Detectors for the Next Linear Collider

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Snowmass
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Requirements
physics $\rightarrow$ subsystems

LC Physics Resource Book
High Energy IR: L, SD
Low Energy IR: P

Performance studies

Cost estimates

IR Issues

Time structure

190 bunches/train ⇒ 1.4 ns bunch spacing

⇒ crossing angle (20 mrad)

and detector integration effects

Solenoid effects

IR Layout

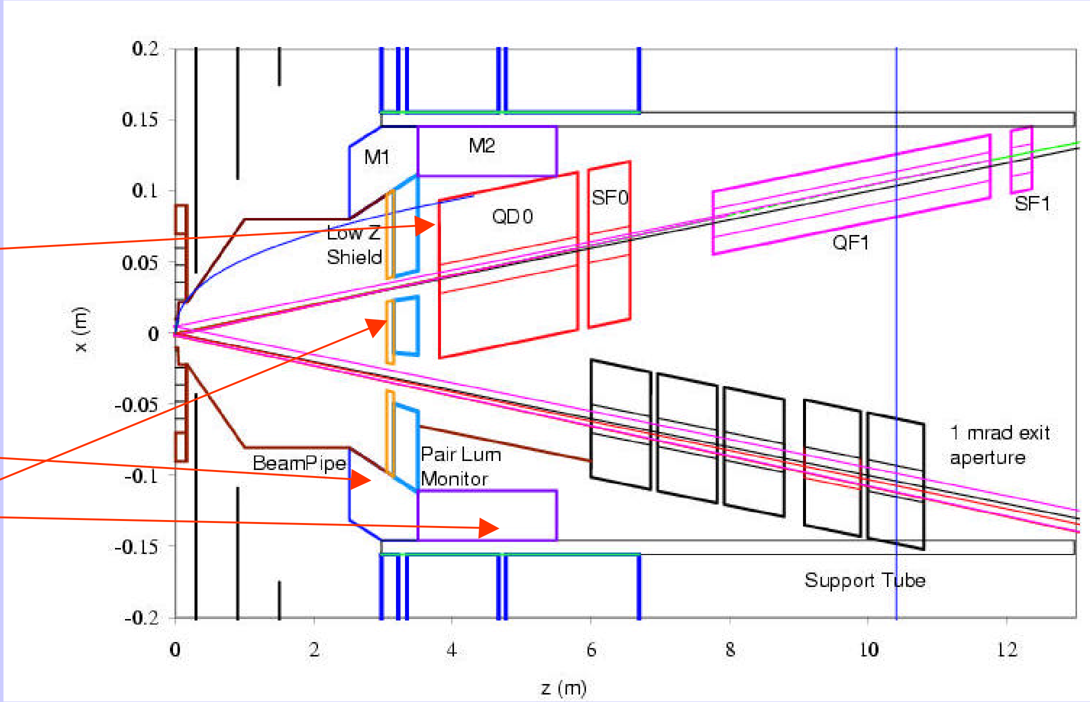
$L^* = 3.8$ m

Masks

M1 - W/Si

M2 - W

Low-Z



IR Issues

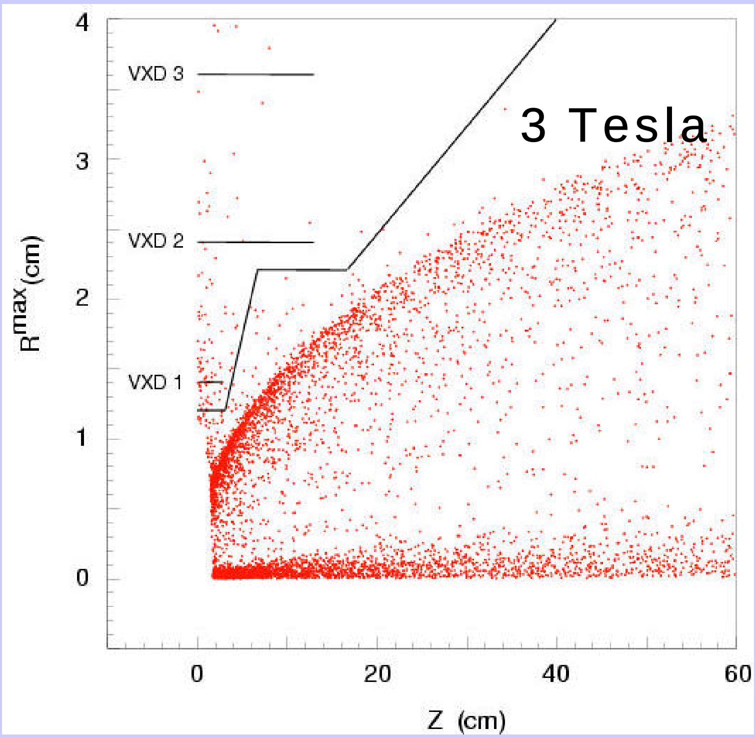
Small spot size issues

- nm vertical stability required
  - ⇒ permanent magnets for QD0 and QF1
- passive compliance + active suppression
  - 15 ns response within bunch train

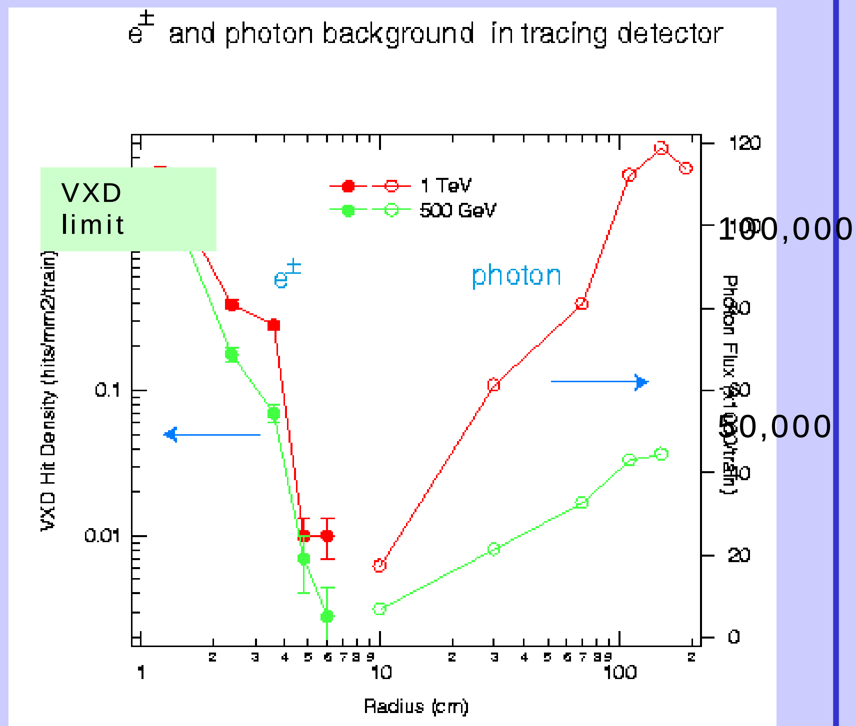
Beam-beam interaction

- broadening of energy distribution (beamstrahlung)
  - 5% of power at 500 GeV
- backgrounds
  - e^+e^- pairs
  - radiative Bhabhas
  - low energ tail of disrupted beam
  - neutron “back-shine” from dump
  - hadrons from gamma-gamma

IR Issues

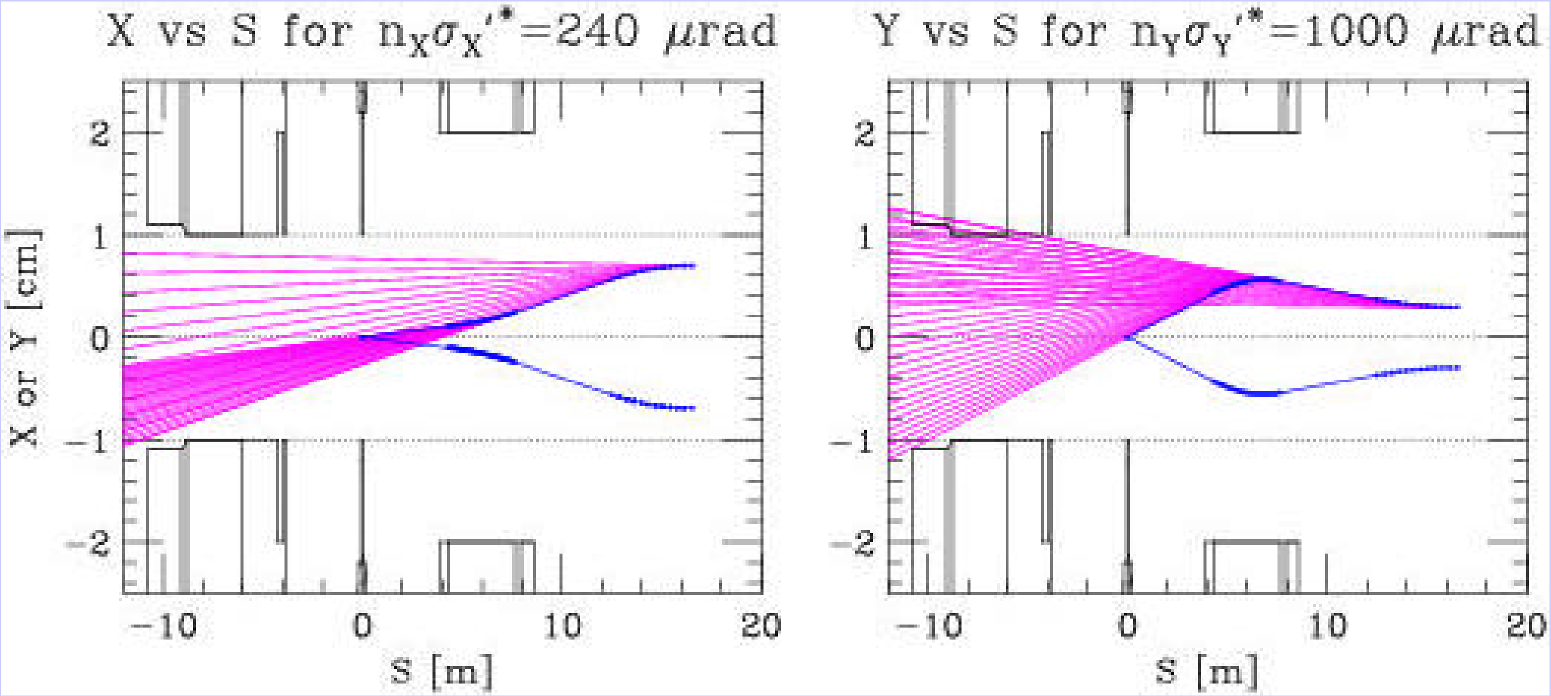


e⁺e⁻ pairs



Hits/bunch train/mm² in VXD, and photons/train in TPC

IR Issues



Synchrotron radiation photons from beam halo in the final doublet

halo limited by collimation system

Detector Requirements

Vertex Detector

- physics motivates excellent efficiency and purity
- large pair background from beamstrahlung
  - $\rightarrow$ large solenoidal field ($\geq$ 3 Tesla)
- pixelated detector [$(20\ \mu m)^2 \rightarrow 2500$ pixels/mm^2]
- min. inner radius (< 1.5 cm), ~5 barrels, < 4 μm resol,
  - thickness < 0.2 % X_0

Calorimetry

- excellent jet reconstruction
  - eg. W/Z separation
- use energy flow for best resolution
  - (calorimetry and tracking work together)
- fine granularity and minimal Moliere radius
- charge/neutral separation $\rightarrow$ large BR^2

Detector Requirements

Tracking
- robust in Linear Collider environment
- isolated particles (e charge, μ momentum)
- charge particle component of jets
  - jet energy flow measurements
- assists vertex detector with heavy quark tagging
- forward tracking (susy and lum measurement)

Muons
- high efficiency with small backgrounds
- secondary role in calorimetry ("tail catcher")

Particle ID
- dedicated sub-system not needed for primary physics
  goals at high energy
- some particle ID might be built into other subsystems
  - eg. dE/dx in TPC

LC Physics Resource Book Detectors

High Energy IR

Two options:

1.) L

conventional large detector based on the early American L (Sitges/Fermilab LCWS studies)

2.) SD (silicon detector)

motivated by energy flow measurement

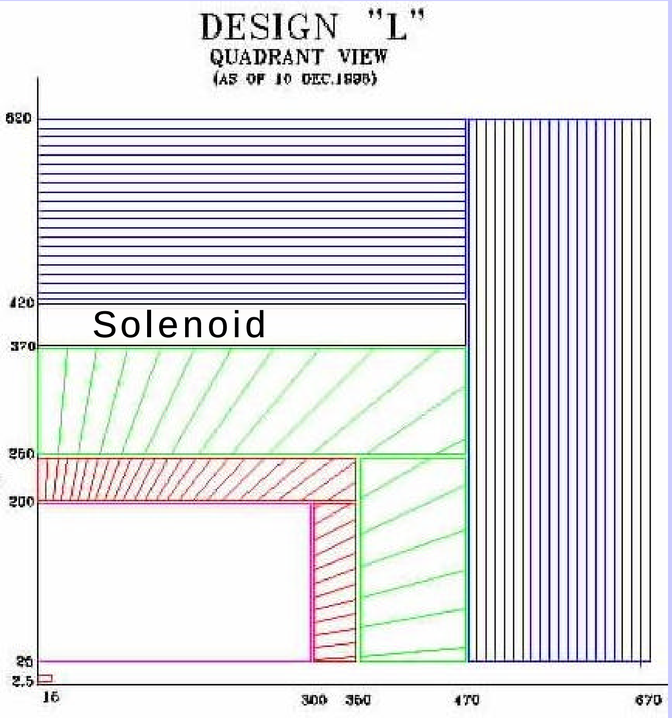
Low Energy IR

One option is presented

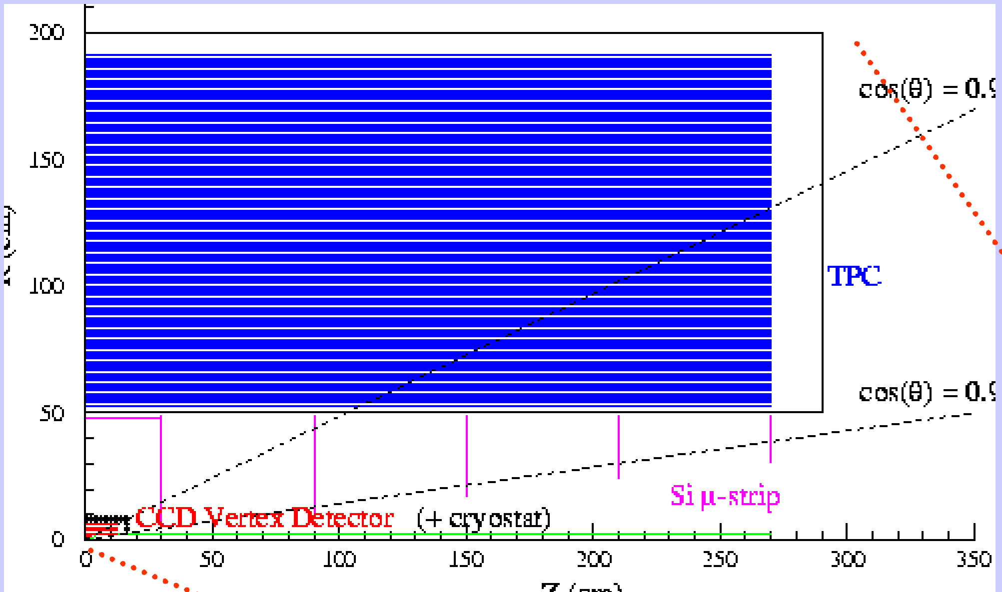
P (precision)

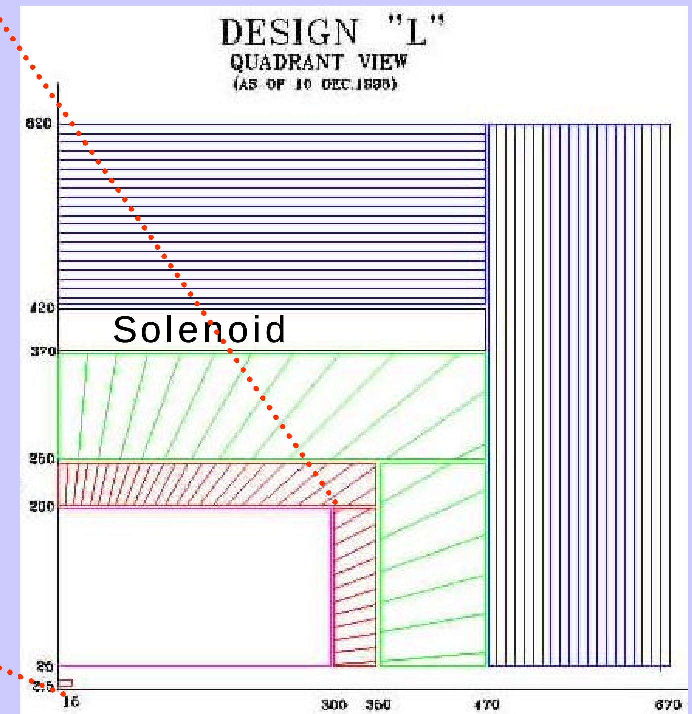
Resource Book L Detector

5 barrel CCD vertex detector
3 Tesla Solenoid
        outside hadron calorimeter
TPC Central Tracking (52 $\rightarrow$ 190 cm)
Intermediate Si strips at R=48 cm
Forward Si discs (5 each)
Pb/scintillator EM and Had calorimeter
        EM   40 x 40 mrad^2
        Had   80 x 80 mrad^2
Muon - 24 5 cm iron plates with gas
        chambers (RPC?)



Resource Book L Detector

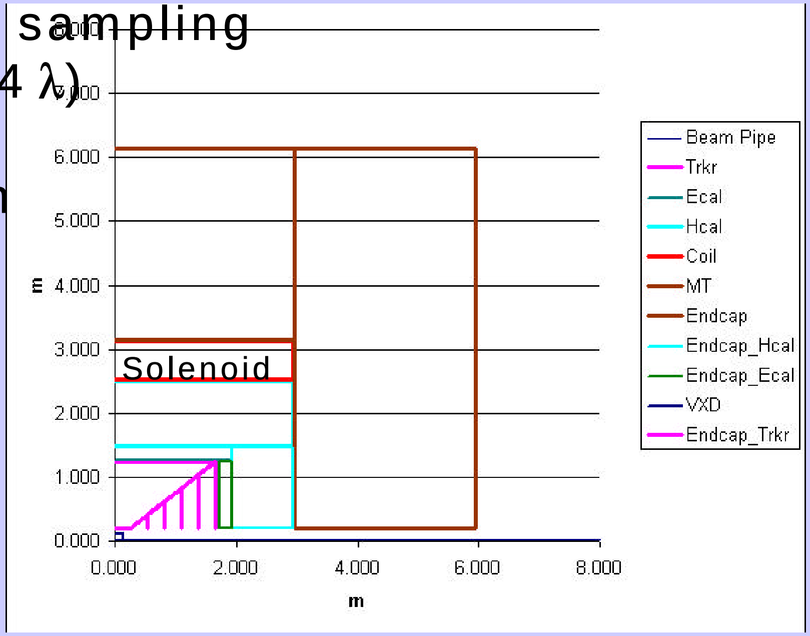




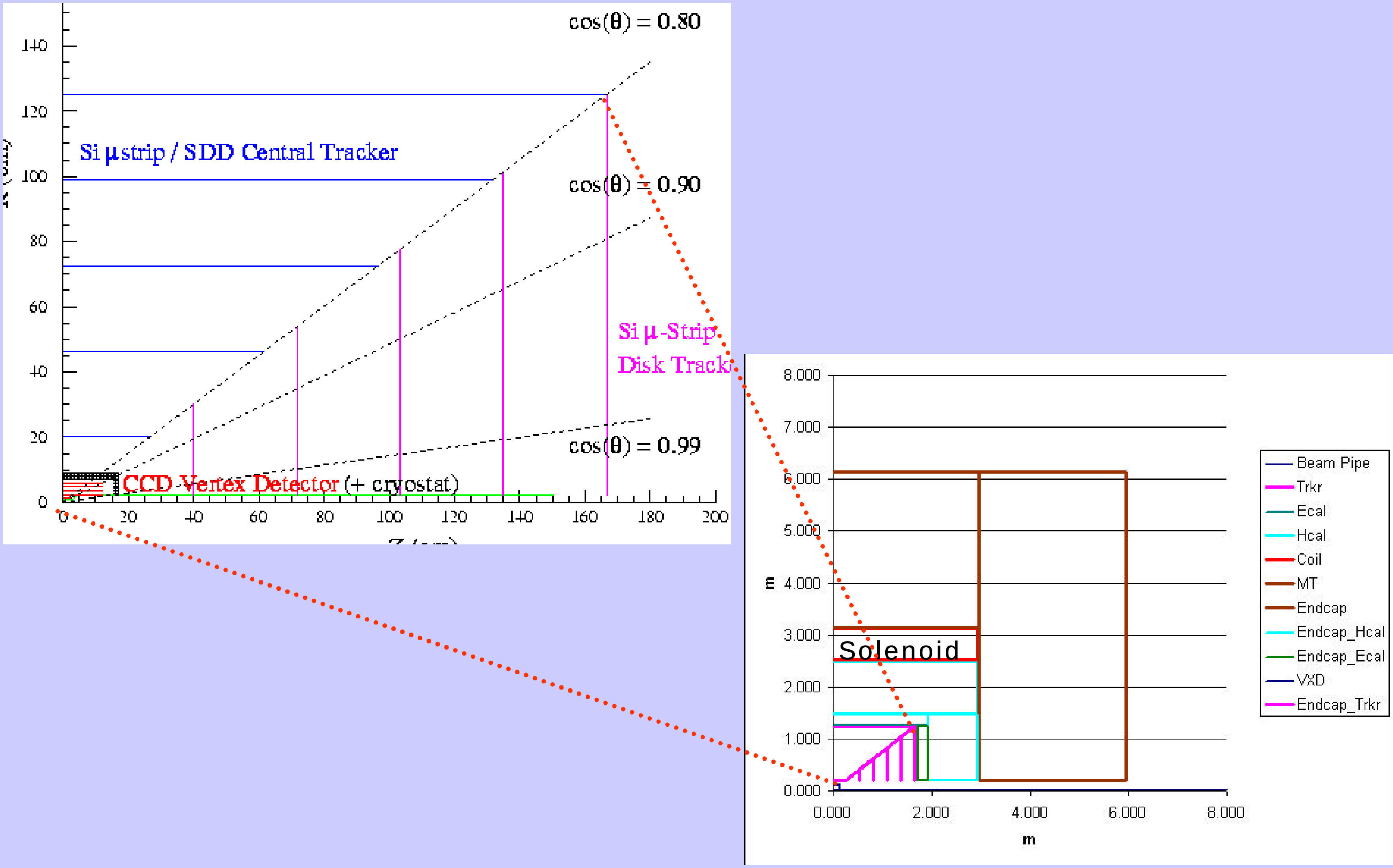
Detectors, Jim Brau, Snowmass, July 9, 2001

Resource Book SD Detector

5 barrel CCD vertex detector
5 Tesla Solenoid
 outside hadron calorimeter
Silicon strips or drift (20 → 125 cm) 5 layers
Forward Si discs (5 each)
W/silicon EM calorimeter
 0.5 cm pads with 0.7 X_0 sampling
and Cu or Fe Had calorimeter (4 λ)
 80 x 80 mrad^2
Muon - 24 5cm iron plates with
 gas chambers (RPC?)



Resource Book SD Detector



Resource Book HE Detector Comparison

	L	SD
Solenoid	3 T	5 T
R(solenoid)	4.1 m	2.8 m
BR^2 (tracking)	12 m^2T	8 m^2T
R_M (EM cal)	2.1 cm	1.9 cm
trans.seg / R_M	3.8 0.6 (6th layer Si)	0.26
R_{max}(muons)	645 cm	604 cm

Resource Book P Detector

5 barrel CCD vertex detector
3 Tesla Solenoid
    inside hadron calorimeter
TPC Central Tracking (25 $\rightarrow$ 150 cm)
Pb/scintillator or Liq. Argon EM
  and Hadronic calorimeter
    EM   30 x 30 $mrad^2$
    Had   80 x 80 $mrad^2$
Muon - 10 10cm iron plates w/ gas
    chambers (RPC?)

Vertex Detector

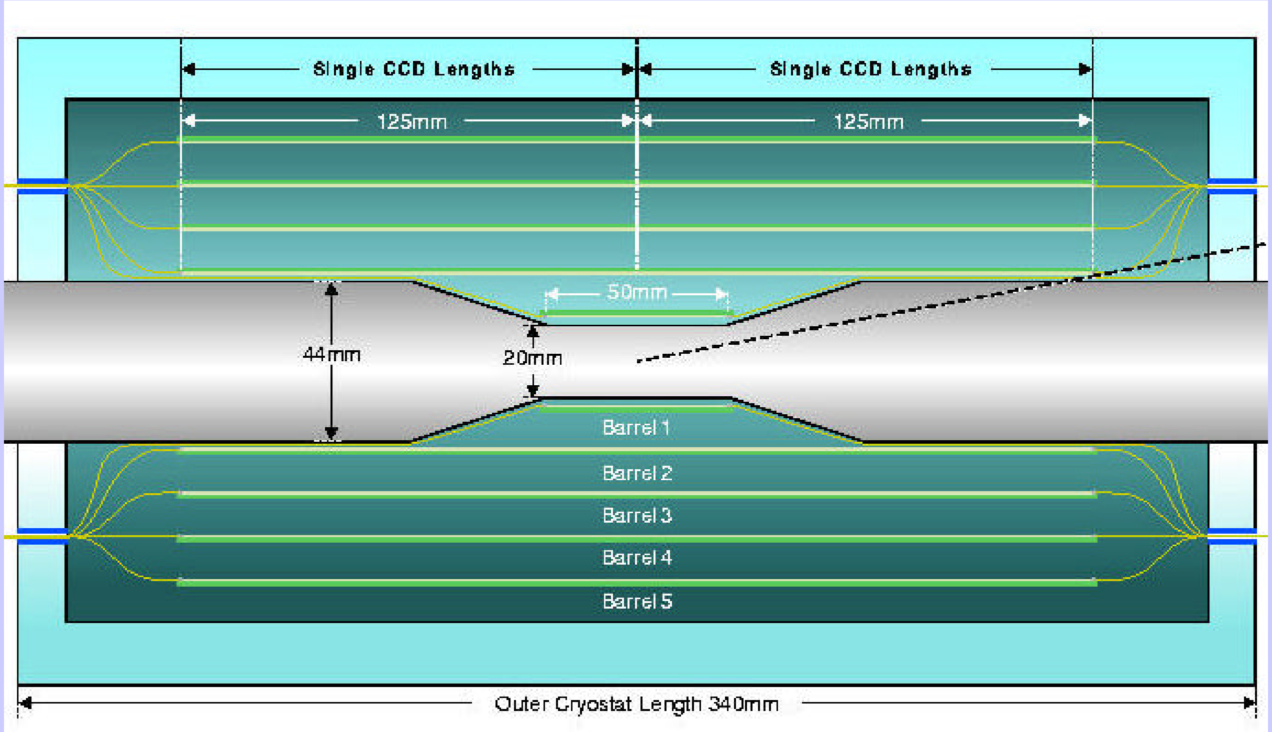
same VXD inside all three detectors (L, SD, and P)

670,000,000 pixels [20x20x20 $(\mu m)^3$]

3 μm hit resolution

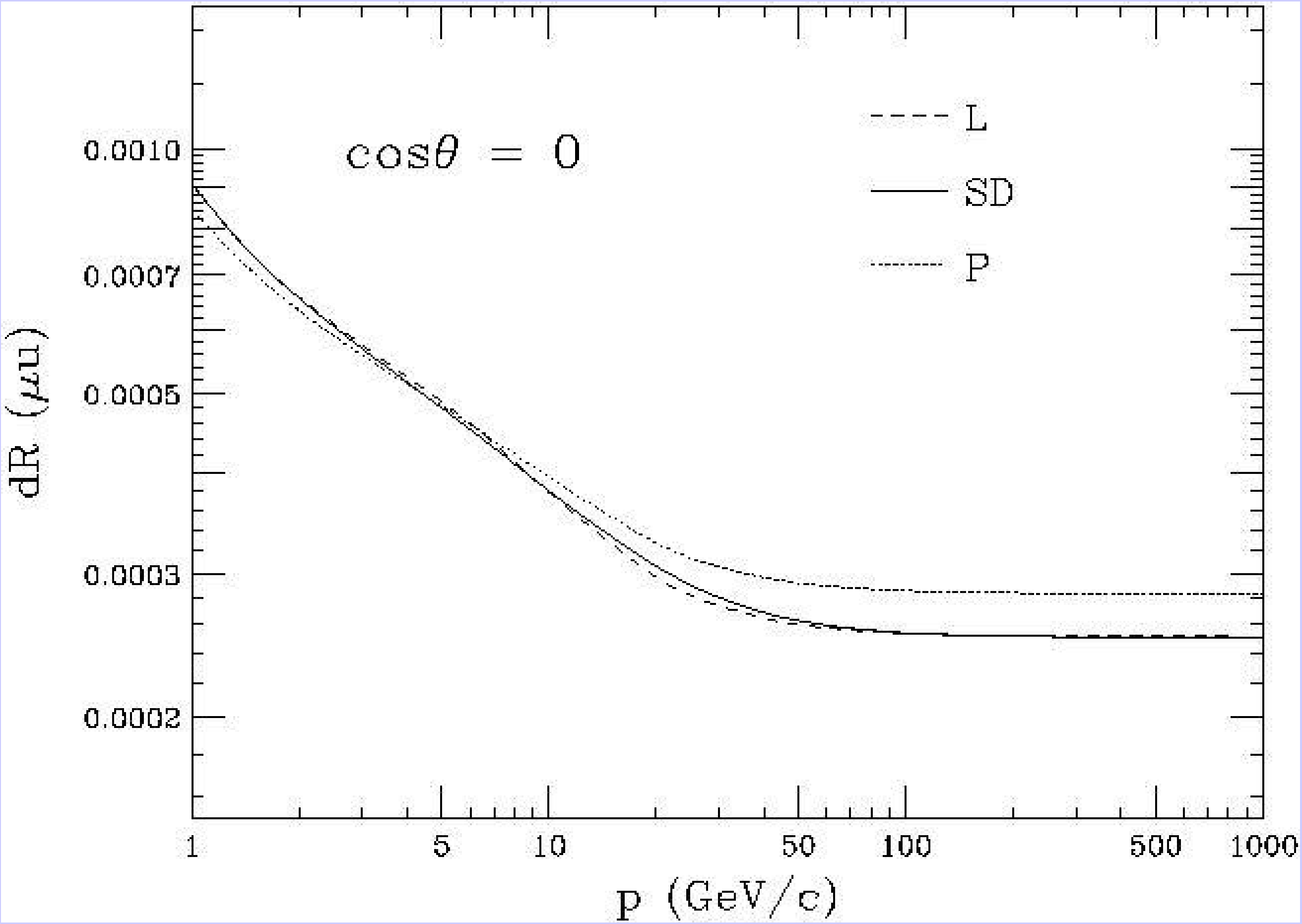
inner radius = 1.2 cm

5 layer stand-alone tracking



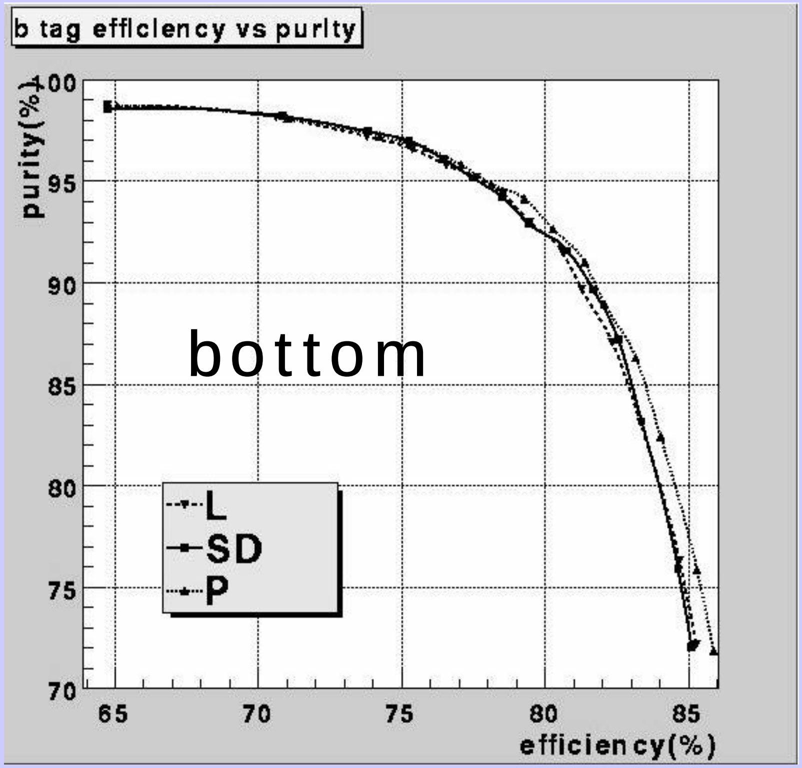
Cos θ = 0.98

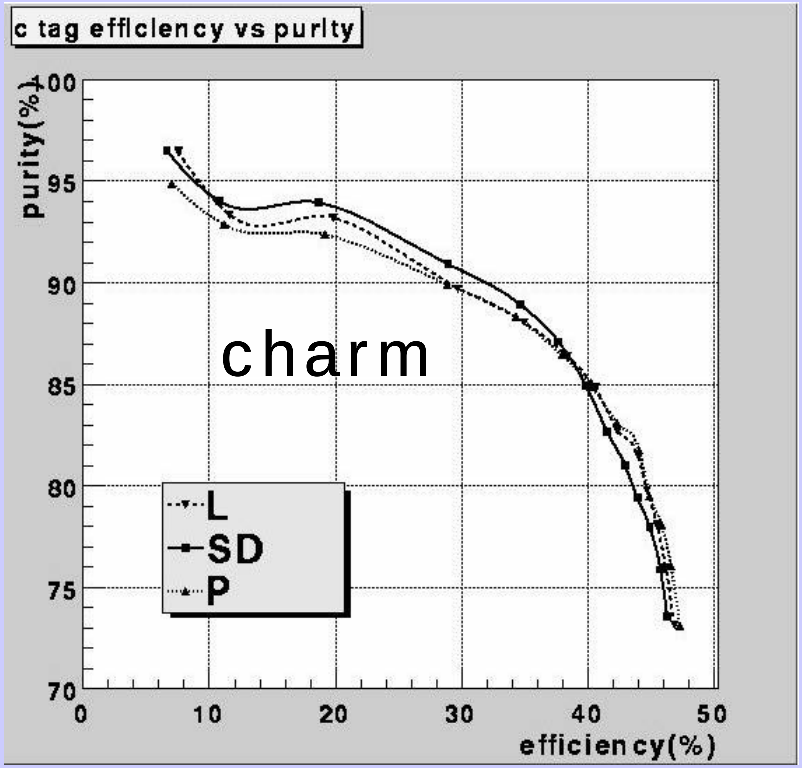
Impact Parameter Resolution



B. Schumm

Flavor Tagging Precision



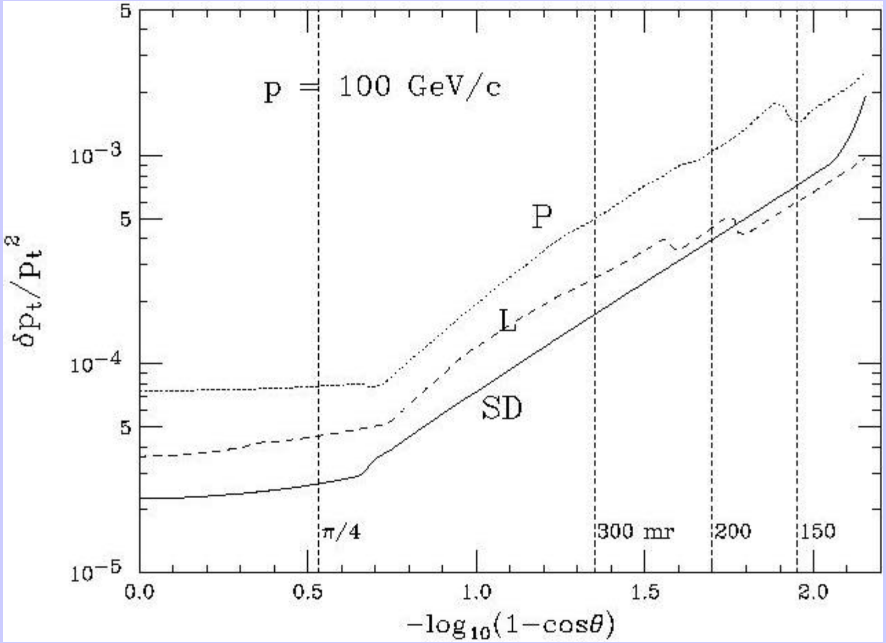


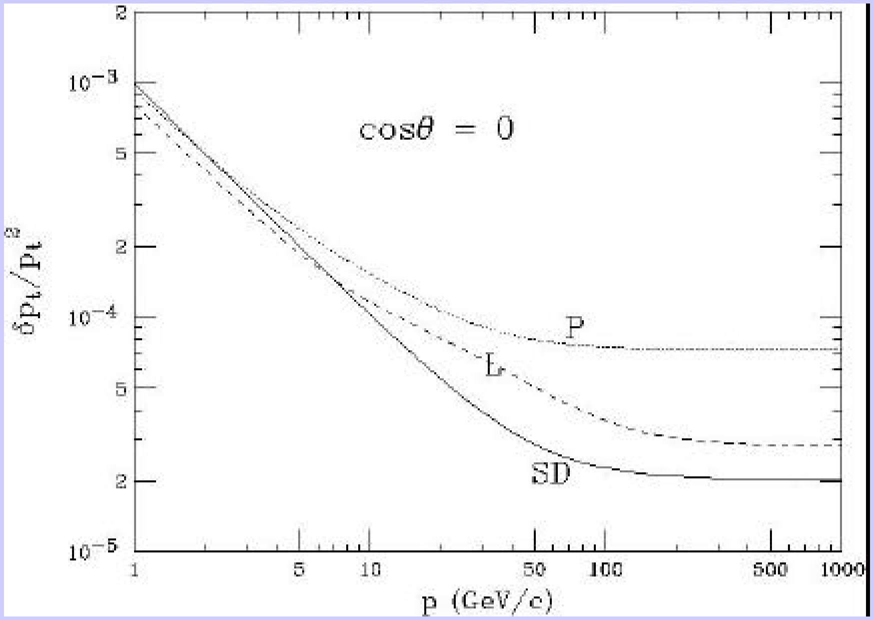
T. Abe

Tracking

	L	SD	P
Inner Radius	50 cm	20 cm	25 cm
Outer Radius	200 cm	125 cm	150 cm
Layers	144	5	122
	TPC	Si drift or μstrips	TPC
Fwd Disks	5	5	5
	double-sided Si	double-sided Si	double-sided Si
B(Tesla)	3	5	3

Tracking Resolution





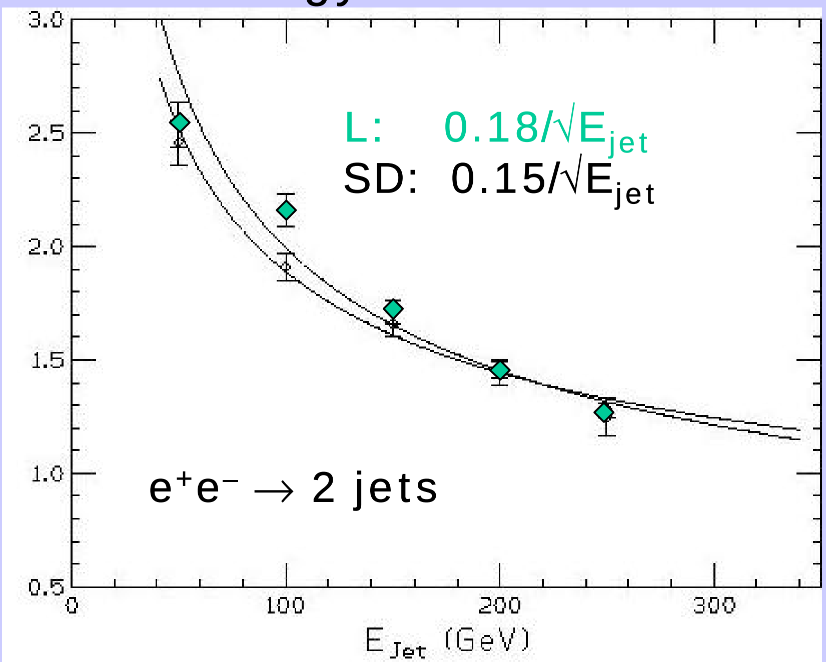
B. Schumm

Calorimeters

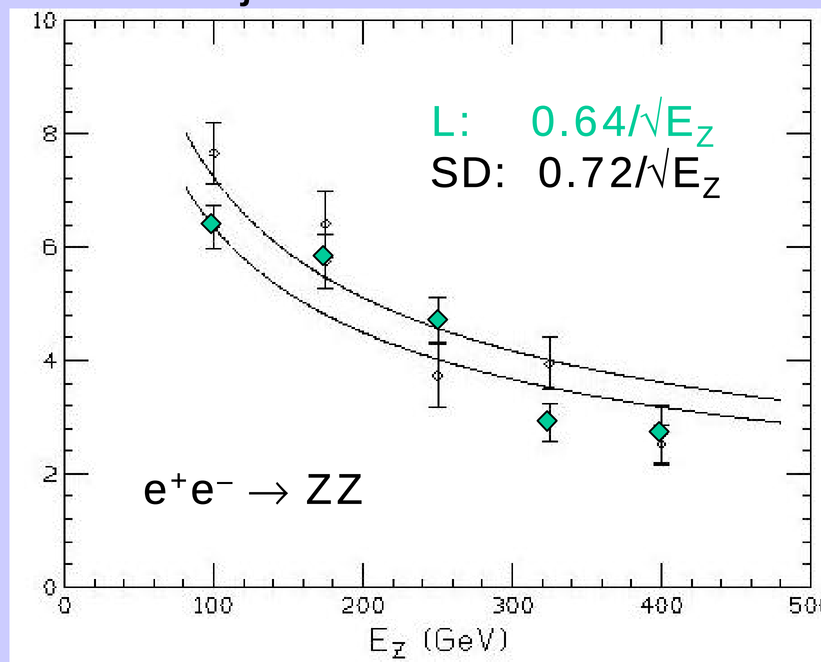
	L	SD	P
EM Tech	Pb/scin (4mm/1mm)x40	W/Si (2.5mm/gap)x40	Pb/scin (4mm/3mm)x32
Had Tech	Pb/scin	Cu or Fe/RPC (or Pb)	Pb/scin
Inner Radius	196 cm	127 cm	150 cm
EM-outer Radius	220 cm	142 cm	185 cm
HAD-outer Radius	365 cm	245 cm	295 cm
Solenoid Coil	outside Had	outside Had	between EM/Had
EM trans. seg.	40 mr	4 mr	30 mr
Had trans. seg.	80 mr	80 mr	80 mr

Calorimeter Resolution

Jet energy resolution



Di-jet mass resolution



These are idealized studies, and resolutions will be worse.

R. Frey

EM resolution:

L: $\sigma_{EM} / E = (17\% / \sqrt{E}) \oplus (\sim 1\%)$

SD: $\sigma_{EM} / E = (18\% / \sqrt{E}) \oplus (\sim 1\%)$

Muon Detection

Model L

24×5 cm Fe plates + RPCs

$\sigma_{r\theta} \approx 1$ cm (x 24) $\sigma_z \approx 1$ cm (x 4)

coverage to ~ 50 mrad

Model SD

24×5 cm Fe plates + RPCs

$\sigma_{r\theta} \approx 1$ cm (x 24) $\sigma_z \approx 1$ cm (x 4)

coverage to ~ 50 mrad

Model P

10×10 cm Fe plates + RPCs

$\sigma_{r\theta} \approx 1$ cm (x 10) $\sigma_z \approx 1$ cm (x 2)

coverage to ~ 50 mrad

Cost Estimates

General considerations:
- Based on past experience
- Contingency = ~ 40%
- Designs constrained

HE IR

L	359.0 M$
SD	326.2 M$

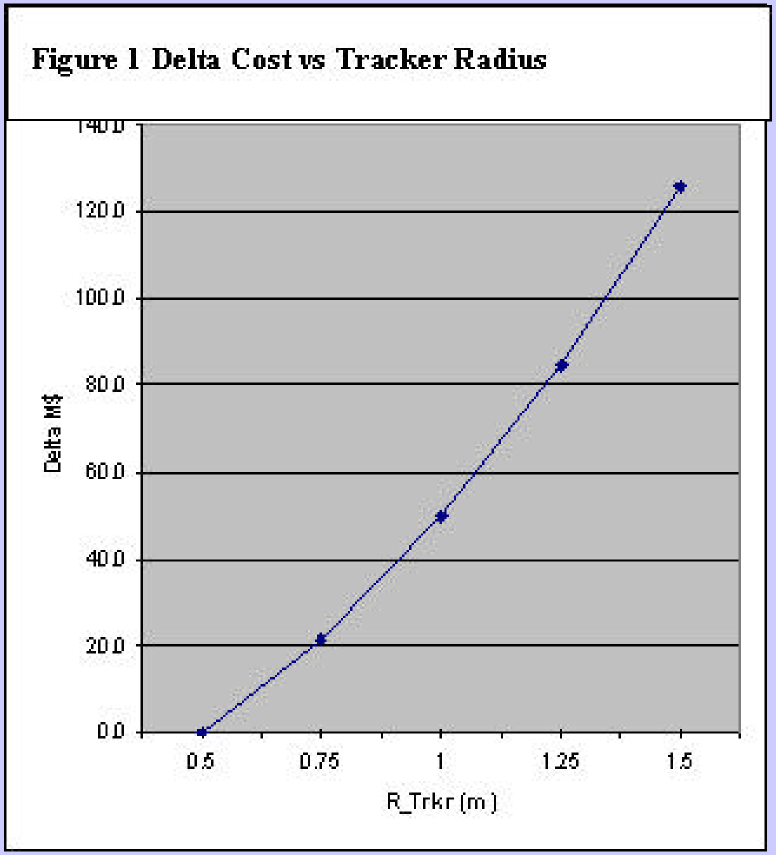
LE IR

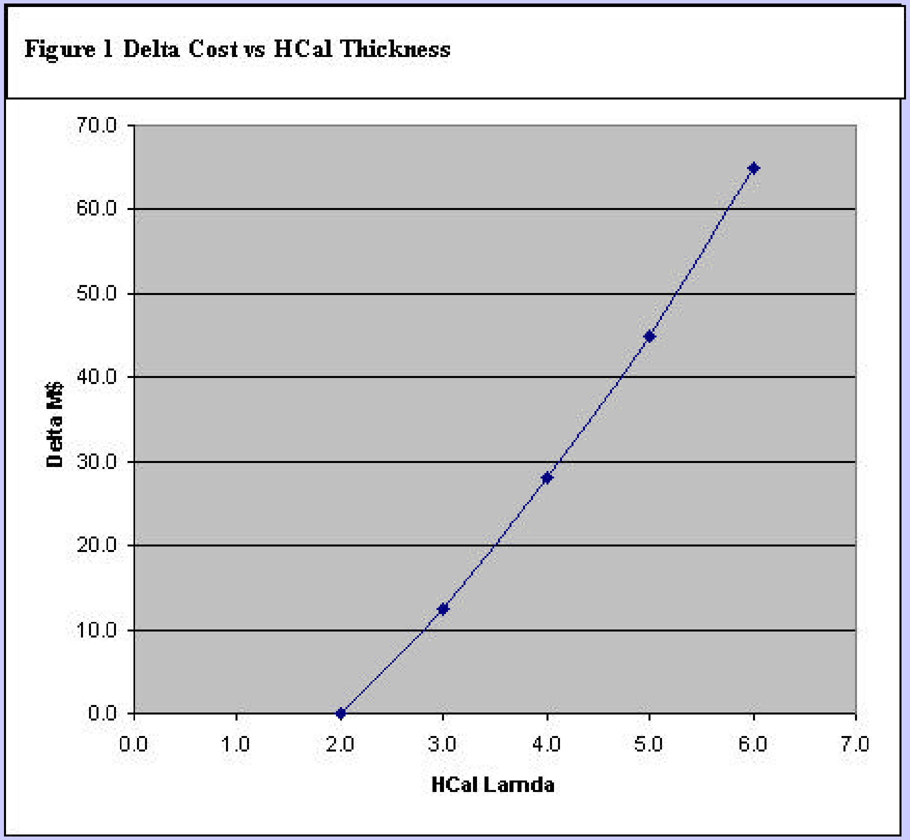
P	210.0 M$

Cost Estimates

	L	SD	P
1.1 Vertex	4.0	4.0	4.0
1.2 Tracking	34.6	19.7	23.4
1.3 Calorimeter	48.9	60.2	40.7
1.3.1 EM	(28.9)	(50.9)	(23.8)
1.3.2 Had	(19.6)	(8.9)	(16.5)
1.3.3 Lum	(0.4)	(0.4)	(0.4)
1.4 Muon	16.0	16.0	8.8
1.5 DAQ	27.4	52.2	28.4
1.6 Magnet & supp	110.8	75.6	30.5
1.7 Installation	7.3	7.4	6.8
1.8 Management	7.4	7.7	7.4
SUBTOTAL	256.4	242.8	150.0
1.9 Contingency	102.6	83.4	60.0
Total	359.0	326.2	210.0

Cost Estimates





Snowmass Study Questions

http://sbhep1.physics.sunysb.edu/~grannis/lcquestions.txt

III. Detectors
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1. What are the physics reasons for wanting exceptional jet energy (mass) resolution? How do signal/backgrounds and sensitivities vary as a function of resolution? Is mass discrimination of W and Z in the dijet decay mode feasible, and necessary?

2. How does energy flow calorimetry resolution depend on such variables as Moliere radius, $\Delta\theta/\Delta\varphi$ segmentation, depth segmentation, inner radius, B field, number of radiation lengths in tracker, etc.?

Snowmass Study Questions (continued)

3. What benefits arise from very high precision tracking (e.g. silicon strip tracker); what are the limitations imposed by having relatively few samples, by the associated radiation budget? What minimum radius tracker would be feasible?

4. Evaluate the dependence of physics performance on solenoidal field strength and radius.

Conclusions

Three detectors are under being studied for the Snowmass "Orange Book"

L - conventional large detector, optimized for High Energy

SD - silicon detector, designed to optimized energy flow
"alternative high energy detector"

P - upgraded SLC/LEP class detector, designed for the lower energy LC operation

Initial cost estimates:

L	359 M$
SD	326 M$
P	210 M$