Overview of ALERT AI-assisted Track Reconstruction and Particle Identification Project

The 11th workshop of the APS Topical Group on Hadronic Physics

3/15/25

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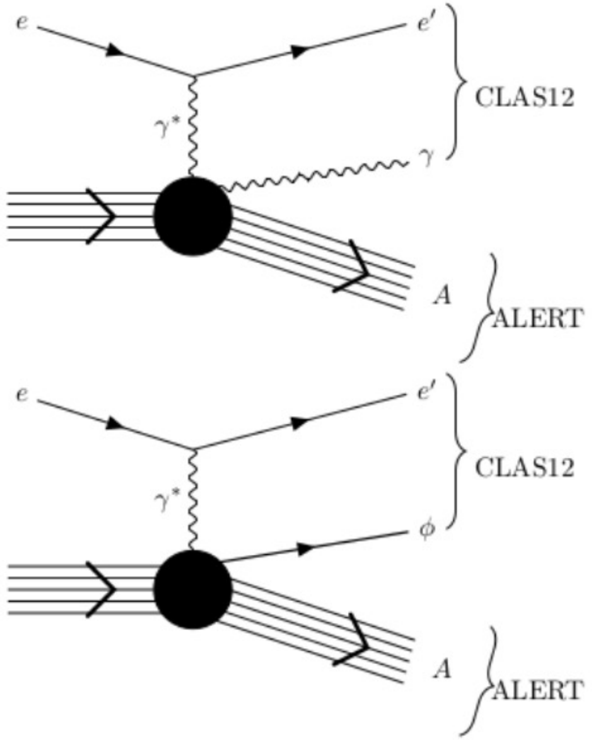
Outline

ALERT Physics Program

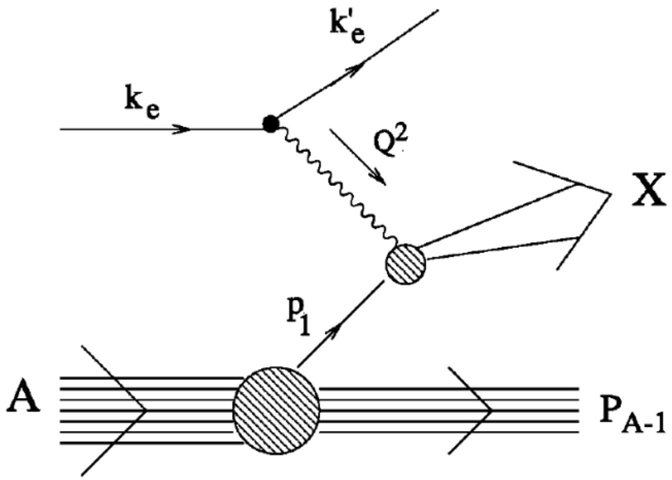
Comprehensive studies QCD in nuclei and associated medium modifications

Coherent DVCS on ^{4}He



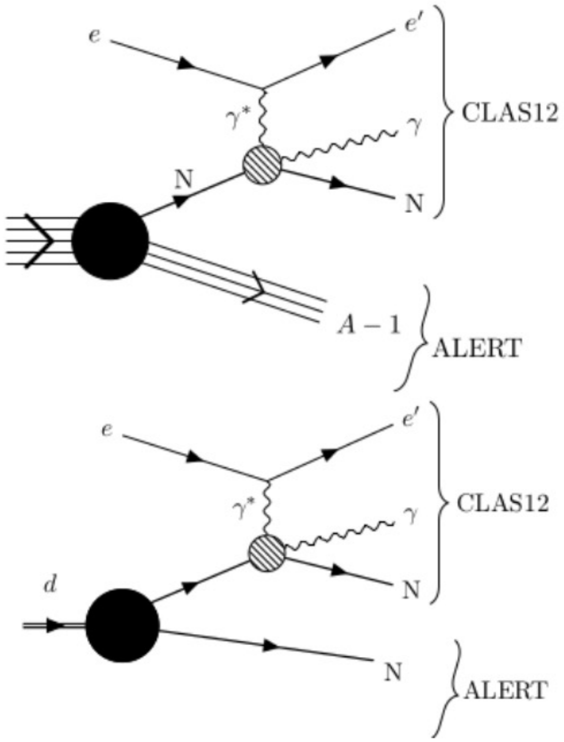
Explore the partonic structure of ^{4}He with Generalized Parton Distributions

DIS on ^{4}He and ^{2}H



Test the Final State Interactions and rescaling model

Incoherent DVCS on ^{4}He (^{2}H)

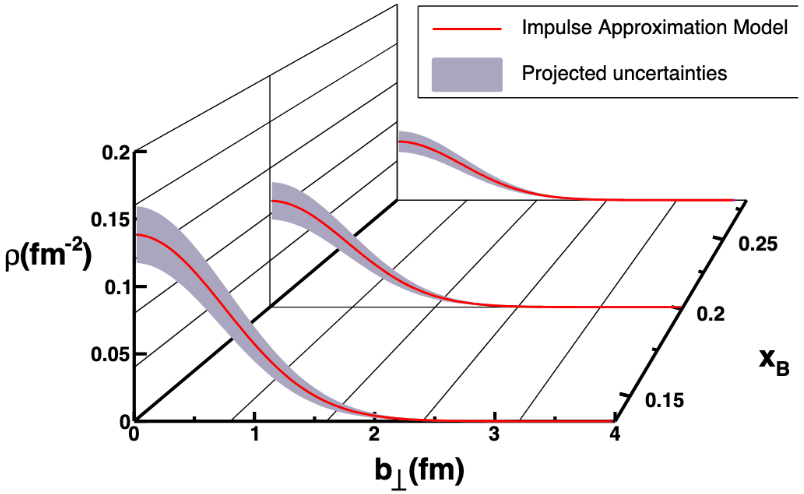


Explore the 3-D structure of modified nucleons in light ions ^{2}H,^{3}H, and ^{3}He (^{1}H or neutron)

ALERT Physics Program

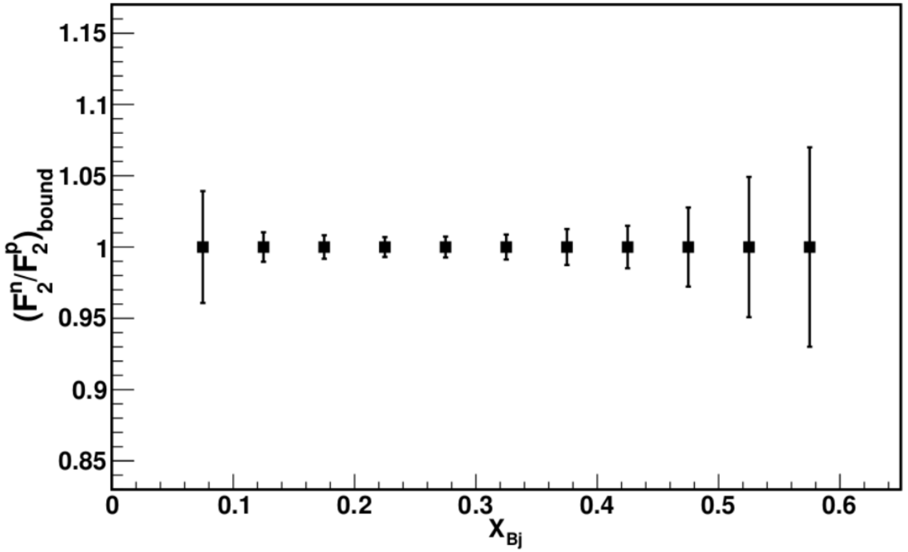
Comprehensive studies QCD in nuclei and associated medium modifications

Coherent Process on ^{4}He



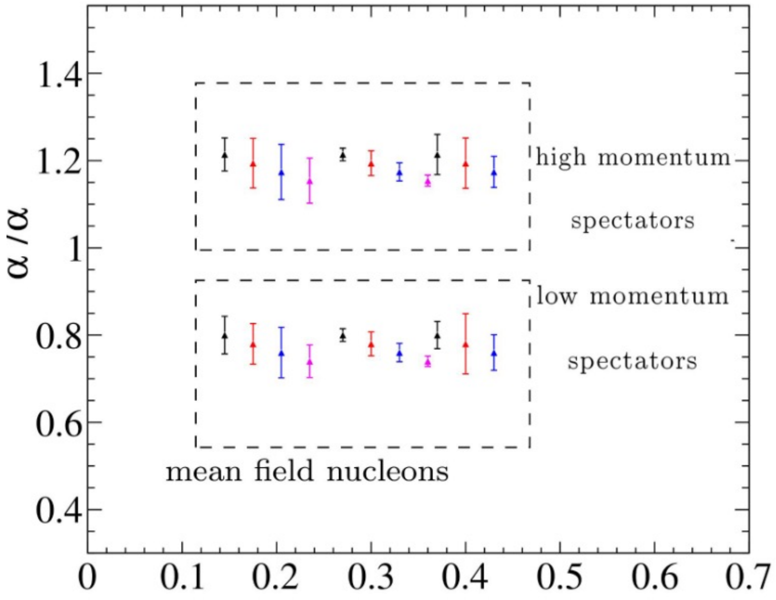
Extract quark and gluon GPDs in a dense nucleus; in this case, GPD H is obtained for both quarks and gluons in ^{4}He

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



Measure the F_2 structure function of a weakly bound nucleon in ^{4}He and compare it to the ^{2}H case. Control FSIs with tagged fragments

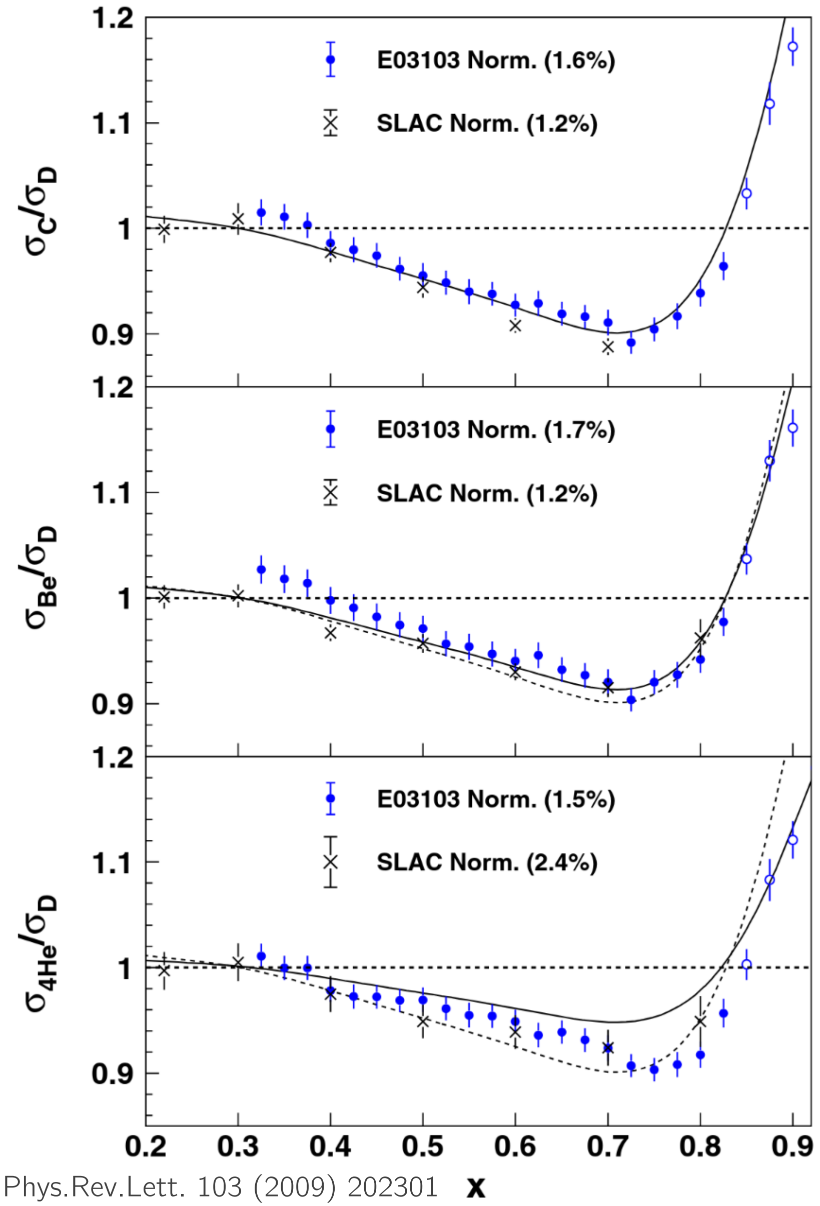
Incoherent Process on ^{4}He and ^{2}H



Extract quarks GPDs for bound nucleons and thus understand the effect of FSIs

In-medium Structure and Effects

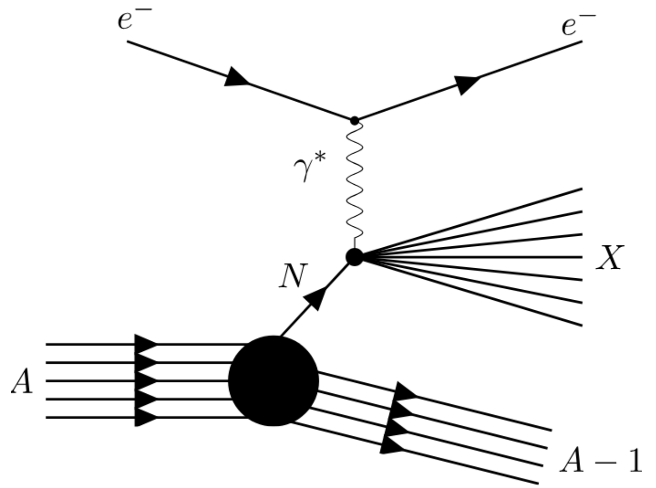
- Modifications of bound nucleons properties and dynamics:
  - EMC effects at moderate Bjorken *x*, and shadowing at small *x*
  - Significant even for ^{4}He
  - Many models for the EMC effect
- The EMC effect remains a mystery
  - What is the origin of the EMC effect?
  - How is the nucleon modified in nuclear medium?
- Nuclear modifications of DIS cross sections were probed by CERN, SLAC, and JLab experiments.
- Clear explanations may arise from studying the nuclear modifications via other reactions, such as Deeply Virtual Compton Scattering and Deeply Virtual Meson Production…
- What is the partonic structure of nuclei?

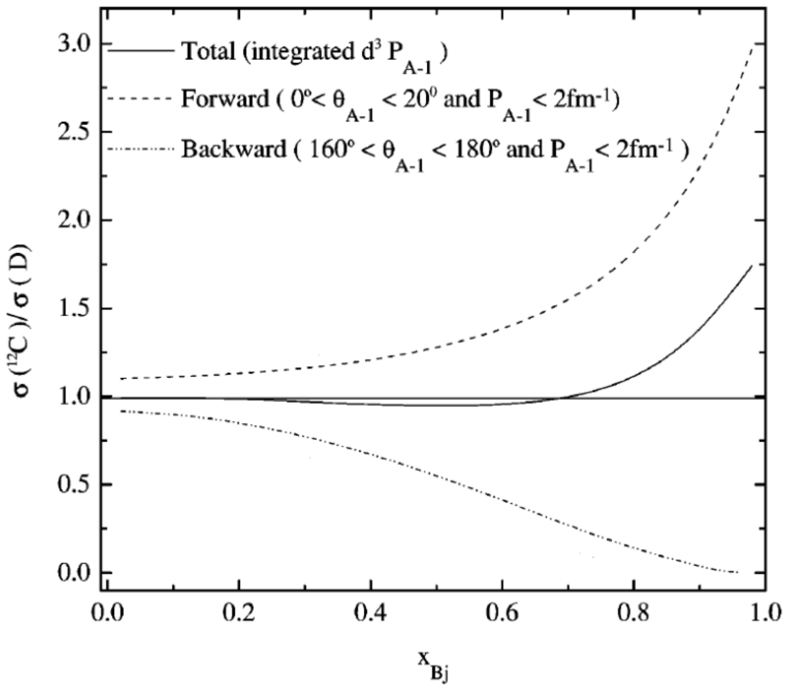


J. Seely et al. Phys.Rev.Lett. 103 (2009) 202301

Tagged DIS and the EMC effect

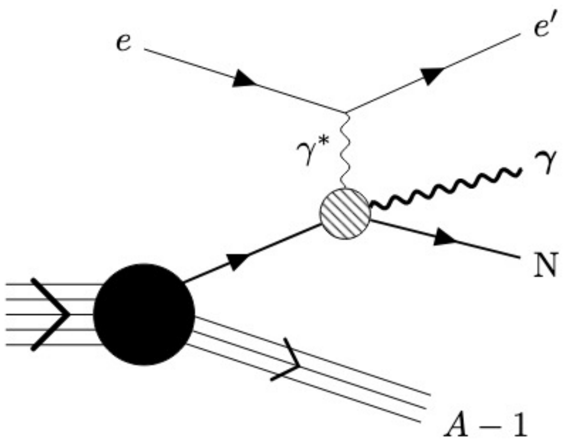
- Tagging ⇒ better understanding of the nuclear effects.
- Tagging implies measuring the characteristics of the spectator part
- Measurement with tagging ⇒ nuclear configuration selection via spectator kinematics:
  - On-shell extrapolation ⇒ access to free nucleon structure
  - Control initial state interactions
  - Control and constrain final state interactions
- Study the EMC effect for backward and forward configuration to distinguish between models
- Compare conventional models and alternative models:
  - Conventional: nuclear binding and Fermi motion
  - Alternative: modifications in quark confinement size or nucleon swelling



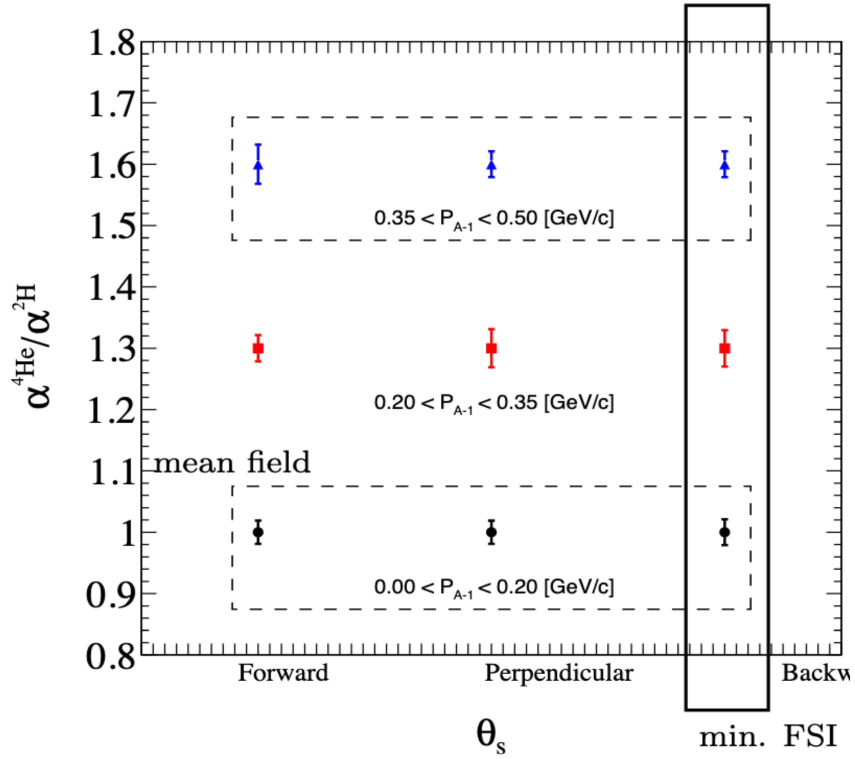


Spectator-Tagged DVCS

- DVCS links the EMC effect and Short-Range Correlations (inelastic and quasi-elastic):
  - DVCS is used to study Generalized Partons Distributions
  - Forward limit: GPDs reduce to longitudinal parton distributions ⇒ may explain the EMC effect
  - Off-forward limit: GPDs reduce to form factors ⇒ describe quasi-elastic scattering off the nucleon

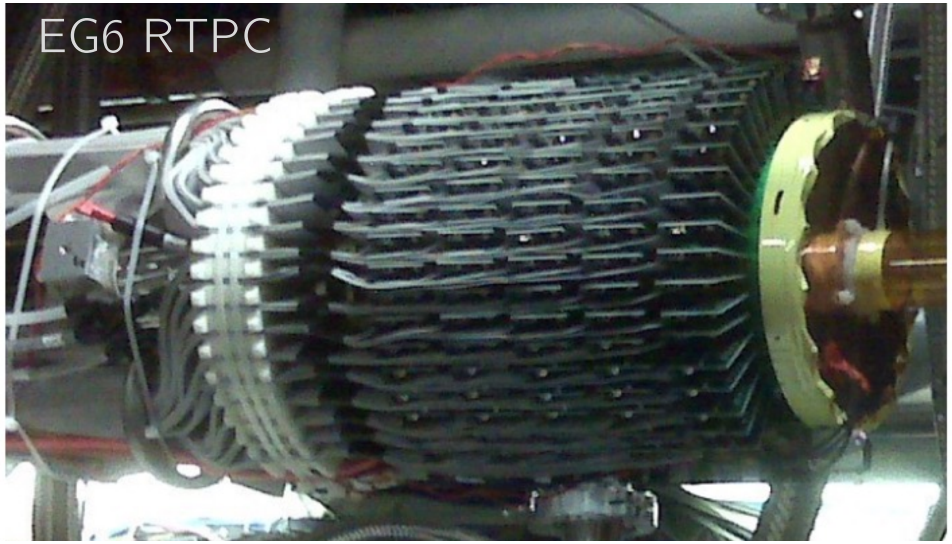


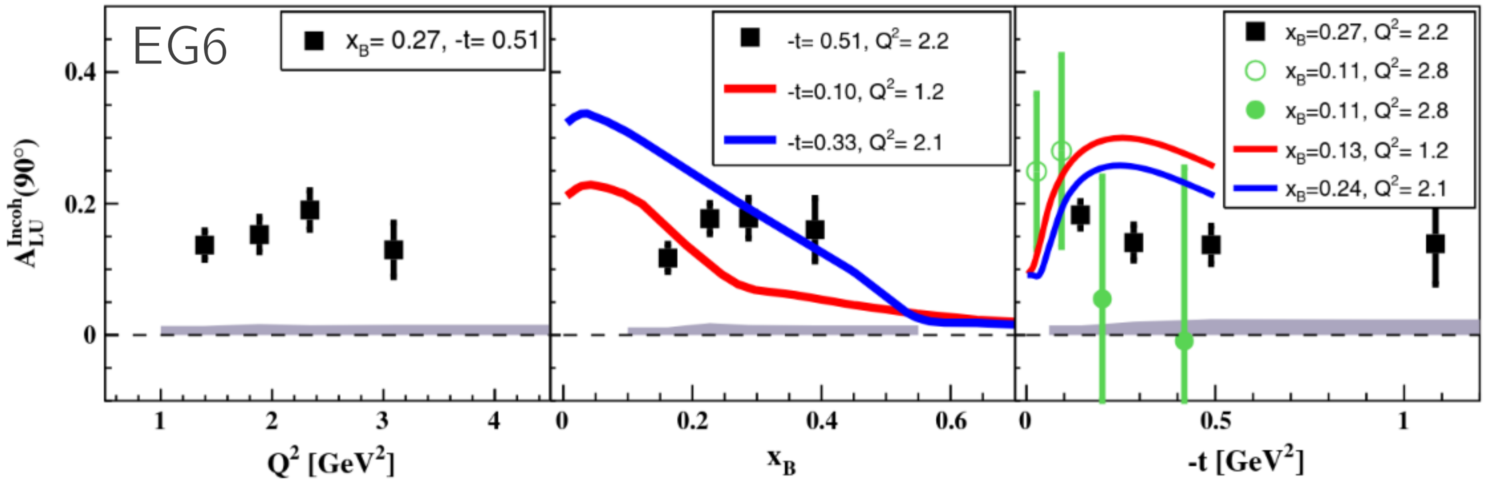
- DVCS allows a partonic level interpretation and in-medium nucleon tomography
- Tagged DVCS provides a way to quantify and control the nuclear effects
- Identify struck nucleon via tagging ⇒ separate mean field nucleons (low momentum) from SRC (high momentum) nucleons



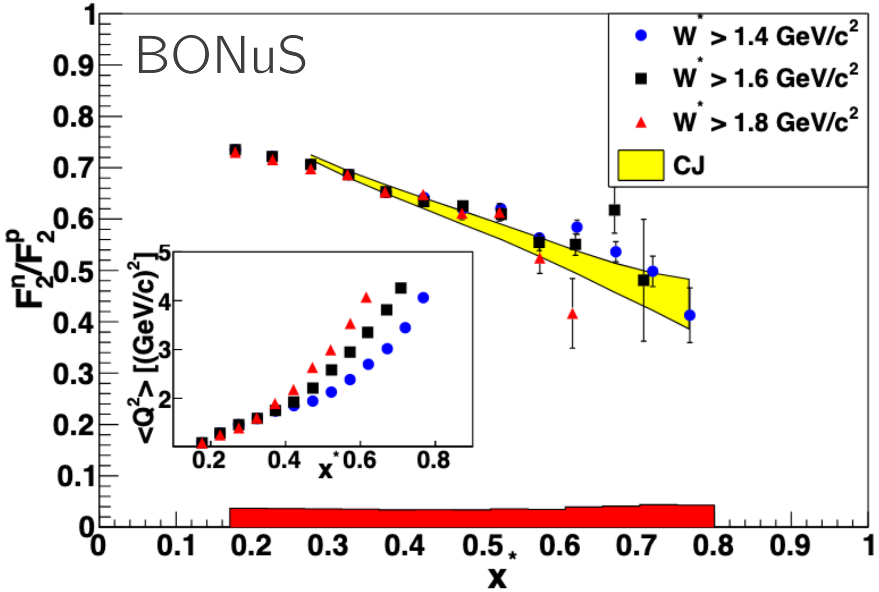
Previous Experiments at Jefferson Lab

- Two previous 6 GeV CLAS experiments: **EG6** and **BONuS**
- Both use Radial Time Projection Chamber to detect the recoil fragment
- Main limitations:
  - EG6: had long drift time and lacked full Particle IDentification capabilities (identified only ^4He)
  - BONuS: had long drift time and only detect recoil proton





M. Hattaway *et al.*, Phys. Rev. Lett. 119, (2017) 202004
M. Hattaway *et al.*, Phys. Rev. Lett. 123, (2019) 032502

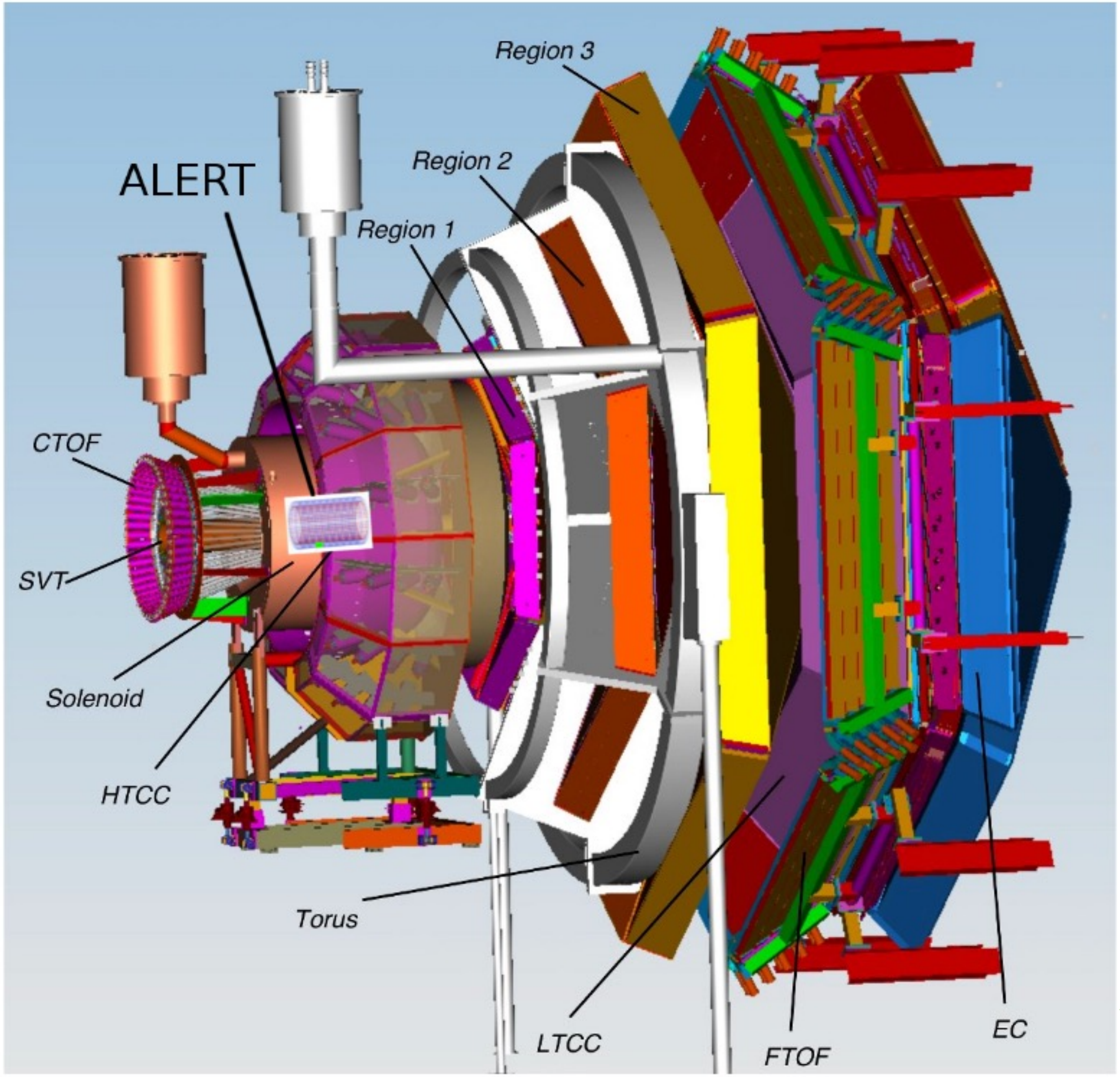


S. Tkachenko *et al.*, Phys. Rev. C **89**, (2014) 045206

ALERT Experiment Setup

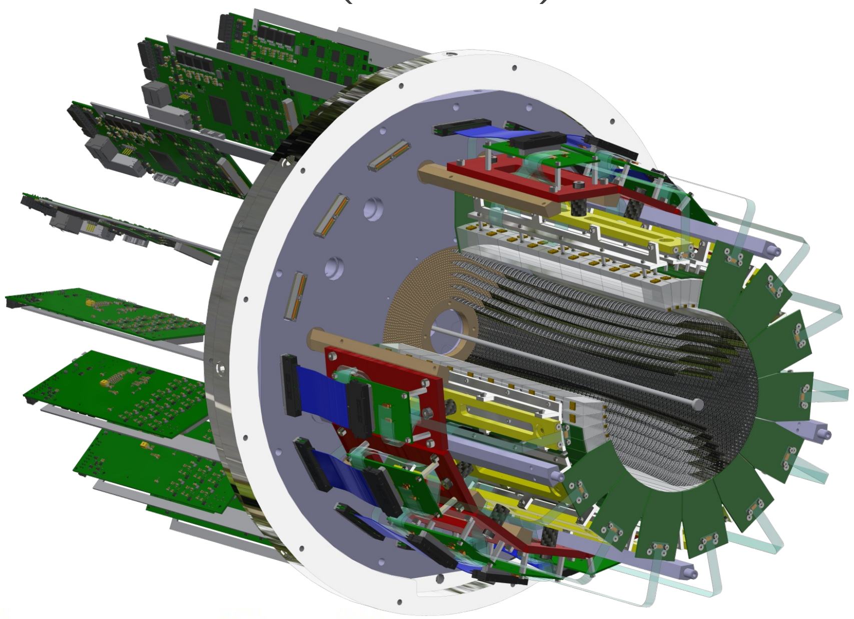
- The ALERT experiment will take place in Hall B at Jefferson Lab
- CLAS12: detect scattered electrons and forward scattered hadrons
- ALERT: detect recoil spectators or coherently scattered nucleus

- ALERT Goals:
  - Aim to identify light ions: p, ^2H, ^3H, ^3He, and ^4He
  - Detect the lowest momentum possible, down to 70 MeV/c for proton
  - Handle high CLAS12 rates and luminosities (10^{35} cm^2s^{-1})



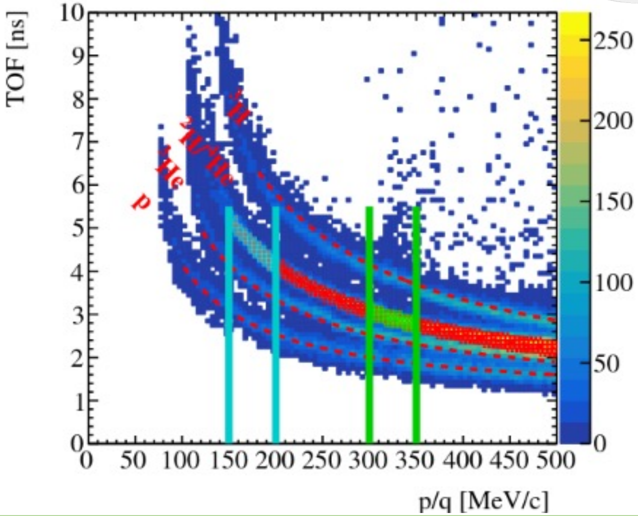
ALERT Experiment Setup

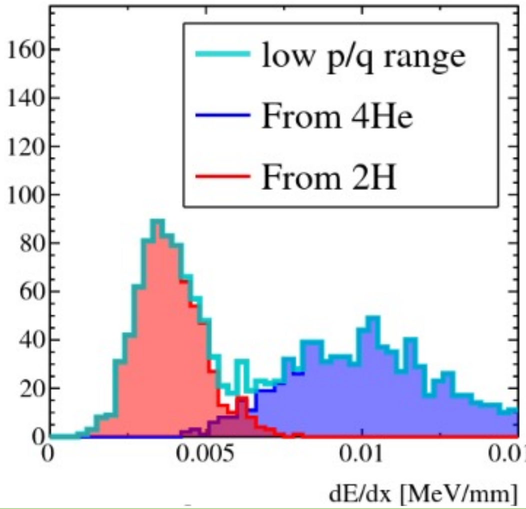
- ALERT have two sub-detectors: A Hyperbolic Drift Chamber (AHDC) and A Time of Flight (ATOF)



ATOF

- Time of flight: used for Particle IDentification
- Small barrel of segmented scintillators
- The TOF measurement is degenerate for ^{2}H and ^{4}He, but *dE/dx* can distinguish the two nuclei bands



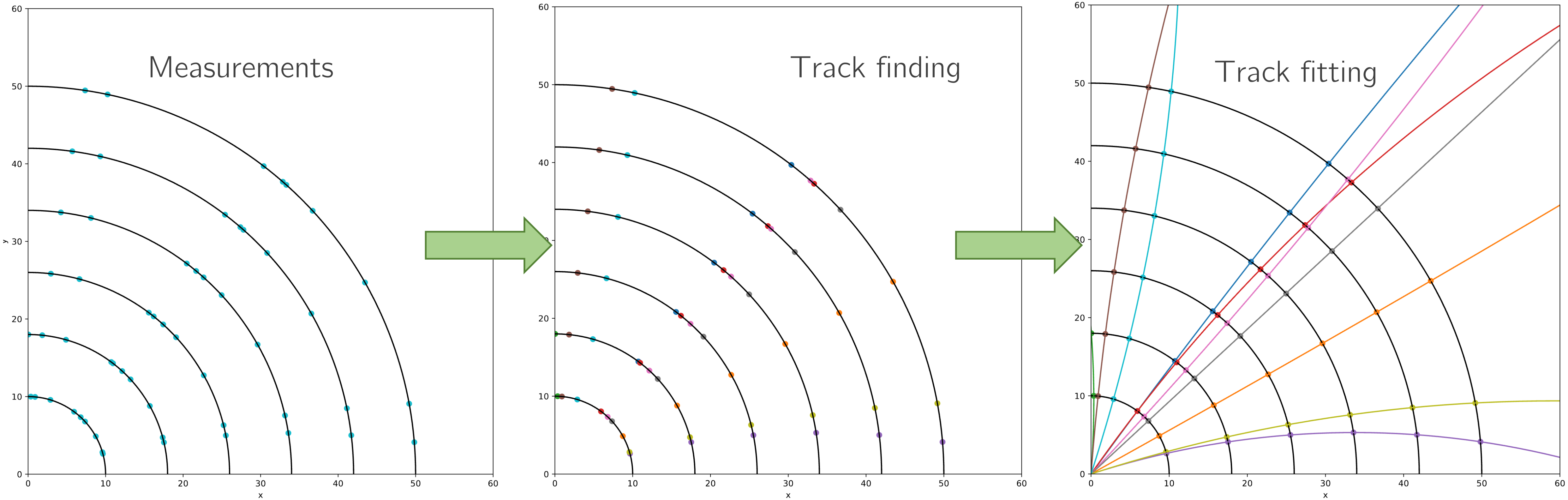


AHDC

- Aluminum wire: 2 mm apart
- 20-degree stereo angle (hyperbolic shape)
- 5 superlayers, each composed of 2 layers
- 576 signal wires (6 ground wires of each signal)

Track Reconstruction

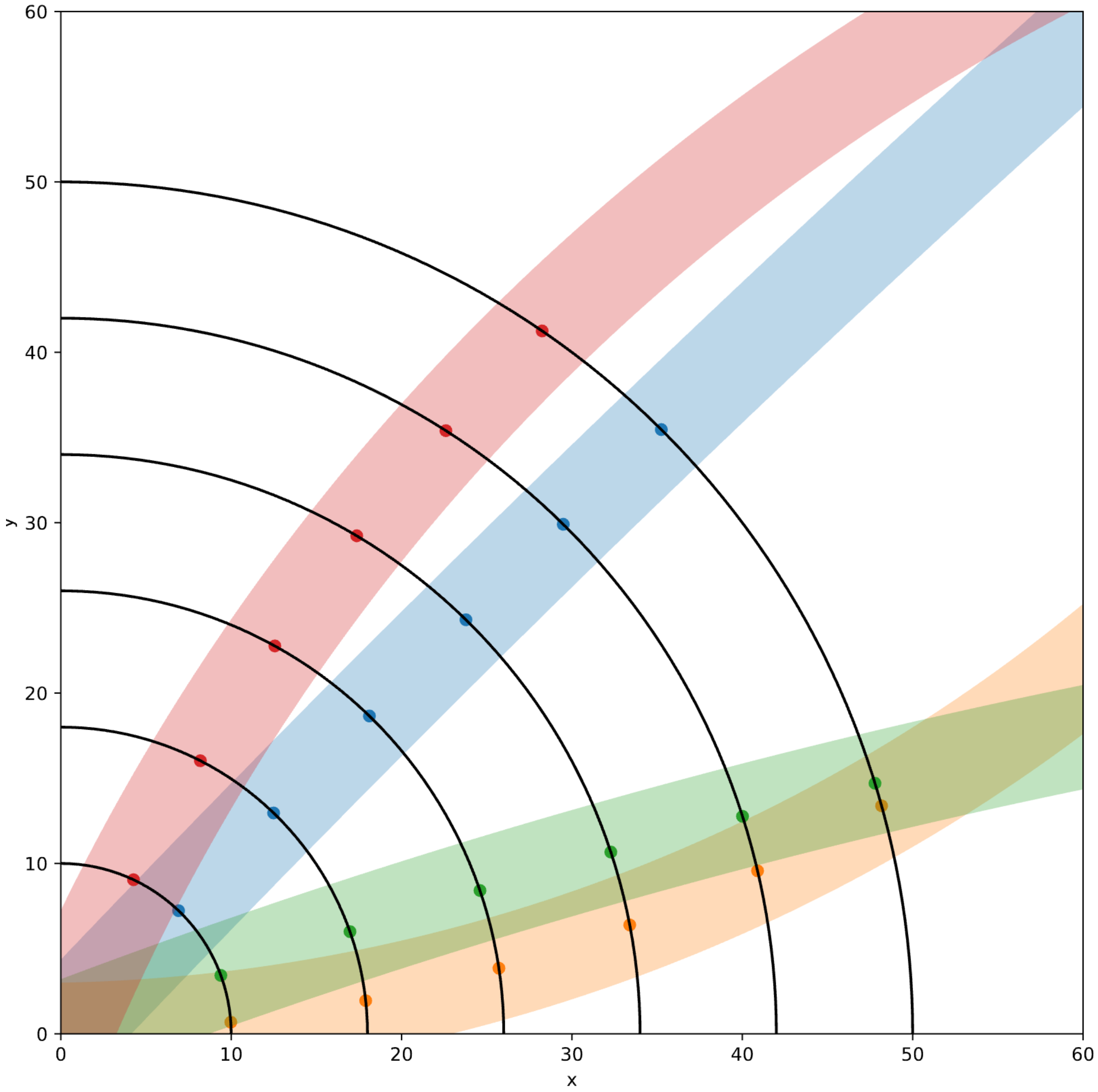
- Aim to reconstruct the momentum and trajectory of (charged) particles
- Two stages of track reconstruction:
  - Track finding: Identifying which hits came from the same charged particle
  - Track fitting: Fitting hits to a single track to extract track parameters (momentum and position)



Track Finding

- Track finding is a clustering problem:
  - Set of points (hits) ⇒ cluster in sets (tracks) originating from the same particle
  - Hits: particles deposit energy when interacting with the detector material
  - Tracks: reconstructed sequences of hits representing charged particle trajectories

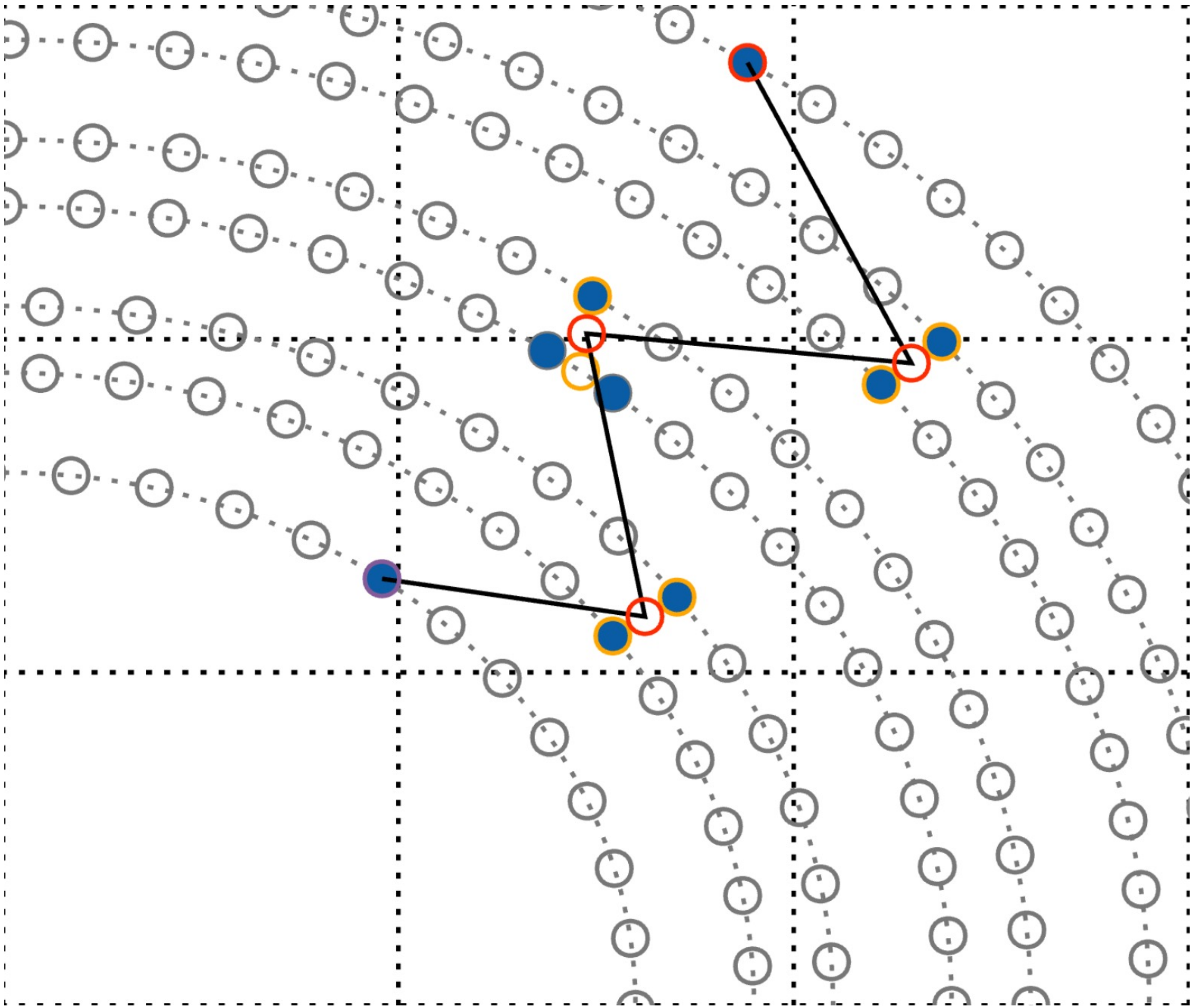
- Different algorithms:
  - Distance between hits + fit
  - Hough transform
  - Combinatorial Kalman Filter
  - Artificial Intelligence models (MLP, GNN...)



Clustering and Track Candidates

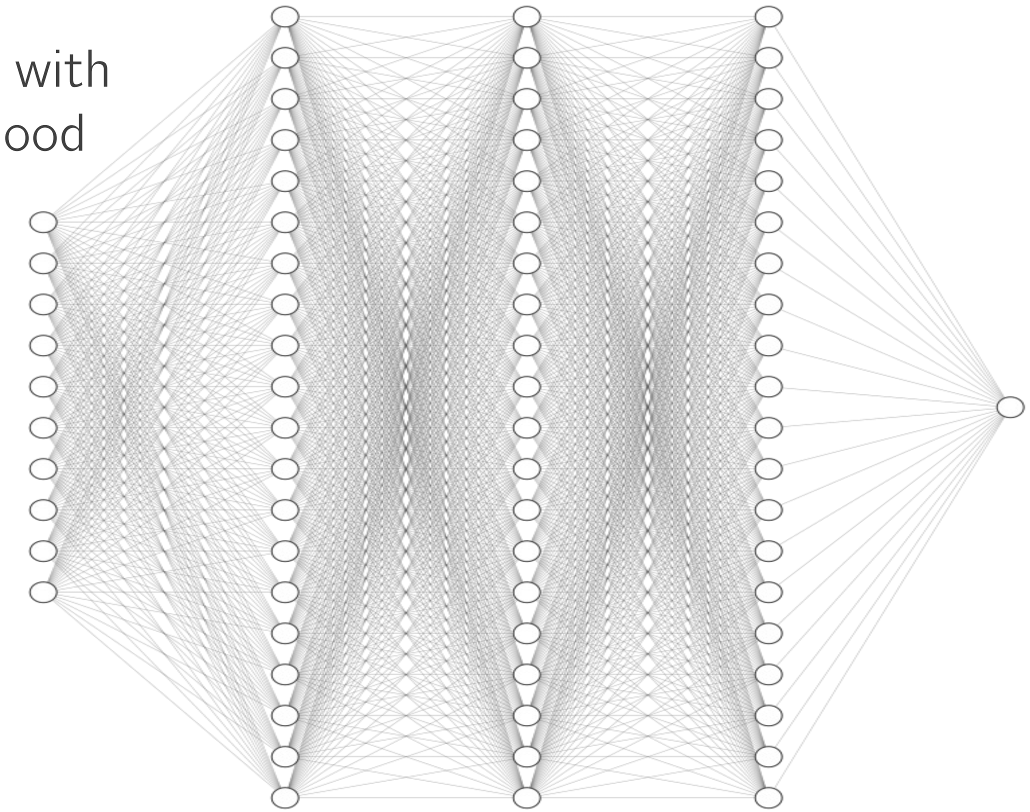
- First step, find all track candidates:
  - Clustering ⇒ merging hits close in the x-y plane to reduce the combinatorial background
  - Merge hits on the same layer that are one wire apart into precluster
  - Merge precluster in the same superlayer that are less than 8mm apart into super-precluster
  - Generate all track candidates with 5 super-preclusters (one on each superlayer)

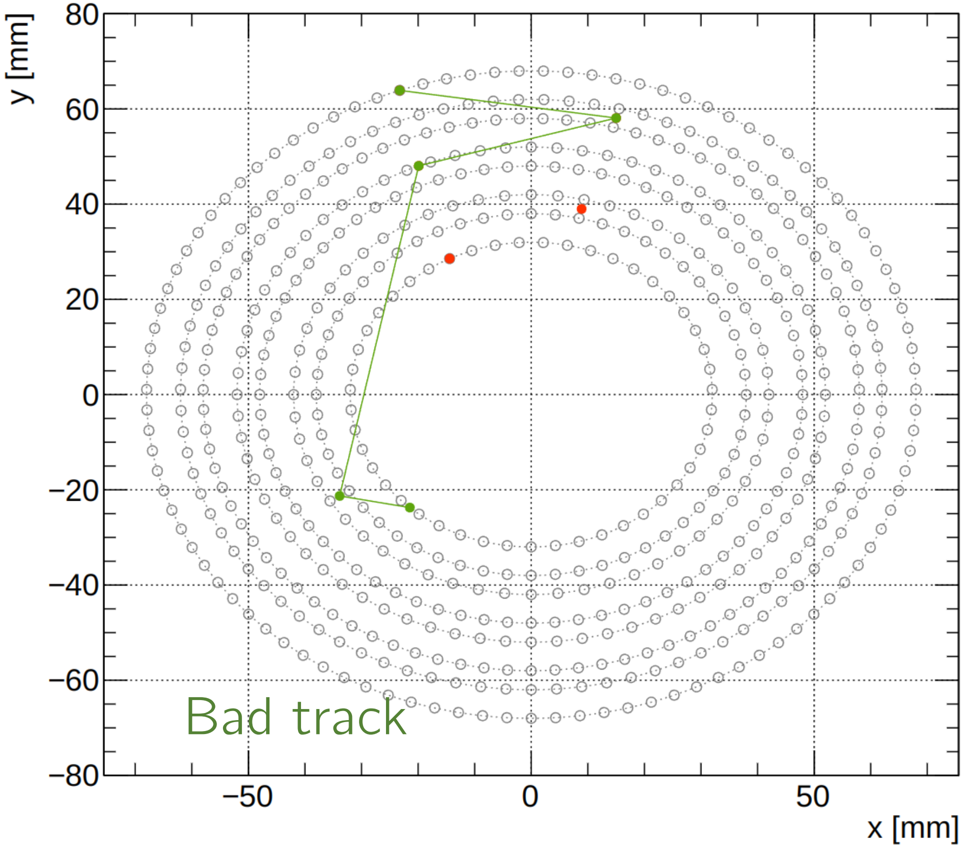
- Generate around 40/100k track candidates per event with super-precluster/raw hits



AI-assisted Model and Training

- Model: MultiLayer Perceptron, 10 inputs, 1/3/5 hidden layer (20/100 neurons), 1 output
- Inputs: *x* and *y* position of the five super-preclusters
- Good and bad tracks for the training:
  - Good tracks: GEANT4 simulation (proton with p ∈ [70, 250] MeV/c, φ ∈ [0, 360]°, θ ∈ [60, 120]° and Vz ∈ [-15, 15] cm)
  - False tracks: Interchanging randomly up to two super-preclusters with another event
- Output: Number between 0 and 1, with 0/1 means bad/good track

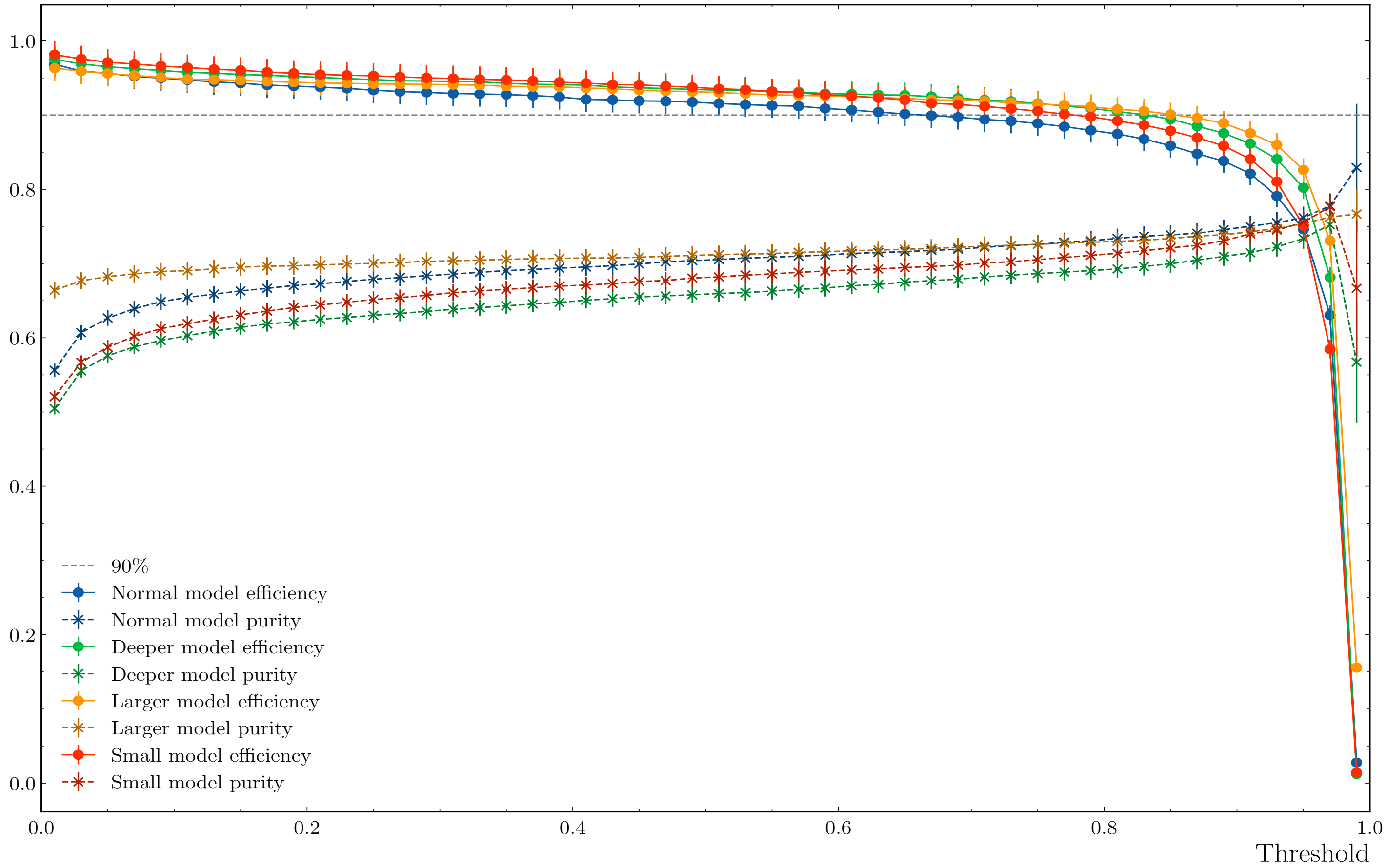




Efficiency and Purity vs. Threshold

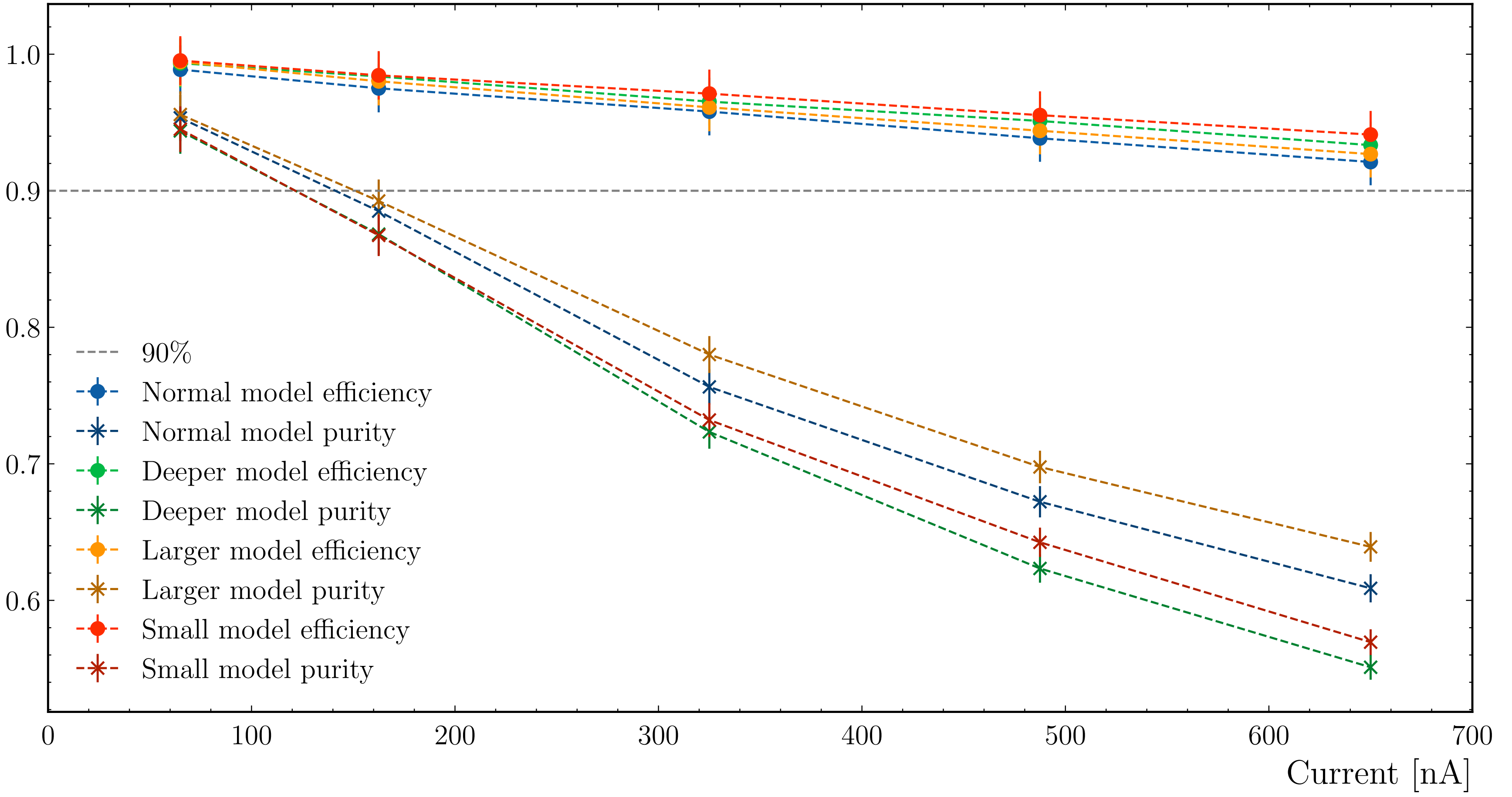
- Threshold: if output above/lower than the threshold ⇒ good/bad tracks
- To evaluate the model:
  - Efficiency: Number of good tracks classified as good normalized by number of events.
  - Purity: Number of good tracks classified as good normalized by number of tracks (good or bad) classified as good.
- Events need to have at least one track candidate.
- Set the threshold to 0.2 to have a higher efficiency

- Blue: model with 20 neurons in 3 hidden layers
- Orange: model with 100 neurons in 3 hidden layers
- Green: model with 20 neurons in 5 hidden layers
- Red: model with 20 neurons in 1 hidden layer



Efficiency and Purity vs. Current

- Efficiency is always higher than 90% and the purity is between 55% and 95%



- Blue: model with 20 neurons in 3 hidden layers
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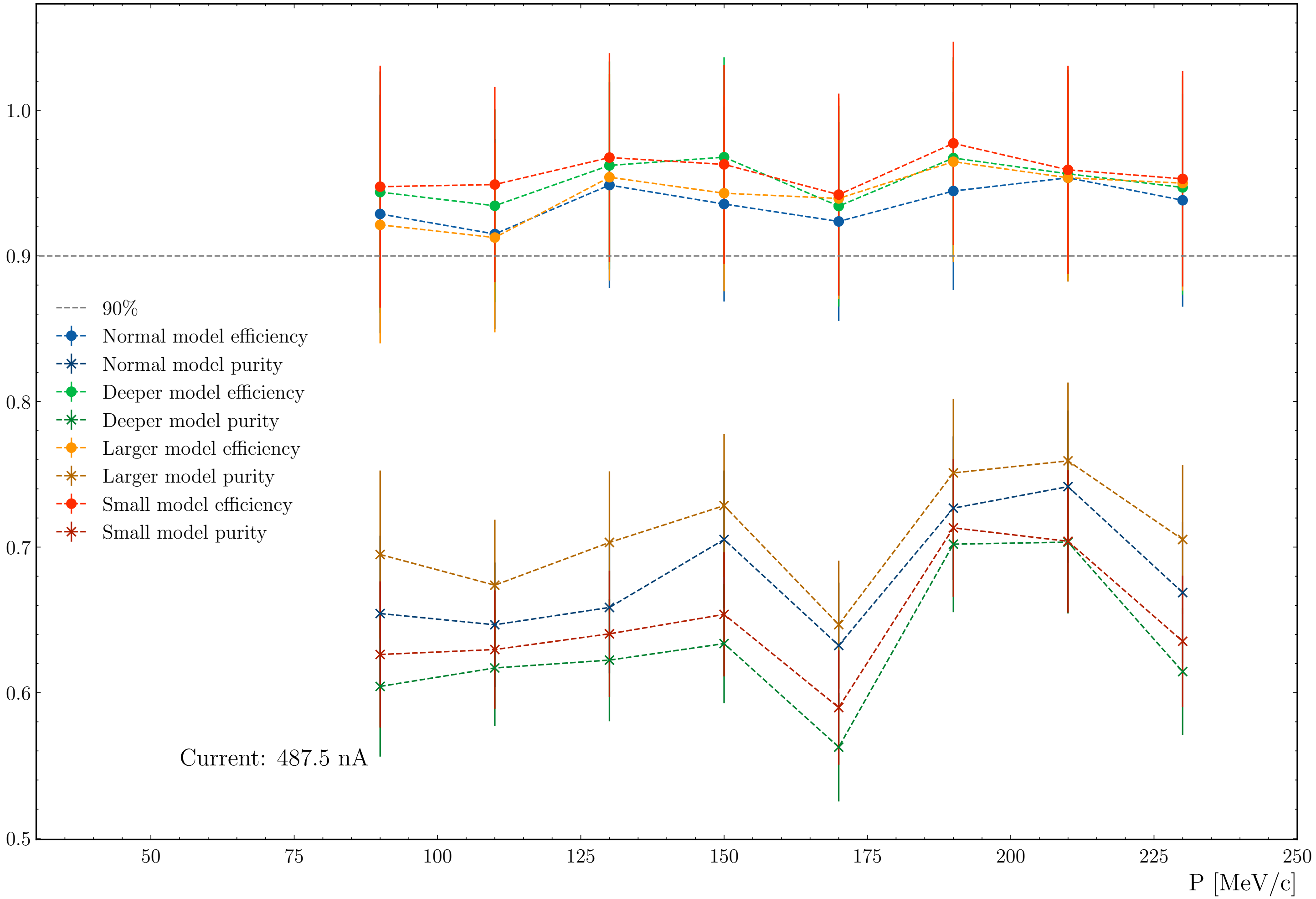
Efficiency and Purity vs. Momentum

- Background is generated with current I = 487.5 nA
- Constant efficiency and purity across the momentum range



- Blue: model with 20 neurons in 3 hidden layers
- Orange: model with 100 neurons in 3 hidden layers
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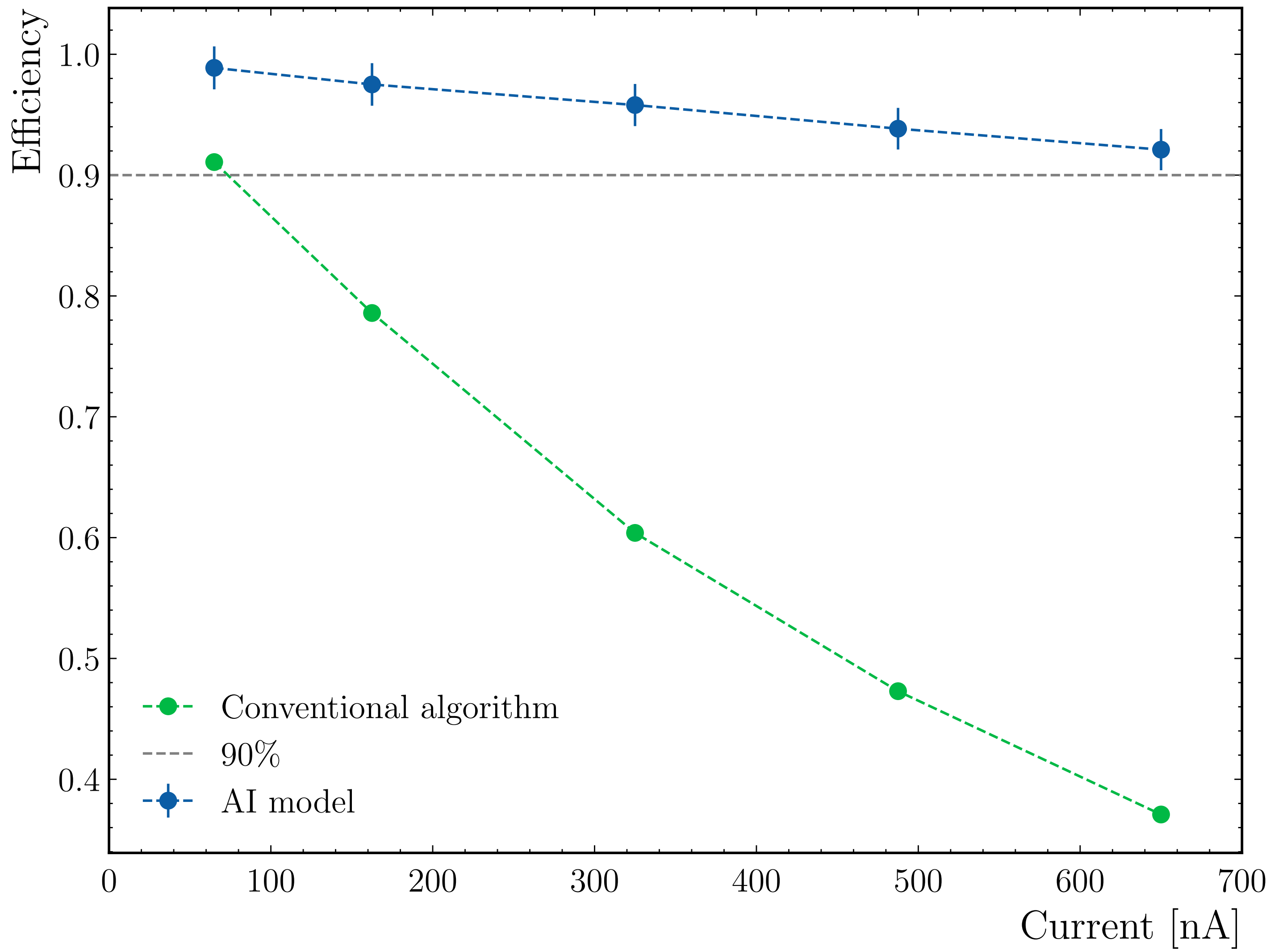
Conventional vs. AI-assisted Track Finding

- Feed both algorithms with track candidates



Summary and Outlook

- ALERT physics program:
  - Tagged processes will provide insight into the origin of the EMC effect
  - Tagged DIS measurements will help differentiate between models
  - Tagged DVCS will bridge the gap between partonic and nucleonic interpretations of the EMC ratio
  - Tagged measurements have better control on uncertainties associated with FSIs

- We have developed an AI-assisted MLP for track finding:
  - Evaluated the model's efficiency and purity as a function of momentum, threshold, and current
  - Compared efficiency of conventional and AI-assisted algorithms
  - Efficiency is always higher than 90%
- Future work:
  - Check the efficiency and purity of real data using elastic scattering
  - Improve the model with other information as input (energy deposited and angle between hits)

Thanks

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