CEPC Calorimeters and Mechanics

Yong Liu (IHEP), for the CEPC Calorimeter Group

Oct. 22, 2021

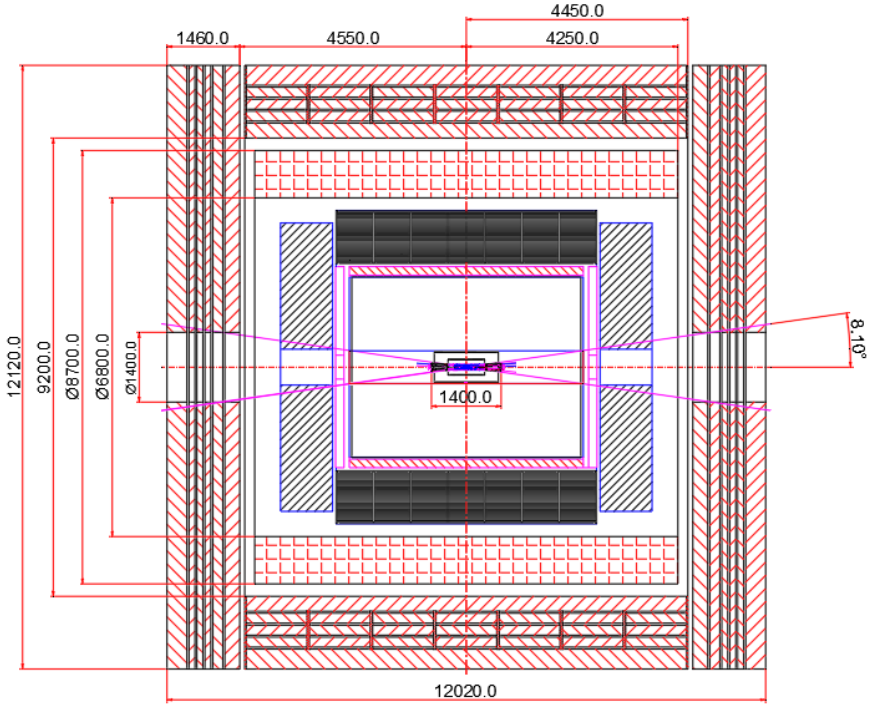
Workshop on CEPC Detector & MDI Mechanical Design, Dongguan

Outline

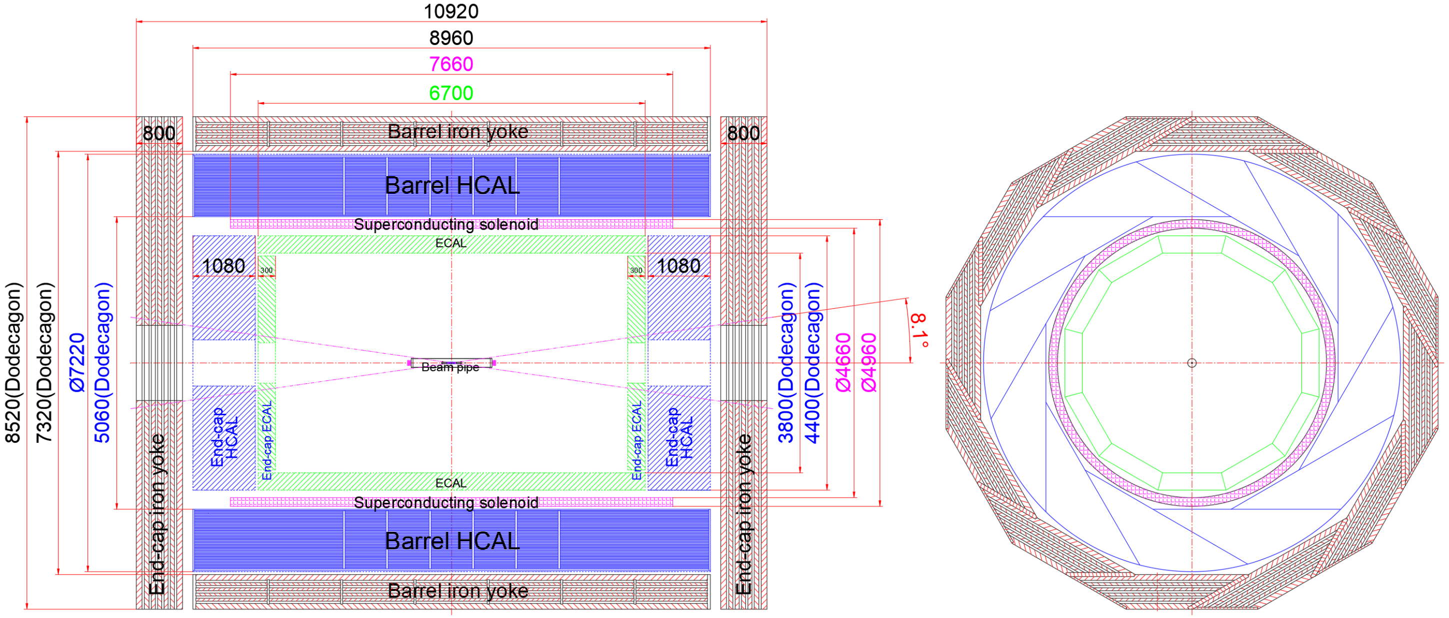
- Calorimeters for CEPC: recap
  - Technology options and mechanical structures
- R&D and key questions (selected) on calorimeter mechanics
  - Presented at CEPC Day and PhysDet Plenary Meetings
  - Boundary effects in the crystal ECAL concept
  - HCAL geometry designs and considerations
  - Existing designs/efforts for scalable designs: integration into a final detector
  - R&D activities for AHCAL prototype and mechanics
  - Solenoid between ECAL and HCAL

CEPC detector mechanics: reminder

- CEPC detector layout is evolving: several options proposed

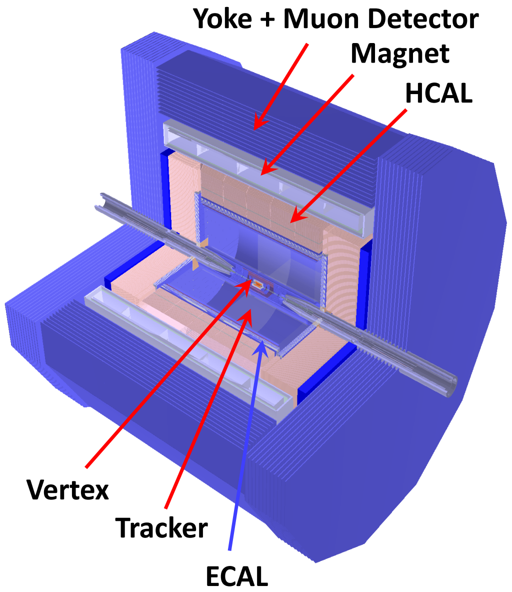


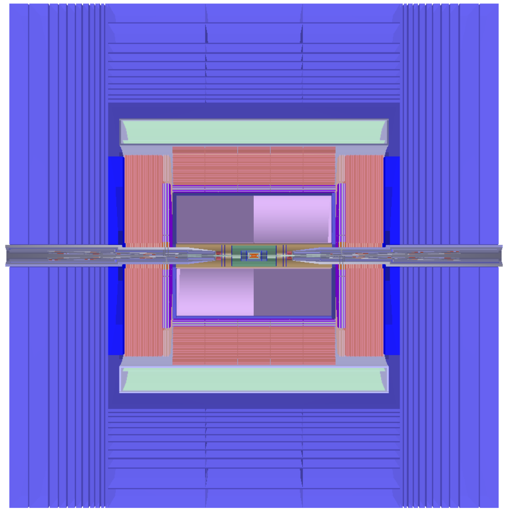
A detector layout in the Mechanics Workshop 2020 by Quan Ji (IHEP)

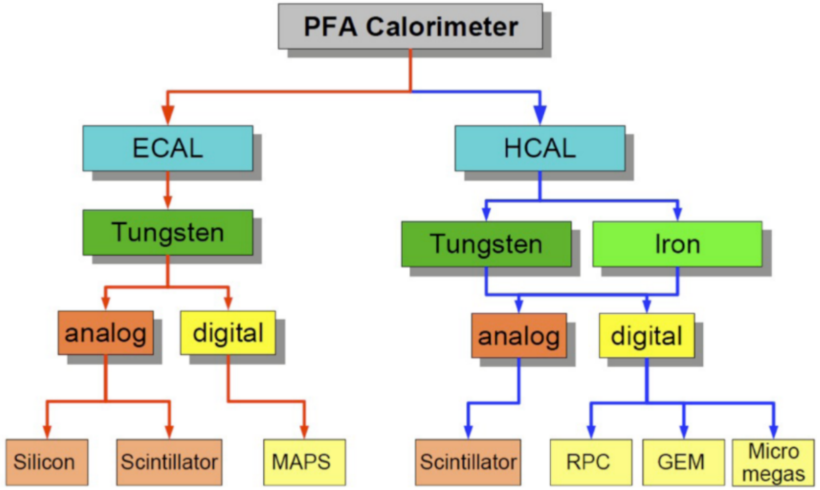


A new detector layout in the Yangzhou Joint Workshop 2021 by Quan Ji (IHEP)

CEPC calorimetry options: highly granular

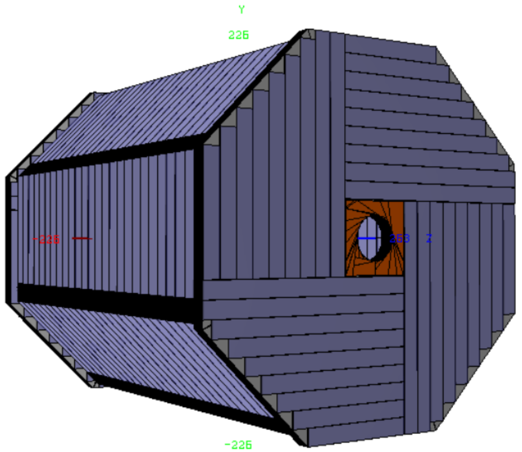


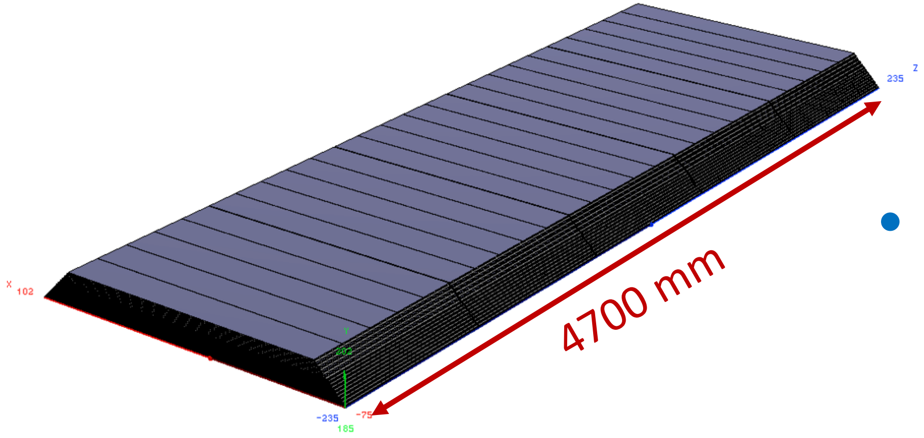


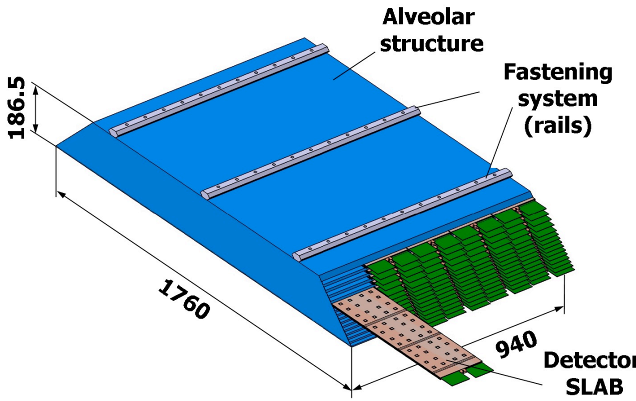


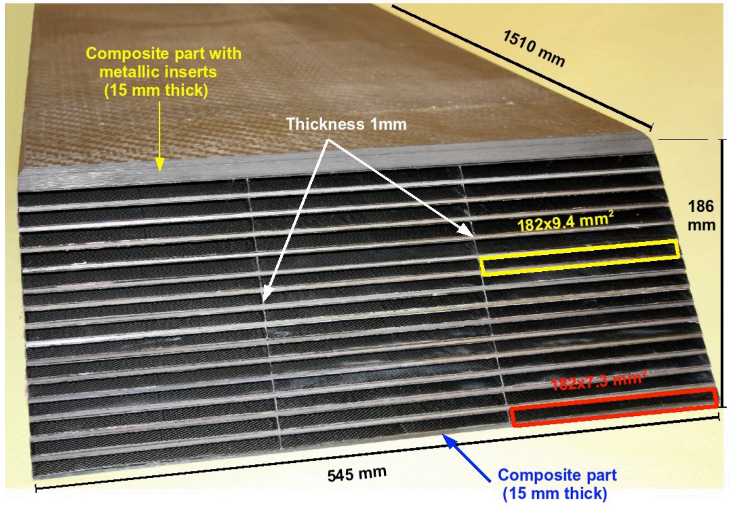
- PFA calorimeters with high granularity
  - Precision measurements of jets
- CEPC ECAL options
  - Scintillator-Tungsten: a prototype completed
  - Silicon-Tungsten: efforts in CMS HGCAL
  - Crystal: a novel concept (homogeneous)
- CEPC HCAL options
  - Plastic scintillator tiles and SiPMs (AHCAL)
    - CEPC-AHCAL prototype is being developed
  - RPC-based (SDHCAL)
    - Further R&D for the CALICE prototype
  - Scintillating glass (tiles) and SiPMs
    - A novel concept under study

Electromagnetic Calorimeter (ECAL): general layout



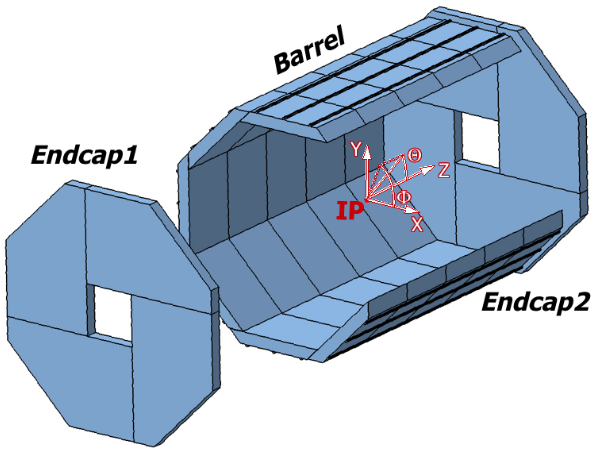


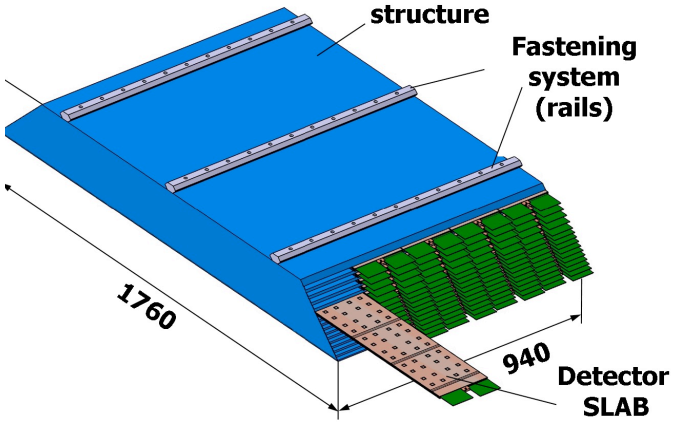


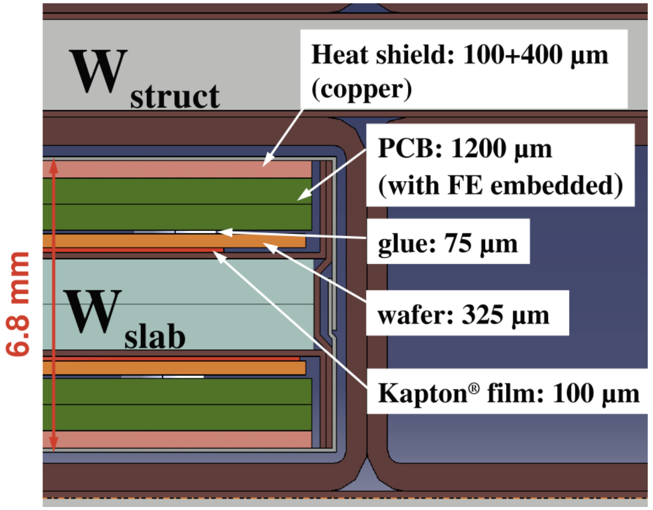


- ECAL structure
  - 1 barrel part, 2 endcap parts
  - 30 layers deep (longitudinal), 24X0
- Barrel ECAL
  - 8 (octaves) staves in barrel
  - 5 trapezoid modules per stave
  - 5 columns per module
    - 186 mm wide
- Endcap ECAL
  - 4 quadrants per section
    - Radius: 400 ~ 2088 mm
  - 100 mm gap between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

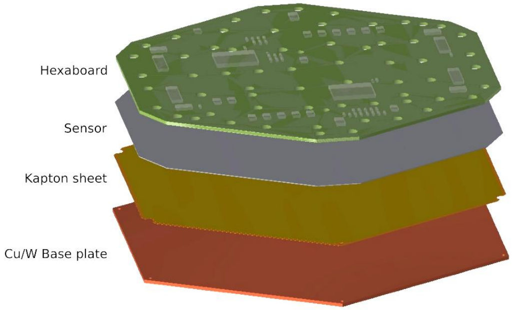
ECAL: Silicon-Tungsten option

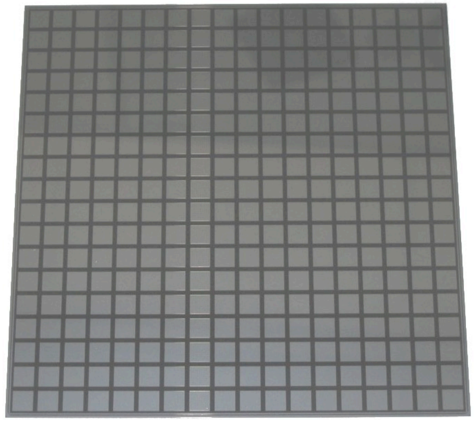




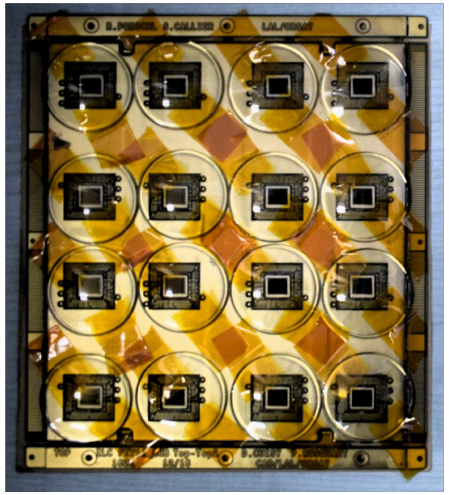


Silicon Module for CMS-HGCAL





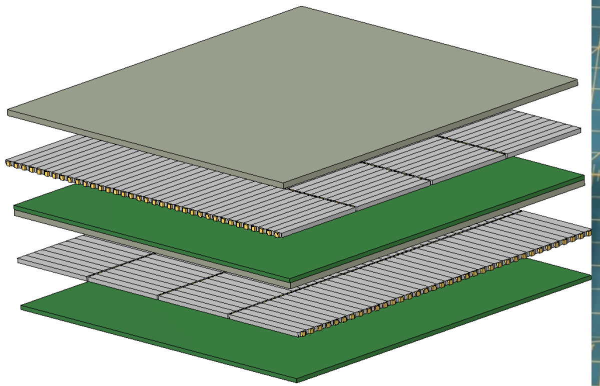
Silicon sensor

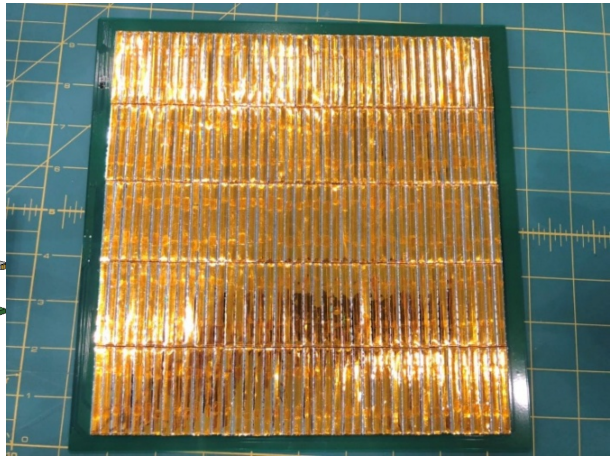


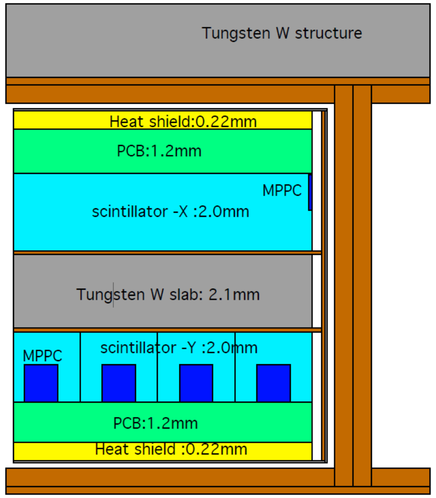
Chip-On-Board (CALICE)

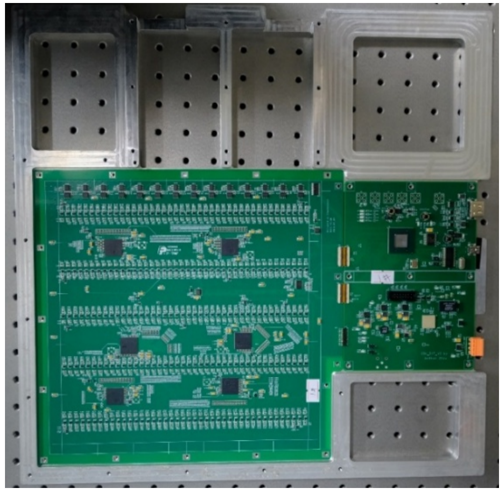
- Sensitive layers: stringent requirement on space
  - Silicon sensors: 0.32~1.0 mm thick (0.5mm baseline)
  - PCB + ASICs: 1.8 mm thick (challenging)
  - COB 1.2mm thick demonstrated: ASICs wire-bonded
- Same detector technology in CMS-HGCAL project
  - Major focus on radiation hardness and active cooling (-35 degrees with dual-phase CO2)
  - Endcap regions: extra challenges due to geometry

ECAL: Scintillator-Tungsten option





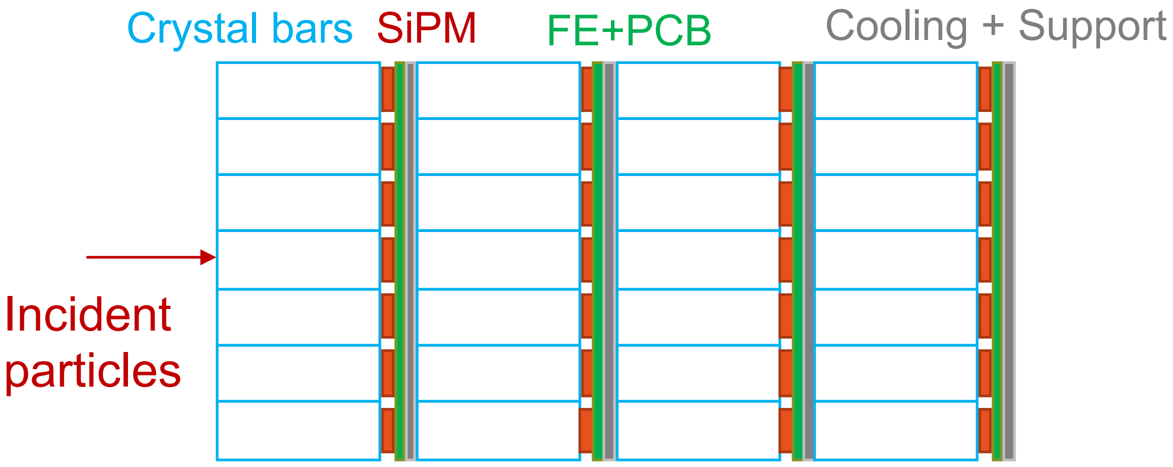




- Sensitive layers: challenges from space
  - Scintillator strips: 2mm thick
  - PCB + ASICs: considerably thicker than 1.2 mm in design specs (quite challenging)
- CEPC ScW ECAL prototype constructed
  - Over 6700 channels, 32 layers, air cooling
- Open issues
  - Scalable design for final detector, active cooling

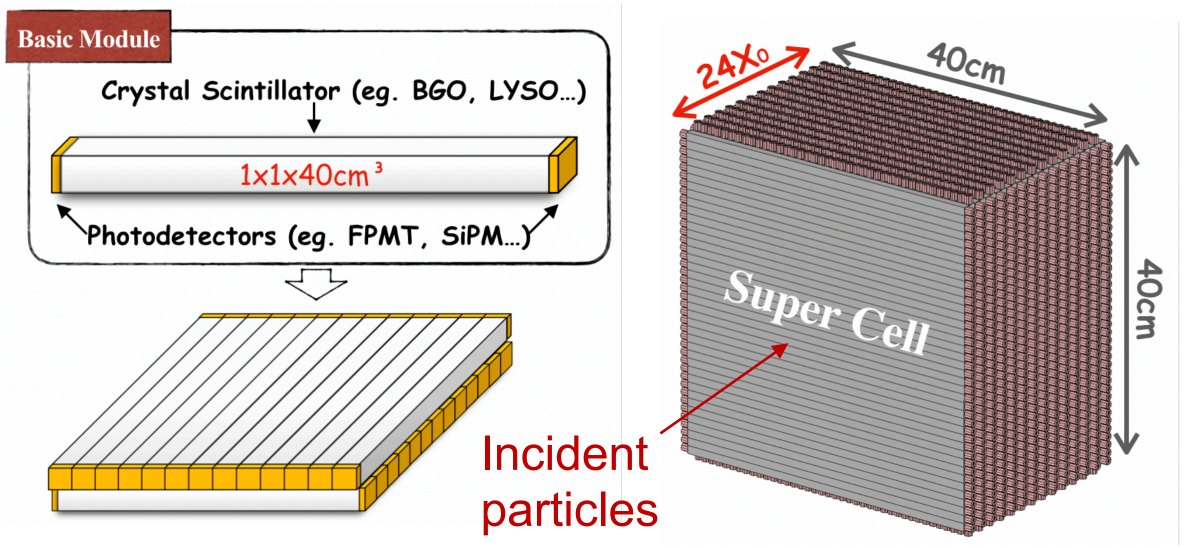
New concept: 4D crystal ECAL

Design 1: short bars



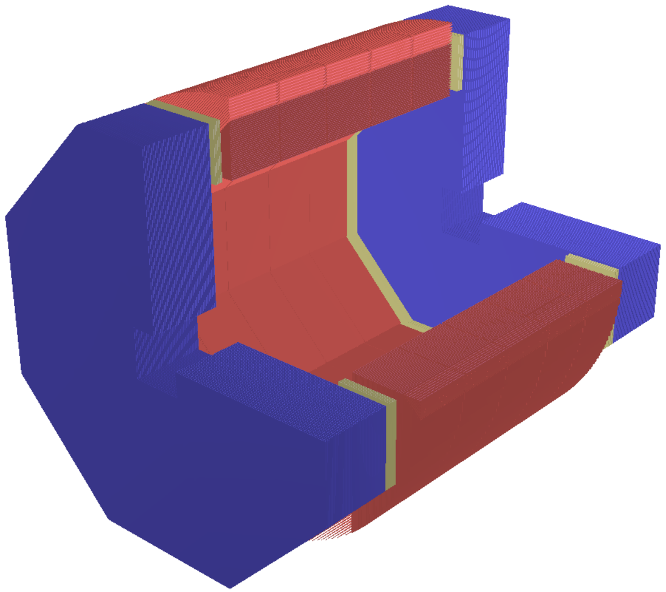
- A natural design compatible with PFA
  - Fine segmentation in Both longitudinal and transverse
  - Single-ended readout with SiPM

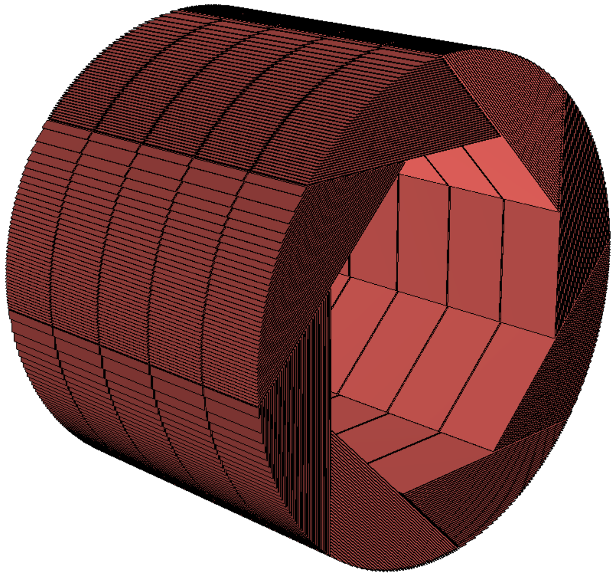
Design 2: long bars



- Long bars: 1×40cm, double-sided readout
  - Super cell module: 40×40cm
  - Crossed arrangement in adjacent layers
  - Fine longitudinal granularity
- Save #channels and minimize dead materials between crystals
- Timing at two sides: positioning along bar

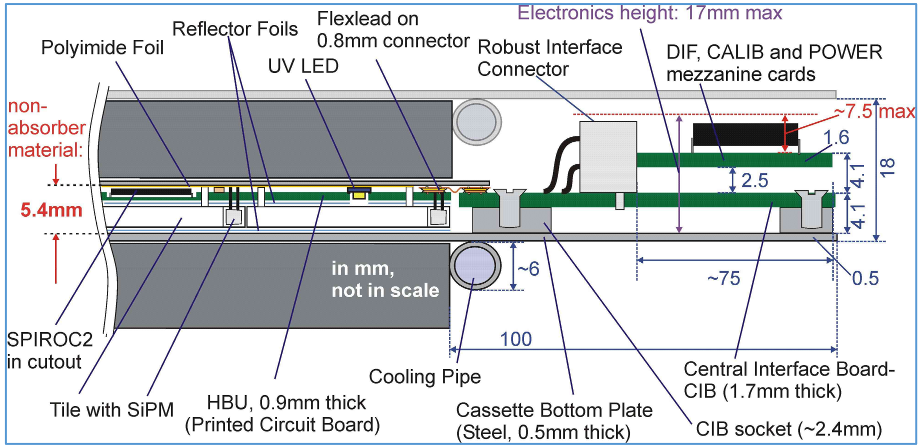
Hadronic Calorimeter (HCAL)



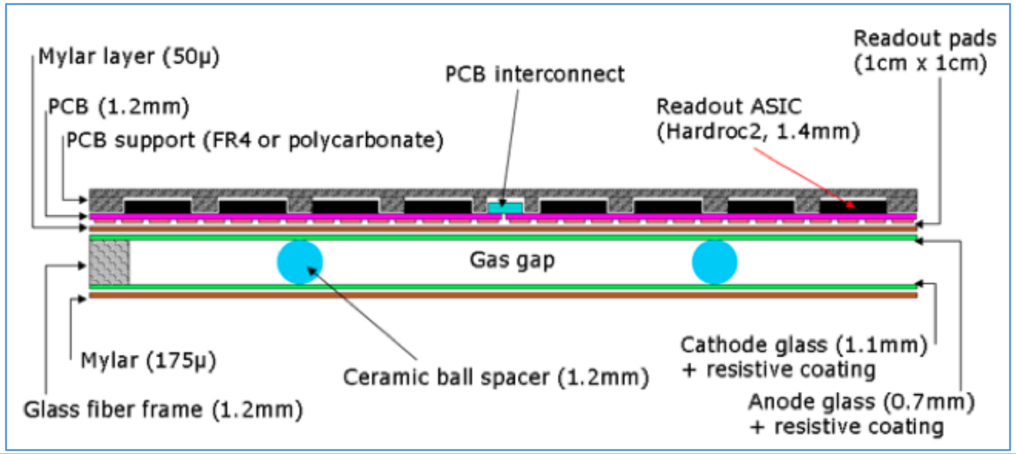


- HCAL structure
  - 1 barrel part, 2 endcap parts
  - 40 layers in depth
- Barrel HCAL
  - Radius: 2058mm to 3144mm
- Endcap HCAL
  - Along Z: 2650mm to 3736 mm

Scintillator tiles with SiPMs



Large-area RPCs



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  - HCAL geometry designs and considerations
  - Existing designs/efforts for scalable designs: integration into a final detector
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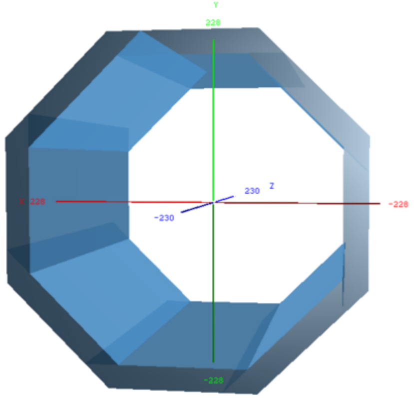
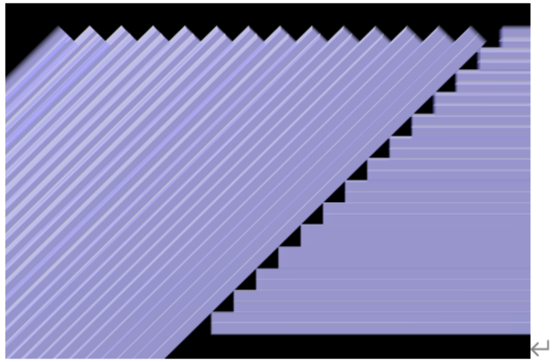
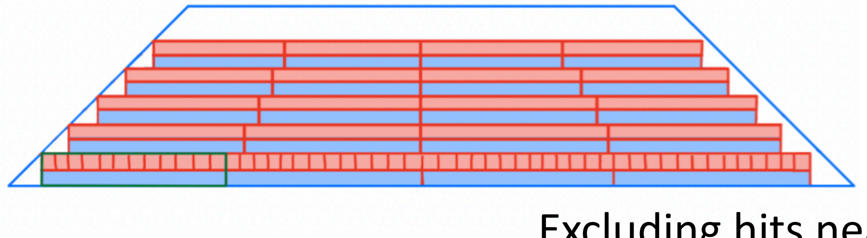
Presentation at CEPC Day (July 29, 2021)
Recent progress on the CEPC crystal calorimeter (Yong Liu)

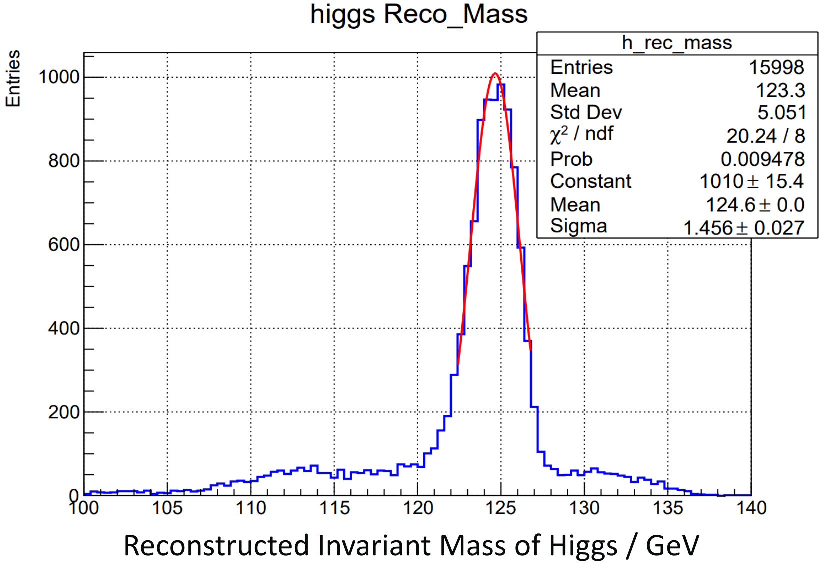
4D crystal ECAL concept: boundary effects to physics

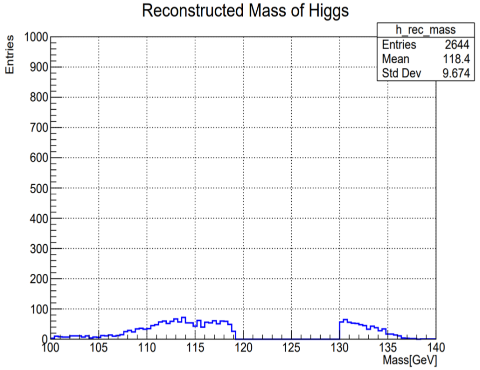
- Full simulation studies
  - $ZH(Z \to \nu\nu, H \to \gamma\gamma)$ at 240 GeV
- Significant impacts of the geometry boundaries (between different modules)
  - Structures around Higgs invariant mass peak
- Need smart designs to minimize these effects

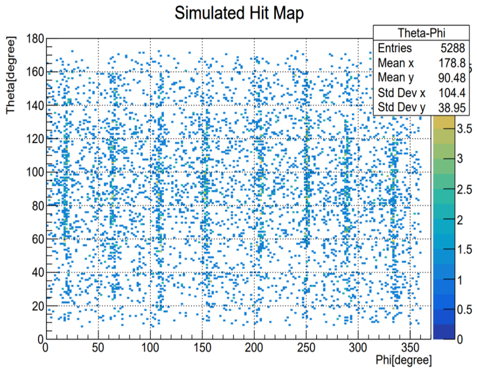




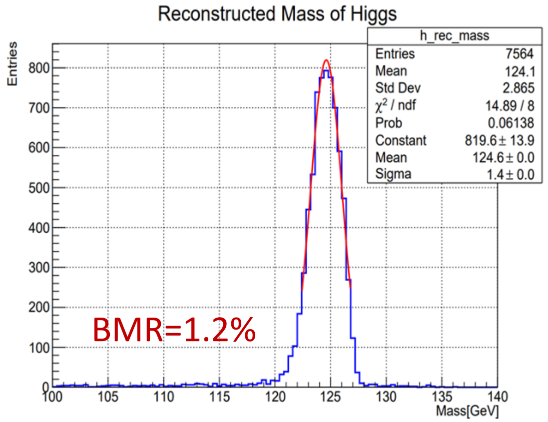








Excluding hits near gaps



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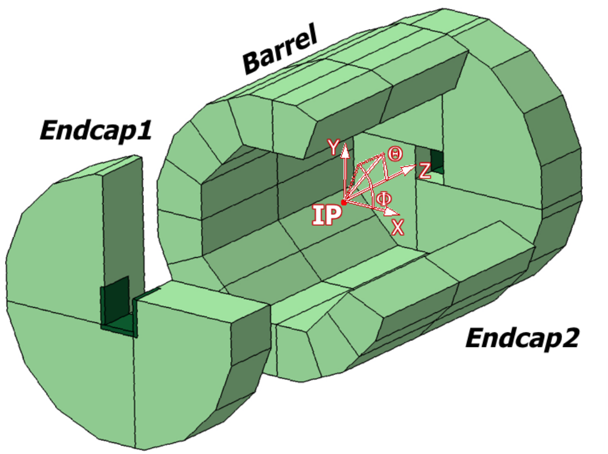
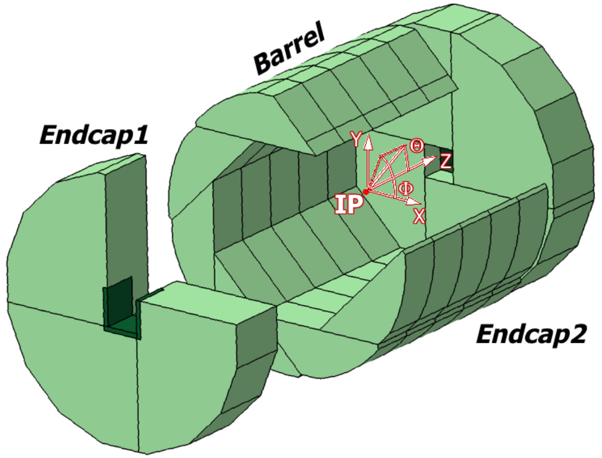
Presentation at CEPC Day (May 23, 2021):
HCAL mechanics: studies and discussions (Yong Liu)

HCAL layouts: context

- Two major designs proposed
  - Originated from ILD: ILD LOI (2010), ILC TDR Volume 4 (2013)
- Discussions within the CEPC calorimeter group meetings
  - Comparisons between the two designs: pros and cons
  - Major focus on the barrel part
  - + mechanical expert: Prof. Quan Ji (IHEP)



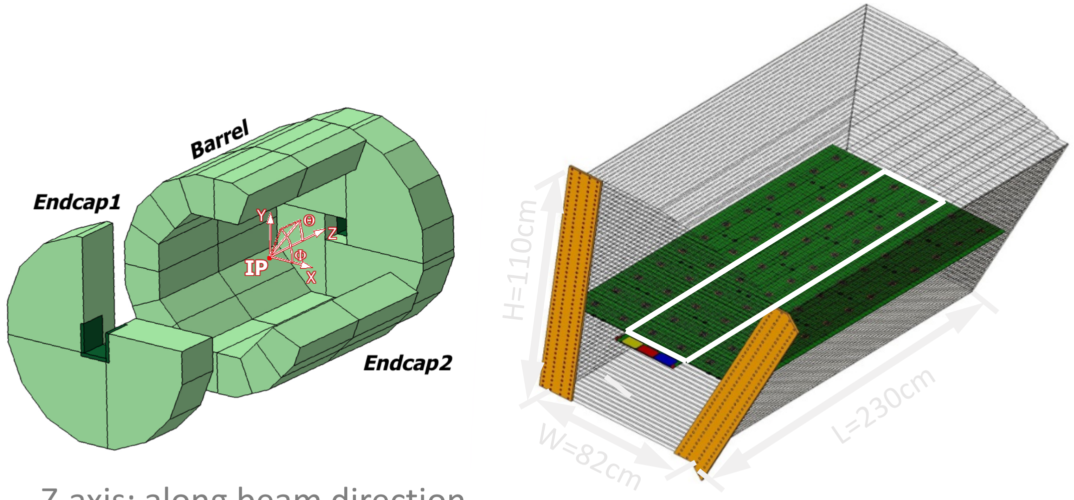
Layout 1: symmetric barrel



Layout 2: asymmetric barrel

HCAL layouts: comparison

HCAL Layout 1



Z-axis: along beam direction

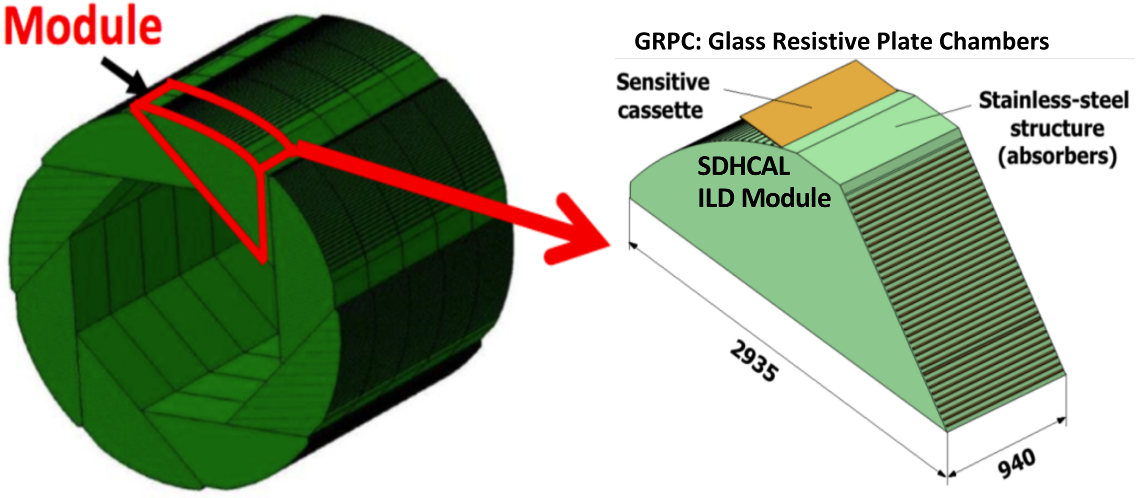
Symmetric Layout

+ Similar module sizes: friendly for QA/QC

? Projectile cracks from IP (z, φ): possible impacts to performance
  Simulation studies show negligible effects (results in backup slides)

– Difficulty for installation and maintenance from each side (along z)
  - Extra challenges for some designs of longer barrel HCAL (8-9m long);
    (Reminder: 4.7m for HCAL in ILD and CEPC CDR)

HCAL Layout 2



Asymmetric/spiral Layout

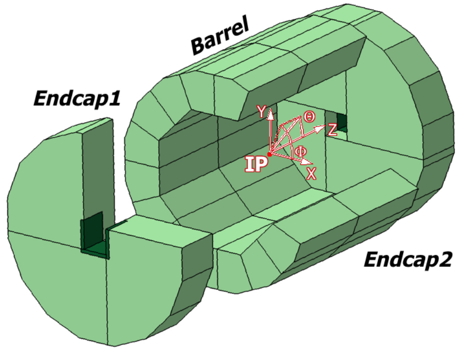
+ Avoid projectile cracks from IP along (z, φ)

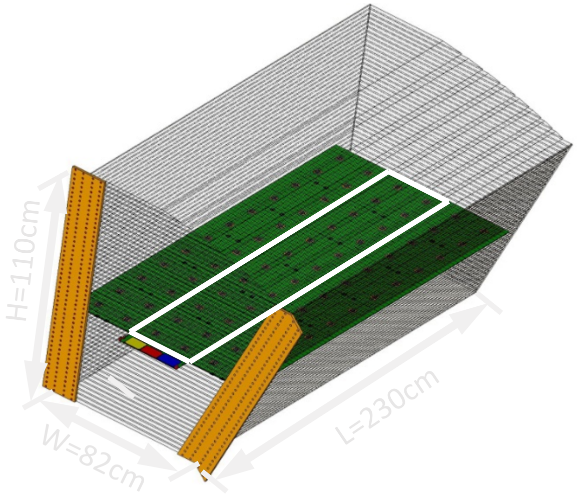
+ Handy for installation and maintenance (along outer radius)

– Very different module sizes: challenges for QA/QC

HCAL layouts: comparison

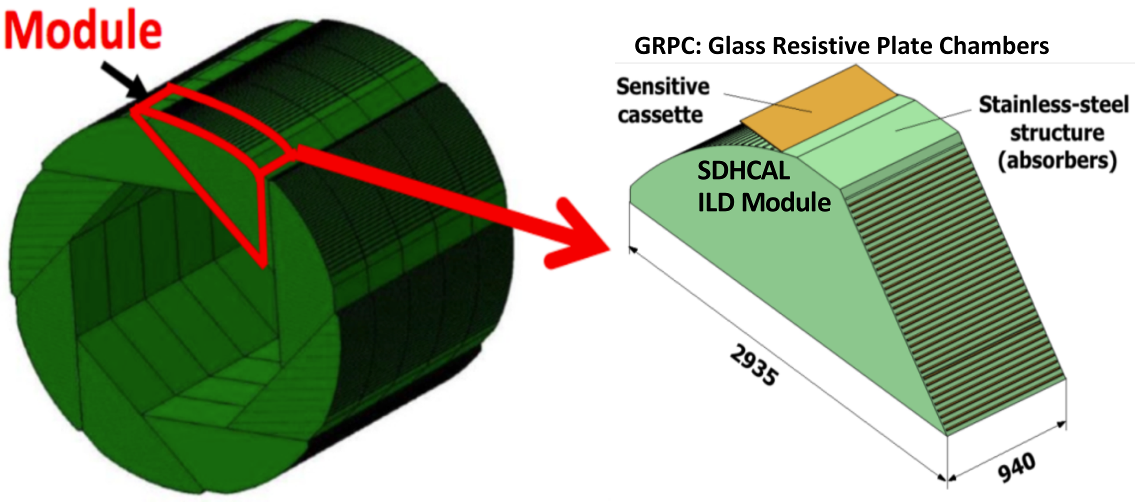
HCAL Layout 1





Z-axis: along beam direction

HCAL Layout 2



Symmetric Layout

+ Similar module sizes: friendly for QA/QC

? Projectile cracks from IP (z, φ): possible impacts to performance

Simulation studies show negligible effects (results in backup slides)

– Difficulty for installation and maintenance from each side (along z)

  – Extra challenge for longer barrel HCAL designs (8-9m long); **ILD 4.7m**

Asymmetric/spiral Layout

+ Avoid projectile cracks from IP along (z, φ)

+ Handy for installation and maintenance (along outer radius)

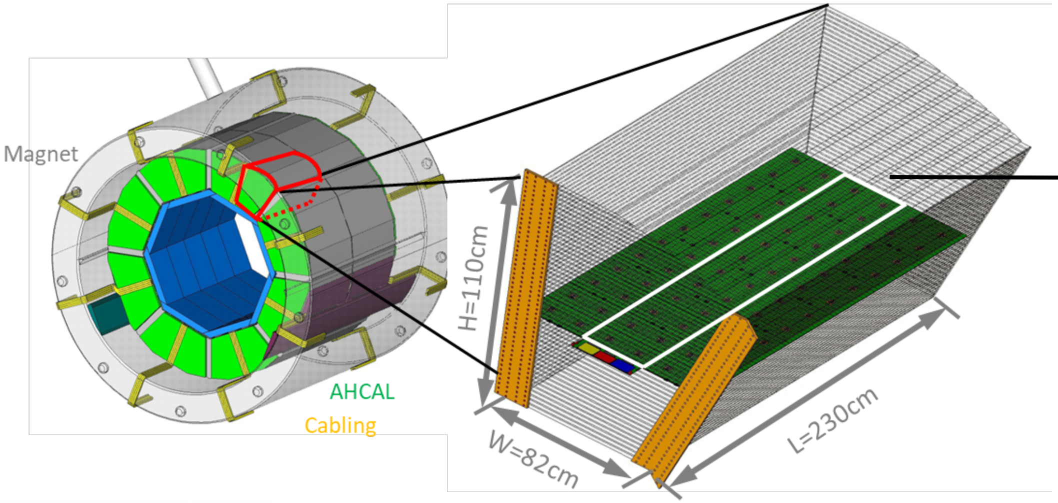
– Very different module sizes: challenges for QA/QC

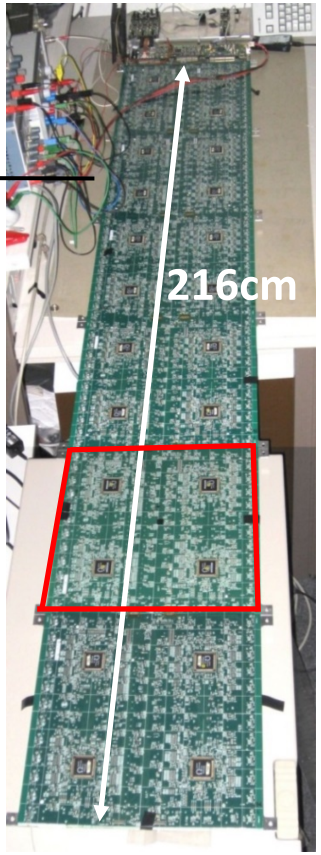
Technical challenges for both layouts:
(1) production/assembly of long modules: 2~4m in Layout 1; ~3m in Layout 2
(2) active cooling system and its integration with mechanics

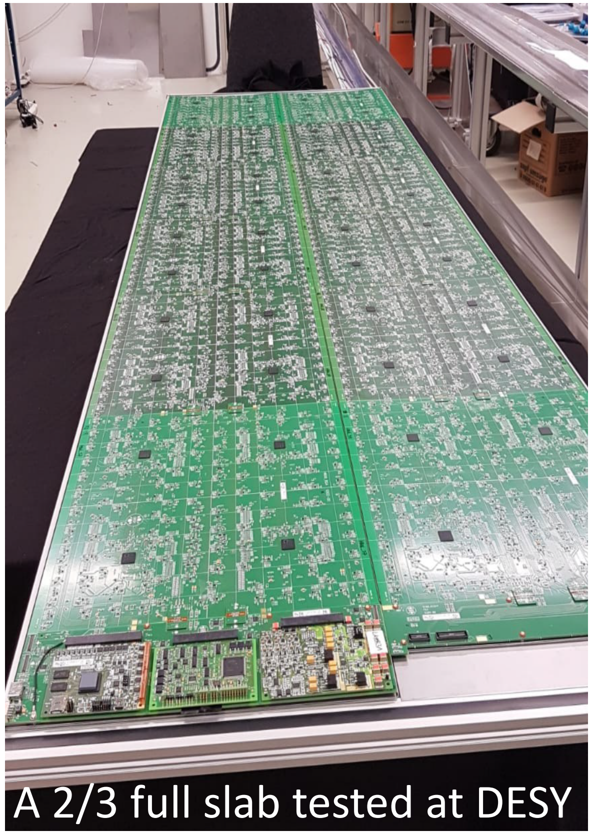
Ongoing R&D efforts to address the challenges (next pages)
(1) ~2m long AHCAL slabs (DESY); ~1x2m RPC+PCB (Lyon)
(2) Simulation studies of an active cooling system (SJTU)

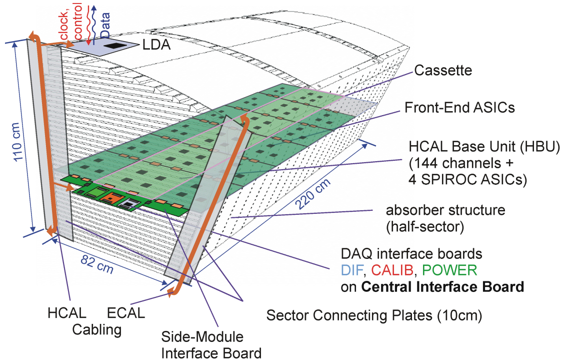
HCAL modules for the final detector

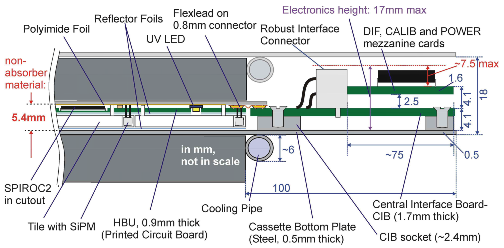
- Ongoing R&D efforts within CALICE to realise large-scale modules
  - Analog HCAL option: “SiPM-on-Tile” technology with steel plates
  - Efforts to test full-sized layers at DESY: aim for <u>1.1x2.2m² full slabs</u> at ILD

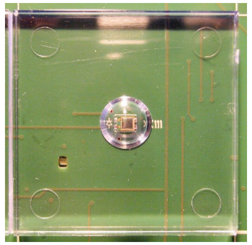












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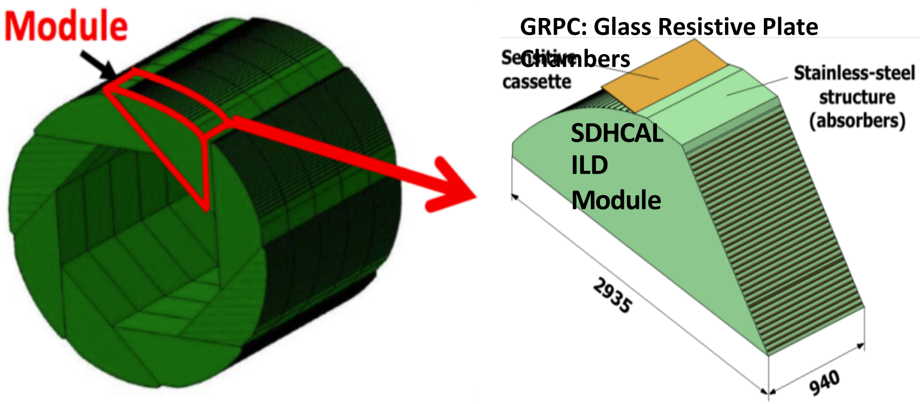
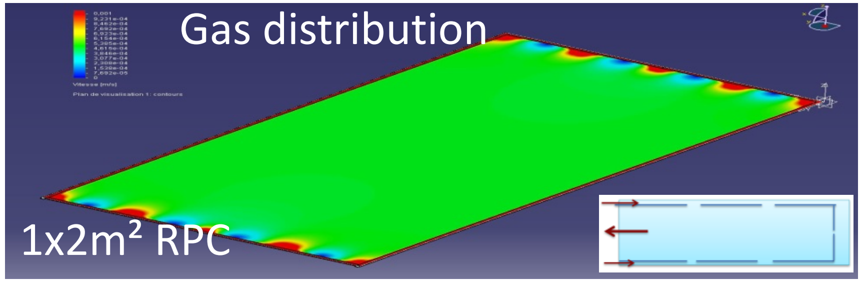
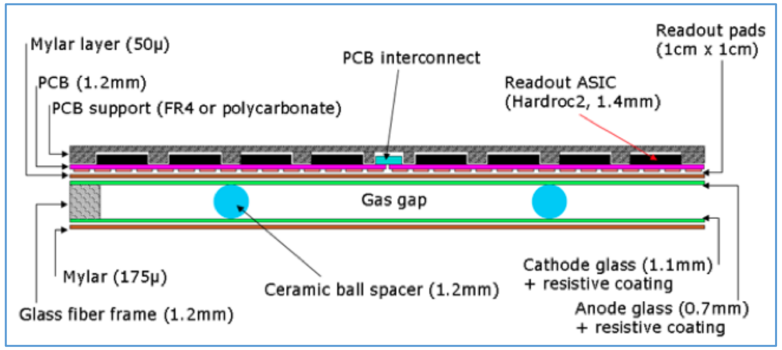
HCAL modules for the final detector

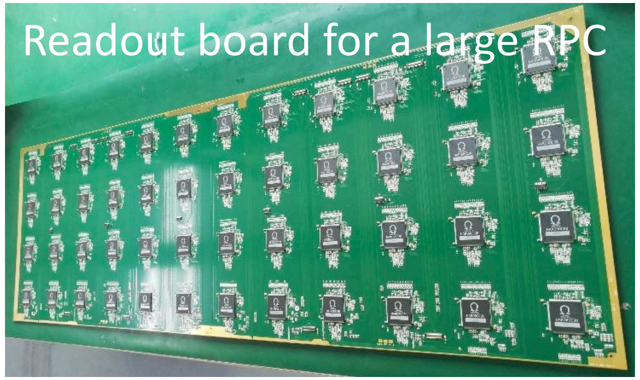
- Ongoing R&D efforts within CALICE to realise large-scale modules
  - Semi-digital HCAL option: large-scale RPC technology with steel plates
  - Efforts to build full-sized layers at Lyon: aim for full <u>1x3m² slabs</u>



Assembled 1x2m² large RPC, 1x0.33m² PCBs

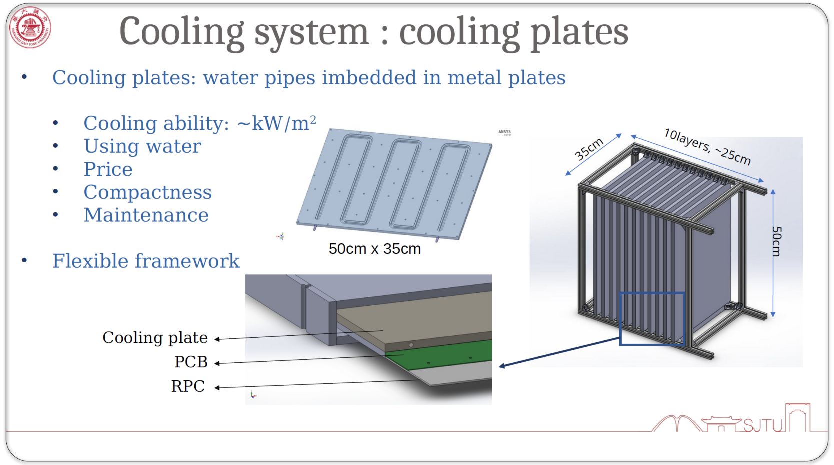


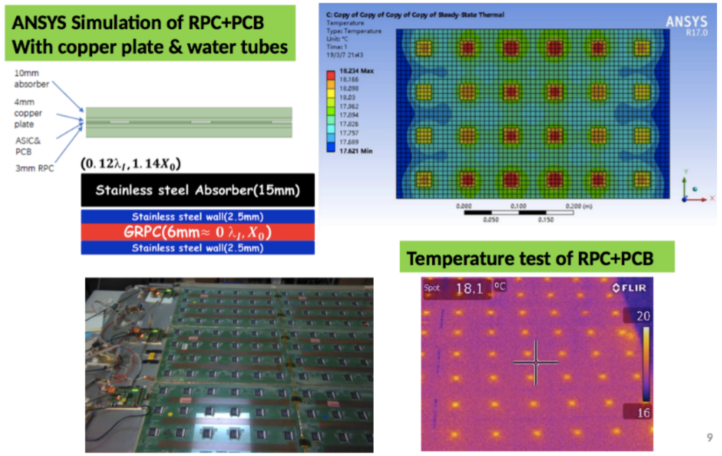




HCAL active cooling

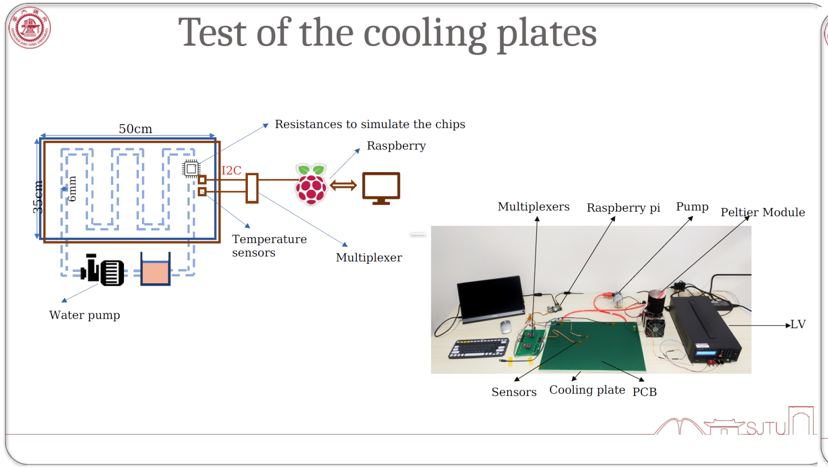
- Active cooling studies for SDHCAL at SJTU and Lyon
- Ongoing cooling studies for AHCAL prototype: different ASICs (SPIROC2E) and lower granularity

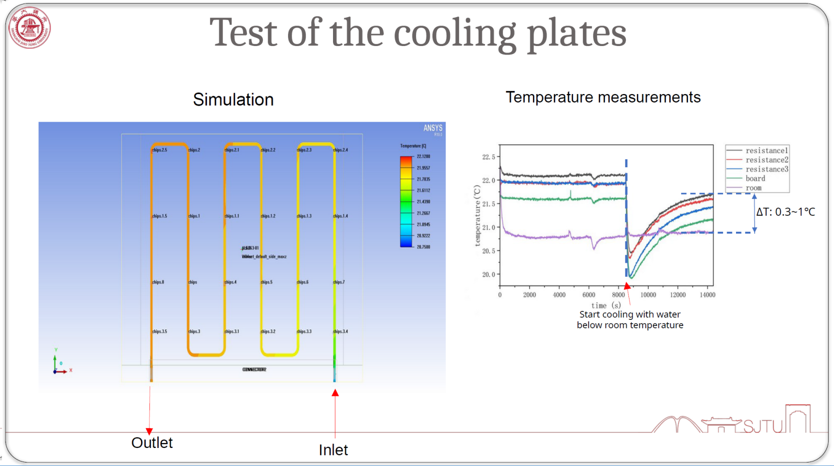




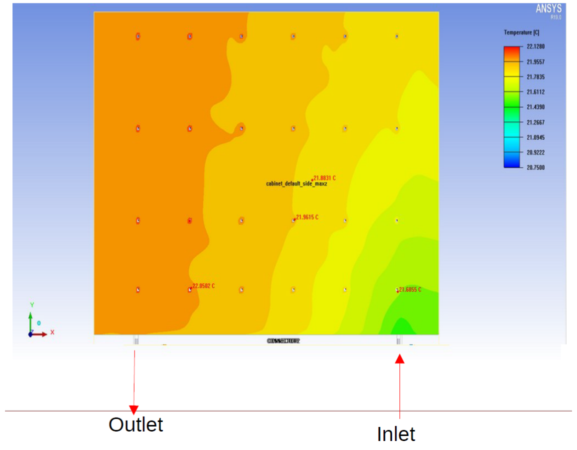
Synergies with the CEPC MOST-2 AHCAL prototype construction (40 layers, 72cmx72cm per layer)

SDHCAL Electronics, Gas Flow and Cooling at CALICE Collaboration Meeting Mar. 2021





Simulation



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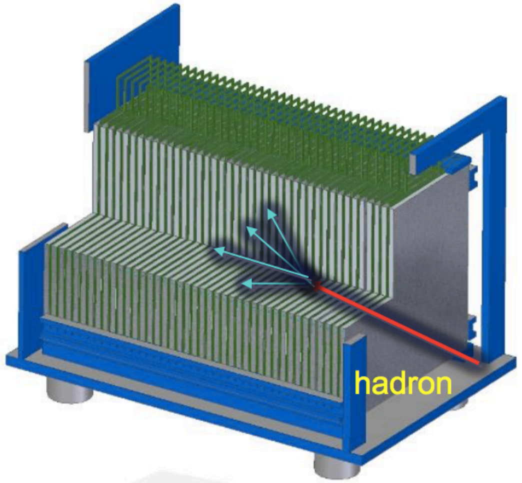
Presentation at CEPC PhysDet Plenary Meeting (Sep. 29, 2021) :
Status of AHCAL (Yunlong Zhang)

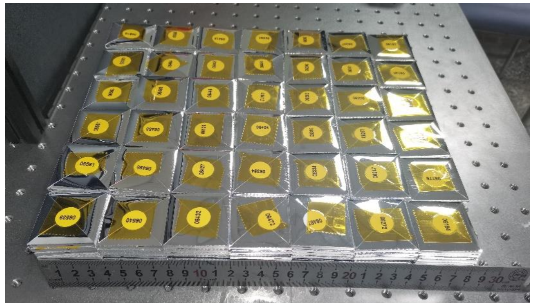
CEPC-AHCAL prototype

- AHCAL prototype development
  - Synergies on HCAL mechanics
  - Task of MOST-2 project
- AHCAL: sampling calorimeter
  - 40 layers with scintillator tiles (3mm) and steel absorber plates (20mm)
  - Transverse size: 72cm ╳ 72 cm
  - In total ~13k readout channels
- Mechanics
  - Single Layer: “cassette” to fix flexible PCB and improve stability + light isolation
  - System level: integration of 40 layers
  - Engineer collaboration: IHEP and USTC

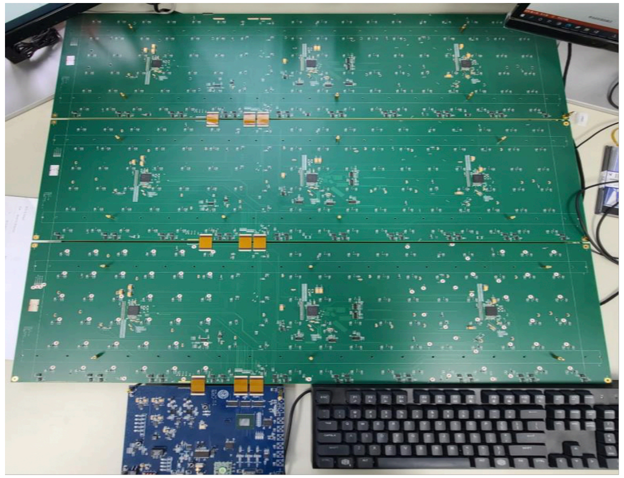
CEPC-AHCAL prototype structure



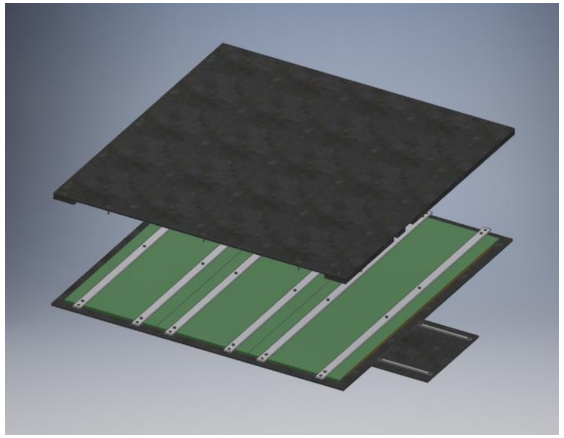
Scintillator tiles (wrapped): 40x40x 3 mm



HCAL Readout Module: HBU

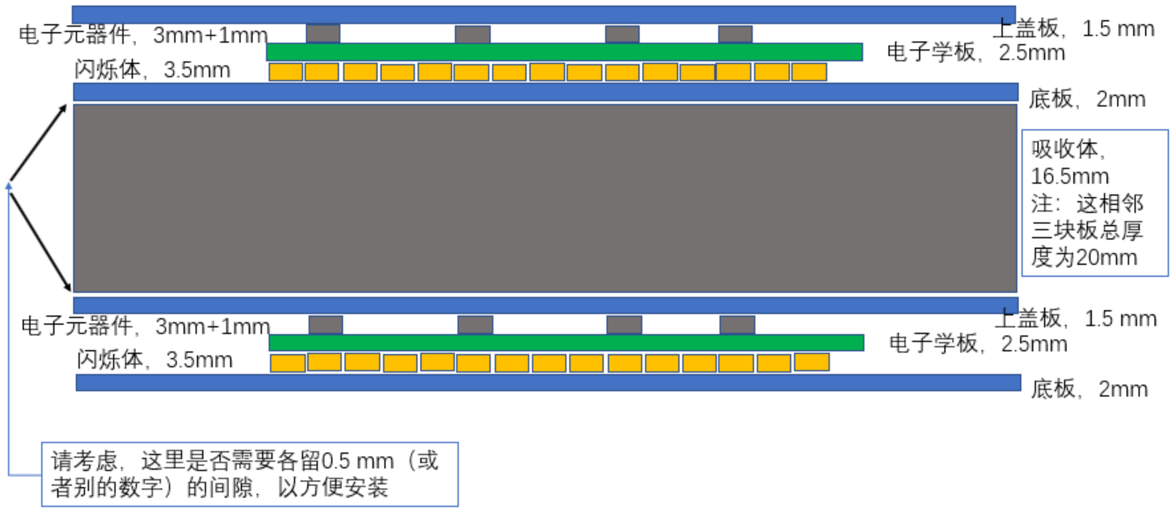


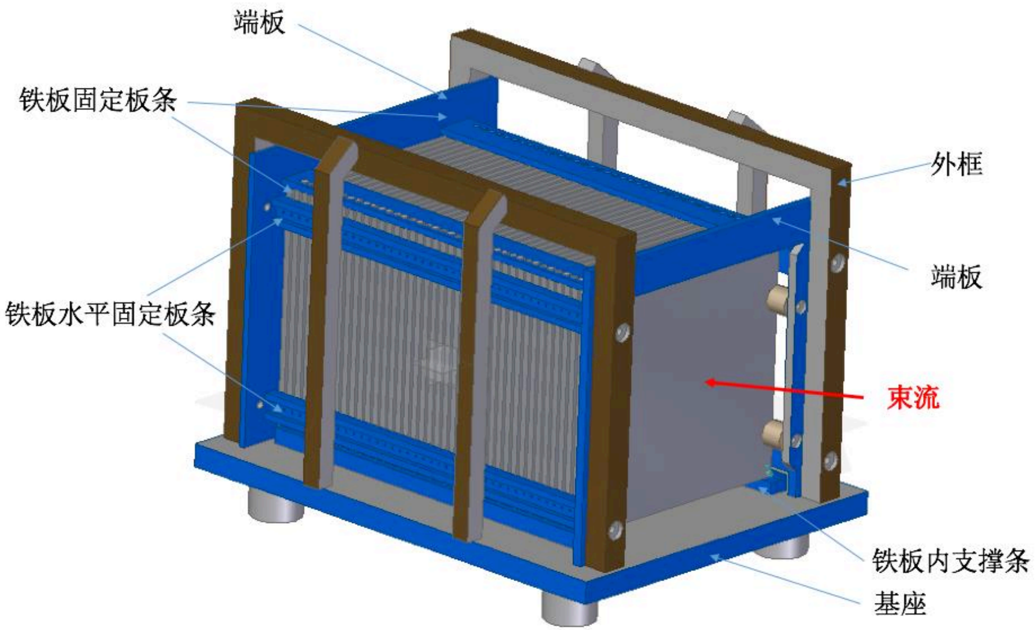
Cassette for HBU



CEPC-AHCAL prototype: mechanics

- Single Layer: cassette structure (iron)
  - To fix flexible PCB and improve stability, for further transportation and integration
  - To reduce the environment light to minimum
- System level: integration of 40 layers
  - Directly install 40 cassettes into the supporting structure





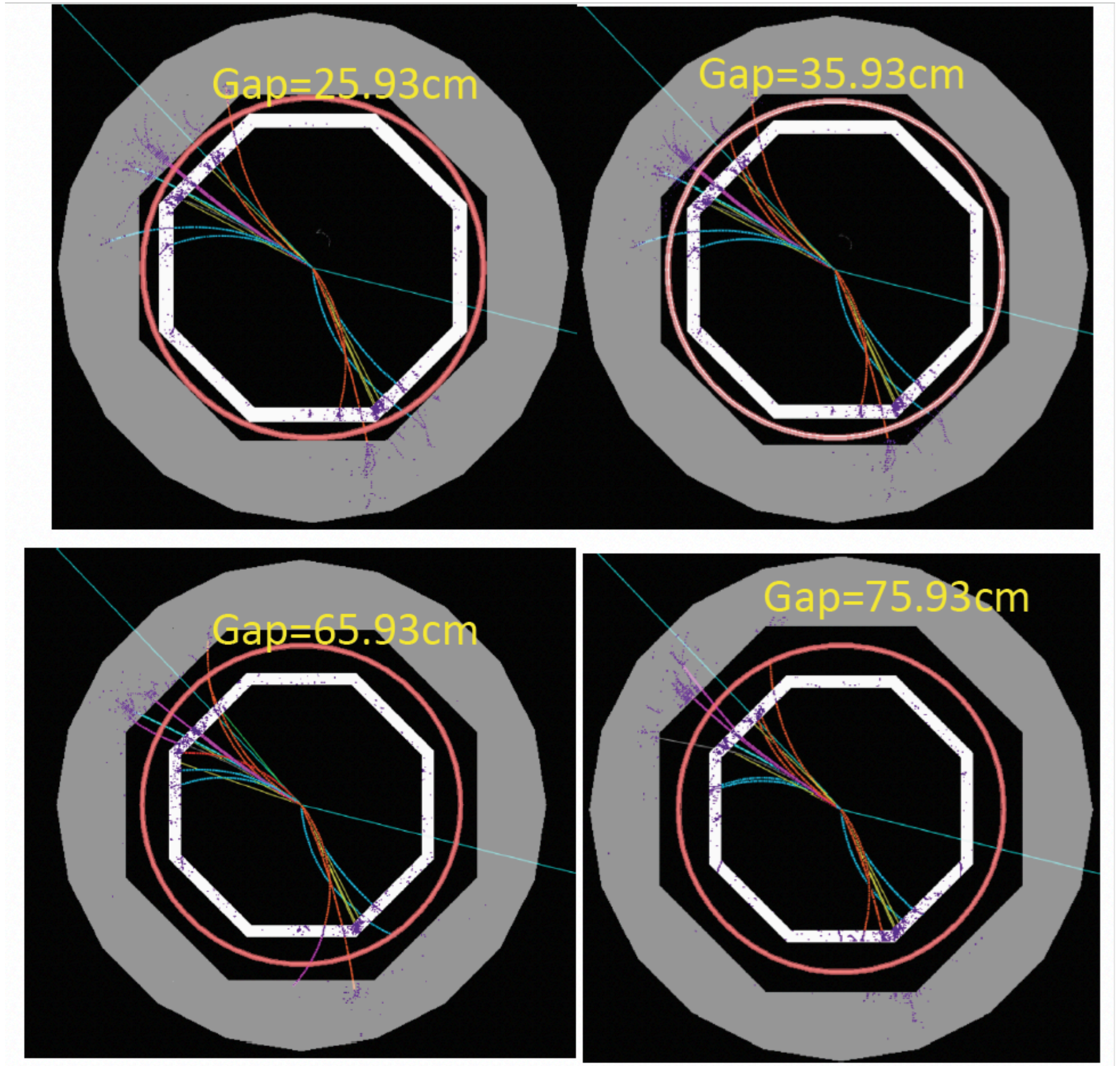
Outline

- Calorimeters for CEPC: recap
  - Technology options and mechanical structures
- R&D and key questions (selected) on calorimeter mechanics
  - Presented at CEPC Day and PhysDet Plenary Meetings
  - HCAL geometry designs and considerations
  - Existing designs/efforts for scalable designs: integration into a final detector
  - R&D activities for AHCAL prototype: mechanics and cooling
  - Solenoid between ECAL and HCAL

Presentation at CEPC Day (Dec. 28, 2020):
Physics impact of a solenoid between ECAL and HCAL (Manqi Ruan)

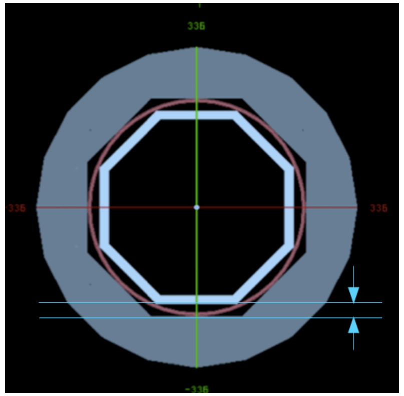
New idea: solenoid between ECAL and HCAL

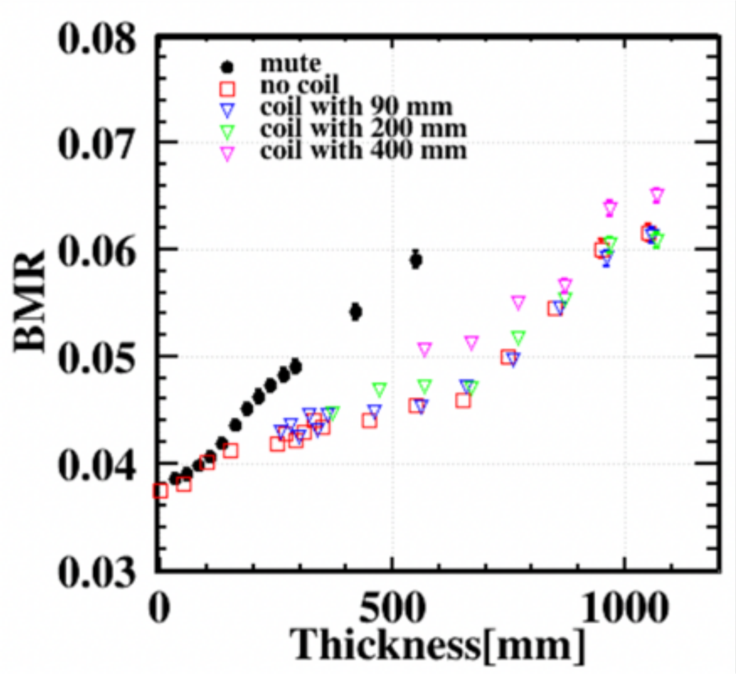
- Motivations
  - Smaller solenoid to reduce cost
  - Use return yoke as HCAL to further save cost
- Full simulation studies
  - Impact of space: put solenoid (round shape) between ECAL and HCAL
  - Impact of dead materials: from solenoid mechanics and all services
  - Higgs: Boson Mass Resolution (BMR)



New idea: solenoid between ECAL and HCAL

- Conclusions from simulation
  - BMR is sensitive to both space (gap between ECAL/HCAL) and material budget
  - Minimal space (169mm) for solenoid
    - 8% degrade of BMR (3.8%->4.1%)
  - Solenoid materials + gap, BMR degrades
    - 1X0 & 260 mm gap: 10%
    - 2.2X0 & 370 mm Gap: 15%
    - 4.4X0 & 570 mm Gap: 32%





- Ongoing studies on this idea
  - Divide HCAL into two parts
  - Solenoid between inner and outer HCAL

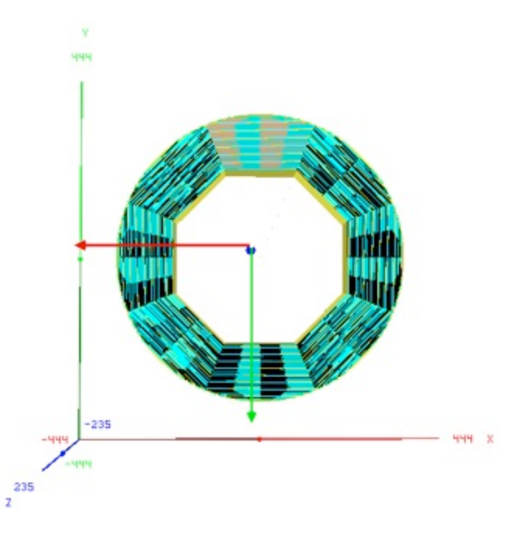
Summary and prospects

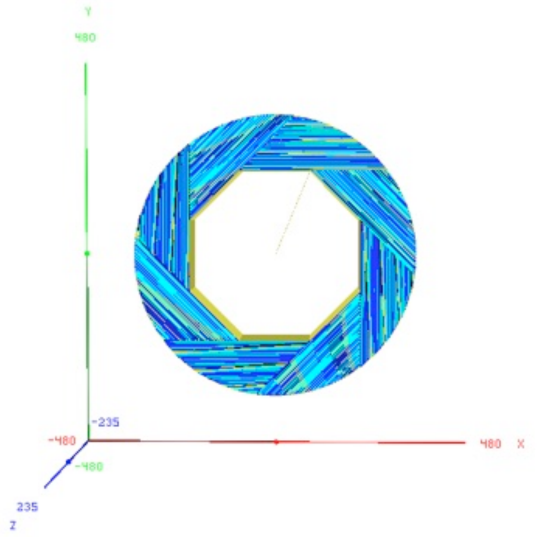
- Progress on calorimeter mechanics since the Workshop 2020
  - Target on specific tasks and selected key questions, given the person power
- Synergies with calorimeter prototype developments
- New calorimeter concepts emerging
  - Focus on simulation studies on impacts to physics performance
  - To address mechanics challenges, also need brain storming, fresh blood, etc.
- Joint efforts within CALICE collaboration
- Potentials to extend cooperation with domestic institutions
  - E.g. new mechanics designs, new materials, reliable simulation, prototyping for validation, etc.

Thank you!

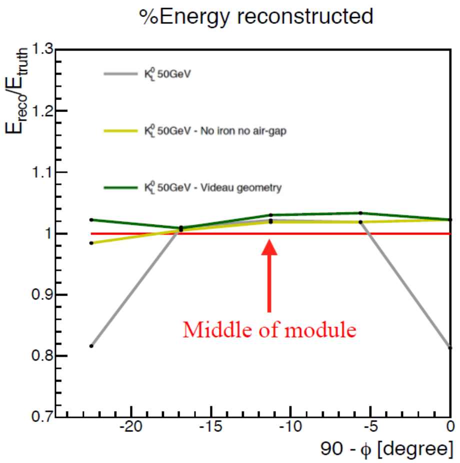
Spare Slides

HCAL mechanics: simulation studies within CALICE

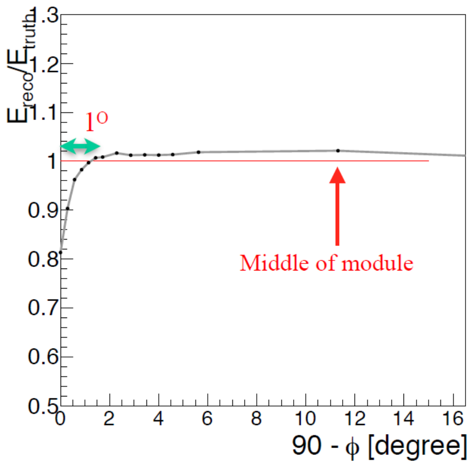




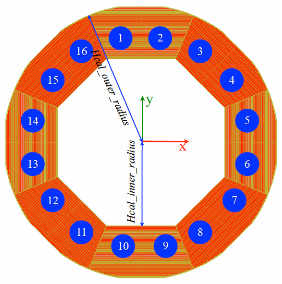
- Comparison of HCAL structures
  - Realistic symmetric structure with gaps
  - Ideal symmetric structure w/o iron and air gaps in φ
  - Asymmetric structure
- Loss of energy response and resolution due to cracks
- But this effect is negligible when integrating over all φ angles
  - Can be further mitigated by corrections

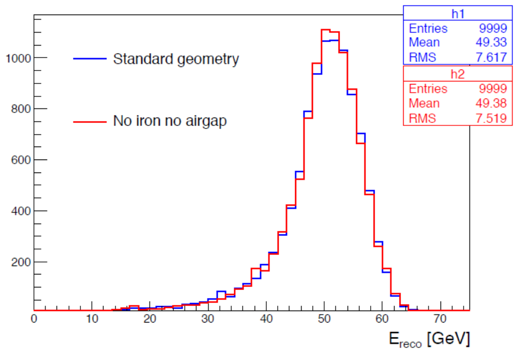


Finer phi steps



For single particle





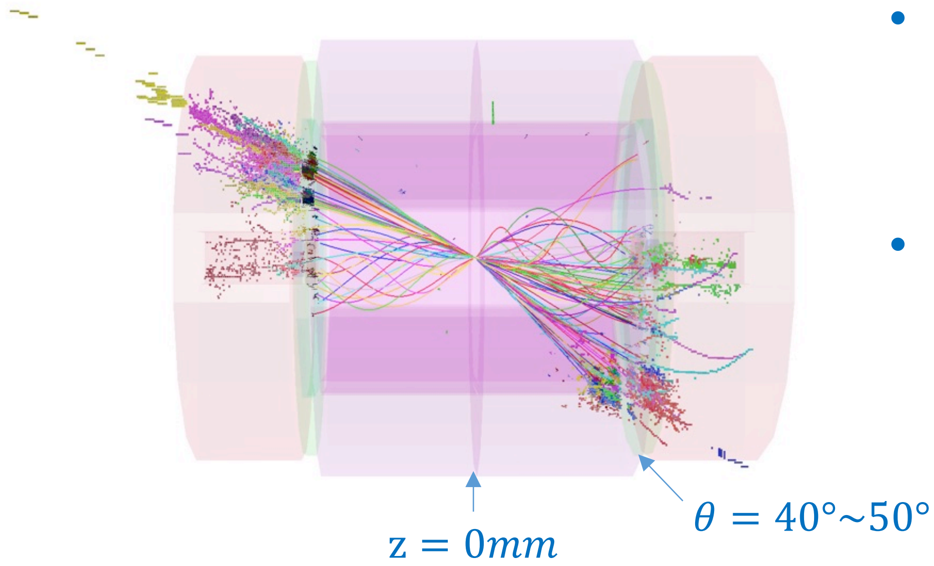
Fit Gaus90

Mean: 50.6938
Sigma: 5.07267
Res(Gaus90) = 10%

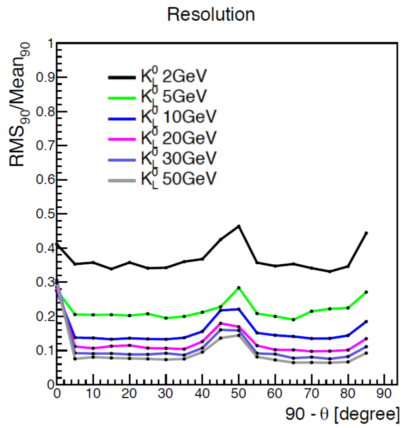
Mean: 50.7438
Sigma: 5.15704
Res(Gaus90) = 10.2 %

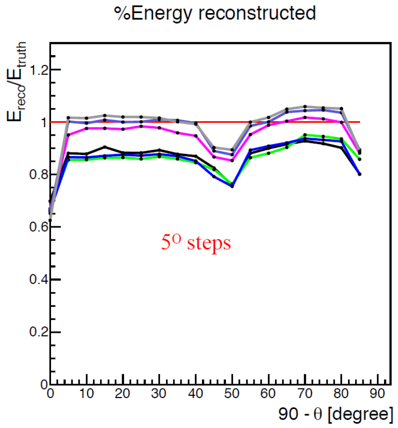
H.L. Tran, AHCAL optimisation using Pandora, LCWS2015

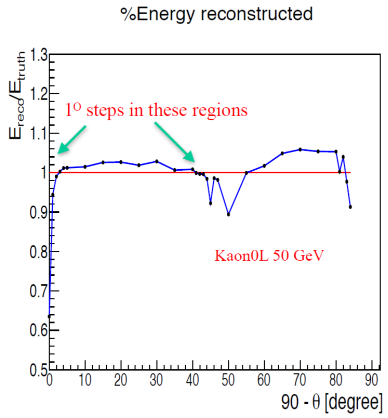
HCAL mechanics: simulation studies within CALICE



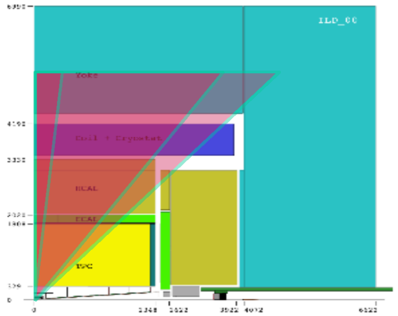
- Loss of energy response and resolution
  - At central iron plate $(z = 0)$
  - In transition region between barrel and endcap
- Can be mitigated by
  - Theta-dependent correction
  - Asymmetric barrel around the central plane $(z = 0)$: e.g. staircase like

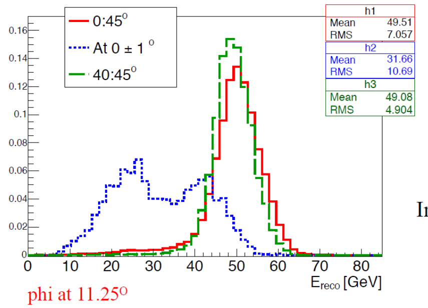




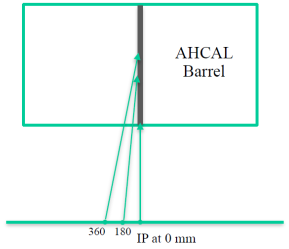


Effect of supporting structure (*r*,theta) plane

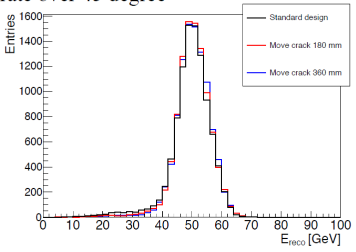




phi at 11.25°



Integrate over 45 degree



➢Middle stave iron support seems to have stronger effect on energy reconstruction.

Possible improvements:

- Cluster's energy correction as a function of theta
- Or: Asymmetric design: middle stave iron support is not anymore "middle"

H.L. Tran, AHCAL optimisation using Pandora, LCWS2015