Charged Particle Tracking Issues for a Linear Collider Detector

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Santa Cruz Linear Collider Retreat
Parallel Session on Tracking
UCSC – June 28, 2002

Conventional Wisdom:

"Easy" to build linear collider detector
(e.g., clone SLD or a LEP detector)

- Statement more or less true, but maximizing physics output argues for more aggressive approach
- Will discuss here how to be more aggressive in tracking charged particles

Physics Drivers (a sampling)

Good momentum resolution: [$\delta(1/pt) \sim 5 * 10^{-5}\ GeV^{-1}$]

- Clean Higgs signal from dilepton recoil mass
- End-point mass spectra in SUSY cascades

Good pattern recognition / 2-track separation

- Jet energies in W^+W^- final states
  (Energy-flow algorithm)

Physics Drivers (a sampling)

Good forward tracking

[$|\cos(\theta)| \rightarrow 0.99$; $\Delta\theta \sim 10^{-5}$ rad; $\delta(1/p_t) \sim 2 * 10^{-4}$ GeV^{-1}]

- New t-channel processes (e.g., chargino production)
- Differential luminosity measurement
  (scanning top-pair threshold line-shape)

LEP/SLC detectors not useless for these measurements, but one would like to do them very well

What tracker designs have been studied?

Asia:

- CCD vertex detector
- Large-volume drift chamber (DC)

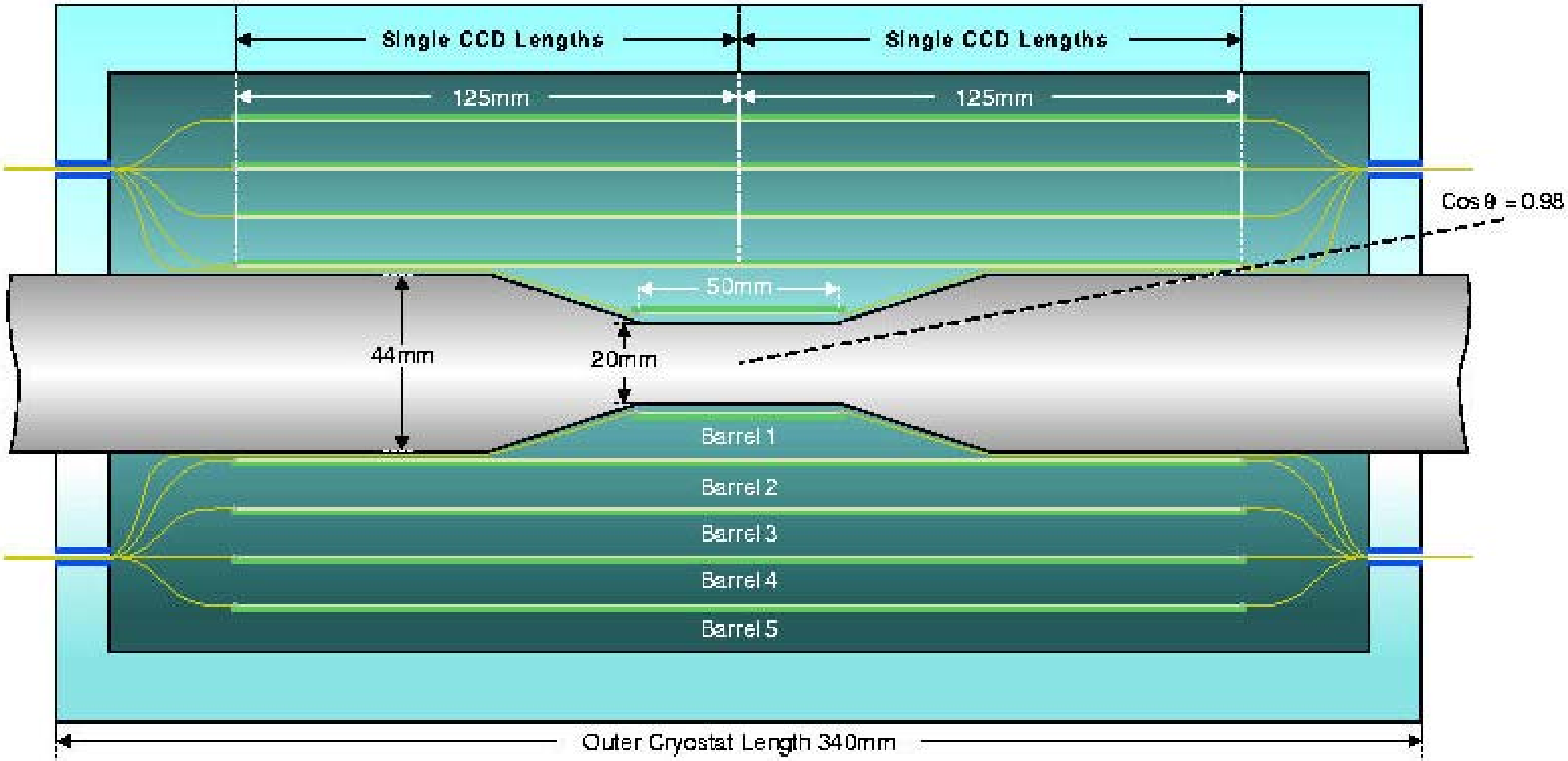
Europe:

- CCD, CMOS or hybrid pixel vertex detector
- Large-volume time projection chamber (TPC)
- Forward active pixel and silicon microstrip disks,
  straw chamber behind TPC endcap, silicon “envelope” for TPC

North America:

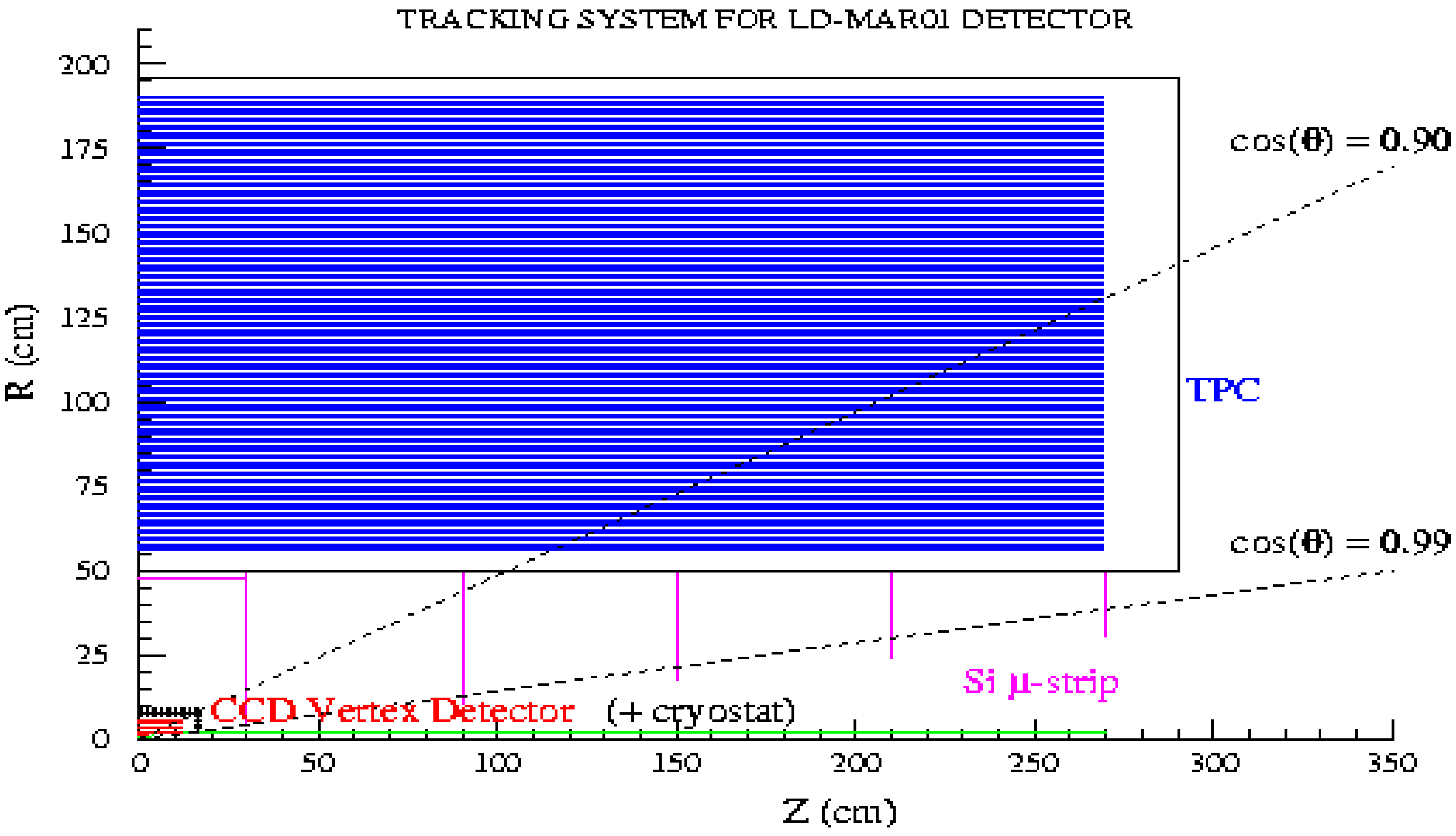
- CCD vertex detector
- Large-volume TPC or large-radius silicon tracker (drift / microstrip)
- Forward silicon microstrip disks

Vertex detector baseline (Europe & North America)



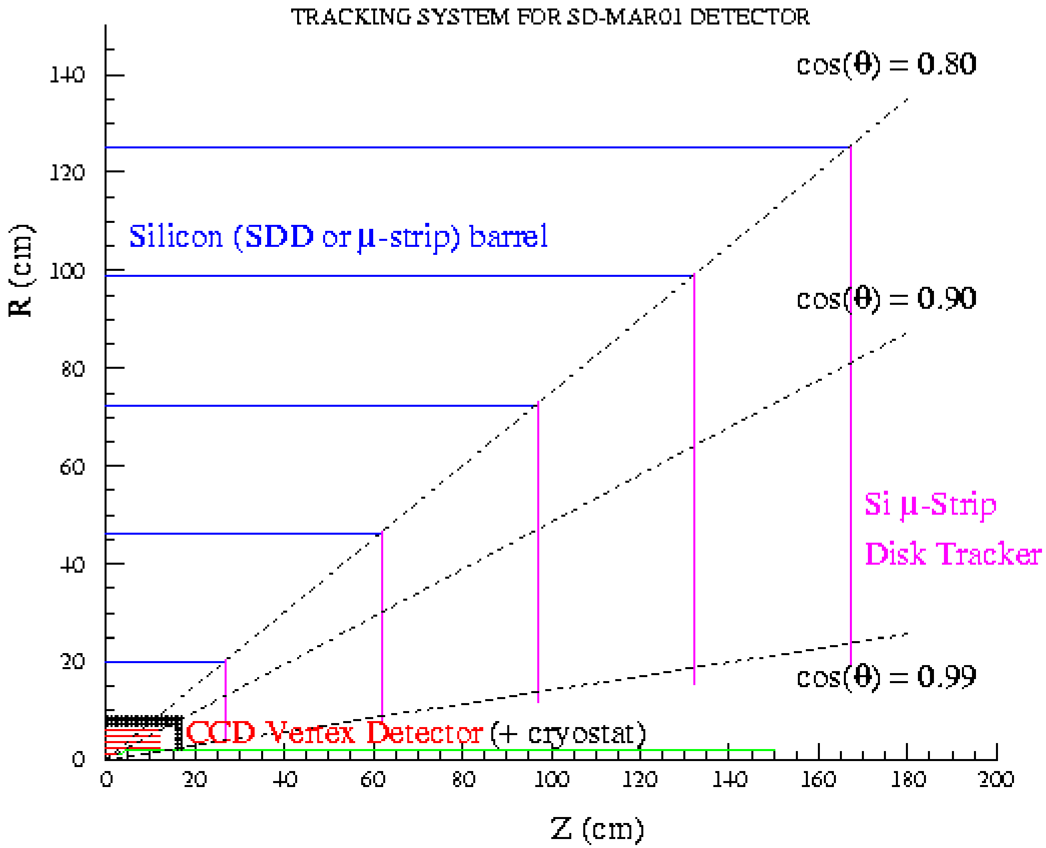
Central tracker LD baseline (North America)

B = 3.0 T

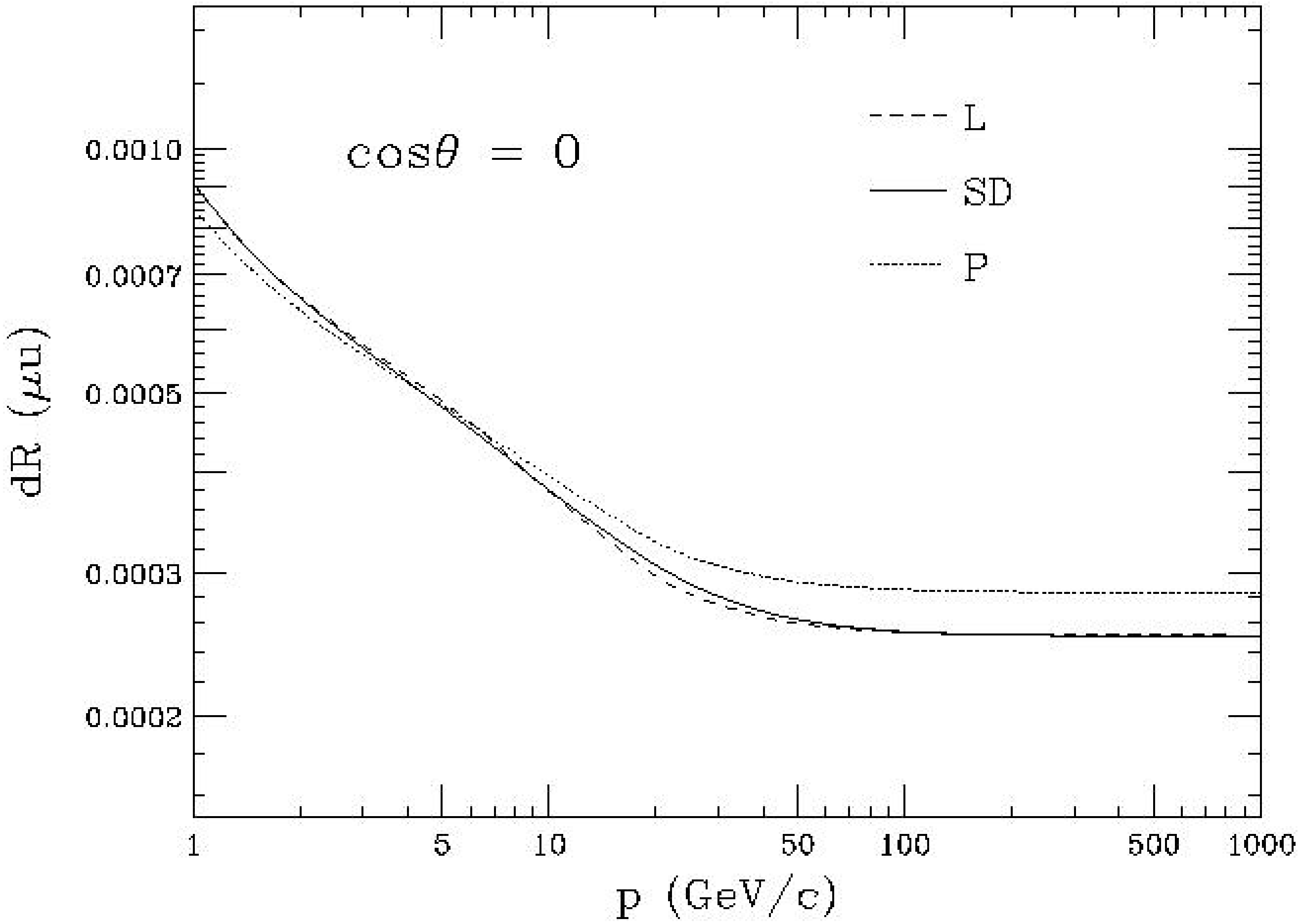


Central tracker SD baseline (North America)

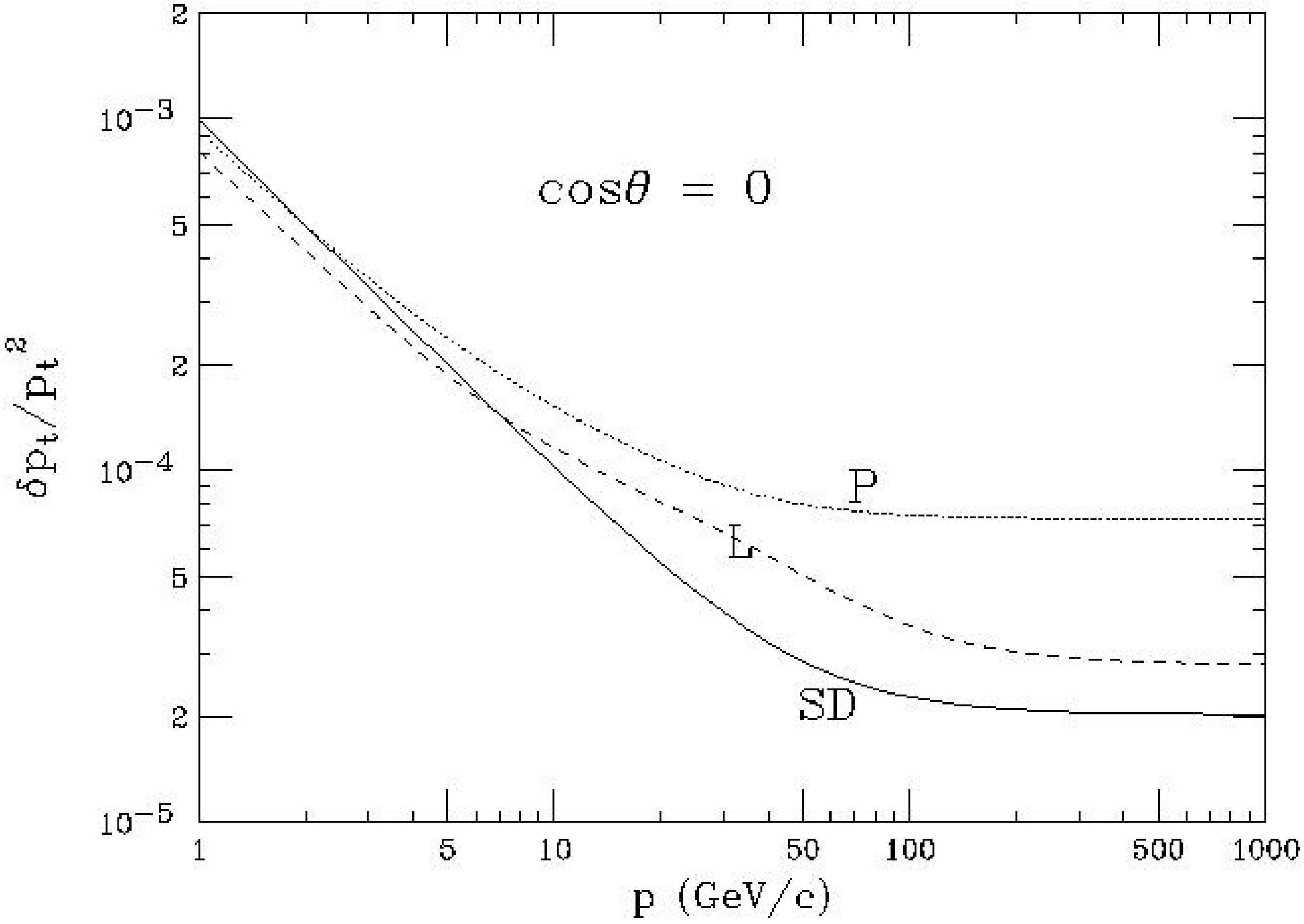
B = 5.0 T



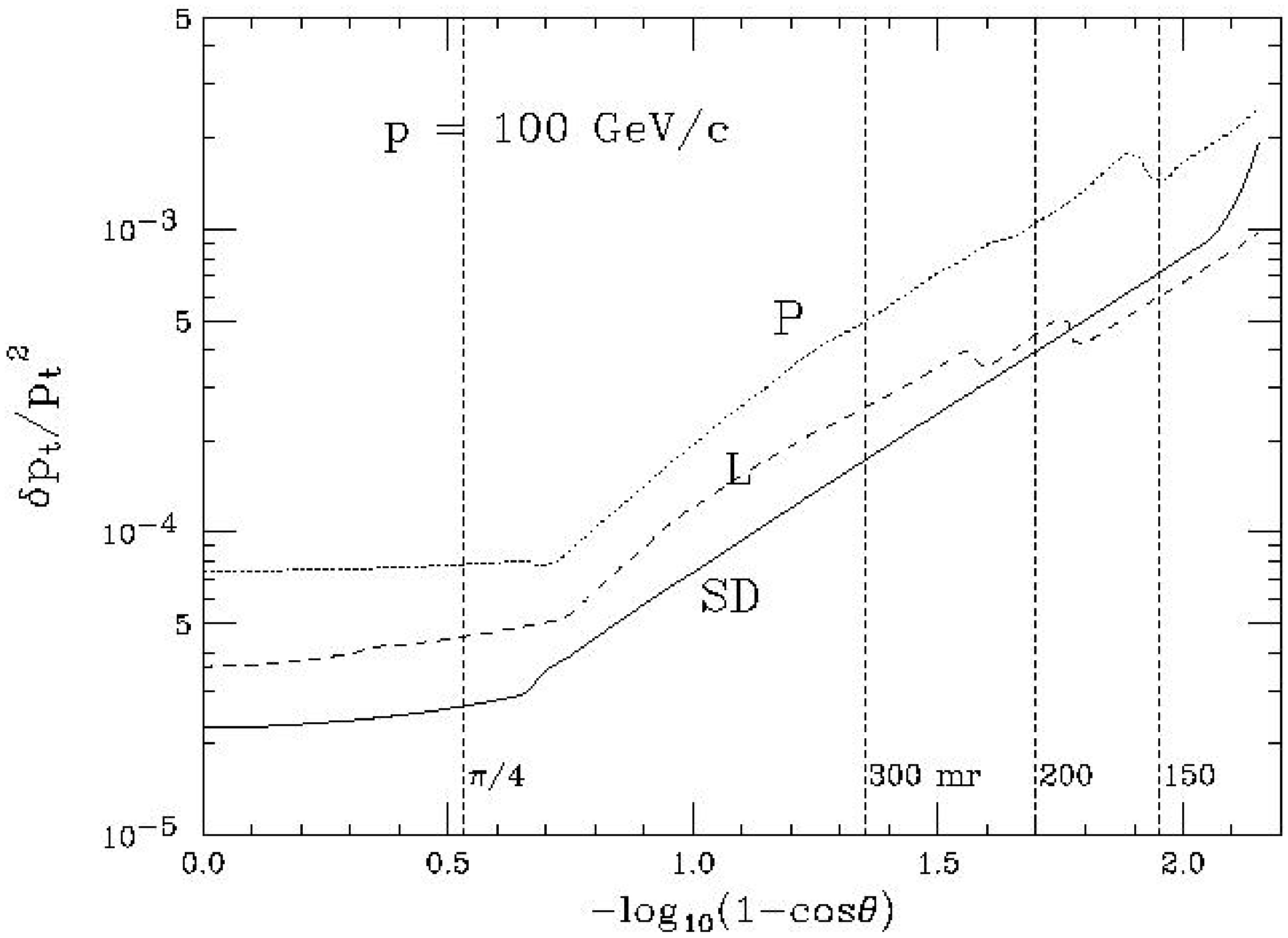
Expected Impact Parameter Resolutions (vs p) - B.Schumm



Expected Momentum Resolutions (vs p)



Expected Momentum Resolutions (vs cos θ)



Technical Issue: Pattern Recognition

3-D vs 2-D technologies:

- Gas: TPC vs DC
- Silicon: Drift vs Microstrips
- 3-D eases reconstruction, improves robustness w.r.t. backgrounds (SR photons, $\gamma\gamma \rightarrow$ jets). May penalize 2-D resolutions

- Few precise hits (silicon) vs many coarse hits (gas)
  - Effect on 2-track separation? → Energy flow
  - Reconstruct long-lived decays?
  - Cope with large machine backgrounds?
  - Pointing to shower max in calorimeter → Energy flow

- Does pixel vertex detector provide enough “stand-alone” tracking (seeding) to make above choices non-critical?

Technical Issue: Tracker Material

- Degrades momentum resolution at low p_t.
- Increases secondary backgrounds from machine
- Converts gammas, causes bremsstrahlung
- Can degrade electromagnetic calorimetry

Technical Issue: Intermediate Tracking

(gas chamber designs)

- Depending on R_{max} of Vdet and R_{min} of central tracker, a precise silicon layer at gas chamber R_{min} improves δp by up to factor of two

- Might help pattern recognition (might hurt!)

- Offers possible bunch tagging via precise timing to disentangle two-photon crud, machine backgrounds (e.g., scintillating fiber)

Technical Issue: dE/dx

- Capability “comes for free” in gas chambers, but electronics to exploit it is not free

- Some capability possible with silicon, but useful mainly for tagging very heavy (exotic) particles

- Do we need it?
  - Identifying high-energy electrons will be easy, anyway.
  - Do we care enough about K/π separation to let dE/dx influence tracker design choice?

Technical Issue: B Field

- High magnetic field creates variety of problems related to Lorentz angle:
  - Large effect in axial drift chamber
  - Not negligible in Si μstrips
  - Distorts signal in older-style TPC wire anode readout

- On the bright side, high B field reduces transverse diffusion in TPC

Technical Issue: Exploiting TPC Resolution

- Diffusion limit to intrinsic TPC spatial resolution not yet realized by wire planes with inductive pad readouts

- Can new micropattern gas detectors (and electronics) do much better at reasonable cost?

- Can positive ion feedback (affects field uniformity) be controlled well enough?

Technical Issue: Mechanical Support of Si

- Long, possibly daisy-chained ladders envisioned
- Want to minimize material and maintain rigidity (material also associated with front-end electronics and cooling infrastructure)
- Alternative: live with non-rigid structure using ATLAS-style real-time alignment

  (chirped interferometry)

How do we make choices?

We need:

- Simulations, Simulations, Simulations!
  (fast and full Monte Carlo)
- Detector R&D to ground simulations in reality.

Next presentation (B. Schumm) proposes list of prioritized simulation and detector R&D studies

Will now give overview of work accomplished or well in progress on tracking simulations and R&D

Tracking Simulation Studies to Date*
(Only North American work shown here)

- Tracker design (LBNL, Michigan, UCSC, SLAC)
- Parametrized resolutions – Fast MC (UCSC, SLAC)
- Track reconstruction / pattern recognition
  (LBNL, Michigan, Oregon, SLAC, Wayne State)
- Detailed detector response (Carleton, Wayne State)
- Design impact on physics (Michigan)

*Does not include work on vertex reconstruction

Central Tracker R&D (overview)

- Time Projection Chamber
  - Mostly Europe, some Canada, U.S.
  - Concrete design, R&D focused, funded
  - Web site: http://www.desy.de/flc/tpc/tpc_main.html
- Drift chamber
  - Mostly Japan
  - Concrete design, R&D well focused, funded
  - Web site: http://www-jlc.kek.jp/subg/cdc/index-e.html
- Silicon (drift & microstrip)
  - Mostly U.S. (recent European interest in “envelope”)
  - Competing designs, R&D funds only now available
  - Web site: http://scipp.ucsc.edu/SILC/

Ongoing TPC R&D

- Readout scheme (Aachen, Carleton, DESY, Karlsruhe, LBNL, MIT, MPI, NIKHEF, Novosibirsk, Orsay, Saclay)
  - Optimizing spatial resolution for given electronics channel count
  - GEM vs MicroMEGAS vs wires
  - Suppressing ion feedback (e.g., multi-GEMS, gating grid)
- Readout pad shape (Aachen, Carleton, DESY, LBNL, MPI)
  - Affects channel count, intrinsic spatial resolution, 2-track resolution, and dE/dx resolution
  - Chevrons (clever splitting/ganging) vs induction
- Gas mixture (DESY, Krakow, MIT, Saclay, Novosibirsk, MPI)
  - Drift velocity (resolution vs fast clearing)
  - Quenching with hydrocarbons vs reducing neutron backgrounds
  - Aging
  - Affects field cage design

Ongoing TPC R&D

- Electronics (Carleton, LBNL, NIKHEF, MPI)
  - Need $O(10^6)$ pads to exploit intrinsic x-y TPC granularity
  - Need high-speed sampling (~100 MHz) to exploit intrinsic granularity and dE/dx
- Mechanics (LBNL, MPI)
  - Minimize material in inner/outer field cages, endplates
  - Eliminating wire readout helps!
  - But high-speed sampling may require cooling, despite low duty cycle
- Calibration (LBNL, NIKHEF, MPI)
  - Laser system? Add "z" chamber at outer radius?
  - Rely on Z resonance running?
- Simulation (Aachen, Carleton, DESY, NIKHEF)
  - Readout scheme modelling for design optimization
  - Optimizing pad size & shape

Ongoing Drift Chamber R&D
(KEK)

- Controlling/monitoring wire sag over 4.6 meters
- Uniform spatial resolution (85 microns) over chamber volume
- Good 2-track resolution (<2 mm)
- Stable operation of stereo cells
- Gas gain saturation (affects dE/dx, 2-track resol)
- Lorentz angle effect on cell design
- Wire tension relaxation (Al)
- Optimizing gas mixture
- Neutron backgrounds (planned)

Ongoing Silicon R&D
(mostly just getting started)

- Thinner silicon strips (LPNHE-Paris, Santa Cruz, SLAC)
  - Reduce material of tracker
  - Presents support / stabilization challenge

- Short vs long strips (LPNHE-Paris, Santa Cruz, SLAC)
  - Short gives timing precision but more FEE in fiducial volume
  - Long minimizes material, reduces noise,
    but sacrifices timing
  - Choice dependent on expected backgrounds

Ongoing Silicon R&D

- Barrel/disks support structure

  (LPNHE-Paris, Santa Cruz, SLAC, Wayne State)

  – Want low-mass, stiff support
  – ATLAS alignment scheme reduces stiffness demands

- Power-switching μstrip readout chip

  (LPNHE-Paris, Santa Cruz, SLAC)

  – Exploiting low duty cycle of collider
  – Reduce cooling infrastructure material
  – Stability?

Ongoing Silicon R&D

- Other strip readout issues (LPNHE-Paris, Santa Cruz, SLAC)
  - Lorentz angle in high B-field
  - p-side readout for “stereo”?
  - Time-walk compensation, dE/dx measurement?
  - More electronics integration

- Specific Silicon Drift Detector Issues (Wayne State)
  - Improve spatial resolution to <10 microns (x-y, r-z)
  - Increase drift length
  - Low-mass readout for FEE in fiducial volume

Proposed tracking studies
(simulations and R&D)

- Cornell (D. Peterson) -- NSF
  Pattern recognition (applying CLEO DC algorithms to TPC)

- Cornell / Purdue (D. Peterson, I. Shipsey) -- NSF
  Development of TPC readout R&D laboratory

- Hampton (K. Baker) -- NSF
  Exploration of properties of prospective TPC gases

- Indiana / Notre Dame (R. Van Kooten, M. Hildreth) – DOE
  Investigation of intermediate tracker based on scintillating fibers

Proposed tracking studies
(simulations and R&D)

- Michigan (K. Riles) – NSF
  Physics impact of tracker design (Higgs, SUSY); alignment R&D

- MIT (U. Becker, P. Fisher) – DOE
  GEM development and testing

- Santa Cruz (B. Schumm) – DOE (funded)
  Silicon microstrip R&d (discussed earlier)

- Wayne State (R. Bellwied) – NSF
  Silicon drift detector simulations and detector prototyping

Summary:

- Much simulations work to be done in detector design evaluation & optimization
- Technology choice for central tracker still very much up in the air. TPC and DC options have received most study
- Readout technology for TPC option still wide open
- Silicon central tracking options (microstrip or drift) need much more R&D attention
- Several new groups joining the effort soon

Help is needed and welcome!