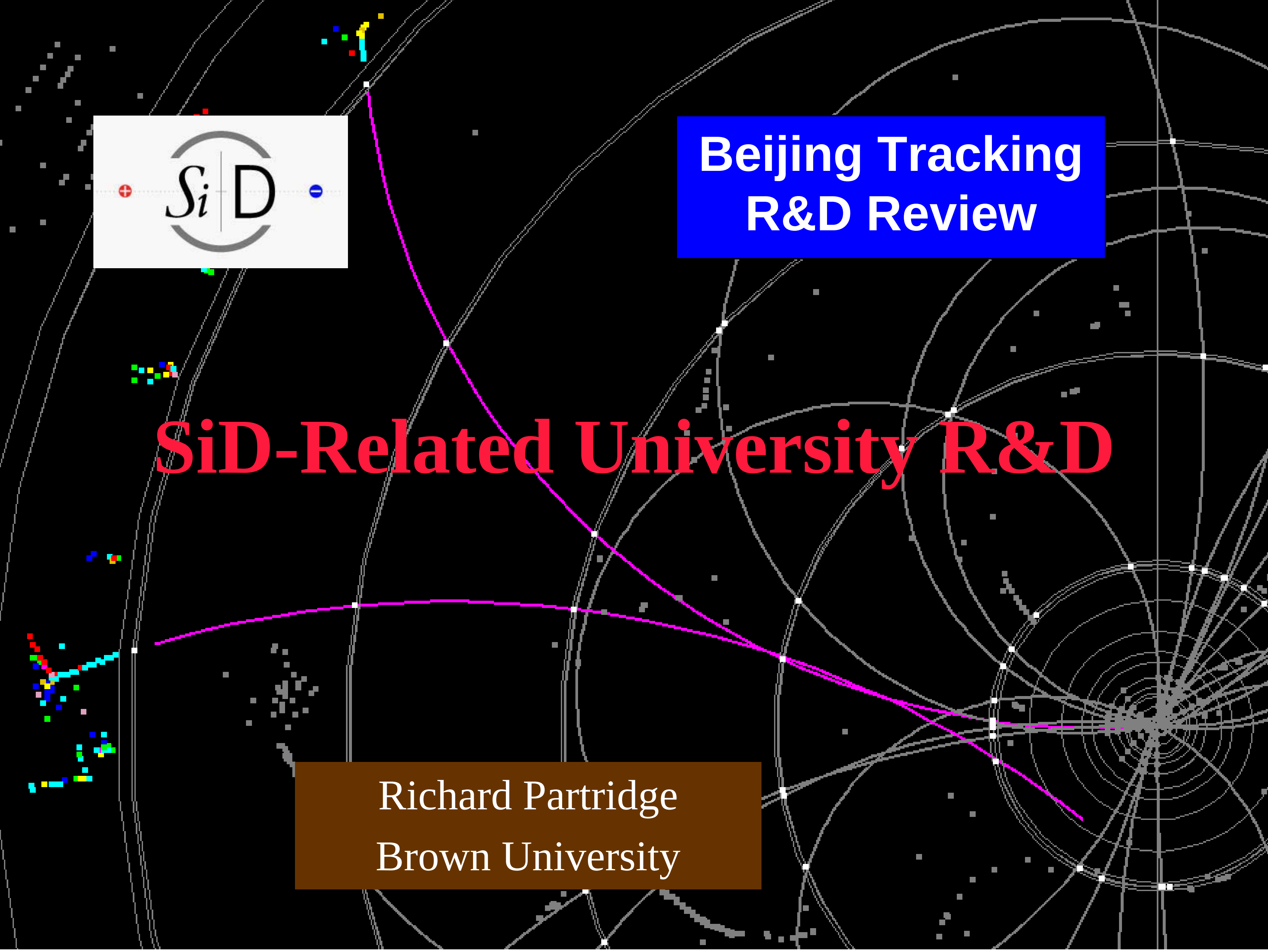


Beijing Tracking
R&D Review

SiD-Related University R&D

Richard Partridge
Brown University

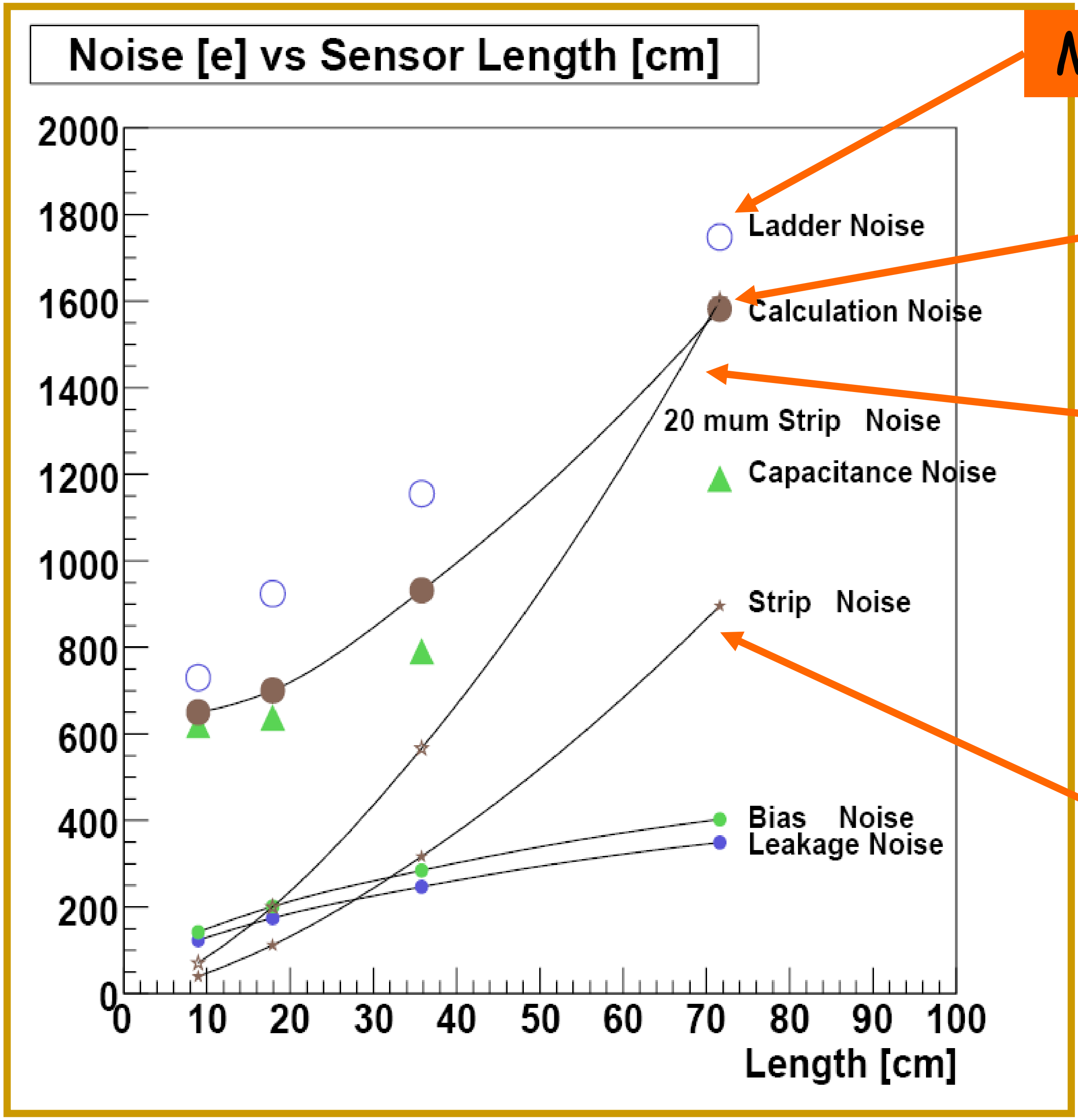
Introduction

- In the US, the university LC R&D program is proposal driven
  - Proposals are developed independently by interested university groups
  - Proposals are selected for funding based on peer review
  - No explicit coordination between SiD and university R&D program, but there is a significant level of collaboration
- FY07 proposals were submitted in December
  - 5 continuation proposals
    - Frequency Scanning Interferometry (Michigan – presented in Bill Cooper's talk)
    - Thin Silicon (Purdue – presented in Tim Nelson's talk)
    - Time-over-threshold readout chip (Santa Cruz – presented in SiLC session)
    - **Vertex Seeded Tracking (Colorado)**
    - **Calorimeter Assisted Tracking (Kansas State)**
  - 1 new proposal
    - **Charge Division Readout (Brown, Santa Cruz)**
- This talk will focus on readout efforts and simulation studies
  - There are **additional simulation efforts at Brown, Fermilab, Oregon, Santa Cruz, and SLAC** not funded by the university program included in this talk

Readout Chip Efforts

- KPiX (Davis, Oregon, SLAC)
  - Details presented in Tim Nelson’s talk
  - Readout chip employed in baseline design
  - Charge sensitive amplifier measures collected charge
  - 4 Analog buffers, readout between bunch trains
  - Works with AC or DC coupled devices
- LSFTE - Time Over Threshold (Santa Cruz)
  - Details presented by Bruce Schumm as part of SiLC presentations
  - Digital FE output - no analog buffering
  - Input charge is related to duration of comparator output
  - Digital architecture allows operation in higher occupancy regions
- Charge Division Readout (Brown, Santa Cruz)
  - New effort – details given in this talk
  - Charge sensitive amplifier measures collected charge
  - Shaper optimized for charge division readout
  - DC coupled device

LSFTE Time Over Threshold Chip



Measured noise

Sum of estimates

Projected strip noise for 20 μm strip (not part of estimate)

Estimated strip noise actual 60 μm strip (part of estimate)

Charge Division Readout

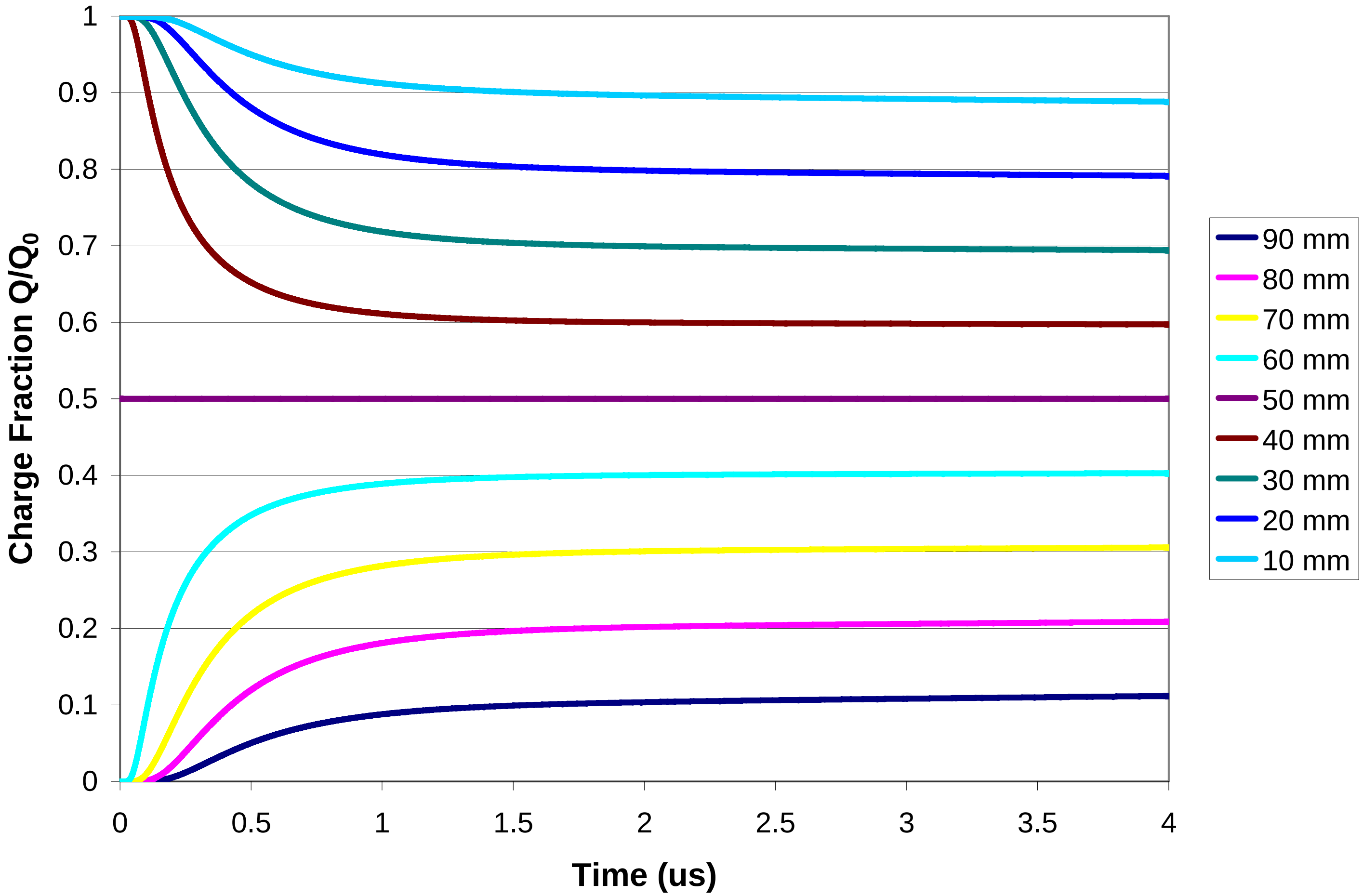
- SiD baseline design has axial barrel layers with ~10 cm z segmentation
- A new R&D effort has begun to explore the use of charge division to measure the z coordinate of hits
- Radeka has shown that with optimized shaping, the noise only depends on the detector capacitance, and not the resistance:

$$\frac{\sigma_z}{L} = \frac{\sqrt{1.17kTC}}{Q_0}$$

- For 1 pF/cm capacitance, a 10 cm long detector would achieve a resolution on the z-coordinate of 5.5 mm
- Tracks that traverse all 5 tracker layers would have a resolution on tanλ of 0.007
- Compared to stereo readout, less material, cost, and precision

Charge Division Readout

- Simple spread-sheet simulation illustrates technique
  - Distributed R-C network that uses implants as the resistive medium
  - Charge sensitive amplifiers with 550 pF dynamic capacitance (same as SVX4)



Charge Division Readout Plans

- Put a test sensor on the double metal sensor submission
  - Simple DC coupled detector with bonding pads on both ends of the implant
- Develop spice simulation of detector, amplifier, and shaper circuits and use these simulations to optimize the front end for making the charge division measurement
- Fabricate a small test chip that will allow the charge division technique to be evaluated

Simulation Overview

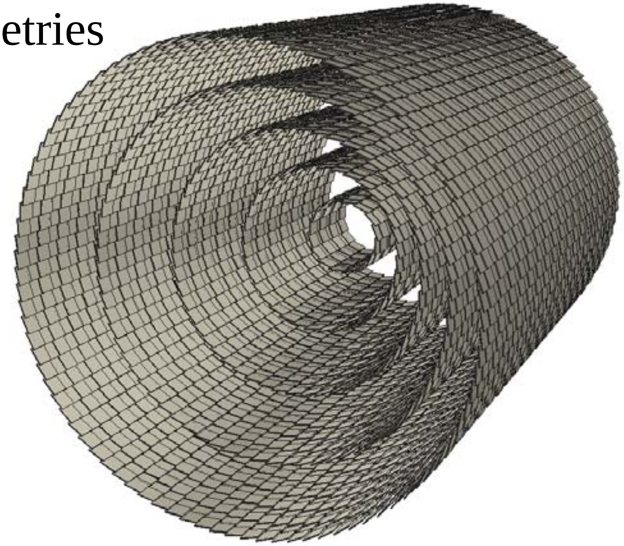
- Simulations studies are vital for both characterizing detector performance and optimizing the detector design
- Our simulation R&D goals include:
  - Develop detailed tracking simulations with full simulation of detector response, track finding, and track fitting
  - Study the tracking performance of the baseline design for both prompt and non-prompt tracks
  - Optimize the number and location of tracking layers
  - Optimize the forward tracker design (sensor geometry, strip orientations)
  - Evaluate the impact of incorporating barrel stereo layers, charge division readout
  - Study the impact of changing the size of the tracking volume
  - Study the impact of changing the magnetic field
- Several groups involved in tracking simulations
  - Brown, Colorado, Fermilab, Kansas State, Oregon, Santa Cruz, SLAC
  - Efforts are generally fractions of an FTE/institution

Simulation Elements

- Simulation Infrastructure
  - Take “Pythia” output and produce tracker hits and associated error matrix
- Track Finding
  - Find collections of tracker hits consistent with a helical trajectory
  - Modern algorithms typically utilize multiple track finding algorithms
  - Vertex Seeded Tracking uses fine-resolution 3D hits in vertex detector to form track seeds, which are then extended into the outer tracker
    - Robust tracking for tracks that originate near the IP
  - Stand Alone Tracking find tracks using the outer tracker hits
    - Identify tracks from secondary decays inside the outer tracker
  - Calorimeter Assisted tracking uses MIP stubs in the fine-grained EM calorimeter to form track seeds, which are then extended into the outer tracker
    - Identify tracks from secondary decays within the outer tracker
- Track Fitting
  - Determine the track parameters and error matrix associated with a collection of tracker hits found by the track finding algorithms
  - Two approaches: Kalman Filter and Weight (covariance) Matrix methods

Simulation Infrastructure

- SLIC provides GEANT4-based detector simulation (SLAC)
  - Output is position and energy of energy depositions in active detectors
  - Currently supports cylindrical and disk geometries
  - Working on supporting planar detectors
- Hit digitization (Oregon, SLAC)
  - Turn energy deposits into strip charges
  - Cluster strips to form hits
- Vertex digitization code complete
  - Charge deposition modeled on CCD
- Outer tracker digitization code in progress
  - Strip charge deposition model complete
  - Work in progress to finish strip digitization

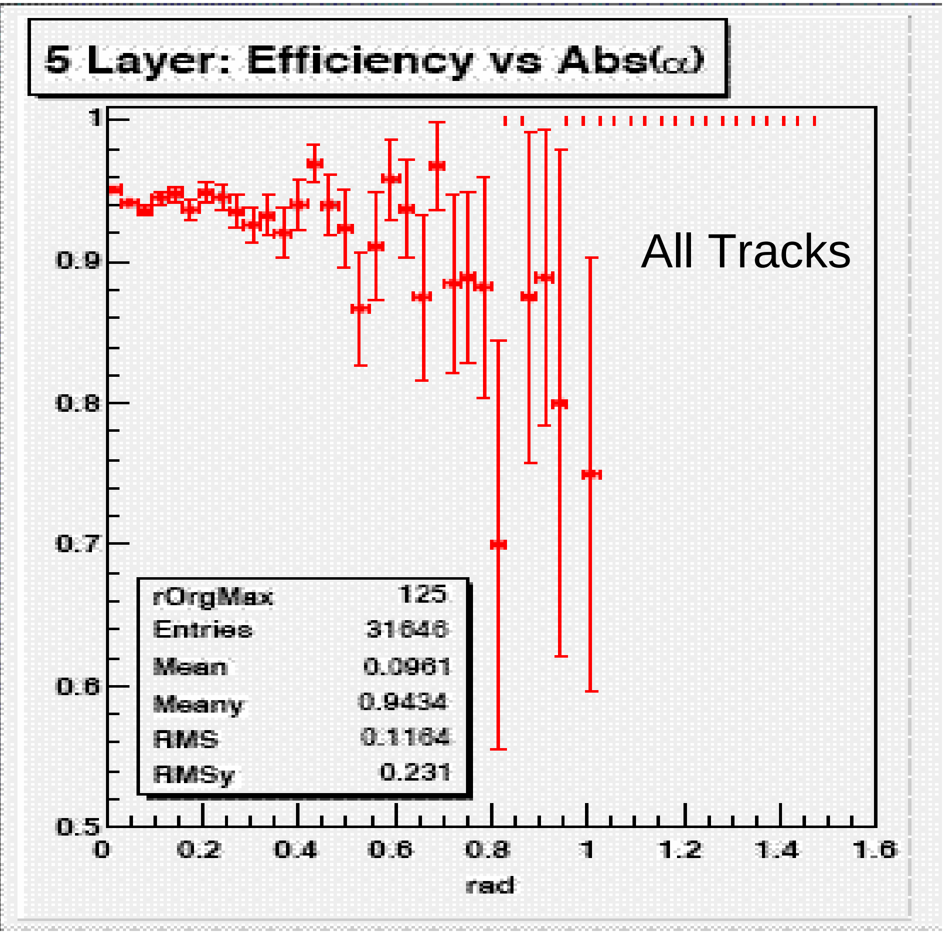


Vertex Seeded Tracking

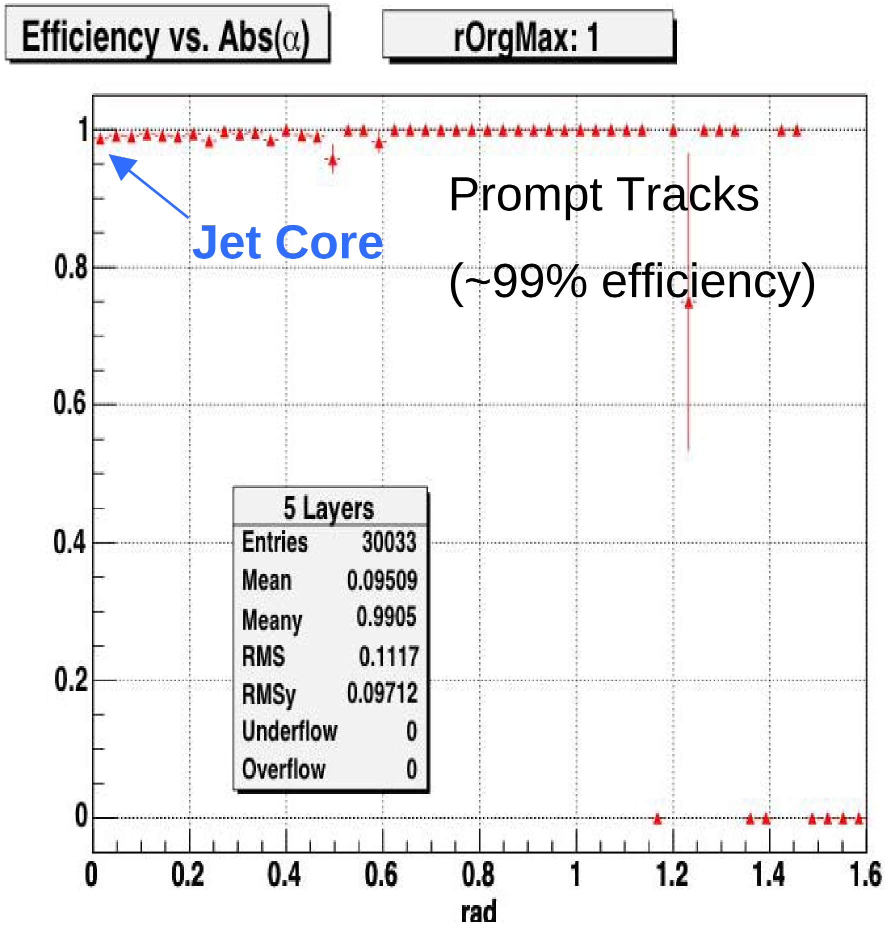
- ~95% of the tracks originate inside the inner layer of the vertex detector
- These tracks typically have 10 precisely measured hits
  - 5 3D pixel hits in the vertex detector
  - 5 hits in the outer tracker
    - Barrel tracker provides precise r-ϕ measurements with coarse (10 cm) z segmentation
    - End disks use stereo to provide precise 3D hits
    - Forward disk technology to be determined
- Vertex Seeded Tracking takes advantage of the finely segmented pixel detectors to form the initial track seeds
- Seeds are extended into the outer tracker, providing validation of the track seed and precise measurement of the track parameters
- Brown, Colorado, Fermilab, Oregon, and Santa Cruz groups are contributing to the Vertex Seeded Tracking effort

Vertex Seeded Tracking Efficiency

- Measure tracking efficiency as a function of α, the angle between the track and the thrust axis, for $q\bar{q}$ events at 500 GeV



All Tracks



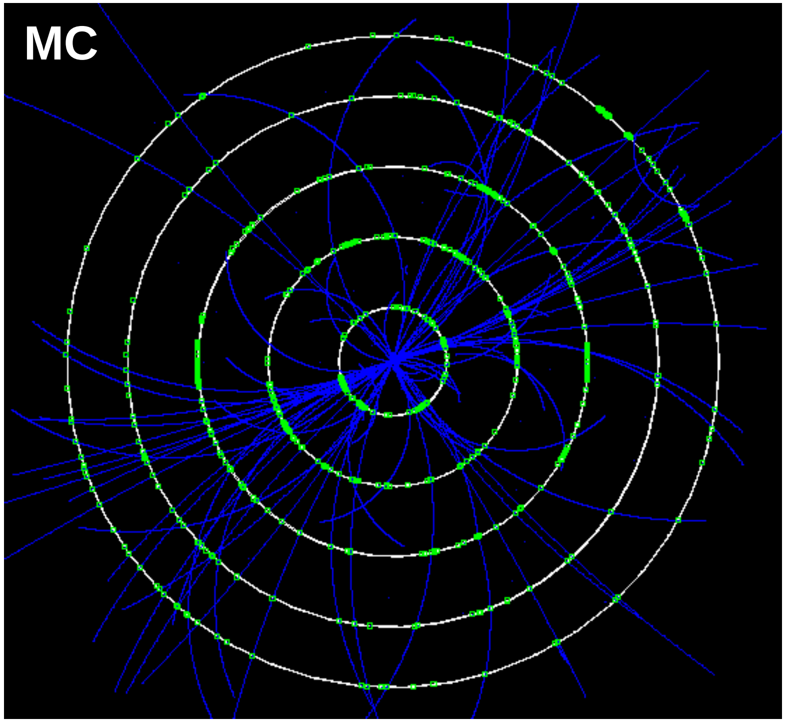
Jet Core

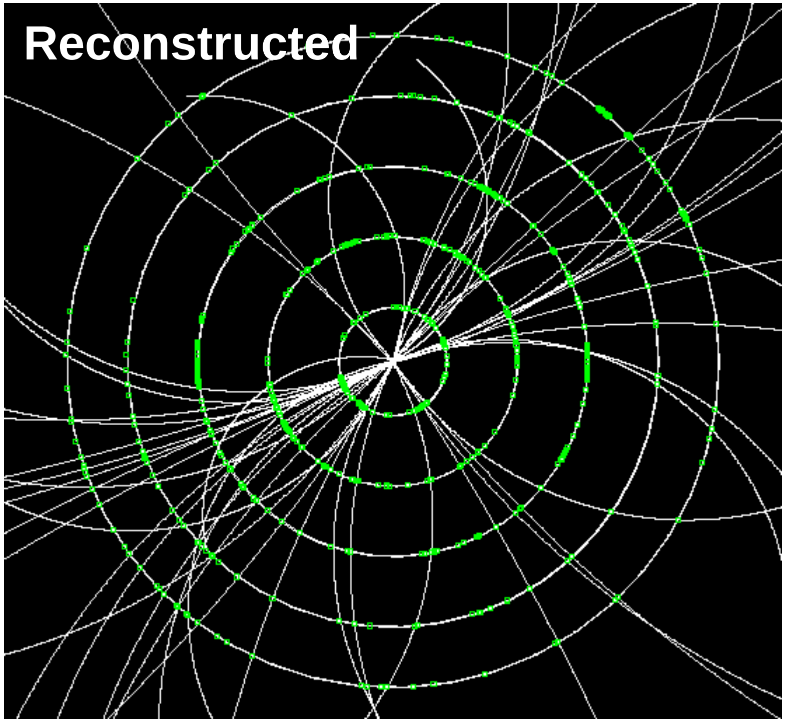
Prompt Tracks

(~99% efficiency)

Stand Alone Tracking

- Stand Alone Tracking finds tracks using just the outer tracker
  - Of particular interest are high p_T heavy quark decays that have large decay lengths and few/no vertex detector hits
  - Preliminary results are promising

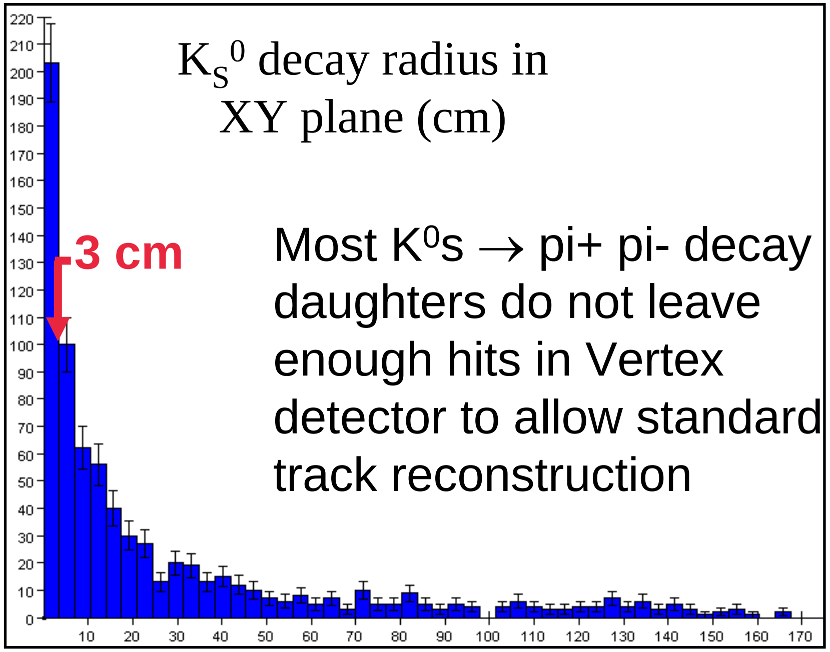




- Fermilab, SLAC, and Santa Cruz are contributing to the Stand Alone Tracking effort

Calorimeter Assisted Tracking (KSU)

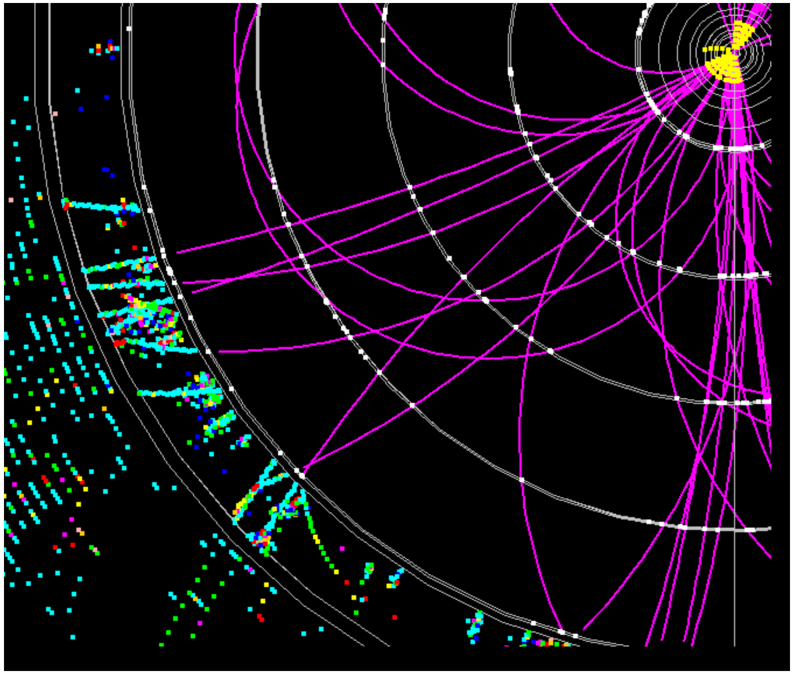
- Vertex Seeded Tracking requires 3 or more vertex detector hits to form seed
- Most K_S decays fail this requirement ($r_{decay} > 3$ cm)



K_S^0 decay radius in XY plane (cm)

3 cm

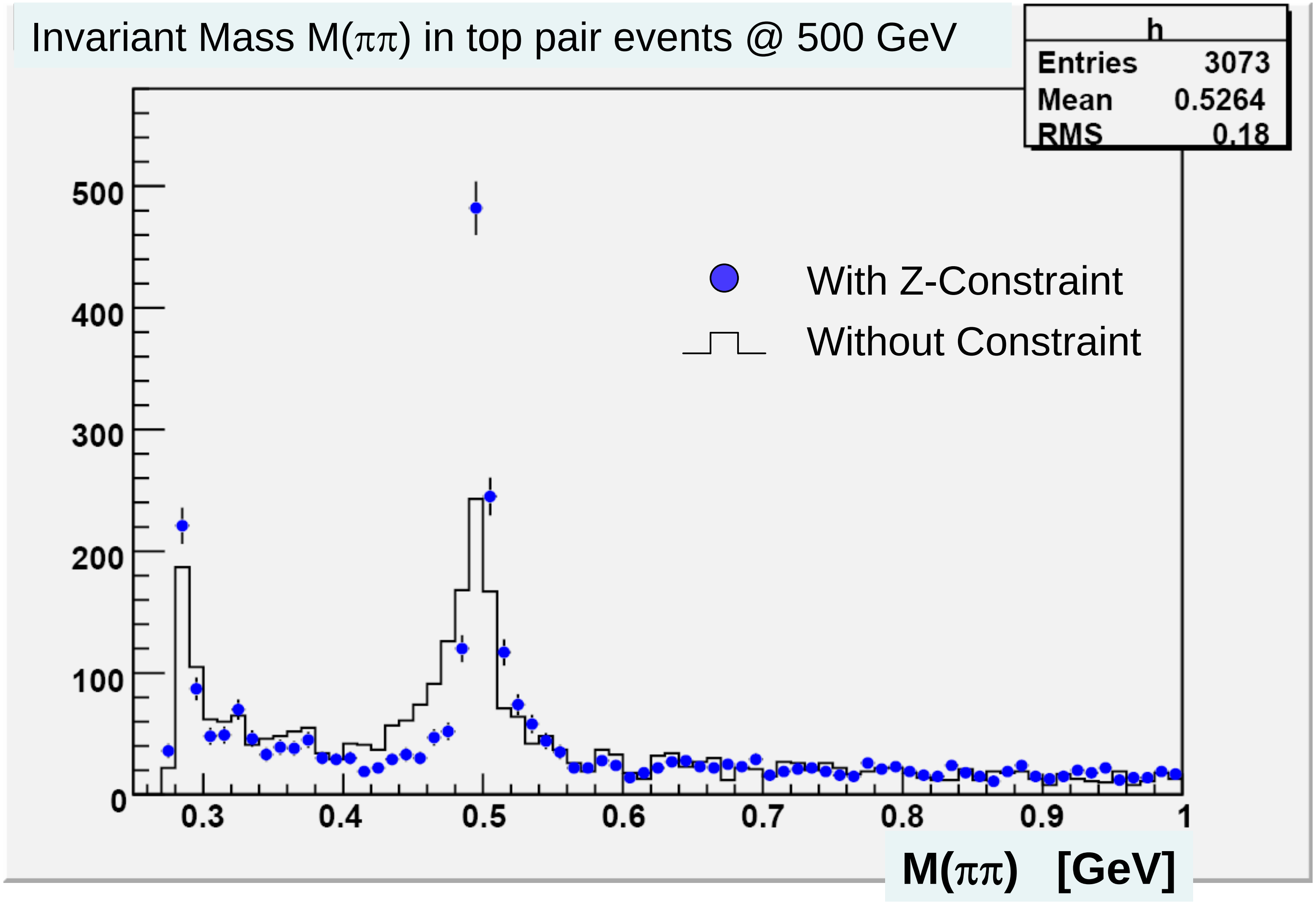
Most K^0s → pi+ pi- decay daughters do not leave enough hits in Vertex detector to allow standard track reconstruction



- Finely segmented EM cal produces clear MIP stubs
- Follow MIP stub back into outer tracker and associate tracker hits

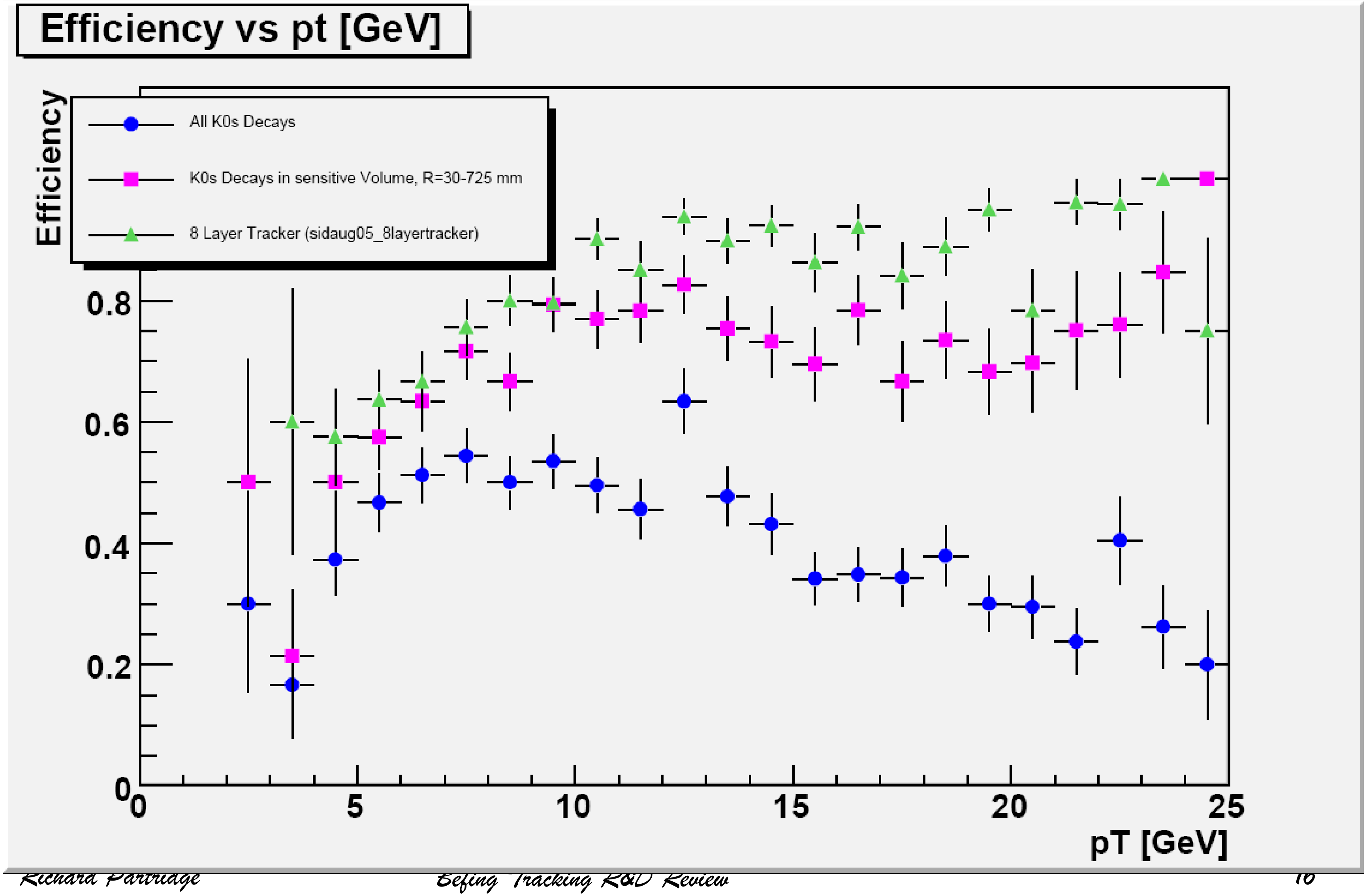
V Mass using Cal. Assisted Tracking

- Clear K_S, γ conversion peaks above combinatoric background



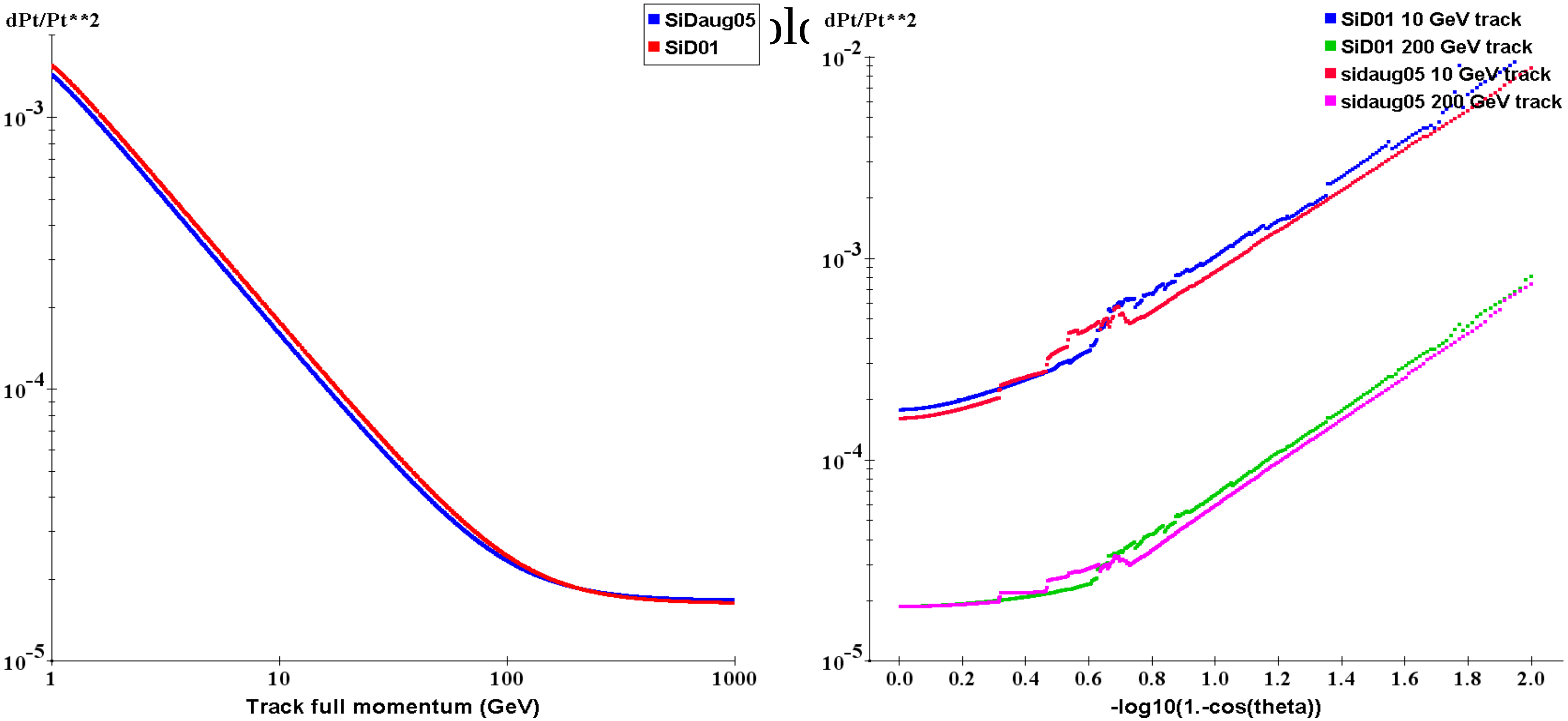
K_S Efficiency (Single Particle Events)

- We reconstruct ~80% of all reconstructable K_S with p_T>10 GeV



Track Fitting and Resolution

- Weight Matrix and Kalman Filter fitters have been developed
- SiD tracker has $\sigma(p_T)/p_T \sim 0.2\%$ for $\theta = 90^\circ$, $1 < p_T < 100$ GeV



Tracking R&D Summary

System	Work Package	Institutions
Mechanical	Mechanical Support Design	Fermilab, SLAC, Washington
	Module Design	Fermilab, SLAC
	Frequency Scanning Interferometry	Michigan
Sensor	Double Metal Sensor	Fermilab, SLAC, Tokyo
	Thin Silicon	Purdue
	Sensor Characterization and Testing	New Mexico, SLAC
Readout	KPiX Readout	Davis, Oregon, SLAC
	Time Over Threshold Readout	Santa Cruz
	Charge Division Readout	Brown, Santa Cruz
Cable	Tracker KPiX Cable	New Mexico, SLAC
Simulation	Simulation Infrastructure	Oregon, SLAC
	Vertex Seeded Tracking	Brown, Colorado, Fermilab, Oregon, Santa Cruz
	Stand Alone Tracking	Fermilab, Santa Cruz, SLAC
	Calorimeter Assisted Tracking	Kansas State (Bonn)
	Fitting and Resolution	Oregon, Santa Cruz, SLAC

Conclusions

- The SiD Tracking effort is founded on a few key principles
  - Take full advantage of the superb hit resolution, two-track separation, design flexibility, and timing properties offered by silicon strip detectors to provide robust tracking capability that meets the ILC physics goals
  - Aggressively work to minimize the material in the tracking volume
  - Optimize the tracker as one element of an integrated detector design
- A comprehensive R&D program has been put in place to perform the R&D required to succeed in this effort
  - This program is unlikely to be static, as historically we have benefited by the rapid pace of advances in semiconductor manufacturing technology
- During these talks, we have tried to highlight our R&D plans and the status of our R&D efforts – further details can be found in our written report