Anomaly Detection and Stability Measurement in the CMS Pixel Luminosity Telescope

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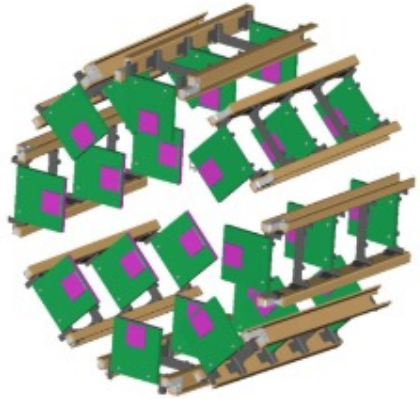
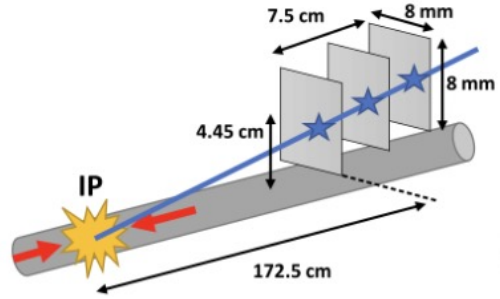
Background



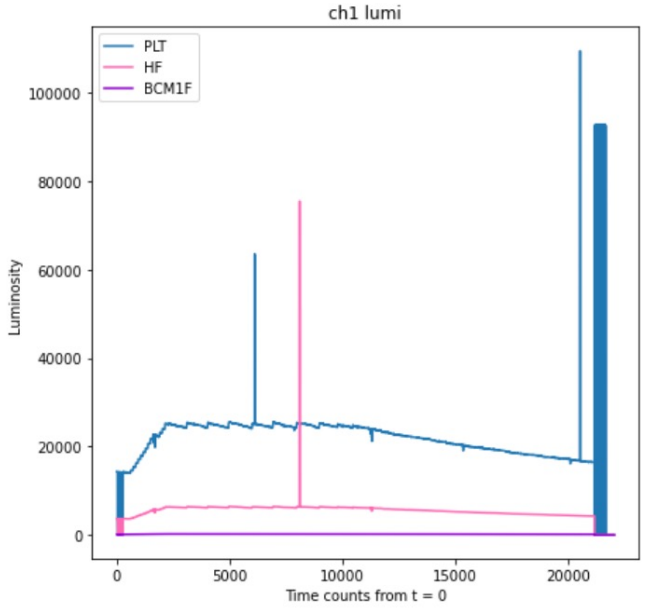
- The BRIL (beam, radiation, intensity and luminosity) group delivers luminosity measurements to CMS using the following detectors:
  - **PLT:** *pixel luminosity telescope*
  - **BCM1F:** *fast beams condition monitor*
  - **HF:** *hadronic forward calorimeter*
  - **PCC:** *pixel clustering counting*
  - **RAMSES:** *radiation monitoring system for the environment and safety*

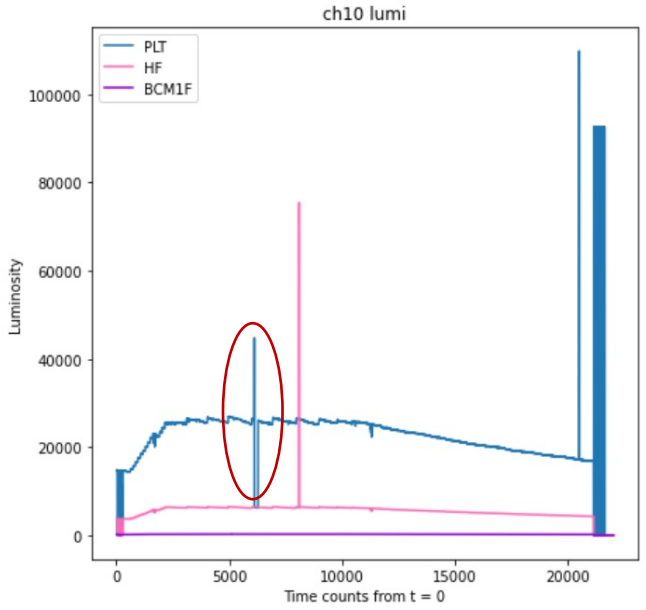


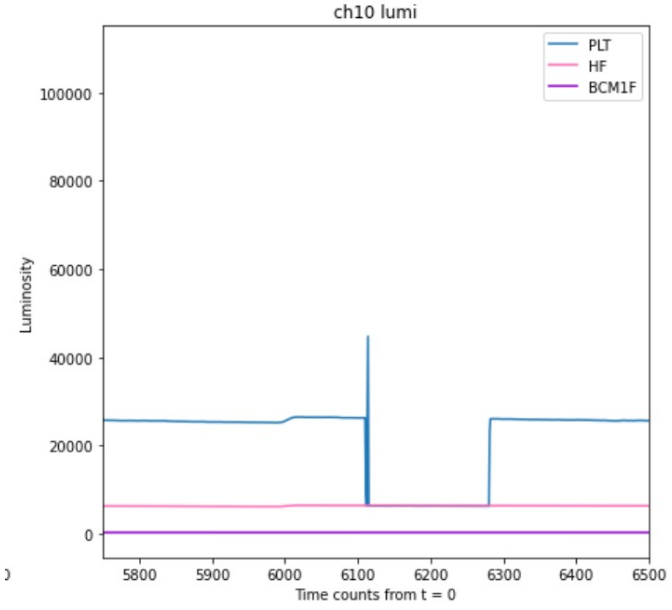
- PLT consists of 16 channels arranged shown to the right and consist of three silicon sensor planes
  - Luminosity hits are recorded from particles that hit all three planes on that channel
- Want to deliver accurate data to limit uncertainty ($\lesssim 1\%$) on integrated luminosity measurement for CMS

Detecting anomalies in data

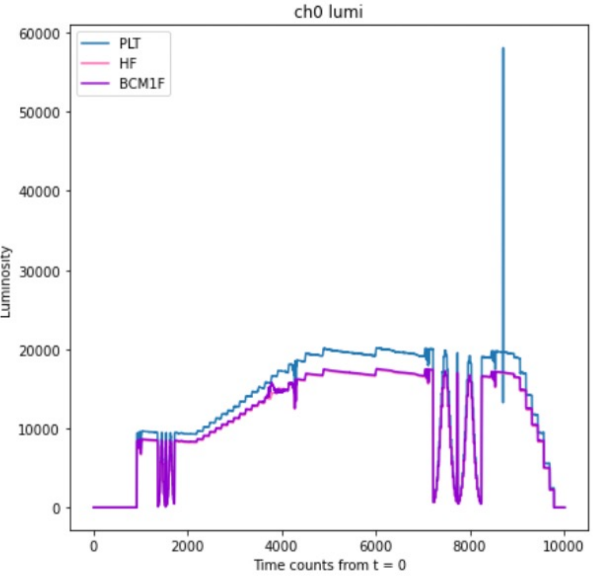
- We need to be able to detect outliers in the data, so they are removed for the final integrated luminosity calculation
- Also important to track overall shift of luminosity data per channel over longer time interval

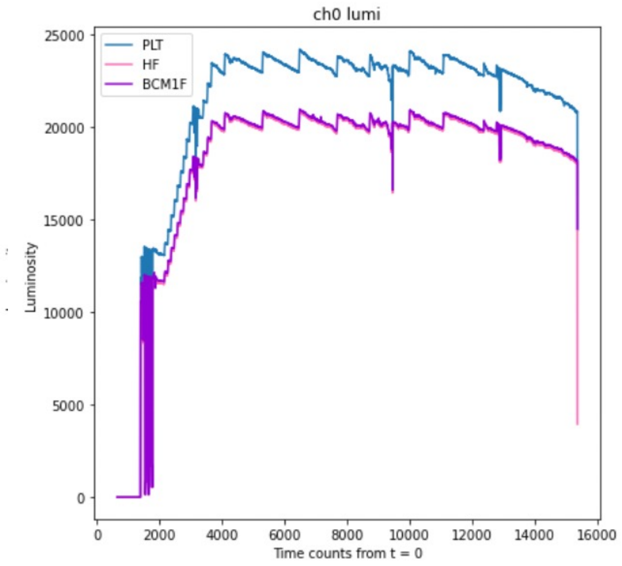


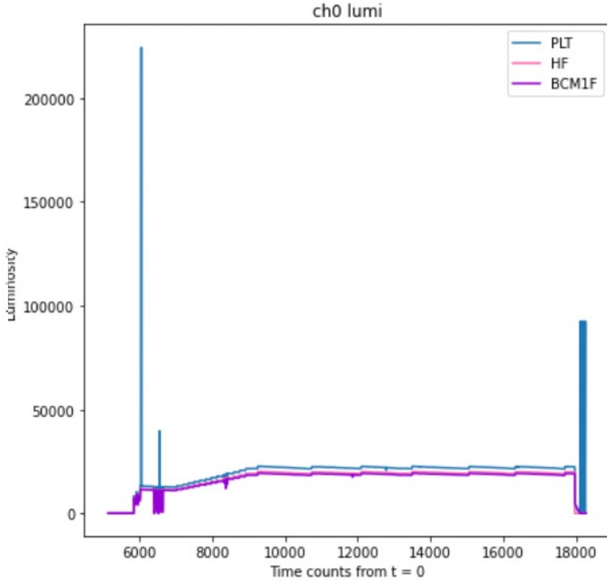


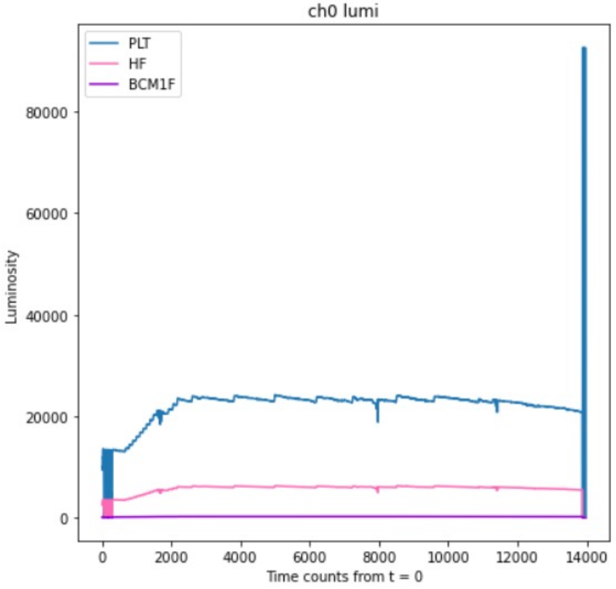


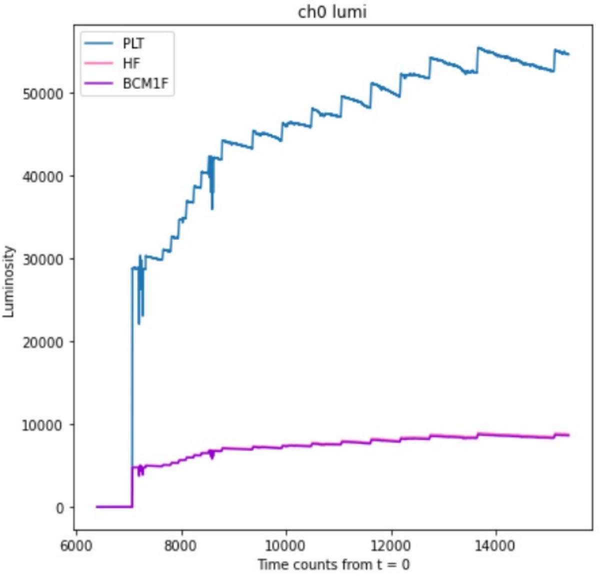
Example data

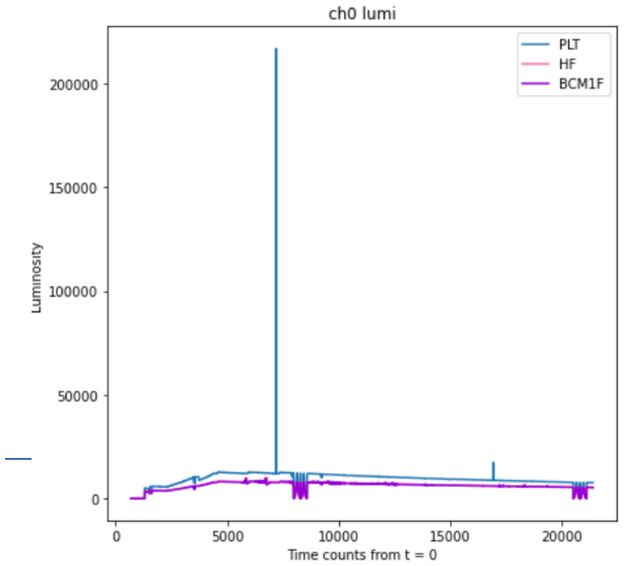


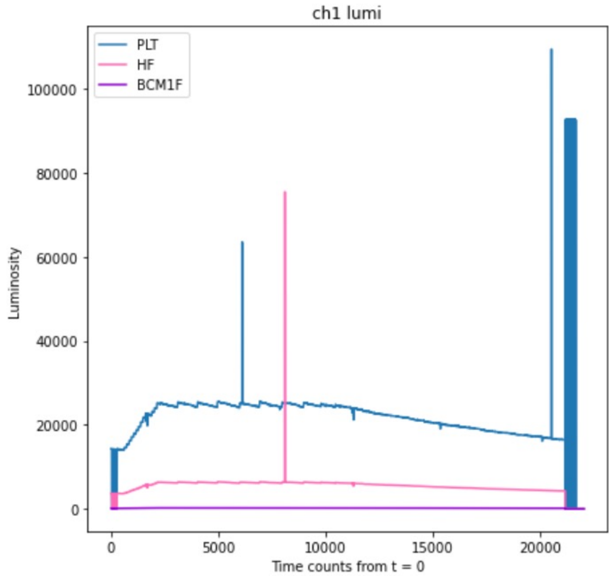


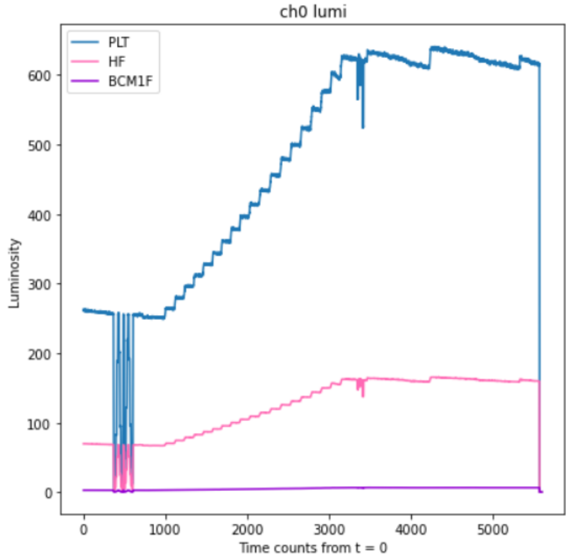










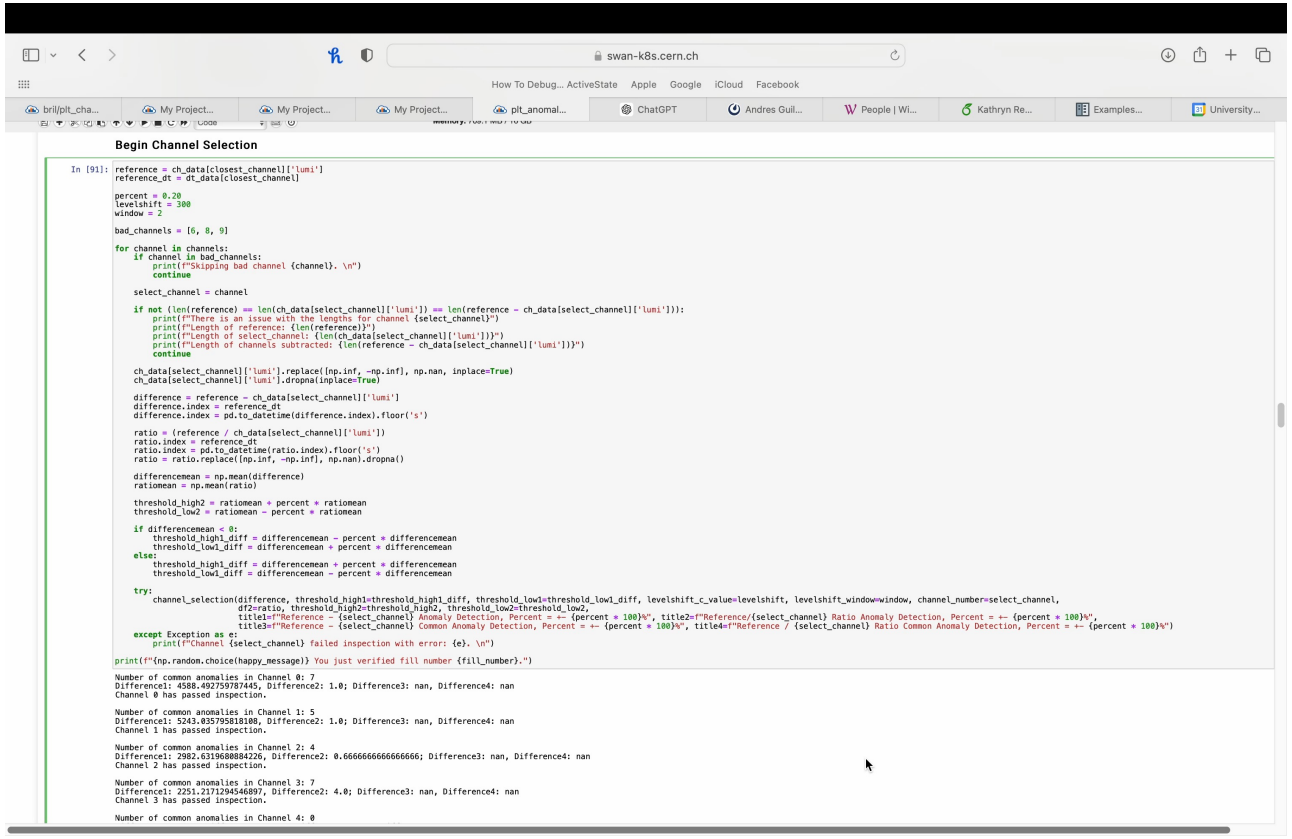


Constructing the algorithm

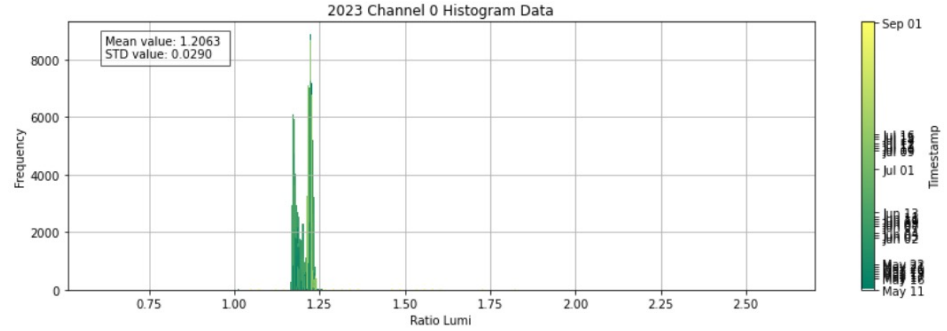
- The algorithm consists of a combination of detectors in adtk, each tuned to detect anomalies that reside above or below certain threshold values or pick up values due to unexpected spikes
  - Documentation here: adtk documentation package
  - Need to ensure we don't flag emittance scan in the process!
- Additionally, BRIL needed a channel selection tool, specifically for 2023 PLT data – created a more generalized version
  - Channel selection tool counts the number of anomalies flagged per channel
  - If enough anomalies are flagged, then it checks the distribution of these anomalies
  - If one condition is not met, the channel fails and needs to be inspected further
  - Multiple scenarios are accounted for to account for variety in data

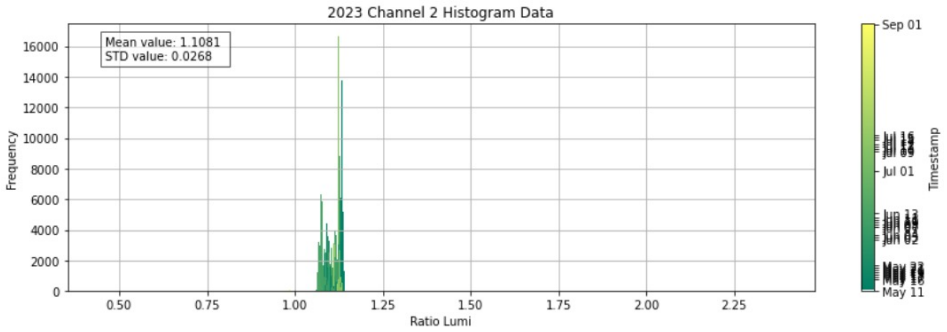
Applying to data

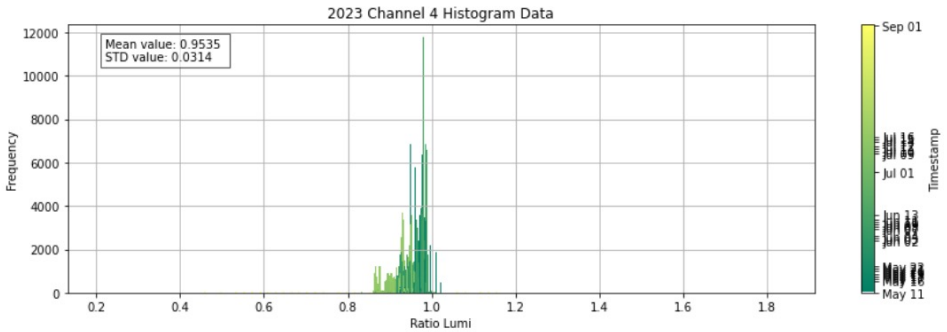
- Example of loading a data file into the algorithm to check if channels have passed or failed inspection
- Second code cell shows further inspection of a failed channel
- Following this, fills are appended to histograms to keep track of the channel shapes as time evolves

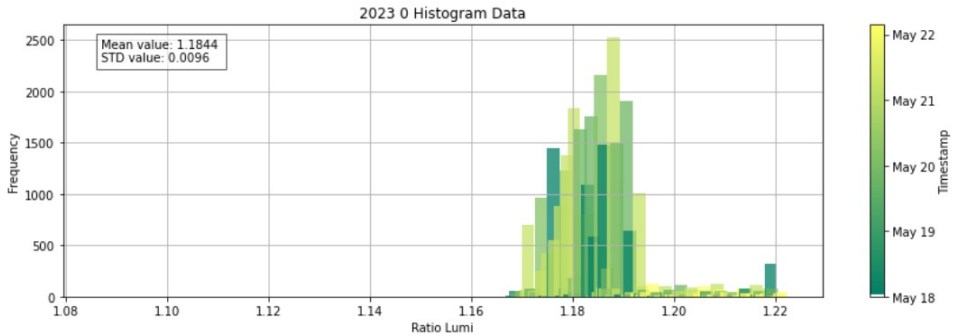


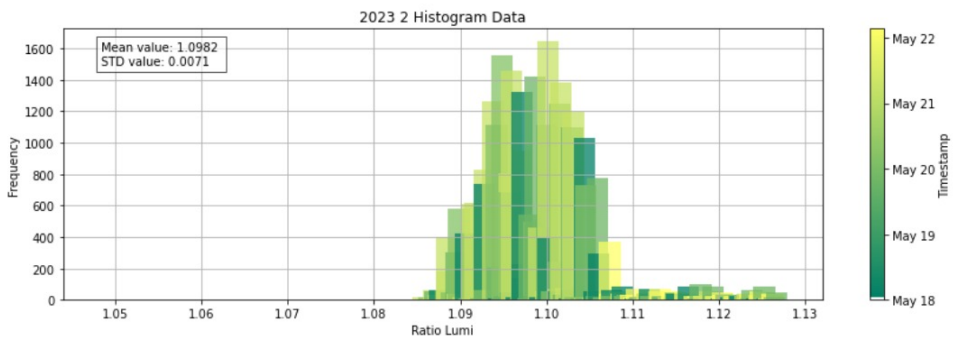
Results

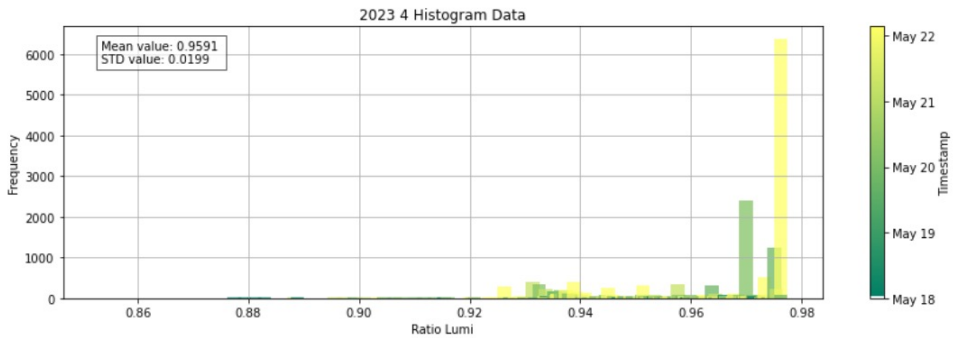






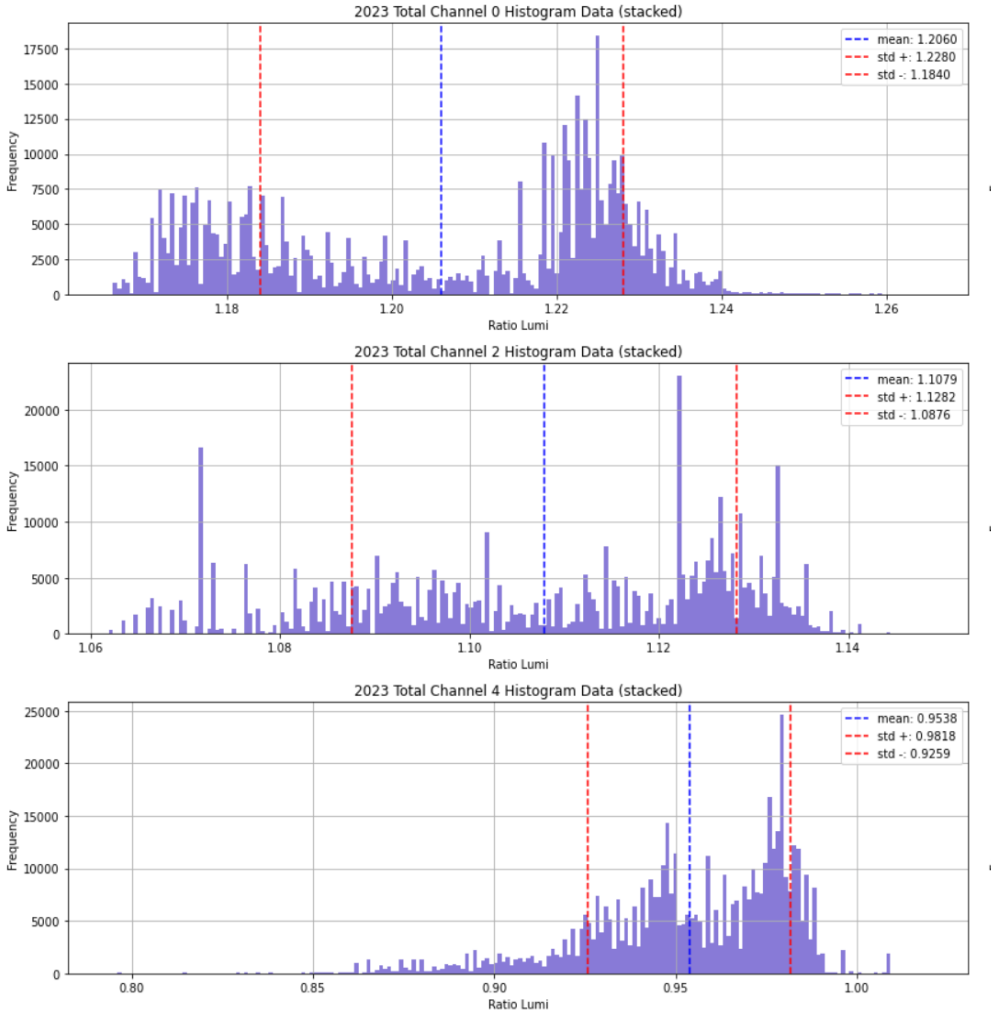


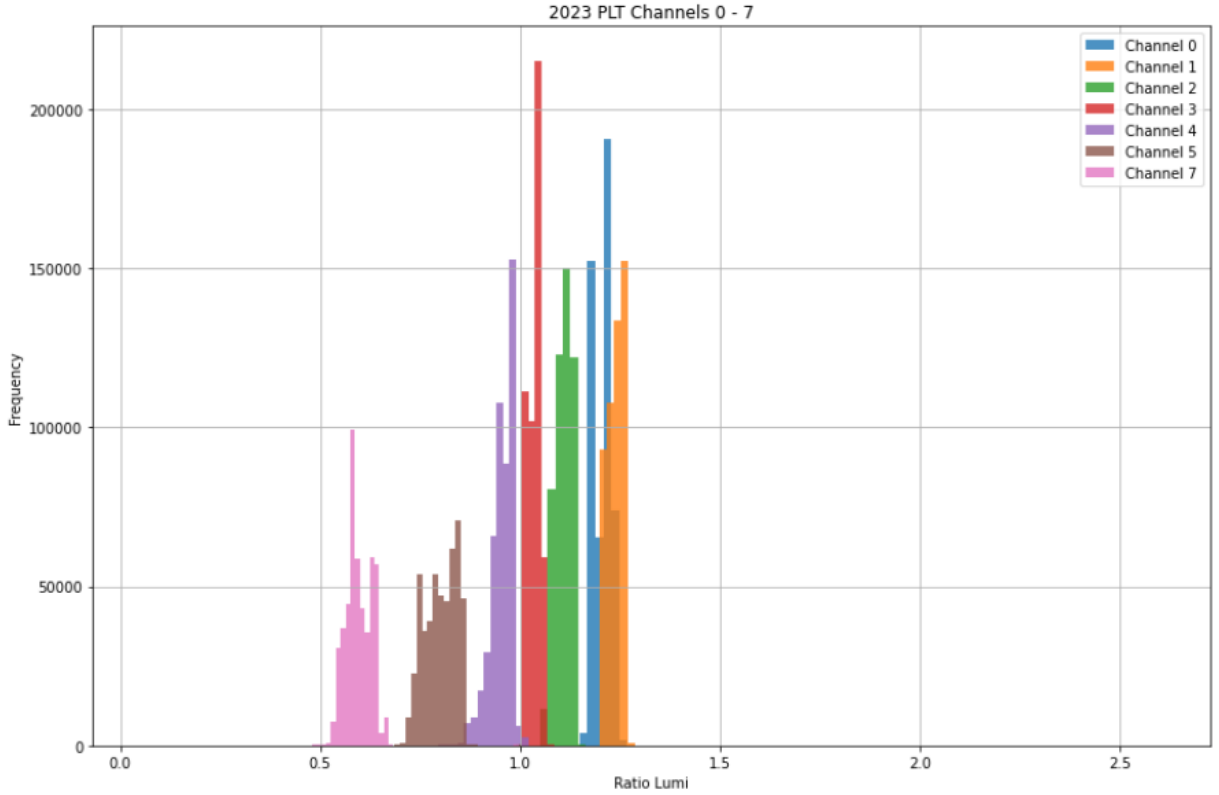




We can display n number of fills around the particular fill loaded in to examine how the luminosity shifts in short- and long-term time-scales

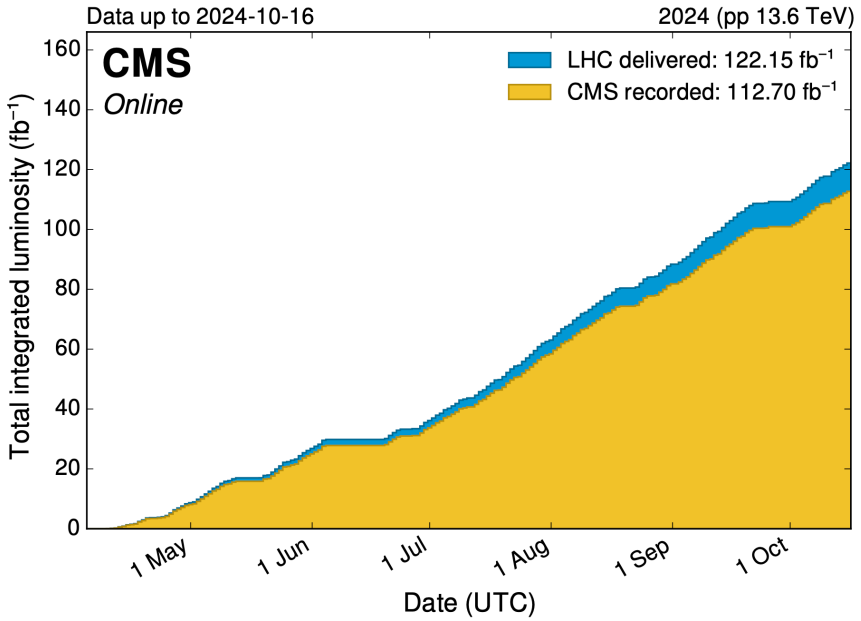
Results


2023 Total Channel 0 Histogram Data (stacked)
mean: 1.2060
std +: 1.2280
std -: 1.1840
Frequency
Ratio Lumi
2023 Total Channel 2 Histogram Data (stacked)
mean: 1.1079
std +: 1.1282
std -: 1.0876
Frequency
Ratio Lumi
2023 Total Channel 4 Histogram Data (stacked)
mean: 0.9538
std +: 0.9818
std -: 0.9259
Frequency
Ratio Lumi


2023 PLT Channels 0 - 7
Channel 0
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 7
Frequency
Ratio Lumi

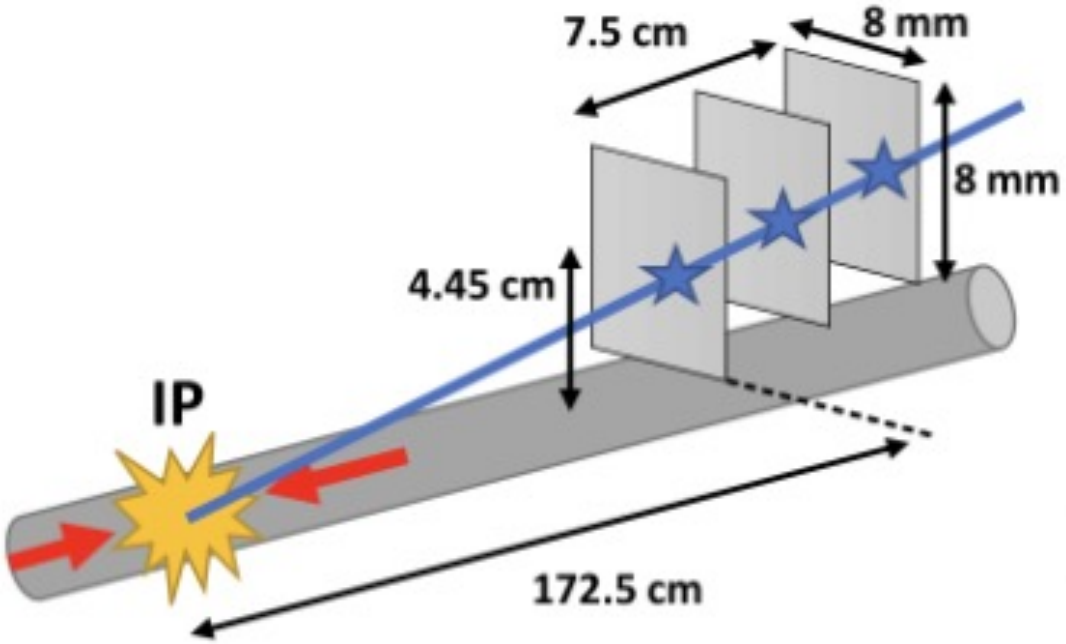
Conclusion

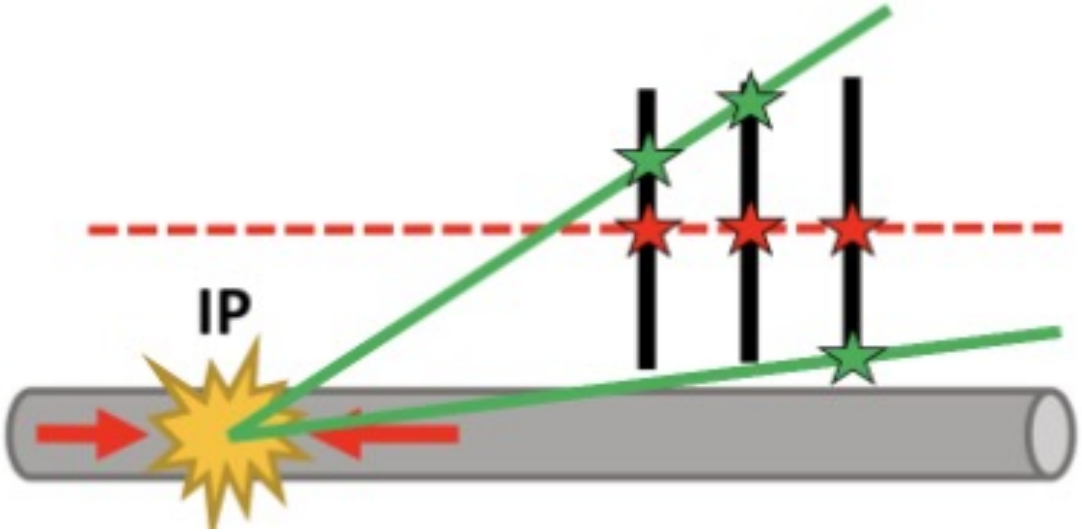
- Through visualizing data across runs, the histograms match what is expected for PLT behavior
- This base algorithm has since been expanded upon in ongoing efforts to run on any detector type and is ready to be deployed, with future goals of having it run autonomously
- Let's keep delivering great integrated luminosity for CMS by eliminating one anomaly at a time!



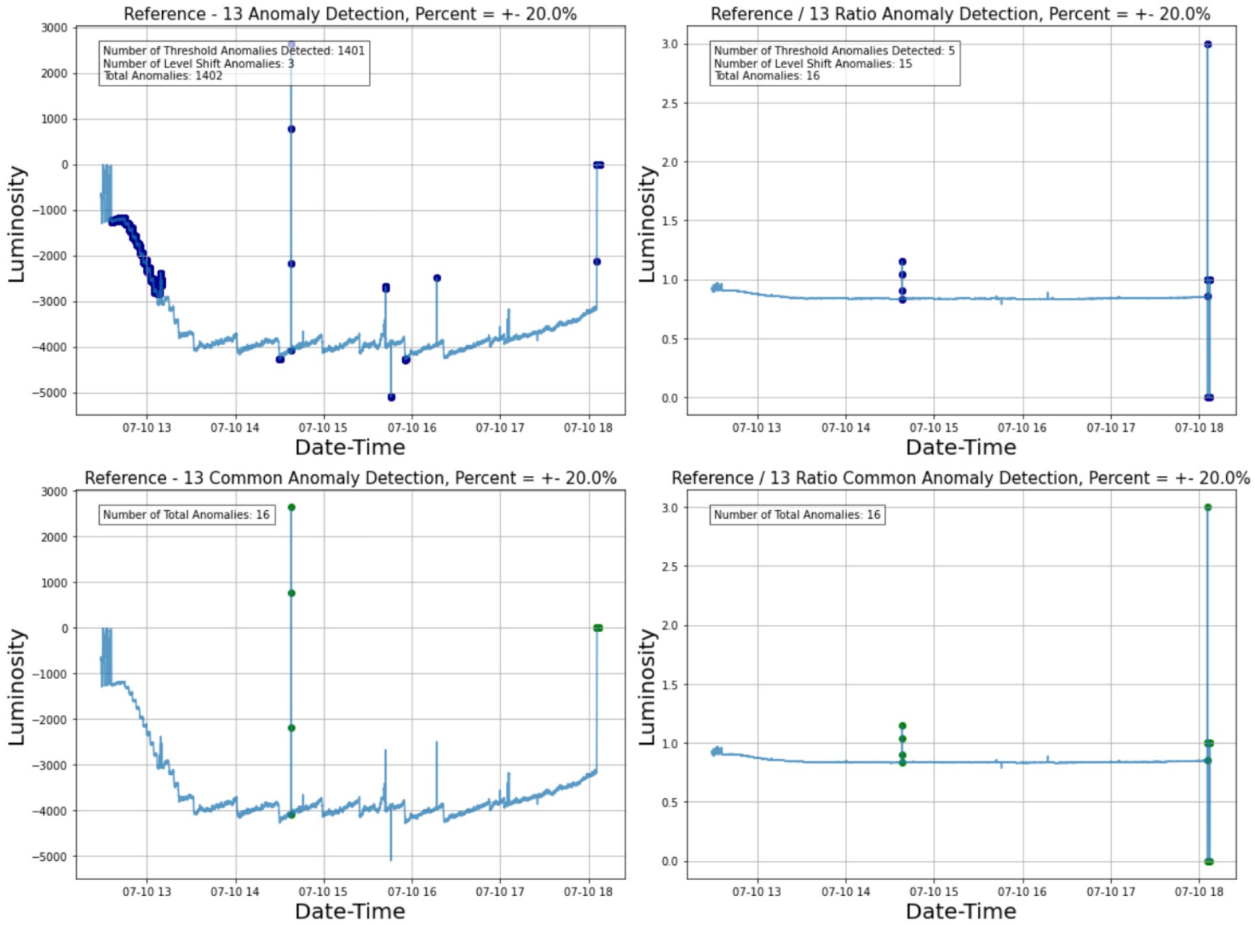
Thank you to the CERN REU program, University of Michigan, my advisors Andres and Francesco, and SLAC National Laboratory for hosting!

Backup


7.5 cm
8 mm
8 mm
4.45 cm
IP
172.5 cm


IP

Example of benefit using both a ratio and difference comparison for anomalies



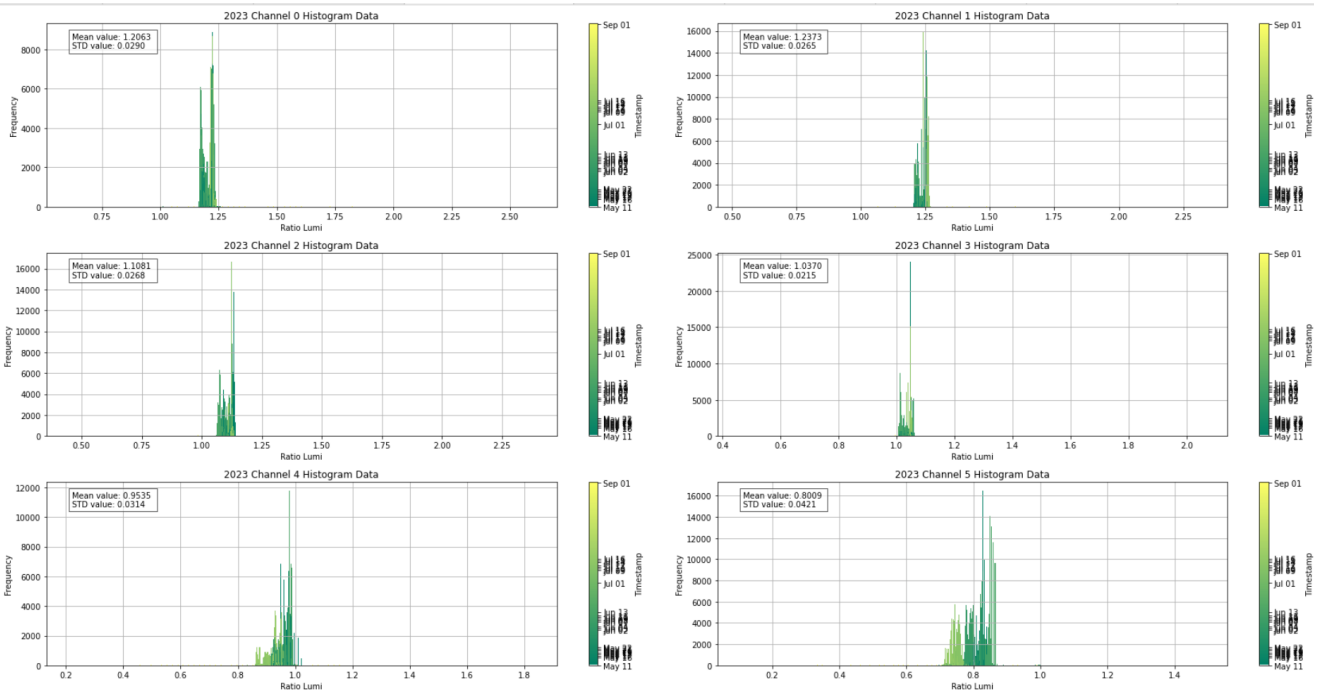
Results

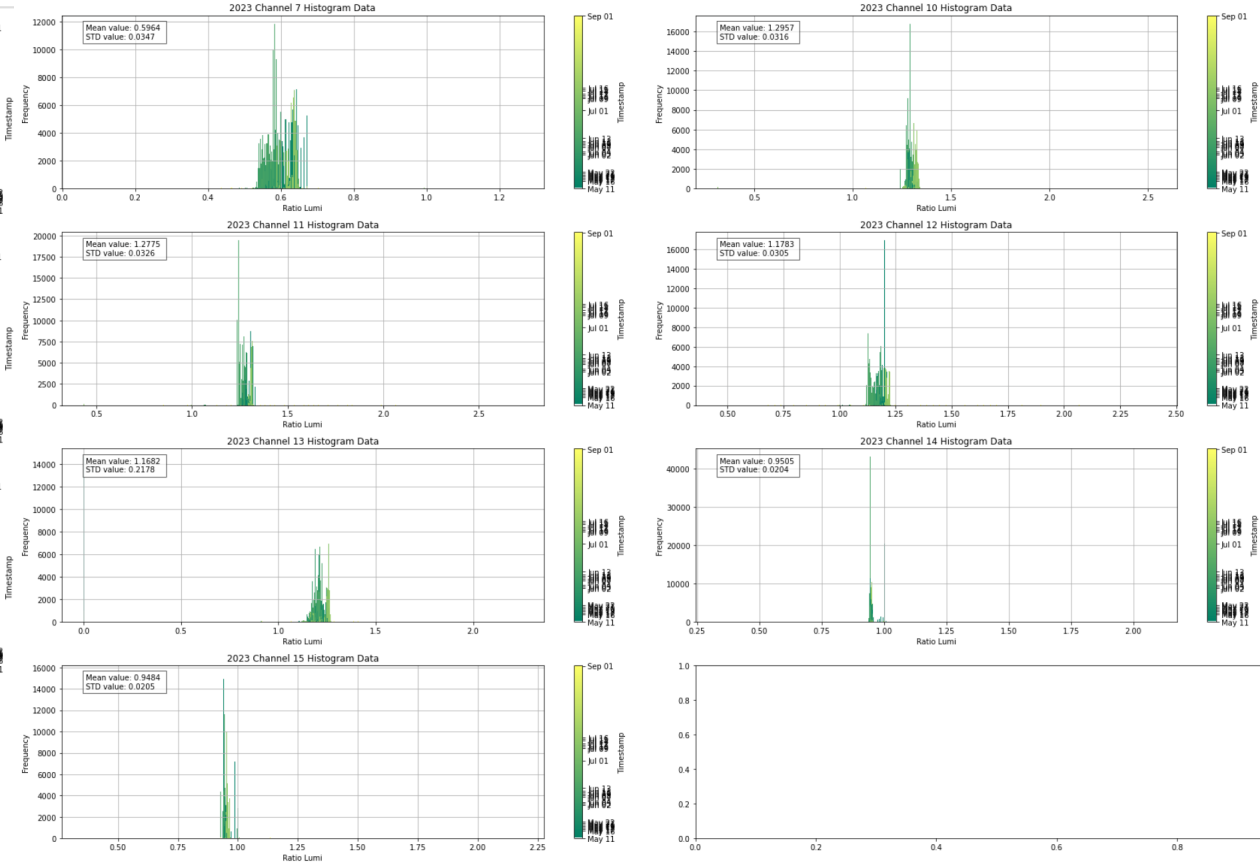
- Look at the overall histograms (next slides) for each channel and in addition information about all fills examined
- Note: channels 6, 8, 9 are known to be bad so we skip looking at them
- In total 37 fills have been verified for 2023 PLT data

PLT Channel Histogram Data

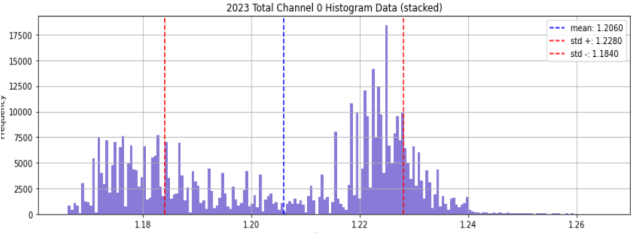
	Mean	Std	Spread	Std Low	Std High	Points Above 1 Sigma	Points Below 1 Sigma	Percent Error	Meets 1 Sigma Expectation
0	1.206005	0.022000	0.099217	1.184004	1.228005	68231	128258	40.190101	No
1	1.236973	0.018575	0.082032	1.218399	1.255548	84810	119969	41.883948	No
2	1.107874	0.020301	0.086400	1.087573	1.128175	86577	94595	37.052747	No
3	1.036991	0.014791	0.065520	1.022200	1.051782	72784	123076	40.049239	No
4	0.953811	0.027954	0.225678	0.925857	0.981766	59834	70306	26.634140	Yes
5	0.801124	0.039704	0.202342	0.761420	0.840828	106145	112757	44.800874	No
7	0.595441	0.030815	0.177896	0.564626	0.626256	122052	84340	42.229752	No
10	1.295180	0.016851	0.100340	1.278329	1.312031	88079	70424	32.405882	No
11	1.278451	0.020782	0.081375	1.257668	1.299233	96179	84794	37.009172	No
12	1.180223	0.021358	0.086059	1.158865	1.201581	94841	116781	43.274447	No
13	1.207884	0.027760	0.165793	1.180124	1.235645	83452	88160	36.043249	No
14	0.947960	0.006992	0.068808	0.940968	0.954952	32105	16632	9.966096	Yes
15	0.948098	0.012585	0.078030	0.935513	0.960683	39203	6176	9.279428	Yes

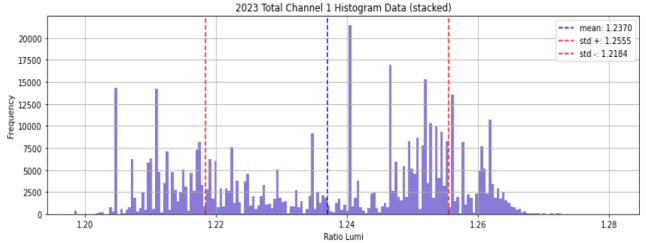
Results

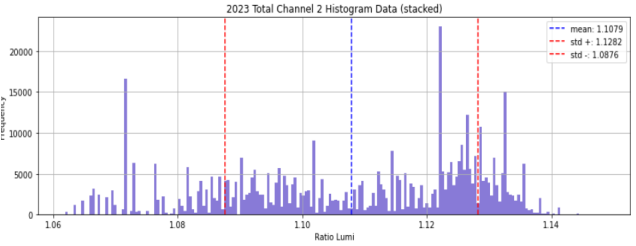

2023 Channel 0 Histogram Data
Mean value: 1.2063
STD value: 0.0290
2023 Channel 1 Histogram Data
Mean value: 1.2373
STD value: 0.0265
2023 Channel 2 Histogram Data
Mean value: 1.1081
STD value: 0.0268
2023 Channel 3 Histogram Data
Mean value: 1.0370
STD value: 0.0215
2023 Channel 4 Histogram Data
Mean value: 0.9535
STD value: 0.0314
2023 Channel 5 Histogram Data
Mean value: 0.8009
STD value: 0.0421
Frequency
Ratio Lumi
Timestamp
Sep 01
Jul 01
May 11

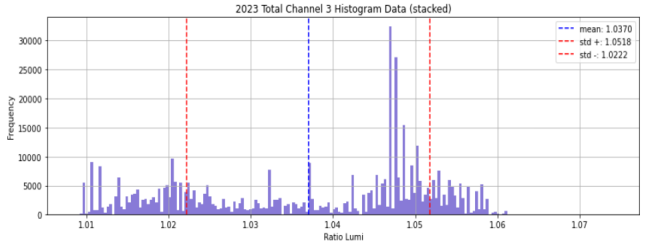

2023 Channel 7 Histogram Data
Mean value: 0.5964
STD value: 0.0347
2023 Channel 10 Histogram Data
Mean value: 1.2957
STD value: 0.0316
2023 Channel 11 Histogram Data
Mean value: 1.2775
STD value: 0.0326
2023 Channel 12 Histogram Data
Mean value: 1.1783
STD value: 0.0305
2023 Channel 13 Histogram Data
Mean value: 1.1682
STD value: 0.2178
2023 Channel 14 Histogram Data
Mean value: 0.9505
STD value: 0.0204
2023 Channel 15 Histogram Data
Mean value: 0.9484
STD value: 0.0205
Frequency
Ratio Lumi
Timestamp
Sep 01
Jul 01
May 11

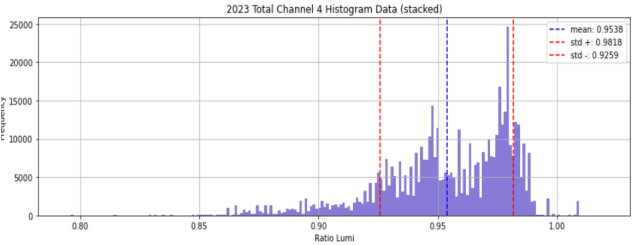
Results

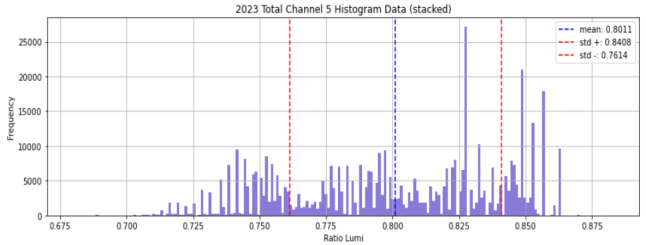

2023 Total Channel 0 Histogram Data (stacked)
mean: 1.2060
std +: 1.2280
std -: 1.1840
Frequency
Ratio Lumi

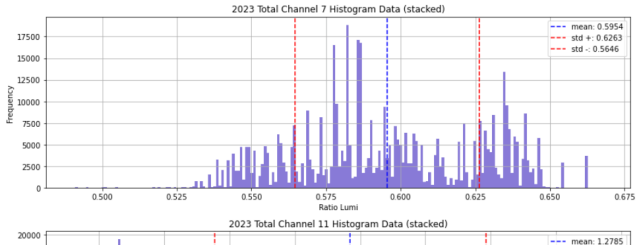

2023 Total Channel 1 Histogram Data (stacked)
mean: 1.2370
std +: 1.2555
std -: 1.2184
Frequency
Ratio Lumi

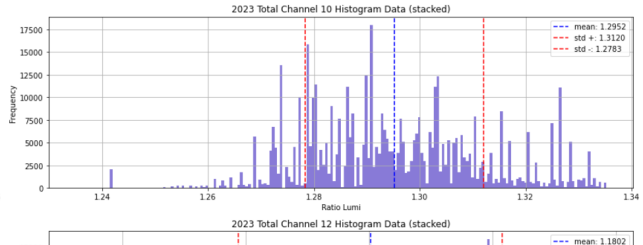

2023 Total Channel 2 Histogram Data (stacked)
mean: 1.1079
std +: 1.1282
std -: 1.0876
Frequency
Ratio Lumi

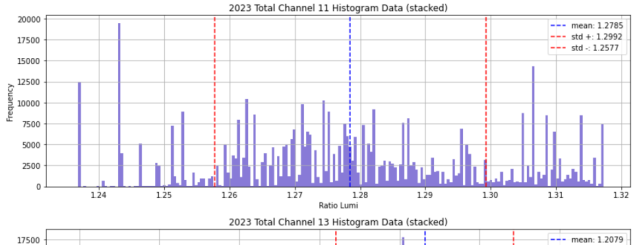

2023 Total Channel 3 Histogram Data (stacked)
mean: 1.0370
std +: 1.0518
std -: 1.0222
Frequency
Ratio Lumi

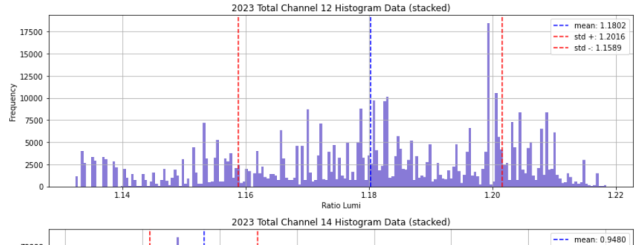

2023 Total Channel 4 Histogram Data (stacked)
mean: 0.9538
std +: 0.9818
std -: 0.9259
Frequency
Ratio Lumi

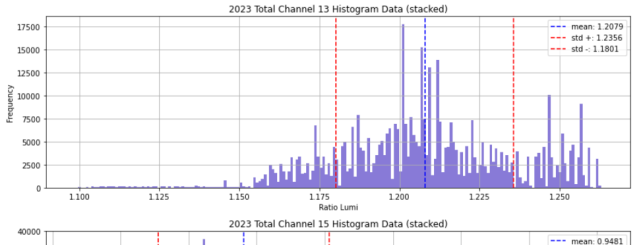

2023 Total Channel 5 Histogram Data (stacked)
mean: 0.8011
std +: 0.8408
std -: 0.7614
Frequency
Ratio Lumi

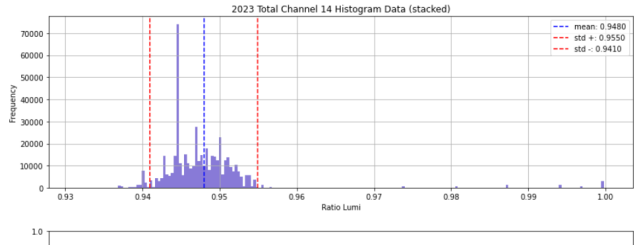

2023 Total Channel 7 Histogram Data (stacked)
mean: 0.5954
std +: 0.6263
std -: 0.5646
Frequency
Ratio Lumi

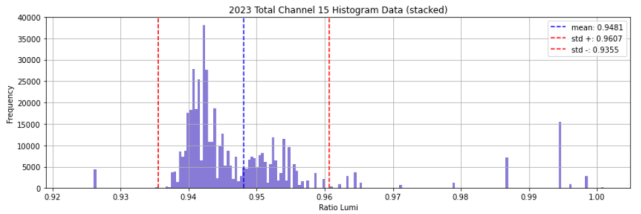

2023 Total Channel 10 Histogram Data (stacked)
mean: 1.2952
std +: 1.3120
std -: 1.2783
Frequency
Ratio Lumi


2023 Total Channel 11 Histogram Data (stacked)
mean: 1.2785
std +: 1.2992
std -: 1.2577
Frequency
Ratio Lumi

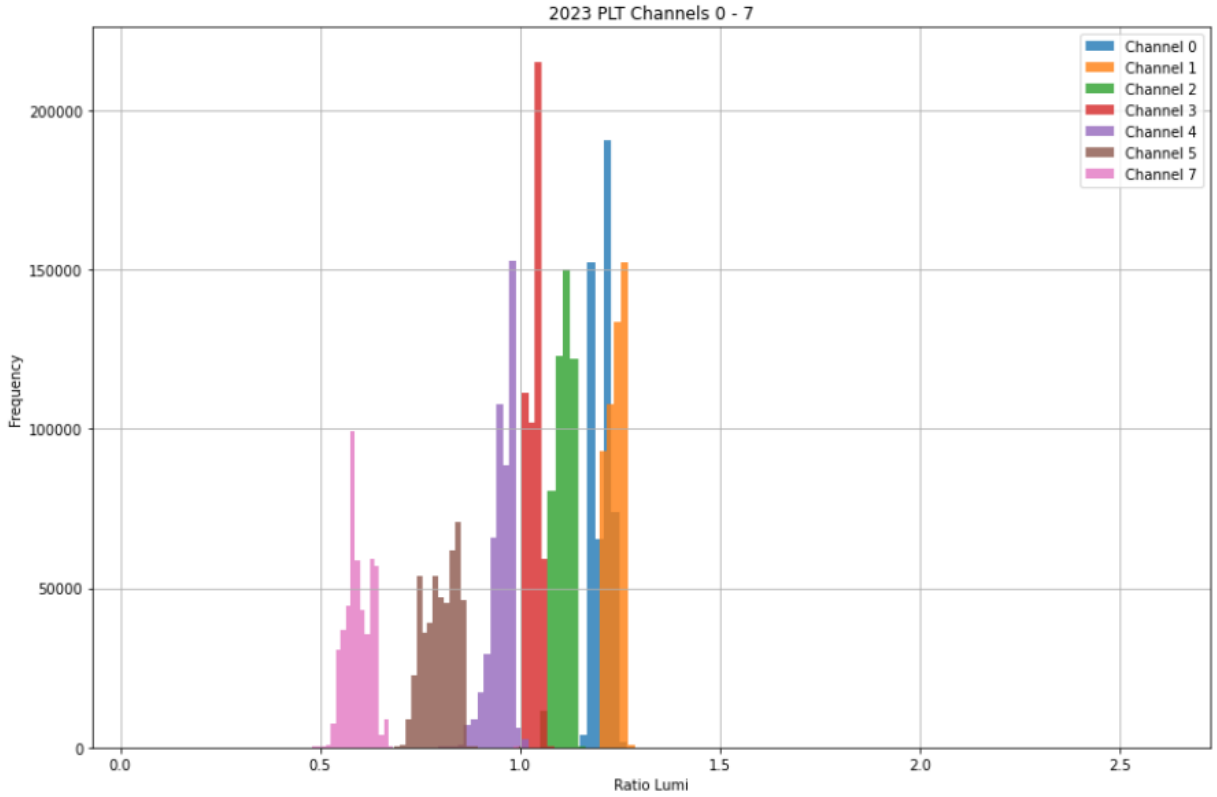

2023 Total Channel 12 Histogram Data (stacked)
mean: 1.1802
std +: 1.2016
std -: 1.1589
Frequency
Ratio Lumi


2023 Total Channel 13 Histogram Data (stacked)
mean: 1.2079
std +: 1.2356
std -: 1.1801
Frequency
Ratio Lumi


2023 Total Channel 14 Histogram Data (stacked)
mean: 0.9480
std +: 0.9550
std -: 0.9410
Frequency
Ratio Lumi


2023 Total Channel 15 Histogram Data (stacked)
mean: 0.9481
std +: 0.9607
std -: 0.9355
Frequency
Ratio Lumi

Results


2023 PLT Channels 0 - 7
Channel 0
Channel 1
Channel 2
Channel 3
Channel 4
Channel 5
Channel 7
Frequency
200000
150000
100000
50000
0
0.0
0.5
1.0
1.5
2.0
2.5
Ratio Lumi