Detectors for the Next Linear Collider

Jim Brau
Univ. of Oregon

Johns Hopkins
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Requirements
- physics $\rightarrow$ subsystems

Detector designs have been studied
- TESLA, JLC, Am-L, Am-S

Orange Book
- High Energy IR: L, SD
- Low Energy IR: P

Performance studies

Cost estimates

Detector Requirements

Vertex Detector

- rates demand excellent efficiency and purity
- large pair background from Beamstrahlung
  - $\rightarrow$ large solenoidal field
- pixelated detector
- min. inner radius (< 1.5 cm), ~5 barrel, < 4 μm resol,
  - thickness < 0.2 % X_0

Calorimetry

- excellent jet reconstruction
- 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

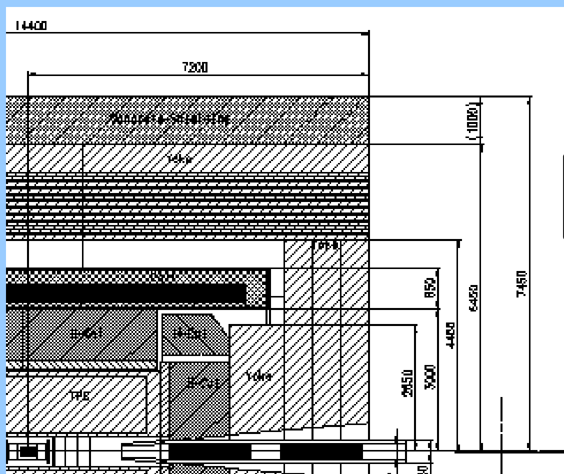
Tracking
- Robust in Linear Collider environment
- Isolated particles (e charge, μ momentum)
- Charge particle component of jets
  - jet energy flow measurements
- Assists vertex detector with heavy quark tagging
- Forward tracking (susy and lum measurement)

Muons
- <u>High efficiency</u> with small backgrounds
- Secondary role in calorimetry ("tail catcher")

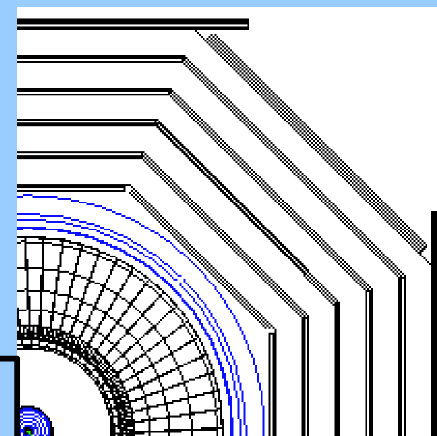
Particle ID
- Dedicated sub-system not needed for
  energy frontier physics?
- Some particle ID can be built into other subsystems

Detectors which have been studied

TESLA

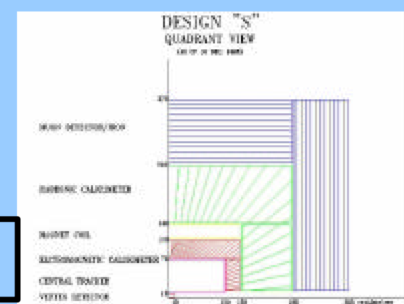


JLC



Detector	Radius	B
TESLA	7.4m	4T
JLC	~8 m	2-3 T
L	6.2m	3T
S	3.7m	6T

L



S

Orange Book Detectors

High Energy IR

Two options:

1.) L

conventional large detector based on the American L

2.) SD (silicon detector)

motivated to optimize energy flow measurement

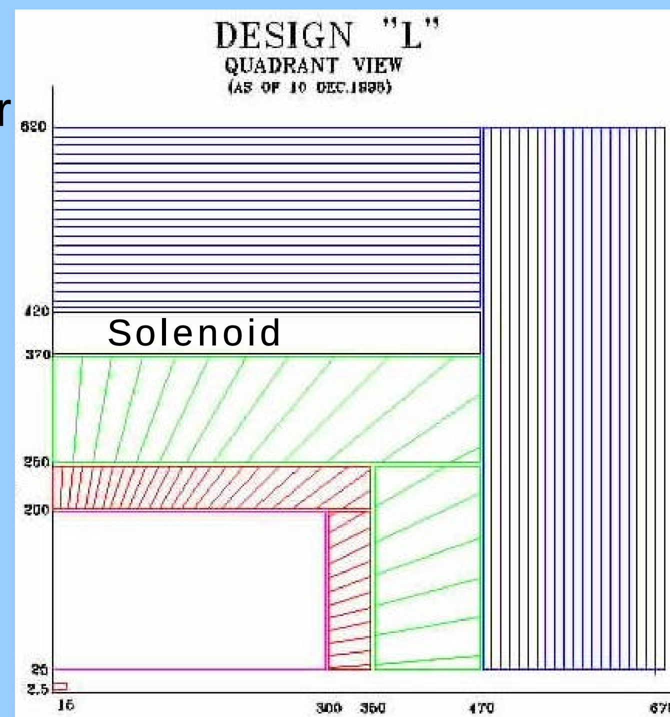
Low Energy IR

One option is presented

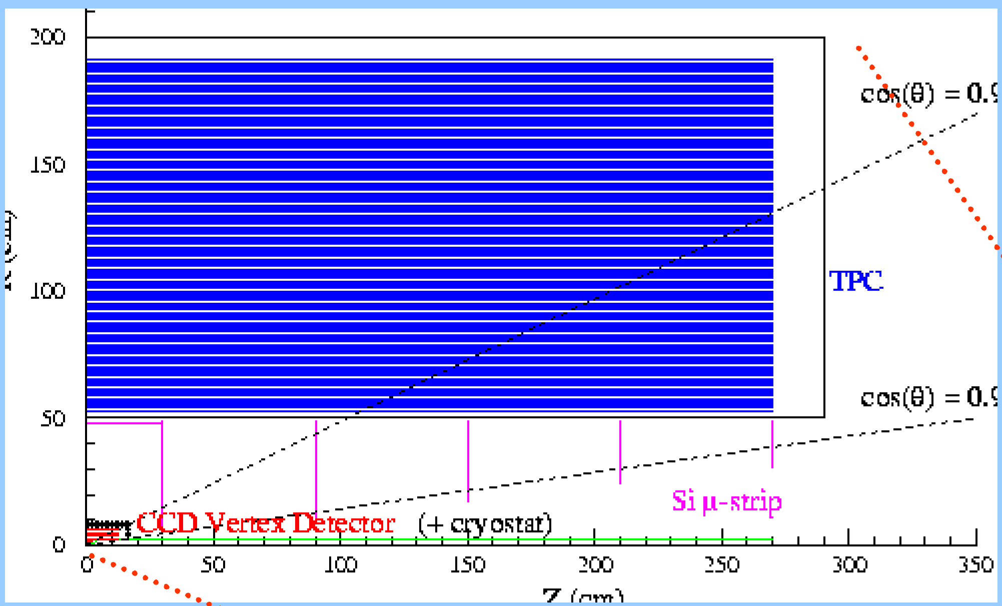
P (precision)

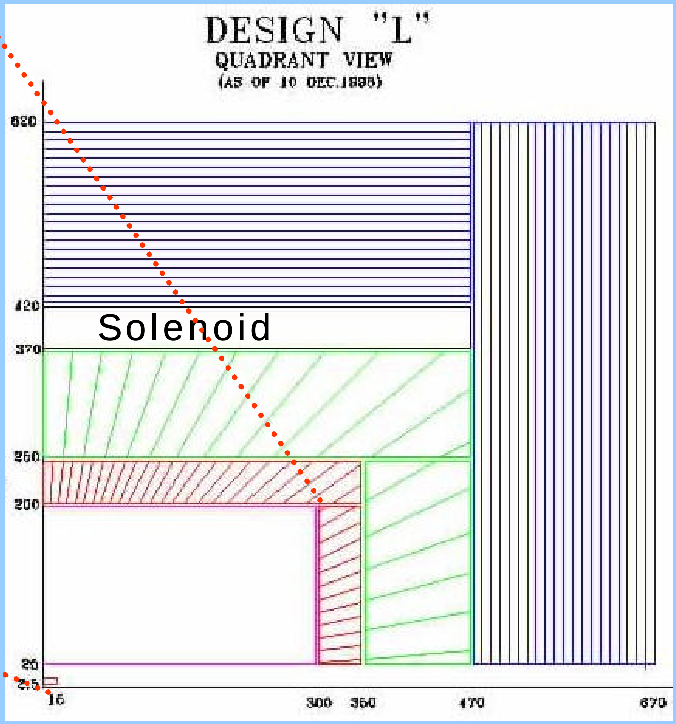
Orange Book L Detector

5 barrel CCD vertex detector
3 Tesla Solenoid
    outside hadron calorimeter
TPC Central Tracking (52 → 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?)



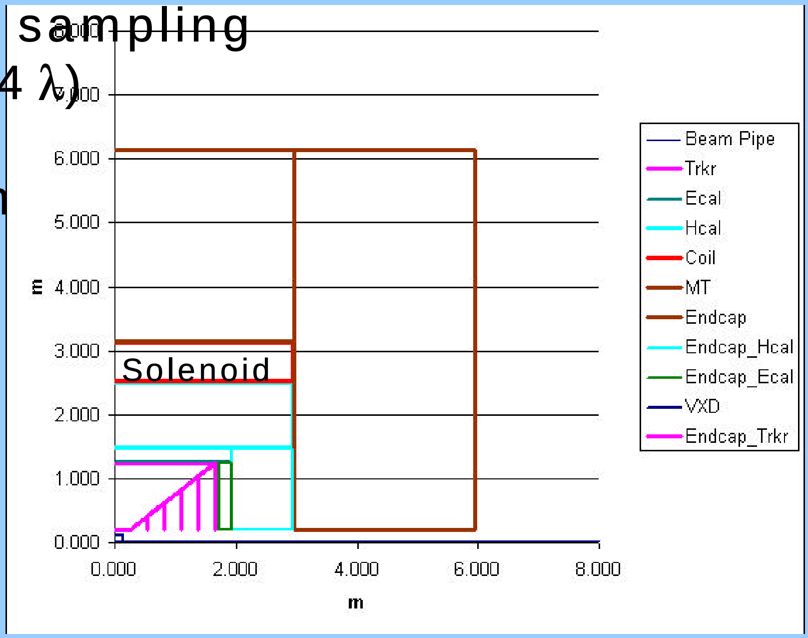
Orange Book L Detector



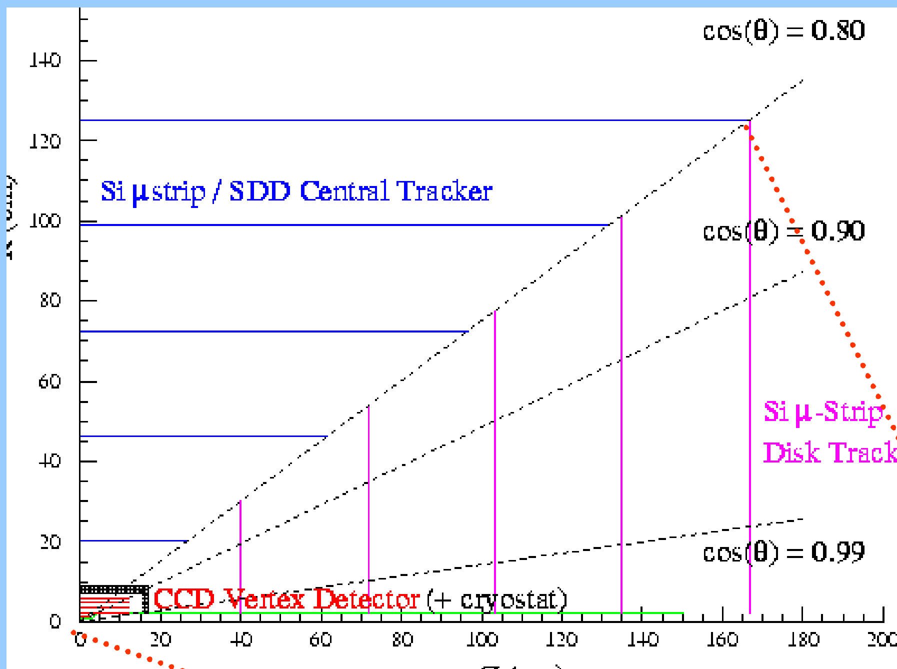


Orange Book SD Detector

5 barrel CCD vertex detector
5 Tesla Solenoid
    outside hadron calorimeter
Silicon strips (20 $\rightarrow$ 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?)

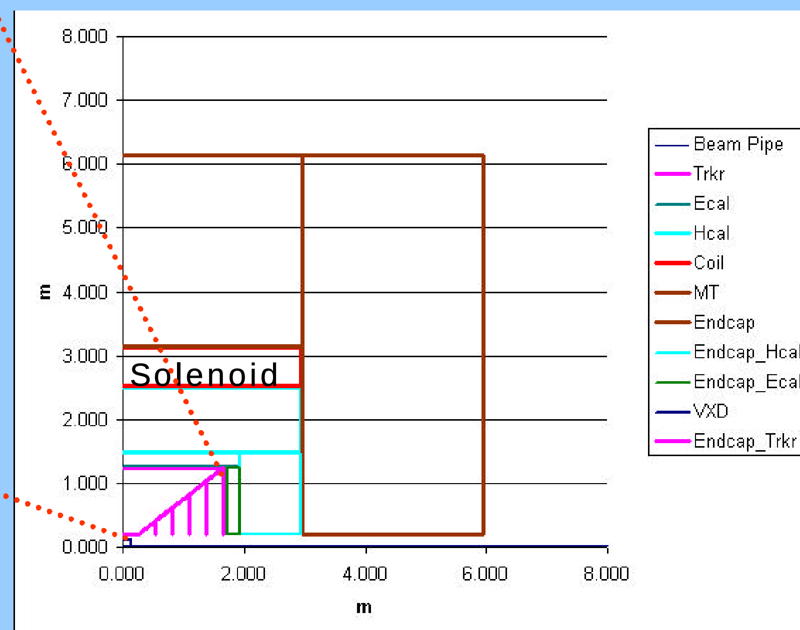


Orange Book SD Detector



Now old lay-out

This has recently changed
to squared-off barrel design



Orange 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	0.26
	0.6 (6th layer Si)	
R_{max}(muons)	645 cm	604 cm

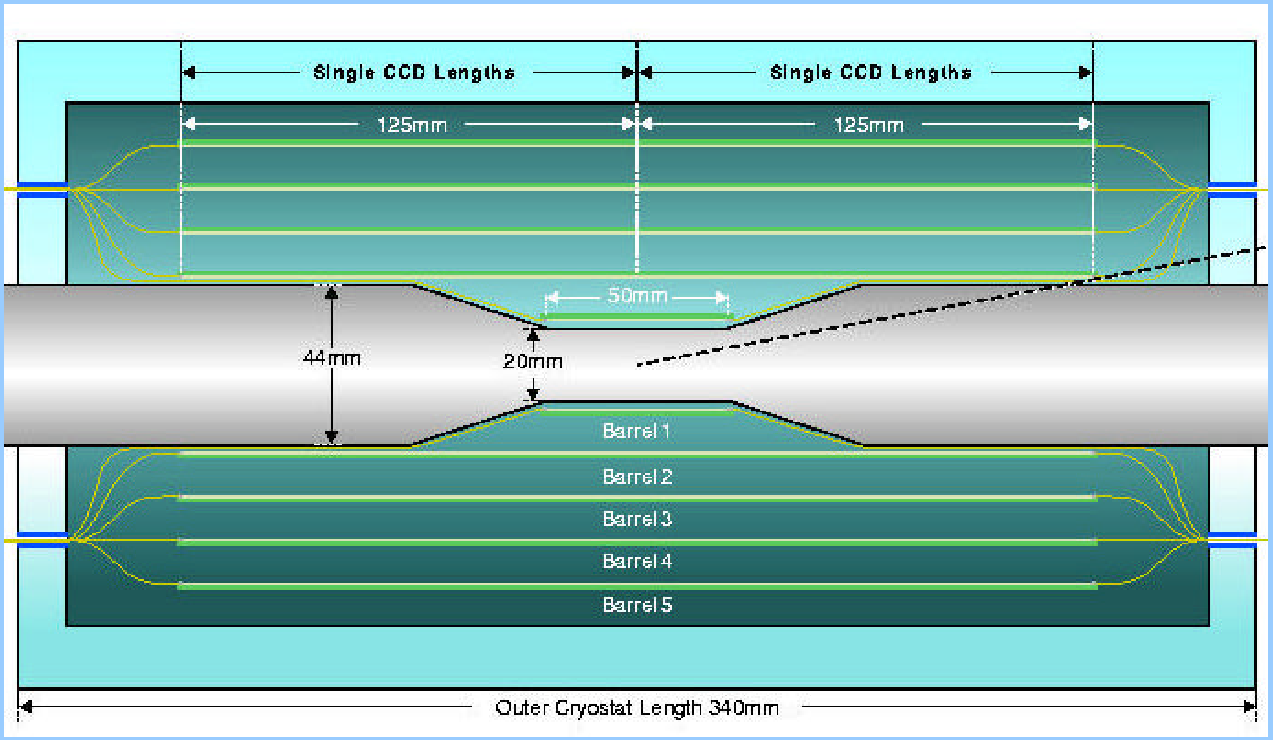
Orange Book P Detector

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

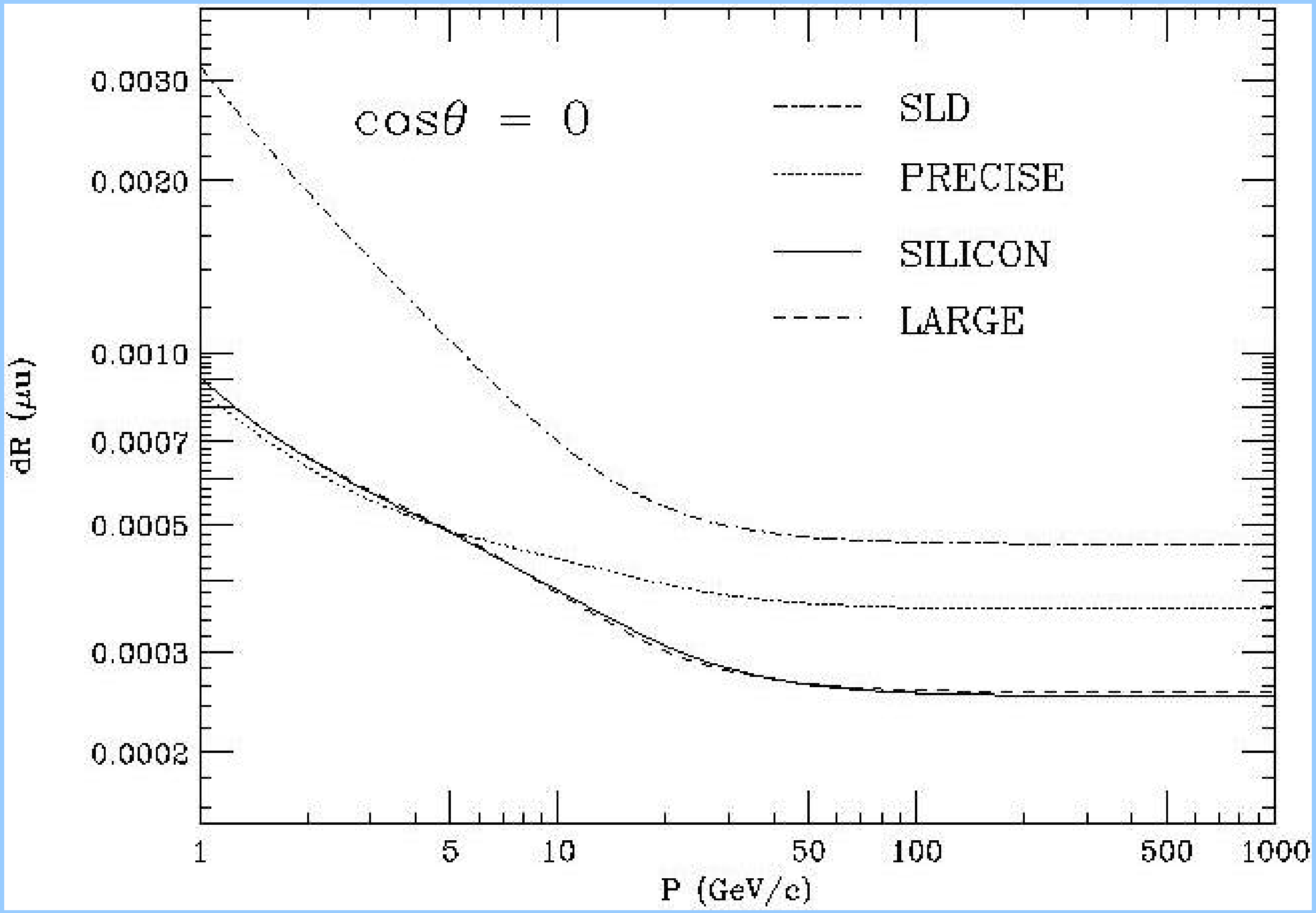
same detector inside all three detectors (L, SD, and P)
670,000,000 pixels [20x20x20 (μm)^3]
3 μm hit resolution
inner radius = 1.2 cm

5 layer stand-alone tracking



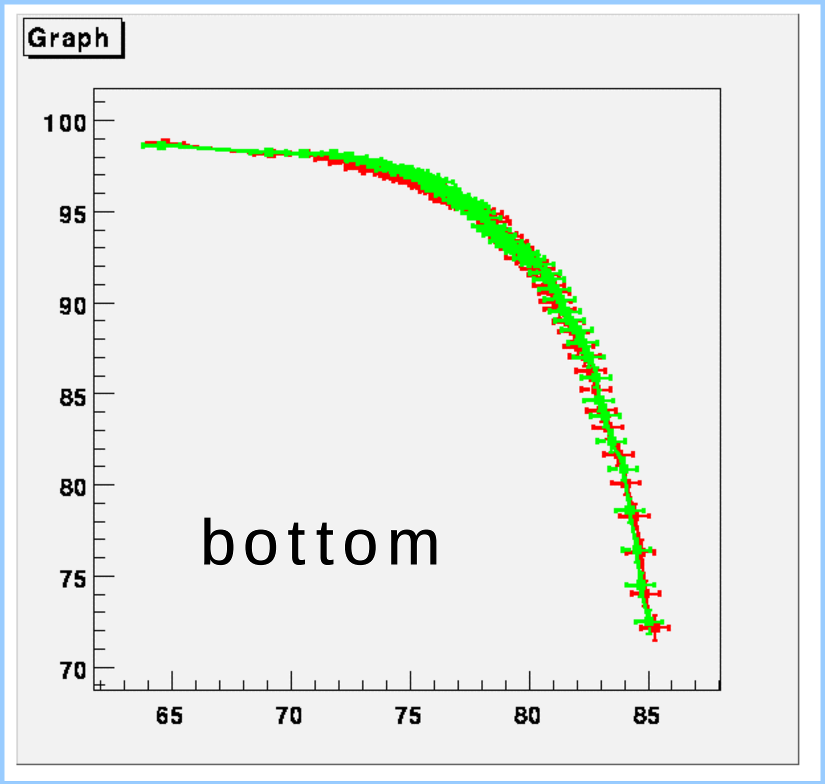
Cos θ = 0.98

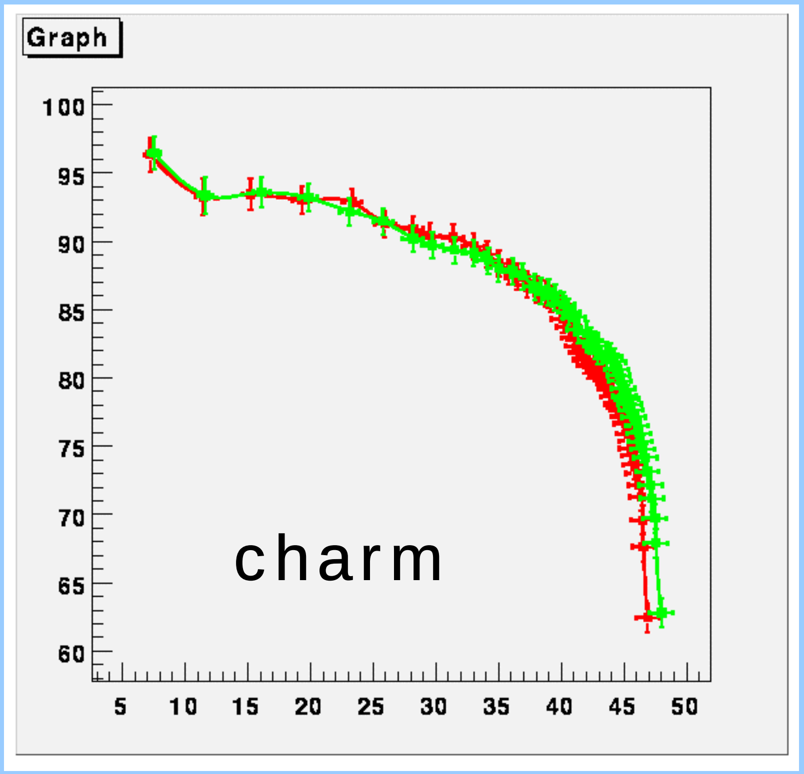
Impact Parameter Resolution



B. Schumm

Flavor Tagging Precision



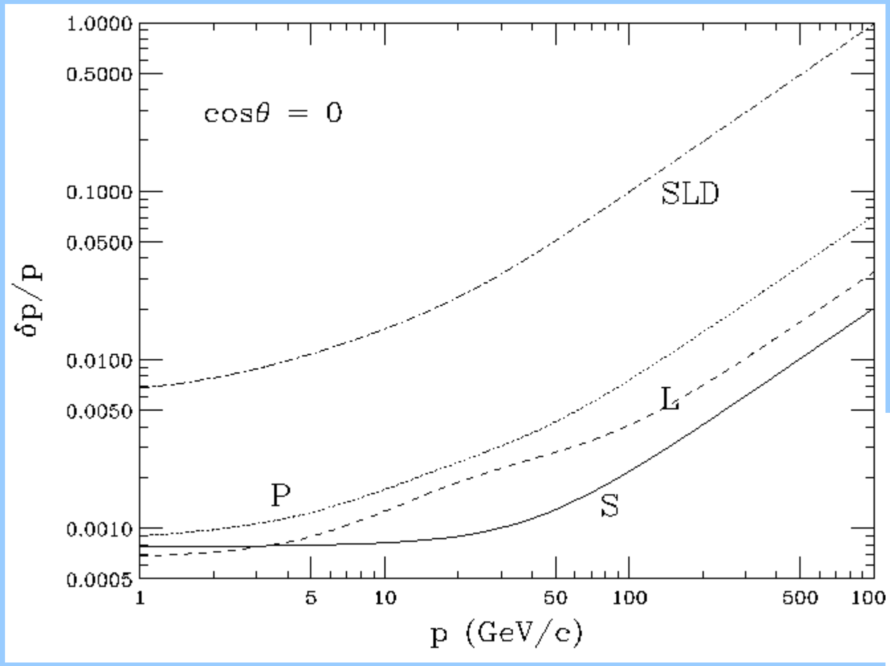


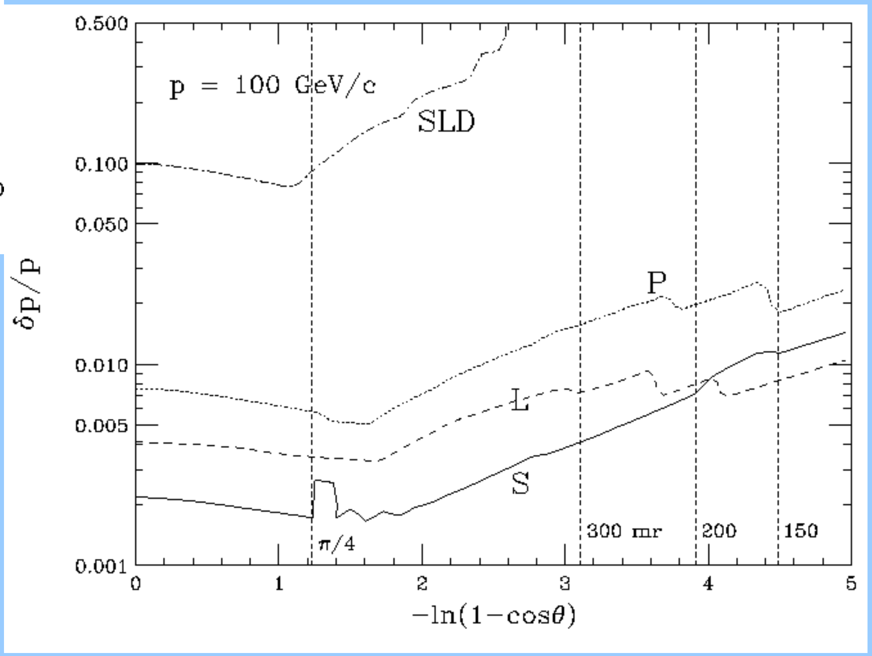
T. Abe

Tracking

	L	SD	P
Inner Radius	50 cm	20 cm	25 cm
Outer Radius	190 cm	125 cm	150 cm
Layers	144	5	122
Fwd Disks	5	5	5
B(Tesla)	3	5	3

Tracking Resolution





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Calorimeters

	L	SD	P
EM Tech	Pb/scin	Si/ W	Pb/scin or Pb/LA
Had Tech	Fe/scin	Fe/scin	Fe/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
Inside Coil	EM+Had	EM+Had	EM cal
EM trans. seg.	40 mr	4 mr	30 mr
Had trans. seg.	80 mr	80 mr	80 mr

Calorimeter Resolution

EM resolution:

- L: $\sigma_{EM} / E = (12\% / \sqrt{E}) \oplus (1\%)$
- SD: $\sigma_{EM} / E = (15\% / \sqrt{E}) \oplus (1\%)$
- P: $\sigma_{EM} / E = (15\% / \sqrt{E}) \oplus (1\%)$

Precision of energy flow strategy under study

Estimated hadronic resolution:

- L: $50\% / \sqrt{E} \oplus 2\%$
- SD: $40\% / \sqrt{E} \oplus 2\%$
- P: $50\% / \sqrt{E} \oplus 2\%$

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

Orange Book Chapter 6 Outline

(T. Abe, J. Brau (editor), M. Breidenbach, G. Fisk, R. Frey,
N. Graf, T. Markiewicz, K. Riles, B. Schumm, R. Wilson, et al)

<u>Detectors for the NLC</u>
(Total length: 26 pages)

Introduction (1 page)

Discussion of subsystem issues and options
(1-2 pages each)

1. Beamline
2. Vertex
3. Tracking
4. Calorimetry
5. Muon System
6. Magnet
7. Particle ID
8. Electronics and DAQ

Detectors
(3-5 pages for each of three detectors)

1.) High Energy Options
  A.) American L design
  B.) Alternative Design

2.) Low Energy IR Detector
  Example low energy detector (refined P)

Summary and Conclusions (1 page)

Orange Book Chapter 6 Outline (continued)

Performance Plots

we are planning to produce the following performance plots for each of the three detectors
(some already exist)

Vertex Detector:
- Impact parameter resolution vs. p
- Flavor tagging: eff. vs purity for b
  - eff. vs purity for c

Tracking:
- Tracking resolution vs. p and cos θ
- Track finding eff. vs. backgrounds ($\gamma/e^{\pm}/cm^2$) for 100 GeV jet
- Mass resolution for Z and light Higgs

Calorimeter:
- Jet Energyresolution vs. Ejet
- W/Z mass resolution vs. E(W/Z)
- dijet mass resolution vs Ejet

Muons:
- Muon eff vs. p

Cost Estimates

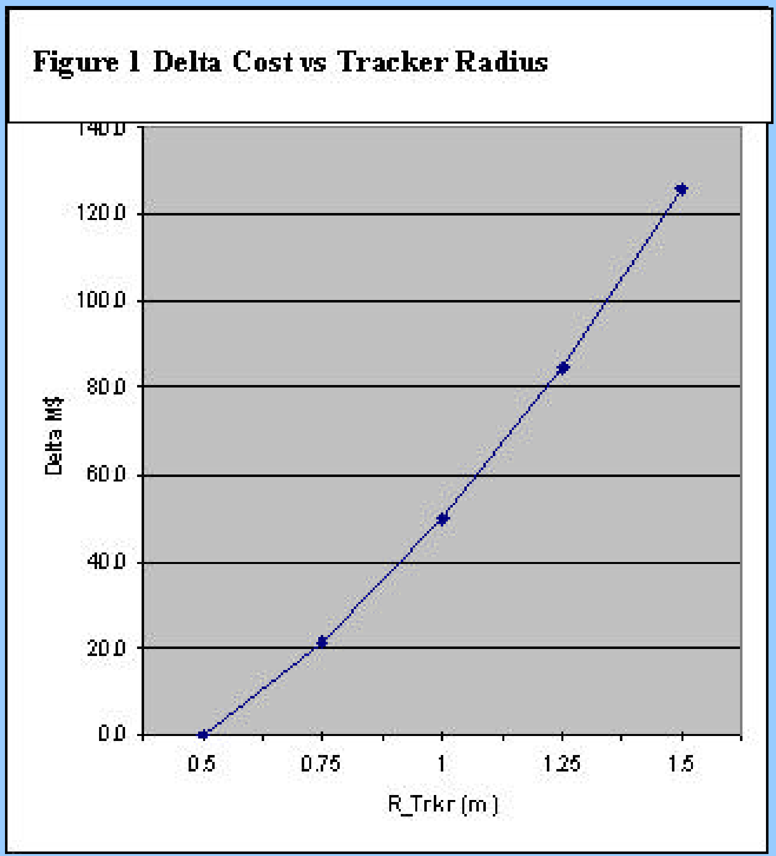
General considerations:
- Based on past experience
- Contingency = ~ 40%
- Designs constrained

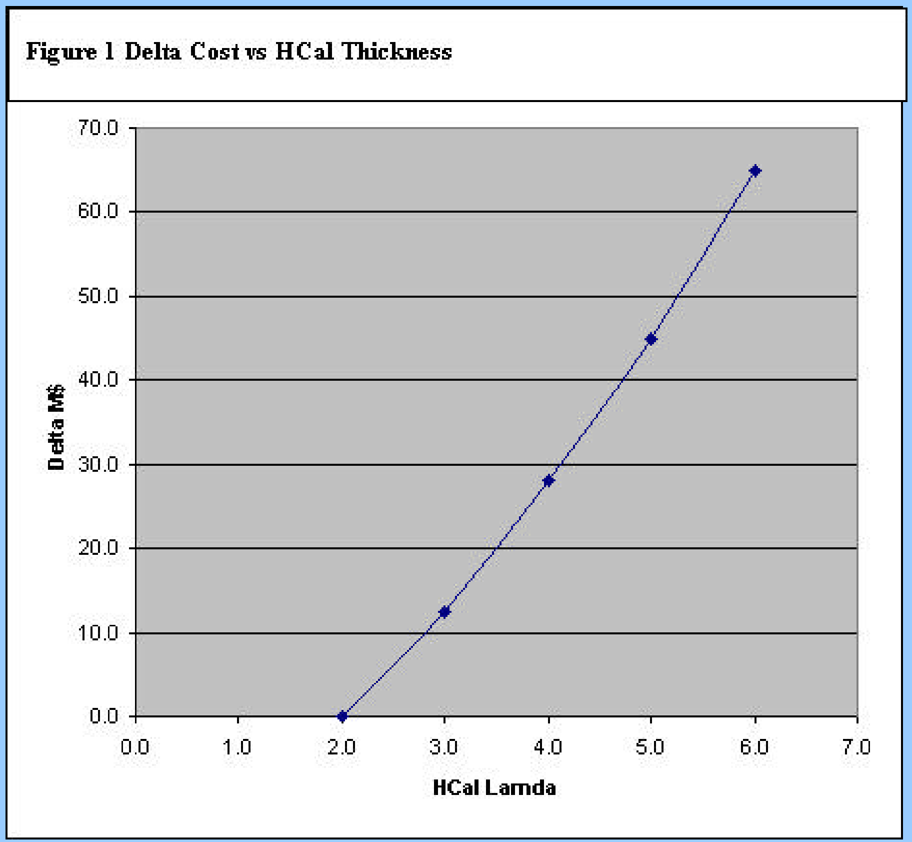
HE IR	
L	359 M$
SD	295 M$
LE IR	
P	210 M$

Cost Estimates

	L	SD	P
1.1 Vertex	4.0	4.0	4.0
1.2 Tracking	34.6	12.5	23.4
1.3 Calorimeter	48.9	56.3	40.7
1.3.1 EM	(28.9)		(23.8)
1.3.2 Had	(19.6)		(16.5)
1.3.3 Lum	(0.4)		(0.4)
1.4 Muon	16.0	16.0	8.8
1.5 DAQ	27.4	38.2	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	218.0	150.0
1.9 Contingency	102.6	77.0	60.0
Total	359.0	295	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 phi 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	295 M$
P	210 M$