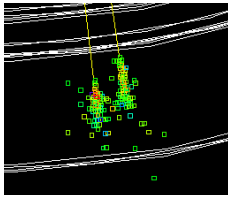


SiD Silicon Tungsten ECAL

SLAC-Oregon-Davis

SiD ECAL R&D collaboration

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

SLAC National Accelerator Laboratory

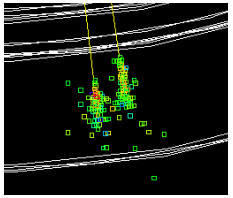
J. Brau, R. Frey, D. Strom, Craig Gallagher (tech), D. Mead, W. McCann (grad students), K. Travis (undergrad)

U. Oregon

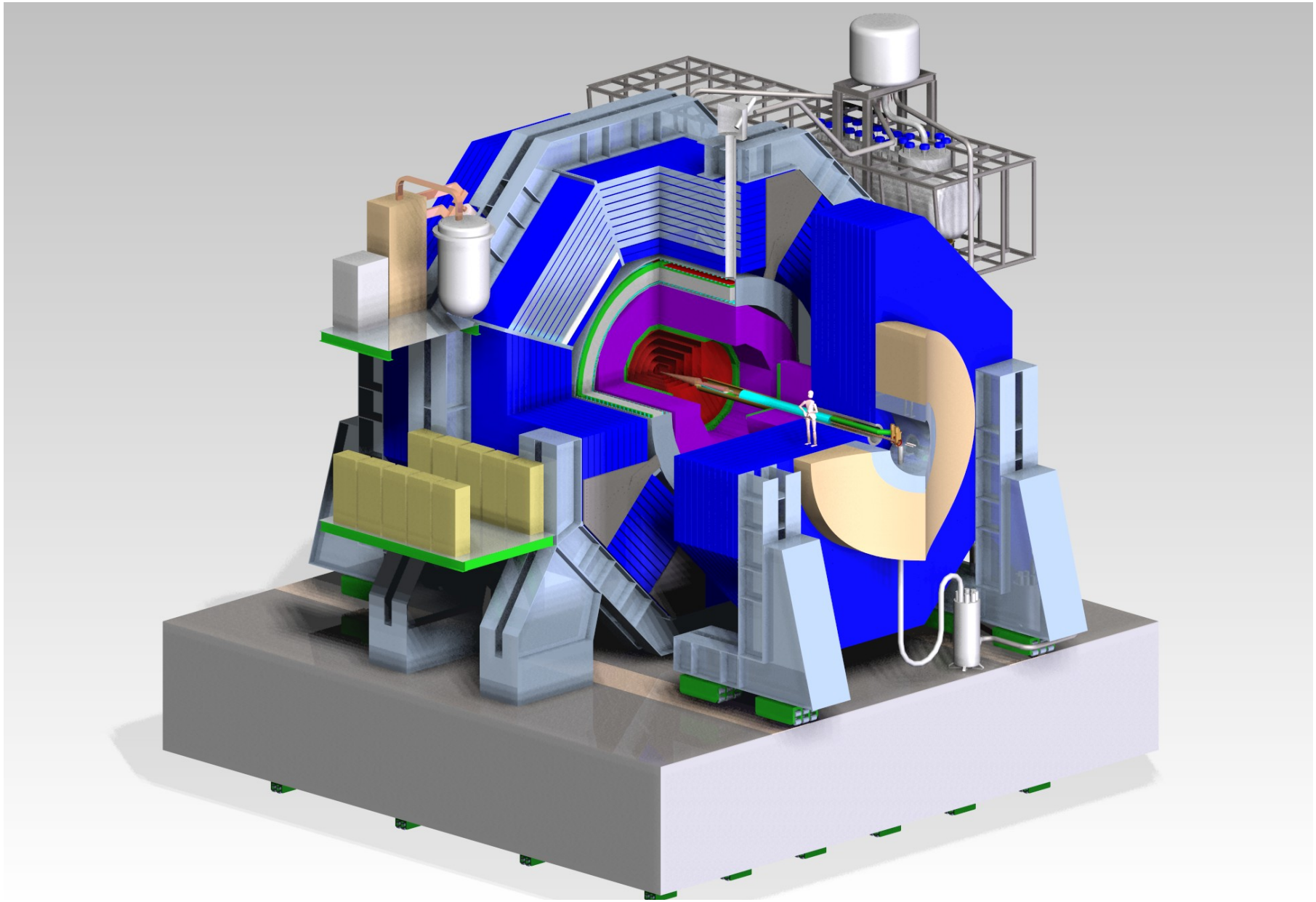
B. Holbrook, M. Tripathi, M. Woods (grad student)

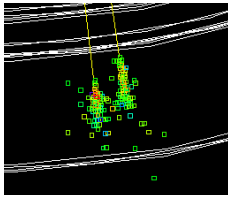
UC Davis

Presented by J. Brau

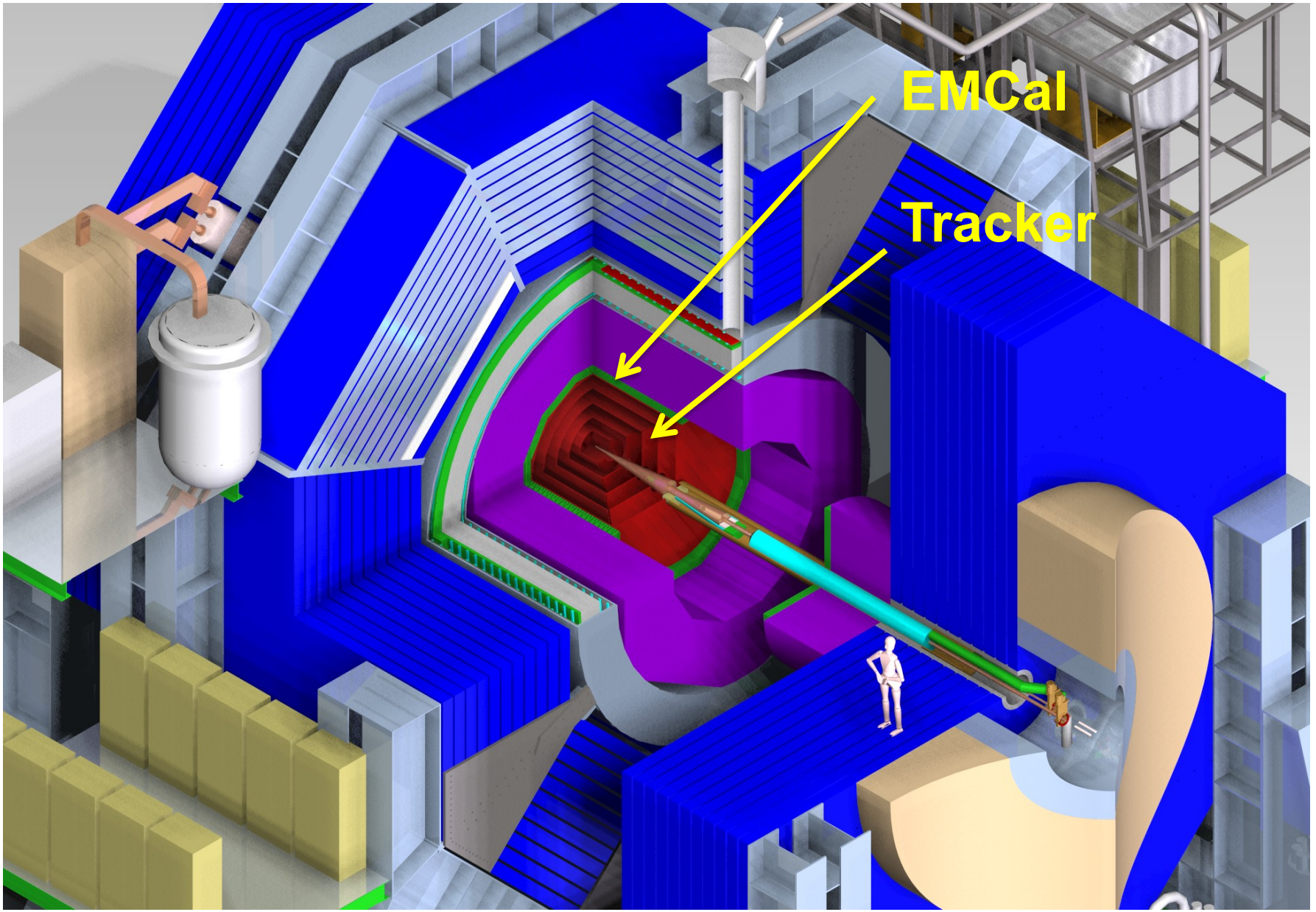


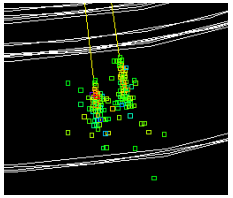
SiD





SiD





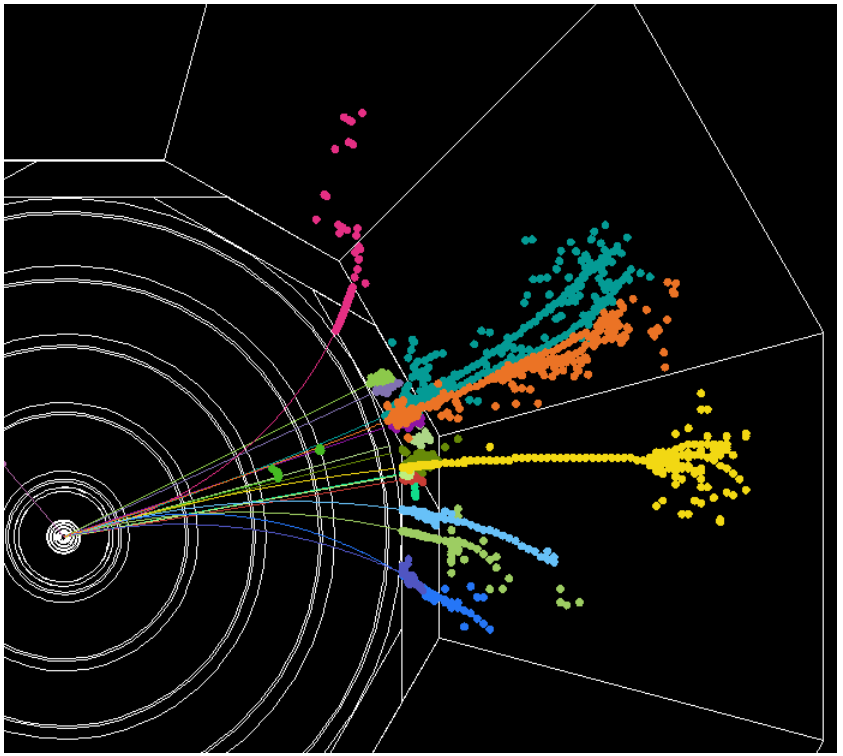
Particle Flow Calorimetry

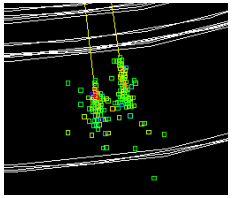
SiD is designed for Particle Flow Calorimetry

Promises superb jet energy resolution

- Tracker measures charged momentum
- Calorimeters measure neutral energy after excluding energy from charged tracks
- Fine segmentation required!
- Current invariant mass resolution <4%
  Z's to light quarks at ILC500.

SiD has been developing a silicon-tungsten calorimeter to achieve the highly granular Ecal requirements of the PFA concept

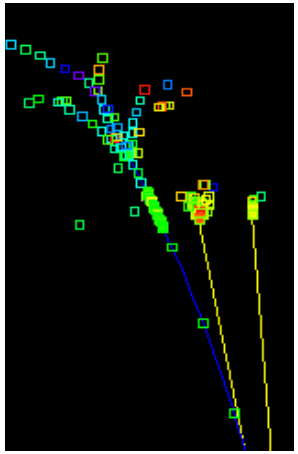


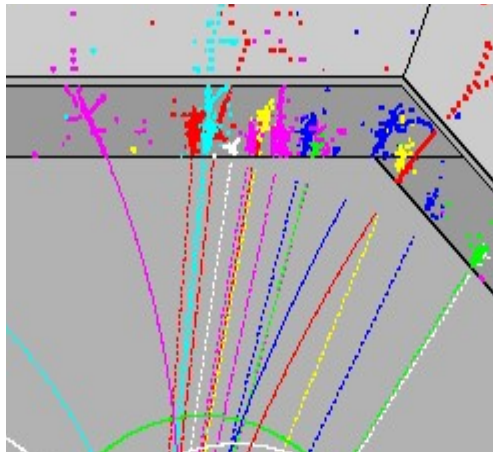


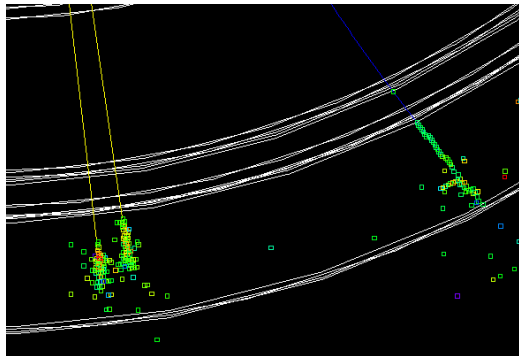
An "Imaging ECal": Motivated by LC Physics

Guiding principles: Measure all final states and measure with precision

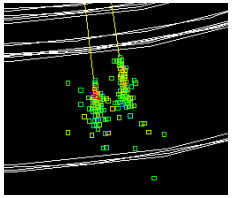
- Multi-jet final states (t-chan, missing E, combinatorics)
  - π° measurement should not limit jet resolution
  - id and measure h° and $h^\pm$ showers
  - track charged particles
- Tau id and analysis
  - Unique window on BSM
- Photons
  - Energy resolution, e.g. $h \rightarrow \gamma\gamma$
  - Vertexing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







⇒ Imaging (E)Calorimetry can do all this ("particle flow")



“SiD” Si-W R&D team

M. Breidenbach, D. Freytag, N. Graf,
R. Herbst, G. Haller, J. Jaros, T. Nelson
SLAC National Accelerator Laboratory

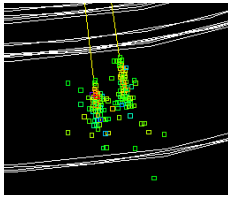
- KPiX readout chip
- downstream readout
- mechanical design and integration

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

- detector development
- readout electronics
- testing and integration

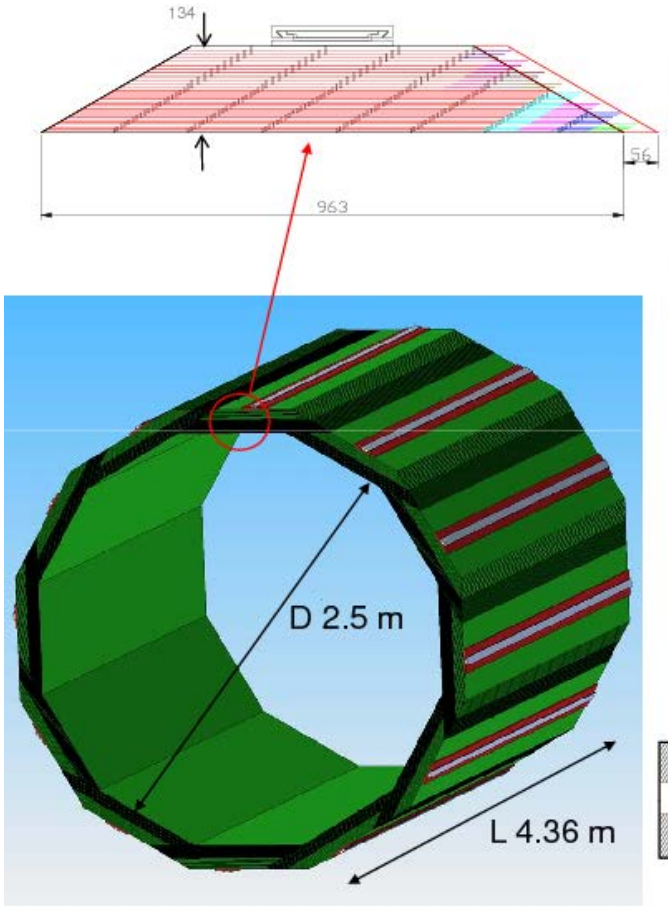
B. Holbrook, M. Tripathi,
M. Woods (grad student)
UC Davis

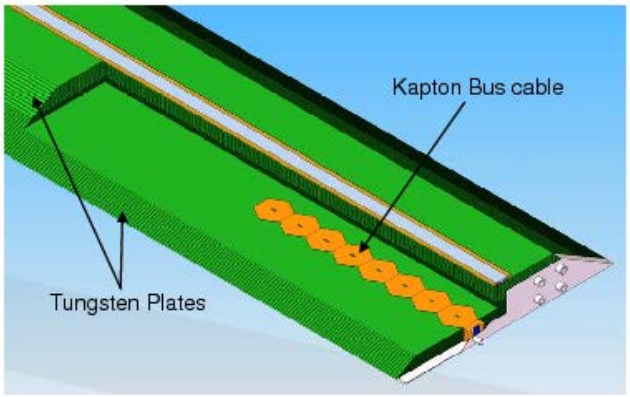
- interconnects
- testing and integration

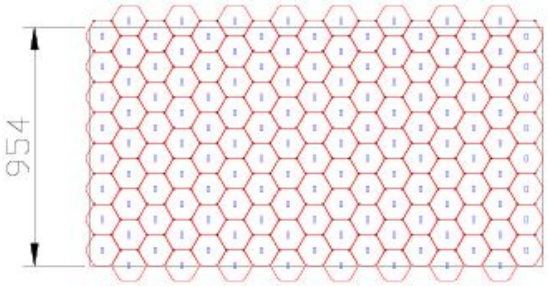


The SiD ECal Baseline

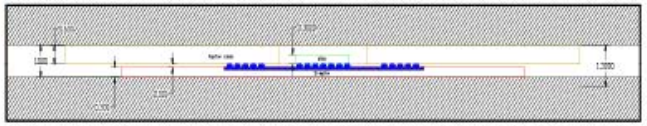
An imaging calorimeter: 30 layers tungsten interleaved with 30 layers pixellated silicon







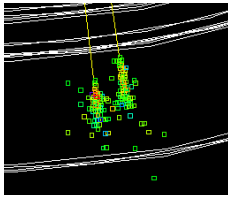
Hexagon sensors arrangement



detector module between tungsten plates

Baseline configuration:

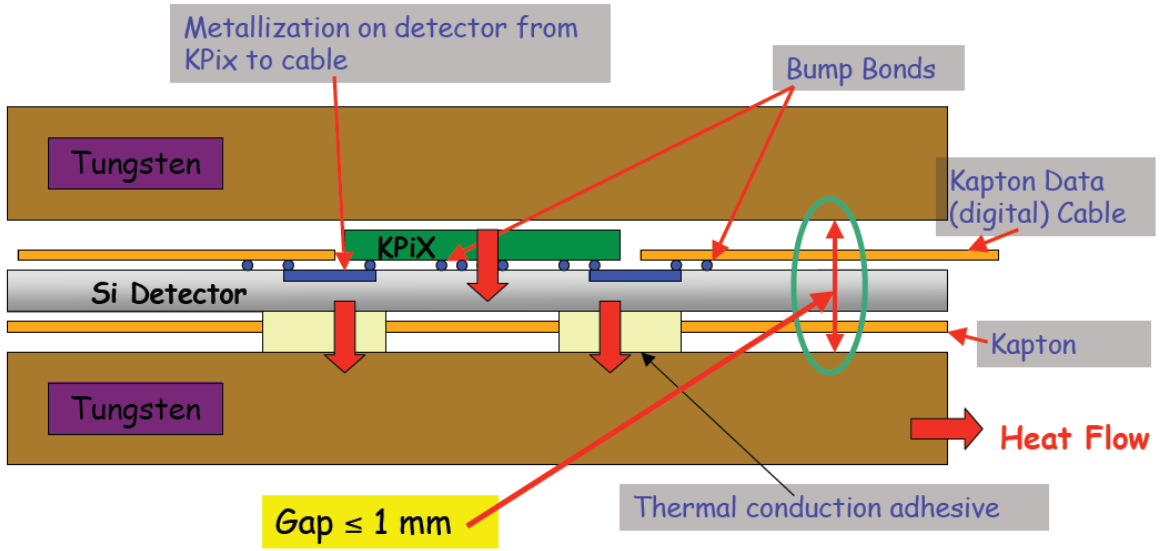
- transverse: 12 mm^2 pixels
- longitudinal: (20 x 5/7 X_0) + (10 x 10/7 X_0) ⇒ 17%/sqrt(E)
- 1 mm readout gaps ⇒ 13 mm effective Moliere radius

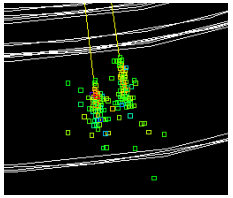


The R&D program – overview

- Physics requirement: 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

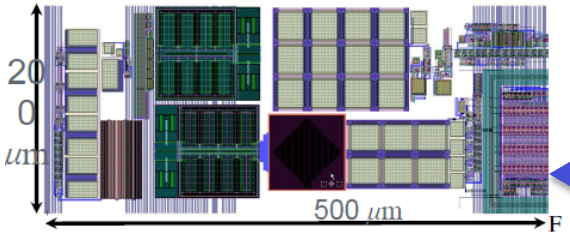
  ⇒1024 pixel sensors are digitized by single chip (KPiX) with power pulsing which is bump-bonded to the sensor
- The R&D provides the required baseline ECal components (except large-scale mechanics) – now nearly completed



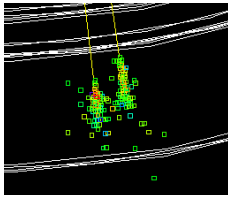


KPiX – System on a Chip

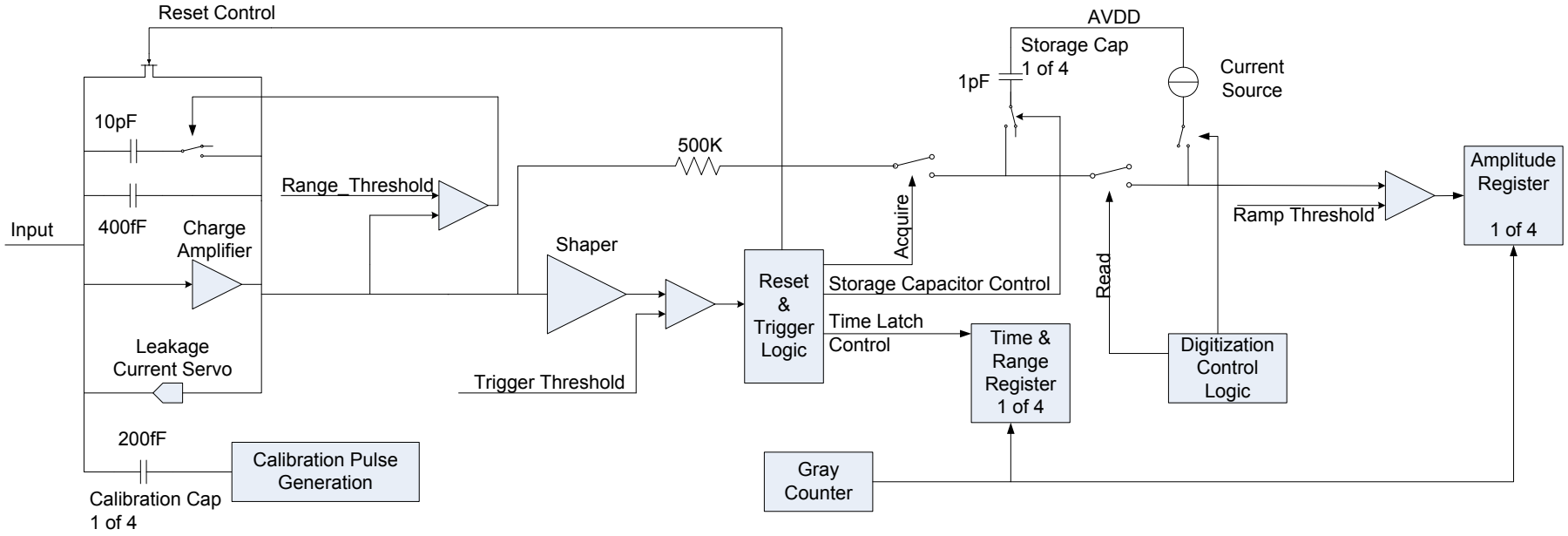
- KPiX is a 1024 channel intended to bump bond to Si detectors, optimized for the ILC (1 ms trains, 5 Hz rate):
  - Low noise dual range charge amplifier w 17 bit dynamic range.
  - Power modulation w average power <20 μW/channel (ILC mode).
  - Up to 4 measurements during ILC train; each measurement 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)



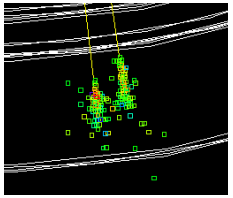
One pixel, 200 x 500 μmeters



KPiX – Simplified bock diagram of single channel

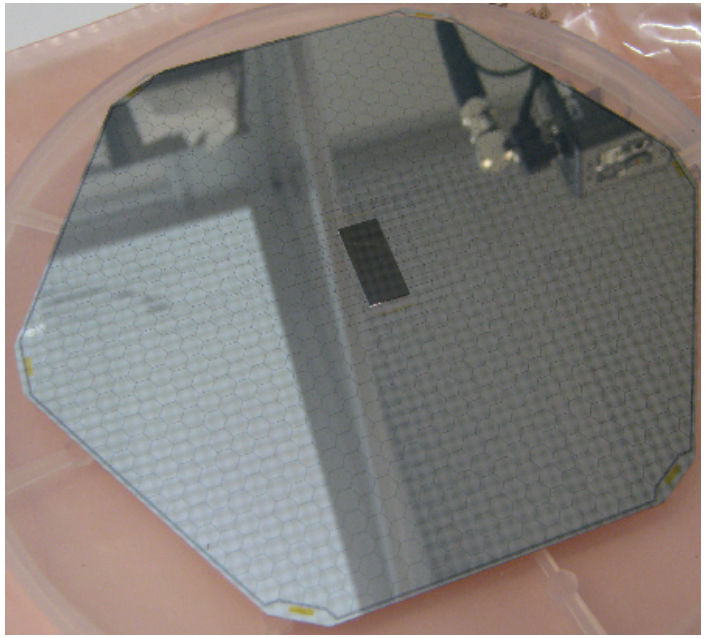


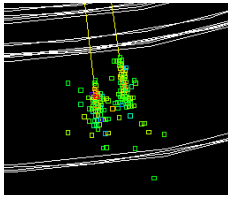
Many more details are in:
"KPiX, An Array of Self Triggered Charge Sensitive Cells Generating Digital Time and Amplitude Information," D. Freytag et al. 2008 IEEE Nuclear Science Symposium (NSS)
http://slac.stanford.edu/cgi-wrap/getdoc/slac-pub-13462.pdf



Interconnects - I

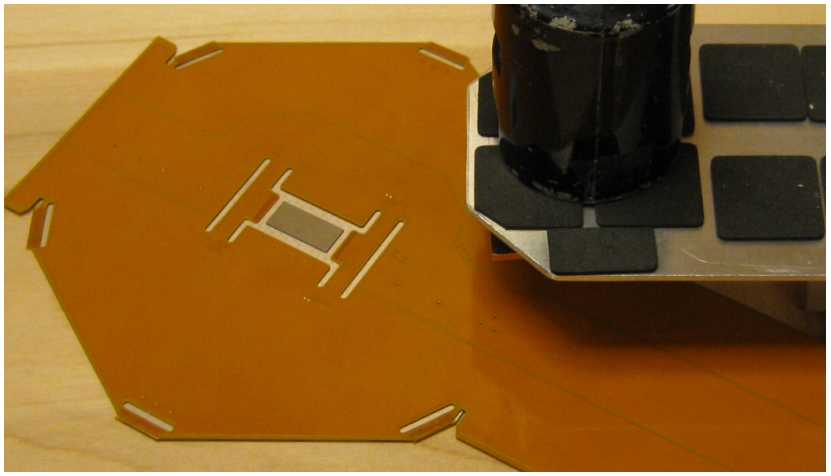
- The Hamamatsu sensors have Al bonding pads → Al oxide
- The KPiX chips (v-A) come from TSMC with eutectic Sn-Pb solder bumps
- The sensors must be processed to remove oxide and build Ti+W+Ni+Au stack to allow bonding
- After some false steps, enlisted IZM to prepare the sensors (Ar ion etch + sputtering) and complete the bump bonding.
- This has been (mostly) successful and has allowed us to move forward
- Prototype module has 30 layers. So far, 15 sensors processed by IZM.

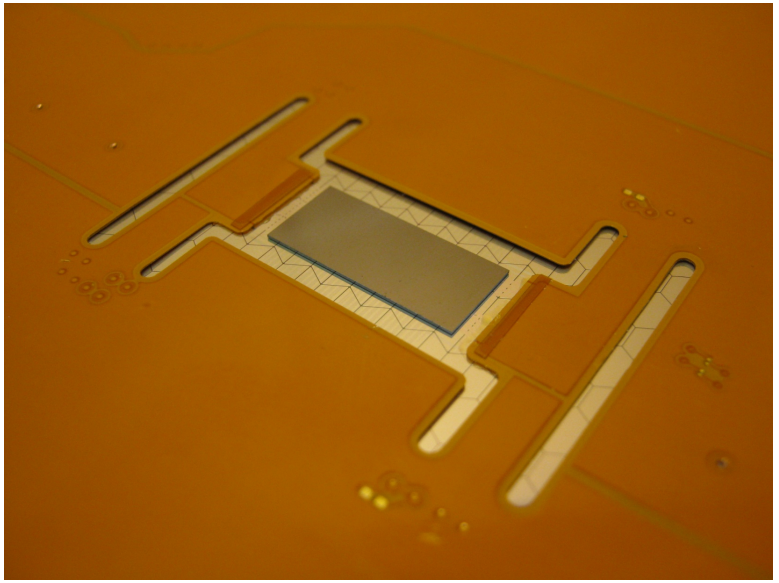


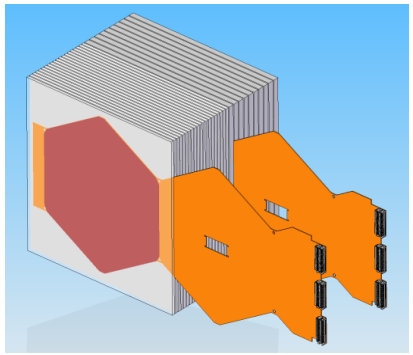


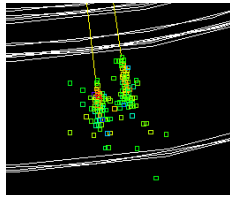
Interconnects - II

- The flexcable provides power and control in and the (multiplexed) digital data out
- It is solder bonded to the sensor at UC Davis with a lower-temperature solder
- Height above sensor is 1 mm.
- Current status: 12 sensors fully outfitted. 9 are being evaluated in a Si-W stack at SLAC with cosmic rays.

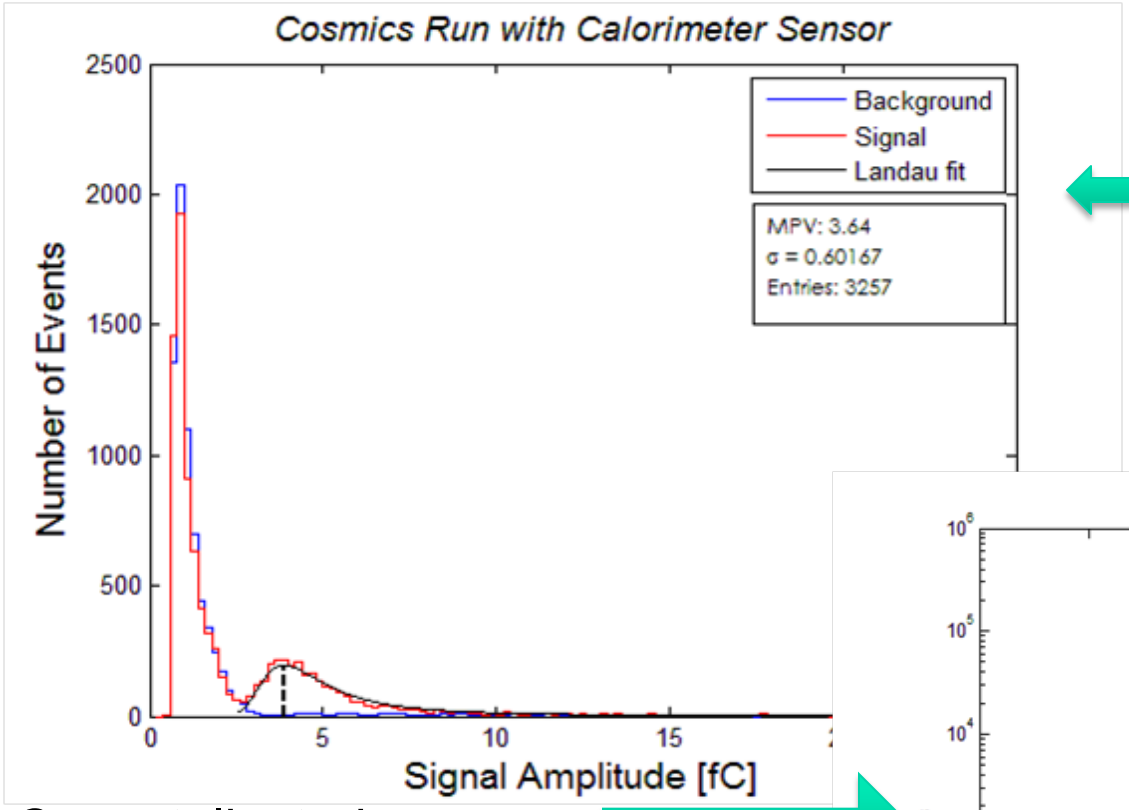




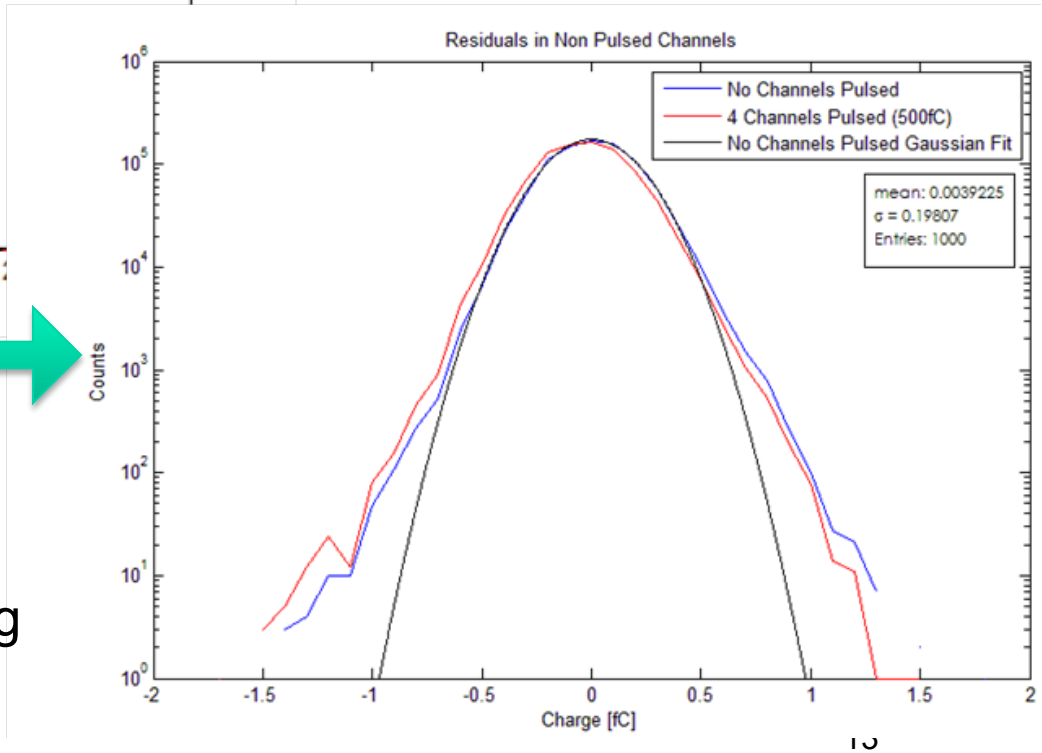




Basic performance is very good



Cosmic MIPs

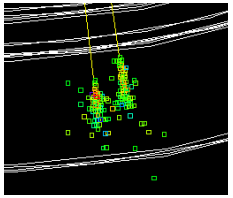


Cross talk study:

Red: 4 pixels pulsed at 500 fC,
all other channels shown.

Blue: no pixels pulsed.

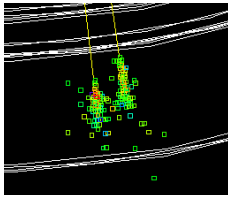
Good isolation – but only testing feedthrough from 4 pixels

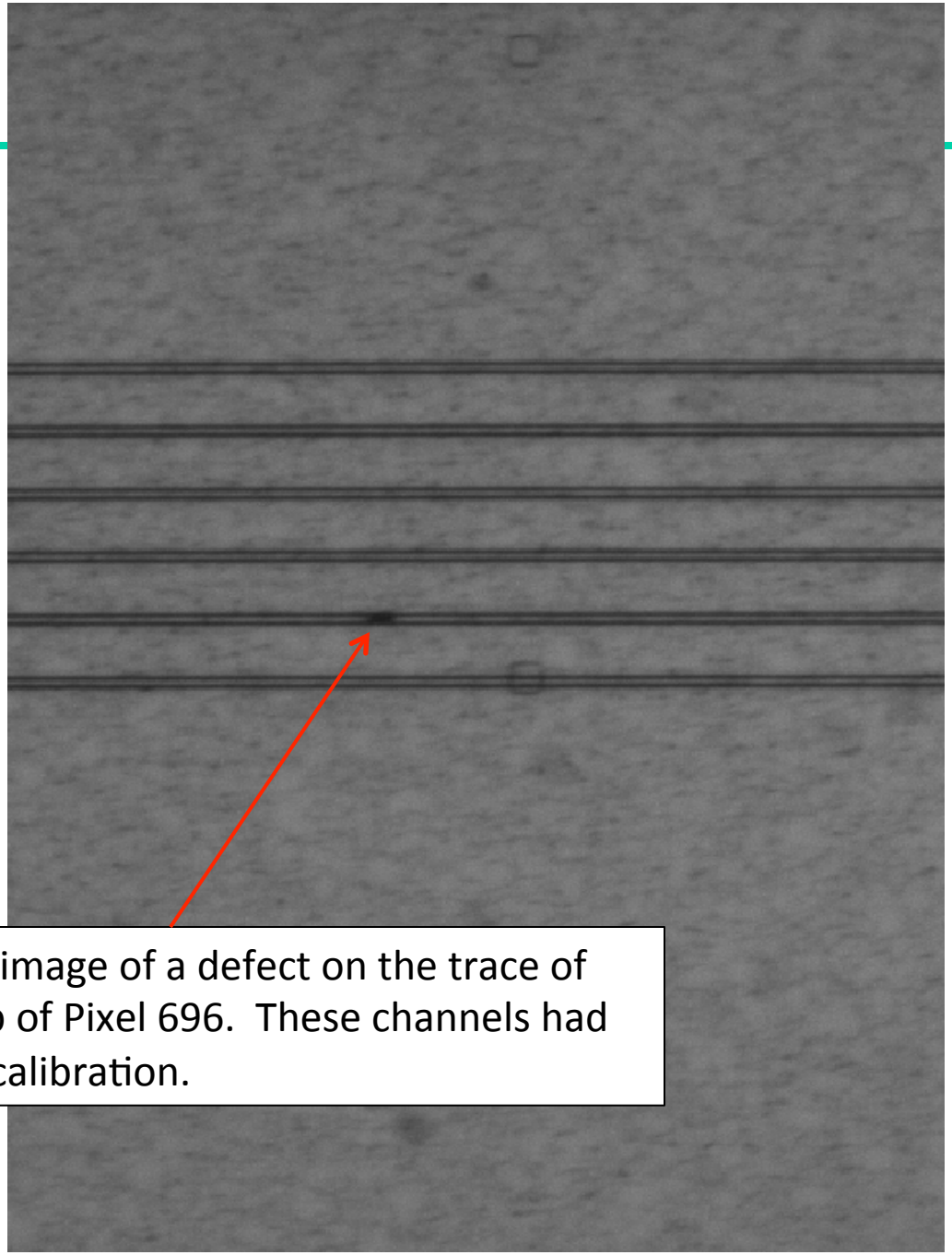


Discovery of pixel shorts

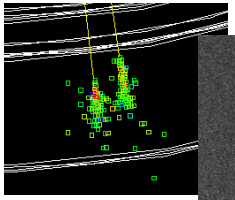
- Crosstalk study looks good for ~90% channels
- However, we find that ~10% of pixels have shorts or opens
  - Mostly shorts
  - “Shorts” are connected to another pixel (crosstalk)
- Inspection found that these “shorts” were associated with visually identified defects
- The defects were not found on sensors pre-IZM
- Leading hypothesis is that IZM processing (ion wash) led to ESD or ESD-like damage

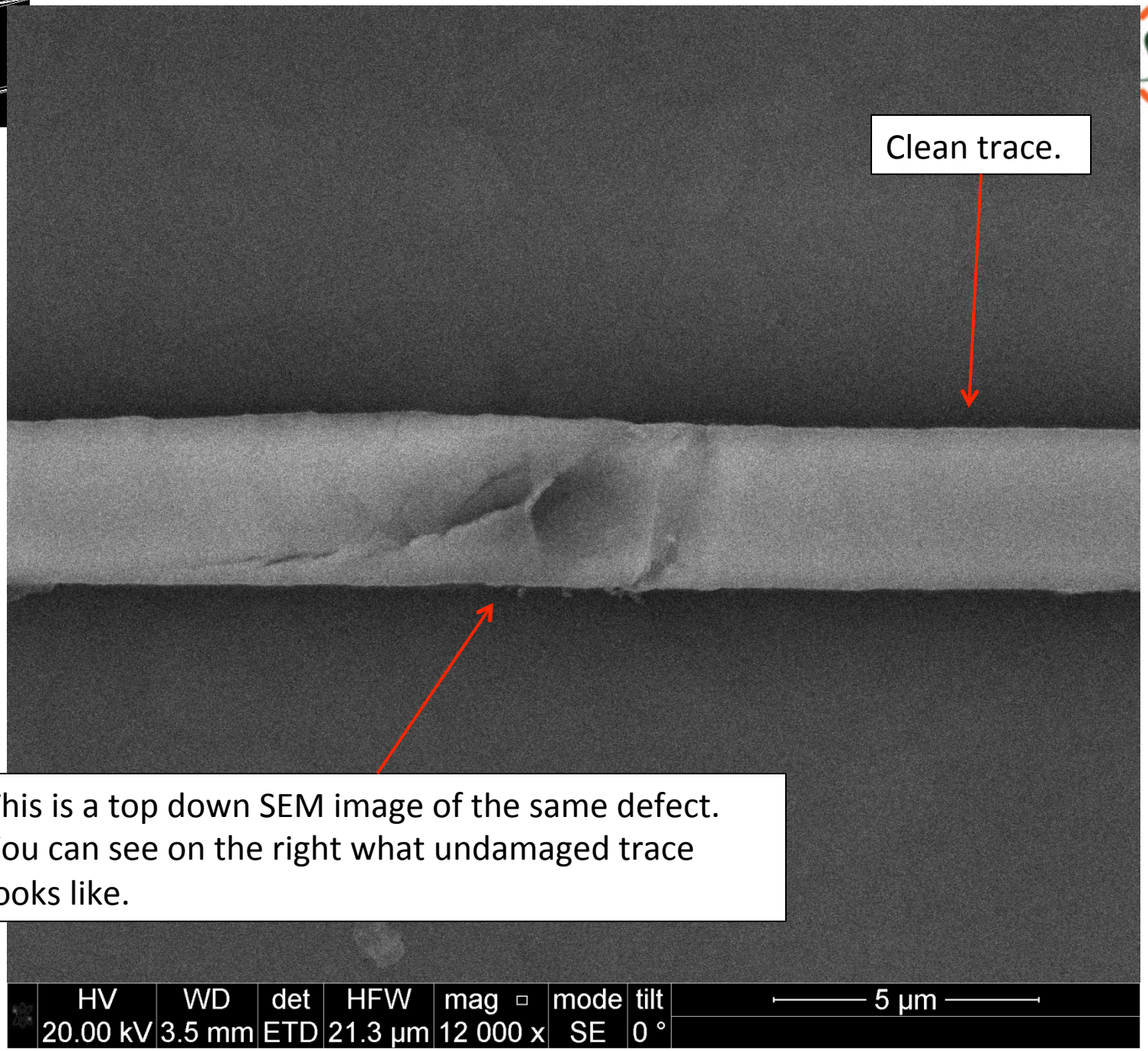
- We will outfit the test beam prototype with these sensors

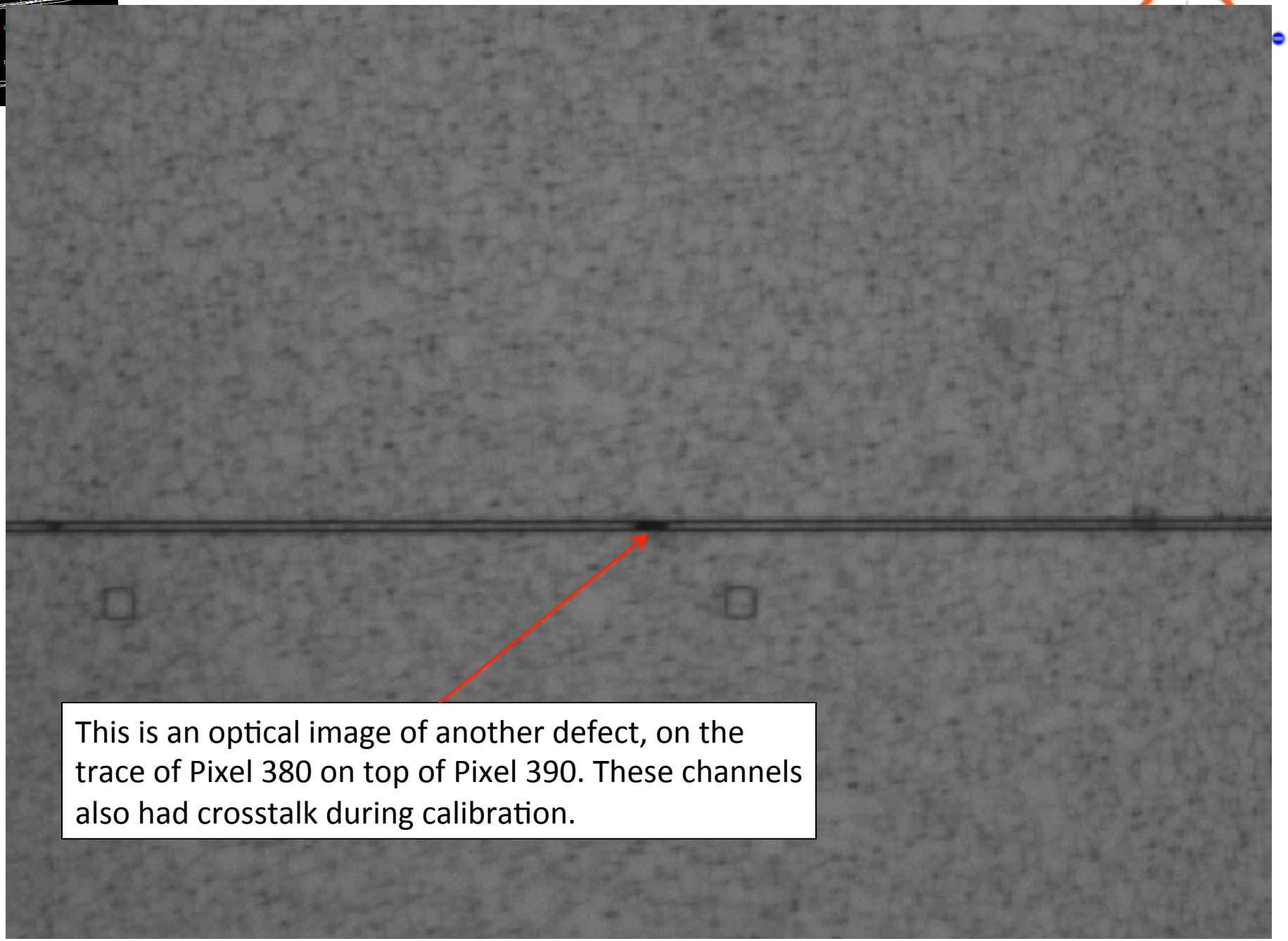


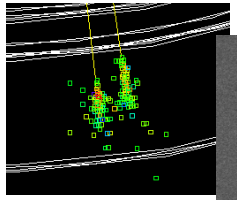


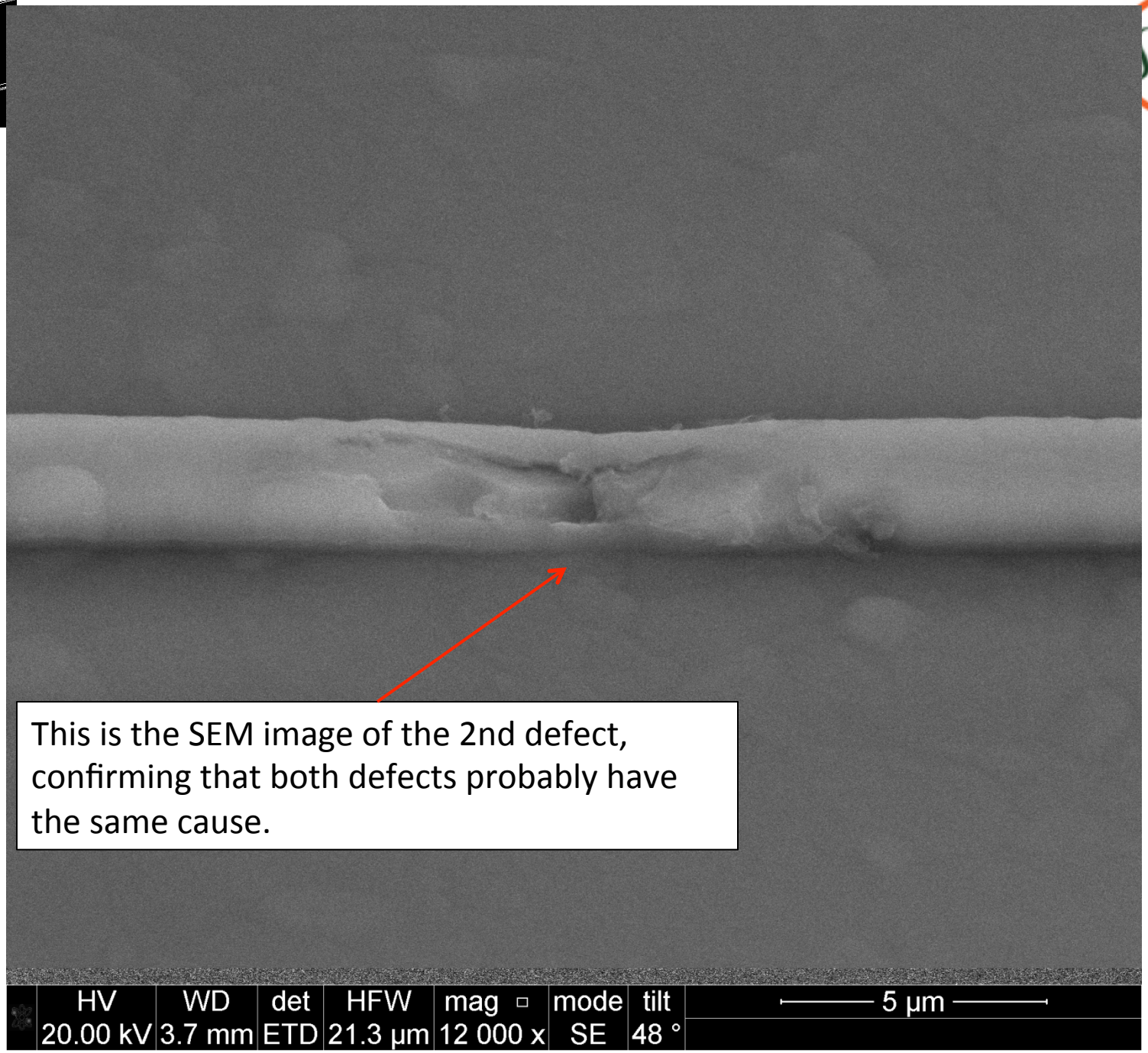
This is an optical image of a defect on the trace of Pixel 1016 on top of Pixel 696. These channels had crosstalk during calibration.



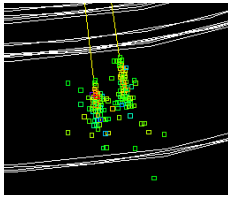

Clean trace.
This is a top down SEM image of the same defect. You can see on the right what undamaged trace looks like.
HV 20.00 kV
WD 3.5 mm
det ETD
HFW 21.3 µm
mag 12 000 x
mode SE
tilt 0 °
5 µm


This is an optical image of another defect, on the trace of Pixel 380 on top of Pixel 390. These channels also had crosstalk during calibration.



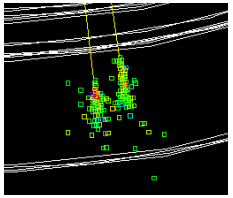


This is the SEM image of the 2nd defect, confirming that both defects probably have the same cause.



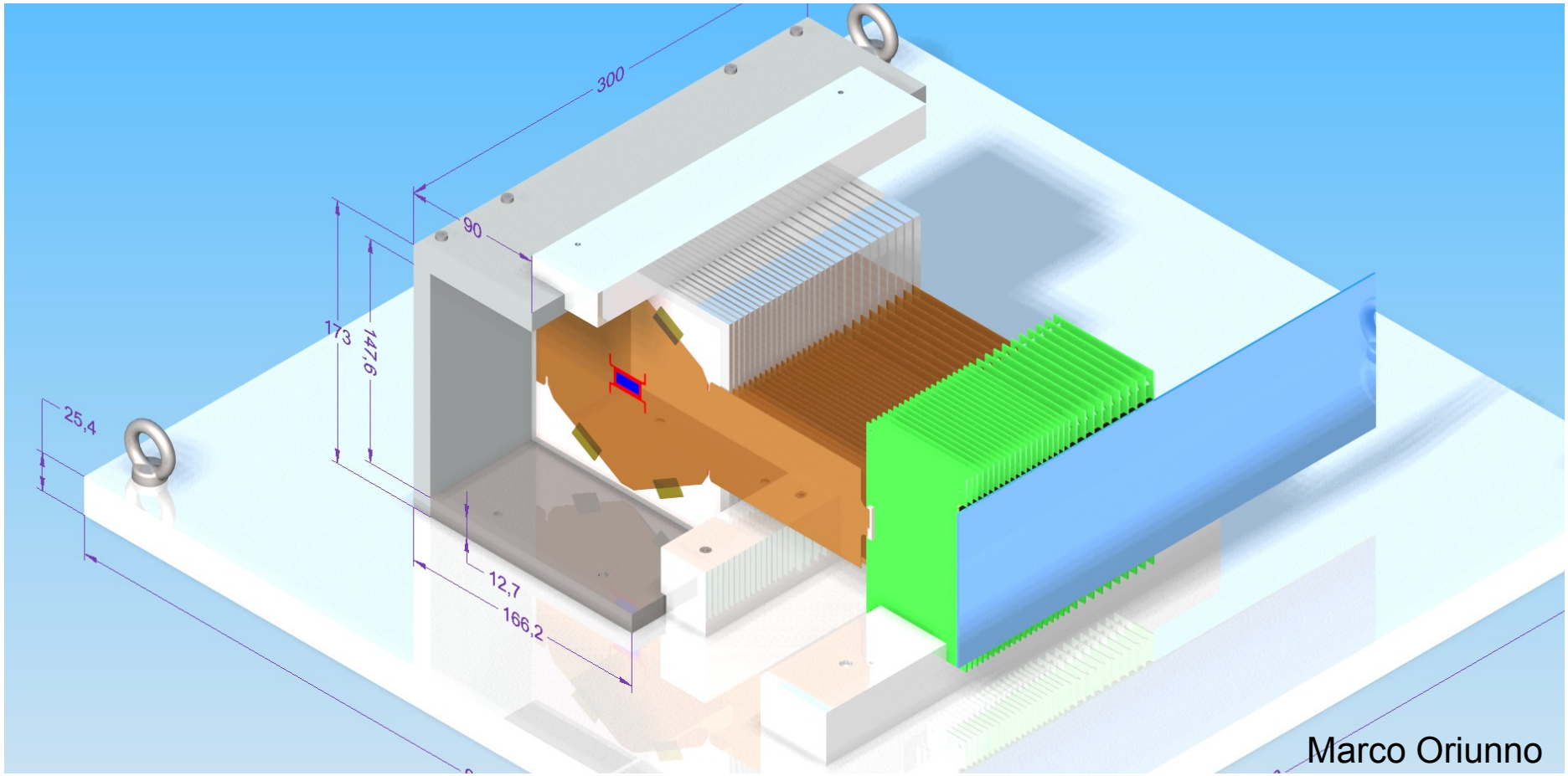
Next steps

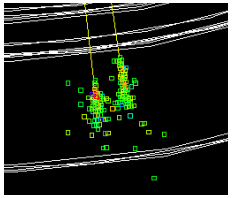
- Test beam at SLAC
  - Initial run in July
    - System checkout, initial performance
  - Expect additional running in Fall 2013 and/or Winter 2014
    - Hopefully with all 30 layers
    - Explore energy and spatial resolution, etc
- Next round of prototyping
  - Hamamatsu has expressed interest in also providing the under-bump metallization processing if we order a new set of sensors
    - Other (more minor) improvements would be included
  - US-Japan Collaboration program now expected to provide funding for next round of sensors



On to the test beam…

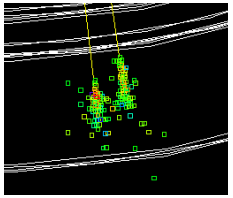
- Scheduled for revived SLAC ESA beamline starting July 2013
- <15 of the full 30 layers; All layers for later running in 2013-14



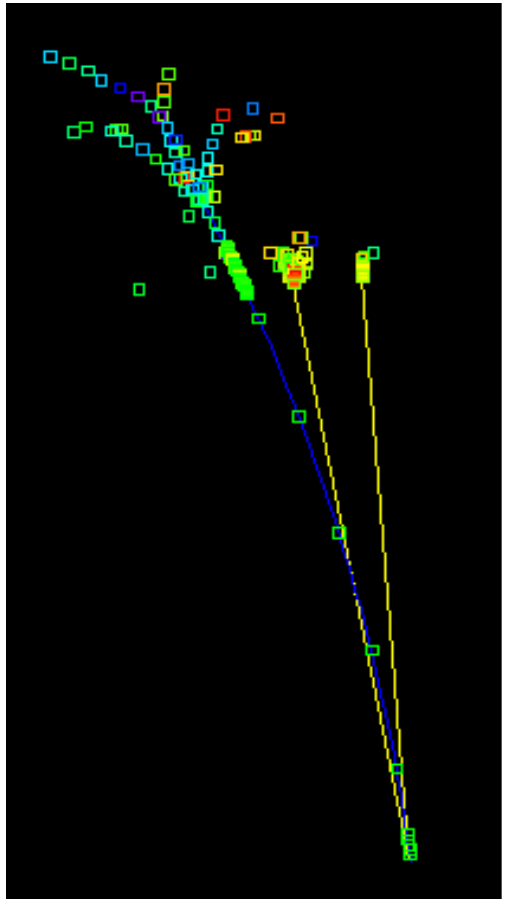


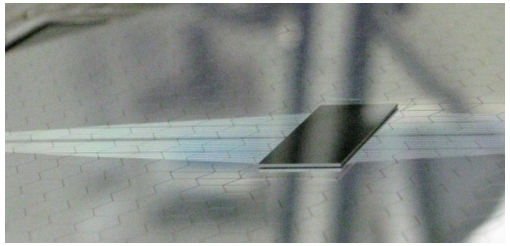
Revived SLAC ESA test beam

- 5-10 GeV positrons
- Well localized and controllable beam
- LC-like time structure with highly synchronized bunches
  - Exactly what KPiX was designed to do
- Small number of particles per bunch (e.g. 0,1,2,…)



Summary and outlook



- Goal: Make exquisite measurements at ILC to uncover new physics.
- We think we know how to do this.
- An imaging ECal is an important component.
- Our silicon-tungsten technology is the baseline for the SiD concept.

- We have made good progress toward the goal of a **final concept** for the SiD Si/W Ecal.
- Test beam and analysis scheduled in 2013:
  - We are nearing a significant milestone of this R&D.