An ECAL for the SiD detector

Topics:

- Motivation and Concept
- Silicon Sensors
- Mechanical Design
- Electronics
- Sensor Tests

Collaborators

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Mechanical Design	**Electronics**	**Bump Bonding** Mechanical Design **Cabling**	**Electronics** Mechanical Design Simulation	**Si Detectors** Mechanical Design **Simulation**

Design Requirements
Optimal contribution to the reconstruction of multijet events:

- Excellent separation of photons 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:

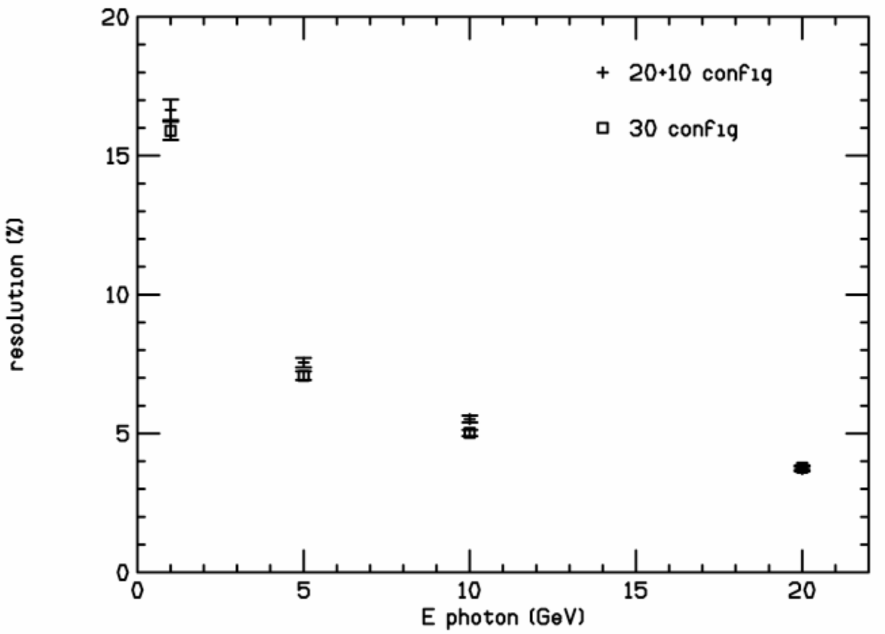
Jet reconstruction important for many physics processes.

Longitudinal Sampling

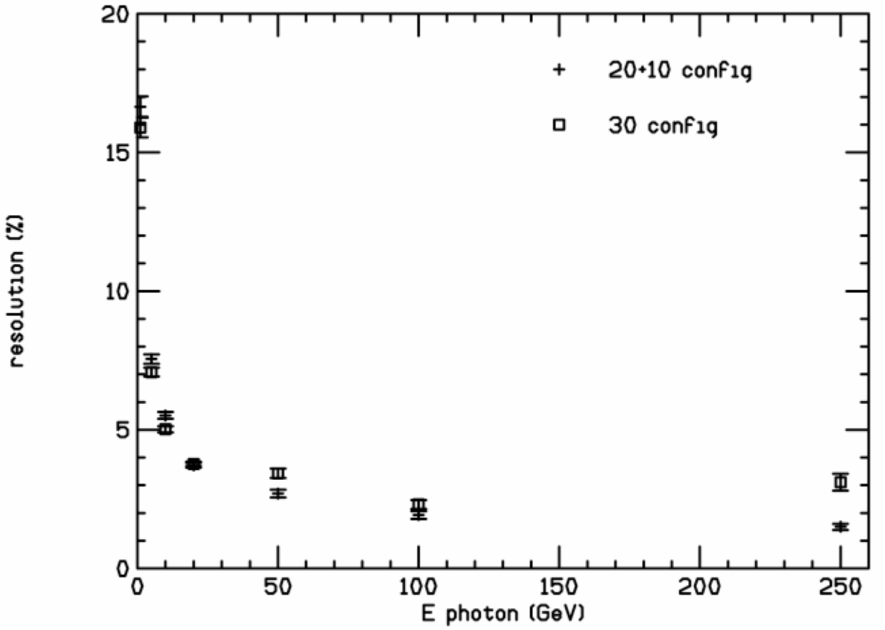
- Energy resolution is ~ 20%/sqrt(x/E) where x is the sampling fraction in X_0 (if HE showers contained)
- Implies we need approximately ~ 30 X_0 for highest E
- Energy flow is not critically dependent on ECAL energy resolution
- Consider designs with fine sampling in front and coarser sampling in back

Possible Scheme
20 layer 0.71 X_0 (2.5mm)
10 layer 1.42 X_0 (5.0mm)

Resolution for 1-20 GeV photon energy comparable for two configurations

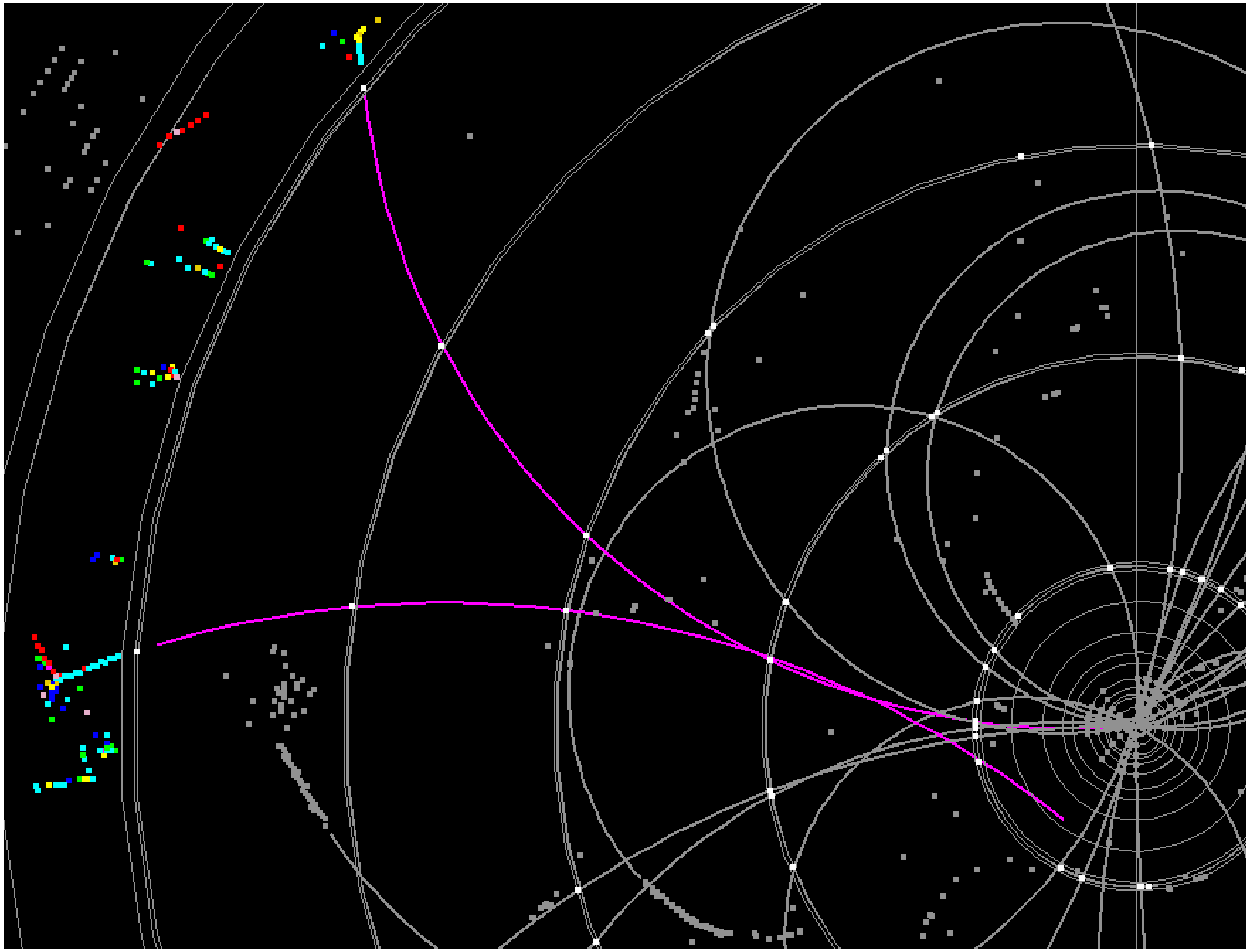


Resolution at the highest energies is considerably better for 20 + 10 configuration (leakage)



NB results are for ecal only, assume pure W

Large number of samples useful for tracking, 100% efficiency not required:



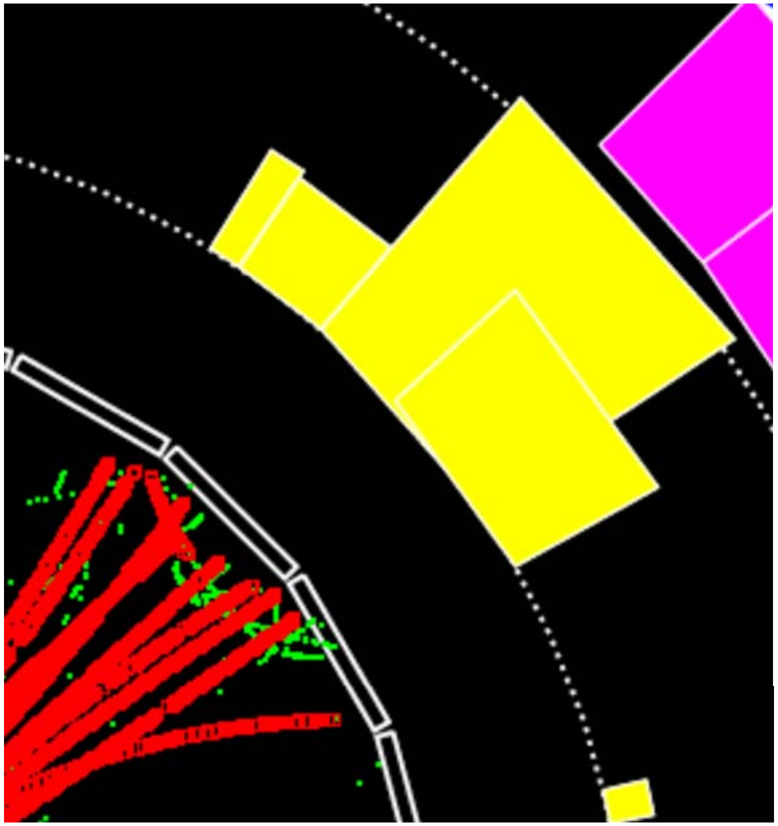
K0s tracking from von Toerne

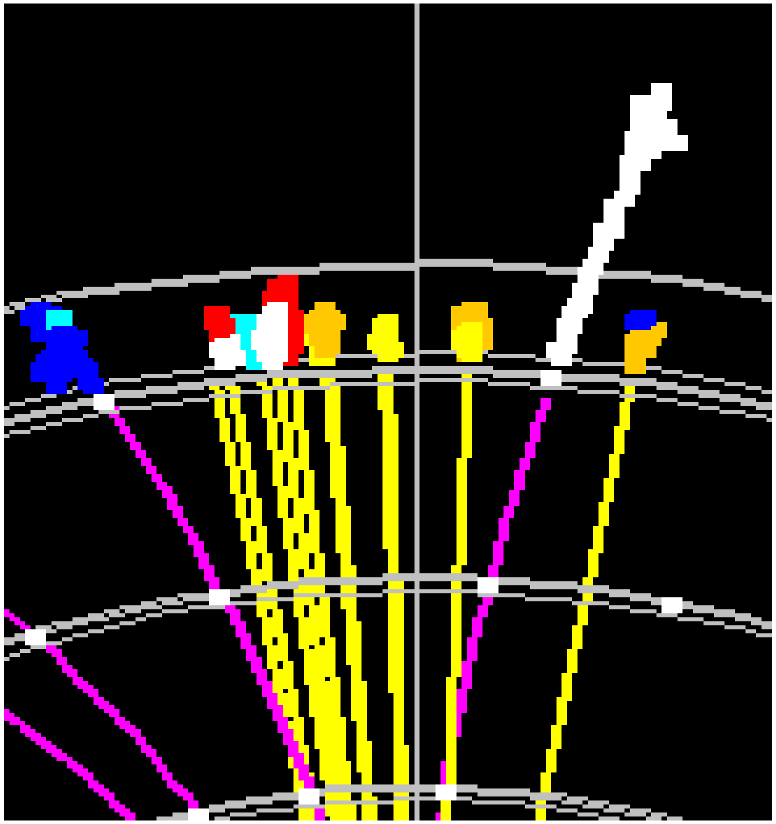
LEP granularity, difficult to resolve individual photons

Can't benefit from cluster-centroid track matching

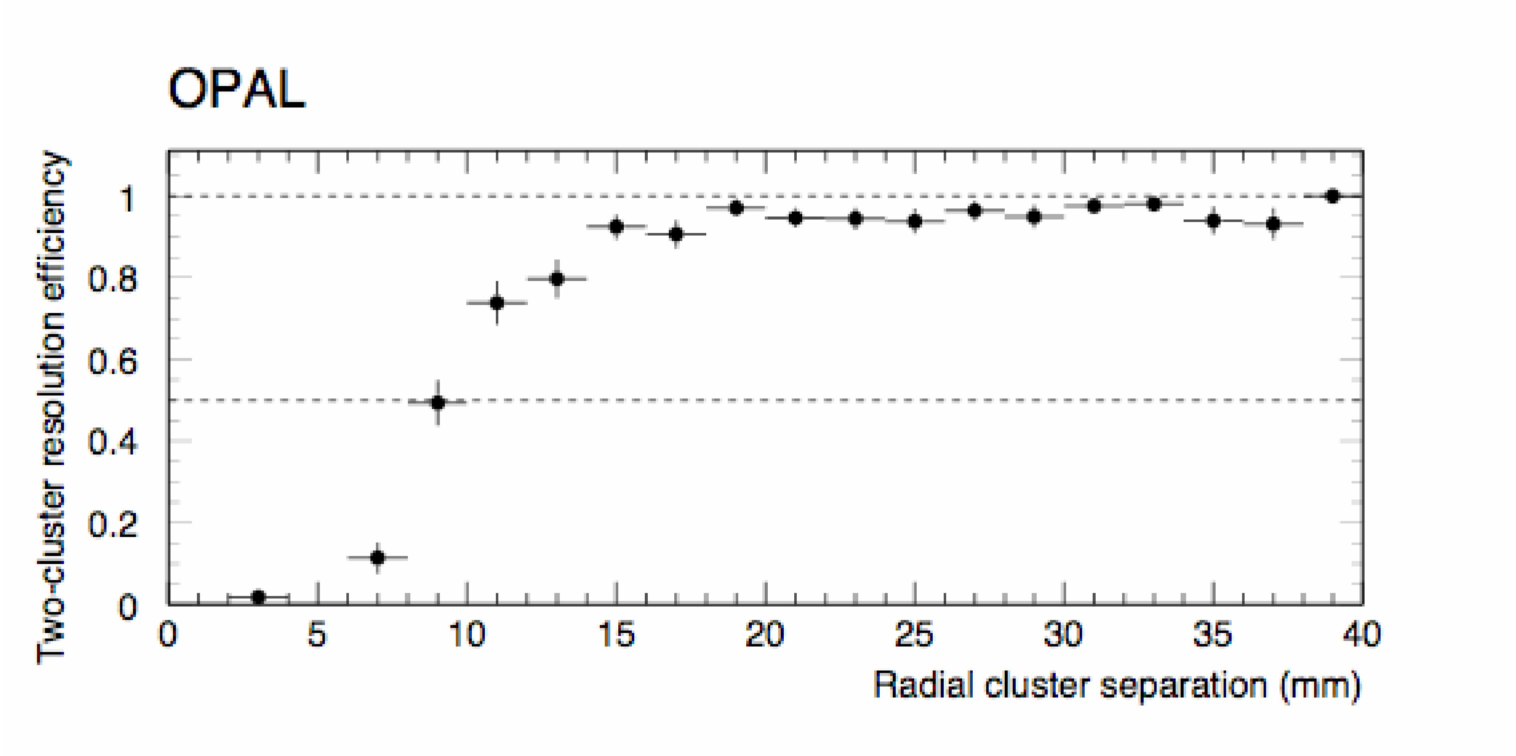
ILC granularity must be sufficient to resolve photons

Can benefit from cluster-centroid track matching





Example: OPAL SiW luminosity monitor
($1X_0$ radiator, 3mm gap, 2.5mm pads, $R_M \sim 17$mm)



Cluster can be resolved when separated by 9mm, corresponding $\sim 0.5\ R_M$.

Must be able to resolve photons to successfully match tracks and clusters, suggested figure of merit for energy flow f_E:

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

Here, R_{cal} is the radius of the calorimeter, R_M is the Moliere radius and d_{pad} is the pad size.

We can resolve clusters to 0.5 R_M if pads are 0.25 R_M

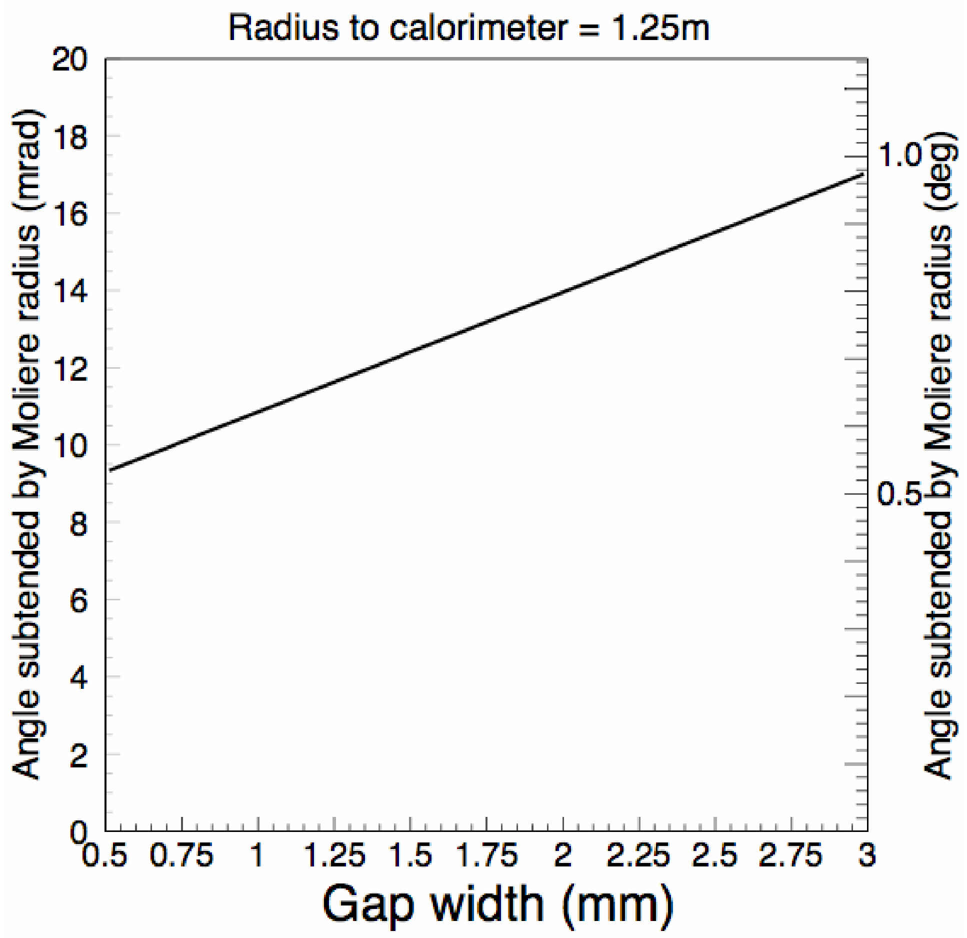
Increasing R_{cal} increases the cost of the whole detector

$\Rightarrow$ concentrate on d_{pad} and R_M

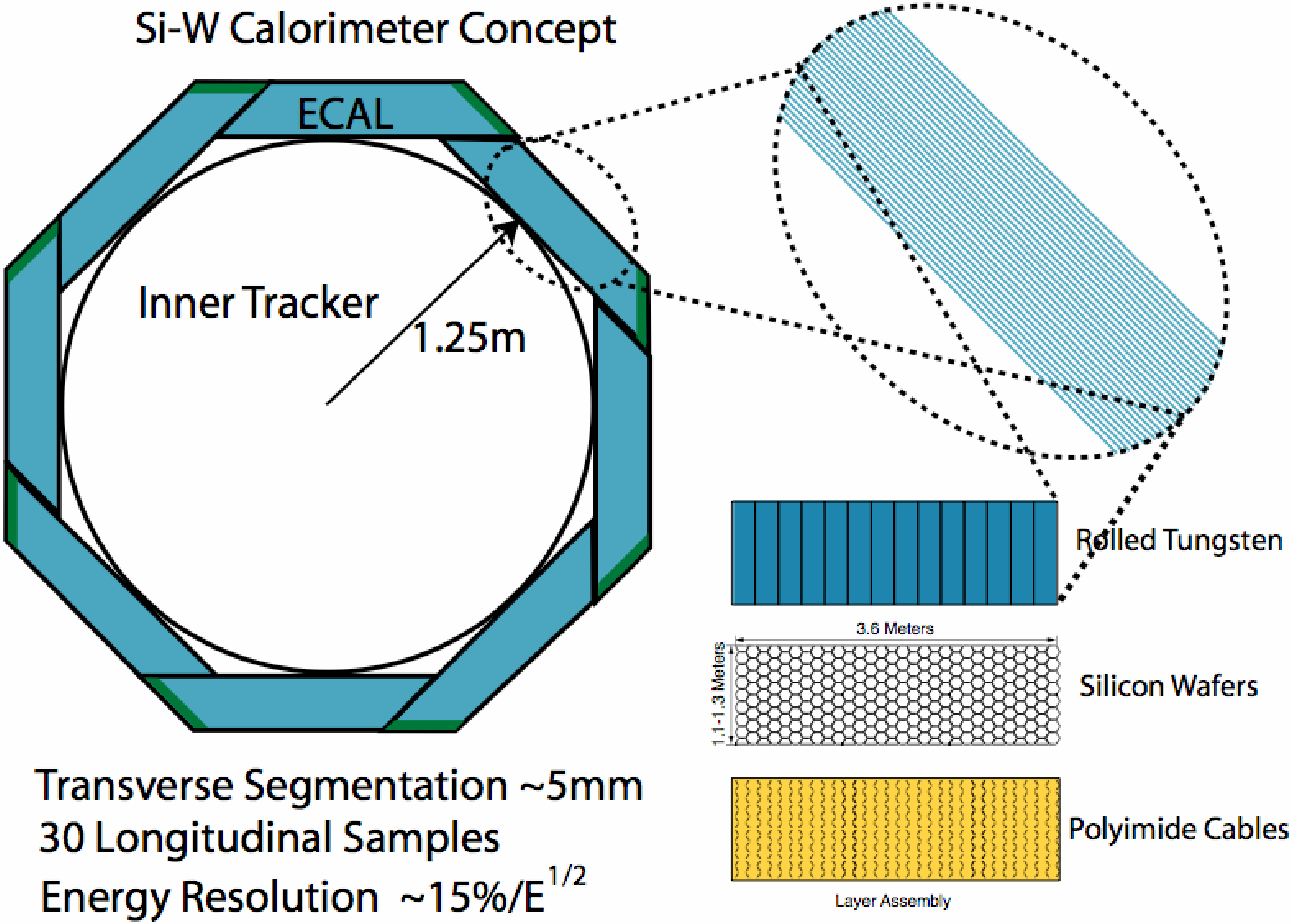
Critical parameter for is R_M the gap between layers

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



Si-W Calorimeter Concept



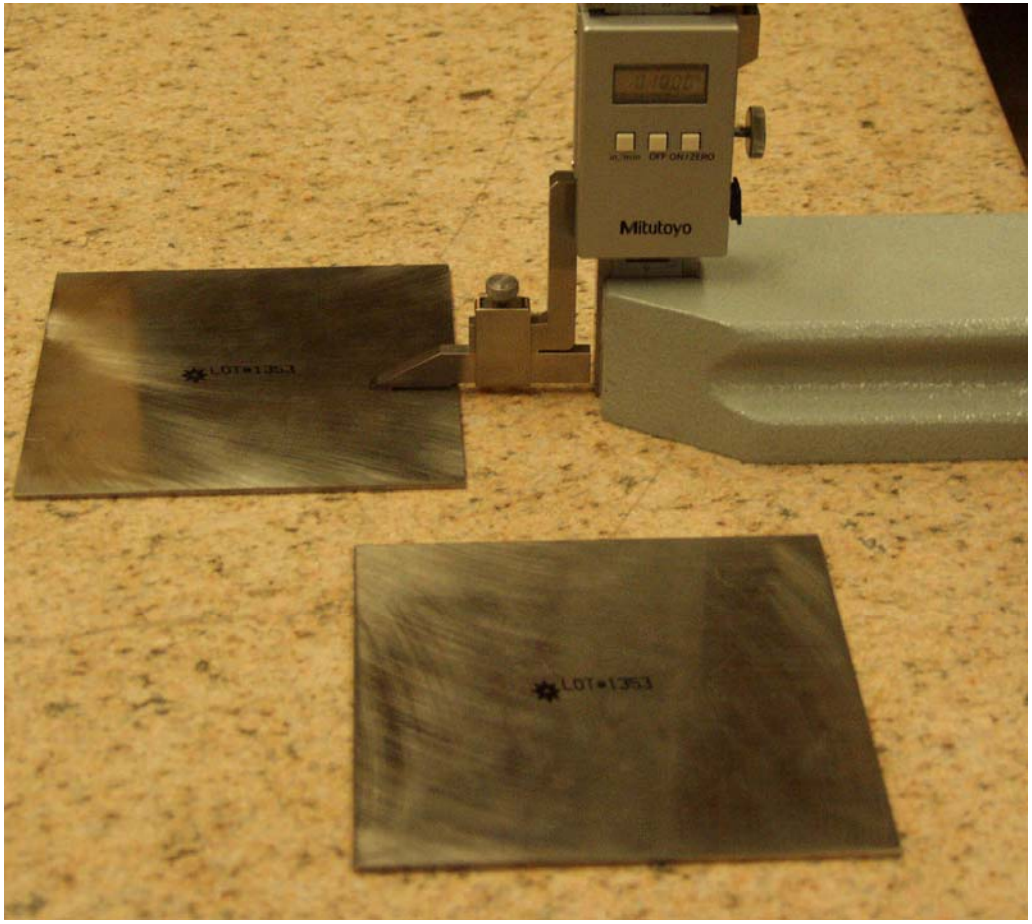
Transverse Segmentation ~5mm

30 Longitudinal Samples

Energy Resolution $\sim 15\%/E^{1/2}$

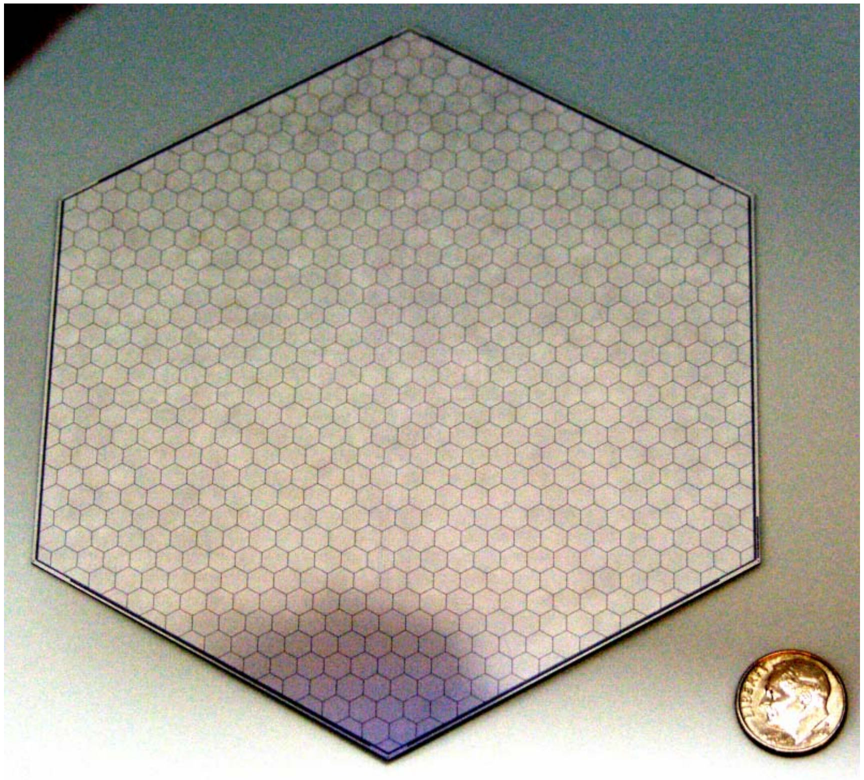
Tungsten Absorber

- Excellent Tungsten vendor located
- Test beam tungsten in hand (10cm x 10cm)
- Vendor can roll plates as large as 10cm x 100cm
- Tolerances look okay



Silicon Sensors

- Silicon is likely to be the main cost driver
- Use a hexagonal shape to use as much of the silicon wafer as possible
- Silicon sensors can be segmented very finely
- Limit on granularity given by electronics power, second order costs from electronics



Detector Segmentation

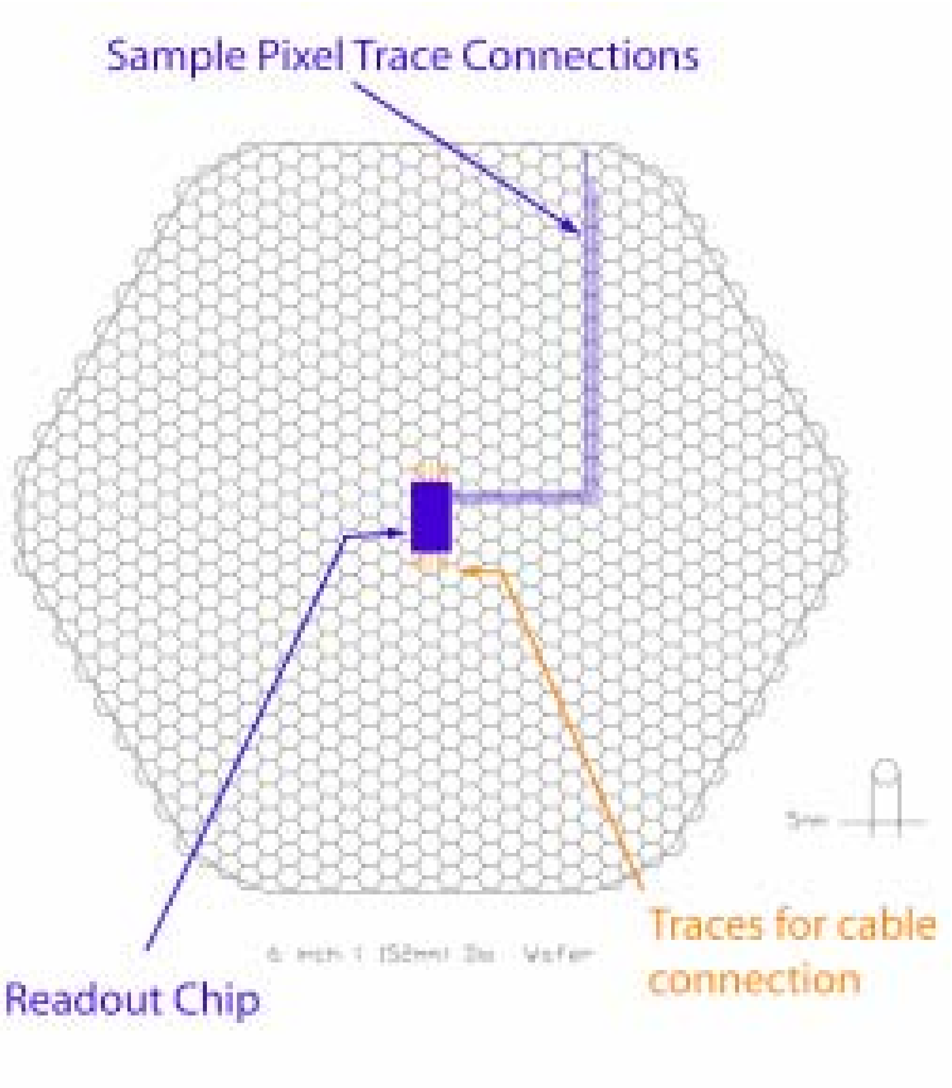
Readout each wafer with a single chip

Bump bond chip (KPiX) to wafer

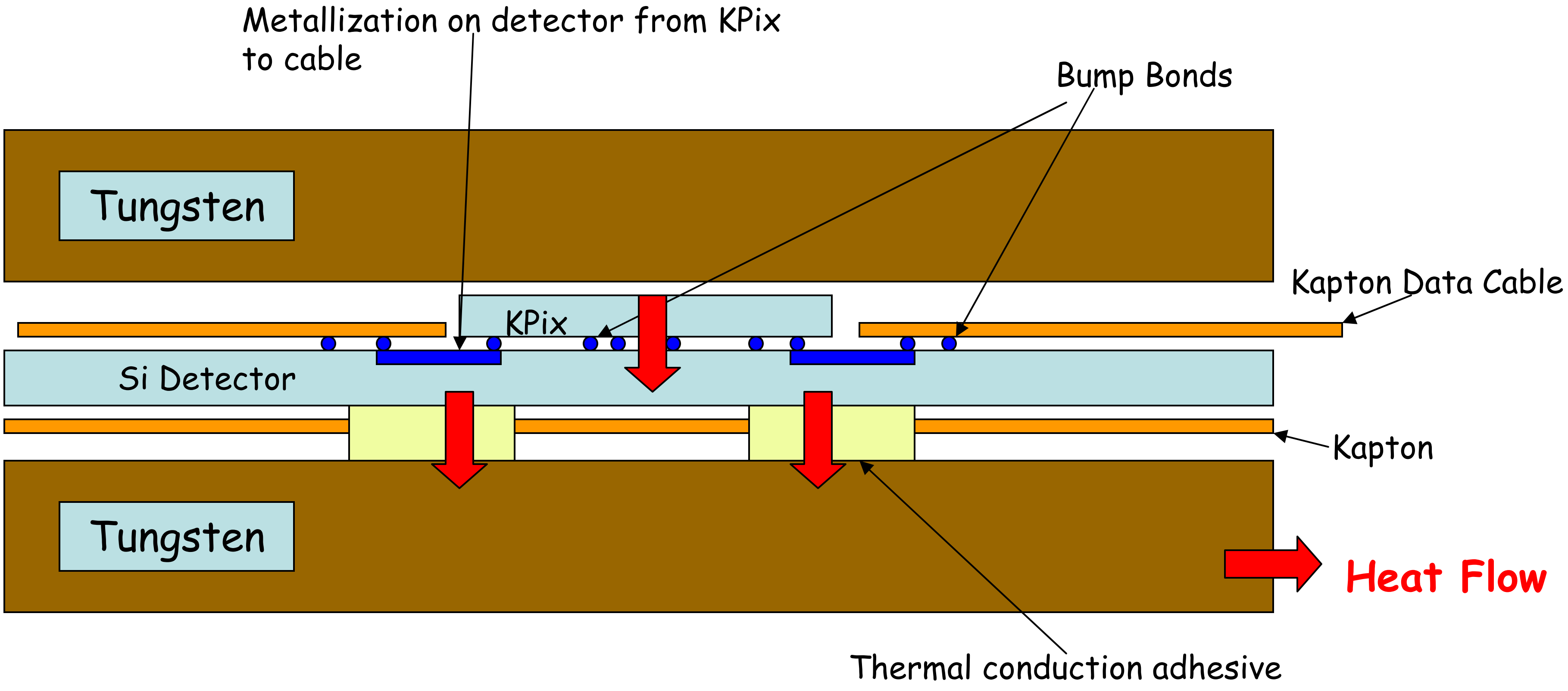
To first order cost independent of pixels /wafer

Hexagonal shape makes optimal use of Si wafer

Channel count limited by power consumption and area of readout end chip

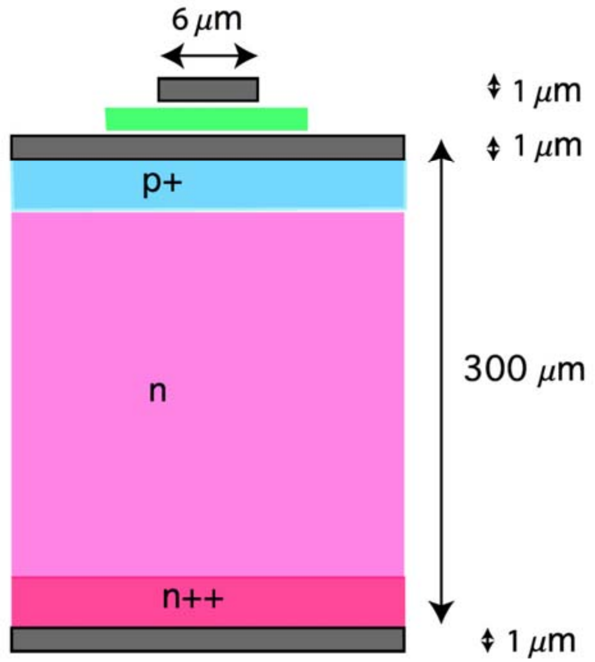


EMCal Schematic Cross section



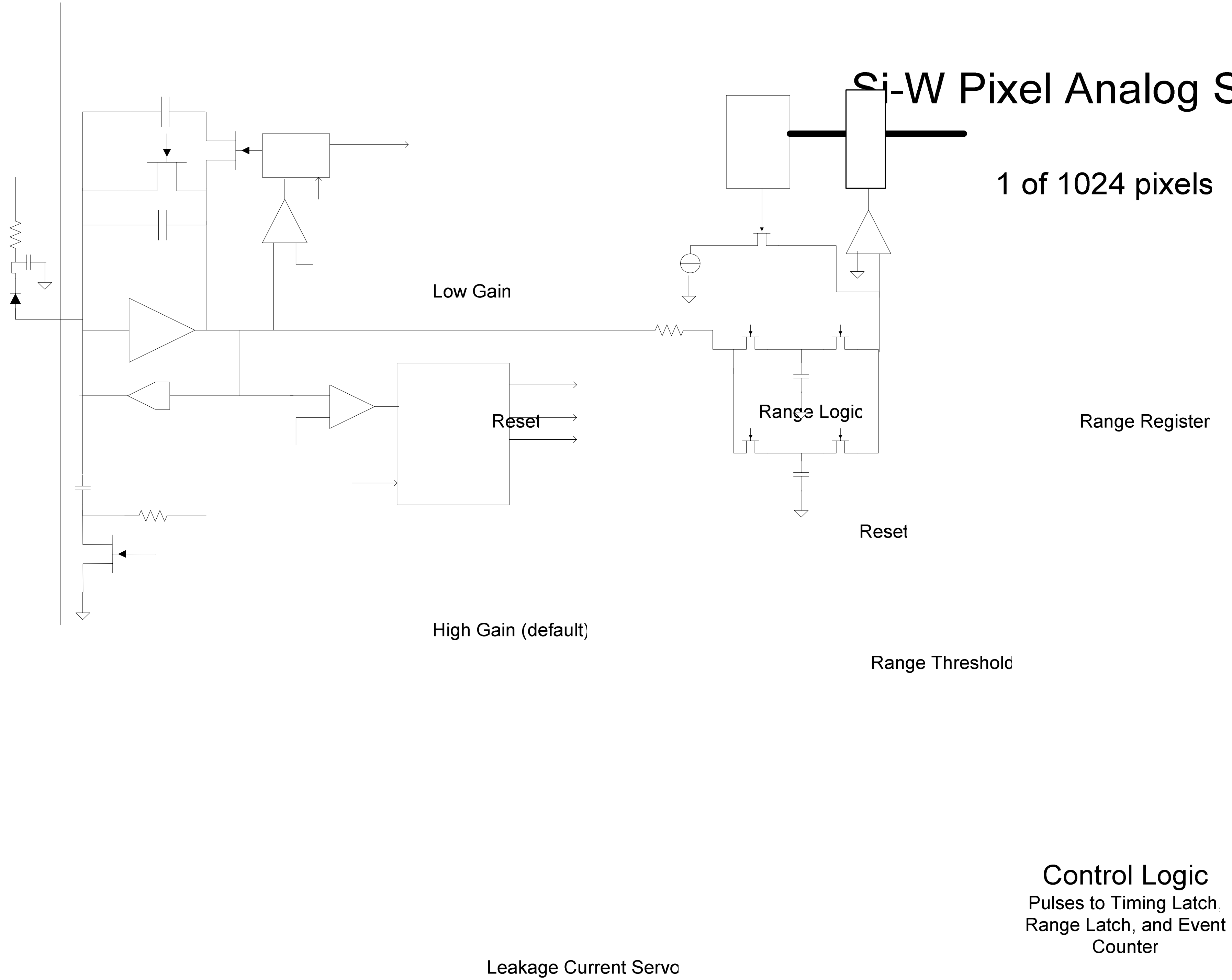
Electronics requirements

- Signals
  - <2000 e noise
  - Require MIPs with S/N > 7
  - Max. signal 2500 MIPs (5mm pixels)
- Capacitance
  - Pixels: 5.7 pF
  - Traces: ~0.8 pF per pixel crossing
  - Crosstalk: 0.8 pF/Gain x Cin < 1%
- Resistance
  - 300 ohm max
- Power
  - < 40 mW/wafer ⇒ power cycling
    (An important LC feature!)
- Provide fully digitized outputs of charge and time on one ASIC for every wafer.



Si-W Pixel Analog S

1 of 1024 pixels



Pulse “Shaping”

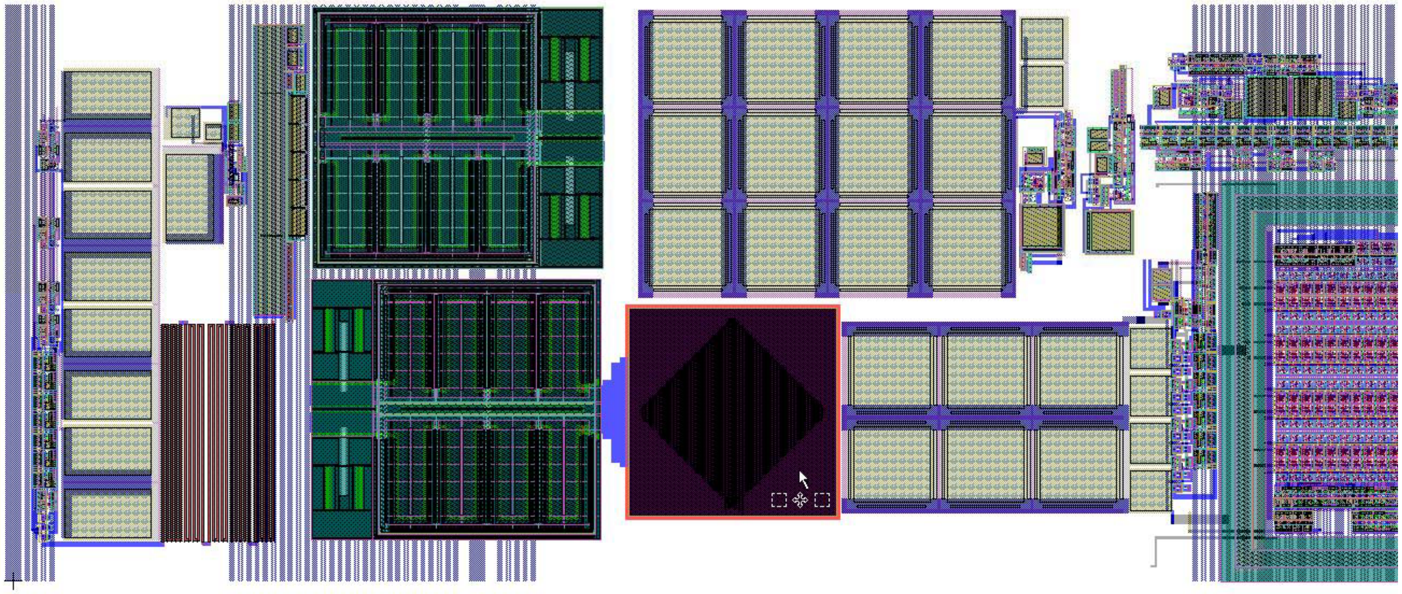
- Take full advantage of synchronous bunch structure:
  - Reset (clamp) feedback cap before bunch arrival. This is equivalent to double correlated sampling, except that the “before” measurement is forced to zero. This takes out low frequency noise and any integrated excursions of the amplifier.
  - Integration time constant will be 0.5 – 1 μsec. Sample *synchronously* at 2 – 3 integration time constants.
  - Time from reset 1 – 3 μsec, which is equivalent to a 1 – 3 μsec differentiation.

- Noise: ~1000 e^- for ~ 20 pF. (100 microA through input FET).

Power

			Cold Train/Bunch Structure				
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

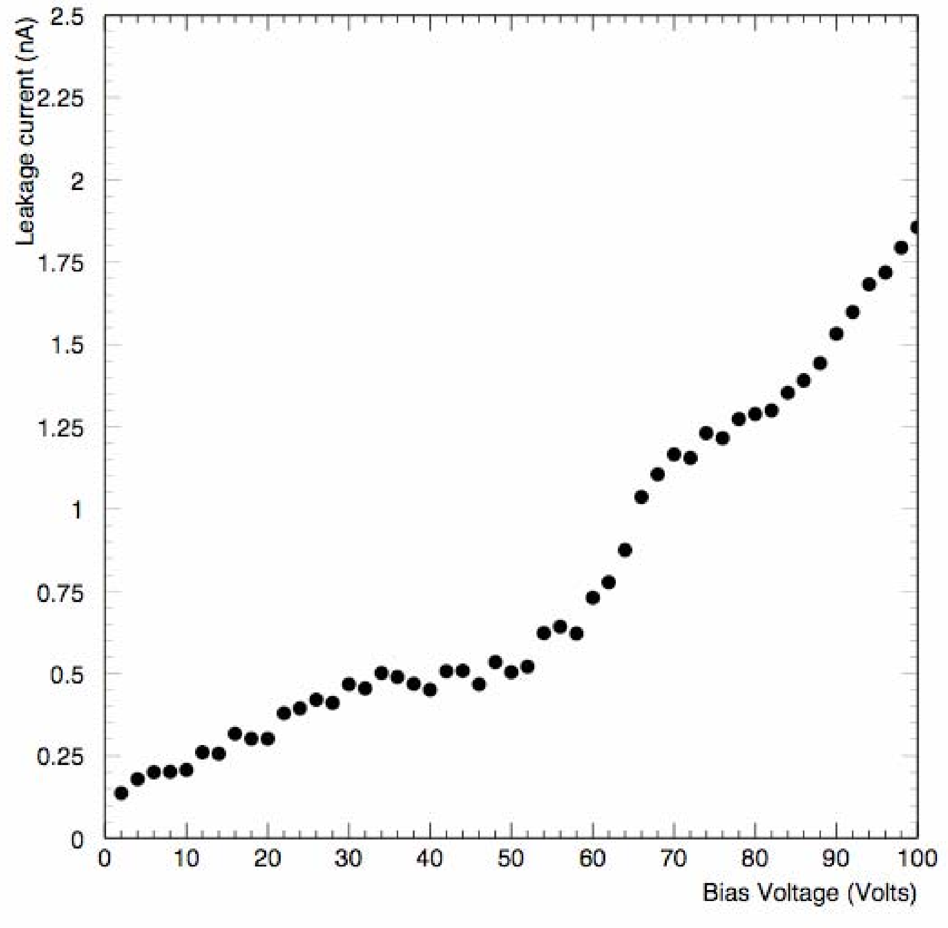
KPix Cell 1 of 1024



- First prototypes currently under test at SLAC
- Next submission will include external trigger for test beam

Measurements on Prototypes

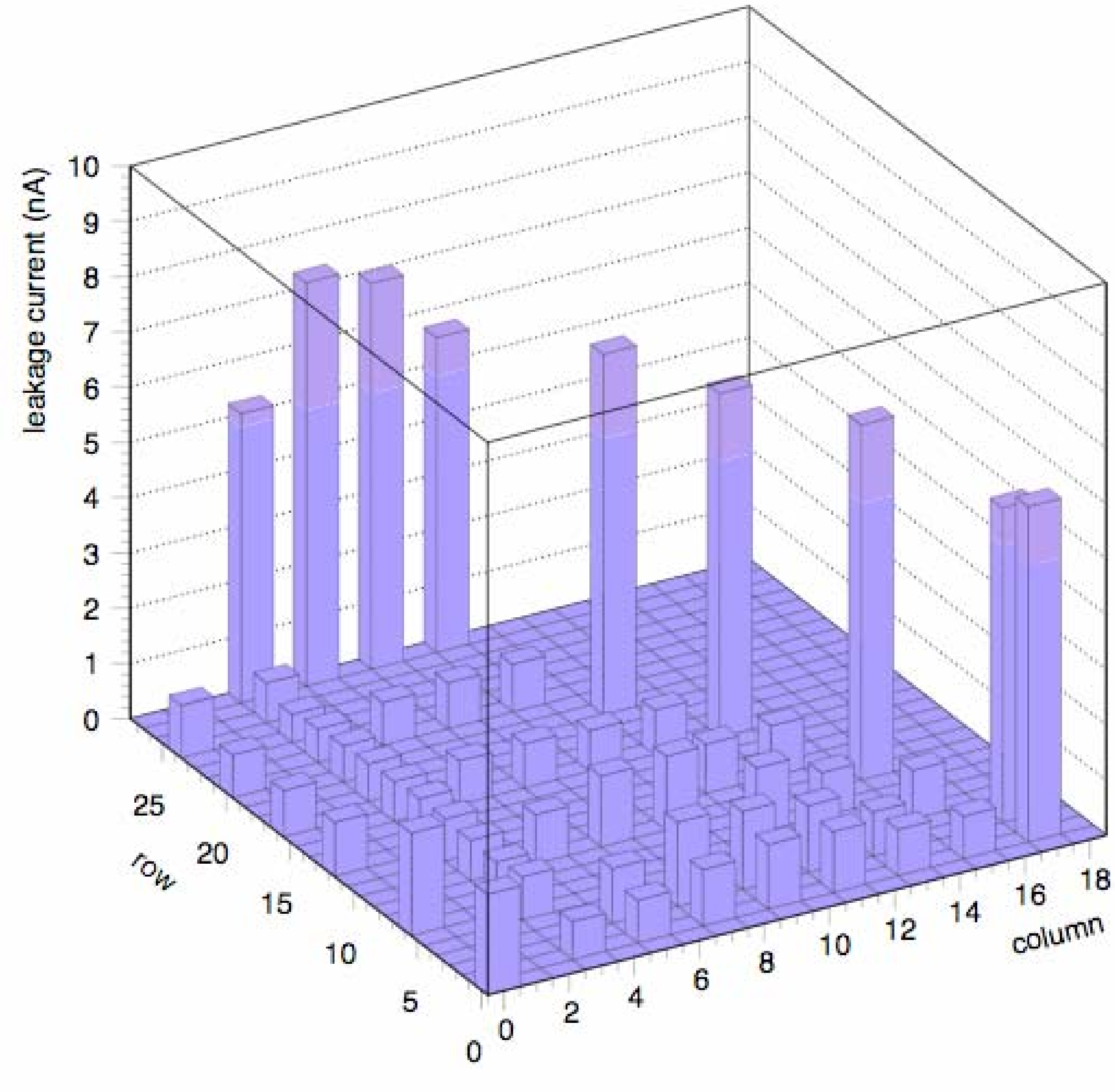
Leakage current looks fine:
(10nA for 1microsecond gives
only 250 electrons noise)



Neighboring pixels not grounded

Spot check of leakage current in one quadrant is as expected.

Edge pixels have larger currents. In these tests the guard ring was left floating.



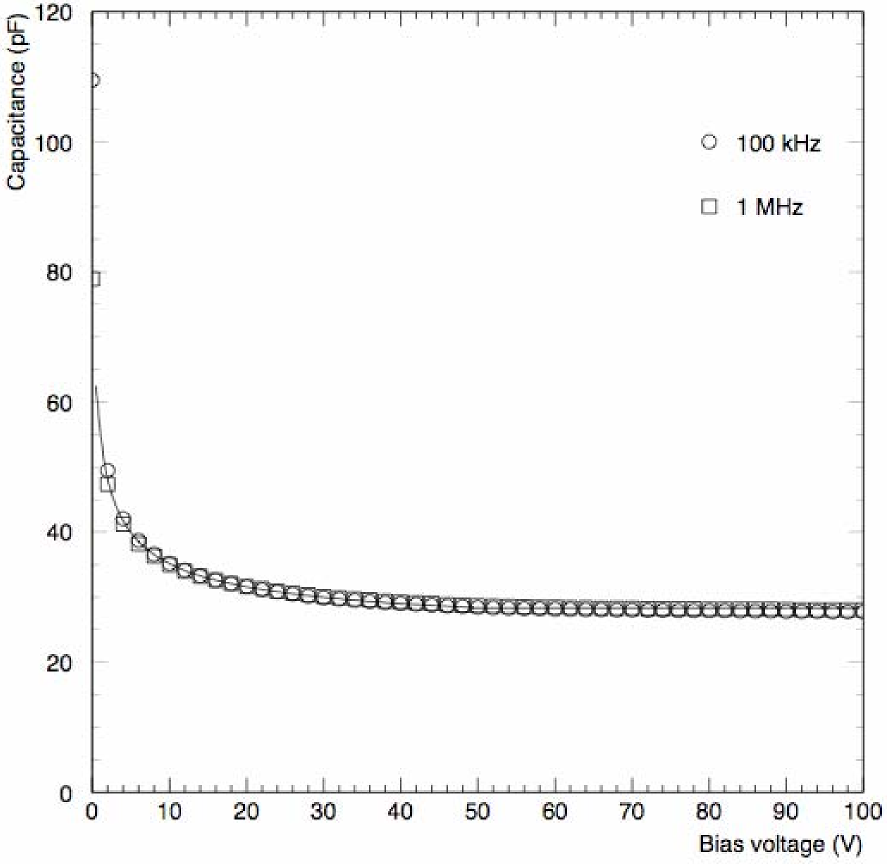
Measurement of resistance slightly larger than nominal

Series resistance for 1 micron × 6 micron traces:

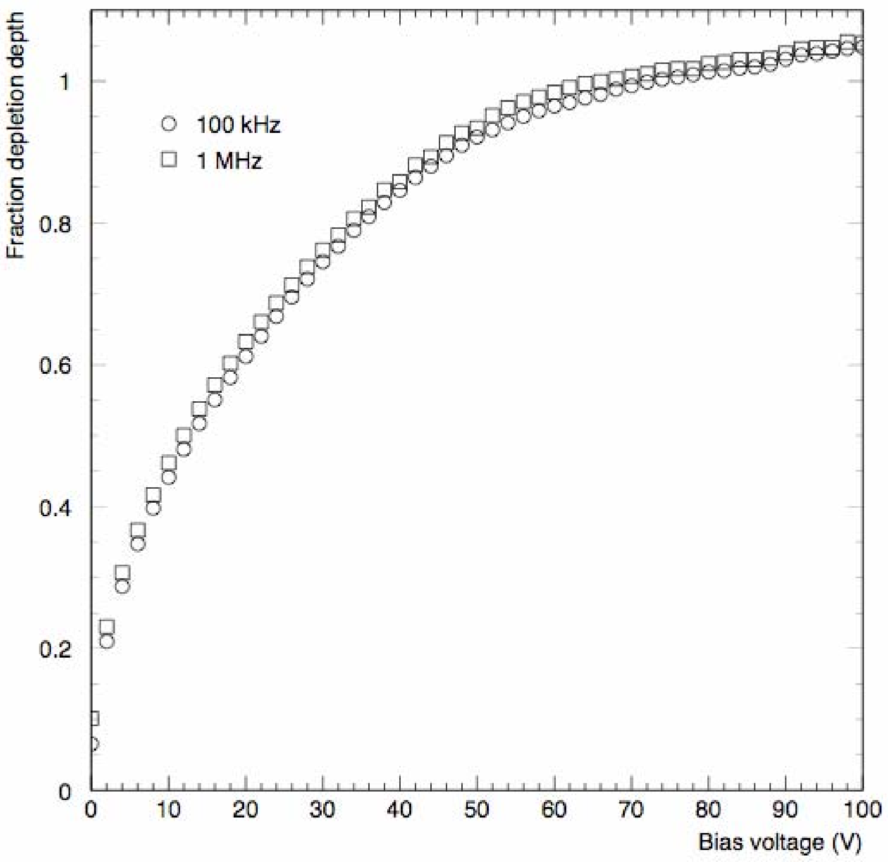
Expected (pure Al)	Measured
47 Ohms/cm	(57± 2) Ohms/cm

Additional measurements underway

Total resistance for longest traces can be a noise driver.

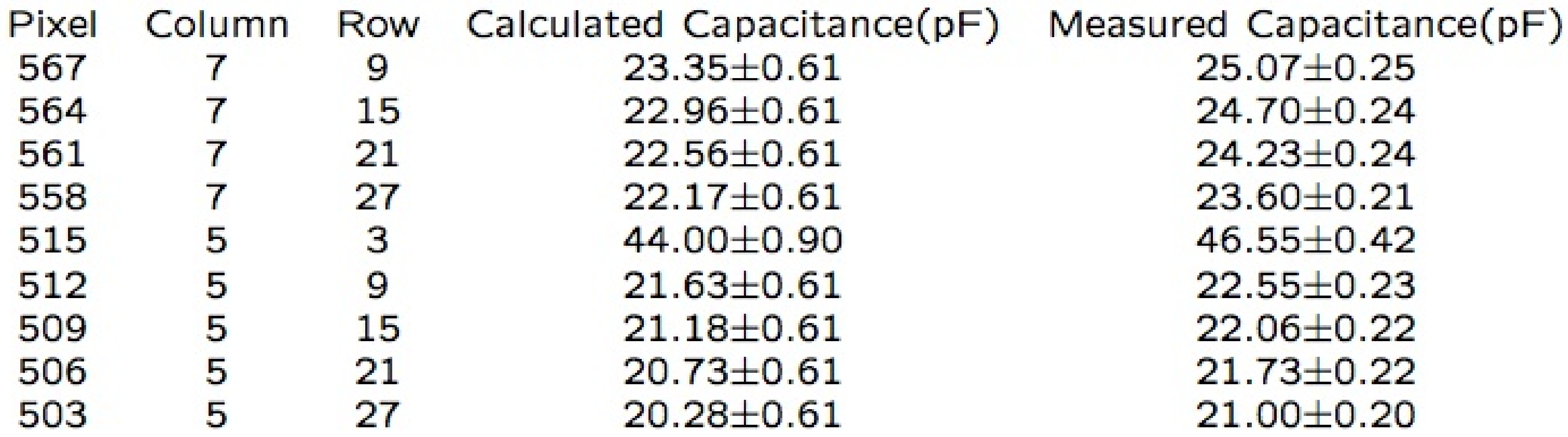


C-V curve as measured in the lab



Relative depletion

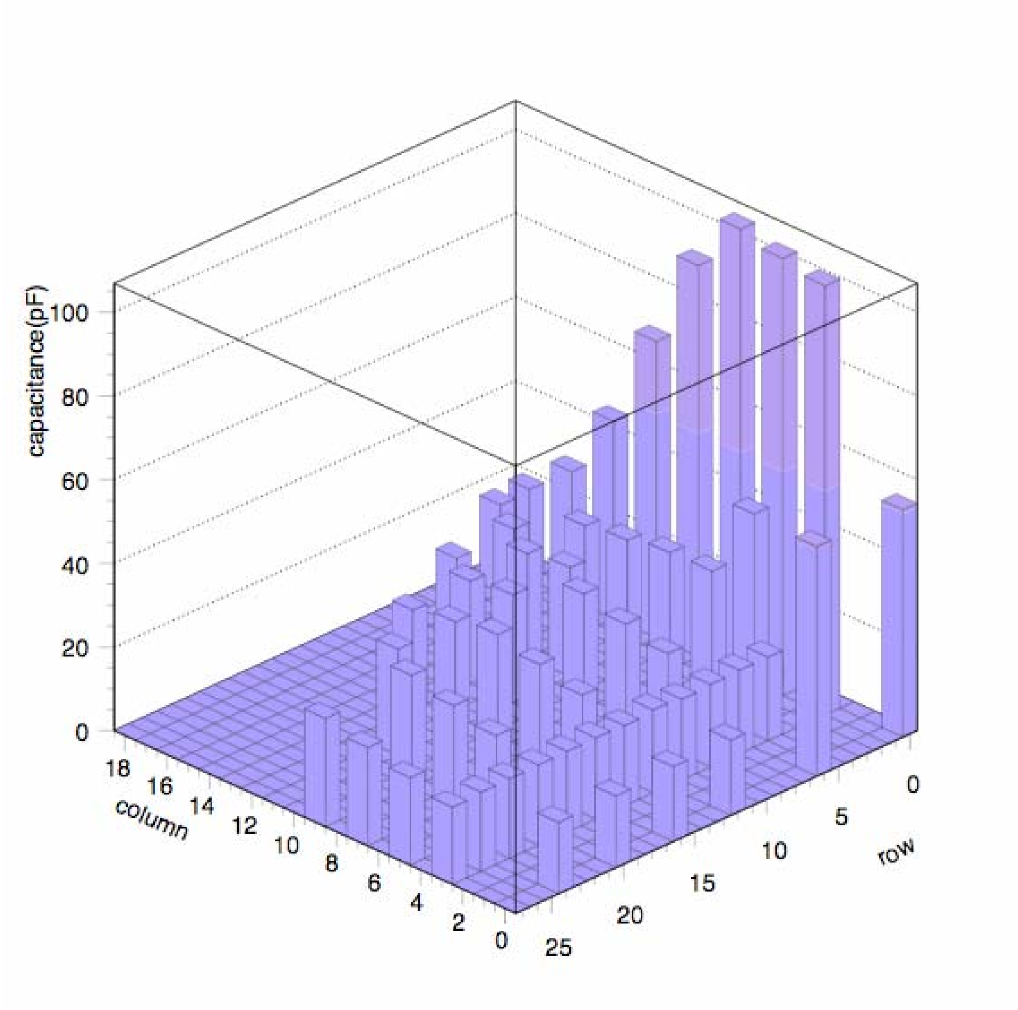
Comparison expected and measured stray capacitance



Pixel	Column	Row	Calculated Capacitance(pF)	Measured Capacitance(pF)
567	7	9	23.35±0.61	25.07±0.25
564	7	15	22.96±0.61	24.70±0.24
561	7	21	22.56±0.61	24.23±0.24
558	7	27	22.17±0.61	23.60±0.21
515	5	3	44.00±0.90	46.55±0.42
512	5	9	21.63±0.61	22.55±0.23
509	5	15	21.18±0.61	22.06±0.22
506	5	21	20.73±0.61	21.73±0.22
503	5	27	20.28±0.61	21.00±0.20

Measurement agrees with expectation for 0.9 micron thick oxide and 6 micron wide traces (3.1 pF/cm)

Spot check of capacitances in one quadrant is as expected.



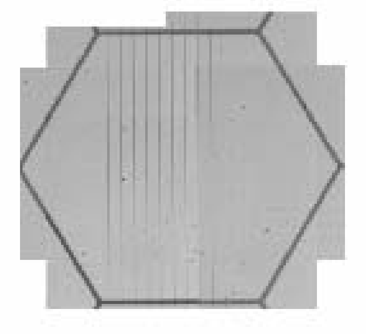
Impact of Detector Technology on Detector Design

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

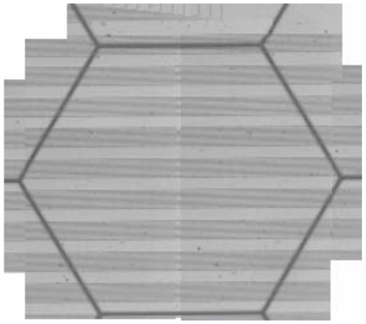
Small impact on tagging performance since bad channels can be de-weighted in determining the average time of a track

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

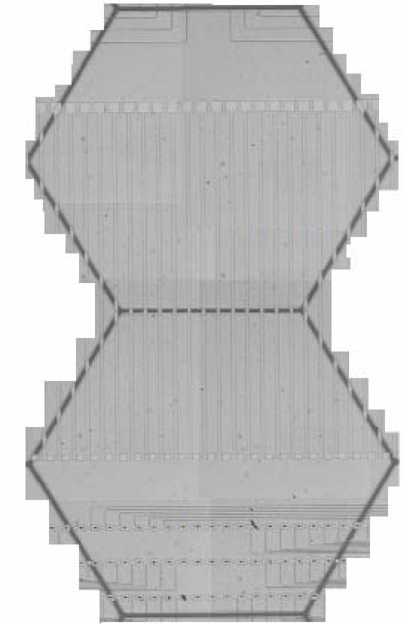
Could lead to inefficiency late in the bunch train due to buffer overflow a)



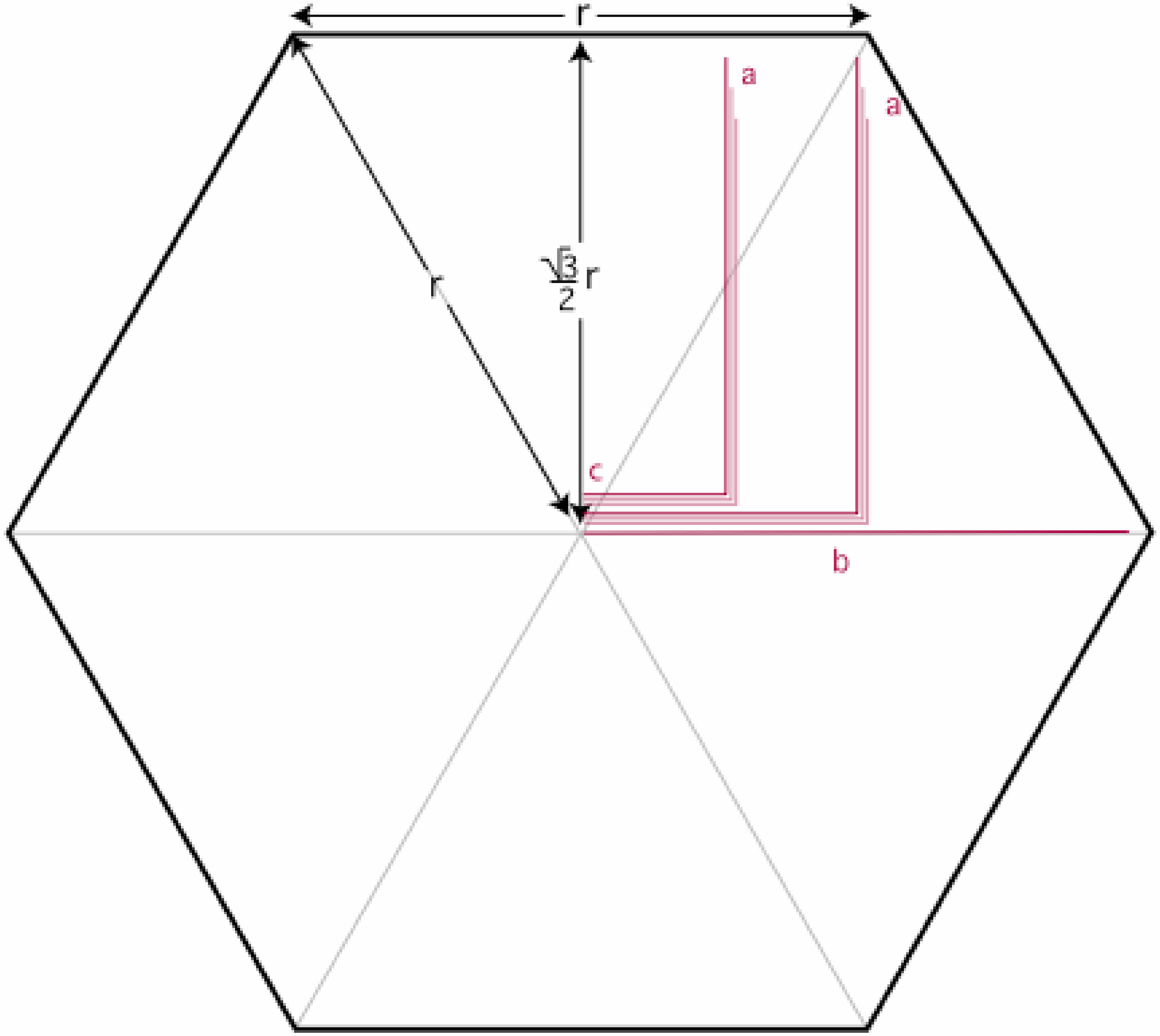
b)



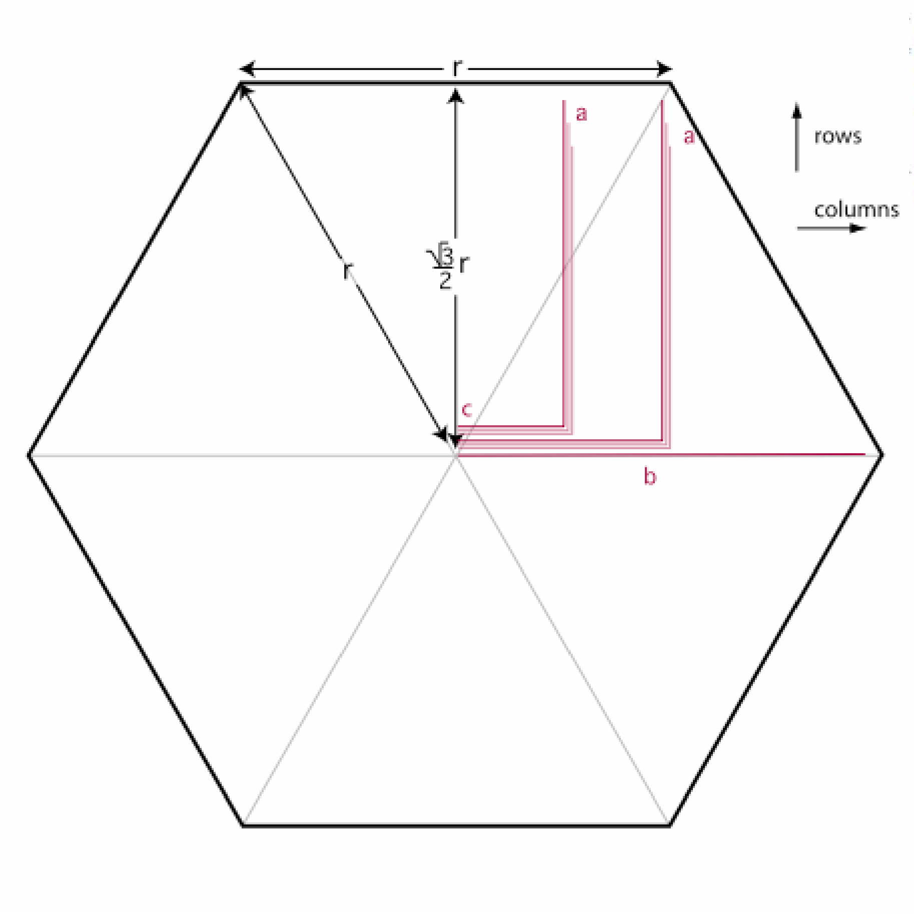
c)

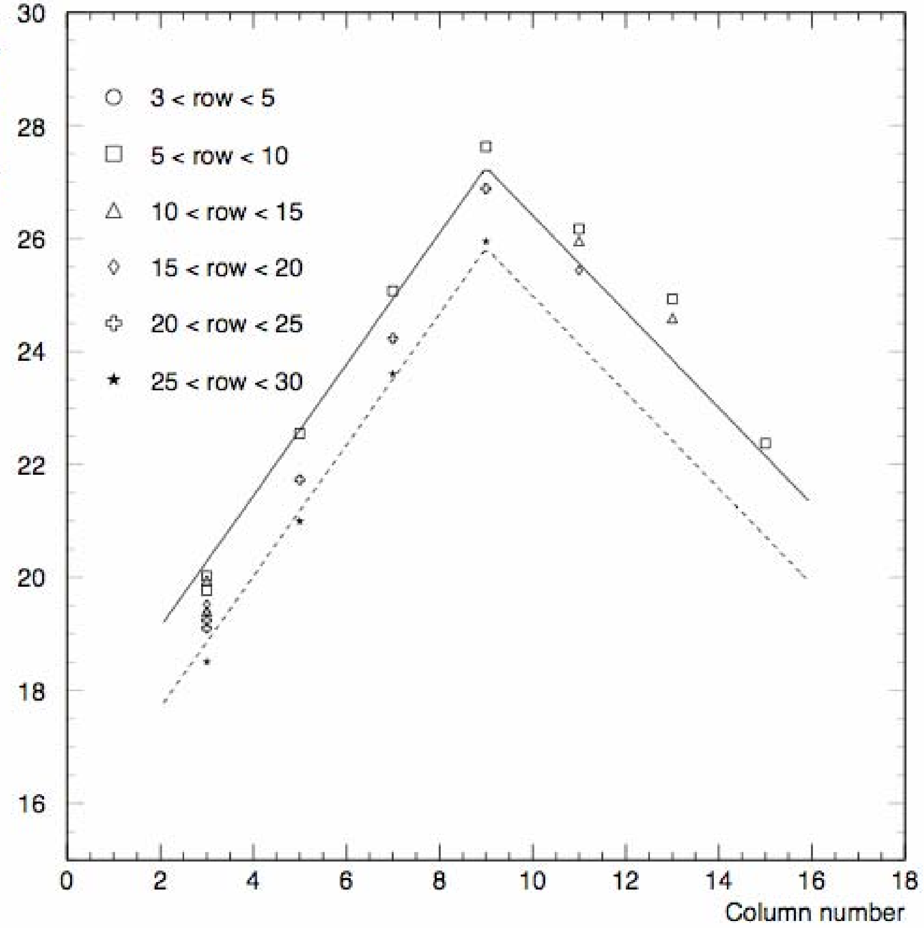


Examples of capacitances

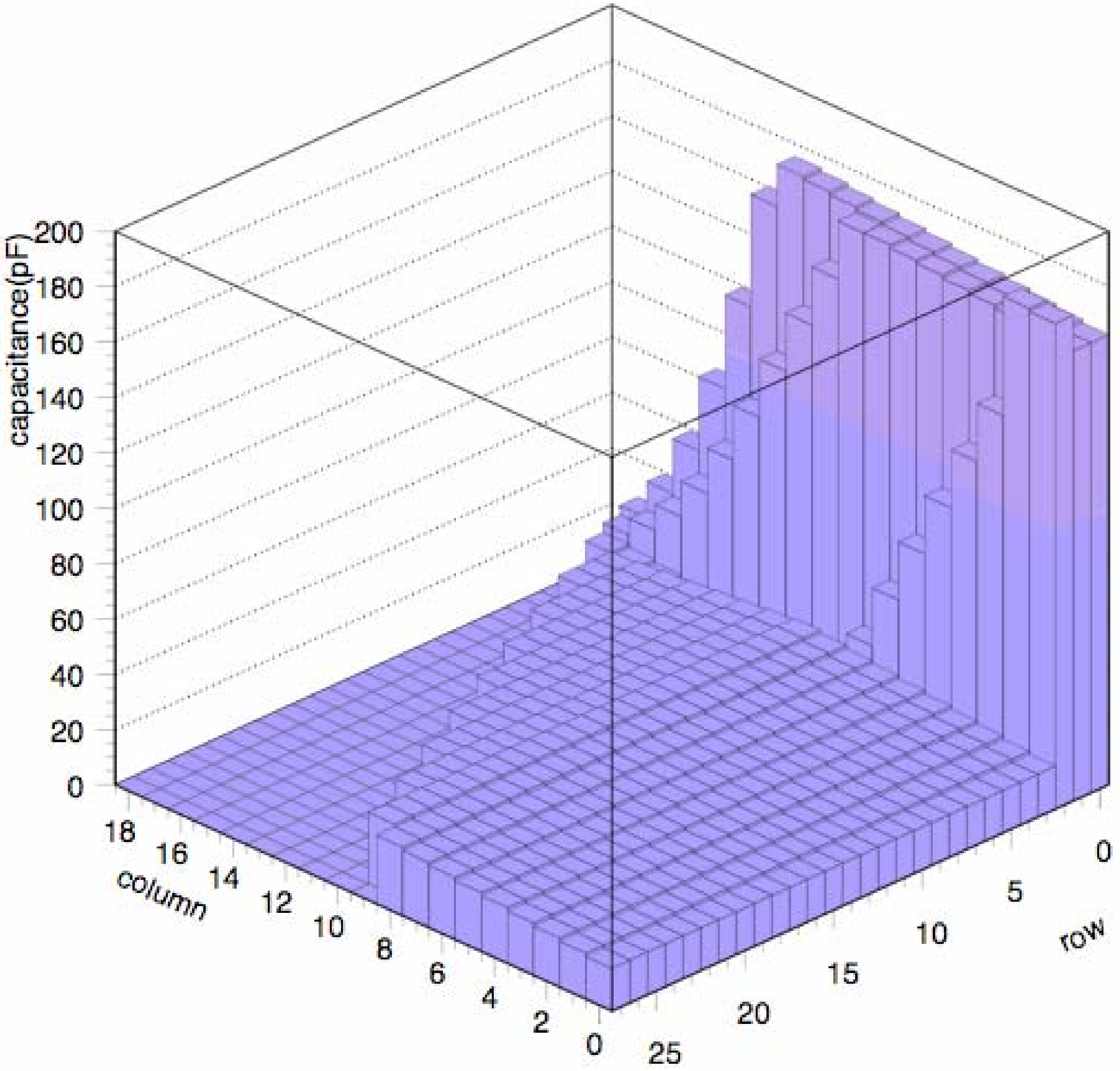


Note that all pixels in a given row have nearly the same capacitance:





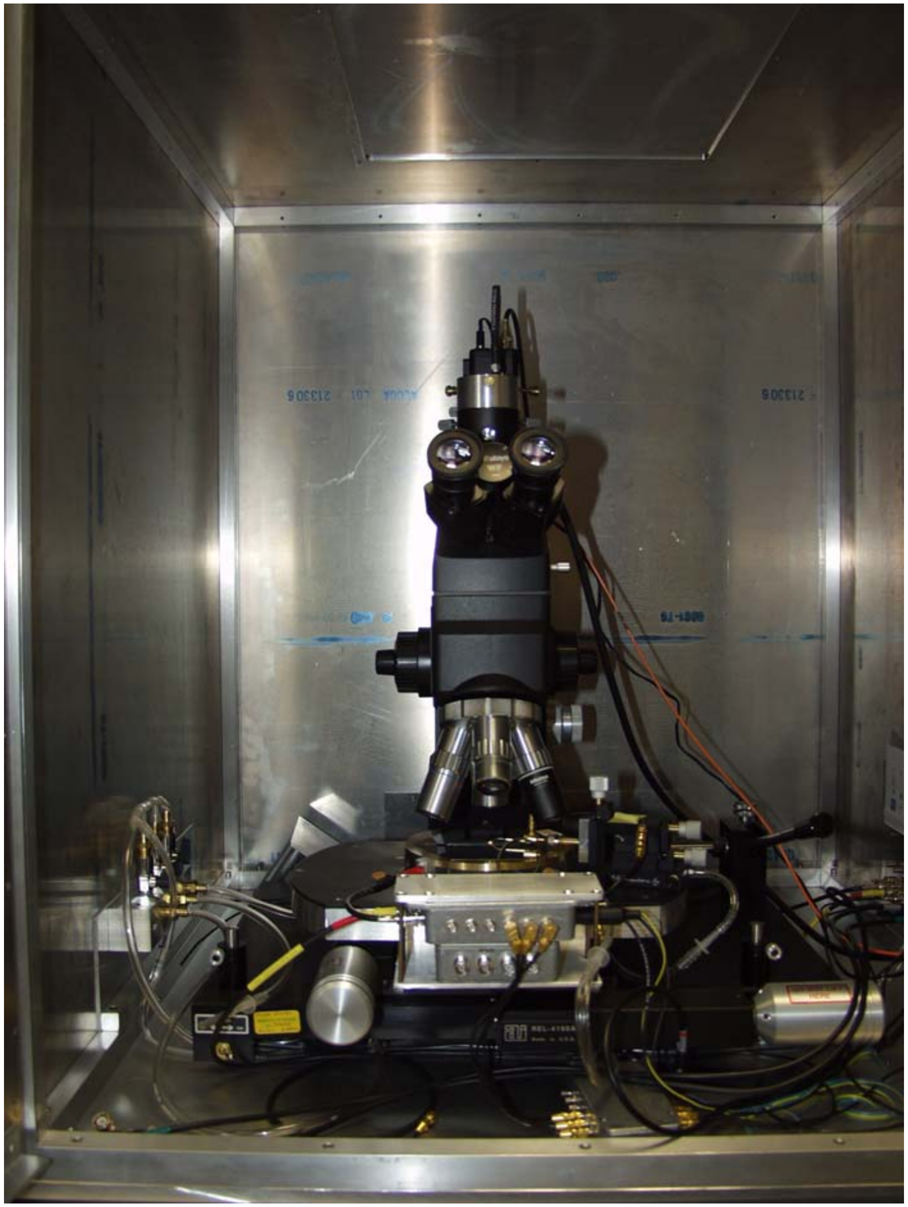
A simple model is under development for use in Monte Carlo simulations:



(Over estimates capacitance in region b because of unused channels in the 32 X 32 channel array)

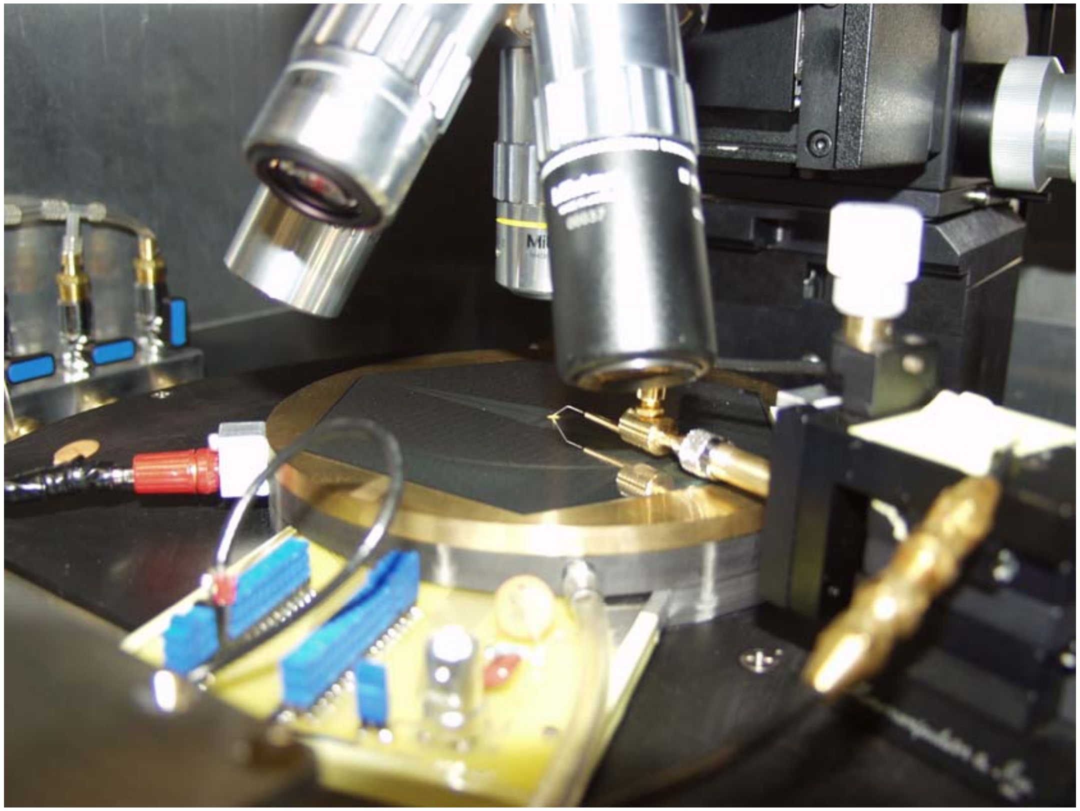
Teststand for cosmics, laser and sources

- Modified probe station, allows laser to be target on entire detector
- IR microscope objective used to focus laser to ~10micron spot
- Bias applied to backside of detector using insulated chuck



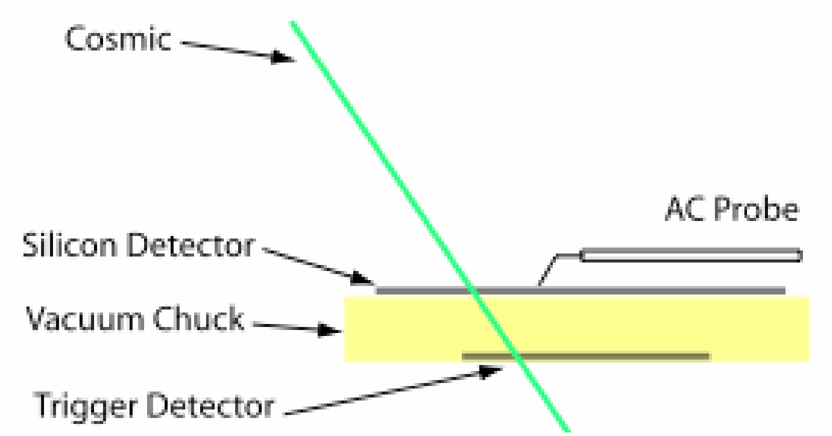
Test Setup -- detector probing

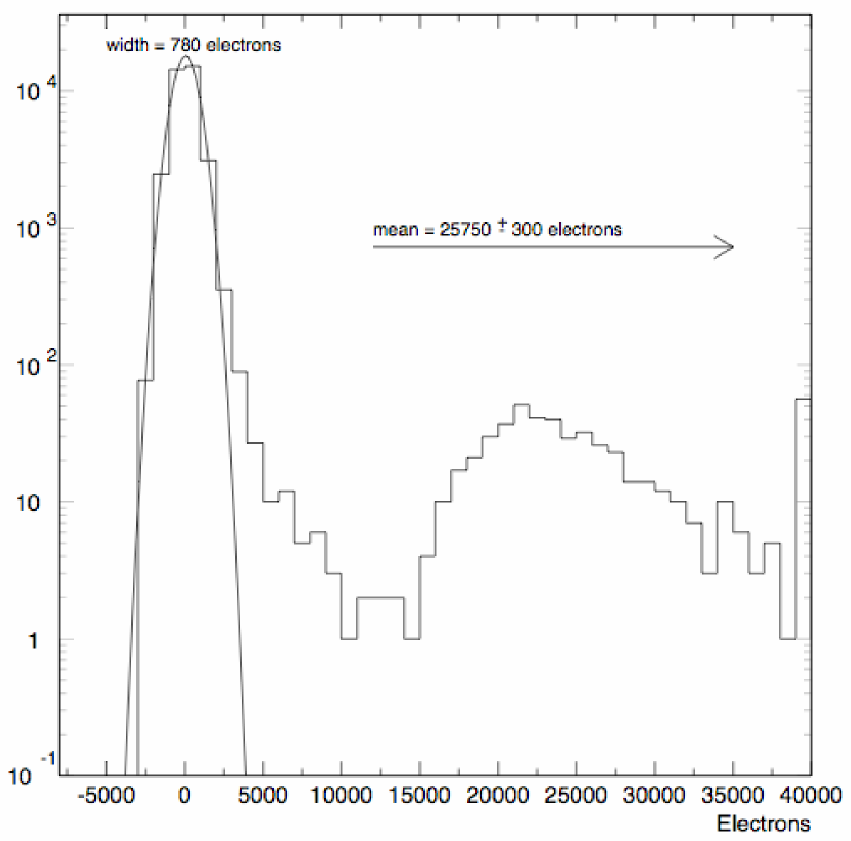
- Contact made to test pads on bump bonding array using an AC probe
- Cables add ~20pF of additional capacitance, but noise performance is somewhat better than readout chip
- Use AMPTEK 250F preamp, shapers with ~1 microsec shaping and a digitizing oscilloscope to mockup expected electronics
- PC board with 1cm x 1cm silicon pad detector used for cosmic trigger visible under chuck

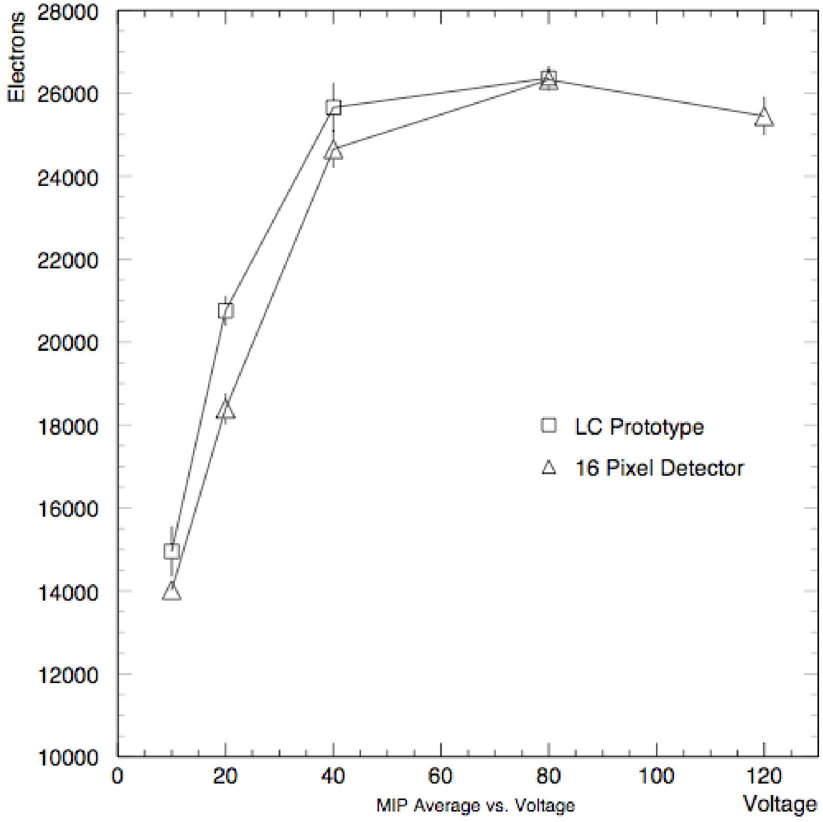


Response of detectors to Cosmics

(Single 5mm pixel)
Simulate LC electronics
(noise somewhat better)

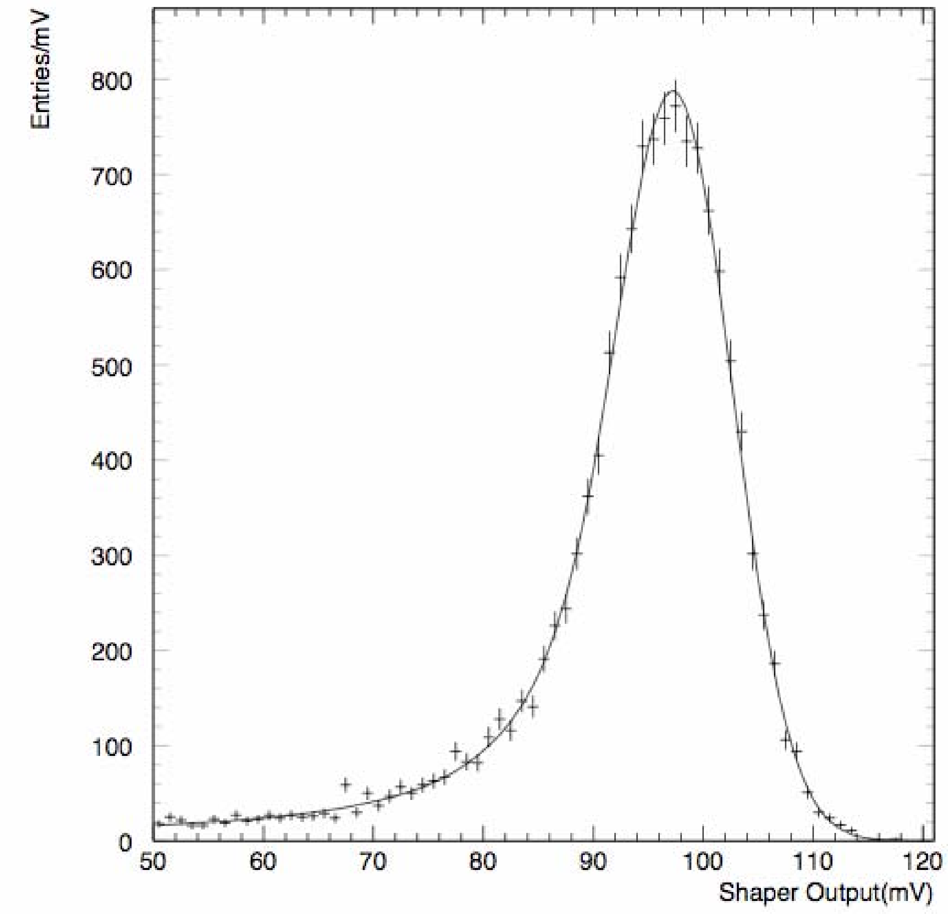






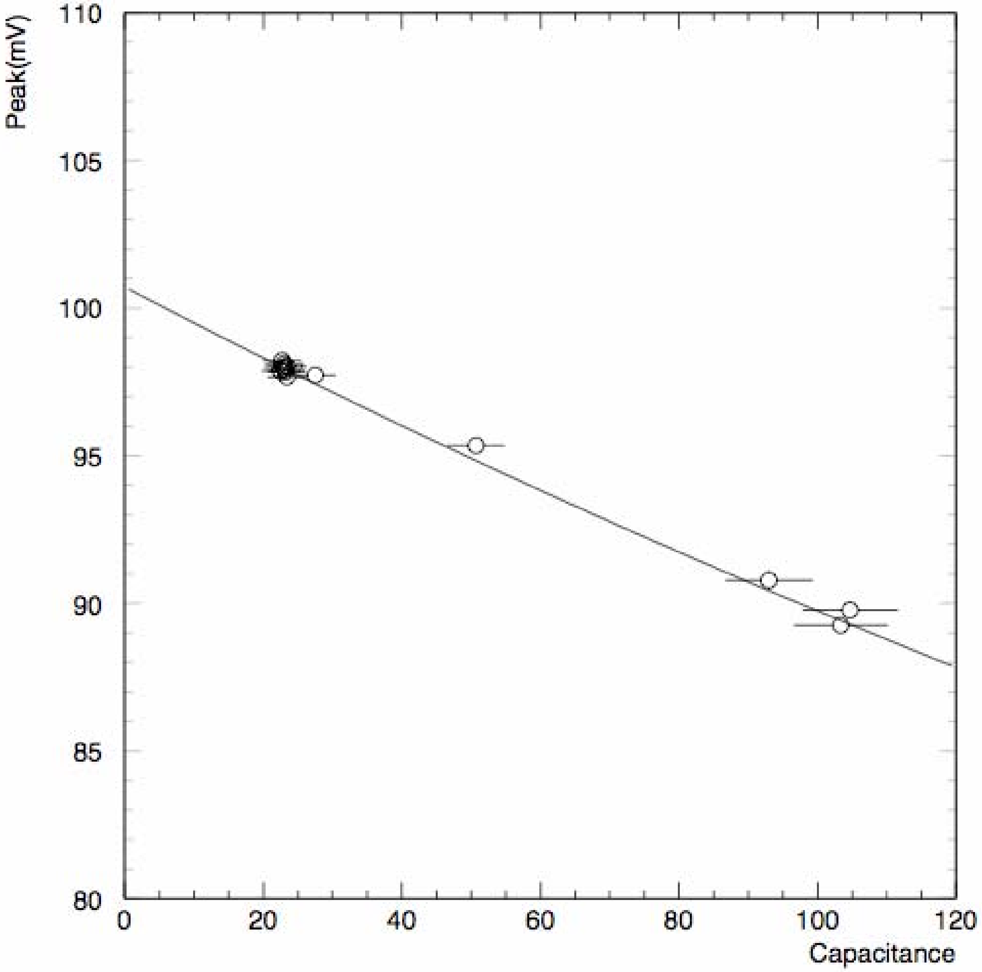
Errors do not include 10% calibration uncertainty

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

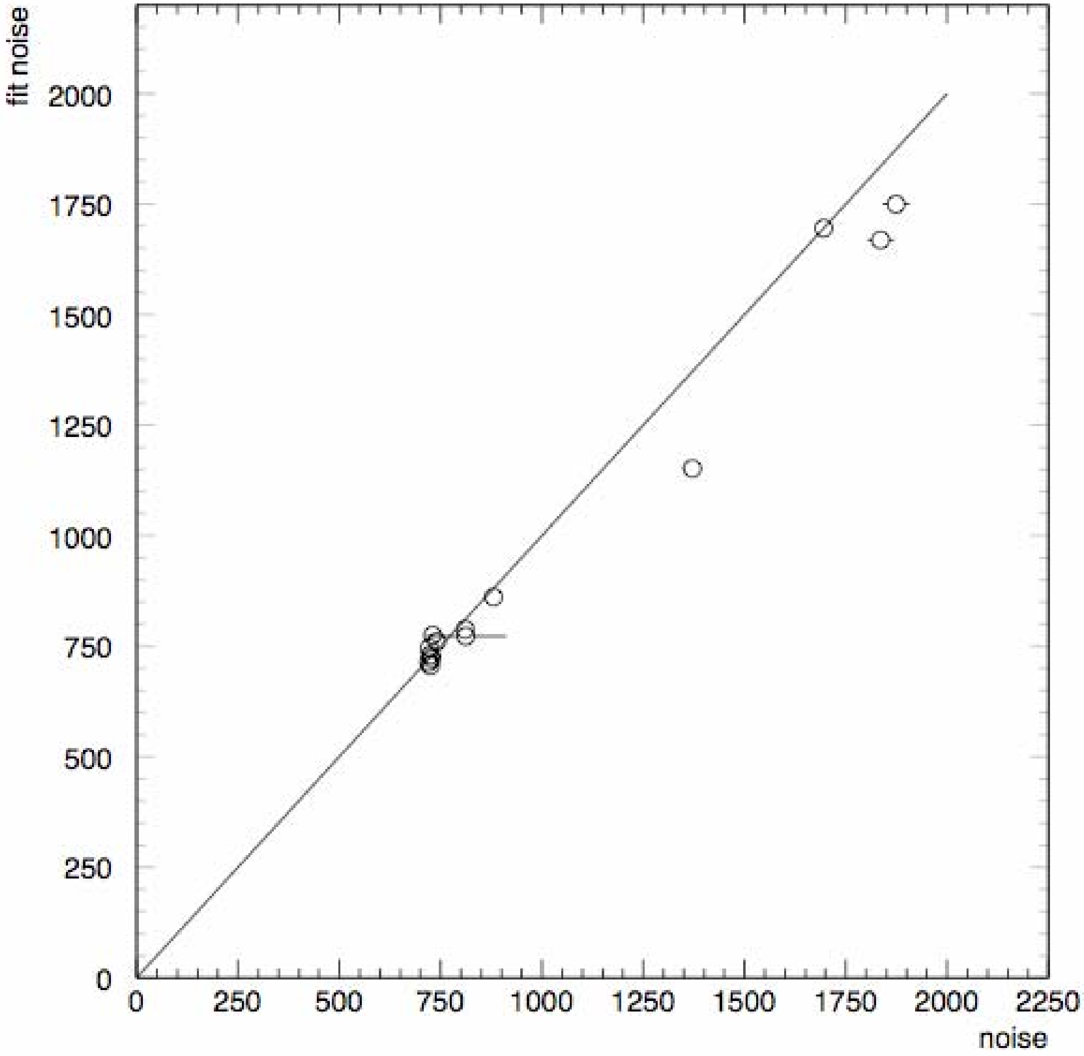


Possible ~1% wafer-wafer calibration?

Mean calibration value versus capacitance



Slope is determined by “dynamic” capacitance of our laboratory electronics C_{dyn} ~790pF

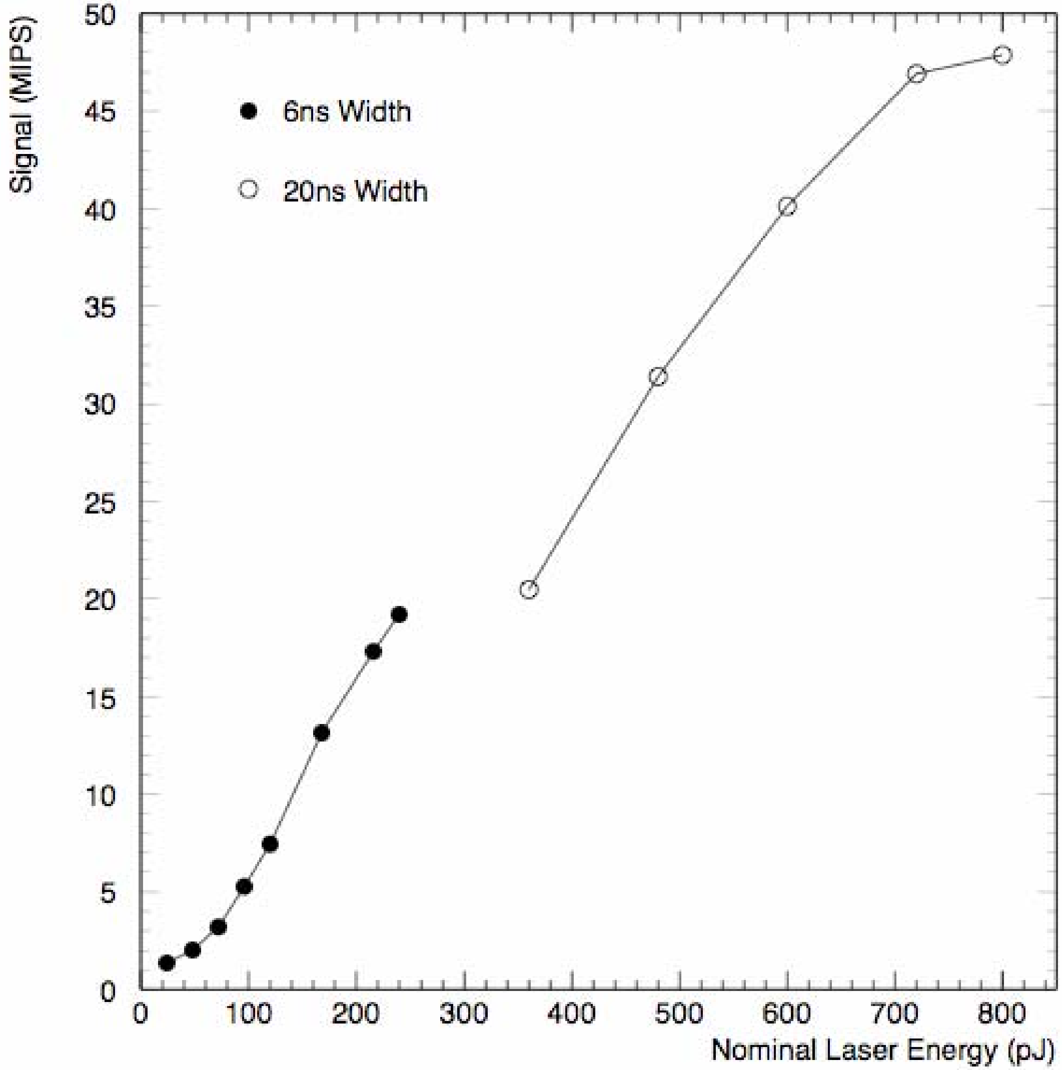


Noise is consistent with expectation from capacitance and series resistance

Laser studies

Use 1024nm laser that penetrates the entire silicon wafer

The nonlinearities are probably due entirely to the difference between nominal and true laser power



Conclusion

- 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
- Some minor changes needed for cold design