Linear Collider Detector

- Silicon Detector
  - Motivation
  - Simulation
  - Description
  - Status

LC Detector Requirements

- a) Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states.
- b) Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks).
- c) Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread .
- d) Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum.
- e) Timing resolution capable of separating bunch-crossings to suppress overlapping of events .

Detector Response Simulation

- Flexible software framework to study performance as a function of R_{cal}, $\vec{B}$, etc.
- Inclusion of beamline elements, masks,…
  - All backgrounds included (machine, physics,…)
- Better detector modelling:
  - Real geometries, support material, etc.
- Improved simulation of detector response
  - digitization, merged hits, "ghost" hits, eff's

SLAC Simulations Group: N. Graf,
G. Bower,T. Behnke, R. Cassell, A. Johnson

Detector Response Simulation II

- Determine detector response as a function of basic parameters → "slopes".
- Use SD as pivot point from which to extrapolate.
- Systematic understanding of the complete detector.
- *Ab initio* reconstruction:
  - Track finding & fitting, calorimeter cluster reconstruction from realistic detector hits.

International Collaboration

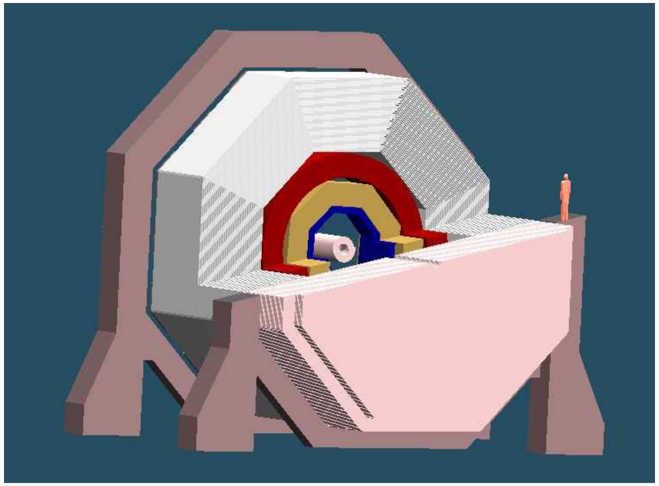
- Both simulation environments can now model the other's detectors in Geant4.
- European and American efforts have converged on common MC data I/O format.
  - Allows swapping of detectors.
- Aiming for common reconstruction environment and output format.
  - Direct reconstruction comparison, code sharing!

SD (Silicon Detector)

- Conceived as a high performance detector for NLC
- Reasonably uncompromised performance

But

- Constrained & Rational cost

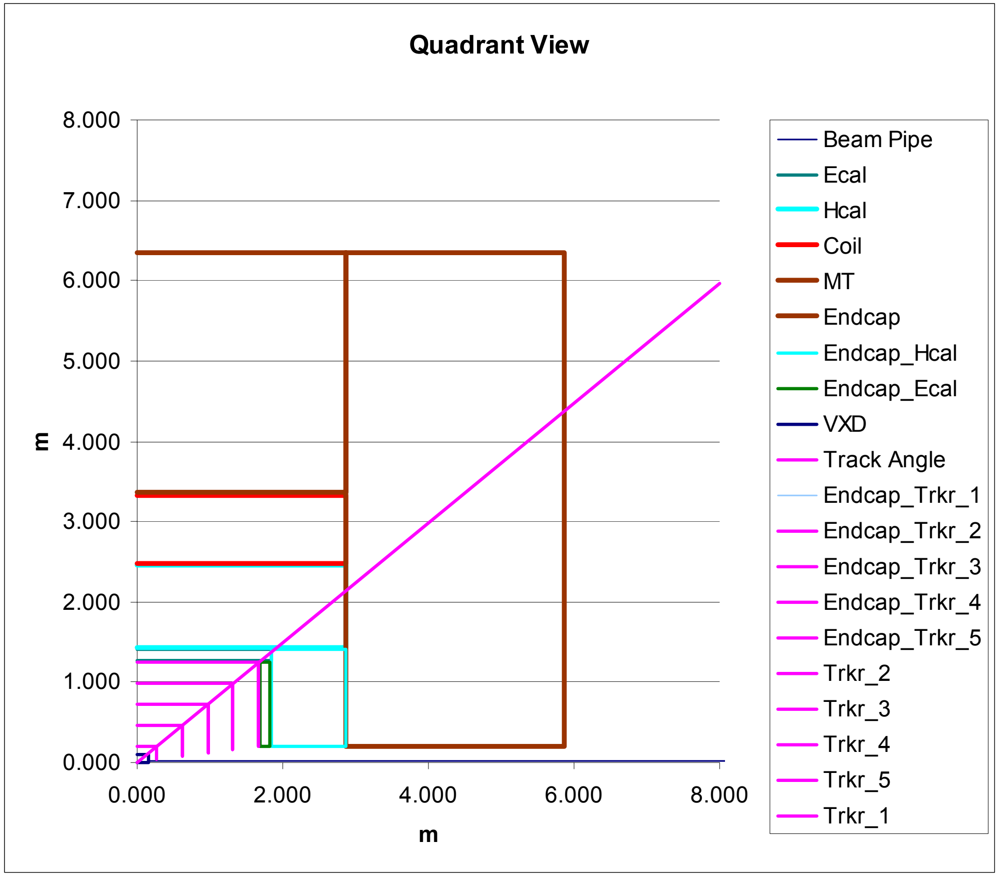


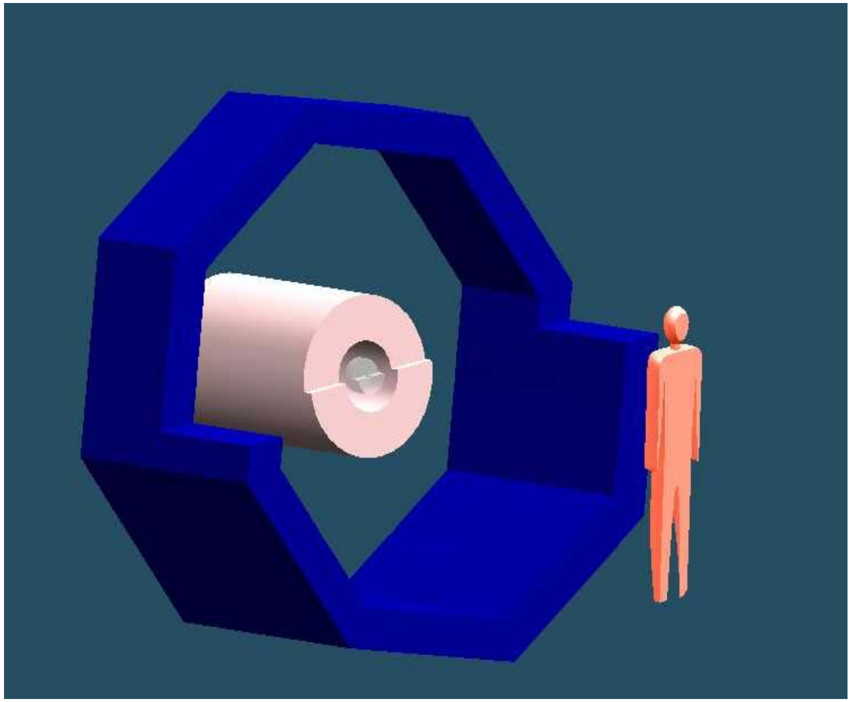
- *Accept* the notion that excellent energy flow calorimetry is required, and explore optimization of a Tungsten-Silicon EMCal and the implications for the detector architecture…

Architecture arguments

- Silicon is expensive, so limit area by limiting radius
- Get back BR^2 by pushing B (~5T)
  - *This argument may be weak, considering quantitative cost trade-offs. (see plots)*
- Maintain tracking resolution by using silicon strips
- Buy safety margin for VXD with the 5T B-field.
- Keep (?) track finding by using 5 VXD space points to determine track – tracker measures sagitta.

SD Configuration





Scale of EMCal
& Vertex Detector

Vertex Detectors

- Design CCD's for
  - Optimal shape ~2 x 12 cm
  - Multiple (~20) ReadOut nodes for fast readout
  - Thin -≤ 100 μ
  - Improved radiation hardness
  - Low power
- Readout ASIC
  - No connectors, cables, output to F.O.
  - High reliability
  - Increased RO speed from SLD VXD3
  - Lower power than SLD VXD3

Vertex Detectors, continued

- Mechanical
  - Eliminate CCD supports, “stretch” Si.
  - Very thin beampipes??
  - Cooling
- Simulation
  - Quantify/justify needs
- SLD VXD3 has been removed from SLD for damage analysis of CCD’s.

Silicon Tracker

- SLC/SLD Prejudice: Silicon is robust against machine mishaps; wires & gas are not.
- SD as a *system* should have superb track finding:
  - 5 layers of higly pixellated CCD's
  - 5 layers of Si strips, outer layer measures 2 coordinates
  - EMCal provides extra tracking for Vee finding - ~1mm resolution!

- Mechanical:
  - Low mass C-Fiber support structure
  - Chirped Interferometry Geodesy (Oxford System) Atlas has developed a beautiful chirped interferometric alignment system – a full geodetic grid tieing together the elements of their tracker. Can such a system reduce requirements on the space frame precision and stability – reducing its mass and cost?

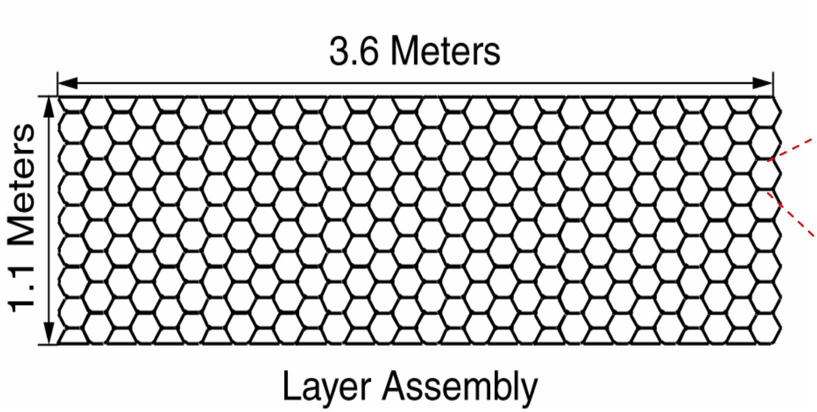
Tracker, continued

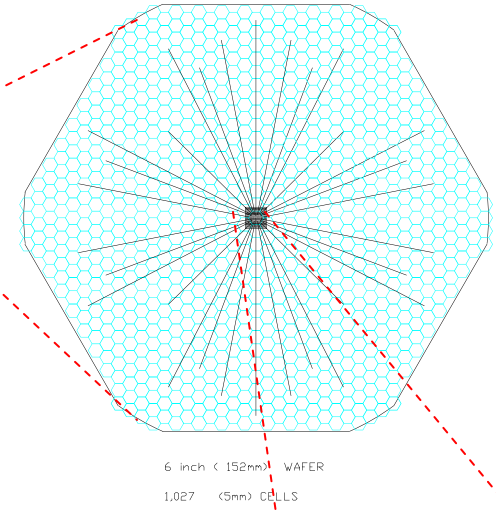
- Silicon Development
  - Build on GLAST development,
    - Utilize GLAST detector style w bond pads on both ends, and
    - Develop special ladder end detector w bump bond array
    - Reduce mass, complexity at ends
  - Tracker Electronics Architecture:
    - Plan is to string 10 cm square detectors to barrel half lengths and readout from ends.
    - Design "end" detectors to route strips to rectangular grid for bump bonding to read out chip (ROC).
    - ROC is ASIC with all preamplification, shaping, discrimination, compression, and transmission functionality. Includes power pulsing.
    - Hasn't been done!
    - Electronics:
      - Develop RO for half ladder (~1.5 m)

Silicon Tungsten EMCal

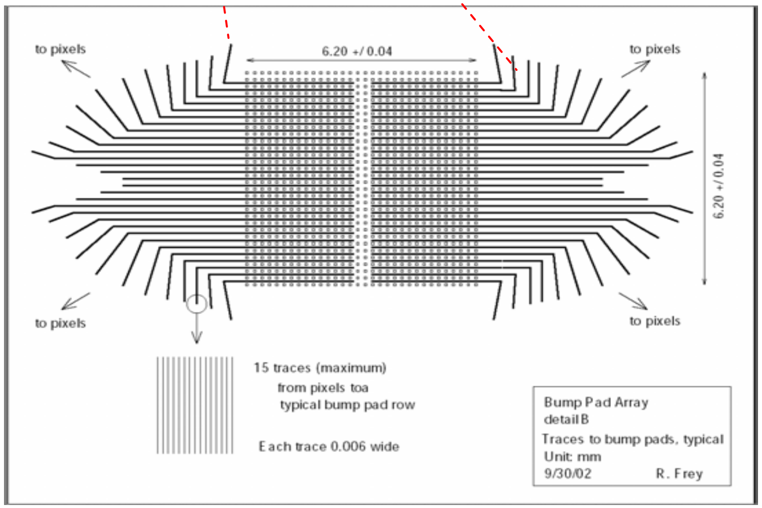
- Figure of merit something like BR^2/σ,
  - where $\sigma = r_{pixel} \oplus r_{Moliere}$
- Maintain the great Moliere radius of tungsten (9 mm) by minimizing the gaps between ~2.5 mm tungsten plates. Dilution is $(1+R_{gap}/R_w)$
  - Could a layer of silicon/support/readout etc. fit in a 2.5 mm gap? (Very Likely)
  - Even less?? 1.5 mm goal?? (Dubious)
- Requires *aggressive* electronic-mechanical integration!

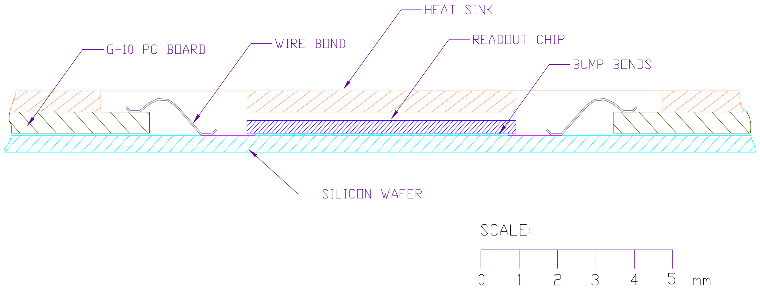
Structure



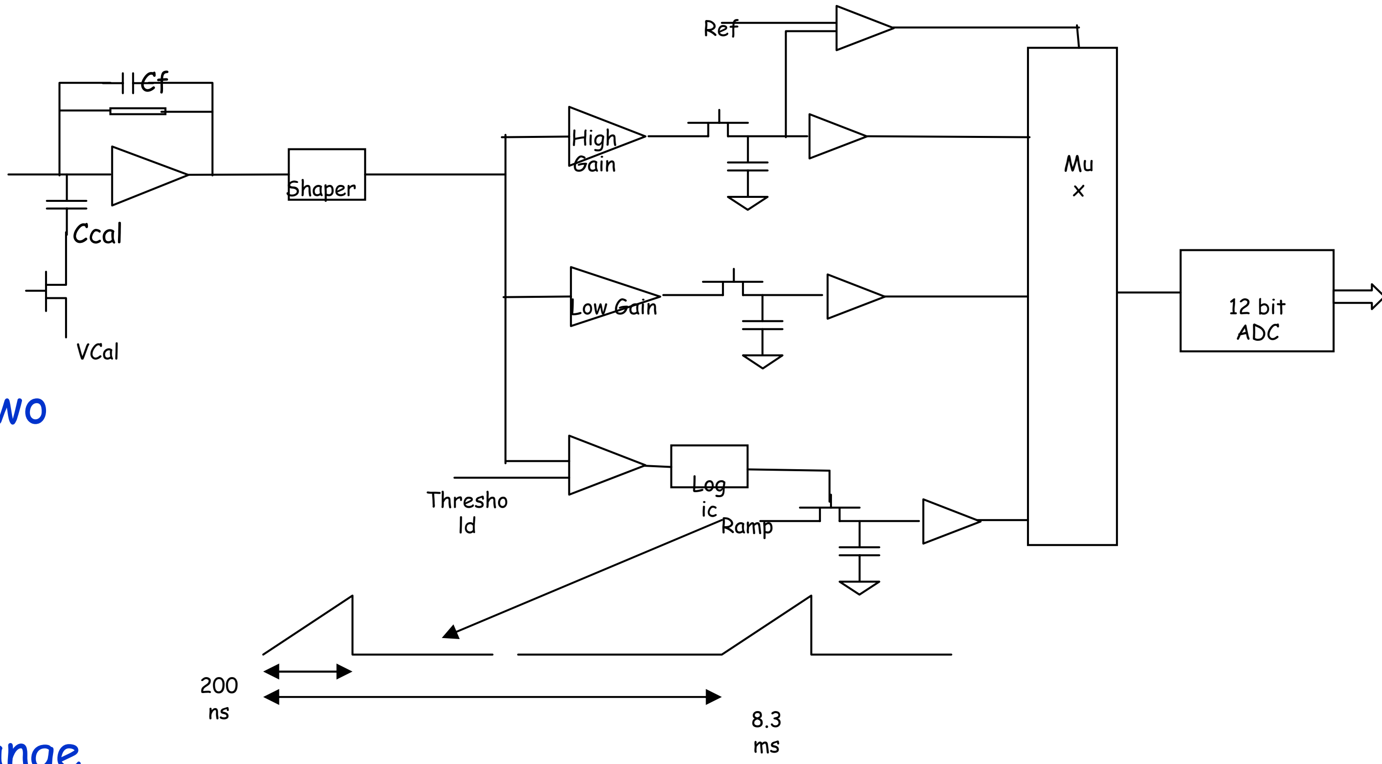


Pixels on 6" Wafer





Electronics Architecture



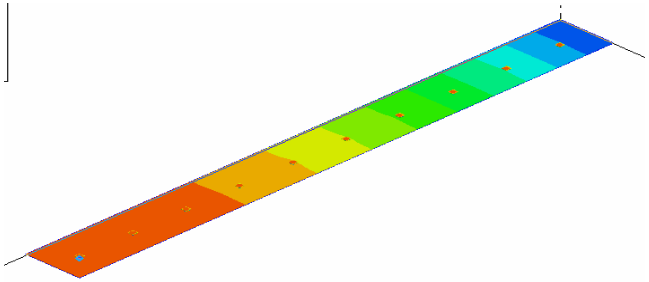
Charge amplifier and shaper followed by two amplifiers with gains G1,G2 and sample & holds.

Comparator logic to select appropriate range Mux and 12 bit ADC

Studying options for timing…

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: $\Delta T \sim 14^0 C$.

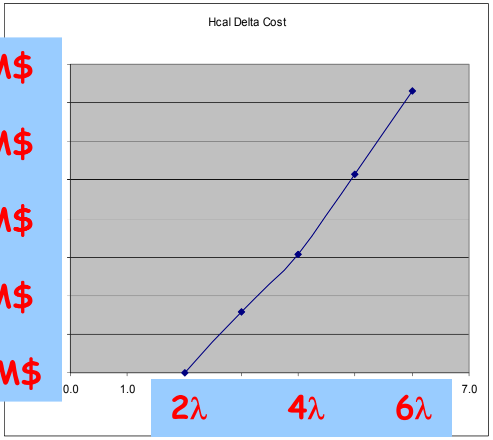


- OK, but need power pulsing!!! ..and maintaining the noise/resolution is a serious engineering challenge.

HCal

- Hcal assumed to be 4 λ thick, with 46 layers 5 cm thick alternating with 1.5 cm gaps.
- Prefer "digital" detectors, eg high reliability RPC's (Have they been invented yet???) Probably glass RPC.
- Hcal radiator non-magnetic metal – probably copper or stainless
  - Tungsten much too expensive
  - Lead possible, but mechanically more painful.
- Hcal thickness important cost driver, even though Hcal cost small. And where is it relative to coil?

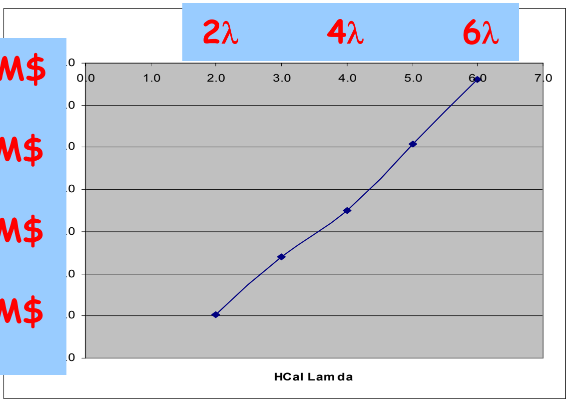
HCal Location Comparison



80 M$
60 M$
40 M$
20 M$
0 M$

2λ 4λ 6λ

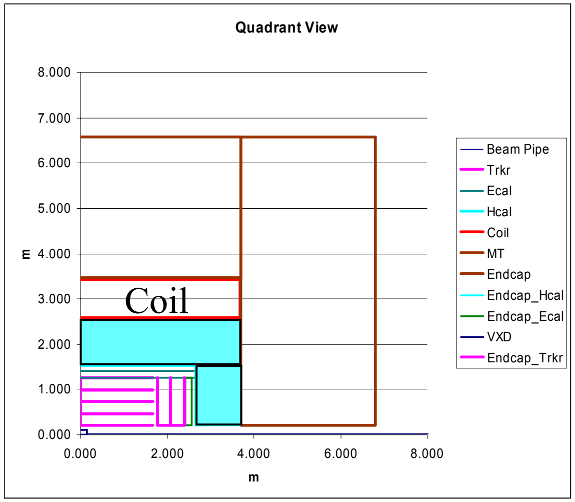
Scale - Relative to 4 λ Inside!!

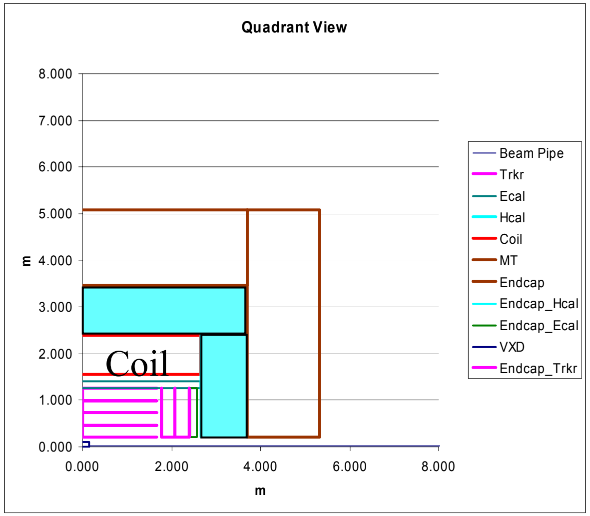


2λ 4λ 6λ

0 M$
-10 M$
-20 M$
-30 M$

Hcal
inside
coil



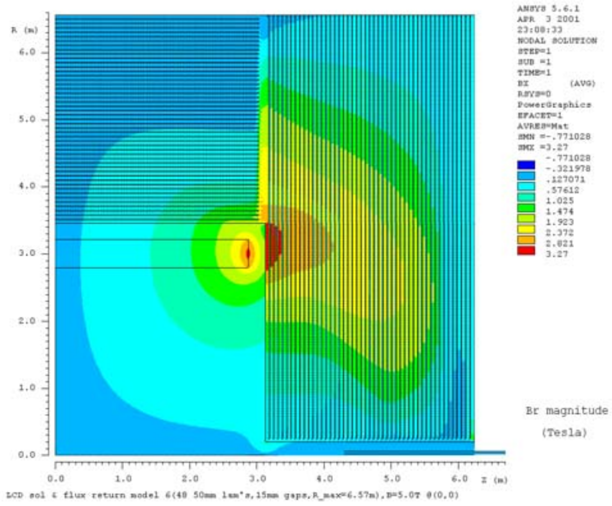


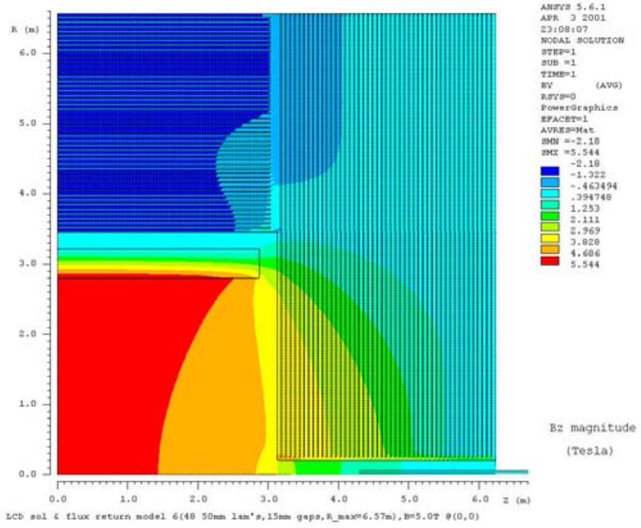
HCAL
outside
coil

Coil and Iron

- Solenoid field is 5T – 3 times the field from detector coils that have been used in the detectors. - CMS will be 4T.
- Coil concept based on CMS 4T design. 4 layers of superconductor about 72 x 22 mm, with pure aluminum stabilizer and aluminum alloy structure.
- Coil Δr about 85 cm
- Stored energy about 1.5 GJ (for Tracker Cone design, R_Trkr=1.25m, $\cos\theta_{barrel}$=0.8). (TESLA is about 2.4 GJ) [Aleph is largest existing coil at 130 MJ]

B_r



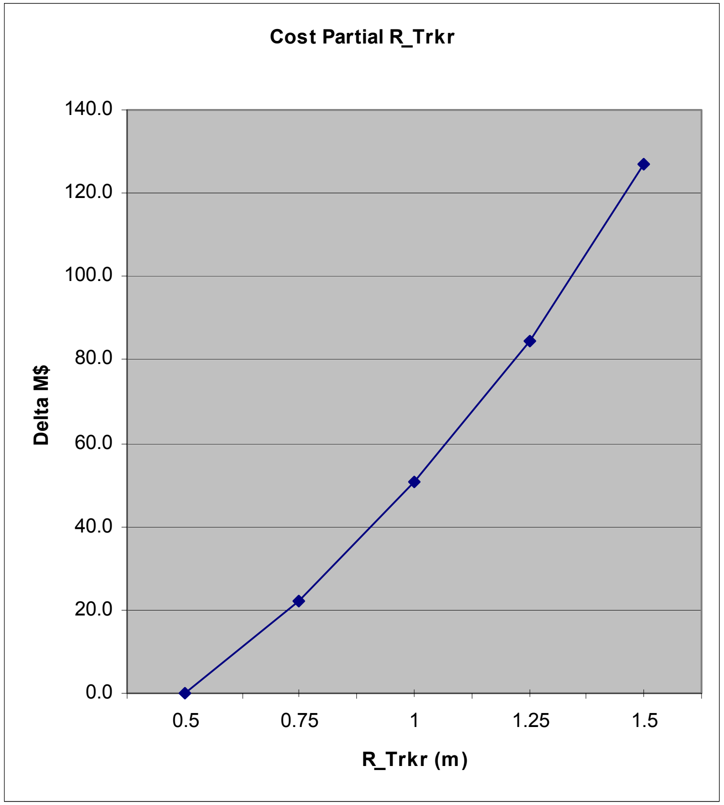


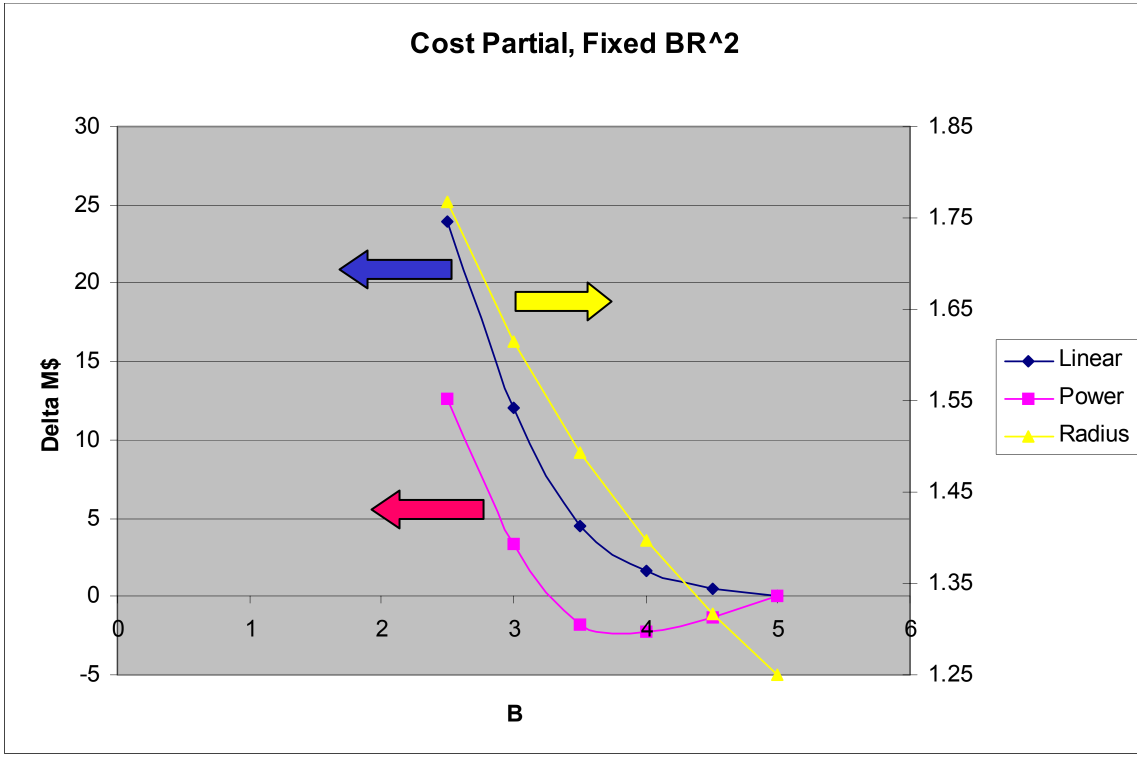
B_z

Flux Return/Muon Tracker

- Flux return designed to return the flux! Saturation field assumed to be 1.8 T, perhaps optimistic.
- Iron made of 5 cm slabs with 1.5 cm gaps for detectors, again “reliable” RPC’s.

More Cost trade-offs





Δ $ vs R_Trkr

~1.7M$/cm

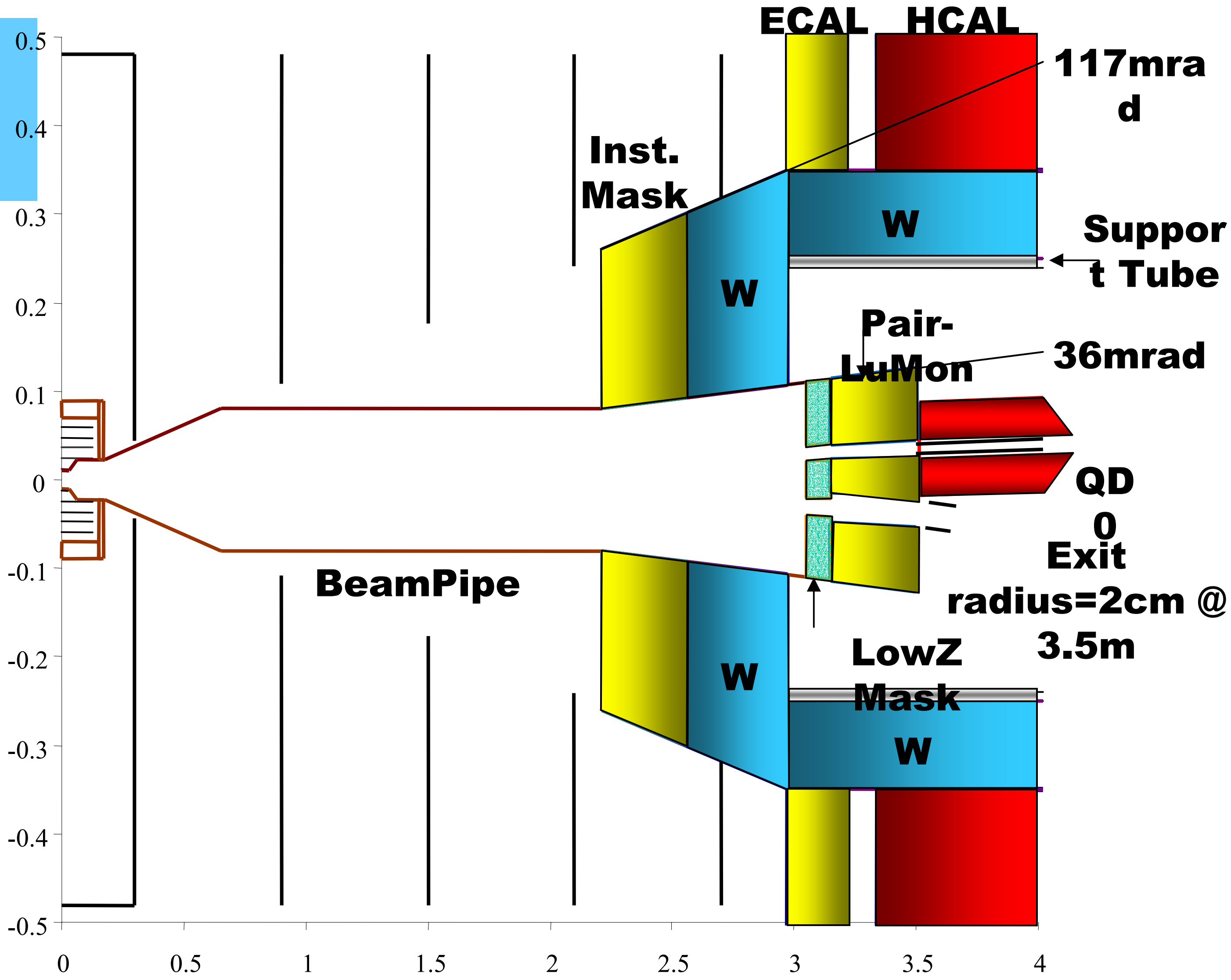
Delta $, Fixed BR^2=5x1.25^2

Beamline Instrumentation

- High Priority Items:
  - dL/dE analysis
    - complete analysis to extract both tail and core
    - understand external inputs (asymmetries, offsets)
    - possible to extract correlations (energy, polarization)?
  - Extraction line studies
    - expected distributions with disrupted beam
    - expected backgrounds at detectors
  - Forward Tracking/Calorimetry
    - Realistic conceptual design for NLC detector
    - Expected systematics eg: alignment
  - Beam Energy Width
    - Understand precision of beam-based techniques
    - Possible with x-line WISRD?

ALCPG Beamline Instrumentation Working Group:
M. Woods /E. Torrence/D. Cinabro

Forward Detector

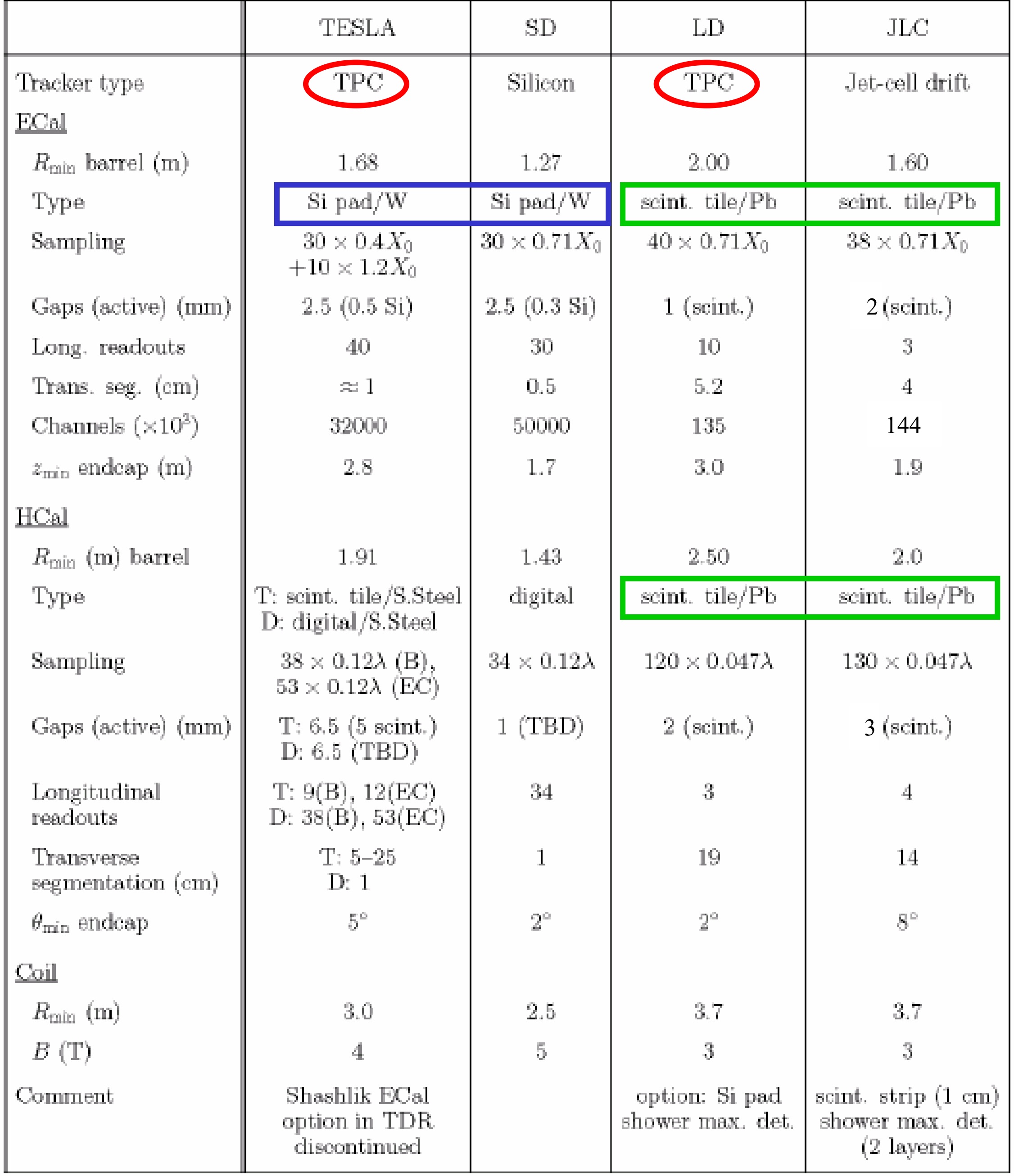


NLC Forward Masking, Calorimetry & Tracking
2003-04-01

ALCPG IR/Backgrounds Working Group:
T. Markiewicz, S. Hertzbach

Comparison of Detector Configurations

(Ray Frey)



	TESLA	SD	LD	JLC
Tracker type	TPC	Silicon	TPC	Jet-cell drift
ECal				
$R_{\rm min}$ barrel (m)	1.68	1.27	2.00	1.60
Type	Si pad/W	Si pad/W	scint. tile/Pb	scint. tile/Pb
Sampling	$30 \times 0.4 X_0$ $+10 \times 1.2 X_0$	$30 \times 0.71 X_0$	$40 \times 0.71 X_0$	$38 \times 0.71 X_0$
Gaps (active) (mm)	2.5 (0.5 Si)	2.5 (0.3 Si)	1 (scint.)	2 (scint.)
Long. readouts	40	30	10	3
Trans. seg. (cm)	≈ 1	0.5	5.2	4
Channels ($\times 10^3$)	32000	50000	135	144
$z_{\rm min}$ endcap (m)	2.8	1.7	3.0	1.9
HCal				
$R_{\rm min}$ (m) barrel	1.91	1.43	2.50	2.0
Type	T: scint. tile/S.Steel D: digital/S.Steel	digital	scint. tile/Pb	scint. tile/Pb
Sampling	$38 \times 0.12\lambda$ (B), $53 \times 0.12\lambda$ (EC)	$34 \times 0.12\lambda$	$120 \times 0.047\lambda$	$130 \times 0.047\lambda$
Gaps (active) (mm)	T: 6.5 (5 scint.) D: 6.5 (TBD)	1 (TBD)	2 (scint.)	3 (scint.)
Longitudinal readouts	T: 9(B), 12(EC) D: 38(B), 53(EC)	34	3	4
Transverse segmentation (cm)	T: 5–25 D: 1	1	19	14
$\theta_{\rm min}$ endcap	5°	2°	2°	8°
Coil				
$R_{\rm min}$ (m)	3.0	2.5	3.7	3.7
B (T)	4	5	3	3
Comment	Shashlik ECal option in TDR discontinued		option: Si pad shower max. det.	scint. strip (1 cm) shower max. det. (2 layers)

Cost Control

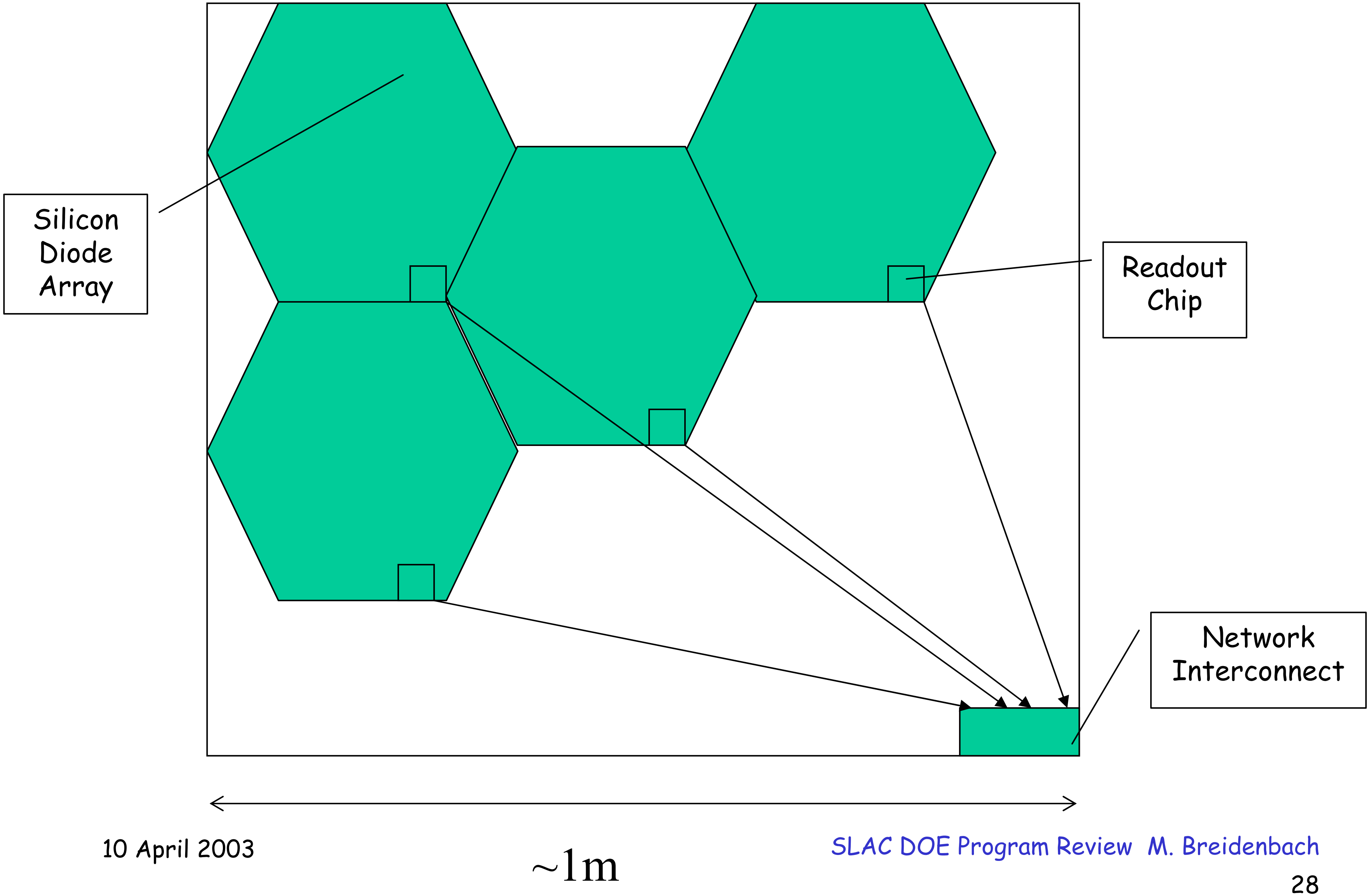
- Good sense requires cost control:
  - Detectors will get about 10% of the LC budget: 2 detectors, so $350 M each
  - We will want the most physics capability we can imagine: Great
    - Vertexing- Stretched CCD's
    - Tracking –Silicon Strips
    - B – 5T
    - EMCal – Silicon-tungsten
    - Hcal – Cu(??) – R^{2}PC
    - Muon Tracking – Fe- R^{2}PC
- Is this a sensible approach?

Status

- Serious work *beginning* at SLAC & universities.
- Document (~ old fashioned CDR) in ~2 years.

Extras

EMCal Readout Board



Luminosity, Energy, Polarization

- Beam Energy

  ΔE_{beam} ~ 200 ppm from 350 - 1000 TeV
  Upstream BPM + Downstream WISRD Spect.

  $\mu\mu\gamma$ in forward detector (~200 mRad)

- Polarization

  $\Delta P/P$ ~ 0.25% (P_e- only) $\Delta P/P$ ~ 0.10% (P_e+ also)
  Downstream Compton polarimeter
  t-channel WW scattering

- Absolute Luminosity

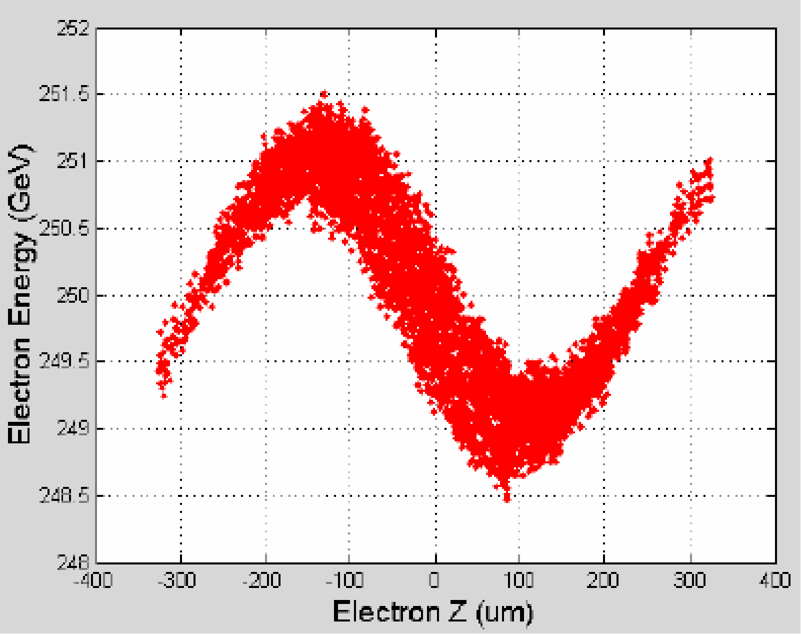
  $\Delta L/L$ ~ 0.2% (adequate, not perfect)
  Forward calorimeter around 50 - 200 mRad

- Luminosity Spectrum

  Core width to ~ 0.1%, tail level to 1%
  e^+e^- acolinearity (necessary but not sufficient!)

Strategy document just completed

Luminosity Spectrum



Acolinearity problems

- Energy, dL/dE both correlated with position along bunch.
- Measures boost, not s'
- Energy imbalance, width imbalance must be input
- Independent real-time width measurements?
- 200 uRad kicks from disruption alone (larger than target accuraccy)
- Many other offsets/degrees of freedom which must be input.

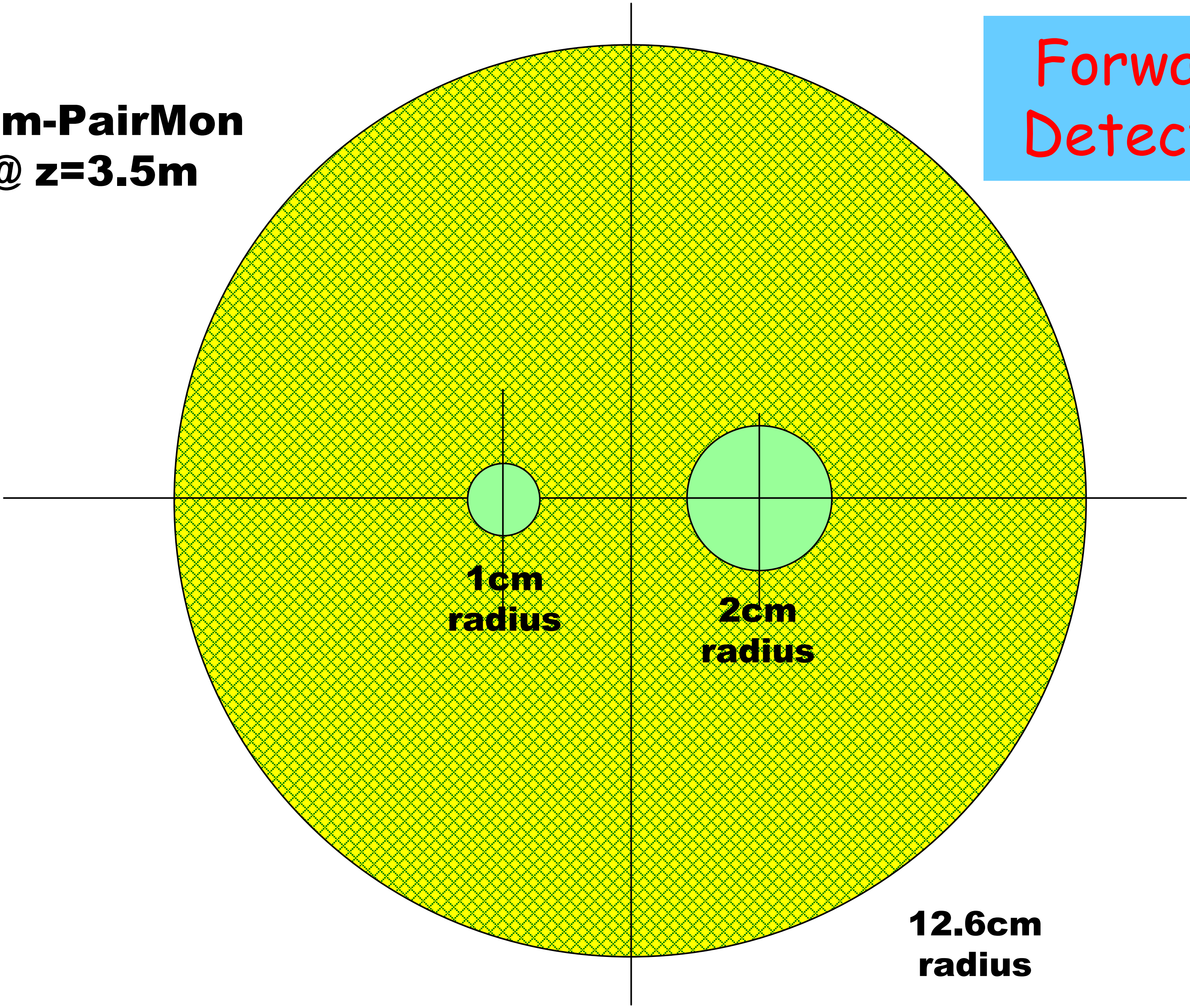
Putting together complete analysis including ‘realistic’ mis-aligned machine decks from TRC report

Beamline Instrumentation

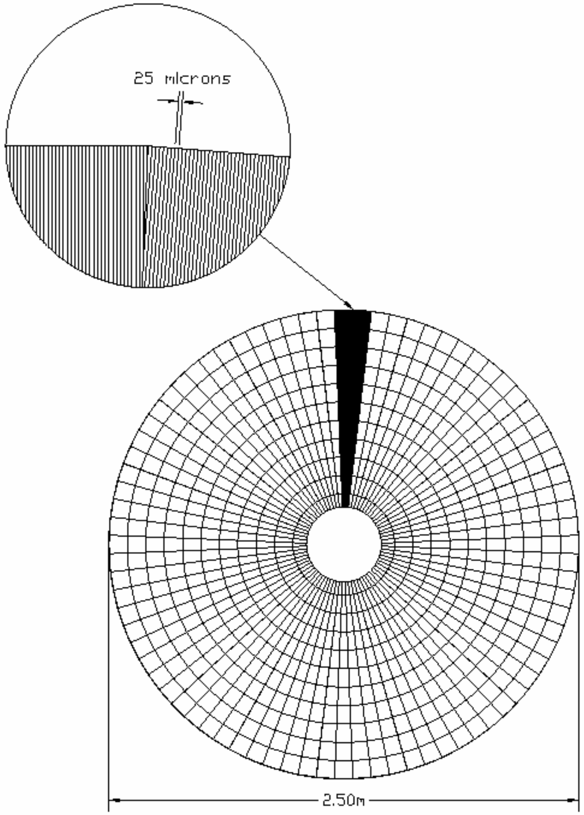
- Ongoing R&D Work:
  - Luminosity
    - dL/dE analysis (SLAC, Wayne St.)
    - Beamstrahlung Monitor (Wayne St.)
    - Pair monitor (Hawaii, in collab. with Tohoku)
    - Forward calorimeter (Iowa St.)
  - Energy
    - WISRD spectrometer (UMass, Oregon)
    - BPM spectrometer (Notre Dame)
  - Polarization
    - x-line simulations (SLAC, Tufts)
    - Quartz fiber calorimter (Iowa, Tennessee)

→ Many important topics uncovered...

Lum-PairMon
@ z=3.5m



SD Endplate Study



SD Momenter Endplate Study - Mar. 03