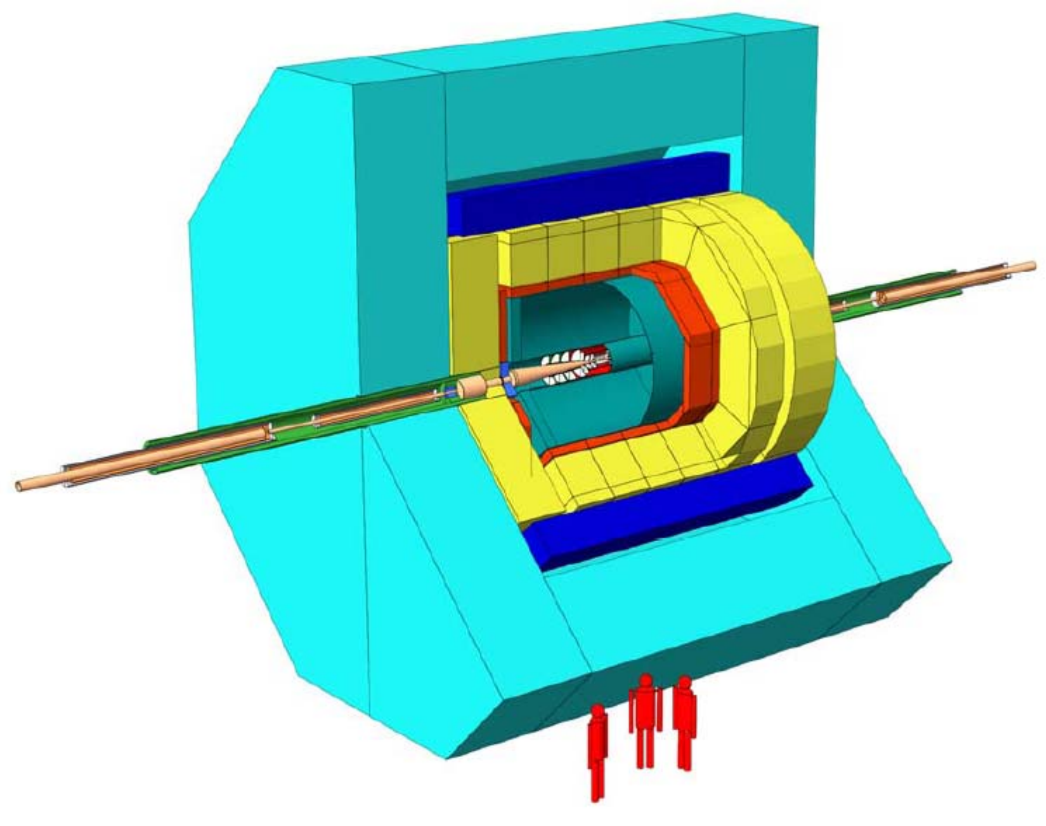
Overview of
The Large Detector Concept (LDC)



Graham W. Wilson, Univ. of Kansas

Outline

Origins. Design Criteria

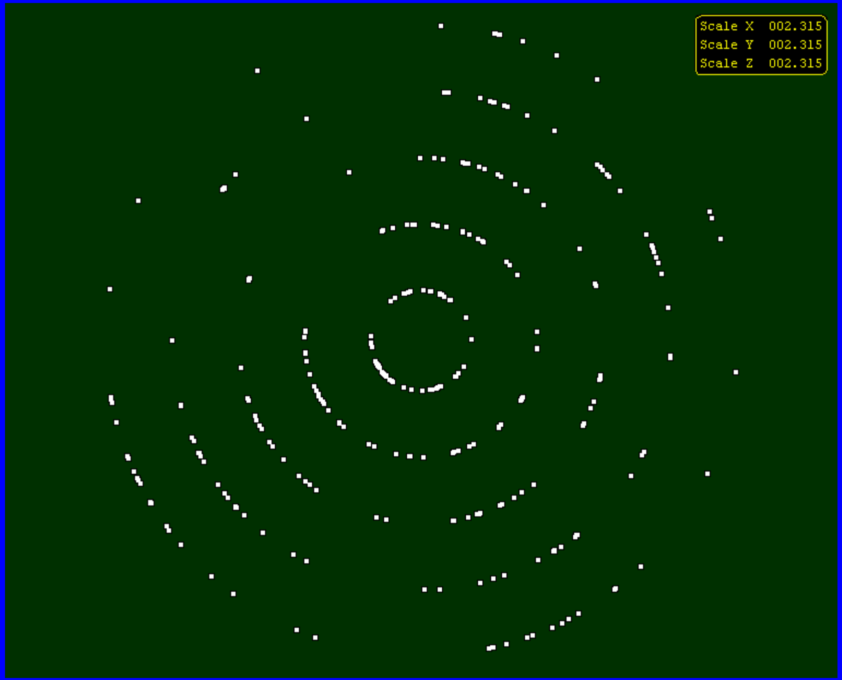
Quick Tour

- VTX
- TPC
- Tracking
- ECAL
- HCAL
- Forward CALs
- Solenoid

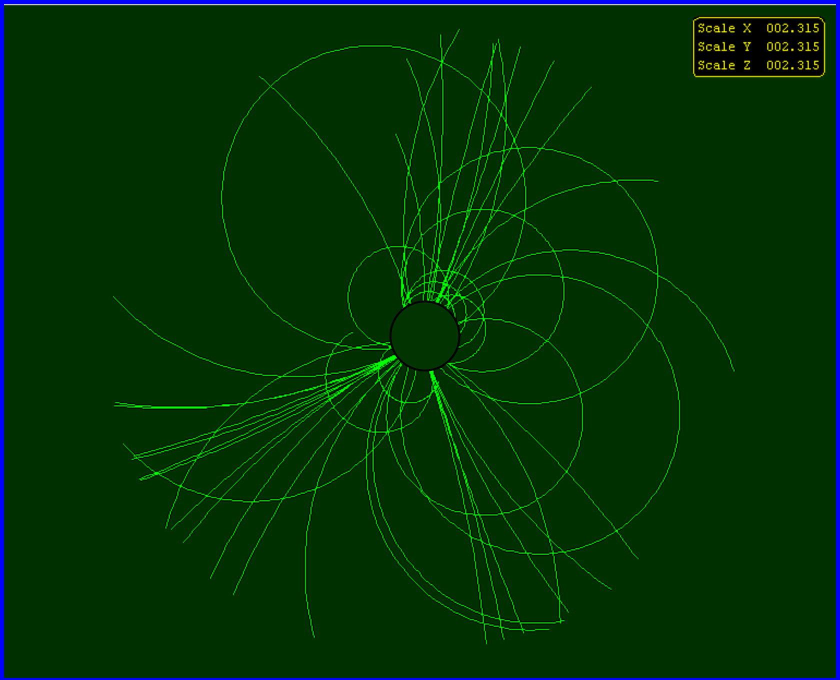
Particle-flow performance

Silicon or Gaseous Central Tracking Detector?

silicon



gaseous



same event

The detector we are planning to build is more akin to an electronic bubble chamber than a LHC detector but with true 3D volume pixels and exquisite calorimetry too.

Origins (and documentation)

- TESLA CDR, 1996
- U.S. Large Detector
- TESLA TDR, 2001
  - Starting point for LDC. B=4T CMS-like solenoid.
- LDC Sketch Document, 2005
  - Many open questions - only now starting to be addressed
  - Emphasis on integrated detector design
- LDC (Large Detector Concept) Detector Outline Document, 2006
  - Snap-shot of status as of Summer 2006
- ILC RDR – Detectors, 2007

See www.ilcldc.org for more info on LDC study

LDC Design Philosophy

- Physics needs should drive the detector design
- Experience particularly from LEP, points towards:
  - Particle-flow for complete event reconstruction
  - A highly redundant and reliable tracking design which emphasizes pattern recognition capabilities, low mass tracking, “dE/dx for free”, and V^0 reconstruction (K_S, Λ, γ conversion)
  - A fine granularity calorimeter
  - Ultra-hermetic
- Cost is viewed as something to be justified by the physics not as a hard limit in itself.
- Accelerator and tracking system should be designed with sufficient safety margin to operate reliably.

What kind of physics ?

- Processes central to the perceived physics program :
  - f fbar at highest energy
  - Zh
  - Zhh
  - sleptons
  - charginos
- These will emphasize:
  - Jet energy resolution (assumed to be done with particle flow) aiming at 30%/√E for W/Z separation
  - Hermeticity
  - Granularity
  - Leptons, taus, b, c tagging

Detector design requirements

- Detector design should be able to do excellent physics in a cost effective way.
  - both the physics we expect, and the new unexpected world that awaits
- Very good **vertexing** and **momentum** measurements

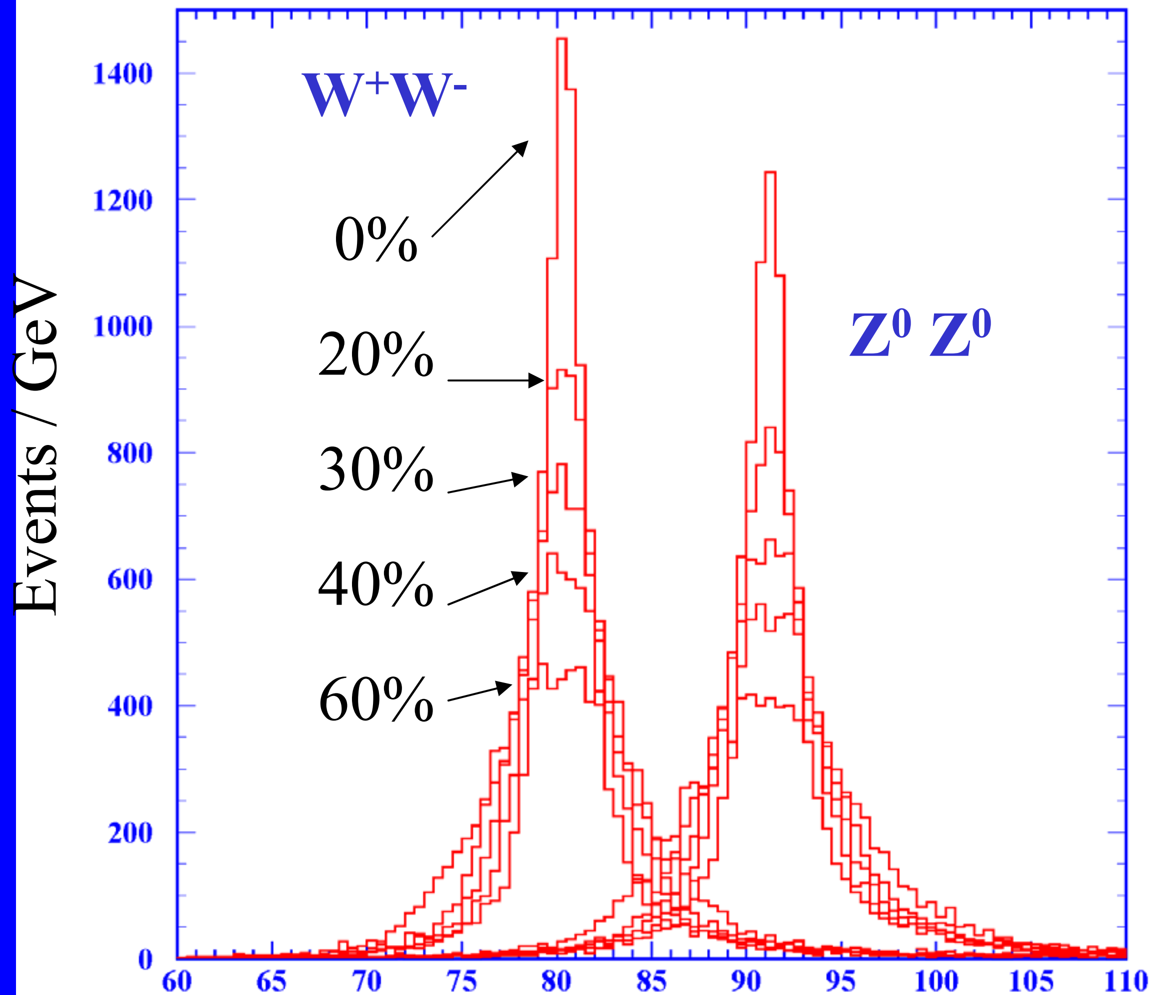
  $\sigma_b = 5 \oplus 10/(p\beta \sin^{3/2}\theta)\ \mu m$ $\sigma(1/p_T) \leq 5 \times 10^{-5}\ GeV^{-1}$
- Good **electromagnetic energy** measurement.

$$\sigma_E/E \approx 10\%/\sqrt{E}\ (GeV) \oplus 1\%$$

- The physics demands hermeticity and the physics reach will be significantly greater with state-of-the art **particle flow**
  - Close to 4π steradians.
  - Bubble chamber like track reconstruction.
  - An integrated detector design.
  - Calorimetry designed for resolving individual particles.

$$\sigma_{E_{jet}}/E_{jet} \approx 30\%/\sqrt{E_{jet}}\ (GeV)$$

Di-jet mass distribution vs E_{jet} resolution



No kinematic fits, just direct measurement

Average di-jet mass (GeV)

Comparing $e^+e^- \rightarrow WW$ and

$e^+e^- \rightarrow ZZ$ at $\sqrt{s}$=300 GeV

(hadronic decays only, assume WW:ZZ = 1:1 for illustration, and assuming perfect assignment of particles to bosons)

Reality = 7:1 !

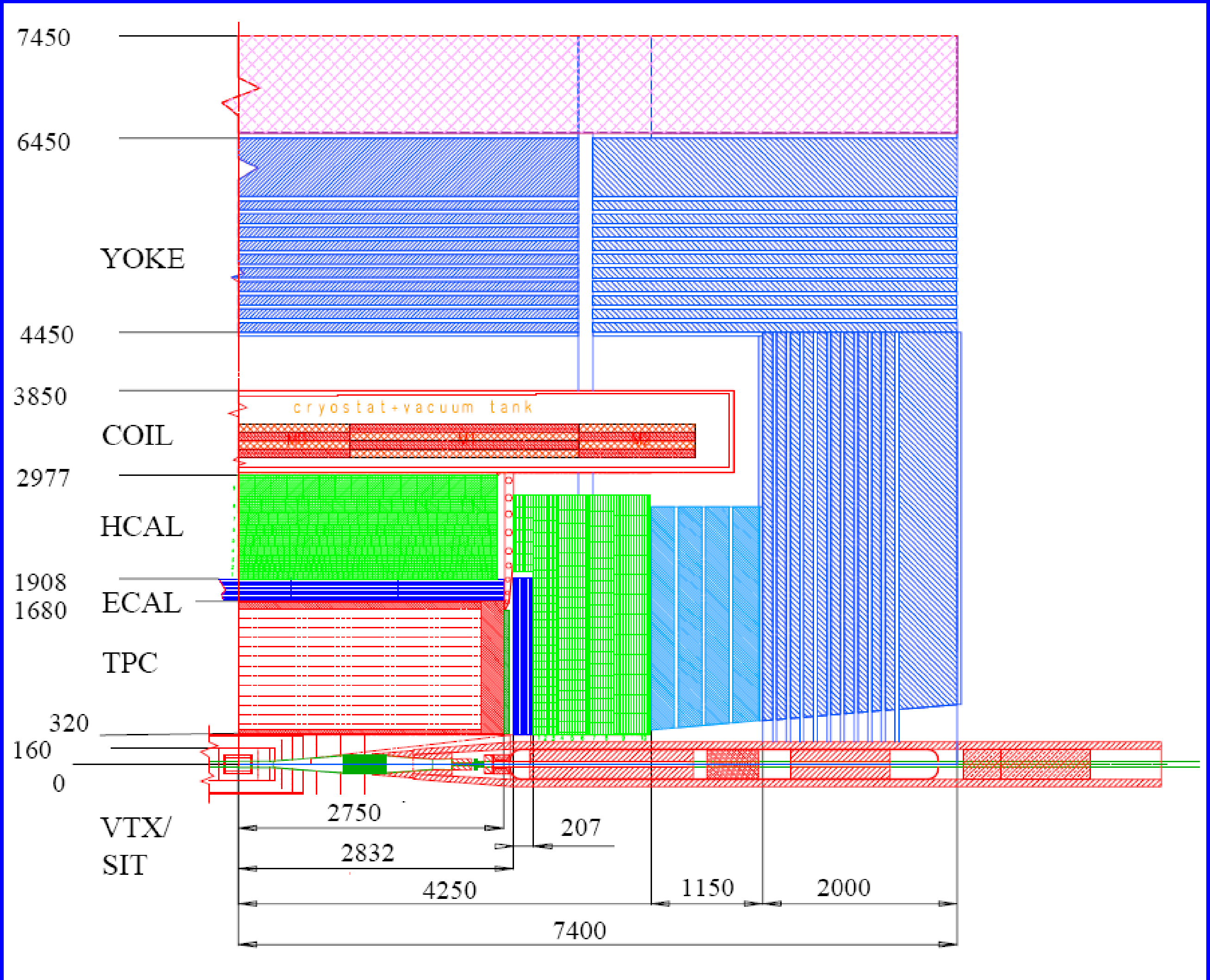
$\sigma(E_{jet}) = xx\%\sqrt{E_{jet}(\text{GeV})}$

30%$\sqrt{E_{jet}}$ is a good target for 75 GeV jets. Physics (Γ_W=2 GeV) may demand even more !

Detector Design Choices

- Consensus that the tracker should be a true imaging type tracker, almost certainly a TPC
- and that the calorimetry and tracking have to work together to do an excellent job of particle flow
- Retain a general-purpose detector concept aiming at doing physics in a new regime.
- The ECAL probably Tungsten and quite a lot of Silicon.
- HCAL: analog and digital options under study.

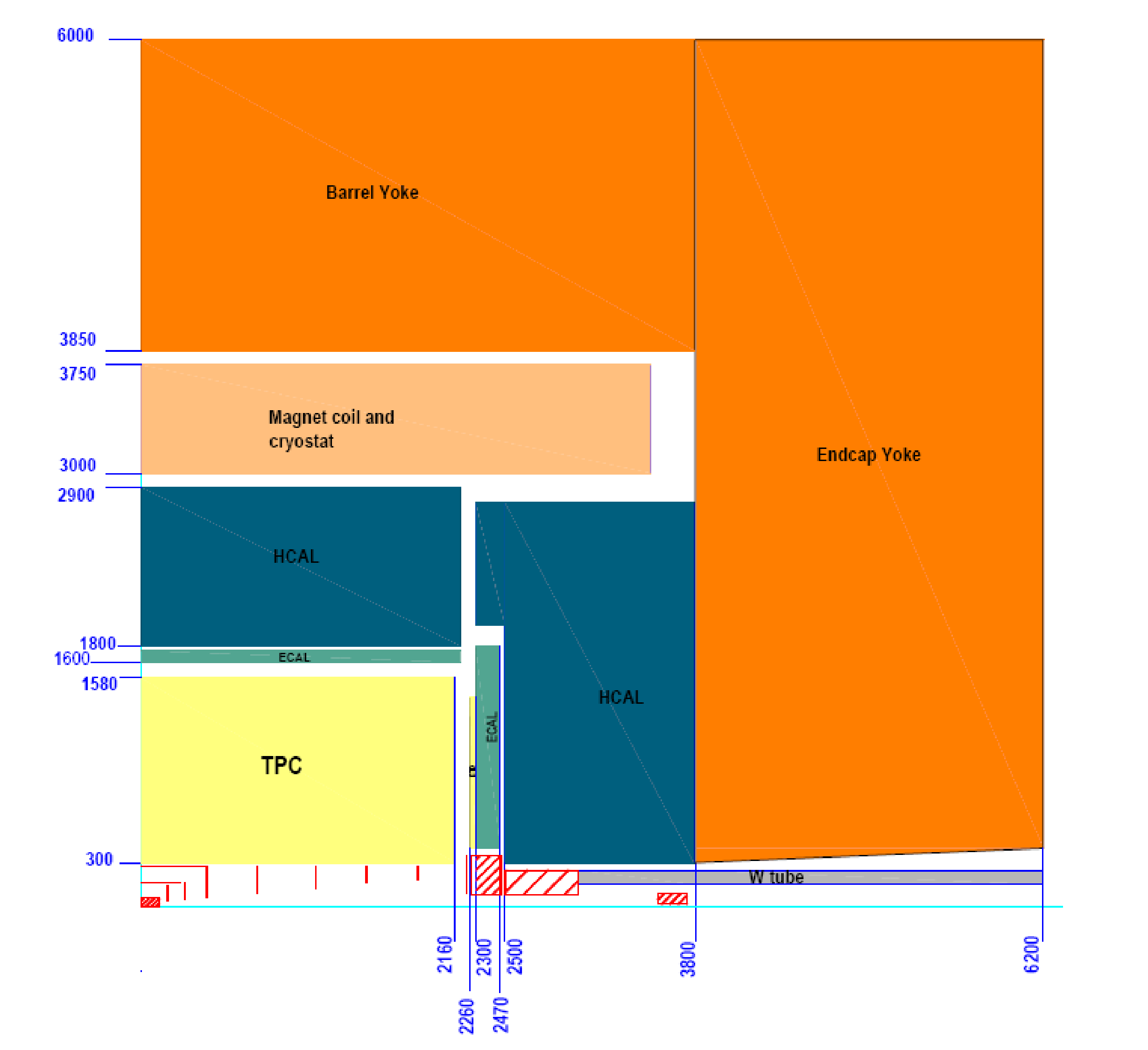
LDC00Sc Quadrant view (B = 4 T)



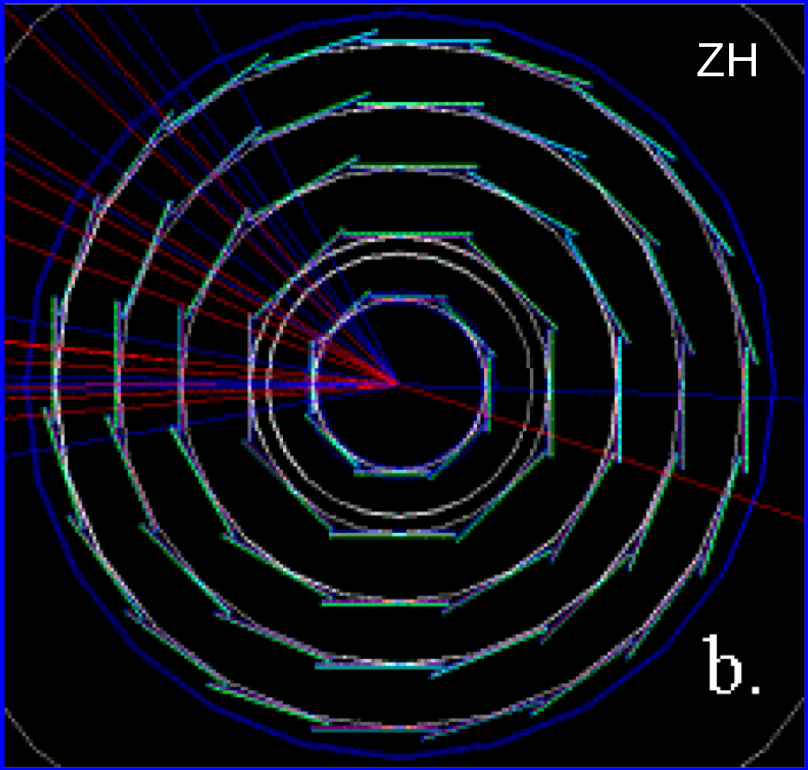
LDC concept started from TESLA TDR

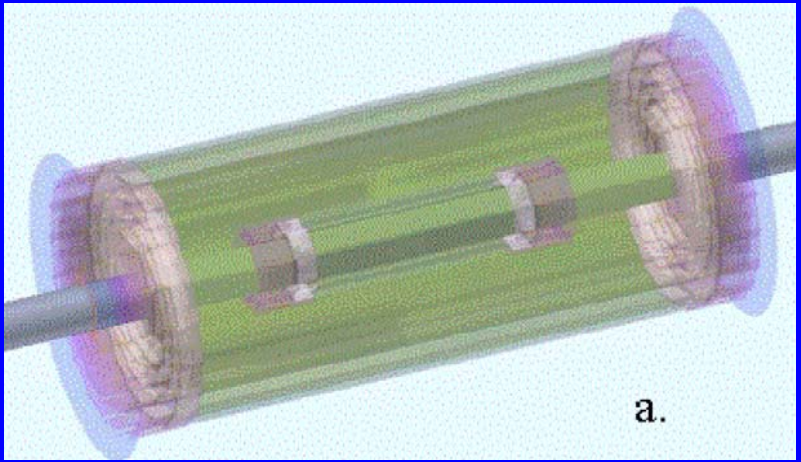
LDC Sketch Document is an excellent resource for understanding some of the reasoning for where we started from, and the *many* still open questions

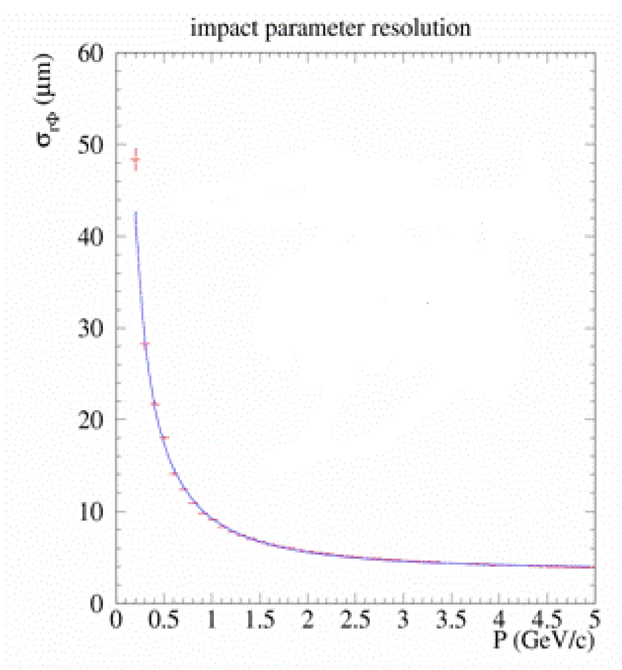
LDC Quadrant View



Vertex Detector



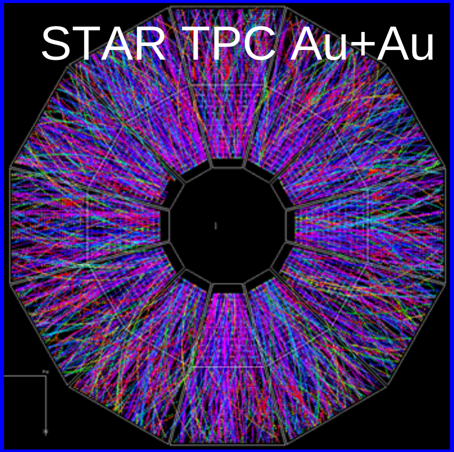




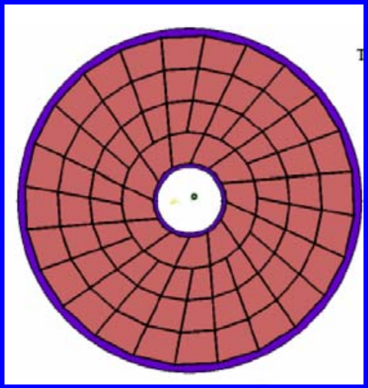
5-layer device. 5 layer coverage to |cosθ| < 0.9.

Pixels : many technologies … see VTX Review.

Inner layer at r=1.6 cm for B=4T

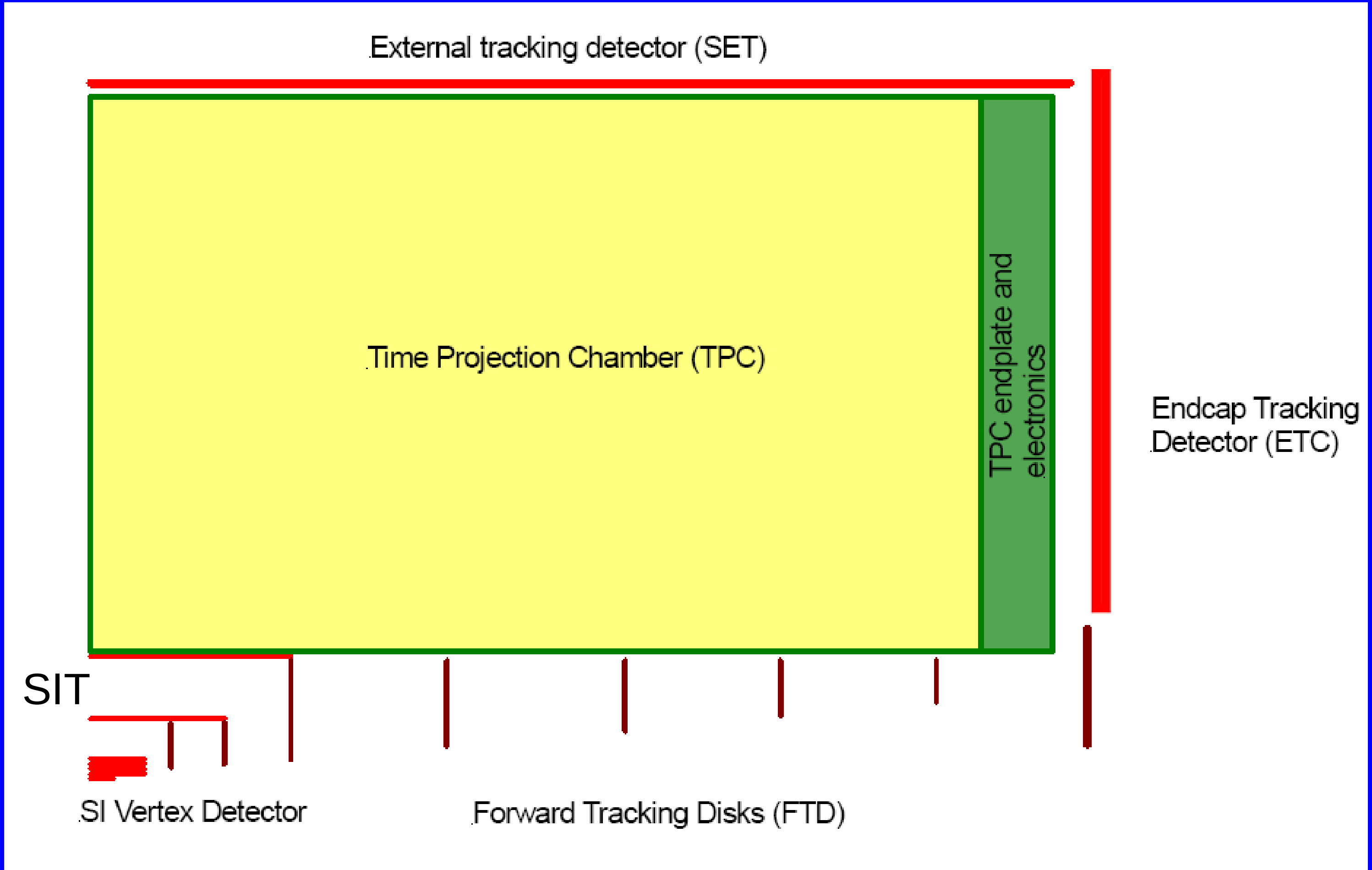


Main Tracker: TPC



Supplemented by stand-alone VTX tracking, SIT + Forward tracking disks.

SET and ETC are track-cal linking options.



$3\ 10^9$ volume pixels.

200 points per track.

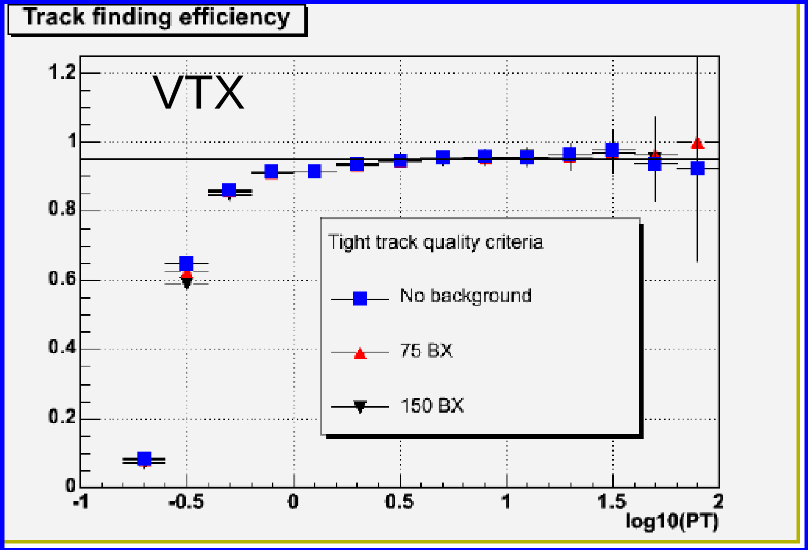
Single-point resolution

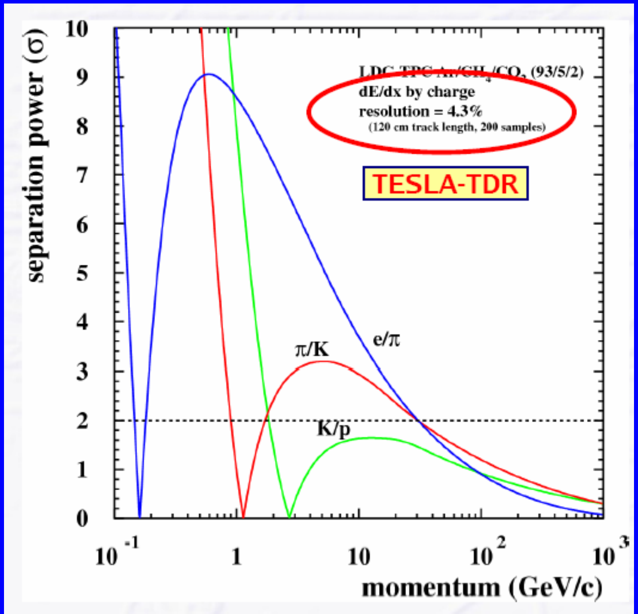
100 μm r-ϕ,

2 mm r-z

$|\cos\theta| < 0.98$

Overall Tracking Performance

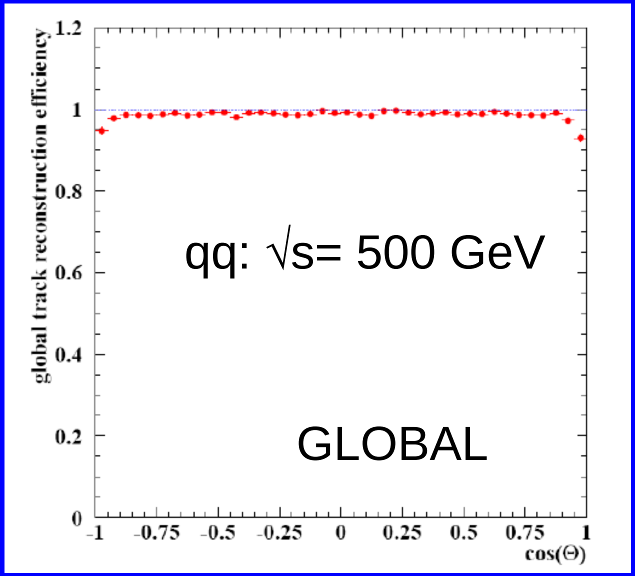




High efficiency.

Can be improved further.

Results from MARLIN framework in progress

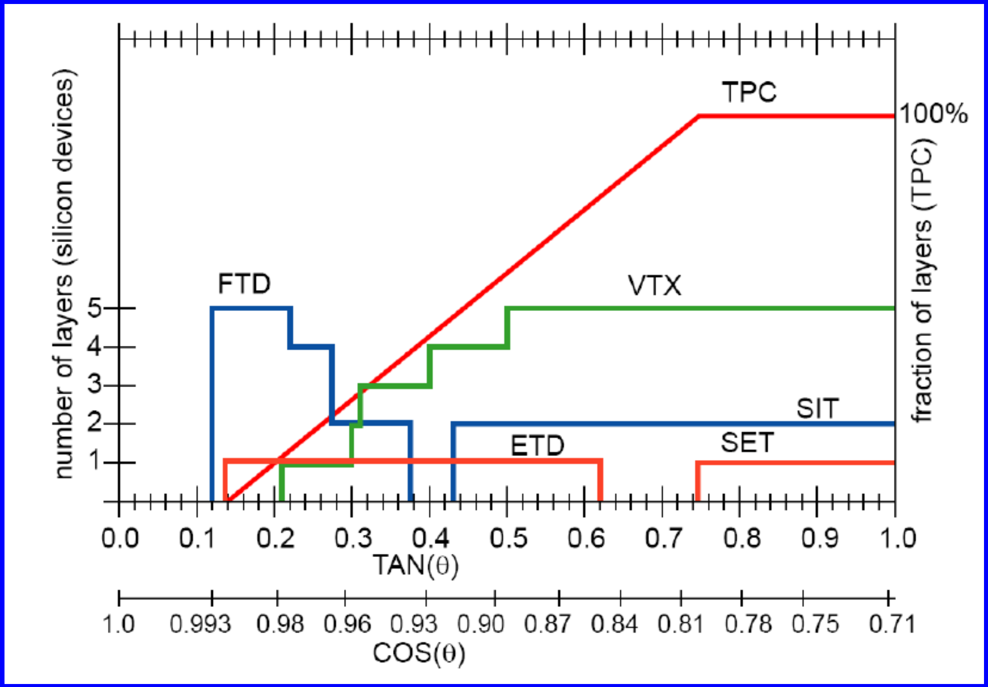


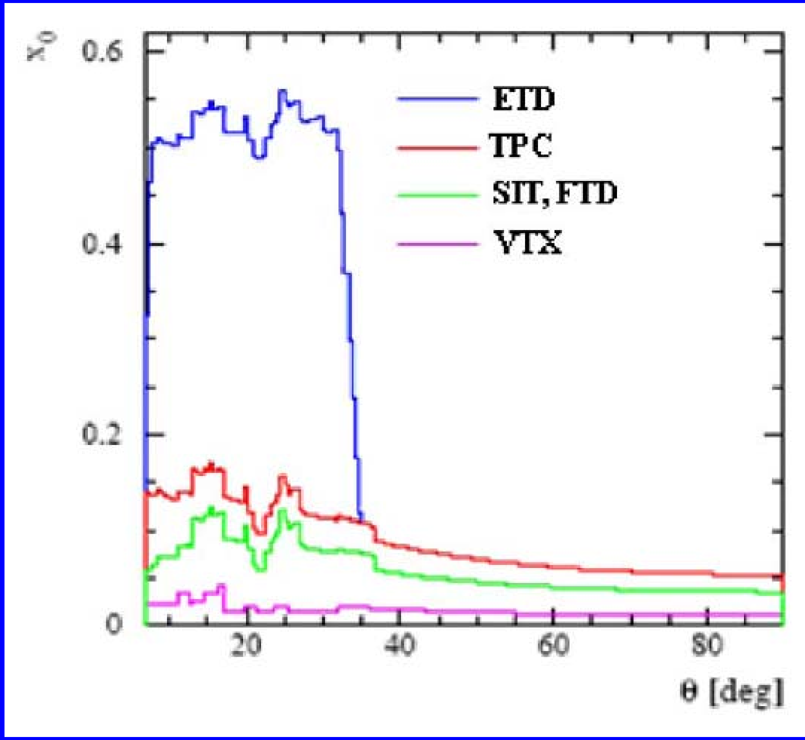
dE/dx performance similar to ALEPH, OPAL

Expected occupancy < 0.5%

Should be robust to ×20.

Tracking: Acceptance + Material



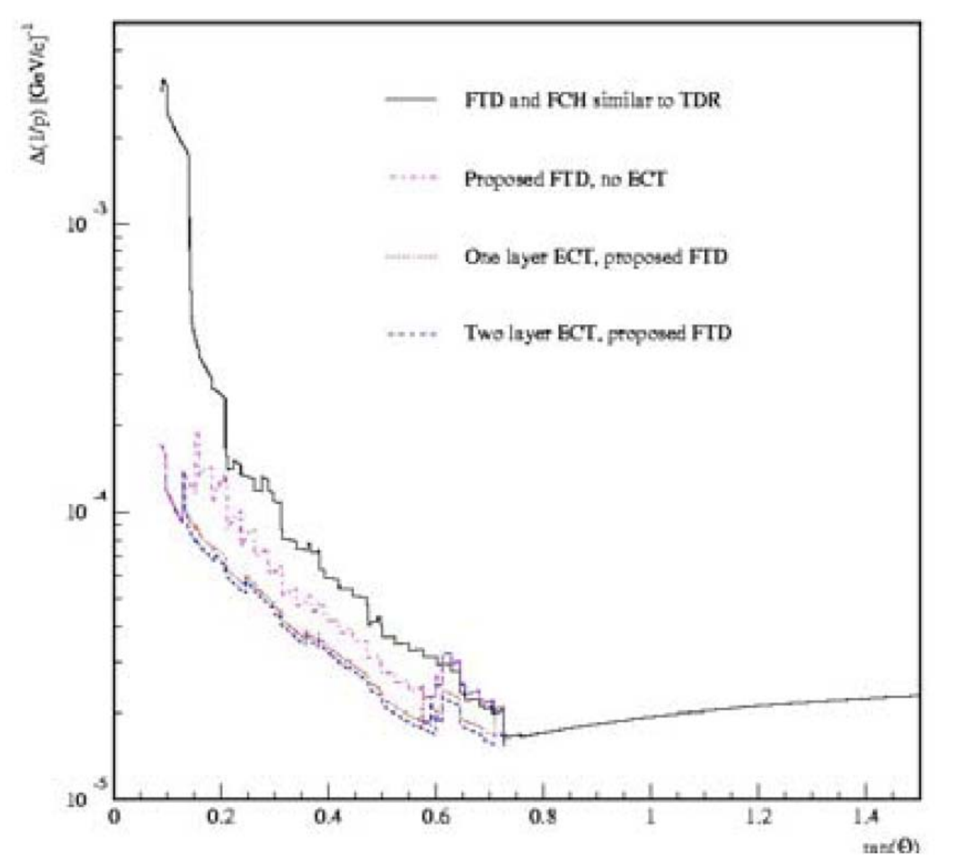


Forward tracking disks should ensure good quality track reconstruction to the edge of the TPC acceptance.

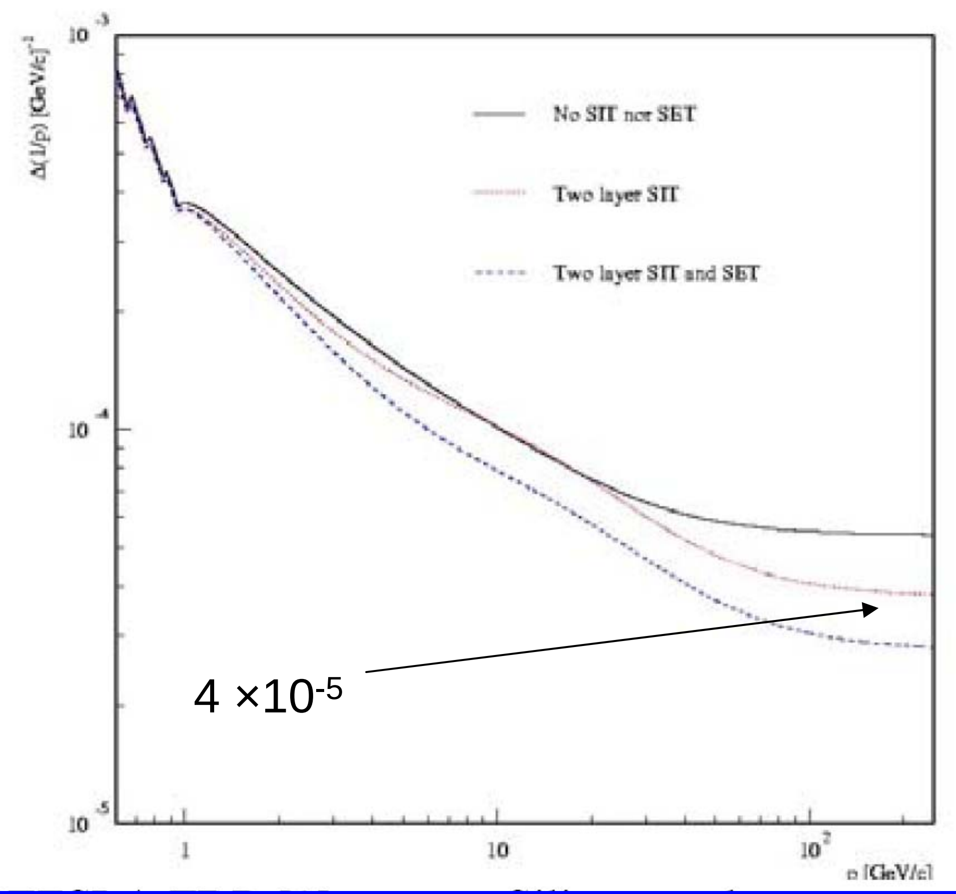
Does the VTX have enough layers if it is also needed for reconstruction of soft tracks ?

(ETD material only an issue for track-cal matching).

Tracking: Momentum Resolution



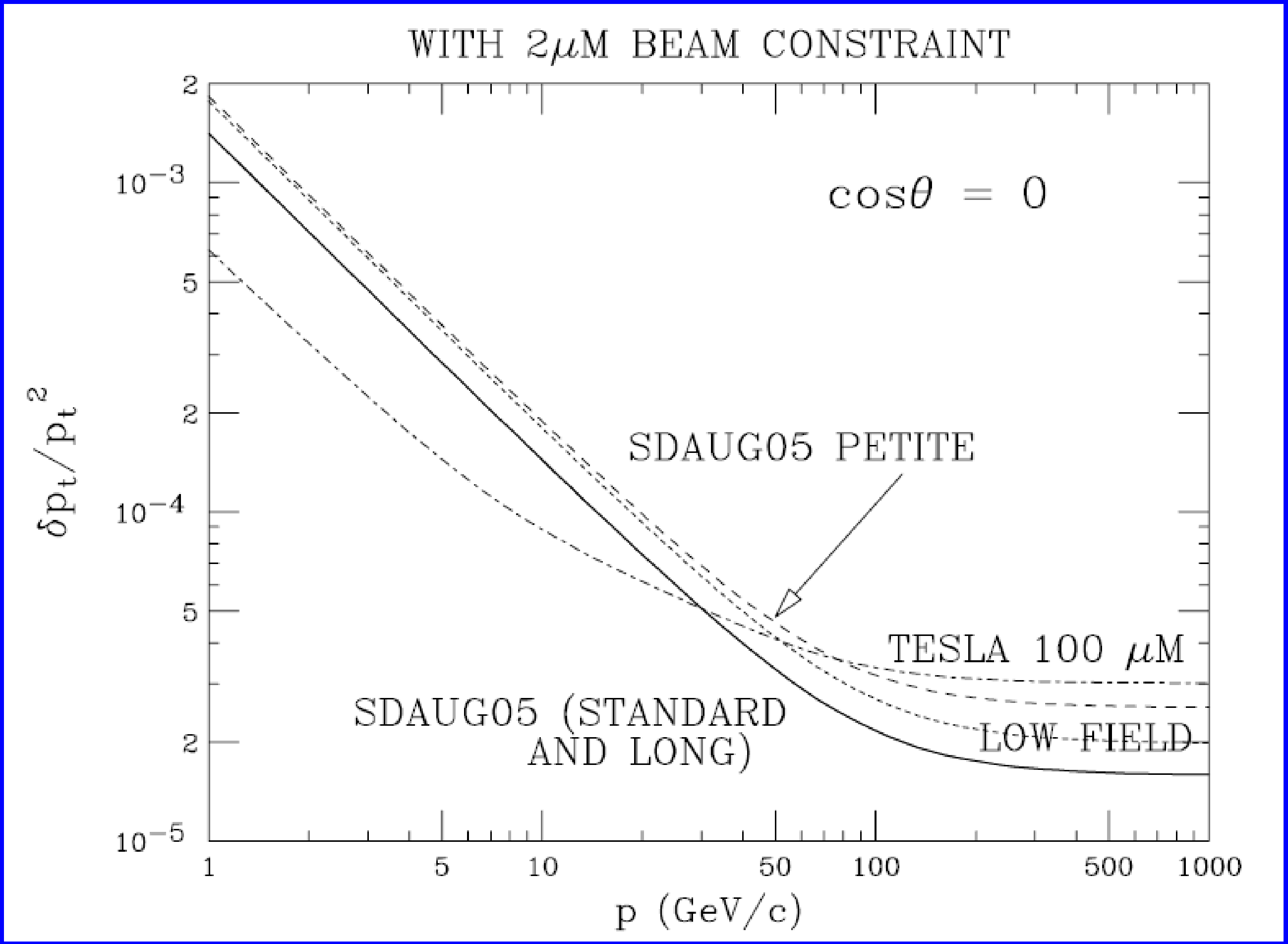
tanθ



Momentum (GeV/c)

IF needed, can push to larger R.

Compare with SiD (from SiD DoD)

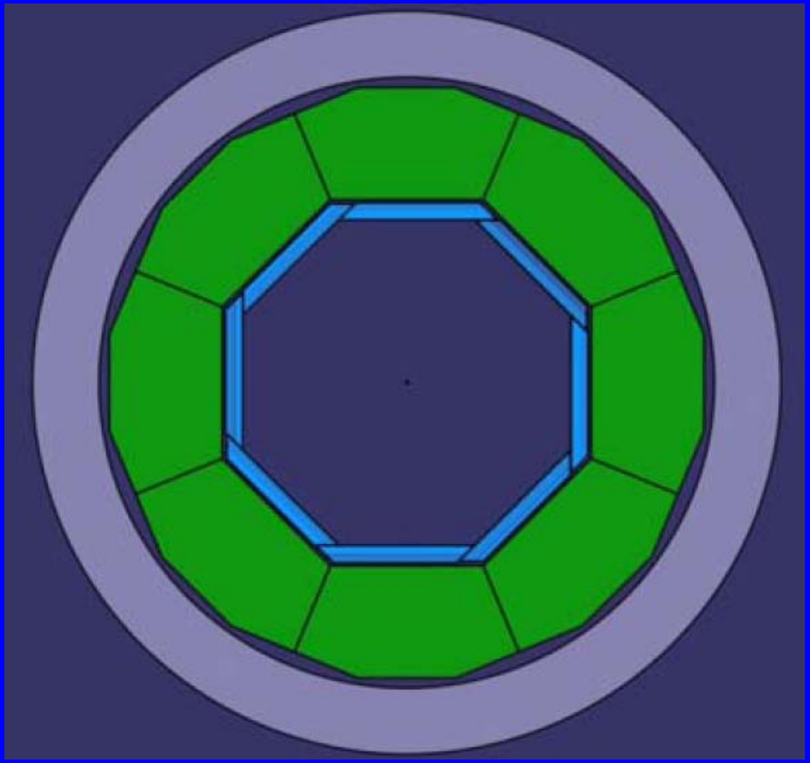


LDC does significantly better job for tracks with $p_T < 10$ GeV.

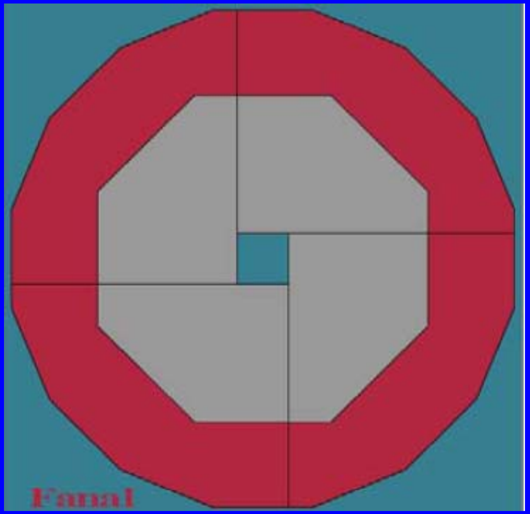
Less material as expected so less multiple scattering, photon conversions.

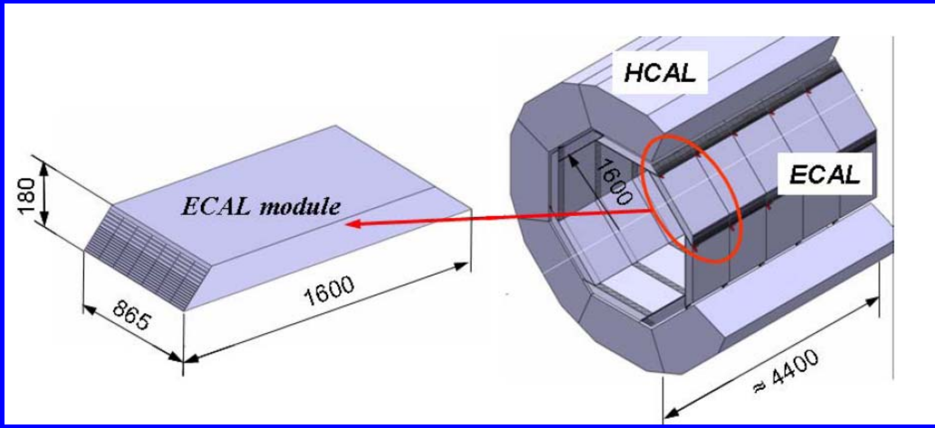
Are the material estimates accurate ?

Calorimetry



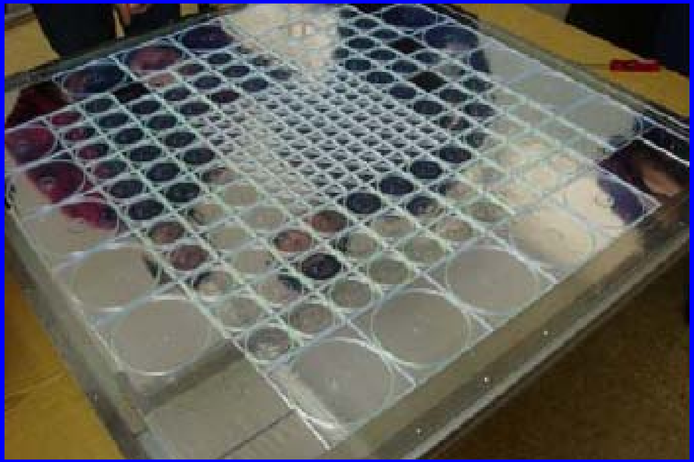
8-fold way inside 4T solenoid





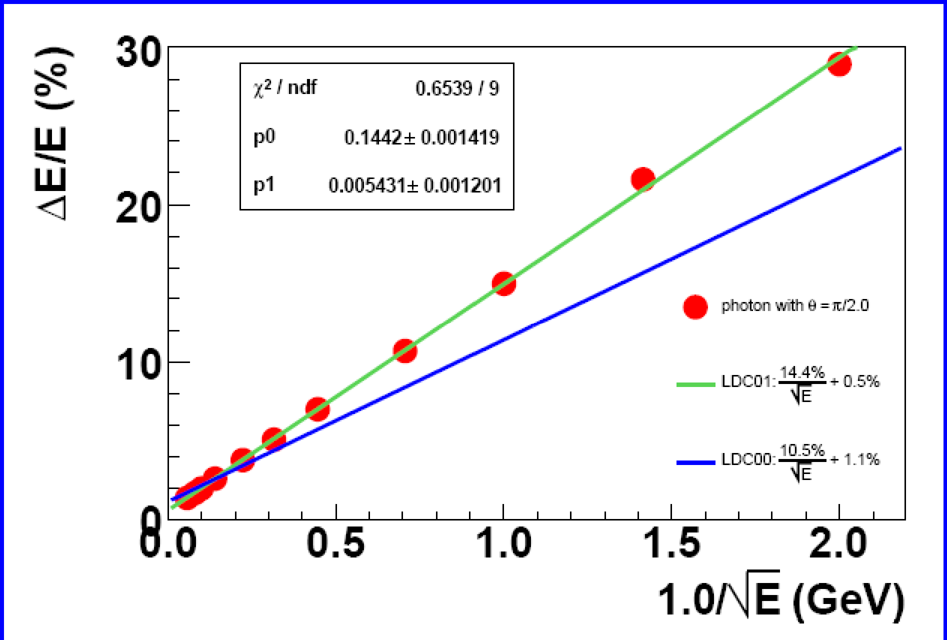
Calorimetry Technologies

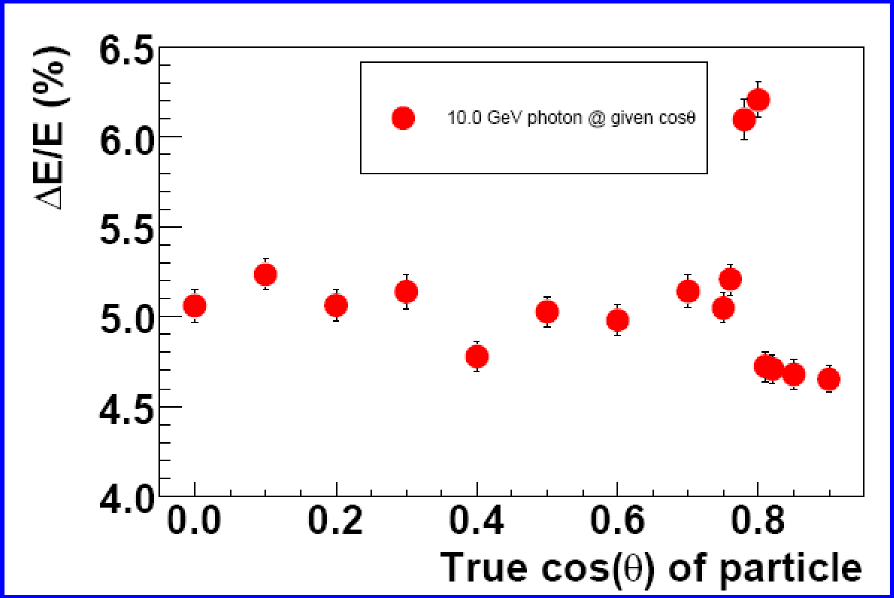
- ECAL
  - Silicon-W (as tested in CALICE)
  - 525 μm Si, transverse cell-size 5mm*5mm
  - LDC00Sc has 30 layers ($0.4X_0$ per layer) + 10 ($1.2X_0$ per layer)
  - LDC01: $20*0.6X_0 + 9*1.2X_0$
- HCAL
  - Analog : Scintillator + Stainless Steel.
    - Tiles with Si-PM readout
    - 40 layers, 4.5λ, 5mm Sc, 3cm*3cm.
  - Digital : Gas + Stainless Steel.
    - RPCs or GEMs, 1cm*1cm



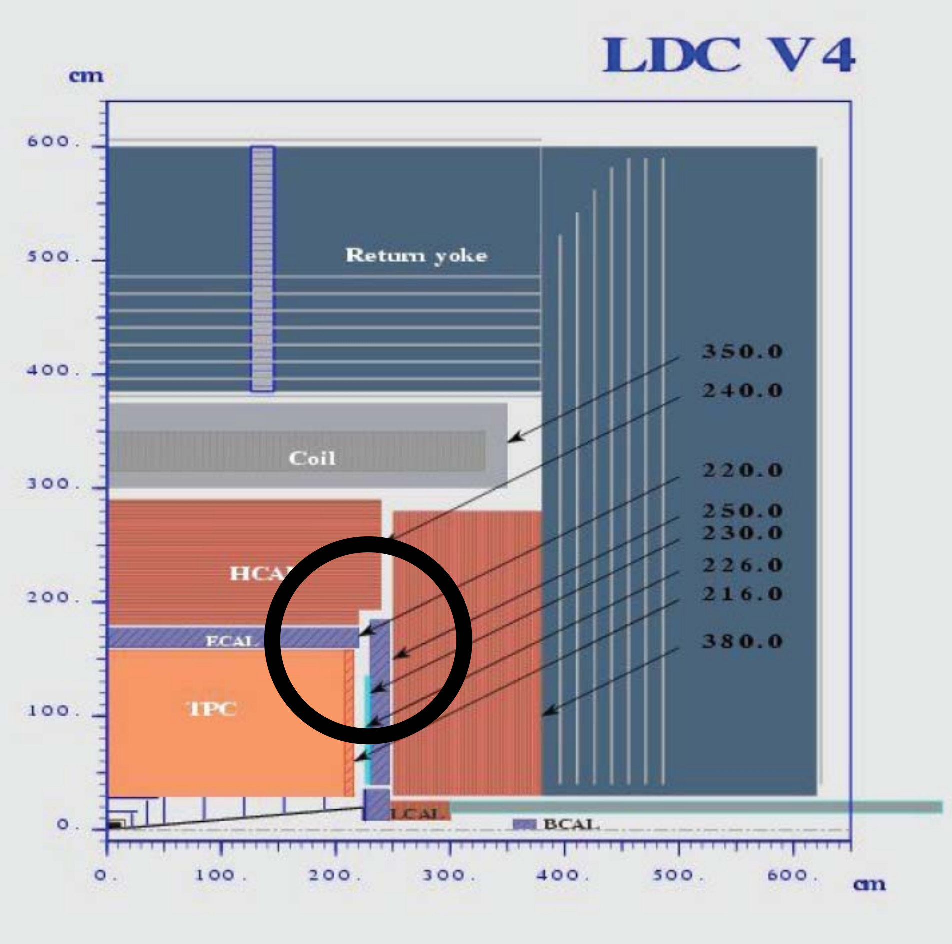
ECAL Performance

Evaluated with realistic geometry



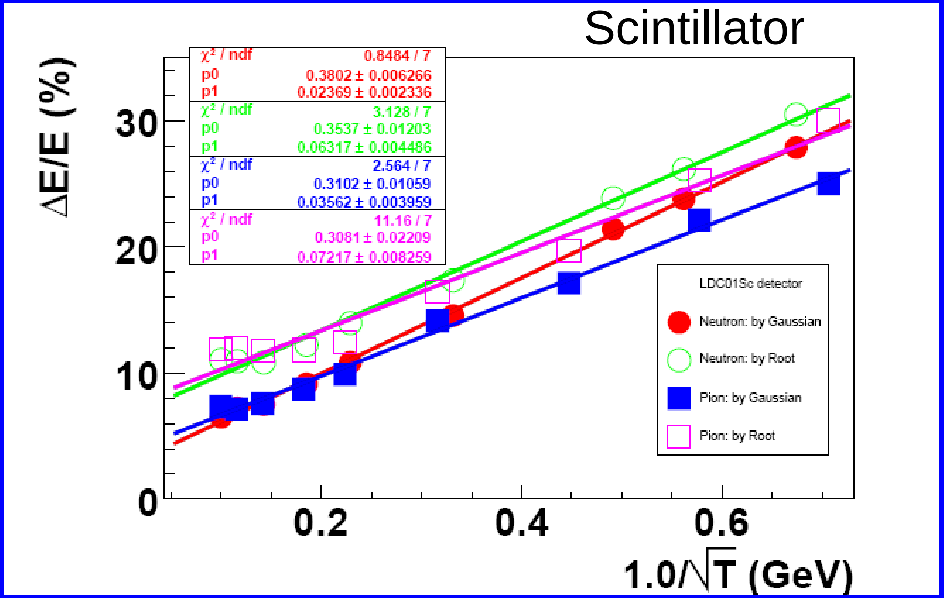


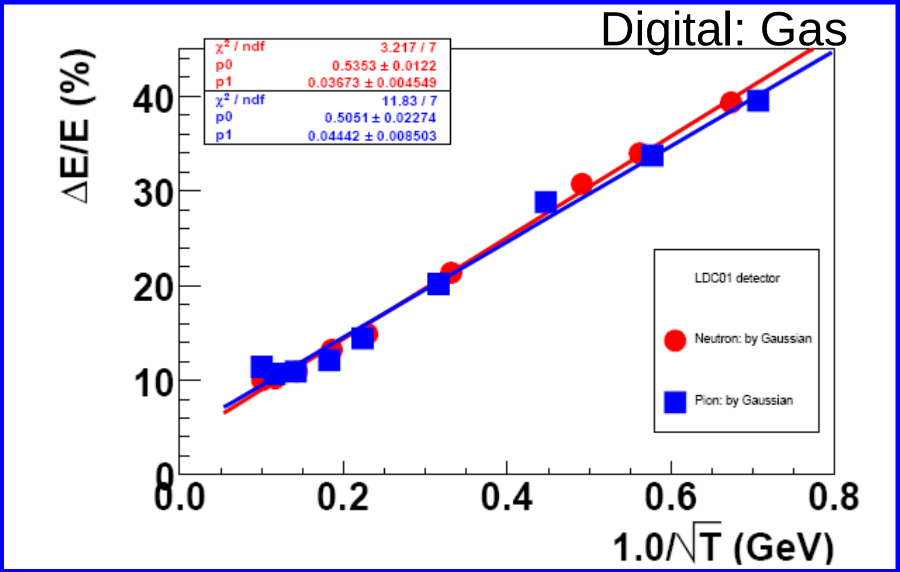
Newer barrel/endcap overlap design looks as if this small local broadening should be cured (see V4 picture)



LCWS07 iteration has the overlap improved. (and cable paths)

HCAL Performance

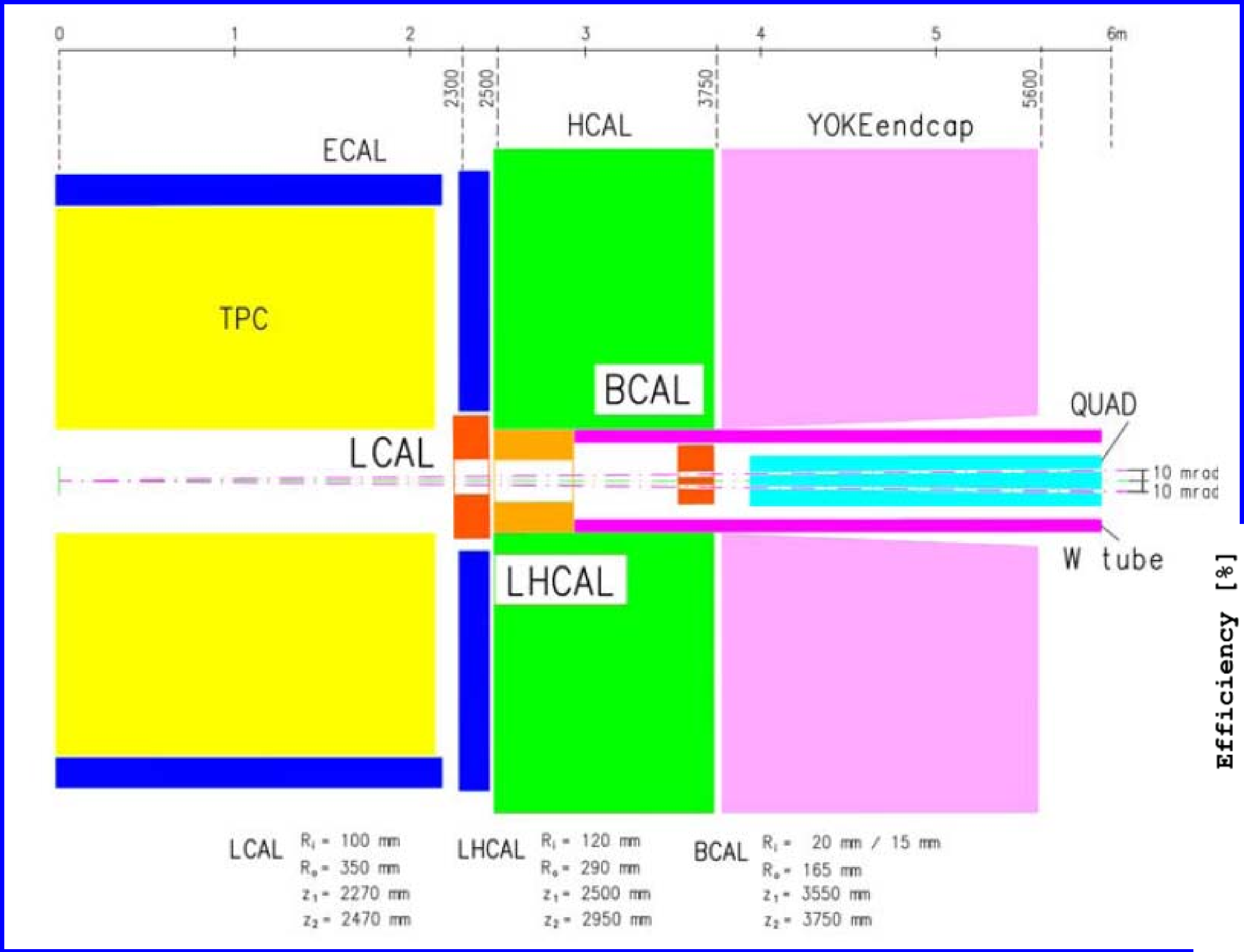




Geant 4.8.0 LCPhysicslist

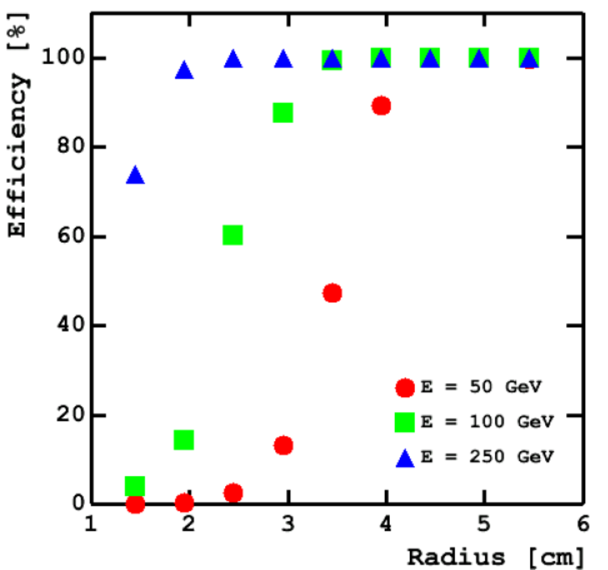
Forward Region

See Karsten's talk for more details.

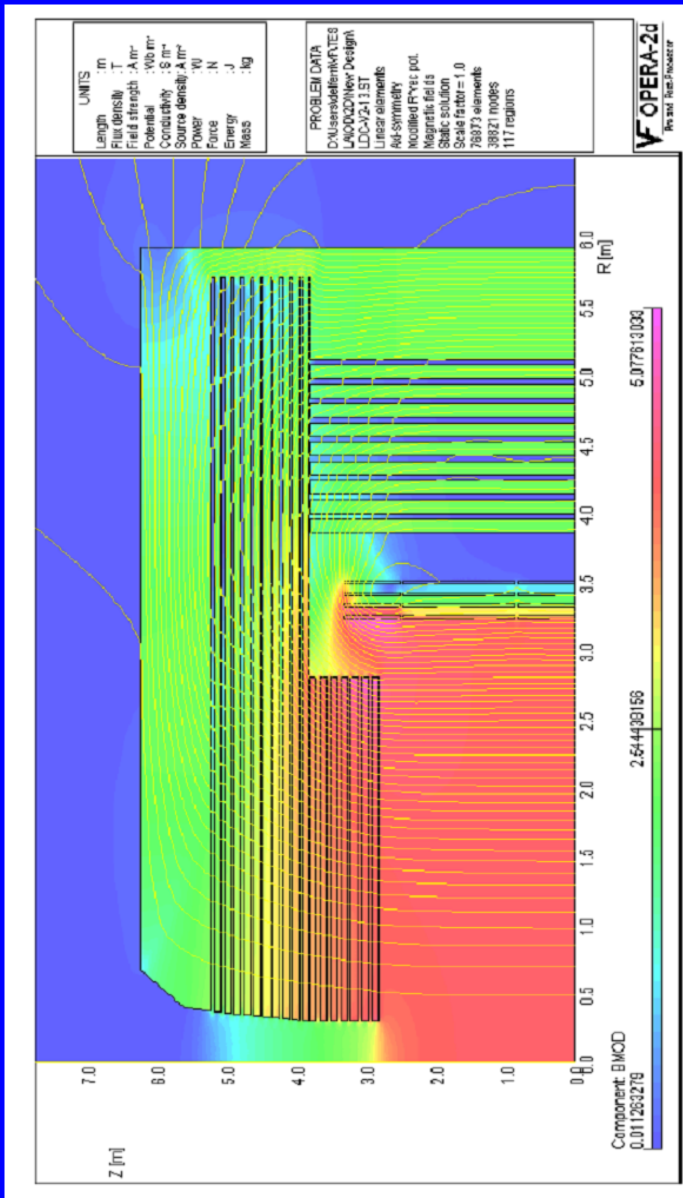


Designing the ECAL/LCAL overlap well should be a priority

BCAL Electron Detection



Solenoid a la CMS



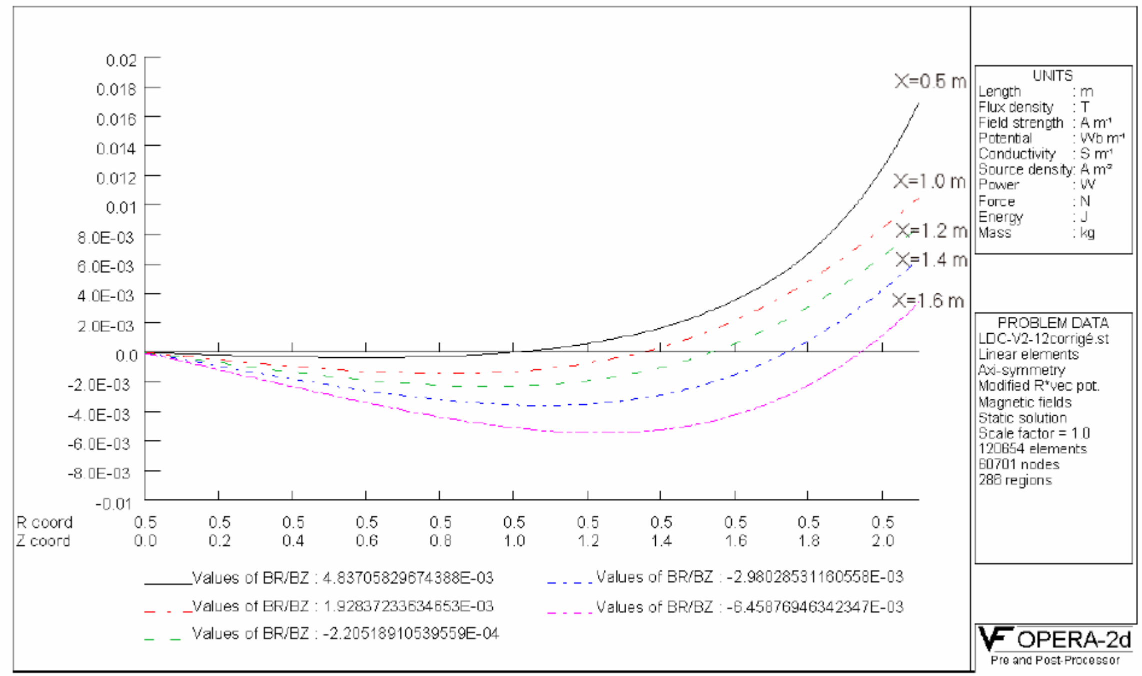


Figure 59: Field Integral homogeneity □B_r/B_zdz between z=0 and z=2.1m for R=0.5m, R=1m, R=1.2m, R=1.4m and R=1.6m

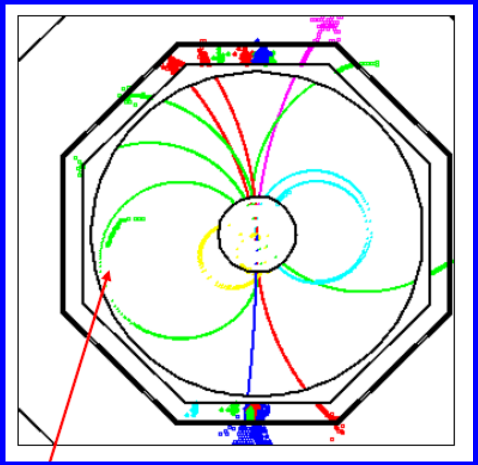
Non-uniformities can be designed to be small, and field will be mapped.

Flux Return

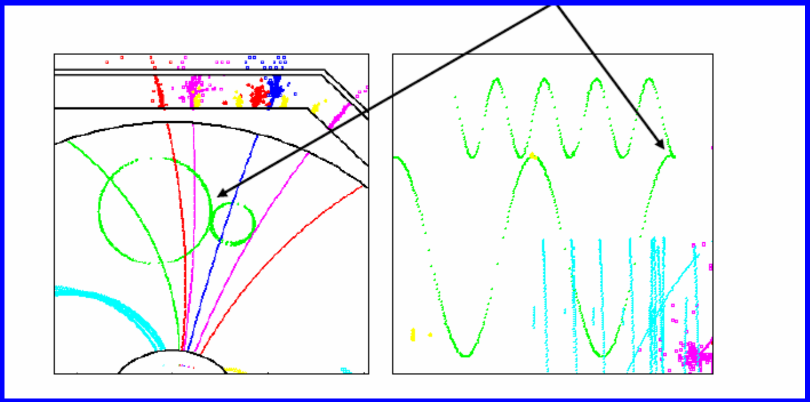
- Instrumented
- (does this affect field homogeneity / cost ?)

Particle-Flow Performance

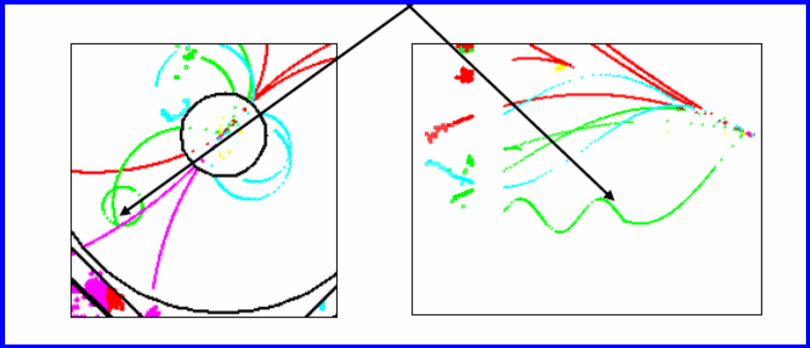
Recent studies by M. Thomson show that correct treatment of tracks is very important. Detector with a TPC is well placed to sort this out.



Track-cluster matching for loopers

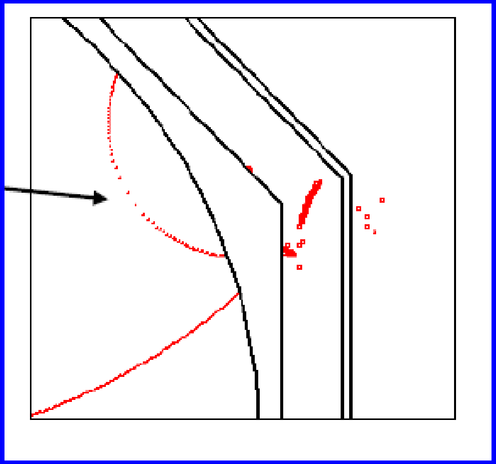


V^0's



Kinks

See 5/9 phone meeting.



Back-scatter

Particle-Flow Performance Summary

Studies so far have used MC info for hit-track association. Results expected soon with full tracking included.

Starting to really have the tools available to do detector optimization in the context of particle flow.

A good time for YOU to get involved.

M. Thomson

LDC00Sc (63 layer HCAL)

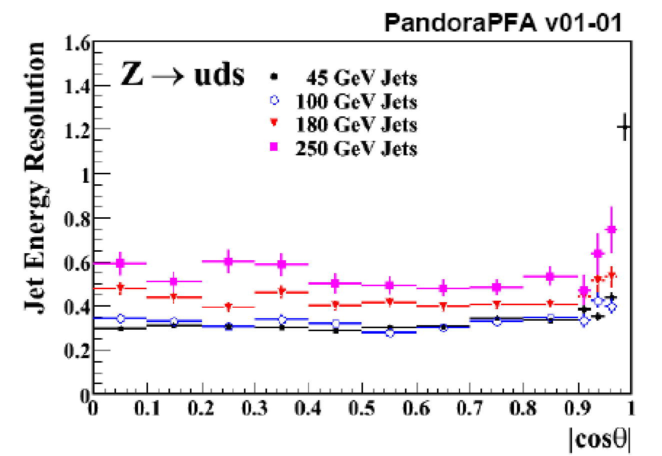
PandoraPFA v01-01

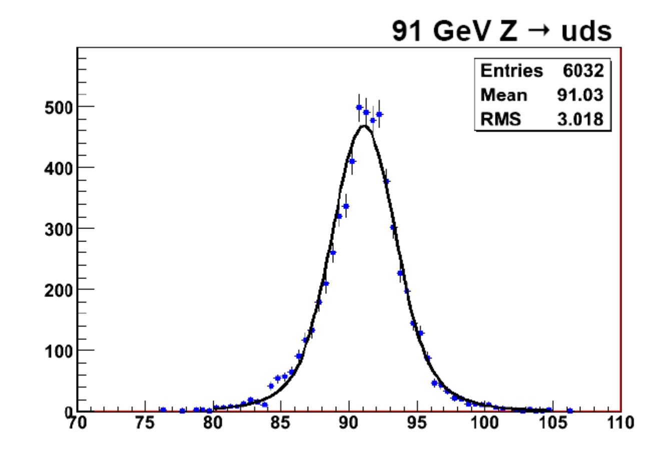
E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\|\cos\theta\|<0.7$	σ_E/E_j
45 GeV	0.295	4.4 %
100 GeV	0.305	3.0 %
180 GeV	0.418	3.1 %
250 GeV	0.534	3.3 %

PandoraPFA v02-α

E_{JET}	$\sigma_E/E = \alpha/\sqrt{E_{jj}}$ $\|\cos\theta\|<0.7$	σ_E/E_j
45 GeV	0.226	3.3 %
100 GeV	0.293	2.9 %
180 GeV	0.392	2.9 %
250 GeV	0.534	3.3 %

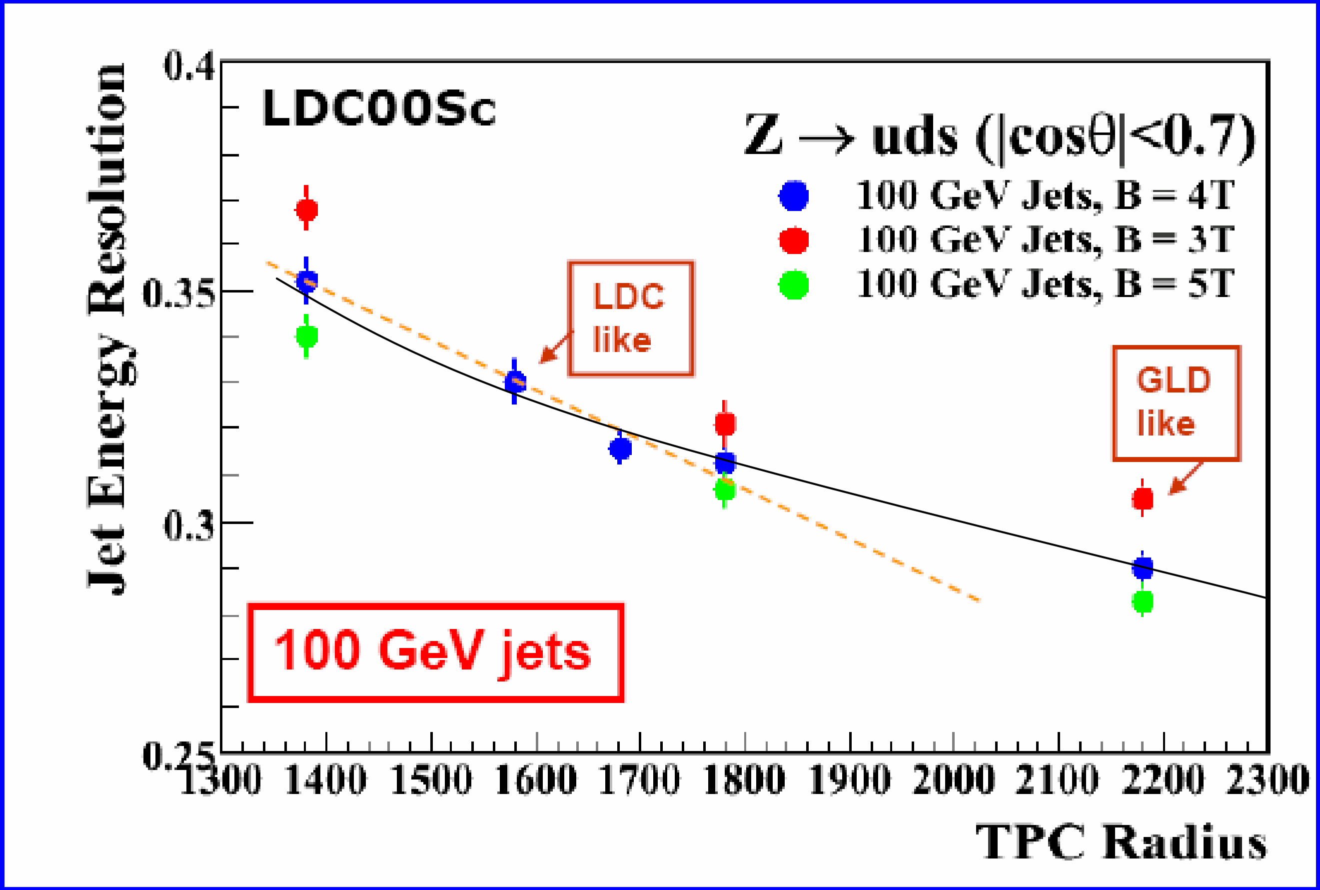
★ For 45 GeV jets, performance now equivalent to **(22.6±0.3)%/√E**





Performance close to beam-pipe will need attention

Particle-flow → Detector directions ?



Higher R much more valuable than high B.

Presumably the decreasing slope implies that intrinsic resolution not confusion starts to dominate at high R.

(The ultimate PFA would potentially have very little dependence on B, R)

LDC00Sc Performance Summary

- Detector design should be able to do excellent physics in a cost effective way.
  - both the physics we expect, and the new unexpected world that awaits

- Very good **vertexing** and **momentum** measurements.

  $\sigma_b = 3.6 \oplus 8.5/(p\beta\sin^{3/2}\theta)\ \mu m$ $\sigma(1/p_T) = 4 \times 10^{-5}\ GeV^{-1}$

- Good **electromagnetic energy** measurement.

$$\sigma_E/E \approx 10\%/\sqrt{E\ (GeV)} \oplus 1\%$$

- The physics demands hermeticity and the physics reach will be significantly greater with state-of-the art **particle flow**
  - Close to 4π steradians.
  - Bubble chamber like track reconstruction.
  - An integrated detector design.
  - Calorimetry designed for resolving individual particles.

$$\sigma_{E_{jet}}/E_{jet} = 23\%/\sqrt{E_{jet}\ (GeV)}$$

(45 GeV jets, cheated track PATREC)

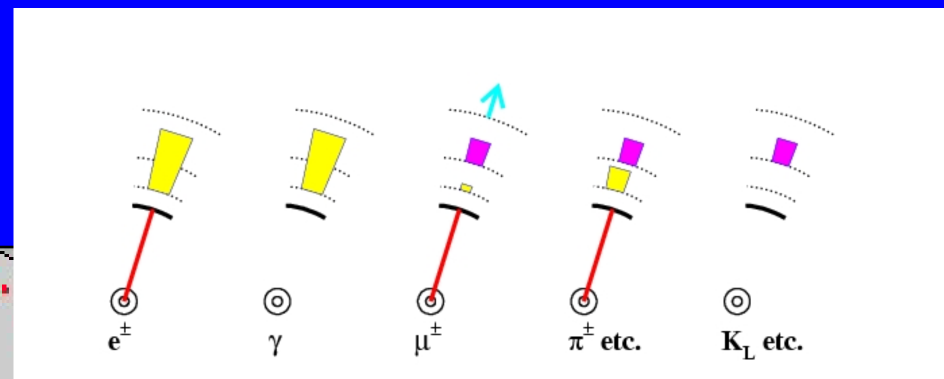
Conclusion: Design goals look achievable. Lots of fun work to do on really designing the detectors and understanding and optimizing their combined performance.

Extra Slides

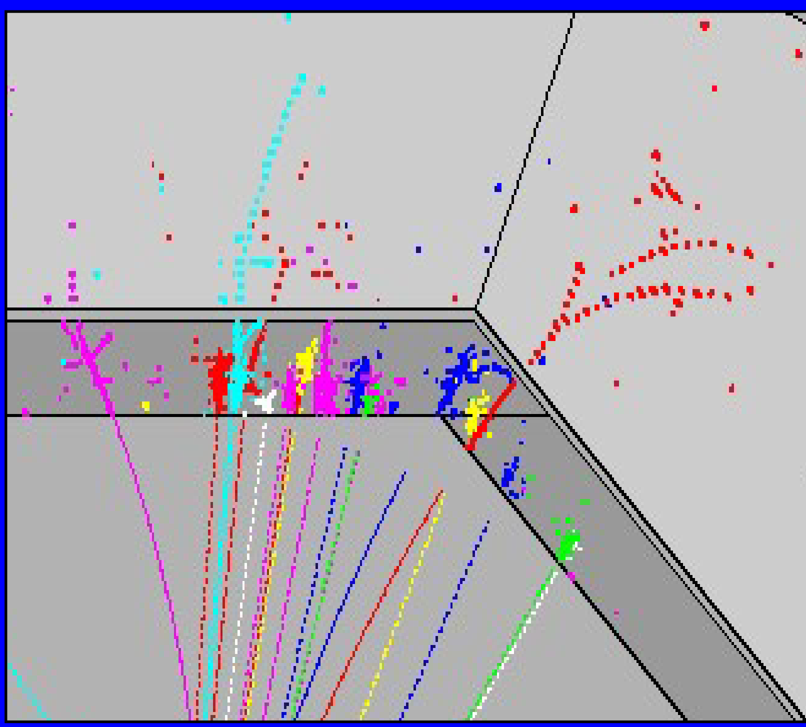
What is particle flow ?

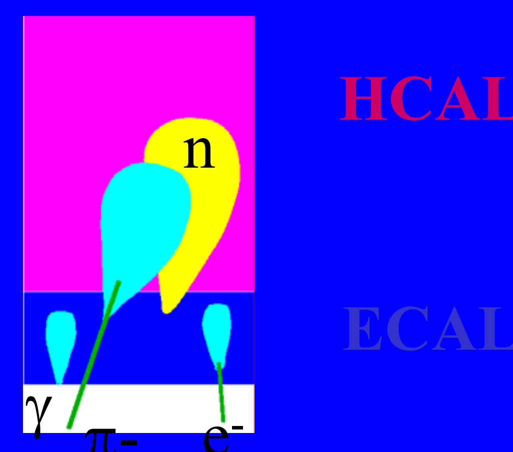
See Henri Videau’s talk at Paris LCWS for a thorough introduction

Particle-by-particle event reconstruction

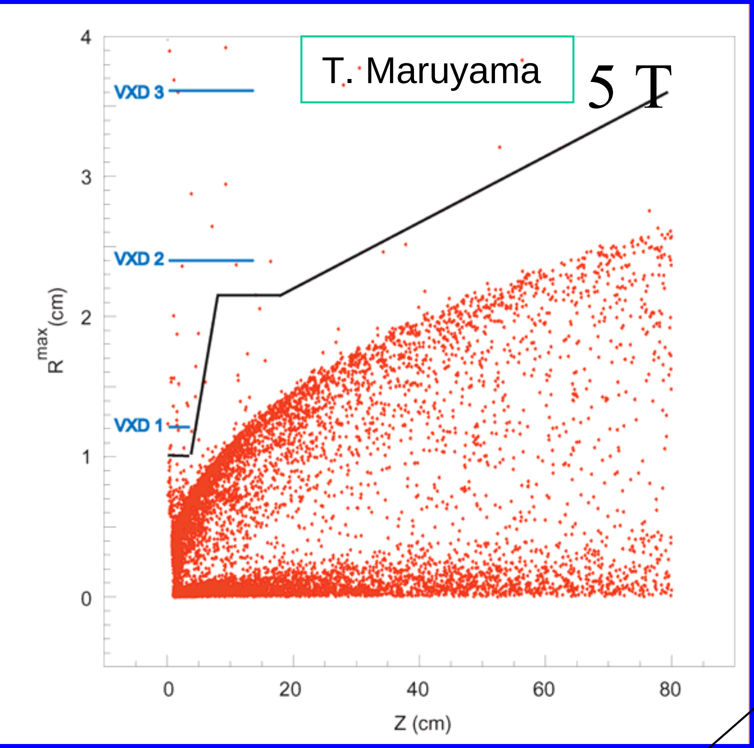


T E T T H

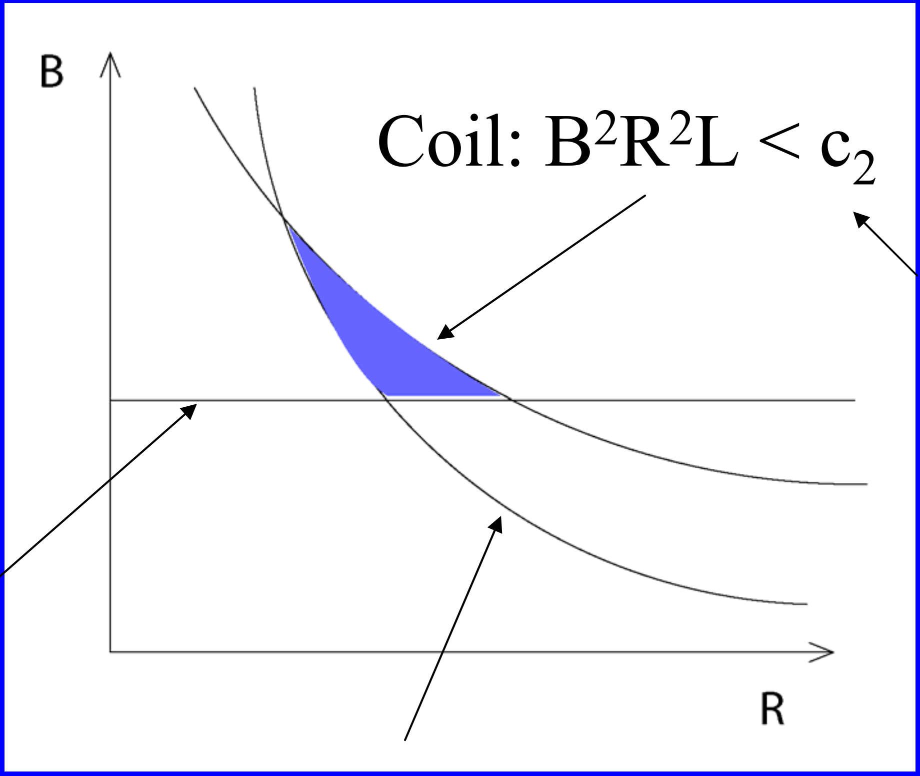




Large or small detector ?



A naïve approach



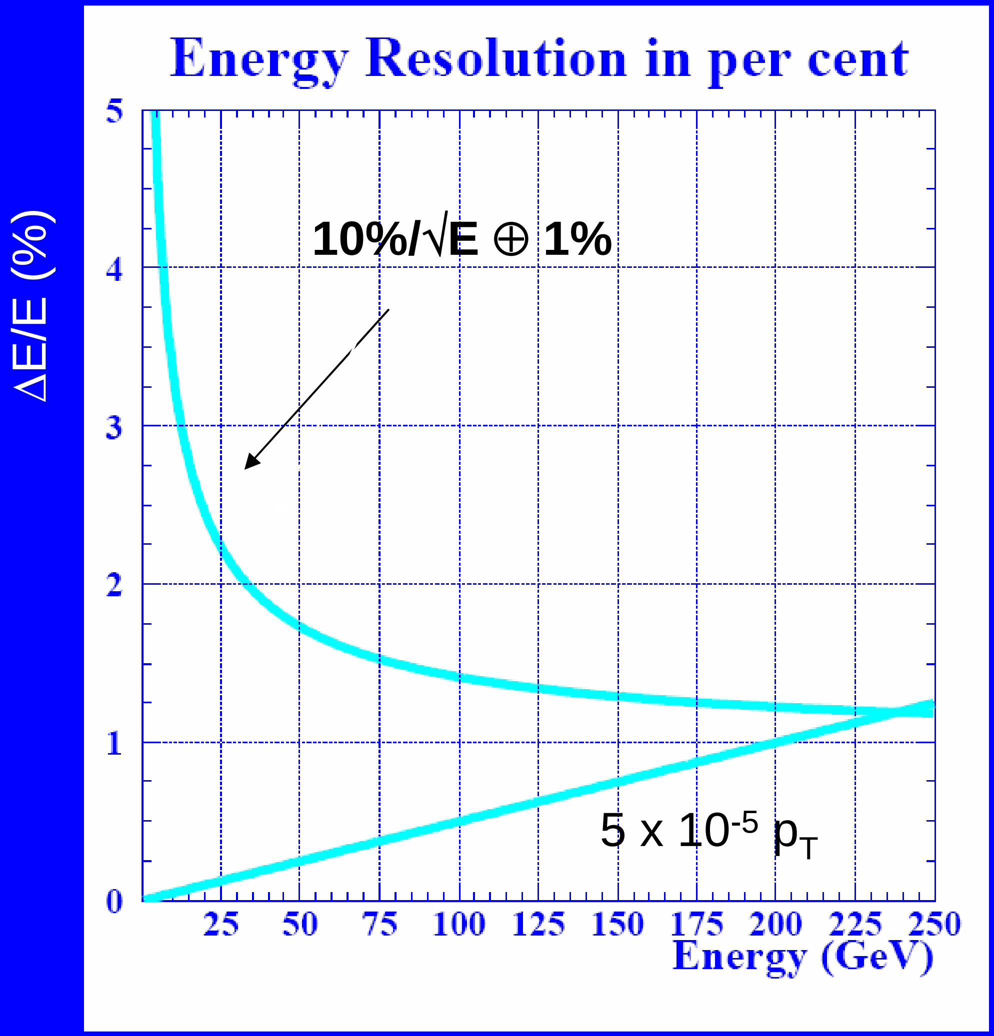
(R. Frey, LCWS2004)

The pairs background and
the VXD inner radius
⇒ minimum B

Particle flow: $BR^2 > c_1$??

Momentum resolution : $BR^2 > c_3$

Comparison of tracker momentum resolution with ECAL energy resolution vs Energy



Even for electrons, the tracker should do better than the calorimetry …… (modulo bremsstrahlung ….)

For charged pions, it is even clearer that intrinsic calorimeter charged pion resolution is not the issue IF we have a highly efficient tracker and can identify which energy depositions in the calorimeters are caused by charged pions.

Comparisons

- If the same momentum resolution specs are required, then by definition, the TPC-like tracking choice (which is also complemented with VTX tracking and other specialized tracking devices) implies that B R_{ECAL}^2 is greater than for SiD
- Particle-flow performance may depend strongly on BR_{ECAL}^2.
  - LDC is 10 T m^2 (TESLA was 11 Tm^2)
  - GLD is 13 T m^2
  - LDC' , GLD' likely to be around 12 T m^2
  - SiD DOD = 8 T m^2
  - ALEPH = 5 Tm^2
- Currently, it looks like the dependence in the region we have been investigating is much slower than this. (=> not dominated by confusion ??). For neutrals not clear that B helps at all.