Developing an AI Tracking for the CLAS12 ALERT Program

10th workshop of the APS Topical Group on Hadronic Physics
April 12, 2023

Mikhail Yurov
Mississippi State University

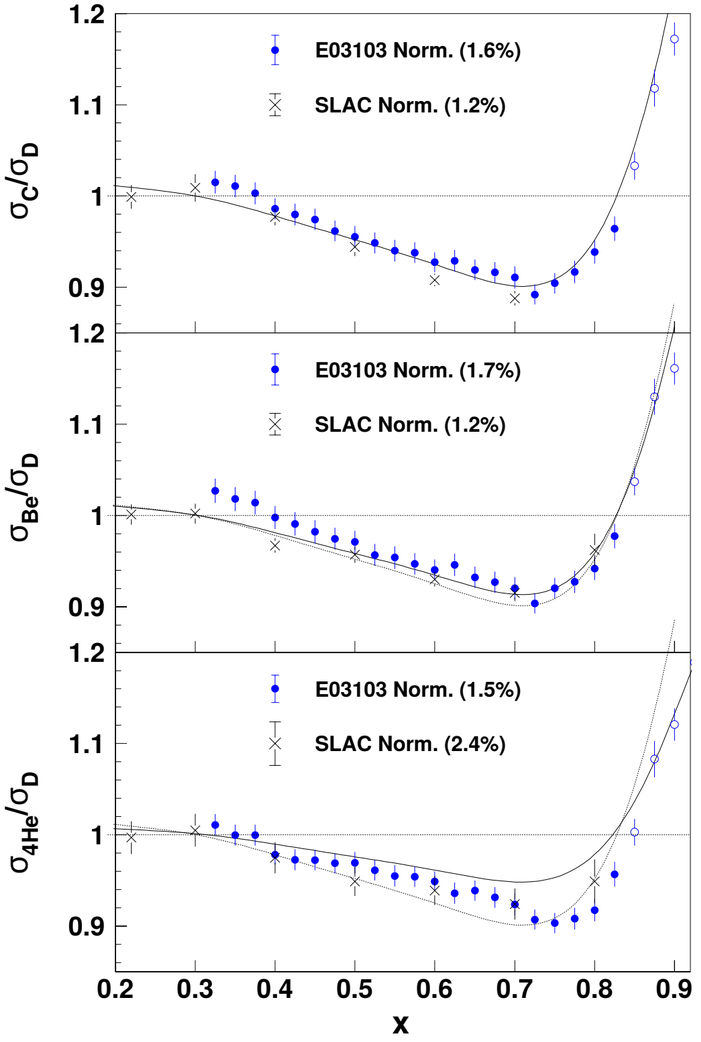
Outline

- ALERT scientific program
- ALERT detector design
- AI applications for ALERT tracking
- Next steps

Nuclear Effects in QCD

- Modification of bound nucleons properties and dynamics
  - EMC effect at intermediate x, shadowing at smaller x, …
  - studied in DIS, significant change in longitudinal momentum distribution of quarks inside the bound nucleon
  - theoretically, no unifying physical picture of the EMC origin

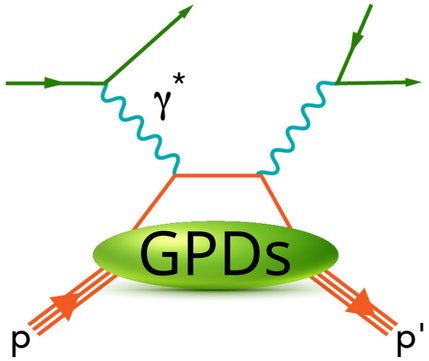
- Would the exploration of transverse spatial structure of hadrons in nuclei provide a new insight?
  - hard exclusive processes - DVCS, DVMP, …
  - comparison to free proton results - novel experimental method of understanding the properties of bound nucleons

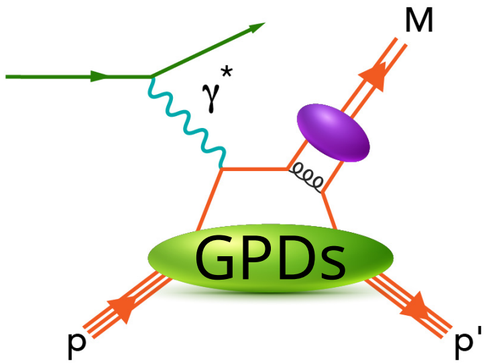


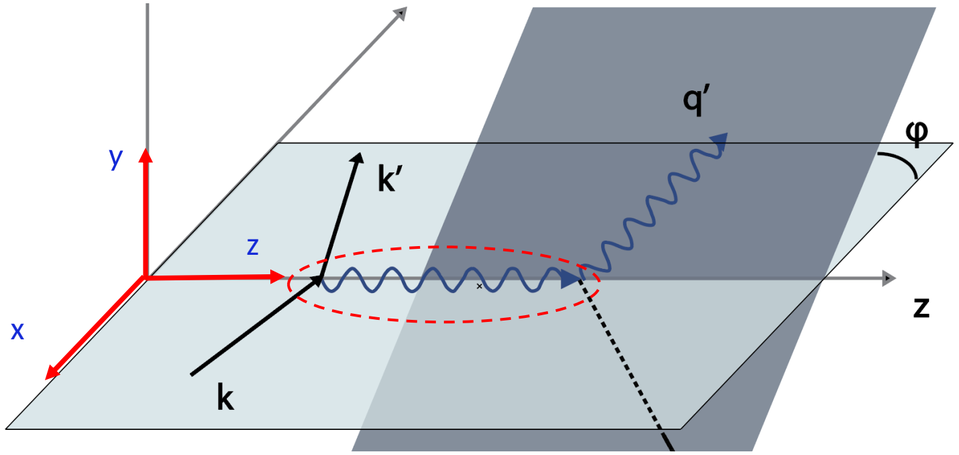
J. Seely et al. Phys.Rev.Lett. 103 (2009) 202301

Generalized Parton Distributions

- GPD framework
  - information about the momentum and spatial degrees of freedom of the quarks and gluons inside hadrons
  - experimental efforts (JLab, HERA, CERN) predominantly focus on proton (neutron) studies
  - DVCS is the cleanest probe (DVMP)

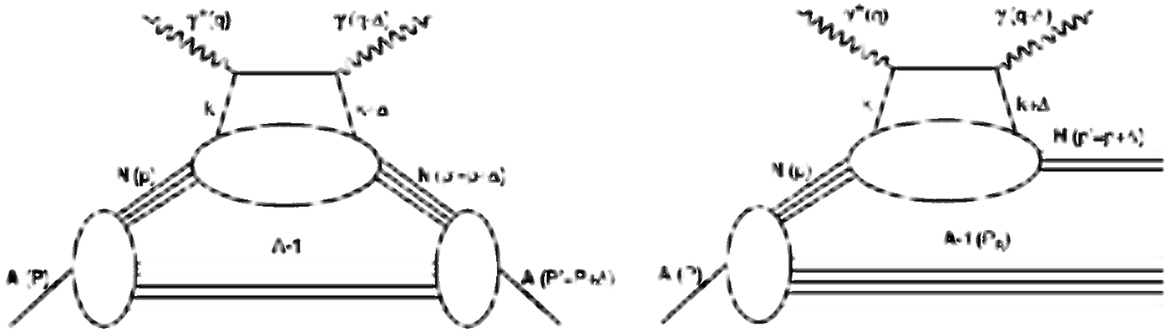






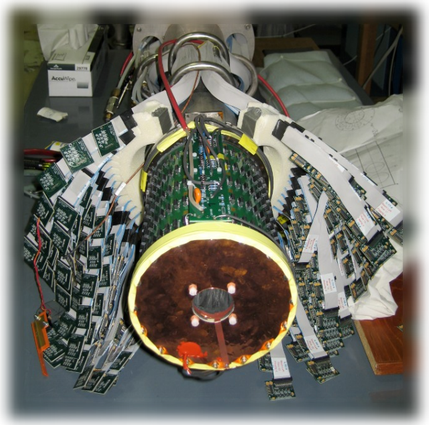
Nuclear DVCS

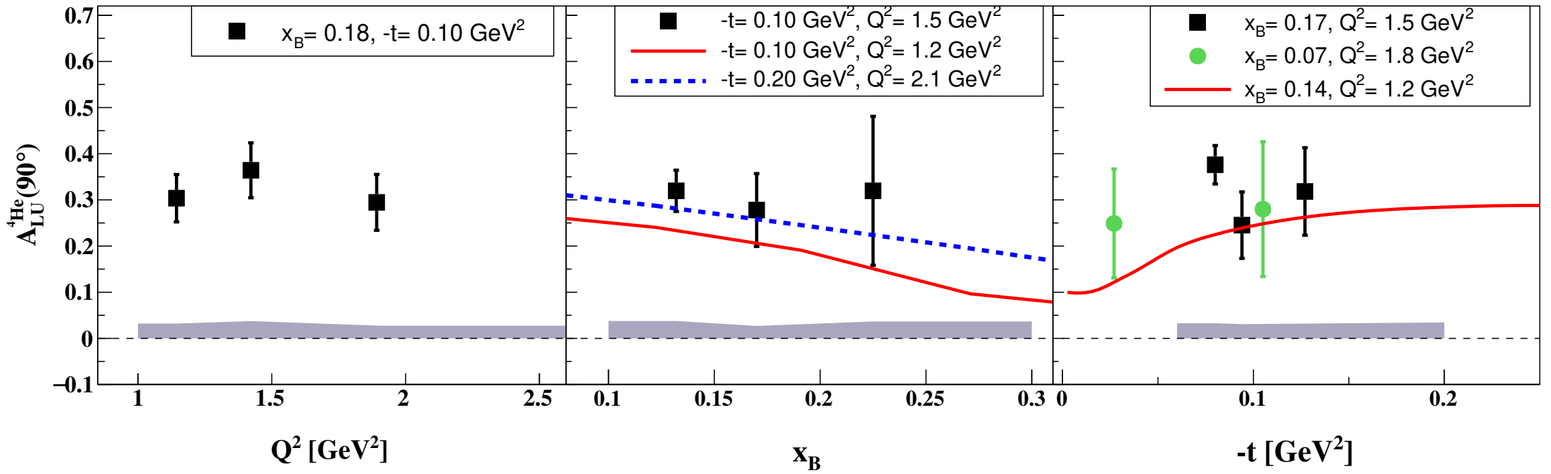
- Recent technology advances provide new prospects of studying DVCS in nuclei
- Nuclei allow access to the spin
  - nuclei allow access to the spin: spin-0 with 2 GPD; spin-1/2 with 8 GPDs; spin-1 with 18 GPDs
  - 4He nucleus - spin-0, large EMC, high core density and binding energy
- Exclusive electro-production of a photon in nuclear target via two distinct processes
  - coherent scattering - nucleus recoils as a whole
  - incoherent scattering - nucleus breaks up



Nuclear DVCS

- Coherent DVCS experimental status
  - detection of the low energy recoil nucleus is very challenging
  - Hermes, JLab - sizeable asymmetries; not fully exclusive; limited reach
  - CLAS (E08-024) pioneered measurements of exclusive coherent DVCS off ^{4}He



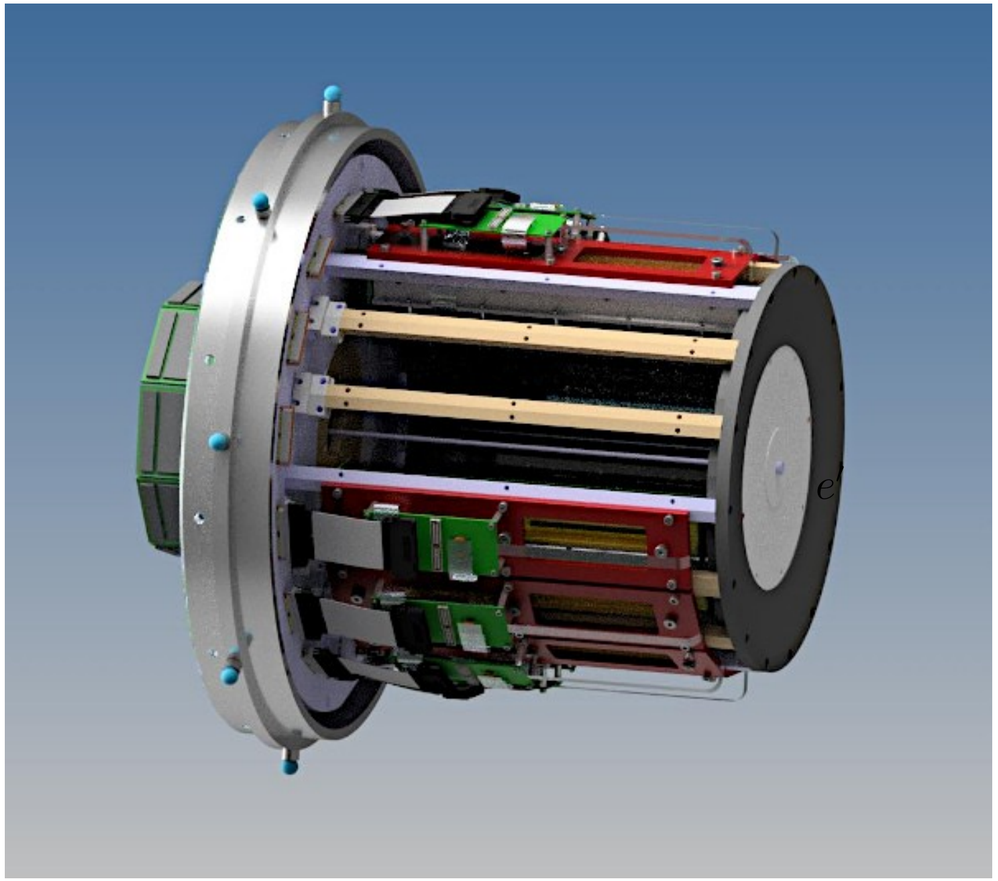


M. Hattawy, PRL 119, 202004 (2017)

ALERT Project

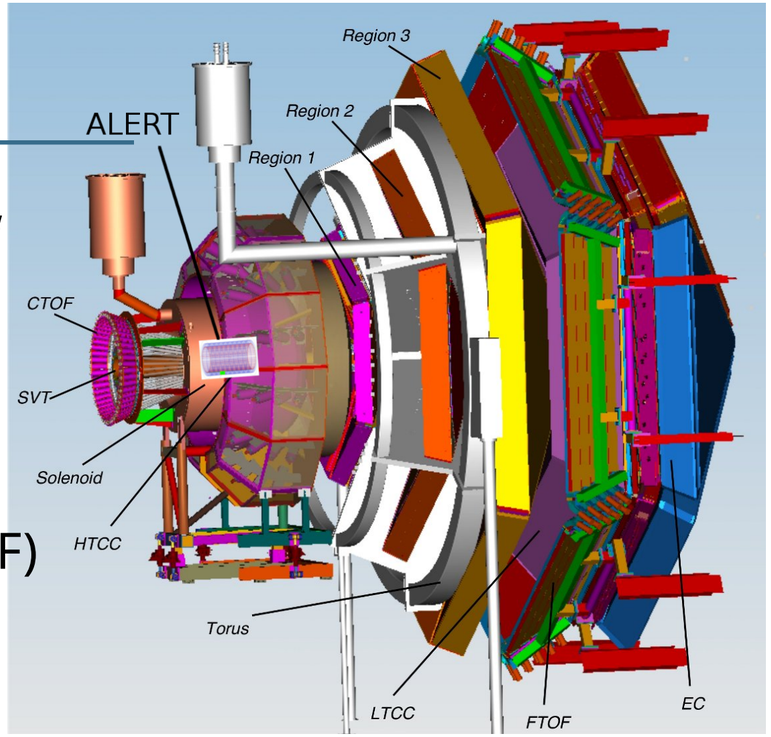
- A Low Energy Recoil Tracker (ALERT) Collaboration
  - ANL, IJCLab, JLab, NMSU, Temple, MSState

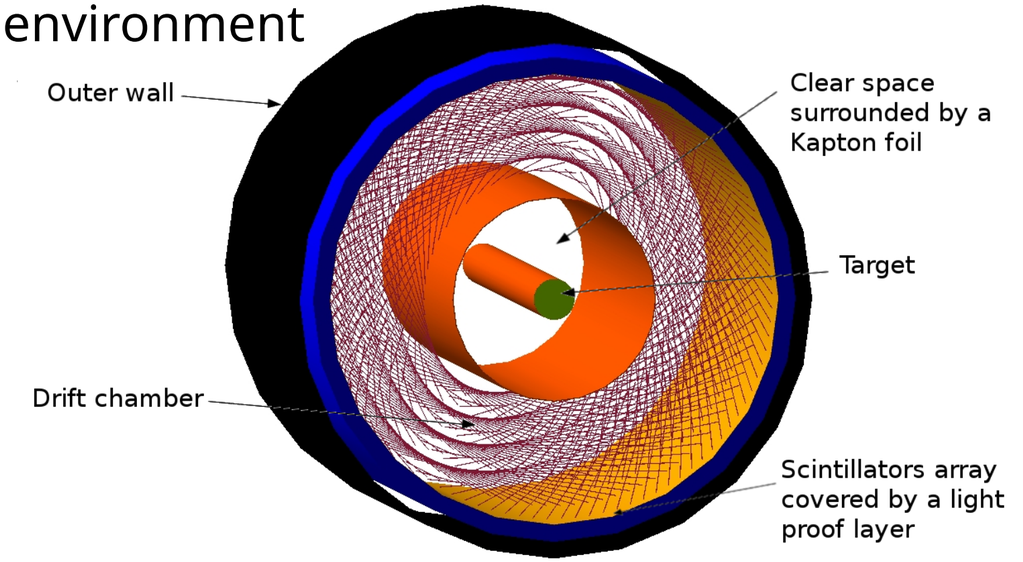
- Centered around A Low Energy Recoil Tracker
  - nuclear DVCS and DVMP on helium-4
    $^4\mathrm{He}(e, e'\ ^4\mathrm{He}\ \gamma)$
    $^4\mathrm{He}(e, e'\ ^4\mathrm{He}\ \phi)$
  - tagged DVCS on helium-4 and deuterium
    $^4\mathrm{He}(e, e'\gamma p + {}^3\mathrm{H}\ )$
    $^4\mathrm{He}(e, e'\gamma\ \ + {}^3\mathrm{He})n$
    $^2\mathrm{He}(e, e'\gamma\ \ + p\ )n$
  - tagged EMC on helium-4 and deuterium
    $^4\mathrm{He}(e, e' + {}^3\mathrm{H}\ )X$
    $^4\mathrm{He}(e, e' + {}^3\mathrm{He})X$
    $^2\mathrm{He}(e, e' + \ \mathrm{p}\ )X$



ALERT Project

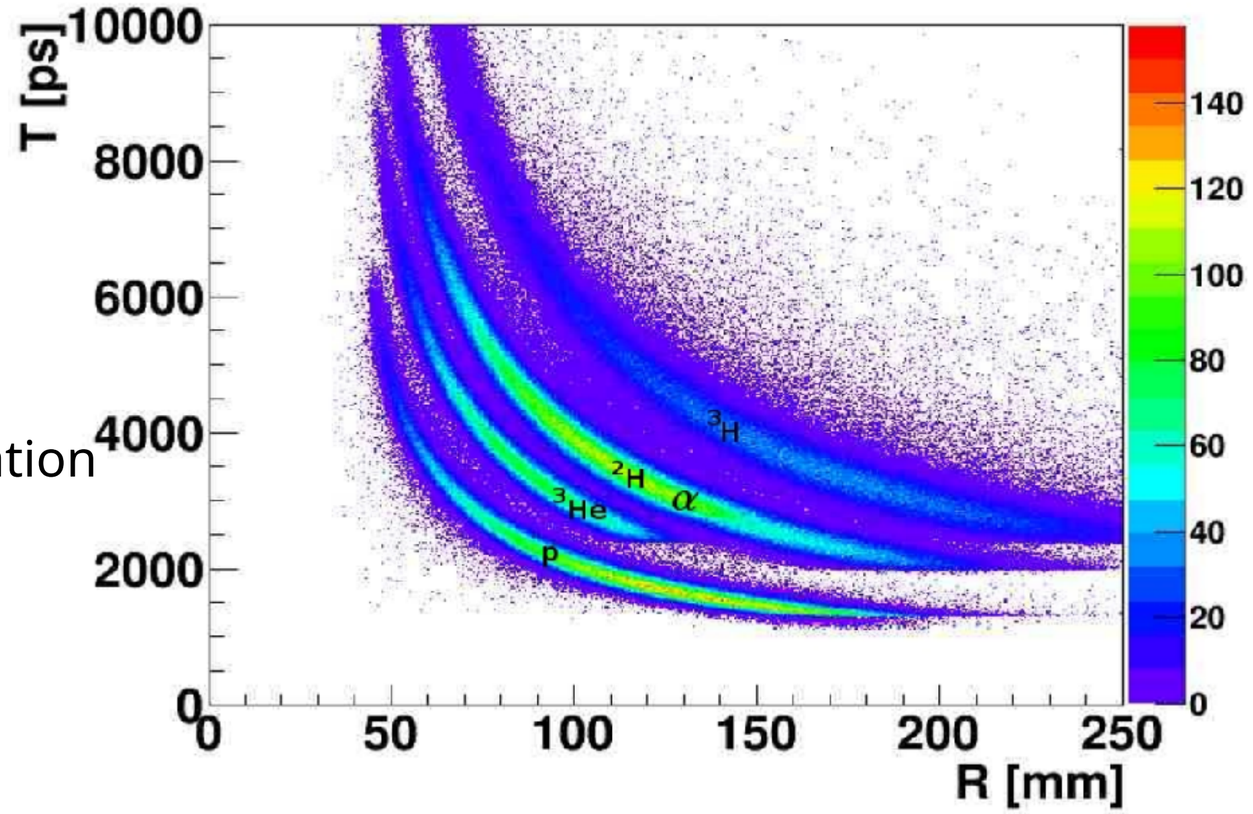
- experimental setup: CLAS12 + ALERT + 4He gas target straw
  - CLAS12 - forward electron and photon detection
  - ALERT - coherently scattered nucleus or the recoiling spectator
  - ALERT - Hyperbolic drift chamber (AHDC) + scintillator array (ATOF)
- ALERT performance requirements
  - Run at CLAS12 luminosity limit - high rates, radiation environment
  - Detection of the lowest momentum possible
  - PID of light ions: H, ^{2}H, ^{3}H, ^{3}He, and ^{4}He
  - independent trigger for background rejection





ALERT Project

- Challenging detection of the low energy recoil nucleus
- Conventional tracking
  - Kalman filter implementation
  - efficiency in high background environment
  - execution time
- Particle identification
  - degeneracy in the deuteron and 4He separation
  - use dE/dx
  - scintillator topology

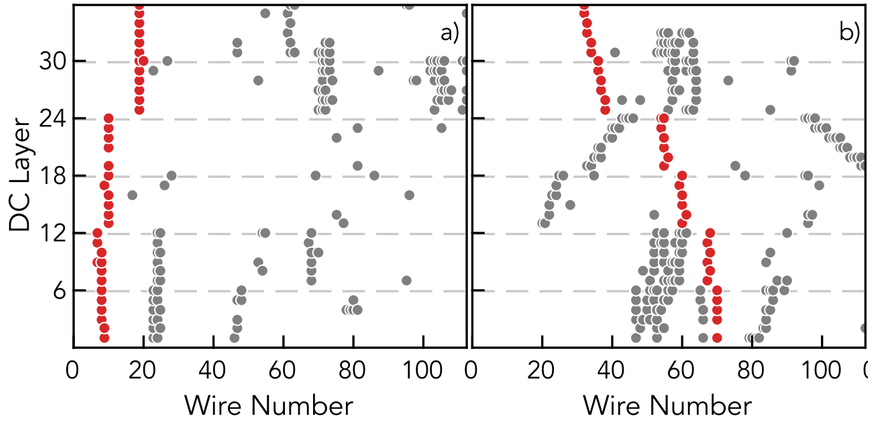


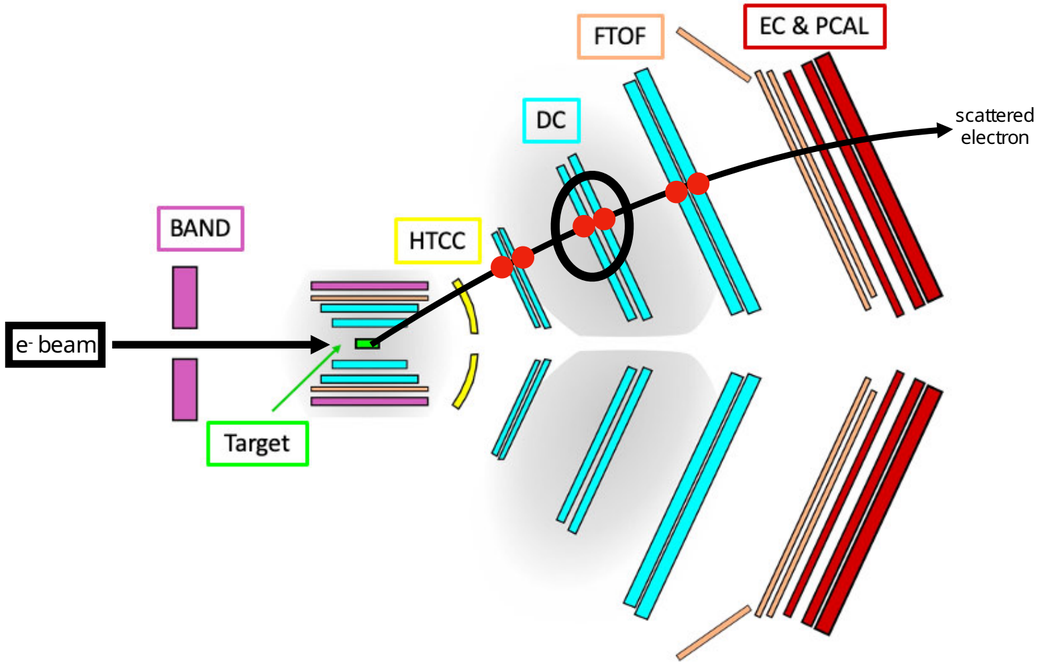
CLAS12 AI Program

- Offline
  - tracking applications: candidate finding, de-noising, track segment predictions
  - calorimetry: clustering for calorimeters, splitting clusters
  - PID: RICH Cherenkov particle identification
- Online
  - Level-3 trigger: data reduction with online electron identification
- ALERT
  - will be integrated in CLAS12 reconstruction framework
  - following the footsteps of the CLAS12 AI project

ALERT AI Applications

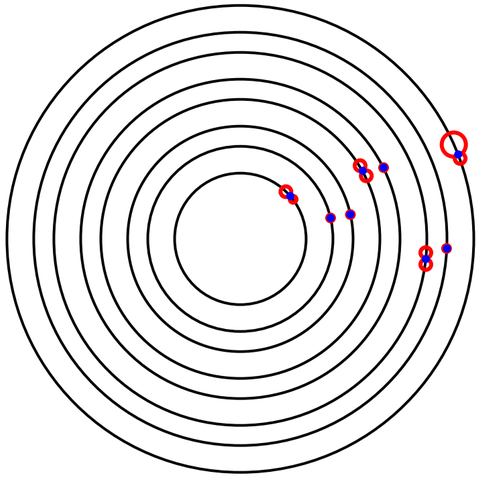
- Track candidate finding
  - (G. Gavalian) CLAS12 "Java for Machine Learning (ML)" lib
  - "j4ml" lib includes several ML models
  - offers unified interface
- ML models tested for CLAS12 drift chambers
  - Convolutional Neural Networks (CNN)
  - Multi-Layer Perceptrons (MLP)
  - Extremely Randomized Trees (ERT)
  - Recurrent Neural Networks (RNN)
- Started with MLP for ALERT





ALERT AI Applications

- AHDC geometry
  - 8 layers of wires organised in 5 superlayers, +/- 10 deg stereo angle
  - number of wires in each layer 47, 56, 56, 72, 72, 87, 87, 99
  - precluster is a group of nearby 1-2 hits in the same layer

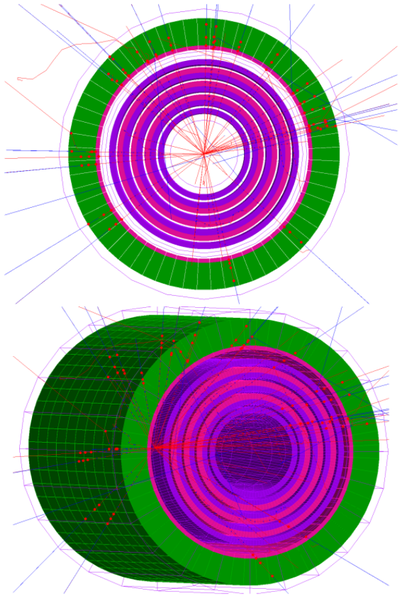


AHDC event in XY view

- MLP model is being used as a classifier for AHDC track candidates
  - constructed hit map image based on AHDC precluster bank
  - cluster position in each layer is used as an input to MLP
  - network consists of input, 3 hidden and output layers

ALERT AI Applications

- Full CLAS12 Geant4 Monte Carlo (GEMC) and ALERT MC simulations
  - GEMC simulation with conventional CLAS12 + ALERT reconstruction
  - single track protons for training and evaluation samples



ATOF in green & magenta; AHDC in purple & red. *GEMC* geometry.

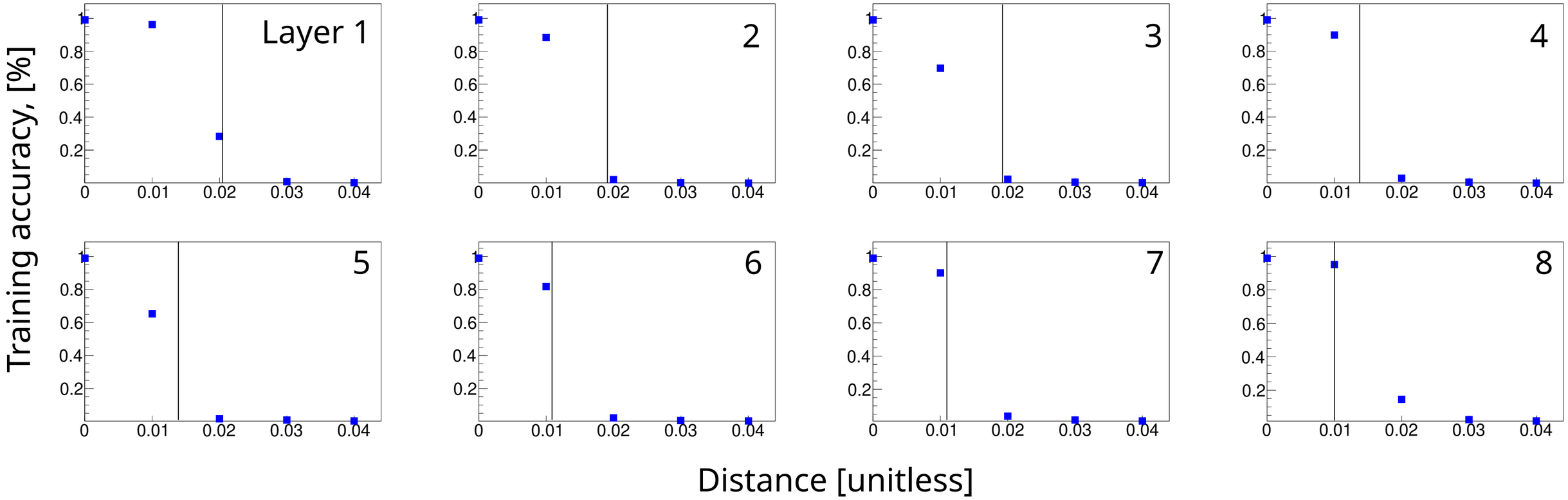
- Sample preparation
  - true tracks are identified by conventional algorithms from MC
  - required single precluster in each layer for a true track
  - false tracks are constructed by randomly interchangin up to 3 preclusters from different event
  - to balance the trained dataset by constructing 50% true + 50% false tracks

ALERT AI Applications

- Preliminary accuracy evaluation (no background hits)
  - 400k proton tracks in the trained sample
  - similarly constructed evaluation sample; ~ 98% training accuracy
- Check whether could distinguish the very similar true and false tracks
  - construct false track by replacing a precluster in one layer by a minimal distance
  - check if minimal distance is comparable with angular separation between neighboring wires
  - use normalized angular separation between wires as a distance $\mathrm{d} = \delta\phi_{\mathrm{min}}/360$

ALERT AI Applications

- Training accuracy as a function of the scanned background hit position
  - vertical line indicates minimal distance between neighboring wires in each layer



ALERT AI Applications

- Next steps tracking
  - check against realistic simulated background (3% expected AHDC occupancy)
  - performance comparison with CNN, ERT, RNN models
  - performance comparison with conventional tracking algorithms
- Particle identification
  - PID based on energy deposition in AHDC for improved track fitting
  - PID based on dE/dx and TOF (incorporate ATOF)
- Developing AI-assisted reconstruction package
  - follow the CLAS12 recipe

Summary and Outlook

- ALERT detector enables comprehensive program to study nuclear effects
  - Nuclear GPDs, Tagged EMC, Tagged DVCS
  - construction is underway
  - expected to run in 2024
- Low energy recoil detection is challenging
  - AI-assisted tracking and PID to improve performance (already at work with CLAS12)
  - AI tools for ALERT reconstruction is steadily progressing

This work is supported in part by the U.S. DOE award # DE-FG02-07ER41528

THANK YOU