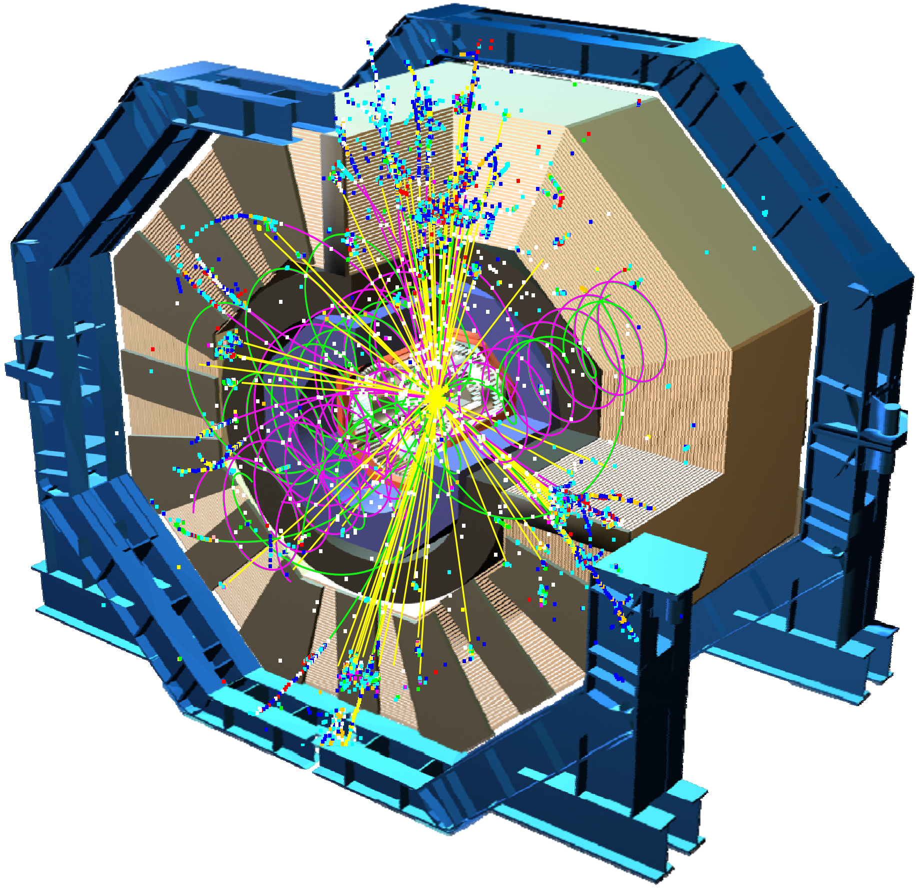
SiD – a concept for ILC



LCFOA - 2006

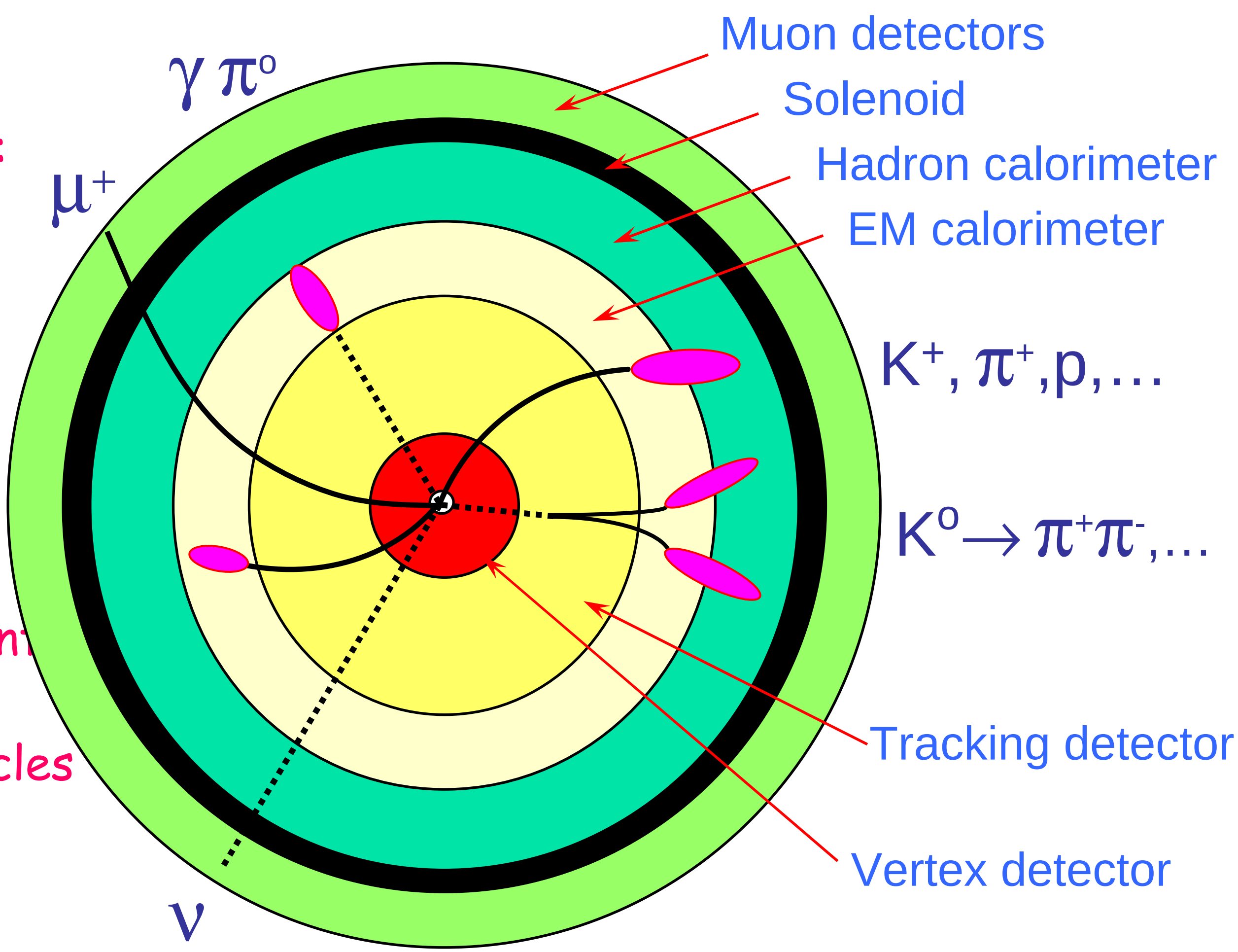
Functional Schematic of a Linear Collider Detector

- Fully wrap the interaction point with detectors

- Precision measurements: no perturbation of any particle property; "massless" detectors

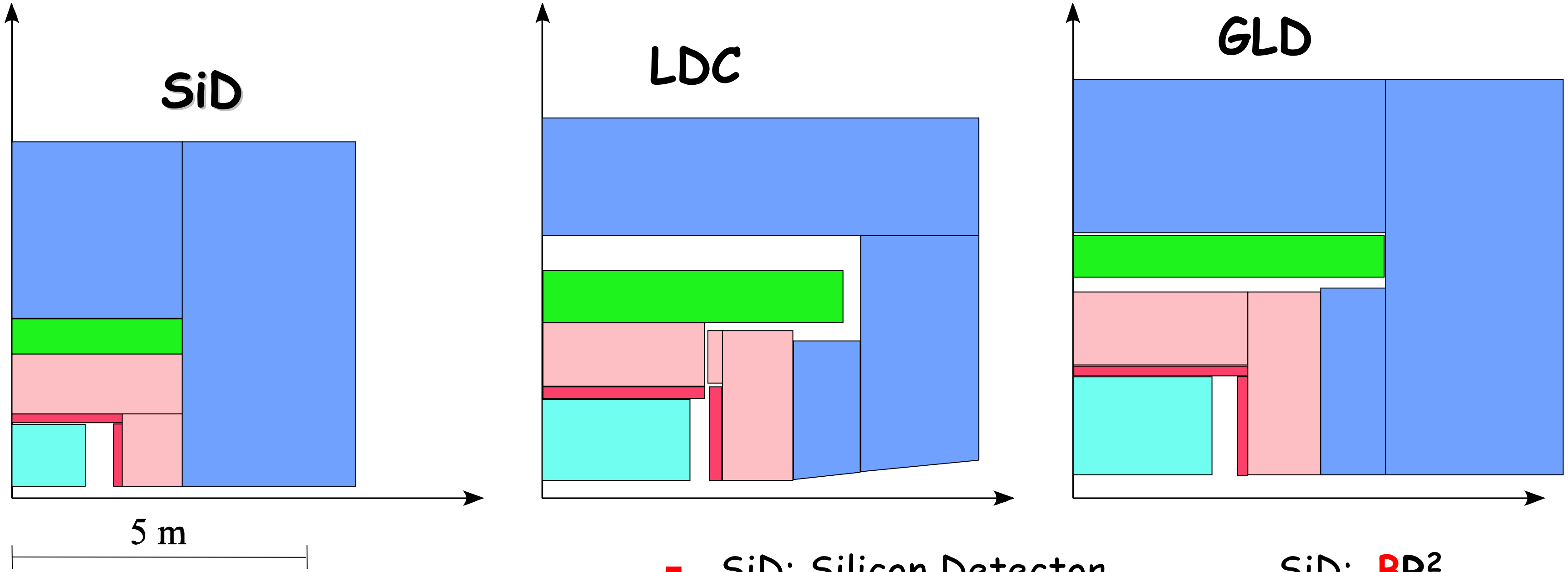
- After precision and tracking measurements, calorimetric measurement particle absorption

- Track penetrating particles



Detector Concepts

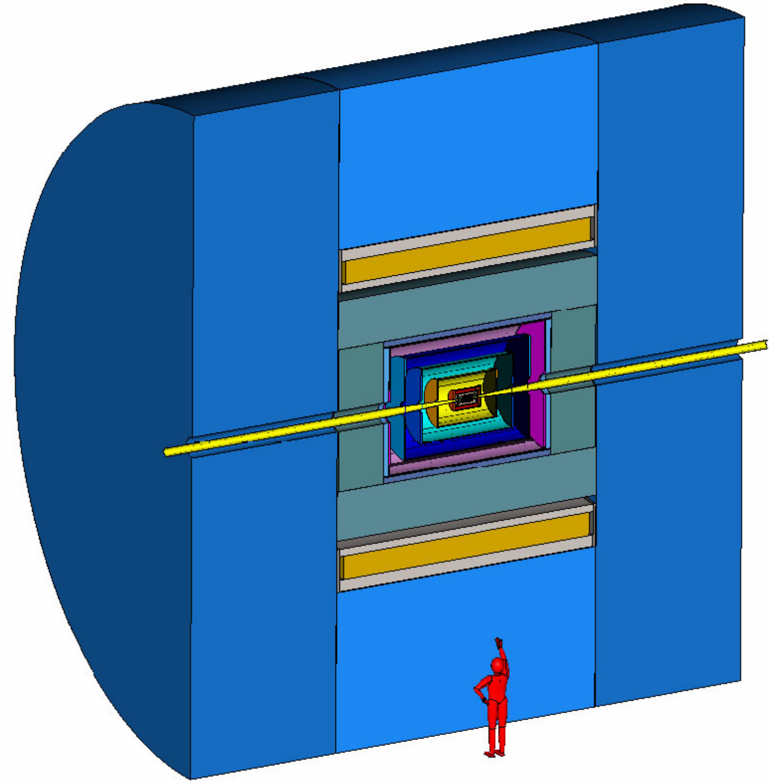
- Three + 1 detector concepts

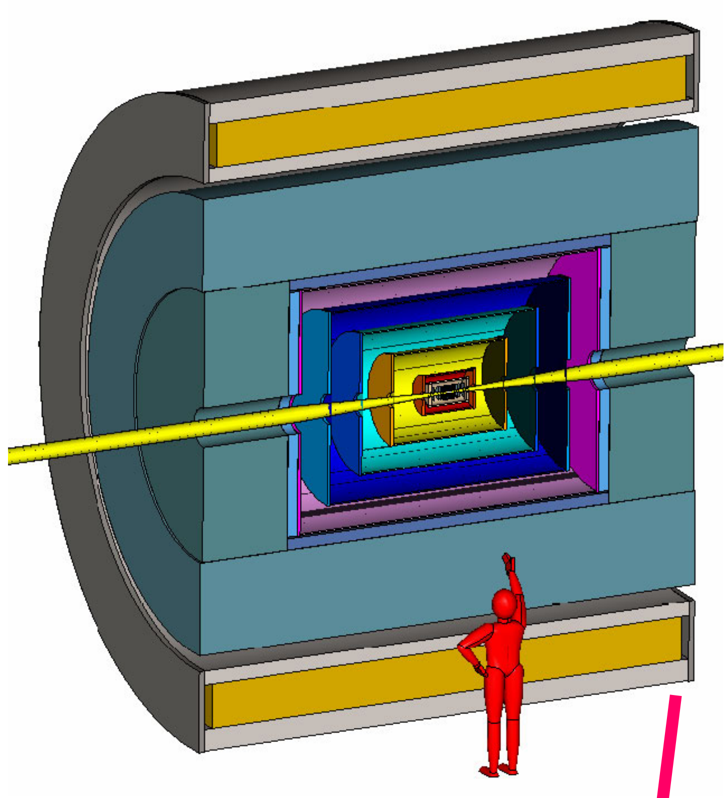


- Main Tracker
- EM Calorimeter
- Had Calorimeter
- Cryostat / Solenoid
- Iron Yoke / Muon System

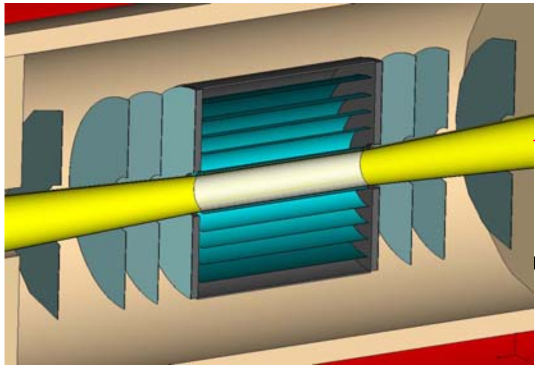
- SiD: Silicon Detector — SiD: BR^2
  - Small, 'all' silicon
- LDC: Large Detector Concept — LDC: $B\ R^2$
  - TPC based
- GLD: Global Large Detector — GLD: $B\ R^2$

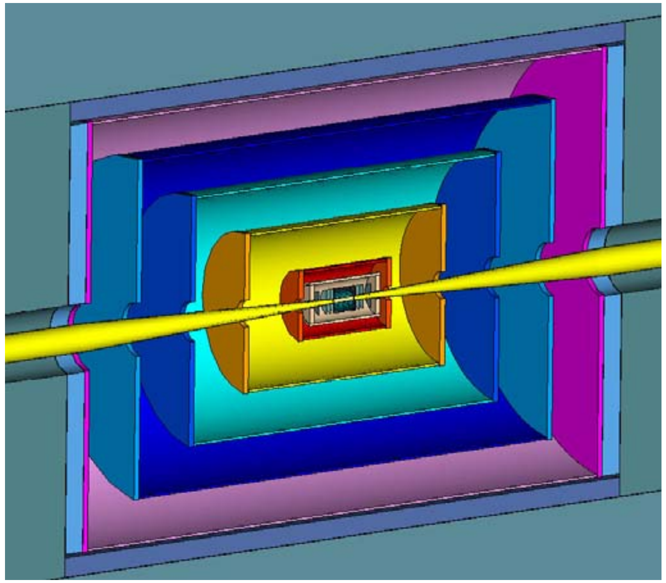
SiD – the example for this talk



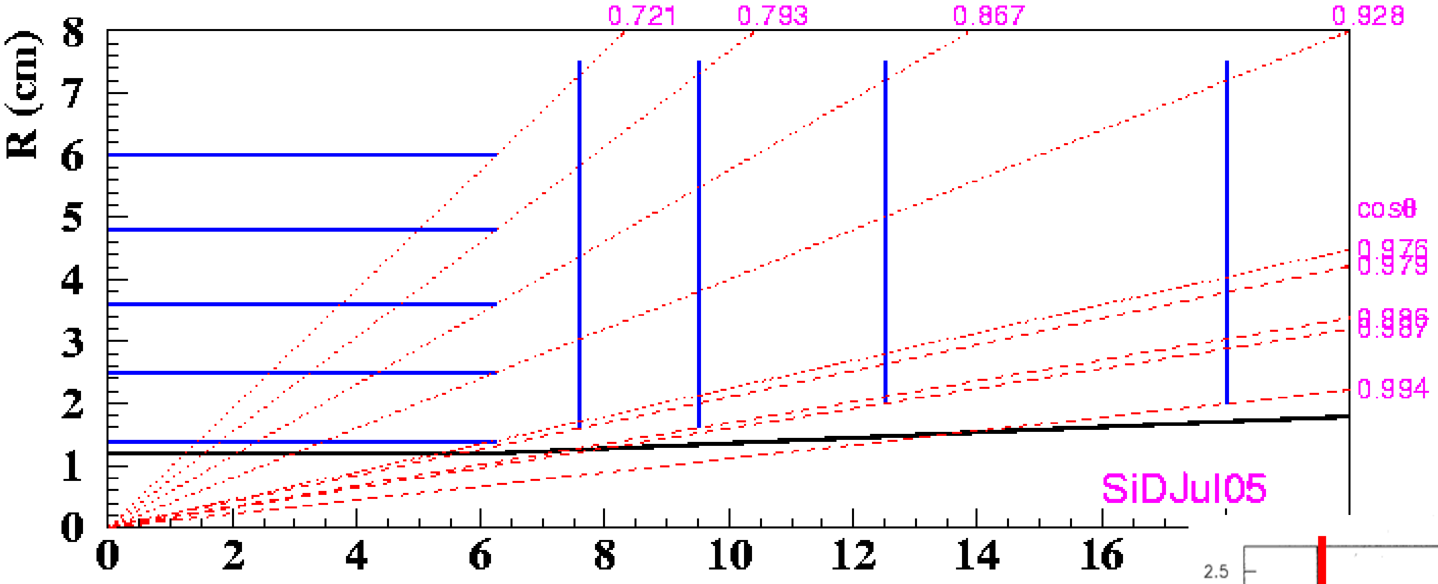


A high performance detector for the LC
Uncompromised performance
BUT Constrained & Rational cost

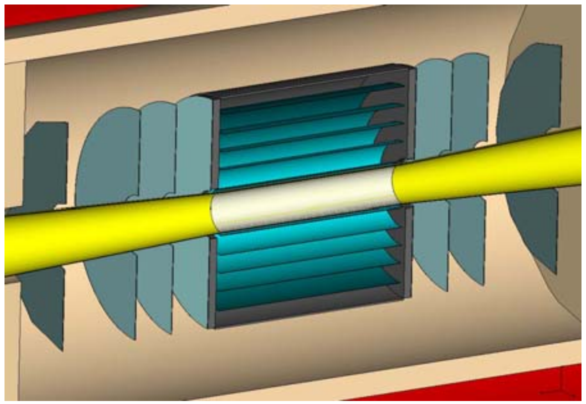




Vertexing= VXD

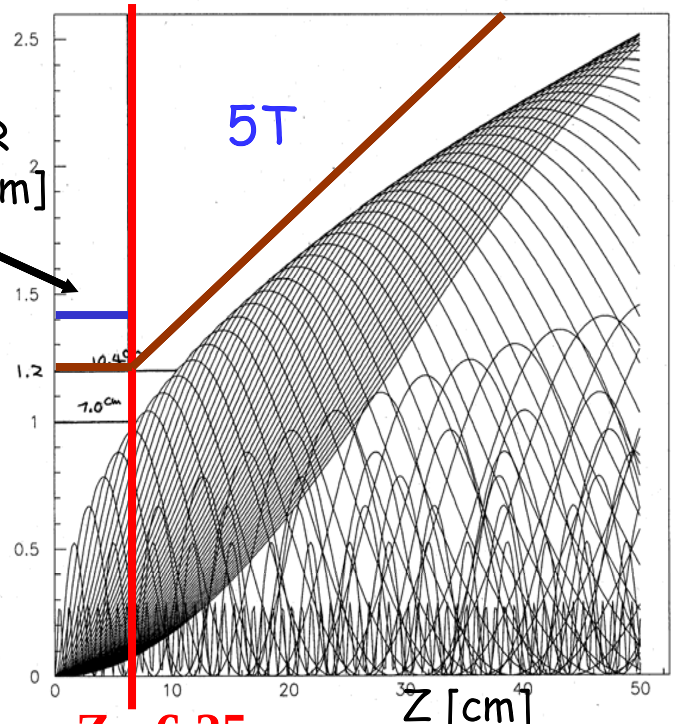


5 barrel layers
4 end disks



Design drivers:

Smallest radius possible
Clear pair background

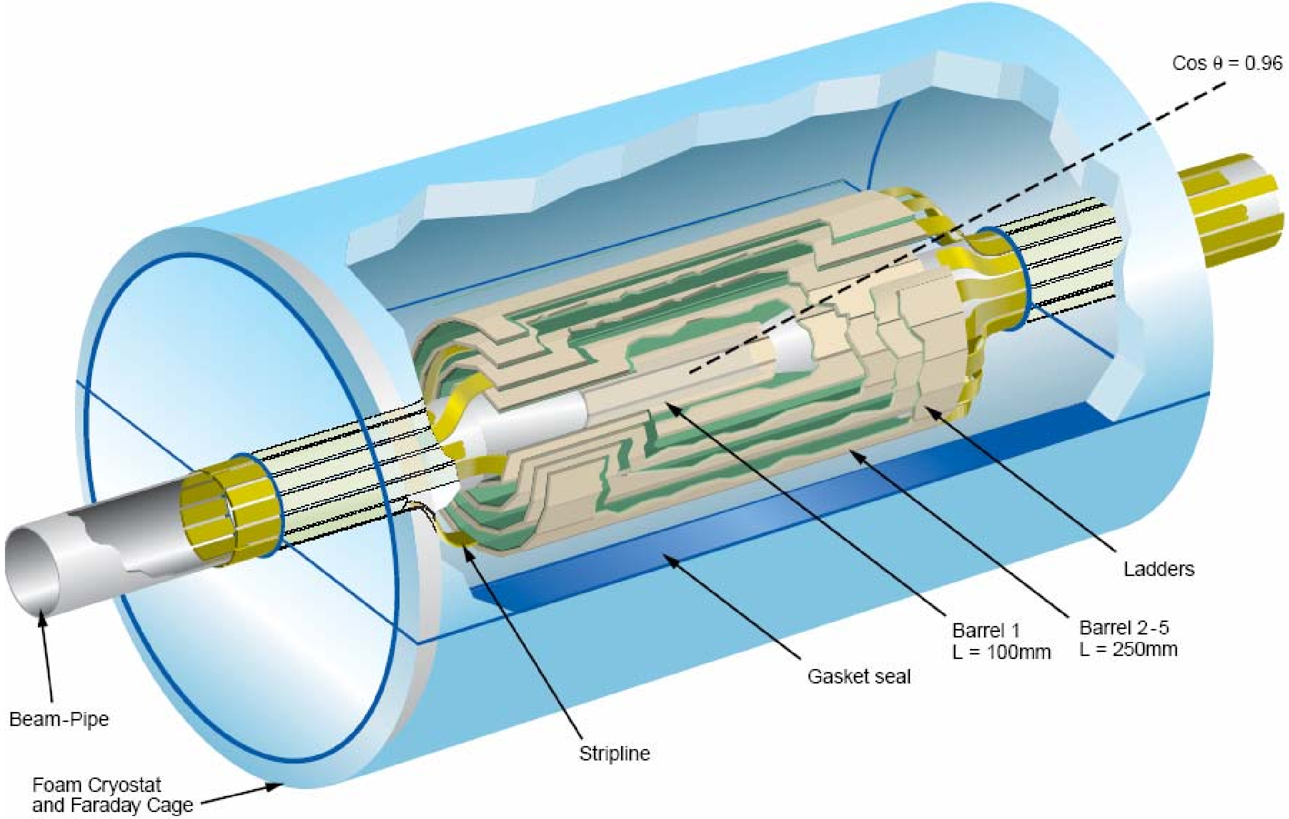


Role:

Ultra precise measurement of tracks near the interaction point. Measure decays of unstable particles a few microns from the IP. Determine track parameters for subsequent momentum measurement.

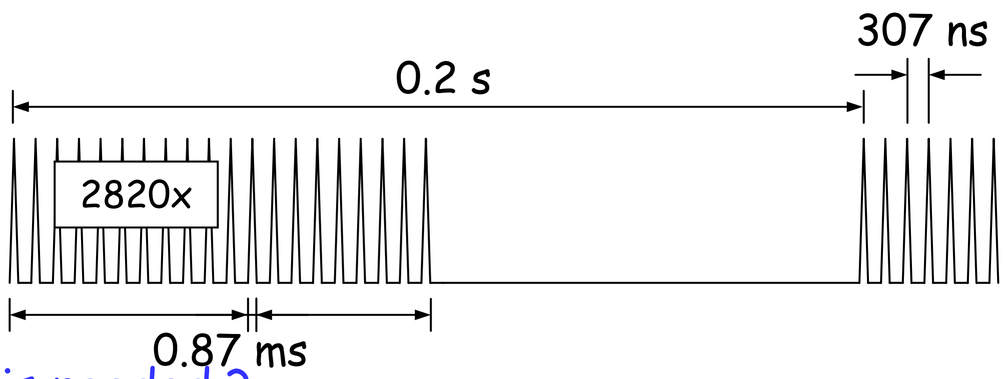
Generic Vertex Detector

- Multi-layered, high precision device
  - Very thin, low mass detectors; layer thickness of 0.1% X_0 per layer
    - 20 μm of Si is 0.02% X_0
  - High granularity: 5 - 20 μm pixels; 10^9 pixels for barrel detector
  - Low power dissipation
  - Radiation tolerant; inner layer at R_{in} = 14 mm
- Generic option employs ccd readout, with good experience from SLC
  - Operating T ≤ -40 °C
- But ILC Beam structure ill suited to CCD's. Intensive R&D for better sensor.



Sensors: The Challenge

- Beam structure



- What readout speed is needed ?
  - Inner layer 1.6 MPixel sensors
    - Once per bunch = 300ns per frame : *too fast*
    - Once per train ~100 hits/mm^2 : *too slow*
    - 5 hits/mm^2 => 50μs per frame: may be tolerable
      - Note: fastest commercial imaging ~ 1ms / MPixel
- How thin? How radiation hard ? How low the power consumption ?
- Major R&D effort in CMOS sensors
  - Fast CCD's
    - Pixel = active element is pixel
  - MAPS detectors
    - Monolithic = read-out electronics and sensor are integrated on the same substrate
    - Active = an amplifier (and as much as we can fit) is integrated into each pixel
    - Sensor

R&D on Active Pixels

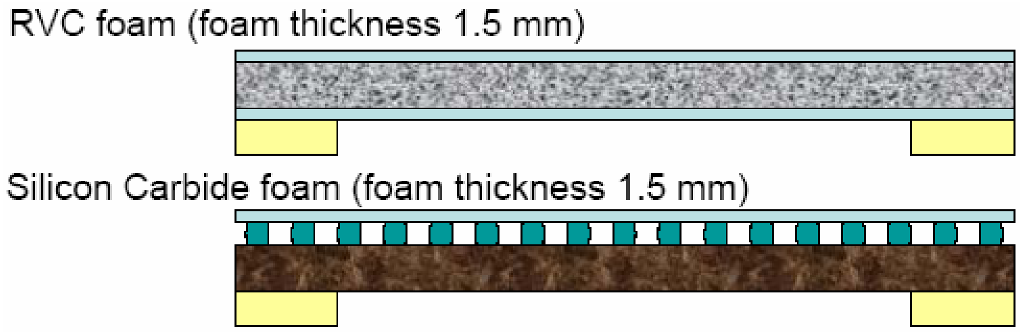
- Active pixels are very promising as particle detectors
- Drivers for particle detectors are common with industry
  - Improve charge sensing system
  - Control of epitaxial layer; number of metal layers
  - number of capacitors per pixel
  - Fast readout and fast signal processing; low power consumption
  - Small and 'massless'; operation at room temperature
  - Radiation tolerant
- Moreover, these detectors hold clear promise as imaging detectors for industrial applications
- However, to date there is very little common R&D between academia and industry and industry participation, with its vast expertise, is highly welcome (existing participation mainly in Europe)

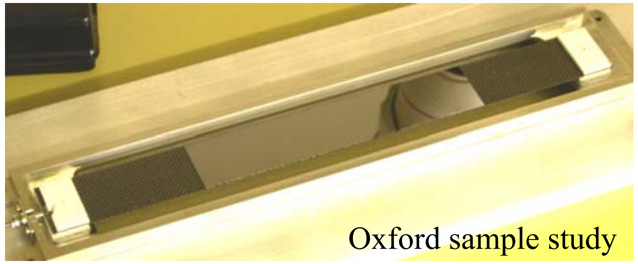
Industries: SOI: American Semi-Conductor, Boise, Idaho
thinning: Aptek Industries, San Jose, CA

MAP: Sarnoff Laboratories N.J.

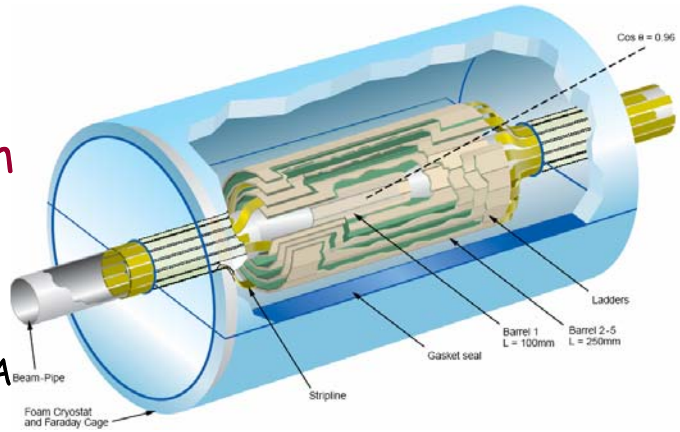
Materials R&D

- Materials R&D critical for successful design
- Ladder structures for vertex detector need to be thin and not deflect
  - same CTE as Si; good thermal conductivity; stiff





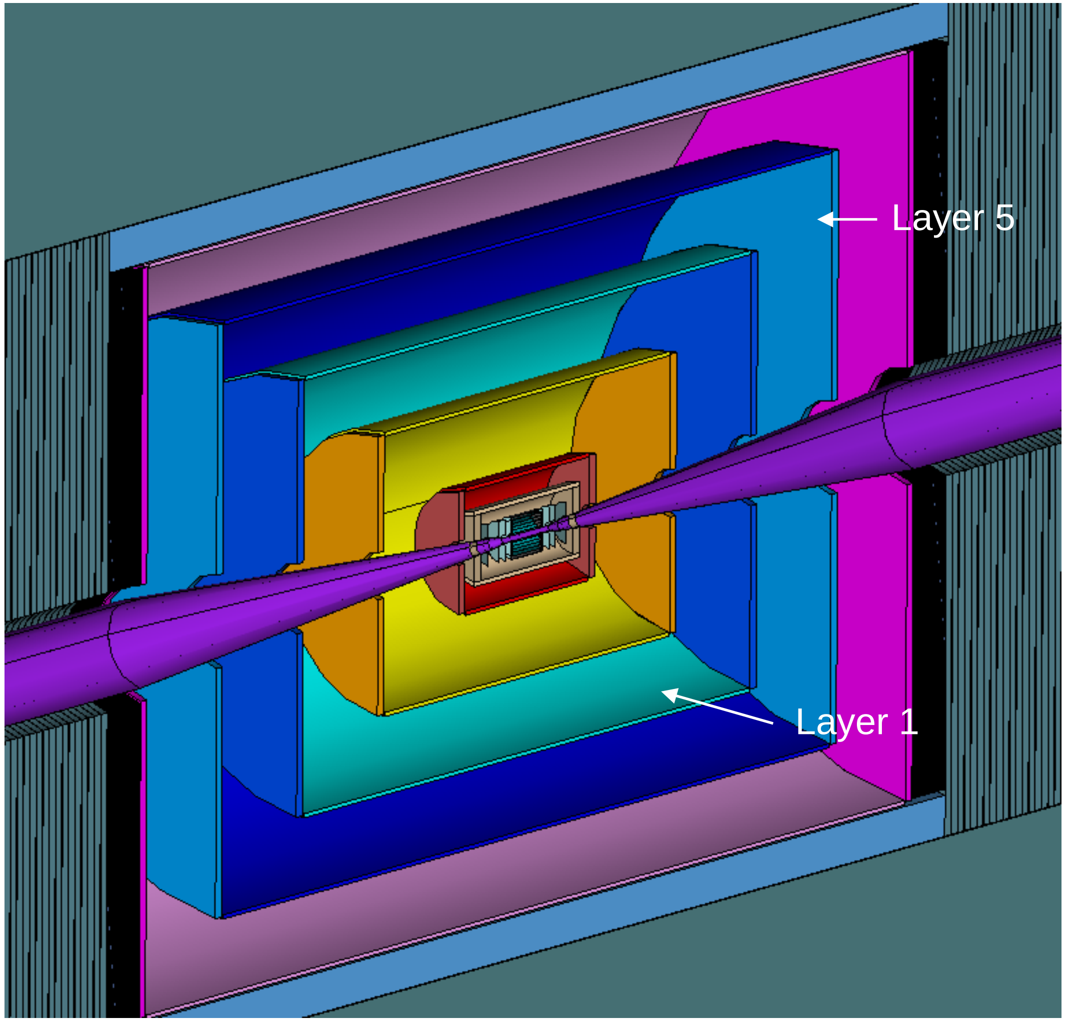
- Various support materials being studied
  - 8% Silicon Carbide Foam
  - 3% Reticulated Vitreous Carbon (RVC) foam
  - Other materials ?



Industries: ERG Materials and Aerospace Corporation, Oakland, CA
Ultrament, Pacoima, CA

Tracker (Momenter??)

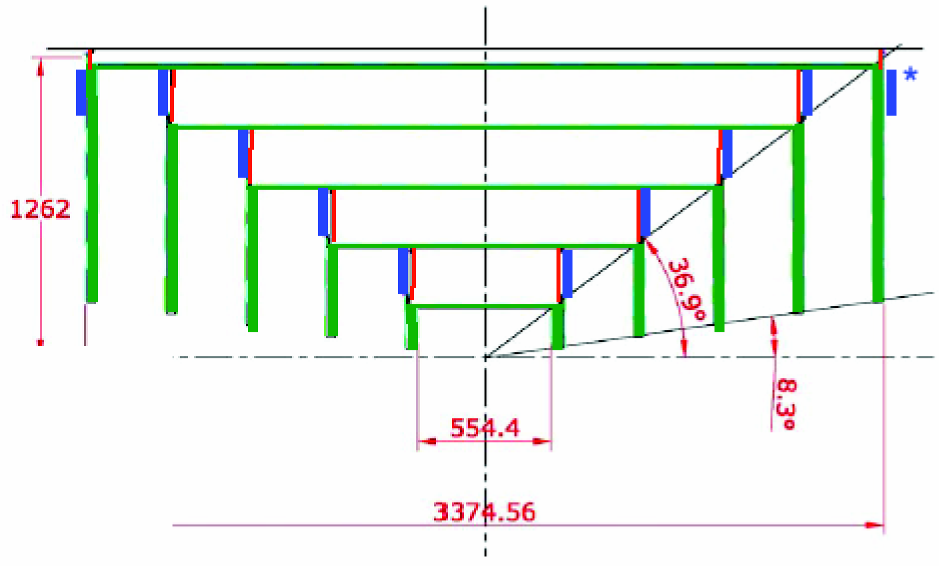
- 5-Layer silicon strip outer tracker, covering R_{in} = 20 cm to R_{out} = 125 cm, to accurately measure the momentum of charged particles

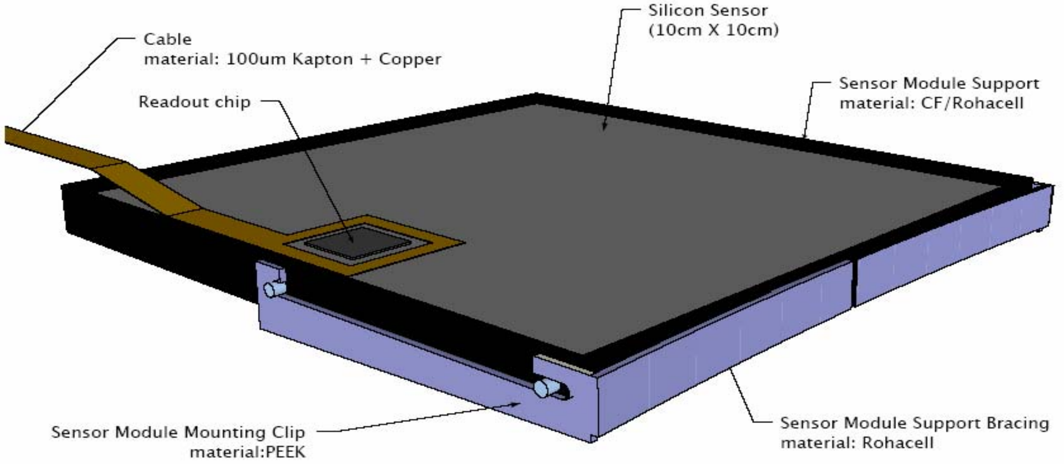


- Support
  - Double-walled CF cylinders
  - Allows full azimuthal and longitudinal coverage
- Barrels
  - Five barrels, measure Phi only
  - Eighty-fold phi segmentation
  - 10 cm z segmentation
  - Barrel lengths increase with radius
- Disks
  - Five double-disks per end
  - Measure R and Phi
  - varying R segmentation
  - Disk radii increase with Z

Tracking I

- Sensor/Power/readout motherboard modular

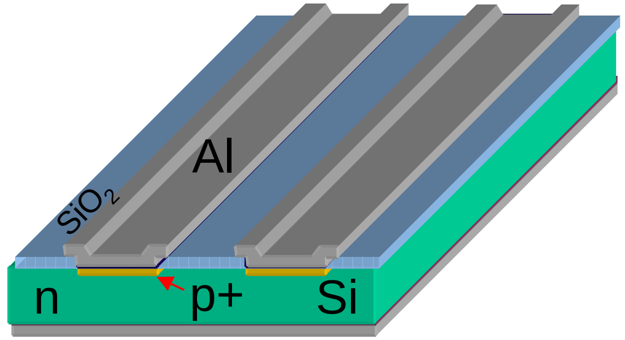


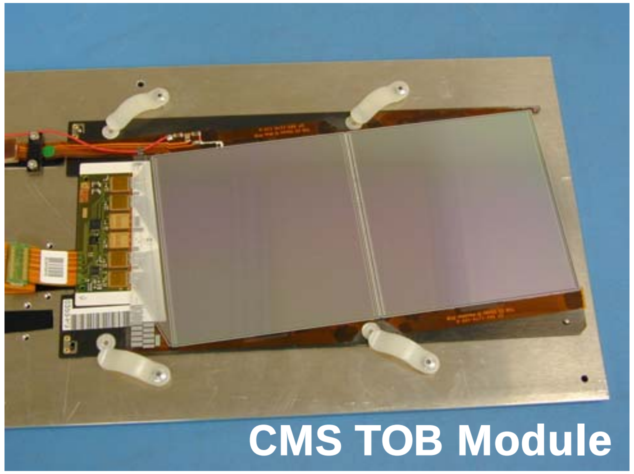


- Cylinders tiled with 10x10cm sensors with readout chip
- Single sided (ϕ) in barrel
- R, ϕ in disks
- Modules mainly silicon with minimal support (0.8% X_0)
- Overlap in *phi* and *z*

Silicon Strip Detectors

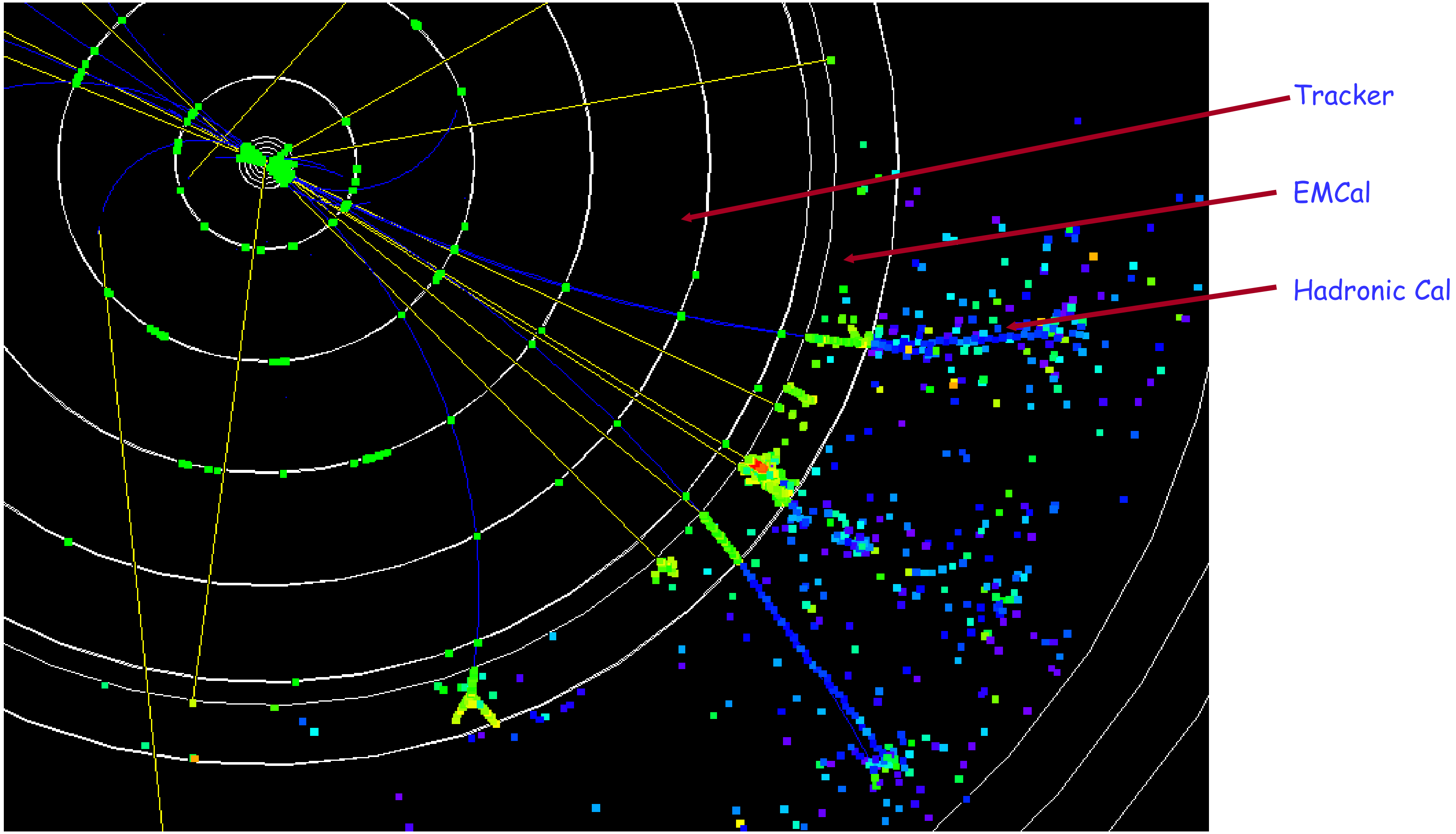
- Silicon wafers
  - FZ, high resistivity silicon, p-on-n
  - 6" wafers, 300 mm thick
  - strip pitch 50 mm
  - sensor size ~10 x 10 cm^2
- Tracker scale
  - Current price for processed Si \$6/cm^2
  - Total Si cost \$6.0M
- Industry issues
  - Cost reduction
  - Explore double-sided sensors
  - Module fabrication (>10,000) in industry





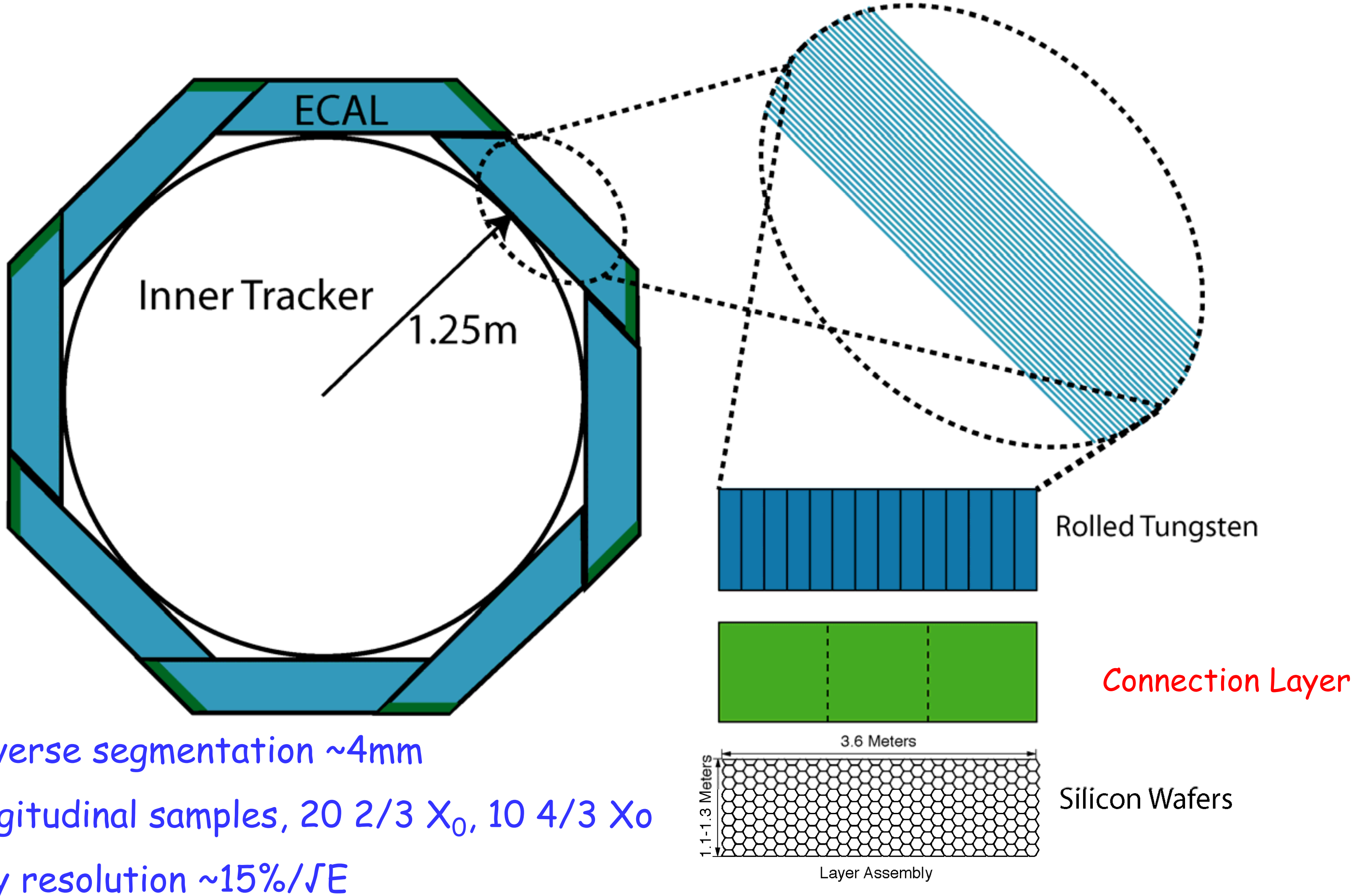
Industries: **CiS, Erfurt, Germany**
Colibrys, Neuchatel, Switzerland
Eurisys, Strasbourgh, France
ELMA, Zelenograd, Moscow
Hamamatsu Photonics, Hamamatsu City, Japan
Micron Semiconductor, Lancing, Great Britain
ONSemi (TESLA), Roznov pod Radhostem, Czech Republic
SGS-Thompson (ST) Microelectronics, Catania, Sicily, Italy
Sintef, Oslo, Norway

SiD Calorimetry



- We would like a detector which can examine new physics processes in detail…Requires new levels of pixelization.

EMCal Concept



Transverse segmentation ~4mm

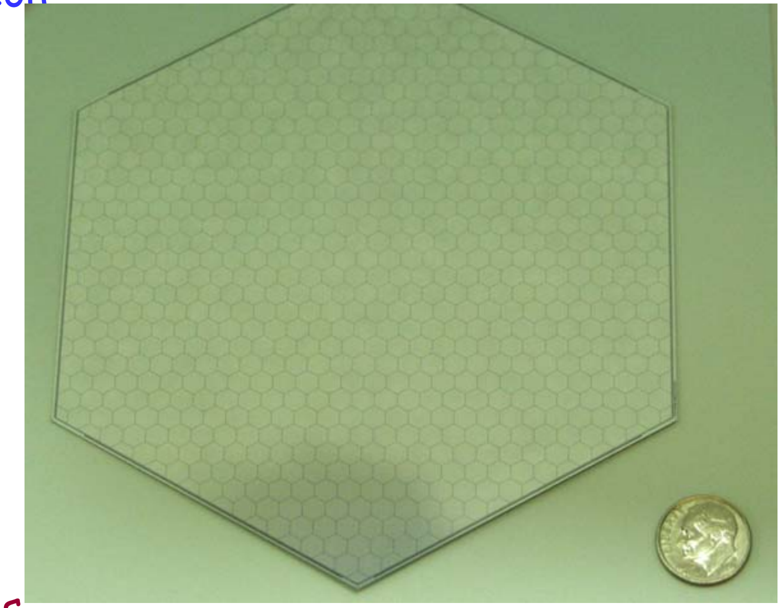
30 longitudinal samples, 20 2/3 X_0, 10 4/3 Xo

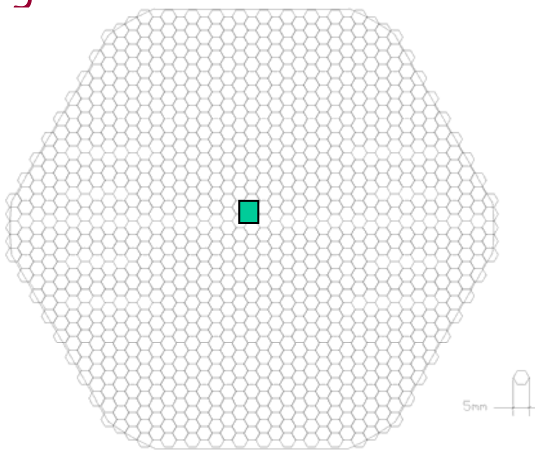
Energy resolution ~15%/√E

Gap ~1mm, effective Moliere radius ~12 mm

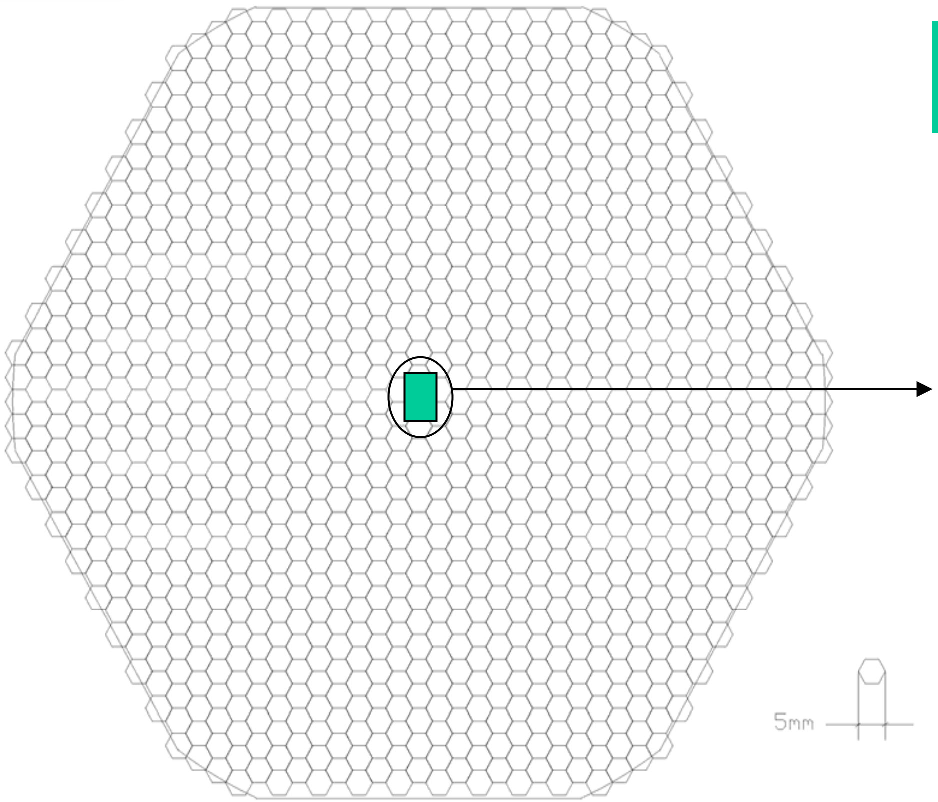
EM Calorimetry

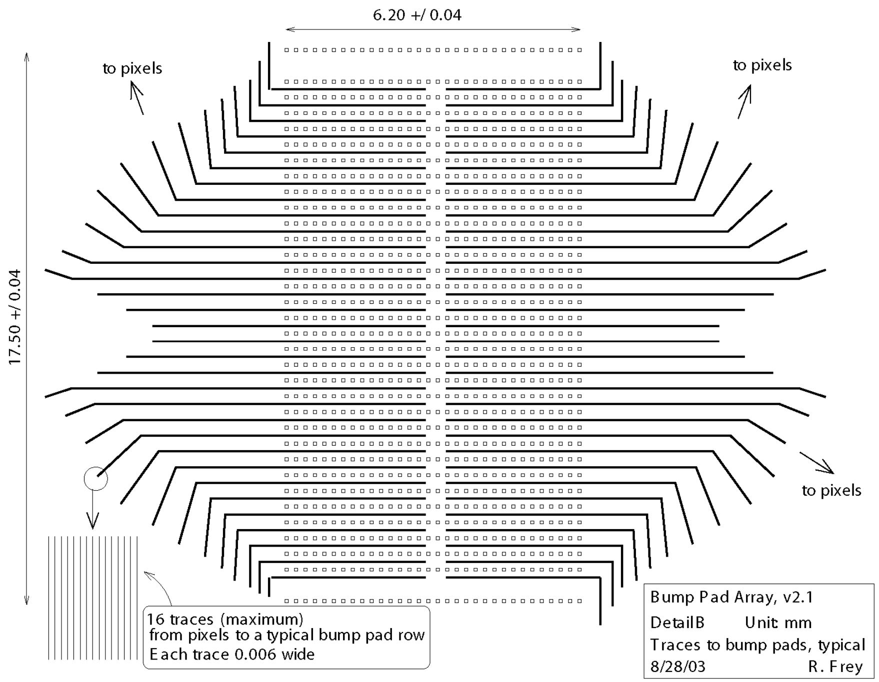
- Proposed active medium for EM calorimeter: silicon
- Silicon from 6" wafers
  - Same as for silicon strip detectors
  - p-on-n silicon
  - 300 μm thick
- Transverse segmentation
  - 5 x 5 mm^2 hexagonal pixels
  - 1024 channels per wafer, one ASIC/wafer
  - Total 50 10^6 readout channels
- Scale
  - Area of ~ 1300 m^2 of silicon ; ~90,000 wafers
  - Total silicon cost $25M assuming a cost of $2/cm^2
  - ~40 tonnes 2.5 mm tungsten; ~40 tonnes 5 mm tungsten
- Industry
  - Same industries as for strip detectors
  - H.C. Starck



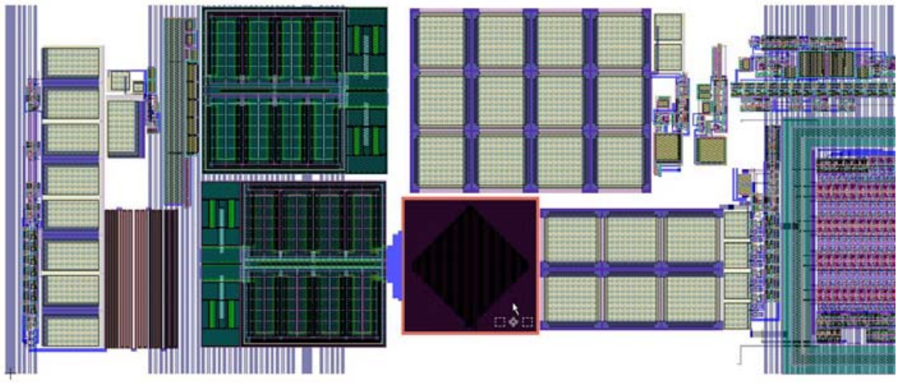


Wafer and readout chip connections





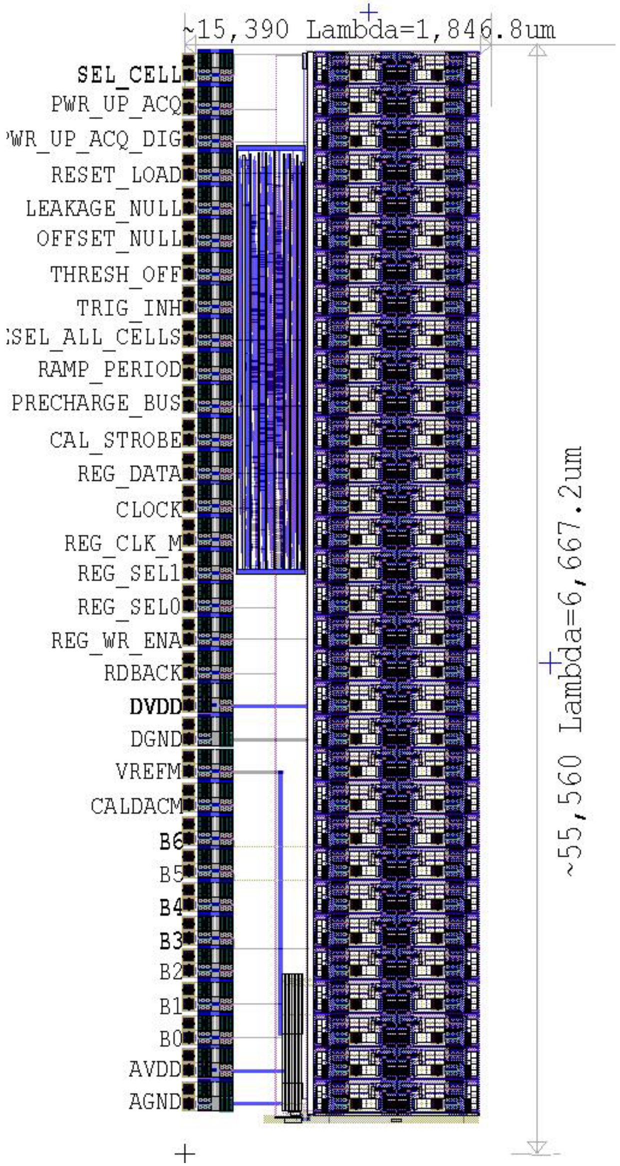
KPiX SiD Readout Chip



One cell. Dual range, time measuring, 13 bit, quad buffered. Very low noise; very low power.

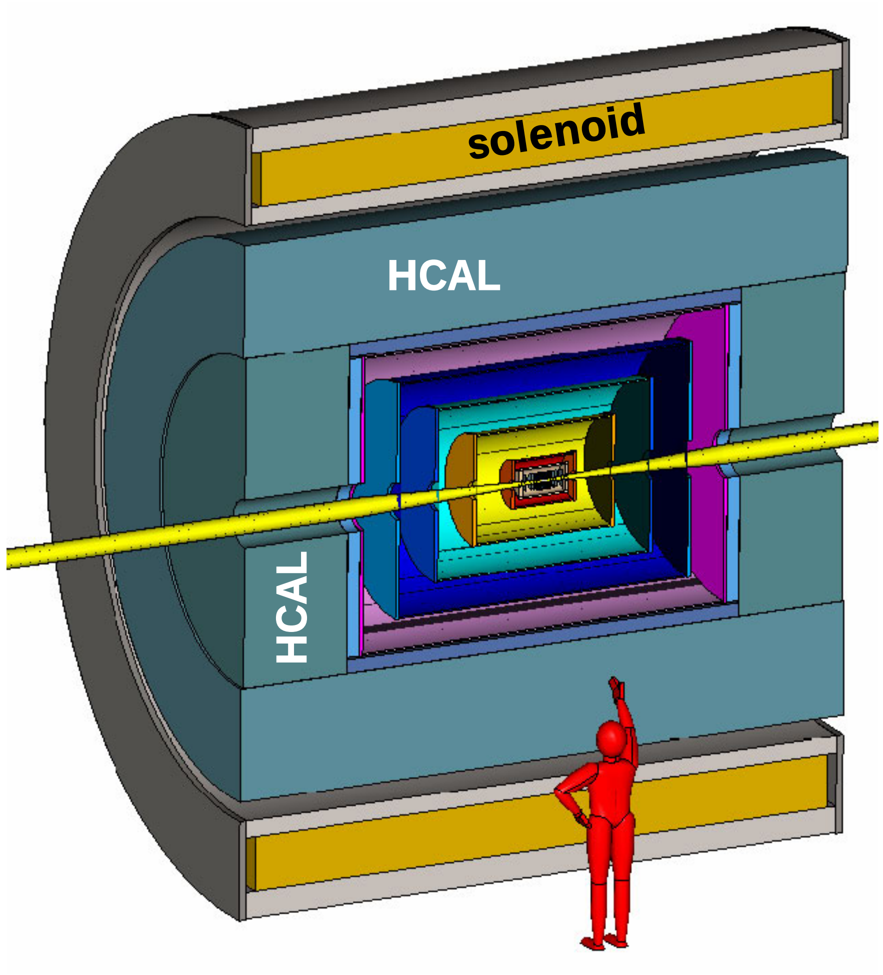
TSMC 0.25 micron technology

Prototype: 2x32 cells: full: 32x32



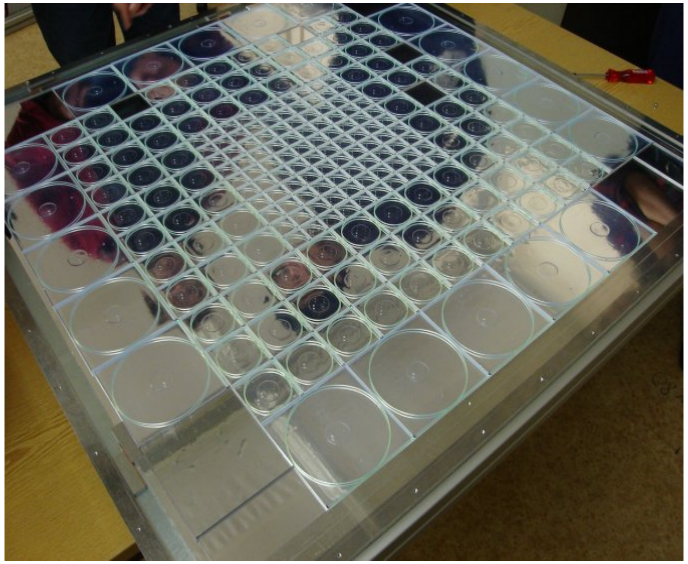
Hadron Calorimetry

- Sampling calorimeter with steel (or tungsten) as absorber
  - Radial extent
    R_i = 139 cm, R_o =237 cm
  - 35 - 55 layers, ~2.0 cm sampling
  - Transverse segmentation:
    1x1 - 5x5 cm^2
- Active media
  - Resistive Plate Chambers (RPC's)
  - Gas Electron Multipliers (GEM's)
  - Scintillator
- Scale
  - Area of ~3000 m^2
  - Weight ~400,000 kg of steel
  - Total of 30 10^6 readout channels

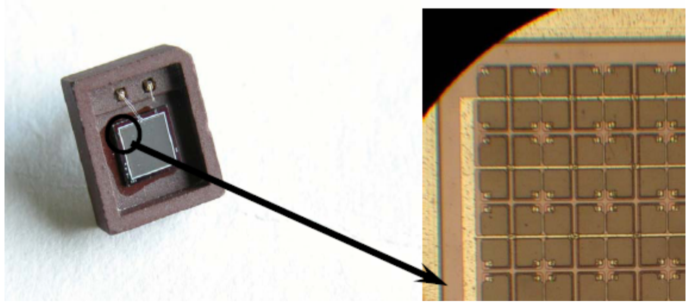


Scintillator HCAL

- Scintillator with WLS fiber
  - Industry leaders Kuraray and Saint Gobain (Bicron).
- Readout through Silicon Photo Multipliers
  - Pixel Geiger Mode APDs
  - Gain 10^6, bias ~ 50 V, size 1 mm^2 with about 1000 pixels
  - QE x geometry ~ 15%
- Larger devices with greater sensitivity in the blue are desirable so that they can be coupled directly to the scintillator without the WLS fiber
- Fast reset devices; minimize rate dependence

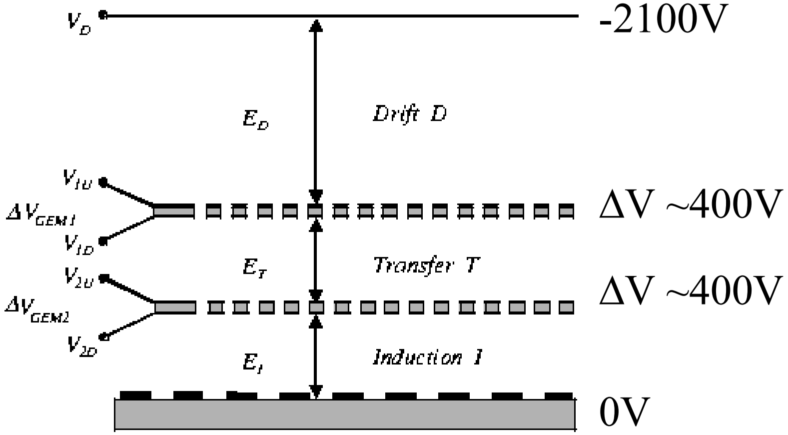


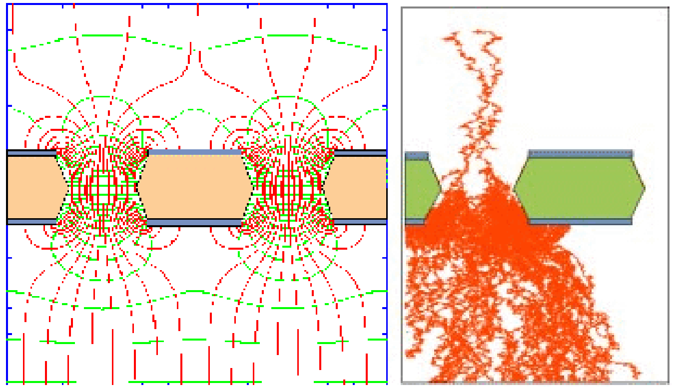
SiPM 3x3 mm^2, 5625 pixels

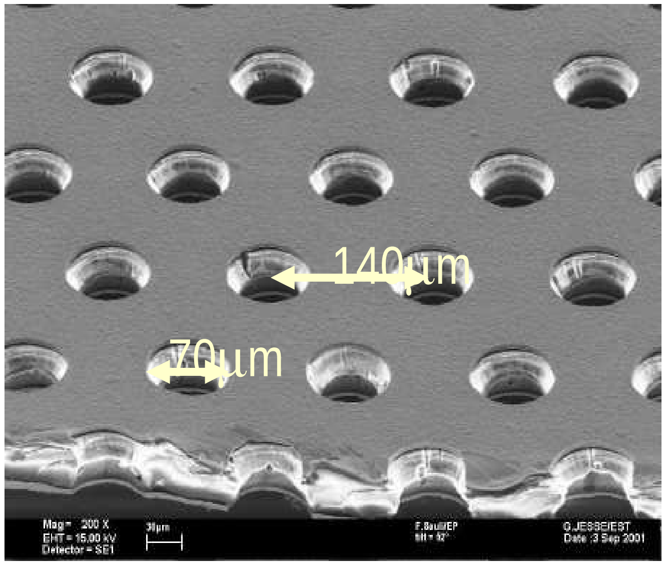


Industries: Advanced Photonix, Camarillo, CA
aPeak, Newton, MA
CPTA, Moscow; MEPhI and Pulsar, Moscow
Hamamatsu Photonics, Hamamatsu City, Japan (to Japanese Academia)

Gas Electron Multiplier Calorimetry







- Active medium is a gas (Ar/CO_2)
- Signal multiplication takes place in holes of two copper foils separated by kapton
- Amplification uses 2 or 3 stages

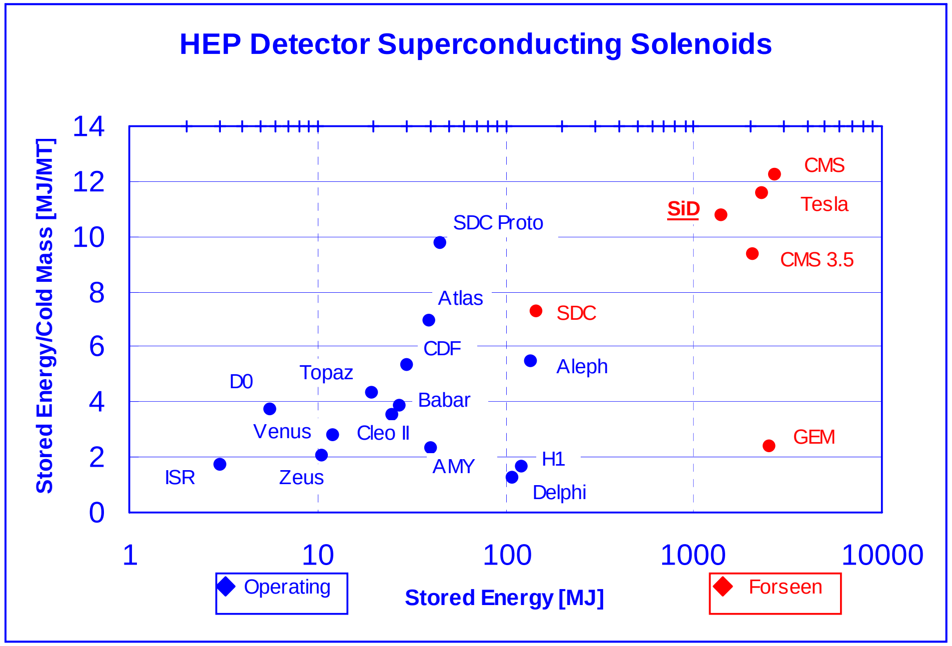
- Current limitation is the size of the copper foils
  - Maximum size 30 x 30 cm^2
  - Cost < $1k/$m^2$

Industries: 3M

Solenoid

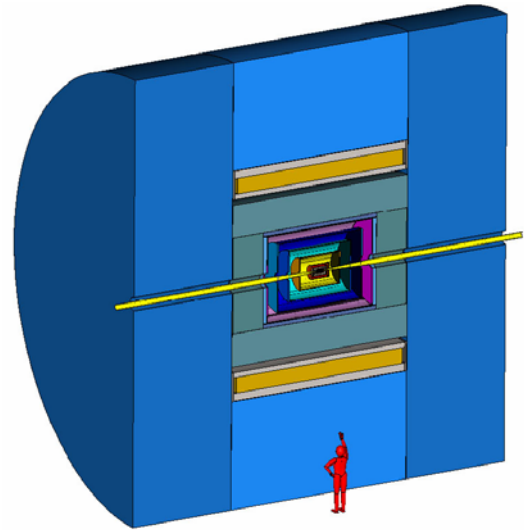
- All detector concepts employ a solenoid
- SiD field: B(0,0) = 5T (not done previously)
  - Clear Bore Ø~ 5m; L = 6 m: Stored Energy ~ 1.4 GJ

SiD Half-coil 6 layers x116 t/l

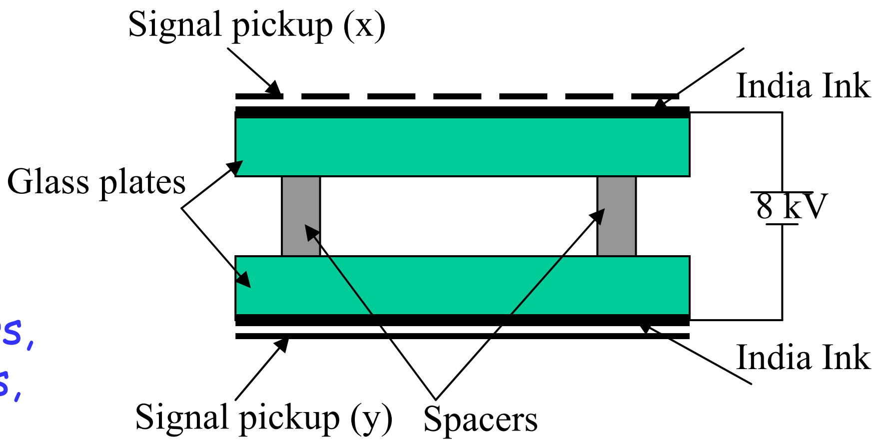


- CMS Magnet Specifications
  - B=4 T, 2.7 GJ
    Ø = 6 m, L = 13 m
- Built as collaboration of 6 institutions: CERN, SACLAY, ETHZ/FNAL, INFN Genoa, UWisc
- With >14 major industrial partners
  - Sumitomo (Japan)
  - Alusuisse (Switzerland)
  - Outokumpu (Finland)
  - Brugg (Switzerland)
  - Nexans (Switzerland)
  - Techmeta (France)
  - Kawasaki Heavy Industry (Jp)
  - Comptoise Industrie (France)
  - Hudong Heavy Machinery (Cn)
  - DWE (Germany)
  - Criotec (Italy)
  - SES (Islamabad, Pakistan)
  - Ansaldo (Italy)
  - Air Liquide (France)

Muon System



- Outer detector consists of an array of detectors to track deep penetrating particles (muons) and acts as a flux return for the B-fiels
  - Steel absorber
    - 24 10 cm plates
    - $3 \cdot 10^6$ kg ($4 \cdot 10^6$ kg) central (ends)
  - Large area; low cost detectors
    - Area of ~5000 m^2
    - scintillator bars and WLS fibers with multi-anode PMT readout
      - Hamamatsu, Phillips
    - Resistive Plate Chambers
      - passing charged particle induces an avalanche, which develops into a spark
      - The discharged area recharges slowly through the high-resistivity glass plates
- Anticipate that all assembly of the detectors, as well as the associated readout electronics, will be done by industry.



SiD Scale

- Vertex Detector
  - Assume detector 16 x 60 mm. Then 200-300 detectors…
- Tracker
  - ~80 m^2 Si detector. Most strips, forward may be pixels
  - ~8500 modules
- EMCal
  - ~1200 m^2 Si detector
  - ~90,000 readout chips and associated cables, electronics
  - ~80 tonnes tungsten
- HCal
  - ~3000-4000 m^2 detector – RPC, GEM, scintillator
  - ~500 tonnes tungsten or 400 tonnes steel
- Solenoid
  - ~1.4 Gigajoule stored energy
  - ~25 km superconducting winding
- Muon System
  - ~5000 m^2 detectors
  - 3-4 kilotonnes steel

Summary

- An ILC detector is a substantial project, though small compared to the machine.
- There are significant areas of R&D, particularly for pixel detectors, that require industrial participation and may have broader application.
- Many of the subsystem components are of a scale that will require industrial participation.
- This is a step in what we hope will be a productive and mutually beneficial dialogue between the ILC detector community and industry