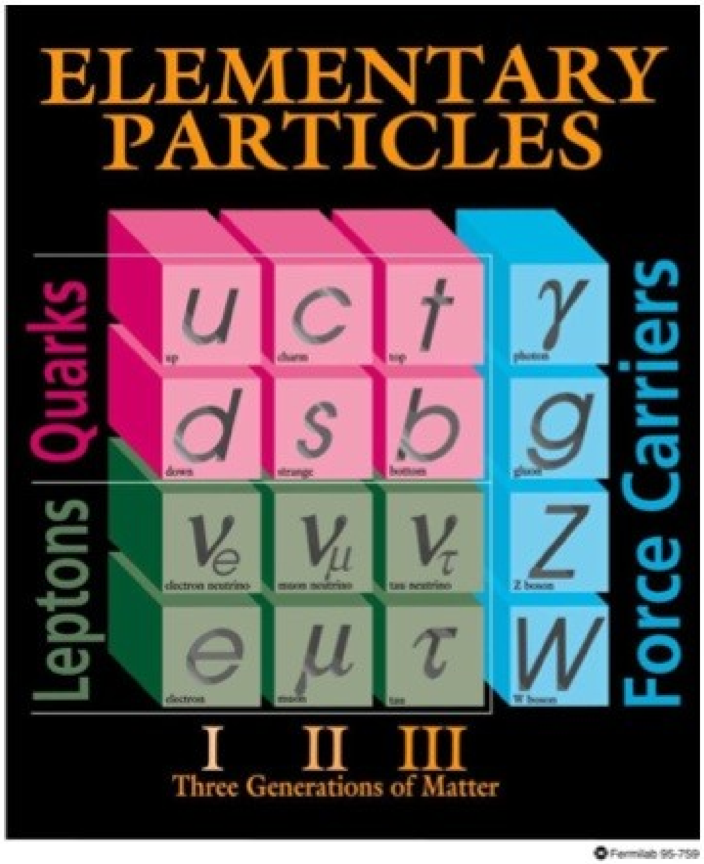
Pattern recognition in new generation highly granular calorimeters

Roman Pöschl

Siminole Meeting 26/1/2010

Where do we stand today?

Standard Model of Particle Physics

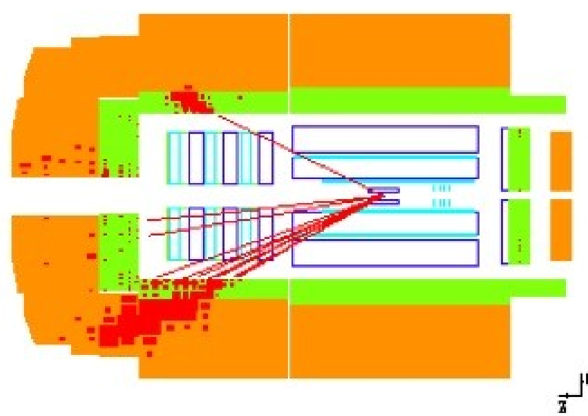


All matter is composed of 12 Fermions
'Lepton and Quarks'
Interactions are mediated by Vector Bosons
'Force Carriers'

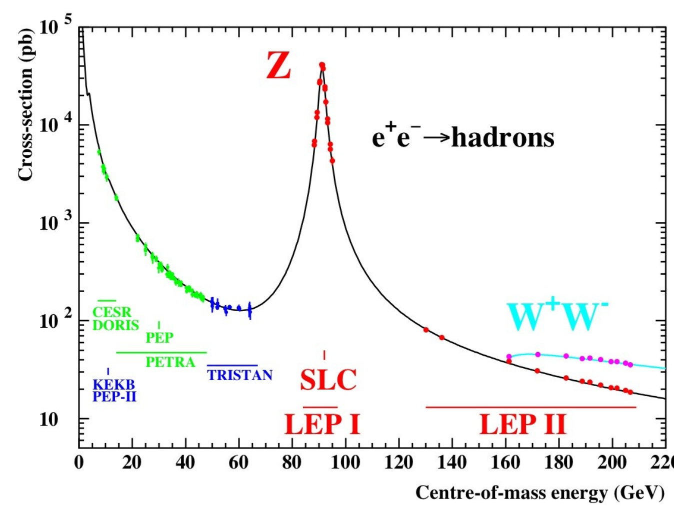
- All matter which surrounds us is composed by the particles of the Generation I

The other generations contain particles observed in the accelerators of the 20th century

e quark scattering at HERA

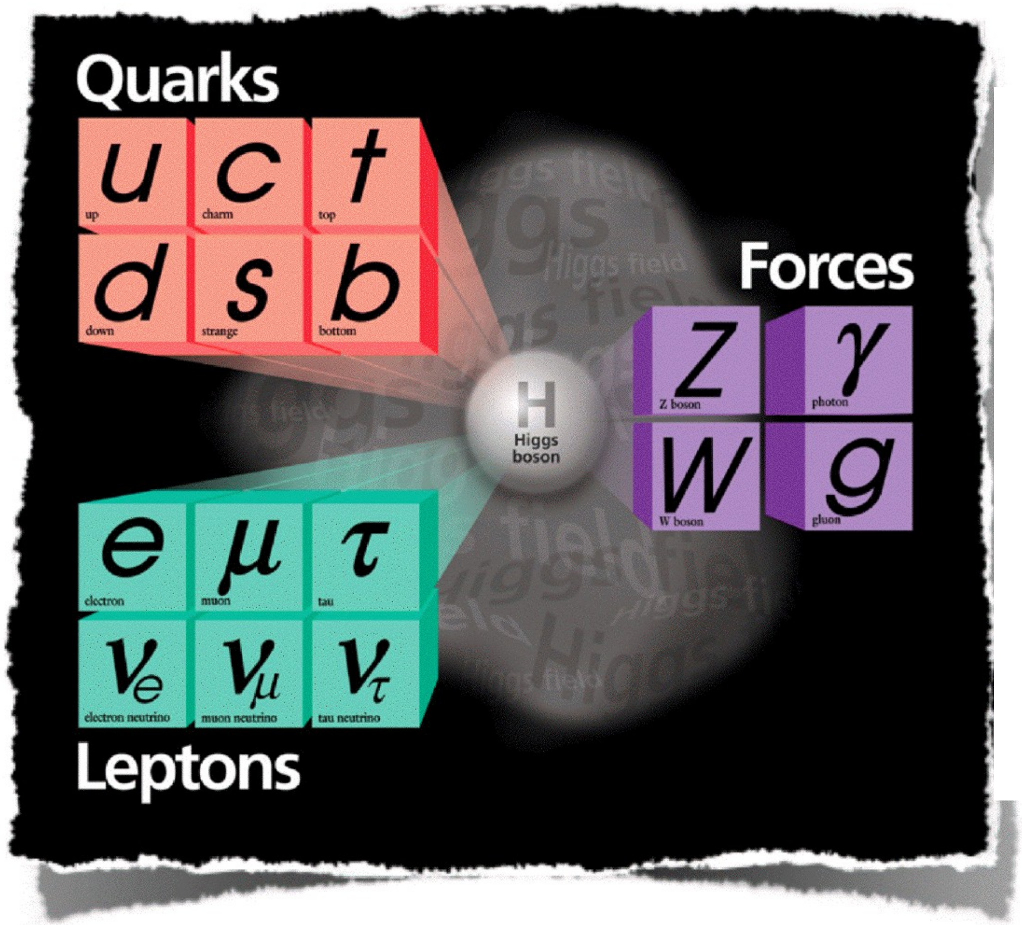


$e^+e^- \rightarrow \gamma/Z \rightarrow$ HADRONS

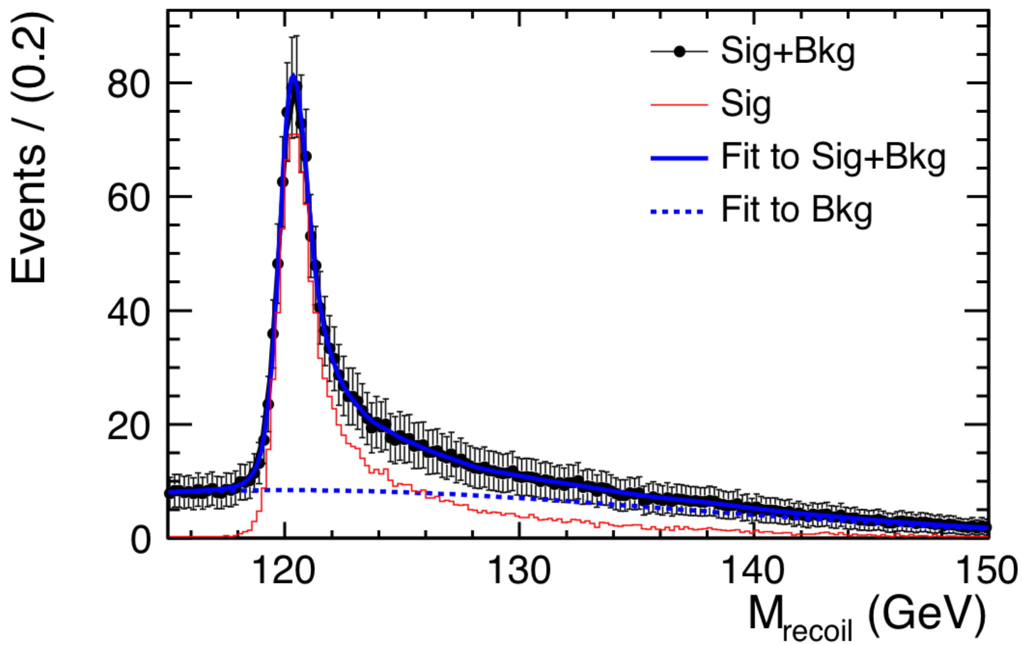


Beyond (?) the Standard Model of particle physics

SM explains elements of ordinary matter as
quarks and leptons – fermions with spin 1/2
interacting via force carriers – bosons with spin 1



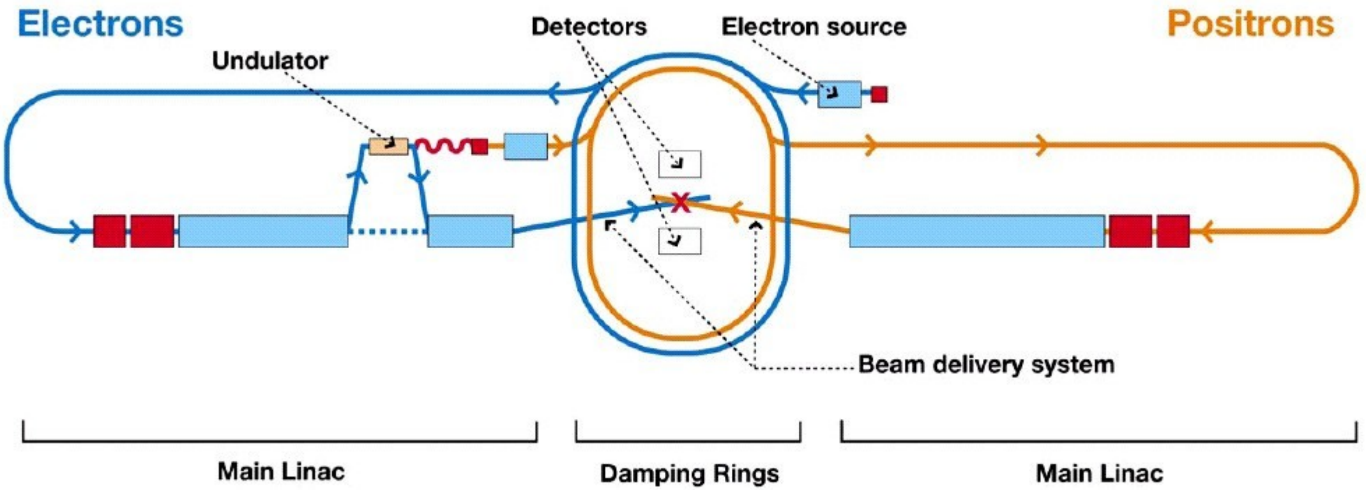
Simulation of Higgs signal at
International Linear Collider



Higgs Boson is missing piece of Standard Model
Chase for Higgs Boson is at full swing at the LHC
Elementary spin 0 particle – Portal to New Physics?
LC would allow complete tomography of Higgs

The International Linear Collider ILC

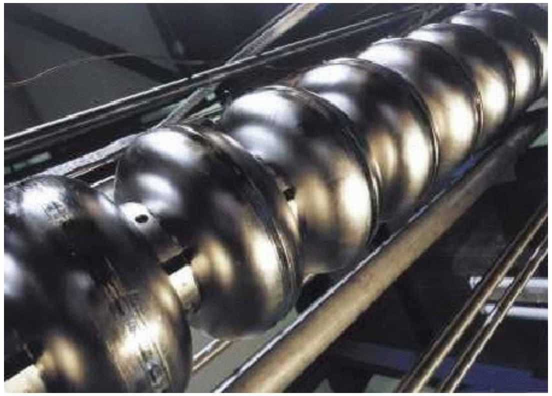
Linear Electron-Positron Collider



Total Footprint 31 km

Main parameters

- $\sqrt{s}$ adjustable from 200 – 500 GeV
- Luminosity → $\int Ldt$ = 500 fb^{-1} in 4 years
- Ability to scan between 200 and 500 GeV
- Energy stability and precision below 0.1%
- Electron polarisation of at least 80%
  Option: Polarised Positrons
- The machine must be upgradeable to 1 TeV



Technology for Main Linac

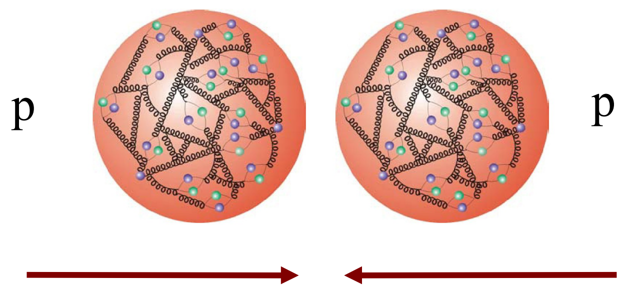
Superconductive RF cavity

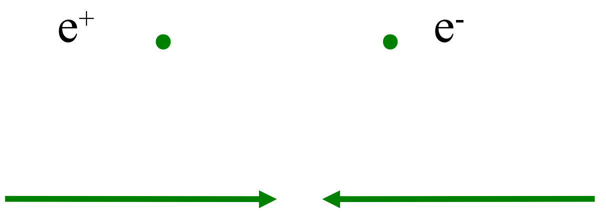
ITRP Recommendation 2004

Present outlook
→ Technical design report 2012
→ R&D Project for higher Energies CLIC

Why Electron Positron Machine?

Note: ILC will probably be put into operation after major LHC discoveries. Why is the ILC still needed?





- p = composite particle:
  unknown √s of IS partons,
- parasitic collisions
- p = strongly interacting:
  huge SM backgrounds,
  highly selective trigger needed,
  radiation hard detectors needed

- e = pointlike particle:
  known and tunable √s of IS particles,
  polarisation of IS particles possible,
  kinematic contraints can be used
- e = electroweakly interacting
  low SM backgrounds,
  no trigger needed,

Electron Positron Collider – Best premises for precision measurements

Detector Requirements

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

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

Impactparameter: $\sigma_{d0} < 5 \oplus 10/(p[\mathrm{GeV}]\sin^{3/2}\theta)\ \mu m$ **(1/3 x SLD)**

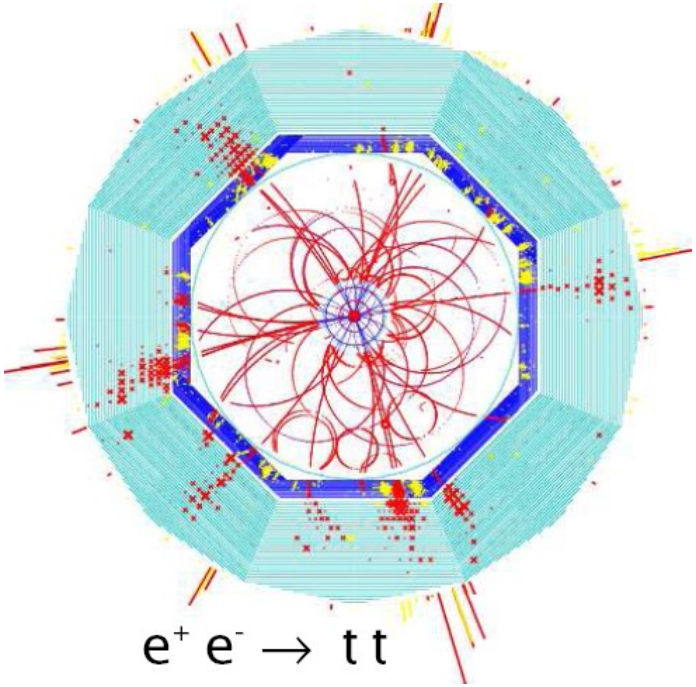
(c/b-tagging)

Jetenergy : $dE/E = 3\text{-}4\%$

(Measurement of W/Z Mass with Jets)

Hermeticity : $\theta_{min} = 5$ mrad

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



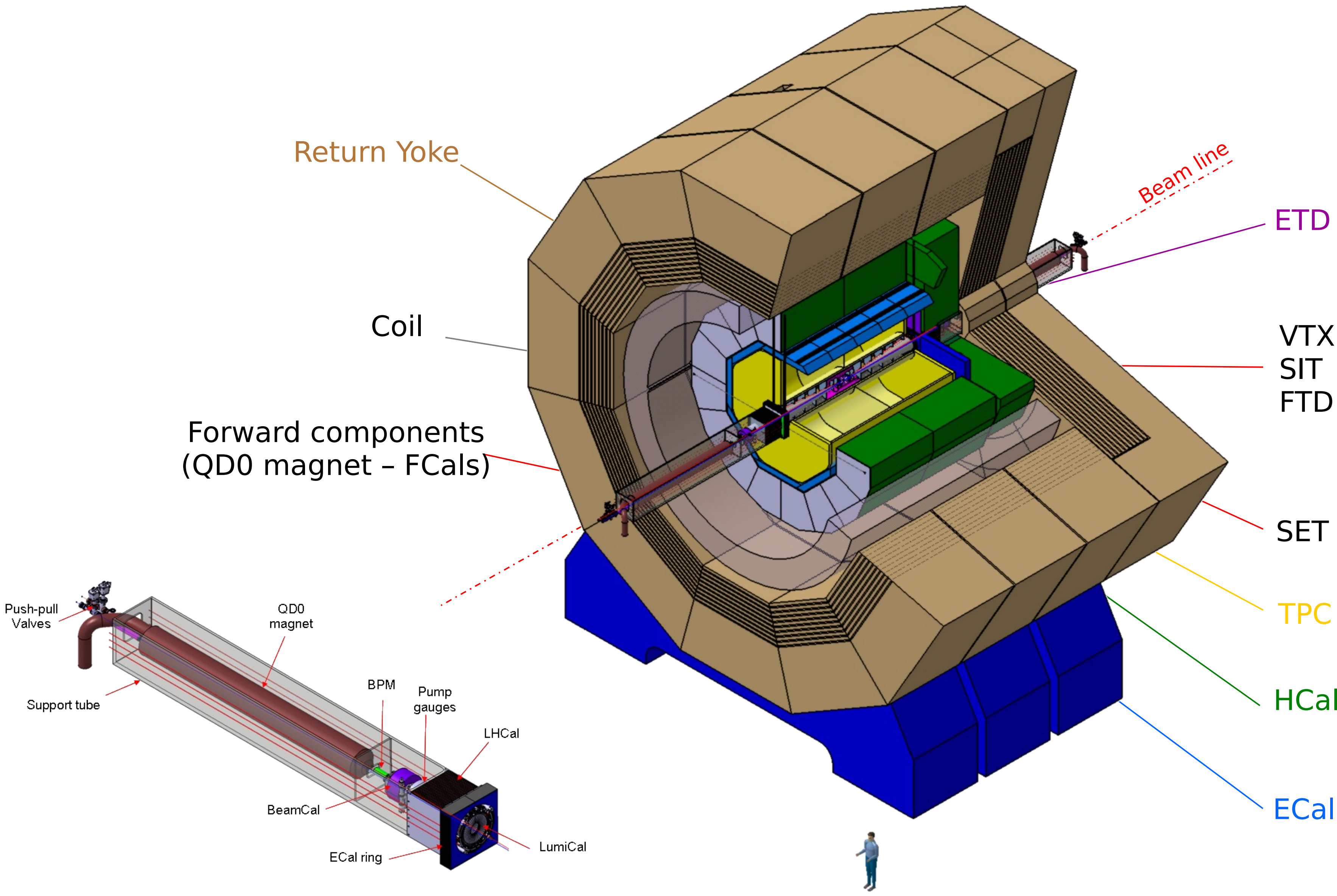
$e^+ e^- \rightarrow t\,t$

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

Therefore:

- **high Granularity**
- **good track Measurement**
- **good Track Separation**

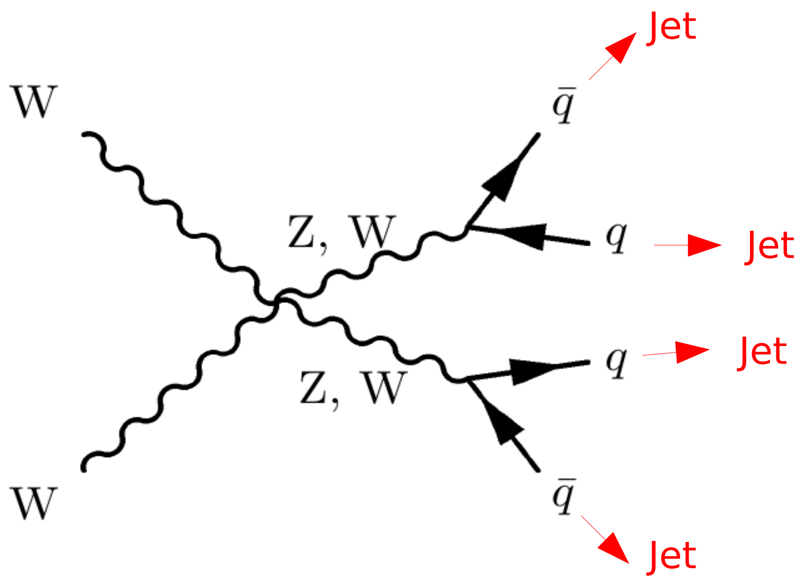
The ILD Detector



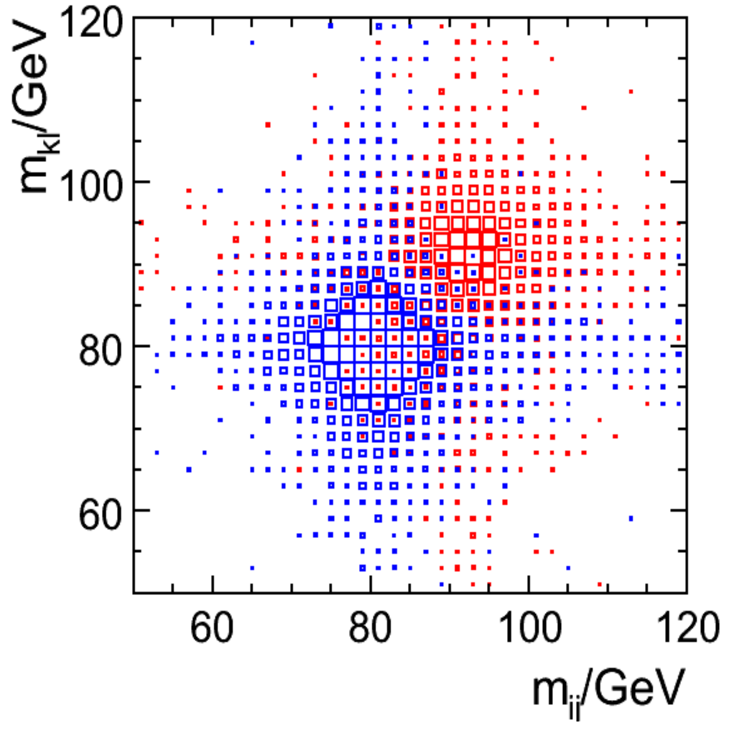
Letter of Intent in 2009 – Based on full detector simulation

Hadronic final states at the ILC

e.g. Boson Boson Scattering



W, Z separation in the ILD detector

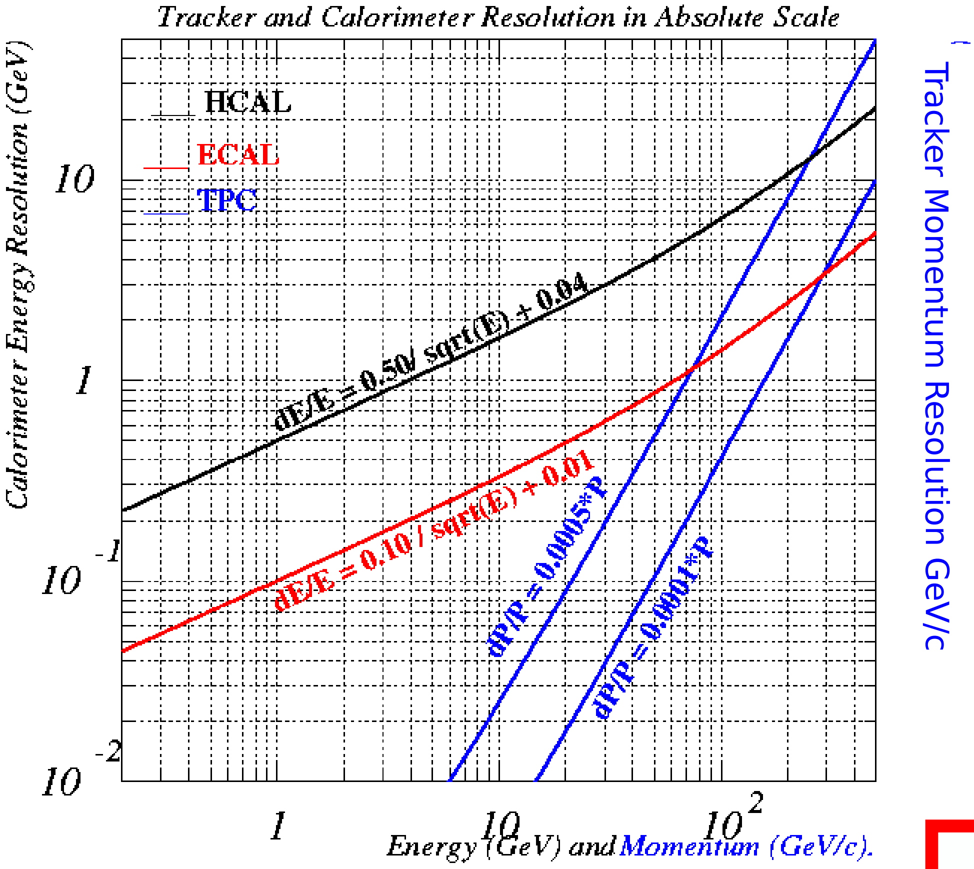


Remember: $M_Z - m_W \approx 10$ GeV

- Need excellent jet energy resolution to separate W and Z bosons in their hadronic decays

Jet Energy Resolution

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



Jet energy carried by …

- Charged particles ($e^{\pm}$, $h^{\pm}$,$\mu^{\pm}$)): 65%
  Most precise measurement by Tracker
  Up to 100 GeV

- Photons: 25%
  Measurement by Electromagnetic Calorimeter (ECAL)

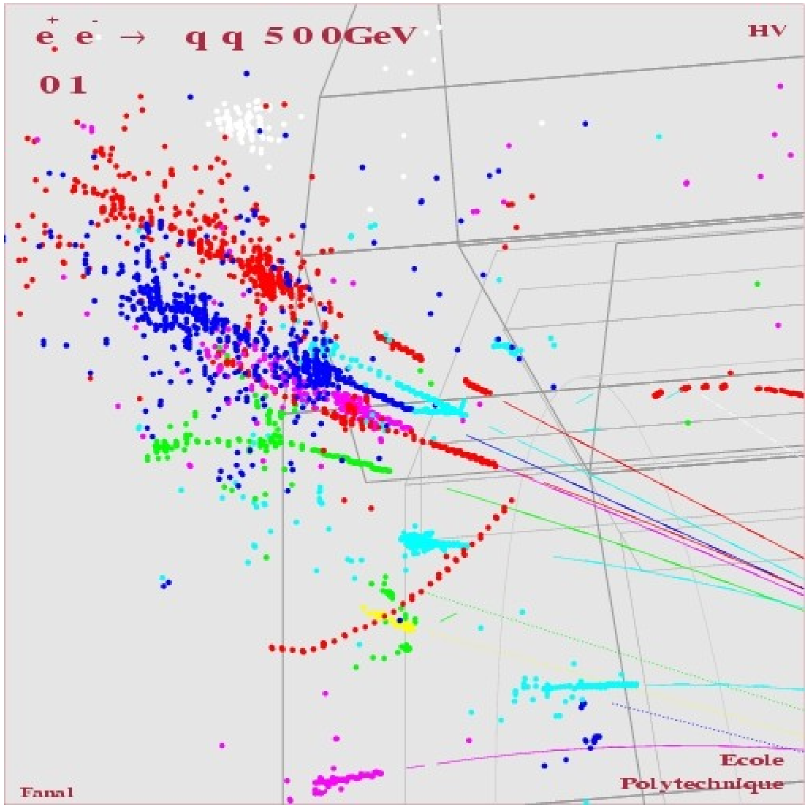
- Neutral Hadrons: 10%
  Measurement by Hadronic Calorimeter (HCAL) and ECAL

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

Confusion Term

- Base measurement as much as possible on measurement of charged particles in tracking devices

- Separate of signals by charged and neutral particles in calorimeter



- Complicated topology by (hadronic) showers

- Correct assignment of energy nearly impossible

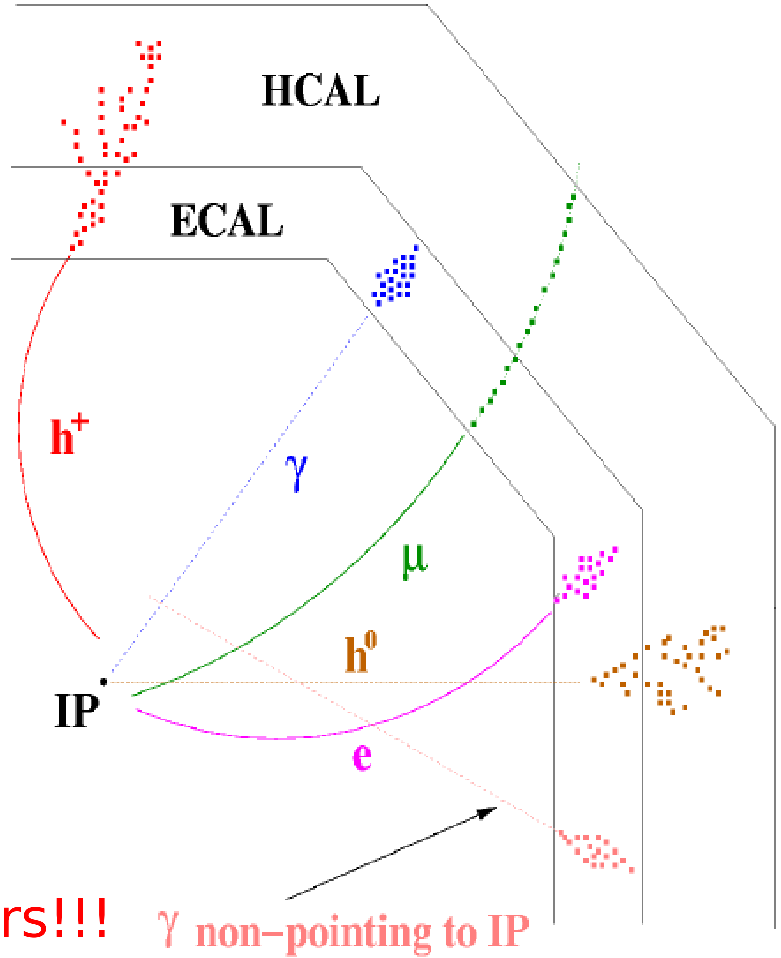
$\Rightarrow$ Confusion Term

Need to minimize the confusion term as much as possible !!!

Detector and Calorimeter Concept – Particle Flow

Jet energy measurement by measurement of **individual particles**
Maximal exploitation of precise tracking measurement

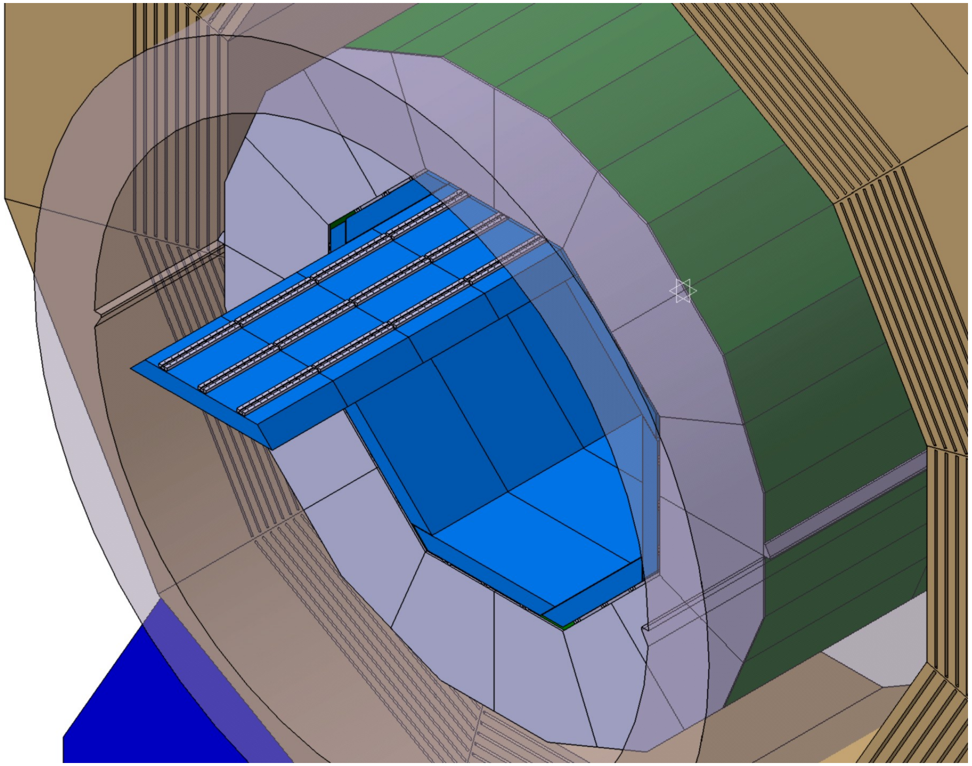
- large radius and length
  - to separate the particles
- large magnetic field
  - to sweep out charged tracks
- "no" material in front of calorimeters
  - stay inside coil
- small Molière radius of calorimeters
  - to minimize shower overlap
- **high granularity of calorimeters**
  - to separate overlapping showers



Physics Goals at the ILC demand the Construction of Highly Granular Calorimeters!!!
Emphasis on tracking capabilities of calorimeters

R&D for an Electromagnetic Silicon Tungsten Calorimeter – SiW Ecal

The SiW Ecal in the ILD Detector



Basic Requirements

- Extreme high granularity
- Compact and hermetic

Basic Choices

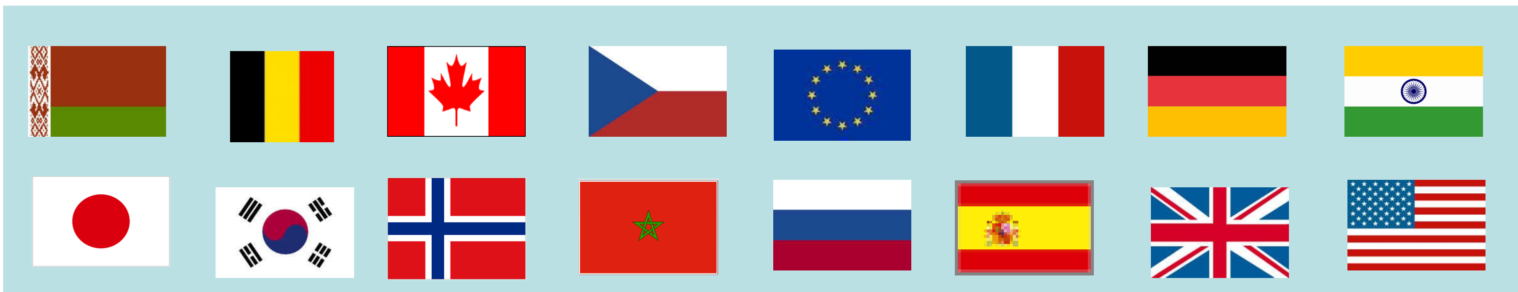
- Tungsten as absorber material
  - X_0=3.5mm, R_M=9mm, λ_I=96mm
  - Narrow showers
  - Assures compact design
- Silicon as active material
  - Support compact design
  - Allows for pixelisation
  - Large signal/noise ratio

SiW Ecal designed as Particle Flow Calorimeter

The CALICE Collaboration

Calorimeter for ILC

Calorimeter R&D for the ilc



~300 physicists/engineers from >50 institutes
and 16 countries from 4 continents

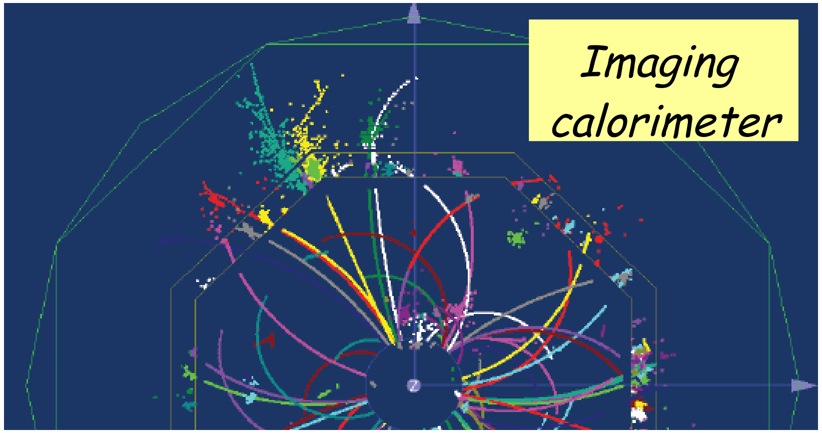
- Integrated R&D effort

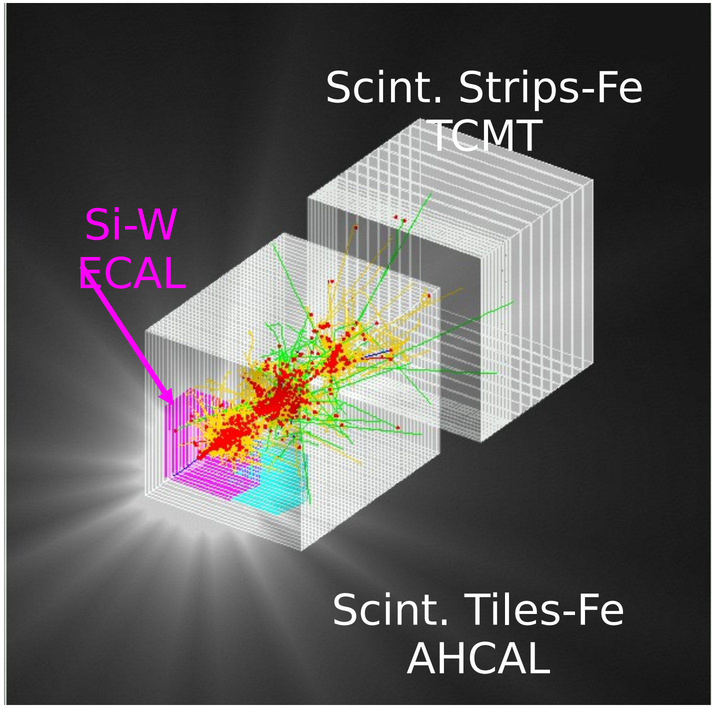
- Benefit/Accelerate detector development due to *common* approach

The Calice Mission

Final goal:

A highly granular calorimeter optimised for the Particle Flow measurement of multi-jets final state at the International Linear Collider

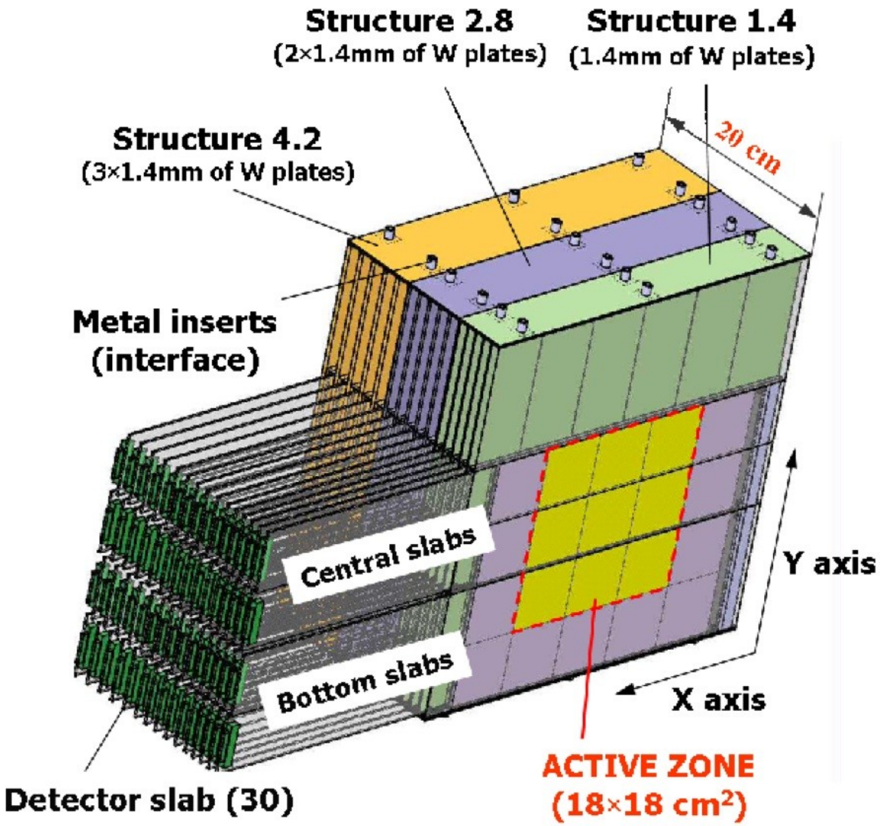




Intermediate task:

Build prototype calorimeters to
- Establish the technology
- Collect hadronic showers data with unprecedented granularity to
  - tune clustering algorithms
  - validate existing MC models

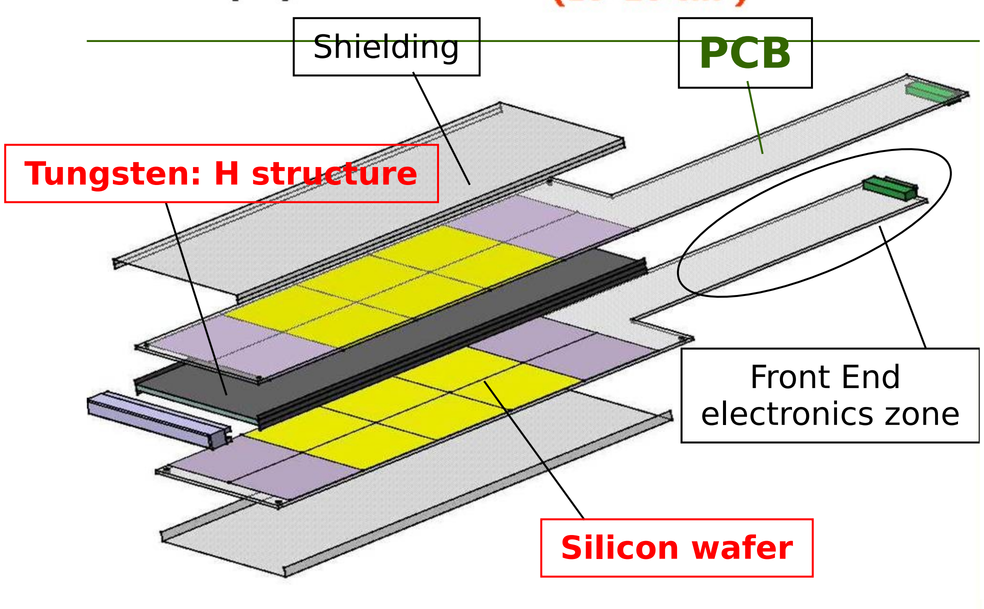
SiW Ecal Physics Prototype



30 layers of Tungsten:

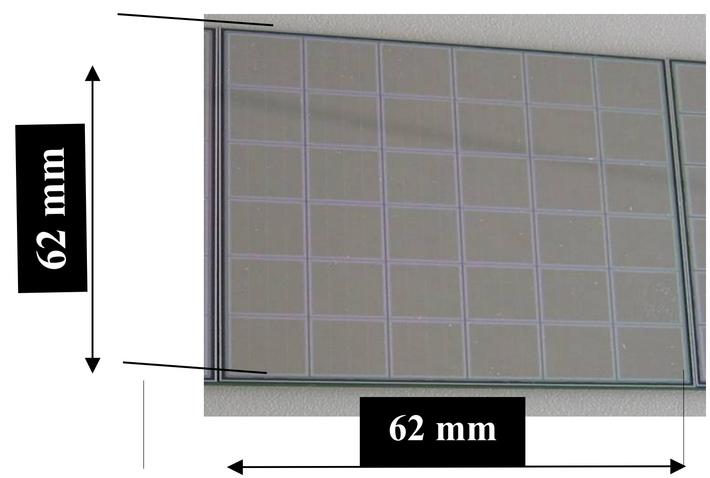
- 10 x 1.4 mm (0.4 X_0)
- 10 x 2.8 mm (0.8 X_0)
- 10 x 4.2 mm (1.2 X_0)
  - 24 X_0 total

½ integrated in detector housing
⇒ Compact and self-supporting detector design



6x6 PIN Diode Matrix

Resistivity: 5kΩcm - 80 (e/hole pairs)/µm



Thickness:
525µm

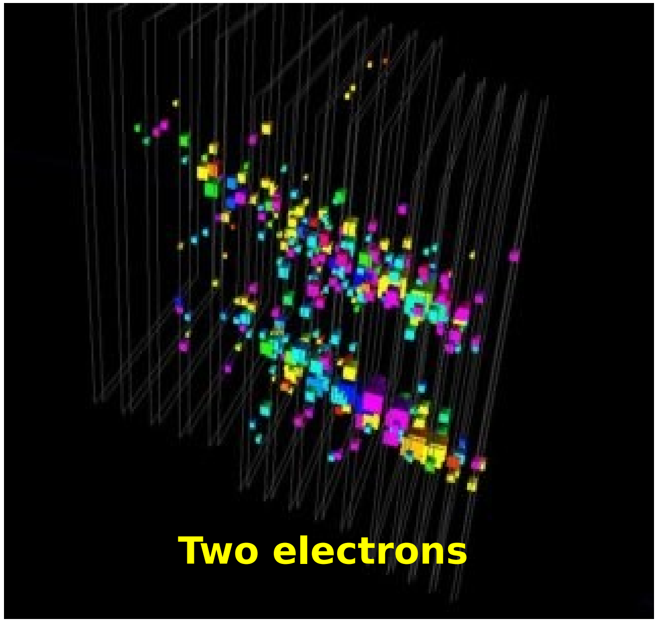
Total: 9720 Pixels/Channels

Large Scale Beam Tests

Experimental Setup

Zoom into Ecal

Particle Distance~ 5 cm
→ No Confusion !!!



- Beam tests at DESY, CERN and FNAL

- Beam tests provide well defined initial conditions
  i.e. energy and type of particle is well known as well as impact point and impact angle

- Large statistics accumulated in past years by (to e.g. train algorithms)

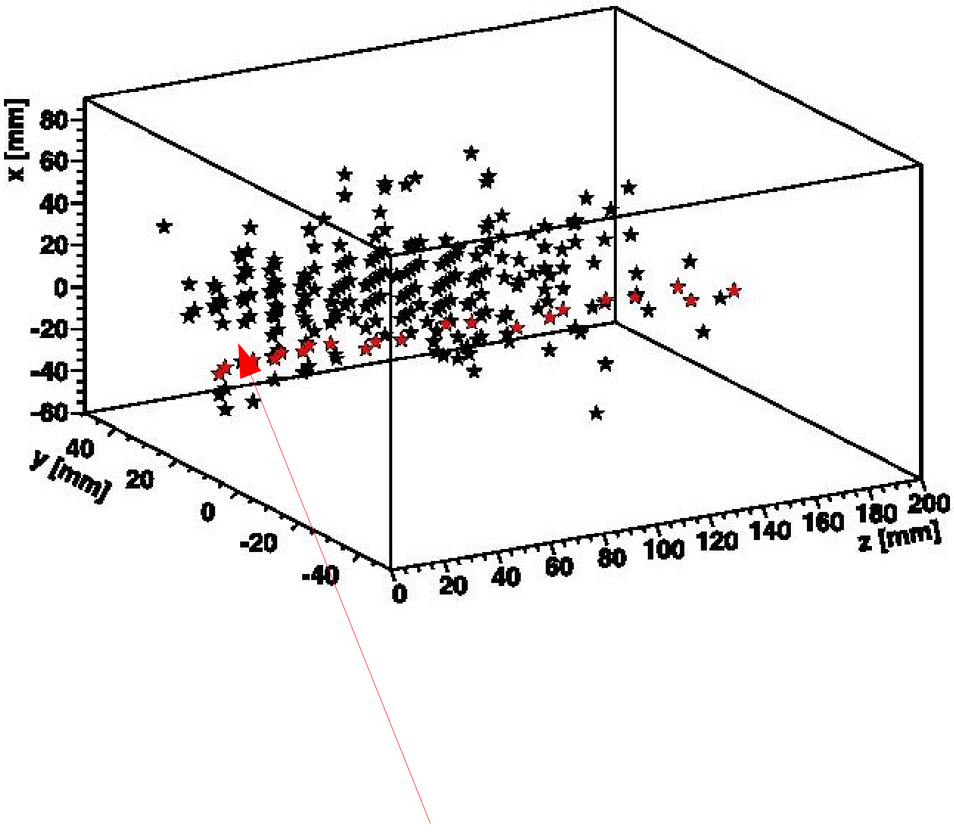
- Large statistics to come in coming years

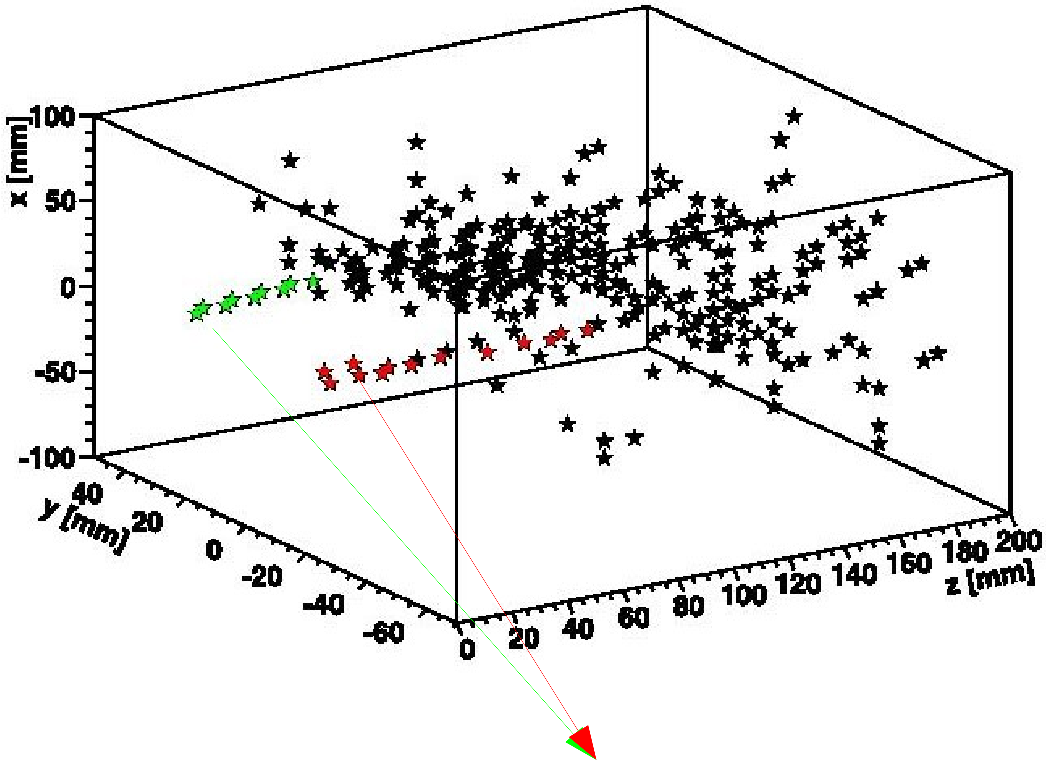
Exploiting the high granularity – Particle separation

High granularity allows for application of advanced imaging processing techniques

E.g. Hough transformation

Events recorded in test beam





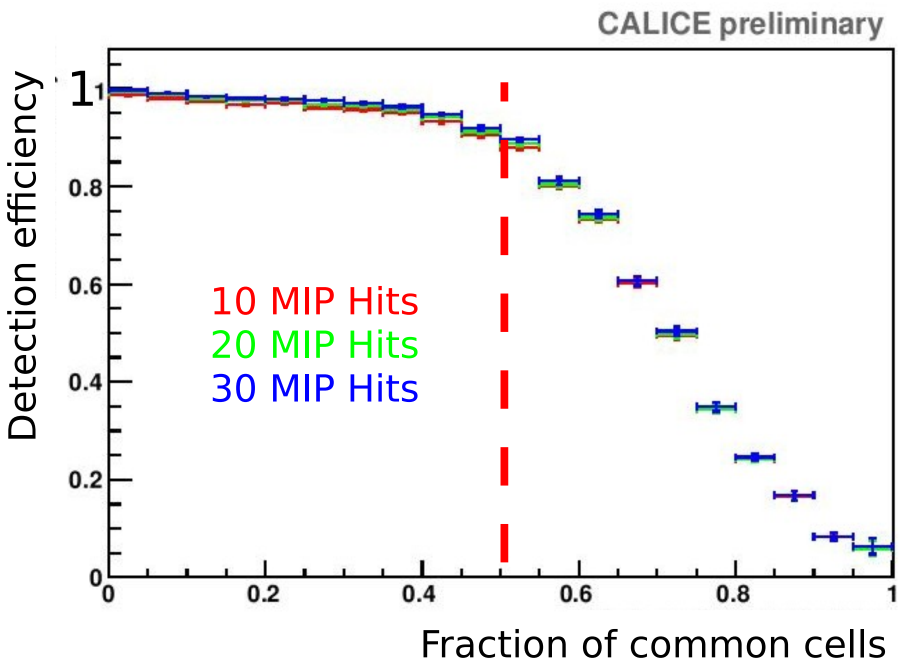
Two pions entering the SiW Ecal

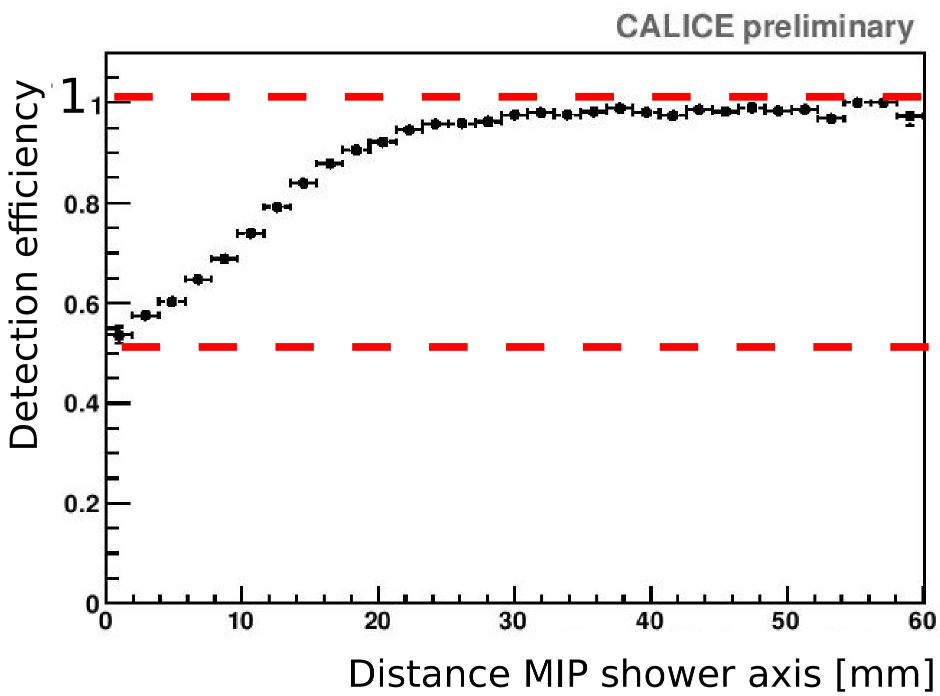
Secondary muon within electron shower

Particle separation – cont'd

Efficiency of particle separation

Separation MIP <-> Electron





E -> 100% for up to 50% shared hits

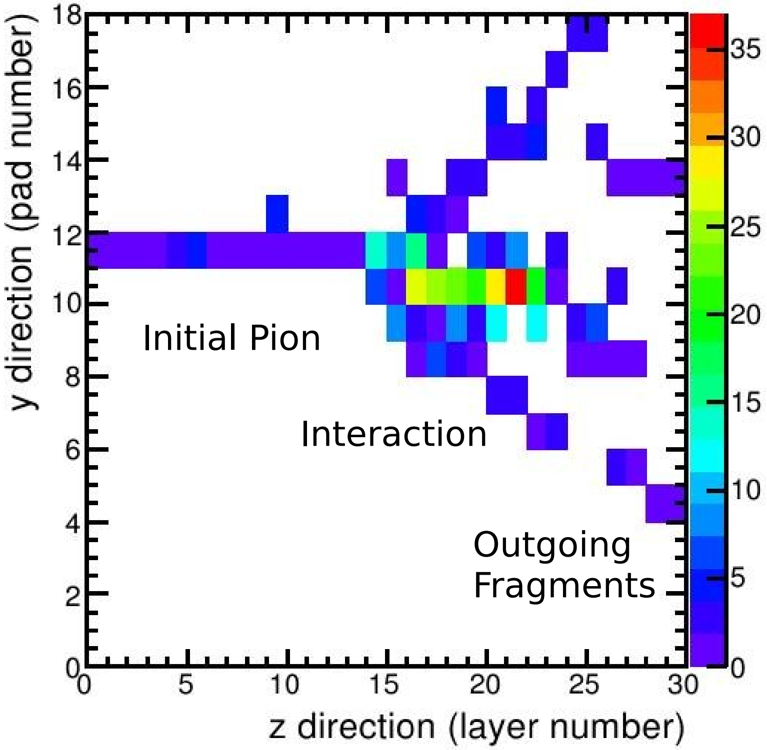
Independent of hits generated by MIP

Full separation for distances > 2.5 cm

Granularity and hadronic cascades

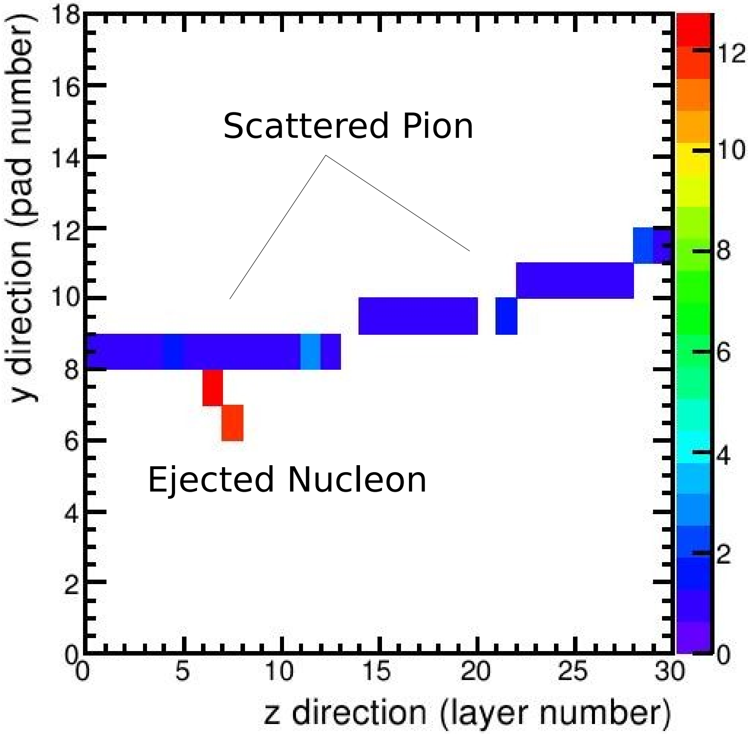
(Start of) Hadronic showers in the SiW Ecal

Complex and impressive



Inelastic reaction in SiW Ecal

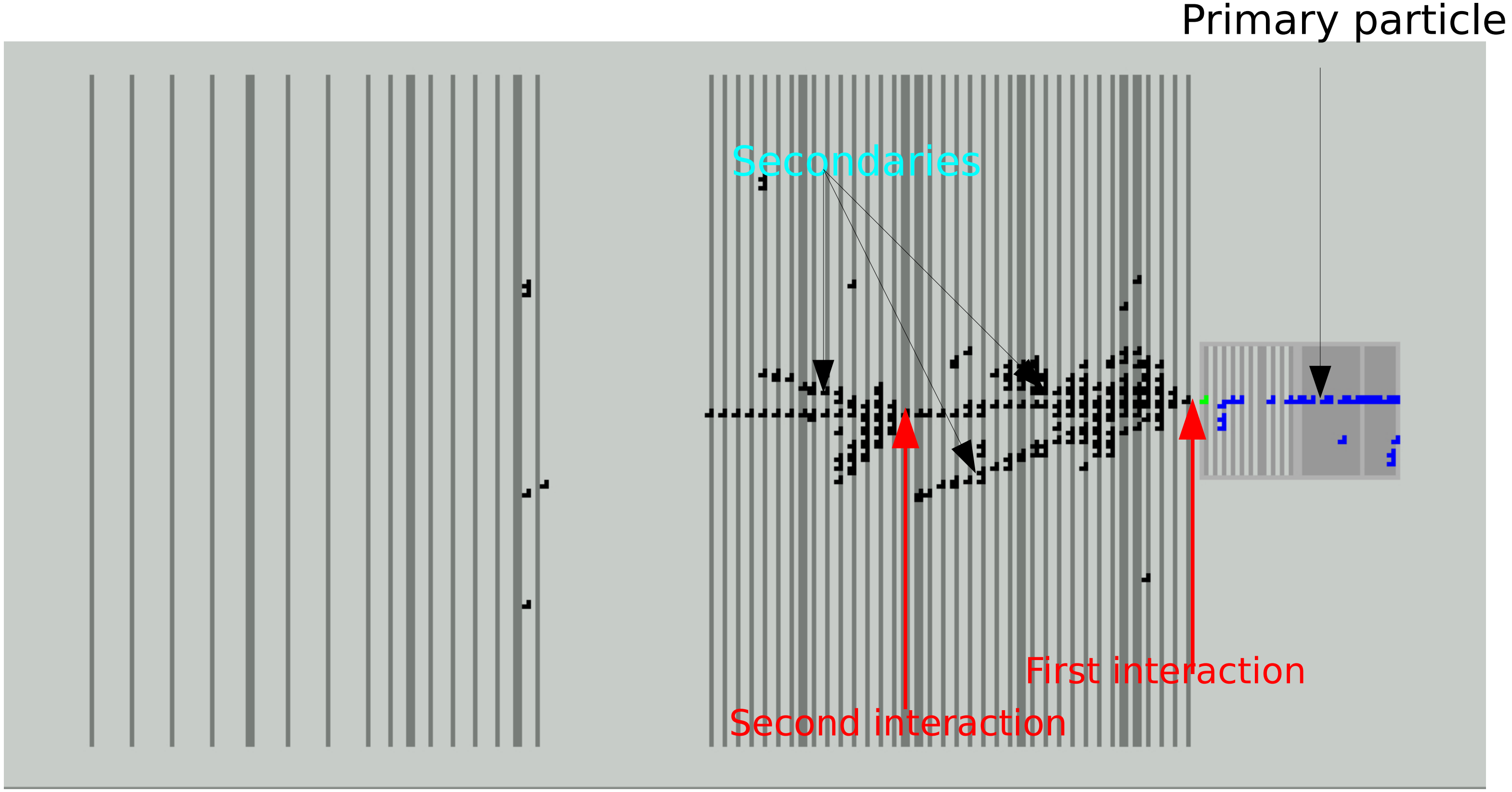
Simple but nice



Short truncated showers

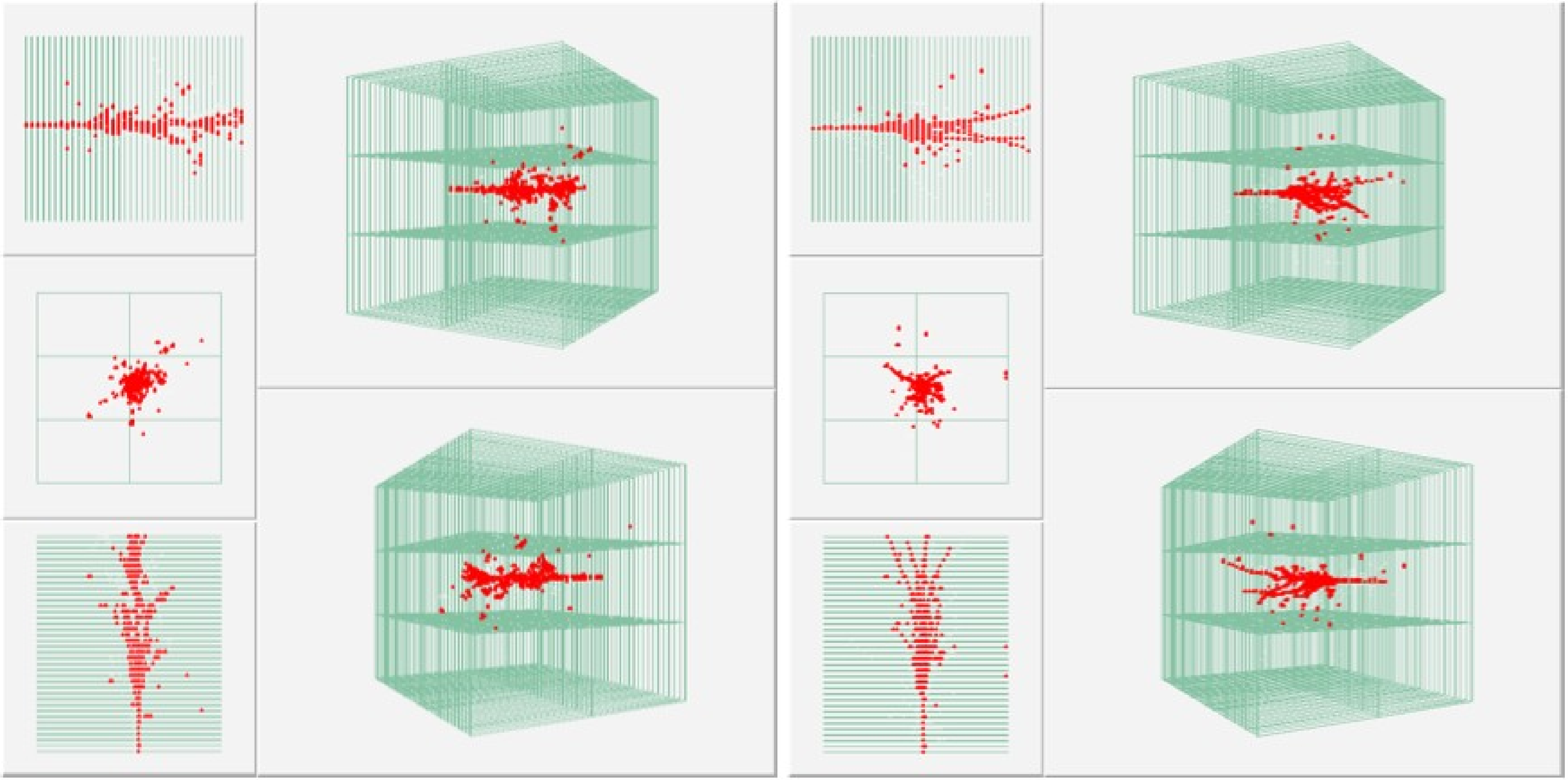
High granularity permits detailed view into hadronic shower

Hadronic showers extend well beyond the Ecal



The goal must be to identify the interaction points and to associate the secondaries correctly to the promary particle

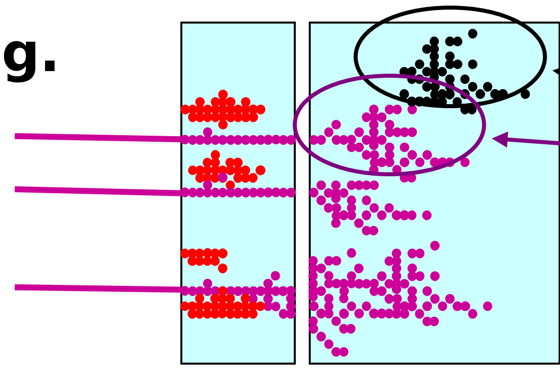
Hadronic showers come in various forms



Reconstruction of a Particle Flow Calorimeter:

- ★ **Avoid double counting of energy from same particle**
- ★ **Separate energy deposits from different particles**

e.g.

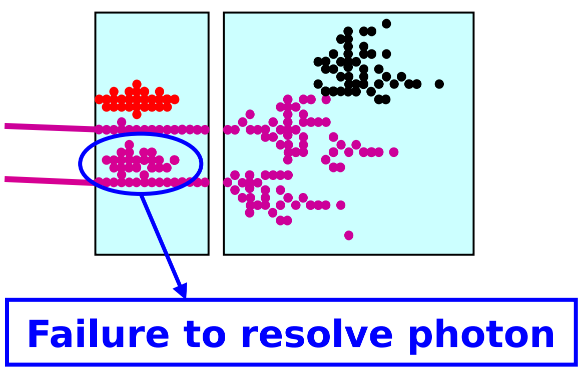


If these hits are clustered together with these, lose energy deposit from this neutral hadron (now part of track particle) and ruin energy measurement for this jet.

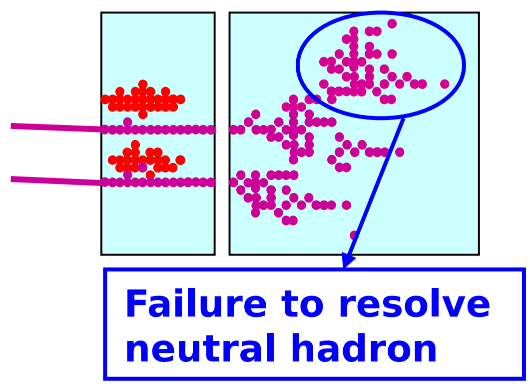
Level of mistakes, "confusion", determines jet energy resolution not the intrinsic calorimetric performance of ECAL/HCAL

Three types of confusion:

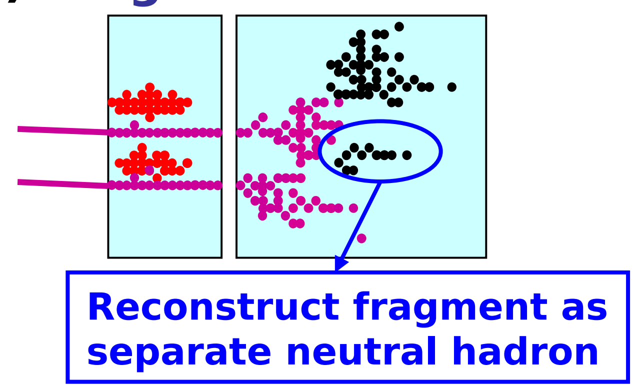
i) Photons



ii) Neutral Hadrons



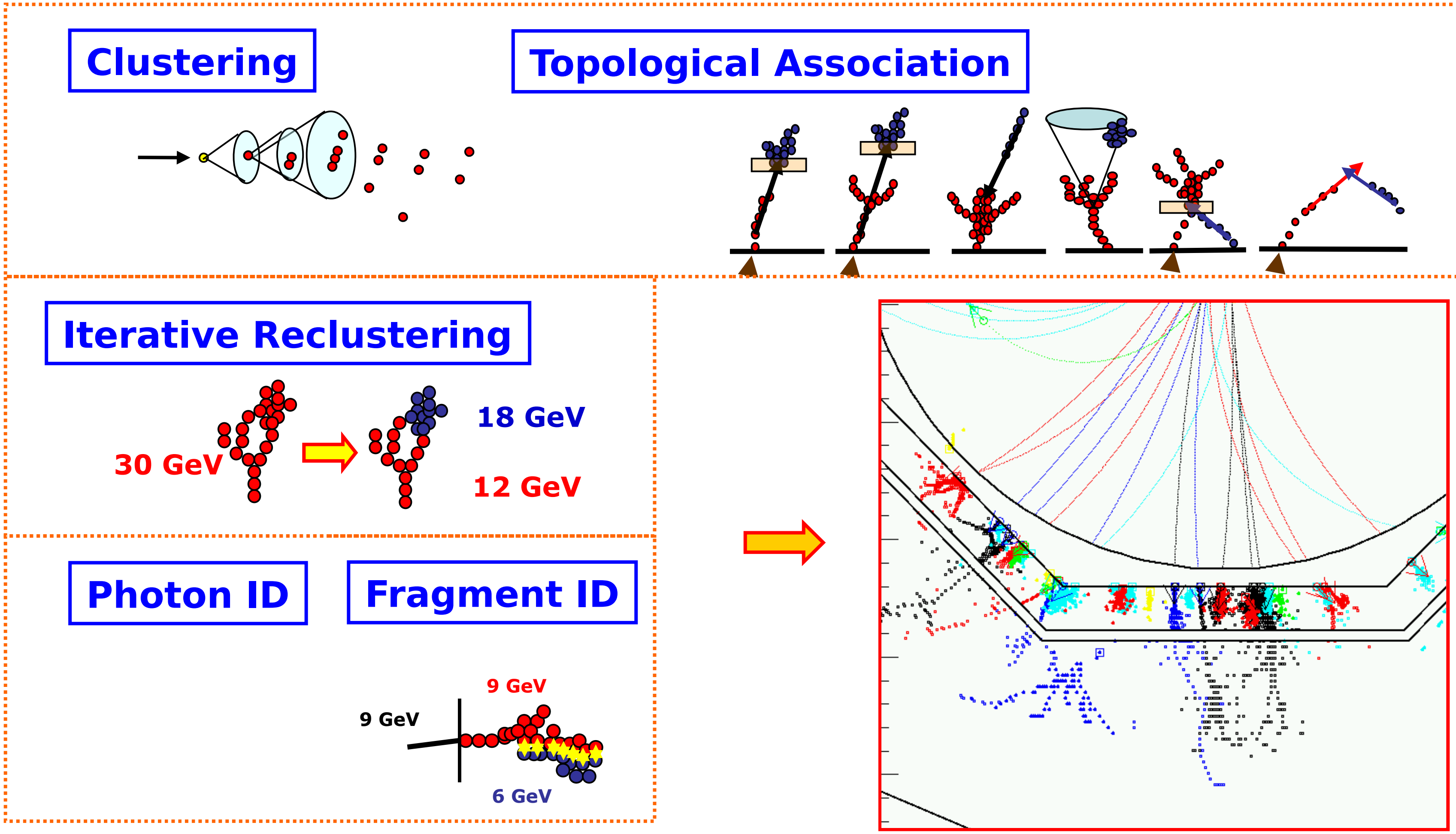
iii) Fragments



Particle Flow Algorithms in practice

★ **Highly non-trivial !**

e.g. PandoraPFA consists of a number complex steps (not all shown)



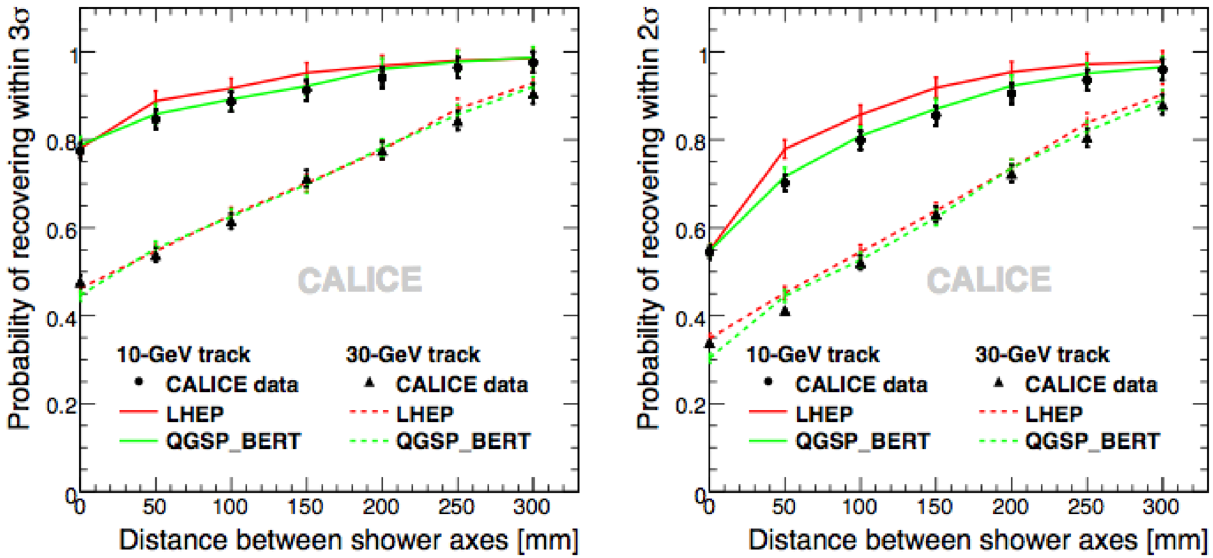
More on Pandora PFA see: M. Thomson, NIM A 611 (2009) 25

Application of Pandora to real (beam test) data

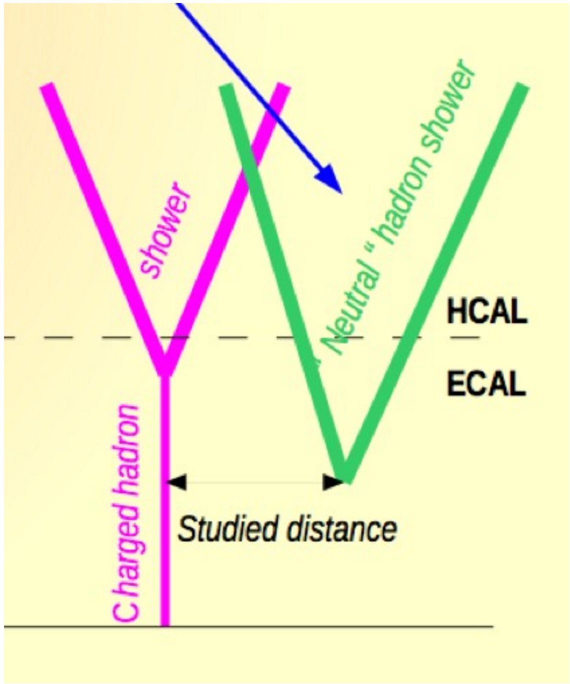
Advantage: Hadron showers not well modelled by simulation

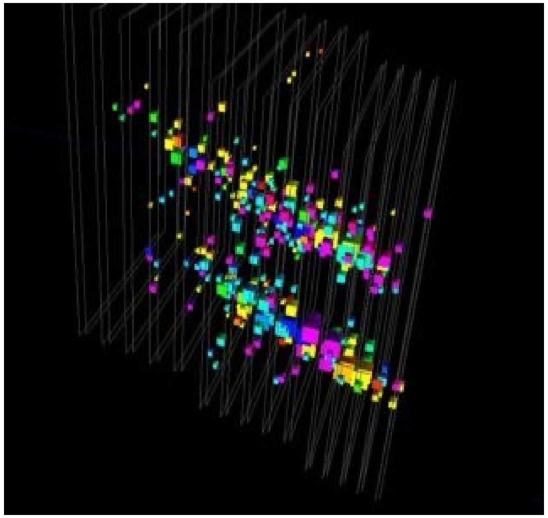
Simple configuration: Two particles in detector

10 GeV 'charged particle'
10 (30) GeV 'neutral' particle in neighbourhood



CALICE Collaboration, JINST 3 (2008) P08001





Already remarkable performance
but
still room for improvement!!!!

Summary

- ILC is essential to understand the physics at the TeV scale
  Decision on realisation depends crucially on first LHC results

- Detector concept is built on Particle Flow
  Successful particle Particle flow requires highly granular calorimeters

- Already considerable results with existing algorithms
  However clear room for improvement

- High granularity provides new quality for particle reconstruction
  Search for fresh ideas to fully exploit the potential of the Calorimeters
  Which algorithms could be adequate?
  Where are limits?
  Synergies with other fields of science in which pattern recognition
  And (non trivial) separation of objects is of interest.
  See also at seminar of Manqi Ruan (LLR) on 14/2/12, approach with fractal dimensions

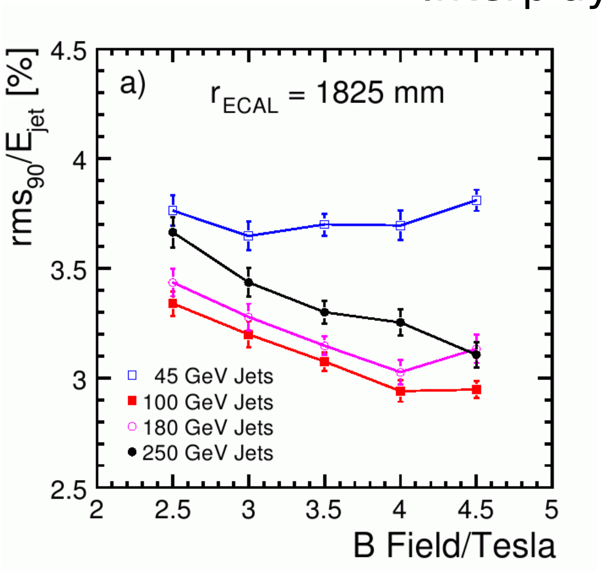
- Existing data sets and competences in detector simulation

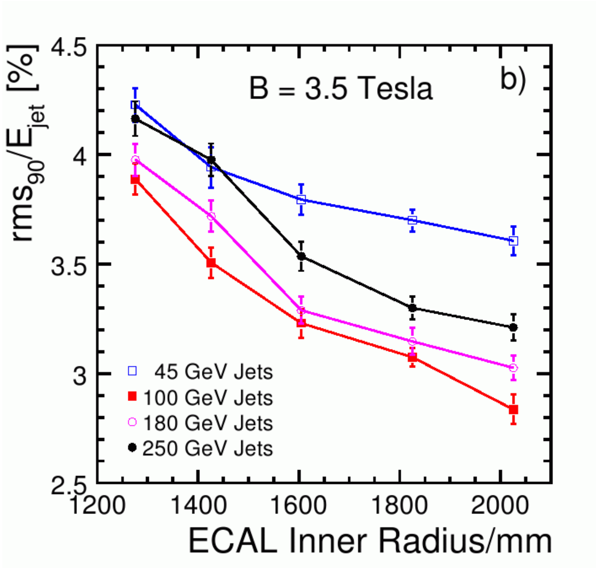
Backup Slides

SiW Ecal Optimisation

Optimisation using Jet Events and Pandora Particle Flow Algorithm

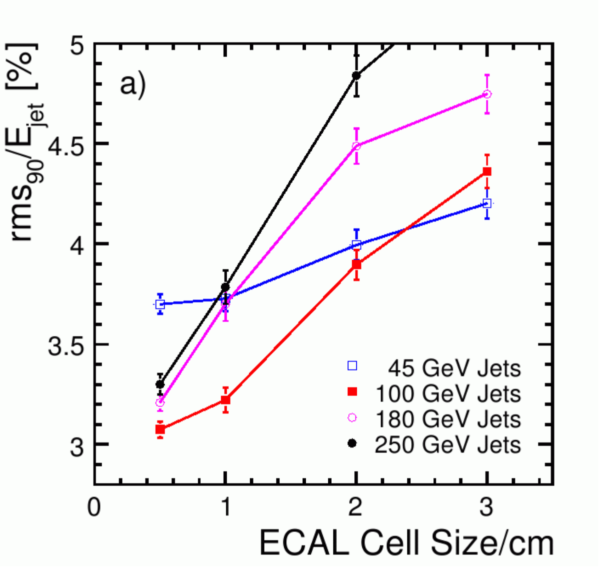
Interplay B-Field and inner radius of Ecal





Radius more important than B-Field

Lateral granularity of Ecal



Jet Energy resolution strongly sensitive on cell dimensions
- Better separation power
- Importance grows towards higher energies

High granularity of Ecal is crucial for precision measurements