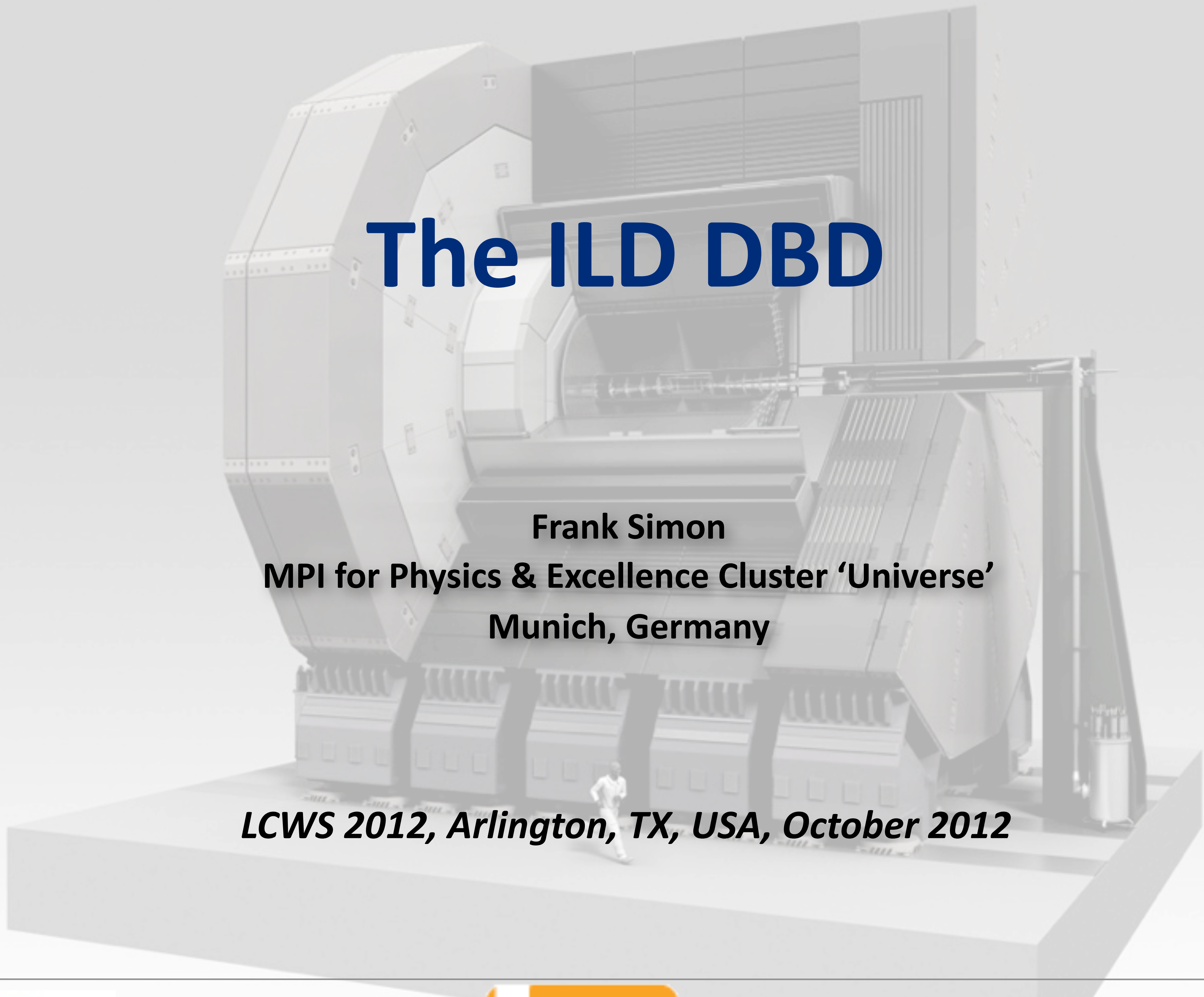

The ILD DBD

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LCWS 2012, Arlington, TX, USA, October 2012

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Excellence Cluster
Universe

Outline

- The ILD Concept
  - Overview
  - Subsystems
- The ILD Detector System
- Software & Performance
- Summary

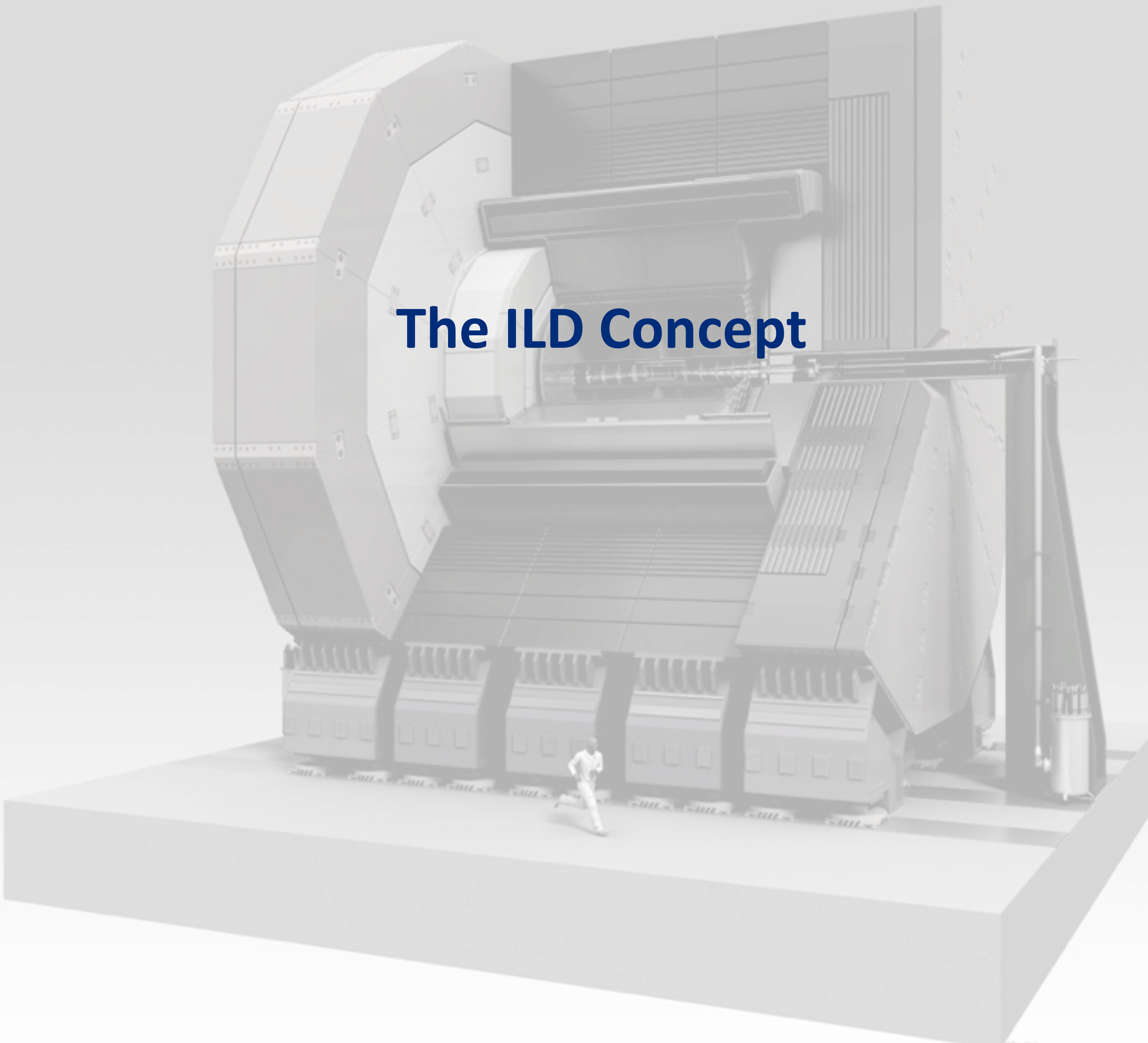
From the LOI to the DBD

- LOI published early 2009
  - ILD evolved out of two similar detector concepts: GLD and LDC

- Since 2009: Progress in all areas
  - Updated detector design, including realistic engineering
  - Substantial progress in demonstration of technologies with prototypes and test beams
  - Improved and partially redeveloped reconstruction software and simulation model

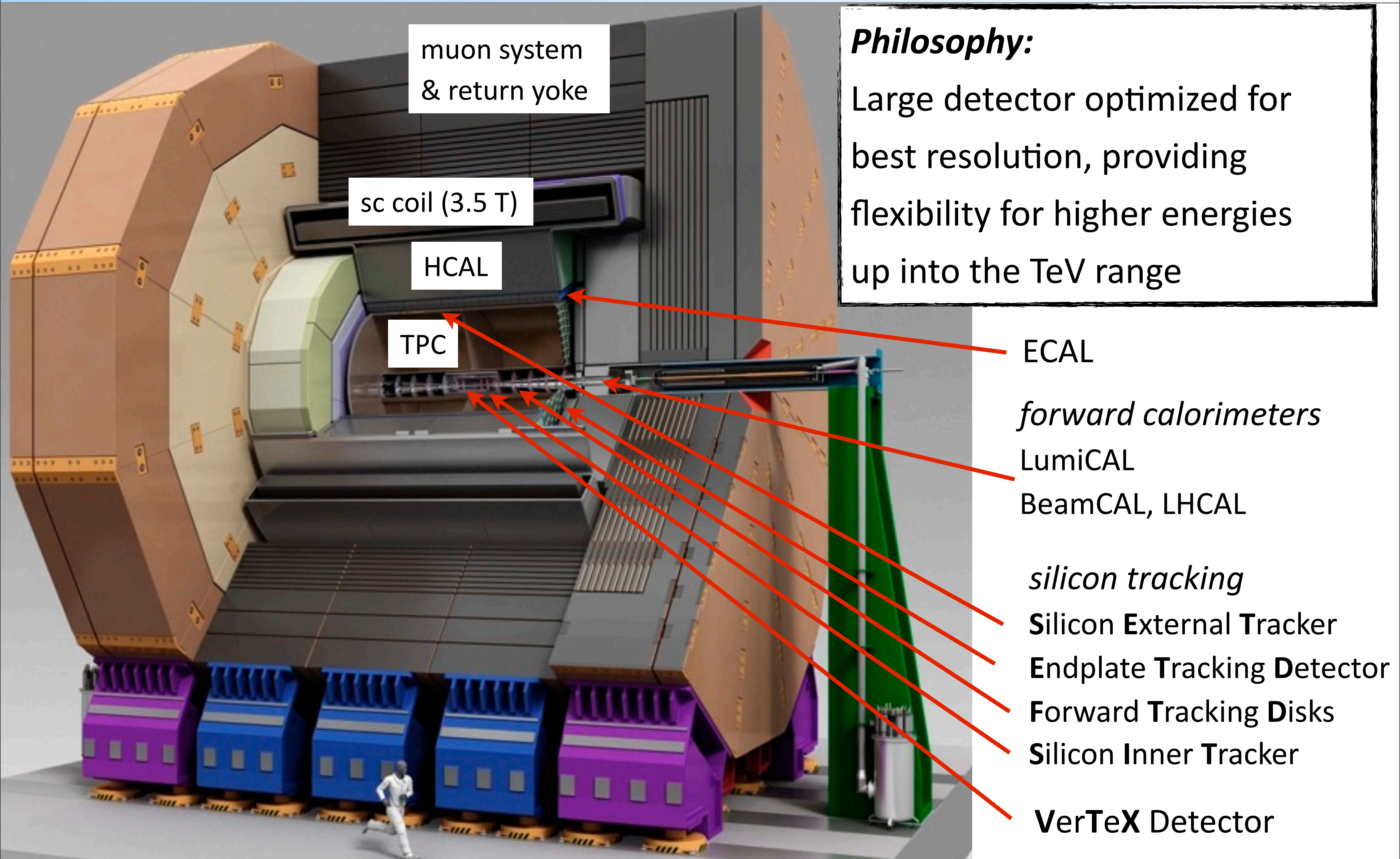
▸ Overall: Substantial steps forward in all aspects of ILD

The ILD Concept



ILD - Overall Design

Philosophy:
Large detector optimized for best resolution, providing flexibility for higher energies up into the TeV range

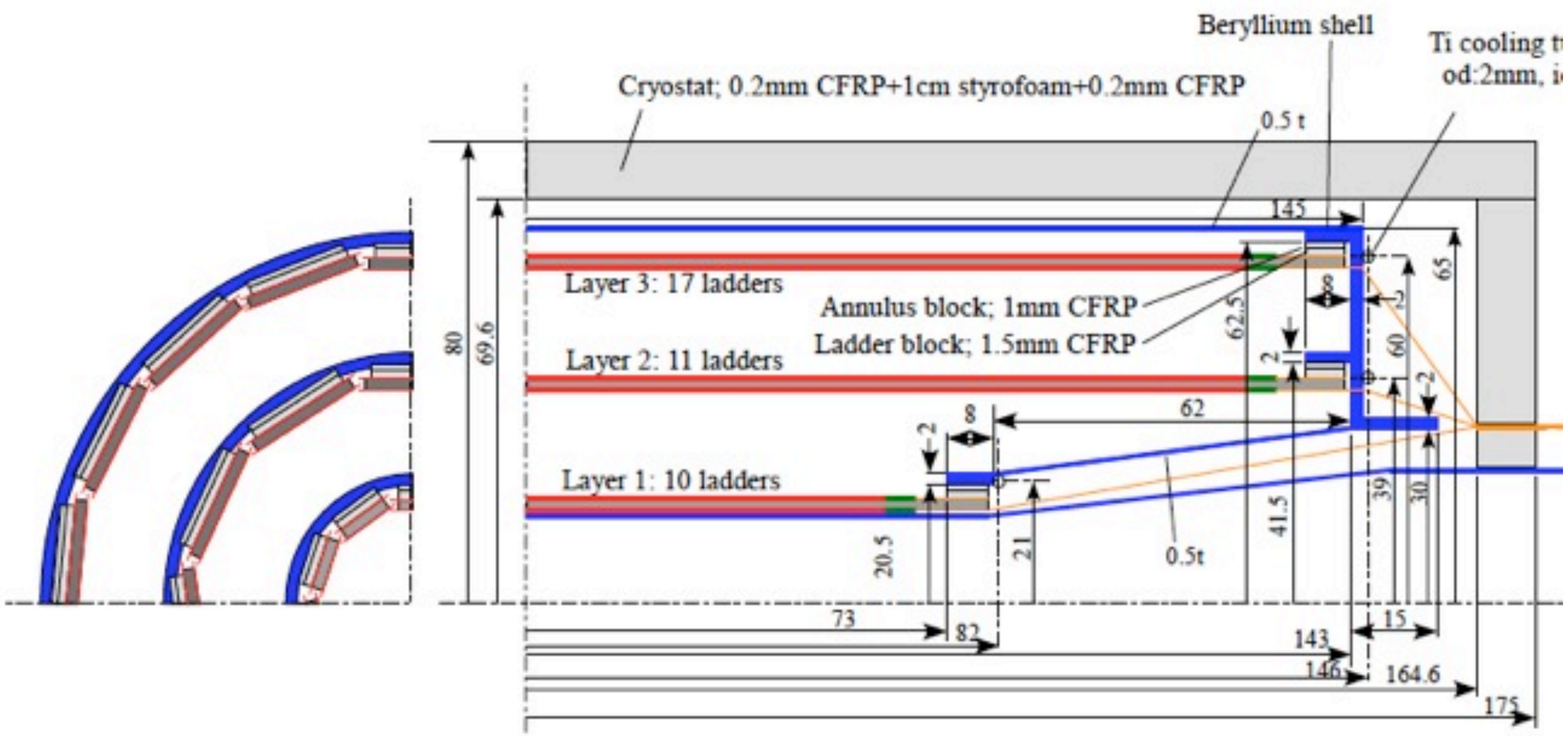


ILD Design - General Considerations & Challenges

- Performance goals set by physics
  - Jet energy resolution < 3% - 4% over full relevant energy range
  - Track momentum resolution $\delta(1/p_T) \simeq 2 \times 10^{-5}/\mathrm{GeV}/c$
  - Excellent vertexing for b & c identification

- Resulting main requirements and challenges
  - Highly granular PFA calorimeters
  - Low material budget in front of calorimeter
  - Power-pulsing, low power consumption
  - Triggerless readout
  - Highly integrated electronics

The Vertex Detector



- Performance goal:

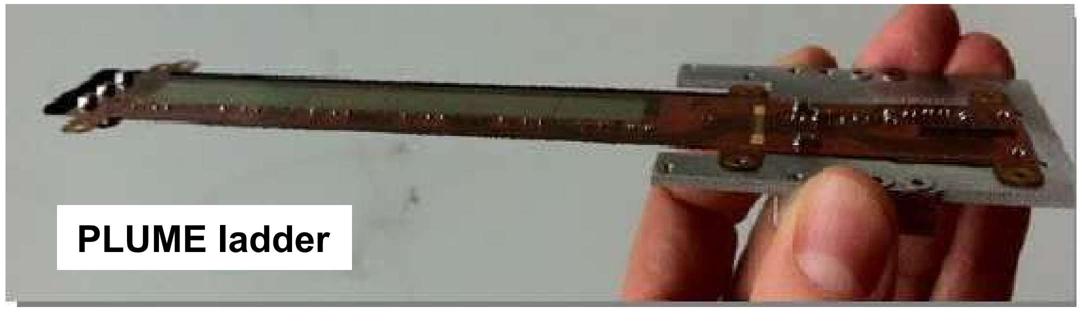
$$\sigma_b < 5 \oplus 10/p\beta \sin^{3/2}\theta \ \mu m$$

- Requirements:
  - Spatial resolution < 3 µm close to IP
  - Material budget < 0.15% X_0 per layer
    - low power consumption!
  - Pixel occupancy not exceeding a few %

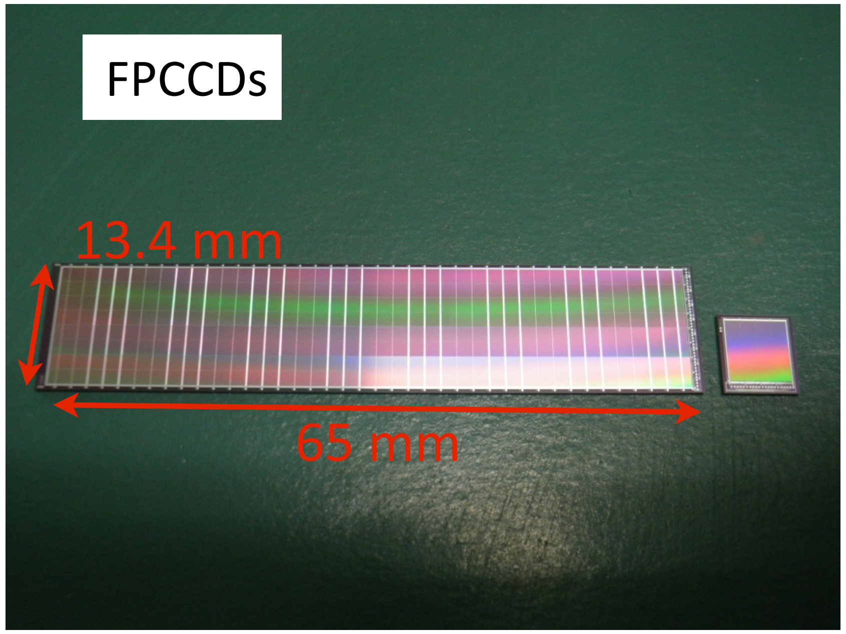
- VTX design:
  - 3 (almost) cylindrical layers pairs from 16 mm to 60 mm
    - Alternative: 5 single layers, from 15 mm to 60 mm
  - Several technologies under study: CMOS Pixel Sensors, Fine Pixel CCDs, DEPFET, use of multiple technologies an option
  - Time stamping depends on technology

Vertex Detector Technologies

- Active development of several technologies, synergies with LHC & others
  - All provide low material budget by thin sensitive layers
  - Trade-off between readout speed and pixel size (no time stamping)
- CMOS pixel sensors
  - ~ 17µm pixel precision layers, 17 x 85 μm^2 pixel fast layers to reduce effective occupancy
  - Low material double layer “PLUME” demonstrated



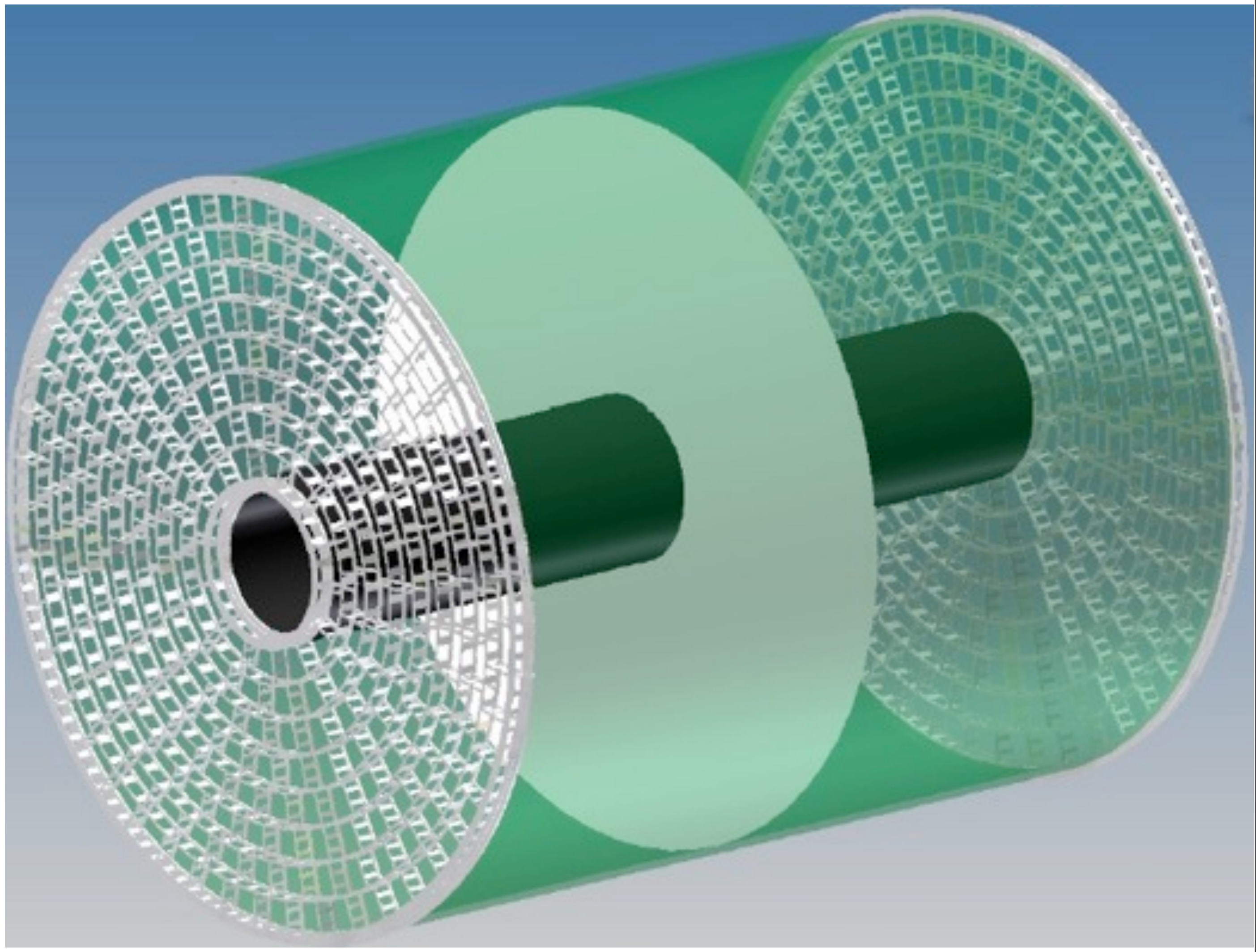
- FinePitch CCDs
  - ~ 5 µm pixels in inner layers, ~10 µm pixels further out
  - Small prototype successfully tested, (almost) full size prototype availabe



- DEPFETs
  - ~ 20 µm pixels, all-silicon modules with integrated support structure

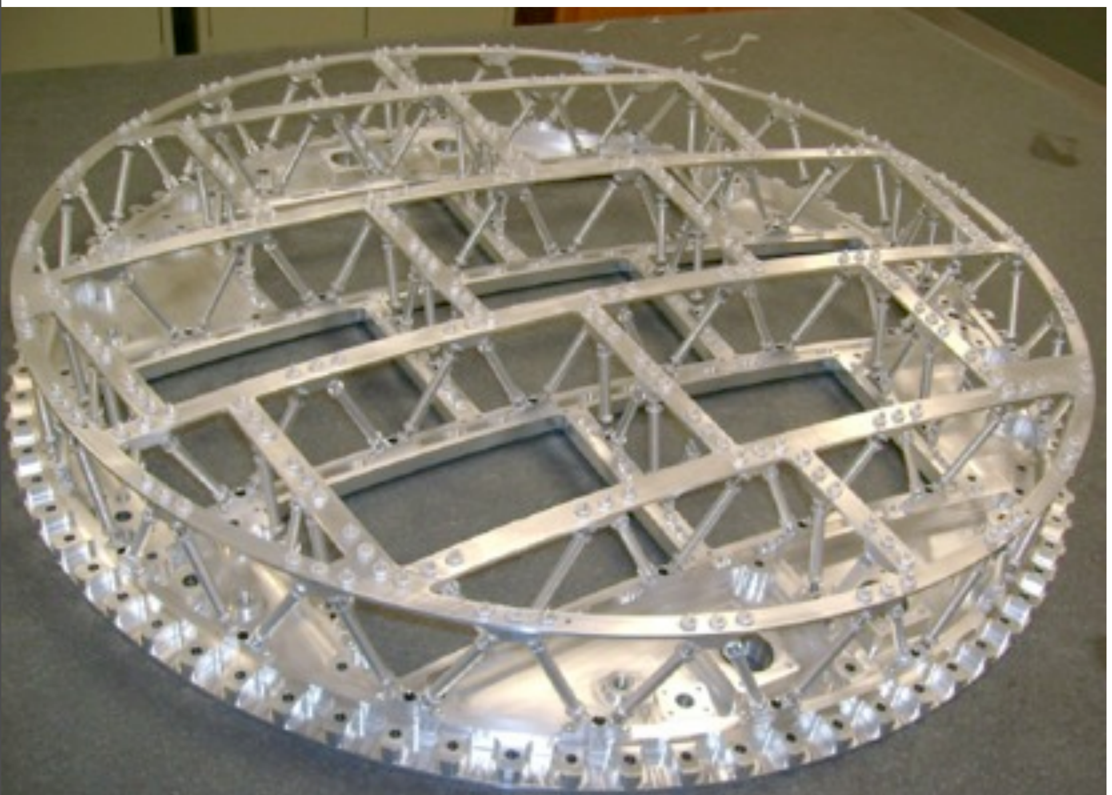
The Main Tracker: TPC

- Main tracker philosophy:
  Continuous tracking for excellent pattern recognition and dE/dx capability instead of best possible single point resolution
- The ILD TPC
  - Up to 224 space-points per track
  - Single point resolution < 100 µm in rϕ
  - Two-hit separation ~ 2 mm in rϕ
  - Low material budget: 5% X_0 in barrel region, <~ 25% X_0 in the endcaps
  - Standalone momentum resolution
    $$\delta(1/p_T) \simeq 10^{-4}/\mathrm{GeV}/c$$



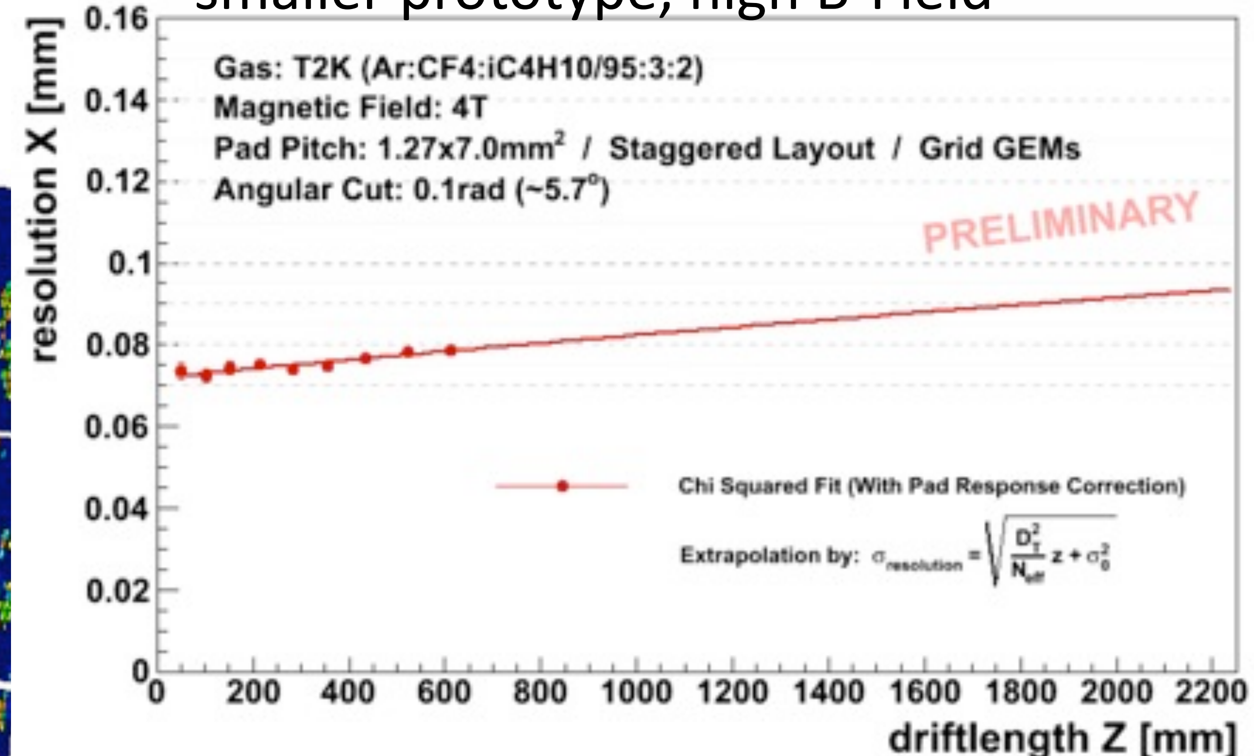
Two main readout options:
GEMs, Micromegas
Alternative: pixel detectors

TPC Development

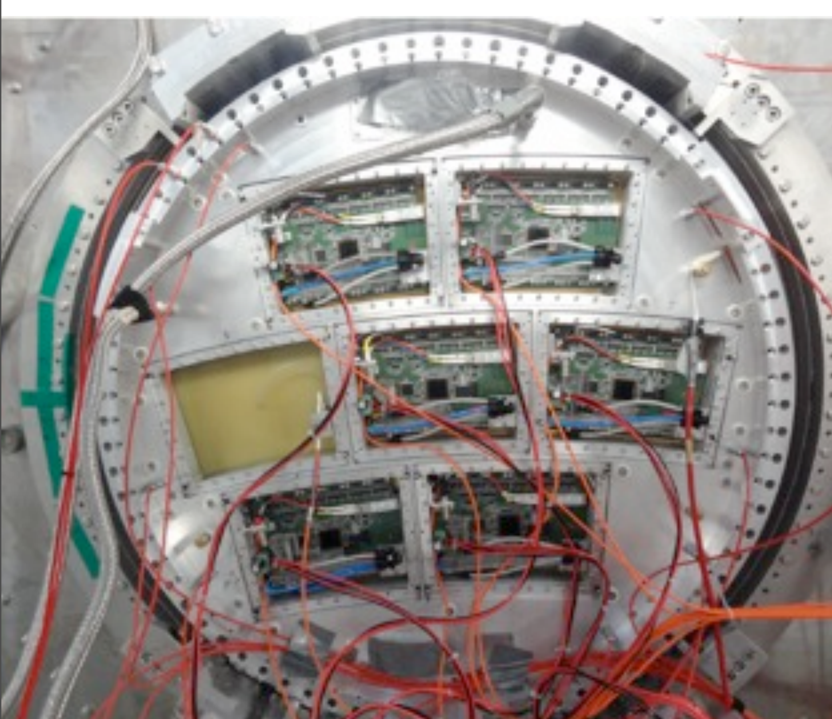


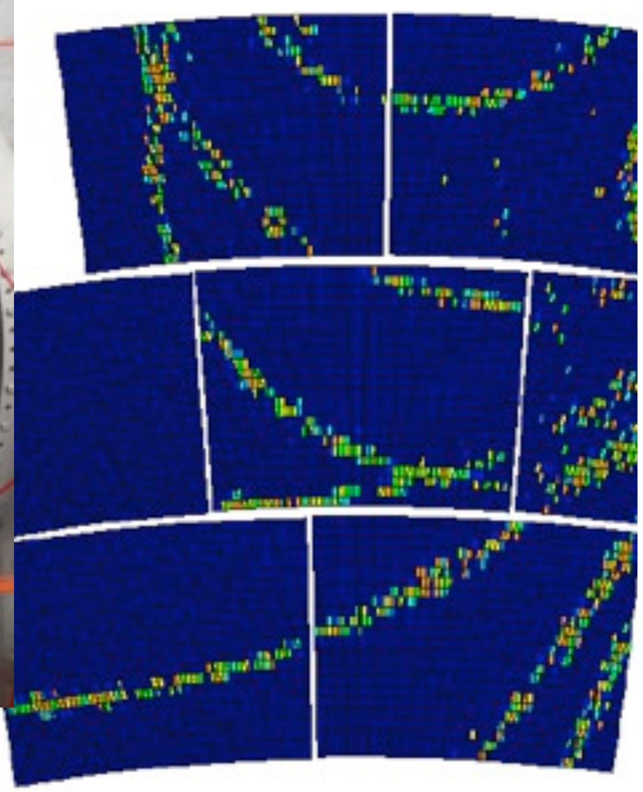
- Large prototype with “space frame” endplate
- Test in magnetic field up to 4 T
- Two readout technologies already tested: Triple-GEM, Micromegas

smaller prototype, high B-Field

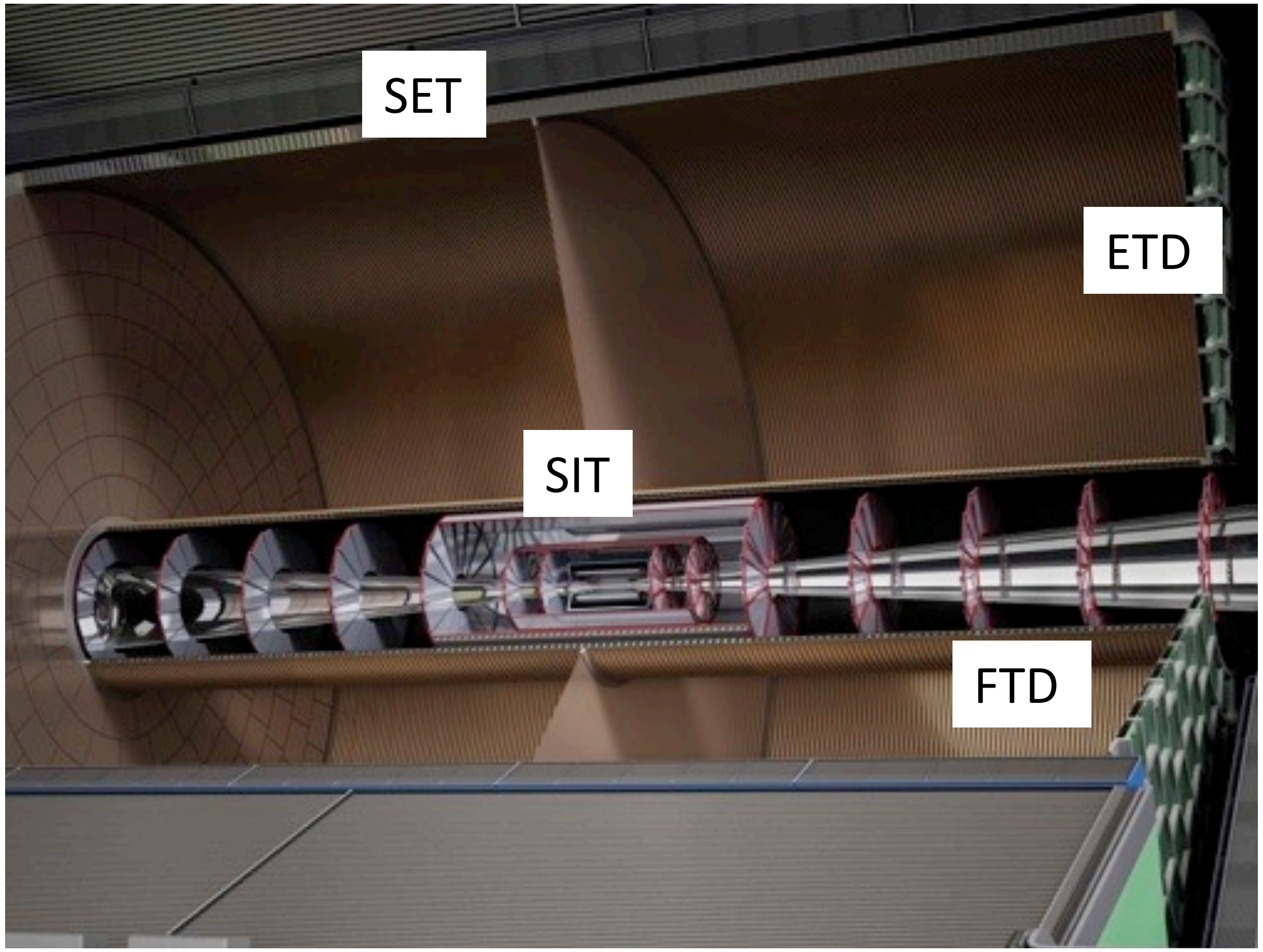


extrapolated resolution < 100 µm also beyond 2000 mm!





The Silicon Trackers



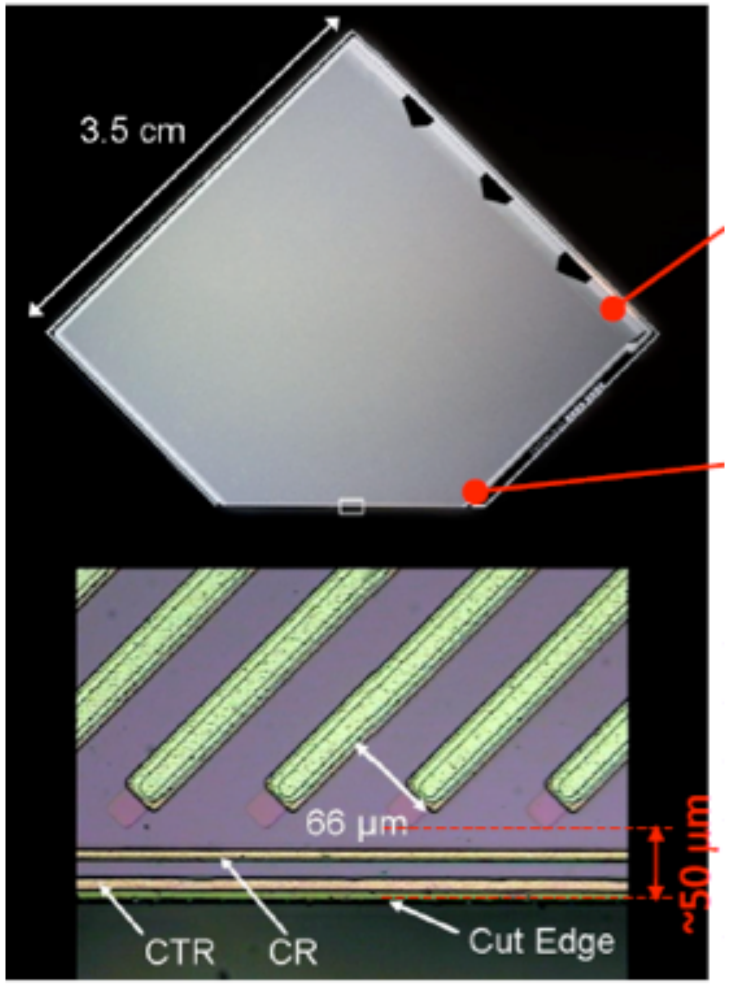
- Silicon tracking to complement the TPC main tracker:
  - Improved resolution
  - Time-stamping
  - Calibration of distortions & alignment
  - Extended coverage in the forward region
- Combined tracker resolution:
  $\delta(1/p_T) \simeq 2 \times 10^{-5}/\text{GeV}/c$

- Inner tracking barrel SIT - 2 fake double-sided strip layers, 2 space points
- Outer tracking barrel SET - 1 fake double sided strip layer, 1 space point
- Outer forward tracking layer ETD - 1 fake double sided strip layer, 1 space point
- Inner forward tracker FTD - 7 disks (2 pixel, 5 strip)

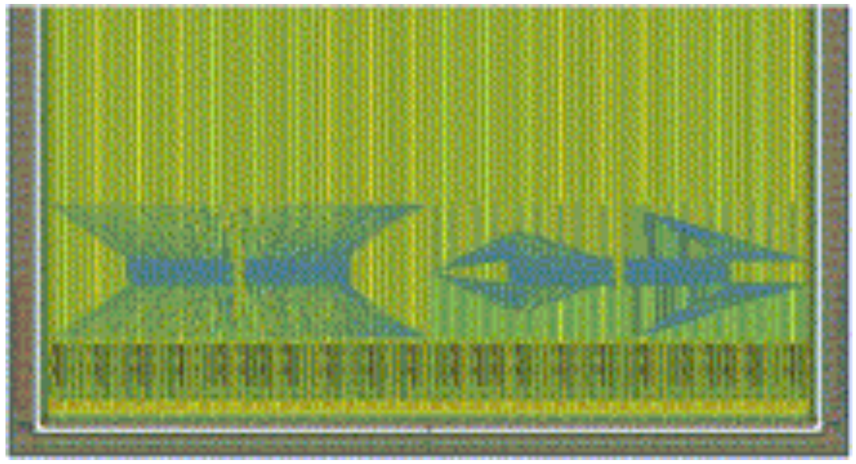
▸ Common technology & design for all strip sensors in the silicon trackers

Silicon Tracker Technology

- Philosophy: Compact, simple and cost-effective modules
  - Edgeless sensors and integrated pitch adapters developed in synergy with LHC upgrades

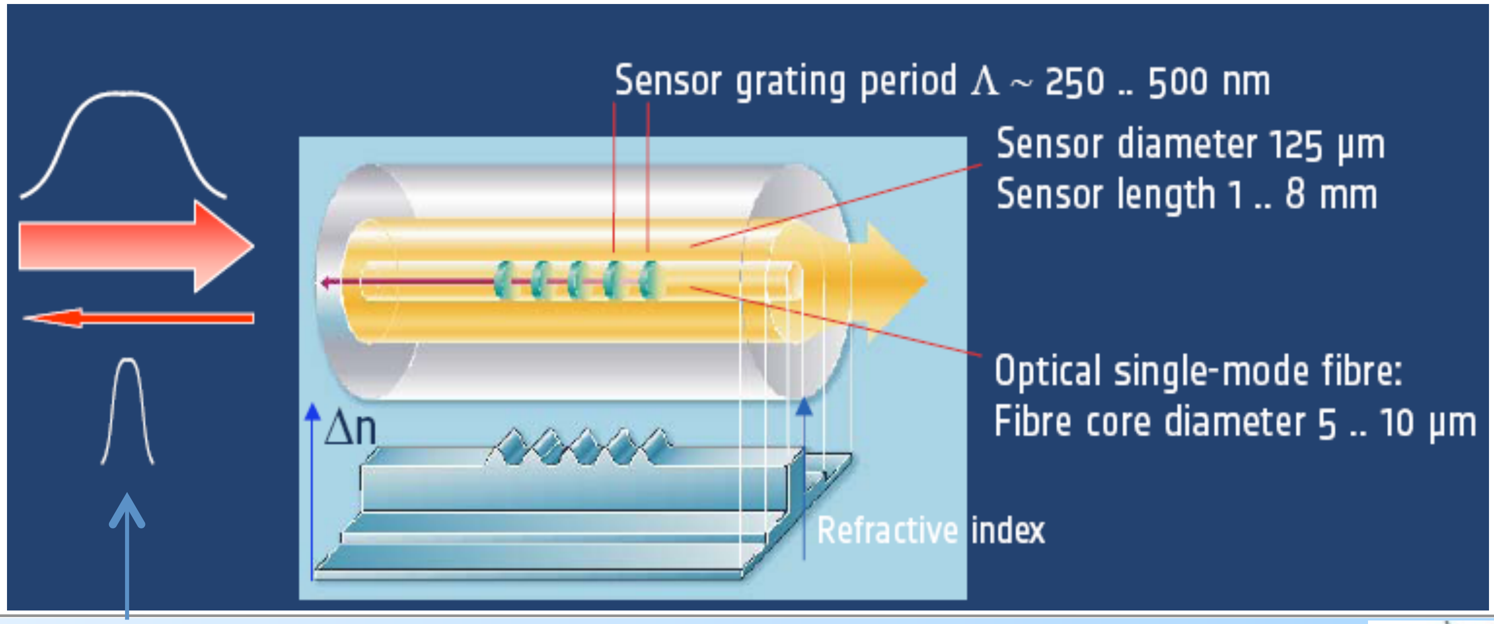


Only 50μm from end of strip to end of sensor!!!

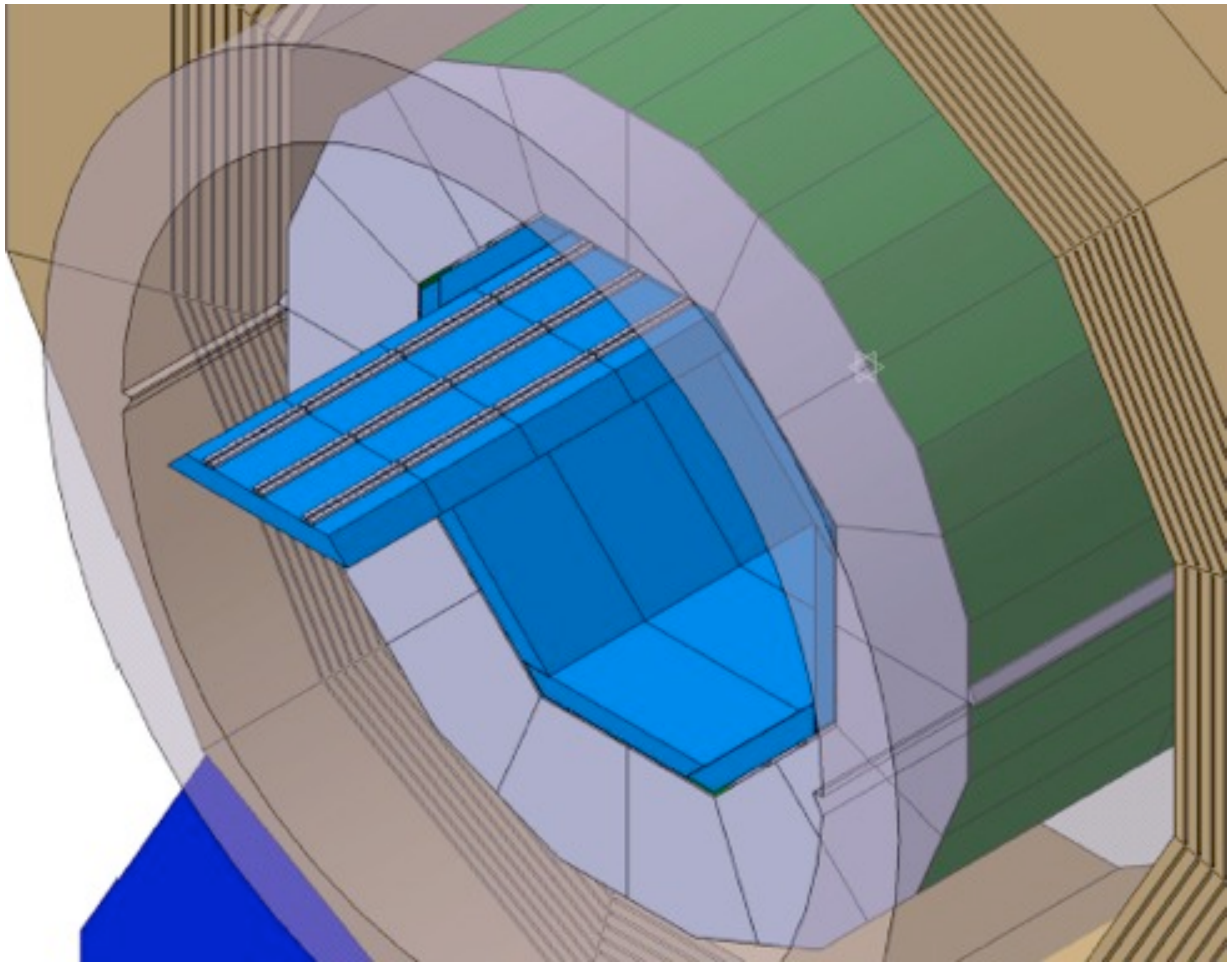


integrated pitch adapter in a second metal layer

Interferometric monitoring of FTD with fiber-optic sensors: Monitor changes of environmental parameters, vibrations, ...



The Main Calorimeters



- Main calorimeters optimized for particle flow:
  - High granularity
  - Small Molière radius in ECAL for good particle separation & photon identification
  - Sufficient depth of the HCAL to limit leakage also at 1 TeV
  - Compact design to fit inside magnet

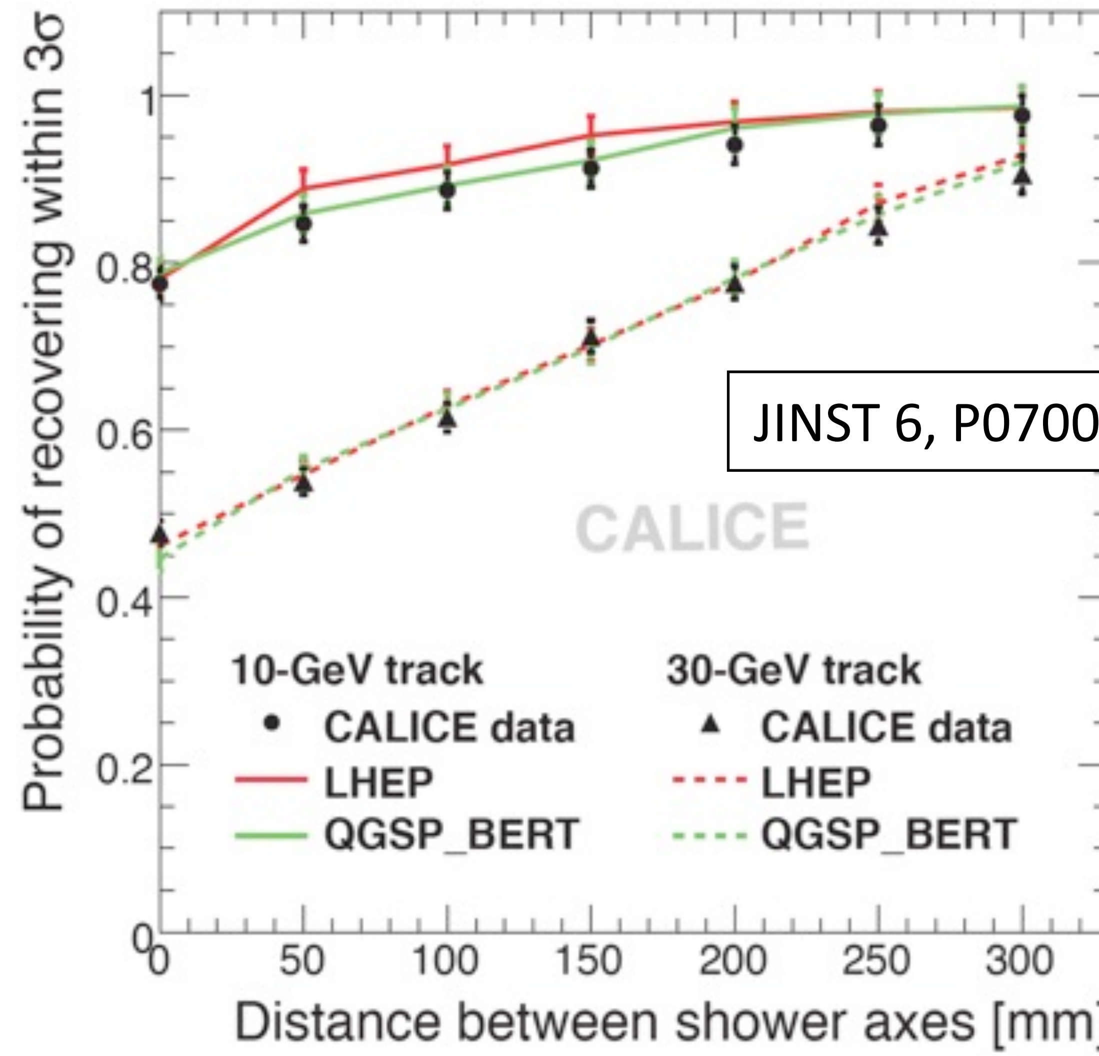
- ECAL with tungsten absorbers and silicon and/or scintillator readout
- HCAL with steel absorbers
  - Analog - Scintillator tiles with SiPMs
  - Semi-digital - Glass RPCs with 2 bit readout, Micromegas as alternative

Calorimeter R&D

- Calorimeter technology for ECAL & HCAL developed by CALICE:
  Combined test-beam experiments to demonstrate PFA calorimetry

One highlight:
Shower separation with PandoraPFA in the SiW-ECAL and AHCAL physics prototypes

- Good agreement with simulations demonstrates realism of our full detector simulations & physics studies

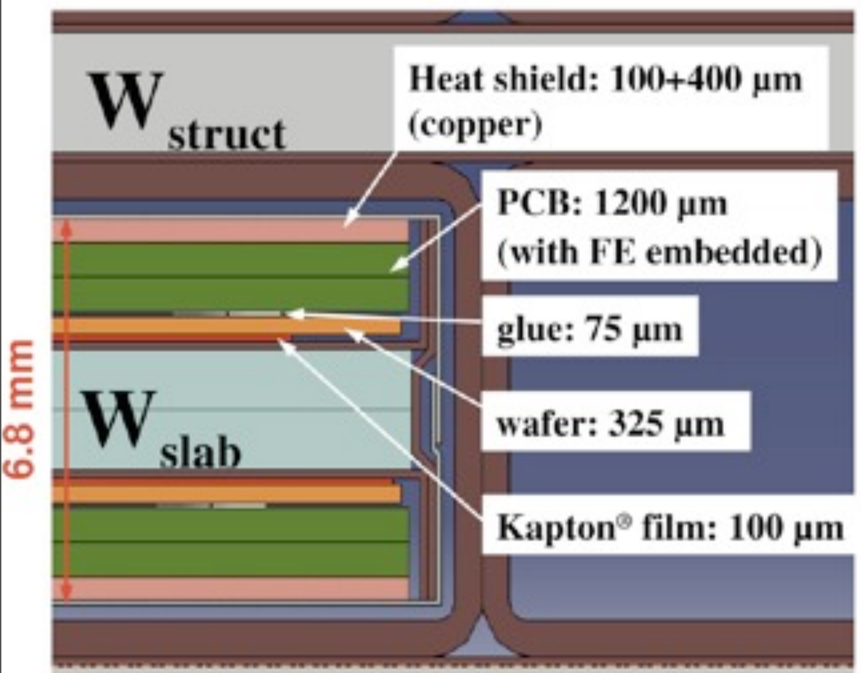


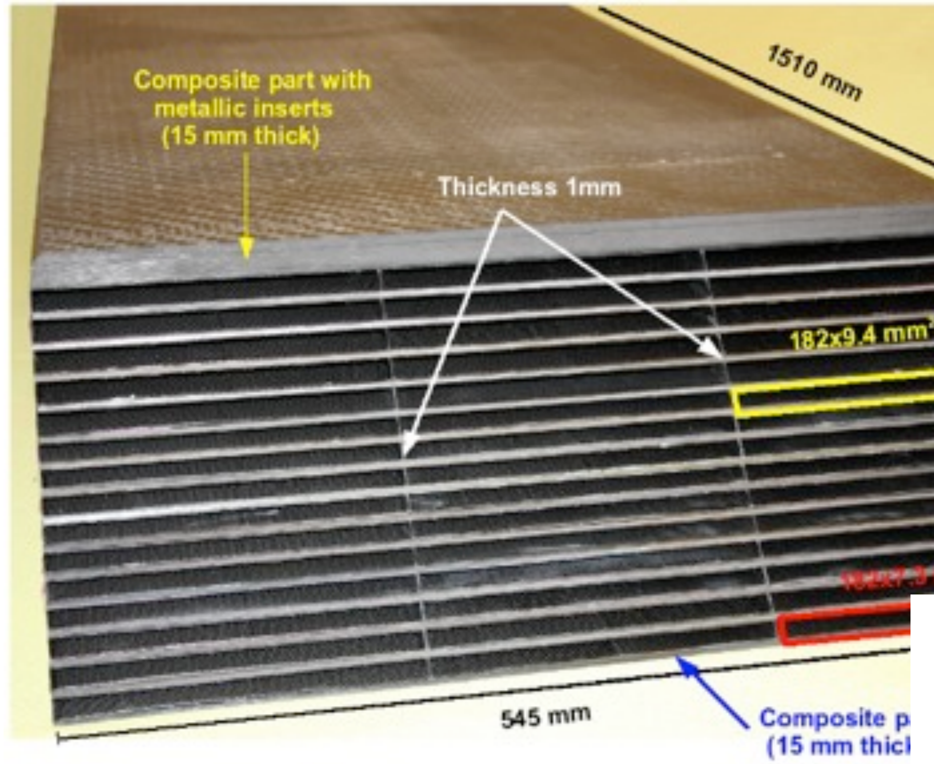
JINST 6, P07005 (2011)

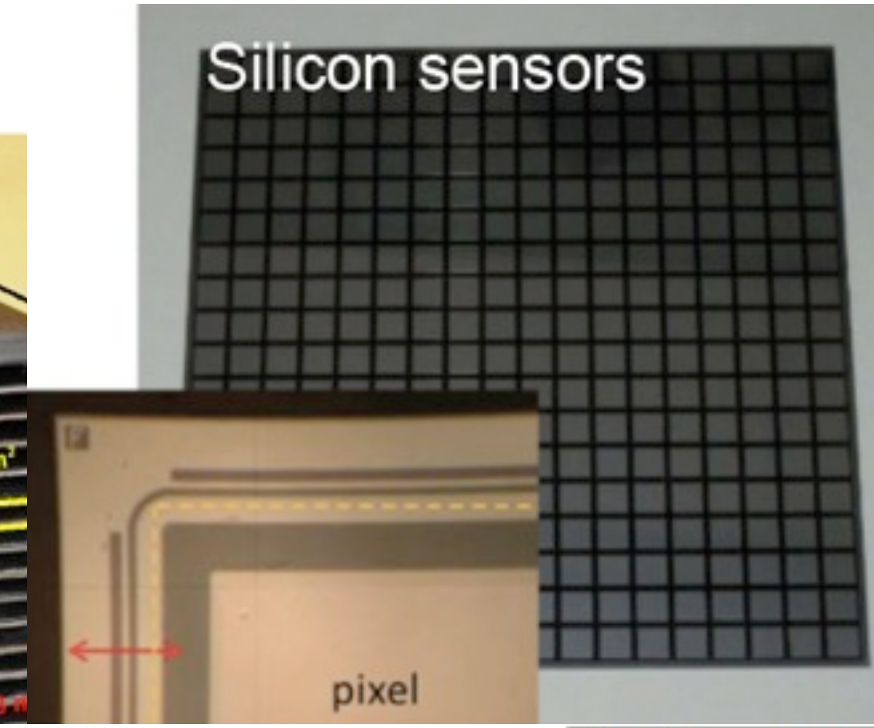
- Readout ASICS for all calorimeter types with a common basis
- Common DAQ system, data format:

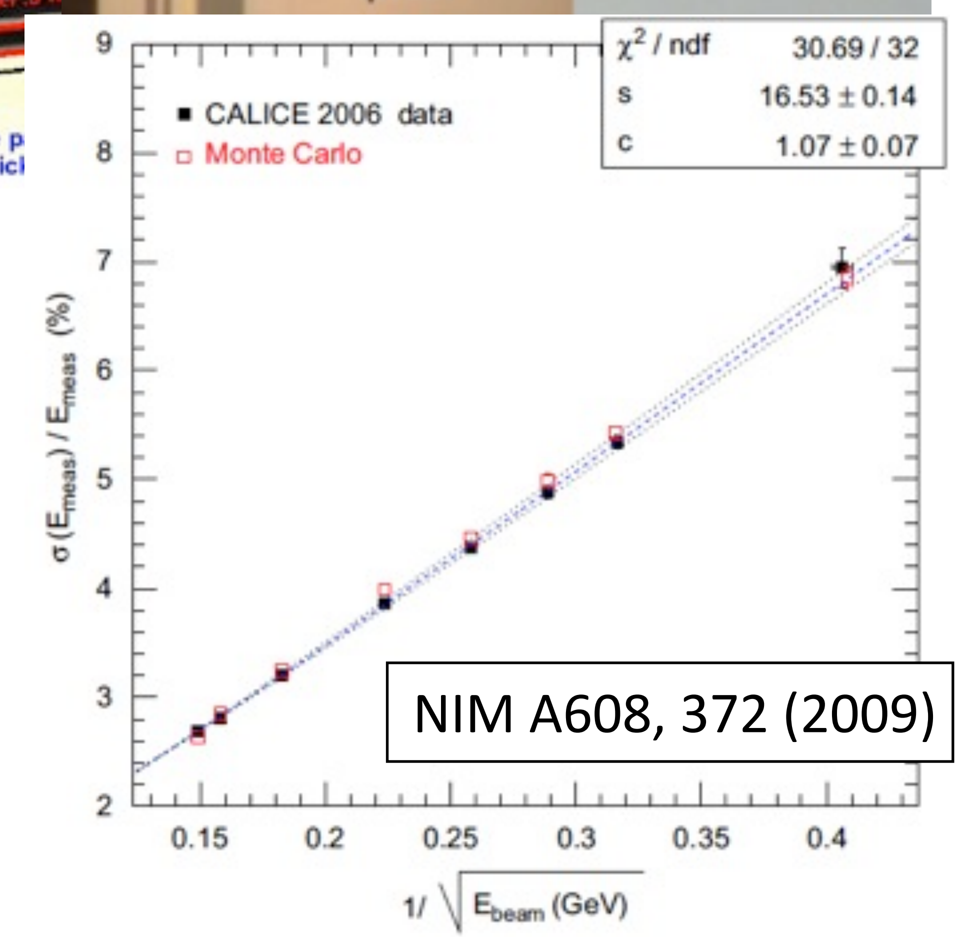
The SiW ECAL

- PIN silicon pad readout with 5.5 x 5.5 mm^2 pads









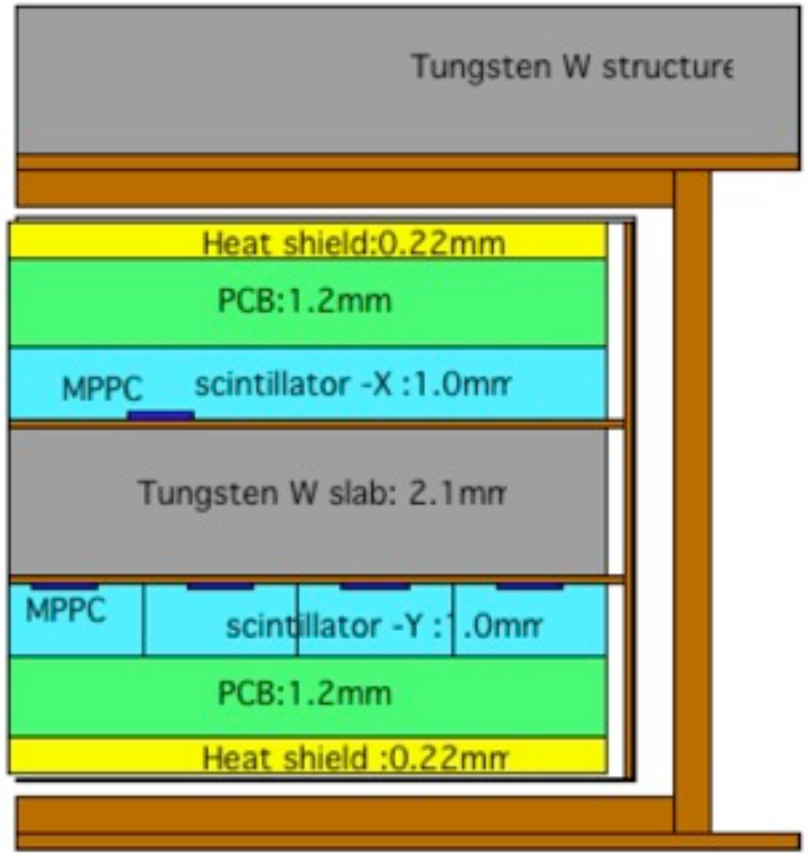
NIM A608, 372 (2009)

6.8 mm per double layer

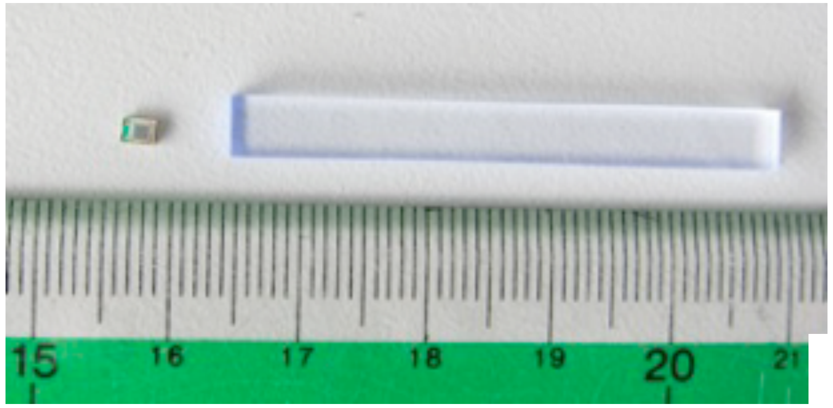
Complete tungsten structure for technological prototype exists

Well-established technology: physics prototype in various beam times since 2006

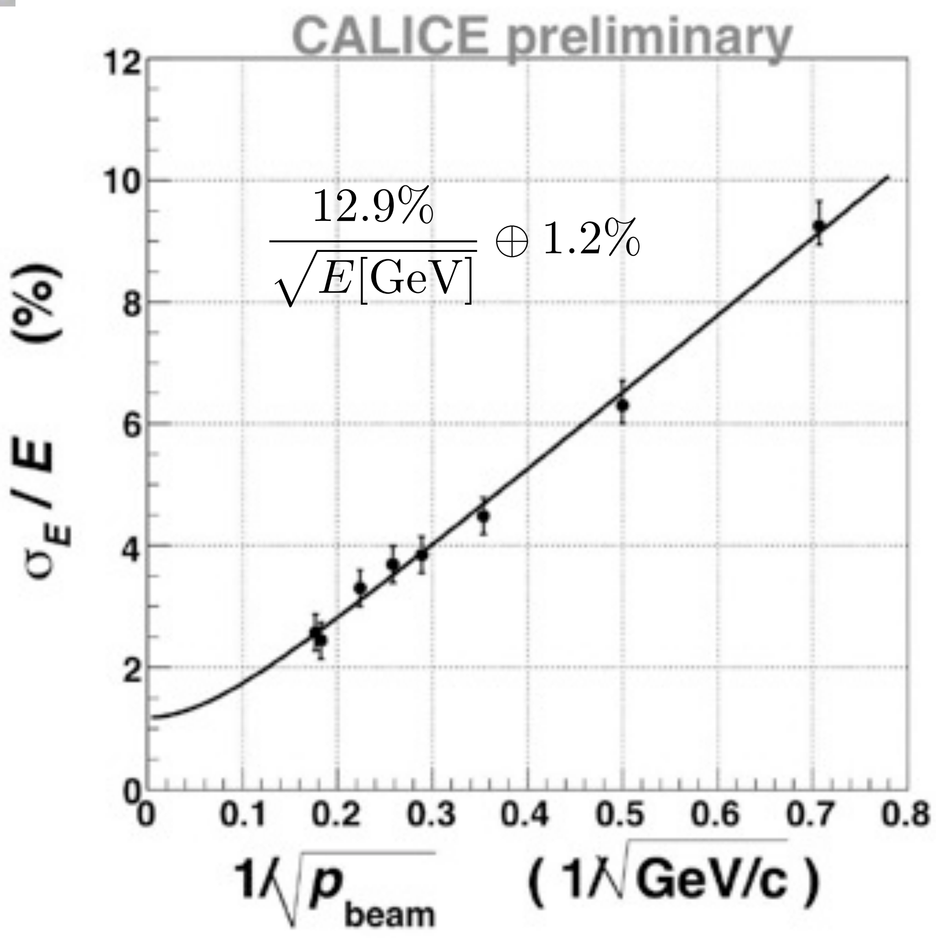
The Scintillator ECAL



- Scintillator strips (5 x 45 x 1 mm^3) read out with SiPMs
  - 6.9 mm per double layer, 0.1 mm more than SiW ECAL
  - Electronics based on AHCAL design - synergies!



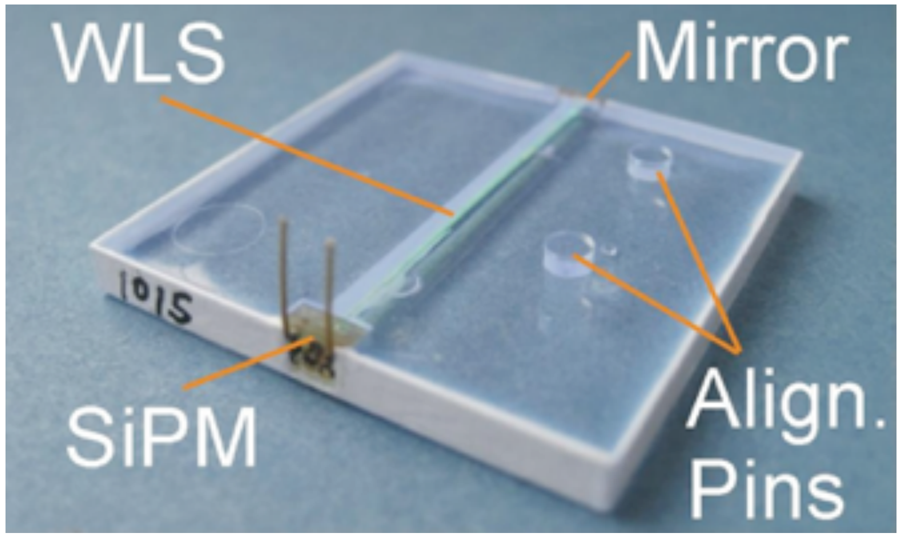
Extensive tests with a physics prototype, first module of technological demonstrator now in test beam at DESY



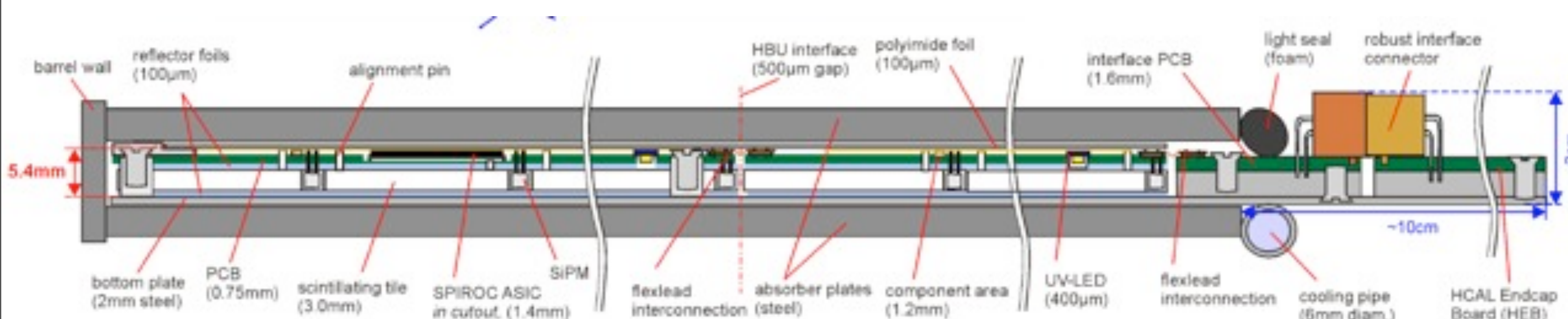
- Recover 5 x 5 mm^2 granularity with strip-splitting algorithm
- SiPMs / MPPC with higher smaller pixels under study to increase dynamic range
- Hybrid solutions together with Si layers (interleaved or as two sections) possible

The Analog HCAL

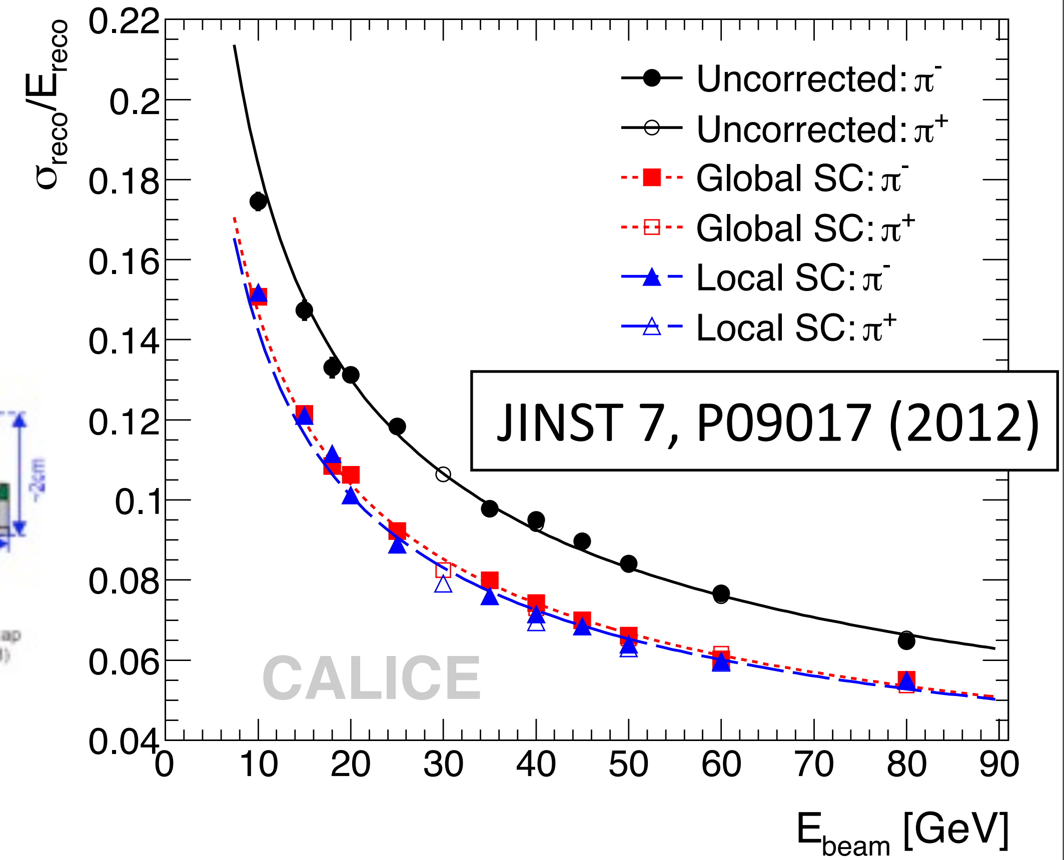
- Based on 3 x 3 x 0.3 cm^3 scintillator tiles with embedded SiPM



Well-established technology: Extensive tests in beam with a 8 000 channel system since 2006

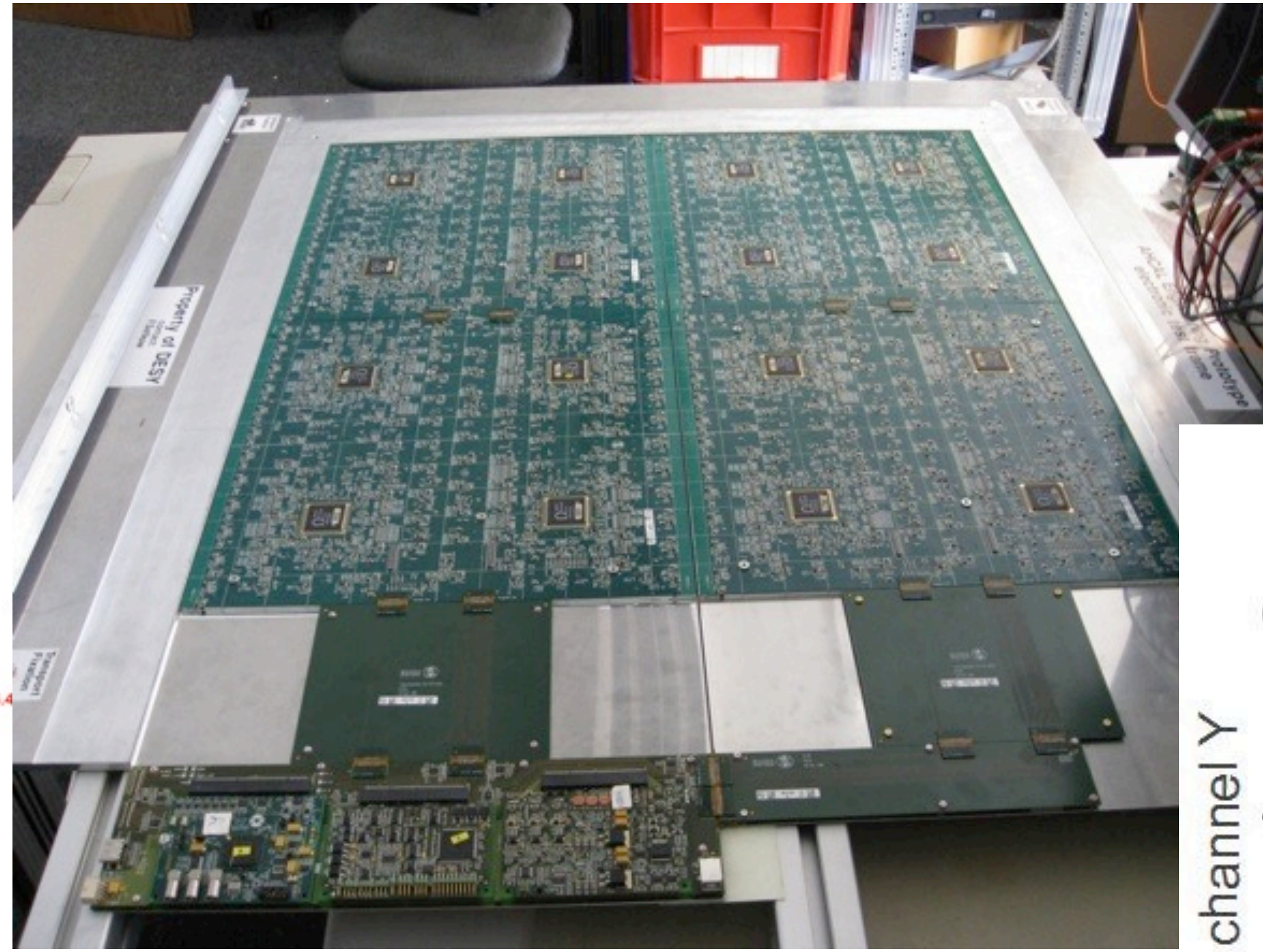


Compact design: < 6 mm non-absorber material per layer



Hadronic energy resolution of physics prototype with software compensation: 45%/√E ⊕ 1.8%

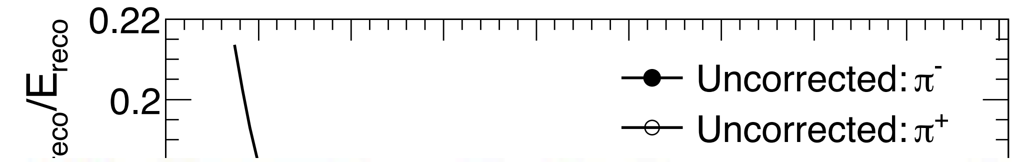
The Analog HCAL

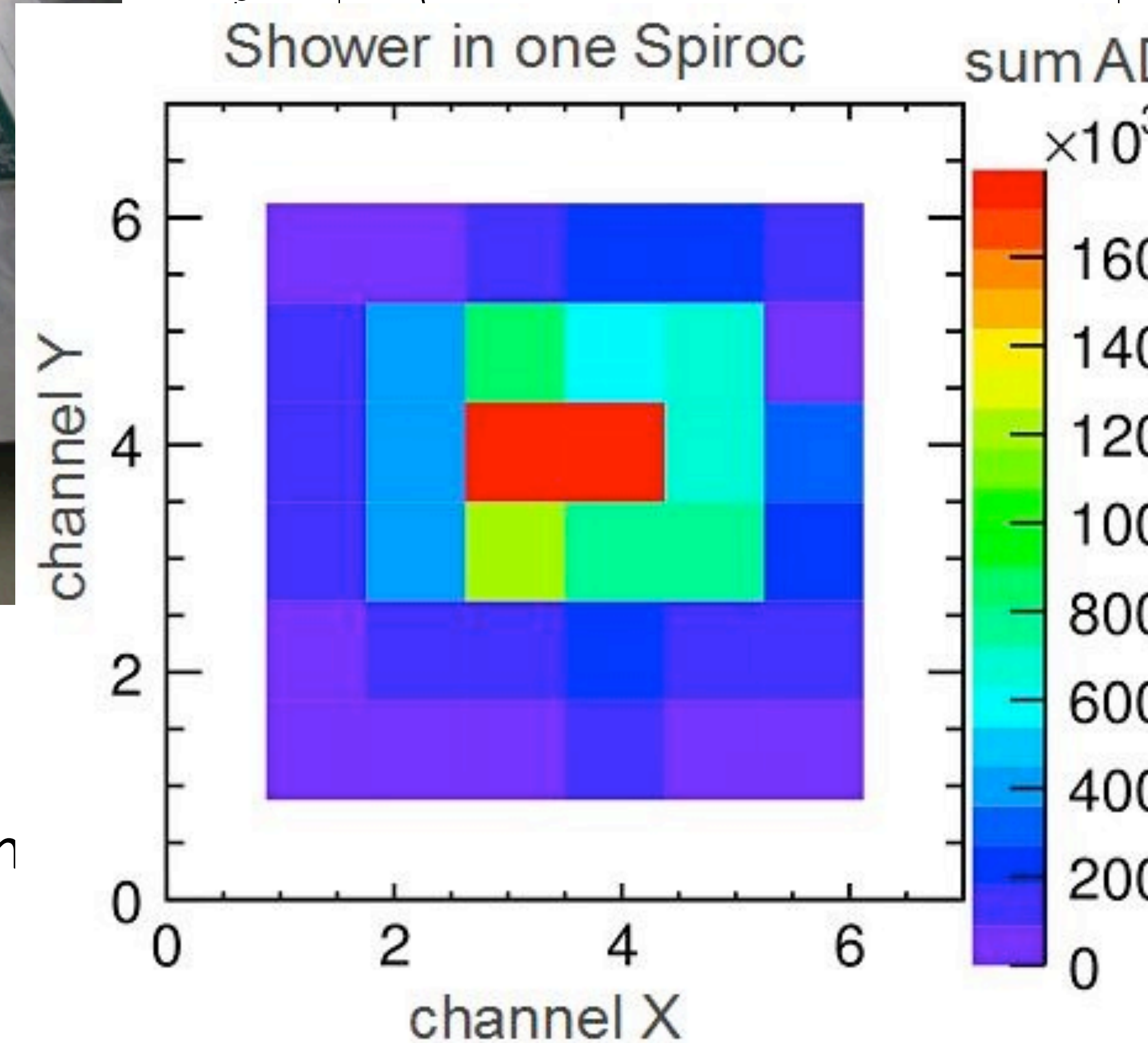


mbedded SiPM

technology: Extensive tests in beam

nnel system since 2006

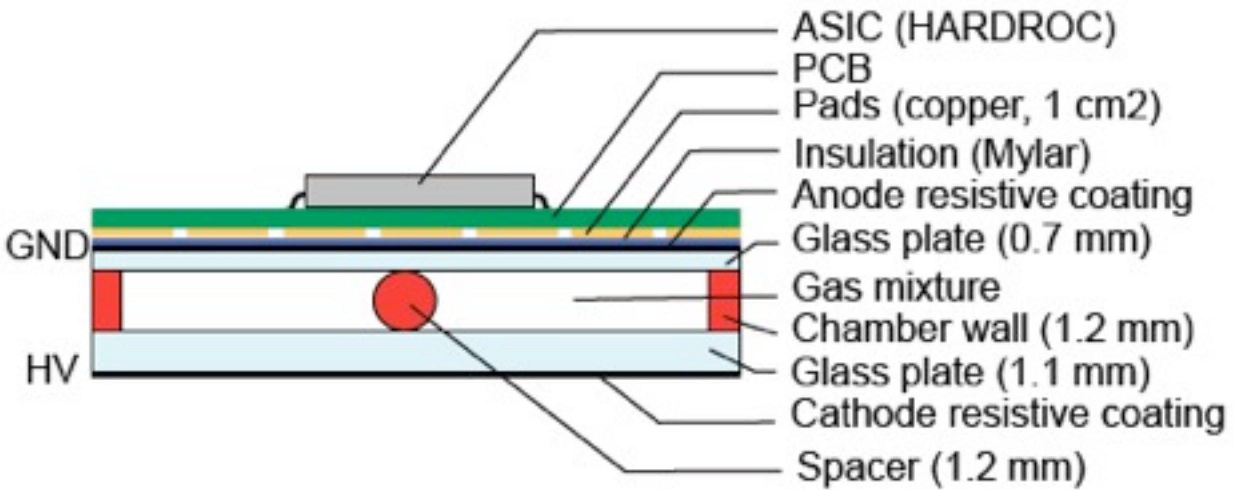




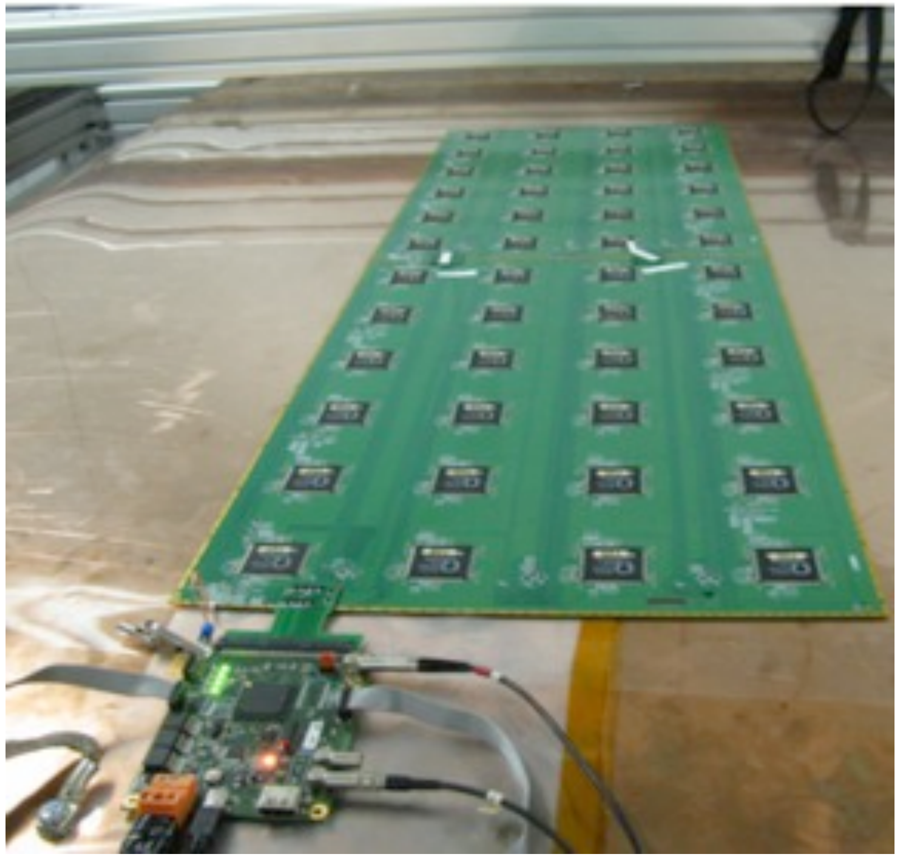
First units (144 channels) of technological demonstrator currently in test beam: - embedded electronics, power pulsing, online zero suppression channel-by-channel auto-trigger, time stamping

The Semi-Digital HCAL

- Glass RPCs with 1 cm^2 pads
  - 3 thresholds per channel: allows to keep linearity to higher energies, improved resolution at high energies compared to purely digital mode



Full 1 m^3 technological prototype with 48 layers,
430k channels & power-pulsing successfully tested in beam



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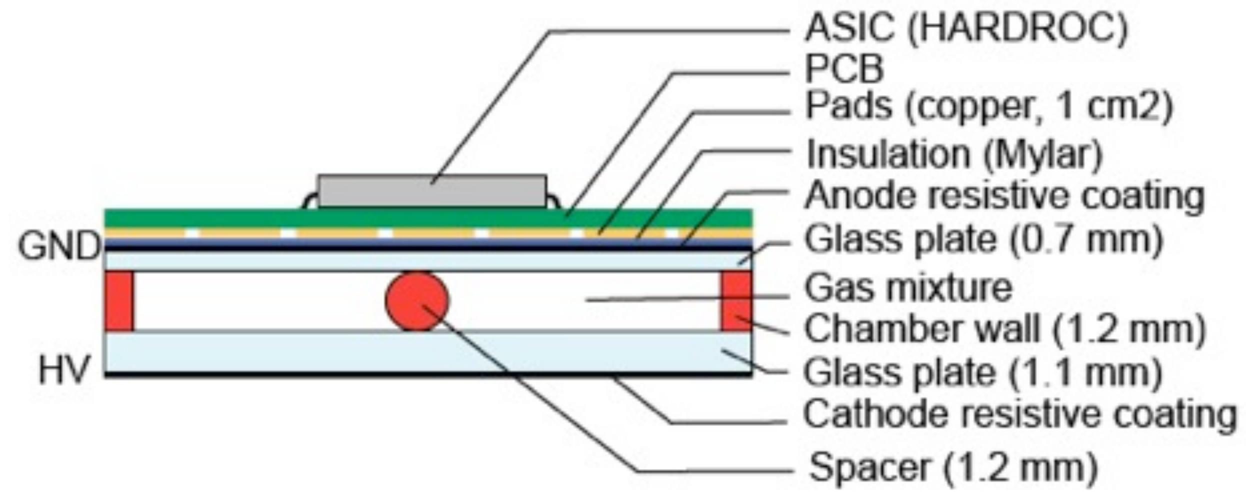

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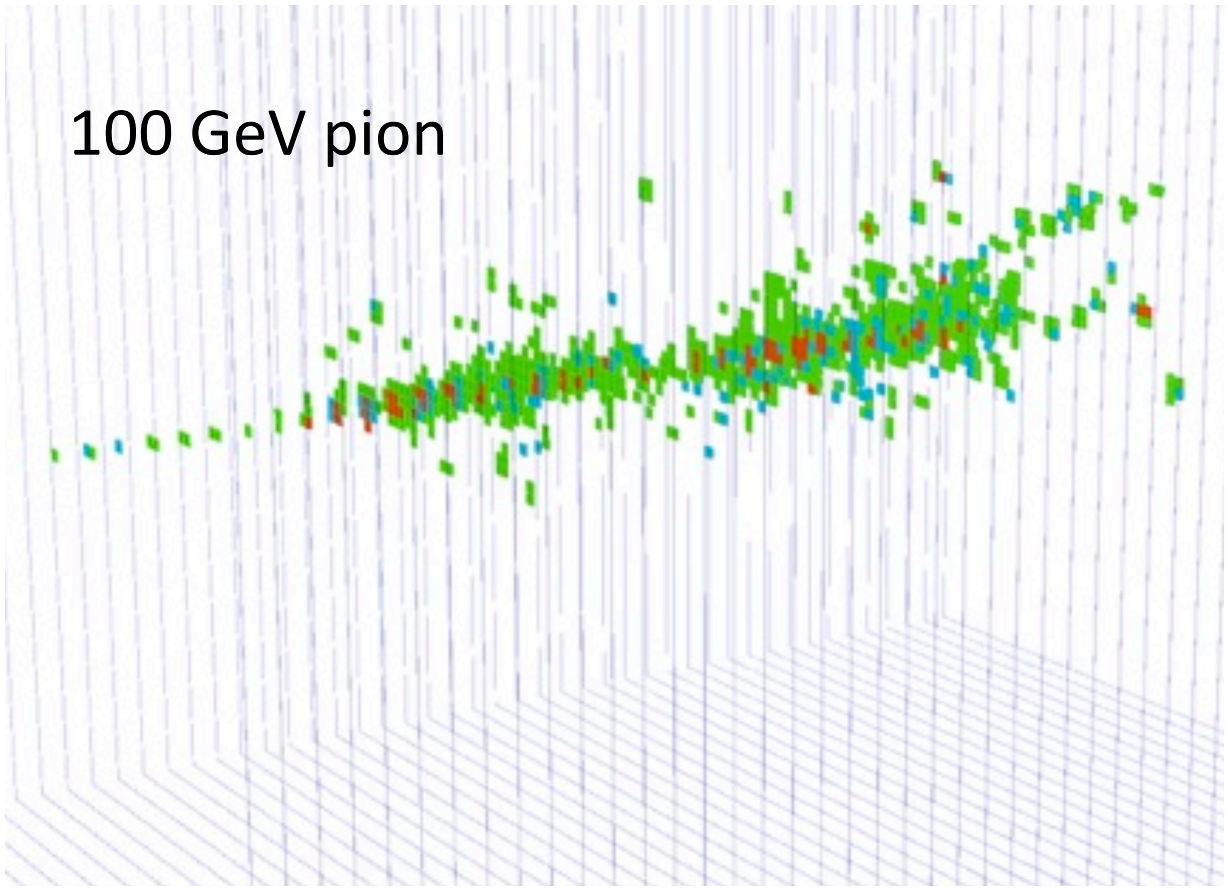
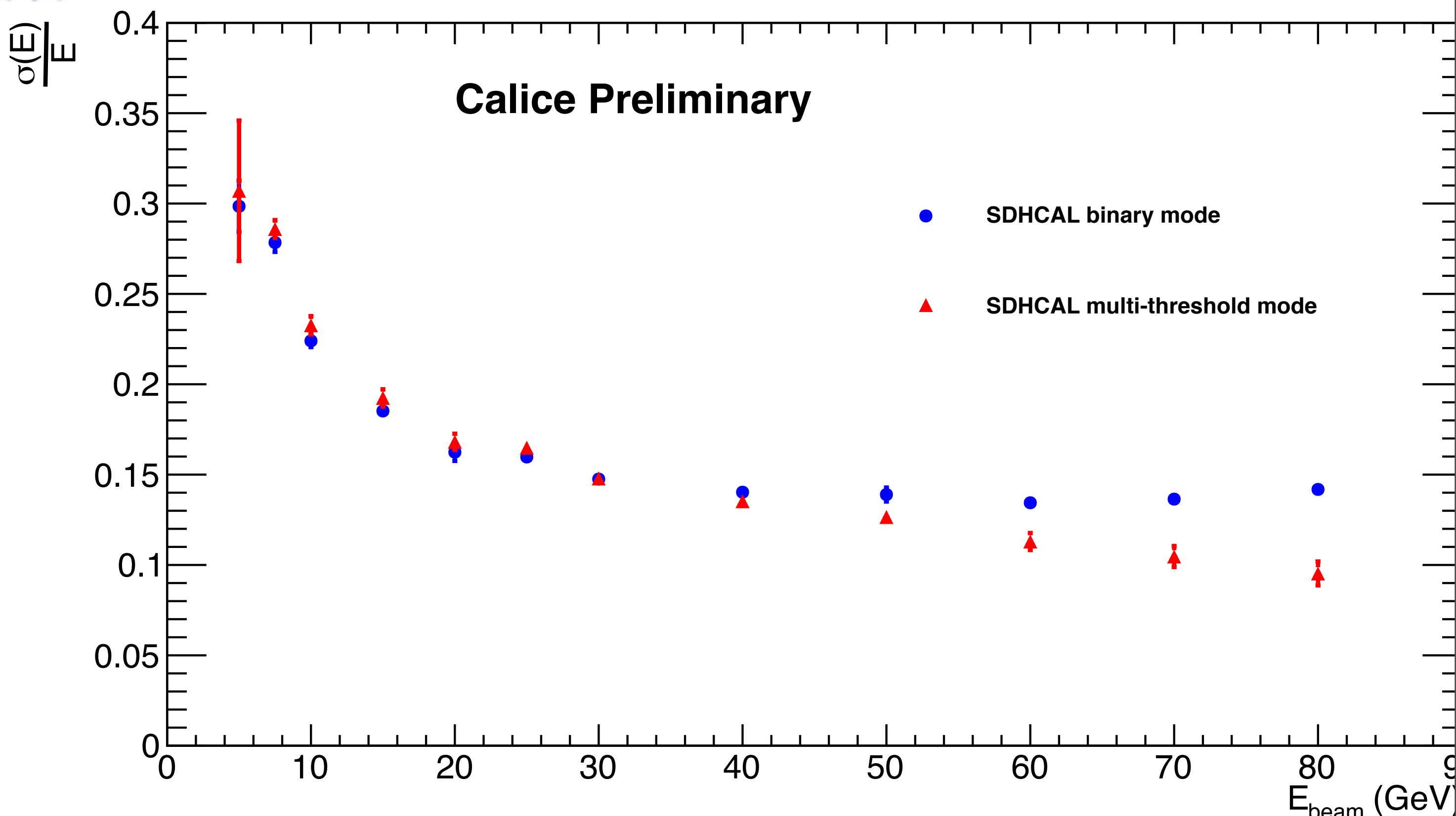
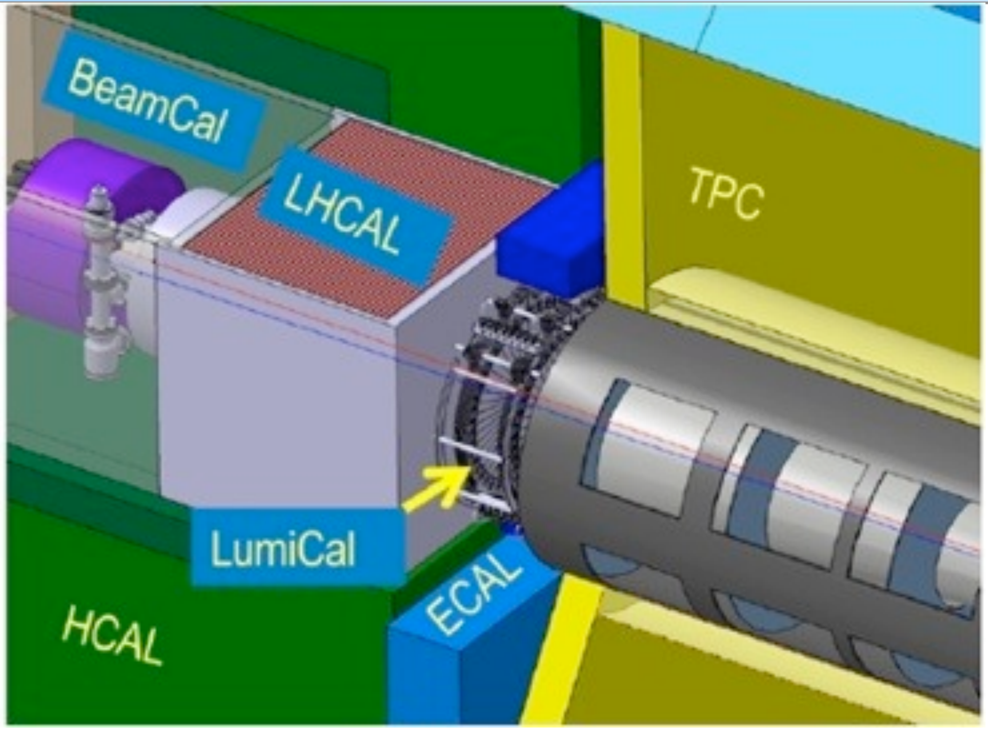


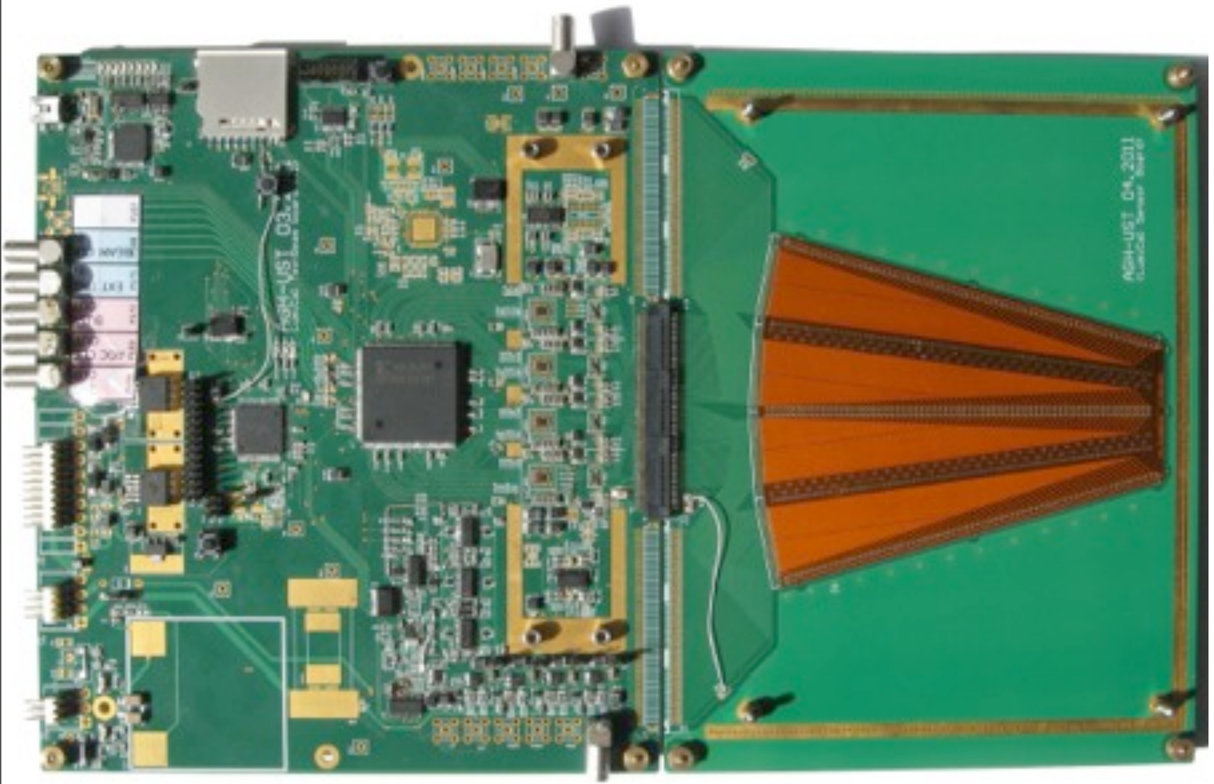


Forward Calorimeters

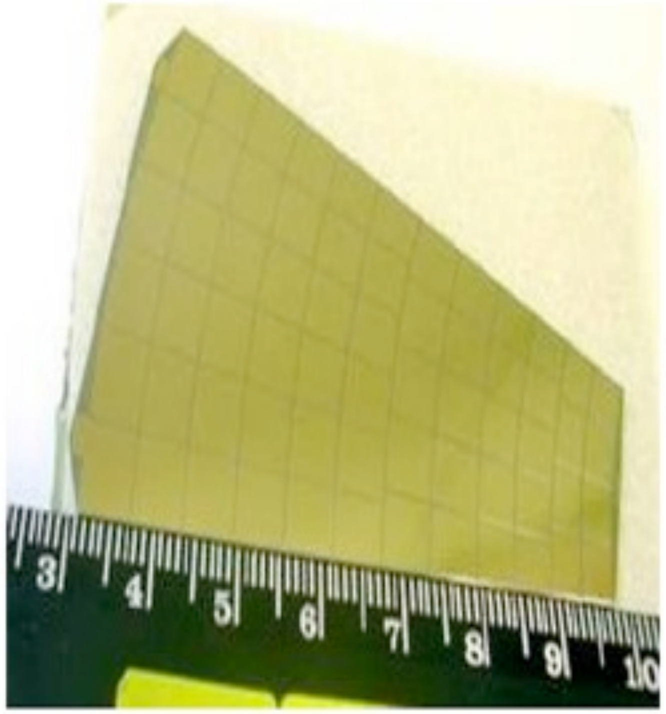


- Luminosity measurement at the 10^{-3} level with LumiCal
- Bunch-by-bunch luminosity monitoring and fast feedback for beam steering with BeamCal
- Extended coverage to low polar angles
- ▸ The only subsystems with substantial radiation hardness requirements!

Silicon sensors for LumiCal - tested in beam



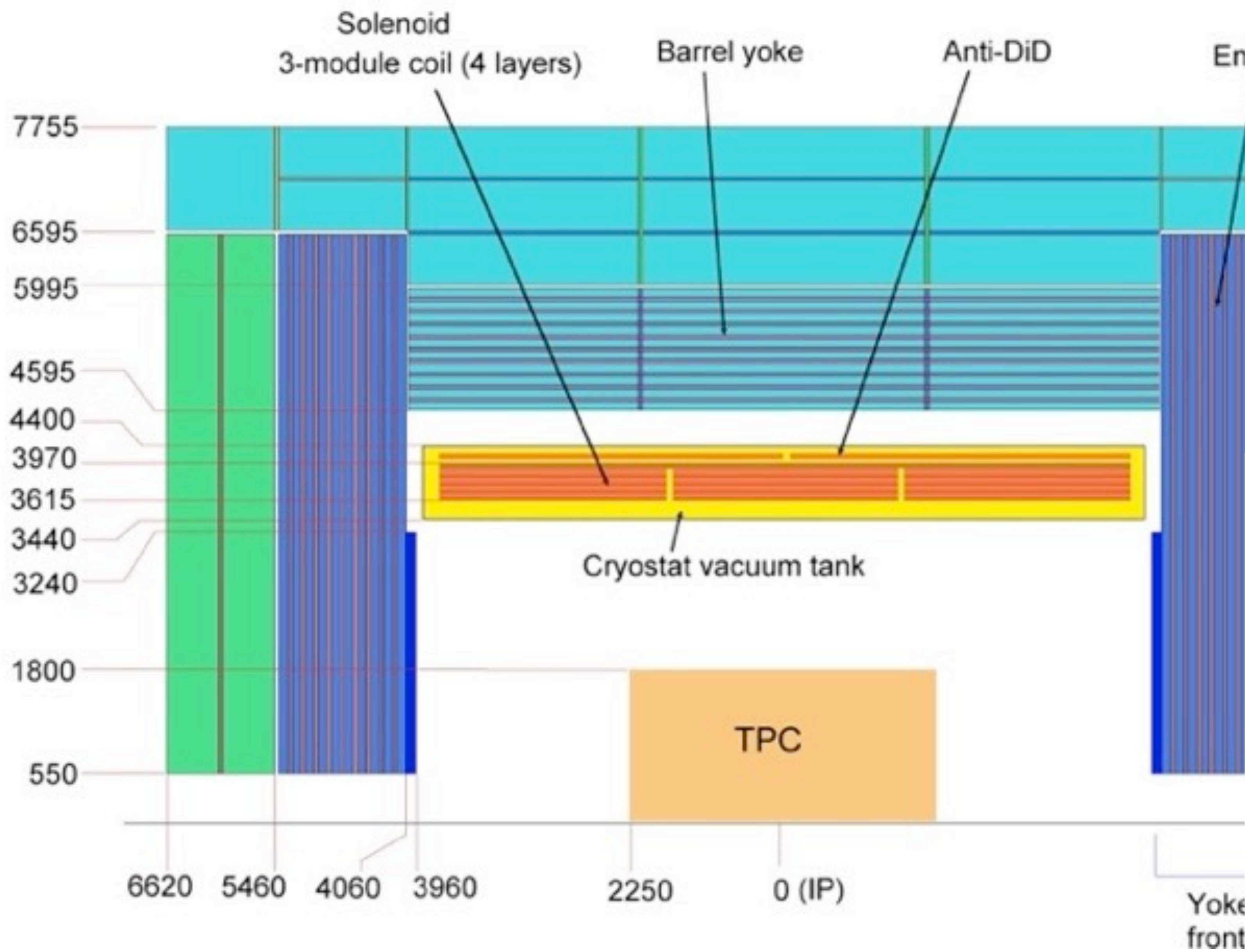
GaAs sensors and CVD Diamond for BeamCal



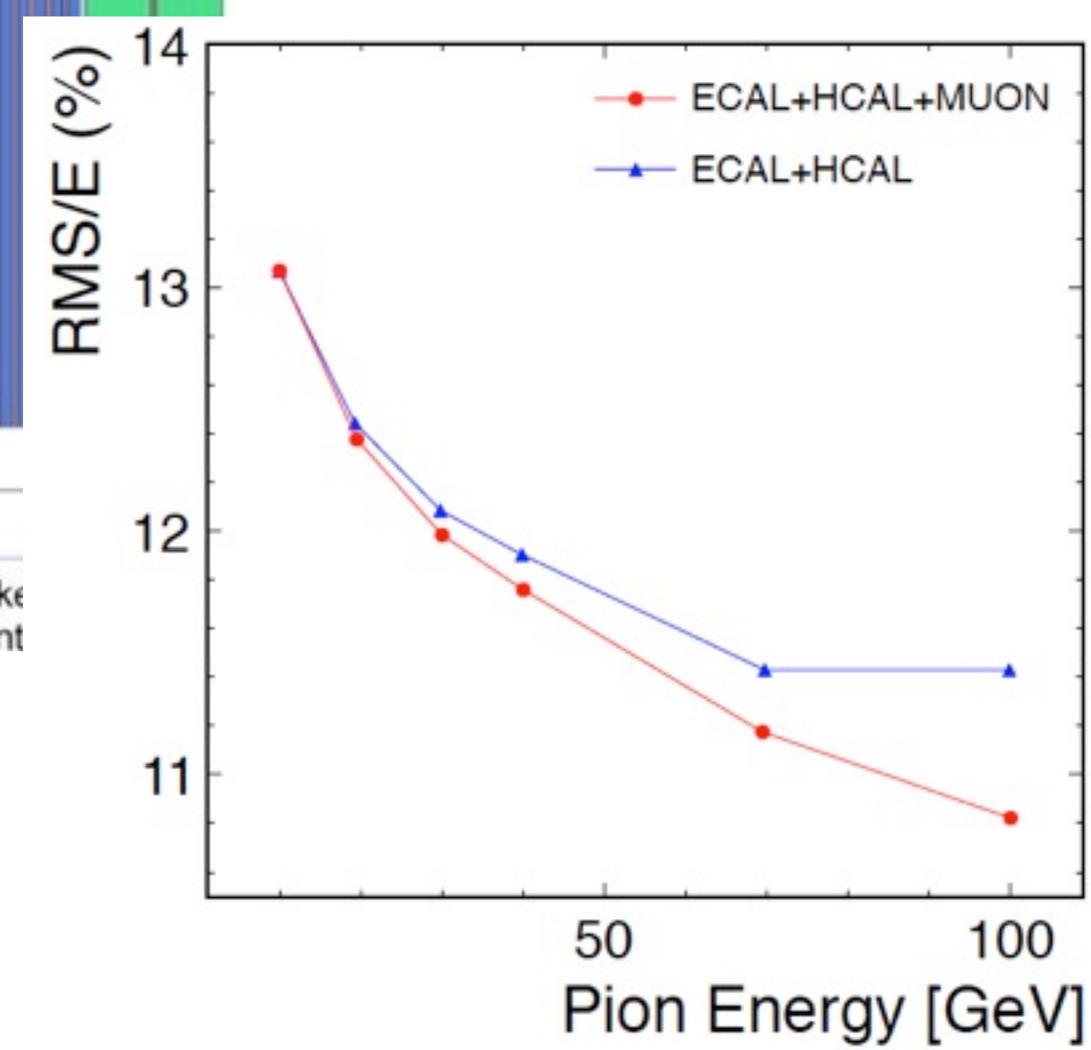
CVD Diamond shows excellent radiation hardness

GaAs shows a reduction of the charge collection efficiency to 20% after 7 MGy, still sufficient for MIP detection

Muon System, Yoke and Coil



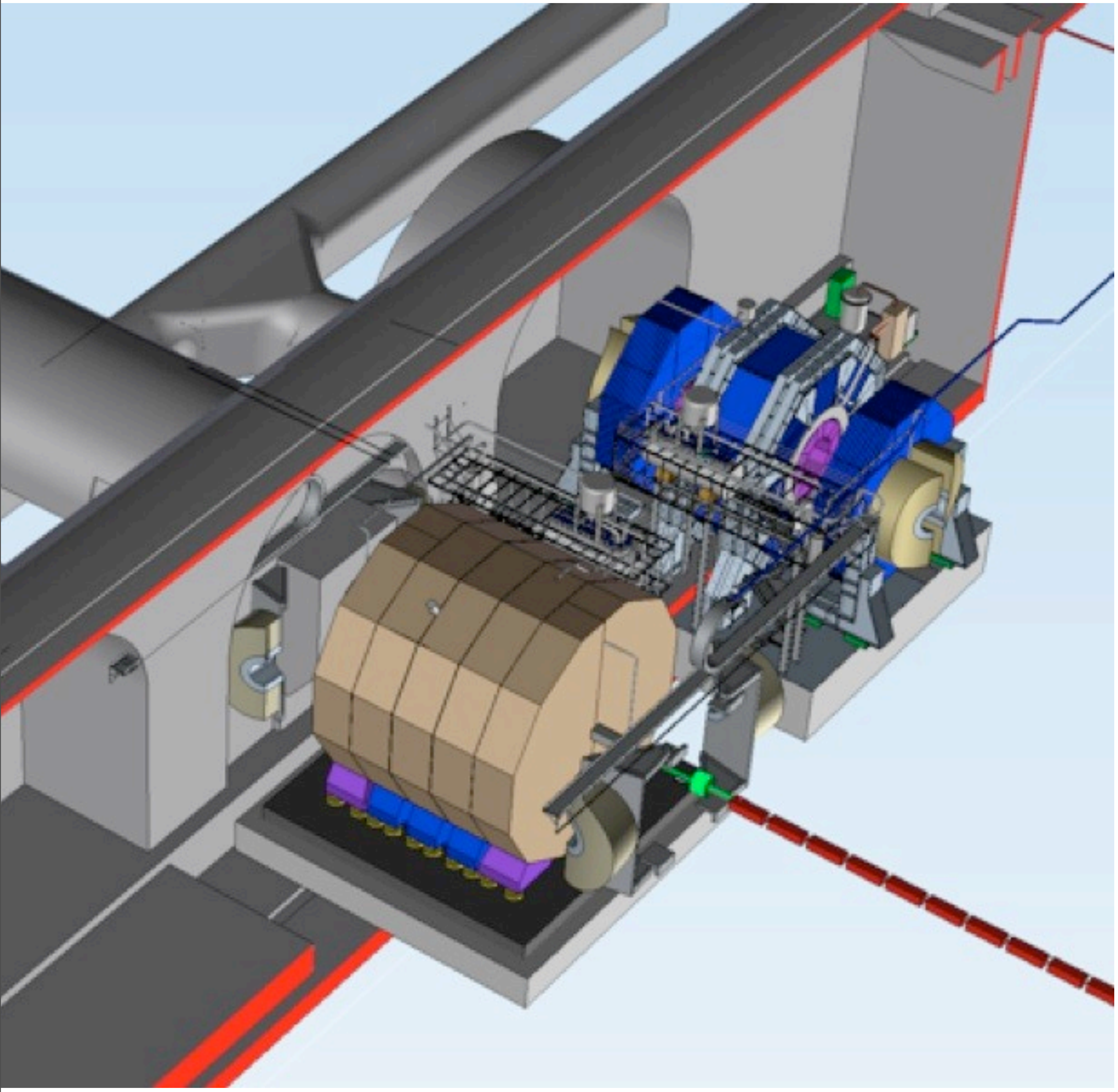
Default operations at 3.5 T, magnet designed for 4 T to allow flexibility at higher energy



- Instrumented iron yoke: Muon tracking and tail-catching
- ~ 10 mm thick, ~ 30 mm wide up to 2.7 m long extruded scintillator strips with SiPM readout

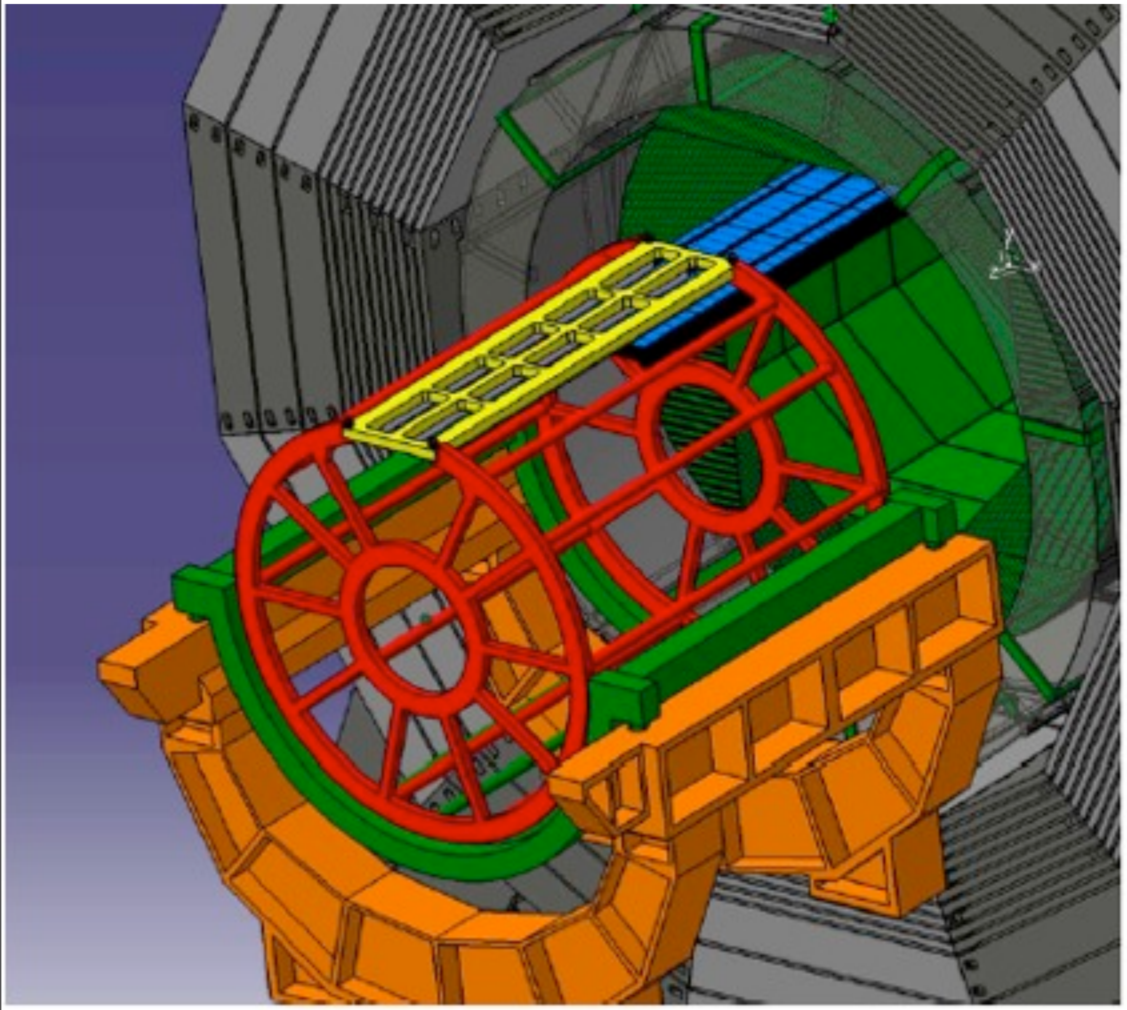
The ILD Detector System

ILD Mechanical Design

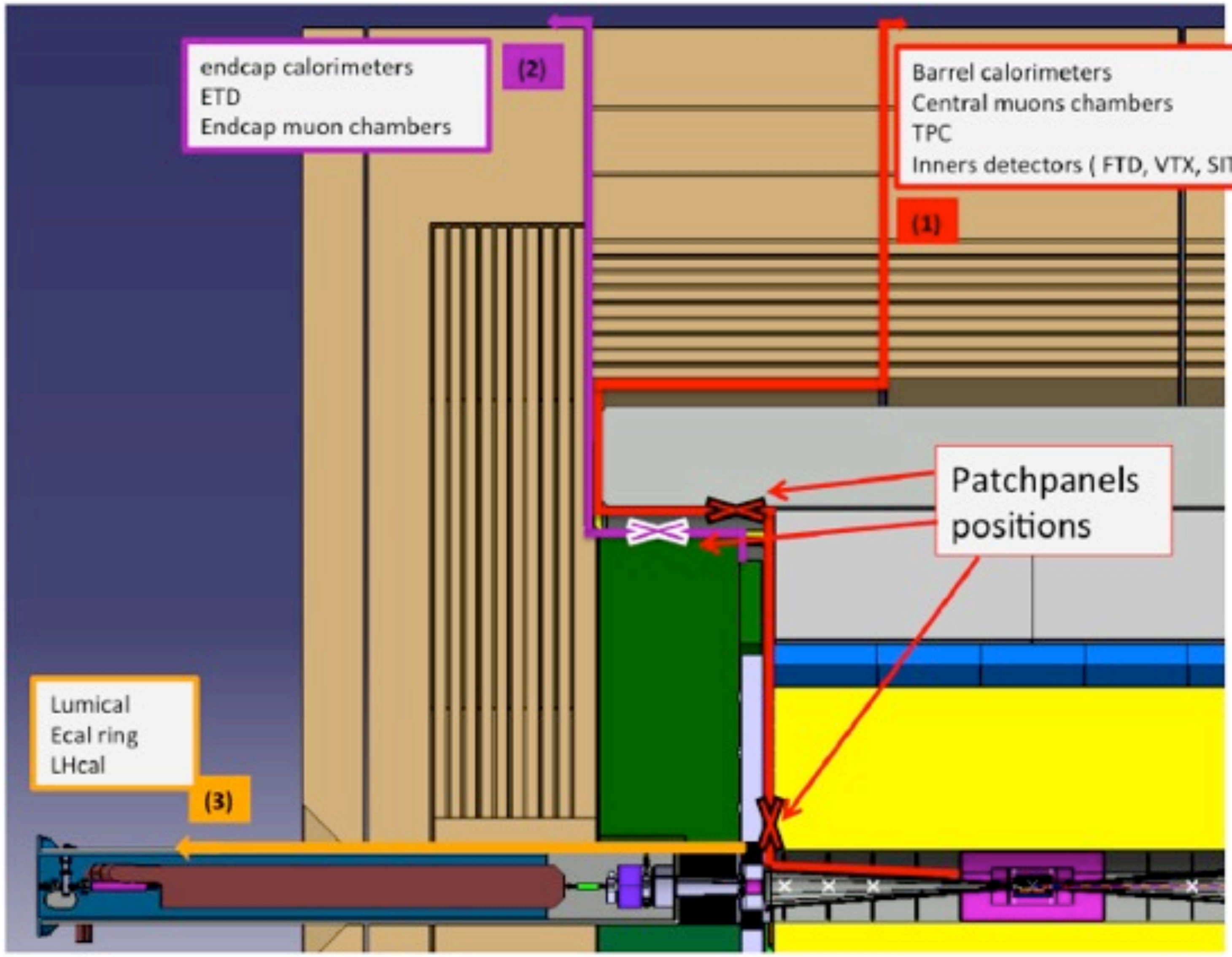


- 5 Yoke rings
  - Mounted on air cushions for easy moving during assembly / dis-assembly / maintenance
- Central ring carries cryostat and solenoid:
  - Supports calorimeters, TPC and outer Si trackers
  - Inner detector & beam pipe supported from TPC

ILD Integration

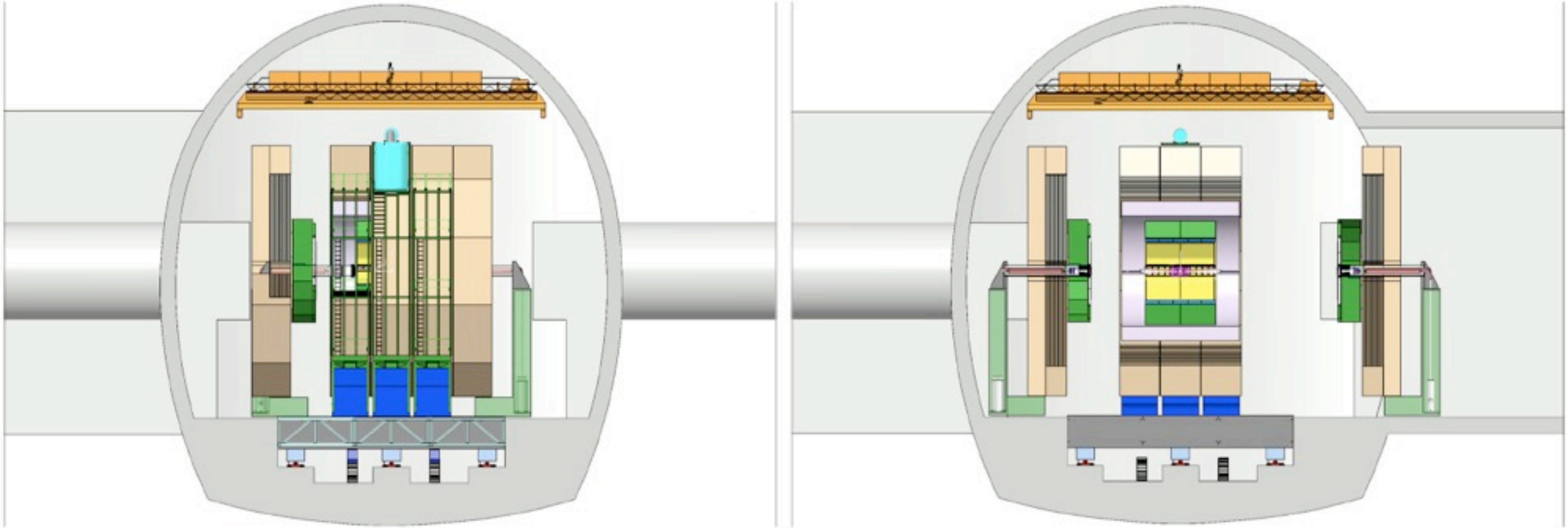


- Assembly strategy with dedicated installation fixtures



- Service paths inside of the detector for power, data, cooling

The Experimental Hall



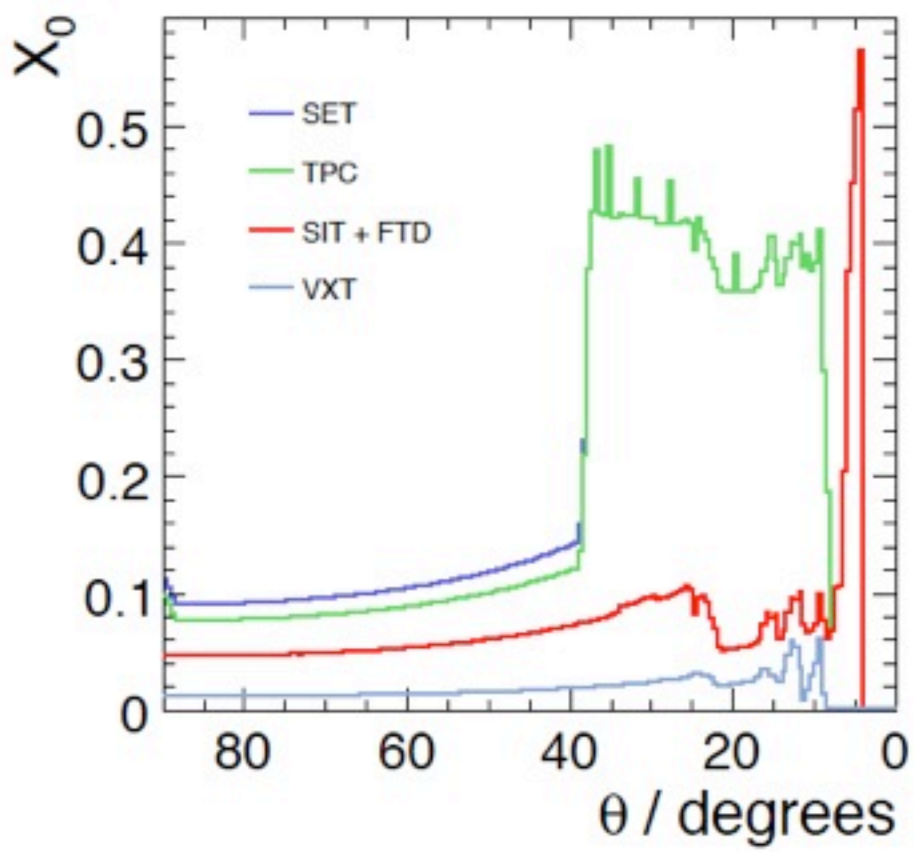
- Size of cryostat defines minimum diameter of access tunnel required for installation
  - For vertical access: Assembly of yoke rings and central detector system within cryostat on surface: 18 m diameter required
  - For horizontal access: Assembly of yoke rings and other large components in detector hall: > 8.7 m diameter required

ILD Software & Performance

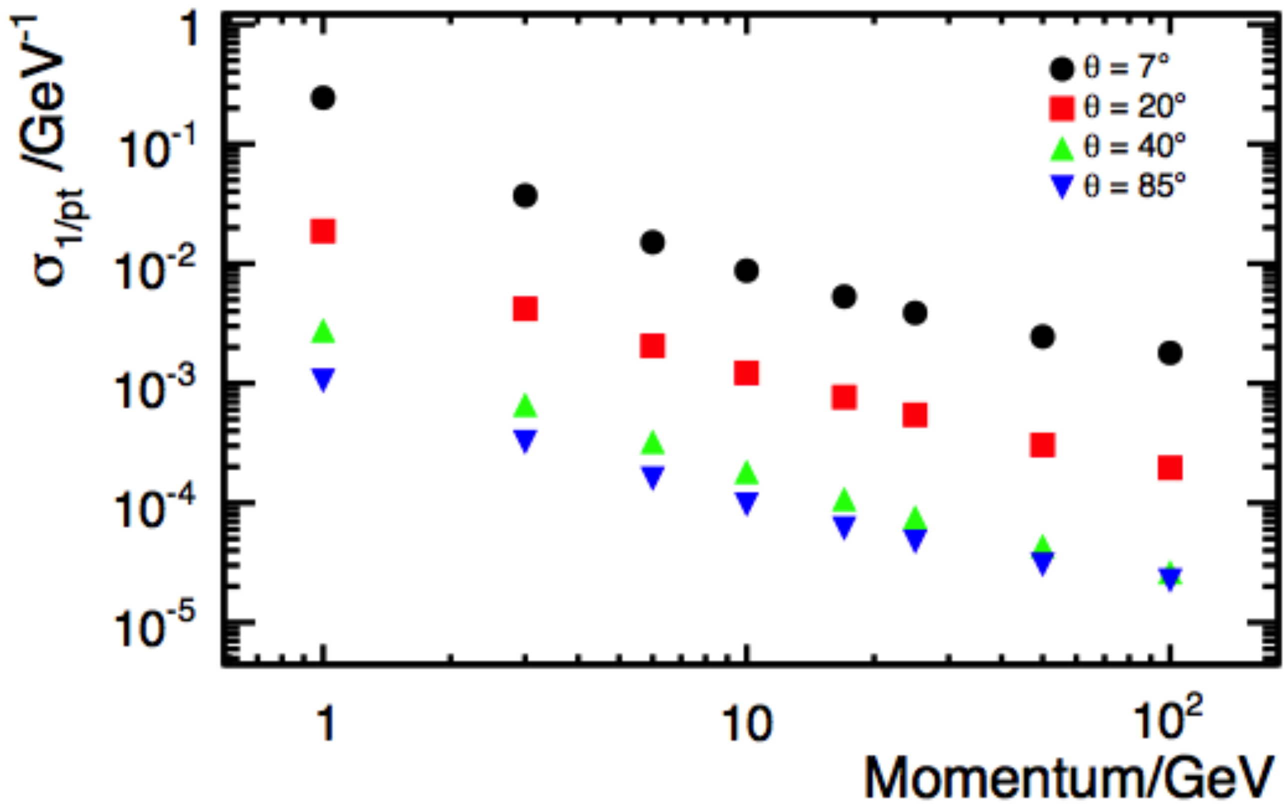
ILD Simulation & Reconstruction

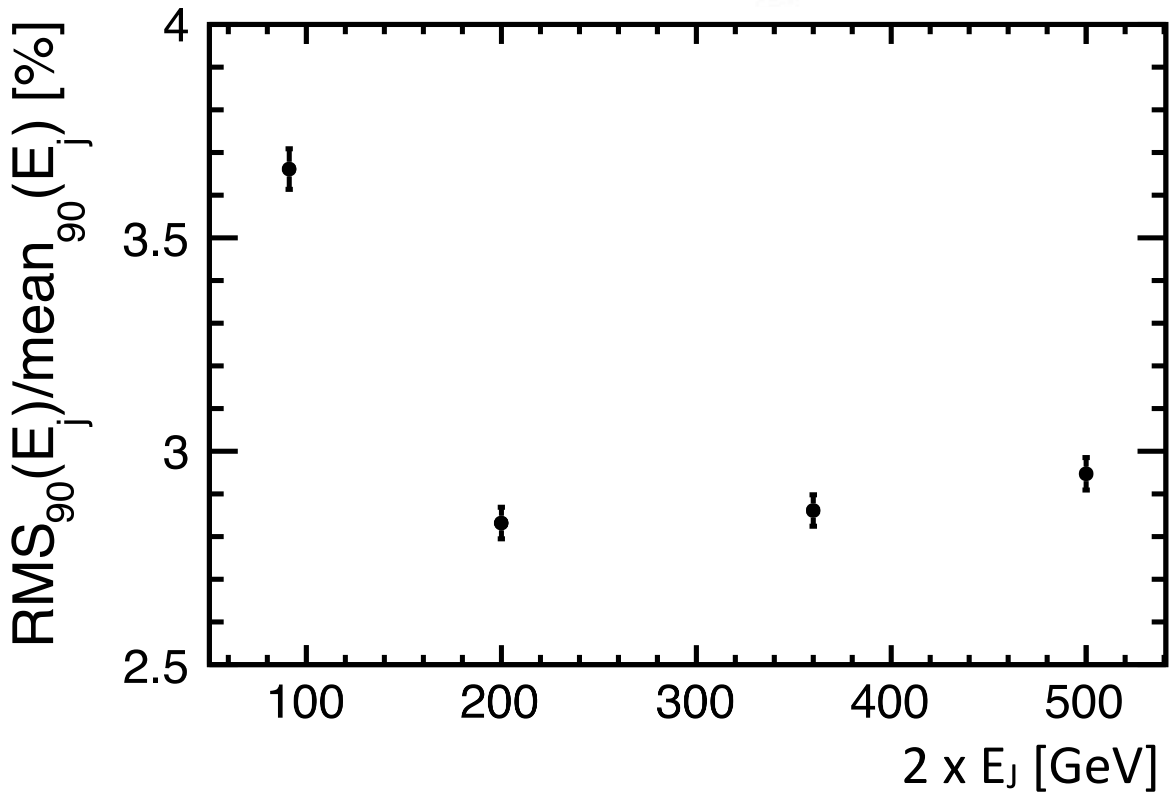
- Significant enhancements compared to the LOI
  - Increased realism in the detector description
    - Realistic geometry of most subsystems: Individual modules in trackers, engineering details (mechanical supports, electronics, cooling, cabling, ...)
    - Inclusion of dead material, cracks, ...
    - Material budget estimates based on R&D activities
  - Improved reconstruction software
    - New generation of PandoraPFA
    - Proper treatment of silicon strips
    - Completely new Kalman-Filter-based tracking
    - New flavor tagging based on boosted decision trees trained with fully simulated events

ILD Material & Performance



- Realistic description of material budget



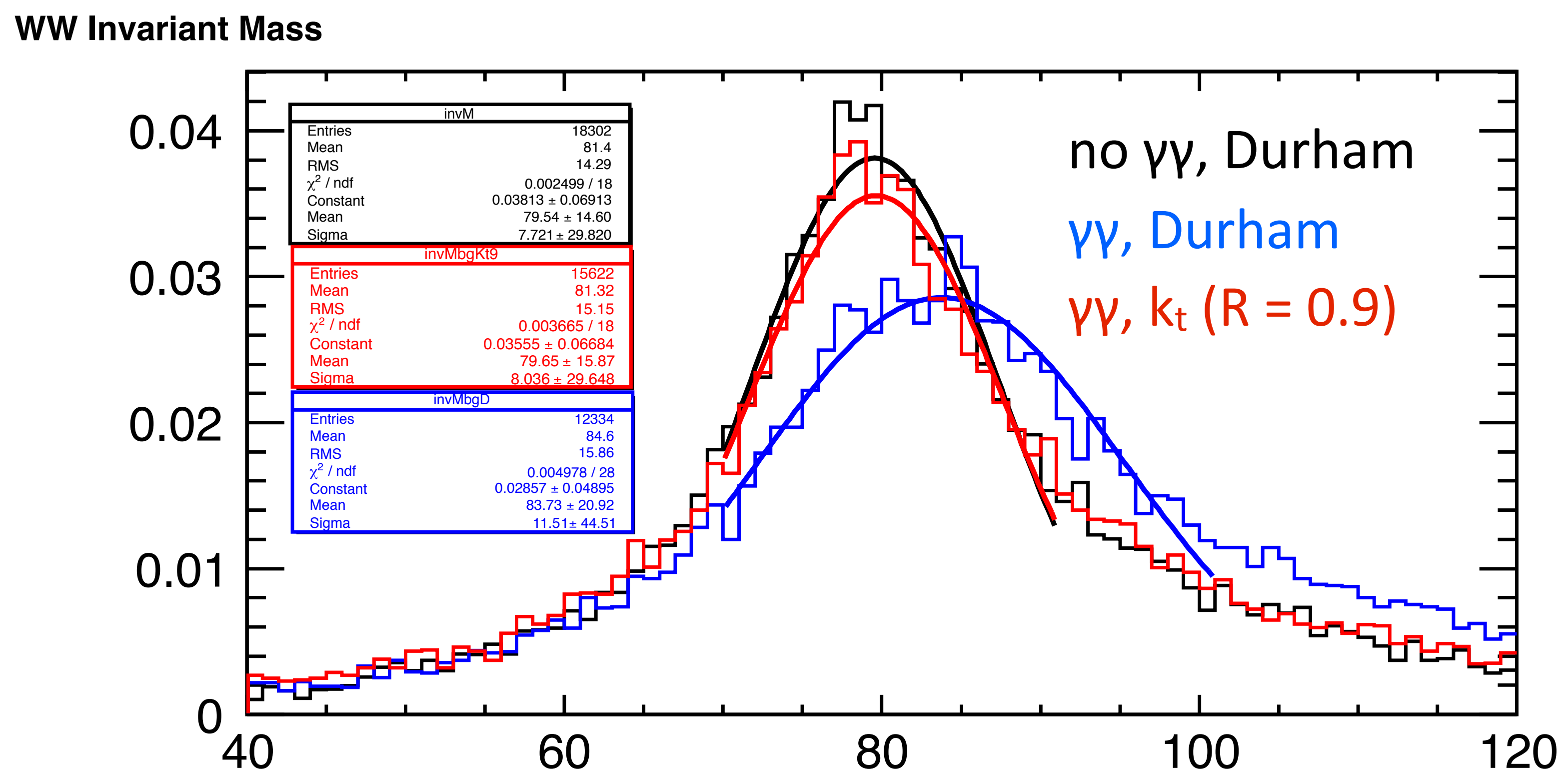


- PandoraPFA performance exceeding requirements over wide energy range (Goal: 3% - 4%)

- Performance of new tracking for single muons - resolution reaches asymptotic value of 2 x 10^{-5}/GeV, defined as resolution goal of tracker

ILD Physics Performance

- Intense analysis efforts towards the DBD, presentations in various sessions here in Arlington
  - Benchmark processes at 1 TeV
    - $e^+e^- \to H\nu\nu$
    - $e^+e^- \to W^+W^-$
    - $e^+e^- \to ttH$
  - Benchmark process at 500 GeV
    - $e^+e^- \to tt$
  - Additional studies, such as Higgs self-coupling, top asymmetries, ...



- New compared to LOI: Inclusion of $\gamma\gamma \to$ hadrons background
  - LHC - inspired jet finding, successfully used at CLIC, to mitigate influence of background: k_t jet finder instead of Durham

ILD Physics Performance

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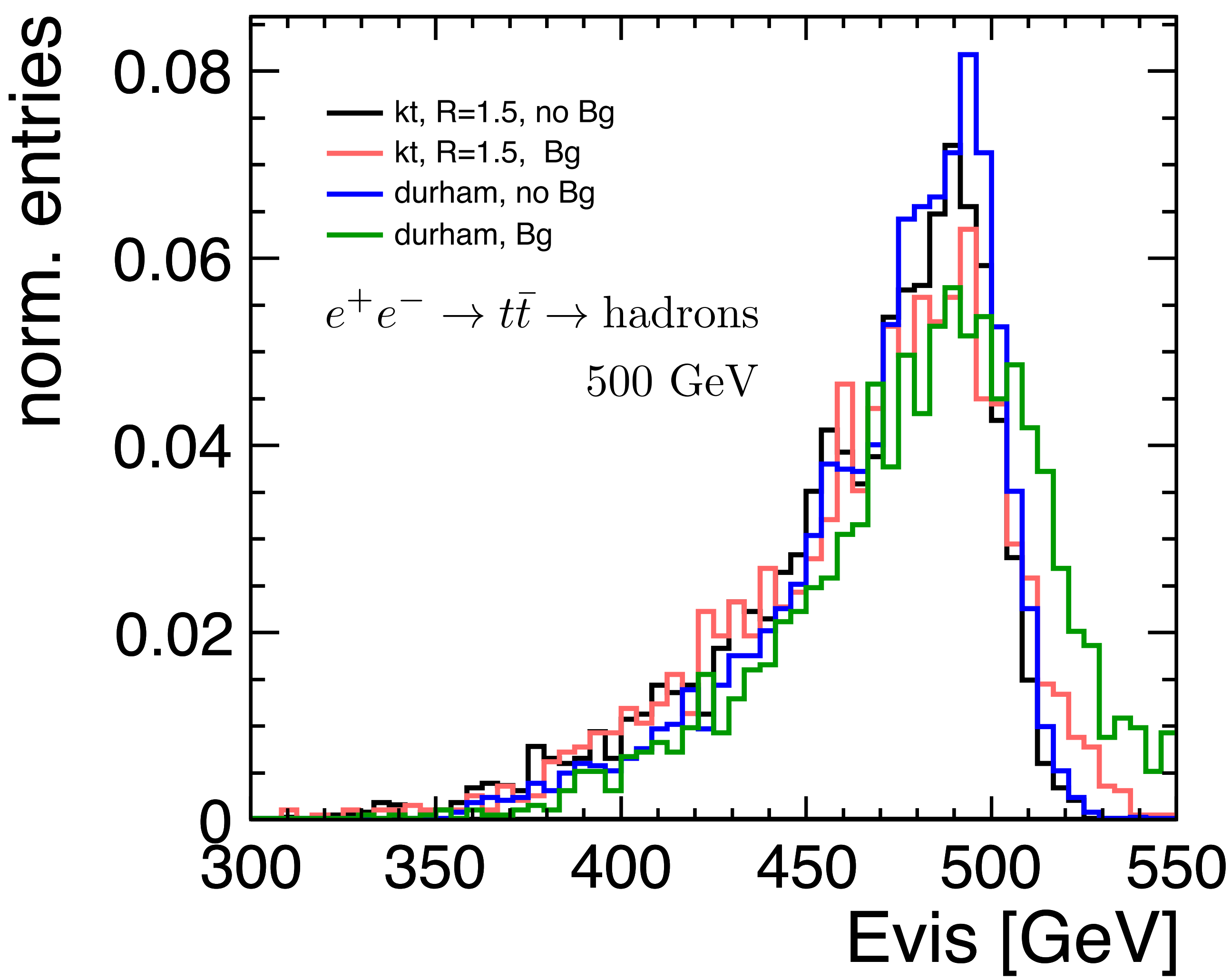

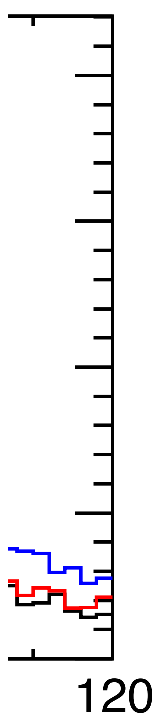

- LHC - inspired jet finding, successfully used at CLIC, to mitigate influence of background: k_t jet finder instead of Durham parameters optimized for different energies

Summary

- ILD is a PFA-based large detector concept optimized for best resolution and flexibility for energies up into the TeV region
  - Low-mass high-resolution vertex detector
  - Main tracker built around a large TPC providing excellent pattern recognition and silicon envelope trackers delivering momentum resolution and forward coverage
  - Highly granular calorimeters (em and hadronic), total thickness of ~ 7 λ
  - Moderate solenoidal field: 3.5 T (can be operated up to 4 T)
- Technology of many key components has been demonstrated
  - Low-mass silicon detectors, highly granular calorimeters with various technologies, power pulsing, ...
- Significant progress on realistic engineering - support, services, ...
- Realistic simulation model: Dead material, cracks, realistic geometries
- Improved reconstruction code: Tracking, PFA, Vertexing
- Physics studies well on the way

Summary

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  - Hi...
  - M...
- Tech...
  - Lo... ies, po...

All of this (and more) is being summarized in the DBD:

Document well on the way

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And a large number of presentations on various topics this week

- Significant progress on realistic engineering - support, services, ...
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