# Silicon Tracker Design for the ILC

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# Tracking at the Energy Frontier

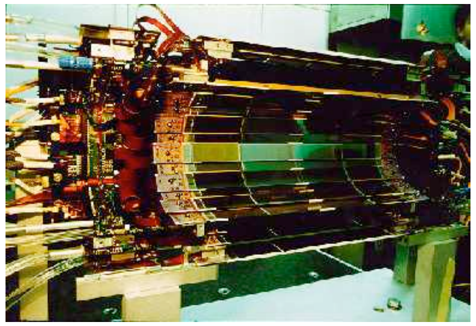
**With increasing $E_{CM}$ & $\mathcal{L}$, a few stubborn problems drive tracker design:**

- Precise $P_T$ measurement requires huge detectors / high fields / precise spacepoint measurements
- High occupancies and dense jets require fine readout granularity for pattern recognition
- High rates often require very fast readout
- Need for high radiation tolerance

**Silicon has become the standard answer, squeezing out gaseous tracking from the inside out.**

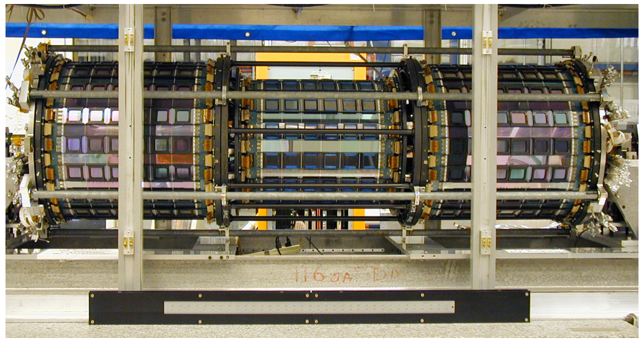
DELPHI

3 layers, $r_{max}$ = 11cm



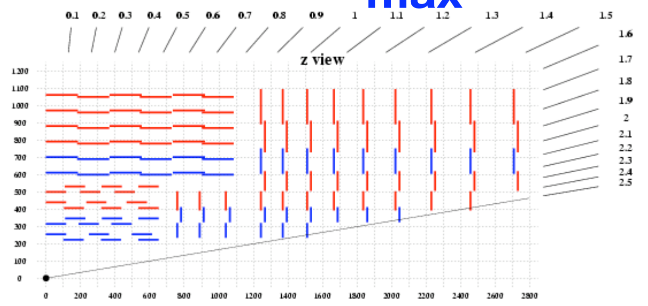
CDF

8 layers, $r_{max}$ = 28cm



CMS

12 layers, $r_{max}$ > 1m



# The Price of Silicon

**Evolution towards all-silicon tracking has come at the cost of more material...**

***Is this unavoidable?***

- **Where low-$P_T$ performance is critical, low-mass silicon strip detectors have been built: <1% $X_0$/layer (e.g. B-factories)**
  - ***However*, such detectors are highly-optimized, hand-assembled vertexing detectors: gas still used at large radius for tracking**
- **Large silicon trackers (CMS, ATLAS) must be simple, highly-modular, and mass-producible...**

**Conventional Wisdom: such trackers too massive for ILC**

# Possible Solutions

## TPC

- Requires a much larger tracking volume: everything else grows too
- Requires development of new gaseous tracking technologies

*or*

## *A new kind of silicon tracker*

- Design a mass-producible, LHC-sized silicon tracker without the LHC-sized material budget
- Appears to require surprisingly little new technology

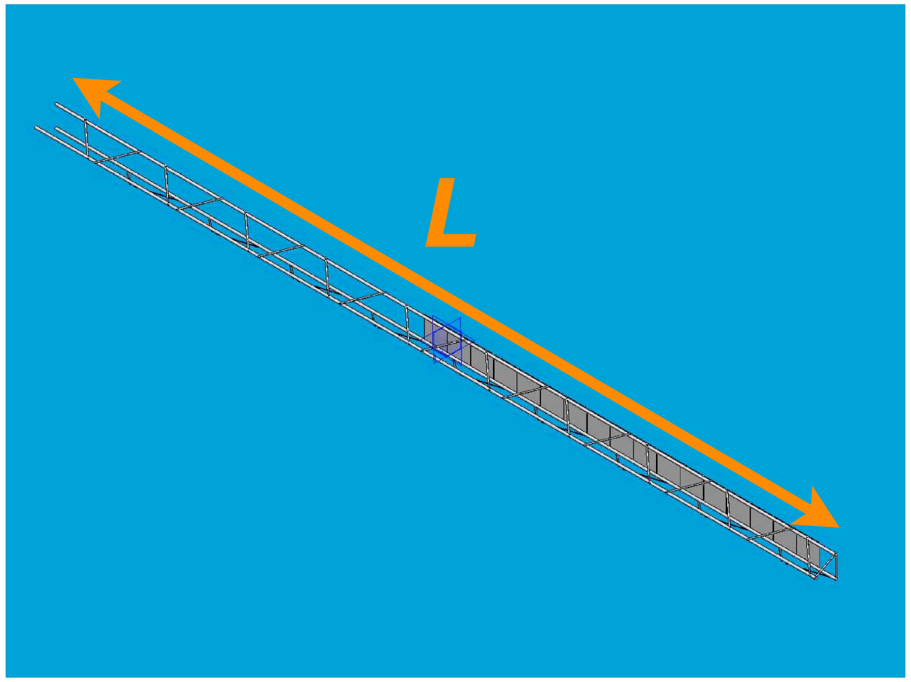
# ILC Environment is Unique

**"This ain't LEP!"** *- John Jaros* **...** ***This ain't the LHC, either!***

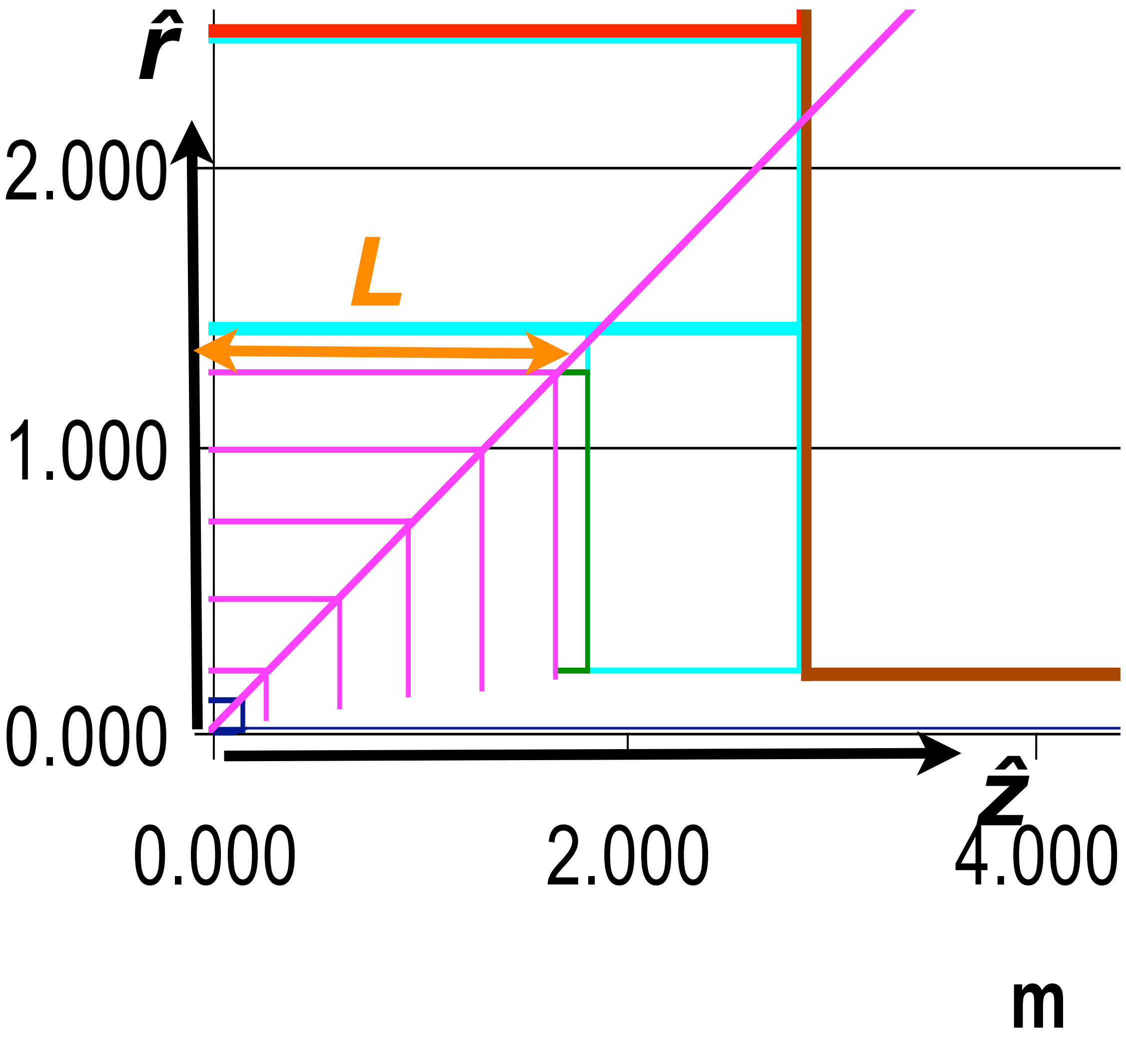
- **Relatively low radiation dose**
  - ⇒ **active silicon cooling unnecessary**
- **Low occupancies and long, quiet period for readout**
  - **readout chips need not be continuously powered**
    - ⇒ **active cooling of front end electronics not necessary**
    - ⇒ **mass of conductor needed to supply power is greatly reduced**
  - **noisy readout electronics (digital) not needed during bunch train**
    - ⇒ **material serving to isolate digital signals from silicon can be eliminated**
- ***5-layers of*** **pixels mitigates need for stand-alone pattern recognition**
  - ⇒ **fewer layers will suffice**
  - ⇒ **configuration can focus on momentum measurement: single-sided?**

# SiD Starting Point

- 5 layers: central barrels and forward disks
- single-sided: measure r-phi only
- very long daisy-chained ladders to minimize readout material

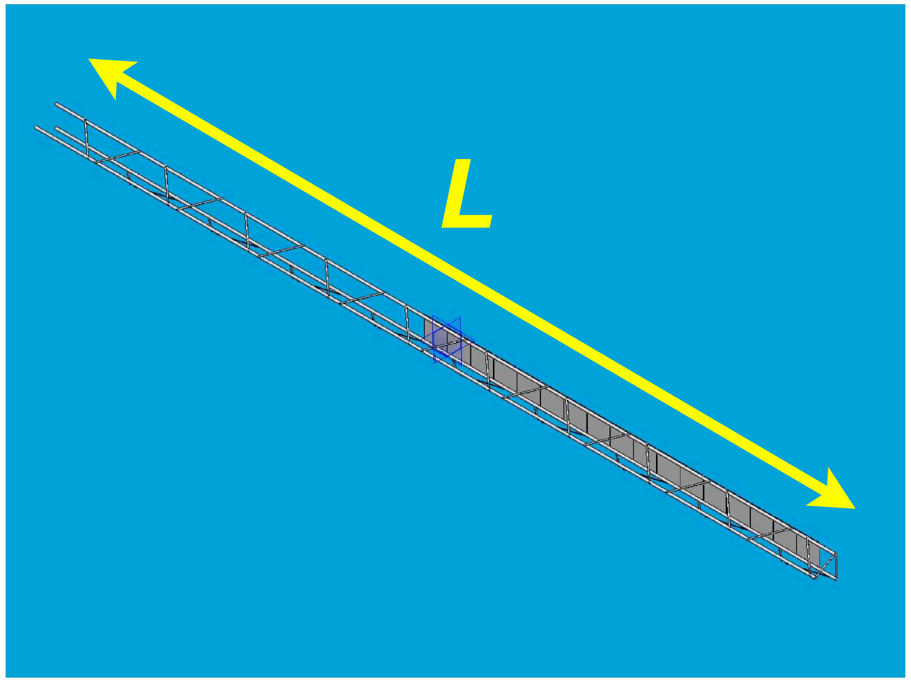


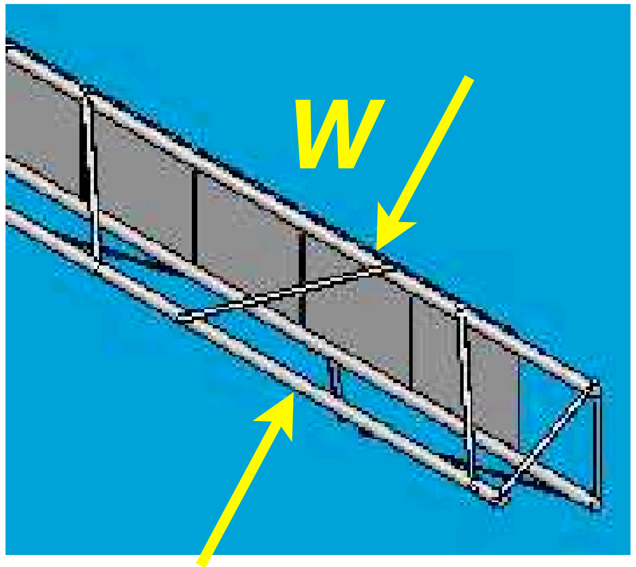

1/4 view of SiD starting point



# Problems with Long Ladders

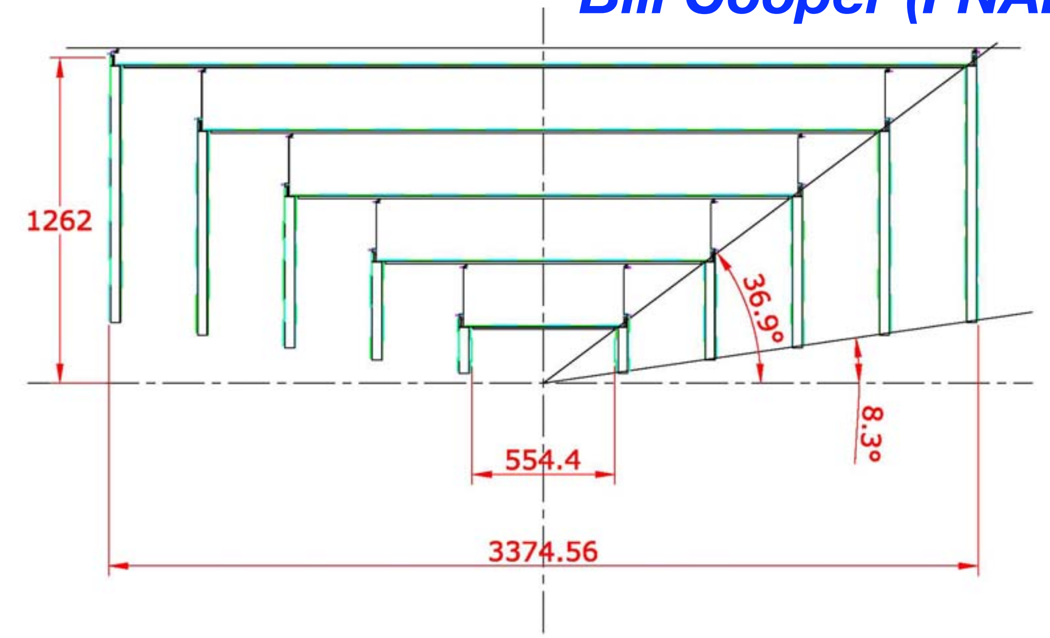
- **Very large capacitance**
  - marginal S/N threatens resolution & efficiency
- **Assembly and handling are very difficult**
  - wirebonding may be almost impossible
  - many steps, each carries risk of total loss...
  - loss of many components and much effort
  - Installation difficult, in-situ replacement likely impossible
- **Structural rigidity/robustness problematic**
  - as ladder grows in length, width must increase $\propto L^3$ for rigidity
  - making this robust (strong) adds to material



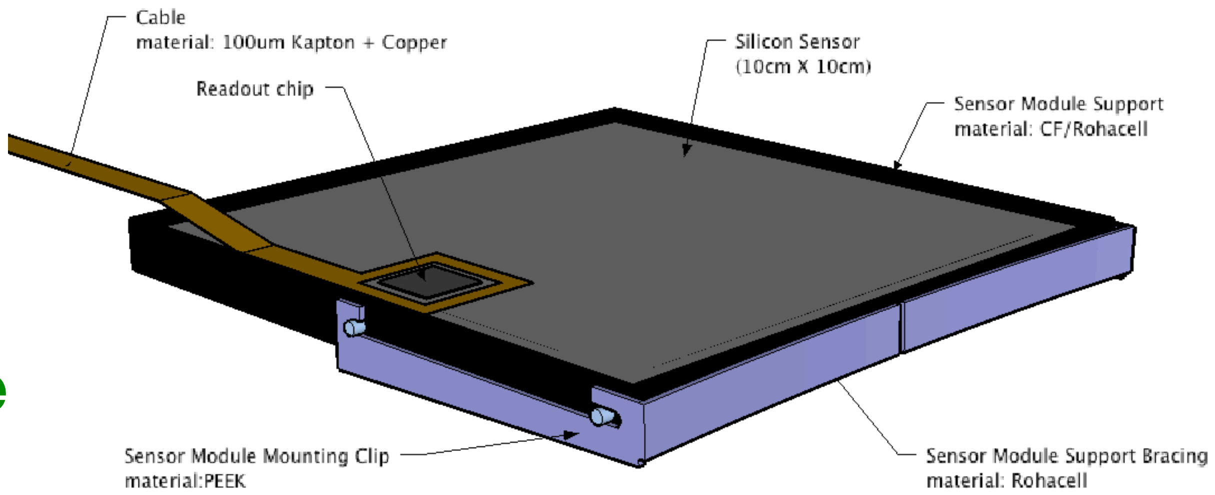



# Alternative: Small Modules

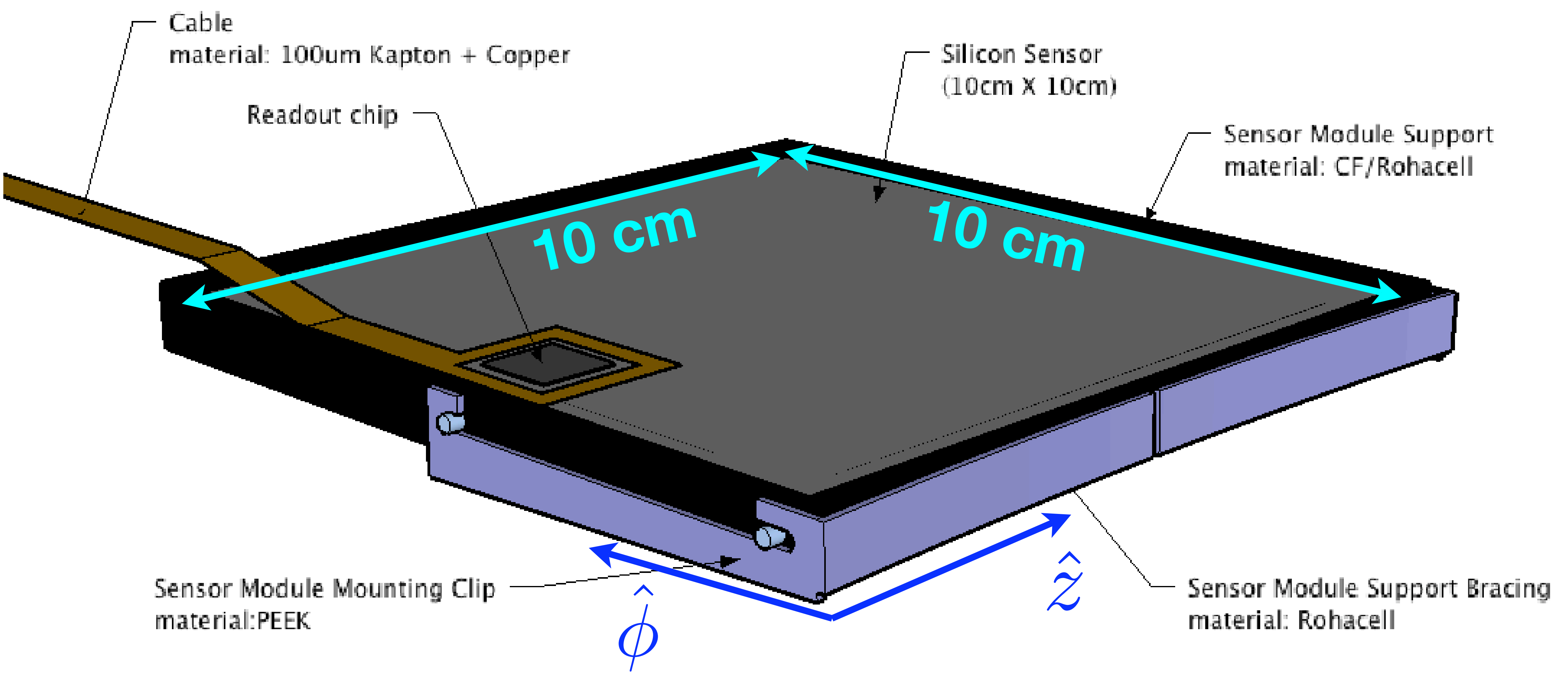
Bill Cooper (FNAL)




- *Shift responsibility for rigid/robust support onto underlying structure:* **Nested, closed carbon-fiber / Rohacell cylinders (a la D0 CFT, Atlas SCT)**
- *Tile cylinders with small, simple modules, each with own readout*
  - **Very high S/N (~20)**
  - **Simple, low-risk assembly**
  - **"One hand" installation/handling: even in-situ replacement possible**

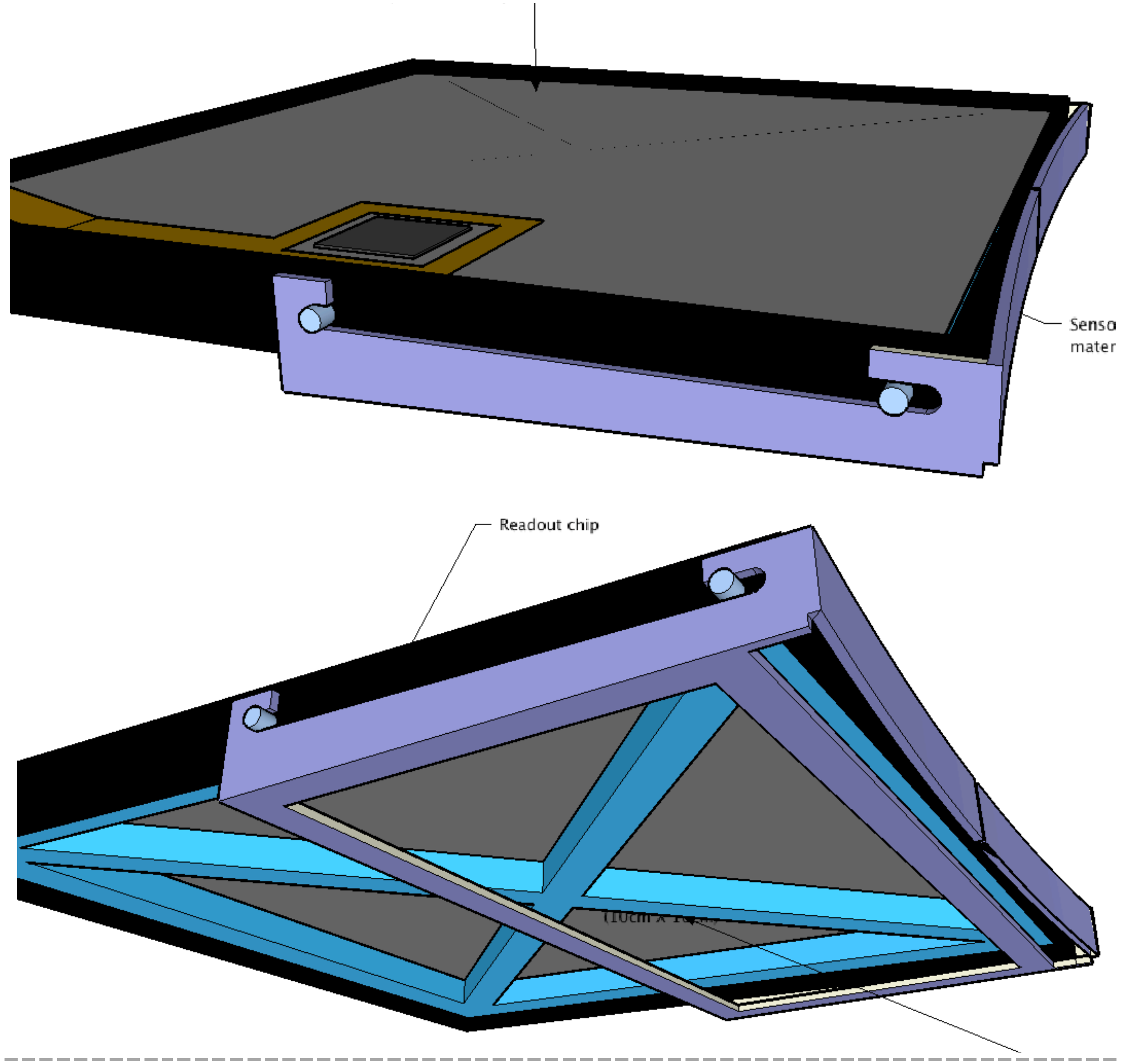


# Short Module Design



# Short Module Design

- Single-sided sensor: module can be double-sided
- Carbon-fiber/rohacell frame clips into PEEK mount
- Chip bonds directly to sensor: double-metal readout
- Thin Kapton data/power cable bonds directly to silicon
- No cooling
- No hybrid or pitch adapter

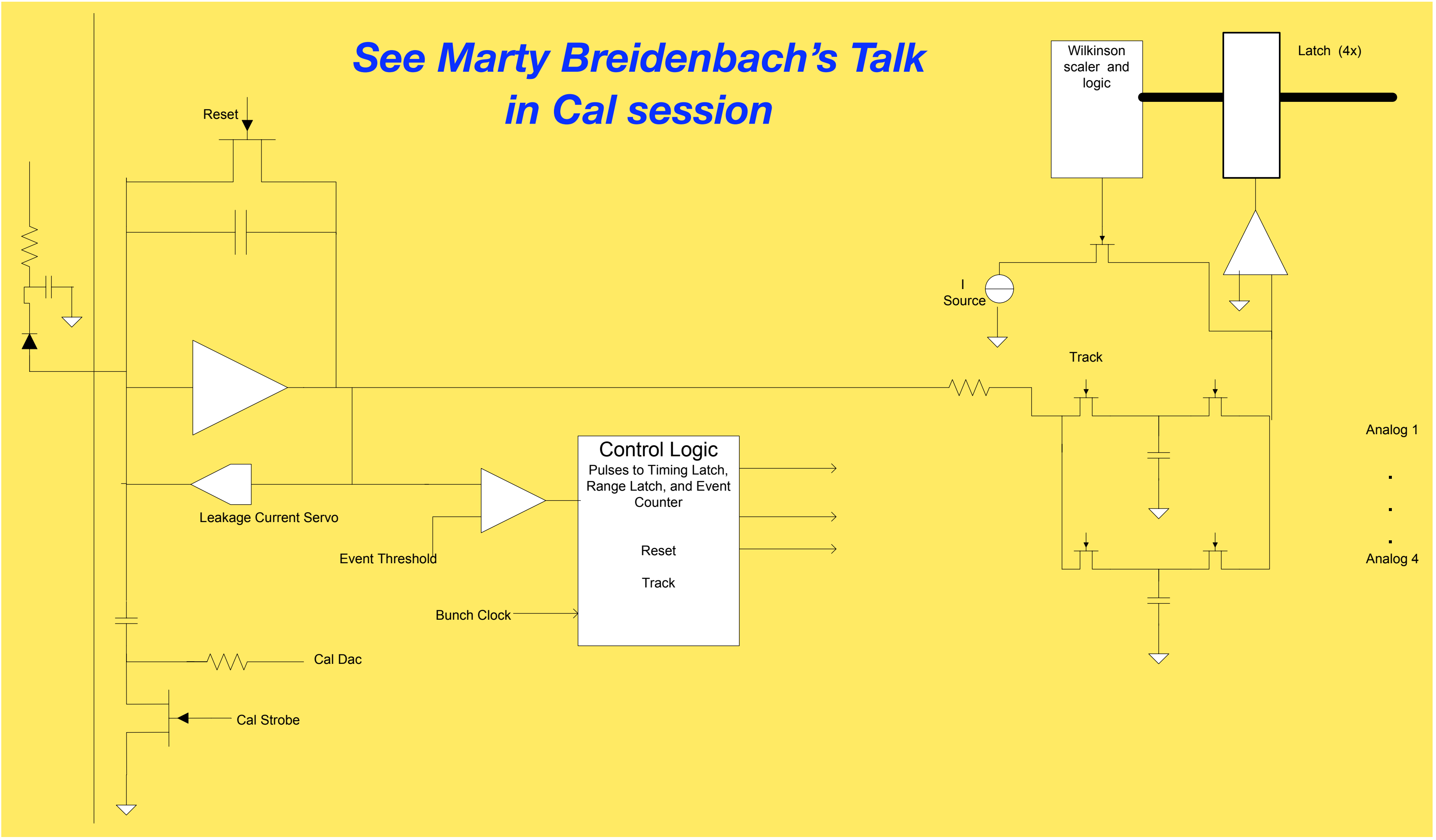


# Readout Chip

## Design of the readout chip is key!

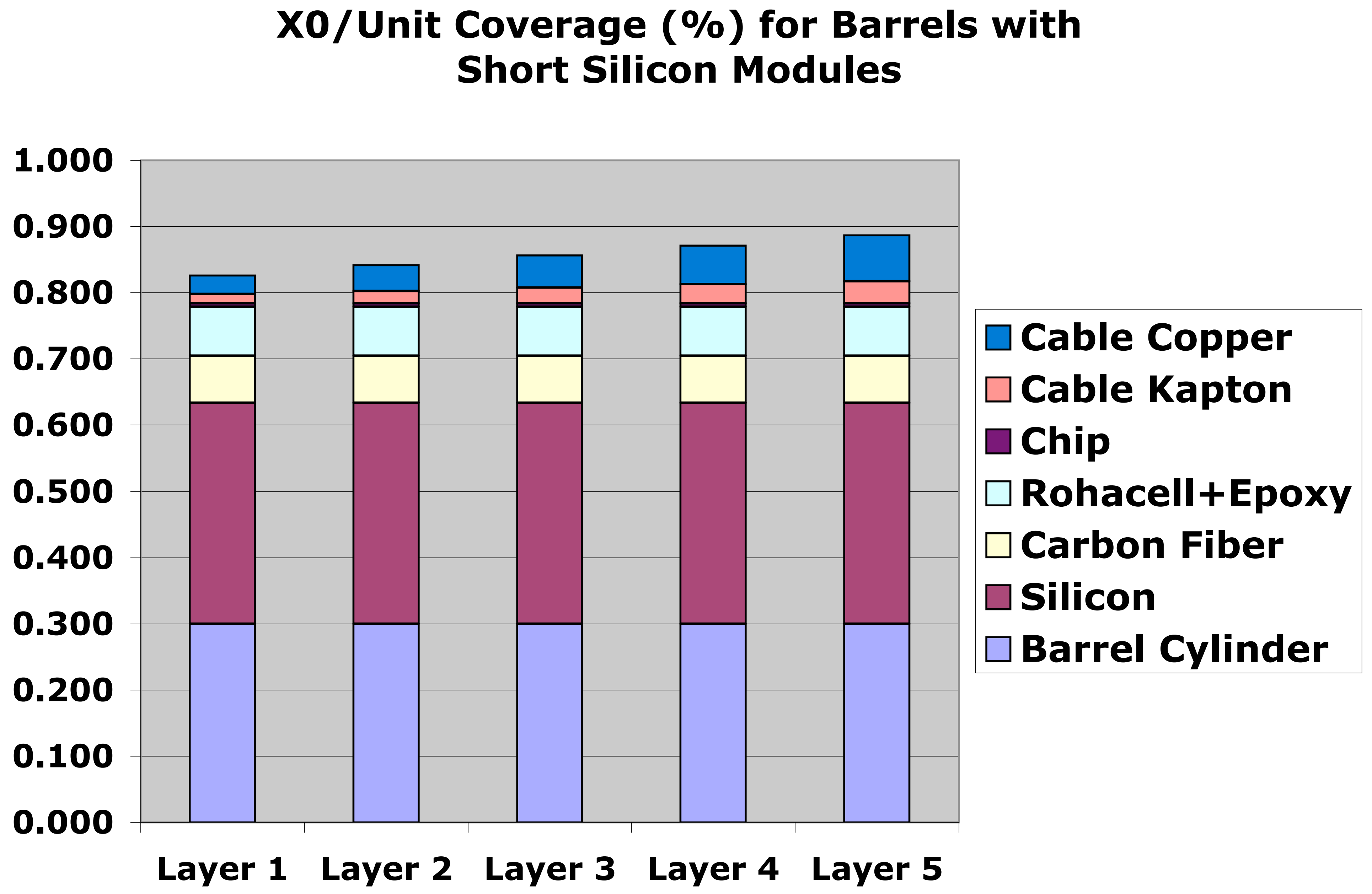
- Derives basic function from Si-W ECAL chip being developed at SLAC
- Power (current) throttled back during most of machine cycle
- Digital section quiet during entire train
- 4 buffers/channel with beam-crossing stamp

See Marty Breidenbach's Talk in Cal session




⇒ Only see hits from a single bunch crossing during track reconstruction

# Barrel Material



# Single-hit Resolution

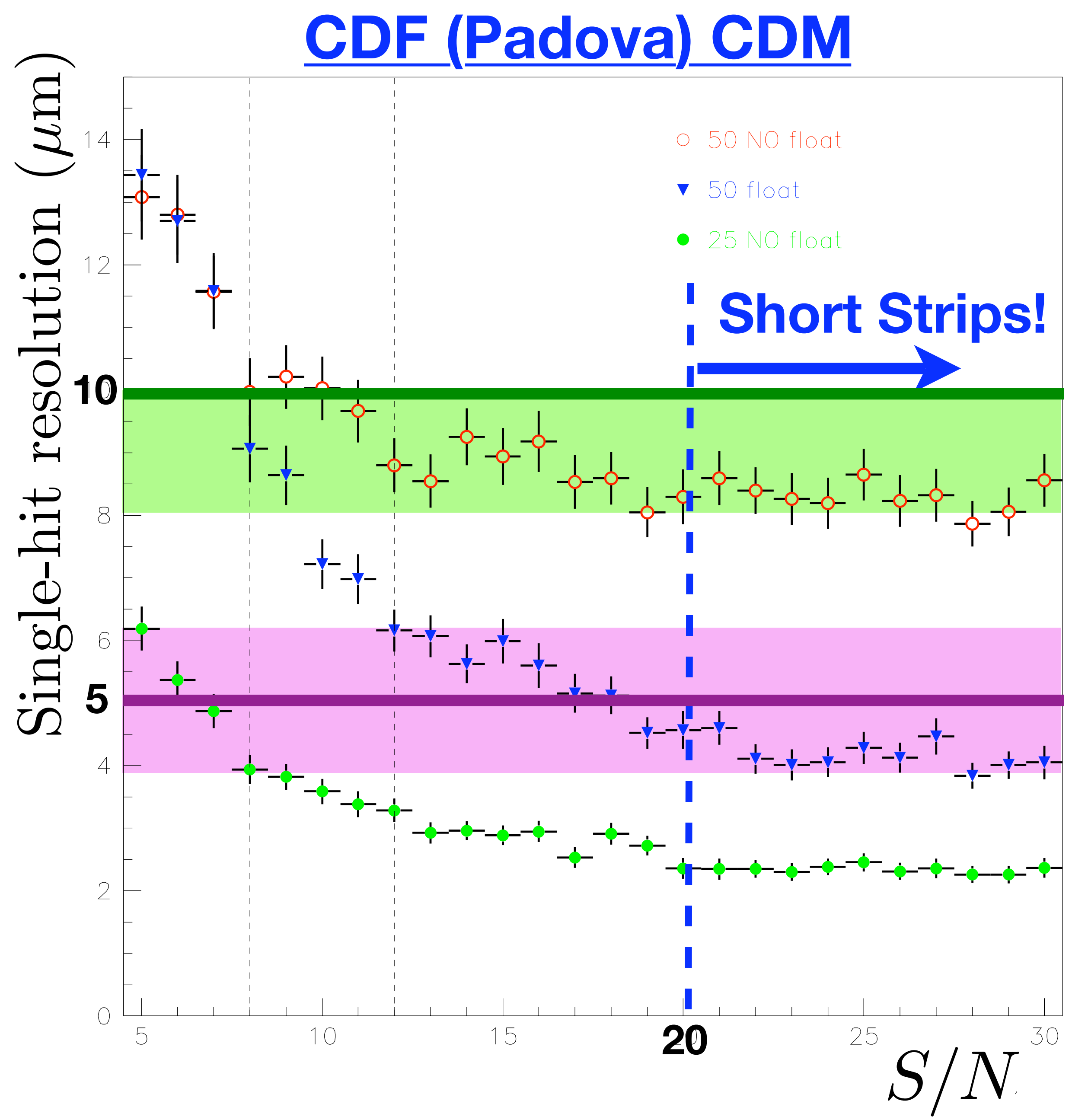
- **Conservative: ~50 micron pitch, read out every strip**

$$\Rightarrow \sigma_{hit} < 10\mu m$$

***However, for short modules, capacitance will be <15pf***

- **S/N > 20**
- **Profit enormously from floating intermediate strips (50/25)**

$$\Rightarrow \sigma_{hit} \approx 5\mu m$$



# Barrel Performance

## *Physics performance as function of tracking precision*

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$

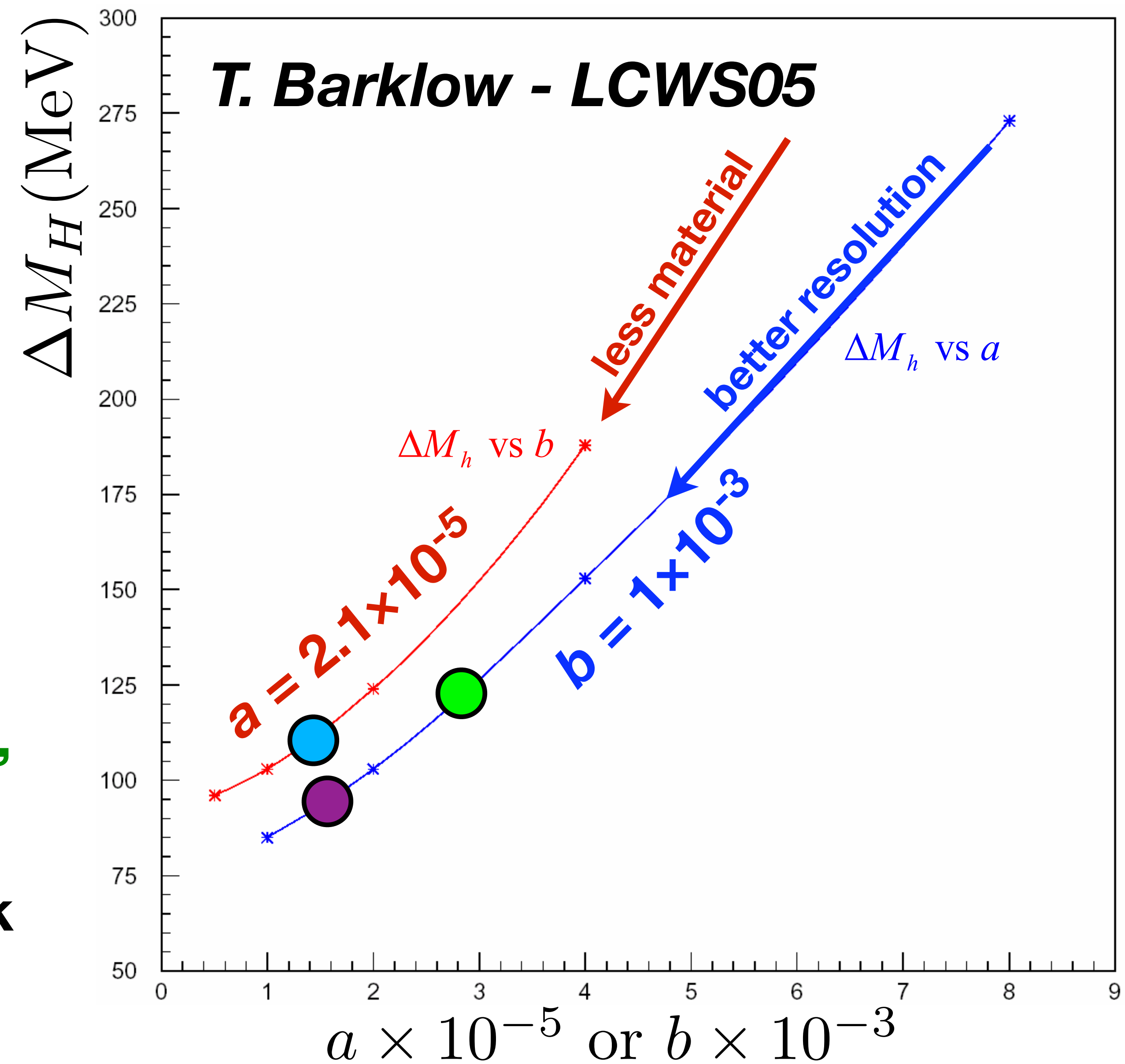
$$b = 1.4 \times 10^{-3}$$

$$\sigma_{hit} = 10\mu m \Rightarrow a = 2.8 \times 10^{-5}$$

$$\sigma_{hit} = 5\mu m \Rightarrow a = 1.4 \times 10^{-5}$$

- **For Higgs resolution from *ZH, Z→$\mu\mu$*, performance is excellent**
- **Other examples: see T. Barklow's talk**

⇒ **Low-$p_T$ performance also good**



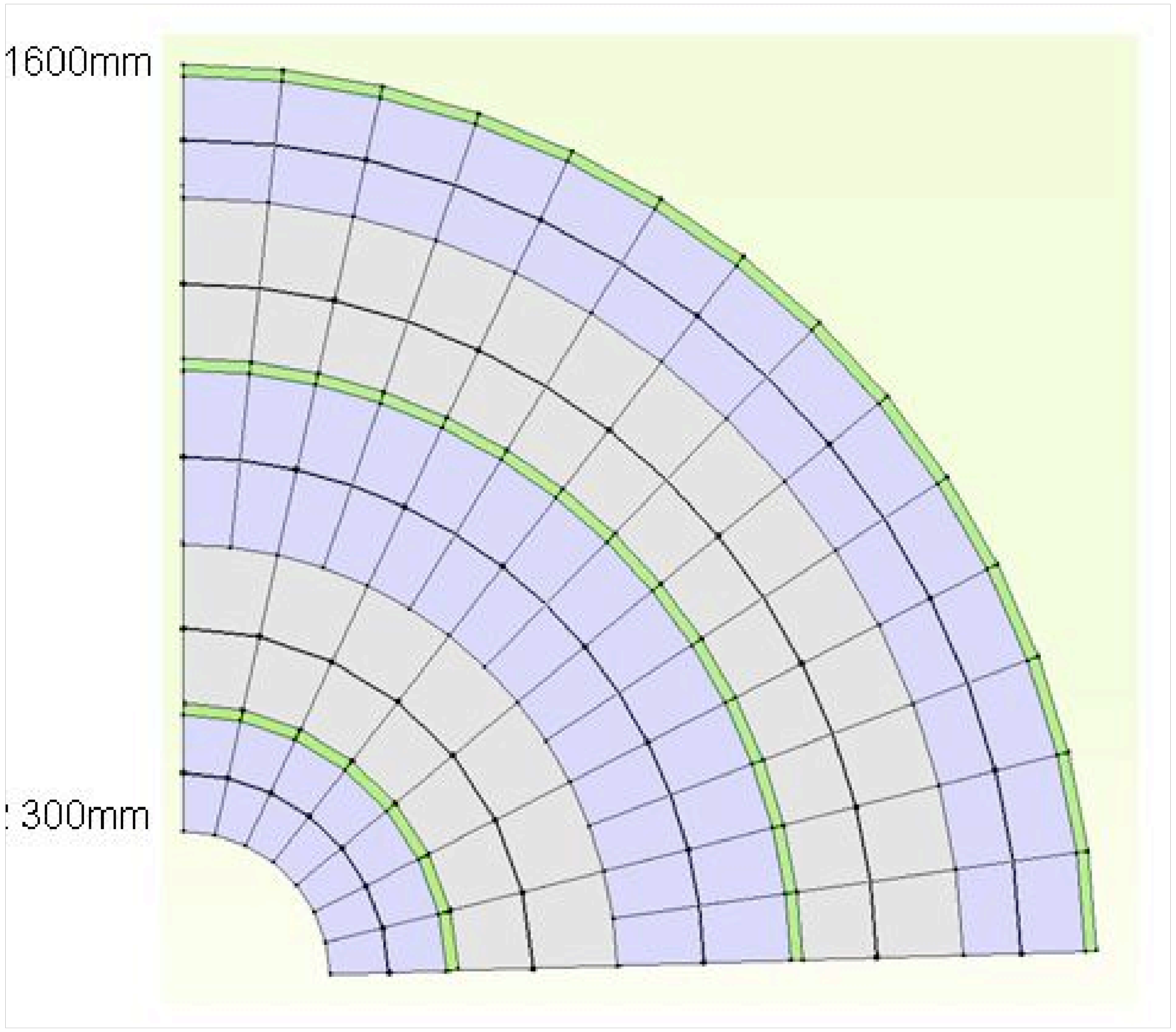
# Forward Disks

**Disks are natural, integrated part of the mechanical design, but details are not yet clear**

- single or double-sided?
- wedges? hexagons?
- strip orientations?

**Considering difficulties experienced by previous similar systems, development of tracking algorithms together with design seems prudent**

*Aurora Savoy Navarro (LPNHE)*

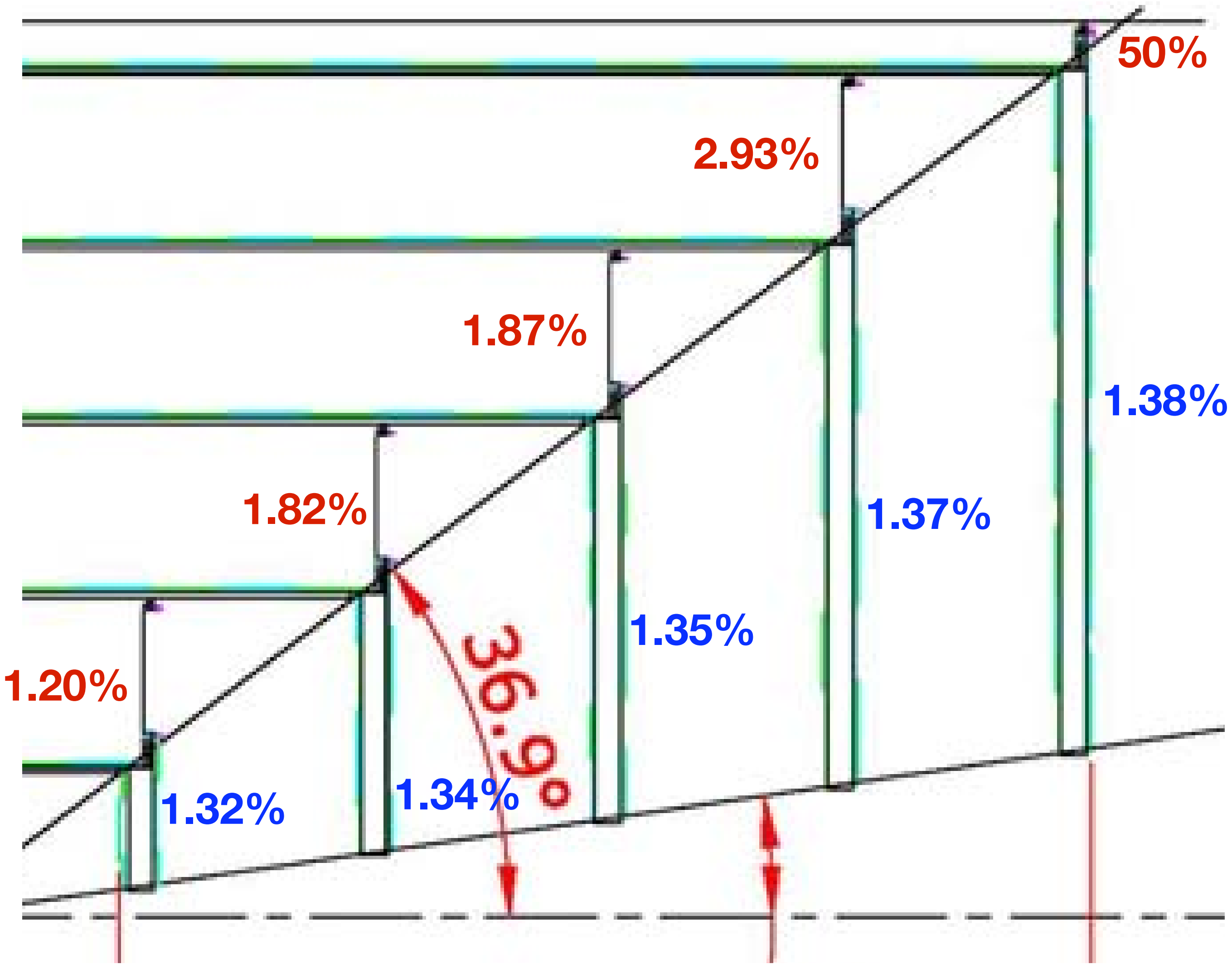


# Forward Disks

Keeping material down will be a challenge for all concepts

- Developed worst-case scenario for simulations
  - double-sided modules on disks
  - support rings for barrels/disks
  - power distribution and cables for barrels+disks (uses DC/DC conversion to save on Copper)

  note small but concentrated material at outer "corner"



# Summary

- A large, modular, all-silicon tracker can be built for the ILC within a very tight material budget: eliminating cooling and hybrids are key
- Short modules provide excellent high-momentum and very good low-momentum performance while allowing for a smaller (and less expensive) Si-W calorimeter:  if desired, longer modules might improve latter at cost of former.
- Short module design should provide some degree of stand-alone pattern recognition for a single bunch-crossing: needs study
- Much to do before Snowmass, especially on forward disks: detector module ready for simulation
- Investigating parts availability and assembly requirements needed to develop fully engineered design