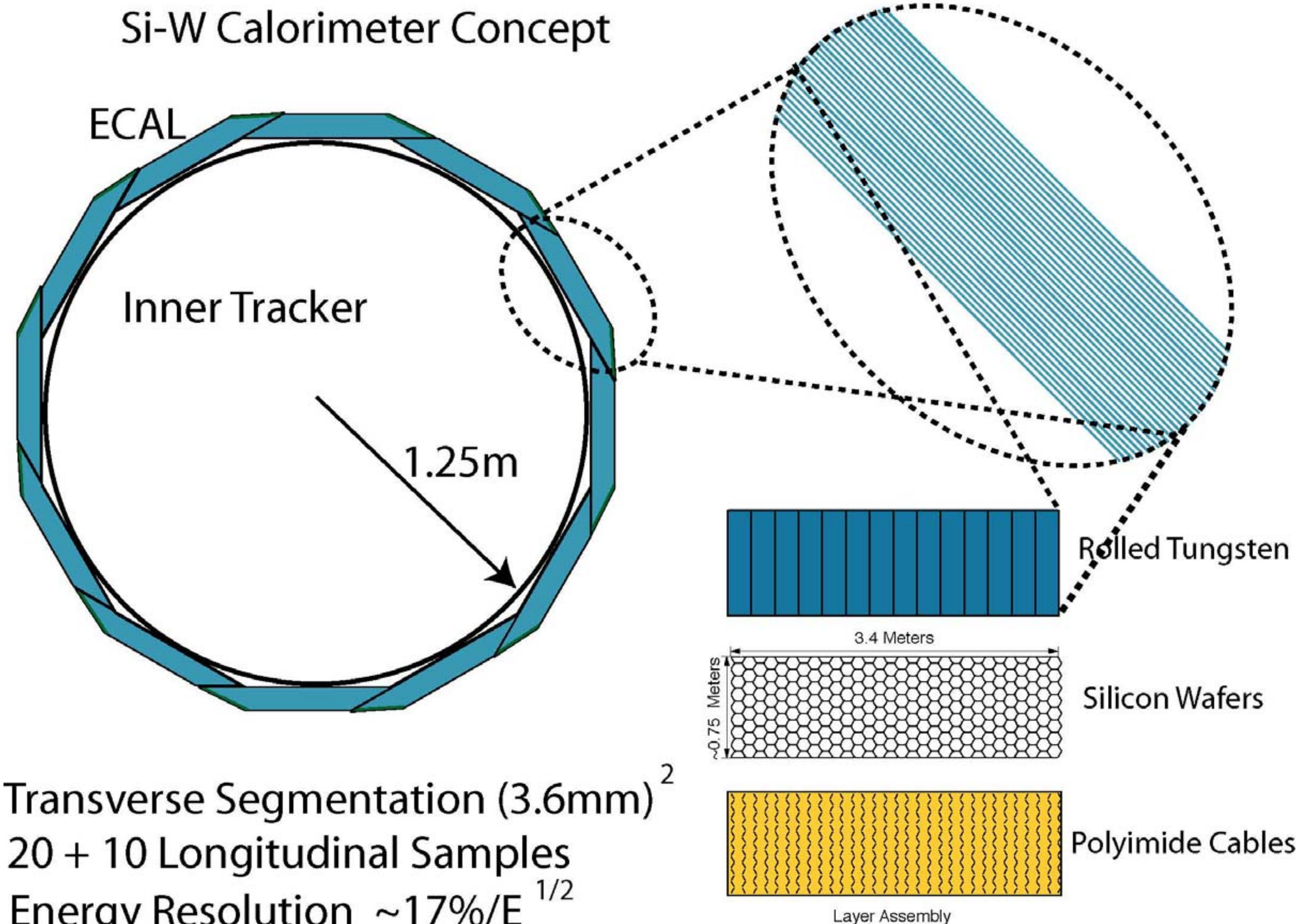
A Silicon-Tungsten ECal with Integrated Electronics for the ILC -- status



<u>Baseline configuration:</u>

- 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 $\Rightarrow$ 13 mm effective Moliere radius

Currently optimized for the SiD concept

Si/W ECal R&D Collaboration

M. Breidenbach, D. Freytag, N. Graf, R. Herbst, G. Haller, J. Jaros *Stanford Linear Accelerator Center*	• KPiX readout chip • downstream readout • detector, cable development • mechanical design and integration
J. Brau, R. Frey, D. Strom, undergraduates *U. Oregon*	• detector development • readout electronics
V. Radeka *Brookhaven National Lab*	• readout electronics
B. Holbrook, R. Lander, M. Tripathi *UC Davis*	• cable development • bump bonding
S. Adloff, F. Cadoux, J. Jacquemier, Y. Karyotakis *LAPP Annecy*	• mechanical design and integration

Goals of the R&D

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

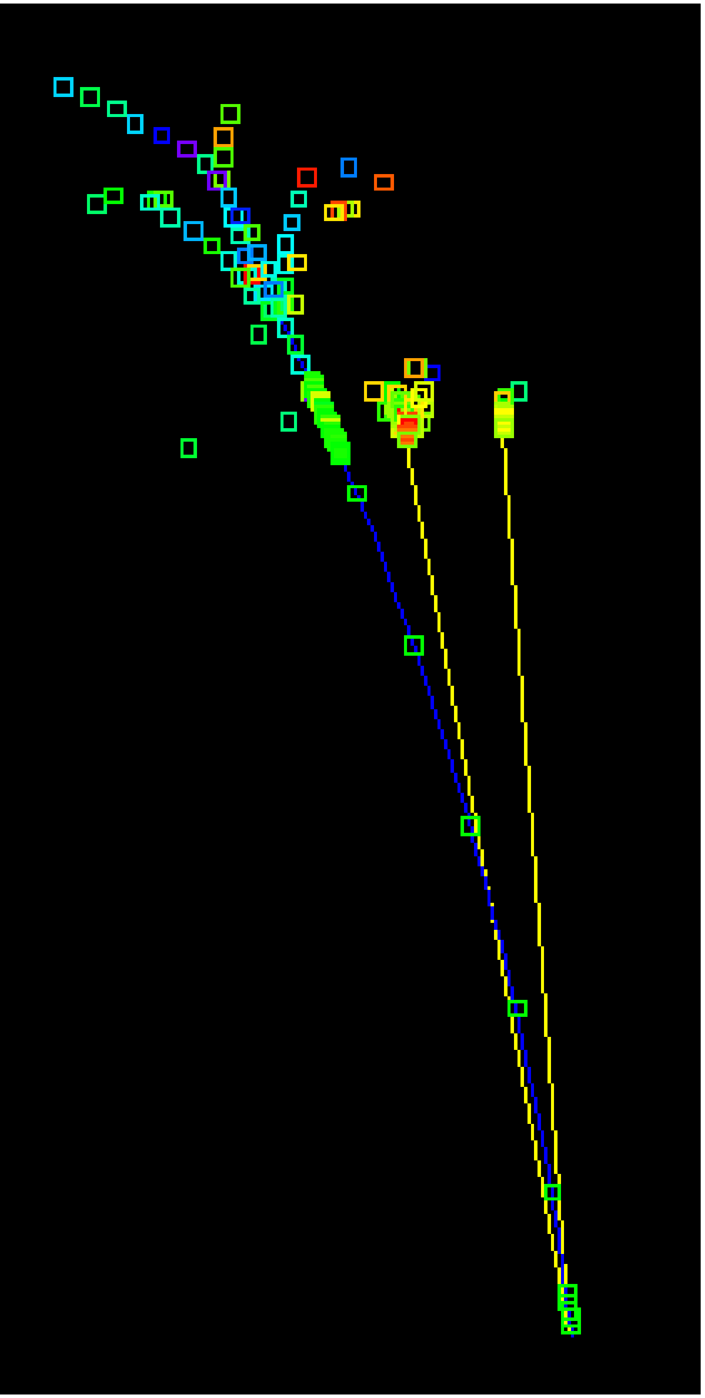
- The physics case calls for a dense (small R_m), highly segmented "imaging calorimeter" with modest EM energy resolution

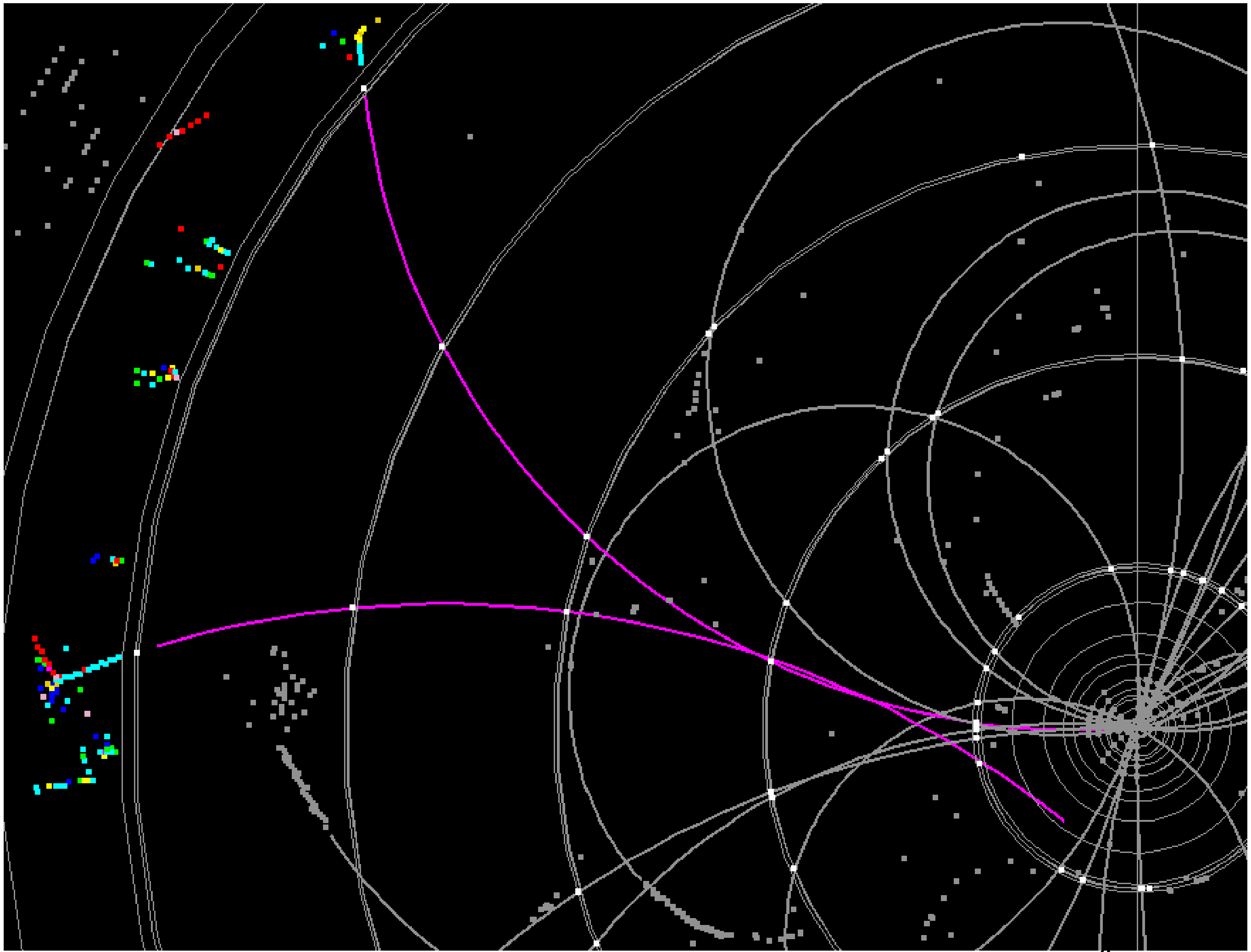
  $\Rightarrow$ W-Si pixel sampling calorimeter
- The key to making this practical is a highly integrated electronic readout:
  - readout channel count = pixel count /~1000
  - cost $\approx$ independent of cost for segmentation > 2-3 mm
    - 3.6 mm is current default
  - allows for a small readout gap (1 mm) $\Rightarrow$ small effective R_m (13 mm)
  - low power budget (passive cooling)
  - handles the large dynamic range of energy depositions (few thousand)
- This takes some time to develop (getting close).

An "Imaging Calorimeter"

A highly segmented (in 3-D) ECal provides a general pattern recognition capability:

- PFA: particle separation in jets
- id of specific objects/decays: e.g. tau
- tracking (charged and neutrals)

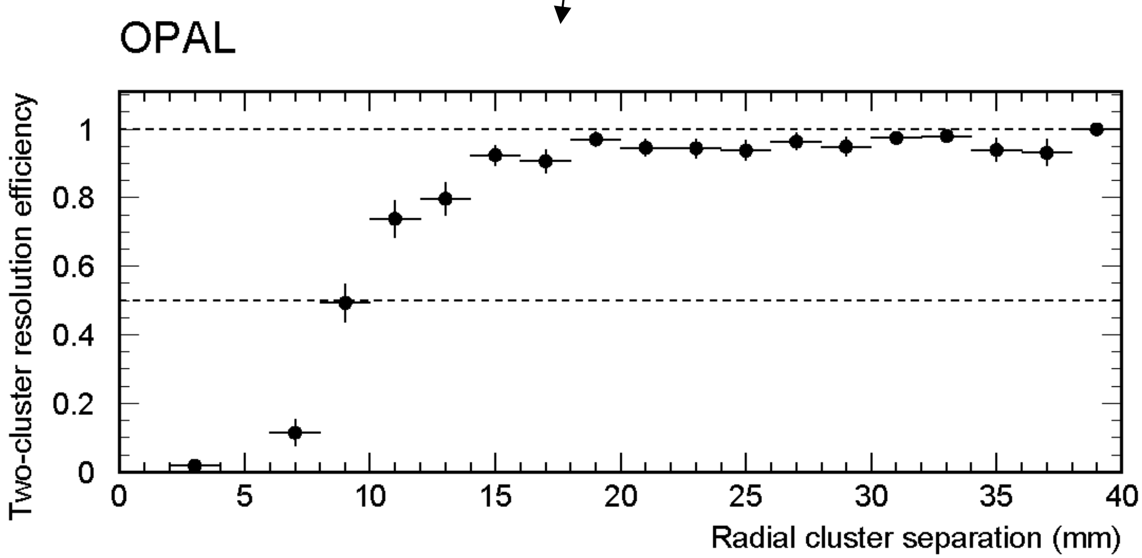




Segmentation requirement

- In general, we wish to resolve individual photons from jets, tau decays, etc.
- The resolving power depends on Moliere radius and segmentation.
- We want segmentation significantly smaller than R_m

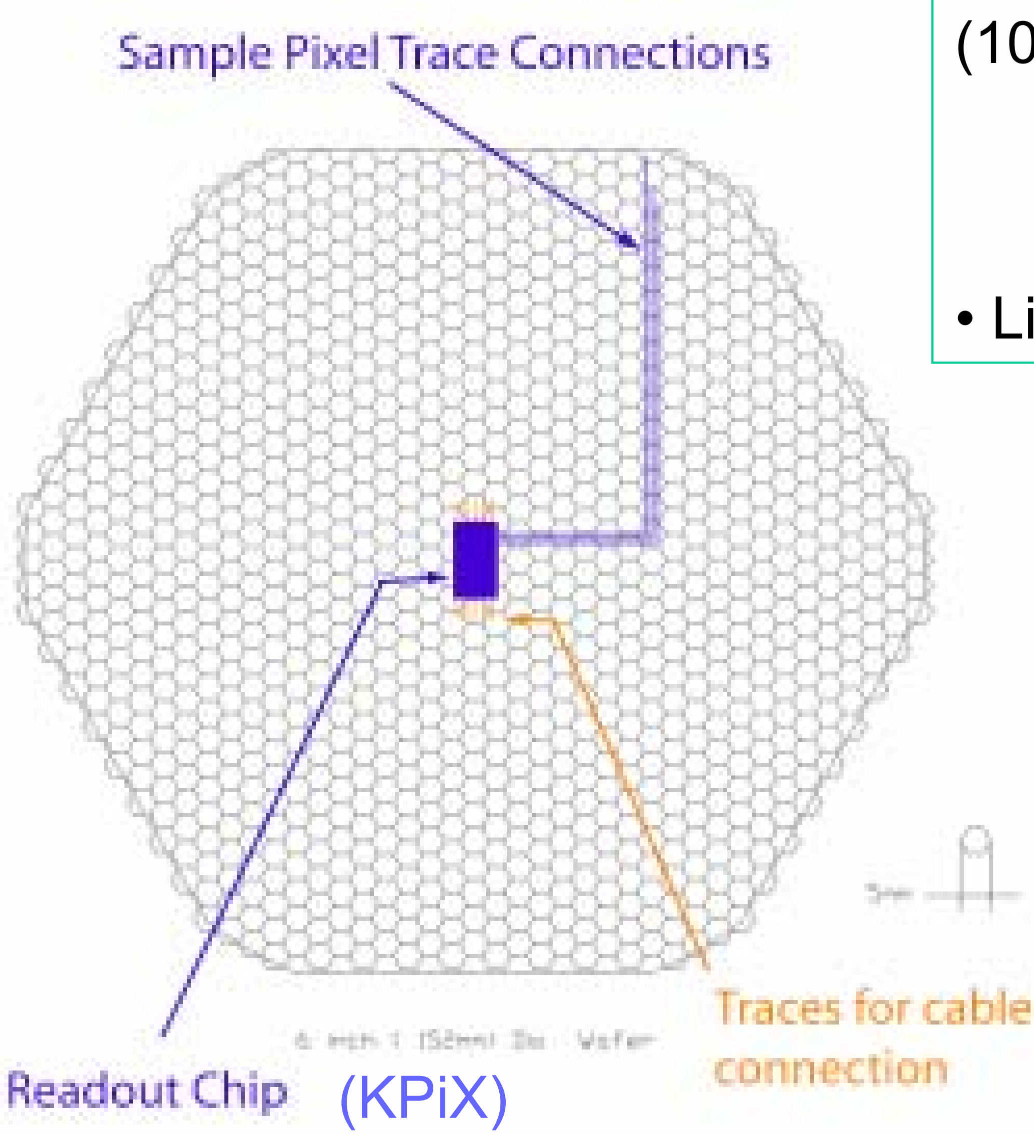
Two EM-shower separability in LEP data with the OPAL Si-W LumCal (David Strom) :



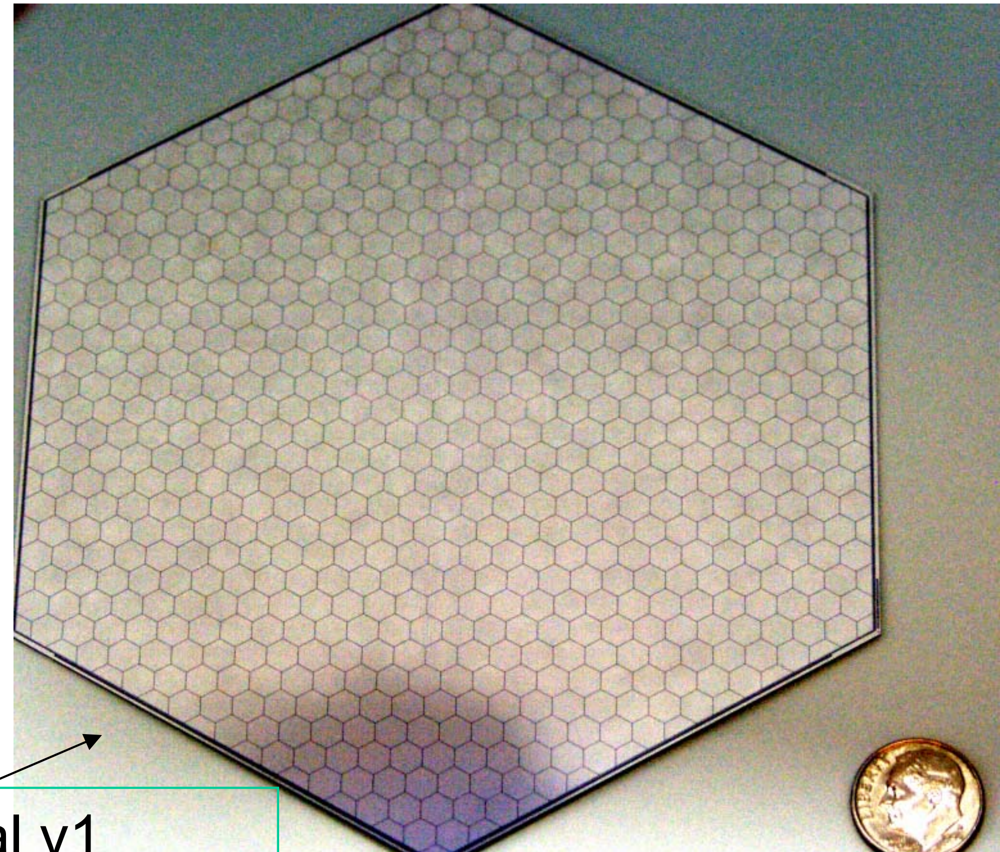
$$f_E \simeq \frac{R_{cal}}{\sqrt{R_M^2 + (4d_{pad})^2}}$$

$$d = 2.5\text{mm} \;,\; R_M \sim 17\text{mm}$$

Silicon detector layout and segmentation



- One KPiX readout chip for the sensor (1024 pixels, 6 inch wafer)
  - KPiX also being considered for Si tracker and DHCal with GEMs
- Limit on seg. from chip power ($\approx$2 mm^2)

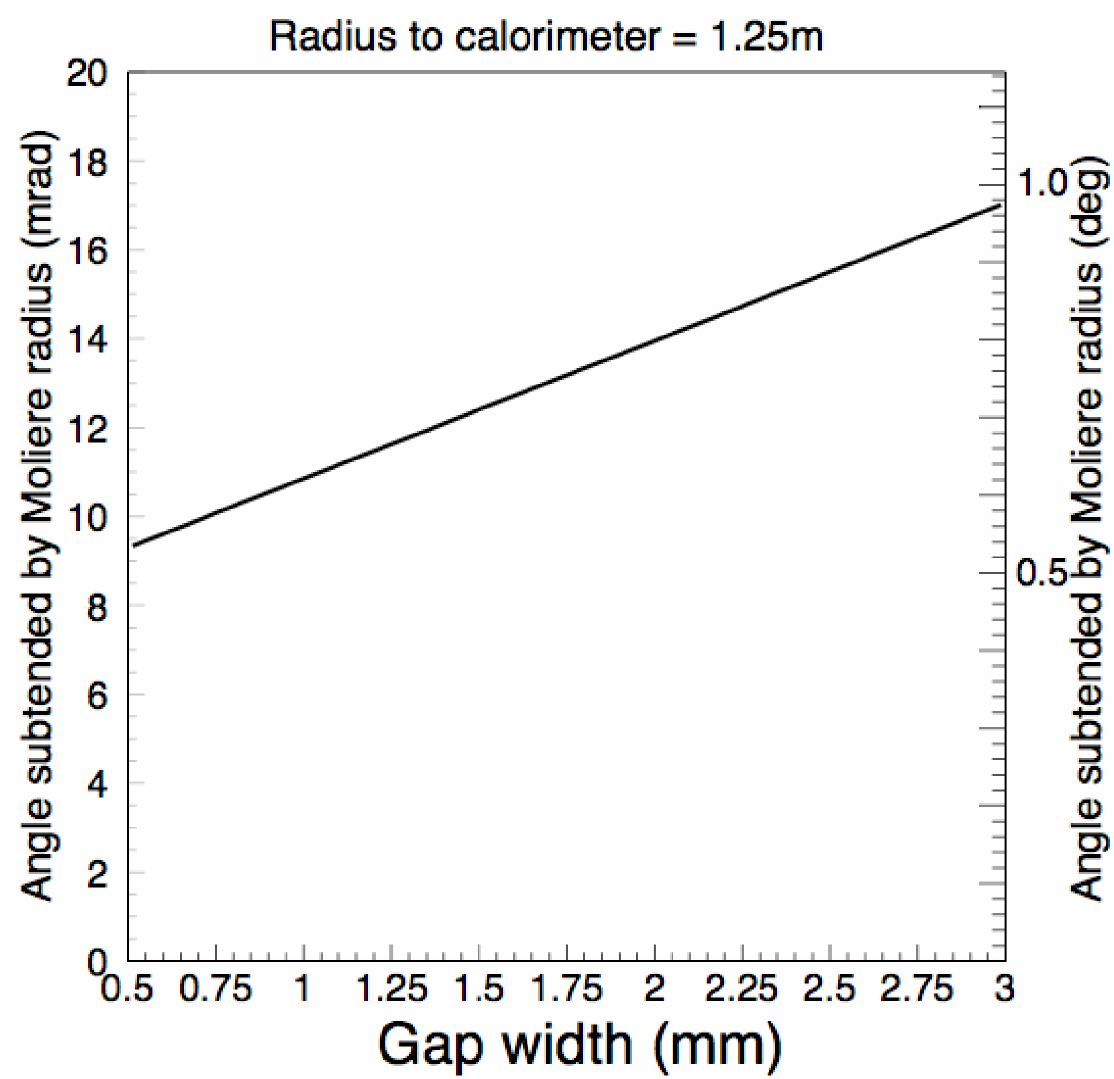


Fully functional v1 prototype (Hamamatsu)

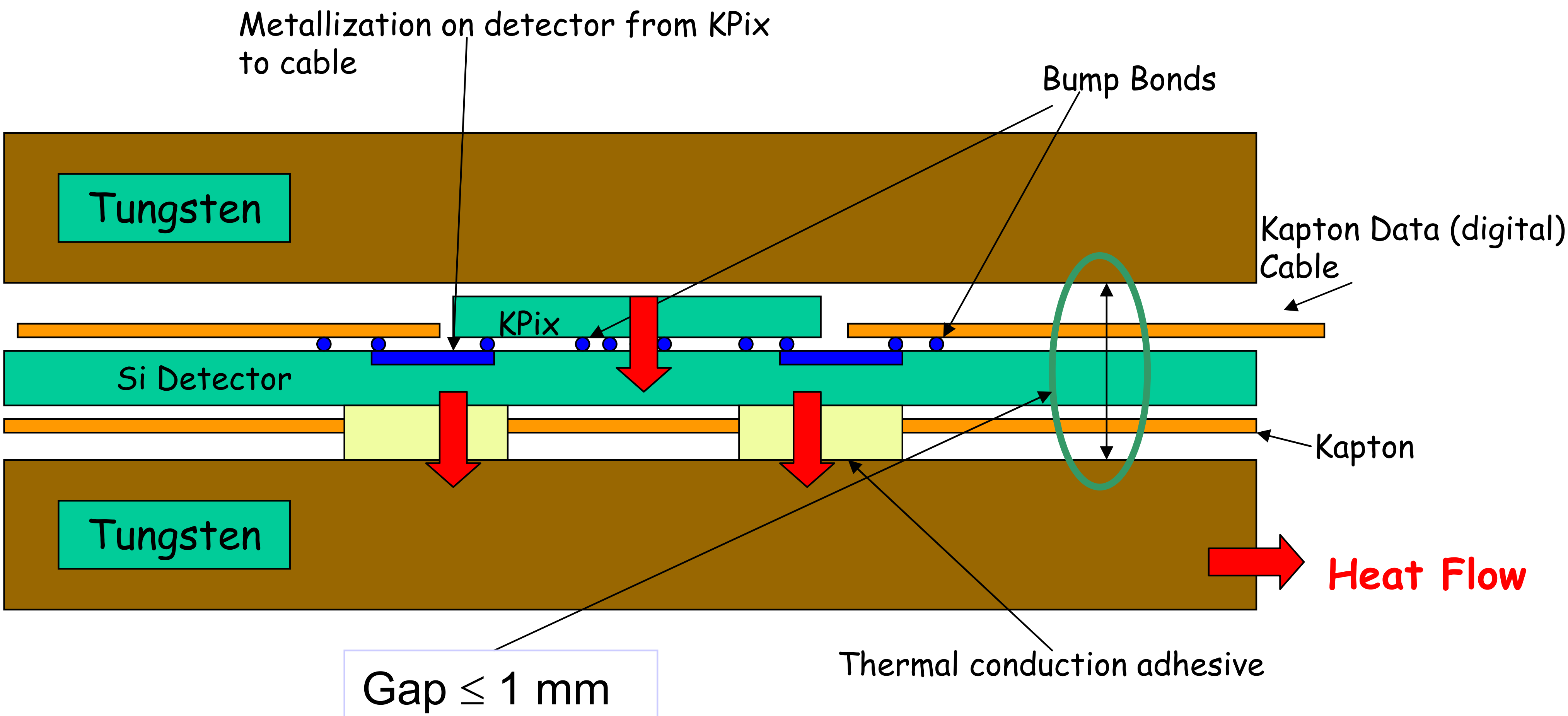
Critical parameter for R_M is the gap between layers

Config.	Radiation length	Molière Radius
100% W	3.5mm	9mm
92.5% W	3.9mm	10mm
+1mm gap	5.5mm	14mm
+1mmCu	6.4mm	17mm

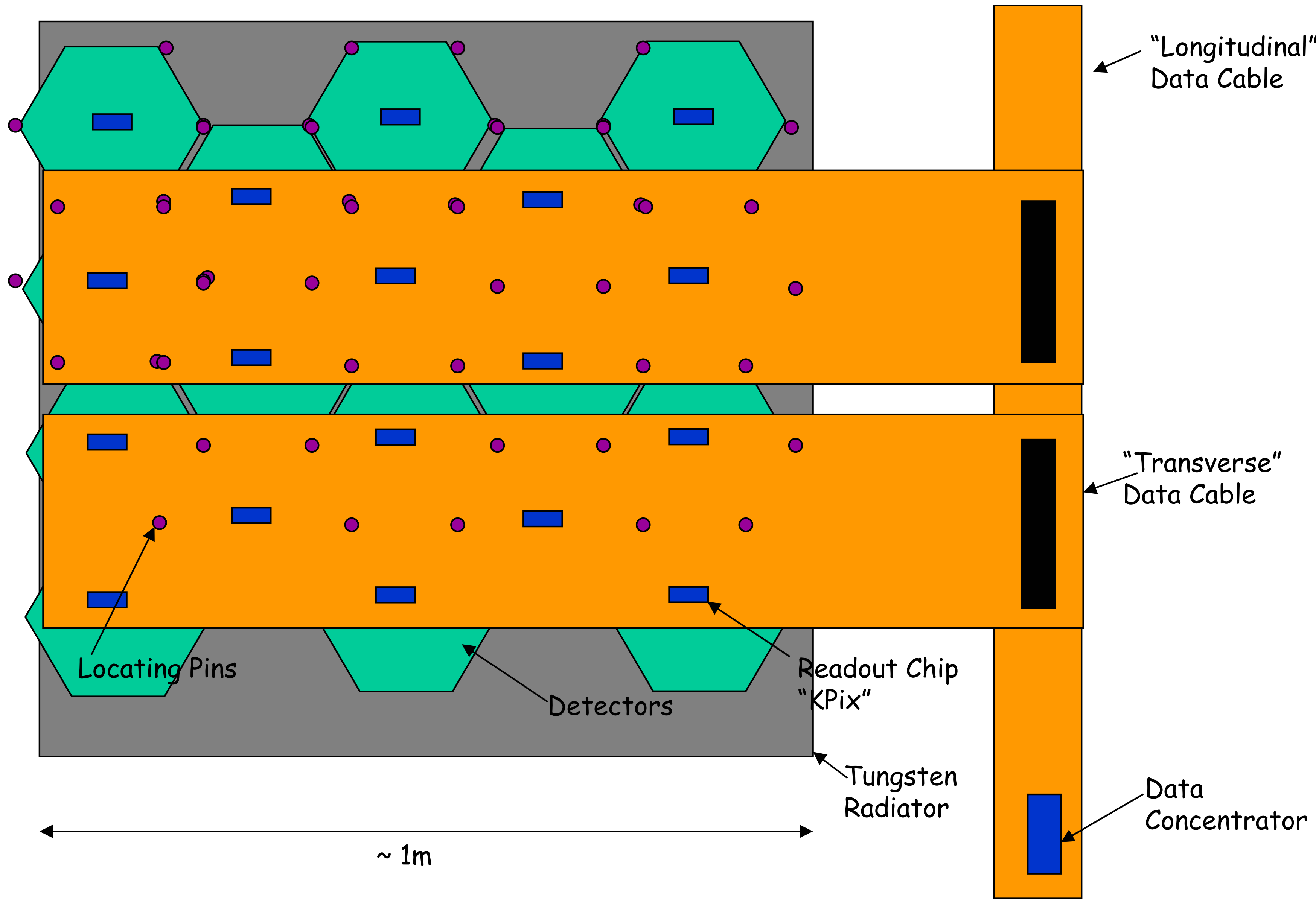
Assumes 2.5mm thick tungsten absorber plates



readout gap cross section -- schematic

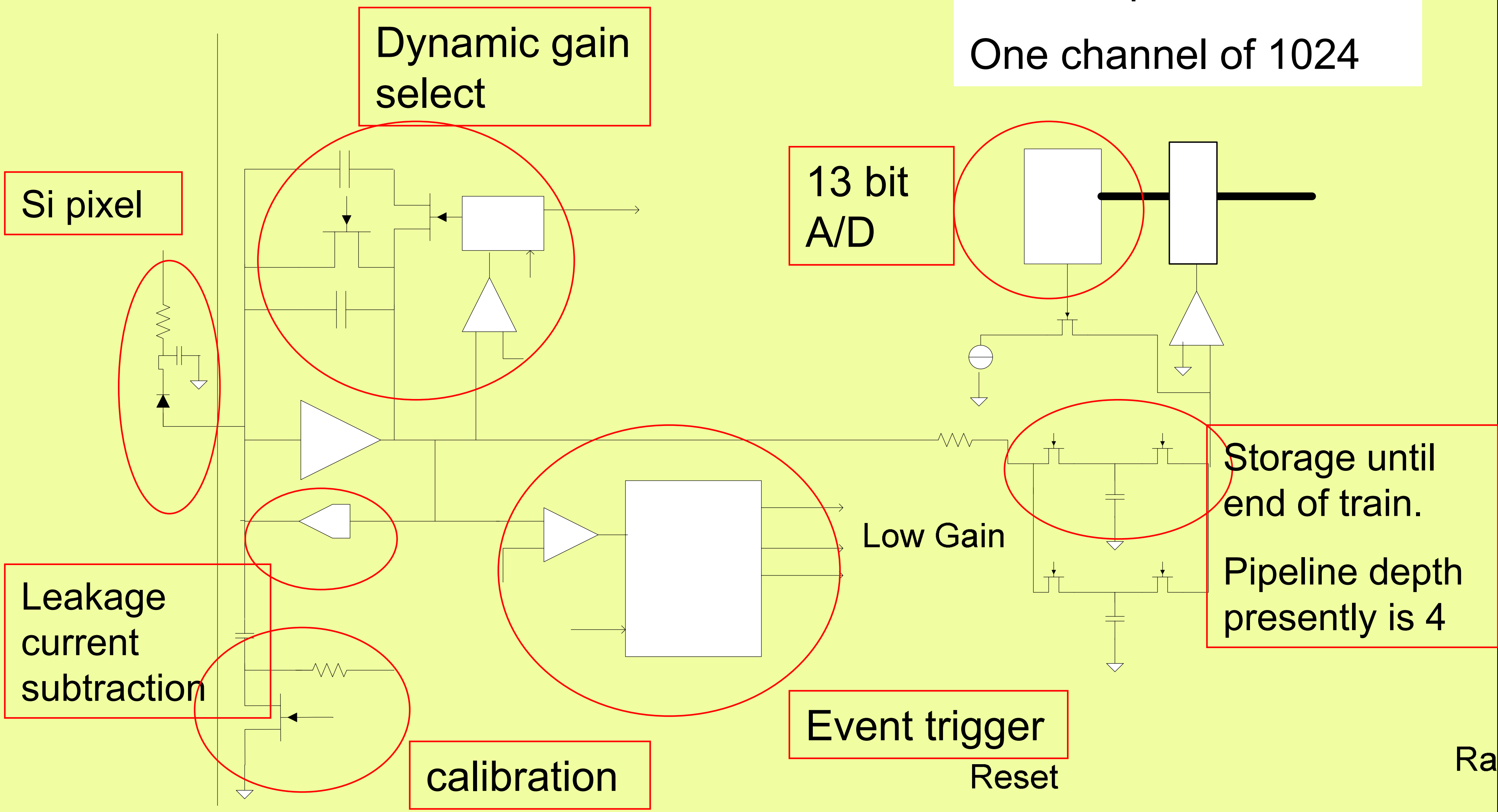


Conceptual Schematic – Not to scale

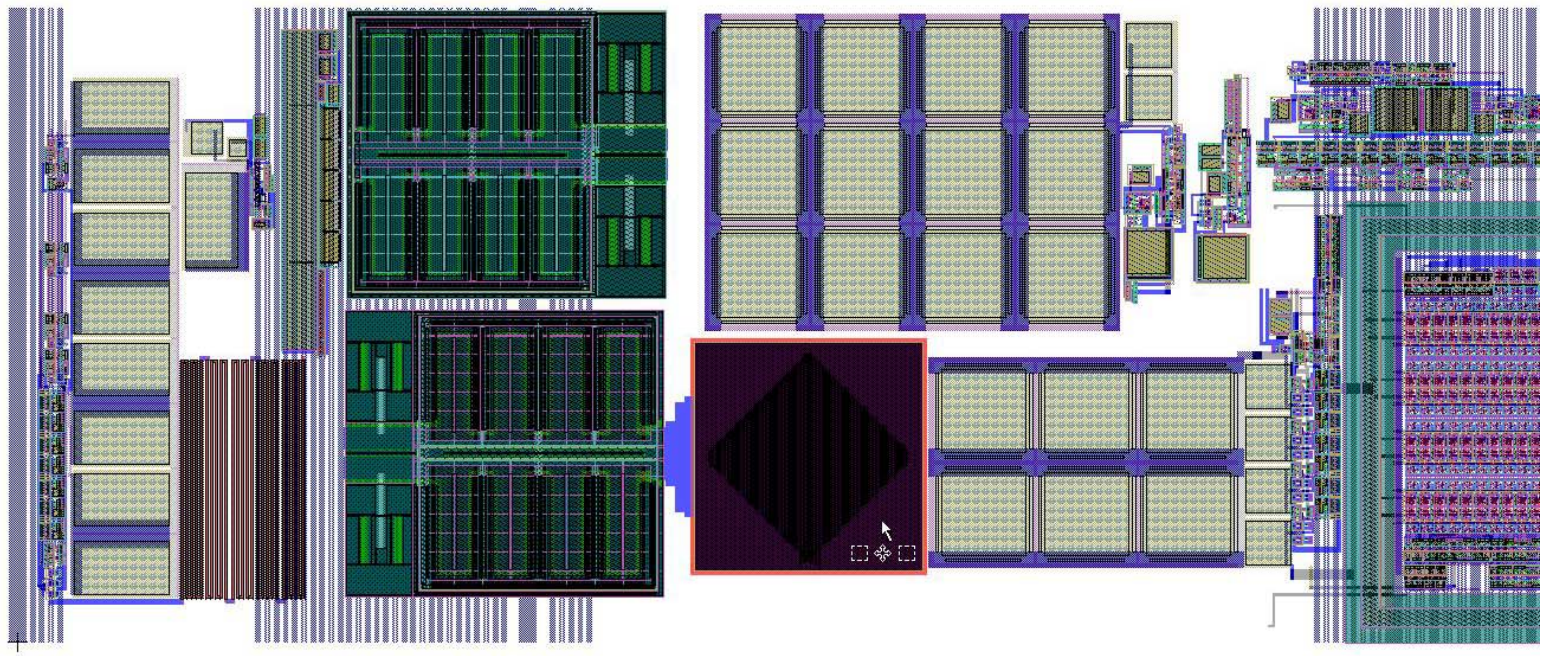


KPiX chip

One channel of 1024



KPiX Cell 1 of 1024



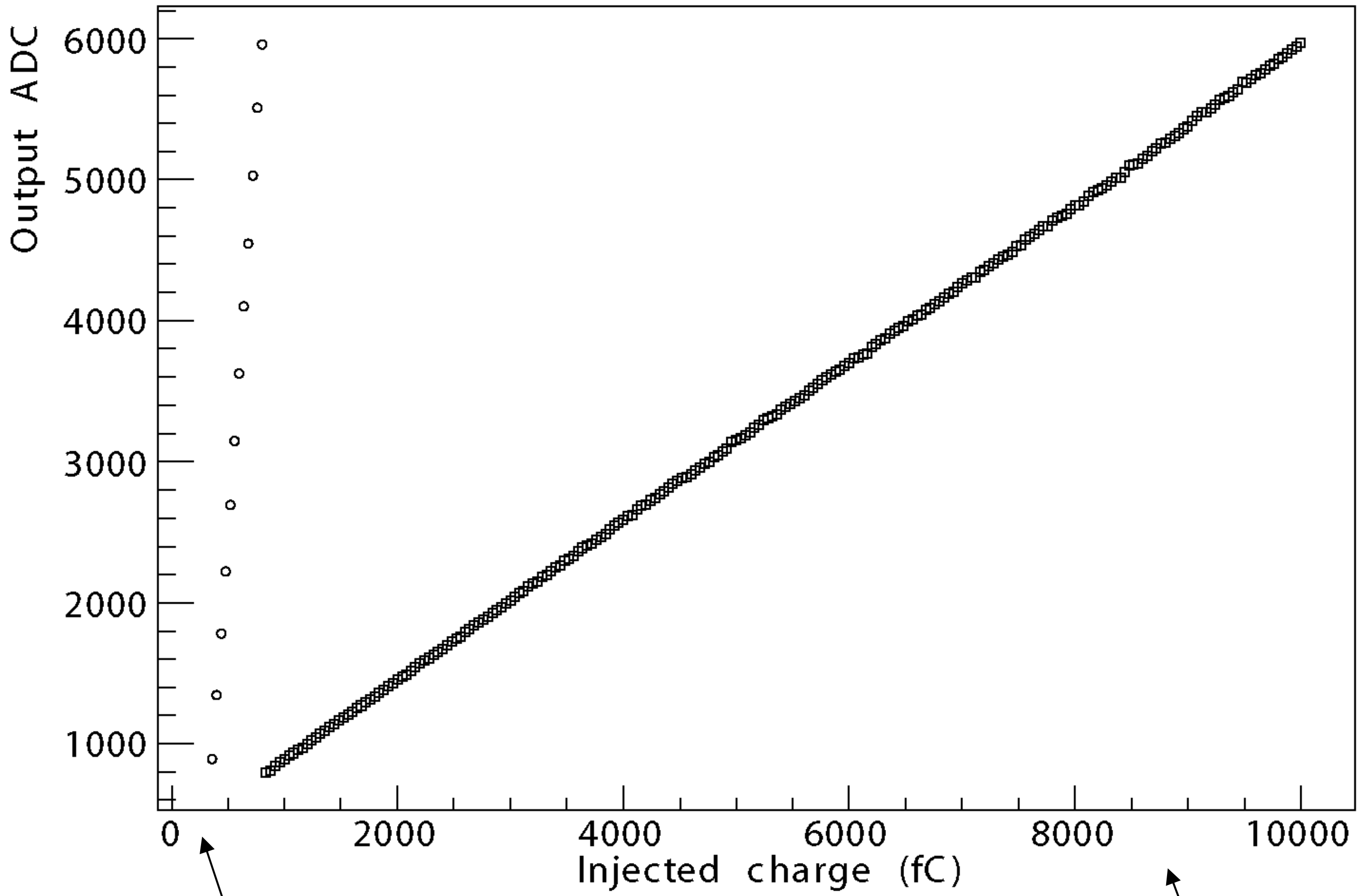
64-channel prototypes:

- v1 delivered March 2006
- v4 currently under test

It's a complicated beast – will need a v5 before going to the full 1024-channel chip

Dynamic Range

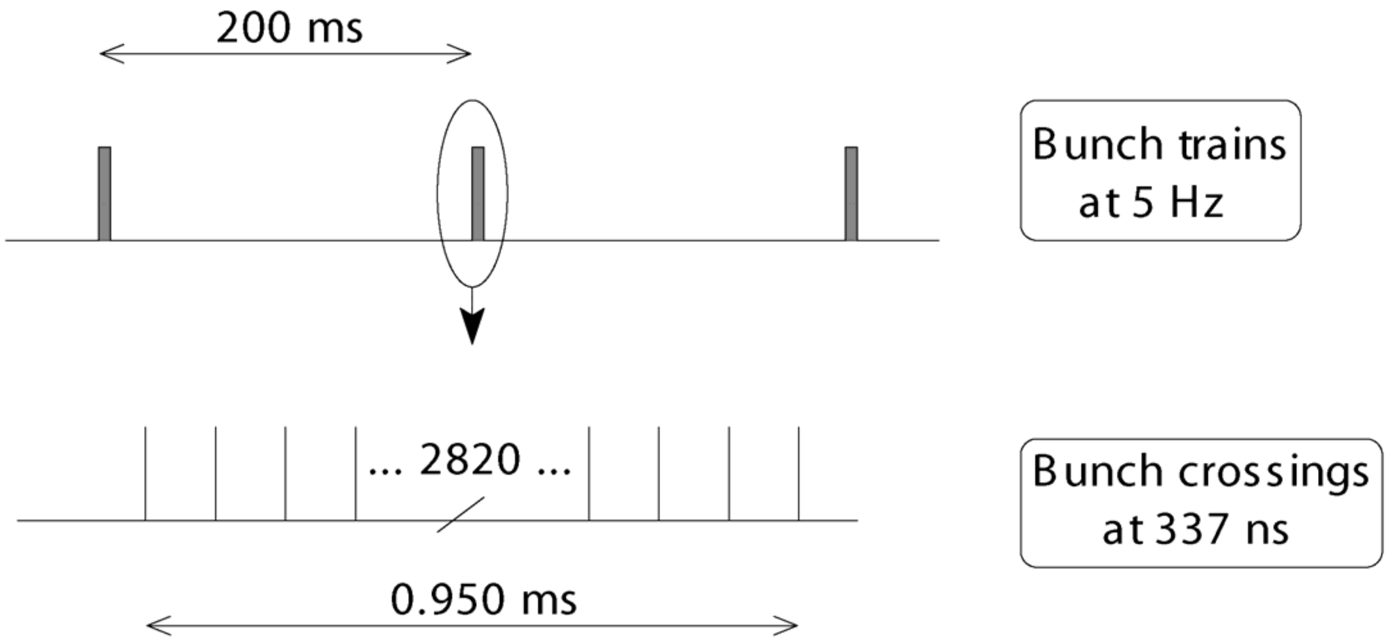
KPiX-2 prototype on the test bench



1 MIP (4 fC)

Max signal: 500 GeV electron

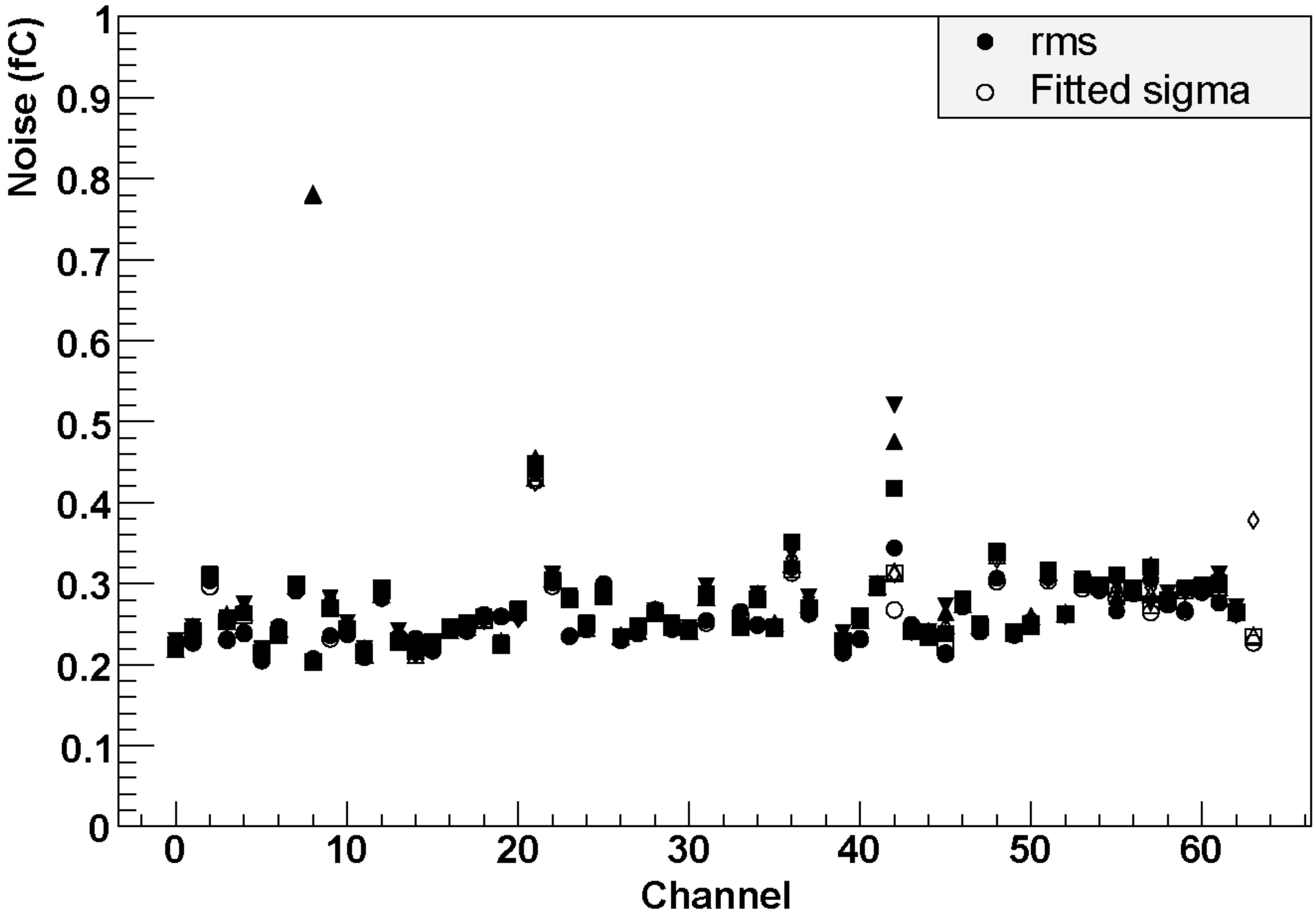
Power



Phase	Current (ma)	Instantaneous Power (mw)	Time begin (us)	Time End (us)	Duty Factor	Average Power (mw)	Comments
All Analog "on"	370.00	930.00	0.00	1,020.00	5.10E-03	4.7	Power ok with current through FET's
Hold "on", charge amp off	85.00	210.00	1,021.00	1,220.00	9.95E-04	0.2	
Analog power down	4.00	10.00	1,020.00	200,000.00	9.95E-01	9.9	
LVDS Receiver, etc		3.00	0.00	200,000.00	1.00E+00	3.0	Receiver always on.
Decode/Program		10.00	1.00	100.00	4.95E-04	0.0	Sequencing is vague!
ADC		100.00	1,021.00	1,220.00	9.95E-04	0.1	
Readout		50.00	1,220.00	3,220.00	1.00E-02	0.5	
Total						18.5	Total power OK

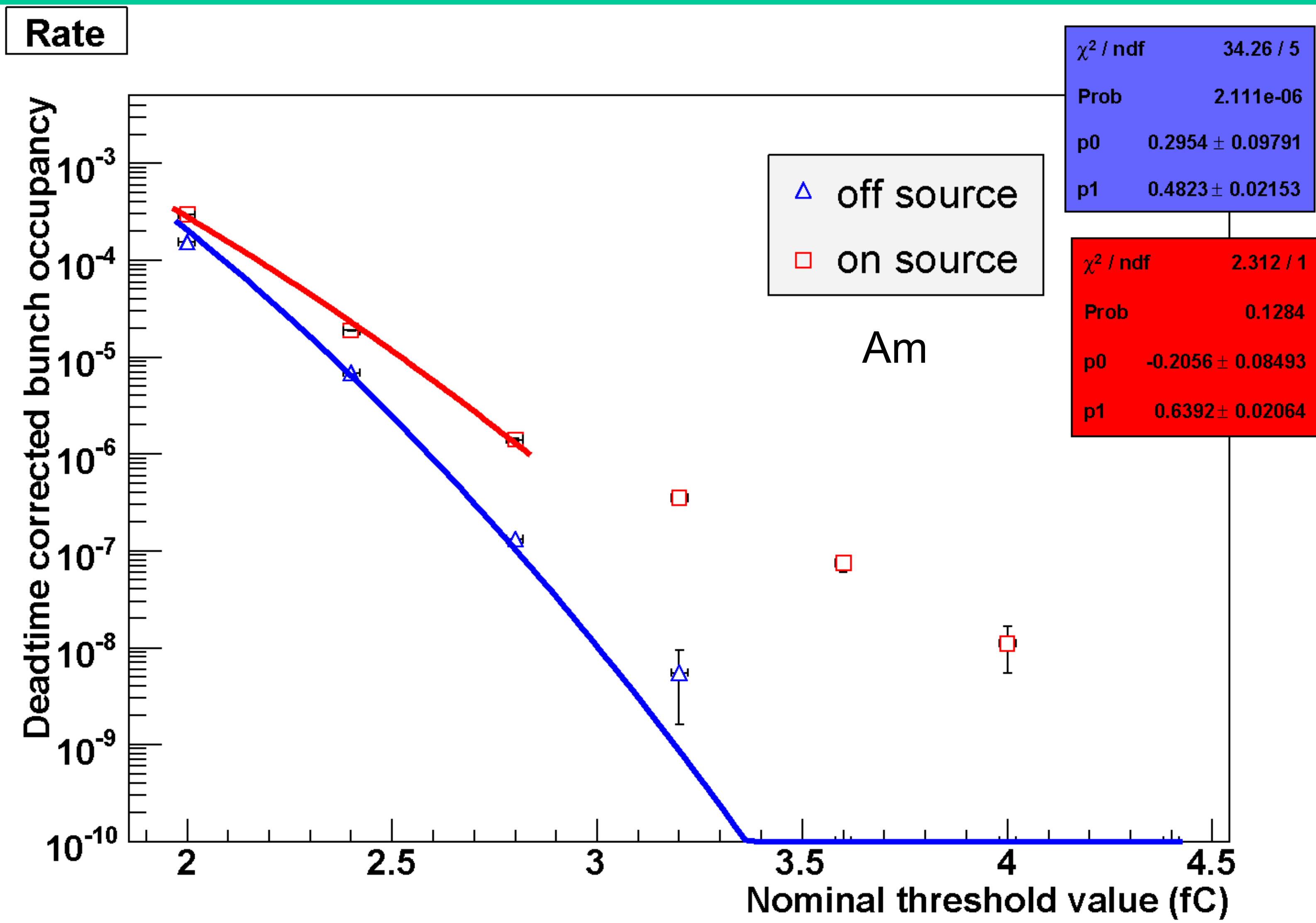
Passive conduction of 20 mW to module end (≈75 cm) via the tungsten radiator results in a few °C temperature increase ⇒ OK !

Noise in KPiX-4



- 1 MIP = 3.9 fC $\Rightarrow$ meets ECal S/N spec of 8/1
- outliers probably due to routing issues

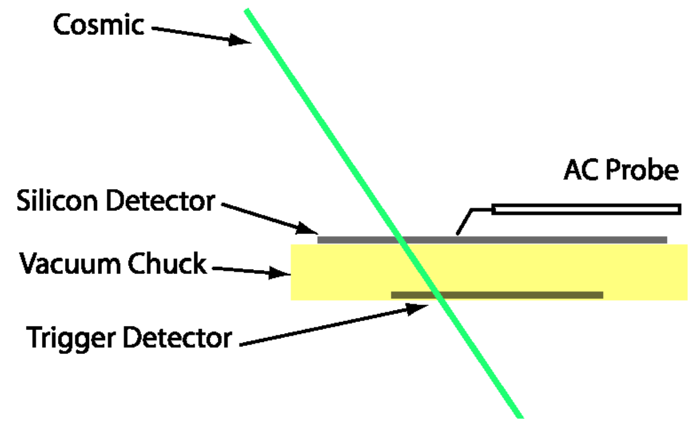
Noise is gaussian

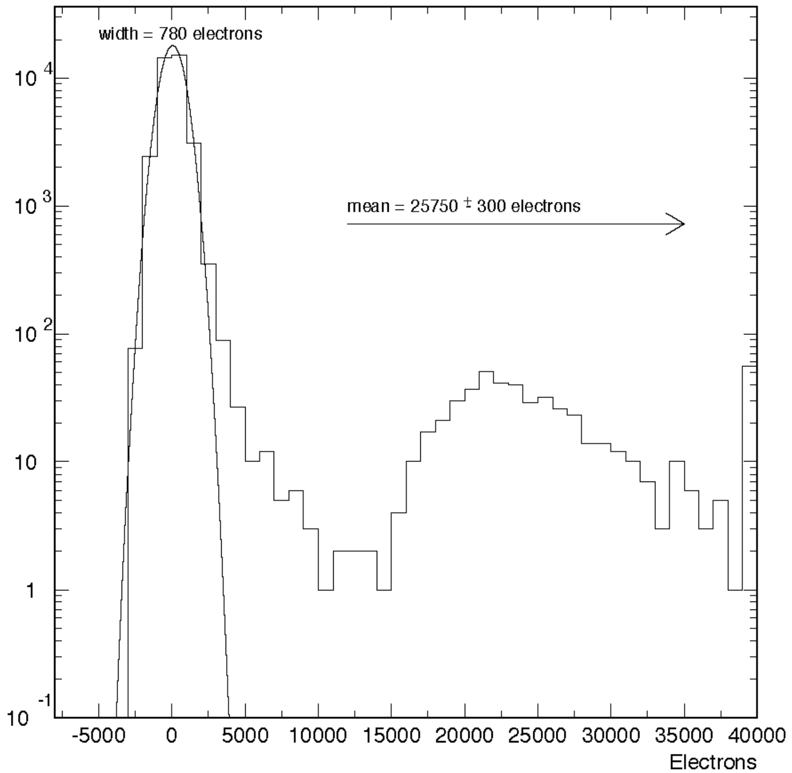


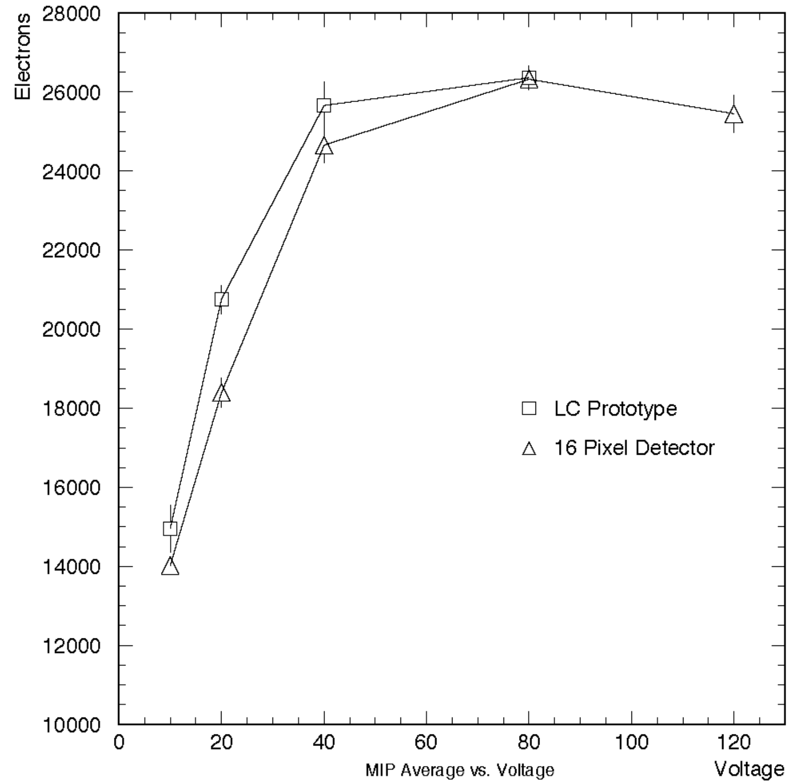
- Can set threshold at ≈ 0.5 MIP

prototype Si detector studies

Response of detectors to Cosmics
(Single 5mm pixel)
Simulate LC electronics
(noise somewhat better)

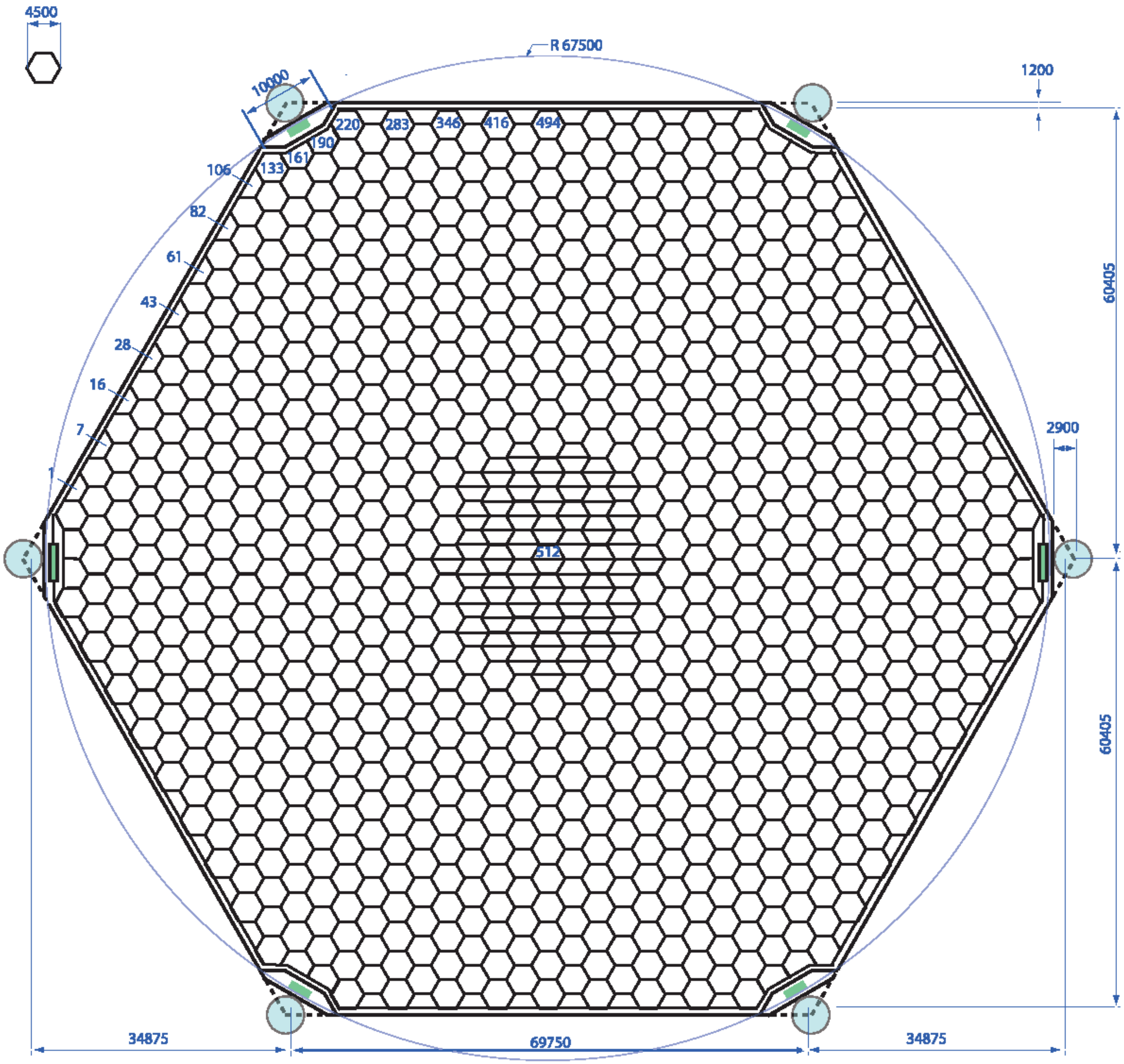






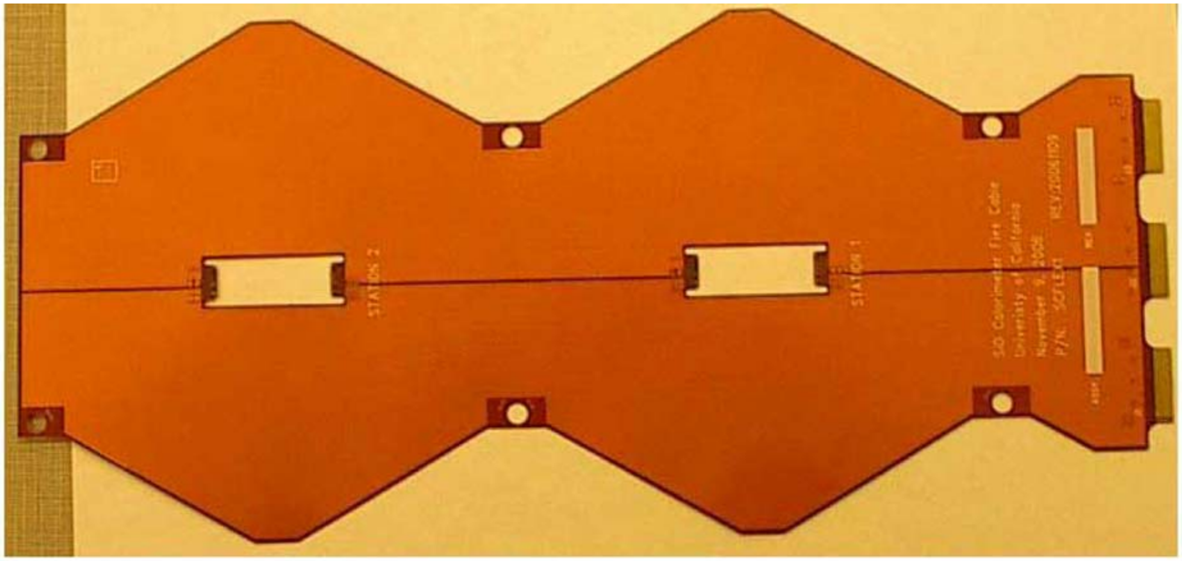
Errors do not include ~ 10% calibration uncertainty (no source calibration)

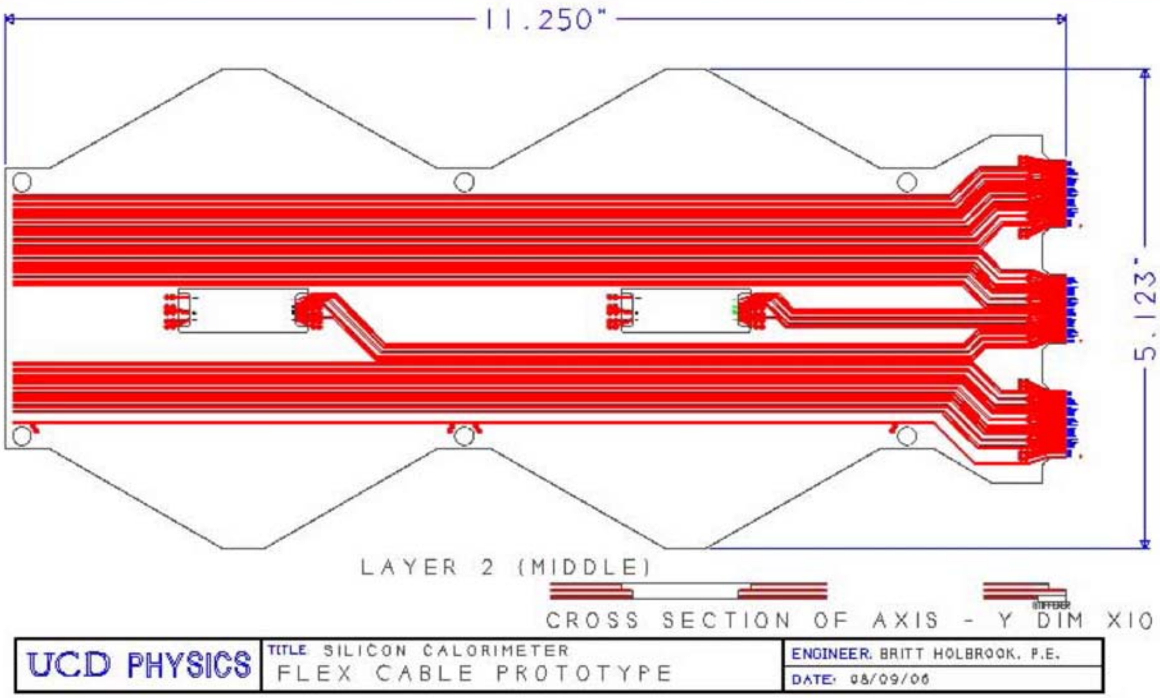
v2 Si detector – for full-depth test module



- 6 inch wafer
- 1024 13 mm^2 pixels
- improved trace layout near KPiX to reduce capacitance
- procurement in progress (it will take 6-12 months to complete the 40-wafer purchase – funding limited)

Readout flex cable (digitized signals, power&control)





- First prototype:
  - 2 stations
  - Buried signal layer between power and ground
  - Wire bond connections
  - No problem for prototypes
- For ECal:
  - ~6 stations: should be OK
  - Would like to determine length limit for next round (vias and multi-layers difficult for ~1m)

Status Summary and Plans (near term)

- KPiX readout chip
  - Currently studying v4 prototype (2x32 channels)
  - Submit v5 in next few weeks (4x32 channels)
    - Improved biasing of MOS capacitors; new poser bus for comparators
    - Optimized shaper time constants
  - Perhaps submit 1024-channel KPiX in Fall
- Silicon sensors
  - v2 prototype submitted to industry (40 sensors)
  - Schedule funding limited – hope to acquire sensors Fall-Winter
- Readout flex cable – short version for first module OK
- Bump bonding – first trials (UC Davis) just starting

→ All of the above: a full-depth, single-wafer wide module

→ Test in a beam: (1) electrons; (2) hadrons with HCal

The R&D leading to an “ILC-ready” Si-W ECal technology is progressing well

Extra stuff...

R&D Milestones and test beams

I. Connect (bump bond) prototype KPiX to prototype detector with associated readout cables, etc
   - Would benefit from test beam (SLAC?) - 2007
   - A “technical” test

II. Fabricate a full-depth ECal module with detectors and KPiX-1024 readout – functionally ≈equivalent to the real detector
   - Determine EM response in test beam – late 2007-8
   - Ideally a clean 1-30 GeV electron beam (SLAC?)

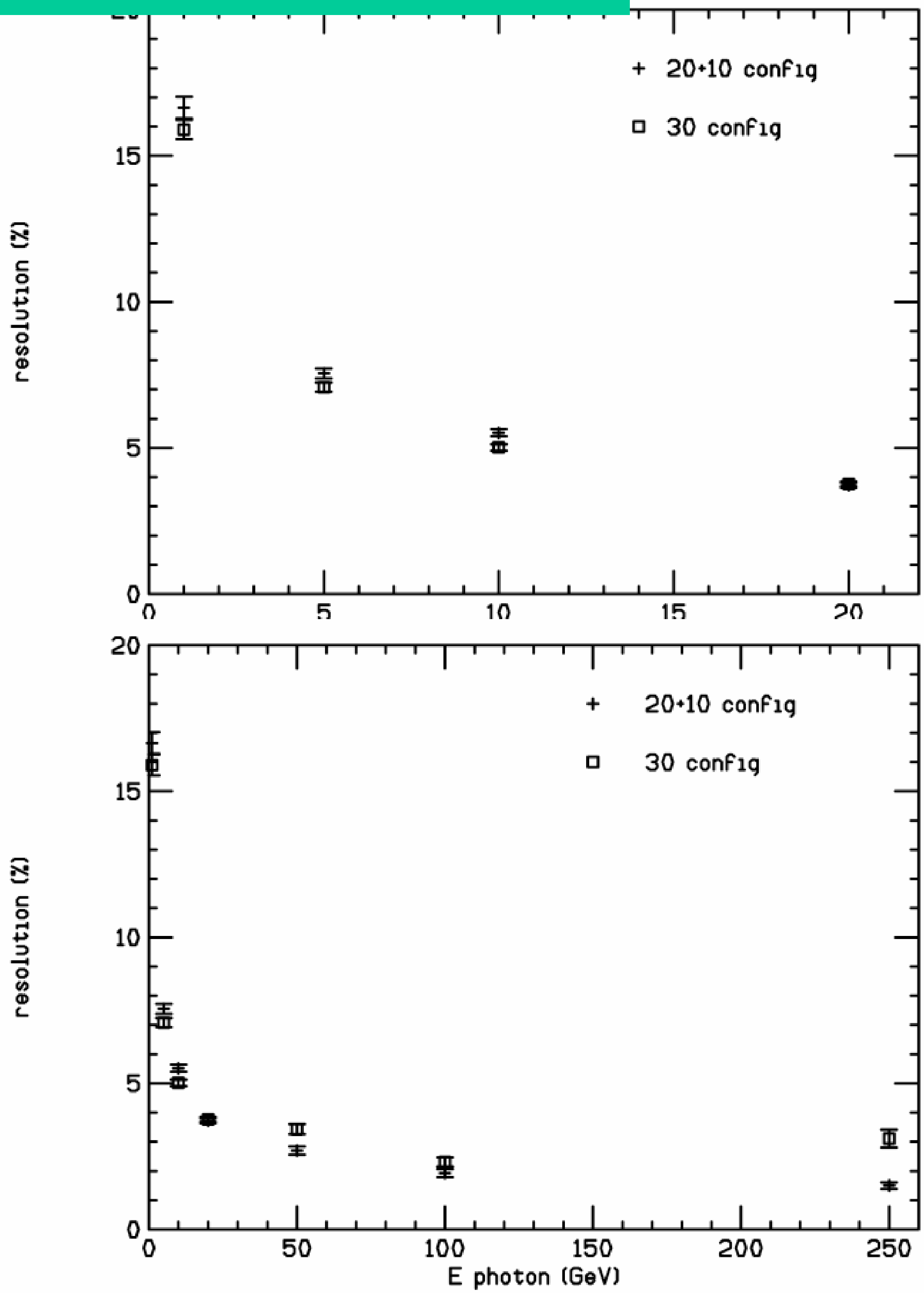
III. Test with an HCal module in a hadron beam (FNAL?) – 2008-?
   - Test/calibrate the hadron shower simulations; measure response

IV. Pre-assembly tests of actual ECal modules in beam – >2010-?

Longitudinal Sampling

<u>Compare two tungsten configurations:</u>

- 30 layers x 5/7 X_0
- (20 x 5/7 X_0) + (10 x 10/7 X_0)

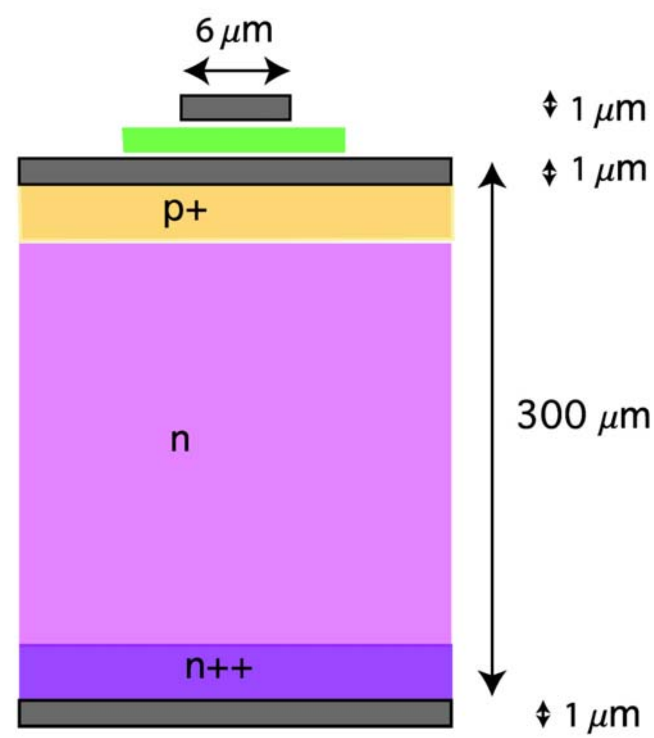


- Resolution is 17% / √E , nearly the same for low energy (photons in jets)
- Better for the 20+10 config. at the highest energies (leakage) ⇒ adopt as baseline

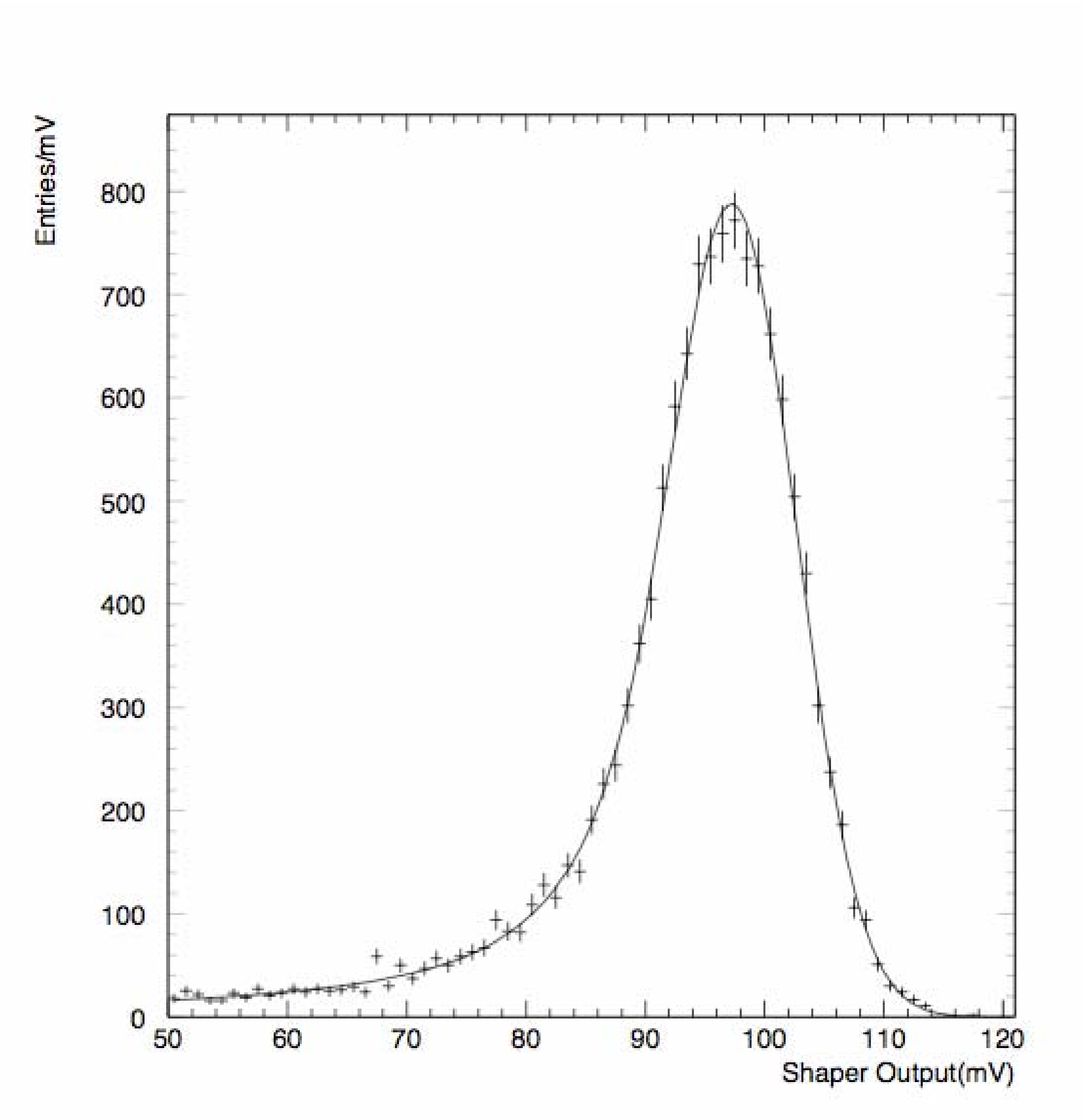
Electronics requirements

- Signals
  - <2000 e noise
  - Require MIPs with S/N > 7
  - Large dynamic range: Max. signal is ≈2500 MIPs (for 5mm pixels)
- Capacitance
  - Pixels: 5.7 pF
  - Traces: ~0.8 pF per pixel crossing
  - Crosstalk: 0.8 pF/Gain x Cin < 1%
- Resistance (traces)
  - 300 ohm max
- Power
  - If < 40 mW/wafer ⇒ allows passive cooling (as long as power is cycled off between bunch trains)
- Provide fully digitized, zero suppressed outputs of charge and bx time on one ASIC for every wafer.

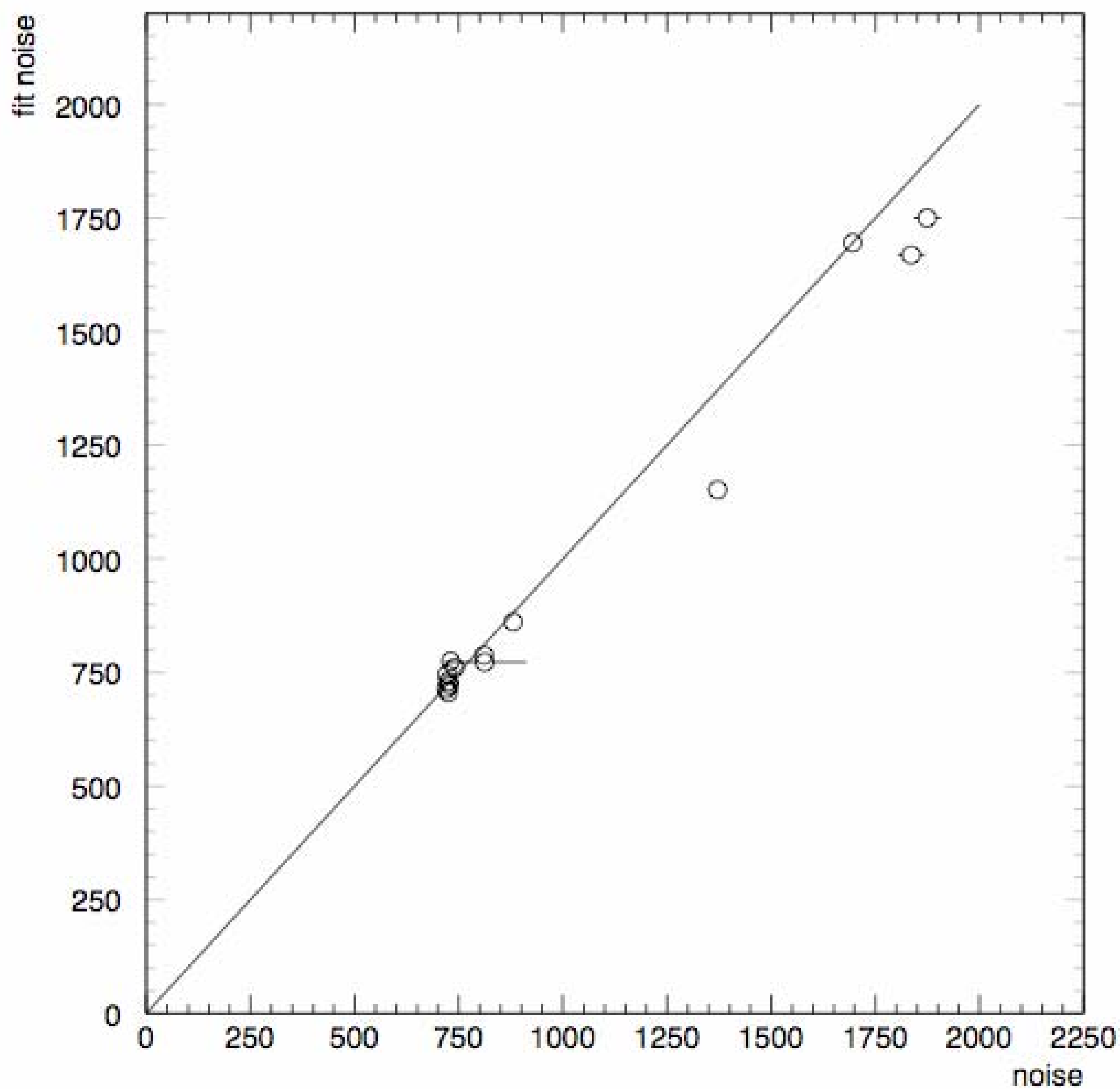
Use DC-coupled detectors: only two metal layers (cost)



Response of Detectors to 60KeV Gamma's from Am^{241}



Possible ~1% wafer-wafer calibration?



Noise is consistent with expectation from capacitance and series resistance