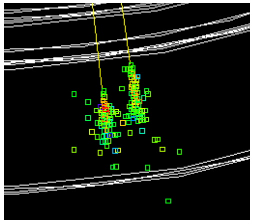
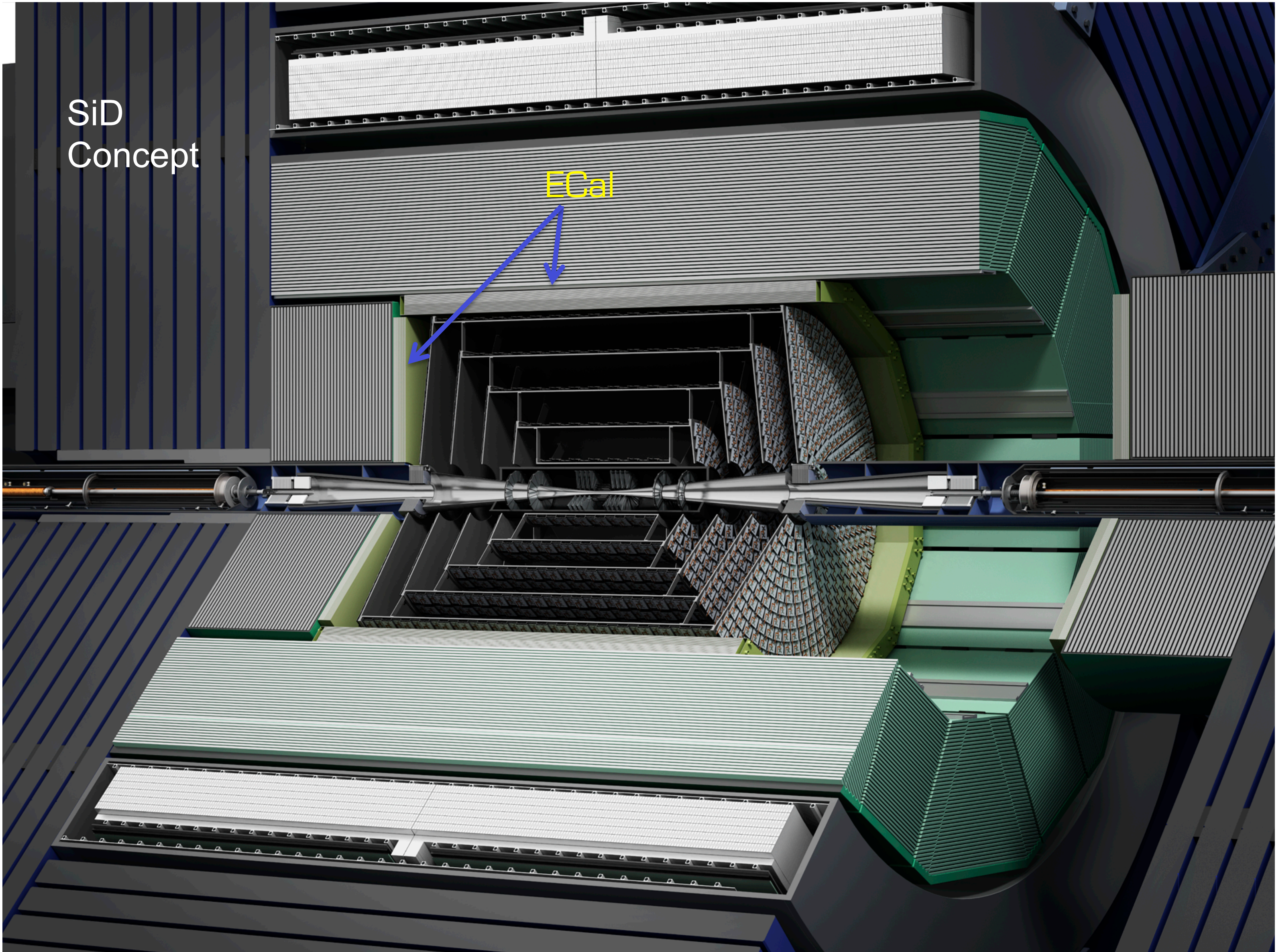


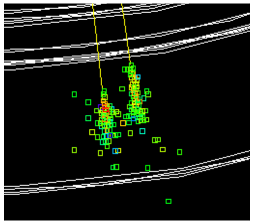
Collaboration

M. Breidenbach, D. Freytag, N. Graf, G. Haller, R. Herbst,
J. Jaros, T. Johnson, D. Onoprienko, M. Oriunno,
B. Reese, J. Russell, K. Skarpaas, C. Sund
SLAC National Accelerator Center

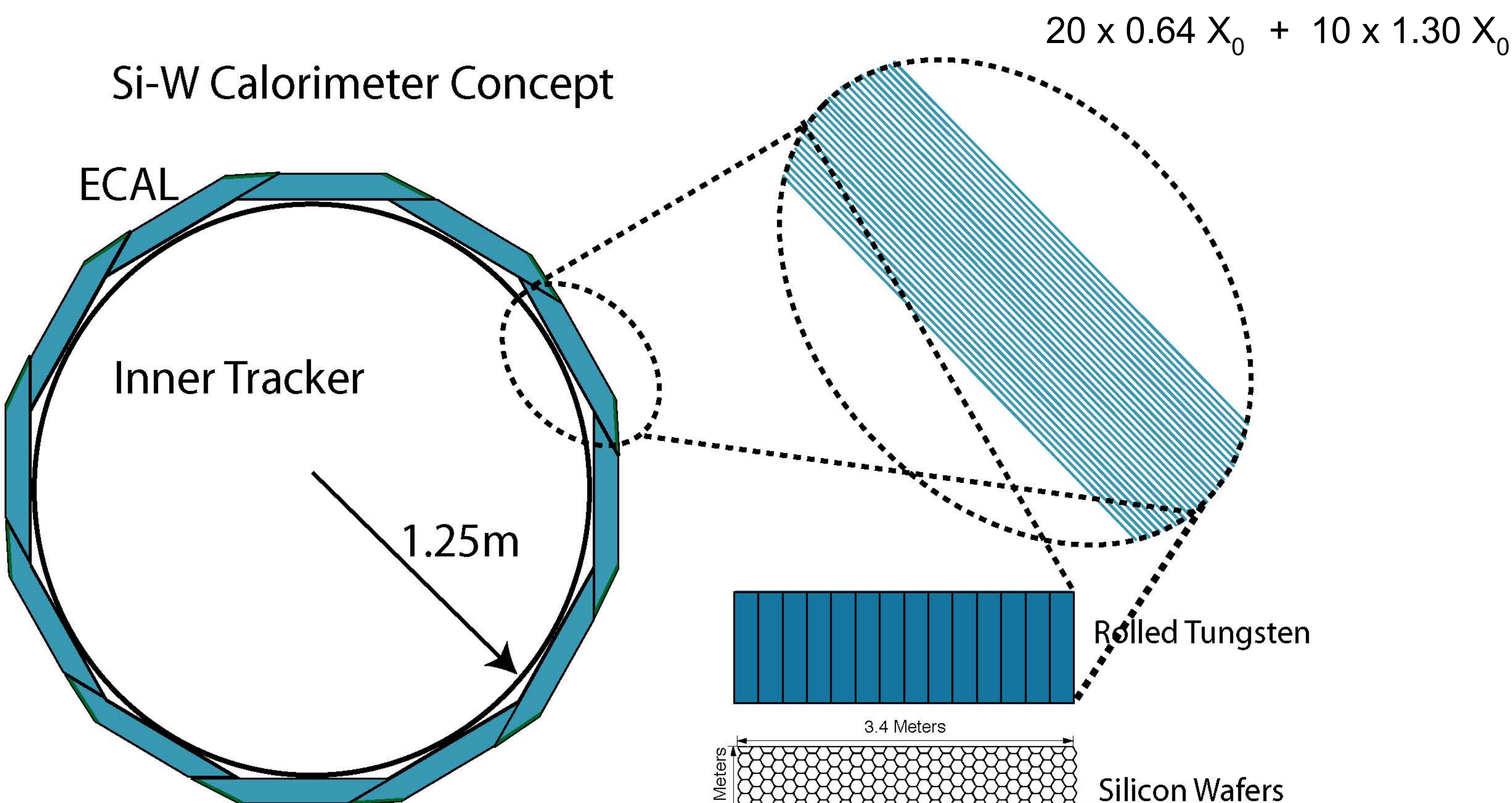
J. Brau, R. Frey, C. Gallagher, D. Strom,
W. McCann, D. Mead (grad students),
K. Travis (undergraduate)
U. Oregon

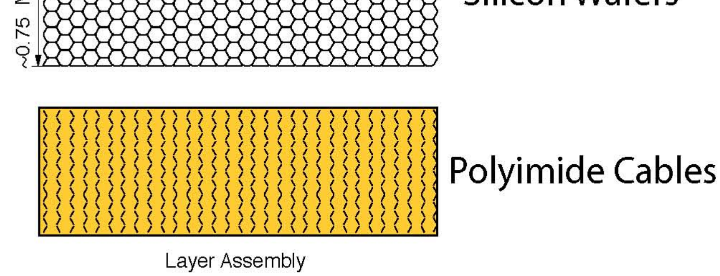
B. Holbrook, C. Neher, M. Tripathi, students
UC Davis


SiD
Concept
ECal



Schematic of EM Cal for SiD

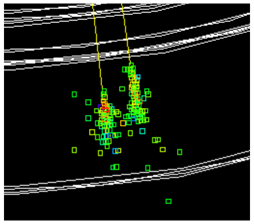




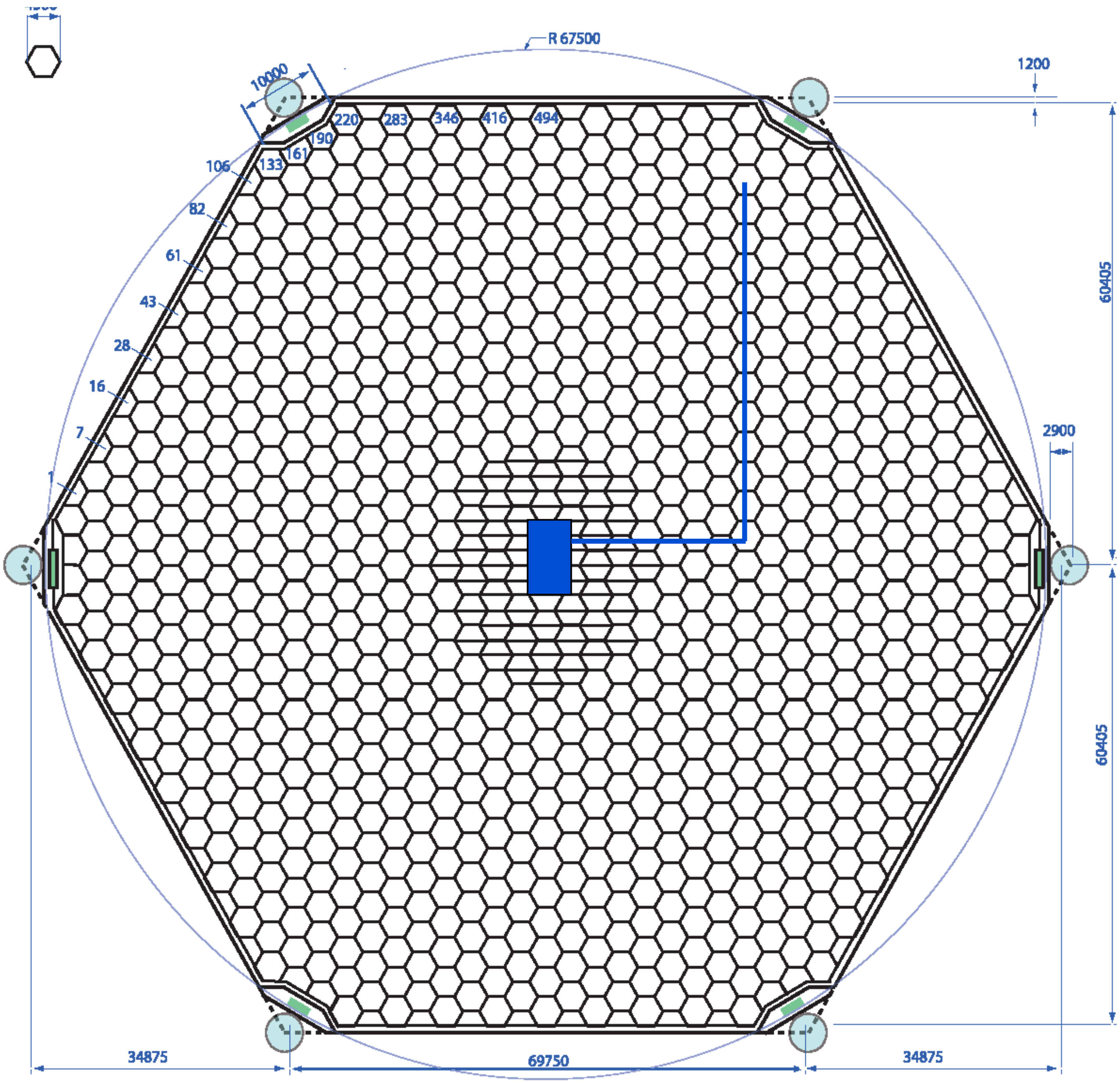
Transverse Segmentation $(3.6\text{mm})^2$

20 + 10 Longitudinal Samples

Energy Resolution $\sim 17\%/E^{1/2}$

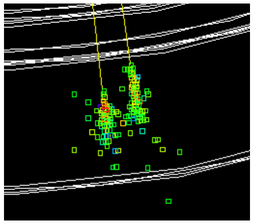


Si sensors

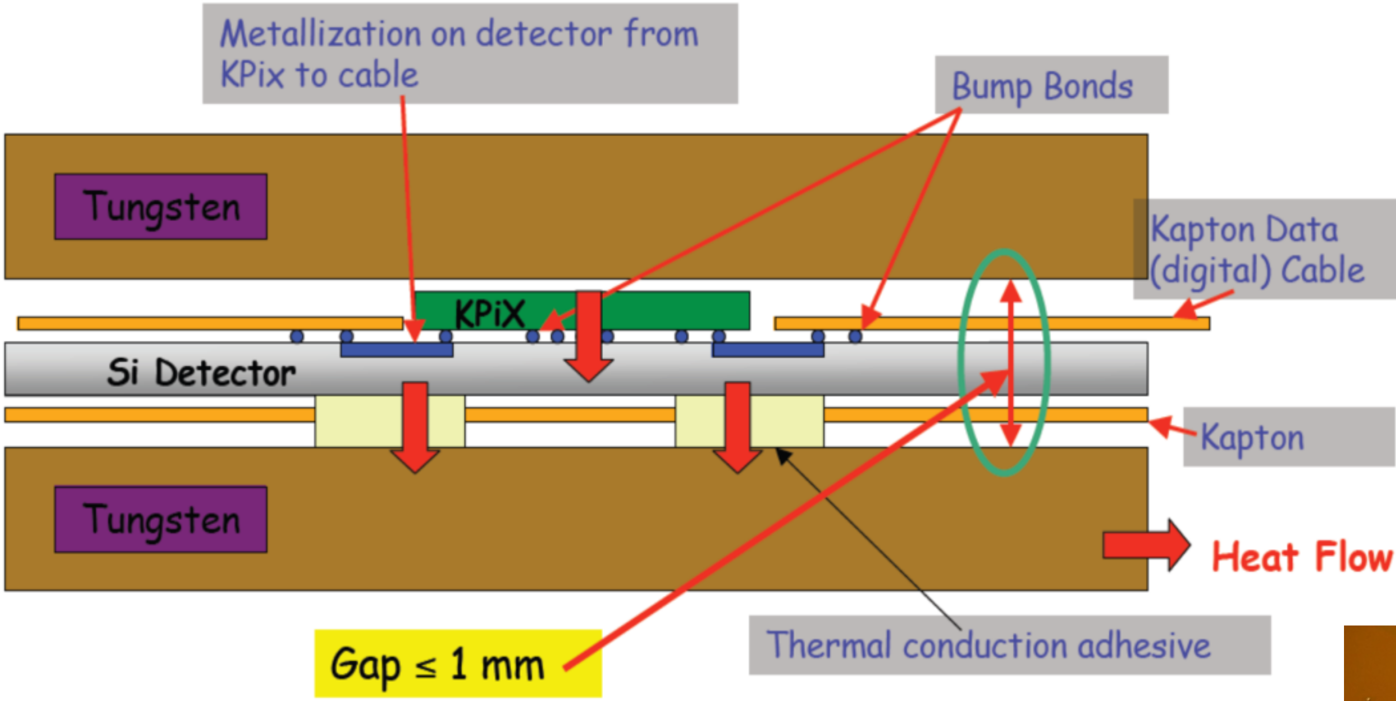


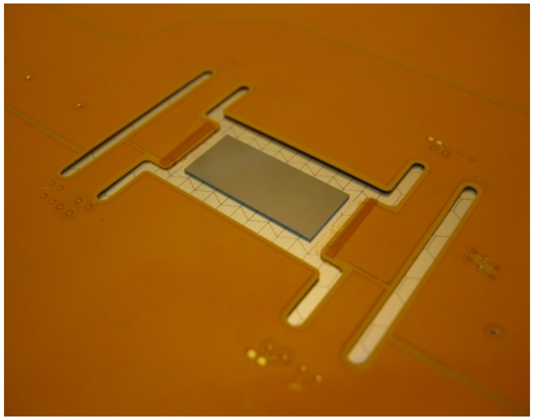
- 6 inch wafers
- 1024 13 mm^2 pixels
- KPiX readout is bump-bonded directly to sensor
- DC readout; 2 metal layers

KPiX ASIC and sample trace

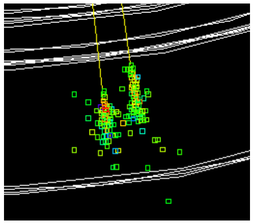


Gap Structure

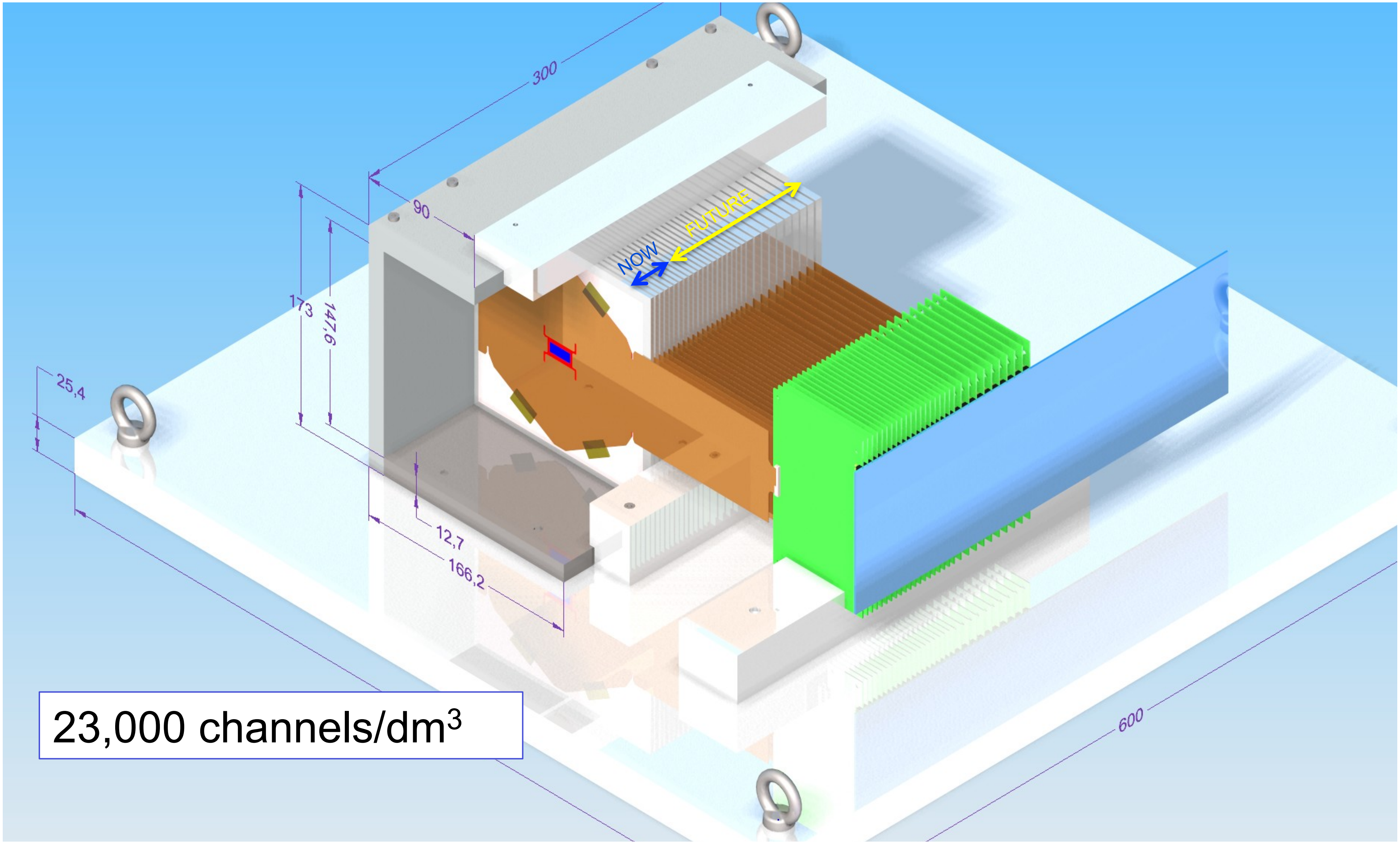




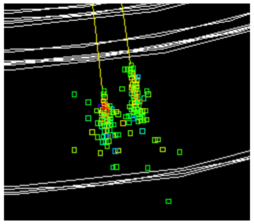
- KPiX and cable bump-bonded to the sensor
- ~1 mm gap: minimize Moliere radius, keep calorimeter compact: 9.5 mm (W only) ➔ 12 mm
- Tungsten plates thermal bridge to cooling on edge



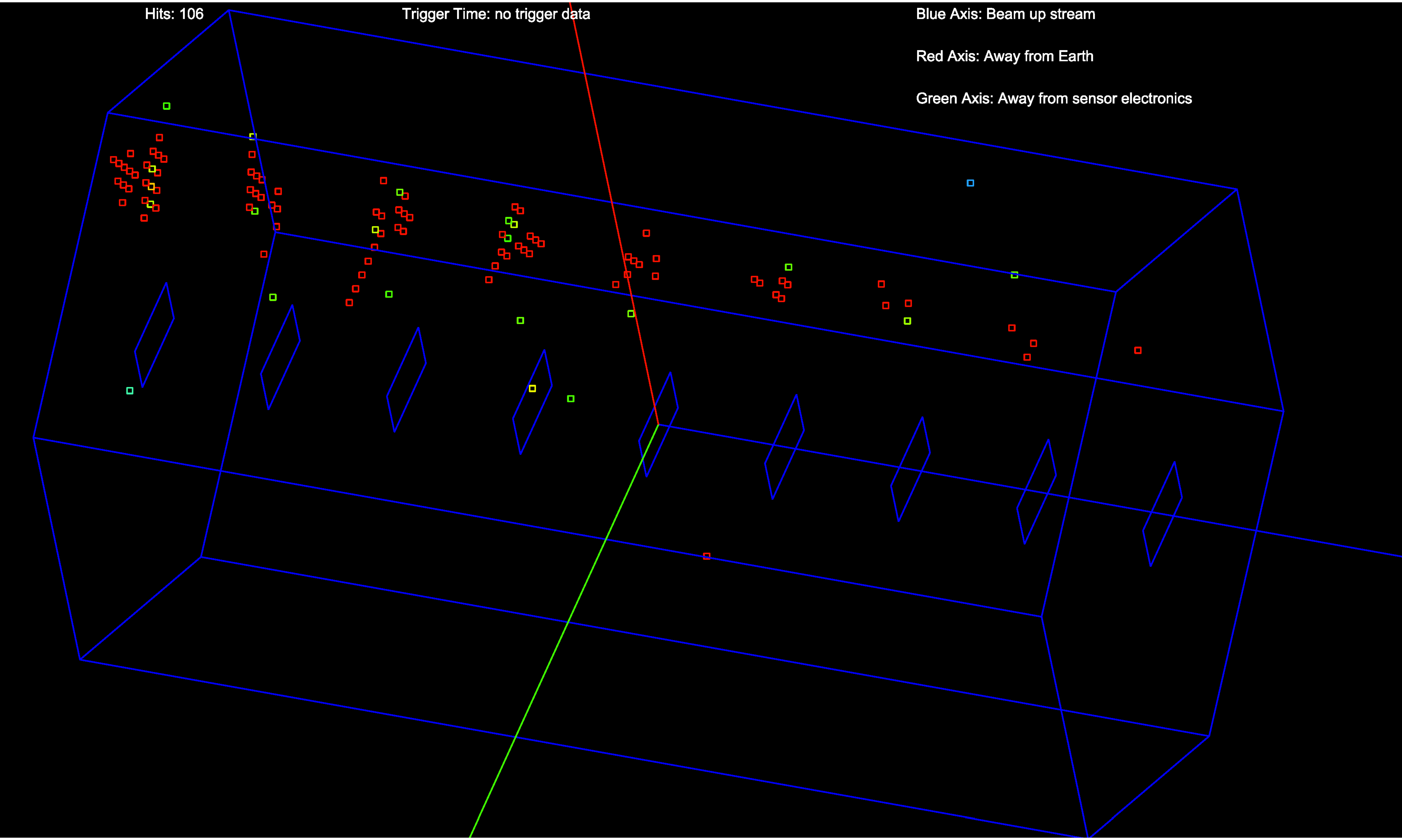
Initial test beam module for SLAC beam test
9 Si + 8 W layers (~ 6 X_0) of 30 layers

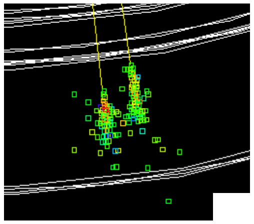


23,000 channels/dm^3

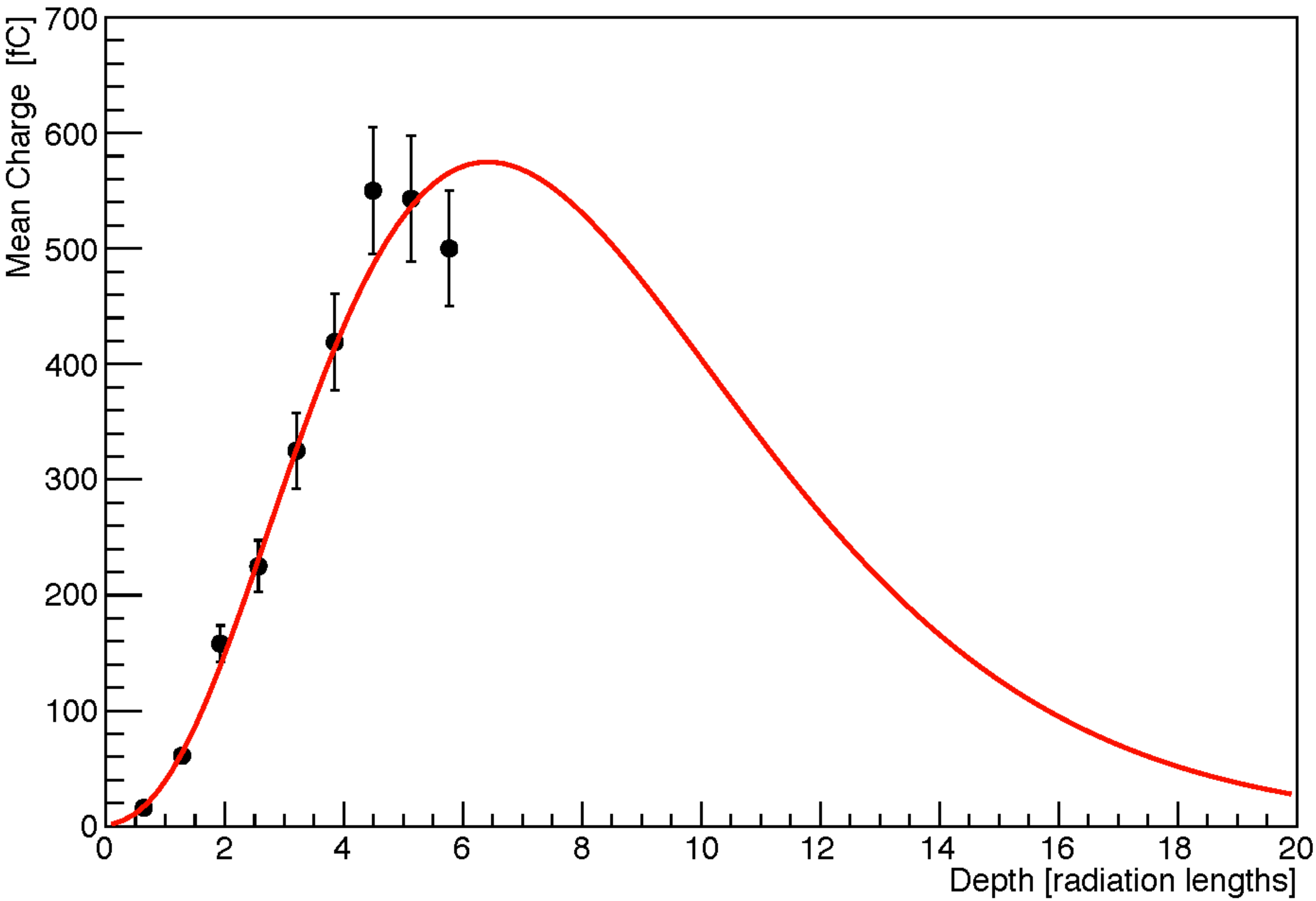


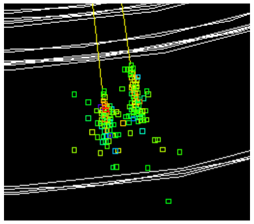
single-electron showers (12 GeV electrons)





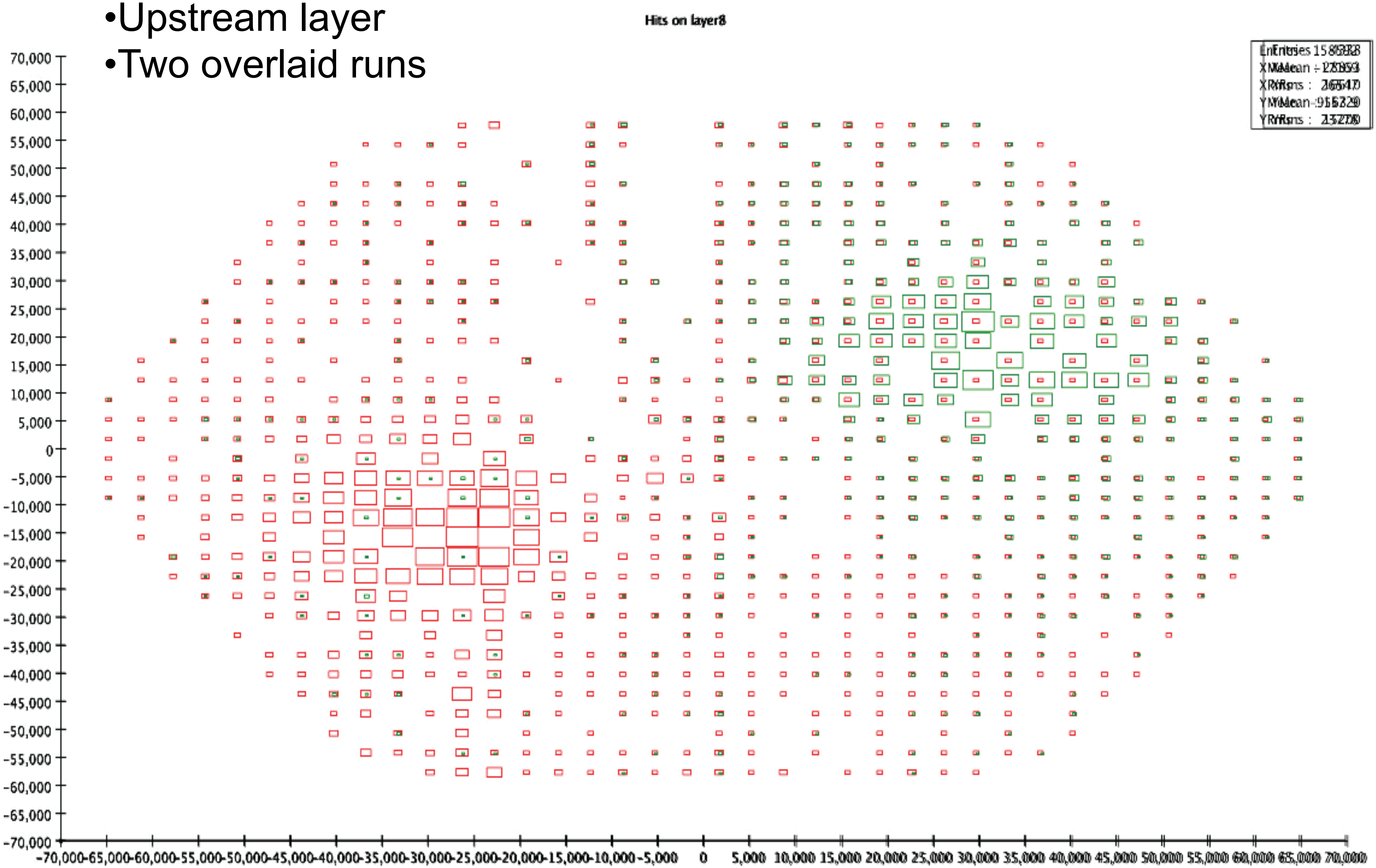
profile in depth

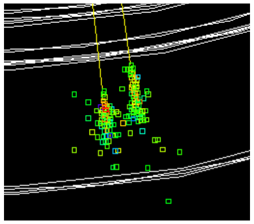




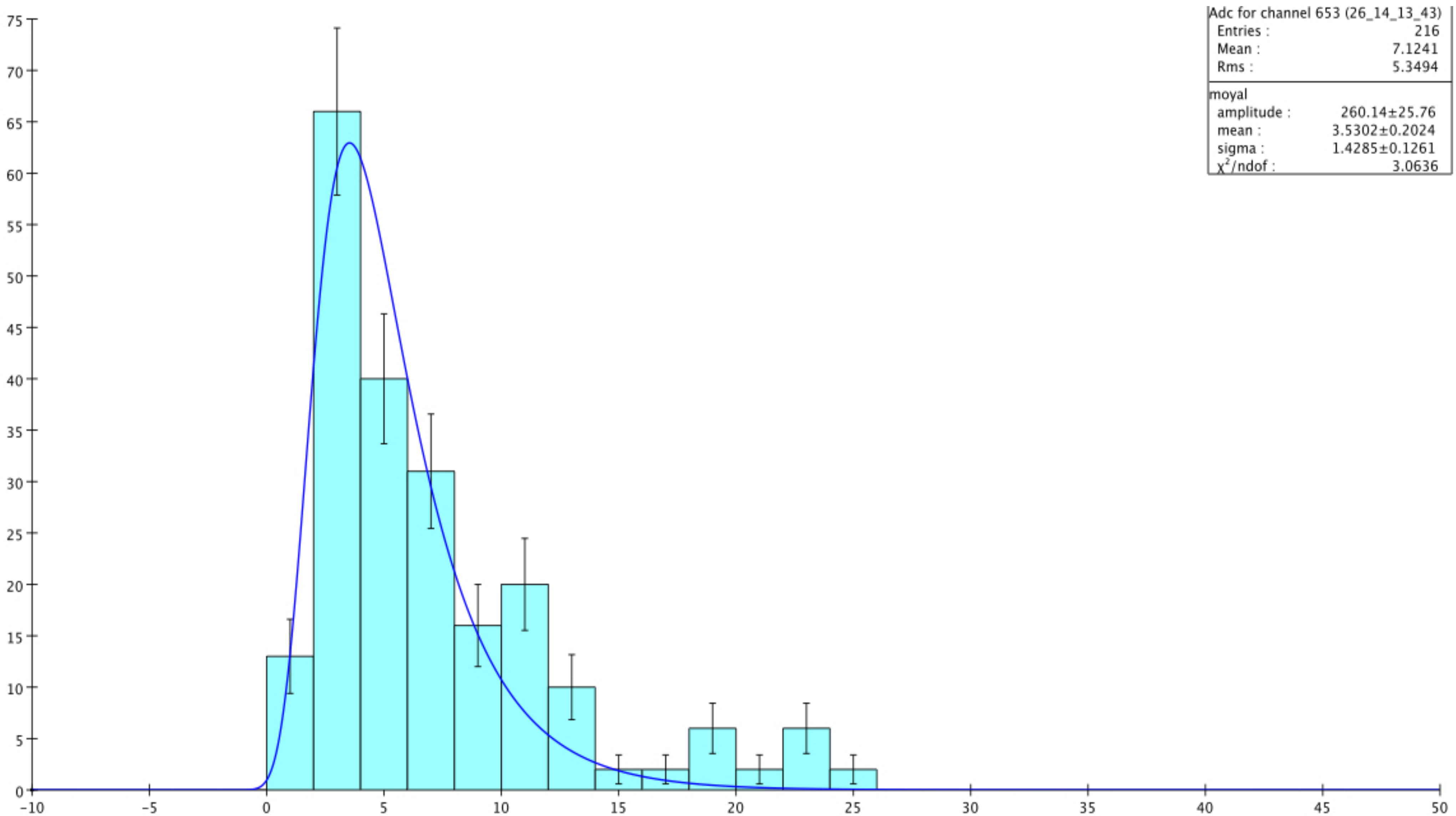
beam size

- Upstream layer
- Two overlaid runs

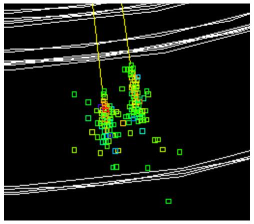




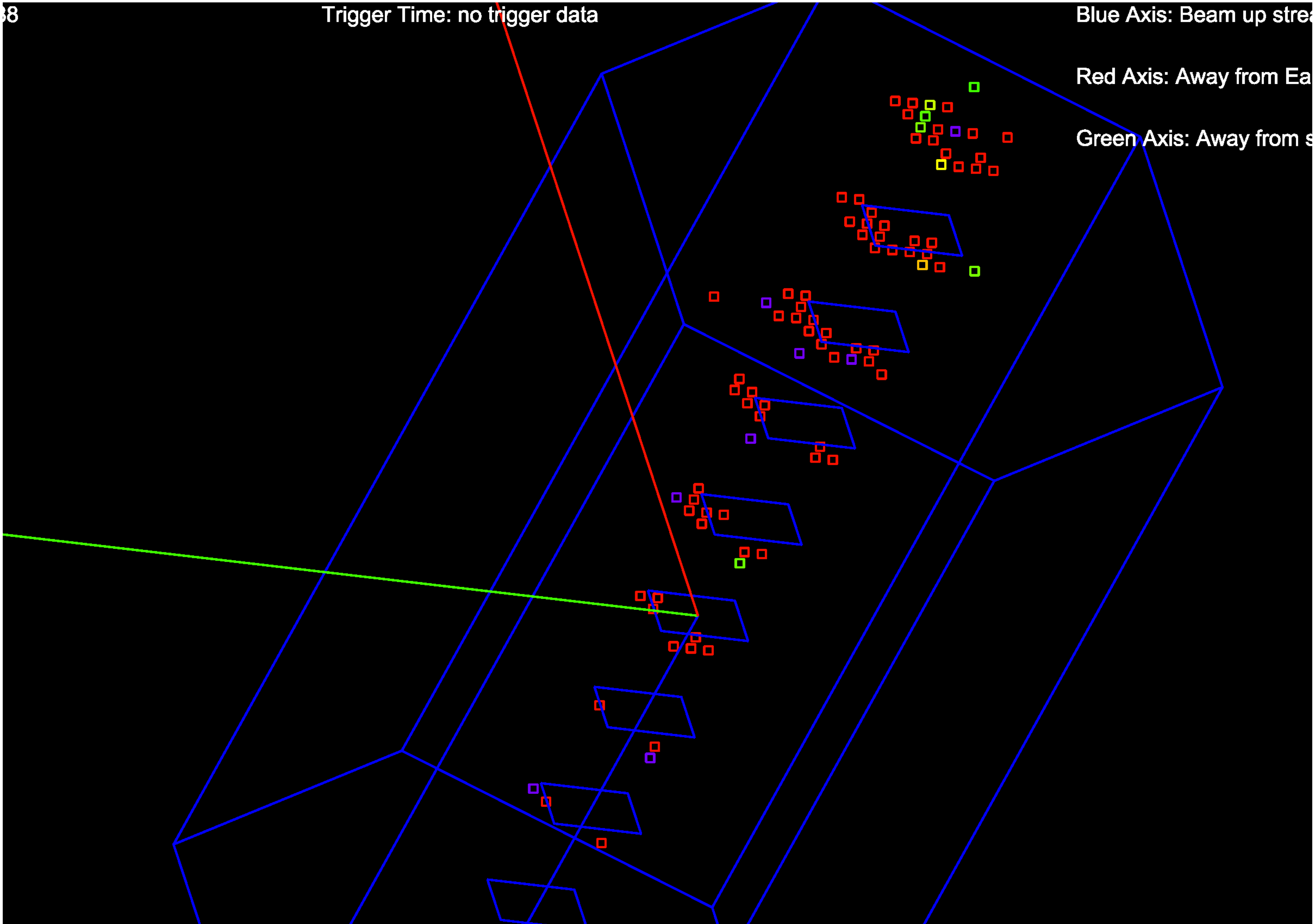
Upstream layer - MIPs



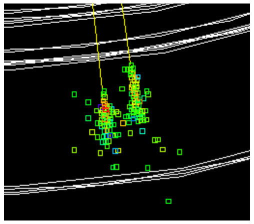
detected charge, fC



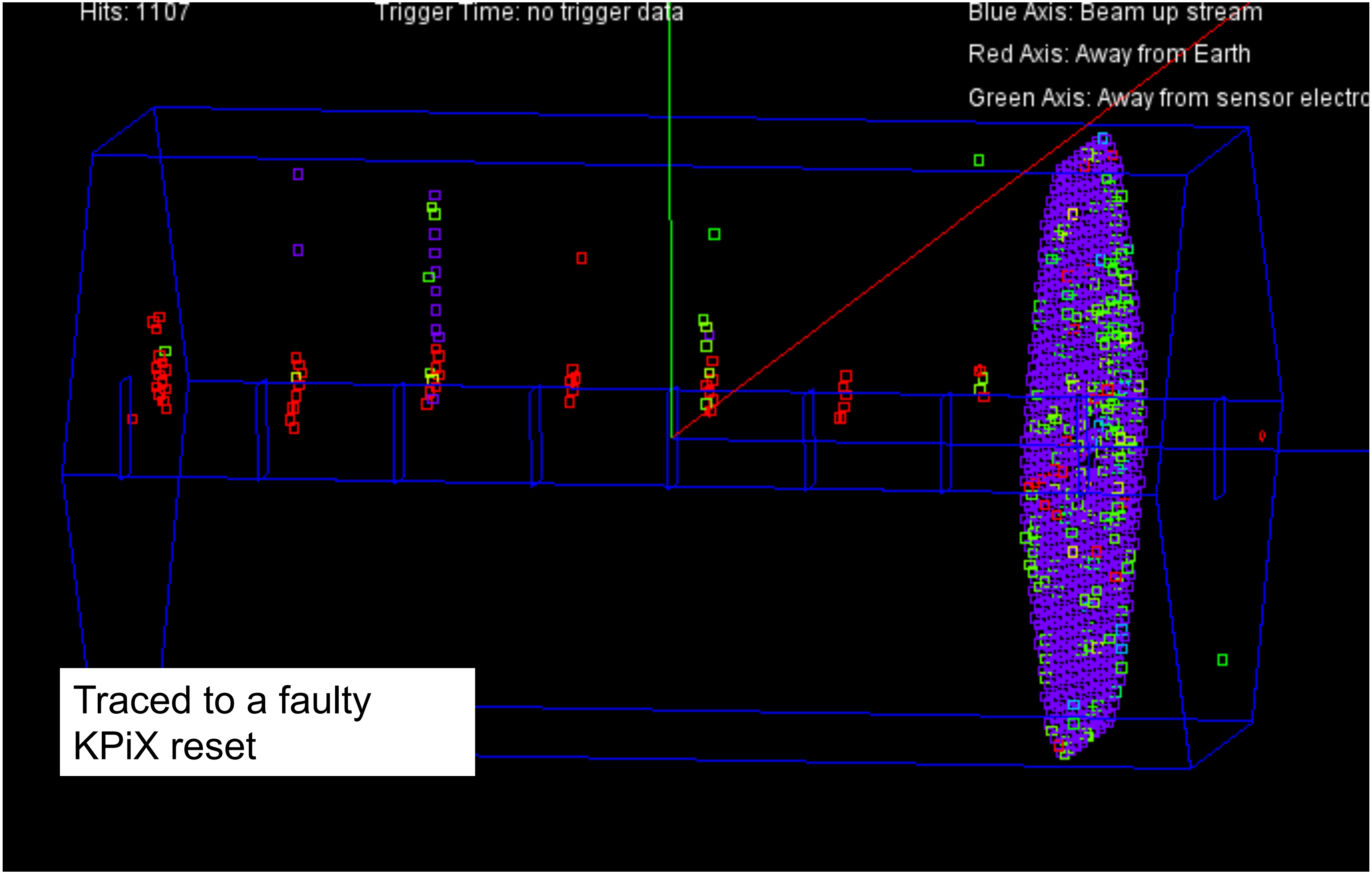
2 electrons



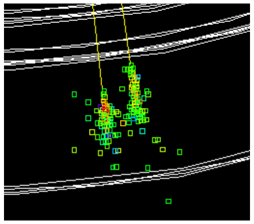
38
Trigger Time: no trigger data
Blue Axis: Beam up strea
Red Axis: Away from Ea
Green Axis: Away from s



“monster events” with many negative amplitude and out of time hits



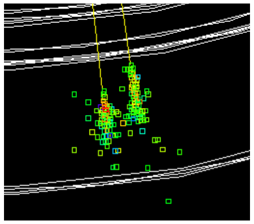
Traced to a faulty KPiX reset



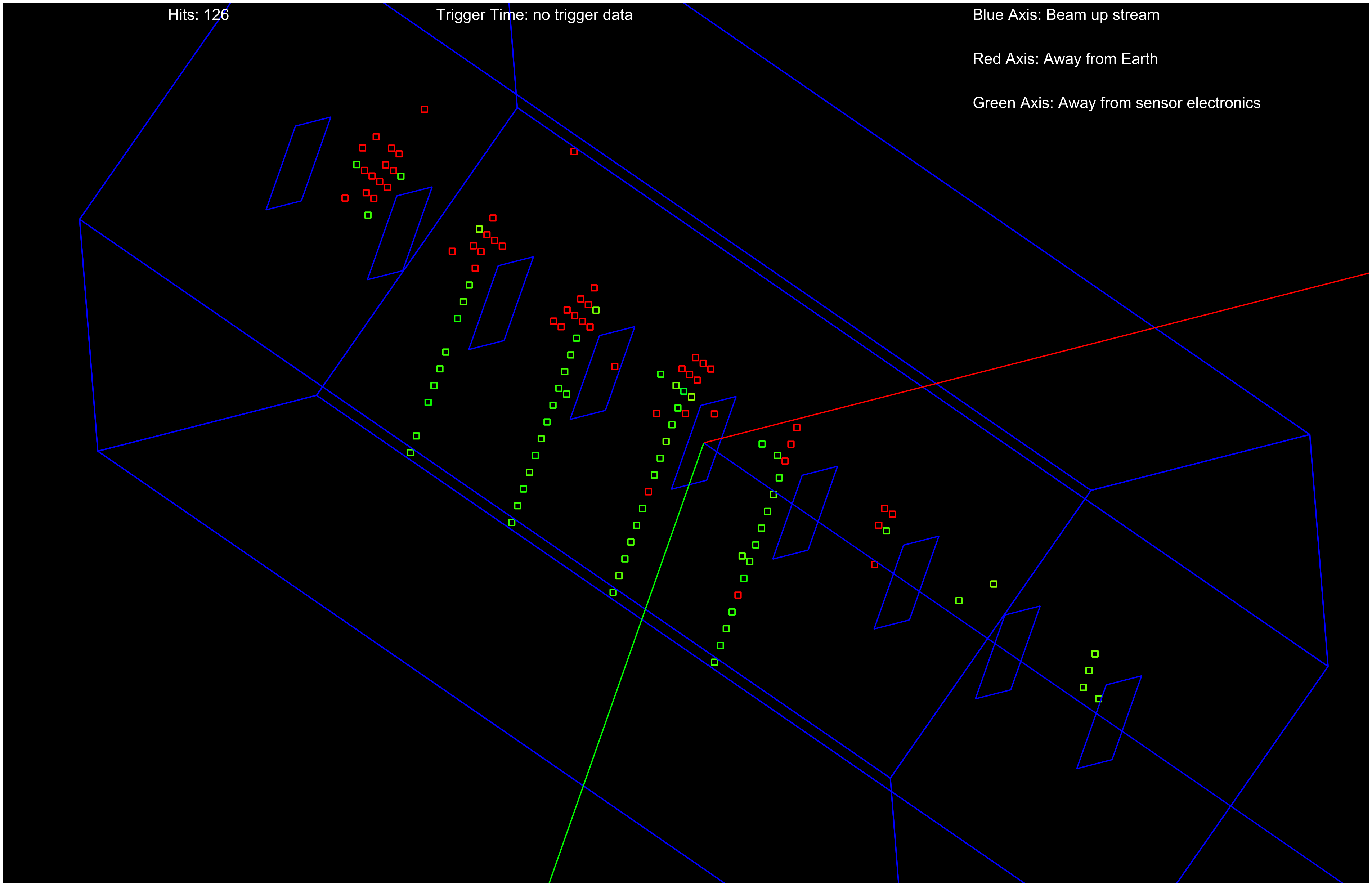
Technical Lessons (so far)

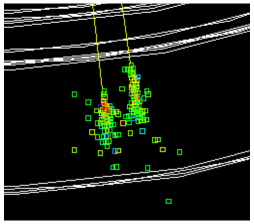
- Bump bonding to sensors with Al pads can be very difficult…
  - Enlisted IZM to establish Au under-bump metallization and bump-bond the KPiX chips
  - Came back with ~10% dead/shorted channels: Suspect the etching process
  - Don't dice the sensors until bonding issues are fully controlled
  - Worked with Hamamatsu to consolidate process:
    - Able to put down Au layer – avoids etching step
    - Not able to do the in-house bump bonding on large 6 inch sensors

- Problems identified in beam test
  - "monster event" problem identified
  - Found possible issues with parasitic couplings…



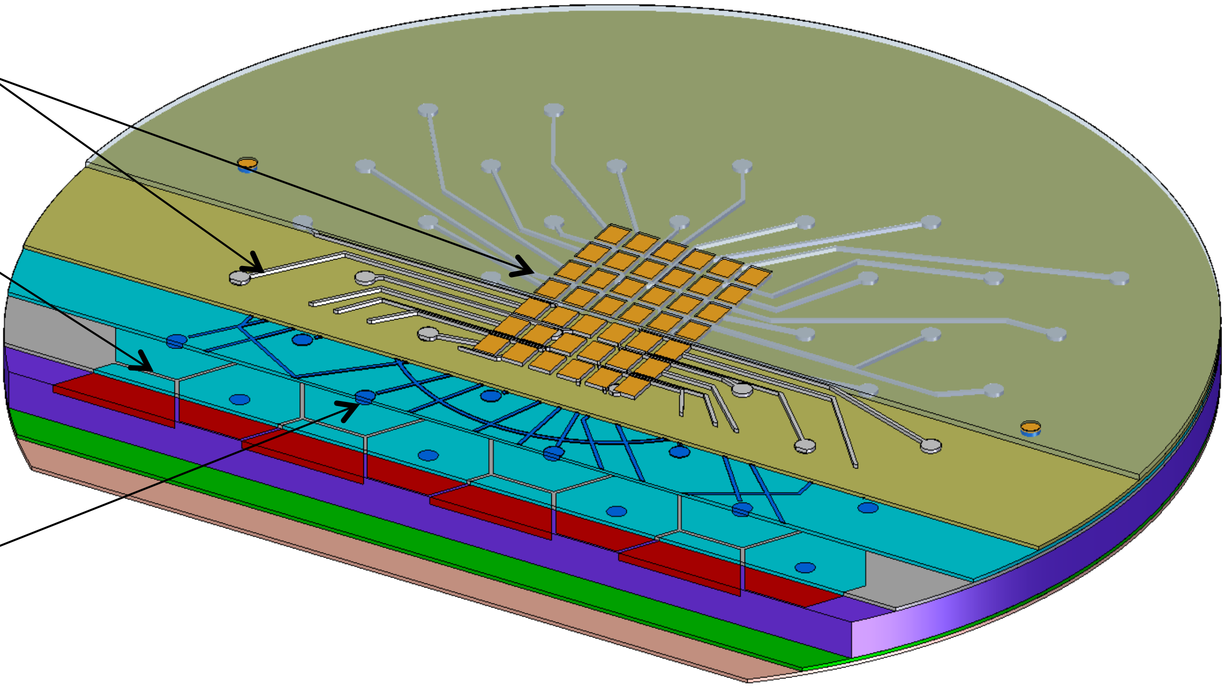
low-amplitude hits along signal trace – parasitic coupling





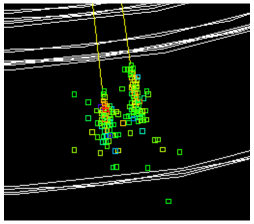
Sensor trace scheme to mitigate parasitic couplings

In present design, metal 2 traces from pixels to pad array run over other pixels: parasitic capacitances cause crosstalk.

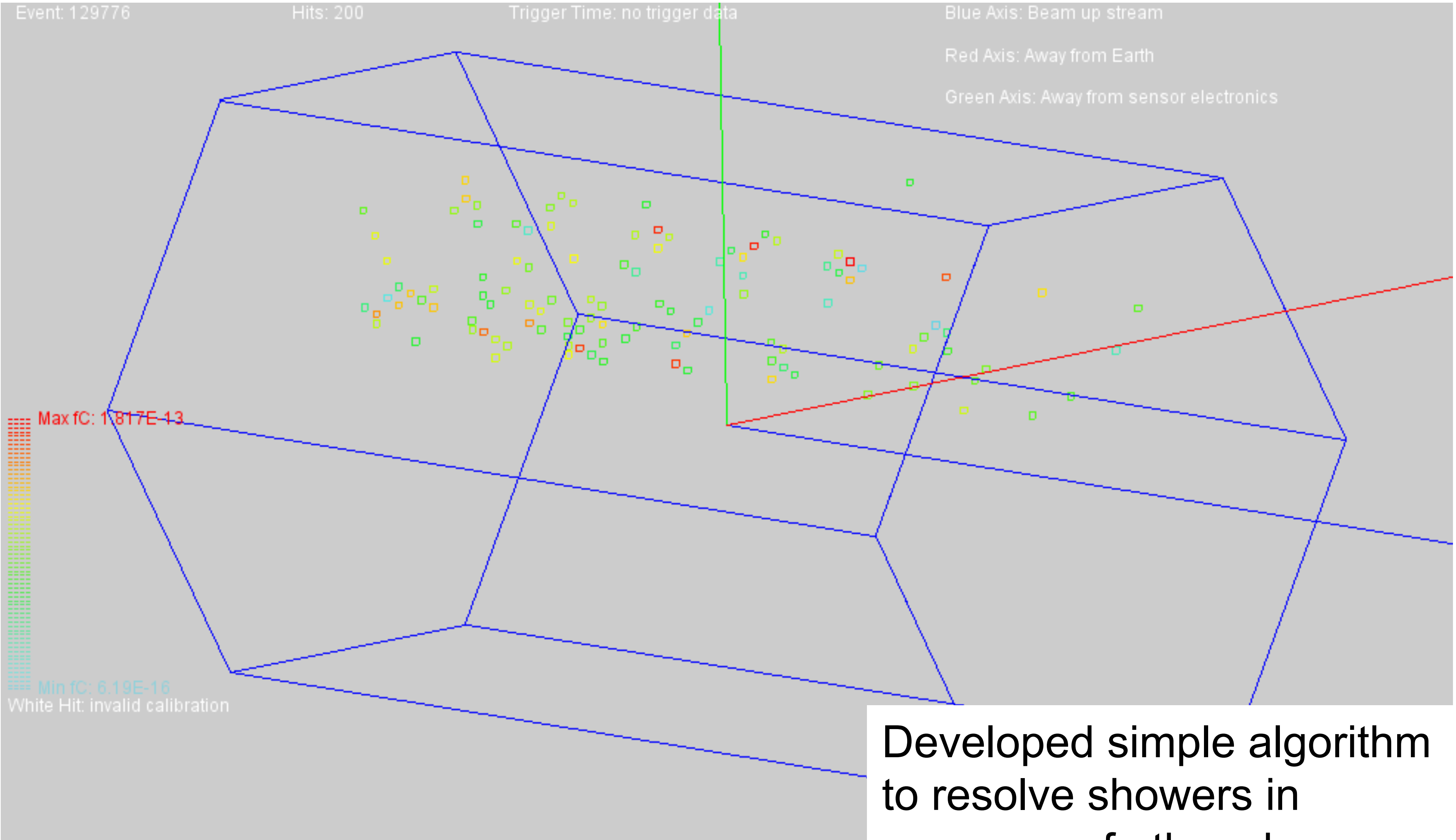


New scheme has "same" metal 2 traces, but a fixed potential metal 1 trace shields the signal traces from the pixels.

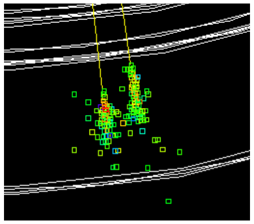
Hamamatsu is willing to implement this if there is a next round of sensor R&D.



2-shower resolution

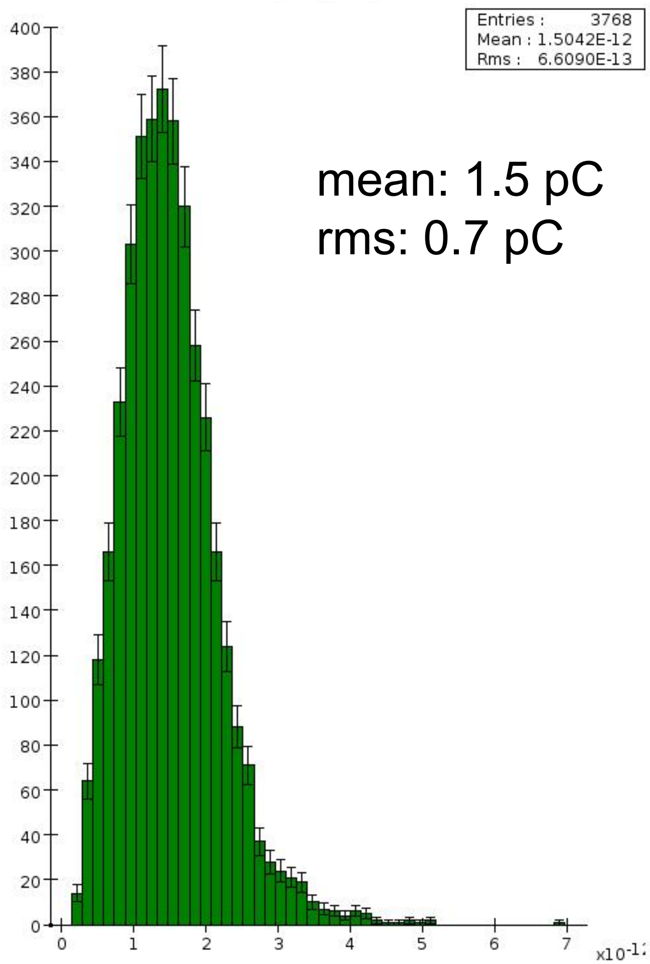


Developed simple algorithm to resolve showers in presence of other showers



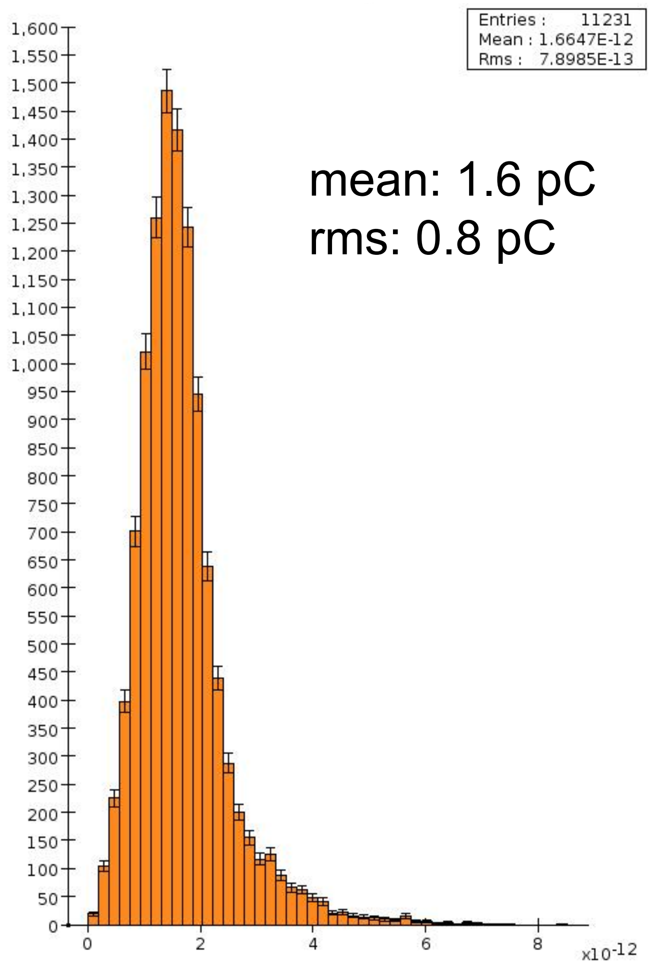
shower energy for reconstructed 2-electron events [preliminary]

single showers in 2-electron events



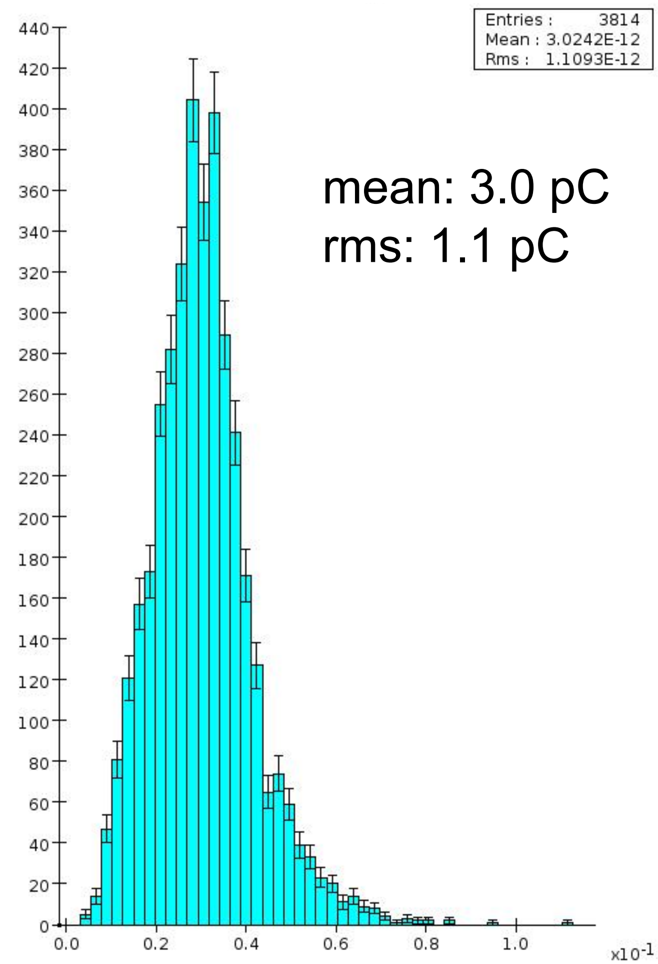
mean: 1.5 pC
rms: 0.7 pC

total energy in 1-electron events

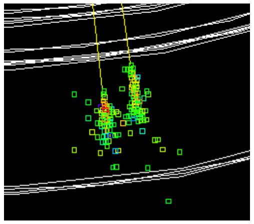


mean: 1.6 pC
rms: 0.8 pC

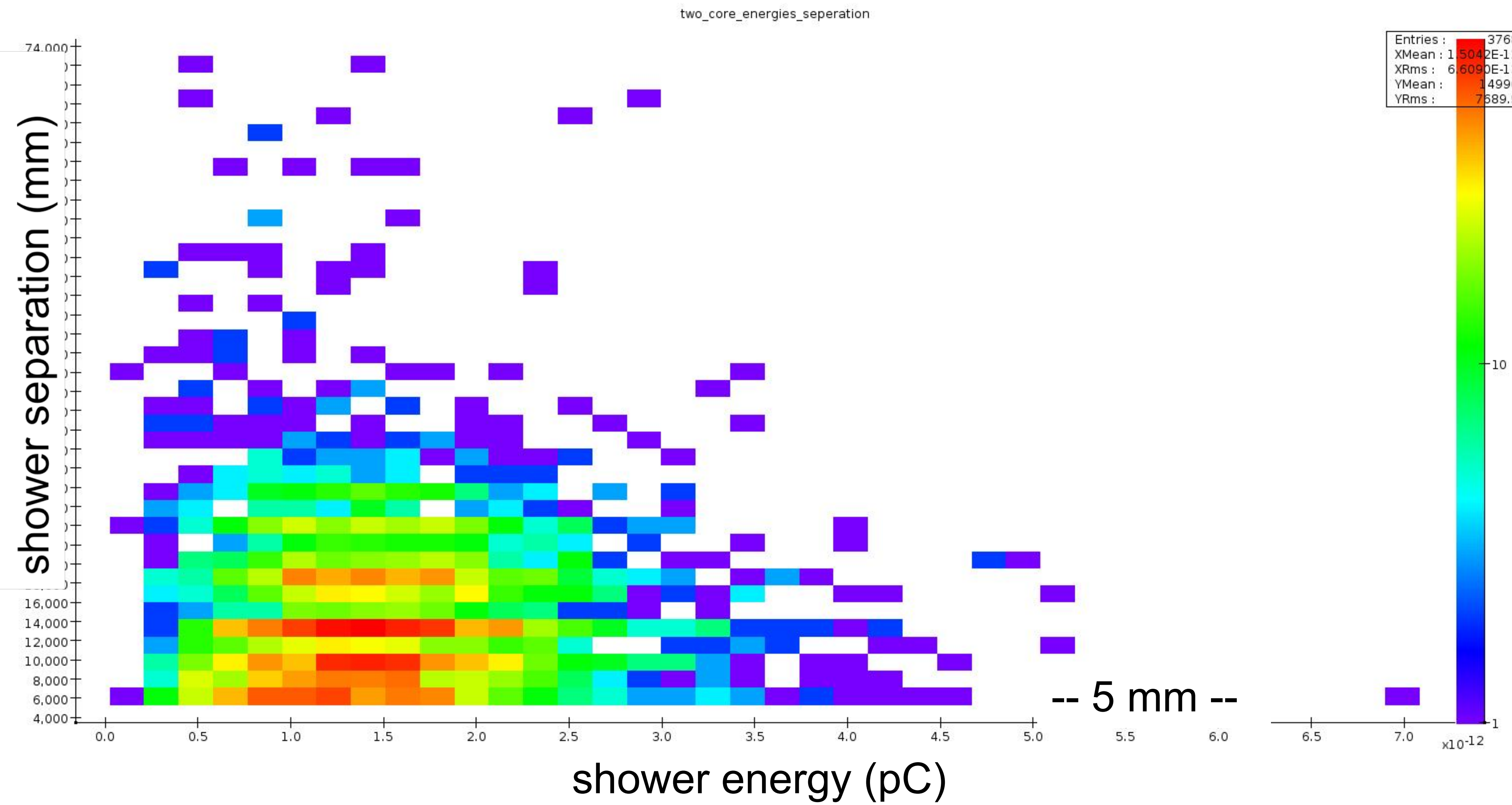
total energy in 2-electron events

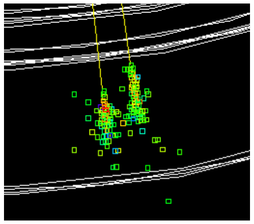


mean: 3.0 pC
rms: 1.1 pC



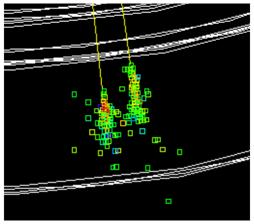
reconstructed 2-electron events: shower separation vs shower energy [preliminary]





Summary

- Silicon-tungsten continues to be an excellent technology for imaging calorimetry
  - Particle flow for jet and tau reconstruction at colliders
- A prototype has been designed and developed
  - Highly integrated readout with 1 mm readout layers is the key
  - Prototype design could be implemented as-is in an ILC detector
- Initial beam test results: promise and problems
  - Technical issues with proposed or enacted solutions
  - Resolving showers: 2-shower separation ~ 2-3 pixel size
    - More sophisticated algorithms
    - Compare with simulations
- Hope to continue the R&D



Addendum: shower algorithm

Assumptions:

Incident particles enter detector orthogonal to wafer planes

Spatial distribution of hits becomes more "noisy" at higher radiation lengths

All peritinent hits occur in sensor times in [751, 753]

Process:

All hits within acceptable time frames are collected and organized into lists by sensor layer.

All hit magnitudes are weighted linearly by 10 - sensor layer. Thus, weights of hits in the first layer equal the magnitude of the hit multiplied by 9. Hits in the second layer are weighted by their magnitude multiplied by 8, and so on. This is done to prevent more complex distributions at greater shower development from dominating the statistics.

After the hits have been weighted all layers are summed onto a single plane. This yields a list of weighted hit sums, one for each pixel address that was hit on any layer. for example if channel 42 had a hit magnitude of 0.1 on the first layer, 1.2 on the second, 4.3 on the fourth, and no hits on any other layer, then that channel would be given a total weighted magnitude of 0.1*9 + 1.2*8 + 4.3*6 = 36.3.

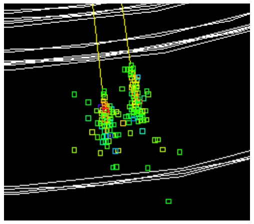
This list of weighted magnitudes is then compared against itself to find local maxima.Hits are assumed to be local maxima then are ran through filters to determine if they are not.

There is a check to determine how many hits there are in the cells neighboring the test cell. For hexagonal cells there must be hits in at least 4 (6 possible) of it's neighboring cells. For half hex cells there must be at least 3 (4 possible) hits in neighboring cells. The selection criteria is less than the total possible number of neighboring cells because the roughly 10% to 15% of dead cells would pull down the statistics otherwise.

If the magnitude of a test cell is less than that of any of it's neighbors then it is removed from the list of potential peak cells.

Next the magnitude of each of the surviving peak cells is compared the the highest magnitude of any of the peak cells. If the magnitude of the test cell is less than F times the maximum magnitude of any peak cells then it is removed from the list. F was chosen to be 0.5 by looking at the distribution of incident particle counts over an entire run and comparing that to a poison distribution of the expected number of incident particles. SLAC reports that incident particle count statistics should follow a poison distribution to a very high precision for their beam.

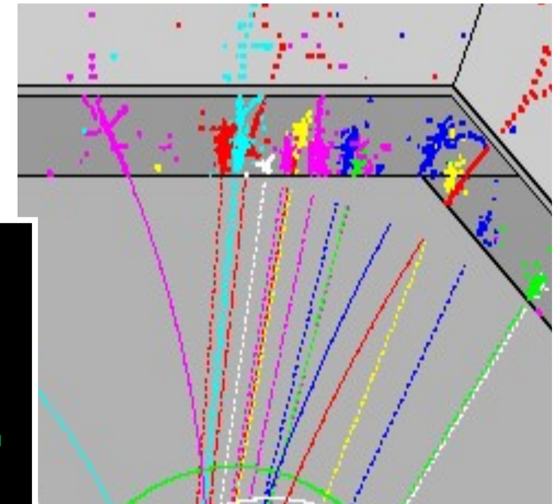
After this filtering we are left with a list of cell adresses that should contain the central core of showers eminating from incident particles.

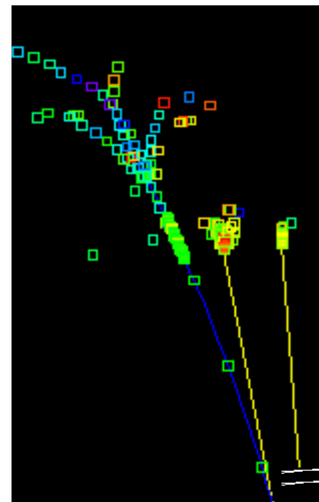


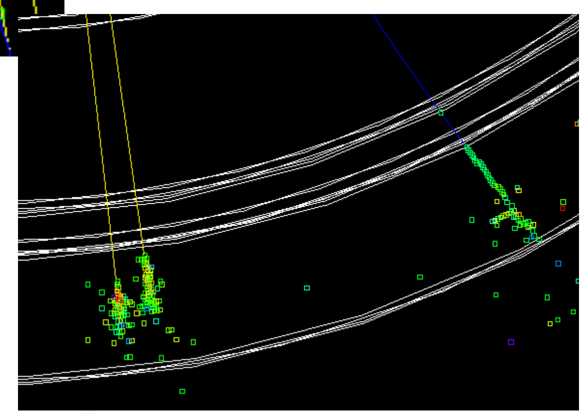
An “Imaging ECal”: Motivated by LC Physics

Guiding principles: Measure all final states and measure with precision

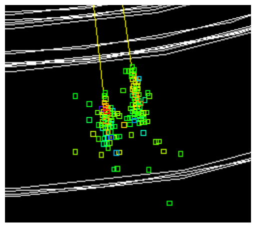
- Multi-jet final states (t-chan, missing E, combinatorics)
  - π° measurement should not limit jet resolution
  - id and measure h° and h± showers
  - track charged particles
- Tau id and analysis
  - Unique window on BSM
- Photons
  - Tracking of photons/neutrals
  - Vertexing of photons ($\sigma_b \sim 1$ cm), e.g. for GMSB
- Electron id
- Bhabhas and Bhabha acollinearity
- Hermiticity





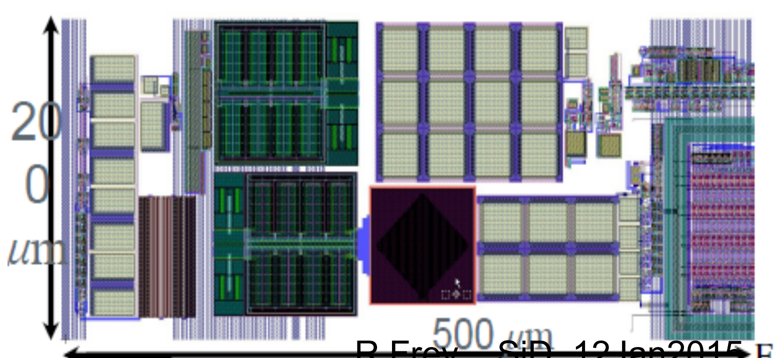


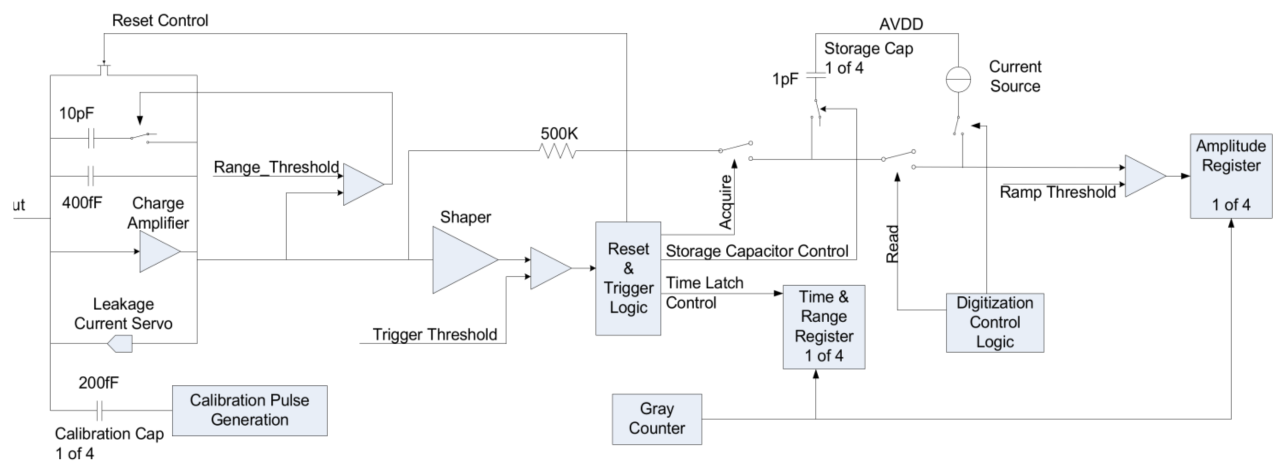
$\Rightarrow$ **Imaging Calorimetry can do this (“particle flow”)**

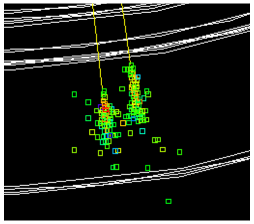


KPiX – a readout system on a chip

- A 1024 channel system bump bonded directly to the Si Sensors
- Optimized for the ILC, with multi-hit recording during the train, and digitization and readout during the inter-train gap (199 ms).
- Front-end power down during inter-train gap. Mean power/channel < 20 μW.
- Large dynamic range (for calorimetry) by dynamically switching the charge amp feedback cap: 1 to 2500 MIPs
- Pixel level trigger; trigger bunch number recorded.
- 0.15 fC noise floor







Silicon-tungsten calorimetry in HEP

- Introduced as small-angle luminometers at electron-positron colliders
  - SLD at the SLC
  - ALEPH and OPAL at LEP
- Being considered for 4π electromagnetic calorimeters for future electron-positron colliders
  - SiD concept for ILC
  - ILD concept for ILC
  - CLIC
- Other colliders
  - CMS upgrade: endcap EM calorimeter
  - Muon collider?
- Astrophysics
  - Pamela