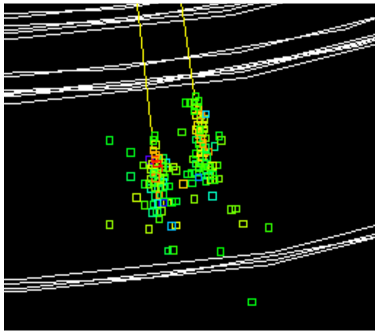


Update on End Station A Experiment T-511 Silicon-Tungsten Prototype Calorimeter with KPiX Readout

M. Breidenbach, D. Freytag, N. Graf, G. Haller, R. Herbst, J. Jaros

SLAC National Accelerator Center

J. Brau, R. Frey, C. Gallagher, D. Strom,

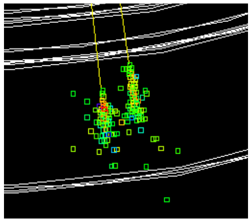
W. McCann, D. Mead (grad students),

K. Travis (undergraduate)

U. Oregon

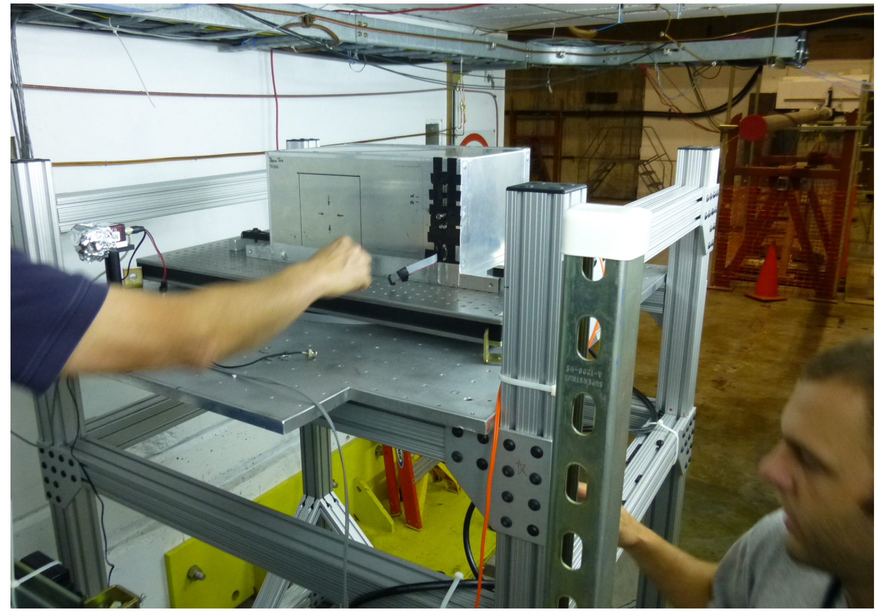
B. Holbrook, M. Tripathi, grad students

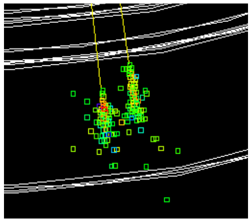
UC Davis



T-511 Overview

- SLAC End Station A
- 4 half-days of good running, July 26-29
- 12.1 GeV electrons
- particles per pulse: ~ 0.5 to ~ 5
- well-defined beam
- movable x-y platform
- upstream instrumentation: one plastic scintillator
- remote control and monitoring at CLA
- online analysis using JAS (thanks to Dima Onoprienko, Tony Johnson)
- excellent support from SLAC (thanks to Carsten Hast, Christine Clarke)

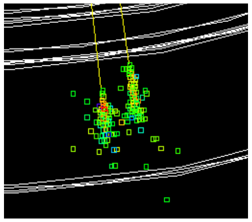




runs

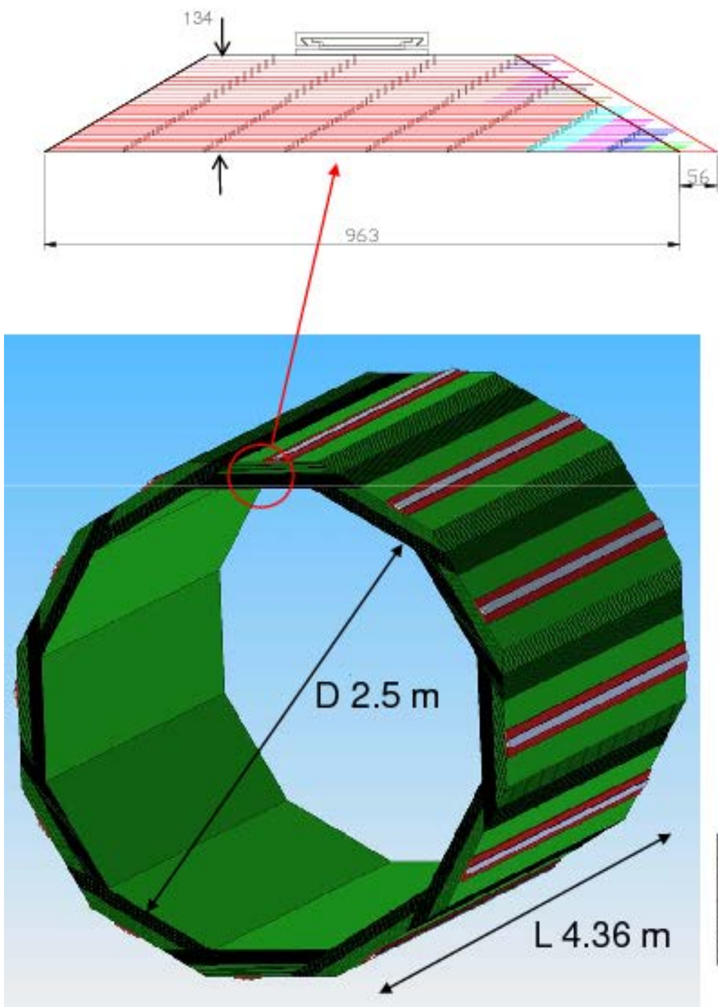
2013_07_26_01_30_53	Calibration Run
2013_07_26_09_07_01	No Beam at start of run
2013_07_26_10_05_12	Collecting while beam is dialed in
2013_07_26_10_37_59	Collecting while beam is dialed in
2013_07_26_10_41_28	Collecting while beam is dialed in
2013_07_26_12_16_13	Collecting while beam is dialed in
2013_07_26_14_13_43	Changed position from previous, collecting
2013_07_26_17_13_16	Zenon camera test file
2013_07_26_18_27_37	DacThresholdA Scan, DacThresholdA=245
2013_07_26_19_26_31	DacThresholdA Scan, DacThresholdA=235
2013_07_26_20_31_15	DacThresholdA Scan, DacThresholdA=240
2013_07_27_10_29_14	DacThresholdA Scan, DacThresholdA=240
2013_07_27_11_01_46	DacThresholdA Scan, DacThresholdA=247
2013_07_27_12_27_15	DacThresholdA Scan, DacThresholdA=243
2013_07_27_16_30_10	DacThresholdA Scan, DacThresholdA=230
2013_07_27_17_31_04	DacThresholdA Scan, DacThresholdA=250
2013_07_27_18_48_15	Beam on KPiX Chip
2013_07_27_19_23_18	HoldTime Scan, DiffTime Half, HoldTime=32
2013_07_27_19_38_35	HoldTime Scan, DiffTime Normal, HoldTime=64
2013_07_27_19_47_43	HoldTime Scan, DiffTime Half, HoldTime=32
2013_07_27_20_04_17	HoldTime Scan, DiffTime Half, HoldTime=8
2013_07_27_20_27_06	HoldTime Scan, DiffTime Half, HoldTime=48
2013_07_27_20_40_21	HoldTime Scan, DiffTime Half, HoldTime=8
2013_07_27_20_43_27	HoldTime Scan, DiffTime Half, HoldTime=24

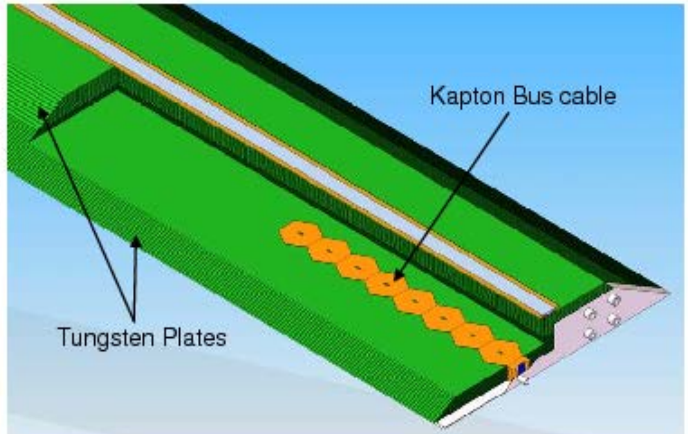
2013_07_28_09_46_04	Collecting while beam is dialed i
2013_07_28_10_24_50	Checking config
2013_07_28_10_40_49	Checking config
2013_07_28_11_42_24	HoldTime Scan, HoldTime=24
2013_07_28_12_34_22	HoldTime Scan, HoldTime=32
2013_07_28_13_15_30	HoldTime Scan, HoldTime=16
2013_07_28_14_09_55	HoldTime Scan, HoldTime=8
2013_07_28_15_01_17	Beam intermittent, magnets had
2013_07_28_15_44_12	Checking operation after magnet
2013_07_28_16_56_14	Beam on KPiX Chip
2013_07_28_17_34_07	Beam on KPiX Chip, particles pe
2013_07_28_18_16_40	DacRangeThreshold Scan, DacRa
2013_07_28_18_40_29	DacRangeThreshold Scan, DacRa
2013_07_28_19_25_54	DacRangeThreshold Scan, DacRa
2013_07_28_20_02_40	DacRangeThreshold Scan, DacRa
2013_07_28_20_33_31	DacRangeThreshold Scan, DacRa
2013_07_29_11_14_58	Collecting while beam is dialed i
2013_07_29_14_35_42	Non-standard config file
2013_07_29_15_58_34	Ignore this file
2013_07_29_16_12_24	Baseline run for DacRangeThresh
2013_07_29_16_57_21	DacRangeThreshold Scan, DacRa
2013_07_29_17_15_10	DacRangeThreshold Scan, DacRa
2013_07_29_18_50_52	DacRangeThreshold Scan, DacRa
2013_07_29_19_29_09	DacRangeThreshold Scan, DacRa

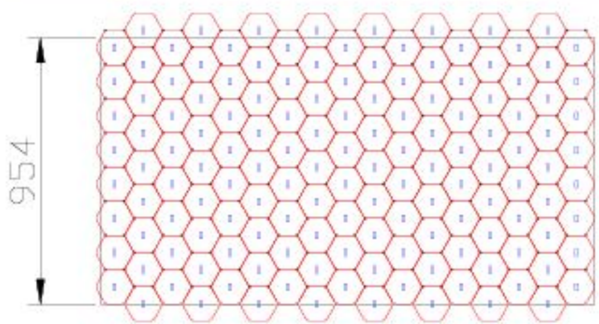


The SiD ECal Baseline

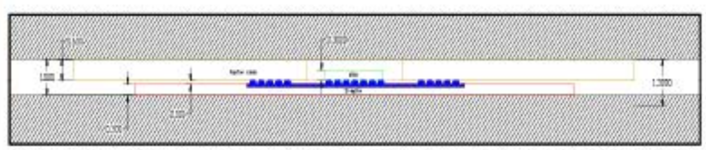
An imaging calorimeter: 30 layers tungsten interleaved with 30 layers pixellated silicon







Hexagon sensors arrangement

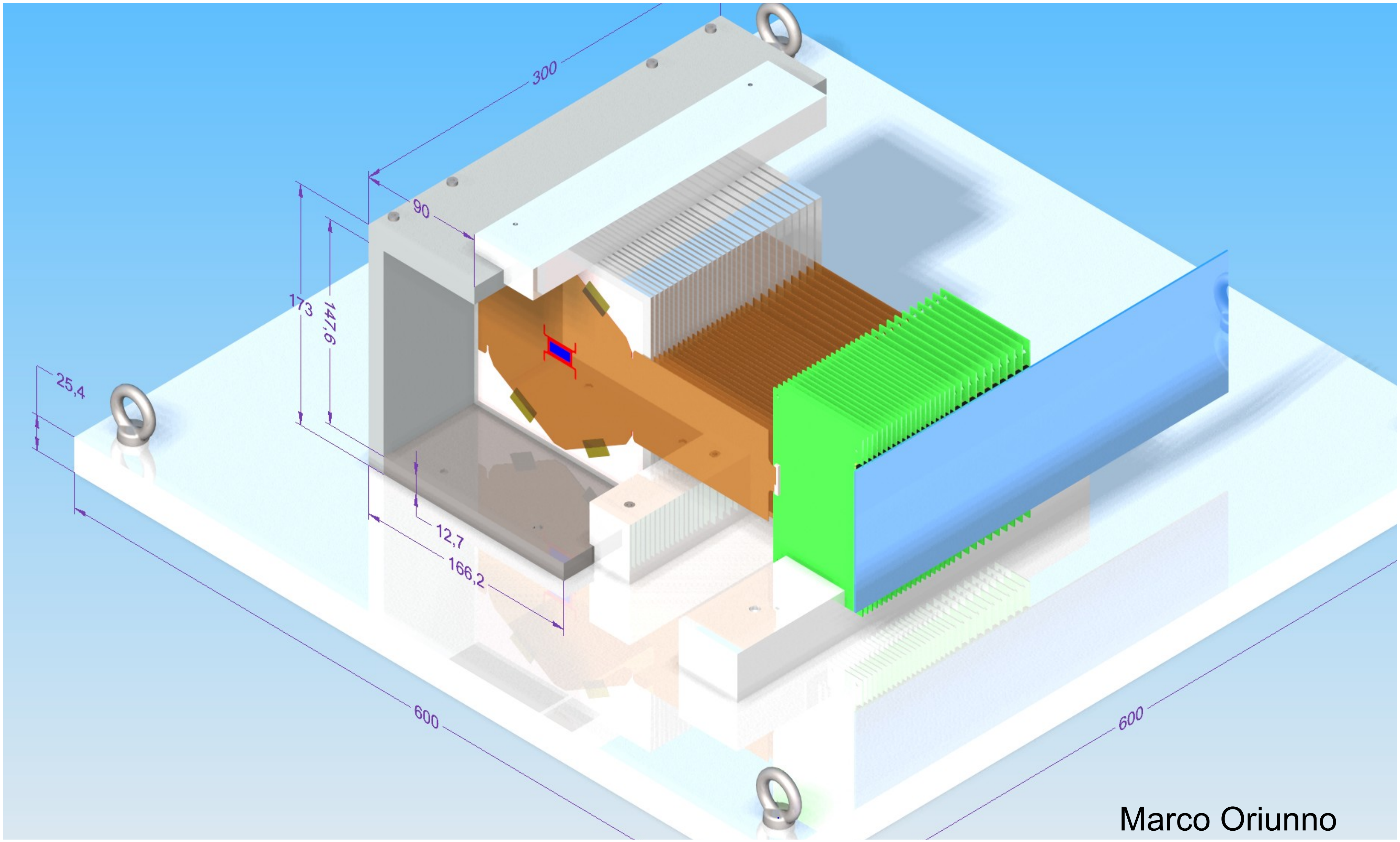


detector module between tungsten plates

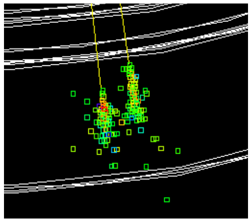
<u>Baseline configuration:</u>

- transverse: 12 mm^2 pixels
- longitudinal: $(20 \times 5/7\ X_0)$ + $(10 \times 10/7\ X_0)$ $\Rightarrow$ 17%/sqrt(E)
- 1 mm readout gaps $\Rightarrow$ 13 mm effective Moliere radius

R&D goal: Test beam module – 30 layers with same long. profile as SiD

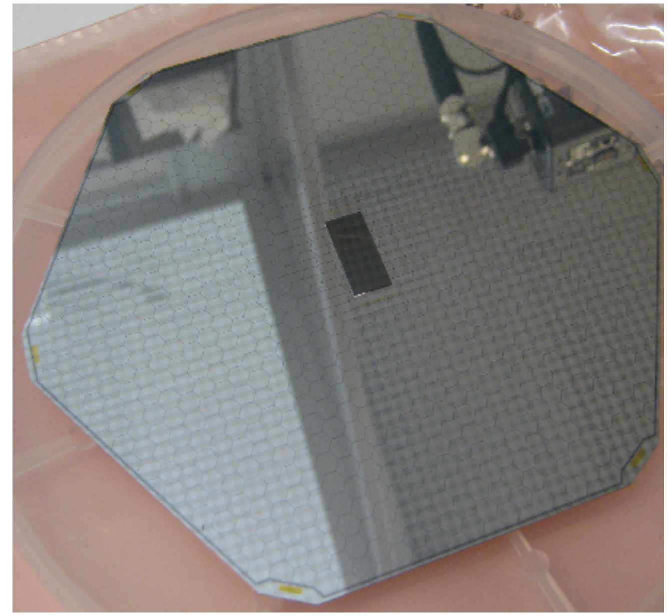


Marco Oriunno

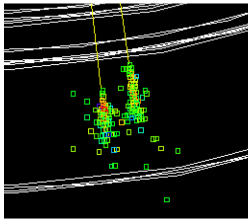


Interconnects update

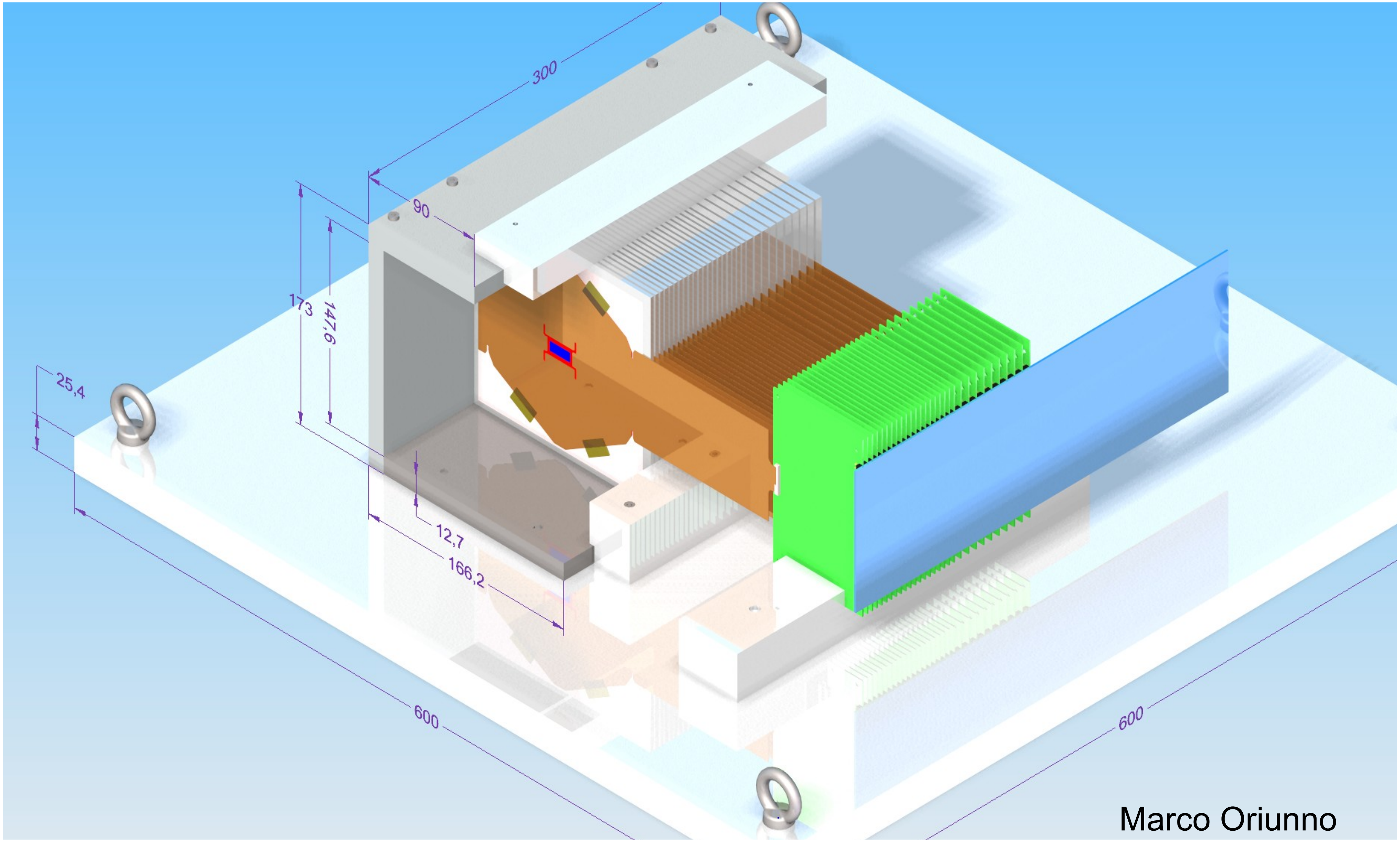
- The Hamamatsu sensors have Al bonding pads → Al oxide
- The KPiX chips (v-A) come from TSMC with eutectic Sn-Pb solder bumps
- Enlisted IZM to prepare the sensors (Ar ion etch + sputtering) and complete the bump bonding.

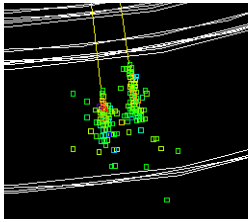


- We find that 10% of pixels have shorts or opens
  - Mostly shorts
  - "Shorts" are connected to another pixel (crosstalk)
- Inspection found that these were associated with visually identified defects ➔ Leading hypothesis is that IZM processing (ion wash) led to ESD or ESD-like damage
- The first batch of these sensors used in test beam prototype.

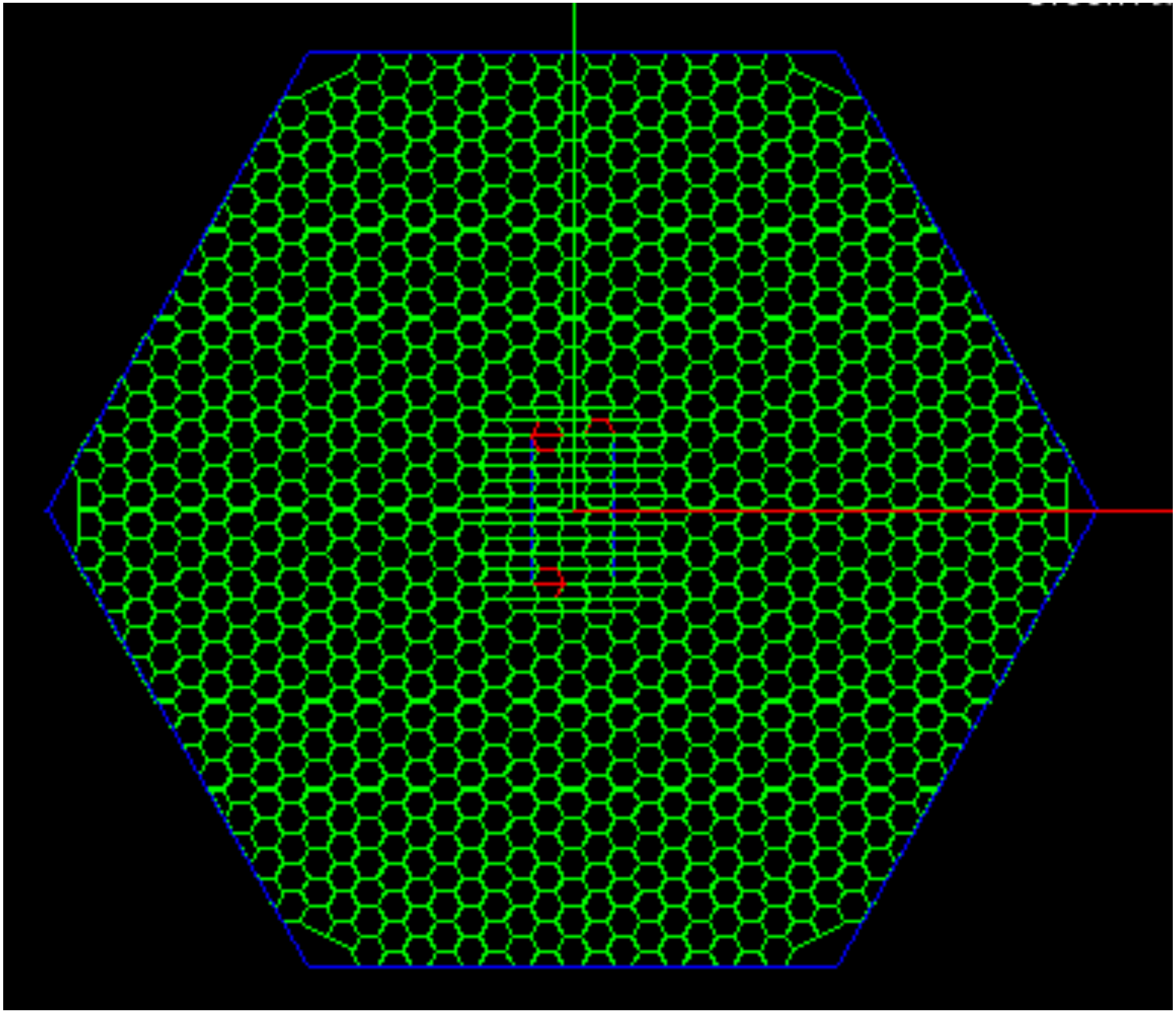


Initial test beam module for T-511
only 9 Si + 8 W layers (~ 6 X_0)

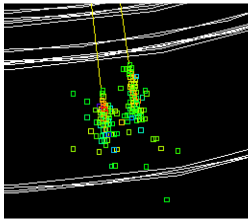


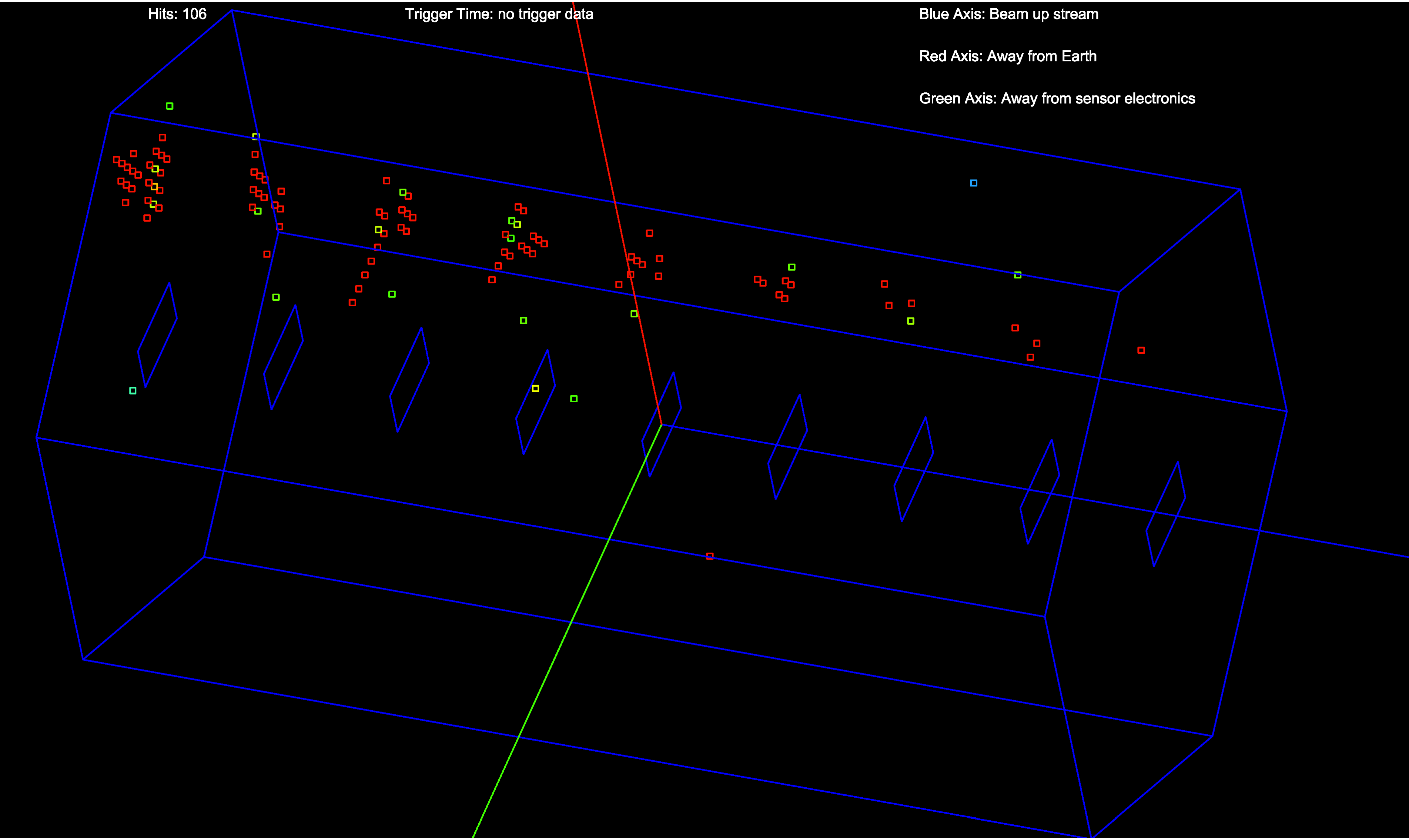


event display – Kyle and Dylan

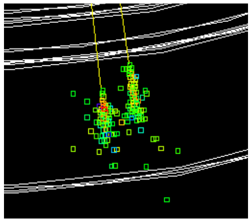


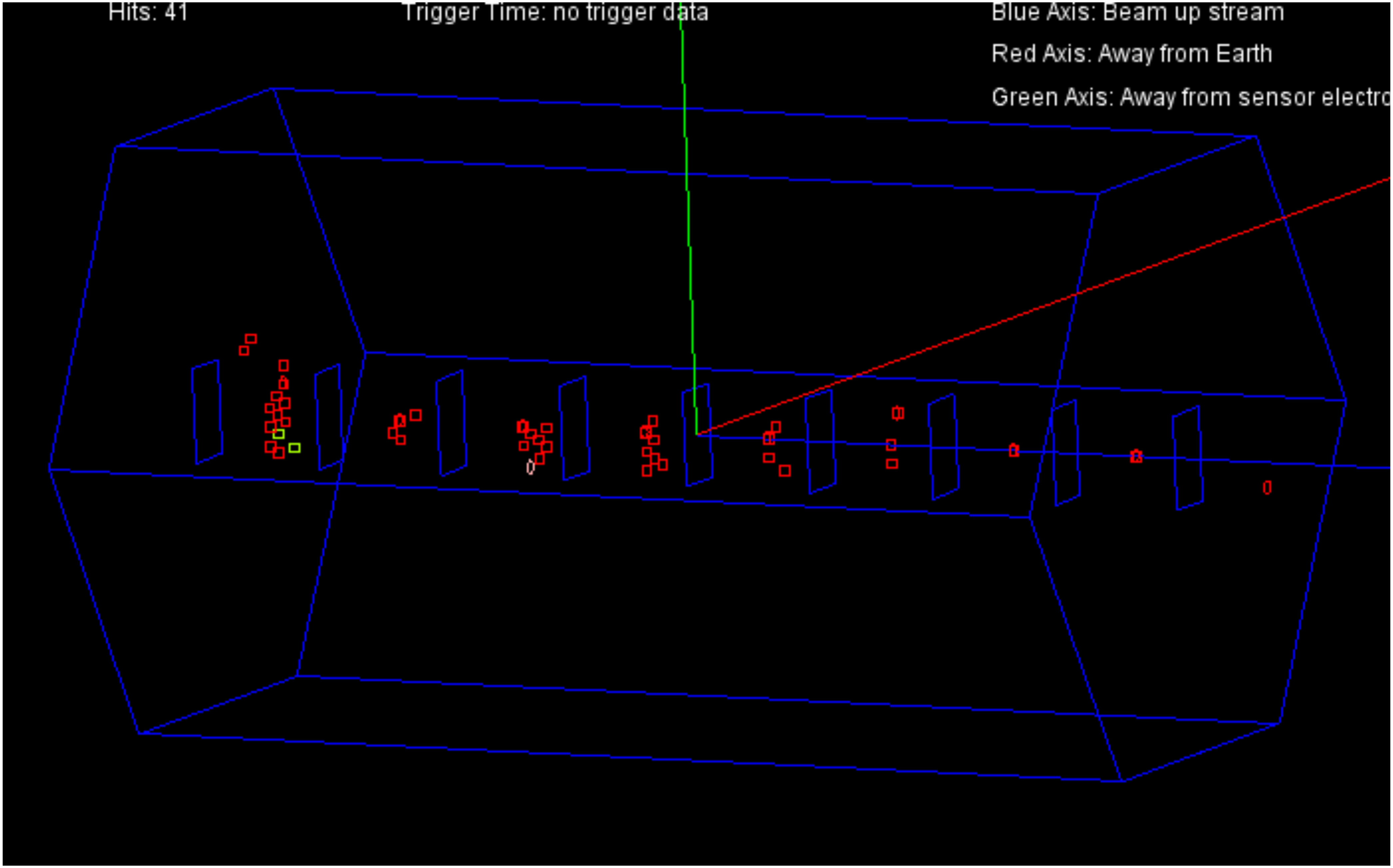
single-electron showers



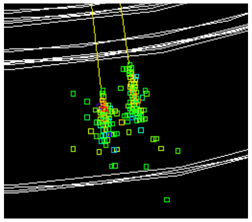


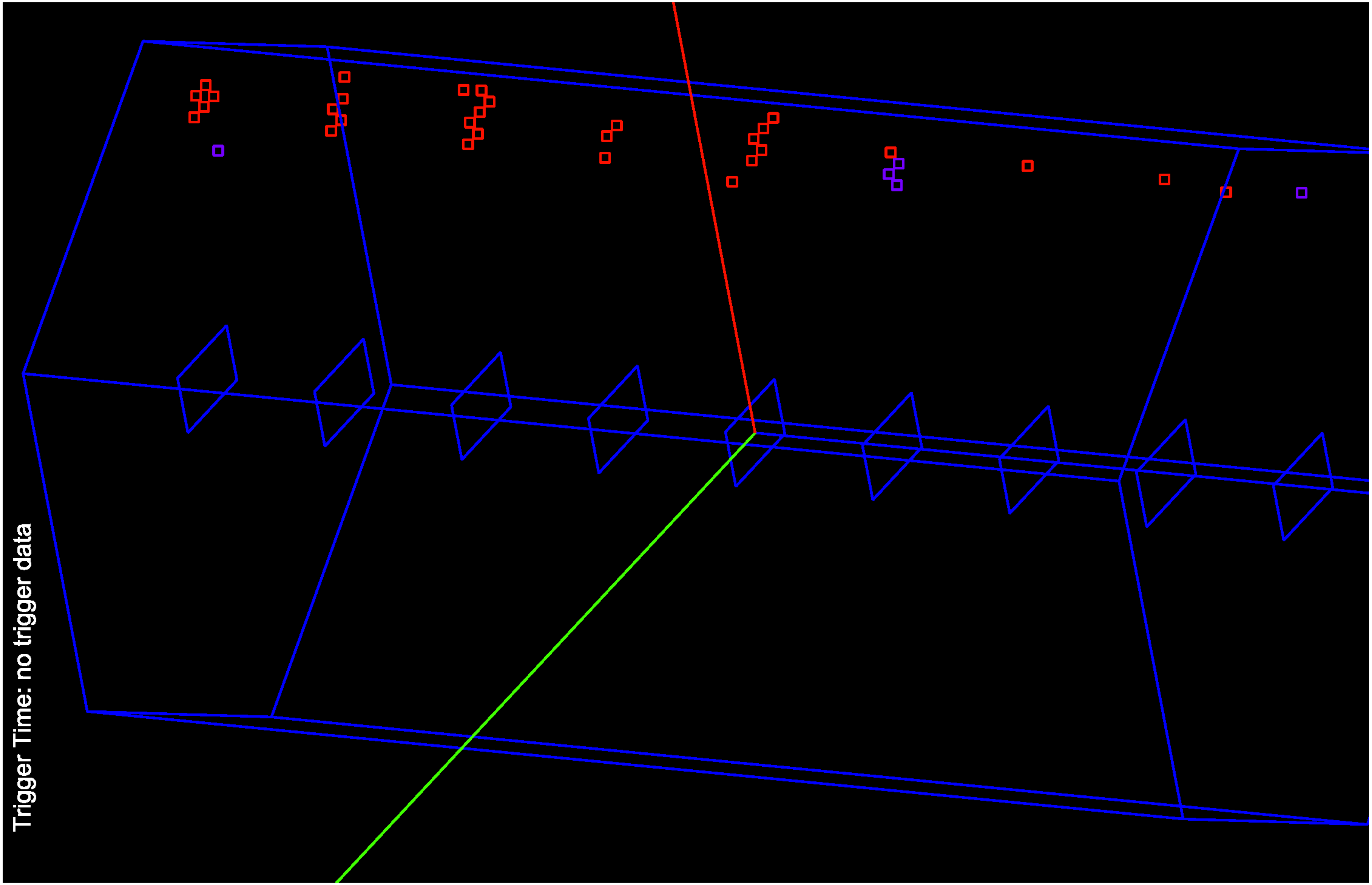
another one-electron event

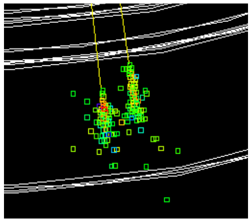




another one-electron event

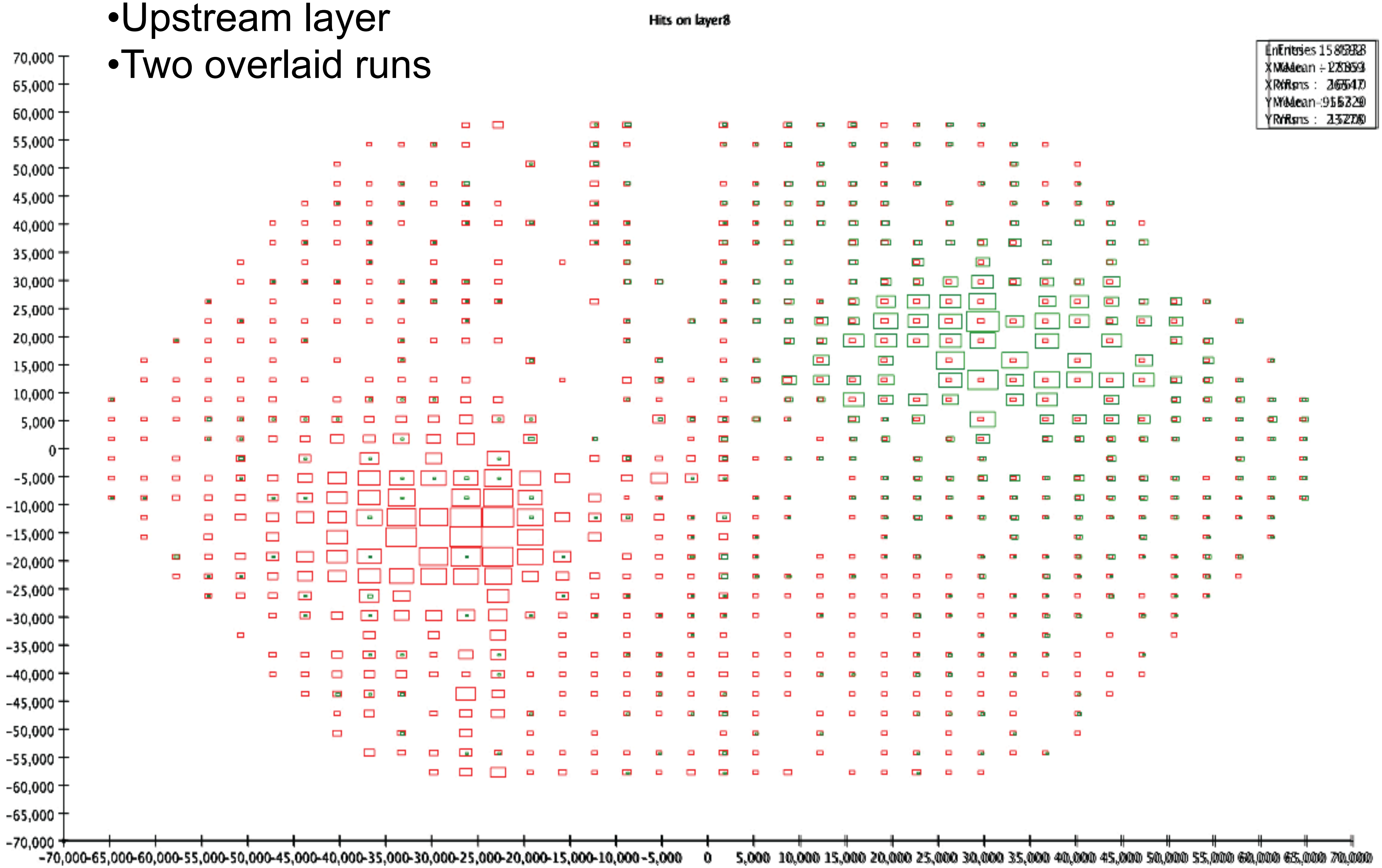


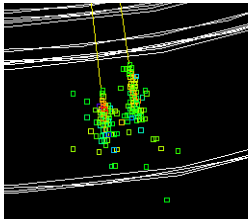




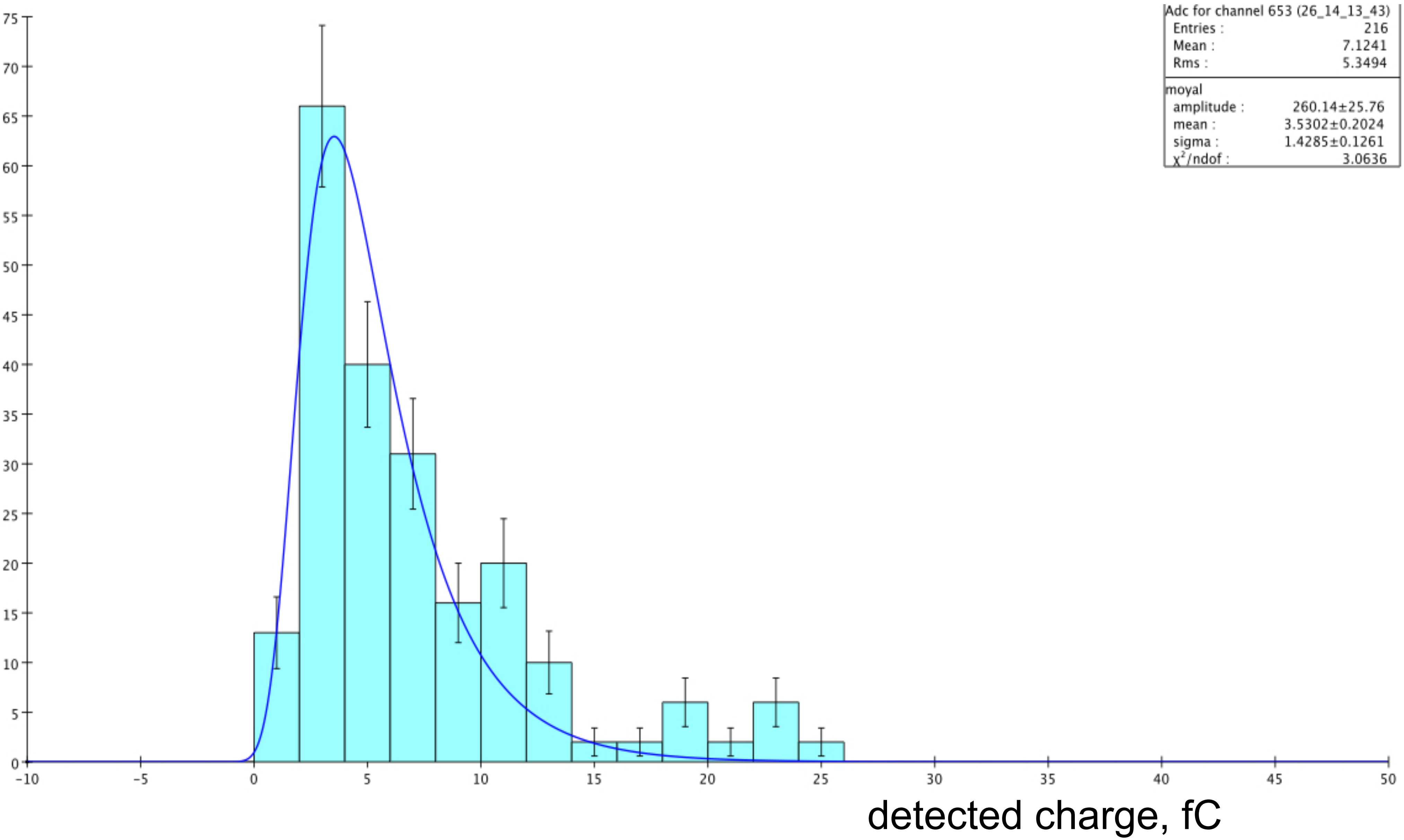
beam size

- Upstream layer
- Two overlaid runs

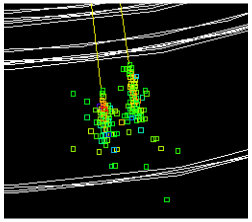


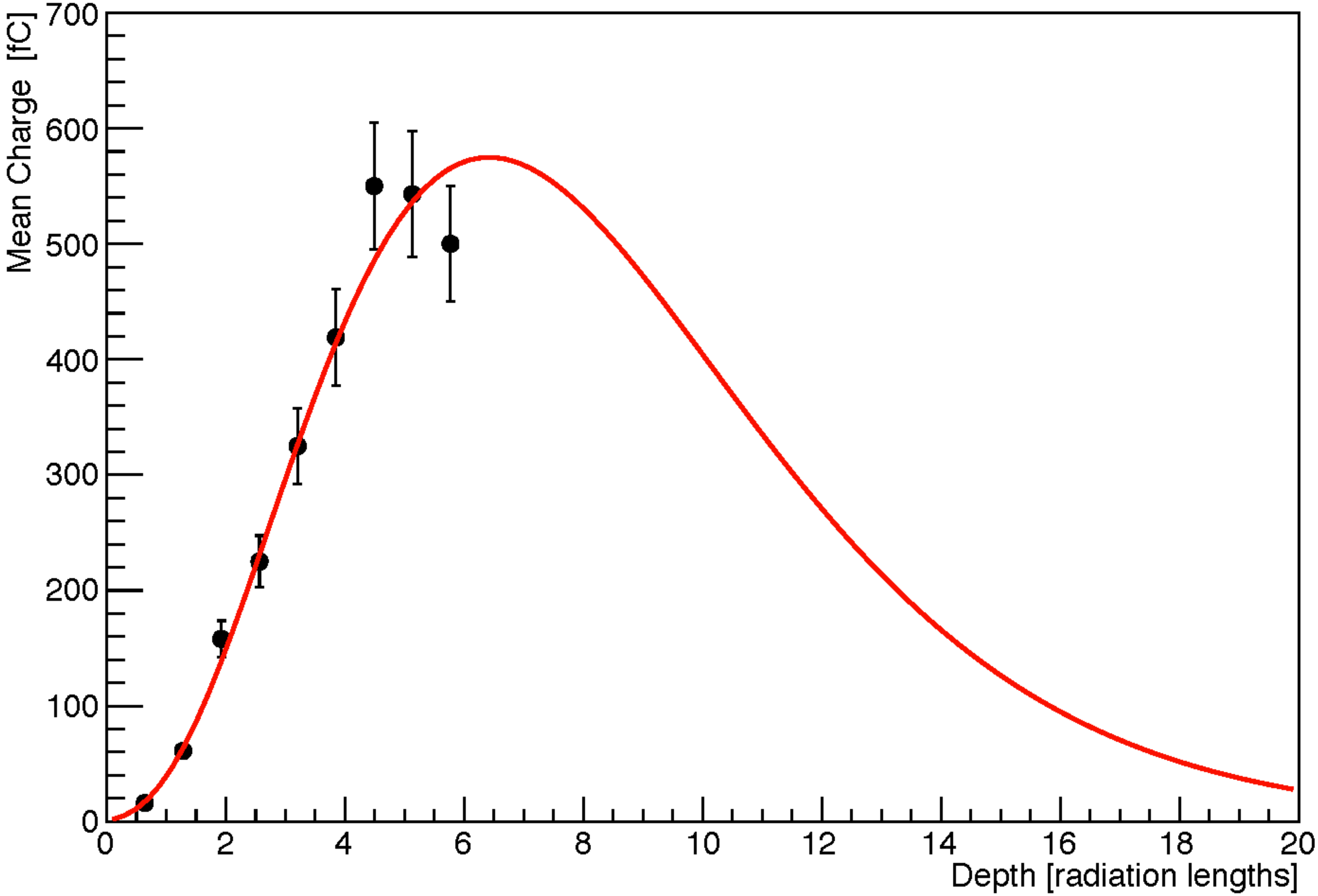


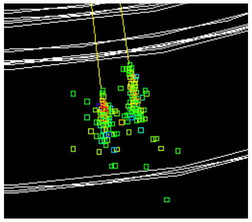
Upstream layer - MIPs



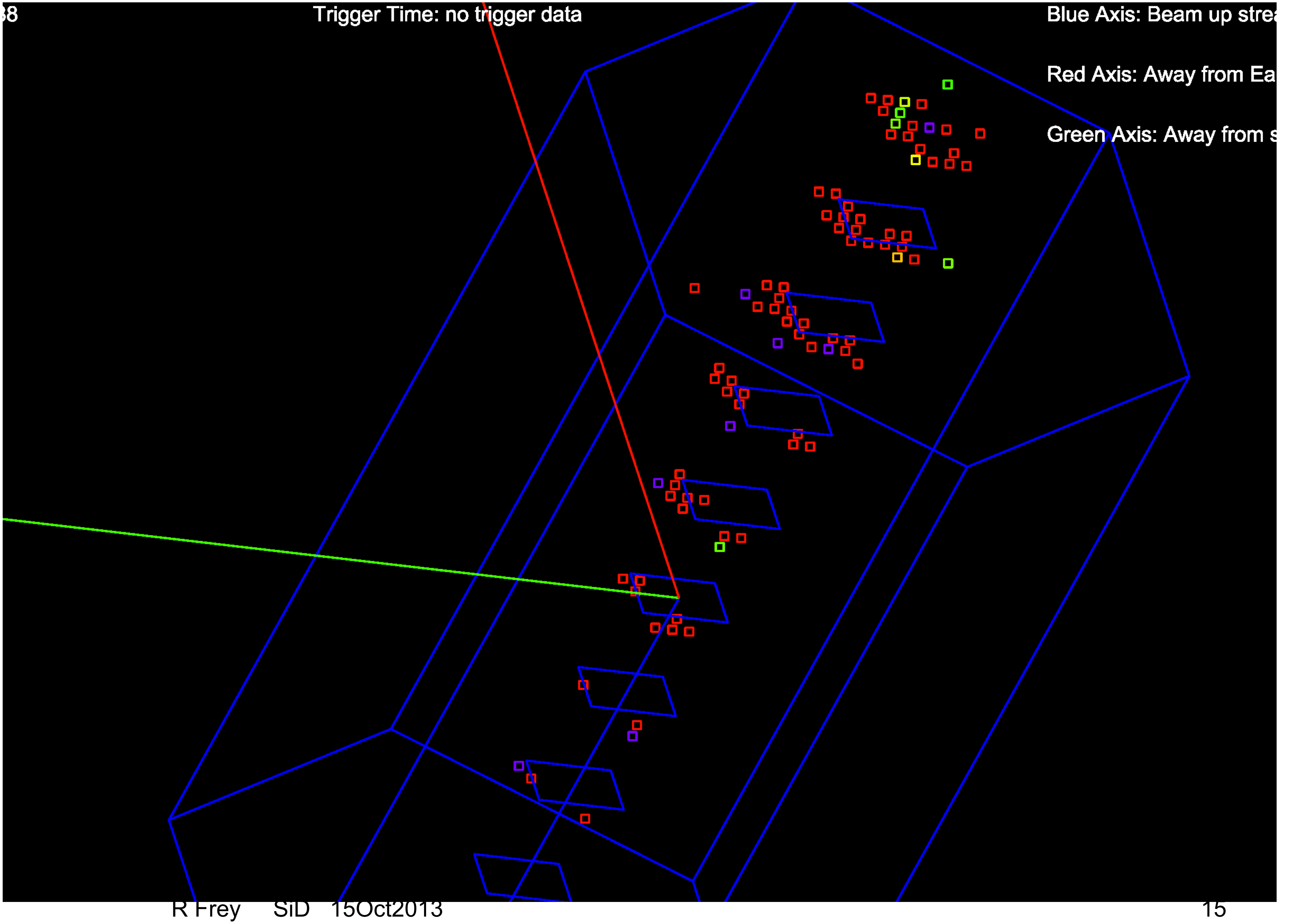
profile in depth

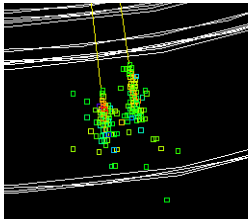




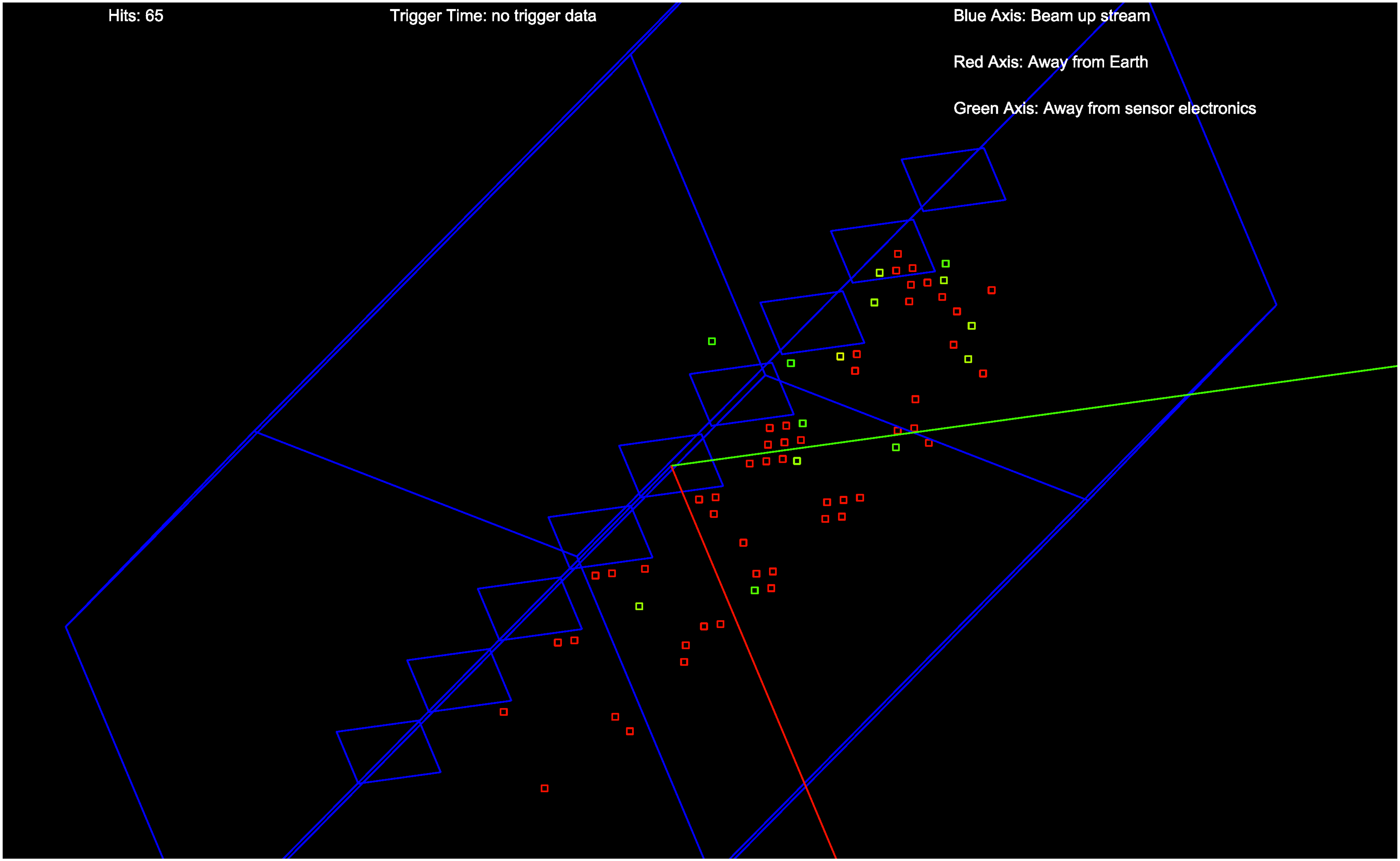


2 electrons

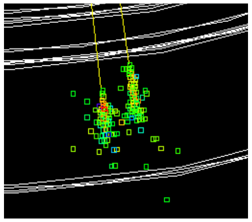

Trigger Time: no trigger data
Blue Axis: Beam up strea
Red Axis: Away from Ea
Green Axis: Away from s

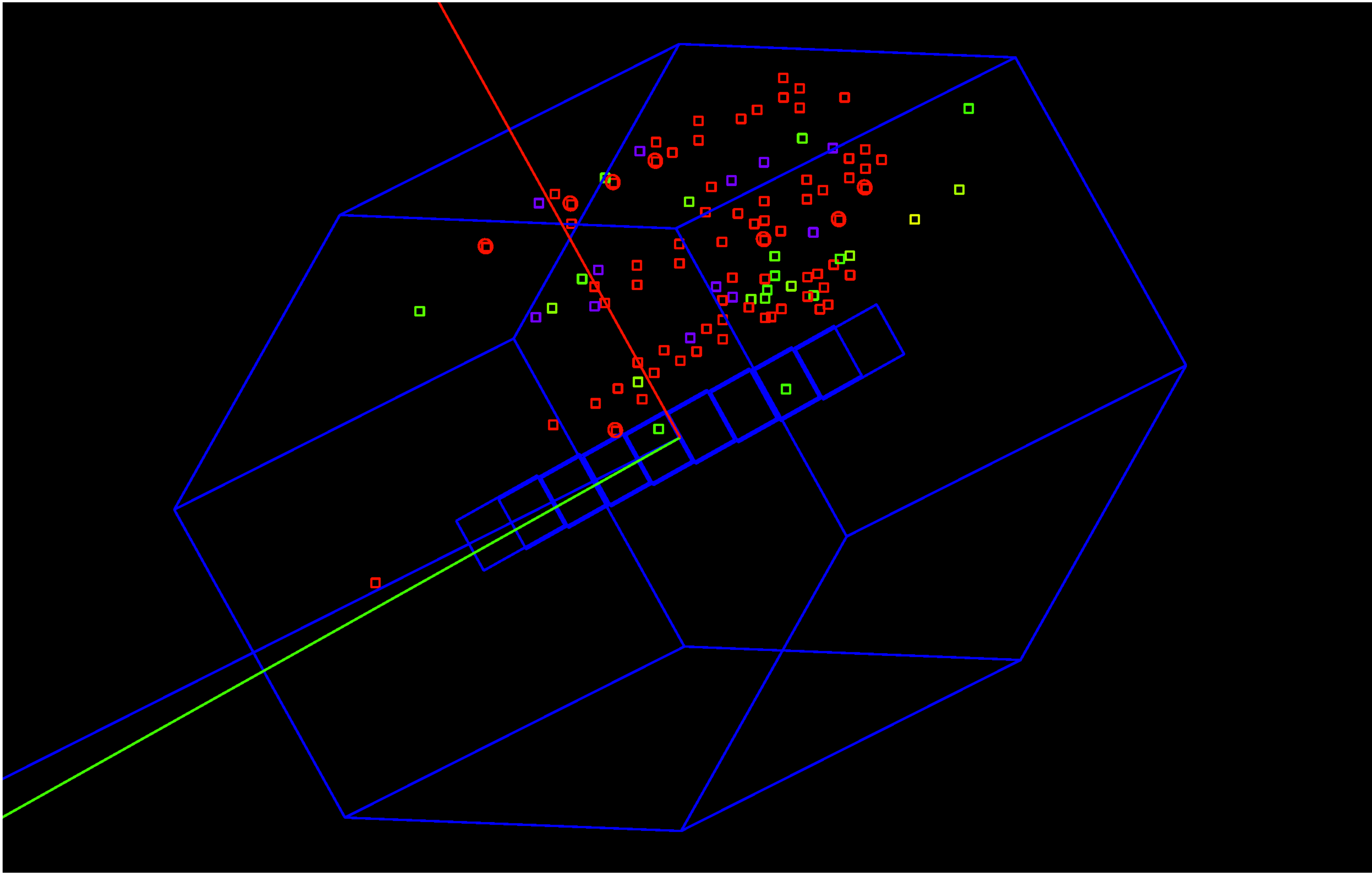


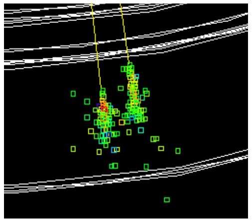
2 electrons


Hits: 65
Trigger Time: no trigger data
Blue Axis: Beam up stream
Red Axis: Away from Earth
Green Axis: Away from sensor electronics

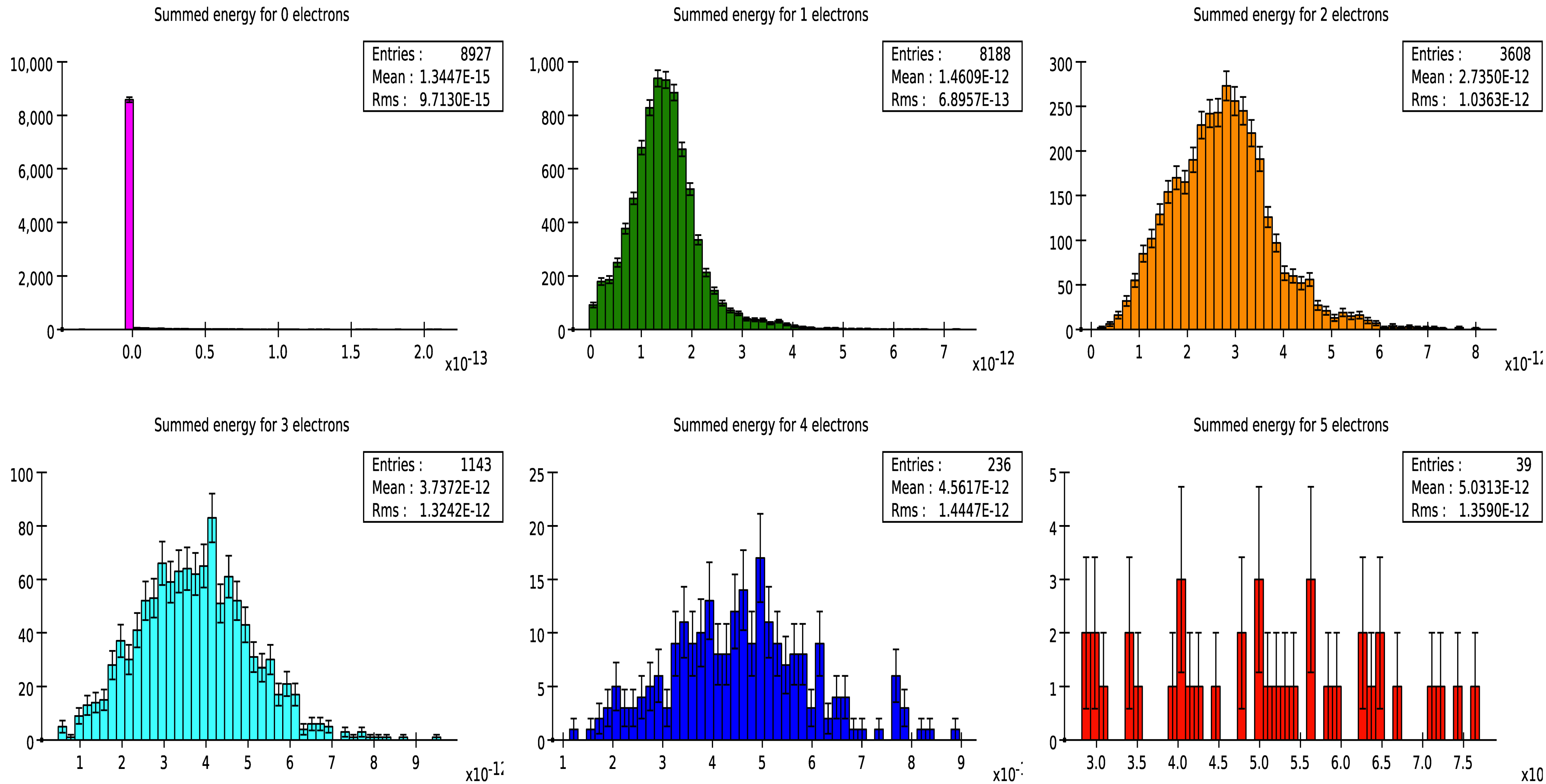
three electrons

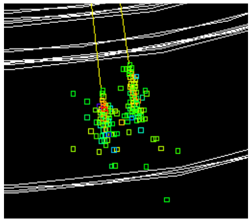




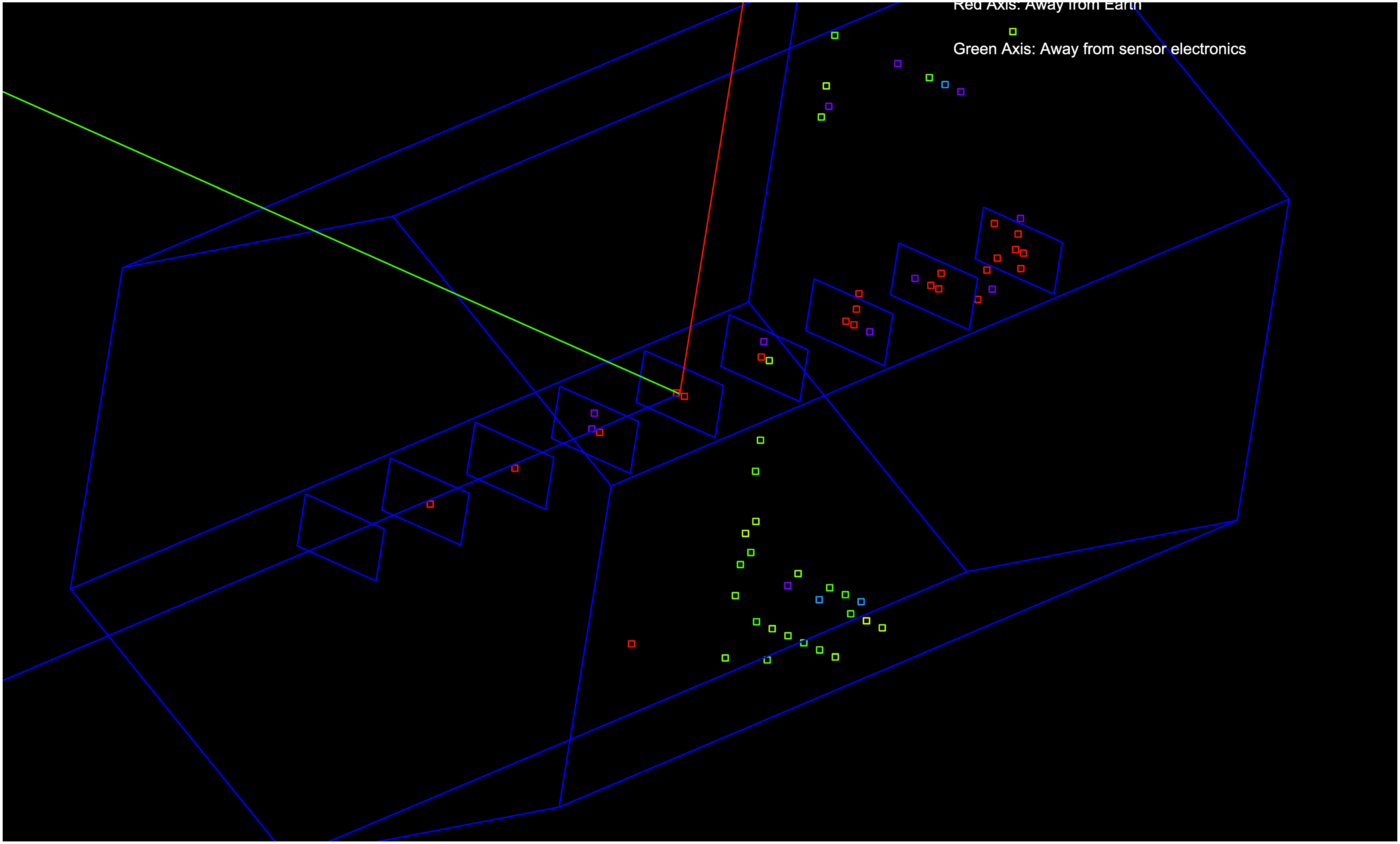


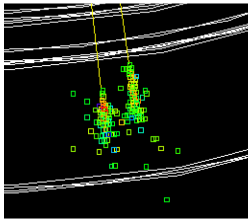
pattern recognition to separate electrons -- 1st attempt



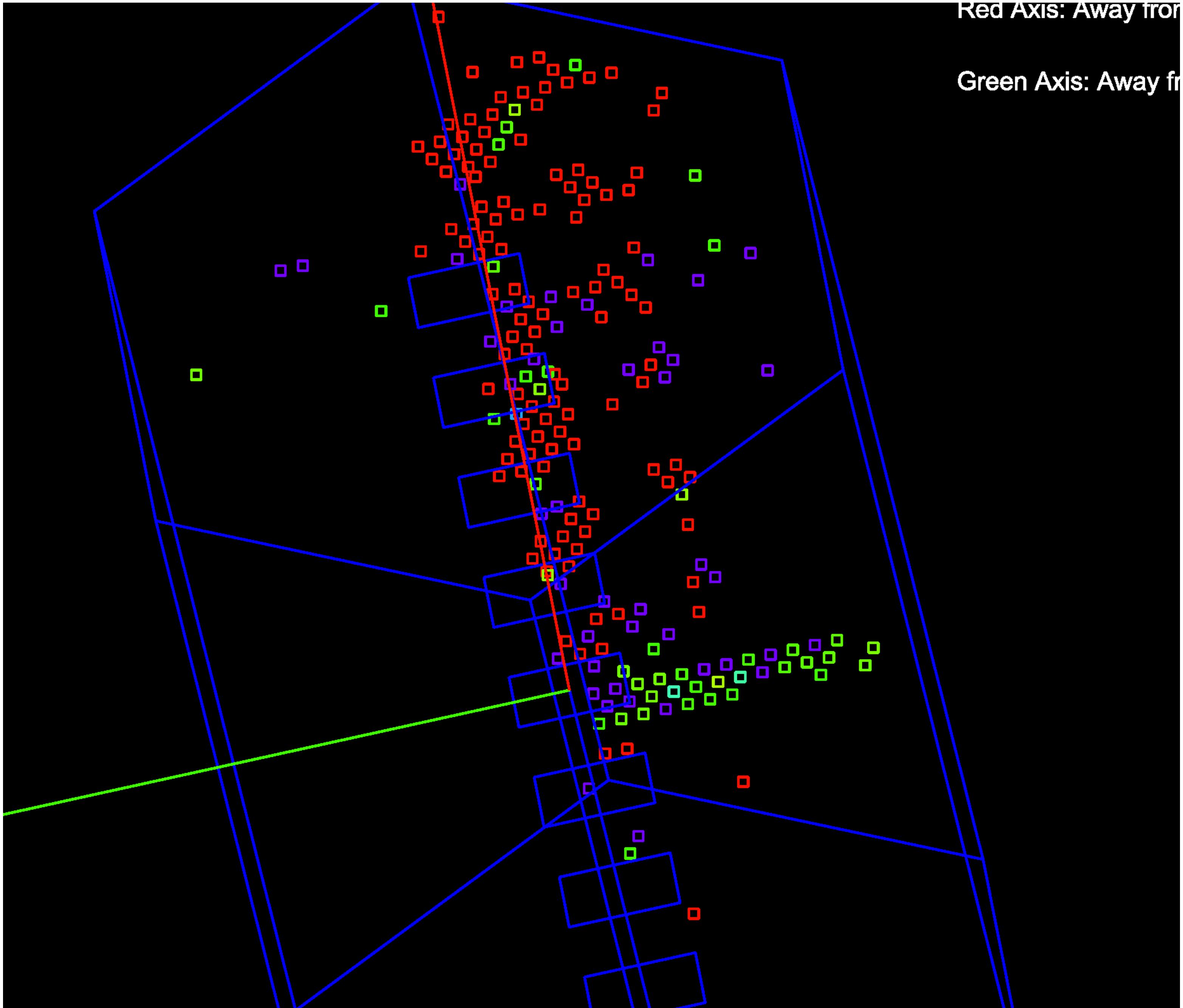


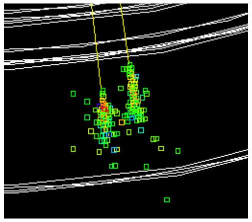
some events with non-physical negative-amplitude hits



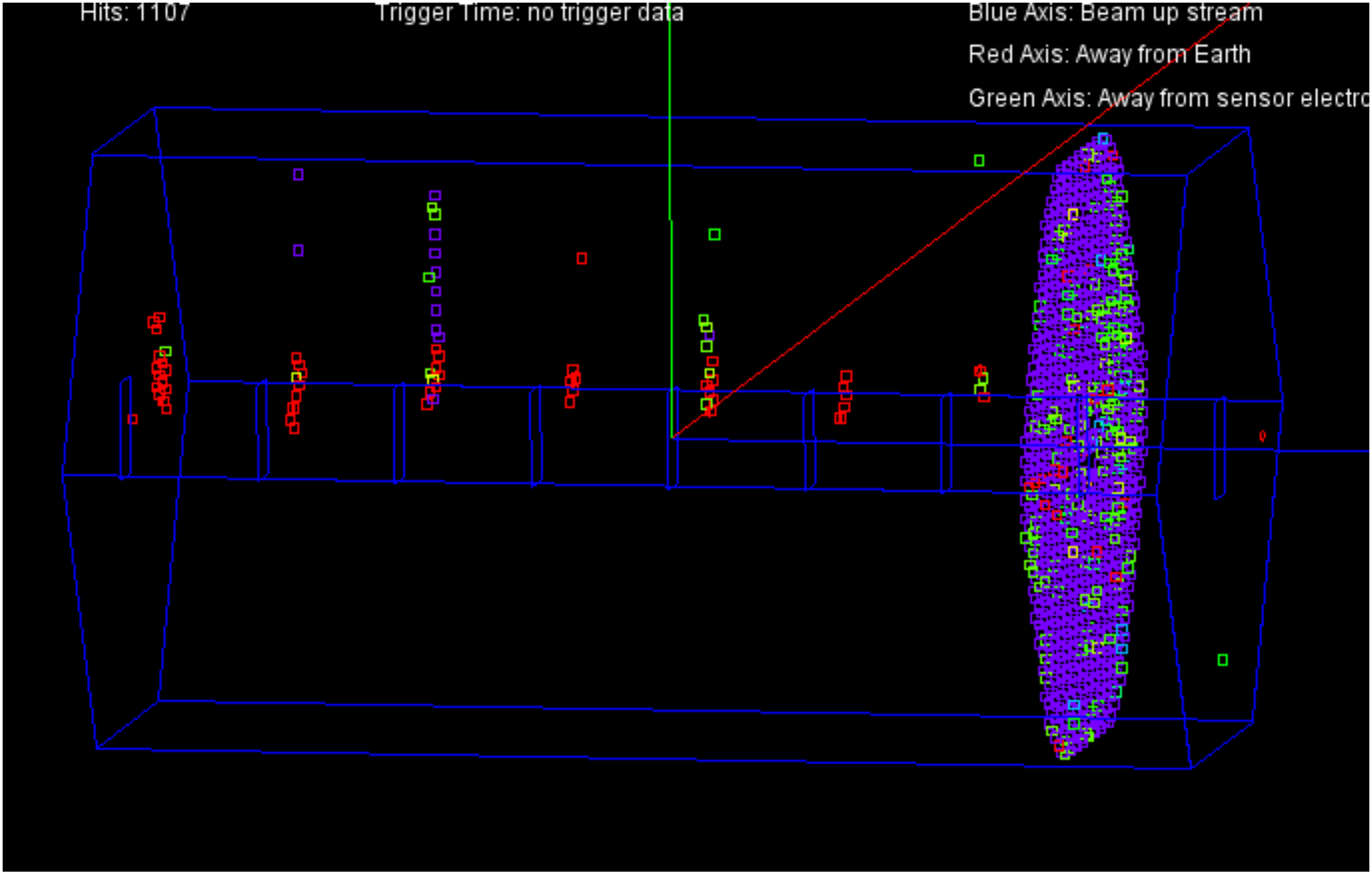


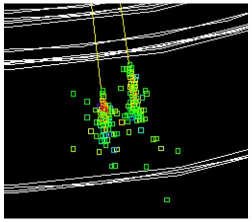
more non-physical hits



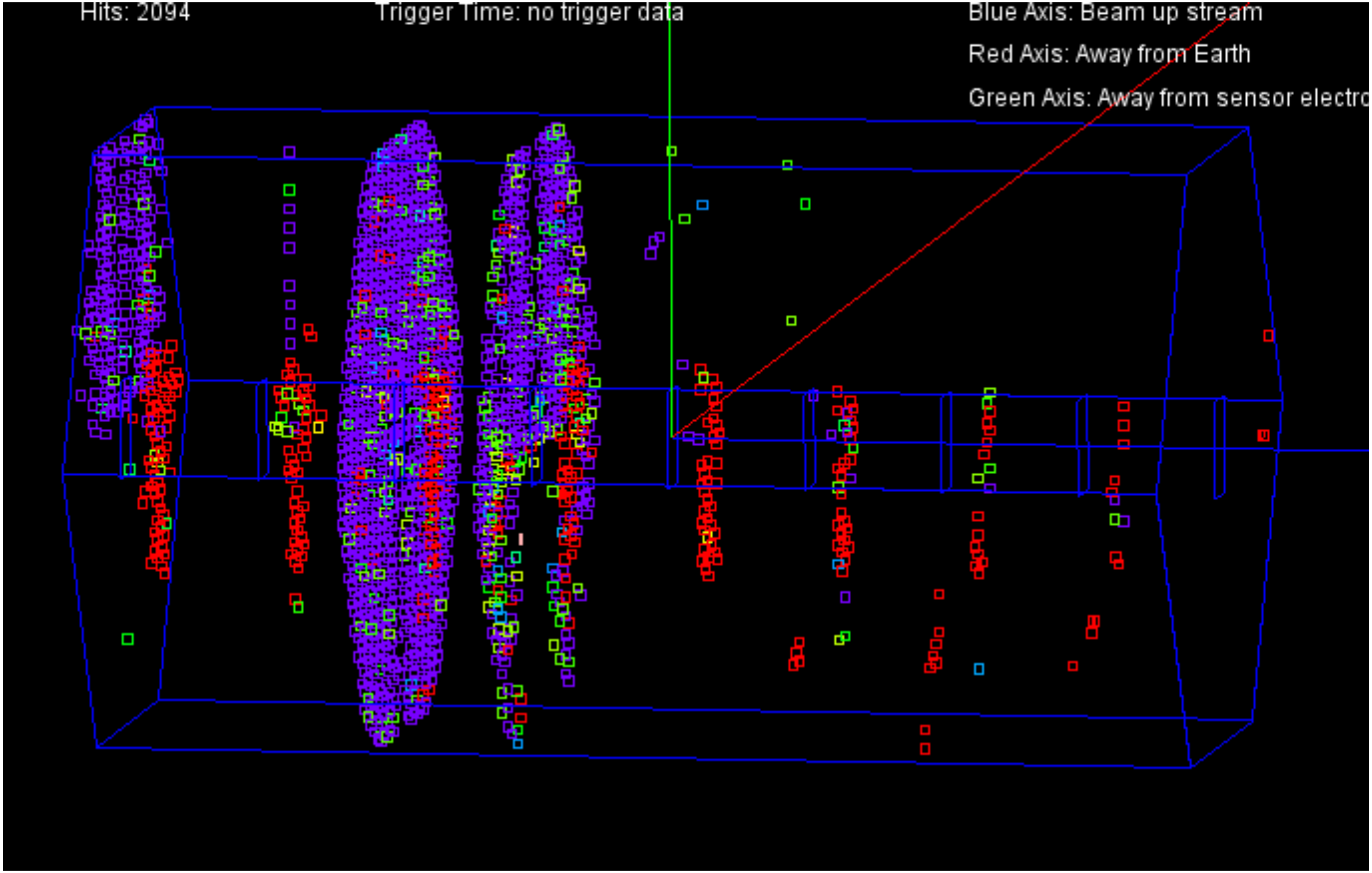


"monster events" with many negative amplitude and out of time hits



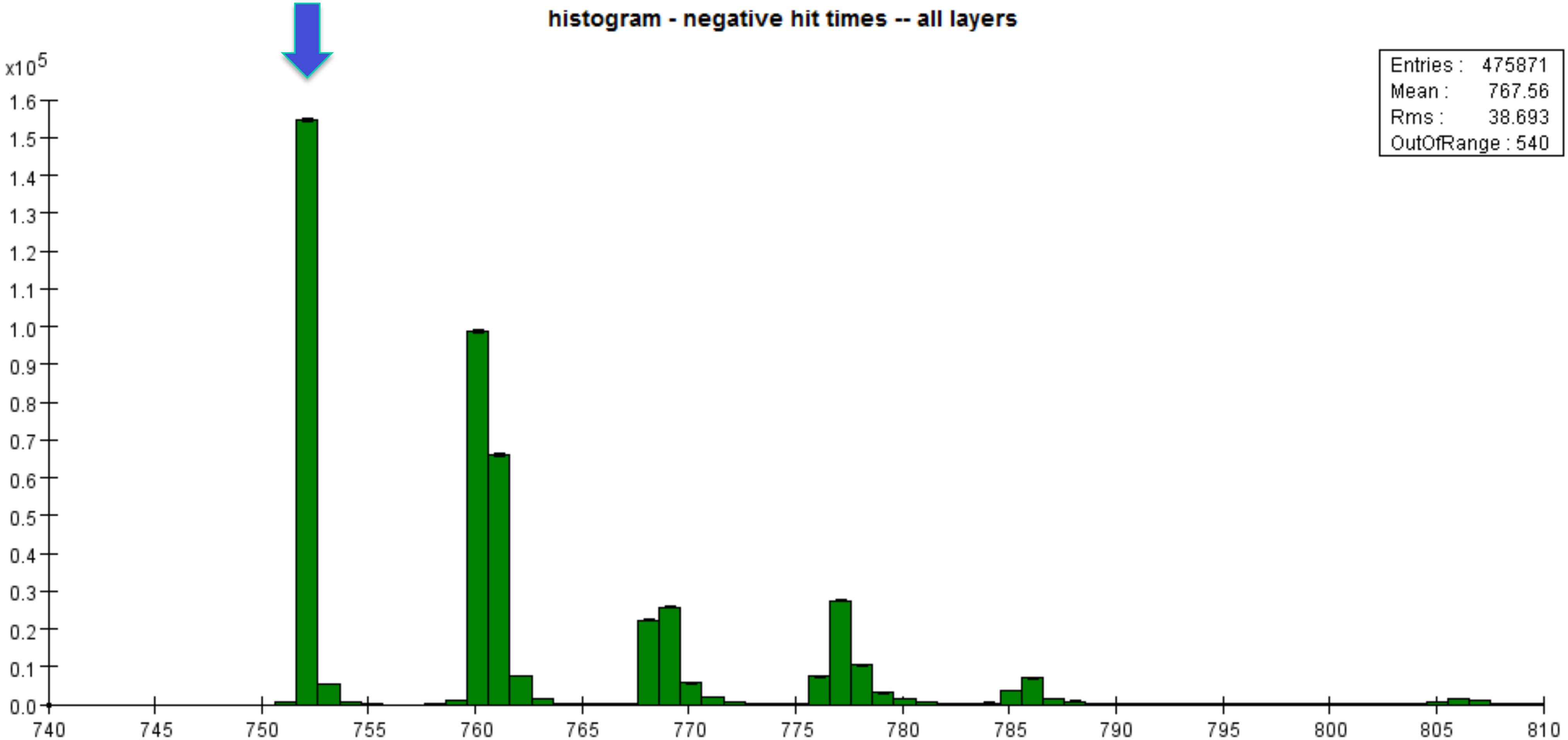


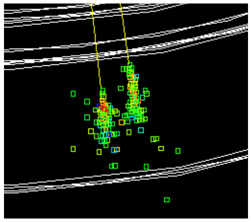
monster behavior increases with more hit pixels (multi-electrons)



times of negative-amplitude hits

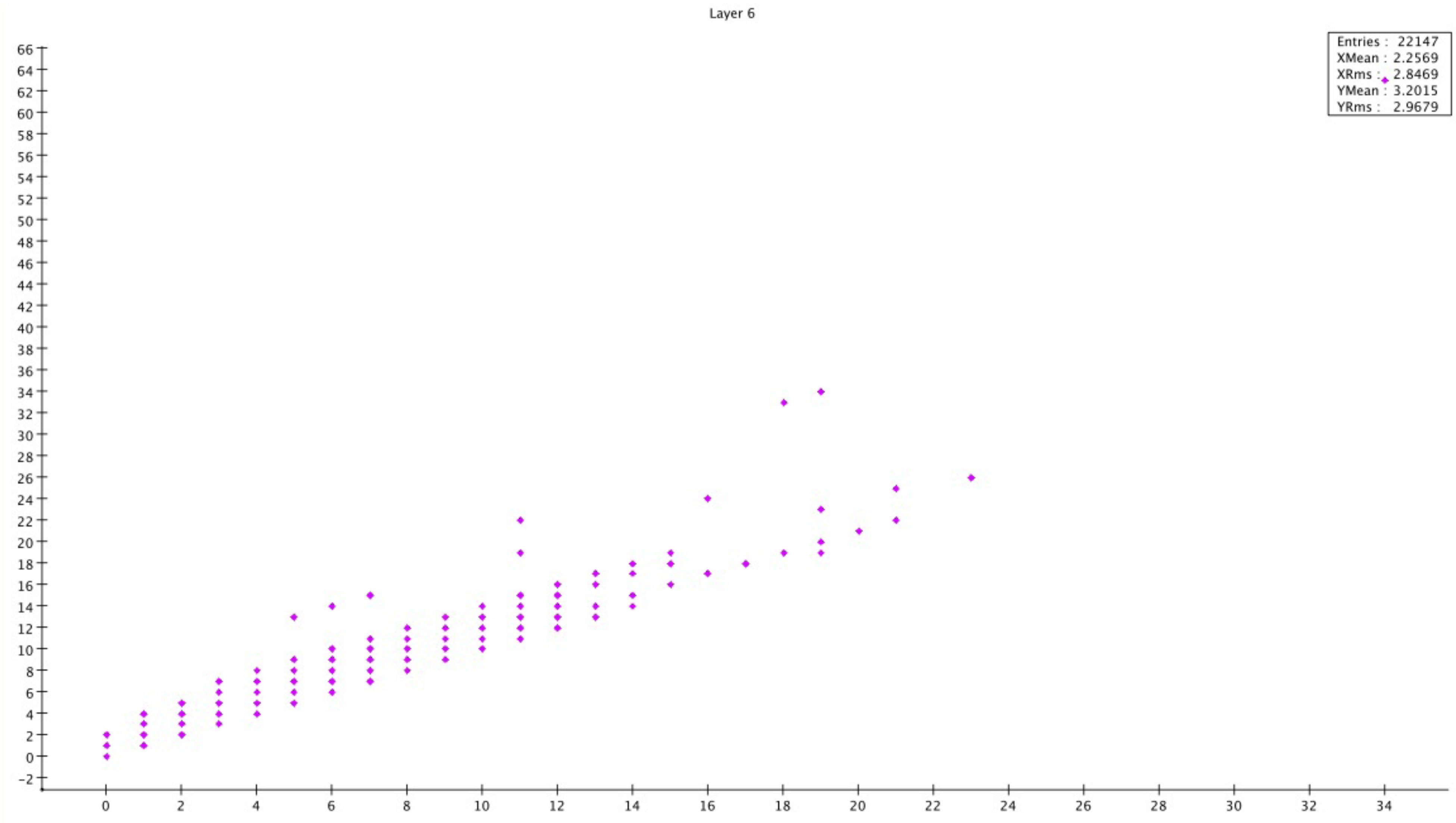
beam time

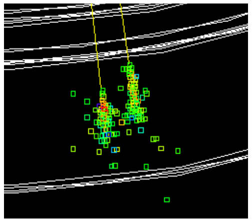




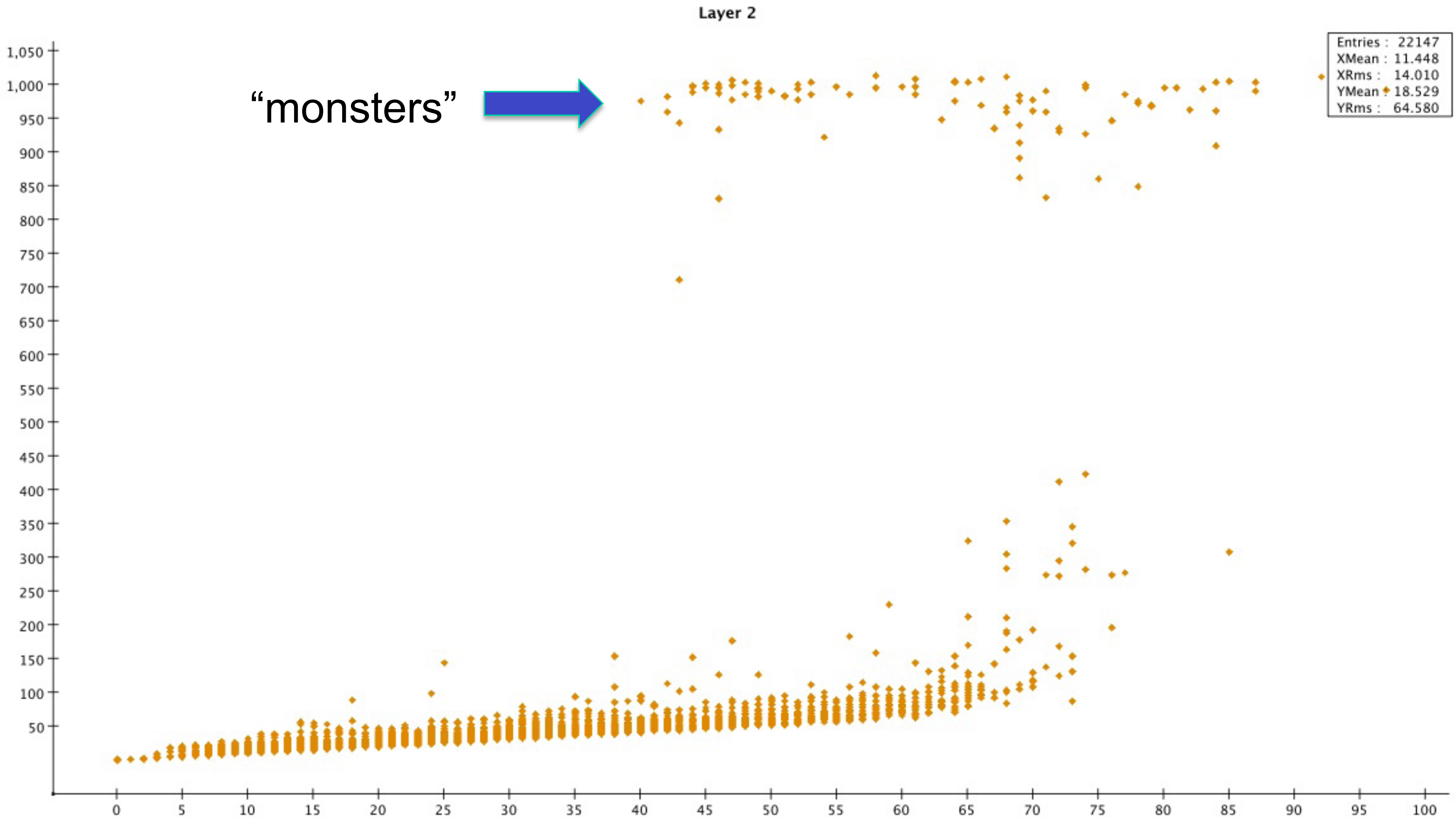
all hits vs in-time hits

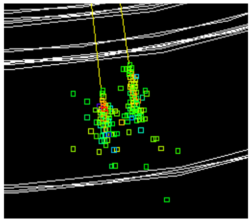
- Single electrons
- Layer 6



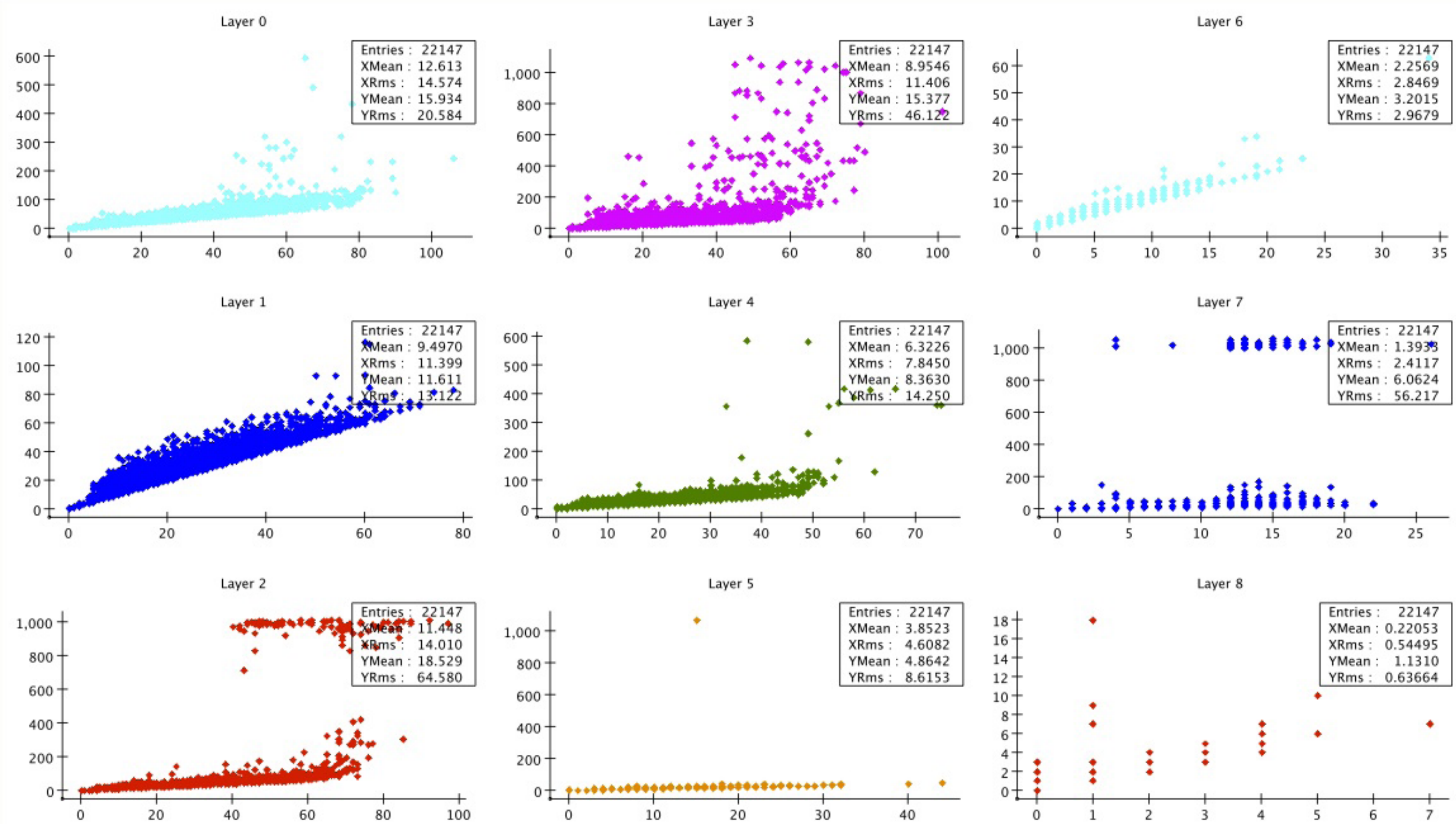


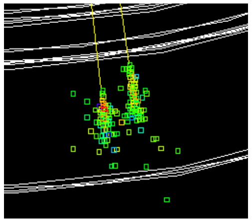
same for layer 2



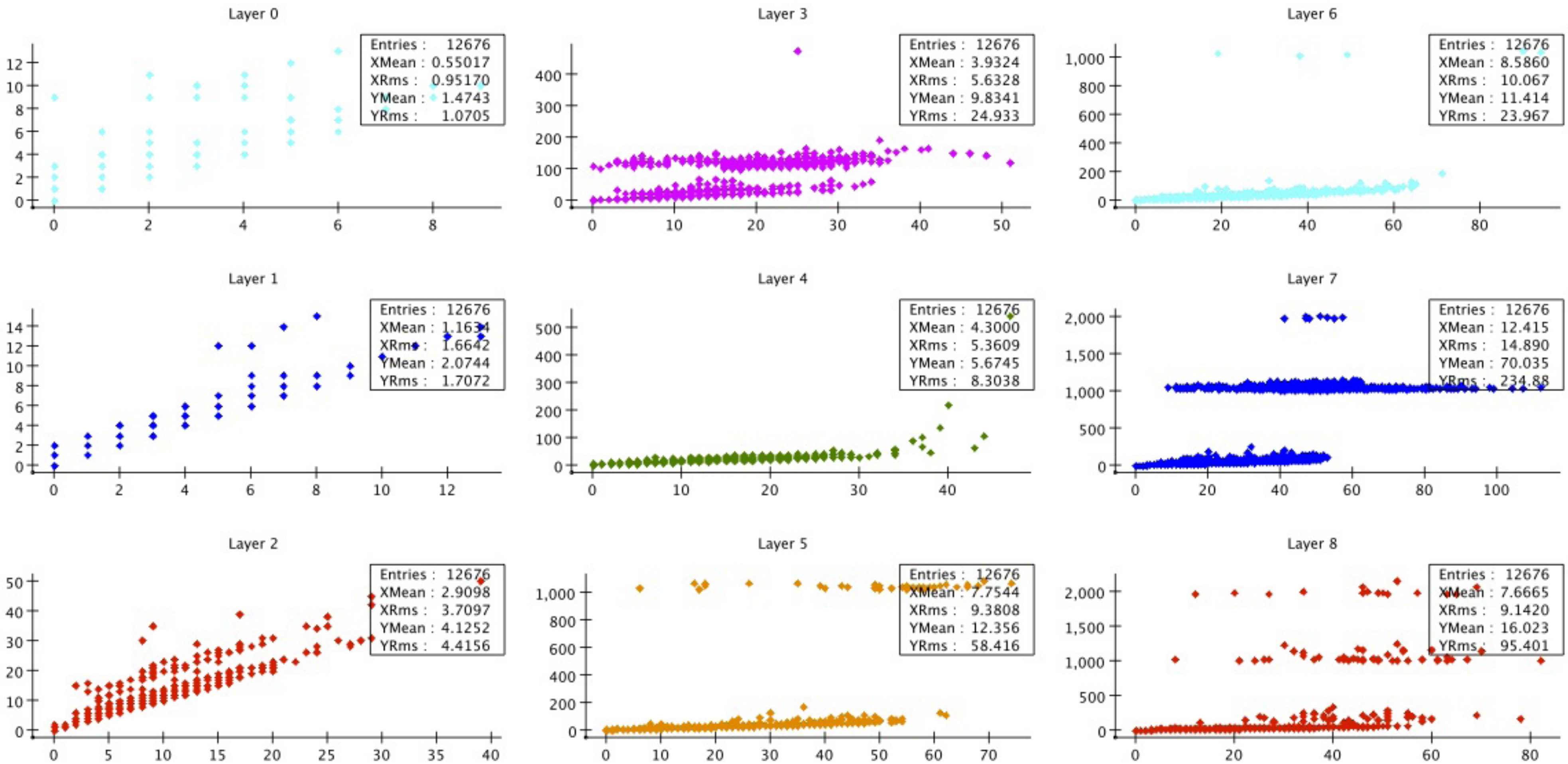


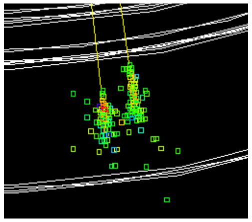
all layers – single electrons





Same, but for 5-electron run





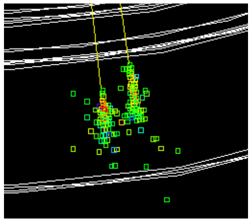
Summary

- Successful test beam run with partially outfitted prototype
- Excellent ESA test beam
- Silicon-tungsten calorimetry still works ;-)

- Uncovered some unexpected behavior
- Unphysical negative-amplitude hits – current hypotheses:
  - Small number of in-time hits: cross-talk in sensor and baseline shift of KPiX virtual ground
  - Many out of time hits for some layers when many hit pixels: associated with KPiX resets? cascading?

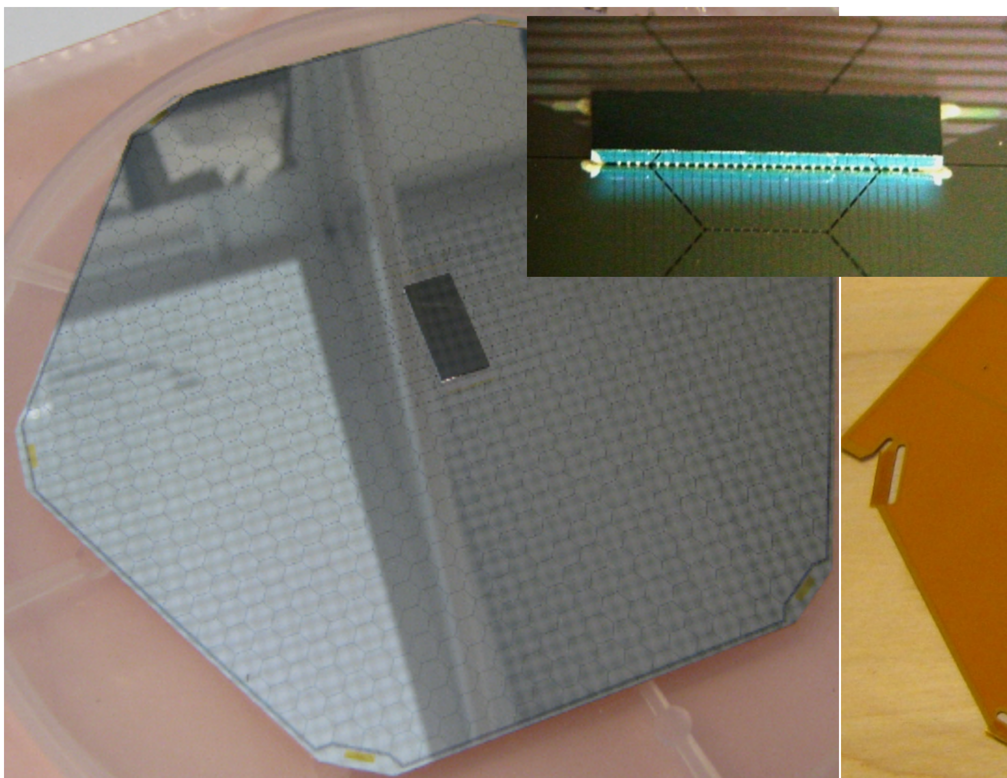
- Other questions about thresholds and A/D range (Ryan's talk)

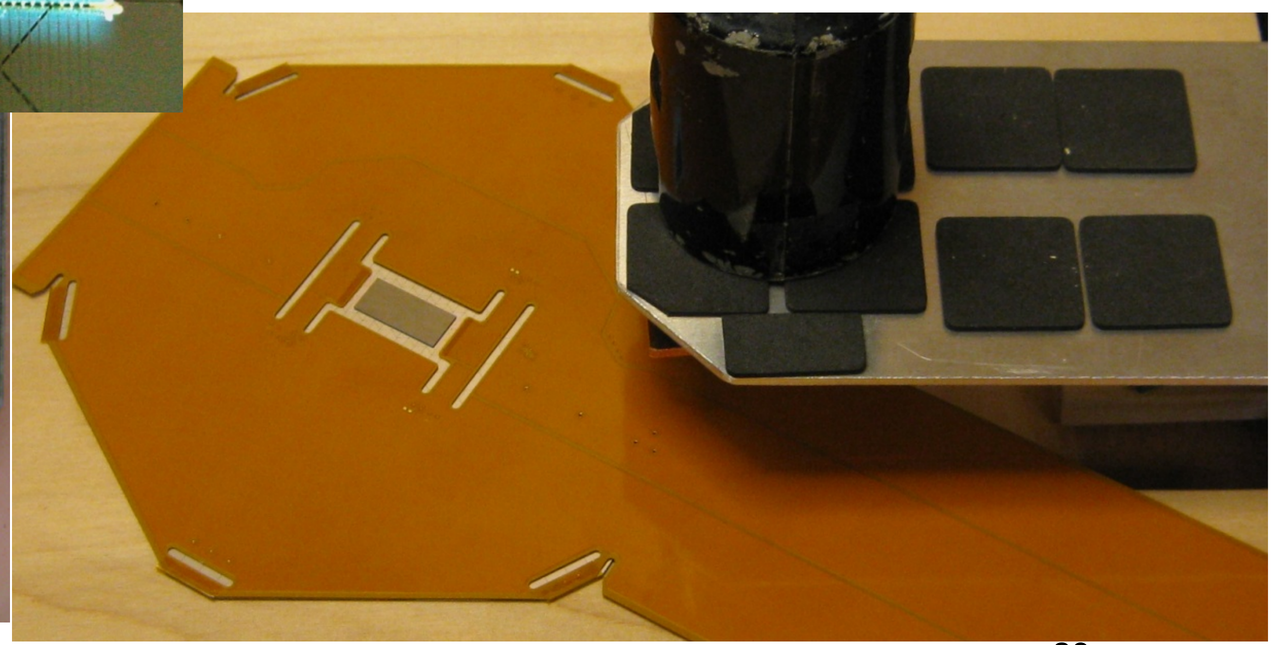
- Work in progress…



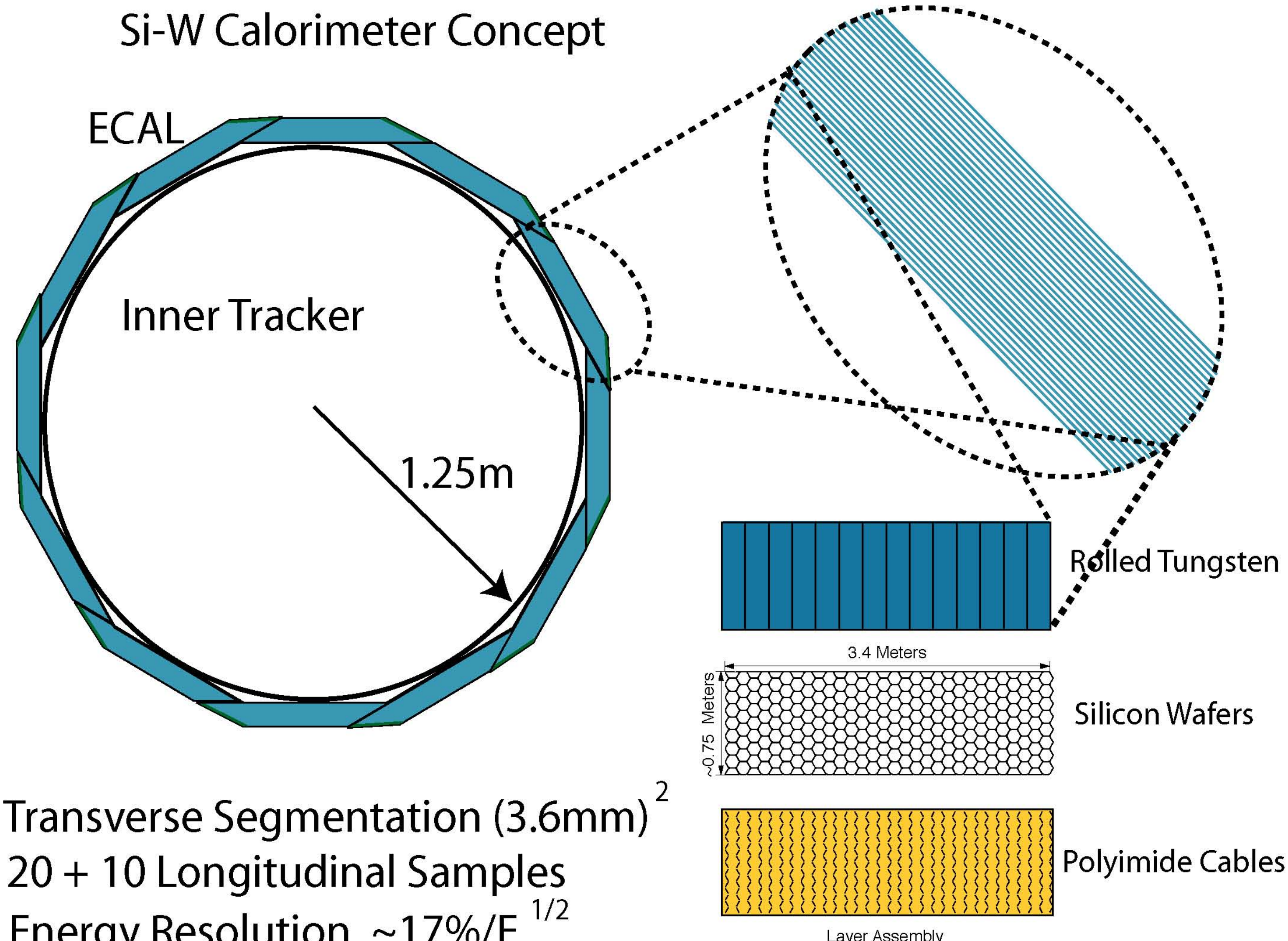
The R&D program

- Physics: A highly-segmented *imaging* ECal with small Moliere radius which can image MIPs to 500 GeV EM showers without melting
- The key element: a highly integrated electronic readout
  - ~1024 pixel sensors readout and digitized by single chip (KPiX) with power pulsing which is bump-bonded to the sensor
- The R&D provides the required baseline ECal components (except large-scale mechanics) – now nearly completed





Si/W imaging ECal for SiD

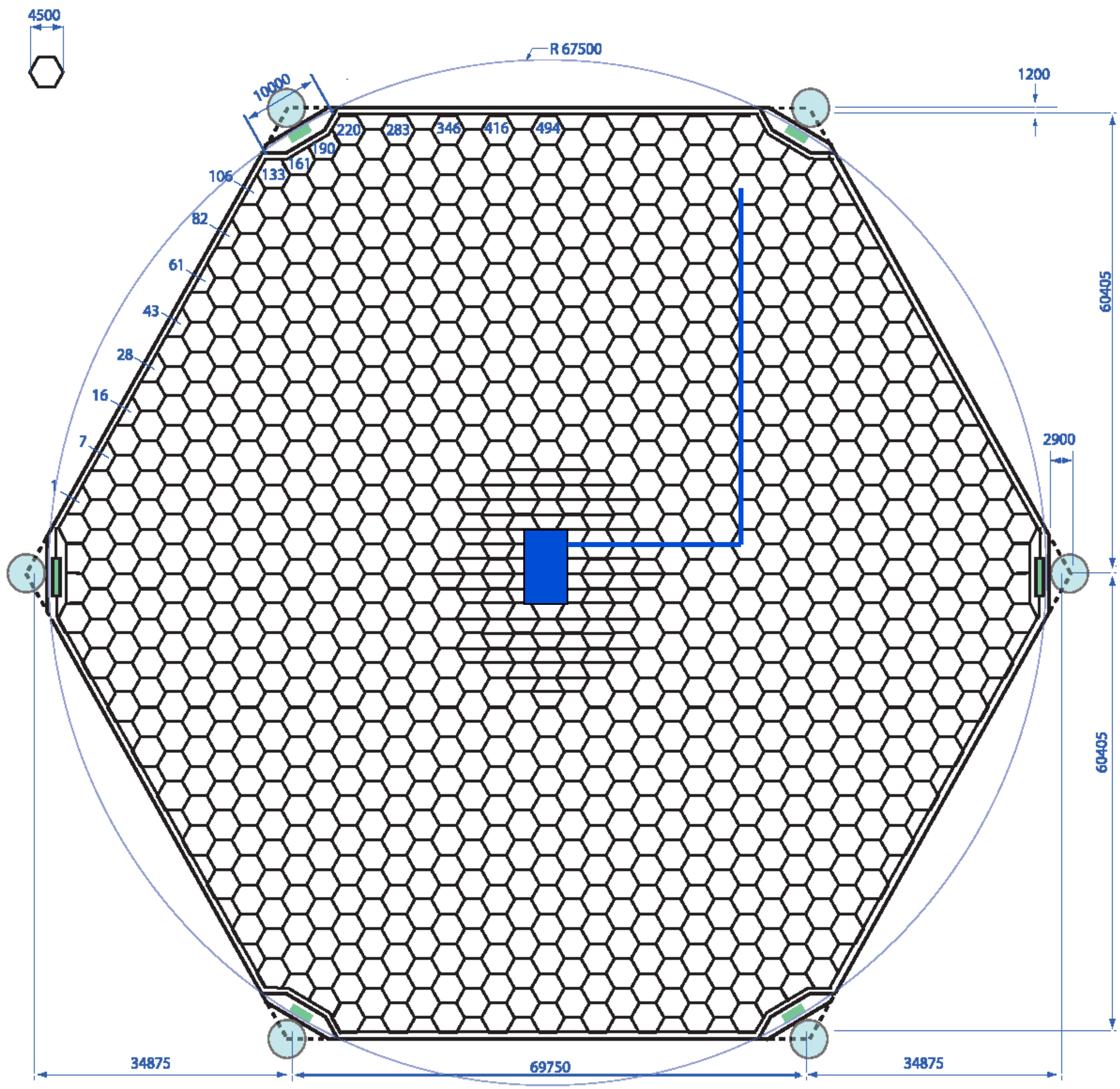


Transverse Segmentation $(3.6\text{mm})^2$
20 + 10 Longitudinal Samples
Energy Resolution ~$17\%/E^{1/2}$

Baseline configuration:

- transverse seg.: 13 mm^2 pixels
- longitudinal: $(20 \times 5/7\ X_0) + (10 \times 10/7\ X_0) \Rightarrow$ 17%/sqrt(E)
- 1 mm readout gaps ⇒ 13 mm effective Moliere radius

Si sensors



- 6 inch wafers
- 1024 13 mm^2 pixels
- KPiX readout is bump-bonded directly to sensor

KPiX ASIC and sample trace

goals of the R&D

Design a practical ECal which (1) meets (or exceeds) the LC physics requirements (2) with a technology that would actually work at a LC…

- Physics: A highly-segmented *imaging* Si-W ECal: Very collimated EM showers and MIP tracking; only modest EM energy resolution OK
- The key to making this practical is a highly integrated electronic readout
  - 1024 pixels and 1024-channel readout chip (KPiX) with power pulsing
- Readily segmented silicon: 13 mm^2 is current default
- Interconnects give small readout gap (1 mm): ⇒13 mm eff. Moliere radius
  - Bump-bond KPiX directly to Si sensor
  - Flex cables to outside