Linear Collider Detectors

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- Many open issues for LC detectors
- Physics goals involve low event rates with relatively low backgrounds
  - opportunity for novel approaches

The “next” Linear Collider

The “next” Linear Collider proposals include plans to deliver **a <u>few hundred</u>** <u>fb</u>$^{-1}$ of integrated lum. per year

		TESLA (DESY-Germany)	JLC-C (Japan)	NLC/JLC-X * (SLAC/KEK-Japan)
L_{design}	(10^{34})	3.4 → 5.8	0.43	2.2 → 3.4
E_{CM}	(GeV)	500 → 800	500	500 → 1000
Eff. Gradient	(MV/m)	23.4 → 35	34	70
RF freq.	(GHz)	1.3	5.7	11.4
Δt_{bunch}	(ns)	337 → 176	2.8	1.4
#bunch/train		2820 → 4886	72	190
Beamstrahlung	(%)	3.2 → 4.4		4.6 → 8.8

* US and Japanese X-band R&D cooperation, but machine parameters may differ

Detector Requirements

There is perception that Linear Collider Detectors are trivial

Not true!

But requirements are orthogonal to hadron collider requirements

Here are some comparisons

Tracker thickness:

CMS	0.30 X_0
ATLAS	0.28 X_0
LC	0.05 X_0

Vertex Detector layer thickness

CMS	1.7 % X_0
ATLAS	1.7 % X_0
LC	0.06% X_0

Detector Requirements

Vertex Detector granularity

CMS	39 Mpixels
ATLAS	100 Mpixels
LC (Telsa)	800 Mpixels

ECAL granularity (detector elements)

CMS	76 x 10^3
ATLAS	120 x 10^3
LC(Tesla)	32 x 10^6

Unburdened by high radiation and high event rate, the LC can use

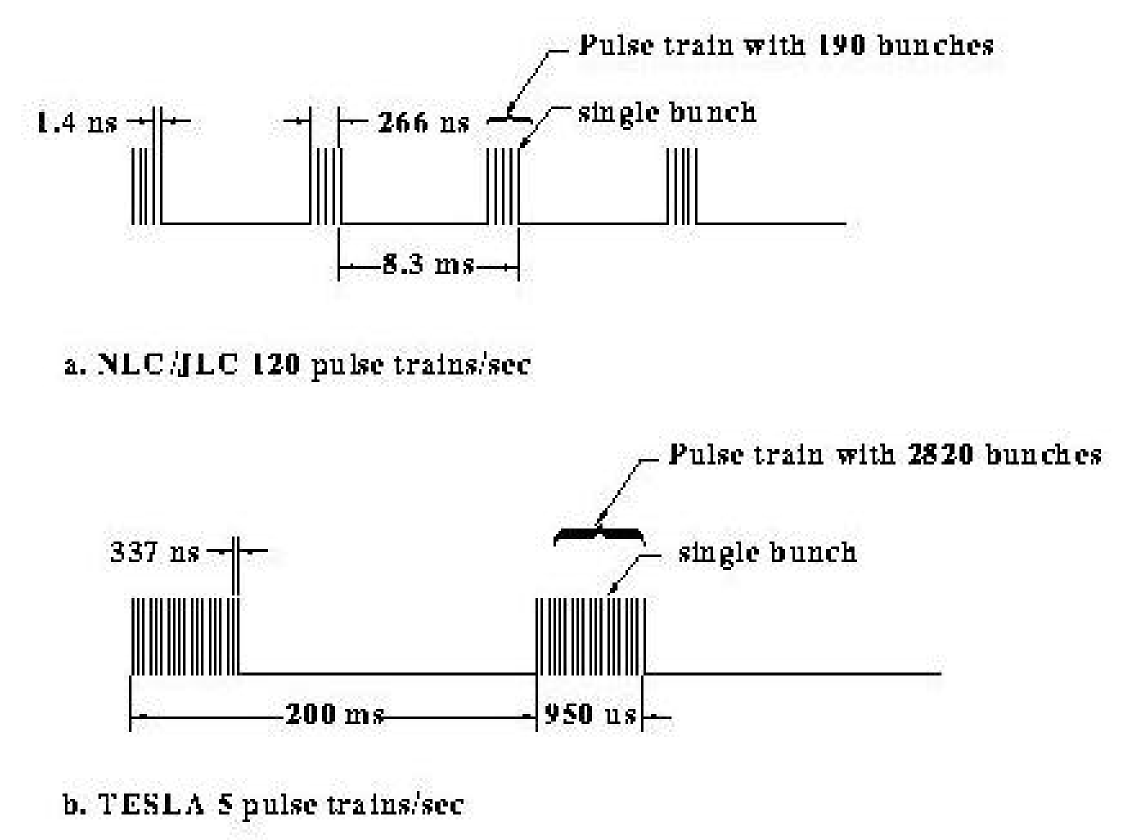
6 times less material in tracker
vxd 3-6 times closer to IP
35 times smaller pixels and 30 times thinner vxd layers
> 200 times higher ECAL granularity (if it's affordable)

IR Issues

Time structure

NLC (JLC)

Tesla



a. NLC/JLC 120 pulse trains/sec

b. TESLA 5 pulse trains/sec

IR Issues

Time structure

NLC (JLC)

190 bunches/train ⇒ 1.4 ns bunch spacing

⇒ crossing angle (20 mrad) - (8 mrad for JLC)

might want to time-stamp within train?

Tesla

2820 bunches/train ⇒ 950 μsec long

no crossing angle, but could have one

very much higher duty cycle (how to deal with?)

IR Issues

Solenoid effects

transverse component of solenoid must be compensated - straight forward

NLC - L Detector

IR Layout

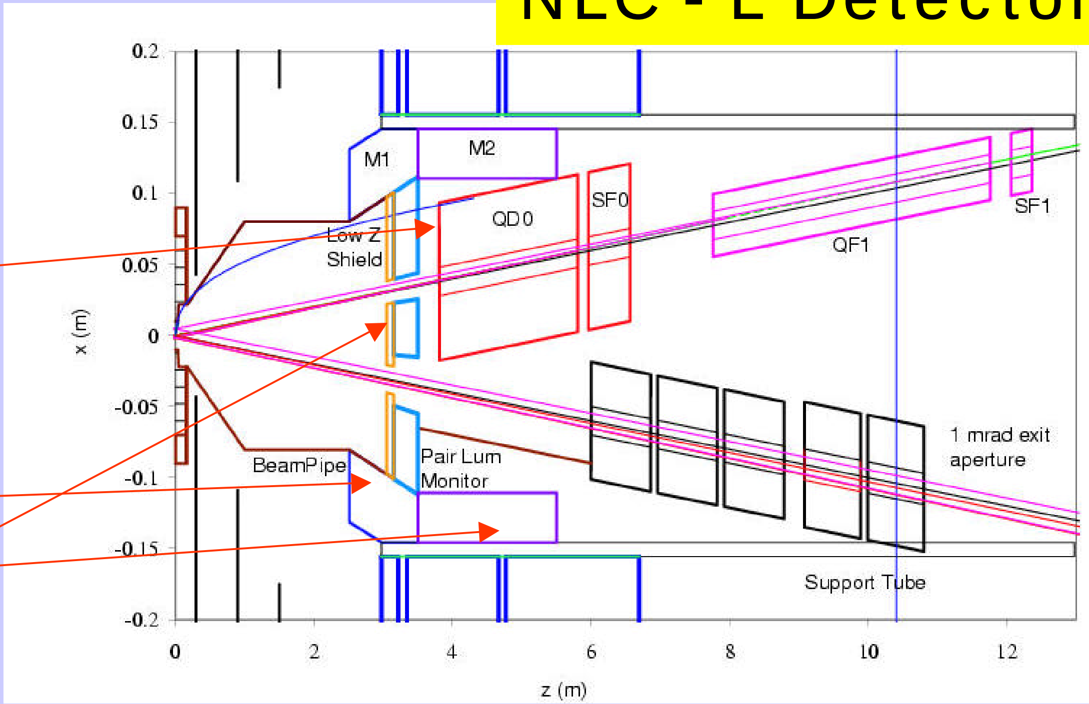
L* = 3.8 m

Masks

M1 - W/Si

M2 - W

Low-Z



IR Issues

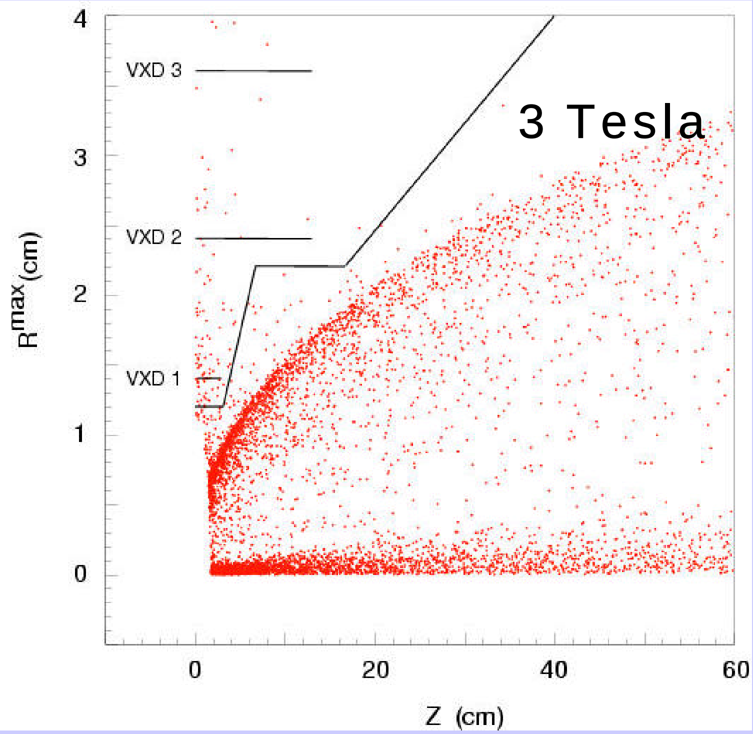
Small spot size issues

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

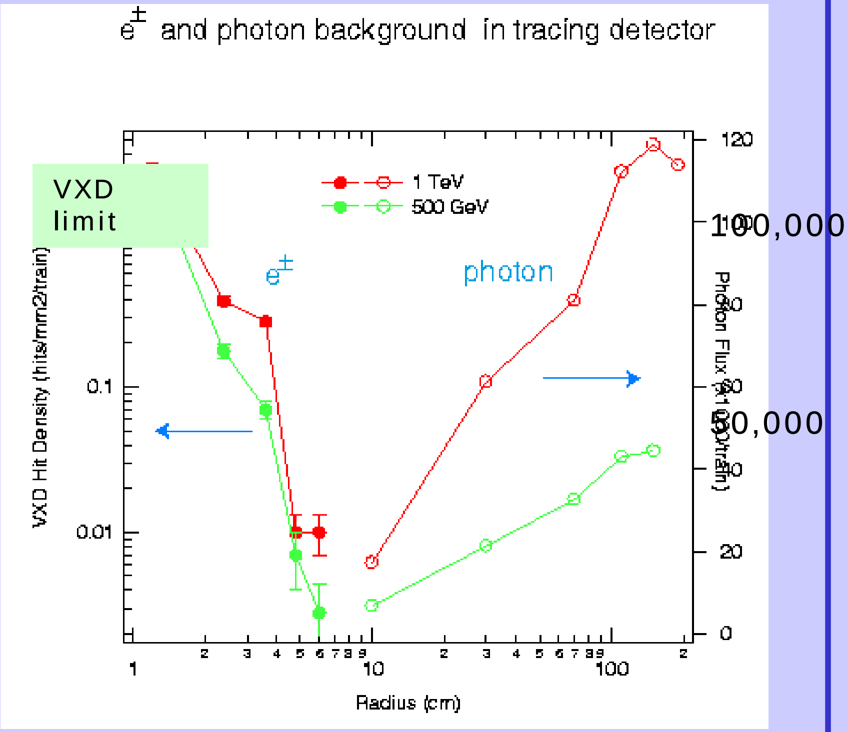
Beam-beam interaction

- 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

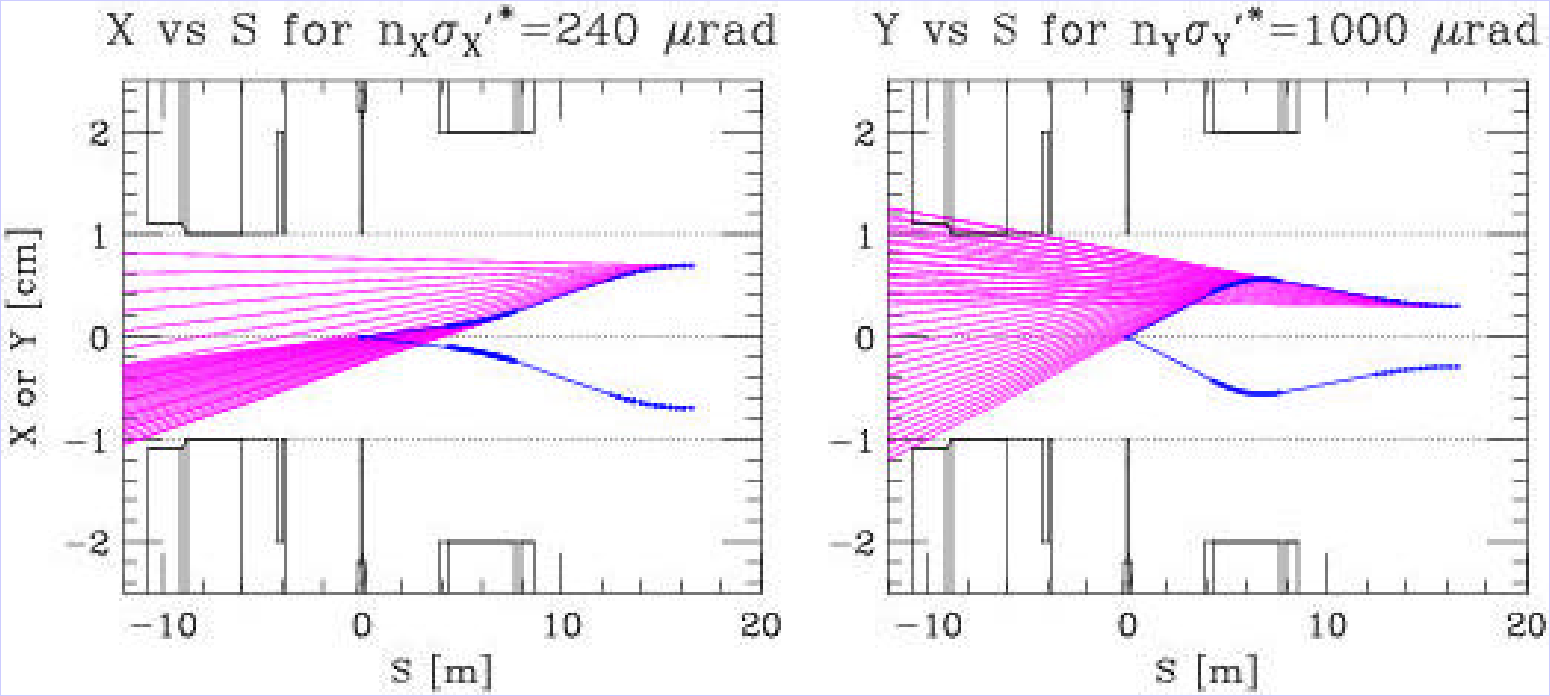


e^+e^- pairs



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
  - → large solenoidal field (≥ 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 → large BR^2

Detector Requirements

Tracking

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

Muon system

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

Particle ID

- dedicated system not needed for primary HE physics goals
- particle ID built into other subsystems (eg. dE/dx in TPC)

Beamline requirements

Beam energy measurement

- Need 50-100 MeV (10^{-4}) precision
  - SLD WISRD technique is probably adequate (needs work)
  - TESLA plans BPM measurement pre-IP (needs work)
- Luminosity spectrum
  - acolinearity of Bhabhas
  - question - can it be extracted from WISRD?
- What about effect of beam disruption

Polarization measurement

- SLD achieved 0.5% - same technique at NLC should give 0.25%
- TESLA plans only before IP (is this okay? NLC bias says no)
- Positron polarization helps dramatically

LC Detectors

Tesla TDR Detector

American High Energy IR
- 1.) L
  - conventional large detector based on the early American L (Sitges/Fermilab LCWS studies)
- 2.) SD (silicon detector)
  - motivated by energy flow measurement

JLC Detector
- 3 Tesla

LC Detectors

<u>TESLA TDR</u>

- “pixel” vertex detector
- silicon/W EM calorimeter (energy-flow)
- 4 T coil

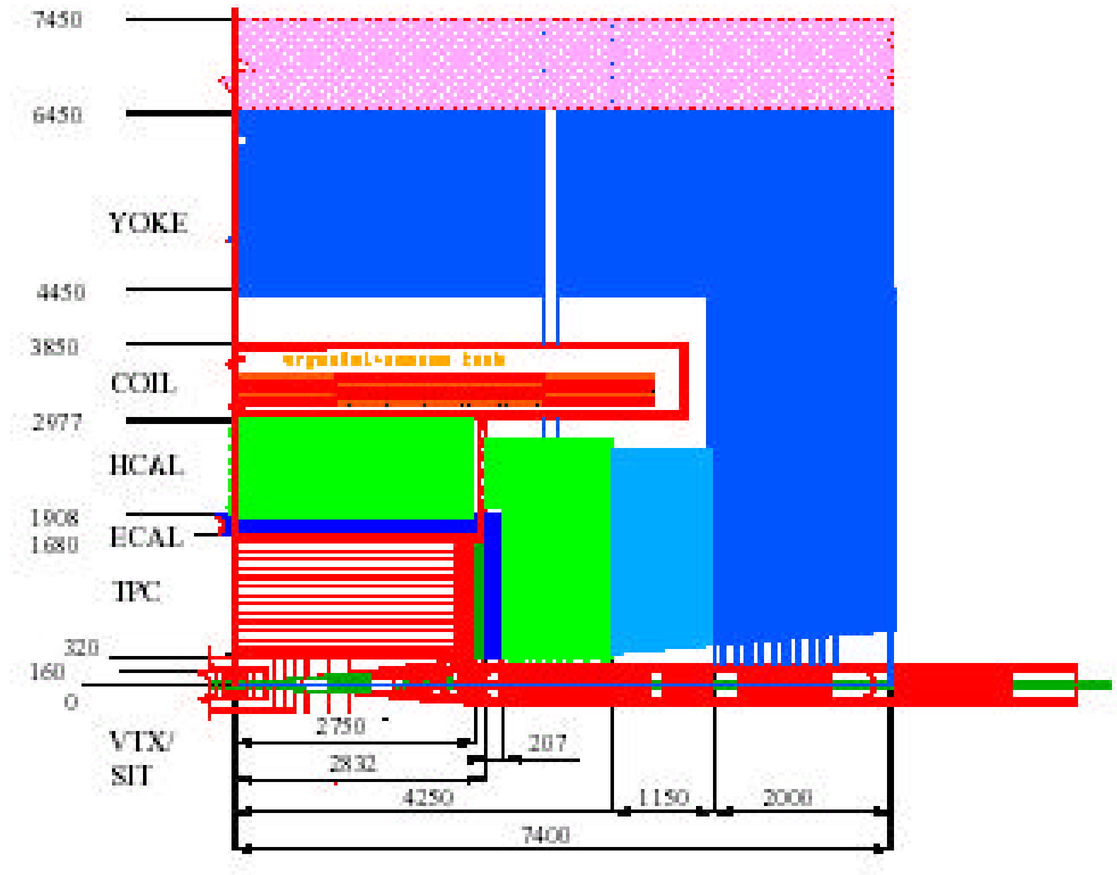
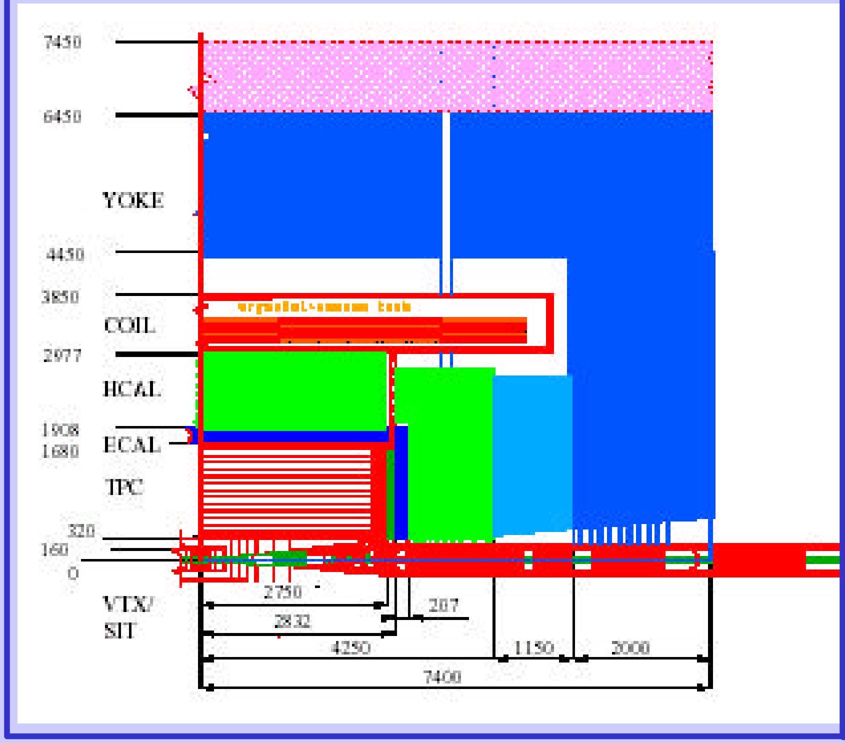
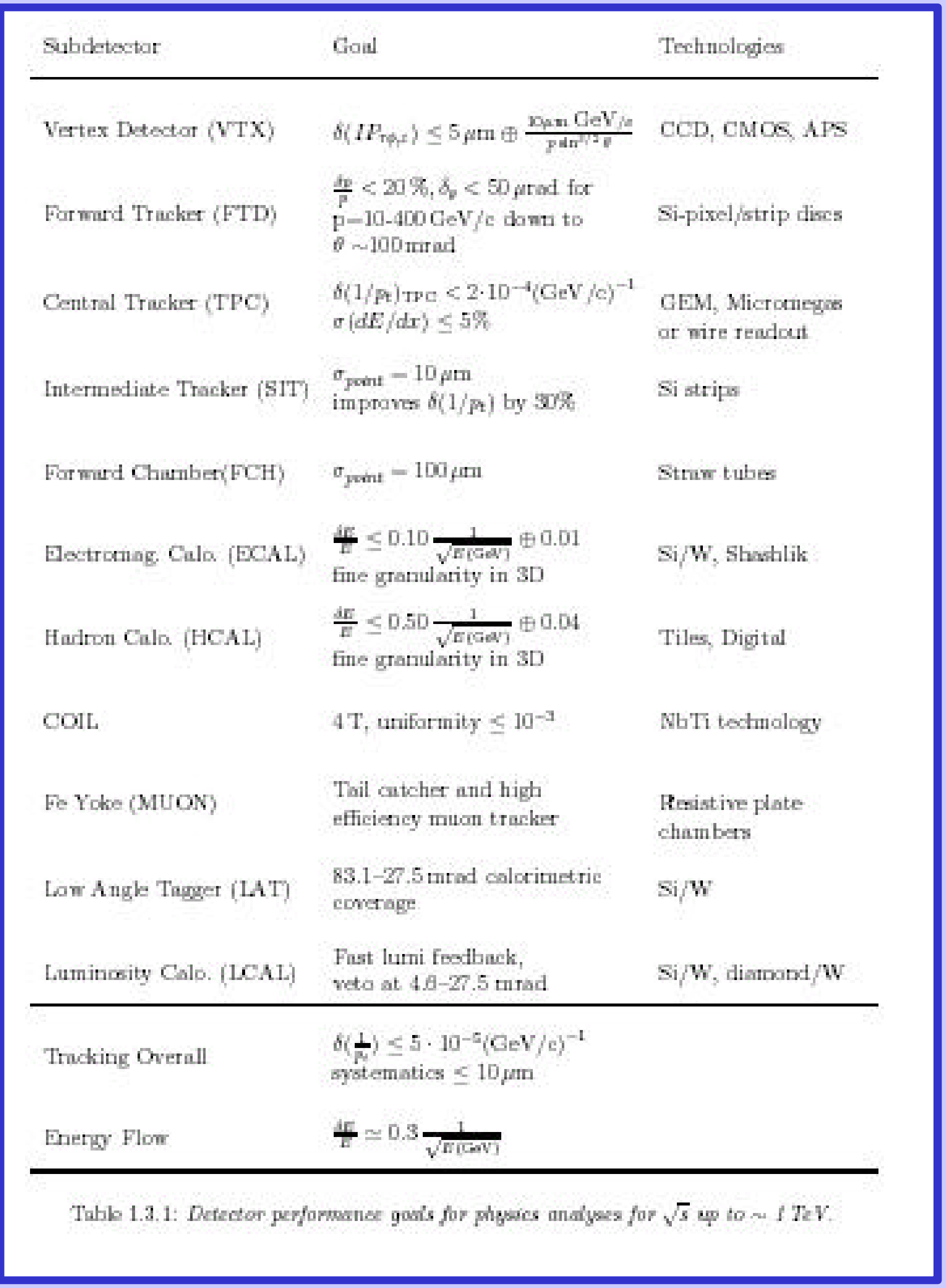


Figure 1.1.1: *View of one quadrant of the TESLA Detector. Dimensions are in mm.*

LC Detectors

- TESLA TDR



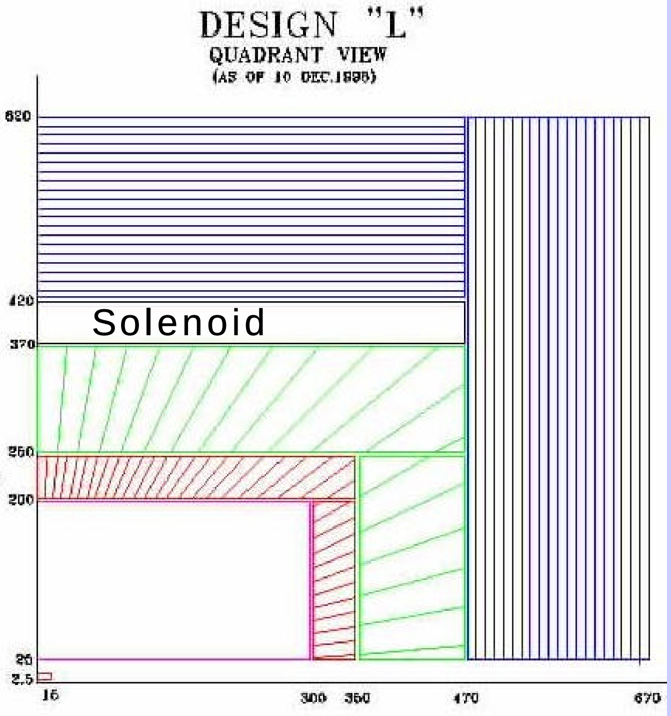


Subdetector	Goal	Technologies
Vertex Detector (VTX)	$\delta(IP_{r\phi,z}) \leq 5\,\mu\mathrm{m} \oplus \frac{10\,\mu\mathrm{m\ GeV}/c}{p \sin^{3/2}\theta}$	CCD, CMOS, APS
Forward Tracker (FTD)	$\frac{dp}{p} < 20\,\%$, $\delta_\theta < 50\,\mu\mathrm{rad}$ for p=10-400 GeV/c down to $\theta \sim 100\,\mathrm{mrad}$	Si-pixel/strip discs
Central Tracker (TPC)	$\delta(1/p_t)_{\mathrm{TPC}} < 2\cdot 10^{-4}(\mathrm{GeV}/c)^{-1}$ $\sigma\,(dE/dx) \leq 5\%$	GEM, Micromegas or wire readout
Intermediate Tracker (SIT)	$\sigma_{point} = 10\,\mu\mathrm{m}$ improves $\delta(1/p_t)$ by 30%	Si strips
Forward Chamber(FCH)	$\sigma_{point} = 100\,\mu\mathrm{m}$	Straw tubes
Electromag. Calo. (ECAL)	$\frac{dE}{E} \leq 0.10\,\frac{1}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$ fine granularity in 3D	Si/W, Shashlik
Hadron Calo. (HCAL)	$\frac{dE}{E} \leq 0.50\,\frac{1}{\sqrt{E(\mathrm{GeV})}} \oplus 0.04$ fine granularity in 3D	Tiles, Digital
COIL	4 T, uniformity $\leq 10^{-3}$	NbTi technology
Fe Yoke (MUON)	Tail catcher and high efficiency muon tracker	Resistive plate chambers
Low Angle Tagger (LAT)	83.1–27.5 mrad calorimetric coverage	Si/W
Luminosity Calo. (LCAL)	Fast lumi feedback, veto at 4.6–27.5 mrad	Si/W, diamond/W
Tracking Overall	$\delta(\frac{1}{p_t}) \leq 5\cdot 10^{-5}(\mathrm{GeV}/c)^{-1}$ systematics $\leq 10\,\mu\mathrm{m}$	
Energy Flow	$\frac{dE}{E} \simeq 0.3\,\frac{1}{\sqrt{E(\mathrm{GeV})}}$	

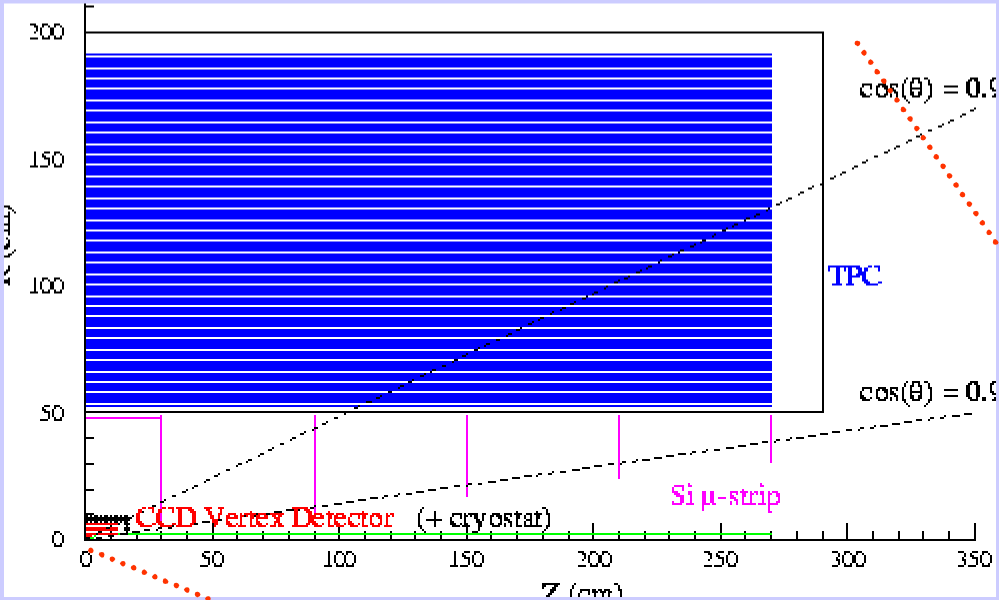
Table 1.3.1: *Detector performance goals for physics analyses for* $\sqrt{s}$ *up to* ~ *1 TeV.*

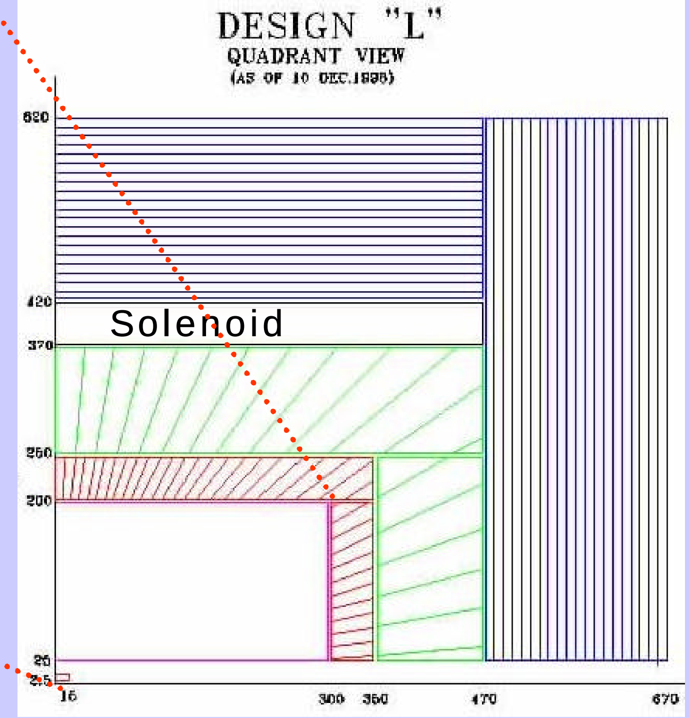
Resource Book L Detector

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?)



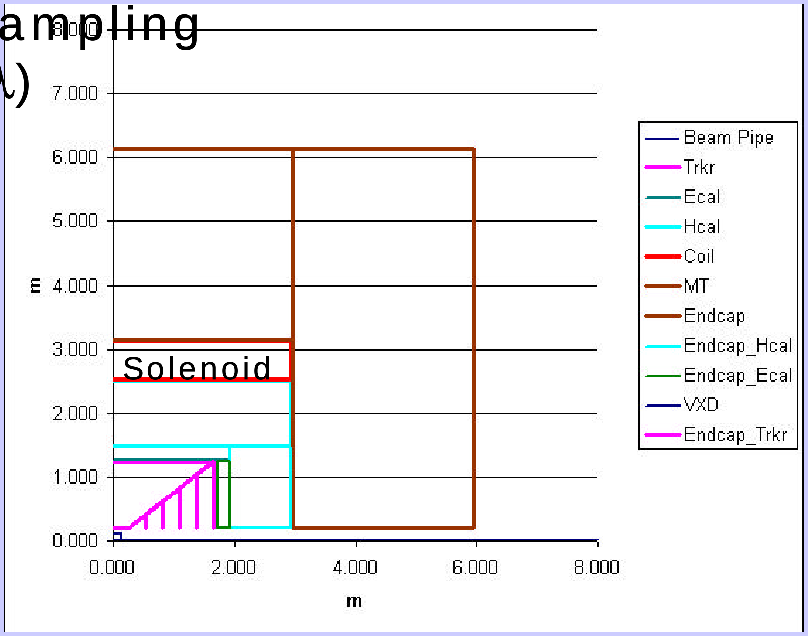
Resource Book L Detector



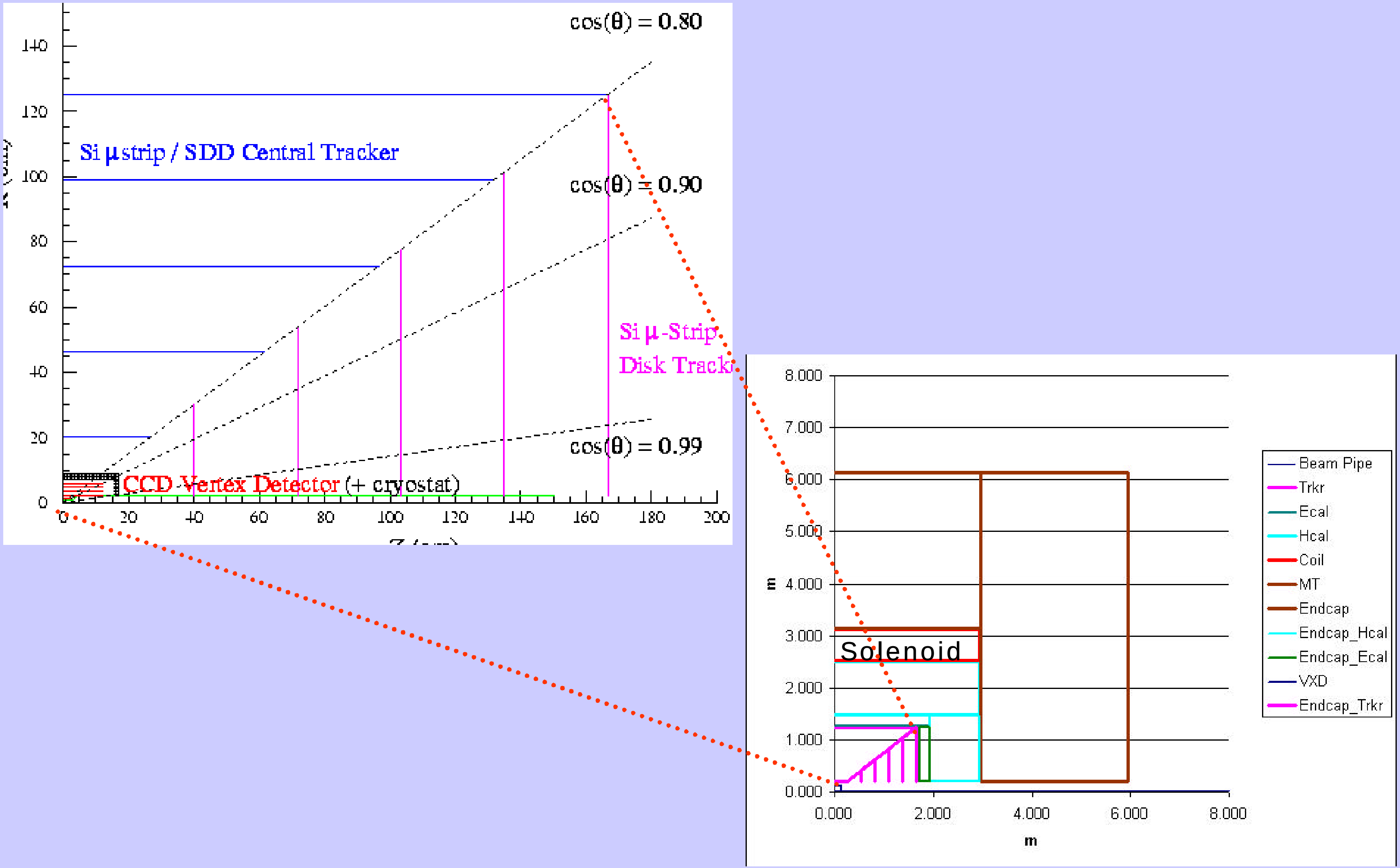


Resource Book SD Detector

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
$\frac{\text{trans.seg}}{R_M}$	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 → 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?)