First Results with the Prototype Detectors of the Si/W ECAL

David Strom – University of Oregon

- Physics Design Requirements
- Detector Concept
- Silicon Detectors - Capacitance and Trace Resistance
- Implications of Accelerator Technology Choice
- MIPS, sources and laser

Si-W work – personnel and responsibilities

M. Breidenbach, D. Freytag, N. Graf, G. Haller,J. Deng
SLAC

R. Frey, D. Strom
UO*

V. Radeka
BNL

SLAC	UO*	BNL
Electronics, Mechanical Design, Simulation	**Si Detectors**, Mechanical Design, Simulation	**Electronics**

* This work includes contributions from Oregon students Tyler Neely and Eric Fitzgerald.

ECAL Design Requirements

- Optimal contribution to the reconstruction of multijet events:
  - Excellent separation of γ's from charged particles
    Efficiency $>95\%$ *for energy flow*
  - Excellent linkage of ECAL with tracker (important for SiD)
  - Good linkage of ECAL with HCAL
  - Good reconstruction of $\pi^{\pm}$, detection of neutral hadrons
  - Reasonable EM energy resolution ($< 15\%/\sqrt{E}$)

Physics case: jet reconstruction important for many physics processes.

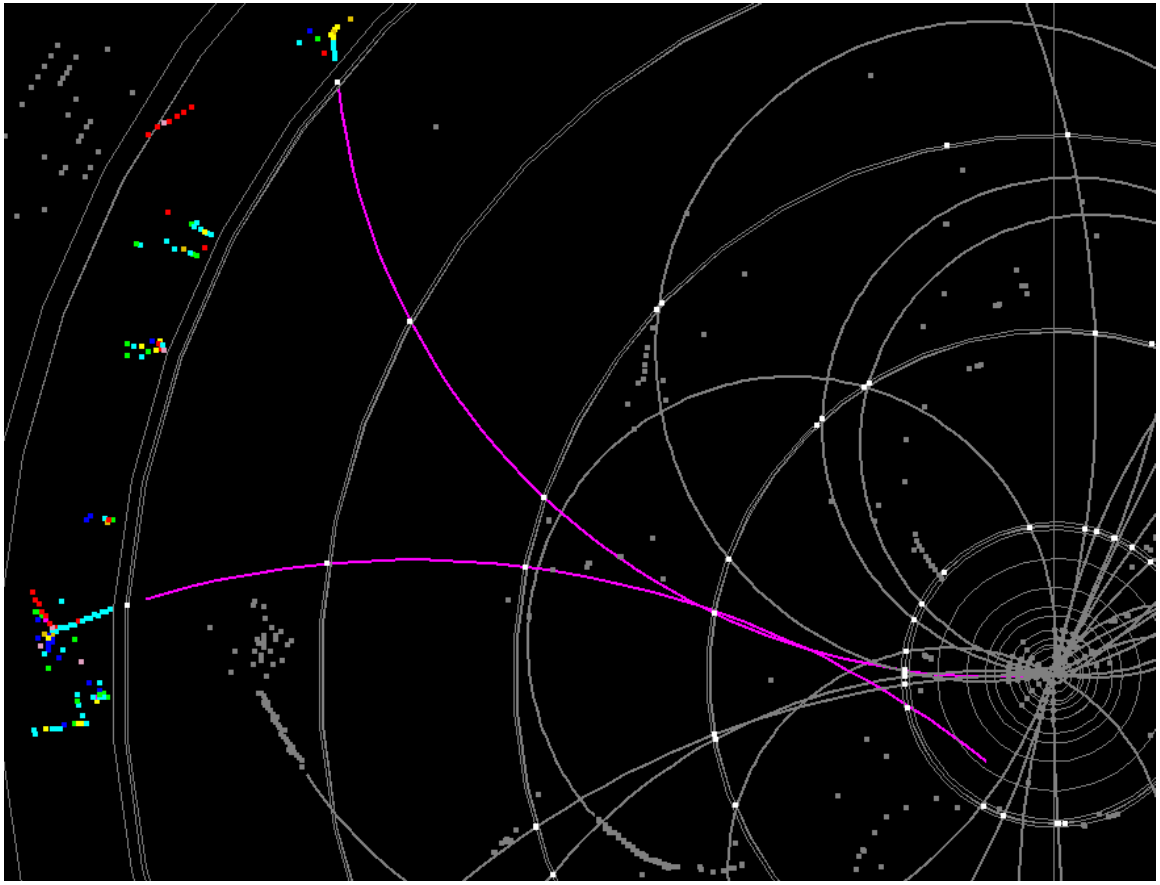
- Longitudinal Sampling, 30 layers needed for EM energy resolution

$$\frac{\sigma_E}{E} \sim 20\%\sqrt{\frac{X}{E}}$$

X is the sampling in radiation length.

- Useful for K^0 tracking, etc.

- **Can tolerate small, random inefficiency**



See talks by Eckhard von Toerne

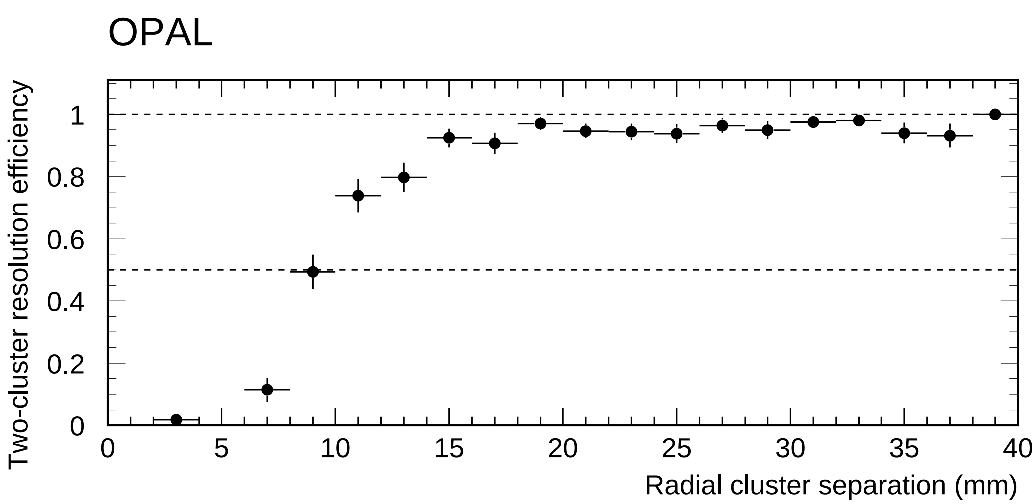
Importance of Granularity

- Figure of merit for energy reconstruction is

$$f_E \simeq \frac{max(R_M, 4d)}{R_{cal}}$$

where R_M is the Molière radius, d is the detector pad size and R_{cal} is the inner radius of the calorimeter (factor of 4 somewhat arbitrary)

Example (OPAL SiW luminosity monitor, $1X_0$ radiator, 3mm gap)



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

- The costs of the calorimeters, coil, and muon system have

$$\text{cost} \propto R_{cal}^{n}$$

where n is $\sim 2-3$.

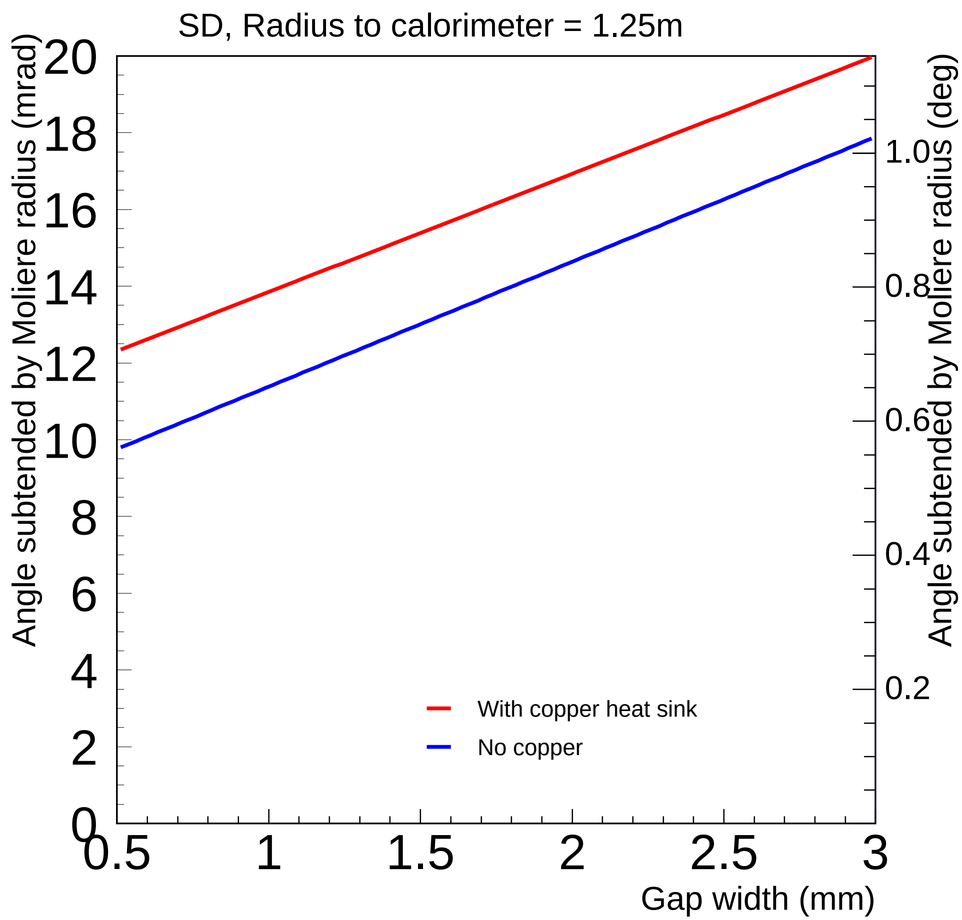
- Thus a 10% increase in the Molière radius of the calorimeter leads to a $>20\%$ increase in cost of the detector for constant f_e.

- Conclusion: try and make the calorimeter as dense as possible

Critical parameter: gap between tungsten layers.

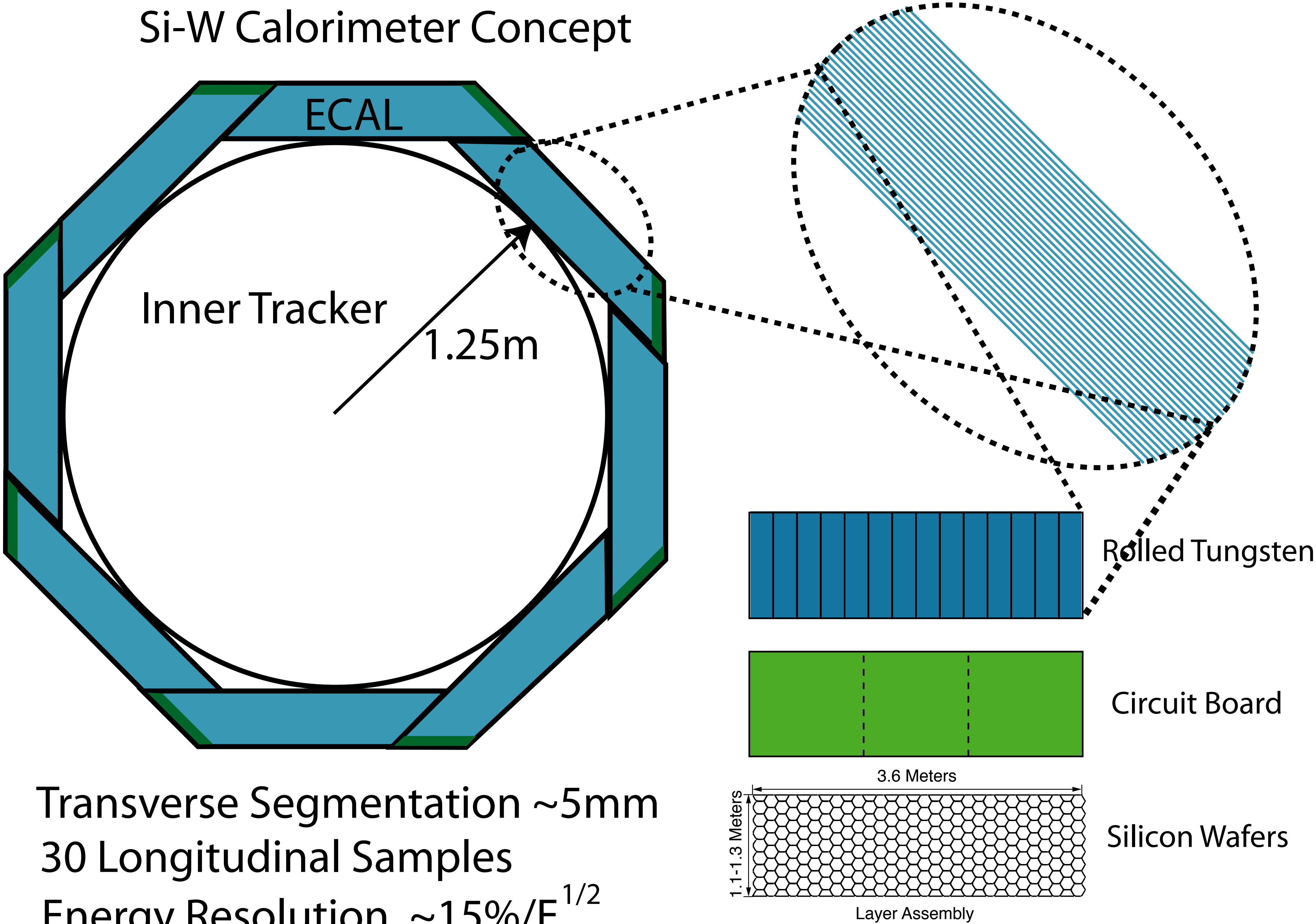
Config.	Radiation length	Molière Radius
100% W	3.5mm	9mm
92.5% W	3.9mm	10mm
+1mm gap	5.5mm	14mm
+1mmCu	6.4mm	17mm

Assumes 2.5mm thick tungsten absorber plates



Calice 3mm gap with 1.7m TESLA radius gives $\frac{R_M}{R_{Cal}} = 13$mrad

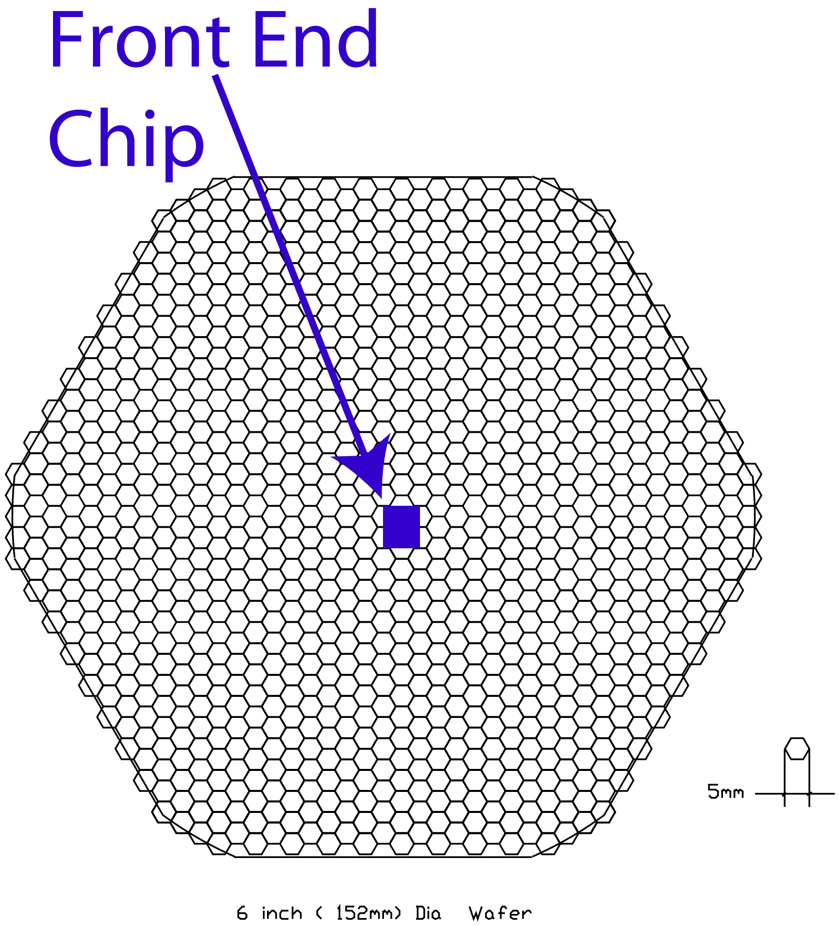
Si-W Calorimeter Concept



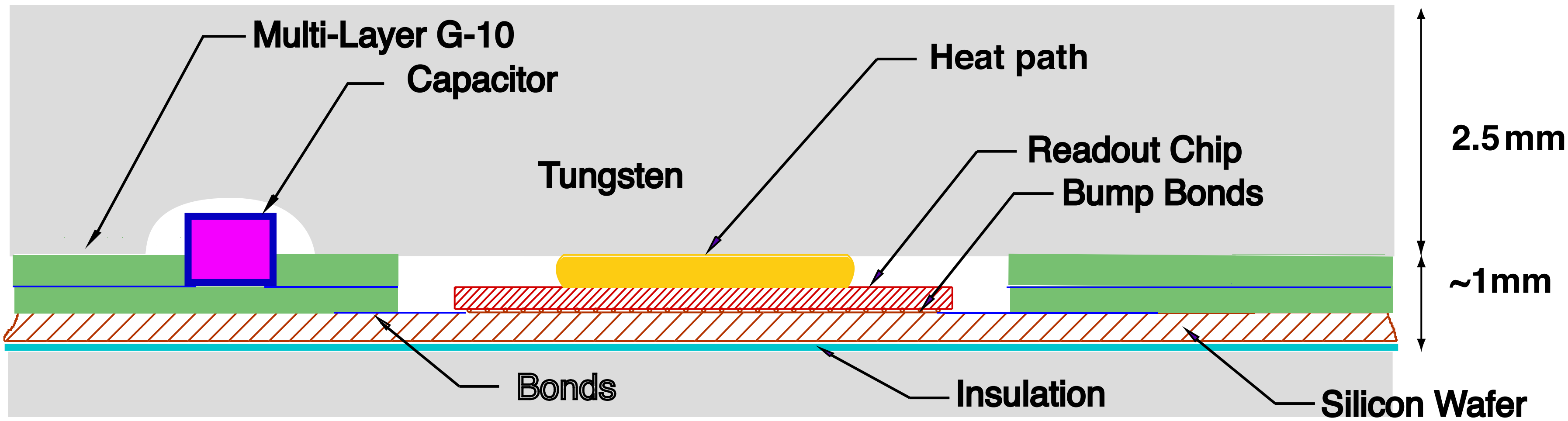
Transverse Segmentation ~5mm
30 Longitudinal Samples
Energy Resolution ~15%/$E^{1/2}$

Silicon Concept

- Readout each wafer with a single chip
- Bump bond chip to wafer
- To first order cost independent of pixels /wafer
- Hexagonal shape makes optimal use of Si wafer
- Channel count limited by power consumption and area of front end chip
- May want different pad layout in forward region



Critical parameter: minimum space between tungsten layers.



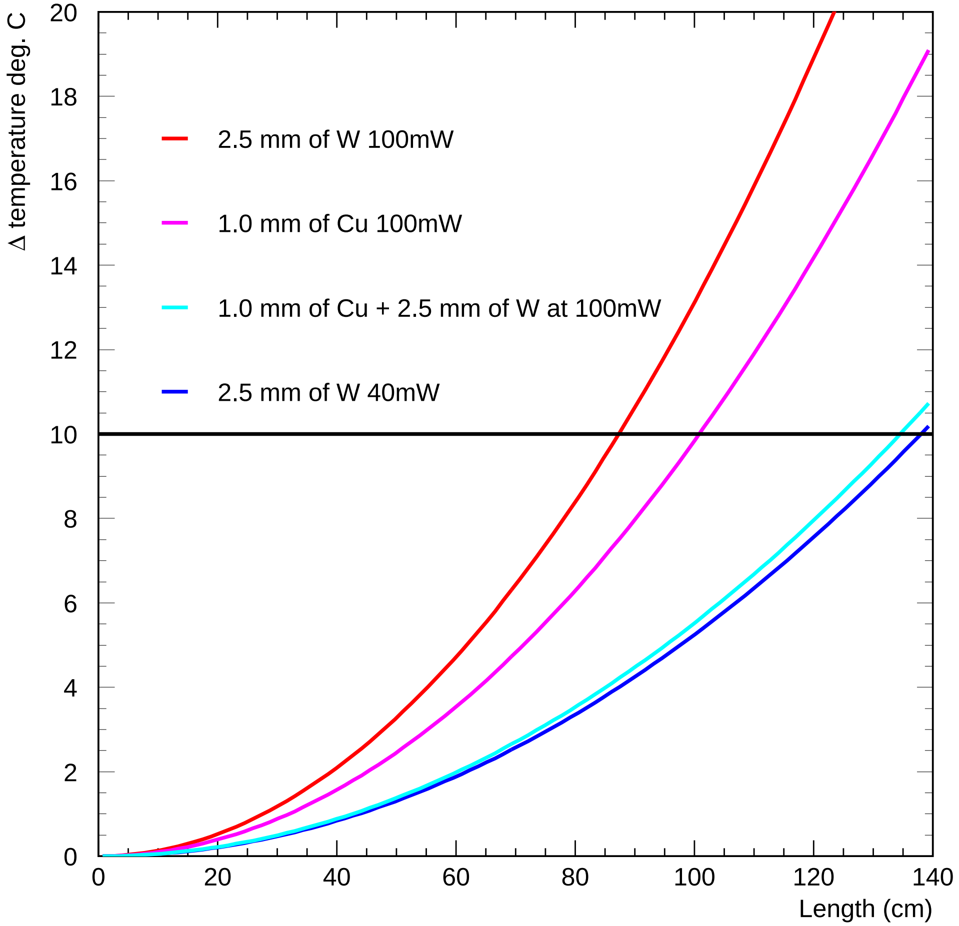
Evolving capacitor packaging may eliminate need for dimples.

Can we get the heat out?

Back of the envelope calculation of change in temperature:

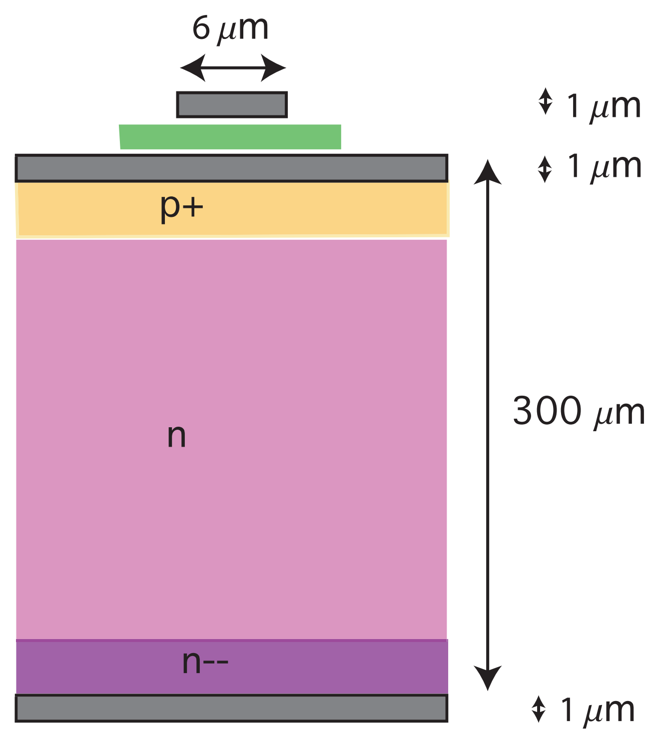
- Thermal Conductivity of W alloy 120W/(K-m)
- Thermal Conductivity of Cu 400W/(K-m)

Need to reduce heat to below 100mW/wafer.

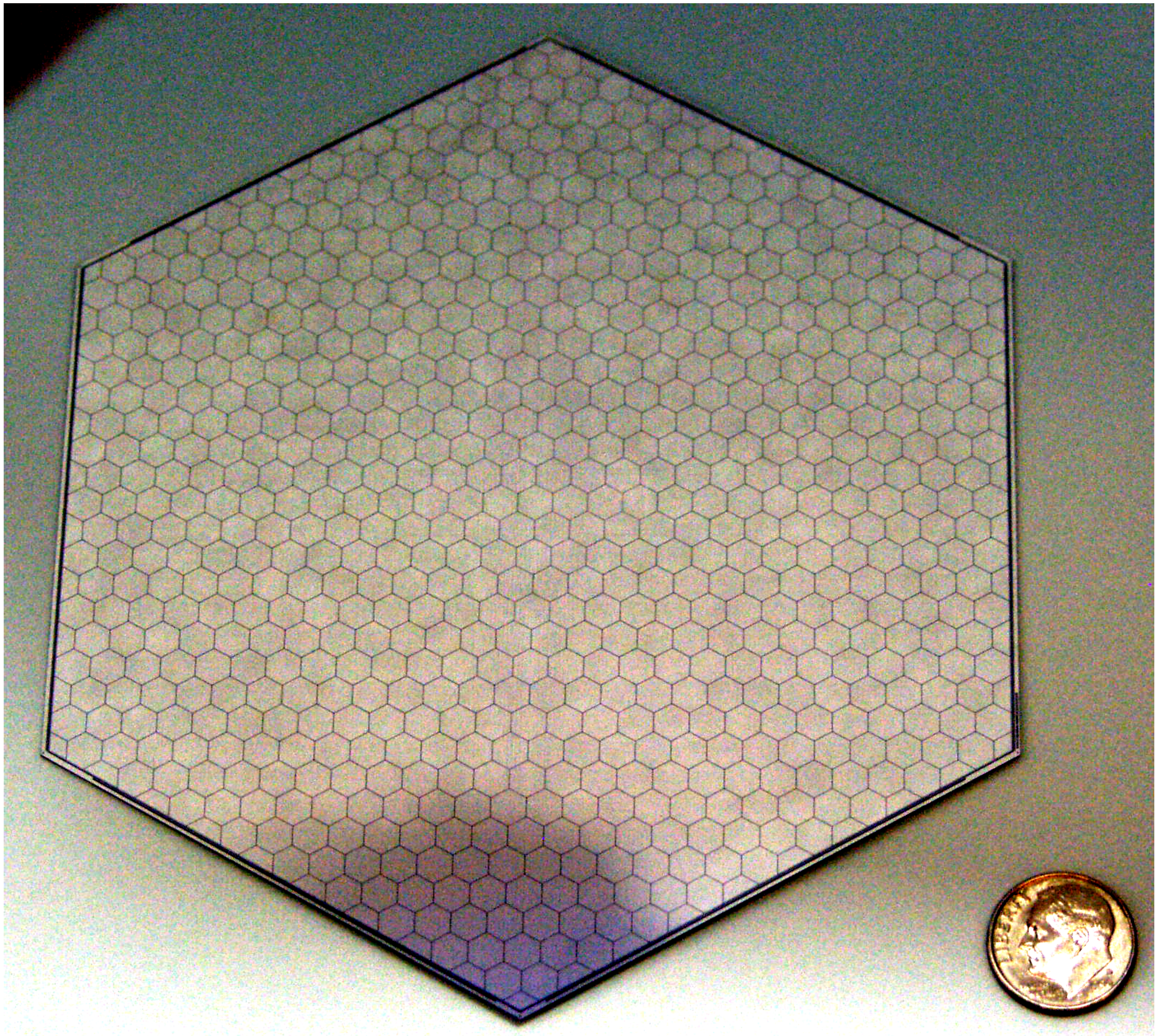


Silicon Detector Design

- DC coupled detectors (avoids bias resistor network)
- Two metal layers
- Keep Si design as simple as possible to reduce cost
- Cross talk looks small with current electronics design
- Trace capacitances (up to 30pF) are bigger than the 5pF pixel capacitance

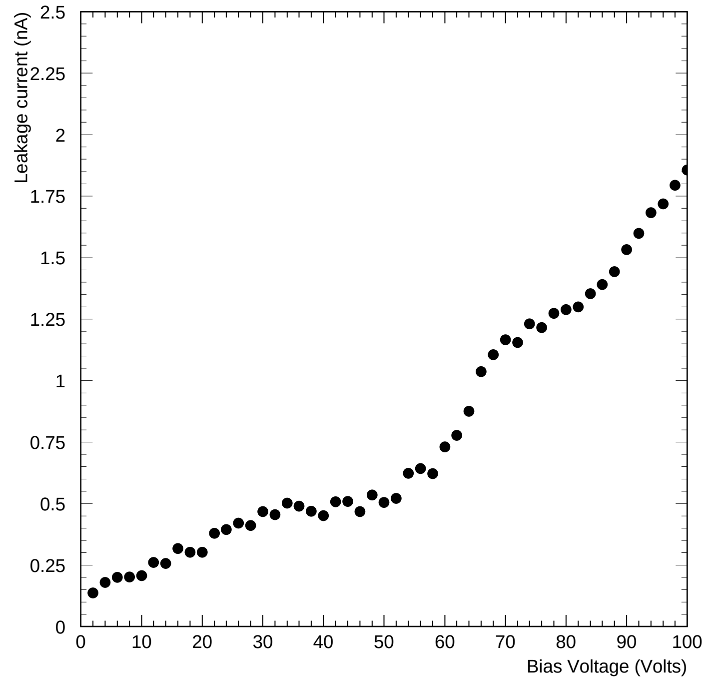


Ten Hamamatsu detectors are in hand



Measurements on Silicon Detector Prototypes

Leakage Current Looks Fine:



(10nA for 1μs gives only 250 electrons noise)

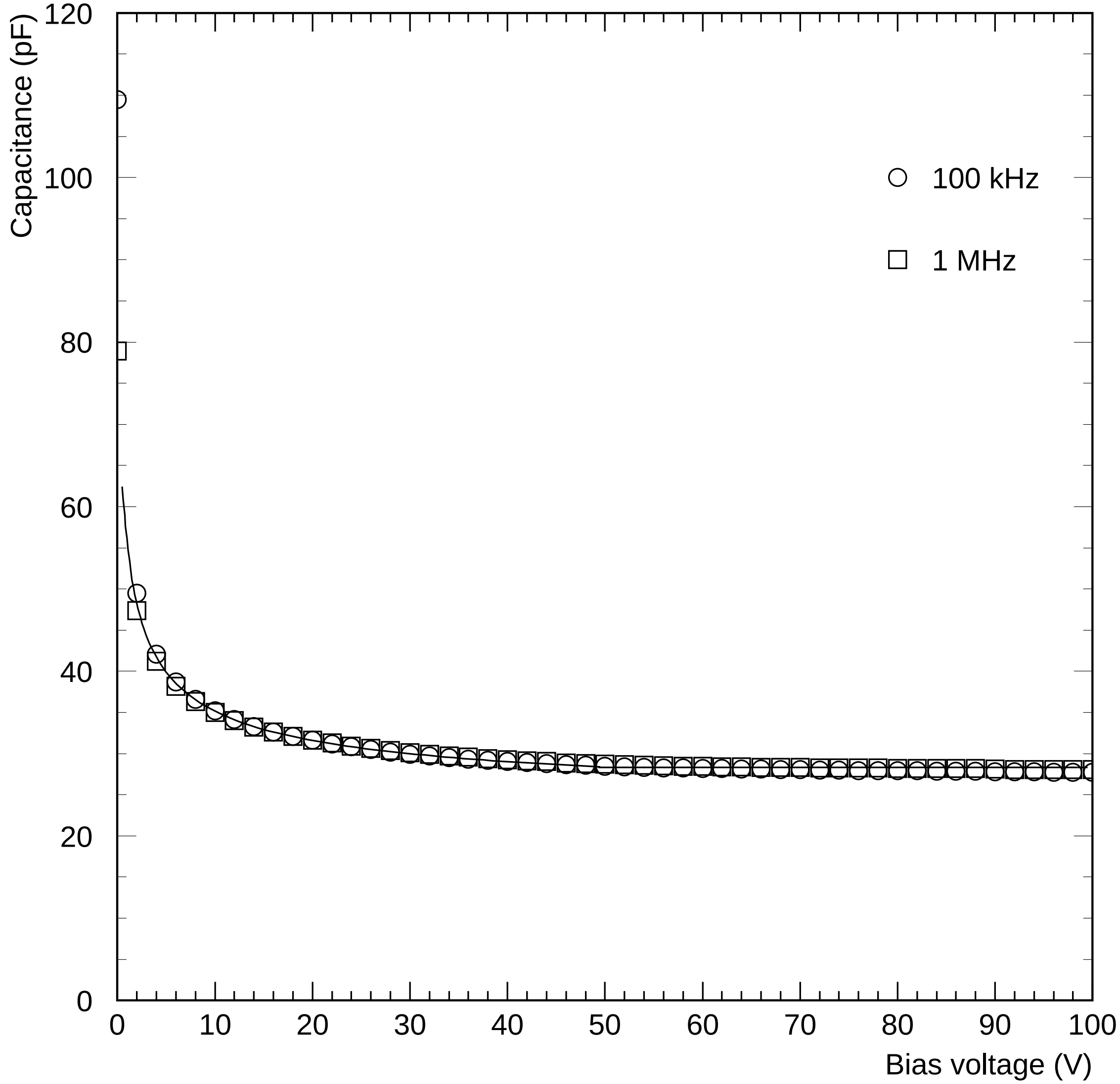
NB: Neighboring pixels are not grounded.

Expected contributions to detector capacitance:

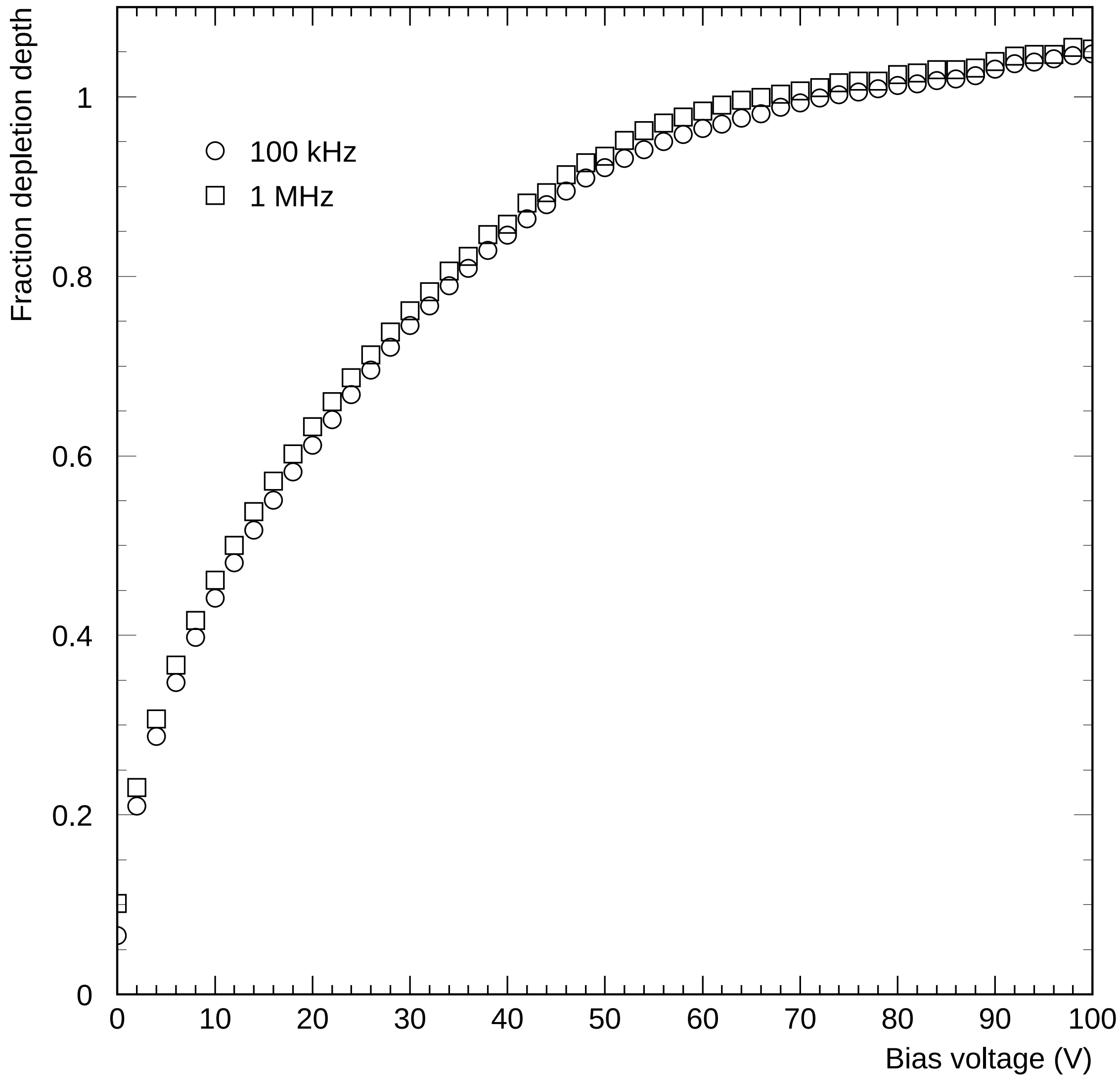
- 5.7pF from pixel capacitance (C_{geom})
- $\sim$ 20pF for sum of trace capacitance and capacitance from other traces connecting to other pixels. (C_{stray})
- Pixels under the bump-bond array have additional stray capacitance from probing and bonding pads (currently $\simeq$ 100pF)

Expected curves

$$\begin{aligned} C_{tot} &= C_{stray} + C_{geom}\sqrt{\tfrac{V_{dep}+V_{bi}}{V_{bias}+V_{bi}}} \qquad & V_{bias} < V_{dep} \\ C_{tot} &= C_{stray} + C_{geom} \qquad & V_{bias} > V_{dep} \end{aligned}$$



Typical CV curve as measured in lab



Relative depletion depth as a function of voltage.

Mean stray capacitance measurement obtained from a fit to the CV curve:

Expected	100kHz	1 MHz
23.0 ± 0.2 pF	21 ± 1 pF	22 ± 1 pF

$\Rightarrow$ **Measurement agrees with expectation for 0.9 μm thick oxide and 6μm wide traces (3.1 pF/cm).**

Series resistance for 1μm by 6 μm :

Expected (pure Al)	Measured
47 Ω/cm	$(57 \pm 2)\Omega$/cm

$\Rightarrow$ **Measurement slightly larger than nominal**

Impact of Detector Technology on Detector Design

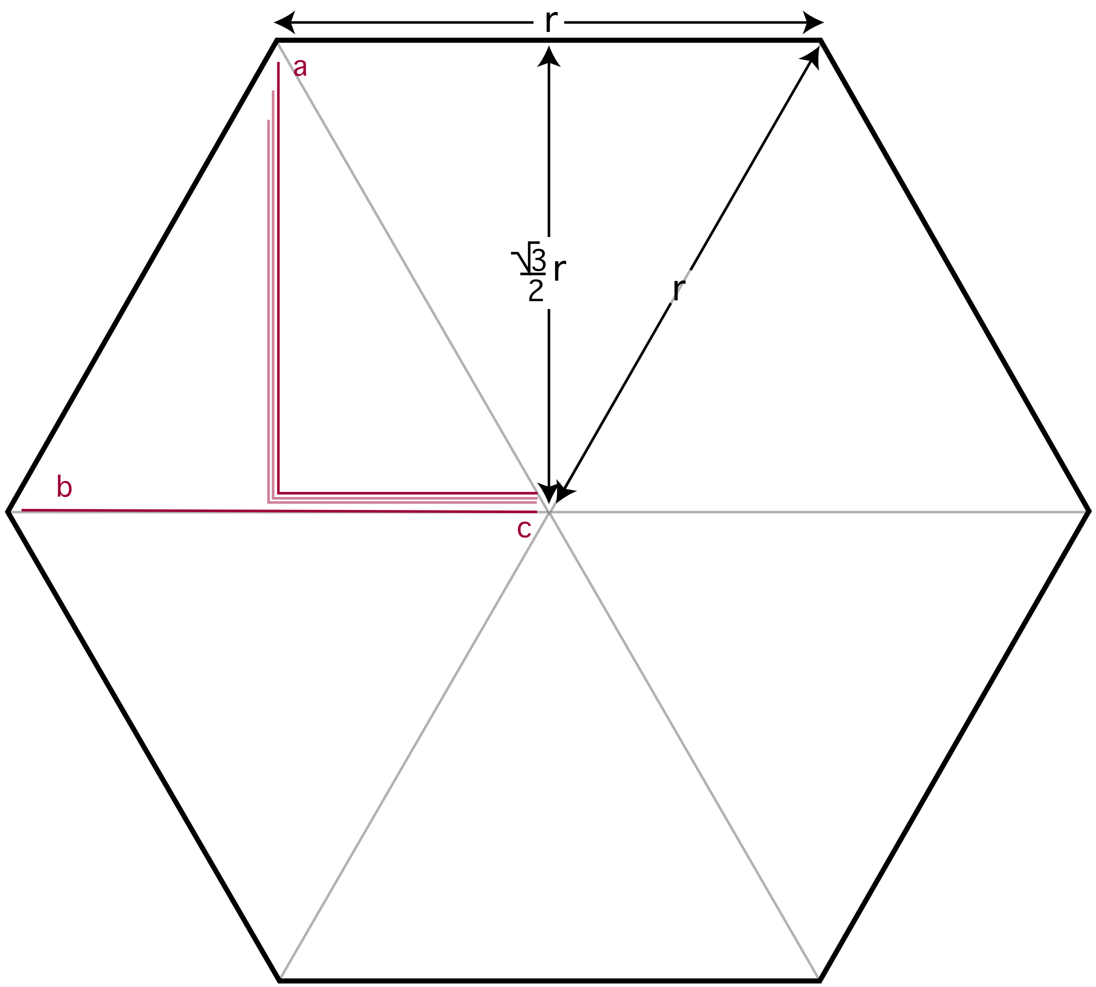
⇒ In a warm machine, exceptional pixels with large capacitance or series resistance lead to degraded time tag measurements

- Small impact on tagging performance since bad channels can be de-weighted in determining the average time of a track

⇒ In a cold machine, exceptional pixels with large capacitance or series resistance lead to a higher rate of noise events in buffers

- Could lead to inefficiency late in the bunch train due to buffer overflow

Location of high resistance and capacitance pixels



a.) Longest trace $\sim 10\,\text{cm}$

b.) Radial trace $\sim 7\,\text{cm}$

c.) Congested area near bump bond array

• For areas a and b fundamental limit to noise is given by (for e.g. correlated double sampling)

$$ENC_{R_s} \sim C_{tot}\sqrt{4\frac{KT}{q_e^2}R_s\frac{1}{2\tau}}$$

where R_s is the series resistance, C_d and τ is the shaping time of the electronics.

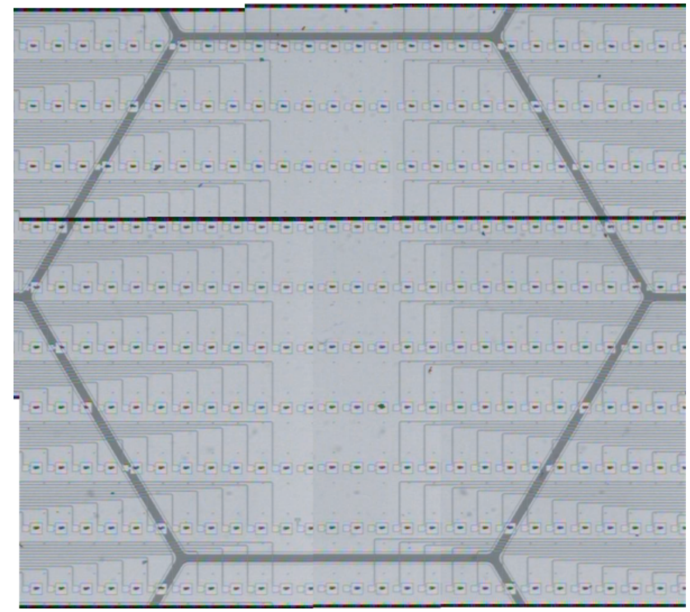
• For $\tau = 1\mu$s, $R_s = 580\,\Omega$ and $C_{tot} = 40\,$pF this gives ∼600 electrons noise, which is not really a problem.

• We can slightly improve noise performance by decreasing the trace width, perhaps by a factor of 2, i.e.

$$ENC_{R_s} \propto \sqrt{w}$$

where w is the trace width.

• In region c, near the bump bonding array, we will have a large number of traces crossing a pixel. No series resistance, but amplifier FET noise similar:



Possible ways to decrease capacitance in region c:

• Move probing pads on to pixels.

• Decrease trace width in area near central pixels, here

$$ENC_{amp} \propto w$$

• Use a long skinny chip (e.g. 100 μm x 600 μm grid)

After these three measures, worst case capacitance is $\sim$70 pF.

Other more radical alternatives

- Polyimide (kapton) can be used instead of SiO_2 as insulator for traces

- Oxide thickness to 5μm possible.

- Minumum trace with probably 10μm

- Could reduce stray capacitances by a factor of 2 or more

Hamamatsu does not currently provide metal-on-polyimide products, but we could increase the thickness of the wafer and the SiO_2.

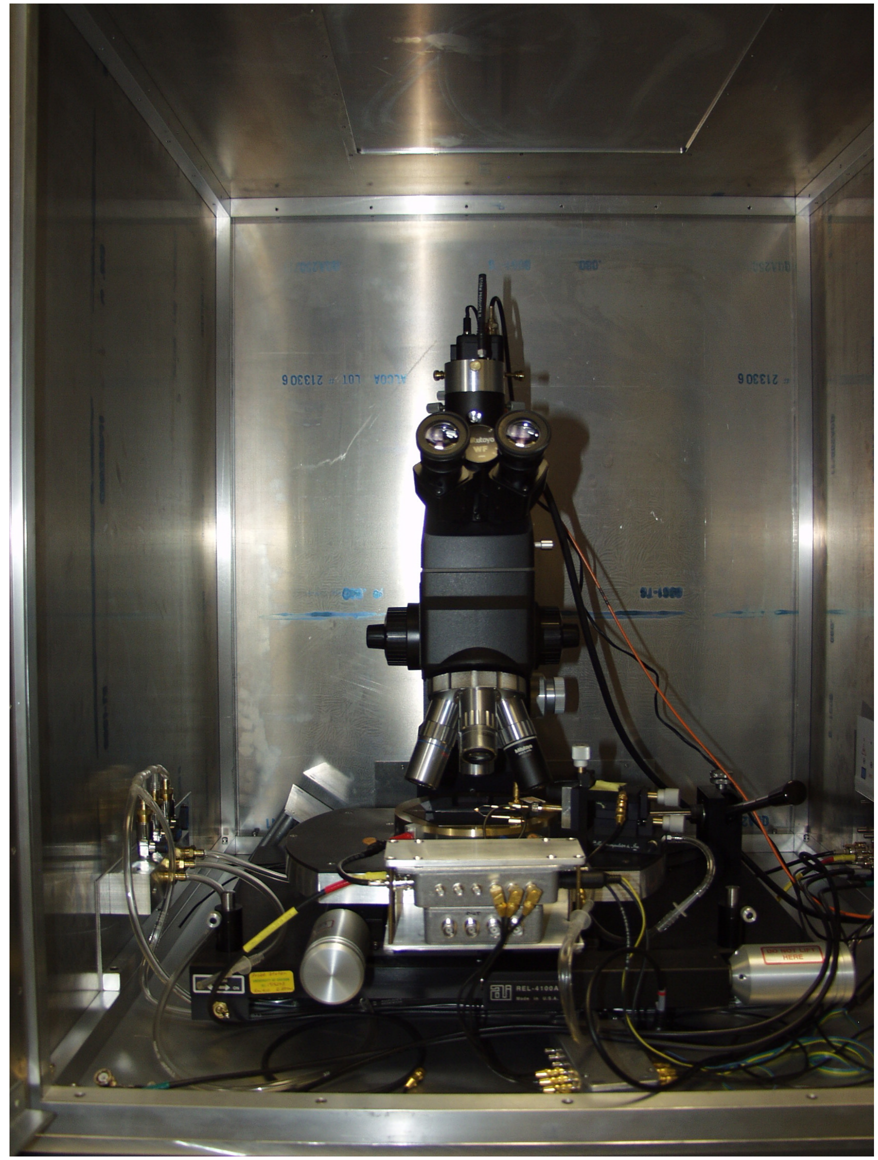
SINTEF (Norway) may be producing detectors based on 6 inch wafers with metal-on-polyimide within the next year. (Possible collaboration with Brookhaven to produce masks.)

Test Setup for Cosmics, Sources and Laser

- Modified probe station, allows laser to be target on entire detector

- IR microscope objective used to focus laser to $\sim 10\,\mu$m spot

- Bias applied to backside of detector using insulated chuck



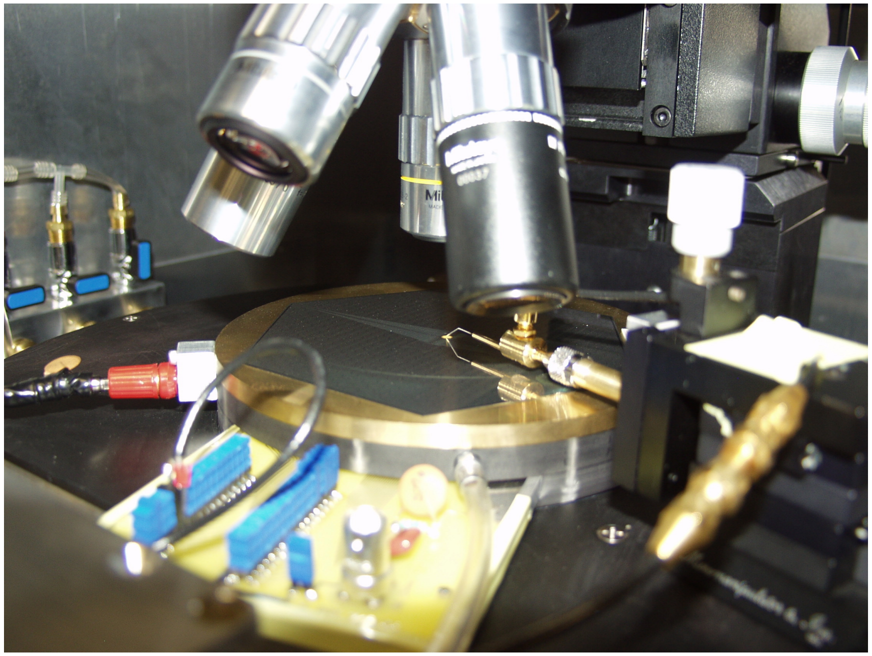
Test Setup – detector probing

- Contact made to test pads on bump bonding array using an AC probe

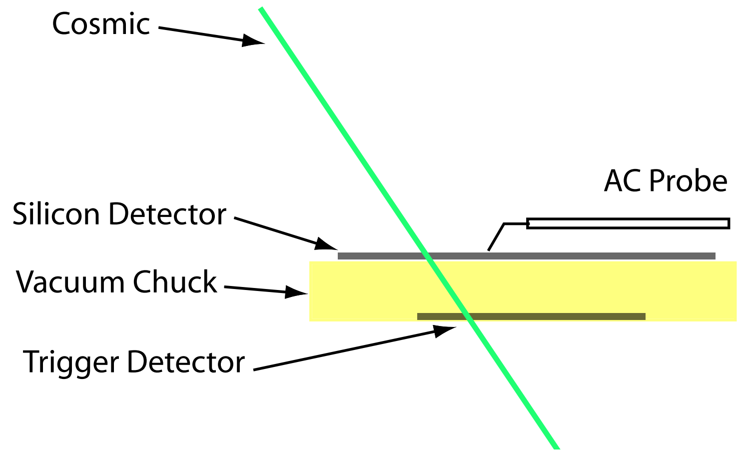
- Cables add $\sim$ 20 pF of additional capacitance, but noise performance is somewhat better than readout chip

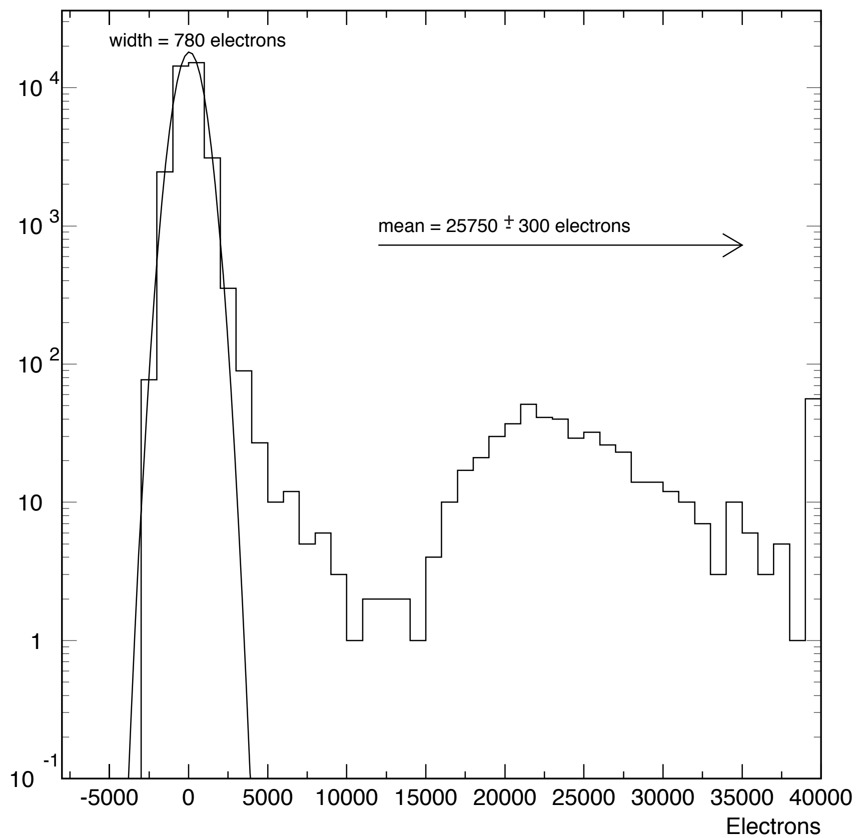
- Use AMPTEK 250F preamp, shapers with $\tau \simeq 1\mu$s and a digitizing oscilloscope to mockup expected electronics

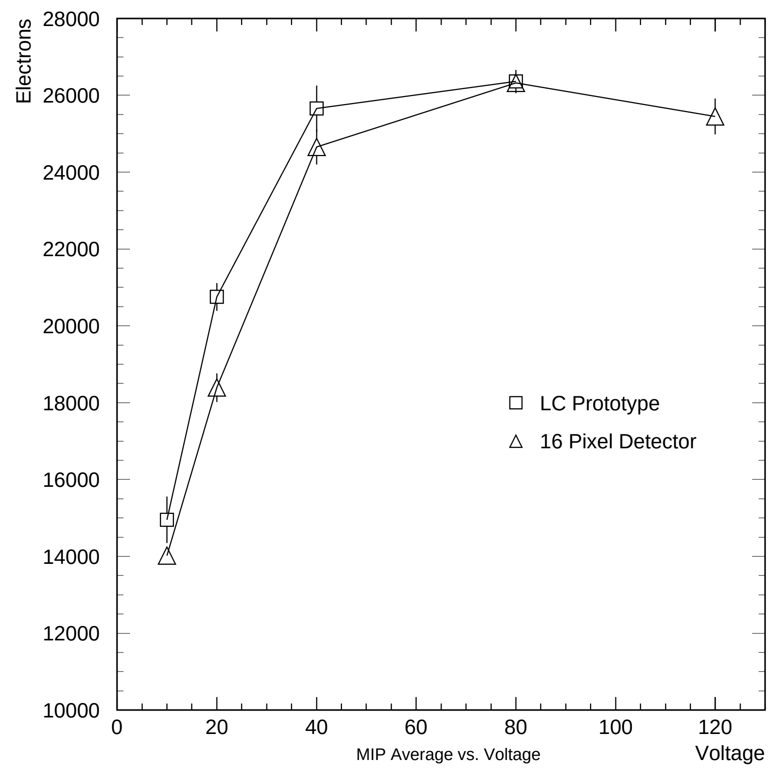
- PC board with 1 cm $\times$ 1 cm silicon pad detector used for cosmic trigger visible under chuck



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

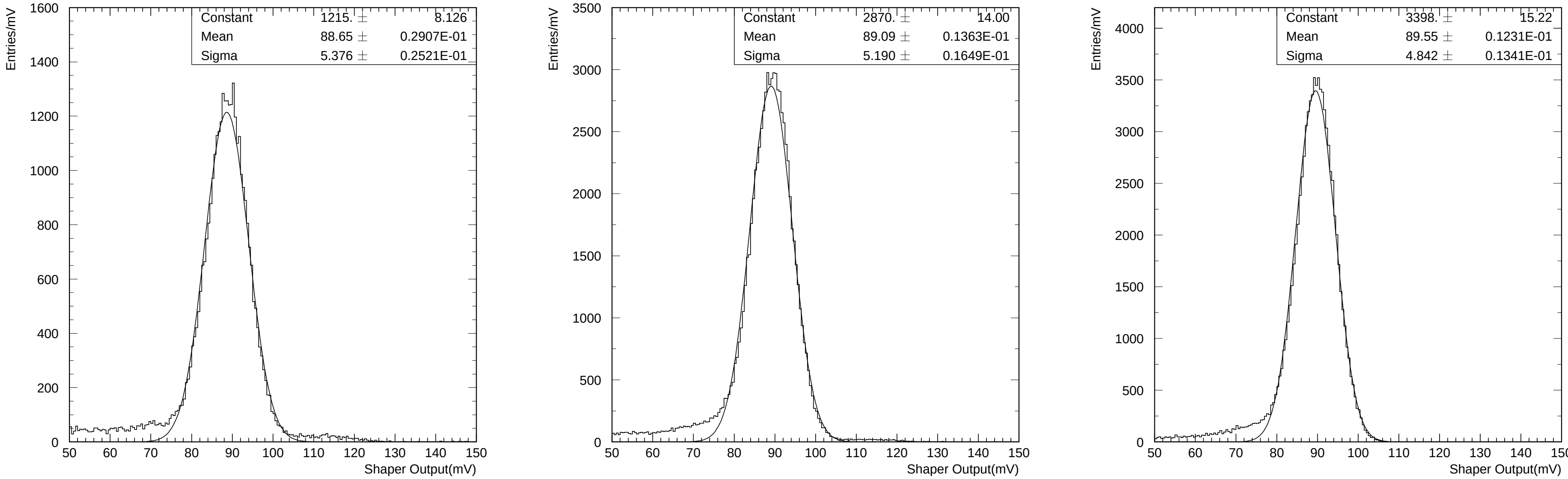






Errors do not include ∼ 10% calibration uncertainty (no source calibration)

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



Possible $\sim$ 1% wafer-wafer calibration?

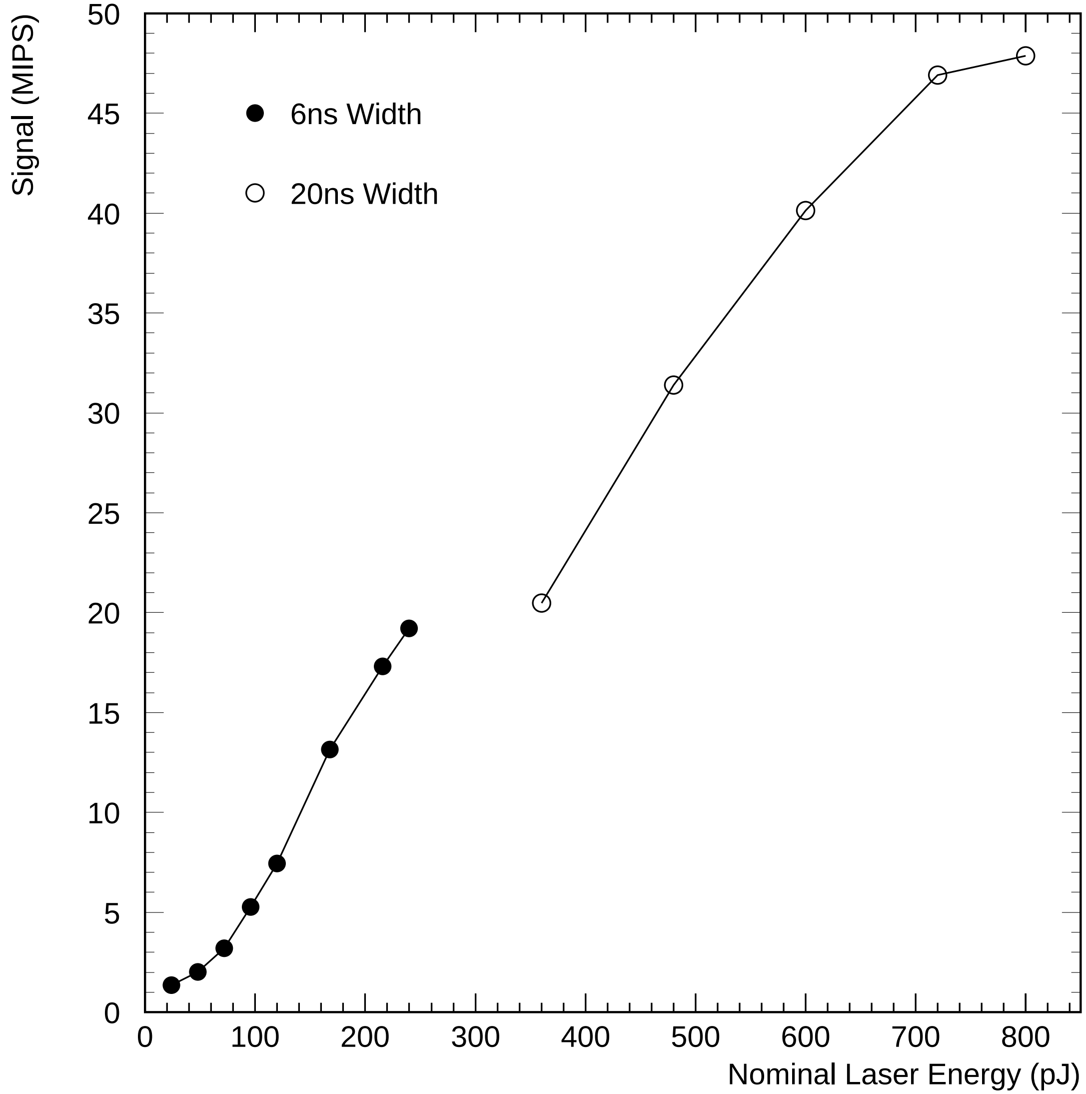
Width of distributions corresponds to $\sim$ 1000 electrons noise. Pixels under test are on outer edge of wafer – includes larger series resistance contribution than cosmic data.

Laser Studies

$\lambda = 1064\,\mathrm{nm}$

IR penetrates into wafer

Allows controlled study of large and small pulses



Conclusions

- A narrow gap silicon–tungsten detector for LC physics is attractive
- First round of prototype silicon detectors perform as expected
- Detectors can be produced with workable values of stray capacitance and series resistance
  $\Rightarrow$ some minor changes needed for cold design