Fine grained SiW ECAL for a linear collider detector

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- ECAL Design Requirements
- The "SD" Detector
- Silicon and Electronics
- Warm versus Cold
- Timing resolution
- Plans

Si-W work – personnel and responsibilities

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

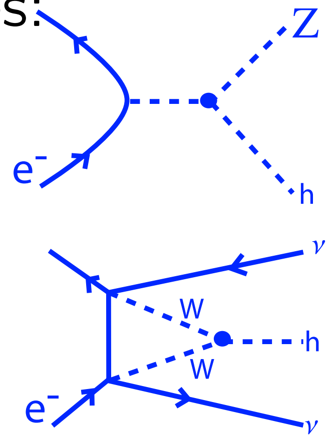
Primary ECAL Design Requirements

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

Physics case: jet reconstruction important for many physics processes.

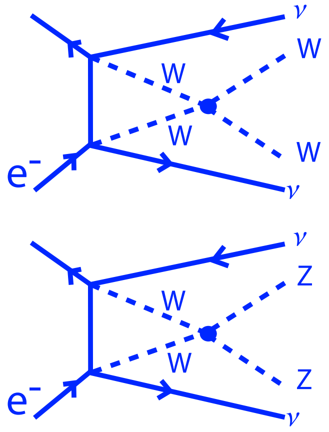
⇒ A principal goal of a linear collider is the determination of Higgs branching ratios using the processes:

$$\begin{aligned} e^+e^- &\rightarrow Zh \\ e^+e^- &\rightarrow h\nu\bar{\nu} \end{aligned}$$



⇒ Excellent jet energy resolution is needed for the later process. Precision tests may also be of interest, e.g., measurement of quartic gauge couplings:

$$\begin{aligned} e^+e^- &\rightarrow ZZ\nu\bar{\nu} \\ e^+e^- &\rightarrow WW\nu\bar{\nu} \end{aligned}$$



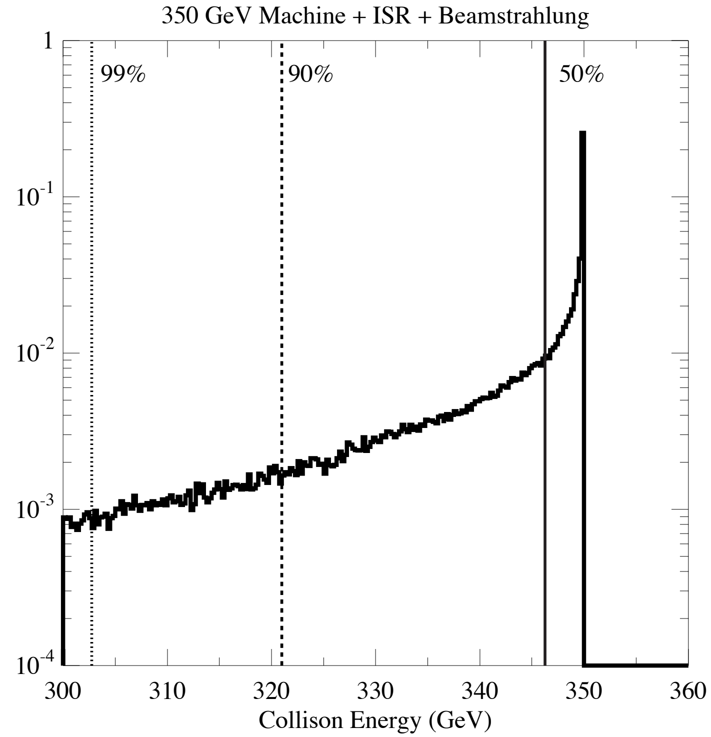
Use all final states.

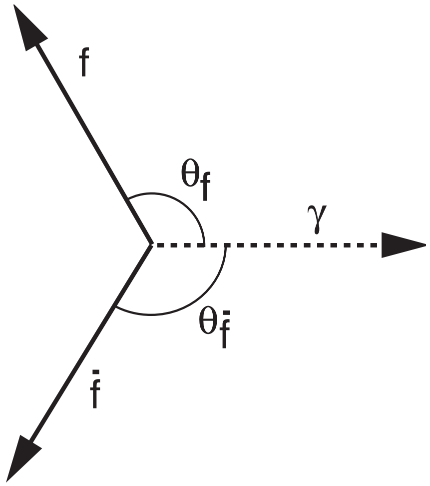
- Reconstruct Bhabhas and deconvolve luminosity spectrum
  - *Position resolution* $\sim 100\mu m$*, bias* $\sim 25\mu m$ *in endcap*
  - Good energy resolution for 500 GeV electron showers.

Luminosity spectrum is important for

- $t\bar{t}$ threshold (m_t, α_s, $t\bar{t}h$ coupling)
- $e^+e^- \rightarrow f\bar{f}$, important for limits on extra dimensions and "contact interactions"

- Position resolution important for understanding single hard photons from beamstrahlung

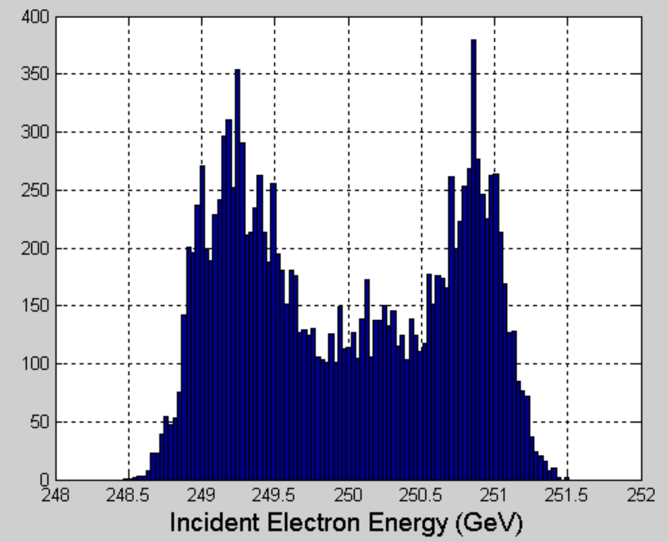


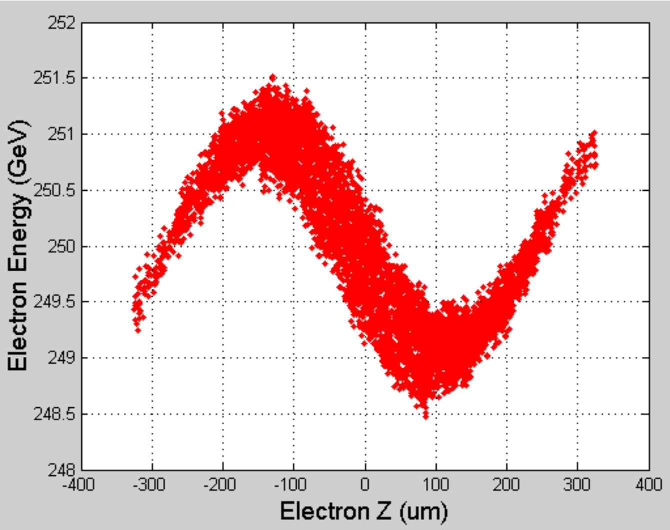


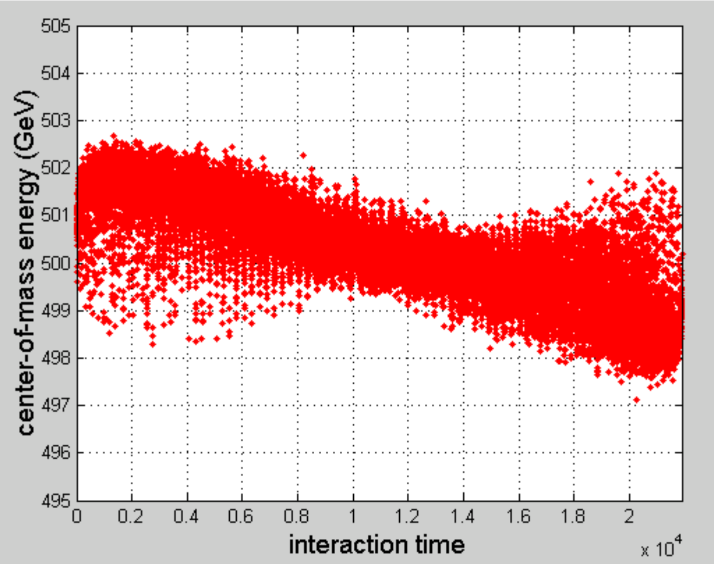
$$\frac{\sqrt{s'}}{\sqrt{s}} = \sqrt{1 - \frac{2\sin(\theta_f + \theta_{\bar{f}})}{\sin(\theta_f + \theta_{\bar{f}}) - \sin\theta_f - \sin\theta_{\bar{f}}}}$$

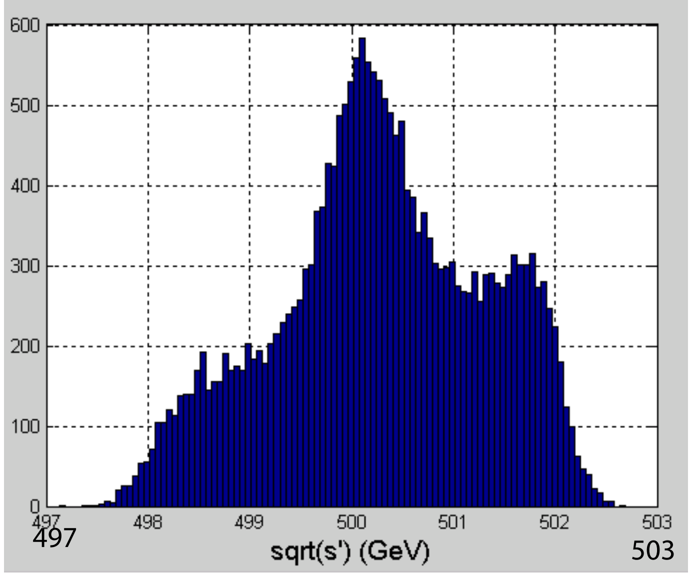
- Well understood energy resolution needed to understand linac beam energy spread

(NLC 500 Results from Torrence and Woods – beamstrahlung off)









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

  τ's are important in many "New Physics" models:

  - In many SUSY models staus are the lightest sfermions
  - Many models have special couplings for the heaviest generation (extra couplings may explain large top mass)
  - Tau polarization may be important in differentiating New Physics scenarios from each other

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 $\sim 1\ cm$
- Good background immunity
  - Bunchlet identification
  - High granularity

SD (”Silicon detector”)

Design constraints impacting calorimetry
(See talk by M. Breidenbach at Cornell*)

- Excellent jet-energy reconstruction using combined tracking and calorimetry (i.e. “energy flow”)
- Excellent momentum resolution for lepton pairs in processes such as (e.g. $e^+e^- \to hZ \to \mu^+\mu^- X$)
- Excellent reconstruction of detached vertices from B’s (e.g. 5 layer CCD vertex detector)
- Cost compatible with $\sim$ 5%/detector of machine cost, perhaps $350M/detector

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*`http://blueox.uoregon.edu/~lc/cornell-detectors.html`

- Main trade off is magnetic field versus detector radius with figure of merit

$$f_p = BR^2$$

- SD option: 5 T magnetic field, 1.25m calorimeter radius
  Optimization limited by maximum field
  Helps confine background e^+e^- pairs to beam pipe

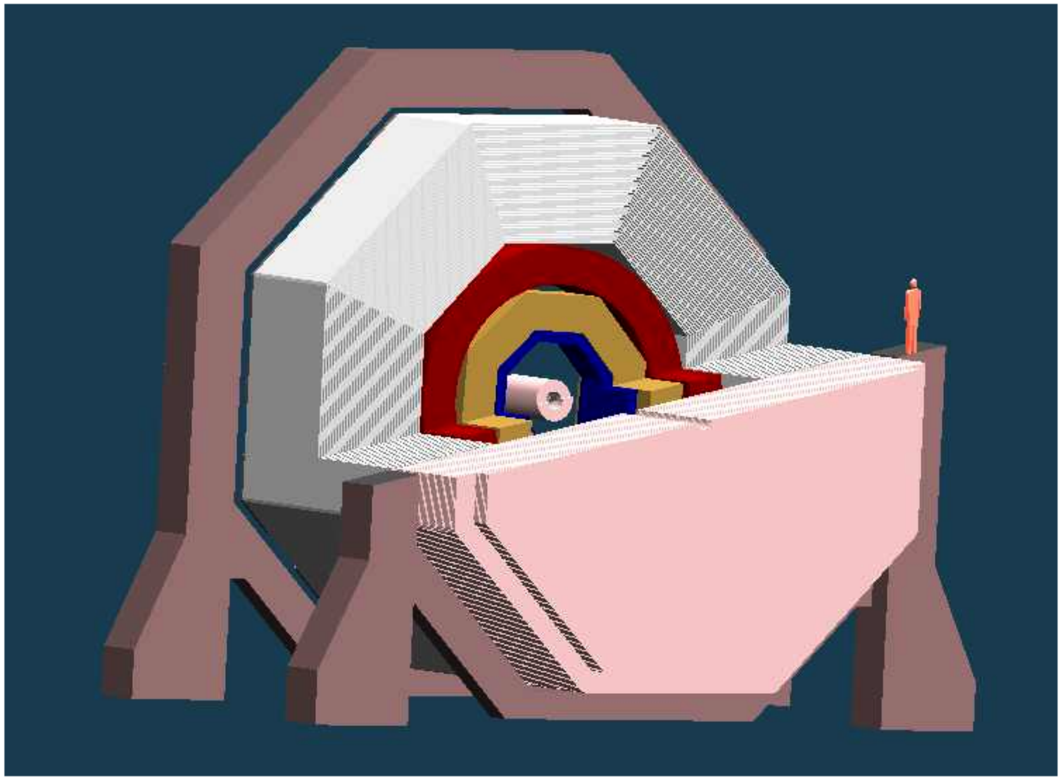
- Stored Energy is less than TESLA ($\sim$ 1.5GJ versus $\sim$ 2.4GJ)

- Reduces Si area and cost

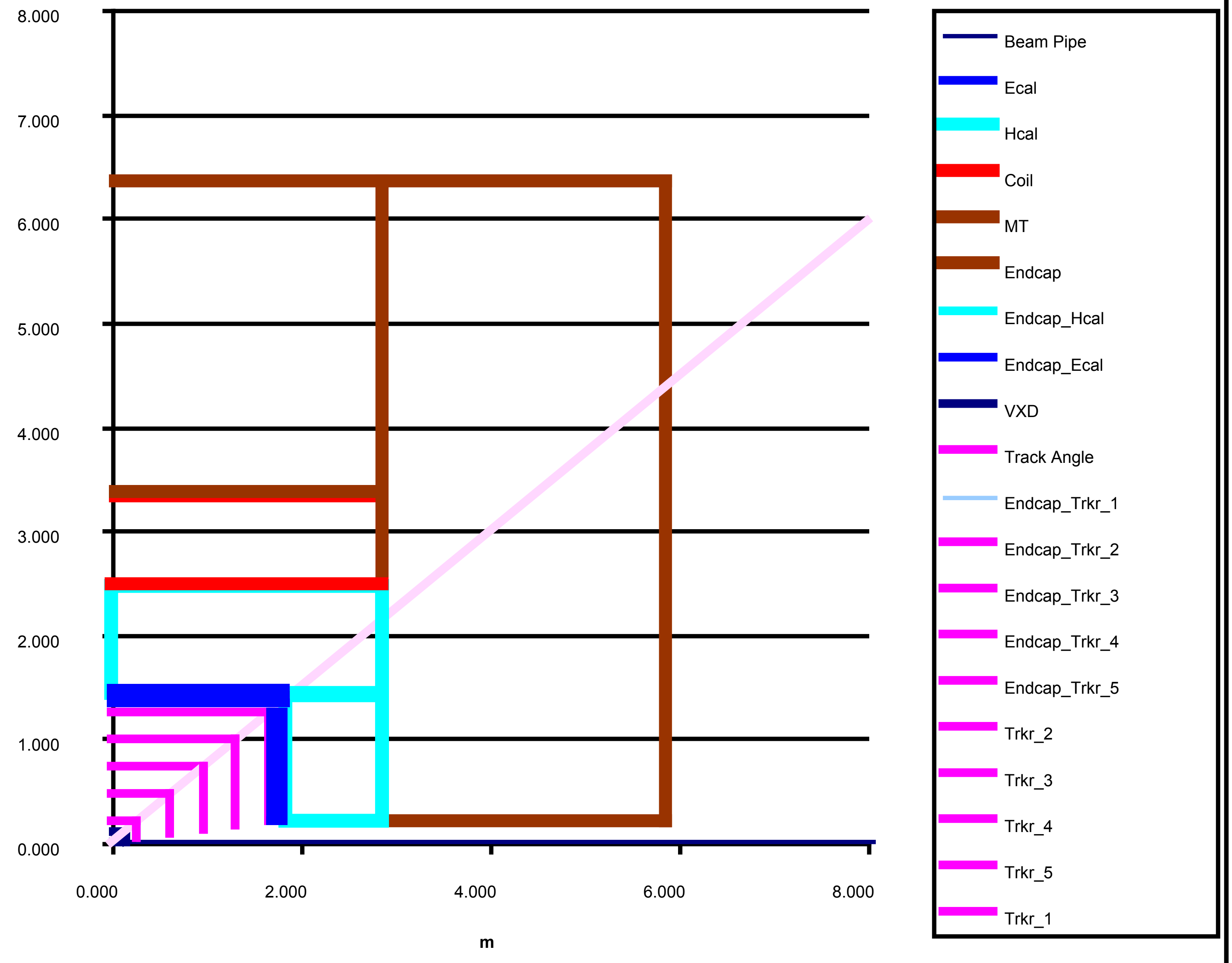
- Places premium on ECAL granularity
  (strive for a very dense detector)

Cut-away view

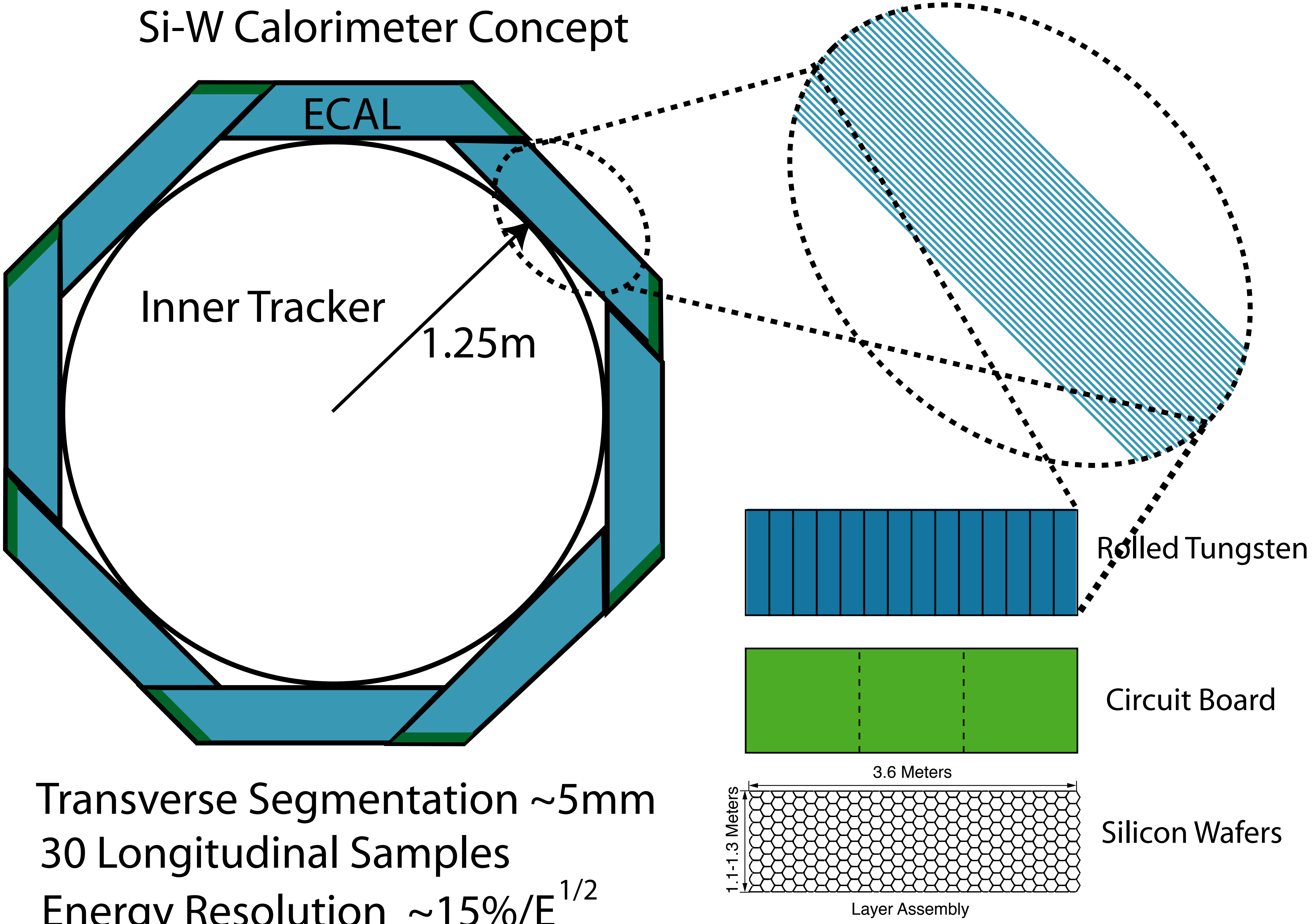
- 5 layer CCD vertex Detector
- Silicon tracker
- SiW ECAL (**blue**)
- HCAL inside of coil (**brown**)
- Coil (**red**)



Quadrant View



Si-W Calorimeter Concept



Transverse Segmentation ~5mm

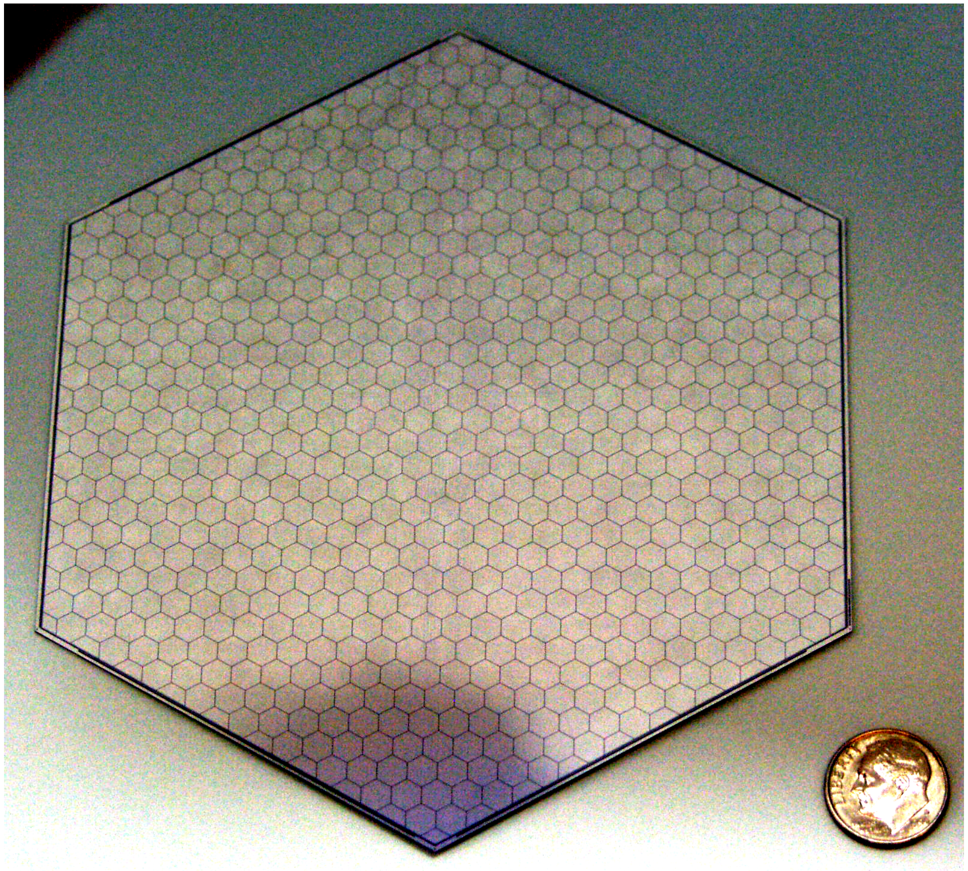
30 Longitudinal Samples

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

Electronics and Silicon Design

(Discussed in detail in Silicon Calorimetry Session)

- Use hexagonal 5mm pixels on 6 in wafers
- Use DC coupling to simplify wafer processing
- Readout chip bump bonded to wafer
- Electronics have a large dynamic range (0.1 - 2000 MIPs) with at least 0.5% resolution
- Cost first order insensitive to pixel size
- Power is main constraint on density



Importance of Granularity

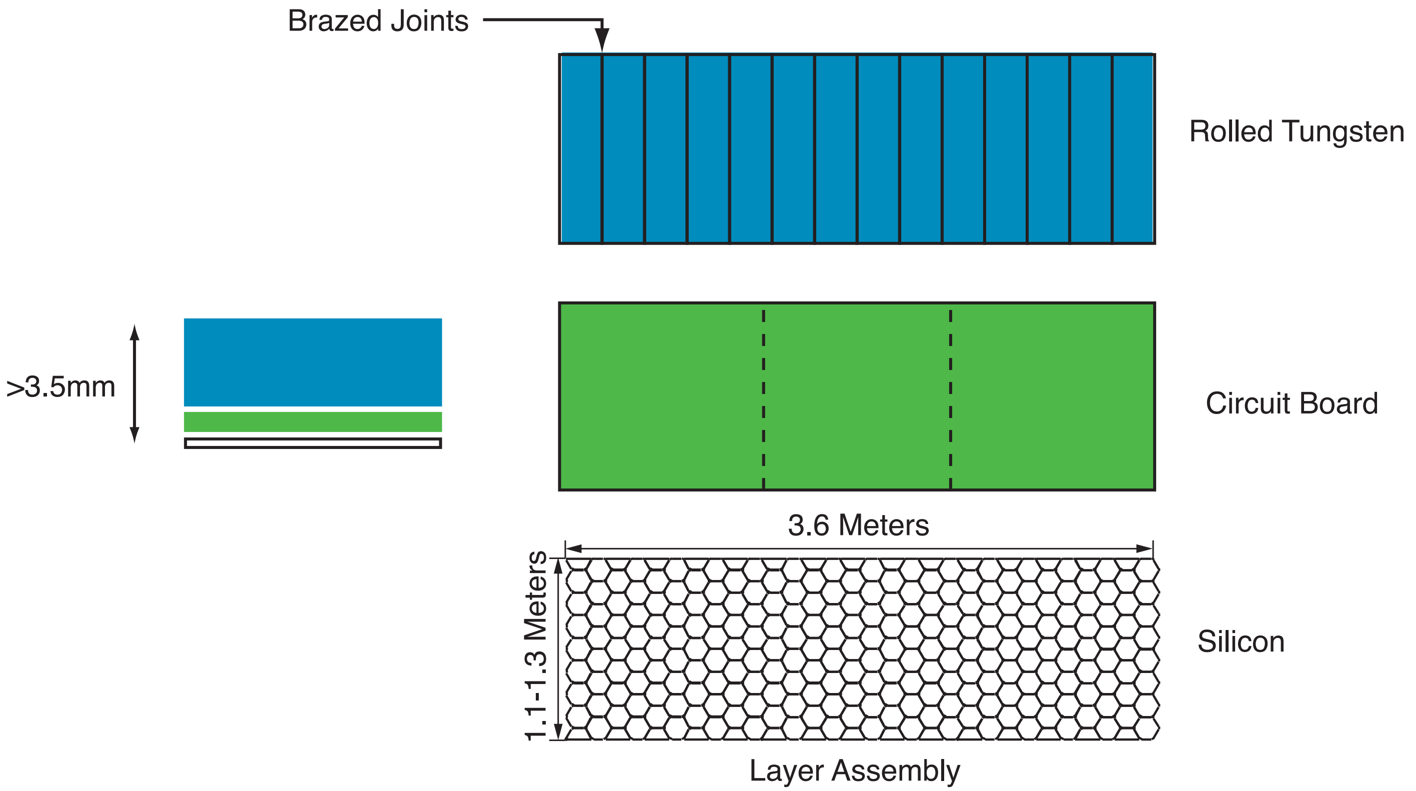
- Figure of merit for energy reconstruction is
$$f_E = \frac{R_M}{R_{cal}}$$
where R_M is the Molière radius and R_{cal} is the inner radius of the calorimeter

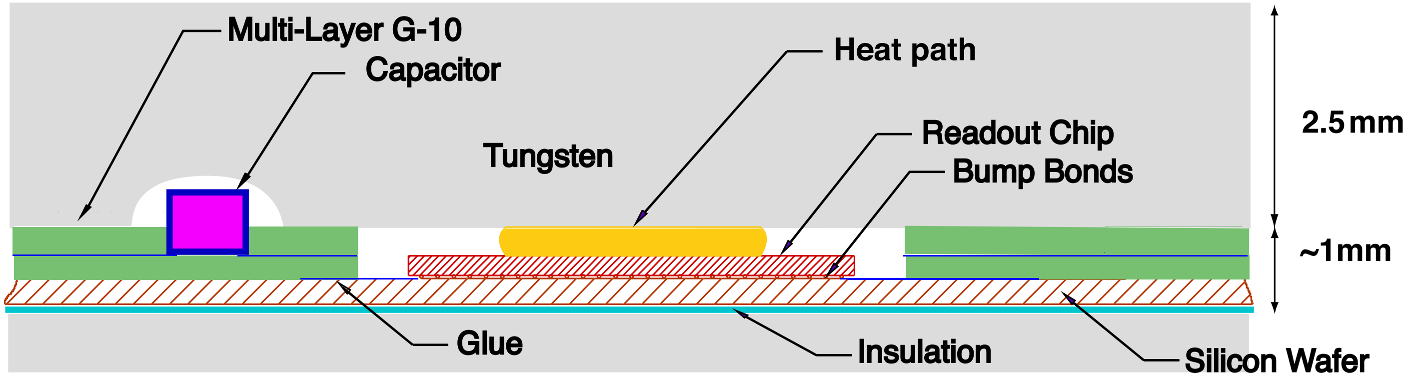
- The costs of the calorimeters, coil, and muon system have
$$\text{cost} \propto R_{cal}^n$$
where n is $\sim 2-3$.

- 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

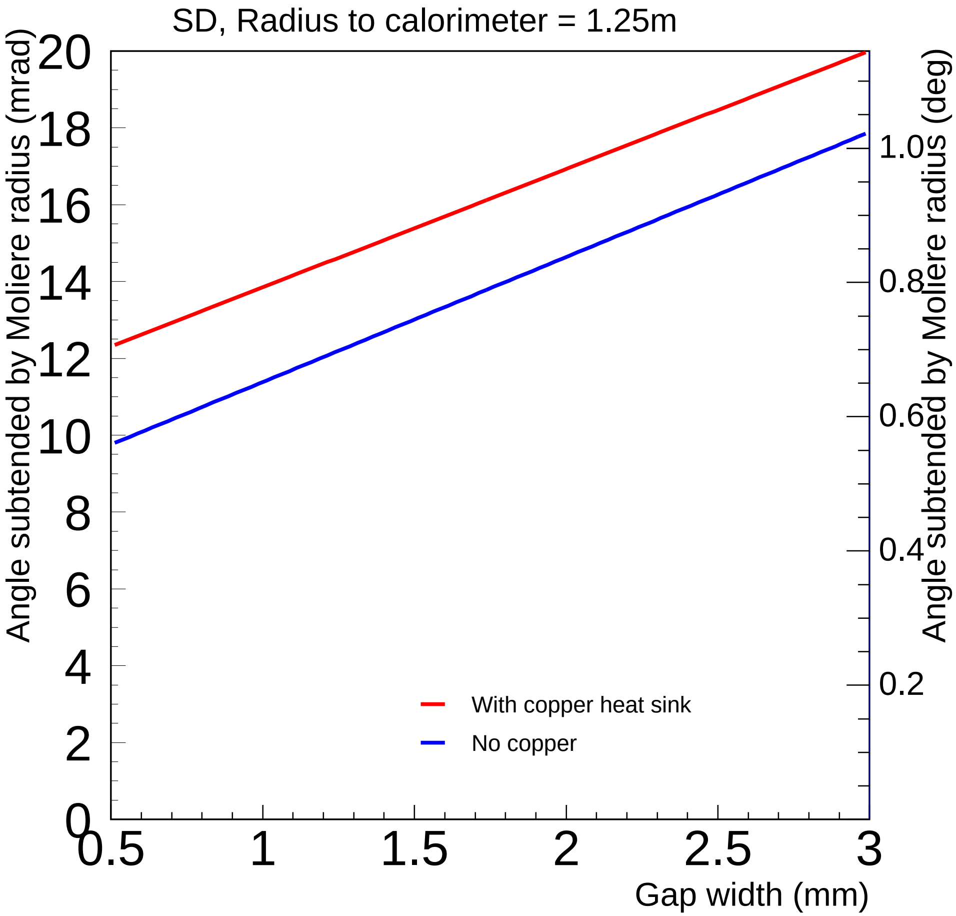
Layout goal(?):


Brazed Joints
Rolled Tungsten
>3.5mm
Circuit Board
3.6 Meters
1.1-1.3 Meters
Silicon
Layer Assembly


Multi-Layer G-10
Capacitor
Tungsten
Heat path
Readout Chip
Bump Bonds
2.5mm
~1mm
Glue
Insulation
Silicon Wafer

Critical parameter: gap between tungsten layers.

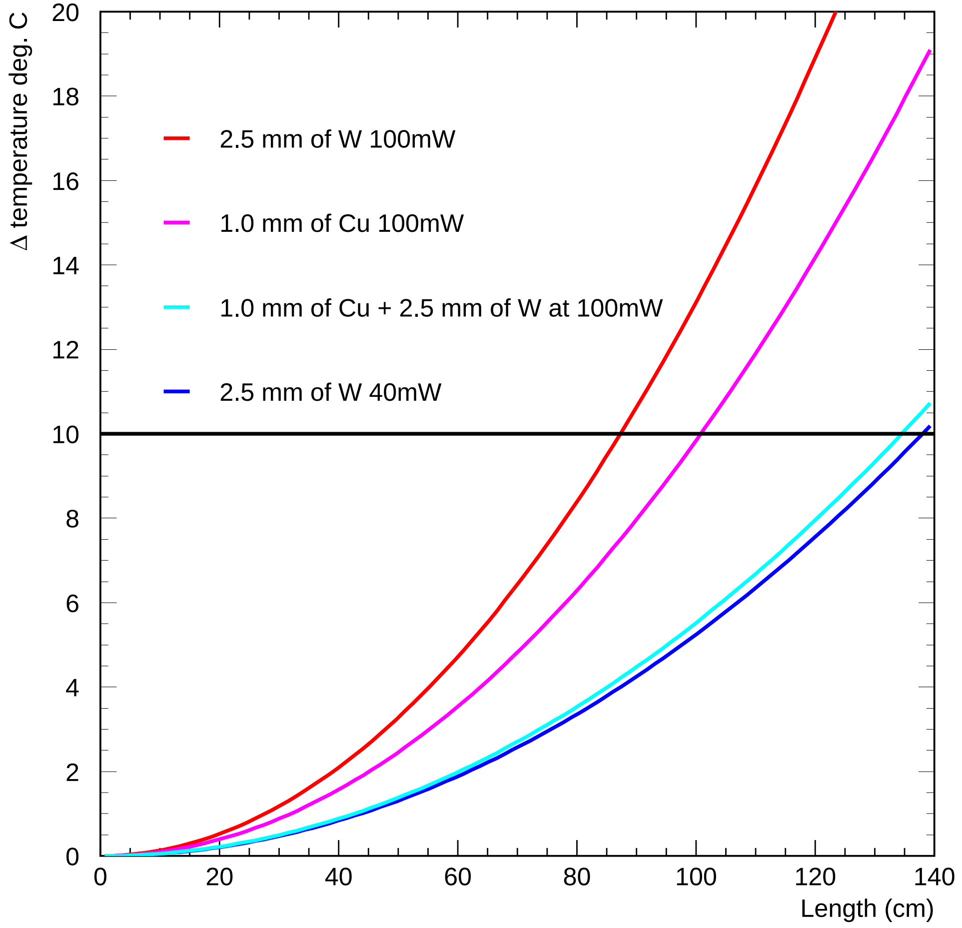
Config.	Radiation length	Molière Radius
100% W	3.5mm	9mm
92.5% W	3.9mm	10mm
+1mm gap	5.5mm	14mm
+1mmCu	6.4mm	17mm



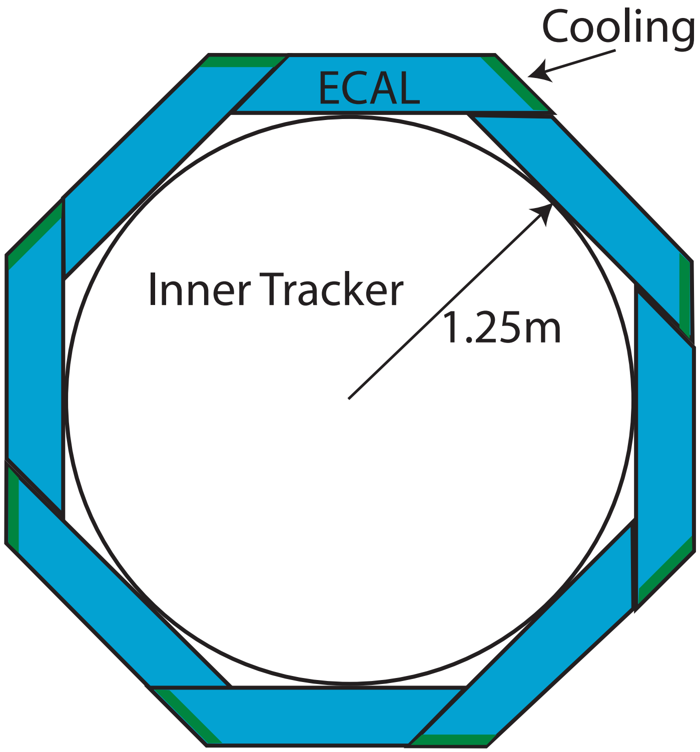
Calice 3mm gap with 1.7m TESLA radius gives $\frac{R_M}{R_{Cal}} = 13\text{mrad}$

Important system level design issue for the calorimeter will be dealing with the heat produced by the electronics.

⇒ **Largest unknown is power consumption of the electronics**



Pessimistically assume cooling from one end only



Warm – Cold Machine Differences

- ECAL design was developed in the context of a warm (X-band) linear accelerator. Will it still work for a cold (superconducting) machine?

- Main difference is the bunch structure:

Technology	Repetition rate	Bunch train length	Bunch separation
Warm	120 Hz	192 (0.270 μs)	1.4 ns
Cold	5 Hz	2820 (950 μs)	337 ns

Power Pulsing

- Assuming a 10μs turn on time for power pulsing, duty cycle of pulsed power:

warm	1/833
cold	1/206

- Non-pulsed is $\sim$ 1% of “ON” power and dominates!

- Slower electronics possible for warm machine, so less power needed in ”ON” state than for cold machine

Overall slight advantage for warm machine
Not a basis for choosing one or the other machines

Technology choice impact on electronics

- Current electronics provides timing at the few ns level for the warm machine (see next slide)

- Bunch ID for the cold machine is easy, but pipelined electronics needed (can't integrate over 2820 bunches)

- We expect that our electronics could be adapted for the cold machine, but effort is currently concentrated on warm machine

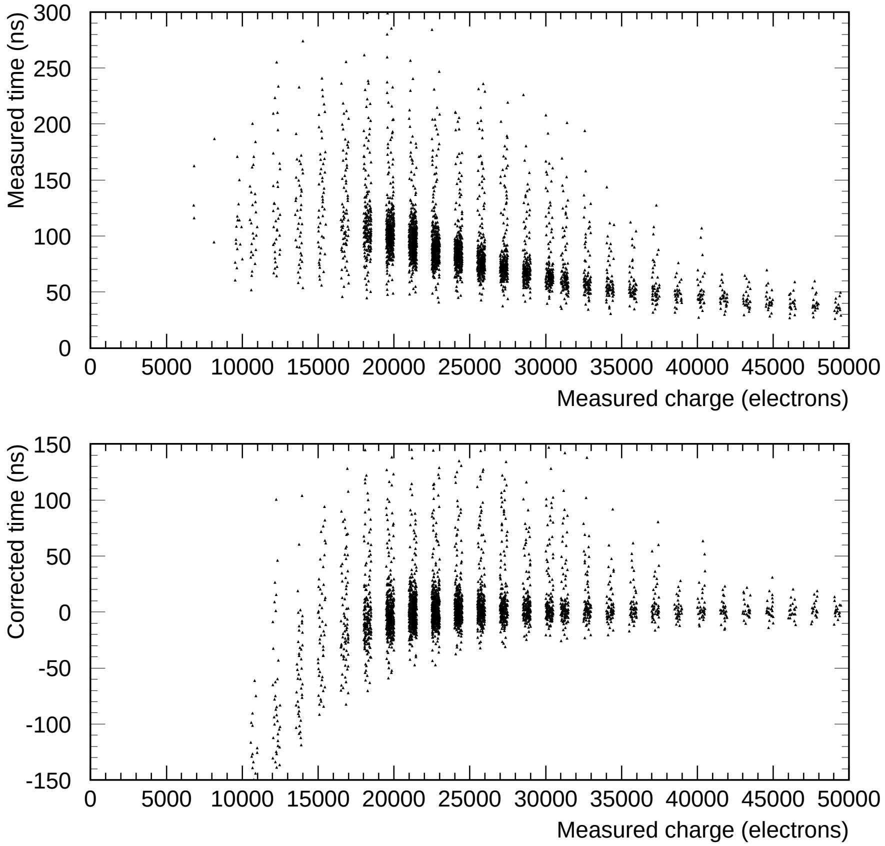
Toy Monte Carlo Studies of Timing Resolution for 30 Samples

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

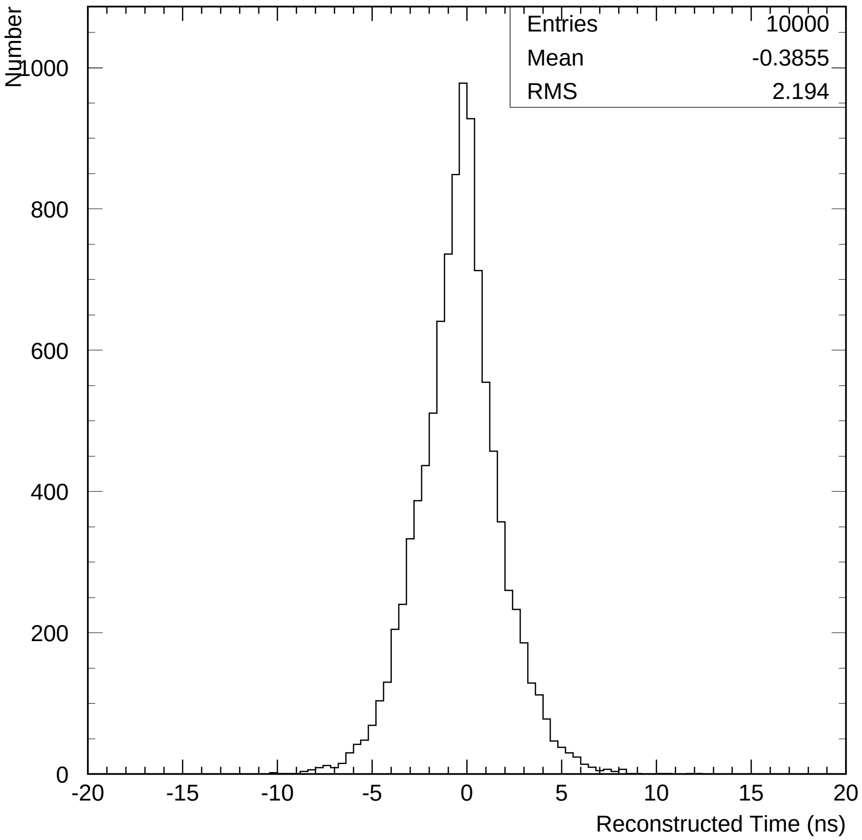
- Each MIP has 30 samples at random distances from the read-out chip
- Threshold for timing measurement is 8,000 electrons.
- Input FET has $g_m = 1.5\text{mS}$ and the noise contribution from the rest of the amplifier is equal to input FET except for the "floor" noise.
- The charge measurement has a 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 signals 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

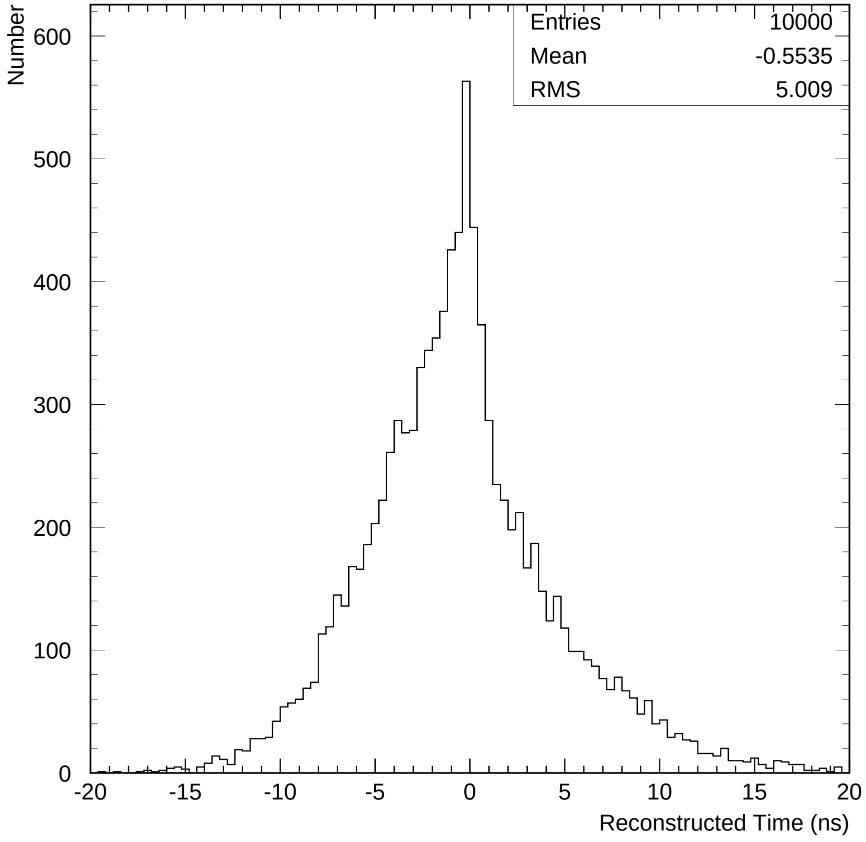


Time versus charge for mips

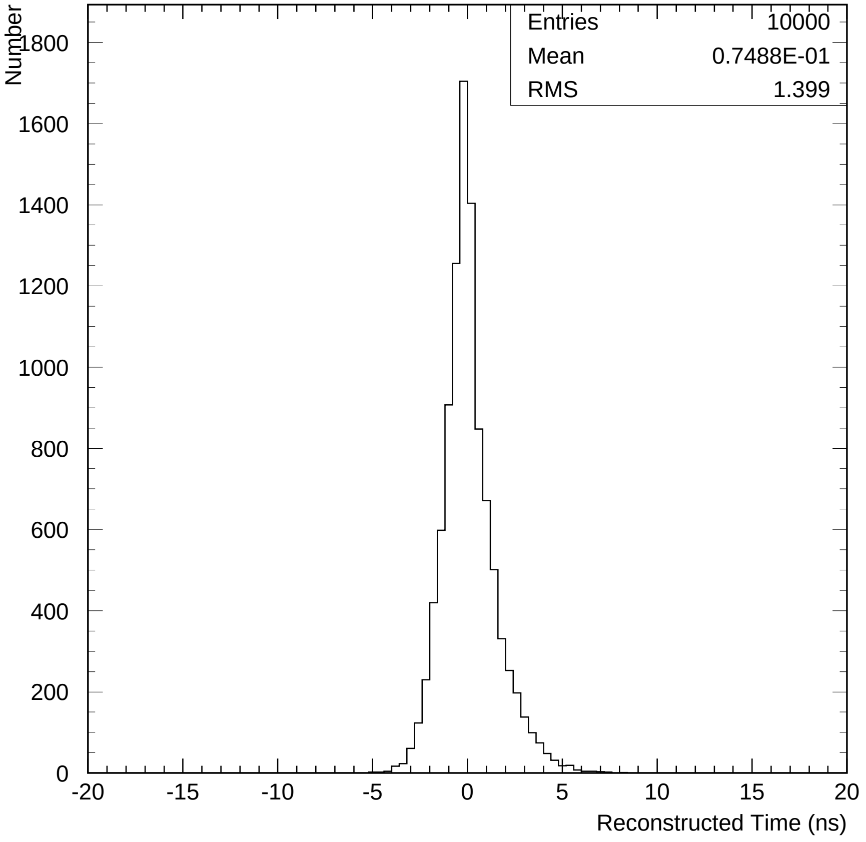


30 sample average time

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

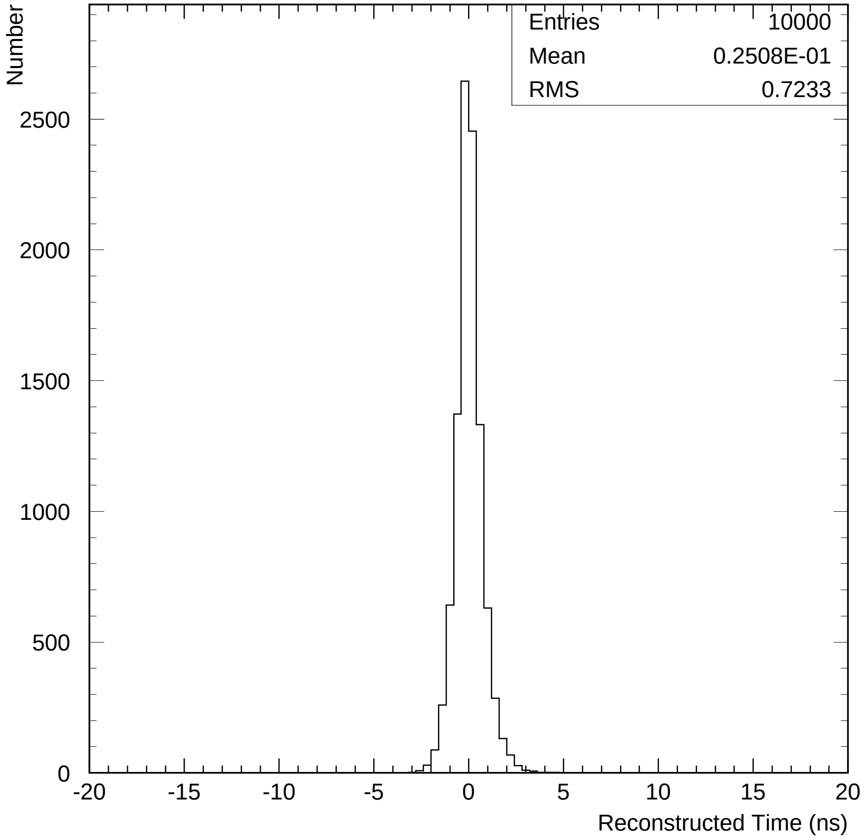


30 sample average 200ns time constant



30 sample average time 50ns time constant

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



Needs to be demonstrated in a test beam!

Si-W Status and Plans

- Design of first silicon detectors complete
  $\Rightarrow$ Prototypes in hand

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

- Mechanical conceptual design started
  $\Rightarrow \sim$ 1mm gap between layers without a copper heat sink may be possible

- Hope to build 30 layer test module within next two years