Calorimetry for a CLIC experiment

Main information source:

ECFA linear collider workshop, Warsaw:
http://ecfa2008.fuw.edu.pl/

What do we learn from of ILC calorimetry

To overcome known shortfalls from LEP/LHC experience, new concepts/technologies are chosen for ILC:

- **Based on Particle Flow Algorithm**
  - Highly segmented (13-25 mm^2) ECAL (analog)
  - Very highly segmented ECAL (digital)
  - Highly segmented (1 cm^2) HCAL (digital)
  - Segmented HCAL (analog)
- **Based on Dual (Triple) readout**
  - Sampling calorimeter
    - Plastic fibres
    - Crystal fibres (<= materials studies)
  - Fully active calorimeter (EM part)
    - Crystal-based

Method and Engineering difficult, but conventional

Limited in energy-range to a few hundred GeV

Method and Engineering difficult and non-proven

Not limited in energy range

Until there is a full-size (min. 1 m^3) prototype fully tested and fully calibrated, one cannot be sure that the proposed concepts match the requirements

General issues derived from ILC experience:

Use solenoid geometry (à la CMS, SiD)
Place ECAL and HCAL inside the solenoid

Use ILC calorimetry technologies (there are already too many)
- Start with the most advanced concept (e.g. SiD)
- Address in particular its validity for the higher energies at CLIC

For later….
- Dual readout calorimetry has interesting features. Physics use and technology far from being mature. Neutron component too slow for CLIC use? *We shall give the dual readout option proper attention at some point in time.*

Work plan: how to get started

Get started with SiD based simulation
(most well-defined for the moment)
ECAL: W/Si (~20 X_0)
HCAL: FE/Scint (analog and digital)

Study jet performance (single jets, and also X→di-jet mass resolution)
Study ECAL performance through X→2-lepton (or X→4-lepton) processes
Software: PandoraPFA or FastMC *(parametrisation,see talk Barklow, Warsaw 10/6/2008)*

Parameters to vary:
Jet energy up to 500 GeV ??
Parent X particle mass from 80 GeV to ?? GeV
Vary the magnetic field (4-5 T)
HCAL depth from 4 Λ_{int} to 7 Λ_{int}
Inner radius of ECAL (120-150 cm ←depends on tracking performance)
Vary HCAL segmentation
Vary Barrel length
(e.g. see talk Marcel Stanitzki, Warsaw 10/6/2008, 14.30 hrs)

Effect of the CLIC time structure (1)

Look at the simulation level and at the hardware level

Hardware:

Get input from electronics experts:

- How to use a short shaping time while maintaining resolution (required # of ADC bits). LHC expertise will help.
- Look at techniques of “Restoring Baseline” and “Tail Cancellation”

Dual readout timing issues:

- Reflected optical signal at full depth is ~20 nsec, in addition to inherent timing from nuclear showering effects
- Neutron shower component has 20 nsec decay time. Probably excluded to make use of it for CLIC.

Simulation:

- Vary the number of overlapping background events accordingly
- See how strategically placed detector layers with high time resolution can help resolving ambiguities
- **Is there a need for time-stamping in calorimetry?**

Effect of the CLIC time structure (2)

ILC time structure allows for power pulsing.
Therefore calorimeter can be very compact, as no cooling is needed.

Si/W ECAL of SiD has only 1.25 mm gap for Si layer

Assess feasibility of power pulsing for CLIC (50Hz, 10^{-5} duty factor)

This will drive ECAL compactness

Back-up slides

What do we learn from of ILC calorimetry

Requirements for ILC calorimetry are dominated by:

- High-precision jet reconstruction (mass reconstruction with jets)
- Mass reconstruction in 2-lepton, 4-lepton, 6 lepton (neutrinos) events
- Good $\pi 0$ reconstruction (including 2γ vertexing)
- $\pi 0$ resolution shall not limit jet resolution

Energy resolutions required

(for ILC, with similar values quoted in the 2004 CLIC report):
Electrons, photons: typically $\sigma E/E = 15\%/\sqrt{E}$ quoted
Single Hadrons: $\sigma E/E = 60\%/\sqrt{E}$ ← actually, momentum resolution will be used instead
Jets: $\sigma E/E = 30\%/\sqrt{E}$ (below 100 GeV), $\sigma E/E$ = 3-4% (above 100 GeV)
(with $\sigma E/E = 60\%/\sqrt{E}$ => $\sigma E/E = 30\%/\sqrt{E}$ giving factor 1/1.4 in luminosity)

ILC jets go up to up to ~200 GeV in energy

The three ILC detector concepts

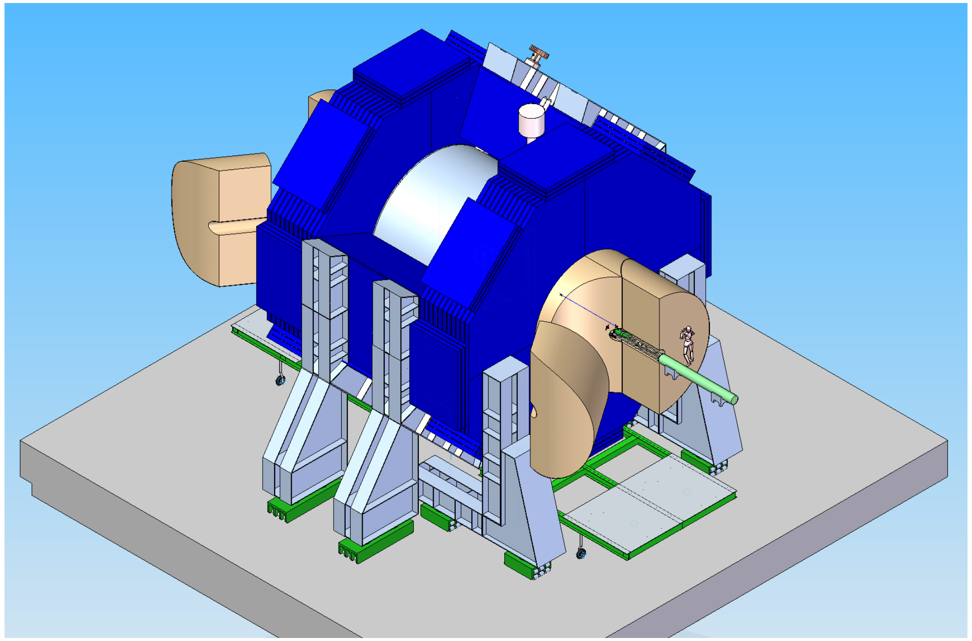
(with emphasis on central calorimetry)

the SiD concept

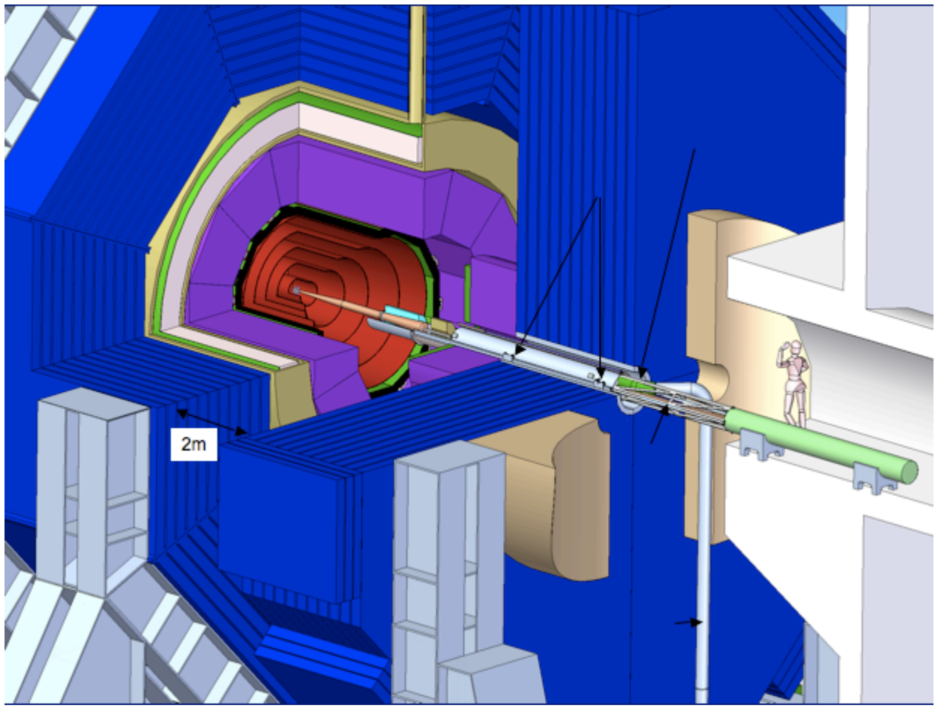
"Jet Energy measurement =PFA" is the basis of the SiD design

http://silicondetector.org/

Compact: 12m x 12m x 12 m

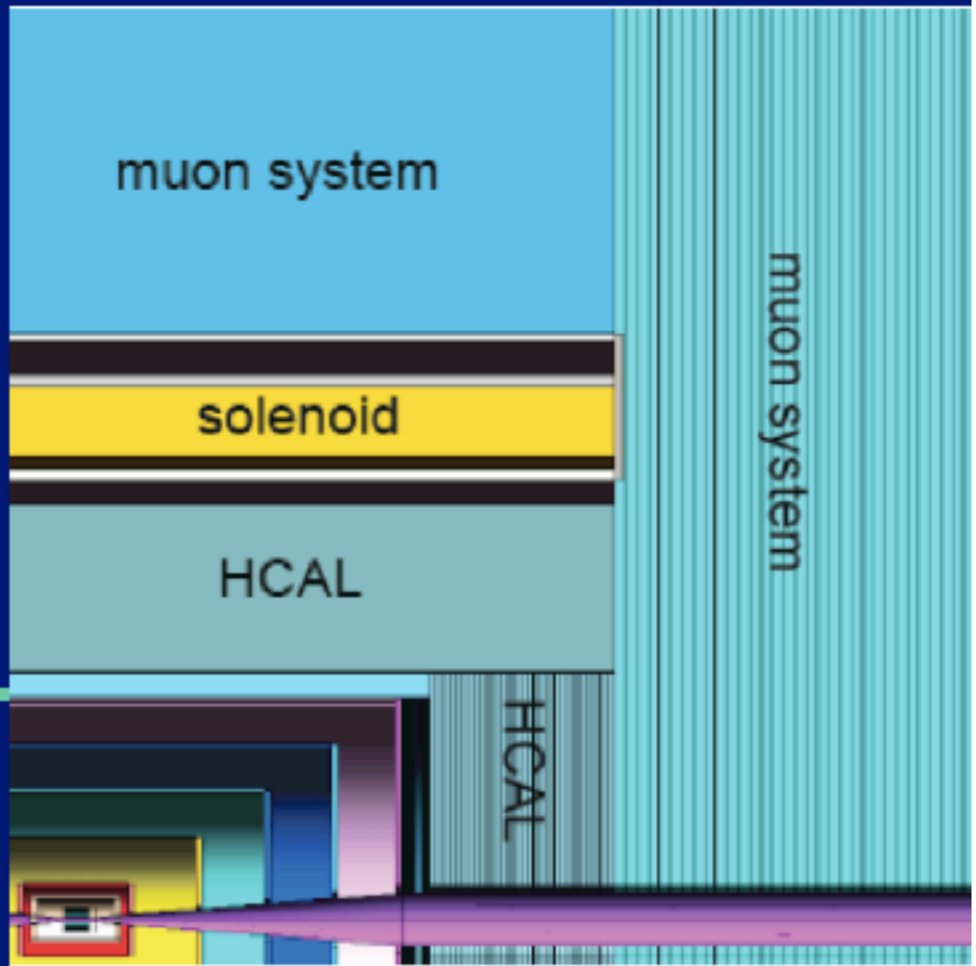


- Si/W for the ECAL
- Digital calorimetry for HCAL
- Limit calorimeter radius (costs)
- Boost B-field (5T) to maintain BR^2
- Si tracking system for best momentum resolution and lowest mass (5 layers)
- Pixel Vertex detector for best pattern recognition (5 layers)



49 groups from 8 countries

SiD Starting Point
Details & Dimensions



Flux return/muon
R_{in} = 333 cm
R_{out} = 645 cm

Solenoid: 5 T; R_{in} = 250 cm

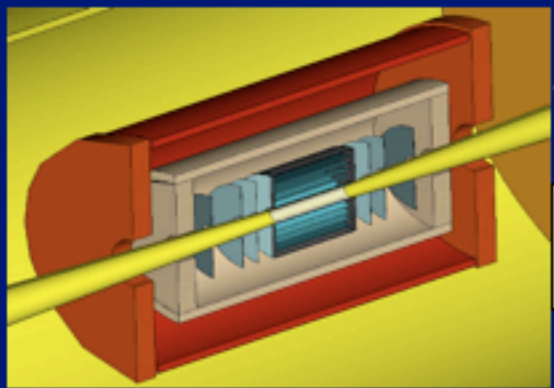
PFA

HCAL Fe: 34 layers; R_{in} = 138 cm

EMCAL Si/W: 30 layers R_{in} = 125 cm

Si

Si tracking: 5 layers; R_{in} = 18 cm



Vertex detector:
5 barrels, 4 disks; R_{in} = 1.4 cm

SiD ECAL

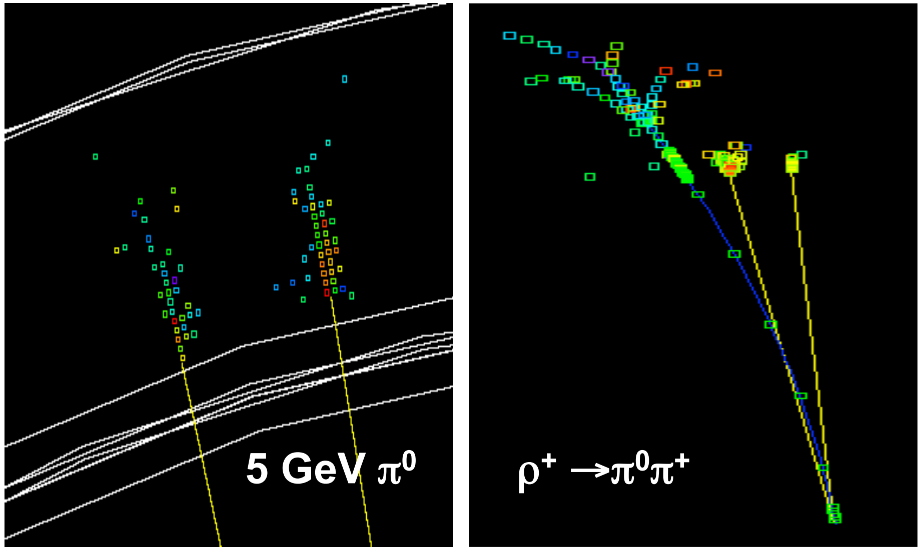
Measure EM energy in dense jets for PFA

Isolate photons from π^0's; improve energy resolution.

Discriminate between different τ decay modes. Use $\tau \rightarrow \rho\nu$ to analyse τ polarization.

Measure mip trajectories for outside-in tracking and muon id.

material	R_M
Iron	18.4 mm
Lead	16.5 mm
Tungsten	9.5 mm
Uranium	10.2 mm



first 20 layers x 2.5 mm thick W
then 10 layers x 5 mm thick W
1mm Si detector gaps
Preserve Tungsten $\rho_{M\ eff}$= 13mm

Highly segmented Si pads 13 mm^2
ADC 13-bits

$\sigma_E/E = 17\% / \sqrt{E}$

SiD HCAL

- Isolate neutral hadronic energy from charged particle showers and photons (PFA)
- Track mips for muon id & PFA

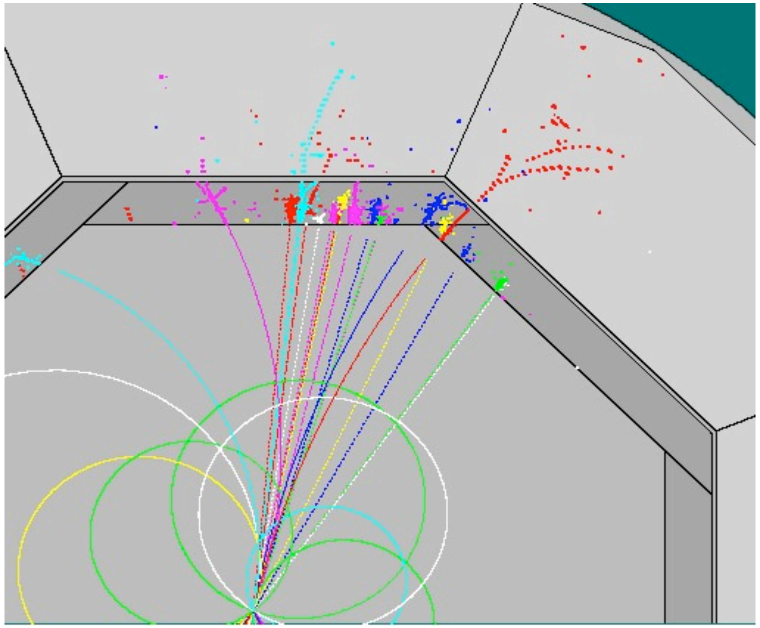
Iron slabs (~20 mm) + optional detector technologies

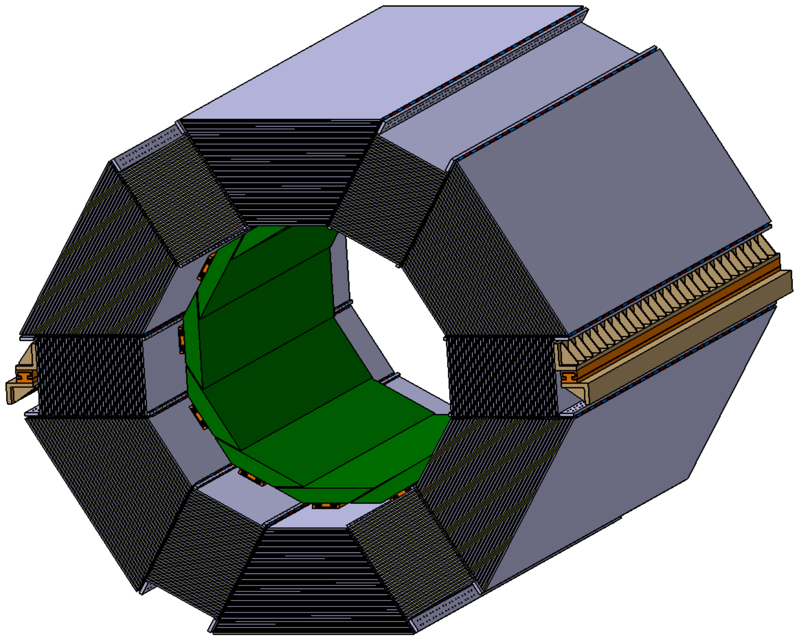
- RPC
- GEM
- Micromegas
- Scintillator+SiPM

1 x 1 cm^2 transverse segmentation

40 layers >4Λ thick !!

ΔE/E = 60-80%/√E for neutrals
ΔE/E = 30%/√E for jets <100 GeV
ΔE/E = 3-4% for jets >100 GeV





In parallel (new SiD effort)
Simulation studies on total absorption crystal-based calorimeter using dual-readout

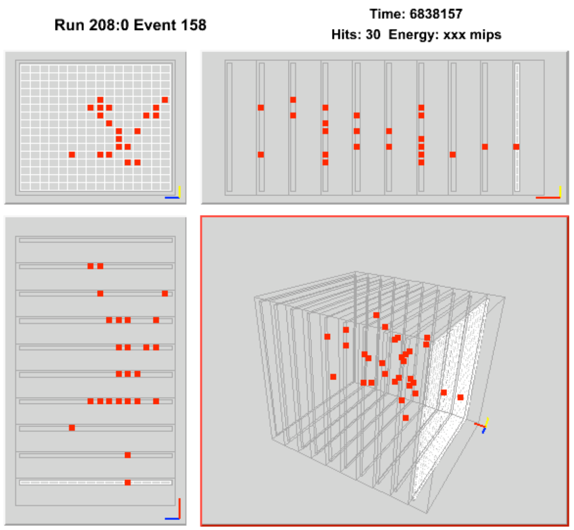
Digital HCAL concept

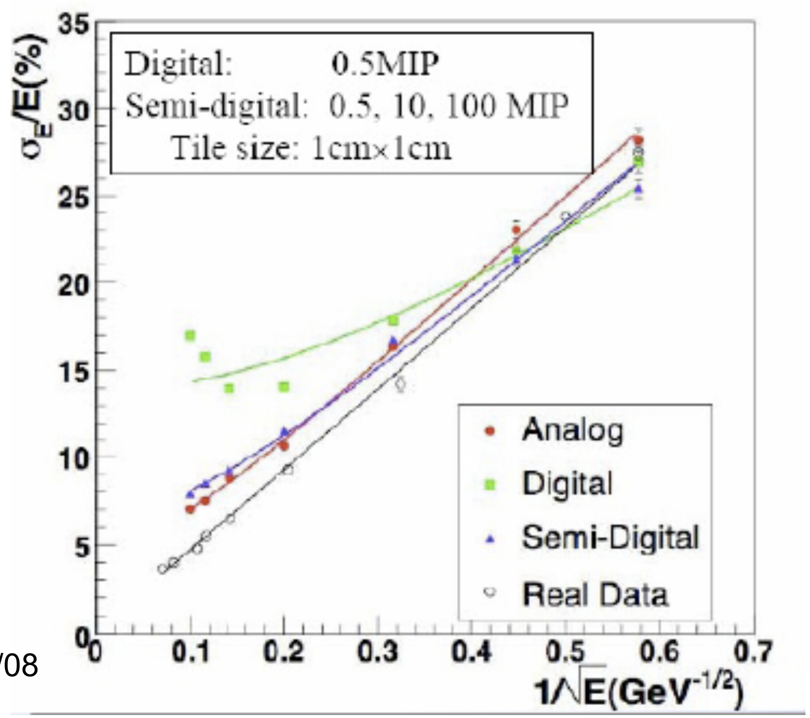
Optimized for the application of Particle Flow Algorithms

Trades resolution on a small number of cells (towers) in traditional calorimeters with low (one-bit) resolution on a large number (~10^7 – 10^8) of cells

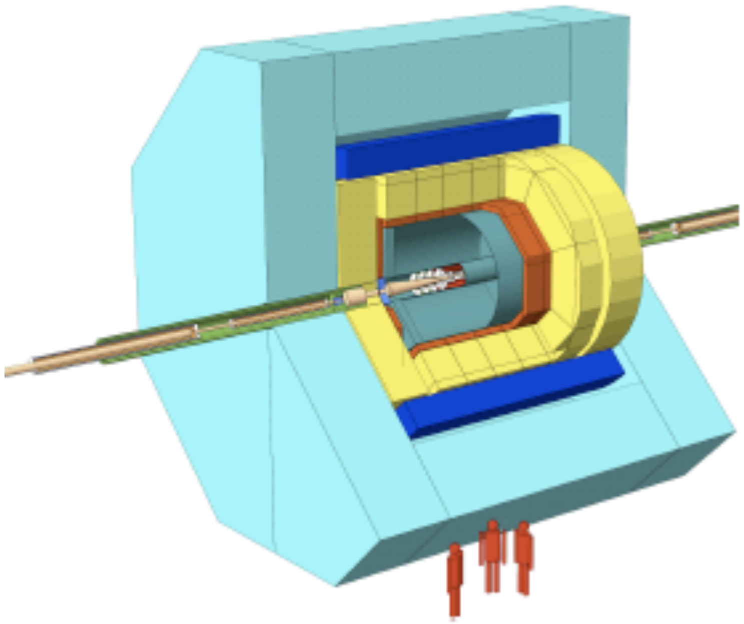
Novel concept which needs to be validated.
Simulation studies ongoing.
At present only (too) small prototypes.

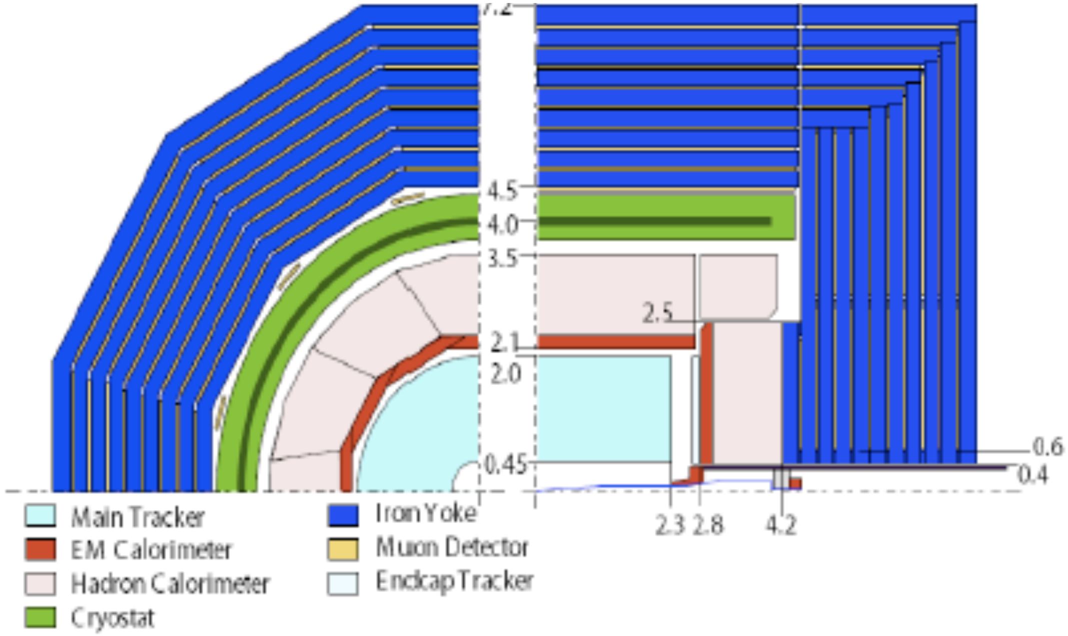
Aiming for a 1m^3 prototype with 400000 channels by the end of 2009 (USA + Europe?).
Cell sizes 1*1 cm^2
Active medium options: RPC, GEM Micromegas
USA: 1-bit
Europe: 3-bits (0.5, 10, 100 mip)





the ILD concept





LDC DOD:
see http://www.ilcldc.org

Large Detector Concept

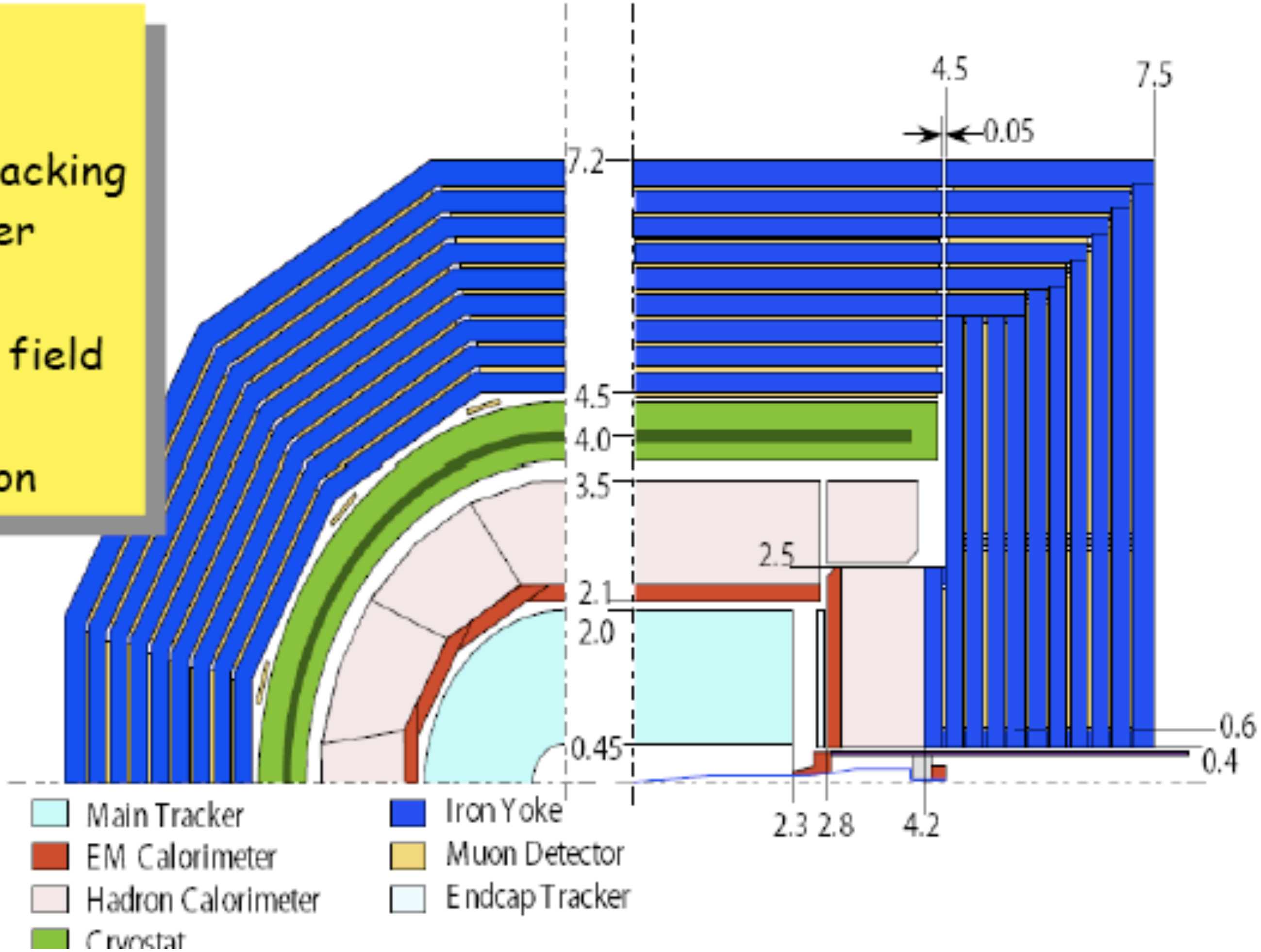
GLD DOD
see arXiv:physics/0607154v1

Global Detector Concept

170 groups from 28 countries

Basic ILD layout

- High precision Vertex
- Large Volume TPC
- (nearly) complete SI tracking
- Particle Flow calorimeter
- Excellent hermeticity
- 3-4T central solenoidal field
- Iron Return Yoke with
  Muon instrumentation



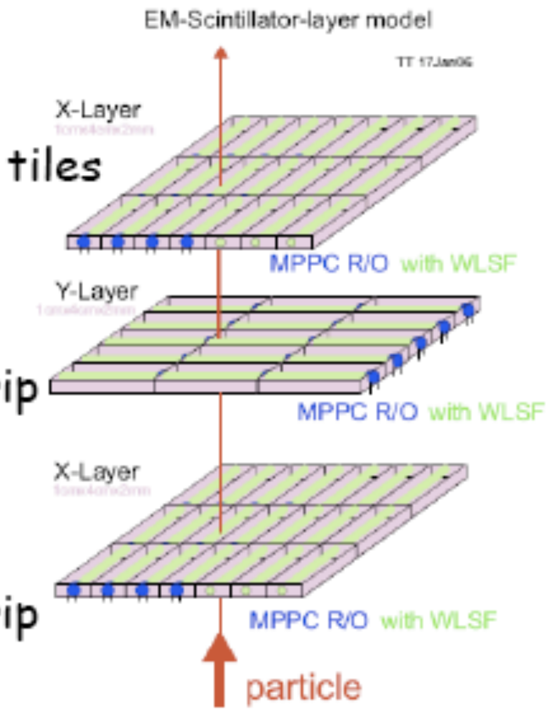
- Reliable, **redundant** tracking system
- High precision calorimetry based on particle flow for best jet energy reconstruction and excellent particle ID
- Hermeticity

ILD ECAL technology

Particle flow calorimetry:

small cells, small Moliere radius

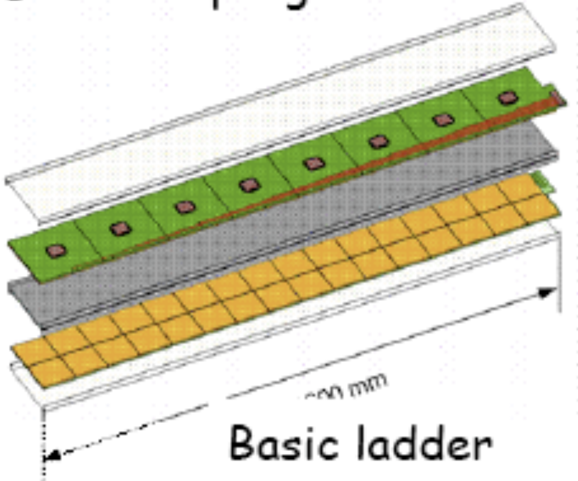
Strip or tiles



strip

strip

LDC: Si-W sampling calorimeter



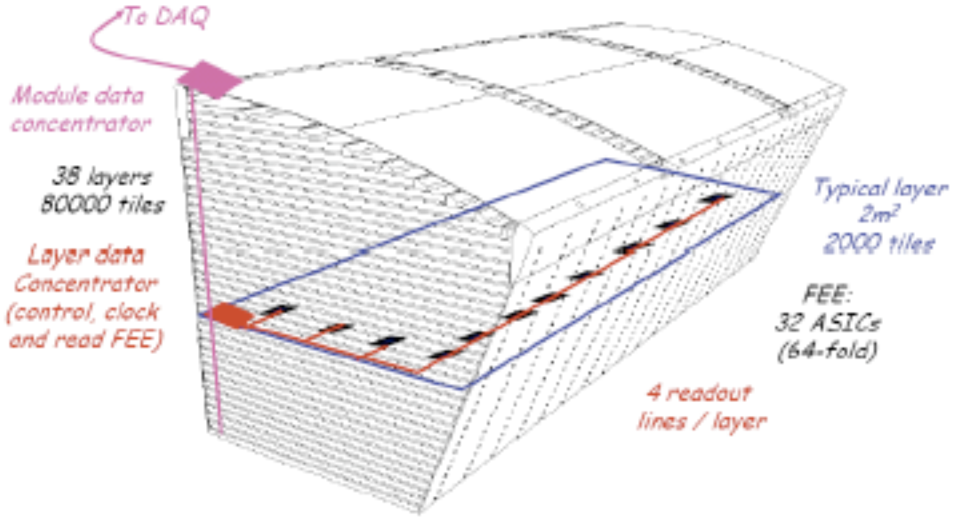
Basic ladder design

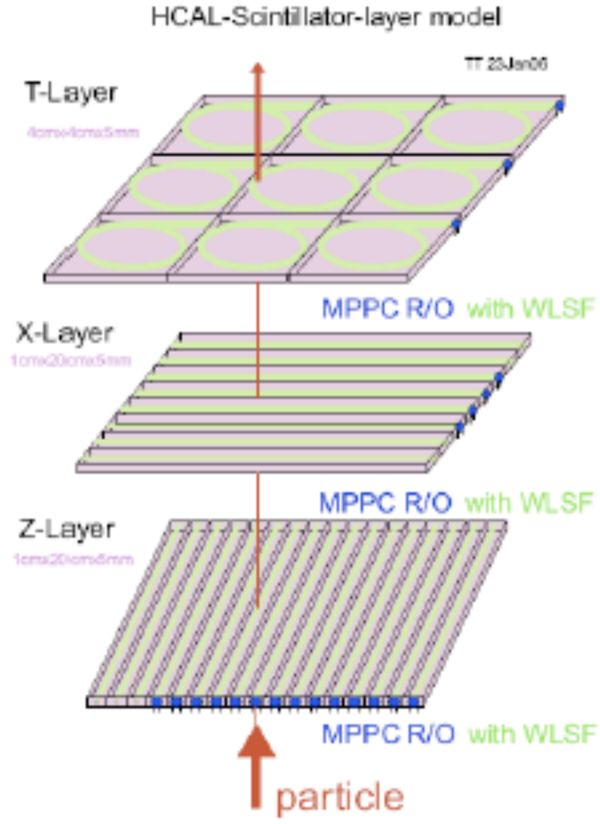
GLD: Scintillator-Pb sampling calorimeter

ILD HCAL technology

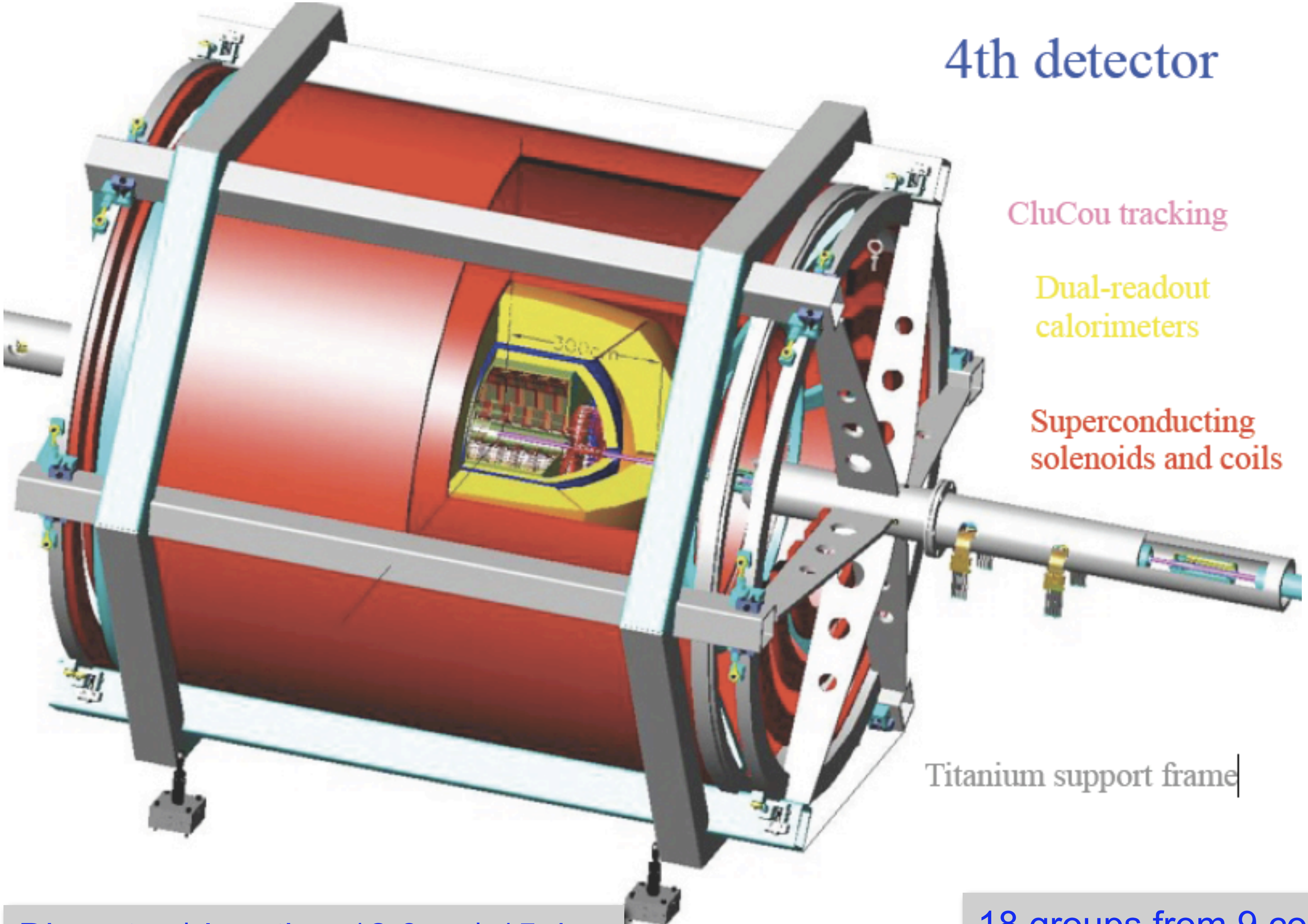
Two options are under investigation:

Analogue Scintillator tile - Fe sampling
digital Fe-sampling





the 4th concept



Diameter * length = 12.8 m * 15.4 m

18 groups from 9 countries

4^{th} concept calorimetry

ECAL

•Crystal dual-readout with fine lateral segmentation for π^0 reconstruction and precision EM measurement

HCAL

•Deep fiber calorimeter like DREAM, but optimized;

•Time-history of scintillating fibers for neutron measurement, particle ID, and sub-ns time-of-flight;

•Time-history of Cerenkov fibers for baseline and inter-bunch monitor, and for sub-ns time-of-flight.

•Modest: about 20K fiber and 80K crystal channels.

ILC LoI benchmark processes
to demonstrate detector performance

Compulsory LOI Benchmarking List

At a Dec 7 meeting between Sakue Yamada and representatives of SiD, ILD, 4th Concept, and the WWS, it was agreed that the following reactions will be used for LOI Physics Benchmarking:

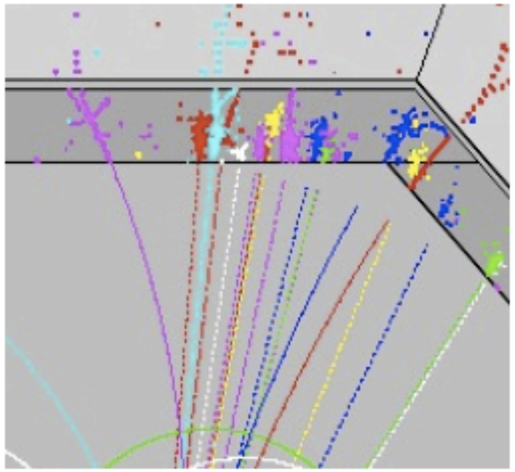
1. $e^+e^- \to Zh, \to \ell^+\ell^- X,\, l = e, \mu;\;\; m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV
2. $e^+e^- \to Zh,\, Z \to q\bar{q}, \nu\bar{\nu};\;\; h \to c\bar{c},\, \mu^+\mu^-;\;\;\; m_h = 120$ GeV at $\sqrt{s}$=0.25 TeV
3. $e^+e^- \to \tau^+\tau^-$, at $\sqrt{s}$=0.5 TeV
4. $e^+e^- \to t\bar{t}$ at $\sqrt{s}$=0.5 TeV
5. $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_1^- / \tilde{\chi}_2^0\tilde{\chi}_2^0 \to W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0 \;/\; ZZ\tilde{\chi}_1^0\tilde{\chi}_1^0$ at $\sqrt{s}$=0.5 TeV

N.B.: The physics observables that are to be measured have not yet been determined.

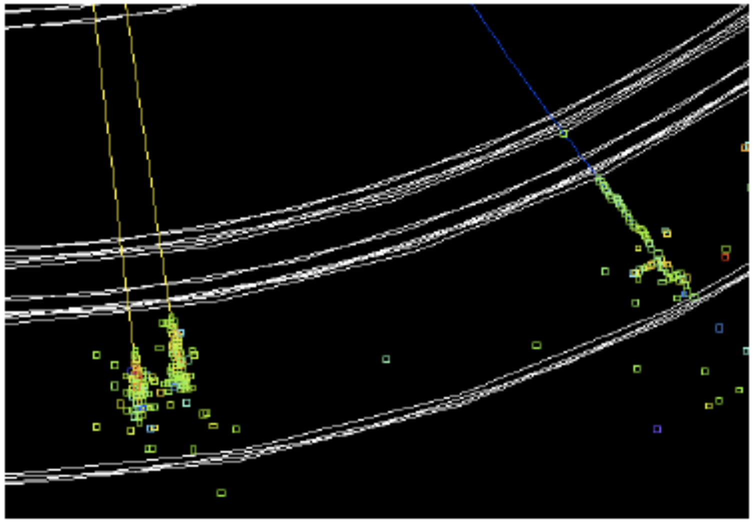
SiD ECAL physics objectives

- Multi-jet final states (Higgs, Top ..)
  - π° measurement should not limit jet resolution
  - identify and measure hadronic showers
  - track charged particles
- τ id and analyses
- Photons
  - Energy resolution, e.g. $h \rightarrow \gamma\gamma$
  - Vertexing of photons ($\sigma_b \sim 1$ cm), e.g. for SUSY studies
- Electron ID
- Bhabhas and Bhabha acollinearity
- Hermiticity

=> imaging calorimetry



Jet Environment



$\tau^+ \rightarrow \rho^+ \nu \quad (\pi^+ \pi^o \nu)$