The ALERT Experiments
An update

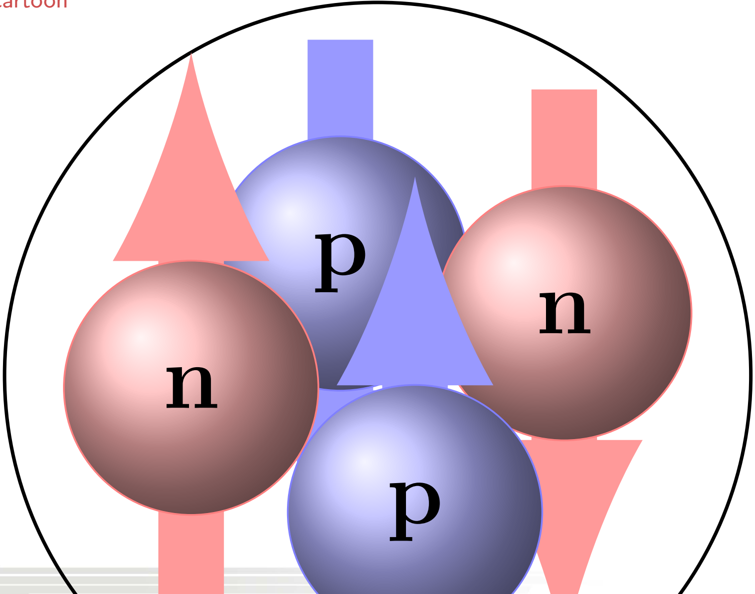
Whitney R. Armstrong

Argonne National Laboratory

March 30, 2017

The Partonic Structure of the α Particle

A cartoon



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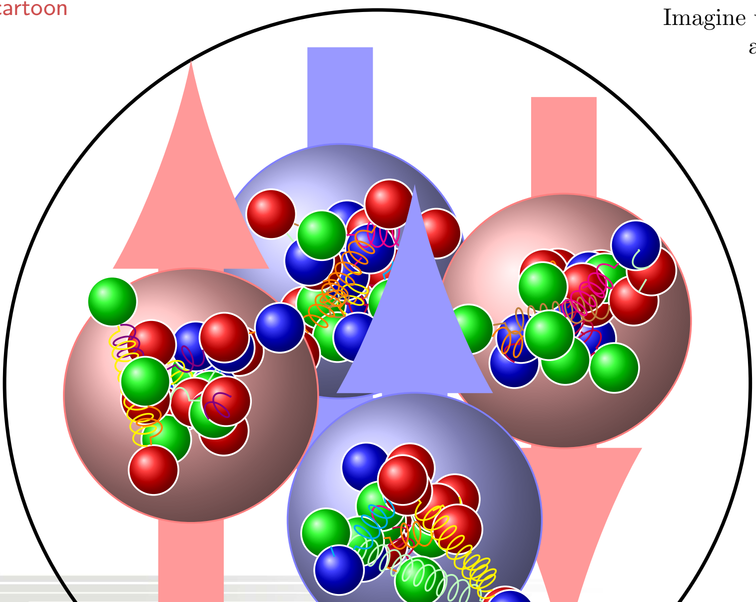

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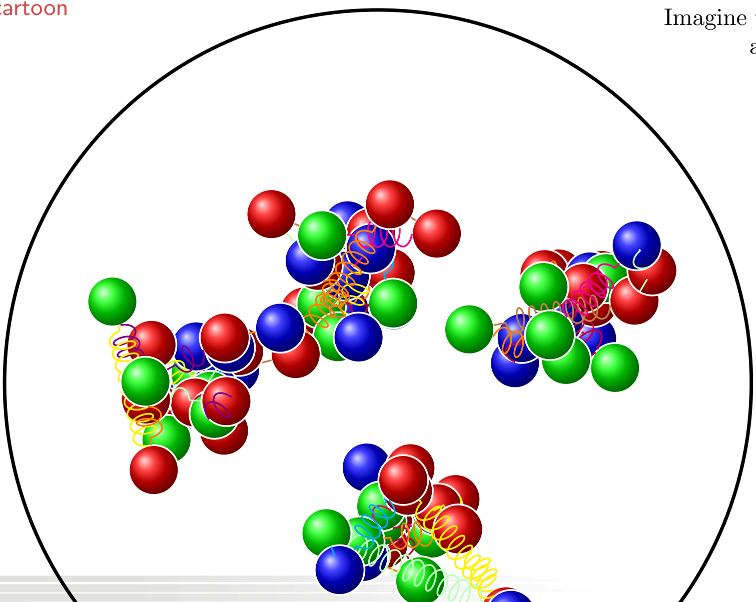

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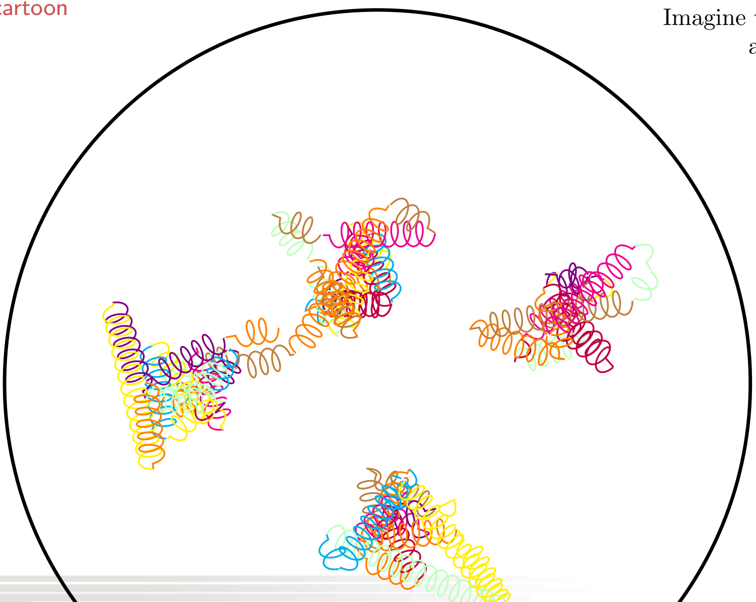

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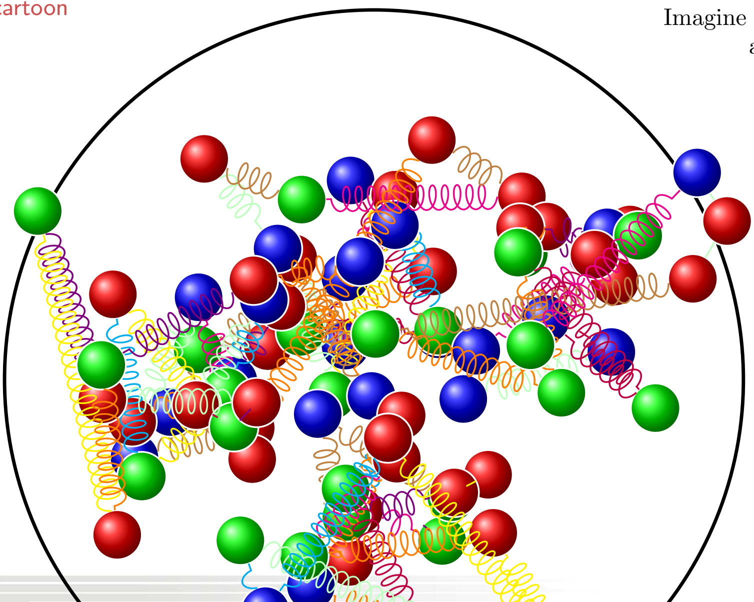

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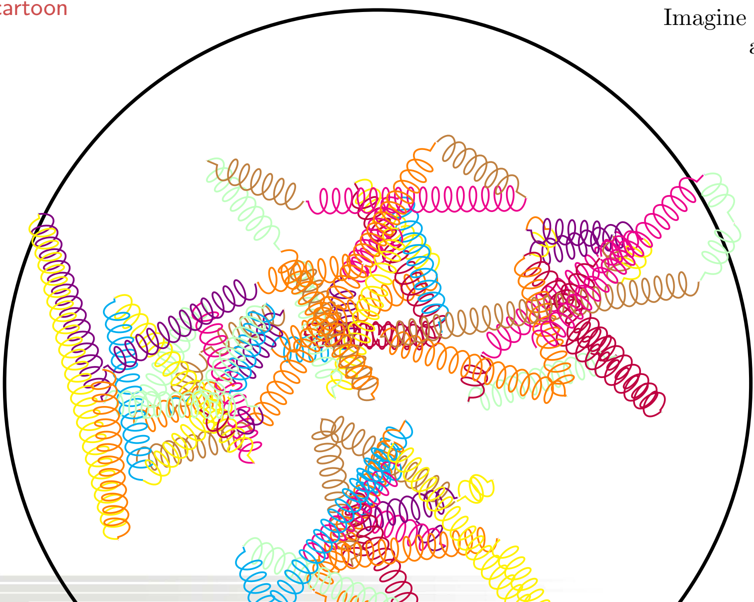

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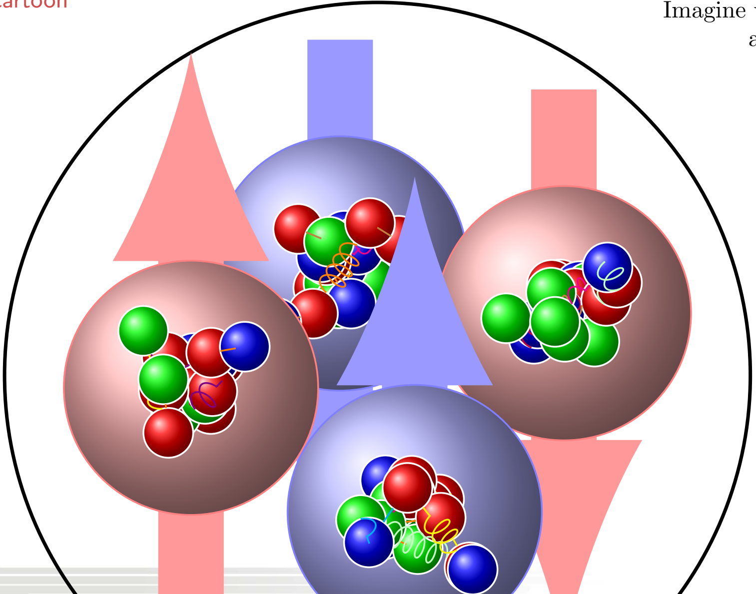

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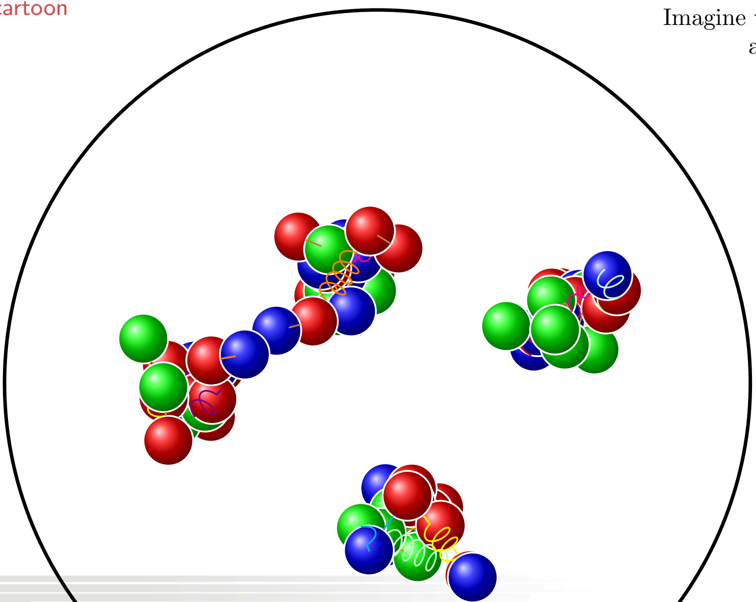

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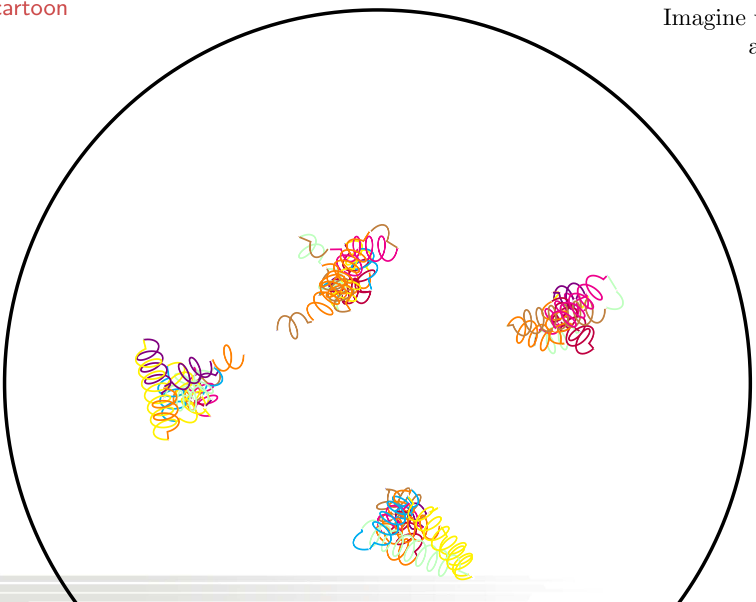

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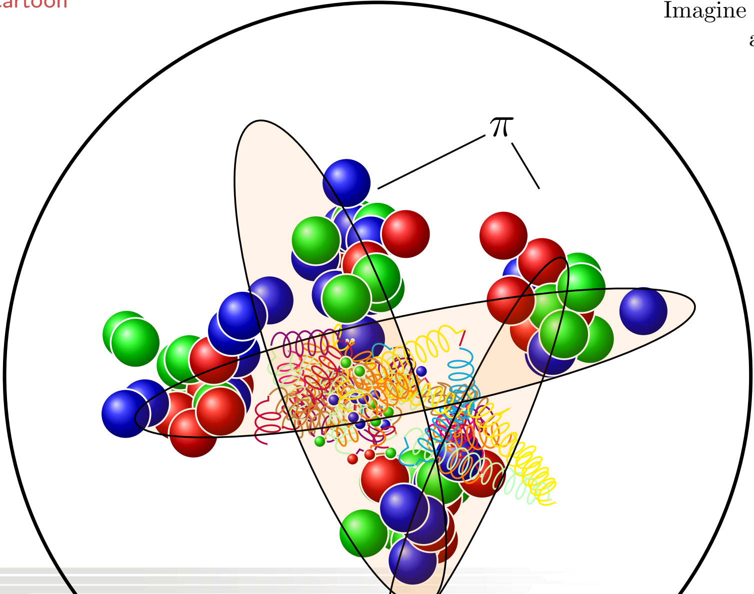

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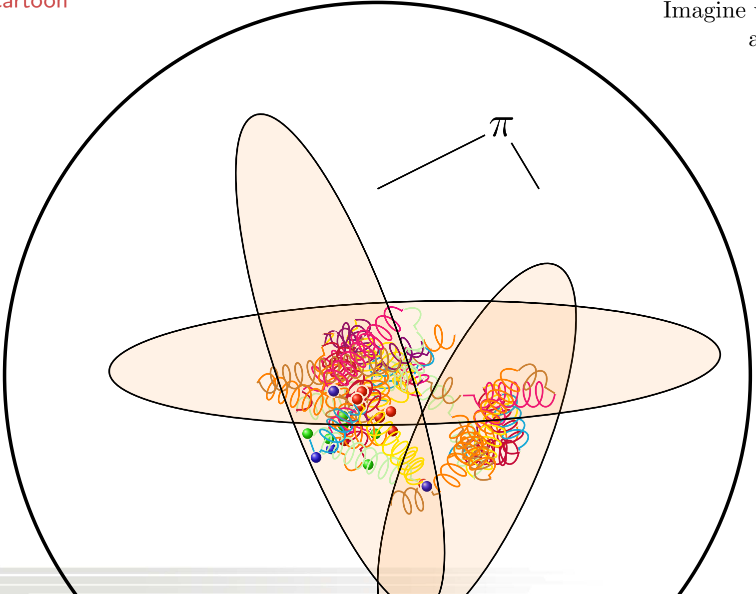

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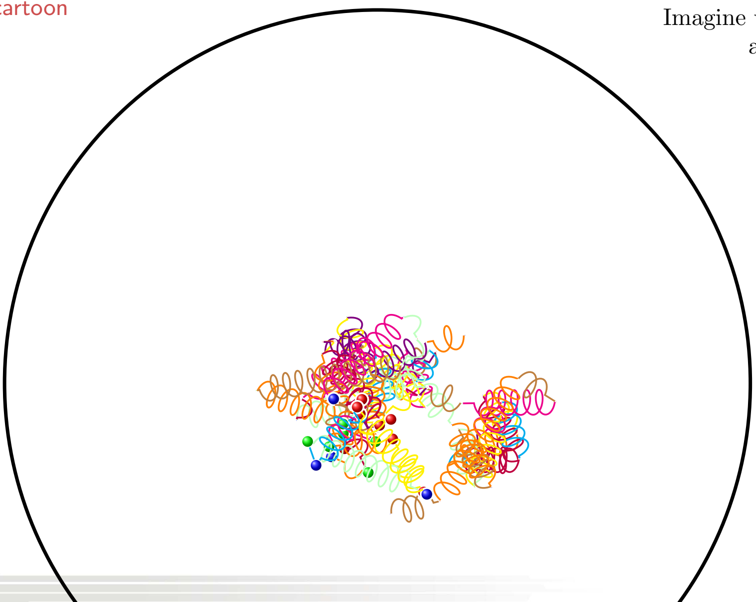

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Hadron Tomography

The basic strategies using electron beams

Hadron Tomography

The basic strategies using electron beams

- Deep-Inelastic Scattering (DIS)
  $\rightarrow$ **1D** - Longitudinal parton momentum distribution
- Elastic Scattering
  $\rightarrow$ **2D** - Transverse charge distribution integrated over all x
- Deeply Virtual Compton Scattering (DVCS)
  $\rightarrow$ **3D** - Transverse **quark** distribution at fixed x
- Deeply Virtual Meson Production (DVMP)
  $\rightarrow$ **3D** - Transverse **gluon** distribution at fixed x

x = fraction of hadron's LC momentum carried by parton

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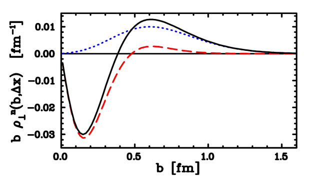
Key insight - G. Miller

FT is 2D (not 3D) yielding transverse charge distributions.

$$\rho_\perp(b_\perp) = \int \frac{d^2q}{(2\pi)^2} e^{iq\cdot b_\perp} F_1(Q^2)$$

As $x \rightarrow 1$:

- proton - all momentum carried by u-quark at center (positive)
- neutron - all momentum carried by d-quark at center (negative)



Miller and Arrington, Phys.Rev. C78 (2008) 032201

neutron $x > 0.23$ is the dashed, $x < 0.23$ is dotted

Partonic Structure of Nuclei

Quark and gluon transverse distributions

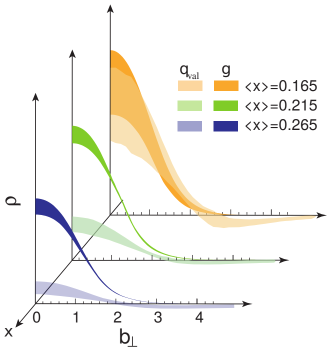
What is the gluon radius of 4He?

- Is the gluon radius the same as the charge radius?
- Is the glue localized in nucleons or in the nucleus?

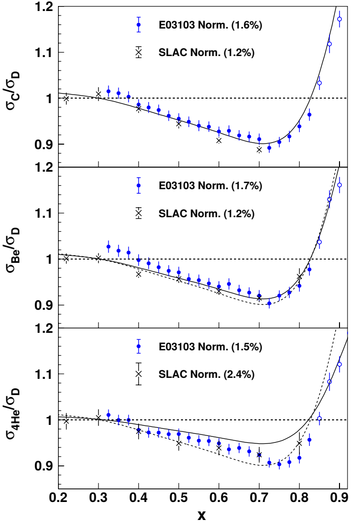
The answers to these questions may significantly guide the **physics and design of an EIC**

Why this measurement is important now: EIC's Oomph factor and gluon saturation

- The longitudinal overlap of low-x gluons from different nuclei is expected to increase the onset of gluon saturation
- However, if the gluons are highly localized, this effect is minimal and gluon saturation will remain out of reach
- The design parameters of an EIC tuned for saturation physics is counter to those for a nuclear tomography program.
- Knowing the transverse gluon distribution is important



EMC Effect



J. Seely et al. Phys.Rev.Lett. 103 (2009) 202301

EMC Effect in DIS

- Is structure function modified?
- Significant even in ^{4}He!
- Origin of effect remains unclear

The ALERT Experiments

A comprehensive program to study nuclear effects

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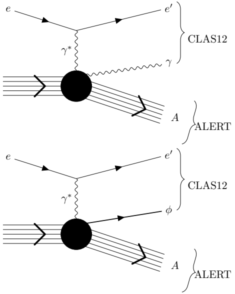
Coherent Processes on ^{4}He

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

Explores the partonic structure of ^{4}He



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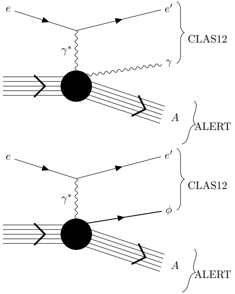
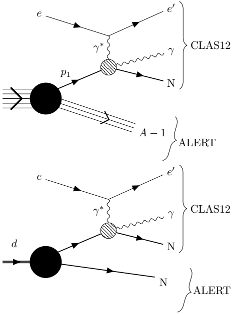


Incoherent processes on ^{4}He and ^{2}H

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

Identify medium modified nucleons



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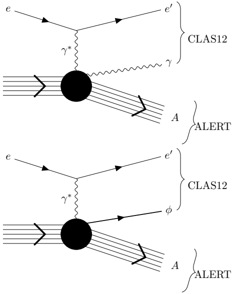

Incoherent processes on ^{4}He and ^{2}H

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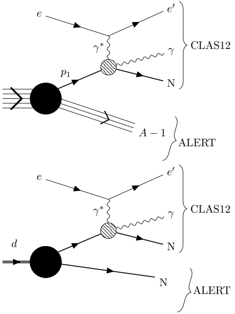
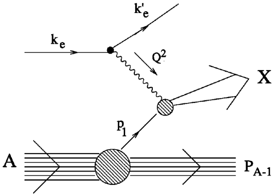


DIS on ^{4}He and ^{2}H : Tagged EMC Effect

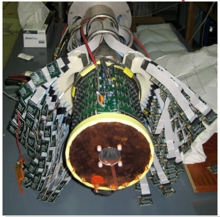
- $^4\mathrm{He}(e, e'{+}^3\mathrm{H})X$ (proton DIS)
- $^4\mathrm{He}(e, e'{+}^3\mathrm{He})X$ (neutron DIS)
- $^2\mathrm{H}(e, e' + p)X$ (neutron DIS)

Test FSI and rescaling models



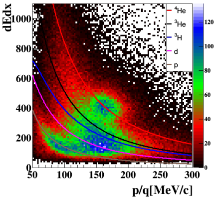
And many more channels for free

Previous Experiment: CLAS EG6



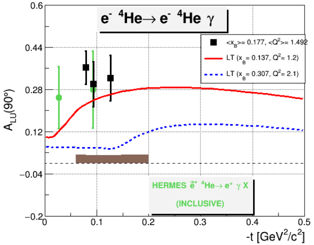
Radial Time Projection Chamber (RTPC)

- Response was slow (drift time)
- PID is insufficient
- Cannot provide trigger
- Rate limited (constantly triggered for readout)

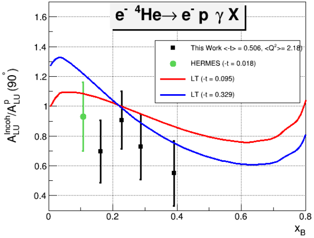


Coherent and incoherent DVCS results

M.Hattawy's EG6 analysis



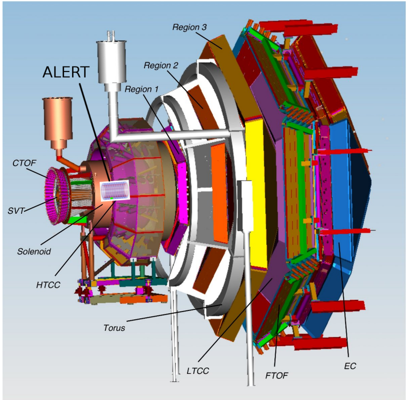
First exclusive coherent DVCS measurement on ^{4}He



Incoherent DVCS measurement plagued by kinematic uncertainties
→ need to tag spectators

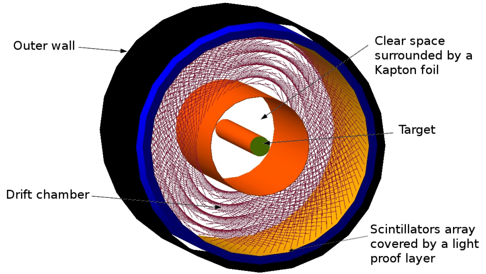
Proposed Setup: CLAS12 + ALERT

- 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**
- Provide **independent trigger**
- Survive high radiation environment
  $\rightarrow$ **high luminosity**



ALERT Design

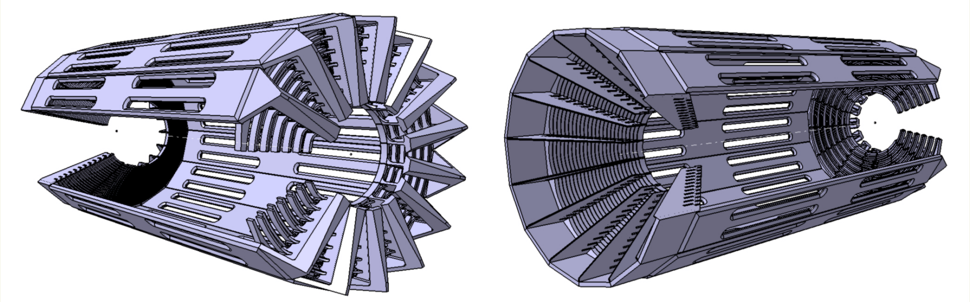
Basic Design

- Detector will surround a ∼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

Drift Chamber Design

- 2 mm wire separation
- 10° stereo angle
- Minimize material (windows/walls)
- Detects $\theta \sim 30°$ to 170°

Ongoing work led by IPN Orsay



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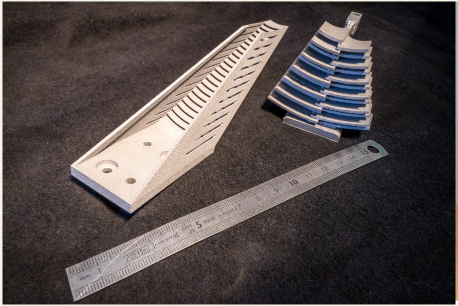

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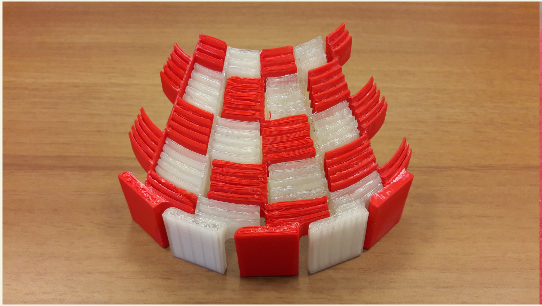
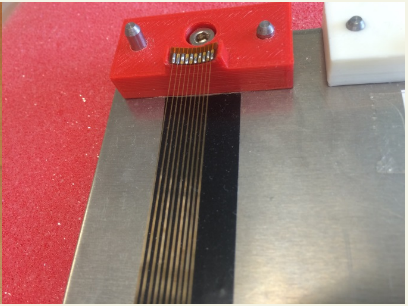
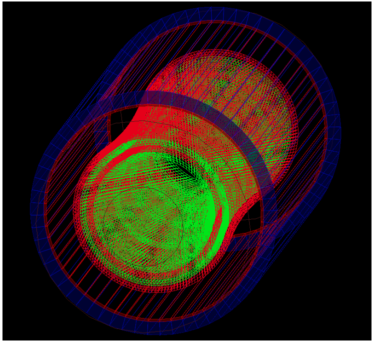




ALERT Design

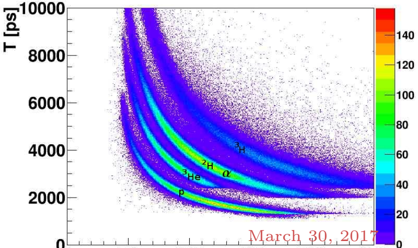
Scintillator Hodoscope Design

- 2 cylindrical layers ∼30 cm long
  1. Inner layer (thin) strips - 2 mm × 9 mm × 30 cm
     SiPM connected to each end of the strip
  2. Outer layer (thick) cells - 2 cm × 9 mm × 3 cm
     Segmented along beam axis (10 outer per 1 inner layer)
     SiPM readout attached to outer surface
- Good time resolution → need fast scint, fast SiPMs with good resolution, and small segmentation of scintillator cells.
- ^{4}He and ^{3}He dominate the signals coming from inner layer
- ^{1}H, ^{2}H, and ^{3}H will typically make it to the second layer depositing most of their energy.



Basic Operating Principles

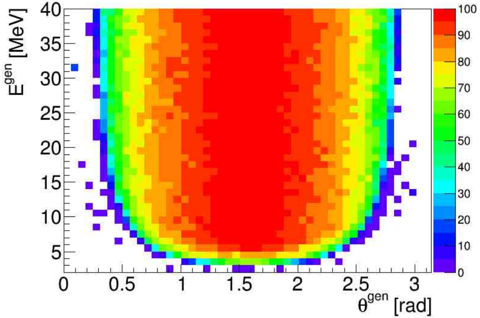
- By design, ALERT is blind to minimum-ionizing particles (where the threshold can be tuned through the gas or electronically)
- For coherent processes where the cross sections are low, so we will compensate by running at the highest possible luminosity with a high threshold, hence, we will cut out all the high energy particles.

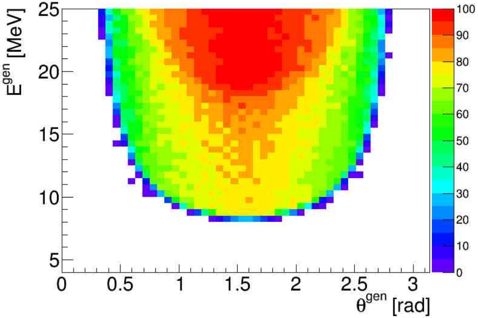


ALERT Simulation

Full Geant4 Simulation

- Acceptances minimum momenta: 70 MeV/c for protons, 240 MeV/c for ^{4}He





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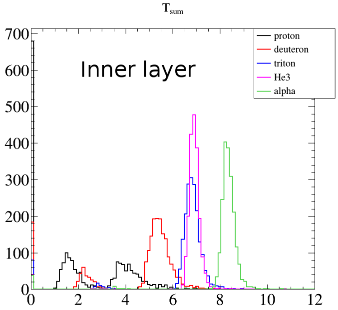

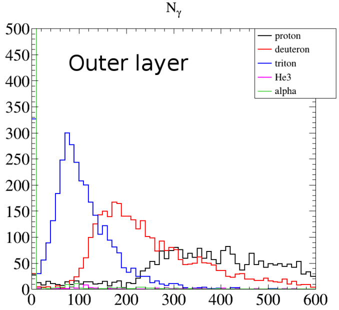

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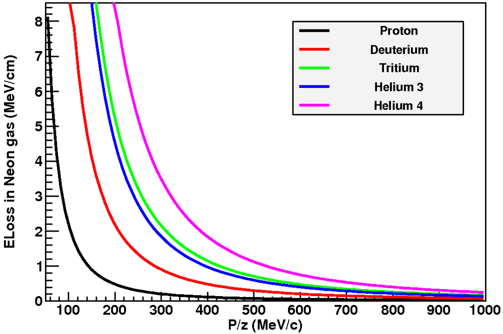

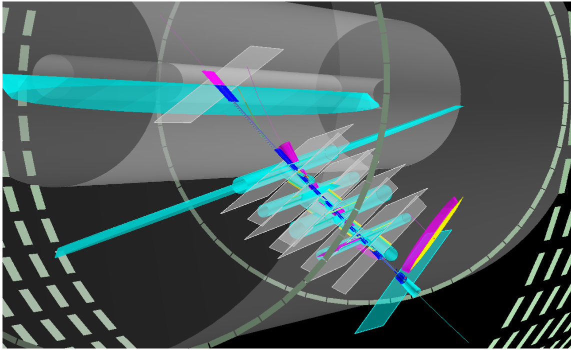

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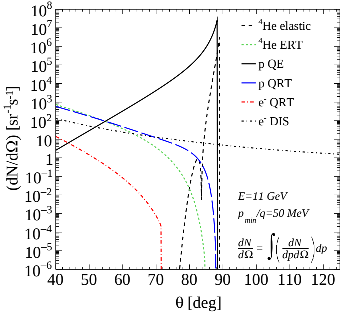
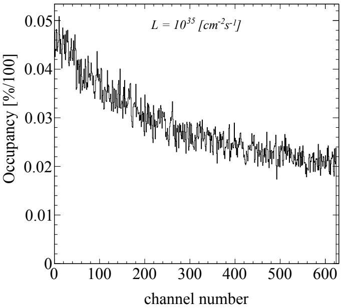
- Detailed scintillator photon yields and timing information → optimize geometry to provide the best PID
- Working on Kalman Filter based track reconstruction → optimize DC wire layout; Also get track dE/dx for PID
- DC hit occupancies simulated - can operate comfortably at nominal CLAS12 luminosity

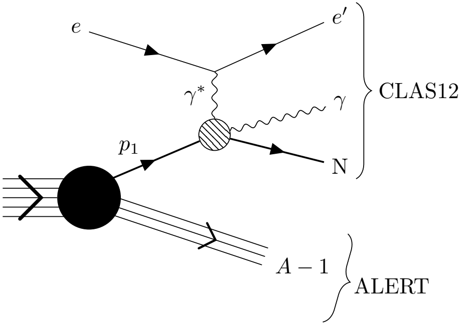




Extracting Asymmetries and Ratios

An illustrative example

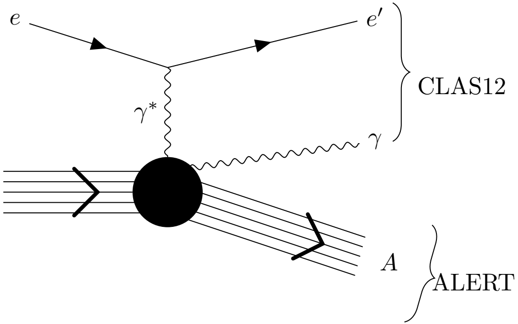
- Incoherent DVCS: 6 dimensional data $(x,\ Q^2,\ t,\ \phi,\ P_s,\ \theta_s)$



Extracting Asymmetries and Ratios

An illustrative example

- Incoherent DVCS: 6 dimensional data (x, Q^2, t, ϕ, P_s, θ_s)
- Coherent DVCS: 4 dimensional data (x, Q^2, t, ϕ)



Extracting Asymmetries and Ratios

An illustrative example

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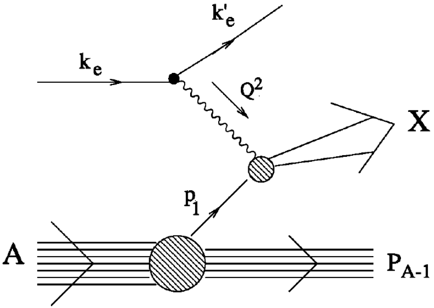
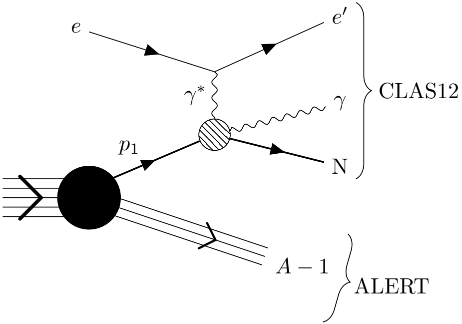
- Coherent DVCS: 4 dimensional data (x, Q^2, t, ϕ)
- Tagged EMC: 4 dimensional data (x, Q^2, P_s, θ_s)



Extracting Asymmetries and Ratios

An illustrative example

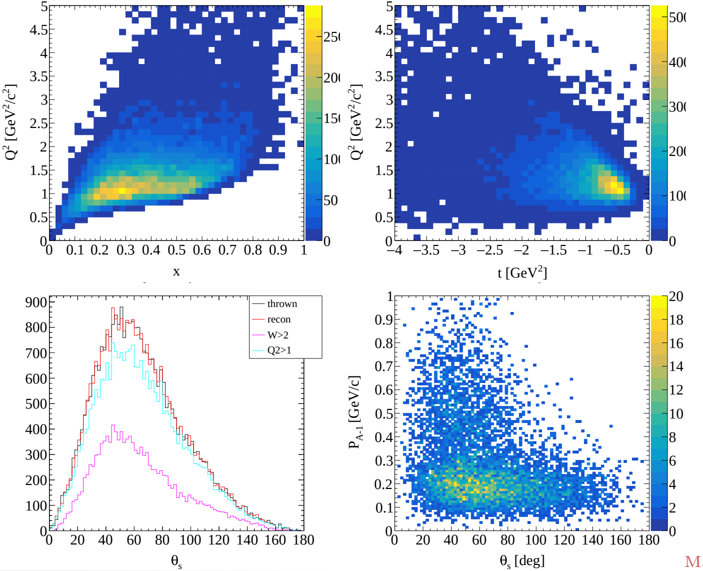
- Incoherent DVCS: 6 dimensional data (x, Q^2, t, ϕ, P_s, θ_s)
- Coherent DVCS: 4 dimensional data (x, Q^2, t, ϕ)
- Tagged EMC: 4 dimensional data (x, Q^2, P_s, θ_s)



As an example, here is how the beam spin asymmetry and off-forward EMC ratios are formed for the 6-dimensional tagged DVCS proposal...

Tagged DVCS Kinematics

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



DVCS Observables

Beam Spin Asymmetries

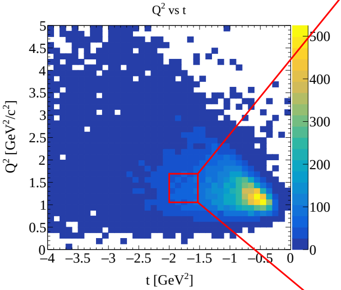
We will measure the DVCS BSA

$$A_{LU}(\phi) = \frac{d\sigma^{\uparrow}(\phi) - d\sigma^{\downarrow}(\phi)}{d\sigma^{\uparrow}(\phi) + d\sigma^{\downarrow}(\phi)}$$

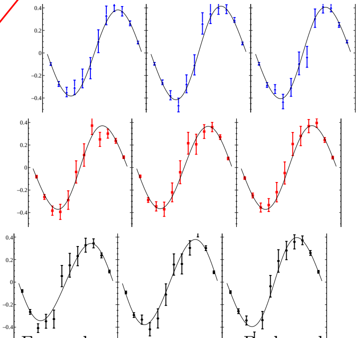
Extract the $\sin\phi$ harmonic

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

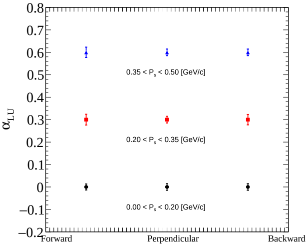
Take bin x, Q^2, t, P_s, θ_s.



Extract harmonic content



Now a 5 dimensional data set.

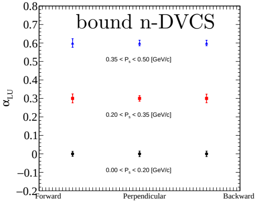


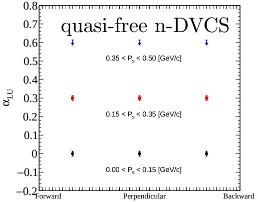
Off-forward EMC Effect Ratios

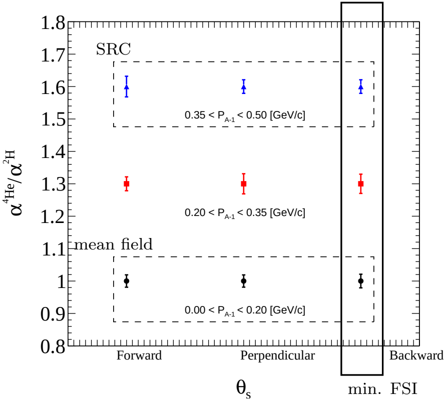
Neutron data from ^{2}H and ^{4}He combined to form ratio

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

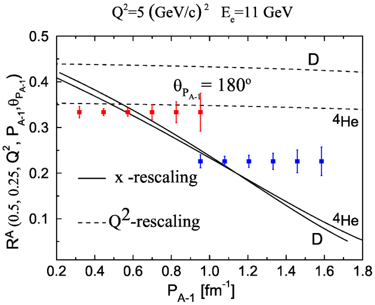
- Ratio is clean experimental quantity
- GPDs do not enter the analysis

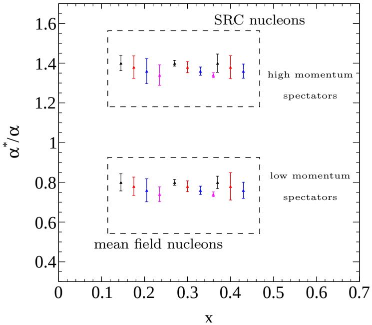






Projected Results: Forward and Off-forward EMC Ratios





Observed deviations from 1

→ medium modifications of nucleons at the partonic level

Rescaling models

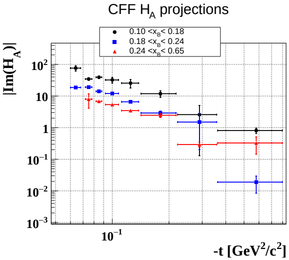
- It is impossible to differentiate x and Q2 rescaling with inclusive measurements but they give very different signature in tagged measurements
- Comparison of ^{2}H to ^{4}He is particularly interesting
  - Iso-scalers
  - ^{4}He is a light nuclei with a sizable EMC effect
  - The two rescaling effects are cleanly separated by the comparison between the two nuclei
  - They complement each other in spectator momentum coverage

C. Ciofi degli Atti et al. Eur. Phys. J., vol. A5 (1999) 191
C. Ciofi degli Atti et al. Phys.Rev. C76 (2007) 055206

^{4}He Transverse Quark and Gluon Densities

Coherent scattering on ^{4}He

DVCS
Charge profile



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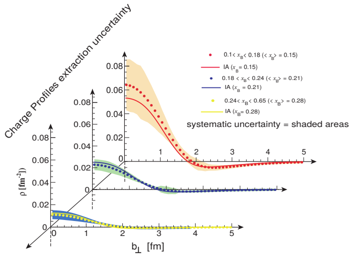
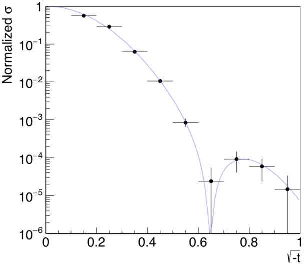


ϕ Production
Gluon profile



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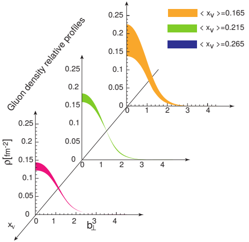

Summary

ALERT Experiments

- Comprehensive program to study QCD in Nuclei
- Measure the transverse quark and gluon distributions in ^{4}He
- Pin down the origin of the EMC Effect

Critical pre-EIC physics

ALERT will provide important early insights for the EIC

ALERT Collaboration

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Backup

Coherent Extraction

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

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

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

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

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