Part II

ILC Detector Concepts

&

The Concept of Particle Flow

ILC R&D Introductory Remarks

As you will see in the following …

Detector development for the ILC is a worldwide effort
Many groups and motivated people are involved

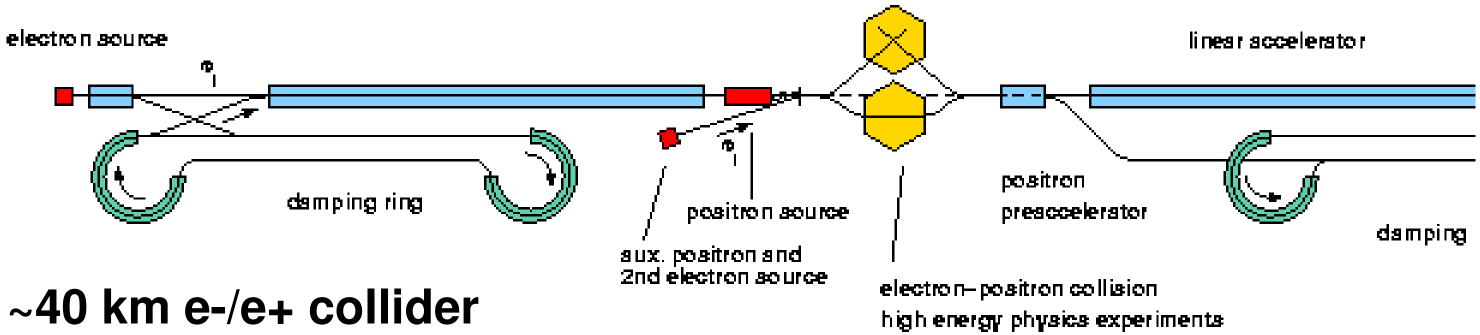
This lecture is more focused on principles rather than on every detail
Cannot do justice to all R&D projects

For a comprehensive overview on ILC activities consult e.g. http://www.linearcollider.org

or check notes on results of R&D for the ILC

http://www-flc.desy.de/lcnotes

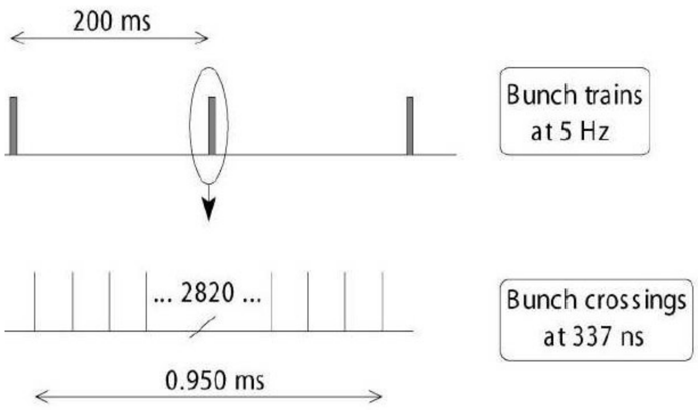
Brief Reminder on the International Linear Collider - ILC



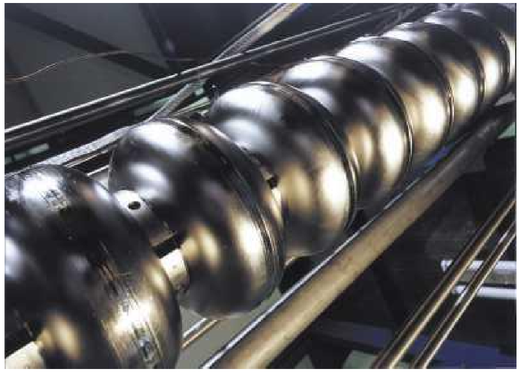
~40 km e-/e+ collider

Energy: 500 – 1000 GeV
Luminosity: 3-6 $10^{34}/cm^2/s$

Beam Bunch structure:



Recommended technology:
Superconductive RF cavity
1.3 GHz frequency



Goal:
minimise the number of bunches integrated
➡ high readout speed: 25-50 MHz

Lepton vs Hadron Machines

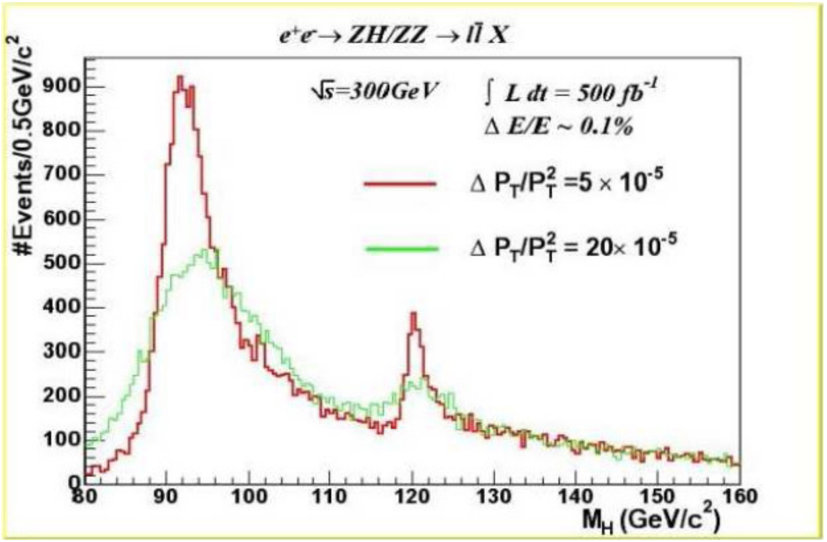
Linear Collider	Hadron Machines (e.g. LHC)
"Driven" by electroweak interactions	"Driven" by strong interactions
"small occupancy	"huge" occupancy
"small" background	"huge" background
"small" rate	"huge" rate
extreme precision	reasonable precision
focus on individual particles	only partial event reconstruction
energy balance	p_t balance

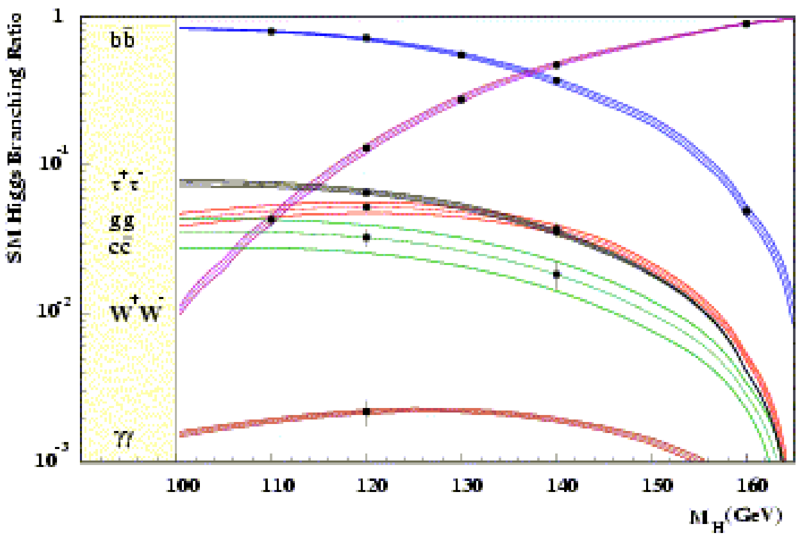
➔ charged and neutral particles
➔ system aspect stressed rather than individual sub-detectors

Challenges of Detector R&D:

- push precision detector technologies to the limit
- optimize detector synergy

Physics requirements





a) Two-jet mass resolution comparable to the natural widths of W and Z for an unambiguous identification of the final states.

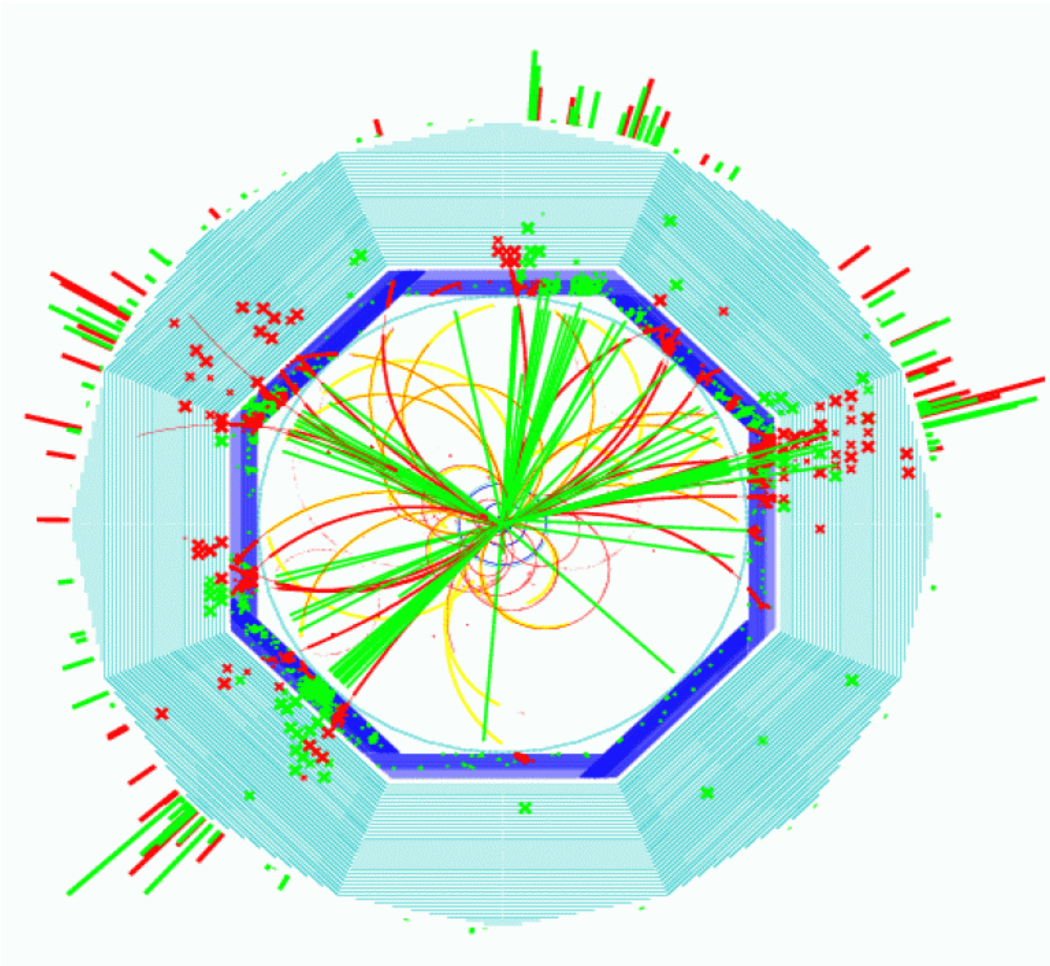
b) Excellent flavor-tagging efficiency and purity (for both b- and c-quarks, and hopefully also for s-quarks).

c) Momentum resolution capable of reconstructing the recoil-mass to di-muons in Higgs-strahlung with resolution better than beam-energy spread .

d) Hermeticity (both crack-less and coverage to very forward angles) to precisely determine the missing momentum.

Main Steps of Measurement

Event at the ILC: .....
Typical Structure of a HEP Event !



Vertex Detectors

Reconstruction of
Interaction point and
decay vertices

Tracking Detectors

Reconstruction of Charged
Particles in the Central
Part

Calorimetry

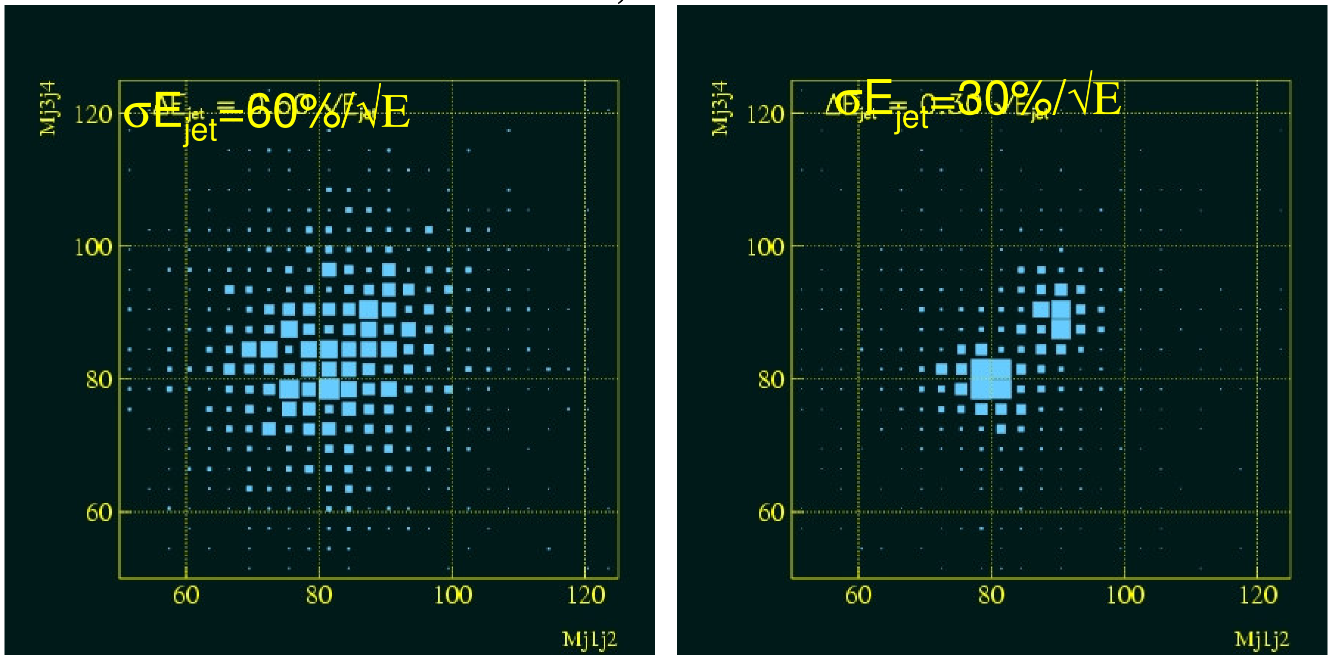
Energy measurement
in the outer part
Traditionally the only mean
to measure the highest energetic
particles

This is what we are aiming for …

Regard: Jet Mass Reconstruction in $e^+e^- \rightarrow WW\nu\nu$, $ZZ\nu\nu$

Need Separation of WW and ZZ: 4 Jets + missing momentum

$$e^+e^- \rightarrow WW\,\nu\bar{\nu} \quad , \quad e^+e^- \rightarrow ZZ\,\nu\bar{\nu}$$



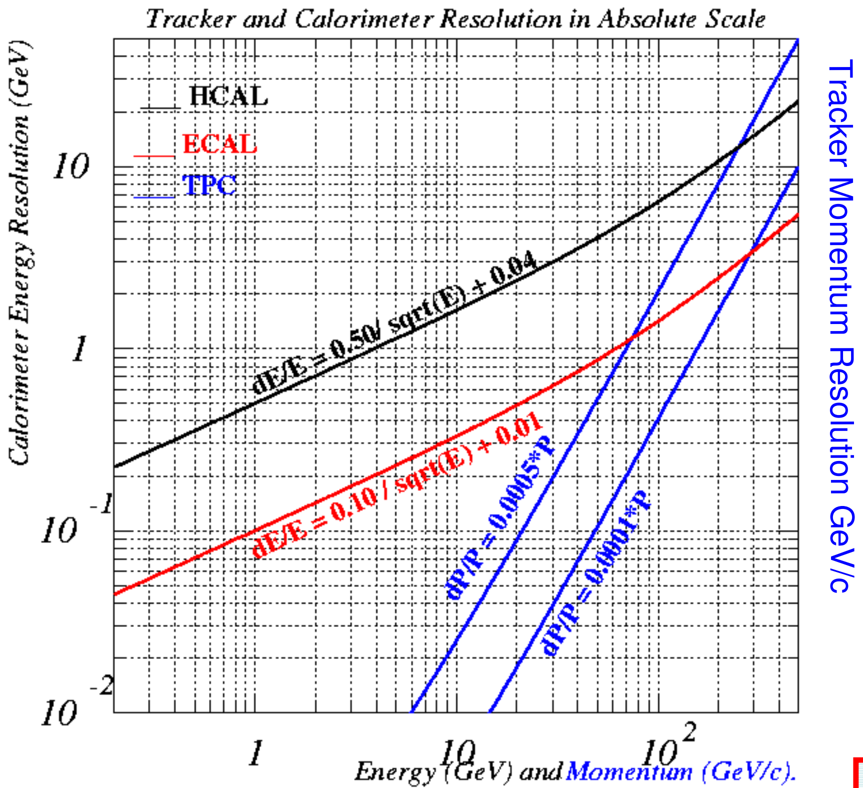
A LEP like detector ILC Detector

30%/√E Jet Energy Resolution needed @ ILC

Practical Limit - Why ??

Energy Resolution

Final state contains high energetic jets from e.g. Z,W decays
Need to reconstruct the jet energy to the utmost precision !

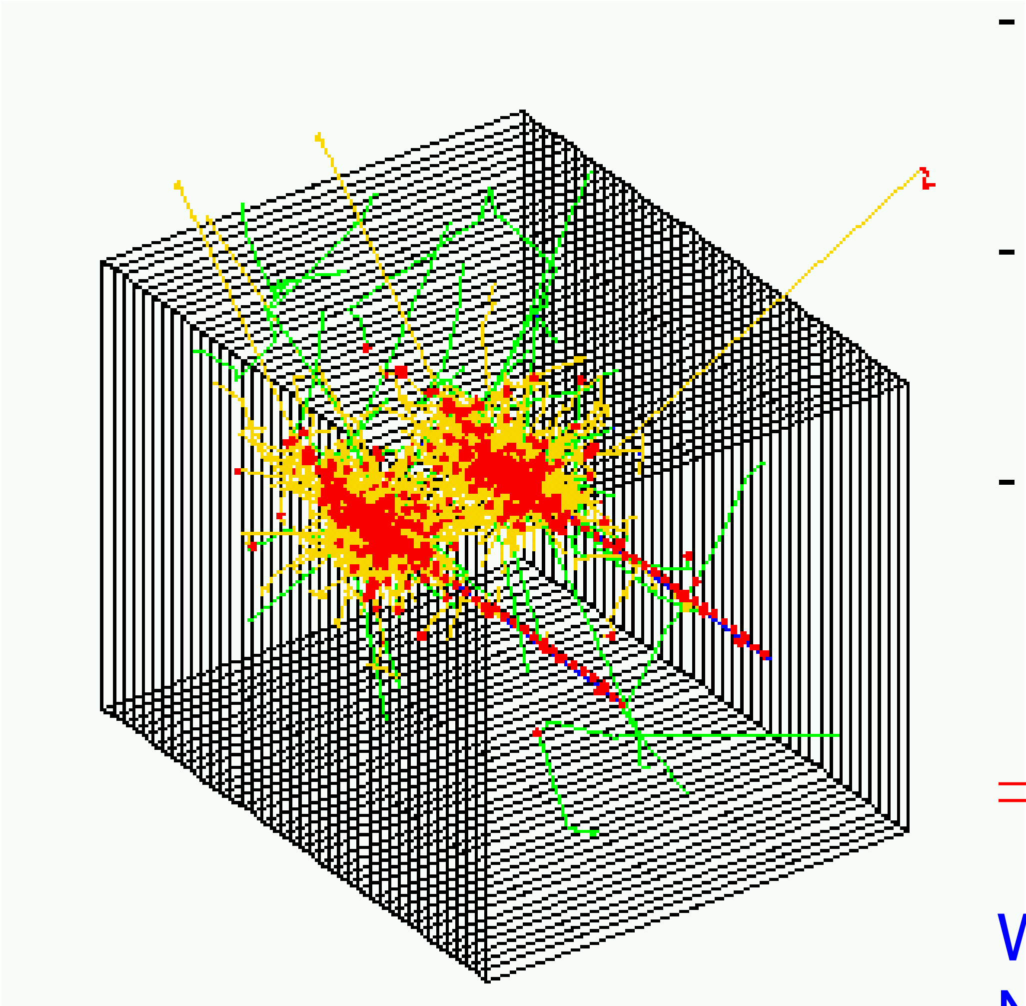


Event Record consists of …

- Charged Particles ($e^{\pm}$, $h^{\pm}$,$\mu^{\pm}$))
  Up to 100 GeV
  Most precise measurement
  by Tracker
- γ
  Measurement by Electromagnetic
  Calorimeter (ECAL)
- Neutral Hadrons
  Measurement by Hadronic
  Calorimeter (HCAL)

$$\sigma_{Jet} = \sqrt{\sigma^2_{Track.} + \sigma^2_{Had.} + \sigma^2_{elm.} + \sigma^2_{Confusion}}$$

Confusion Term



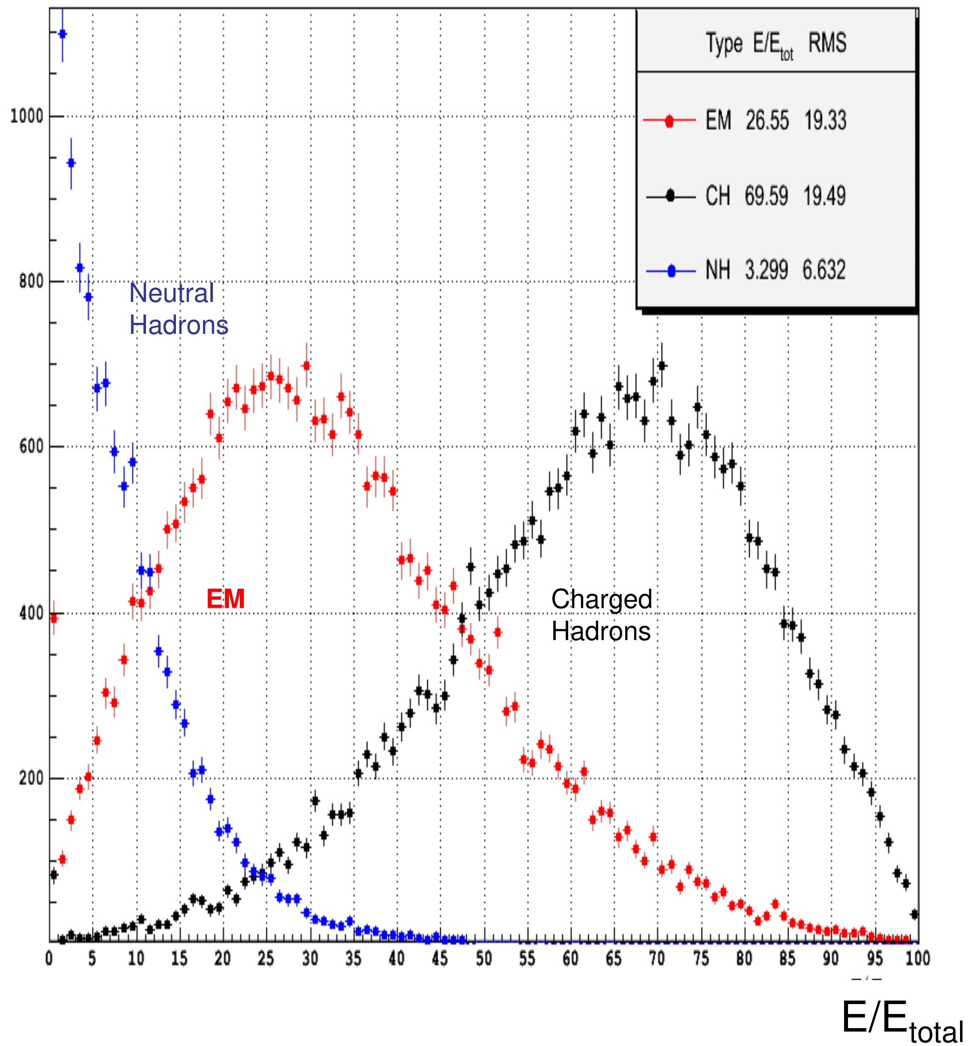
- Two near by Hadrons enter a/the Calorimeter
- Complicated topology by two hadronic showers
- Correct assignment of energy nearly impossible

⇒Confusion Term

We don’t accept it !!!
Need to minimize the confusion term as much as possible !!!

Energy Resolution - “Summary”

Fractional contribution of particle types to event record



Energy Resolution - "Summary"

Fractional contribution of particle types to event record

Particles in Jet	Fraction of Visible Energy	Detector	Resolution
Charged particles	~65%	Tracker	$< 0.005\%\ p_T$ negligible
Photons	~25%	ECAL	$\sim 15\% / \sqrt{E}$
Neutral hadrons	~10%	ECAL + HCAL	$\sim 50\% / \sqrt{E}$

$\sim 18\% / \sqrt{E}$

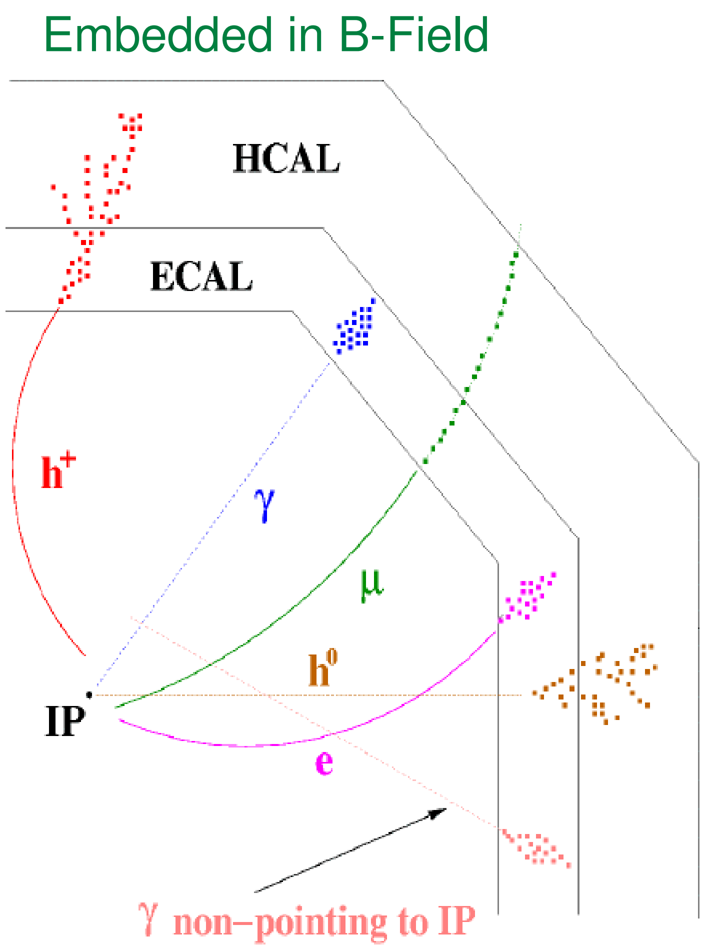
! Minimize Role of Confusion Term !

E/E_{total}

Particle Flow and Detector Layout

For optimal energy resolution:
Need to detect every single particle in the event $\rightarrow$ Particle Flow

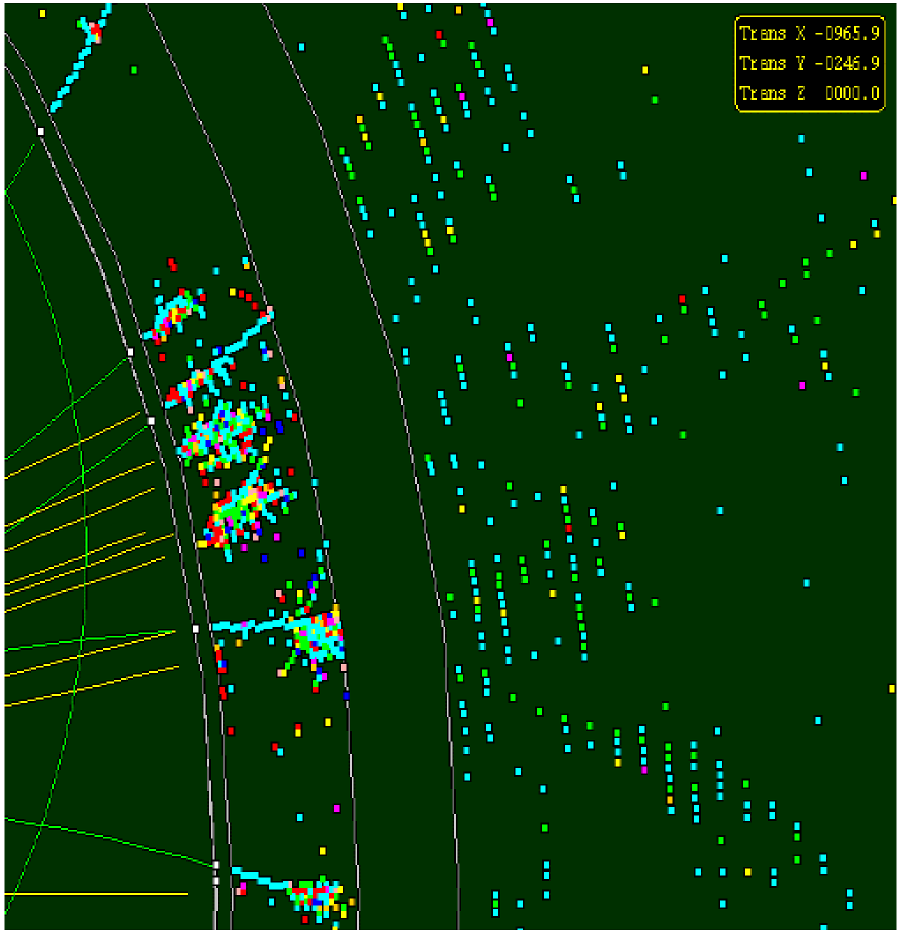
- Find charged particles with tracker and find associated shower in calorimeter
  Difficult for hadrons
  (Shower Track Matching)
  Replace calorimetric energy by track energy
- Find Photons in ECAL
- Find neutral hadrons in HCAL



Need to minimize the role of HCAL
Still need the best HCAL ever built

‘Clean’ Machine yet a hostile Environment

… at least for the precision we’re aiming for



Need to develop a very fine granulated calorimeter

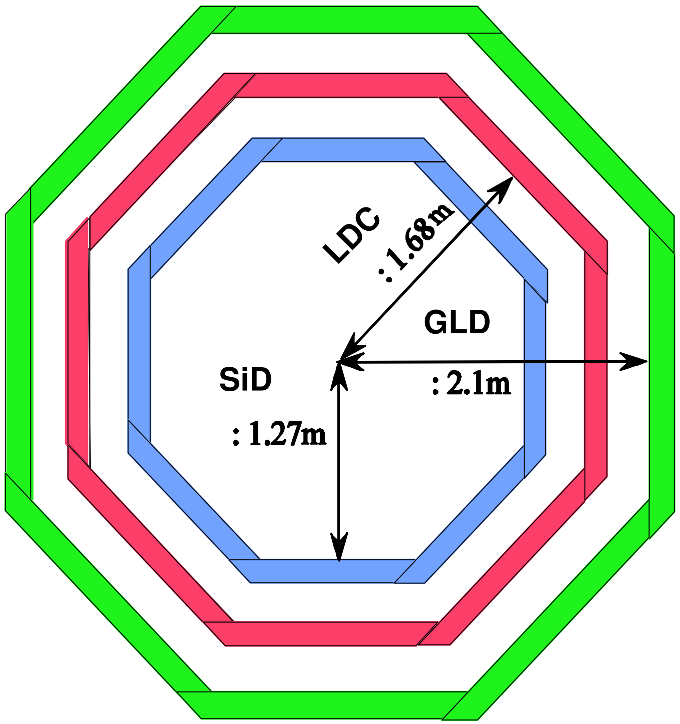
(+ plus ultra intelligent reconstruction algorithms)

Detector Concepts

Concepts currently studies differ mainly in SIZE and aspect ratio

Relevant: inner radius of ECAL: defines the overall scale

ECAL end-view



- Figure of merit (ECAL):

  Barrel: $B\, R_{in}^2 / R_m^{effective}$

  Endcap: "B" $Z^2 / R_m^{effective}$

  R_{in} : Inner radius of Barrel ECAL

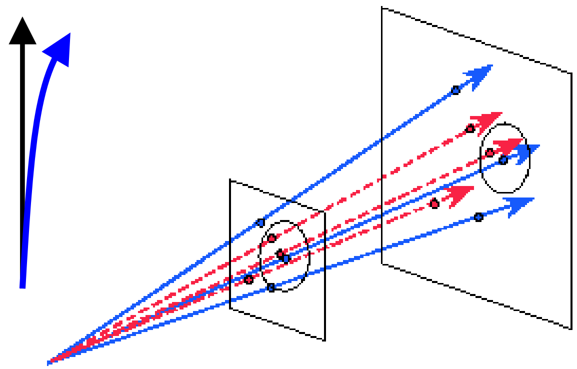
  Z : Z of EC ECAL front face

- Different approaches

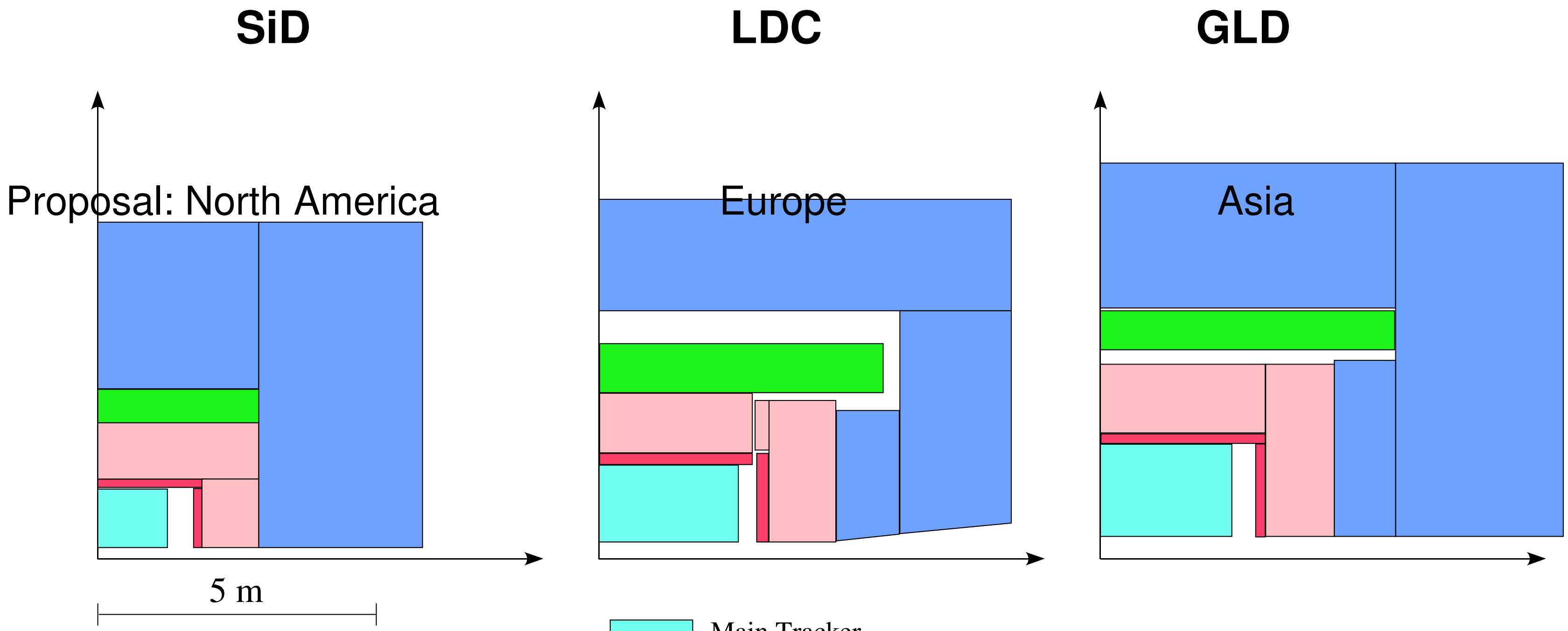
SiD: $\mathbf{B}\, R_{in}^2$

LDC: $B\, R_{in}^2$

GLD: $B\, \mathbf{R}_{in}^2$



Detector Concepts Side Views



SiD = Silicon Detector

LDC = Large Detector Concept
GLD = Huge Detector Concept

The 4th concept: oriented vs. traditional calorimetry (see later)

The detector concepts - Overview

<table>
<tr><th></th><th>Concept</th><th>Vertex Detector</th><th>Tracker</th><th>EM Calorimeter</th><th>Hadronic Calorimeter</th><th>Magnet</th><th>Muons</th></tr>
<tr><td>LDC</td><td>optimised for particle flow</td><td>5-layer Silicon Pixel</td><td>TPC</td><td>Silicon-Tungsten</td><td>Iron-scintillator</td><td>4T</td><td>instrumented flux return</td></tr>
<tr><td>GLD</td><td>Large R, optimised for PFA</td><td>fine-pixel CCDs</td><td>TPC</td><td>Tungsten-scintillator</td><td>Lead-scintillator</td><td>3T</td><td>instrumented flux return</td></tr>
<tr><td>SiD</td><td>low beam background Low €€</td><td>5-layer Silicon Pixel</td><td>Silicon strip</td><td>Silicon-Tungsten</td><td>Iron-RPCs</td><td>5T</td><td>instrumented flux return</td></tr>
<tr><td rowspan="2">4th concept</td><td rowspan="2">Simple & Precise</td><td rowspan="2">Pixels</td><td rowspan="2">TPC</td><td colspan="2">dual/triple readout cal: scintillation,Čerenkov,n</td><td colspan="2" rowspan="2">iron-free 3.5 T dual-solenoid field drift tubes</td></tr>
<tr><td>crystal</td><td>fibre-W</td></tr>
</table>

Table by V. Martin
shown at Linear Collider Physics School 2006 Ambleside/UK

Particle Flow Detector

Concept of Particle Flow influences detector design

- Inner radius of Ecal large enough to separate charged and neutral particles
- Both Ecal and Hcal inside the magnet coil
- To reconstruct particle showers need excellent granularity of Ecal, Hcal
- B-Field and tracking suited for track-shower match

Concrete Implications on design of calorimeter will be addressed in Part III

Detector Requirements

Momentum: $\sigma_{1/p} < 5 \times 10^{-5}$/GeV **(1/10 x LEP)**

(e.g. Z-Mass measurement with charged Leptons)

Impactparameter: $\sigma_{d0} < 5\mu m \otimes 5\mu m/p(GeV)$ **(1/3 x SLD)**

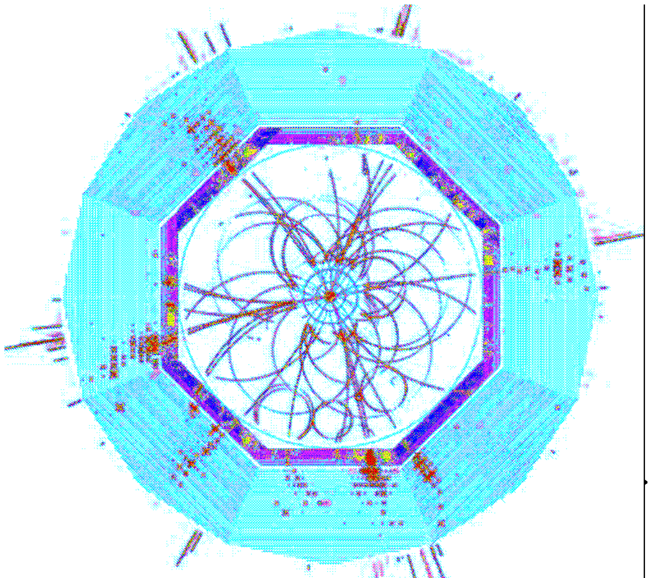
(c/b-tagging, see next part)

Jetenergy : $dE/E = 0.3/(E(GeV))^{1/2}$ **(1/2 x LEP)**

(Measurement of W/Z mass with Jets)

Hermeticity : θ_{min} = 5 mrad

(to detect of events with missing energy e.g. SUSY)



$e^+ e^- \rightarrow t t$

Events with large track multiplicity and a large number of jets (6+) are expected. Therefore:

- **High granularity**
- **Good track measurement**
- **Good track separation**

4 different approaches:

SiD, Large, Huge and 4th detector concepts

GDE Timeline