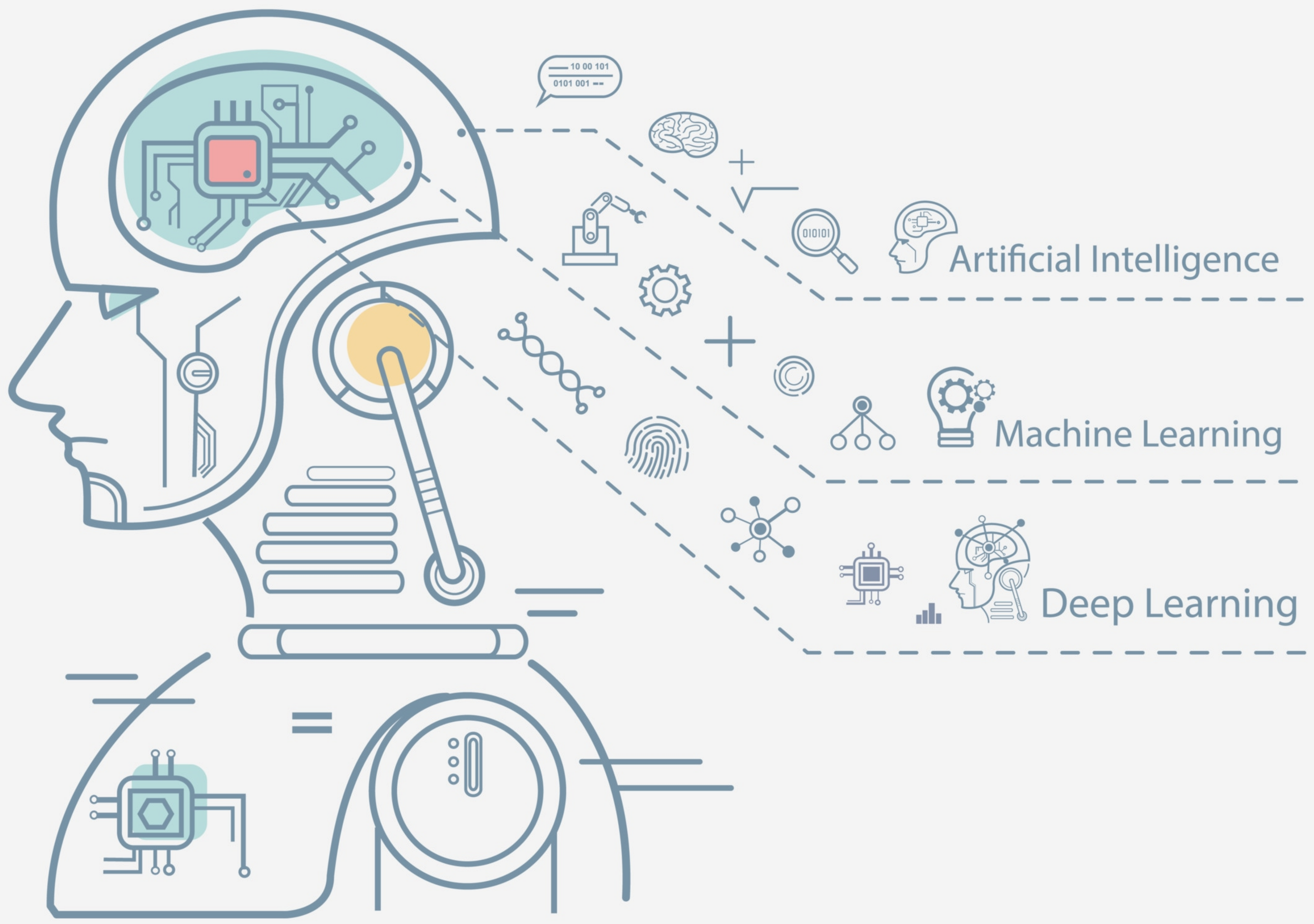
Tracking Particles using AI in CLAS12

Track reconstruction and identification with AI

G.Gavalian (Jefferson Lab)



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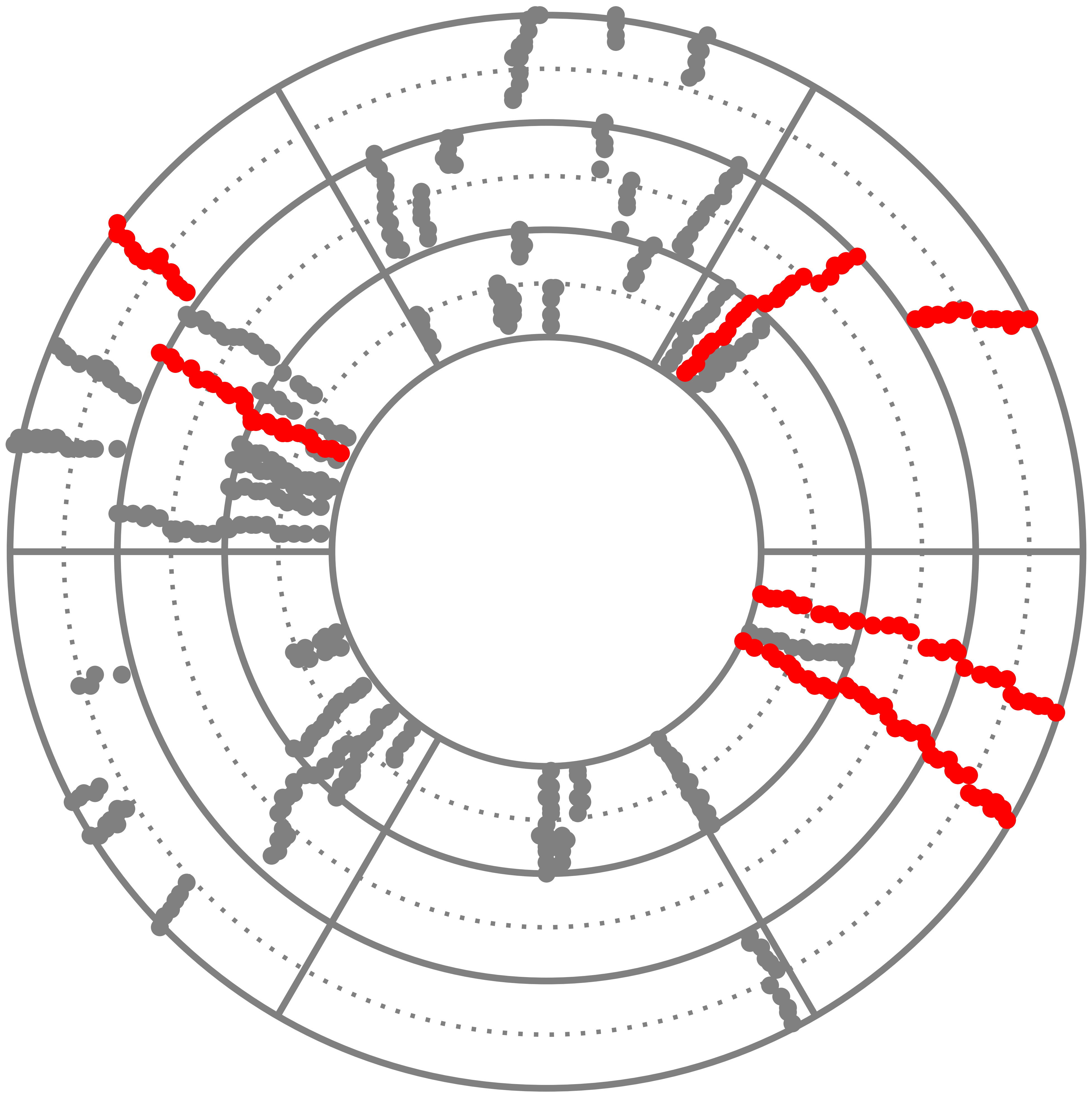
CLAS12 Collaboration Meeting (June 2,2021)

Tracking Challenges

CLAS12 Tracking with Artificial Intelligence



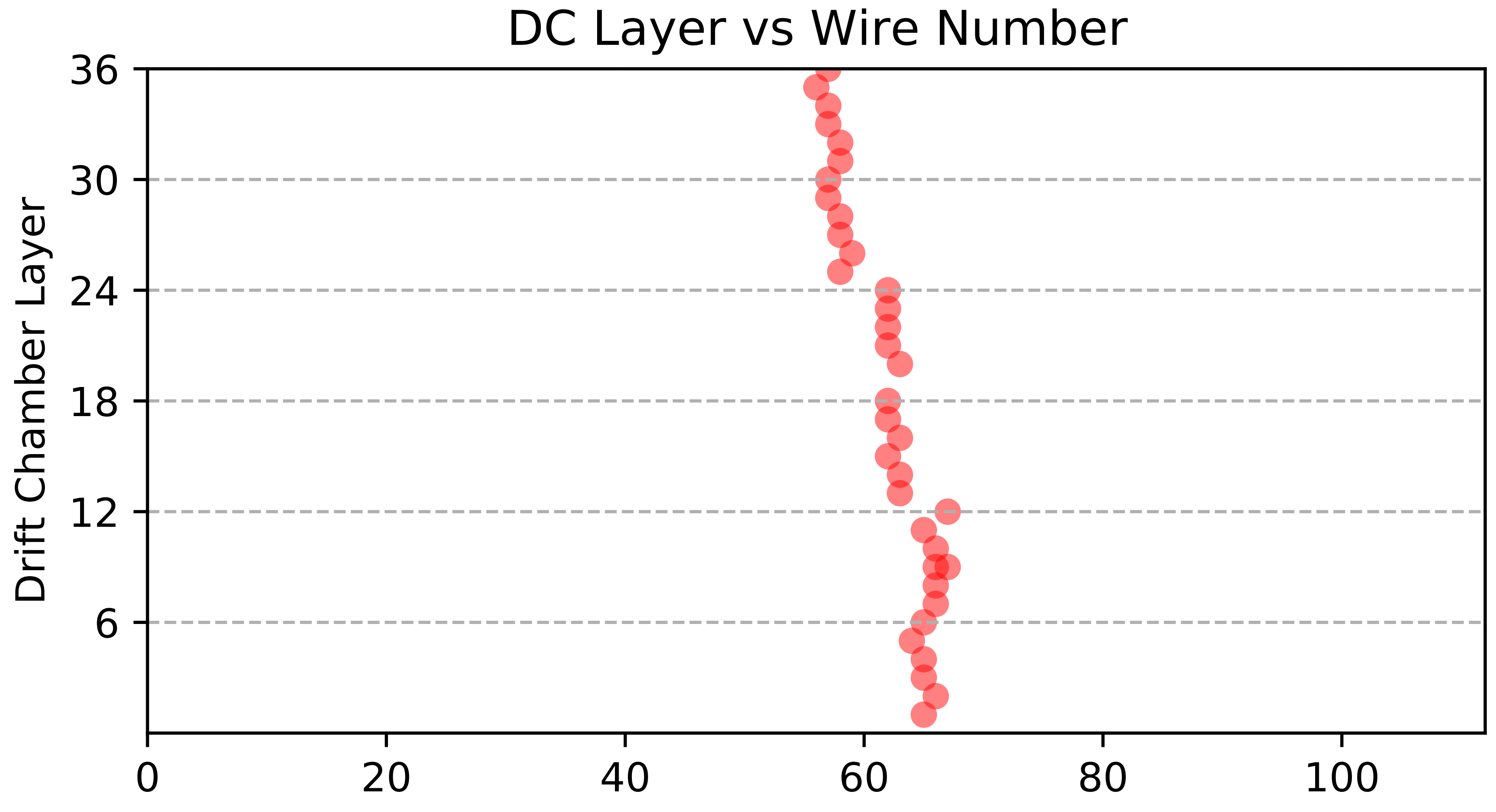
- Tracking is the most computationally intensive part of reconstruction process.
- High combinatorics with increased background
- Many combinations have to be considered to determine best track candidate
- Missing segments (inefficiencies) contribute to missing tracks

Artificial Inteligence

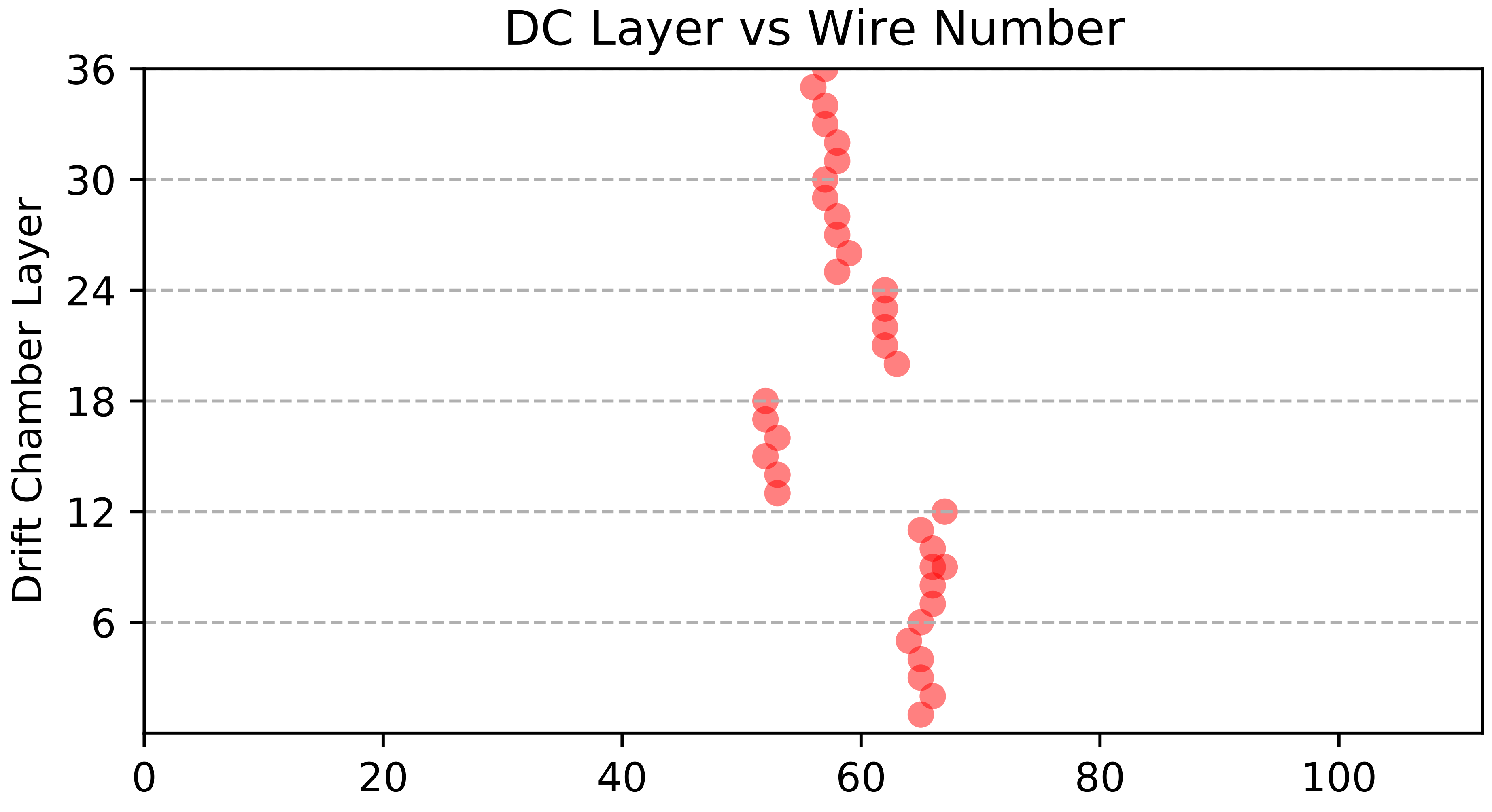
- Can help with identifying right combinations of segments to form a track
- Reduce processing time by only fitting suggested candidates
- Find best 5 segment combinations of tracks by predicting inefficiencies

AI Track (6 Super-Layer)

CLAS12 Tracking with Artificial Intelligence



GOOD TRACK

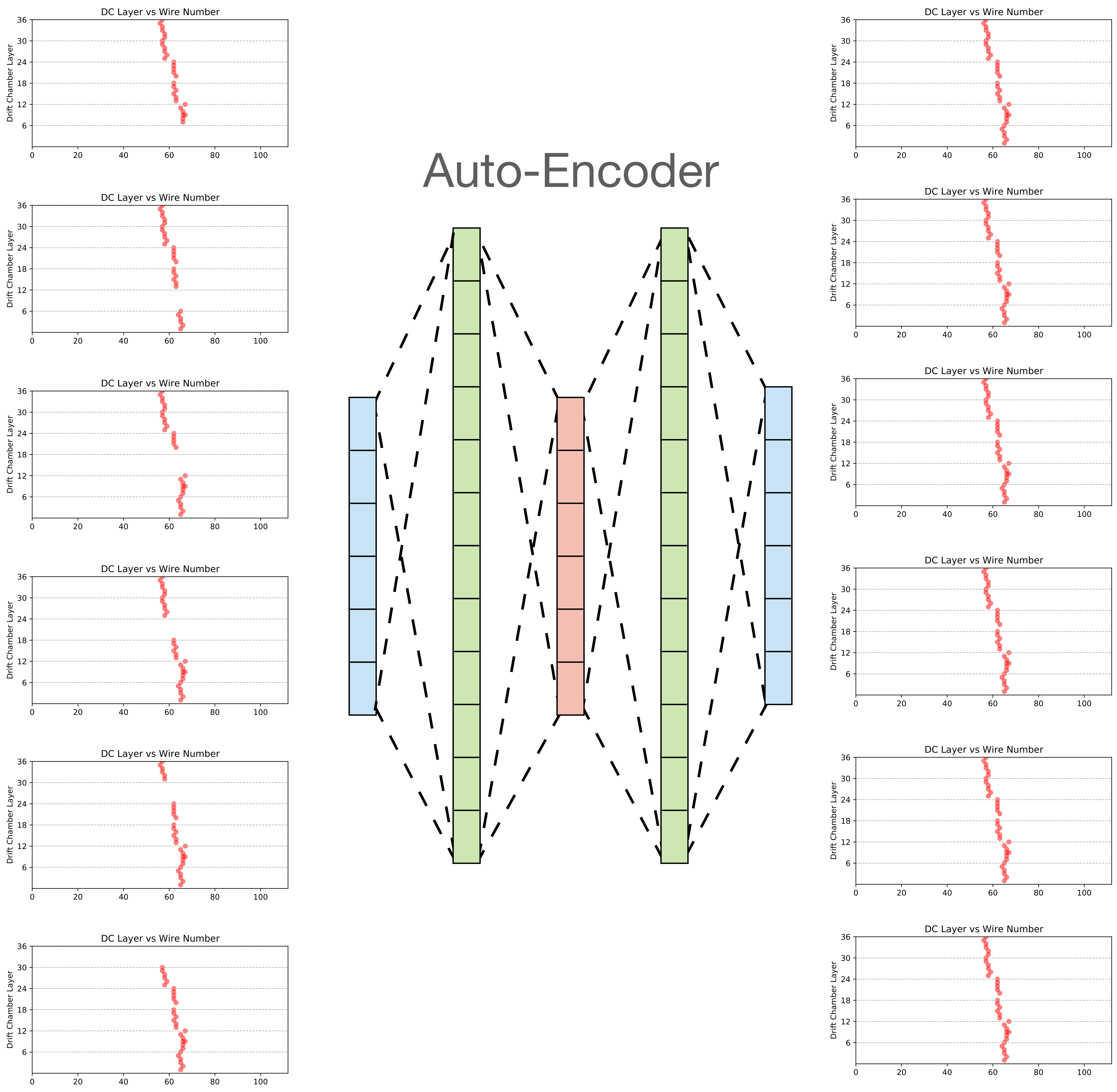


BAD TRACK

- Training sample is composed of real track data for positive sample and a modified track data where one of the segments is replaced with random segment in the drift chamber from the same event
- The segment is chosen to be closest to the track, since we found that network learns best when negative sample is very close to positive sample.
- For CNN an image with dimensions 36x112 was used, for ERT and MLP 6 features were used which are average wire position of the segment in each super-layer.
- (more details on how to chose training sample is in the published work, see Summary)

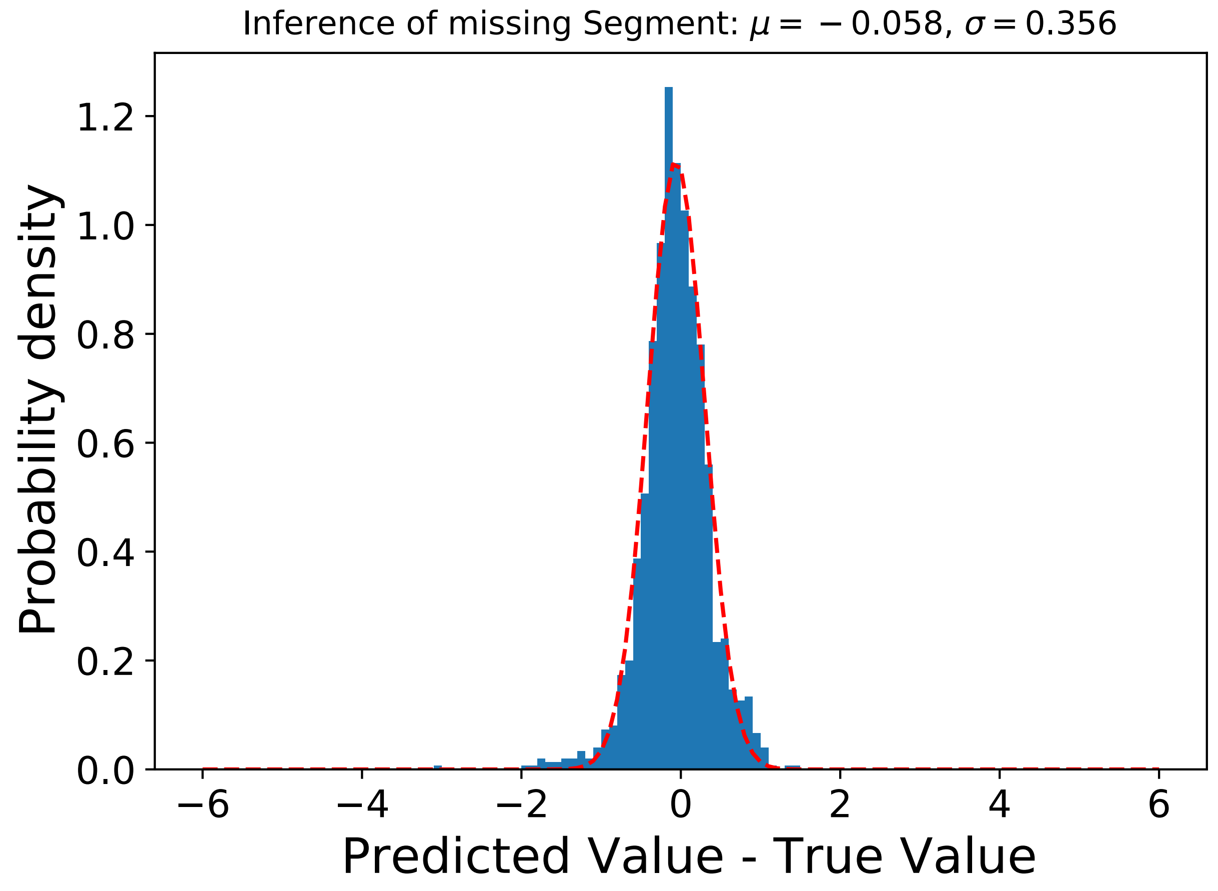
AI Tracking

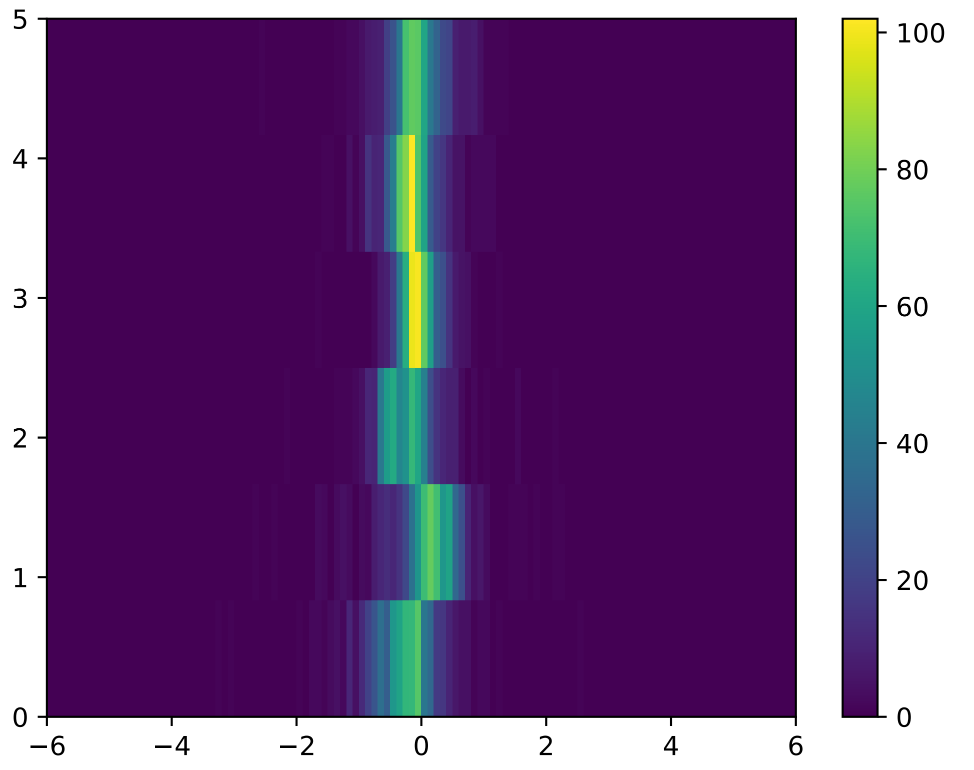
CLAS12 Tracking with Artificial Intelligence



$$(x_1,x_2,x_3,x_4,x_5,x_6)\begin{cases}X(0.0,x_2,x_3,x_4,x_5,x_6)\rightarrow & Y(x_1,x_2,x_3,x_4,x_5,x_6)\\ X(x_1,0.0,x_3,x_4,x_5,x_6)\rightarrow & Y(x_1,x_2,x_3,x_4,x_5,x_6)\\ X(x_1,x_2,0.0,x_4,x_5,x_6)\rightarrow & Y(x_1,x_2,x_3,x_4,x_5,x_6)\\ X(x_1,x_2,x_3,0.0,x_5,x_6)\rightarrow & Y(x_1,x_2,x_3,x_4,x_5,x_6)\\ X(x_1,x_2,x_3,x_4,0.0,x_6)\rightarrow & Y(x_1,x_2,x_3,x_4,x_5,x_6)\\ X(x_1,x_2,x_3,x_4,x_5,0.0)\rightarrow & Y(x_1,x_2,x_3,x_4,x_5,x_6)\end{cases} \quad (7)$$

- Each Fully reconstructed track is corrupted for each super-layer and set as input for auto-encoder
- The output is fully reconstructed track.
- Neural Network learns how to fix the corruption
- Test sample is reconstructed with accuracy of ~0.36 wires.

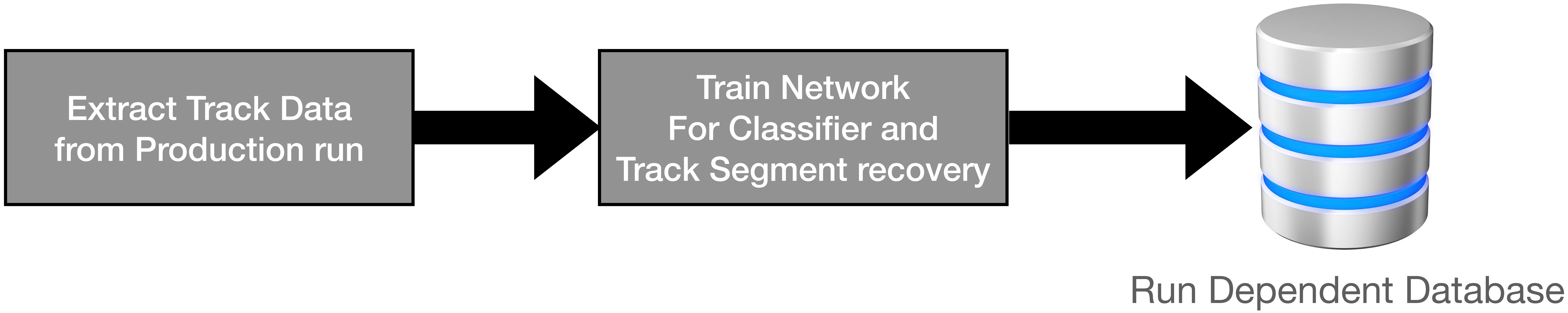




AI Tracking Reconstruction Tools

Tools

- User productivity tools for extracting training data samples from production run and training the network are implemented and documented:
  - https://clasweb.jlab.org/wiki/index.php/CLAS12_AI_tools
- More tools are being developed for visualizing the training results and initial validation of training



- Data for training is taken from cooked files with reconstructed time based tracks
- Command line tools used for training the classifier network and segment recovery network
- The resulting neural networks are stored in Run Dependent Database (custom developed for ML)
- The tracking AI finds appropriate entry in the database depending on RUN number that is being processed

AI Tracking Reconstruction Tools

Tools

- One Database to hold Neural network parameters
- Shipped with COATJAVA distribution as one file
- Database has run number and "flavor" assigned to each Neural Network file for flexibility. (Default flavor will be used if none specified)
- Flavor and run number can be overridden from YAML file.
- Run# selection similar to CCDB.
- Auto-lock prevents overwriting existing neural network by accident. (User manually has to remove an entry to create a new one with training tools)

Network Flavor

RUN number

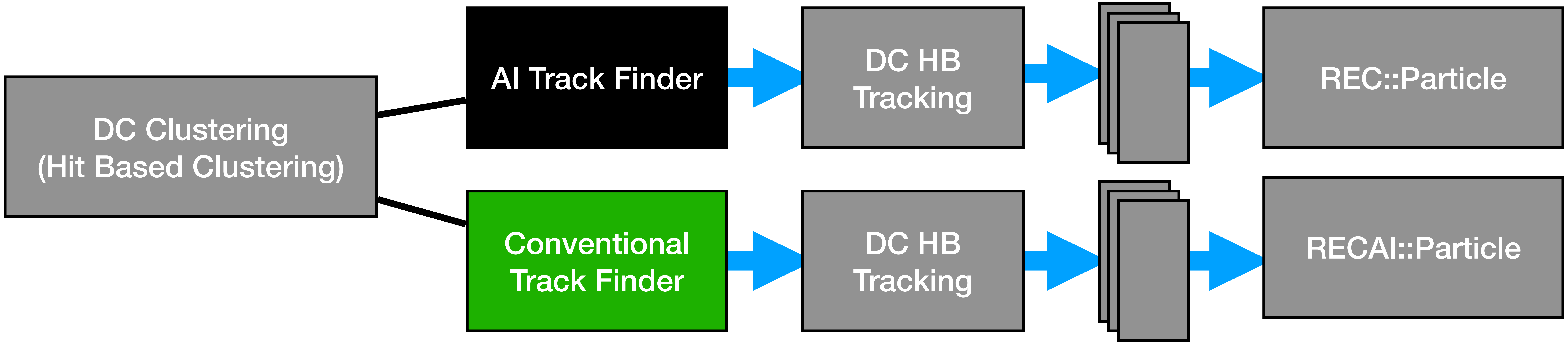
```
------| Run# | flavor | network file -------------------
network/5038/default/trackClassifier.network
network/5038/default/trackFixer.network
network/5038/default/trackParametersNegative.network
network/5038/default/trackParametersPositive.network
network/5089/orchid/trackClassifier.network
network/5089/orchid/trackFixer.network
network/5089/orchid/trackParametersNegative.network
network/5089/orchid/trackParametersPositive.network
network/5610/default/trackClassifier.network
network/5610/default/trackFixer.network
network/5610/default/trackParametersNegative.network
network/5610/default/trackParametersPositive.network
network/6230/default/trackClassifier.network
network/6230/default/trackFixer.network
network/6230/default/trackParametersNegative.network
network/6230/default/trackParametersPositive.network
-----------------------------------------------------------
```

- Interactive tools for listing the content of the database, remove entries and add entries
- Tools for running validation on cooked run for given run number and "flavor"

AI Tracking Reconstruction Tools

Tools

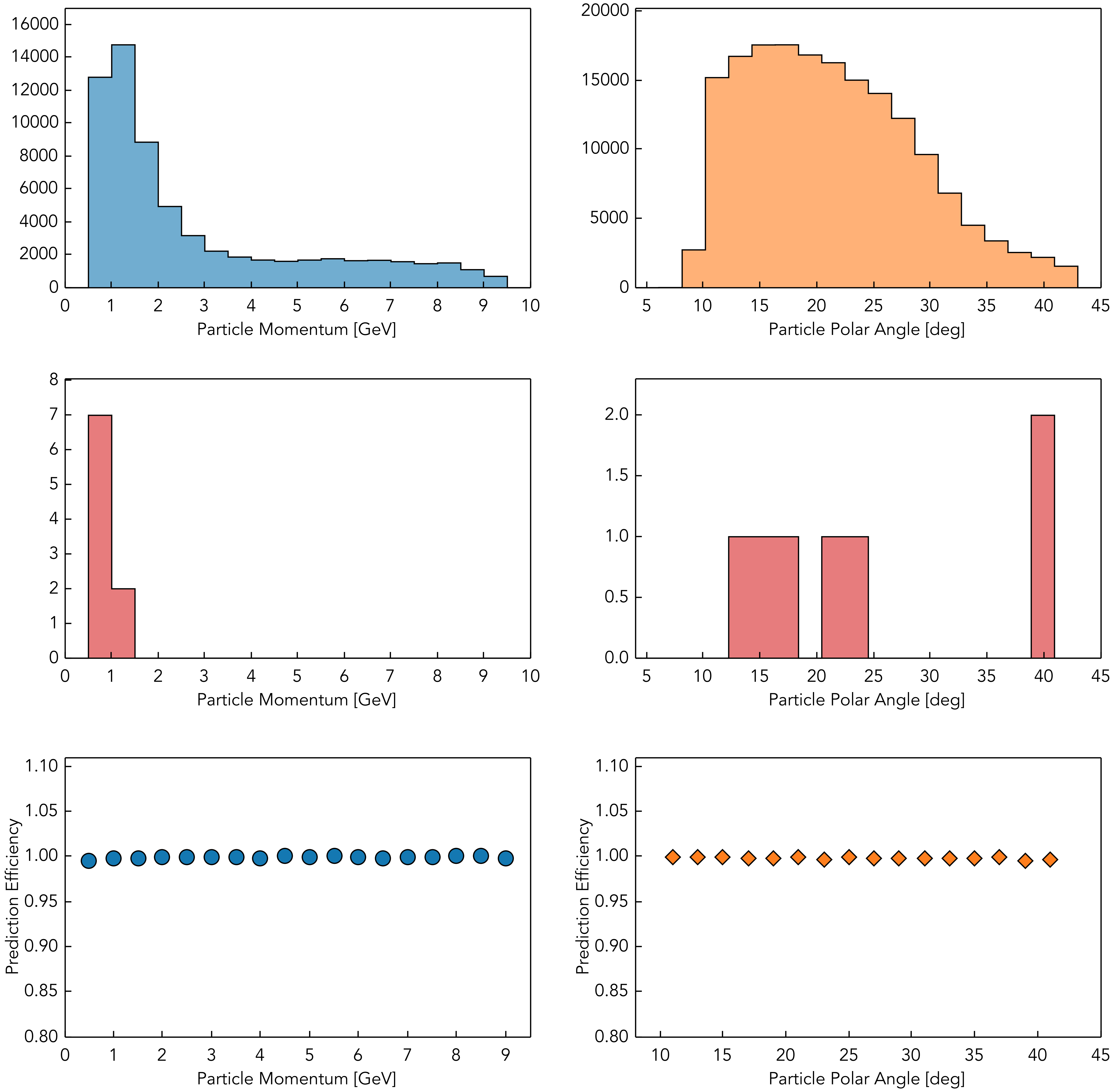
- AI track classification and segment recovery network was implemented as a CLARA service.
- Tracking code was modified to separate clustering from track finding



- Data analyzed in two parallel service compositions with separate output for Time Based Tracking
- The parallel branches produce separate particle banks
- Tracking code in the AI branch is 34% faster compared to conventional branch
- The full chain will be available soon for users to analyze and compare results from AI assisted tracking with conventional tracking.

AI Tracking (Project History)
Track Reconstruction

- Initially the project aimed to identify all track candidates without any loss
- Provide tracking with track candidates so tracking code does not have to spend time on ghost tracks or non-converging tracks
- Improve reconstruction time by considering only valid track candidates.



Lesson Learned:

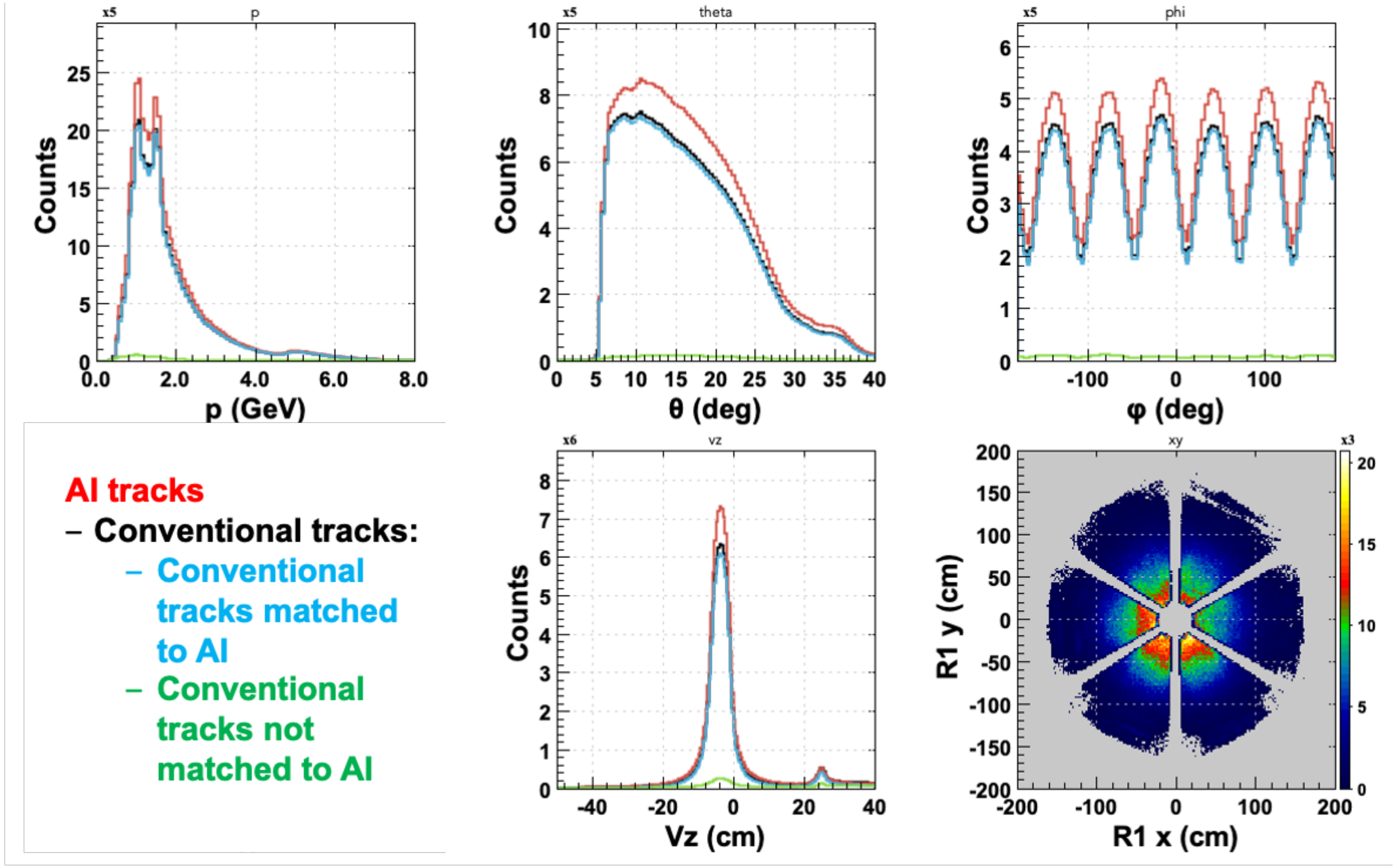
Be careful what you wish for, you may just get more.

AI Validation (all systematic Studies done by R. DeVita)

CLAS12 Tracking with Artificial Intelligence

Track selection:

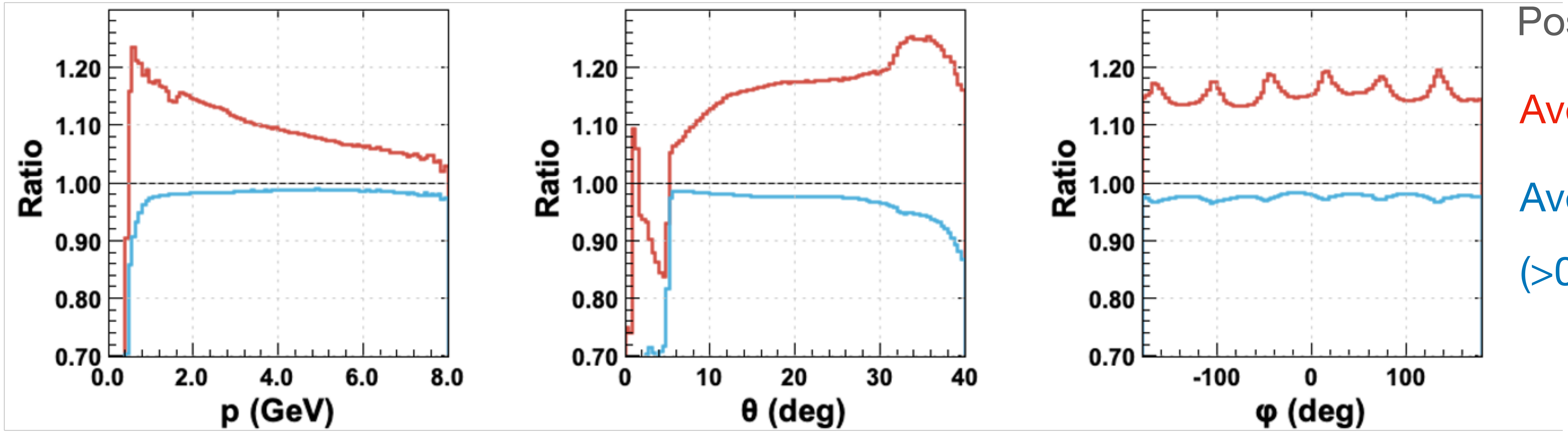
-|vz+5|<10 on all plots except for the vz distribution - chi2/NDF<10 - |chi2pid|<5-RG-A fiducial cuts



AI Validation

CLAS12 Tracking with Artificial Intelligence

- Relative Gain , - Relative Efficiency

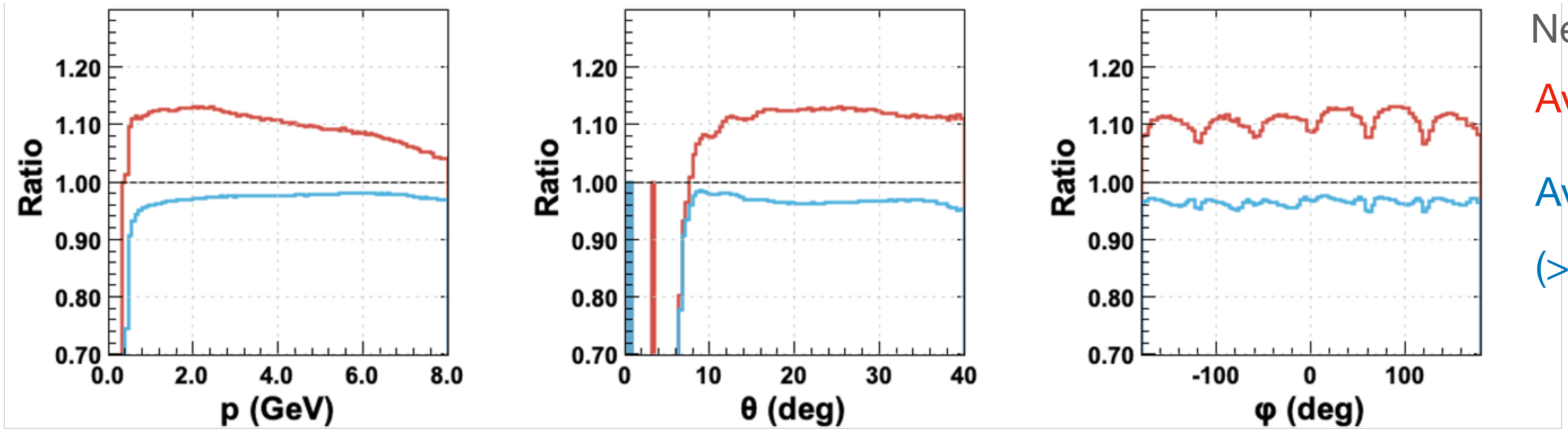


Positive

Average ~1.152

Average ~0.976

(>0.99 with 4 SL match)



Negative

Average ~1.103

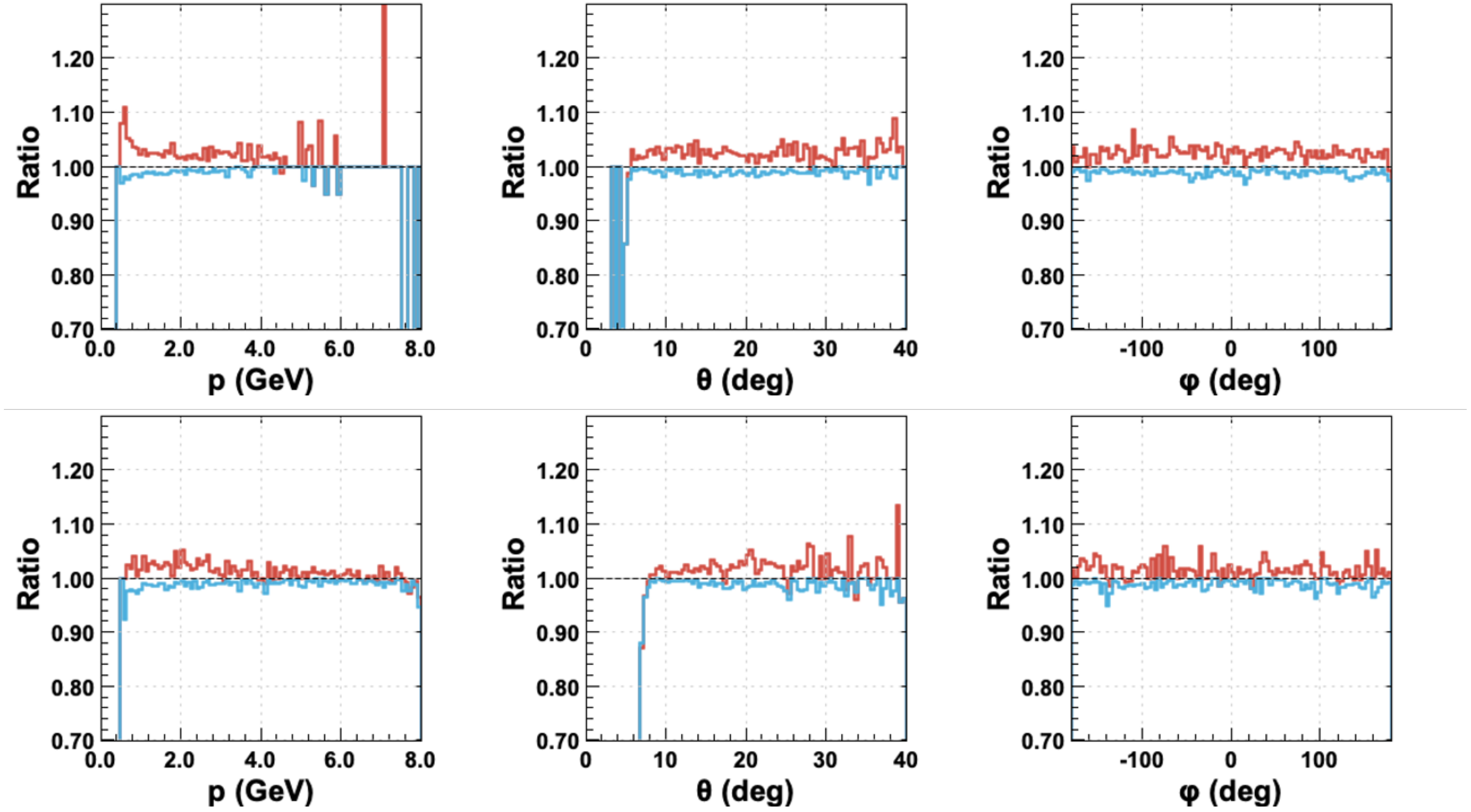
Average ~0.965

(>0.98 with 4 SL match)

AI Validation (MC)

CLAS12 Tracking with Artificial Intelligence

- Relative Gain , - Relative Efficiency



Positive

Average ~1.024

Average ~0.988

Negative

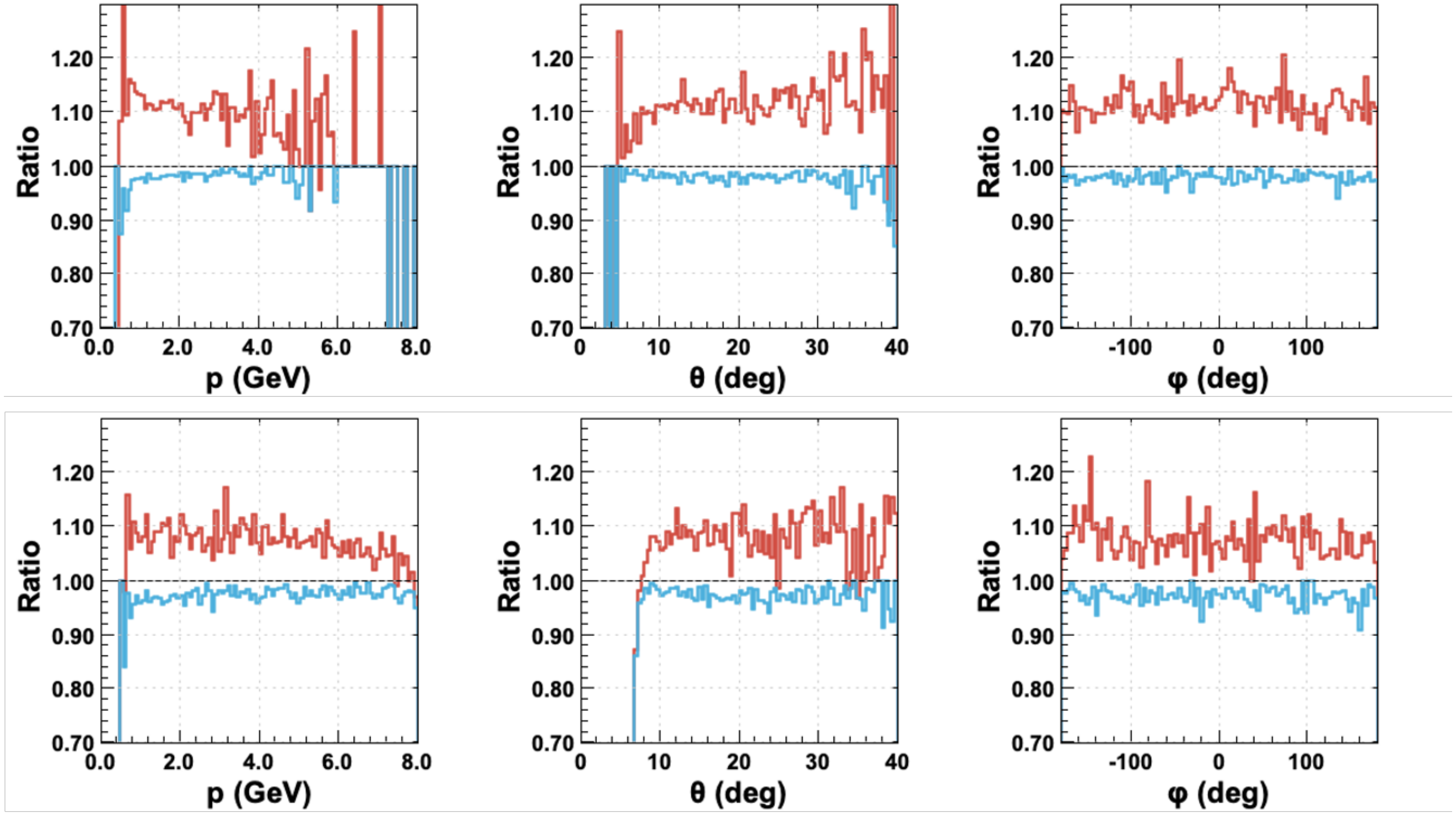
Average ~1.012

Average ~0.988

AI Validation (MC) + 45 nA background

CLAS12 Tracking with Artificial Intelligence

- Relative Gain , - Relative Efficiency



Positive

Average ~1.111

Average ~0.979

Negative

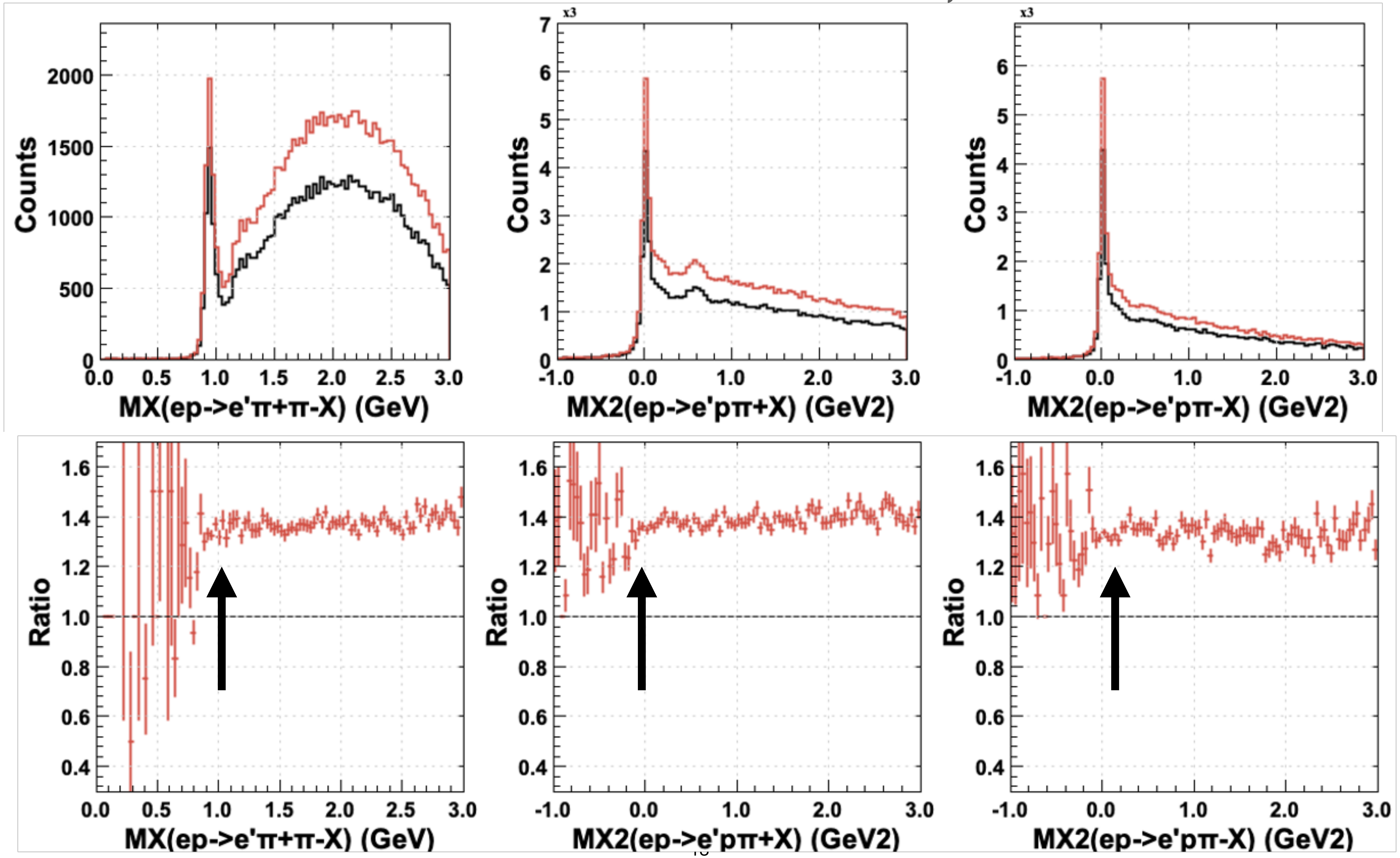
Average ~1.072

Average ~0.973

AI Validation Physics impact

CLAS12 Tracking with Artificial Intelligence

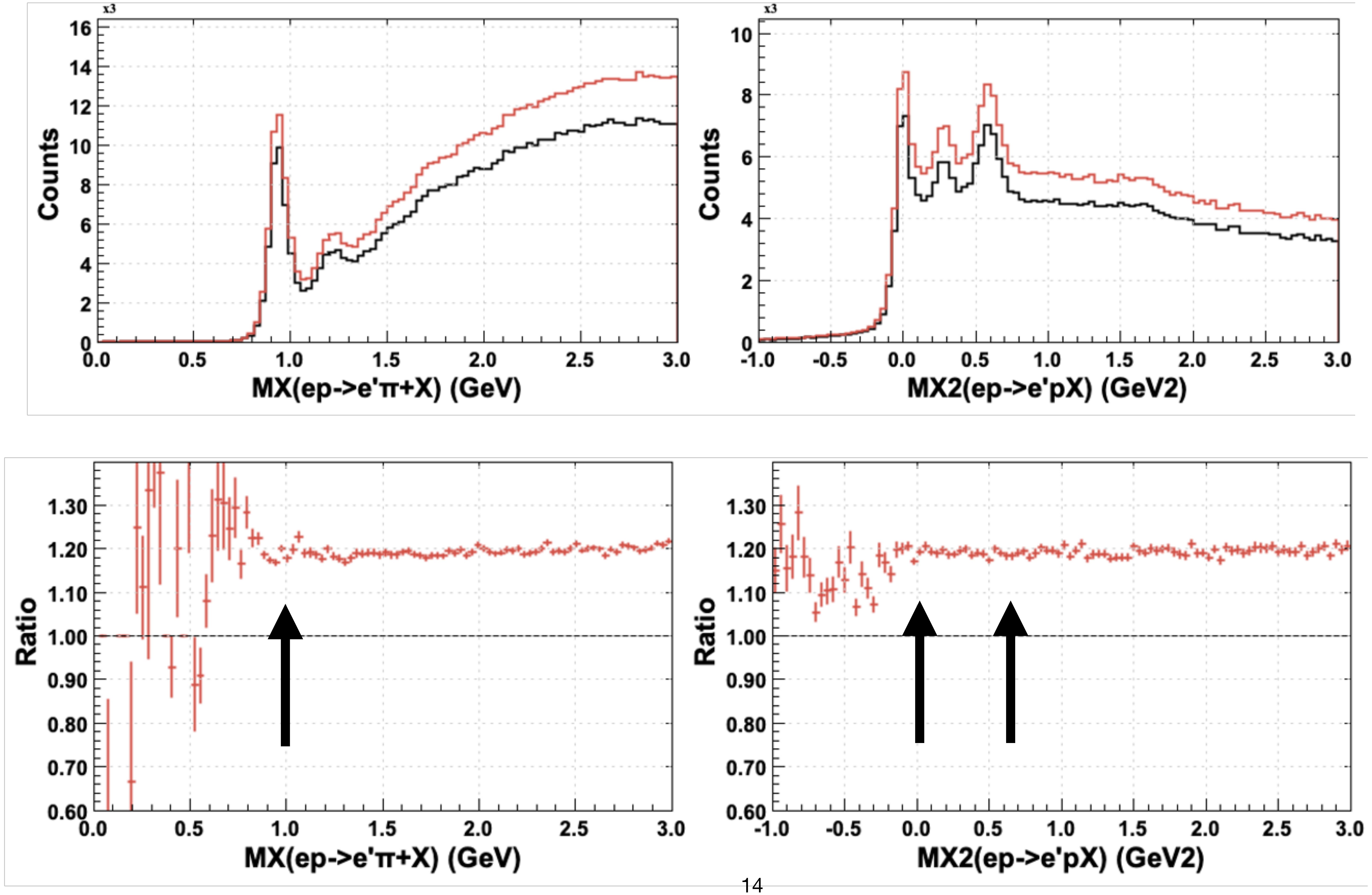
- AI tracks , - Conventional Tracks



AI Validation Physics impact

CLAS12 Tracking with Artificial Intelligence

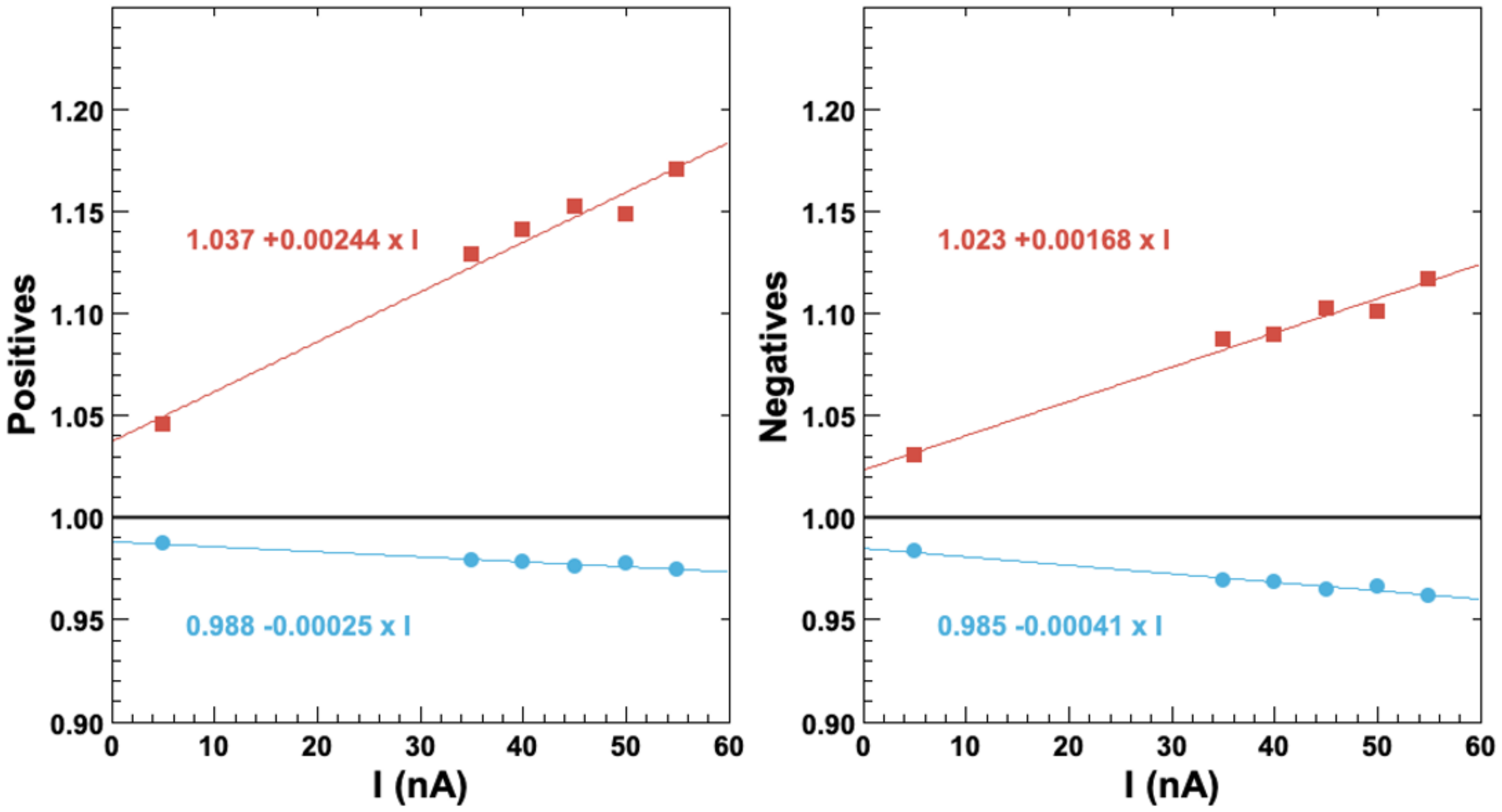
- AI tracks , - Conventional Tracks



AI Validation Luminosity scan

CLAS12 Tracking with Artificial Intelligence

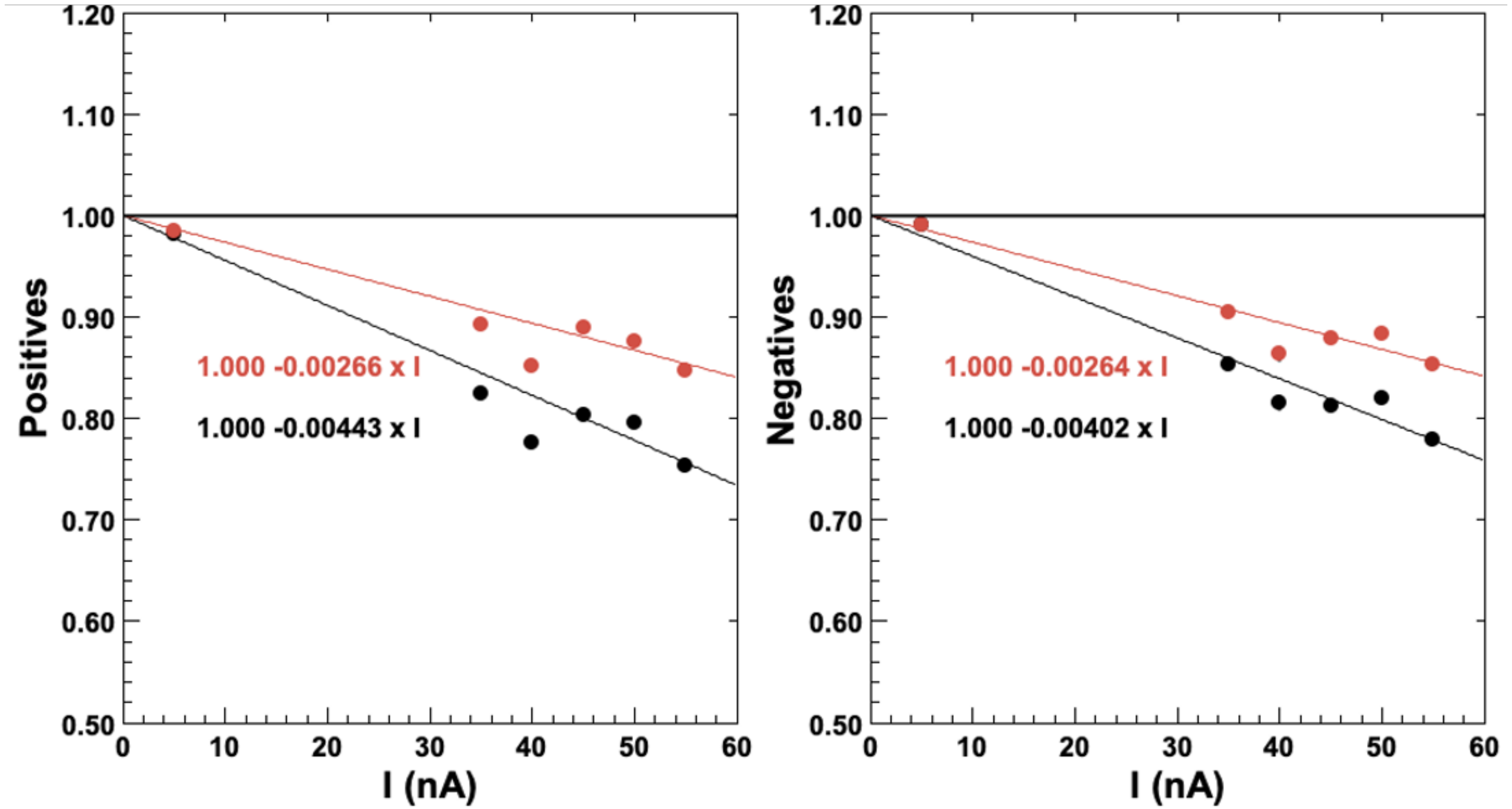
- Relative Gain , - Relative Efficiency



AI Validation Physics impact

CLAS12 Tracking with Artificial Intelligence

- **Absolute reconstruction efficiency** from ratio of $eh^{\pm}/e$ as a function of beam current from RG-A inbending luminosity scan
- Runs: 5418 (5 nA), 5334 (35 nA), 5335 (40 nA), 5038 (45 nA), 5342 (50 nA), 5407 (55 na)



AI Validation Physics impact

CLAS12 Tracking with Artificial Intelligence

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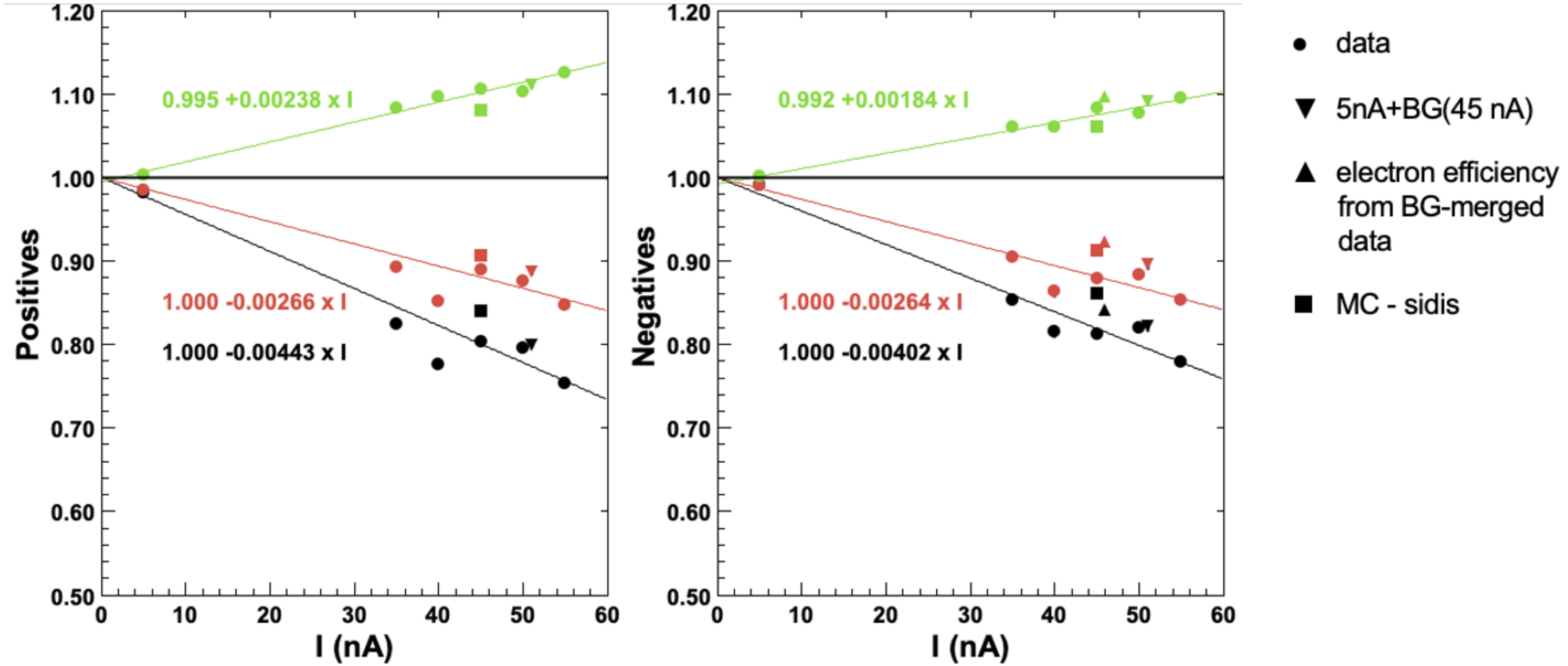

AI Tracking Reconstruction
Process

- The AI track identification software was integrated with the standard reconstruction software.
- Tools are implemented for automated training and deploying trained network, documentation on CLAS12 wiki.
- Archiving software was developed for keeping run dependent (and flavor dependent) networks in organized form and can be used through YAML configuration.

- Studies with data indicate:
  - Efficiency (??) is above 98%.
  - Gain in number of tracks is sizable and is luminosity dependent and significant
  - The "goodness" of the gained tracks is confirmed by physics analysis
- Luminosity Scan analysis
  - Analysis of RG-A Fall 18 scan indicates a relative increase of 6% for negatives and 10% for positives in production conditions (45nA)
  - Analysis of low luminosity data (5nA) merged with background produces consistent results
- MC Analysis
  - Results from MC confirm AI provides higher tracking efficiency (consistent with data)
- The future with AI is here. (Also, the reconstruction is 34% faster with AI track finding)
- The AI reconstructed files will be distributed to analyzers soon to assess physics outcome improvements.

BACKUP SLIDES