Status of CEPC HCAL

Shu Li (TDLI, SJTU)
On behalf of the CEPC Calorimeter Working Group

CEPC Day of 23/09/2020

Sep. 23, 2020

中國科學院高能物理研究所
Institute of High Energy Physics Chinese Academy of Sciences

Content

Content

CEPC Physical Goal

CEPC Physical Goal

- Precise measurement of the Higgs particle's properties
- Explores new physics outside the standard model
- Precise measurement of the electric weak interaction parameters related to Z and W bosons.

Requirements of CEPC HCAL: high granularity

- Jet energy range: 100GeV
- Energy resolution: σ_E/E good than $60\%/\sqrt{E}$
- Jet energy resolution (ECAL, HCAL and tracker combined): $\sigma_E/E \approx 3\% - 4\%$

Operation mode	$\sqrt{s}$ (GeV)	L per IP ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	Years	Total $\int L$ (ab^{-1}, 2 IPs)	Event yields
H	240	3	7	5.6	1×10^6
Z	91.2	32 (*)	2	16	7×10^{11}
W^+W^-	158–172	10	1	2.6	2×10^7 (†)

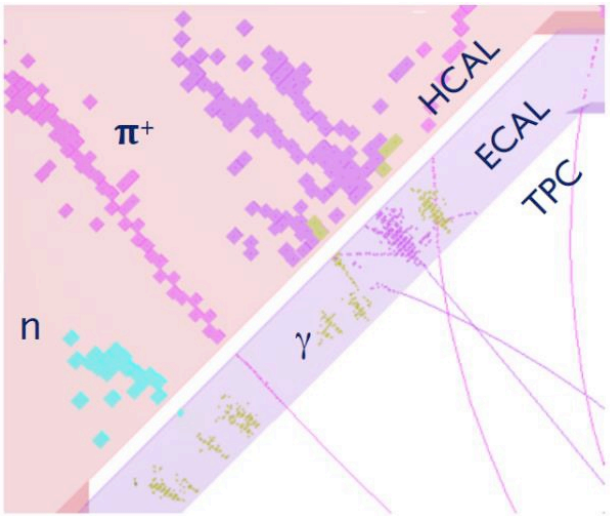
Particle Flow Algorithm

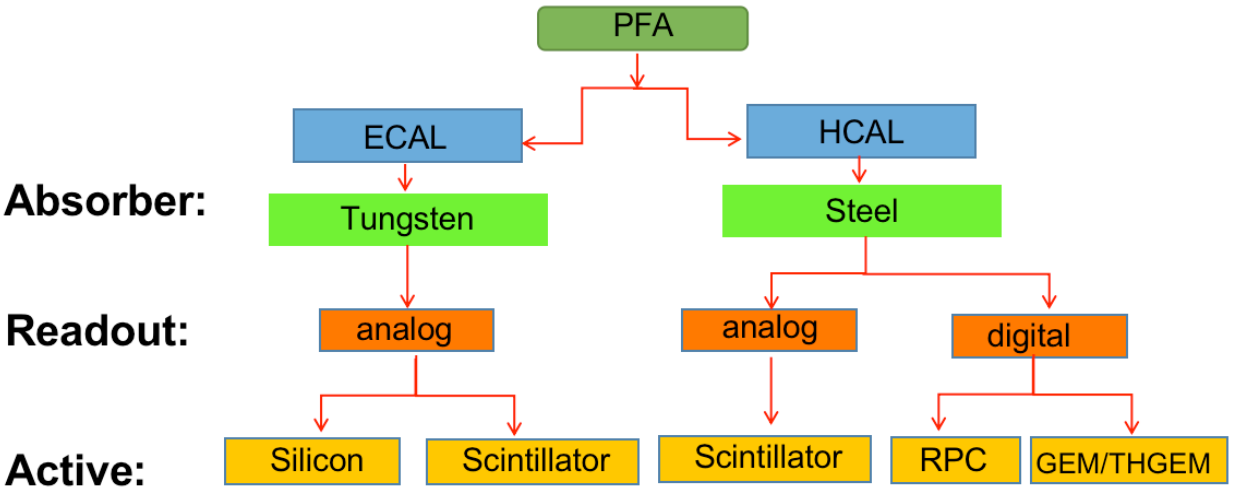
- Traditional calorimetric ($60\%/\sqrt{E(GeV)}$):
  - Measure all components of jet energy in ECAL/HCAL.
  - Approximately 70% of energy measured in HCAL.
- Particle Flow Algorithm:
  - Charged particle momentum measured in tracker.
  - Photon energy measured in ECAL.
  - Only neutral hadron energy (10% of jet energy) measured in HCAL: much improved resolution

Particles in jets	Fraction of energy	Measured with	Resolution [σ^2]
Charged	65 %	Tracker	Negligible
Photons	25 %	ECAL with 15%/√E	$0.07^2\ E_{jet}$
Neutral Hadrons	10 %	ECAL + HCAL with 50%/√E	$0.16^2\ E_{jet}$
Confusion	Required for 30%/√E		$\leq 0.24^2\ E_{jet}$

} 18%/√E

Imaging calorimeter





- AHCAL: Scintillator + SiPM
- SDHCAL: RPC & MPGD

Content

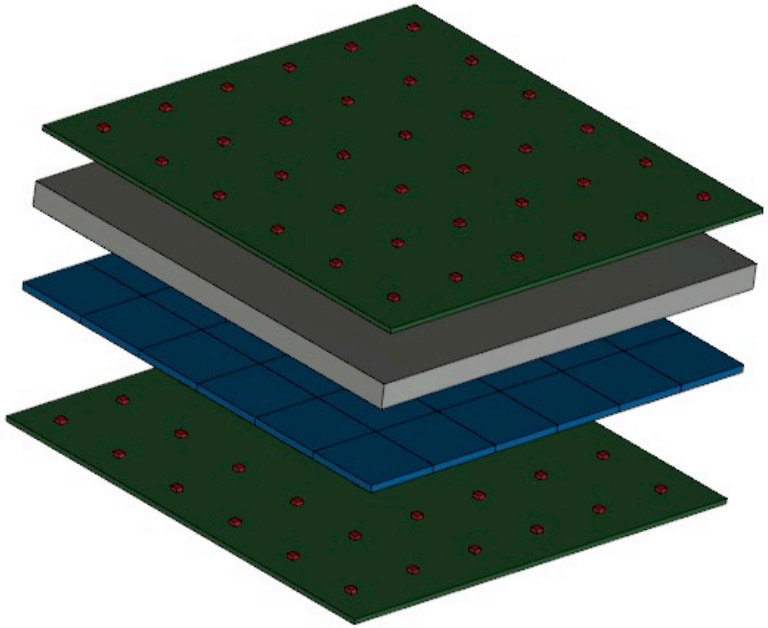
CEPC AHCAL Prototype

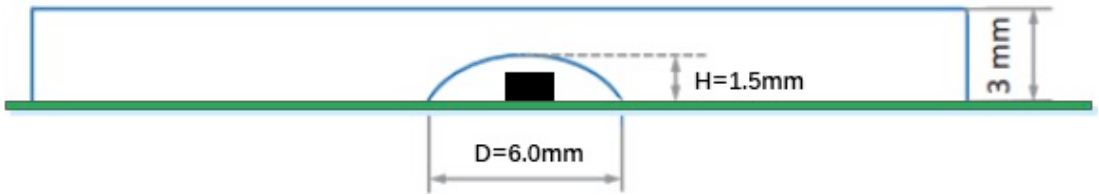
The AHCAL task:

- To validate the CEPC AHCAL option by designing, building and testing a full AHCAL prototype.

CEPC AHCAL: SiPM-on-Tile configuration

- Prototype: 72cm×72cm×100cm with 40 layers
- Detector cell size: 40mm×40mm×3mm
- PCB: 2mm, with SiPMs, temperature sensors and SPIROC2E
- Absorber: steel (20mm Fe)
- Active: scintillator made of polystyrene and wrapped in enhanced specular reflector (ESR) films.





Overall Progress

Participating institutes: USTC+IHEP+SJTU.
Detector

- Developed a PFA-based detector simulation tool and completed the design optimization of the AHCAL prototype
- Developed an injection molding process to produce scintillator tiles that meet quality requirements.
- Developed a tile batch testing system

Electronics

- Developed and validated single-chip front-end readout electronics and the data interface board
- Completed the schematic design of the full-size front-end readout board
- Developed a DAQ system

AHCAL Simulation and Optimization

Result shown for this part from Yukun Shi.

- Optimized the AHCAL design by scanning key design parameters in the simulation
- Simulated with both the simplified geometry and the CEPC official geometry
- Simulated both single hadron and PFA performance

Simulation and Optimization progress: completed the design optimization of the AHCAL prototype, Boson Mass Resolution: 4%.

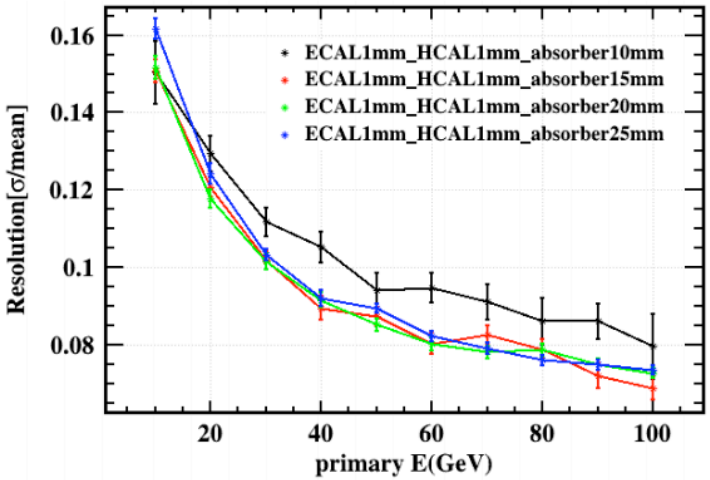
- 40 sampling layers
- Prototype Transverse size optimization: 72cm×72cm
- Absorber thickness optimization: 20mm steel
- Sampling Layer optimization: 3mm scintillator
- 2mm PCB

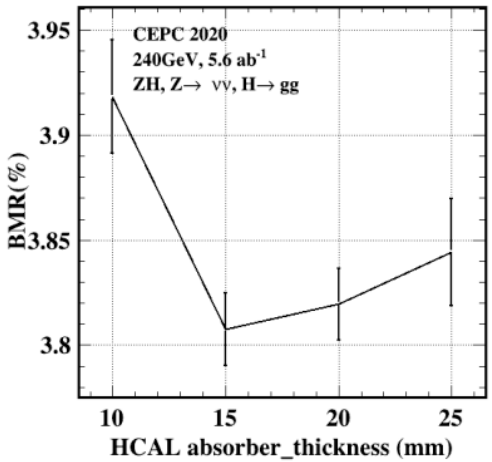
The performance for the AHCAL prototype:

- Linearity: $\pm 1.5\%$
- Resolution: $\frac{48\%}{\sqrt{E(GeV)}} \oplus 3\%$

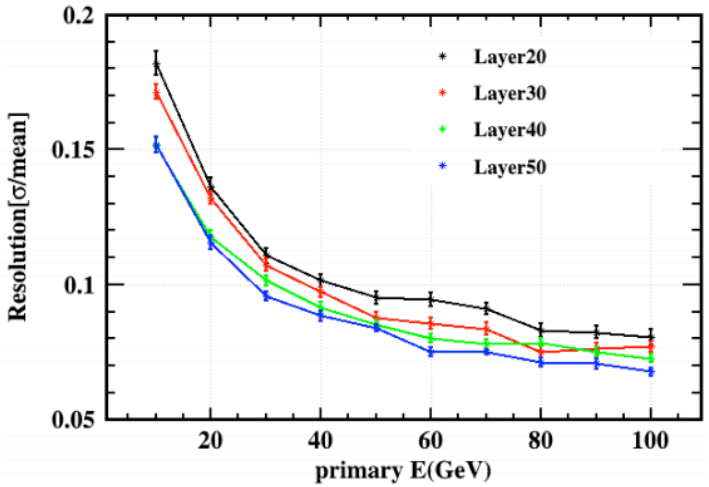
Simulation: Absorber thickness and number of layers

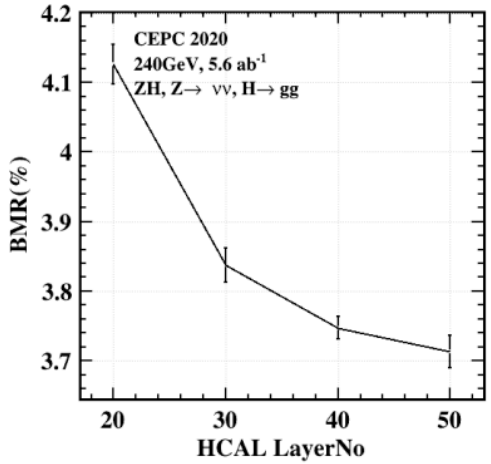
Absorber thickness





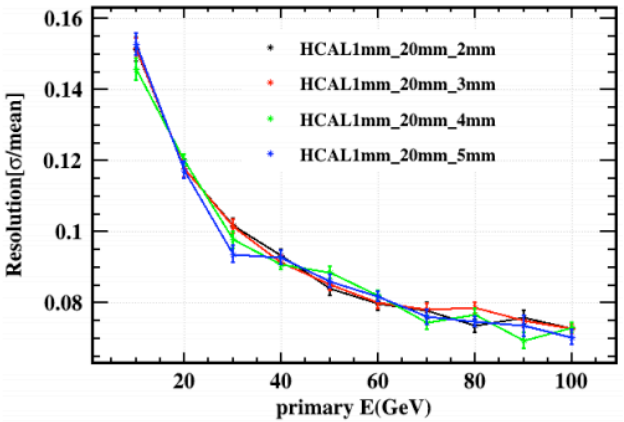
Number of layers

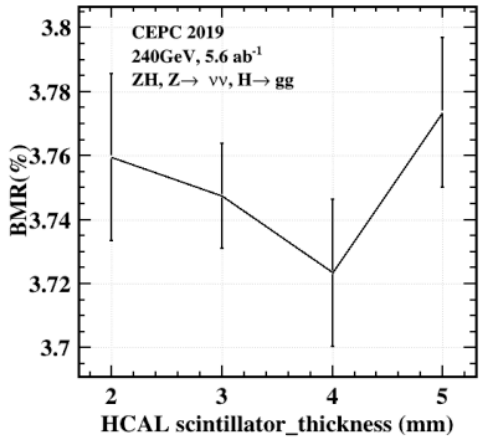




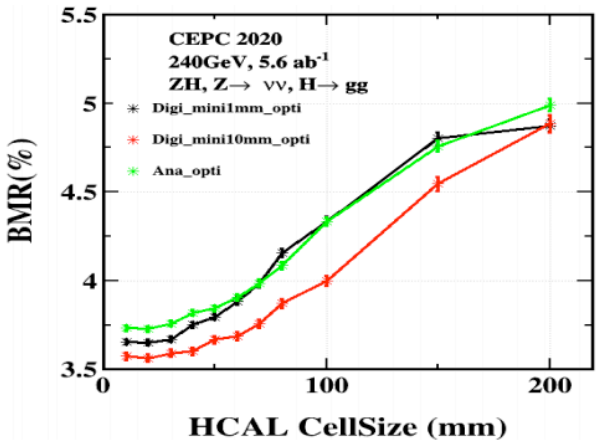
Simulation: Scintillator thickness and cell size

Scintillator thickness





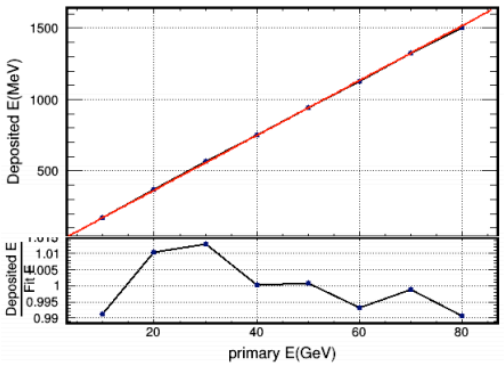
Cell size



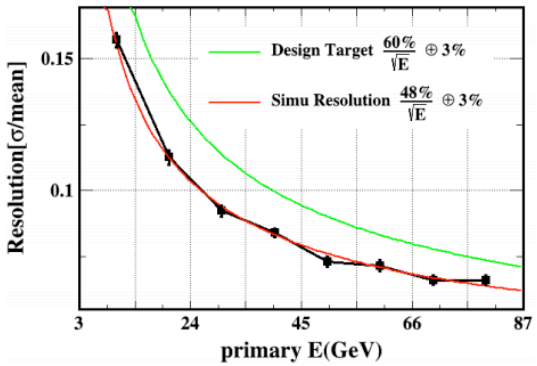
Simulation: AHCAL Prototype Design

- 40 layers
- each layer: 20mm steel + 3mm scintillator + 2mm PCB
- Cell size: $4\times4\ cm^2$
- Transverse size: $72\times72 cm^2$

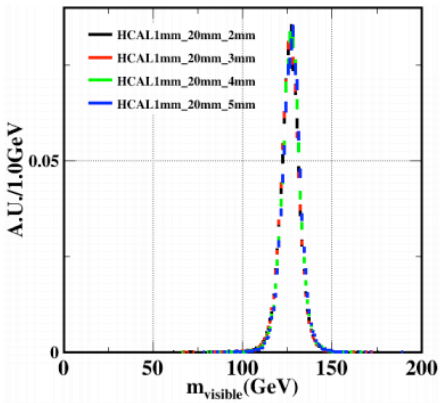
Linearity $<\pm1.5\%$



$\frac{48\%}{\sqrt{E(GeV)}} \oplus 3\%$



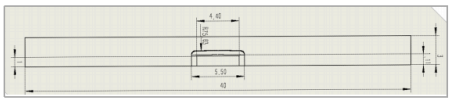
BMR < 4%

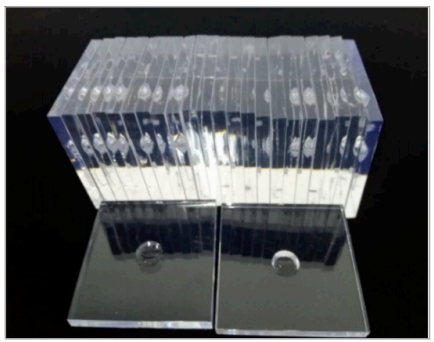


Studies on AHCAL sensitive cells

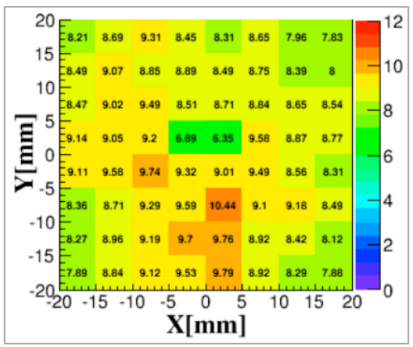
Result shown for this part from Jiechen Jiang.
AHCAL sensitive cells progress:

- Structure of AHCAL tiles:
  - try 3 different dimensions, 3cm×3cm, 4cm×4cm, 5cm×5cm
  - optimized the tile geometry for 4cm cell size
- Material of Scintillator: GNKD PS Tiles (Injection molding scintillator)
  - A lot of effort has been put in increasing the light yield
  - Optimized the injection molding process by adjusting various parameters in the process. Such as Concentration of solute, Time for mixing, Concentration of POPOP and so on.
  - The light yield has reached a reasonable level.
- NDL SiPMs 22-1313-15S is a suitable one for CEPC-AHCAL

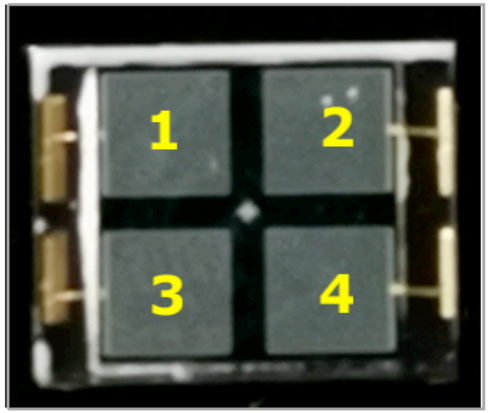




Light yield uniformity < 10%

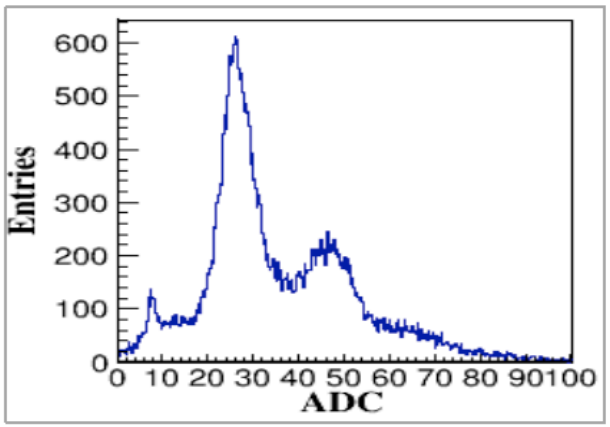


Sensitive Cells: SiPM

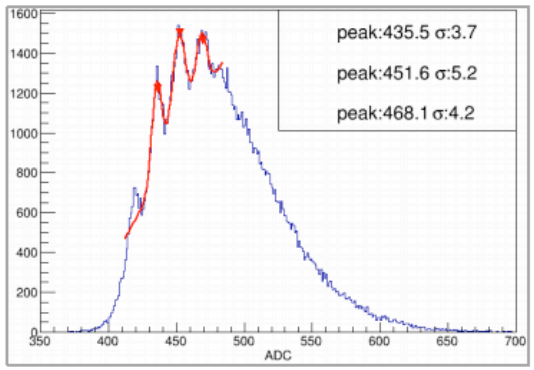


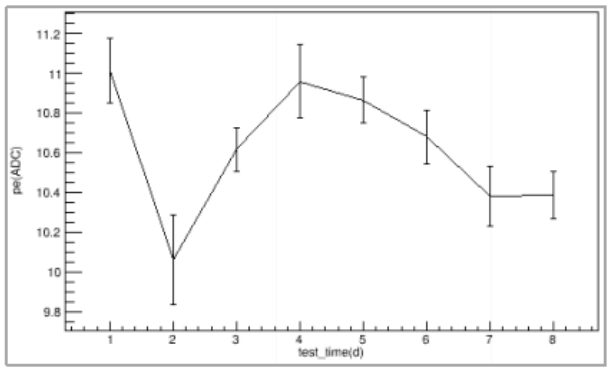
Breakdown[V]	19
PDE@400nm [%]	45
Transverse dimension [mm^2]	4.45×3.65
Thickness [mm]	0.95
Number of Pixel	7400×4

with dedicated readout



Testing with SPIROC-2E





Sensitive Cells: Light Output

- Expected the light yield of the scintillator is greater than 40p.e.
- Expected light yield uniformity around $\pm 10\%$

	Overvoltage	#SiPMs	Tile 2-3 LO
HPK 13360-1325PE	58V	1	14.45 p.e.
NDL 22-1313-15S	23V	1	22.33p.e
		2	46.17p.e.
	22.5V	1	20.12p.e.
		2	41.80p.e.

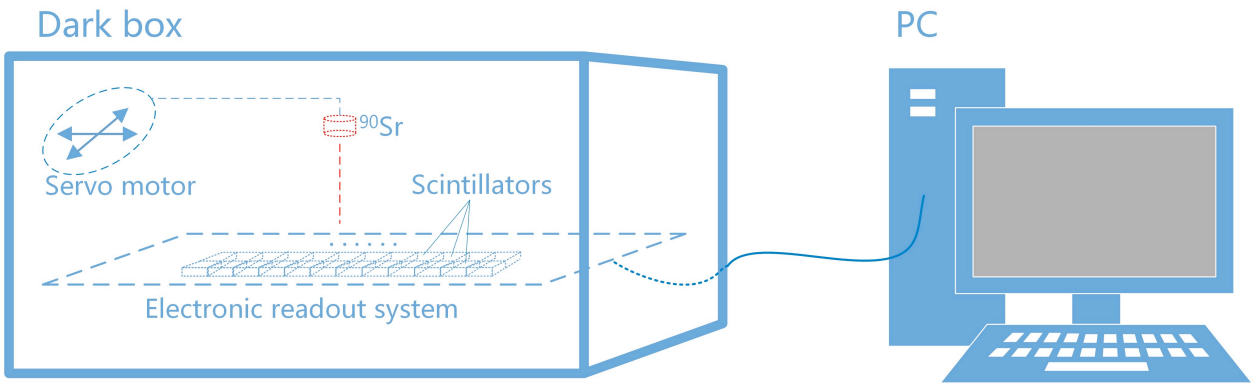
Light yield uniformity $< 10\%$

Development of AHCAL scintillator tile batch testing system

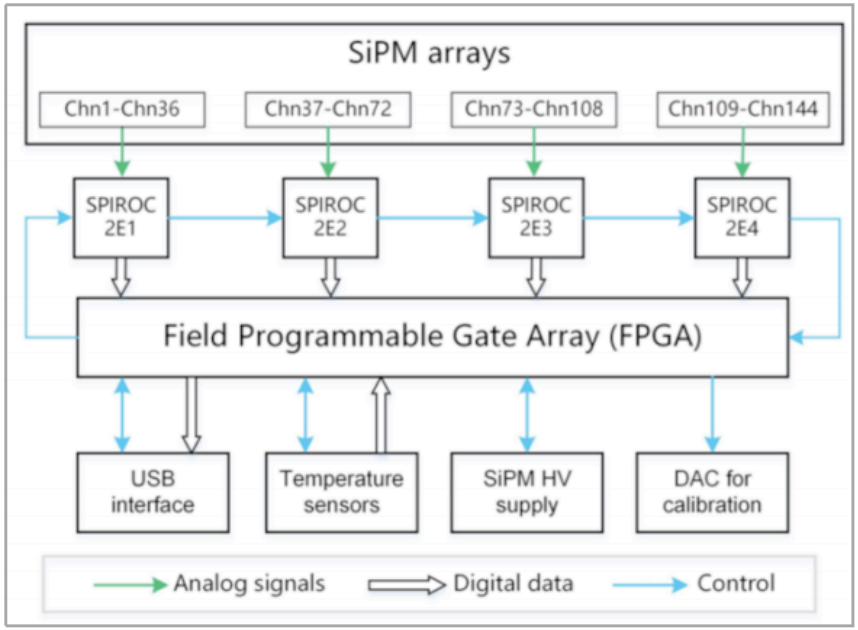
Result shown in this slide from USTC.

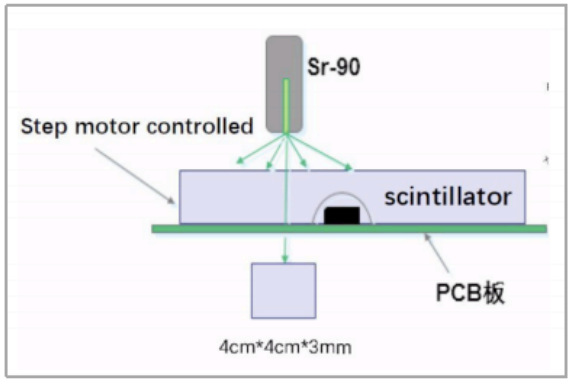
- 3 batch test system in total, USTC one has been finished, and the other 2 in process.
- 4 SPIROC2E+ 144 SiPM (S13360-1325PEs)+FPGA in DIF
- Calibration and Light Yield Measured by batch test system:

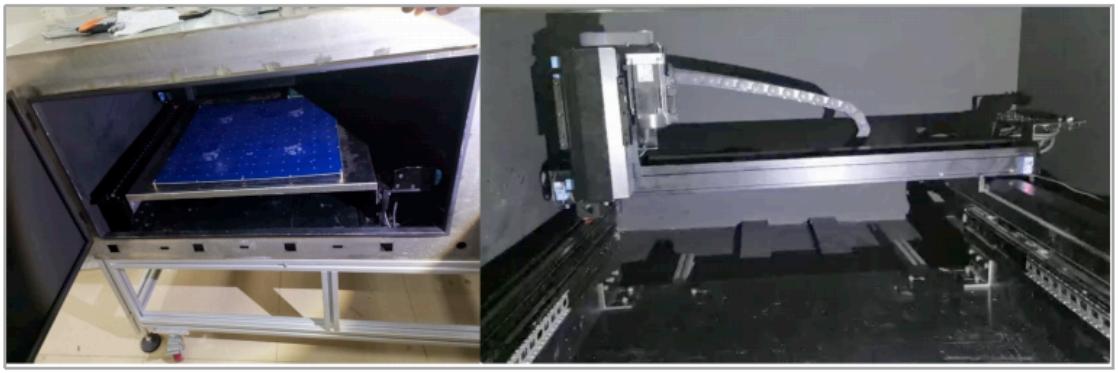
$$LY = \frac{ADC_{MIP} - ADC_{baseline}}{Gain_{SinglePhoton}}(perMIP) \tag{1}$$

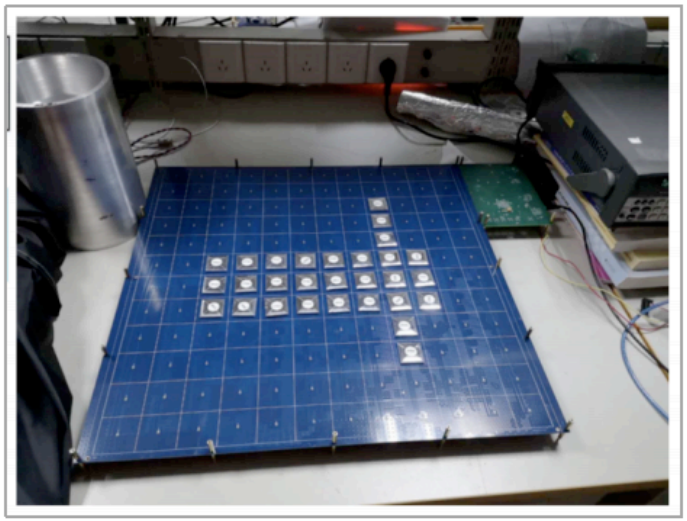


batch testing system







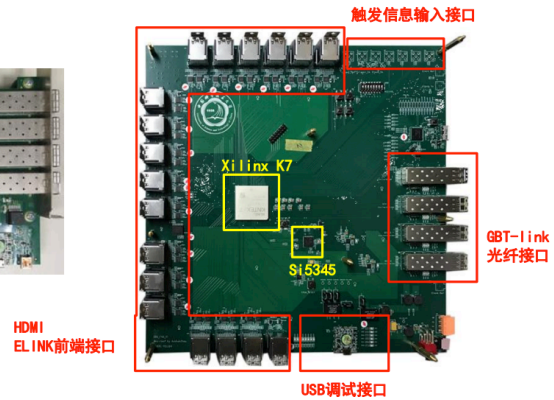


Progress on the development of AHCAL readout electronics and DAQ

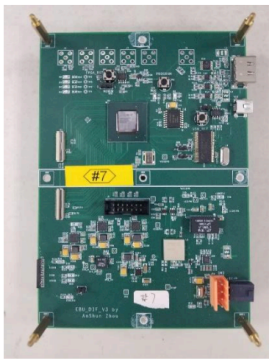
Result shown in this slide from Zhongtao Shen.

- ASIC design: SPIROC2E or KLauS
- HBU design: 18×18 readout channel per layer
  - Besides the function of signal readout, electronics calibration, light calibration and temperature monitor is also implemented on HBU.
  - plan to be finished at the end of this year
- DAQ system development: FELIX card+DAQ board+DIF (Data Interface) boards+HBU

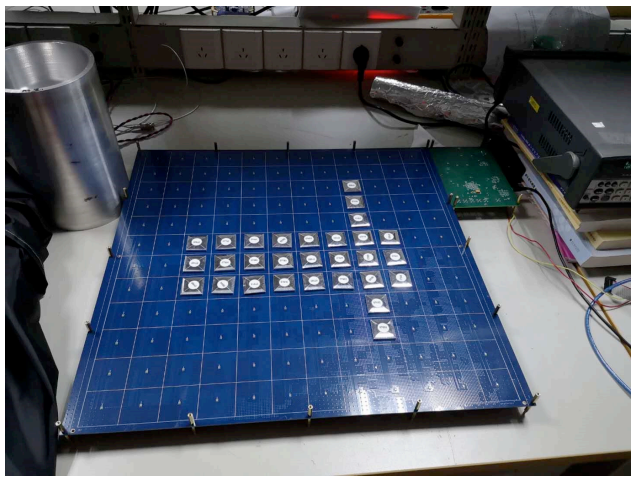
FELIX Card (VC709)



DAQ board



DIF board



Plans for Next Steps

Prototype:

- Scintillator tile: GNKD PS Tile
- SiPM: 370k RMB for NDL (22-1313-15-S)+180k RMB for HMAMMATSU (S13360-1325PEs)

Detector:

- Production of sensitive cells
- Design and assembling of sensitive layers
- Production of sensitive layers

Electronics:

- Development of the full-size front-end readout board
- Production of front-end readout boards and data interface boards

Mechanical part:

- Design of absorb layers and supporting structure

Batch test:

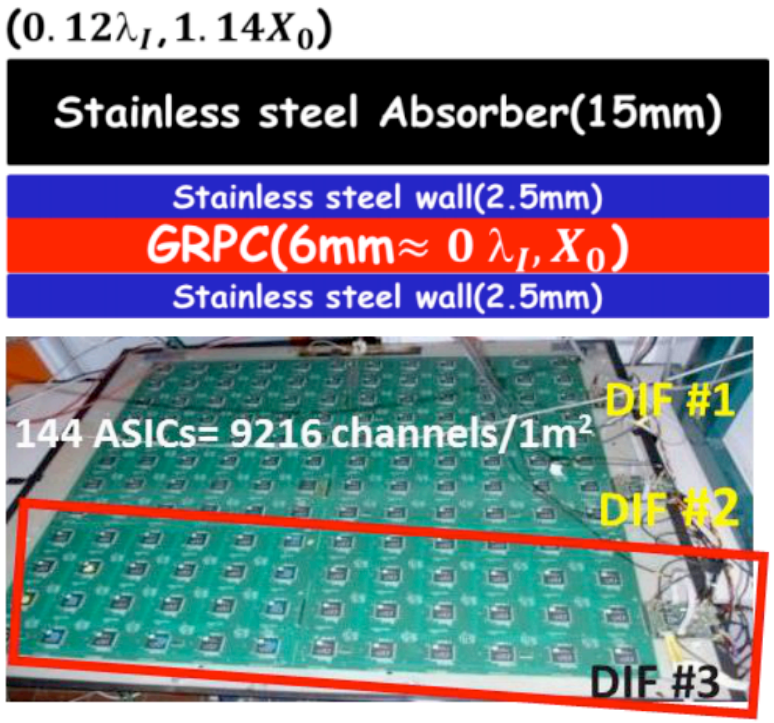
- Make and package 13.6k pieces of scintillator, do batch test (finish before 2021/02).

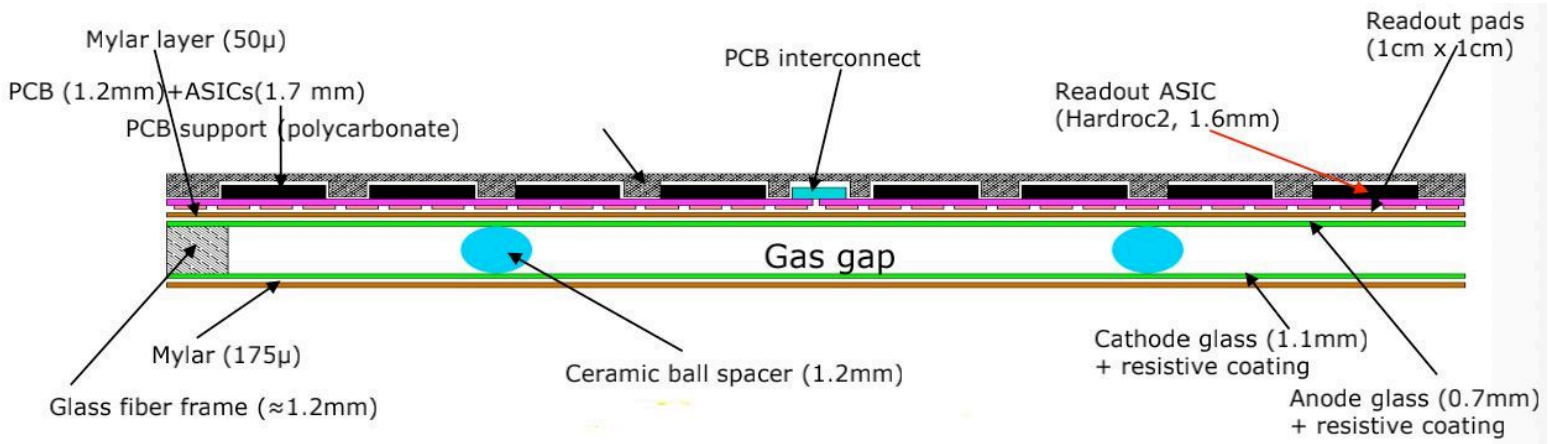
Content

CEPC SDHCAL-GRPC (IPNL+SJTU)

CEPC SDHCAL: based on RPC

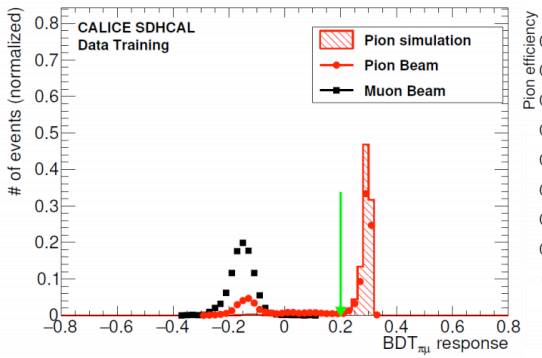
- Prototype: 1m×1m×1.4m with 48 layers
- Detector cell size: 1cm×1cm
- Number of channels: 440K
- Power: 1mW/ch
- Absorber: Stainless steel
- Negligible dead zone
- ASIC HARDROC (64 ch)

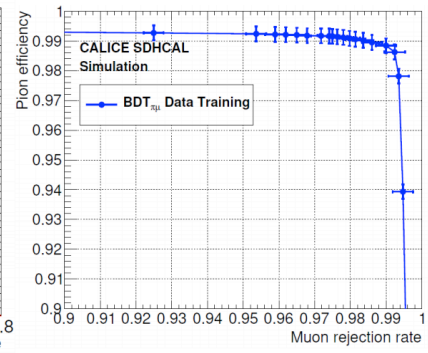


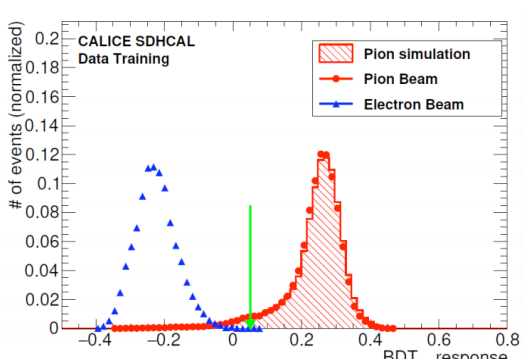


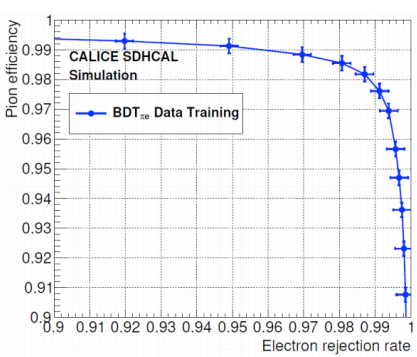
SDHCAL TB: Particle identification

- SJTU+IPNL, arXiv:2004.02972, Accepted by JINST
- Apply BDT to SDHCAL TB data analysis:
  - BDT helps to improve the hadron/e/mu PID, purify TB samples.
  - Keep 98% of pion efficiency and to reject >99.4% of mu.
  - Keep 98% of pion efficiency and to reject >99% of electron.
  - BDT significantly enhance pion selection efficiency of TB samples comparing to standard method, especially at energy up to 40 GeV.



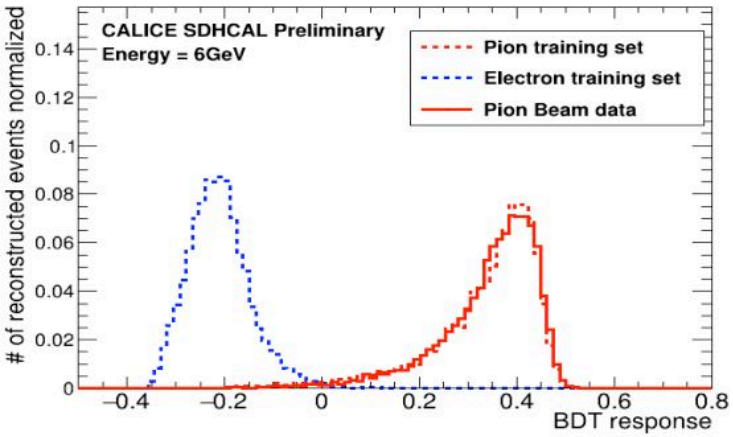


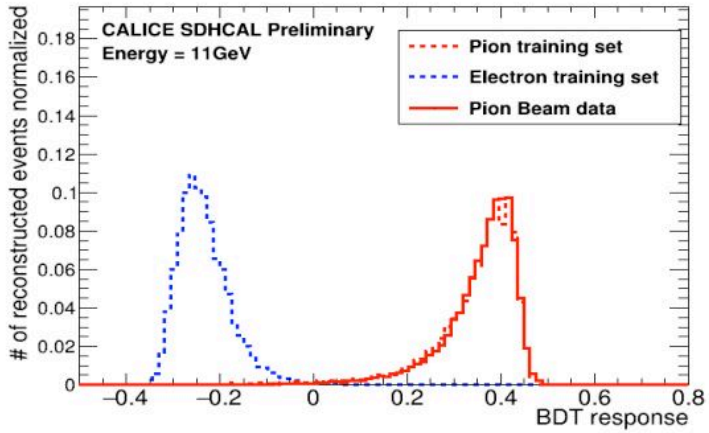


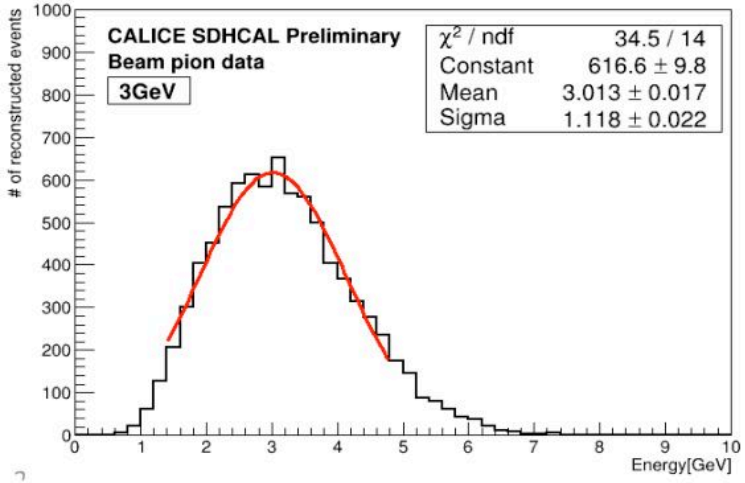


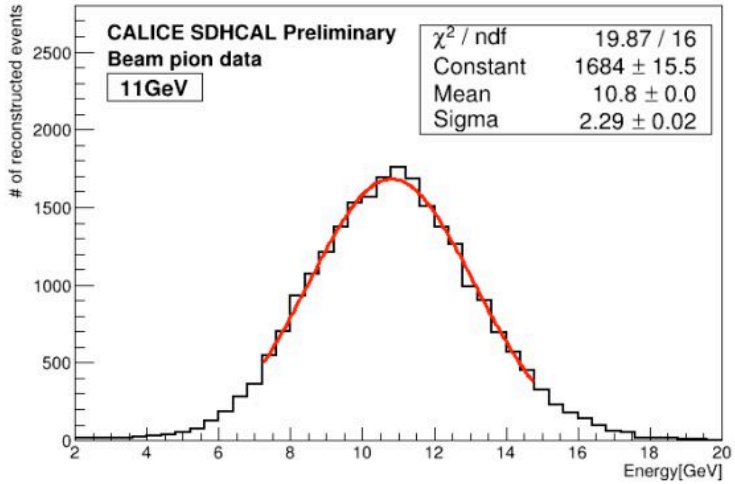
SDHCAL TB: Low Energy

- SDHCAL TB at CERN using low energy (3-11 GeV) pion beam.
- Data and MC simulation for pion samples agree well

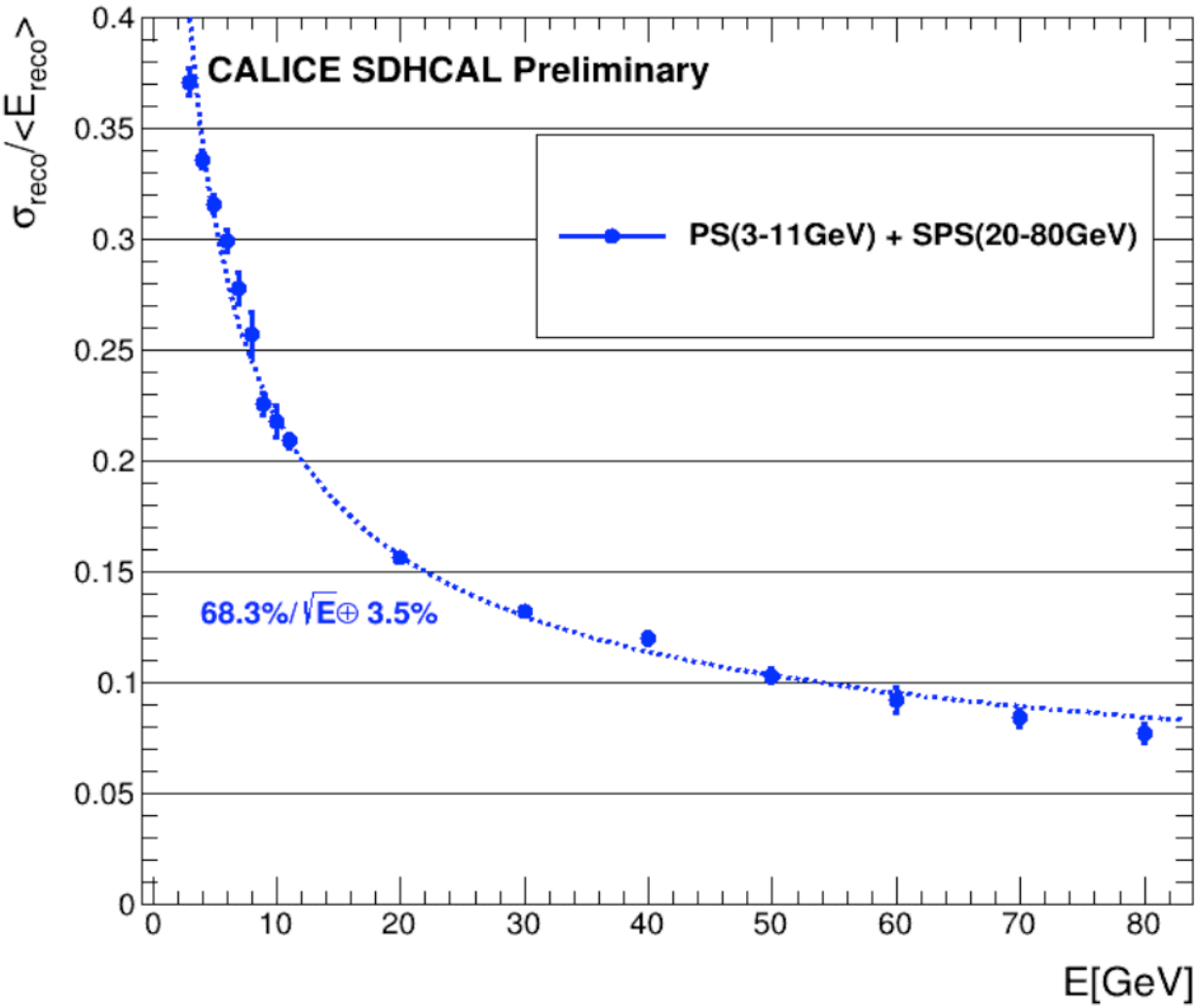






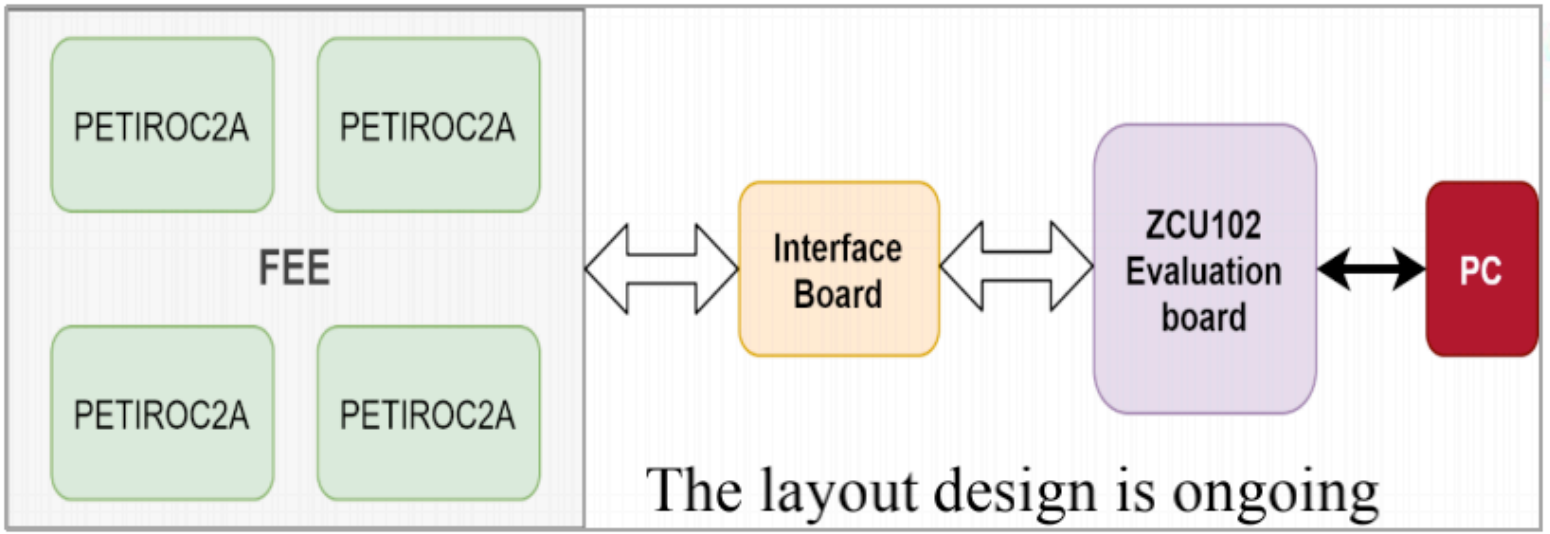


SDHCAL TB: Energy Resolution

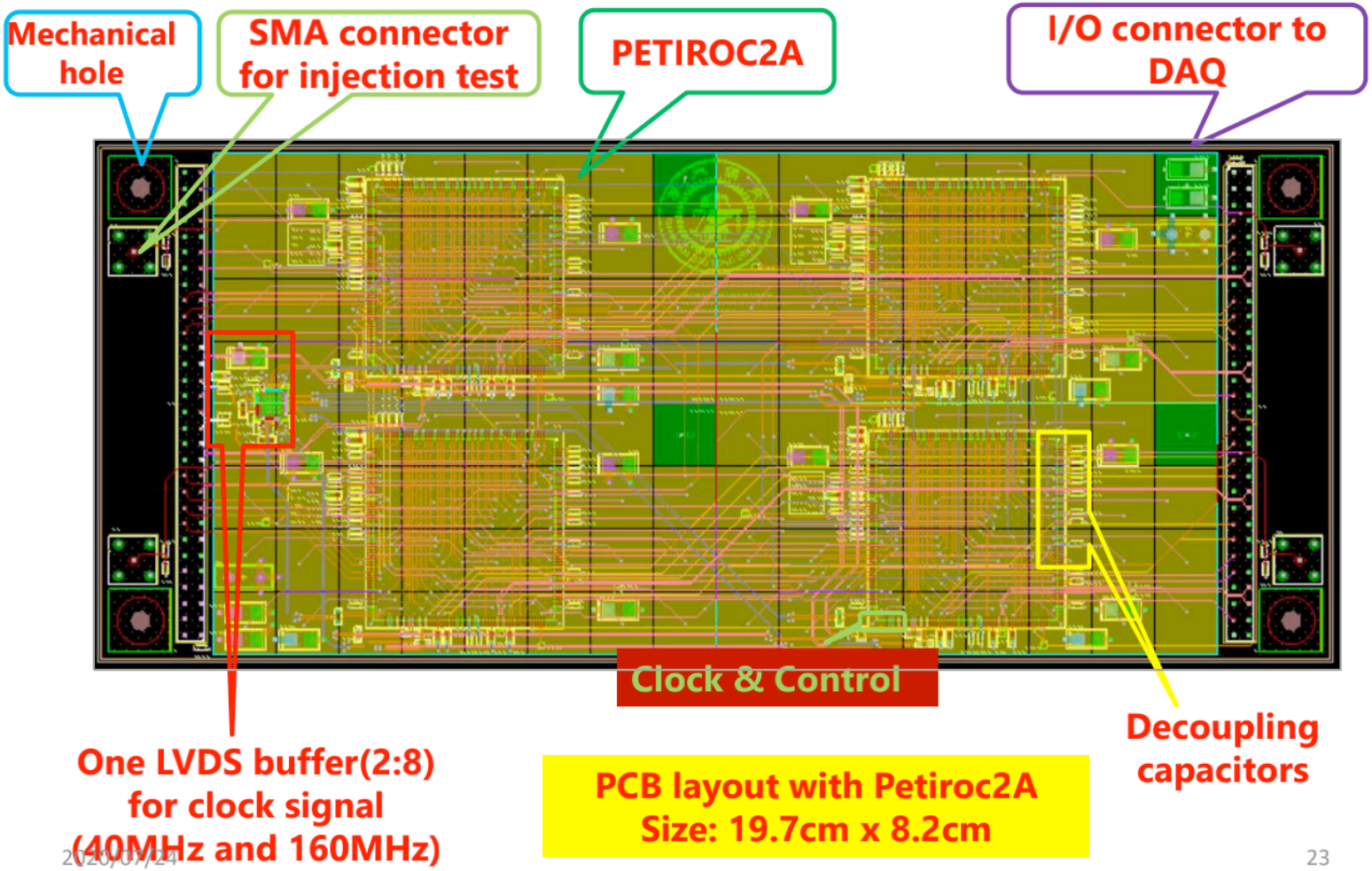


SDHCAL: New Design with 5D

- Purpose: five dimension (5D) SDHCAL:
  - Energy, position (X, Y, Z), timing
- Add MRPC layers in SDHCAL prototype
  - Same size as standard RPC
- Front-end board for MRPC readout
  - Charge and timing measurement simultaneously
  - PETIROC2A (32 channels, size: $2.8 \times 2.8 cm^2$)
  - $<$20ps time jitter



Design of PCB with Petiroc2A by SJTU

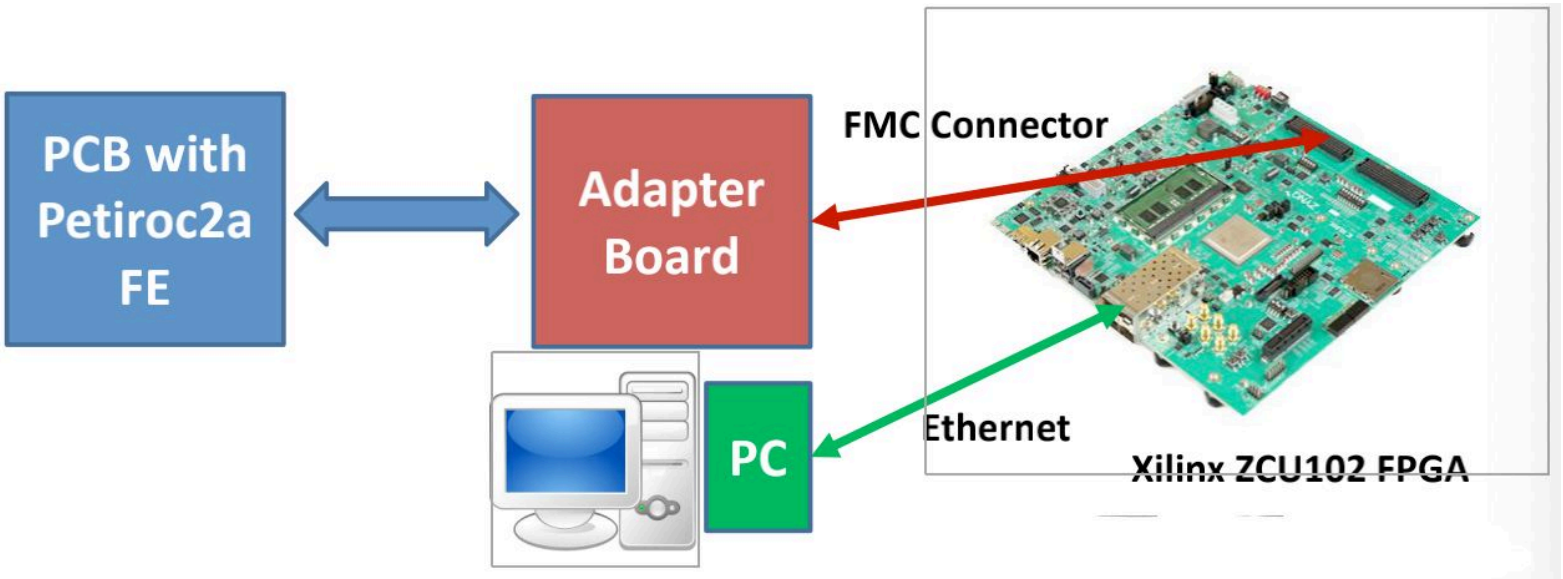


2020/07/24

23

Readout System for Petiroc2A based PCB

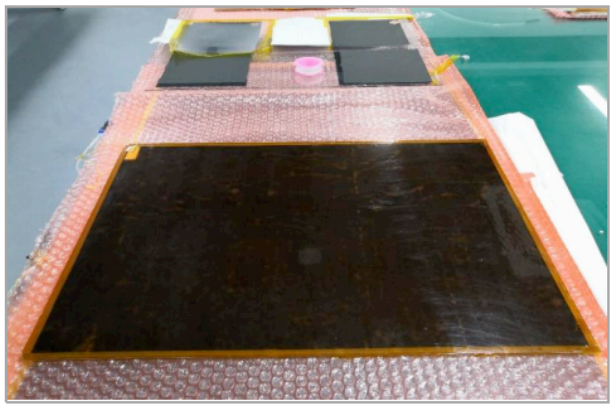
Xilinx ZCU102 has been purchased, readout system is under development.

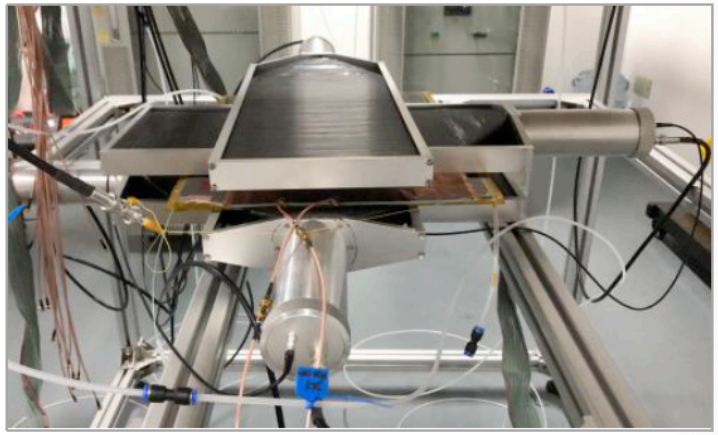


GRPC Construction and Test

- Now: RPC size 35cm×50 cm
- Next step: Large size RPC 1m×1m

GRPC construction in Cleanroom

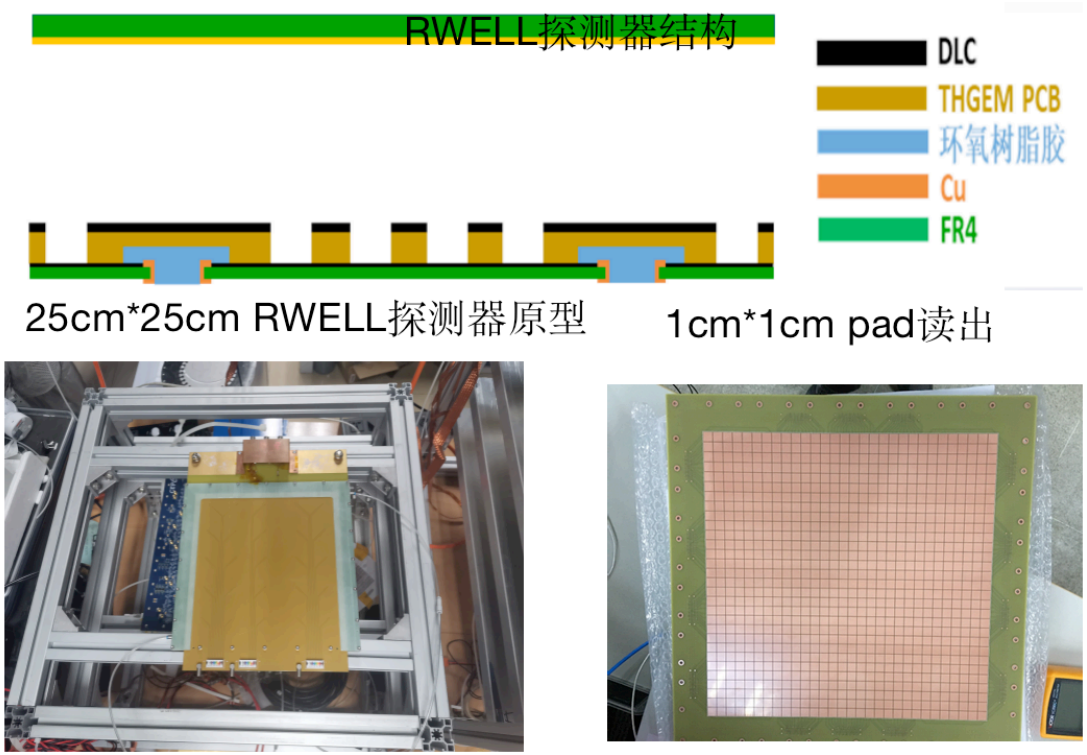




SDHCAL-MPGD: RWELL

Result shown in this slide from USTC.

- Deposition Technology of DLC resistive thin Films
- Made a prototype of 25cm×25cm detector, done a performance test and verification



DLC film deposition and PCB fabrication were greatly affected by the COVID-19 situation, and now it has basically returned to normal.

Content

Summary and Future Plan

CEPC AHCAL: SiPM-on-Tile configuration

- The scintillator cell size 4cm×4cm×3mm, PCB 2mm, absorber 20mm steel
- The light output of both PS and TP tiles can satisfy our requirement.
- New NDL SiPMs 22-1313-15S looks promising
- PS tile production, wrapping, testing is under preparation

CEPC SDHCAL: based on GRPC

- TMVA-BDT improves PID for SDHCAL TB data samples
- Design of FEE and PCB with PETIROC2A for MRPC 5D measurements is ongoing
- Construction and test of GRPC is ongoing

CEPC SDHCAL: based on MPGD

- Deposition Technology of DLC resistive thin Films
- Progress affected by the COVID-19 situation
- Now it has basically returned to normal.

Thank You!.