SD, an Introduction

- SD = 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 modeling:
  - 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
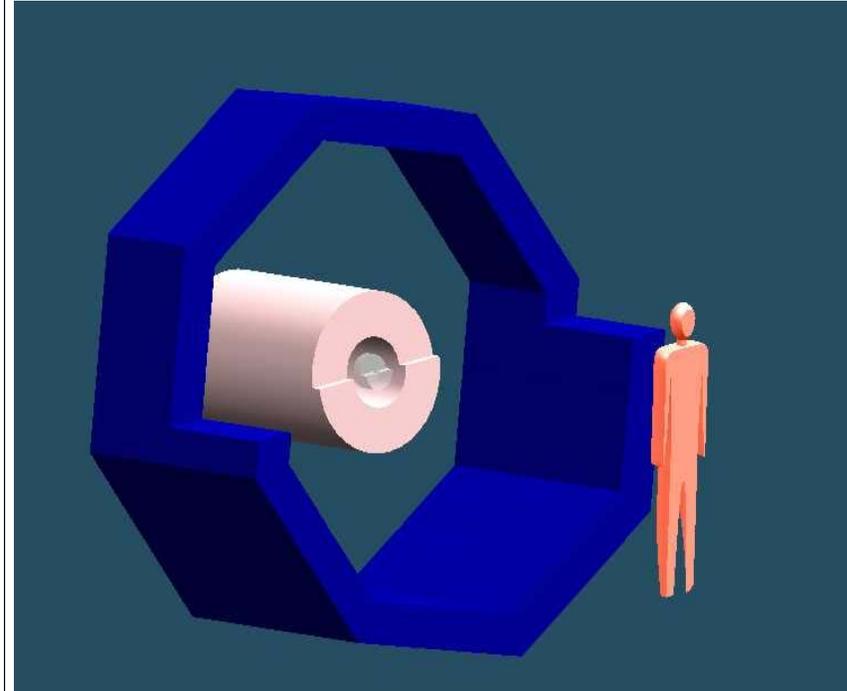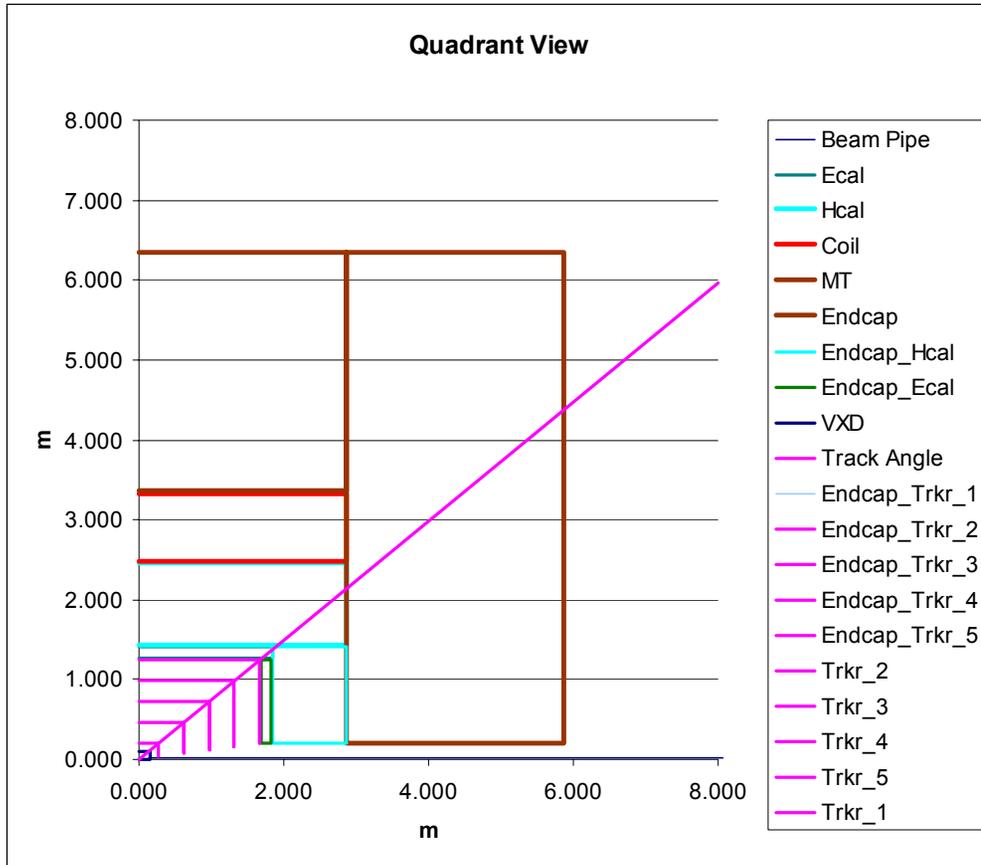- Reasonably uncompromised performance
  But
- Constrained & Rational cost
  - Detectors will get about 10%
  - of the LC budget: 2 detectors,
  - so $350 M each

- *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…
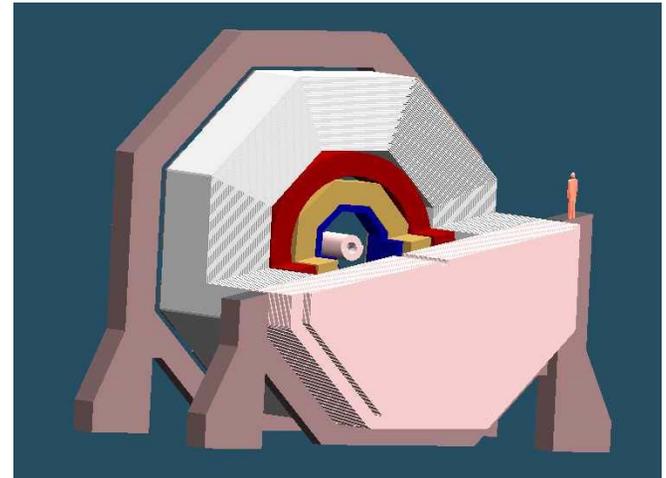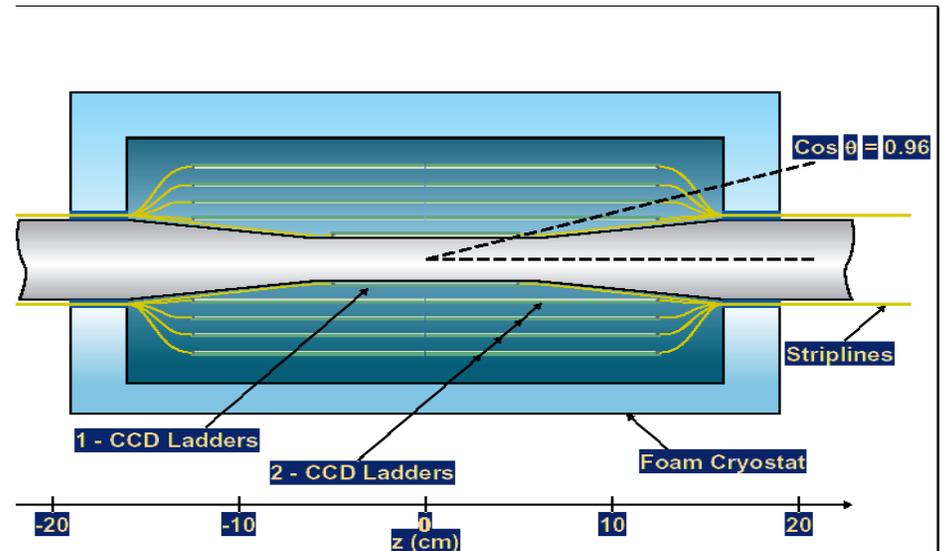
Architecture arguments

- Silicon is expensive, so limit area by limiting radius
- Get back BR^2 by pushing B (~5T)
  - *This argument is very dependent on the cost of Si, which is largely unknown for these quantities....)*
- 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

Quadrant View

Legend:
- 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

Scale of EMCal
& Vertex Detector

Vertex Detectors

- Design CCD's for
  - Optimal shape ~2 x 12 cm
  - Multiple (~18) 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
  - Detailed (preliminary) spec coming along...

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.
- Silicon should be relatively easy to commission – no td relations, easily modeled Lorentz angle, etc.
- 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. Goal is support for a 10 cm x 4 m ladder of ~125 grams!
  - 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?
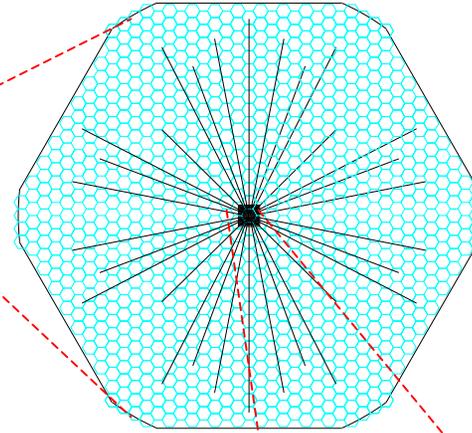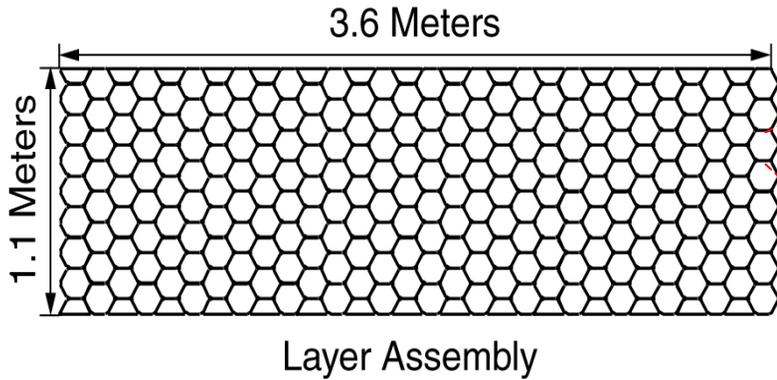
Tracker, continued

- Silicon Development
  - Build on GLAST development,
    - Utilize GLAST detector style w wire bond pads on both ends, and
    - String 10 cm square detectors to barrel half lengths and readout from ends.
    - Reduce mass, complexity at ends
  - Tracker Electronics Architecture:
    - 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!
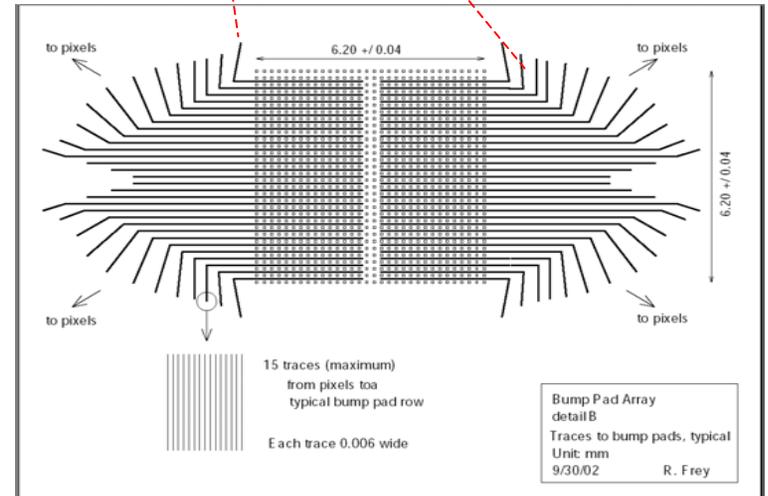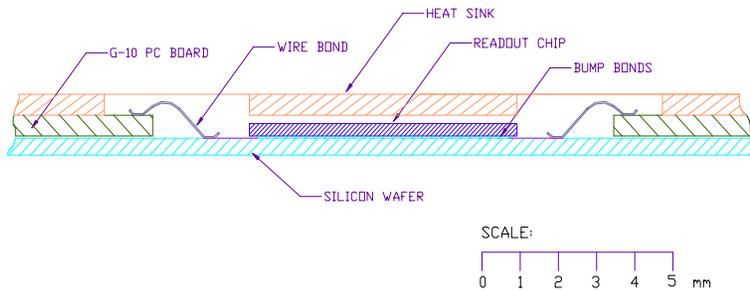
Silicon Tungsten EMCal

- 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

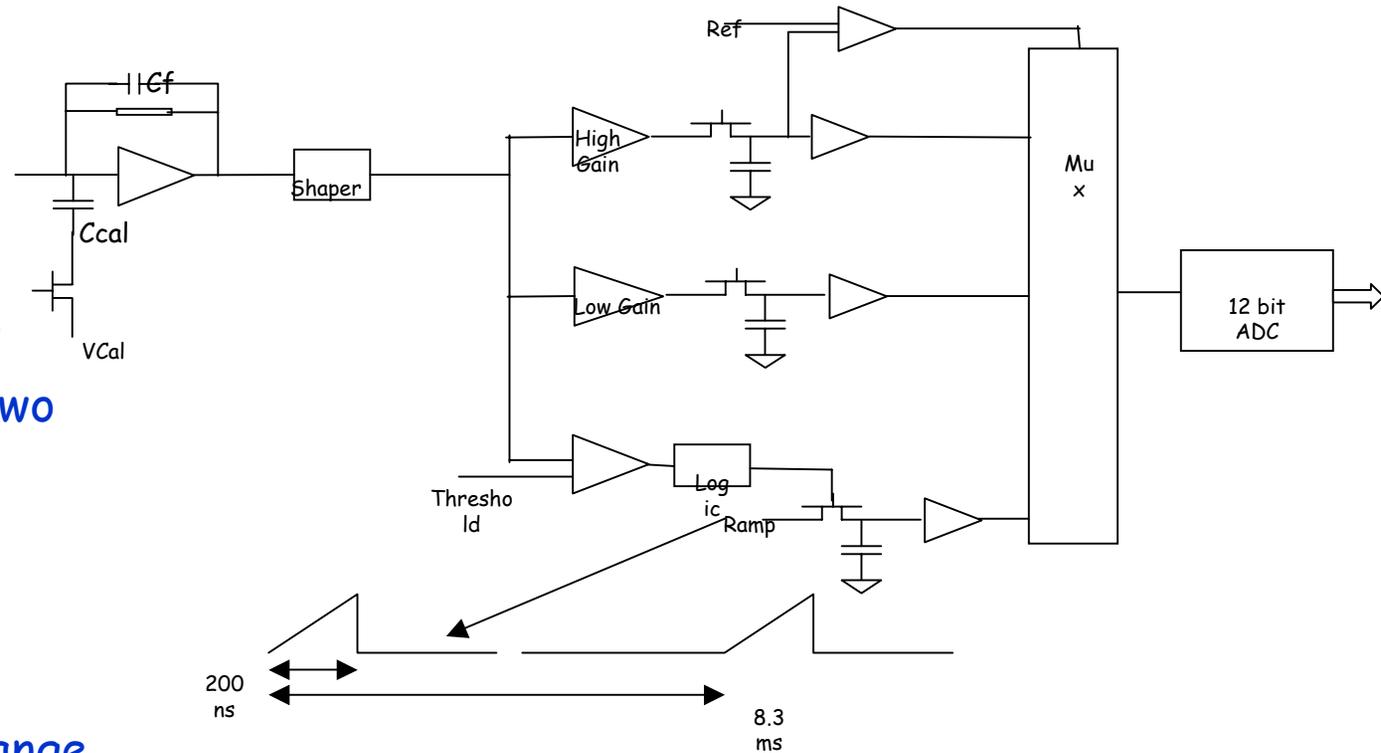3.6 Meters

1.1 Meters

Layer Assembly

Pixels on 6" Wafer

6 inch (152mm) WAFER

1,027 (5mm) CELLS

G-10 PC BOARD
WIRE BOND
HEAT SINK
READOUT CHIP
BUMP BONDS
SILICON WAFER

SCALE:
0 1 2 3 4 5 mm

to pixels   6.20 +/ 0.04   to pixels

6.20 +/ 0.04

to pixels   to pixels

15 traces (maximum)
from pixels toa
typical bump pad row

Each trace 0.006 wide

Bump Pad Array
detailB
Traces to bump pads, typical
Unit: mm
9/30/02   R. Frey

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…

Cf

Ccal

VCal

Shaper

Ref

High Gain

Low Gain

Threshold

Logic

Ramp

Mux

12 bit ADC

200 ns

8.3 ms

ALCPG   M. Breidenbach

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: $\Delta T \sim 20^0 C$.
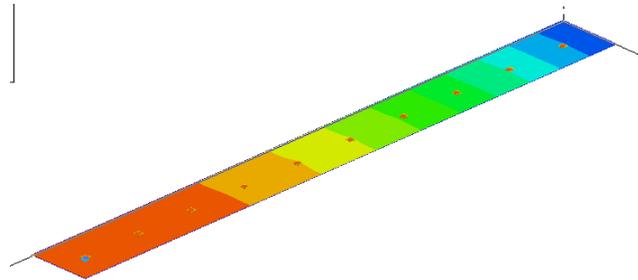
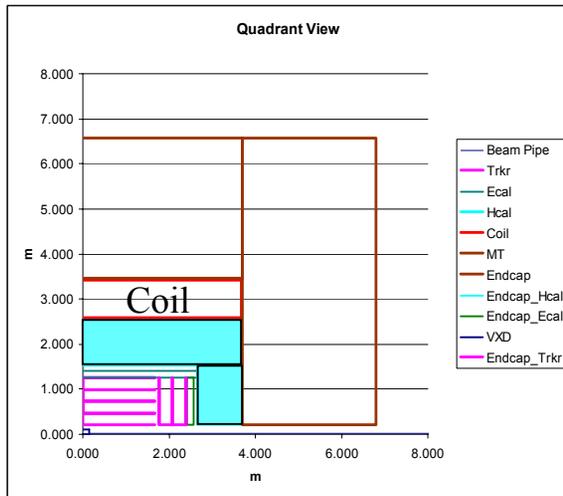- OK, but need power pulsing!!! ..and maintaining the noise/resolution is a serious engineering challenge.

HCal

- Hcal assumed to be 4 λ thick, with 46 layers 5 cm thick alternating with 1.5 cm gaps.
- Prefer "digital" detectors, e.g. 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.
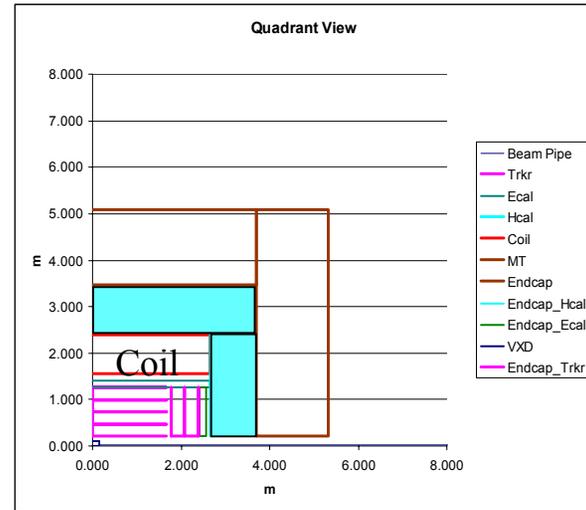- Hcal thickness important cost driver, even though Hcal cost small. And where is it relative to coil?

HCal Location Comparison

Scale – Relative to 4 λ Inside!!
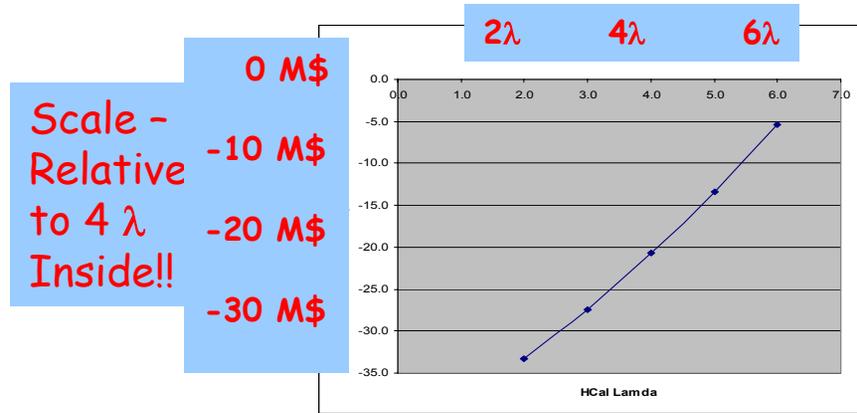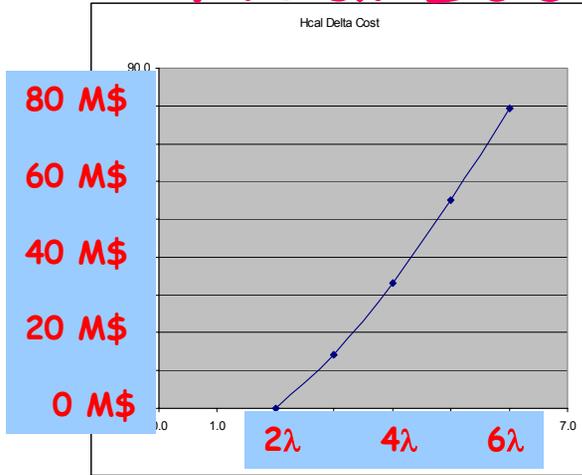
Hcal inside coil

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]
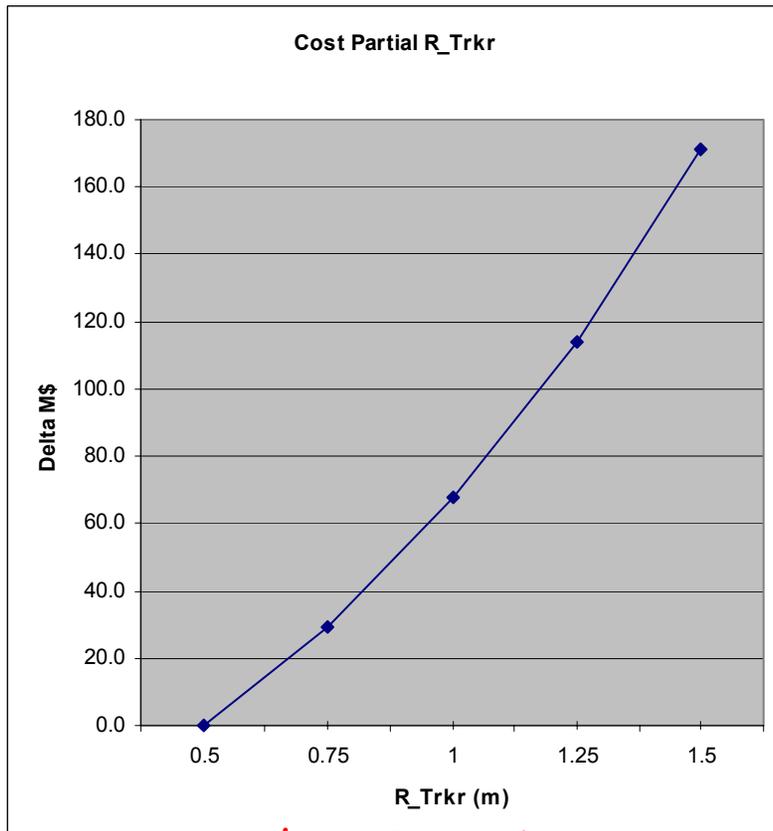
B_r

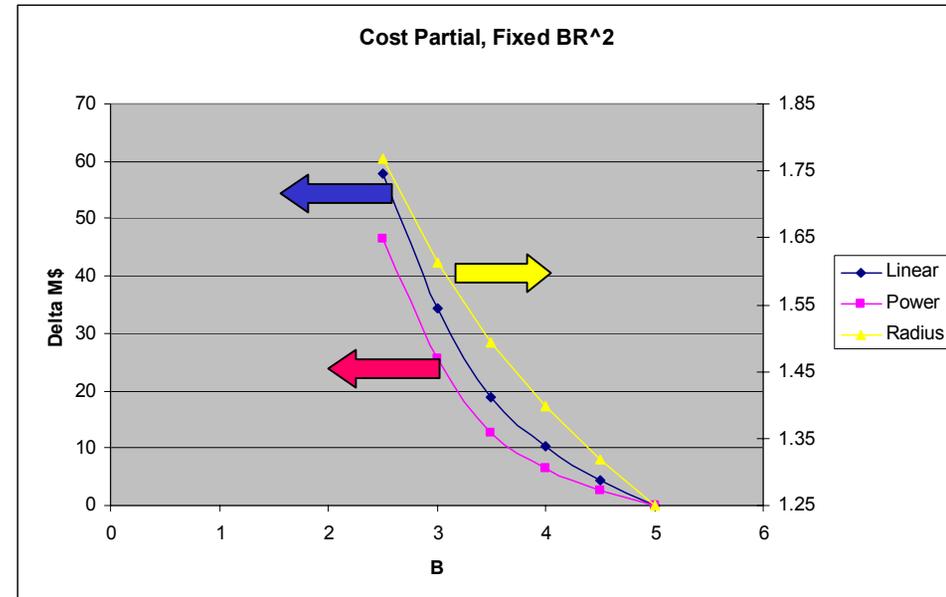B_z
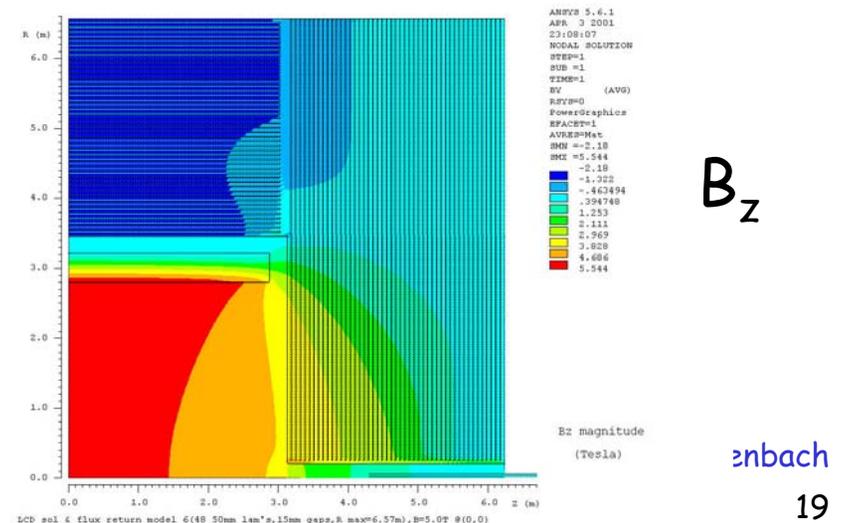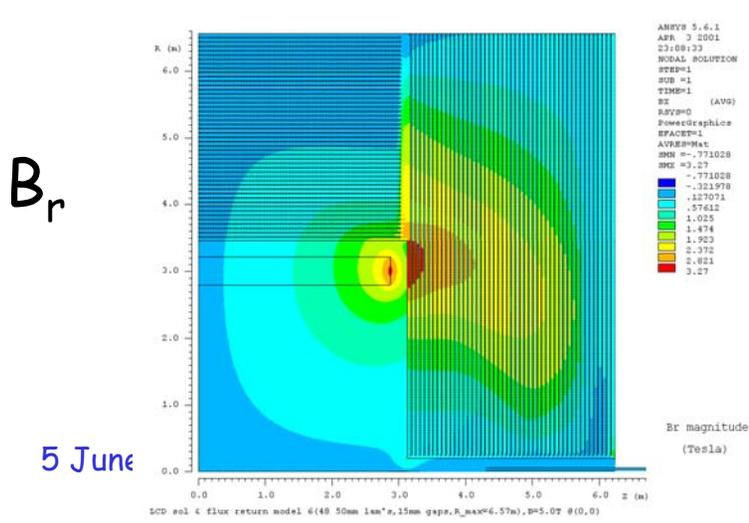
Flux Return/Muon Tracker

- 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

Caveat: Based on Si @ $6/cm², W @ $100/Kg.
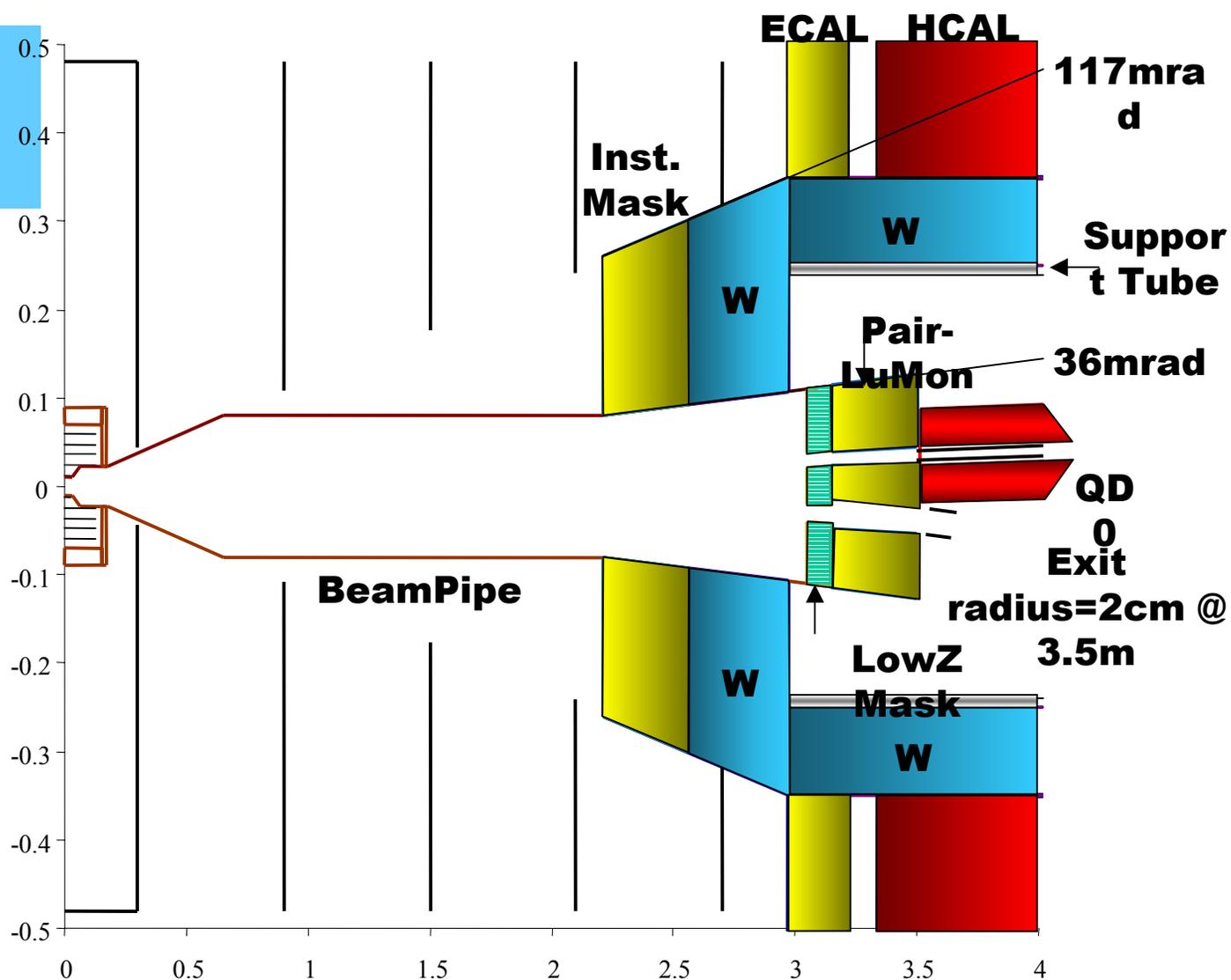

Cost Partial R_Trkr

Δ$ vs R_Trkr
~1.8M$/cm

Cost Partial, Fixed BR^2

Legend: Linear, Power, Radius

Delta $, Fixed BR²=5x1.25²

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

5 June 2003

ALCPG   M. Breidenbach

Comparison of Detector Configurations

(Ray Frey)

	TESLA	SD	LD	JLC
Tracker type	TPC	Silicon	TPC	Jet-cell drift
ECal				
R_{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_{min} endcap (m)	2.8	1.7	3.0	1.9
HCal				
R_{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
θ_{min} endcap	5°	2°	2°	8°
Coil				
R_{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)

Status

- Serious work *beginning* on a coherent, optimized design at SLAC & universities.
- Document (~ old fashioned CDR) in ~2 years.

Extras

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

EMCal Readout Board

Silicon Diode Array

Readout Chip

Network Interconnect

~1m
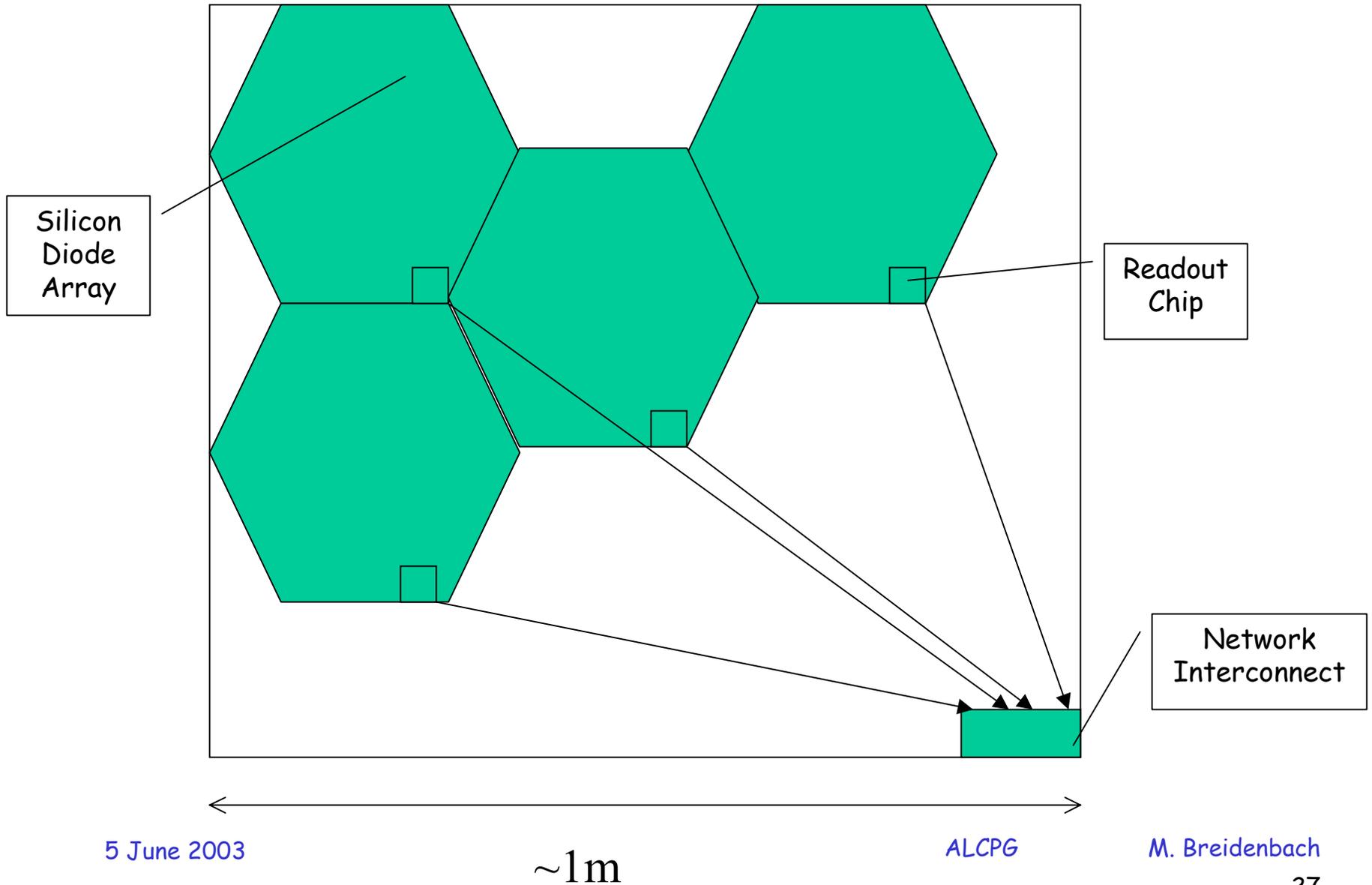
Luminosity, Energy, Polarization

- ## 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

  Strategy document
  just completed

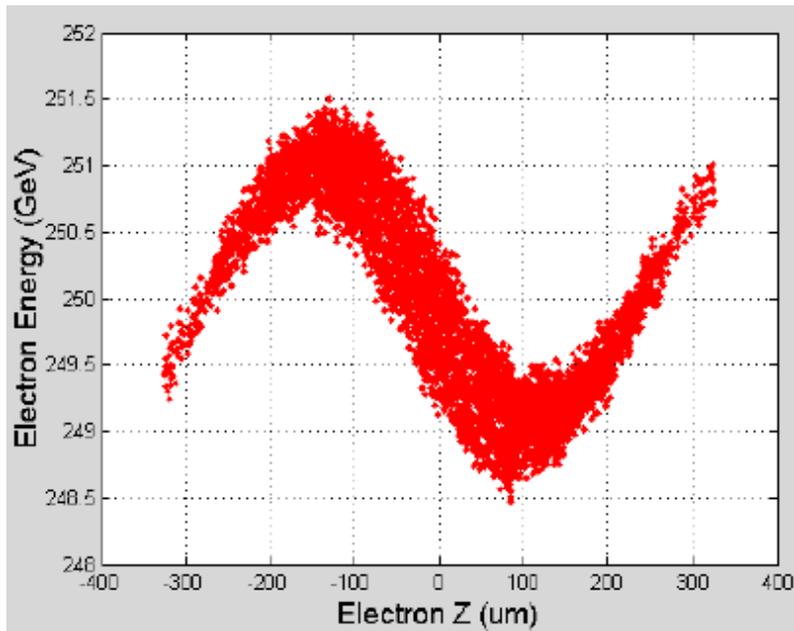- ## Absolute Luminosity

  $\Delta L/L$ ~ 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!)

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)
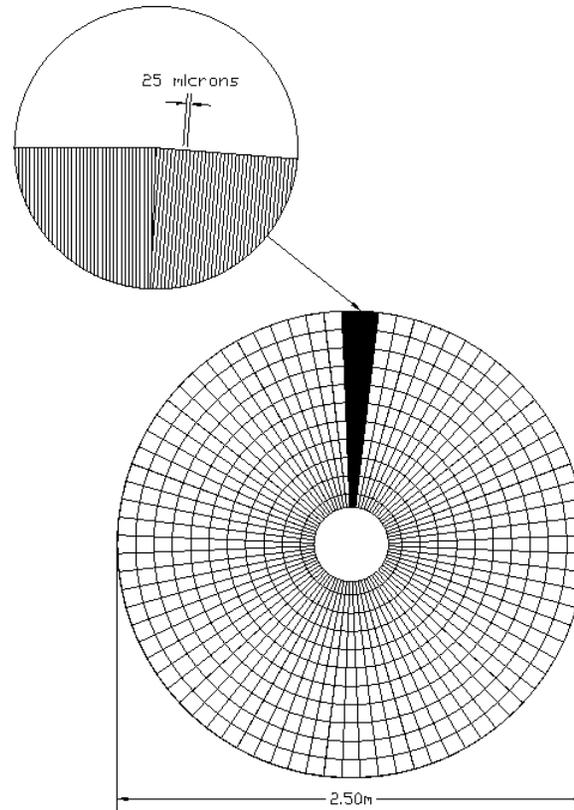   - Quartz fiber calorimter (Iowa, Tennessee)

  - $\rightarrow$ Many important topics uncovered...

Lum-PairMon @ z=3.5m

Forward Detector

1cm radius

2cm radius

12.6cm radius

SD Endplate Study

25 microns

2.50m
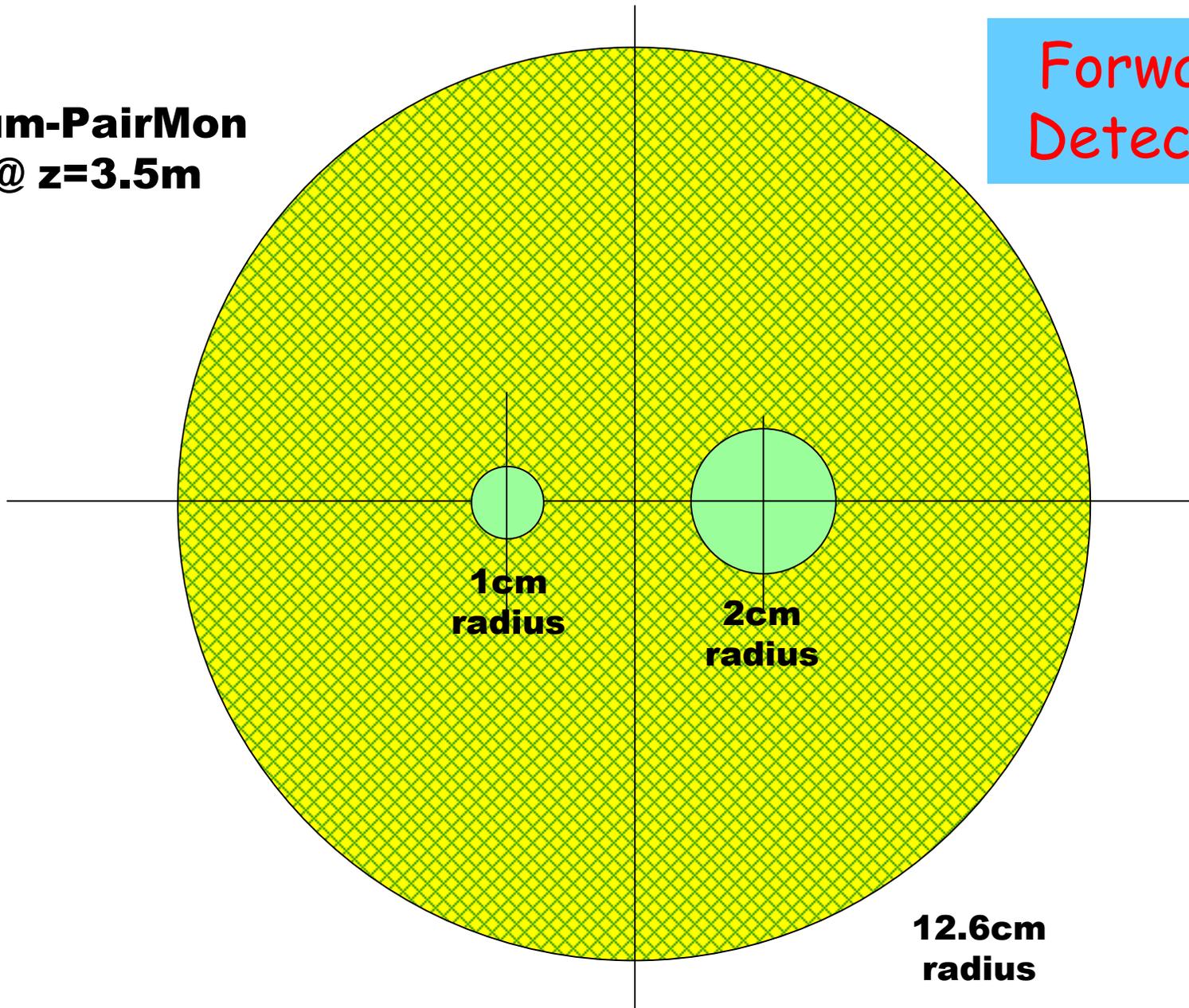
SD Momenter Endplate Study – Mar. 03