SiD Detector Overview

Andy White

U.Texas at Arlington

(for SiD Detector Group)

April 2004 LCWS Paris

An overall approach:

- Concepts
  - Ideas
    - Studies
      - Results

SiD Detector - Physics

- Resolve W/Z's in multi-jet final states (a tracking/cal issue)
- Bottom and charm tagging from VXD
- Excellent momentum resolution for most challenging physics cases (e.g. hZ w/ Z-> $\mu\mu$)
- Forward tracking for e.g. selectrons
- Full coverage/hermeticity for missing energy/momemtum determination

SiD Detector Approach

✦ Start from Si/W ECAL for energy flow

✦ Minimize size/cost of ECAL => space constraints on tracking system (R)

✦ Recover momentum resolution (~BR^2) by raising magnetic field to 5 Tesla.

✦ Use pixel VXD for efficient pattern recognition

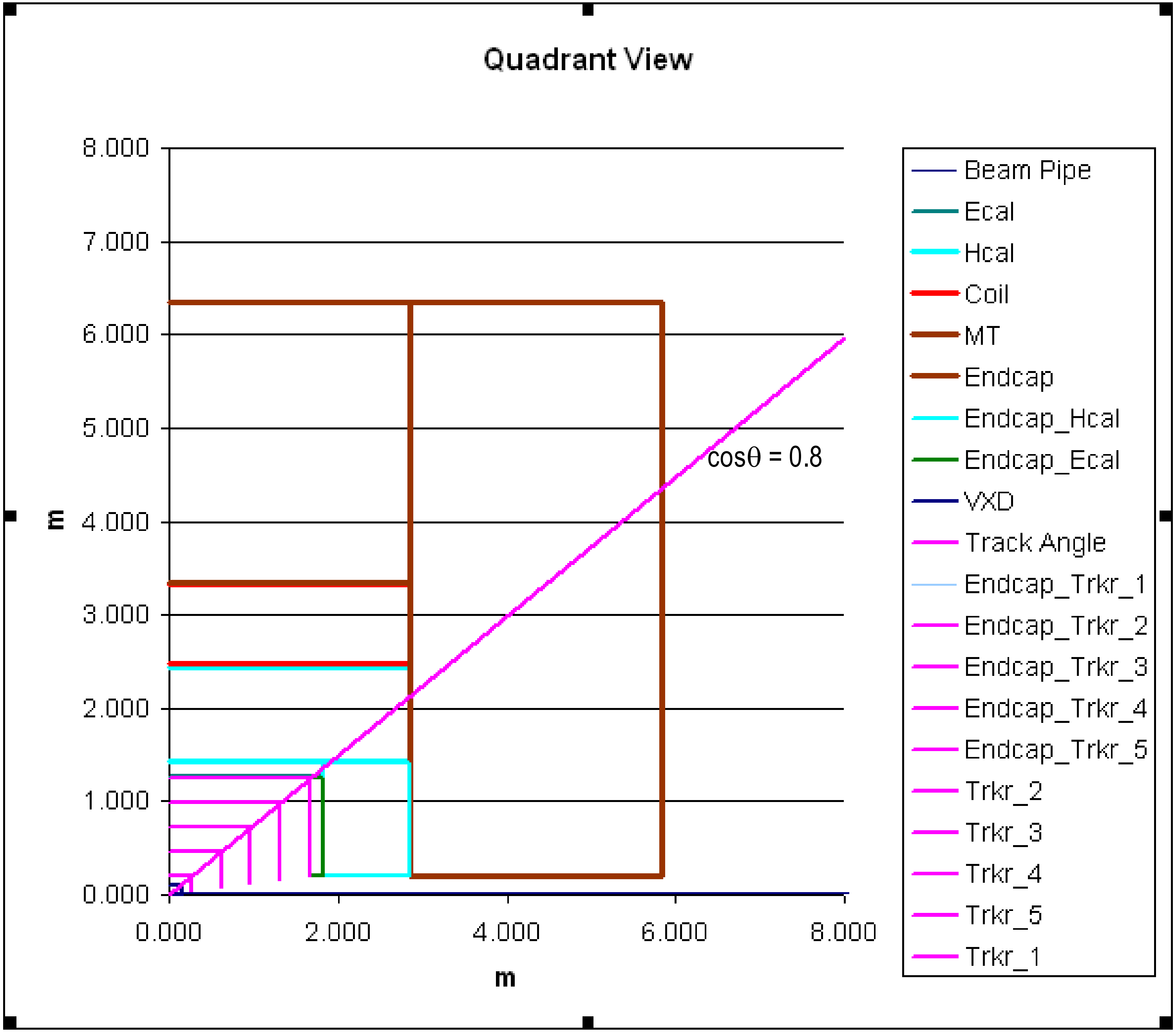
✦ Use Si strips in tracker (5-layers) for good $\Delta p/p$, pattern recognition, and input charge trajectories for Cal EFlow.

SiD Detector Approach

- ✦Compact tracking + ECal allows smaller HCal – important if the "digital" approach is adopted.
- ✦ Keep HCal inside the solenoid.
- ✦ "Simple" muon system – iron slabs + Scintillator strips/RPC/GEM? Also acts as tail-catcher.
- ✦ Consider timing of tracking, ECal, for background reduction by track/bunch association.

SiD Detector

SiD


Quadrant View
8.000
7.000
6.000
5.000
4.000
3.000
2.000
1.000
0.000
m
0.000
2.000
4.000
6.000
8.000
m
cosθ = 0.8
Beam Pipe
Ecal
Hcal
Coil
MT
Endcap
Endcap_Hcal
Endcap_Ecal
VXD
Track Angle
Endcap_Trkr_1
Endcap_Trkr_2
Endcap_Trkr_3
Endcap_Trkr_4
Endcap_Trkr_5
Trkr_2
Trkr_3
Trkr_4
Trkr_5
Trkr_1

Calorimeter System Design

LC Physics demands excellent jet i.d./energy resolution, and jet-jet invariant mass resolution.

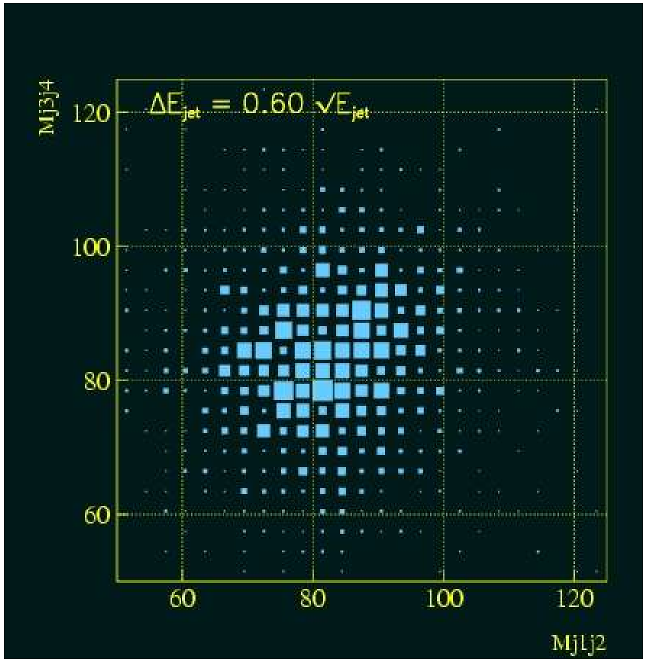
Energy Flow approach holds promise of required solution and has been used in other experiments effectively.

-> Use tracker to measure Pt of dominant, charged particle energy contributions in jets; photons measured in ECal.

-> Need efficient separation of different types of energy deposition throughout calorimeter system

-> Energy measurement of only the relatively small neutral hadron contribution de-emphasizes intrinsic energy resolution, but highlights need for very efficient "pattern recognition" in calorimeter.

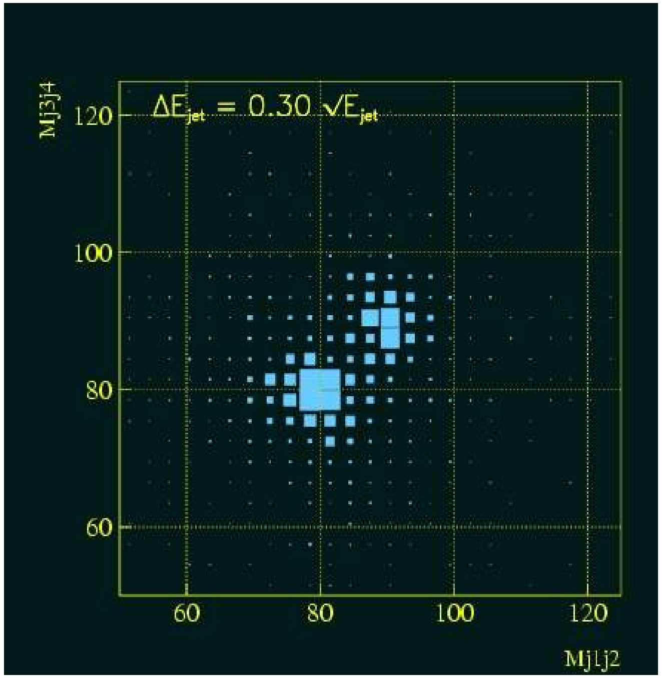
Importance of good jet energy resolution



60%/√E

Simulation of W, Z reconstructed masses in hadronic mode.

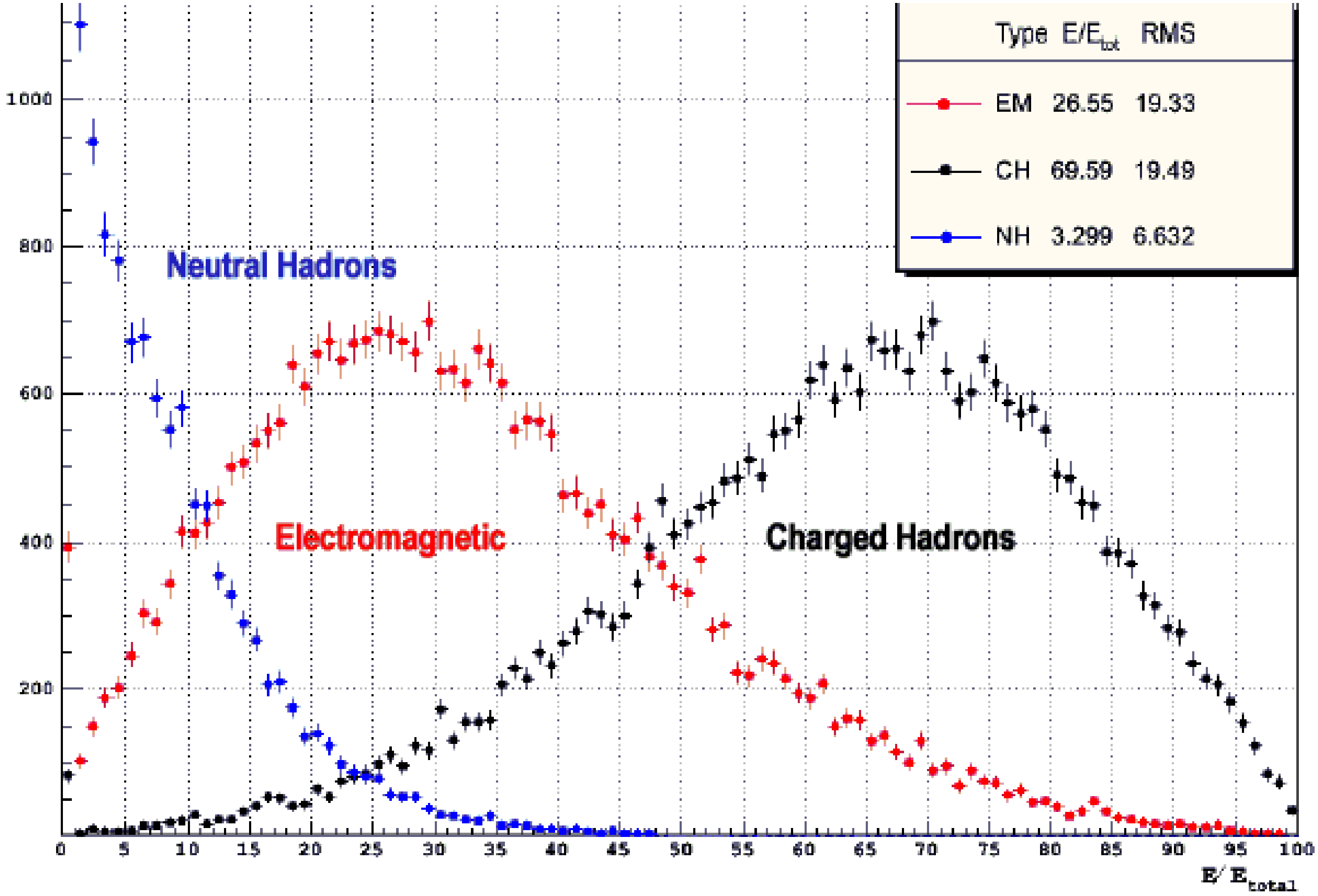
30%/√E



(from CALICE studies

shown at ALCPG/Cornell: M. Schumacher)

Fraction Energy of Particles in Jets



ECal System Design

- Emphasize jet energy and jet-jet invariant mass resolution.

- Require a dense ECal with small Moliere radius and:

-> fine transverse segmentation to accurately determine photon shower locations

-> fine longitudinal segmentation for efficient charged particle tracking through the ECal, and to separate charged and neutral particles for EFlow.

- These characteristics also allow e.g. detection of photons from secondary vertices in SUSY processes.

ECal System Design

Other design issues:

-Timing reqs? Bunch i.d. ? Many layers…

- Operation in a strong magnetic field.

- Hermetic – minimize intrusions, gaps, dead material

- Minimize costs – design for ease of production

- Robust, reliable design

- Inner radius of endcaps/radiation hardness?

SiD - Electromagnetic Calorimeter

- R(min) = 1.27m, R(max) = 1.42m.

- Tungsten layers/silicon diode detectors

- Present ideas: 2.5mm W for first 20 layers,

  5.0mm W for last 10 layers.

- Total 28.6 X_0

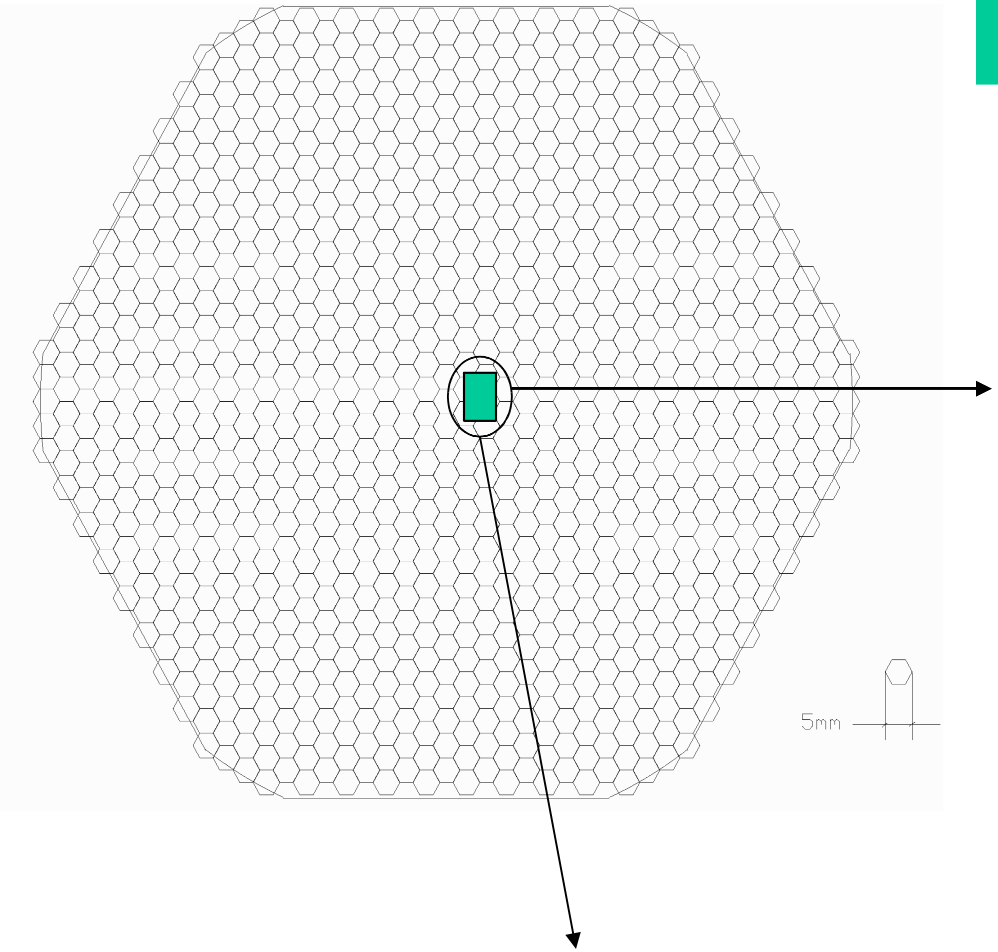
- Recent work to reduce gap -> 1mm plausible, copper layer has gone.

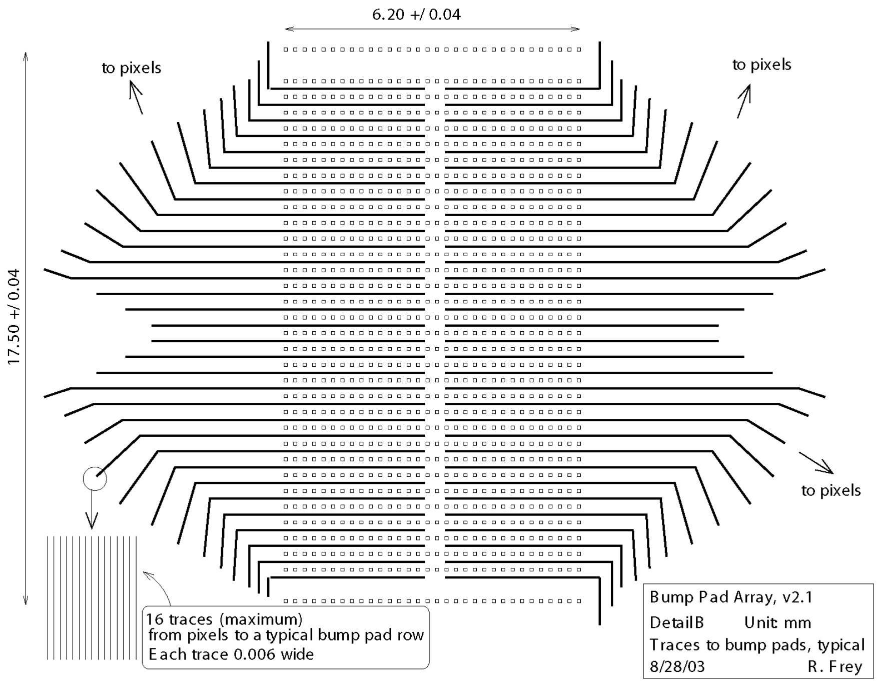
- 5-layer motherboard only 0.5 mm + “bury” the bypass capacitors/or notch the tungsten.

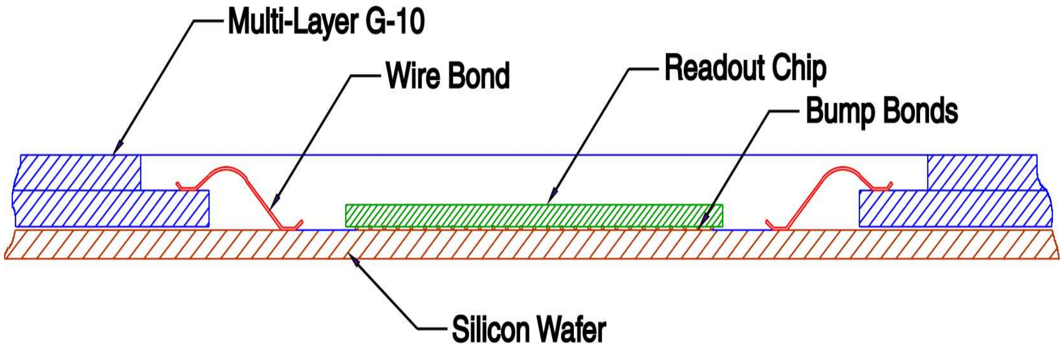
SLAC-Oregon Si-W ECal R&D

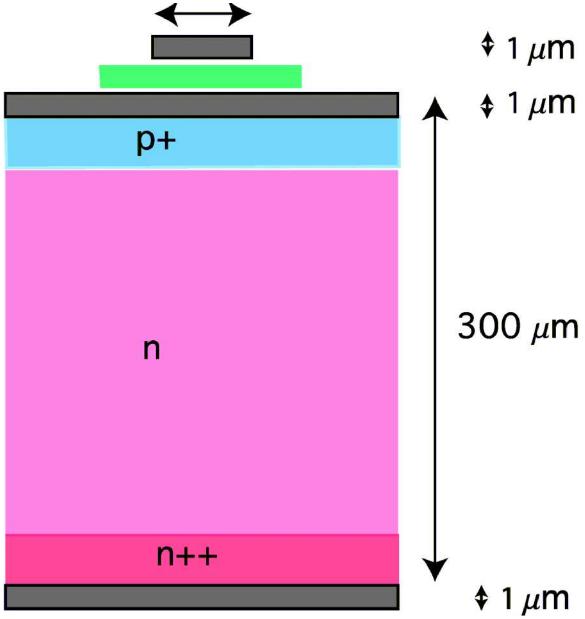
- Silicon-tungsten ECal is ~ideal realization
- Goal: **How to make it practical while maintaining performance…**
- Highly integrated electronic readout (reduce cost and complexity)
- Simple, robust silicon detector design (low cost)
- Flexible design relative to eventual performance optimization
  - e.g. transverse segmentation nearly independent of cost
- Initial prototypes:
  - Pixels are 5 mm x 5 mm x 0.6 X_0
  - A detector element (wafer) is ≈800 pixels with **<u>one</u>** full readout chip
  - Readout includes 2000 dynamic range and timing at few ns level
  - Power off when no beams ⇒ simple, passive cooling
- Technical tests of initial prototypes - thermal, noise, resolution
- Construct a full-depth module: 15cm x 15cm x 30 X_0
  - Ready for test beam in 2005
- First prototype silicon detectors delivered Jan/04
- Electronics design converging for initial chip order early '04

Wafer and readout chip









SiD Detector Design (cont.)

Magnetic Field

- Choice of Si/W ECal + cost/size constraints then leads to high magnetic field requirement to achieve large BR^2.

(For ECal inner radius/tracker outer radius = 1.27m, $B = 5T$ yields $BR^2 = 8$)

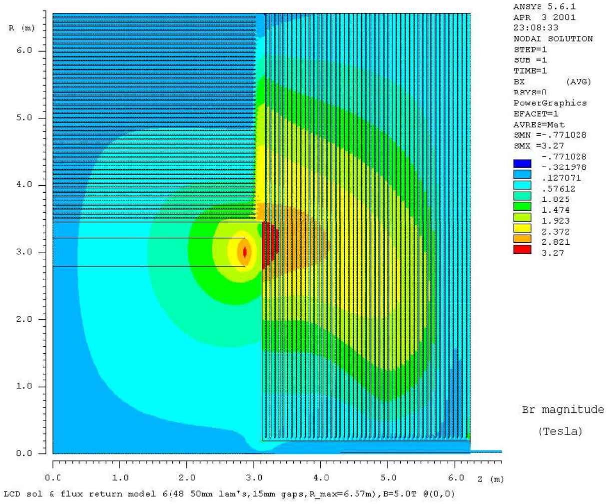
-> Momentum resolution

-> Particle separation for EFlow

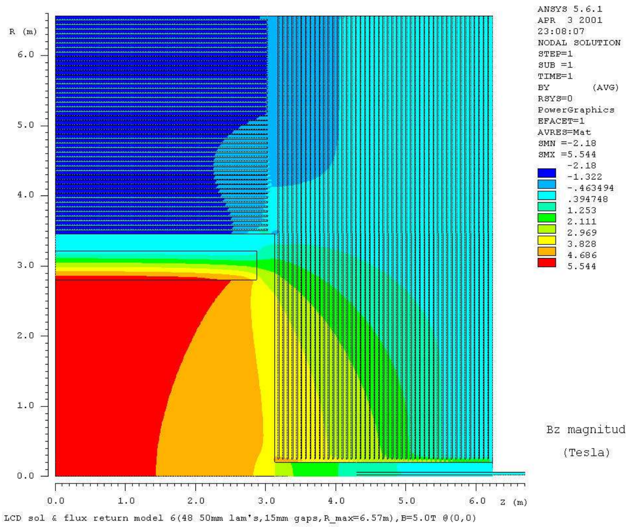
SiD - Solenoid

- Contains all except muon system
- High field – 5T for BR^2, pair containment
- 5 layers of "CMS" conductor + more structural aluminum – fits space foreseen.
- Stored energy ~1.5GJ (cf. TESLA ~2.4 GJ)

B_r

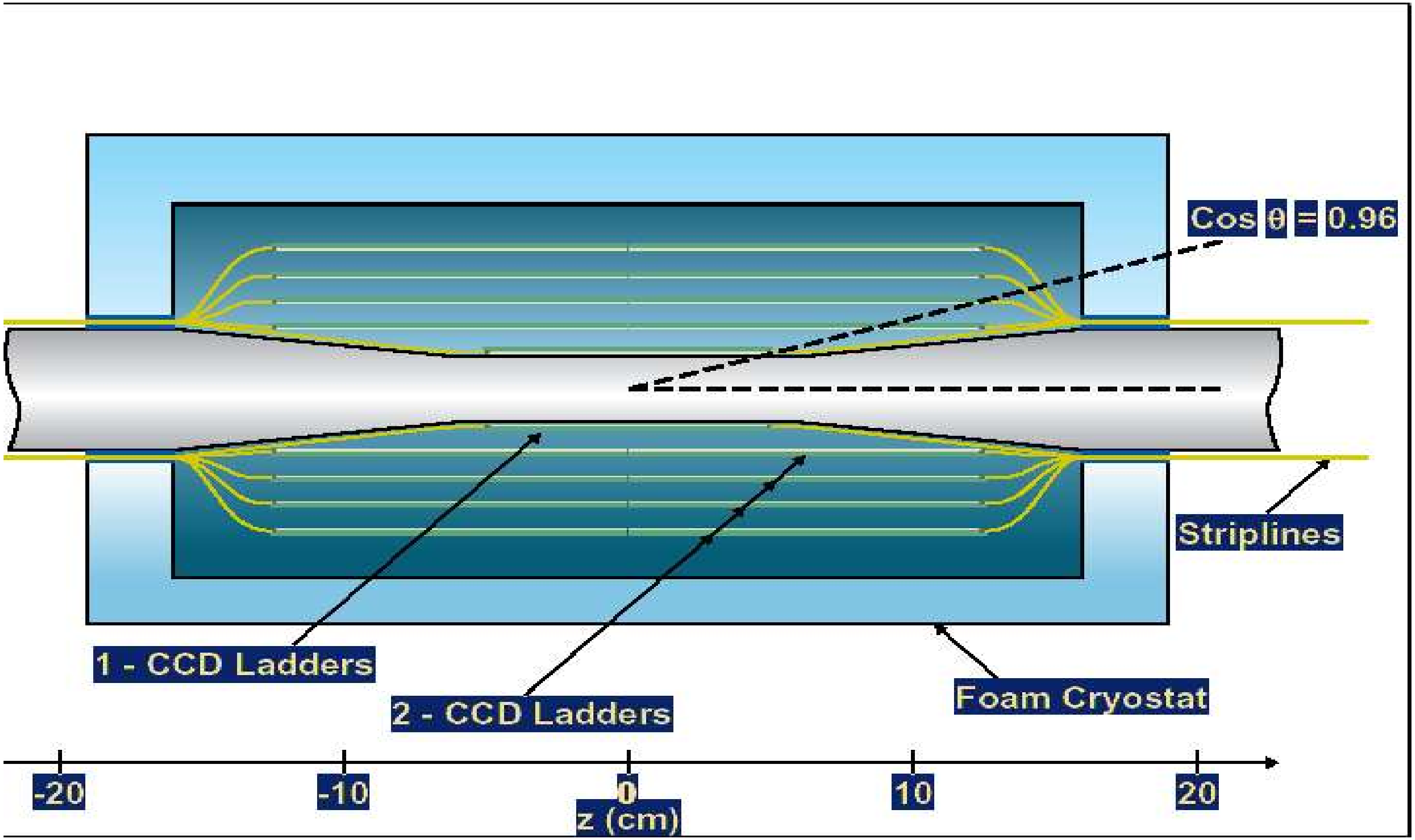


B_z



From M.Breidenbach, ALCPG/Cornell 2003

SiD – Vertex Detector



SiD - Vertex Detector

- Build on SLD/VXD3 success

- Require: high purity, efficient b,c tagging; charge tagging; efficient link to central tracking

- Design: 5 layers of CCD - expect $\varepsilon \sim 95\%$ for pat.rec.

- Inner radius: ~1.5 cm

- Thin ~0.2% X_0

- Point resolution: < 4μm

- Coverage: $\cos\theta < 0.97$

- High reliability; faster readout/lower power than SLD VXD3

SiD – Vertex Detector + endplates

- Extension of barrel CCD system forward

- shorten barrel CCD system to contain cost

- barrel endplate?

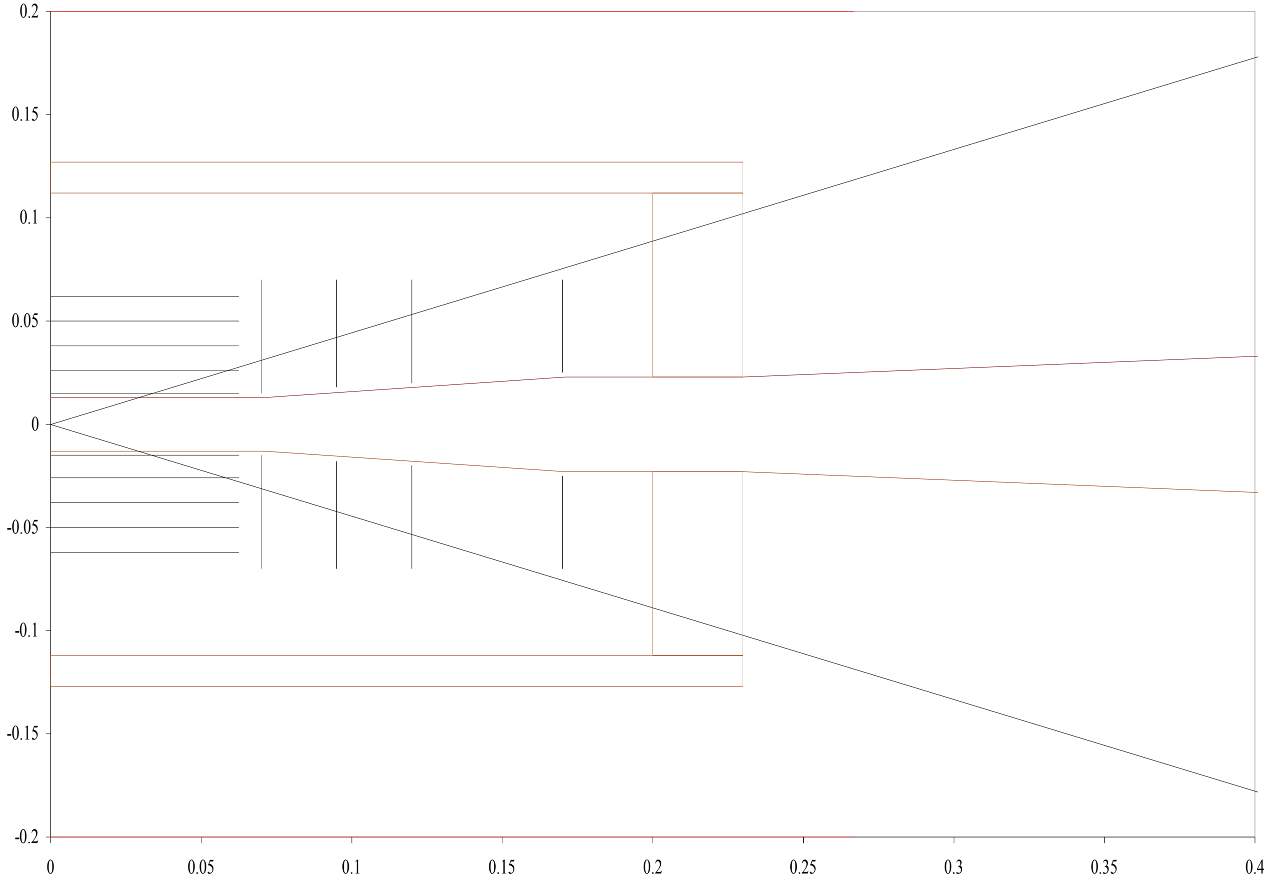
- 4 CCD forward layers -> coverage to cosθ < 0.98 with 4-5 points/track

- Results on – momentum, impact parameter, and dip-angle resolutions

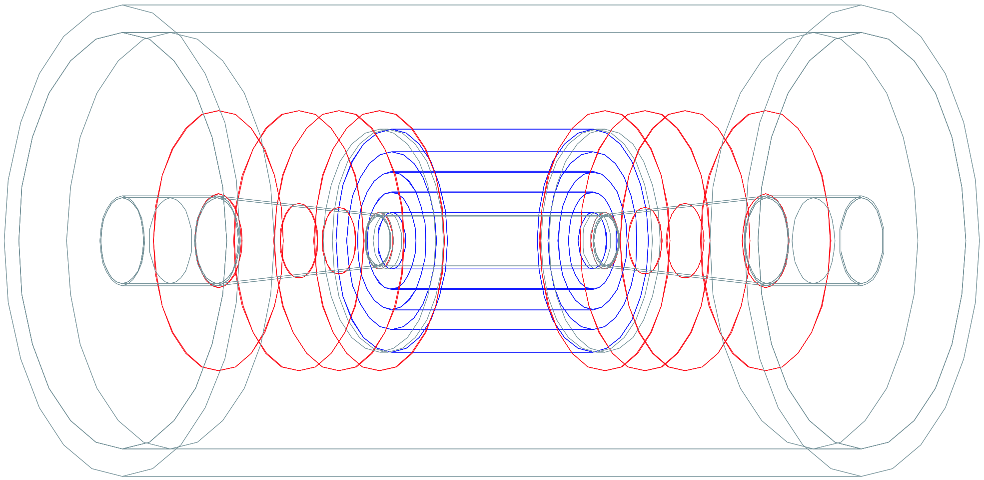
-> Improved performance for impact parameter resolution in forward direction

-> Improved forward flavor tagging

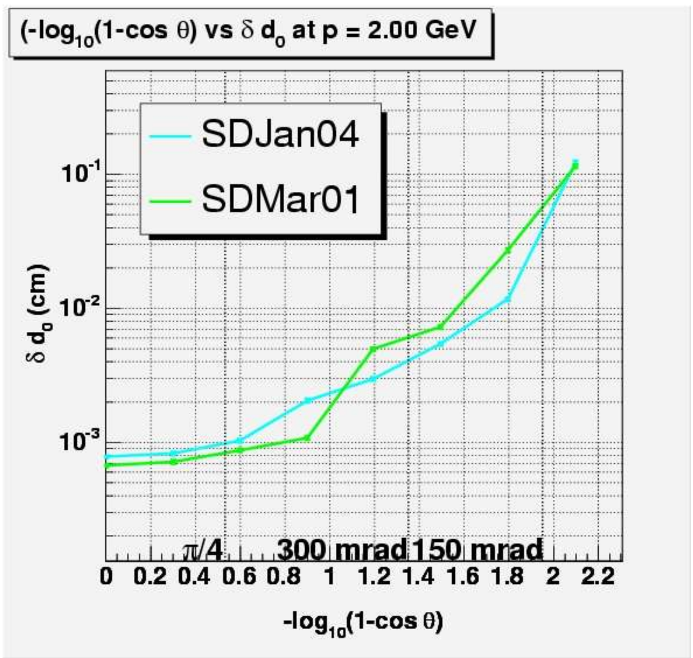
SiD - Vertex Detector + endplates

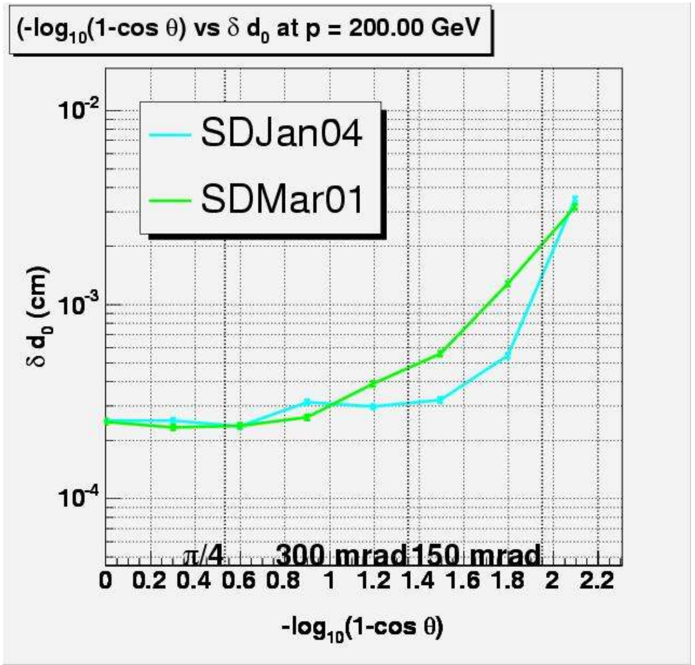


SiD – Vertex Detector + endplates Performance Study

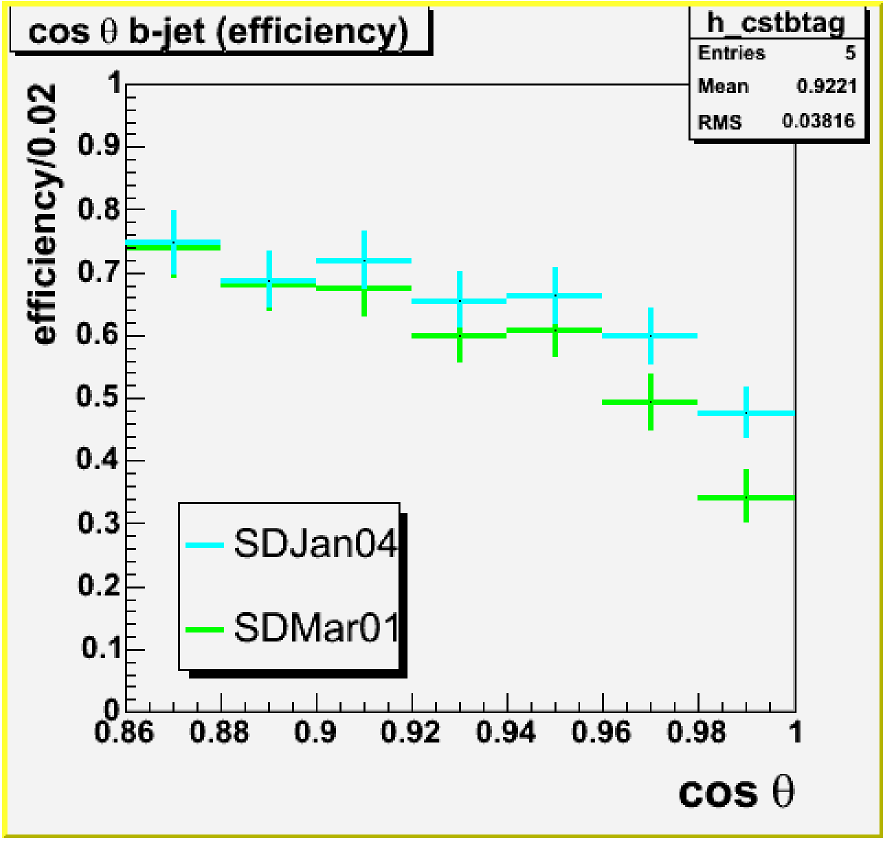


T. Abe – Full Simulation



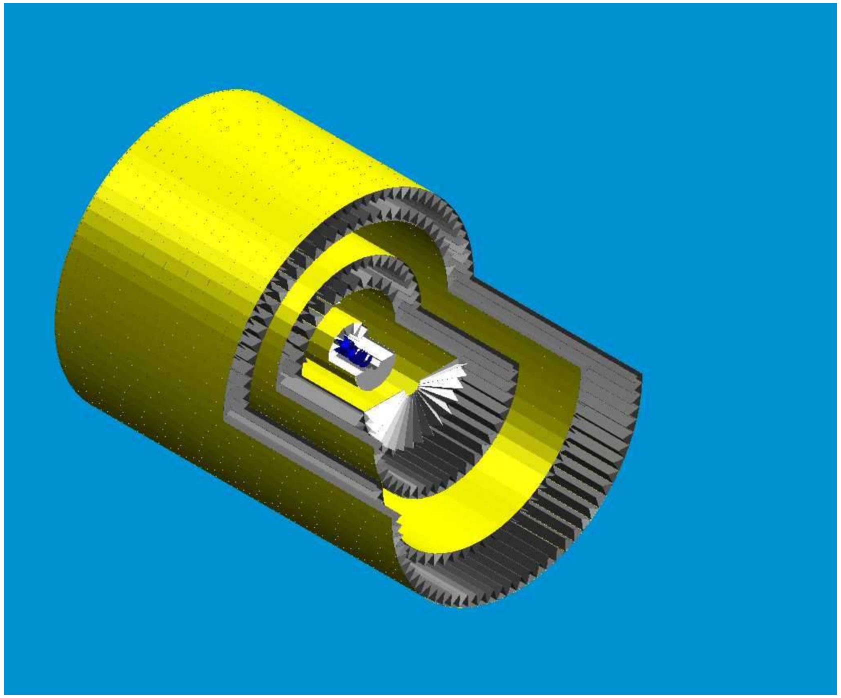


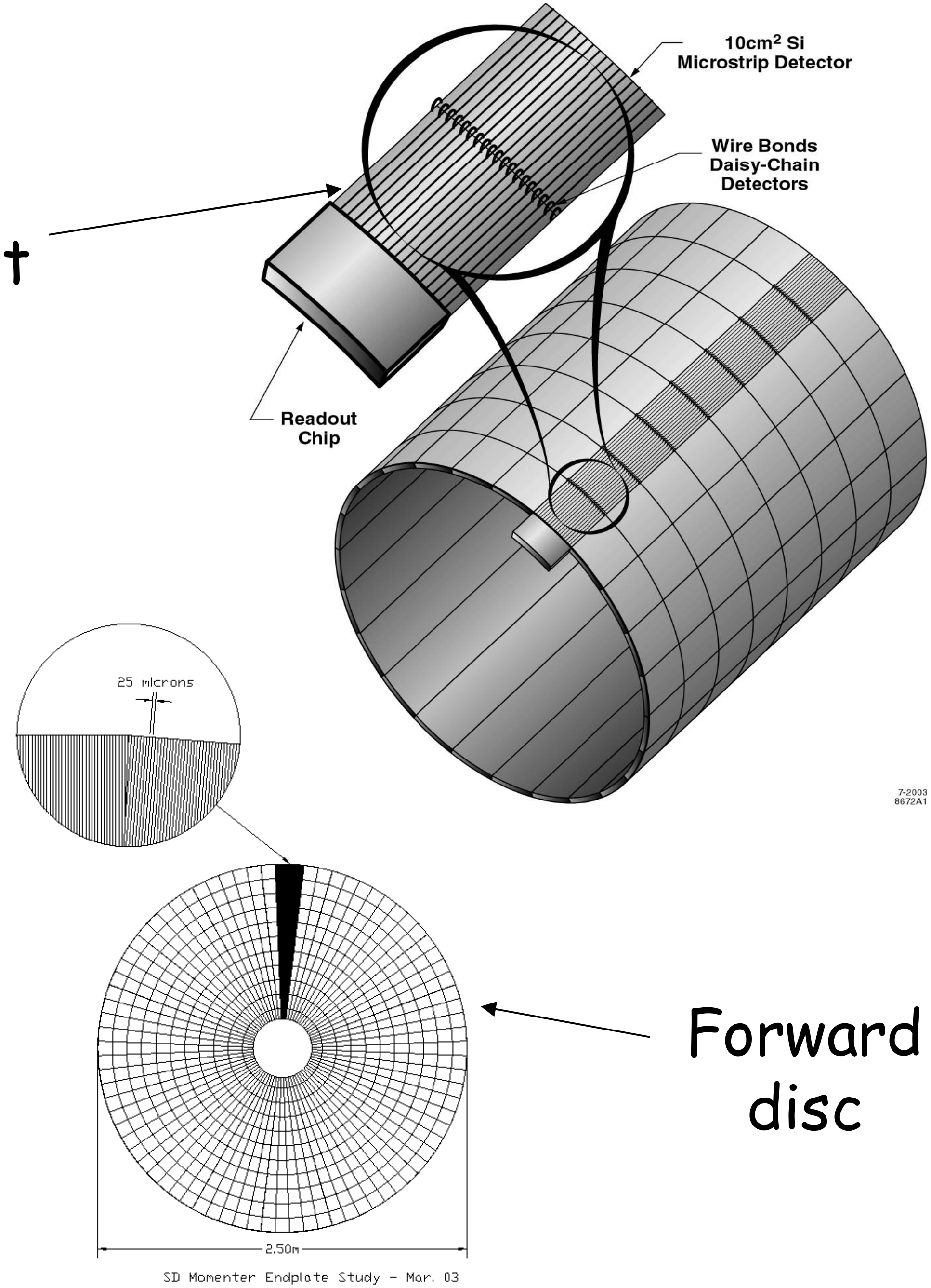
SiD - Vertex Detector + endplates Performance Study



SiD - Tracker

“Tiled” concept





SD Momenter Endplate Study - Mar. 03

Forward disc

SiD - Tracker

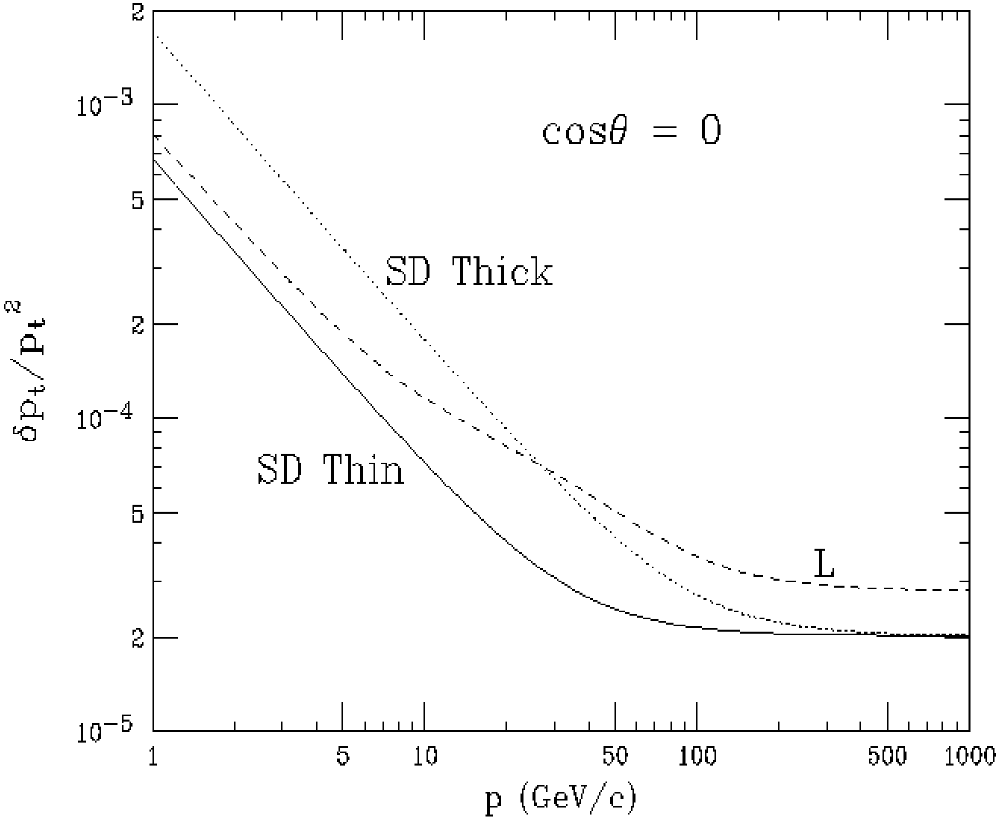
- Full pattern recognition requires efficient connection between VXD hits and tracker hits.

-> CCD VXD has 490 μm accuracy for extrapolation to 1st layer of barrel tracker, and once connection is made, extrapolating again to 2^{nd} barrel layer has 74 μm accuracy (figures from Steve Wagner study).

-Success in full pattern recognition depends on understanding, and dealing with:

- Machine backgrounds
- Physics backgrounds
- Noise

SiD Tracker Performance



SiD - Tracker Issues

- high spatial resolution requirement -> Si strips

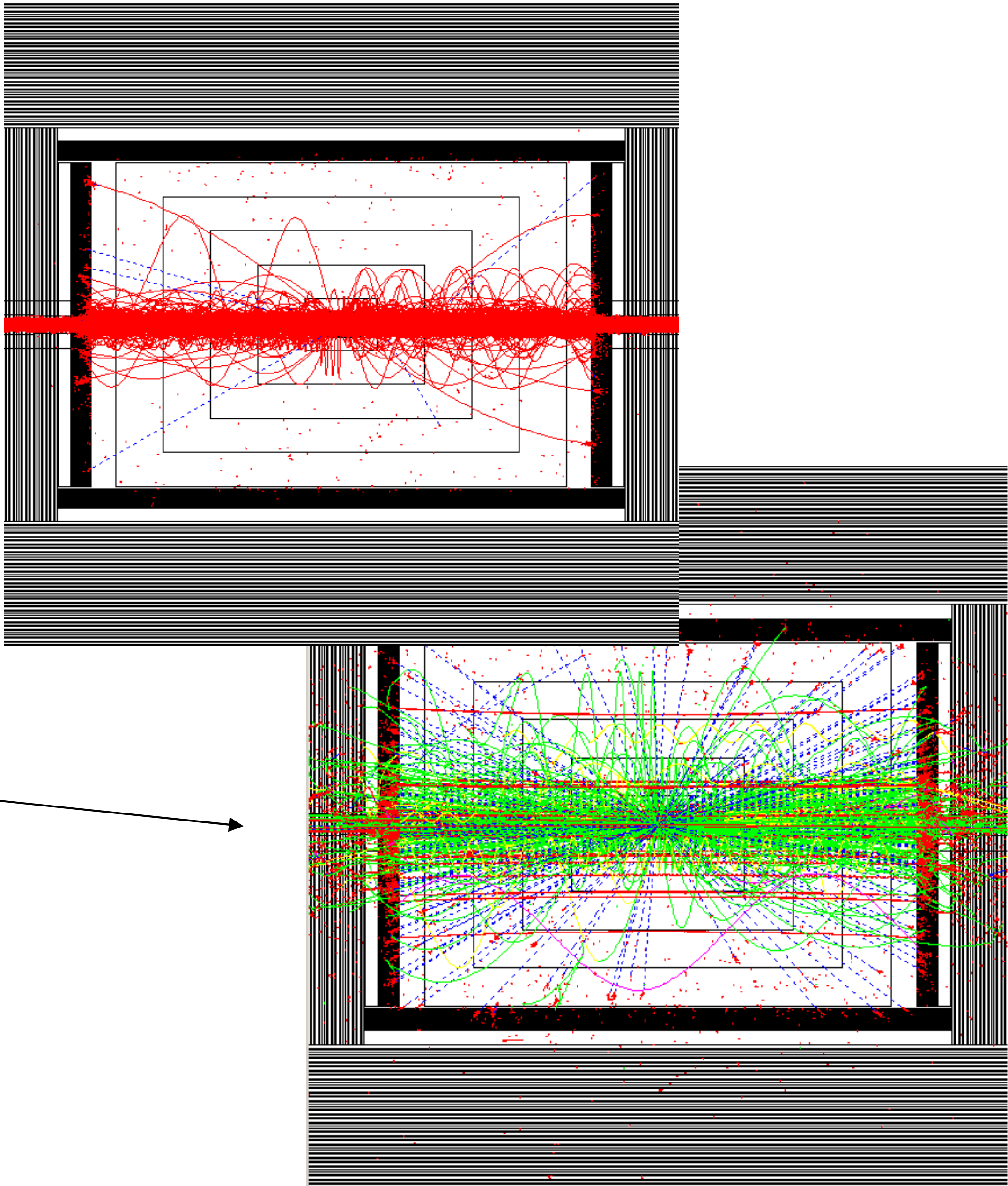
- … SLD -> Si robustness (vs. wire/gas)

- keep material budget low

- for EFlow, want good multiparticle separation (for reliable tracking of individual particles into calorimeter)

- Mechanical support – simple composite cylinders (carbon fiber/hexcel)

SiD - Tracker Issues



Occupancies/Train

8600 e^+e^- pairs

35k γ's (~MeV)

154 $\mu^+\mu^-$ pairs

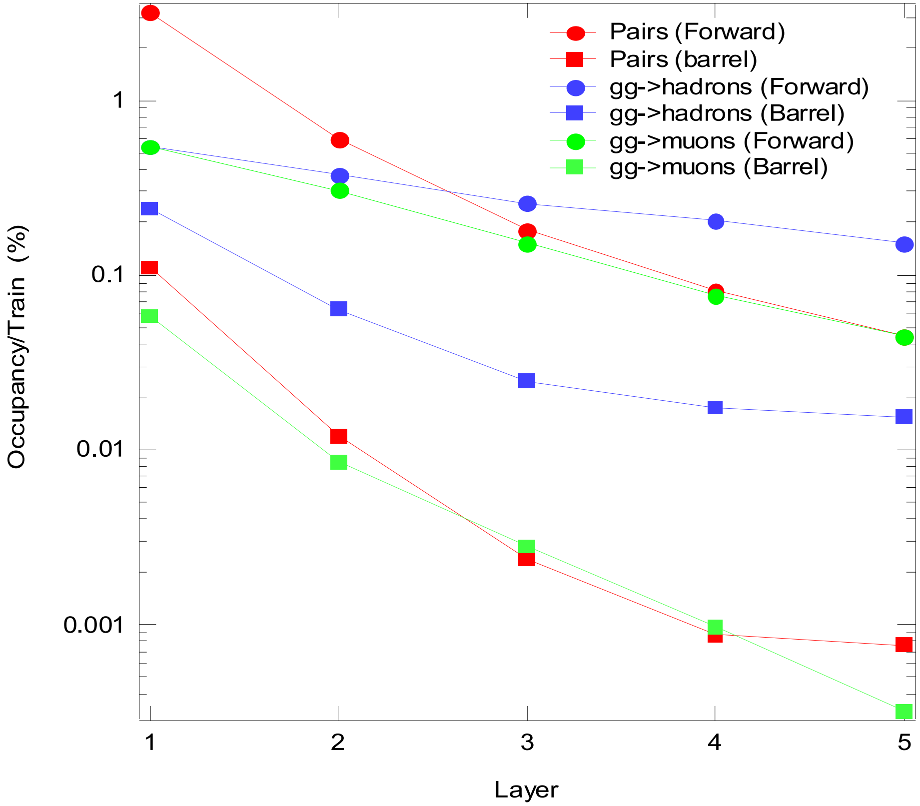
56 had events

New result – T.Barklow
SLAC/ALCPG

SiD - Tracker Issues

- Charged particle occupancies

- Worst backgrounds - pairs and $\gamma\gamma$ -> hadrons <1%



- Photon conversion occupancies low ~0.1 - 0.4%

(John Jaros - talk at this meeting)

SiD - Tracker Design

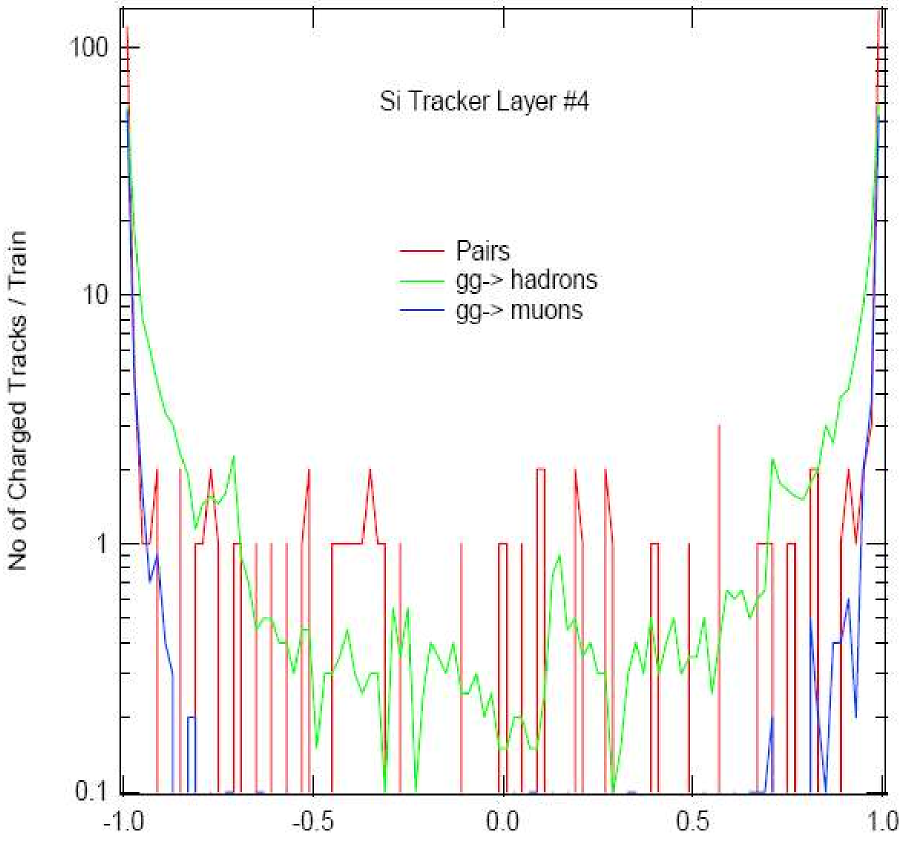
- Track Occupancies/train

- Barrel #tracks ~ physics

- Forward – higher occupancies

- What will the actual machine backgrounds be?

- Expect CCD/VXD + Barrel pattern recognition to be OK.



SiD - Tracker Design

- Can timing be used to associate hits with bunch crossings within train?

  -> prospect of significantly reduced track occupancies with timing information.

  -> simplify forward tracking with timing (+ radial subdivision of forward layers?)

- Use ECal Si timing also?? 30 layers

SiD - Tracker - Pattern Recognition

- study by Steve Wagner (SLAC)

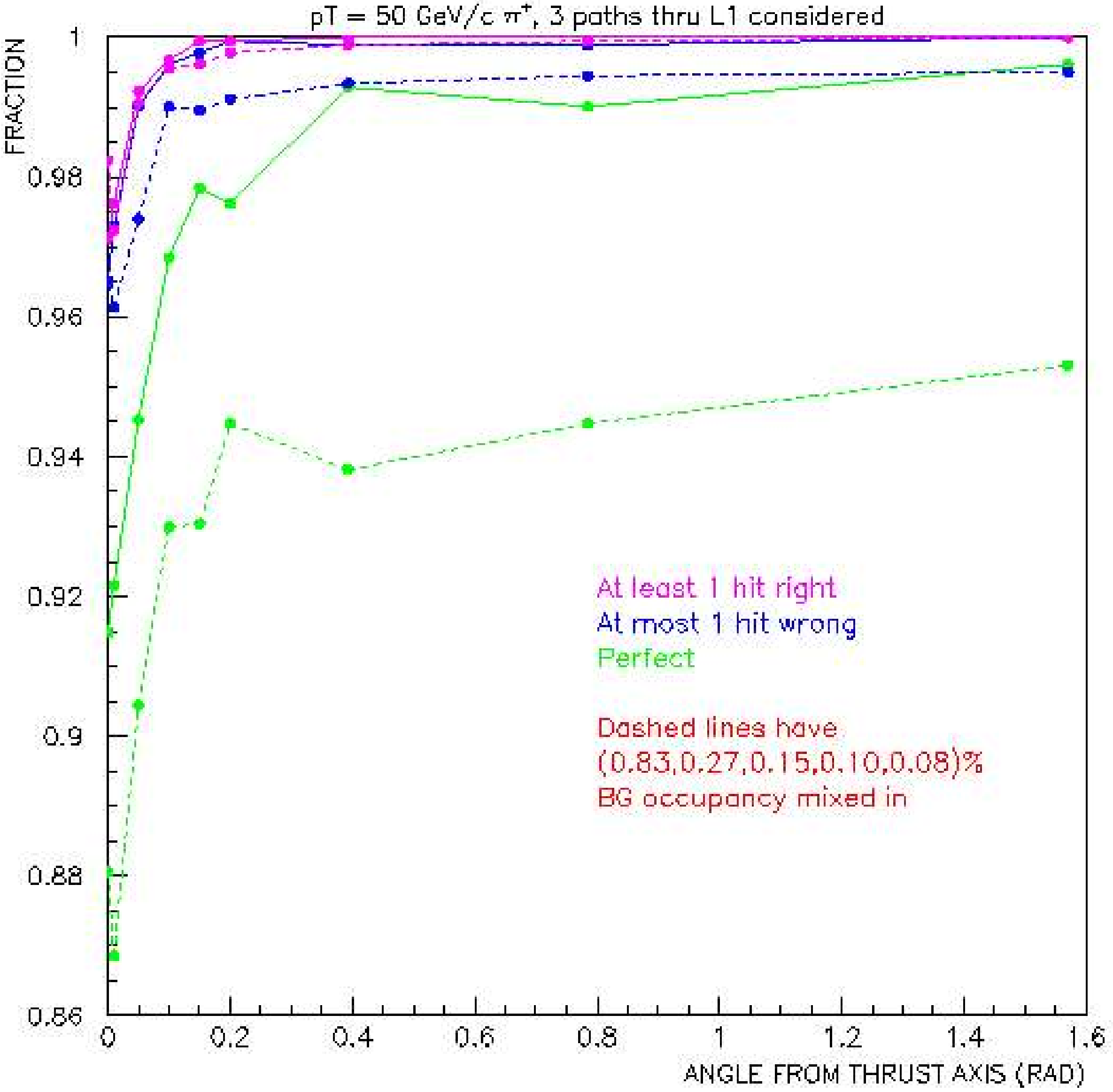
- use VXD hits -> project to tracker, include hits, refit, and iterate

- explore success of finding correct hits on probe track – including √s =500 GeV q qbar events, then add full backgrounds

- look at fraction of tracks with 5 hits, 4 hits, etc. found as a function of the angle between the probe track and the Thrust axis of jet

- then add "tiling" of barrel tracker -> essentially recover pre-background performance … and still have timing to add as further improvement…

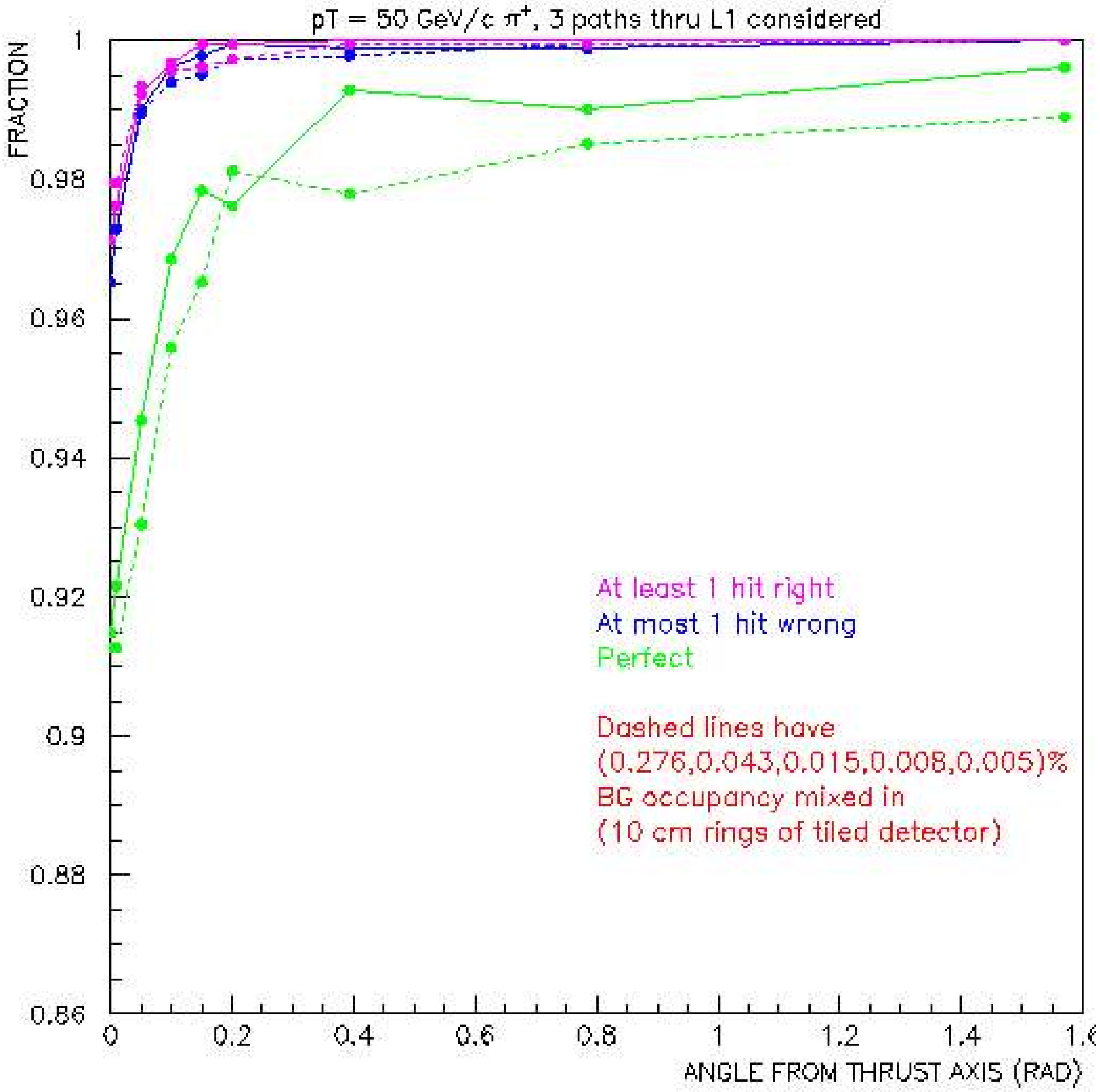
50 GeV/c probe track, with q qbar event and all backgrounds



Mainly photons ($\gamma\gamma$, pairs only significant for L1 in tracker)

50 GeV/c probe track, with q qbar event and all backgrounds

Improvement with tracker “tiling”



HCAL Requirements

Physics requirements emphasize segmentation/granularity (transverse AND longitudinal) over intrinsic energy resolution.

- Depth $\geq 4\lambda$ (not including ECal ~ 1λ)

-Assuming EFlow:

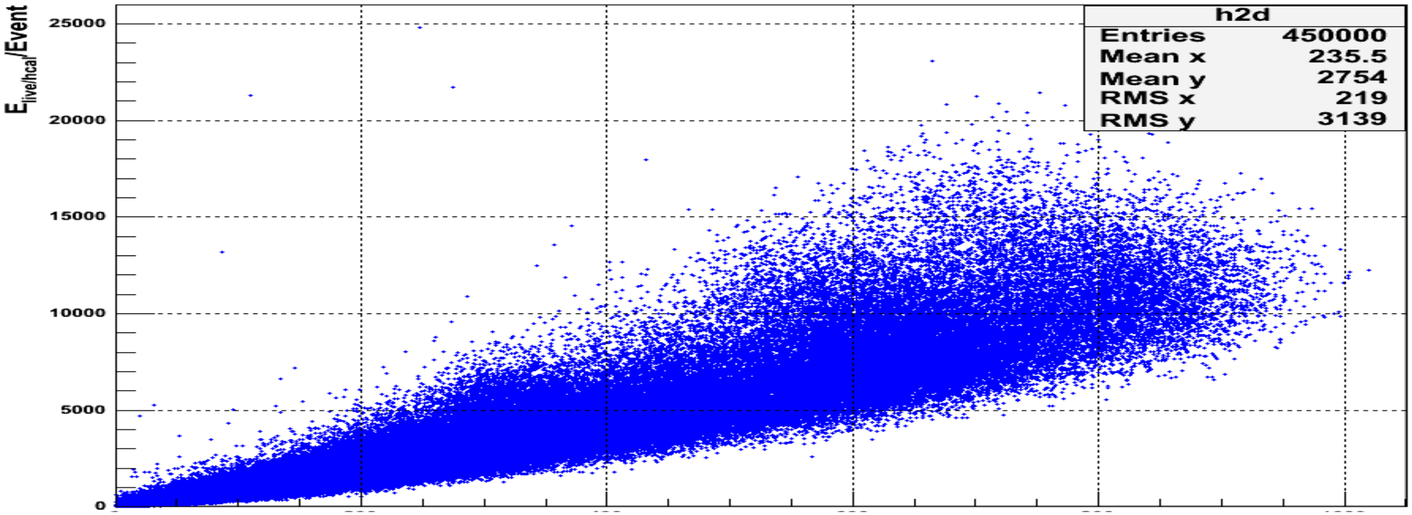
- sufficient segmentation to allow efficient charged particle tracking.

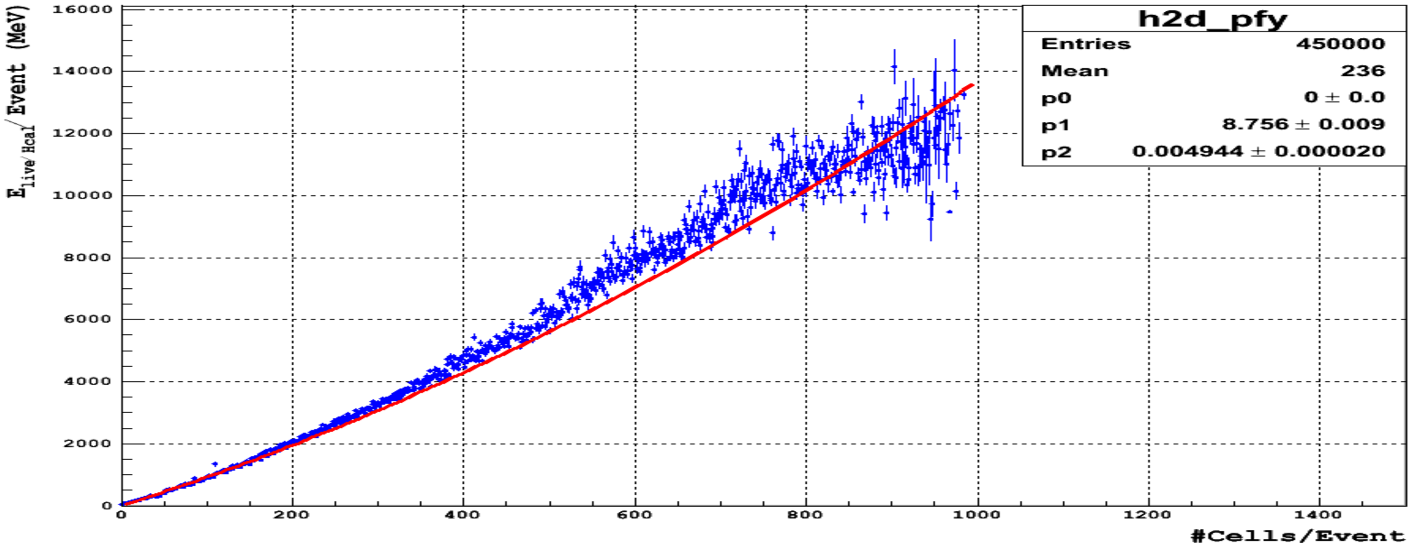
- for "digital" approach – sufficiently fine segmentation to give linear energy vs. hits relation

- efficient MIP detection

- intrinsic, single (neutral) hadron energy resolution must not degrade jet energy resolution.

Digital calorimetry – counting cells





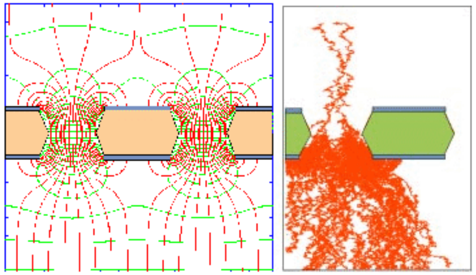
SiD - Hadronic Calorimeter

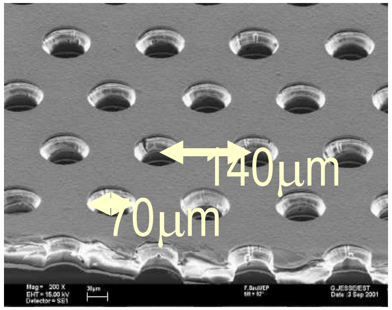
- Requirements for efficient EFlow implementation in a digital HCal:

  - high hit efficiency/layer
  - low cross-talk/hit
  - fine granularity
  - time resolution?

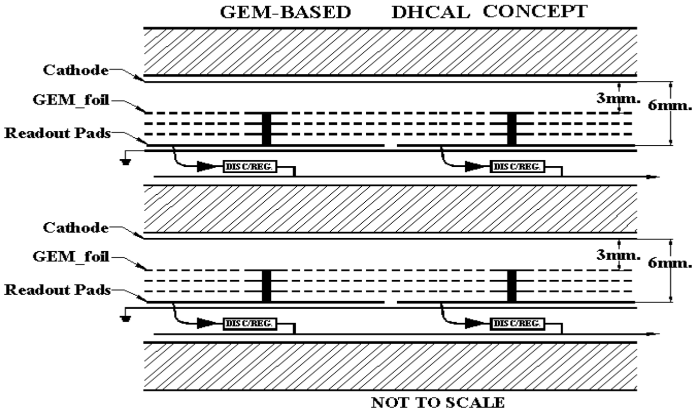
DHCAL using GEM technology

GEM – a flexible technology – ideal for high degree of segmentation

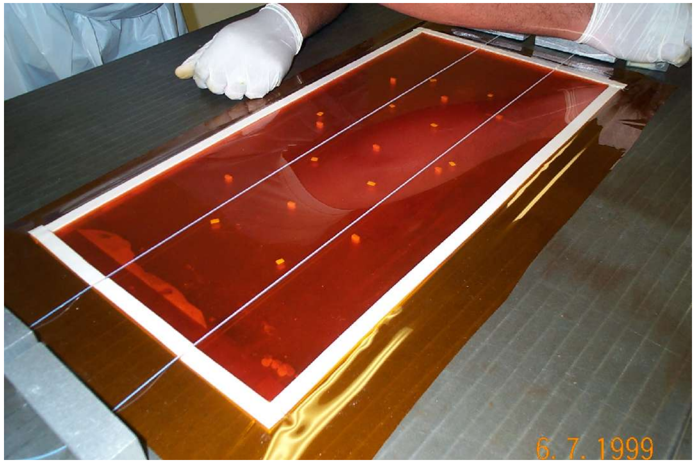


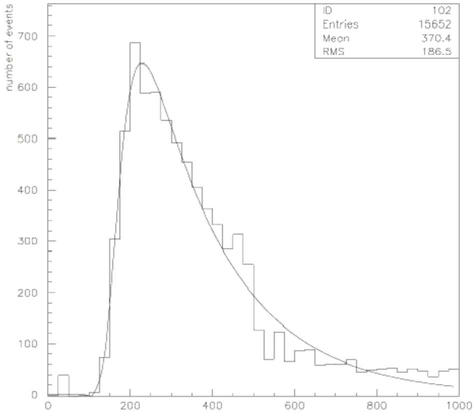


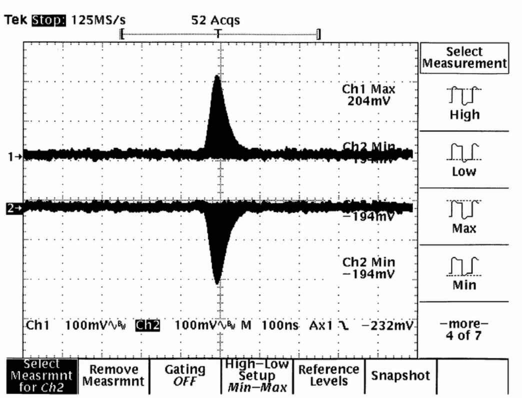
Develop DHCAL GEM design



Prototype GEM layer







Signal Amplitude (mV)

University of Texas at Arlington

DHCAL with Resistive Plate Chambers

Argonne National Laboratory
Boston University
University of Chicago
Fermilab
IHEP Protvino, Russia
(KEK, Japan)

Goal: construction of 1 m^3 prototype section

→ validate technology
→ detailed measurements of hadronic showers
→ validate MC simulation

Resistive Plate Chambers

- **Suited for DHCAL**

  - Simple and flexible technology
  - Cheap: all materials commercially available
  - Reliable: no ageing problems ever observed with glass as resistive plates ☺
  - Thin: detectors with t < 10 mm feasible
  - Readout can be segmented into small pads: of order 1 cm^2

- **R&D so far** (in U.S.)

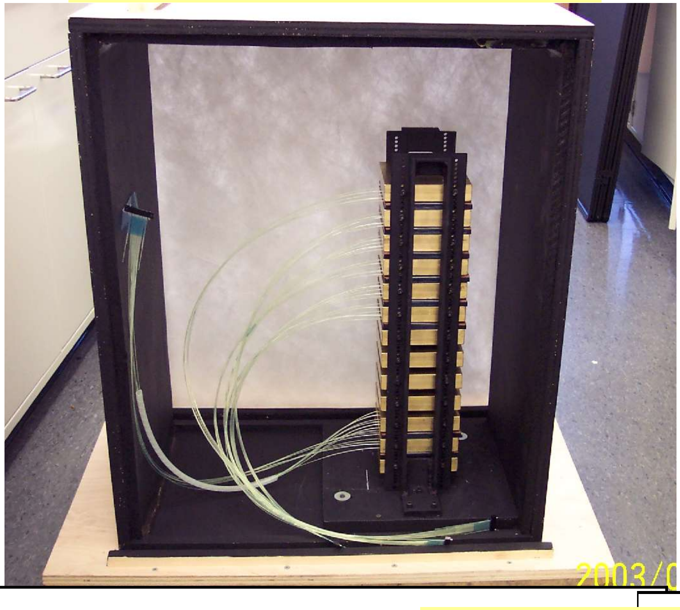
  - Built four chambers
  - Extensive tests with single pads
  - Extensive tests with multiple pads
  - Measurements with different gases
  - Measurements of geometrical acceptance
  - Design of larger chambers well advanced

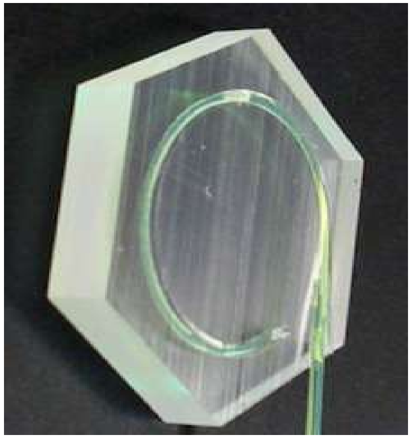
Developed expertise in RPC technology

Chamber design for prototype section almost complete

Tile/fiber HCal

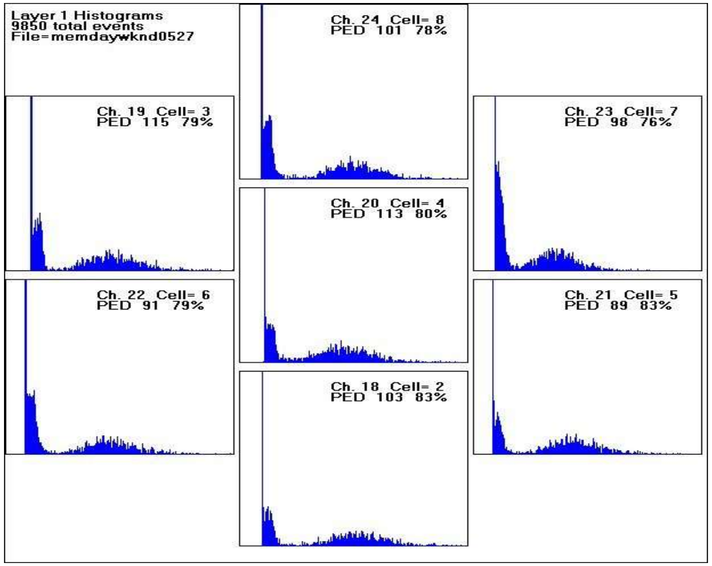
NIU 84 ch.Layer Stack

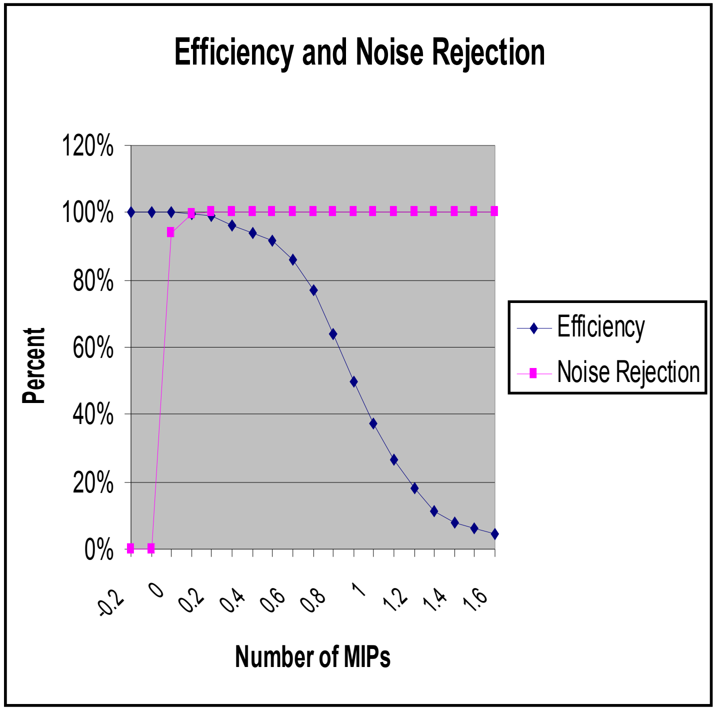




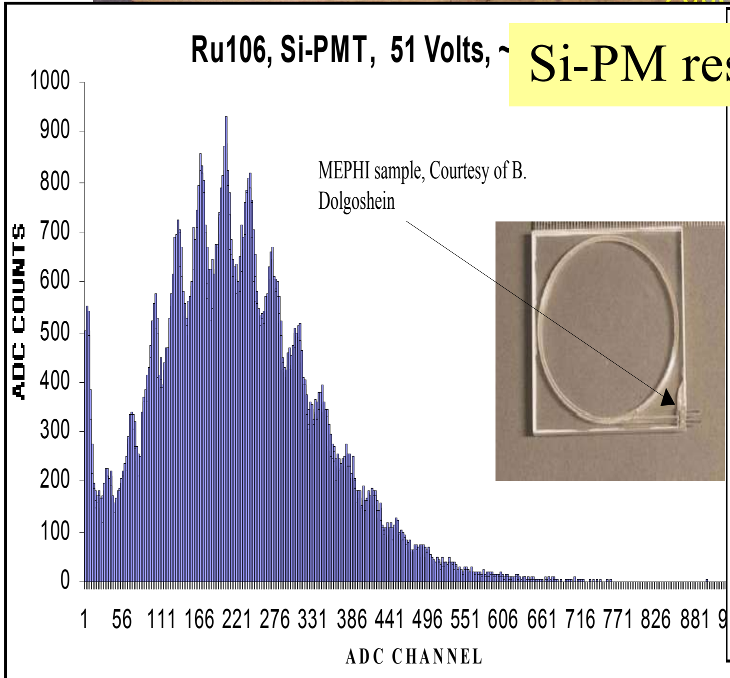
>10 p.e. for both PMT and Si-PM

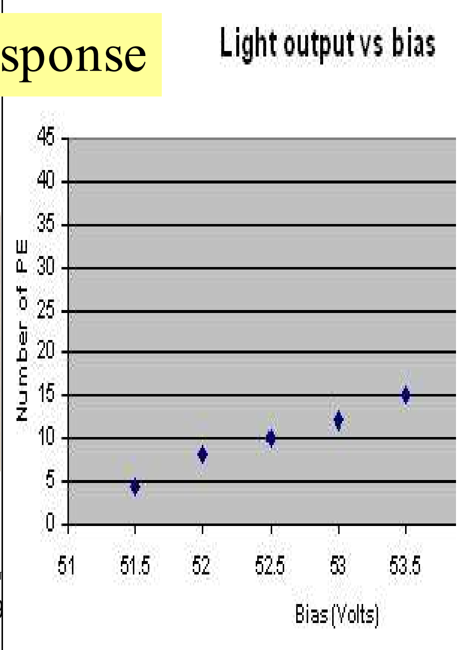
PMT Response





Si-PM response





SiD - Muon System

- Issues: Muon i.d. and momentum determination, for full range of Pt's (inc. low energy muons from e.g. SUSY decays)

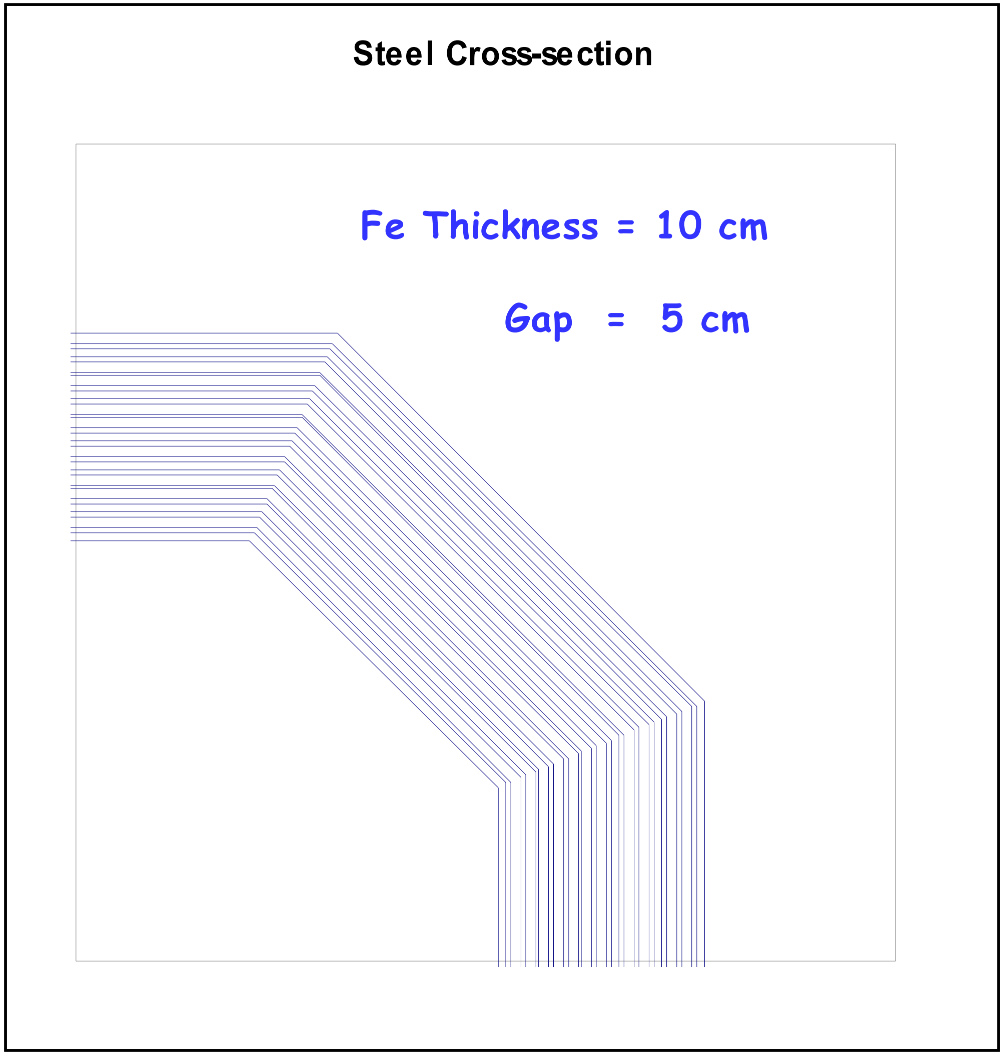
- Role of muon system as flux return/hadronic cal. tail-catcher/support structure

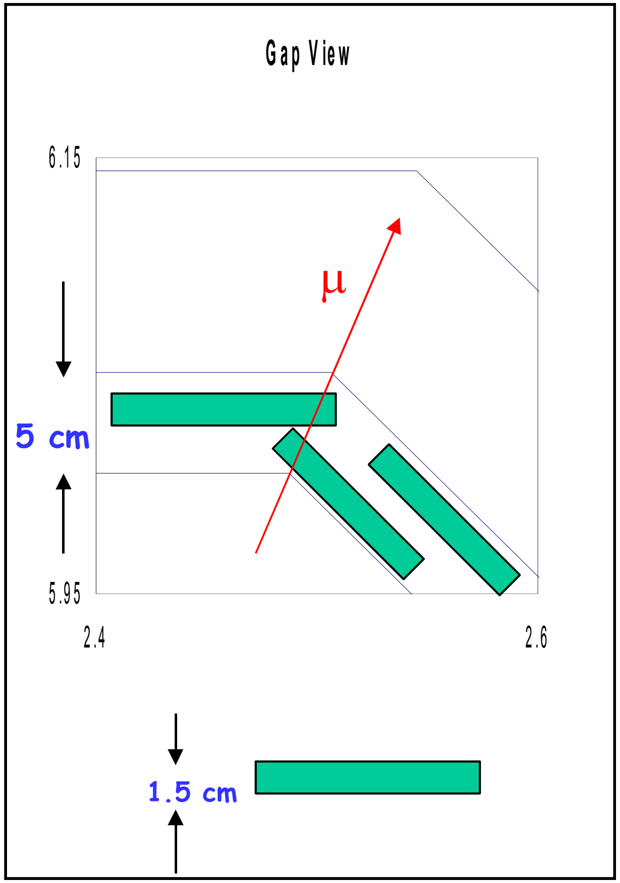
- Hit density/backgrounds in muon system?

- Interaction with e.g. digital calorimeter (tracking muons through a fine grain calorimeter)

- Choice of muon plane technology (scintillator, RPC, GEM,...)

SiD - Muon System - Layout

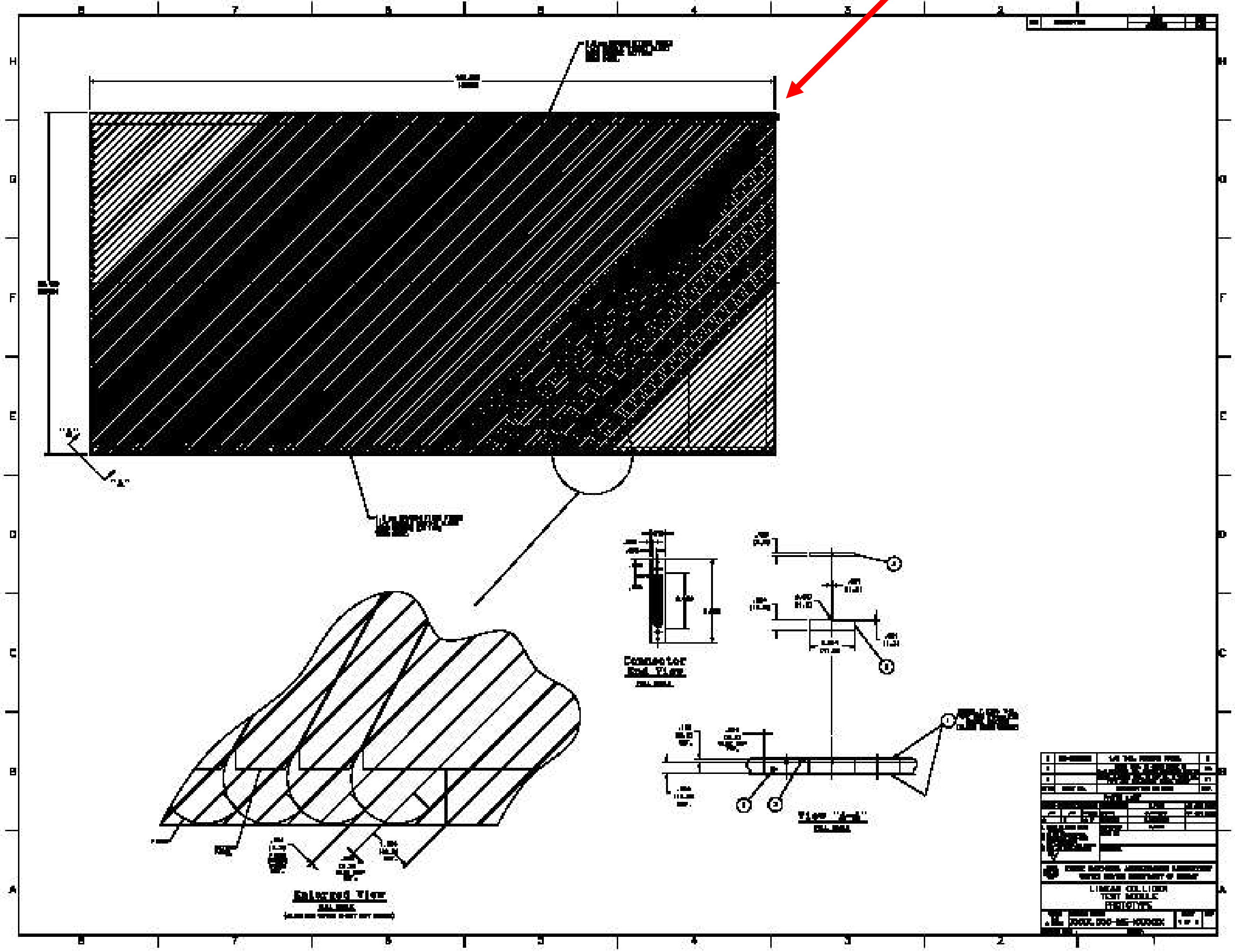




SiD - Muon System

Extruded scintillator
plus WLS fiber system

All fibers to
this corner.



SiD - Conclusions

- Overall SiD concept well established
- Exploring variations/improvements in subsystems
- Studies/prototyping supporting design goals
- Much remains to be done!

SiD - Additional Slides

Physics examples driving calorimeter design and requirements (1)

Higgs production e.g. $e^+e^- \rightarrow Z\,h$ ← Missing mass peak or bbar jets

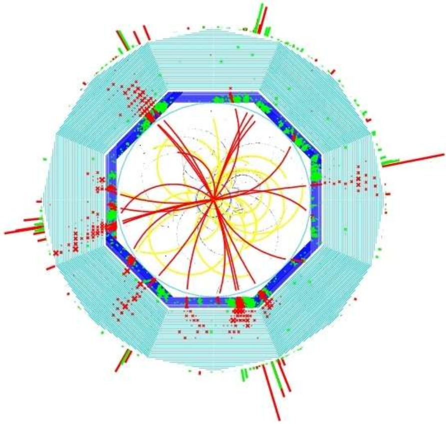
separate from WW, ZZ (in all jet modes)

Higgs couplings e.g.

- g_{tth} from $e^+e^- \rightarrow tth \rightarrow WWbbbb \rightarrow qqqqbbbb$!

- g_{hhh} from $e^+e^- \rightarrow Zhh$

Zhh→qqbbbb



Higgs branching ratios $h \rightarrow bb$, WW^*, cc, gg, $\tau\tau$

(all demand efficient jet reconstruction/separation and excellent jet energy + jet-jet mass resolution)

Physics examples driving calorimeter design and requirements (2)

Strong WW scattering:

separation of e^+e^- -> $\nu\nu WW$ -> $\nu\nu qqqq$

e^+e^- -> $\nu\nu ZZ$ -> $\nu\nu qqqq$

and e^+e^- -> $\nu\nu tt$

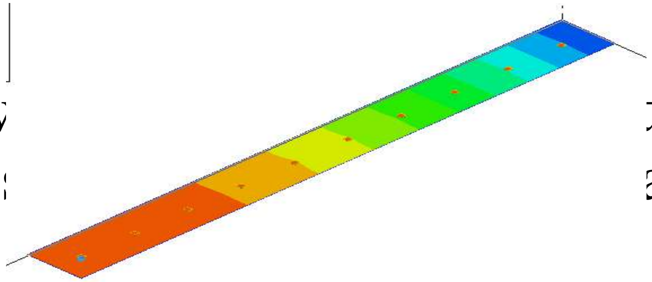
(no beam constraint)

Supersymmetry:

e.g. gauge-mediated SUSY with long-lived NLSP -> γG requiring good measurement of photon(s) from secondary vertices.

Thermal Management

- Cooling is a fundamental problem: GLAST system is ~2 mW/channel. Assume 1000 pixels/wafer and power pulsing duty factor for NLC of **10^{-3}** (10 μsec @120 Hz), for 2 mW average power. Preliminary engineering indicates goal of under 100 mW ok.
- Assume fixed temperature heat sink (water cooling) at outer edge of an octant, and conduction through a ~1 mm thick Cu plane sandwiched with the W and G10: $\Delta T \sim 20^{0}C$.



- OK, but need pov aining the
  noise/resolution i allenge.