SPIN 2023

Advancements in Online Monitoring and Visualization for SpinQuest

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U.S. DEPARTMENT OF ENERGY | Office of Science

Fermilab

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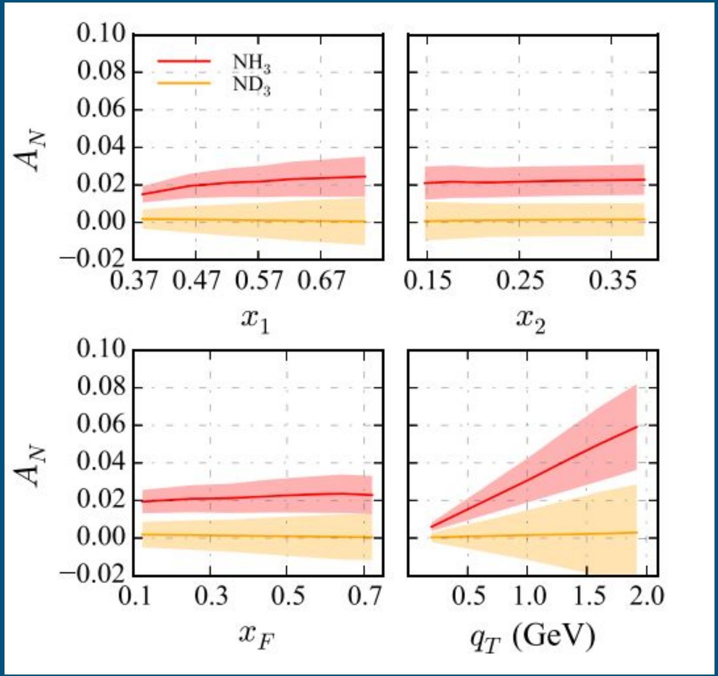
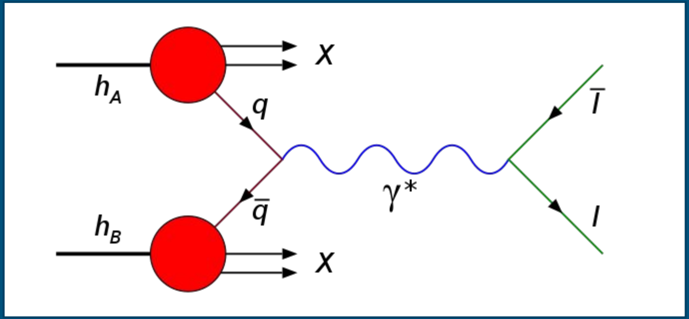
Overview:

- SpinQuest and the goal
  - Studying TMD's
  - The Experimental Setup
- Purpose of Online Monitoring and Visualization
  - Asymmetries
  - Monitoring the health of the detectors
- The process of studying reconstruction
  - In depth Reconstruction Visualization
  - Future work
- Summary

SpinQuest

- Goal
  - Are the sea quarks orbiting around the spin axis of the nucleon?
  - Test QCD prediction
  - Compare with other experiments
- SpinQuest will perform the first measurement of the Sivers asymmetry in Drell-Yan pp scattering from the sea quarks.
- See Ishara talk on Spin





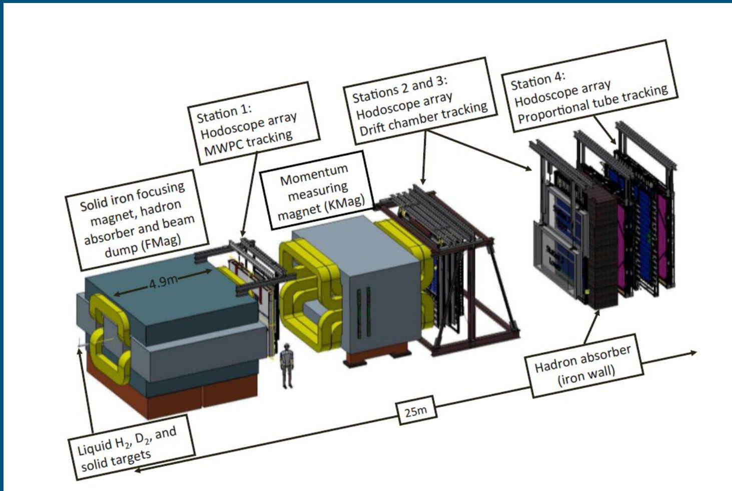
$$f^{\perp q DY}(x, p_T^2) = -f^{\perp q SIDIS}(x, p_T^2)$$

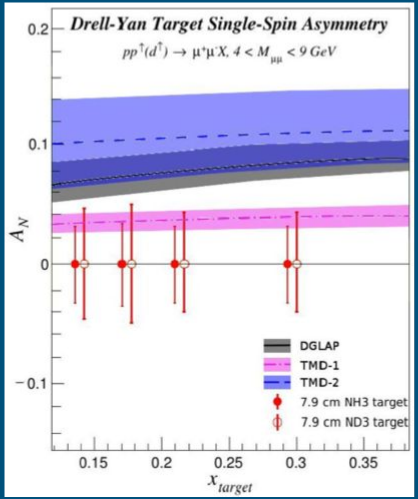
Jaffe-Manohar Sum Rule

$$\Delta S = ½ = ½\Delta\Sigma + \Delta G + \boxed{L_q + L_g}$$

False Asymmetries

- Diurnal effects
- Weather(hot and cold cycles)
- Hardware:
  - Cooling systems malfunctioning
  - Target alignment
  - Magnet health
  - Detector health
- Predicted Sensitivity
  - Beam:
    - Luminosity ~ 1%
    - Drifts < 2%
    - Scraping ~ 1%
  - Target:
    - Polarization ~ 2%
    - Density ~ 1%
    - Alignment ~ 0.5%
    - TE Calibration: P ~ 2.5% d: ~ 4.5%
    - Radiation damage ~ 3%
    - Packing fraction ~ 2%
    - Dilution factor ~ 3%
- Detection of False Asymmetries is **VITAL**



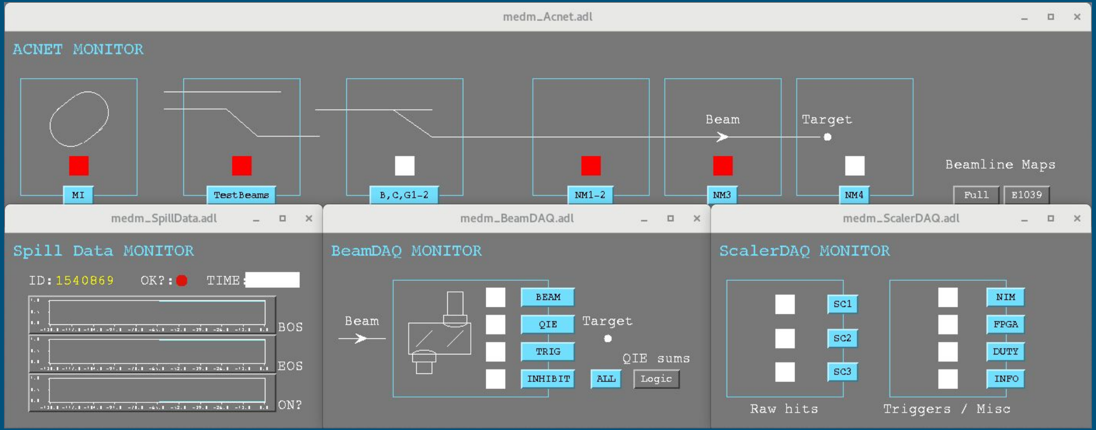


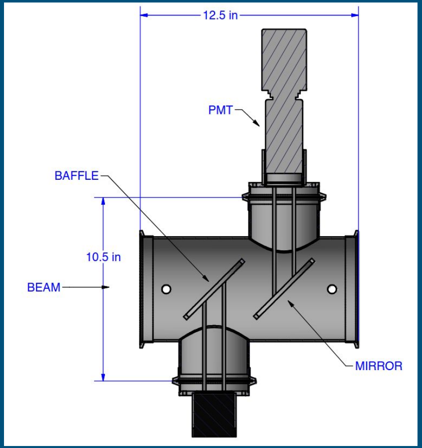
Systems that require monitoring

- Beam cherenkov
- Luminosity monitor
- Drift Chambers
- Proportional Tubes
- Fiber hodo
- Scintillation hodo
- Nim and FPGA Trigger

The Experimental setup

- **Beam**
  - 120 GeV Unpolarized Proton beam collides with polarized proton target
  - “Slow Spill” 1 spill ~ 20-60,000 events in 4 seconds
    - max annual proton count is $7X10^{17}$ protons/year
  - Highest proton intensity ever attempted on a solid polarized target.
  - **Beam Intensity Monitor** (BIM) senses when the beam intensity is above a (programmable) threshold.
    - Cherenkov counter
    - Provide a bucket by bucket beam signal



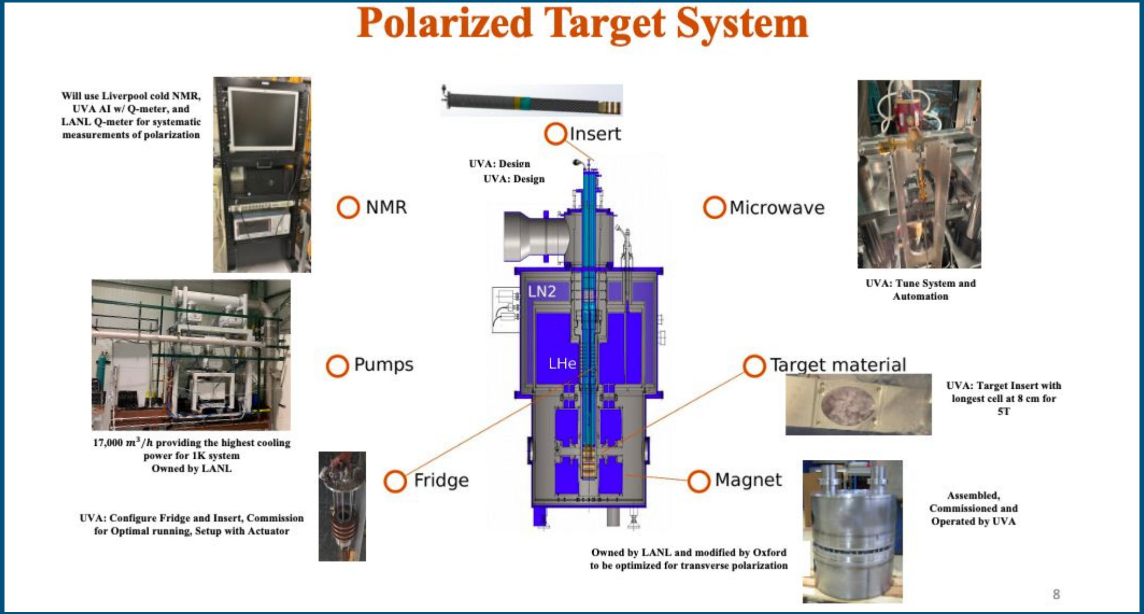


arXiv:1706.09990v2 [physics.ins-det] 9 Feb 2019

Target System

- Proton Target NH3 and Neutron Target ND3
- 5T superconducting split coil magnet
- ^{4}He evaporation refrigerator
- 140 GHz microwave source
- 17000 m3/hr pumping system
    - *Monitoring of non-target interactions:* ladder, cup, NMR-coils

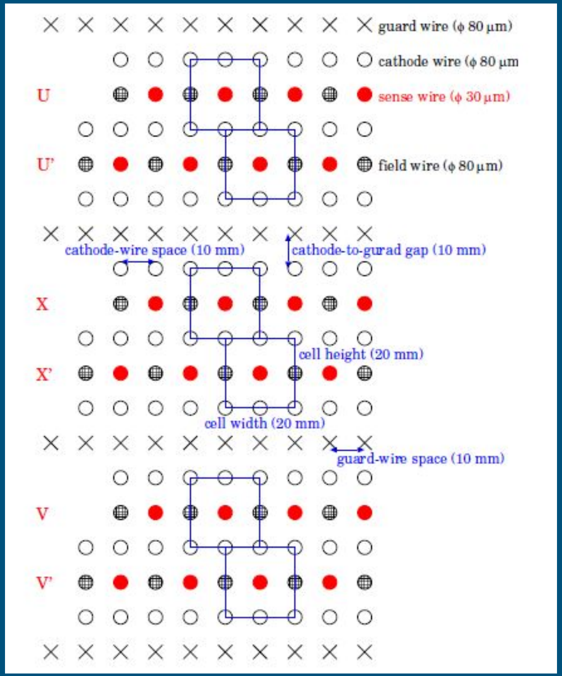
SPTG-TechNote-17003

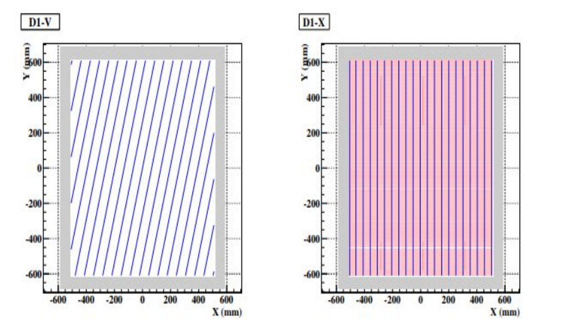


See Farooq talk on SpinQuest and Vibodhas on the fridge.

Drift Chambers

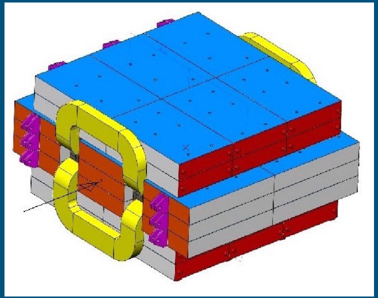
- Drift chamber: Array of wires used to determined the position.
- There are 4 drift chambers each with 6 detector planes.



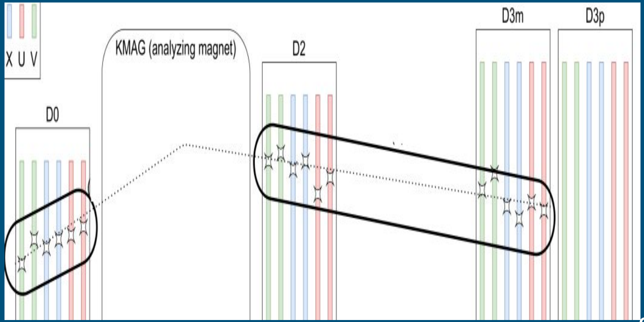


(a) V plane (b) X plane

Kei Nagai: Recent Measurement of Flavor Asymmetry of Antiquarks in the



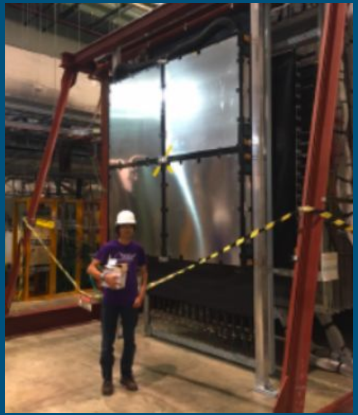
https://arxiv.org/pdf/1706.09990.pdf

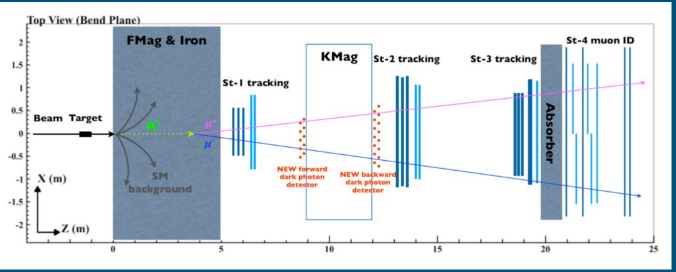


Eric Fuchey Status of GPU-based online reconstruction program

Hodoscope

- Paddle and Fiber Hodoscopes
  - There are 4 paddle hodoscopes stations
  - 2 Dark Photon (Fiber Hodo) Stations
- Pair with DC determines hit location!
  - Element ID and Detector ID
- Paddle hodos used for trigger. Requires monitoring

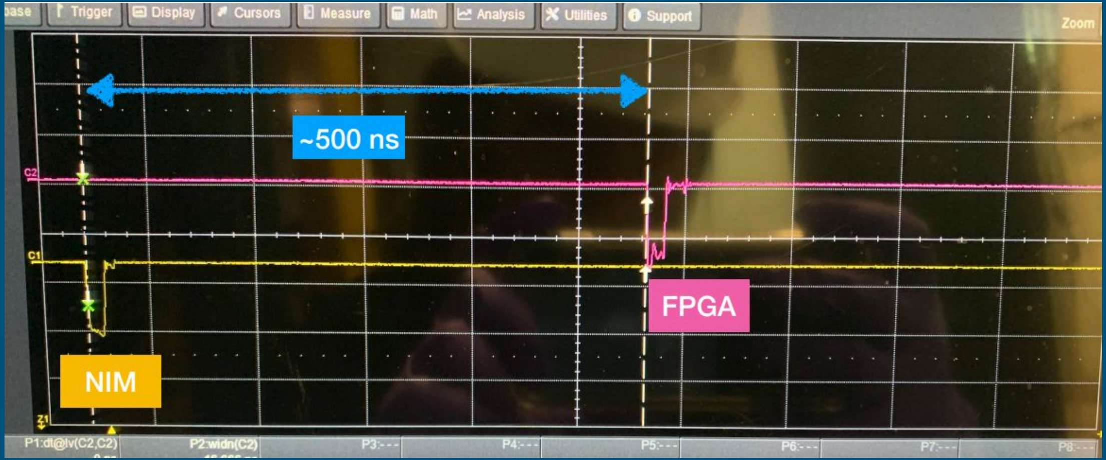


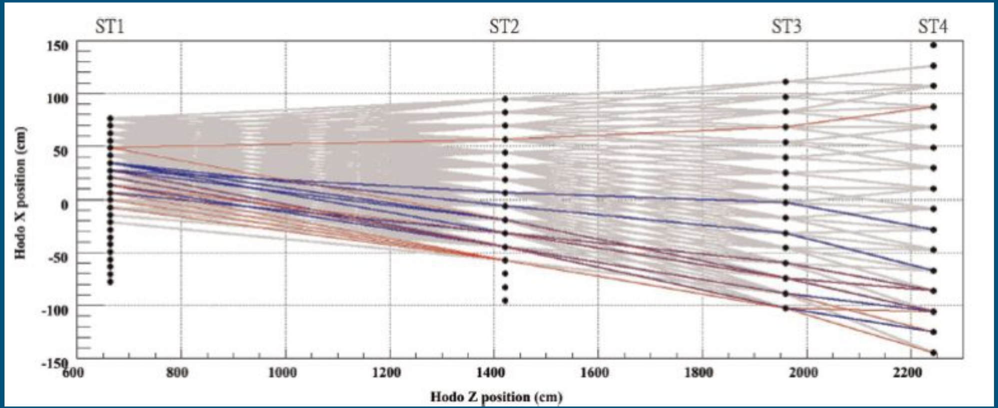


https://indico.cern.ch/event/782953/contributions/3460138/attachments/1887698/3113670/DarkPhoton.pdf

Trigger and hardware

- Triggers:
  - FPGA main trigger
  - Nim Trigger look for hits at the edges where DY is.
- TDC and ADC
  - Timing and channel information
- DAQ
  - monitor error rates

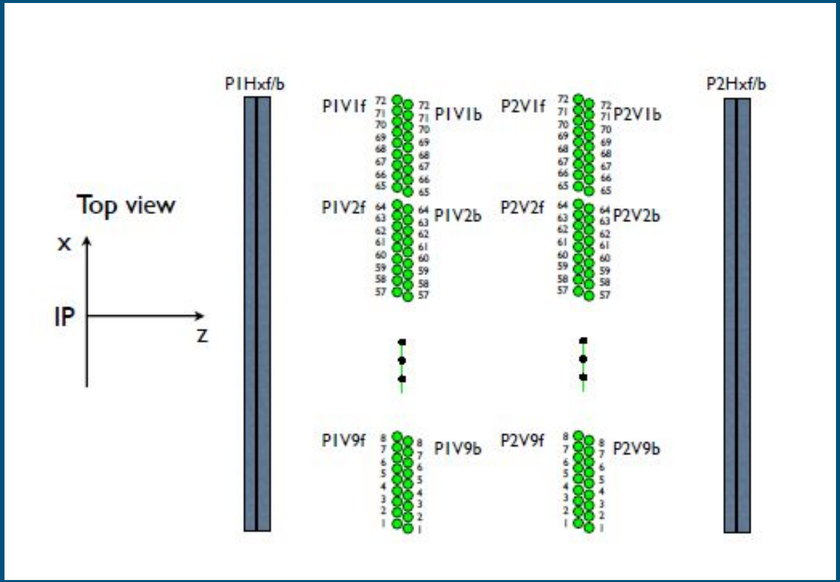


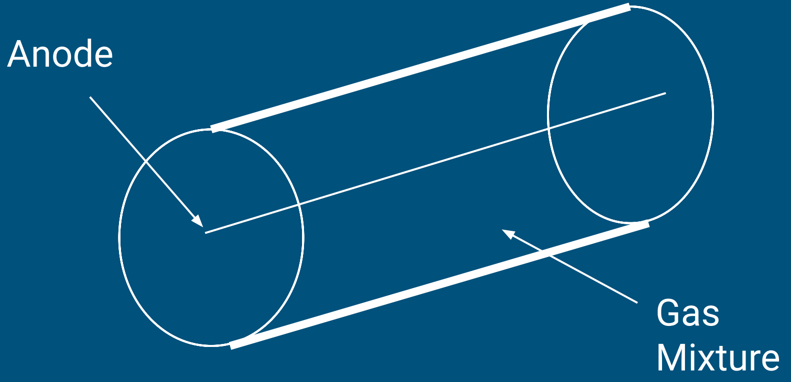


SpinQuest/E1039 FPGA Trigger Minjung Kim

Proportional Tubes

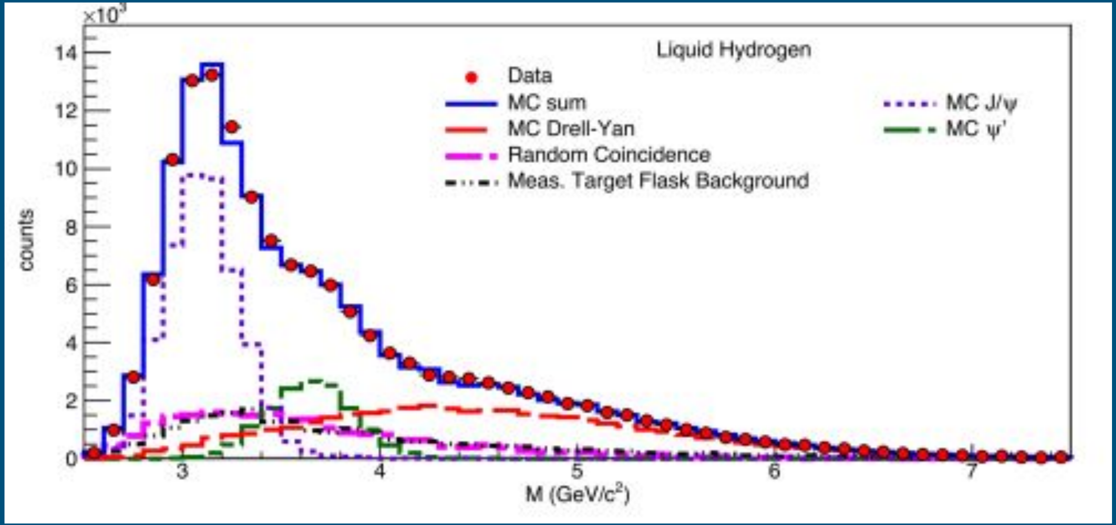
- Muon Identification
- 4 layers of proportional tube planes.
  - Each plane is made of 9 proportional tube modules
  - each module hold 16 proportional tubes
- Typical muon transverse two tubes per plane





Reconstruction

- Goal Obtain four-momenta!
- Poor reconstruction Correlate to:
  - Hardware Malfunctions
  - Changes in the target
  - Cool System errors
- Reconstruction is critical to calculating asymmetries



Nature 590 561-565 2021

$$\frac{d^2\sigma}{dx_b dx_t} = \frac{4\pi\alpha^2}{x_b x_t s}\Sigma e_q^2[\overline{q_t}(x_t)q_b(x_b) + q_t(x_t)\overline{q_b}(x_b)]$$

Challenges with Monitor Incoming Data

- We **need** to detect false asymmetries
- Target polarization must be kept at its maximum
- We want to **Quickly display Event information**
- We must be able to see the reconstruct a every stage
    - Roughly 1 dimuon from the target per 30k events

A new approach:

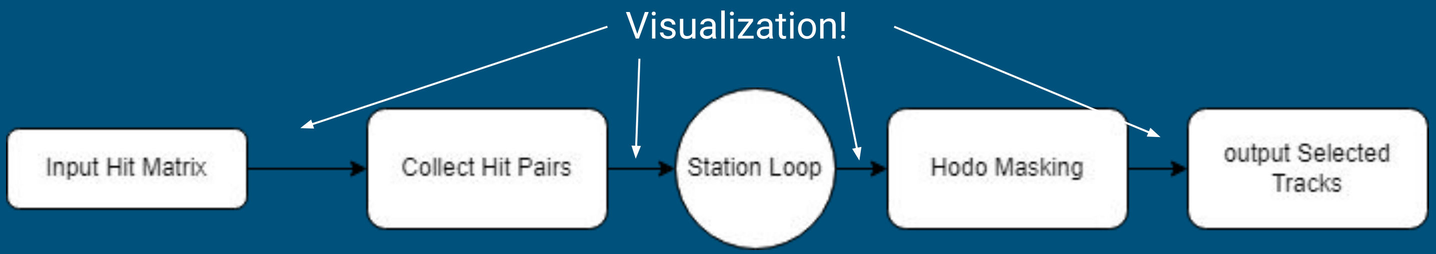
1 spill ~ 20-60,000 events in 4 seconds per minute

Geometric

- CPU focused
- Uses Geometry
- Slower reconstruction
- Efficiency:
  - Precision 92%
  - Recall 9%

AI

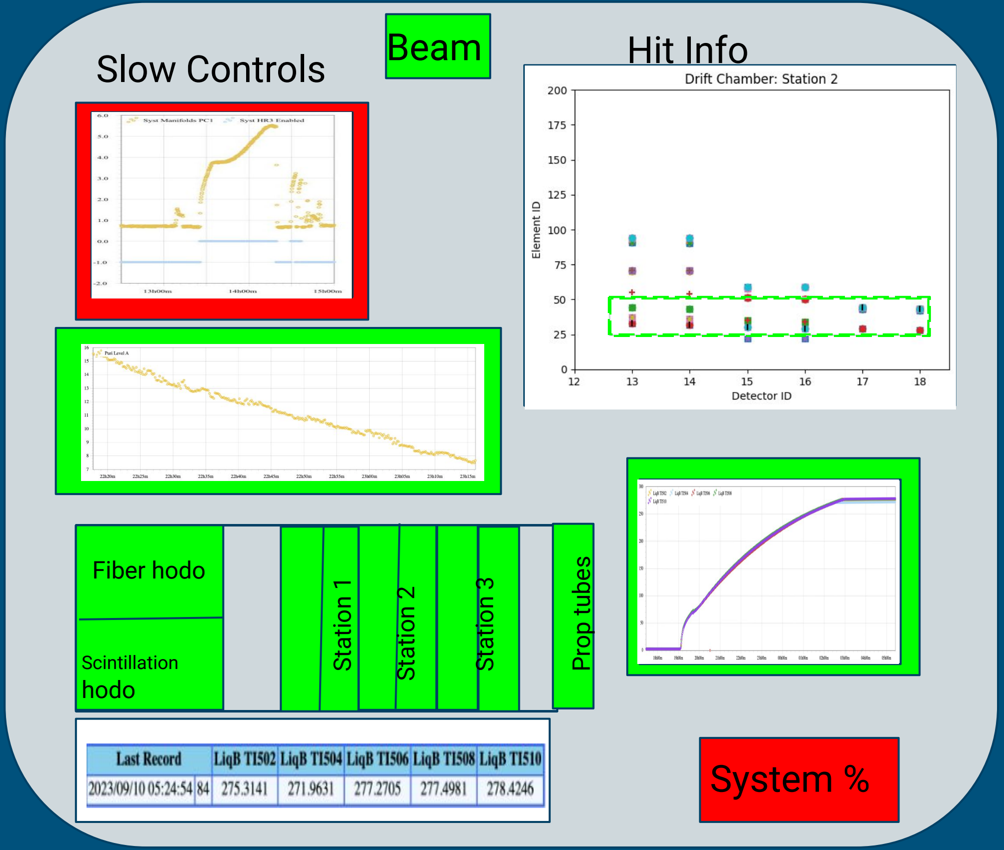
- GPU accelerated
- Uses CNN+multiple DNN's
- Quick reconstruction
- Efficiency:
  - Precision 99%
  - Recall 54%



AI Monitoring

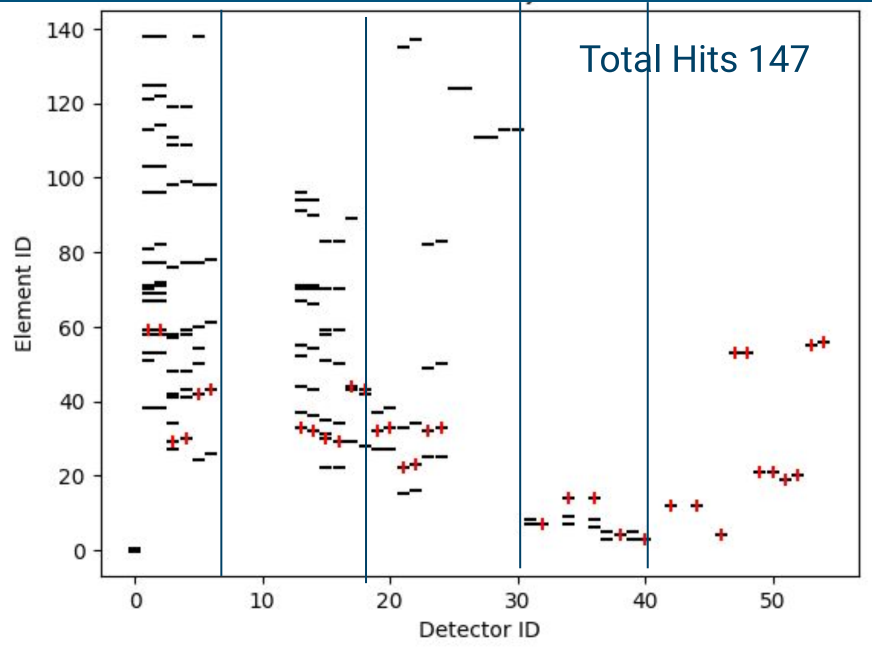
- Used in
  - Online monitoring:
    - Pattern recognition
    - Alarm systems
  - Visualization
    - Quickly create script chart
    - Slow Controls
    - Numerical display. Spill Rate
    - Detector health
- Want:
  - Ability to choose trigger or trigger mask (set of triggers) for each monitoring plot.
  - Ability to overlay any histogram with a reference histogram
  - Reliable Event display

Interface mockup

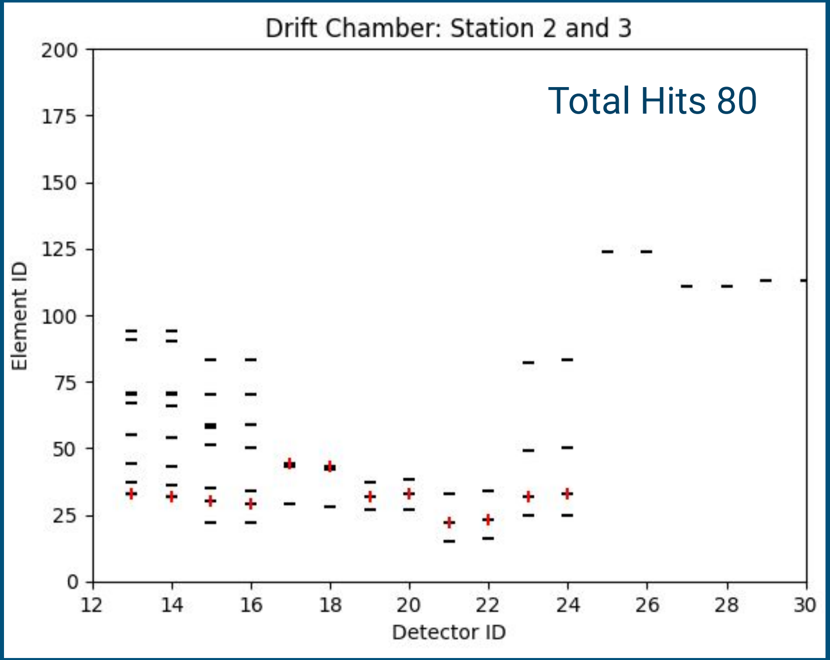


Visualization of a Spill

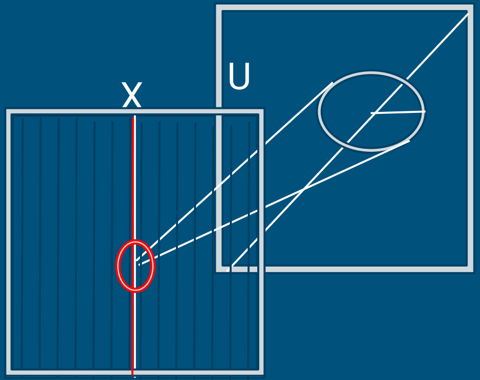
Before hit pairing

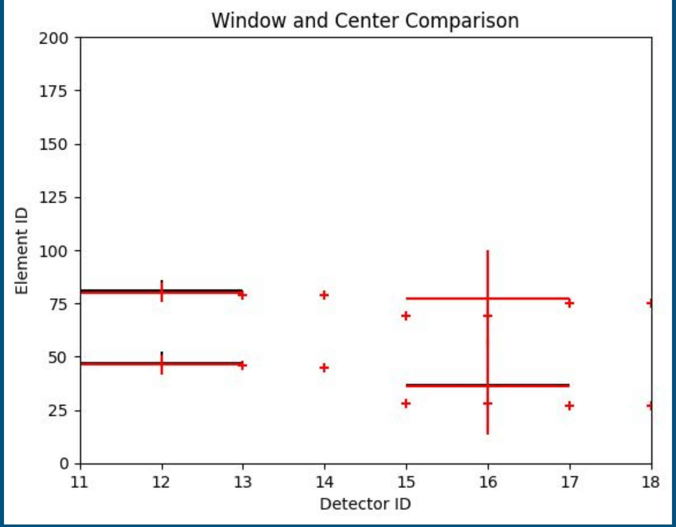


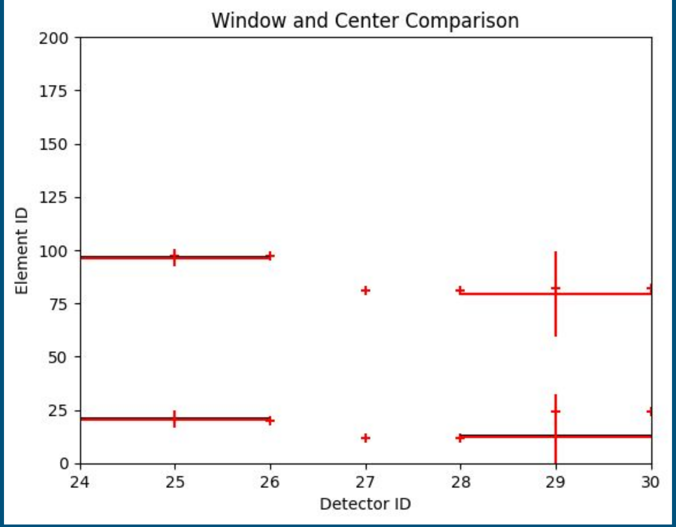
After hit pairing



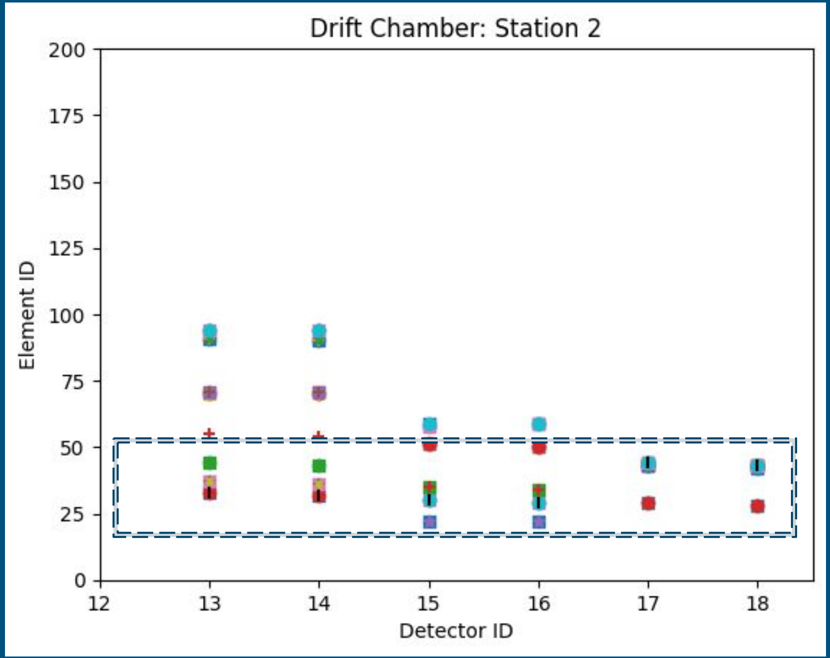
Window Visualization

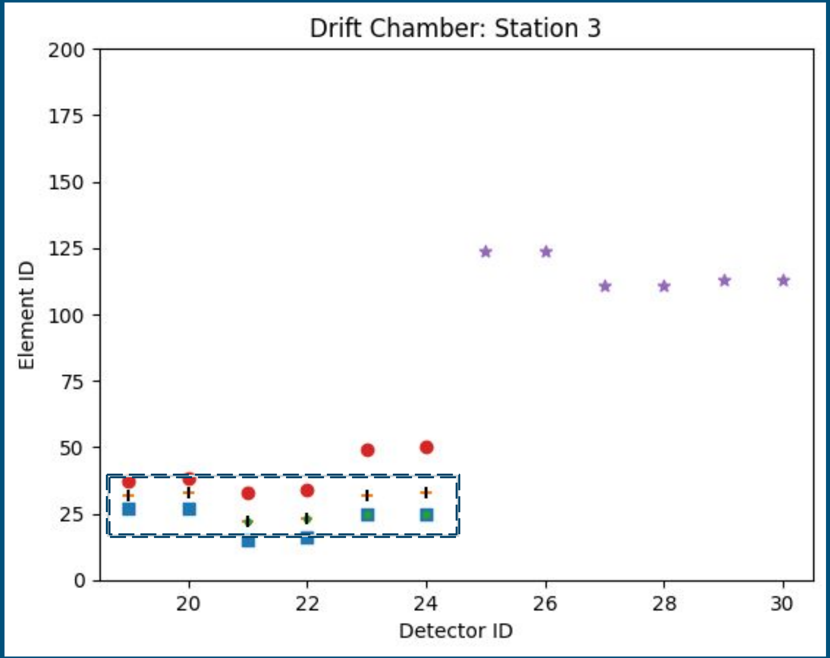






Tracklet Visualization

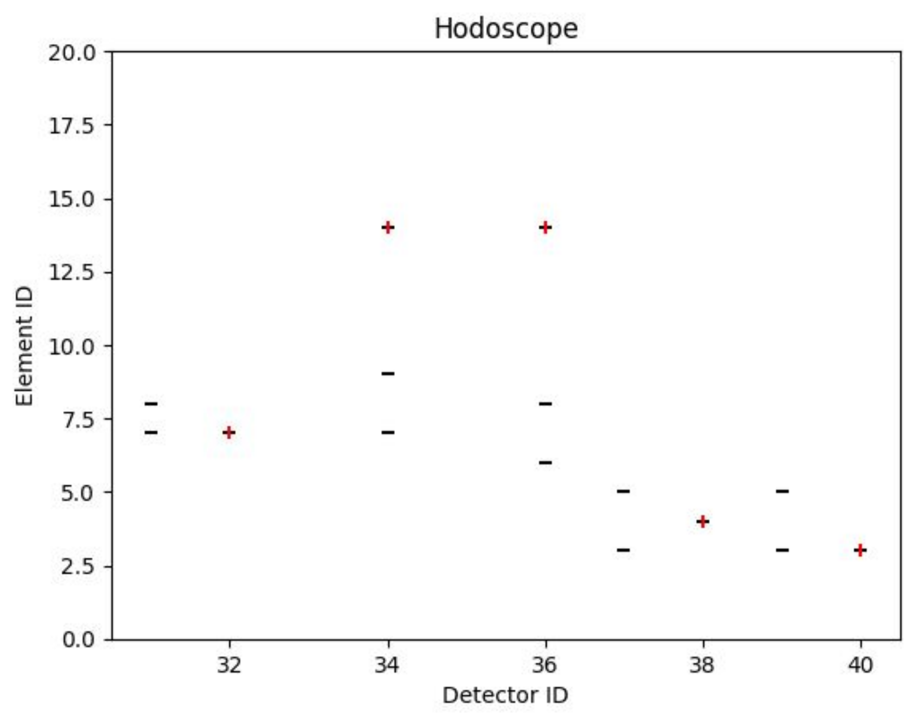




58 Hits
45 Tracklets combinations

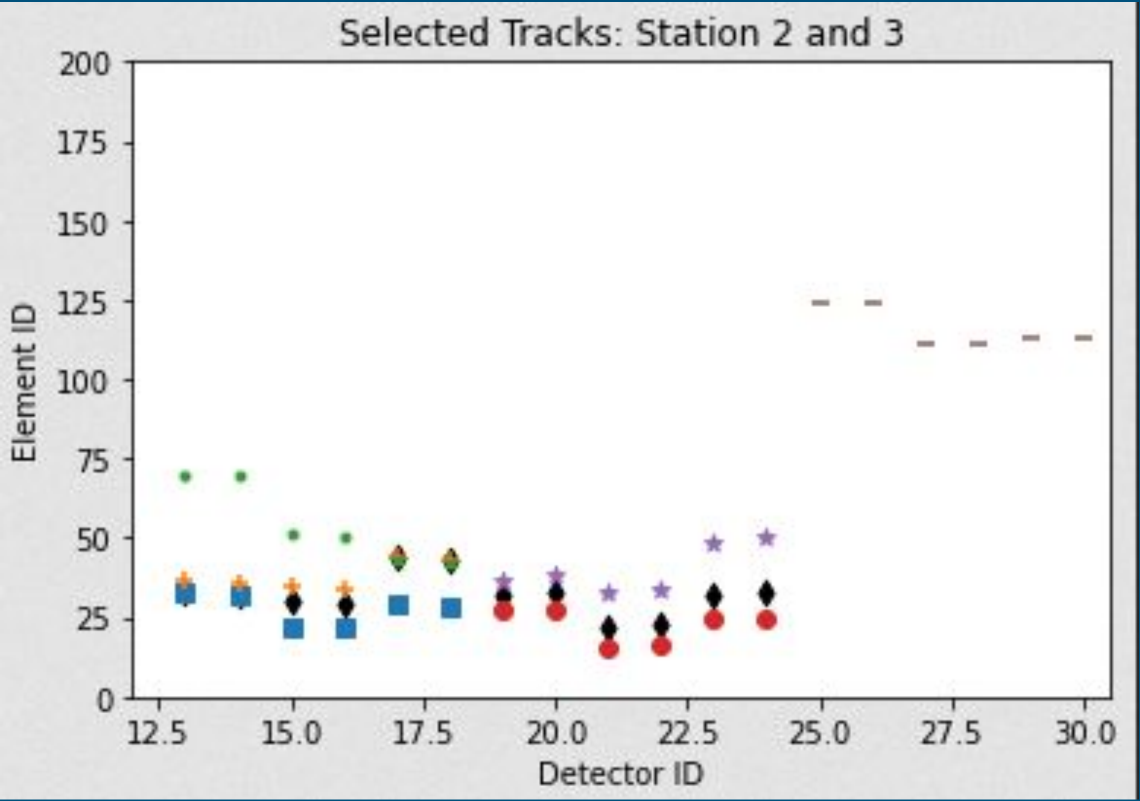
Hodoscope Matching

- Compares hits from DC to hit range on hodoscope.
- Can be tuned for cleaner results.

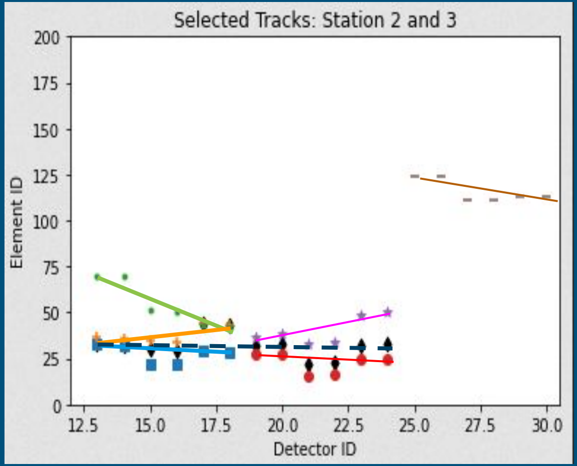


Tracklets Before AI integration

- 6 Track combinations.
- 36 hits remain.
- A removal of 44 hits!



Display



AI

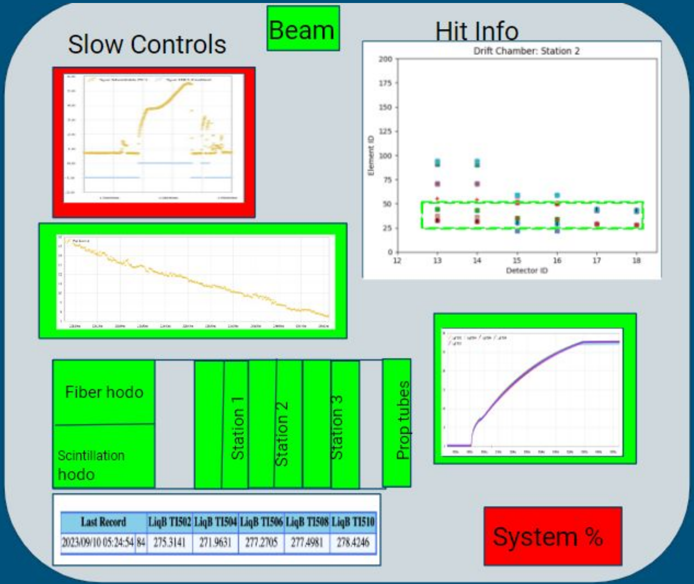
X-Slope

Y-Slope

X0

Y0

Four momenta



- Options for interface
  - Dearpygui
  - VisPy
  - plotoptix

Summary

- We need a robust online monitoring and visualization package for SpinQuest that can benefit from gpu acceleration and AI.
- We already have created some visualizations for the target and hodoscope.
- This software is written to utilize:
  - Numba GPU Acceleration
  - DearpyGui Interface Display
  - Tensorflow Machine Learning
- Future work:
  - Global track Display and Vertex Display
  - create displays for slow controls and create an interface.
  - Display track information in a XY view

Thank You

Backup Slides

Geometry

$$URadius = \left| \frac{1}{2} * XWireSpan * \sin(UWireAngle) \right| + TXMax \, | (ZPositionofUhit - ZPositionofXhit) | \cos(UWireAngle) + TYMax \, | (ZPositionofUhit - ZPositionofXhit) | \sin(UWireAngle) + 2 * WireSpacing + \delta$$

$$VRadius = UHitWireSpacing * 2 * \cos(UWire) + | (ZPositionofUHit + ZPostionofVHit - 2 * ZPostionofXHit) * \cos(UWire) * TXMax | + | (ZPostionofVHit - ZPostionofUHit) * \sin(UWire) * TYMax | + 2 * UHitWireSpacing$$

$$VCenter = 2 * UCenter - WirePositionofUHit$$

$$UCenter = WirePositionofXHit * \cos(UWire)$$

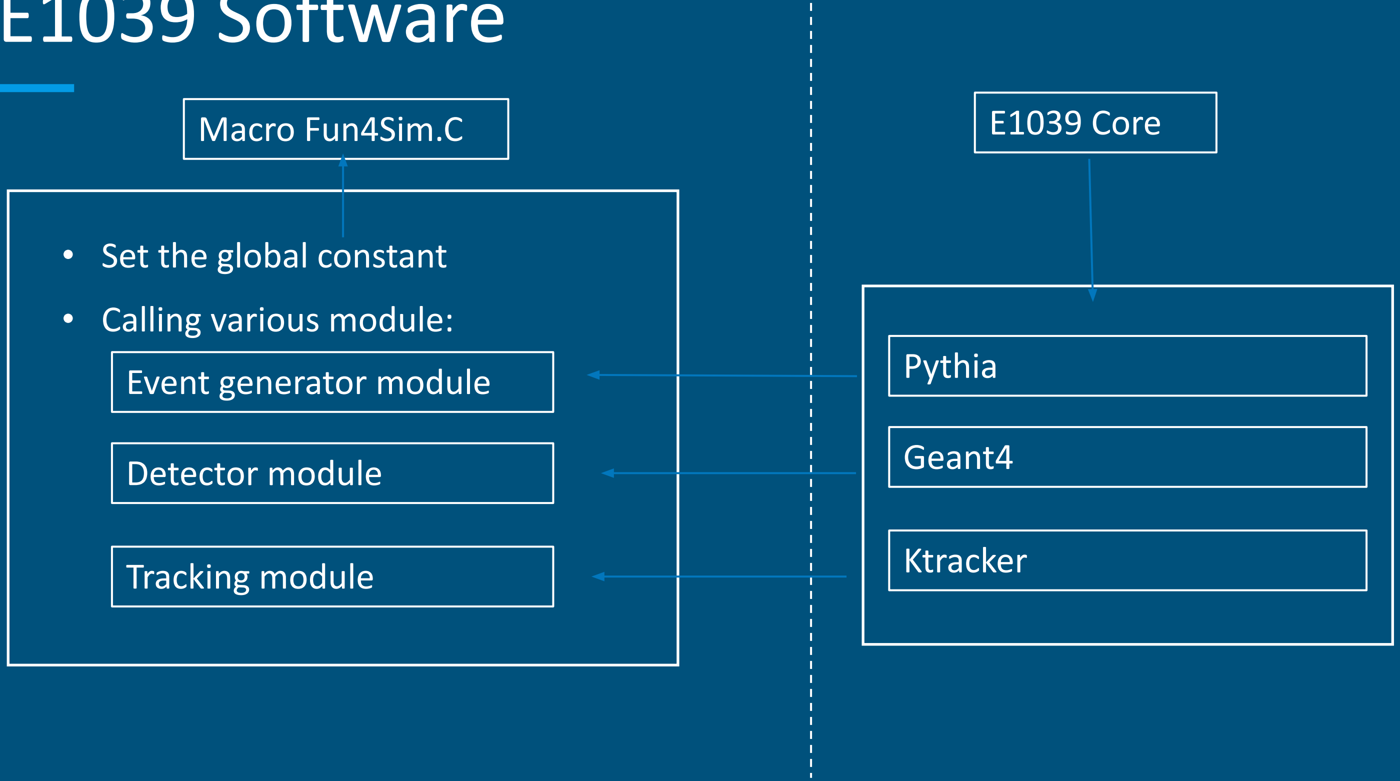
$$WirePosition = \left(elementID - \frac{(NumberofElements + 1)}{2}\right) * WireSpacing + [XPlaneOffSet + X0 * \cos(UWire) + y0 * \sin(UWire) + \delta$$

Precision: (true positive)/(true positive + false positive)

Recall: (true positive)/(true positive + false negative)

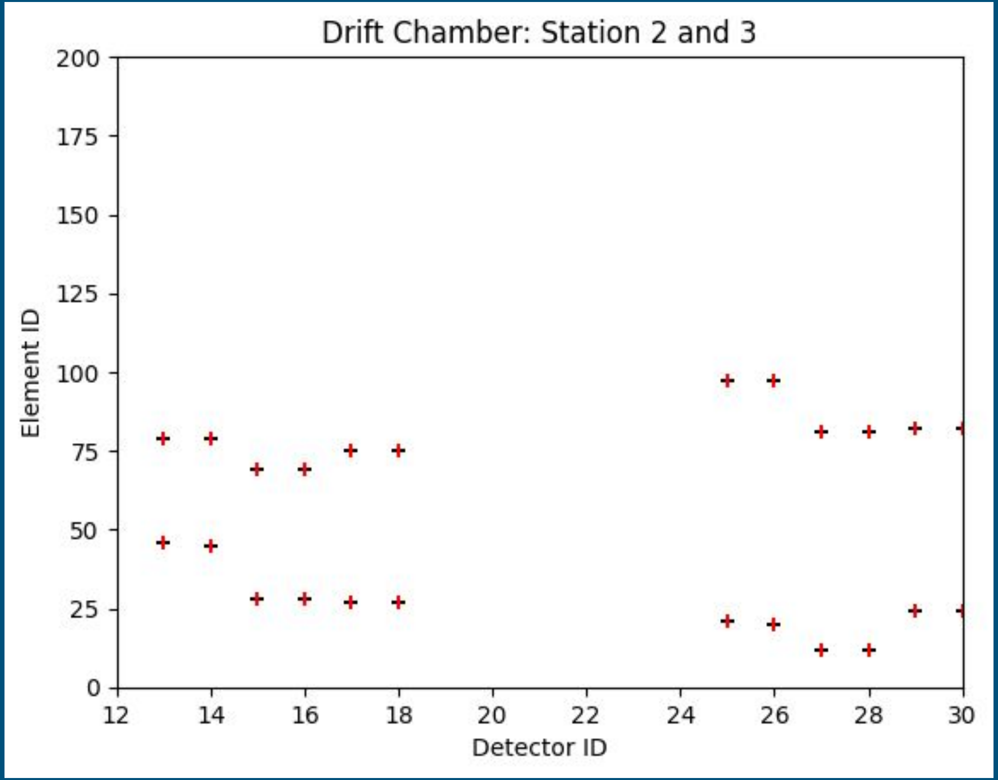
Done with realistic simulated Dimuon events

E1039 Software



E1039 is designed to be modular & user friendly

Ktracker comparison



Geometry

	0	1	2	4	5	7	10	11	12	15	26
	DetID	Z	NumElems	Spacing	X-offset	x0	Cosine	wireSpan	y0	Sine	delta
1	1	594.582	201	0.635	0.159	-0.794	0.971457	121.92	2.689	0.237214	-0.04147
2	2	595.218	201	0.635	-0.159	-0.794	0.971457	121.92	2.689	0.237214	0.002111
3	3	617.274	160	0.635	0.159	-0.552	1	121.92	2.743	-0.00054	-0.19835
4	4	616.638	160	0.635	-0.159	-0.552	1	121.92	2.743	-0.00054	-0.27684
5	5	640.444	201	0.635	0.159	-0.423	0.971109	121.92	2.791	-0.23864	-0.3835
6	6	641.079	201	0.635	-0.159	-0.423	0.971109	121.92	2.791	-0.23864	-0.40794
7	7	688.614	384	0.5	0	0.349	0.970595	137.16	-0.173	-0.24072	0
8	8	689.214	384	0.5	-0.25	0.349	0.970595	137.16	-0.173	-0.24072	0
9	9	689.814	320	0.5	0	0.349	0.999998	137.16	-0.173	0.00187	0
10	10	690.414	320	0.5	-0.25	0.349	0.999998	137.16	-0.173	0.00187	0
11	11	691.014	384	0.5	0	0.349	0.969688	137.16	-0.173	0.244345	0
12	12	691.614	384	0.5	-0.25	0.349	0.969688	137.16	-0.173	0.244345	0
13	13	1315.01	128	2.021	-0.505	-2.45704	0.969546	264.16	-0.73359	-0.24491	-0.04574
14	14	1321.99	128	2.021	0.505	-2.44096	0.969546	264.16	-0.73641	-0.24491	-0.06071
15	15	1340.31	112	2.083	-0.521	-0.82135	0.999996	264.16	-0.04402	0.002721	0.150169
16	16	1347.29	112	2.083	0.521	-0.81665	0.999996	264.16	-0.06198	0.002721	0.172412
17	17	1365.43	128	2.021	-0.505	-0.46511	0.968944	264.16	-0.80055	0.247278	-0.00335
18	18	1372.42	128	2.021	0.505	-0.48147	0.968944	264.16	-0.78931	0.247278	-0.00033
19	19	1922.59	134	2	0.5	-1.009	0.970033	166	78.6891	0.242974	-0.29897
20	20	1924.59	134	2	-0.5	-1.01243	0.970033	166	78.6905	0.242974	-0.30135
21	21	1928.49	116	2	0.5	-1.01929	1	166	78.6933	0.000462	0.038053
22	22	1930.49	116	2	-0.5	-1.02271	1	166	78.6947	0.000462	0.03978
23	23	1934.76	134	2	0.5	-1.02957	0.970302	166	78.6975	-0.2419	0.376155
24	24	1936.76	134	2	-0.5	-1.033	0.970302	166	78.6989	-0.2419	0.379188
25	25	1885.91	134	2	-0.5	-2.69882	0.97043	166	-79.5892	0.241385	-0.14254
26	26	1887.91	134	2	0.5	-2.69402	0.97043	166	-79.5889	0.241385	-0.14075
27	27	1891.64	116	2	-0.5	-2.6844	0.999999	166	-79.5882	-0.00114	0.080718
28	28	1893.64	116	2	0.5	-2.6796	0.999999	166	-79.5878	-0.00114	0.08174
29	29	1897.89	134	2	-0.5	-2.66998	0.969927	166	-79.5871	-0.2434	0.290204
30	30	1899.89	134	2	0.5	-2.66518	0.969927	166	-79.5868	-0.2434	0.292514
31	31	669.055	23	7.0025	0	-0.76518	1	69.85	-35.062	0.000997	-0.1464
32	32	669.409	23	7.0025	0	-0.83482	1	69.85	34.788	0.000997	-0.0732
33	33	656.125	20	7.0025	0	39.19	0.00099	140.117	-0.04913	1	0.6588
34	34	655.755	20	7.0025	0	-39.55	0.00099	140.117	0.029134	1	0.4758
35	35	1405.08	19	12.6825	0	64.4455	5.74E-05	241.285	-0.41043	1	-0.52
36	36	1404.78	19	12.6825	0	-67.5545	5.74E-05	241.285	-0.40237	1	-0.65
37	37	1420.95	16	12.6825	0	-0.93741	0.999996	152	-76.0406	0.002939	0.52
38	38	1421.27	16	12.6825	0	-1.38415	0.999996	152	75.9594	0.002939	0.52
39	39	1958.34	16	14.27	0	0.016535	1	167.64	-84.1908	-0.00053	0.145875
40	40	1958.9	16	14.27	0	0.105385	1	167.64	83.4492	-0.00053	0.145875
41	41	2130.27	16	23.16	0	66.04	-3.7E-06	365.797	0	1	-2.11297
42	42	2146.45	16	23.16	0	-66.04	-3.7E-06	365.797	0	1	-0.35216
43	43	2200.44	16	23.16	0	66.04	-3.7E-06	365.797	0	1	-1.17387
44	44	2216.62	16	23.16	0	-66.04	-3.7E-06	365.797	0	1	-1.40865
45	45	2251.71	16	19.33	0	-0.27492	1	182.88	-92.0383	-0.00011	0.49119
46	46	2234.29	16	19.33	0	-0.29404	1	182.88	90.7328	-0.00011	-0.19647