Optimizing Dimuon Reconstruction in SpinQuest

Speaker: Jay
Adviser: Dustin Keller

Outline

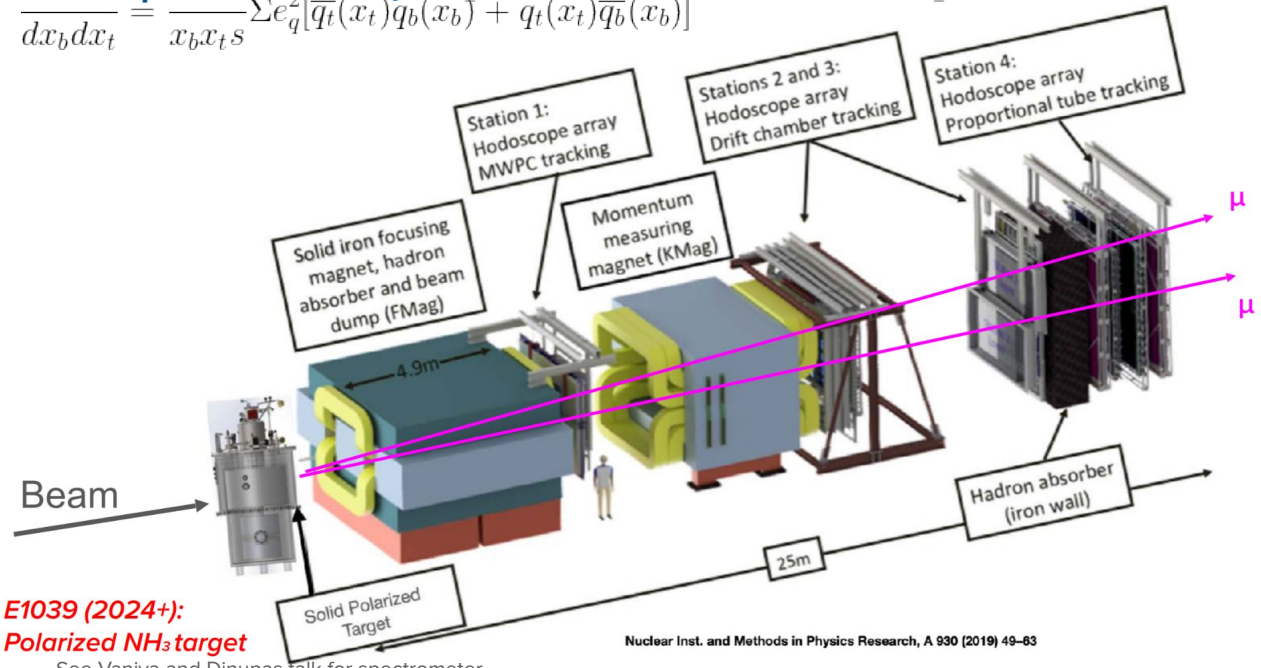
- Motivation
- Target and spectrometer
- Reconstruction
- Q-Tracker
- Improvements

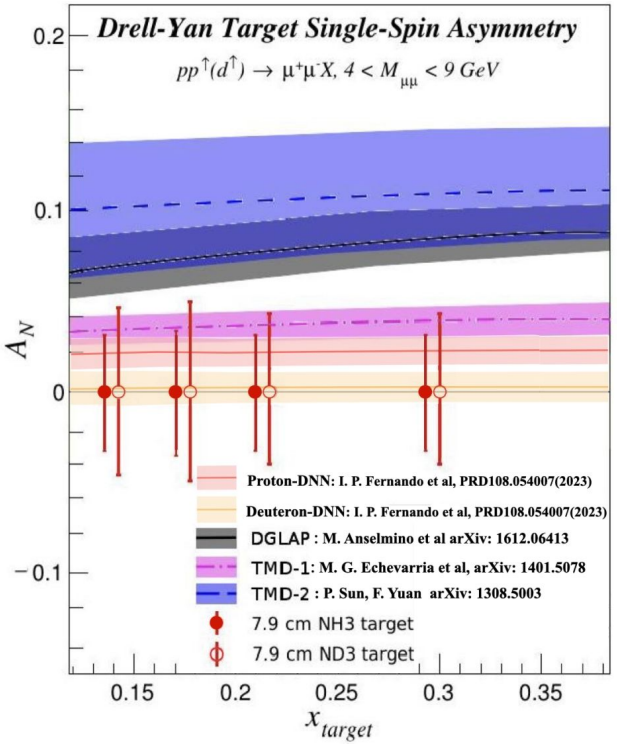
This work was supported by the U.S. Department of Energy (DOE) Contract No. DE-FG02-96ER40950.

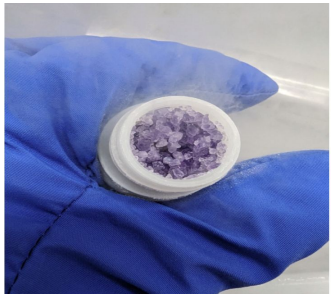
SpinQuest: Polarized Target DY Experiment

- 120 Gev proton Beam
- 4 seconds spills with ~ 2.5X10^12 protons per second.
- Aim to have the highest instantaneous proton intensity on a polarized target!

$$\frac{d^2\sigma}{dx_b dx_t} \doteq \frac{4\pi\alpha^2}{x_b x_t s}\Sigma e_q^2[\overline{q}_t(x_t)\bar{q}_b(x_b) + q_t(x_t)\overline{q}_b(x_b)]$$





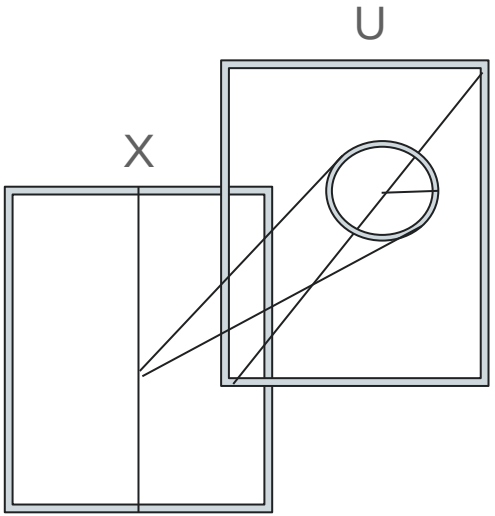


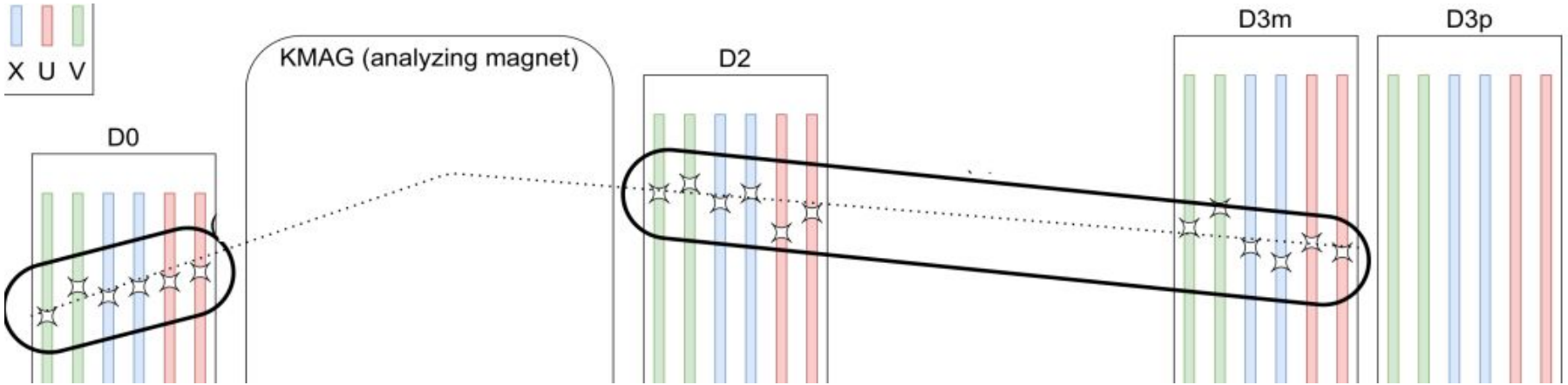
E1039 (2024+): Polarized NH_3 target

See Vaniya and Dinupas talk for spectrometer

Reconstruction

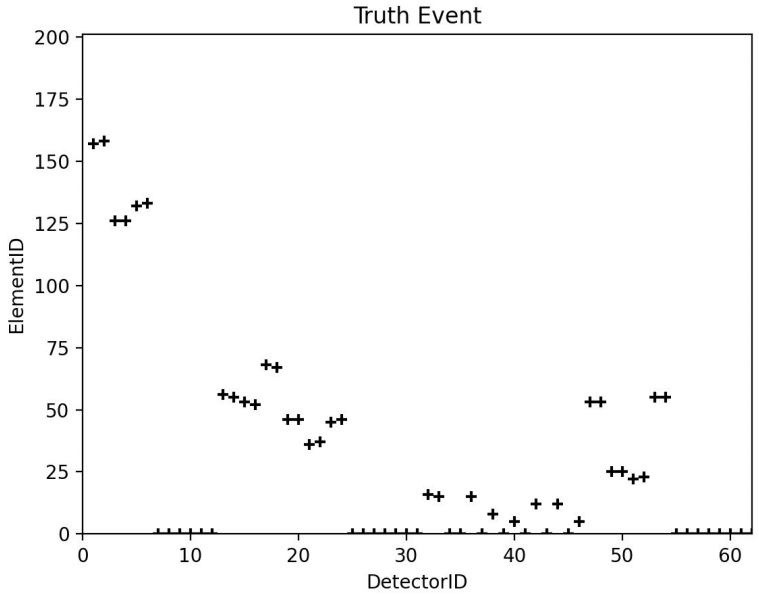
- Goal: Obtain the vertex and four momentum from the detected particle.
- Filter out all tracks except for those that come from the target.
- Currently only complete tracks are reconstructed.

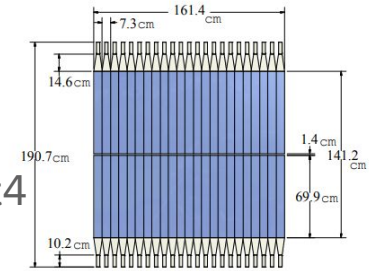




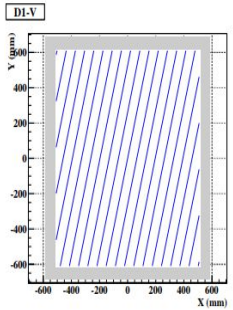
Hit matrice

- Every run has a multiple spills. 4 seconds spills with ~ 2.5X10^12 protons per second.
- Every spill has ~ 5-10K events.
- Generated Events stored in a boolean matrix.
- The spectrometer has several detectors planes. Each detector plane has several elements.
- Where element ID and detector ID overlap, is a hit local to that detector plane.
- Every event has several hits.
- This structure is simulated using Geant4 and Pythia and stored in root files.

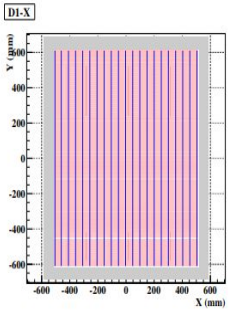




Hodoscope Array 1X



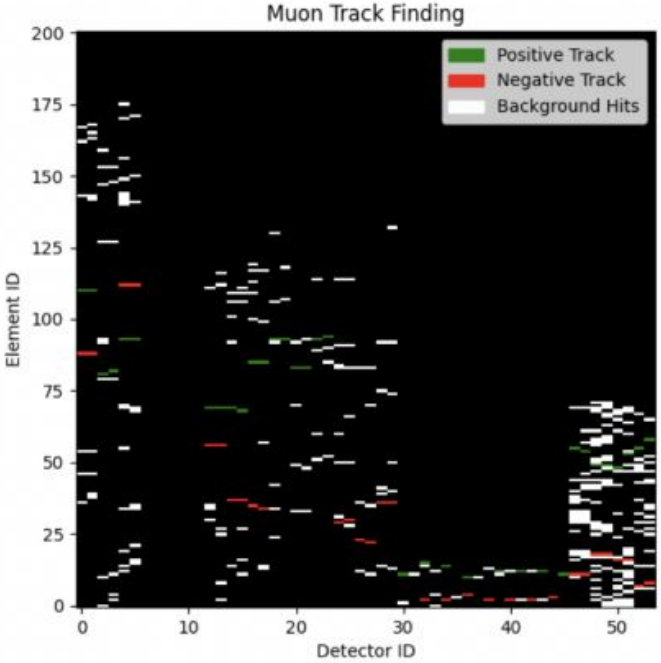
(a) V plane

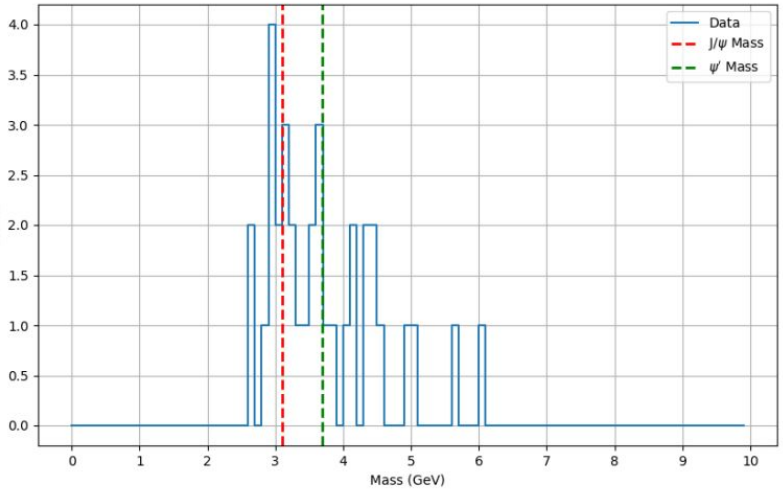


(b) X plane

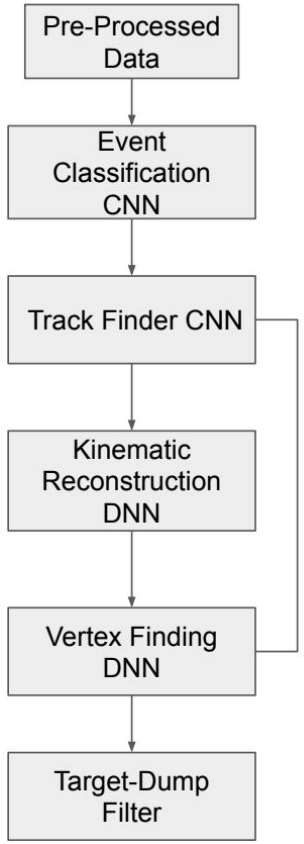
Q-Tracker

- A system of models used to perform reconstruction.
- Started as a system of CNNs and DNNs.
- Is currently in alpha but beta plans to enhance the project.
- Reconstructs 20K events ~ 15 seconds.



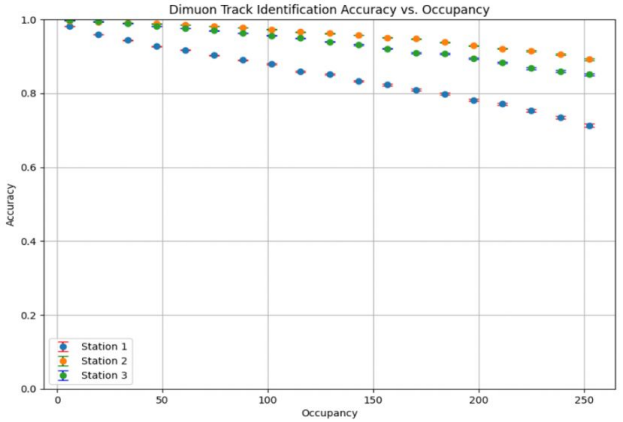


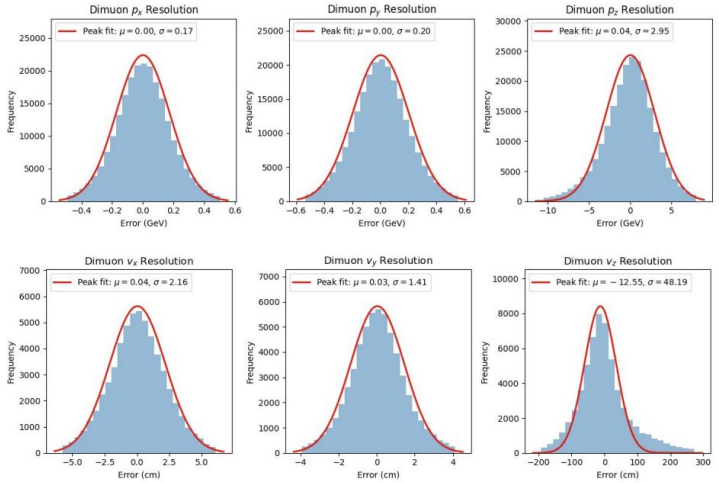
ALPHA

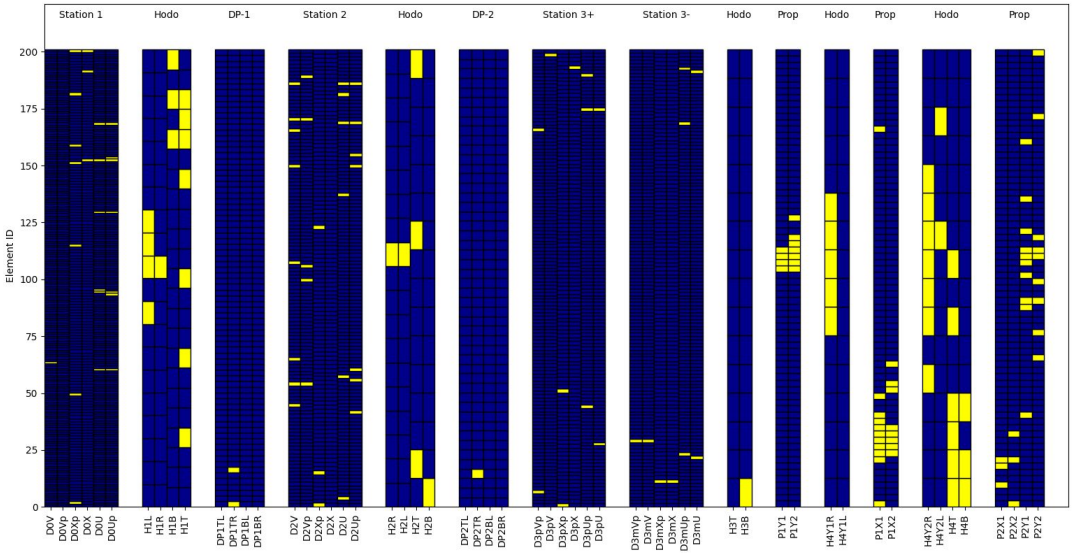


Q-Tracker: Alpha

- Solely used for speed. Reconstruction within seconds.
- Allows for Quick reconstruction of spills for online monitoring.
- Limited to events with only 1 dimuon track.

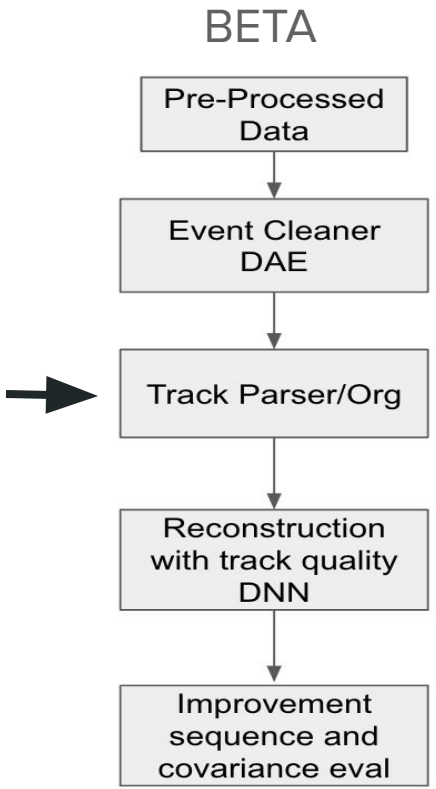






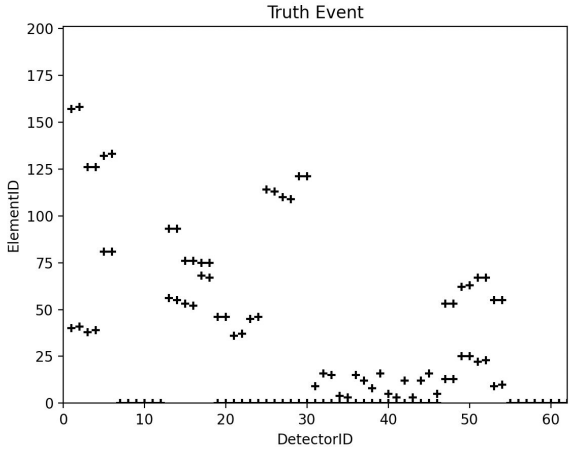
Q-Tracker: Beta

- Objective: Robust reconstruction for offline.
- Quantifying the error of the models is key to being “robust”.
- Training:
  - Generate a robust set of training MC that mimics SpinQuest Spills.
  - Contain: Partial tracks from target/Dump/Gap.
  - Replicate background from electronic noise, clustering, and edge hits.
  - Stored in a universal format.
- Quality Metric:
  - A benchmark to compare other results to.
  - Measure how the error propagates through the model.
  -
- Structure:
  - Piecewise multi-model structure for component systematic studies.
  - Probabilistic interpretation of output errors.
  - Highly tuned and matched MC events (hit matrices) to train the model sequences.
- Currently working on the Track Parsing Model.

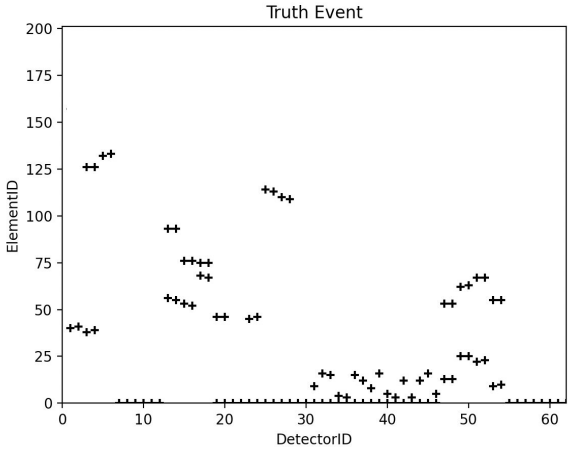


Optimizing the model: Track Organizer and Quality metric

- Goal: Quantify how well a model can reconstruct a muon track. The error of the model.
- **Track Quality metric depends on:**
  - Probability of the track being reconstructable.
  - Number of hits that make up the track.
  - Occupancy of the event
- How does the error changes with different event complexity?

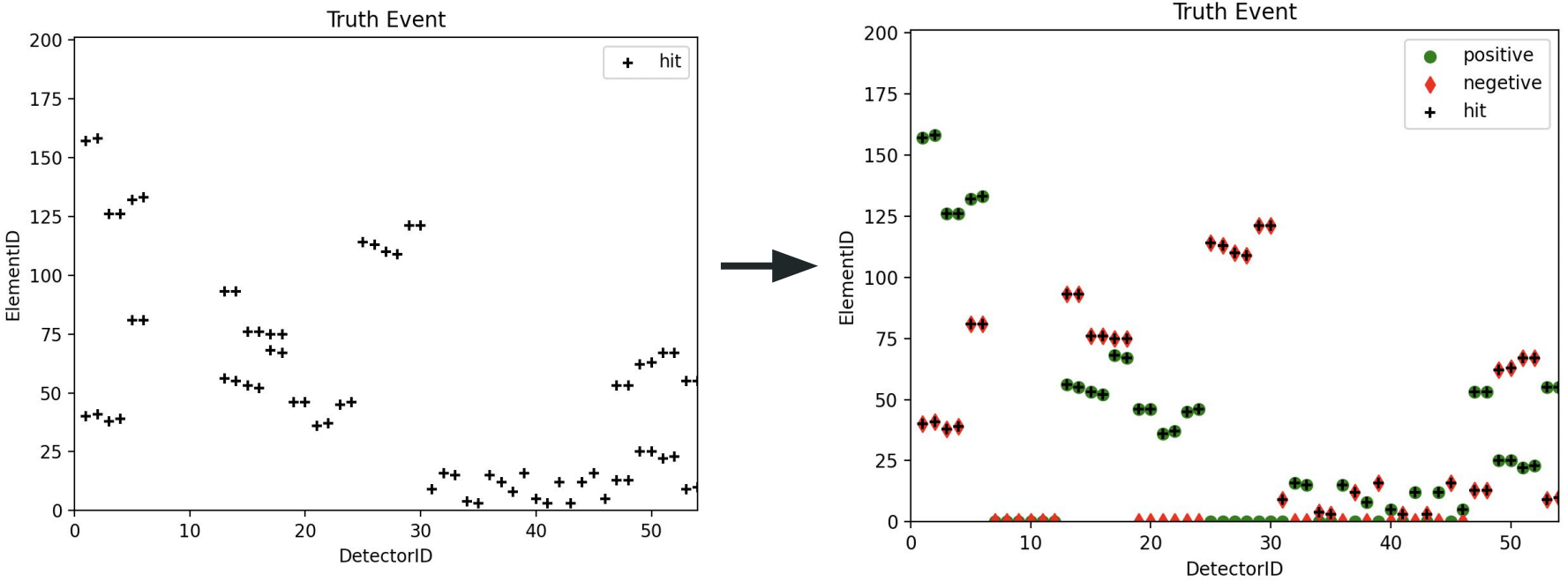


Vs



Organizing the Tracks

Identify 2 **clean** hit arrays: Positive Muon Track and Negative Muon Track



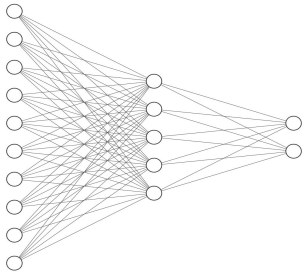
Challenges: Data and Tuning

- Preprocessing Data in Batches.
- Incremental Learning.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Pred_i - True_i|$$

$$Residual = True - Pred$$

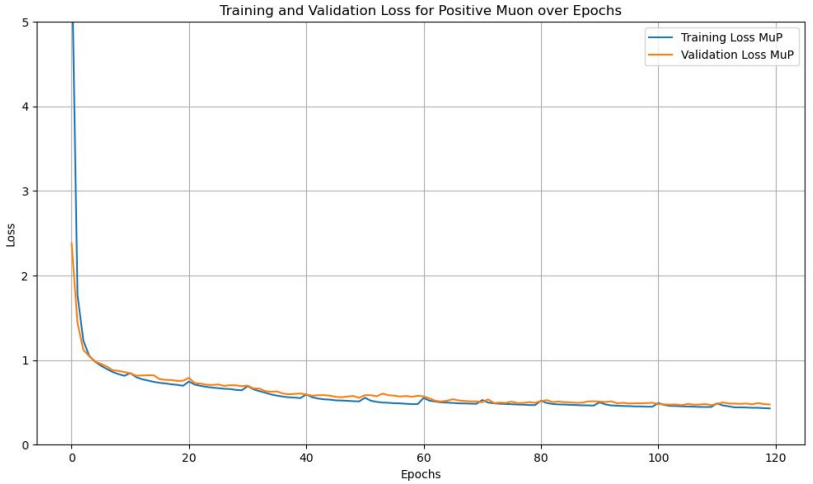
$$Error = \frac{True - Pred}{True}$$

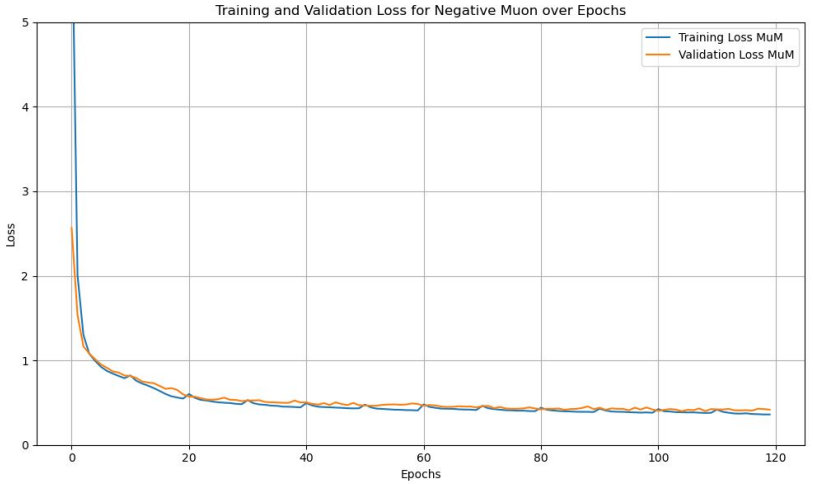


Not to scale

Layer (type)	Output Shape	Param #	Connected to
input_1 (InputLayer)	[(None, 62, 201)]	0	[]
flatten (Flatten)	(None, 12462)	0	['input_1[0][0]']
dense (Dense)	(None, 128)	1595264	['flatten[0][0]']
dense_1 (Dense)	(None, 64)	8256	['dense[0][0]']
dense_2 (Dense)	(None, 128)	8320	['dense_1[0][0]']
dense_3 (Dense)	(None, 128)	8320	['dense_1[0][0]']
output_1 (Dense)	(None, 62)	7998	['dense_2[0][0]']
output_2 (Dense)	(None, 62)	7998	['dense_3[0][0]']

Total params: 1,636,156
Trainable params: 1,636,156
Non-trainable params: 0





Preliminary result

Conclusion

- SpinQuest is a polarized target DY experiment at fermilab setting records for polarization and highest instantaneous proton intensity on a polarized target.
- UVA has an ongoing effort to provide fast reconstruction in the form of:
  - Q-Tracker alpha which is focused towards online monitoring and online reconstruction.
  - Q-Tracker beta which is focused toward robust offline reconstruction.
- While Q-Tracker alpha is pushing the limits of speed, 20k events in 15s, Q-Tracker beta will start by quantizing how error propagates within the model.
- Model error is being studied via identifying very clean hit arrays to perform reconstruction on, using the residual of the predictions as a quality metric.
- The quality metric aims to improve track selection and expand the reach of ML reconstruction.

Thinking of Joining SpinQuest: dustin@virginia.edu
https://spinquest.fnal.gov