Silicon Tungsten Calorimetry

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- Design Consideration
- Silicon Detector Design
- Electrons and Noise
- Mechanical Design
- Timing resolution
- Plans and lab activity
- Si-W Mechanical Design

Si-W work – personnel and responsibilities

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Electronics, Mechanical Design, Simulation	**Si Detectors**, Mechanical Design, Simulation	**Electronics**

Primary ECAL Design Requirements

- Excellent separation of γ's from charged particles
  Efficiency $> 95\%$ for energy flow

- Good reconstruction of $\pi^{\pm}$, detection of neutral hadrons

- Reasonable EM energy resolution ($< 15\%/\sqrt{E}$)

- Reconstruct τ's and measure polarization (separate π, ρ, a_1, e's)

- Reconstruct Bhabhas and deconvolve luminosity spectra
  Position resolution $\sim 100\mu m$, bias $\sim 25\mu m$ in endcap

Secondary ECAL Design Requirements

- Excellent electron identification in jets (tag and b/c quarks)
- Partial reconstruction of b/c hadrons in jets
- Good γ impact resolution for long lived SUSY neutrals ~ 1 *cm*
- Good background immunity
  - Bunchlet identification
  - High granularity

SiW Design Consideration

- Transverse shower size scales with Molière radius (9mm in pure W, 16mm in pure Pb)

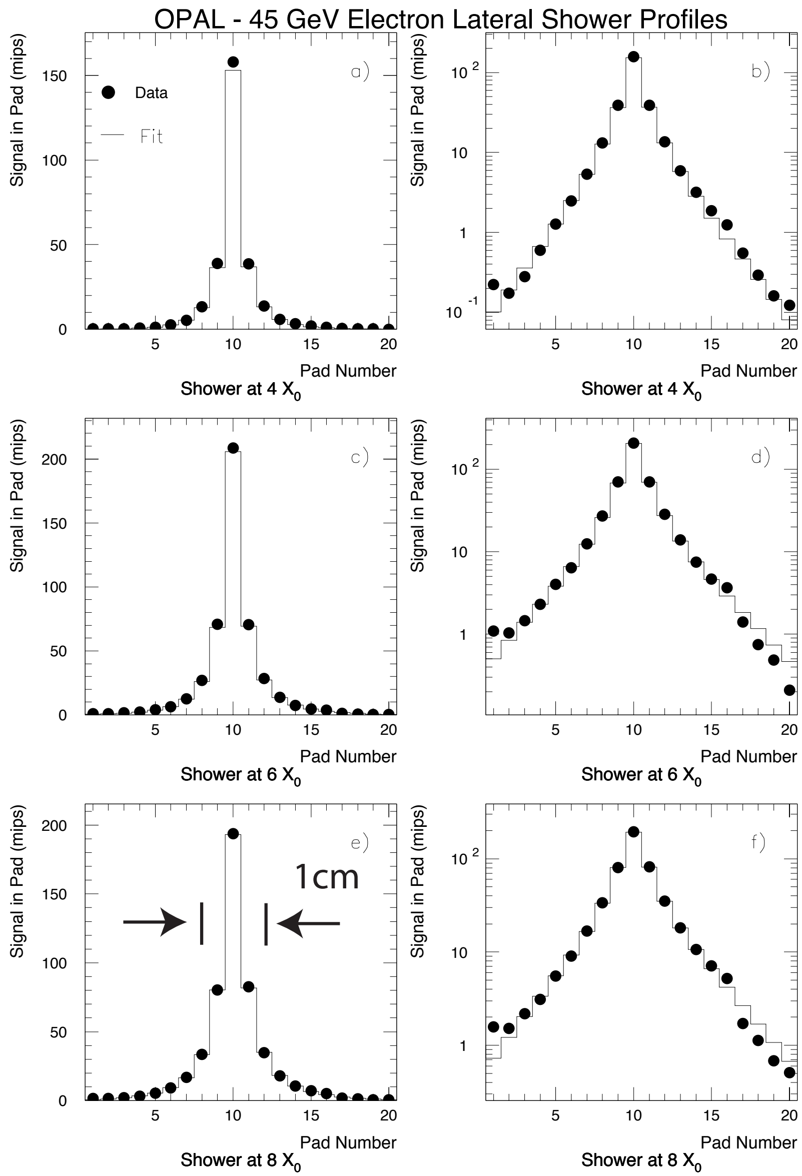
  ⇒ *Minimize gaps between layers of absorber*

  ⇒ *Use a high purity W alloy*

- Sample between 1/2 and 2/3 of X_0 (1.75mm to 2.5mm of W)

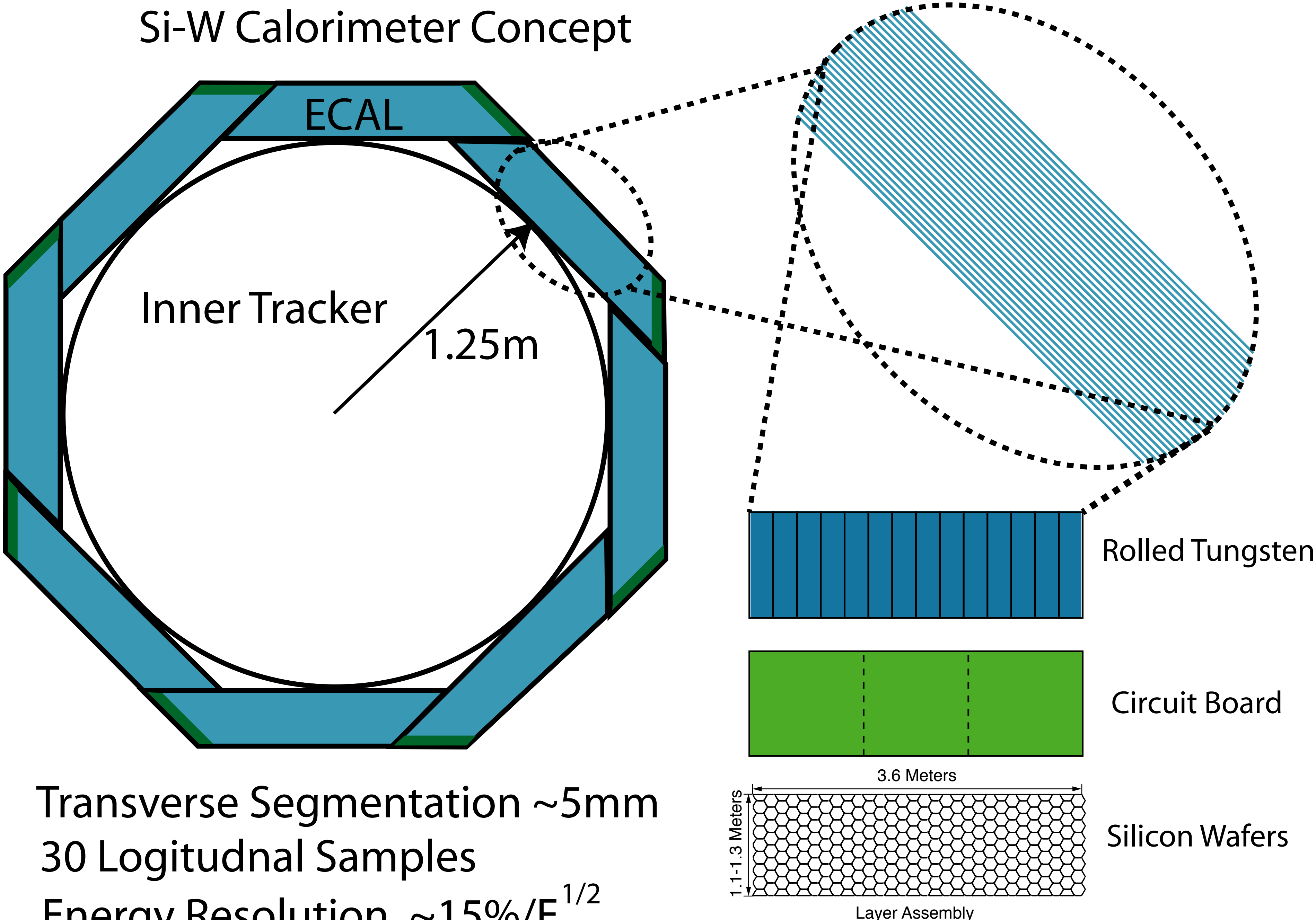
- Allow for detector segmentation at a fraction of the Molière radius

  ⇒ *Use* $\sim 5mm$ *pads*



$1\,X_0$ sampling, 2.8 mm gap

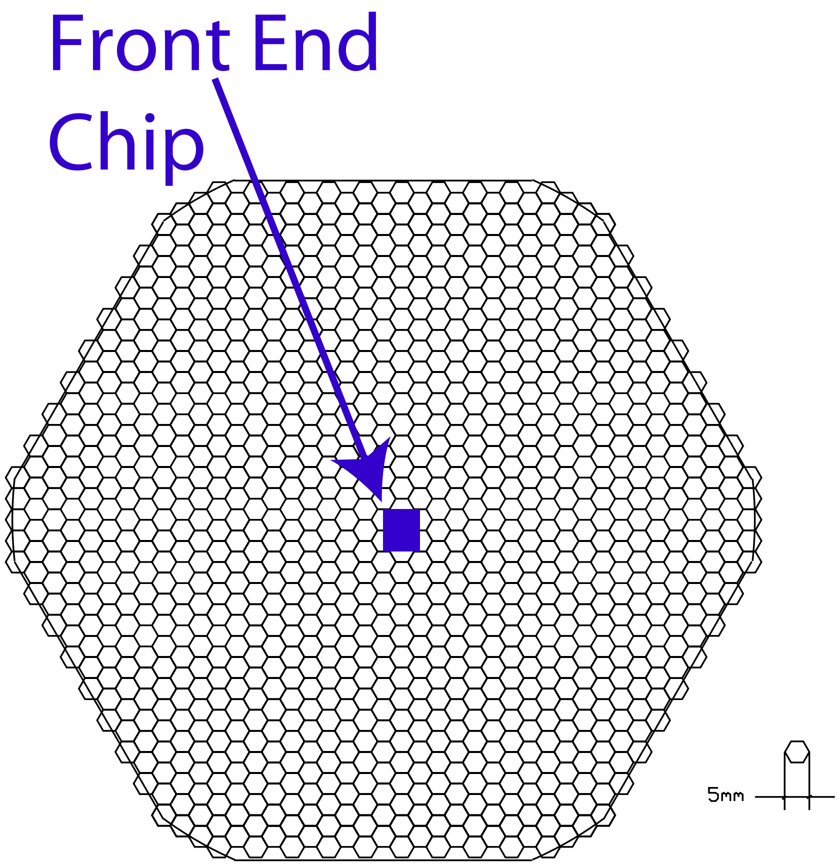
Si-W Calorimeter Concept



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

Silicon Concept

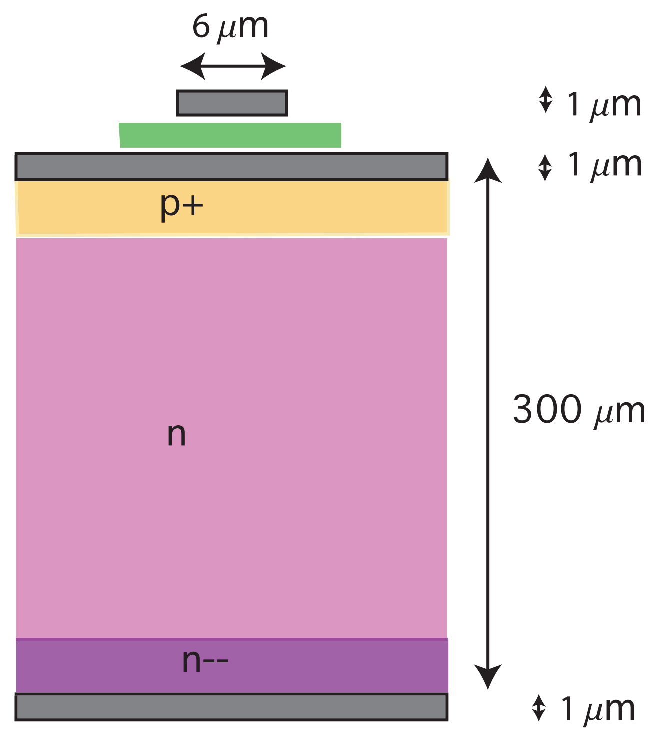
- Readout each wafer with a single chip
- Bump bond chip to wafer
- To first order cost independent of pixels /wafer
- Hexagonal shape makes optimal use of Si wafer
- Channel count limited by power consumption and area of front end chip
- May want different pad layout in forward region



6 inch (152mm) Dia Wafer

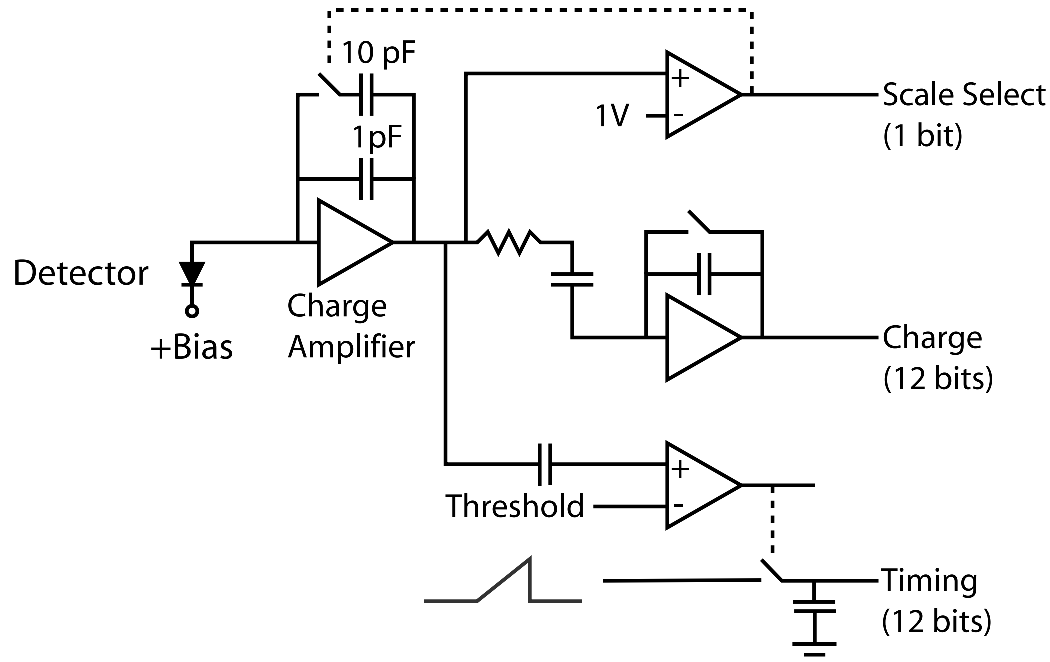
Silicon Design Details

- DC coupled detectors
- Two metal layers
- Keep Si design as simple as possible to reduce cost
- Cross talk looks small with current electronics design



Electronics Design

- Chip area driven by feedback capacitor on charge integrator and 3V supply.
  Need 2000 MIP (8 pC) dynamic range for 500 GeV electrons.
  ⇒ 10pF feedback capacitor
  ⇒ Effective 16 bit dynamic range
- Novel design uses two different feedback capacitors
- 5 to 10ns timing possible
- Current in input transistor pulsed *duty cycle* $< 10^{-3}$
- Expect power << 40mW/wafter



Warm versus Cold Machines

• Present electronics design is optimized for a warm machine.

• In a cold machine a digital pipeline would be needed for for each channel as integration over the very long bunch trains would not be possible.

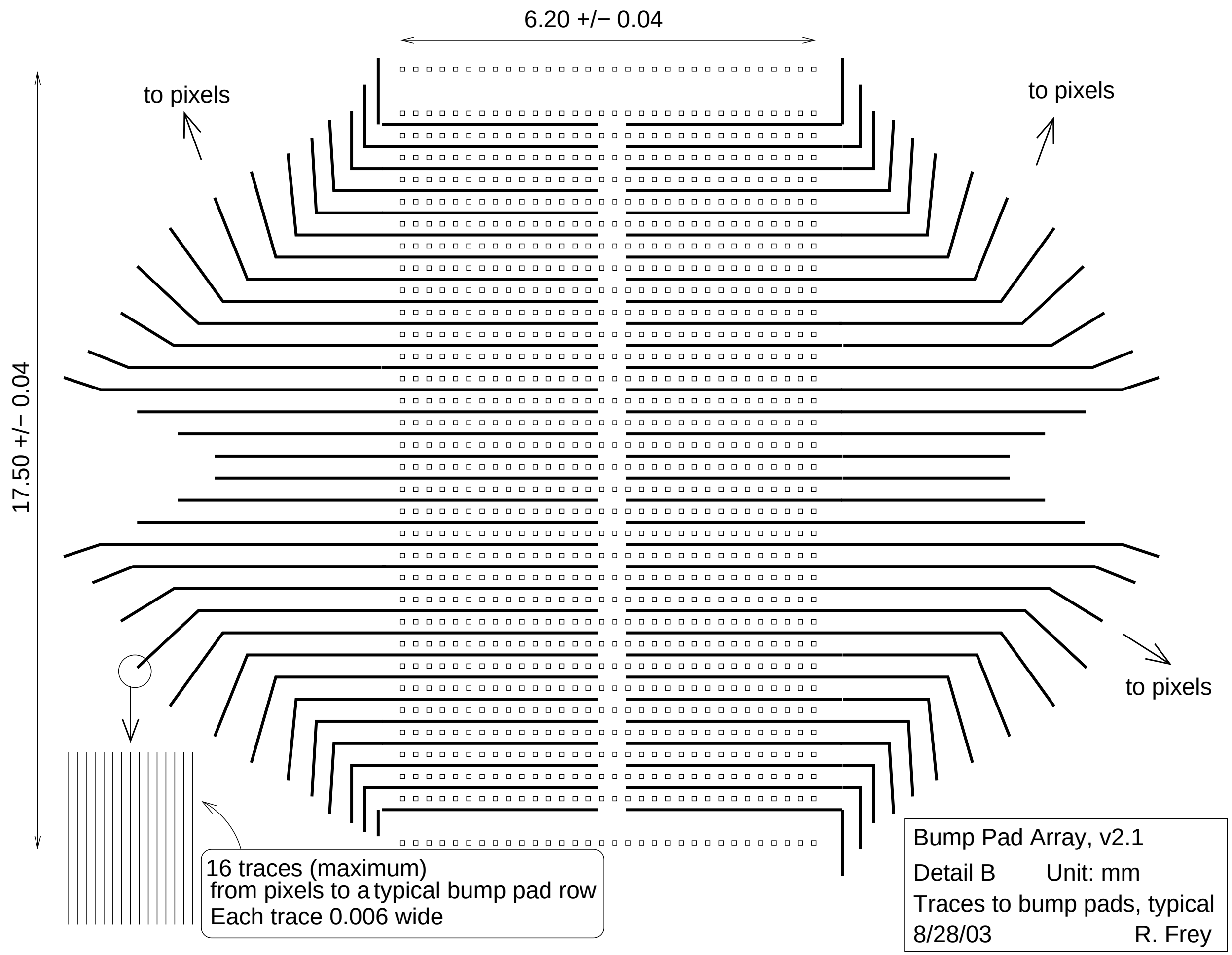
⇒ Comparator presently foreseen for timing circuit could be used to trigger ADC and record bunch number

• The main impact of a cold machine would be increased power consumption and complexity in the digital portion of the chip.
(The increased power consumption is a second order effect.)

⇒ Simpler warm machine electronics a good place to start

Si Prototypes

- Design completed
  Provisional grid spacing for bump-bonding



Si Prototype properties – leakage current and noise

- Radiation damage to detectors is probably dominated by neutrons, $\sim 10 \times 10^{10}/\text{cm}^2$

$$\Rightarrow < 10\text{nA /pixel leakage current}$$

- Expect typical leakage current at start of life < 1nA/pixel

- Noise from leakage current at end-of-life for 1μs sampling time (can be adjusted) and DC coupling scheme is < 350 electrons

- The dynamically switchable feedback capacitor scheme requires the full dynamic range only in the initial charge amplifier.

$\Rightarrow$ Very high power would be needed in much of the electronics chain to keep the noise floor at the equivalent of 400 electrons.

- Present design has noise:

$$\sim 20 - 30e/\text{pf}$$

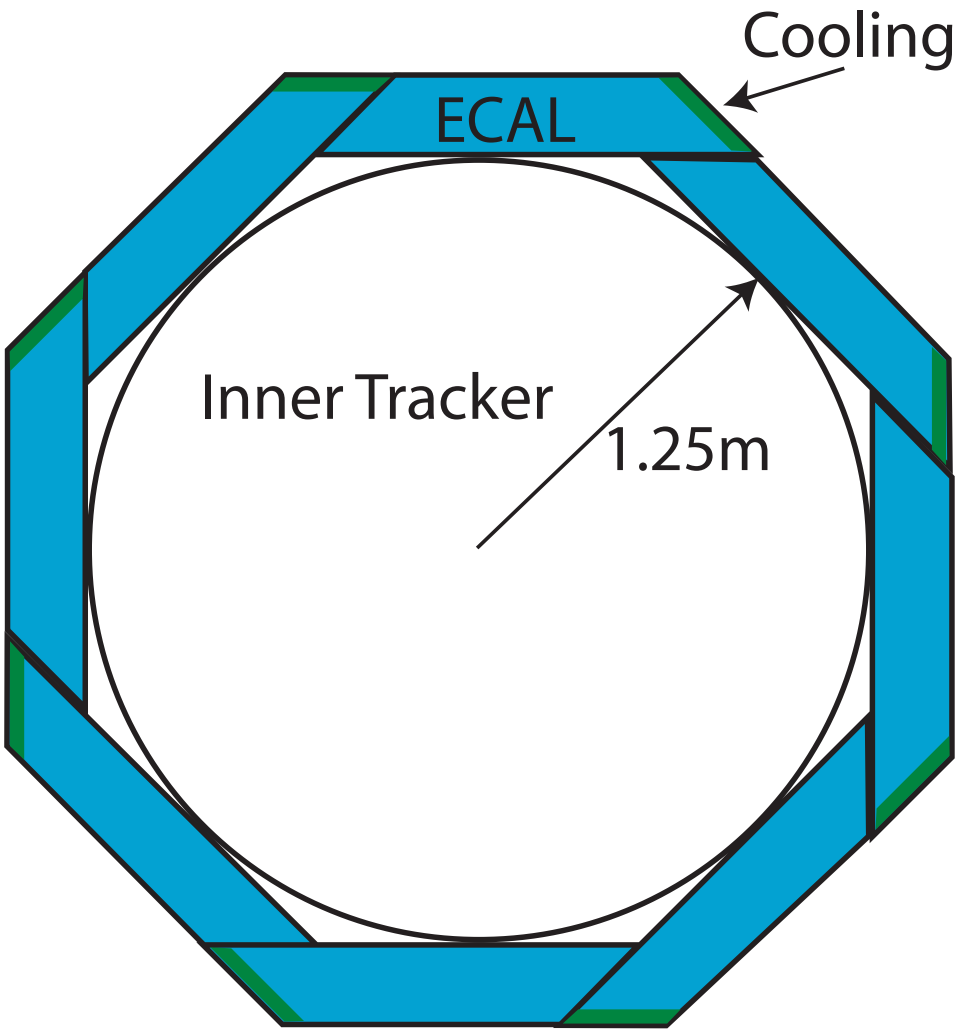
For most channels the value of C_{input} is dominated by stray capacitance of the trace connecting the pixels to the electronics:

$$C_{input} \sim 5.7\text{pF(pixel)} + 12\text{pF(trace)} + 10\text{pF(amp)} \sim 30\text{pF}$$

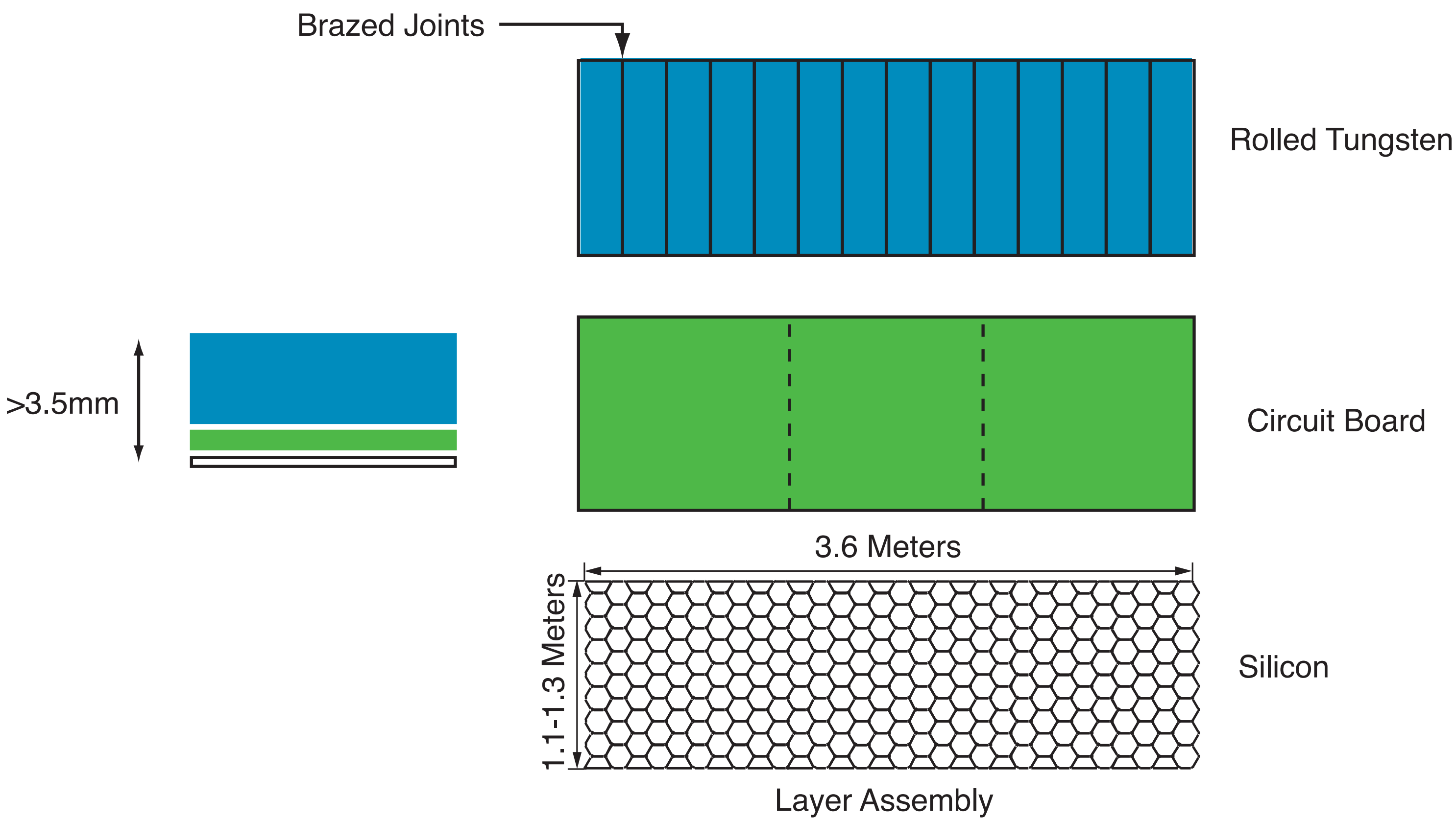
$$\longrightarrow\ \sim 1000 \text{ electrons noise (c.f. 24,000 from MIP)}$$

Fitting it all together

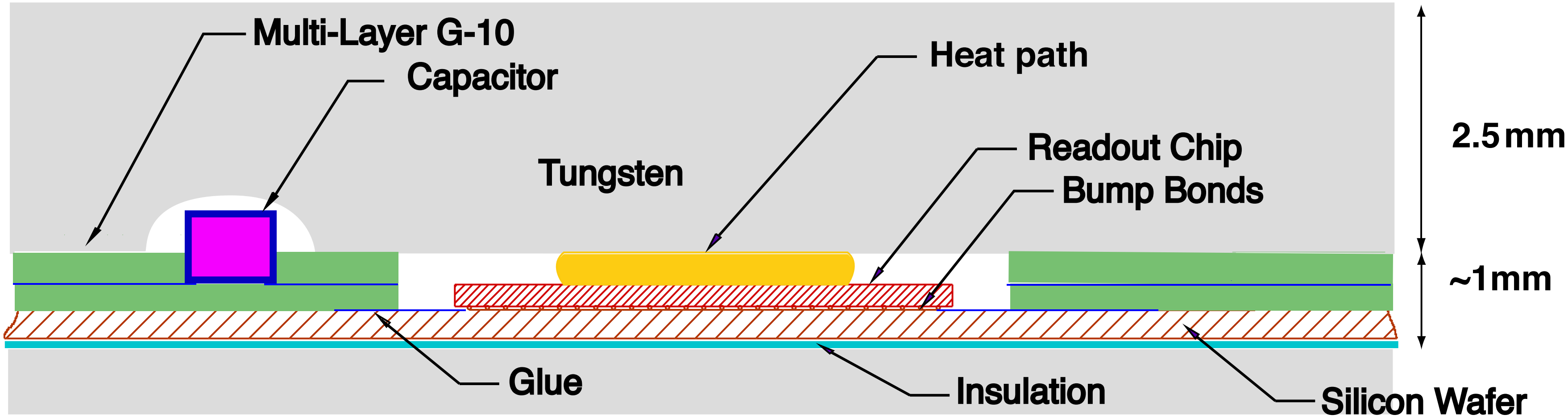
- Cartoon of possible barrel calorimeter configuration
- Assume heat flows along tungsten and/or copper heat sink to cooling water (green)
- Longest path for heat flow < 1.4m



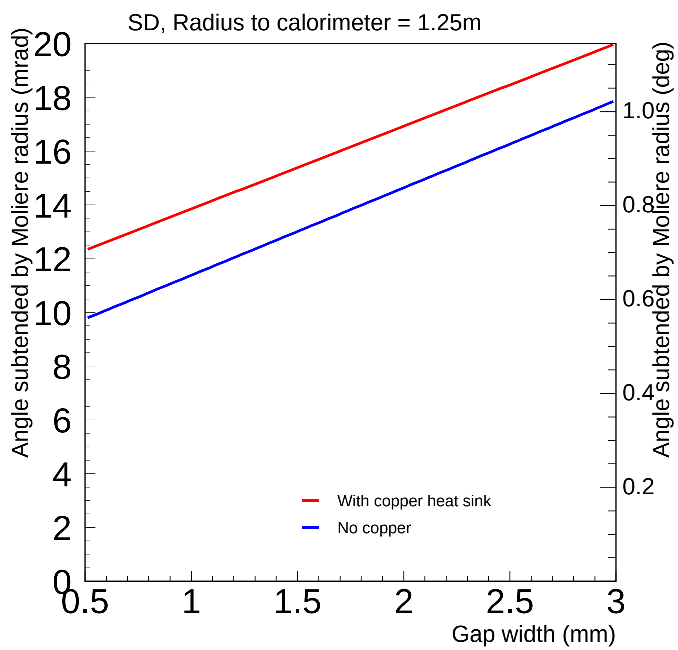
Layout of Individual calorimeter layers:



Critical parameter: minimum space 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



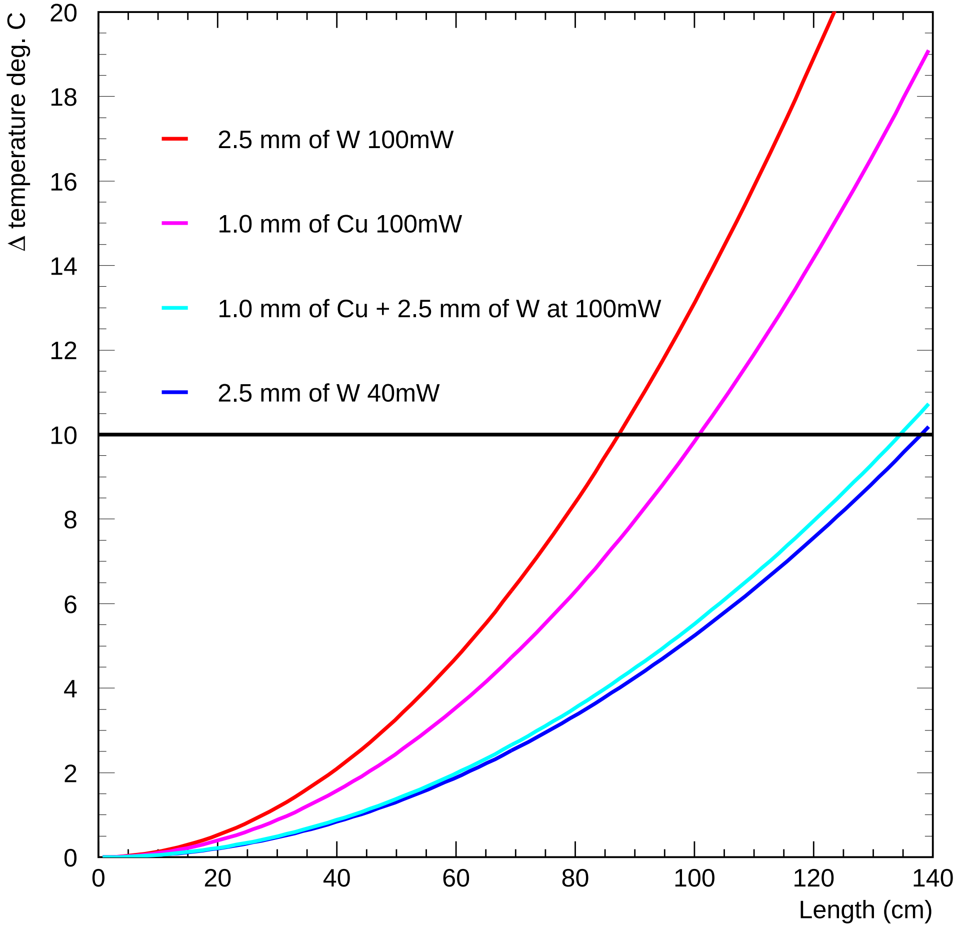
Heat flow

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.

Physical model test in progress



Prototype Tungsten Pieces

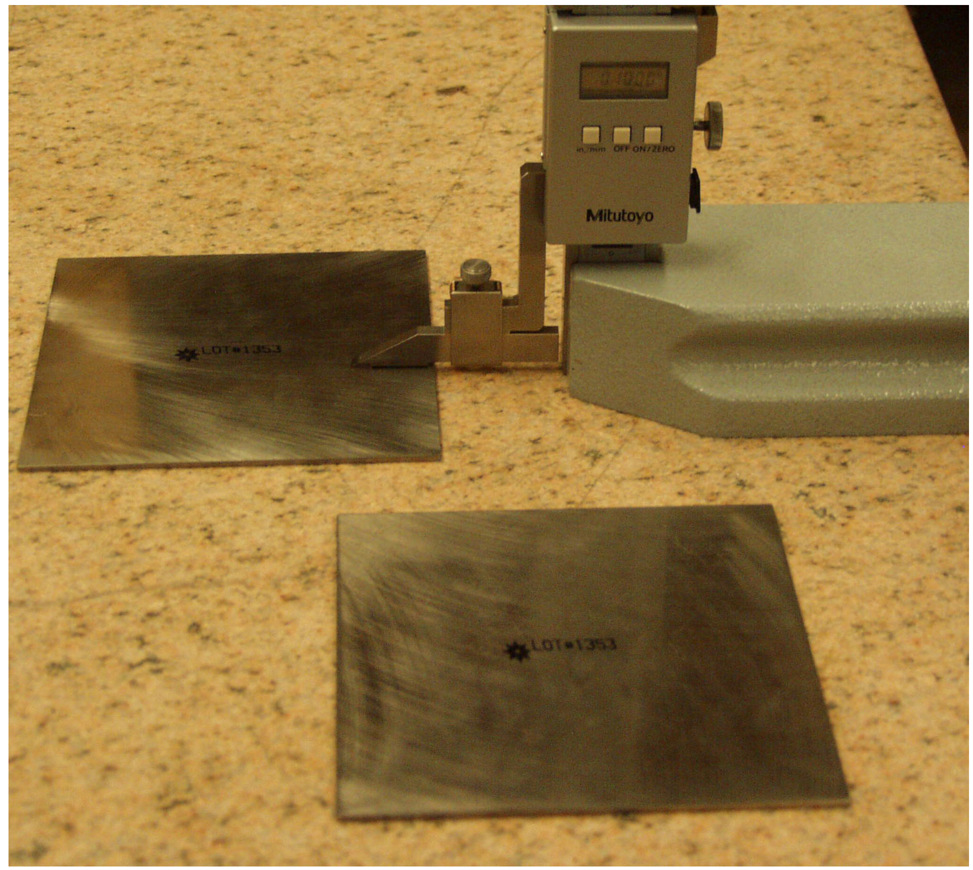
- OPAL tungsten ground to size (almost more expensive than tungsten itself!)

- Prototype rolled pieces (92.5% W) look fine (some grinding still needed)

- Quality better than OPAL

- 1 m long pieces possible

- Thickness variation $< 30\mu$m



Summary of Granularity – *Most important figure of merit*

- With 92.5% W and 1 mm gap we can have a Molière radius of

$$\sim 14\,\mathbf{mm}$$

which has an angular size of **11 mrad** at 1.25 m

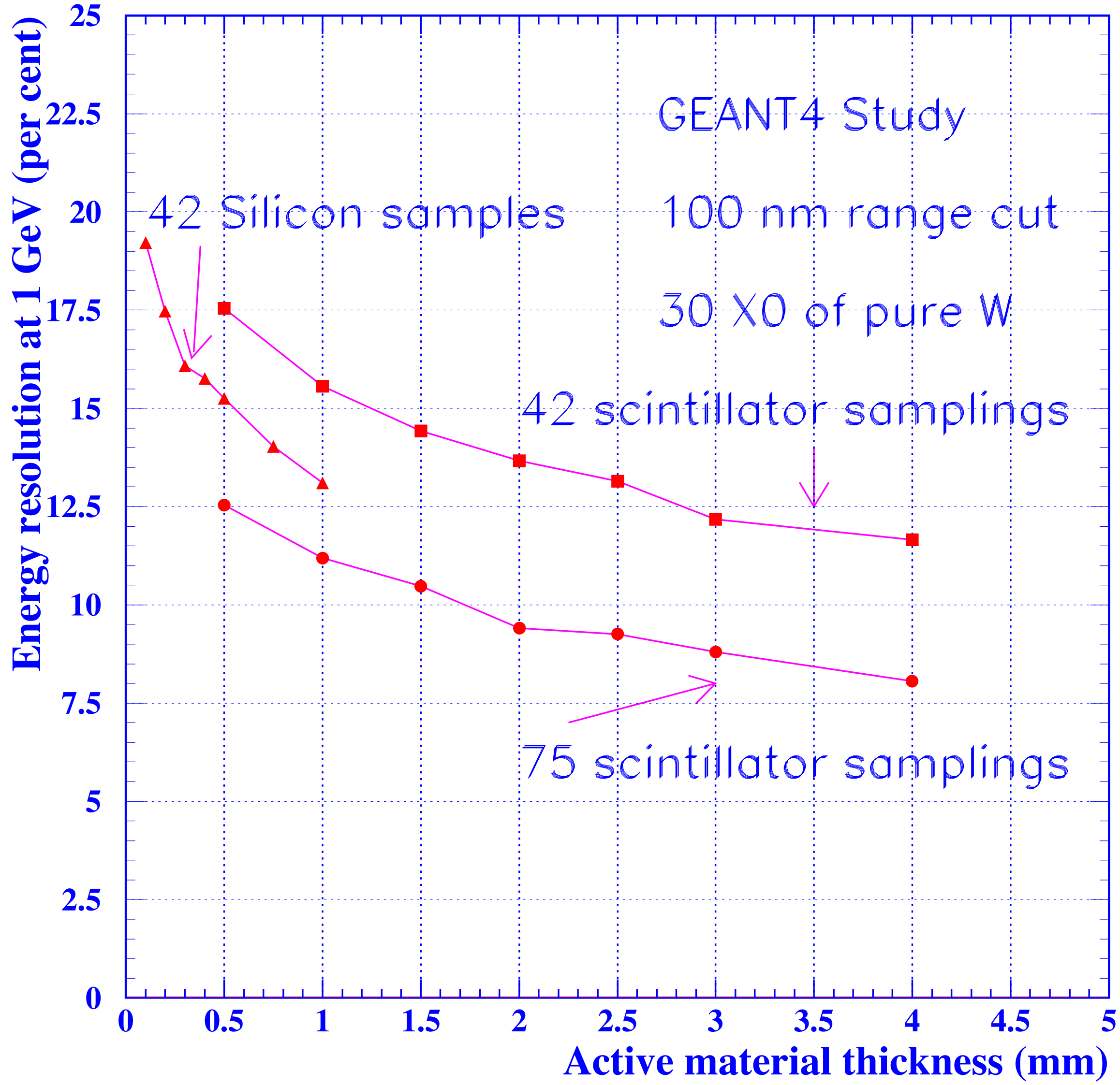
⇒ provided we can keep the power down to **40 mW** wafer

- *This will be challenging, but may be possible*

What about energy resolution ⇒

Geant 4 simulation of energy resolution from Graham Wilson

- 1 GeV photons
- 0.1 μm range cuts
- 42 and 75 layers of W
- Si apparently benefits from subMIP energy deposits – can we see this in a real detector?



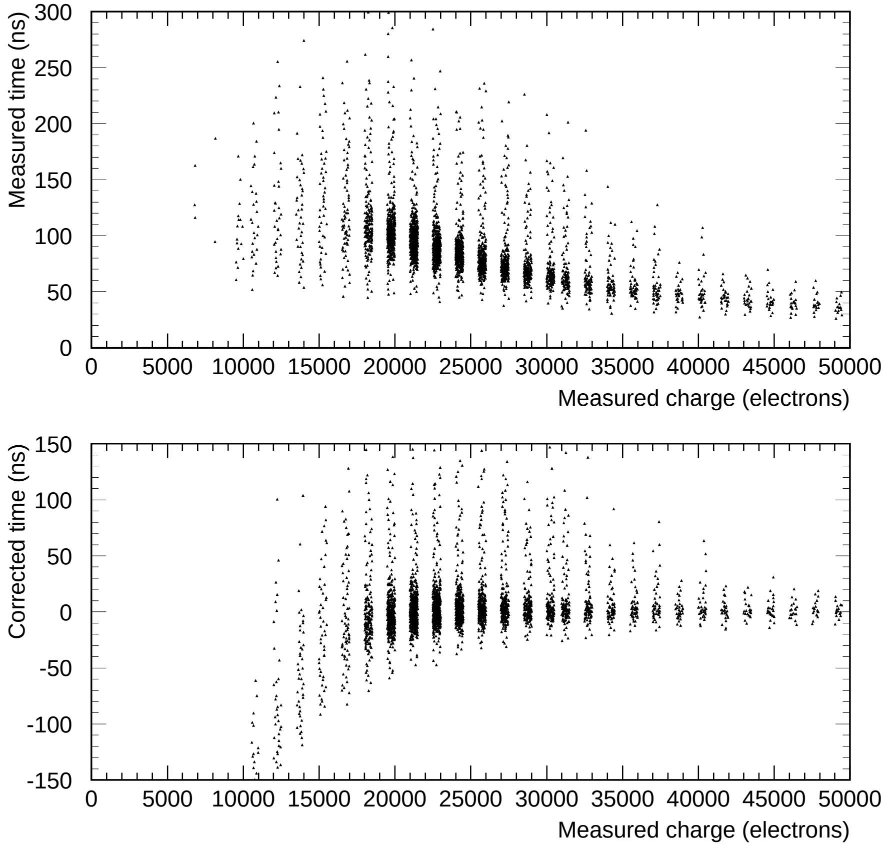
Toy Monte Carlo Studies of Timing Resolution for 30 Samples

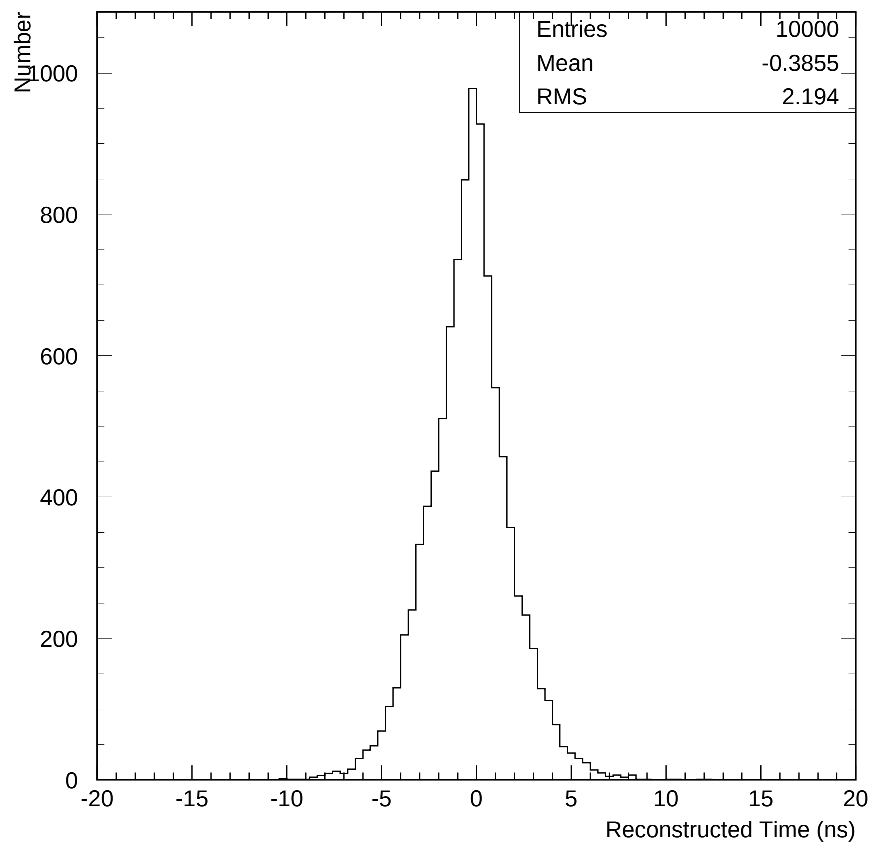
Assumptions – wild guesses – (waiting for real electronics model):

- Each MIP has 30 samples at random distances from the read-out chip
- Threshold for timing measurement is 8,000 electrons.
- Input FET has $g_m = 1.5$mS and the noise contribution from the rest of the amplifier is equal to input FET except for the "floor" noise.
- The charge measurement has a noise floor of either 0 or 4000 electrons
- Time constant for charge measurement is 200 ns.
- Time constant for the time measurement is 50 or 200 ns.
- The noise in the timing and charge circuits are uncorrelated
- Random 5% channel to channel variation in threshold
- Random 1% event-to-event variation in threshold
- Random 5% uncertainty in constants used for correction.
- Reject time measurements far from mean

Sample Timing Results

200 ns time constant, no noise floor

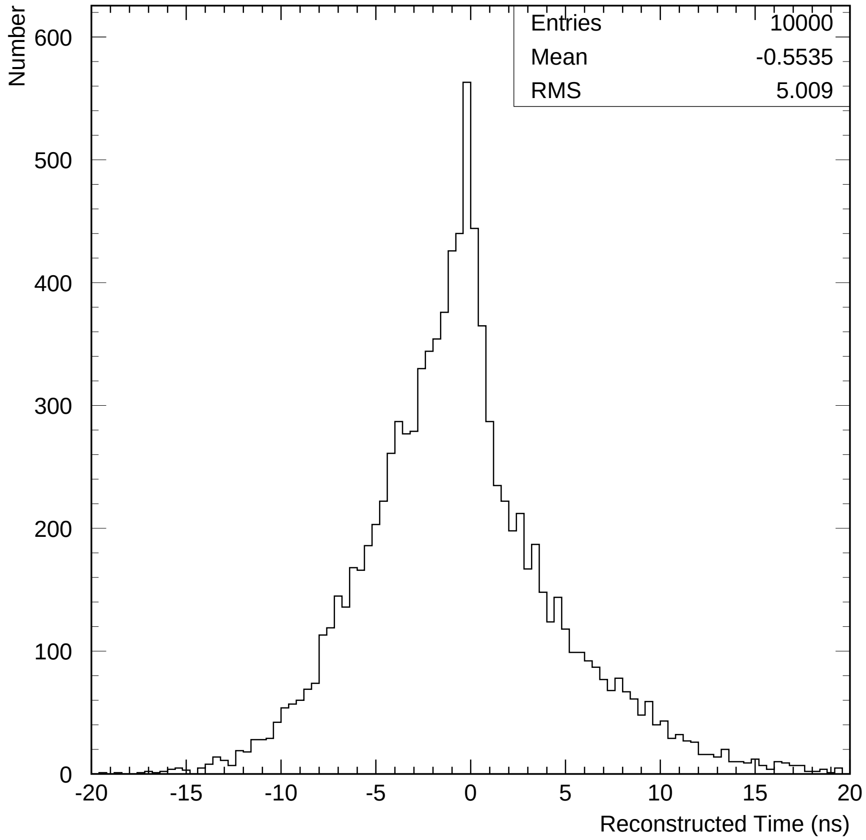




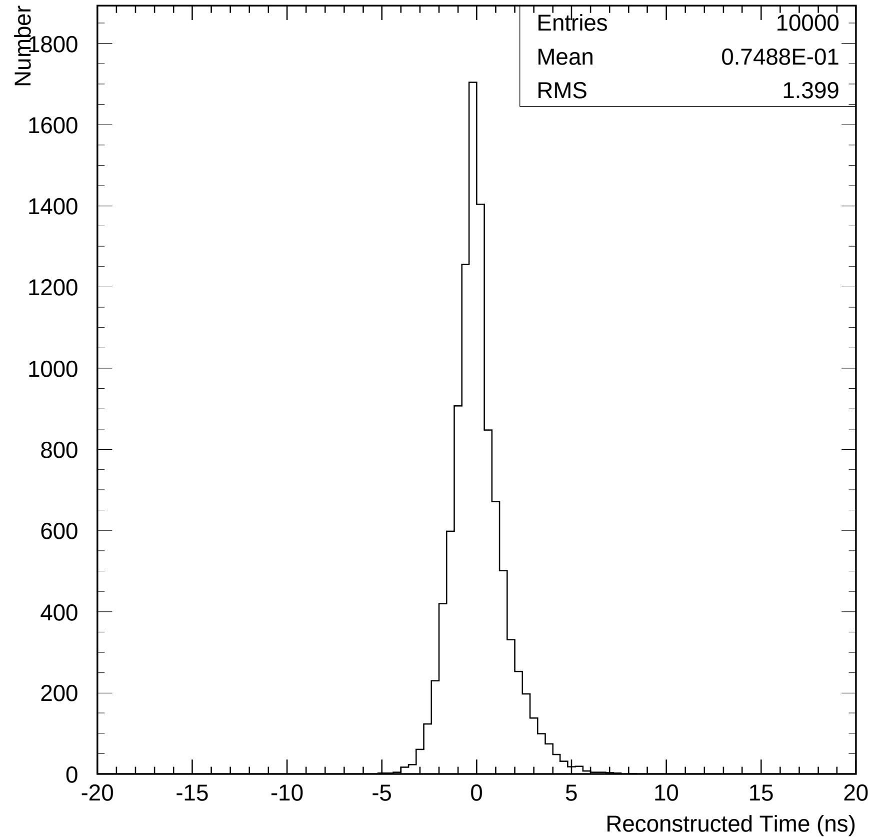
Time versus charge for mips

30 sample average time

Including a 4000 electron noise floor (not needed in new electronics design):

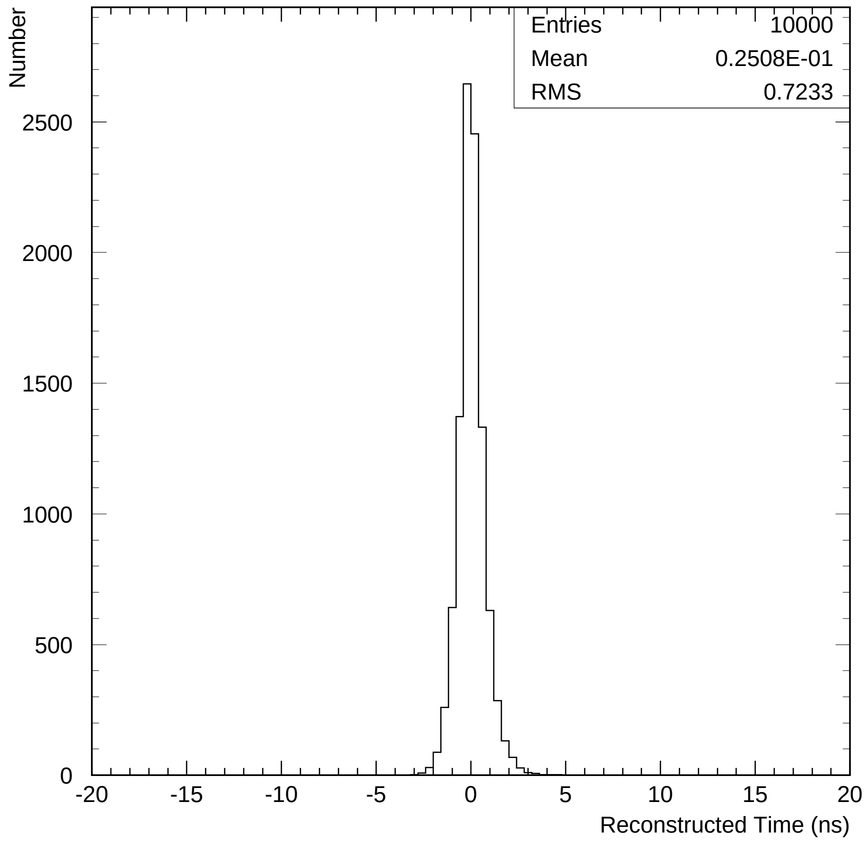


30 sample average 200ns time constant



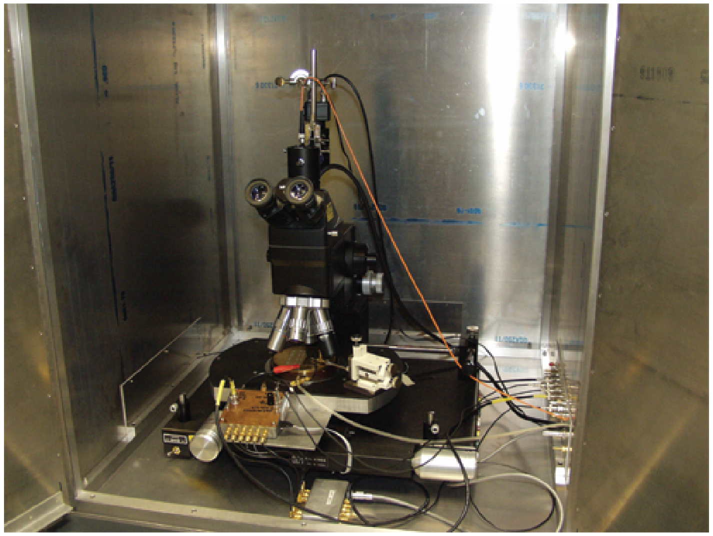
30 sample average time 50ns time constant

With no noise floor (eg use switchable feedback capacitor) and 50ns time constant:

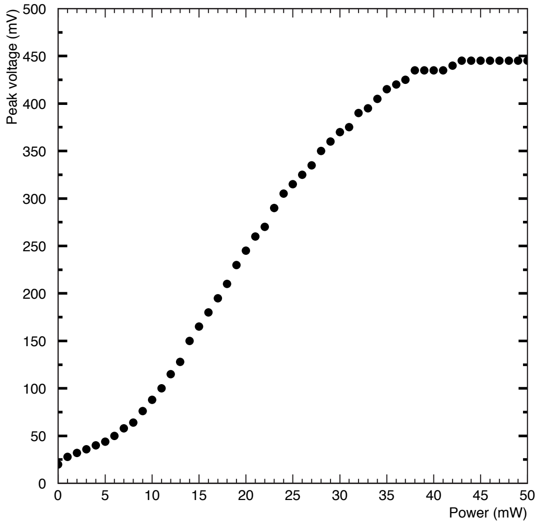


Practice with 6x6 1cm^2 cell detectors:

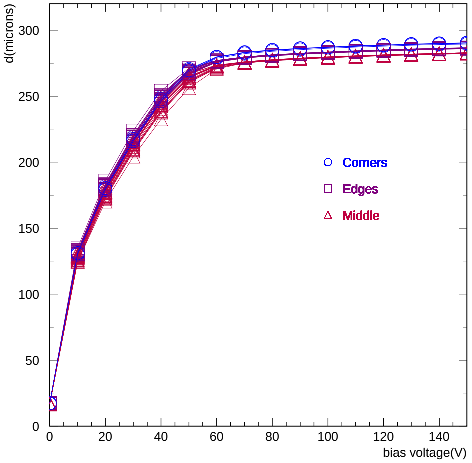
Probe station



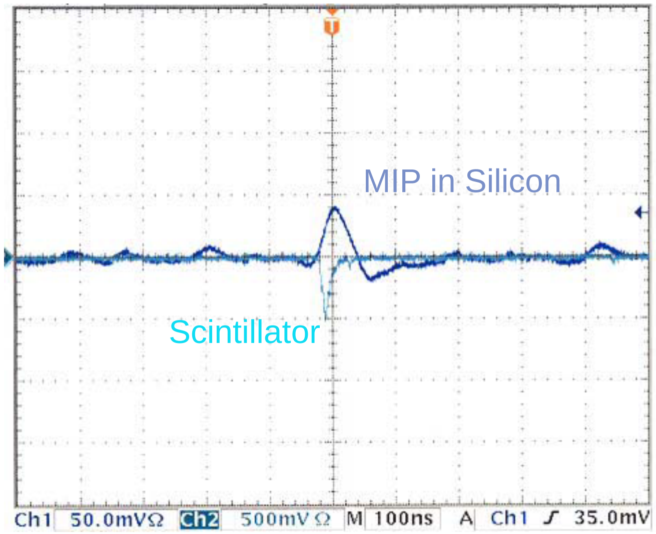
IR laser



Depletion depth from CV curve



MIP with scintillator



Si-W status

- Design of first silicon detectors complete
  $\Rightarrow$ Prototypes will arrive in early '04

- Electronics design well advanced
  $\Rightarrow$ Expect to be ready for submission in early '04

- Mechanical conceptual design started
  $\Rightarrow$ $\sim$ 1mm gap between layers without a copper heat sink may be possible
  $\Rightarrow$ Gap size depends crucially on power consumption

Si-W Near Term Plans

- Produce prototype electronics – early next year
- Test bump bounding electronics to detectors in '04
- Ready for Test Beam in '05
- Confirm thermal model and explore best coupling method of chips to absorber
- Simulation job list:
  - Optimize sampling for energy resolution
  - Compare GEANT 4 /EGS and data on Eres versus silicon thickness
  - Optimize pixel layout
  - Would more granularity help?
  - How sensitive is energy flow to Molière radius?