

Charged Particle Tracking Issues (Vertexing, Central & Forward Tracking)

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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
- See talks by Frey / Fisk for discussion of calorimetry / muon system. See Graf talk on simulation infrastructure.
- See talk by Heuer for overview of international detector R&D effort.

Acknowledgements

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Physics Drivers (a sampling)

Good primary / secondary vertex reconstruction (b vs c):

- B(H->cc) [distinguish SM from SUSY Higgs]
- Charm-tag W^+W^- final states [strong coupling]

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

- 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; $\delta(1/pt) \sim 2 * 10^{-4}$ GeV $^{-1}$]

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

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)

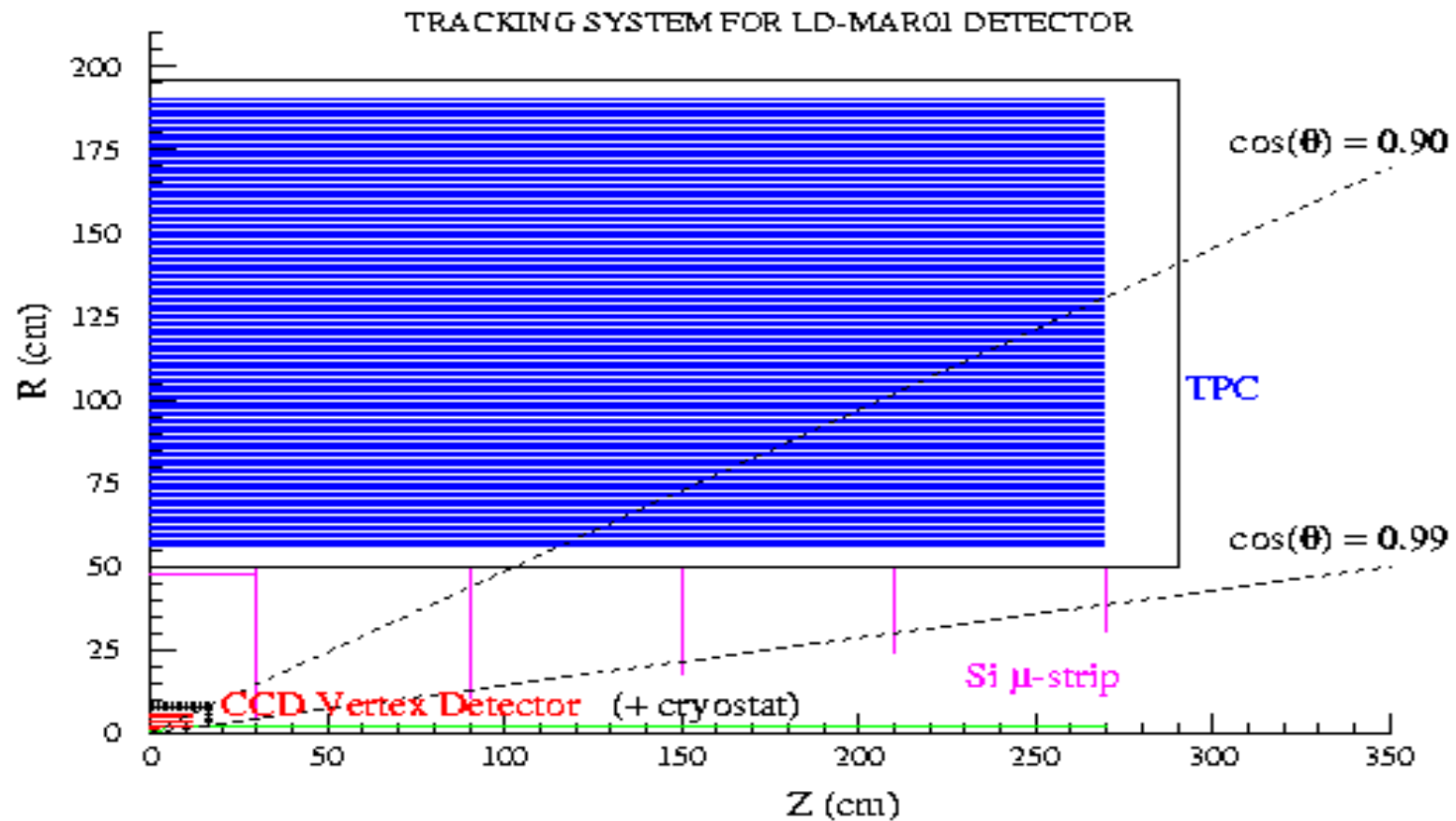
Europe:

- 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

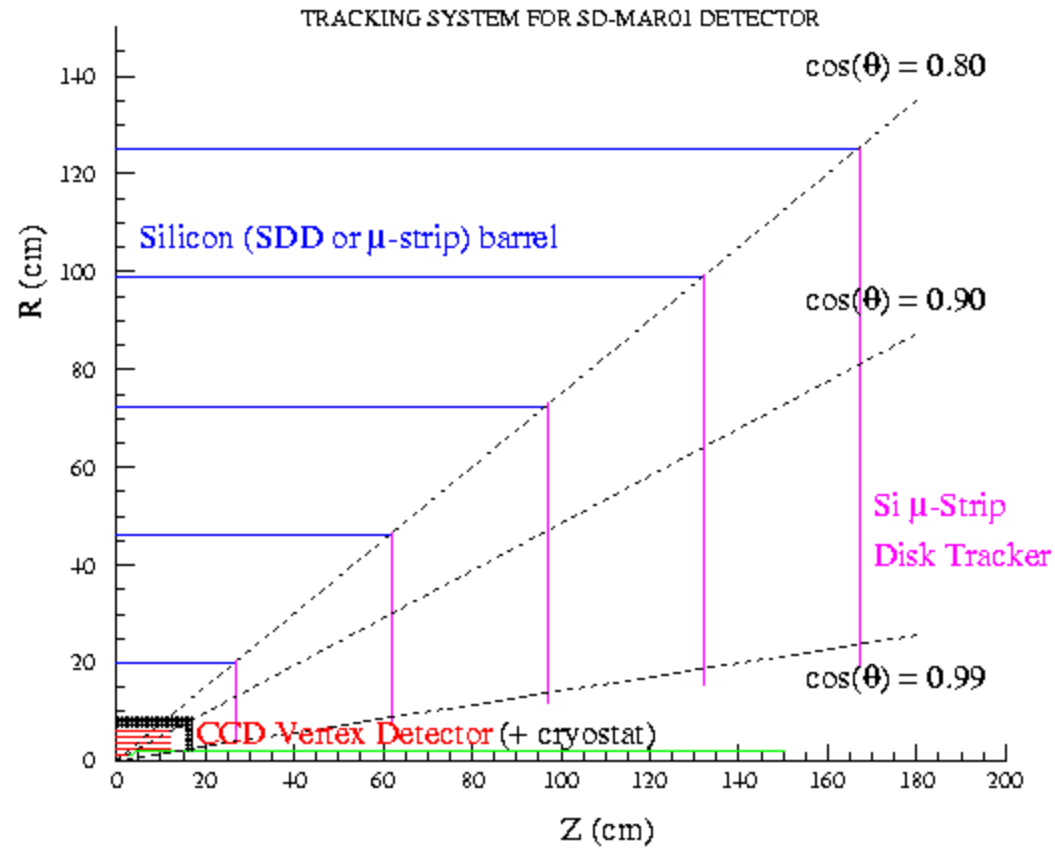
North America:

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

Central tracker LD baseline (North America)



Central tracker SD baseline (North America)

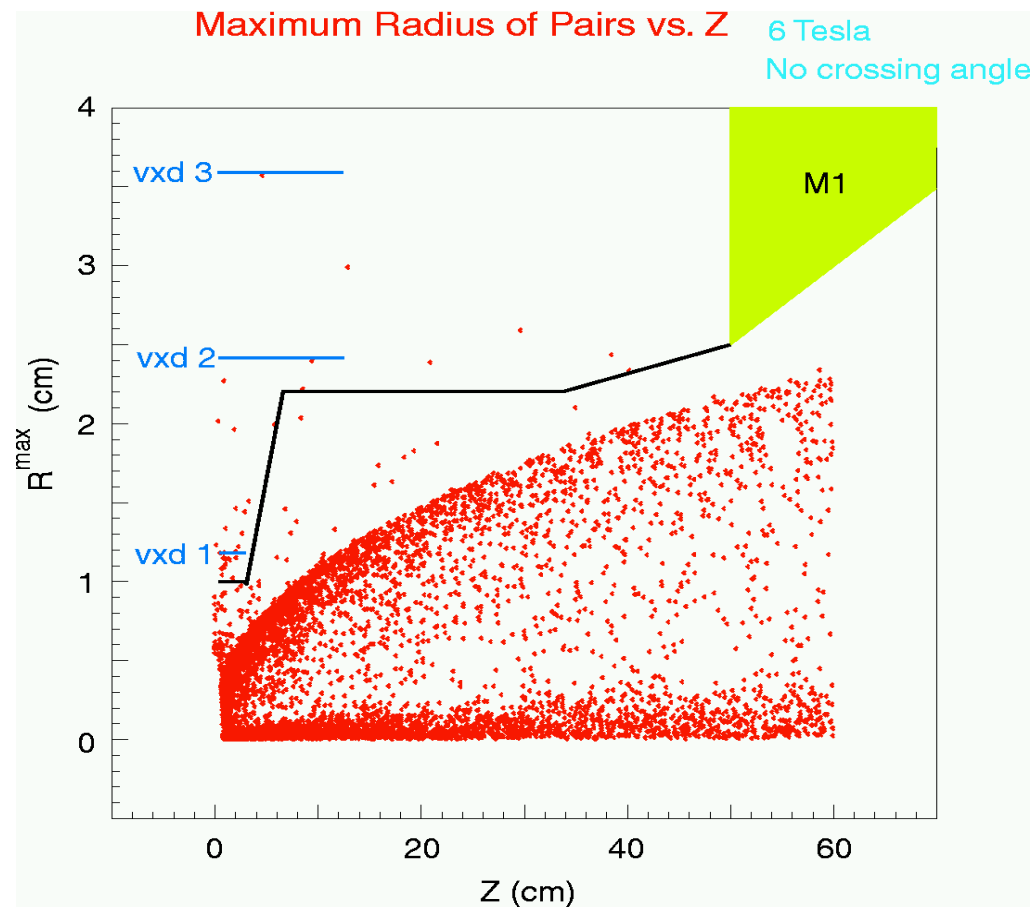


Technical Issues

Radius of innermost layer of vertex detector:

- Fierce background from Bethe-Heitler pairs
(see figure)
 - Drives B-field magnitude
 - Pushes tolerance on background calculations
- Neutron backgrounds drive required rad-hardness

Pair Background (plot from T. Markiewicz)



Technical Issues

Tracker material

- Make vertex detector layers as thin as possible to reduce degradation of impact parameter resolution
 - **Probably important**
- Minimize material in central tracker too to reduce degradation of momentum resolution
 - **Desirable, but perhaps not critical**
- Reduce secondary backgrounds from machine

Technical Issues

Pattern recognition – Vertex Detector

- Want pixellated vertex detector
(**CCD vs Active (monolithic/hybrid) Pixels**):
 - Reconstruct primary / secondary vertices accurately
 - Provide “seed” tracks for central / forward trackers
- CCD’s provide superior spatial resolution, but readout time a problem with Tesla bunch train and expected backgrounds.
- Active pixels fast and radiation-hard, but thick & coarse.

Technical Issues

Pattern recognition – Central Tracker

- 3-D vs 2-D technologies:
 - Gas: **TPC** vs **DC**
 - Silicon: **Drift** vs **Microstrips**
 - 3-D eases reconstruction and improves robustness against backgrounds (SR photons, $\gamma\gamma \rightarrow$ jets). May come at higher cost.
- Few precise hits (silicon) vs many coarse hits (gas)
 - Effect on 2-track separation? \rightarrow **Energy flow**
 - Reconstruct long-lived decays?
 - Cope with large machine backgrounds?
 - Pointing to shower max in calorimeter \rightarrow **Energy flow**
- Does pixel vertex detector provide enough “stand-alone” tracking (seeding) to make above choices non-critical?

Technical Issues

Intermediate Tracker (needed for gas trackers?)

- 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 Issues

What about 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 Issues

Mechanical / electronic ramifications of thin silicon

- Ultra-thin CCD's can be “stretched” to maintain rigidity without support structure
 - Mechanical challenge
- Silicon microstrip ladders can be built long to get front-end electronics out of fiducial volume.
 - Affects shaping time of electronics, could be a problem in high-background environment

How do we make choices?

We need:

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

Will present:

- My (abbreviated) tracking simulations wish list
Note: much work already underway & reported
- Overview of ongoing tracking detector R&D

A Tracking Simulations Wish List

Fast Monte Carlo:

- Where do we reach diminishing returns on impact parameter resolution in measuring Higgs charm vs bottom branching ratios? How thin do pixel layers really need to be?
- Where do we reach diminishing returns on momentum resolution in measuring Higgs recoil mass and slepton mass end-point spectra, taking into account particle decay widths, initial state radiation, and beam energy spread?

A Tracking Simulations Wish List

Fast Monte Carlo:

- Compelling 500 GeV physics example where material budget in central tracker matters:
 - What $\delta p/p$ do we need at 1 GeV? (10^{-2} , 10^{-3} , 10^{-4})?
 - What photon conversion rate is unacceptable? (10%)?
- Compelling 500 GeV physics example where dE/dx buys us much.

A Tracking Simulations Wish List

Full Monte Carlo:

- Robust, reasonably optimized track reconstruction for North American LD and SD baseline designs, including:
 - Non-cheat reconstruction from hits in Si barrel microstrip option
 - Non-cheat reconstruction from hits in Si forward disk microstrips
 - Self-contained vertex detector tracking with extrapolation outward
- Comparison of energy flow performance among the 3-D, 2-D, silicon, gaseous options
(e.g., WW vs ZZ all-hadronic final states, overlaps with calorimeter wish list!)

A Tracking Simulations Wish List

Full Monte Carlo:

- Realistic study of benefits arising in LD design from:
 - Intermediate silicon layer just inside the TPC (pat. rec., $\delta p/p$)
 - Intermediate sci-fiber layer in same place (timing)
 - Outer “z” (straw/silicon) layer (pointing into calorimeter)
 - Outer endcap (straw/silicon) layer (better $\delta p/p$ at low θ)

(“realism” includes, e.g., systematic alignment errors, backgrounds from multiple bunches, and calorimeter backsplash)

A Tracking Simulations Wish List

Full Monte Carlo:

- TPC E-field distortion by ionic space charge
 - Proponents confident that new readout schemes (GEM, MicroMEGAS) and gating grid adequately suppress avalanche ion feedback
 - Primary ionization said to be okay too for expected machine backgrounds
 - What if backgrounds are much worse?
(need really full Monte Carlo to study!)

A Tracking Simulations Wish List

Full Monte Carlo:

- Wire saturation in drift chamber from larger-than-expected accelerator backgrounds:
 - Synchrotron radiation background (1 MeV Compton curlers)
 - Muons from beam halo hitting collimators

Ongoing or Planned R&D for Vertex Detector (overview)

- CCD's
 - Europe, North America, Asia
- Hybrid, Monolithic, & DEPFET Pixels
 - Europe

Ongoing or Planned CCD R&D

- **Minimizing material:** (JLC, LCFI*, Oregon, Yale)
 - Thinner silicon
 - Stretched silicon
 - Room-temperature operation
- **Coping with radiation** (JLC, LCFI, Oregon, Yale)
 - Manufacture of harder detectors
 - Techniques for reducing / coping with damage (charge injection, lower temperature)
- **Speed up readout** (LCFI, Oregon, Yale)
 - Higher clock speed
 - Parallel column readout
 - Integration

*LCFI Collaboration: Bristol, Glasgow, Lancaster, Liverpool, Oxford, RAL

Ongoing or Planned Hybrid Pixel R&D

(CERN, Helsinki, INFN, Krakow, Warsaw)

- Reducing total thickness
- Improving spatial resolution
 - Smaller pitch
 - Interleaved sensors exploiting capacitive induction

Ongoing or Planned CMOS Pixel R&D

(also known as MAPS = Monolithic Active Pixel Sensor)

(Strasbourg)

- Development (!)
- Larger wafers
- Thinner substrate
- More integrated readout

Ongoing or Planned DEPFET* Pixel R&D

(MPI)

- Development (!)
- Thinner layer and readout
- Thinner, integrated readout
- Improving spatial resolution (smaller pitch)

*Similar to MAPS but with high-resistivity silicon, FET in readout chain, readout from sides (for now)

Ongoing or Planned R&D for Central Trackers (overview)

- Time Projection Chamber
 - Mostly Europe, some Canada, U.S.
 - Concrete design, R&D focused, funded
- Drift chamber
 - Mostly Japan
 - Concrete design, R&D well focused, funded
- Silicon (drift & microstrip)
 - Mostly U.S.
 - Competing designs, R&D strapped for funds

Ongoing or Planned 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 or Planned 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 z 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?
 - “Z” chamber at outer radius?
- **Simulation** (Aachen, Carleton, DESY, NIKHEF)
 - Readout scheme modelling for design optimization
 - Optimizing pad size & shape

Ongoing or Planned 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 or Planned Silicon R&D

- 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 or Planned 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 μ strip readout chip (LPNHE-Paris, Santa Cruz, SLAC)
 - Exploiting low duty cycle of collider
 - Reduce cooling infrastructure material
 - Stability?

Ongoing or Planned 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

To learn more about many of these simulation and R&D issues, attend tomorrow afternoon's parallel sessions on

- Vertexing *
- Tracking *
- Simulations *

Summary:

- Much work to be done in detector design optimization
- Much work to be done in detector R&D, especially for silicon designs

Help is needed and welcome!