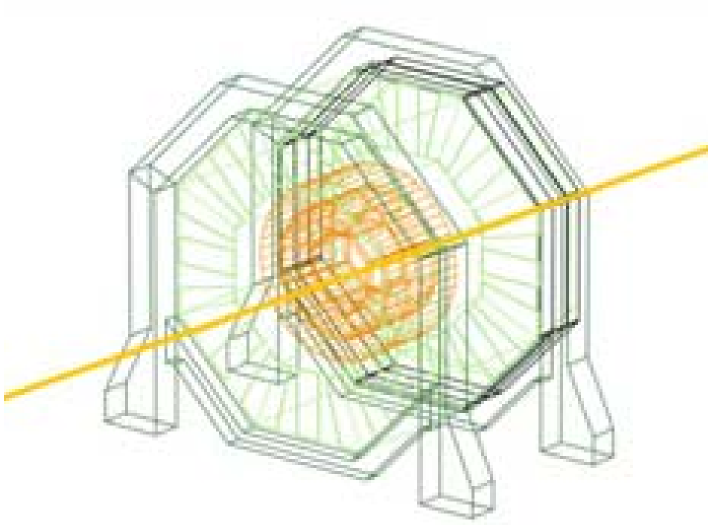
Tracking Status
in the
SiD Detector Concept

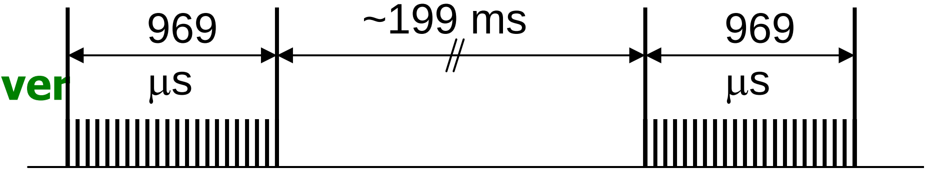


Marcel Demarteau

For the SiD Tracking Group

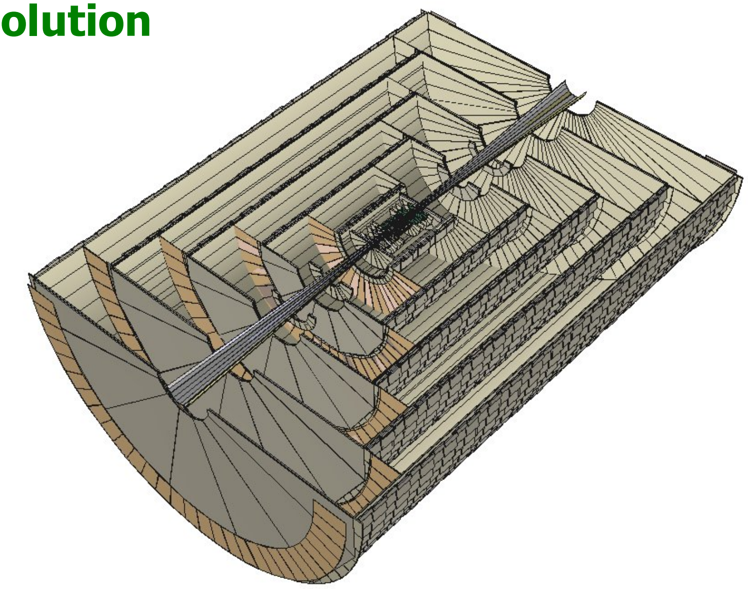
ECFA 08
Warsaw, June 9-12, 2008

Tracking Detector



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

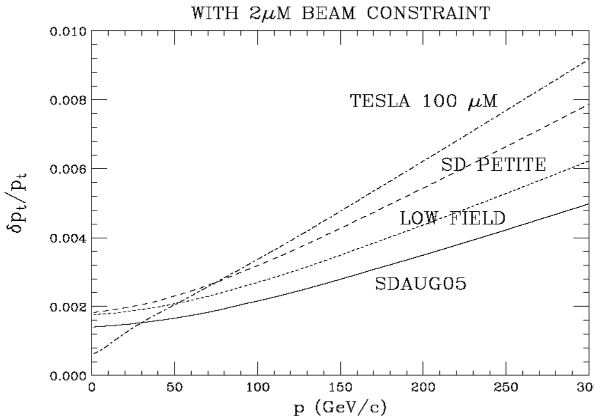
- **Tracking detector requirements**
  - **Transparency: 0.8% X_0 per layer over full fiducial volume**
  - **Low power consumption (~600 W) to allow air cooling**
    - Requires power pulsing
  - **Good point resolution and momentum resolution**
    - Strip pitch of 25 µm
    - $\sigma(1/p) = 2\ 10^{-5}\ (\mathrm{GeV}^{-1})$ 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**



- **Outline for this presentation:**
  - **Hardware activities**
  - **Software activities**

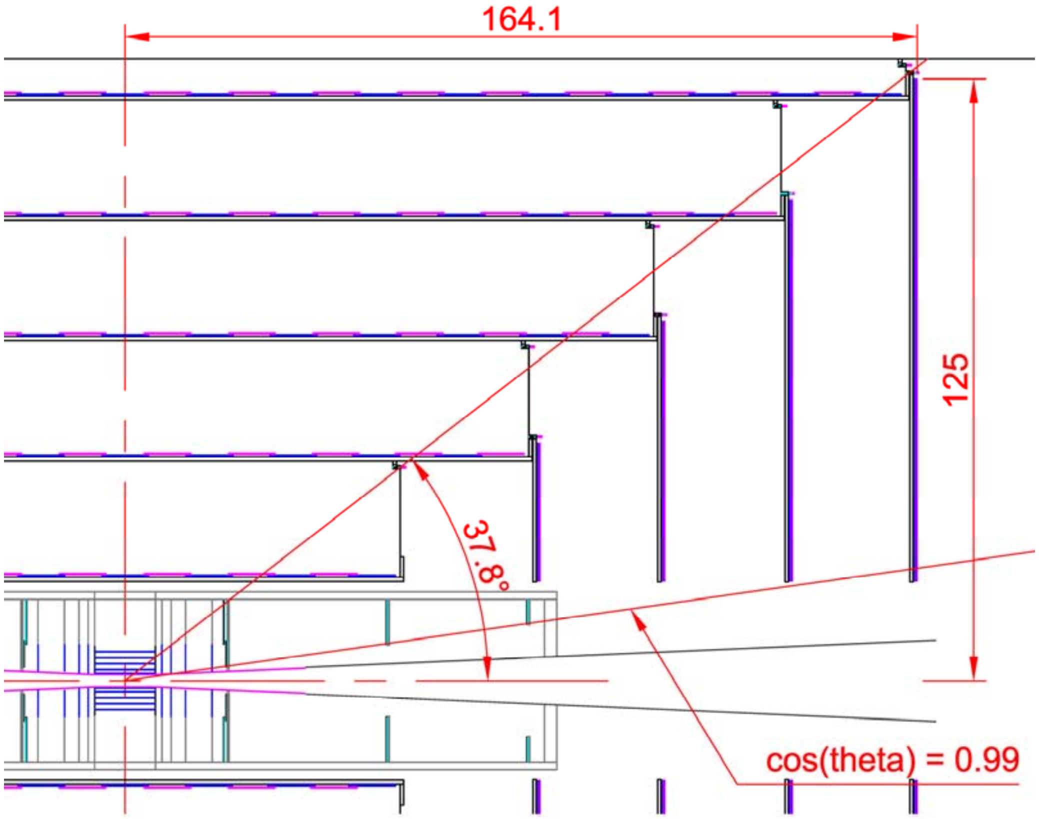
Tracking Detector Technology

- **Essentially two technology options**
  - **Gaseous tracking**
  - **Silicon tracking**
- **One of the main premises of the SiD detector concept is Si-based tracking**
  - **Mature technology which allows emphasis on phi resolution**
    - Superior asymptotic p_T resolution
  - **Single technology throughout the tracking volume**
  - **Single bunch crossing time stamping**
  - **Allows for flexibility in minimizing material distribution through fiducial volume**
  - **Allows for flexibility in granularity (long vs. short strips, pixels)**
- **Other differences with gaseous tracking**
  - **Many layers may compromise material budget compared to 90^0 tracks in TPC**
  - **Worse momentum resolution at low p_T compared to gaseous tracker for 90^0 tracks**
  - **Fewer hits available for pattern recognition**



Tracking Detector 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



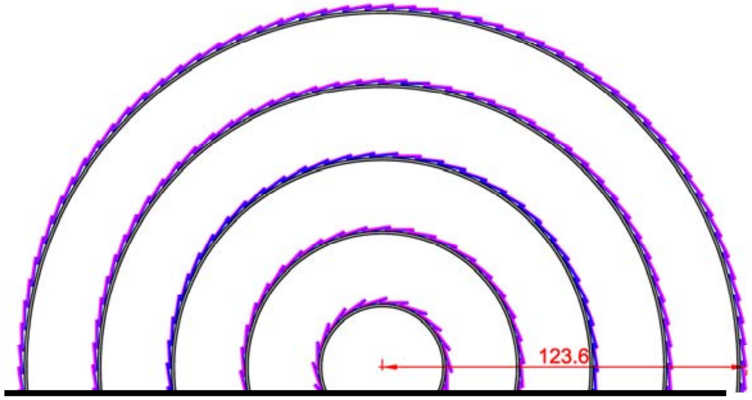
- **Support**
  - Double-walled CF cylinders
  - Allows full azimuthal and longitudinal coverage
- **Barrels**
  - Five barrels, measure Phi only
  - 10 cm z segmentation
  - Barrel lengths increase with radius
- **Disks**
  - Four double-disks per end
  - Measure R and Phi
  - varying R segmentation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

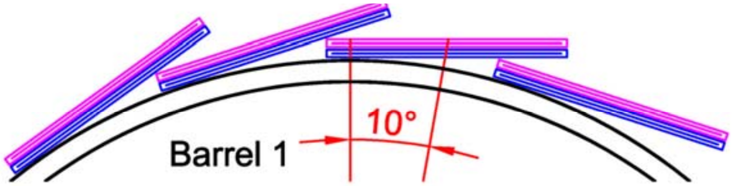
Tracking Detector Barrel Design

- **Each barrel is tiled with sensor modules**
  - **Overlapping modules in r-ϕ and z; no dead areas**
- **Sensor module is rotated to partially compensate for Lorentz angle in 5T field**

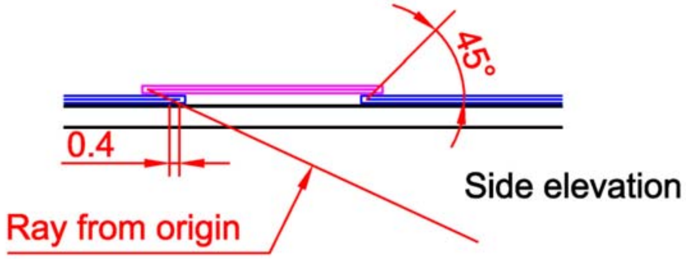
Layer	# Phi	# Z	Rot. Angle	R (cm)
1A	20	7	10.12°	21.75
1B	20	6	9.94°	22.15
2A	38	9	7.03°	46.75
2B	38	10	6.97°	47.15
3A	58	13	6.60°	71.75
3B	58	12	6.57°	72.15
4A	80	15	6.60°	96.75
4B	80	16	6.58°	97.15
5A	102	19	6.58°	121.75
5B	102	18	6.56°	122.15

- **Layout corresponds to 8686 barrel sensors, each with 1840 readout channels**
  - **Strip/Readout pitch = 25/50 μm**





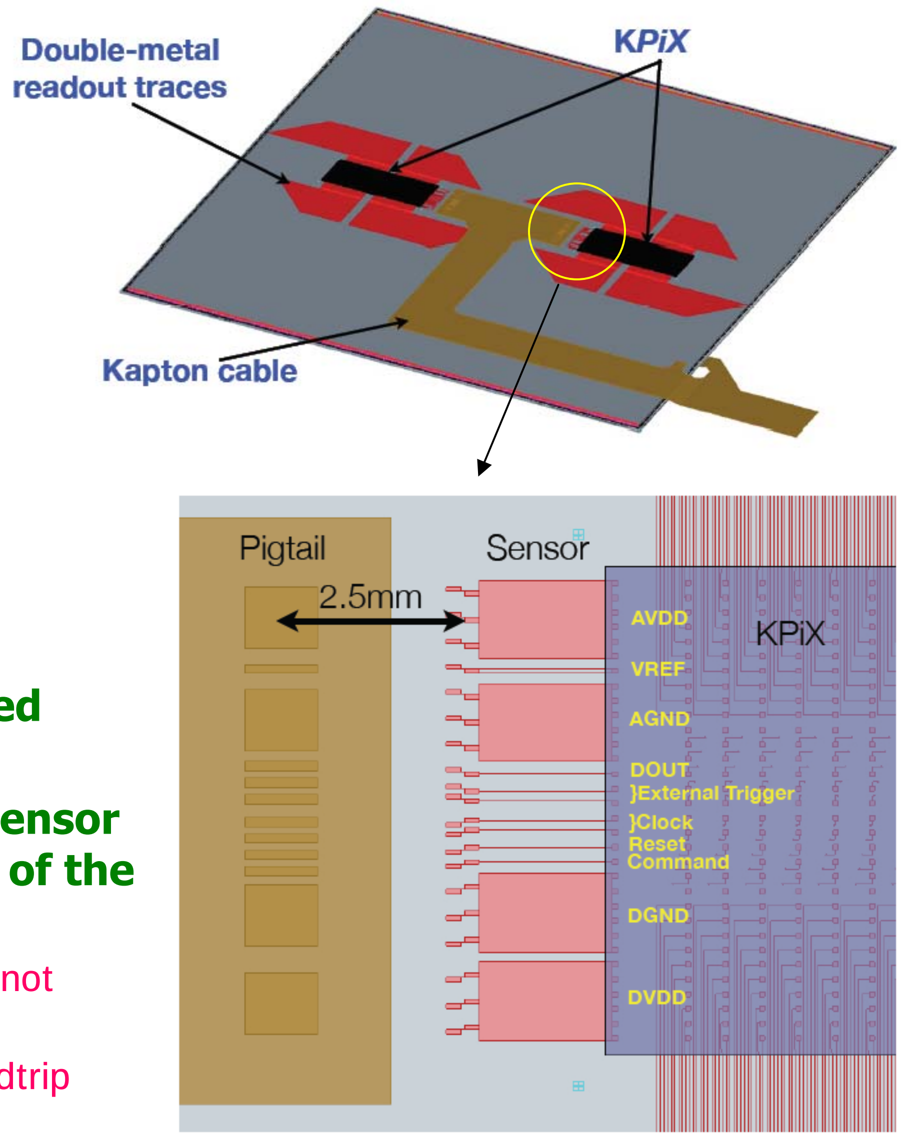
Detail: sensor phi overlap



Detail: sensor z overlap

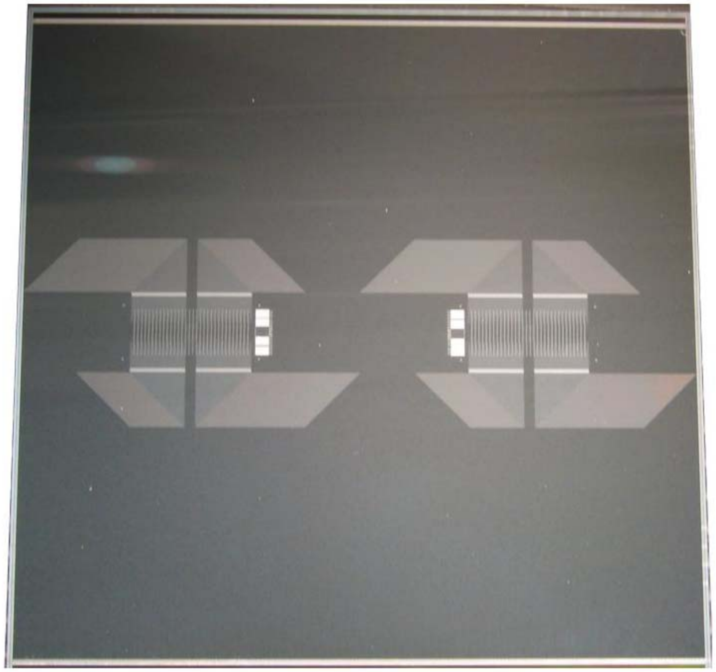
Barrel Sensors

- **Hybrid-less design**
  - 93.5 x 93.5 mm^2 sensor from 6” wafer with 1840 (3679) readout (total) strips
  - Strip/Readout pitch = 25/50 µm
  - Read out with two 1024-channel asics (kPix) bump-bonded to sensor
  - Routing of signals through 2nd metal layer, optimized for strip geometry
    - Minimize capacitance and balance with trace resistance for S/N goal of 25
  - Power and clock signals also routed over the sensor
  - ‘Pigtail’ cable connects kPiX and sensor to concentrator boards at the end of the barrels
    - Traces for Digital Control and Readout not bussed
    - Power and Ground traces $R < 1\Omega$ roundtrip

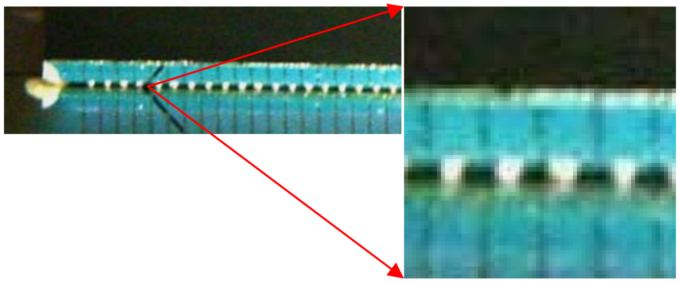


Prototyping Status

- Sensors ordered from Hamamatsu
- Twenty full size sensors received April '08
  - V_{dep} ~ 40 V
  - Bad channels < 1/10,000
  - Characterization ongoing
- Some specifications
  - implant/sense strip width: 8/9 µm
  - 4µm double-metal readout width
    - C=14-18 pF for 95% channels, 20 pF max
  - R < 350 Ω for all channels
  - Expected goal of S/N = 20-25 with kPiX
- Forty charge division sensors and forty smaller scale sensors for tests with prototype kPix devices
- 64-channel KPiX-V7 in hand
  - Can proceed to connect sensor to chip
- Gold stud bump-bonding proceeding at UC Davis (sensors can also be wirebonded)
  - First attempts by Palomar Technologies on KPiX-5 and ECal prototype sensors somewhat successful
  - Only 96% yield on first two test chips
    - Corrosion problem between epoxy used for making final bond and Al pads
  - Process is being debugged



ECal example of bump bonded kpix chip

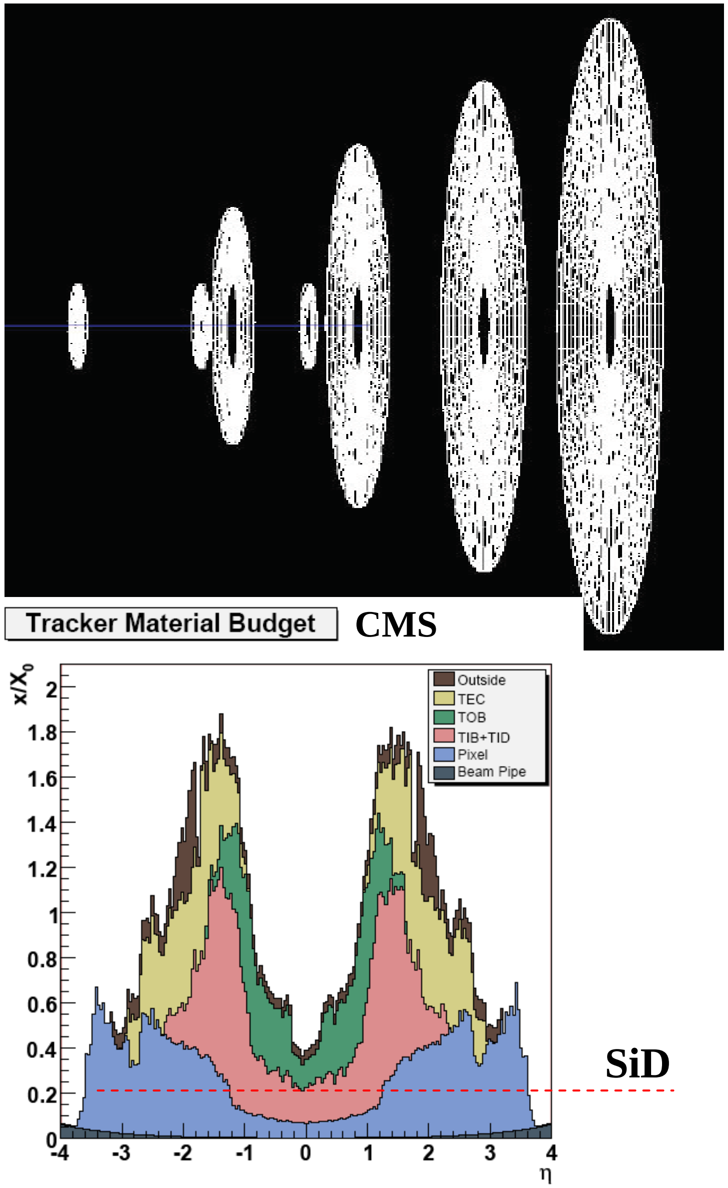


Forward Tracker

- 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!

- An area with a lot of commonality between many projects



Power

- **Assume an average power dissipation of 20 μwatts per channel (consistent with kPiX design assumptions)**
  - **8686 barrel sensors, each with1840 readout channels**
  - **4738 disk sensors (sum of two ends)**
    - Phi overlap was assumed to be provided by a pinwheel geometry.
    - Each disk was assumed to measure two coordinates.
    - Disk power has been estimated assuming that, on average, each sensor has the same area and number of readout channels as do barrel sensors
  - **Power cycling has been assumed to reduce peak power by a factor of ~80**

- **There are other heat sources:**
  - **Power dissipated in cabling ~ 4% additional load**

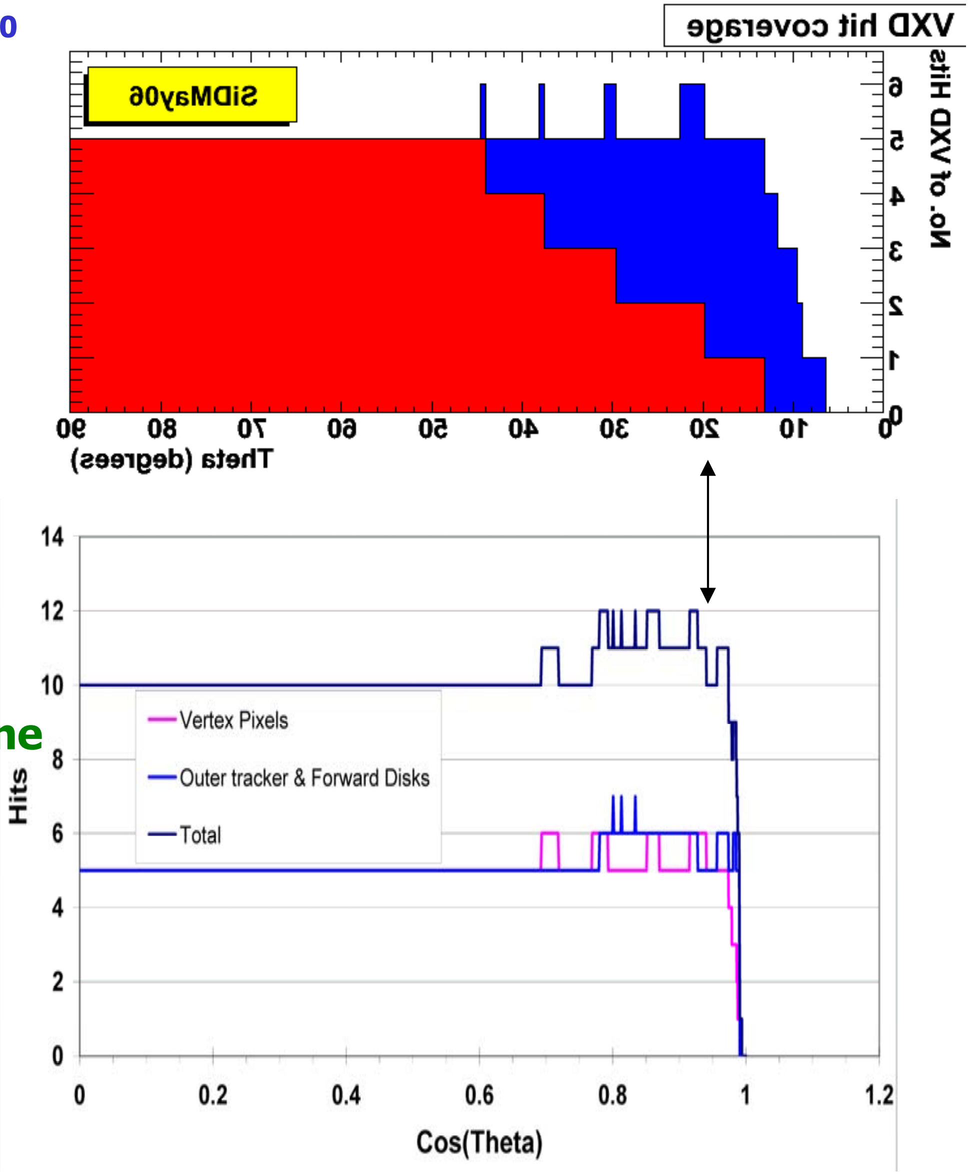
- **Without power pulsing heat load is 80*500 Watts = 40 kW**

- **How does serial powering change this picture?**

Barrels	P (watts)	Disks	P (watts)
Barrel 1	9.6	Disk 1	10.9
Barrel 2	26.6	Disk 2	28.2
Barrel 3	53.4	Disk 3	52.2
Barrel 4	91.3	Disk 4	83.1
Barrel 5	138.9		
Sub-total	**319.8**	**Sub-total**	**174.4**

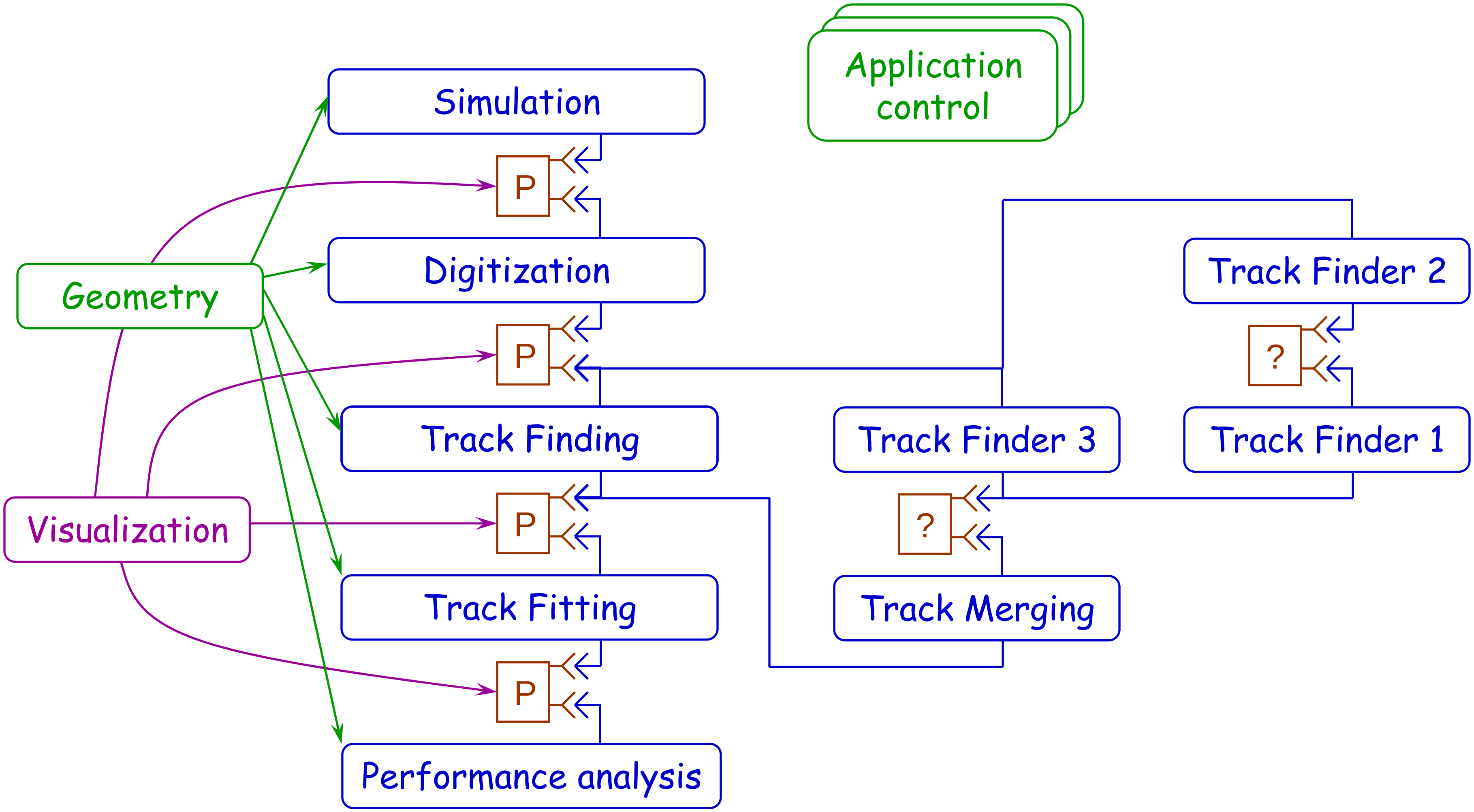
Simulation Studies

- Uniform coverage up to angles of 11^0
  - Full coverage of 5 VXD hits and 5 OT hits up to |cosθ| ~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

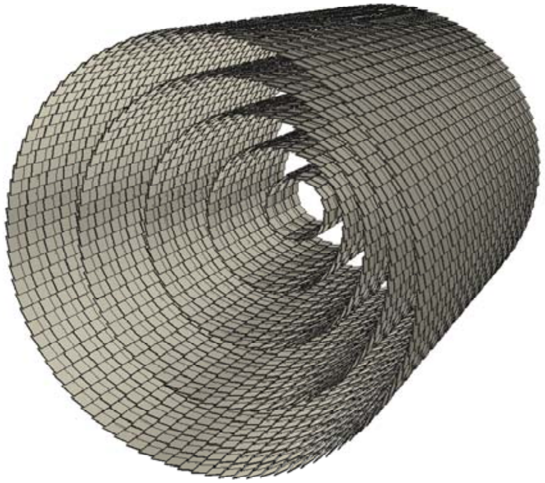
- **Tools required:**

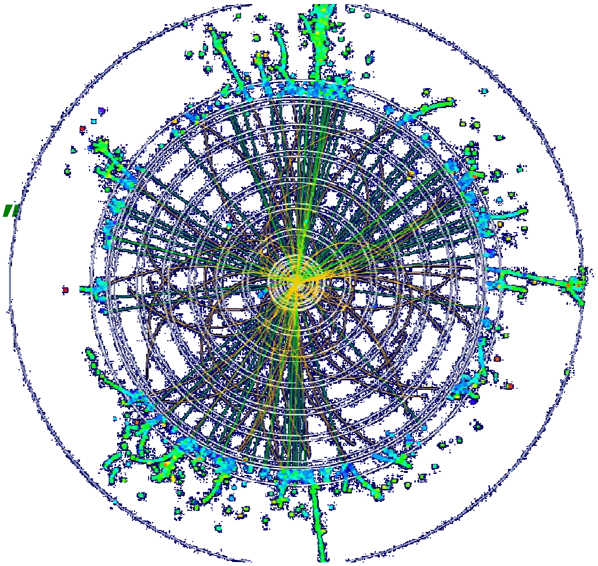


from: D. Onoprienko

Tracking Simulations

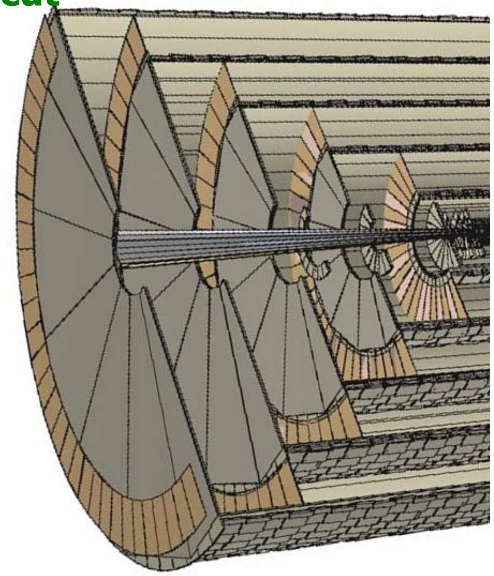
- Substantial effort has been devoted to developing versatile tracking simulation package for SiD
  - SLIC GEANT4 detector simulation with geometry specified by xml file
- Detector modeling
  - Geometry can be represented in full detail with:
    - Planar poly-hydra geometry definition
    - Virtual segmentation that subdivides cylinders and disks
  - 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"
- Track Finding Algorithms
  - Seed-based Stand-Alone Tracking
  - Vertex seeded tracking
  - Conformal mapping algorithm
  - Calorimeter seeded tracking





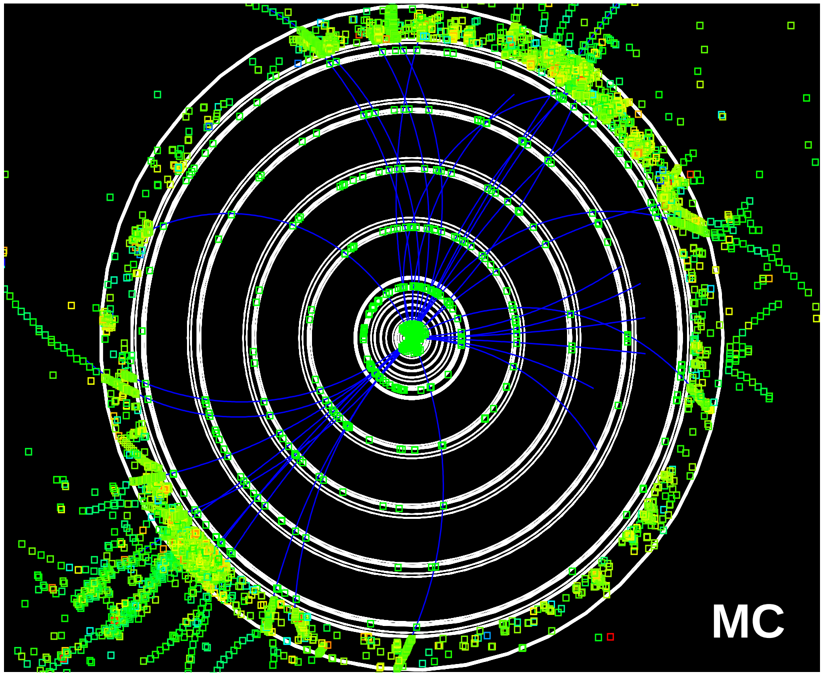
SeedTracker

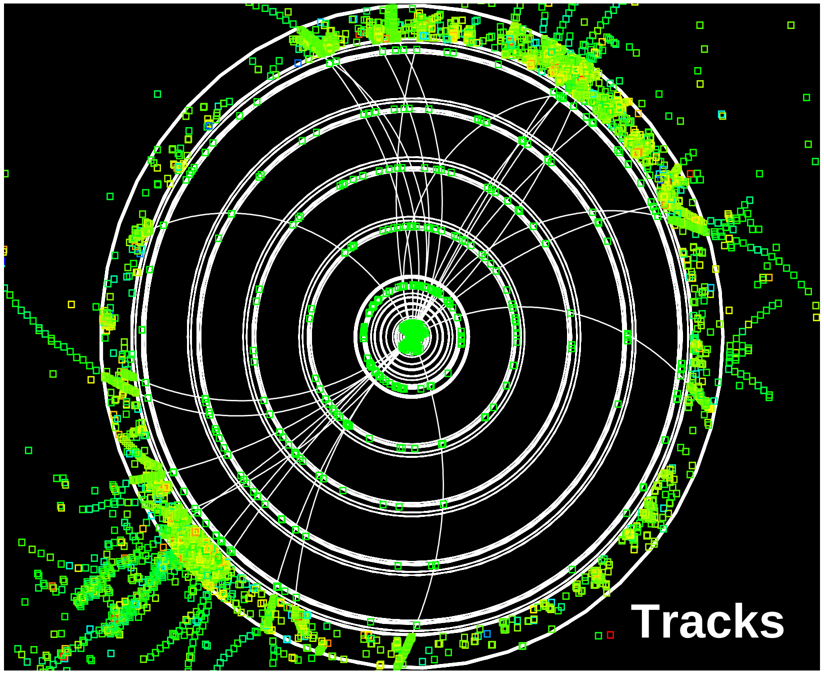
- **Seed Tracker Algorithm:**
  - **Form track seed candidate by picking 3 hits from the seed layers and extend track to additional layers to determine helix**
    - Seeds can be selected from any combination of pixel, axial strip, and stereo strip layers
    - User defined strategies specify seed layers, additional layers, and cuts
    - Strategies can be Outside-in, Inside-out, mixed barrel/endcap, etc.
- **SeedTracker uses a χ^2 function for essentially all decisions**
  - **χ^2 takes into account residuals from the helix fit, any pulls required to meet kinematic constraints (eg $p_T > x$)**
  - **Multiple scattering in dead / active material is accounted for**
  - **No geometry parameters - geometry taken from detector description**
  - **No tuning parameters – all cuts / decisions derived from χ^2 cut**
- **Tracker endcap stereo layers are separated by 4 mm**
  - **Nearly 3 orders of magnitude greater than the ~7 μm intrinsic strip resolution**
- **Unless the track is traveling normal to the sensor planes, the x-y hit position will be different in the two stereo sensors**
- **Resolved using iterative method**
  - **First fit of a track seed is used to estimate helix so multiple scattering errors can be calculated**
  - **Calculate stereo hit positions**
  - **Re-fit including multiple scattering errors**



Performance Seedtracker

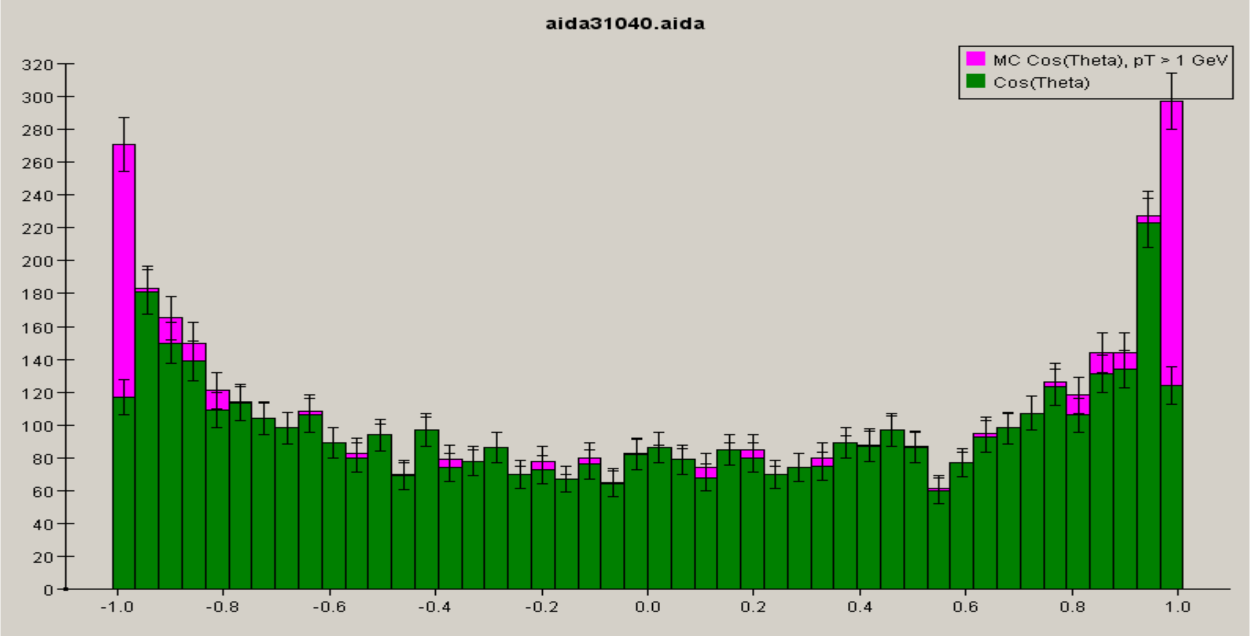
- **Seed Tracker Algorithm:**
  - **Form track seed candidate by picking 3 hits from the seed layers and fit seed candidate to determine helix**
  - **Confirm seed candidate by looking for hits in confirm layers**
  - **Extend seed candidate by looking for hits in extend layers**
  - **Eliminate duplicates**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





Performance Seedtracker

- First result of full pattern recognition over full angular range



- Tools now in place to start characterizing the tracker
- Note that virtual segmentation is in place, so changing strips to pixels, adding additional hits, is straightforward
- Kalman fitter is currently still missing, but is being worked on.

Concluding Remarks

- **Tools are now becoming available to the end-users and optimization of the design with realistic scenarios can commence**

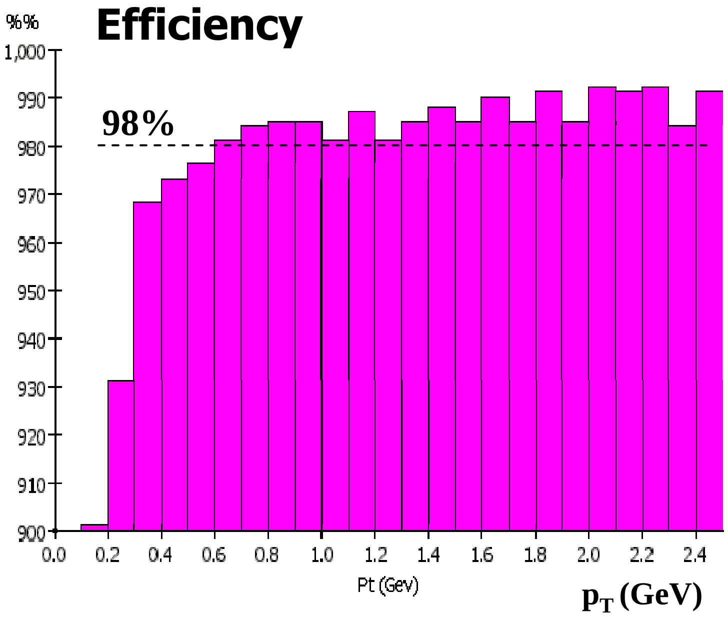
- **Some of the priorities:**
  - **Characterizing the performance of the design in the traditional metric**
  - **Characterizing the performance of the design in the physics metric**
  - **Optimizing the design**
    - Trade-off between short barrels and momentum resolution
    - Added benefit of outer layer being pixellated
    - Number of layers
    - Forward tracking problem is a generic problem
      - Tiling
      - Stereo readout

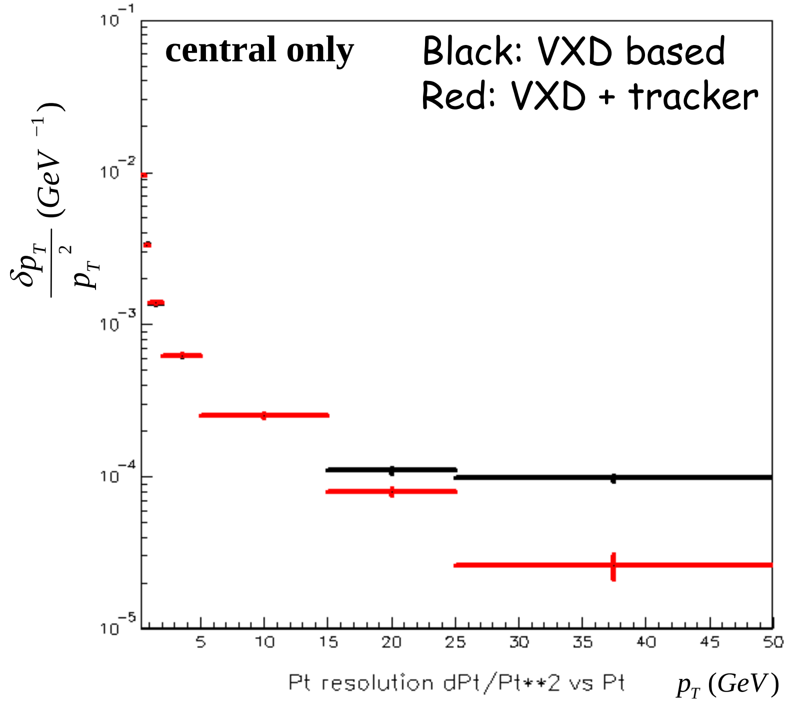
- **Some issues are wide-ranging and have applicability beyond the ILC**
  - **Technology issues that apply to other projects**

- **SiD welcomes collaboration in all areas**
  - **Received HPK sensors and are willing to share sensors with other institutions**
  - **Characterization of tracking, especially in forward region and optimization of geometry**
  - **Benchmarking physics processes**

Performance

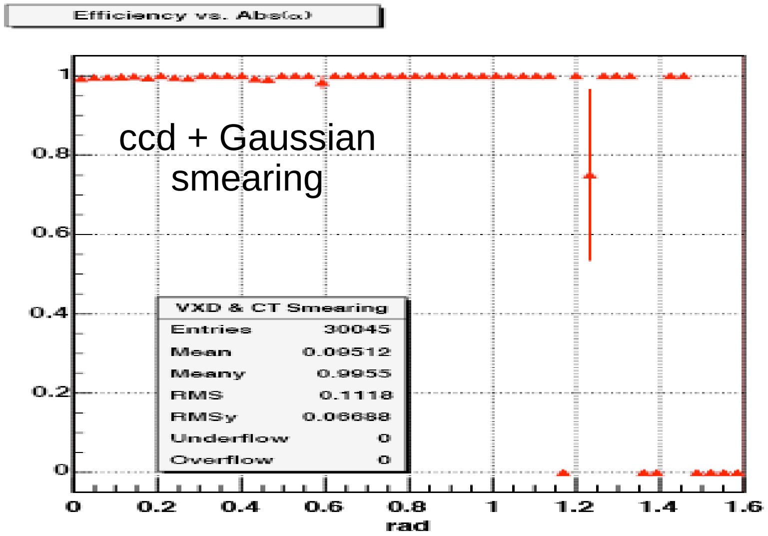
- **Vertex detector seeded pattern recognition (3 hit combinations)**
  - **ttbar-events, full detector simulation and digitization, √s = 500 GeV, background included**
    - Efficiency and purity for prompt tracks is good
      - Fake rate <1%; all forward and at low p_T
    - Momentum resolution for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

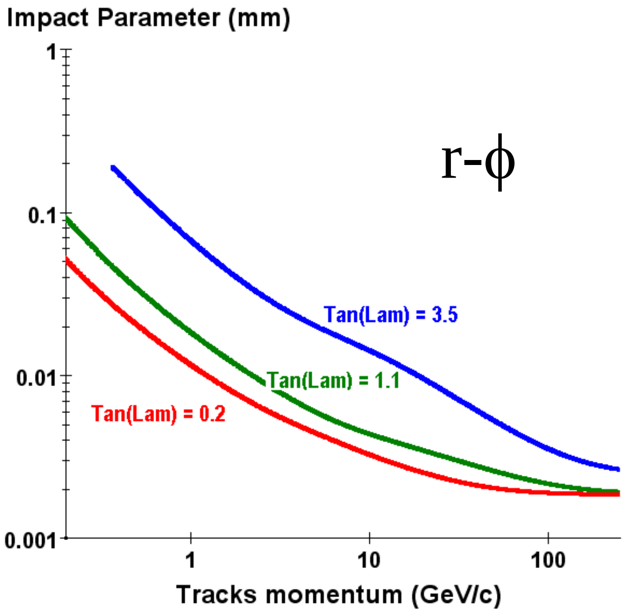


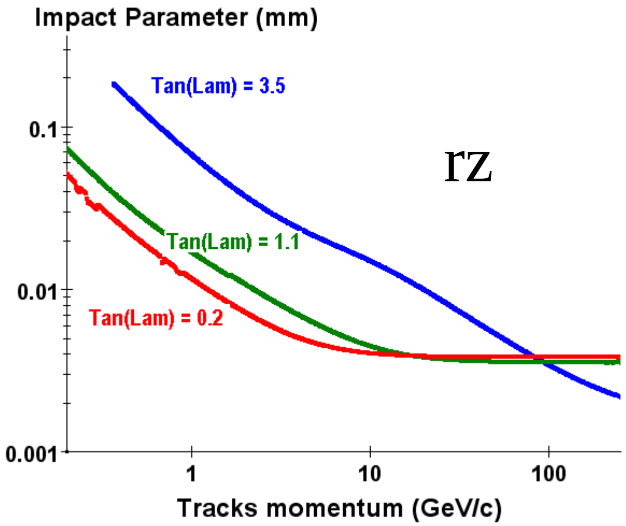


Performance

- **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







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

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**