SiD EMCal Progress

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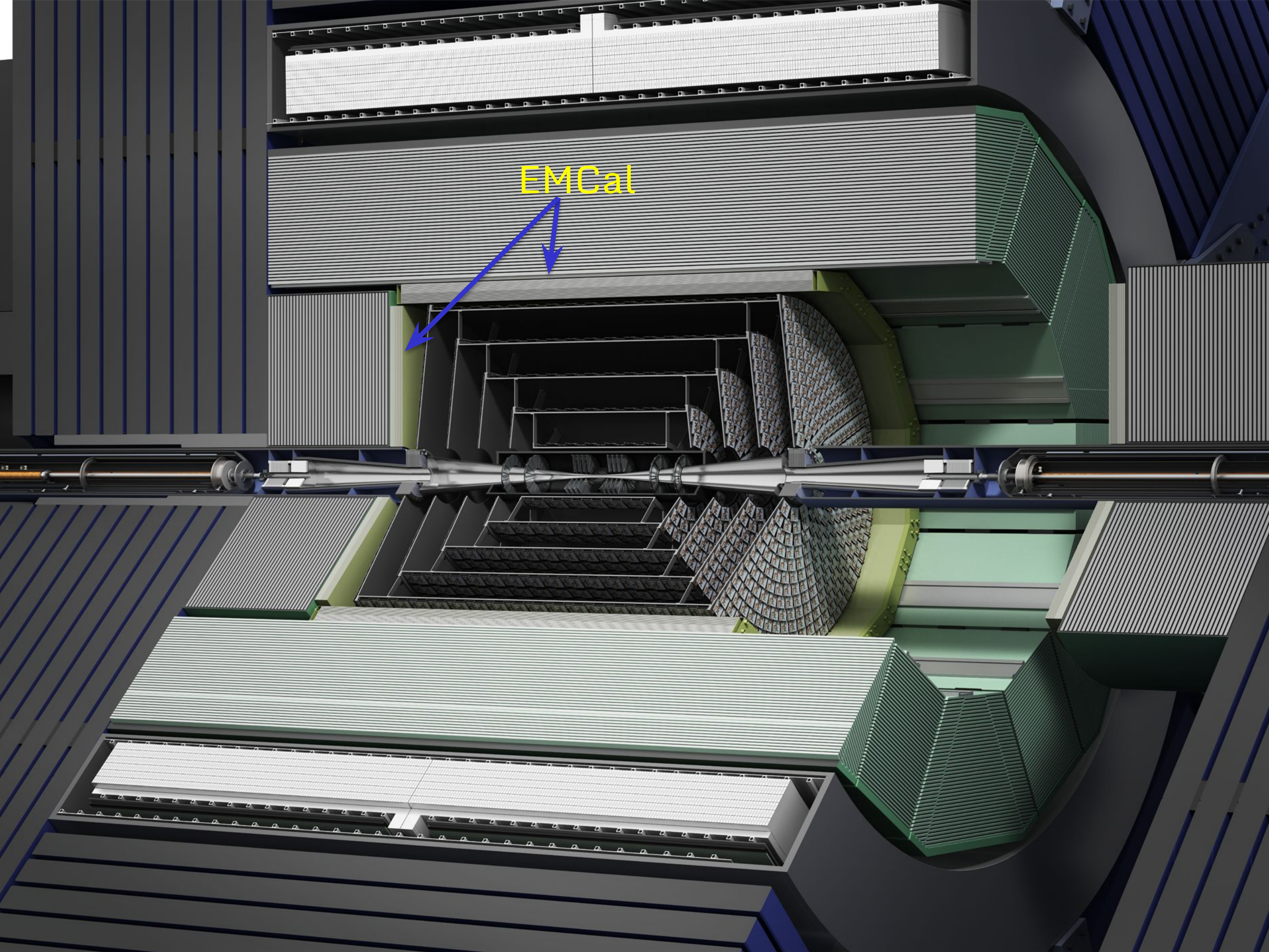
Calor 2018
University of Oregon

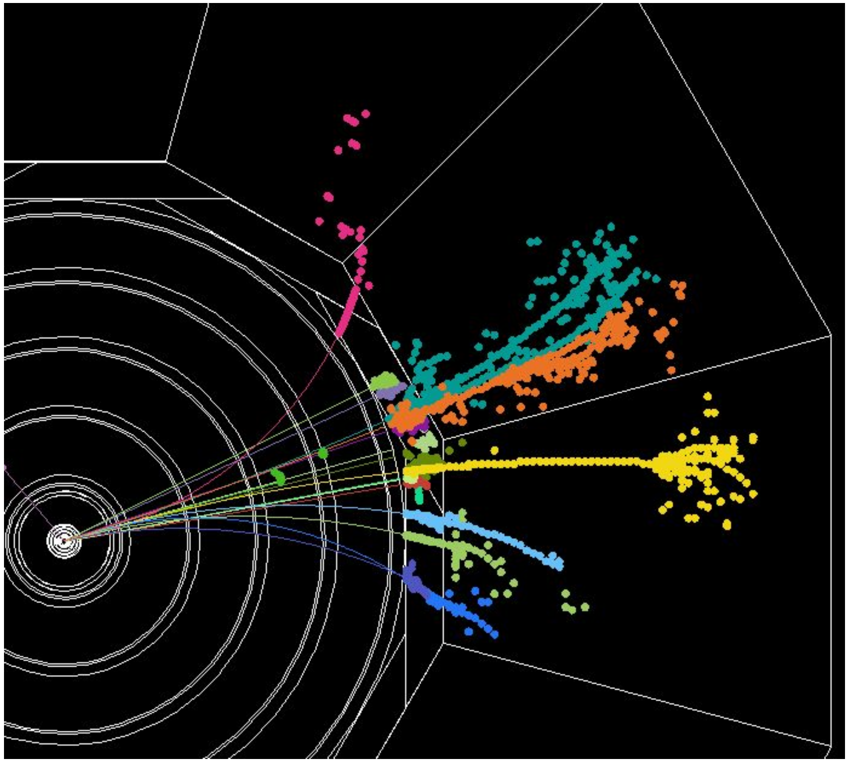
Outline

- Some context and history
- Mechanical Progress
- Beam test & major implications
- Possible new sensor design
- Multiplicity studies
- KPiX modifications


EMCal

Calorimetry- Optimized for Particle Flow

- SiD ECAL
  - Tungsten absorber
  - 20+10 layers
  - $20 \times 0.64 + 10 \times 1.30\ X_0$
- Baseline Readout using
  - 5x5 mm^2 silicon pads

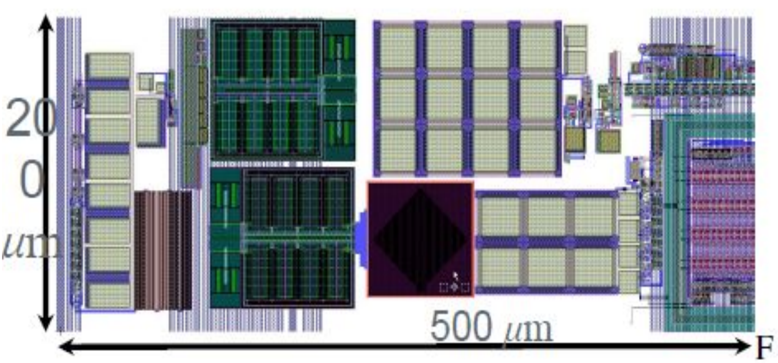


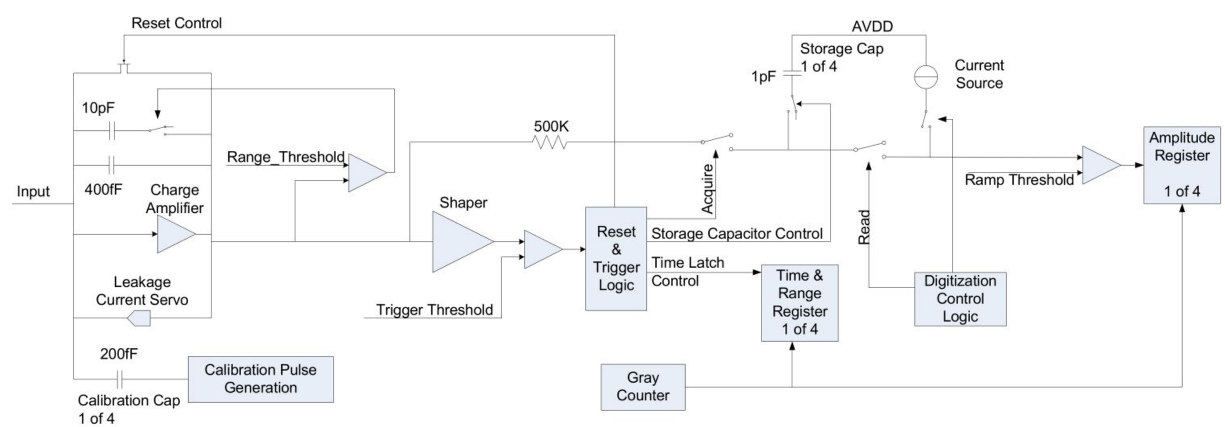
- SiD HCAL
  - Steel Absorber
  - 40 layers
  - $4.5\ \Lambda_i$
- Baseline readout
  - 3x3 cm scintillator w SiPM's

Particle flow significantly improves jets resolution by reducing contribution of hadron calorimeter resolution.

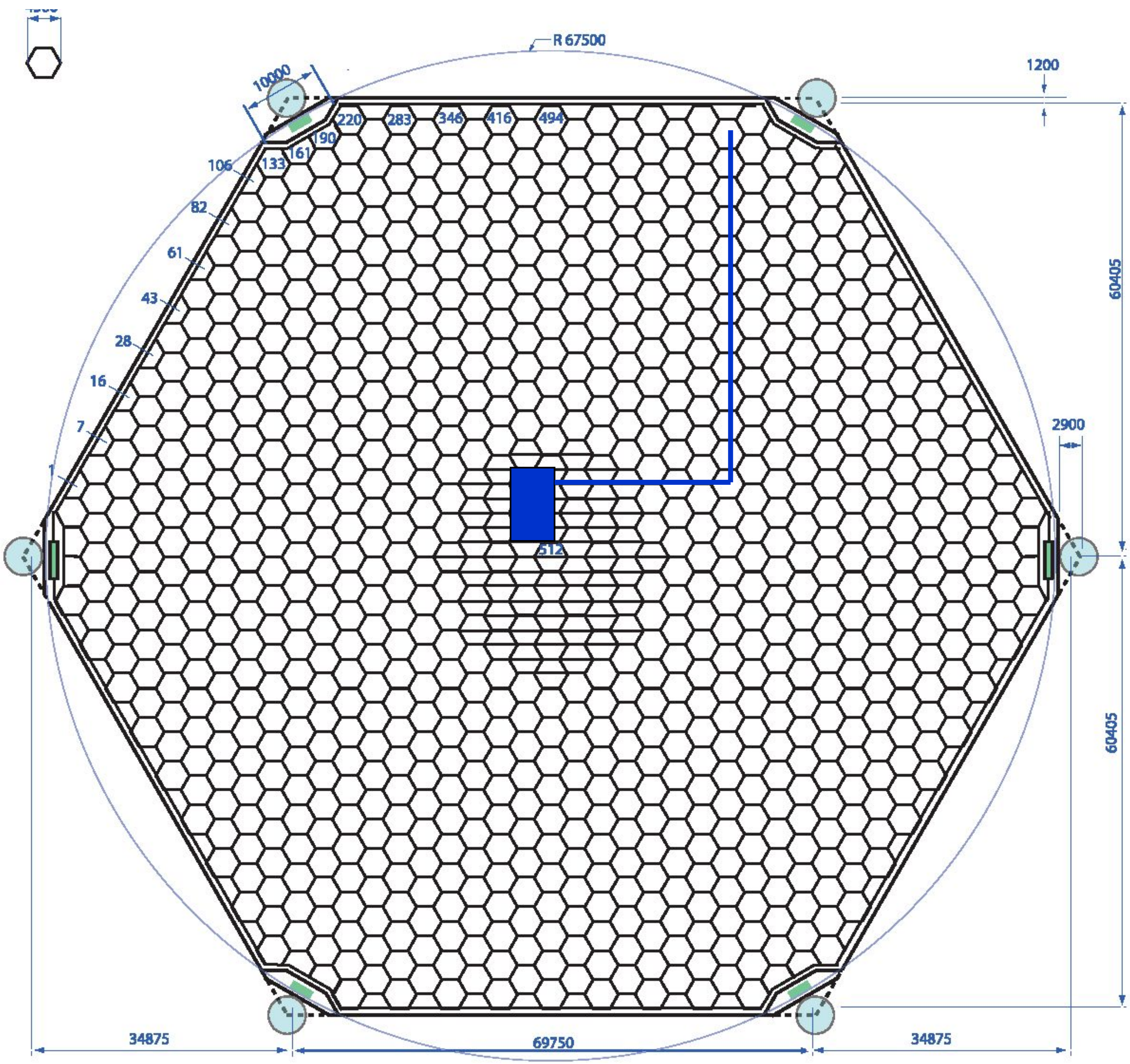
KPiX – a readout system on a chip

- A 1024 channel system to be bump bonded directly to large Si Sensors – enabling the Si Tracker and EMCal.
- 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.
- Pixel level trigger; trigger bunch number recorded.





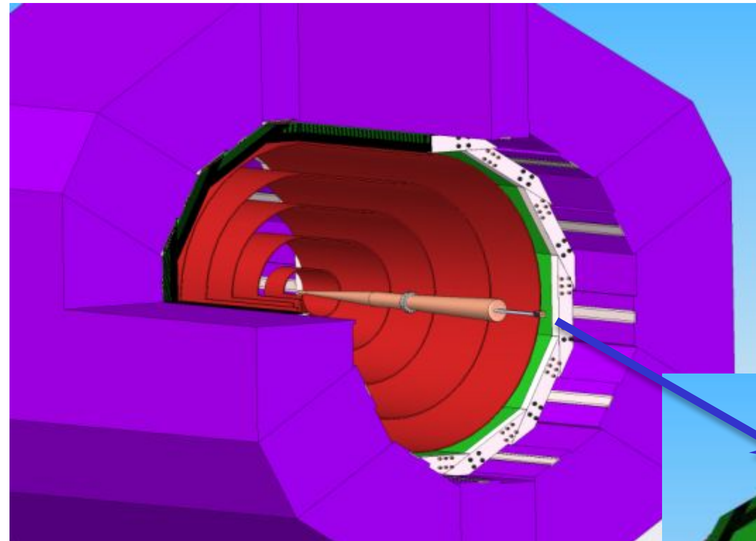
Si sensors

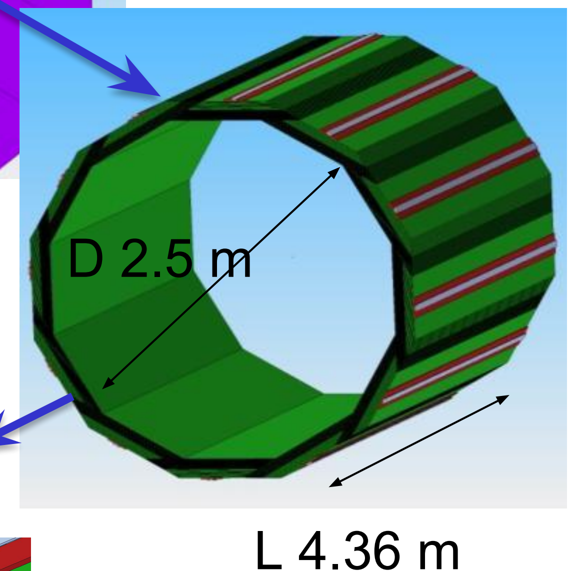


- 6 inch wafers
- 1024 13 mm^2 pixels
- KPiX readout is bump-bonded directly to sensor

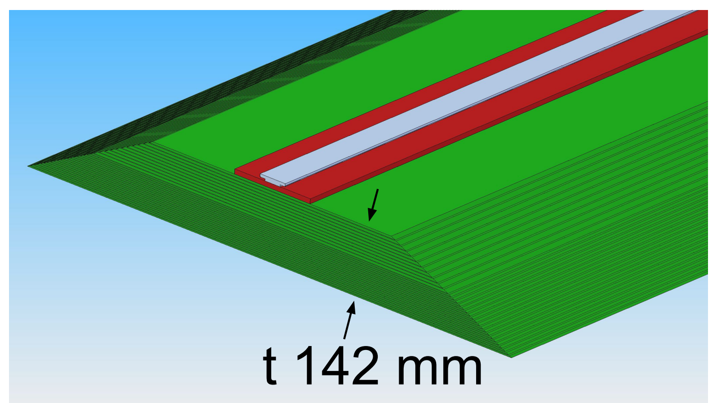
KPiX ASIC and sample trace

Compact Electromagnetic Calorimeter w 13 mm Moliere Radius



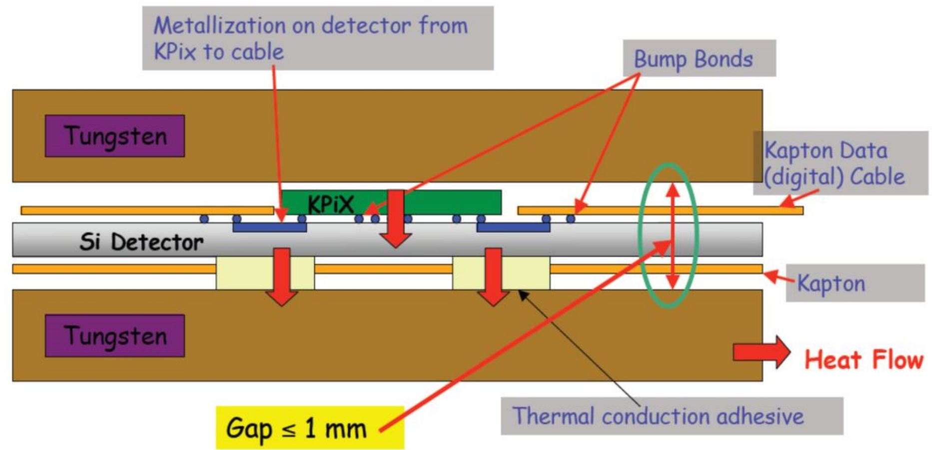


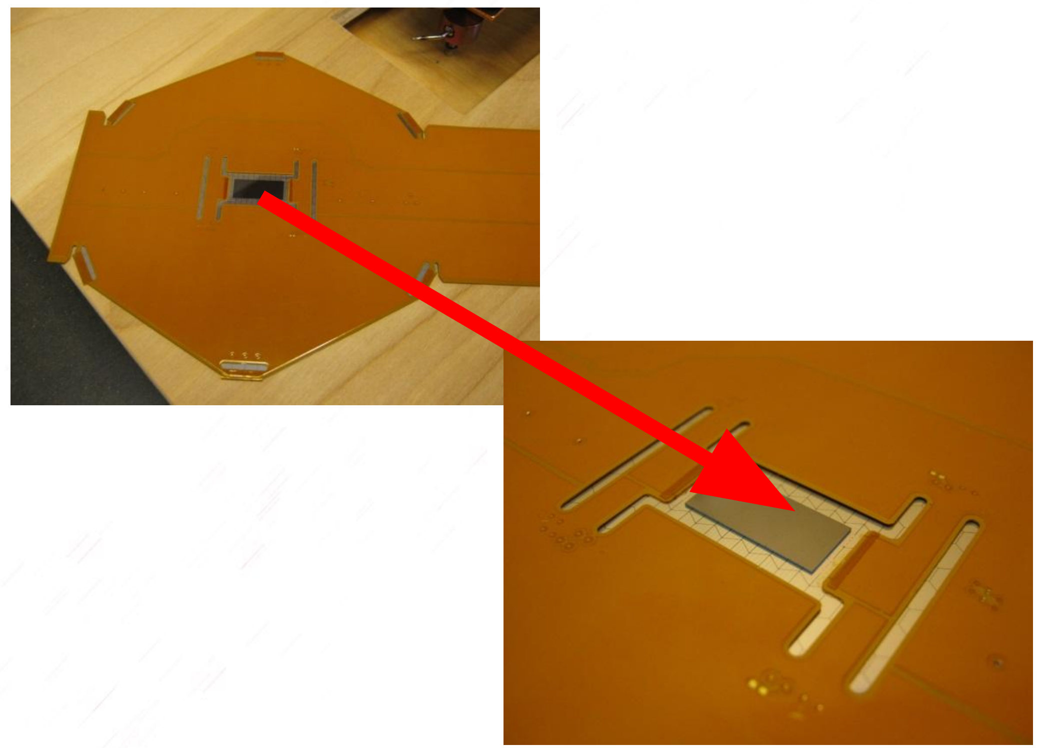
20 layers 2.5 mm W (5/7 X0)
10 layers 5 mm W (10/7 X0)
30 gaps 1.25 mm w Si pixels sensors
29 X_0; 1 λ
$\Delta E/E = 17\%/\sqrt{E}$



Gap Structure

- One ECAL Si sensor
- KPiX and cable bump-bonded to the sensor
- ~1 mm gap: minimize Moliere radius, keep calorimeter compact
- Tungsten plates thermal bridge to cooling on edge

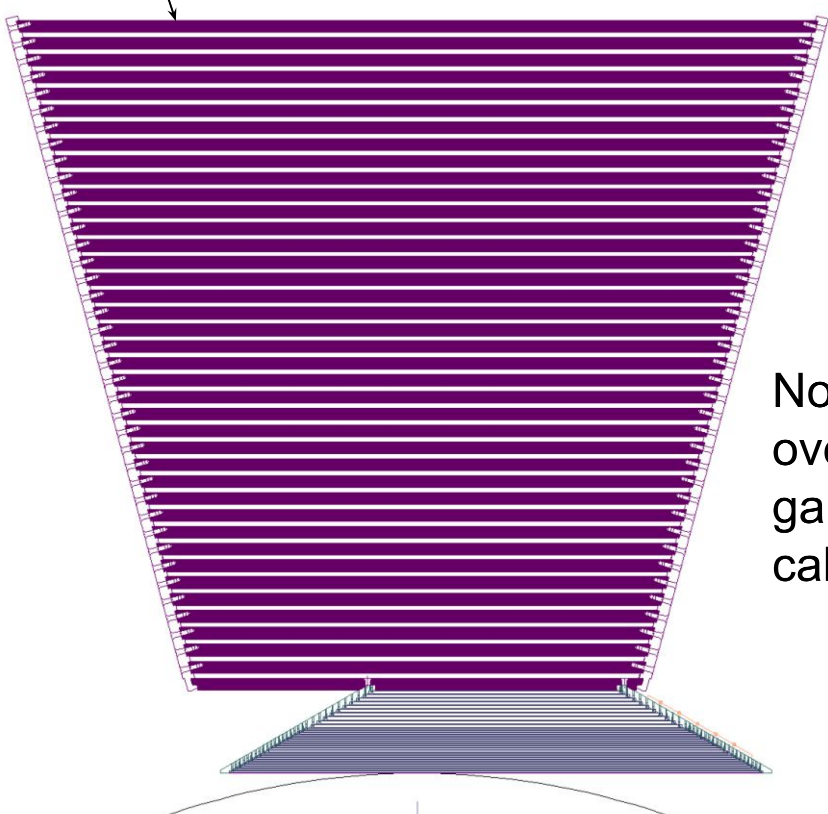




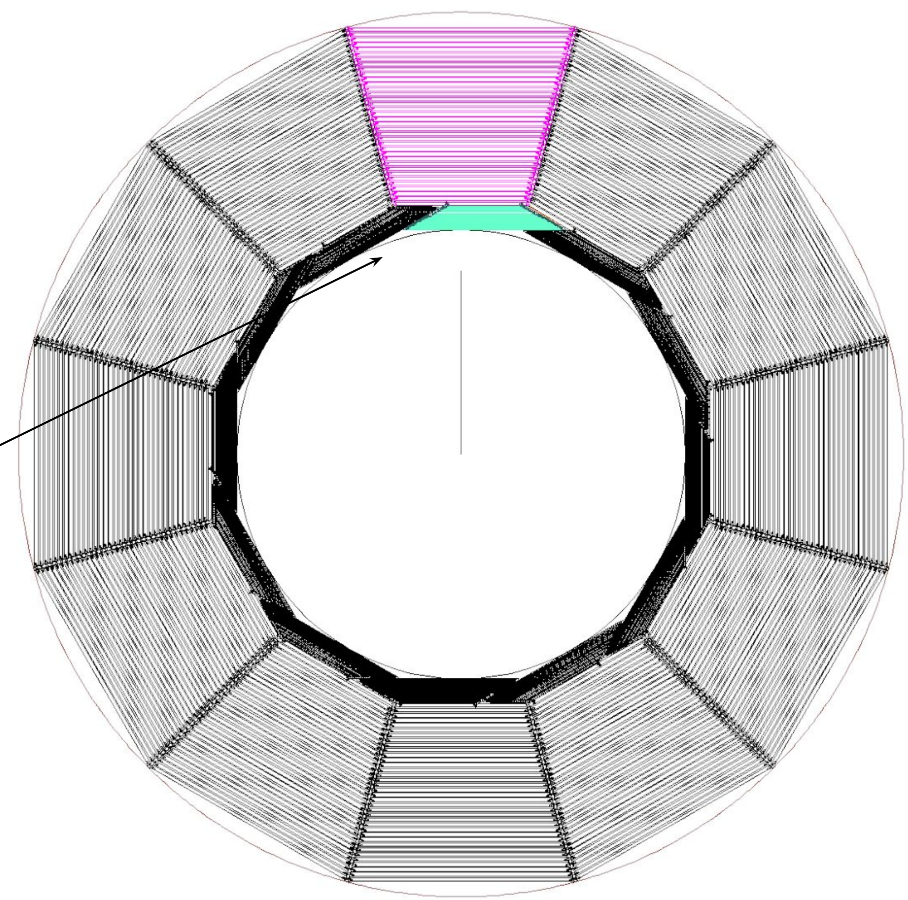
Mechanical Design

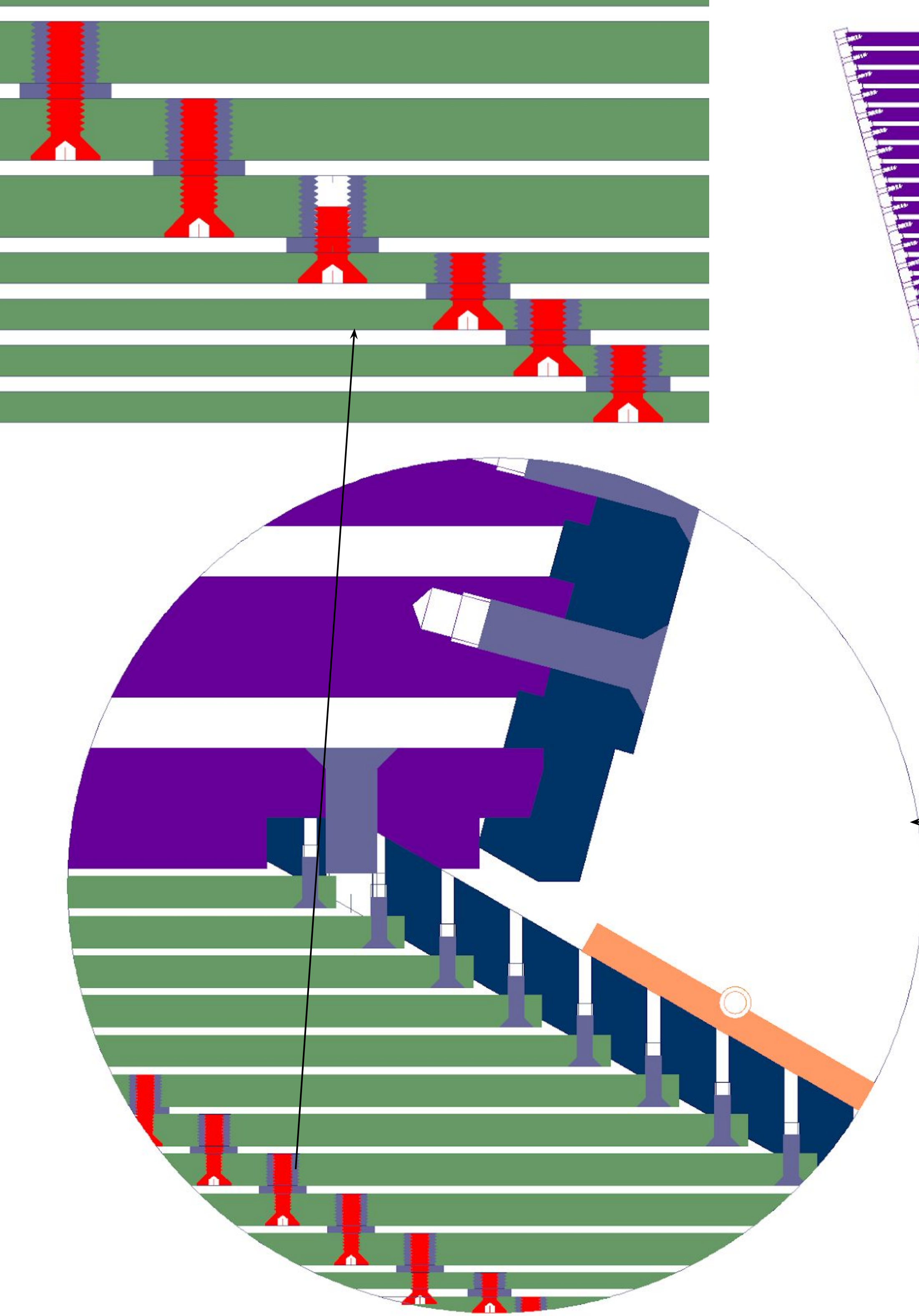
ECAL module is built on first layer of HCal

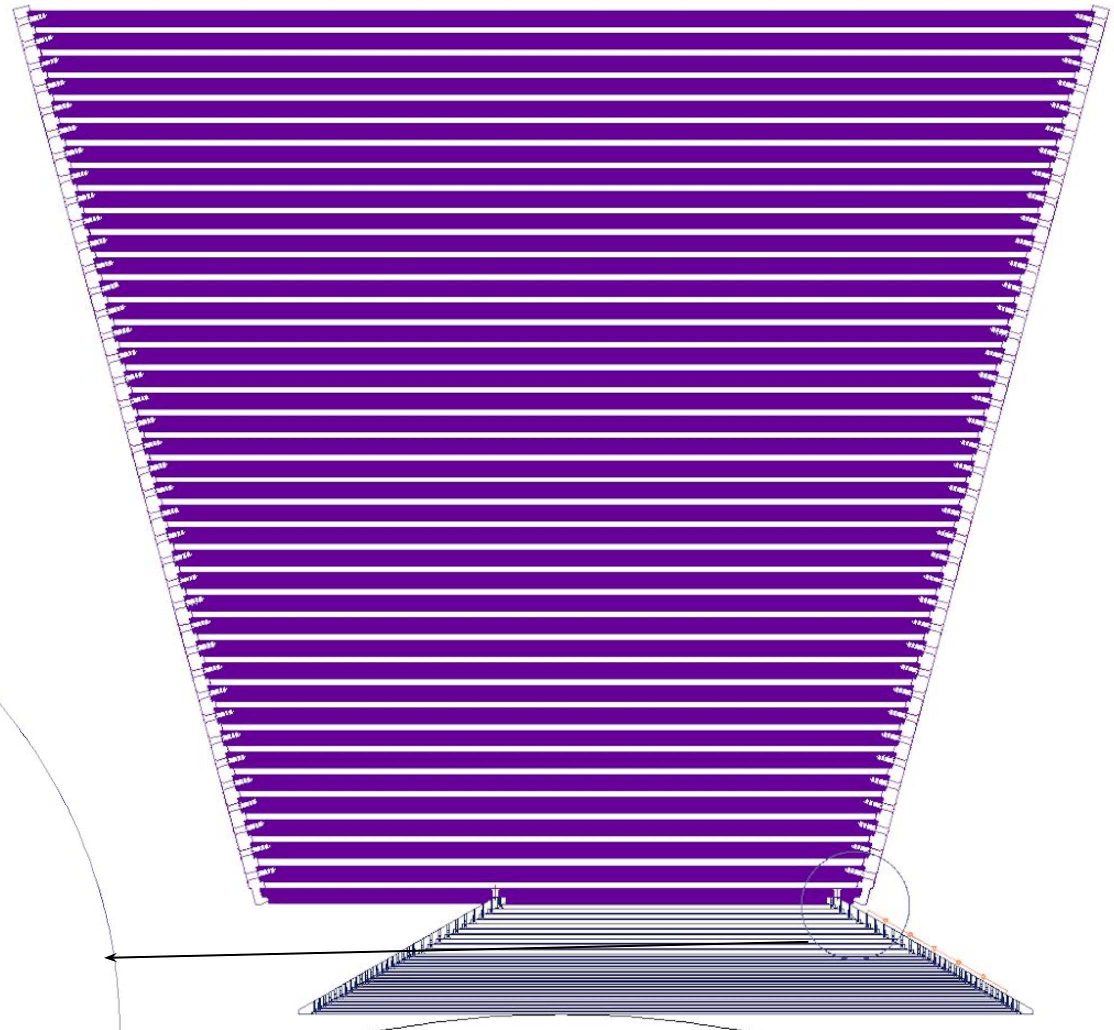
HCAL module supports ECAL module



Note module overlap: No gaps; service cables at ends.







- HCal plates supported by interlaced grooved straps
- EmCal plates screwed to support plates tied to inner Hcal plate. Inner Hcal plate “belongs” to EMCal module.
- Tungsten plates tied to each other with plausible screws and spacers

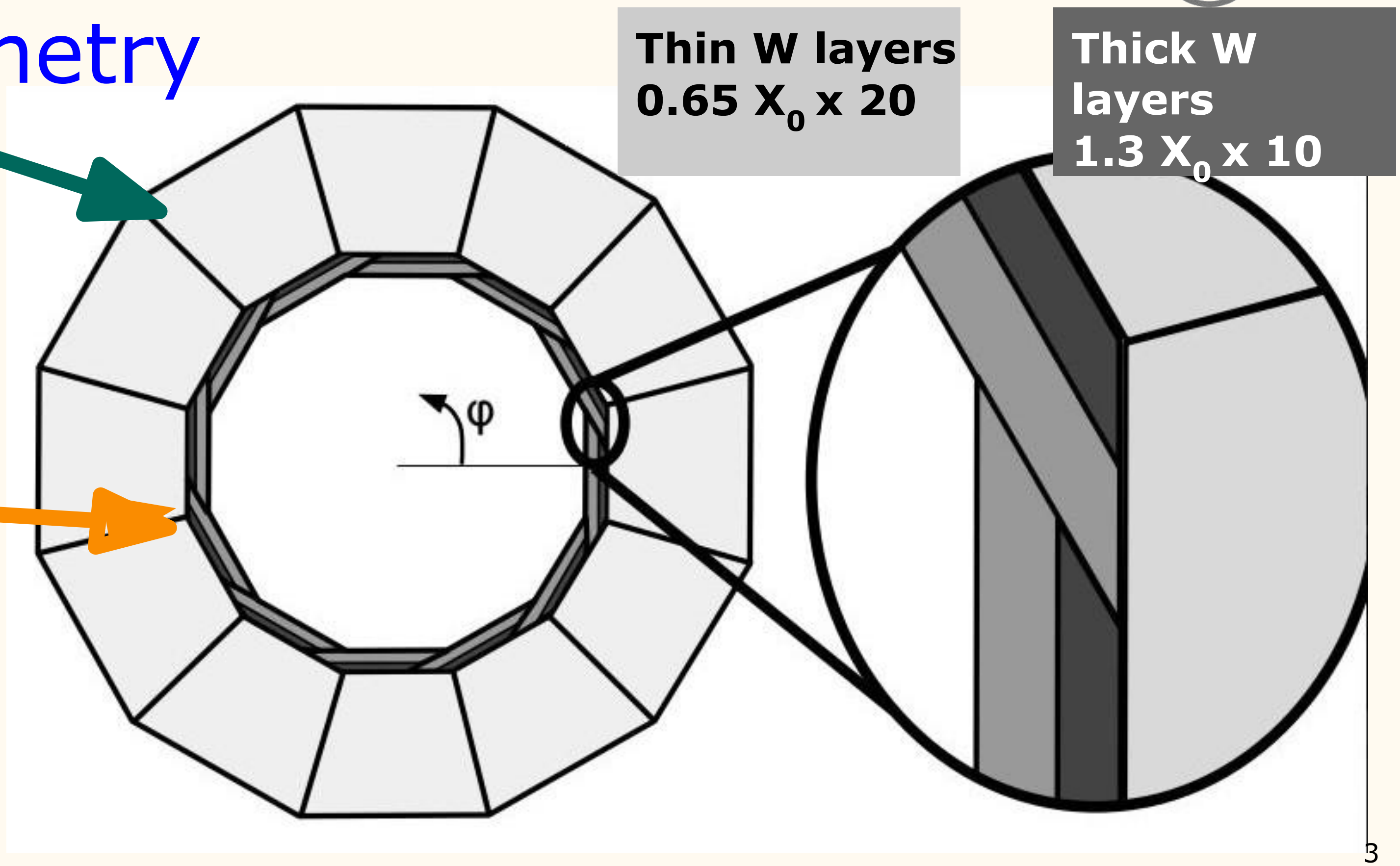
Calorimeter Geometry

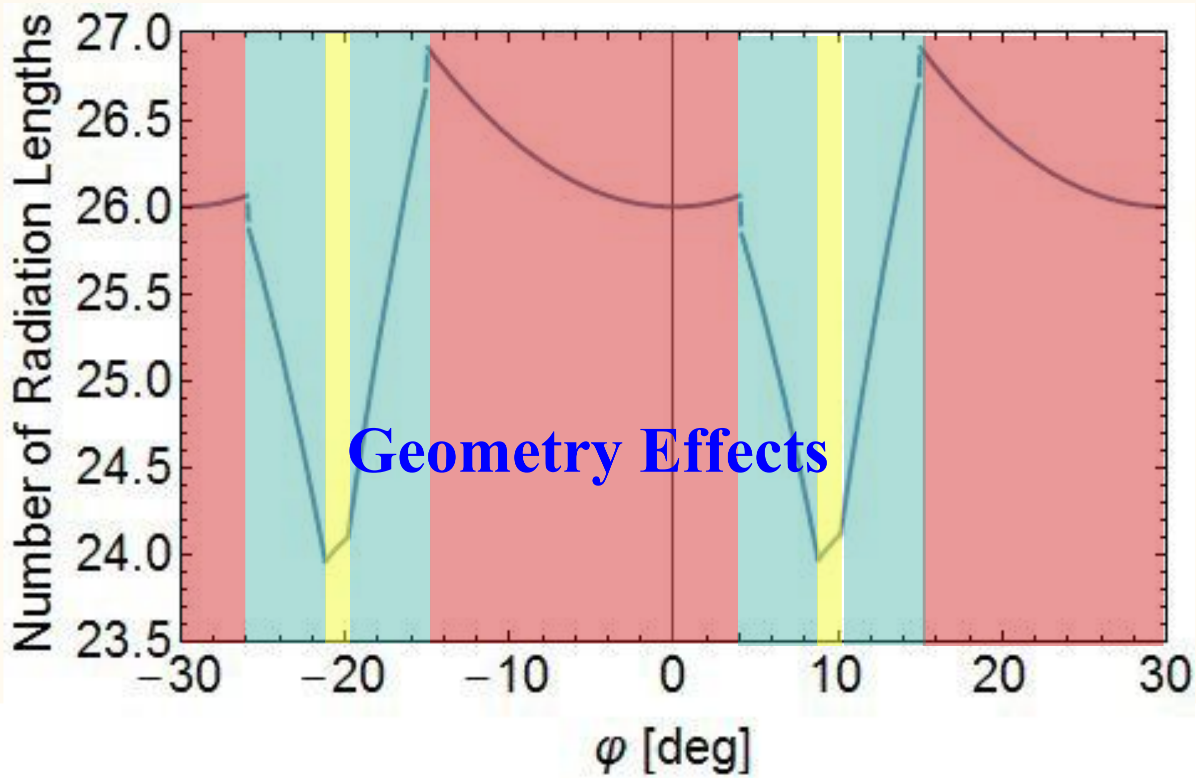
HCal

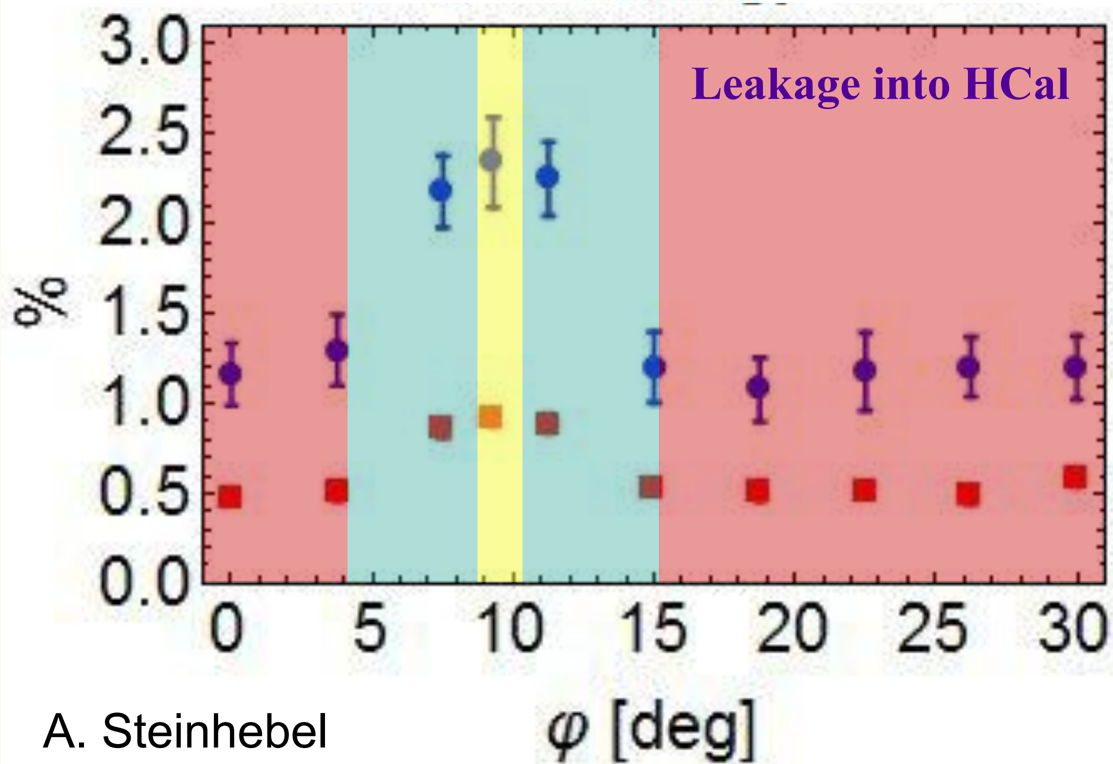
Scintillator sampling calorimeter Steel/polystyrene

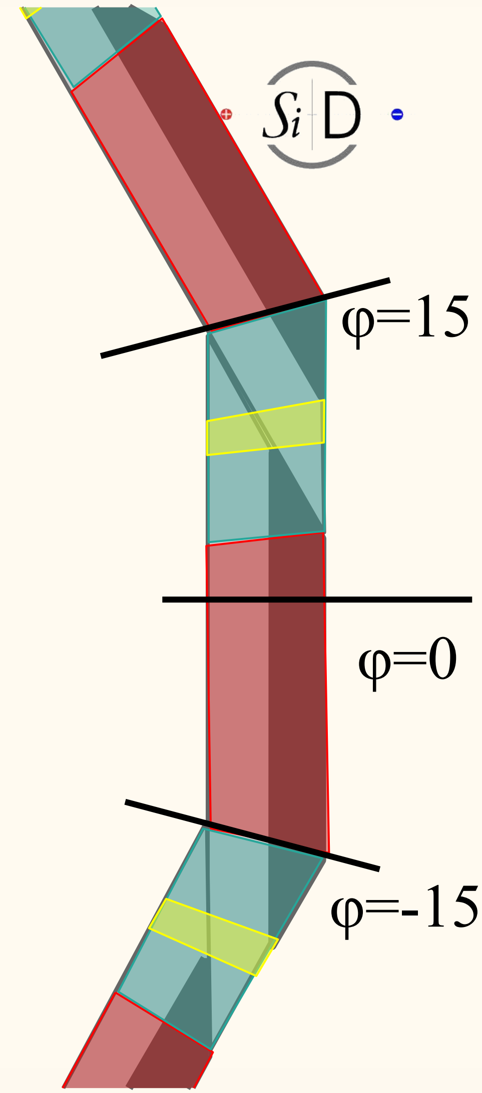
ECal

Solid state sampling calorimeter Tungsten alloy/silicon





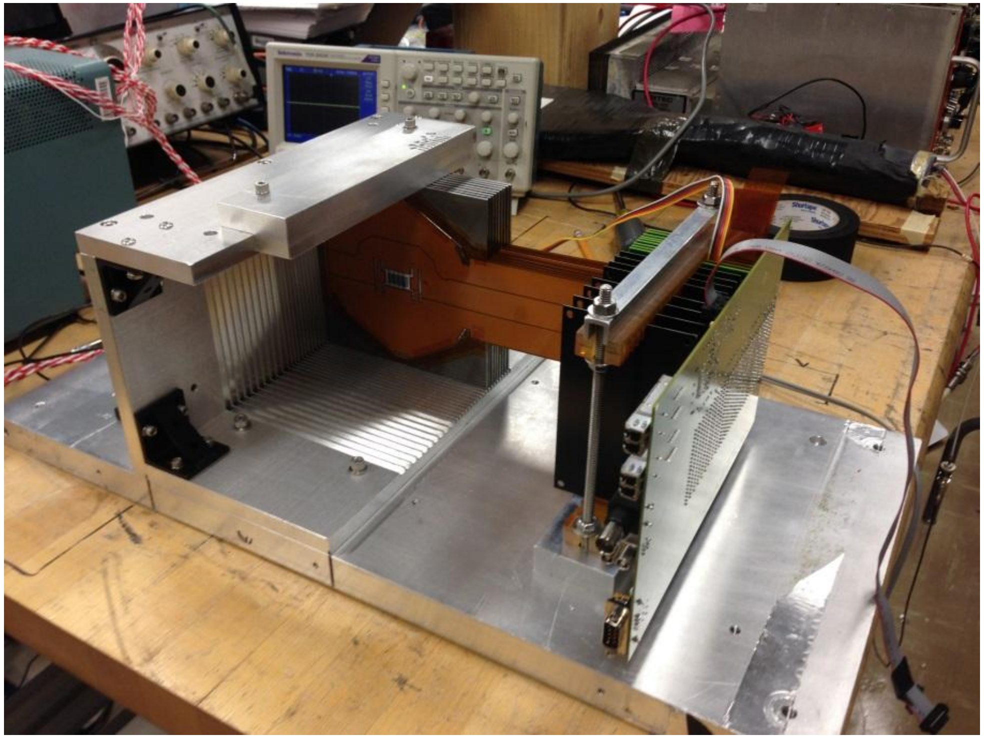




100 GeV Photons

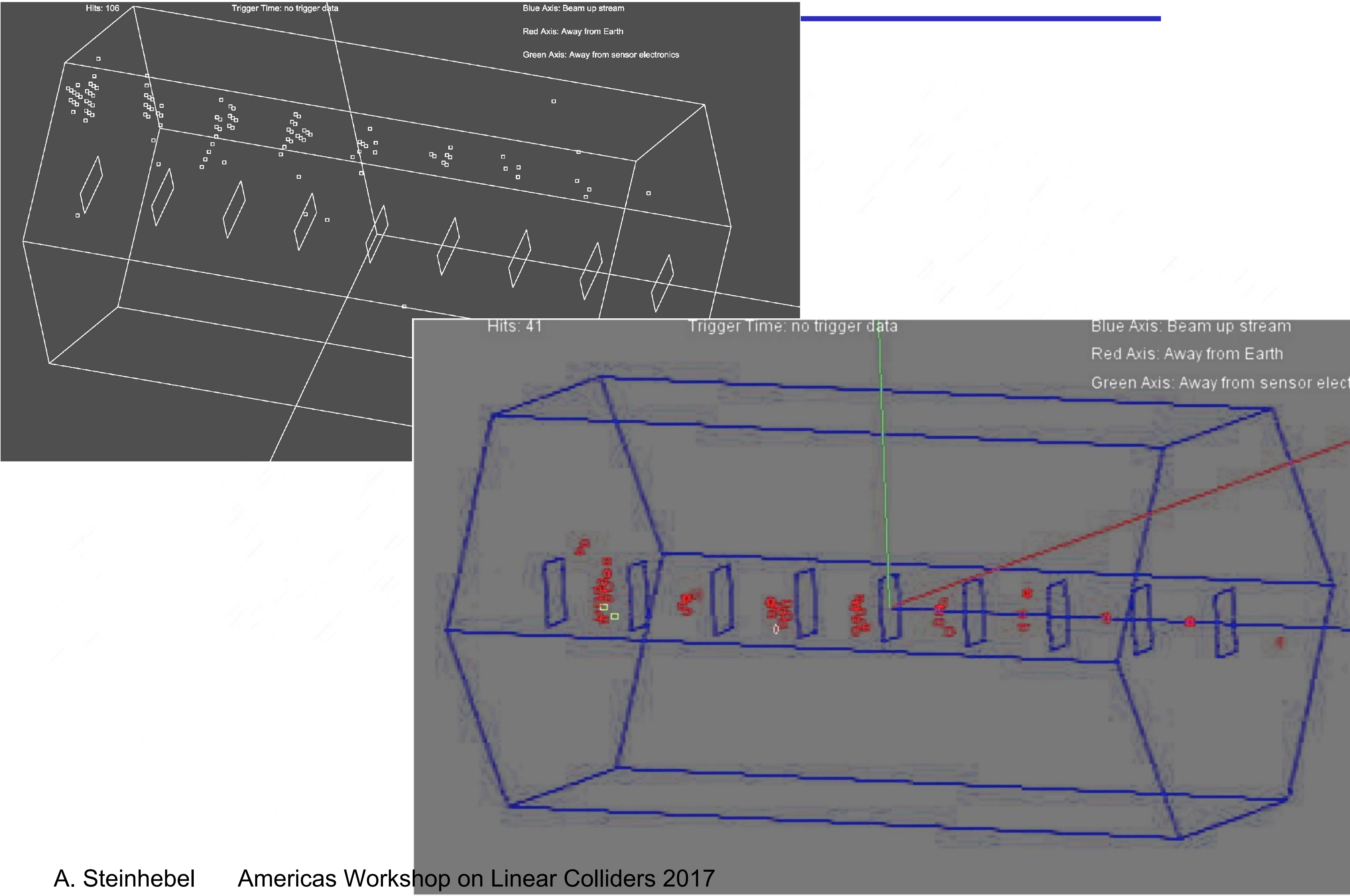
10 GeV Photons

Test beam Ecal prototype design – with SiD longitudinal profile



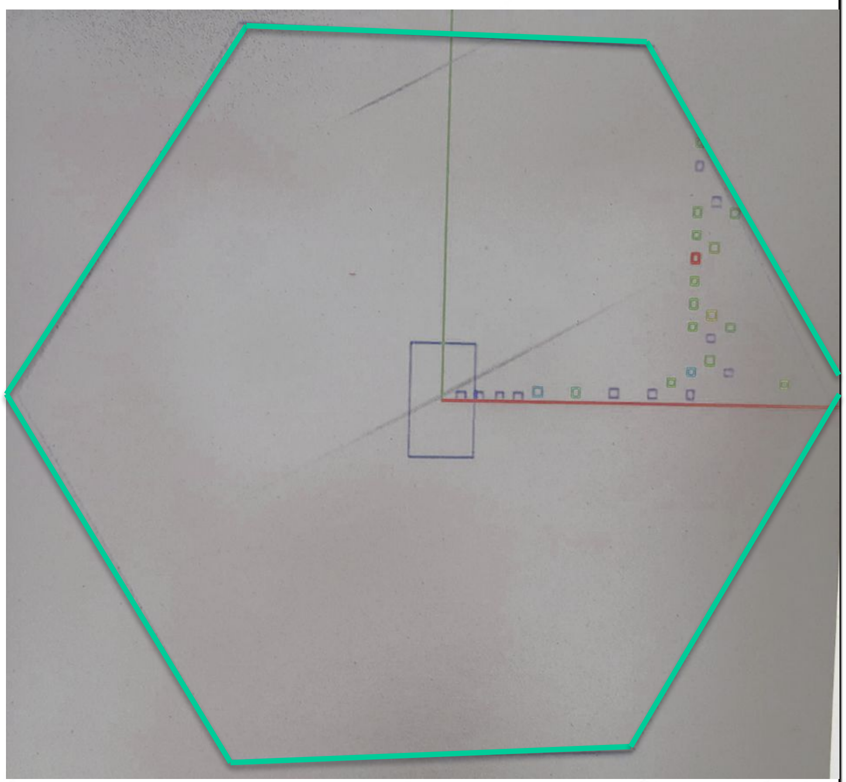
- First system test EMCal sensors in SLAC End Station A beam.
- Utilized (finally!) successfully bump bonded KPiX to sensor and sensor to cable.
- Uncovered issues related to many pixels triggered simultaneously. One part of solution may be on sensor:

Single-Electron Showers

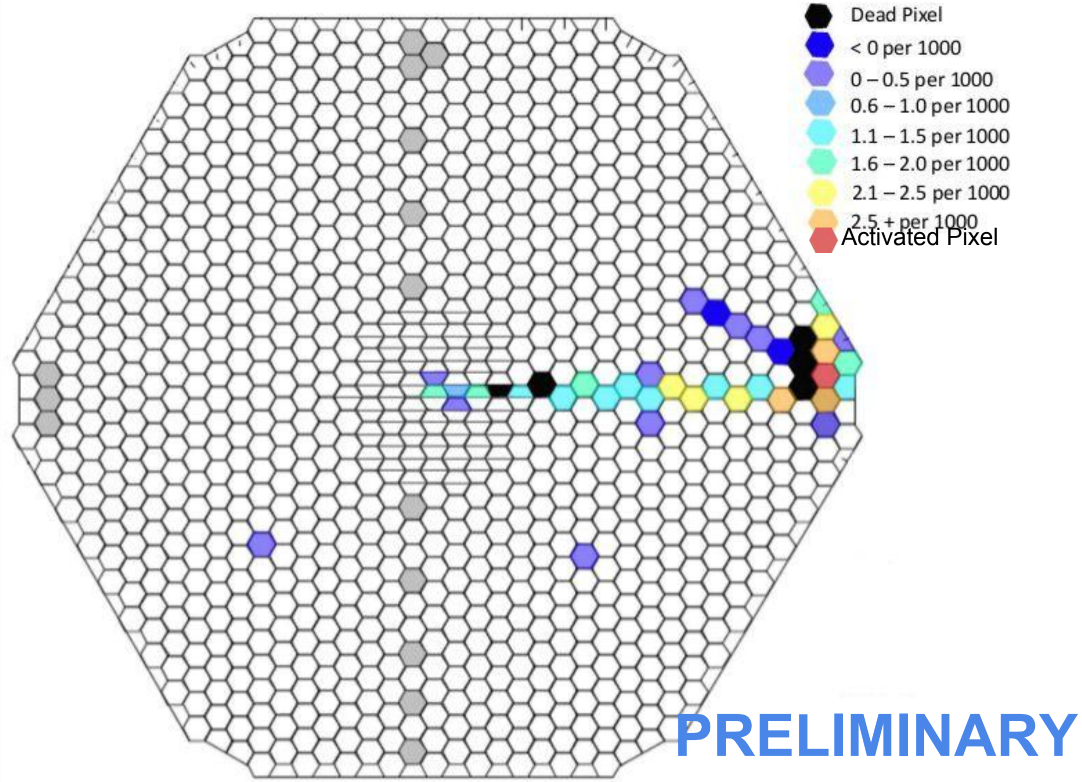


Cross-Talk on Test Beam Sensor

SLAC Test Beam



Probe-Tested Sensor

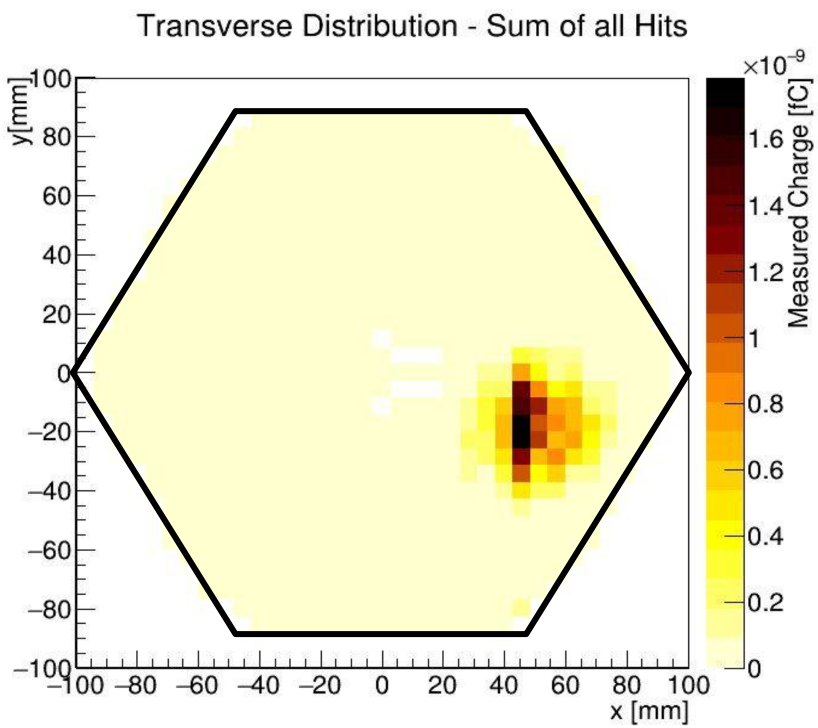


- Additional signal detected in pixels along trace of activated pixel (cross talk)
- Should be reduced with new shielded KPiX model

Work done at the University of Oregon:
C. Gallagher

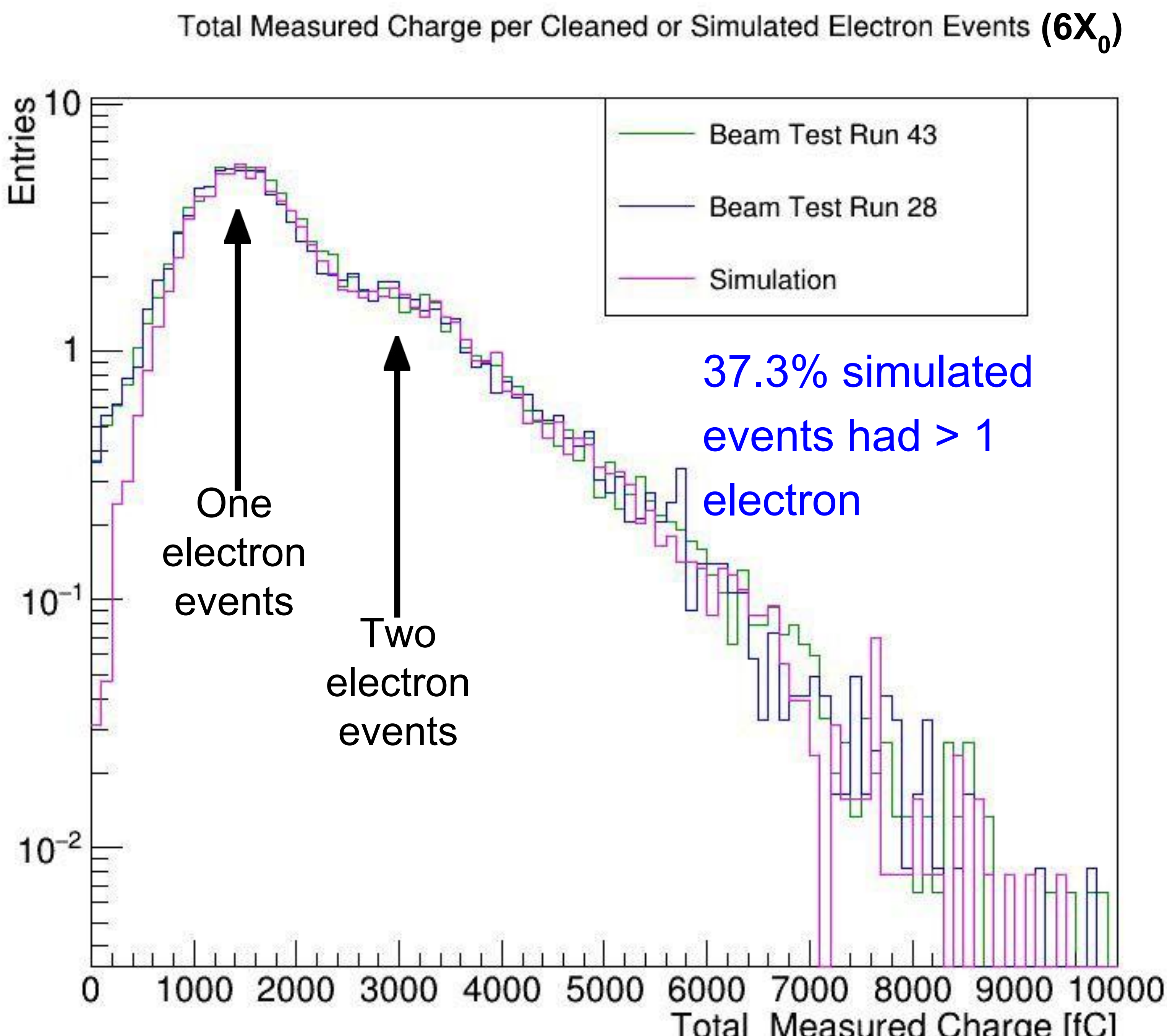
Simulation of Test Beam

- Geant4 - generated electron showers through 9 simulated Si layers (6 X_0 tungsten)
- Poisson distribution of events with 1, 2, 3, 4, or 5 simultaneous electrons
  - <n>=0.8725
- Random exc
- Normal distr om center



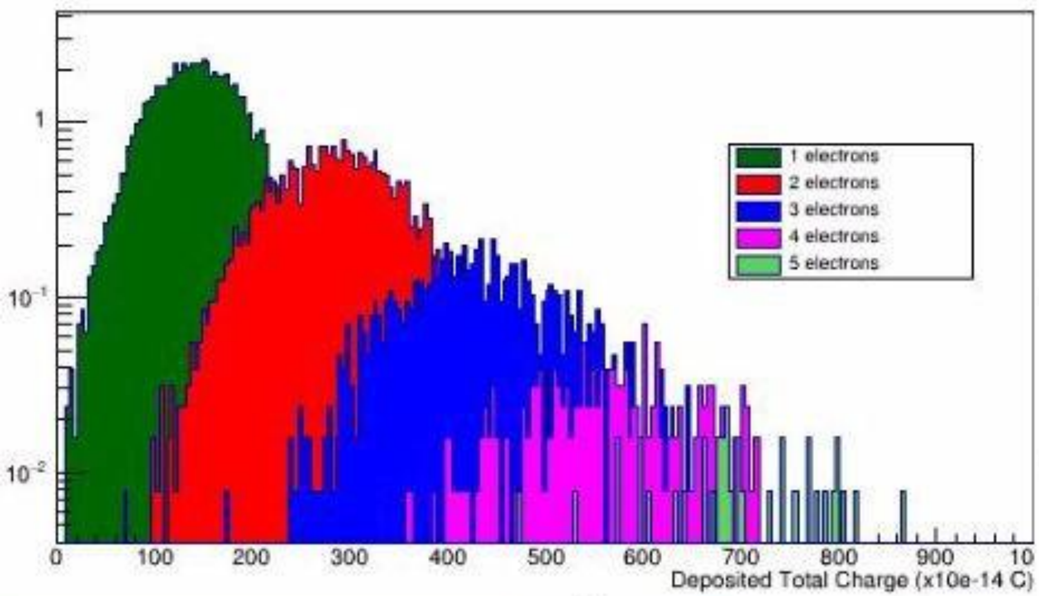
Work done at the University of Oregon: A. Steinhebel, J. Barkeloo, D. Mead

Simulation vs. Data

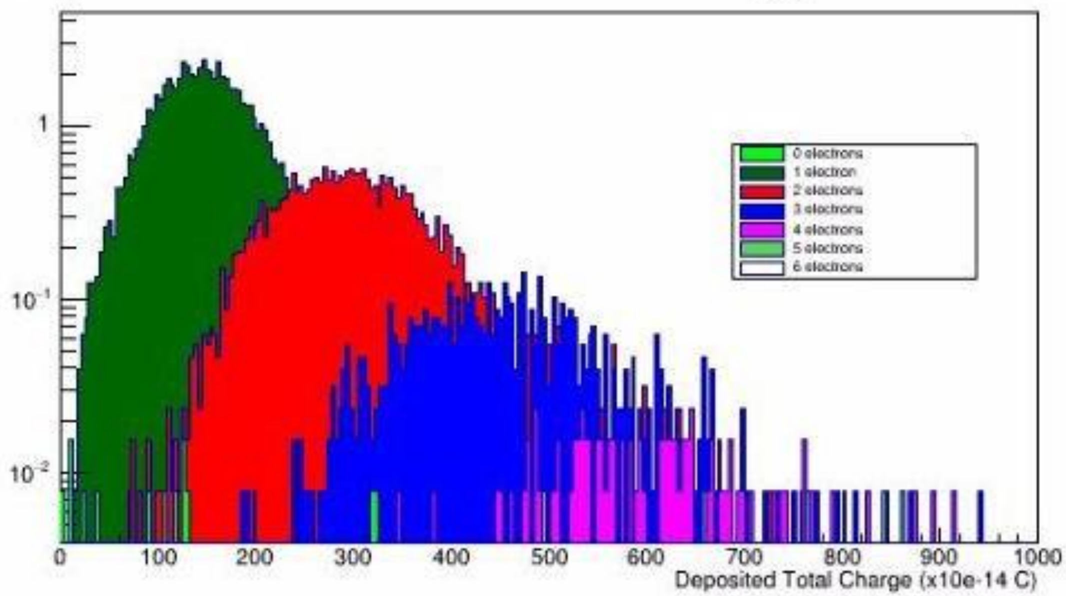


Counting Electrons in 6 X_0

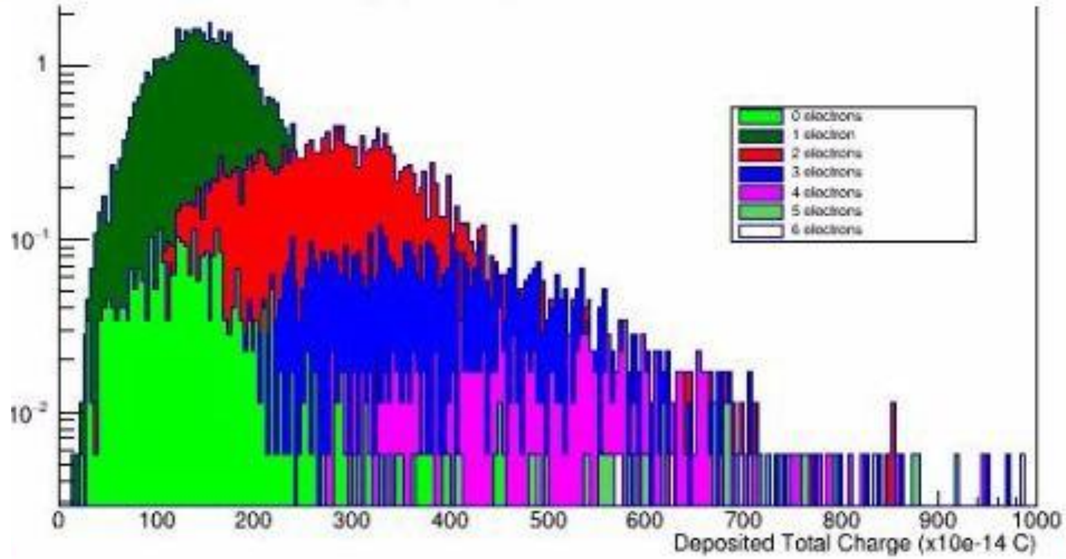
Electron Events -Simulation Truth



Electron Events -Simulation Tagged

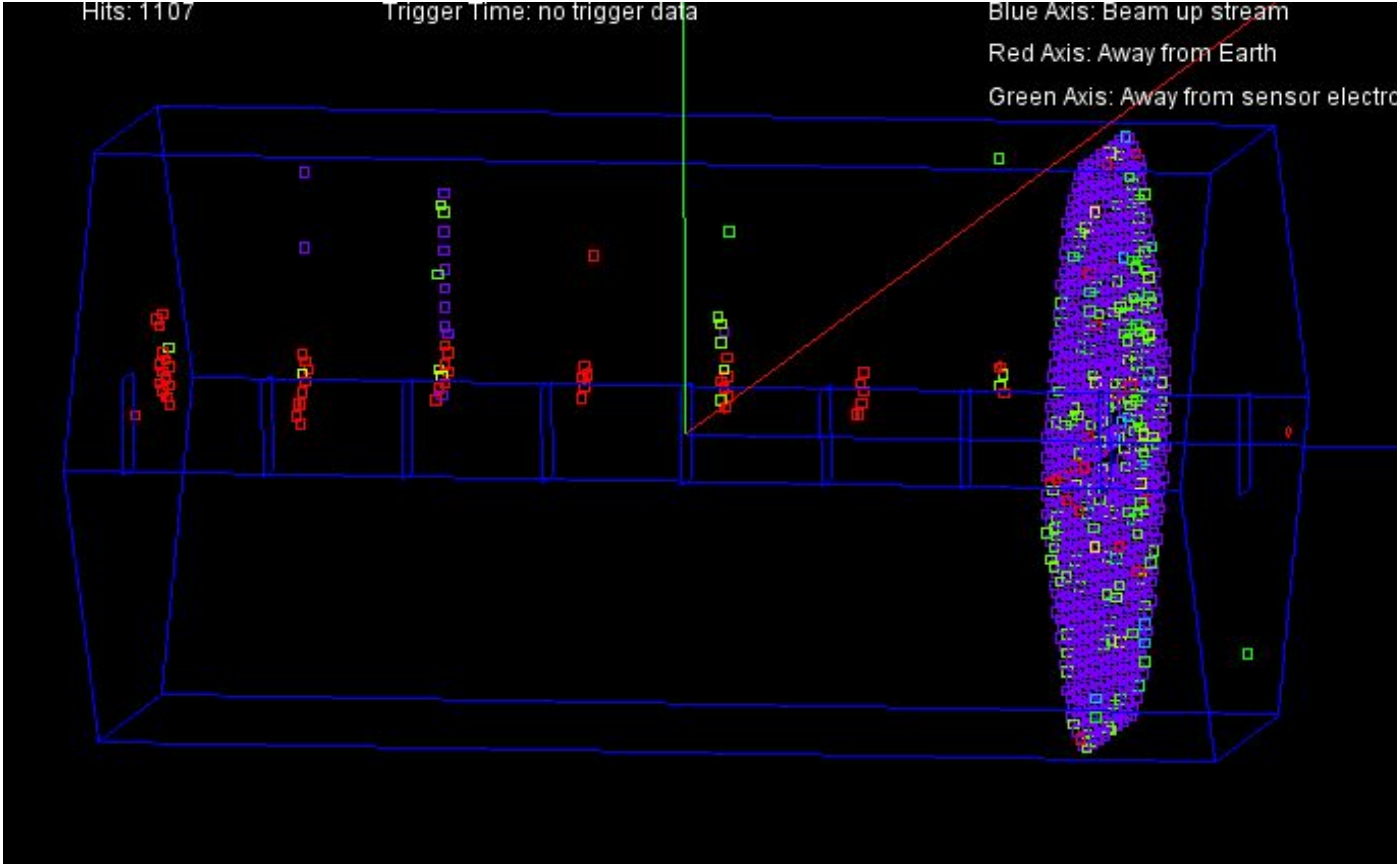


Electron Events -
Test Beam Tagged



1 electrons
2 electron
3 electrons
4 electrons
5 electrons
6 electrons
6 electrons

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

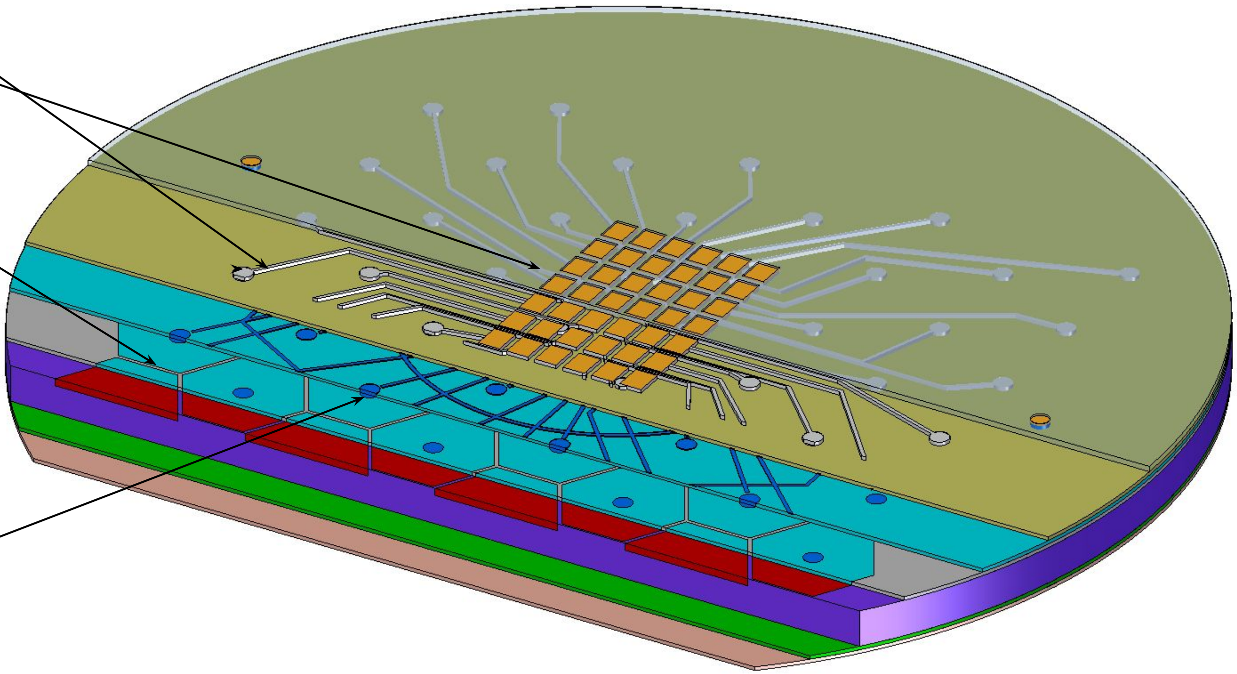


Major Lessons (so far)

- Bump bonding to sensors with Al pads can be very difficult…
    - Require sensor foundry build final pad stack.
- EMCal can have huge number of pixels hit simultaneously, causing synchronous disturbances as pixels reset…Problem understood, small changes in KPiX design.
- Sensors with ROC’s can have issues with parasitic couplings…

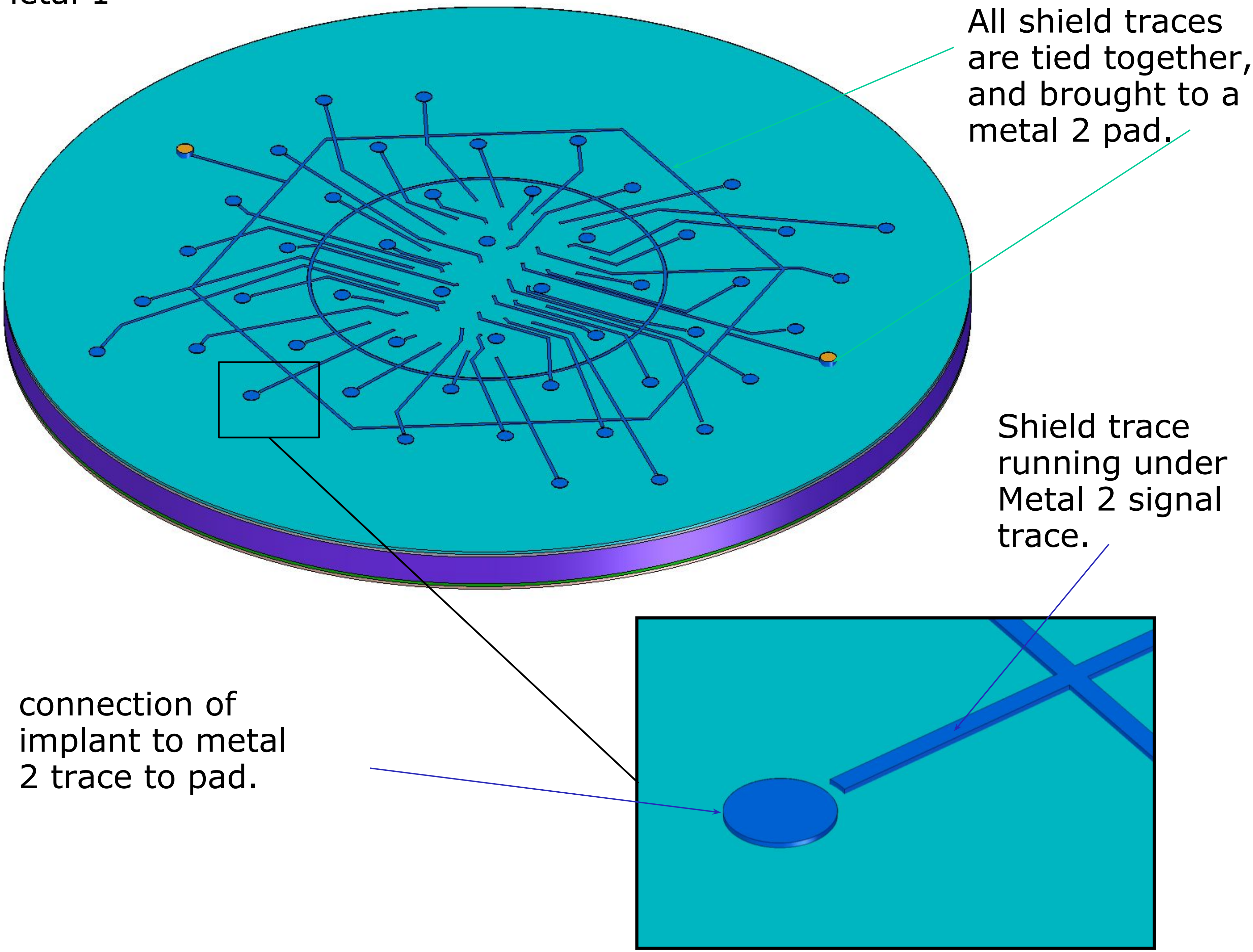
Sensor Traces

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



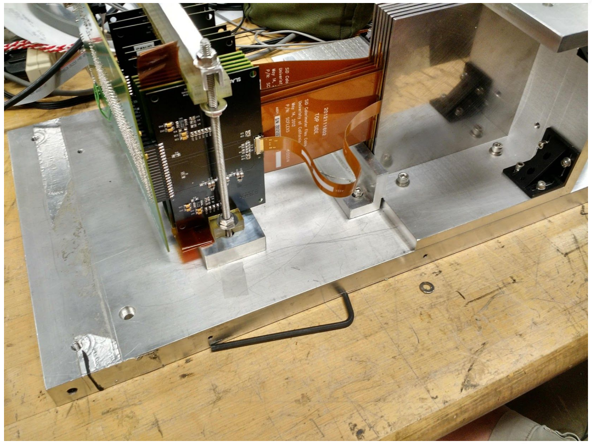
New scheme has “same” metal 2 traces, but a fixed potential metal 1 trace shields the signal traces from the pixels.

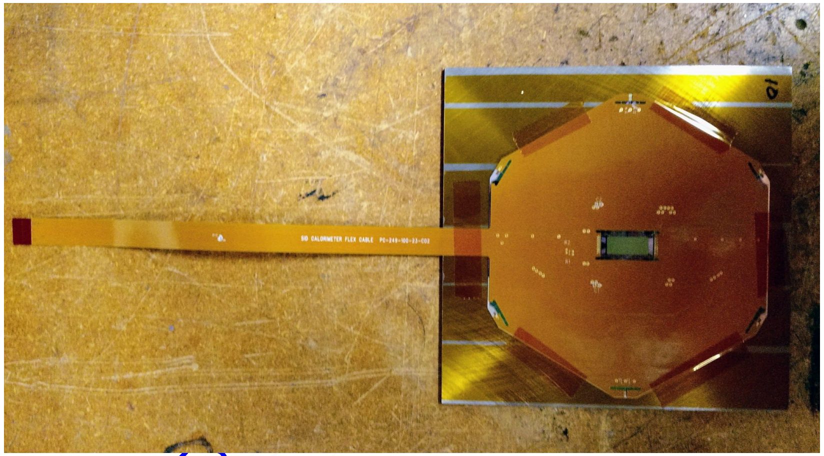
Metal 1


All shield traces are tied together, and brought to a metal 2 pad.
Shield trace running under Metal 2 signal trace.
connection of implant to metal 2 trace to pad.

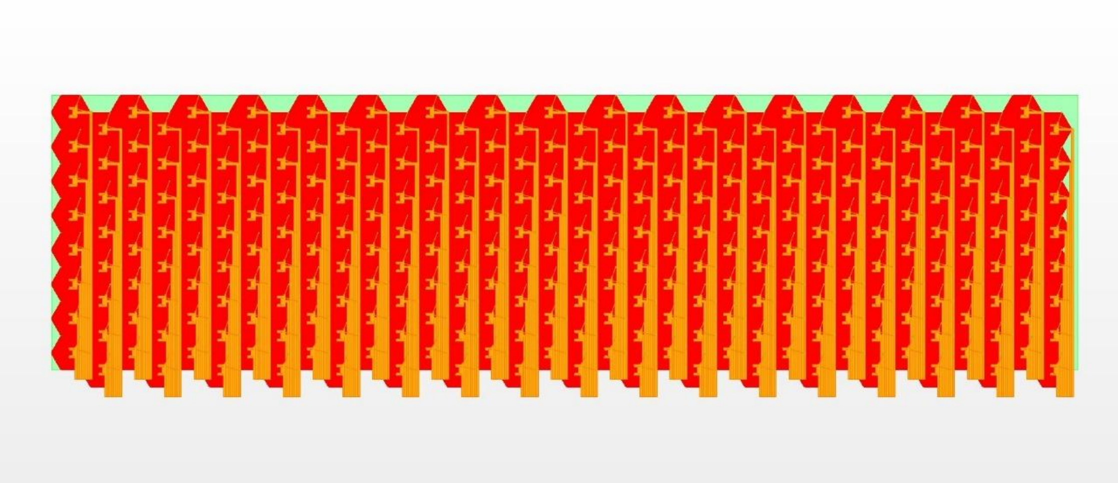
Shielded Sensors have been built

- UBM built at fab; bump bonding of KPiX easy
- Idea for cable rapidly evolving. Going to one cable per sensor, with cable tails arranged to lie parallel across sensors.
- Wire bond cable rather than bump bond. Bump bonding too fussy a technique for cable.
- Testing beginning – ~~no results yet~~. Sensor and KPiX calibrate. Means all KPiX to sensor and cable to sensor connections good.

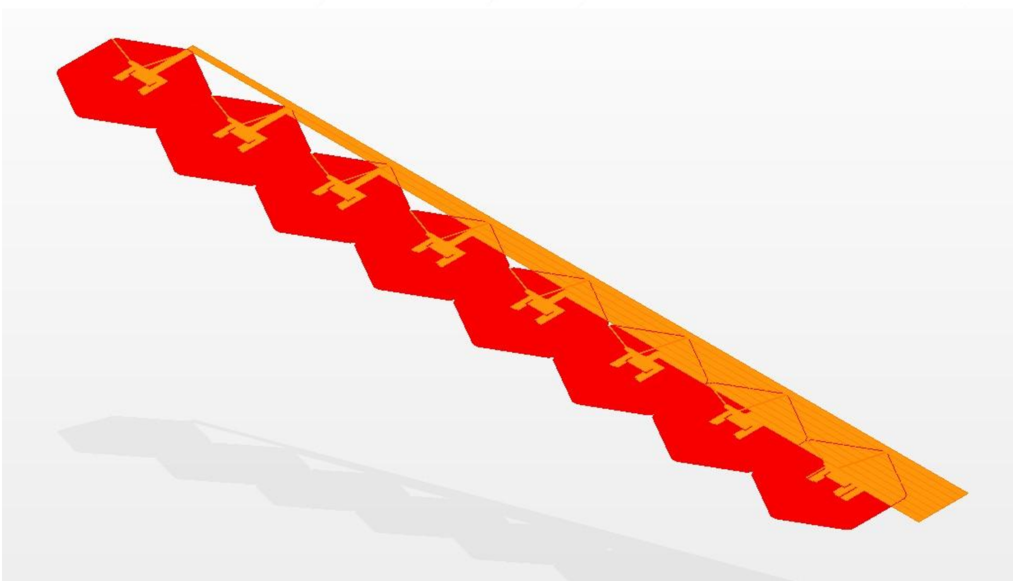


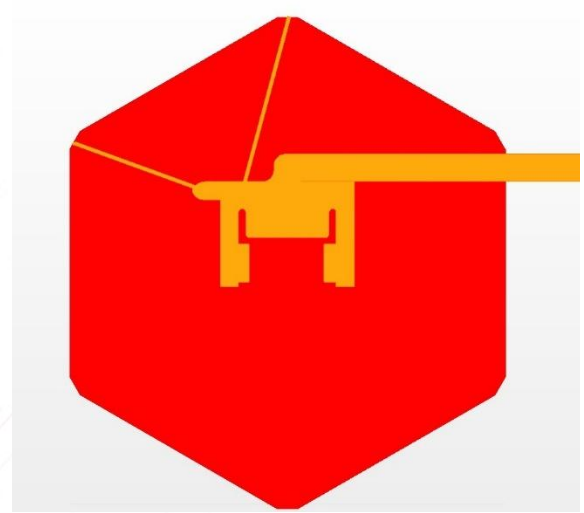


New Cable Concept



Full width Barrel Layer (largest)
Cables run to exposed edge



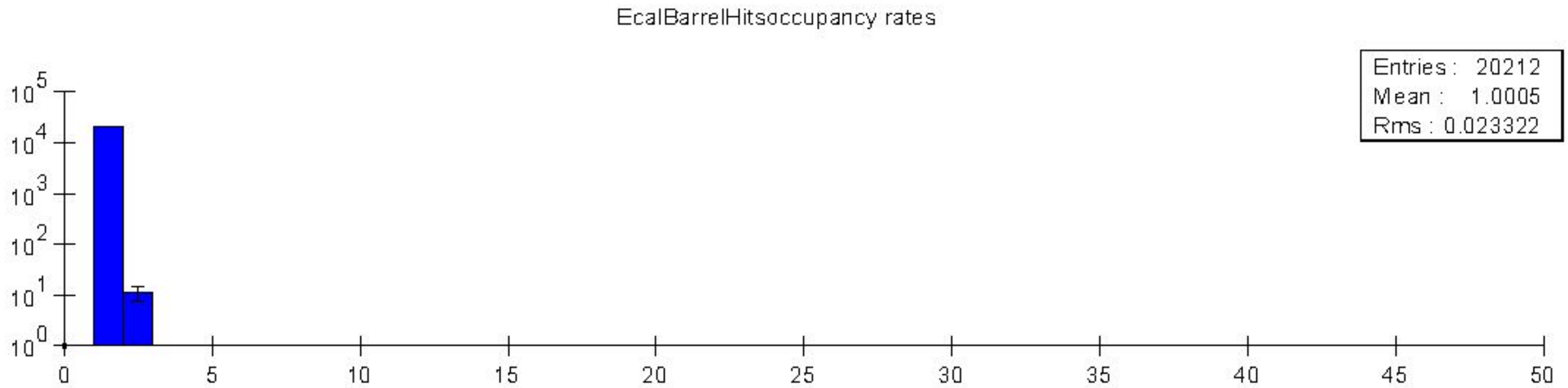


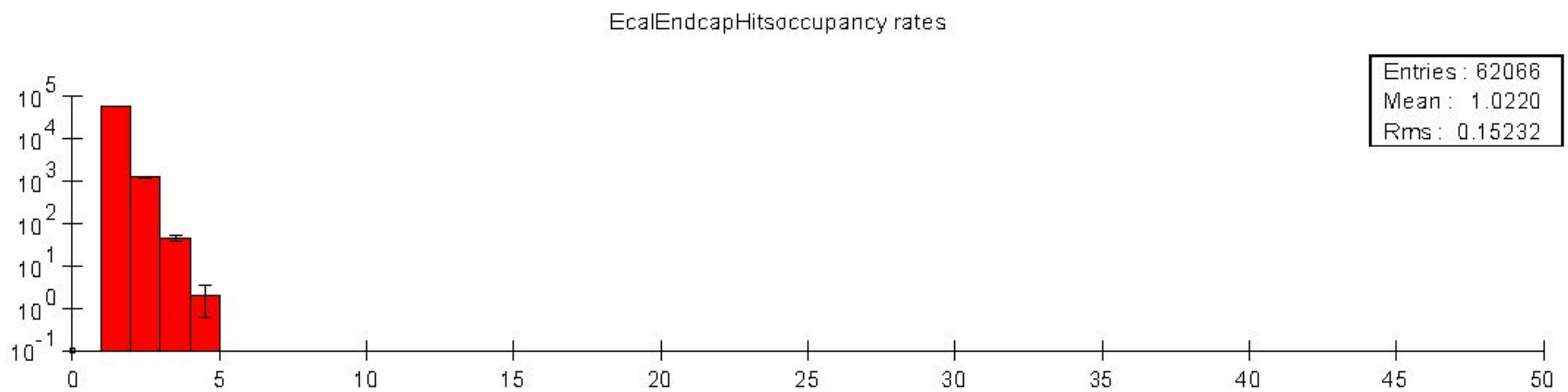
Multiplicity

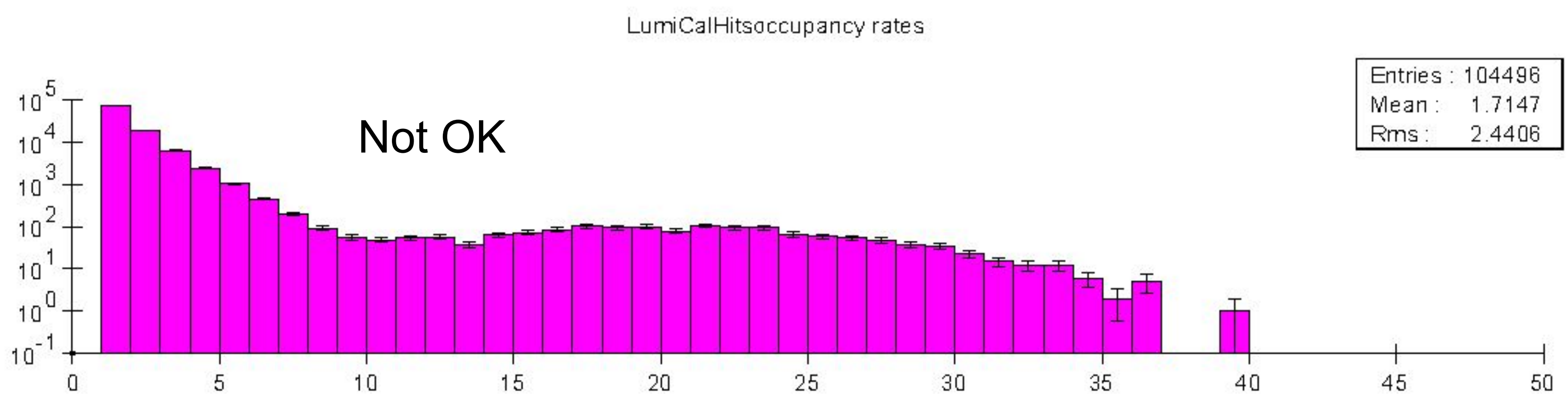
- There have been indications that forward multiplicity might be more than 4 buffer KPiX could handle.
  - Long known that BeamCal required BEAN chip, which digitizes every pulse.
- Study only has Guinea Pig pairs so far;
- Bhabhas must be added before concluding anything!

Have generated one train's worth of pairs resulting from beam-beam interactions at 500GeV - 1325 bunches

Represent nominal ILC luminosity, "high-luminosity" running would be x2


EcalBarrelHitsoccupancy rates
Entries : 20212
Mean : 1.0005
Rms : 0.023322


EcalEndcapHitsoccupancy rates
Entries : 62066
Mean : 1.0220
Rms : 0.15232


LumiCalHitsoccupancy rates
Entries : 104496
Mean : 1.7147
Rms : 2.4406
Not OK

Multiplicity

- Bhabhas must be added
- Lumical must be studied to see if high multiplicity is only first layers, which might not need to be instrumented.
- Study KPiX to see if more buffers might be added, preserving architecture.
- Study somewhat different architecture – preconceptual ideas only…

2019 - kPixM (monolithic pixel sensor: MAPS) (*if funding available*)

SLAC, Argonne

Based on KPiX readout chip experiences

Design and fabricate two types of MAPS:

- For ECAL (kPixM-Cal)
- For tracking (kPixM-trk)

Two major challenges:

- Design reticle scale MAP sensors
- Integrate together into full size sensor modules - 10-20 cm square.

The kPixM family:

SLAC

General characteristics

- Amplitude and Timing extraction on N bunches per train in each pixel (N=1 for the tracker, N=16 for the calorimeter)
- Synchronous (time-variant operation)
- Ultra-large Area beyond reticle size (stitching)
- System-on-chip approach (limited IO required
- Platform based design
- Sparse readout
- Power Pulsing
- Calibration per pixel
- Temperature monitoring and tracking
- Auxiliary Monitoring

	kPixM-Trk	kPixM-Cal
Pixel size	50x500 μm²	1000x1000 μm²
Array	200x2400	100x94
Full Size	Stitched 5x5 reticles	Stitched 5x5 reticles
Max. Signal	1fC	1pC
Effective ENC	<200e-	<1000e-
Filtering	LP + CDS	LP + CDS
S/N	>20	>4
In pix mem. depth	1 bucket	16 buckets
ADC resolution	12 bits	12 bits
DC Power cons.	~ 20μW/pix	~ 20μW/pix
Power pulsing	Yes	Yes

SiD Workshop 2016 20

Summary

- There is progress towards a mechanical conceptual design of the EMCal!
- The beamtest demonstrated expected behavior of the prototype but showed different crosstalk issues in the sensor and KPiX.
- There is a shielded design now beginning testing.
- Evaluation of expected forward multiplicities is ongoing. This will influence KPiX evolution.