Probing the Partonic Sturcture of ^{4}He with Deep Exclusive Processes

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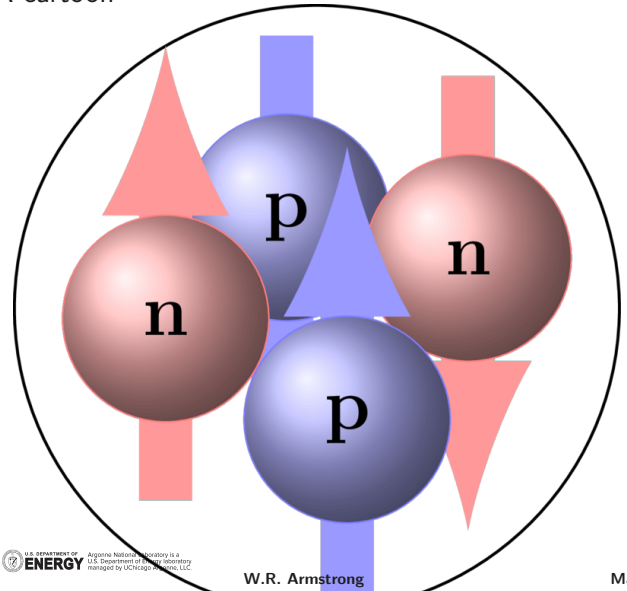
Overview

- Motivation: Partonic structure of ^{4}He
- Accessing quark and gluon GPDs
- ALERT Experiments with CLAS12
- Summary

The Partonic Structure of the alpha particle

A cartoon



- Two goggles to view the nucleus

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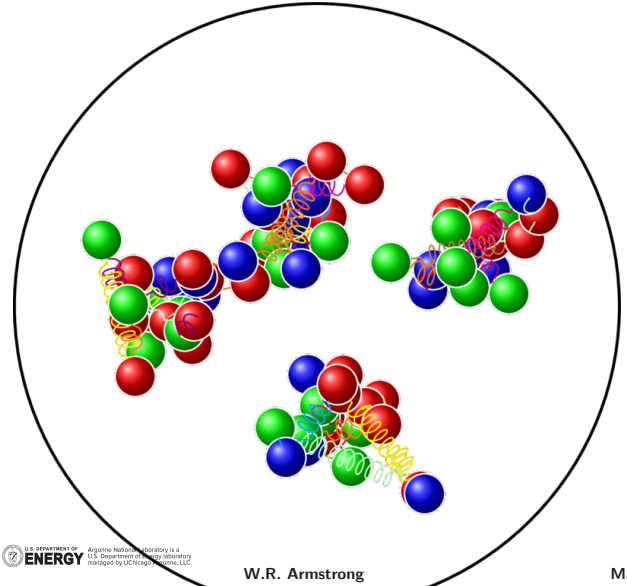

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- Coherent DVCS to probe the charge profile

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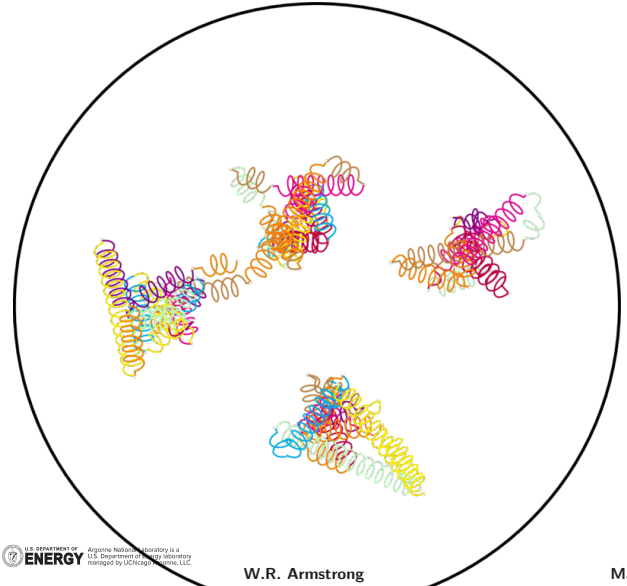

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- Coherent DVCS to probe the charge profile
- Coherent ϕ production to probe the gluon profile

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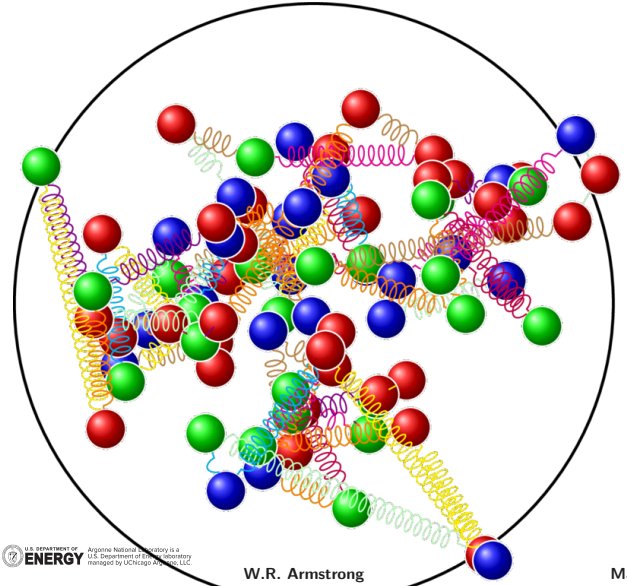


- Two goggles to view the nucleus
- Coherent DVCS to probe the charge profile
- Coherent ϕ production to probe the gluon profile
- How does the gluonic form factor compare to the charge?

Coherent DVCS and ϕ production on ^{4}He

Why ^{4}He?

- Spin-0 isoscaler nucleus
- One chiral even leading twist GPD.

- What goes into data analysis?
- What can be extracted from data?

Coherent DVCS cross section:

$$\frac{d^5\sigma^\lambda}{dx_A dQ^2 dt d\phi_e d\phi} = \frac{\alpha^3}{16\pi^2}\frac{x_A\, y}{Q^4\sqrt{1+\epsilon^2}}\frac{|\mathcal{T}_{BH}|^2 + |\mathcal{T}^\lambda_{DVCS}|^2 + \mathcal{I}^\lambda_{BH*DVCS}}{e^6}$$

Coherent DVCS beam spin asymmetry

$$A_{LU} = \frac{d^5\sigma^+ - d^5\sigma^-}{d^5\sigma^+ + d^5\sigma^-}.$$

Coherent ϕ production cross section:

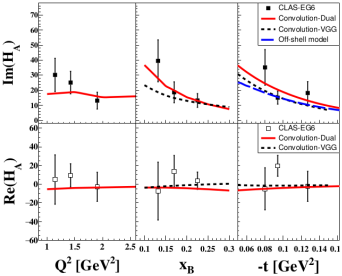
$$\frac{d\sigma_L}{dt}(^4\mathrm{He}) \propto |\langle H_g\rangle|^2$$

Accessing the Quark GPDs

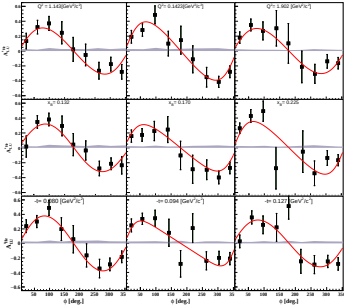
Coherent DVCS

- Complex-valued Compton form factor: $\mathcal{H}_A$.
  Neglecting anti-quarks: $H_A(\xi,\xi,t) = \Im m(\mathcal{H}_A)$.
- Compute Fourier coefficients for beam spin asymmetry
- Fit angular distribution to get harmonic parts of A_{LU}

$$A_{LU}(\phi) = \frac{\alpha_0(\phi)\,\Im m(\mathcal{H}_A)}{\alpha_1(\phi) + \alpha_2(\phi)\,\Re e(\mathcal{H}_A) + \alpha_3(\phi)\left(\Re e(\mathcal{H}_A)^2 + \Im m(\mathcal{H}_A)^2\right)}$$



CLAS eg6 (Hattawy, et.al. PRL 2017)



$$\alpha_0(\phi) = \frac{x_A(1+\epsilon^2)^2}{y} S_{++}(1)\sin(\phi)$$

$$\alpha_1(\phi) = c_0^{BH} + c_1^{BH}\cos(\phi) + c_2^{BH}\cos(2\phi)$$

$$\alpha_2(\phi) = \frac{x_A(1+\epsilon^2)^2}{y}\left(C_{++}(0) + C_{++}(1)\cos(\phi)\right)$$

$$\alpha_3(\phi) = \frac{x_A^2\, t(1+\epsilon^2)^2}{y}\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)\cdot 2\,\frac{2-2y+y^2}{1+\epsilon^2}$$

Accessing Gluons in ^{4}He

Deeply Virtual ϕ production

Gluon form factor

$$|\langle H_g \rangle|(t) \propto \sqrt{\frac{d\sigma_L}{dt}(t - t_{min}) \Big/ \frac{d\sigma_L}{dt}(0)}$$

$$\frac{d\sigma_L}{dt}(^4\mathrm{He}) \propto |\langle H_g \rangle|^2$$

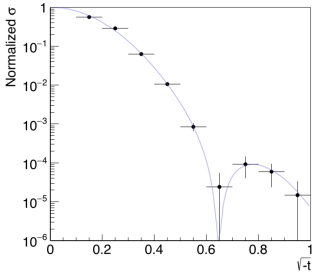
Extracting longitudinal cross section:

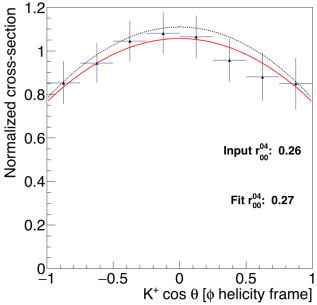
$$\frac{d\sigma_L}{dt} = \frac{1}{(\epsilon + 1/R)\Gamma(Q^2, x_B, E)} \frac{d^3\sigma}{dQ^2 dx_B dt}$$

Using SCHC to determine $R = \sigma_L/\sigma_T$:

$$W(\cos\theta_H) = \frac{3}{4}\left[(1 - r^{04}_{00}) + (3r^{04}_{00} - 1)\cos^2\theta_H\right]$$

$$r^{04}_{00} = \frac{\epsilon R}{1 + \epsilon R}$$

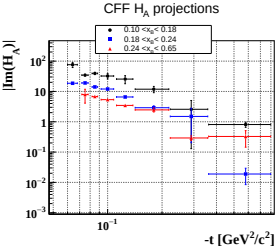




4He Transverse Quark and Gluon Densities

Coherent scattering on ^{4}He

DVCS
Charge profile



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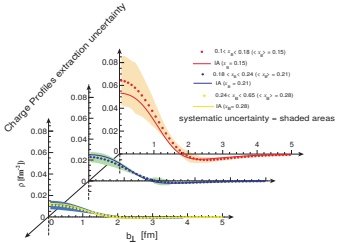
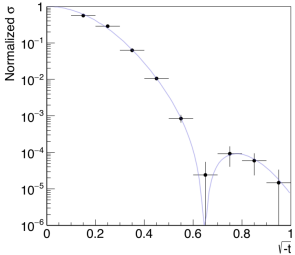


ϕ Production
Gluon profile



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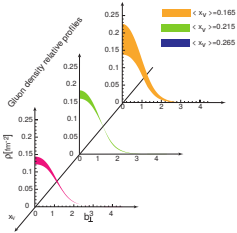


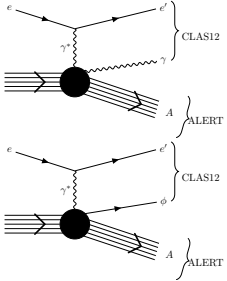
The ALERT Experiments

A comprehensive program to study nuclear effects

Coherent Processes on ^{4}He

- ^{4}He$(e, e'\ ^4$He $\gamma)$
- ^{4}He$(e, e'\ ^4$He $\phi)$

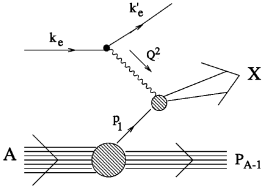
Explores the partonic structure of ^{4}He



DIS on ^{4}He and ^{2}H : Tagged EMC Effect

- ^{4}He$(e, e' +^3$H)X (proton DIS)
- ^{4}He$(e, e' +^3$He)X (neutron DIS)
- ^{2}H$(e, e' + p)$X (neutron DIS)

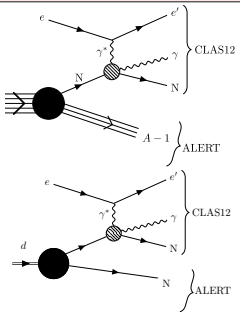
Test FSI and rescaling models



Incoherent processes on ^{4}He and ^{2}H

- ^{4}He$(e, e'\gamma\, p +^3$H)
- ^{4}He$(e, e'\gamma +^3$He$)n$
- ^{2}H$(e, e'\gamma + p)n$

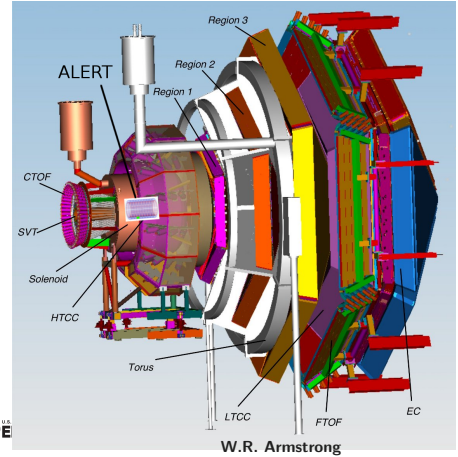
Identify medium modified nucleons



And many more channels for free

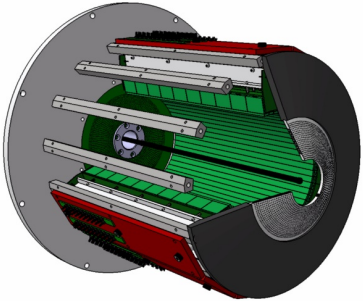
Proposed Setup: CLAS12 + ALERT

- Use CLAS12 to detect scattered electron, e', and forward scattered hadrons.
- A low energy recoil tracker (ALERT) will detect the spectator recoil or coherently scattered nucleus



ALERT requirements

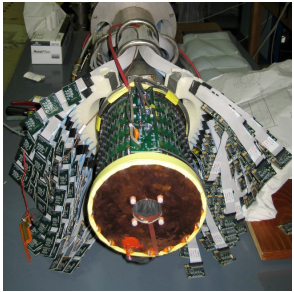
- Identify light ions: H, ^{2}H, ^{3}H, ^{3}He, and ^{4}He
- Detect the **lowest momentum** possible (close to beamline)
- Handle **high rates**
- Survive high radiation environment
  $\rightarrow$ **high luminosity**

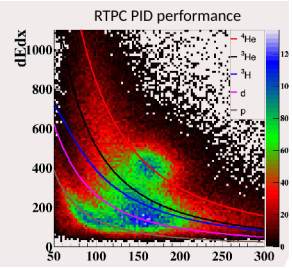


A Low Energy Recoil Tracker (ALERT)

Past experiences

- Existing (eg6) and proposed (BONUS) RTPC detectors do not meet experimental needs
- eg6 RTPC was slow and lacked full PID capabilities
- BONUS12 RTPC similar and only detect protons





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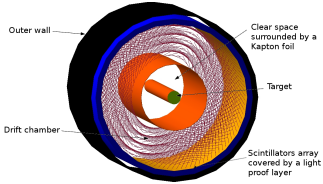
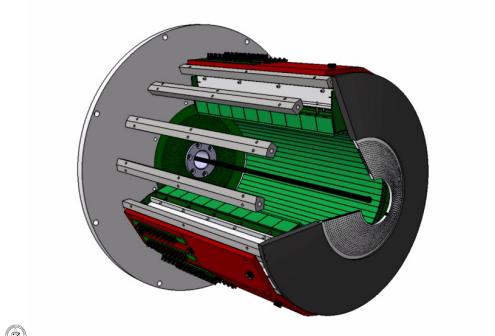


ALERT Design

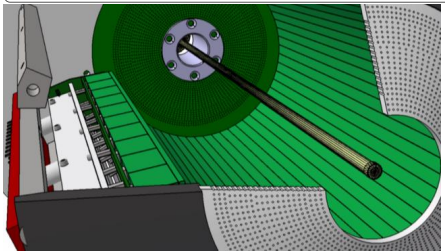
Basic Design

- Detector will surround a $\sim$3 atm gas target cell which is 6 mm in radius and constructed with 25 μm kapton walls
- Hyperbolic drift chamber with 10° stereo angle.
- Outer scintillator hodoscope for PID

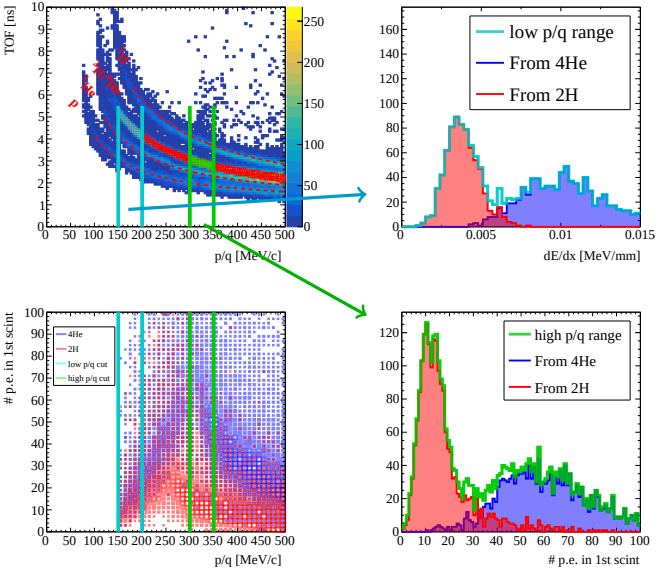


Hyperbolic Drift Chamber (HDC) Design

- 2 mm wire separation
- 10° stereo angle
- Minimize material (windows/walls)
- Detects $\theta \sim 30^\circ$ to 170°
- Acceptance minimum momenta:
  protons $\rightarrow$ 70 MeV/c
  ^{4}He $\rightarrow$ 240 MeV/c



ALERT Time-of-flight (ATOF)



Design Parameters

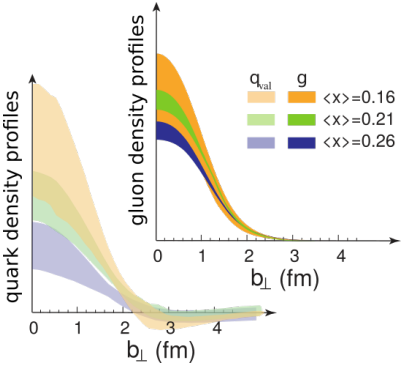
Need < 150 ps time resolution

Inner bar thickness : 3 mm.
Outer wedge thickness : 2 cm.

TOF separates light ions, except ^{4}He and ^{2}H which have same m/q ratio

Summary

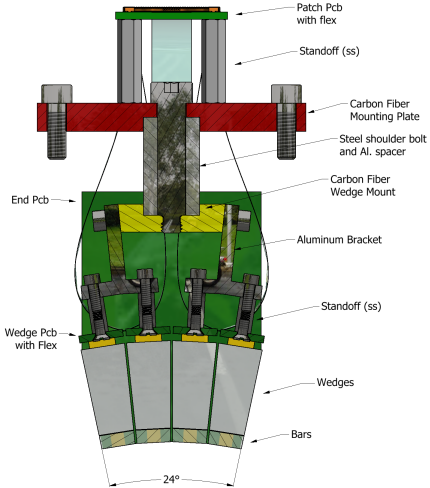
- Quark and gluon structure of ^{4}He can be accessed in deep exclusive processes
- Transverse spatial charge and gluonic matter distributions will be extracted.
- ALERT will produce datasets for coherent and incoherent DVCS/DVMP on ^{4}He and ^{2}H.
- ALERT should run at Jefferson Lab in summer 2024

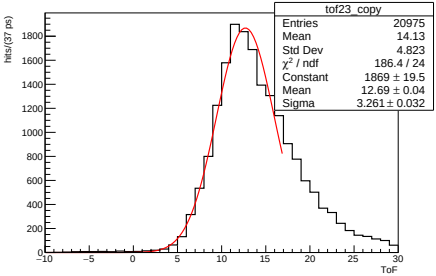


Thank you!

backup

ATOF Module Construction and Performance Tests

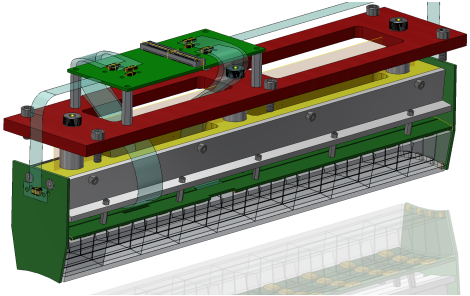


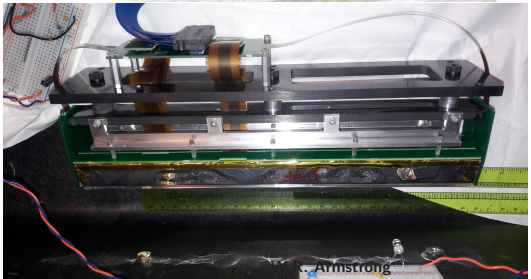


- Tested wedge time resolution with ^{241}Am source
- $\sigma \simeq 85 - 125\text{ps}$
- Observed tails in timing peak due to large source area $\rightarrow$ future improvement.
- No data corrections or fine tuning of ASIC config $\rightarrow$ **Easily meeting 150 ps timing requirement of experiment!**

ATOF Prototype Module

Americium-241 source placed against the module's inner bar scintillator at various locations





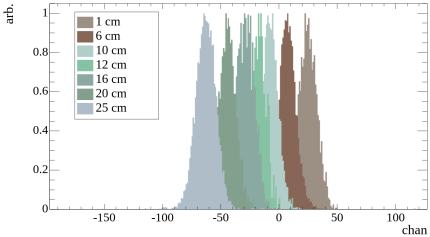


Figure : the tdc difference for the module's bar sipms for different locations of the ^{241}Am source.