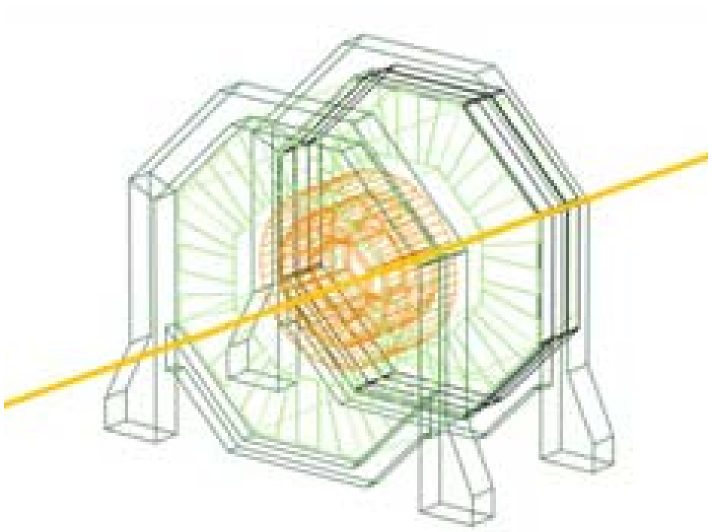
The SiD Detector Concept

Opportunities in Vertexing and Tracking



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For the SiD Tracking and Vertexing Group

TILC08
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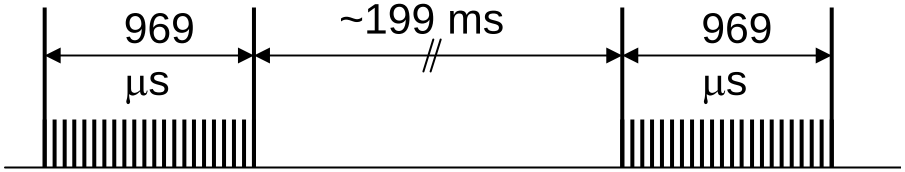
2. Brown University
3. Caltech
4. Fermilab
5. Kansas State University
6. LPNHE Université de Paris 6/IN2P3-CNRS
7. Oxford University
8. Rutherford Appleton Laboratory
9. SLAC
10. UCSC
11. University of Colorado
12. University of New Mexico
13. University of Oregon

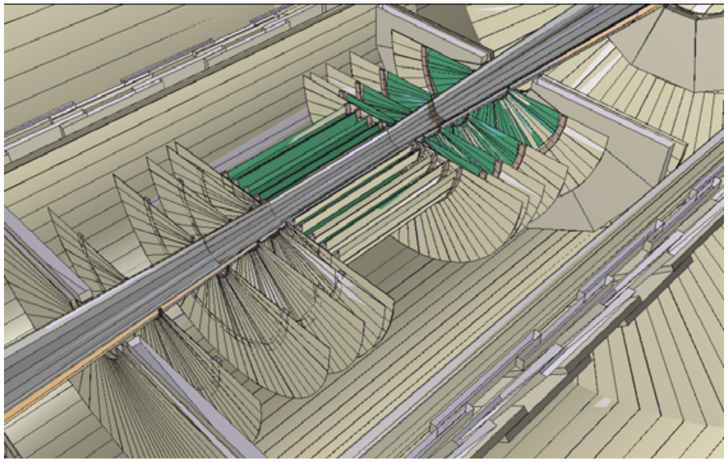
apologies to those we forgot

Pixel Detector

- **Pixel detector requirements**
  - **Transparency: 0.1% X_0 per layer (equivalent of 100 μm of Si)**
  - **Low power consumption (~50 W for 1 Giga pixels)**
  - **High resolution thus small pixel size**
    - Excellent point resolution (< 4 μm)
    - Superb impact parameter resolution ($5\mu m \oplus 10\mu m/(p \sin^{3/2}\theta)$)
  - **Good angular coverage; robust pattern recognition (track finding in vtx alone)**
  - **Modest radiation tolerance for ILC applications**
  - **EMI immunity**



ILC Beam structure:
Five trains of 2625 bunches/sec
Bunch separation of 369.2 ns

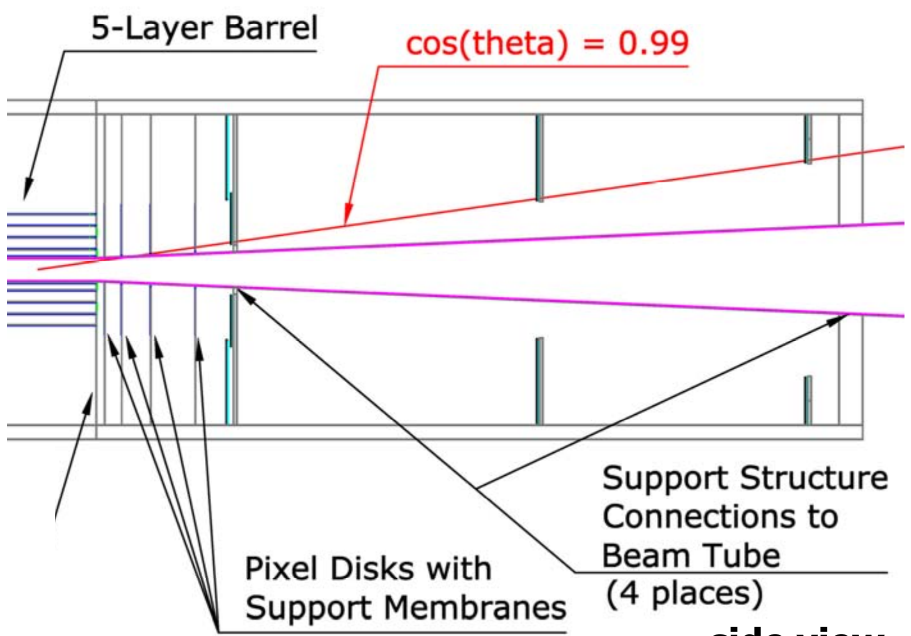


- **Combination of small pixels, short integration time, low power required for ILC is difficult to achieve**
  - **Small pixels tend to limit the amount of circuitry that can be integrated in a pixel**
  - **Small pixels also mean that the power/pixel must be kept low**

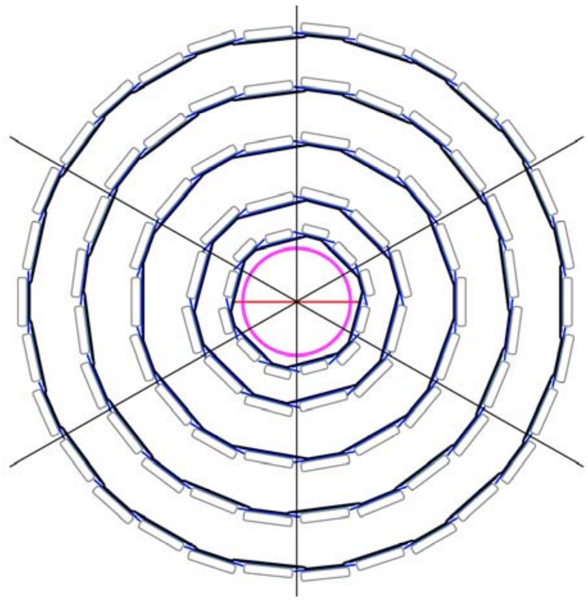
- **The low occupancy/pixel/train (~0.5%) means that a sparse scan architecture would be appealing if:**
  - **Signal/noise is high**
  - **Enough electronics can be integrated on a pixel**

Pixel Detector Mechanical Design

- Baseline vertex detector has a central, 5-layer barrel, two 4-plane end disk assemblies and three additional disks per end for extended coverage
- All elements are supported indirectly from the beam tube via double-walled, carbon fiber laminate half-cylinder
- Barrel Region
  - Five layers
  - Longitidunal coverage: ± 62.5 mm
  - Radial coverage: 14 < R < 61 mm
- Forward regions
  - Four disks
  - z = ± 72, ± 92, ± 123, ± 172 mm
  - Radial coverage: R < 71 mm



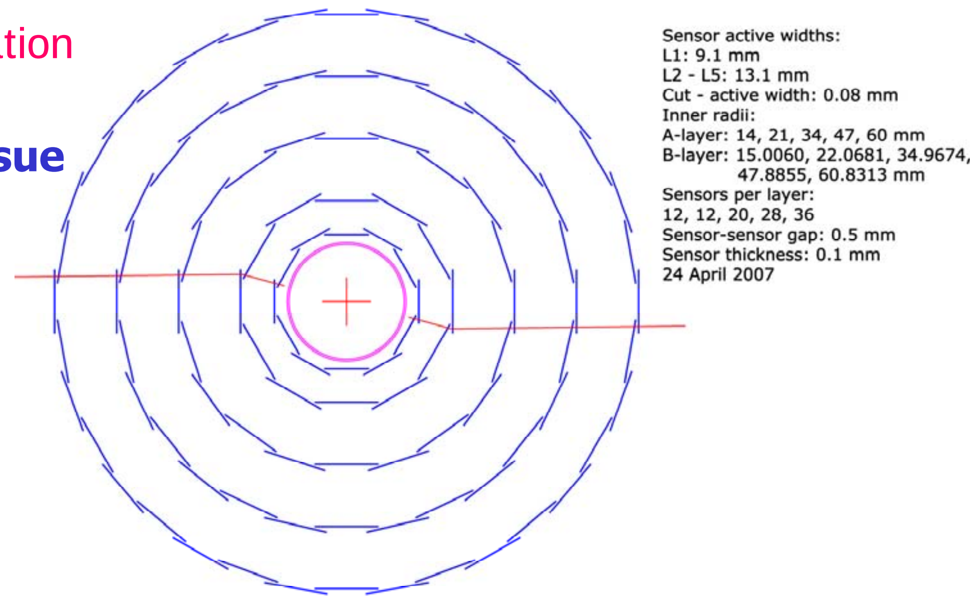
side view



end view

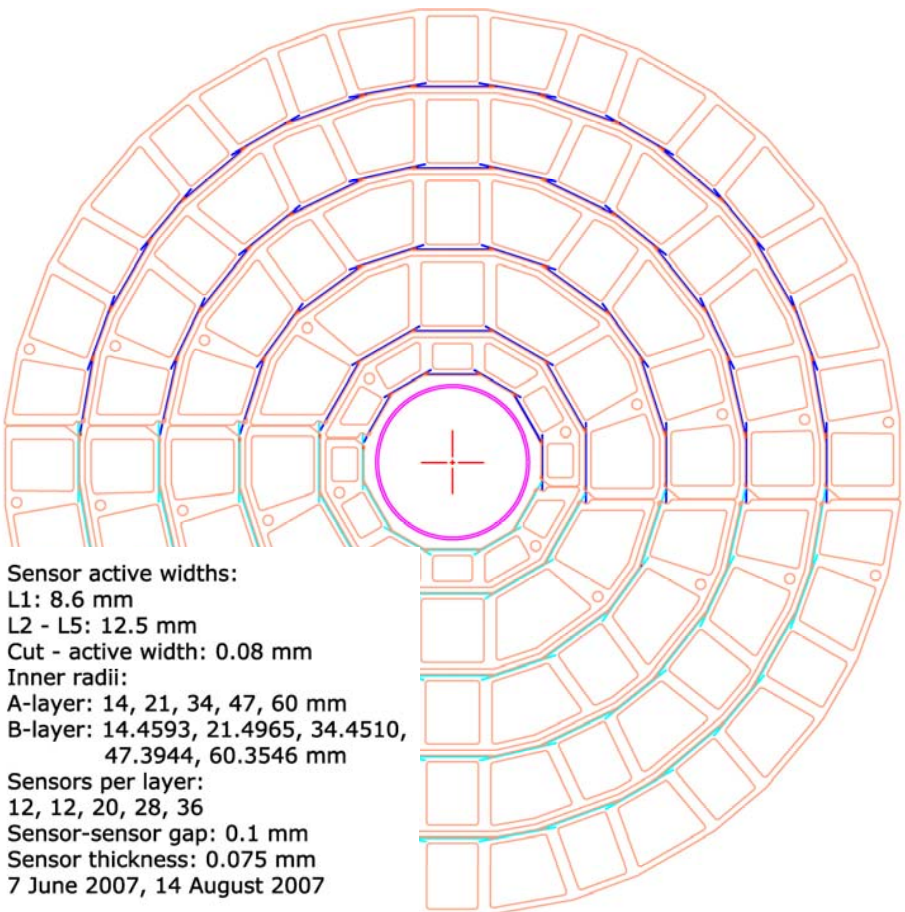
Mechanical Layout: V1

- **New layout compared to original baseline design**
  - **Sensor counts increased in L3, L4, L5 to obtain multiples of 4 and fully identical barrel halves**
- **Goal of understanding how to optimize the geometry of the carbon fiber / epoxy composite frame to minimize deflection due to gravity and temperature changes.**
- **Various configurations being studies**
  - **4-layer (0,90,90,0 degree) lay-up**
    - The maximum gravitational deflection vector is about 0.6 µm in each case.
  - **3-layer CF structures**
    - mass optimization and minimization of thermal deflections.
- **Thermal distortions are a serious issue for sensors below ~ 10 ^{0}C**



Mechanical Layout: V2

- **All Silicon layout: proposed to mitigate CTE issues**
  - **Uses only the silicon sensors in "cylindrical" portions of the structure**
- **Sensors glued to one another along edges by thin beads of epoxy and supported by thin, flat carbon fiber/epoxy end membranes**



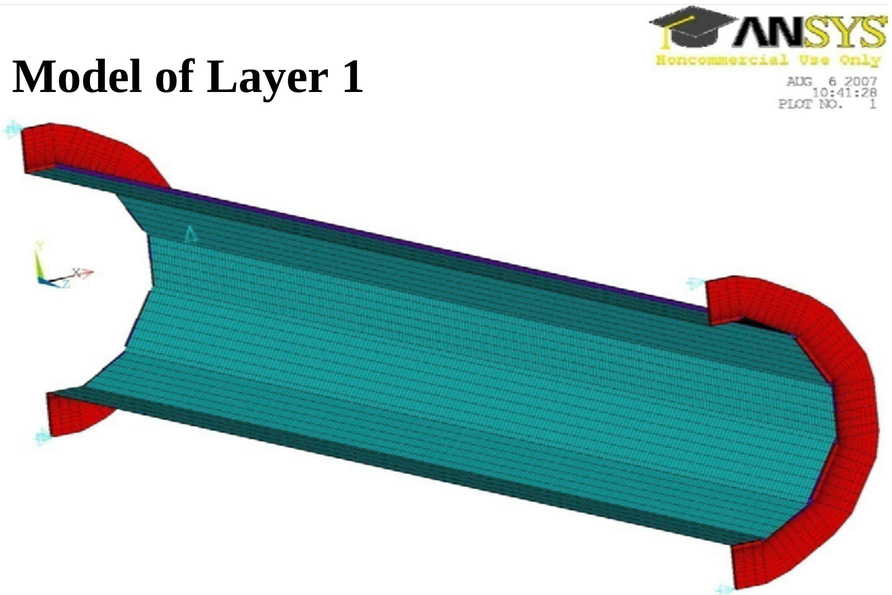
- **75 µm silicon thickness assumed**
  - **Could be modified for thicker or thinner sensors**
- **Parametric FEA model for all 5 layers of this detector (UW)**

All silicon mechanical prototype

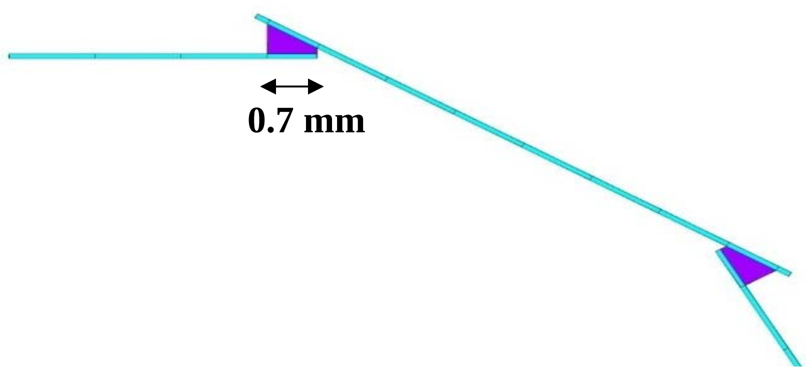
Mechanical Layout: V2

- **All silicon layout**

Model of Layer 1



Detail of glue joints



- **FEA study of gravitational sag and maximal displacements for a ΔT of 10 ^{0}C**

Layer	Gravity (μm)	Δx (μm)	Δy (μm)	Δz (μm)
1	0.1	0.9	1.8	5.3
2	0.1	1.0	3.0	5.6
3	0.3	1.6	4.0	5.8
4	0.6	2.6	5.7	6.2
5	1.4	4.4	8.1	6.6

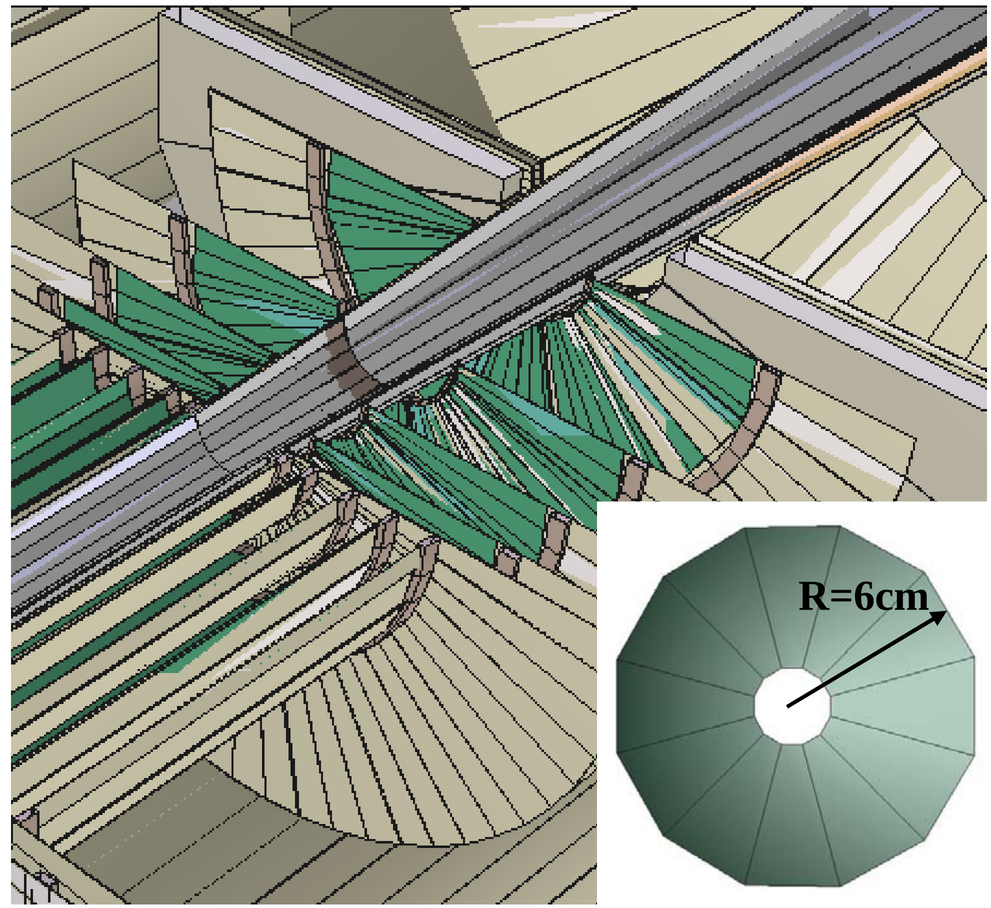
- **Note that the Z deflection is composed mainly of the simple change in length of the detector**
  - **Results independently verified by LCFI collaboration**
- **Less temperature dependent than CF support structures**

Mechanical Layout: Forward Region

- **Forward pixel detectors are notoriously difficult to build in low mass, low power configuration with very little additional mass due to cables**

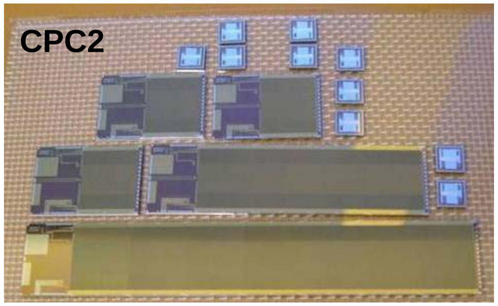
- **Currently thinking of silicon disks with support and readout at the periphery**

- **Area not well studied; many open issues**
  - **Long barrels vs short barrels**
  - **Cable routing**
  - **Power delivery**

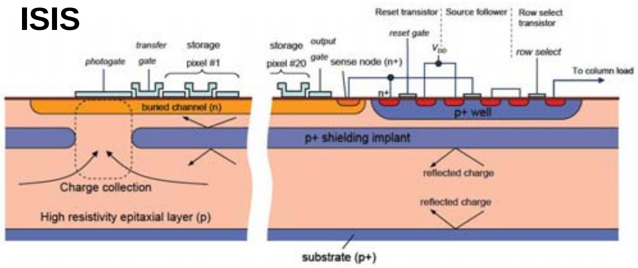


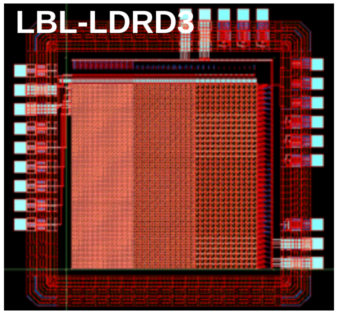
Vertex Detector Sensor Technology

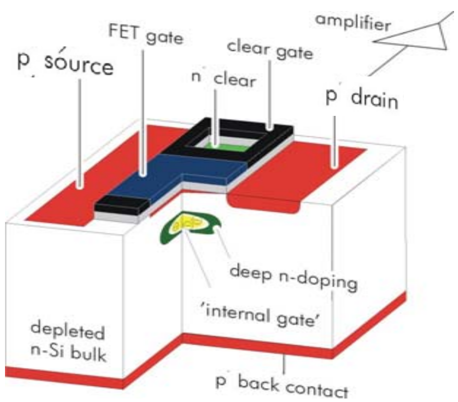
- **Collaborating with many specific sensor R&D groups and considering broad spectrum of technologies**
- **CCD's**
  - **Column Parallel (LCFI)**
  - **ISIS (LCFI)**
  - **Split Column (SLAC)**
- **CMOS Active Pixels**
  - **Mimosa series (Ires)**
  - **INFN**
  - **LDRD 1-3 (LBNL)**
  - **Chronopixel (Oregon/Yale)**
- **SOI**
  - **American Semiconductor/FNAL**
  - **OKI/KEK**
- **3D**
  - **VIP (FNAL)**
- **DEPFET (Munich)**



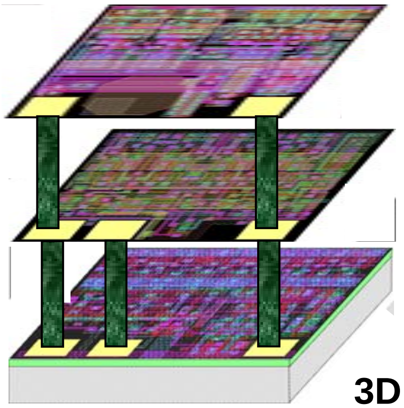
ISIS







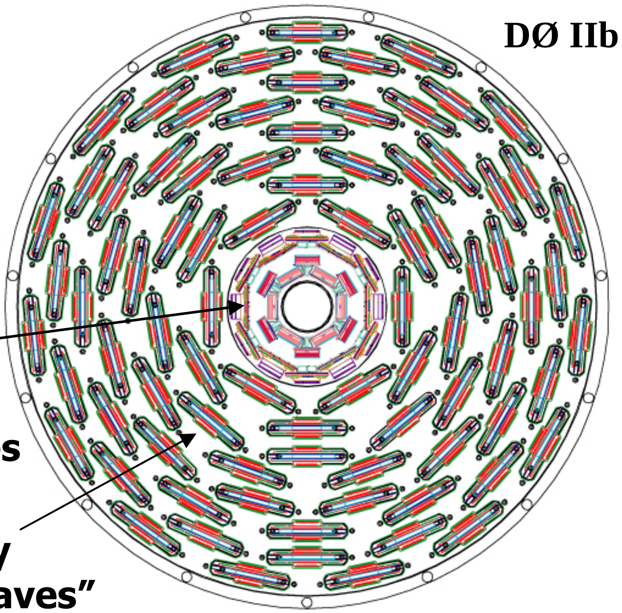
DEPFET



3D

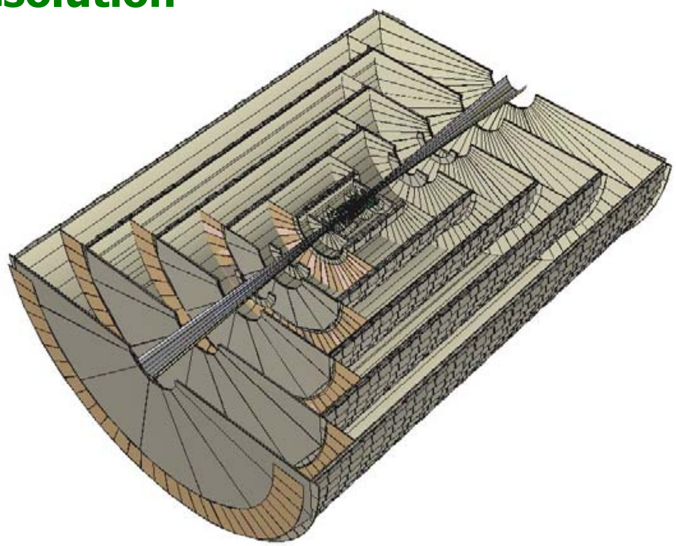
Vertex Detector Sensor Technology

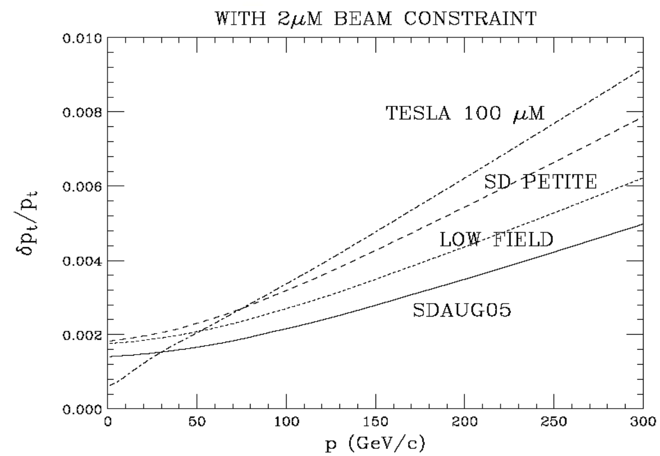
- So far no 'ideal' technology that performs best in all categories
  - Attempts to reduce hit density via faster readout or time stamping seem to be invariably associated with more power
- Issues
  - The first layer carries a large weight in determining the ultimate impact parameter resolution and is in the most dense environment
    - May compromise on power to get lowest hit density and best time stamping
  - Services and handling of Lorentz forces much more important for outer layers but should not compromise performance
  - End cap sensor issues are very different from barrel
    - Tracks nearly perpendicular; Lorentz forces less of an issue
- Considering the option of mixed technologies both for support and sensors
  - e.g. Dzero Run IIb, CDF/Dzero Layer 0
- We need new, clever ideas !



Tracking Detector

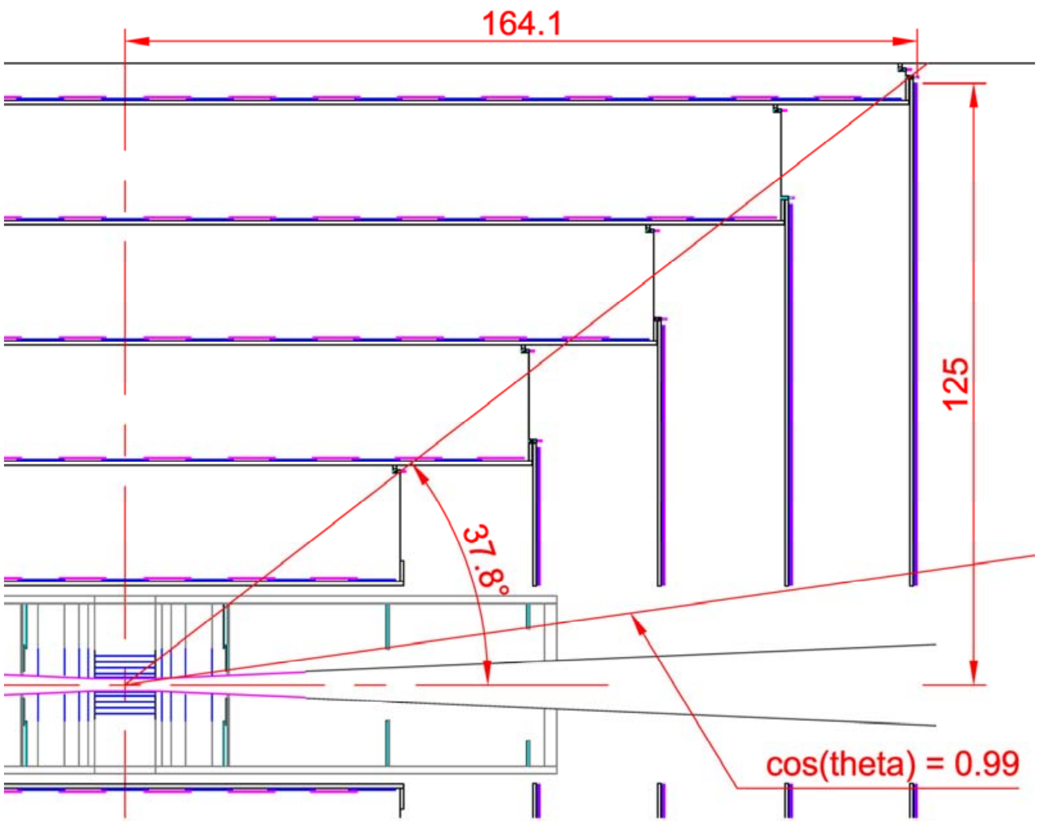
- **Tracking detector requirements**
  - **Transparency: 0.8% X_0 per layer average over full fiducial volume**
  - **Superb point resolution and momentum resolution**
    - Strip pitch of 25 μm
    - $\sigma(1/p) = 2\ 10^{-5}\ (GeV^{-1})$ at 90 degrees
  - **Good angular coverage; robust pattern recognition**
    - Single bunch timing
    - Very high tracking efficiency for PFA
  - **Robust against aging and beam accidents**
  - **Modest radiation tolerance**
- **Silicon technology chosen**
  - **Mature technology which allows emphasis on phi resolution**
    - Superior asymptotic p_T resolution
  - **Allows for flexibility in minimizing material distribution through fiducial volume**





Tracker Mechanical Design

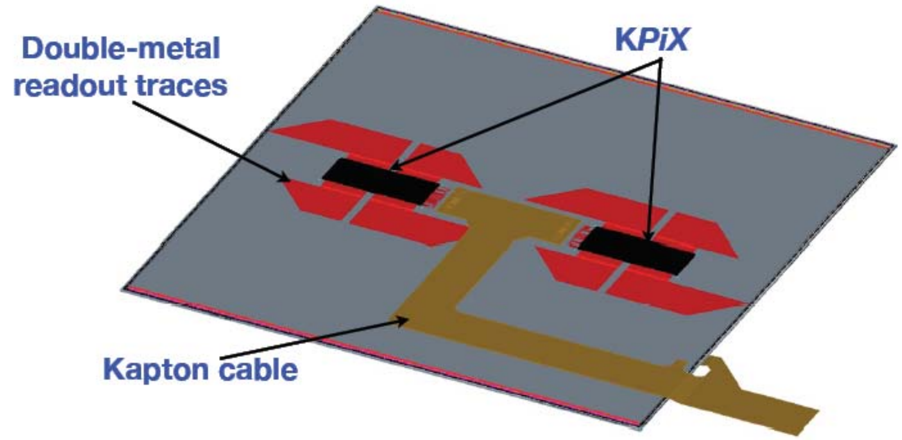
- 5-Layer silicon strip outer tracker, covering R_{in} = 20 cm to R_{out} = 125 cm
- Barrel – Disk structure: goal is 0.8% X_0 per layer



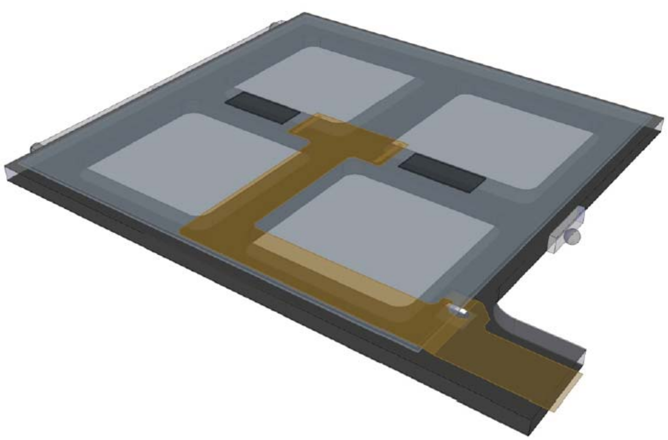
- Support
  - Double-walled CF cylinders
  - Allows full azimuthal and longitudinal coverage
- Barrels
  - Five barrels, measure Phi only
  - 10 cm z segmentation
  - Barrel lengths increase with radius
- Disks
  - Four double-disks per end
  - Measure R and Phi
  - varying R segmentation
  - Disk radii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

Sensor and Module Design

- **Hybrid-less design**
  - **93.5 x 93.5 mm^2 sensor from 6" wafer with 1840 (3679) readout (total) strips**
  - **Read out with two asics (kPix) bump-bonded to sensor**
  - **Routing of signals through 2nd metal layer, optimized for strip geometry**
    - Minimize capacitance and balance trace resistance for S/N goal of 25
  - **Power and clock signals also routed over the sensor**



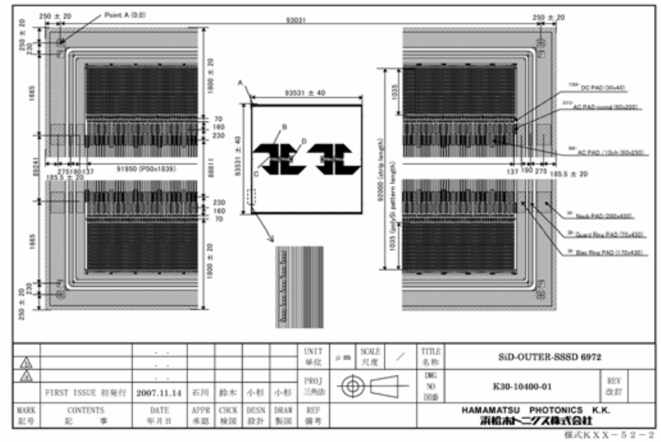
- **Module support**
  - **Minimal frame to hold silicon flat and provide precision mounts**
    - CF-Rohacell-Torlon frame w/ ceramic mounts
    - CF-Torlon clips glue to large-scale supports
  - **Ease of large scale production, assembly and installation/replacement**

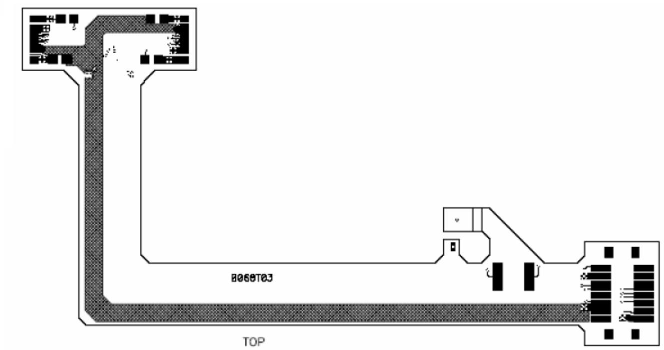


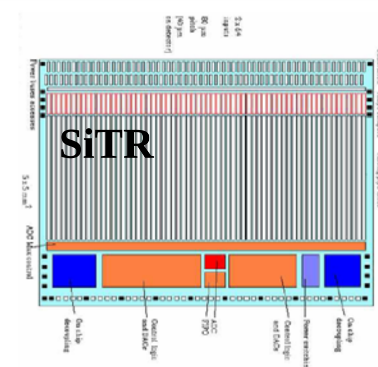
- **Power pulsing for tracker allows for air cooling**
  - **Factor of >80 in power reduction**
  - **But have to deal with enormous Lorentz forces**

Prototyping Status

- **Sensors ordered from Hamamatsu; due May '08**
- **64-channel KPiX-V5/6 in hand**
  - **ADC noise too high**
  - **KPiX64-V7 submitted to resolve noise issue**
- **Gold stud bump-bonding proceeding at UC Davis in collaboration with ECAL (sensors can also be wirebonded)**
- **Prototype pigtail cable design completed by Univ. New Mexico**
  - **¼ oz. Cu on 50μm Kapton, 8mm width**
  - **2 power+ground pairs, 8 control/ro lines**
  - **HV pair for sensor bias**
- **Ongoing studies of thin sensors**
  - **Purdue group 200μm thin Si, S/N>18**
  - **Fermilab thinned and laser annealed**
- **Alternative readout of sensors**
  - **UCSC, long shaping time, TOT**
  - **LPNHE/Paris, SiTR chip, 130 nm, 128 channels**
- **Double-sided silicon options pursued by Korea**
- **A lot of room for collaboration and additional studies**





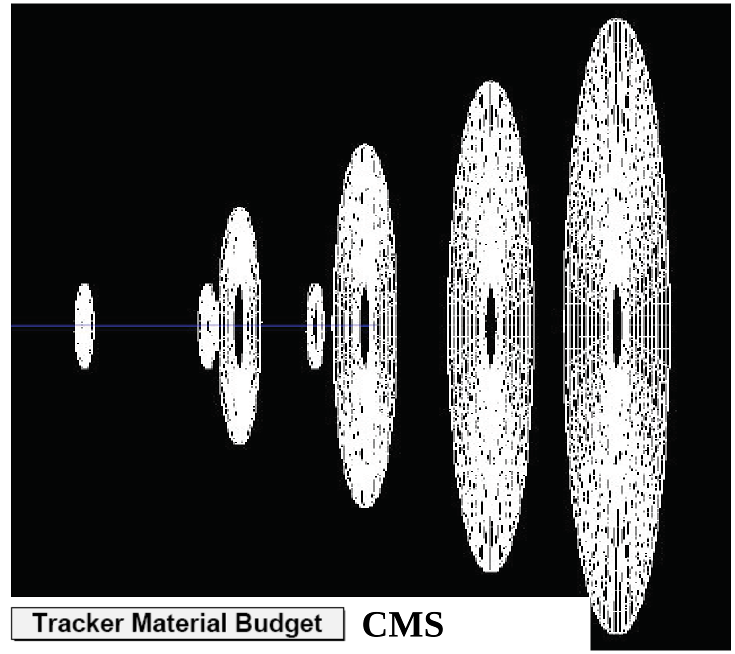


Forward Tracker

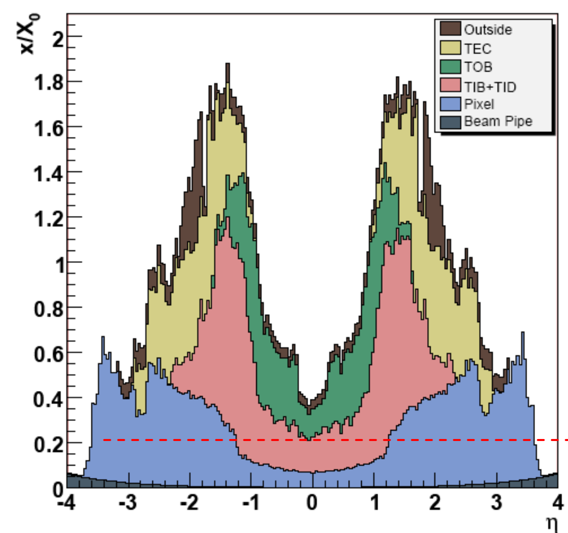
- Barrel cylinders capped by CF-Rohacell forward disks
- Design rather conventional, analogous to designs for other detectors (LHC)
- Close attention paid to one serious short-coming of existing designs: material budget
- Still many outstanding issues:
  - Tiling
  - Readout segmentation
  - Applicability of double-sided silicon
  - Robustness of pattern recognition
  - Integration of very far forward disks
  - Services and cable plant
  - Power pulsing and Lorentz forces

- Needs input from simulation!

- Plenty of room for contributions !



CMS

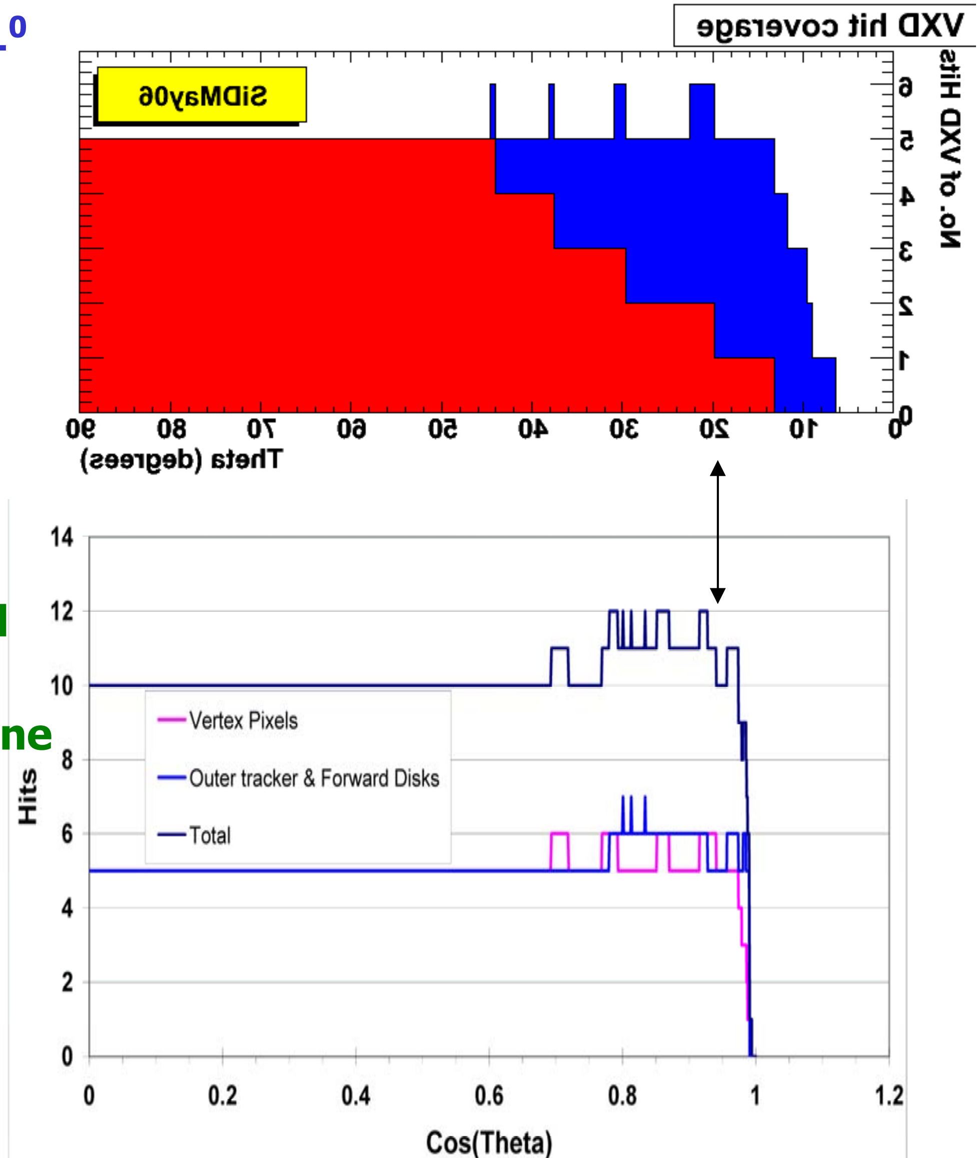


Simulation Studies

- **Uniform coverage up to angles of 11^0**
  - **Full coverage of 5 VXD hits and 5 OT hits up to $|\cos\theta| \sim 0.98$**
- **Thus, baseline geometry exists**

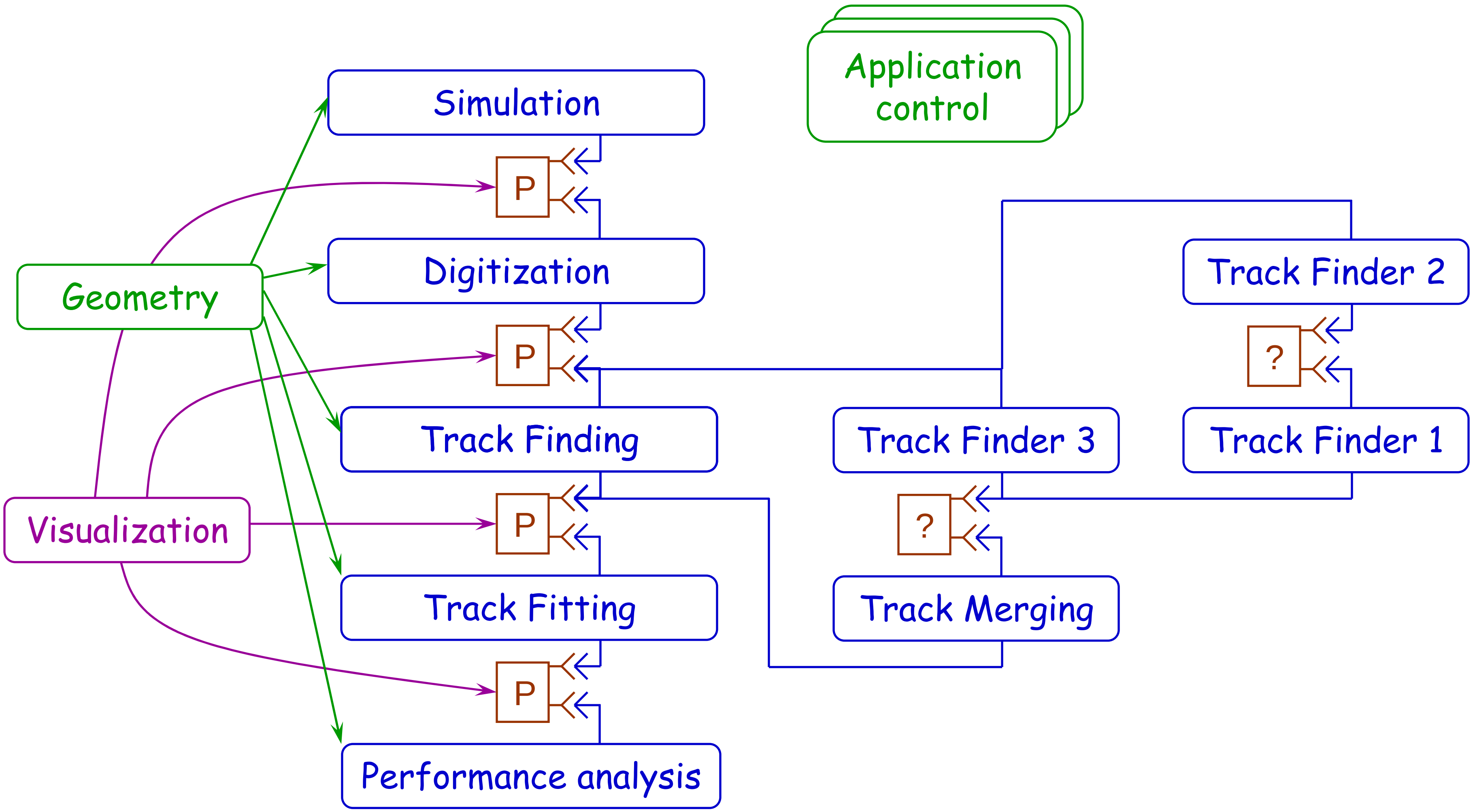
- **Design now needs to be "benchmarked" and optimized**

- **Ideally, the design optimization is an iterative process:**
  - **Start from a baseline design and understand its performance**
  - **Perform variations on the baseline to establish "performance derivatives"**
  - **Establish new baseline design with improved performance**
  - **Repeat until you achieve convergence**



Tracking Toolkit

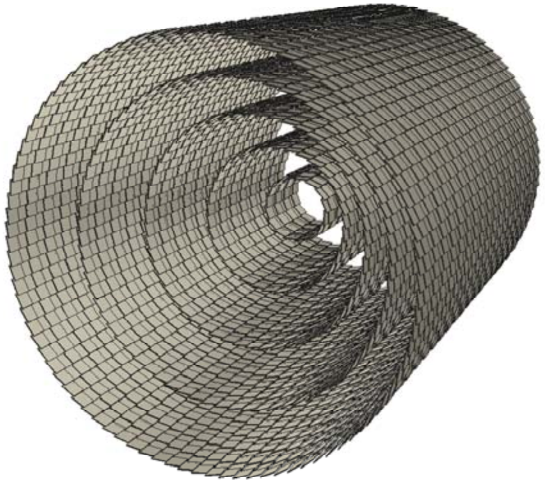
- **Tools required:**

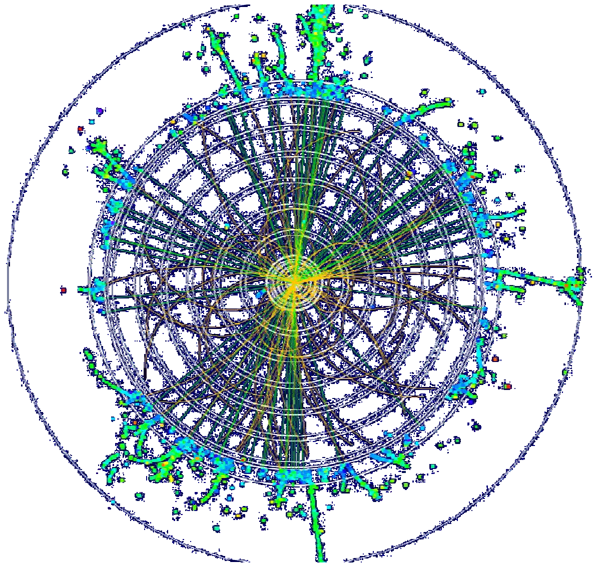


from: D. Onoprienko

Tracking Toolkit Inventory

- **Detector modeling**
  - **Complete barrel and disk geometry available**
    - Poly-hydra geometry definition
    - Virtual segmentation
  - **Output is a "hit"**
- **Digitization**
  - **Complete simulation of charge deposition in vertex pixels (ccd) and strips available**
  - **Output is clustering of hits to form "tracker hits"**
    - Ghosting still an issue
- **Track finding algorithms**
  - **Vertex seeded tracking (complete)**
  - **Conformal mapping algorithm (complete)**
  - **Stand alone outer tracking (in progress)**
  - **Calorimeter seeded tracking (complete)**
- **Track fitting algorithms**
  - **Weight matrix**
  - **Kalman filter**
  - **Fast helix finder for track finding**





Optimization Process

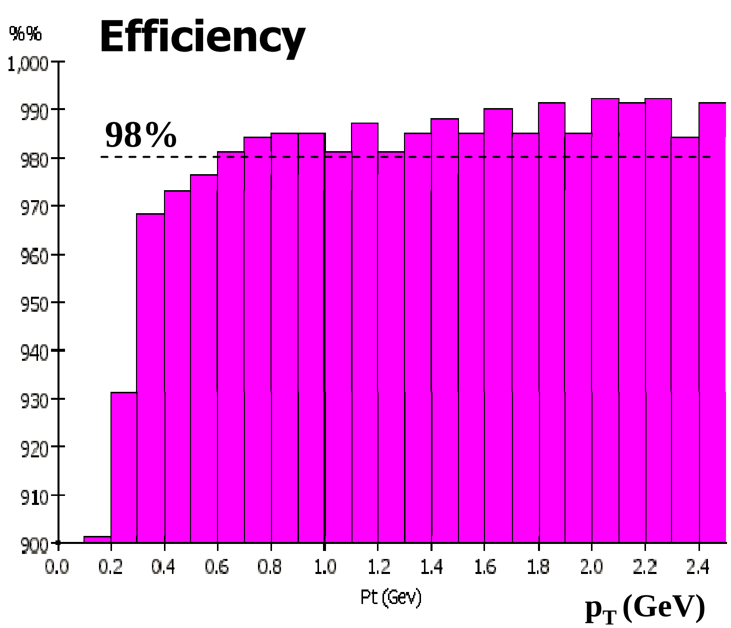
- **Generally two metrics used:**
  - **Traditional metric: efficiency, coverage, resolution, fake rate, …**
  - **Physics metric: benchmark processes, integrated detector performance (PFA); receives non-uniform weight**

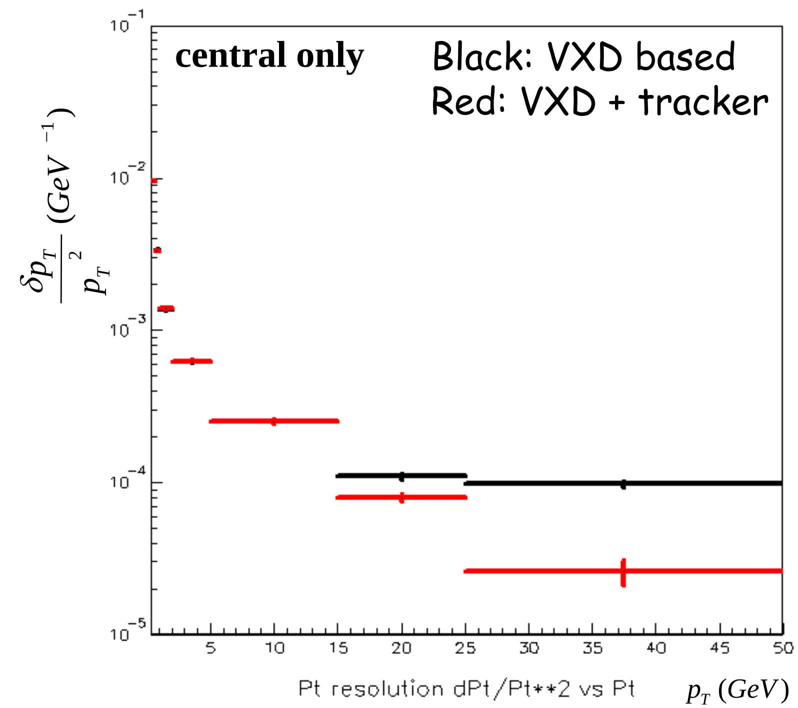
- **Caveat Emptor: this only works if**
  - **Your performance metrics are relevant to the ILC physics program**
    - Danger #1 – optimize for an irrelevant physics benchmark
    - Danger #2 – fail to optimize for the actual requirements needed at the ILC
  - **Your simulation tools are sensitive to the design variations that will ultimately improve performance**
    - Danger #3 – the simulation tools, not the detector design, limit the measured performance
    - Danger #4 – the level of simulation modeling is too coarse and misses important effects
  - **Your backgrounds and hardware performance requirements are realistic**
    - Danger #5 – backgrounds will be worse than expected
    - Danger #6 – hardware problems will not allow simulated performance to be achieved
- **Important to retain / demonstrate "performance contingency"**

From: R. Partridge

Performance

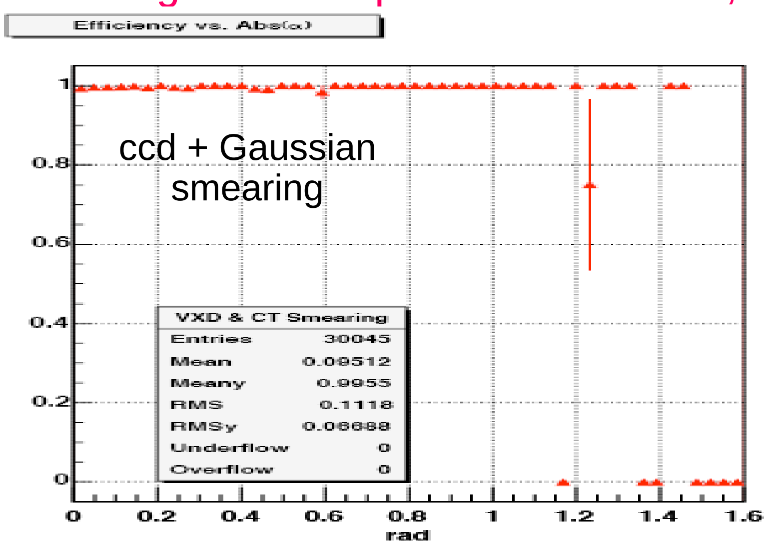
- **Vertex detector seeded pattern recognition (3 hit combinations)**
  - **ttbar-events, full detector simulation and digitization, √s = 500 GeV, background included**
    - Efficiency and purity for prompt tracks is good
      - Fake rate <1%; all forward and at low p_T
    - Momentum resolution for central region only
    - Tracks with p_T < 200 MeV difficult in presence of backgrounds

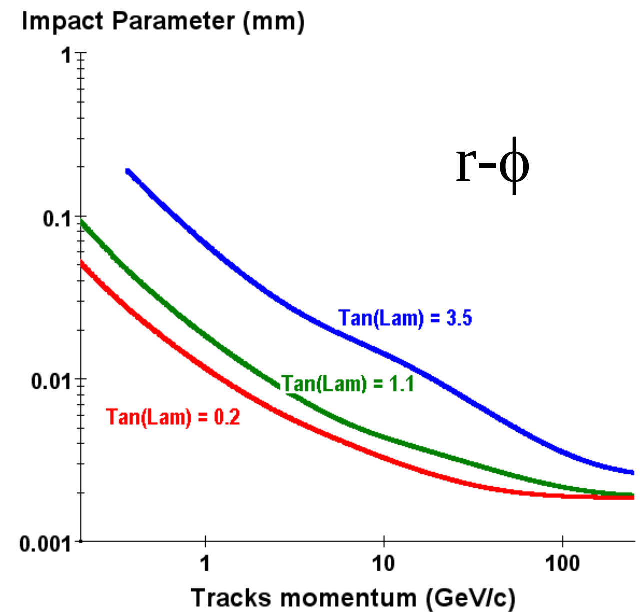


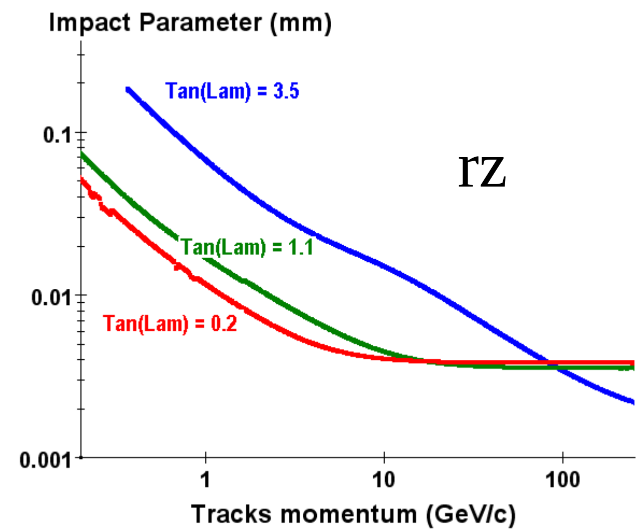


Performance

- **Vertex Seeded Tracking**
  - **Pick three hits in vertex detector and fit helix, pick up hits in outer tracker**
- **Impact parameter**
  - **Resolution in rϕ (rz) plane asymptotically approaches ~ 2μm (4μm) in the limit of high p_T**
- **Tracking in dense environment**
  - **qqbar events at $\sqrt{s}$ = 500 GeV**
  - **Central region only, realistic ccd simulation**
    - Angle with respect to Thrust axis, α

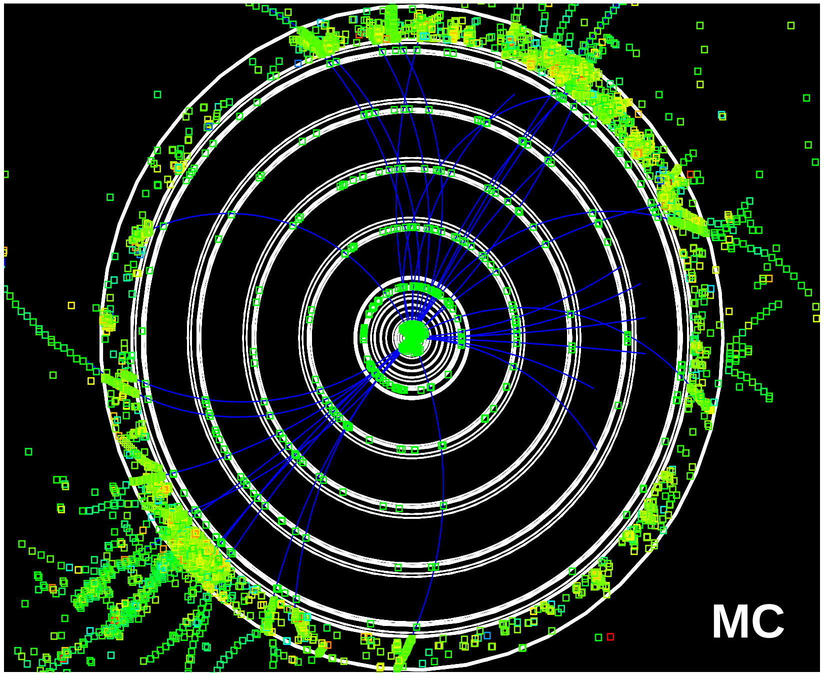


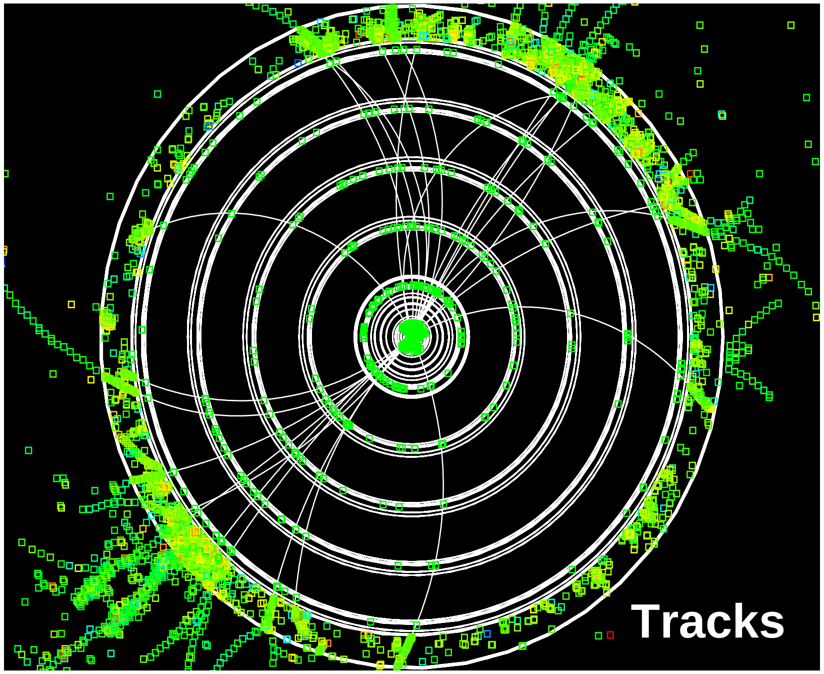




Performance Seedtracker

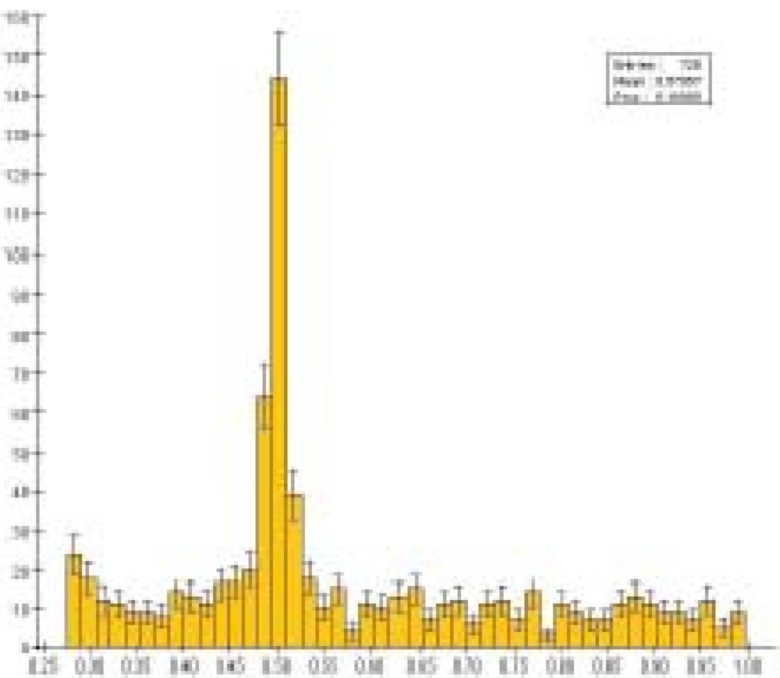
- **Seed Tracker Algorithm:**
  - **Form track seed candidate by picking 3 hits from the seed layers and fit seed candidate to determine helix**
  - **Confirm seed candidate by looking for hits in confirm layers**
  - **Extend seed candidate by looking for hits in extend layers**
  - **Eliminate duplicates**
- **Example for Z → qqbar at √s = 500 GeV, Layers 3,4,5 seed layers**

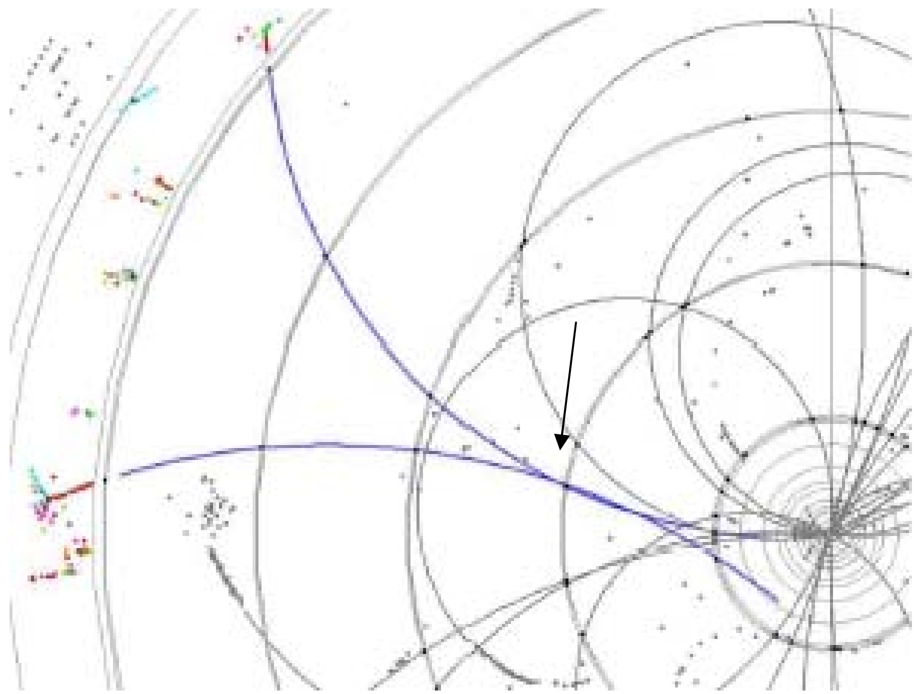




Calorimeter Assisted Tracking

- **With a fine grained calorimeter, can do tracking with the calorimeter**
  - **Find MIP stubs in the calorimeter, extrapolate them into tracker, picking up hits to capture events that tracker pattern recognition doesn't find**
  - **Can be used to reconstruct long-lived particles: K^0_s and Λ or V's in general**
  - **In a sample of simulated Z-pole events: reconstruct ~61% of all charged pions with transverse momentum above 1 GeV, produced by K^0_s**





Help !

- Not all tools in hand yet, notably full track fitting

- Performance characterization not started within fully consistent platform
  - Single particle response
  - Physics processes

- Optimization process not really started
  - Number of layers
  - Long barrels versus short barrels
  - Endcap layout and tiling
  - Segmentation and need for double-sided sensors

- Benchmarking studies
  - Pick your plot
  - e.g. efficiency versus purity for b-jets, c-jets, light quarks
  - Higgs branching ratios
  - ...

Summary

- More work than people to do the work
- Characterizing the performance of the design in the traditional metric has just started; physics metric barely touched, let alone optimization of design
- The problems are challenging and some are rather generic
  - Applicability beyond the ILC
  - Technology issues that apply to other projects
- SiD welcomes new participation in all areas, but especially in the area of benchmarking and simulation !