# Advancements in Online Monitoring and Visualization for SpinQuest in Experimental Nuclear Physics

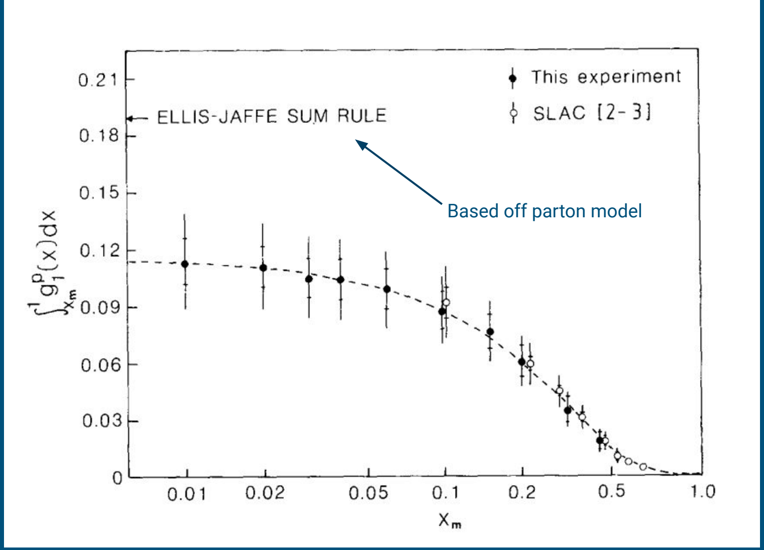
Jordan Daniel Roberts

# Overview:

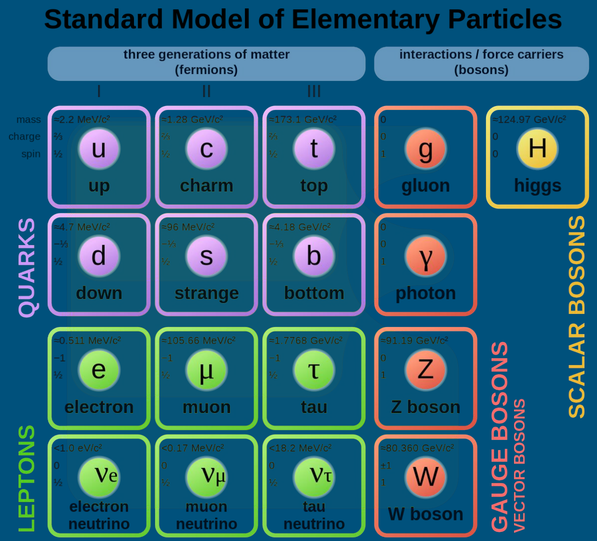
- Physics Overview
  - Proton Spin Crisis
  - TMD’s and Sivers
- SpinQuest and the goal
  - The Experimental Setup
- The purpose of studying reconstruction
  - Asymmetries
- The previous state of the software
  - Fun4All
- The process of studying reconstruction
  - In depth Reconstruction
- Results
  - discussion
- Summary

# The Proton Spin

EMC: Nuclear Physics B328 (1989) 1-35




$\Delta\Sigma(Q2 = 10GeV2) = 0.060 \pm 0.047 \pm 0.069$ consistent with zero!



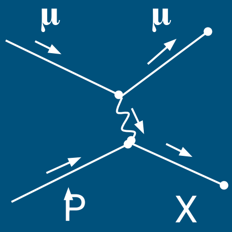

Lattice QCD:

| | $\Delta u$ | $\Delta d$ | $\Delta s$ | $g_A^3$ | $g_A^8$ | $\Delta\Sigma$ |
|---|---|---|---|---|---|---|
| D. de Florian *et al.* ($Q^2$=10 GeV$^2$) | $0.793^{+0.028}_{-0.034}$ | $-0.416^{+0.035}_{-0.025}$ | $-0.012^{+0.056}_{-0.062}$ | | | $0.366^{+0.042}_{-0.062}$ |
| NNPDFpol1.1 ($Q^2$=10 GeV$^2$) | 0.76(4) | -0.41(4) | -0.10(8) | | | 0.25(10) |
| COMPASS ($Q^2$=3 GeV$^2$) | [0.82, 0.85] | [−0.45, −0.42] | [−0.11, −0.08] | 1.22(5)(10) | | [0.26, 0.36] |

PHYS. REV. D 98, 074505 (2018)

Old model of Proton Spin=½=½+½-½

Mass ~ 1 Gev not fully understood ethier!



# Finding the Spin

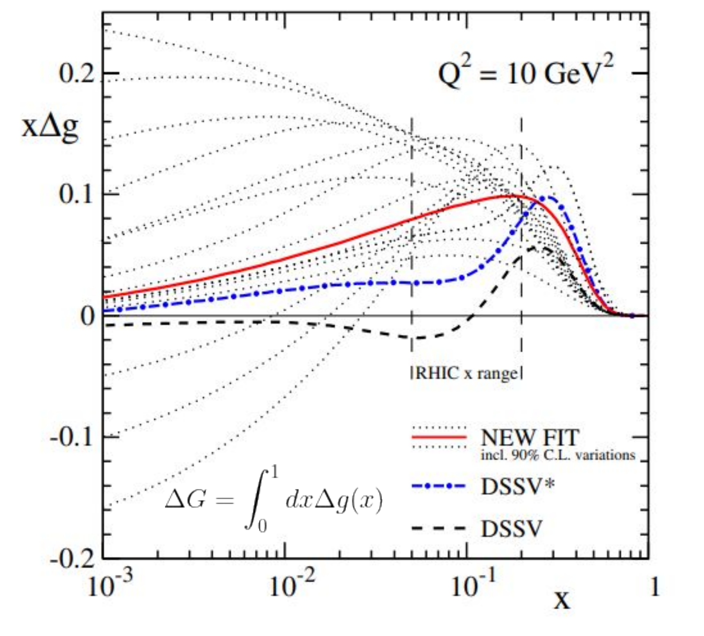
Jaffe-Manohar Sum Rule

$$\Delta S = ½ = ½\Delta\Sigma + \Delta G + L_q + L_g$$

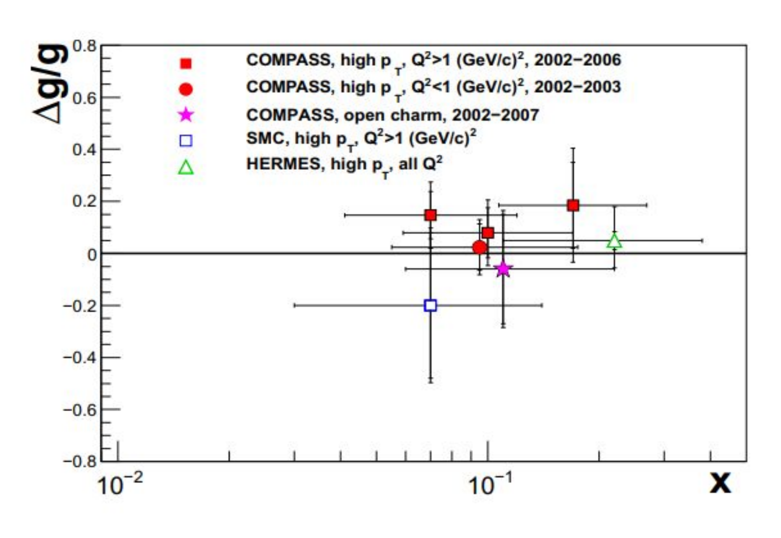
Ji's Sum Rule

$$\Delta S = ½ = ½\Delta\Sigma + L^z_q + J^Z_g$$

STAR




COMPASS




$\Delta G \sim 0$

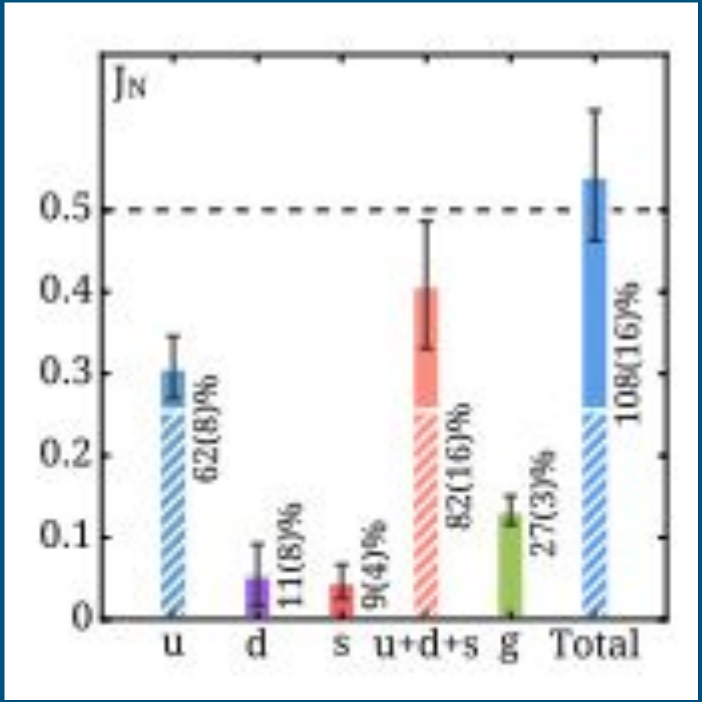
$\Delta S \sim 30\%$

Daniel de Florian, Rodolfo Sassot, Marco Stratmann, and Werner Vogelsang
Phys. Rev. Lett. 113, 012001 – Published 2 July 2014 STAR

Nuclear and Particle Physics Proceedings
Volumes 273–275, April–June 2016, Pages 2084-2090
COMPASS

# Orbital Angular Momentum

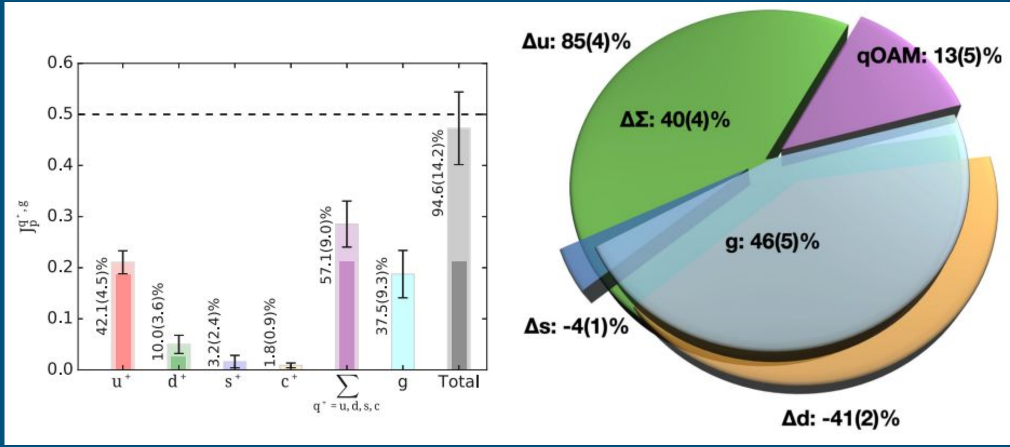
Ji Spin Decomposition




arXiv:1706.02973v3 [hep-lat] 18 Nov 2017

- EIC will probe gluon via SIDIS
- SpinQuest will probe gluon via J/Ψ

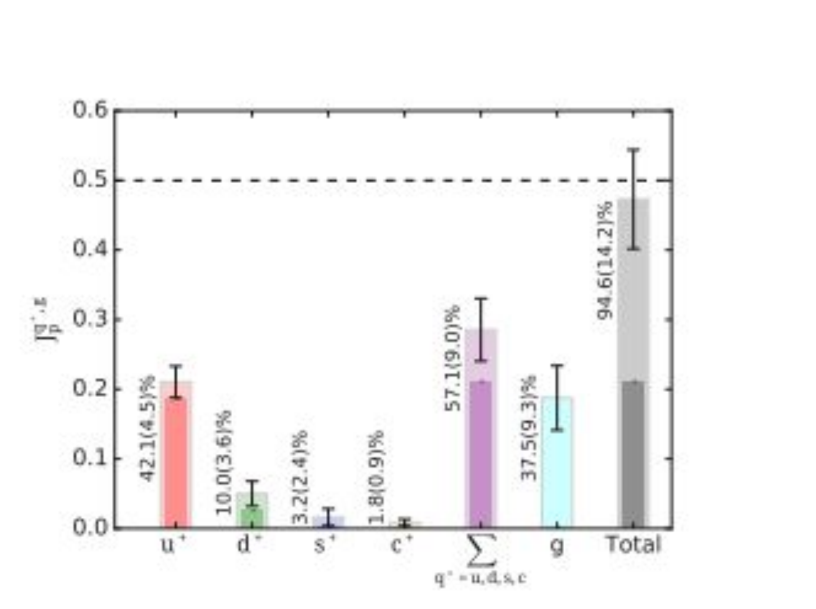
QCD Lattice calculations: Ji left and Jaffe right

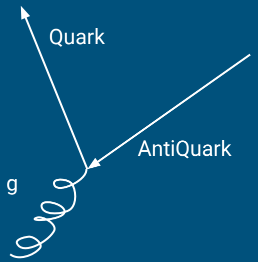


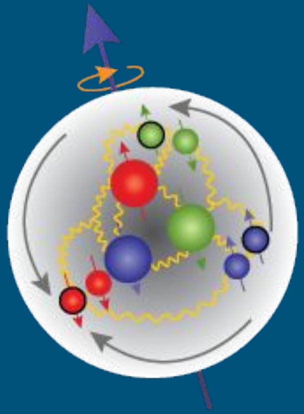

arXiv:2112.08416 [hep-lat]

# Sea Quarks

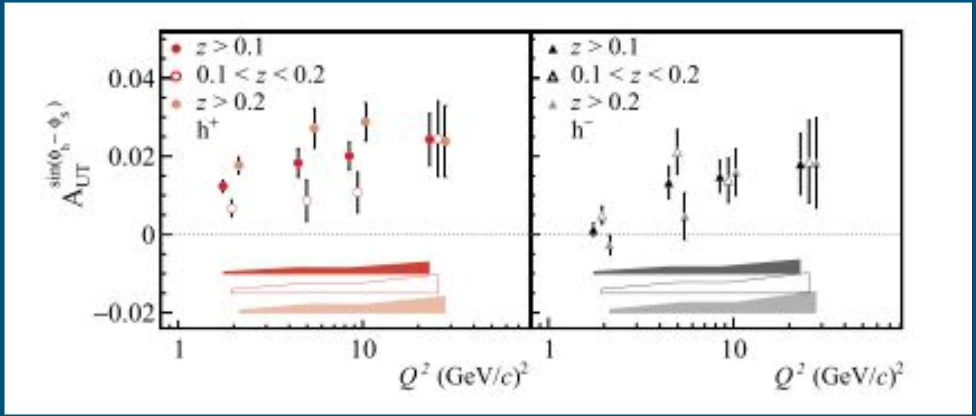
QCD Lattice calculations



SIDIS Sivers at COMPASS




arXiv:2112.08416 [hep-lat]

C. Adolph et al. / Physics Letters B 770 (2017) 138–145

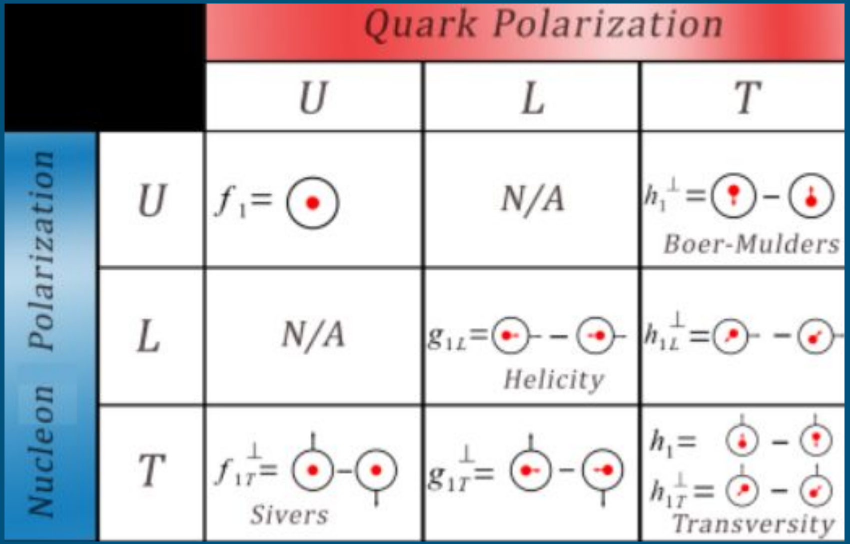
# TMDs and Sivers

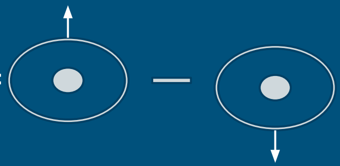
- Transverse momentum functions allows us to analyze the distribution of the transverse momentum and transverse spin.
- Sivers represents the **correlation of the transverse momentum of an unpolarized parton with the spin of a transversely polarized nucleon**.

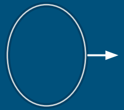
- A non-zero DY sea quark Sivers function asymmetry is indicative of contribution by sea quark OAM.

$$A_N = \frac{\sigma_L^{\uparrow} - \sigma_R^{\uparrow}}{\sigma_L^{\uparrow} + \sigma_R^{\uparrow}}$$

## Leading Twist



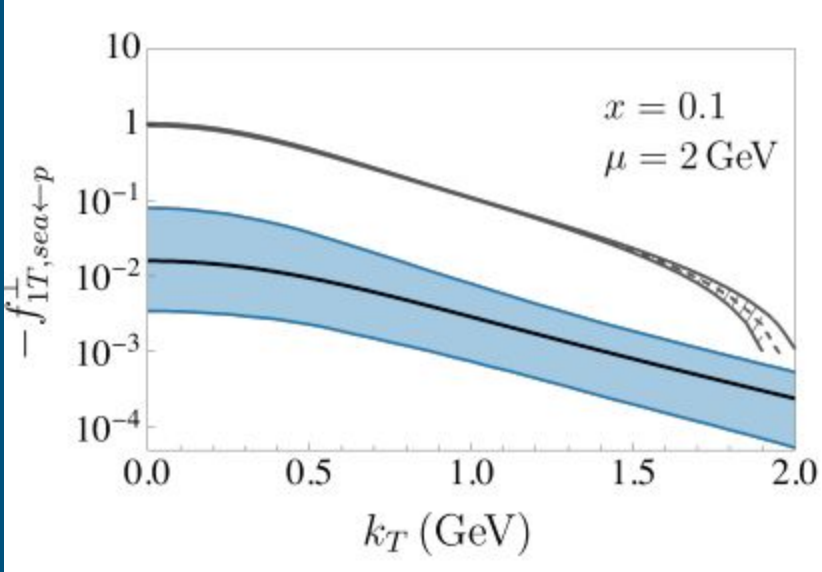

Sivers asymmetry= 

Nuclear spin 

Quark spin 

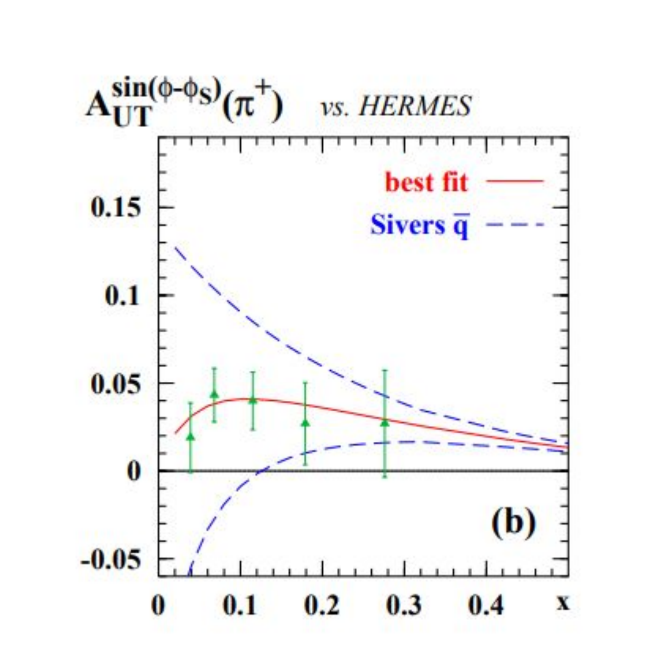
# Results of Sivers

JLab SIDIS Sivers



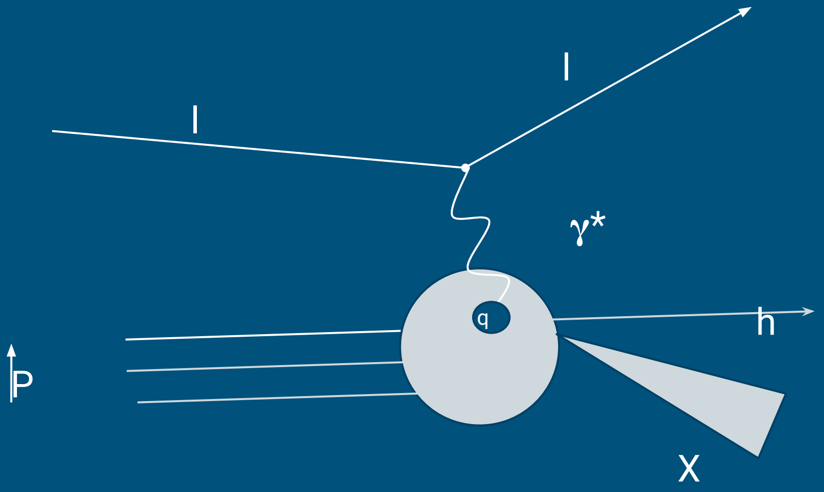

arXiv:2103.03270v1 [hep-ph] 4 Mar 2021

HERMES SIDIS Sivers



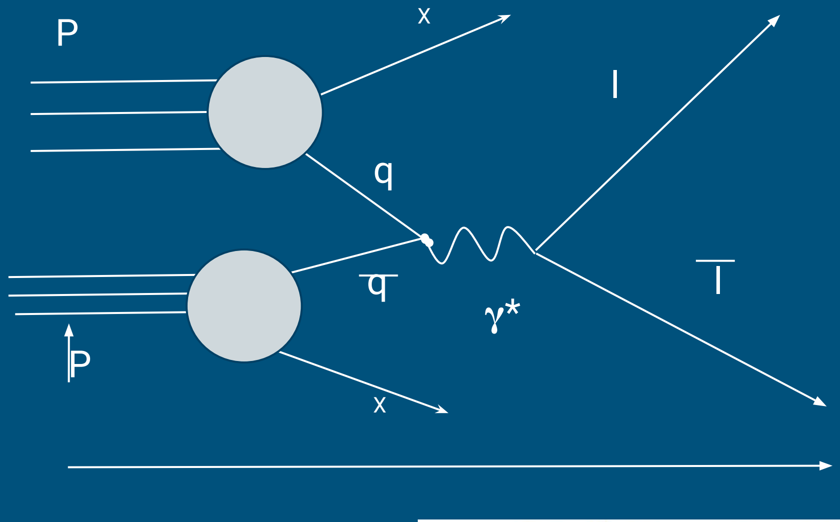

arXiv:0805.2137v1

# Polarized SIDIS




$$A_{UT}^{SIDIS} \propto \frac{\sum_q e_q^2 f_{1T}^{\perp q}(x) \otimes D_1^q(z)}{\sum_q e_q^2 f_1^q(x) \otimes D_1^q(z)}$$

# Polarized DY




$$A_N^{DY} \propto \frac{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_{1T}^{\perp \bar{q}}(x_2) + 1 \leftarrow\rightarrow 2\right]}{\sum_q e_q^2 \left[f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftarrow\rightarrow 2\right]}$$

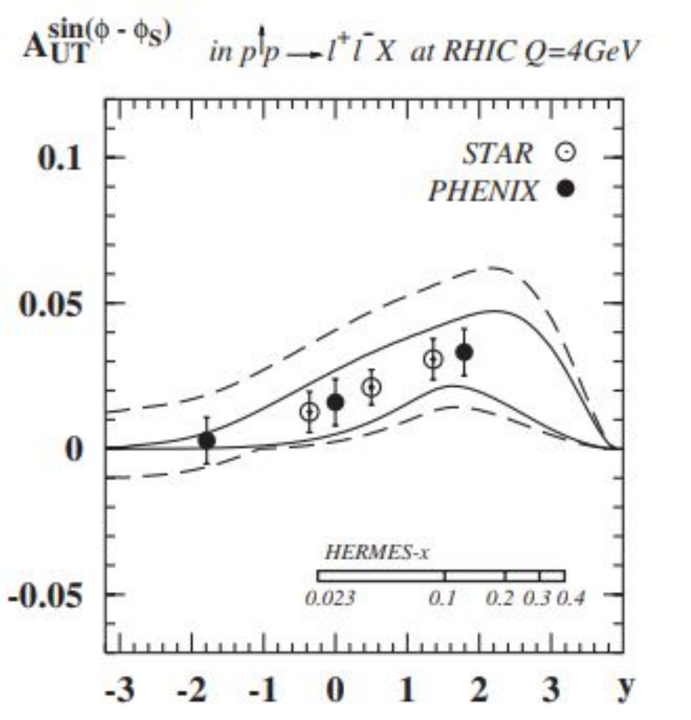
QCD Prediction

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

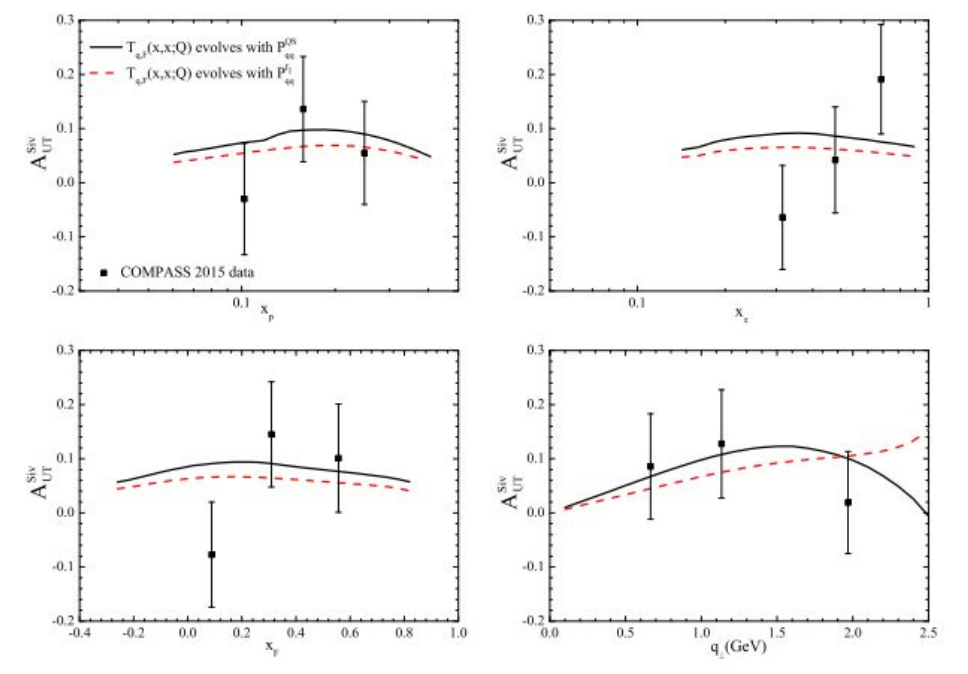
# Sivers DY at RHIC and COMPASS

RHIC Prediction 2006

pion induced Drell-Yan at COMPASS 2018




PHYSICAL REVIEW D 73, 094023 (2006)

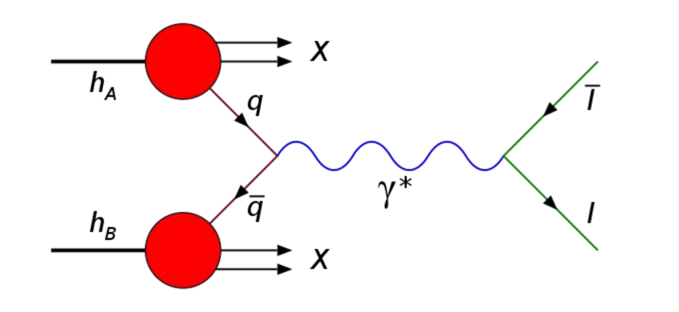



PHYSICAL REVIEW D 97, 054005 (2018)

# SpinQuest

- Are the sea quarks orbiting around the spin axis of the nucleon?
- Testing QCD prediction
- Compare with other experiments
- Non-zero asym = sea quark OAM!
- SpinQuest will perform the first measurement of the Sivers asymmetry in Drell-Yan pp scattering from the sea quarks.

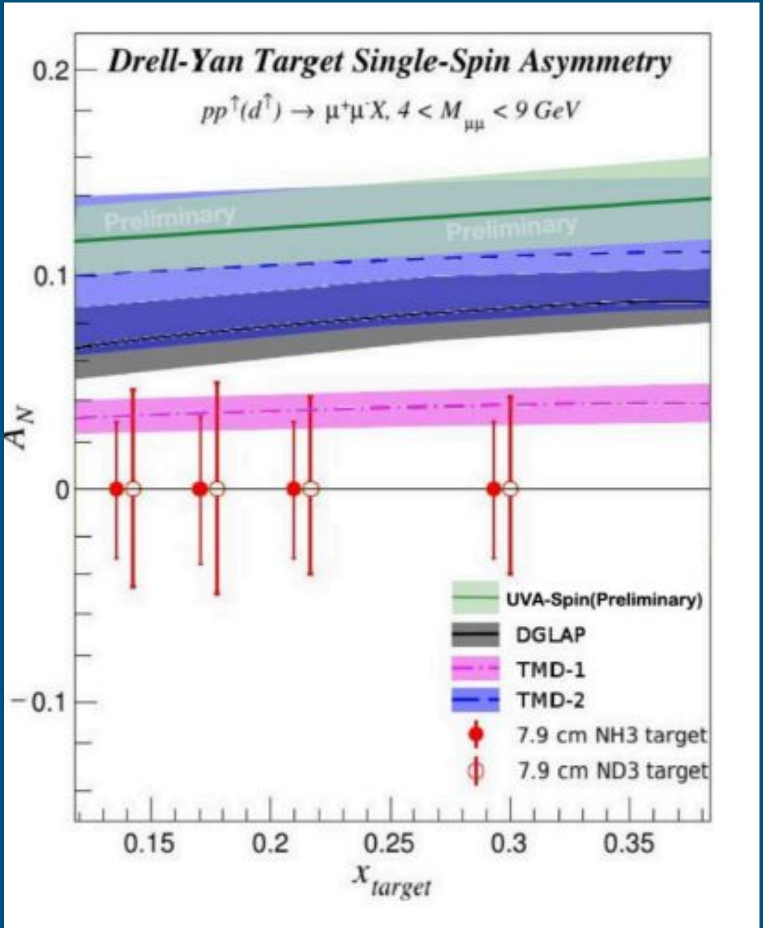
$$f^{\perp q DY}(x, p_T^2) = -f^{\perp q SIDIS}(x, p_T^2)$$




$$A_N^{DY} \propto \frac{\Sigma_q e_q^2 \left[ f_1^q(x_1) \cdot f_{1T}^{\perp \bar{q}}(x_2) + 1 \leftarrow\rightarrow 2 \right]}{\Sigma_q e_q^2 \left[ f_1^q(x_1) \cdot f_1^{\bar{q}}(x_2) + 1 \leftarrow\rightarrow 2 \right]}$$

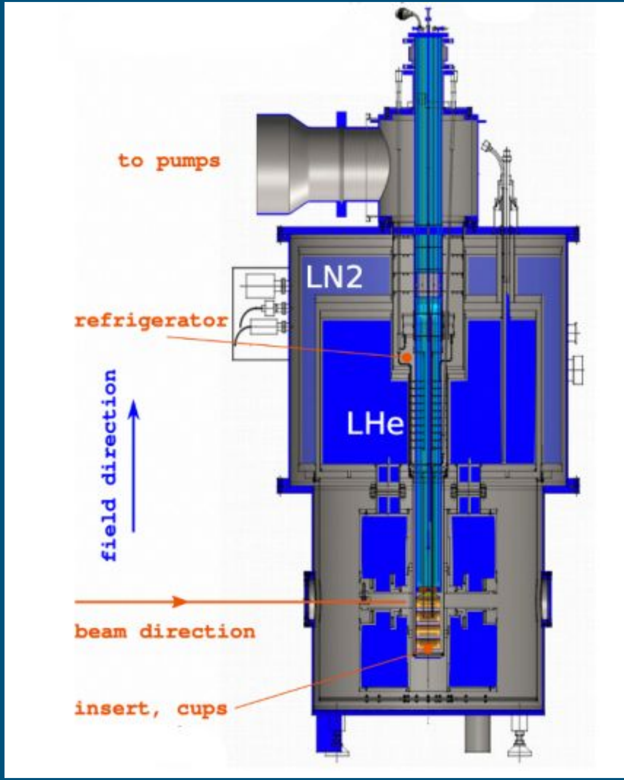
# False Asymmetries

- Diurnal effects
- Weather(hot and cold cycles)
- Hardware:
  - Cooling systems malfunctioning
  - Target alignment
  - Magnet health
  - Detector health
- Predicted Sensitivity
  - Beam~2.5%
  - Target~6-7%
- Detection of False Asymmetries is **VITAL**



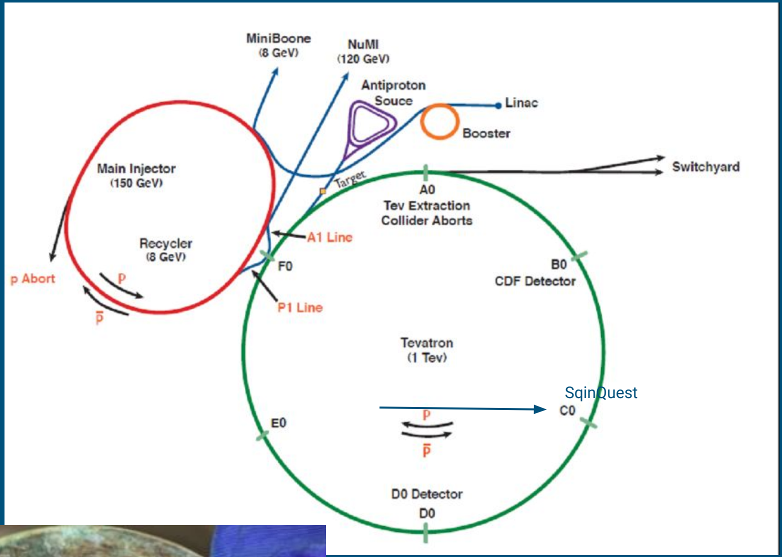
# Sensitivity

- Beam ~ 2.5%
  - Luminosity ~ 1%
  - Drifts < 2%
  - Scraping ~ 1%
- Target ~ 6-7%
  - Polarization ~ 2%
  - Density ~ 1%
  - Alignment ~ 0.5%
  - TE Calibration: P ~ 2.5% d: ~ 4.5%
  - Radiation damage ~ 3%
  - Packing fraction ~ 2%
  - Dilution factor ~ 3%



# The Beam and Target

- Beam
  - 120 GeV Unpolarized Proton beam collides with polarized proton target
  - 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.
- Target
  - Proton Target NH3
  - Neutron Target ND3

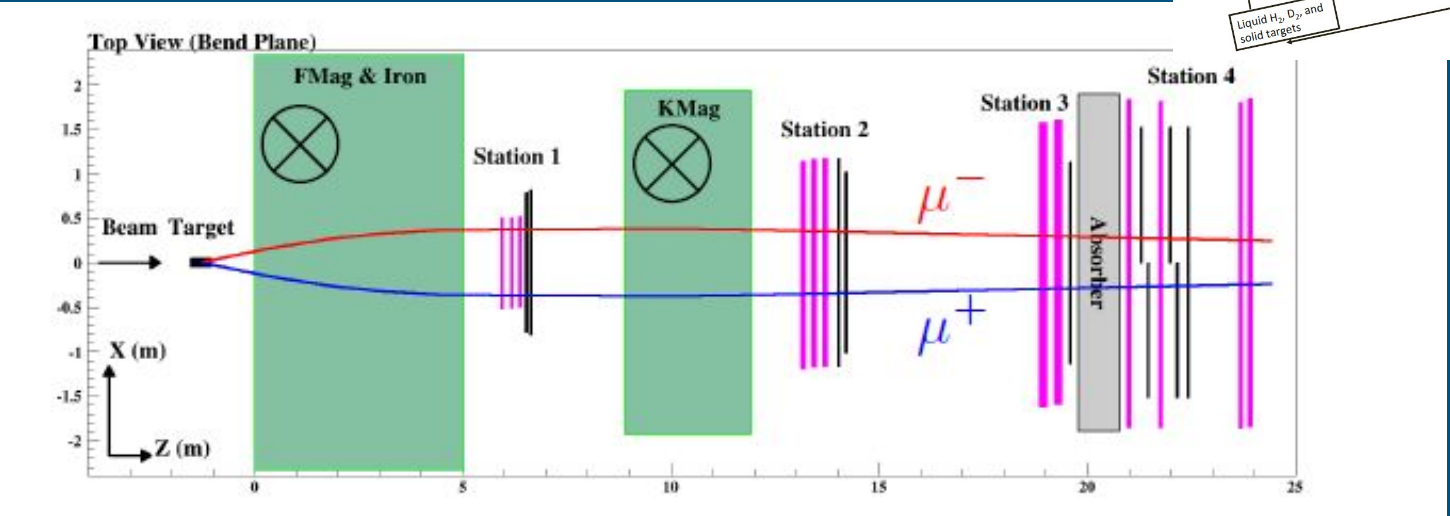


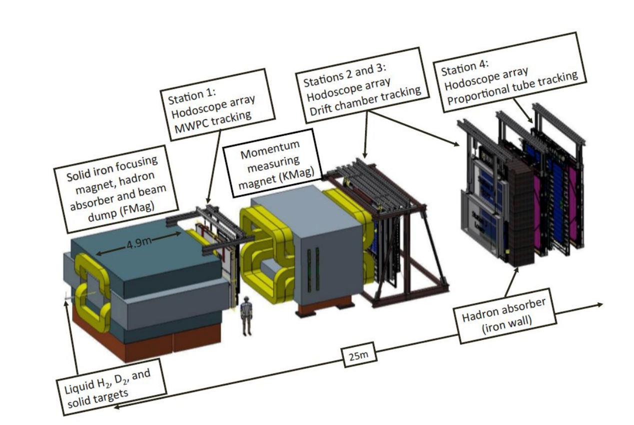

FERMILAB-PUB-20-087-AD-APC

SPTG-TechNote-17003

# The Experimental setup

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

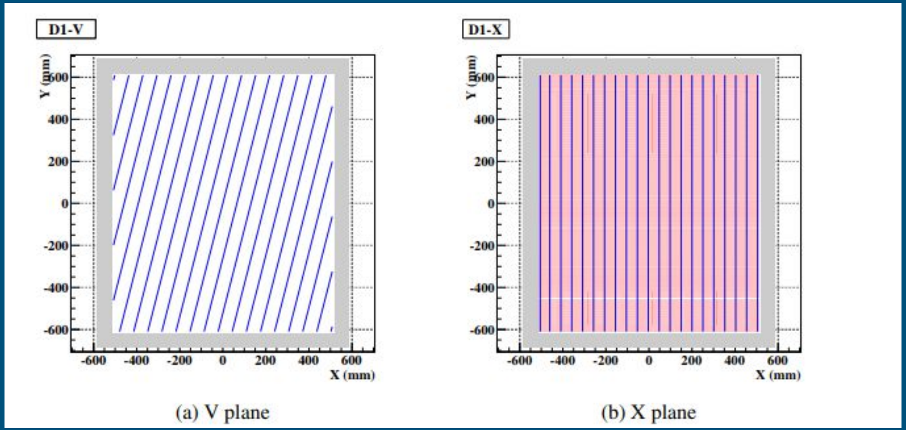


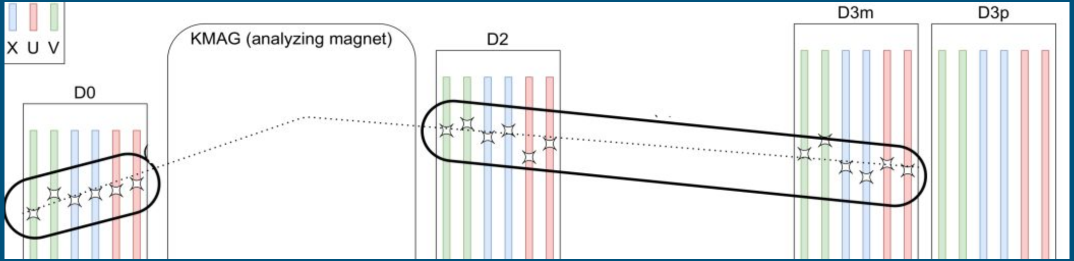

E1039 Proposal

# Station Level

- Drift chamber: Array of wires used to determined the position.
- There are 4 drift chambers each with 6  detector planes.
    - V,V’,X,X’,U,U’
    - Prime planes and U+V deal with left right detection.
- St.1, St.2, St.3p and St.3m



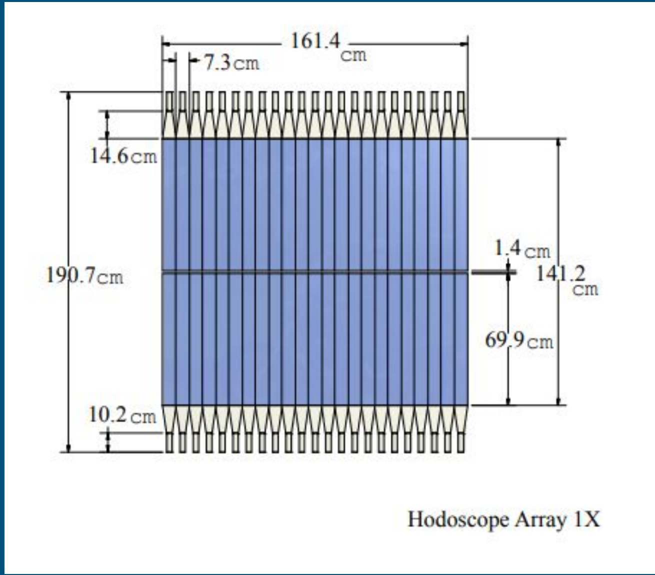

Kei Nagai: Recent Measurement of Flavor Asymmetry of Antiquarks in the Proton by Drell–Yan Experiment SeaQuest at Fermilab




Eric Fuchey Status of GPU-based online reconstruction program

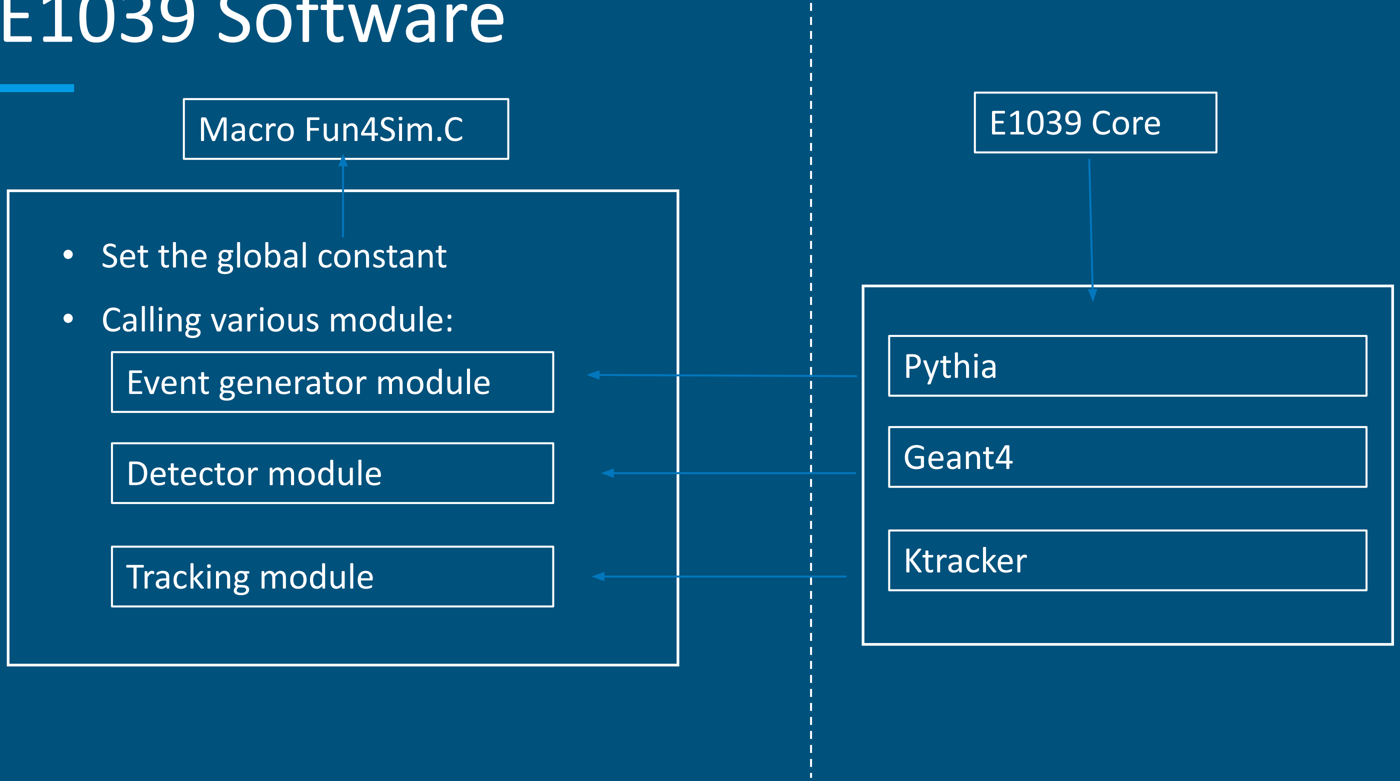
# Station Level

- Hodoscope: Array of scilating paddles used to determined the start time of the ion drift.
- There are 12 hodoscopes
  - 4 in st.1
  - 4 in st.2
  - 2 in st.3
  - 2 in st.4




Kei Nagai: Recent Measurement of Flavor Asymmetry of Antiquarks in the Proton by Drell−Yan Experiment SeaQuest at Fermilab

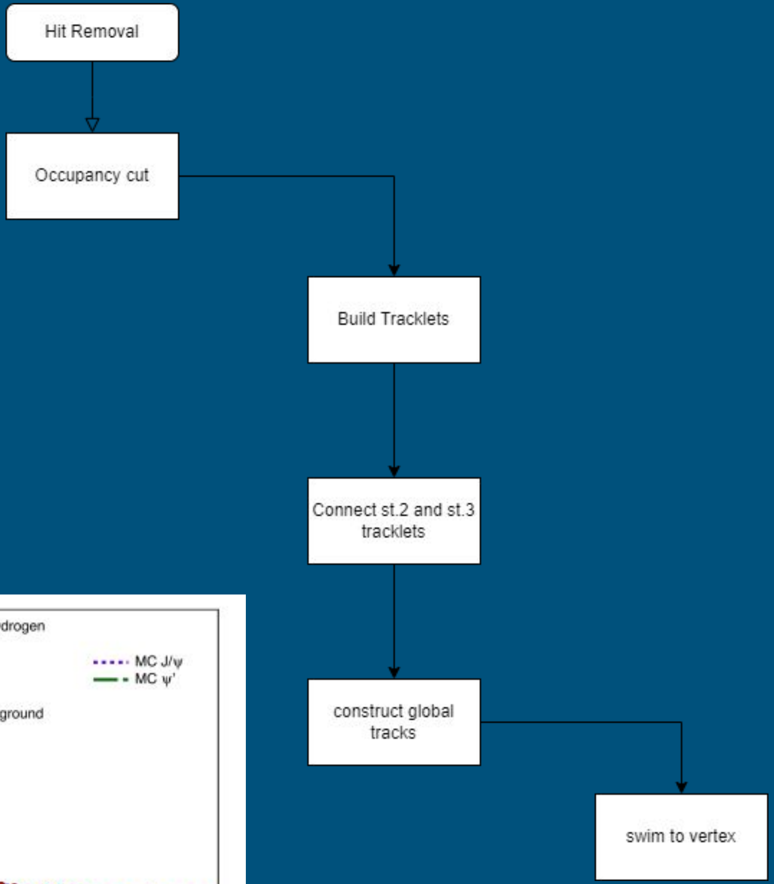
# E1039 Software

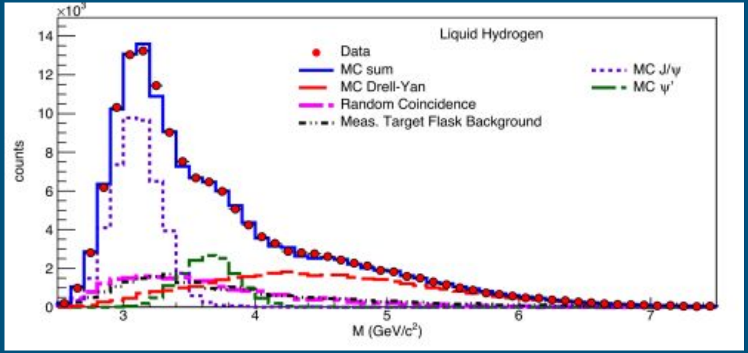



E1039 is designed to be modular & user friendly

# Reconstruction

- Can be broken up in 3 parts:
  - Pre-tracking
  - Single Track Reconstruction
  - Vertex Reconstruction
- Only cares about the final four momenta.
- Made in C++ entangled in Fun4All Class system.



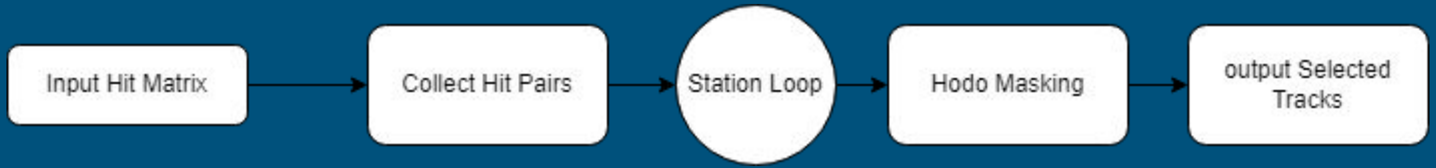




Nature 590 561-565 2021

# Challenges

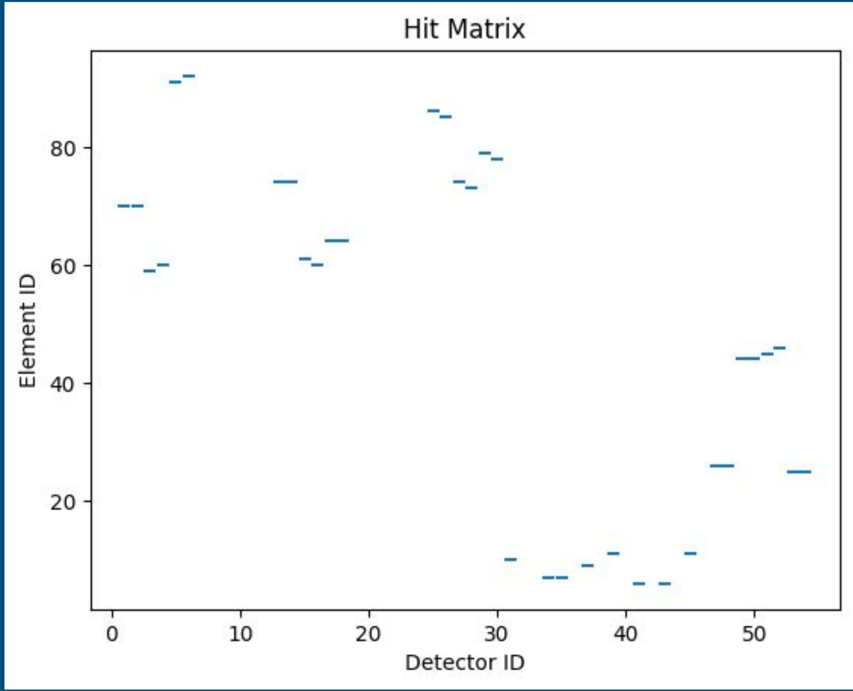
- We **need** to detect false asymmetries
- We must calculate the left right asymmetry **Quickly**
- We must be able to see the reconstruct a every stage
- K Tracker is not optimized for this.

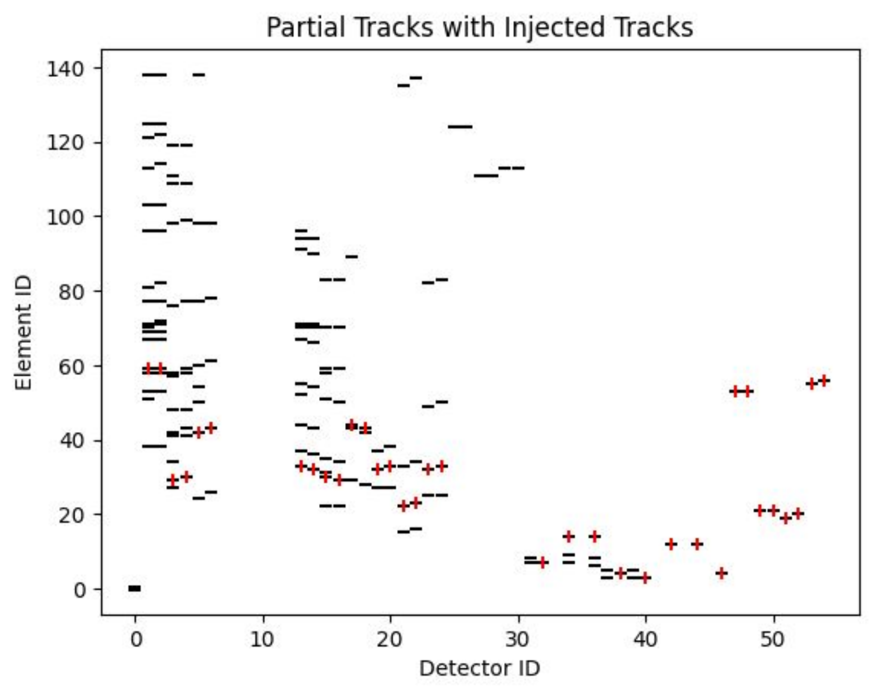
# A new approach: GPU Acceleration




- 1 spill ~ 20-60,000 events in 4 seconds per minute
- Ktracker takes 1 hour and a half to process 20,000 events.
- GPU acceleration predicted to cut this by a factor of 10!

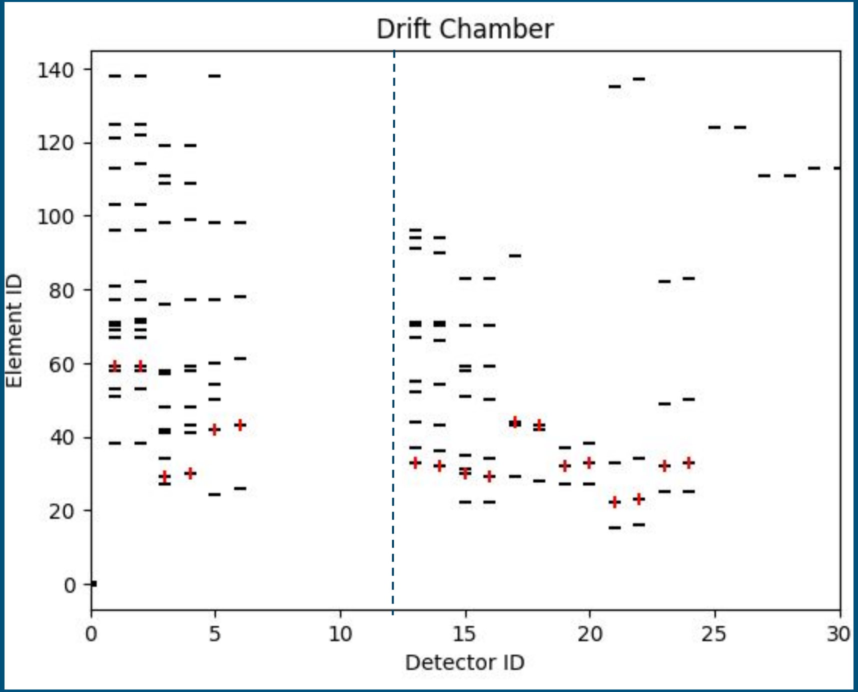
# Simulating a Spill

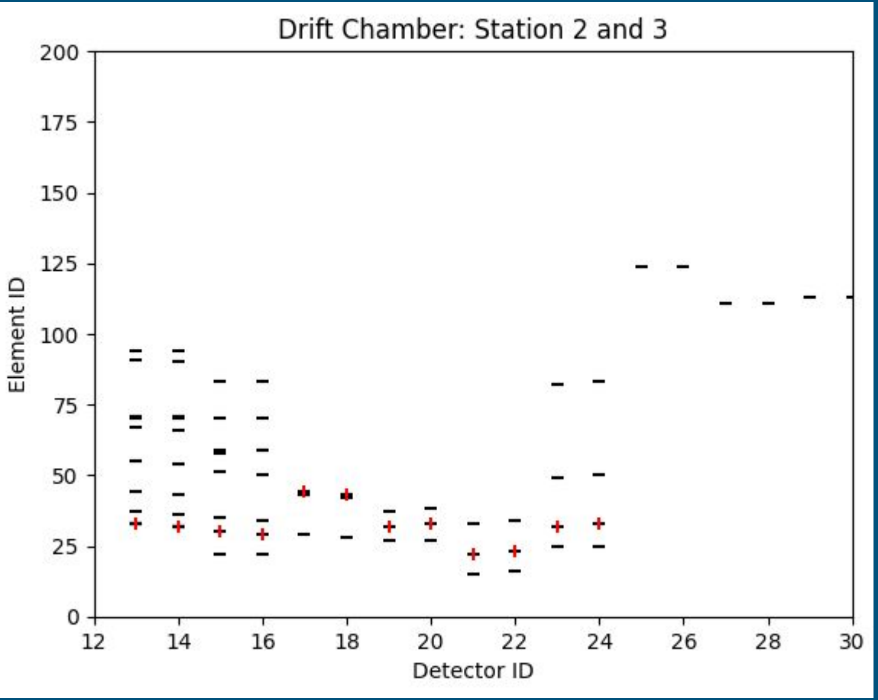



Total Hits 147

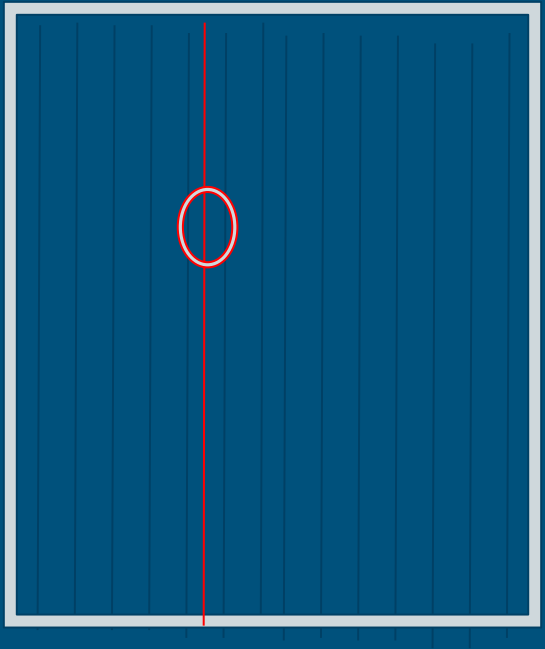
# Hit Pair Selection



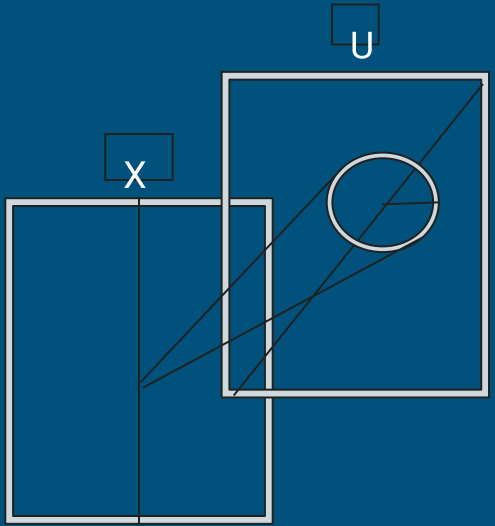

Total Hits 80

# Geometry Position



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

# Geometry Window



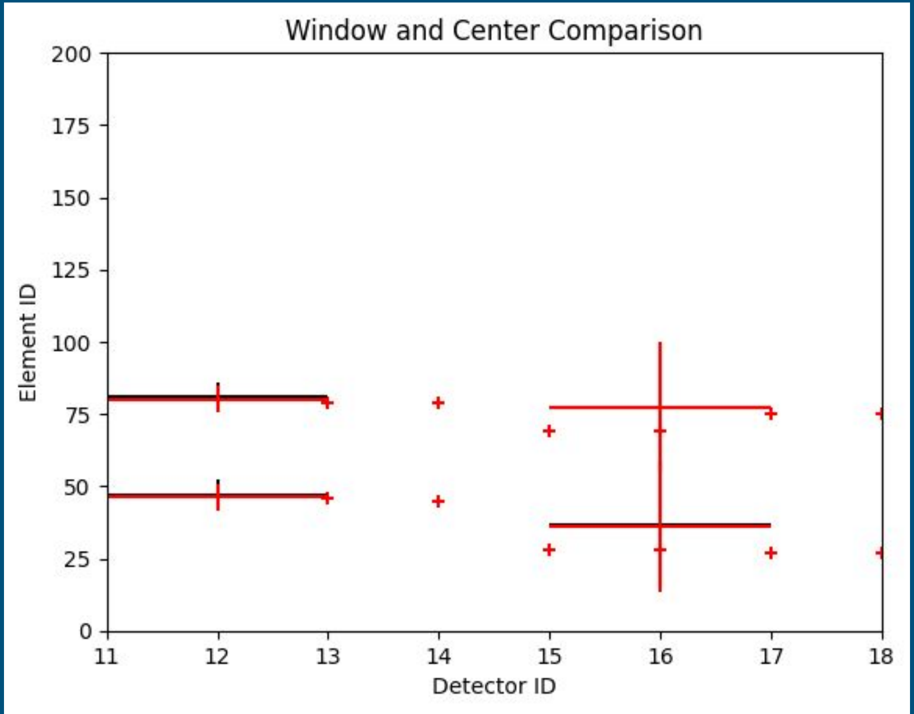

$$URadius = \left|\frac{1}{2} * XWireSpan * \sin(UWireAngle)\right| + TXMax \left|(ZPositionofUhit - ZPositionofXhit)\right| \cos(UWireAngle) + TYMax\left|(ZPositionofUhit - ZPositionofXhit)\right| \sin(UWireAngle) + 2 * WireSpacing + \delta$$

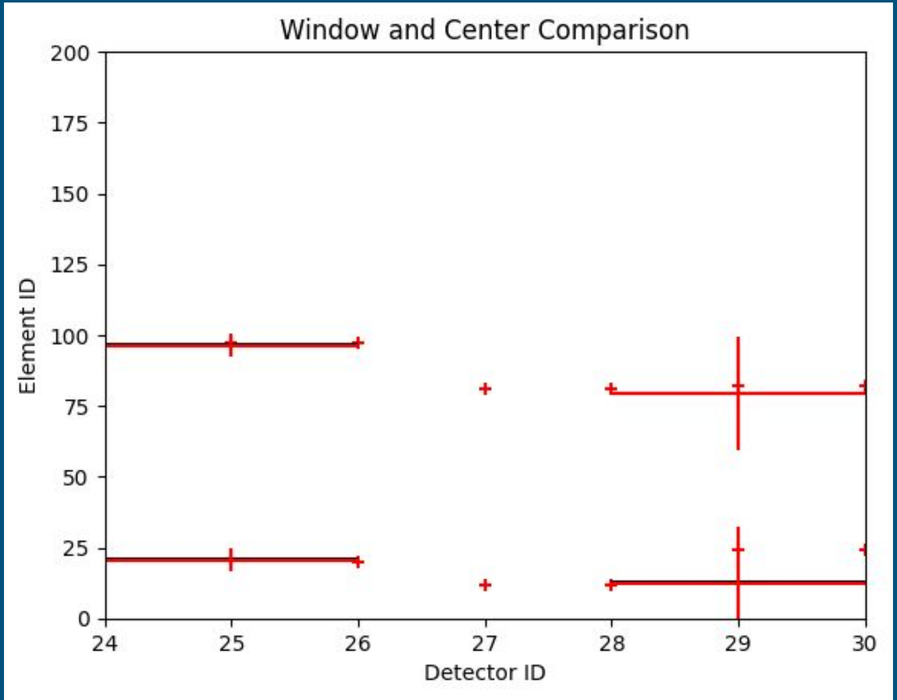
$$VRadius = UHitWireSpacing * 2 * \cos(UWire) + \left|(ZPositionofUHit + ZPostionofVHit - 2 * ZPostionofXHit) * \cos(UWire) * TXMax\right| + \left|(ZPostionofVHit - ZPostionofUHit) * \sin(UWire) * TYMax\right| + 2 * UHitWireSpacing$$

$$VCenter = 2 * UCenter - WirePositionofUHit$$

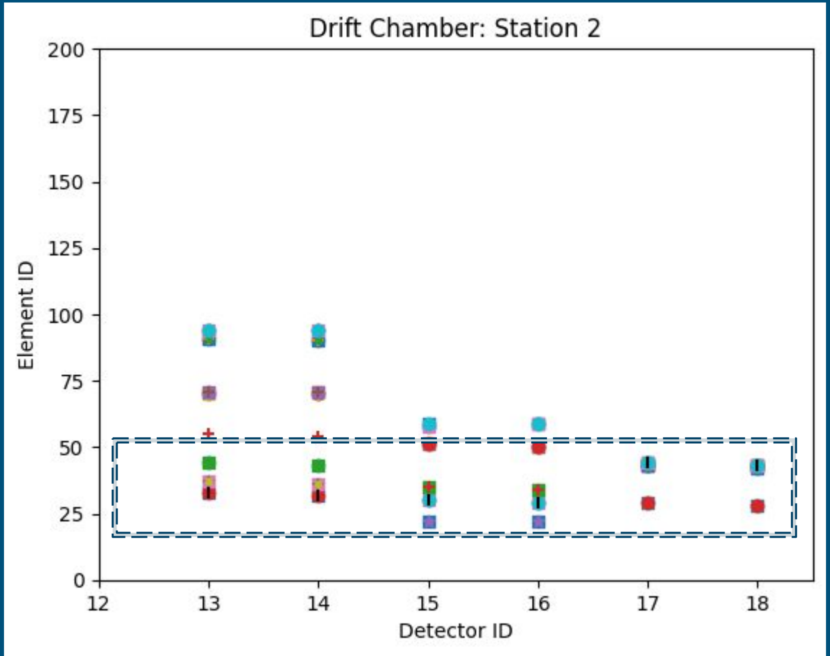
$$UCenter = WirePositionofXHit * \cos(UWire)$$

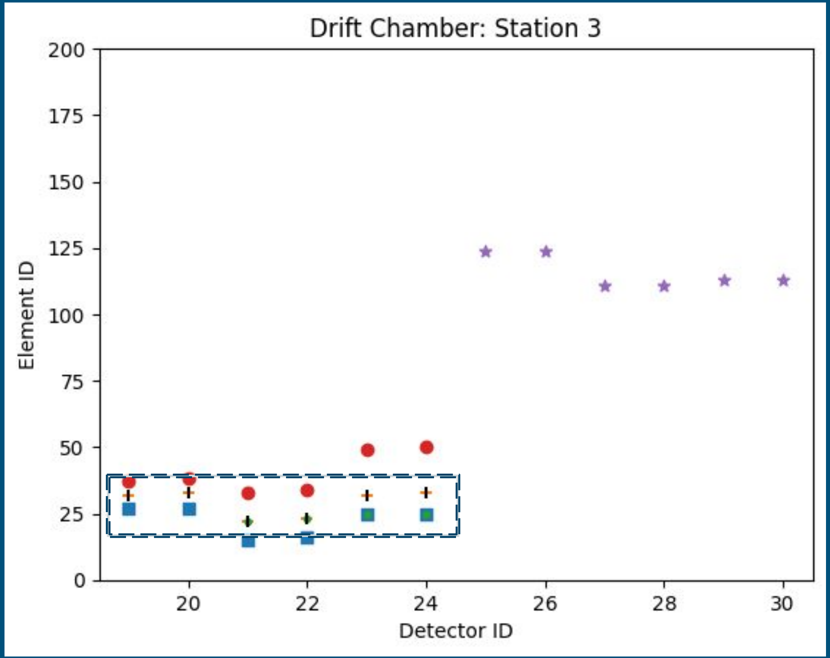
# Window Creation



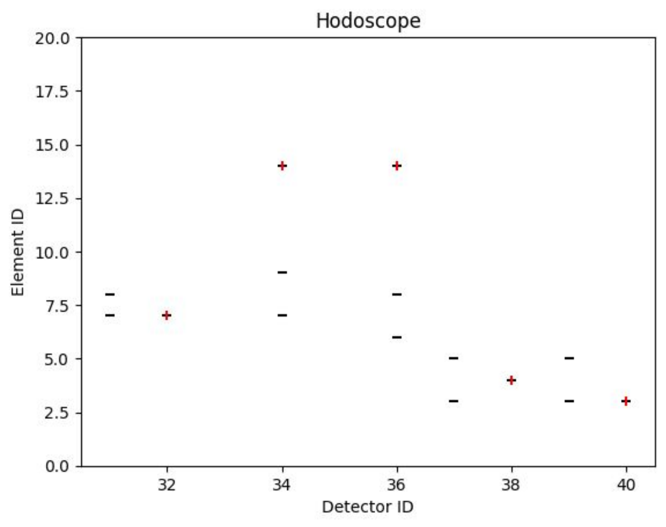
# Tracklet Making

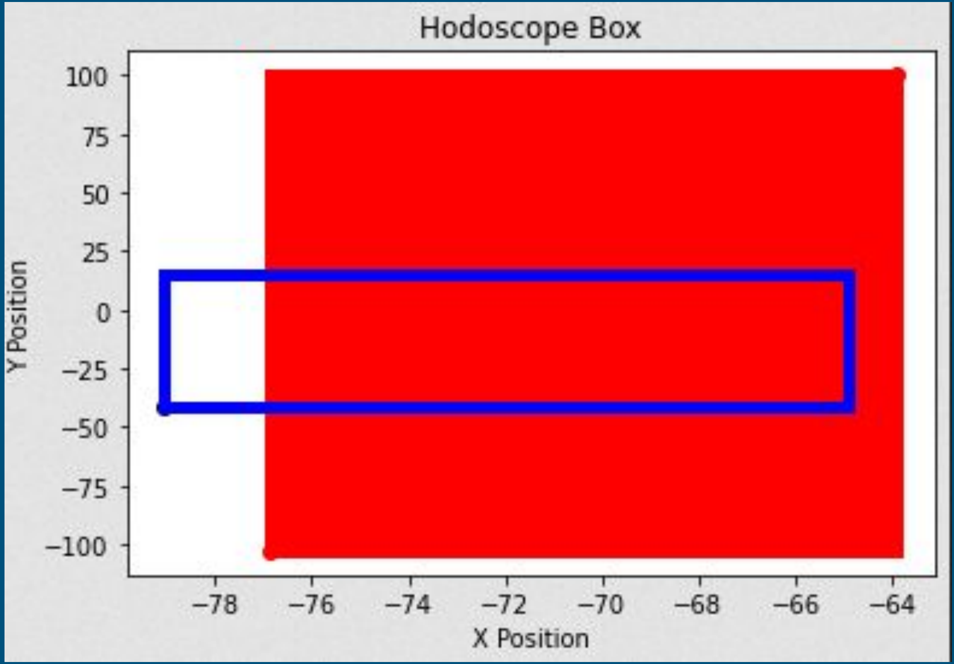



58 Hits
45 Tracklets combinations

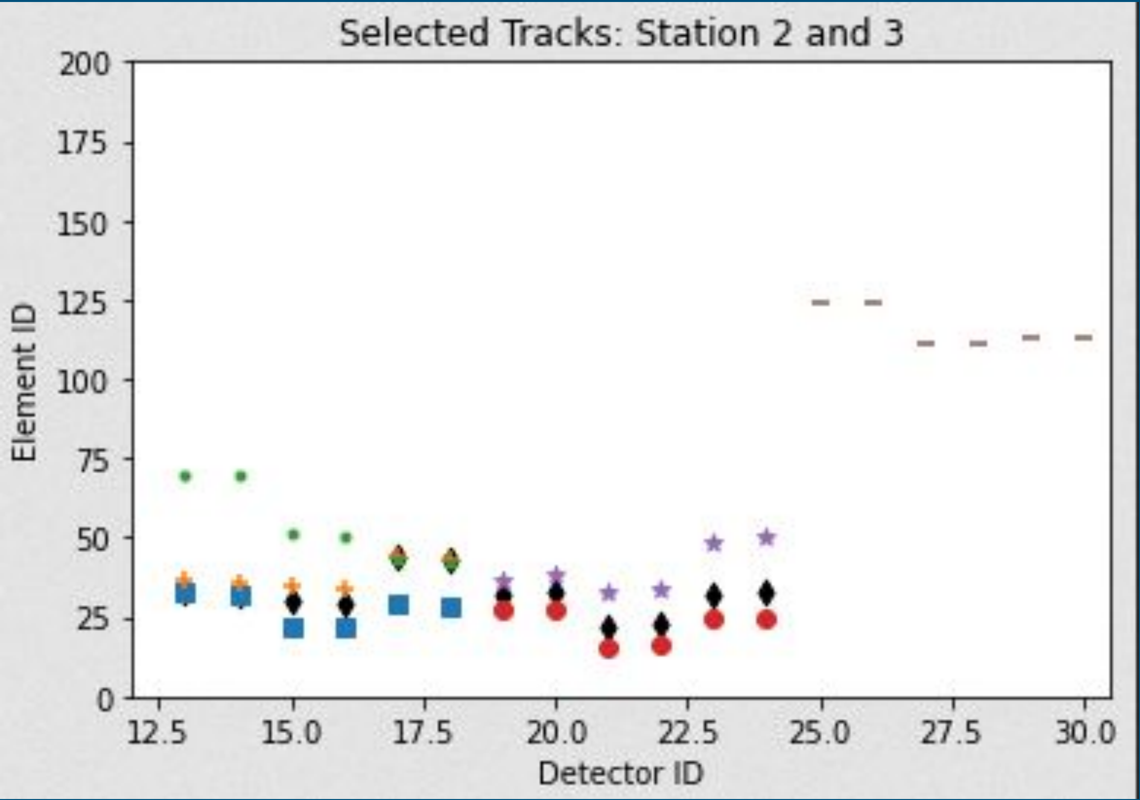
# Hodoscope Matching



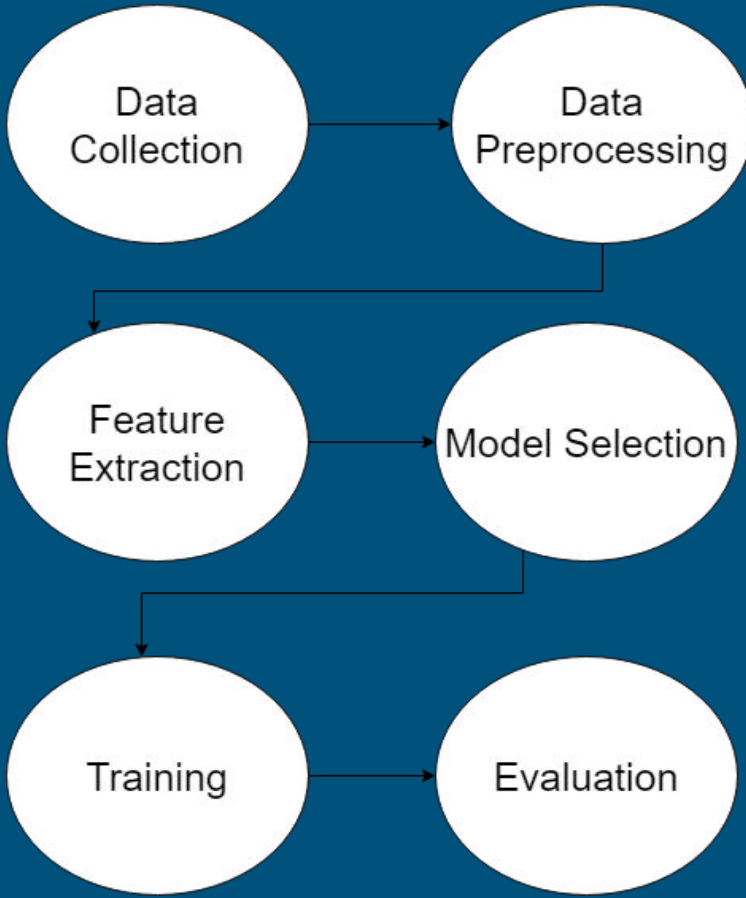
# Tracklets Before AI integration

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



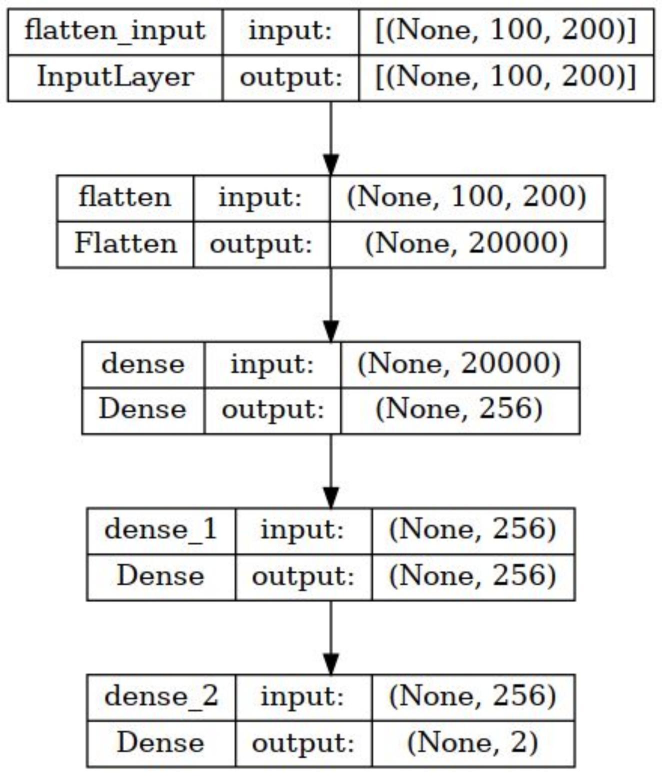
# Machine Learning

- Machine Learning in Nuclear physics allows for
  - Fast Analysis
- Types of machine learning:
  - Supervised learning
  - Unsupervised learning
  - Reinforcement learning
  - And MORE!



# Models

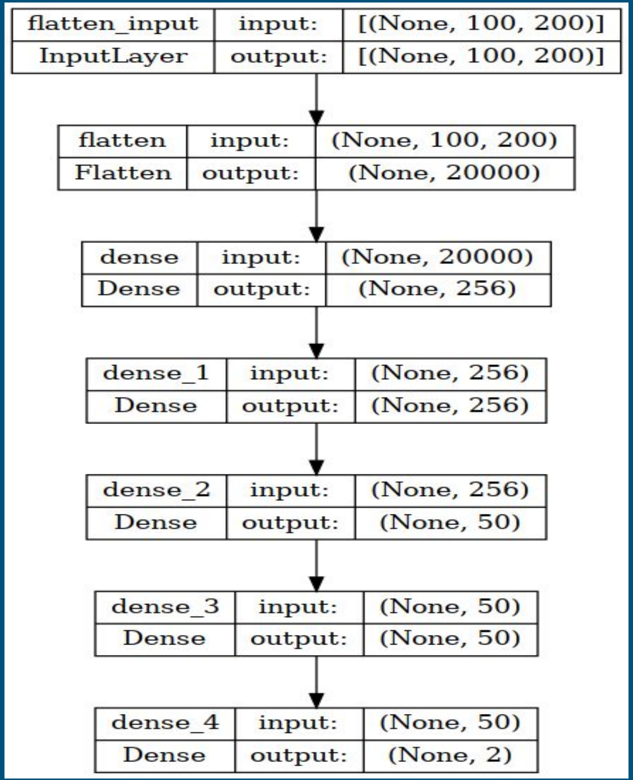
Intercepts




Input

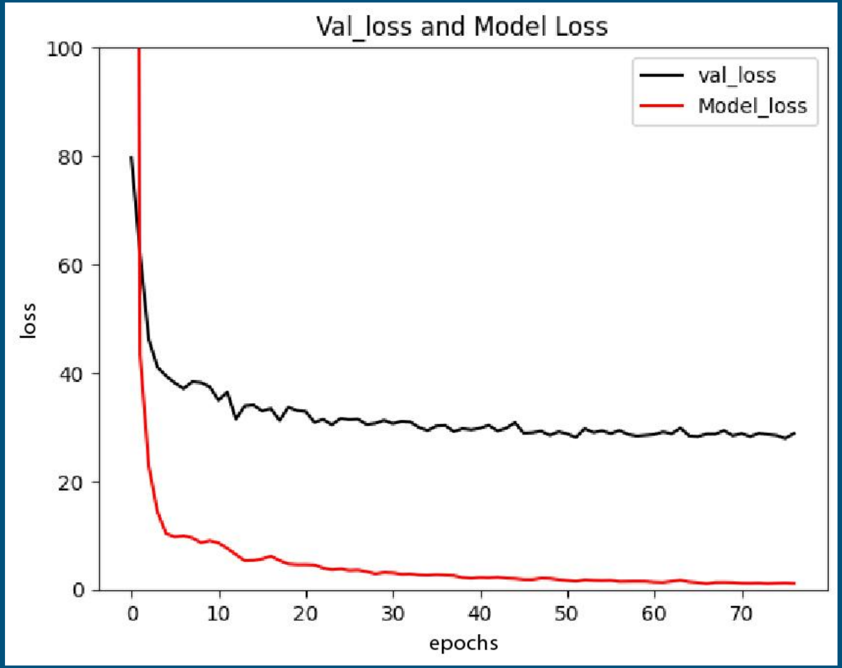
output

Slopes

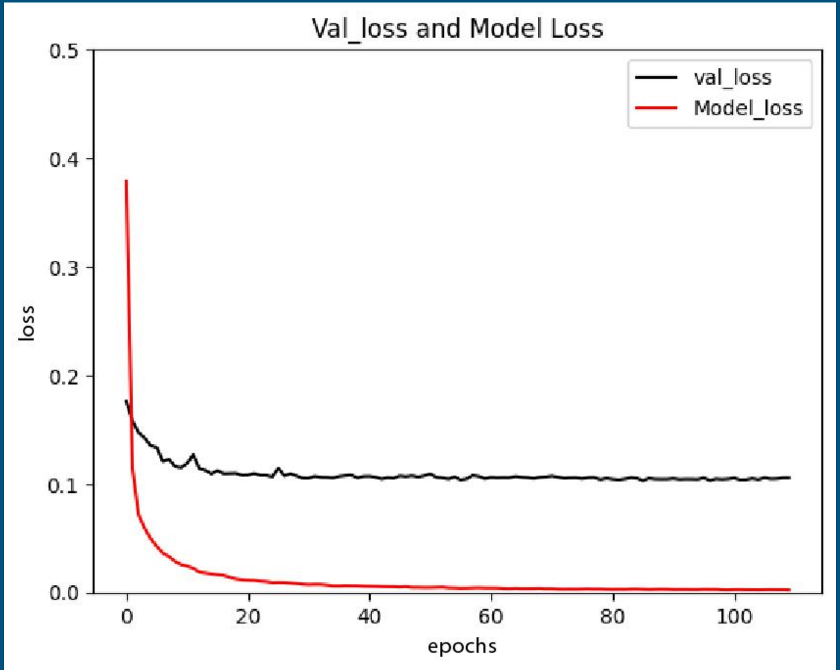


# Loss graphs

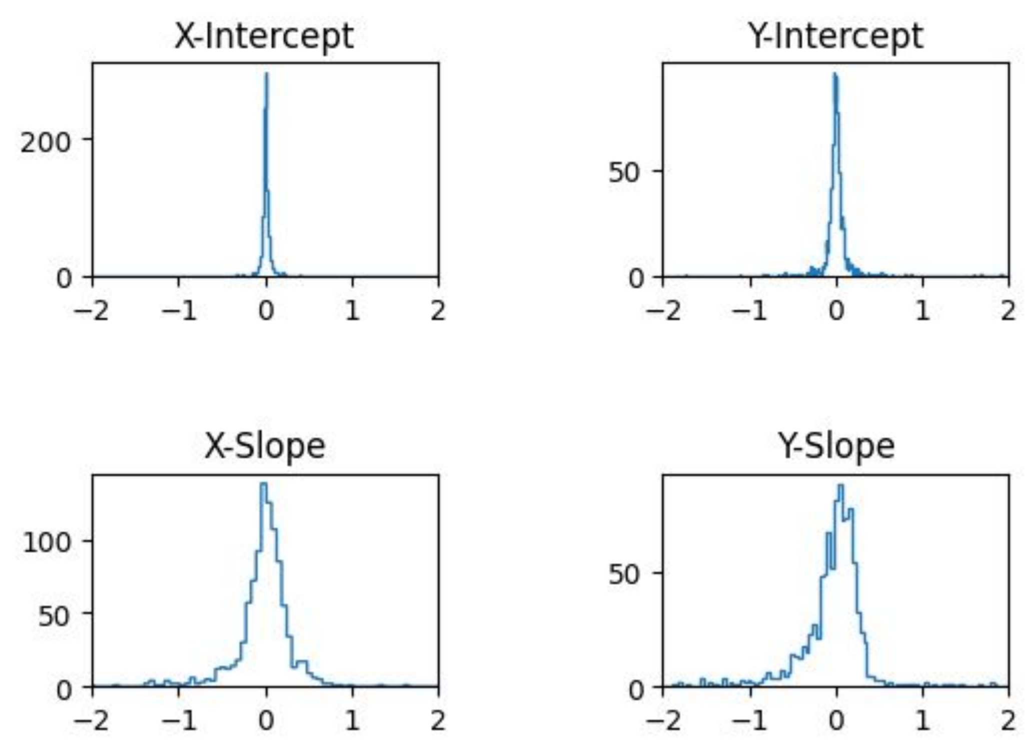
Intercepts



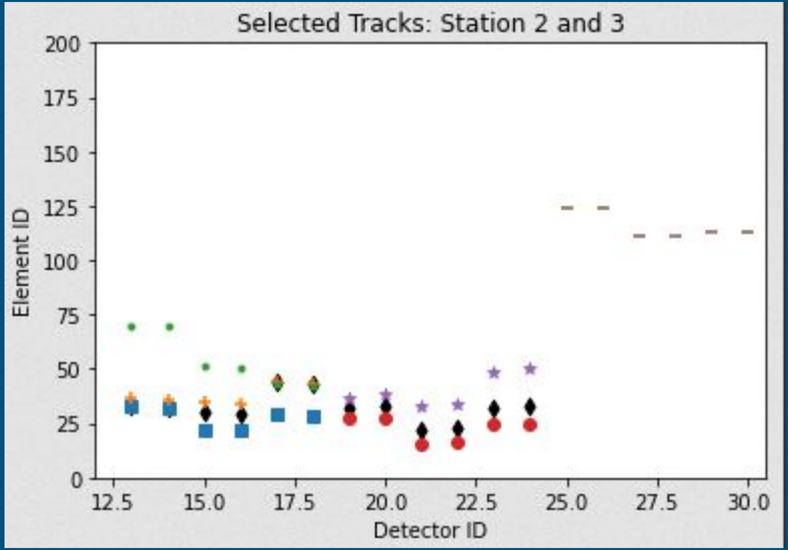

Slopes



# Approximate error



# Detecting False Asymmetries




AI

X-Slope

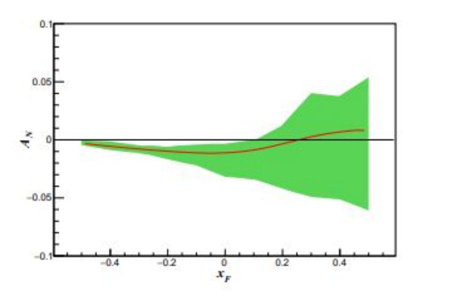
Y-Slope

X0

Y0

Four momenta

Left right Asymmetry



E1039 proposal

- Options for interface
    - Dearpygui
    - VisPy
    - plotoptix

Started with 80 hits
Removed 44 hits
Ending with 36 hits/ 6 tracklets

Precision = 81%
Recall = 53%
Accuracy = 50%

# Conclusion

- A simulated Spill was created matching the occupancy of seaquest.
- We were able to write a program that utilize the core features of K-Tracker to select hits to create Tracks within error.
- This software is written to utilize:
  - Numba GPU Acceleration
  - DearpyGui Interface Display
  - Tensorflow Machine Learning
- We observed an  precision of 81% and accuracy of 50% background removal.
  - Estimated efficiency after AI and hodo tuning to increase

# Thank You

# Citation

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# Backup Slides

# Efficiencity

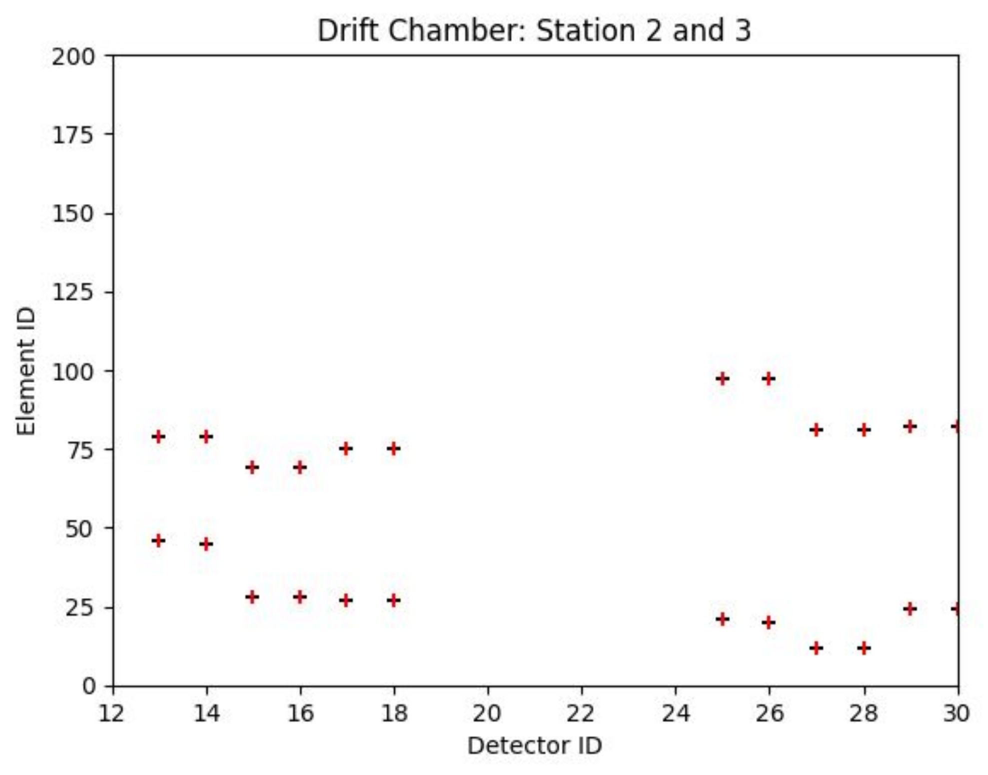
- TP is cases in which it is a background hit and is correctly removed.
- TN is cases in which it is a hit and is kept
- FP is cases  in which it is a hit and is removed
- FN is cases in which it is a background hit and is kept.

$$Precision = \frac{True\ Positive(TP)}{True\ Positive(TP) + False\ Positive(FP)}$$

$$Recall = \frac{True\ Positive(TP)}{True\ Positive(TP) + False\ Negative(FN)}$$

$$\text{Accuracy} = \frac{\text{True Positive} + \text{True Negative}}{(\text{True Positive} + \text{False Positive} + \text{True Negative} + \text{False Negative})}$$

# 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 |