The Silicon Detector Concept

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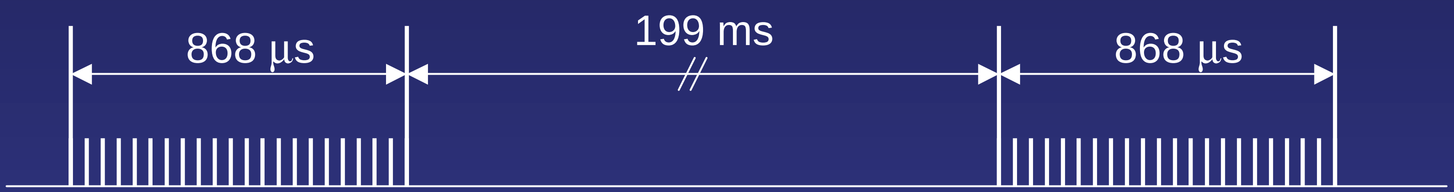
What is SiD ?

- A detector concept based on Si/W calorimeter and Si tracker.
- Silicon detector is
  - fast,
  - robust against background,
  - fine in segmentation, and by now
  - mature.

Time Structure and Event Rates

- There are five trains of 2820 bunches per second (nominal).

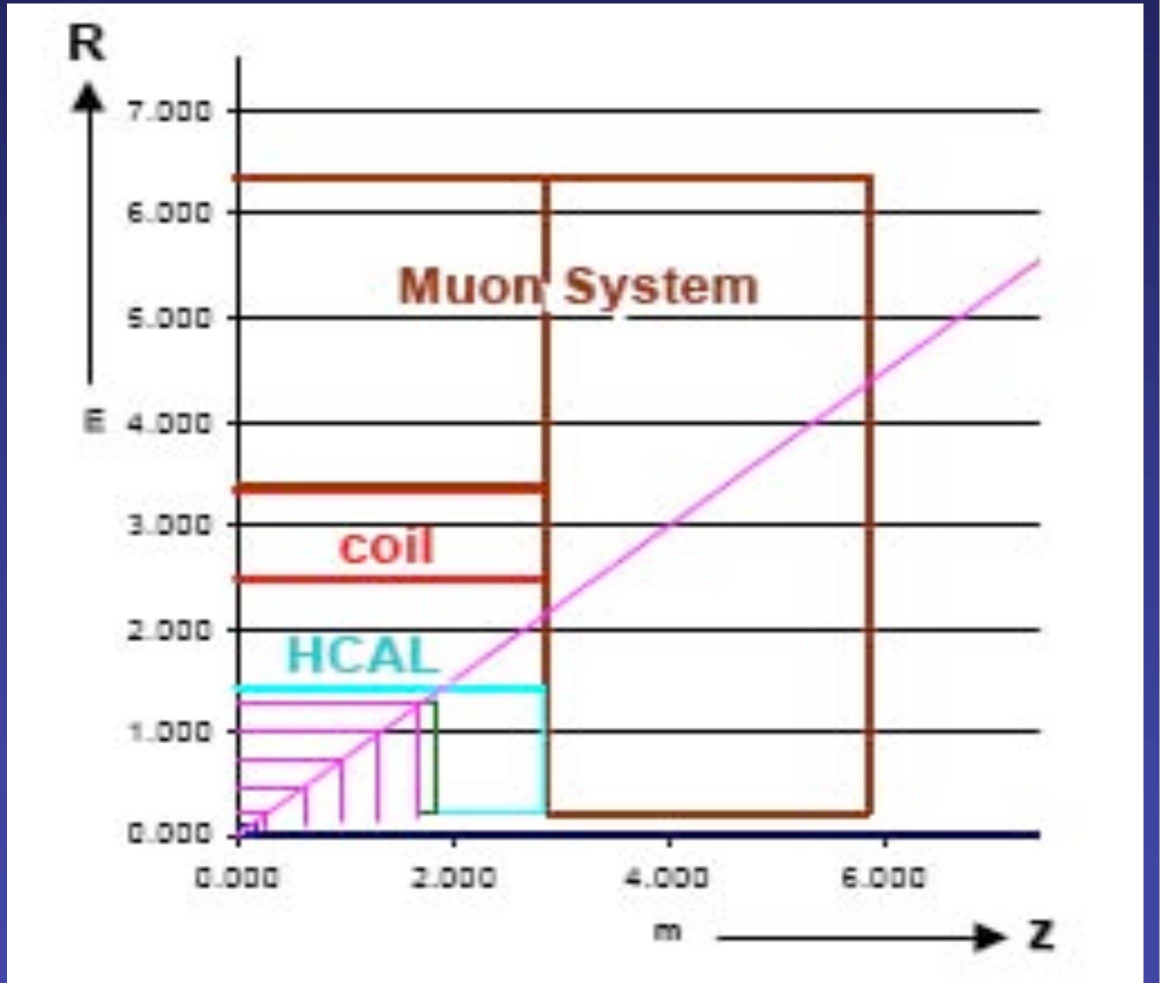


  - bunch separation is 307.7 ns
  - $\mathcal{L} = 3\ 10^{34}\ cm^{-2}s^{-2}$ (at $\sqrt{s}$ = 1000 GeV)
- Event rates
  - At a luminosity of $3\ 10^{34}\ cm^{-2}s^{-1}$
    - $e^+e^- \rightarrow$ qq, WW, tt, HX: 0.1 event / train
    - $e^+e^- \rightarrow \gamma\gamma \rightarrow$ X: ~200 / train
- Background from beamstrahlung
  - $6\ 10^{10}\ \gamma$/ BX
  - 140,000 e^+e^- / BX + secondary particles (n,μ)

Must have a Silicon device (either the tracker or Ecal) to identify the right bunch crossing. True for any of concept studies !!

SiD

- Pixel Vertex detector
- Si trackder
- Si/W is for the ECAL and digital calorimetry for HCAL
- All within 5T magnet
- plus instrumented flux return as a muon detector
- Results in the smallest of the three detector concepts



~ 12m x 12m x 12m

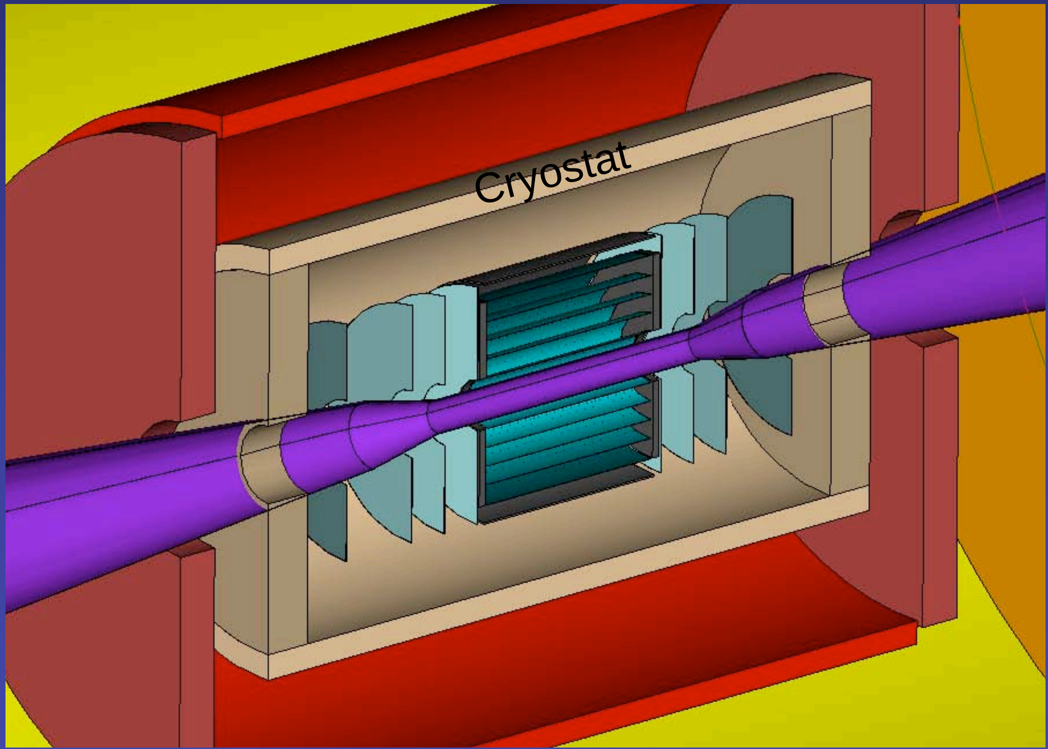
Tracker

Impact parameter resolution : $\sigma_{r\phi} \approx \sigma_{rz} \approx 5 \oplus 10 / (p \sin^{3/2}\theta)\ \mu\mathrm{m}$

Momentum resolution : $\sigma_{P_T} / P_T^2 \approx 5 \times 10^{-5} (\mathrm{GeV}^{-1})$

Vertex Detector

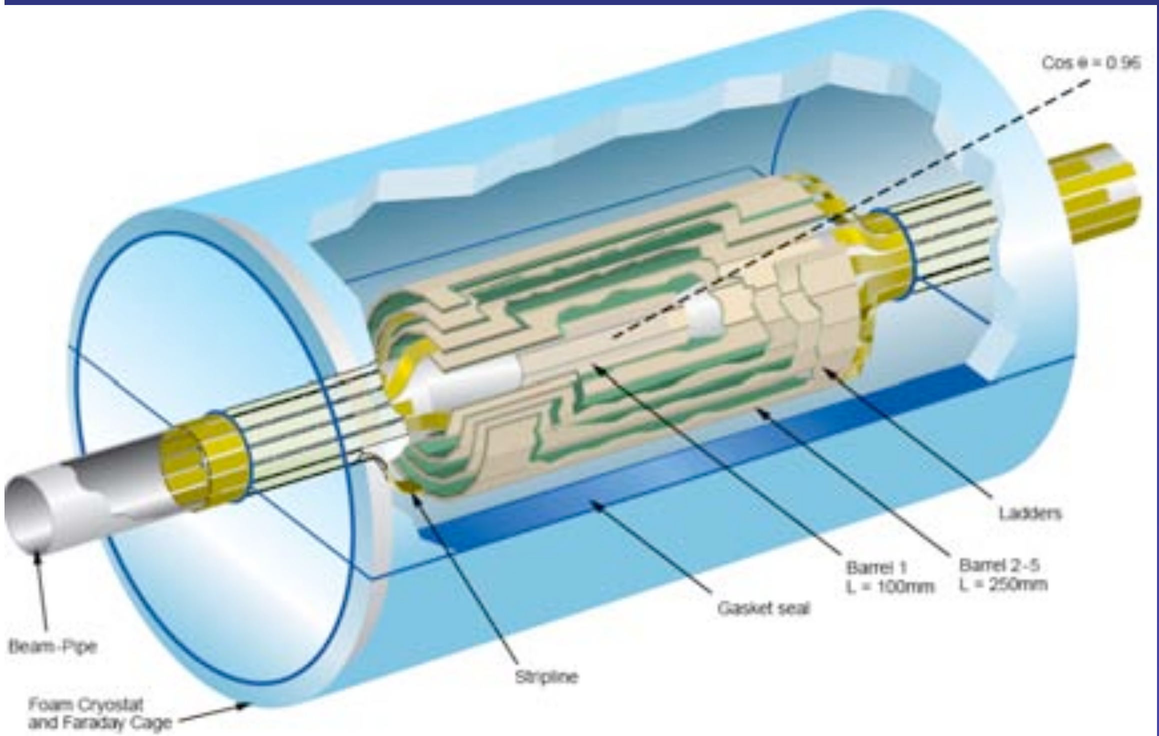
- 5-layer / 4-disk detector covering R_{in} = 14 mm to R_{out} = 60 mm
  - To tag b- and c- jets and tau-leptons with high efficiency reducing background
  - To efficiently perform heavy quark sign selection, via the vertex charge



- Barrels
  - Five barrels
  - 24-fold phi segmentation
  - two sensors covering 6.25 cm each
  - All barrel layers same length
- Disks
  - Four disks per end
  - Inner radius increases with Z
- Support
  - Supported from beampipe

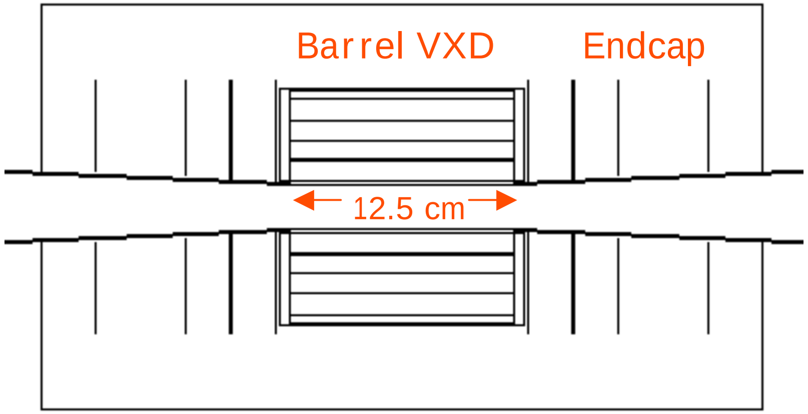
Barrel Design Vertex Detector

- Generic option employs CCD readout:
  - 15 – 20 μm pixel size
  - 10^9 pixels for barrel detector
  - R_{in} = 14 mm (cf. 25 mm SLD, 15mm Belle)
  - Layer thickness of 0.1% X_0 per layer !
    - 20 μm of Si is 0.02% X_0



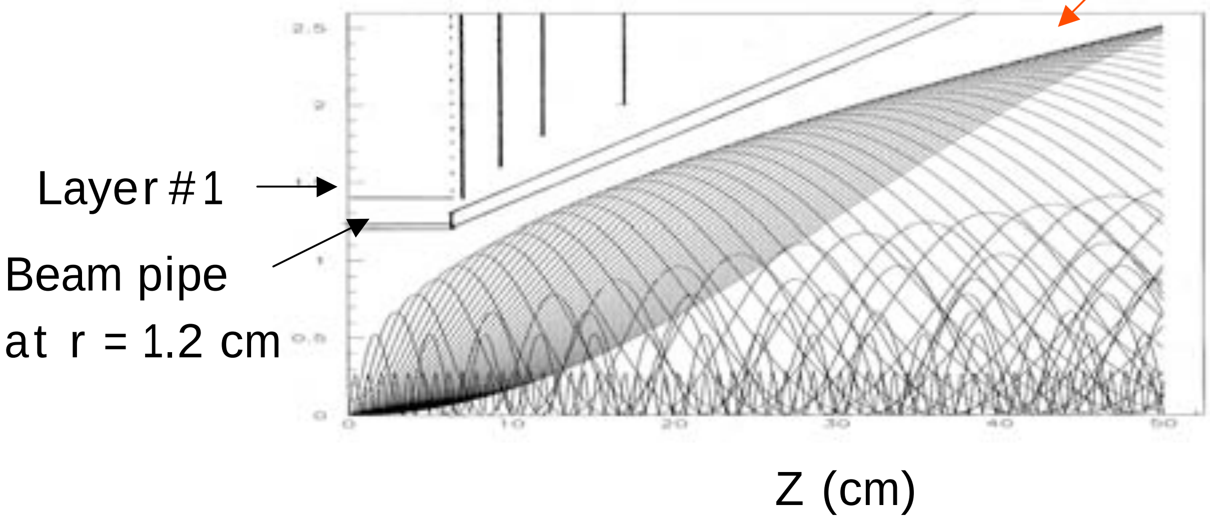
- Disadvantage of CCD readout is that it is slow
  - 20% occupancy in inner layer if integrated over a train
  - Significant concert regarding EMI (SLD experience)
- Many different alternative technologies (CMOS) being pursued
  - DEPFET
  - MAPS
  - HAPS
  - FAPS
  - ISIS
  - SoI
  - …

Beampipe radius a critical parameter, which is determined by the background from e^+e^- -pairs



- Five barrel layers
  r = 1.4, 2.6, 3.7, 4.8, 6.0cm
  z = +/- 6.25 cm
- Four endcap layers
  z = 7.0, 9.5, 12.0, 17cm

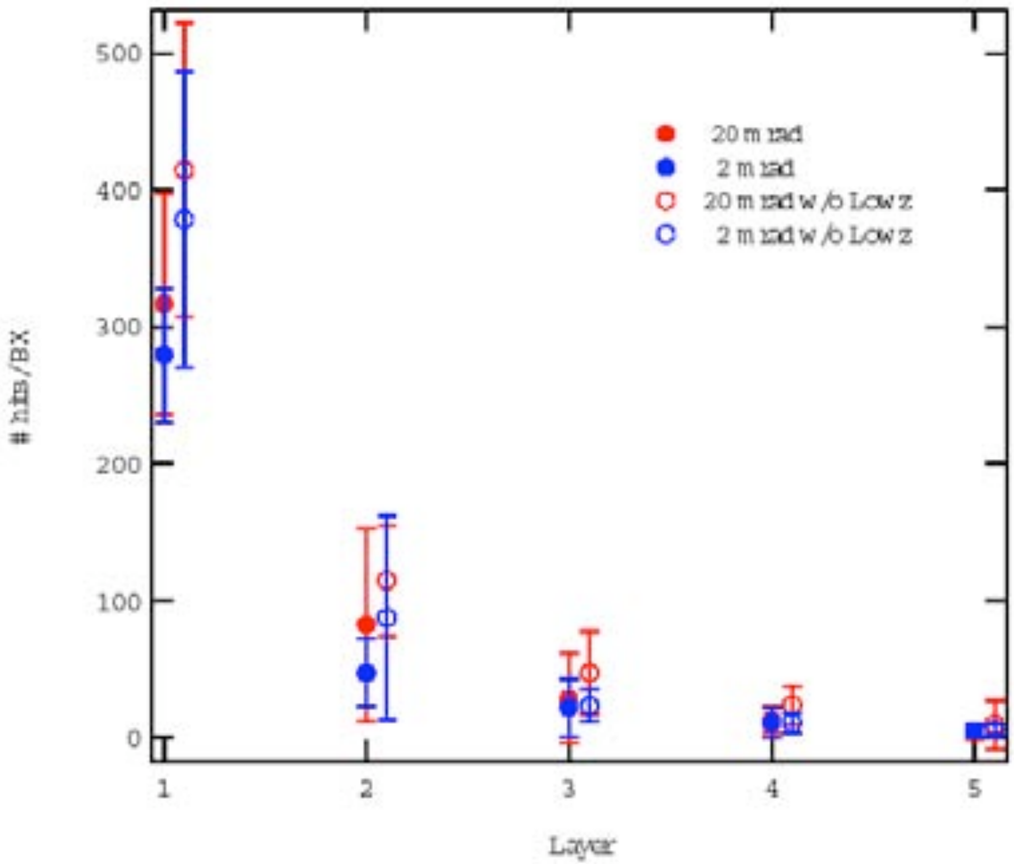
500GeV nominal in 5 Tesla and 20 mrad Xing



Average and RMS of VXD hits over 20 bunches

Full simulation

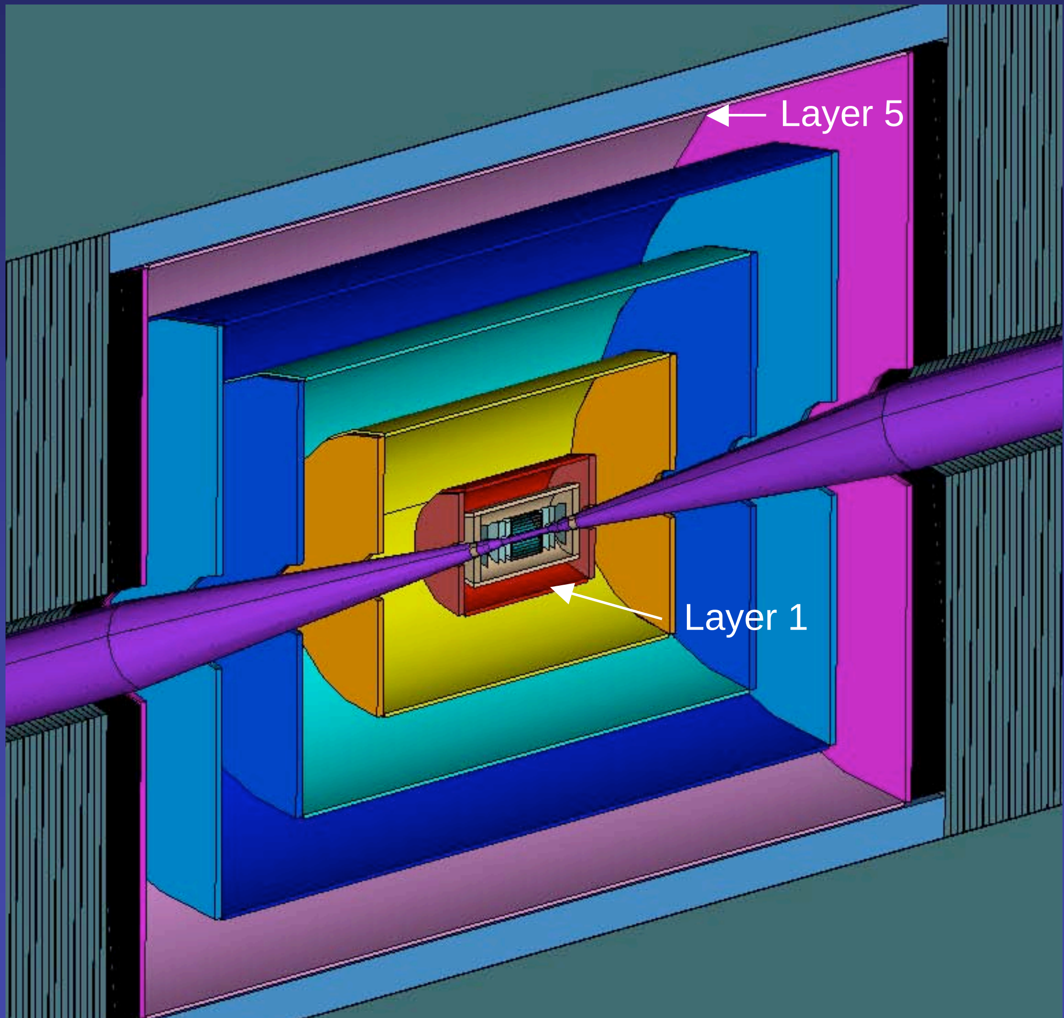
Barrel VXD



- ~10% more hits in 20 mrad crossing angle
- But the difference is small compared to the bunch-to-bunch fluctuation.
- ~30% more hits if no lowz.
- 300 hits/BX (layer #1)
  - 0.027 hits/mm^2/BX
  - 77 hits/mm^2/Train

Silicon Outer Tracker

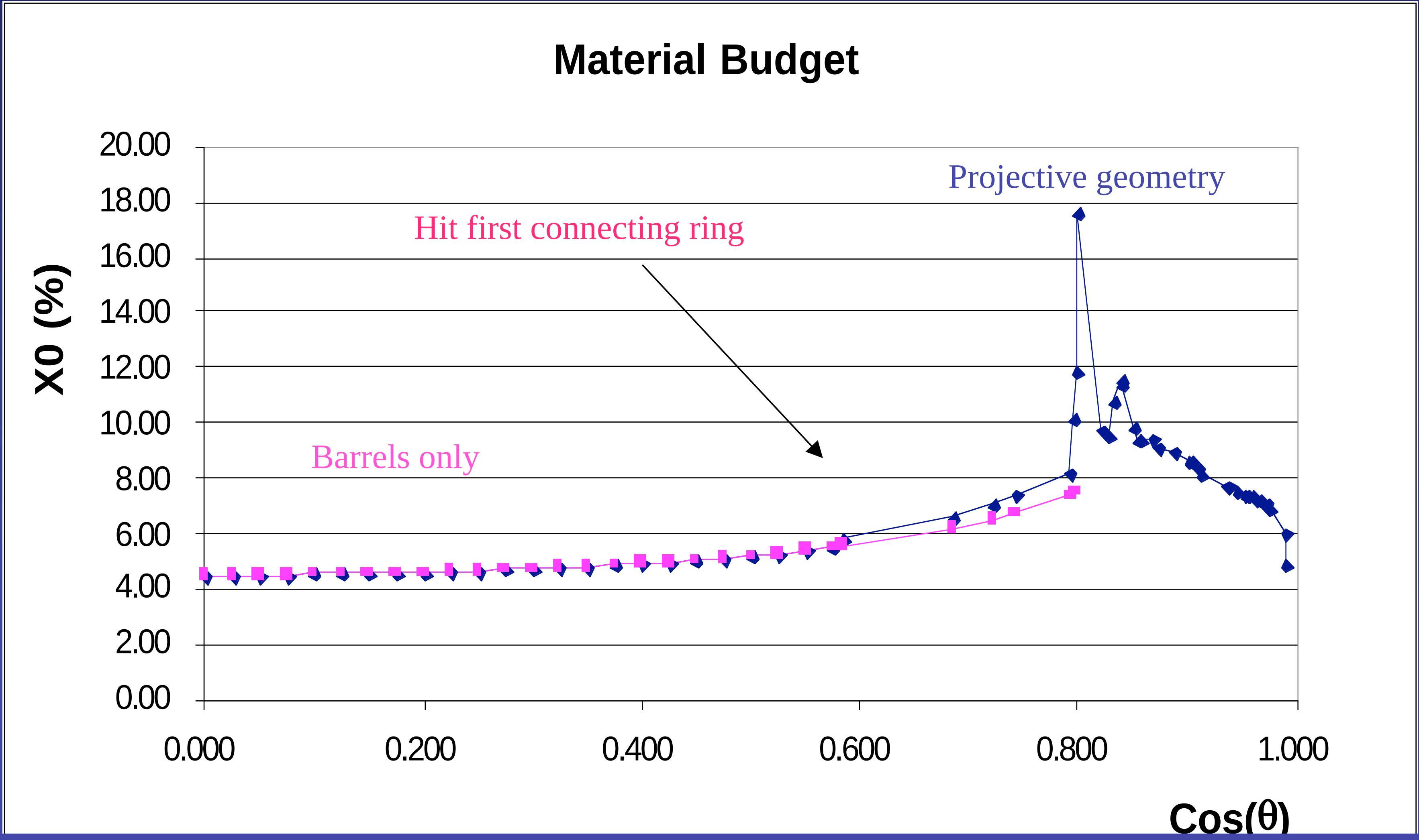
- 5-Layer silicon strip outer tracker, covering R_{in} = 20 cm to R_{out} = 125 cm, to accurately measure the momentum of charged particles



- 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

Material Budget

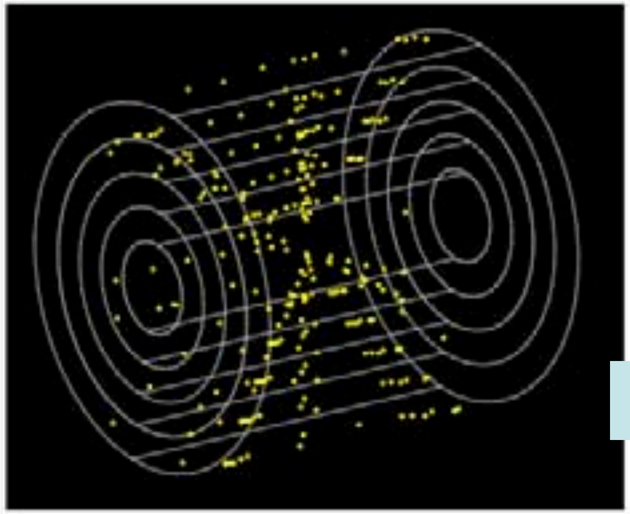
- With current design, possible to stay within 0.8% X_0 per layer at normal incidence

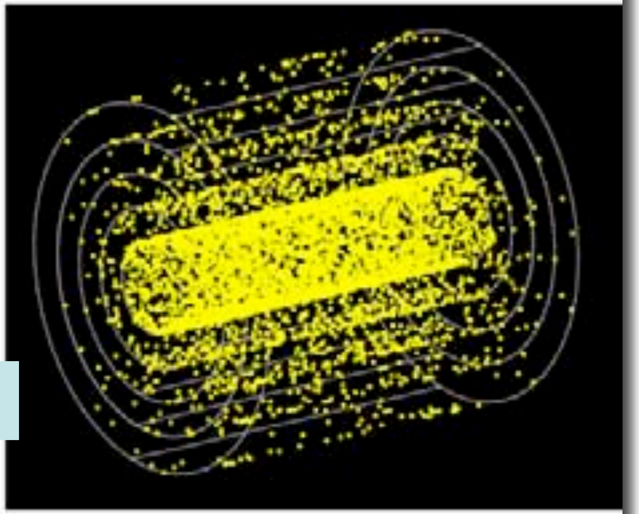


Pattern recognition in SiD

$t\bar{t} \to$ jets → $t\bar{t} \to$ jets + backgrounds

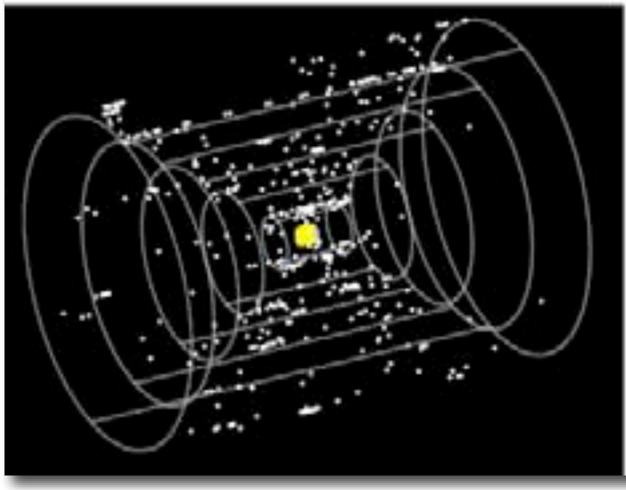
Ecm=500GeV

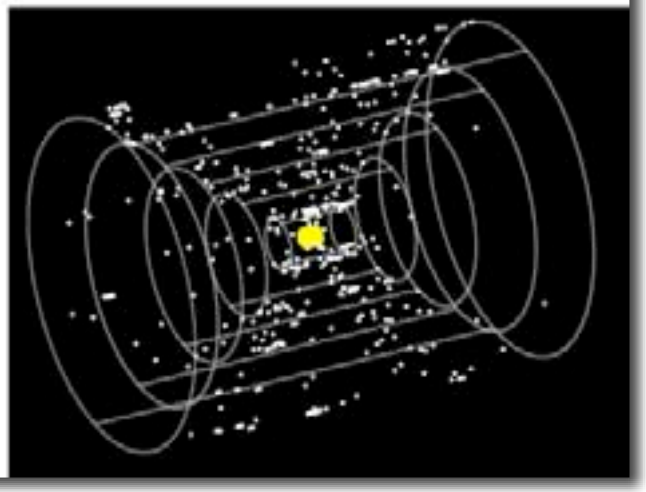




- ≈100 hits/cm^2 in VXD Layer 1

over ~150 beam crossings





- *Tracker sees only physics event*

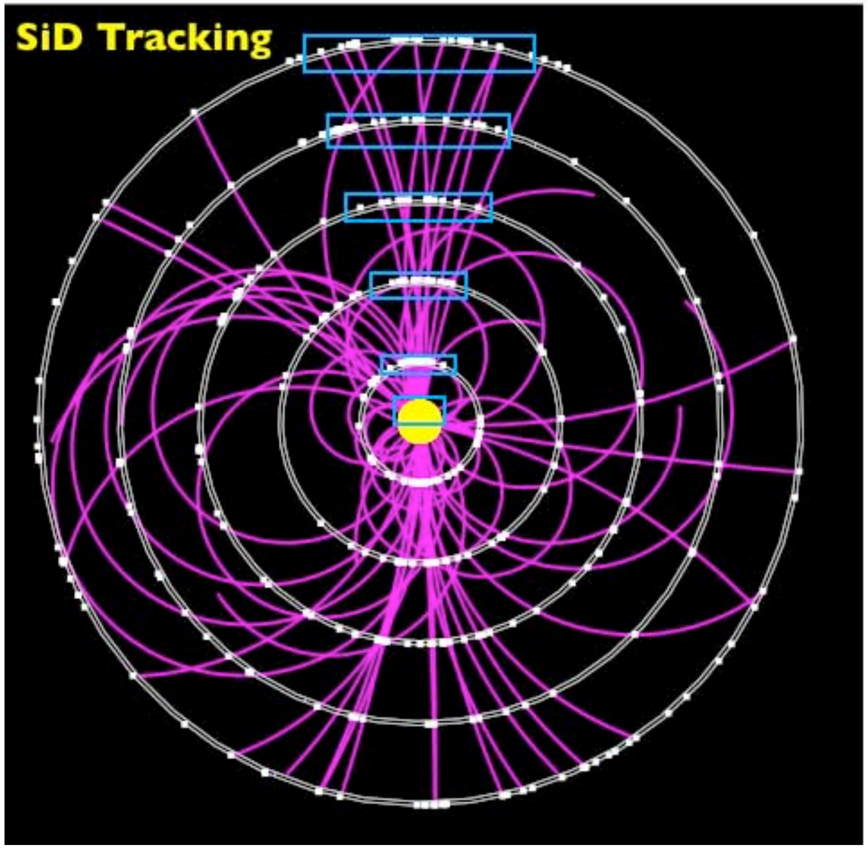
Time stamped even for
150 ns bunch spacing

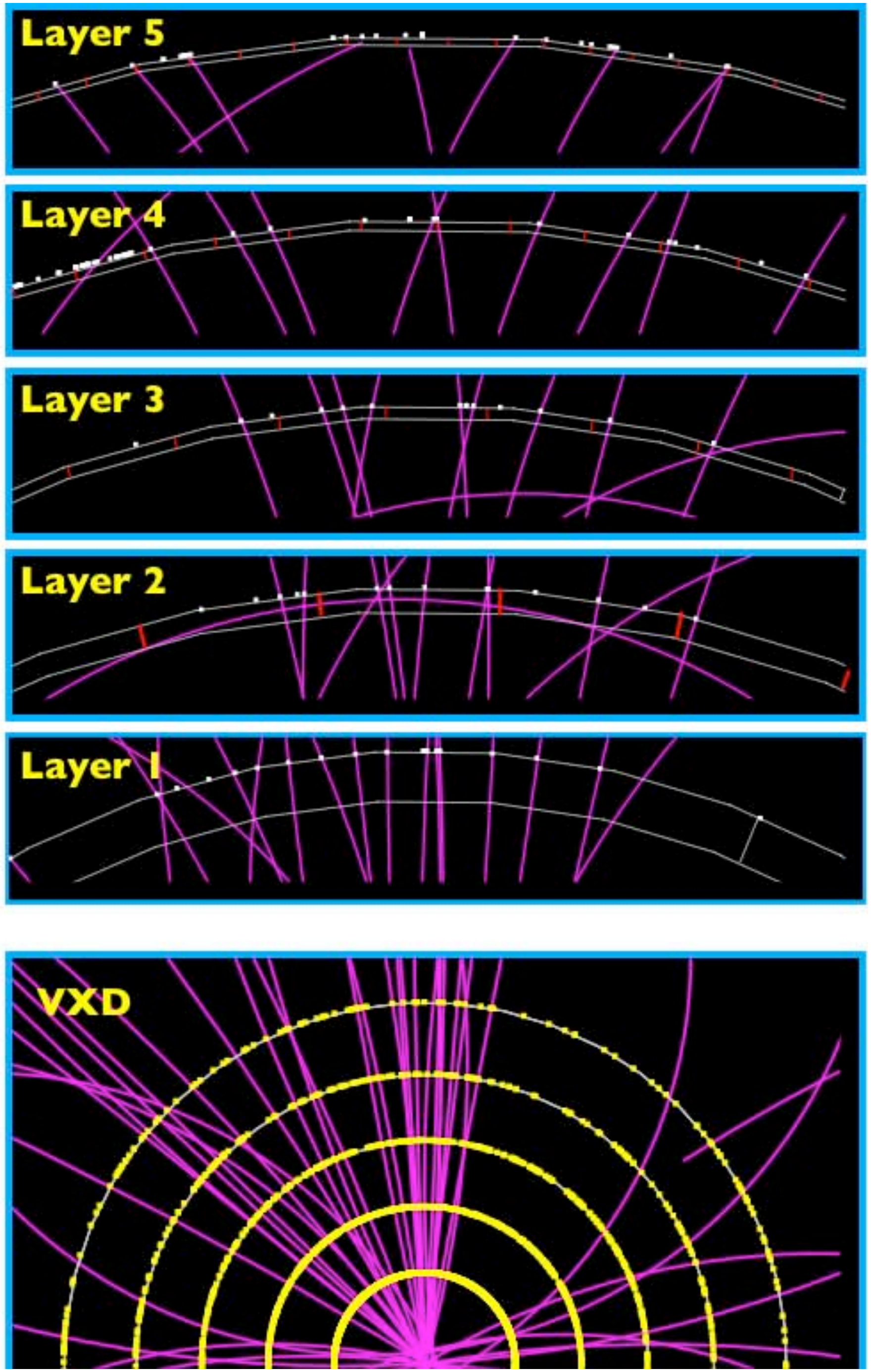
- Begin with

  all combinations of 3D VXD hits.

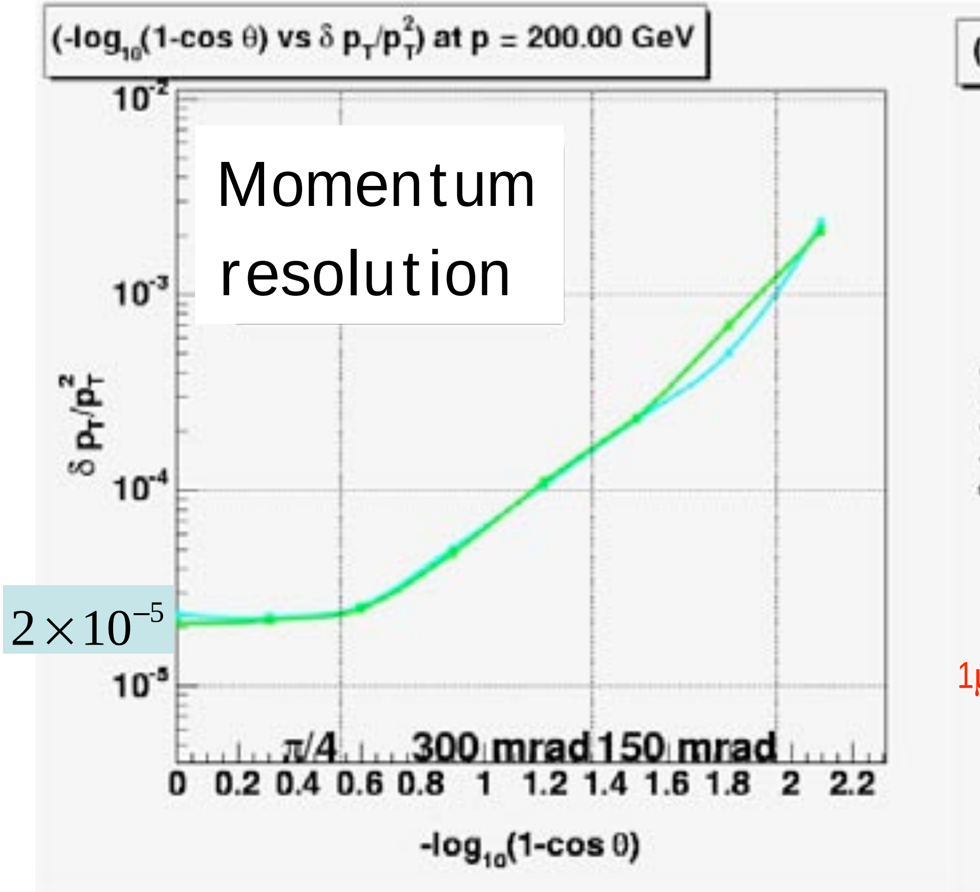
- Attach hits in tracker in 2D

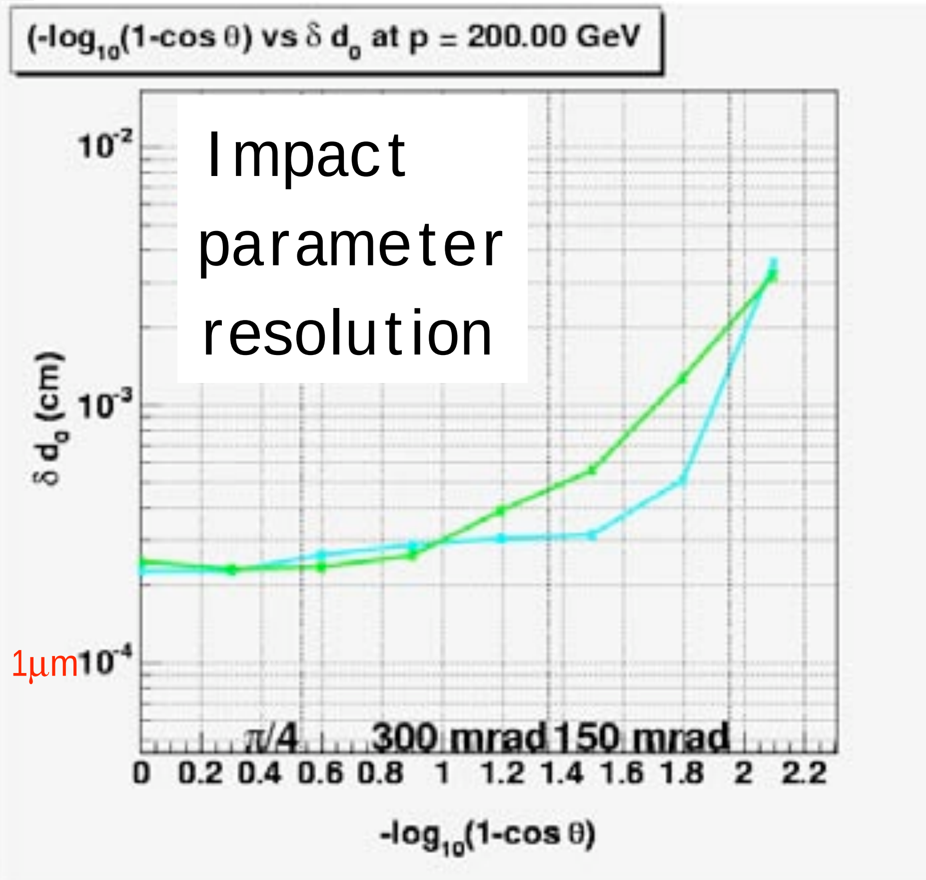
  space to find tracks.





Preliminary study of performance based on GEANT4 (single track study)





$\sigma_{\text{intrinsic}} \approx 7\mu\text{m/point}$

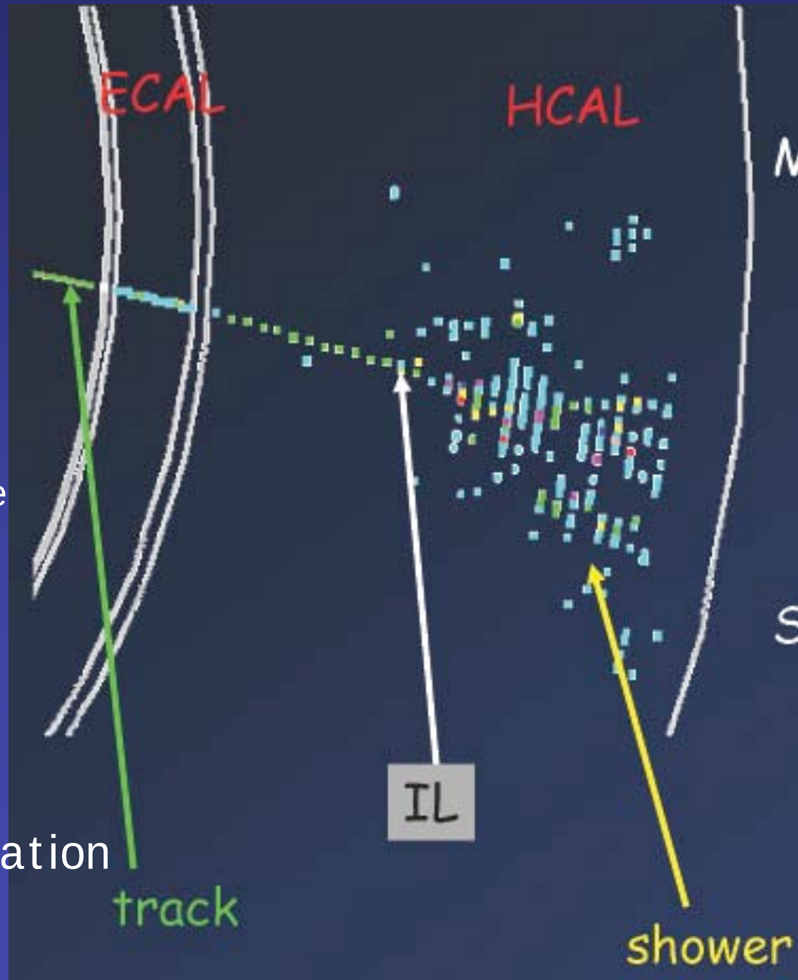
Multiple scattering included

Calorimeter

$$\text{Jet energy resolution : } \frac{\sigma_E}{E} = \frac{30\%}{\sqrt{E(\text{GeV})}}$$

Particle Flow Algorithm

- Measure energies of individual particles, not energy deposition in cal modules.
- Pattern recognize to perform the neutral-charged particle separation in the calorimeter, followed by a substitution of the charged energy with the corresponding measurement from the tracker
  - Step I: Track – Calorimeter cluster matching
    - Identify calorimeter cells belonging to shower from charged track
    - Algorithm based on 'tubes'
    - Use track momentum and eliminate calorimeter cells
  - Step II: Photon Identifier
    - Identify photons in ECAL
    - Use longitudinal and lateral shower profile
  - Step III: Measure neutral hadron energy
    - Excluding charged and em neutrals, apply cone jet algorithm
    - Identify remaining cells as energy from neutral hadrons



Requires fine lateral and longitudinal segmentation and large BR^2

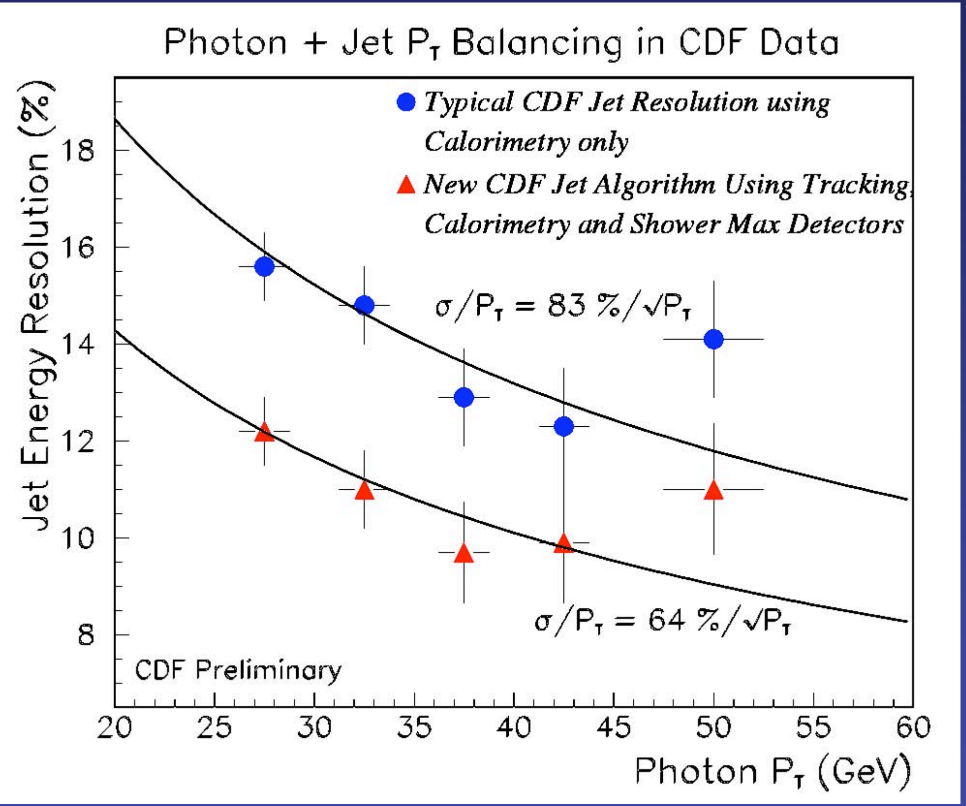
Proof of Principle

- Particle Flow Algorithm applied with the CDF detector
  - Use Photon + Jet data
  - Apply PFA
  - Plot balancing jet energy resolution as function of photon p_T
- Jet energy resolution improved:

$\sigma_E/E = 83\% / \sqrt{E}$ (old)

$\sigma_E/E = 64\% / \sqrt{E}$ (new)

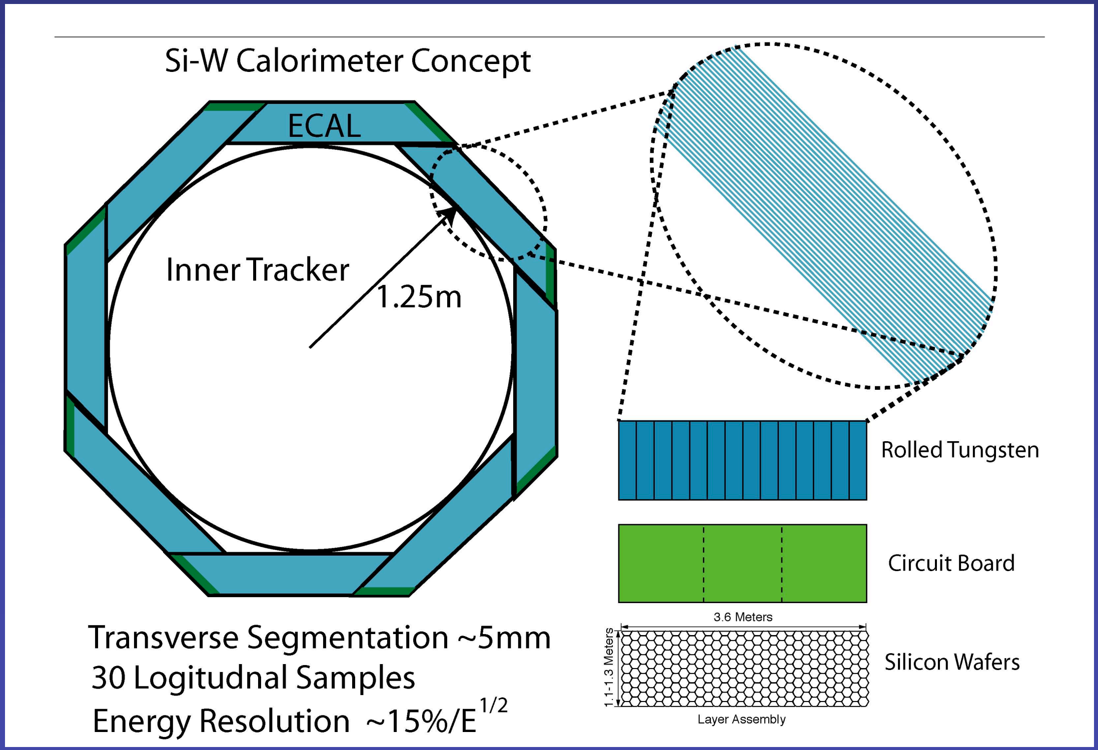
- However, it is not clear if a resolution of 30% / √E is achievable



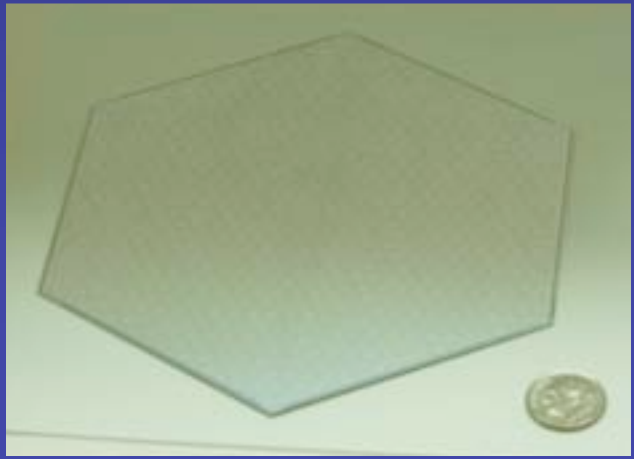
EM Calorimeter

- P-Flow requires high transverse and longitudinal segmentation and dense medium
- Choice: Si-W can provide 5 x 5 mm^2 segmentation and minimal effective Molière radius

Absorber	X_0 [cm]	R_M [cm]
Aluminum	9.05	4.7
Copper	1.44	1.6
Tungsten	0.35	0.9
Lead	0.58	1.6

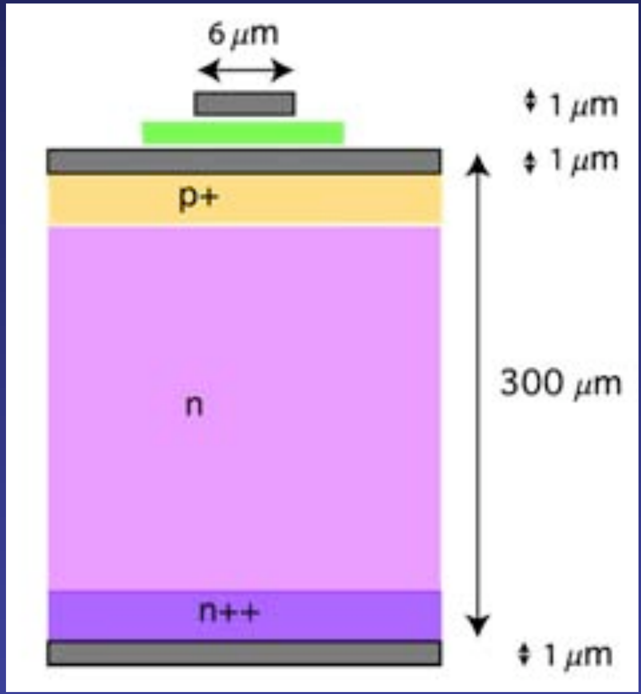


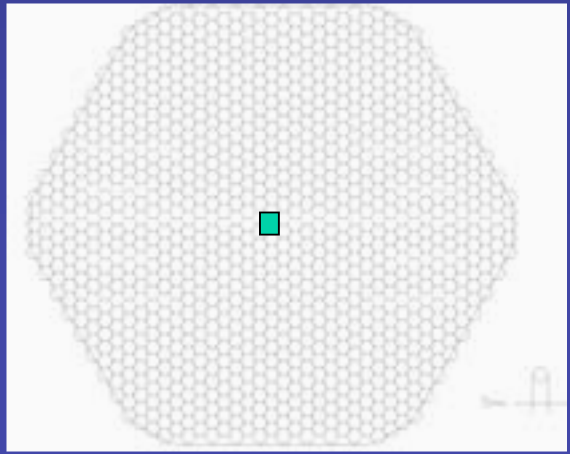
hexagonal SI wafers



EM Calorimeter Configuration

- Silicon from 6” wafers
  - p-on-n silicon
  - 300 µm thick
  - ~ 2000 m^2 of silicon
- Transverse segmentation
  - 5 mm hexagonal pixels
  - 1mm gaps for Si and readout:
    R_m (effective) = 14 mm
- Longitudinal segmentation
  - 30 Layers, 0.25cm thick W, 5/7 X_0 / layer
- Readout through one ASIC per wafer
  - 1024 channels per wafer

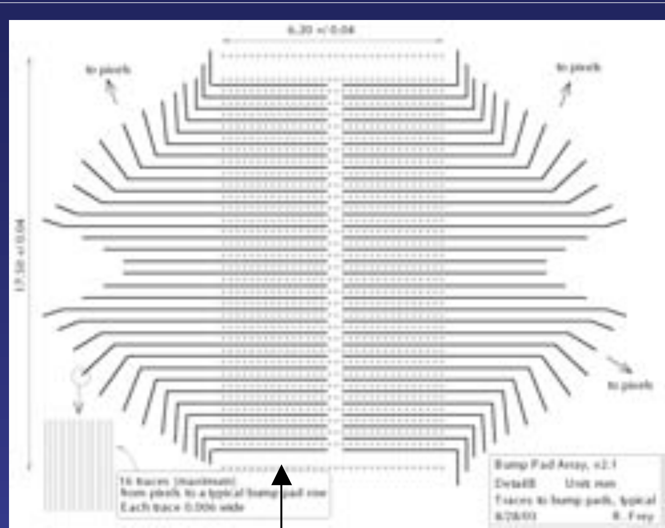




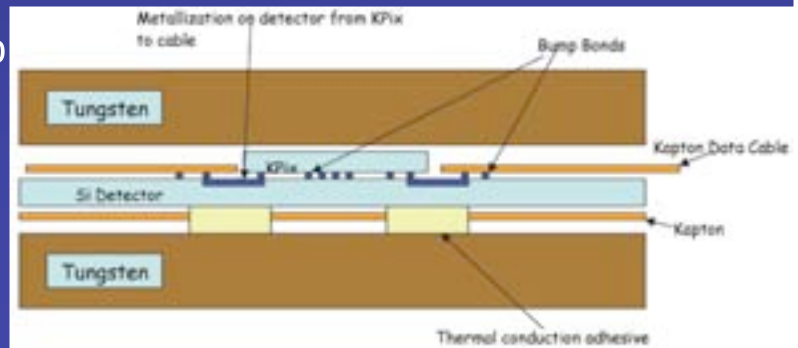
SLAC – Oregon – BNL Collaboration

EM Readout

- ASIC bump bonded to silicon wafer
  - Double metal layer in silicon
- Performance requirements
  - Dynamic range: 0.1 to 2500 MIPs
    - Two ranges
  - S/N > 20
  - Capacitance
    - Pixels: 5.7 pF
    - Traces: ~0.8 pF per pixel crossing
    - Load up to C_L = 40 pF on input amplifier
  - Output
    - Fully digitized, zero suppressed
    - Pulse height + time buffered 4-deep to accommodate multiple hits along train
  - Power
    - < 40 mW/wafer ⇒ power cycling (An important LC feature!)
  - ENC = 200 + 30*C_L

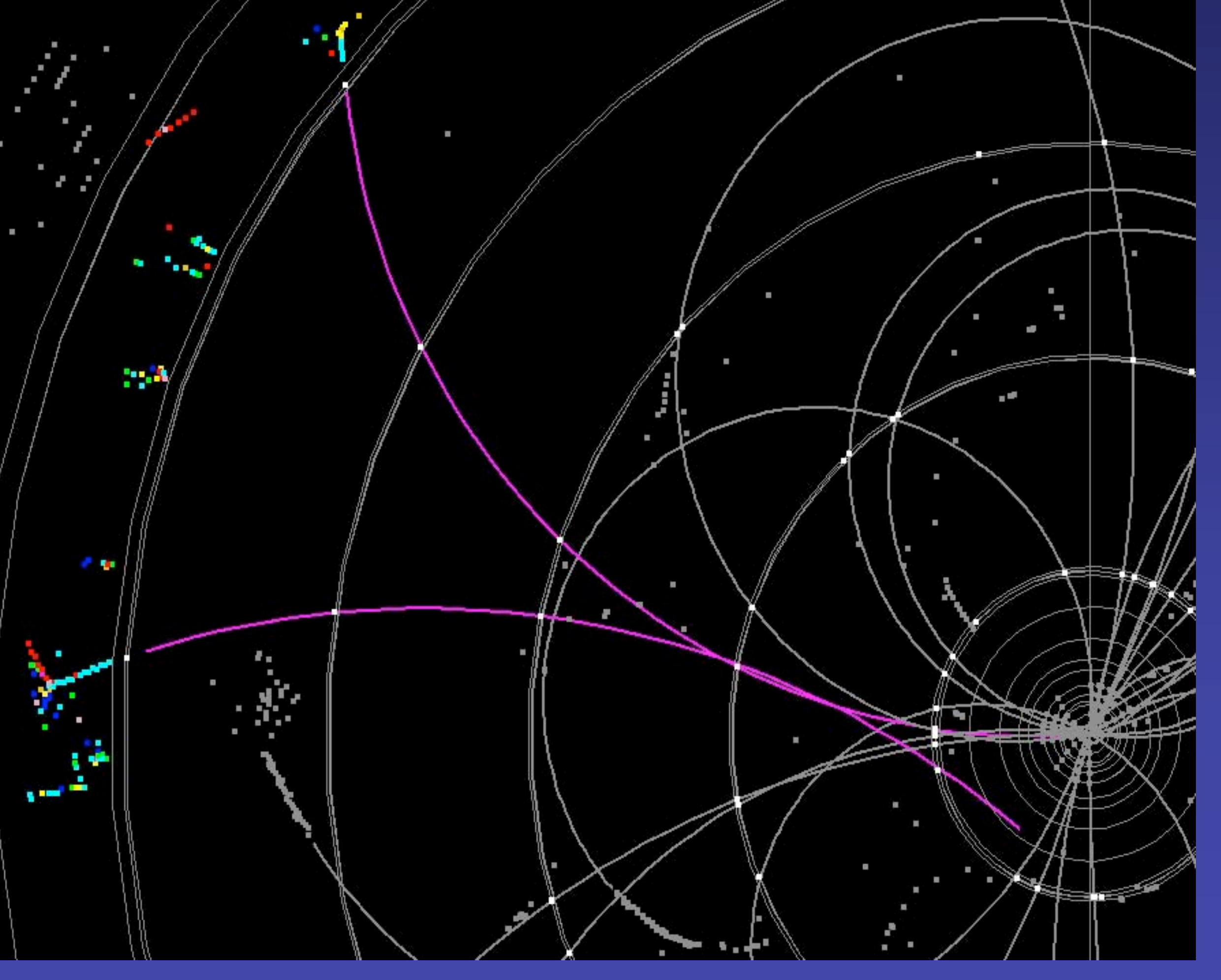


Rows of bumpbonds



Bonus Tracking Calorimeter

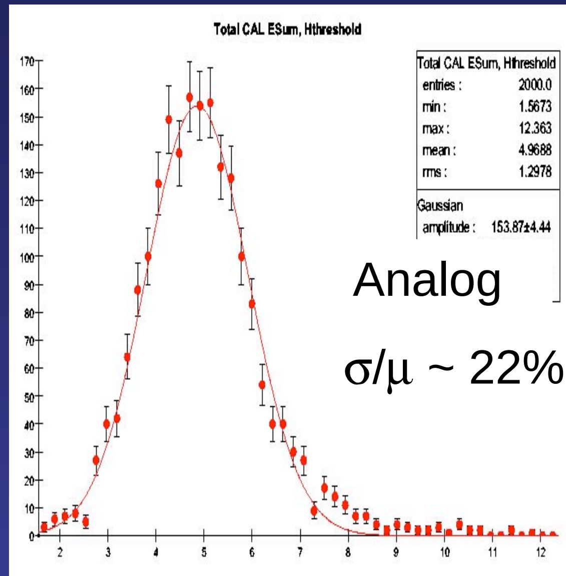
- Can track particles from "the outside-in", starting in the calorimeter
  - Track from outside in: K^0_s and Λ *or* long-lived SUSY!

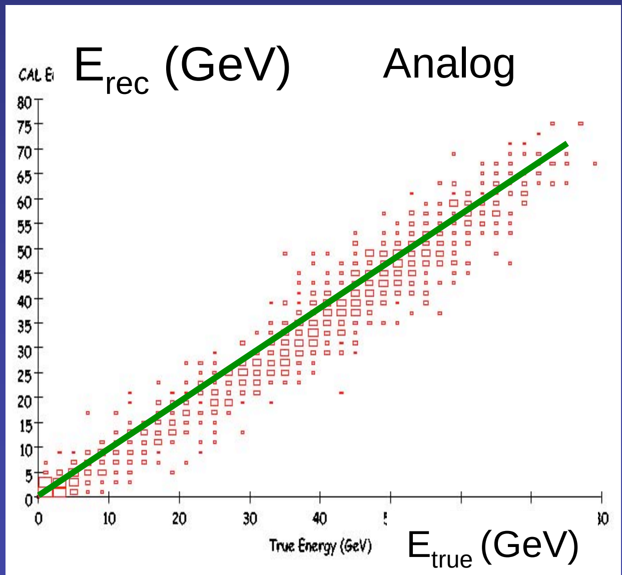


Digital sampling HCAL

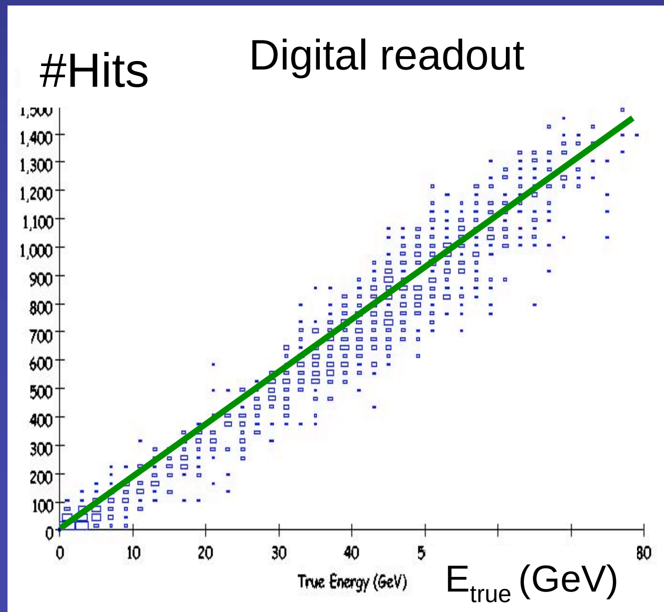
- Digital calorimetry works due to
  - Low density of hadronic showers
  - Linear response to single hadrons
  - Single particle resolution preserved
  - Landau tail reduced

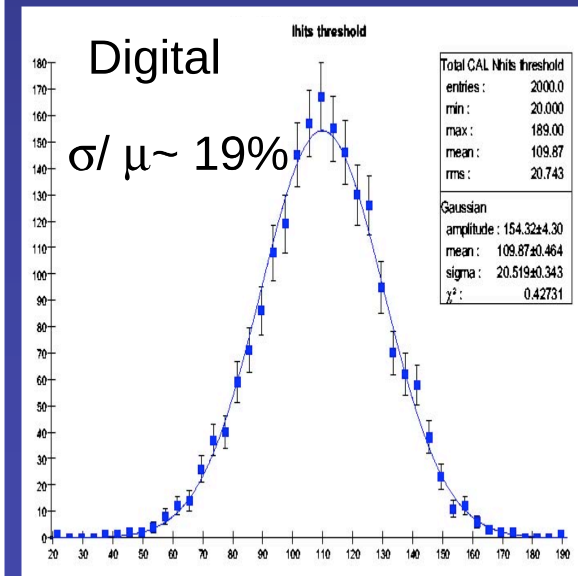
Based on Geant4 simulations, digital readout, 1cm^2 readout pads





Single Particle Resolution
5 GeV π^+, 1 cm^2 pads

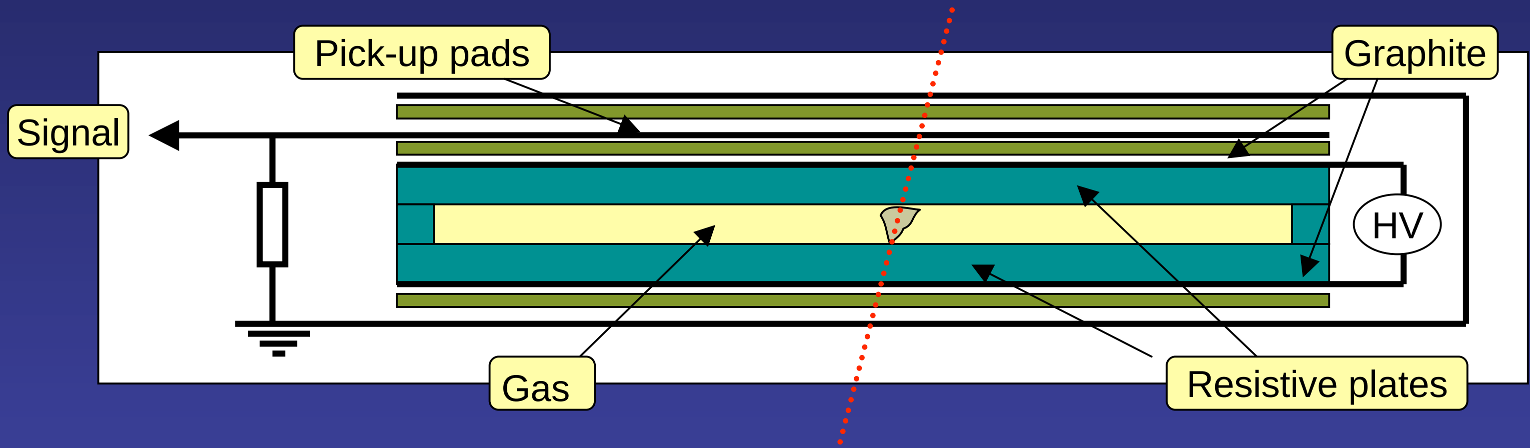




Resistive Plate Chambers

- DHCAL with RPC's are the baseline technology for the SiD
  - Glass as resistive plates; Freon-Isobutane-SF6 as active medium
  - Transverse segmentation 1cm x 1cm

ANL
Boston
Chicago
FNAL
Iowa
ITEP, Moscow

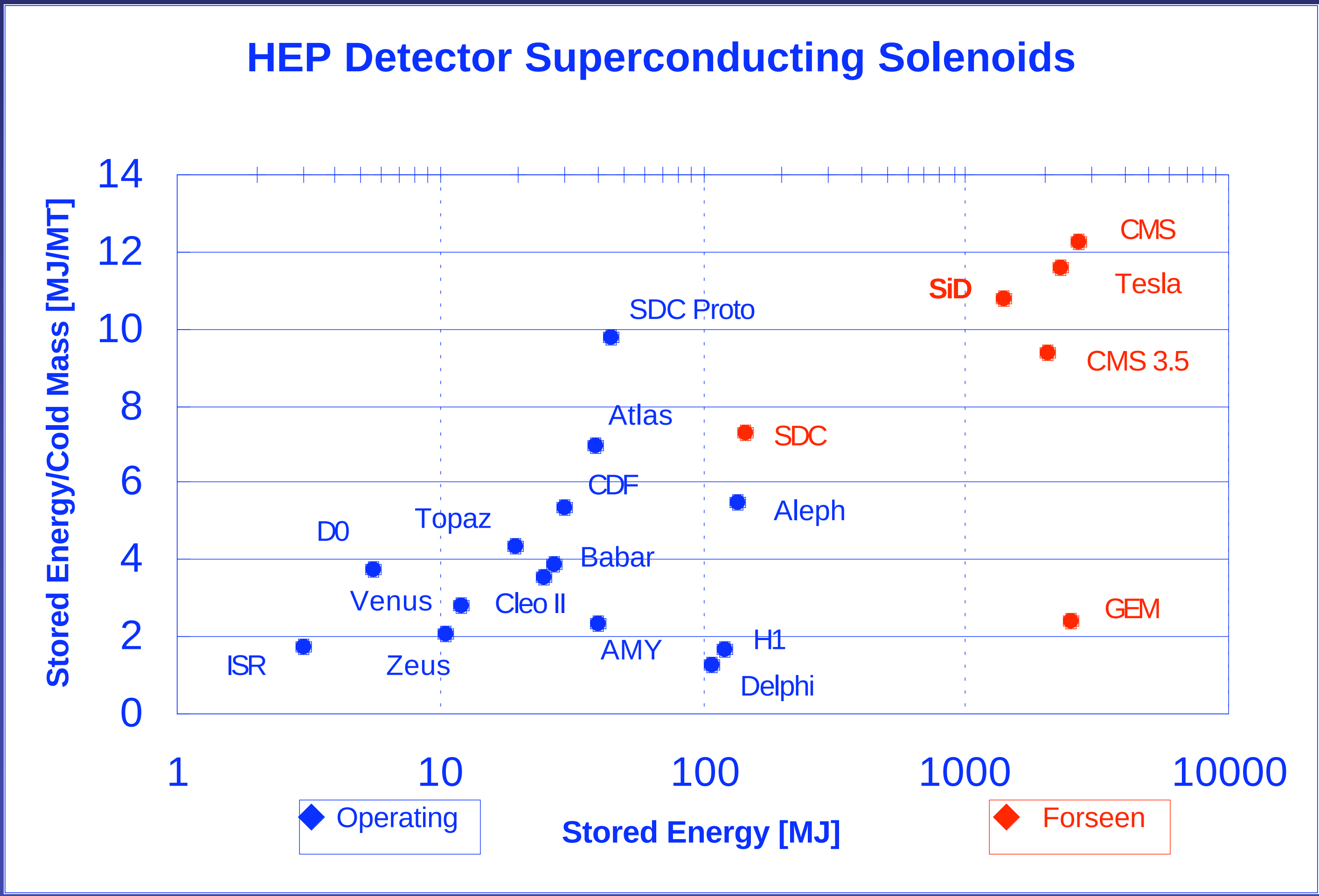


- RPC
  - EM showers narrow in RPC's
  - Had. showers narrow in RPC's
    - Density of gas too low for sizeable neutron cross section
    - Energy deposition has no slow component

- Current parameters:
  - Inside the coil
    - R_i = 139 cm, R_o =237 cm
  - Thickness of 4λ
    - 34 layers of 2.0cm steel
    - One cm gap for active medium
  - Transverse segmentation
    - 1 x 1 cm^2

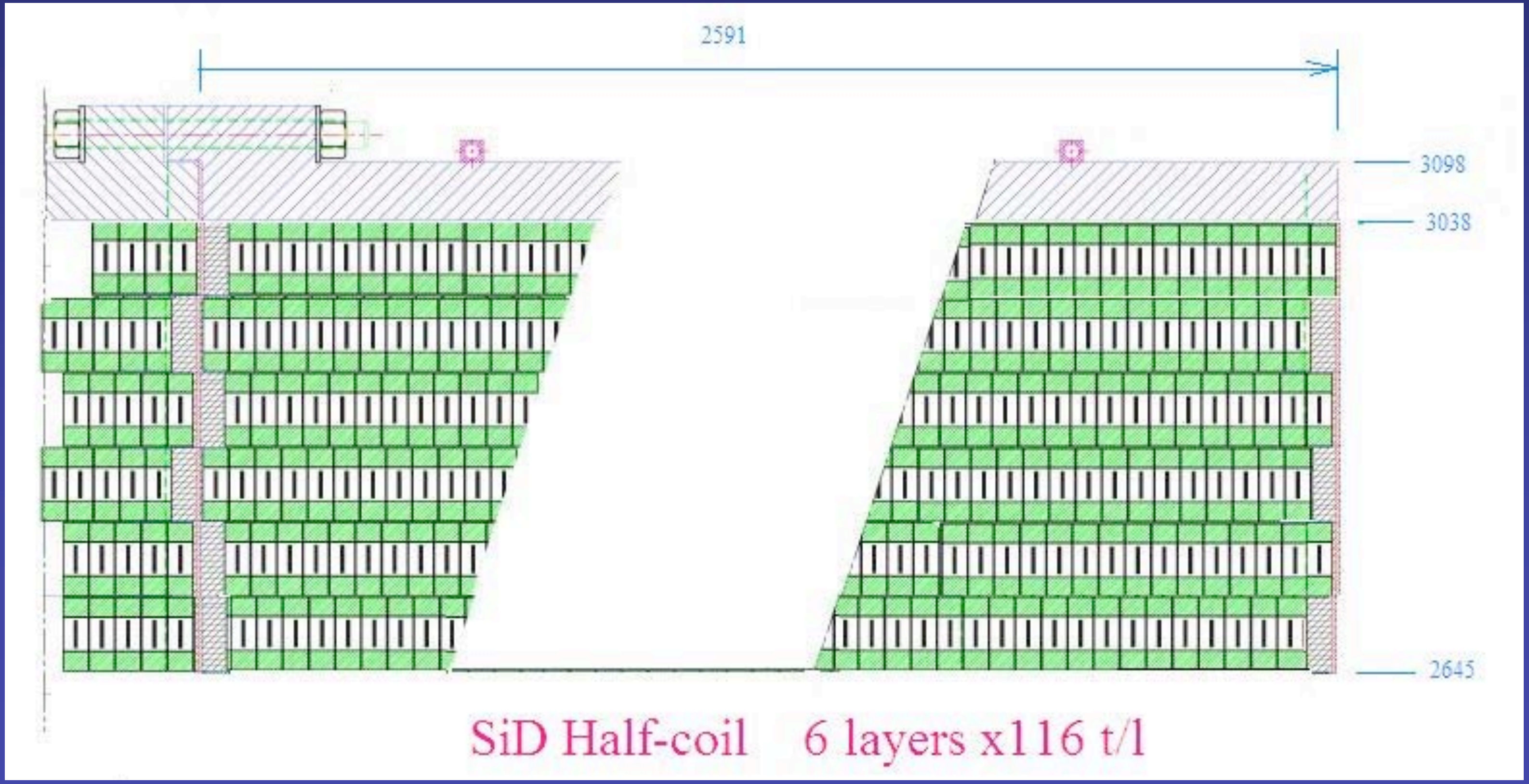
Solenoid

- To retain BR^2, solenoid with B(0,0) = 5T (not done previously)
  - Clear Bore Ø~ 5m; L = 6 m: Stored Energy ~ 1.4 GJ
    - For comparison, CMS: 4 T, Ø = 6m, L = 13m: 2.7 GJ



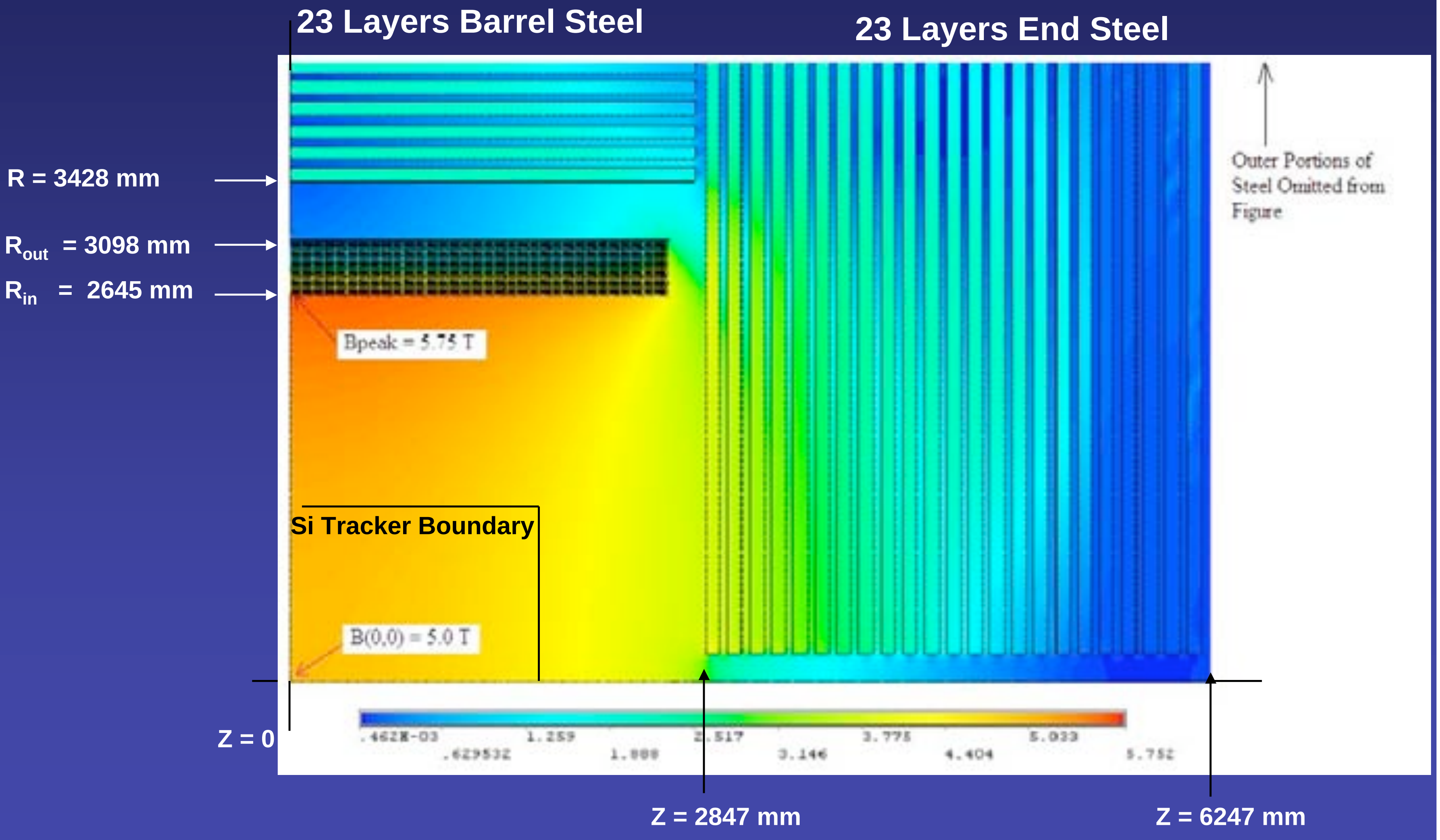
Solenoid

- Initial feasibility completed by Fermilab, preconceptual design based on CMS
  - Credible approach to conductor/winding design
  - Credible engineering approach for industrial fabrication and cost estimates
- More conservative design than CMS : go from 4 winding layers to 6
  - I(CMS)= 19500 A, I(SiD) = 18000 A



Solenoid

- ANSYS modeling of solenoid (2d, 3d)

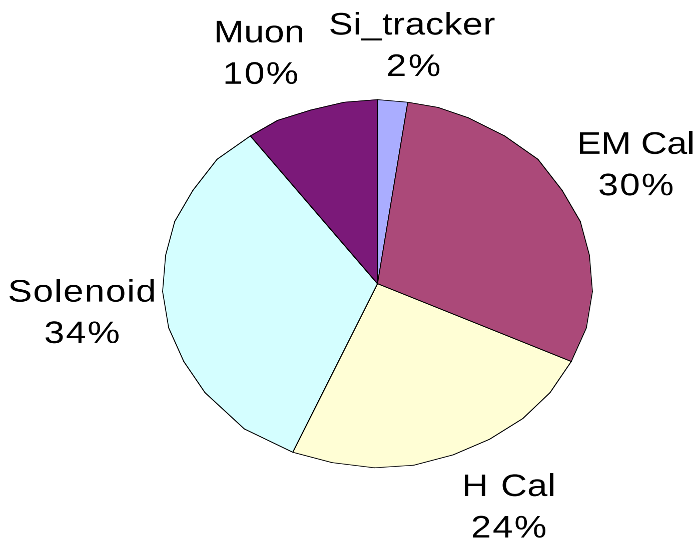


Detector Optimization needs Detector Costs

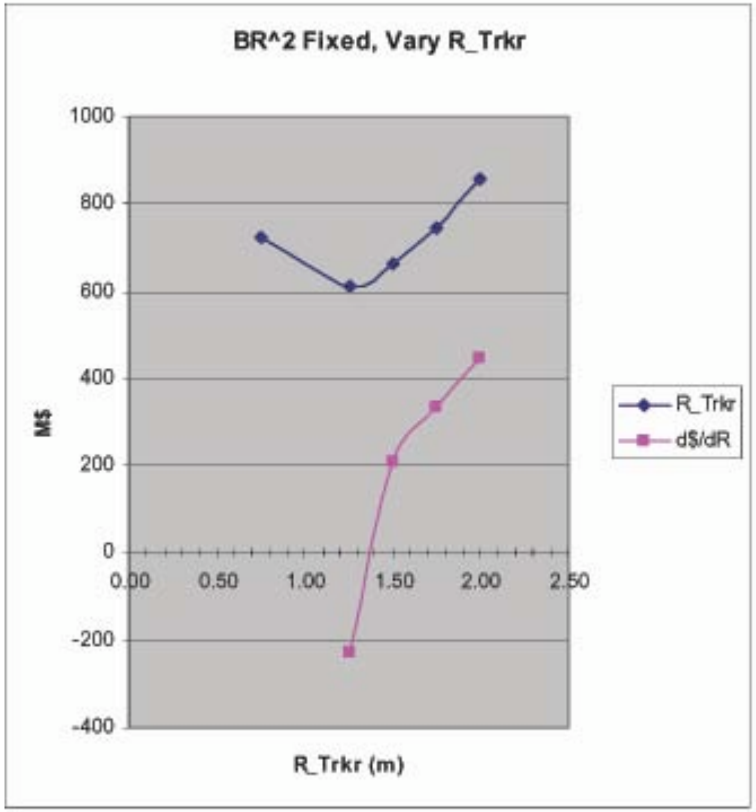
Some Critical Unit Costs

Si Detector (trkr and Ecal)	$2.00/cm^2
Ecal W	$75/kg
Hcal,Muon Detectors	$2000/m^2
Electronics	($100+100 install)/Chip
Solenoid	$0.81(MJ)$^{0.662}$M
Flux return Fe	$3.48/kg

Cost drivers



BR^2 Fixed, Vary R$_{Trkr}$



R_{trkr}=1.25m is optimum.

Current SiD organization

Design Study Coordinators
J. Jaros and H. Weerts
Asian and European Contact Persons H. Aihara and Y. Karyotakis

SiD Executive Committee
Design Study Coordinators
SiD R&D Coordinator A. White
Godfathers M. Breidenbach and J. Brau

SiD Advisory Group
SiD Executive Committee
Working Group Leaders

SiD Working Groups
Benchmarking (T. Barklow), Calorimetry (R. Frey, J. Repond), Costs (M. Breidenbach), Magnet/Flux Return (R. Smith),
Muons (soon!), Simulation (N. Graf), Tracking (M. Demarteau, R. Partridge), Vertexing (D. Su), MDI (P. Burrows, T. Tauchi)

Conclusion

- The (almost) all silicon SiD concept is an aggressive approach to a compact ILC detector.
- Fast and robust.
- Cost control in place.