TOPSiDE and Transformative Measurements at the EIC

Studying nuclear effects from JLab to the EIC

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and the Argonne EIC Collaboration

Argonne National Laboratory

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Spatial and Momentum Tomography of Hadrons and Nuclei - INT-17-3
Supported by ANL LDRD

Outline

1. Introduction and Motivating Questions
   - Partonic structure of Nuclei
   - Nuclear Effects
2. The CLAS12 ALERT Run Group
   - Proposed Measurements
3. Future Directions
   - Extending ALERT physics to the EIC
4. Overview of Argonne's EIC Effort
   - TOPSiDE

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Nuclear Physics and the Nucleon α Particle

From the **first textbook on nuclear physics**

"The general evidence on nuclei strongly supports the view that **the α particle is of primary importance as a unit of the structure of nuclei** in general and particularly of the heavier elements. It seems very possible that the greater part of the mass of heavy nuclei is due to **α particles which have an independent existence in the nuclear structure**."

— Rutherford, Chadwick, and Ellis (1930)

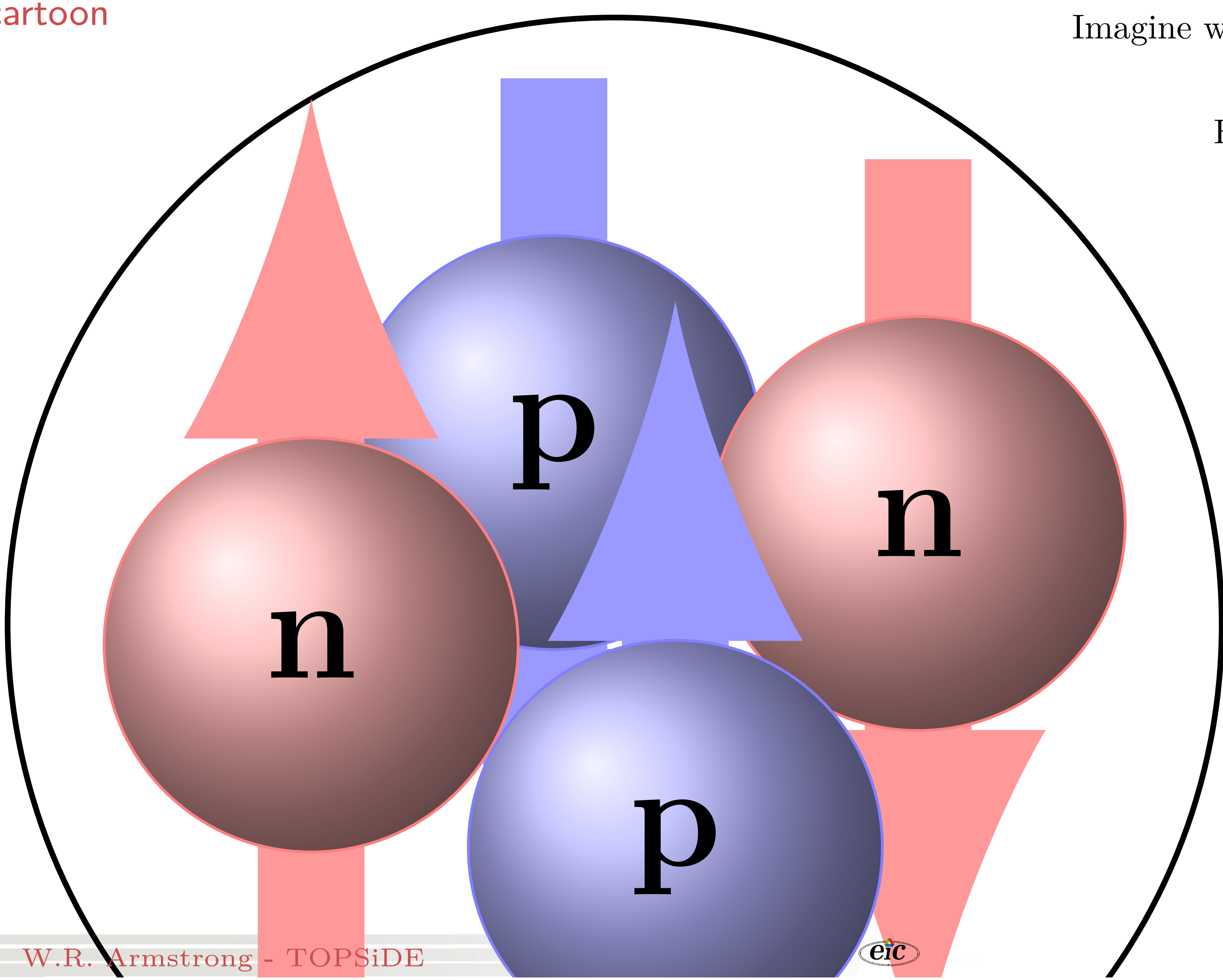
Note: Published about **2 years before the discovery of the neutron.**

Knowledge of the nucleonic structure of the α (i.e. 2p+2n) **transformed our understanding of nuclei.**

How will JLab12 and EIC measurements transform our understanding of nuclei?

The Partonic Structure of the α Particle

A cartoon



Imagine we know nothing about nucleons and could only observe quarks...

How would we "discover" the nucleon degrees of freedom?

Is the nucleon's **gluon** radius the same as its quark radius?

Does the nucleon gluon radius increase in Nuclei?

Do gluons fill the nuclear volume equally?

Is the **gluon radius in the $\boldsymbol{\alpha}$** similar to the quark radius?

Are quarks and/or gluons ever localized?

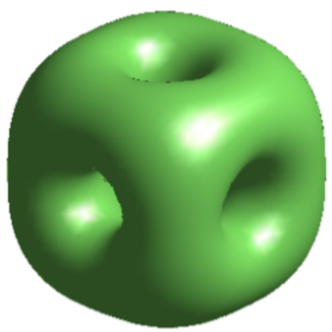
Do gluons clump with quarks?

Does the nucleon's spin decomposition change in nuclei?

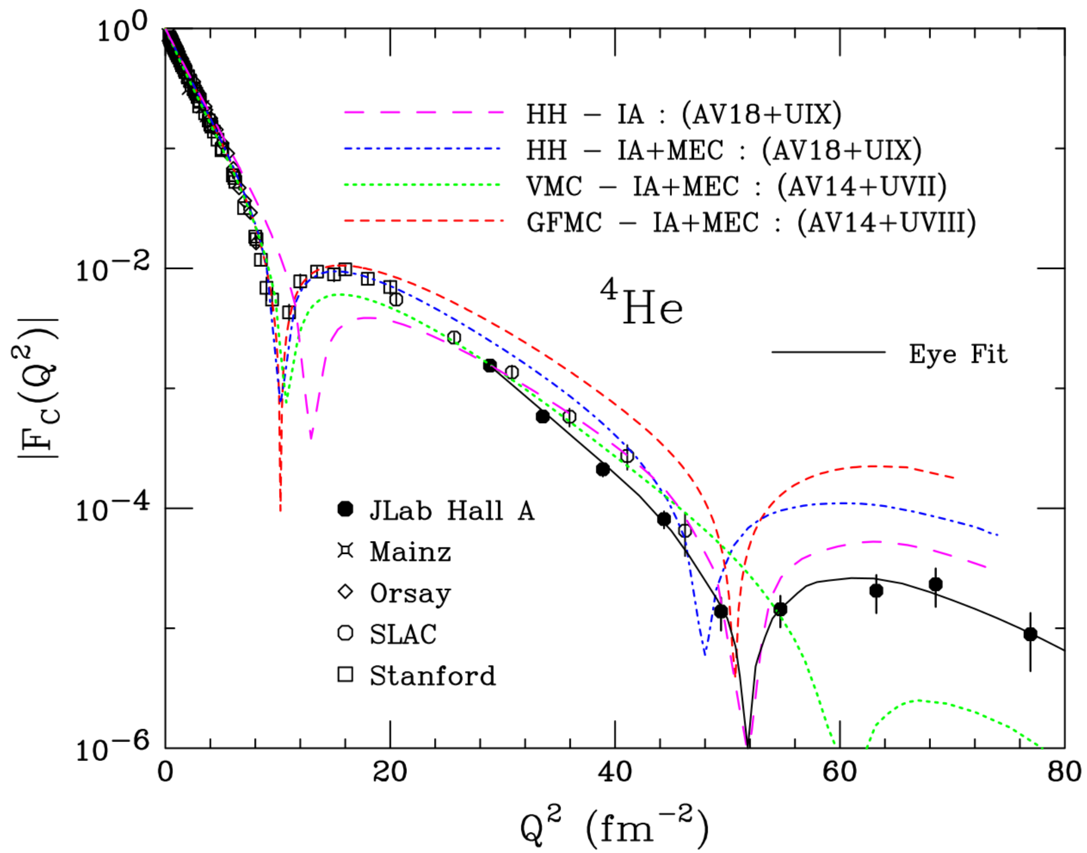
Nuclear Physics and the α Particle

Some things we know.

- Spin-0 → One form factor
- Tightly bound system → smaller radius than ^{3}H and ^{3}He.
- Diffractive Minimum → nucleon clumps make diffraction grating

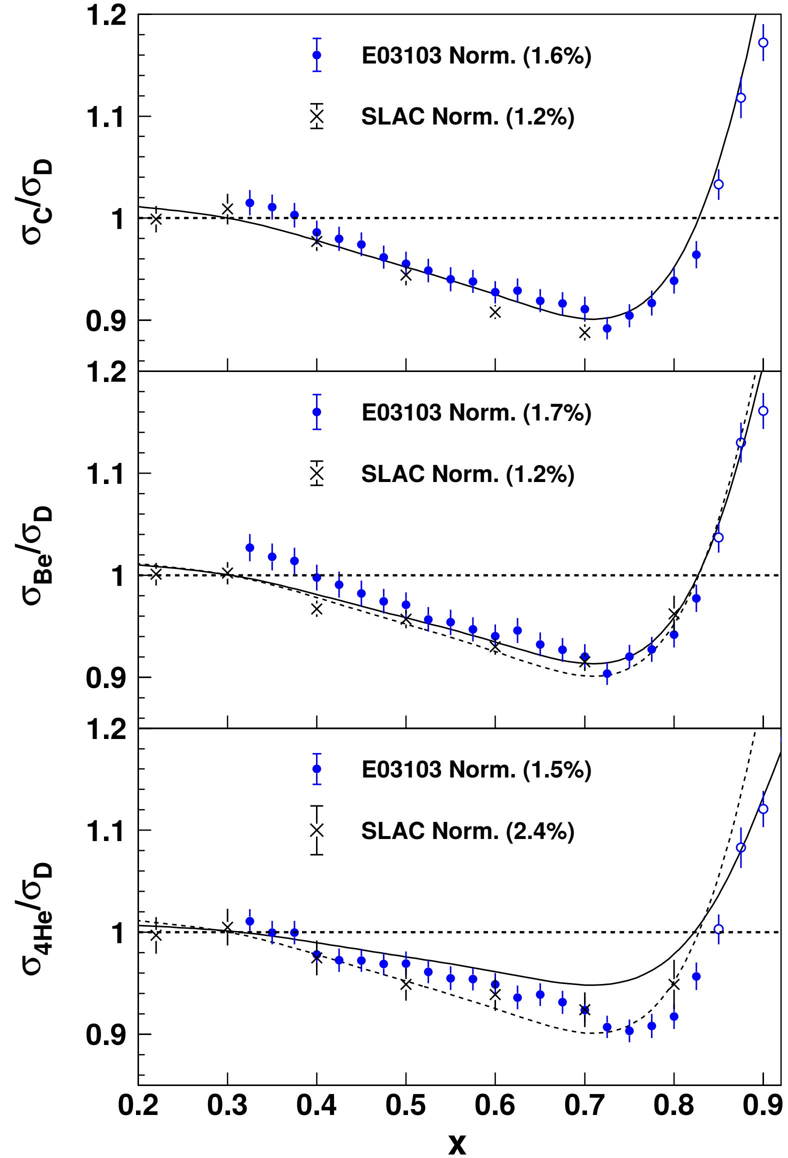


Skyrme Model Karliner, et.al., J.Phys. G43 (2016) no.5, 055104



(Camsonne, et.al., PRL.112. 132503)

EMC Effect in ^{4}He



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

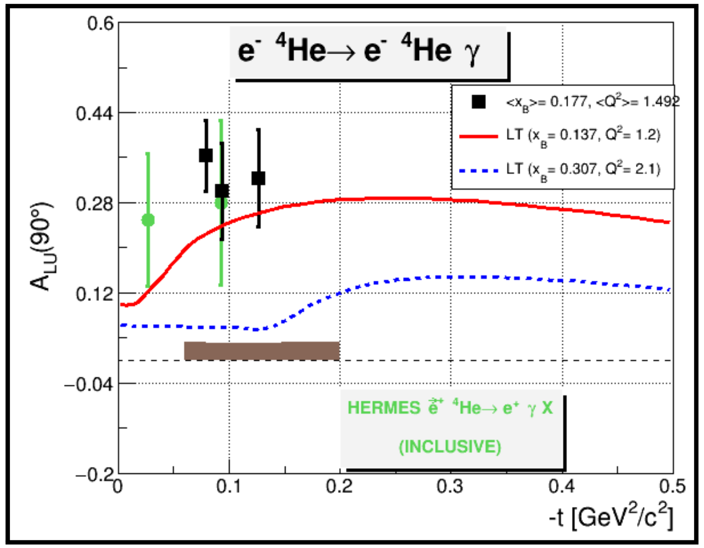
The oldest and most important **nuclear effect** is still puzzling

See my talk from week-1.

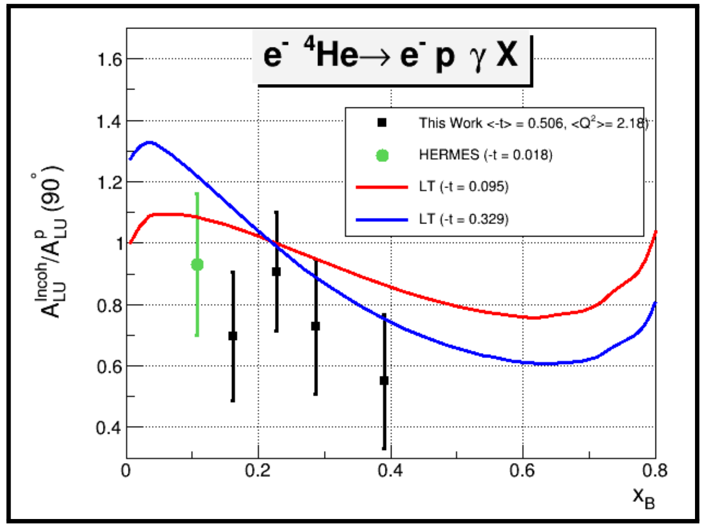
Previous Experiment: CLAS EG6

Coherent and incoherent DVCS results

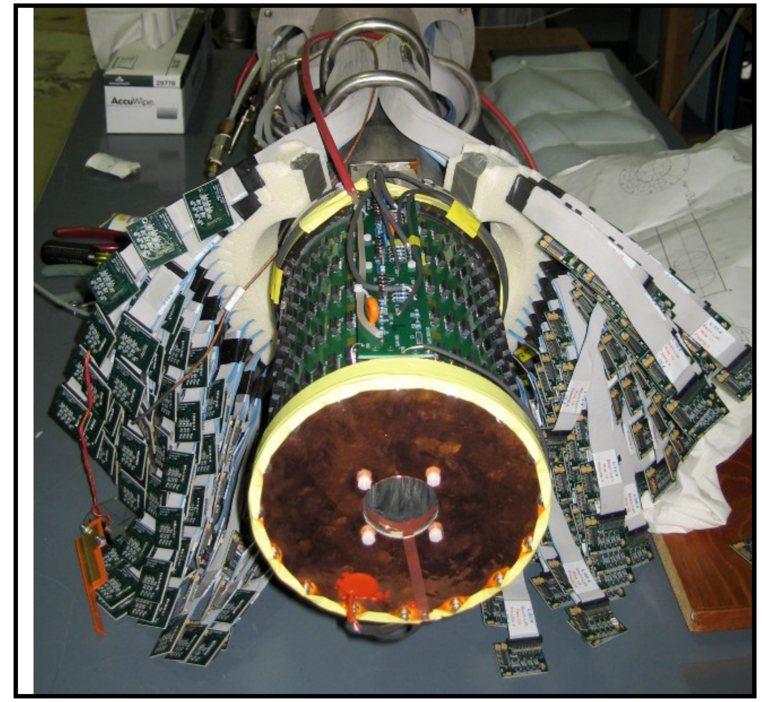
M.Hattaway's EG6 analysis

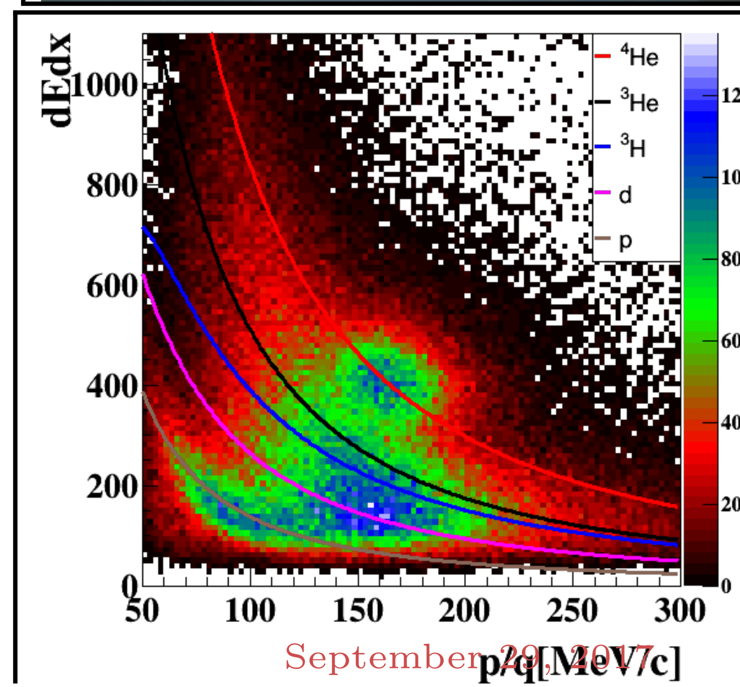


First exclusive coherent DVCS measurement on ^{4}He



Incoherent DVCS measurement plagued by kinematic uncertainties $\rightarrow$ **Need to tag spectators**





Radial Time Projection Chamber (RTPC)

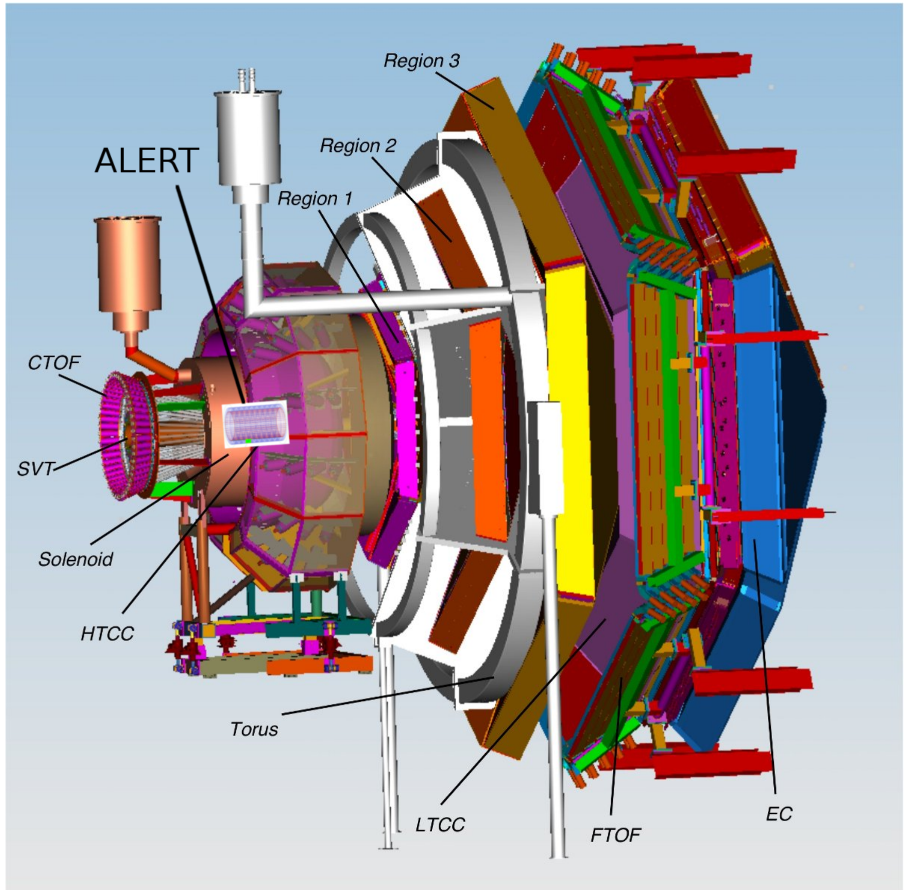
- Response was slow (drift time)
- PID is insufficient $\rightarrow$ Only identifies ^{4}He
- Cannot provide trigger
- Rate limited (constantly triggered for readout)

Outline

ALERT Run Group

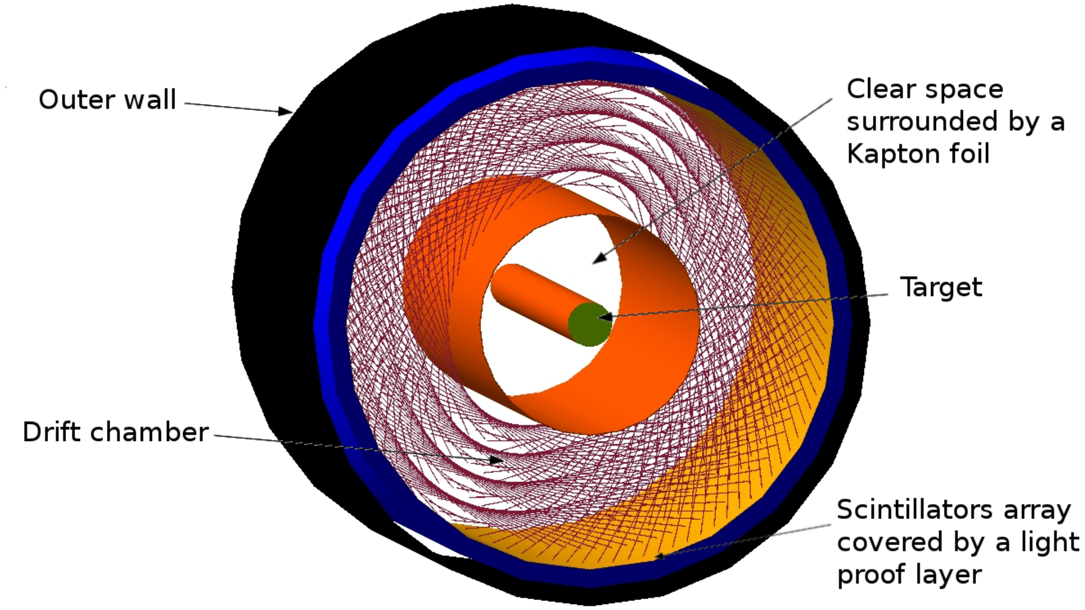
CLAS12 + ALERT detector

- 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



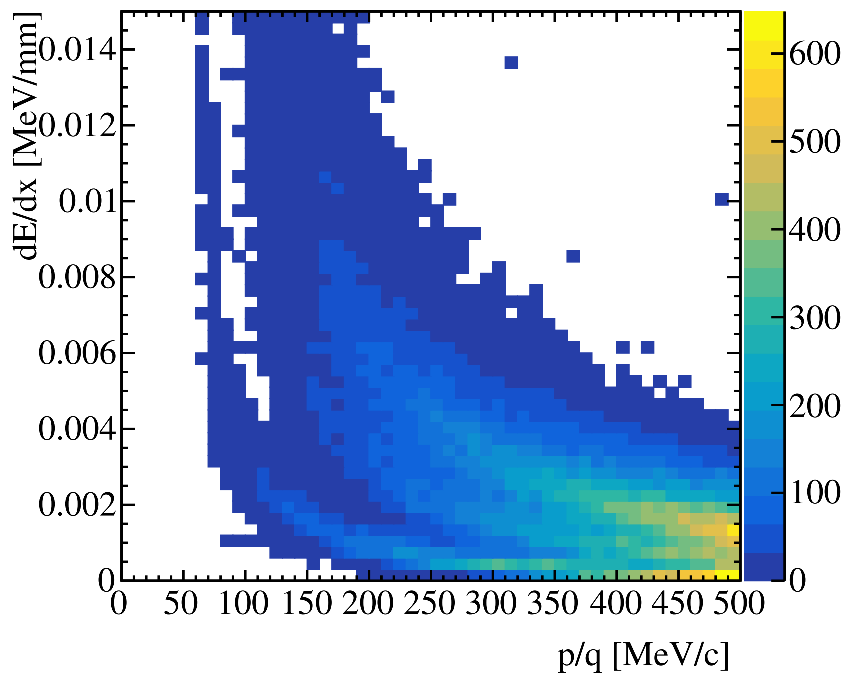
ALERT requirements

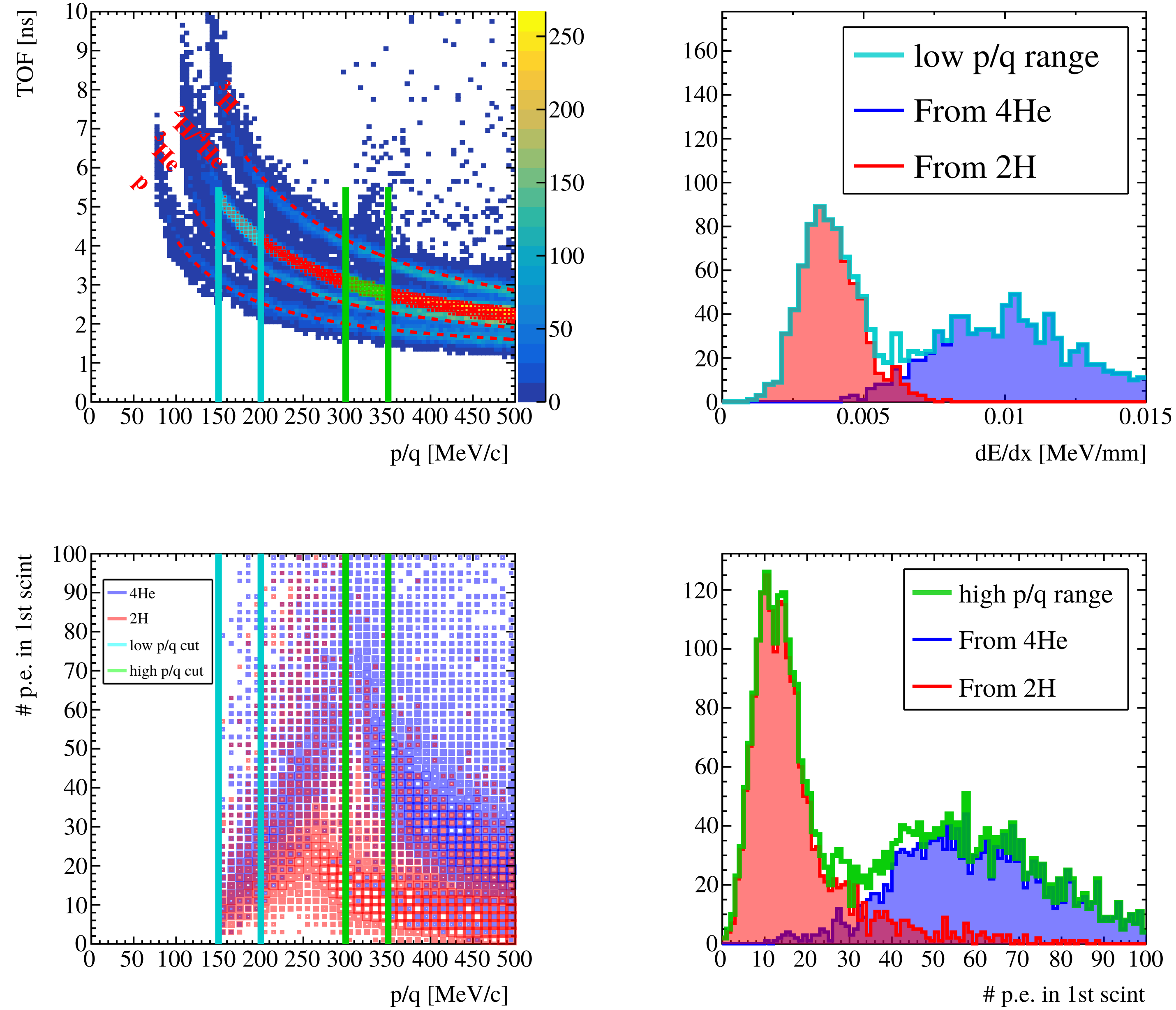
- Identify light ions: H, ^{2}H, ^{3}H, ^{3}He, and ^{4}He
- Detect the **lowest momentum** possible (close to beamline)
- Handle **high rates**
- Provide **independent trigger**
- Survive high radiation environment
  $\rightarrow$ **high luminosity**



ALERT PID

- TOF is degenerate for ^{2}H and ^{4}He.
- dE/dx can separate these.
- At higher p, scintillator topology can also be used to separate.





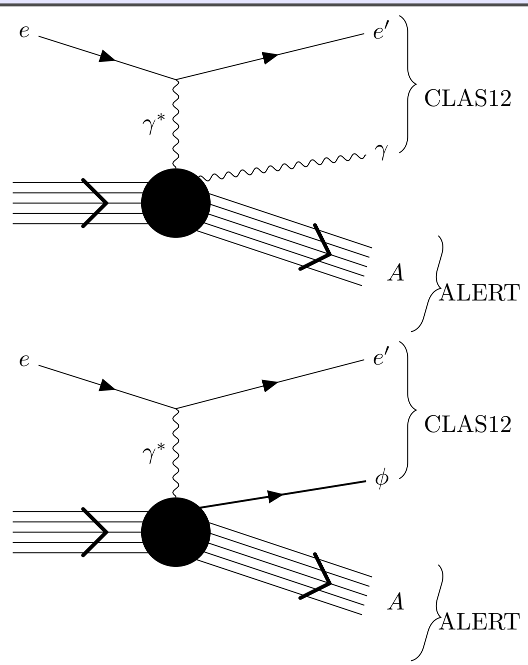
The ALERT Experiments

A comprehensive program to study nuclear effects

Coherent Processes on ^{4}He

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

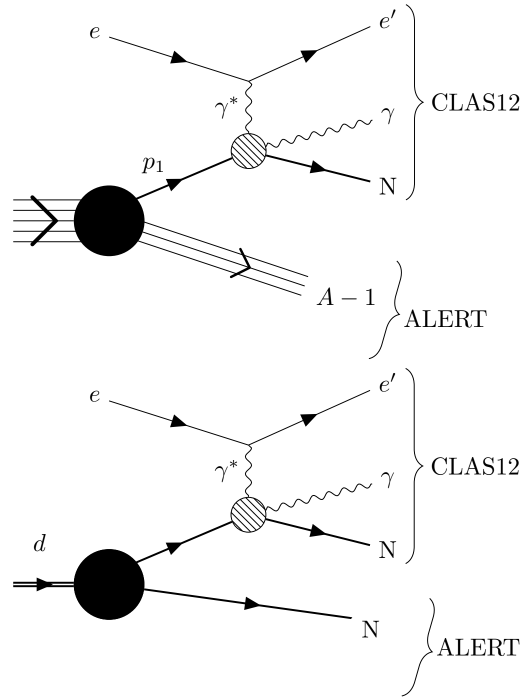
Explores the partonic structure of ^{4}He



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

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

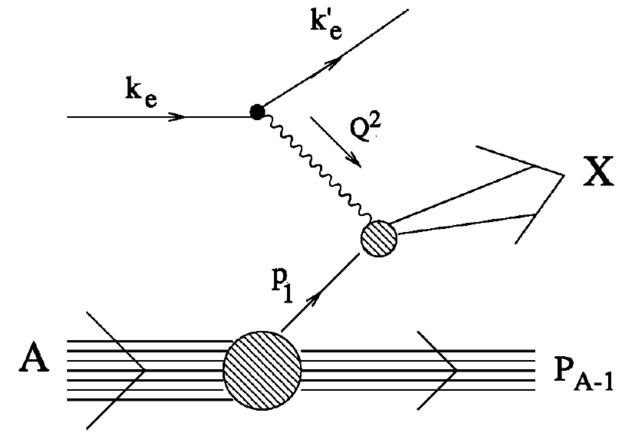
Identify medium modified nucleons



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

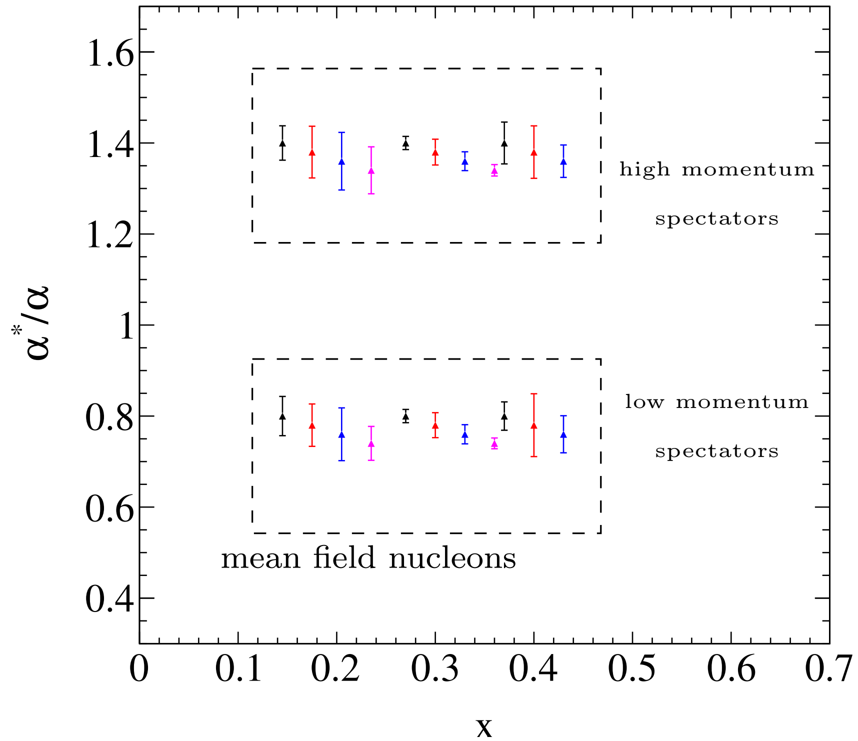
- $^4\mathrm{He}(e, e' + ^3\mathrm{H})\mathrm{X}$ (proton DIS)
- $^4\mathrm{He}(e, e' + ^3\mathrm{He})\mathrm{X}$ (neutron DIS)
- $^2\mathrm{H}(e, e'\ + p)\mathrm{X}$ (neutron DIS)

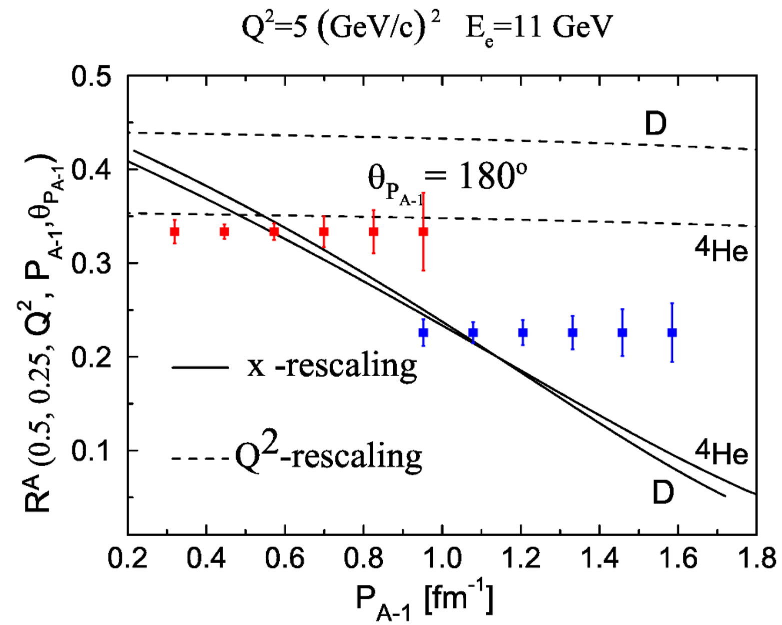
Test FSI and rescaling models



And many more channels for free

Projected Results: Off-forward EMC Ratio





Separated mean field nucleon EMC Effect and SRC nucleon EMC Effect

Observed deviations from 1

→ medium modifications of nucleons at the partonic level

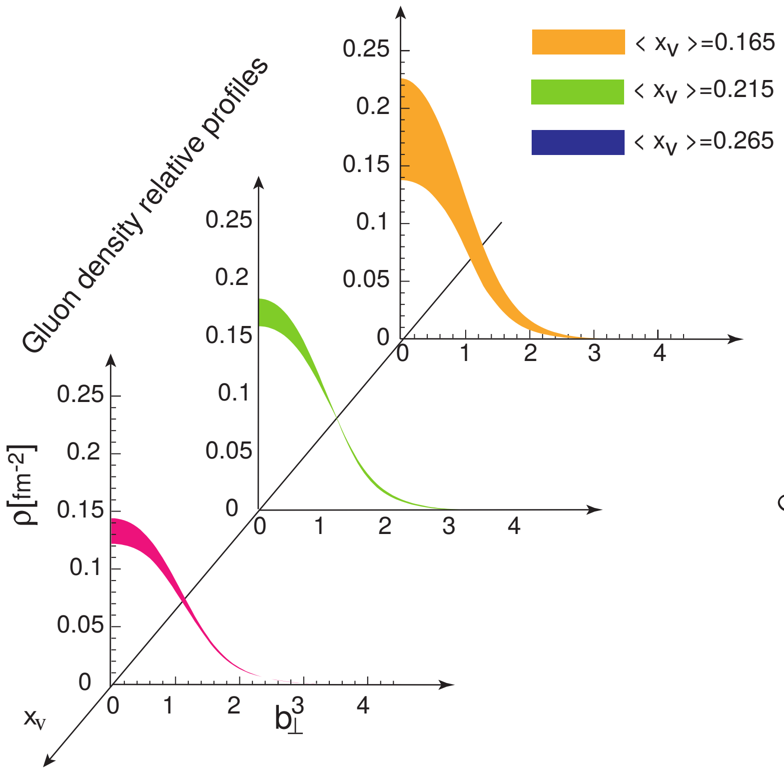
Rescaling models

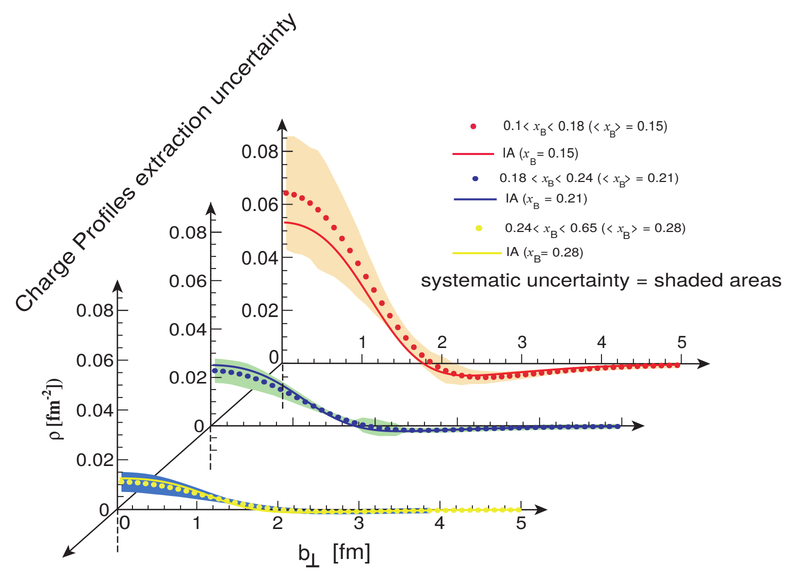
- It is impossible to differentiate x and Q2 rescaling with inclusive measurements but they give very different signature in tagged measurements
- Comparison of ^{2}H to ^{4}He is particularly interesting
  - Iso-scalers
  - ^{4}He is a light nuclei with a sizable EMC effect
  - The two rescaling effects 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

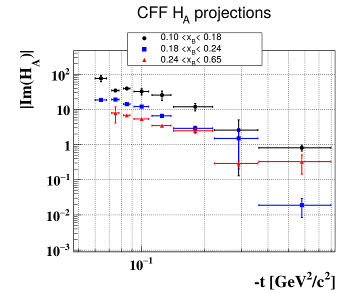
^{4}He Transverse Quark and Gluon Densities

Coherent scattering on ^{4}He

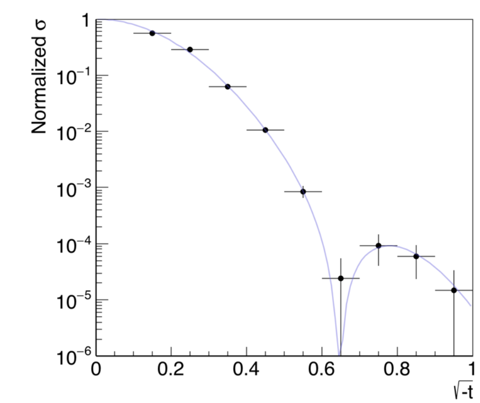




DVCS



ϕ Production



Quark and gluon radii apparent!

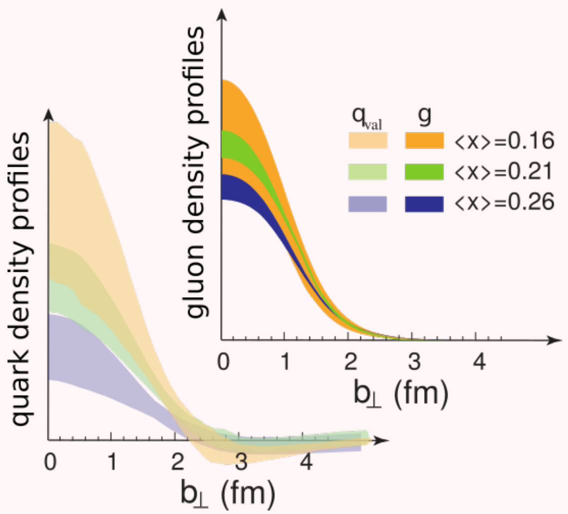
At $x > 0.2$ is the diffractive minimum at the same t value?
Is it washed out at low-x by the sea?

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

ALERT Run Group

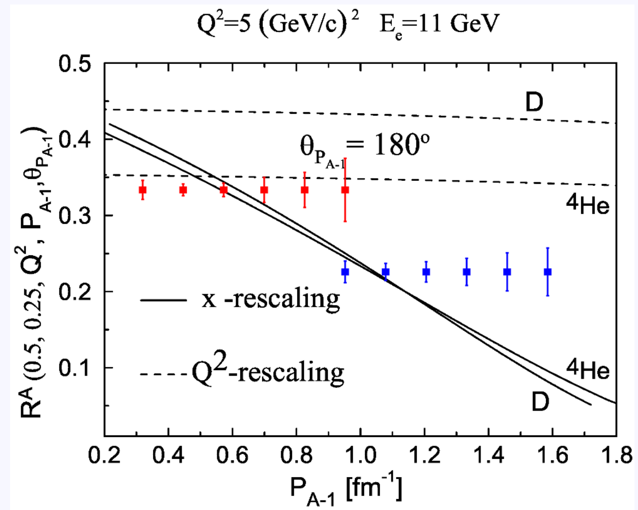
A Comprehensive Program to Study Nuclear Effects

Nuclear GPDs



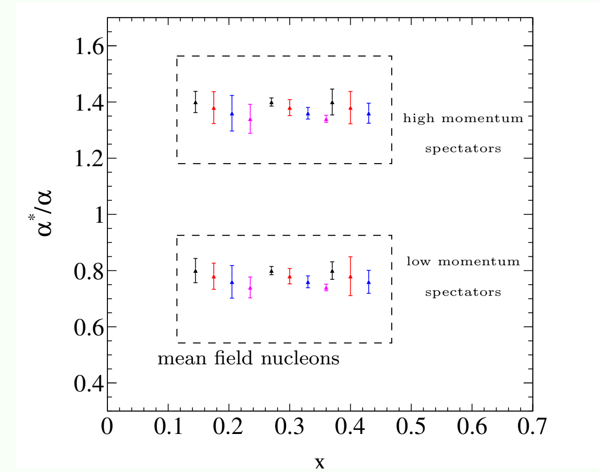
Directly compare quark and gluon radii

Tagged EMC



Address key questions about the EMC effect

Tagged DVCS



Connect partonic and nucleonic modification

ALERT is a bridge from JLab 12 GeV physics to the Electron Ion Collider

Outline

The α particle and the structure of light nuclei

What is the partonic structure of the ground state of ^{12}C and the Hoyle State?

α-cluster model

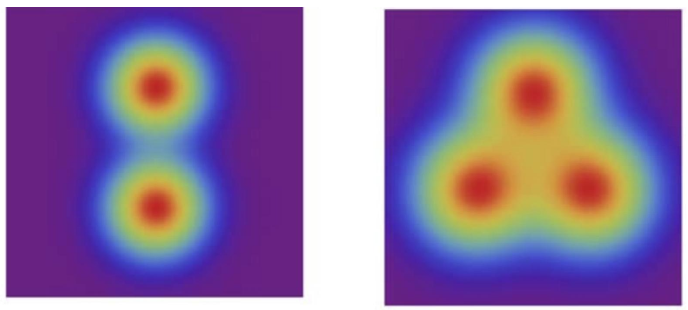
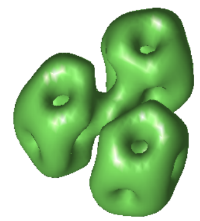


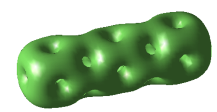
Figure 1 Charge density of ^{8}Be and ^{12}C in ACM.

Della Rocca and Iachello, in progress

Skyrme Model

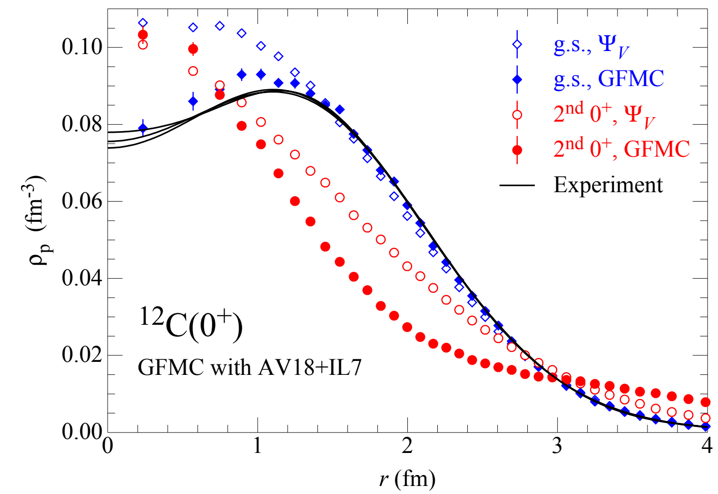


Ground State



Hoyle State?

Karliner, et.al., J.Phys. G43 (2016) no.5, 055104



Carlson, et.al., Rev.Mod.Phys. 87 (2015) 1067

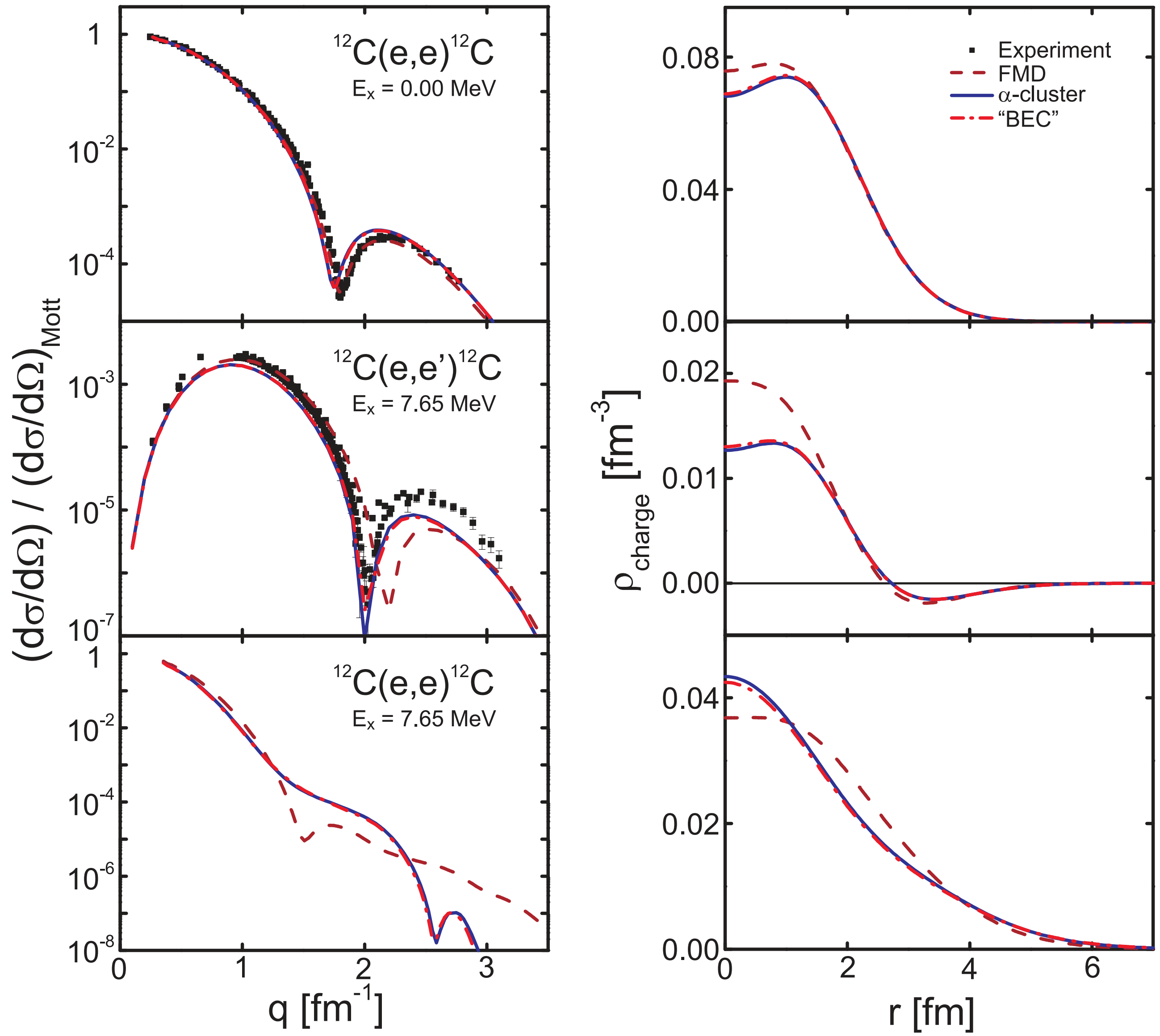
- **QCD dynamically generates the mass** of 98% of the visible universe, i.e., QCD generates the mass of all atomic nuclei
- **The Hoyle State** of ^{12}C is **critically important for nucleosynthesis**.
- ^{12}**C is one of the most important ingredient for life on Earth!**

How can we study the **partonic structure** of the Hoyle state?

- Targets of 2_{nd} 0^+ state ^{12}C do not exist.
- Cannot scatter directly from Hoyle state.

Hard Exclusive processes on nuclei have the ability to probe nuclear structure in terms of quarks and gluons through extractions of transition GPDs (e.g. through the ground-state to Hoyle state transition GPD).

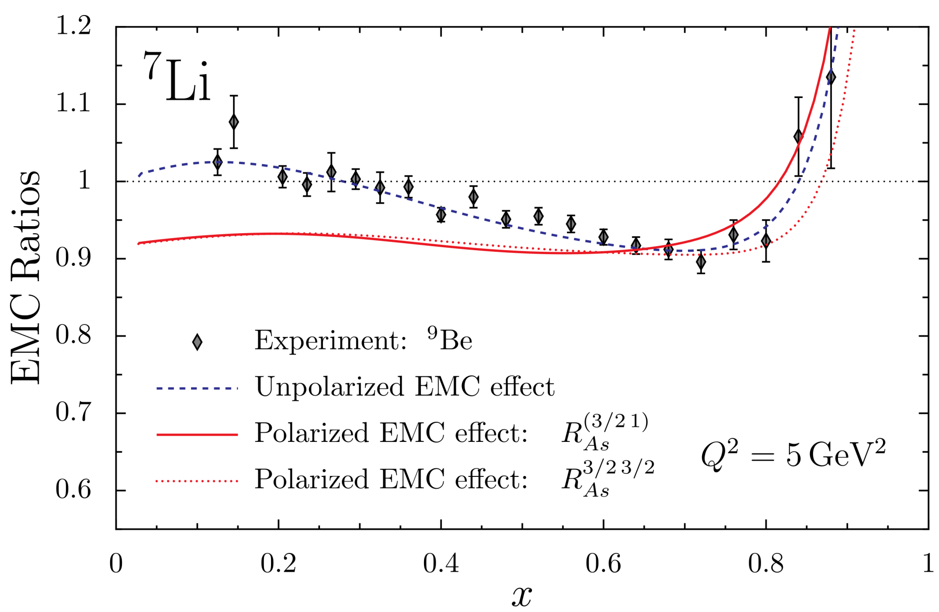
> See talk from Charles Hyde: *Deep Virtual Exclusive Scattering at an Electron Ion Collider: Impact of Detector Design on Physics Program*



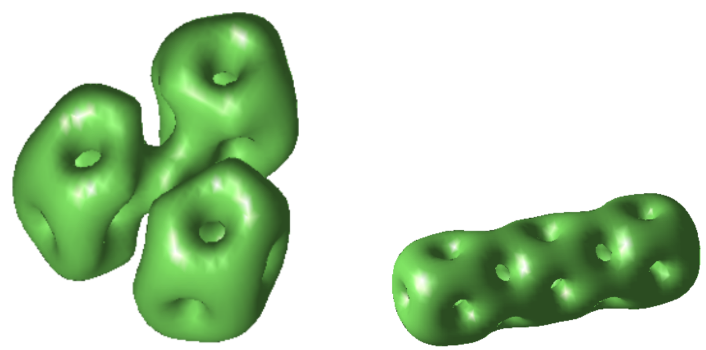
Chernykh, et.al., PRL. 98 (2007) 032501

Nuclear Physics before an EIC

- Can we measure the transverse **quark and gluon** distributions in ^{12}C?
  - Detecting the recoil ^{12}C is very difficult! → need a new detector technology
- Can we measure the **quark and gluon distributions of the α particles inside ^{12}C?**
  - Detecting the recoil α is slightly easier → extension of ALERT run-group
  - A new kind of nuclear EMC effect – αs are the new nucleons
- Can we measure the **quark and gluon distributions of the neutron in inside ^{13}C?**
  - Hard to detect neutron and nearly impossible to detect spectator ^{12}C with a fixed target but very possible with an EIC!
  - Can we polarize ^{13}C at an EIC? Is there a polarized EMC effect of the bound neutron?



Bentz, Cloët, Thomas



Carlson, et.al., Rev.Mod.Phys. 87 (2015) 1067

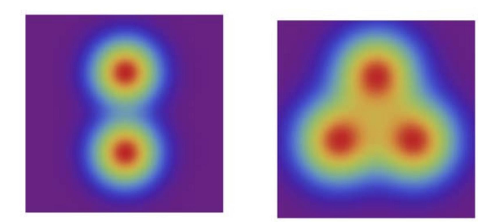


Figure 1 Charge density of ^{8}Be and ^{12}C in ACM.

(Della Rocca, Iachello in progress)

Looking towards the EIC

Will we transform our understanding of hadronic matter?

- What measurements can/will lead to a paradigm shift?
- Is there any room for such a change in understanding?

Electron Ion Collider: The Next QCD Frontier
"Understanding the glue that binds us all"

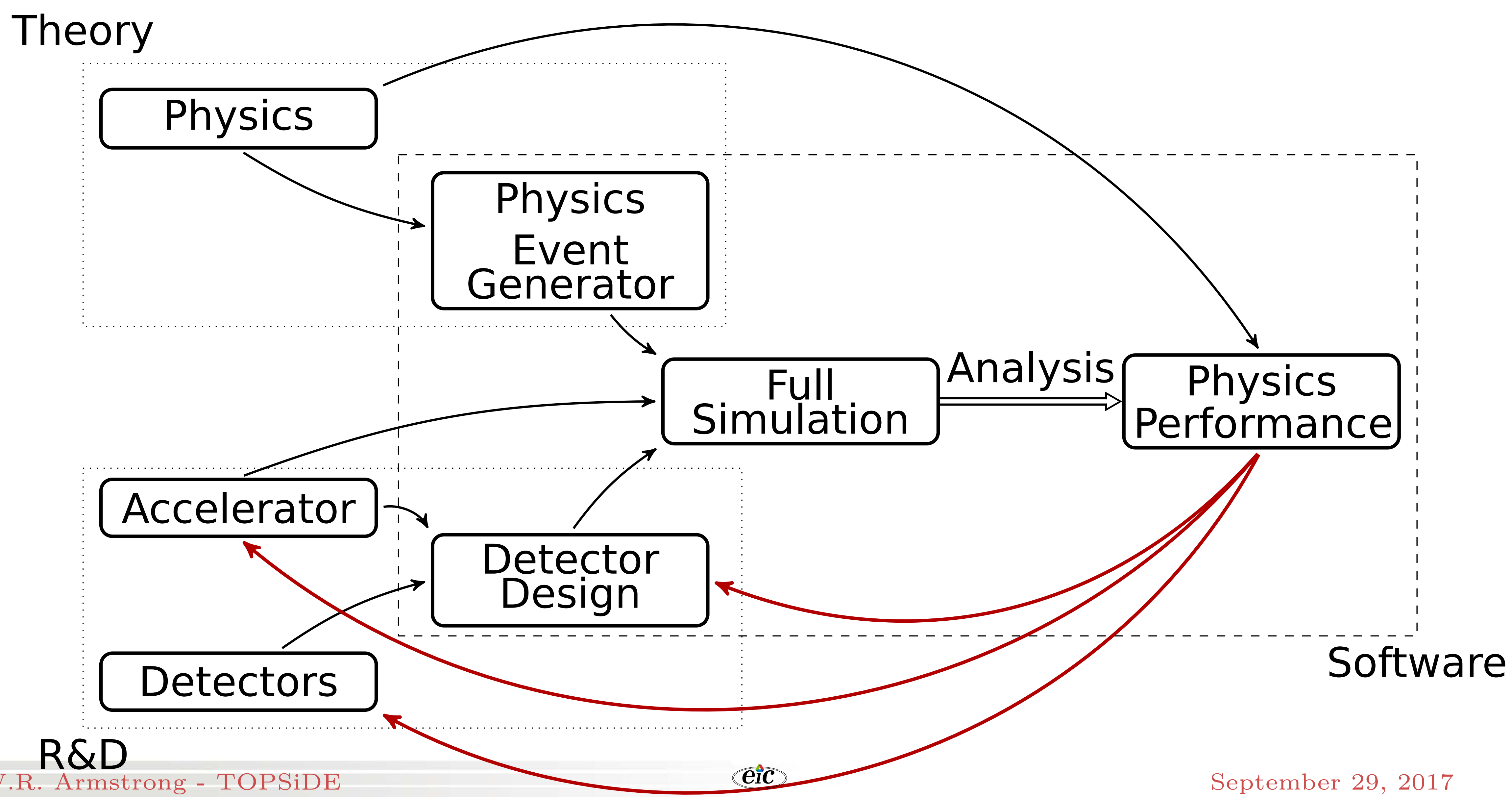
- **Luminosity is the key!** (Nobody will complain about too much luminosity)
- **Day-1 luminosity** $> 10^{34} cm^{-2} s^{-1}$ should be our goal
- Polarized-luminosity as important as Luminosity alone (See R. Ent's talk)
- Polarized deuterons are **critical** for *the next QCD Frontier* in **nuclear physics**
- **Spectator and recoil tagging** allow a **3D image of nuclei** in terms of quarks and gluon to develop.

These allow for transformative measurements on nuclei at the EIC

Outline

EIC effort at Argonne supported through ANL LDRD

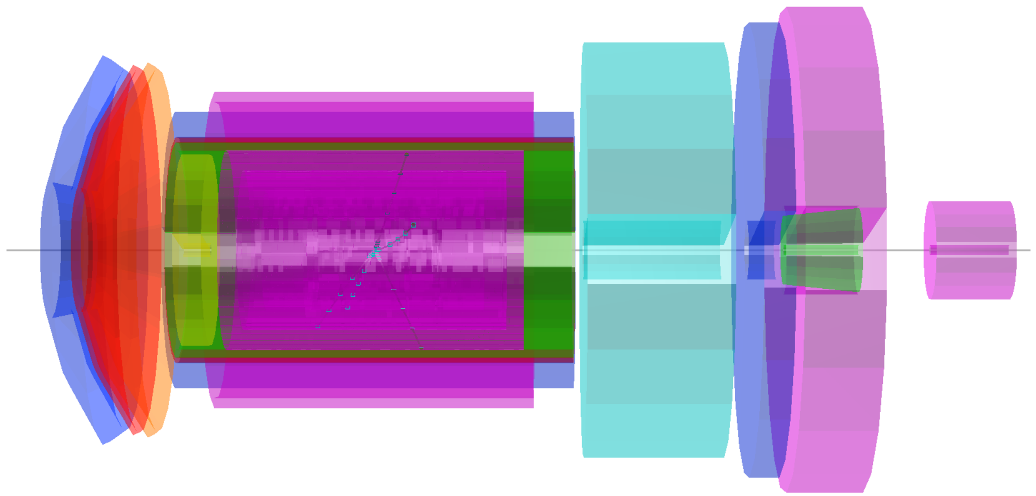
Effort currently dominated by simulation and reconstruction software



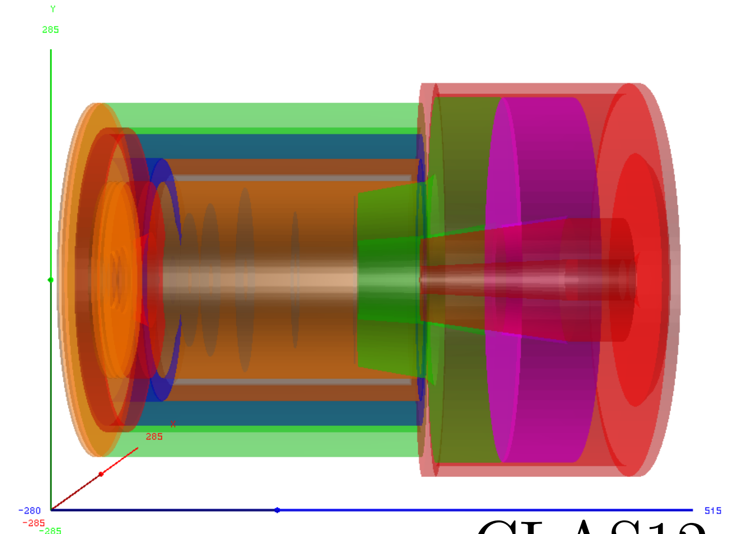
Nuclear Physics Detector Library (NPDet)

NPDet is a **growing collection** of **parameterized detectors** (using DD4hep) which can be used to construct full concept detectors in a single text file.

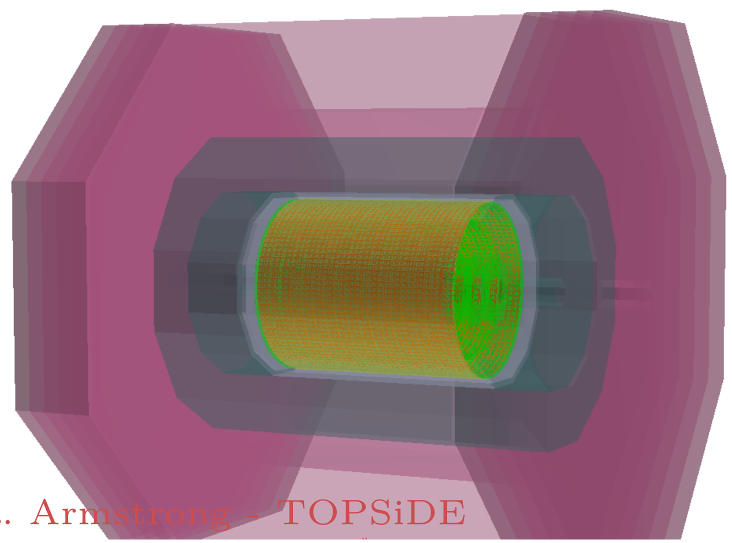
JLEIC (S. Johnston)



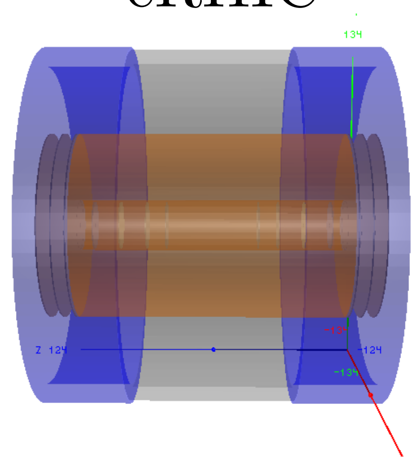
SOLID



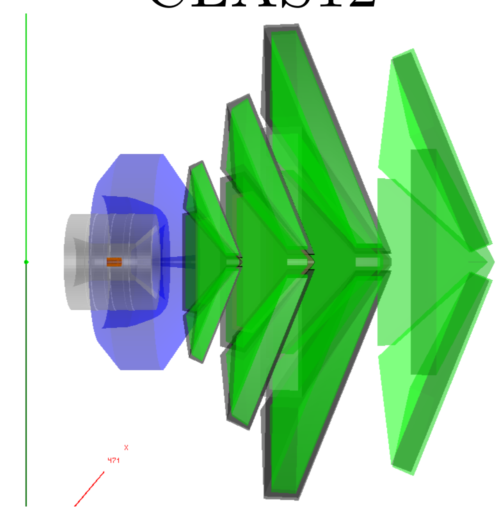
SiEIC → **TOPSiDE**



eRHIC

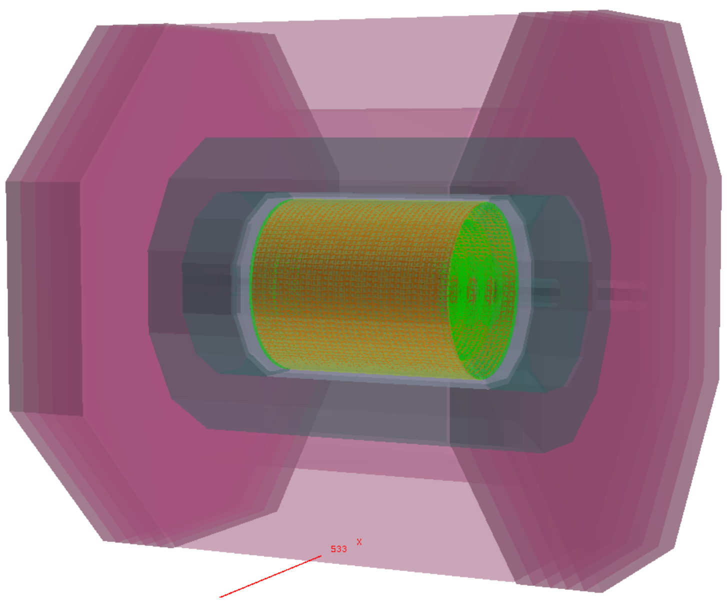


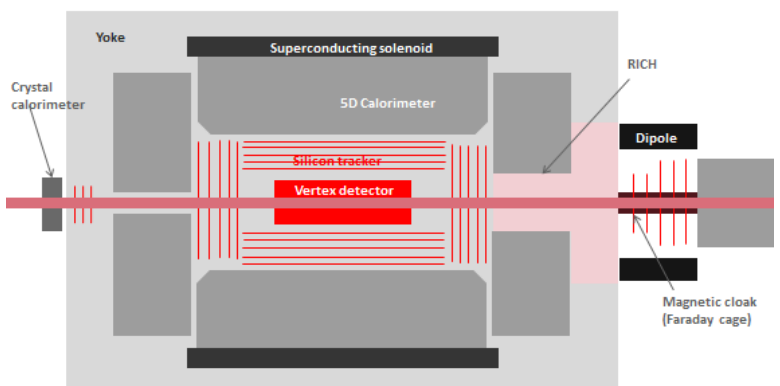
CLAS12



TOPSiDE

Time-of-flight **O**ptimized **P**ID **Si**licon **D**etector for the **E**IC





TOPSiDE Concept: A 5D detector

- PID ($K - \pi - p$ sep.) entirely by silicon TOF
- Silicon detectors for vertex and tracking region.
- Push Si detector time resolution to < 10 ps
- Imaging calorimeters for best photon position and energy measurements
- Simple tracking design improves calorimeter; avoids PID detector hodgepodge
- Use reconstruction algorithms that fully exploit detector (PFA, machine learning, ...)

See José Repond's Talk.

- Exploring new ideas for forward region (100% detection)

On going and Future Developments

The Argonne Team is just getting started (we have actively working for roughly 10 months)

Currently working on

- Generic Track finding tool (S. Johnston)
- HepSim Container integration (D. Blyth)
- Event generator for deuteron observables (A. Freese, I. Cloët)
- Detector Benchmarks (M. Hattawy)
- Physics Benchmarks

Please join us - All are welcome

- Weekly software meetings (Thursday afternoon)
- Bi-Weekly EIC meetings every (every other Friday)
- Create account and use the fast, eic-dedicated gitlab server (`eicweb.phy.anl.gov`)
- Subscribe to the mailing lists (email `warmstrong@anl.gov` to be added)

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
- **ALERT will provide important pre-EIC physics** about the partonic structure of nuclei

Future Work

- Bridge the ALERT physics program to the EIC
- Investigate processes to provide new insights from QCD
- Explore novel EIC nuclear physics with TOPSiDE

Backup Slides