# n3He Frequency Analysis - FFT Results Summary

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March 12, 2018

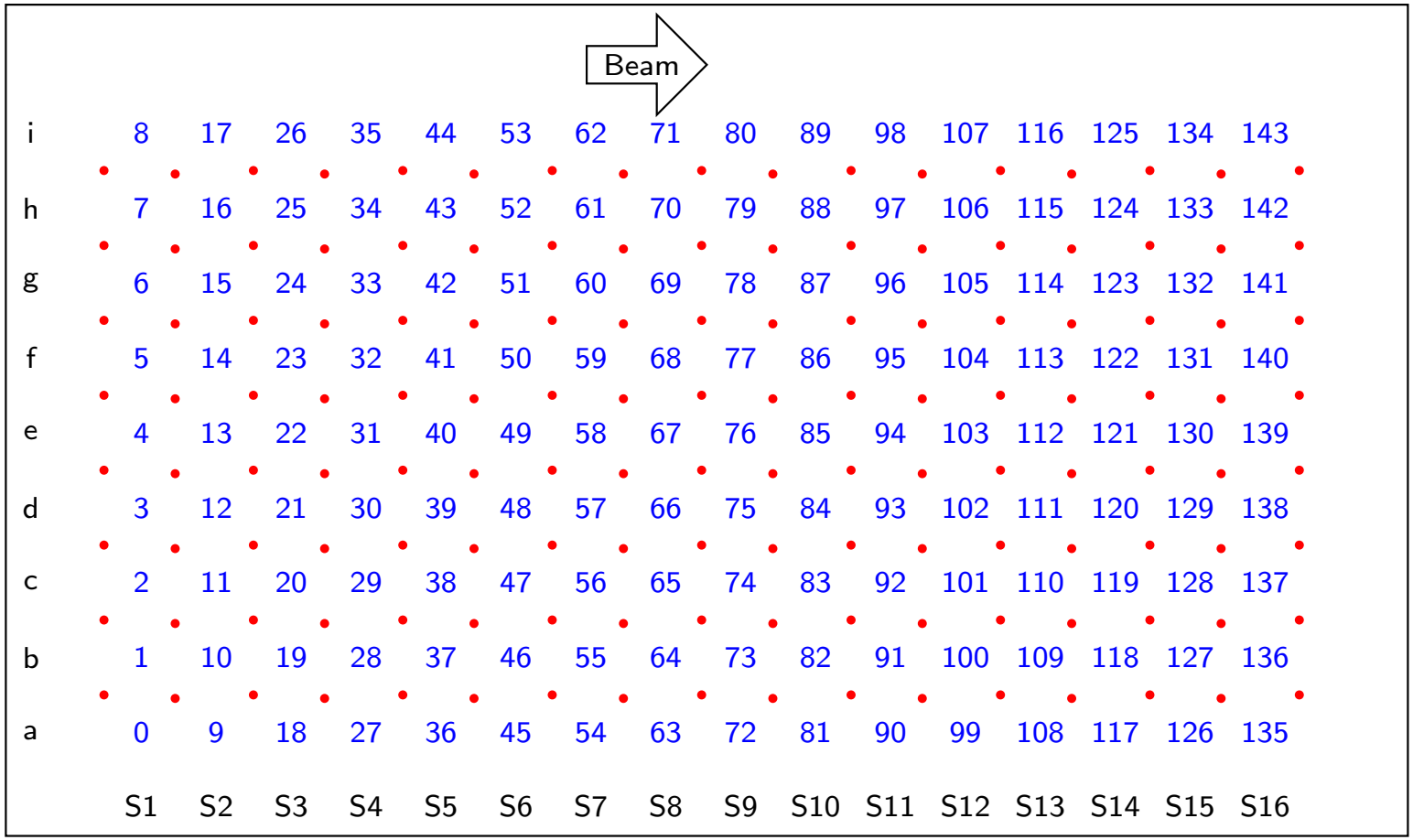
Chamber Layout

Run Selections

Instrumental Asymmetry Calculation Method

Possible Causes

# Signal Wire Numbering




17 HV Frames with 8 wires each

16 signal Frames with 9 wires each

- Signal

# Tuesday Run List

Tuesday Run List

| | Initial Run | Final Run | | Initial Run | Final Run |
|---|---|---|---|---|---|
| T1 | 17784 | 17834 | ST1 | 38386 | 38416 |
| T2 | 19114 | 19158 | ST2 | 38566 | 38588 |
| T3 | 20444 | 20493 | T10 | 45032 | 45054 |
| T4 | 21869 | 21919 | T11 | 46416 | 46466 |
| T5 | 24011 | 24061 | T12 | 49663 | 49697 |
| T6 | 26461 | 26503 | T13 | 51076 | 51127 |
| T7 | 27729 | 27755 | T14 | 52467 | 52517 |
| T8 | 30058 | 30074 | T15 | 56073 | 56076 |
| T9 | 32503 | 32535 | | | |

Runs were taken between 9:00am and 4:00pm while beam was off for maintenance, and the total time each Tuesday the beam was off time was variable.

ST# runs are Tuesdays from the Summer that Kabir used in his beam off Tuesday asymmetry calculations.

# Time Bin and Wire Choices

The time bins and wires that are analyzed for the instrumental asymmetry were chosen to match those used in the physics asymmetry analysis.

- Time bins 5-44 inclusive were analyzed for the chamber wires
- The central row of wires was not analyzed
- Wires 5 and 6 were not analyzed as they did not provide a good signal.
- A total of 126 wires and with 40 times bins were analyzed.

# Beam Off Asymmetry Calculation

The mean wire yield per pulses is calculated as

$$\bar{Y}_{i,j,k} = \frac{1}{40} \sum_{t=5}^{44} Y_{i,j,k,t} \tag{1}$$

where $i$ is the wire number, $j$ is the run number, $k$ is the pulse number, $t$ is the time bin number.
The single wire instrumental asymmetries, $A_{i,j,q}$, were calculated using a simple difference formula normalized by one volt to render it unitless.

$$A_{i,j,q} = \frac{\bar{Y}^{\uparrow}_{i,j,k} - \bar{Y}^{\downarrow}_{i,j,k'}}{1V} \tag{2}$$

where $q$ is the asymmetry number, $k$ and $k^{'}$ are consecutive pulses, $\bar{Y}^{\uparrow}$ is a pulse with spin orientated in the $+\hat{z}$, and $\bar{Y}^{\downarrow}$ in the $-\hat{z}$
Pulse and asymmetry numbers are indexed starting at zero.
Note: Beam on physics asymmetries were calculated over time bins $5 - 44$, and that time bin range was used for all parts of the following analysis.

# Scaling the Instrumental Asymmetry

The physics asymmetry is calculated as:

$$A_{phys} = \frac{1}{G_i}\frac{\bar{Y}_i^{\uparrow} - \bar{Y}_i^{\downarrow}}{\bar{Y}_i^{\uparrow} + \bar{Y}_i^{\downarrow}} = \frac{1}{G_i}\frac{S_i^{\uparrow} + b_i^{\uparrow} - S_i^{\downarrow} + b_i^{\downarrow}}{S_i^{\uparrow} + b_i^{\uparrow} + S_i^{\downarrow} + b_i^{\downarrow}} \tag{3}$$

$$\approx \frac{1}{G_i}\frac{S_i^{\uparrow} - S_i^{\downarrow}}{S_i^{\uparrow} + S_i^{\downarrow}} + \frac{1}{G_i}\frac{b_i^{\uparrow} - b_i^{\downarrow}}{S_i^{\uparrow} + S_i^{\downarrow}} \tag{4}$$

assuming $b_i << S_i$, where $b$ is the beam on pedestal.

So to compare the instrumental asymmetry to the physics asymmetry:

$$A_{i,j,q} = \frac{\bar{Y}_{i,j,k}^{\uparrow} - \bar{Y}_{i,j,k'}^{\downarrow}}{1V}$$

$$\rightarrow A_{i,j,q,scaled} = \frac{\bar{Y}_{i,j,k}^{\uparrow} - \bar{Y}_{i,j,k'}^{\downarrow}}{2\bar{S}_i} \tag{5}$$

where $G_i$ is the geometry factor for wire $i$, and $\bar{S}_i$ is the average beam on signal over all beam on runs for wire $i$.

# Initial Incorrect Asymmetry Calculation Method

- During Summer running most runs started on the same spin state, from this assumed all runs did such that for all $k = even$ pulses were spin up, and all $k = odd$ pulses were spin down.
- For each wire:
  1. Calculate

$$Y_{i,j,k=even,sum} = \sum_{t=5}^{44} Y_{i,j,k=even,t} \tag{6}$$

$$Y_{i,j,k=odd,sum} = \sum_{t=5}^{44} Y_{i,j,k'=odd,t} \tag{7}$$

  2. Form difference: $D_{i,j,q} = Y_{i,j,k=even,sum} - Y_{i,j,k=odd,sum}$
  3. Fill $A_{i,j,q} = D_{i,j,q}/40$ into a separate TH1I histogram for each wire.
  4. Use GetMean() and GetMeanError() for mean and standard error from the histograms
  5. Divide histogram mean and standard error by $2\bar{S}_i G_i$
- Perform weighted sums of the wire values using physics asymmetry uncertainties as shown on slide 9.

# Kabir's Instrumental Asymmetry Weighting Method



**Instrumental Asymmetry**

$$A_i = \frac{Y_i^{\uparrow} - Y_i^{\downarrow}}{Y_i^{\uparrow} + Y_i^{\downarrow}} = \frac{(S_i^{\uparrow} + b_i^{\uparrow}) - (S_i^{\downarrow} + b_i^{\downarrow})}{(S_i^{\uparrow} + b_i^{\uparrow}) + (S_i^{\downarrow} + b_i^{\downarrow})} \approx \frac{S_i^{\uparrow} - S_i^{\downarrow}}{S_i^{\uparrow} + S_i^{\downarrow}} + \frac{b_i^{\uparrow} - b_i^{\downarrow}}{S_i^{\uparrow} + S_i^{\downarrow}} \tag{5}$$

where $b_i^{\uparrow\downarrow}$ is the contribution from pedestal.

$$A_{inst}^i = \frac{1}{G_i} \frac{b_i^{\uparrow} - b_i^{\downarrow}}{2S^i} \tag{6}$$

$$A_{inst} = \frac{\sum_i w_i A_{inst}^i}{\sum_i w_i} \tag{7}$$

$$(\delta A_{inst})^2 = \frac{\sum_i w_i^2 (\delta A_{inst}^i)^2}{(\sum_i w_i)^2} \tag{8}$$

where,

$$w_i = \delta^{-2} A_{phy}^i \tag{9}$$



From meeting on 2017/04/28, Systematics 7, by Kabir.

# Corrected Asymmetry Calculation Method

- For each wire and pair of consecutive pulses $k$ and $k'$:
  1. Determine SF state for two consecutive pulses and assign values:
     - $SF_{i,j,k} = 1$ for SF off and neutron spin up
     - $SF_{i,j,k} = -1$ for SF on and neutron spin down
  2. Stop calculation and give error if pulse sequence is not $\uparrow\downarrow$ or $\downarrow\uparrow$
  3. Calculate $Y_{i,j,k,sum}$ and $Y_{i,j,k',sum}$
  4. Form difference: $D_{i,j,q} = SF_{i,j,k} Y_{i,j,k,sum} + SF_{i,j,k'} Y_{i,j,k',sum}$
  5. Calculate mean and standard error of $D_{i,j,q}$ for each wire over all asymmetries in a run, and divide results by 40.
  6. Divide mean and standard error by $2\bar{S}_i G_i$
- Perform weighted sums of the wire values using physics asymmetry uncertainties as shown on slide 9.

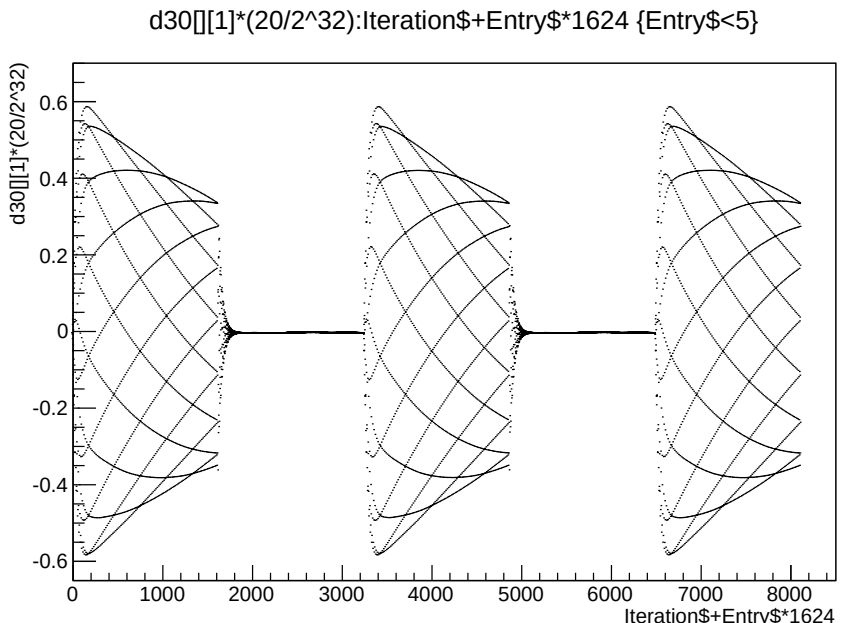
# Spin State Checking Method

- To check if the spin flipper is on or off the average of the absolute value of the spin flipper signal was taken:

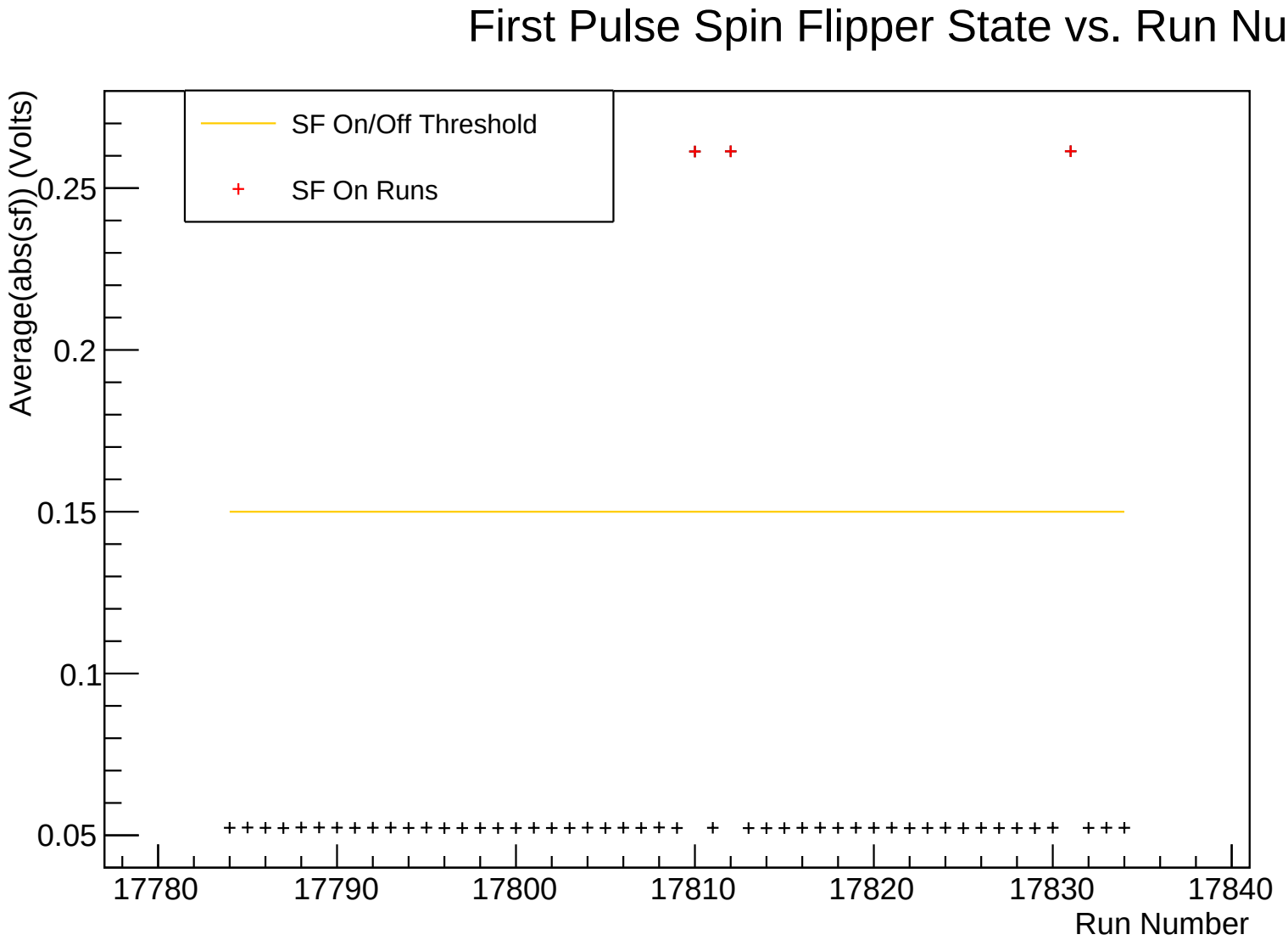
$$SF_{i,k,check} = \frac{1}{1624} \sum_{t=0}^{1} 623 abs(SF_{i,k,t}) \tag{8}$$

where $i$ is the run number, $k$ the pulse number, and $t$ the time bin number.

- $SF_{i,k,check} > 0.15 \rightarrow$ SF on
- $SF_{i,k,check} \leq 0.15 \rightarrow$ SF off



# Spin State Checking Method




Spin sequence consistency was also checked past the first pulse, and were consistence across runs.

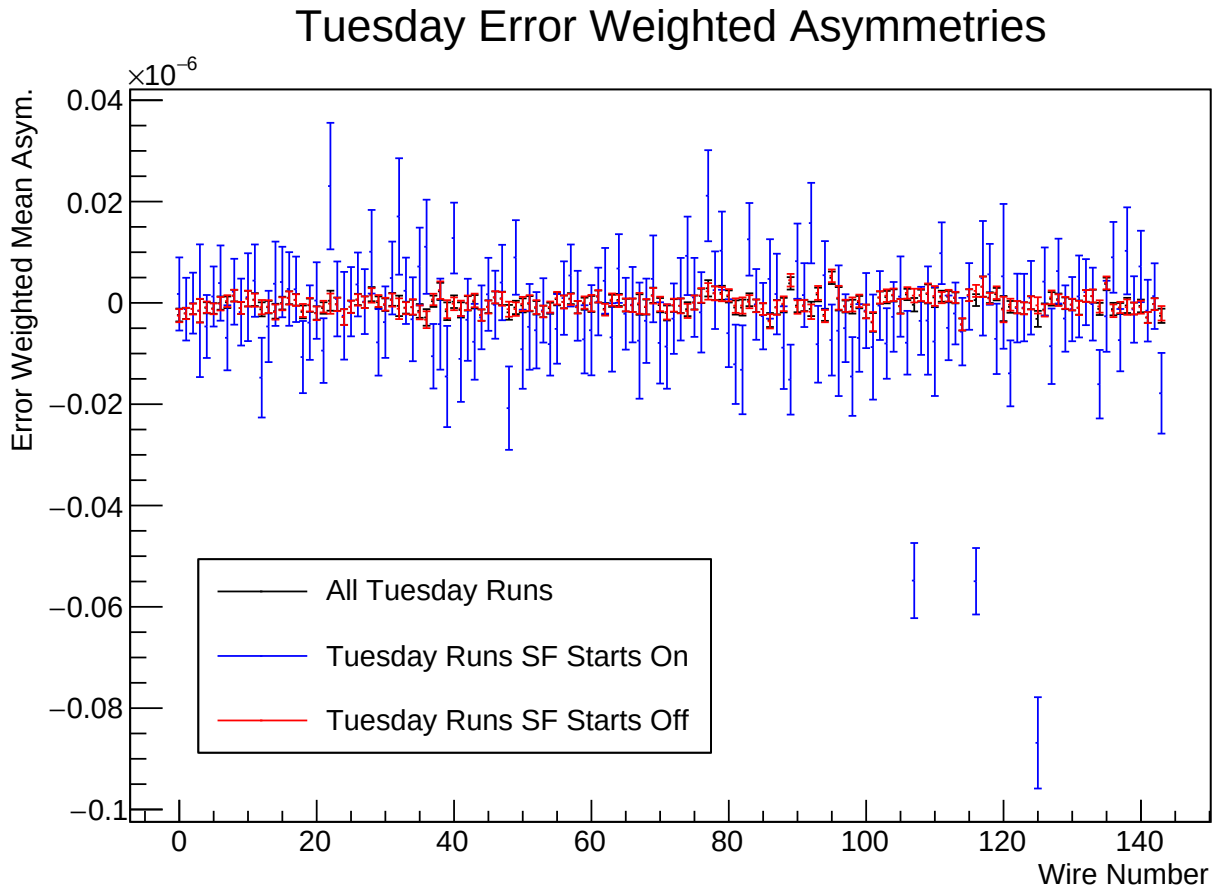
# What does this Change

- Most runs started spin flipper off as was assumed in the incorrect analysis
- Of the 565 beam off Tuesday runs, 16 were found to start spin flipper on.
- This would change the sign of the asymmetry in those 16 runs.

# Tuesday Runs that started SF On

| run number | run number |
|---|---|
| 17810 | 27745 |
| 17812 | 32504 |
| 17831 | 32518 |
| 19150 | 45047 |
| 20478 | 45049 |
| 24039 | 46448 |
| 24049 | 46466 |
| 26490 | 51117 |

# Un-Scaled Wire Asymmetries Following Spin State



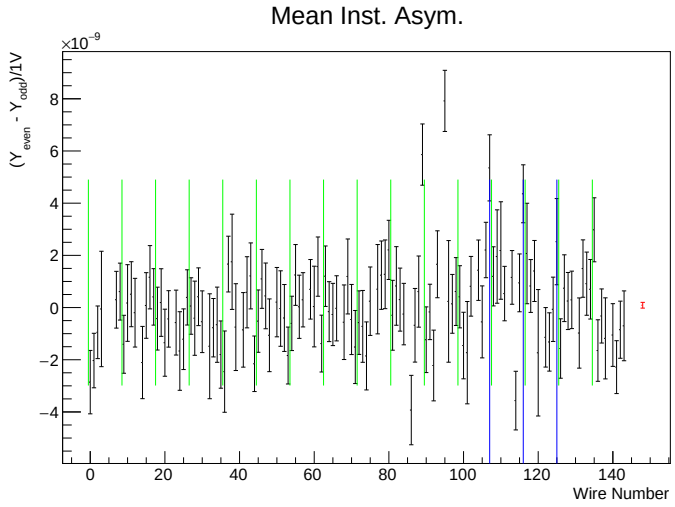

The error weighted average calculated from the mean and standard error of the asymmetry calculated for each run.

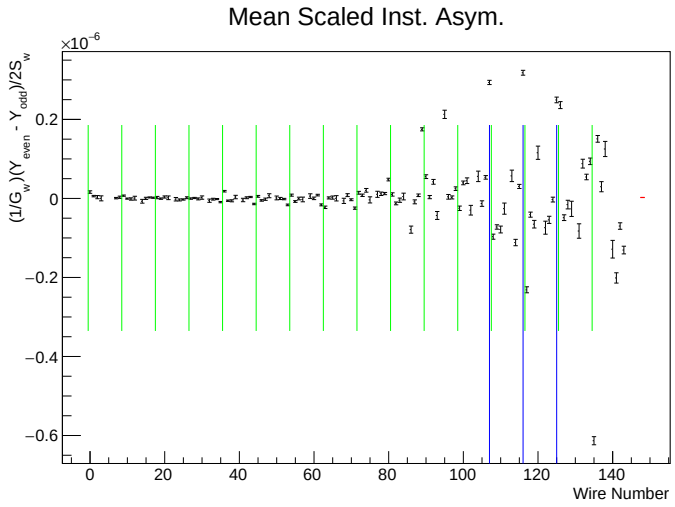
Note: Blue lines switch sign between SF tracked and untracked.

Wires 107, 116, 125 are the outliers

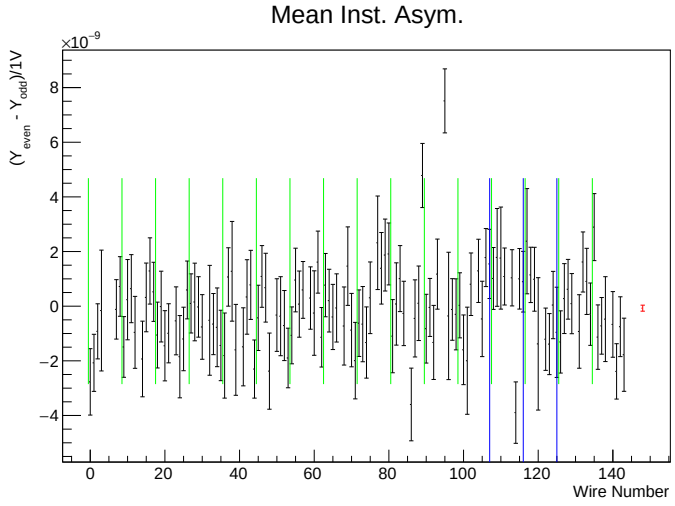
# Scaled Wire Asymmetry Comparison

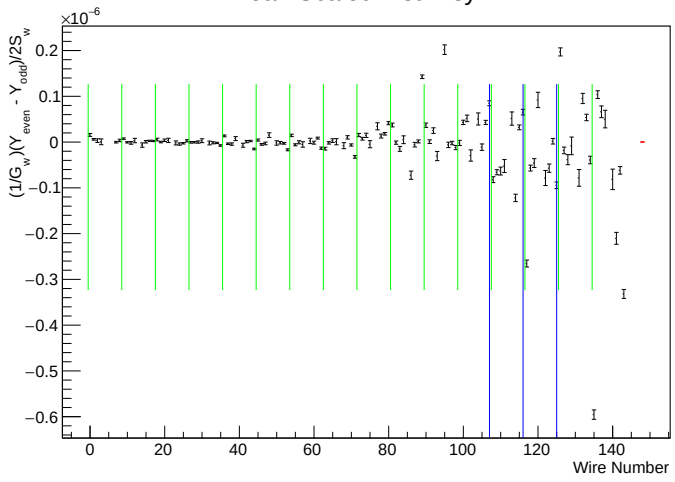
- Incorrect Spin Flipper Tracking




- Correct Spin Flipper Tracking

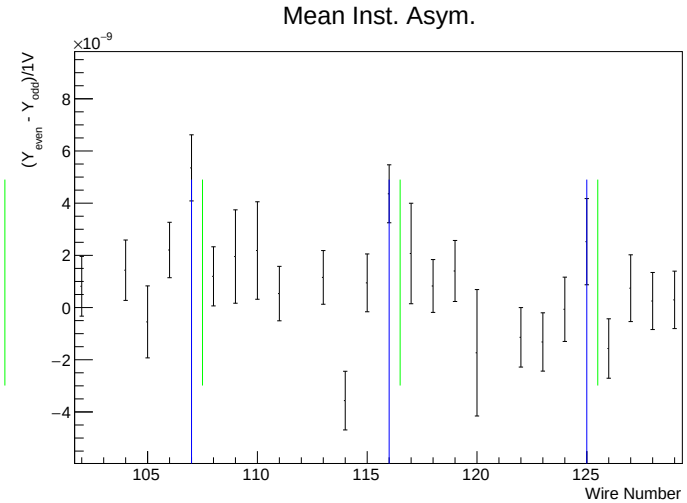


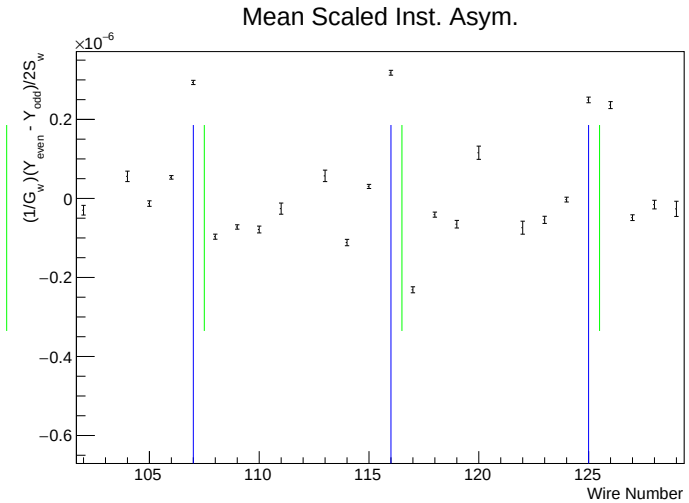




Vertical blue lines indicate position of 3 outlier points from slide 15.

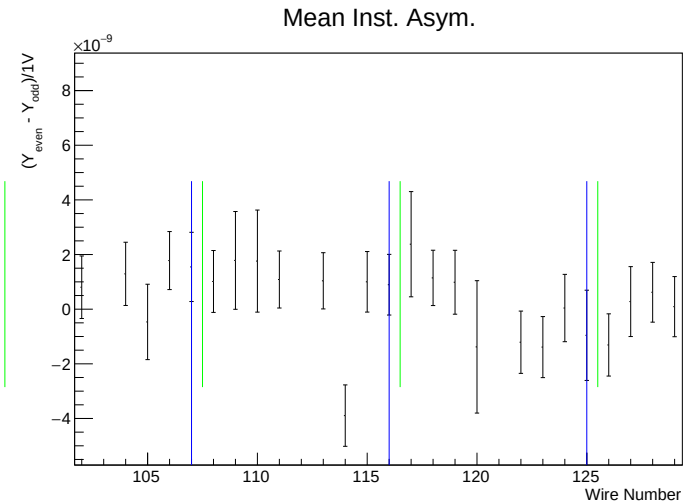
# Scaled Wire Asymmetry Comparison

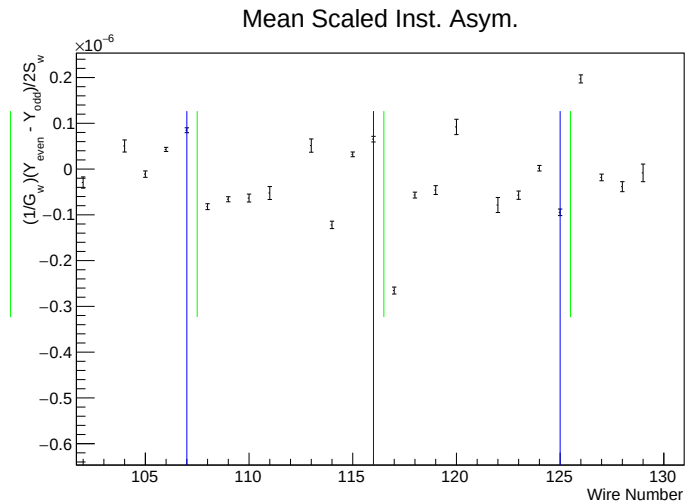
- Incorrect Spin Flipper Tracking




- Correct Spin Flipper Tracking




Vertical blue lines indicate position of 3 outlier points from slide 15.

# Weighted Asymmetry Results

- Incorrect Spin Treatment

$$A_{inst,wrong} = (2.4 \pm 1.97) \times 10^{-9} \tag{9}$$

- New Result Tracking Spin Flipper State

$$A_{inst} = (0.26 \pm 1.97) \times 10^{-9} \tag{10}$$

- Gericke's Result Tracking Spin Flipper

$$A_{inst,G} = (0.26 \pm 1.97) \times 10^{-9} \tag{11}$$

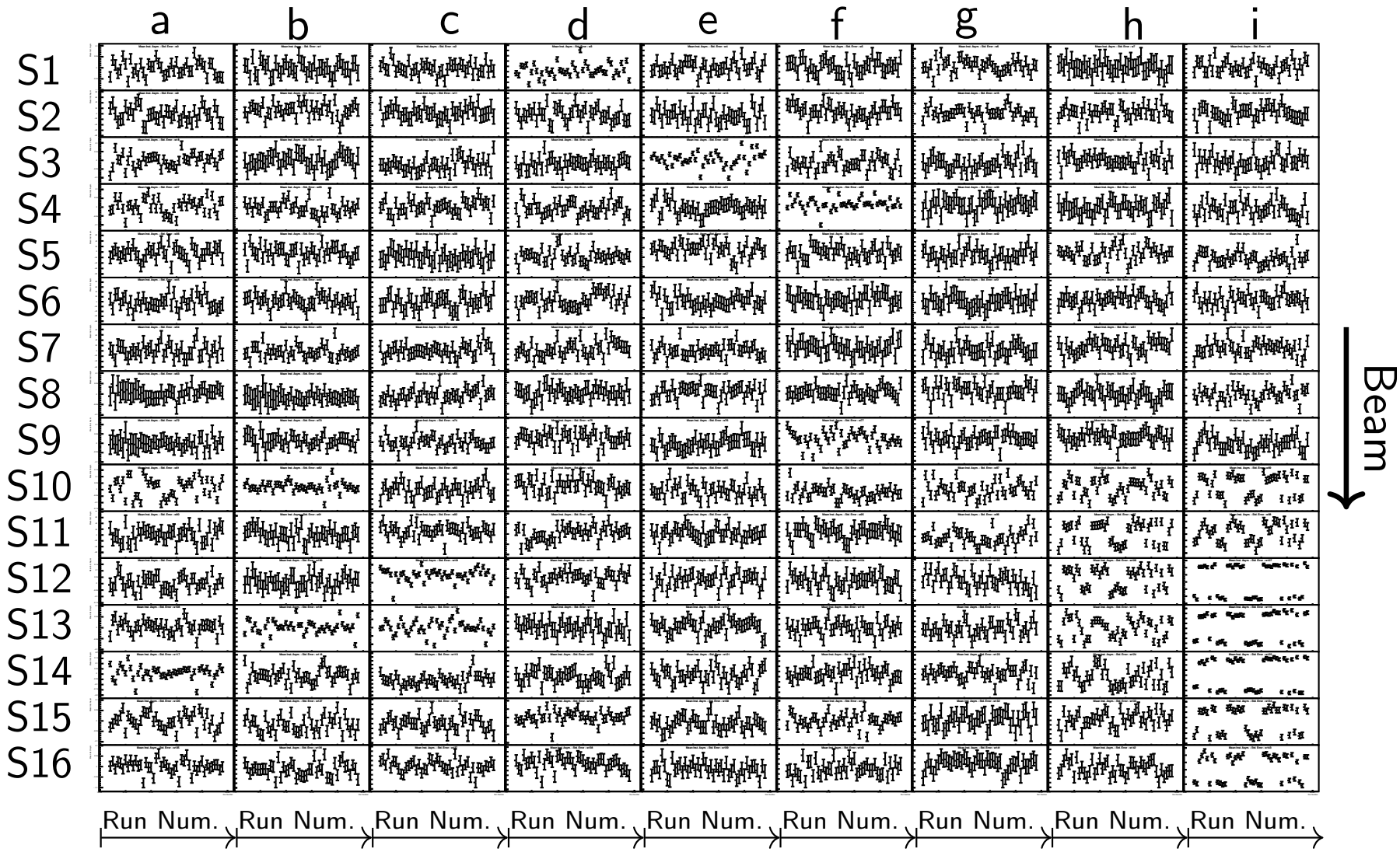
- Kabir's Physics Asymmetry

$$A_{phys,K} = (10 \pm 10) \times 10^{-9} \tag{12}$$

# Summary

- A mistake was made in the initial instrumental asymmetry analysis by not tracking the spin state likely when an initial version of the code was used beyond its intended scope of analysing only a small subset of run and its underlying assumptions was not re-checked before re-using the full analysis.
- After comparing this initial incorrect analysis with Michael Gericke's spin state tracking code, the mistake was found and corrected providing identical answers.
- 3 wires in particular changed their value greatly with the starting spin state of the run
- Since these were edge wires the effect was magnified due to the geometry factors applied to the wires.
- The cause the changes is unknown, and may indicate an electronics issue in approximately 3% of runs.

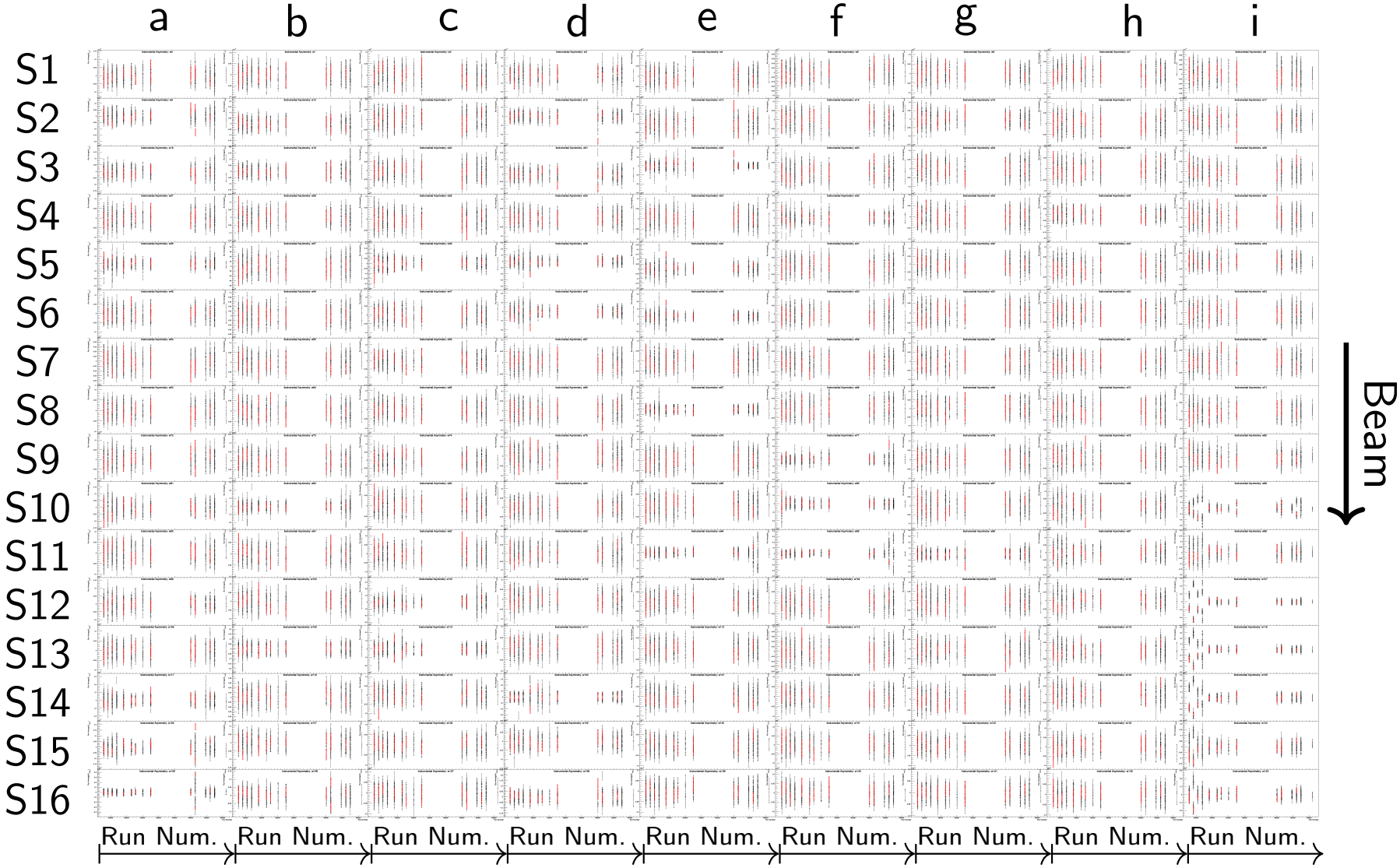
# Tuesday 2 Instrumental Asymmetry




X-axises are all the same. Y-axises are all the different

Row S12-14 in column i are wires 107,116,125.

# Tuesday All Instrumental Asymmetry

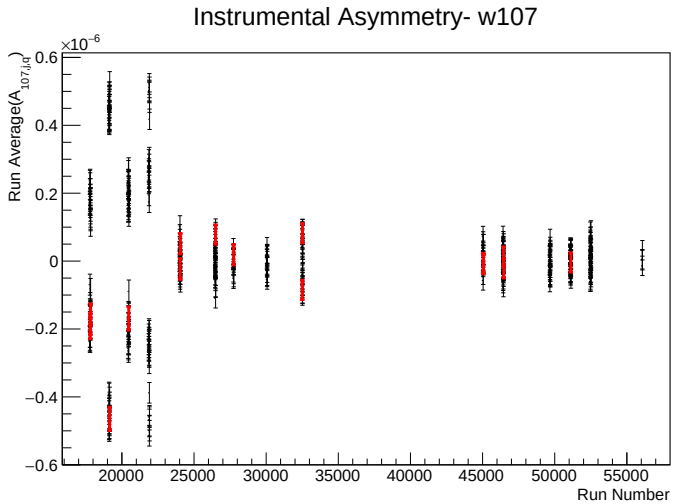


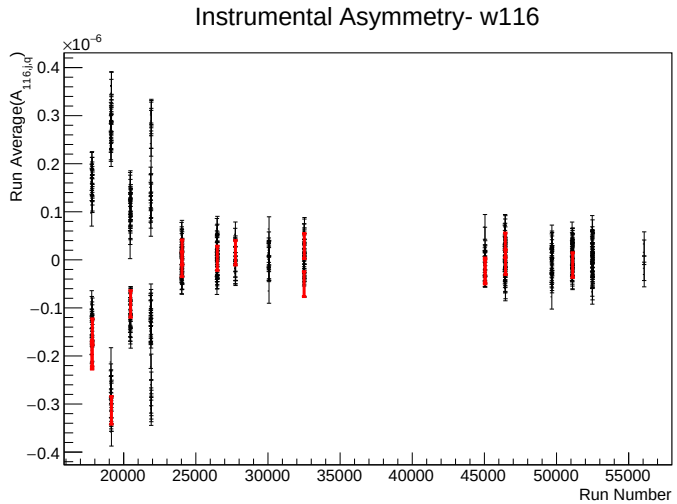

X-axises are all the same. Y-axises are all the different, but labeled.

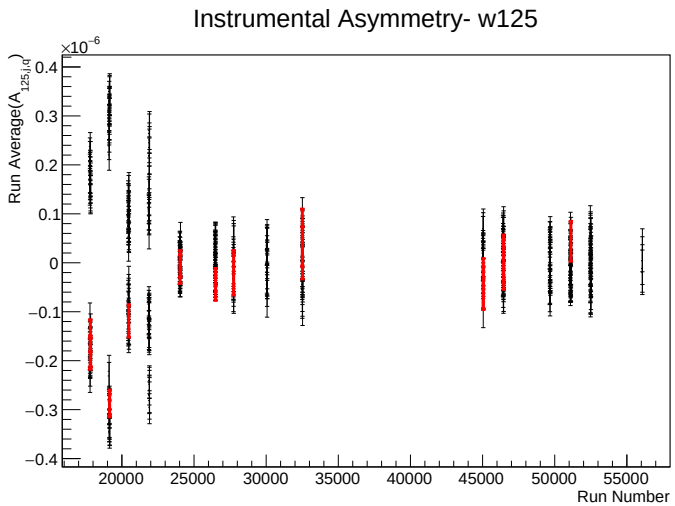
Row S12-14 in column i are wires 107,116 and 125.

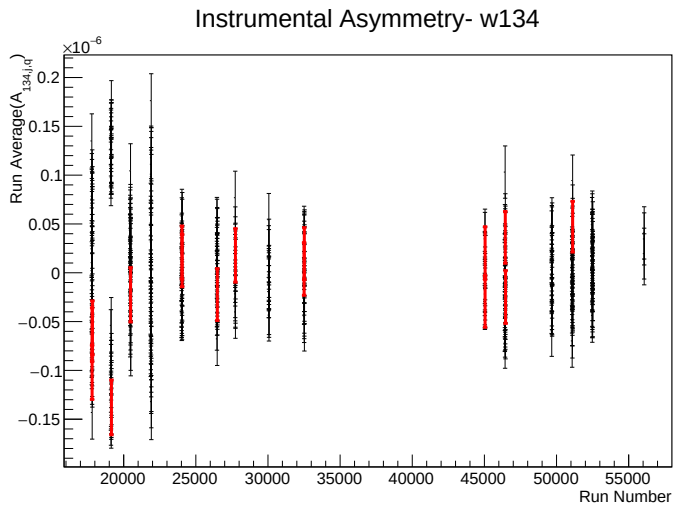
# Tuesday All Instrumental Asymmetry

4 of the 5 bimodal wires from the lower right corner of the previous slide.



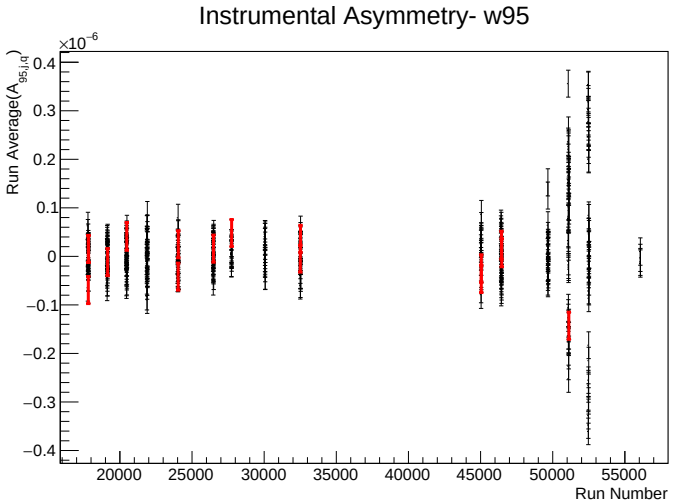



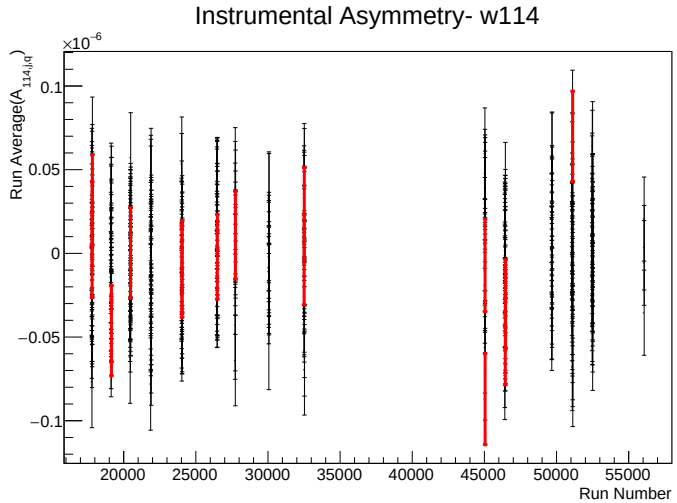



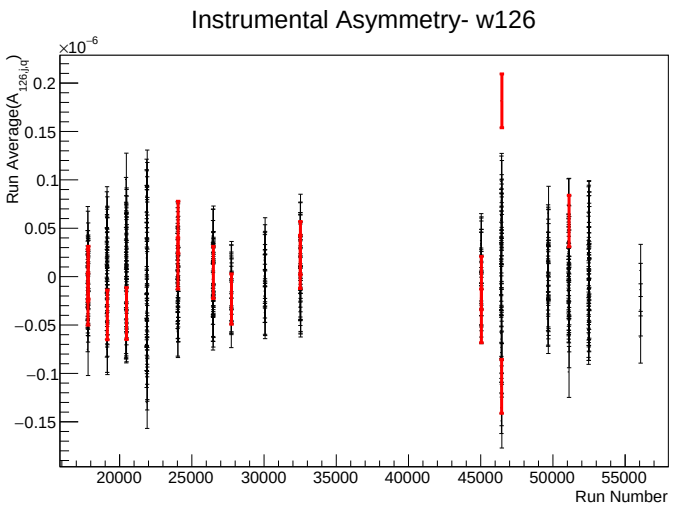

The asymmetry run averages indicated in red are the 16 runs that started spin flipper on.

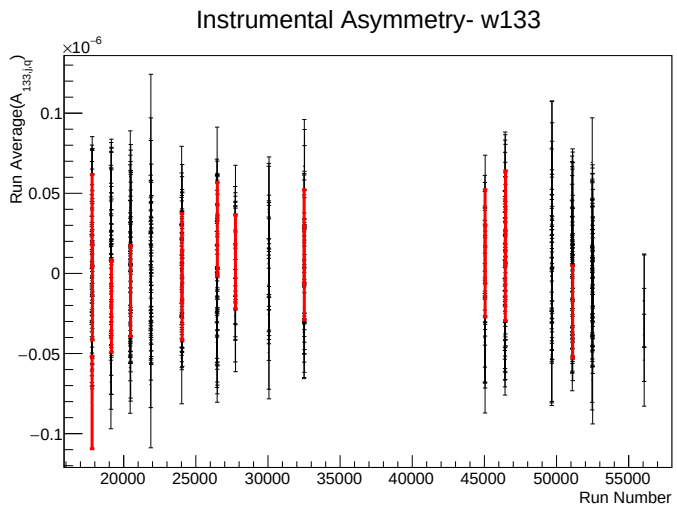
# Tuesday All Instrumental Asymmetry

4 other wires from the target chamber.




The asymmetry run averages indicated in red are the 16 runs that started spin flipper on.