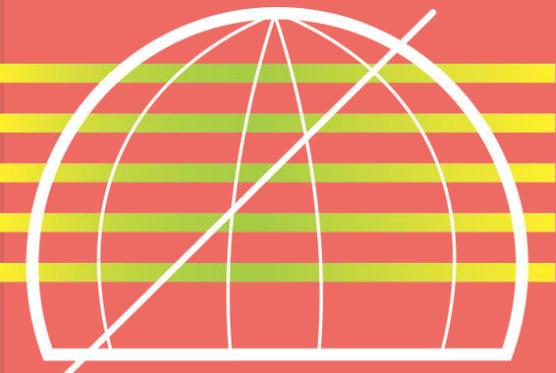


RPC-SDHCAL status

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Shanghai JiaoTong University

For the SDHCAL-CALICE group



RPC 2022

CERN

Outline

CALICE SDHCAL Calorimeter

- 1) Short description
- 2) Energy reconstruction methods, Improvement with PID techniques , Further improvements on energy reconstruction
- 3) Detector homogeneity
- 3) Big size RPC, Timing information

Summary

SDHCAL

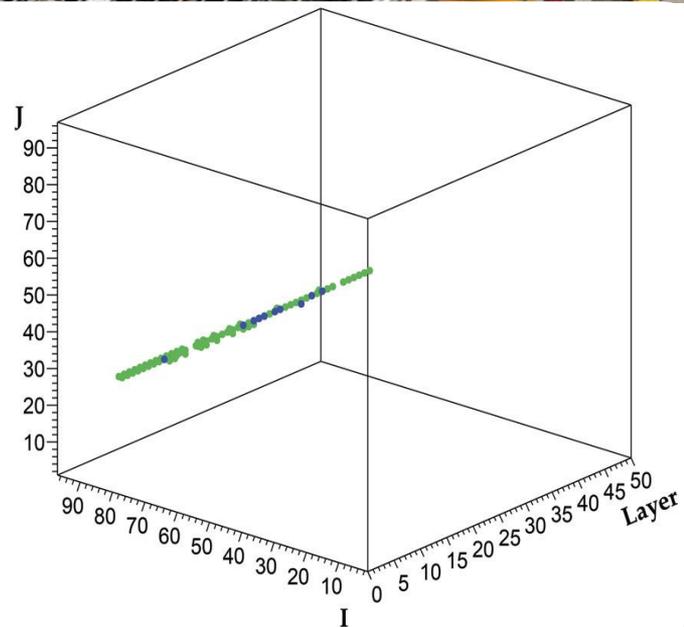
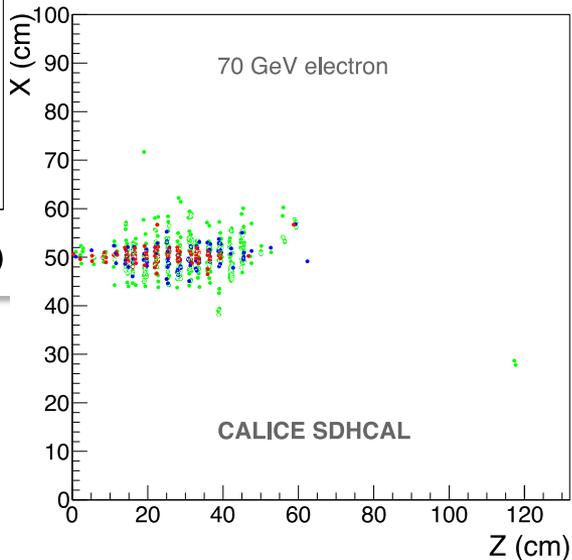
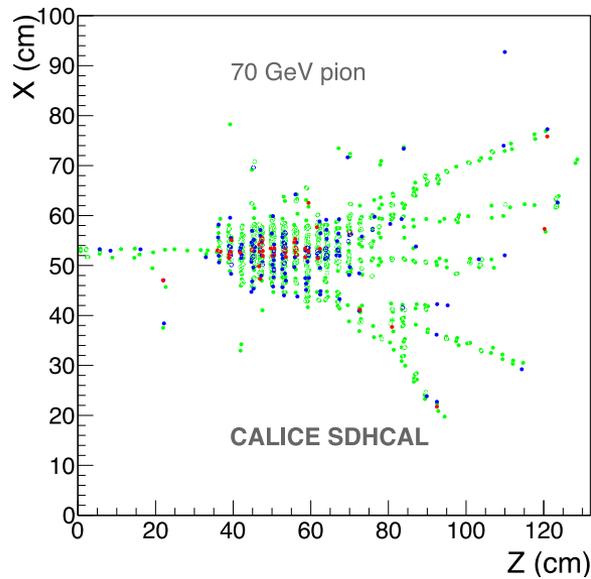
JINST 10 (2015) P10039

- 48 layers ($-6\lambda_T$)
- 1 cm X 1 cm granularity , 3-threshold, 500000 channels
- Power-Pulsed
- Triggerless DAQ system
- Self-supporting mechanical structure



RPC 2022

SDHCAL prototype was exposed to beam particles at CERN PS, SPS in 2012, 2015, 2017 and 2018



Muon rejection: average number of hits/layer < 2

Electron rejection: shower starting after the fourth layer (6 radiation length)

Energy reconstruction

$$E_{\text{rec}} = \alpha(N_{\text{tot}}) N_1 + \beta(N_{\text{tot}}) N_2 + \gamma(N_{\text{tot}}) N_3$$

$$N_{\text{tot}} = N_1 + N_2 + N_3$$

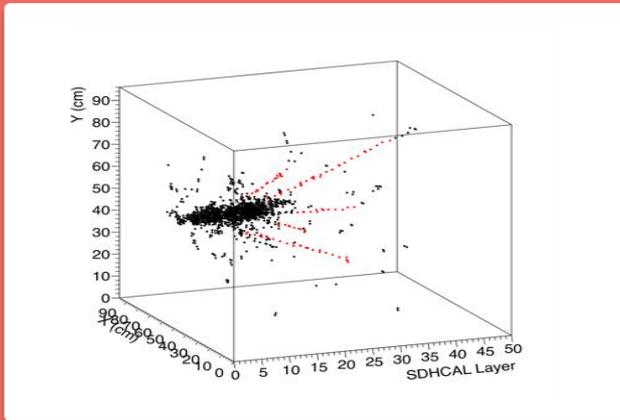
α , β , γ are quadratic functions of N_{tot}

They are computed by minimizing :

$$\chi^2 = (E_{\text{beam}} - E_{\text{rec}})^2 / E_{\text{beam}}$$

Hough-Transform

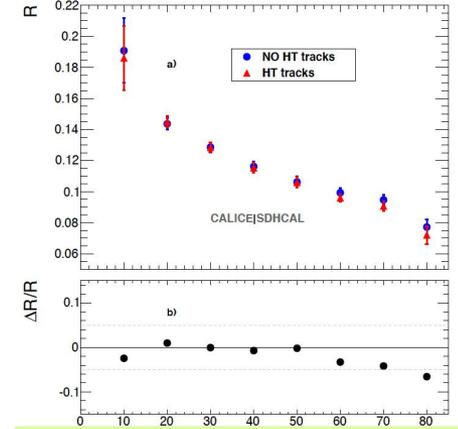
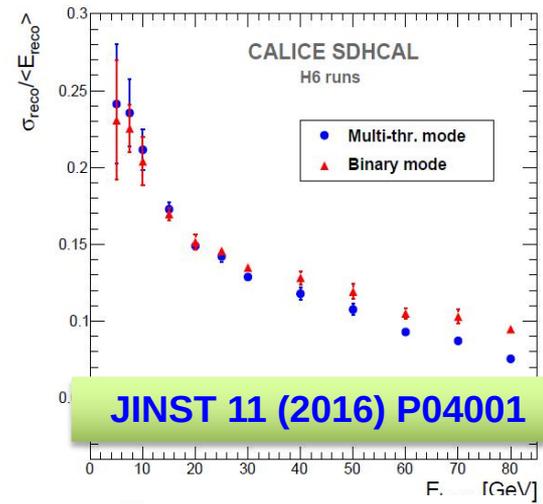
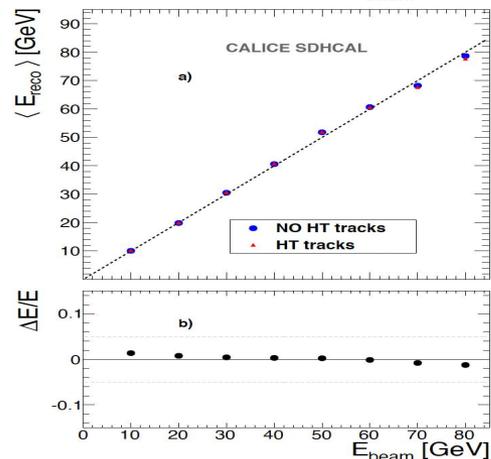
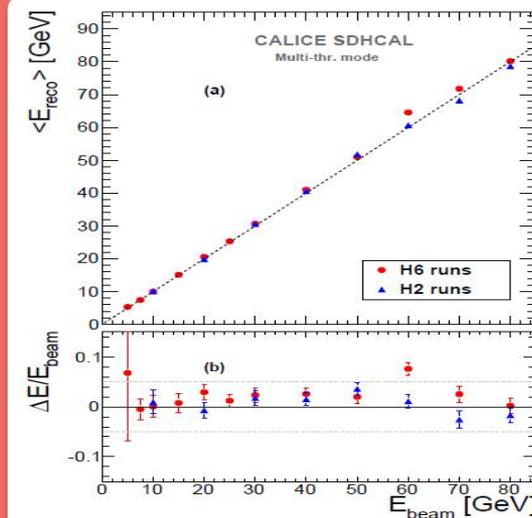
Track segments reconstruction using 3D-Hough Transform helps to apply different treatment to the hits of these segments.



$$E_{\text{rec}} = \alpha(N_{\text{tot}}) N'_1 + \beta(N_{\text{tot}}) N'_2 + \gamma(N_{\text{tot}}) N'_3 + c N_{\text{HT}}$$

$$N_{\text{tot}} = N'_1 + N'_2 + N'_3 + N_{\text{HT}}$$

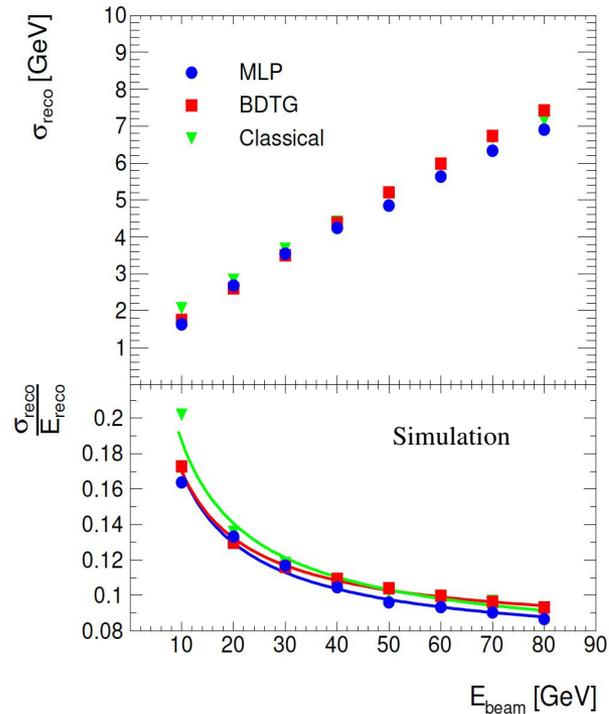
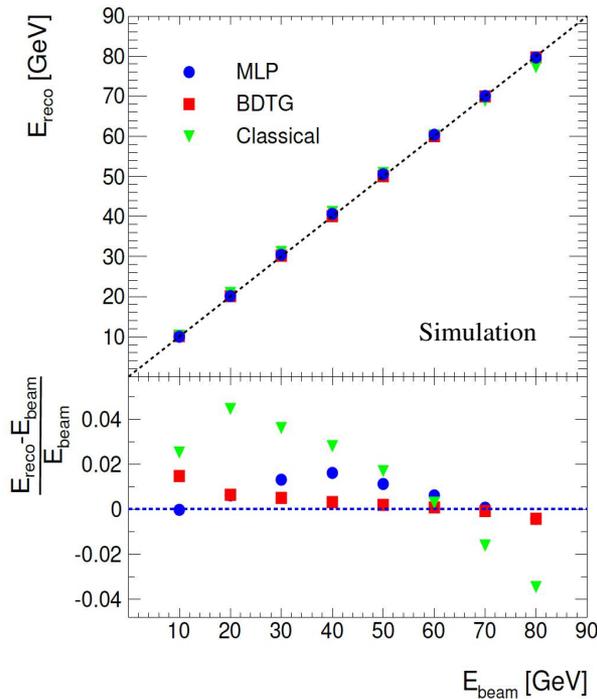
N_1 = #pads with first threshold < signal < second threshold
 N_2 = #pads with second threshold < signal < third threshold
 N_3 = #pads with signal > third threshold



Further improvements on the energy reconstruction

Multi-Variate Techniques

Several MVT methods (NN and BDT) were used to exploit, in addition to N_1 , N_2 and N_3 , the hadronic shower shape information related to its energy thanks to the high granularity of the SDHCAL



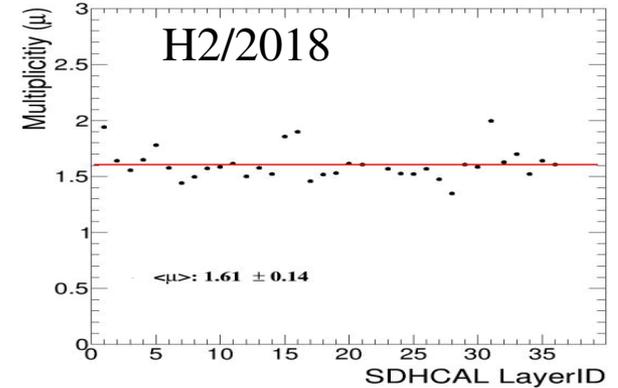
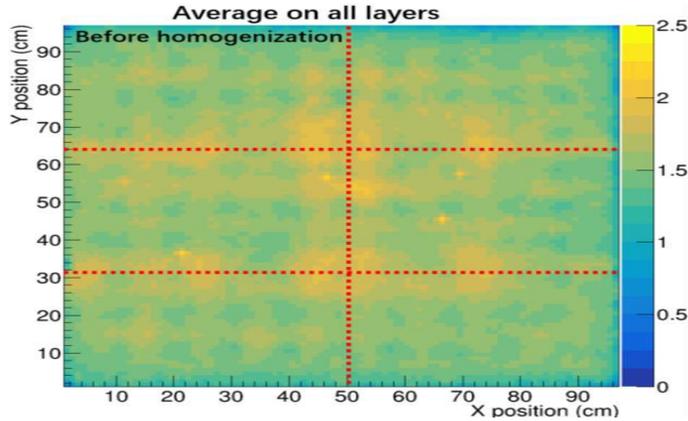
Input Variables	Description
$nHit1$	The number of hits only exceeding the threshold 1
$nHit2$	The number of hits exceeding the threshold 2 but not threshold 3
$nHit3$	The number of hits exceeding the threshold 3
$nHit$	$nHit = nHit1 + nHit2 + nHit3$
$nHough$	Number of hits used to do Hough Transformation
$nCluster$	Number of clusters
$nTrack$	Number of tracks
$nLayer$	Number of layers fired
$Density$	The density of hits
$meanRadius$	Mean of distance between tracks and hits
$InterLayer$	Number of layers when $meanRadius > 5cm$
$begin$	The number of the layer where the shower starts

JINST 14, 2019, P10033

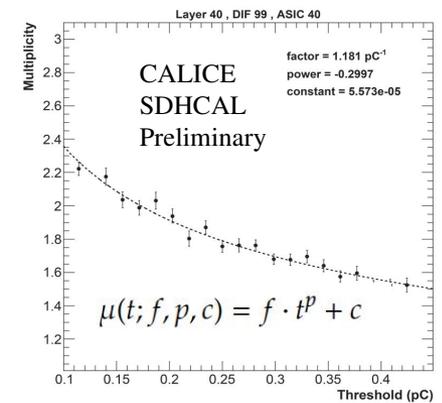
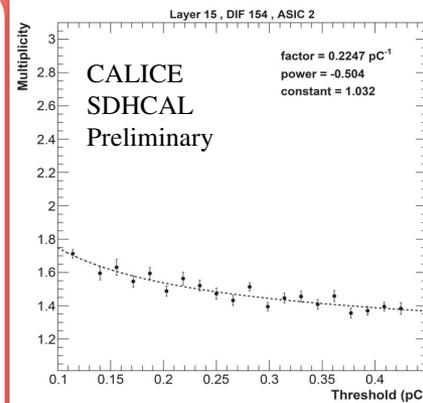
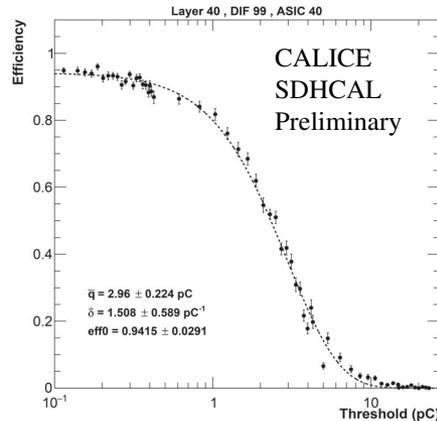
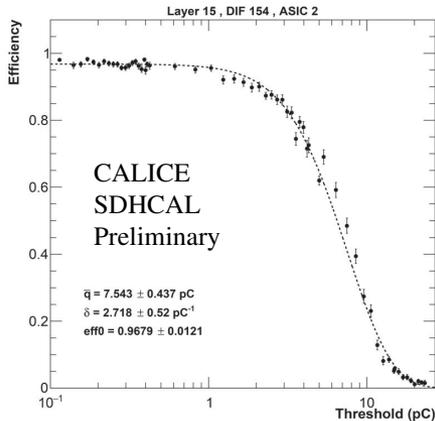
Further improvements on the energy reconstruction

Detector homogeneity

The homogeneity of the detector response is important to achieve better energy reconstruction



Varying the thresholds, using muon runs with different thresholds **Thr1: 0.1-0.42 pC**, **Thr2: 0.4-5**, **Thr3: 4.7-24**. The values of the three thresholds of each ASIC were fixed to obtain same threshold multiplicity (first threshold) and the same efficiency for **thr2** and **thr3**.

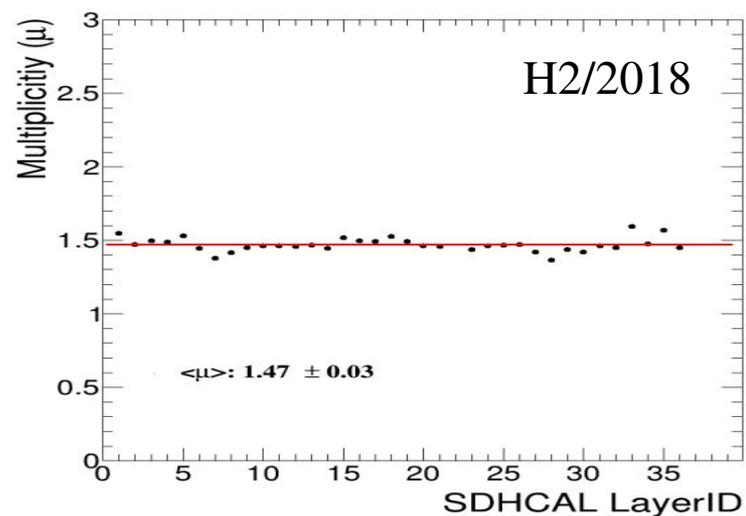
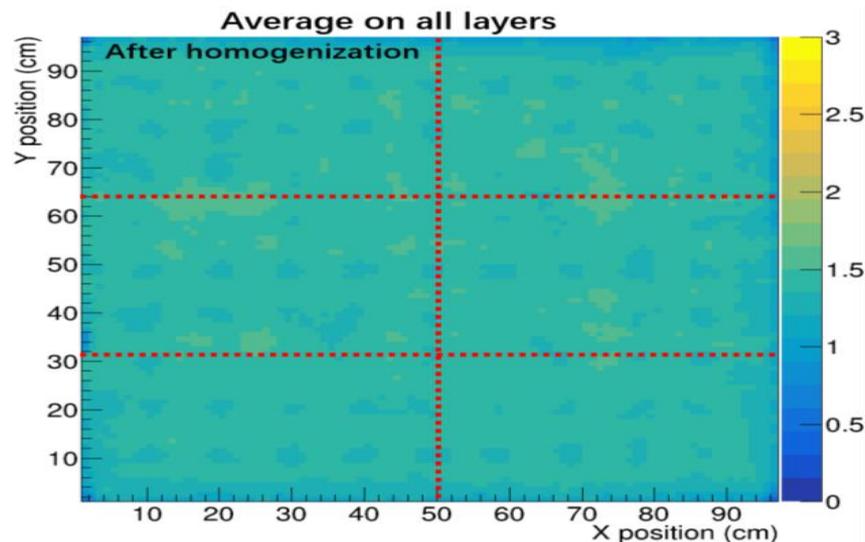
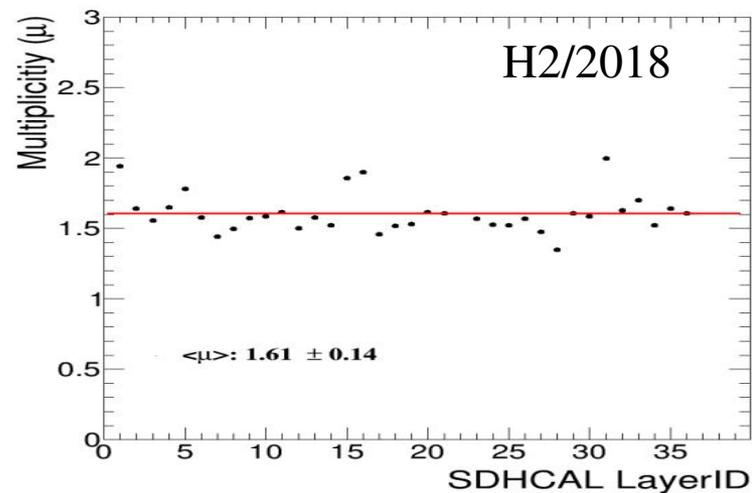
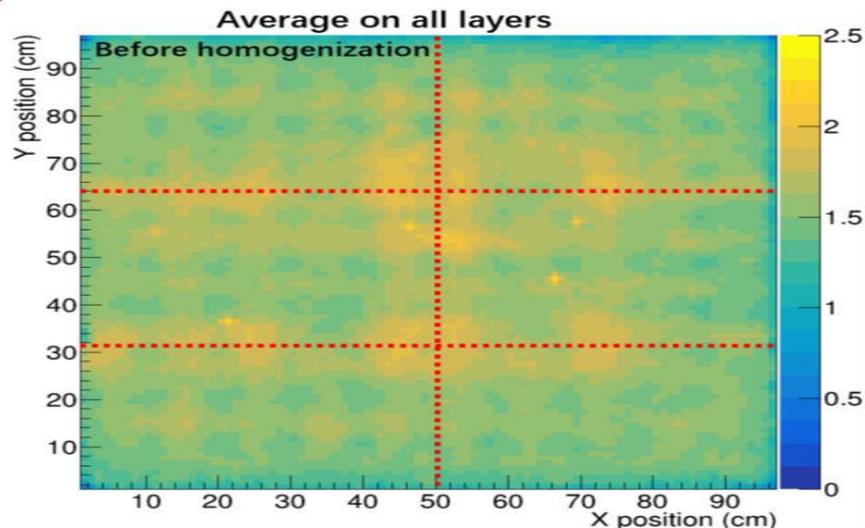


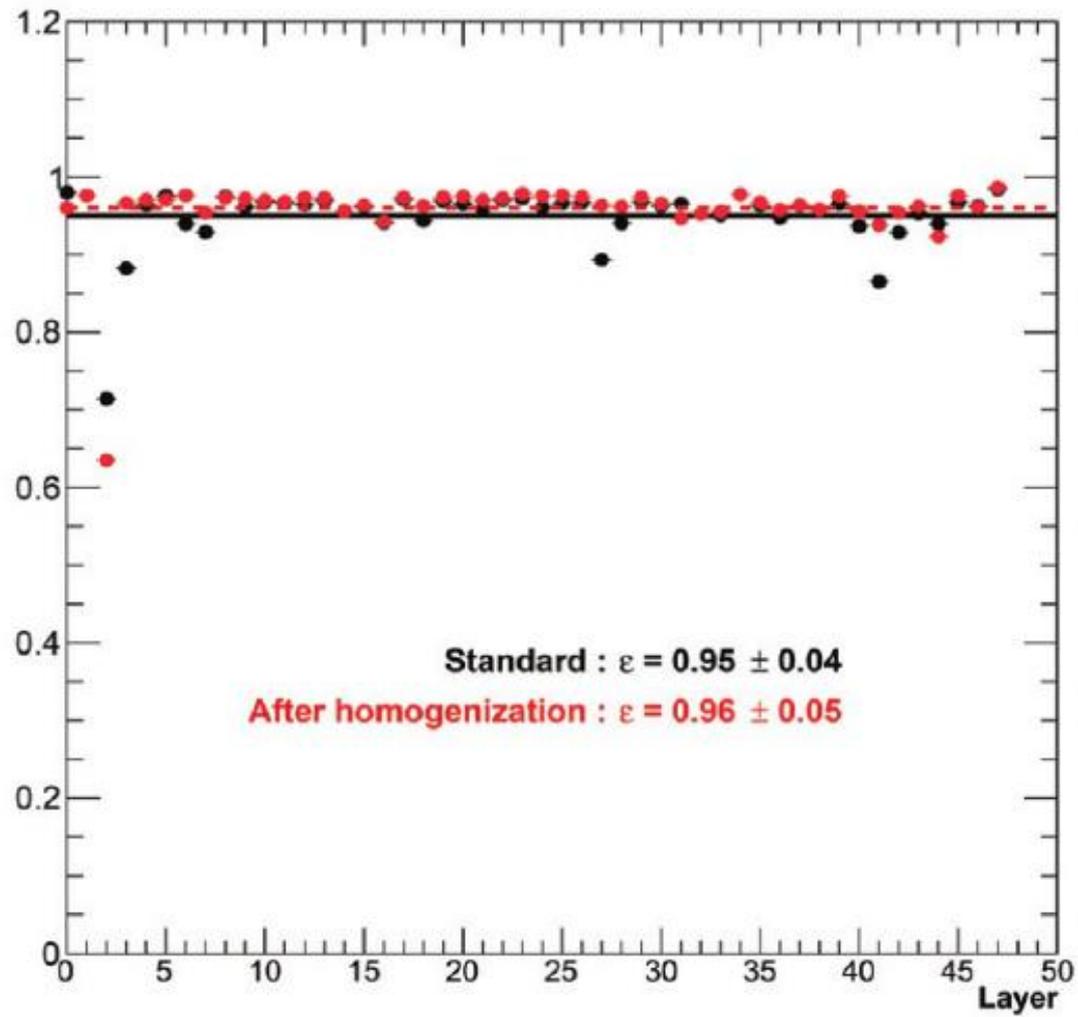
$$\varepsilon(t; \bar{q}, \delta, \epsilon_0) = \epsilon_0 \cdot \left(1 - \int_0^t P(q; \bar{q}, \delta) dq \right)$$

$$P(q; \bar{q}, \delta) = \frac{1}{\Gamma\left(\frac{\bar{q}}{\delta}\right) \delta^{\frac{\bar{q}}{\delta}}} q^{\frac{\bar{q}}{\delta}-1} e^{-\frac{q}{\delta}}$$

Detector homogeneity

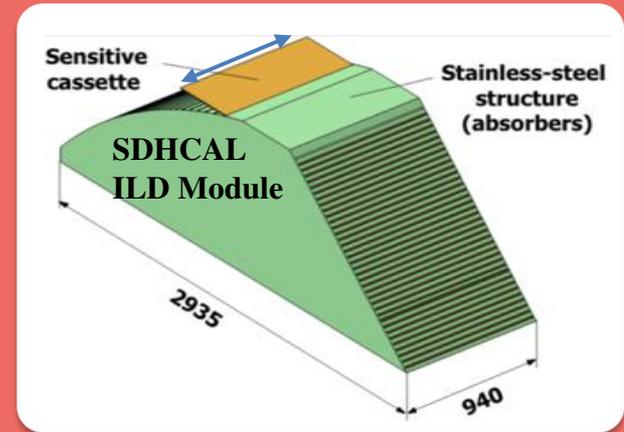
The homogeneity of the detector response is important to achieve better energy reconstruction





SDHCAL R&D towards future colliders

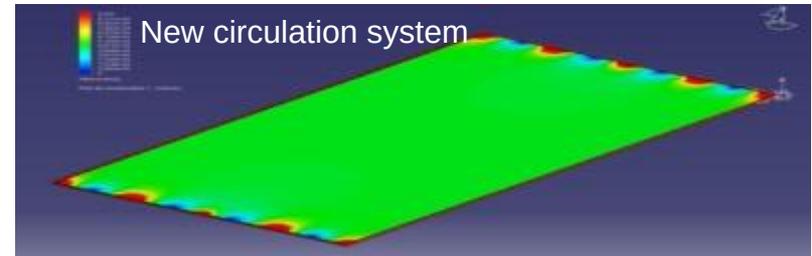
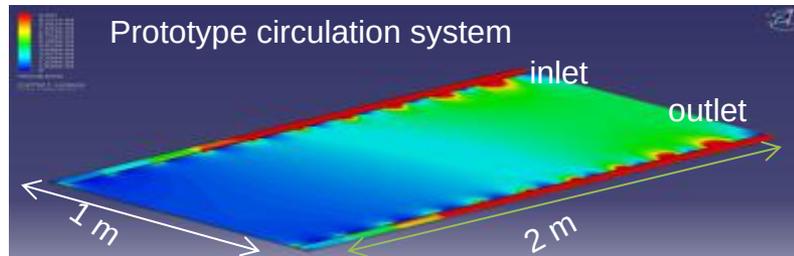
- ❑ Detectors as large as 3m x 1m need to be built
- ❑ Electronic readout should be the most robust with minimal intervention during operation.
- ❑ Mechanical structure with minimal dead zone
- ❑ Include time information **SDHCAL → T-SDHCAL**



New large RPC design

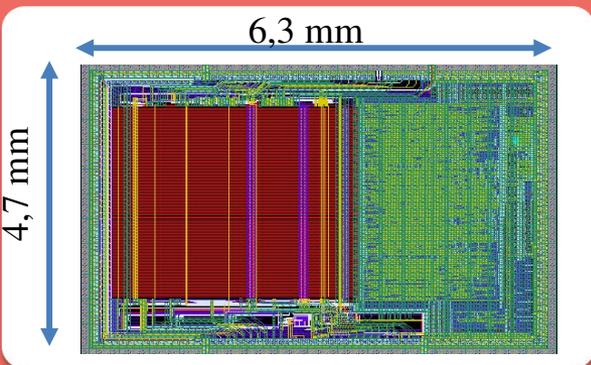
Construction and operation of large GRPC needs some improvements with respect to the present scenario.

- New gas distribution
- Gas gap thickness: better control
- Coating: new paints are tested



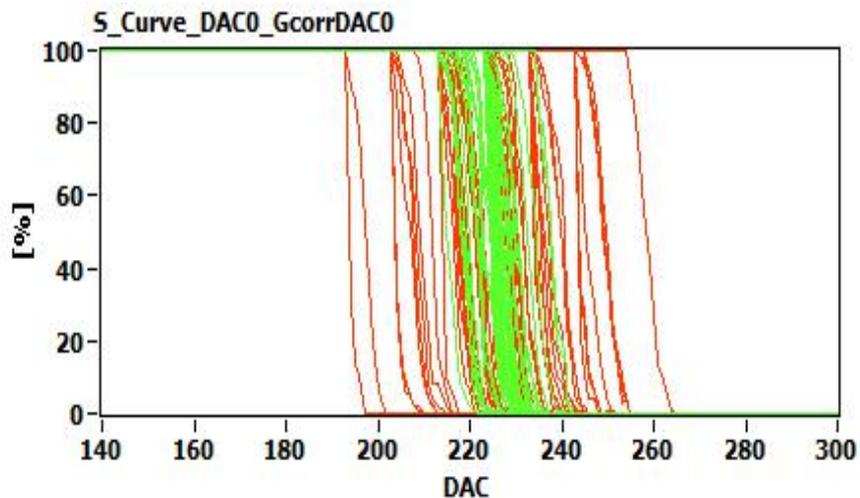
New readout electronics

HR2→HR3

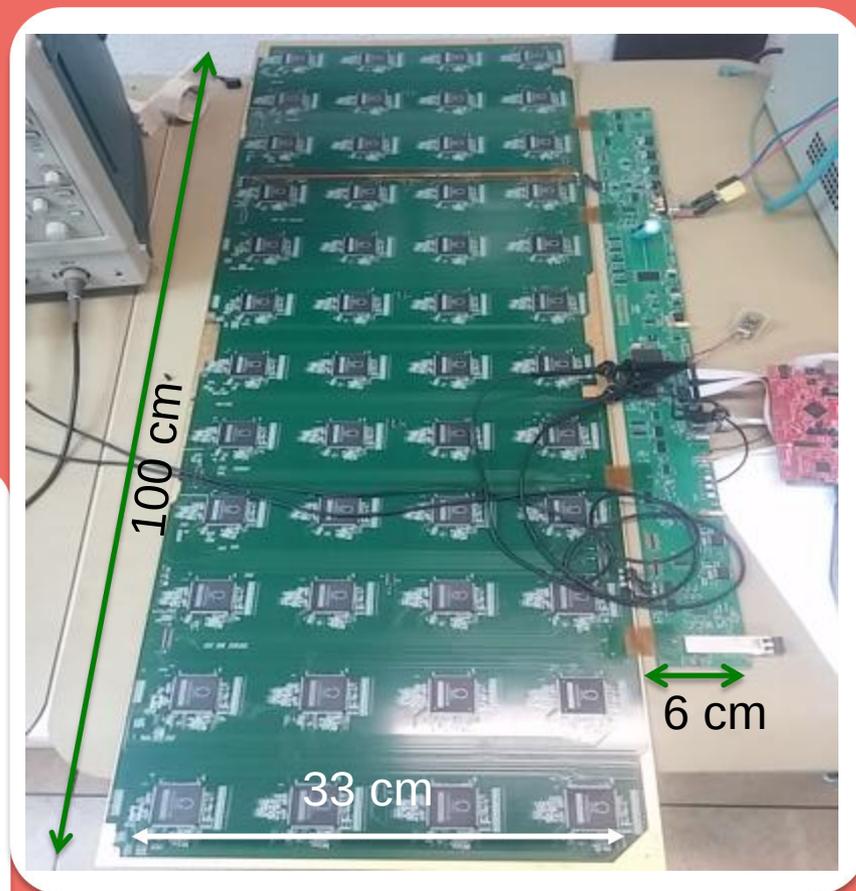


- Larger PCB (**100 cm X 33 cm**)
- Detector InterFace (**DIF**) to read out up to 432ASICs

- Independent channels
- Zero suppress
- Extended dynamic range (**up to 50 pC**)
- I2C link with triple voting for slow control parameters



786 HR3 produced and tested , Yield : 83.3 %

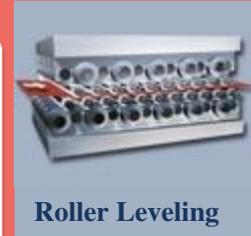


New mechanical structure design

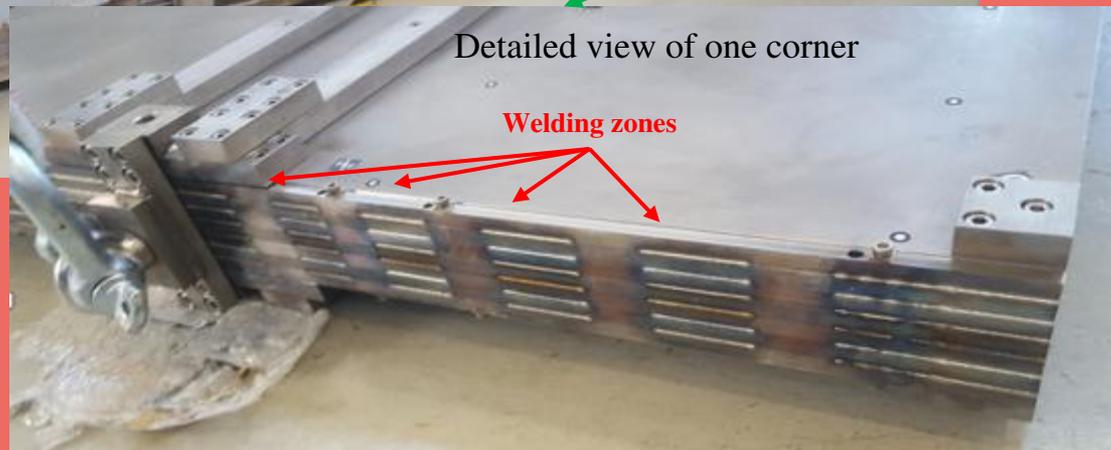
Absorber plates planarity after roller leveling

Planarity

Planarity (μm)	Plate A		Plate B		Plate C	
	Side 1 up	Side 2 up	Side 1 up	Side 2 up	Side 1 up	Side 2 up
Average	469,3	852,6	511,6	596,3	983,4	1038,0
	Plate D		Plate E			
	Side 1 up	Side 2 up	Side 1 up	Side 2 up		
	458,7	546,1	610,2	521,9		



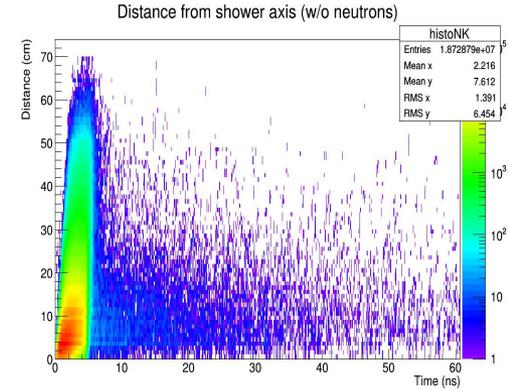
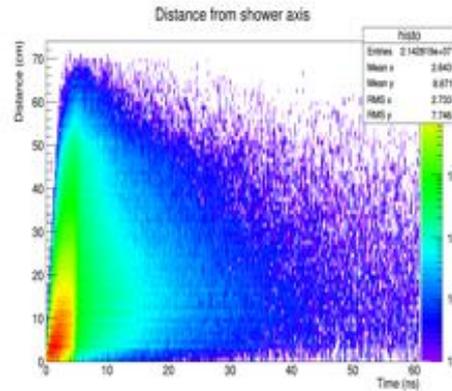
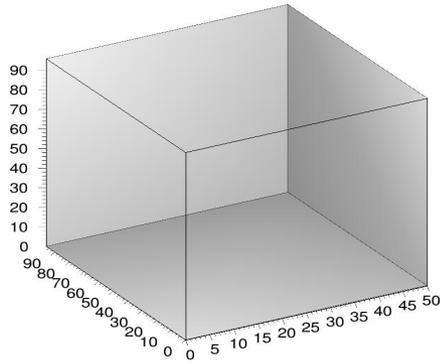
Absorber assembled with Electron Beam welding



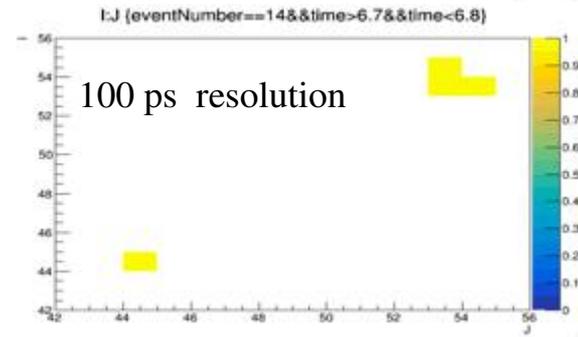
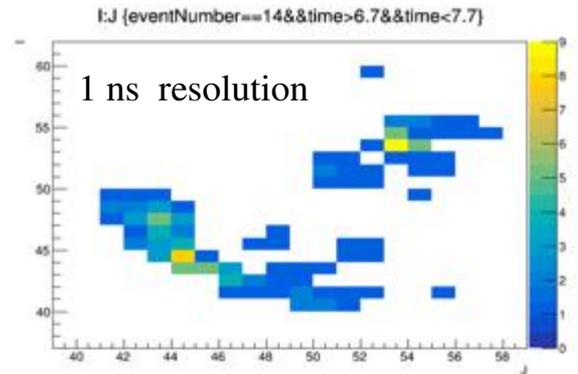
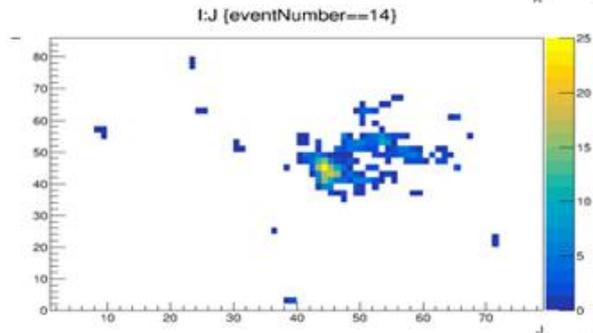
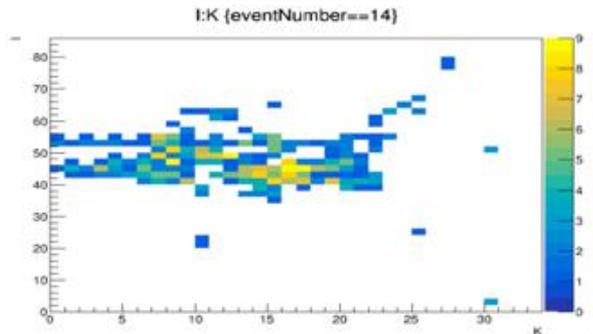
EBW minimizes deformation and reduces dead zones

T-SDHCAL

Timing is an important factor to identify delayed neutrons and **better reconstruct their energy**



Timing can help to separate closely showers and reduce the confusion for a better **PFA** application.
Example: pi-(20 GeV), K-(10 GeV) separated by 15 cm.

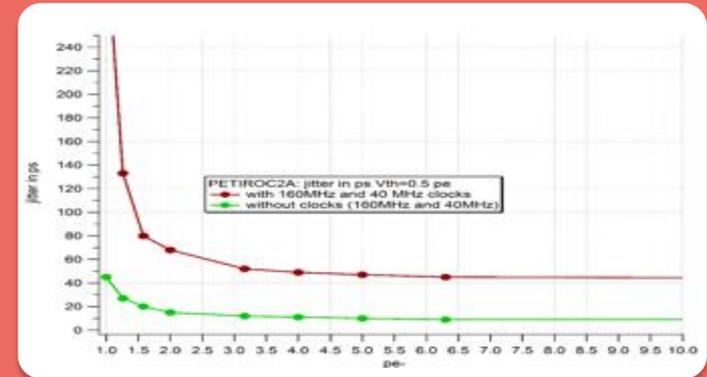
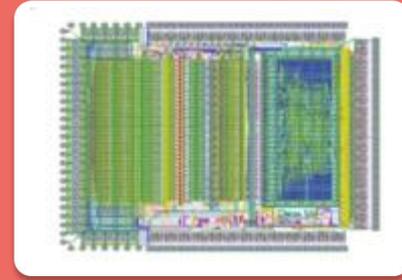


How to achieve an excellent time resolution:

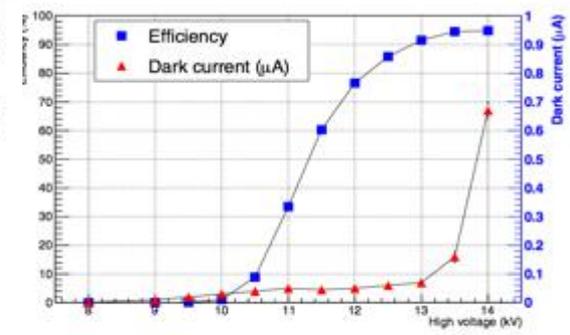
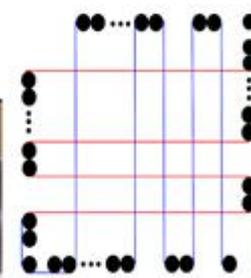
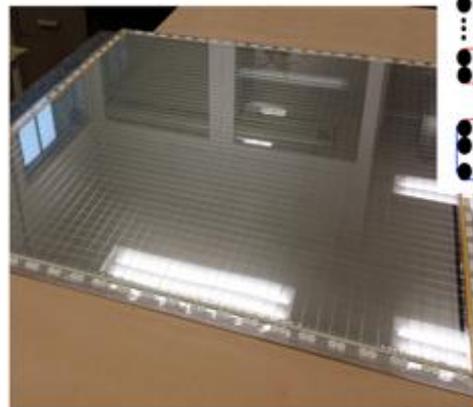
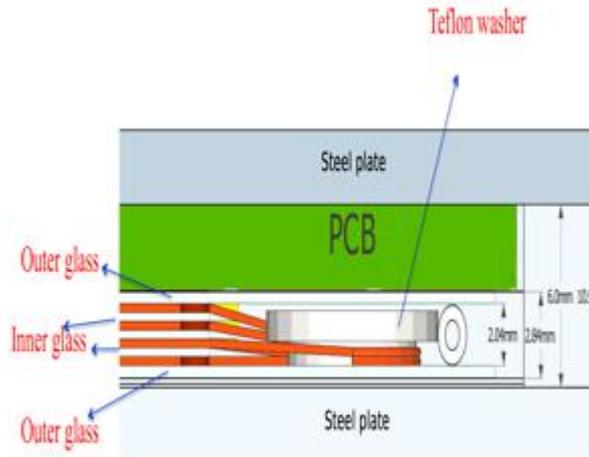
An **ASIC** with a fast preamplifier, precise discriminator and excellent TDC is needed

→ **PETIROC** 32-channel, high bandwidth preamp (GBWP > 10 GHz), < 3 mW/ch, dual time and charge measurement ($Q > 50$ fC) jitter < **20 ps rms @ $Q > 0.3$ pC**

→ TDC either internal or external (delay-line, Vernier, etc... on FPGA as for iRPC CMS upgrade project)

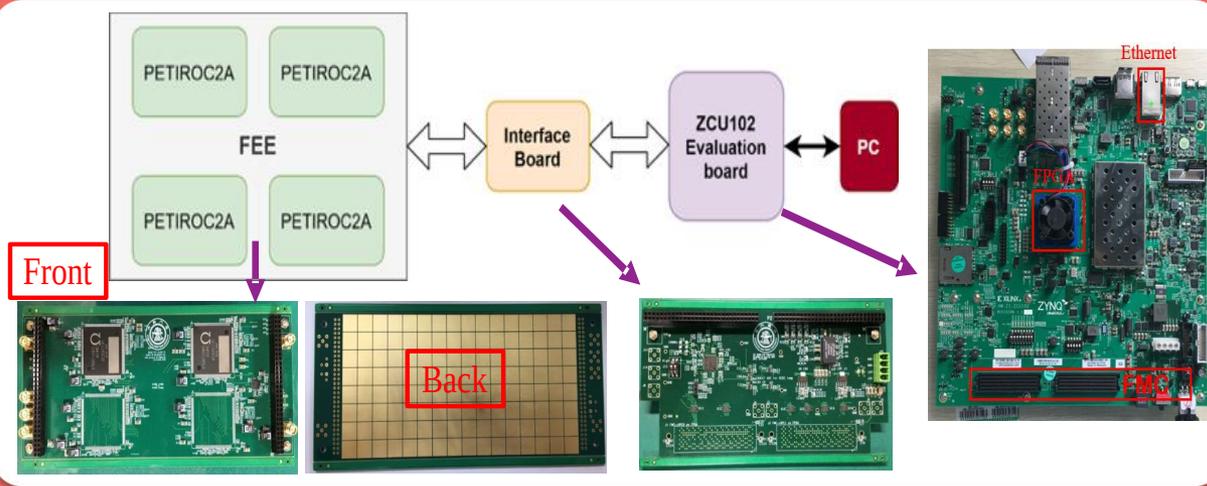


A fast-time DETECTOR : MultiGAP RPC is an excellent candidate. 4-5 gaps of 250 μ m each can provide 100 ps time resolution.

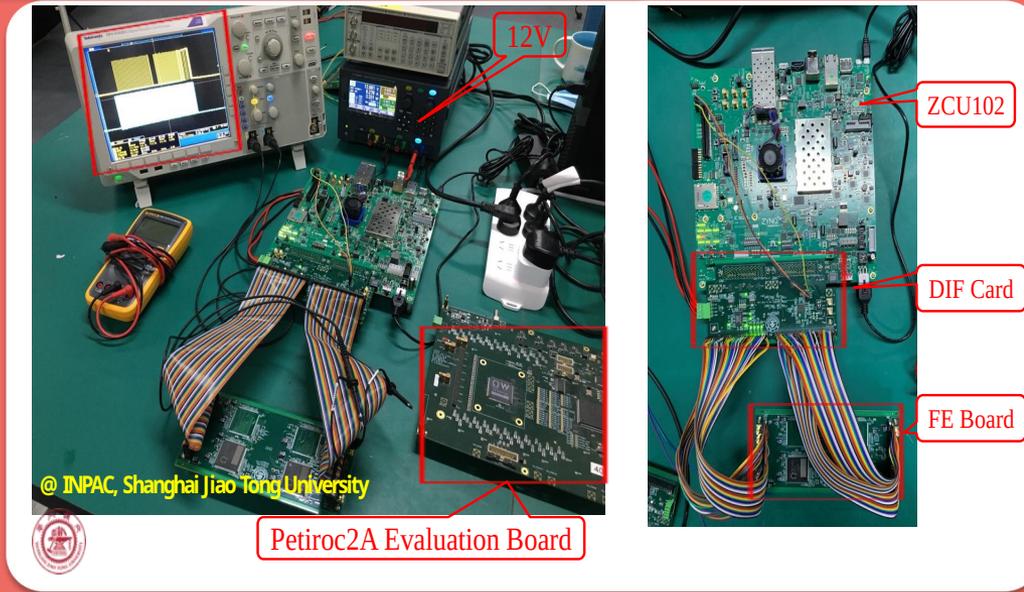


Threshold sets at 114 fC

First step towards transforming SDHCAL into T-SDHCAL



- Front-End Electronics for MRPC readout with high timing resolution.
- The system includes a front-end board (FEB), a detector interface card (DIF) and a data acquisition system (DAQ) based on ZCU102.



Test System and Setup

Summary

- SDHCAL concept with its high granularity provides an excellent tool not only to apply PFA by separating nearby showers but also to measure their energy.
- Results of beam tests validate the concept. Different techniques were used to measure hadronic shower energy; excellent linearity and very good resolution are obtained
- New prototype with large detectors and improved services is on the rails and in principle could be achieved as soon as funding becomes available.
- In the future SDHCAL will exploit precise time information using MRPC. The time information will improve on energy reconstruction by separating delayed neutrons contribution and better estimating it.
- New features such as timing will play important role in future R&D for future colliders. SDHCAL with its (M)RPC is an excellent tool to achieve that.

SDHCAL

The SDHCAL-GRPC is one of the two HCAL options based on PFA and proposed for **ILD of ILC/CEPC**. Modules are made of 48/40 RPC chambers equipped with **semi-digital, power-pulsed electronics** readout and placed in **self-supporting mechanical** structure to serve as absorber as well.

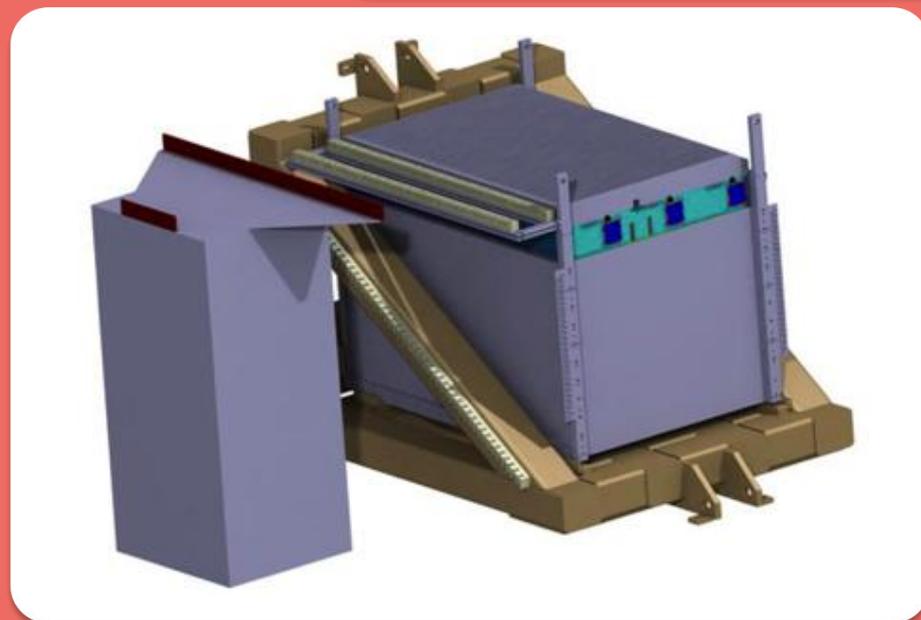
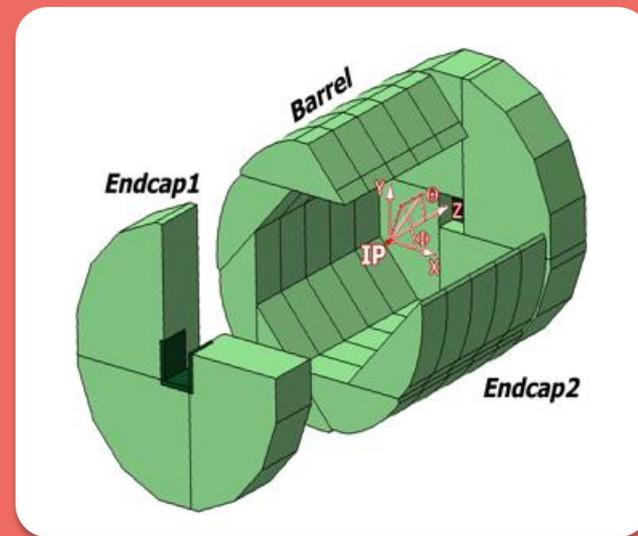
The structure proposed for the SDHCAL :

- Is very compact with negligible dead zones
- Eliminates projective cracks
- Minimizes barrel / endcap separation (**services leaving from the outer radius**)

SDHCAL Technological Prototype should be as much as possible similar to the ILD module and able to study **hadronic showers**

Challenges

- Homogeneity for large surfaces
- Thickness of only few mms
- Lateral segmentation of 1 cm X 1 cm
- Services from one side
- Embedded power-cycled electronics
- Self-supporting mechanical structure



Time correction

