SiD Detector Concept

R&D Perspective

for WWS R&D Panel

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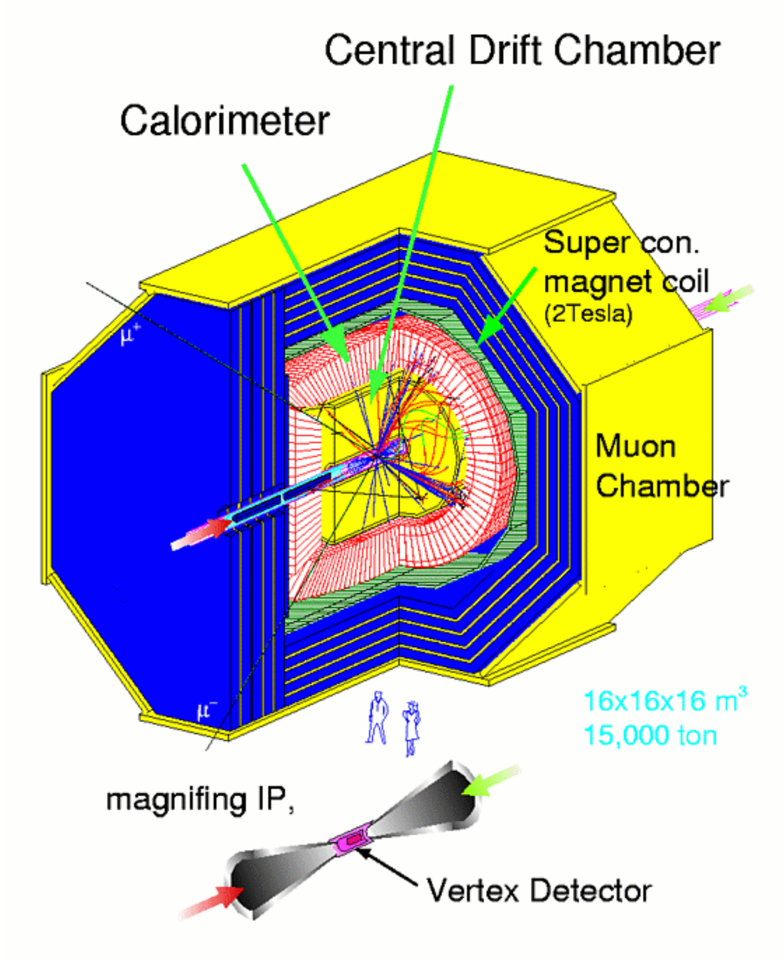
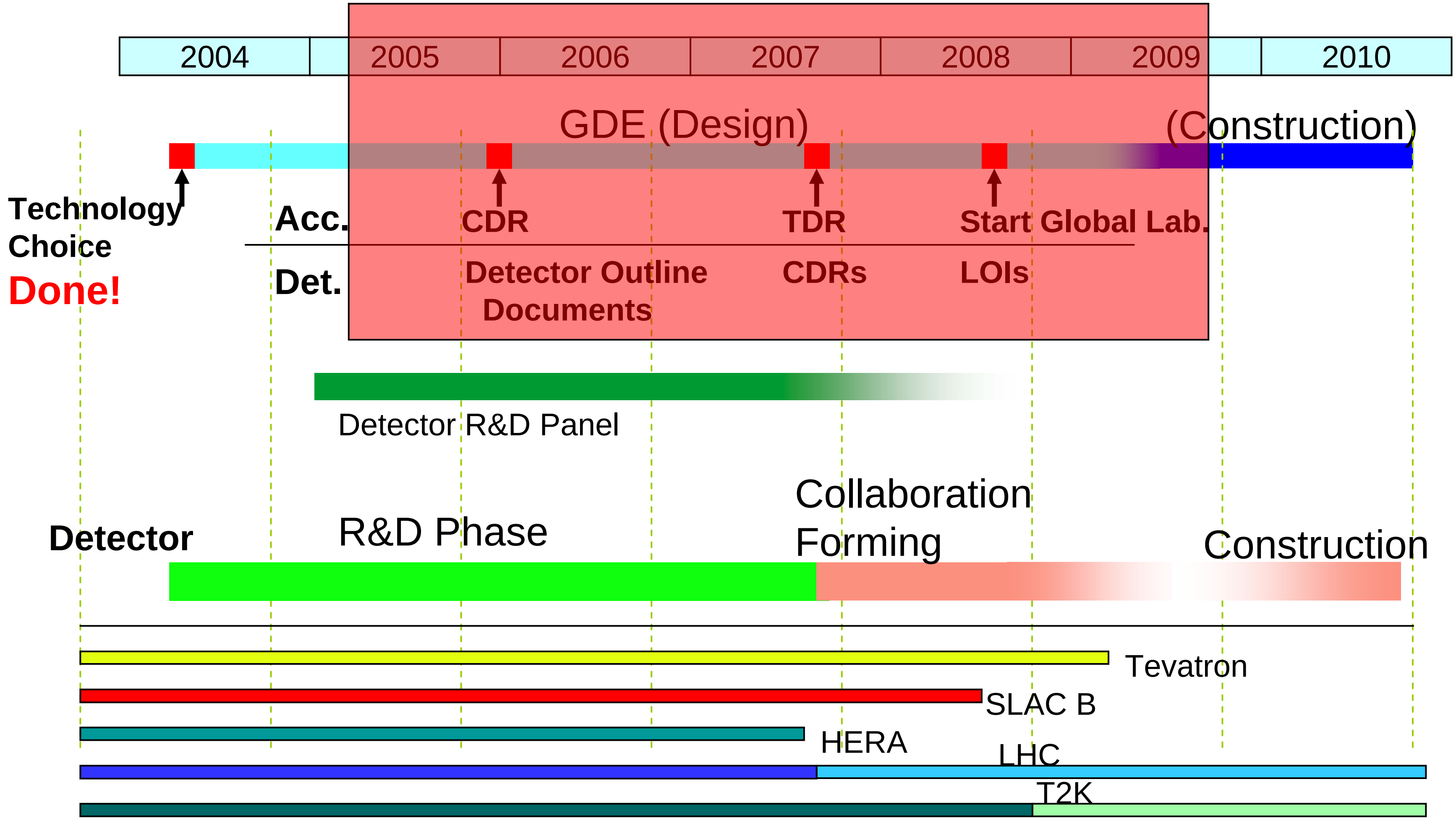
University of Texas at Arlington

Detector Concepts and Challenges

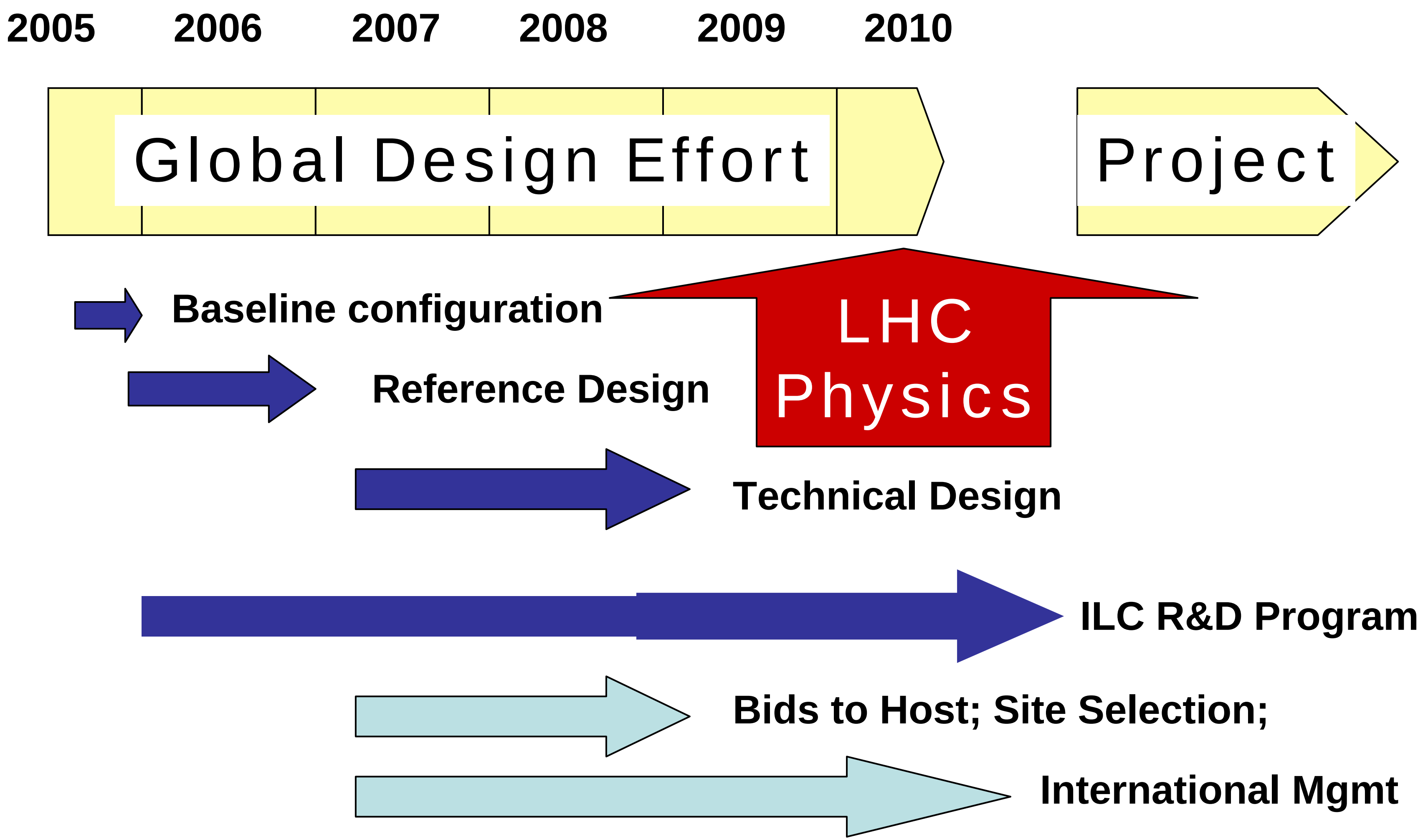


- Three concepts under study
- Typically requires factors of two or so improvements in granularity, resolution, etc. from present generation detectors
- Focused R&D program required to develop the detectors -- end of 2005

“Window for Detector R&D



The GDE Plan and Schedule



Detector R&D Phases

- Present phase (-> FY05) – exploratory R&D, several/many approaches to each subsystem.

- Next phase (FY06-FY08?) - medium scale tests of selected technologies, data analysis, technology(s) comparison, selection

- Design and Prototype phase (FY08-FY09?) – design using selected technology, sector module prototype, testing, analysis, and iteration towards production design.

We need to understand the details of these phases for *each* of the SiD subsystems and the interactions between subsystems.

Note: this 5-year timescale has been discussed/agreed with the WWS R&D Chair.

Detector R&D Phases

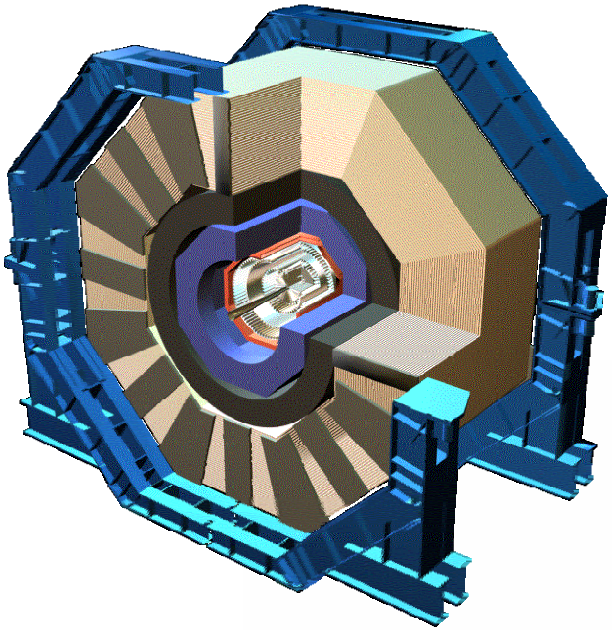
- Each of these R&D phases has associated costs.

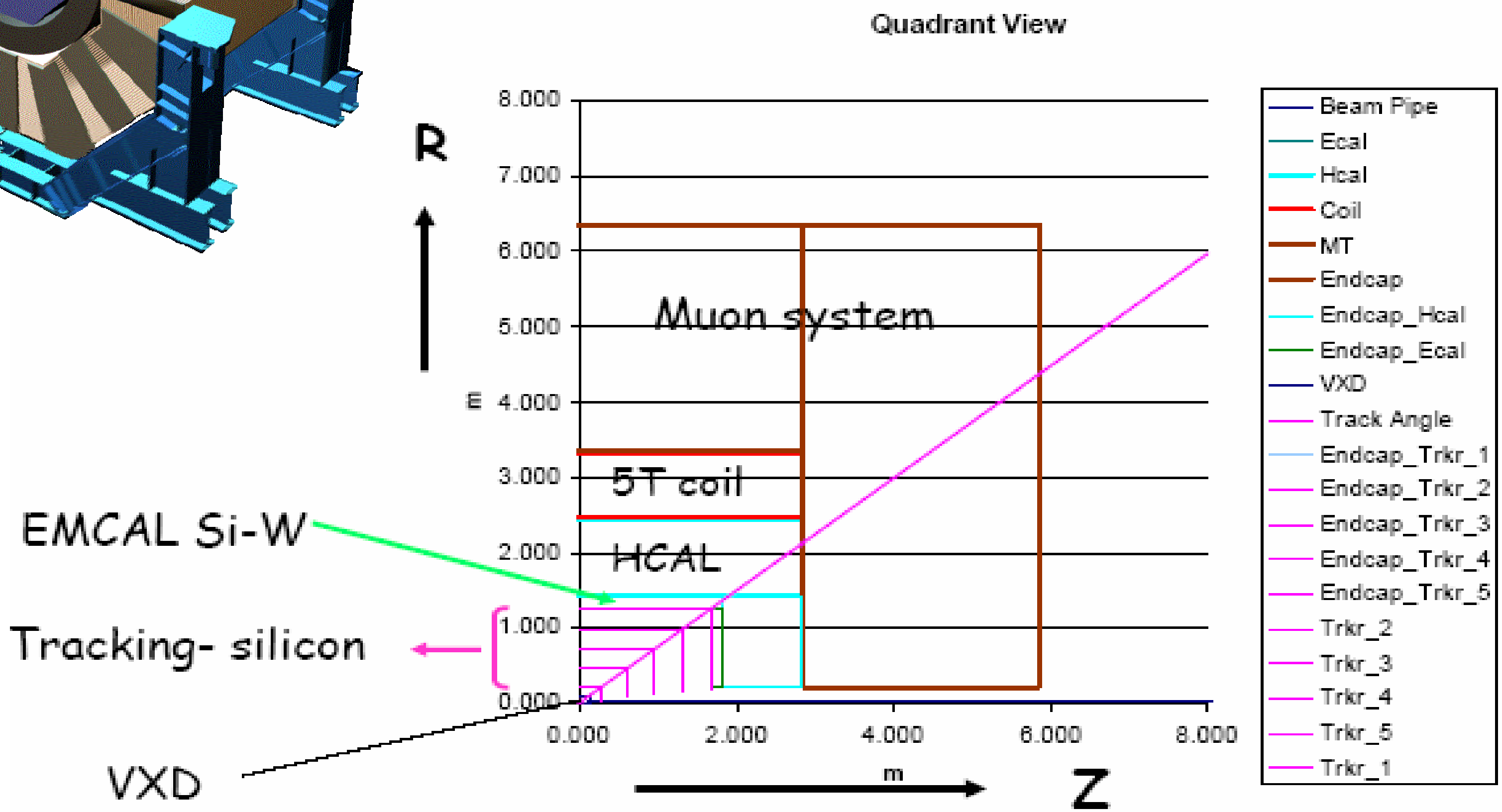
- We need to understand the funding profiles for each SiD subsystem – must be as realistic as possible!

- We need to *prioritize* the many SiD R&D tasks for each phase.

SiD

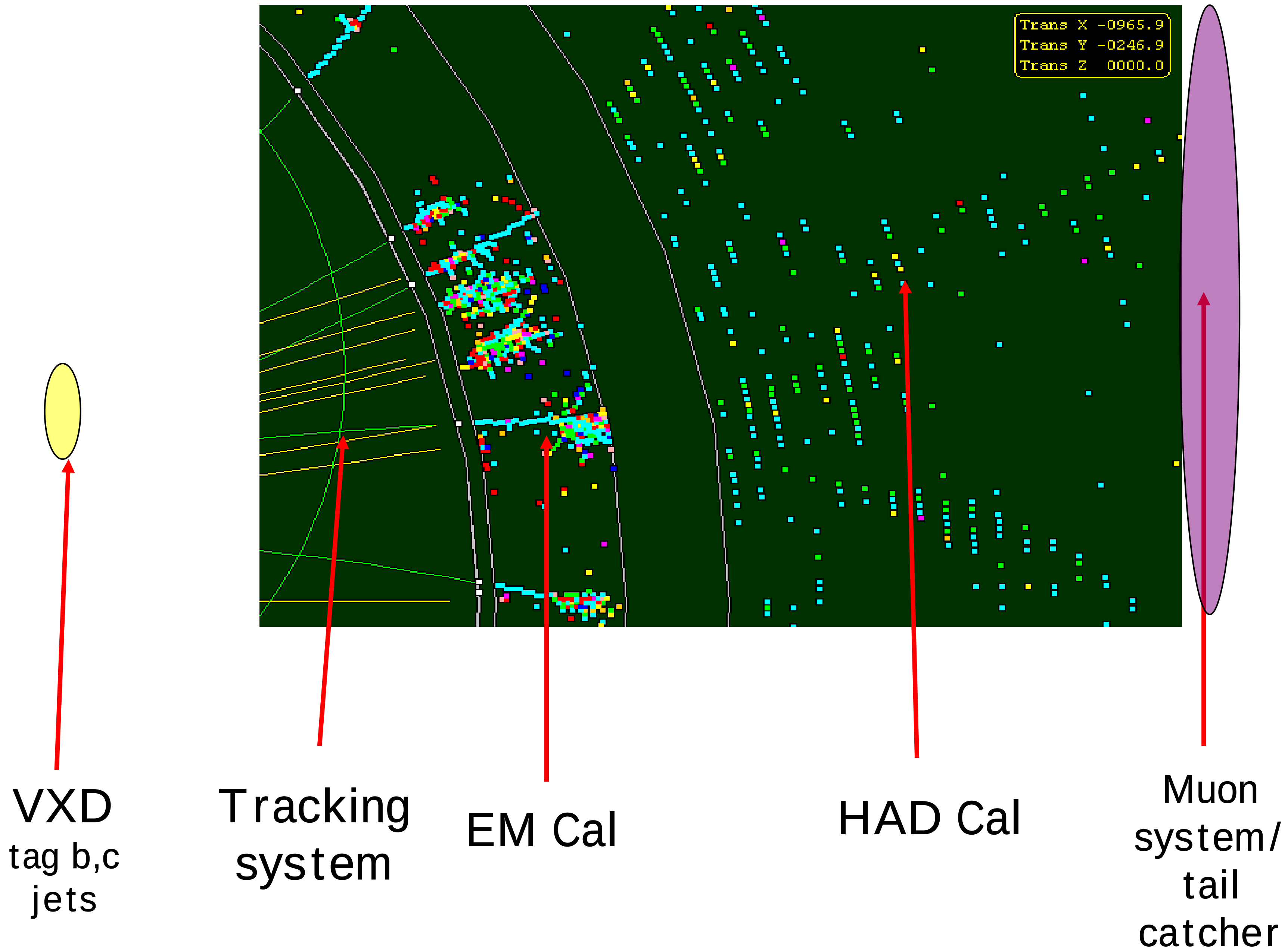
Compact detector





NOT A SMALL DETECTOR

Integrated Detector Design



Integrated Detector Design

We must consider the detector as a *whole* *(even though we often meet as separate "subgroups").*

The tracker not only provides excellent momentum resolution (certainly good enough for replacing cluster energies in the calorimeter with track momenta), but *also* must:

- efficiently find all the charged tracks:

Any missed charged tracks will result in the corresponding energy clusters in the calorimeter being measured with lower energy resolution *and* a potentially larger confusion term.

Integrated Detector Design

- Services for Vertex Detector and Tracker should not cause large penetrations, spaces, or dead material within the calorimeter system – implications for inner systems design.

- Calorimeters should provide excellent MIP identification for muon tracking between the tracker and the muon system itself. High granularity digital calorimeters should naturally provide this – but what *is* the granularity requirement?

- We must be able to find/track low energy (< 3.5 GeV) muons completely contained inside the calorimeter.

SiD R&D Areas

Vertex Detector (Su Dong)
Main vertex detector technology: Monolithic CMOS, small pixels (5µm x 5µm) – with larger pixel readout zones. Aiming for thin devices.

Tracking system (M. DeMarteau, R. Partridge)
Main technology(s): Monolithic pixels; Long and short ladder Si-strips; long shaping time/thin design.

Electromagnetic Calorimetry (R. Frey) Main technology: Silicon/Tungsten.

Hadronic Calorimetry (J. Repond)
Main technology(s): Digital GEM- and RPC-based with steel or tungsten. Scintillator/SiPM.

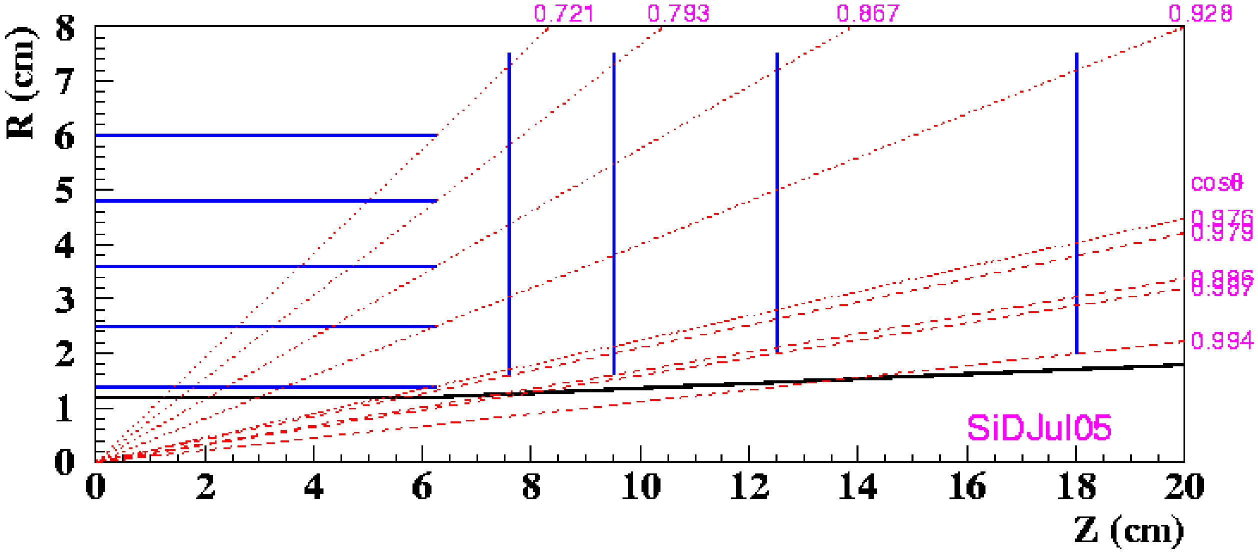
Muon system and tail catcher (H. Band,H.E. Fisk) Main technology: RPC planes or Scintillator planes.

Electronics (M. Breidenbach)

Magnet (R. Smith, F.Kirchner)
Main technology: CMS-style superconductor

Machine Detector Interface (P. Burrows, T.Tauchi) Phil Burrows will identify those MDI items requiring R&D support.

SiD Vertex Detector



Many types of sensors being considered:

CPCCD, ISIS. UK LCFI

MAPs. FNAL

Macro/micro CMOS pixel. Yale/Oregon/Sarnoff

CCDs. Japan

- Barrel 12.5cm + 300μm endcaps – self supporting

- Radius: inner ~1 –1.5cm outer 10cm, 0.2% X_0
  Extend 5 layer tracking over max Ω (5 barrel + 4 forward layers) →improve Ω Coverage, improve σ_{xy}, σ_{rz}

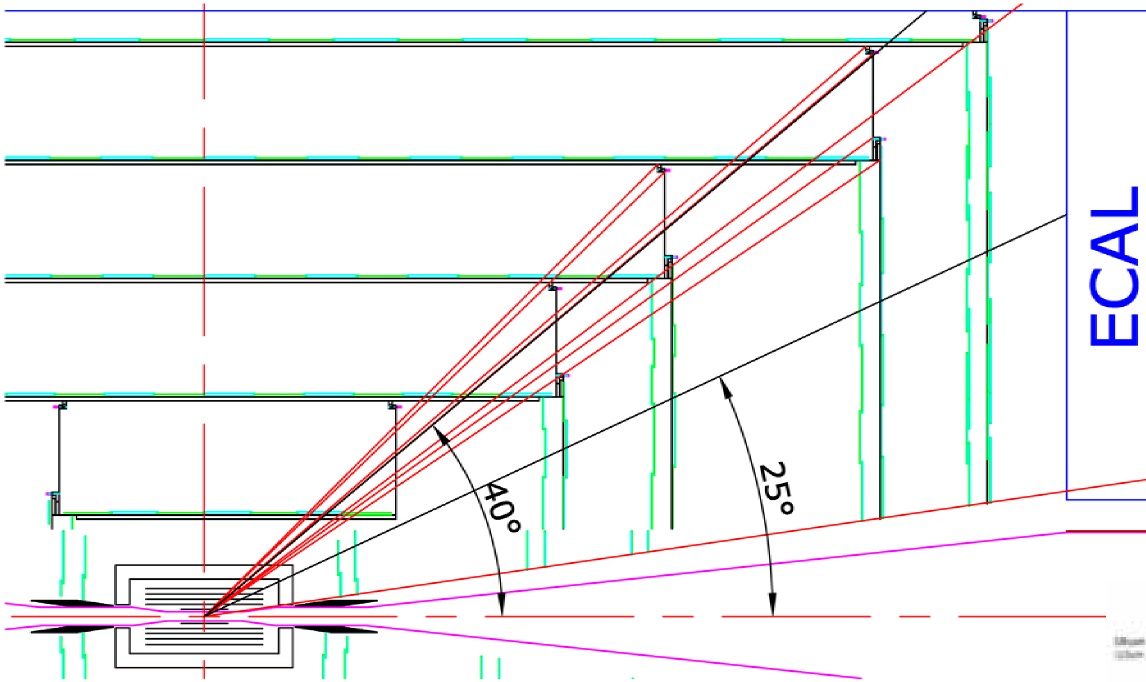
- Sensor to operation cold or just slightly below room temperature ?

- What level of readout is needed (if any) during bunch train (possible show stopper of EMI effect ?)

- Material in barrel endplate?
- ...

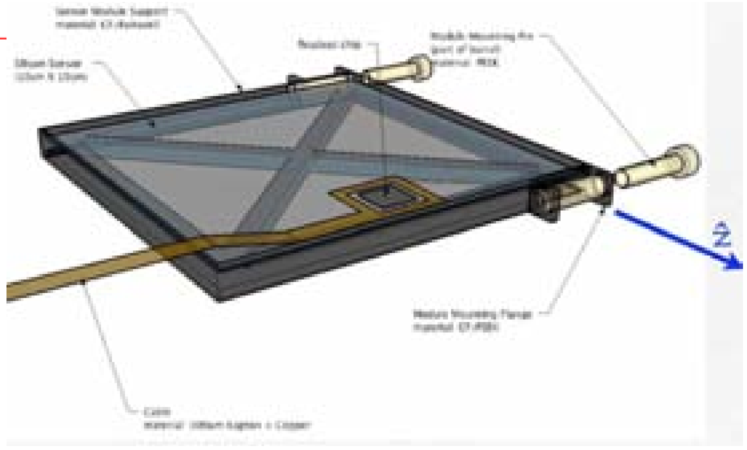
SiD Tracking Detector

- Barrels
  - Five barrels, measure Phi only
  - Eighty-fold phi segmentation
  - 10 cm z segmentation
  - Barrel lengths increase with radius
- Disks
  - Five double-disks per end
  - Measure R and Phi
  - varying R segmentation
  - Disk radii increase with Z



Tracker roll-out over beam pipe for VXD access

Very forward tracking elements mounted on beam pipe

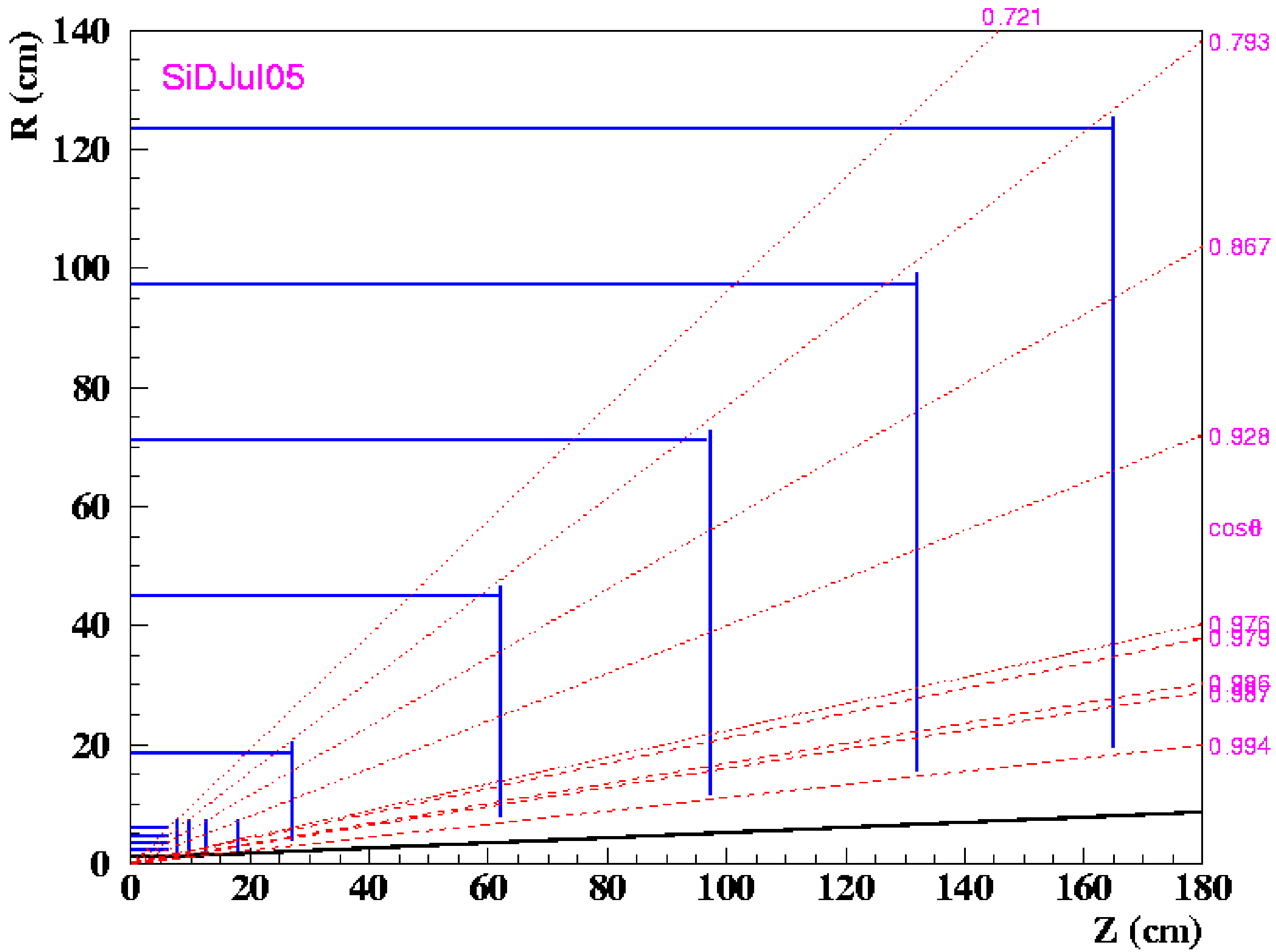


SiD Tracking Detector

Features:

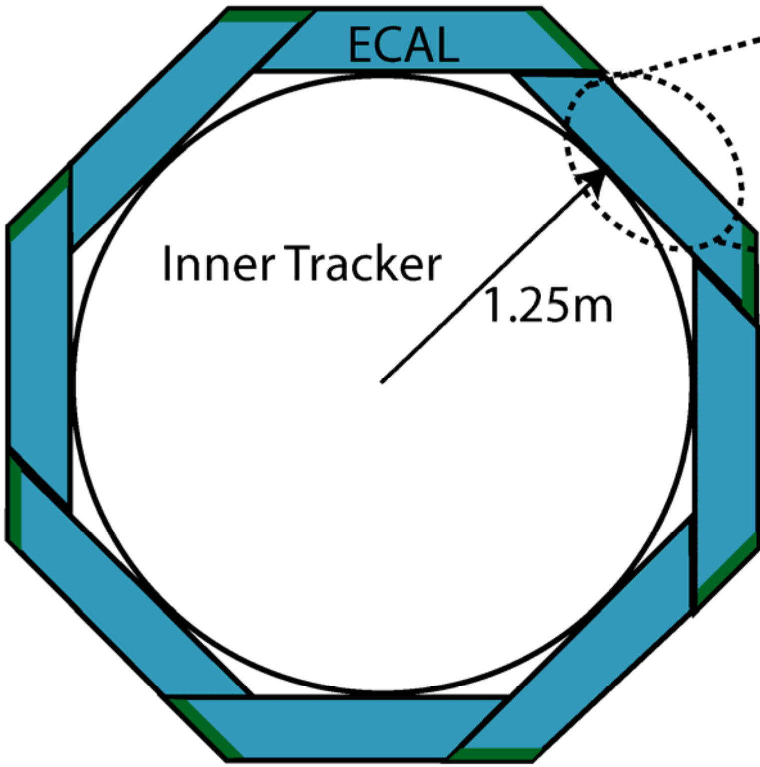
- Compact, 5 layers inside R = 1.25m
- Point resolution O(10μm)
- Progress on short strips (Cal. electronics), long shaping time strips.
- Thin: double-sided disks in forward direction – preserve ECAL performance.
- Stable calibration/alignment(vs. time/dist for wires)
- Robust – SLC/SLD experience

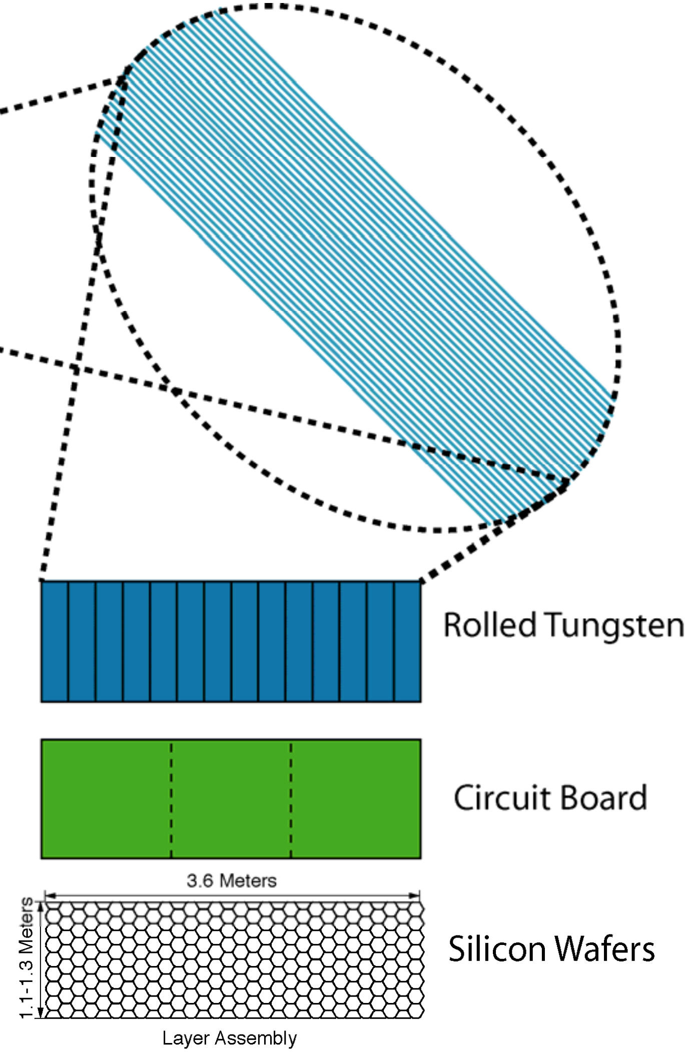
Tracker+VXD matching



SiD ECAL

Si-W Calorimeter Concept





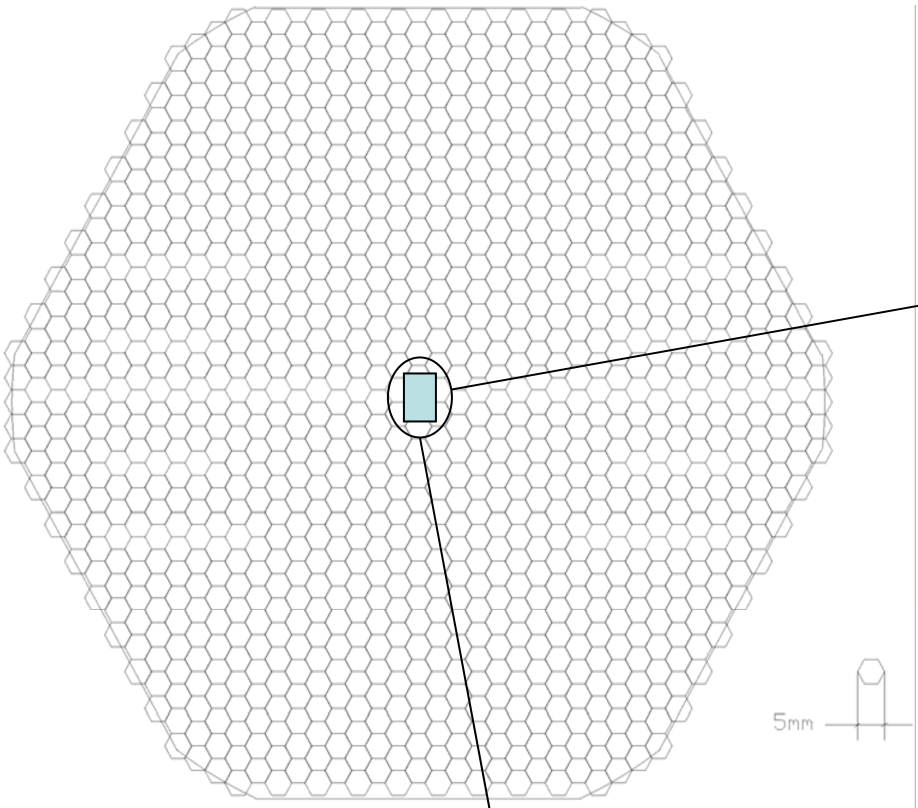
Transverse Segmentation ~5mm

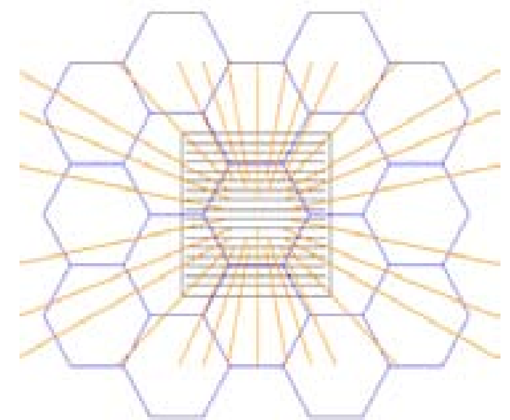
30 Logitudnal Samples

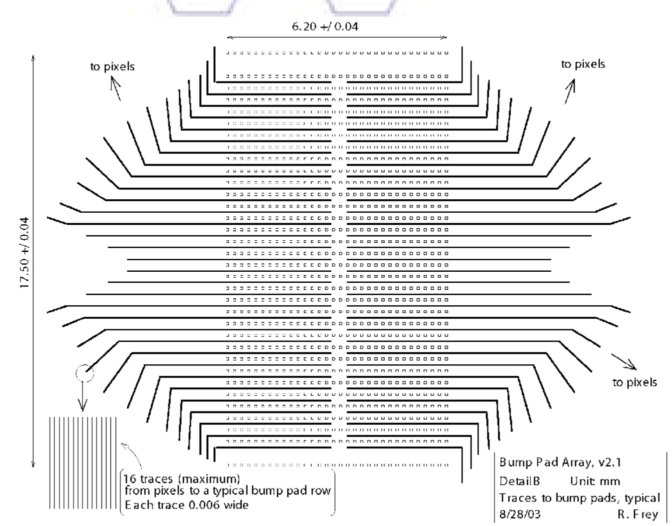
Energy Resolution ~15%/$E^{1/2}$

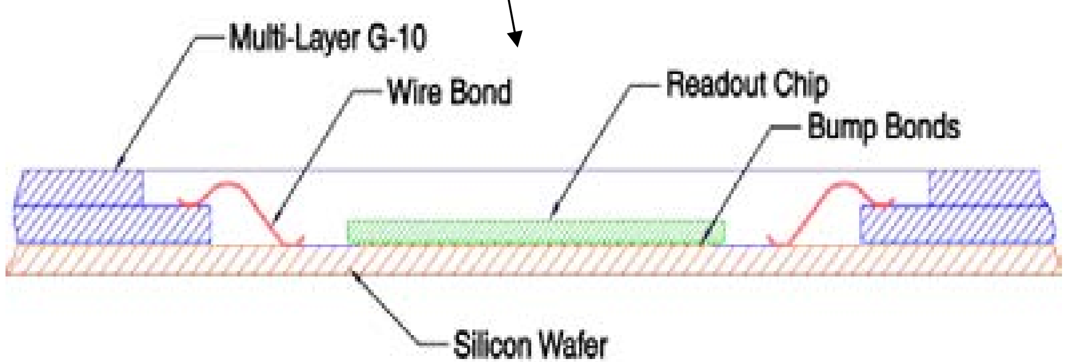
SiD ECAL

Wafer and readout chip



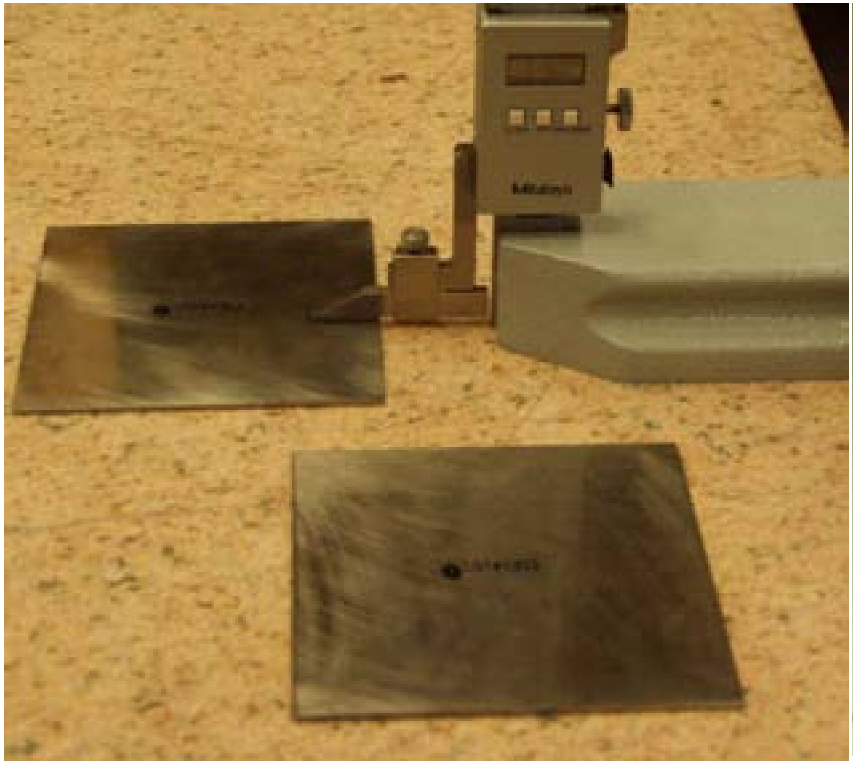


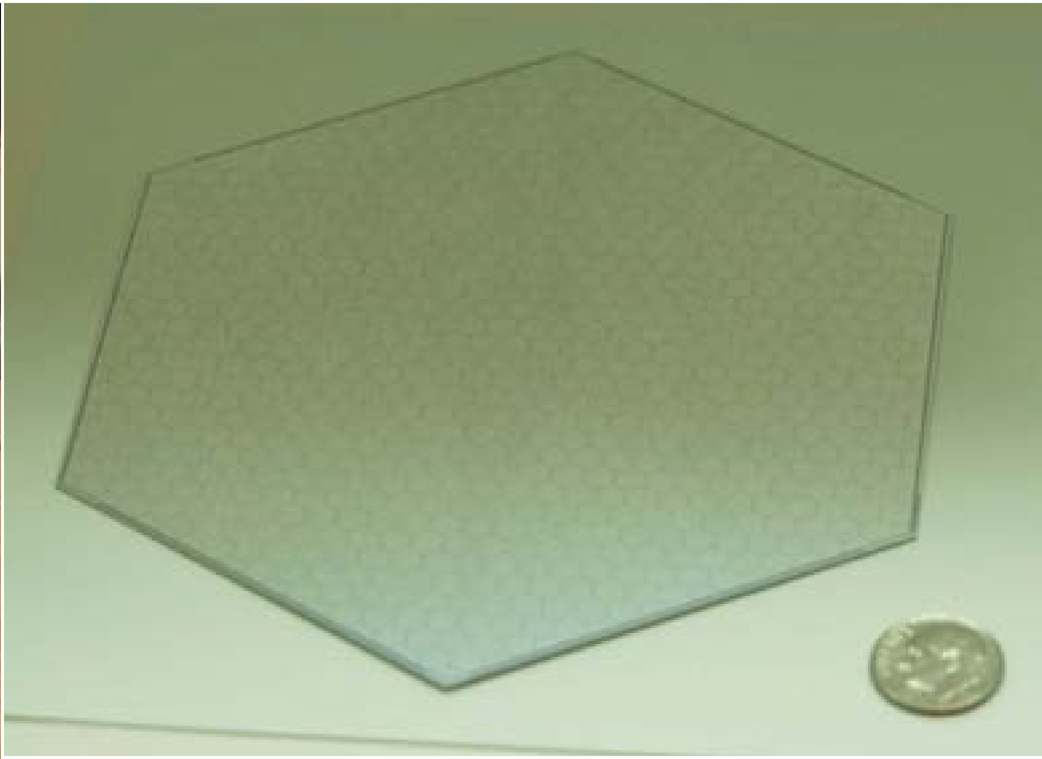




Concept: many channels (1-2K) on one ASIC

SiD ECAL Components in hand





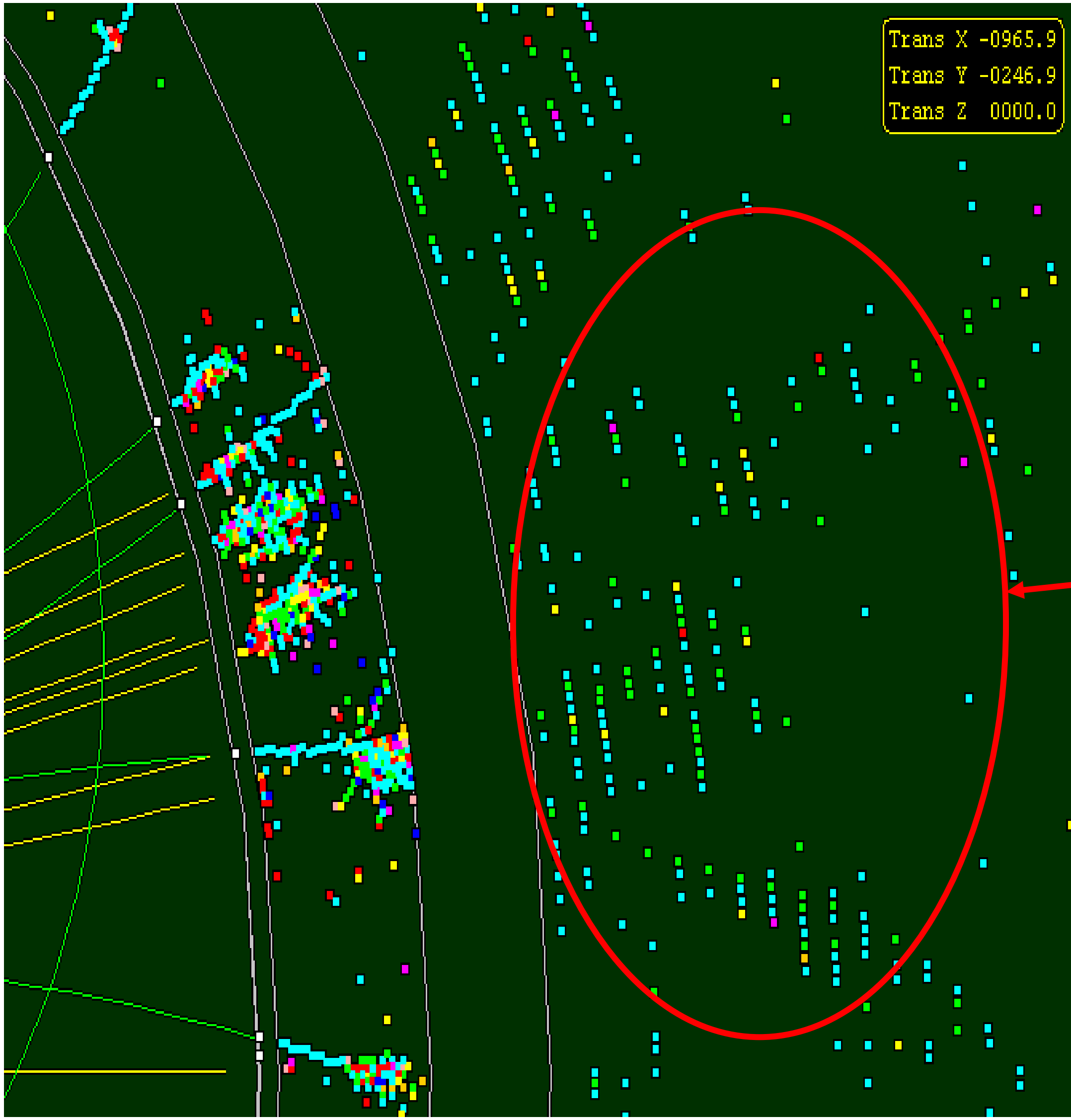
<u>Tungsten</u>

- Rolled 2.5mm
  - down to 1mm OK
- Very good quality
  - < 30 µm variations
- 92.5% W alloy
- Pieces up to 1m long possible

<u>Silicon</u>

- Hamamatsu detectors (10)
- Compatible with design concept for LC ECal (pixel size, traces, bump-bonding pads, etc)
- Lab tests look fine

SiD HCAL

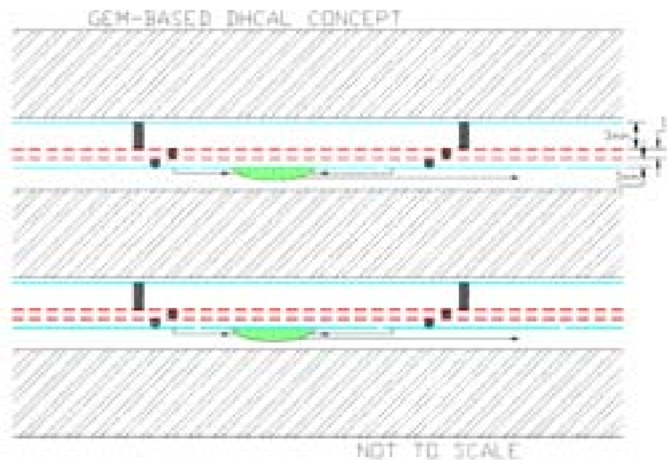


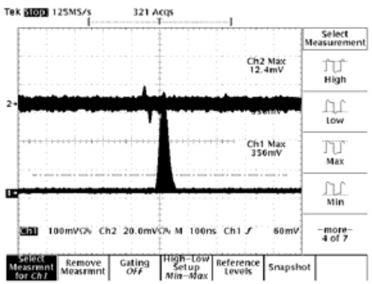
Major challenge – pattern recognition of energy clusters for EFA

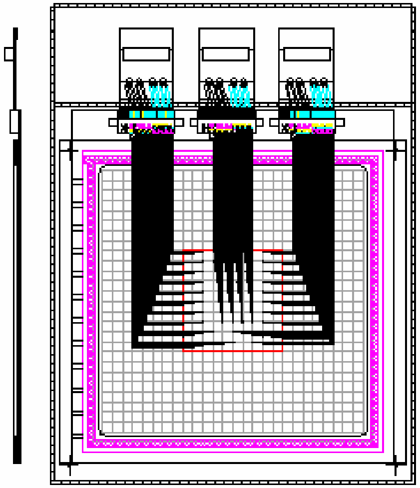
S.Magill ANL

Hadron Calorimeter

(1) Gas Electron Multiplier (GEM) – based DHCAL





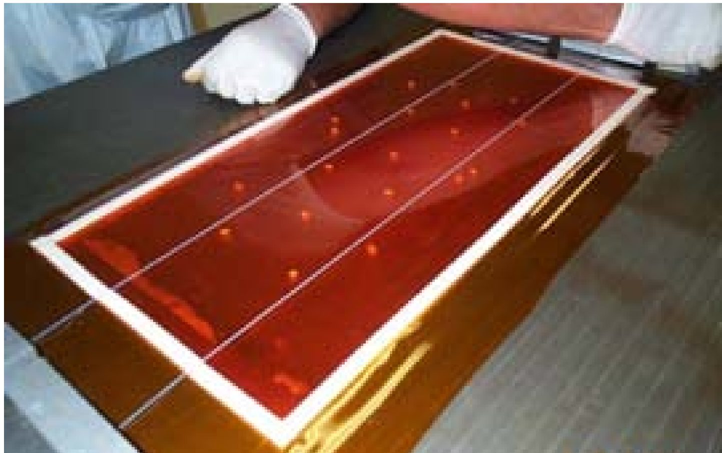


500 channel/5-layer test mid -'05 30x30cm^2 foils

Recent results: efficiency measurements confirm simulation results, 95% for 40mV threshold. Multiplicity 1.27 for 95% efficiency.

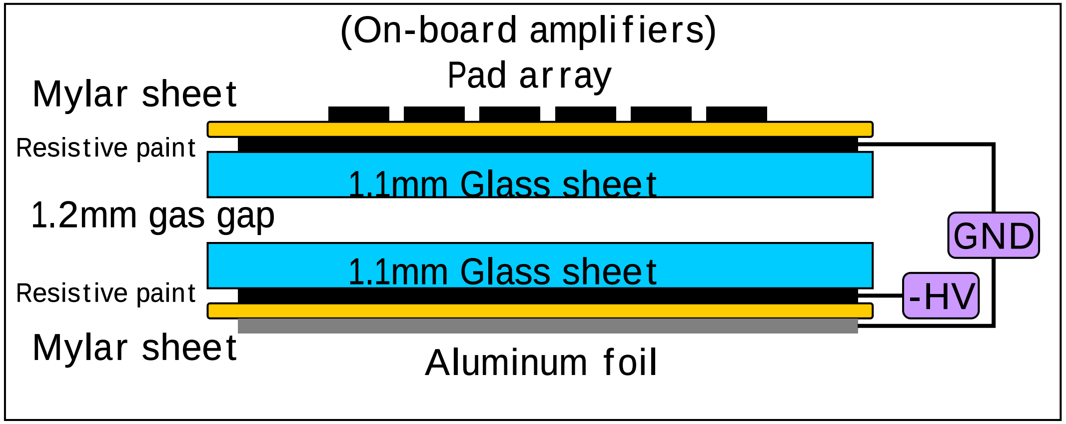
Next: 1m x 30cm foil production in preparation for 1m^3 stack assembly.

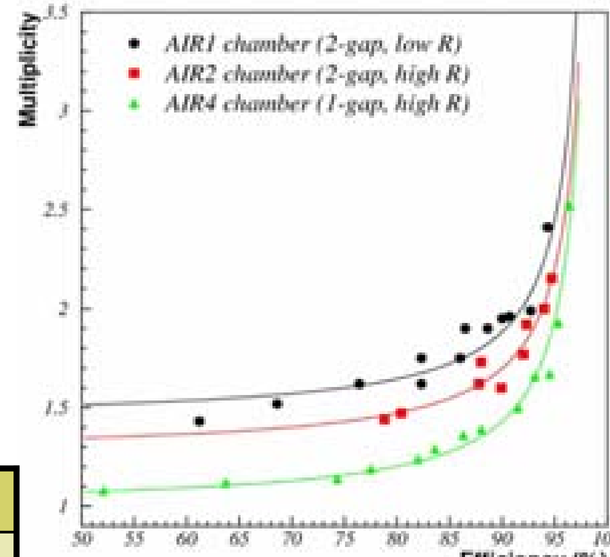
Joint development of ASIC with RPC

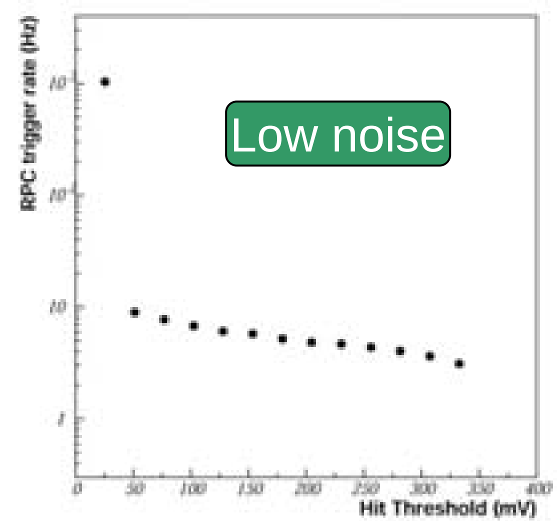


Hadron Calorimeter

(2) Resistive Plate Chamber-based DHCAL

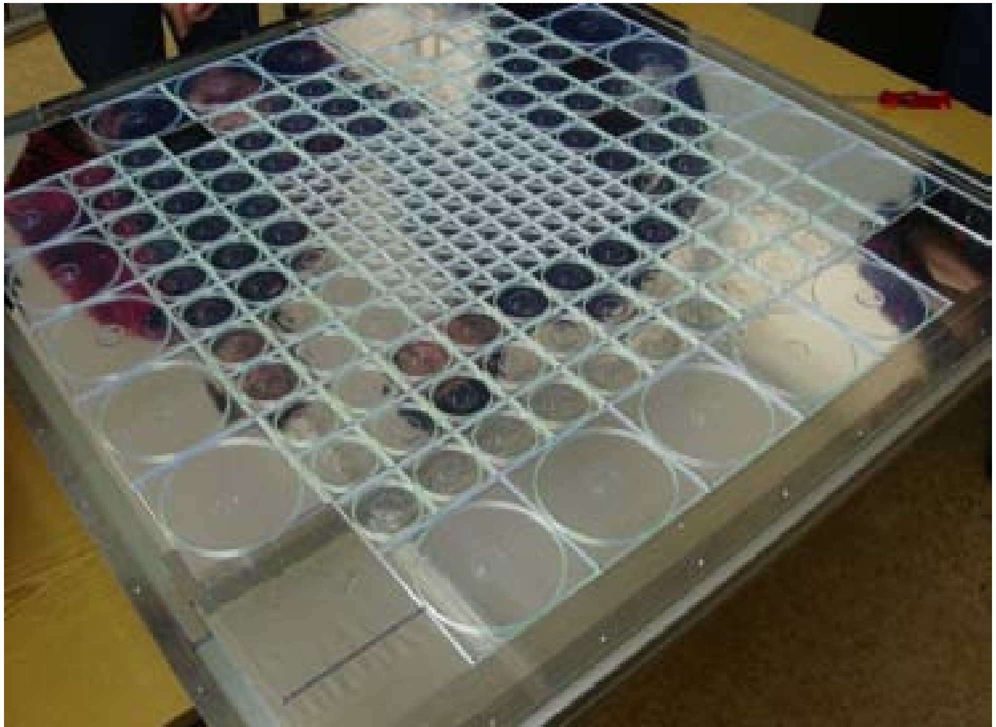




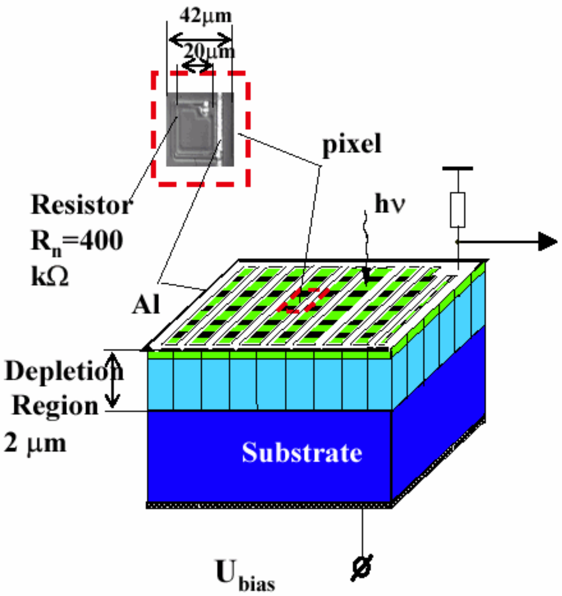


Tests	Results
Charge	Avalanche mode ~0.1 ÷ 5 pC Streamer mode 5 ÷ 100 pC
Efficiency	Greater than 95 % Drops to zero at spacer
Streamer fraction	Plateau of several 100 V where efficiency > 95% and streamer fraction < few percent
1 – gas gap versus 2 – gas gap	Larger Q with 1 – gas gap Similar efficiency
Noise rate	Small ~0.1 – 0.2 Hz/cm^2
Different gases	Best: Freon:IB:SF_6 = 94.5:5:0.5

Hadron Calorimeter



Scintillator/SiPM



Hadron Calorimeter

	Scintillator	GEMs	RPCs
Technology	Proven (SiPM?)	Relatively new	Relatively old
Electronic readout	Analog (multi-bit) or Semi-digital (few-bit)	Digital (single-bit)	Digital (single-bit)
Thickness (total)	~ 8mm	~8 mm	~ 8 mm
Segmentation	3 x 3 cm^2	1 x 1 cm^2	1 x 1 cm^2
Pad multiplicity for MIPs	Small cross talk	Measured at 1.27	Measured at 1.6
Sensitivity to neutrons (low energy)	Yes	Negligible	Negligible
Recharging time	Fast	Fast	Slow (20 ms/cm^2)
Reliability	Proven	Sensitive	Proven (glass)
Calibration	Challenge	Depends on efficiency	Not a concern (high efficiency)
Assembly	Labor intensive	Relatively straight forward	Simple
Cost	Not cheap (SiPM?)	Expensive foils	Cheap

Timescales for LC Calorimeter development

We have maybe 3-5 years to build, test*, and understand, calorimetry for the Linear Collider.

By "understand" I mean that the cycle of testing, data analysis, re-testing etc. should have converged to the point at which we can reliably design calorimeter systems from a secure knowledge base.

This means having trusted Monte Carlo simulations of technologies at unprecedented small distance scales (~1cm), well-understood energy cut-offs, and demonstrated, efficient, complete energy flow algorithms.

Since the first modules are only now being built, 3-5 years is not an over-estimate to accomplish these tasks!

Muon Technologies

Scintillator-based muon system development

Figure 1: A photograph of the pre-prototype module.

U.S. Collaboration

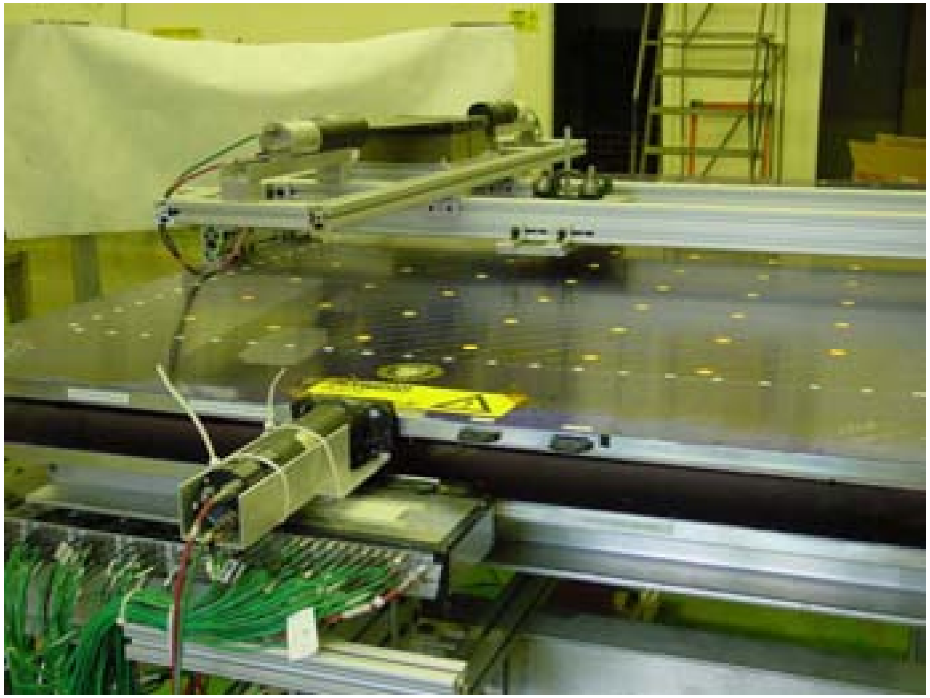
Extruded scintillator strips with wavelength shifting fibers.

Readout: Multi-anode PMTs

GOAL: 2.5m x 1.25m planes for Fermilab test beam

1.25 m X 2.5 m ¼ Scale Prototype

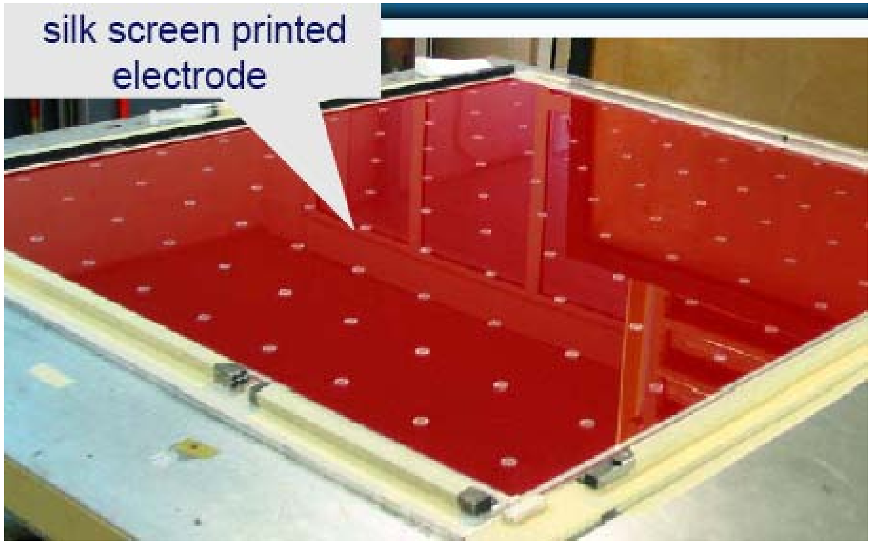
Notre Dame
3/20/2005

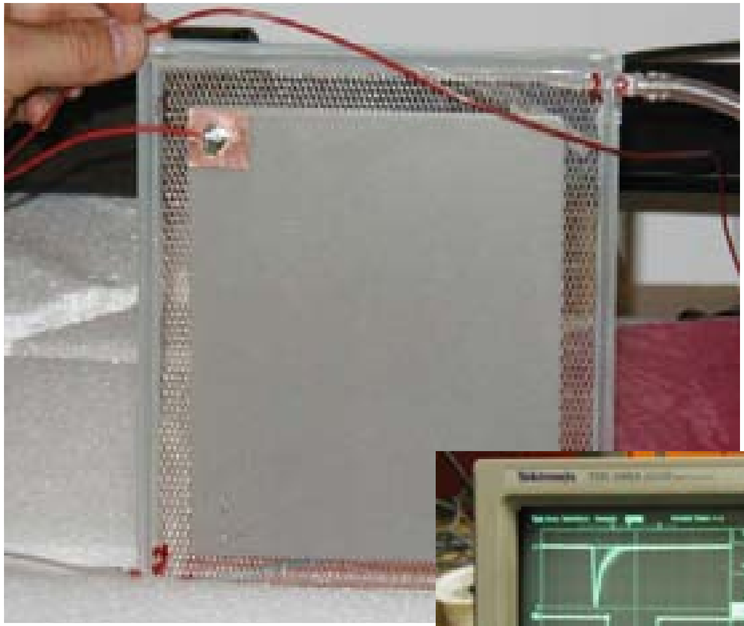


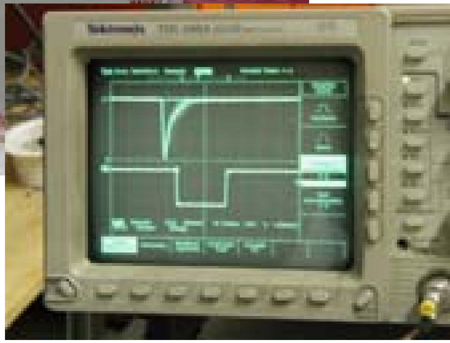
Muon Technologies

RPC planes for muon active layers:

CAPIRE collaboration

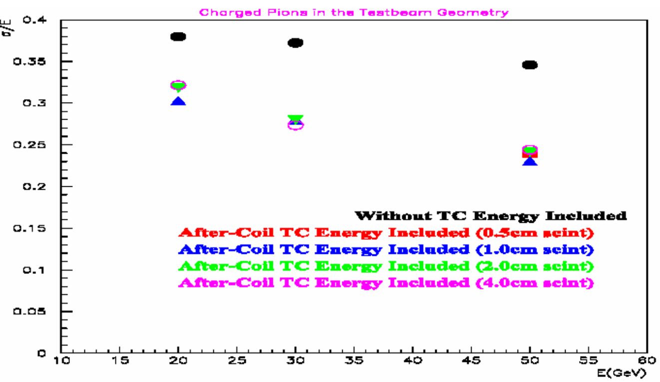






New approach with
“quenching mesh”

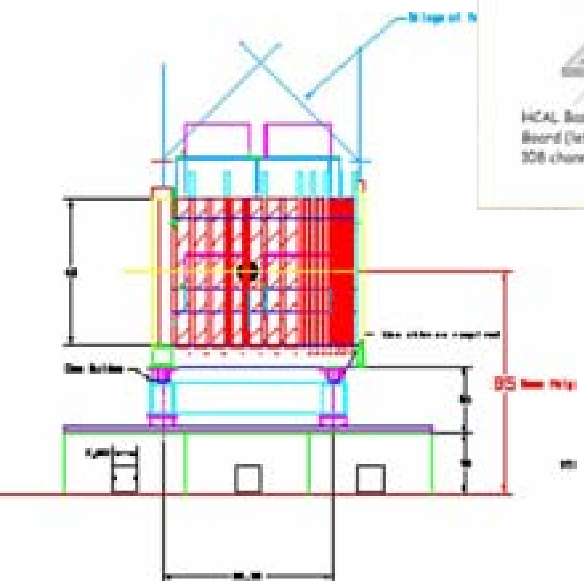
TCMT – CALICE/NIU

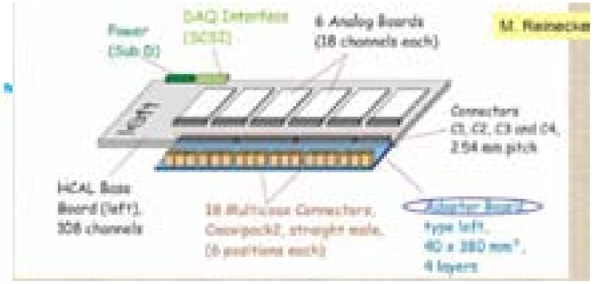


135%/sqrt(E)

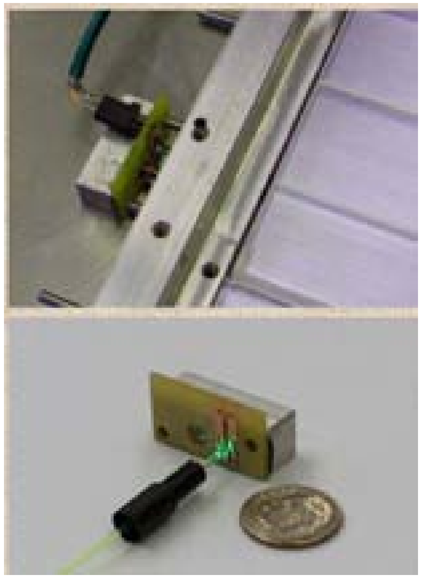
Extrusion

Cassette





Goal: Test Beam Fermilab/2005



SiPM location

Current SiD R&D Projects

Vertex Detector

U. Oregon and Yale, with collaboration/coordination with: University: U. Oklahoma, Labs: SLAC, KEK, FNAL, RAL

Tracking system

a) Monolithic pixels: Fermilab

b) Long shaping time thin Si-strips: UC Santa Cruz with collaborators from Fermilab, LPNHE Paris.

c) Detector mounting frame/materials; the detector technology; detector ROC and cabling: SLAC, Fermilab

d) Thin Si sensors: Purdue University.

e) Simulation and alignment: University of Michigan.

f) Reconstruction Studies: University of Colorado.

g) Simulation Studies for Si tracker: Brown University.

h) Calorimeter-based tracking for Particle Flow and Reconstruction of Long-Lived Particles: Kansas State University, collaborating with Fermilab, SLAC, University of Iowa, Northern Illinois University.

Current SiD R&D Projects

Forward tracking

Main technology: (Simulation study only): University of Oklahoma

Electromagnetic Calorimetry

Silicon/Tungsten. University of Oregon, SLAC, BNL, University of California at Davis.

Hadronic Calorimetry

a) GEM-based: University of Texas at Arlington, University of Washington, Changwon National University, Tsinghua University.

b) RPC-based: Argonne National Laboratory, Boston University, University of Chicago, Fermilab, University of Iowa.

c) Particle Flow Studies (simulation only): University of Iowa.

Muon system and tail catcher

Scintillator planes: Fermilab, NIU, Wayne State, Notre Dame, UC Davis, Indiana

RPC: CAPIRE collaboration

Electronics

SLAC

Current SiD R&D Projects

Magnet

CMS-style superconductor: Fermilab, (France – F. Richard advising).

? What R&D is needed – even with CMS superconductor?

Machine Detector Interface

Need to identify those MDI items requiring R&D support.

-> Need to review all these projects – understand role(s) in SiD.

-> What is missing?

-> What is redudant?

Estimating SiD R&D Funding needs

Experience tells us that the total R&D costs for major detectors (SLD, D0,....) are ~15-20% of the total detector cost.

We can take two approaches to R&D cost estimation:

(1) Top-down – using an estimated percentage of final detector cost for each subsystem.

(2) Bottoms-up – what we have so far, expect in short term, and can extrapolate.

Clearly we have to work towards convergence of these two approaches, in parallel with appropriate scheduling and prioritization of tasks.

“Top-down” SiD R&D Cost Estimate

SiD Subsystem	Cost	Estimated R&D %	R&D Cost	R&D Contingency %	R&D Cost With Contingency	Comment
VXD	6.0	50	3.0	20	3.6	
Tracker	22.9	25	5.7	20	6.9	
EMCal	74.7	20	14.9	20	17.9	
HCal	74.2	15	11.1	20	13.4	
Muon system	52.1	10	5.2	20	6.3	
Electronics	37.5	50	18.8	20	22.5	Note (1)
Magnet	167.1	10	16.7	20	20.1	
MDI	20.0	10	2.0	20	2.4	Cost is pure guess for SiD specific items
TOTALS/AVG	454.5	23.8	77.5	20.0	93.0	

cf. Total SiD cost ~$641M

SiD R&D Report

SiD Detector Concept for the International Linear Collider
Research and Development Report
for WWS R&D Panel
Introduction

The SiD design concept is continuously evolving. R&D on most detector subsystems has started, but generally with rather limited funding. For the purposes of providing information on the status and needs of R&D, this report therefore takes two approaches:
(1) We give a "top-down" estimate (separate file) based on the overall best estimate of the final SiD detector cost, by subsystem, and experienced-based estimates of the R&D as a percentage of final cost. This also involves risk assessment for each subsystem in terms of a contingency for the R&D.
(2)(below) We give a detailed list of the present SiD R&D projects as far as is known and their present/anticipated funding. Clearly there is a large gap in the figures for each subsystem deriving from the two approaches. However, we take this information to be input to the WWS R&D Panel and future deliberations, starting at Snowmass 2005.

Vertex Detector (Su Dong)

Main vertex detector technology: Monolithic CMOS, small pixels (5µm x 5µm) – with larger pixel readout zones. Aiming for thin devices.
Groups involved: Universities: U. Oregon and Yale, with collaboration/coordination with: University: U. Oklahoma, Labs: SLAC, KEK, FNAL, RAL
R&D equipment/manpower: DoE/LCRD $72K FY04
DoE/LCRD (awarded for FY05, requested for FY06, FY07):
FY05 $ 64.5K
FY06 $150K .....etc.

SiD R&D Report

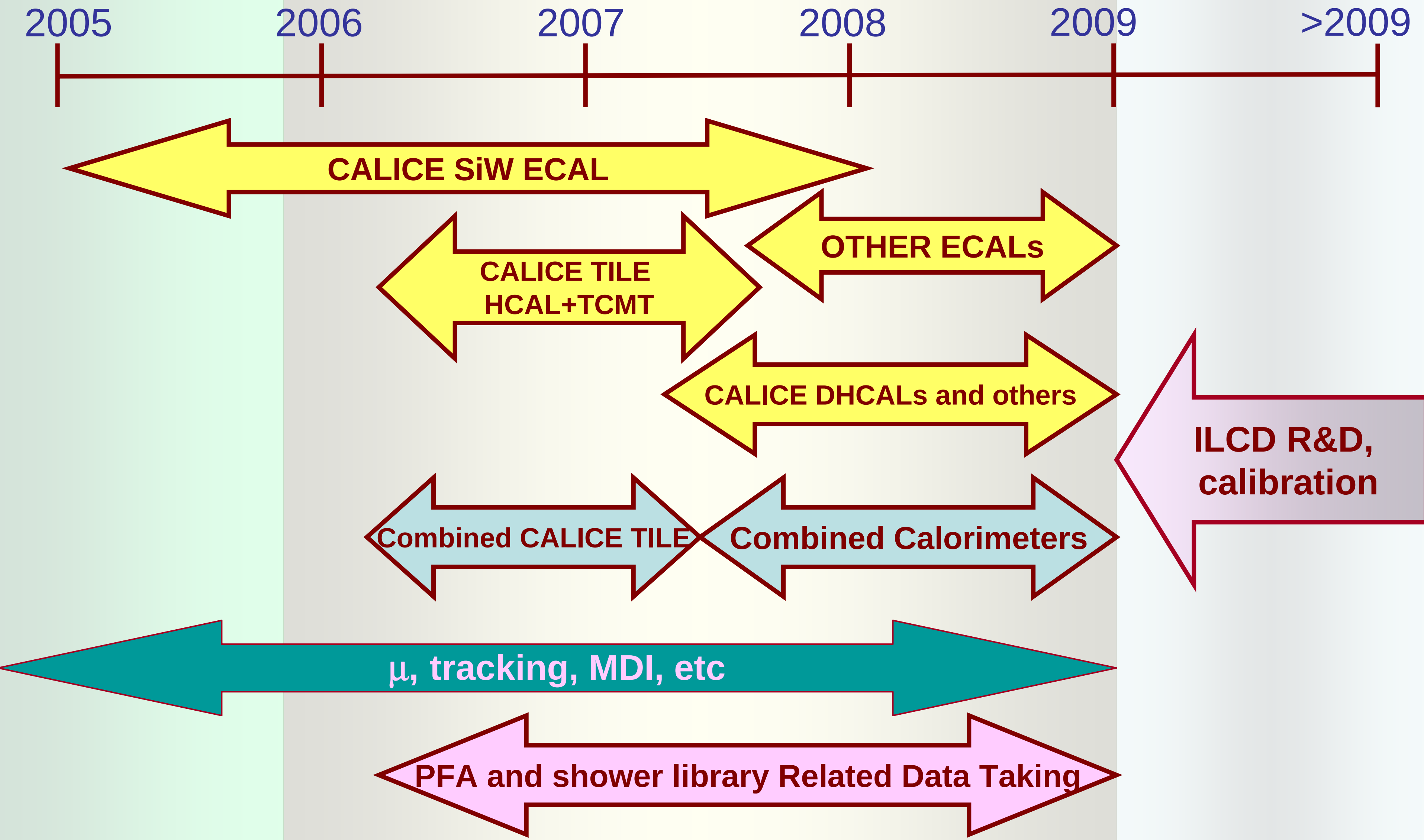
Goals for this meeting:

- Update/correct project descriptions, people, funding for specific current R&D efforts.

- Establish timeline, major steps, funding profiles with subsystem leaders – meetings with each subsystem leader(s)

- Start process of covergence between top-down and bottoms-up estimates.

Timeline of Beam Tests



Phase 0:
Prep.

Phase I: Detector R&D, PFA
development, Tech. Choice

Phase II

From Jae Yu

Timescales for LC Calorimeter and Muon development

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For the calorimeter, this means having trusted Monte Carlo simulations of technologies at unprecedented small distance scales (~1cm), well-understood energy cut-offs, and demonstrated, efficient, complete energy flow algorithms.

Since the first modules are only now being built, 3-5 years is not an over-estimate to accomplish these tasks!

* See talk by Jae Yu for Test Beam details