CEPC Calorimeters and Mechanics

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Mechanics Workshop on the CEPC Accelerator and Detectors,

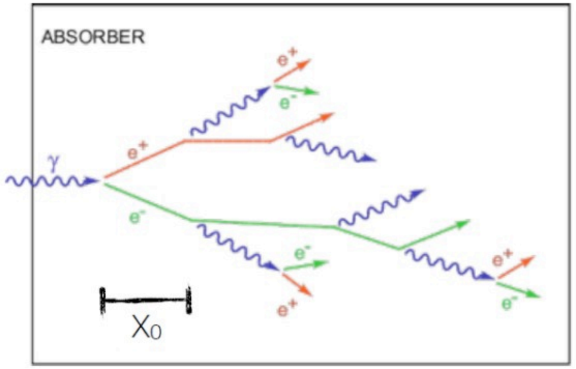
Dongguan, August 28, 2020

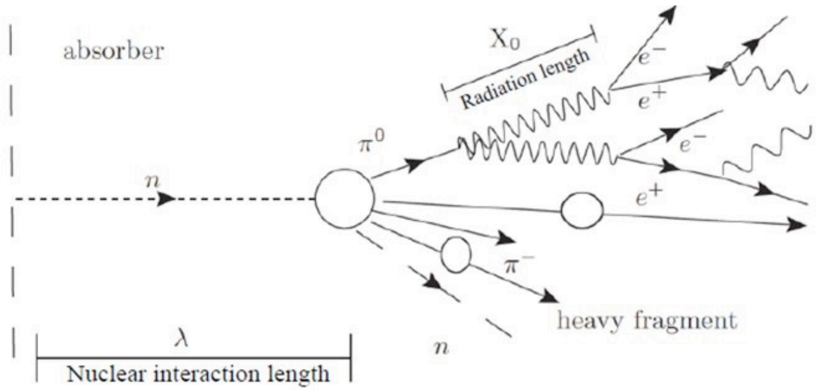
Overview

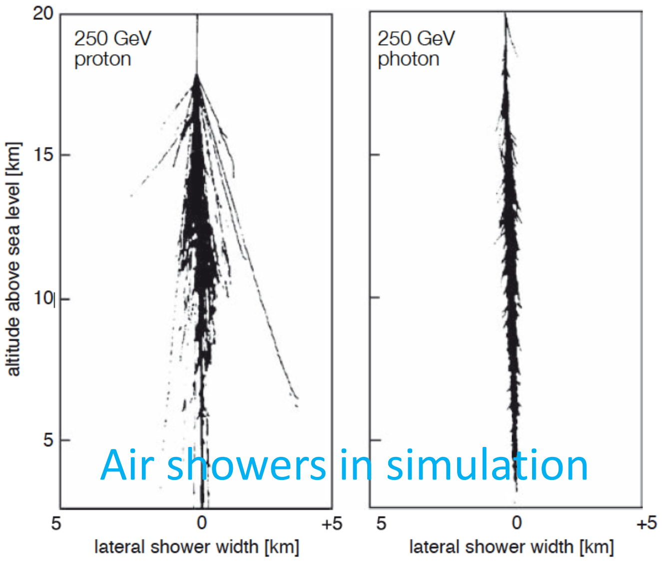
- Introduction: calorimetry
- CEPC calorimeters: baseline design
- A new detector concept for CEPC: alternative option
  - With a crystal calorimeter
- Discussions

Introduction: calorimetry a nutshell

- What is calorimetry in High-Energy Physics?
  - Instruments for measuring **energy** of particles in a destructive way
  - Other quantities: 3D positions, timing
  - Principles
    - Showers initiated by an incident particle: secondary particles in cascades
    - Energy depositions in various forms
      - Ionization, Bremsstrahlung radiation, scintillation, Cherenkov radiation, etc.
    - Final signal ~ total deposited energy

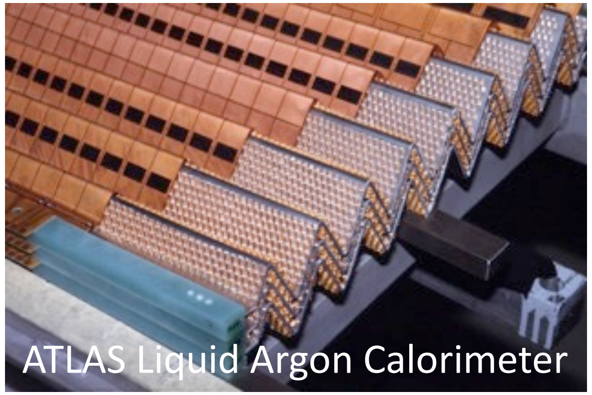


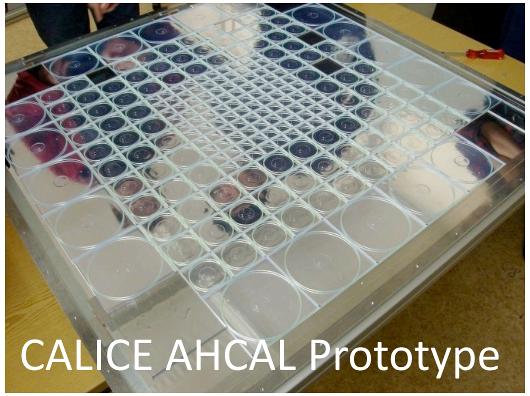




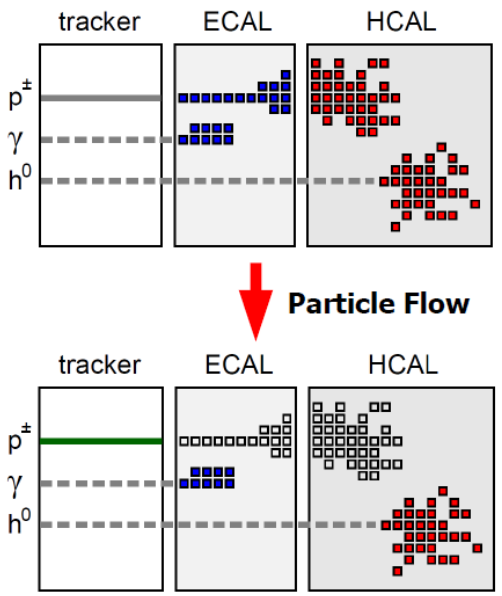
Introduction: calorimetry a nutshell

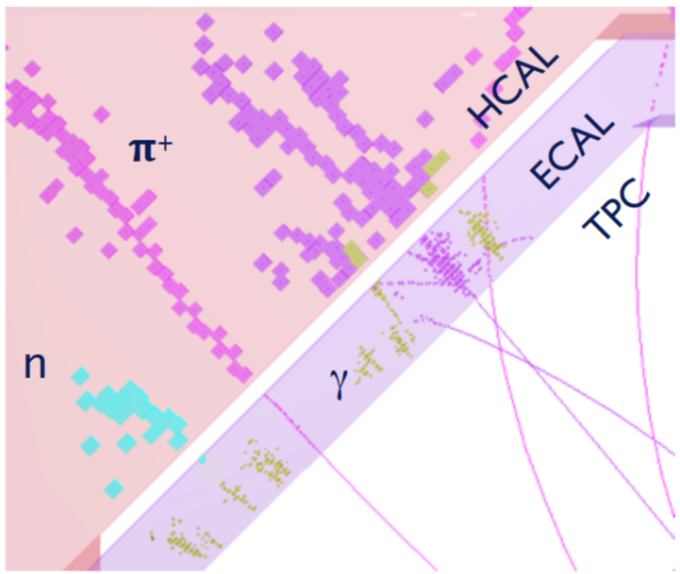
- What is calorimetry in High-Energy Physics?
  - Instruments for measuring **energy** of particles in a destructive way
- Calorimetry categorized by structures
  - Homogenous: high density scintillating crystals (optimal resolution, costly)
  - Sampling: sensitive layers + absorber (compact, cost effective, moderate resolution)
- Calorimetry categorized by shower processes
  - Electromagnetic calorimetry (ECAL): focus on electrons/positrons, gammas
  - Hadronic calorimetry (HCAL): detection of hadrons (pions, kaons, protons, etc.)

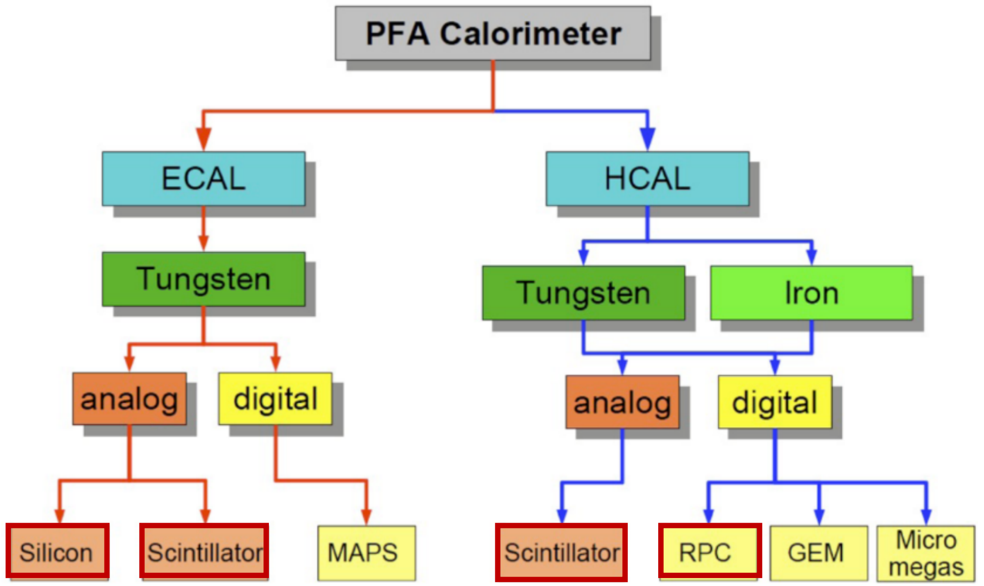




High-granularity calorimeters

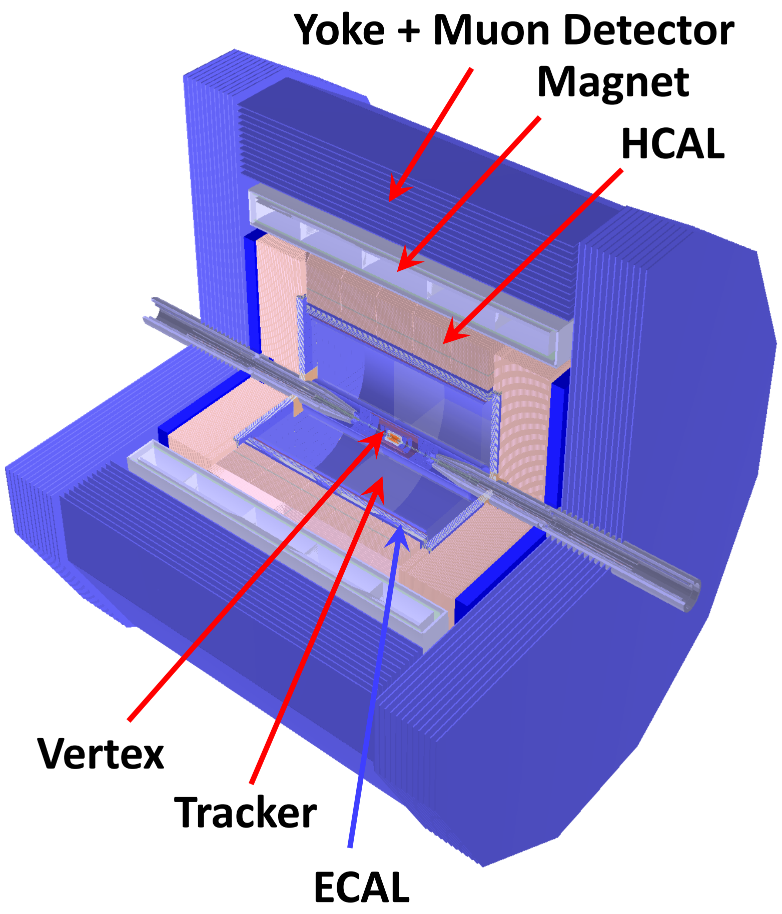


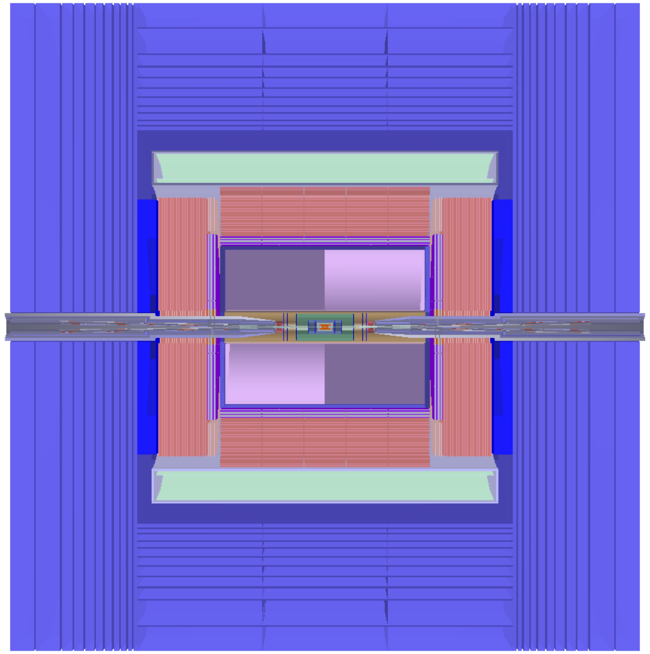


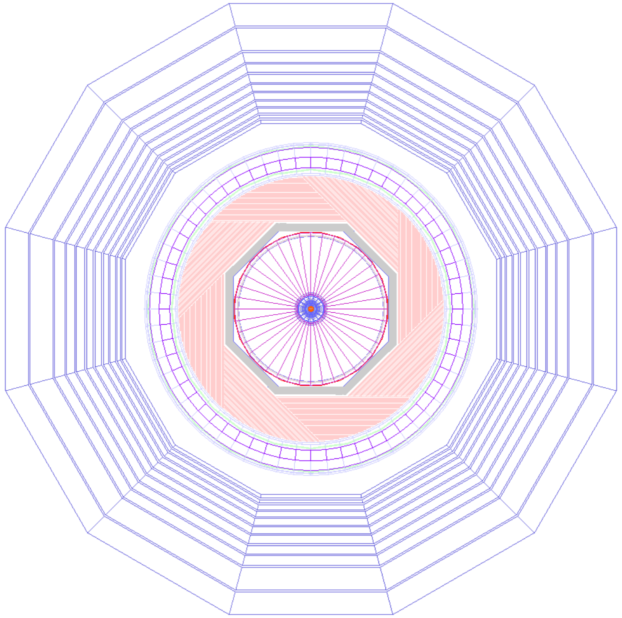


- Particle Flow Algorithm (PFA)
  - Choose sub-detector best suited for each particle type
  - Separate showers of close-by particles in the calorimeters
- High-granularity (imaging) calorimeter
  - Hardware: explosion of readout channels (on the order of 1~10 million)
  - Compact and hermetic: limited space for instrumentation

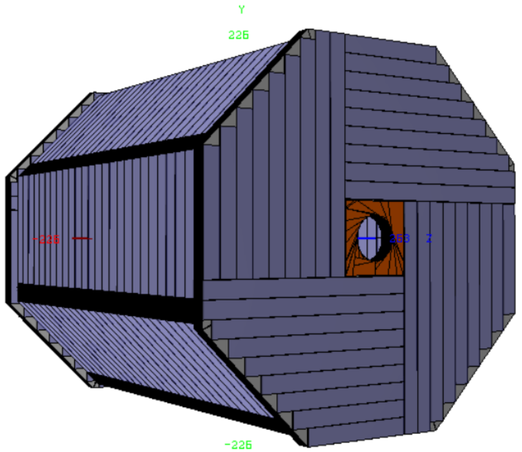
CEPC baseline detector: recap

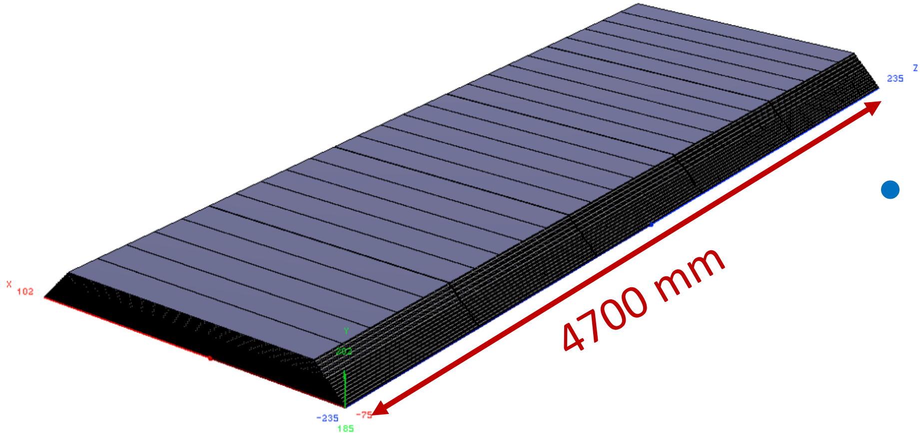


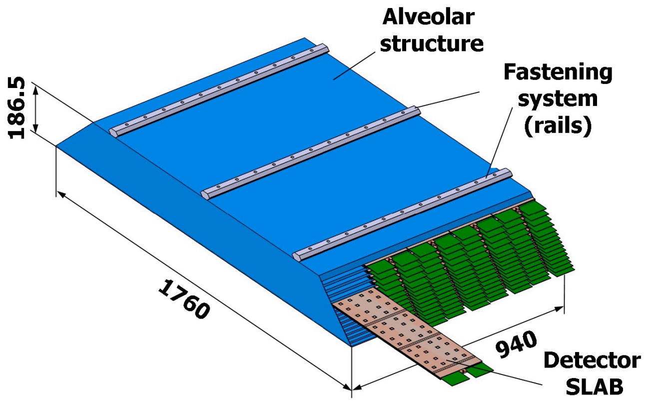


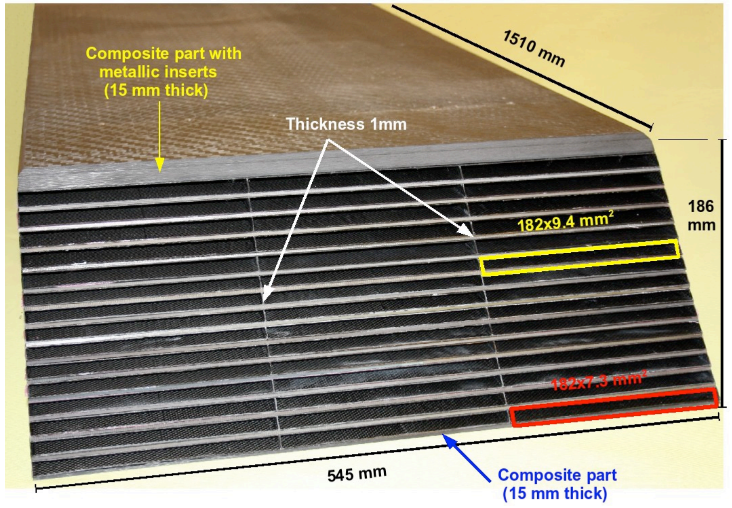


Electromagnetic Calorimeter (ECAL): general layout



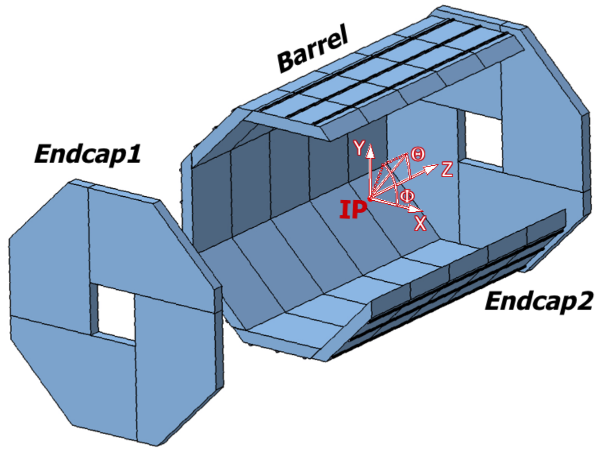


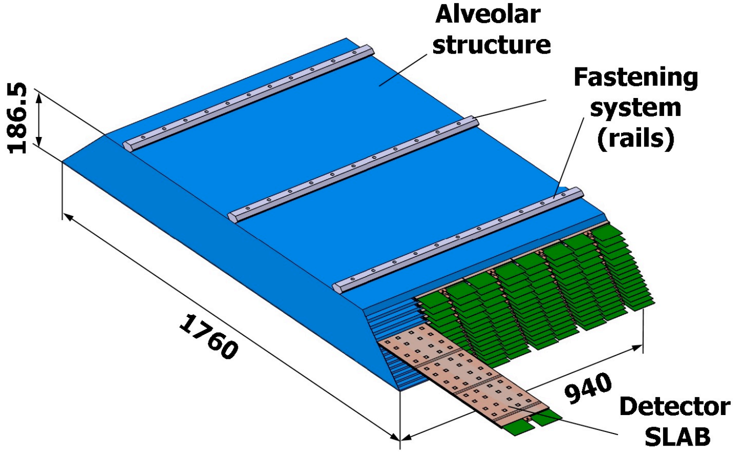


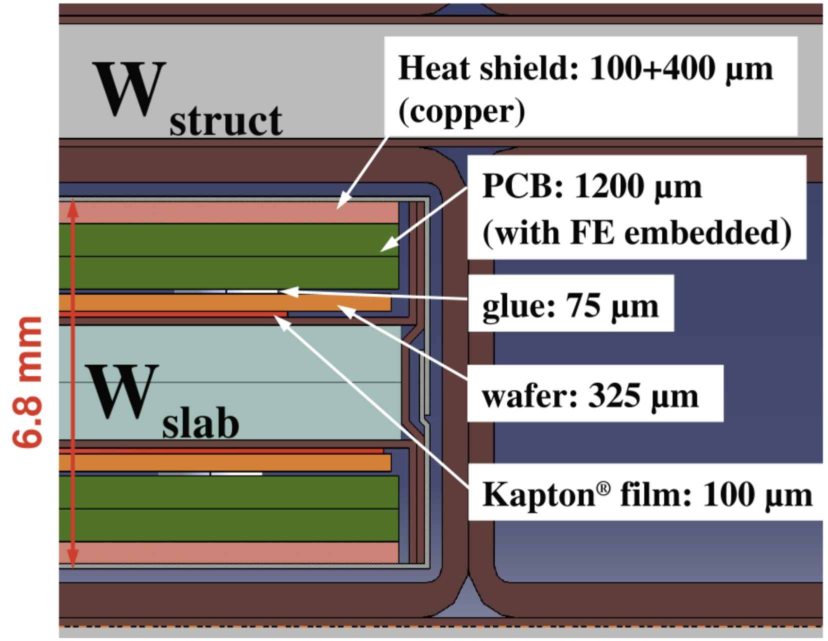


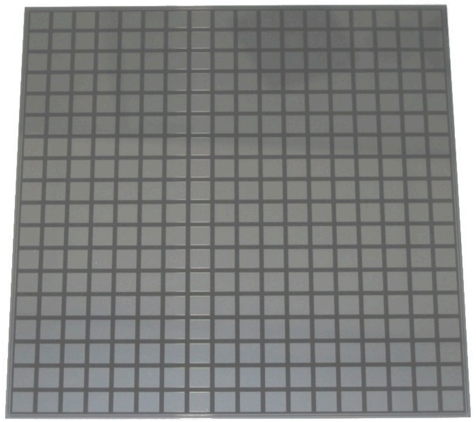
- ECAL structure
  - 1 barrel part, 2 endcap parts
  - 30 layers deep (longitudinal), 24X0
- Barrel ECAL
  - 8 (octaves) staves in barrel
    - 4700 mm long
  - 5 trapezoid modules per stave
  - 5 columns per module
    - 186 mm wide
- Endcap ECAL
  - 4 quadrants per section
    - Radius: 400 ~ 2088 mm
  - 100 mm gap between barrel and endcap: reserved for services

ECAL: Silicon-Tungsten option

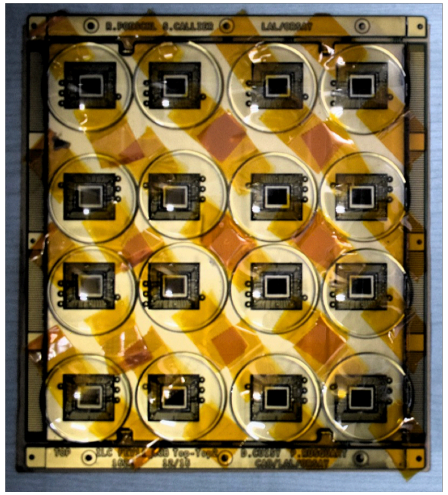








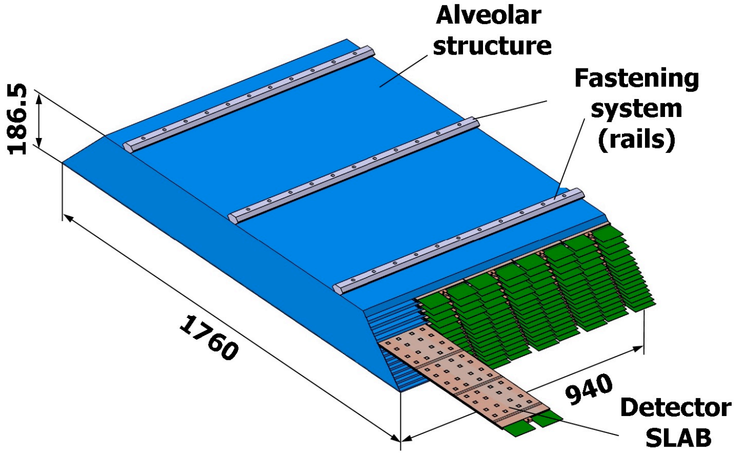
Silicon sensor

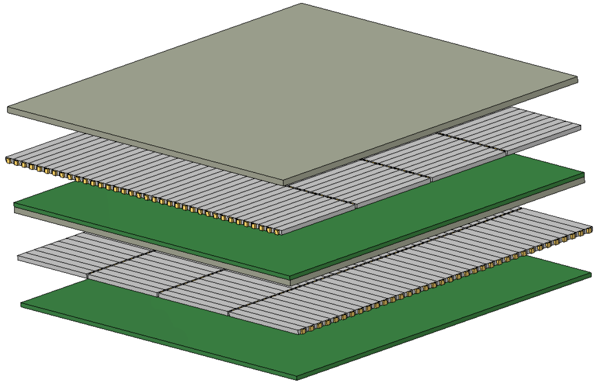


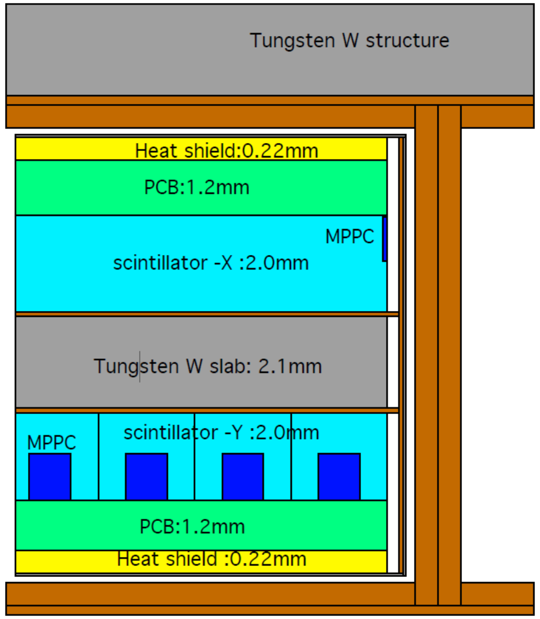
Chip-On-Board

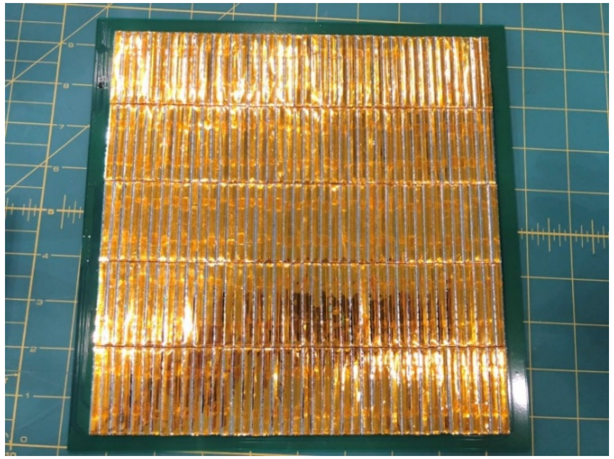
- Sensitive layers
  - Silicon sensors: 0.32~1.0 mm thick (0.5mm baseline)
  - PCB + ASICs: 1.8 mm thick (challenging)
  - Chip-On-Board 1.2mm thick demonstrated, with ASICs wire-bonded

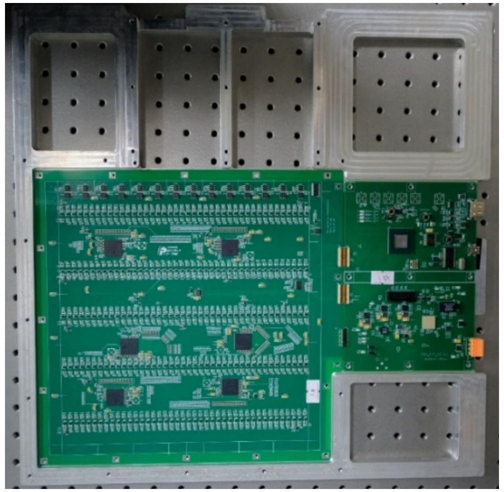
ECAL: Scintillator-Tungsten option





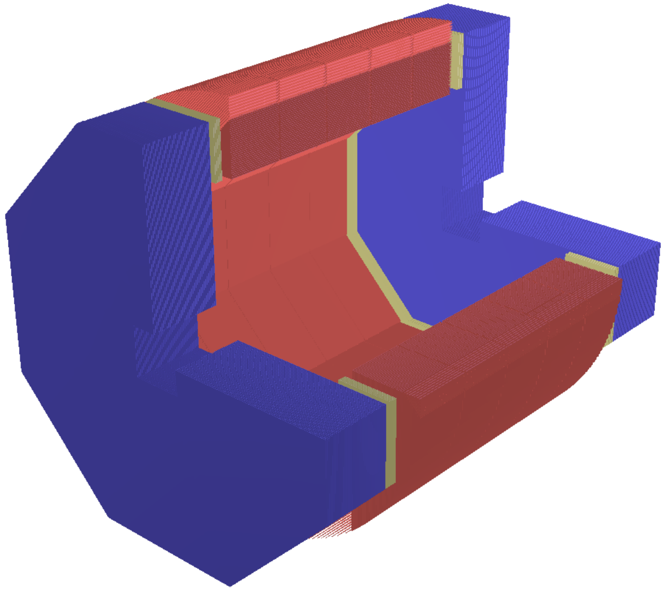


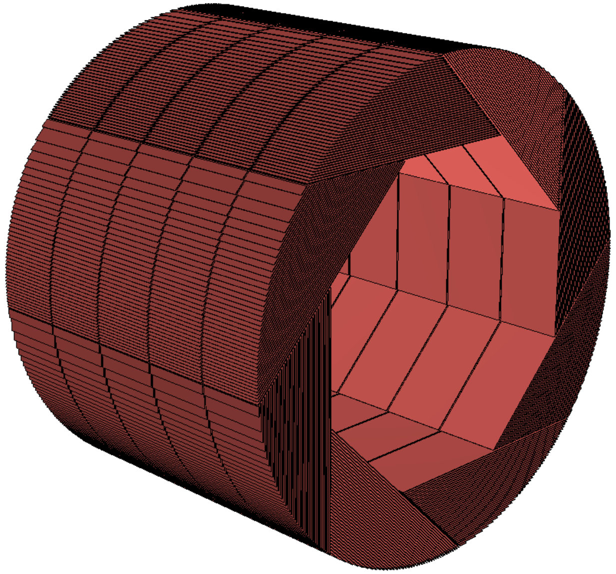




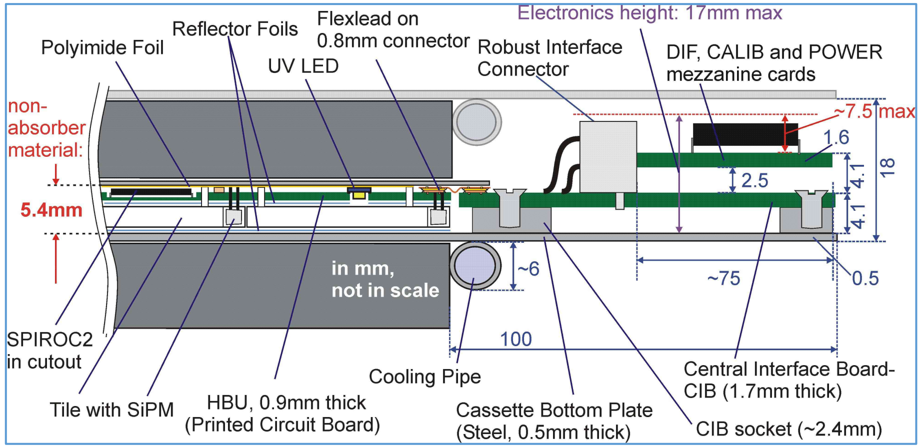
- Sensitive layers
  - Scintillator strips: 2mm thick
  - PCB + ASICs: considerably thicker than 1.2 mm thick specified in the design (too challenging)
- Experiences from building a prototype

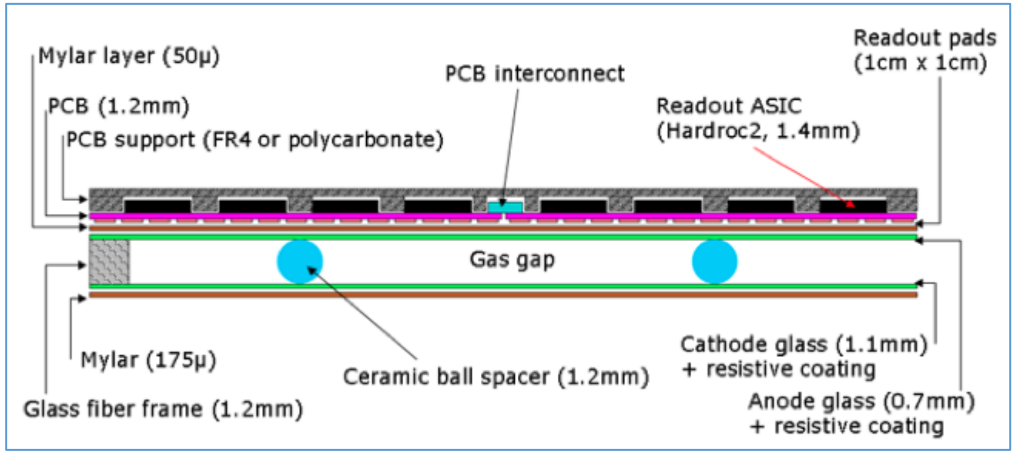
Hadronic Calorimeter (HCAL)





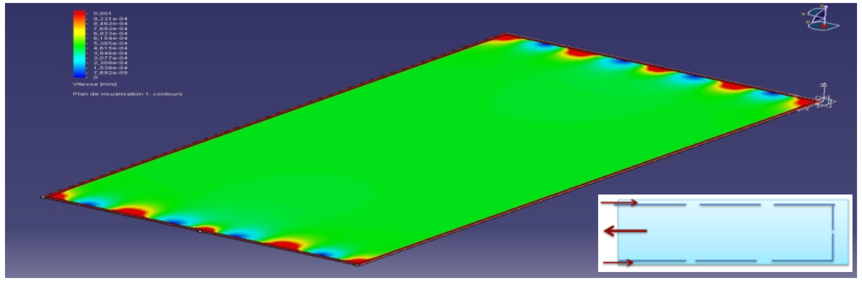
- HCAL structure
  - 1 barrel part, 2 endcap parts
  - 40 layers in depth
- Barrel HCAL
  - Radius: 2058mm to 3144mm
- Endcap HCAL
  - Along Z: 2650mm to 3736 mm

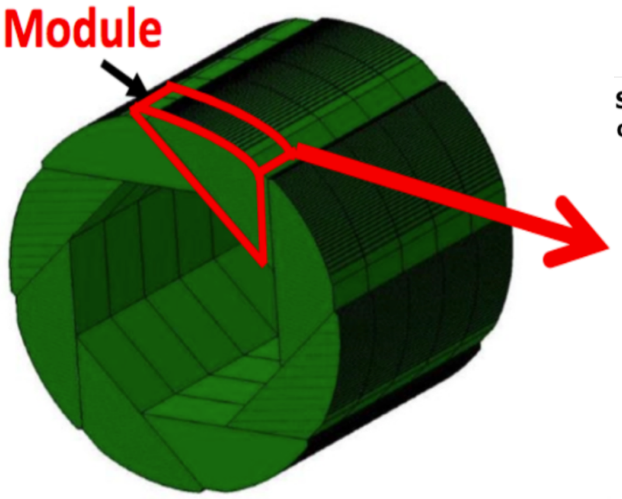


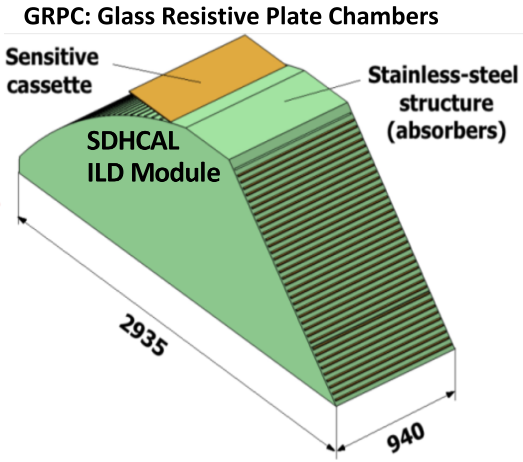


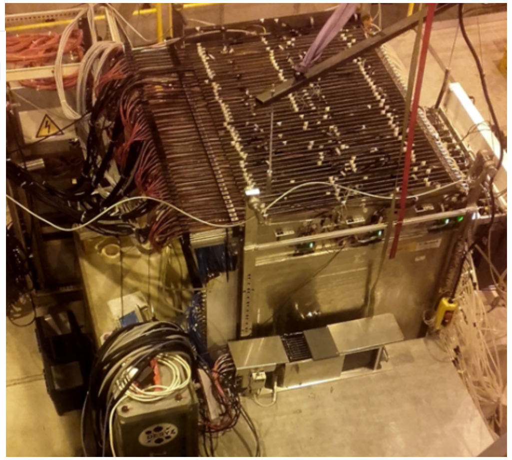
HCAL: RPC-Steel option

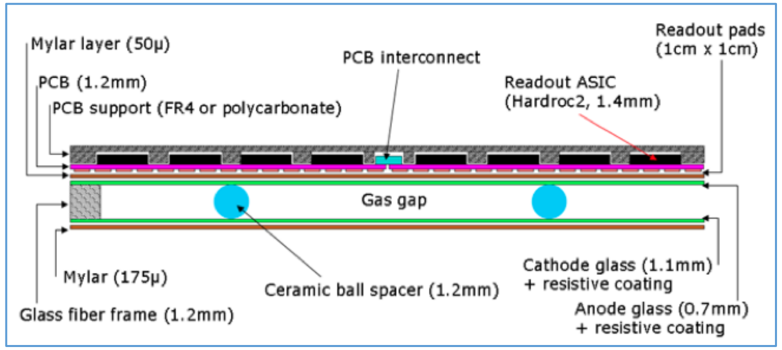
- Semi-Digital HCAL (SDHCAL)
  - Glass RPC: working in avalanche mode
  - 1×1 cm² pads: digital signals (either 0 or 1)
  - Absorber: stainless steel plates (20mm thick)
  - Compact self-supporting structure design
    - Negligible dead zones; eliminates projective cracks





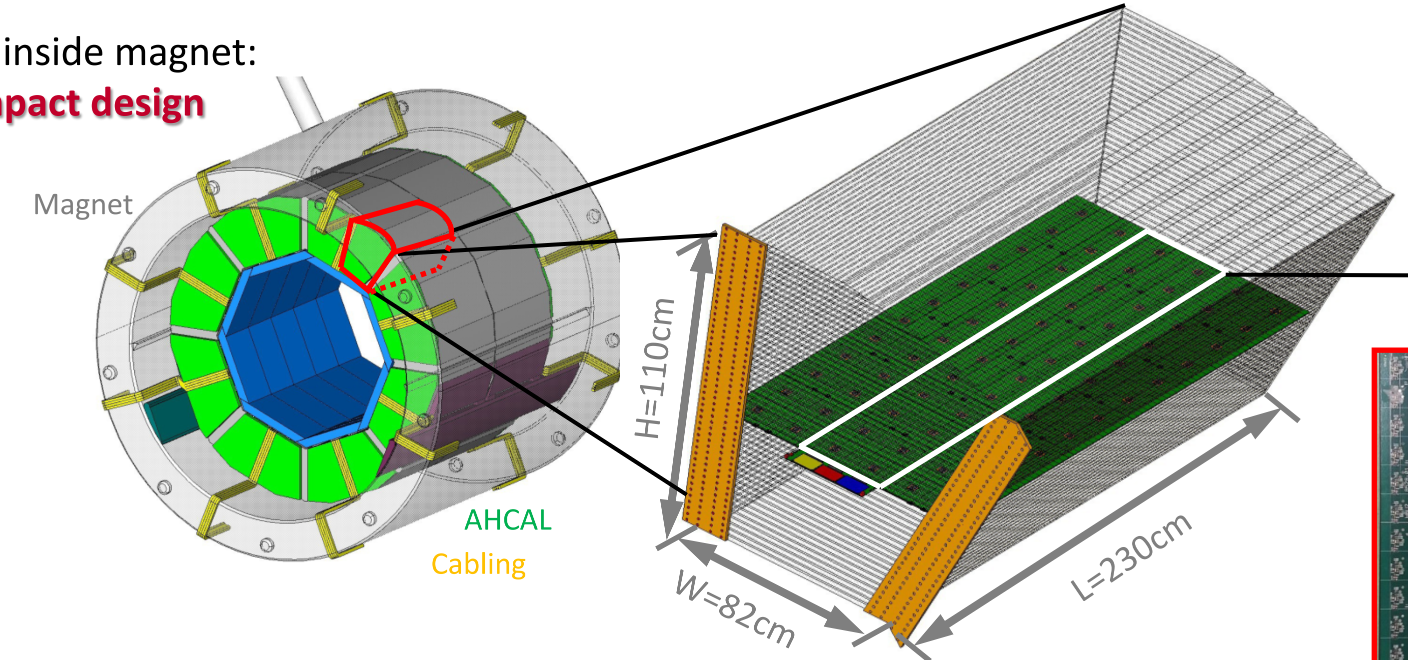


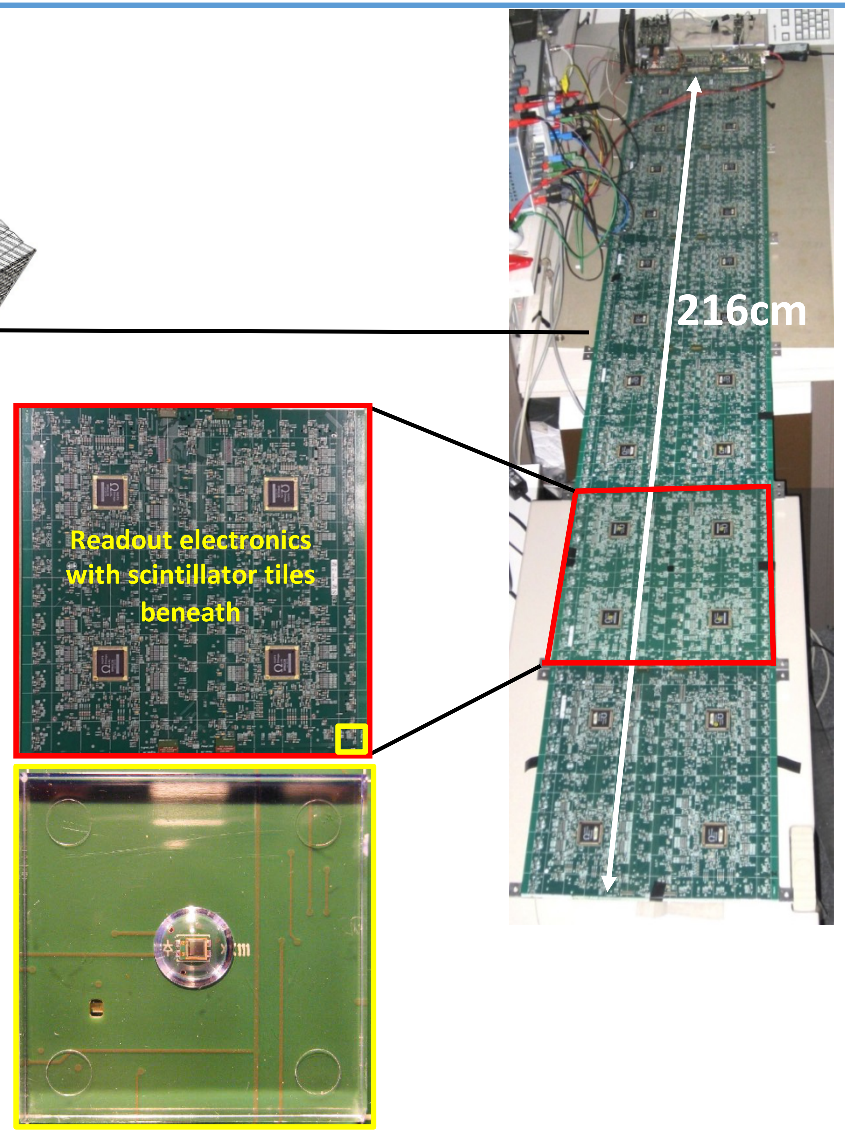




HCAL: Scintillator-Steel option

AHCAL inside magnet:
compact design

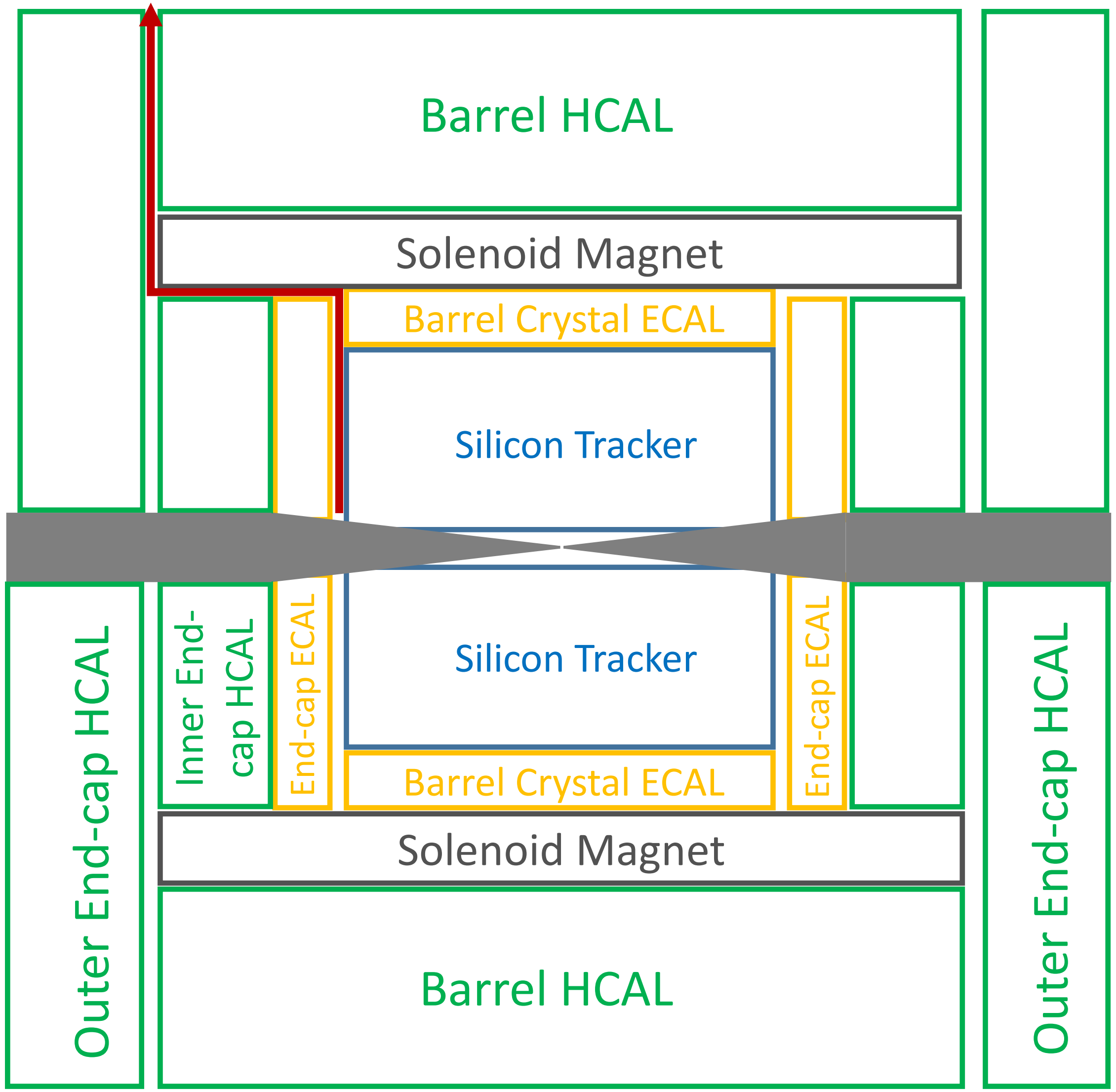




- Analogue HCAL
  - Scintillator tile (30x30x3 mm³) individually read out by SiPM
  - Absorber: stainless steel plates (20mm thick)
  - Electronics fully integrated into active layers
  - HCAL base unit: 36x36 cm² PCB (with 144 channels)

A new CEPC detector concept with a crystal ECAL

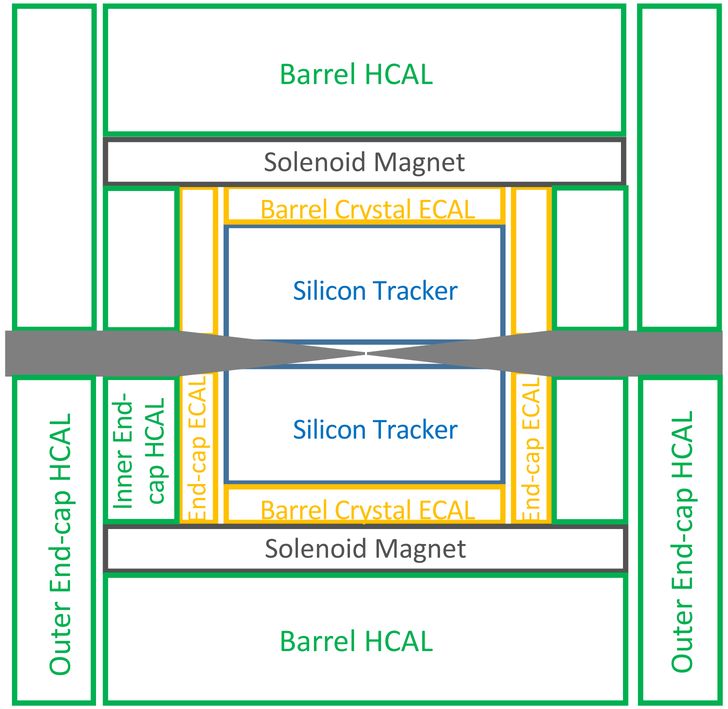
- Vertex
- Silicon tracker
- Crystal ECAL
- Superconducting Solenoid Magnet
- HCAL options: AHCAL or SDHCAL
- Muon detector (not shown)



Services along gaps between barrel and endcap calorimeters

A new CEPC detector concept: details

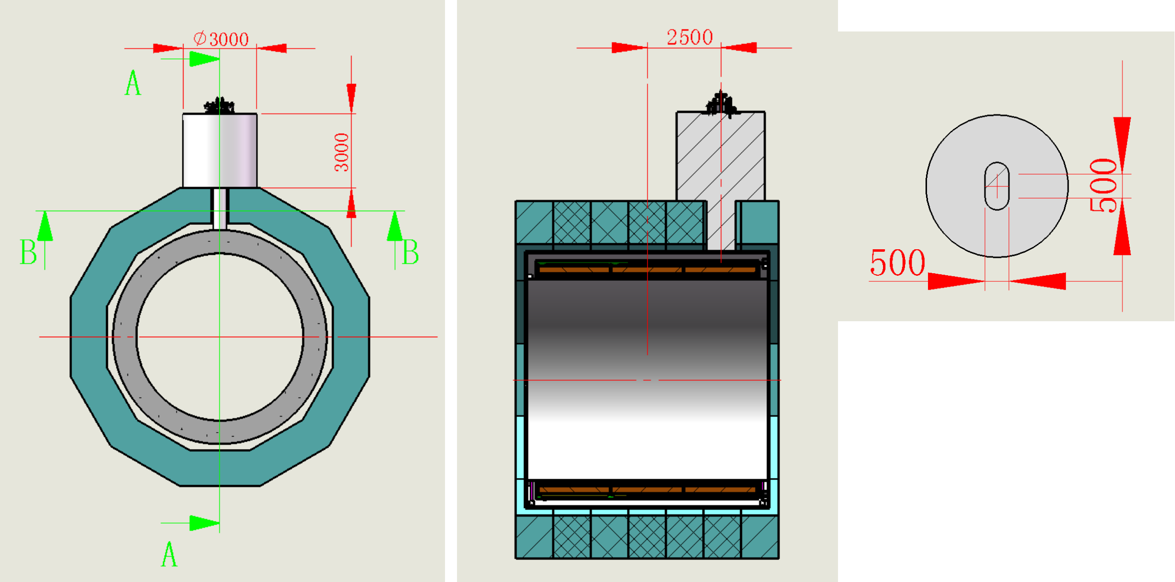
- Vertex and silicon tracker
  - No Time Projection Chamber (TPC)
  - Remains 4.7 m length along Z
  - Potential to shrink outer radius R=1.5m (from 1.8m)
- Crystal ECAL: outside tracker
  - Potential to starting at inner radius R=1.5m
  - Full depth 30~40 cm: crystal + readout +cooling
- Superconducting Solenoid Magnet
  - B-field strength required: 2~3 Tesla
  - Options: HTS (needs proof-of-principle) vs LTS (conventional)
  - Chimney for current leads and cryogenic lines: impact to HCAL?
- HCAL options: AHCAL or SDHCAL (same as previous slides)



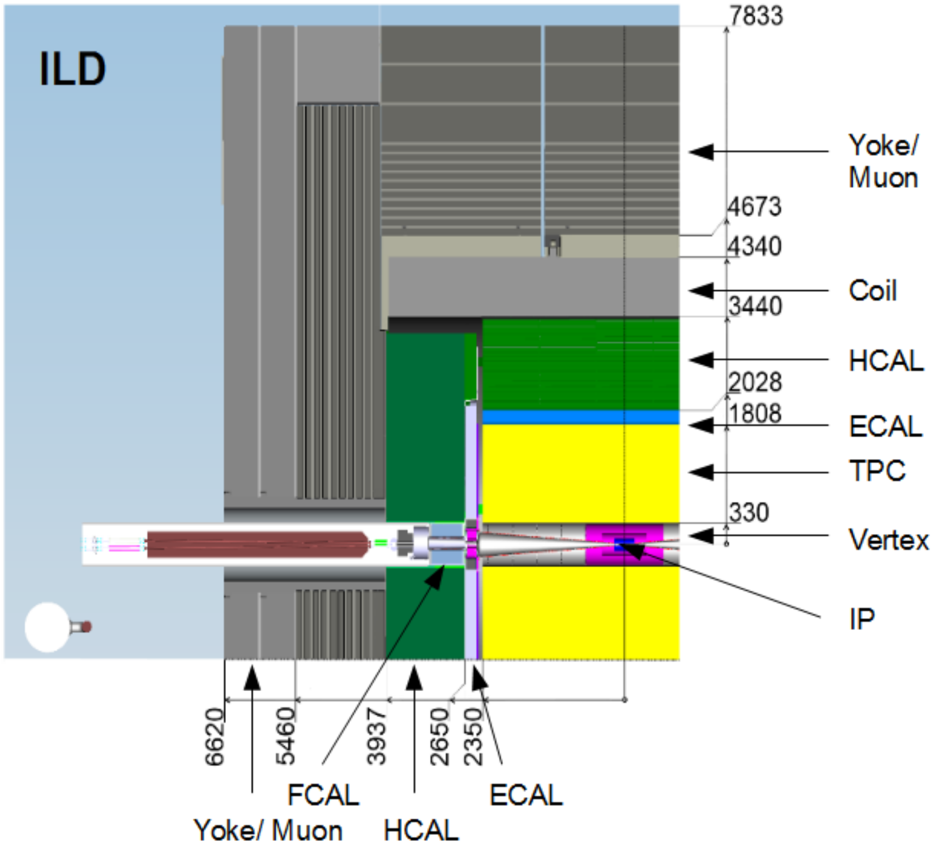
Magnet chimney impact

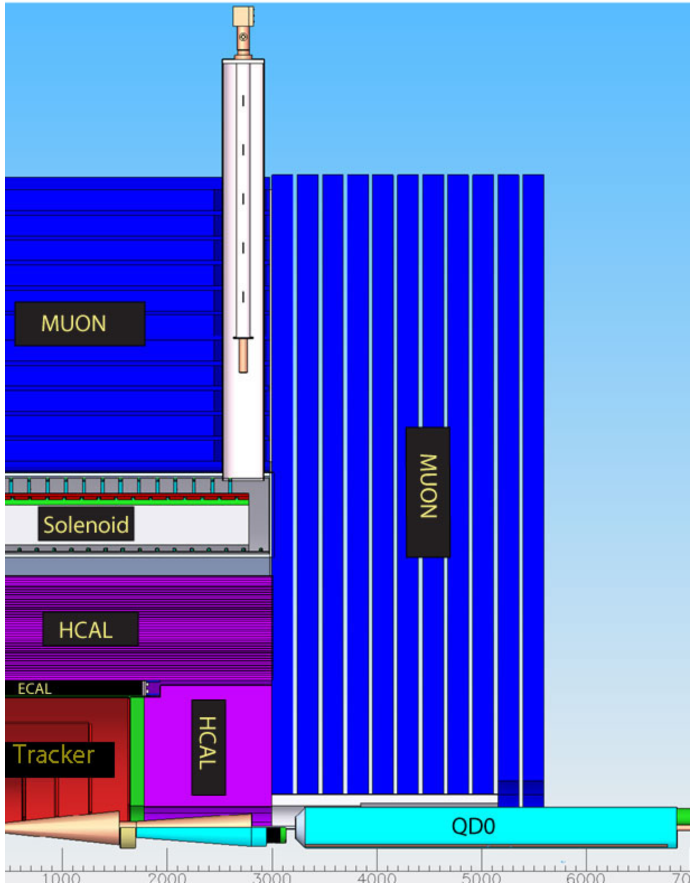
- Magnet placed between ECAL and HCAL
  - Chimney can (substantially) decrease HCAL detection area and efficiency

- Inputs from the CEPC Magnet Group
  - CEPC探测器超导磁体单个阀箱方案
    - 阀箱改为一个，加大，直径Ø3m,高度3m
    - 改为一个异型烟囱，加大,截面约1m×0.5m
    - 低温管引出位置在距磁体中心2.5m位置
    - 烟囱占用边缘2个u探测器环的12点位置



Magnet chimney designs in ILD and SiD





- SiD: two separate iron penetrations will be used, a 70 cm x 40 cm chimney for the current leads and 36 cm diameter chimney for the cryogenic plumbing

CMS Magnet Design

CERN/LHCC 97-10, CMS TDR 1,
The Magnet Project Technical Design Report

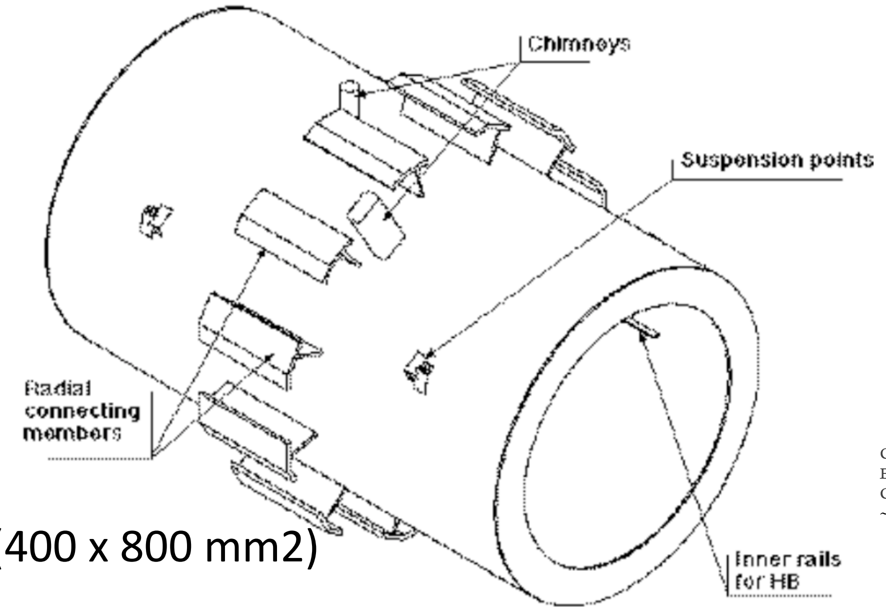
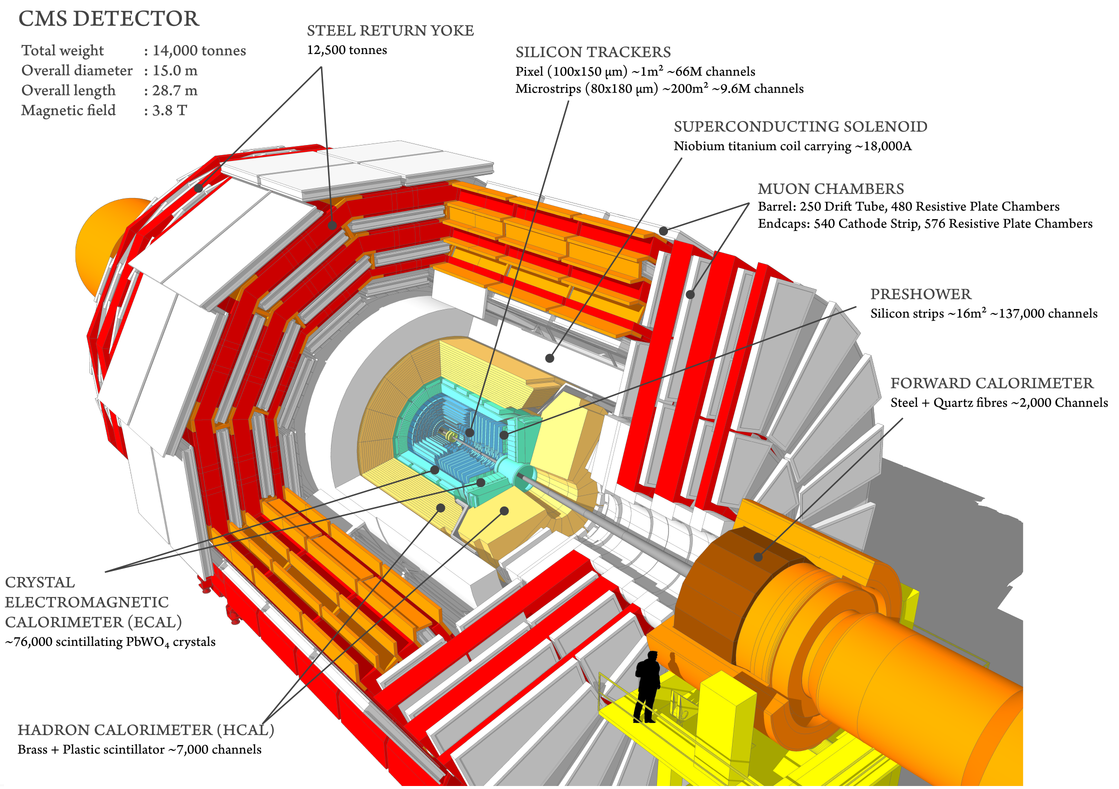


Fig. 9.1: Vacuum Tank general overview.

Vacuum chimney (400 x 800 mm2)



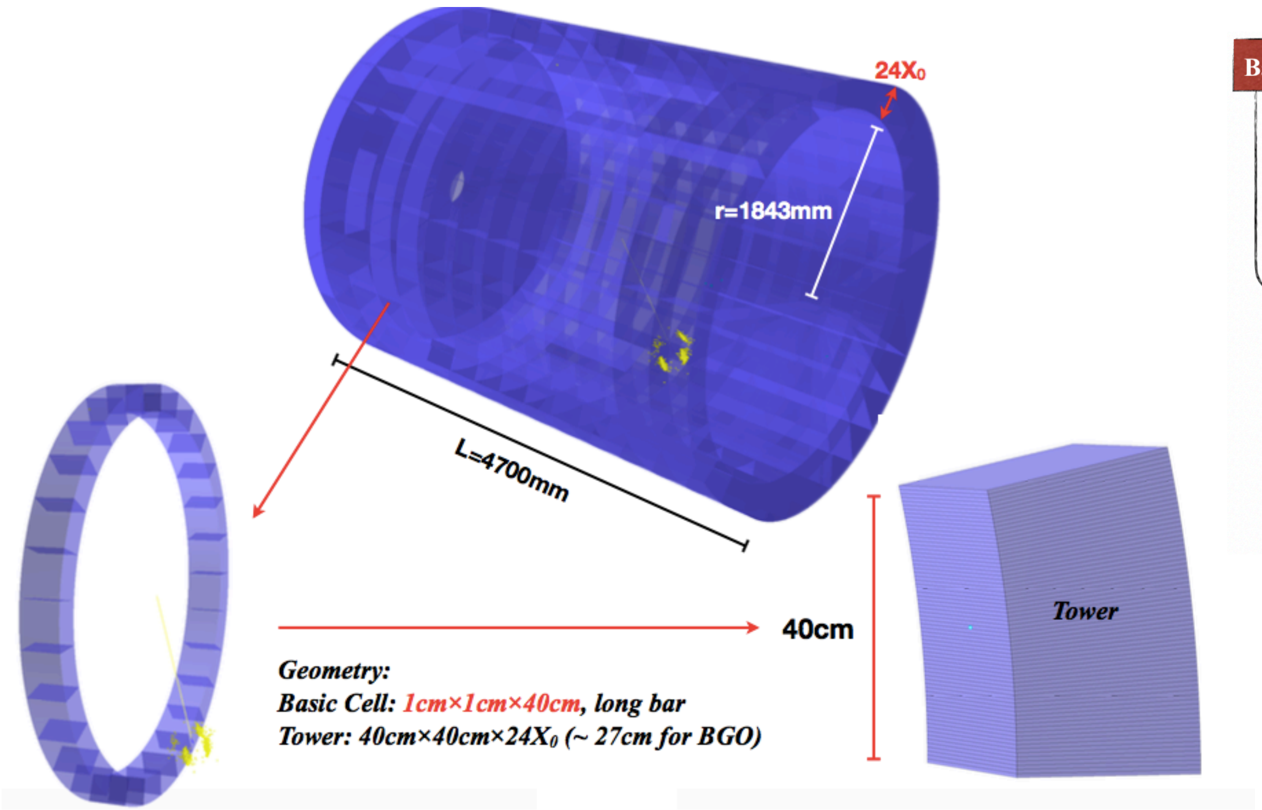
- Two chimneys are situated near the top of the vessel, on each side of the central ring of the barrel yoke. Their purpose is the following:
- i) the vertical chimney contains the cryogenic lines, maintaining the solenoid at 4 K during operation,
- ii) the second one, inclined at 30° to the vertical, contains the electrical leads, and is also used as the main pumping and venting line.

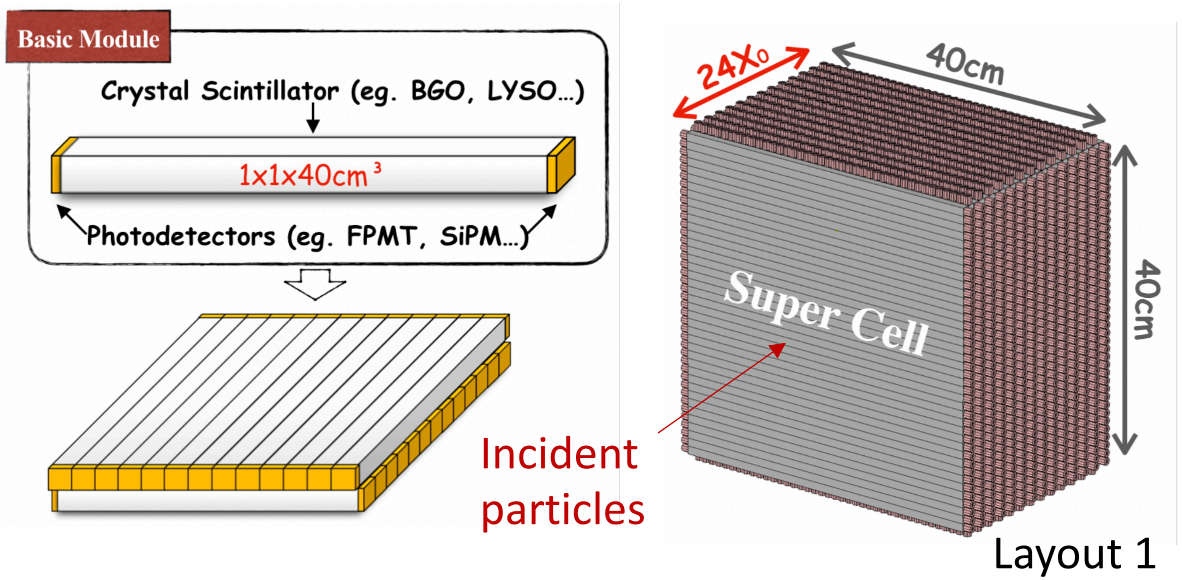
Summary

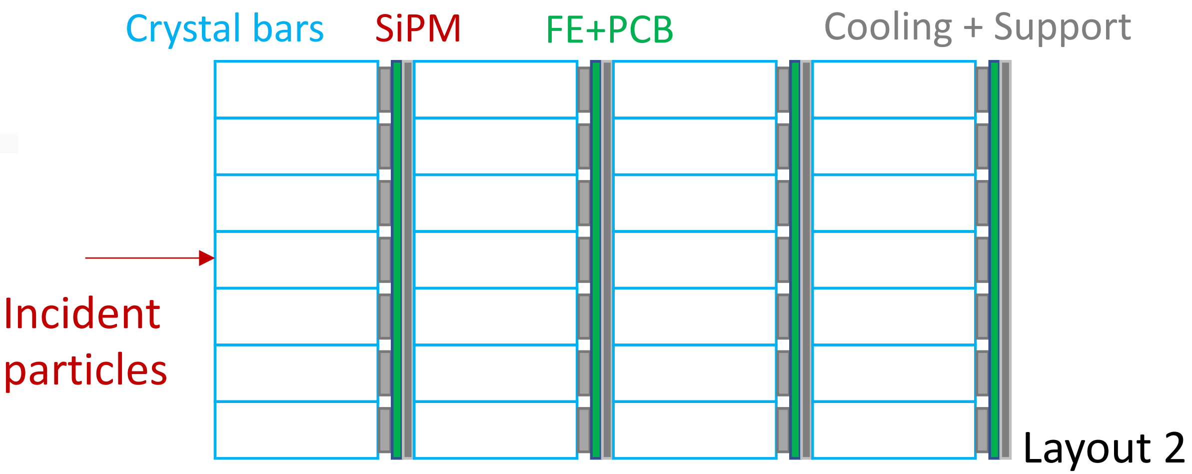
- CEPC CDR baseline calorimeters
  - General layouts based on CALICE and ILD efforts
  - 2 major layouts for HCAL: SDHCAL vs AHCAL
  - Sensitive layers: more realistic thickness numbers from prototyping, further iterations for the mechanics design
- Active cooling design
  - Missing in the current mechanics design
  - Crucial to the circular collider
  - Needs solid inputs on the power consumption
- A new detector concept with crystal ECAL
  - Initiate sub-detector designs and development of software framework and tools
  - Will perform performance studies

Spare slides for more details

Crystal ECAL: design and layouts

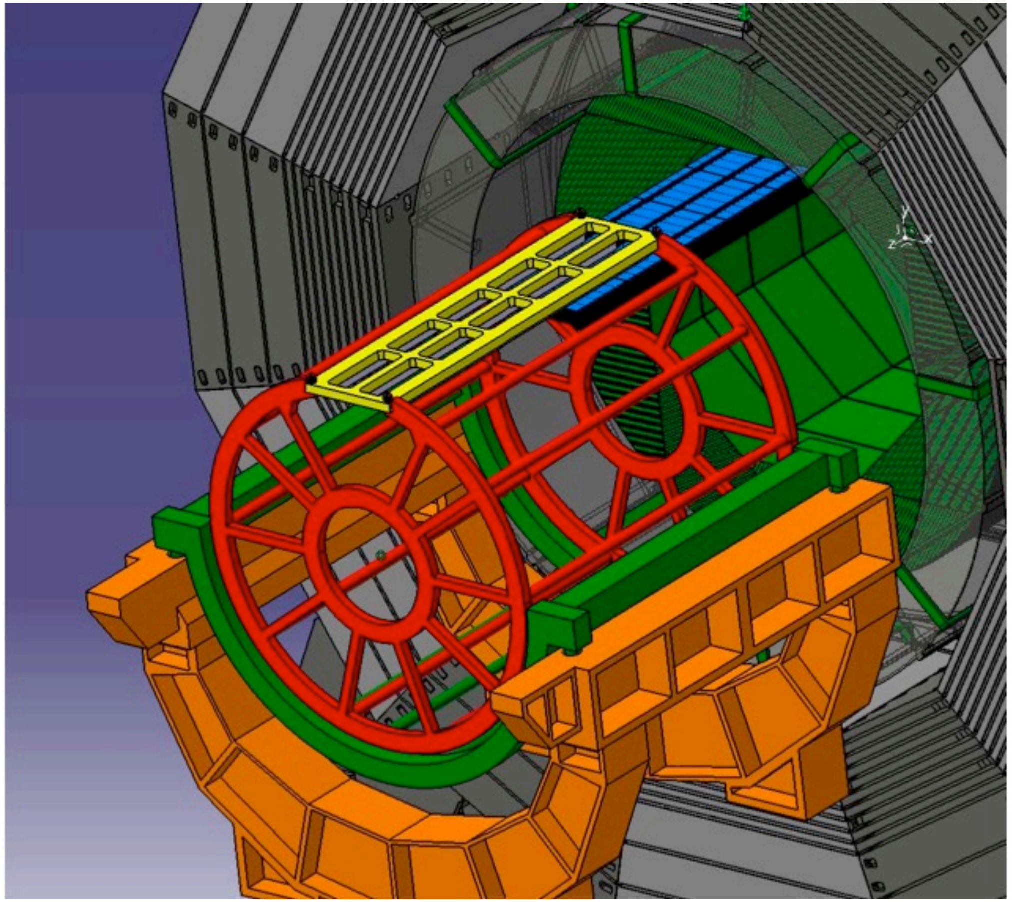


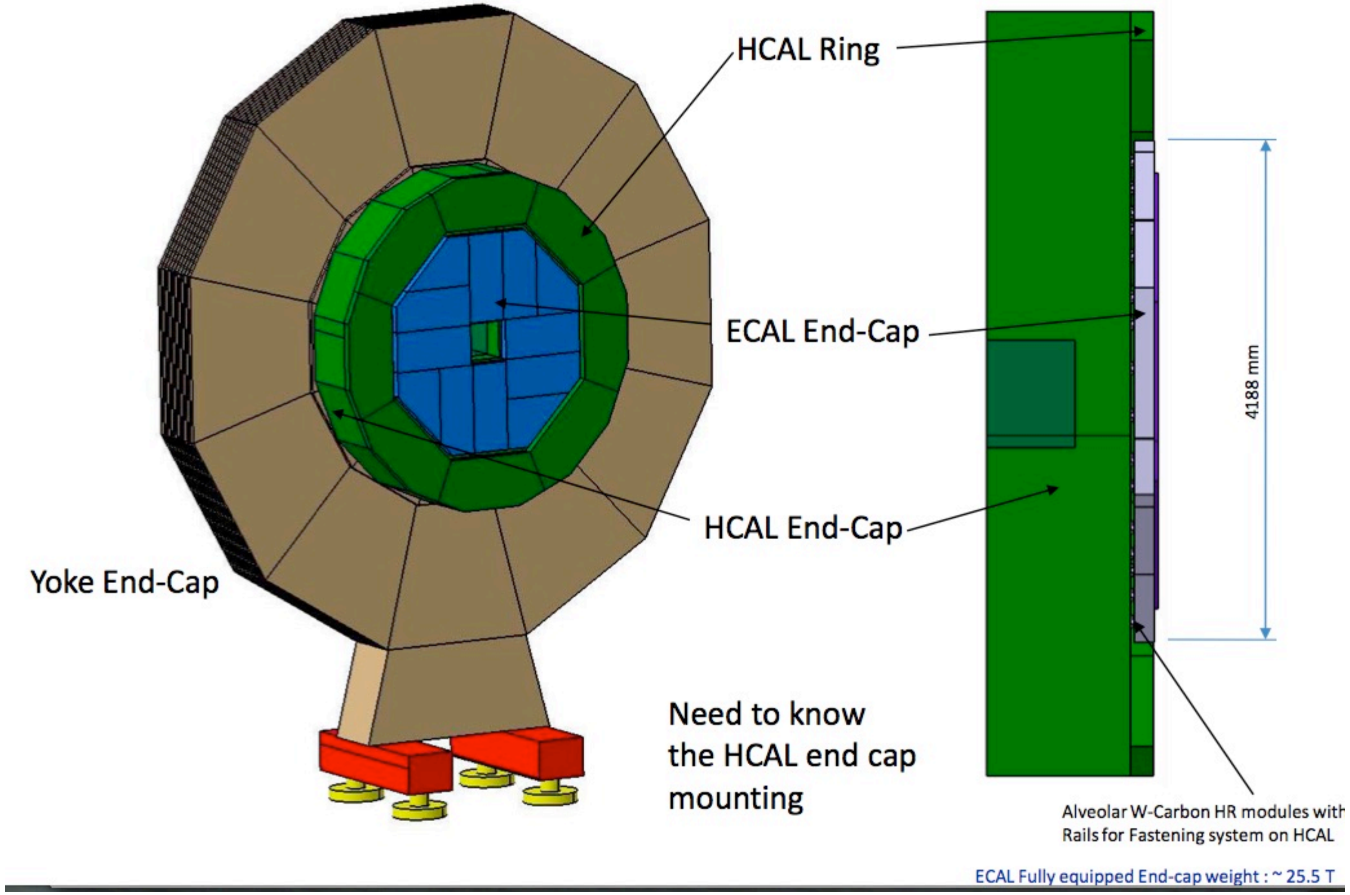




- Crystal ECAL design still in development
- 2 layouts proposed: currently focus on the layout with long bars

Barrel ECAL installation and endcap calorimeters

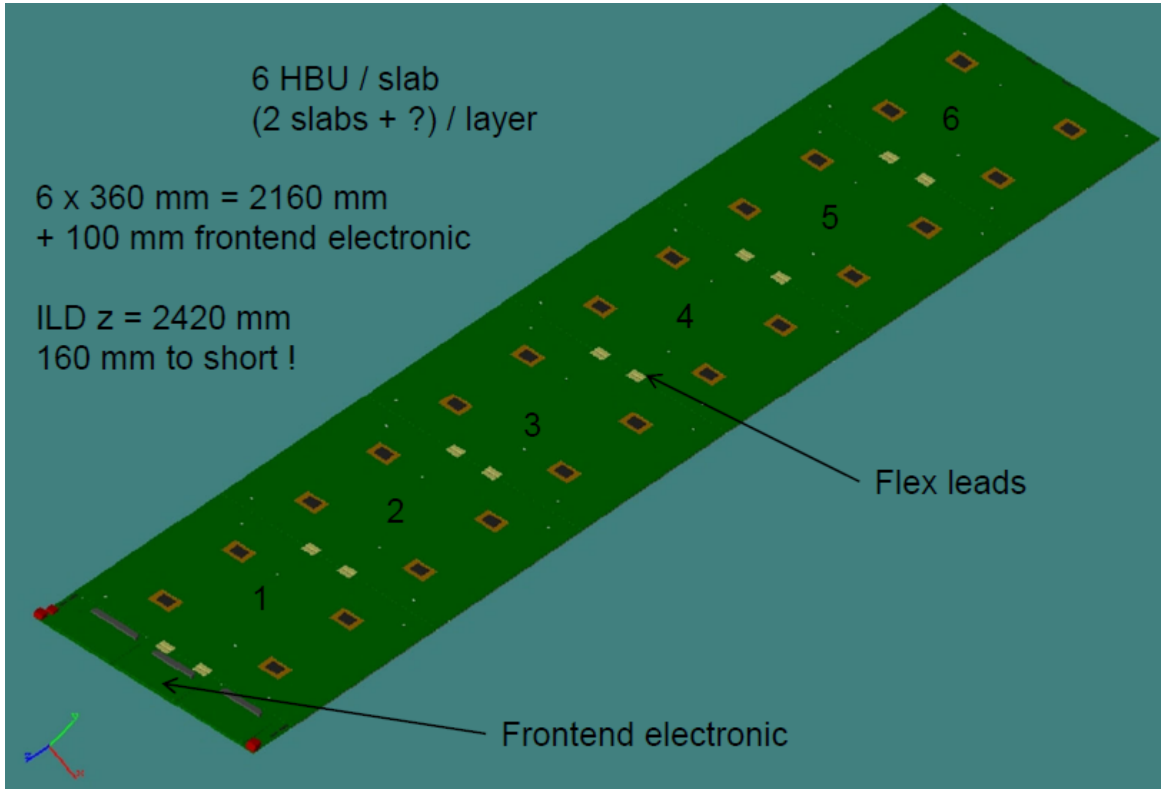


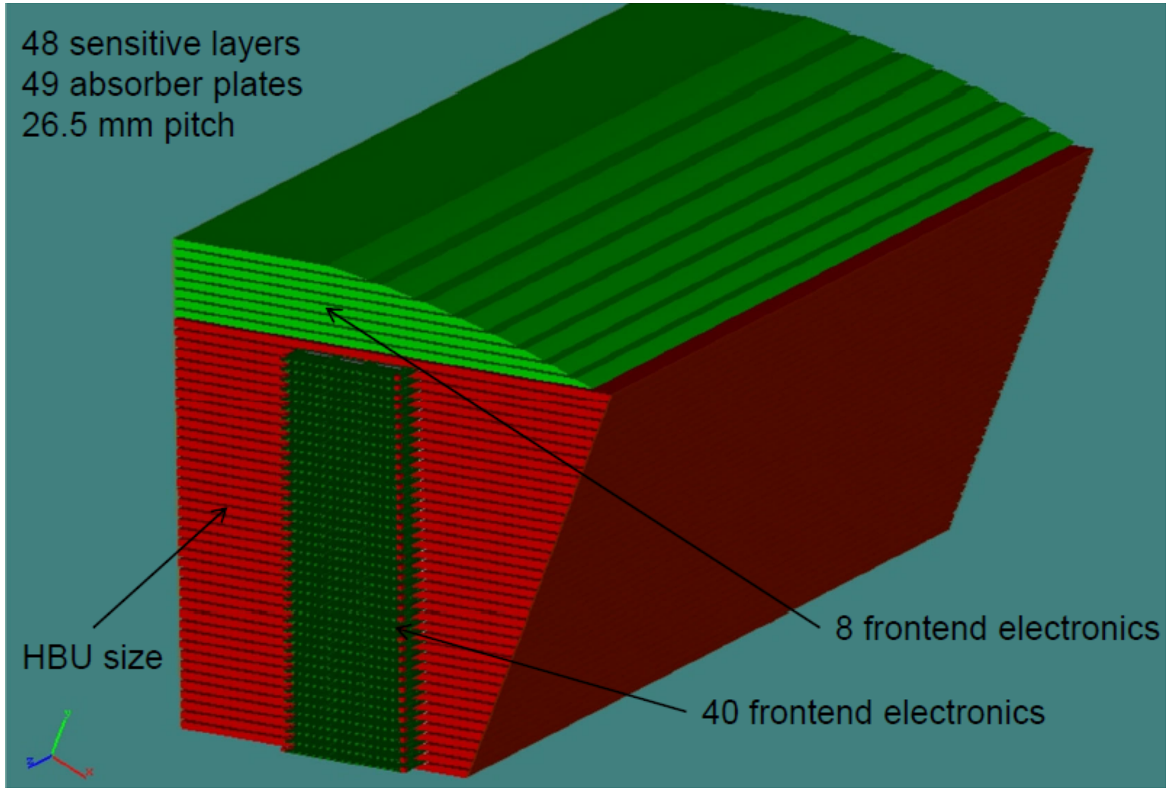


ILC TDR Volume 4: page 257-258,
https://arxiv.org/abs/1306.6329

AHCAL mechanics designs: details

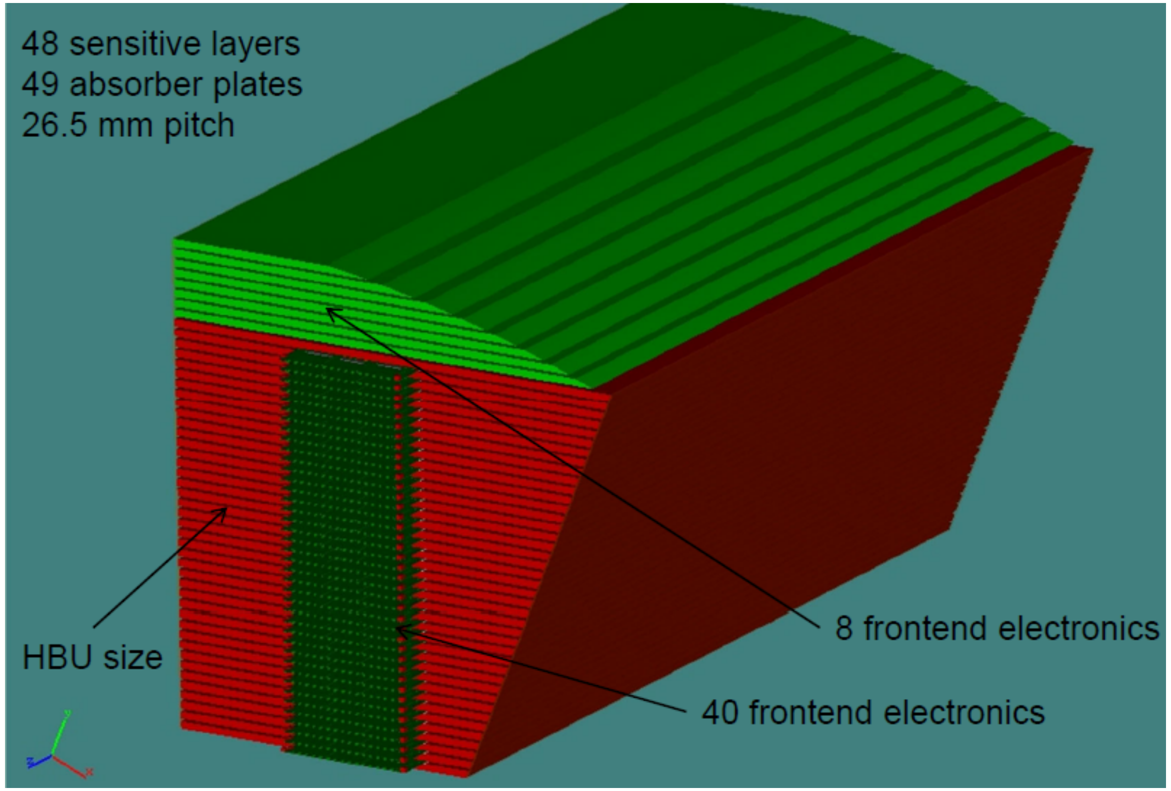
AHCAL Mechanics Design for ILD at ILC by K. Gadow (DESY)

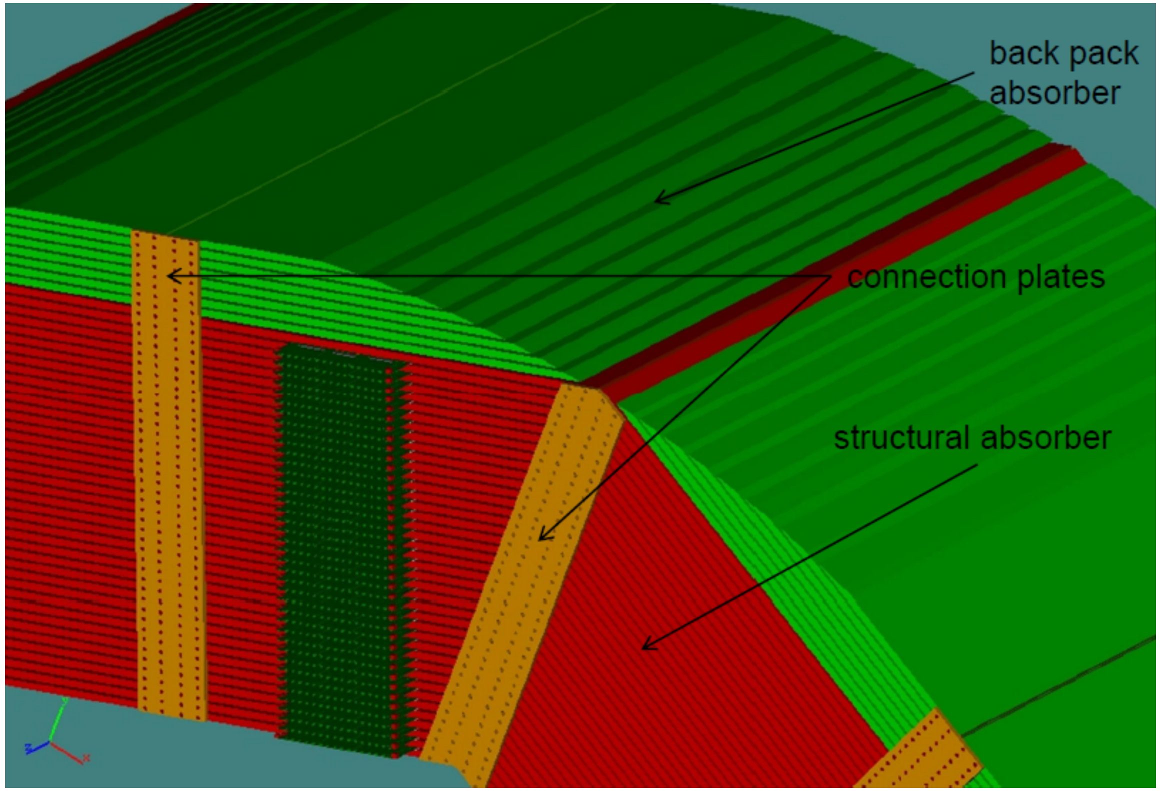




AHCAL mechanics designs: absorber structure

AHCAL Mechanics Design for ILD at ILC by K. Gadow (DESY)

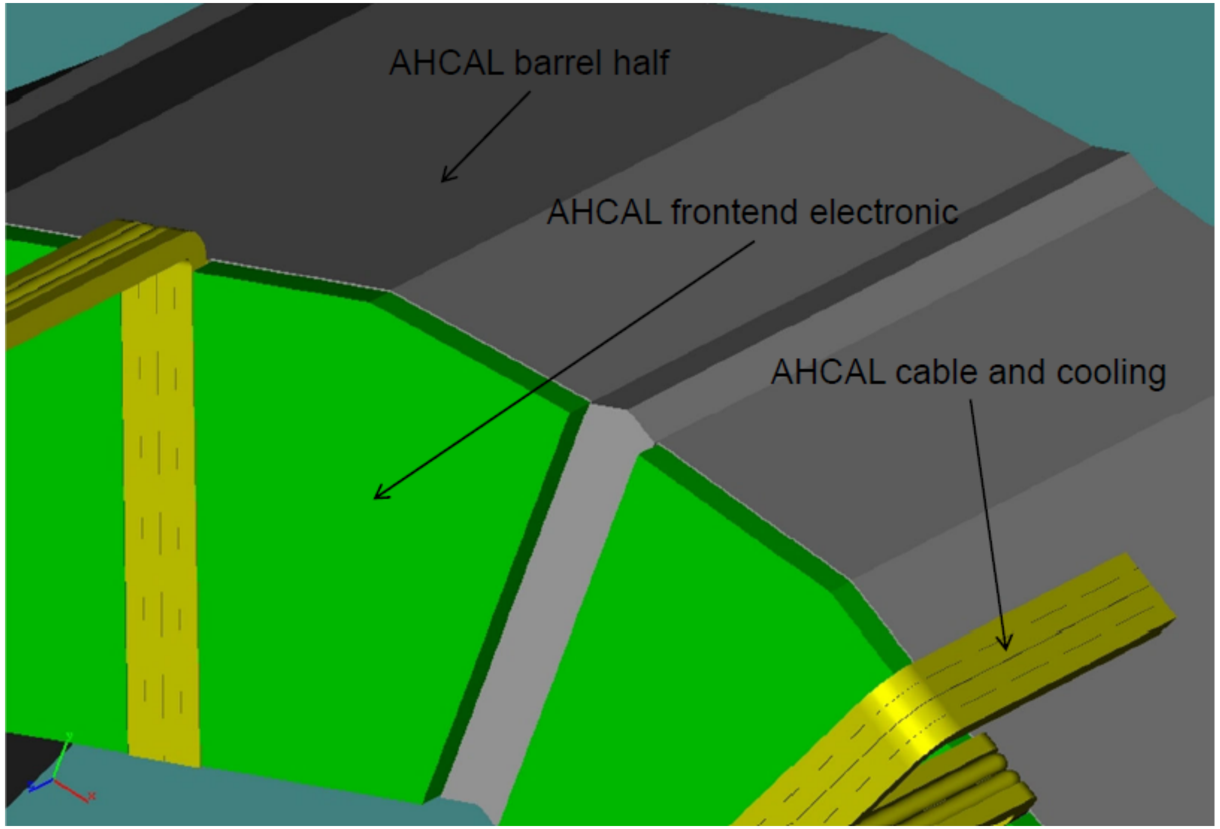


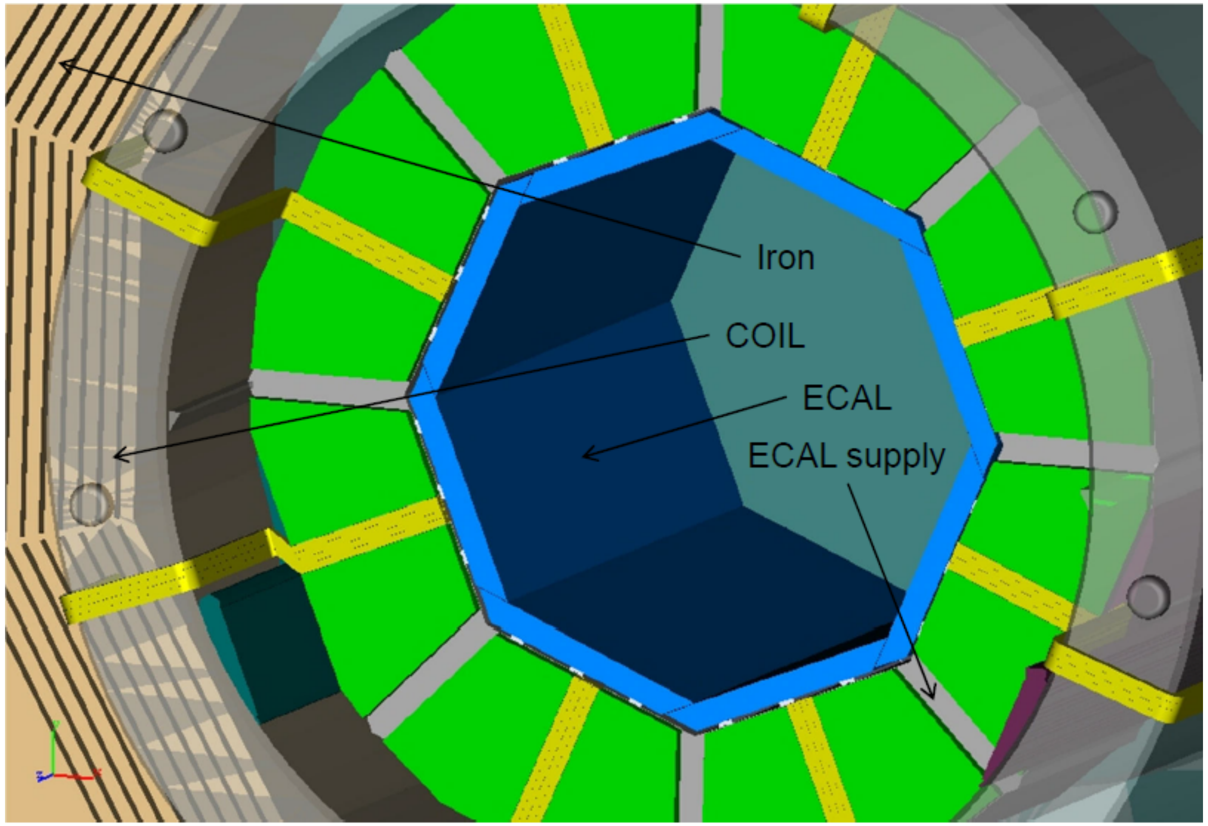


- 2cm thick steel plate (82x216cm²), 40 full layers
- Barrel: 16 segments in phi, 2 segment in Z
- Barrel HCAL absorber weight: on the order of 360 ton

AHCAL placeholder volume and integration with ECAL

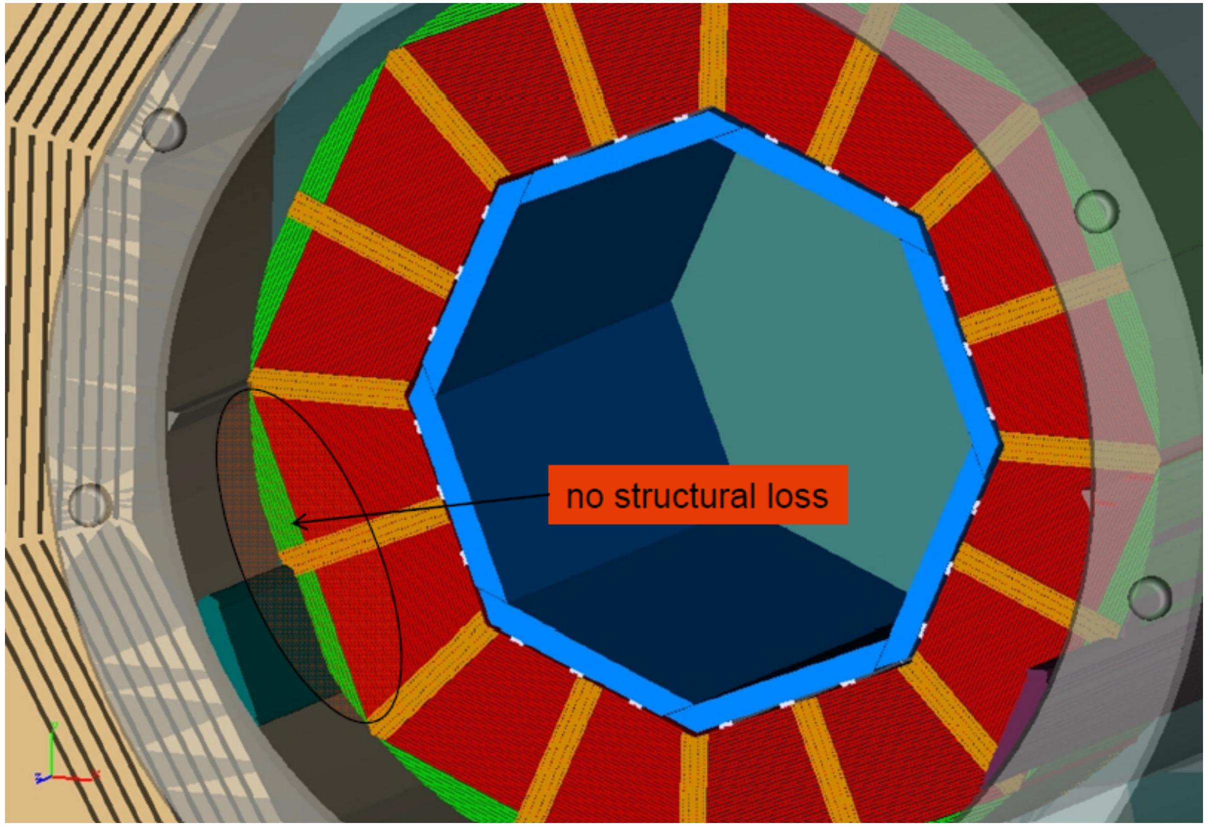
AHCAL Mechanics Design for ILD at ILC by K. Gadow (DESY)

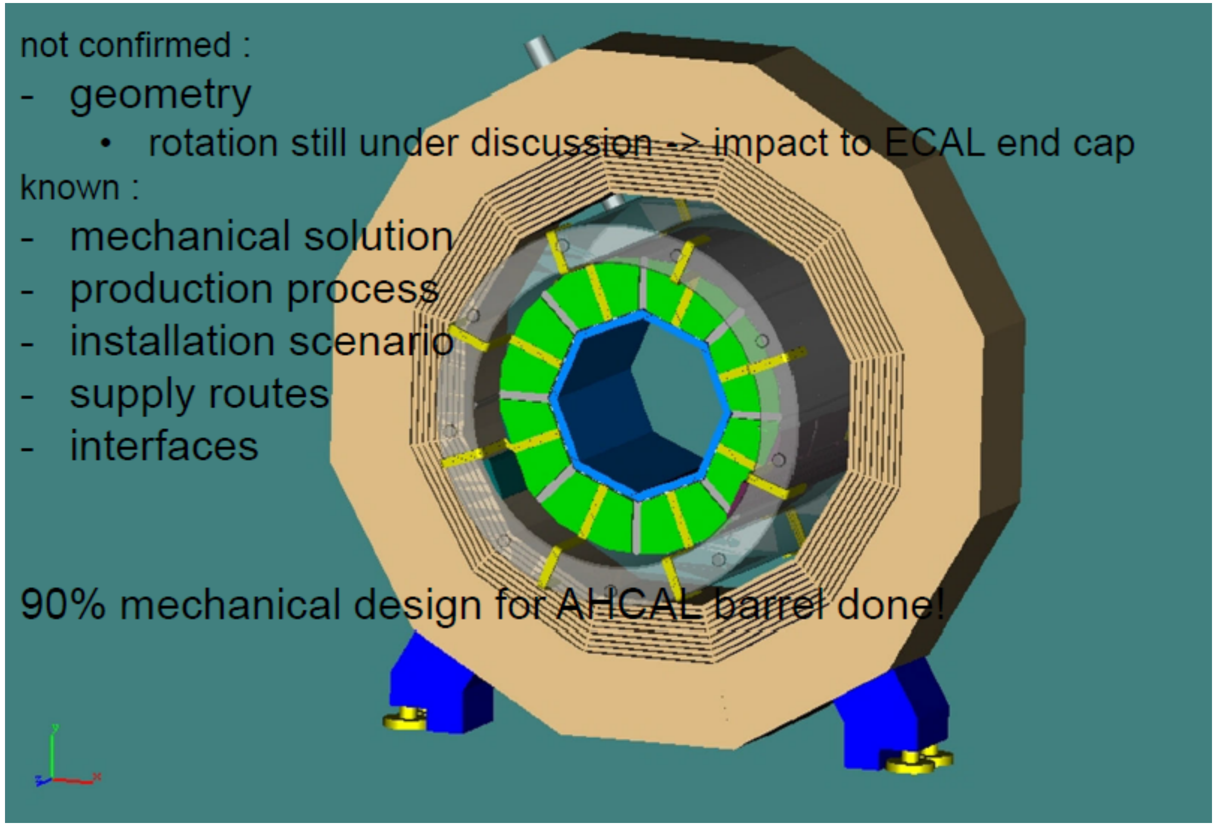




AHCAL barrel support

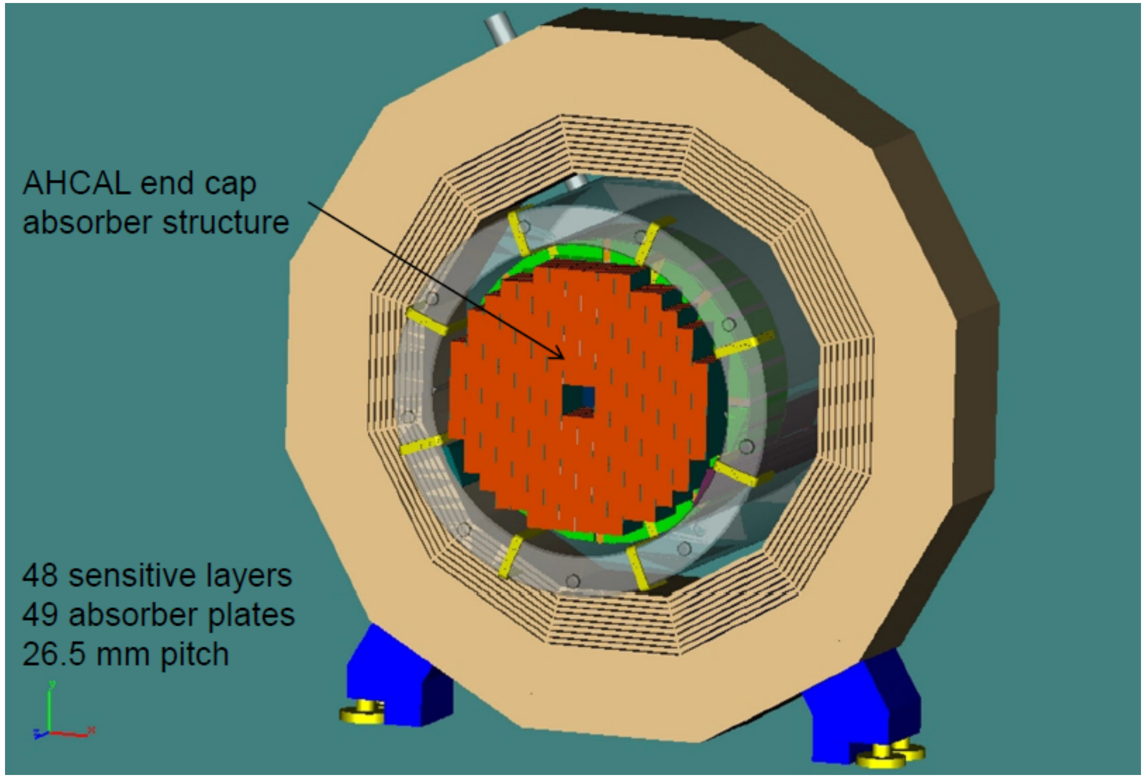
AHCAL Mechanics Design for ILD at ILC by K. Gadow (DESY)

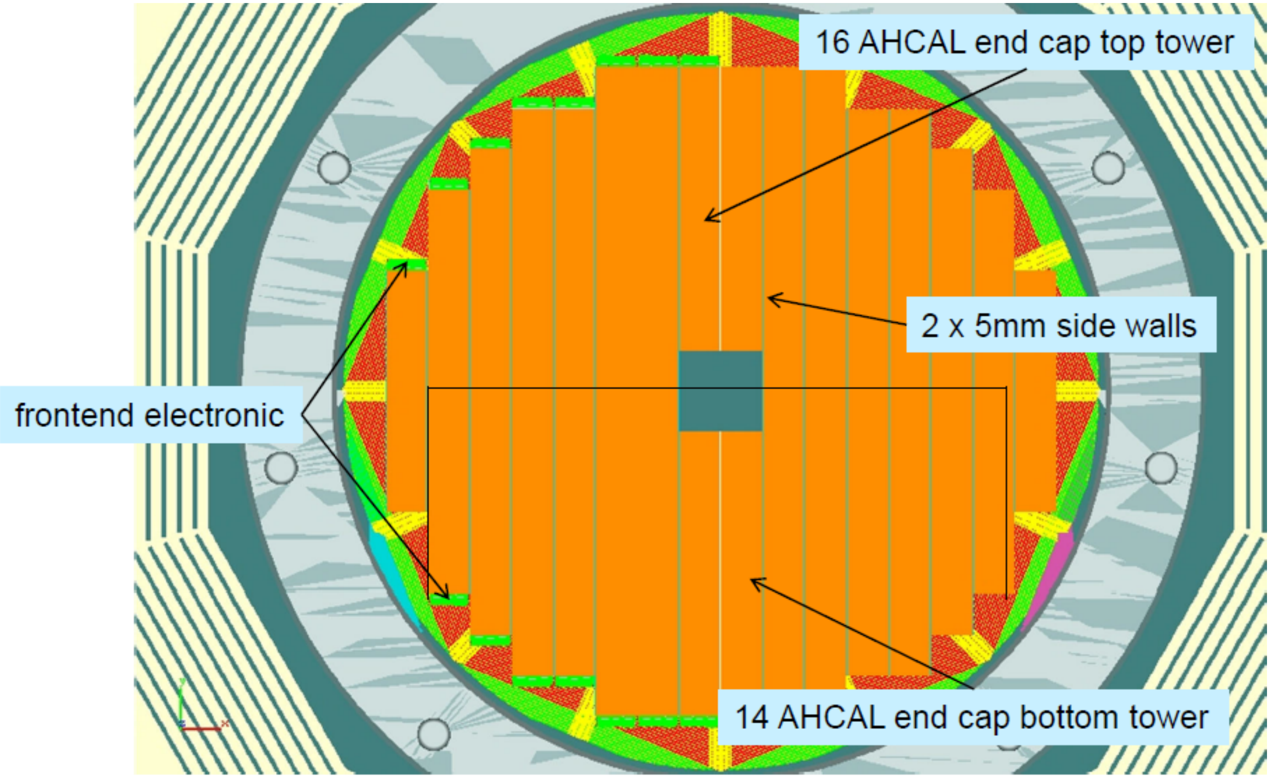




AHCAL endcap mechanics

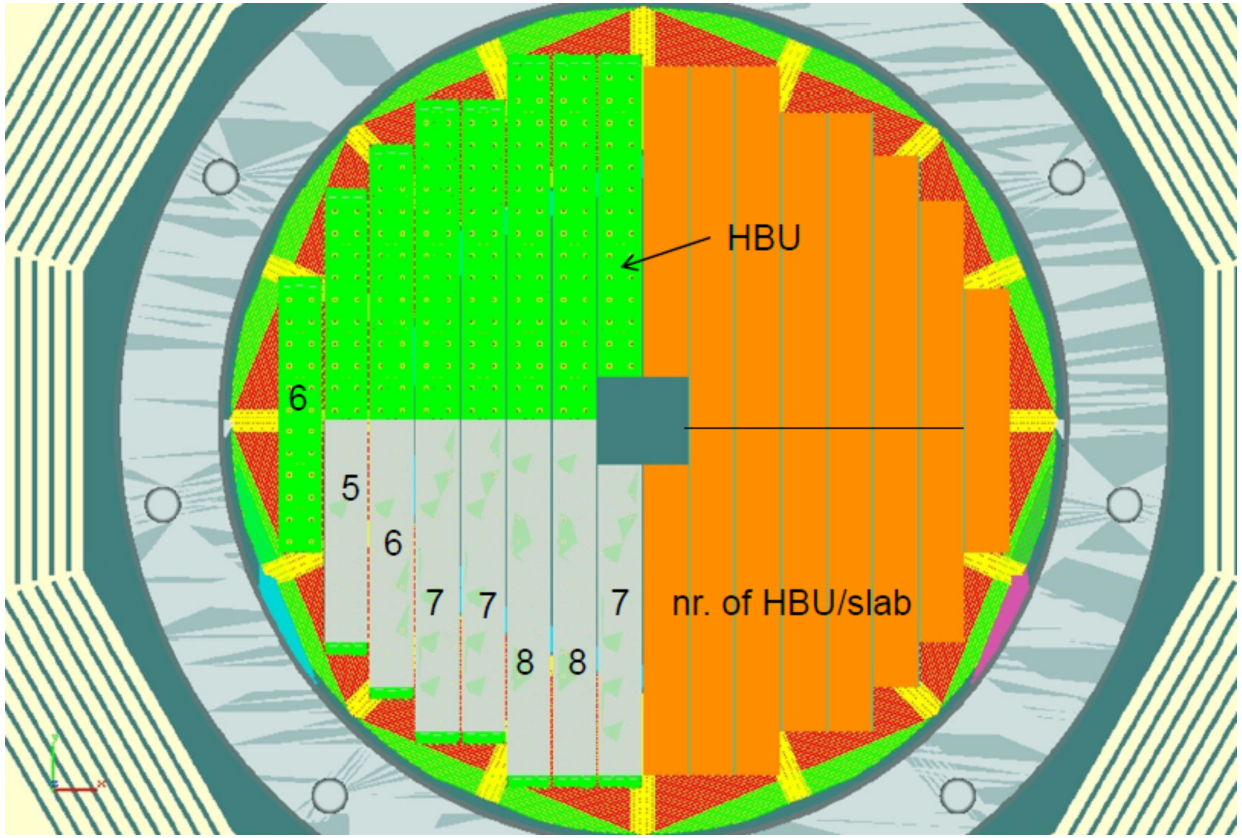
AHCAL Mechanics Design for ILD at ILC by K. Gadow (DESY)

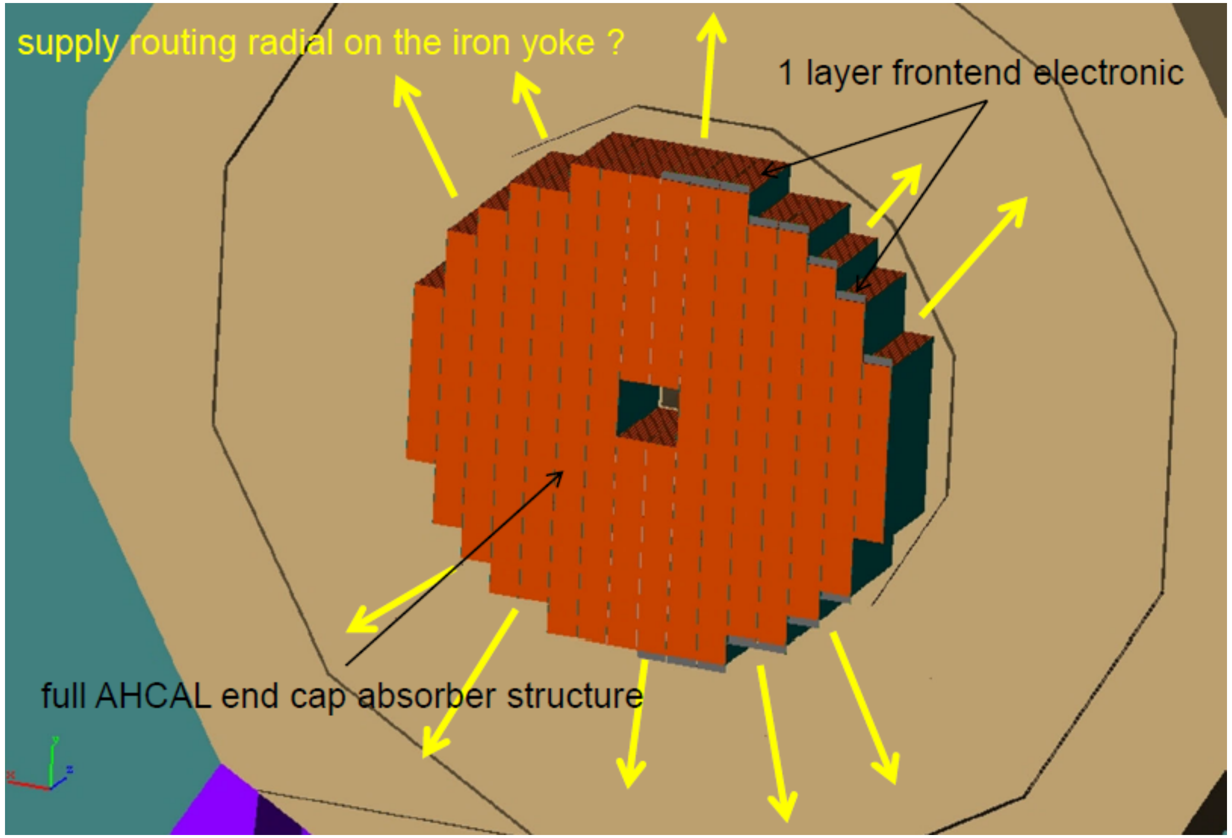




AHCAL endcap mechanics: readout and service

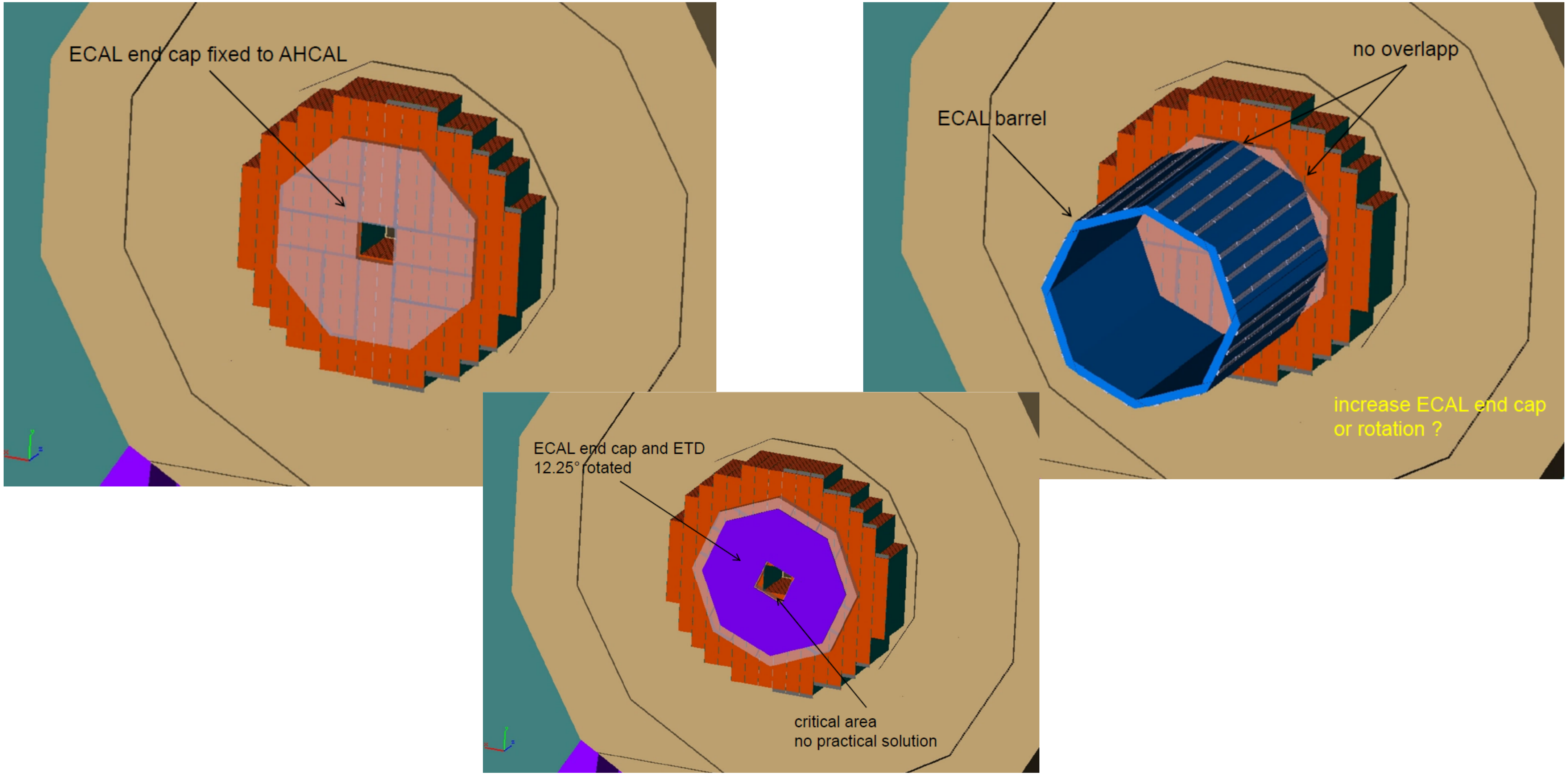
AHCAL Mechanics Design for ILD at ILC by K. Gadow (DESY)



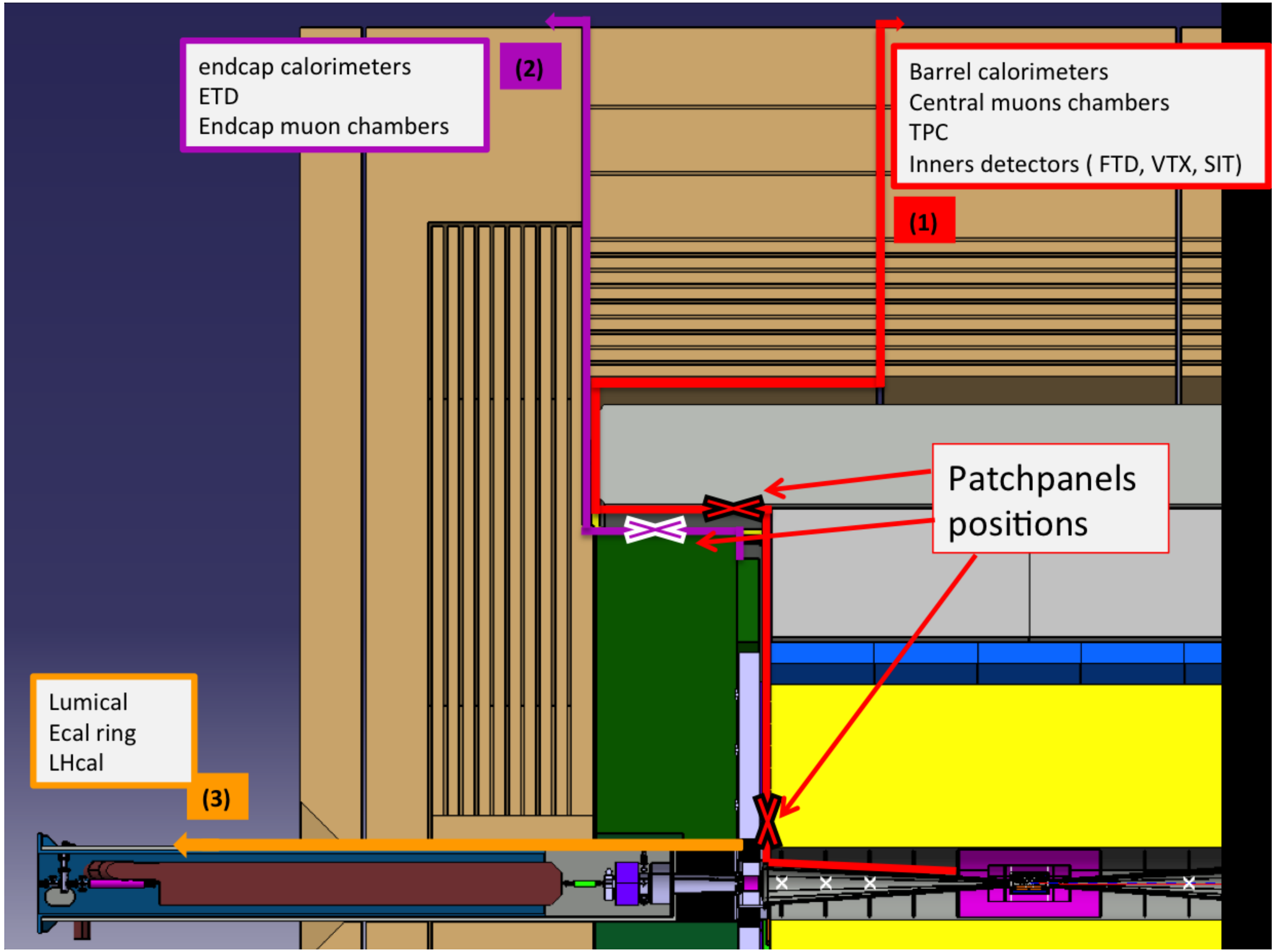


AHCAL endcap with ECAL barrel+endcap

AHCAL Mechanics Design for ILD at ILC by K. Gadow (DESY)



Major services at ILD: cabling, cooling and gases



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