UNIVERSITY OF SOUTH CAROLINA

J/ψ Production off Light Nuclei

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Physics Opportunities with Heavy Quarkonia at the EIC
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Exclusive J/ψ Production off Light Nuclei

Incoherent scattering

- Study of low-energy J/ψN interaction (FSI)
- Bound-nucleon gluonic form factor

- Coherent photoproduction: γA→J/ψA′
  - Nuclear gluonic form factor
  - Imaging of low-x gluons

The J/ψN Interaction

Low-energy $\sigma_{J/\psi N}$ is a relevant quantity to test different predictions for the QCD Van Der Waals interaction and J/ψ-nuclear bound states.

- Direct access to $J/\psi N \rightarrow J/\psi N$ and the elementary J/ψN total cross section

$\sigma_{J/\psi N} < 1$ mb (from J/ψ on N)

$\sigma_{J/\psi N} \sim 3.5$ mb (from *A* dependence of nuclear absorption).

$\sigma_{J/\psi N} \geq 17$ mb (multiple expansion and low-energy theorems in QCD).

$\sigma_{J/\psi N} \sim 7$ mb (two-gluon exchange QCD calculation of interaction potential)

B.Knapp, W.-Y. Lee, P. Leung, S.D. Smith, A. Wijangco et al., Phys. Rev. Lett. 34, 1040 (1975).
R.L. Anderson et al., Phys. Rev. Lett 38, 263 (1977).
D. Kharzeev and H. Satz, Phys. Rev. Lett B334, 155 (1994).
A. Sibirtsev and M.B. Voloshin, Phys. Rev. D 71, 076005 (2005).

The J/ψN Interaction from Photoproduction

By means of cross-section measurement of $gp \to J/\Psi p$

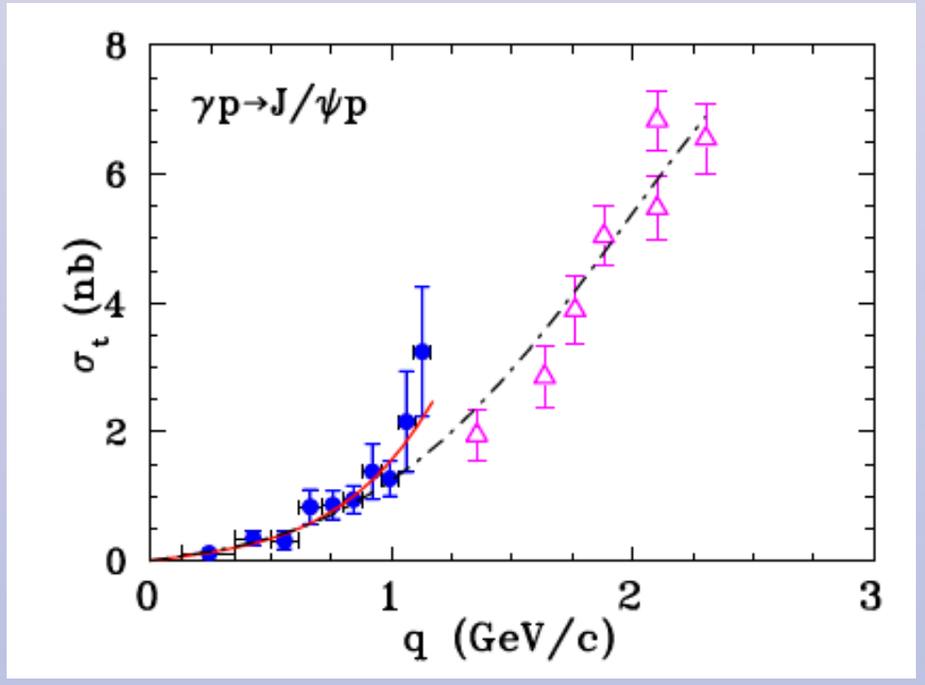
- Vector-Meson Dominance (VMD) and Optical Theorem

$$\left.\frac{ds}{dt}\right|_{gp\to J/y\,p,t=0} = \frac{3\Gamma(J/y \to e^+e^-)}{a\,m_{J/y}} \frac{k^2_{J/y\,p}}{k^2_{gp}} \frac{s^{\,2}_{J/y\,p}}{16p}$$

V. Barger and R.J.N. Phillips, Phys. Lett. B **58**, 433 (1975)

- Scattering length from VMD application

$$s_{tot,gp\to J/y\,p,thr} = \frac{q}{k}\frac{4ap^2}{g^2_{J/yg}}\left|a_{J/y\,p}\right|^2$$



I. Strakovsky et al., Phys. Rev. C **101**, 042201 (R) (2020)

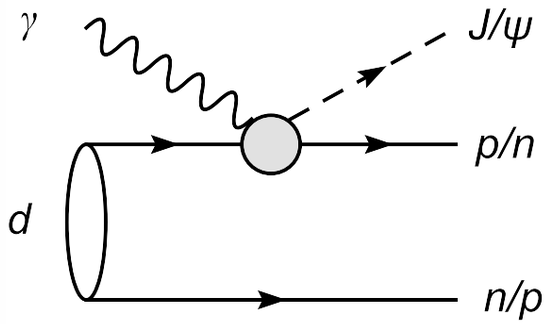
GlueX data: A. Ali et al. (GlueX Collaboration), Phys. Rev. Lett. 123, 072001 (2019).

SLAC data: U. Camerini et al., Phys. Rev. Lett. 35, 483 (1975).

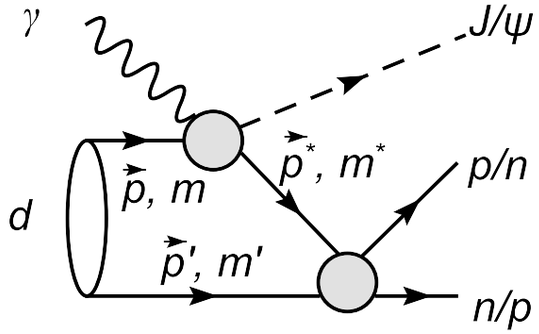
The J/ψN Interaction from Photoproduction

Near-Threshold Incoherent Photoproduction off Deuteron: J/ψN FSI

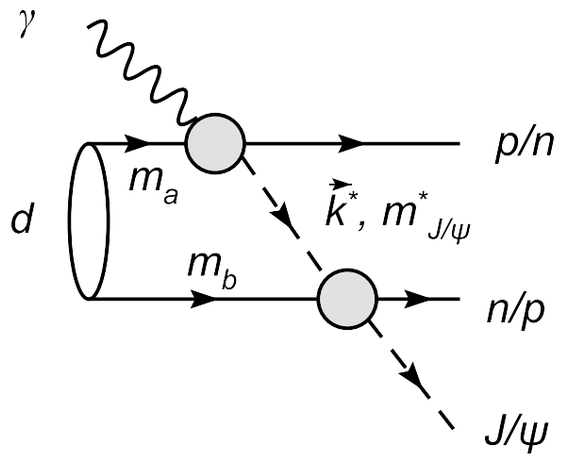
$\gamma d \to pnJ/\psi$



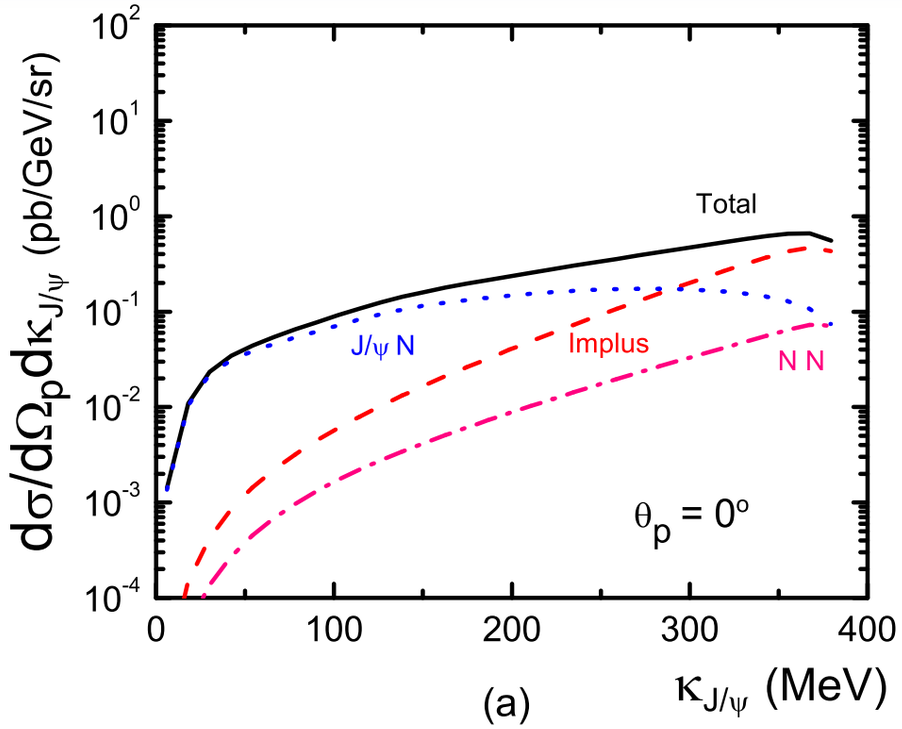
(a) Impulse



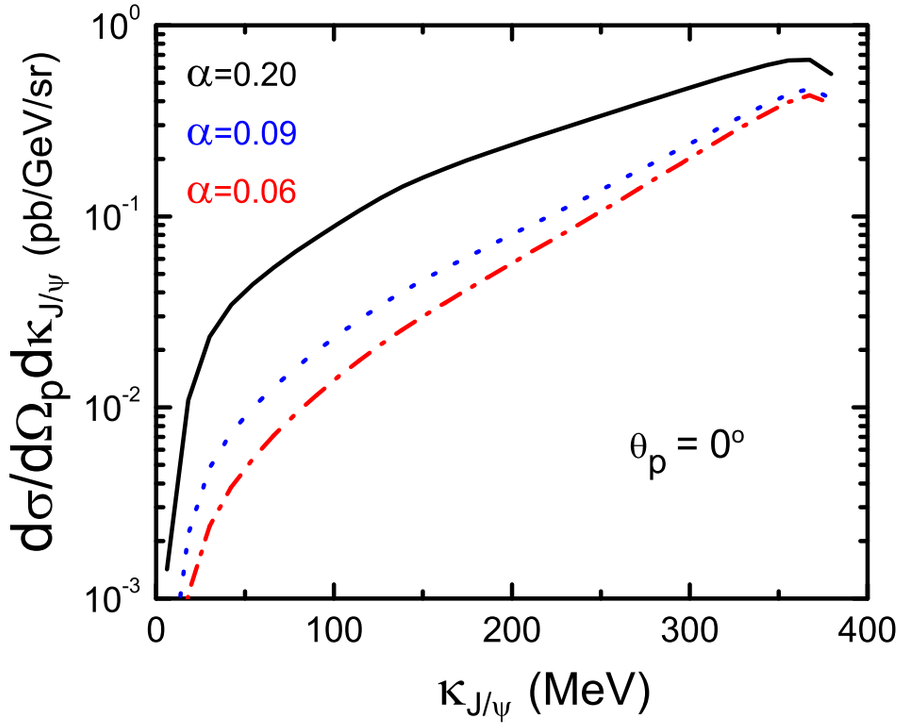
(b) NN Re-scattering



(c) J/ψ N Re-scattering



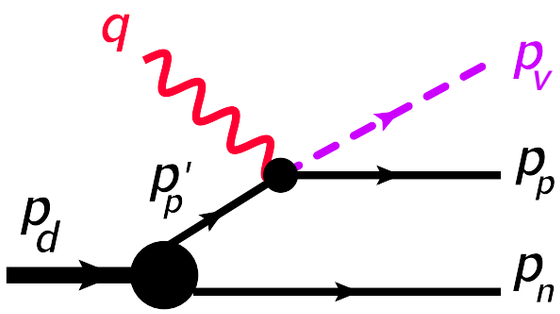
(a)



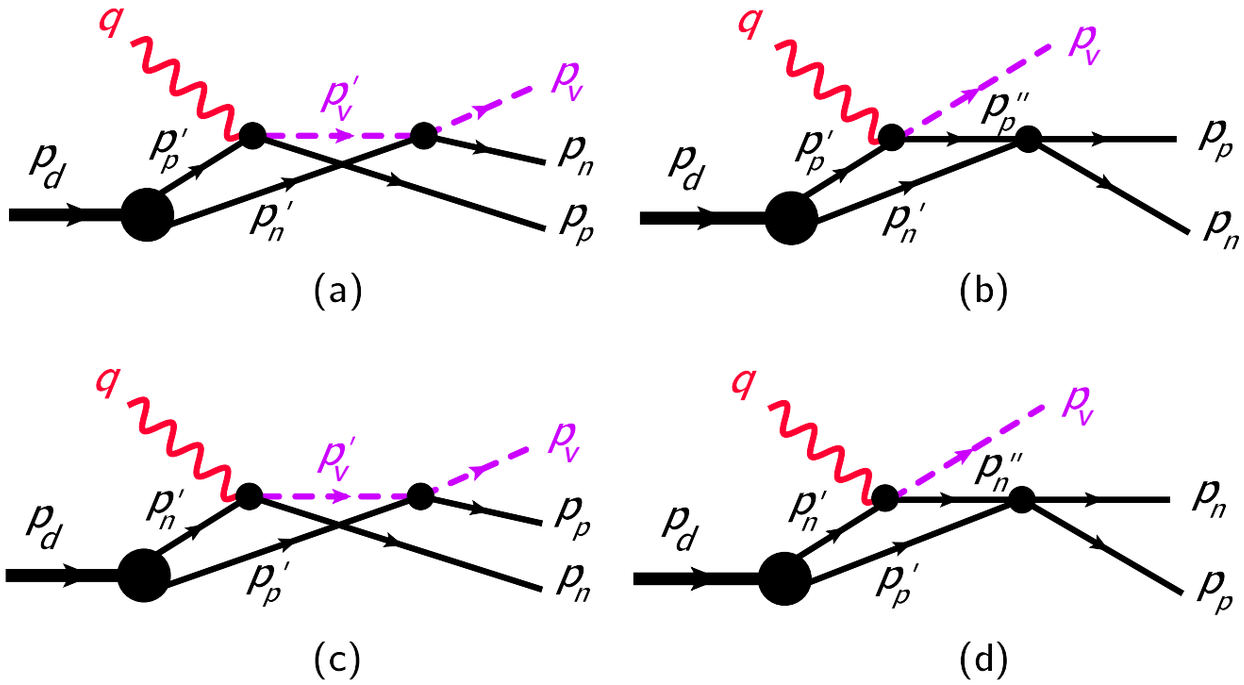
J.-J. Wu, T.-S. H. Lee, Phys. Rev. C **88,** 015205 (2013)

The J/ψN Interaction from Photoproduction

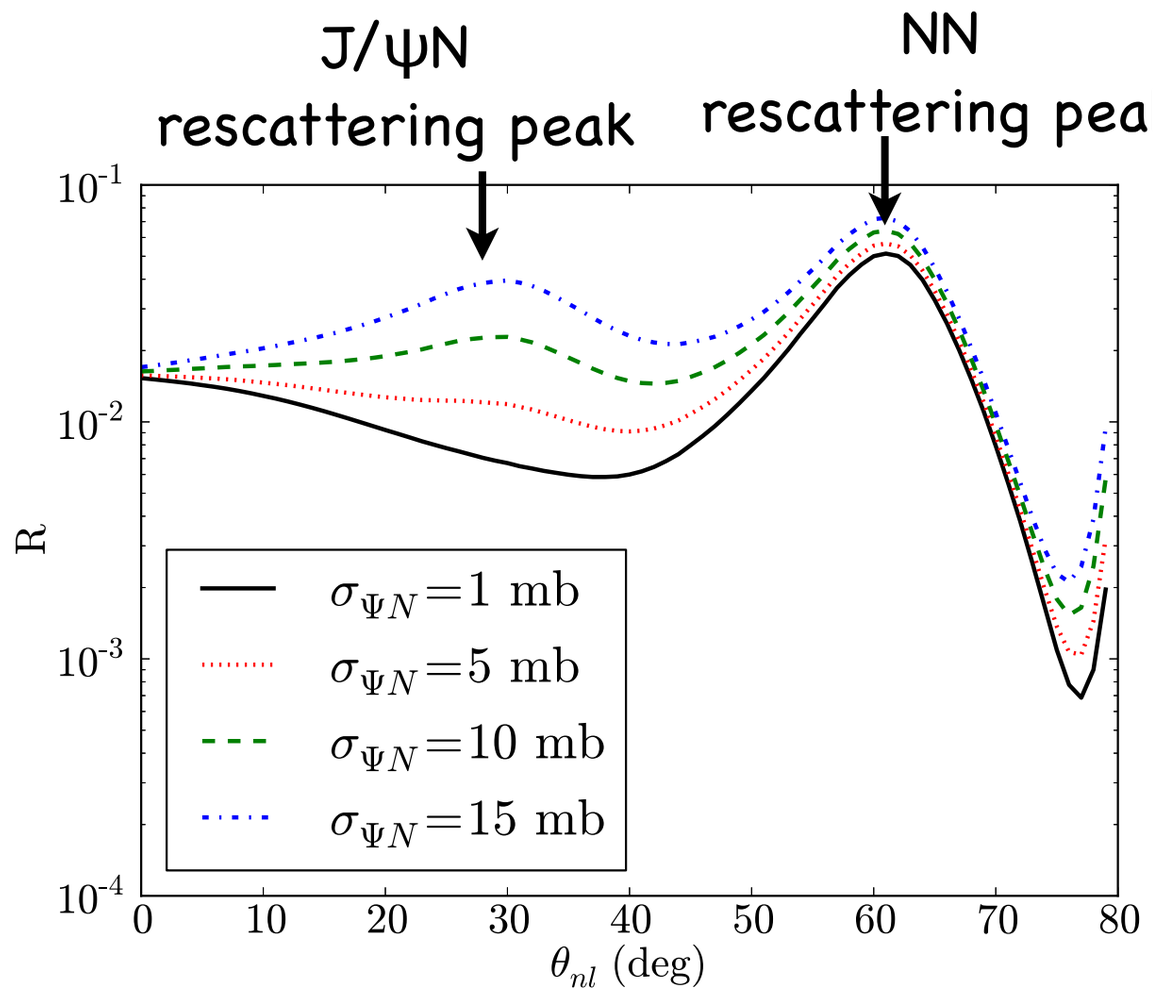
Near-Threshold Incoherent Photoproduction off Deuteron: J/ψN FSI

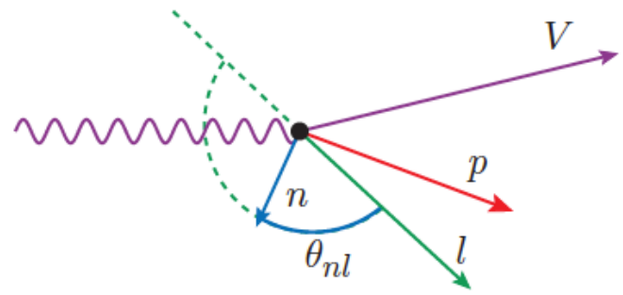


γd→pnJ/ψ



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



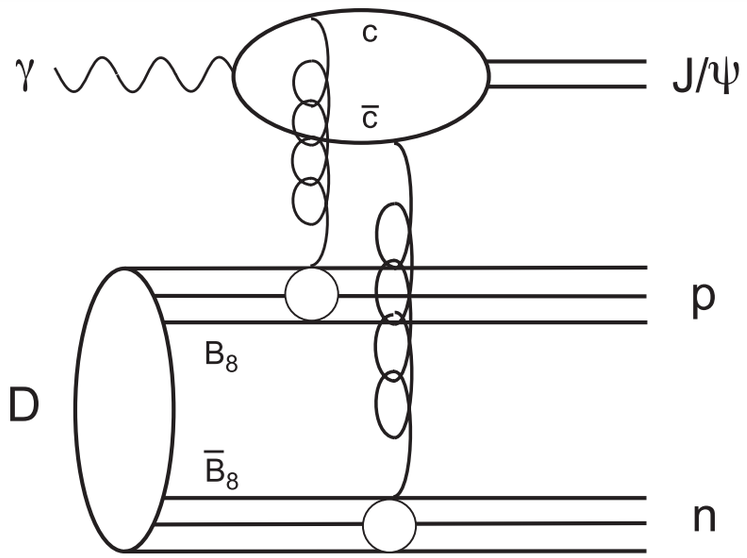


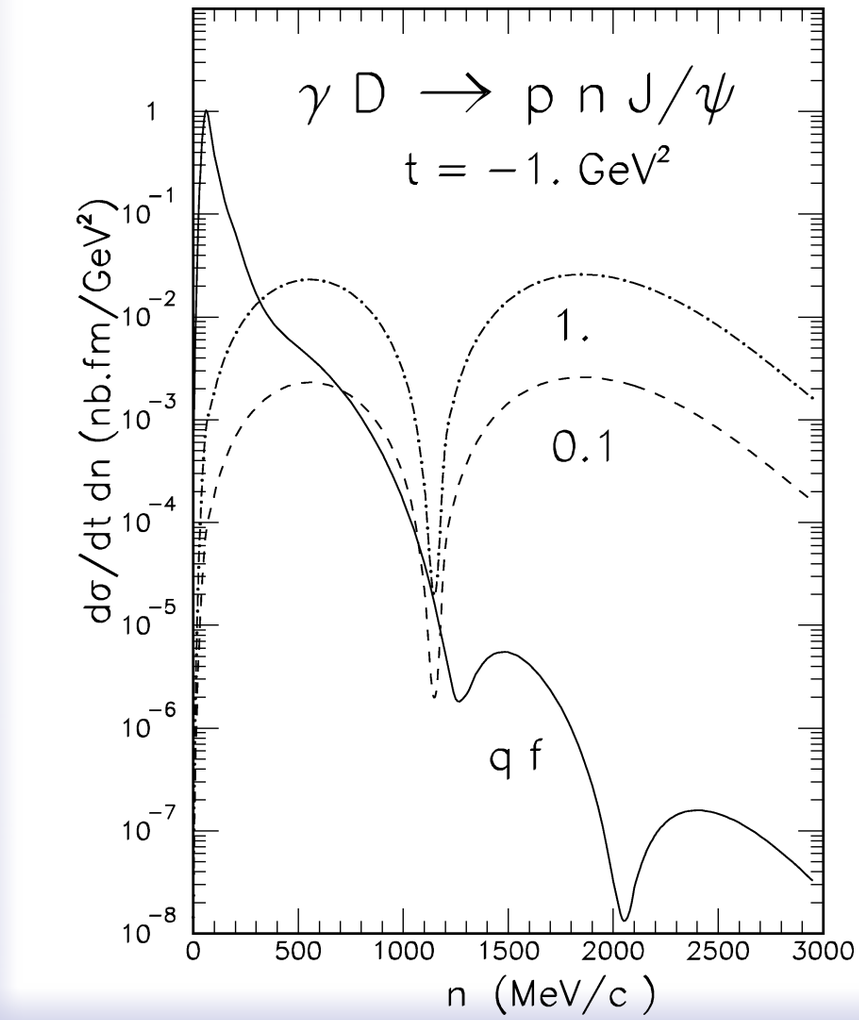
A. Freese, M. Sargsian, Phys. Rev. C **88**, 044604 (2013)

Small-Size Configurations in Nucleus via J/ψ Production

Incoherent Photoproduction off Deuteron: J/ψN FSI

- **Sensitivity to hidden-color component of the deuteron wave function.**





Hidden-color component contribution dominates the cross section above neutron momenta of 500 MeV/c.

May dominate subthreshold photoproduction (on deuteron: E_{thr}=5.66 GeV).

$$\frac{d\sigma}{dt\, d|\vec{n}|} = \left.\frac{d\sigma}{dt}\right|_{\gamma p \to J/\psi p} 4\pi\vec{n}^2 \left[\varphi_{cc}\left(\frac{\vec{n}}{2}\right)\right]^2 \frac{F_1^4(t/4)}{F_1^2(t)}$$

J.-M. Laget, Nucl. Phys. A **581**, 397 (1995); M. Sargsian, private communication; S.J. Brodsky, E. Chudakov, P. Hoyer, J.M. Laget, Phys. Lett. B 498, 23 (2001).

Gluonic Structure of Light Nuclei

Coherent Photoproduction: $\gamma A \rightarrow A' J/\psi$

The t-dependence of the cross section can provide access to the gluonic structure of the nucleus

Hard scale set by the $c\bar{c}$ size $r_\perp \sim 1/m_c = 0.13$ fm. Probe is hard for all Q^2.

- Near-threshold Energies (large $|t_{min}|$, large x, small b) - gluon form factor

$$\frac{ds}{dt} \sim |F_{gg}(x_1, x_2, t, m^2)|^2 = \frac{1}{(1 - t/m_{2g}^2)^4}$$

Formalism for proton. Extension needed for light nuclei.

Universal F_{gg} expected,
independent of μ^2; $m^2_{2g} \sim 1$ GeV^2

- High energies ($|t_{min}| \sim 0$, small x, large b) - imaging of low-x gluons

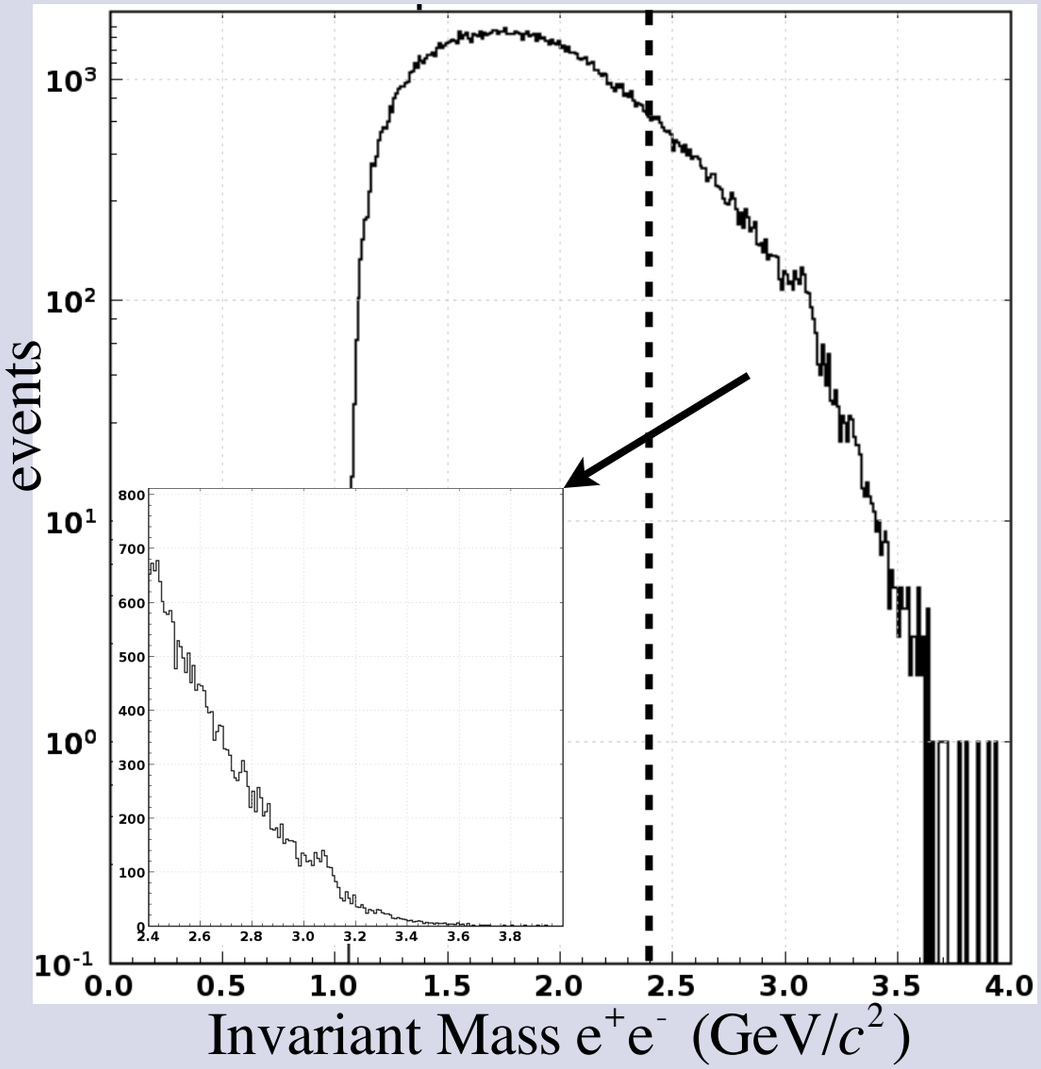
L. Frankfurt and M. Strikman, Phys. Rev. D 66, 031502(R) (2002).

Near-Threshold J/ψ Production off Deuteron

Jefferson Lab PR12-11-003B

M.D. Baker, A. Freese, L. Guo, Ch. Hyde, **Y. Ilieva**, **B. McKinnon**, **P. Nadel-Turonski**, M. Sargsian, **V. Kubarovsky**, **S. Stepanyan**, N. Zachariou, **Zh.W. Zhao**

All data from Spring 2019



Partial data collected in 2019 - 2020 with the CLAS12 Detector in Hall B

Data analysis and received data

- Inclusive yield (Spring 2019 data) ~450 J/ψ (e^+e^-). Analysis is in progress for the exclusive channels (priority to quasi-free production off the proton and neutron)
- Coherent and incoherent study: received only 22% of requested 90 days due to energy drop.
  - Coherent scattering: expected ~1 event /2-3 PAC days. Expected |t|-coverage, 0.3 - 1 $(GeV/c)^2$.
  - Incoherent scattering (FSI): expected < 1 - 2 FSI events/PAC day

Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction

Considered nuclei: d, ^{3}He, ^{4}He, ^{6}Li, ^{12}C, ^{16}O

Kinematic variables: $gA \to J/y\, A'$

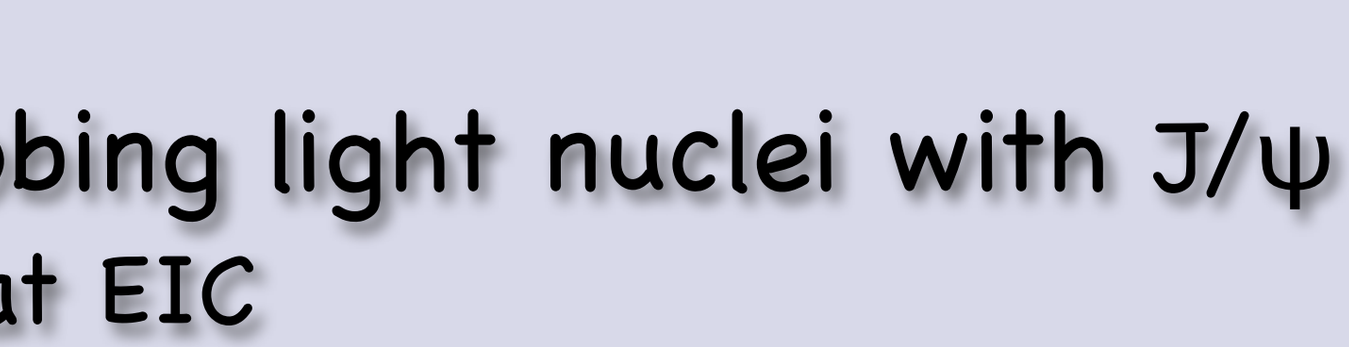
$$W = \sqrt{s} = (\tilde{p}_g + \tilde{p}_A)^2$$

$$t = (\tilde{p}_{A'} - \tilde{p}_A)^2$$

$$x = \frac{M_{J/y}^2}{W^2}$$

$$x_L = 1 - x$$

$$p_T = \sqrt{|t|}$$

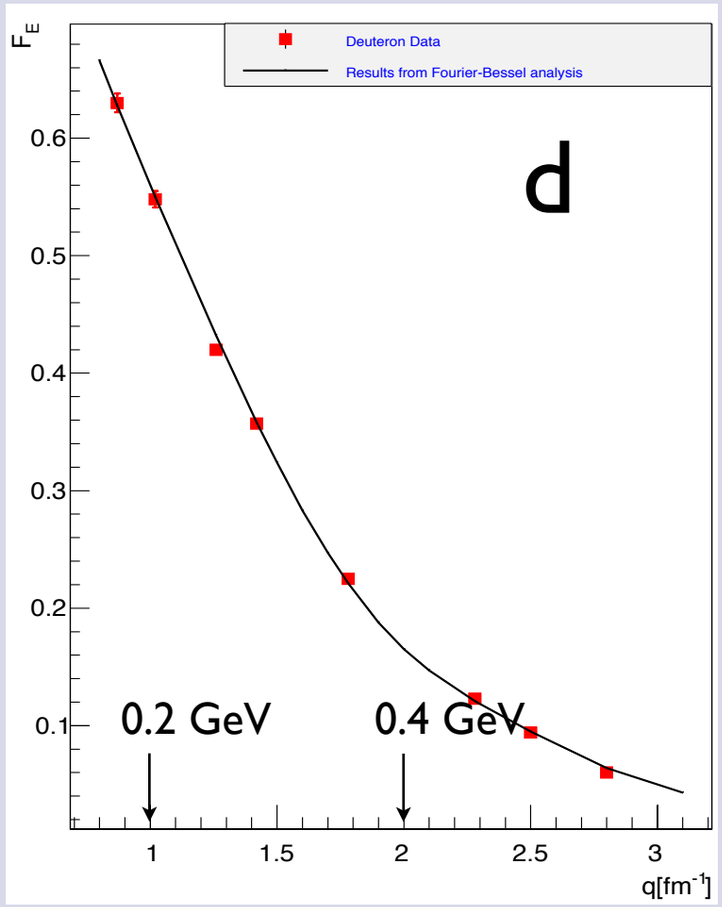


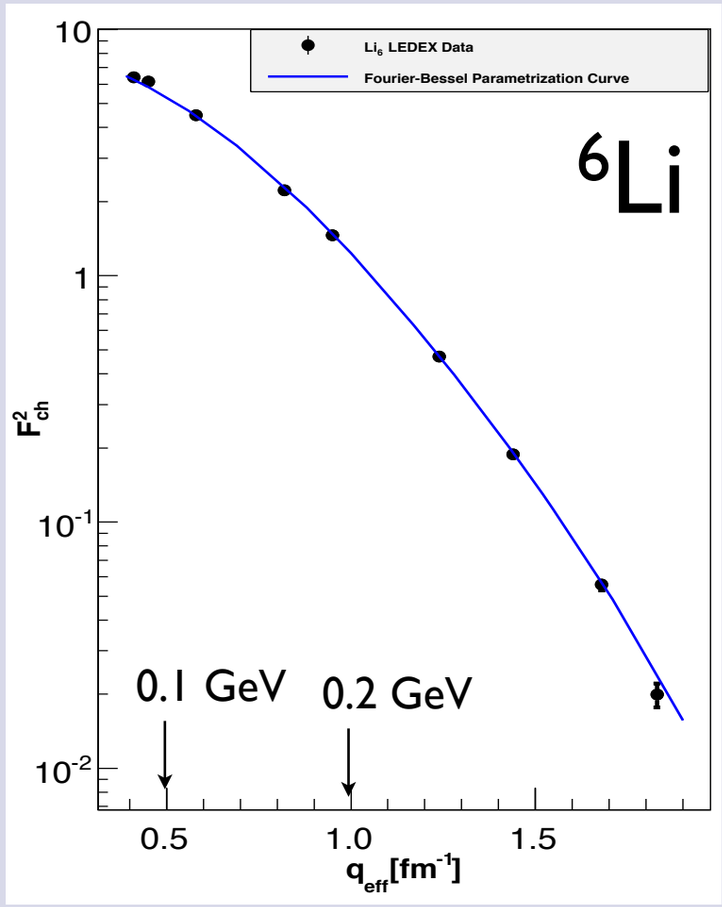
Opportunities for probing light nuclei with J/ψ at EIC

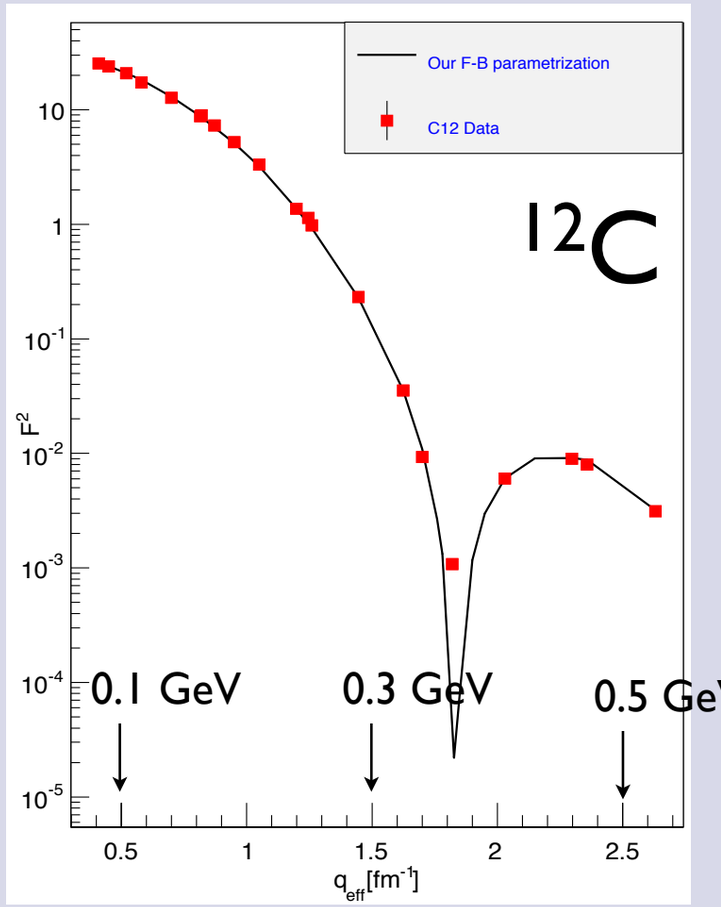
Coherent Quasi-Real Photoproduction: Considerations

Ideally, would detect all final state particles: A', e^+, e^- or A, μ^+, μ^-

Cross section dominated by the nuclear charge form factor







A.A. Kabir, Determination of the charge radii of several light nuclei from precision high-energy electron elastic scattering, Ph.D. Thesis, Kent State University (2015)

Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction: Considerations

To access low-x gluons, high W is critical

Forward detection of the recoil nucleus is highly desirable

- $p_T \lesssim 300 - 400$ MeV/c for gluon imaging at low x
- $|t| \leq 1$ GeV/c is the most feasible due to rapidly decreasing rates; sufficient coverage of the diffraction minima needed for studying effects of nuclear shadowing

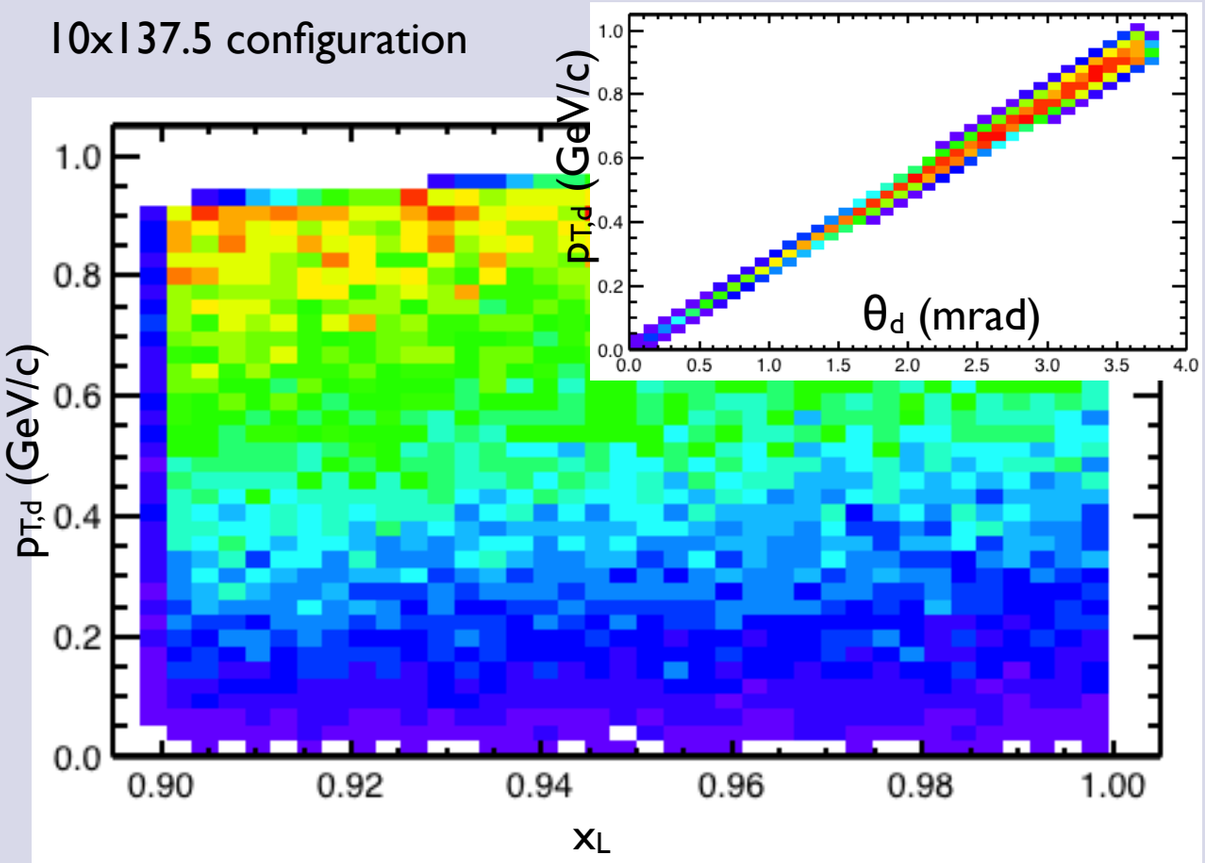
Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction: Considerations

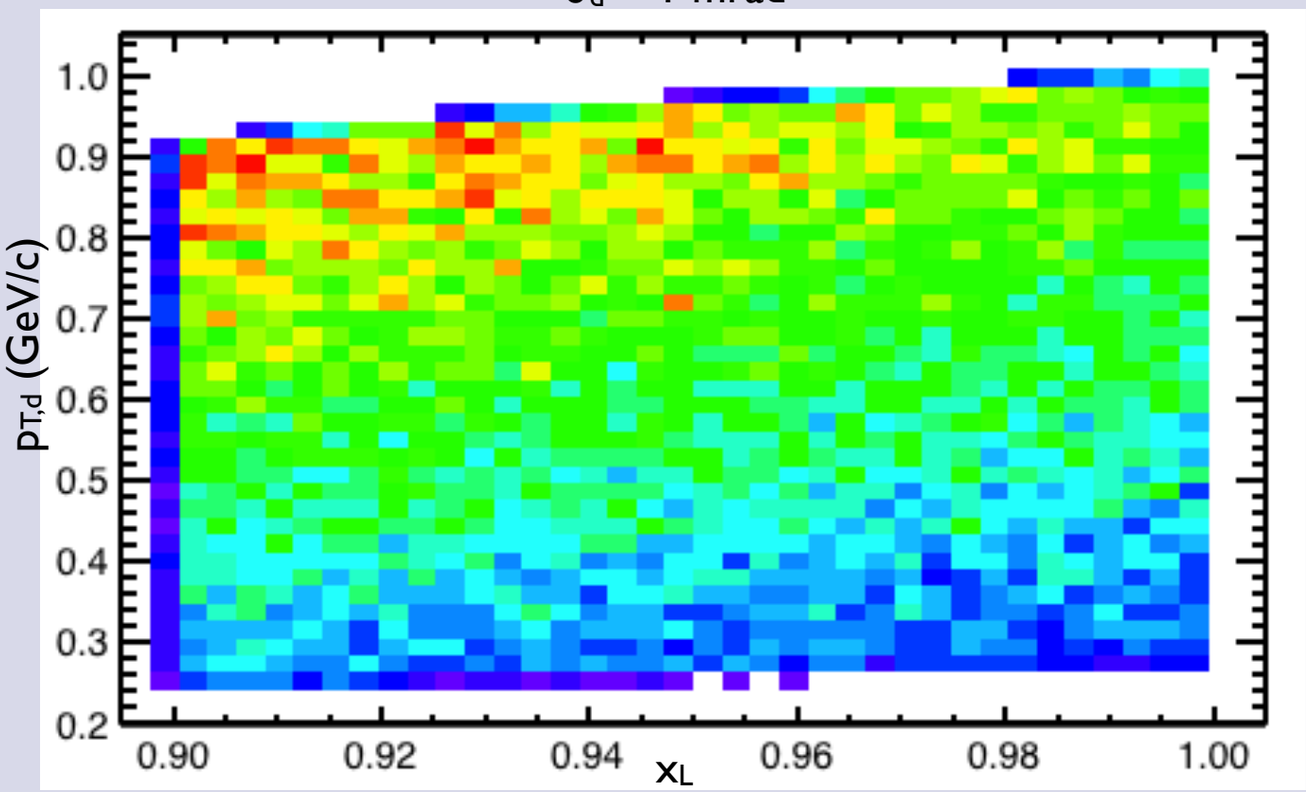
Access to low-x gluons: d

Kinematics of recoiling d: requirements for forward detector

10x137.5 configuration



θ_d > 1 mrad



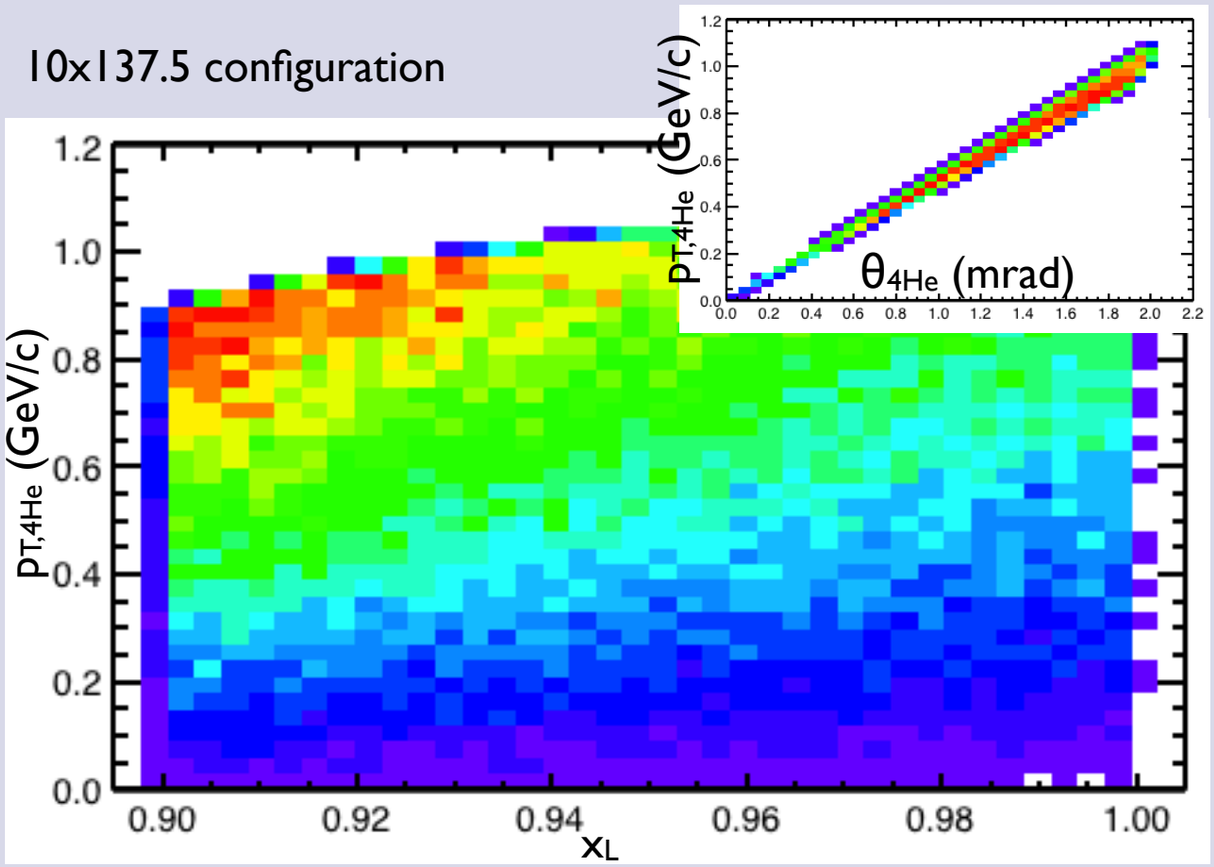
Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction: Considerations

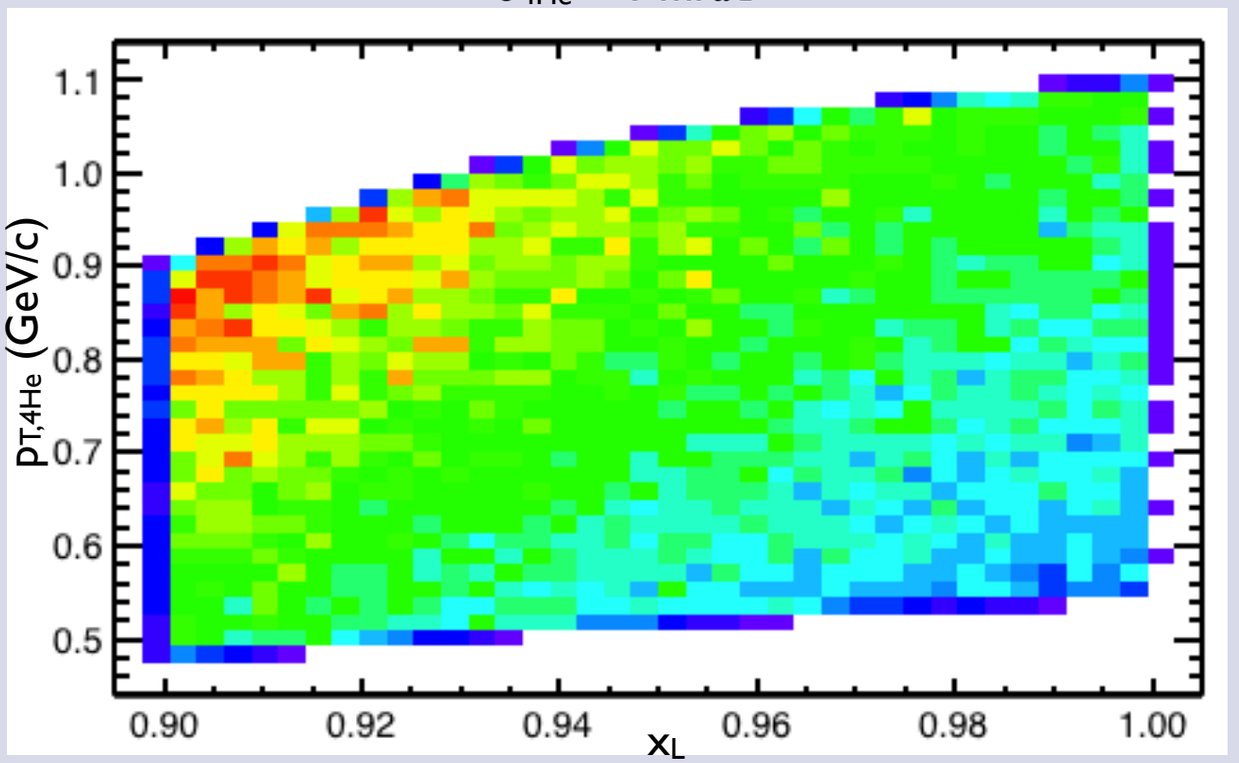
Access to low-x gluons: ^{4}He

Kinematics of recoiling ^{4}He: requirements for forward detector

10x137.5 configuration



θ_{4He} > 1 mrad



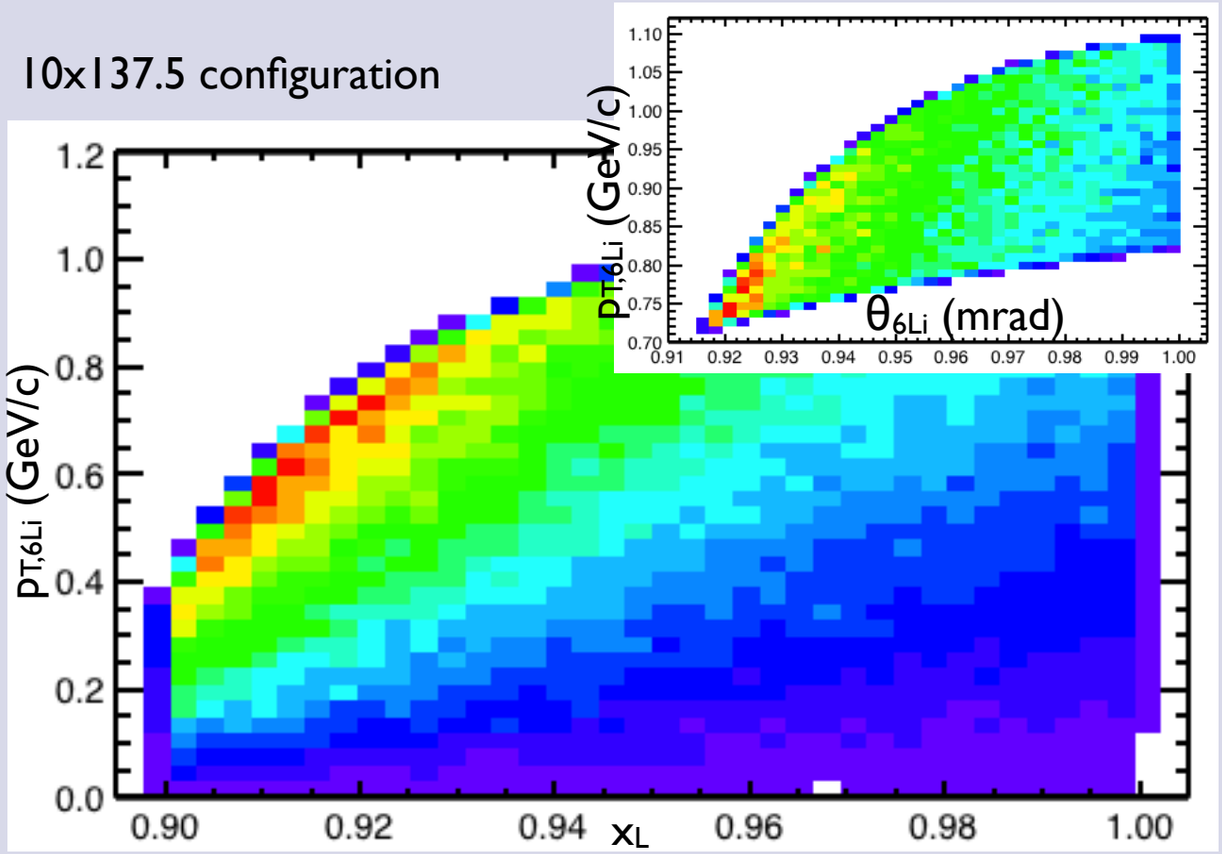
Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction: Considerations

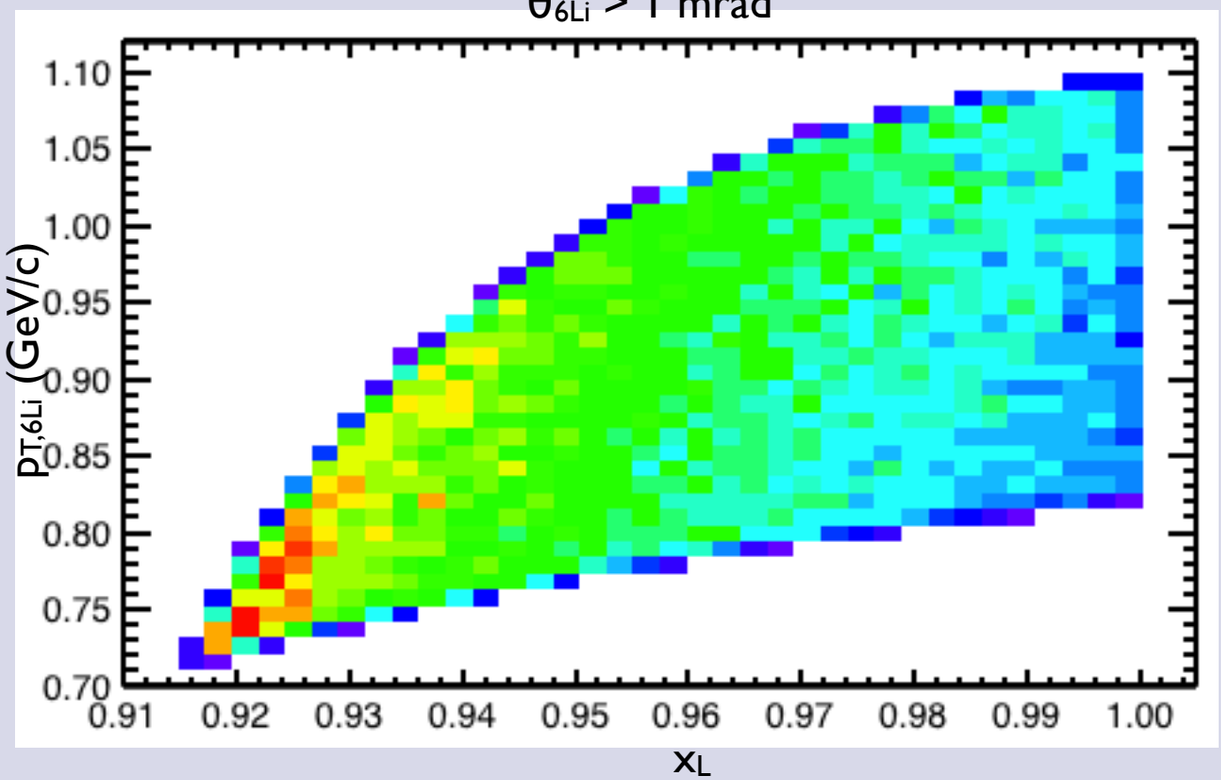
Access to low-x gluons: ^{6}Li

Kinematics of recoiling ^{6}Li: requirements for forward detector

10x137.5 configuration



θ_{6Li} > 1 mrad

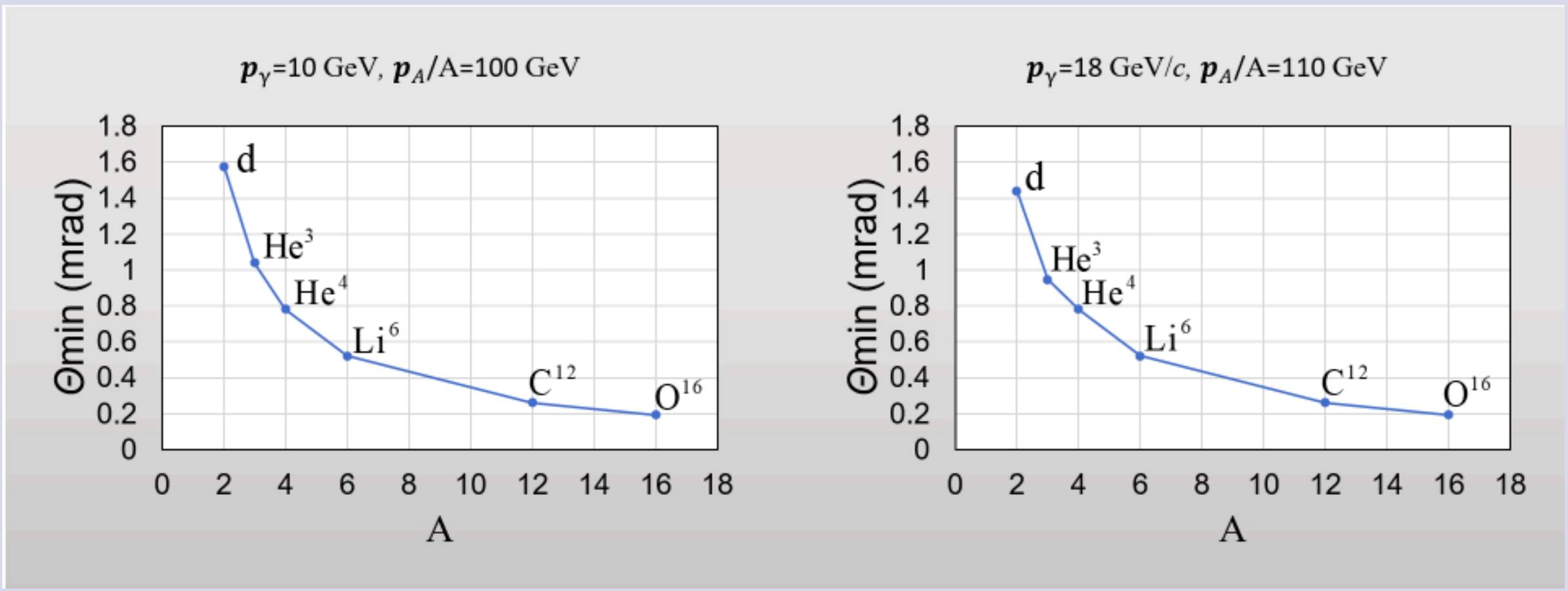


Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction: Considerations

Access to low-x gluons: Overview

Kinematics of recoiling nuclei: overview for $|t_{min}| = 0.1$ (GeV/c)^2



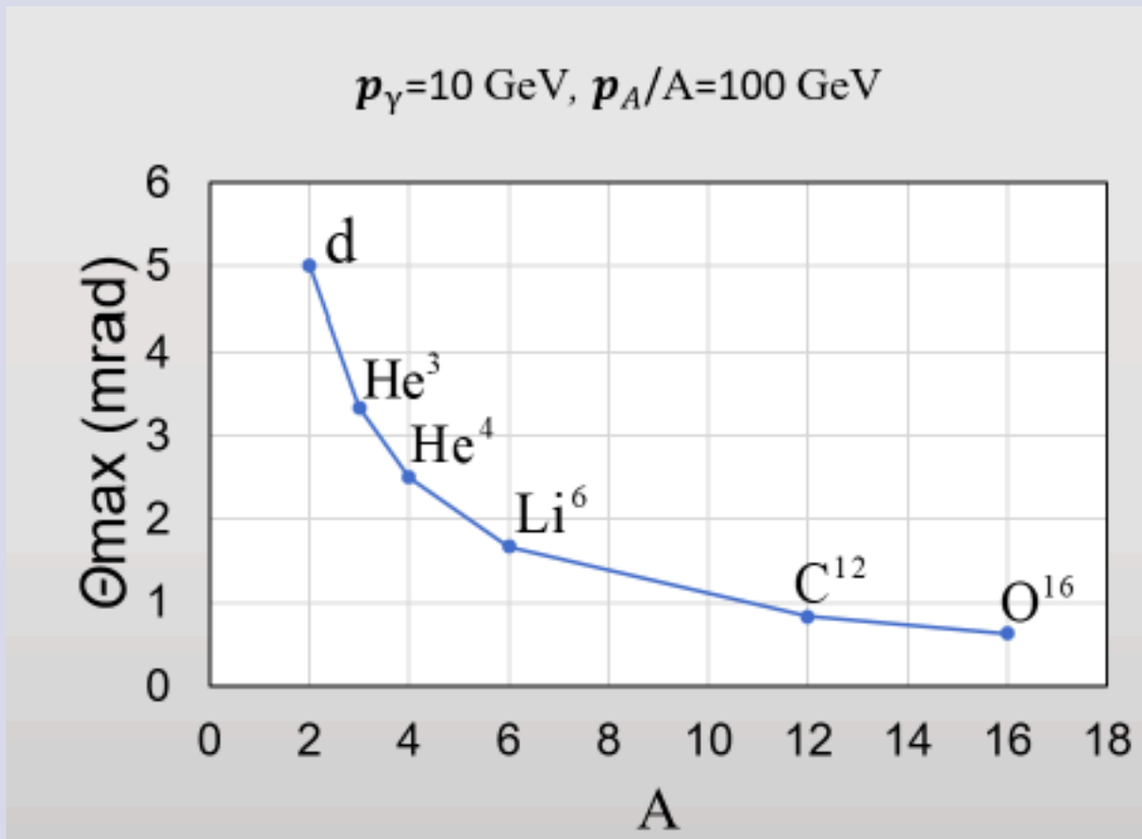
No effect of beams crossing angle

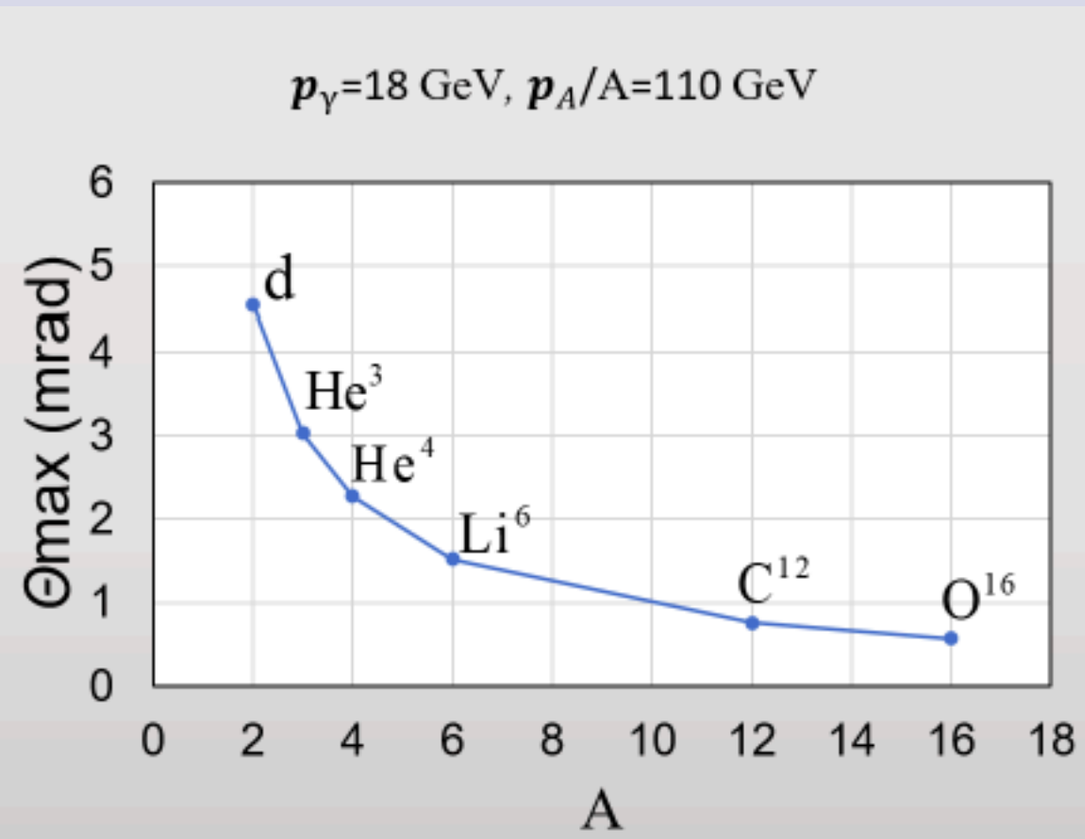
Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction: Considerations

Access to low-x gluons: Overview

Kinematics of recoiling nuclei: overview for $|t_{max}| = 1$ (GeV/c)^2





No effect of beams crossing angle

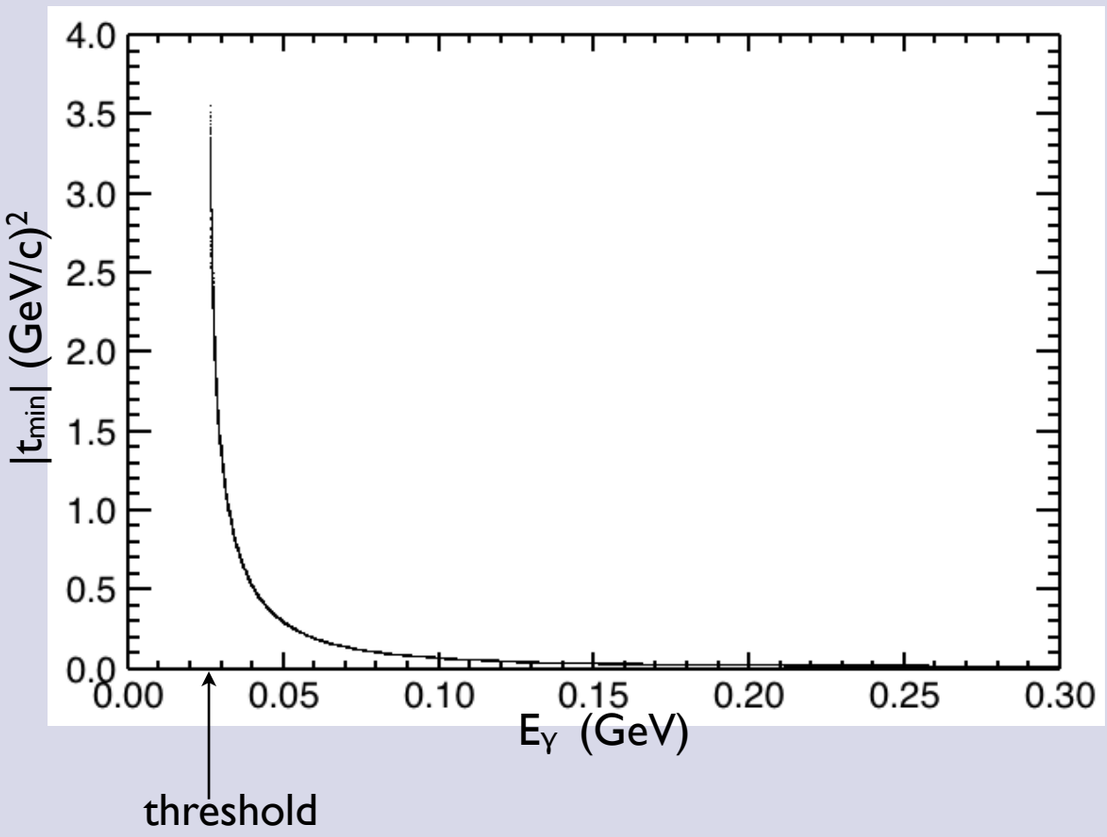
Opportunities for probing light nuclei with J/ψ at EIC

Coherent Quasi-Real Photoproduction: Considerations

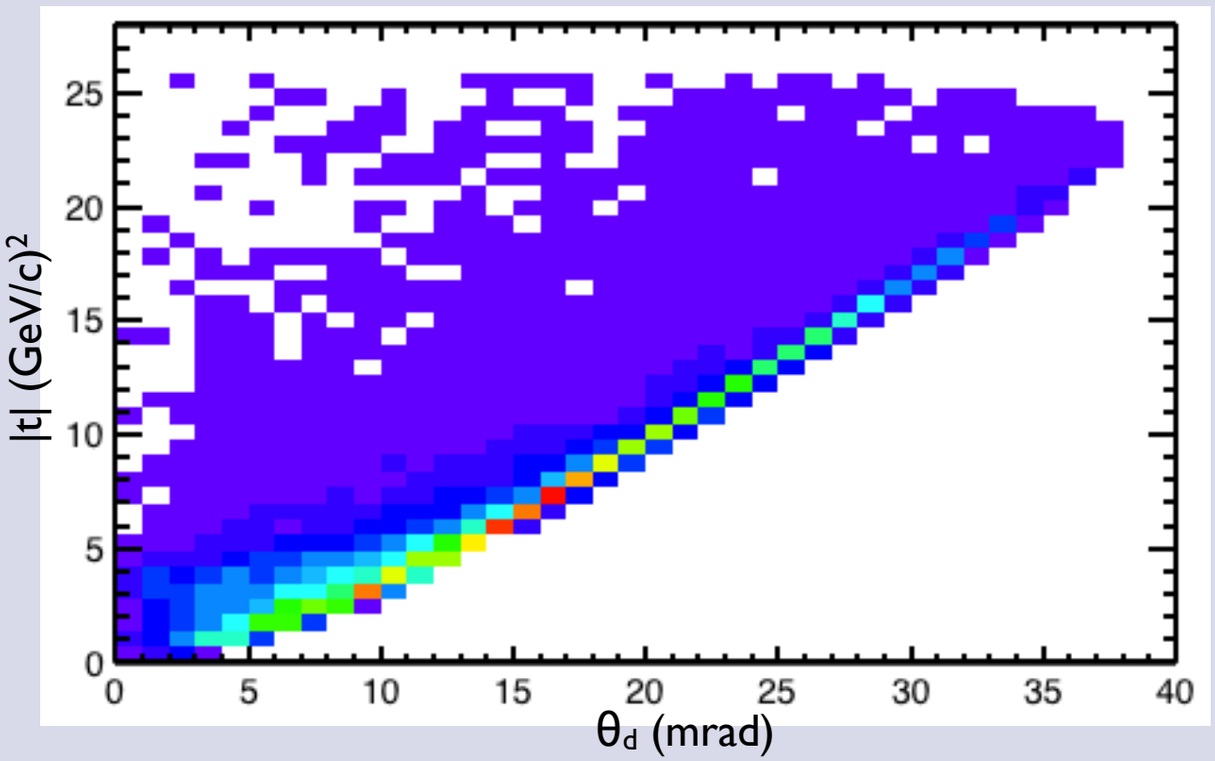
Kinematically, access to coherent production at near-threshold W is feasible

d

10x100 configuration



E_γ < 0.05 GeV



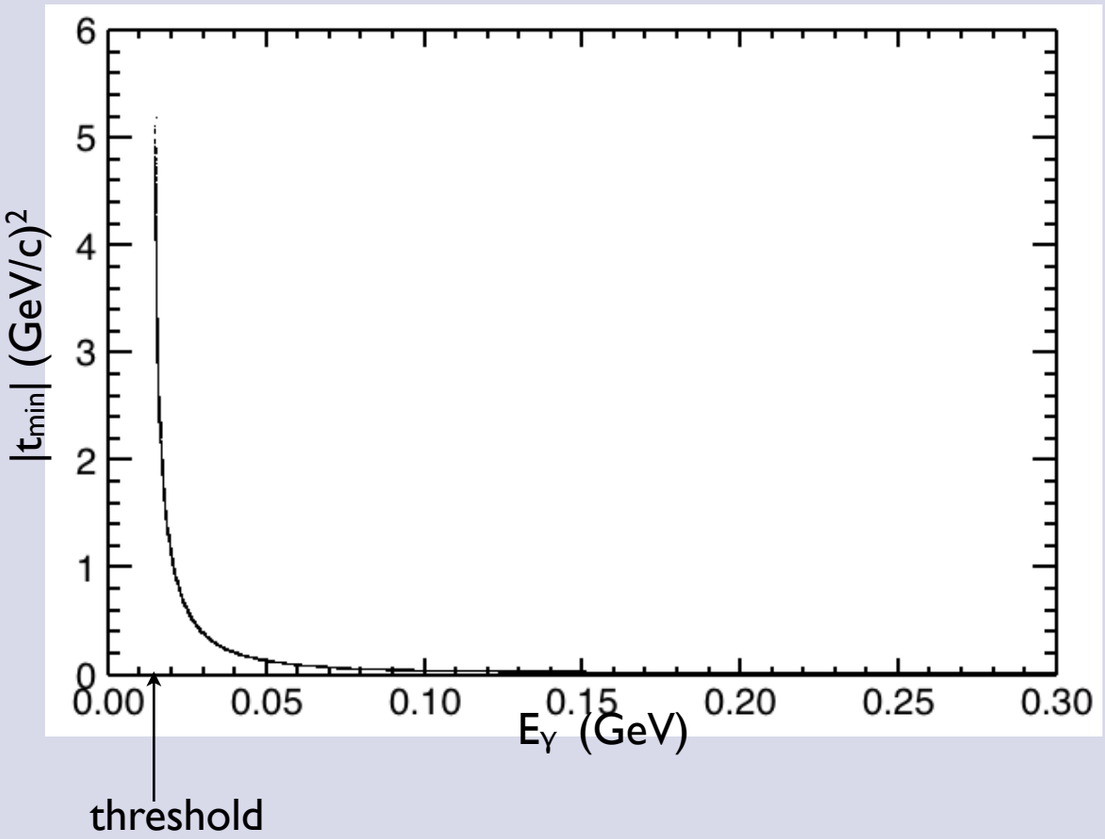
Forward detector acceptance is important

Opportunities for probing light nuclei with J/ψ at EIC

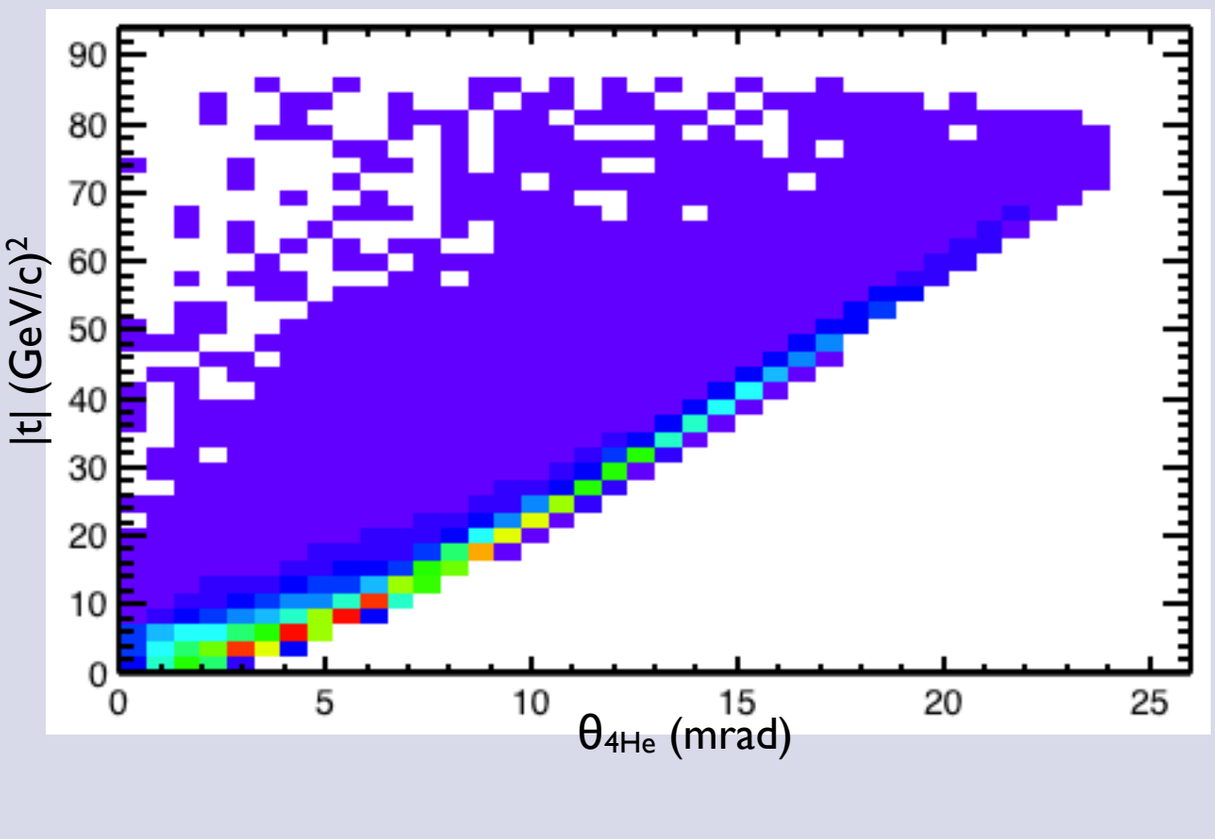
Coherent Quasi-Real Photoproduction: Considerations

Kinematically, access to coherent production at near-threshold W is feasible

10x137.5 configuration ^{4}He



E_γ < 0.05 GeV



Forward detector acceptance is important

Summary

Coherent J/ψ Photoproduction off light nuclei allows to access various aspects of nuclear dynamics (small W vs high W)

- Forward detection is critical to successfully carry out the program (access to low p_T is of importance).
- Phase-space event generator developed - flexible with respect to crossing angle choice, reference frame, final state, output format, etc.
- Kinematic studies with phase space distributions are complete.
- Acceptance and resolution effects (CORE, ECCE, ATHENA) are to be studied next.
- For rate estimates would benefit from cross section estimates from theory groups.

Low-energy J/ψ-N interaction via FSI in incoherent photoproduction is best studied off deuteron

- First experimental glimpse from E12-11-003B with CLAS12 at JLab
- EIC capability needs to be studied

The End