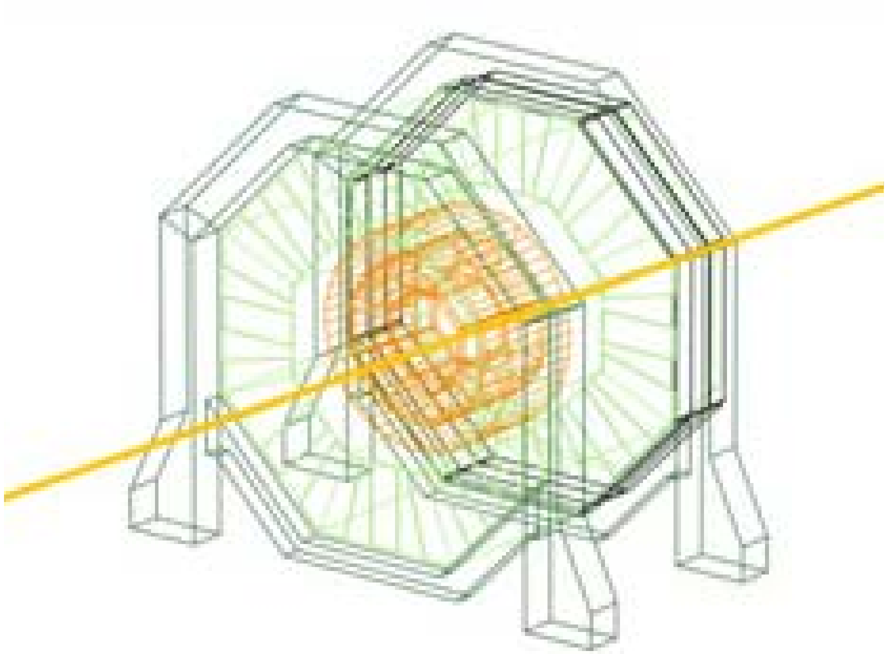
SiD Vertexing and Tracking
Status as of the LOI



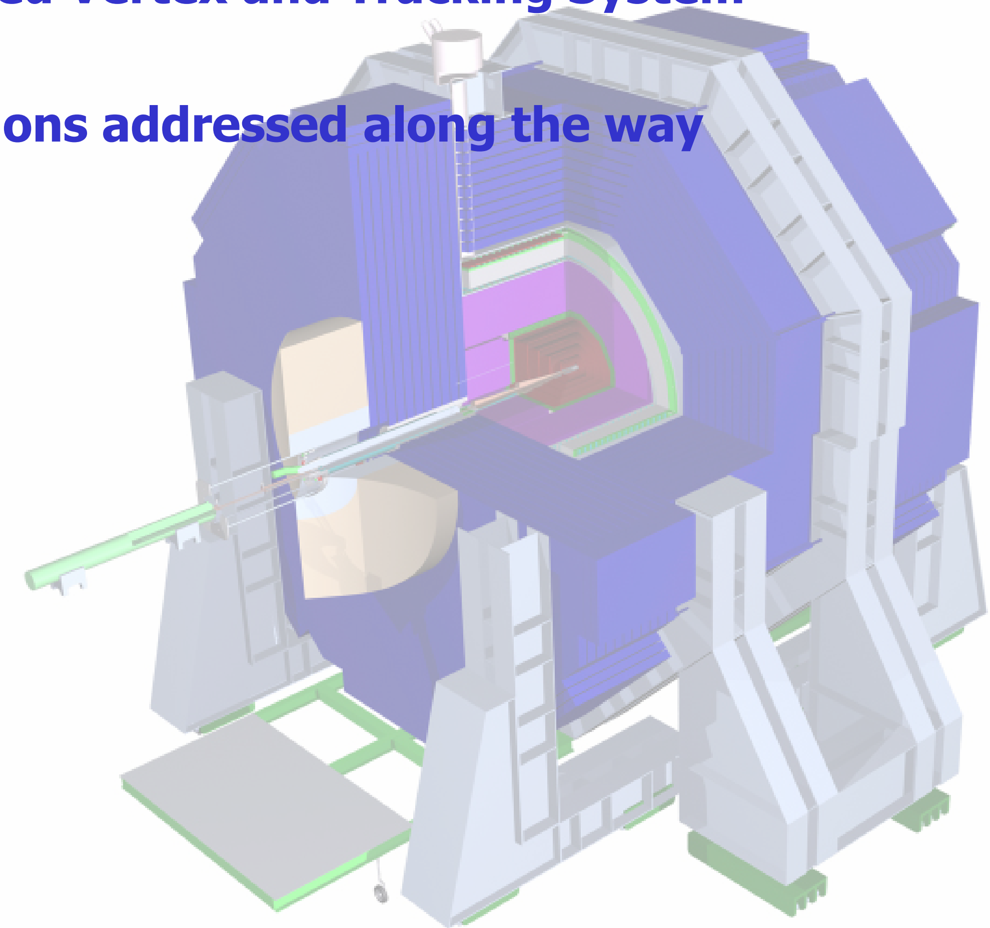
Marcel Demarteau

For the SiD Vertrac Group

TILC09
Tsukuba, April 17-21, 2009

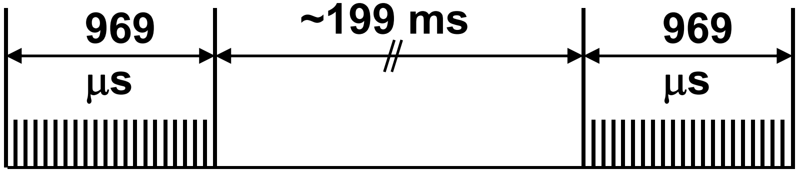
Outline

- **Physics requirements, ILC environment, design constraints**
- **Performance of Integrated Vertex and Tracking System**
- **Some of the IDAG questions addressed along the way**
- **Concluding remarks**



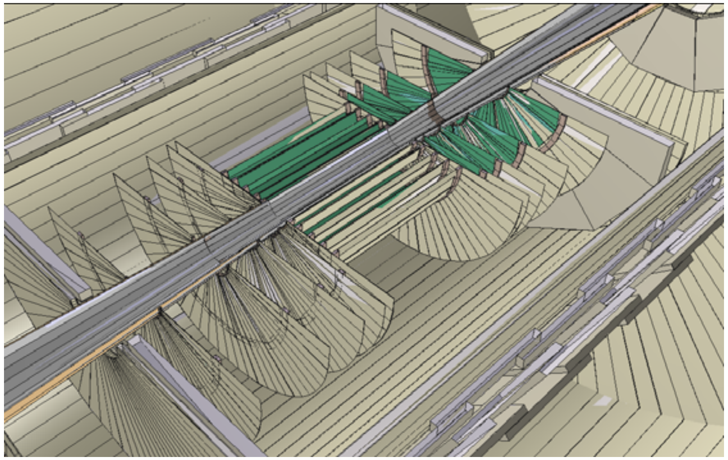
Pixel Detector

- **The physics program at the ILC emphasizes excellent impact parameter and momentum resolution over the full angular region**



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

- **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**

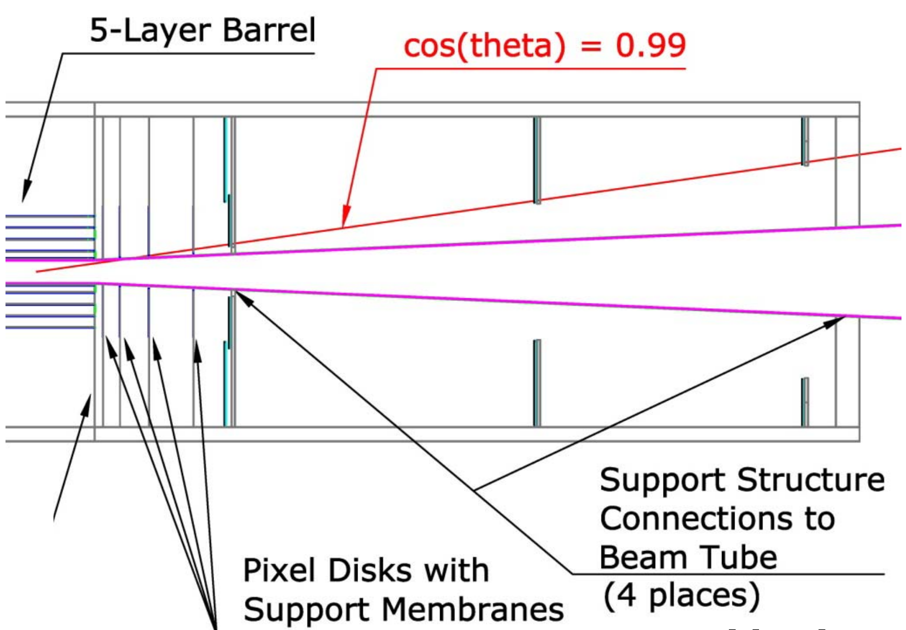


- **Combination of small pixels, short integration time, low power required for ILC is difficult to achieve**
  - **Small pixels tend to limit the amount of circuitry that can be integrated in a pixel**
  - **Small pixels also mean that the power/pixel must be kept low**

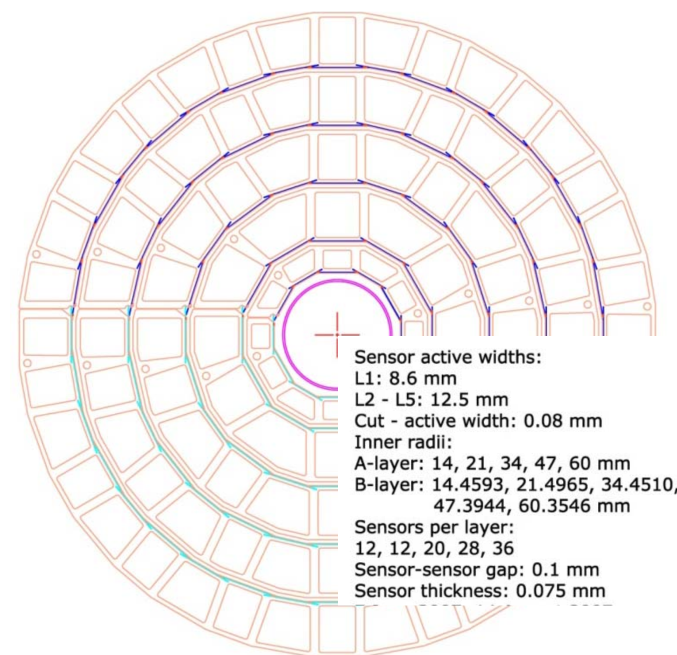
- **No technology choice as of yet**

Pixel Detector Design

- Baseline vertex detector: central, 5-layer barrel, consisting of two sub-assemblies clam-shelled around beam pipe two 4-plane end disk assemblies and three additional disks per end for extended coverage
- All Silicon layout to mitigate CTE issues
  - Uses only the silicon sensors in "cylindrical" portions of the structure
- All elements are supported indirectly from the beam tube via double-walled, carbon fiber laminate half-cylinder
- Sensor thickness of 75 μm assumed, with 20x20 μm^2 pixel size



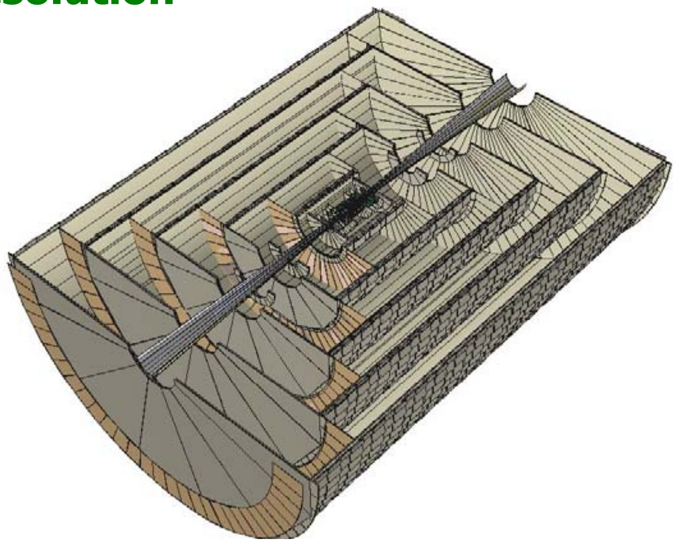
side view



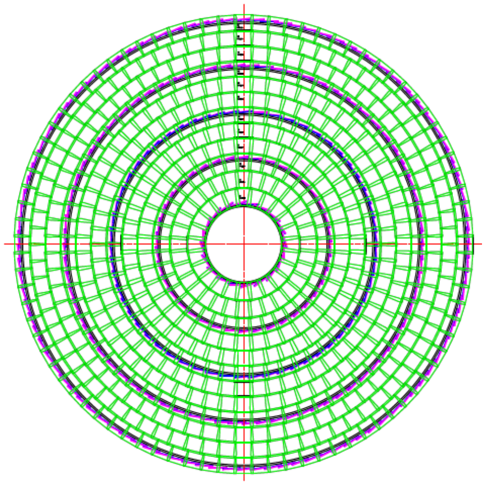
end view

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**

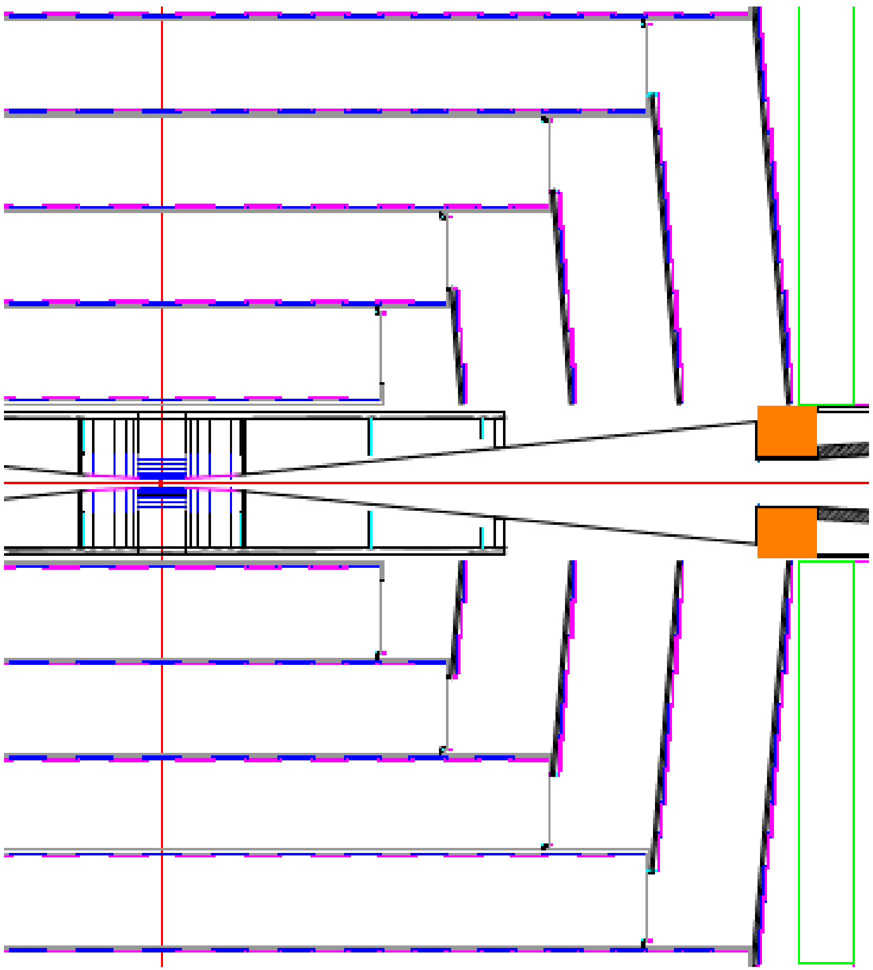


- **Silicon technology chosen**
  - **Mature technology which allows emphasis on phi resolution**
    - Superior asymptotic p_T resolution
  - **Allows for flexibility in minimizing material distribution through fiducial volume**



Tracker Design

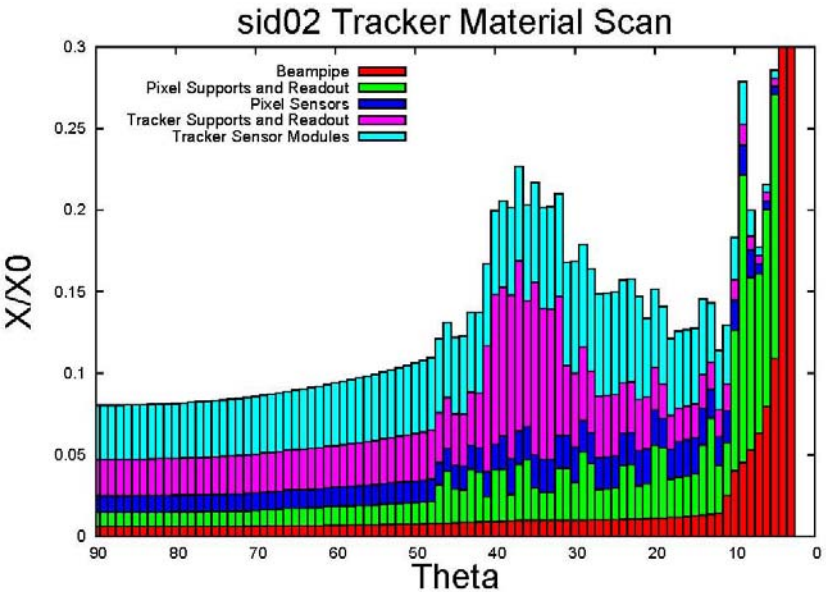
- 5-Layer silicon strip outer tracker, covering R_{in} = 20 cm to R_{out} = 125 cm
- Barrel – Disk structure: goal is 0.8% X_0 per layer

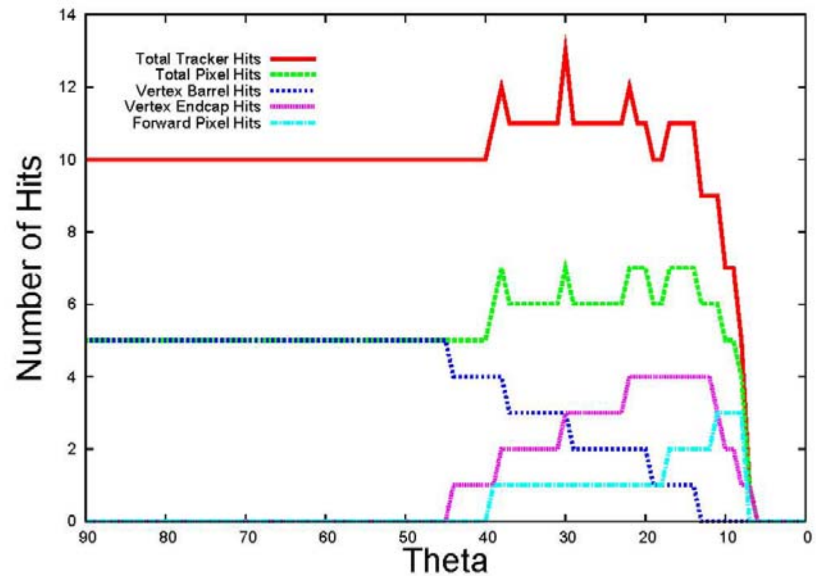


- Support
  - Double-walled CF cylinders
  - Allows full azimuthal and longitudinal coverage
- Barrels
  - Five barrels, measure Phi only
  - 10 cm z segmentation
  - Barrel lengths increase with radius
- Disks
  - Four double-disks per end, lampshade geometry
  - Measure R and Phi
  - Varying R segmentation
  - Disk radii increase with Z
- Note: simulations carried out with disks at 90 degrees to beam line

“Vertrac Detector” Features

- **Although from a technological and mechanical point of view the vertex detector and the outer tracker are individual sub-detectors, we wish to view it as one integrated detector: the “vertrac” detector**



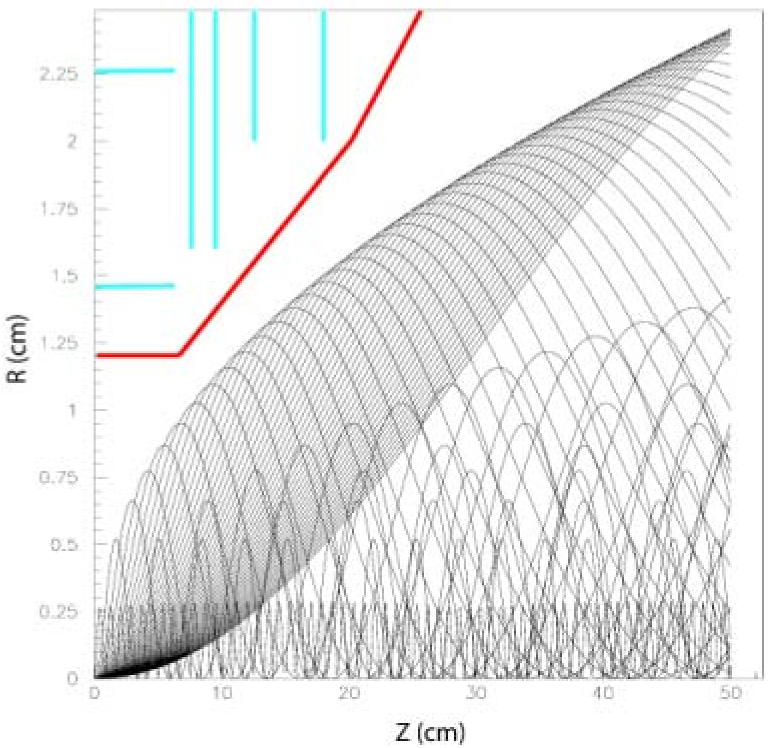


  - **Material budget $X/X_0 < 0.2$ throughout the tracking volume**
  - **There is a uniform coverage of a minimum of 10 hits per track down to small angles**

IDAG Question

- **What is the sensitivity of different detector components to machine background as characterized in the MDI panel**

- **The beam pipe radius is set by the pair background envelope**
- **The design is in conflict with those machine configurations where the beam envelope is increased, such as the low power option**

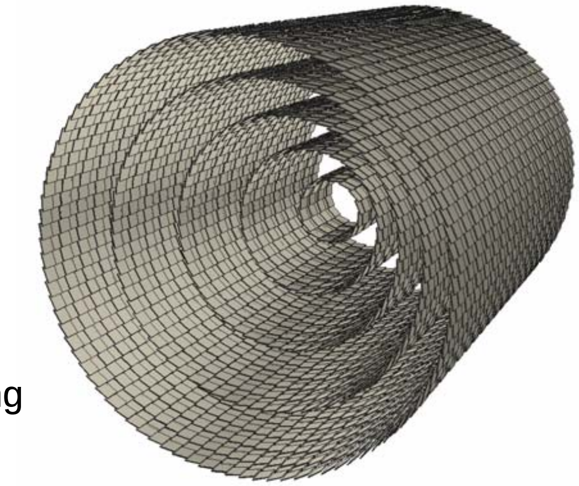


- **The two main vertex detector technologies pursued by SiD – 3D and chronopix – assume single bunch time stamping**

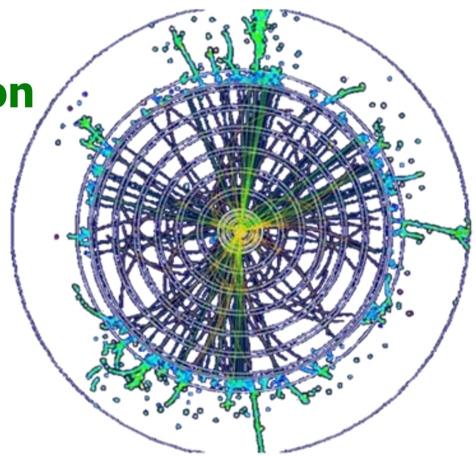
- **Results on tracking performance will be shown with 10 bunch crossings overlaid: no significant degradation in tracking performance**

Detector Modeling

- **Geometry**
  - **Complete barrel and disk geometry available with dead material**
    - Virtual segmentation used for LOI studies
      - Barrel sensors have been approximated by thin cylinders, while the disk sensors have been approximated by planar disks perpendicular to the beamline.
    - Poly-hydra geometry definition
      - Fully segmented detector with individual sensors, overlap and dead material. Allows for detailed tracking and alignment studies



  - **Output is a "hit"**
    - Individual pixels and strips not included in the GEANT4 simulation
- **Digitization**
  - **Charge deposition is calculated from energy deposition generated by Geant4**
  - **Hits are put at center of detector with no smearing to improve speed**
  - **Full ghosting in stereo layers**



IDAG Question

Q: Status of an engineering model describing the support structures and the dead zones in the detector simulation

A: The dead areas and inactive material has been described to a high level of detail in the Monte Carlo simulations. The tools have been developed to take the studies to a next level

Track Finding Strategy

- Track finding begins by forming all possible 3 hit track seeds in three "Seed Layers" specified by the user
  - Loops over all viable combinations of 3 hits in the 3 seed layers
  - Reduce the combinatorics by eliminating hit combinations inconsistent with p_T and impact parameter constraints
- Track finding is guided by a set of user defined "Strategies"
  - A strategy defines layers to be used, their roles, and constraints (e.g. $p_T > x$)
- Nearly all pattern recognition code is agnostic as to the type of hit
  - No differentiation between pixel or strip, barrel or forward sensors
- All decisions based on χ^2 from fits and constraints ($p_T > x$)

Track Finding Algorithm

- **Fit a helix to the 3 seed hits**
  - **First fit without MS errors; determination of the helix parameters $\omega \equiv 1/R$, d_0, ϕ_0, z_0, and $\tan(\lambda)$**
  - **Calculate the MS errors for each hit using this helix**
  - **Perform a second helix fit including MS errors**

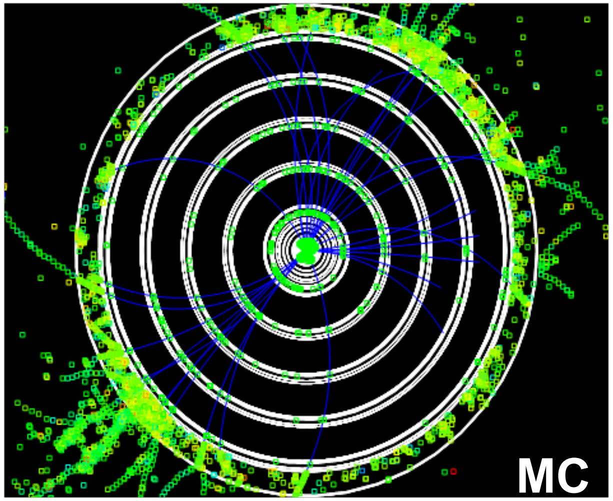
- **Calculate χ^2 from fit and constraints ($p_T>x$) if necessary**
  - **Calculate a constrained χ^2 to estimate the increase in χ^2 needed to pull into compliance with the constraint**
    - Constraints: $p_T > p_T^{min}$, $|d_0| < d_0^{max}$, $|z_0| < z_0^{max}$
    - Example: if $(|z_0| > z_0^{max})$ $\chi^2 = \chi^2 + (|z0| - z_0^{max})^2 / \sigma^2(z_0)$

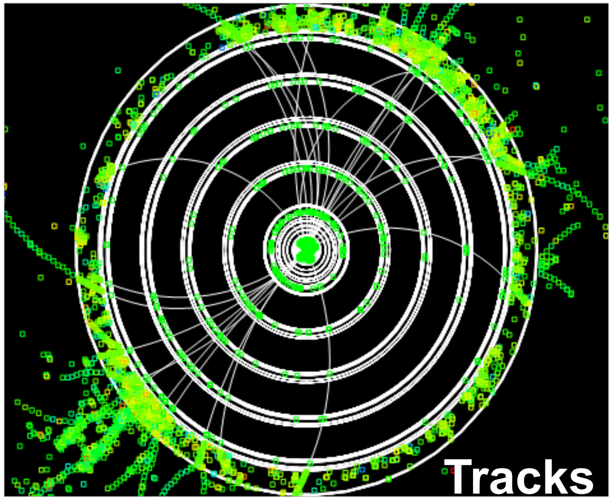
- **Reject seeds that fail the χ^2 cut**

- **Confirm the seed by adding additional hit(s) from confirmation layer(s)**
  - **Perform a helix fit on the new seeds and those that fail the χ^2 cut are eliminated**
  - **Typically, it is found that good performance is achieved with one confirmation layer**

Track Finding Algorithm

- **Extend the seed to include hits in additional tracking layers**
  - **Typically include all additional layers track might traverse**
  - **Each time a new hit is considered, a helix fit is performed and the hit is discarded if it fails the χ^2 cut**
  - **A minimum of 7 hits on a track is required for track candidates**
- **Merge track seeds through a merge algorithm**
  - **Two track candidates are allowed to share a single hit, but if a track candidate shares more than one hit with another candidate, an arbitration scheme is used to select the better candidate. Precedence is given to the candidate with the greatest number of hits, while the candidate with smaller χ^2 cut is selected when the number of hits is equal**





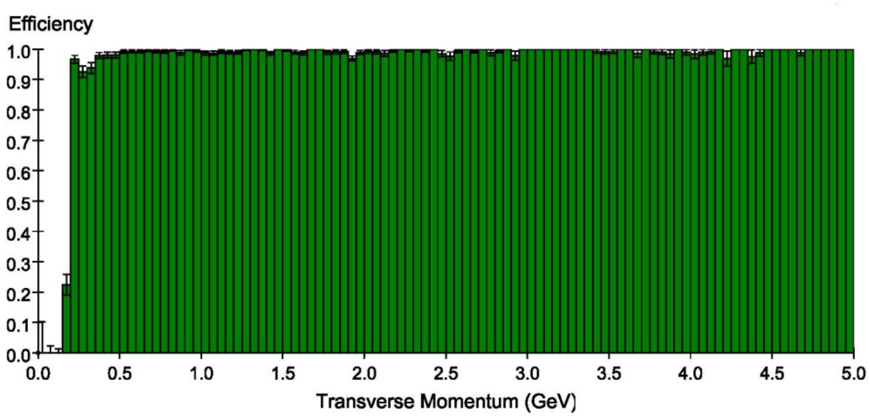
System Performance

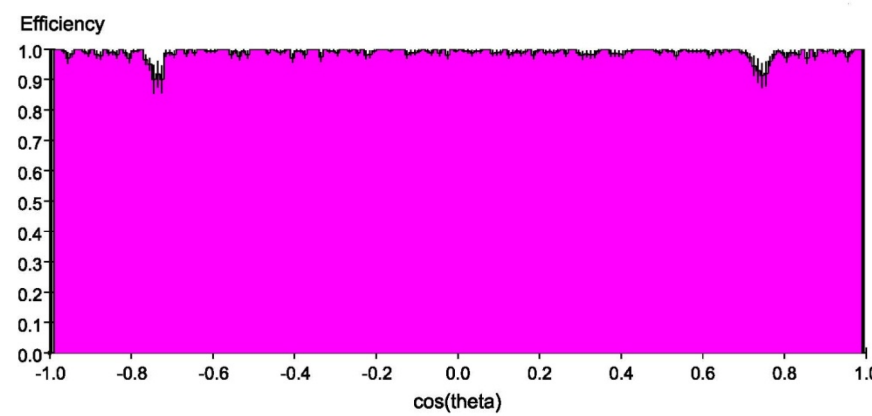
- Overall track finding efficiency for findable tracks in $e^+e^- \rightarrow$ ttbar ($\sqrt{s}$ = 500 GeV) is 99.3% on findable tracks

- Fraction of findable tracks is about 84% of total number of tracks

- Efficiency is uniform in p_T and angle

Selection	Selection Efficiency	Cumulative Efficiency
All Tracks	-	100%
$p_T \geq 0.2$ GeV	$(93.54 \pm 0.11)\%$	$(93.54 \pm 0.11)\%$
$N_{hit} \geq 6$	$(90.91 \pm 0.13)\%$	$(85.04 \pm 0.16)\%$
Seed Hits Present	$(99.78 \pm 0.02)\%$	$(84.85 \pm 0.17)\%$
Confirm Hit Present	$(99.95 \pm 0.01)\%$	$(84.84 \pm 0.17)\%$
$\lvert d_0 \rvert \leq 1$ cm	$(99.80 \pm 0.02)\%$	$(84.65 \pm 0.17)\%$
$\lvert z_0 \rvert \leq 1$ cm	$(99.69 \pm 0.03)\%$	$(84.39 \pm 0.17)\%$
Track Reconstruction	$(99.32 \pm 0.04)\%$	$(83.81 \pm 0.17)\%$





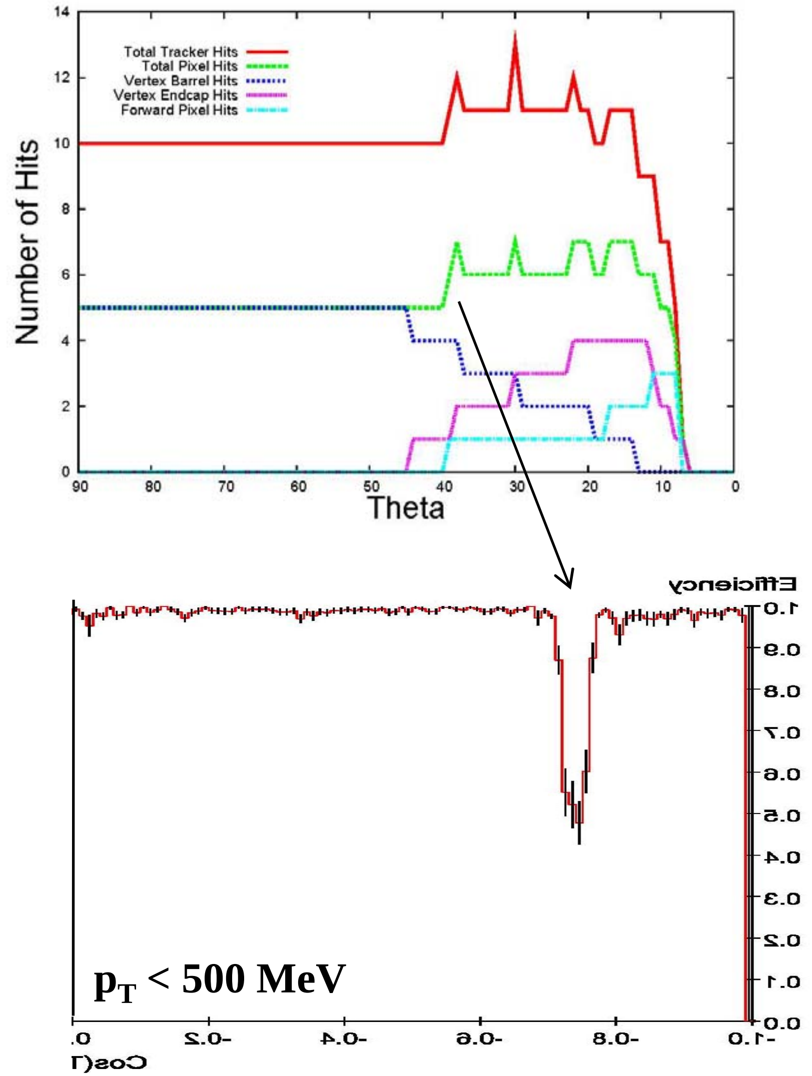
Tracking Efficiency

- **Why is the track finding efficiency not 100% for findable tracks?**

- **All the inefficiency is due to low momentum tracks (p_T < 500 MeV) in the transition region between barrels and disks**
  - **Efficiency is uniform in cos(θ) for p_T > 500 MeV**

- **It is thought that the inefficiency is due to tracks just beyond the pixel barrel acceptance that curl by more than 180 degrees before they get to the seed layers that cover this acceptance region**

- **This may be an artifact of the current tracking algorithm and could be improved upon**

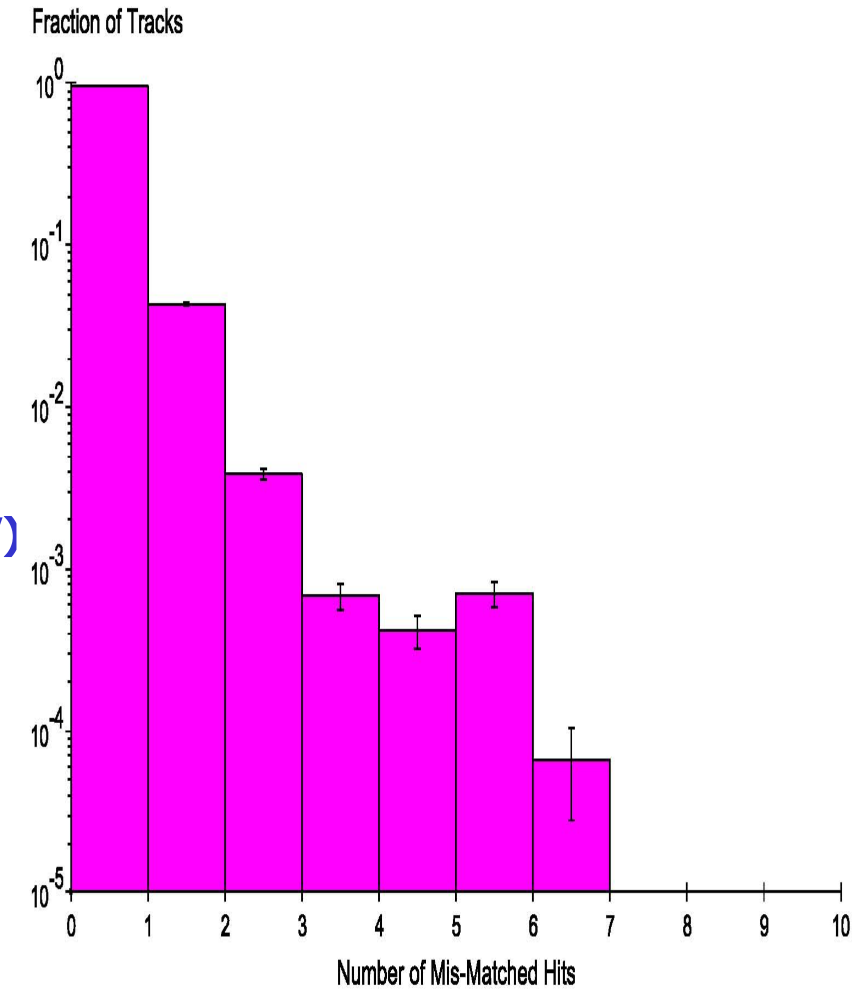


Track Quality

- **A measure of the track quality is the number of mis-assigned hits on a track**
  - **These are hits generated by a different MC particle than the one with the majority of hits on the track**

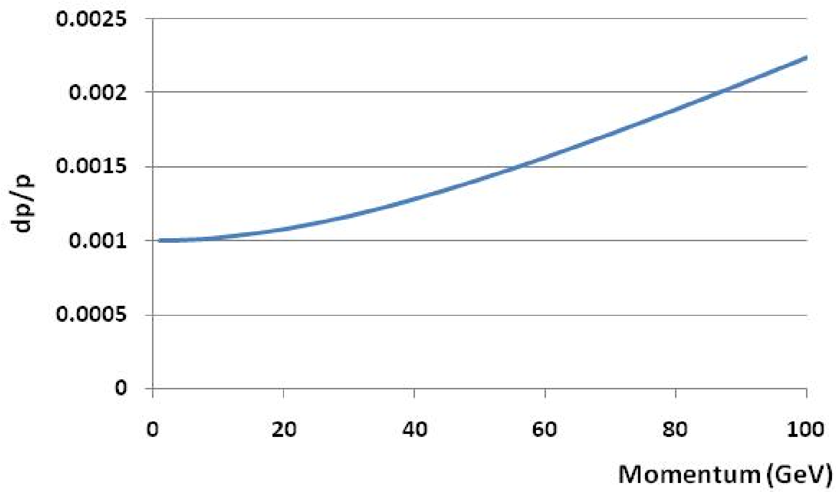
- **More than 99% of tracks have at most one wrong hit on the track**

- **In these events (ttbar at √s = 500 GeV) fake tracks make up only 0.07% of the tracks found**



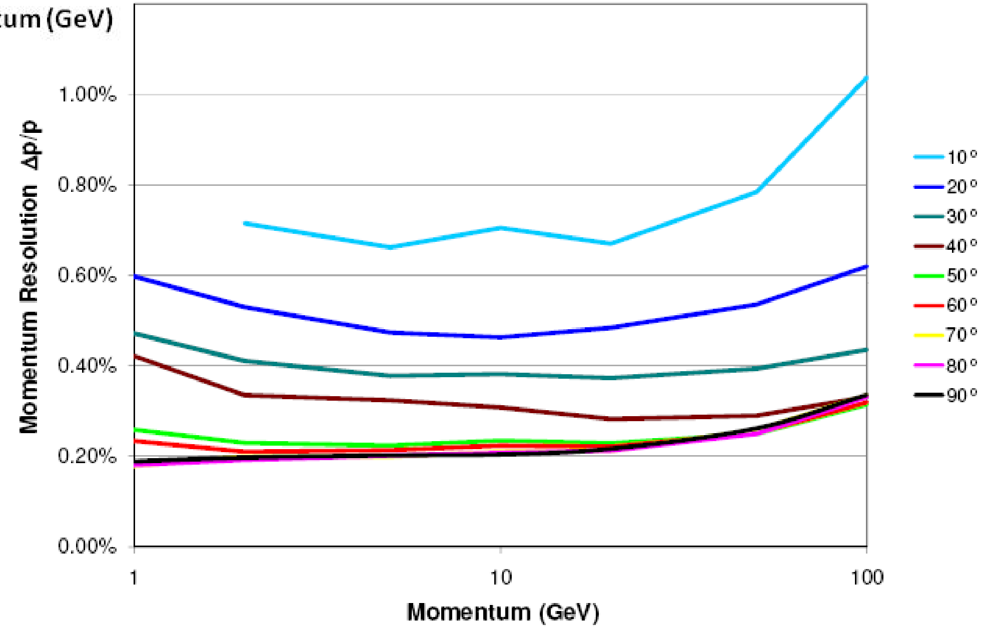
Momentum Resolution

- **Momentum resolution in $e^+e^- \rightarrow$ ttbar ($\sqrt{s}$ = 500 GeV) events**



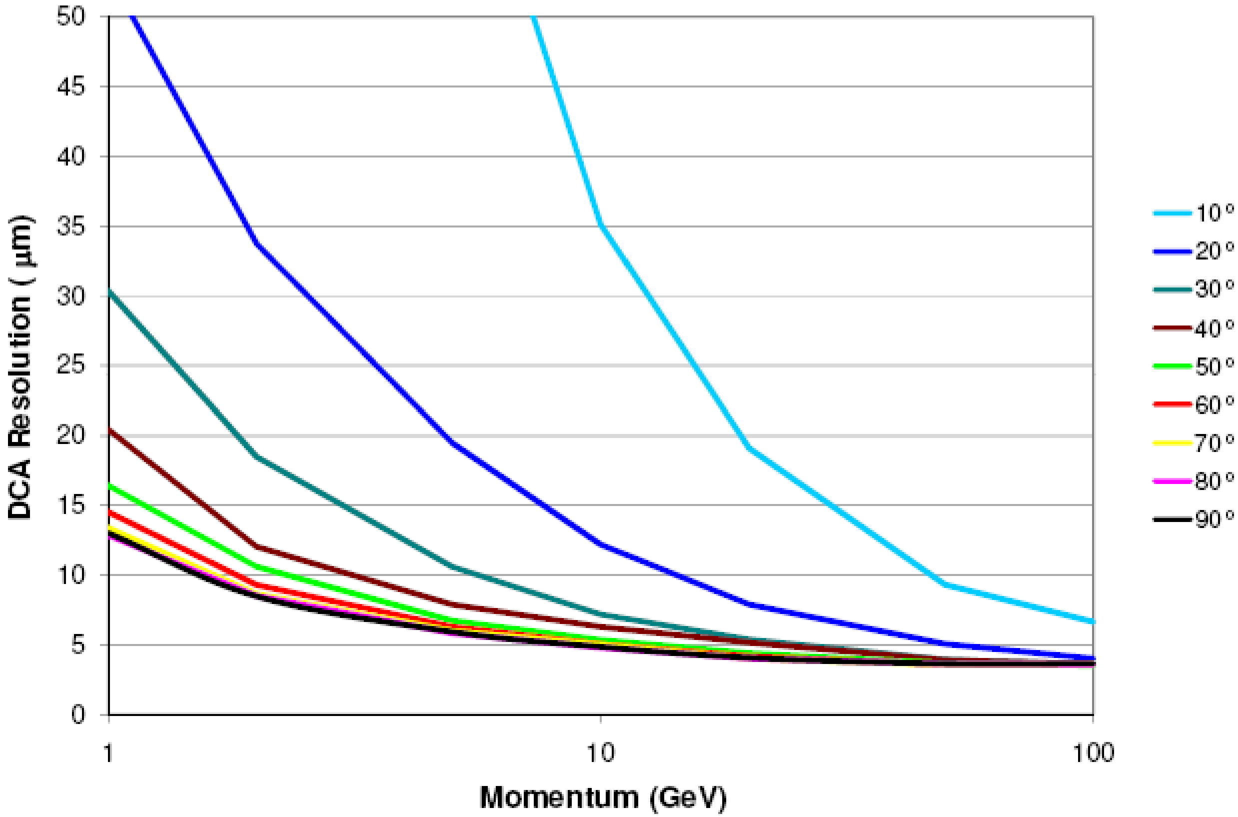
$$\frac{\sigma(p_T)}{p_T^2} = 2 \cdot 10^{-5} \oplus \frac{1 \cdot 10^{-3}}{p_T \sin(\vartheta)} \quad (GeV^{-1})$$

- **Momentum resolution of 0.2% (0.3%) at 10 (100) GeV at large angles**
  - **Slightly better than "design goal" at high momenta**
  - **Slightly worse than "design goal" at low momenta**



DCA Resolution

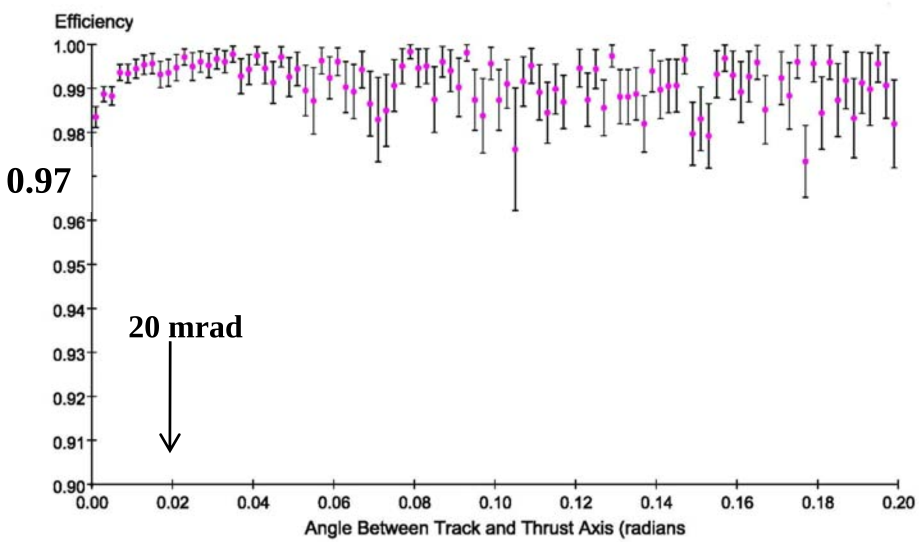
- **Resolution on (x,y) distance of closest approach in $e^+e^- \rightarrow$ ttbar ($\sqrt{s}$ = 500 GeV) events**
- **An asymptotic value of 4 μm is achieved for perpendicular tracks**

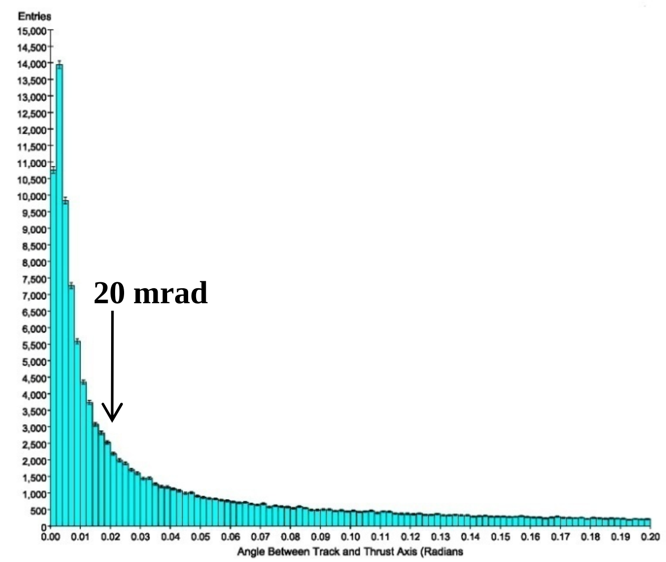


Robustness of Tracking

- The robustness of the SiD tracker has been evaluated under different experimental conditions

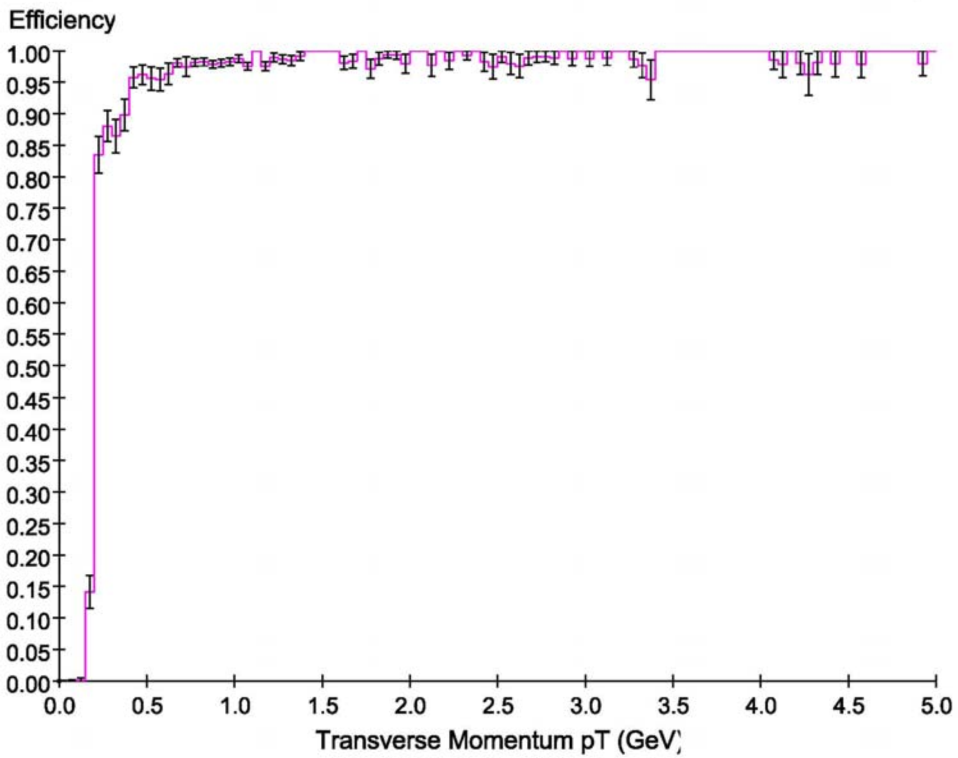
- Tracking in the environment of dense jets
  - $e^+e^- \rightarrow$ qqbar at $\sqrt{s}$ = 1 TeV
- Efficiency as function of track angle with respect to Thrust axis
  - Efficiency drops by ~1% from nominal within 2 mrad (first bin) of jet core
  - Note that the jet energies are 500 GeV





Robustness of Tracking

- **The robustness of the SiD tracker has also been evaluated with the background from 10 bunch crossings overlaid**
  - **$e^+e^- \rightarrow$ bbbar at $\sqrt{s}$ = 500 GeV**
- **In this study the effect of accumulating beam backgrounds over 10 crossings has been mimicked by adding these hits to all pixel devices in the detector. Hits in the silicon strip tracker were added only for a single bunch crossing, in-time with the physics event.**
- **A small loss in efficiency at low pT is observed**
- **Also the fake track rate is slightly higher, about 0.6%. Most of the fake tracks seem to be due to combinatorics.**



IDAG Question

Q: Sensitivity of different detector components to machine background as characterized in the MDI panel

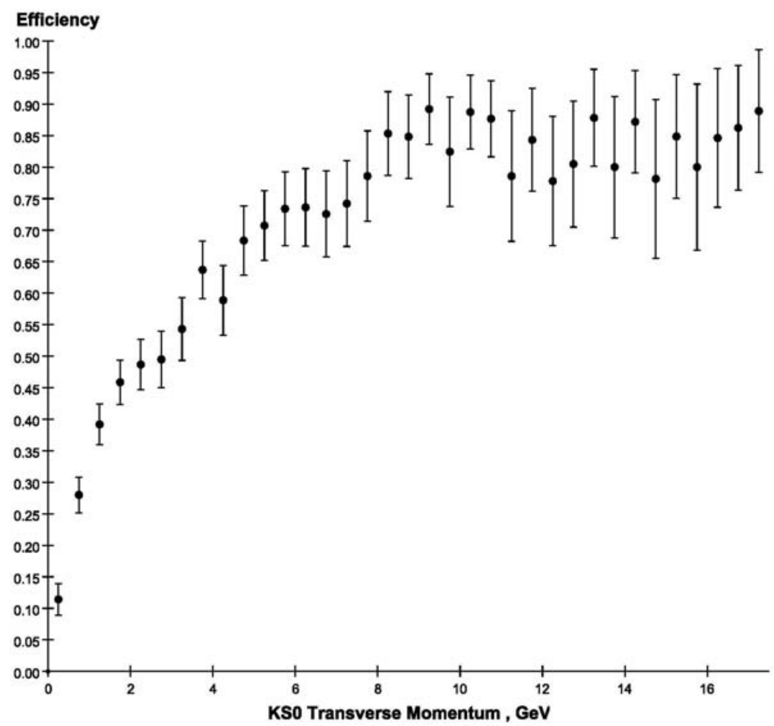
A: Tracking performance evaluated under different background conditions and extreme physics conditions. No significant loss of performance observed. The effect on physics reach of marginal loss in efficiency to be studied

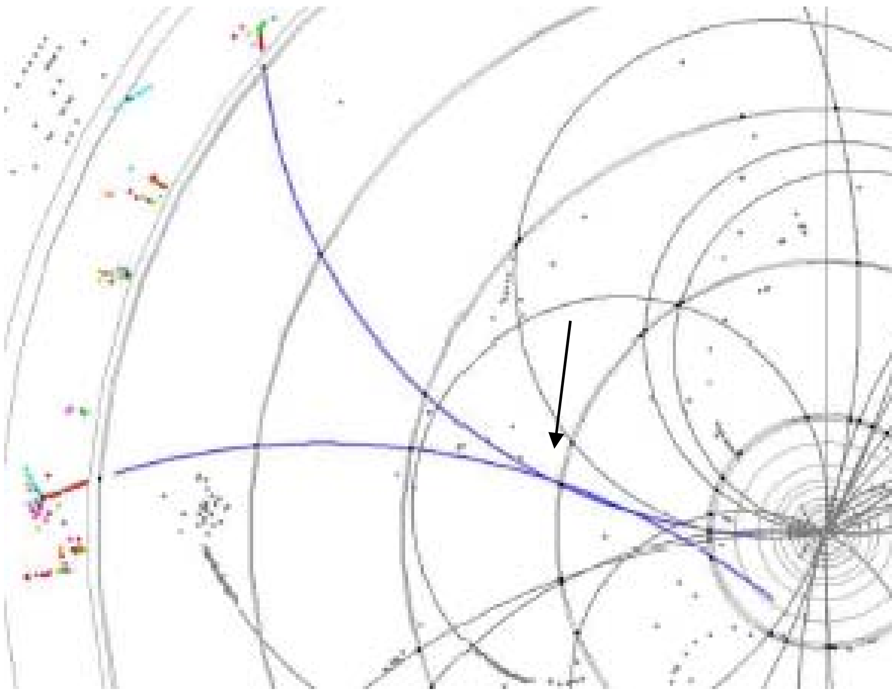
Q: A short statement about the energy coverage, identifying the deterioration of the performances when going to energies higher than 500 GeV and the considered possible detector upgrades

A: Tracking in the jet core for $e^+e^- \rightarrow$ qqbar at $\sqrt{s}$ = 1 TeV tests the limits of the tracking code. No significant degradation of performance has been observed. The effect on physics reach of marginal loss in efficiency to be quantified.

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**
  - **Efficiency for reconstructing K^0_s reaches 80% for K^0_s momenta higher than 8 GeV**





IDAG Question

Q: How was the detector optimized?

A: To be frank, a lot of optimization still needs to be done. The current layout was a very good Ansatz.

Final Remarks

- Studies carried out in the context of the LOI show that an all silicon tracker is robust and achieves the performance parameters required by the physics at an ILC

- Many man-years of work have gone into the development of the design and tools. We are finally in a position to quantitatively compare tracker designs.

- It is our intent to continue the optimization studies to improve upon the existing design in the next few years and study the implications on the physics reach