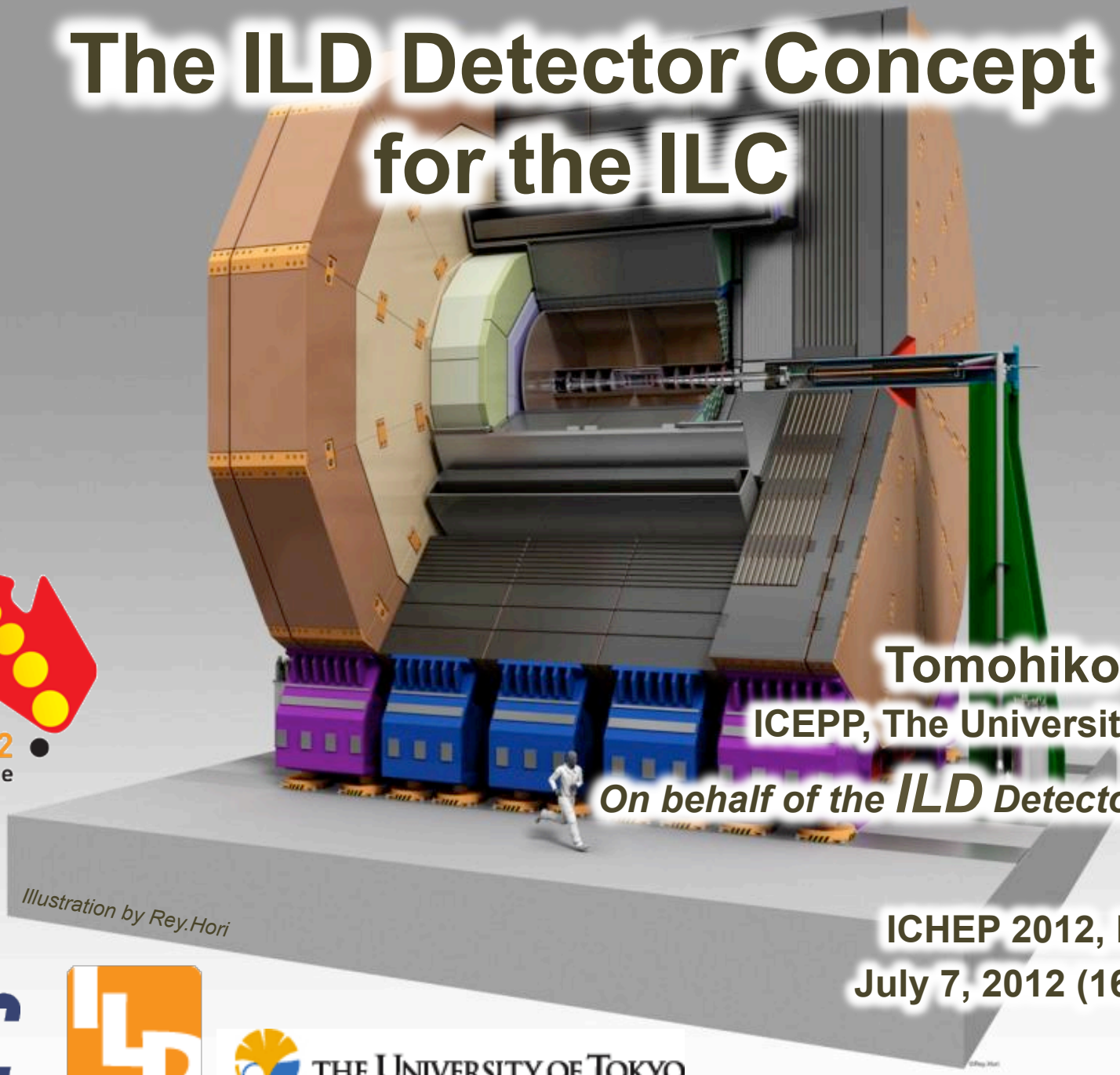
The ILD Detector Concept for the ILC



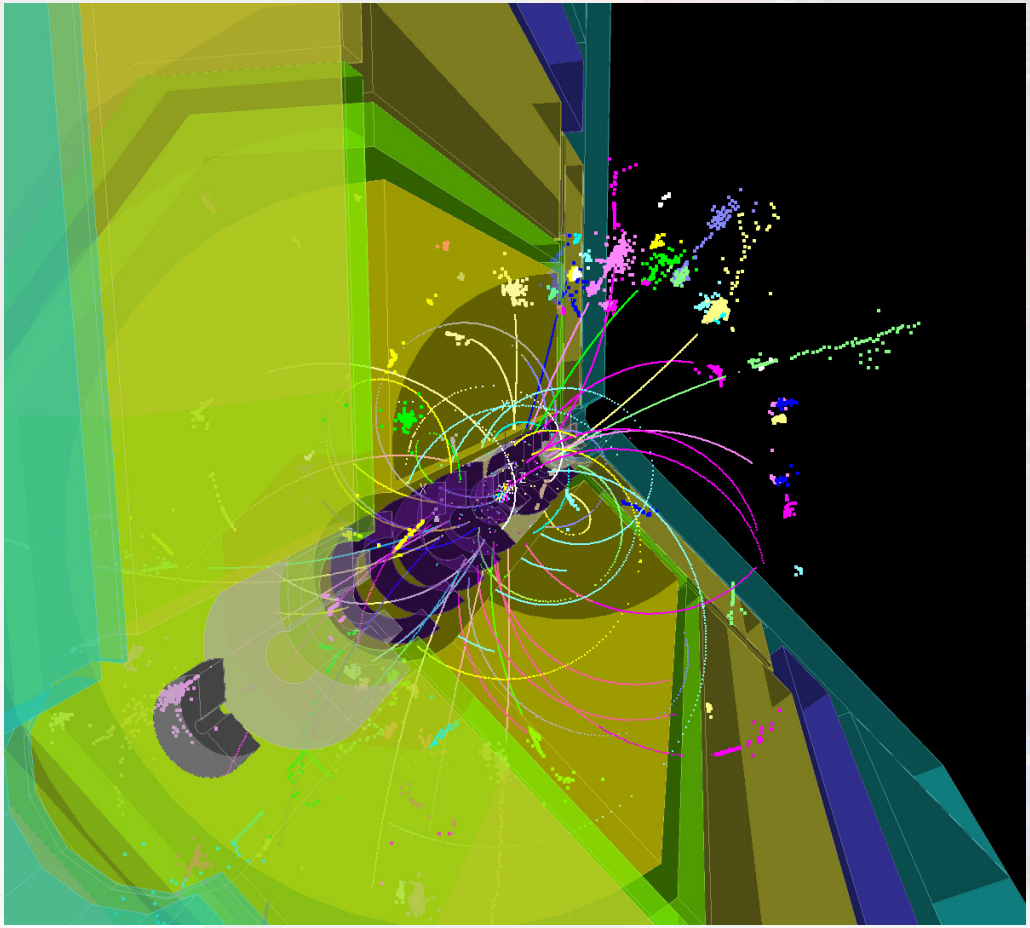
ICHEP2012 Melbourne

Tomohiko Tanabe
ICEPP, The University of Tokyo
On behalf of the ILD Detector Concept

ICHEP 2012, Melbourne
July 7, 2012 (16:50-17:10)

THE UNIVERSITY OF TOKYO

Outline



- Introduction
- Detector subsystems
  - VXD
  - TPC
  - Silicon Tracking
  - ECAL
  - HCAL
  - Forward CAL
  - Tail Catcher / Muon Tracker

  } abstracts combined with this talk
- Overall Integration
- Machine Detector Interface
- Software
- Overall performance
- Benchmark processes
- Summary

Introduction

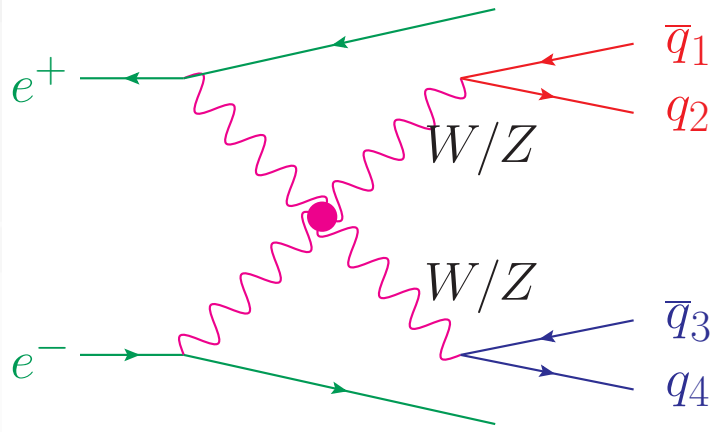
ILC detector for precision physics studies

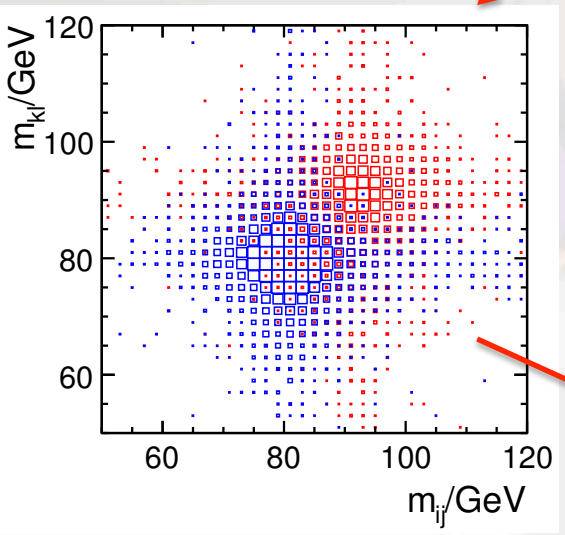
- e.g. Higgs, top, SUSY, …
- Final states with: (many) jets, leptons, invisibles

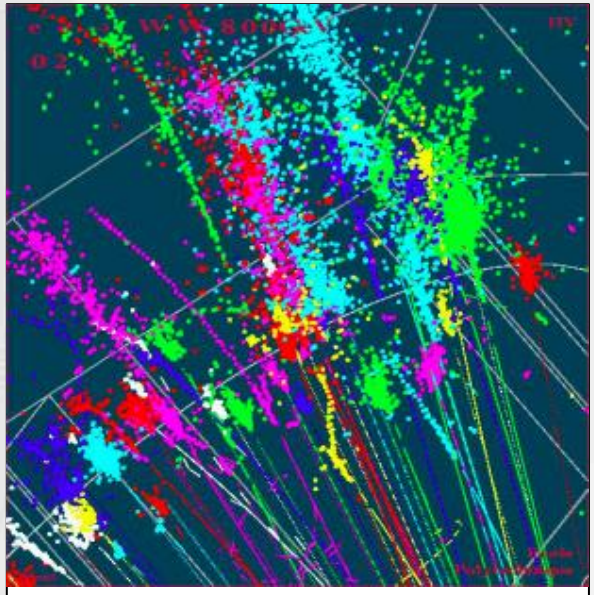
Refer to the following talks:
F. Simon, **"Prospects for Precision Higgs Physics at Linear Colliders"**
M. Vos, **"Top Precision Studies at Linear Colliders"**
T. Suehara, **"Exploring Sypersymmetry with future e+e- Linear Colliders"**

Requirements for the detector:

- Track momentum resolution (e.g. recoil mass)
- Jet energy resolution (e.g. di-jet invariant mass)
- Vertexing capabilities (e.g. flavor tagging)
- Hermeticity (e.g. missing energy determination)







Particle Flow Algorithm
Separate calorimeter hits at the particle level so the best energy measurement can be used for each particle.
Charged tracks : tracker
Photons : ECAL
Neutral hadrons: HCAL

Good W/Z separation
Jet energy resolution
$\sigma(E_{jet})/E_{jet}$ = 3-4%

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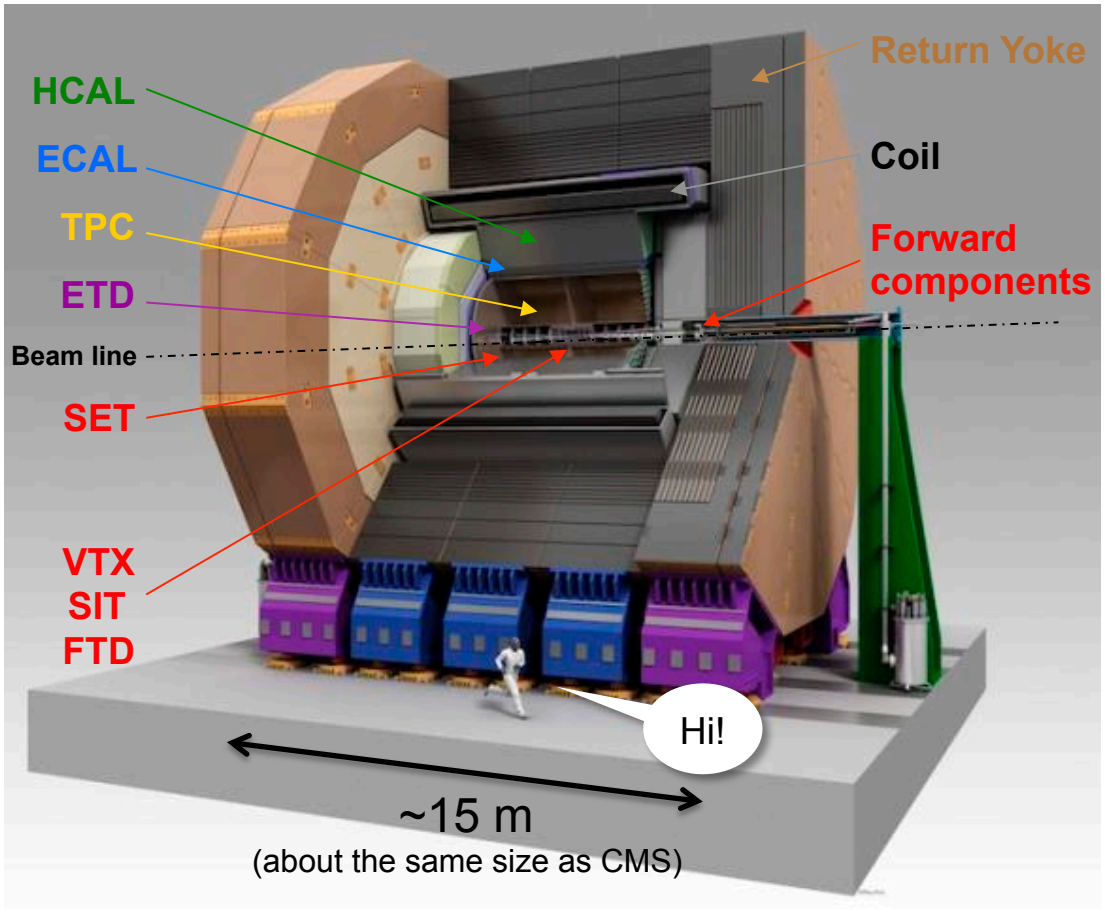
International Large Detector

ILD: optimized for particle flow

- Precision tracking & vertexing
- Highly granular calorimeters [ECAL ~0.5cm, HCAL 1~3cm]
- Large: ECAL inner radius 1.85m
- B-field: 3.5 T
- ECAL + HCAL inside solenoid

- ≈4π coverage
- Triggerless operation
- Low background (except in very forward region)



Current phase: Preparation towards a Detailed Baseline Design
DBD report due end of 2012

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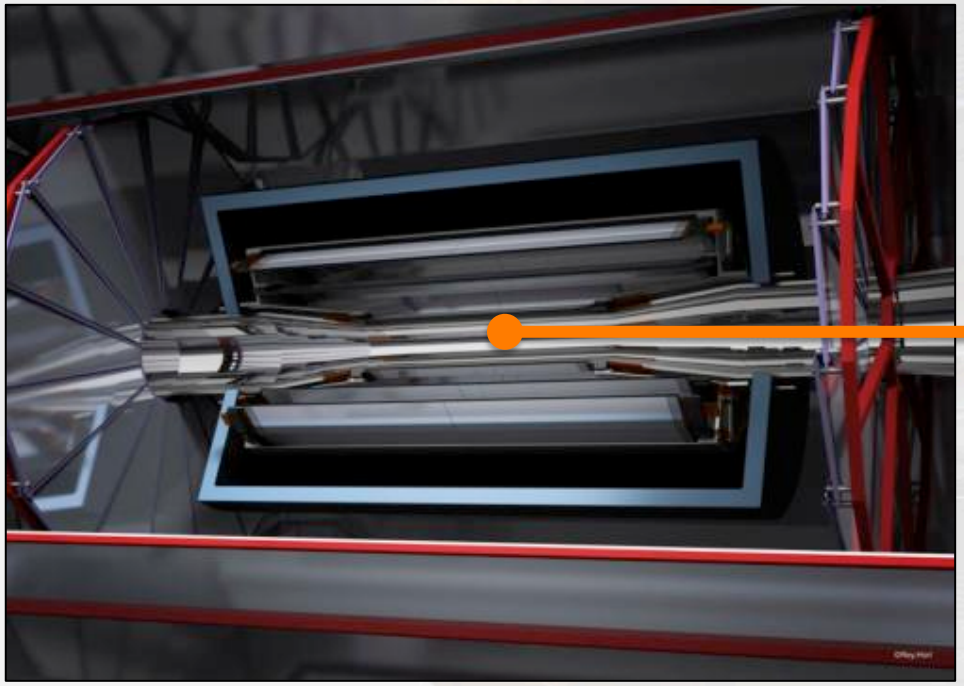
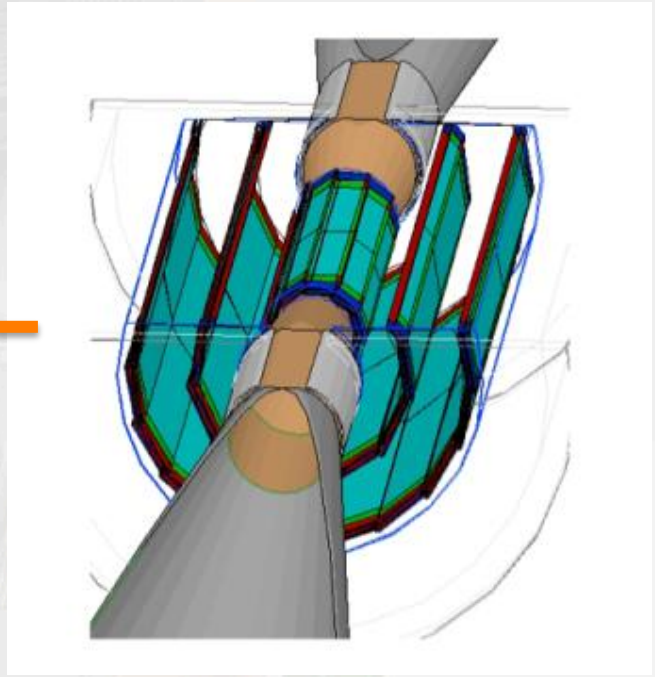
Vertex Detector





- Key to jet flavor tagging via vertex reconstruction
- 3 double layers, r_{min}=16 mm, 3 μm point resolution
- Impact parameter resolution: $\sigma_b < 5 \oplus 10/p\beta \sin^{3/2}\theta$
- Main challenges: beam backgrounds, power consumption, **material budget** (0.2-0.3% X_0 per layer)
- 3 options: **CMOS**, **FPCCD**, DEPFET

Talk by S. Rummel

Vertex Detector – CMOS

CMOS Pixel Sensor R&D:

- MIMOSA-30 & 31 fabricated in Q4/2011; 10μs read-out confirmed for innermost layer (can cope with beam backgrounds) → test beams this summer

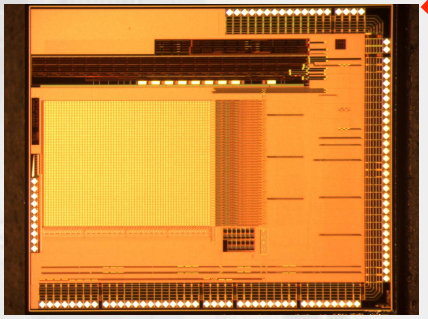
Ladder development:

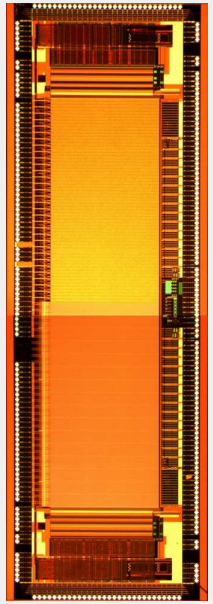
- PLUME (0.6% X_0) **double-sided ladder prototype**: no cross-talk observed, improved impact parameter & pointing resolution.
- New version (0.35% X_0) under construction, test beams this November

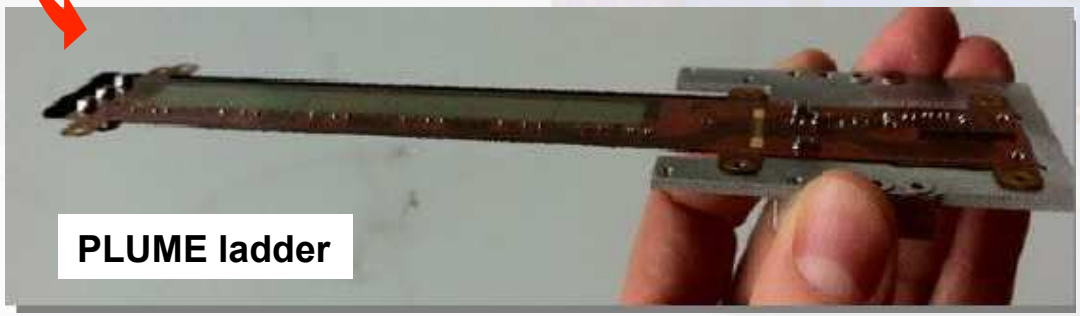
0.18μm technology prototyping:

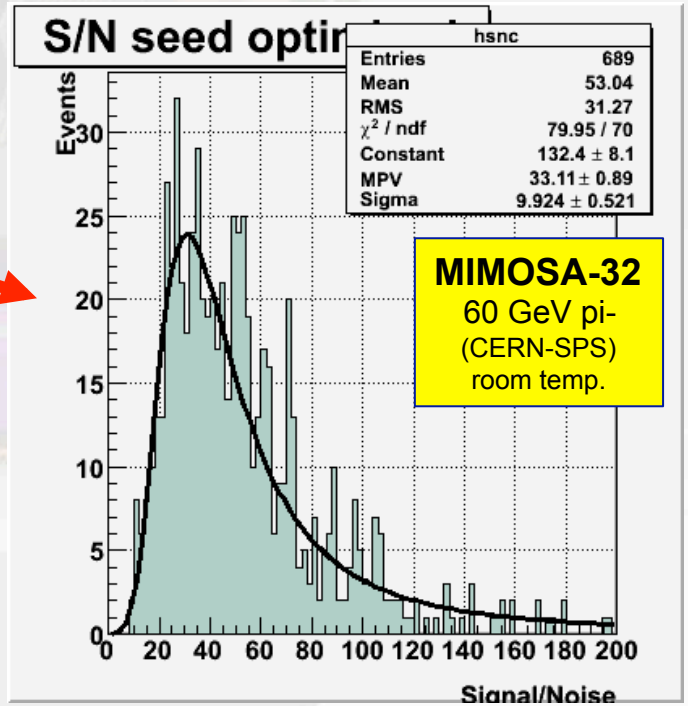
- New 0.18μm process could reduce readout to 1-2μs → can cope with increased background
- MIMOSA-32 fabricated in Q4/2011, test results available.

MIMOSA-30 (innermost)
MIMOSA-31 (outer)









Vertex Detector – FPCCD

FPCCD option:

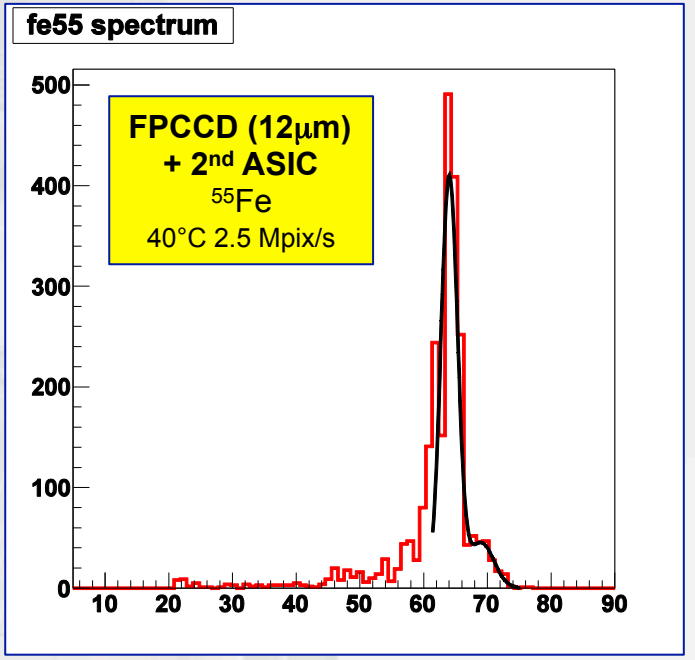
- Fine pixel CCD with pixel size ~5μm
- Fully depleted epitaxial layer ~15μm
- Readout in-between trains (~200ms) → no need for power pulsing

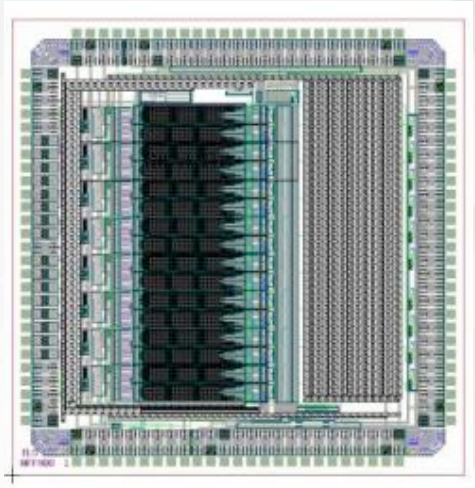
Sensor R&D

- 8μm pixel prototype developed
- Large prototype with 6μm pixel in FY2012
- Thinning technology established ~50μm

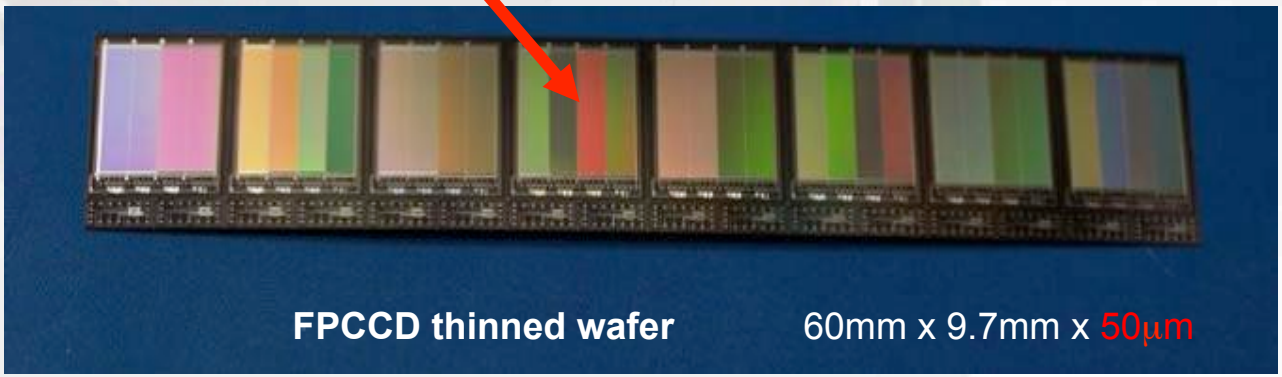
Readout ASIC R&D

- Prototype fabrication twice so far
- New prototype: 10Mpix/s read-out, power consumption of ~5mW/ch (1ch = 2Mpix)

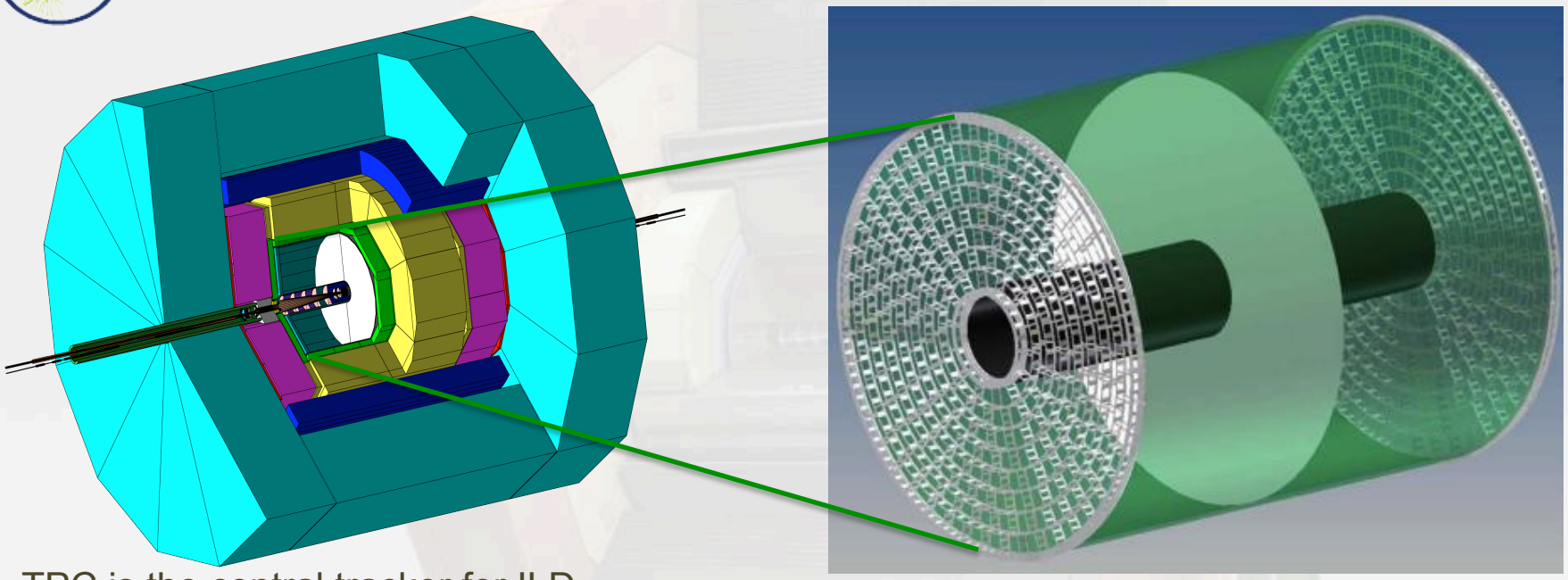




Layout of 3rd ASIC



Time Projection Chamber (1)



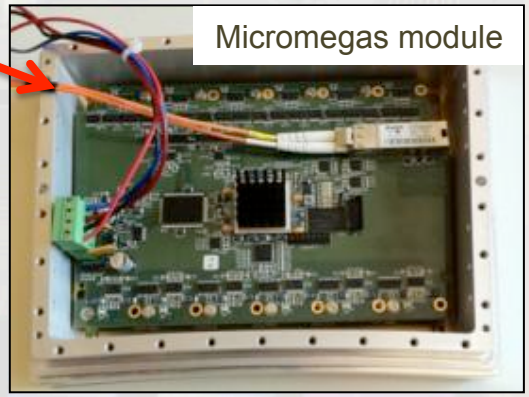
- TPC is the central tracker for ILD
  - Large number of 3D points → continuous tracking
- Low material budget inside the calorimeters important for PFA
  - Barrel: ~5% X_0
  - Endplates: ~25% X_0
- Two options:
  - **GEM:** 1.2x5.4 mm^2 pads, 28 pad rows x 176-192 pads/row
  - **Micromegas:** 3x7 mm^2 pads, 24 pad rows x 72 pads/row
- Alternative: **pixel** read out with pixel size ~55x55 μm^2

Requirements
Momentum resolution:
$\delta(1/p_T) < 9\times10^{-5}$ GeV
Spatial resolution:
$\sigma(r\phi) < 100$ μm
$\sigma(z) < 500$ μm
97% tracking eff. for p_T>1 GeV
dE/dx resolution ~5%

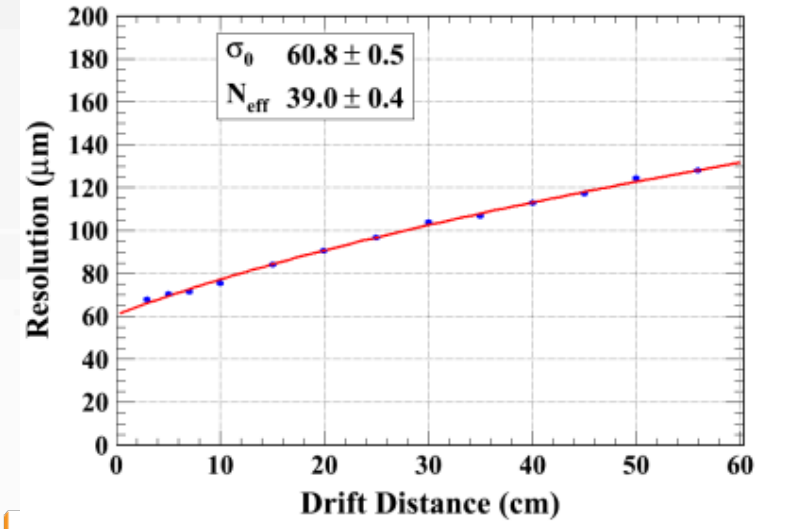
Time Projection Chamber (2)

R&D with TPC Large Prototype (LP)

- Second endplate for LP built & tested, realistic structure, good rigidity, agrees with simulation.
- Magnet module (PCMAG) & test facility upgraded (EUDET @ DESY)
- Test beams this summer for 7 new Micromegas & GEM readout modules

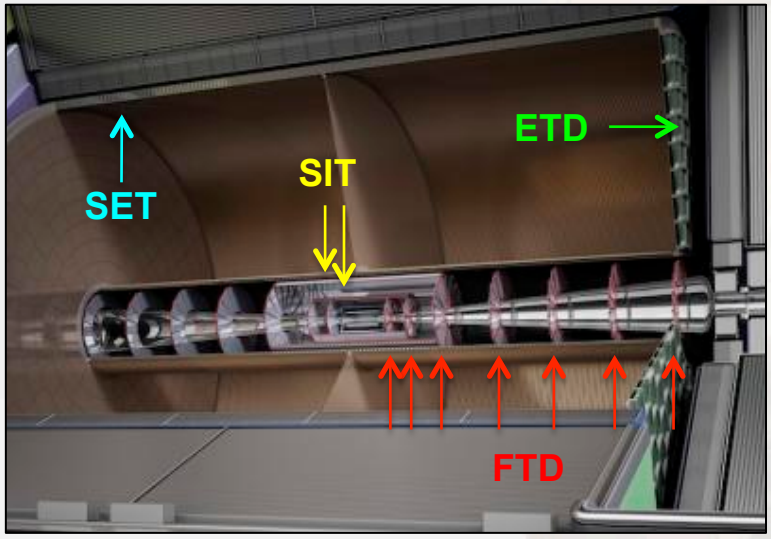


Micromegas: transverse position resolution vs. drift distance (B=1T)



- Readout chip (S-ALTRO16) fully tested, available; implements power-pulsing at chip-level
- New readout chip (GdSP, 128 channel) being developed: 130nm tech, low power (<1mW/ch)
- Effect of migration of ions in gating devices understood better

Silicon Tracking



Extra silicon trackers provide:

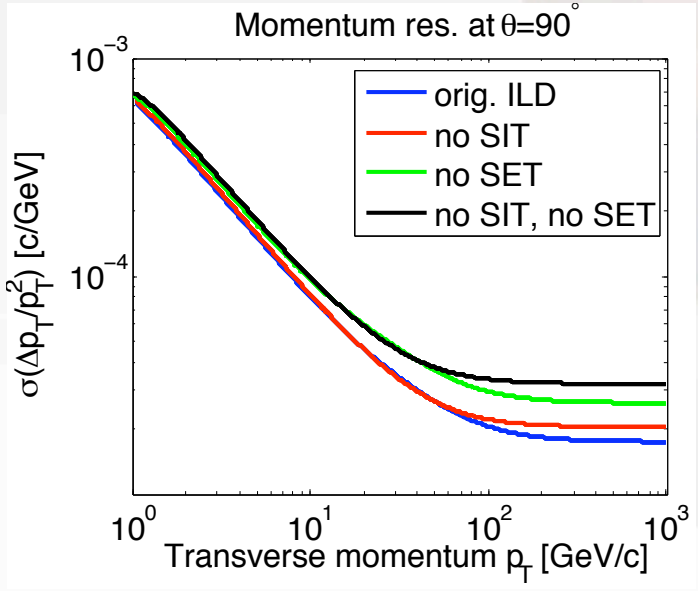
- Better angular coverage (FTD: ~0.15 rad)
- Improve momentum/position resolution
- Time stamping (20-40 ns for beam bunch)
- Calibration & alignment

LHC-LC synergy in R&D:

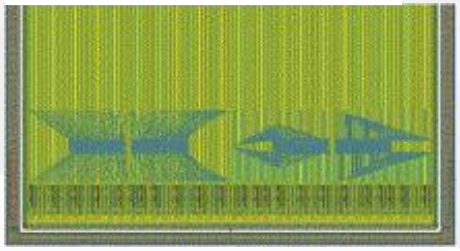
- 10x10cm^2 strip sensor for SIT, SET, ETD
- Edgeless sensors, integrated pitch adapters
- New on-detector electronics, support architecture
- Embedded sensors

Challenges:

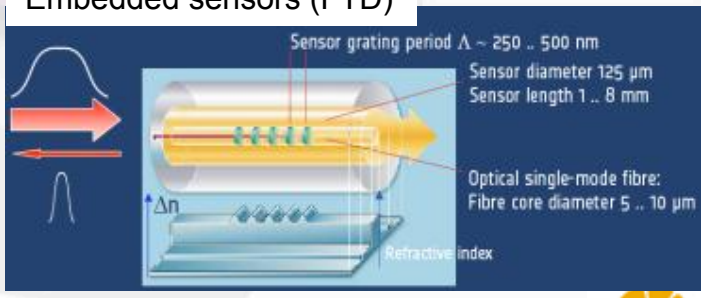
- **Material budget**, low power consumption, high spatial resolution



Integrated pitch adapters



Embedded sensors (FTD)



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Calorimeters

See also: talk by T. Yoshioka (ECAL+HCAL)

ECAL

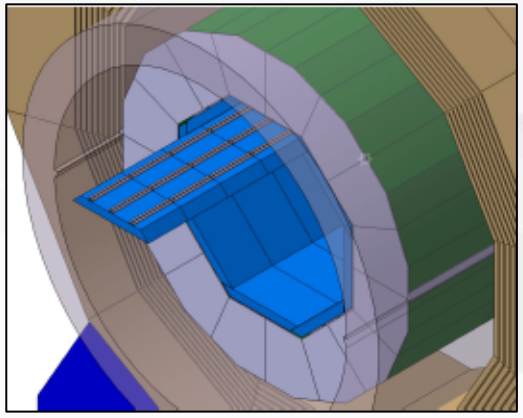
- Tungsten as absorber material
- Silicon and/or scintillator as active material

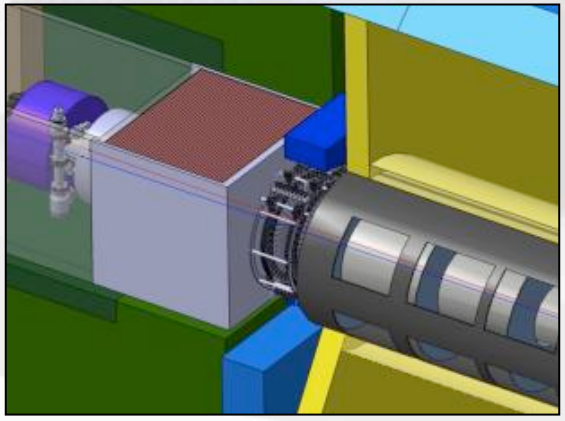
HCAL

- Steel as absorber material
- Analog: scintillator tiles read-out by SiPM
- Semi-digital / (Digital) RPCs

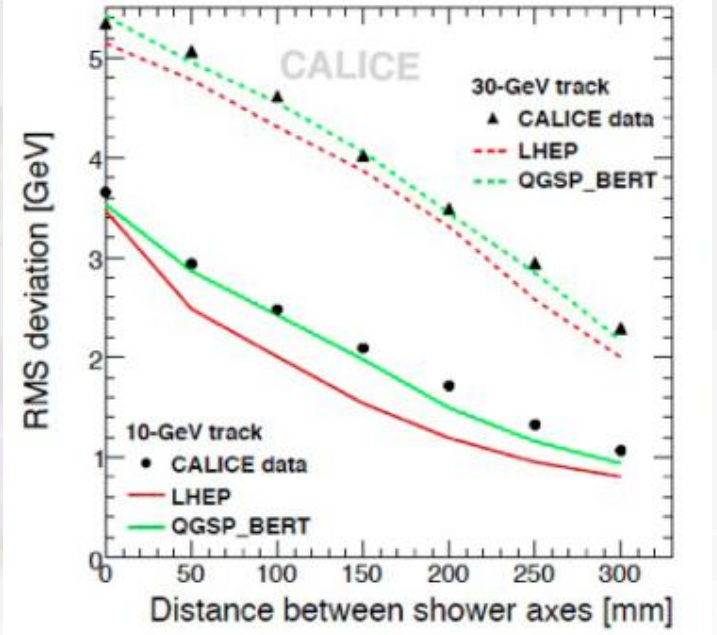
Forward Calorimeters

- Luminosity Calorimeter (LumiCal)
- Beam Calorimeter (BeamCal)
- Forward hadron calorimeter (LHCAL)





Particle Flow with test beam
AHCAL + SiECAL
10 GeV neutral + 10/30 GeV track
[JINST 6, P07005 (2011)]



Good agreement between data and simulation

ECAL

Sampling calorimeter with tungsten as absorber.

→ Compact design, 24 X_0 within 20 cm

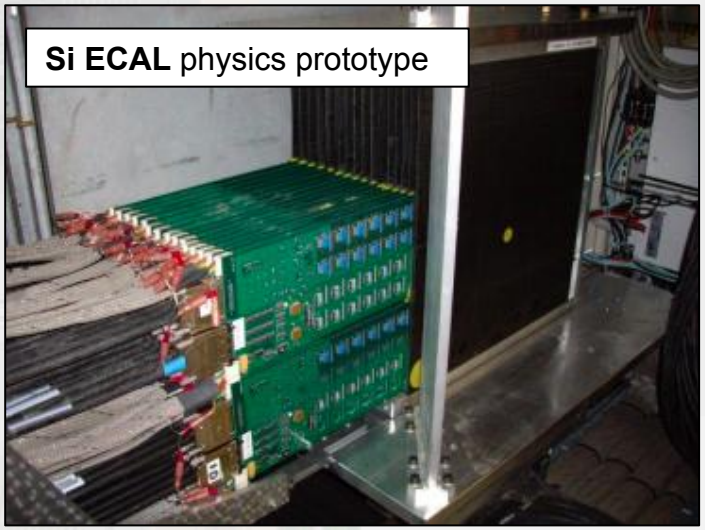
→ Longitudinal segmentation: ~30 layers

Options for active layers:

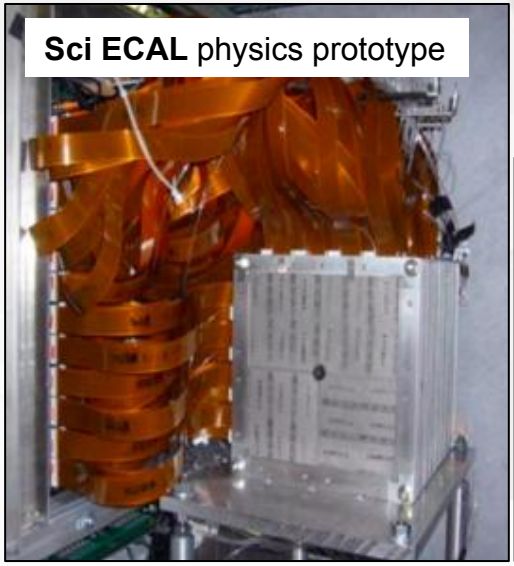
- **Silicon PIN diodes** (0.5 x 0.5 cm^2)
- **Scintillator strips** (0.5 x 4.5 cm^2), MPPC readout
- Silicon/scintillator **hybrid**

Basic performance established; transition from physics prototype to technological prototype ongoing

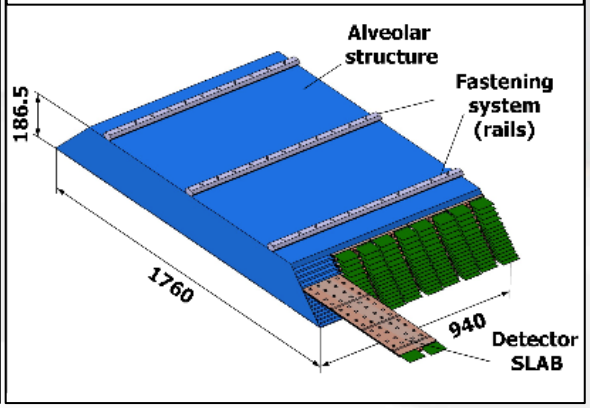
Si ECAL physics prototype



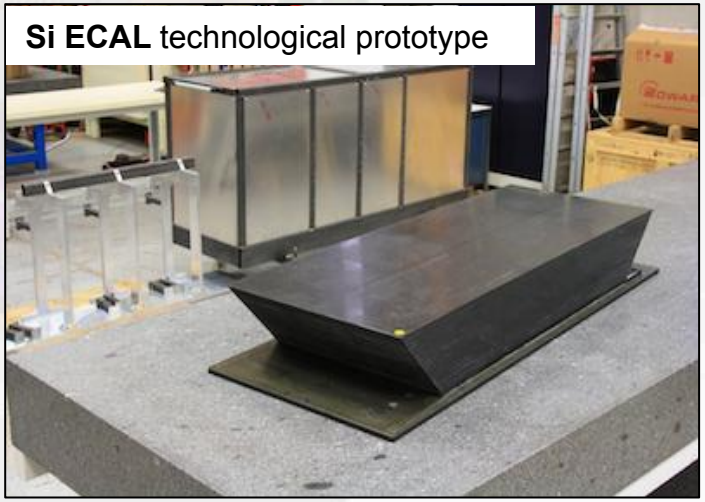
Sci ECAL physics prototype



Sci ECAL technological prototype under development



Si ECAL technological prototype



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HCAL

Absorber material: **steel**. Active material options:

- **Analog HCAL:** 3x3 cm^2 scintillator with SiPM
- **Semi-Digital/(Digital) HCAL:** 1x1 cm^2 glass RPC

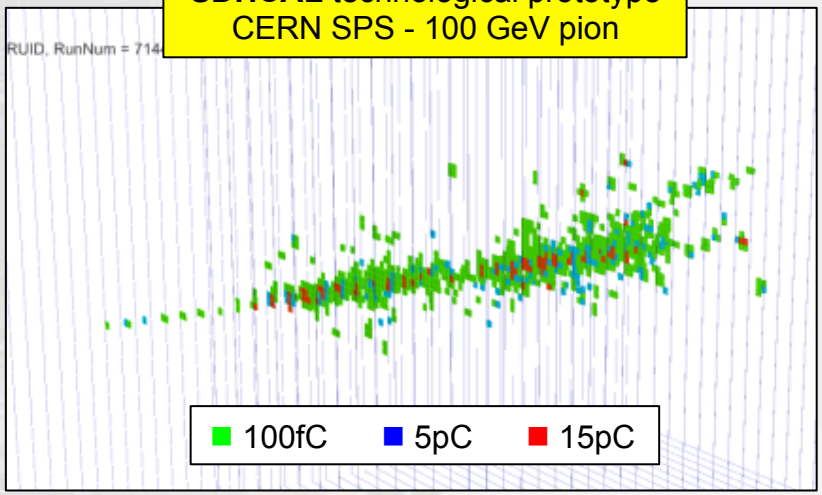
Both have constructed 1 m^3 sized prototypes and exposed them to test beams.

AHCAL: physics prototype with external electronics built. Completed data taking and analysis, validated the simulation and tested first technological demonstrator units.

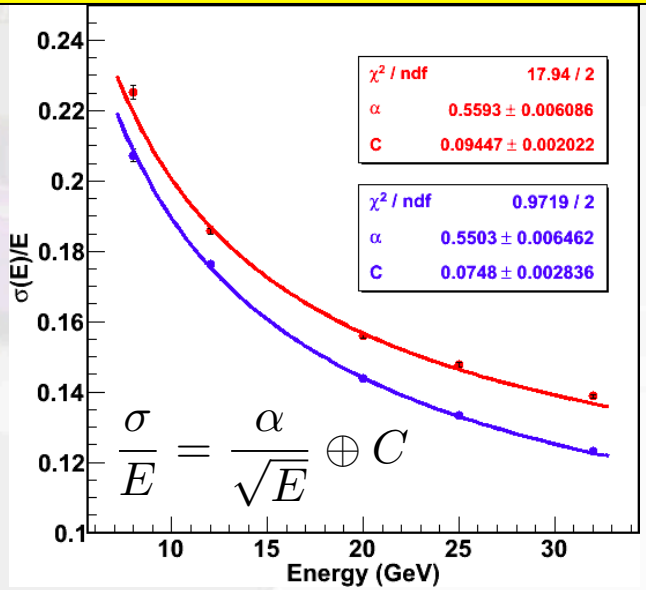
SDHCAL: technological prototype with embedded electronics and power-pulsing built. Data taking is ongoing, first look into data is encouraging.

DHCAL: test beams with physics prototype → proof of principle demonstrated.

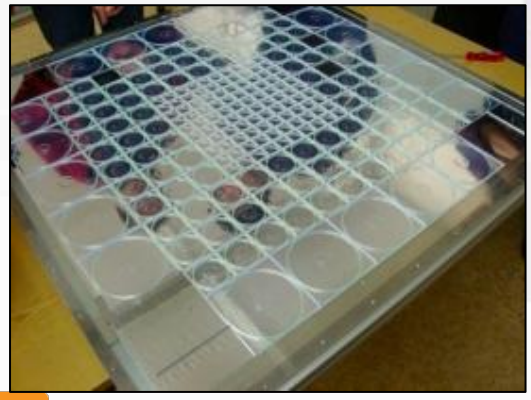
SDHCAL technological prototype
CERN SPS - 100 GeV pion



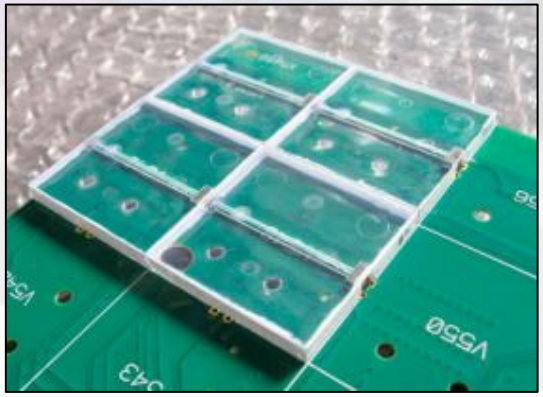
DHCAL test beam: pion energy resolution



AHCAL physics prototype



AHCAL tiles and SiPMs for technological prototype



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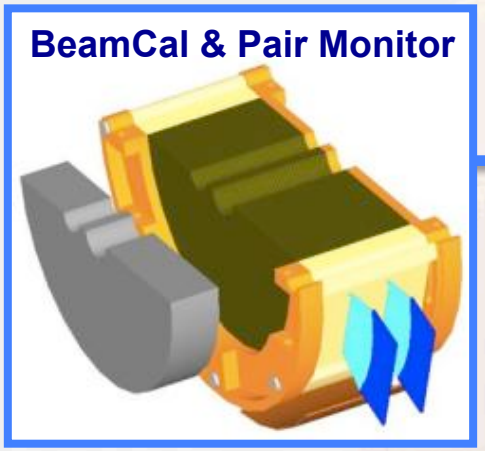
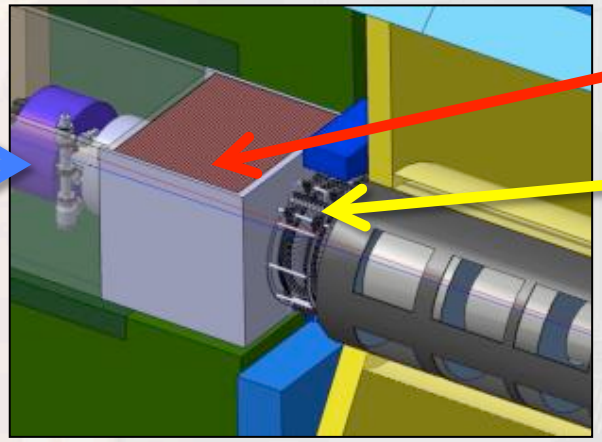
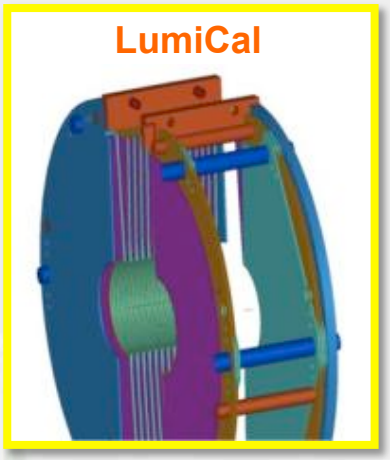
Forward Calorimeters

Poster by O. Novgorodova
"FCAL Test Beam Results"







Forward Calorimeters

- Luminosity measurement
- Hermeticity: electrons + pions down to ~5 mrad (**LumiCal + LHCAL**)
- Assisting beam tuning (fast feedback of BeamCal data to machine)

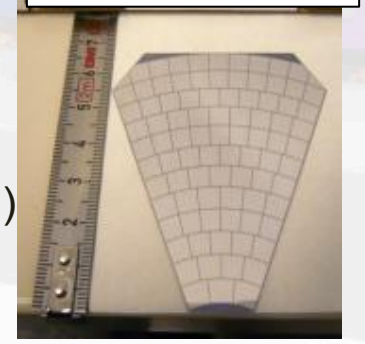
Challenges:

- Radiation hardness (BeamCal), high precision (LumiCal) and fast readout (both)

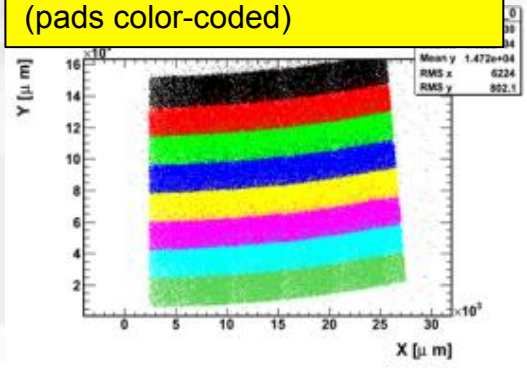
Baseline:

- Sampling calorimeter with tungsten absorber disc (3.5 mm thick)
- LumiCal: Si readout
- BeamCal: GaAs

GaAs pad sensor



Occupancy of beam particles on a fully assembled sensor plane (pads color-coded)



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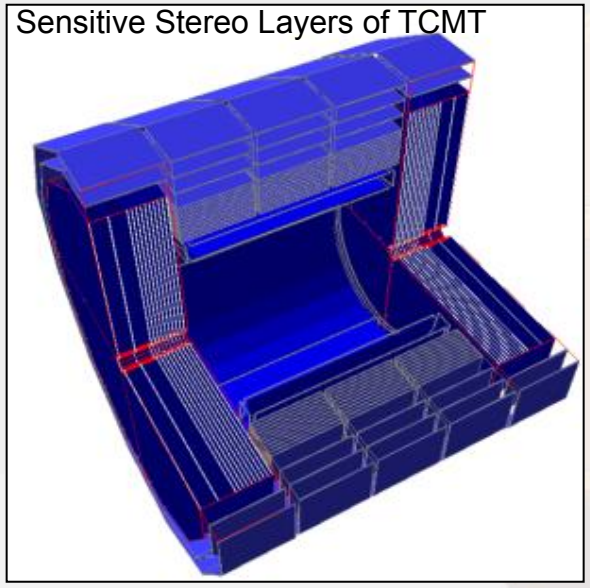
Tail Catcher / Muon Tracker (TCMT)



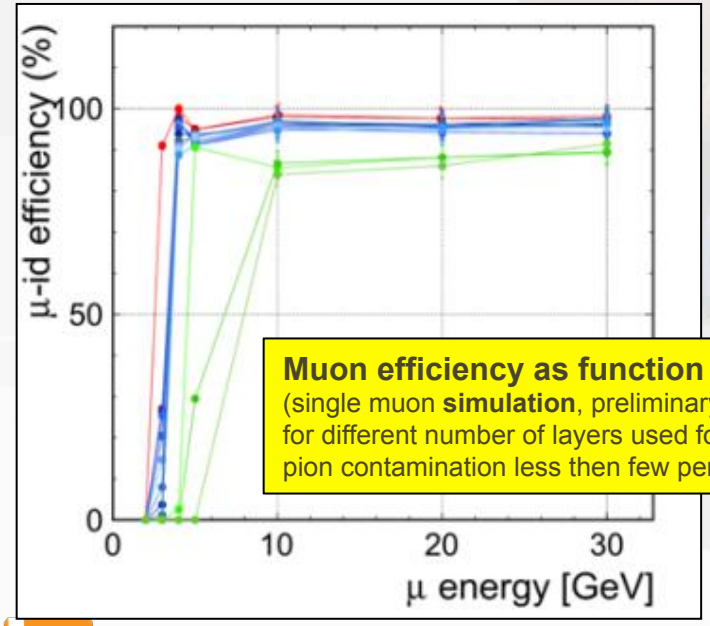
Main tasks:

- Identification and tracking of muons
- Measure the tail of showers escaping the HCAL

Sensitive Detectors:

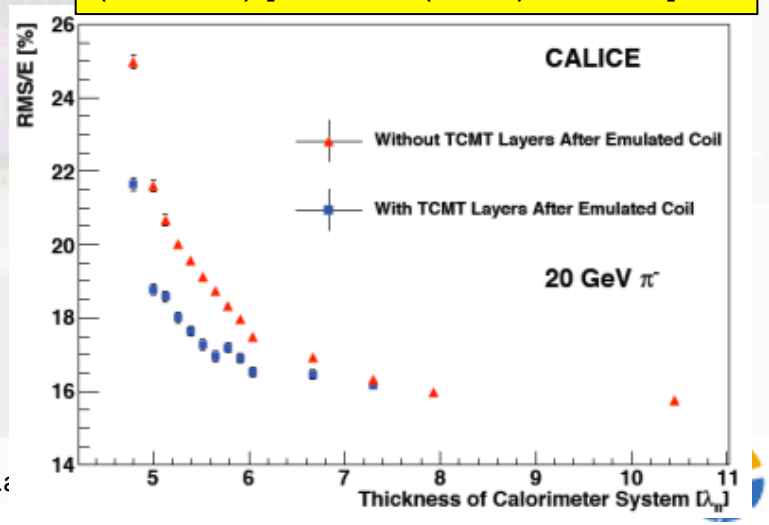
Main option: Scintillation Stereo Strips (10 mm thick, 30 mm wide, max 200 mm long) with WLS and SiPM readout:

- **Barrel:** 14 layers (1st in front of Yoke, 10 with Iron filter 100 mm thick, last 3 with Iron filter 560 mm thick)
- **Endcap:** 12 layers (first 10 with Iron filter 100 mm thick, last 2 with Iron filter 560 mm thick)
- **Cryostat:** 2 additional layers



Muon efficiency as function of energy
(single muon **simulation**, preliminary)
for different number of layers used for identifications
pion contamination less then few percent

Resolution improvement with TCMT
(CALICE) [JINST 7 (2012) P04015]



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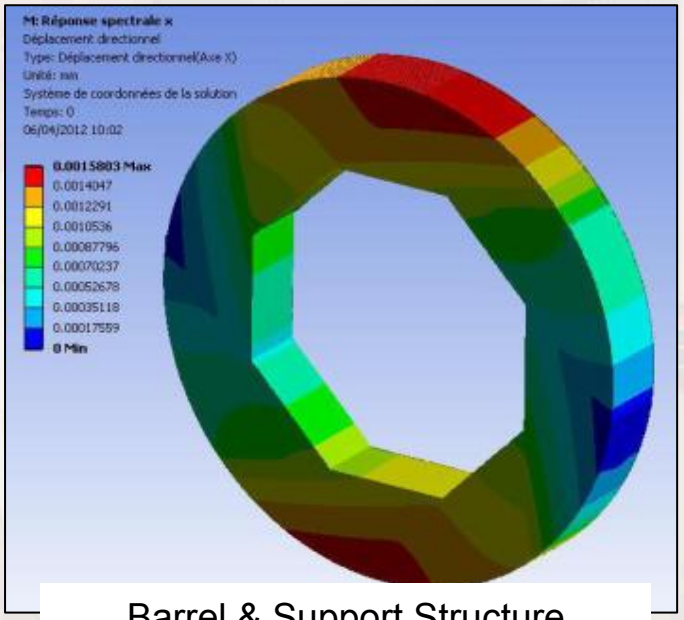
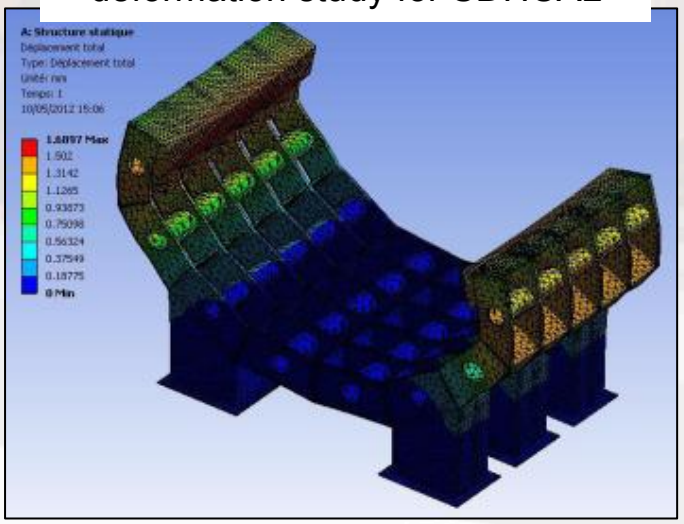
Overall Integration

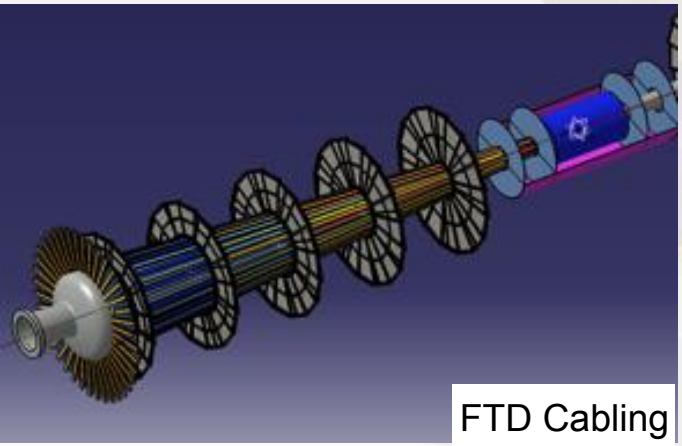
Ongoing detailed studies of over all integration, with realistic cabling and support structure.

- Rigidity of mechanical structure
- Cooling and services
- Monitors for alignment, etc

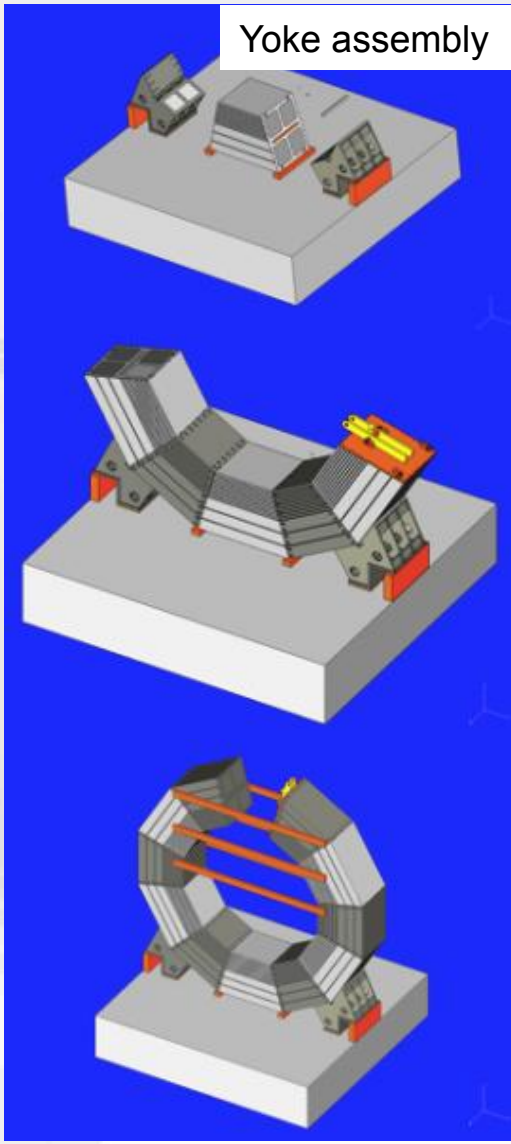


Barrel & Support Structure deformation study for SDHCAL





FTD Cabling



Yoke assembly

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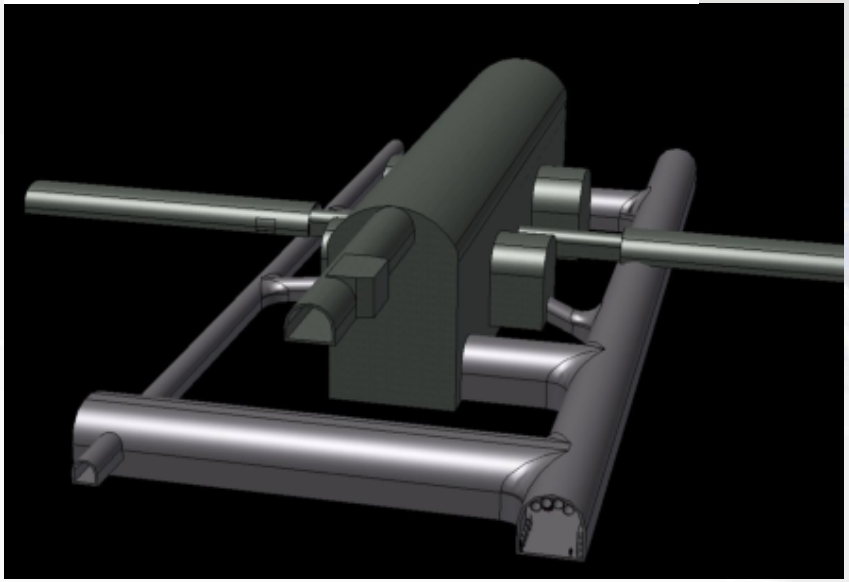
Machine Detector Interface

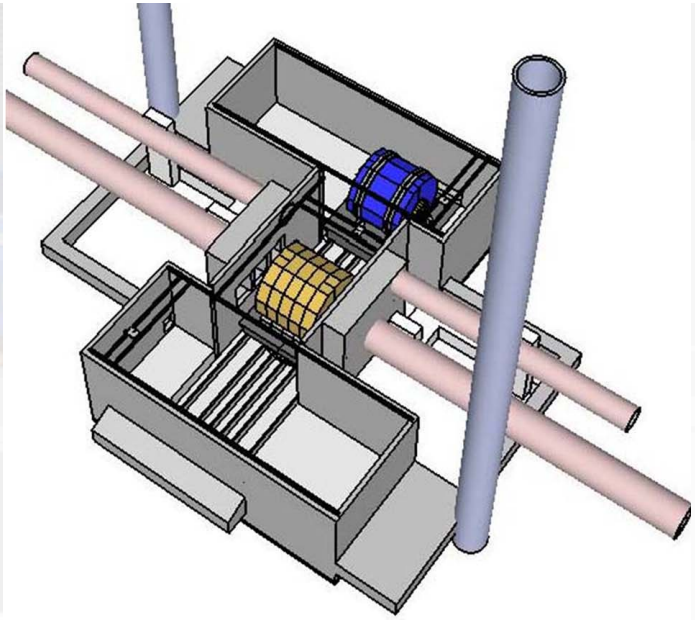
Detector assembly is site-specific

- Non-mountain site: build & test on surface as much as possible, then lower into detector hall (like CMS)
- Mountain site: **limited by horizontal access** tunnel, require underground assembly of many parts.
- ILD is larger than SiD → needs more space. The shape of the assembly area is being optimized to **keep cost containment** while securing **assembly space.**

Experimental hall (mountain site)

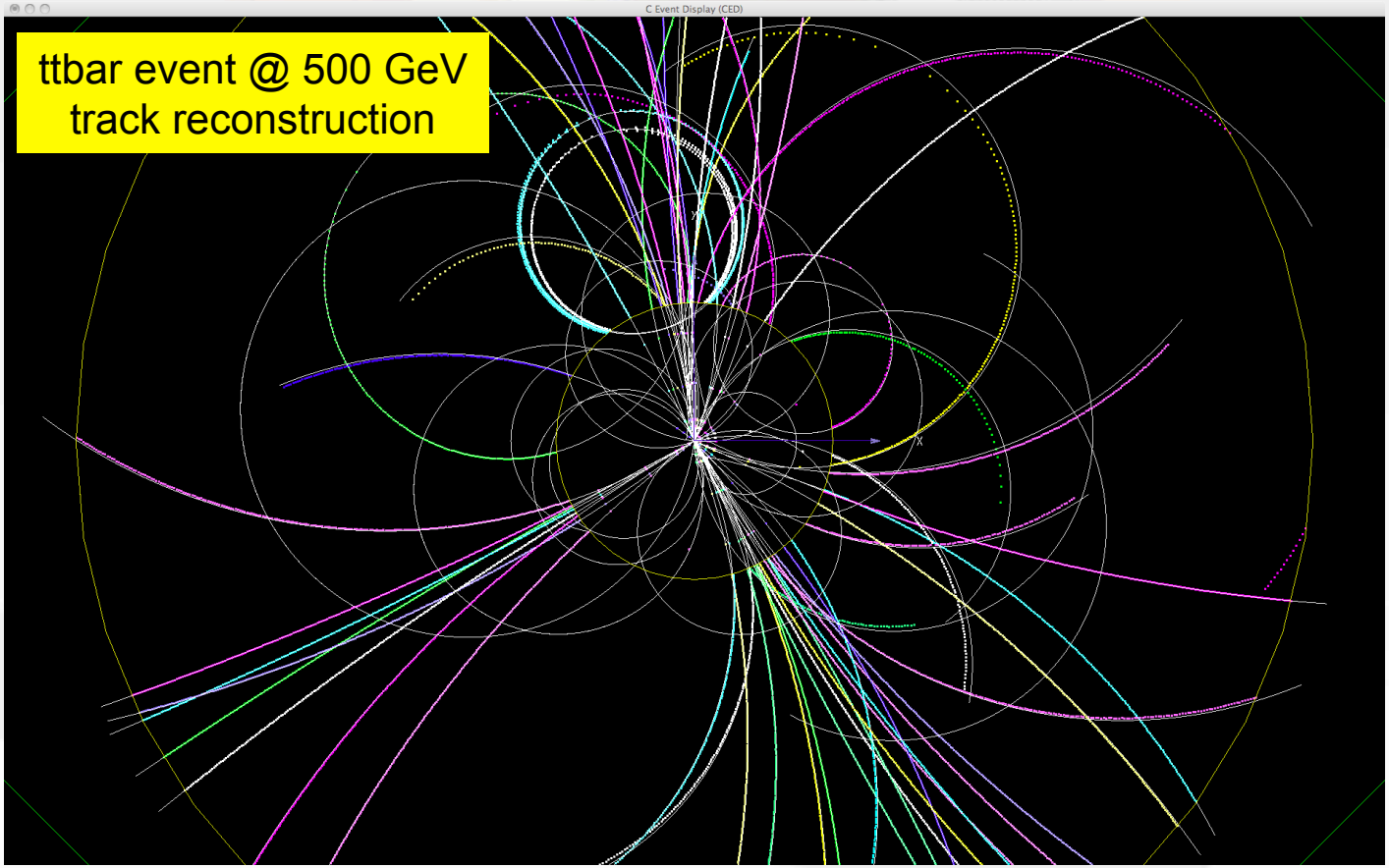


Experimental hall (non-mountain site)



Simulation and Reconstruction Software

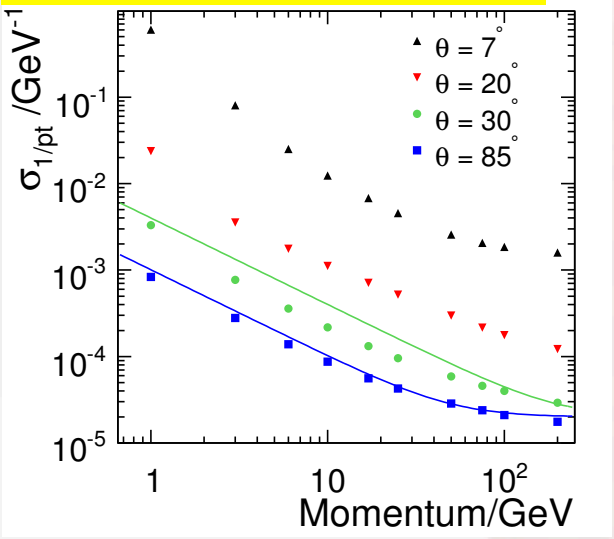
- Detector simulations models implemented with considerably improved realism → validation finished, started mass production for physics analysis
- Overhaul of tracking code to cope with realistic amounts of backgrounds
- Improvements in particle flow (PandoraPFA) and flavor tagging (LCFIPlus)



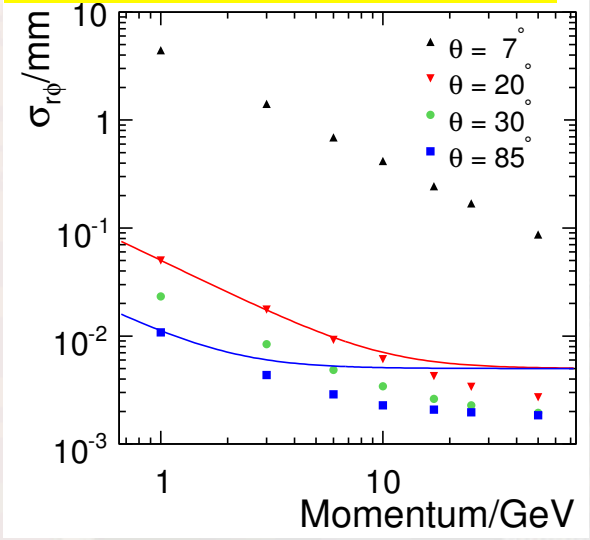
Overall Performance

* LOI performance.
To be updated for DBD.

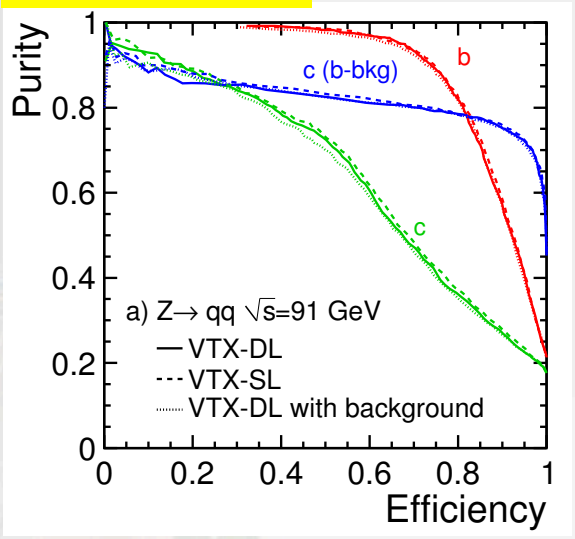
Track Momentum Resolution *



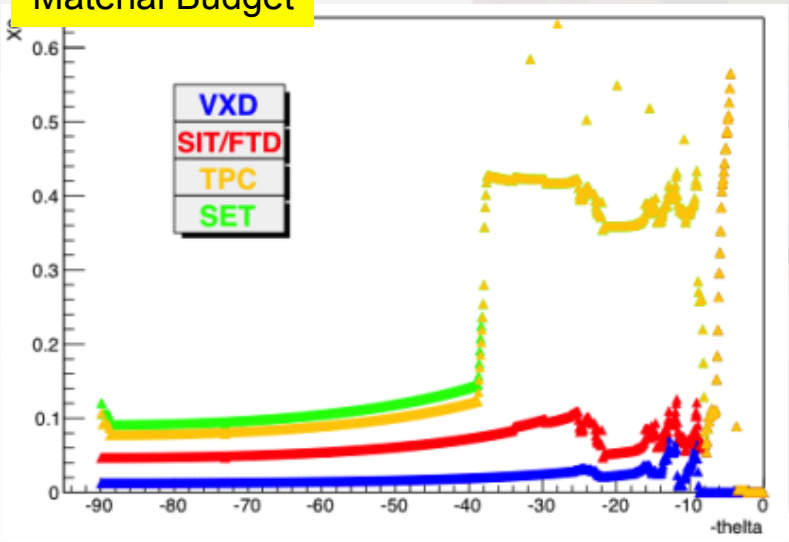
Impact Parameter Resolution *



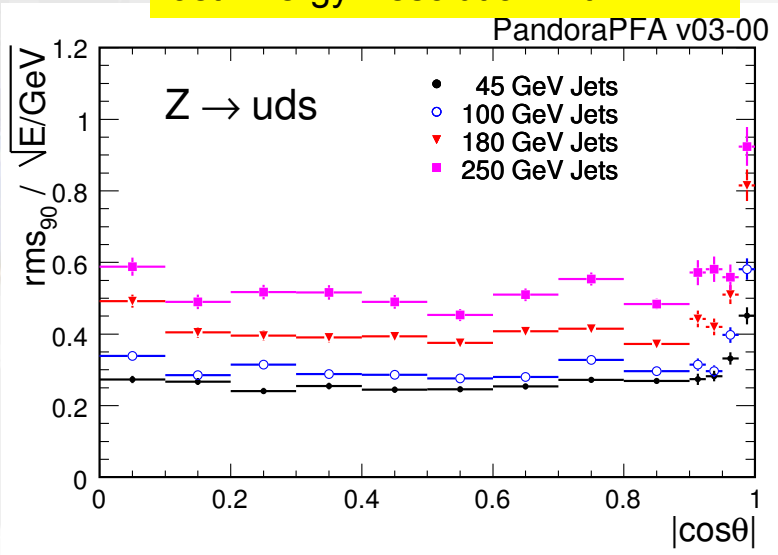
Flavor Tagging *



Material Budget



Jet Energy Resolution with PFA *



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Benchmark Processes

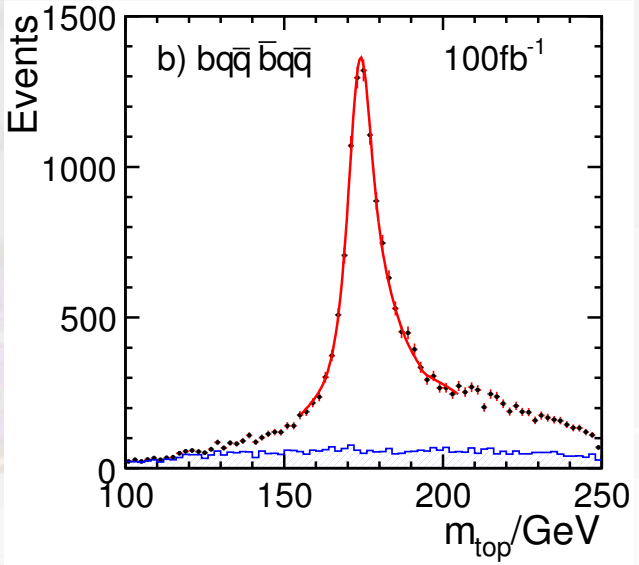
- The following processes will be studied as detector benchmarks for the DBD:
  - $e^+e^- \rightarrow \nu\nu h^0$ at E_{CM}=1 TeV with $h^0 \rightarrow \mu^+\mu^-$, bb, cc, gg, WW^*
    - measure the cross section times branching ratio.
  - $e^+e^- \rightarrow W^+W^-$ at E_{CM}=1 TeV
    - measure in situ the effective left-handed polarization.
  - $e^+e^- \rightarrow tth^0$ at E_{CM}=1 TeV
    - measure the Higgs boson Yukawa coupling to tt.

- Plus one analysis from the LOI (2009) using the latest simulation and reconstruction tools.
  - ILD and SiD have chosen tt at 500 GeV.

- ILD will also update the Higgs self-coupling measurement Zhh at 500 GeV

- **Many more** physics studies completed/ongoing with full detector simulation.

top pair @ 500 GeV LOI
(to be updated)



Analysis ongoing for DBD – mass production has just started.

Summary

ILD is intensifying its efforts towards a detailed baseline design of the detector.

Areas in which significant progress are being made are:

Component R&D

- Construction of prototypes, testing and validation of technologies, test beam results, power-pulsing operation

Integration efforts

- Towards a more realistic, coherent detector

Simulation tools

- Implementation of simulation detector models with increasing realism
- Improvement in event reconstruction software

Physics studies

- Benchmark processes, other processes to enrich the physics case of the ILC

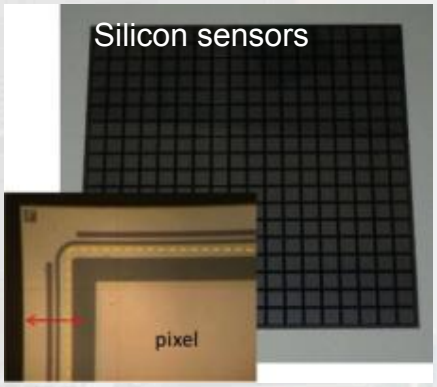
Ambitious program, lots of hard work ahead, but many milestones have been achieved.

We should be in good shape for the DBD (2012) and beyond.

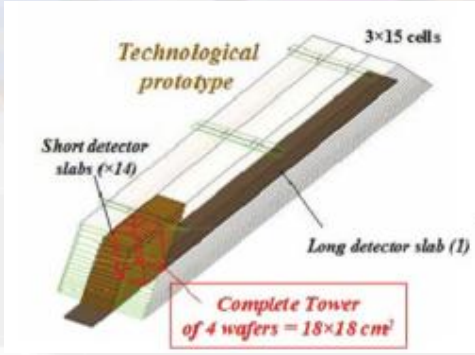
Extra Slides

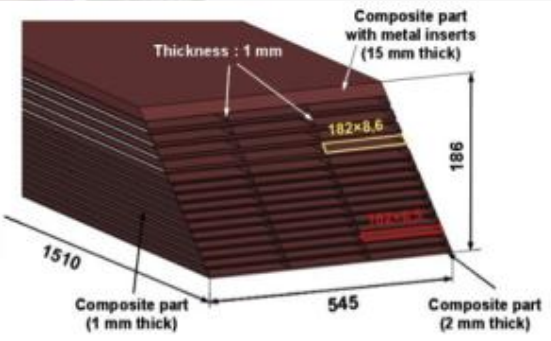
SiECAL

- Sensor R&D: reduced/modified guard ring structure, aspects of large scale production
- Readout ASIC: 35um SiGe, 7.18.5mm2, 64ch/ASIC, low power (~1.5 mW/ch), produced and tested. Power pulsing test July TB
- **Technological prototype completed (Jan 2012)**: alveolar composite/tungsten structure, 15 slabs with integrated FE chips, available for TB



Technological prototype:
Completed Jan. 2012





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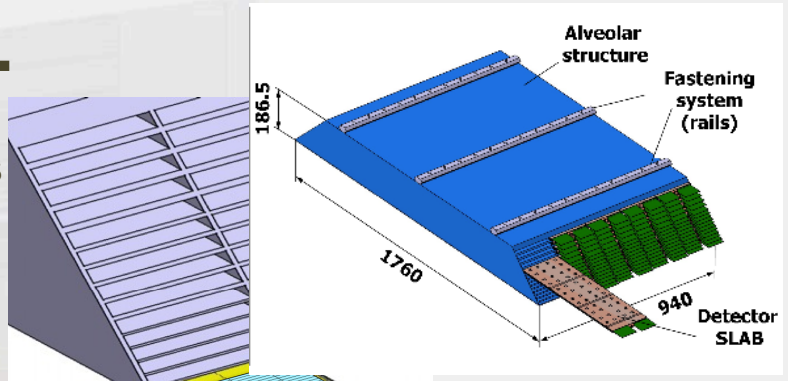
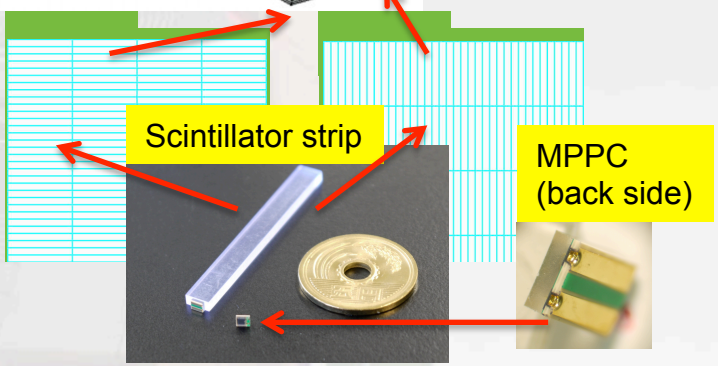
ScECAL

- Scintillator strips as (partial) alternative to silicon pads → help reduce cost of detector
- Analysis of physics prototype 2009 TB
  - after temperature correction, good linearity (<1.5%) and good energy resolution
- One-layer ScECAL **technical prototype under construction**, to be tested at DESY TB September
- Jet energy reconstruction with ***strip splitting algorithm*****:** performance quite good.
- Saturation in MPPC: addressed by increasing number of pixels





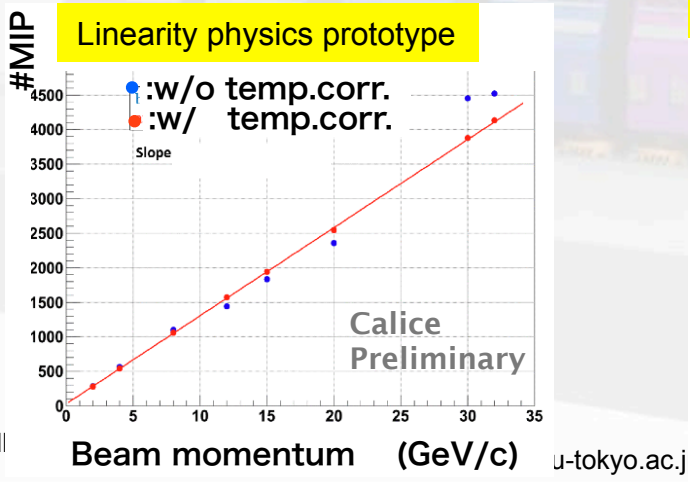
MPPC by HPK

25 um pitch
1600 pix/mm^2

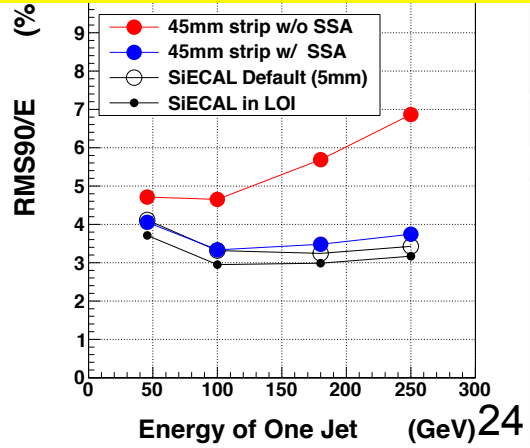
20 um pitch
2500 pix/mm^2

15 um pitch
4400 pix/mm^2

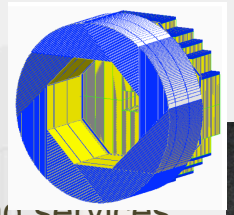
Linearity physics prototype



Strip splitting performance with “Si” strips

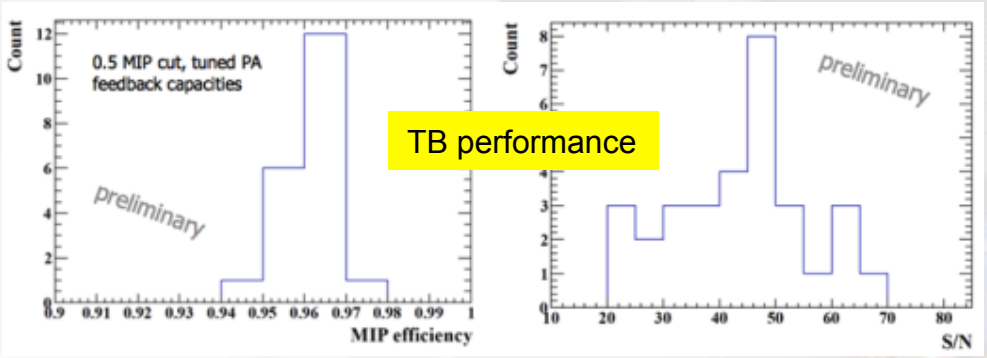


AHCAL

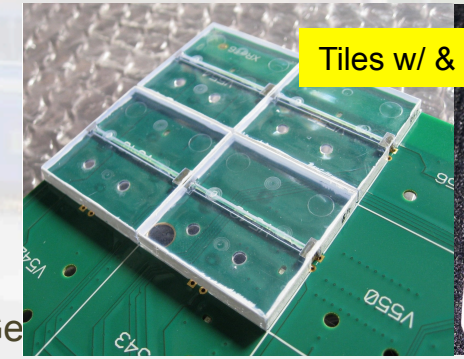


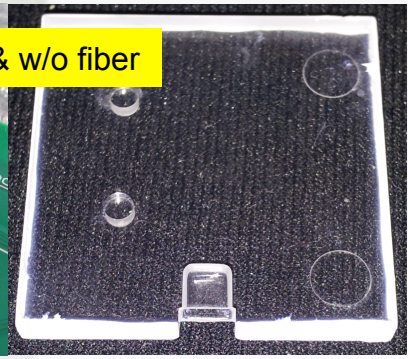
- Engineering and simulation model
  - Simulation model updated, realistic implementation for interfaces and services
  - Second version of barrel geometry implemented

- **Technological demonstrator** for ILD
  - Embedded electronics, power pulsing, zero suppression
  - Auto-trigger and gain equalization established at module level in test beam
  - Full length slab test in preparation: thermal issues, scalability
  - One or two layer beam test in tungsten stack planned, fall 2012
  - Tiles and SiPMs for direct (fiber-less) coupling with mass production technology



- Test beam results
  - Two particle separation with Pandora (+ECAL)
  - More in editorial boards: Geant4 validation low (2-20GeV) and high (8-80GeV) energy data, resolution with software compensation, tracks in showers



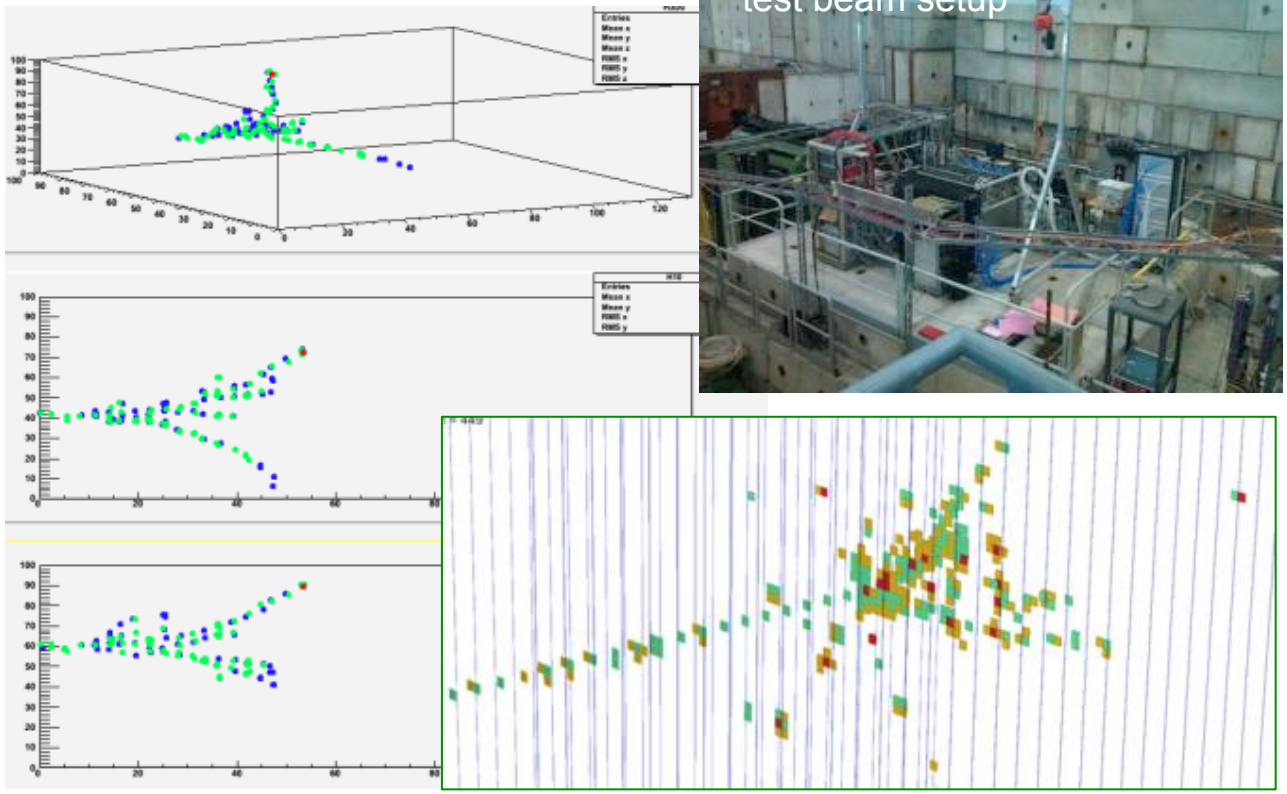


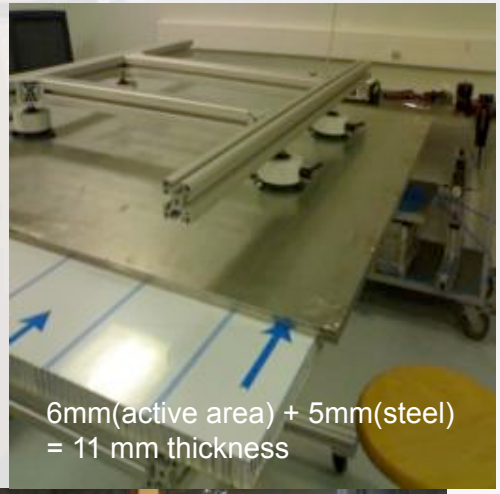
SDHCAL

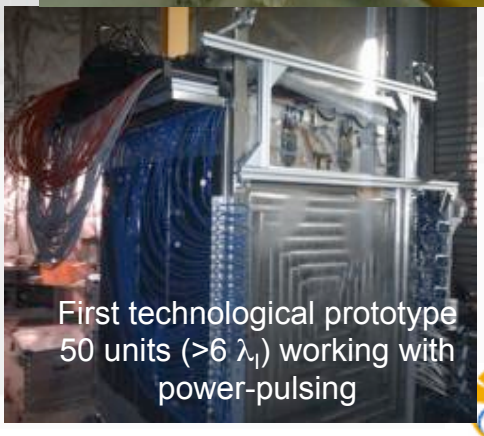
- First technological prototype built:
  - ILD kind, efficiency, compactness, reduced dead zone, self-supporting structure, **power pulsing**

144 ASICs= 9216 channels/1m^2

10 GeV pion events from CERN-PS







Green: ~100 fC. Blue: ~5 pC. Red: ~18 pC

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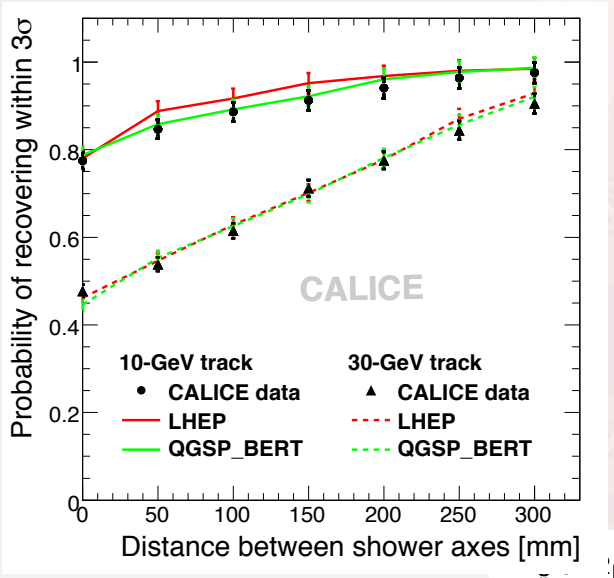
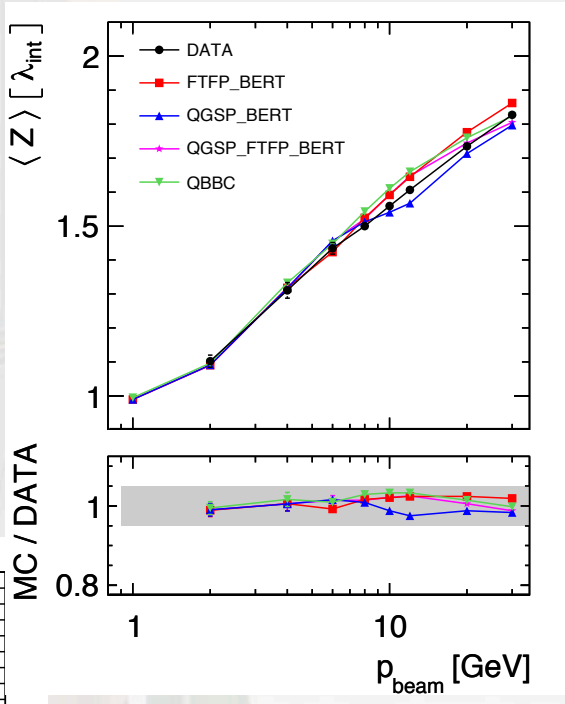
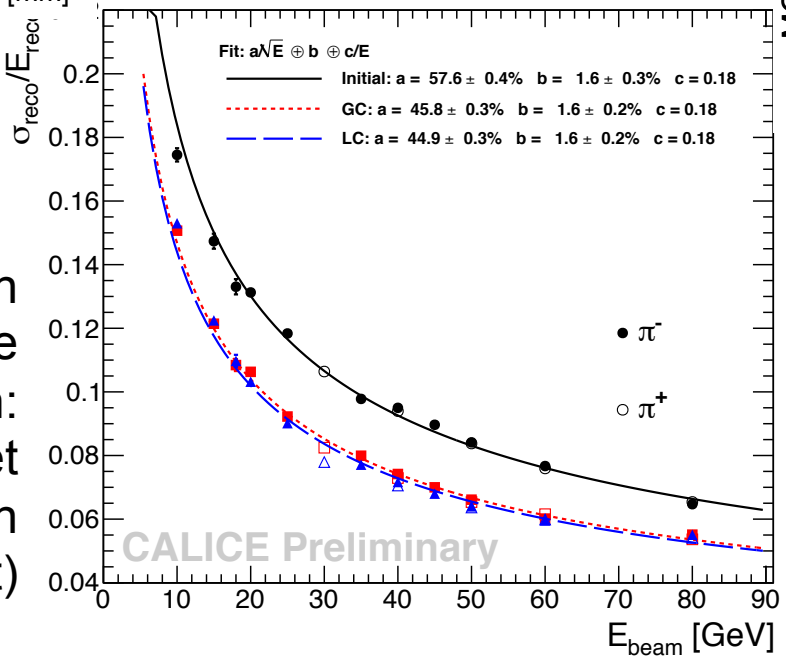
AHCAL test beam results



Two particle separation with Pandora
Published: JINST 6, P07005 (2011)



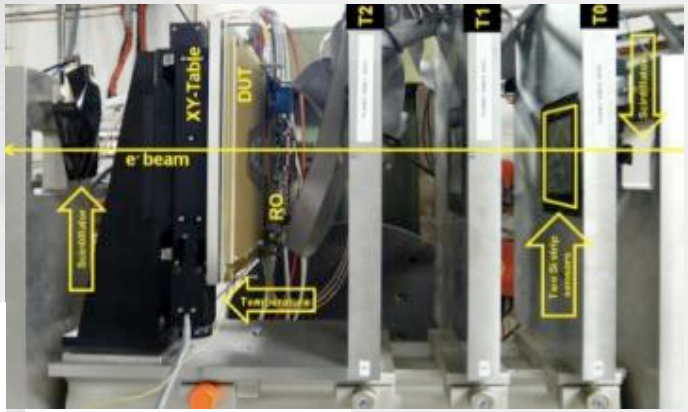


Resolution with software compensation: Improves also jet energy resolution (publication draft)

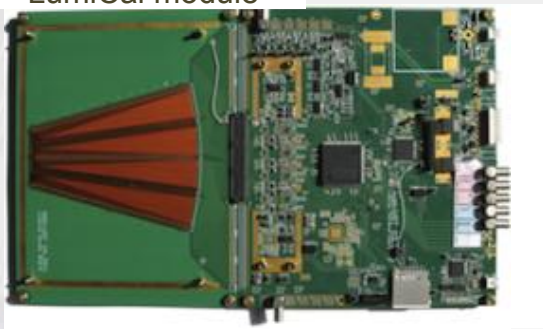
Geant4 comparison of shower profiles from 2 to 80 GeV (publication draft)

Forward Calorimeters

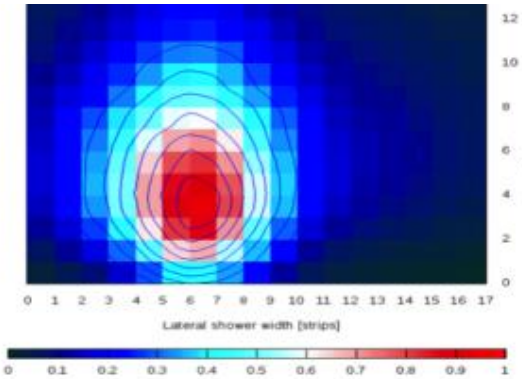
- TB of fully assembled sensor planes in Nov 2011 (32 channels); 50 million trigger for several areas of LumiCal and BeamCal sensors
- Data analysis ongoing; first results very promising.

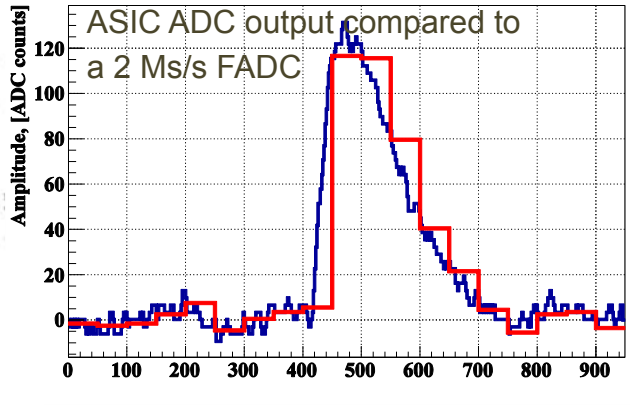


LumiCal module



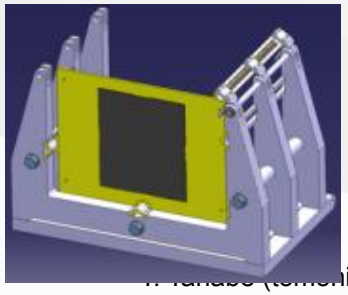
Electromagnetic shower profile measured behind 1X0 absorber

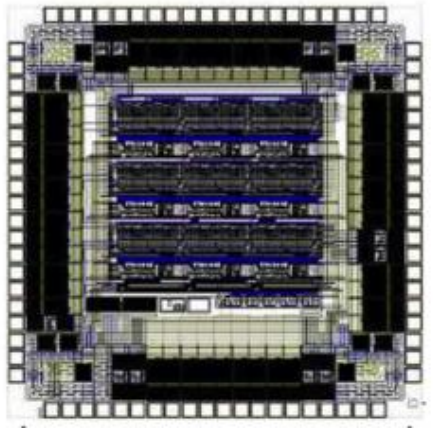




Future plan: prototype calorimeter (AIDA)

- Flexible frame with tungsten absorber planes
- FE and ADC ASICs in 130 nm technology
- Power pulsing
- DAQ (ILD standard)





Pair Monitor prototype sensor with integrated ASIC (SoI, 200 nm technology)