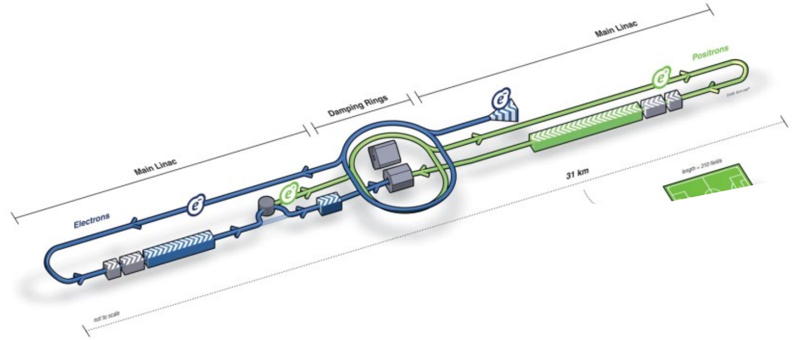
A Detector for the ILC

Ties Behnke, DESY

The ILC

A reminder: The ILC



Electron Positron collisions, 500 (to 1 TeV
Superconducting linac

Very relaxed conditions

Pulsed operation:

- Bunch trains, 1 ms long, bunches every 450ns, inter-bunch 250ms
- Highly focussed flat beams:
  - High luminosity 0.1-1 10^{34} $cm^{-2}s^{-1}$
  - Strong beamstrahlung (20-30 TeV/ interaction)

Very particular background

Mature design, strong synergy with XFEL at DESY
Luminosity values conservative
Parameters designed towards AC power budget: 129 MW@250, 163MW@500GeV

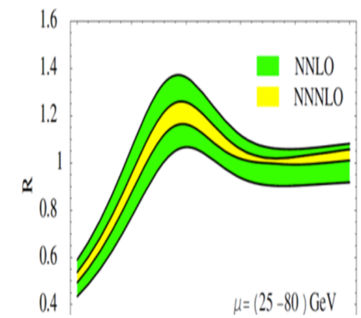
http://arxiv.org/ftp/arxiv/papers/1308/1308.3726.pdf

The Science at the ILC: I

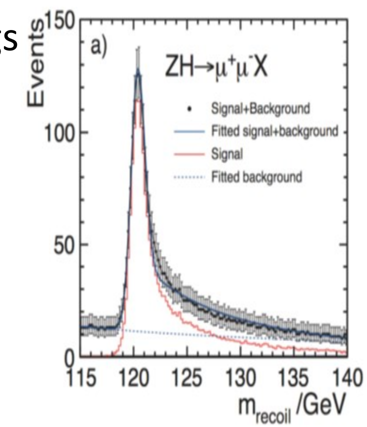
Energy	Reaction	Physics Goal
91 GeV	$e^+e^- \to Z$	ultra-precision electroweak
160 GeV	$e^+e^- \to WW$	ultra-precision W mass
250 GeV	$e^+e^- \to Zh$	precision Higgs couplings
350–400 GeV	$e^+e^- \to t\bar{t}$	top quark mass and couplings
	$e^+e^- \to WW$	precision W couplings
	$e^+e^- \to \nu\bar{\nu}h$	precision Higgs couplings
500 GeV	$e^+e^- \to f\bar{f}$	precision search for Z'
	$e^+e^- \to t\bar{t}h$	Higgs coupling to top
	$e^+e^- \to Zhh$	Higgs self-coupling
	$e^+e^- \to \tilde{\chi}\tilde{\chi}$	search for supersymmetry
	$e^+e^- \to AH, H^+H^-$	search for extended Higgs states
700–1000 GeV	$e^+e^- \to \nu\bar{\nu}hh$	Higgs self-coupling
	$e^+e^- \to \nu\bar{\nu}VV$	composite Higgs sector
	$e^+e^- \to \nu\bar{\nu}t\bar{t}$	composite Higgs and top
	$e^+e^- \to \tilde{t}\tilde{t}^*$	search for supersymmetry

Comprehensive program to study the Higgs boson as precisely as possible

Top

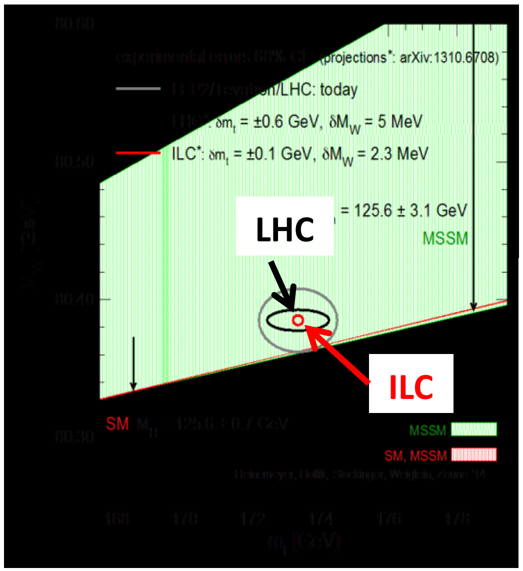


Higgs

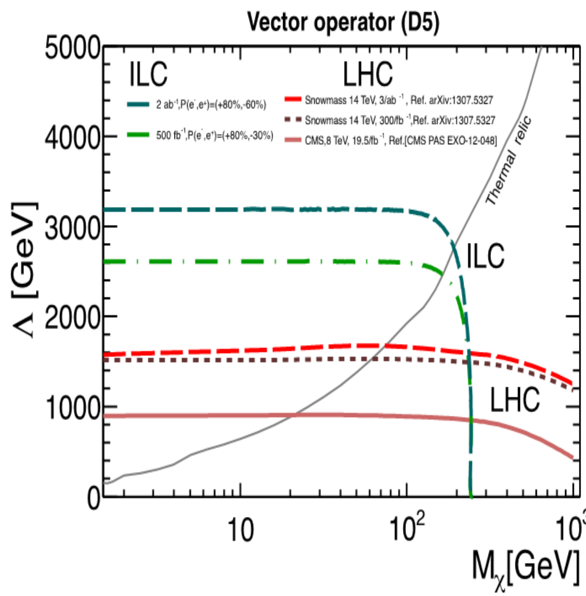


The Science of the ILC: II

Standard Model Particles
(W, Z, top..) are powerful probes of new physics.
ILC will improve the reach significantly

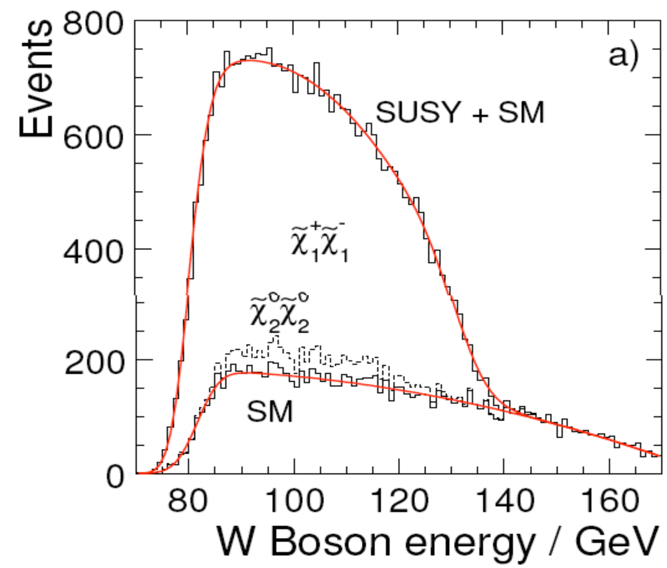


M(W) vs M(top)



Search for dark matter candidates:
ILC complements the LHC

Direct measurements of
new particles



Experimentation at the ILC

Continuous tracking

Imaging calorimeter

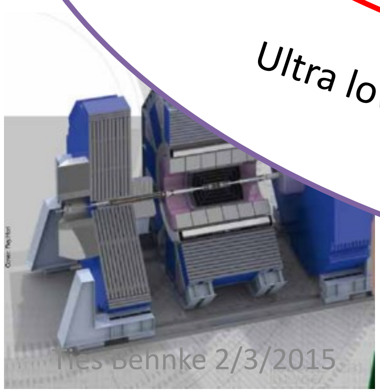
Precision:
- Vertexing
- Tracking
- calorimetry

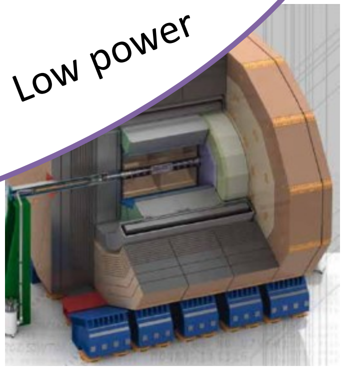
Hermeticity:
- No cracks
- Coverage to small angles

Inclusiveness:
- No HW trigger
- No selective sensitivity

Ultra low-mass

Low power



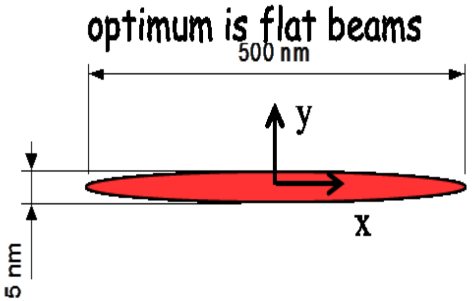


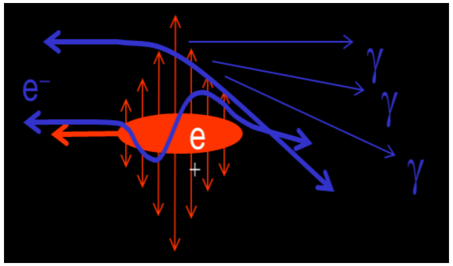
← Push-pull →

ILC conditions

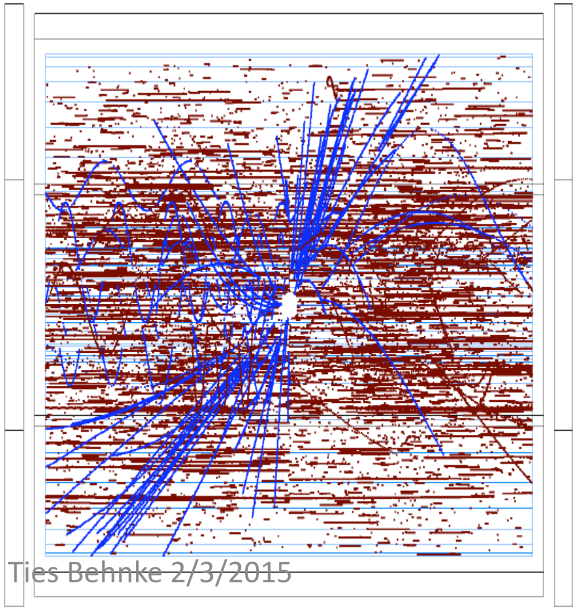
Linear Collider:

- single pass
- Flat beams, highly focused

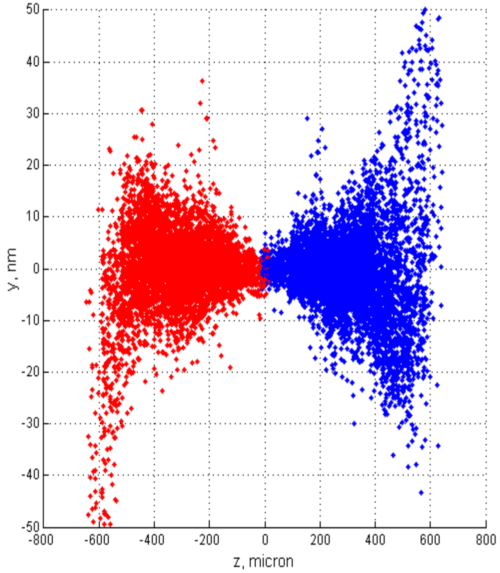




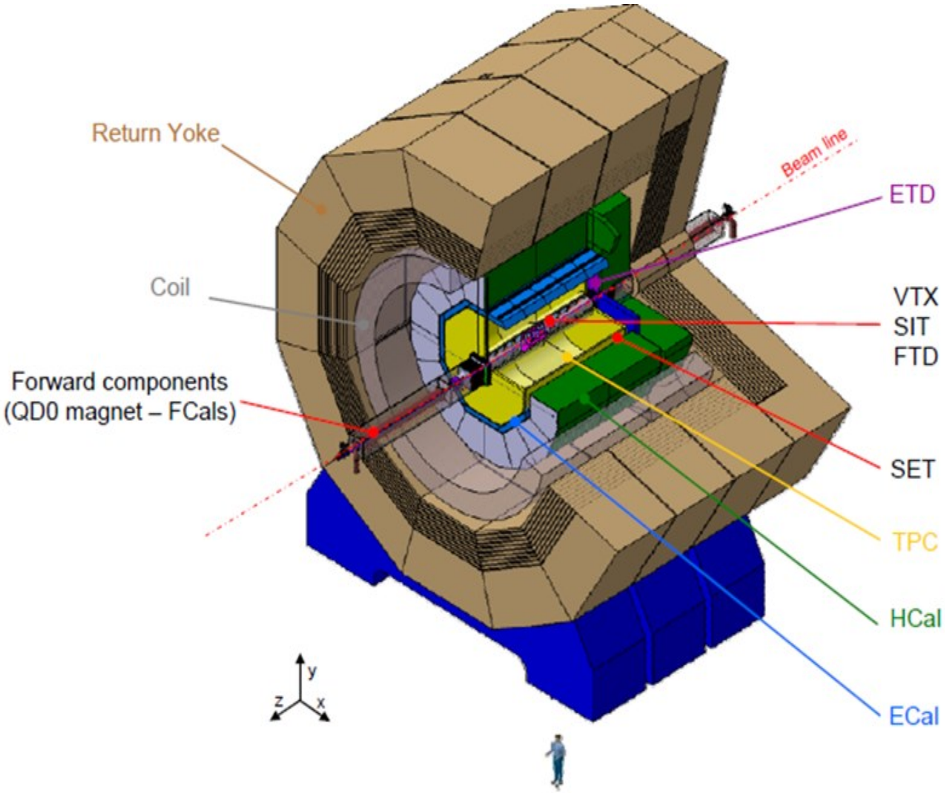
Beamstrahlung is a major source of backgrounds



Event display for a tt event in ILD with beam beam background superimposed.



The ILD Detector



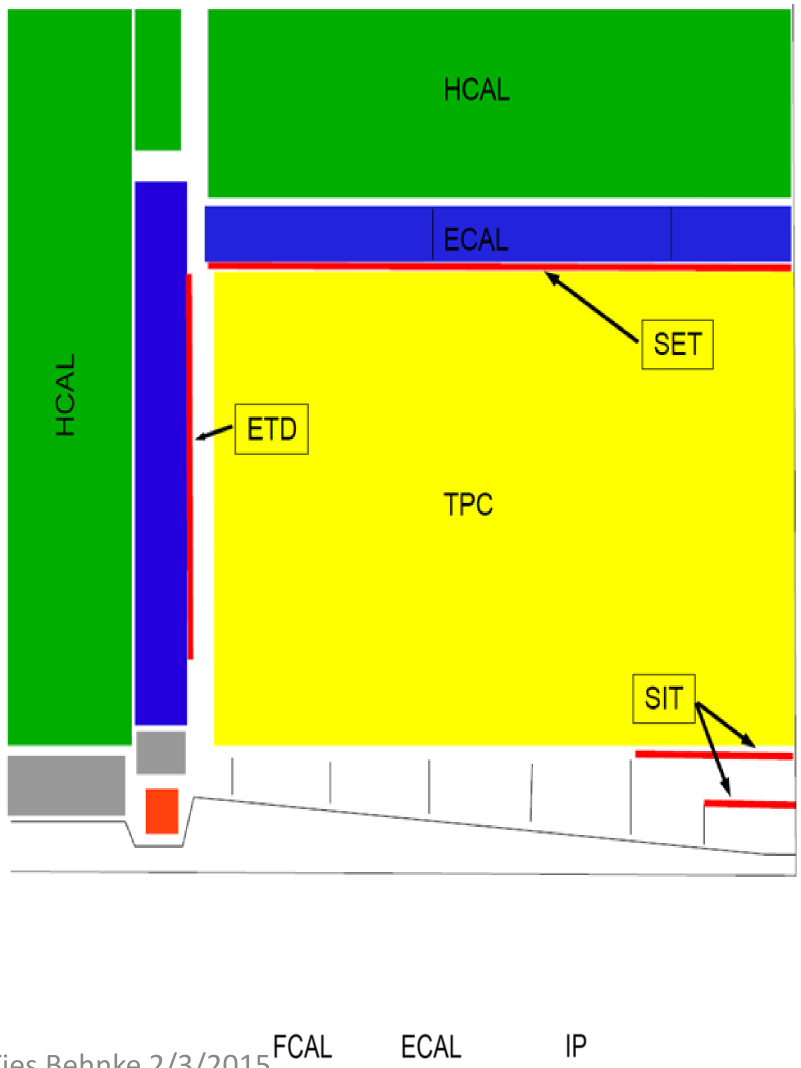
Large magnetic Volume (3.5 T)

- Vertex Detector
- Silicon Tracking
- Time Projection Chamber
- Particle Flow Calorimetry

International group

- Participation from some 60 groups
- Strong contributions from Europe and Japan

ILD: inner detector

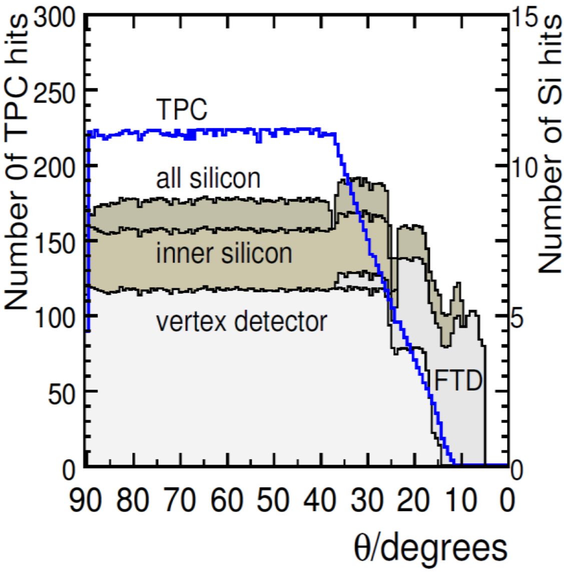


High precision vertex, at low radius

- Driven by beamstrahlungsbackground
- The lower the better

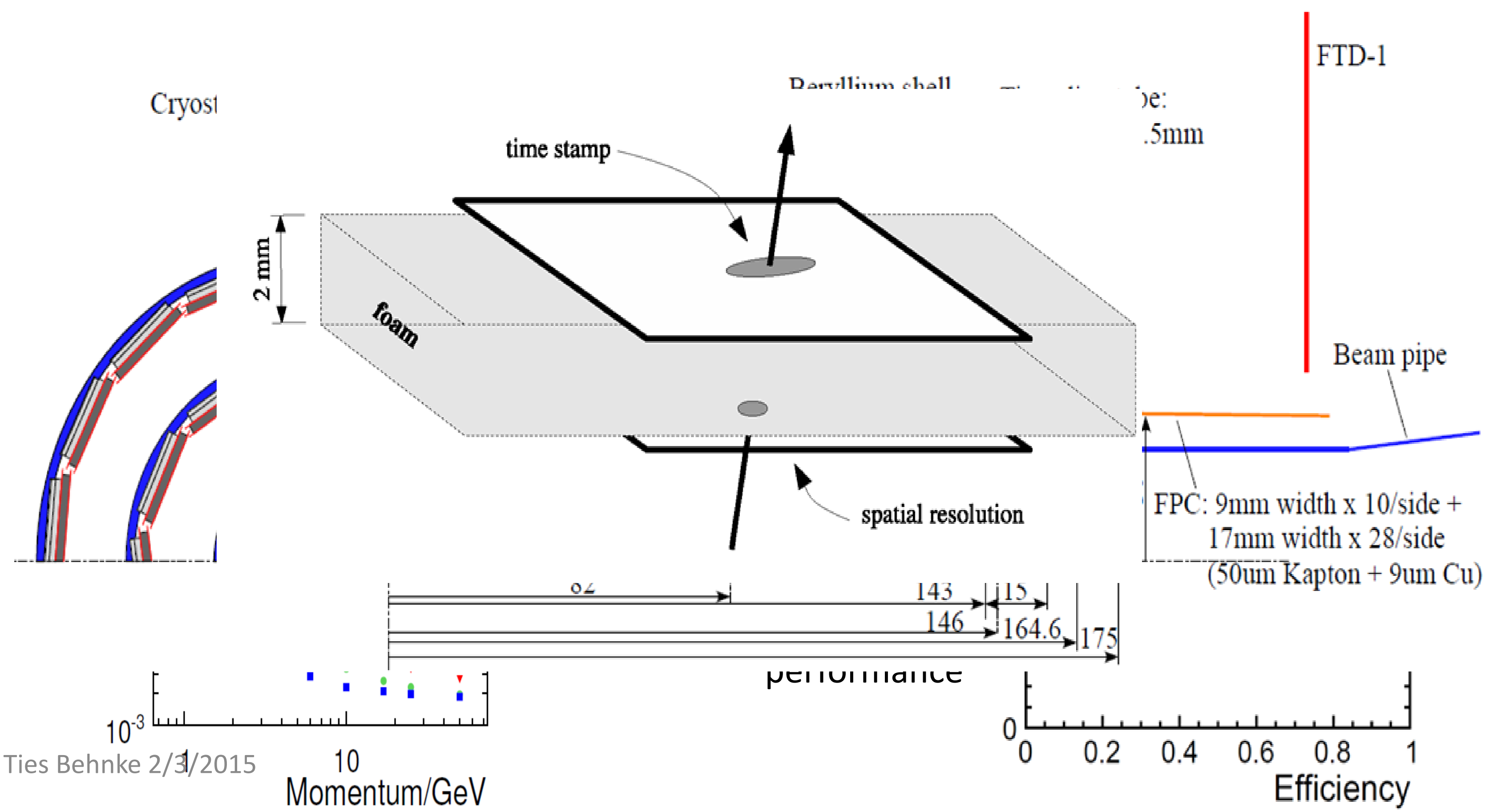
Combined Silicon with gaseous tracking

- High precision
- Large redundancy
- Excellent, stable pattern recognition
- Low material



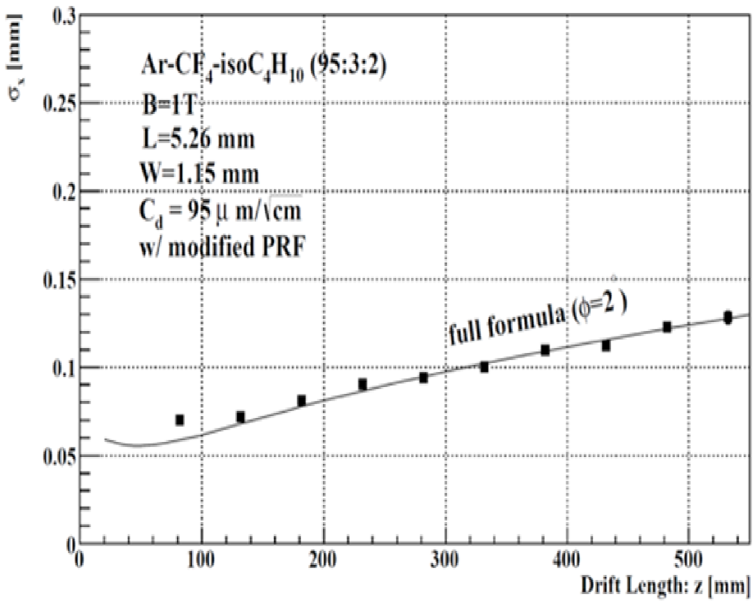
Vertex Detector

	LHC	ILC	Comment
Radiation Level	$>10^{16}$ NEQ (neutron equivalent)/cm^2 (3ab^{-1})	10^{10}NEQ/cm^2/yr	**~O(10^5) difference** FPCCD not a solution at LHC
Readout	40MHz	5Hz (ILD FPCCD)	FPCCD not a



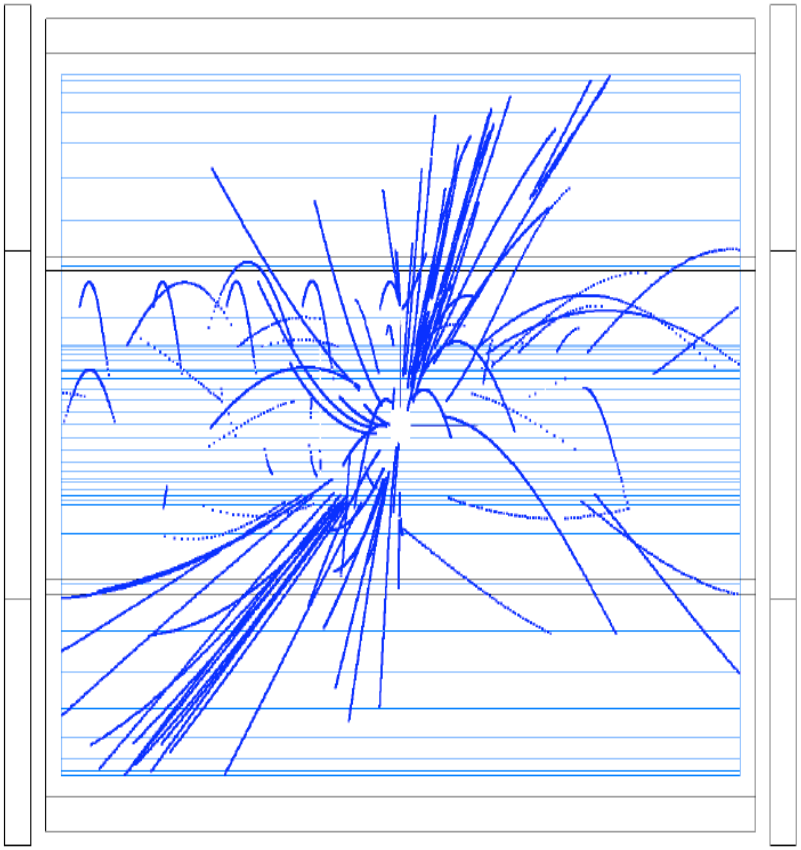
Time Projection Chamber

- 220 space points
- Resolution <100um (60 um asymptotic) in r-Φ
- Resolution ~1mm in z



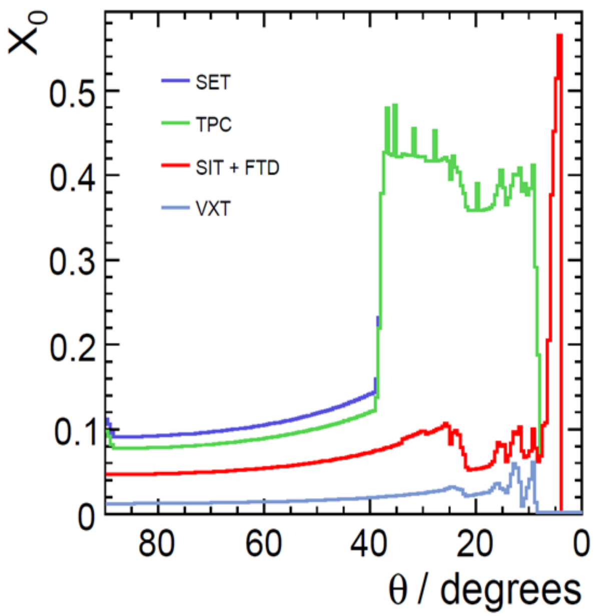
Powerful, stable basis for pattern recognition and track reconstruction.

Time Projection Chamber



- 220 space points
- Resolution <100um (60 um asymptotic) in r-Φ
- Resolution ~1mm in z

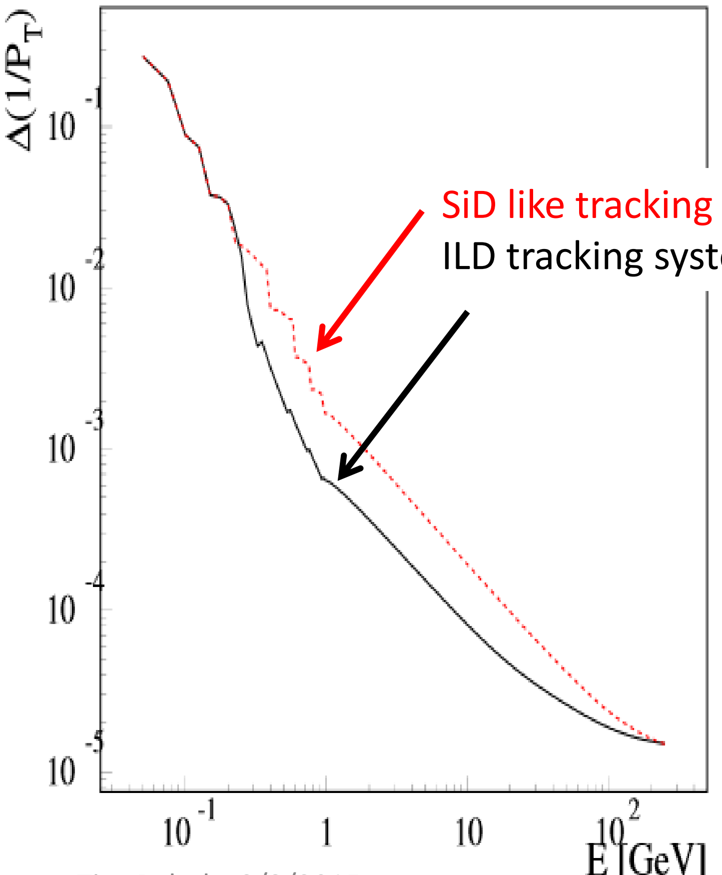
Material budget ILD Detector



Powerful, stable basis for pattern recognition and track reconstruction.

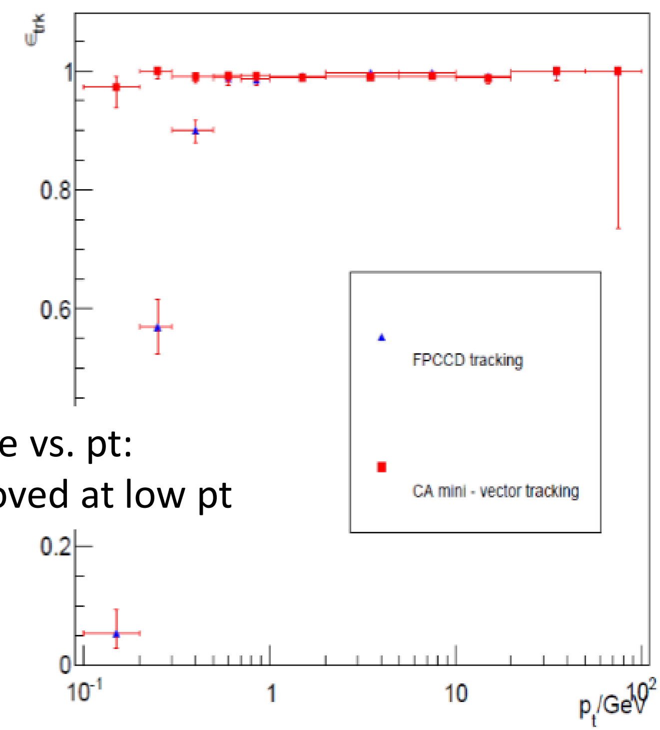
Tracking System

Hybrid tracking system: inner Silicon, large volume TPC, outer Silicon



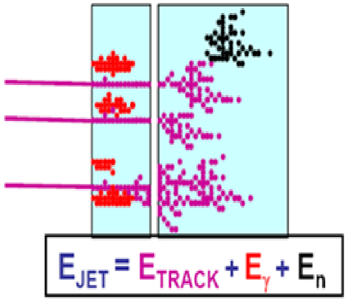
SiD like tracking system in ILD

ILD tracking system



Performance vs. pt:
Much improved at low pt

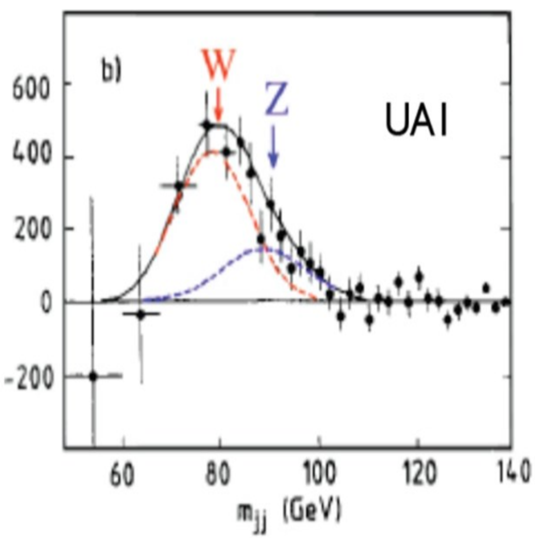
Particle Flow



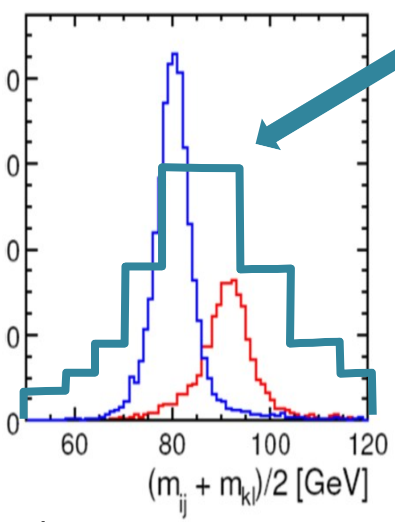
Particle flow is the method of choice for high precision experiments at the ILC.
Requires significantly different calorimeters than previous experiments.

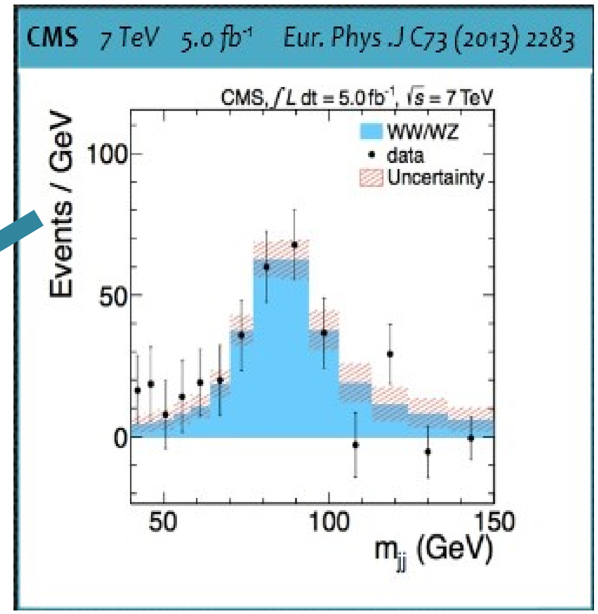
Complex final states (e.g. W/ Z)

Traditional approach



Particle Flow approach



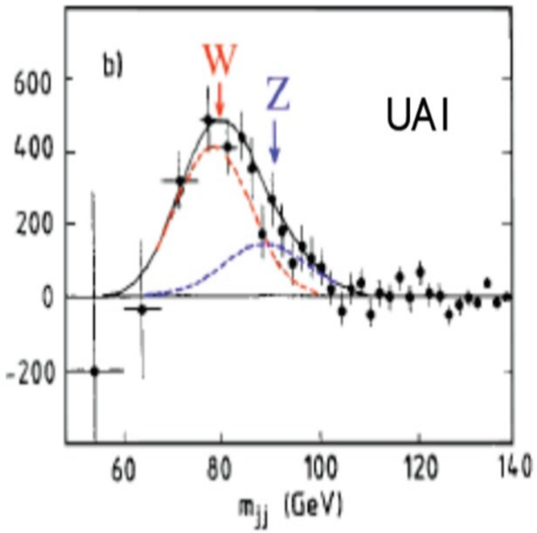


Jet-jet mass resolution

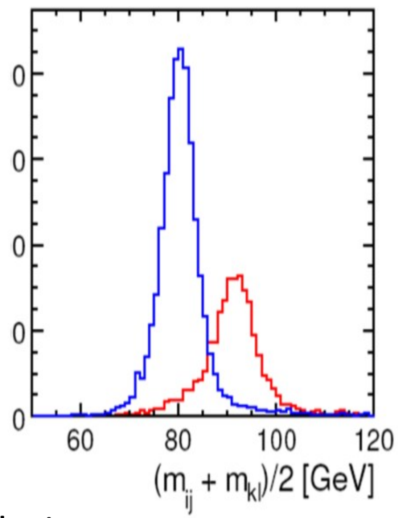
Particle Flow

Complex final states (e.g. W/ Z)

Traditional approach



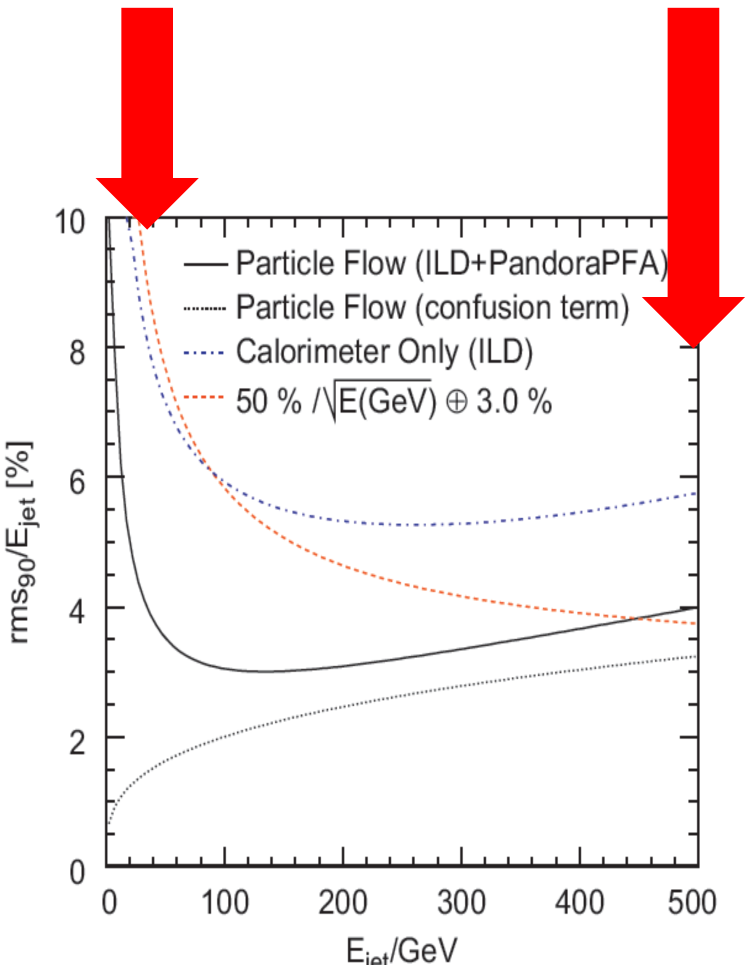
Particle Flow approach



Jet-jet mass resolution

Energy resolution

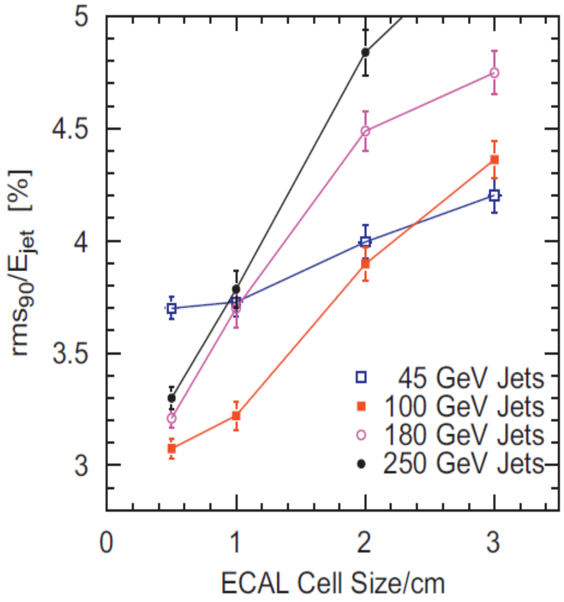
Confusion



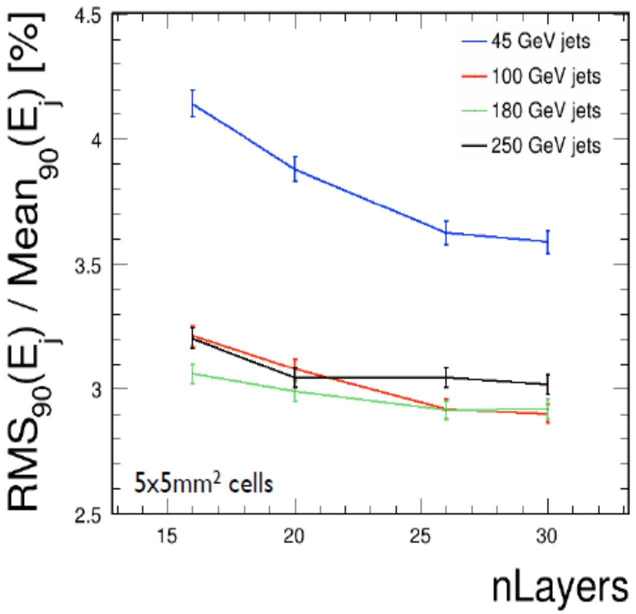
Particle flow is better than pure calorimetry

At high energies the advantage is less.

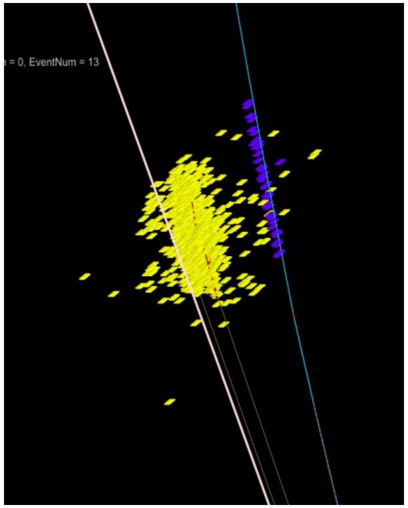
Optimizing a particle flow Calo



Jet energy resolution as a function of the ECAL cell size.



JER as a function of the number of layers in the ECAL (equal thickness)

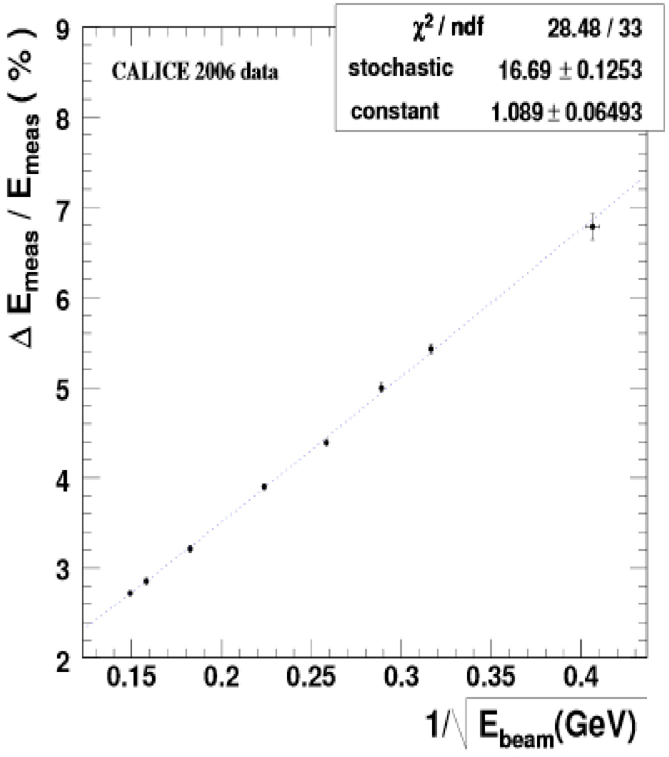


Simulated tau decay in the ILD detector

Small cell size is favored, longitudinal sampling important at low energy

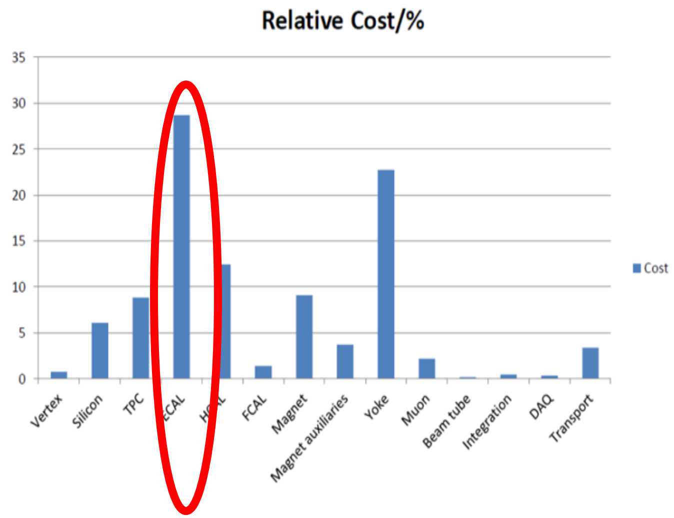
Silicon based Calorimetry

- Sampling calorimeters with silicon based sensitive planes are an attractive option.
- Large progress over the last years in hardware and in understanding
- CALICE: convincing test beam results to demonstrate the feasibility



- Challenge:
  - Integration
  - Costs!

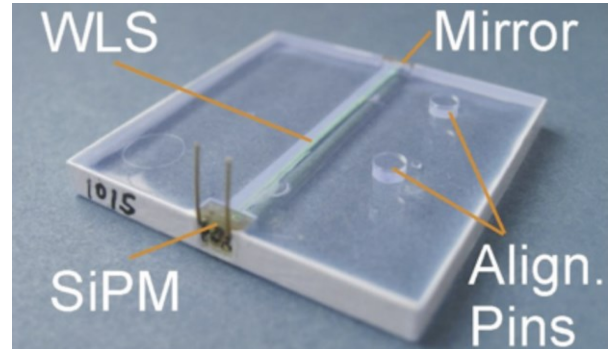
Example: ILD detector at the proposed ILC ECAL 100Mio channels

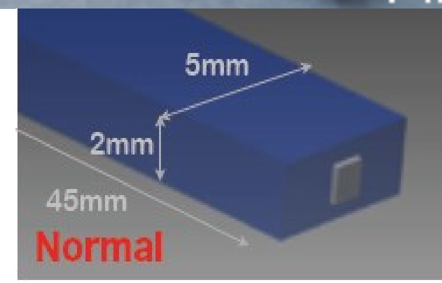


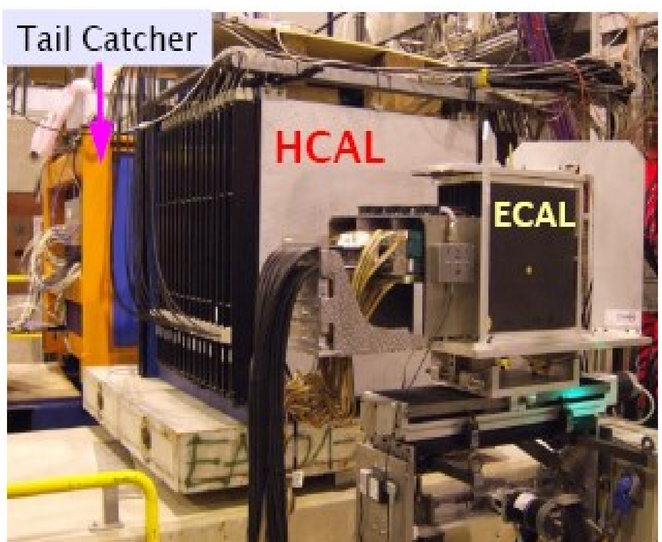
Relative energy resolution of CALICE SI-ECAL

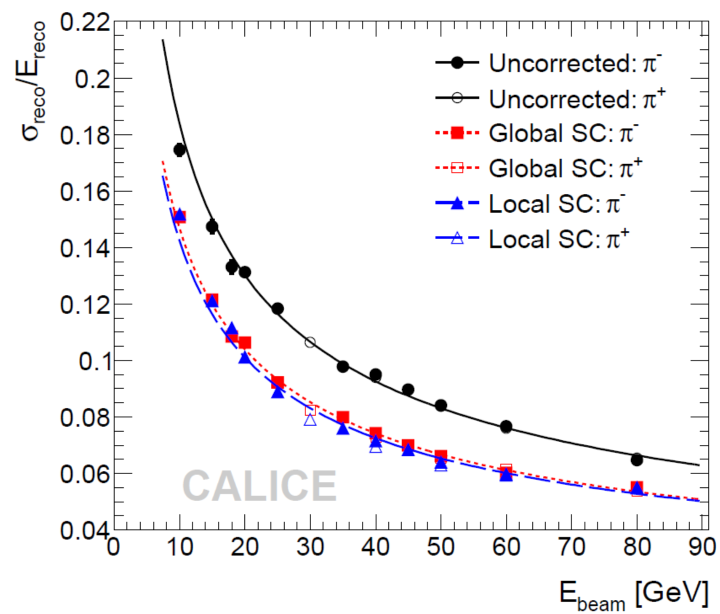
Scintillator Based Calorimeter

- Availablity of SiPM allows highly granular scintillator based designs
- HCAL: 3x3cm^2 segmentation of 3mm thick scintillator read out by SiPM through wavelength shifting fiber (Elimination of WLS under study)
- Software compensation (e/p ~1.2) technique was show to work well through beam tests: 58%/E$^{1/2}$ → 45%/E$^{1/2}$





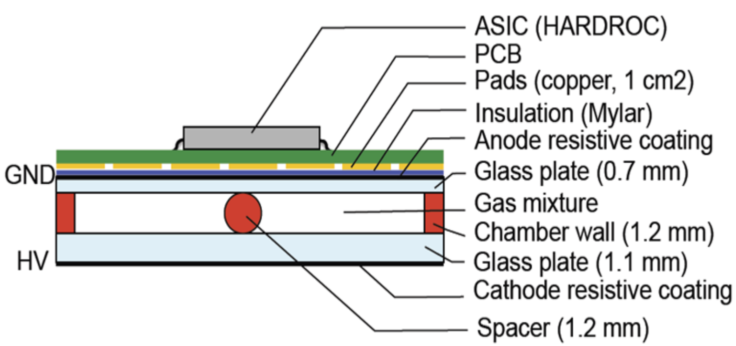




Digital Calorimetry

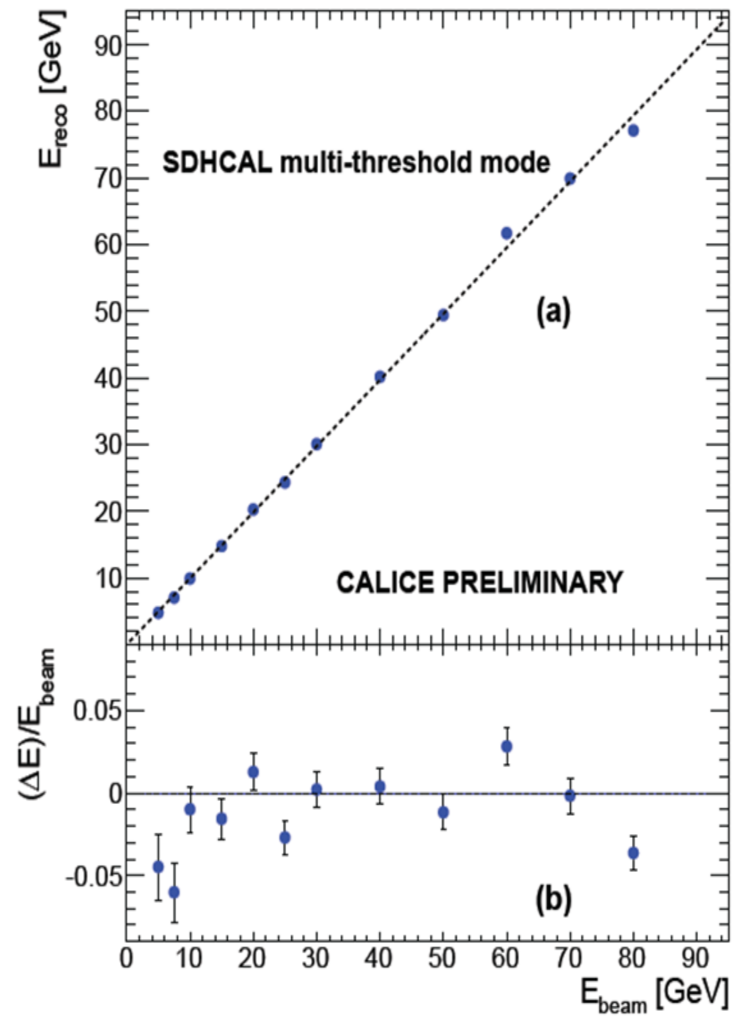
Digital calorimetry:

- Measure the energy of a particle through the number of cells hit
- Was tried already in the 80's (unsuccessfully), has seen a renaissance lately due to the availability of very granular systems.
- Variant is semi-digital aproach



Active medium: gas RPCs

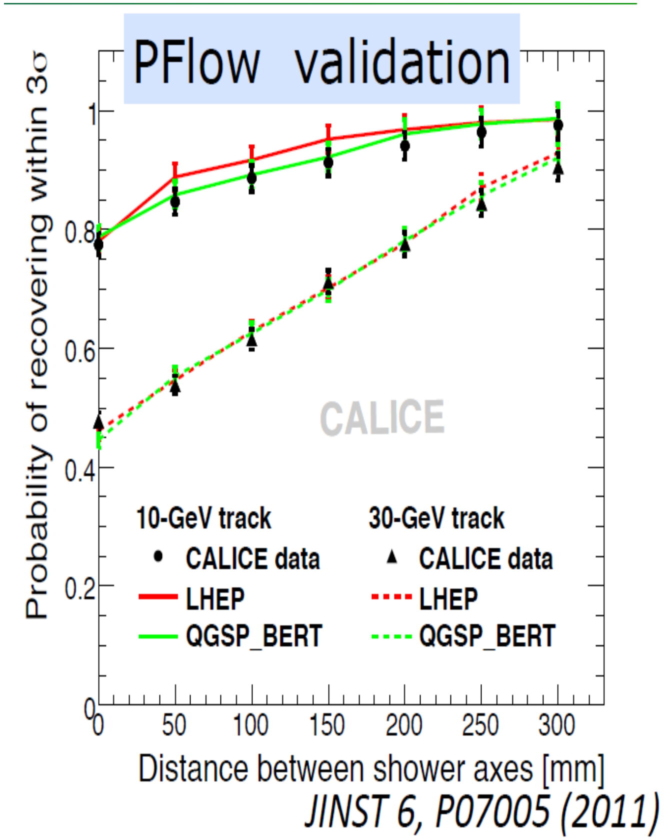
Test beam results from a large prototype detector



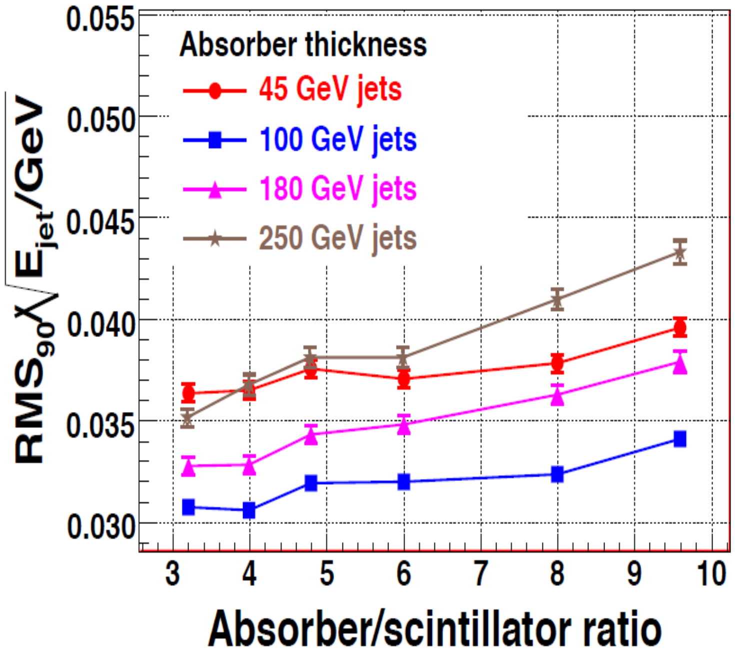
Ties Behnke 2/3/2015

HCAL optimization

Experimental study:
Look into particle separation



Based on 3x3 cm² cells, scintillator

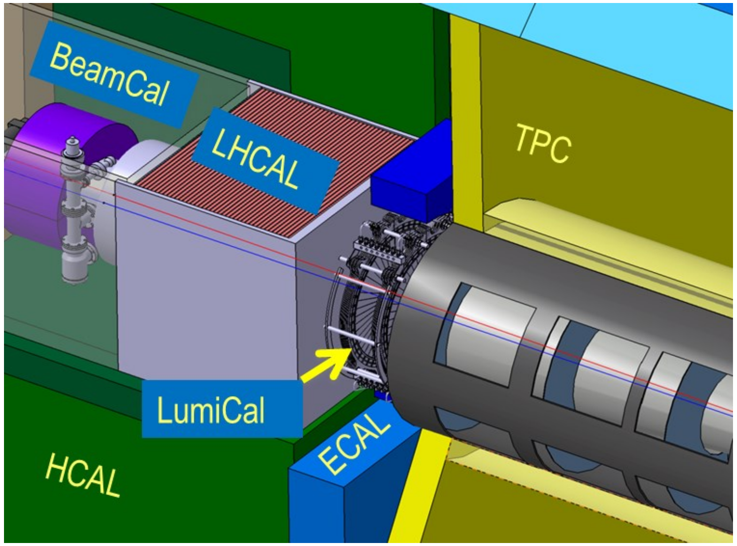


Study of Pflow resolutions vs sampling fraction

Current design seems adequate, but much more work is needed.

Forward calorimeters

- LumiCal
  - Precise ($<10^{-3}$) luminosity measurement
- BeamCal
  - Better hermeticity
  - Bunch-by-bunch luminosity and other beam parameter measurements (~10%)
- LHCAL
  - Better hermeticity for hadrons



	Technology	Coverage
LumiCal	W-Si	31 – 77 mrad
LHCAL	W-Si	
BeamCal	W-GaAs / Diamond	5 – 40 mrad

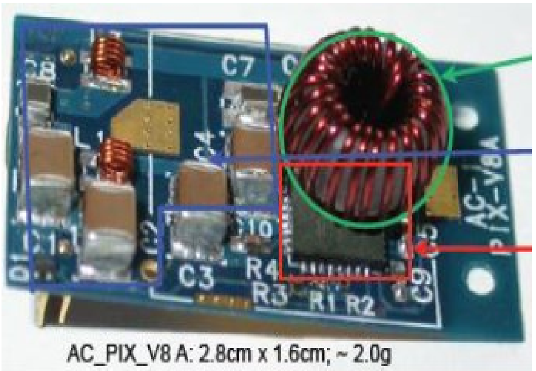
Power Management

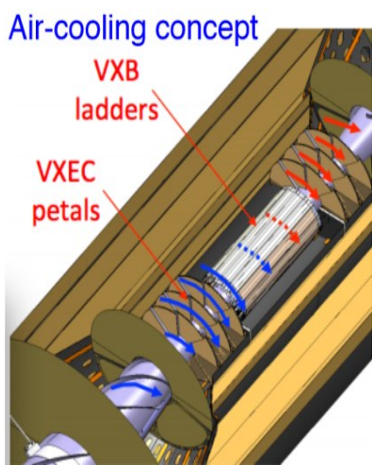
Time structure of the ILC allows for power pulsing:

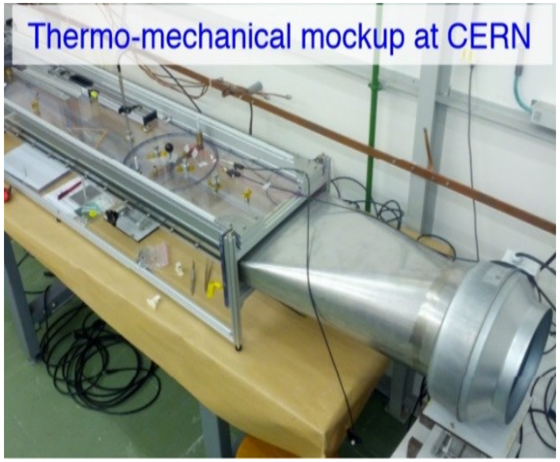
Switch off power in between trains

Combine this with advanced powering concepts to reduce the material.

- Serial powering
- DCDC powering
- Local power storage
- …

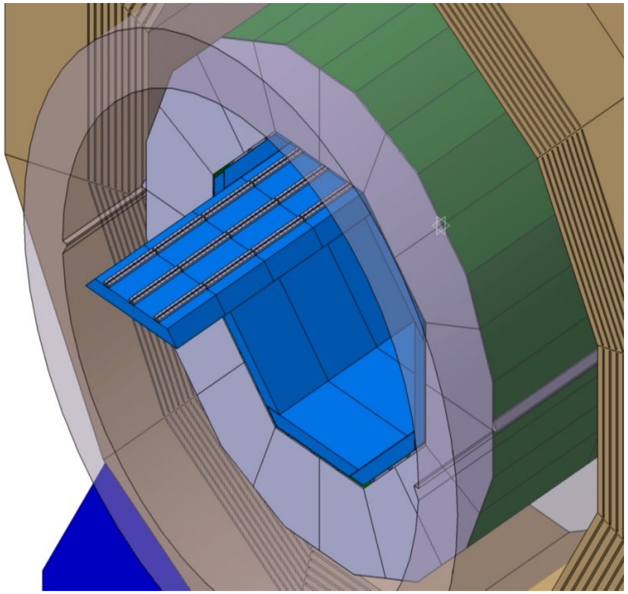






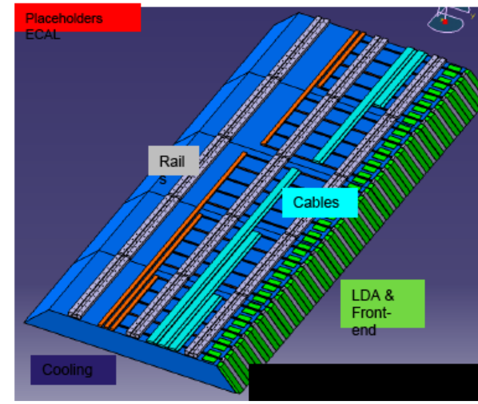
Anticipated power reduction between factor 10-50

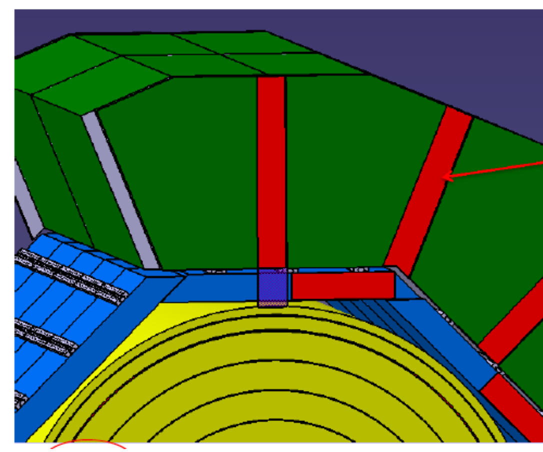
Detector Integration



ILD integration study.

ILD simulation model





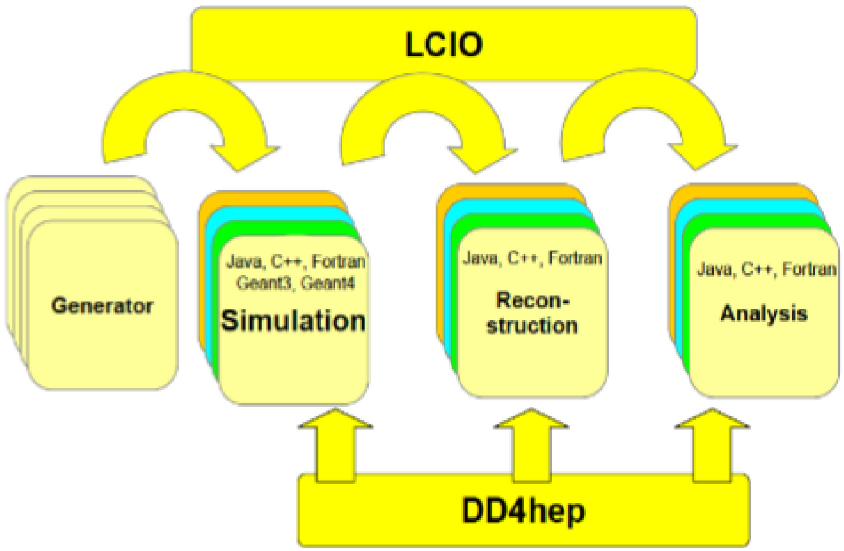
A detailed detector concept exists.
It has been simulated in detail.
Most technologies needed have been demonstrated.
A preliminary engineering has been done.
Site specific studies are ongoing.

Software

Software is a key ingredient for any optimization / design study

It should be

- Powerful
- Transparent
- Easy to use
- Easy to instal
- extensible



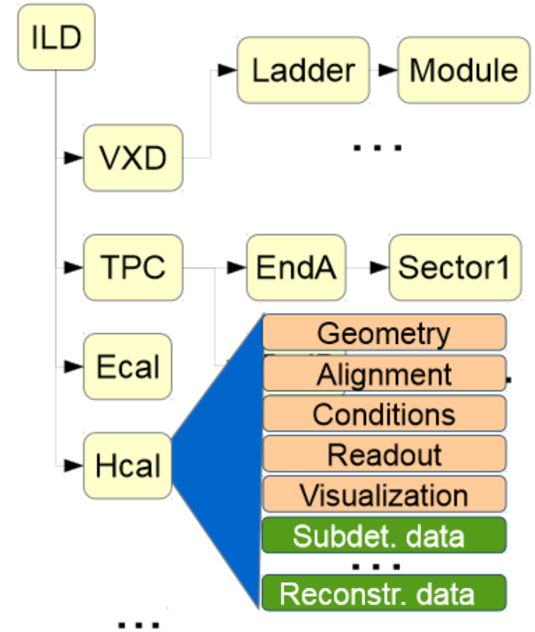
ILC:
Followed early on an approach to standardize software

Cooperation with CLIC

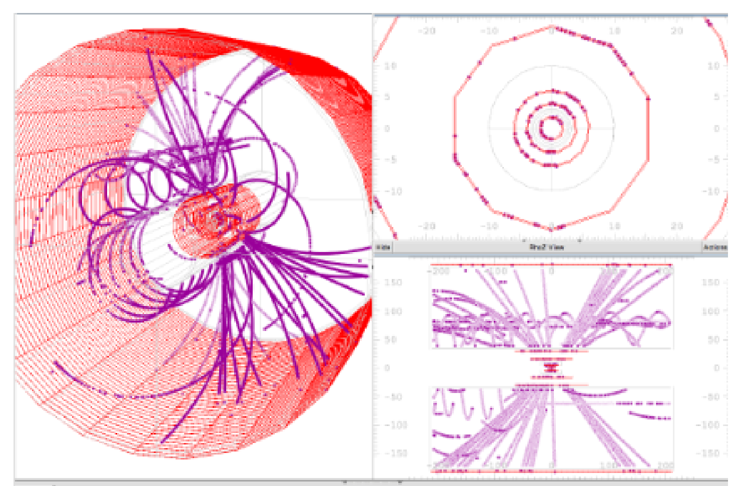
Common event data model
Common geometry description model
Framework programs provide the user a simple means to assemble software

DD4HEP

- Detector is described in a tree-like hierarchy of detector elements
- Elements describe
  - Geometry
  - Material
  - Properties
- Elements connect to
  - Readout, alignment, visualization..

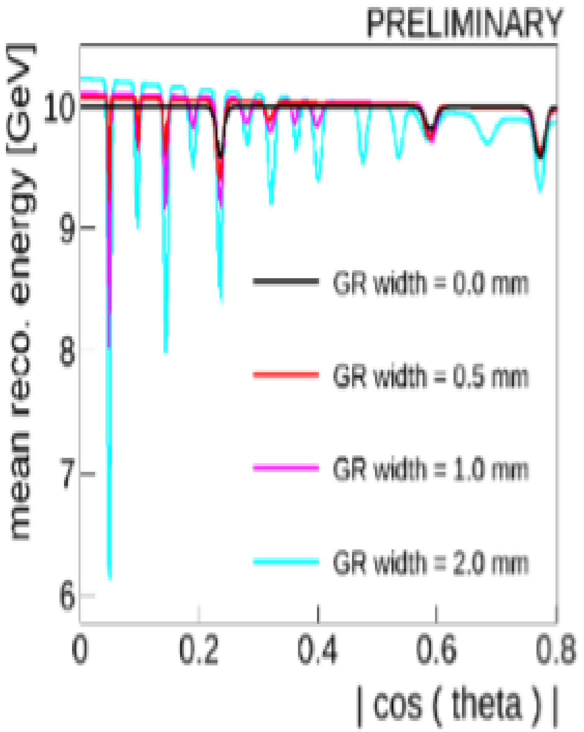


One common tool to describe and handle geometries and properties throught the complete chain!

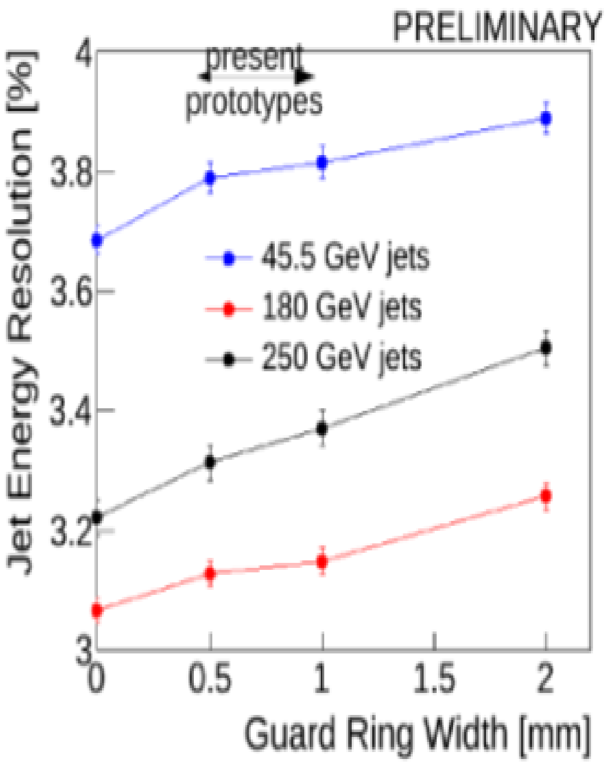


Simulation

Detailed simulation models are crucial to understand precision physics



Reconstructed energy from ECAL
vs. cos(theta):
dips are from dead areas and
guard rings in the Si sensors



Impact of the Jet energy resolution
from different guard ring designs.

Structures

ILD concept group:

- Fairly loose organisation
- Slowly moving towards a more formal “club”, but still far from a collaboration

R&D collaborations

- Technical questions are mostly addressed by R&D collaborations (CALICE, LCTPC, …)
    - Have their own structures
    - Get their own funding
    - Powerful tool to leverage R&D funds from different sources

Cooperation

- Tried to maintain common basis with other groups (concepts, general studies …)
- Common tools played an important role in this.

Summary

Detector studies have been ongoing at the ILC for some time

Integrated detector concepts have been developed

- Fairly detailed designs exist
- Most key technologies are beyond “proof of principle”
- Detailed models of the detector exist

Close cooperation between R&D groups and detector concept group is essential

Next step: much more detailed engineering needed, full integration model is needed, site specific studies are needed.