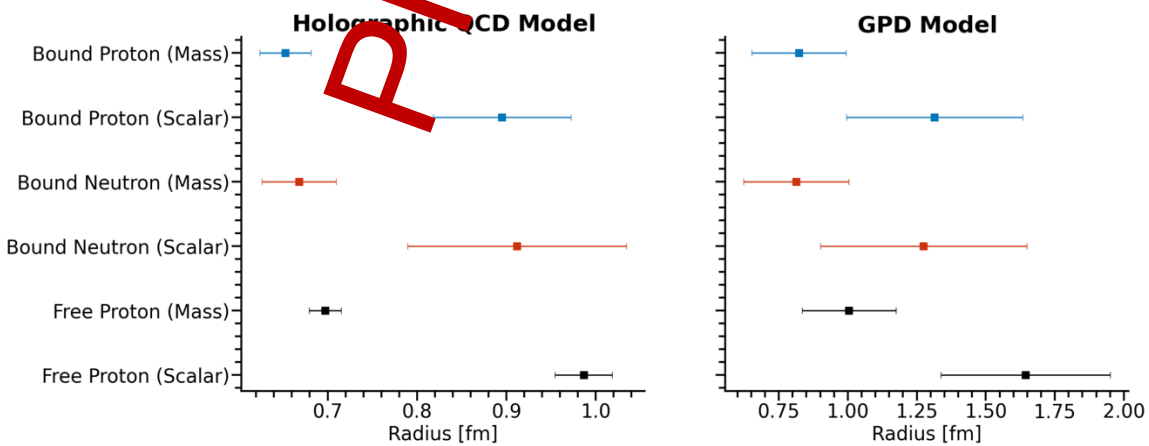
Study of polarization observables (SDMEs) on neutron would allow to probe for:

- An isospin partner to the LHCb pentaquarks?
- Isospin constraints on production mechanism?





PRELIMINARY



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J/ψ

Phys Rev C **88** 044604 (2013)

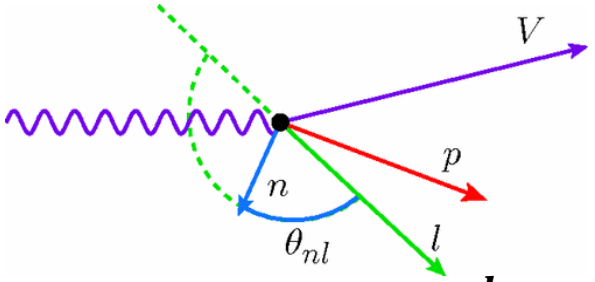
Final State Interactions

Potential to estimate FSI contribution to cross section and model dependent J/ψ – Nucleon cross section.

Low energy J/ψ – Nucleon cross section poorly constrained ⟹ necessary input for study of gluon content of the neutron.

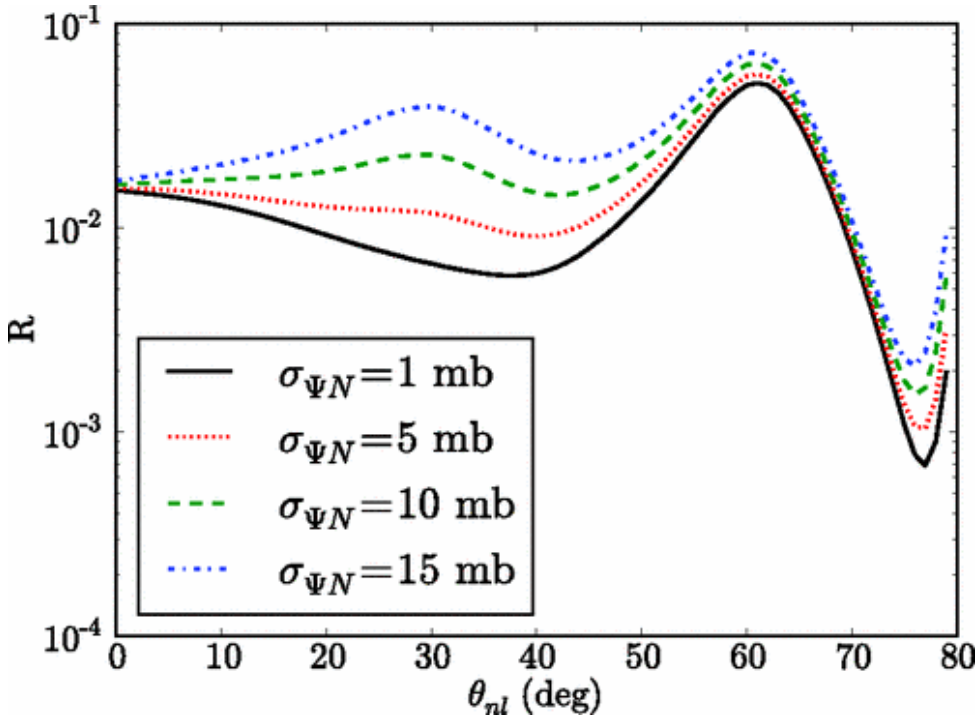
Has implications for QCD Van Der Walls force and potential J/ψ – Nucleon bound states.

Suppression of J/ψ yield in heavy ion collisions is predicted to be a signature of transition from cold nuclear matter to QGP ⟹ constraints from J/ψ – Nucleon cross section.



$$R = \frac{\sigma(p_n = 600\ \text{MeV})}{\sigma(p_n = 200\ \text{MeV})}$$

$$\boldsymbol{l} = \boldsymbol{p_n} + \boldsymbol{p_p}$$



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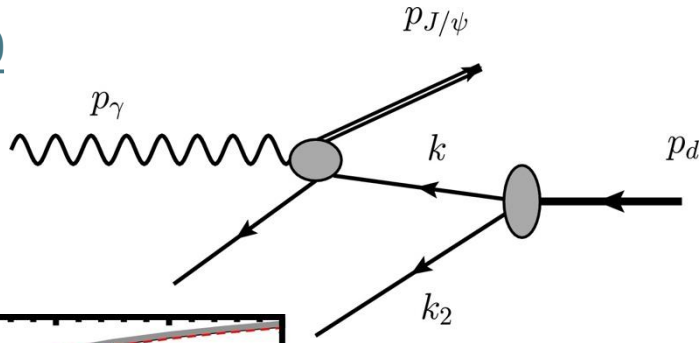
J/ψ

Phys. Lett. B, **803**, 10 35321 (2020)
Phys Rev Lett **134**, 201903 (2025)



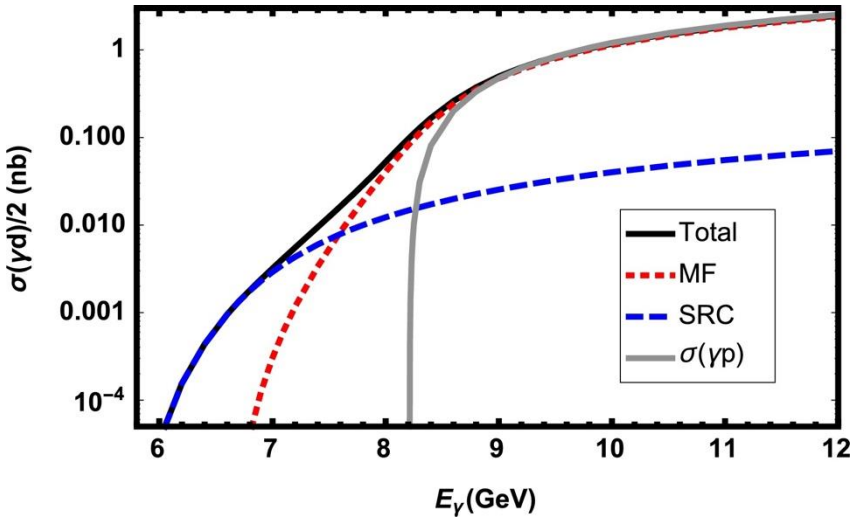
Subthreshold Production

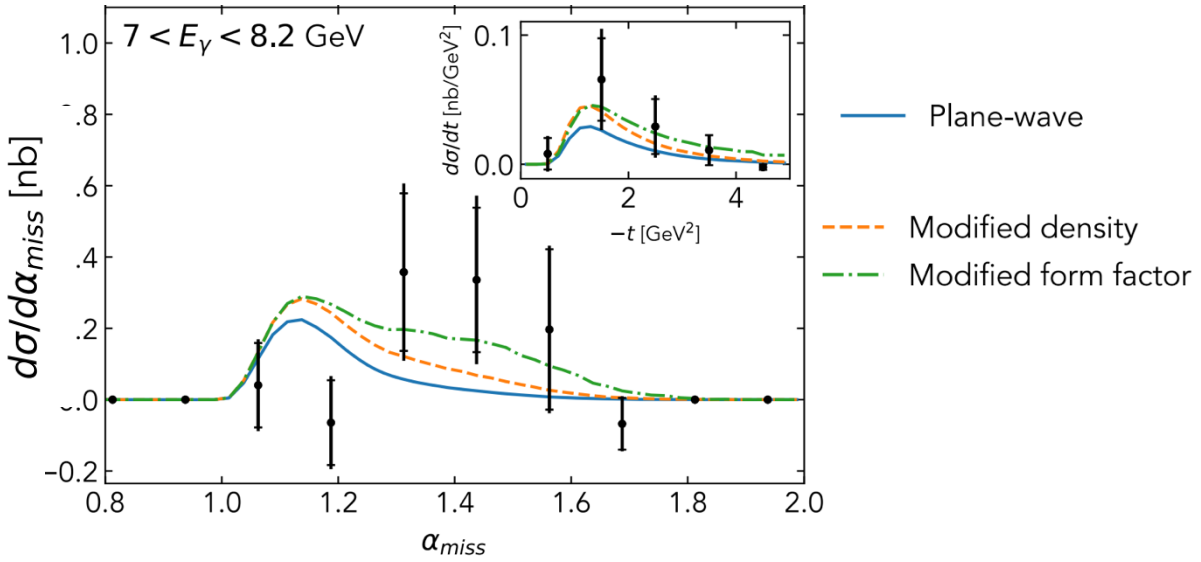
It's been argued that subthreshold production can be a probe of nuclear and SRC structure.

Hypotheses for nuclear in medium effects:

- Subthreshold cross section increased due to bound protons coupling more strongly to J/ψ ⟹ increased gluon density
- t-dependence of the cross section is modified, due to decrease in the slope of the effective gluonic form factor for bound nucleons ⟹ decreased gluon radius

First measurement of subthreshold production (and production on nuclei) from GlueX. Possible hints of increased subthreshold cross section…





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J/ψ

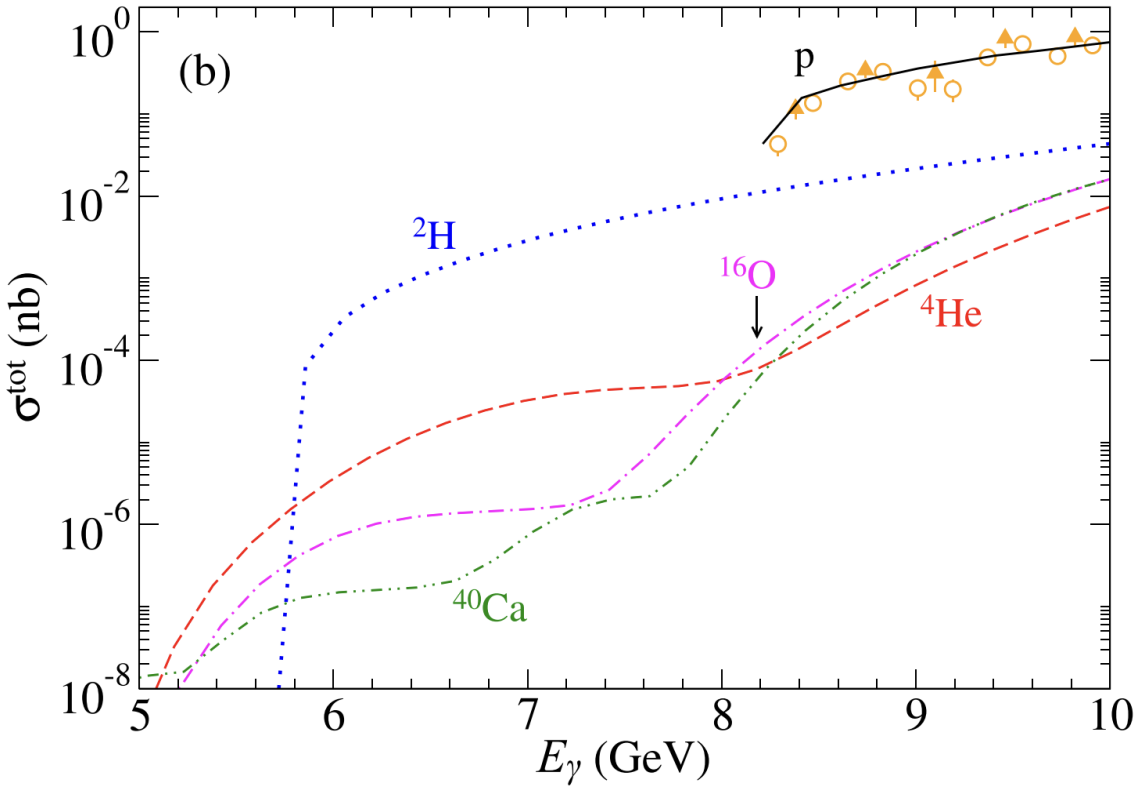
Coherent

Opportunity for coherent J/ψ production on the deuteron.

Assuming dominant gluon-exchange production mechanism, we can relate this to the gluon content of the deuteron.

Experimental complication in having to detect the deuteron to separate coherent/incoherent production. Most likely can only do so in the recoil detector.

Phys Rev C 112, 015206 (2025)



TCS and DDVCS on the Neutron

EPJ A **53** 33 (2016)

GPDs $H^q(x,\xi,t), \quad E^q(x,\xi,t), \quad \tilde{H}^q(x,\xi,t), \quad \tilde{E}^q(x,\xi,t)$

$$\mathcal{H}(\xi,t) = \sum_q e_q^2 \int_{-1}^{1} dx \left(\frac{1}{x-\xi+i\epsilon} - \frac{1}{x+\xi-i\epsilon} \right) H^q(x,\xi,t)$$

CFFs

$$\mathrm{Im}\,\mathcal{H} = -\pi \sum_q e_q^2 \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t) \right]$$

Proton $\mathcal{H}_p = \frac{4}{9}\mathcal{H}^u + \frac{1}{9}\mathcal{H}^d + \frac{1}{9}\mathcal{H}^s$

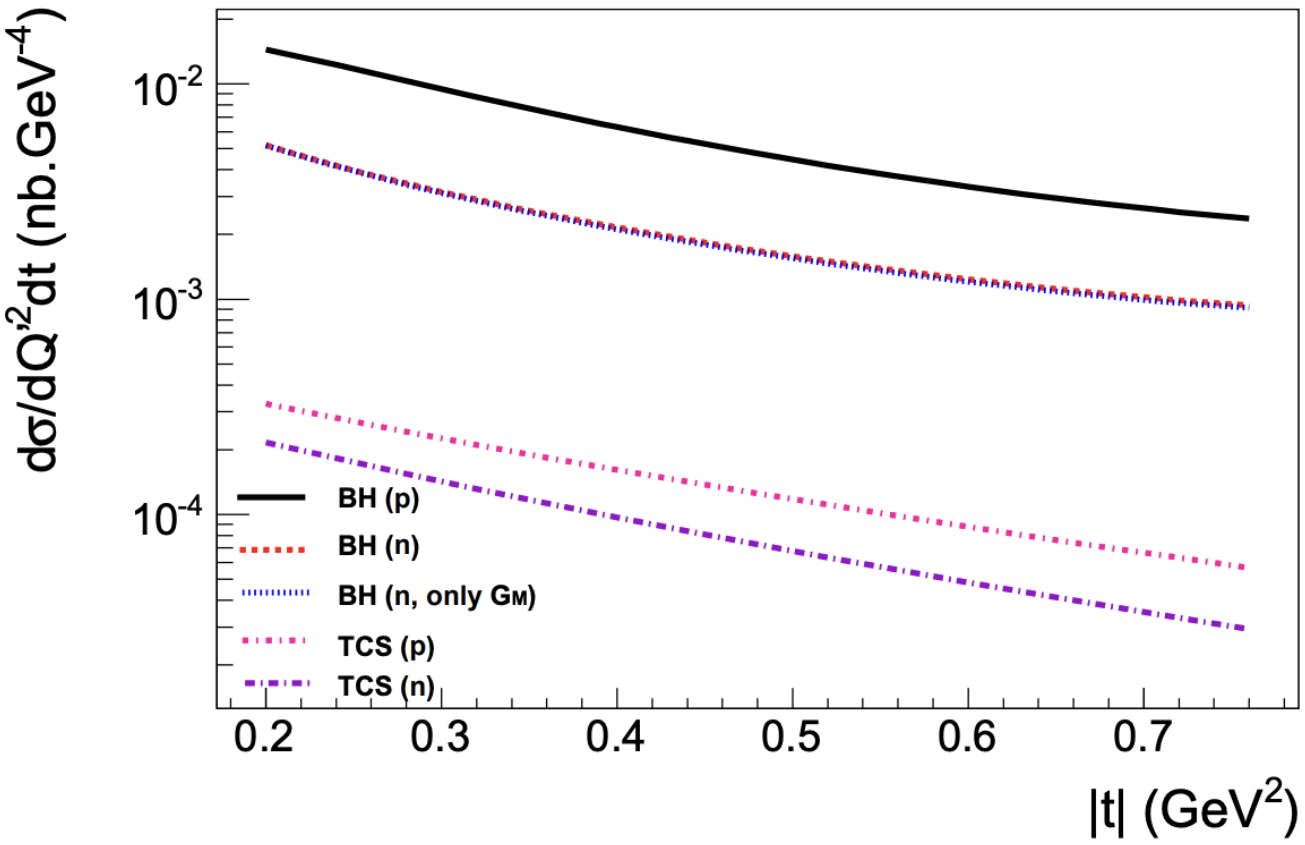
Neutron $\mathcal{H}_n = \frac{4}{9}\mathcal{H}^d + \frac{1}{9}\mathcal{H}^u + \frac{1}{9}\mathcal{H}^s$

$$F_1^p \gg \frac{|t|}{4M^2} F_2^p \qquad F_1^n \approx 0$$

$$A_{LU} \propto \sin\phi\ \mathrm{Im}\left[F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2} F_2\mathcal{E} \right]$$

$$A_{LU}^{TCS} \propto \sin\phi\ \mathrm{Im}\left[F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2} F_2\mathcal{E} \right] \quad \mathcal{H}_{TCS} = \mathcal{H}^*_{DVCS}$$

$$A_{LU}^{DDVCS} \propto \sin\phi\ \mathrm{Im}\left[F_1\mathcal{H}(\xi,\xi') + \xi(F_1+F_2)\tilde{\mathcal{H}}(\xi,\xi') - \frac{t}{4M^2} F_2\mathcal{E}(\xi,\xi') \right]$$



Deuteron GPDs

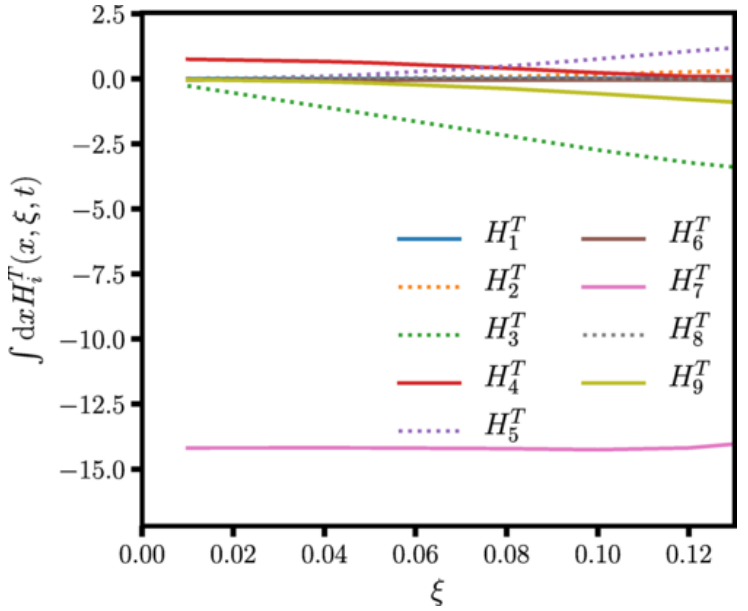
Phys. Rev. D **98**, 074020 (2020)
Phys. Rev. D 99, 094035 (2019)
Phys. Rev. D **100**, 036003 (2019)
EPJC **79**, 476 (2019)
EPJC **85** 361, (2025)
arXiv 2602.18298 (2026)

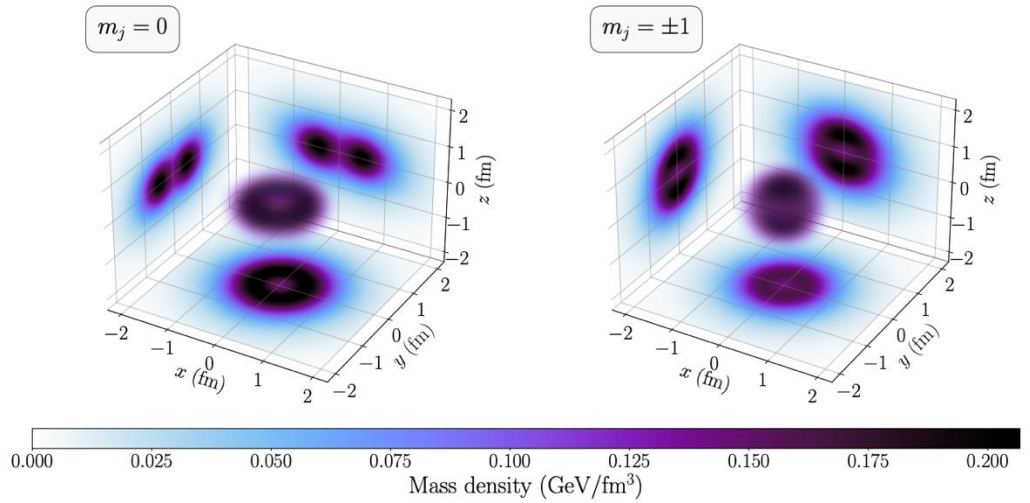
Growing body of work on deuteron GPDs.

In particular, descriptions of deuteron Energy Momentum Tensor and Mechanical Form Factors.

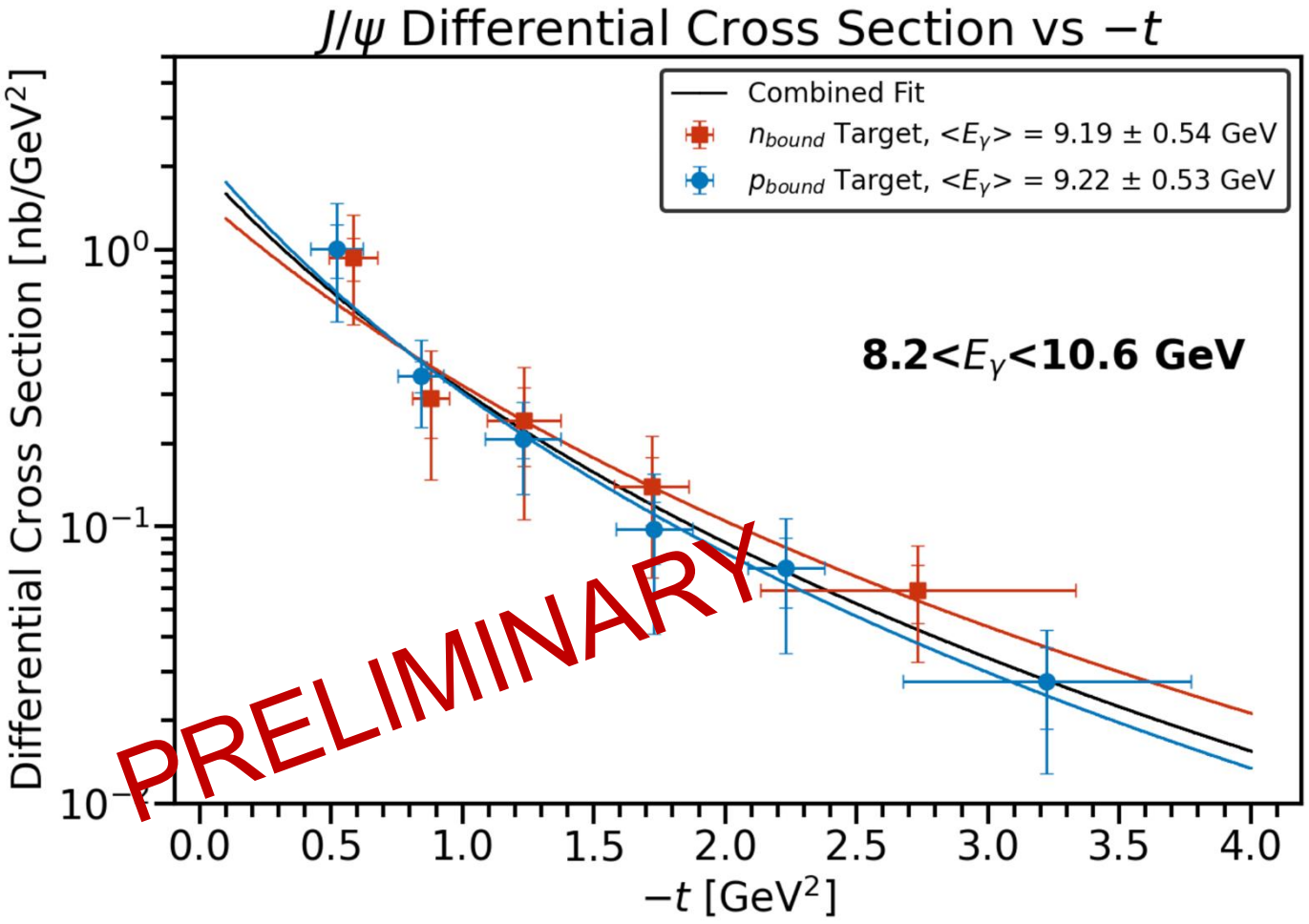
This includes work in holographic QCD formalism that is fairly successful for proton gluon GFFs.

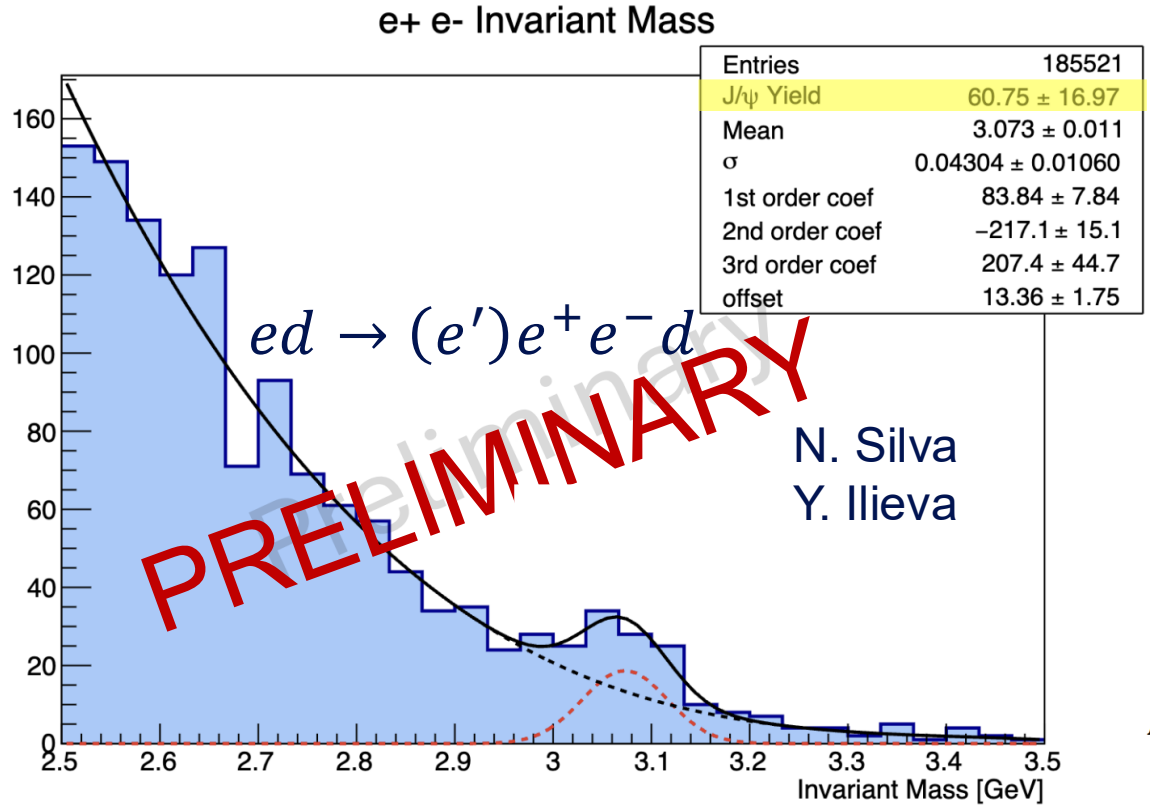
9 leading-twist quark GPDs, and harder to isolate individual GPDs $\Longrightarrow$ no well defined observables (as far as I can tell)





CLAS12 Results J/ψ





Preliminary measurements of total and differential cross section on bound proton and neutron.

Initial analysis of coherent production (at least an order of magnitude fewer J/ψs than on proton) (N. Silva, Y. Ilieva)

CLAS12 Results
TCS on the Neutron
Coherent DVCS

A. Biselli (June 2022)
Coherent DVCS RG-B

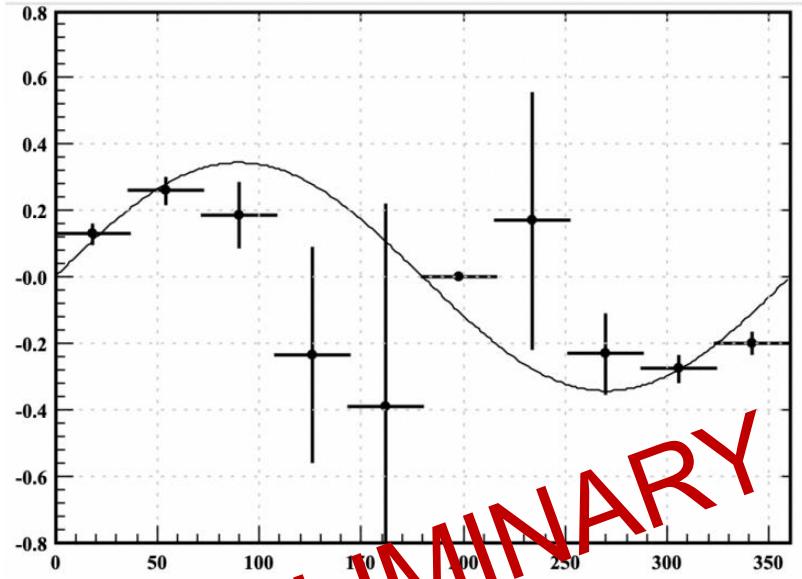
Initial analysis of coherent DVCS in RG-B (A. Biselli).

Rates estimation for incoherent TCS production on the neutron with pass 1 RG-B (K. Gates, D. Sokhan).

Conclusion at the time was that the statistics are too limited. Perhaps pass2, and remaining RG-B data will allow for a TCS on neutron measurement.

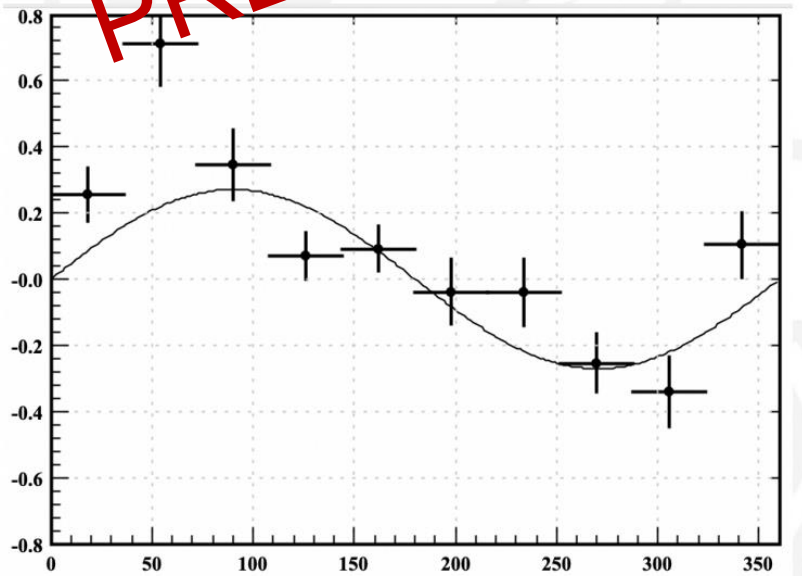
Coherent TCS and DDVCS, and incoherent DDVCS on the neutron are obviously not possible.

FT



PRELIMINARY

FD



Neutron Strategy

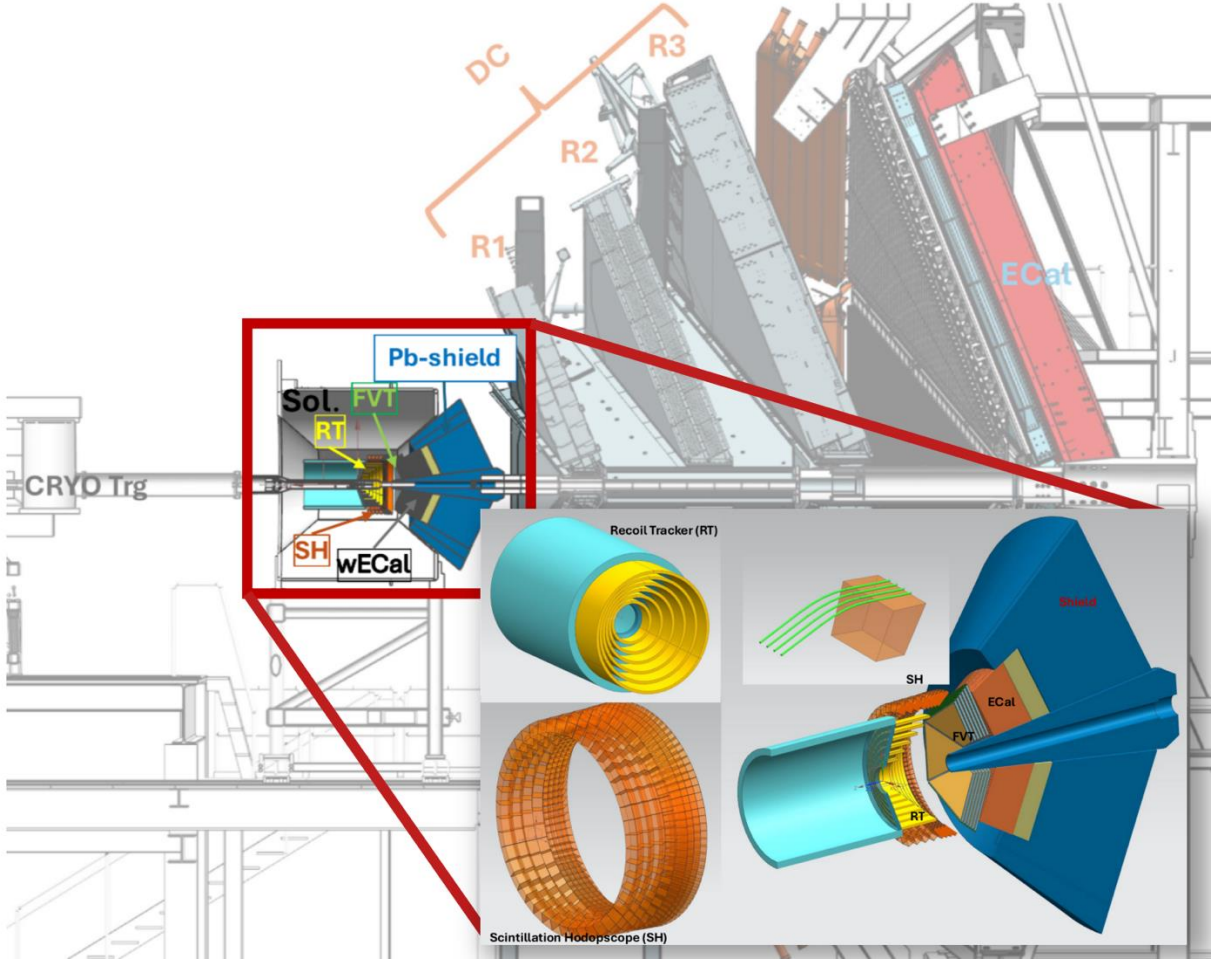
Active Detection

Expect background rates in pre-shielding wECAL to be too high to accurately distinguish neutrons.

Possible with exclusivity to restrict neutron candidates? Good enough timing?

Otherwise, have to verify neutron efficiency in forward ECAL (behind shielding).

Will look into detailed simulations when available.



Neutron Strategy

Phys. Rev. Lett. **99**, 242501 (2007)
Nature Physics **16**, 191–198 (2020)

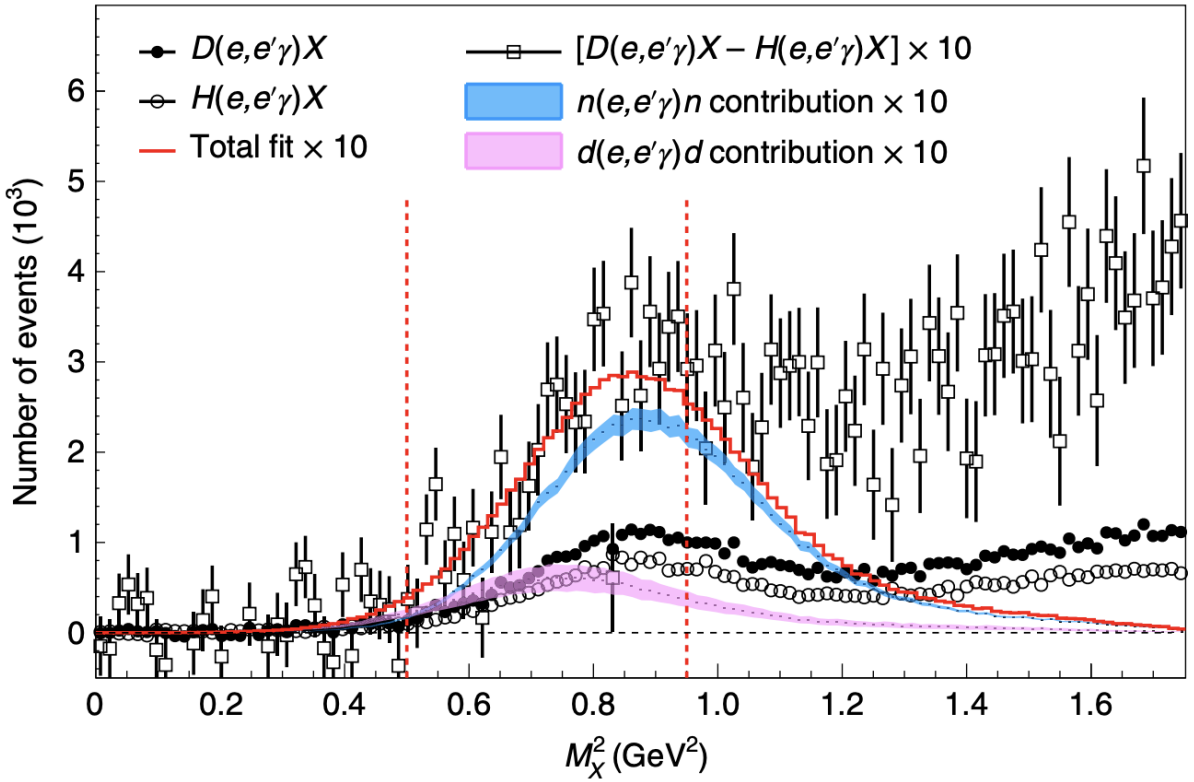
Indirect Measurement

Similar to Hall A DVCS measurement:

- Take data alternating LH2 and LD2 targets
- Do usual analysis
- Normalise LH2 luminosity to LD2 luminosity
- Add fermi motion to LH2 data
- Subtract LH2 data from LD2 data
- Separate coherent and incoherent data using exclusivity variables

Several sources of systematics:

- Alternate LH2 and LD2 targets to reduce run period/detector related systematics
- Fermi smearing model
- Exclusivity separation of coherent/incoherent



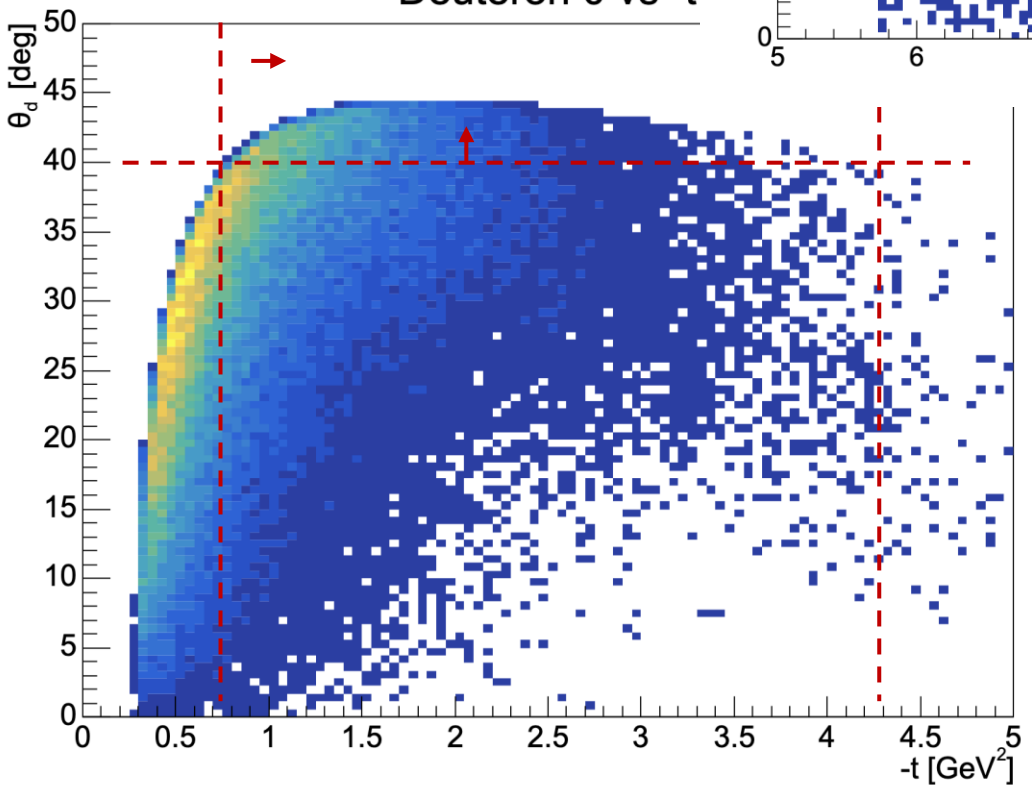
Coherent J/ψ Strategy

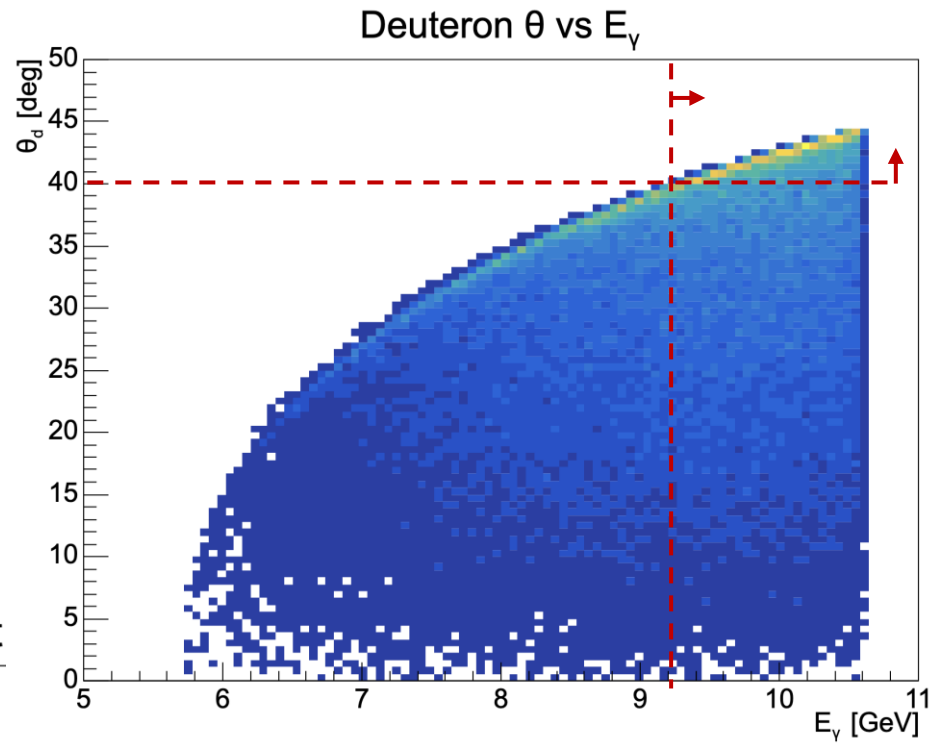
Require recoil deuteron detection to separate incoherent/coherent production.

Should then have resolution in exclusivity variables and timing from hodoscope.

LH2 proposal sees recoil detector starting at $\theta = 40^o$ (i.e. detection for $\theta_d > 40^o$).

Detection in forward tracker & calorimeter too saturated with noise?





Simple event generator with t slope x5 that of incoherent production

Coherent J/ψ Rates Estimation

Cross section from Phys Rev C 112, 015206 (2025) .

Rates estimated as:

$$N_{J/\psi} = \sigma(E_\gamma) * L_{int} * \epsilon(E_\gamma) * Br$$

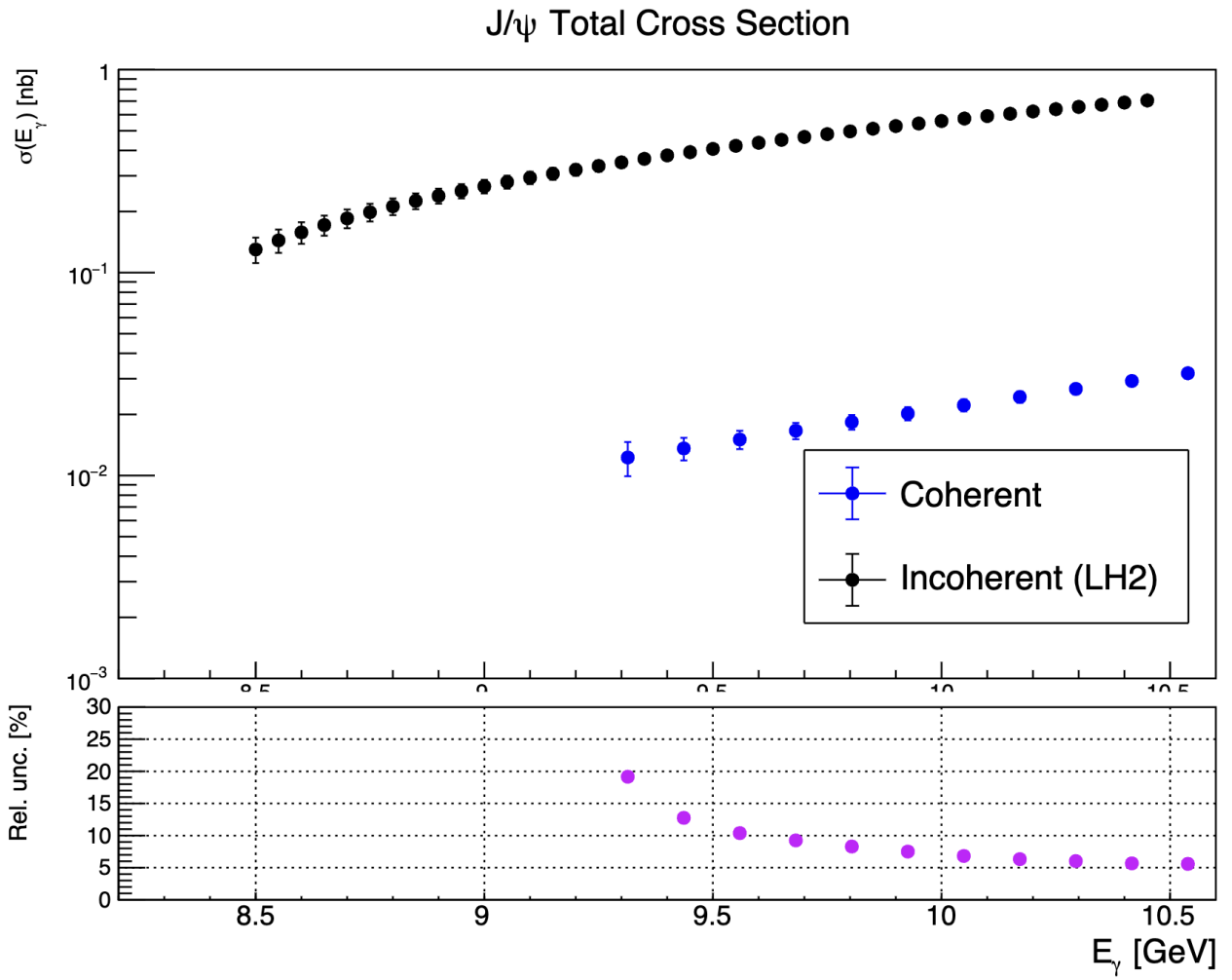
L_{int} for a 7.5 μA beam for 200 days (from LH2 proposal) on a 5cm deuterium target, Br = 6 % for $J/\psi \rightarrow \mu^+\mu^-$

Assume $\epsilon(E_\gamma) = 0.1 * A_d(E_\gamma)$, $A_d(E_\gamma)$ is the acceptance for deuteron in recoil detector as a function of E_γ.

Anticipate ~2000 events (~8000 without requiring d in recoil detector). Assume Poisson statistics (ie $\sigma_N = \sqrt{N}$)

E_γ and t coverage is limited, problem for theory?

- $E_\gamma > 9.2$ GeV , far from threshold (5.66 GeV)
- $-t > 0.7$ GeV^2



Coherent TCS Strategy

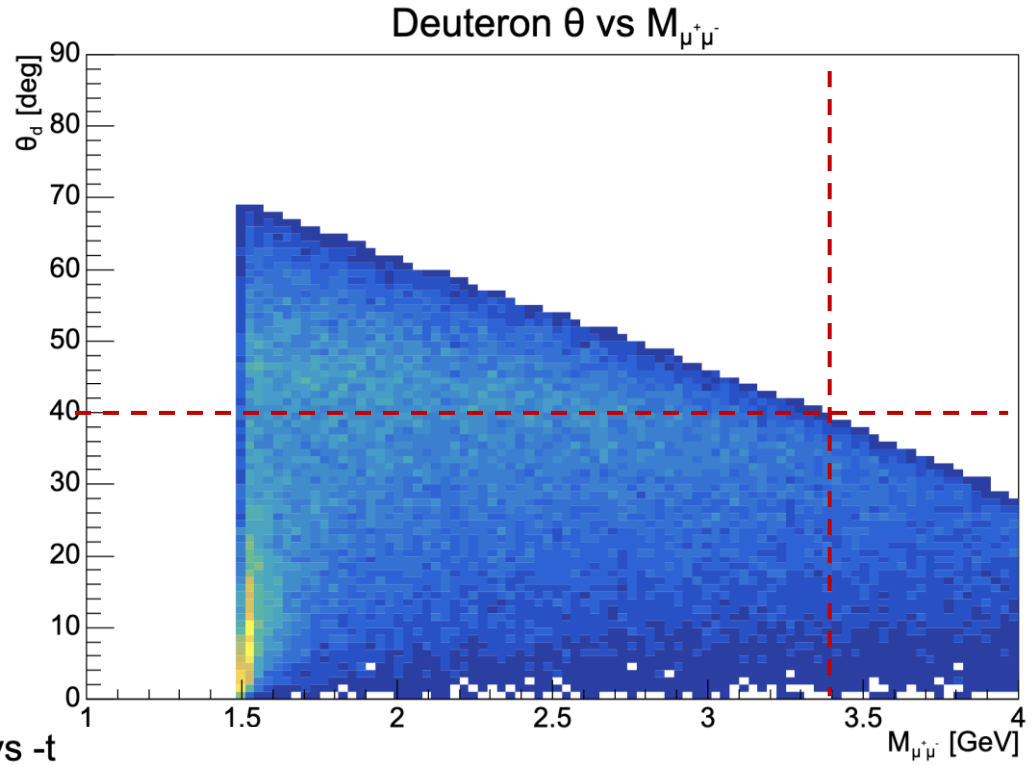
Require recoil deuteron detection to separate incoherent/coherent production.

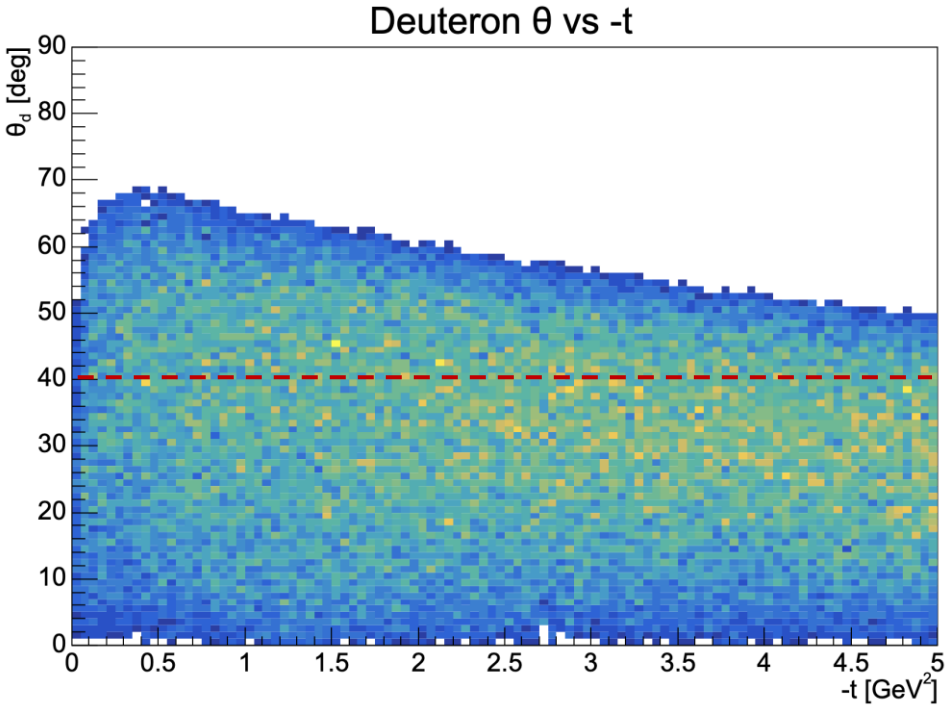
Should then have resolution in exclusivity variables, even without PID?

LH2 proposal sees recoil detector starting at 40^o .

Detection in forward tracker & calorimeter too saturated with noise?

Could not find cross section predictions, suggestions?





TCSGen with deuteron target
Require $M_{\mu^+\mu^-}$>1.5 GeV

Next Steps

Aim is to submit Letter of Intent to this year's PAC.

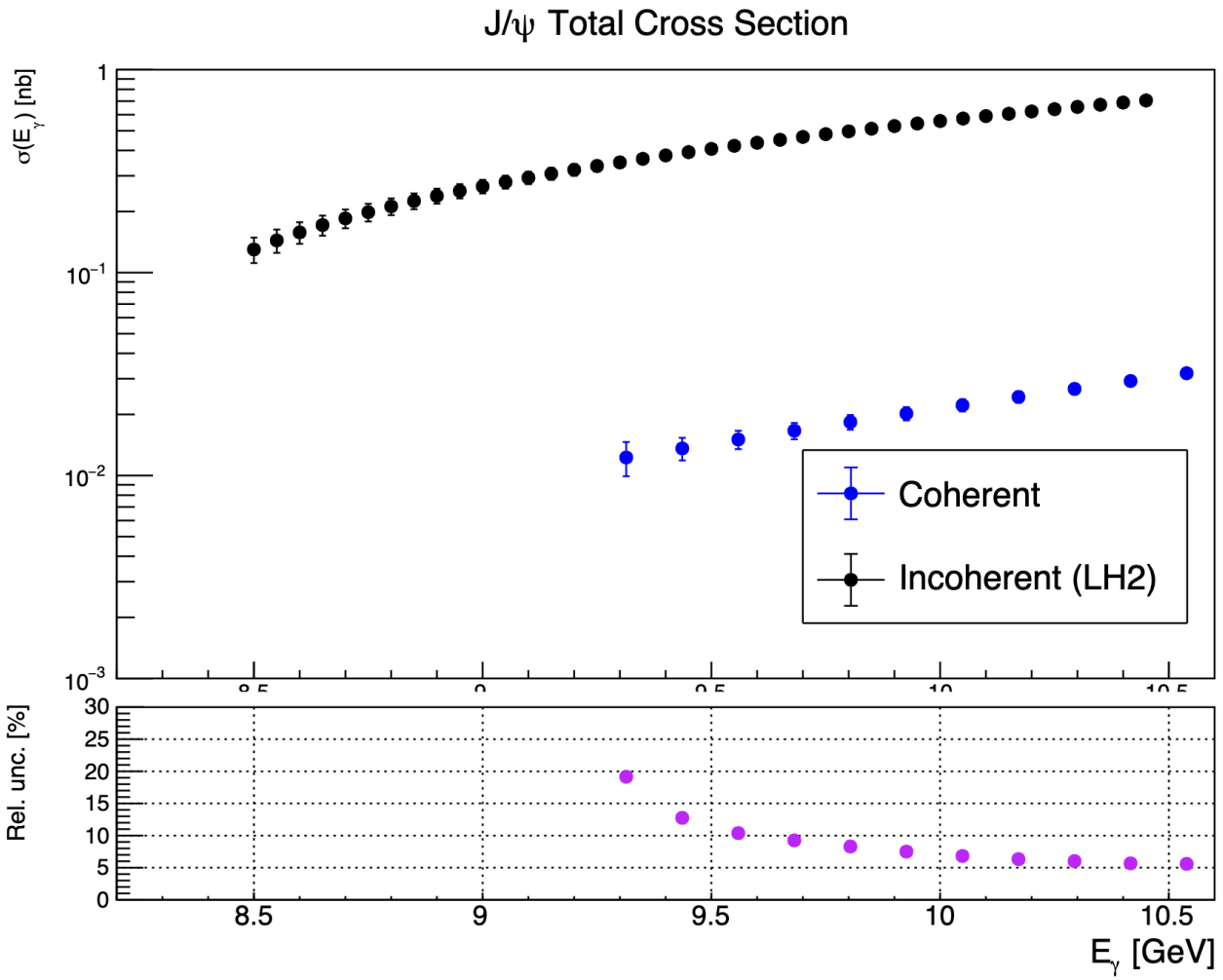
Several questions relating to the measurements:

- Simulate neutron channels to understand neutron detection strategy
- Simulate coherent channels to confirm deuteron detection and resolution on exclusivity variables

At present, cannot find predictions for coherent TCS and DDVCS cross sections, suggestions?

Otherwise, will use simple arguments based on proton/deuteron electromagnetic form factors

Any other physics will strengthen our case – Suggestions?



Back-up Slides

Coherent J/ψ Rates Estimation