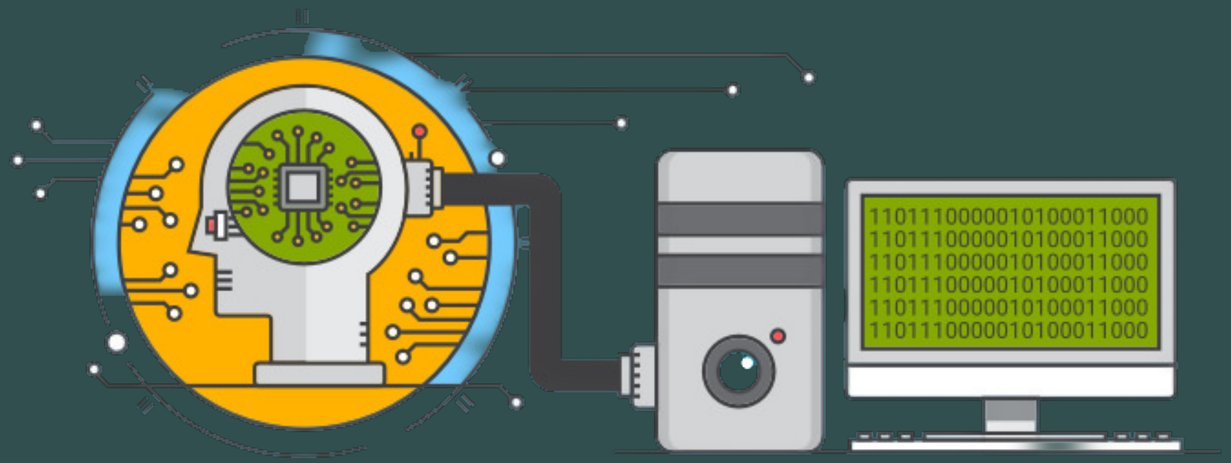
# Real-Time Physics Analysis using AI Track Reconstruction Online

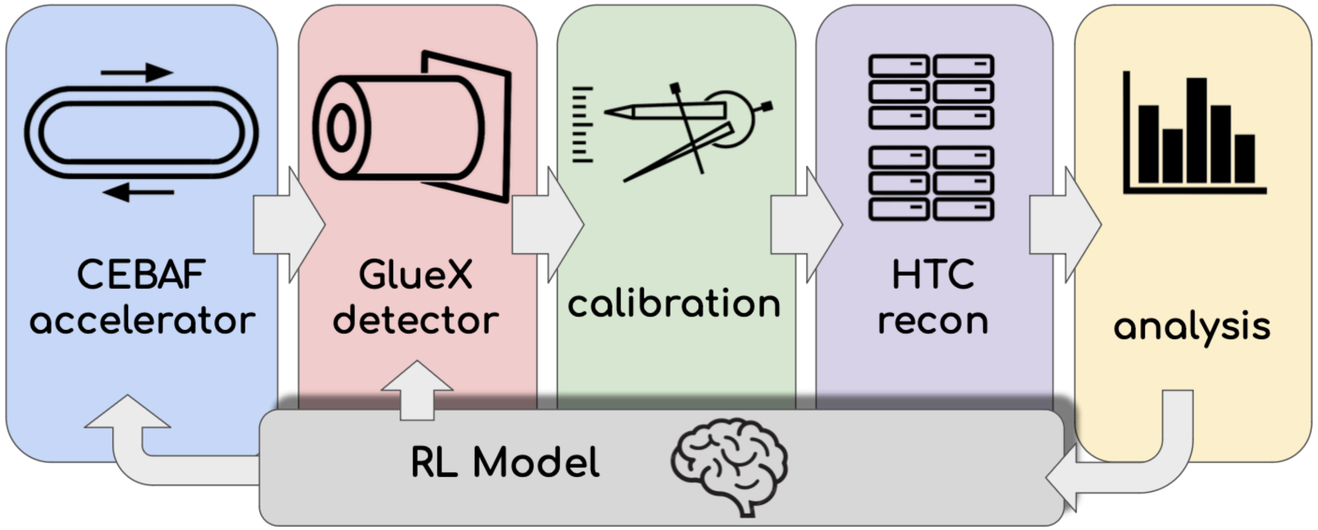
## LDRD Proposal

G.Gavalian (Jefferson Lab)



# Idea

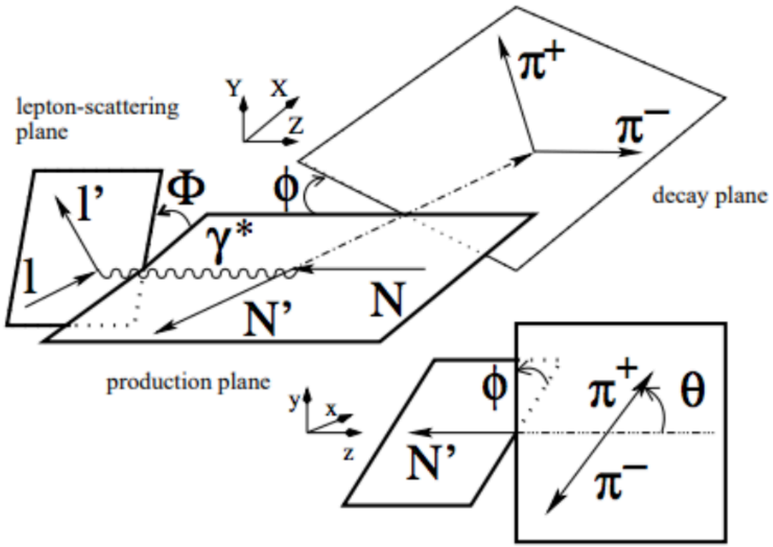





- Automated Experiments
  - Do Online Physics Analysis
  - Measure relevant Observables
  - Provide feedback to the AI to suggest changes in beam parameters (current, energy, etc…)
  - The feedback is provided every hour

- The proposal includes all many experiments:
  - Hall-B CLAS12
  - GlueX (Hall-D)
  - Hall-A

# Idea




$$
\begin{aligned}
W^U(\Phi,\phi,\cos\Theta) = \frac{3}{8\pi^2}\Big[ & \frac{1}{2}(1-r^{04}_{00}) + \frac{1}{2}(3r^{04}_{00}-1)\cos^2\Theta \\
& - \sqrt{2}\mathrm{Re}\{r^{04}_{10}\}\sin 2\Theta\cos\phi - r^{04}_{1-1}\sin^2\Theta\cos 2\phi \\
& - \epsilon\cos 2\Phi\Big(r^{1}_{11}\sin^2\Theta + r^{1}_{00}\cos^2\Theta \\
& \quad - \sqrt{2}\mathrm{Re}\{r^{1}_{10}\}\sin 2\Theta\cos\phi - r^{1}_{1-1}\sin^2\Theta\cos 2\phi\Big) \\
& - \epsilon\sin 2\Phi\Big(\sqrt{2}\mathrm{Im}\{r^{2}_{10}\}\sin 2\Theta\sin\phi \\
& \quad + \mathrm{Im}\{r^{2}_{1-1}\}\sin^2\Theta\sin 2\phi\Big) \\
& + \sqrt{2\epsilon(1+\epsilon)}\cos\Phi\Big(r^{5}_{11}\sin^2\Theta + r^{5}_{00}\cos^2\Theta \\
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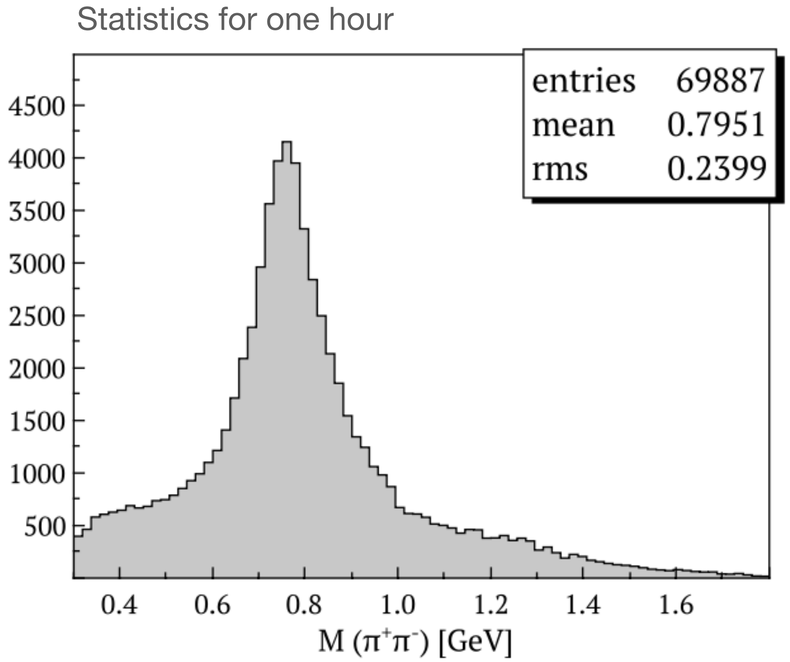
& \quad + \mathrm{Im}\{r^{6}_{1-1}\}\sin^2\Theta\sin 2\phi\Big)\Big],
\end{aligned}
$$

- Hall-B
  - Study rho meson
  - Identify relevant observables that are impacted by beam conditions
  - Provide feedback to the accelerator to change the beam conditions.

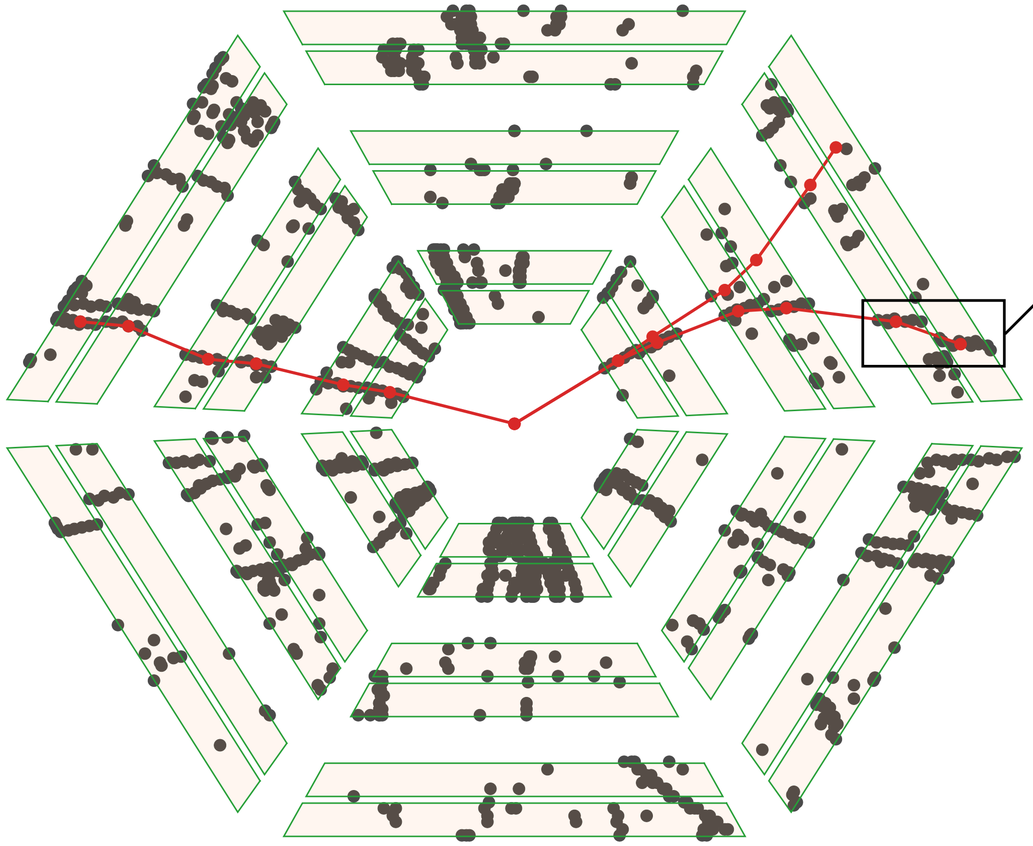


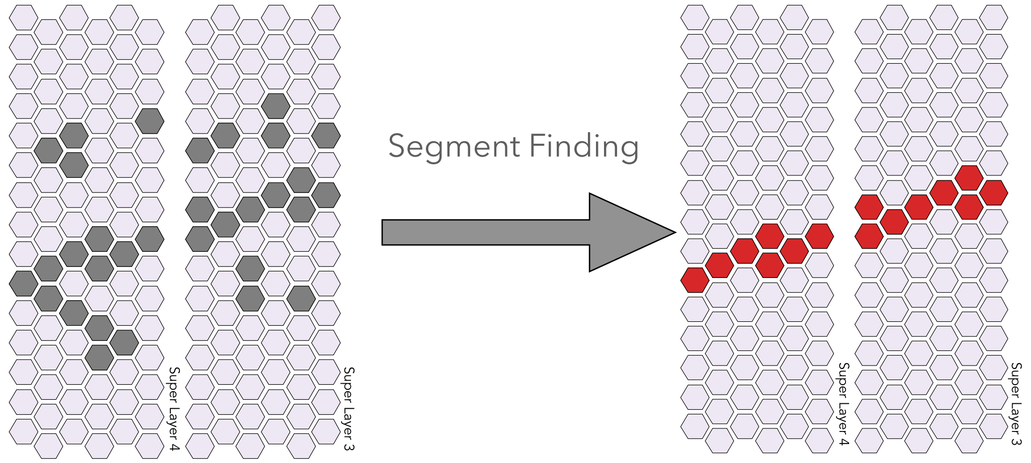

- Challenge:
  - How do you analyze experimental data at data-taking within one hour?
  - DAQ rate is 16 kHz; the reconstruction rate is 1 Hz on a single CPU

# Segment Finding (to be developed)



- 6 sectors with 6 chambers in each sector (called super-layers)
- 6 wire planes in each super layer with 6-degree tilt relative to each other, (112 wires in each plane)



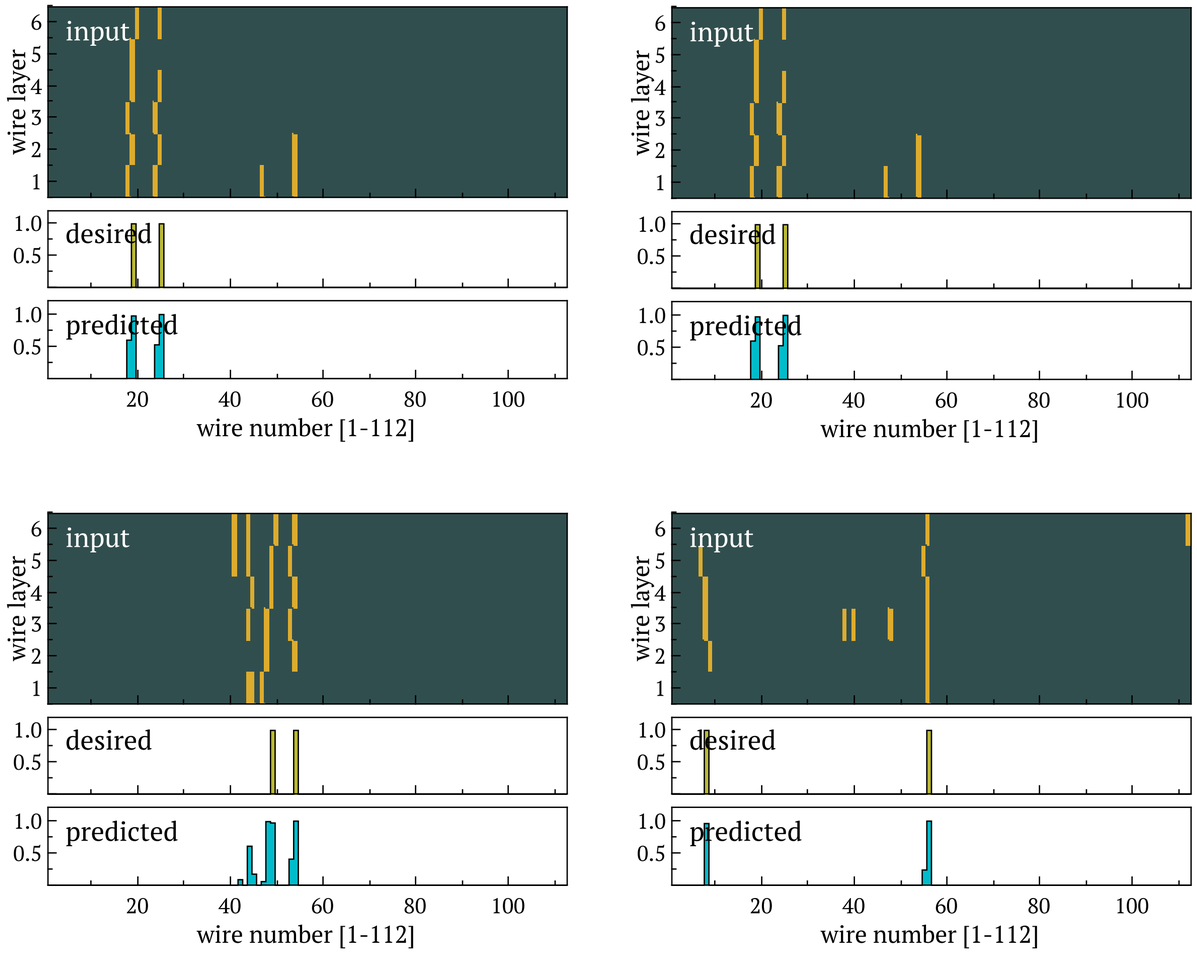


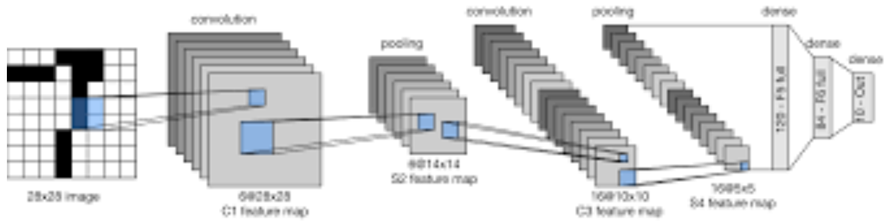

Need to develop fast AI based segment finding algorithm
(The reconstruction segment finder is 6 Hz)
Not suitable for online

- Find segments in each super layer (remove noise)
- Combine 6 segments (one from each super layer) to make a list of possible tracks
- Identify correct combinations of segments that represent a track

# Feasibility tests



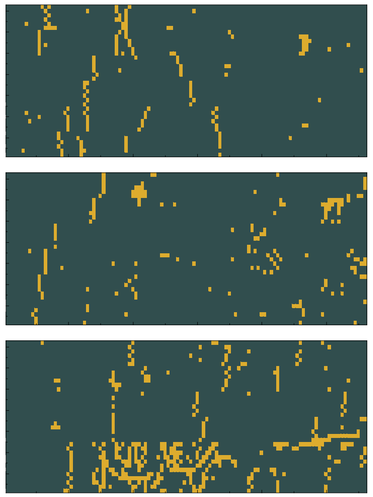


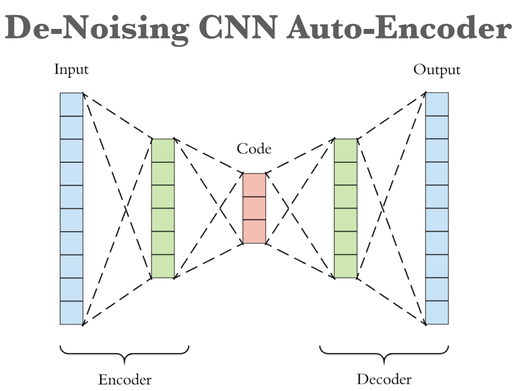



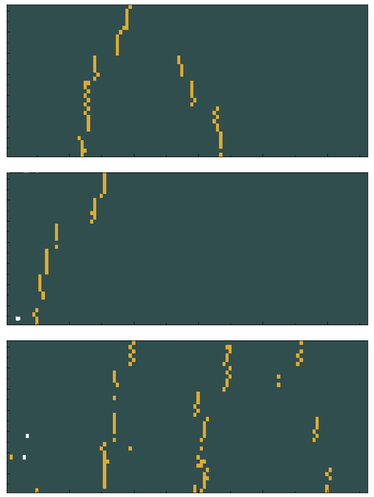

- Clustering Algorithm:
  - Convolutional Neural network with logistic regression to identify possible cluster positions.
  - Currently at 80% efficiency
- Proposed work:
  - Investigate algorithms to identify clusters fast and with higher efficiency

# What do we have now



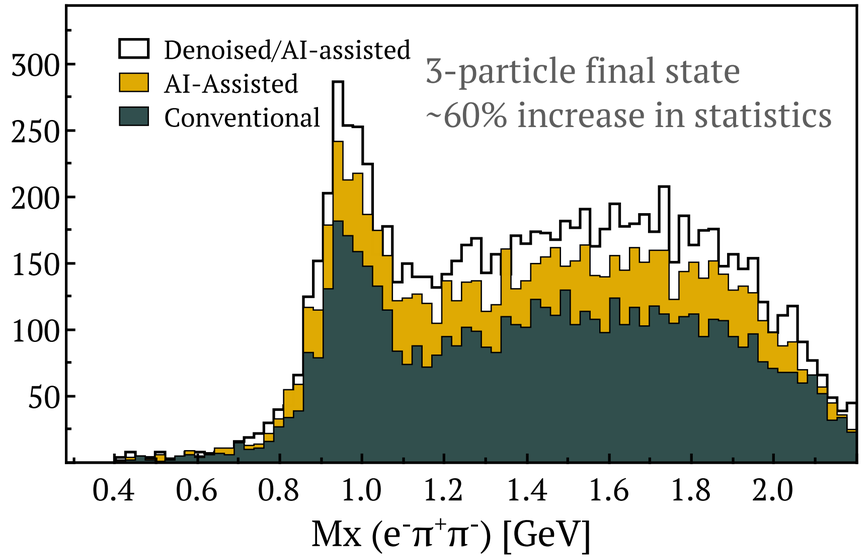




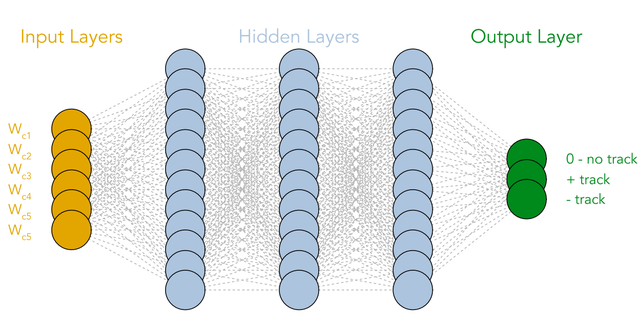



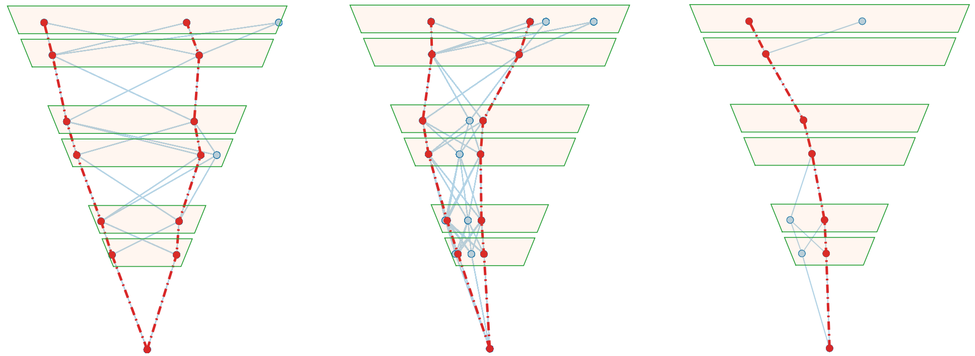
Retains >95% of hits belonging to tracks, and removes >90% of background hits

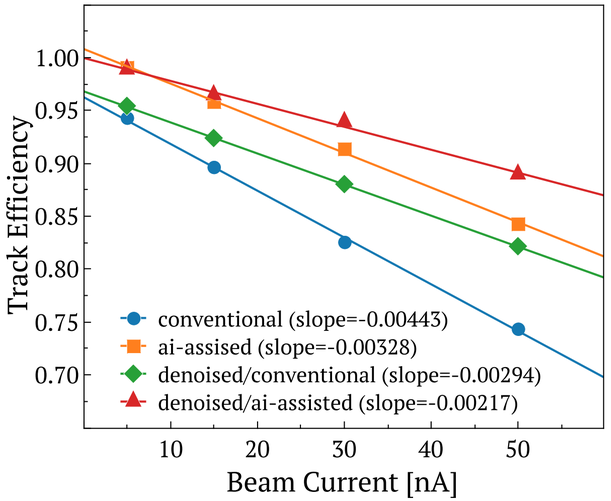
CLAS12 Track Reconstruction with Artificial Intelligence
Gagik Gavalian (Jefferson Lab), Pet all e-Print: 2205.02616 [physics.ins-det]




The Classifier network identifies tracks from segment combinations and identifies track charges. The AI-assisted track identification increased tracking efficiency by **15%-21%** (depending on luminosity)
Improvement of the efficiency slope as a function of luminosity.





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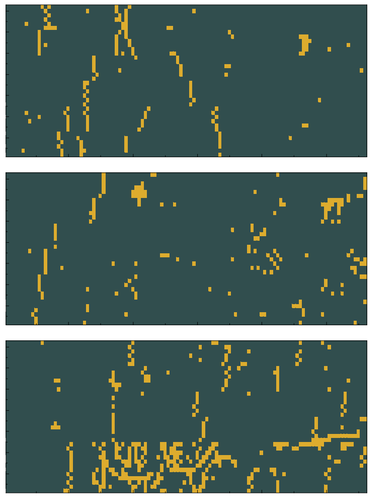

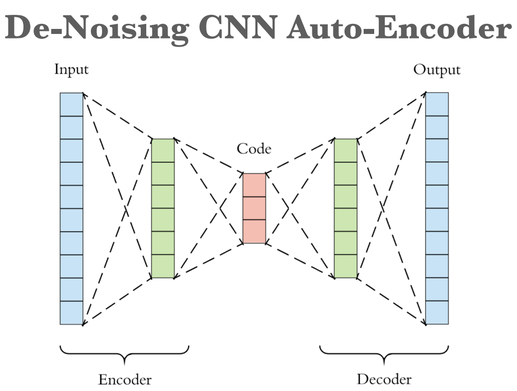


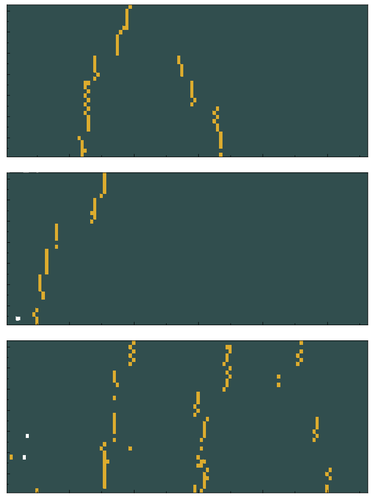

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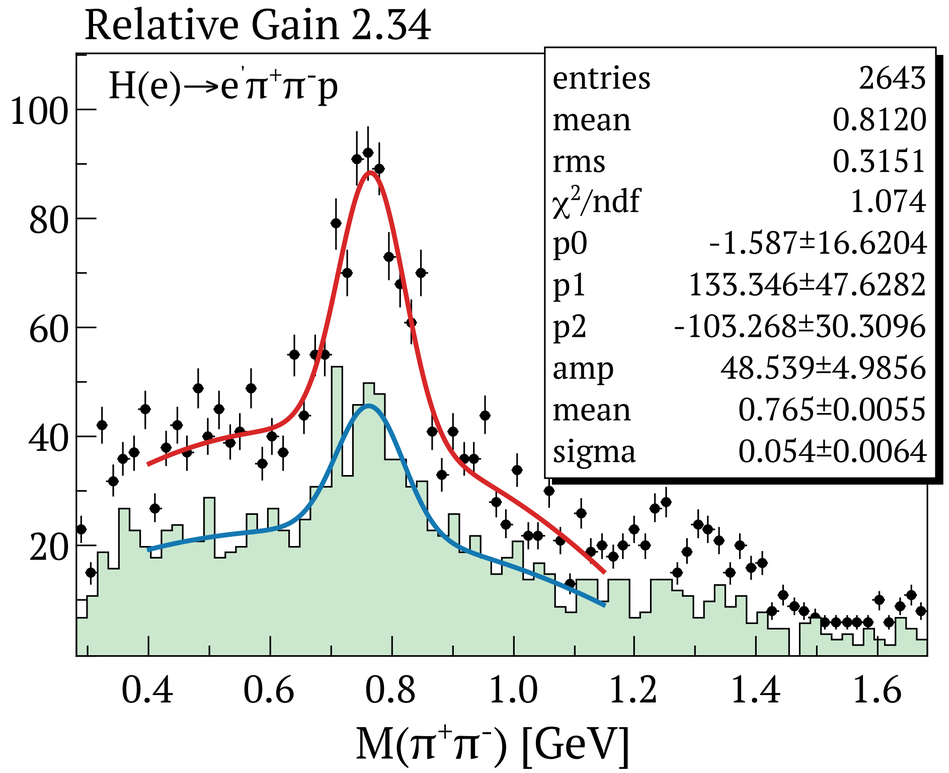


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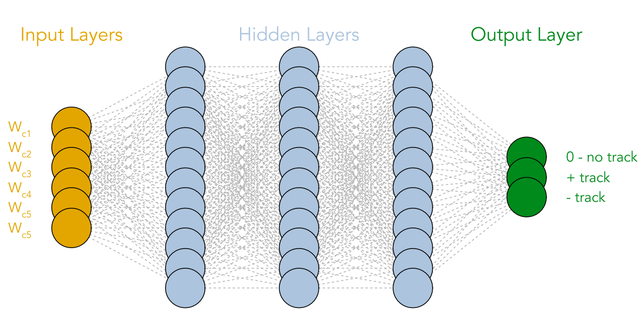
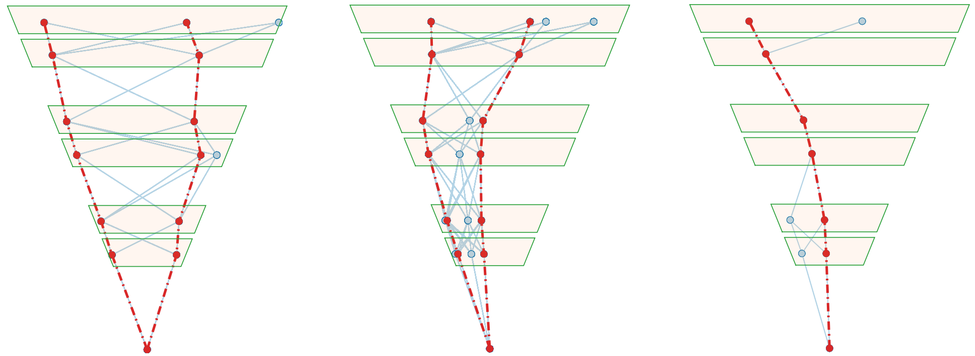
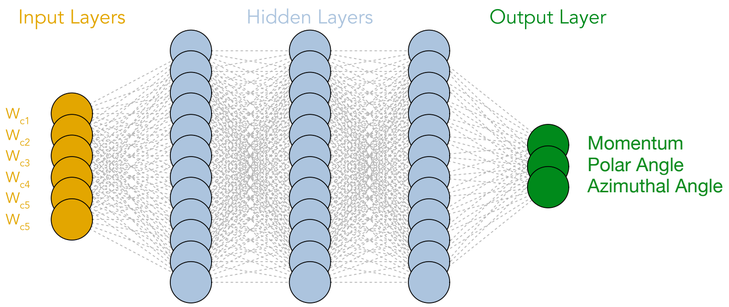


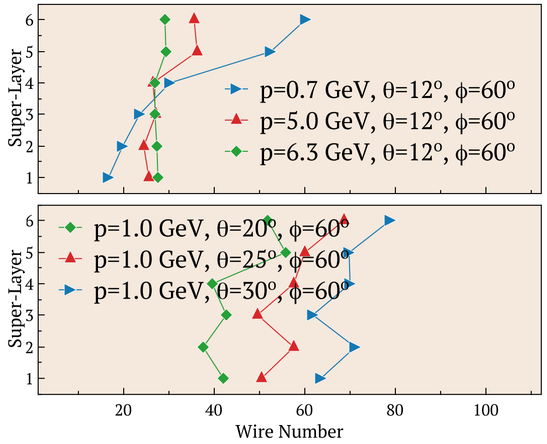



The statistics increase by a factor of 2.34 for exclusive rho mesons when using AI in reconstruction

# What do we have now.

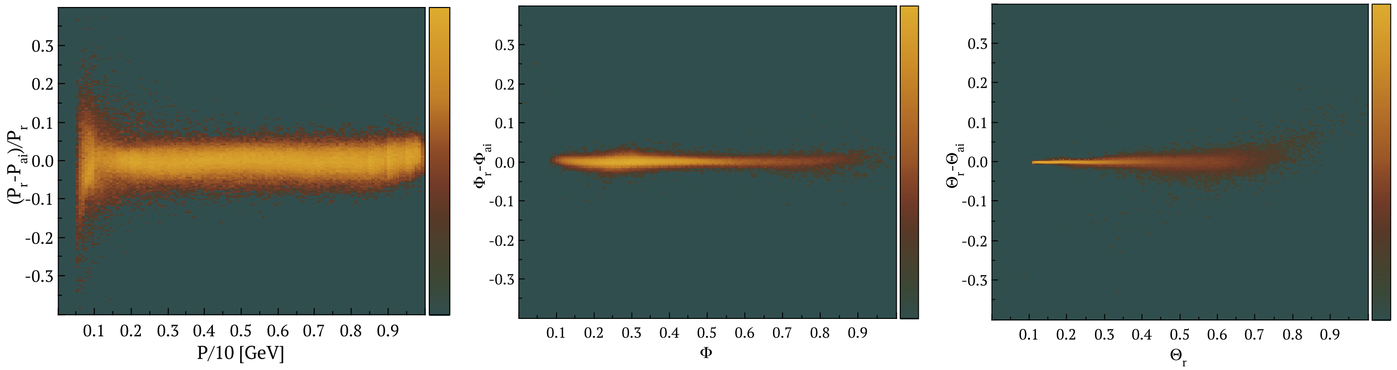




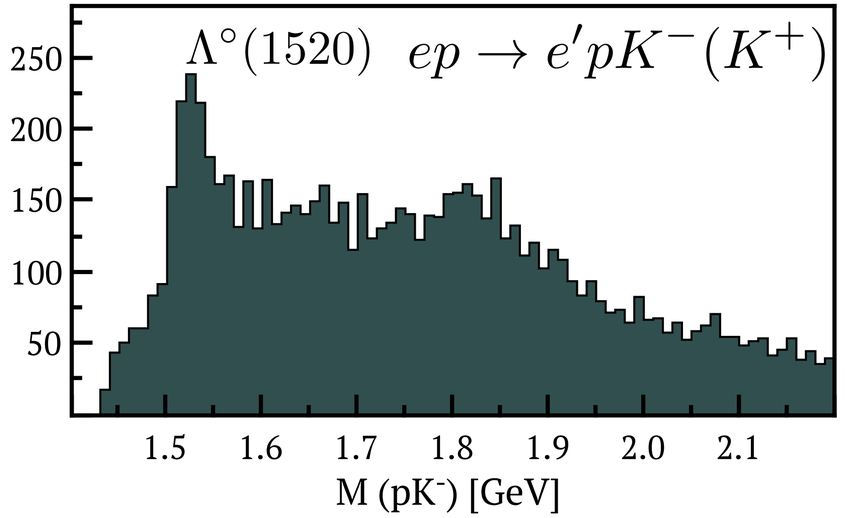



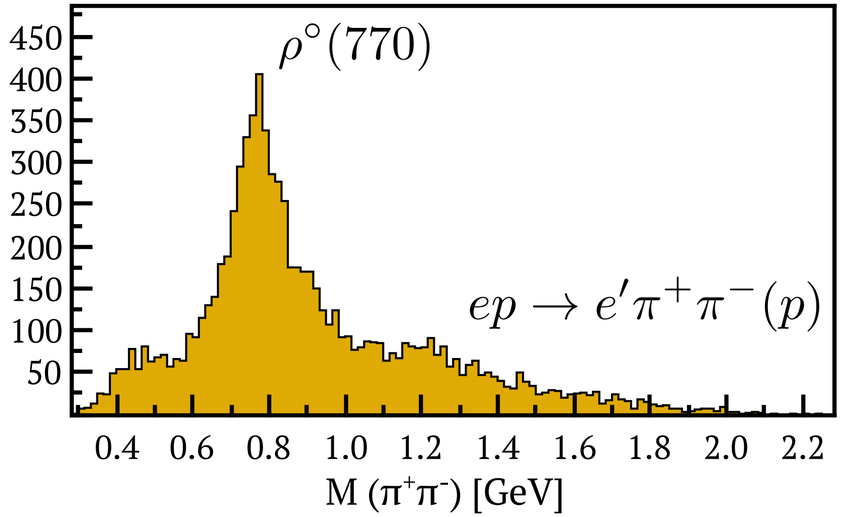

Regression Neural network to predict the track momentum and direction.
The track momentum is reconstructed with an accuracy of 1.4%-1.7%

Physics reactions can be cleanly identified using particle parameters inferred by the neural network.




Distributions calculated from track reconstruction from RAW Drift Chamber hits
Inference speed 96 kHz on a laptop (MacBook M3)



# Conclusion



- **AI approach**
  - Do fast reconstruction of the track with AI, and isolate rho
  - The AI reconstruction is faster than DAQ, making it feasible
  - Analyse rho meson angular observables (asymmetries, modulations, etc..)
  - Determine how the extraction systematic errors change as a function of beam current
  - Build an AI model that can predict the optimal beam conditions for the experiment.