Beam Off Asymmetry Analysis - Final Tuesday Results

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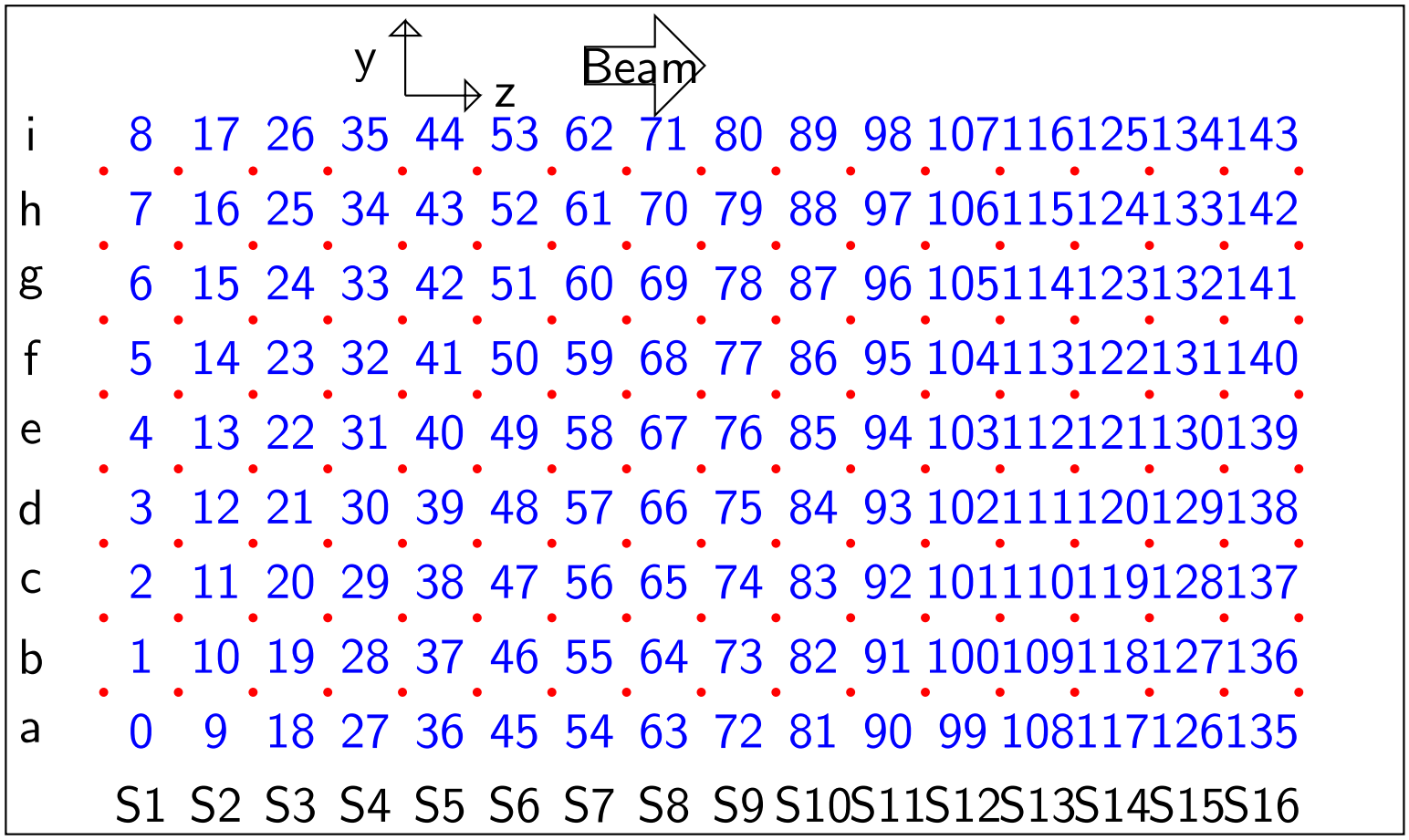
Wire Numbering



- HV 17 HV Frames with 8 wires each
- Signal 16 signal Frames with 9 wires each

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.

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 was variable. ST runs are Tuesdays from the Summer.

Beam Off Asymmetry Calculation

The single wire instrumental asymmetries, $A_{i,j,q}$, were calculated using a simple difference formula normalized by one volt to render it unitless.

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

$$A_{i,j,q} = \frac{\bar{Y}_{i,j,k=\text{even}} - \bar{Y}_{i,j,k=\text{odd}}}{1V} \tag{2}$$

where i is the wire number, j is the run number, t is the time bin number, k is the pulse number, and q is the asymmetry number. 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:

$$A_{i,j,q} = \frac{\bar{Y}_{i,j,k=\text{even}} - \bar{Y}_{i,j,k=\text{odd}}}{1V}$$

$$\rightarrow A_{i,j,q,scaled} = \frac{1}{G_i}\frac{\bar{Y}_{i,j,k=\text{even}} - \bar{Y}_{i,j,k=\text{odd}}}{2\bar{S}_i} \tag{5}$$

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.

Kabir's Method

- For all runs in the desired range For each wire:
  1. Calculate $Y_{i,j,k=\uparrow,sum}$ and $Y_{i,j,k=\downarrow,sum}$ for two adjacent pulses.
  2. Subtract $Y_{i,j,k=\uparrow,sum}$, and $Y_{i,j,k=\downarrow,sum}$
  3. Divide difference by $S_{i,sum}$
  4. Fill value into a separate TH1D histogram for each wire.
  5. Use GetMean() and GetMeanError() for mean and standard error from the histograms
  6. Divide histogram mean and standard error by G_i
- Perform weighted sums of the wire values using physics asymmetry uncertainties as shown on next slide.

Note: $Y_{i,j,k=\uparrow,sum} = \sum_{t=5}^{44} Y_{i,j,t,k=\uparrow}$, and $S_{i,sum}$ is the average of the sum of the time bins for all beam on runs, and

$$\frac{\bar{Y}_i}{\bar{S}_i} = \frac{\frac{1}{40} Y_{i,sum}}{\frac{1}{40} S_{i,sum}} = \frac{Y_{i,sum}}{S_{i,sum}} \tag{6}$$

Kabir's Instrumental Asymmetry 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.

Kabir's Run Counting

Instrumental Asymmetry: Tuesday runs vs Summer runs vs all runs

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Summer runs(Total 677 runs):

$$A_{inst} = (13.12 \pm 1.14) \times 10^{-9}. \tag{11}$$

Tuesday runs (Total 620 runs):

$$A_{inst} = (6.918 \pm 1.15) \times 10^{-9}. \tag{12}$$

All runs (Total 4383 runs):

$$A_{inst} = (3.14 \pm 0.60) \times 10^{-9}. \tag{13}$$

From meeting on 2017/05/12, Systematics 9, by Kabir.

Mark's Method

- For each wire:
  1. Calculate $Y_{i,j,k=even,sum}$ and $Y_{i,j,k=odd,sum}$ for two adjacent pulses.
  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 8.

New Tuesday Asymmetry Results

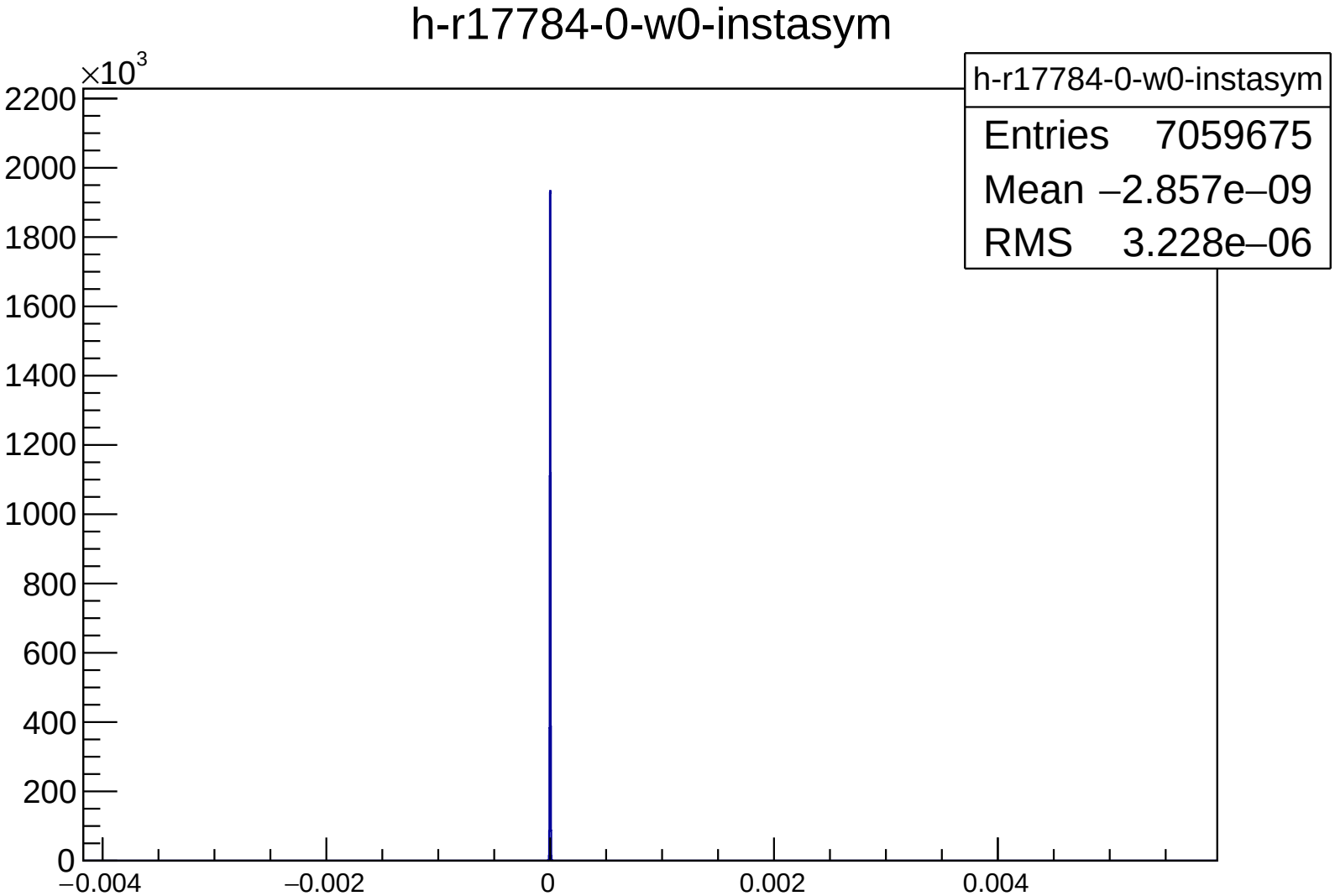
The summer instrumental asymmetries have been discarded due to their large instrumental asymmetry of an unknown origin. Due to this the the 620 Tuesday runs examined by Kabir are reduced by 52 runs that occurred during the summer data taking.

Asymmtry Type	Num. Runs	Asym Value
Summer Tuesday	52	$(49.56 \pm 4.159) \times 10^{-9}$
Non-Summer Tuesday	570	$(2.393 \pm 1.196) \times 10^{-9}$
Kabir's Tuesday	620	$(6.918 \pm 1.15) \times 10^{-9}$
Kabir's All Runs	4383	$(3.14 \pm 0.6) \times 10^{-9}$
Physics Asymmetry		$(10 \pm 10) \times 10^{-9}$

Notes on Histograms from Data Calculations

- When a Root histogram is unzoomed the mean and RMS are calculated from the input values to the histogram
- When a Root histogram is zoomed the displayed mean and RMS are calculated from the displayed bins and the accuracy varies with the bin width
- All histograms below were created with a large number of bins so that all plots can be displayed to the same scale, and then zoomed for display here.
- Therefore the statistics panel on most plots is not an accurate mean or RMS value.

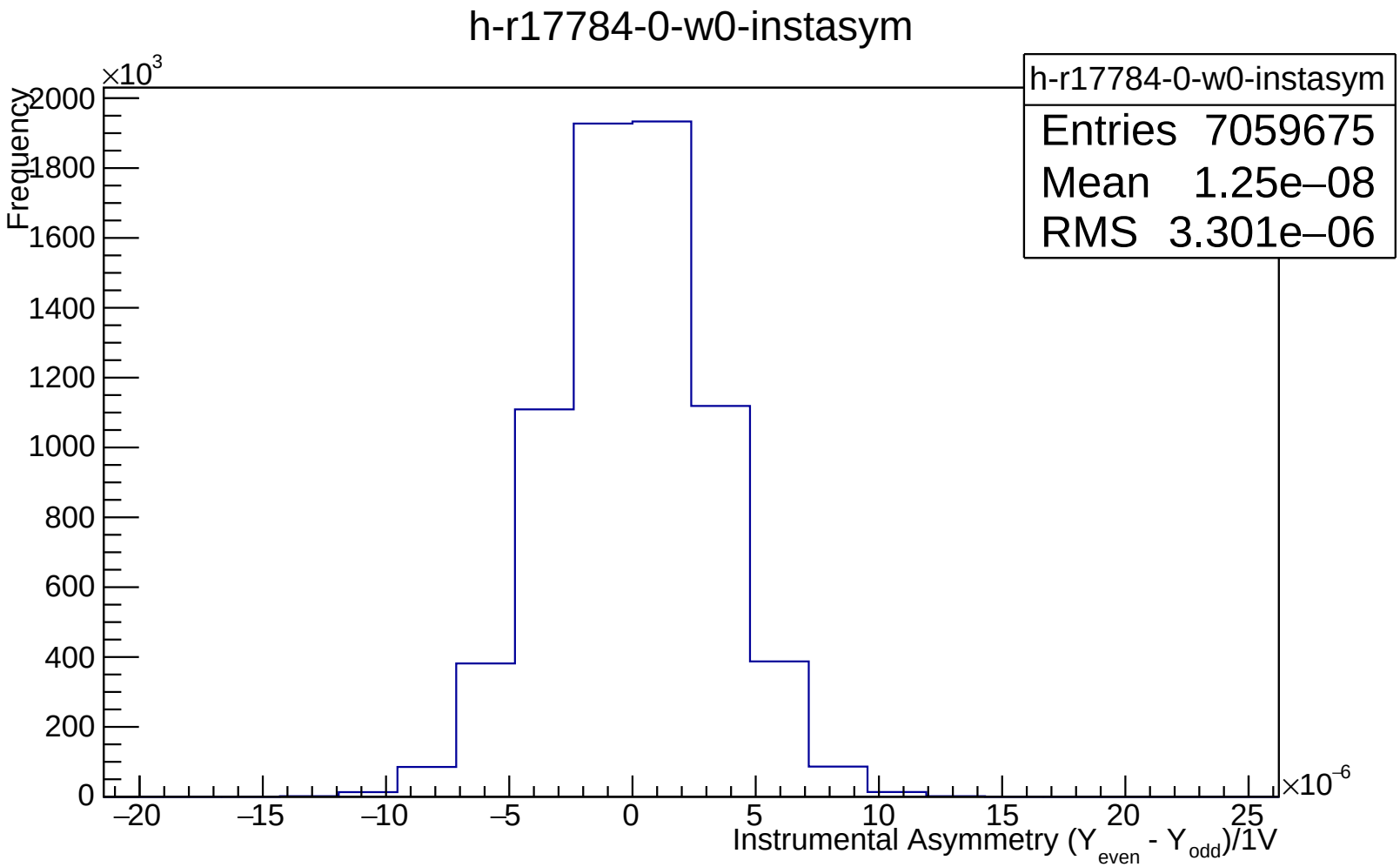
Tuesday Runs - Wire 0 Instrumental Asymmetry



Plot is of the un-scaled instrumental asymmetry.

X-axis not zoomed, statistics are accurate.

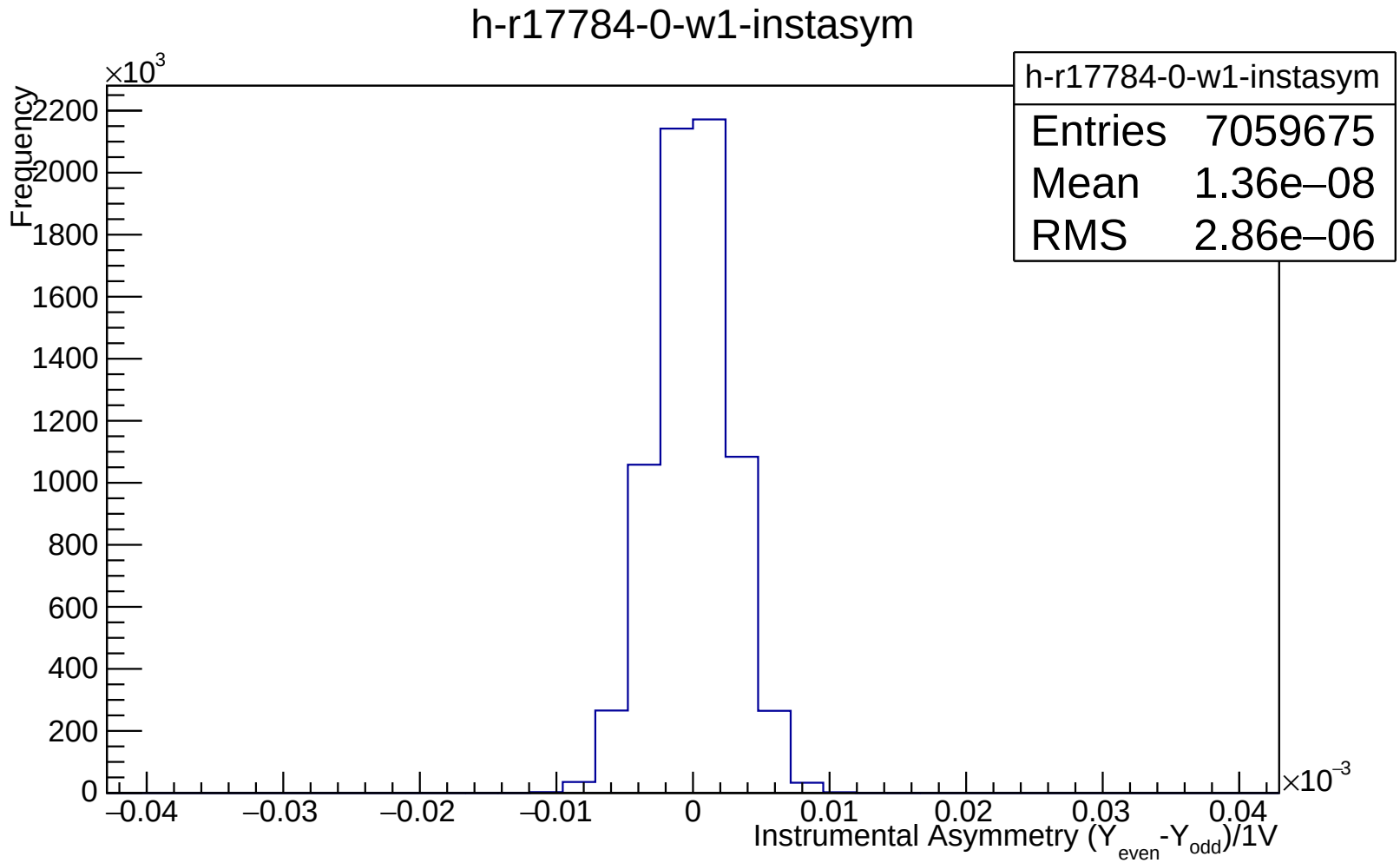
Tuesday Runs - Wire 0 Instrumental Asymmetry



Plot is of the un-scaled instrumental asymmetry.

X-axis is zoomed, statistics are inaccurate.

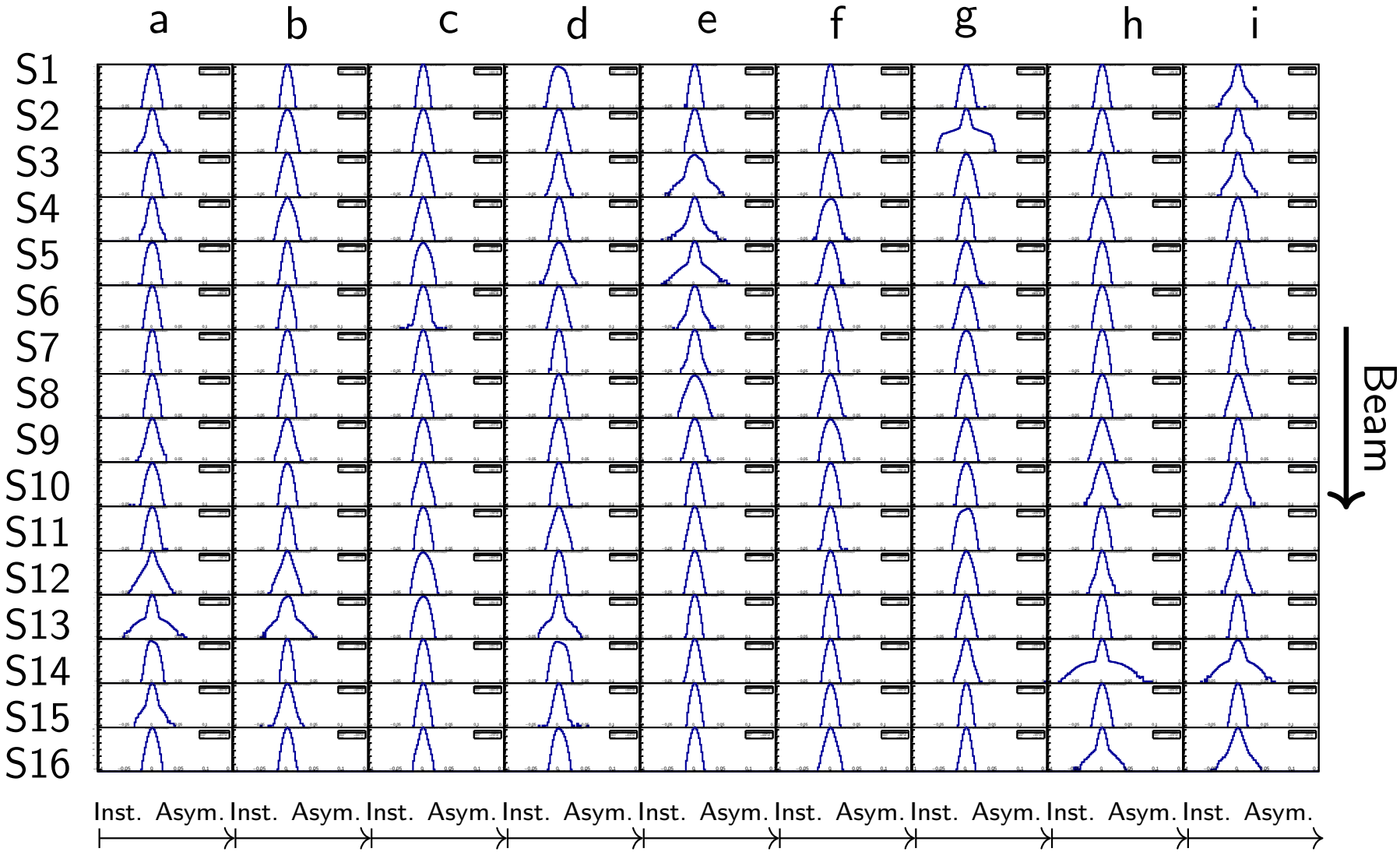
Tuesday Runs - Wire 1 Instrumental Asymmetry



Plot is of the un-scaled instrumental asymmetry.

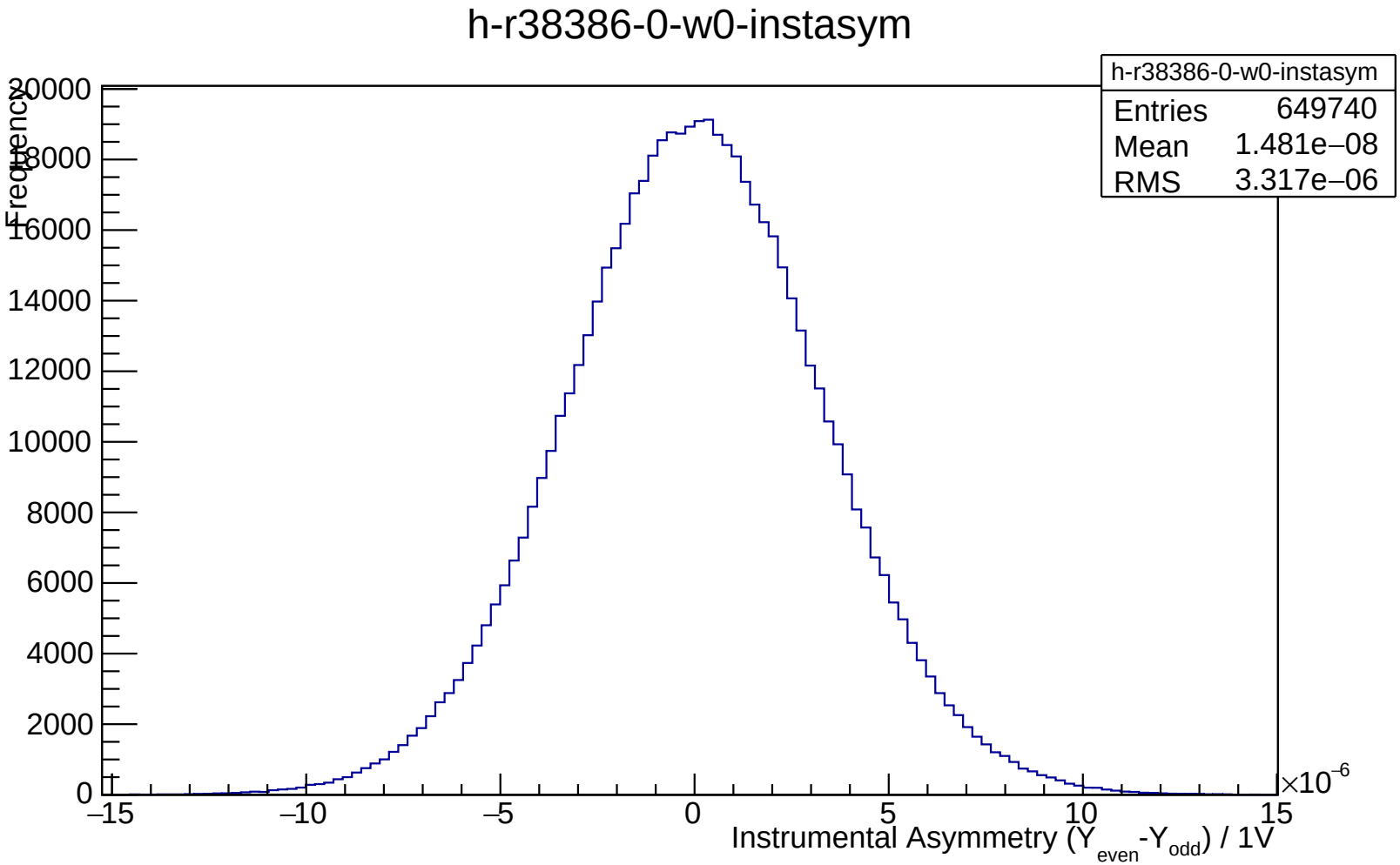
Statistics inaccurate.

Tuesday Instrumental Asymmetry - Panel Plot



X and Y Axis are identical. Log Scale Y-axis. X-axis is also the same as on slide 19. Statistics inaccurate.

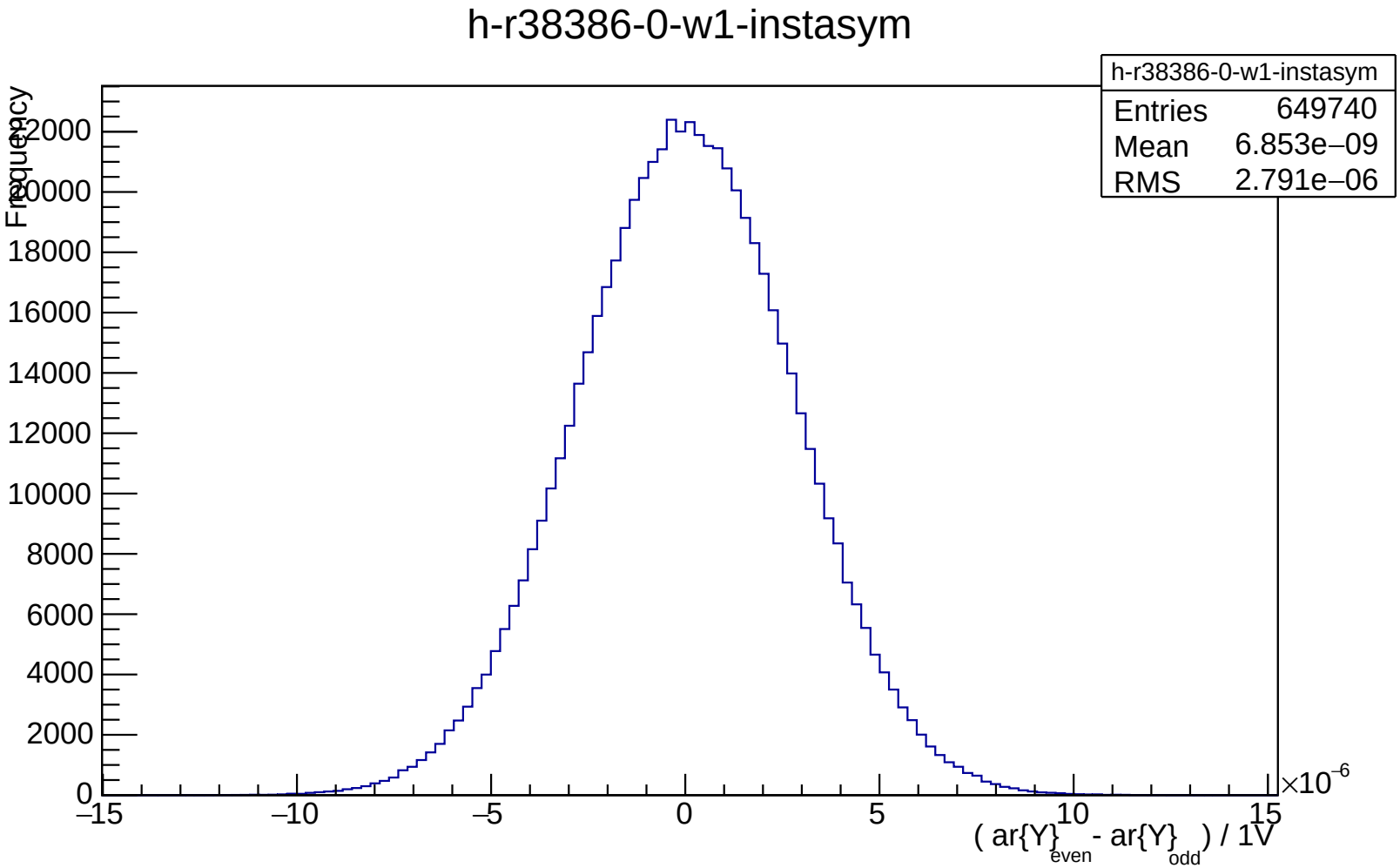
Summer Tuesday Runs - Wire 0 Inst. Asymmetry



Plot is of the un-scaled instrumental asymmetry.

Statistics inaccurate.

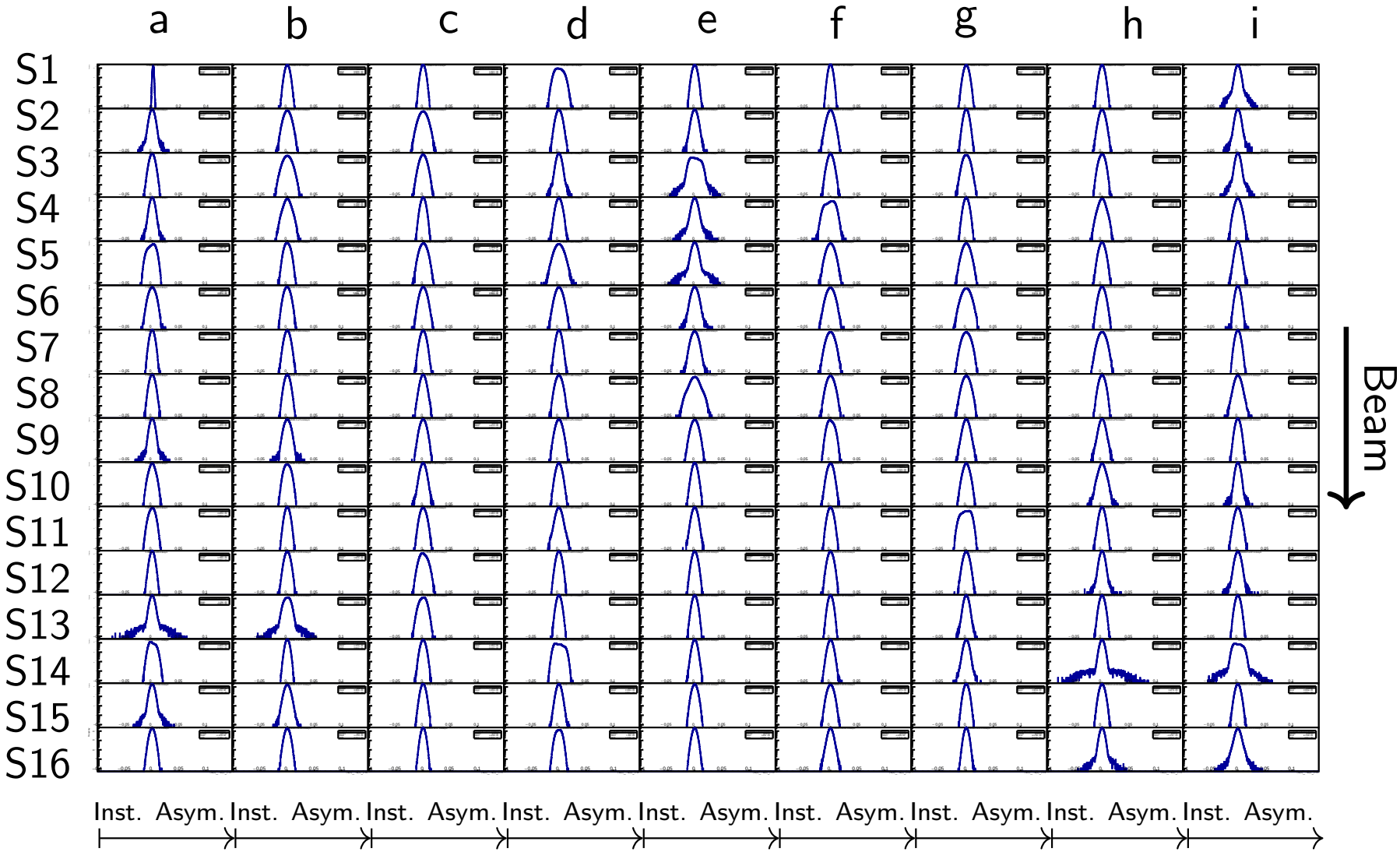
Summer Tuesday Runs - Wire 1 Inst. Asymmetry



Plot is of the un-scaled instrumental asymmetry.

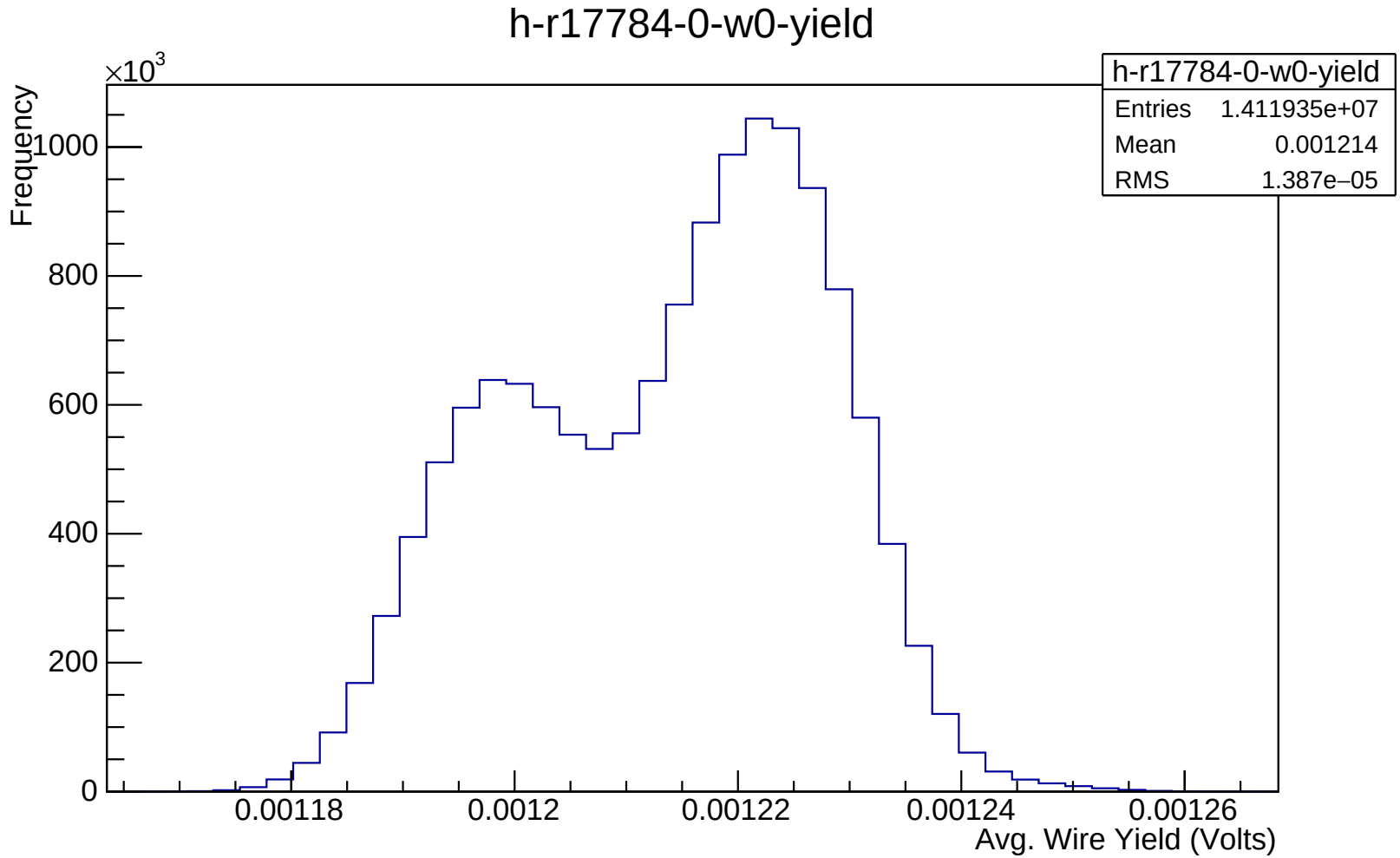
Statistics inaccurate.

Summer Tuesday Wire Yields - Panel Plot



X and Y Axis are identical. Log Scale Y-axis. X-axis is also the same as on slide 16

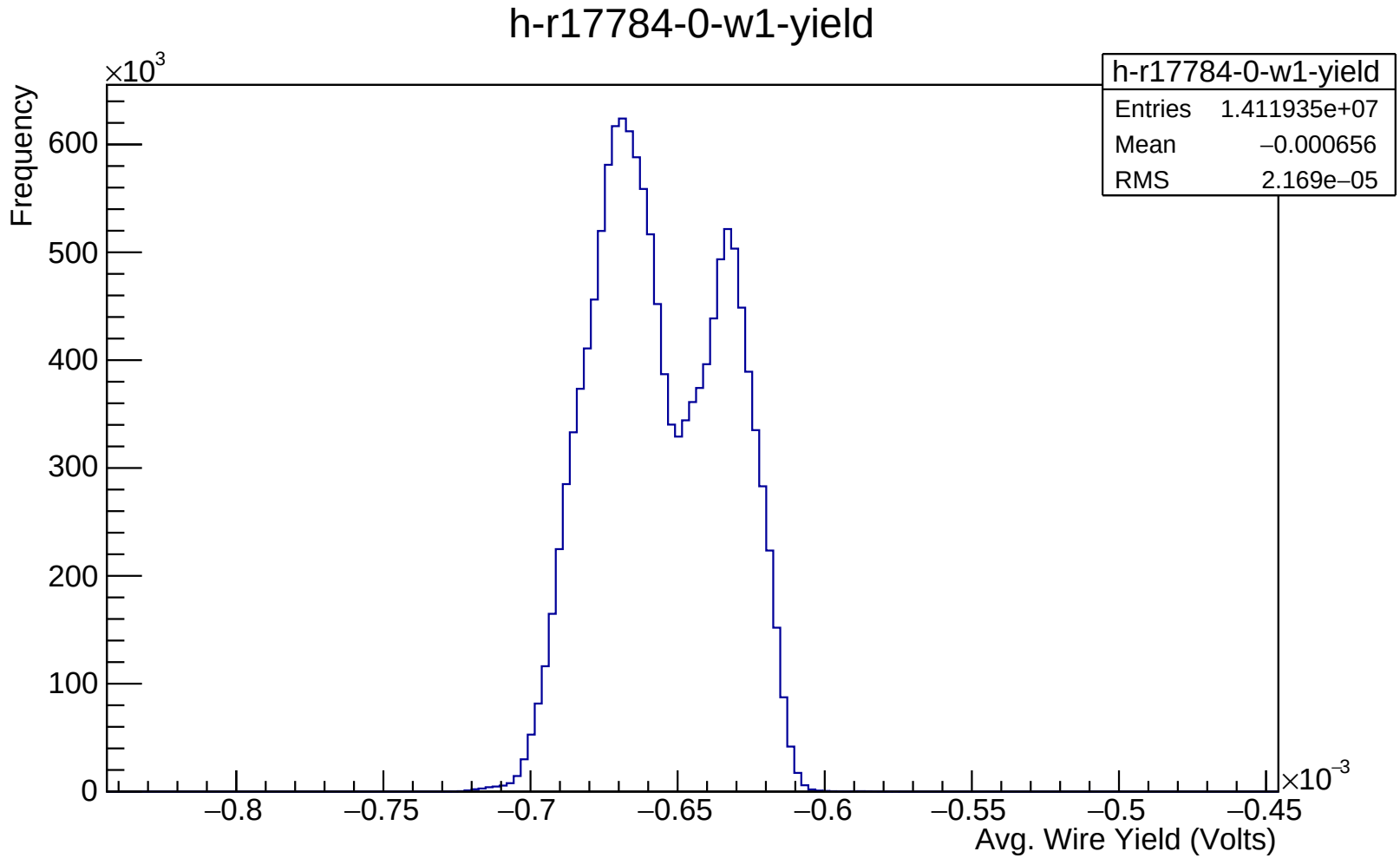
Tuesday Runs - Wire 0 Yield



Plot is of average wire yield over time bin 5-44 with one entry per pulse. Neutron beam was off.

Statistics inaccurate.

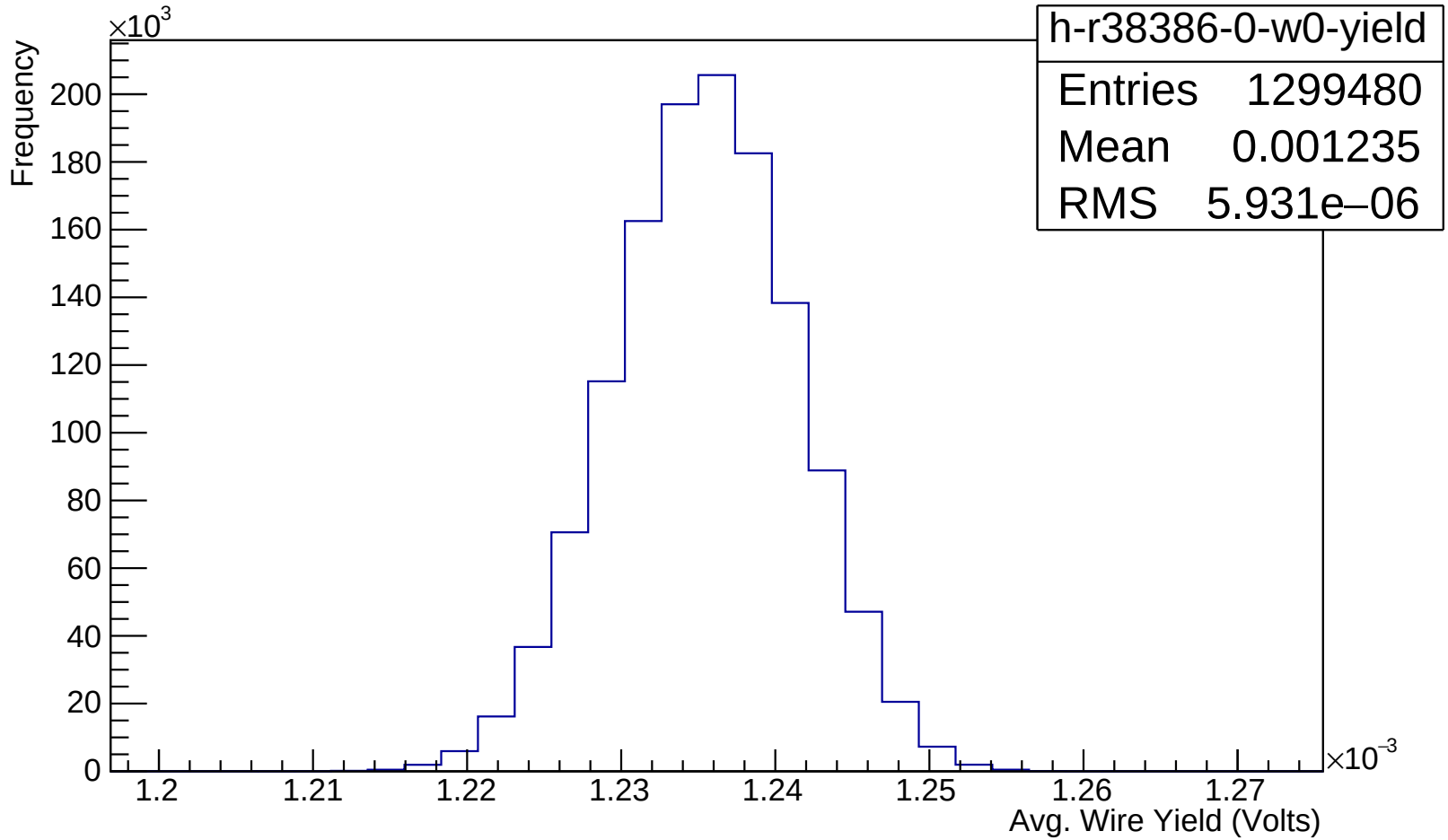
Tuesday Runs - Wire 1 Yield



Plot is of average wire yield over time bin 5-44 with one entry per pulse. Neutron beam was off.

Statistics inaccurate.

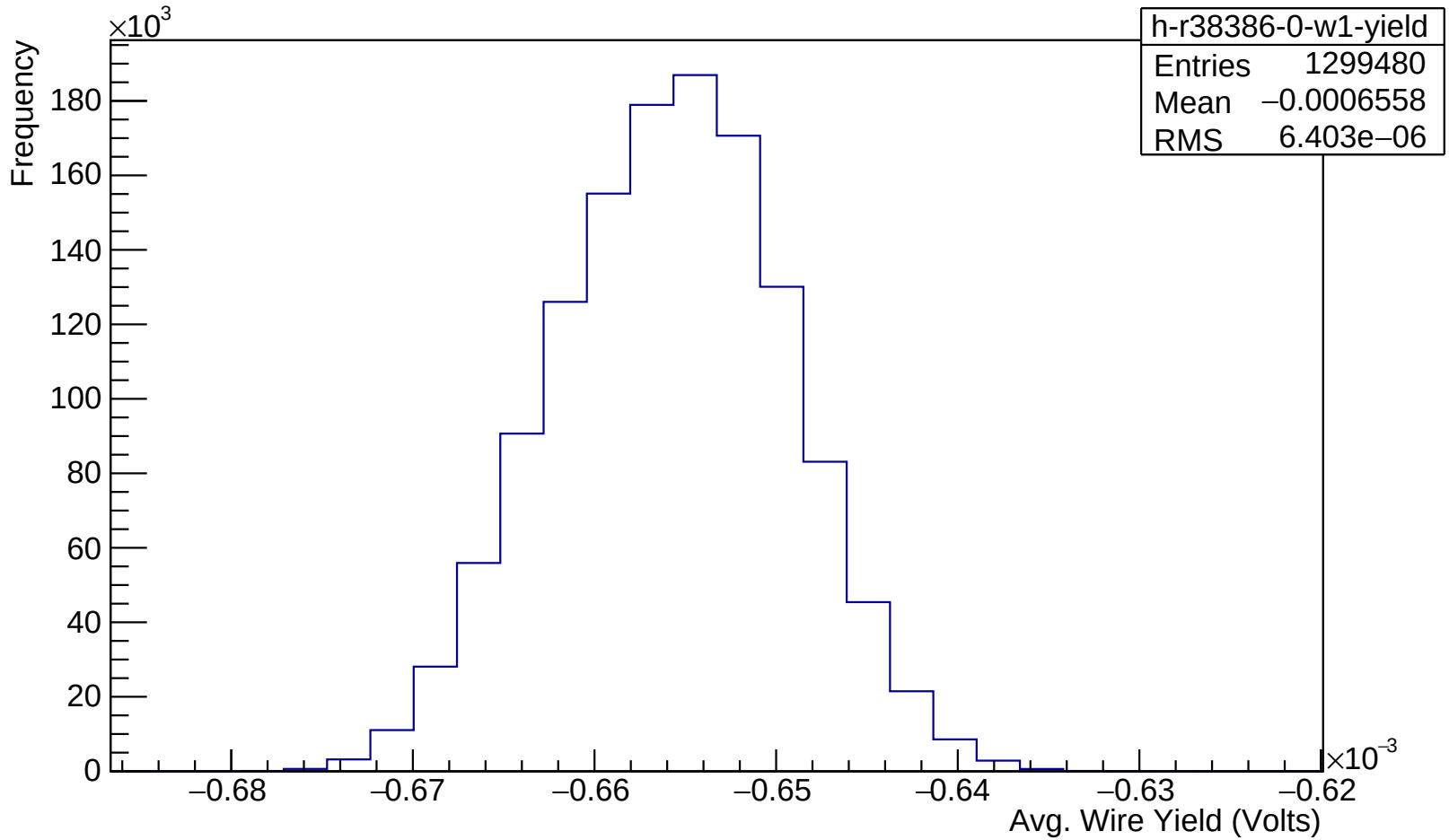
Summer Tuesday Runs - Wire 0 Yield



Plot is of average wire yield over time bin 5-44 with one entry per pulse. Neutron beam was off.

Statistics inaccurate.

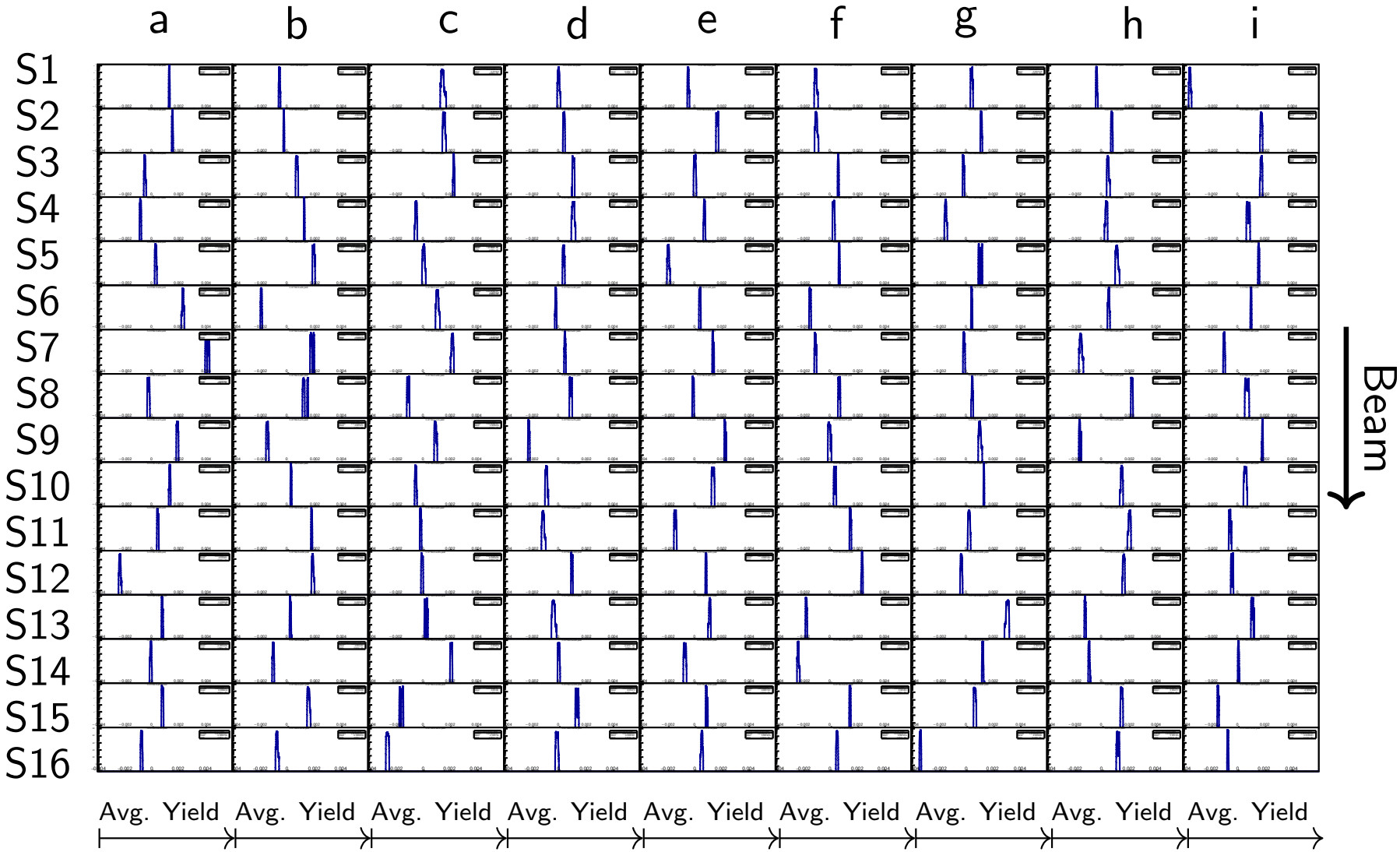
Summer Tuesday Runs - Wire 1 Yield



Plot is of average wire yield over time bin 5-44 with one entry per pulse. Neutron beam was off.

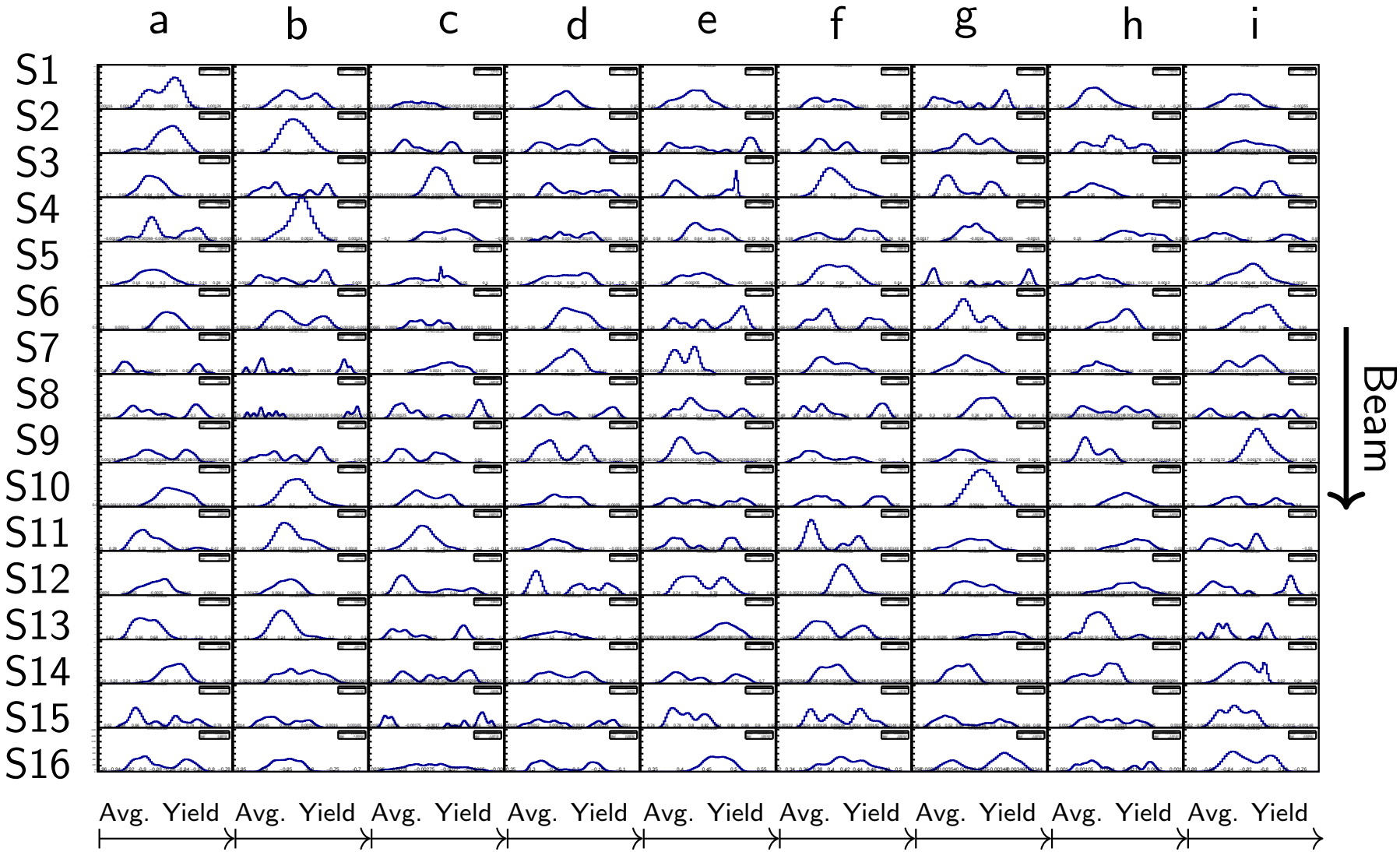
Statistics inaccurate.

Tuesday Wire Yields - Panel Plot



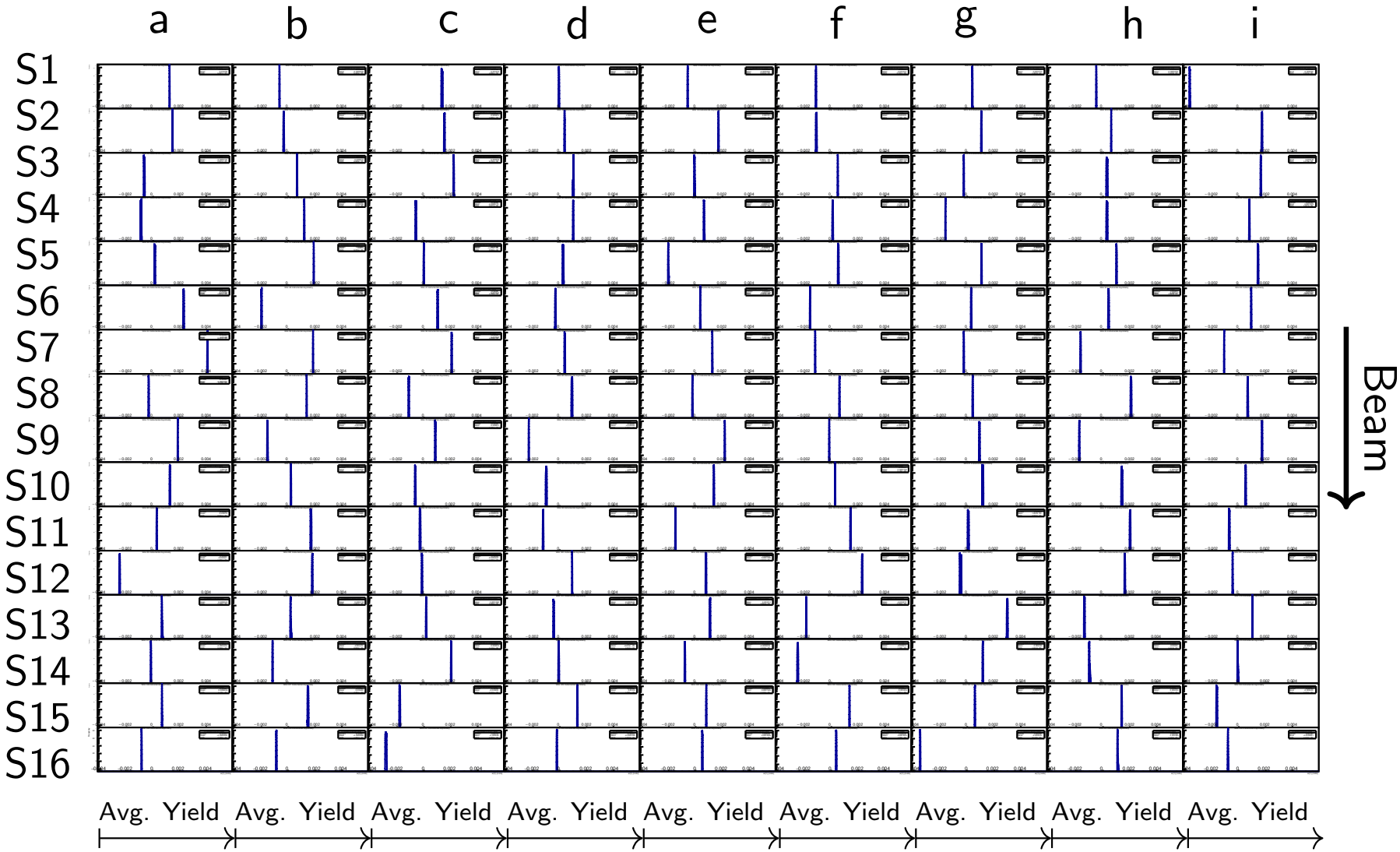
X and Y Axis are identical. Log Scale Y-axis. X-axis is also the same as on slide 26.

Tuesday Wire Yields - Panel Plot



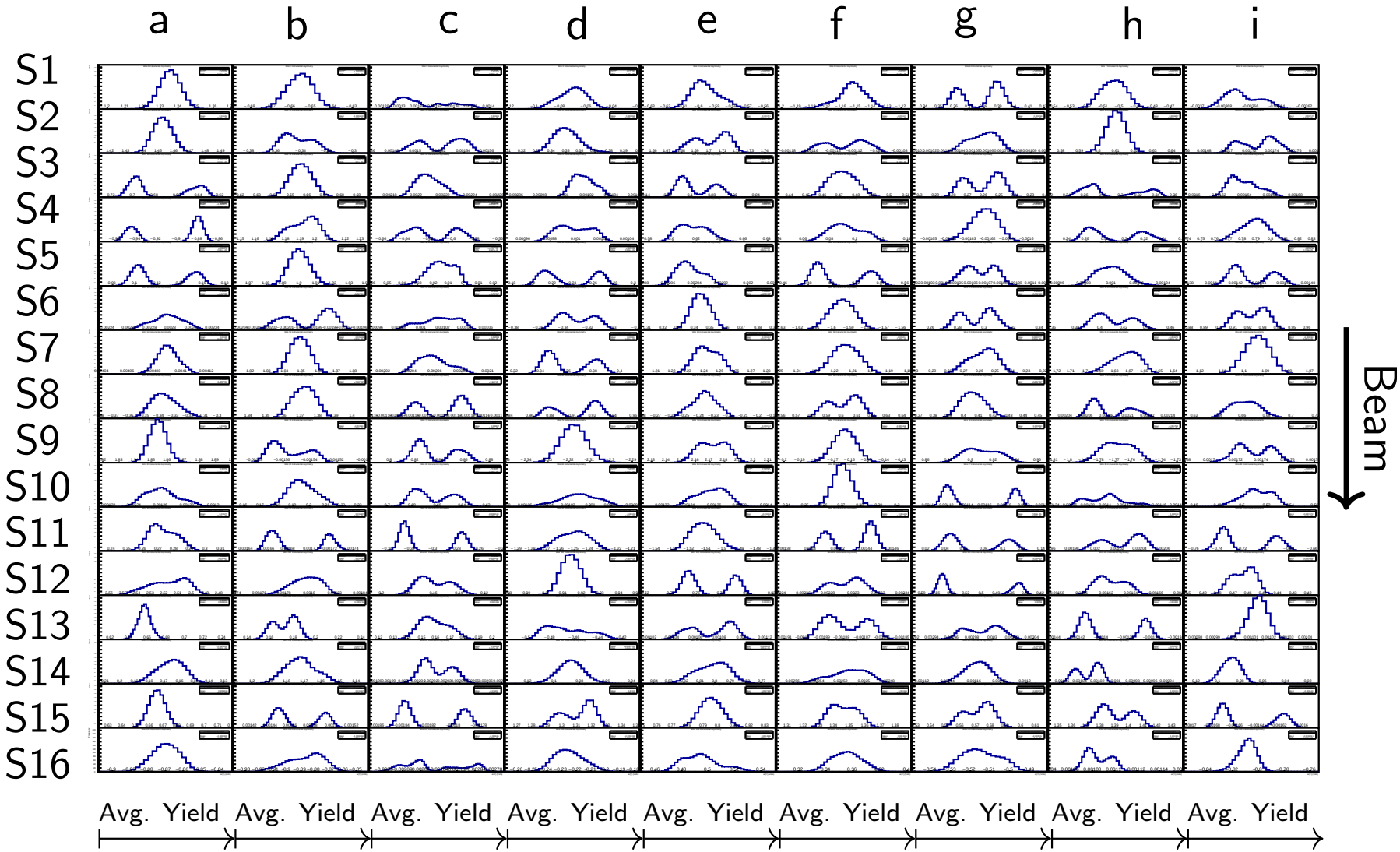
Y Axis are identical. Statistics Inaccurate.

Summer Tuesday Wire Yields - Panel Plot



X and Y Axis are identical. Log Scale Y-axis. X-axis is also the same as on slide 24

Summer Tuesday Wire Yields - Panel Plot



Y-axis are identical. Statistics Inaccurate.

Conclusion

- Instrumental Asymmetry is $(2.4 \pm 1.2) \times 10^{-9}$
- Moving onto Beam On Instrumental Asymmetry as suggested by Dave Bowman

Note: In roughly two weeks I will be working at University of Kentucky on the nEDM experiment, so my time remaining on n3He is limited and needs to be prioritized.

List of Runs

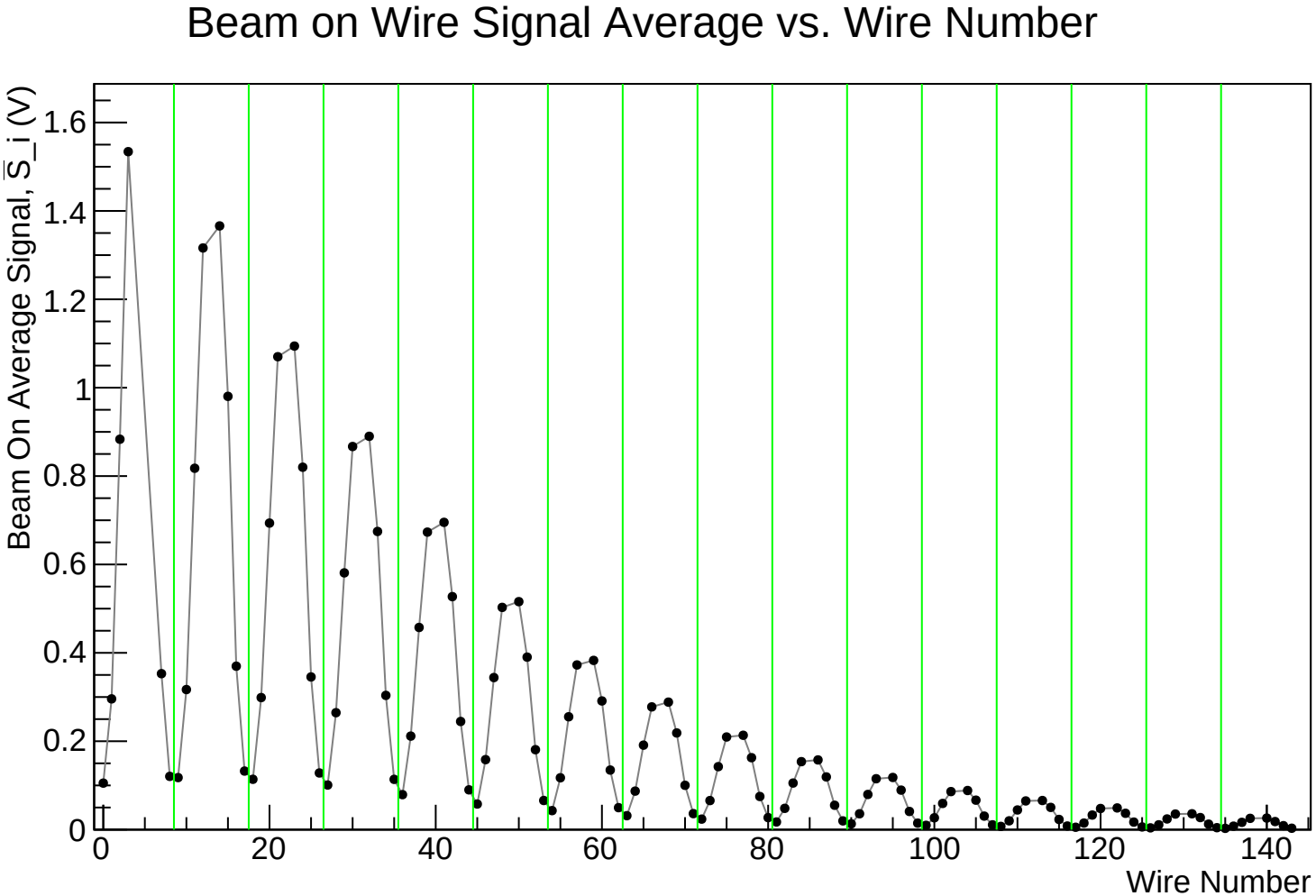
A list of good beam off runs has been provided by Kabir, and are now on the n3He wiki Instrumental Asym. webpage for reference by the group.

Summer Run List

Date Range	Initial Run	Final Run
2015-06-25	38081	38124
2015-06-26	38125	38215
2015-08-03	38216	38301
2015-08-04	38302	38416
2015-08-10	38417	38493
2015-08-11	38494	38657
2015-08-12	38658	38769

Note: From previous analysis showing the out of phase signal for the odd and even pulses that was not replicated in other runs it is believed that there was sound kind of anomalous noise source during the summer running that makes these unsuitable for use in calculating the instrumental asymmetry for comparison to the physic asymmetry.

Beam On Wire Average Values, $\bar{S}_i$



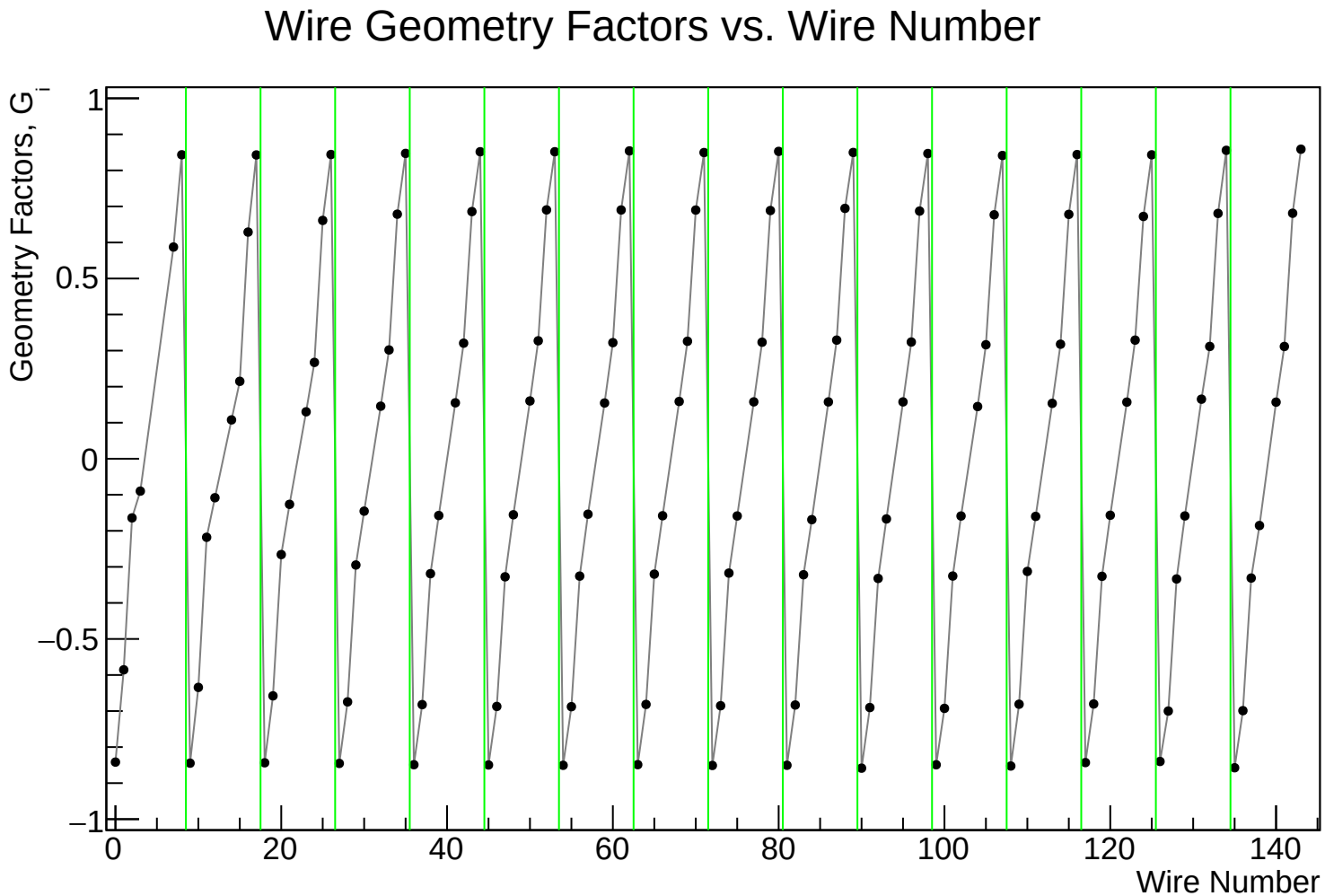
This plot shows the average of the beam on signal over all beam on runs.

Green Lines Separate wire planes. The 2 bad wires in the first plane and all central wire points have been removed from the plot.

Beam On Wire Average Values

	a	b	c	d	e	f	g	h	i
S0	0.105	0.296	0.883	1.53	0	0	0	0.353	0.12
S1	0.118	0.317	0.818	1.32	0	1.37	0.98	0.37	0.132
S2	0.114	0.299	0.694	1.07	0	1.09	0.82	0.345	0.128
S3	0.101	0.265	0.581	0.867	0	0.89	0.675	0.304	0.114
S4	0.0791	0.212	0.457	0.673	0	0.695	0.527	0.245	0.09
S5	0.0579	0.158	0.344	0.503	0	0.516	0.39	0.181	0.0659
S6	0.043	0.117	0.255	0.373	0	0.383	0.291	0.135	0.0497
S7	0.0315	0.0871	0.191	0.278	0	0.288	0.219	0.1	0.0362
S8	0.0238	0.0657	0.142	0.21	0	0.213	0.163	0.075	0.0271
S9	0.0173	0.0481	0.105	0.154	0	0.158	0.119	0.0551	0.0197
S10	0.013	0.0358	0.0795	0.115	0	0.118	0.0893	0.0411	0.0147
S11	0.00974	0.0267	0.0592	0.086	0	0.0885	0.0666	0.0306	0.0108
S12	0.00724	0.0199	0.0444	0.0649	0	0.0658	0.0503	0.023	0.00812
S13	0.00531	0.0148	0.0329	0.0478	0	0.049	0.037	0.017	0.00601
S14	0.00396	0.0109	0.0241	0.0352	0	0.0358	0.0272	0.0124	0.00436
S15	0.00283	0.00781	0.0164	0.0255	0	0.0261	0.0182	0.00892	0.00312

Wire Geometry Factors, G_i

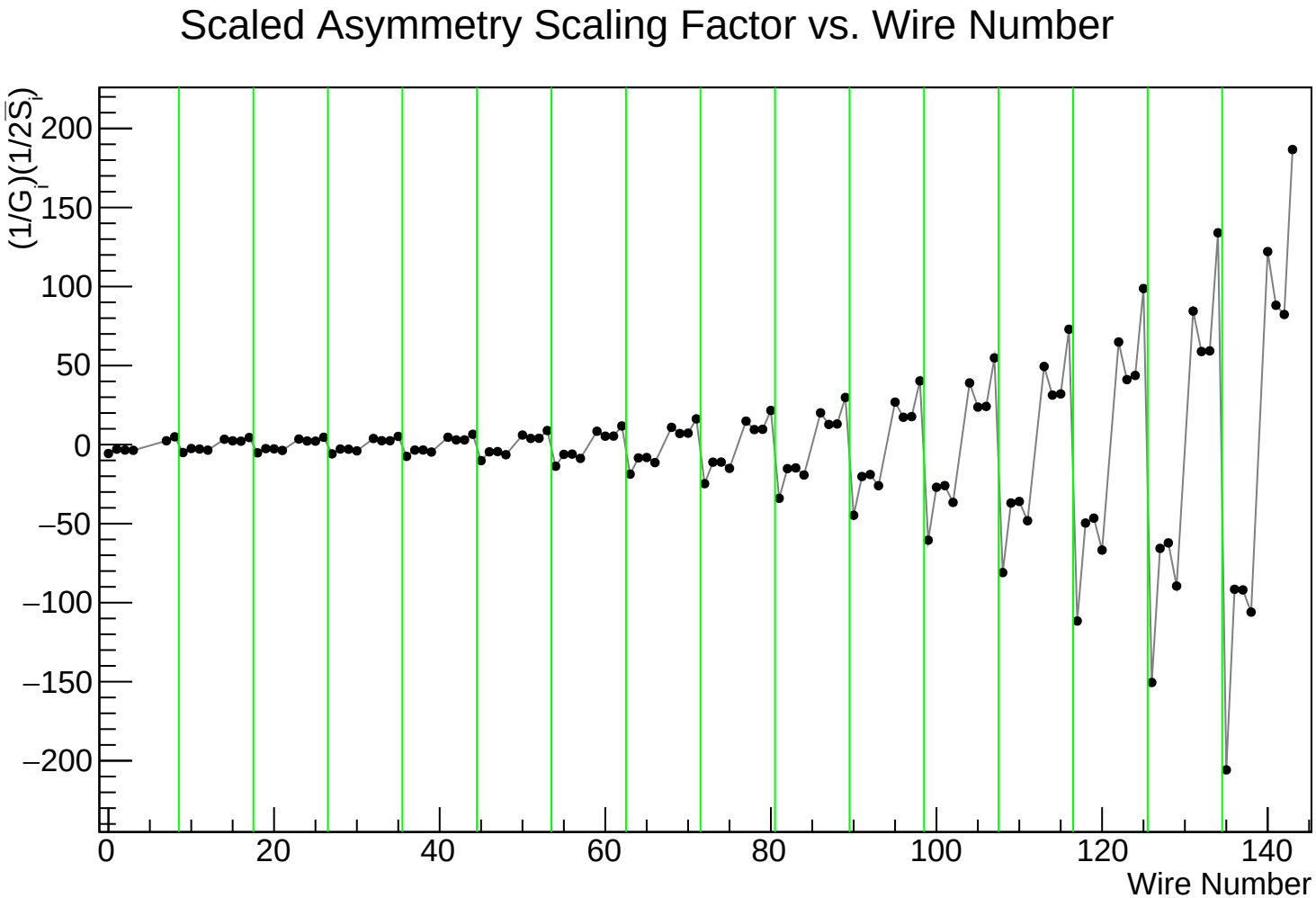


Green Lines Separate wire planes. The 2 bad wires in the first plane and all central wire points have been removed from the plot.

Geometry Factor Values Table

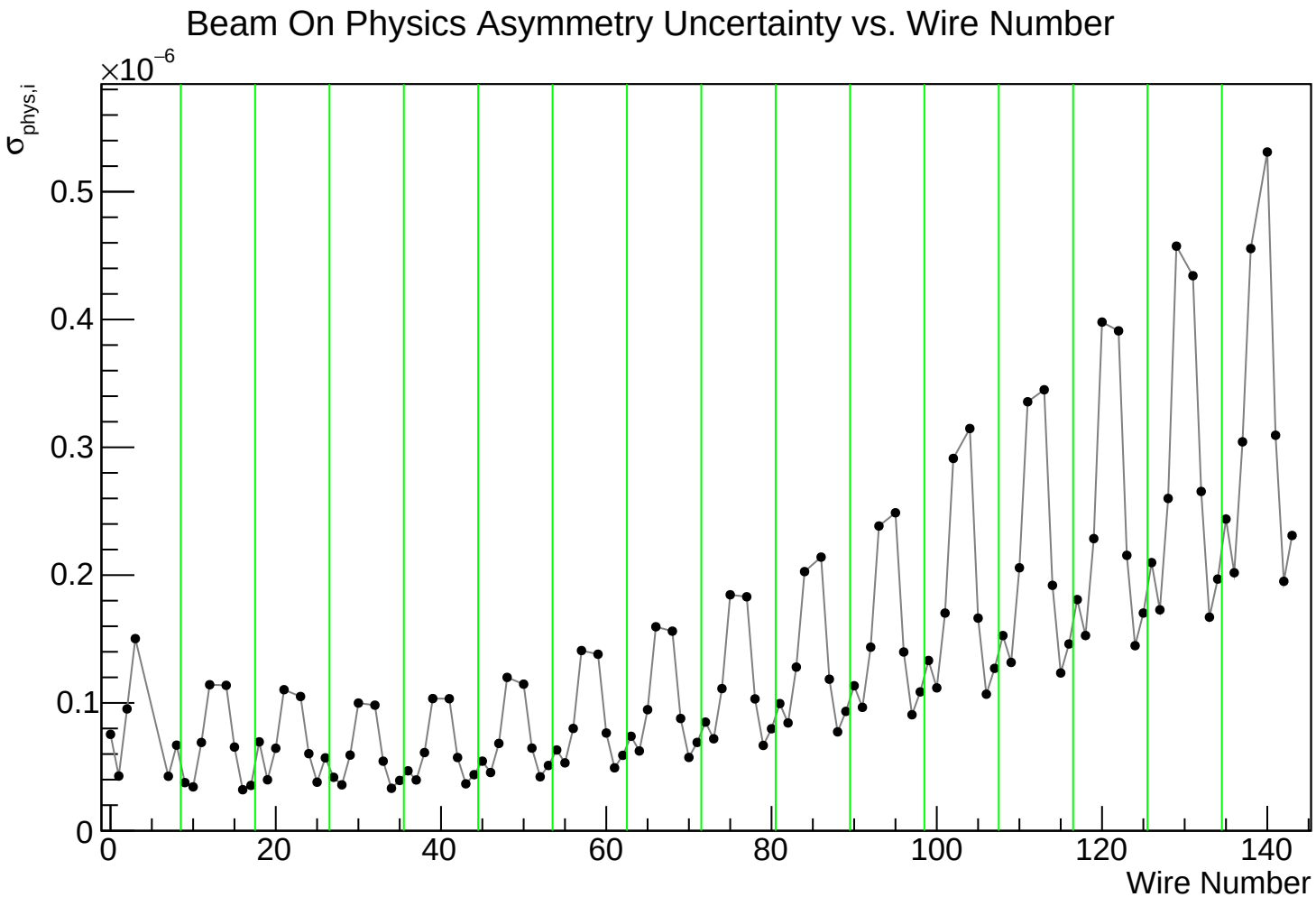
	a	b	c	d	e	f	g	h	i
S0	-0.842	-0.586	-0.164	-0.0899	-0.00131	0.0851	0.163	0.587	0.843
S1	-0.845	-0.634	-0.218	-0.108	0.00105	0.108	0.215	0.629	0.843
S2	-0.844	-0.658	-0.266	-0.127	0.00434	0.13	0.267	0.661	0.844
S3	-0.845	-0.675	-0.295	-0.145	0.000365	0.146	0.302	0.679	0.847
S4	-0.849	-0.682	-0.319	-0.157	-0.000858	0.155	0.321	0.686	0.852
S5	-0.85	-0.687	-0.328	-0.155	0.000823	0.16	0.327	0.69	0.852
S6	-0.851	-0.688	-0.326	-0.154	-0.00077	0.155	0.322	0.69	0.854
S7	-0.849	-0.682	-0.32	-0.158	0.00539	0.159	0.326	0.69	0.85
S8	-0.851	-0.685	-0.317	-0.159	0.00307	0.158	0.323	0.689	0.853
S9	-0.85	-0.683	-0.322	-0.169	-0.00516	0.158	0.329	0.695	0.85
S10	-0.859	-0.69	-0.332	-0.167	-0.0029	0.158	0.324	0.687	0.847
S11	-0.849	-0.693	-0.325	-0.159	-0.00376	0.145	0.316	0.677	0.841
S12	-0.853	-0.681	-0.313	-0.16	0.00342	0.154	0.318	0.678	0.844
S13	-0.843	-0.68	-0.326	-0.157	-0.00868	0.157	0.329	0.672	0.843
S14	-0.84	-0.7	-0.334	-0.159	-0.00571	0.165	0.312	0.681	0.856
S15	-0.857	-0.699	-0.331	-0.185	0.00344	0.157	0.311	0.681	0.859

Scaling Factor $(1/G_i)(1/2\bar{S}_i)$



Green Lines Separate wire planes. The 2 bad wires in the first plane and all central wire points have been removed from the plot.

Physics Asymmetry Uncertainty, $\sigma_{i,phys}$

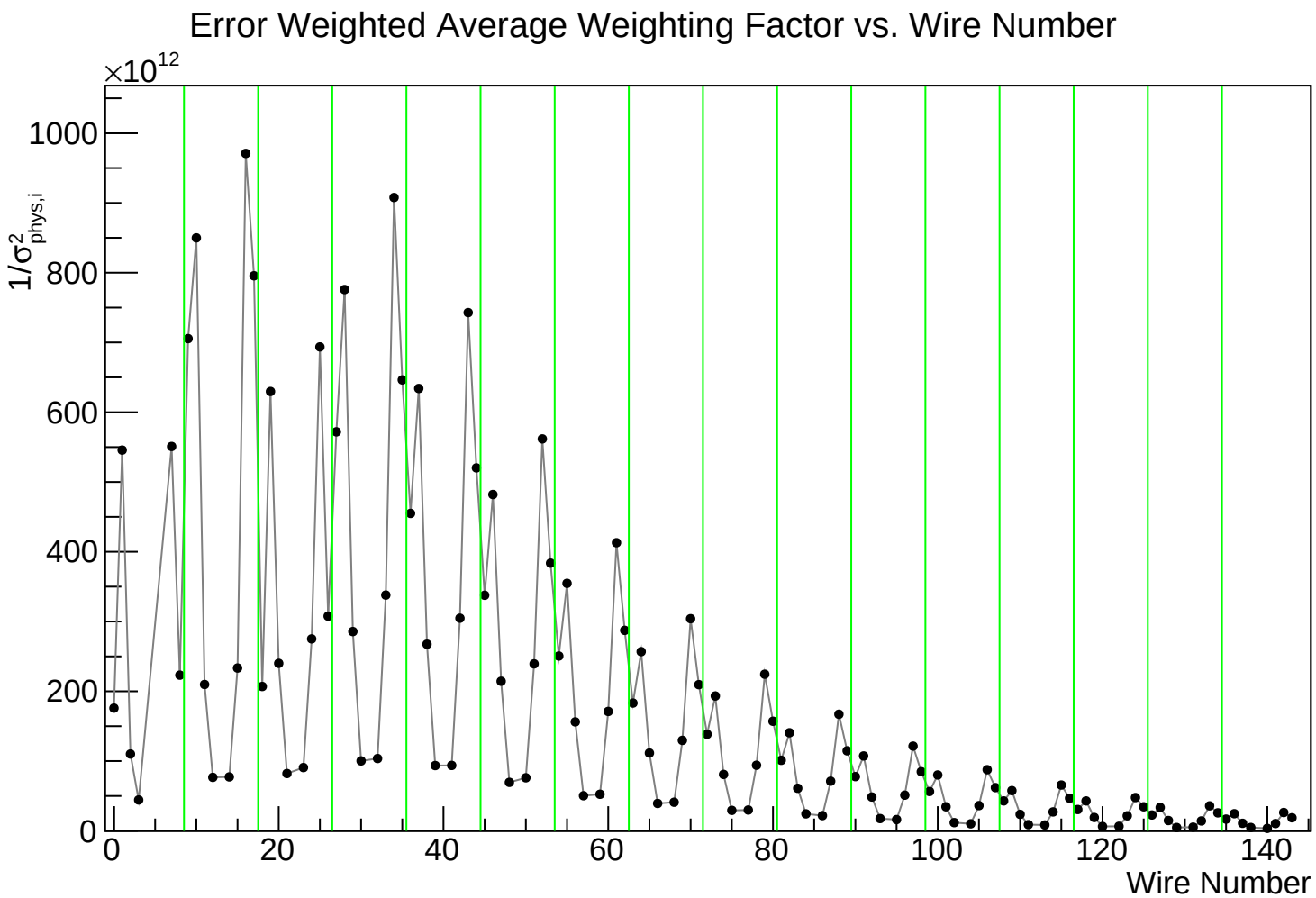


Green Lines Separate wire planes. The 2 bad wires in the first plane and all central wire points have been removed from the plot

Physics Asymmetry Uncertainty Table, $\sigma_{i,phys}$

	a	b	c	d	e	f	g	h	i
S0	7.54e-08	4.28e-08	9.53e-08	1.5e-07	0	0	0	4.26e-08	6.69e-08
S1	3.76e-08	3.43e-08	6.9e-08	1.14e-07	0	1.14e-07	6.55e-08	3.21e-08	3.55e-08
S2	6.95e-08	3.98e-08	6.45e-08	1.1e-07	0	1.05e-07	6.03e-08	3.8e-08	5.7e-08
S3	4.18e-08	3.59e-08	5.92e-08	9.99e-08	0	9.82e-08	5.44e-08	3.32e-08	3.93e-08
S4	4.69e-08	3.97e-08	6.11e-08	1.03e-07	0	1.03e-07	5.73e-08	3.67e-08	4.38e-08
S5	5.44e-08	4.55e-08	6.83e-08	1.2e-07	0	1.15e-07	6.46e-08	4.22e-08	5.11e-08
S6	6.32e-08	5.31e-08	8e-08	1.41e-07	0	1.38e-07	7.64e-08	4.92e-08	5.9e-08
S7	7.39e-08	6.24e-08	9.47e-08	1.6e-07	0	1.56e-07	8.78e-08	5.73e-08	6.91e-08
S8	8.5e-08	7.19e-08	1.11e-07	1.85e-07	0	1.83e-07	1.03e-07	6.67e-08	7.98e-08
S9	9.95e-08	8.43e-08	1.28e-07	2.03e-07	0	2.14e-07	1.19e-07	7.74e-08	9.34e-08
S10	1.13e-07	9.65e-08	1.44e-07	2.38e-07	0	2.49e-07	1.4e-07	9.08e-08	1.09e-07
S11	1.33e-07	1.12e-07	1.7e-07	2.91e-07	0	3.15e-07	1.66e-07	1.07e-07	1.27e-07
S12	1.53e-07	1.32e-07	2.06e-07	3.36e-07	0	3.45e-07	1.92e-07	1.23e-07	1.46e-07
S13	1.81e-07	1.53e-07	2.29e-07	3.98e-07	0	3.91e-07	2.15e-07	1.45e-07	1.7e-07
S14	2.1e-07	1.73e-07	2.6e-07	4.57e-07	0	4.34e-07	2.65e-07	1.67e-07	1.97e-07
S15	2.44e-07	2.02e-07	3.04e-07	4.56e-07	0	5.31e-07	3.09e-07	1.95e-07	2.31e-07

Physics Asymmetry Weighting Factor, $1/\sigma^2_{i,phys}$



Green Lines Separate wire planes. The 2 bad wires in the first plane and all central wire points have been removed from the plot.