American Linear Collider Detector Study Status

Jim Brau
Univ. of Oregon

Seoul, Korea
November 4, 1999

The American study groups
- coordinators: Charlie Baltay and Paul Grannis
- organized within international studies

R&D is now being funded in America
- (emphasizing simulation)

Studies are underway at Fermilab
- evaluate value added by future collider to LHC

Working toward Berkeley meeting in Feb/Mar 2000,
and Fermilab meeting in Oct 2000.

Study of the Physics and Detectors for Future Linear e^+e^- Colliders

Paul Grannis and Charles Baltay, Coordinators

1. **Detector & Physics Simulations**
   Mike Peskin, Tim Barklow, Richard Dubois

2. **Vertex Detector**
   Jim Brau, Tim Bolton

3. **Tracking**
   Keith Riles, Dean Karlen, Chris Hearty

4. **Particle I.D.**
   Hitoshi Yamamoto, Richard Stroynowsky

5. **Calorimetry**
   Frank Porter, Ray Frey

6. **Muon Detector**
   Dave Koltick, Gene Fisk

7. **Data Acquisition/Electronics**
   Tony Barker, Bob Jacobsen

8. **Higgs**
   Rick Van Kooten, Bill Marciano

9. **SUSY**
   Teruki Kamon, Bob Hollebeek, H. Murayama, U. Nauenberg

10. **Other New Particles**
    Slawek Tkaczyk, Joanne Hewett

11. **Top Physics**
    Dave Gerdes, Andreas Kronfeld

12. **QCD, Two Photon**
    Bruce Schumm, Lance Dixon

13. **Electroweak, Strong Gauge Interactions**
    Tim Barklow, Mike Peskin

14. **e-e-, e-gamma, gamma-gamma Options**
    Karl Van Bibber, Clem Heusch, Les Rosenberg

15. **Interaction Regions, Backgrounds**
    Tom Markiewicz, Stan Hertzbach

R&D Program

300 k$+ program this year
200 k$ SLAC
100 k$ Fermilab
(75 k$ requested from NSF)

Emphasis this year on simulation

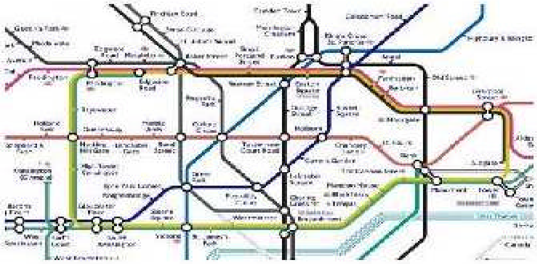
Proposals were reviewed by
C. Prescott (SLAC) -chair
T. Shalk (UCSC), A. Goshaw (Duke)
A. White (UT-Arl.), J. Huth (Harvard)

Next Year: more $?
Eventually advance to prototyping

at Fermilab

Circle Line

Circle Line Tours



Prologue:

Wednesday, September 8, 1999: Fermilab Colloquium

Peter Zerwas (DESY) "Linear Collider Physics with High Luminosity"

Circle Line Tour Seminars:

September 9, 1999, Ian Hinchliffe (LBL)

"Supersymmetry Studies at the LHC"

September 10, 1999, Michael Peskin (SLAC)

"Supersymmetry Studies at Lepton Colliders"

October 21, 1999, Hitoshi Murayama (LBL)

"Higgs and Susy Higgs Studies at a Linear Collider"

October 28, 1999, Daniel Denegri (Saclay)

"Higgs and Susy Higgs Studies at the LHC"

November 11, 1999, Bill Marciano (BNL)

"Muon Collider Physics Opportunities"

December 2, 1999, Sekhar Chivukula (Boston University)

"Strong Dynamics and Technicolor at Future Colliders"

More to come . . .

Convenors: Paul Grannis and Chris Quigg

Two American Detector Models

We have been investigating two specific models

- Choosing any particular detector design is a compromise between competing constraints
  Example:
  1. large tracking volume desirable to optimize tracking resolution
  2. small tracking volume minimizes the volume of the electromagnetic calorimeter
     -> allows aggressive EM calorimeter option

- investigated the <u>two</u> detector models

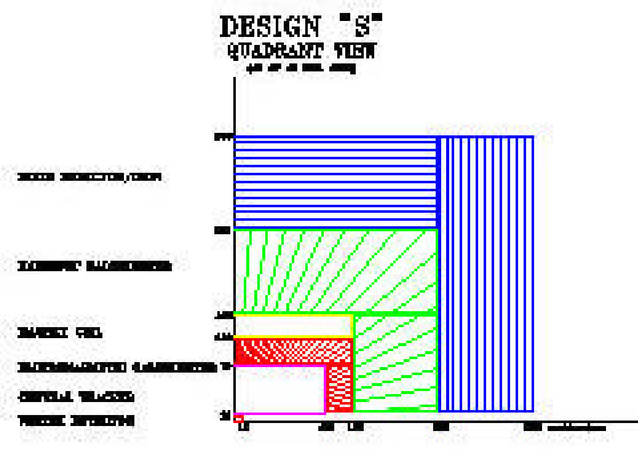
  without prejudice
  to understand trade-offs in performance
  to consider feasibility and identify R&D needs

- The Models were selected to test two different choices for detector configuration:

1. Model L (so far L1 and L2)
    - large detector
    - large tracking volume
        - -> optimal tracking resolution
    - large radius calorimeter
        - -> optimal separation of calorimeter clusters
    - size limits magnetic field
        - -> may limit vertex detector inner radius due to pairs

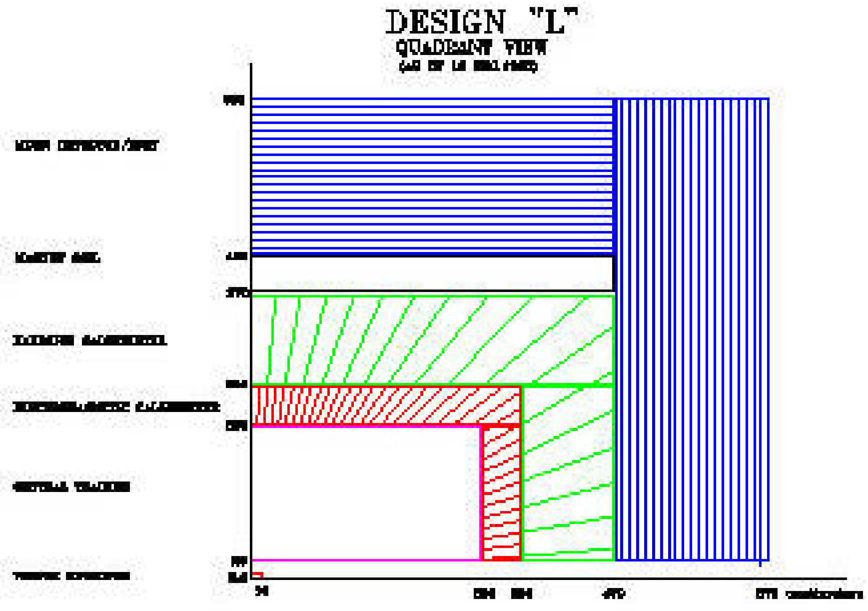
2. Model S (so far S1 and S2)
    - small detector
    - small radius detector
        - -> allows largest magnetic field
    - small radius calorimeter
        - -> allows aggressive calorimeter options
            - high granularity EM (Si/W)
    - large magnetic field
        - -> allowing e^- pair containment and close vertex detector

S1



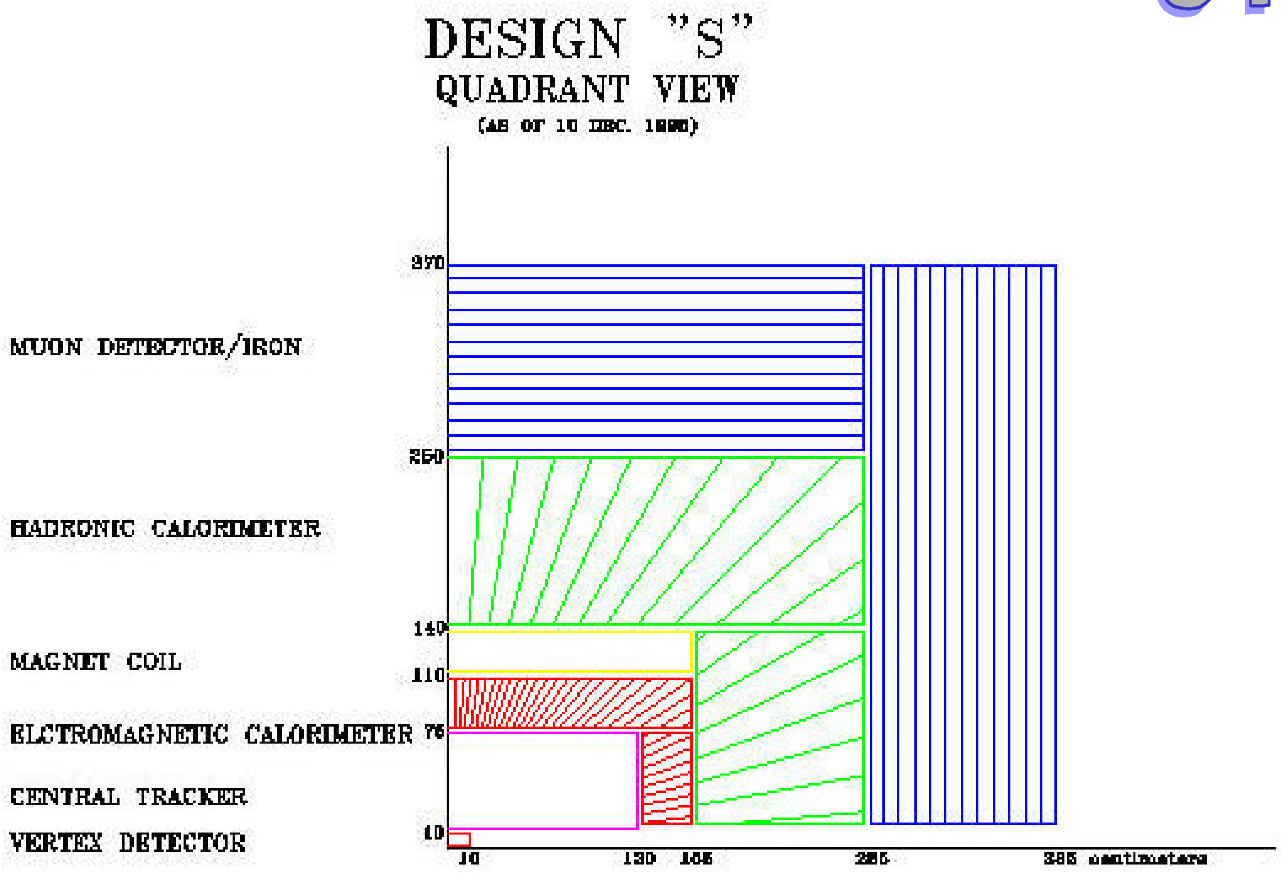
B=6T

L1



B=3T

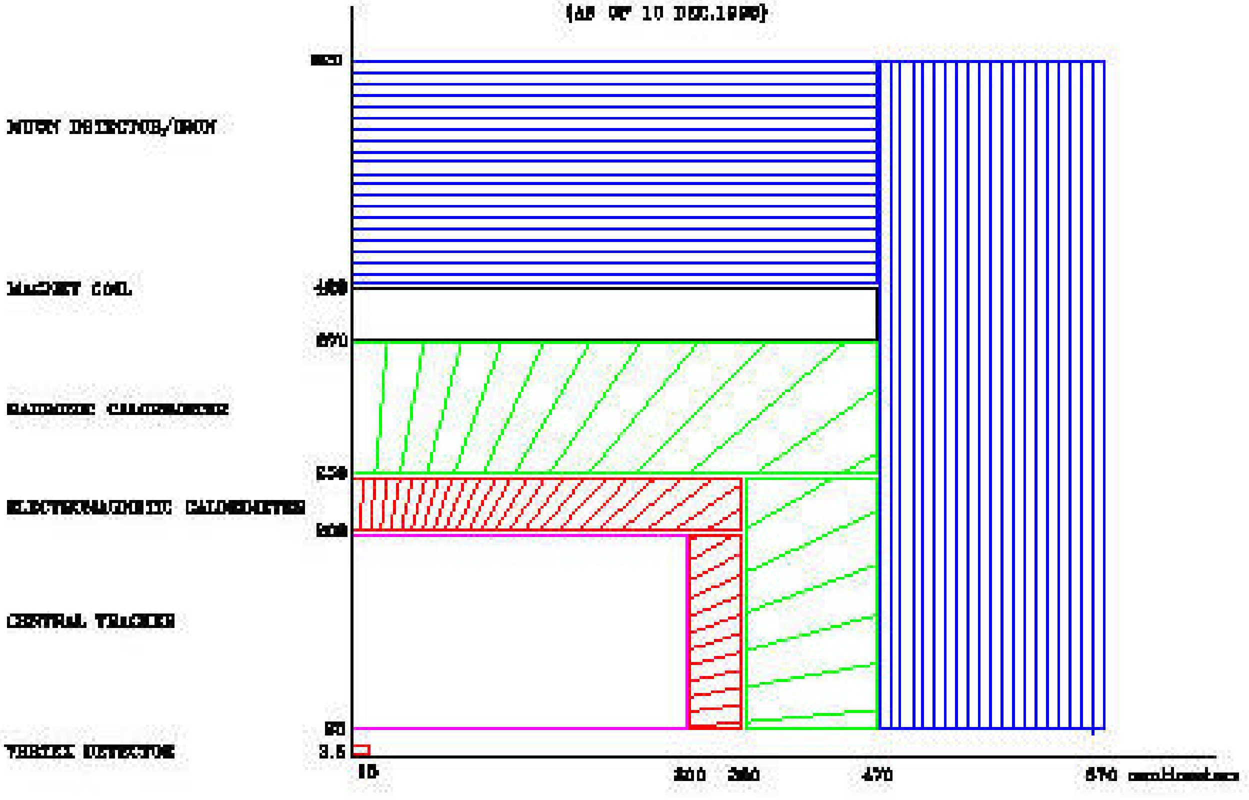
S1


DESIGN "S"
QUADRANT VIEW
(AS OF 10 DEC. 1996)
MUON DETECTOR/IRON
HADRONIC CALORIMETER
MAGNET COIL
ELCTROMAGNETIC CALORIMETER
CENTRAL TRACKER
VERTEX DETECTOR
370
250
140
110
76
10
10
130
185
285
385 centimeters

B=6T

L1

DESIGN "L"
QUADRANT VIEW
(AS OF 10 DEC.1998)



B=3T

Evolution of the Designs

The first designs (L1 and S1) were defined in the Fall of 1998, and they were used for the Sitges studies

These designs (L1 and S1) were held fixed to stabilize the studies, and we have now defined an updated set of parameters (L2 and S2) for the new studies.

Forward tracking added to L design

Smaller radius vert.det. in L design

Finer calorimeter segmentation

North American Simulations

R.Dubois

- Full Simulation
  - flexible geometry specs within some constraints
  - what you get
  - platform support
  - MC Farms

- Fast MC
  - track smear strategy
  - Calorimeter smear

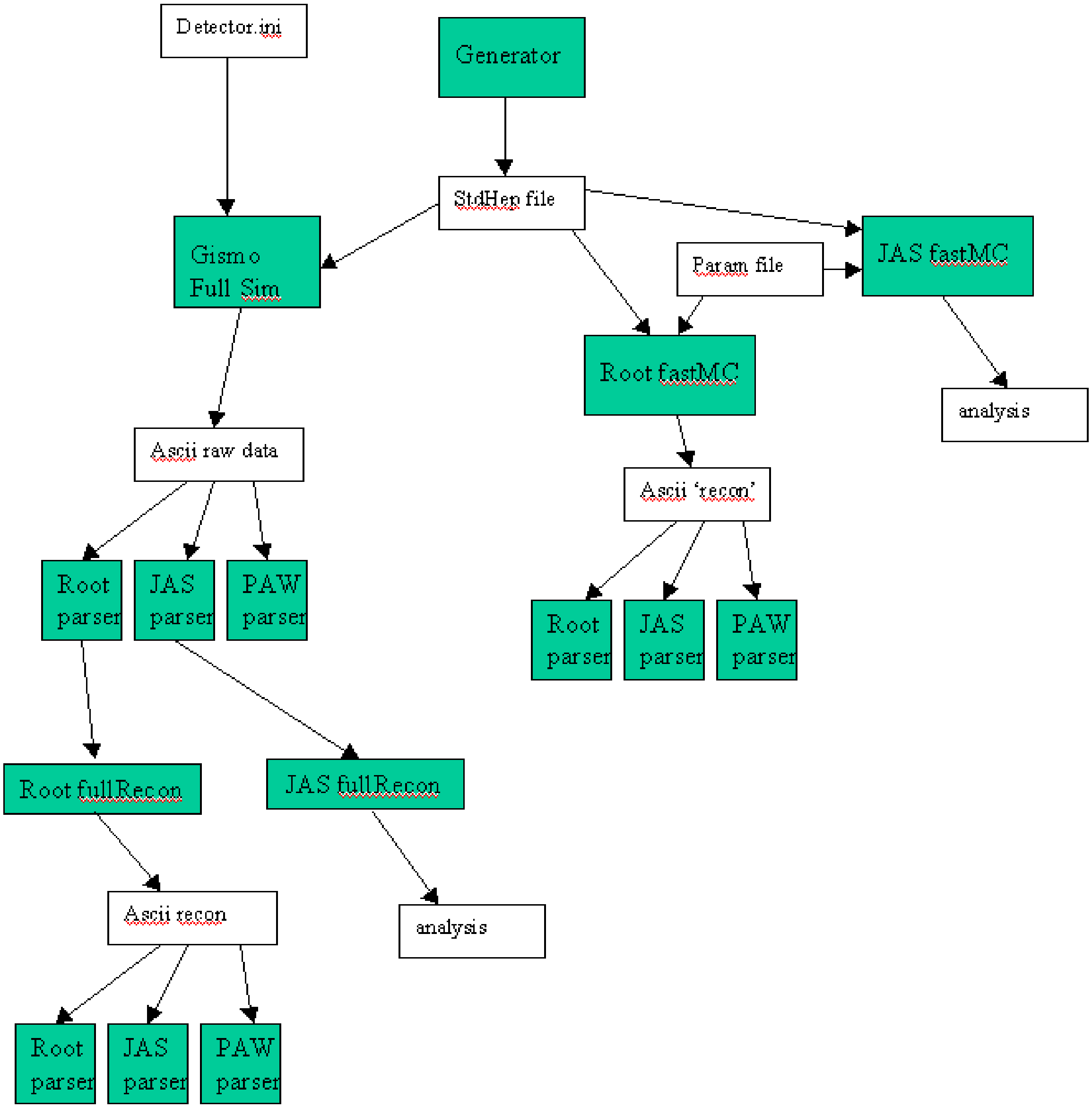
- Use New Tools for Analysis
  - using Root for simulation analysis and FastMC
  - using JAS for all phases
- Plans
  - GEANT4
  - parameters handling
  - event display

30 April 1999

LCWS'99
Sitges, Spain

American LCD Code

LCD Road Map



Detector.ini

Generator

StdHep file

Gismo Full Sim

Param file

JAS fastMC

Root fastMC

analysis

Ascii raw data

Ascii 'recon'

Root parser

JAS parser

PAW parser

Root parser

JAS parser

PAW parser

Root fullRecon

JAS fullRecon

Ascii recon

analysis

Root parser

JAS parser

PAW parser

Tracking

Model L

- optimal resolution
  σ/BL^2
- large radius allows largest track length, leadi
  best resolution

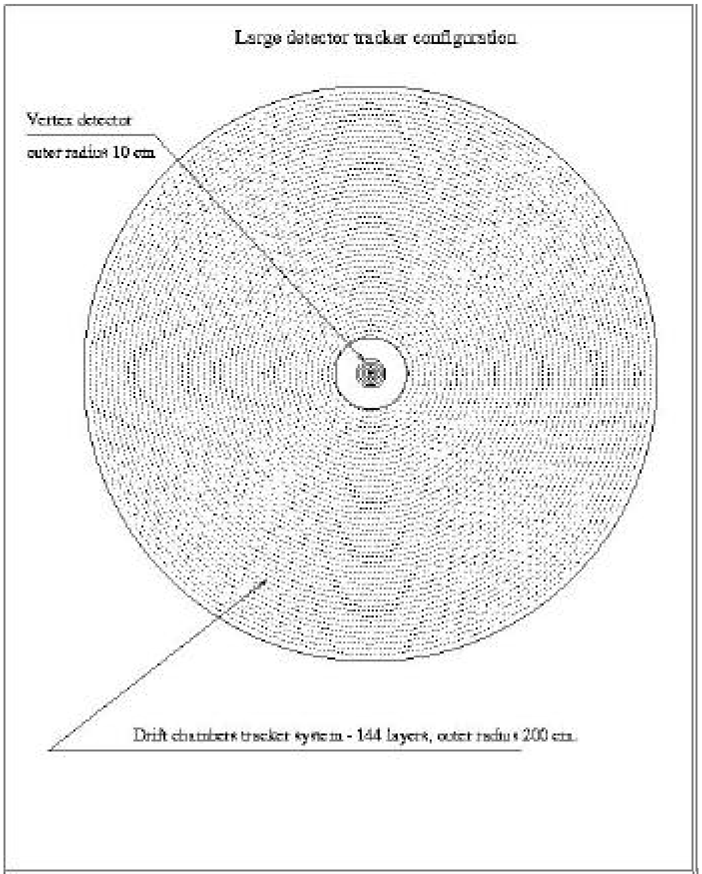
Model S

- smaller tracking volume lead to choice
  of high precision measurements (silicon)
- but silicon has unavoidable larger material
  budget -> multiple scattering
- low momentum resolution compromised by
  multiple scattering

Tracking

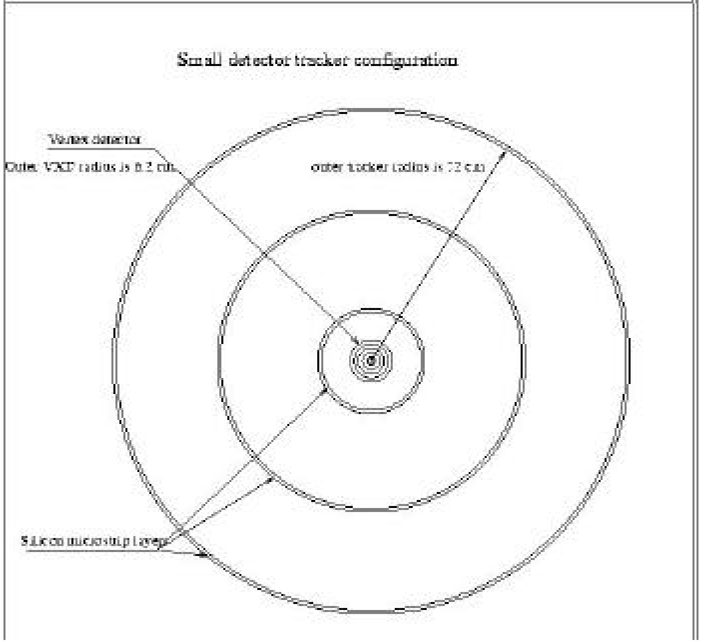
Model L1

TPC


Large detector tracker configuration

Model S1

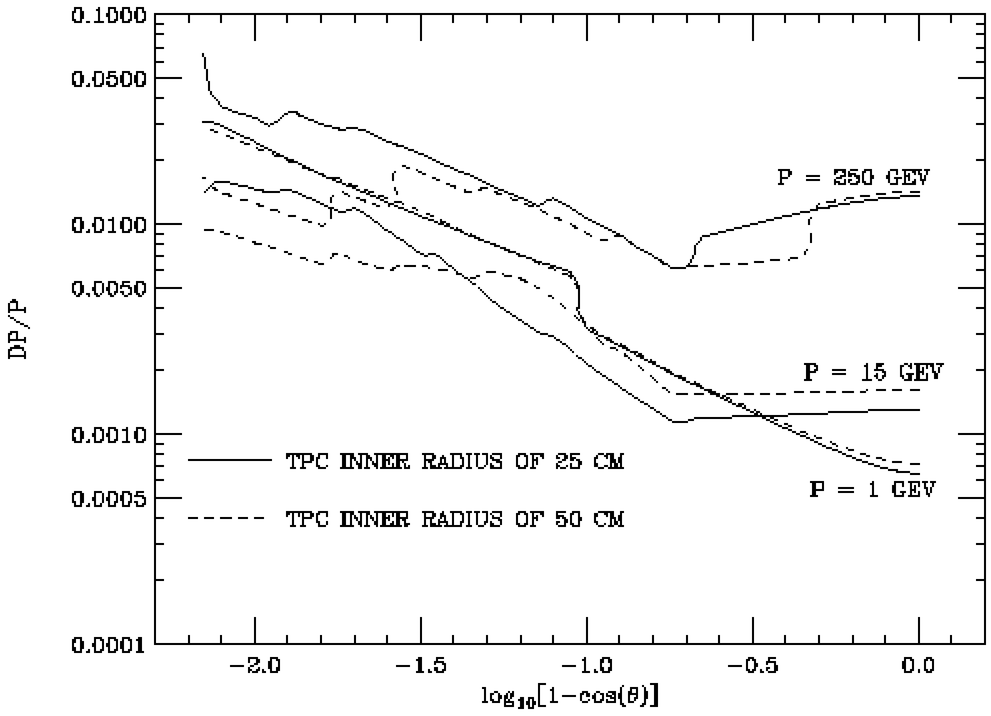
Silicon Drift


Small detector tracker configuration

Revised Tracking: L2

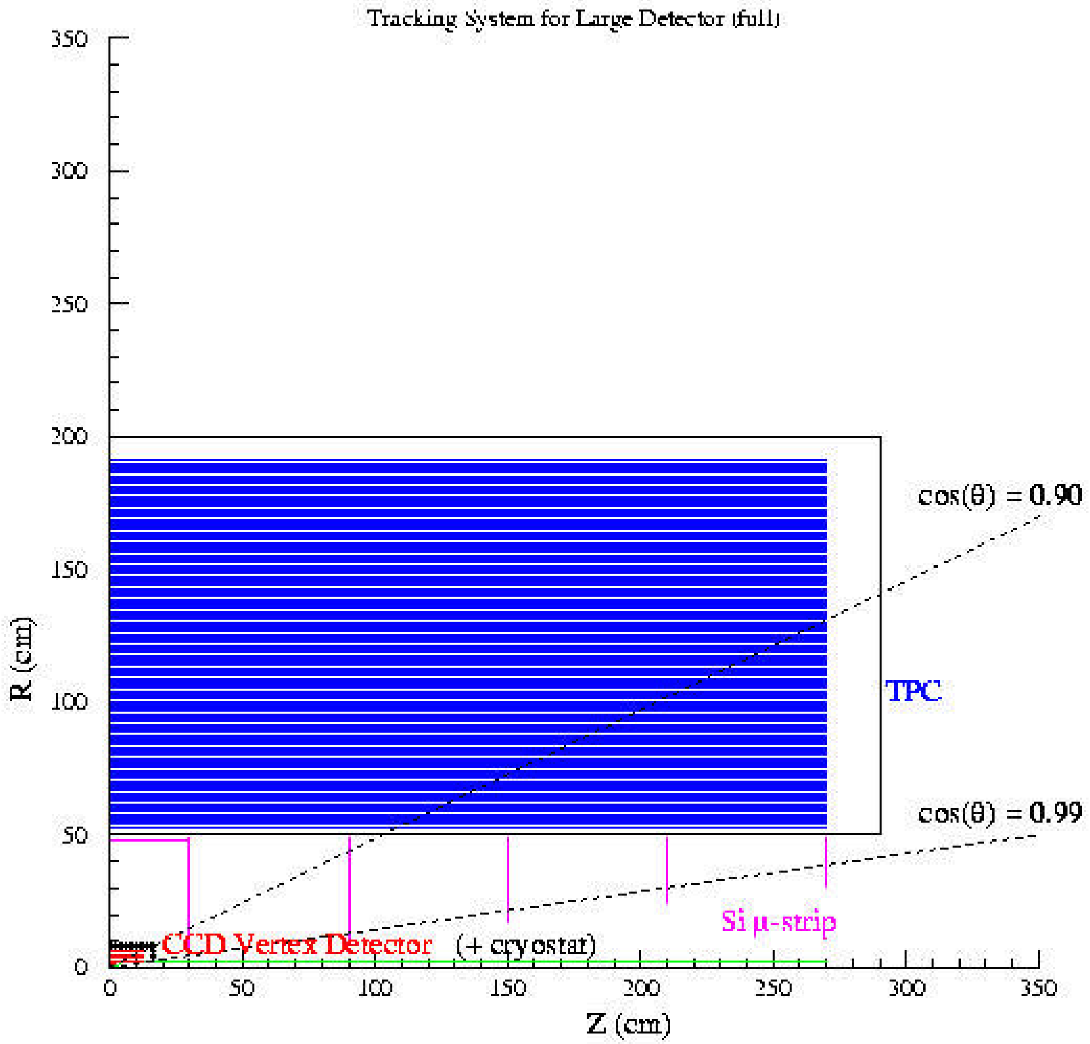
L2 forward tracking

⇒ increase TPC inner radius

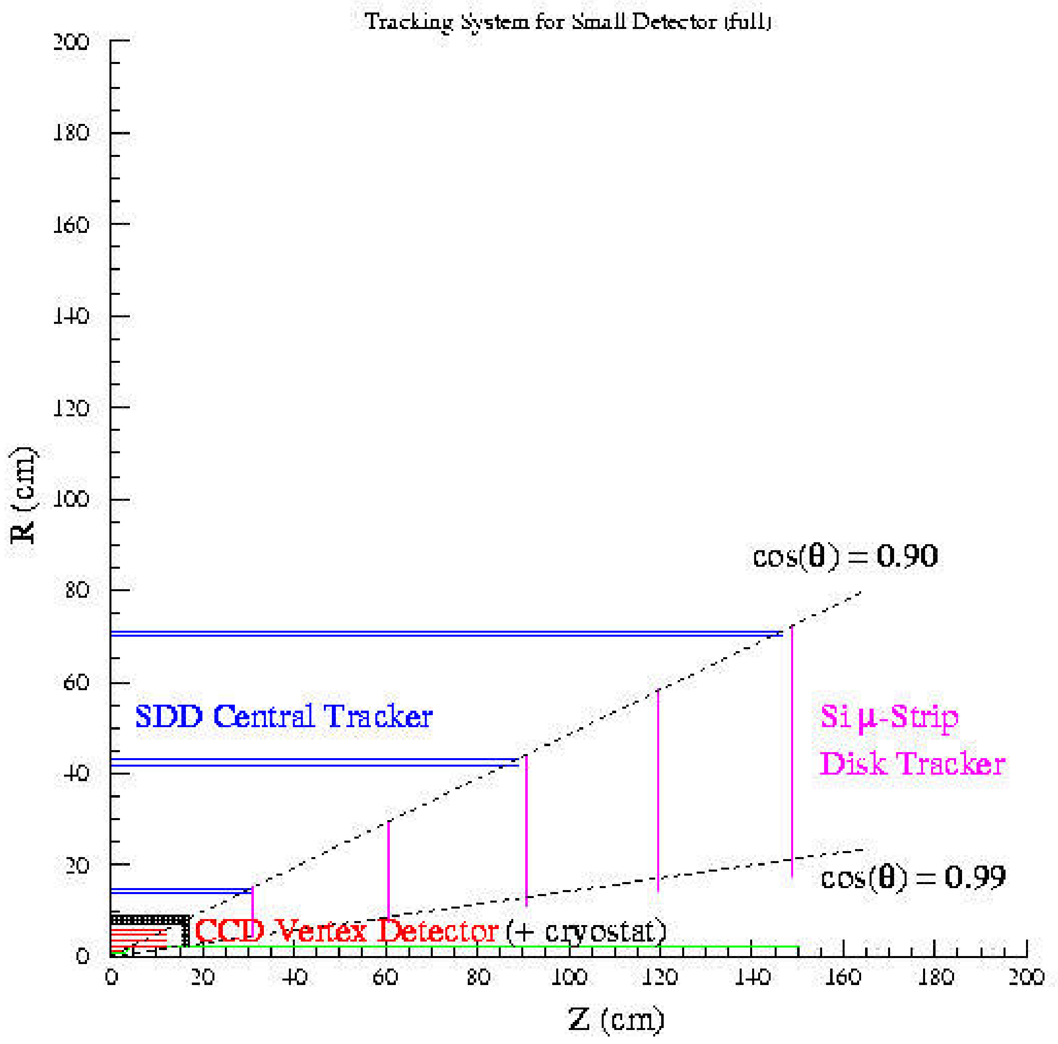


⇑ cos θ =0.90 ⇑ cos θ =0.99 ⇑ cos θ =0.0

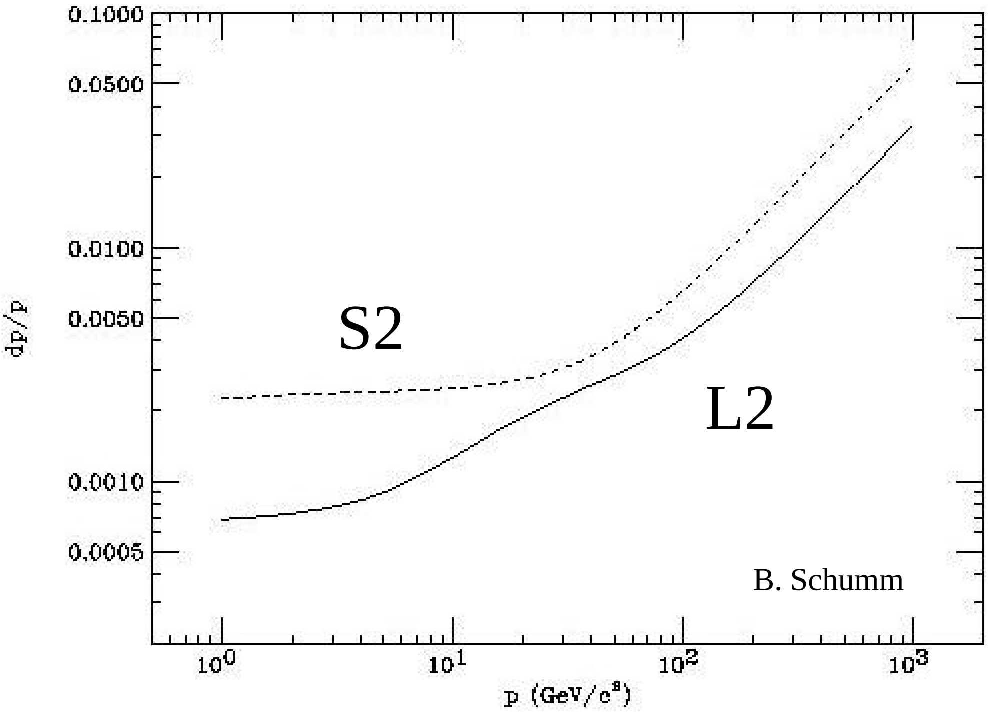
L2 Tracking


Tracking System for Large Detector (full)
R (cm)
Z (cm)
0
50
100
150
200
250
300
350
0
50
100
150
200
250
300
350
cos(θ) = 0.90
cos(θ) = 0.99
TPC
Si μ-strip
CCD Vertex Detector
(+ cryostat)

S2 Tracking


Tracking System for Small Detector (full)
R (cm)
Z (cm)
0
20
40
60
80
100
120
140
160
180
200
cos(θ) = 0.90
cos(θ) = 0.99
SDD Central Tracker
Si μ-Strip
Disk Tracker
CCD Vertex Detector (+ cryostat)

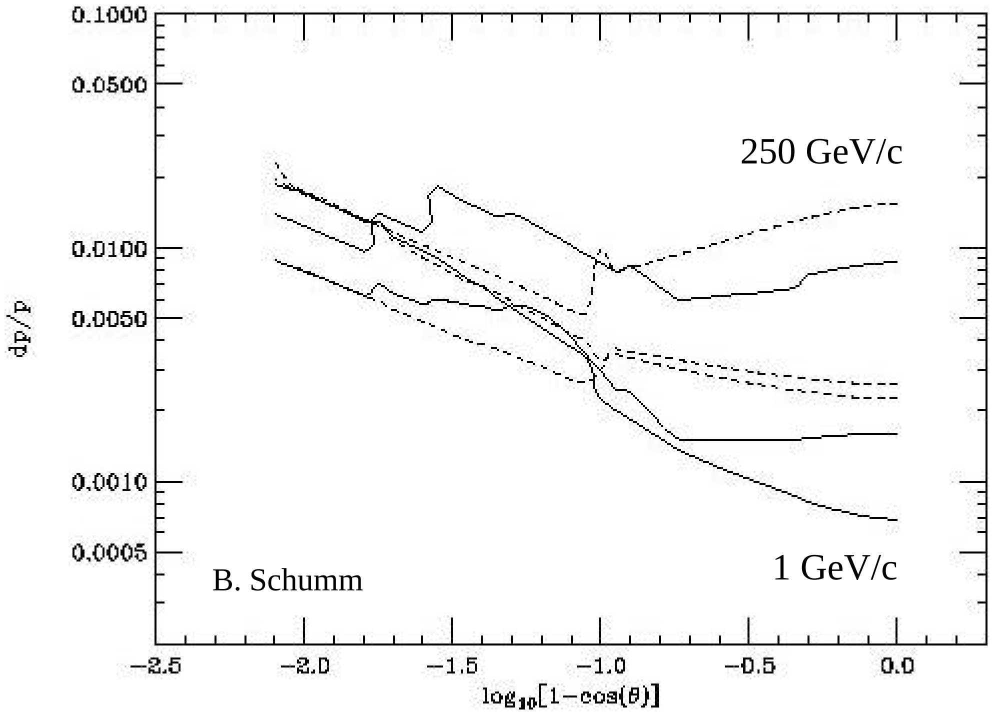
Tracking Resolution



Note: high p advantage for L2 derives from intermediate silicon tracker

Tracking Resolution

1, 15, and 250 GeV/c
L2 (solid) and S2 (dashed)



⇑ $\cos\theta = .99$ ⇑ $\cos\theta = .90$ ⇑ $\cos\theta = 0.0$

Vertex Detector

both detectors assume 5 barrel CCD (5 μm point res.),

Model S

small radius outer detector allows largest
beam-pair constraining with B field
closest to IP (R= 1.2,2.4,3.6,4.8,6.0 cm)

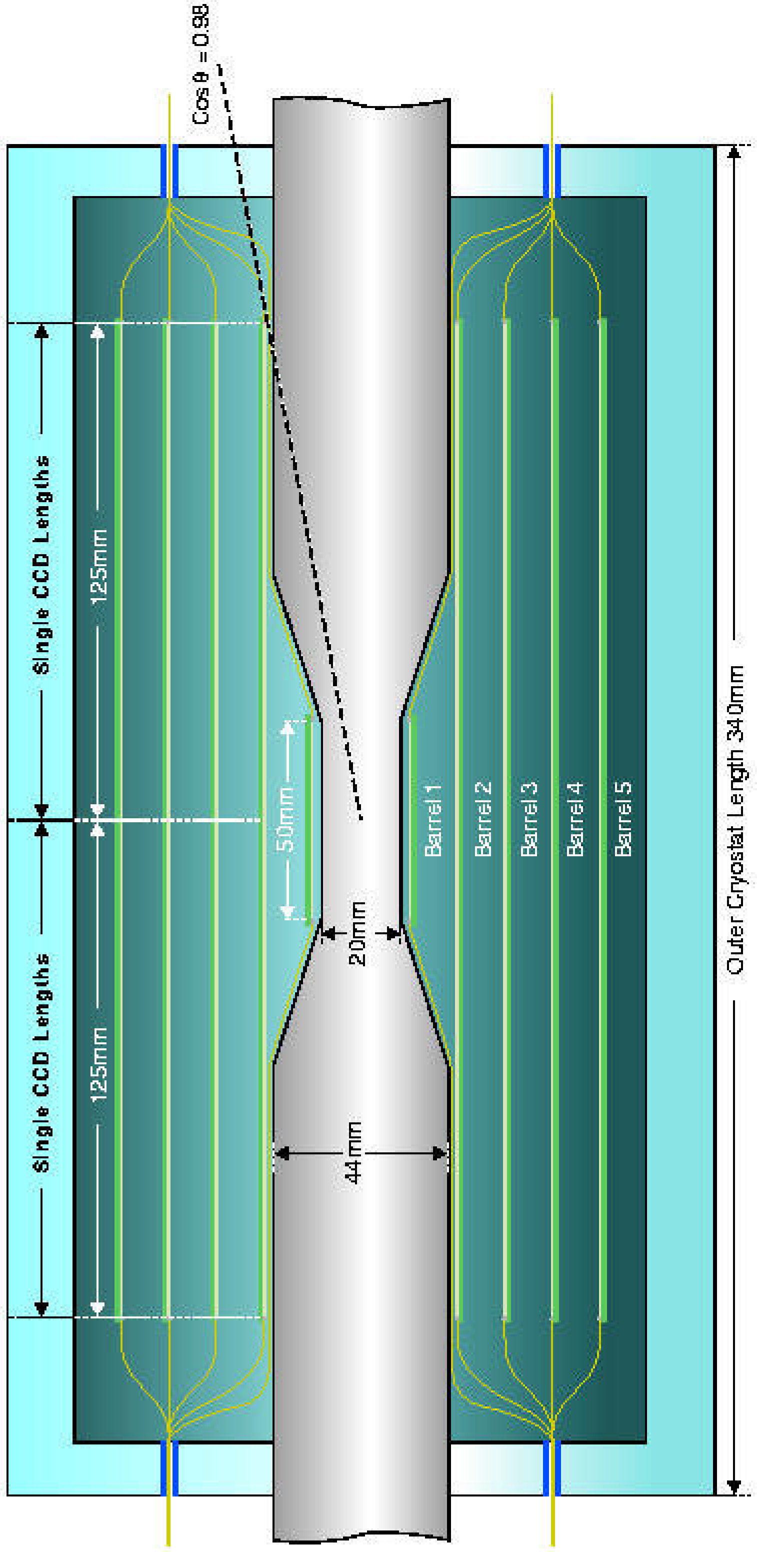
Model L

expect larger backgrounds in the vertex
detector due to smaller magnetic field
L1 assumed 2.4cm inner radius, but
L2 has same VXD as S1 &S2

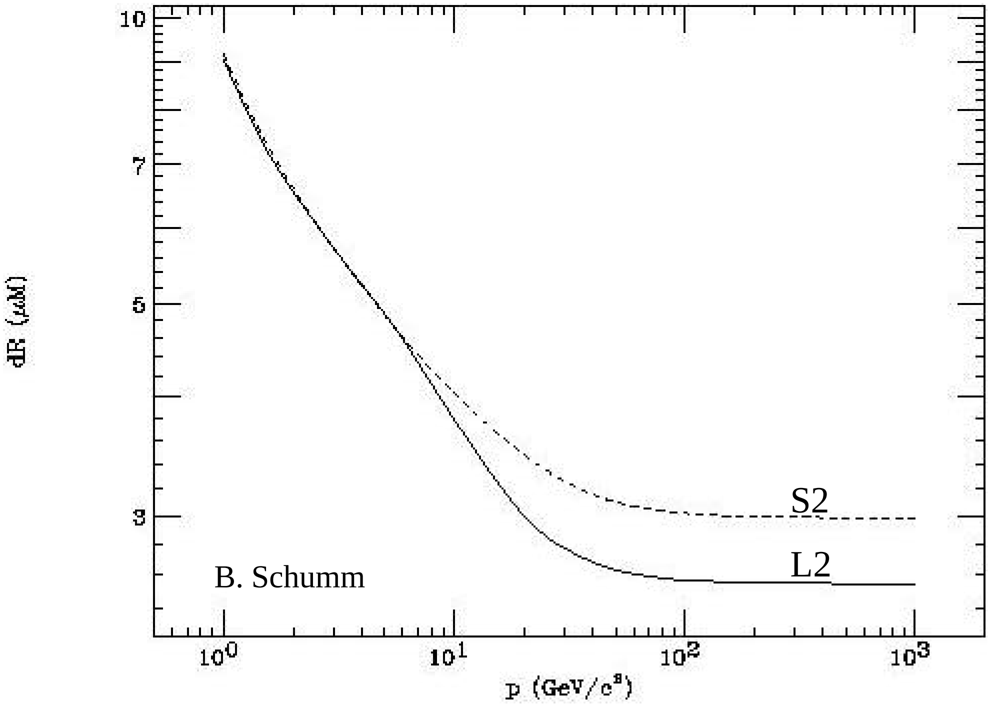
Both → stand-alone tracking

C. Damerell

Suggested layout of Vertex Detector for future e^+e^- Linear Collider (Updated November 1998)



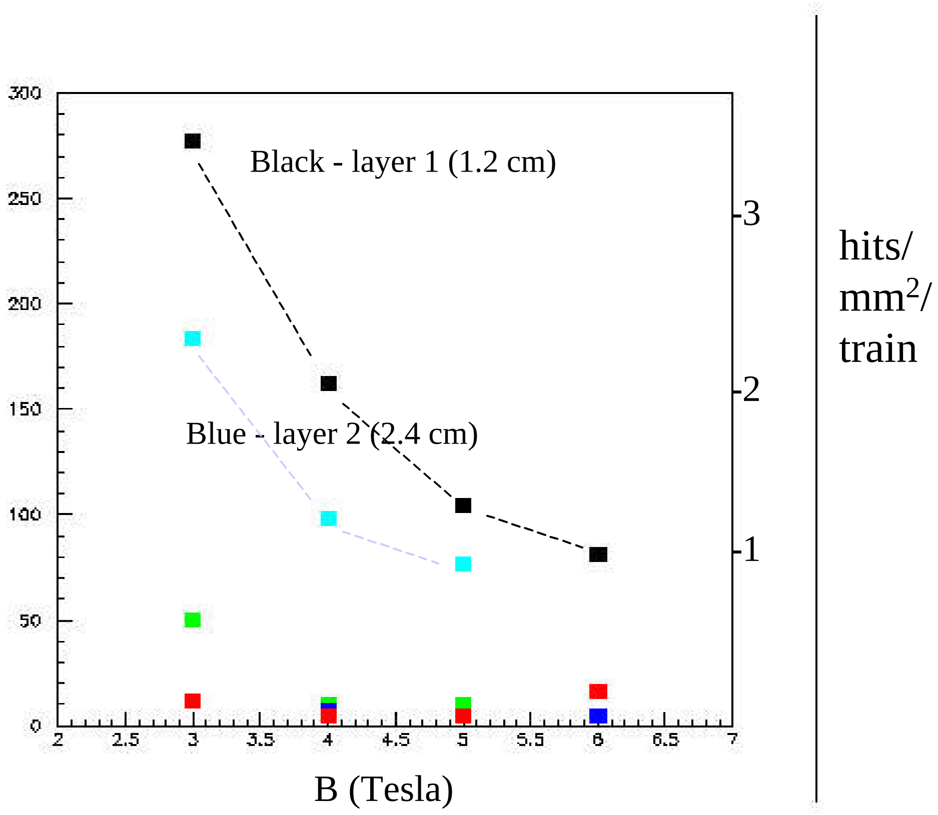
Vertex Detector Resolution



Thin beryllium rings along beam-line reduces backgrounds:

J. Gronberg LLNL 3

Small detector backgrounds with low fields



The beryllium ring reduces the VXD inner layer backgrounds to acceptable levels, even for the lower magnetic field values

IR meeting - September 13, 1999

Radiation Hardness Tests of CCDs

Nick Sinev

LC Background estimates have varied from 10^7 n/cm^2/year
to 10^{11} n/cm^2/year
NOW- best est. 2 x 10^9 n/cm^2/year (Maruyama)

Expected tolerance for CCDs
in the range of 10^9 (C. Damerell) - more study needed

In addition, can one develop procedures to <u>increase tolerance</u>

Radiation damage studies are called for
- improve understanding of issues and sensitivity
- improve radiation hardness
  - flushing techniques
  - bucket shrinking
  - supplementary channels

History of Exposures

(spare SLD VXD3 CCD)

Nov 98	$\sim 2 \times 10^{9}$ n/cm^{2} Pu(Be) $\langle E_n \rangle \approx 4$ MeV	room temperature
Dec98 -Jan 99	Annealing study	100° C for 35 days
Mar 99	$\sim 3 \times 10^{9}$ n/cm^{2} reactor* neutrons $\langle E_n \rangle \approx 1$ MeV ($\sim 1 \times 10^{9}$ n/cm^{2} lower energy)	room temperature
Apr 99	$\sim 1.5 \times 10^{9}$ n/cm^{2} reactor* neutrons $\langle E_n \rangle \approx 1$ MeV ($\sim 1 \times 10^{9}$ n/cm^{2} lower energy)	dry ice cooled (~190K)

Total exposure $\sim 6.5 \times 10^{9}$ n/cm^{2}
mix of source and reactor

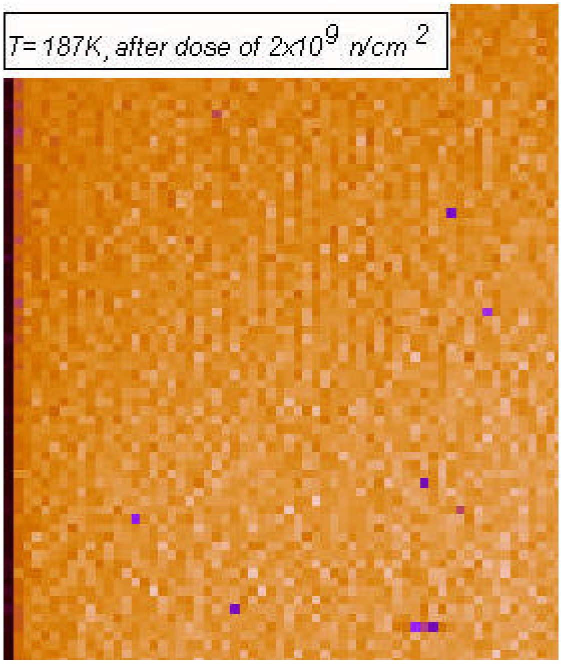
* UC Davis (G. Grim et al)

Defect Results from Exposures

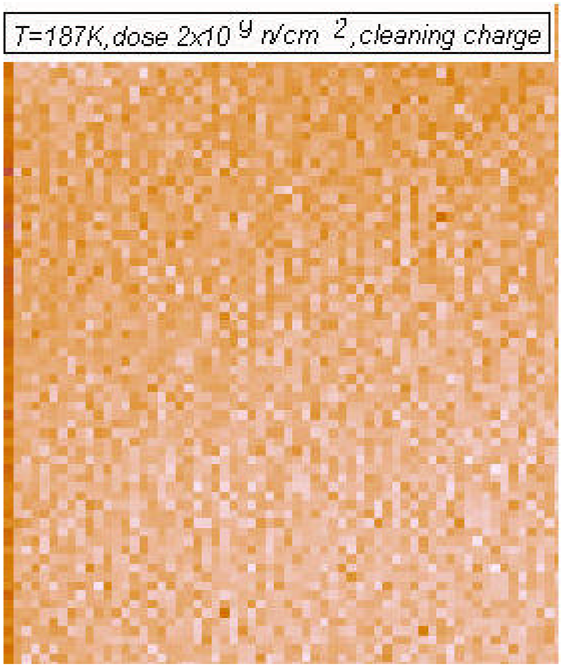
	# defect (> 6 e^-) 800,000 pixels	# defect (>20e^-) 800,000 pixels
Prior to exposure	125	24
Nov 98 exposure ~ 2 × 10^9 n/cm^2 source	916	160
Mar 99 exposure × 10^9 n/cm^2 reactor	5476	442*
Apr 99 exposure + ~ 1.5 × 10^9 n/cm^2 reactor	7036	298*

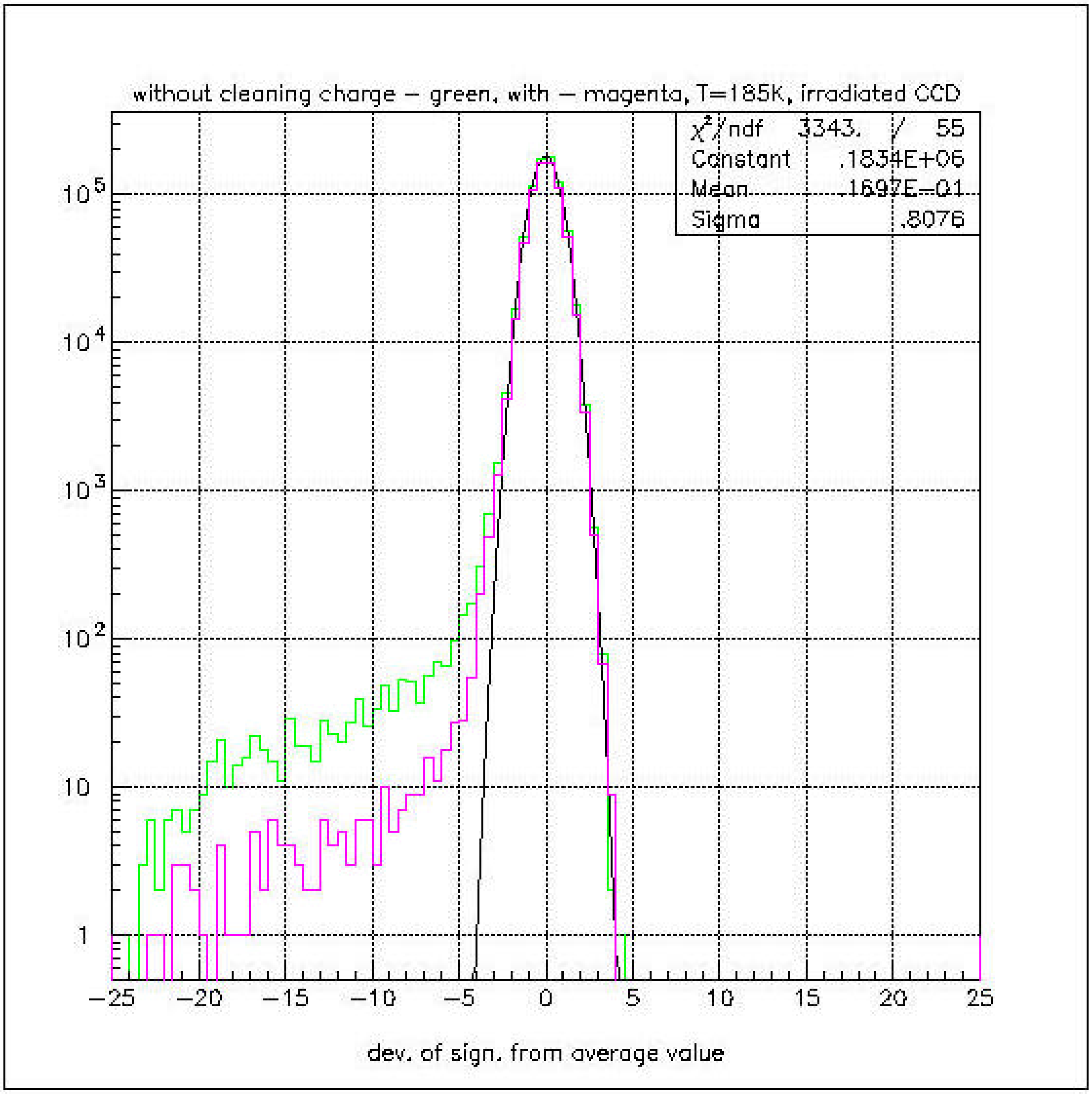
* this surprising decrease
is not understood

Read-out image
after 1st exposure,
showing defect sites



Read-out image
after 1st exposure,
with flushing charge,
showing removal of
defect sites





Flushing technique had been demonstrated; needs to be optimized

For more details on this study see the contribution to the 1999 Seattle NSS:
http://blueox.uoregon.edu/~jimbrau/talks/IEEE99/ieee99.PDF

Calorimeter

Model S1

$\sigma_{EM} / E = (12\% / \sqrt{E}) \oplus (1\%)$

W/silicon pads (1.5 × 1.5 cm^2 pads)

High granularity!

29 X_0, readout 100 longitudinal (potential)

$\sigma_{Had} / E = (50\% / \sqrt{E}) \oplus (2\%)$

Cu/scintillator (40 × 40 $mrad^2$)

76 cm Cu

$l_{EM+Had} = 6.1\ \lambda$

Model L1

$\sigma_{EM} / E = (15\% / \sqrt{E}) \oplus (1\%)$

Pb/scintillator (40 x 40 $mrad^2$)

28 X_0

$\sigma_{Had} / E = (40\% / \sqrt{E}) \oplus (2\%)$

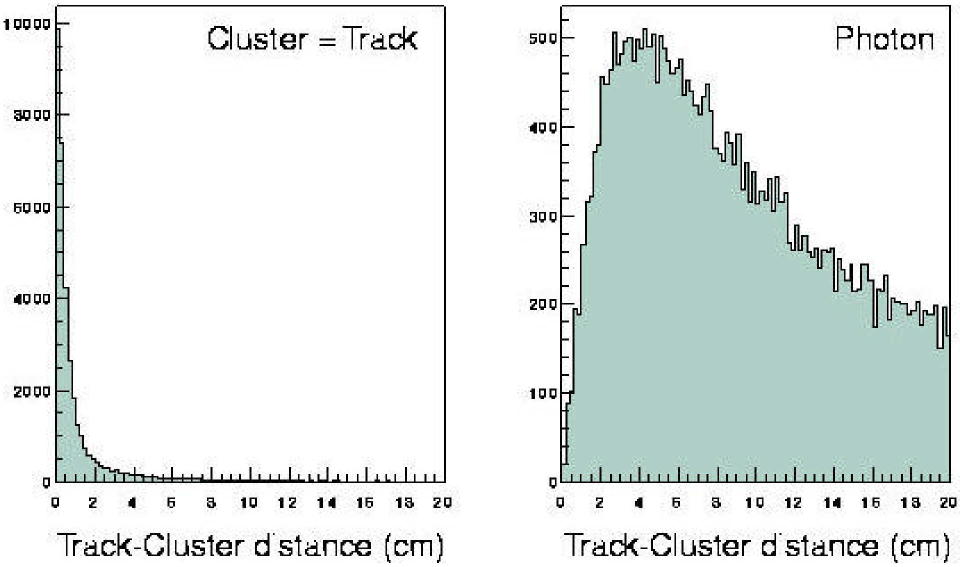
Pb/scintillator (80 x 80 $mrad^2$)

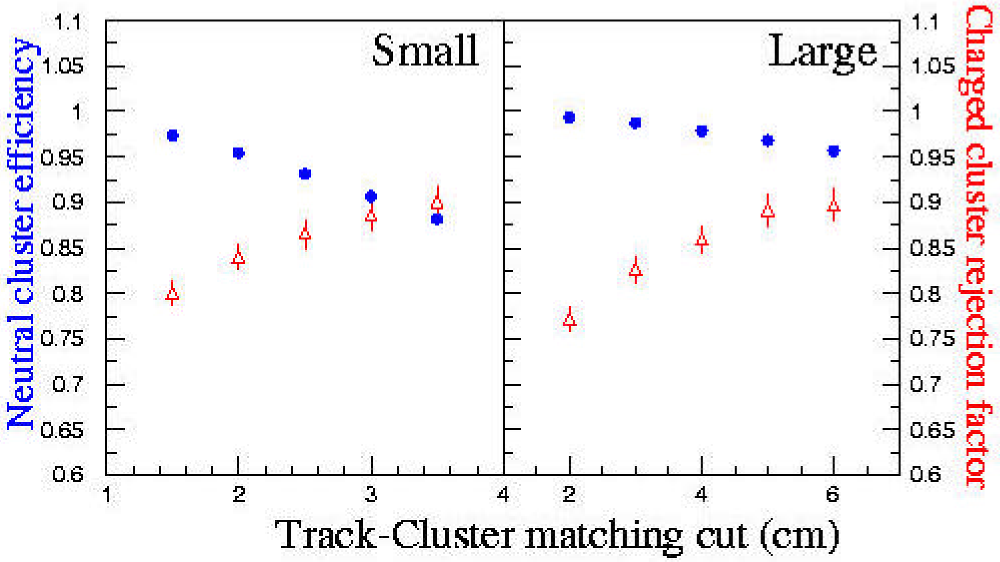
$l_{EM+Had} = 6.6\ \lambda$

Segmentation for S2 and L2 reduced to
20 x 20 $mrad^2$ for all towers

Neutral/charged cluster separation in e+e- --> t tbar

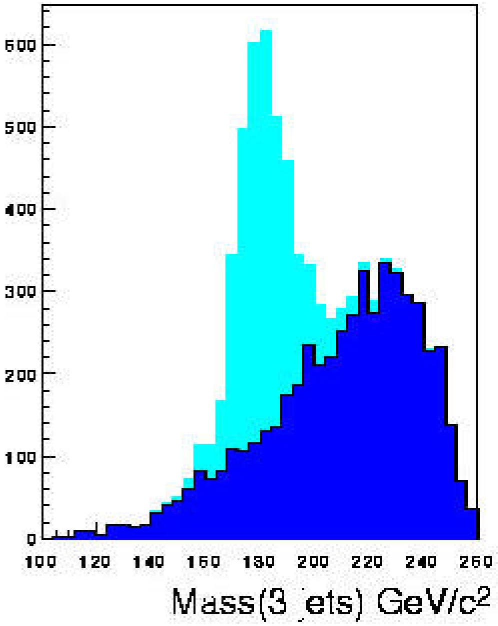
6 jet events

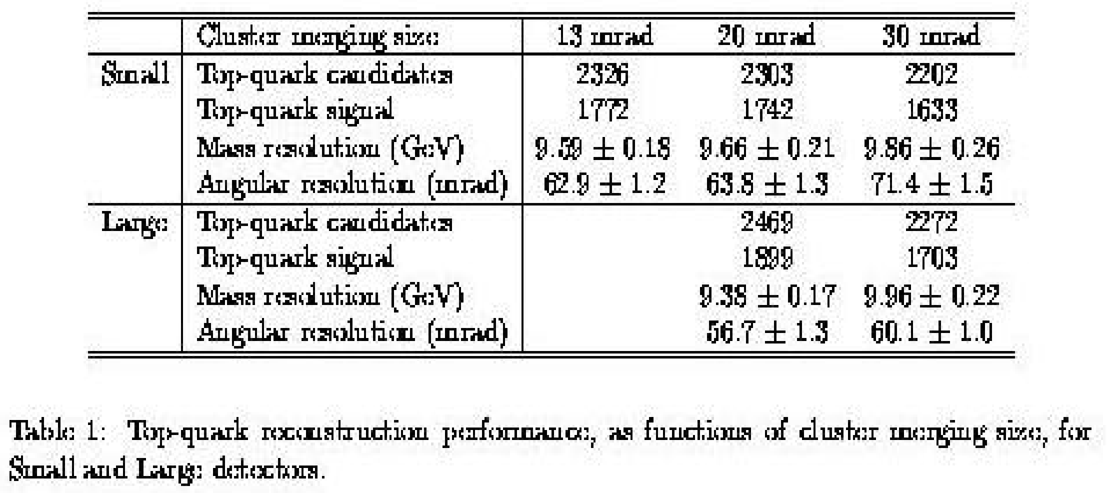




M. I*wasaki*

Neutral/charged cluster separation in e+e- --> t tbar





	Cluster merging size	13 mrad	20 mrad	30 mrad
Small	Top-quark candidates	2326	2303	2202
	Top-quark signal	1772	1742	1633
	Mass resolution (GeV)	9.59 ± 0.18	9.66 ± 0.21	9.86 ± 0.26
	Angular resolution (mrad)	62.9 ± 1.2	63.8 ± 1.3	71.4 ± 1.5
Large	Top-quark candidates		2469	2272
	Top-quark signal		1899	1703
	Mass resolution (GeV)		9.38 ± 0.17	9.96 ± 0.22
	Angular resolution (mrad)		56.7 ± 1.3	60.1 ± 1.0

Table 1: Top-quark reconstruction performance, as functions of cluster merging size, for Small and Large detectors.

M. I*wasaki*

Muon Detectors

Model S

10 × 10 cm Fe plates + gas

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

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

Particle ID

not explicitly included in S or L models

importance under study

see talk but H. Yamamoto

Some Trade-offs Being Investigated

Vertex Detection

R_{inner} => how important?
thickness => 0.12 % X_0 vs. 0.3 - 0.4 % X_0
we want excellent multiple vertex reconstruction
(cascades, eg H → b → c vs. H → c)

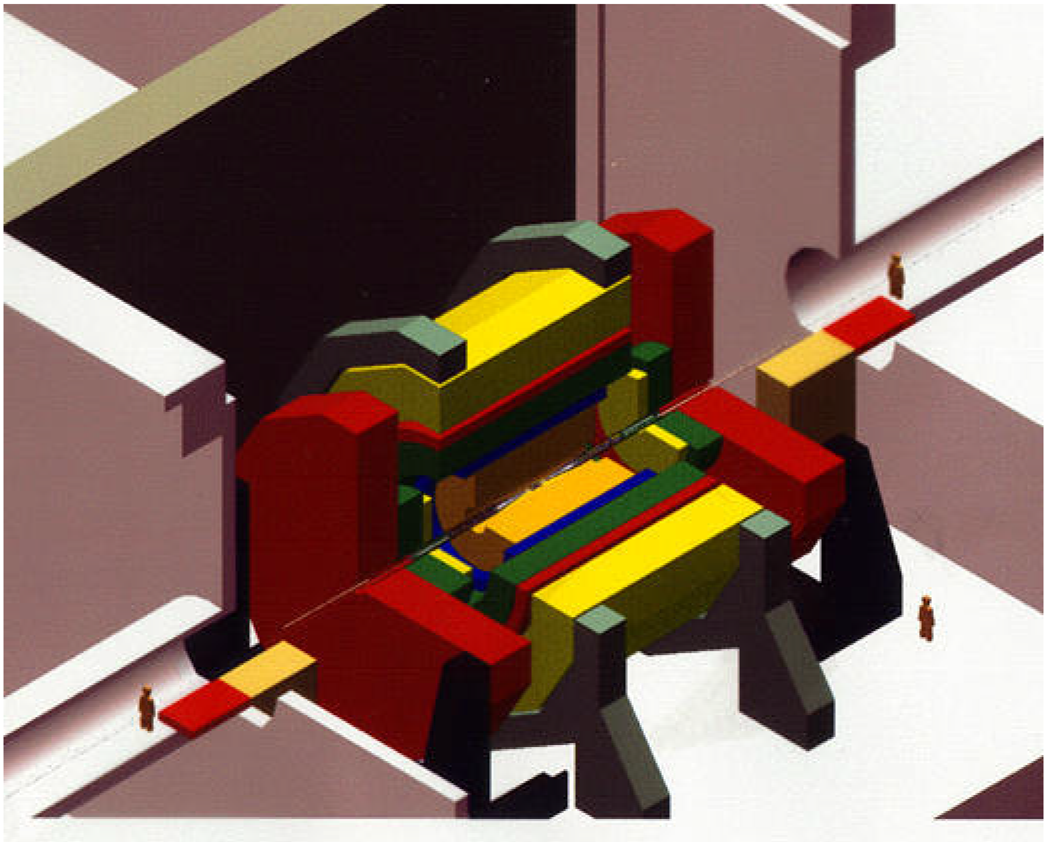
Tracking

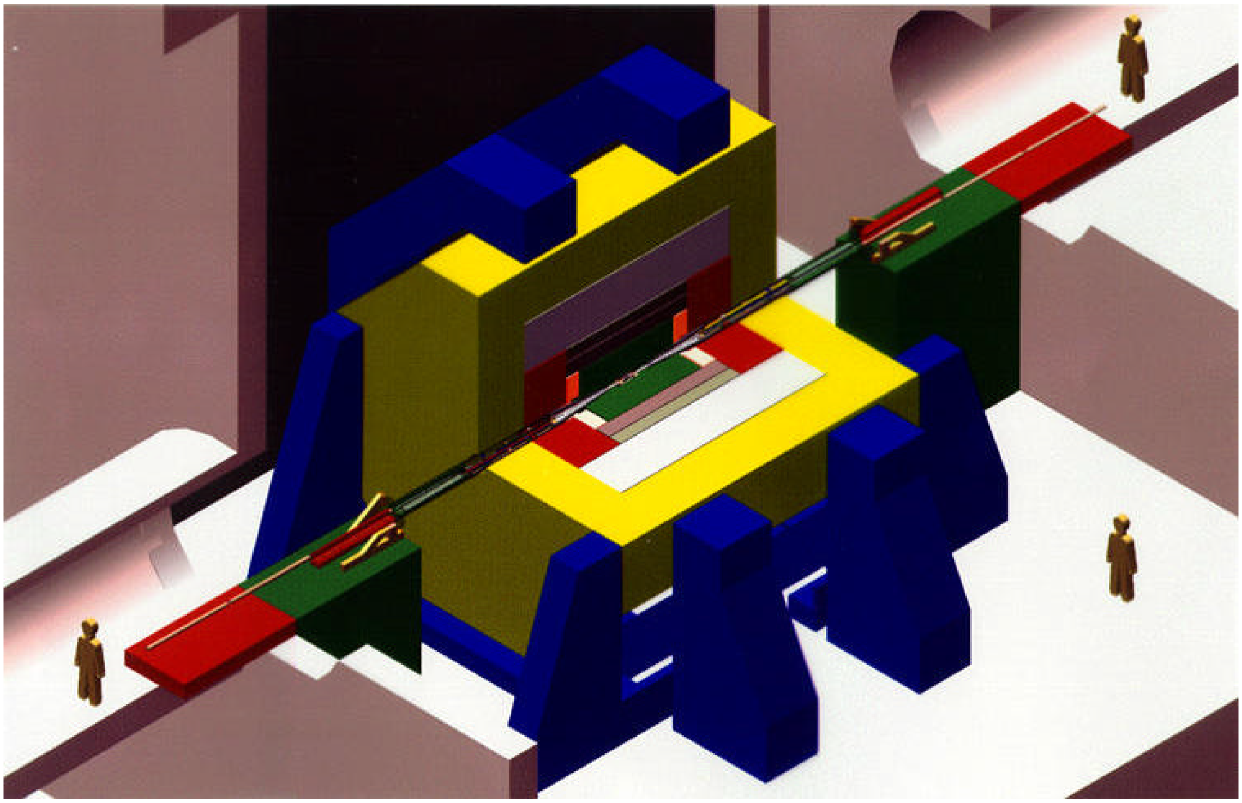
low momentum tracks
=> resolution (multiple scatt.) and efficiency
eg. $e^+e^- \rightarrow \tilde{e}^+\tilde{e}^- \rightarrow e^+e^-X$
effect of tracking resolution on flavor tagging

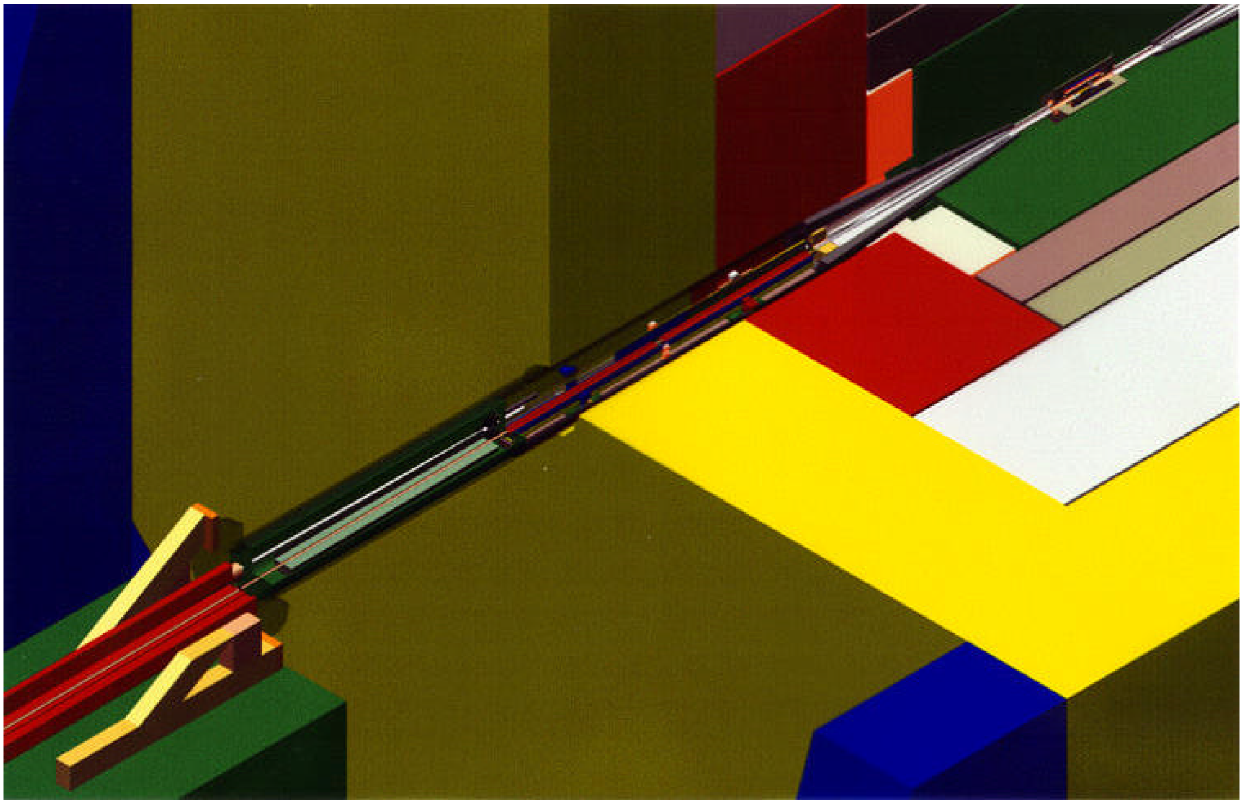
Calorimetry

“energy flow” jets vs. calorimeter jet clustering?
(energy flow = tracking + EM cal + neut.had.)
how small can R be and still untangle neutrals?
W/Z reconstruction
non-pointing gammas
eg. $\tilde{c} \rightarrow \tilde{g}g$

Physicist models are being incorportated into engineering considerations







Summary of American Activities

American working groups studying physics performance of of detector designs (L and S)

Studies underway at Fermilab (Circleline tours) comparing future colliders with LHC

R&D funding has begun, with emphasis on simulation

The American study groups have defined two un-like detectors to explore trade-offs in performance:

Model L

large tracking volume => optimal resolution
large radius calorimeter => cluster separation
B field = 3 T

Model S

small radius calorimeter => aggressive EM
large magnetic field = 6 T
good for vertexing and shower separation

Many contributions to Sitges meeting, but trade-offs are still being studied

Working toward meetings:

March 2000 – Berkeley
Fall 2000 - Fermilab