SiD EMCal Testbeam Prototype

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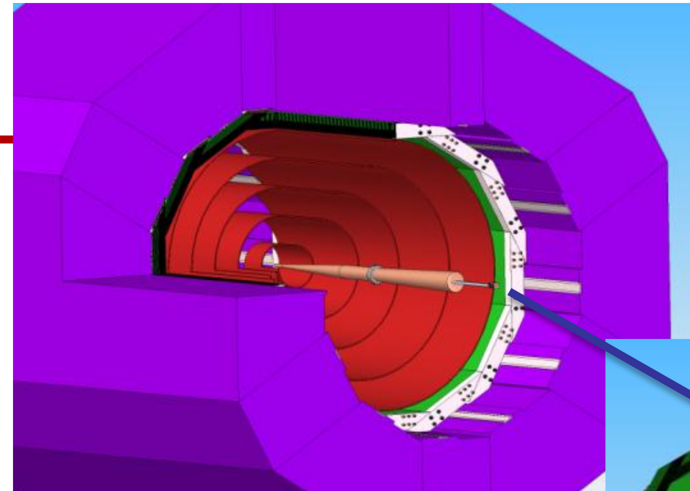
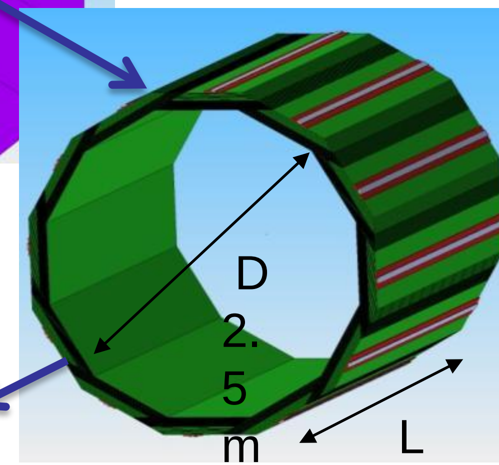
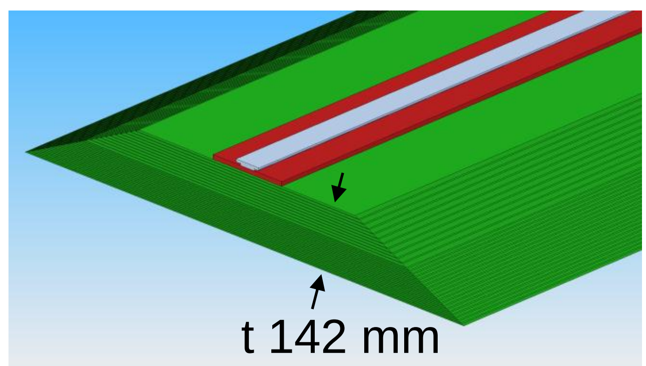
ECAL

Prototype Goals:
•Replicate full EMCal stack and test – 30 sensors.

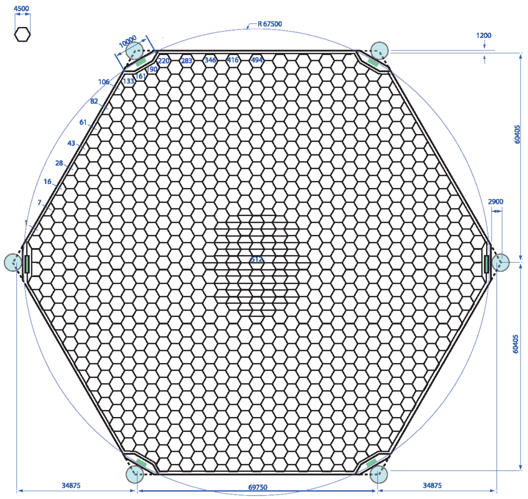


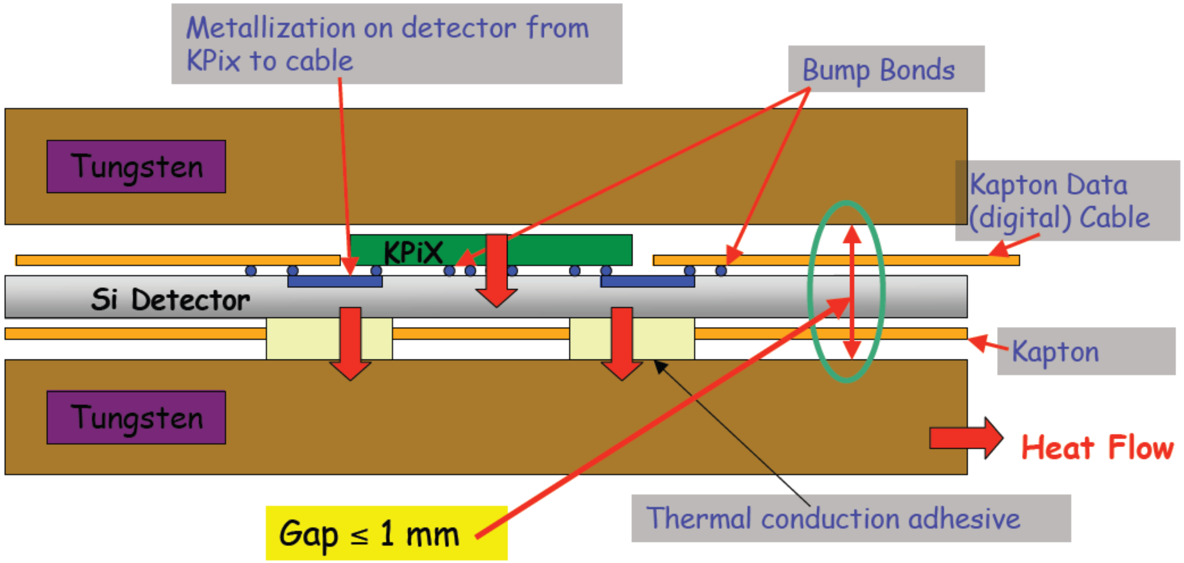


20 layers 2.5 mm W (5/7 X0)
10 layers 5 mm W (10/7 X0)
30 gaps 1.25 mm w Si pixels sensors
29 X_0; 1 λ
$\Delta E/E = 17\%/\sqrt{E}$;
Effective Moliere radius = 13 mm



Details of EMCal Structure.





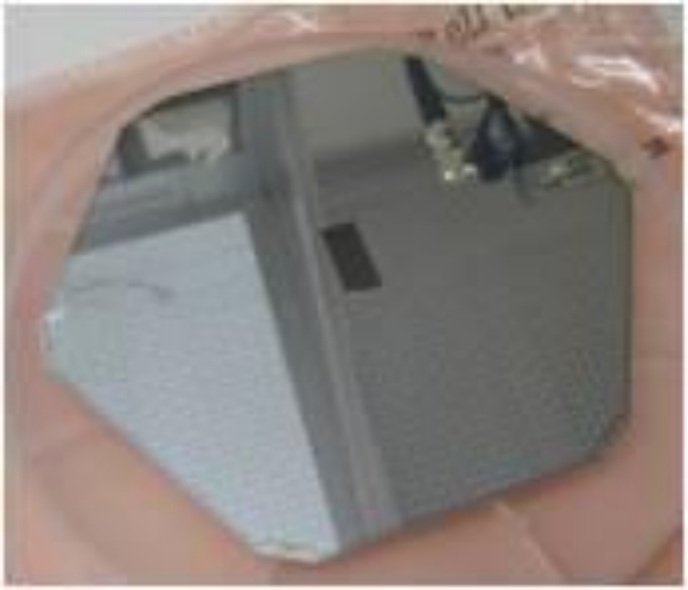
Boundary Conditions

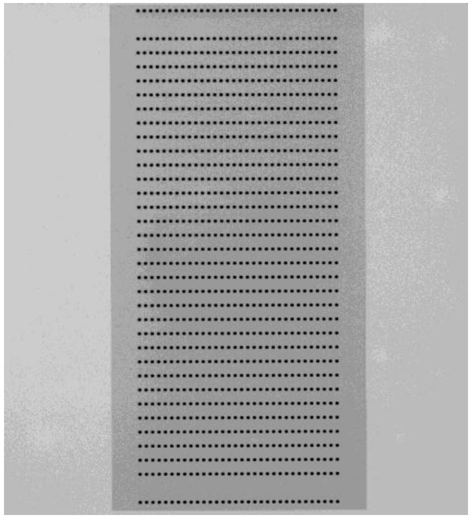
- We have 40 nominally good Hamamatsu sensors.
- We have ~20 nominally bad “mechanical prototype” sensors.
- We have 28 remaining KPiXa (1024 channels).
- The KPiXa’s come from TSMC with eutectic Sn-Pb bumps in place in wells on the chip.

- The Hamamatsu sensors (EMCal and Tracker) come with Al pads, so there is a layer of Al_2O_3 which must be removed…

Under Bump Metallization (UBM)

- UCD put a huge effort into UBM:
  - » Used the mechanical prototype sensors
  - » Zincate – chemistry to remove the Al_2O_3 and plate a stack ending with Au.
  - » Sputtering – to directly implant Ti and then a stack ending with Au.
- With miserable results!
  - » Possible explanation is that there is something else on the pads, but SEM sees only Al and O.
- We finally went to IZM in Germany who use a sputtering process.
  - » They have bonded 2 KPiXa's to 2 mechanical prototype sensors.
  - » They have bonded 15 KPiXa's to 15 "good" sensors. 2 failed IZM (x-ray) QC.

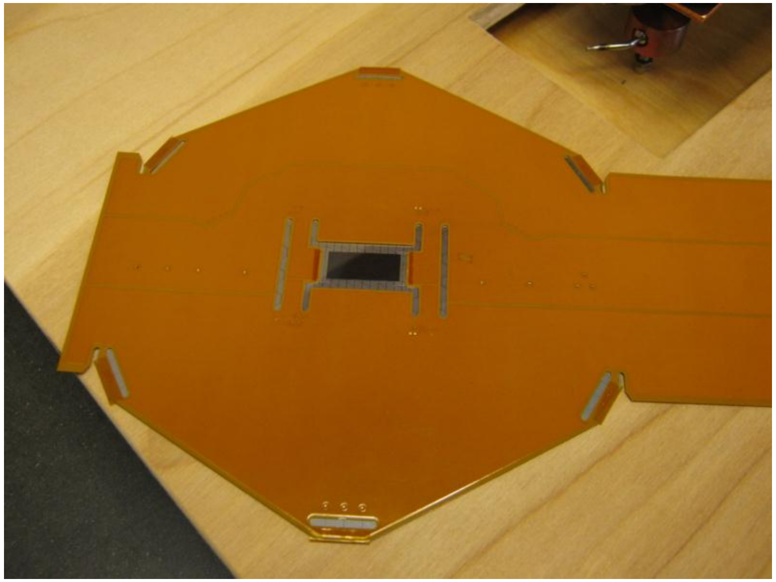


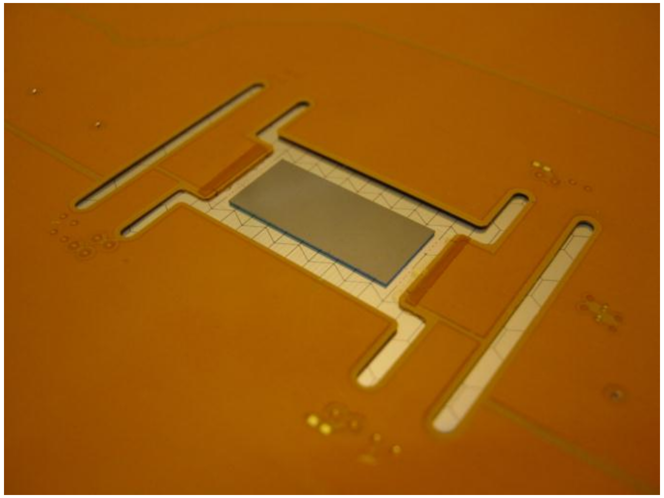


X-ray image of bumps - IZM

Bonded Sensor

- UCD has bonded cables to 5; they are being tested at SLAC.
- UO is probe testing non-cabled assemblies. First results ~now.



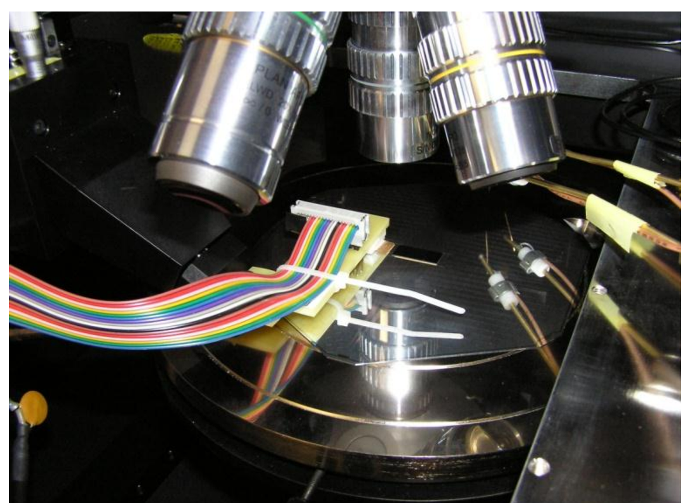


KPiX bump bonded to sensor
Cable bump bonded to sensor
Assembly 1 mm high

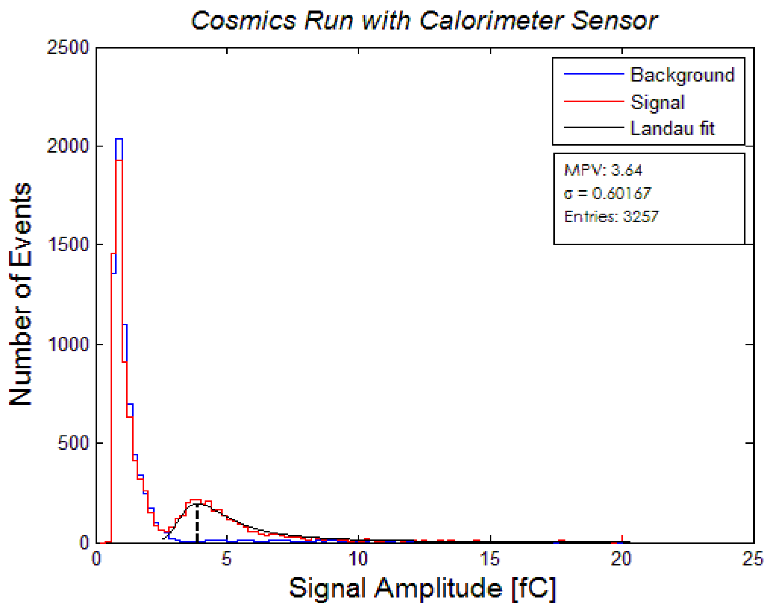
Results…for good sensors

- ~90% of pixels calibrate properly
- ~5% pixels appear to be shorted. Calibration charge is shared between two non-adjacent pixels in the same column. Not understood!!
- Other pixels do not calibrate, being studied now.
- An early suspicion was flux remnants under KPiX, "shorting" bumps or pads. Plans to test this very soon.

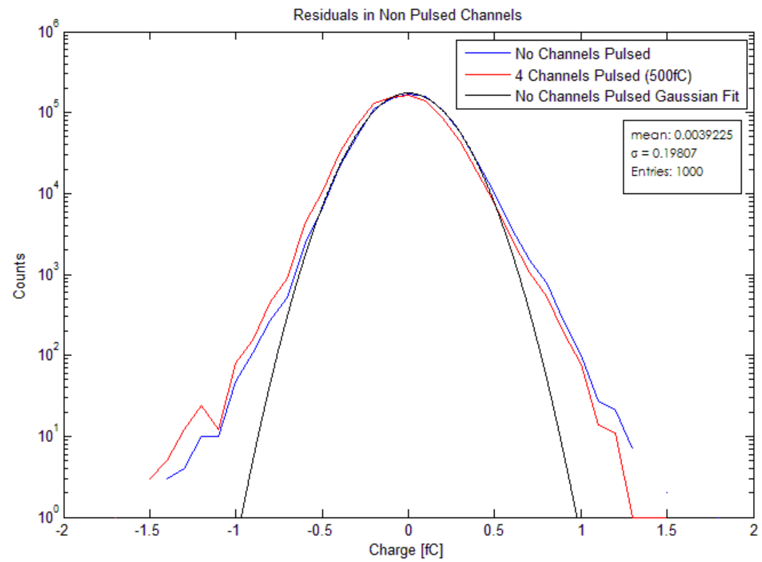
- UO has probed a few other prototype sensors, and sees ~3% opens.
- We do not yet have the corresponding good/open/bad pixel numbers for the UO sensor.



First Performance Studies

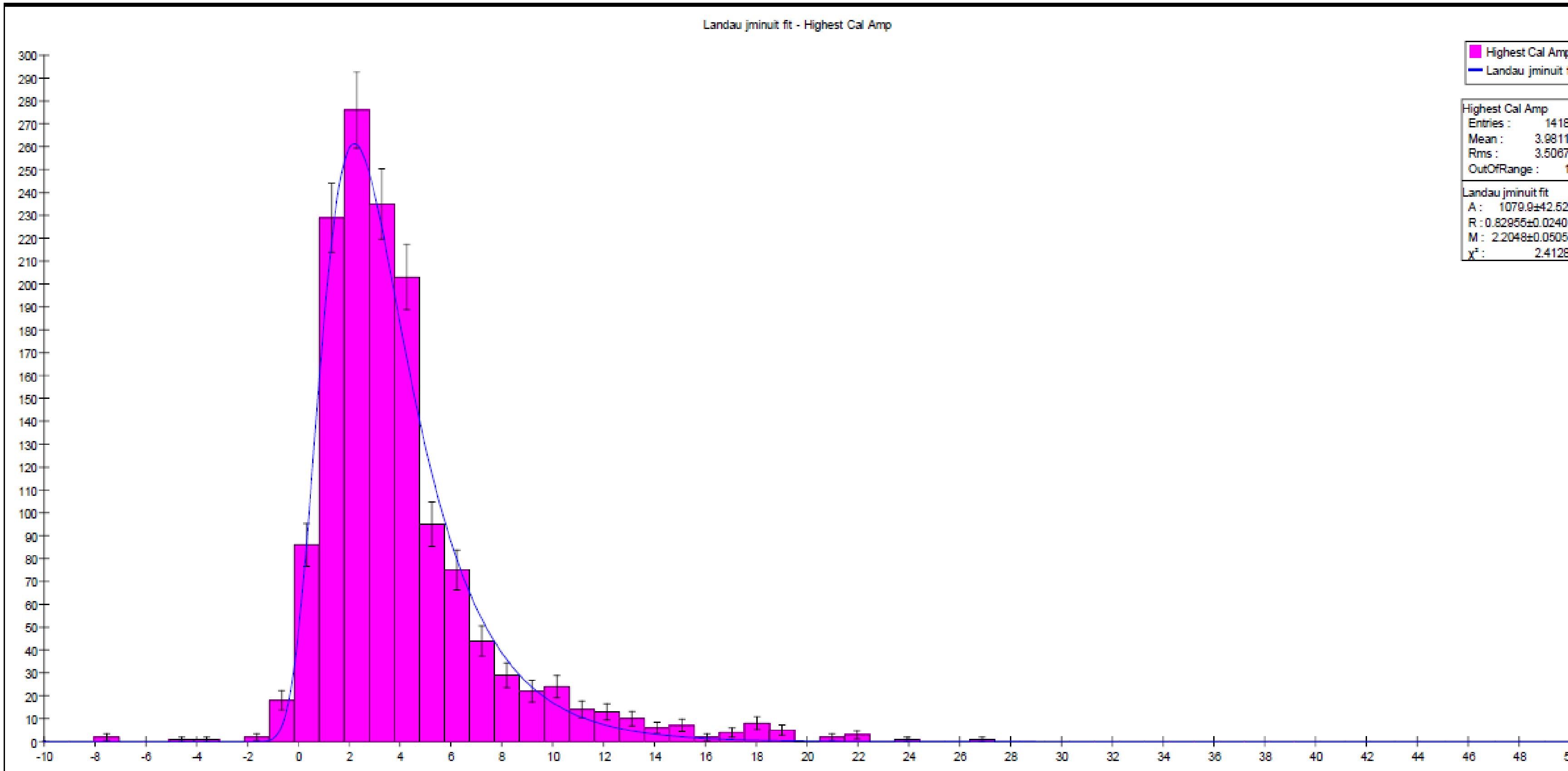


Cosmic telescope trigger

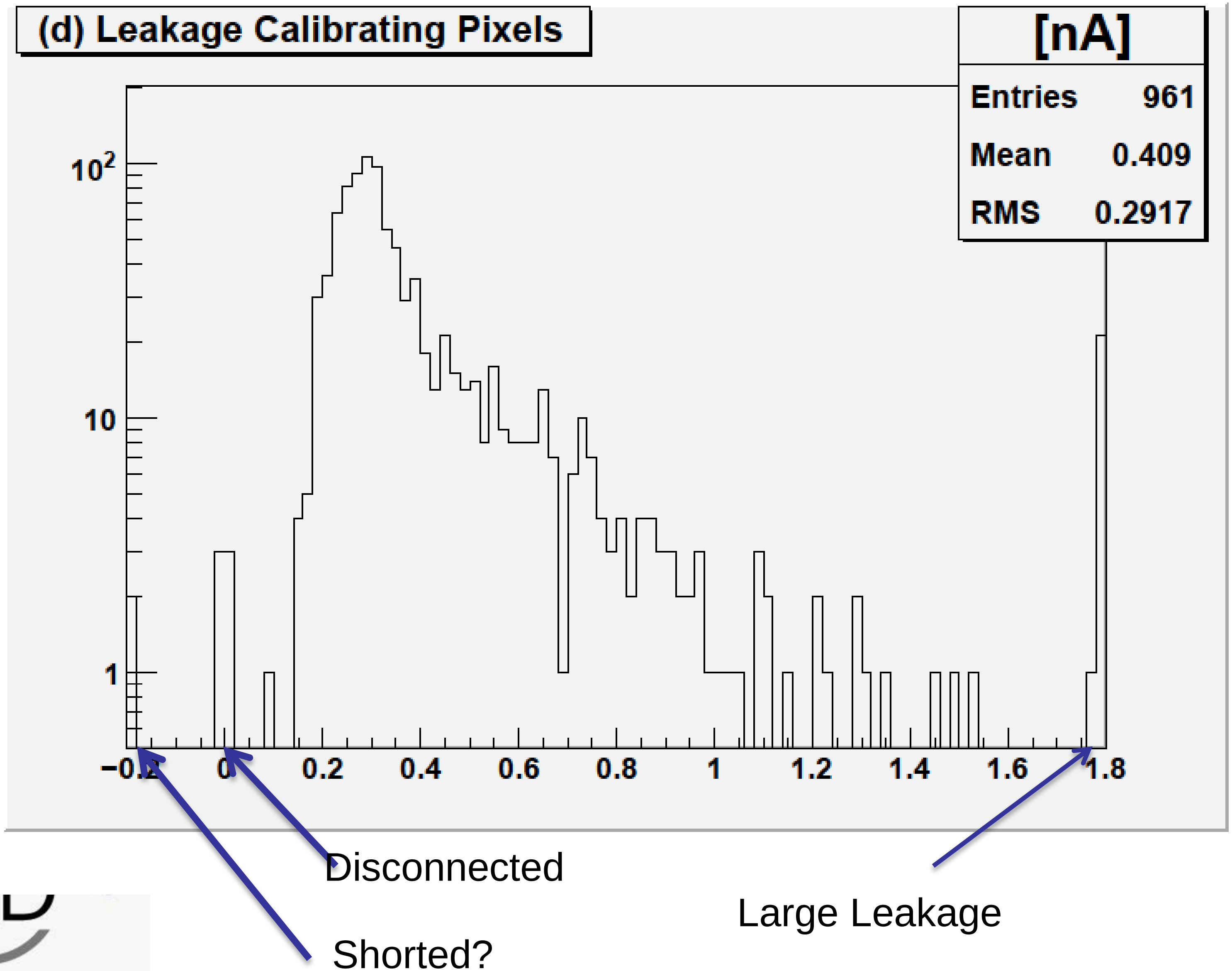


Cross talk Study: Red: 4 pixels pulsed at 500 fC,
All other channels shown. Blue: no pixels pulsed.

Cosmic Rays. KPiX Self Triggered (pixel by pixel)



Sensor 5



(d) Leakage Calibrating Pixels
[nA]
Entries 961
Mean 0.409
RMS 0.2917
10^2
10
1
−0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
Disconnected
Shorted?
Large Leakage

Sensor Status

Assembly	Good Slope	Disconnected Pixel	Good Pixels	Shorted Pairs	Possibly Usable
~~1~~	~~896~~	~~114~~	~~782~~	~~70~~	~~852~~ Mechanical prototype
2	920	20	900	90	990
3	955	12	943	60	1003
~~4~~	~~929~~	~~30~~	~~900~~	~~80~~	~~979~~ Very noisy; bad power connection
5	961	6	955	50	1005

With poor statistics, and using shorted pairs, ~98% of pixels will work.

Performance Comments

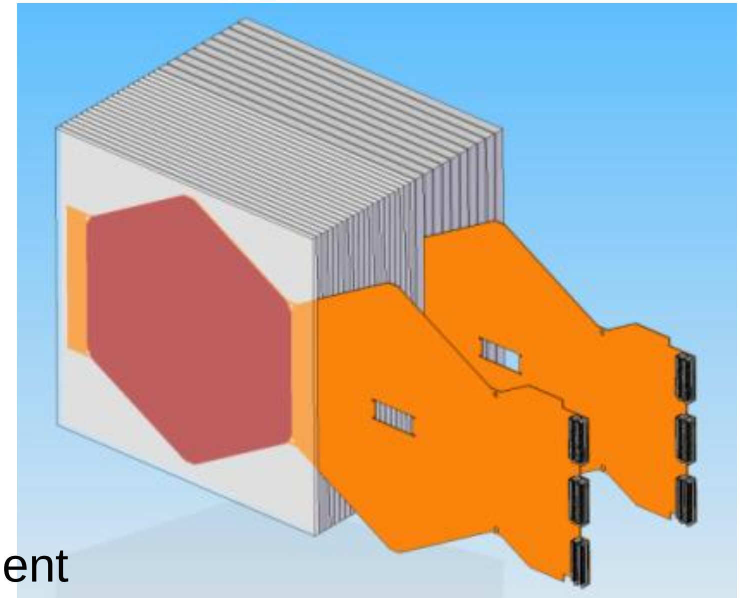
- The first version of the electronics reading out KPiX gave excellent “analog” performance – e.g. self triggered multiplicity was ~1, and there were no “everything lights up” events.
- This indicates that KPiX and its sensor, cable, and enclosure environment is satisfactory.
- The new electronics, suitable for 32 KPiX, needs more work.
- It is probably ok for the testbeam (short window).

Prototype

<u>Silicon sensors</u>: Meet specs. for SiD Ecal
•low leakage current; DC coupled
• sufficient number for prototype (30 layers)

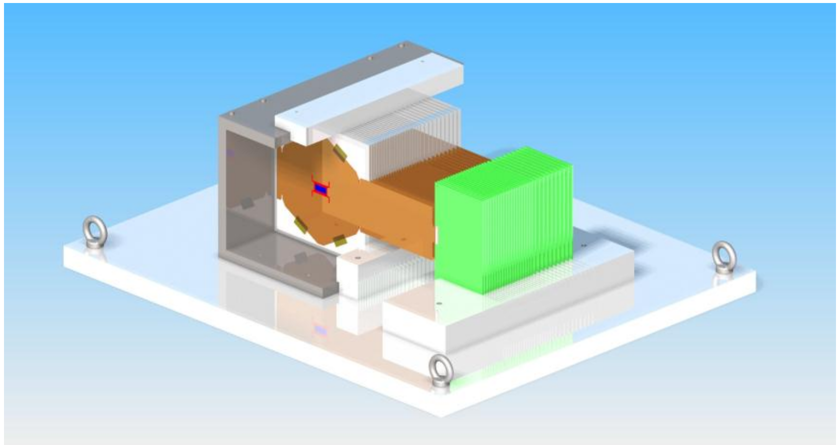
<u>KPiX: </u>prototypes meet SiD specs.:
• low noise (10% of MIP)
• large dynamic range: $\sim10^4$
• full digitization and multiplexed output
• passive cooling (power pulsing)

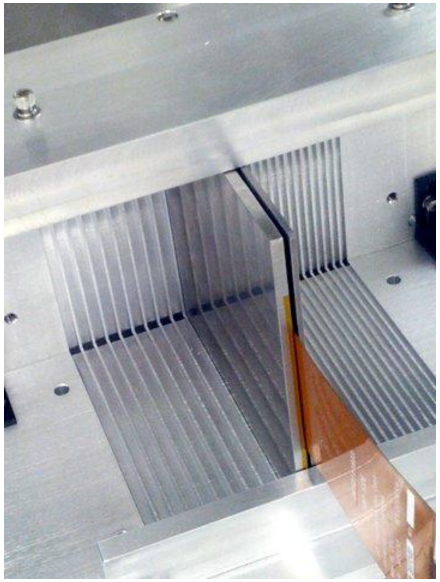
<u>Interconnects</u>:
• Flex cable R&D ok so far – successful attachment to dummy sensors and 1 mechanical prototype.
• Main focus of recent R&D is the KPIX – sensor interconnects … recently successful – we think…

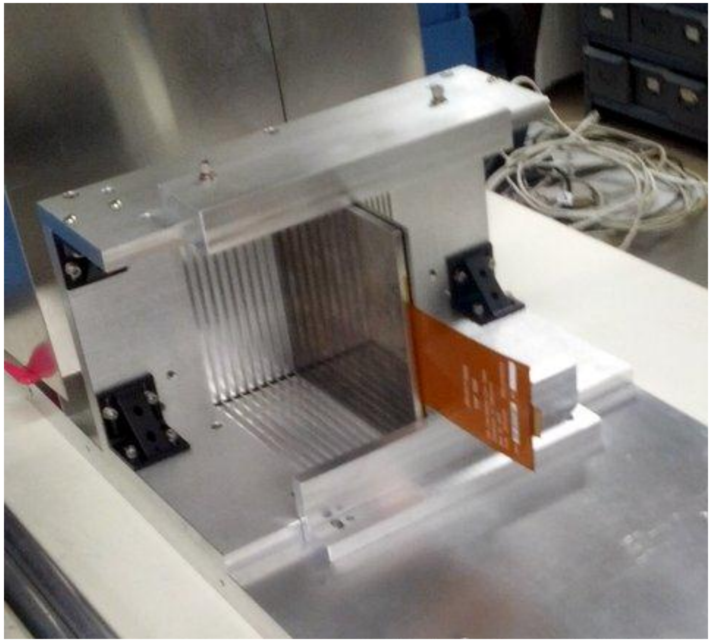


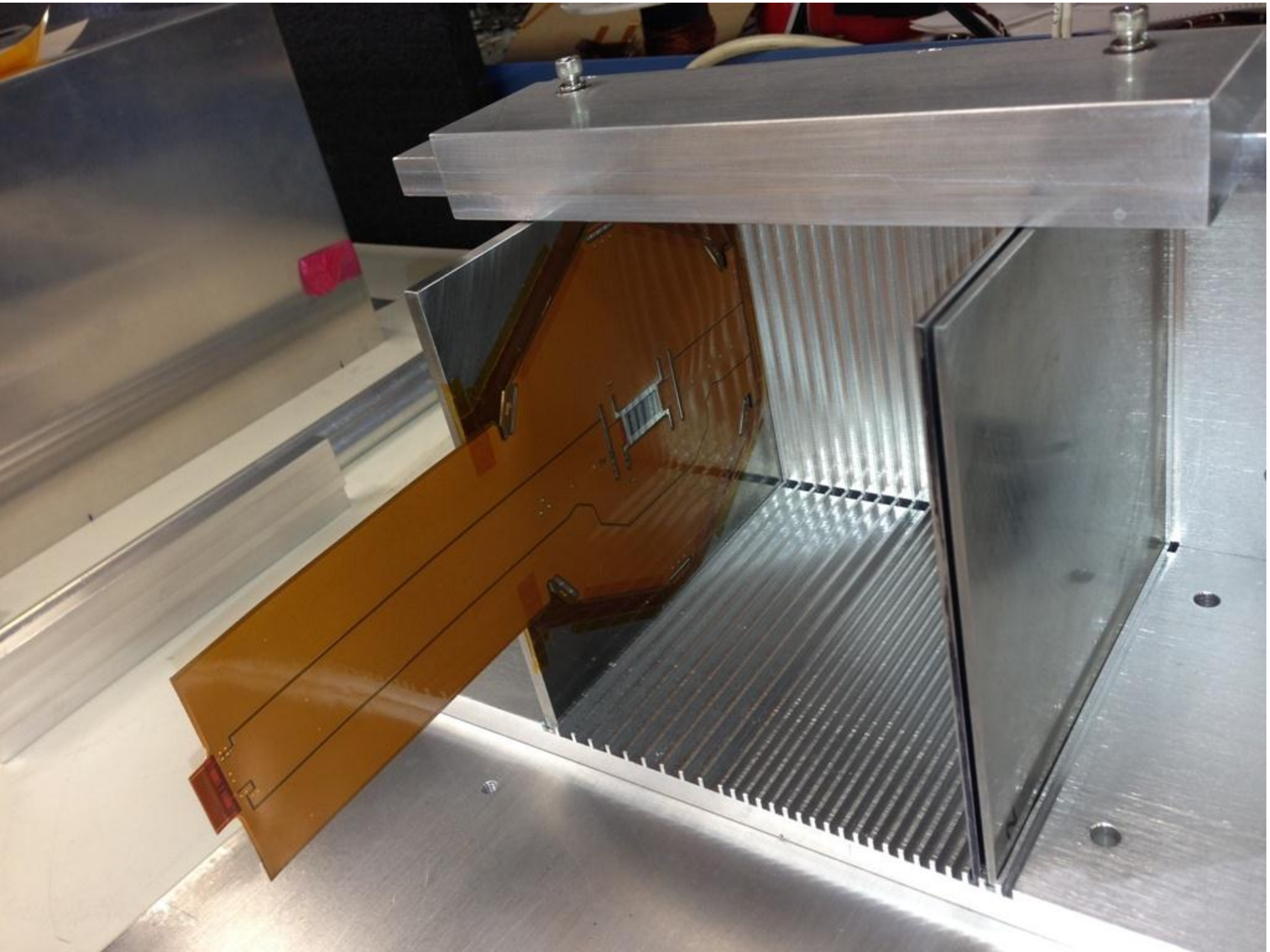
Prototype module – circa LOI

Prototype – Engineering Model

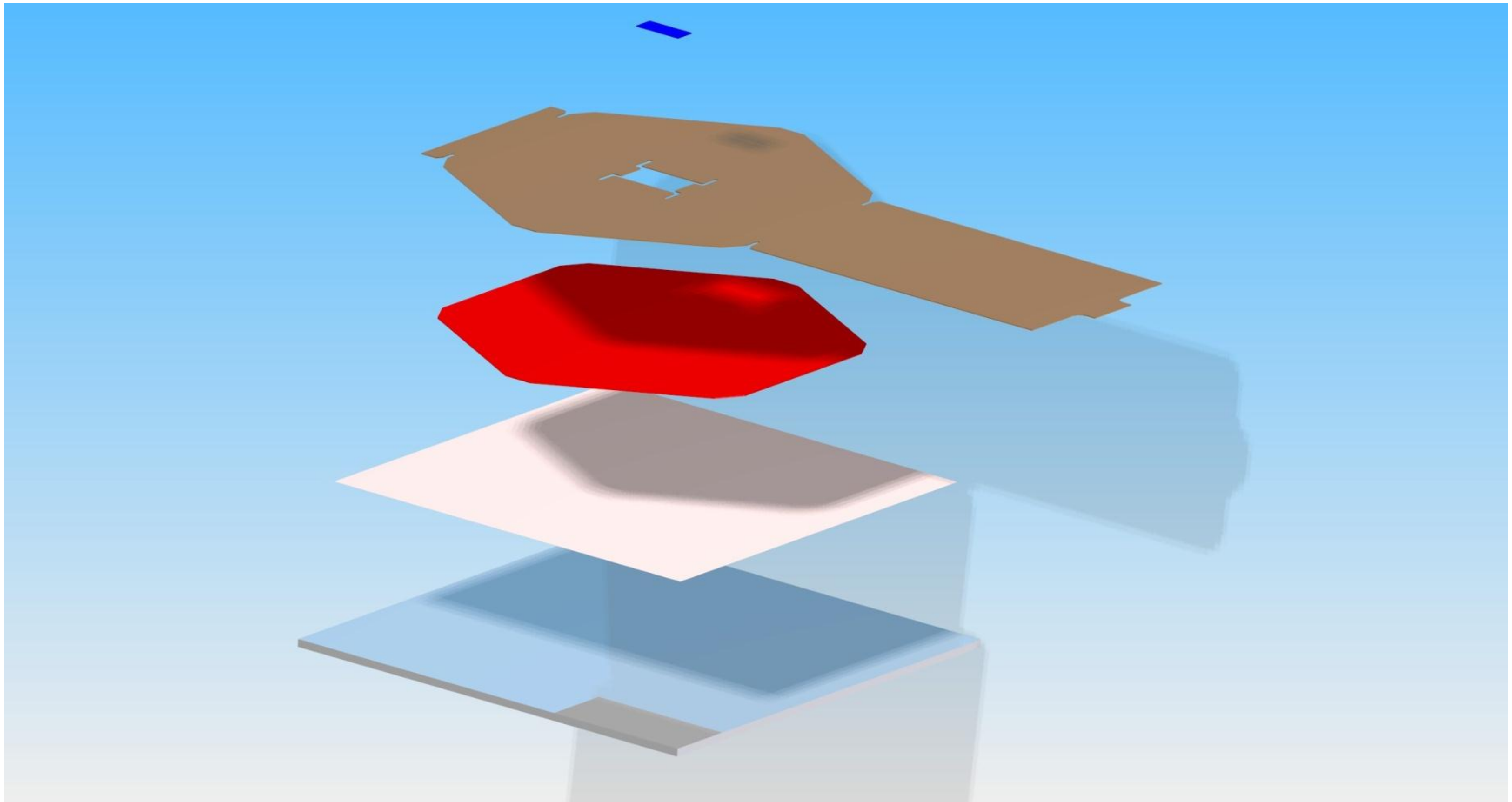




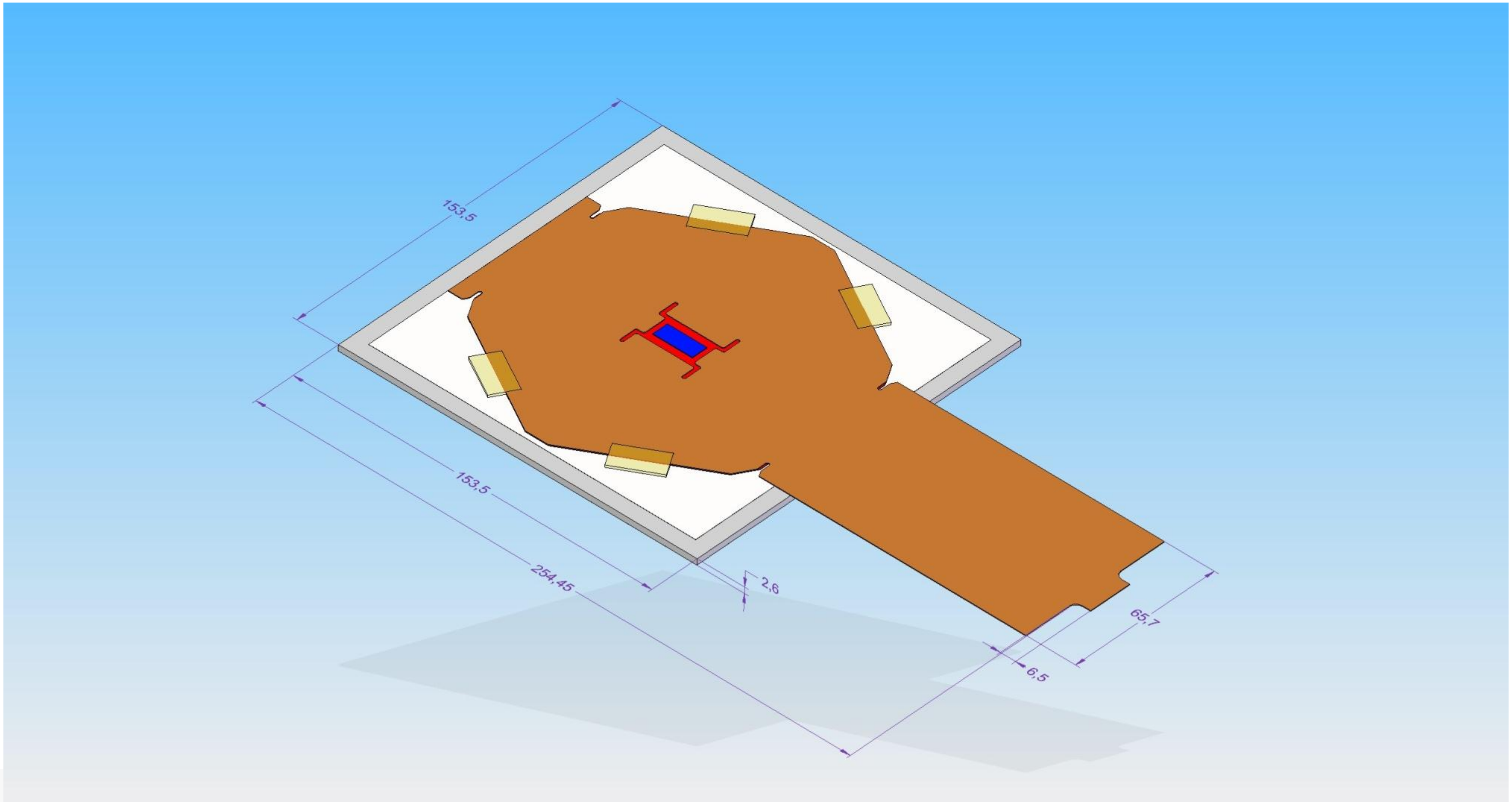


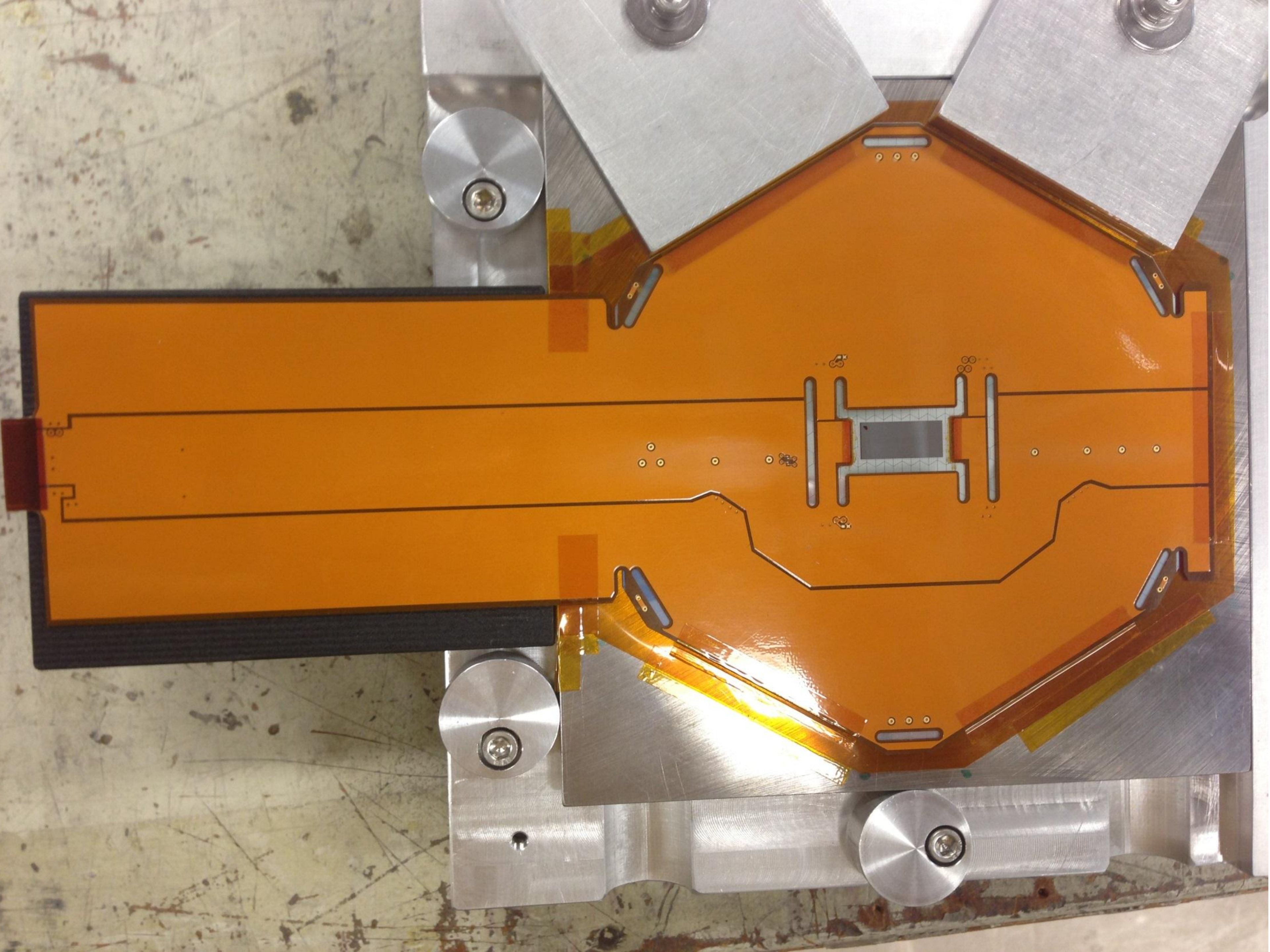


Layer Assembly

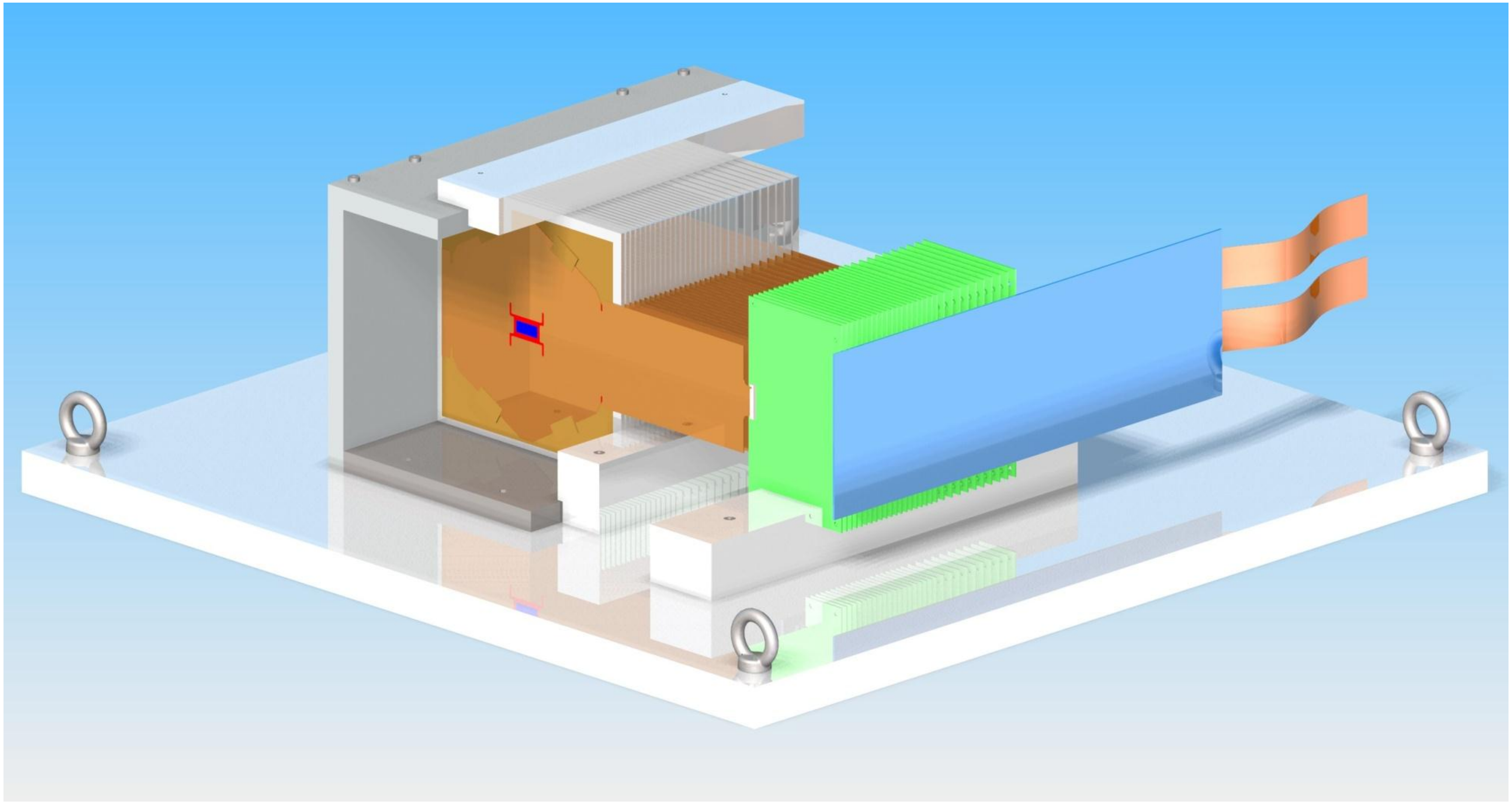


Layer

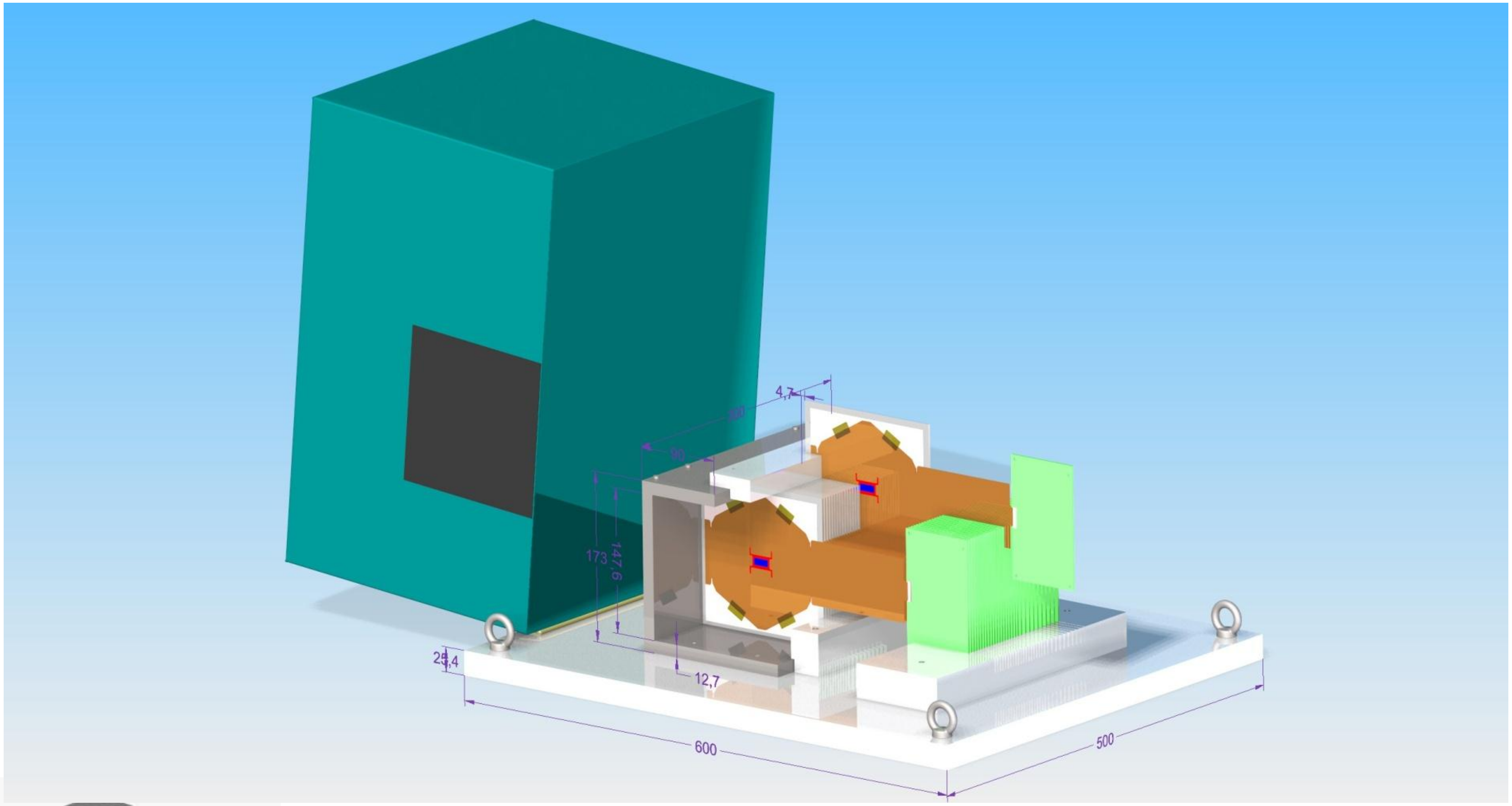




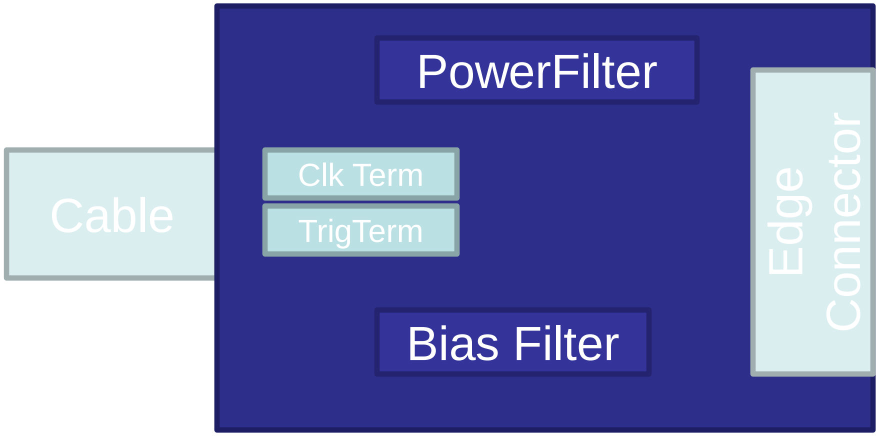
Study showing concentrator board



With Cover

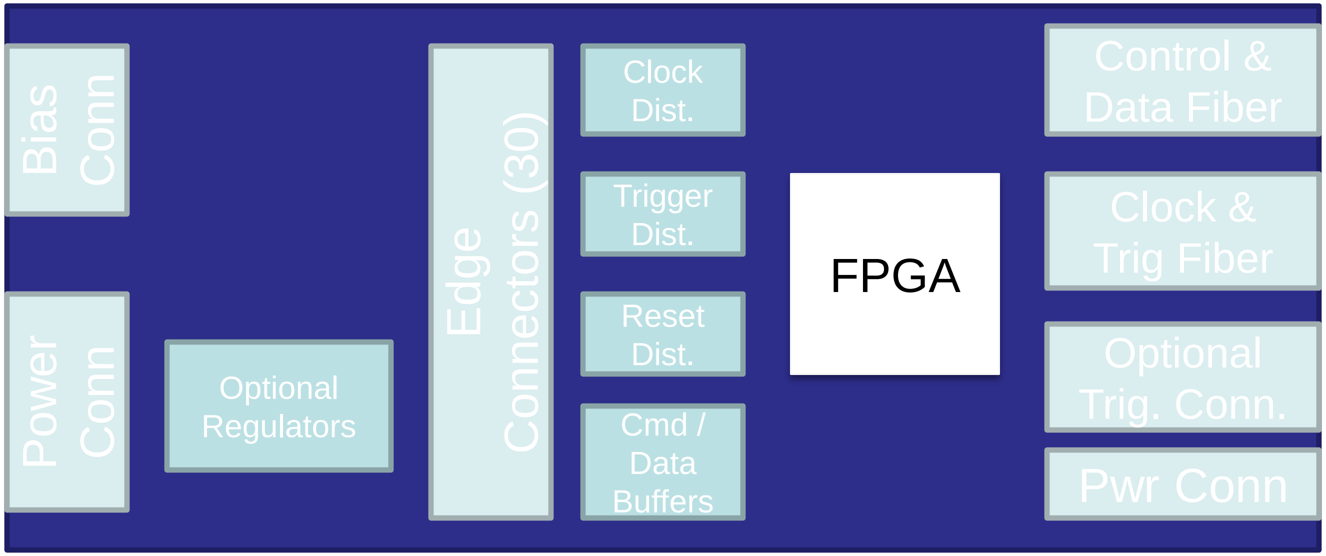


Cable Transition Board



- » Clock & trigger LVDS termination
- » Power supply filtering
- » Bias filtering
- » Edge connector
  - Right angle 0.1” pins
  - 18 pins

Cable Concentrator Board



- Bias input and distribution
- KPIX power input and distribution
  - Direct AVDD/DVDD feed or local linear regulator
- Clock, trigger & reset distribution
- Per sensor command & data connection
- Concentrator FPGA
- Optical control and data interface
  - 3.125gbps PGP
- Optical timing / trigger interface
  - Embedded EVR firmware
  - Optional TTL trigger input
- Separate FPGA power connector

Production

- All W plates are in hand.
- Mechanical structure is complete.
- 40 good sensors sent to IZM.
- 28 KPiXa's (all we have) are sent to IZM.
- IZM has produced 1 batch of 15 for evaluation.
- We hope to do a production run on more KPiX 1024 channel chips.
- Probe testing available at UO.
- UCD has bonded and attached 5 cables.
- Now testing cabled sensors at SLAC.
- Assembly and testing of system (pre-testbeam) at SLAC.

Software

- A new back end system that will handle 32 KPiX is being built, and data and calibration formats have been set.
- Data will be accessible with JAS3, and single KPiX testing is underway.
- UO has built a single event display.

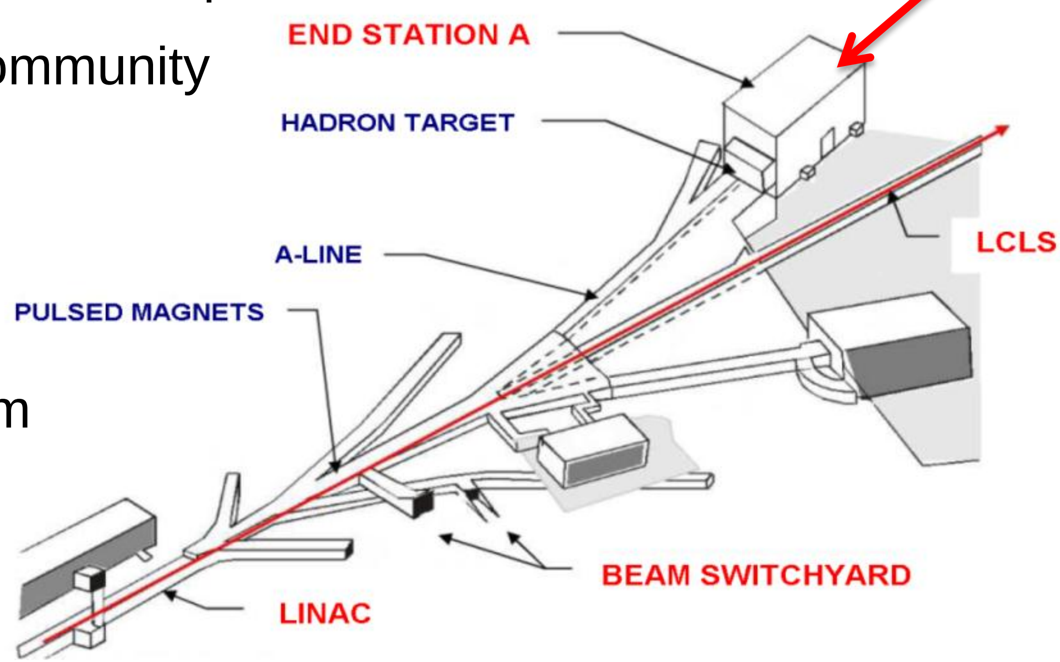
Worries

- The yield from IZM is 13/15. Probably ok for this effort; irrelevant for future.
- The yield on cable to sensor bonding is 4/5. May have to better engineer rework capability. Not relevant to production cables.
- Shorts and other problems on sensor assemblies: This is a major concern.
  - If it is “only” poor flux removal technique, then we can probably fix procedures.
  - Is it a problem on the sensors? Very difficult to prove.

ESTB Mission and Layout

- ESTB will be a unique HEP resource
  - World's only high-energy primary electron beam for large scale Linear Collider MDI and beam instrumentation studies
  - Exceptionally clean and well-defined primary and secondary electron beams for detector development
  - Will serve a broad User community

Pulsed magnets in beam switch yard to send LCLS beam to ESA



Test Expectations

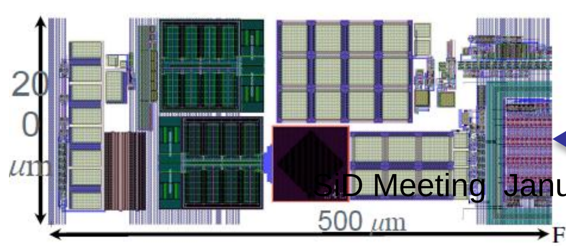
- Expect to take data with a precisely synchronous bunch – what KPiX was designed for.
- Expect to take data at a range of energies and with mean e^+ multiplicity ~1.
- Measure energy and spatial resolution.
- Characterize KPiX in “synchronous” mode: noise, cross talk, channel uniformity, etc.

- Most important – look for problems with the basic approach.

Backup

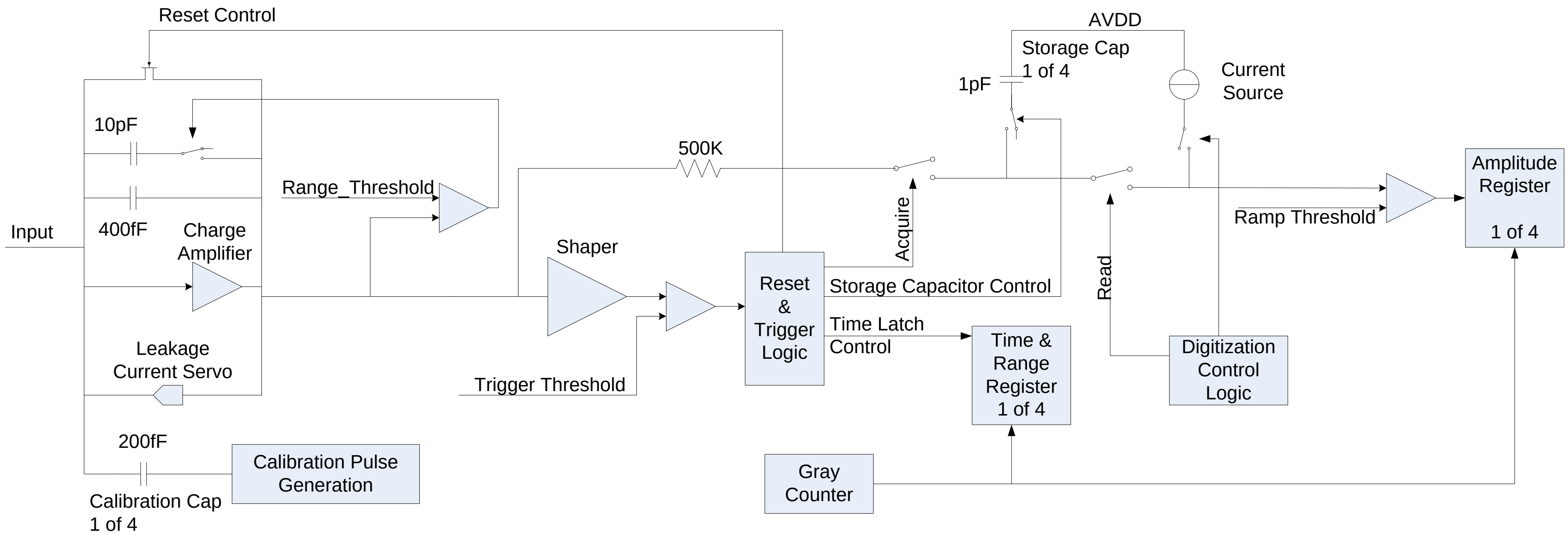
KPiX – System on a Chip

- KPiX is a 1024 channel intended to bump bond to Si detectors, optimized for the ILC (1 ms trains, 5 Hz rate):
  - Low noise dual range charge amplifier w 17 bit dynamic range.
  - Power modulation w average power <20 μW/channel (ILC mode).
  - Up to 4 measurements during ILC train; each measurement is amplitude and bunch number.
  - Digitization and readout during the inter-train period.
  - Internal calibration system
  - Noise Floor: 0.15 fC (1000 e^-)
  - Peak signal (Auto-ranging) 10 pC
  - Trigger Threshold Selectable (0.1 – 10 fC)



One pixel, 200 x 500 μmeters

KPiX – Simplified bock diagram of single channel



Many more details are in:
KPiXD, An Array of Self Triggered Charge Sensitive Cells Generating Digital Time and Amplitude Information. D. Freytag et al. 2008 IEEE Nuclear Science Symposium (NSS)