Tagged DVCS Off Light Nuclei

An ALERT Run Group Proposal for JLab PAC 44

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On behalf of spokespersons,
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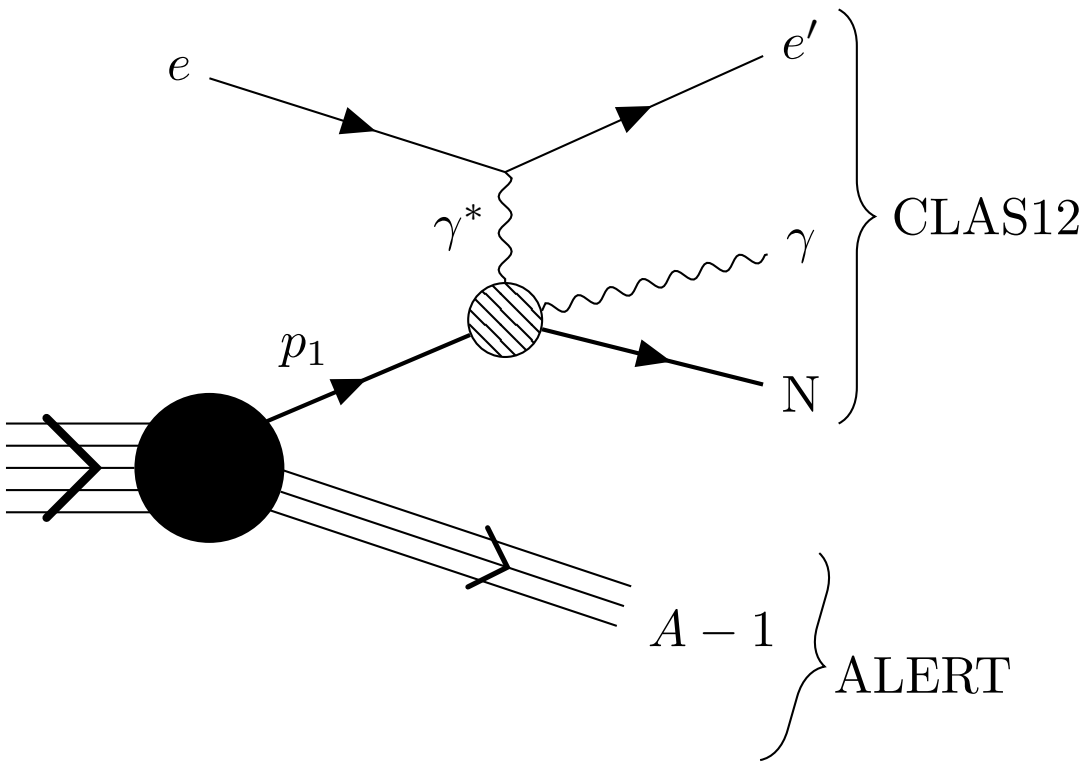
and the ALERT Collaboration

Introduction

- Motivation
- Measurement Technique
- Experiment



Motivation

Unambiguously determine if a nucleon's PDFs are modified in medium.

Nuclear Effects to address

- Mean field nucleons vs short-range correlated nucleons
- Final-state Interactions
- Off-shell nucleons
- **Do modifications to mean field nucleons exist?**

Basic idea

Use exclusivity of tagged DVCS to extract medium modifications at the partonic level and control nuclear effects in a **model independent way**.

The Challenges of Nuclear Effects

A quick overview

Deep Inelastic Scattering

Is $F_2(x, Q^2)$ modified relative to free nucleon?

- DIS on Nuclear targets
  → EMC effect
- Partonic level interpretation
  → Modified PDFs?

Quasi-Elastic Scattering

Are nucleon form-factors modified?

- Inclusive QE scattering
  → Quenching of CSR?
- $x > 1$ → SRCs
  → Are SRCs responsible for EMC Effect?

The Takeaway

Model dependence of FSIs presents a major hurdle to unambiguously concluding mean field nucleons are modified

- → separate mean field from short-range nucleons
- FSI Model dependence
  → Low p_s backward to minimize FSIs

- G_E/G_M
- FSI Model dependence
  → P_y constrains FSI models
- No partonic interpretation

Tagged Incoherent DVCS

A new way to do the same old thing. . . better!

It **combines the beneficial characteristics** of DIS and QE scattering

- DVCS on Nuclear targets → "**Off-forward EMC effect**"
- Spectator tagging → **separate** mean field from short-range nucleons
- Measured BSA → **very sensitive** to medium modifications
- DVCS provides parton level interpretation
- **Unique model independent determination of FSIs**

Main channels

1. $^4\mathrm{He} + \gamma^* \rightarrow \gamma + p + {}^3\mathrm{H}$

   Bound p-DVCS measurement

   Fully detected final state provides unique opportunity to study FSIs

2. $^4\mathrm{He} + \gamma^* \rightarrow \gamma + (n) + {}^3\mathrm{He}$

   Bound n-DVCS measurement

3. $^2\mathrm{H} + \gamma^* \rightarrow \gamma + (n) + p$

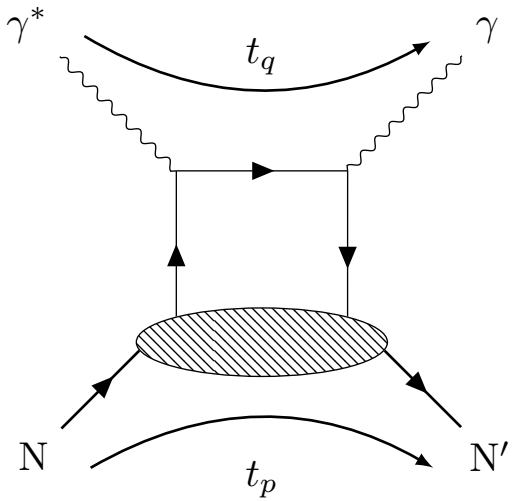
   Quasi-free n-DVCS measurement

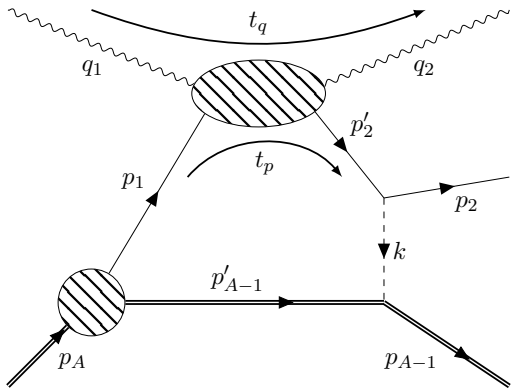
   BSA ratio forming the "Off-forward EMC Effect"

Tagged DVCS Technique: FSIs

Does $t_q = t_p$?

$$t_q = -Q^2 - 2\nu_2(\nu_1 - q_1 \cos\theta_{q_1 q_2})$$





No FSIs

- Born Approx. $\rightarrow t_q$ cleanly measured
- $t_p \rightarrow$ off-shellness effects only
- $\boldsymbol{t_p \simeq t_q}$

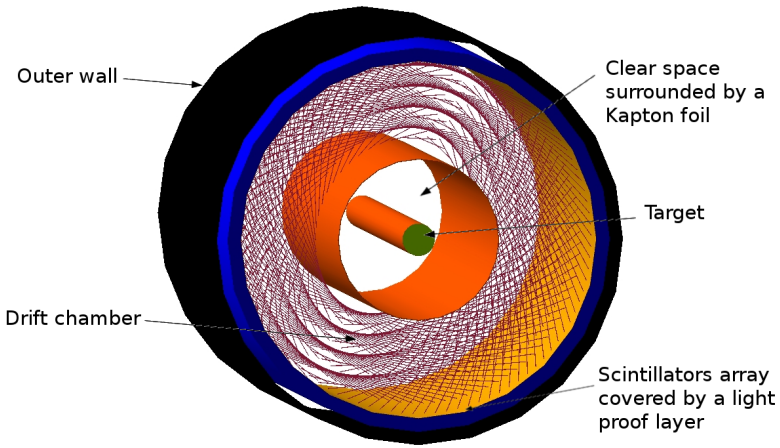
FSIs Present

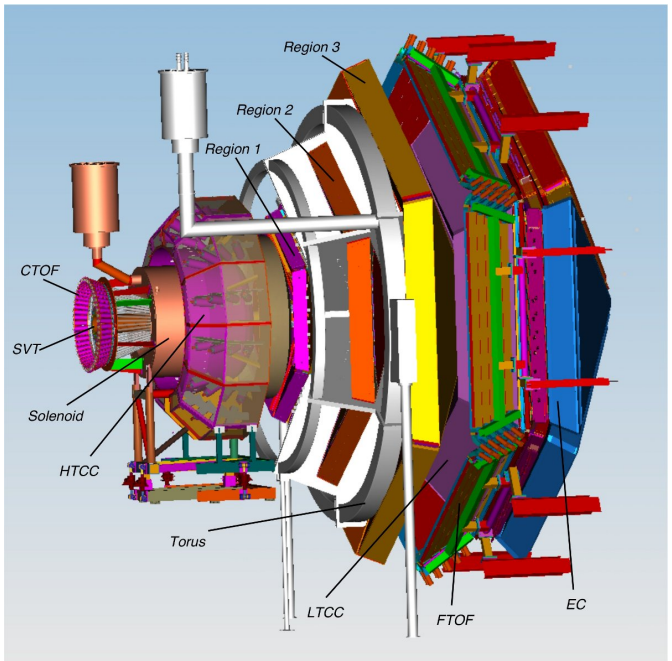
- Born Approx. $\rightarrow t_q$ *still* cleanly measured
- FSIs modify momentum transfer
- $\boldsymbol{t_p \neq t_q}$

Proposed Experiment

CLAS12 + ALERT

Measurements	Particles detected	Targets	Beam time request	Luminosity
ALERT Commissioning	p, d, ^{4}He	^{1}H and ^{4}He	5 days	Various
Tagged EMC	p, ^{3}H, ^{3}He	^{2}H and ^{4}He	$20 + 20$ days	3.10^{34} cm^{-2}s^{-1}
Tagged DVCS	**p, ^{3}H, ^{3}He**	**^{2}H and ^{4}He**	**$20 + 20$ days**	**3.10^{34} cm^{-2}s^{-1}**
Nuclear GPDs	^{4}He	^{4}He	extra 10 days on ^{4}He	6.10^{34} cm^{-2}s^{-1}
Additional Topics	p, d, ^{3}H, ^{3}He	^{2}H and He	$20 + 20 + (10)$ days	$3(6).10^{34}$ cm^{-2}s^{-1}
TOTAL			**55 days**	



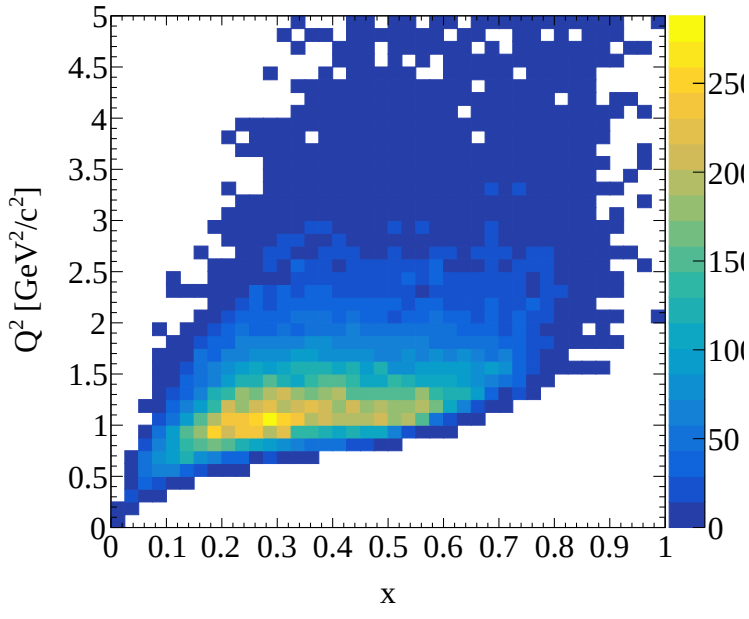


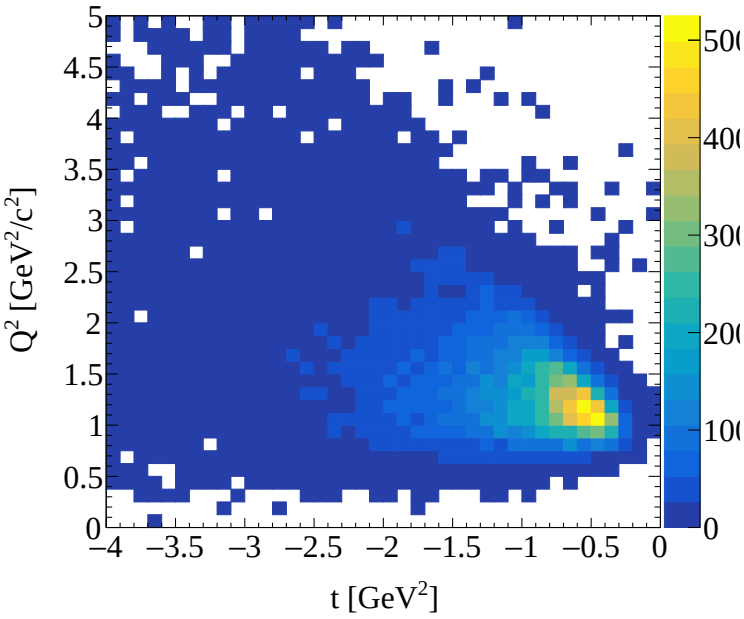
A Low Energy Recoil Tracker

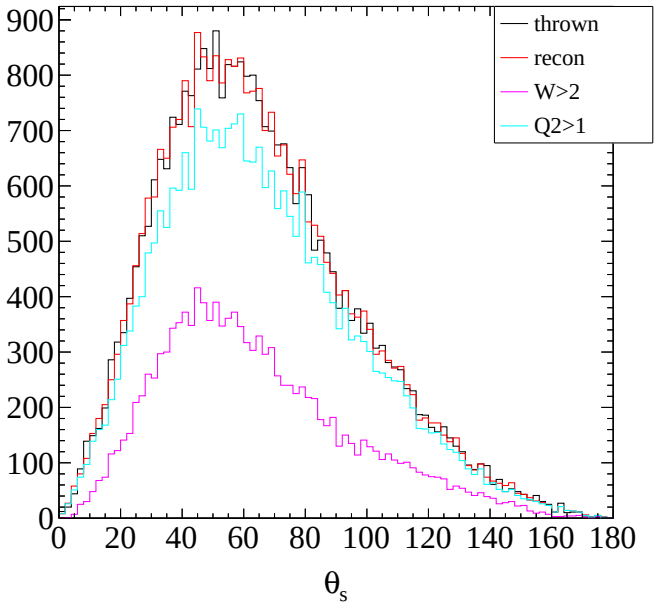
See Nathan Baltzell's talk for more details.

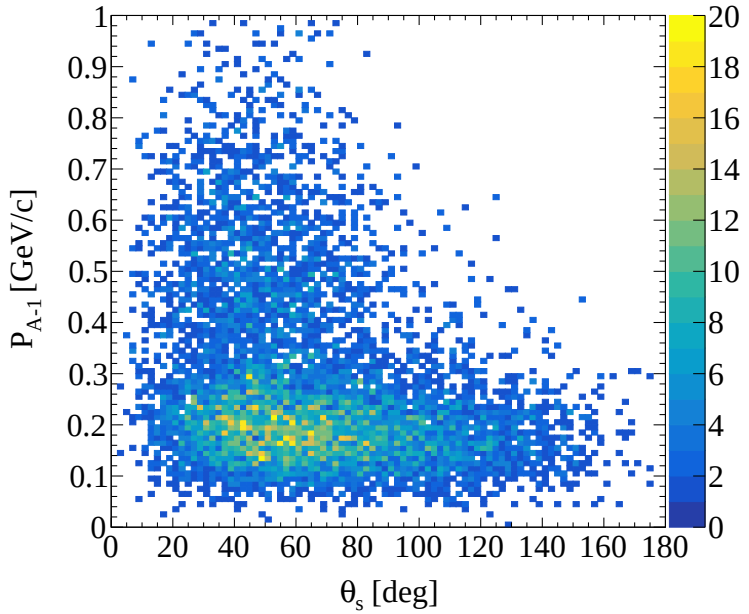
Kinematics

6-dimensional binned asymmetries: x, Q^2, t, ϕ, p_s, θ_s







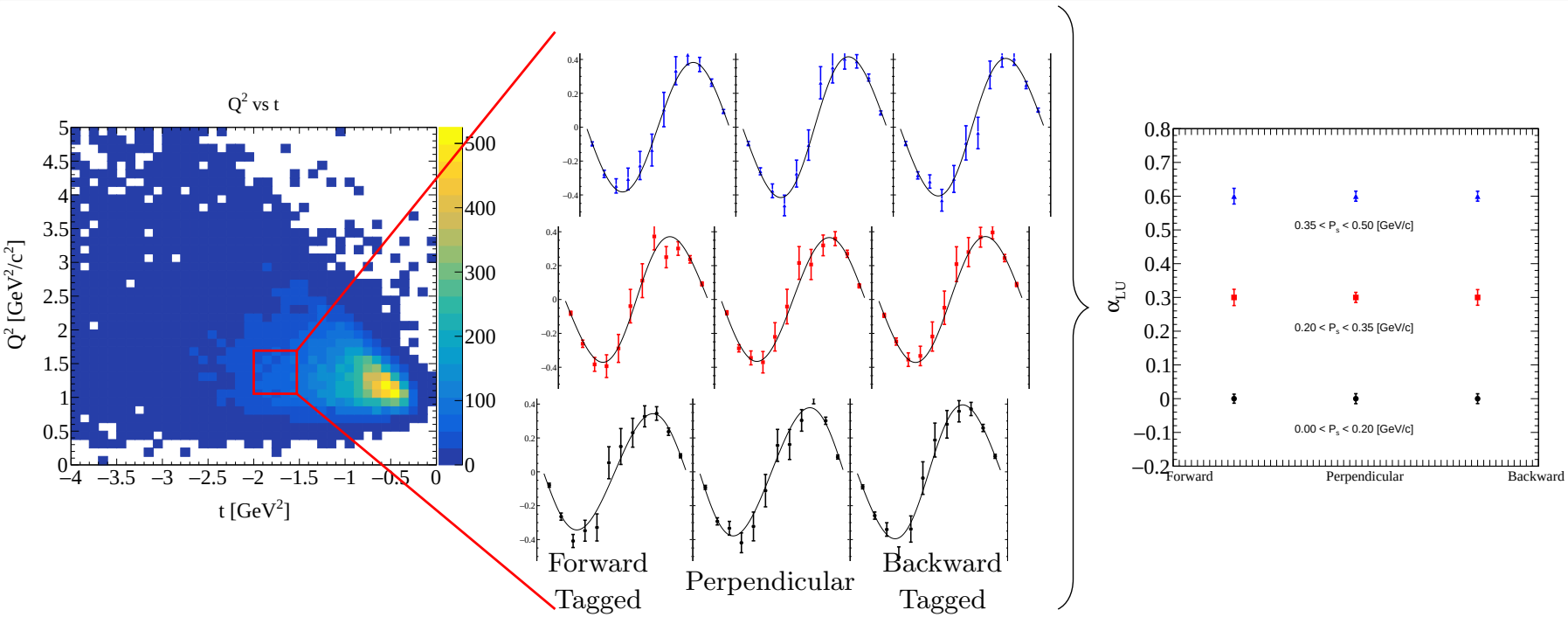


Observables

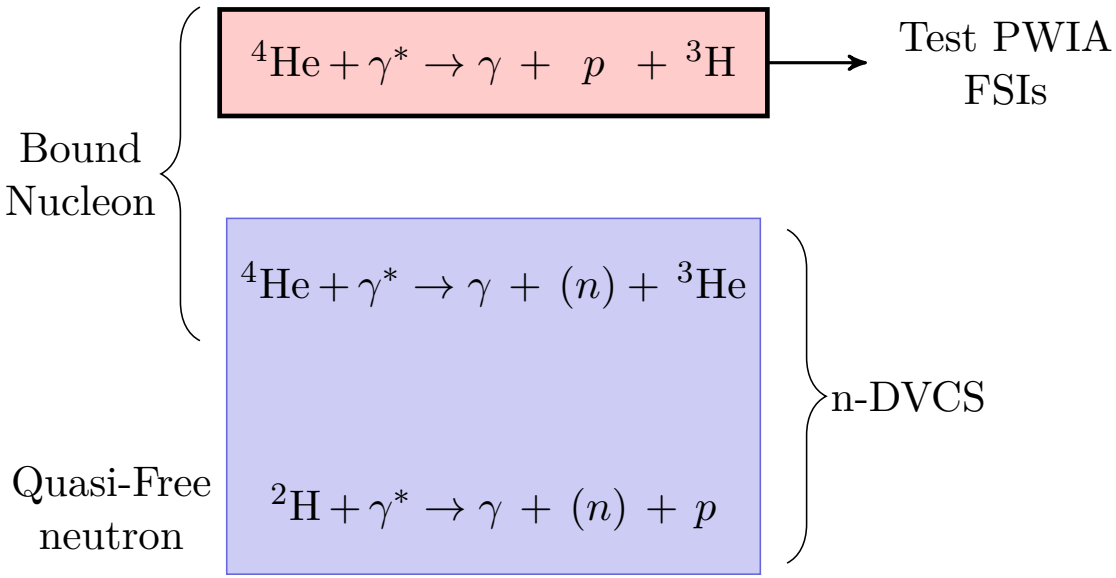
Beam Spin Asymmetries

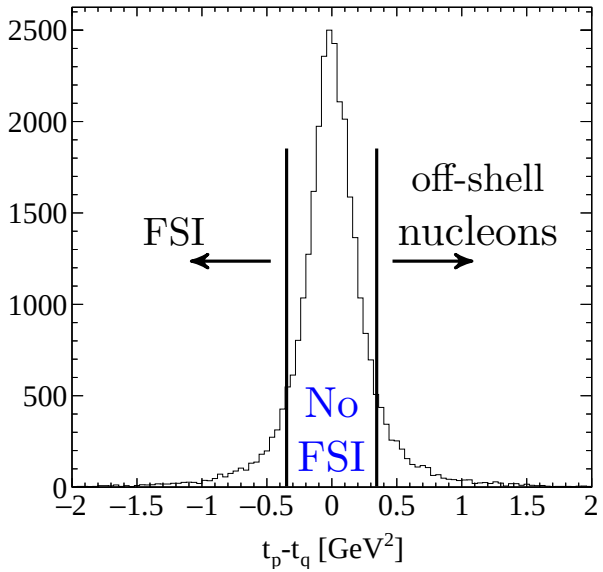
We will measure the DVCS BSA and extract the ϕ harmonic

$$A_{LU}(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)} \qquad A_{LU}^{\sin\phi} = \frac{1}{\pi}\int_{\pi}^{\pi} d\phi \sin\phi A_{LU}(\phi) = \alpha$$



Using p-DVCS to cleanly measure n-DVCS





- Use pDVCS to study FSIs and test the PWIA.
- Identify kinematics without FSIs
- Use charge symmetry → n-DVCS similarly free of FSI

n-DVCS as sensitive probe of medium modifications

Modified SF and modified FF in one measurement

$$A_{LU,n}^{\sin\phi} \propto \mathrm{Im}(F_1^n\mathcal{H}^n - \tfrac{t}{4M^2}F_2^n\mathcal{E}^n + \tfrac{x_B}{2}(F_1+F_2)^n\tilde{\mathcal{H}}^n)$$

- First term $\rightarrow$ suppressed by F_1^n
- Second term $\rightarrow$ Ji's sum rule and quark OAM
- Third term $\rightarrow$ polarized EMC Effect?

Connection to polarized EMC Effect

The third term above is

$$\mathrm{Im}\left((F_1+F_2)^n\tilde{\mathcal{H}}^n\right) = G_M^n(t)\,\mathrm{Im}(\tilde{\mathcal{H}}^n(\xi,\xi,t))$$

The ratio in the forward limit looks like

$$\frac{\text{bound } n}{\text{quasi-free } n} \longrightarrow \frac{\mu_{n^*}}{\mu_n}\frac{g_1^{n^*}(x)}{g_1^n(x)}\,,$$

Clearly n-DVCS with nuclei presents a uniquely sensitive measure of medium modifications

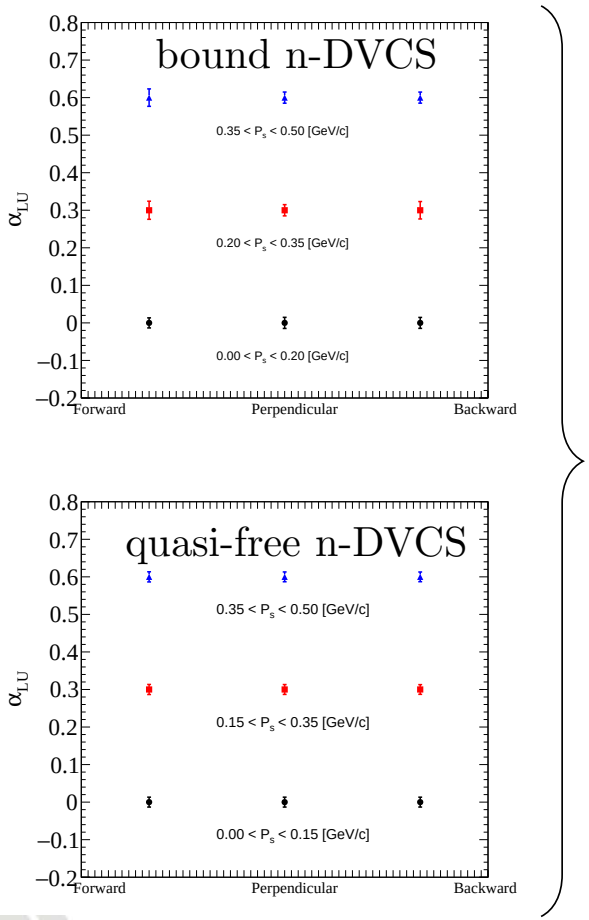
Off-forward EMC Effect Ratios

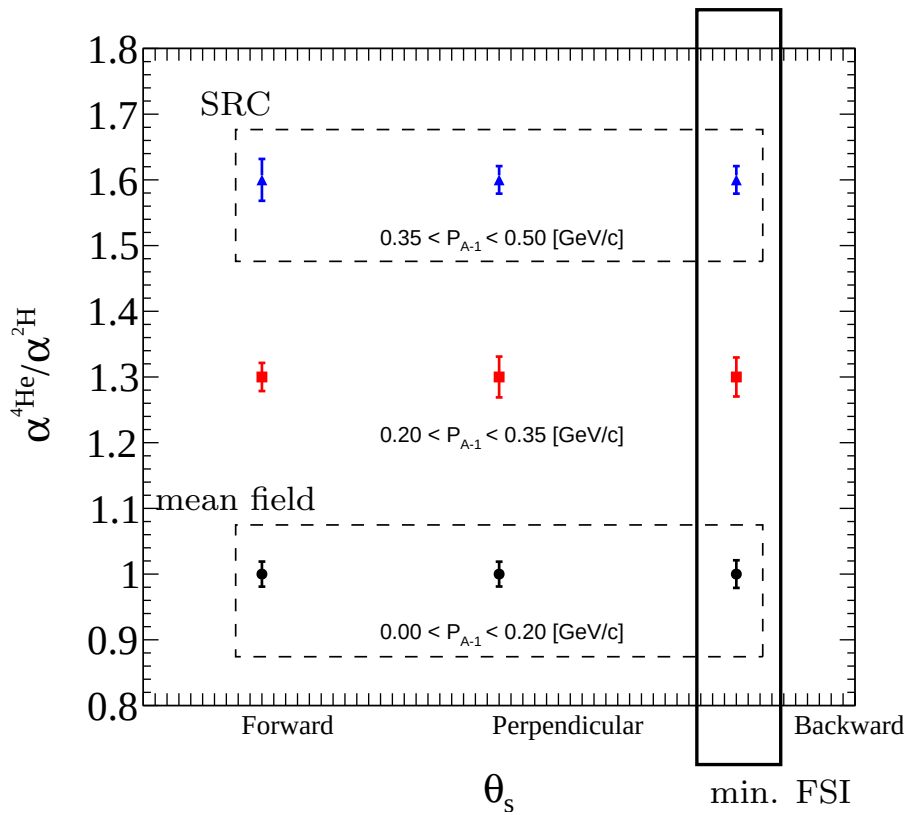
Neutron

$$R_\alpha^n = \frac{\alpha_{n^*}^{(^4\mathrm{He})}}{\alpha_n^{(^2\mathrm{H})}}$$

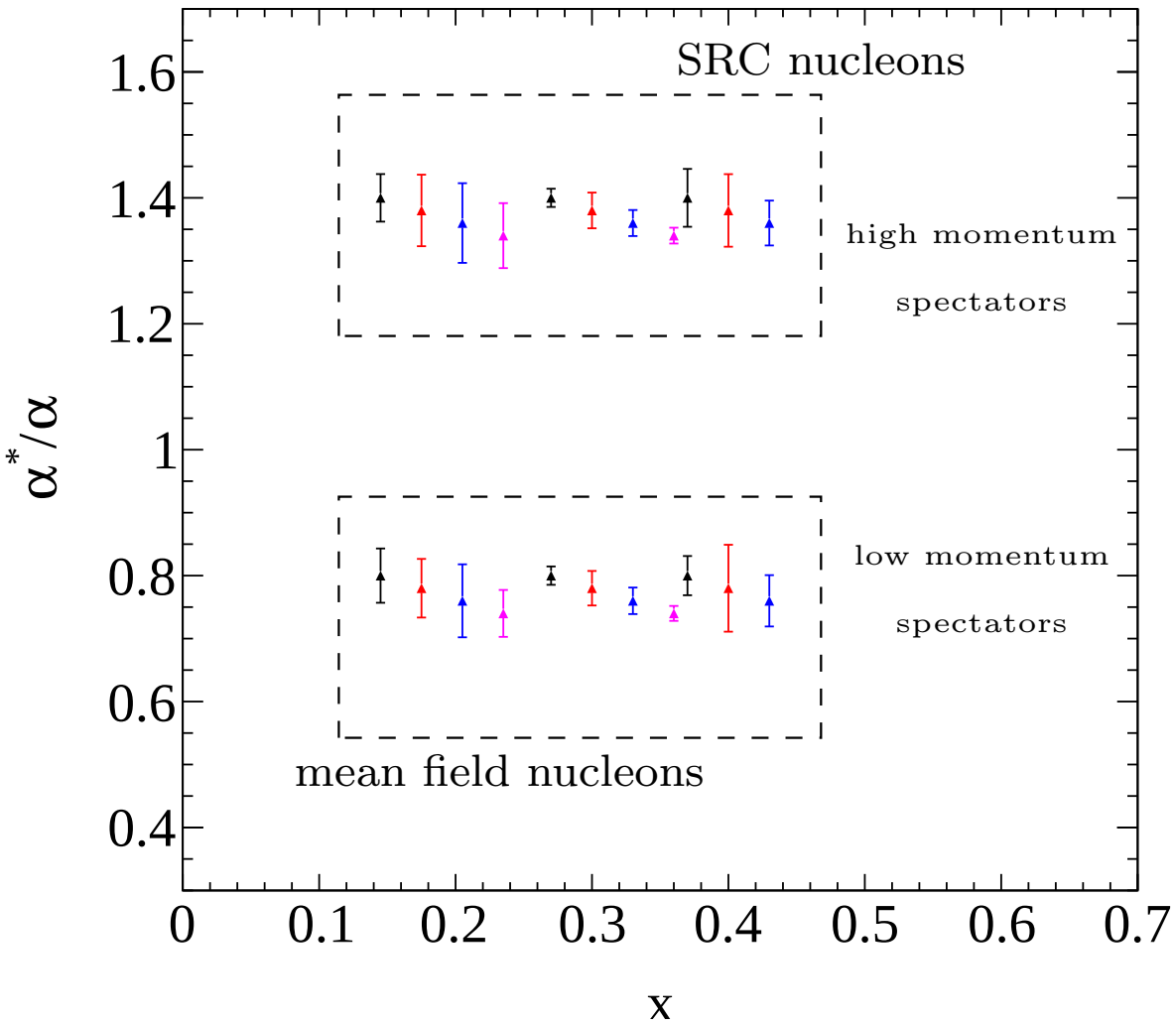
and extract the ϕ harmonic

$$A_{LU}^{\sin\phi} = \frac{1}{\pi}\int_\pi^\pi d\phi \sin\phi A_{LU}(\phi) =$$





Projected Results: Off-forward EMC Ratio



Colors indicate the different t bins which are shifted horizontally for clarity

Separated mean field nucleon EMC Effect and SRC nucleon EMC Effect

Observed deviations from 1

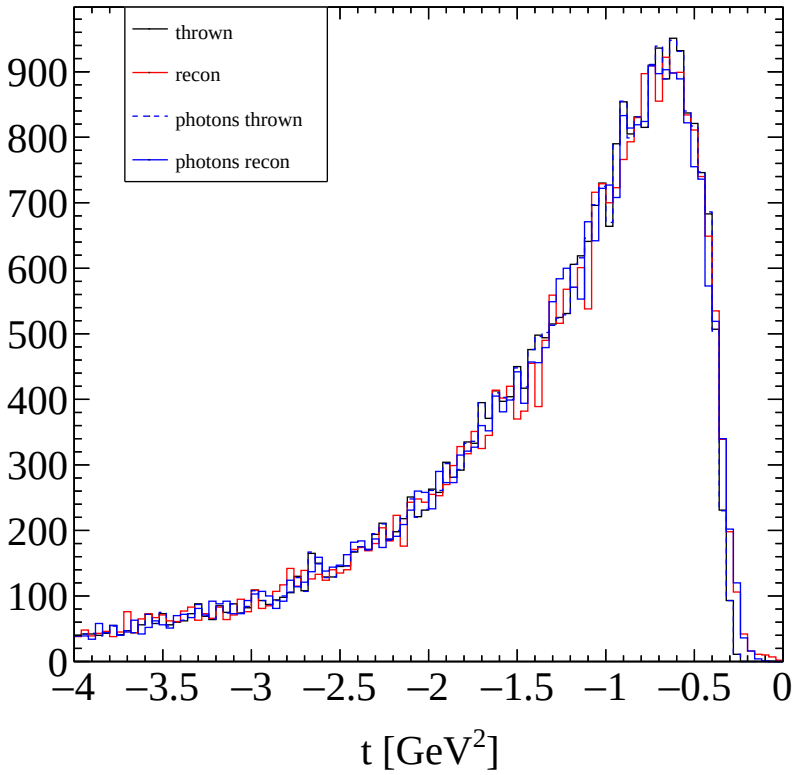
$\rightarrow$ medium modifications of nucleons at the partonic level

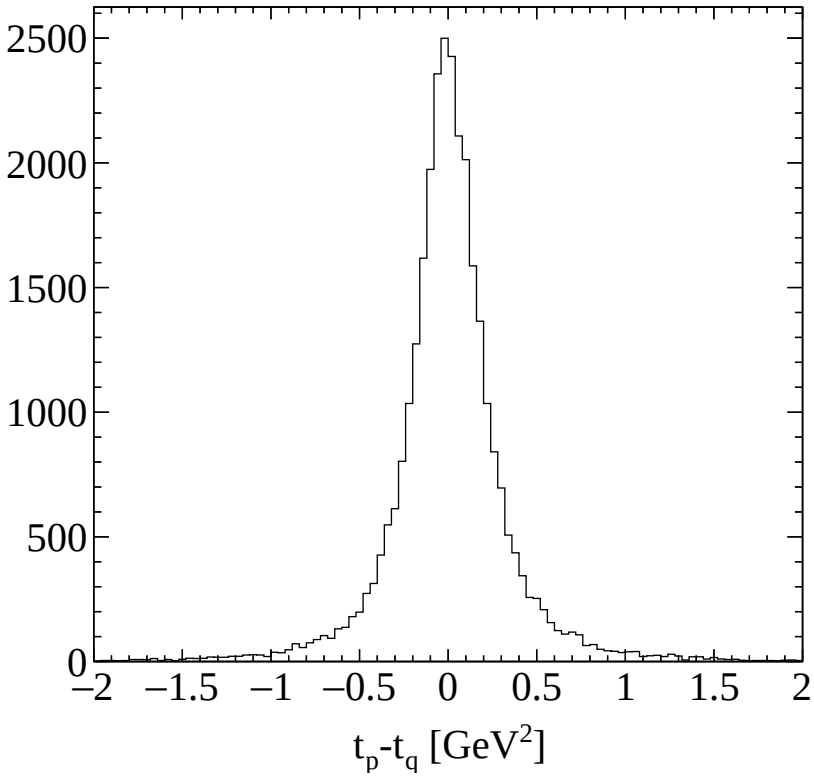
Summary

- Tagged DVCS has unique ability to study FSIs
- Separate FSIs in a model independent way
- Determine unambiguously if mean field nucleon is modified in nuclei
- ^{4}He is the lightest of nuclei where this could easily be done
- BSA and FSI measurements complementary to a wide variety of existing and proposed experiments

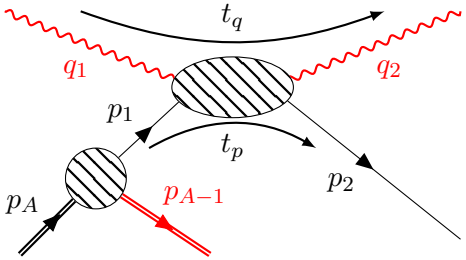
Thank you

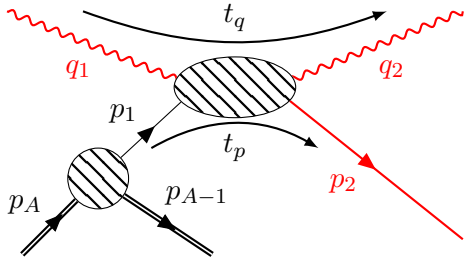
Backup


thrown
recon
photons thrown
photons recon
900
800
700
600
500
400
300
200
100
0
−4
−3.5
−3
−2.5
−2
−1.5
−1
−0.5
0
t [GeV^2]


2500
2000
1500
1000
500
0
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
t_p-t_q [GeV^2]

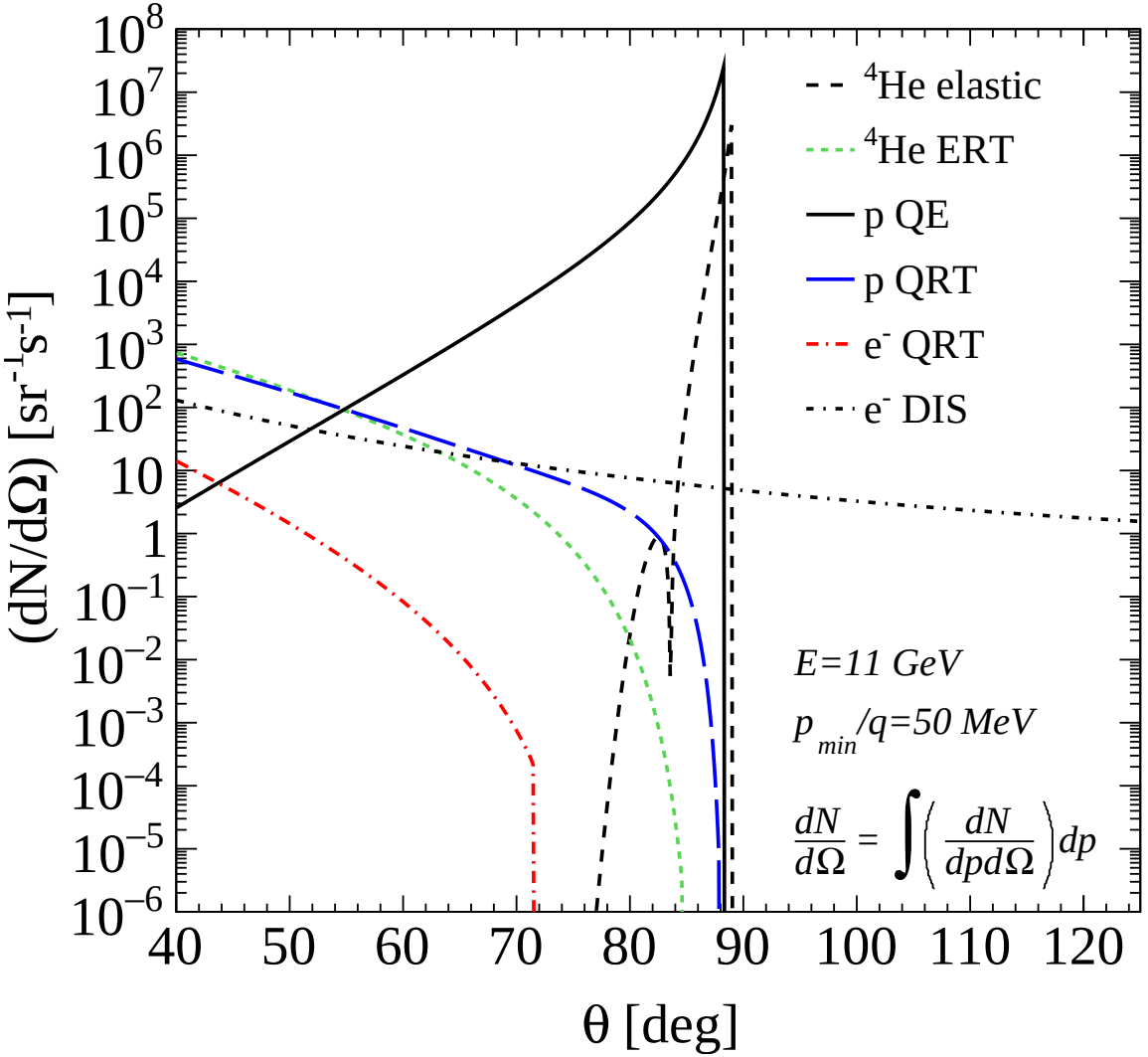
Off-shellness



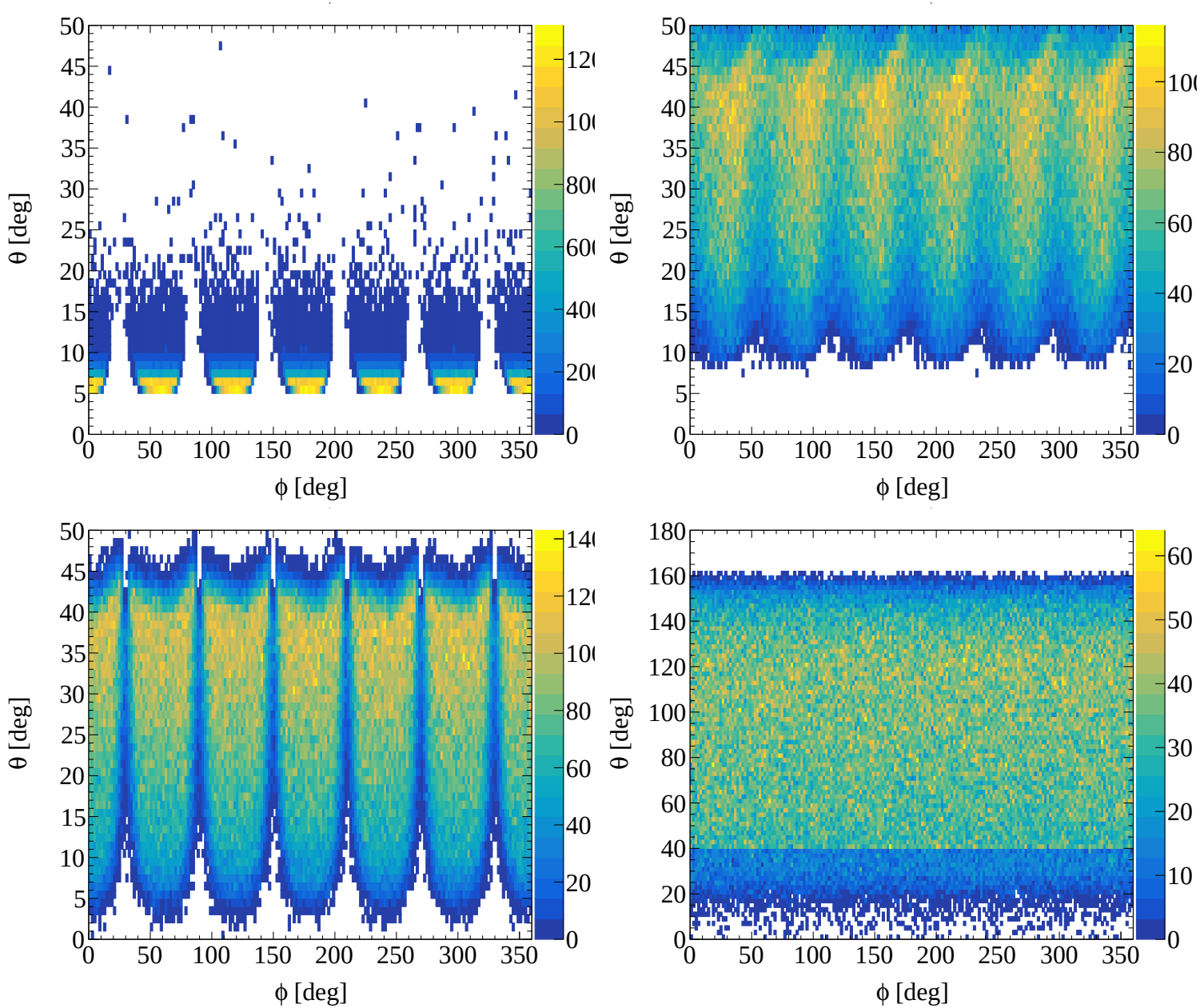


$$t_{\mathrm{FSI}} = 2M^2 - 2(E_1 E_2 + \boldsymbol{p}_{A-1} \cdot \boldsymbol{p}_2) + 2k^0(E_1 - E_2)$$
$$= t_p + 2k^0(E_1 - E_2)$$

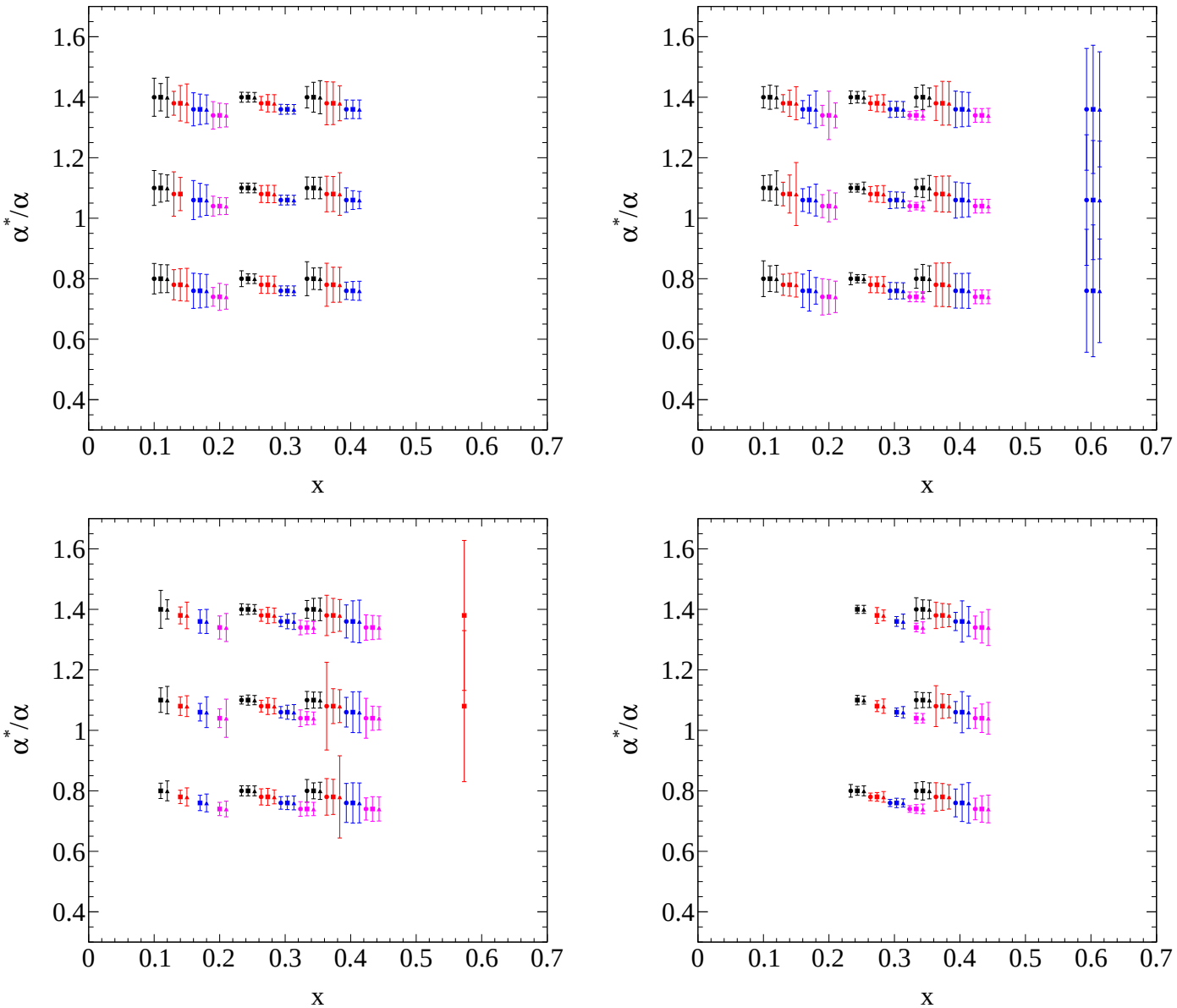
$$\bar{t} = t_p + \overline{M}^2 - M^2 + 2E_2 E_1 \left(1 - \frac{\overline{E}_1}{E_1}\right).$$


(dN/dΩ) [sr⁻¹s⁻¹]
θ [deg]
⁴He elastic
⁴He ERT
p QE
p QRT
e⁻ QRT
e⁻ DIS
E=11 GeV
p_min/q=50 MeV
dN/dΩ = ∫ (dN/dpdΩ) dp

Kinematics

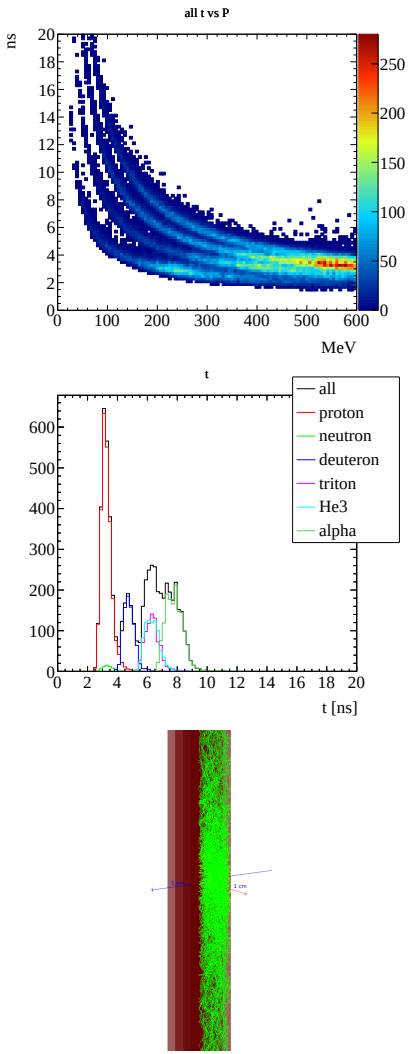


The off-forward EMC ratio for a bound neutron to a quasi-free neutron

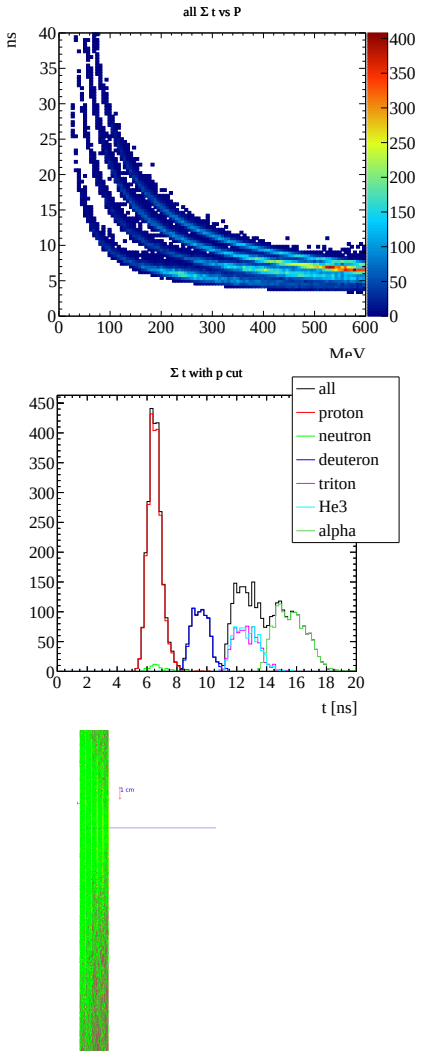


Various Scintillator Simulations

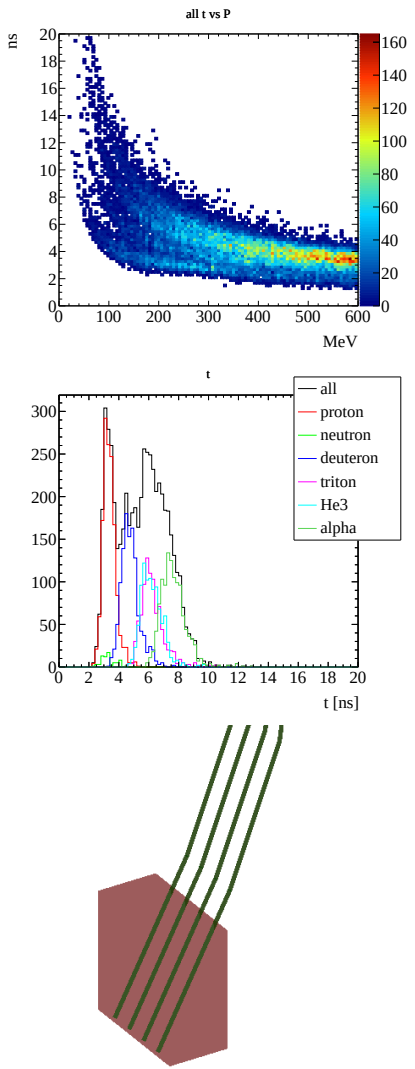
Bar $2\times10\times400$ mm^3 single-end readout



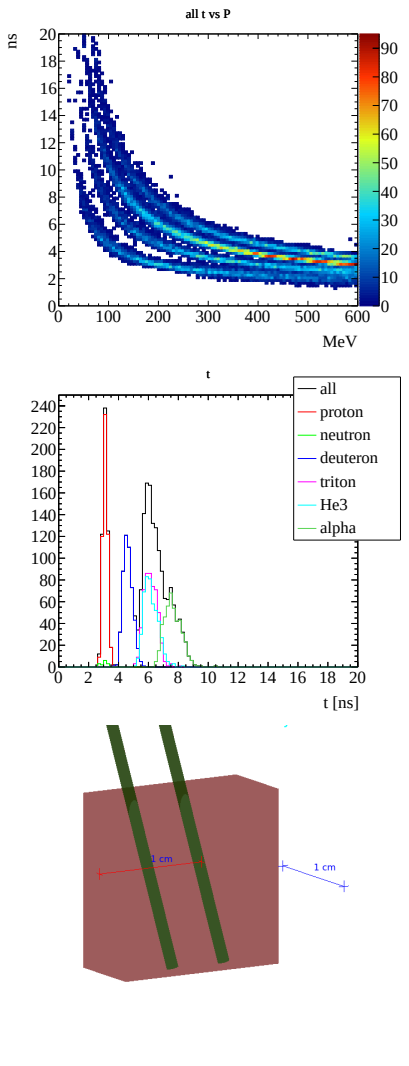
Bar $2\times10\times400$ mm^3 dual-end readout



Tile: $30\times30\times15$ mm^3 Sum readout at fiber ends

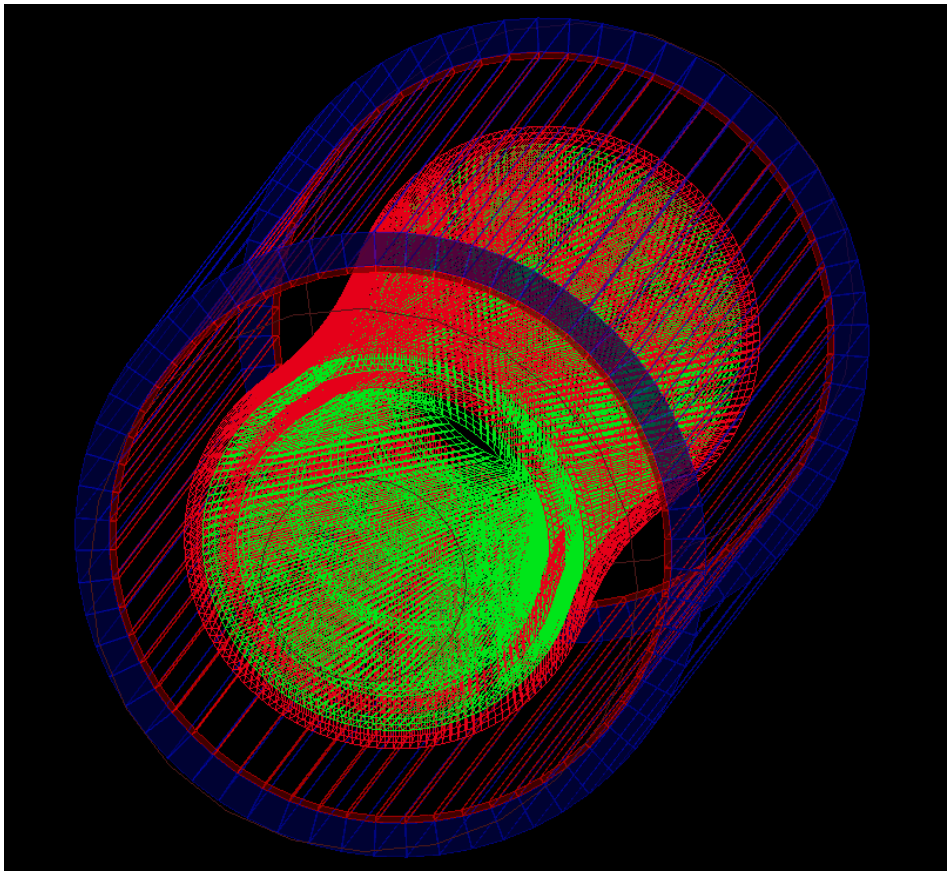


Tile: $15\times15\times7$ mm^3 Sum readout at fiber ends



Dual ended readout or small tiles can work.

Preliminary Design



- Farm install documented: `https://clasweb.jlab.org/wiki/index.php/ALERT_Software`
- Everything is on gitlab
- Full Geant4 simulation for studying recoil detector completed
- Event generator available for producing realistic input

Future Work

- Finish design of scintillator system
- Study different geometry/scintillator combinations
- Determine best way to detect photons: PMTs, SiPM, APDs, ...