Status of the CEPC Sci-ECAL R&D

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On behalf of the CEPC Calorimeter working group

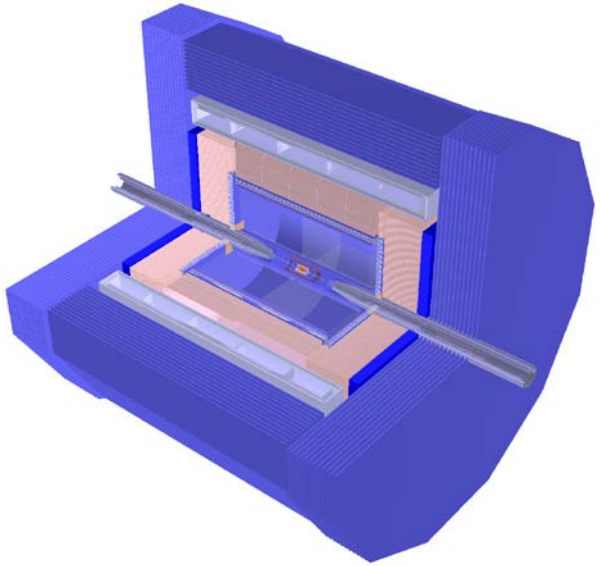
CEPC Plenary Meeting
May, 2020

Outline

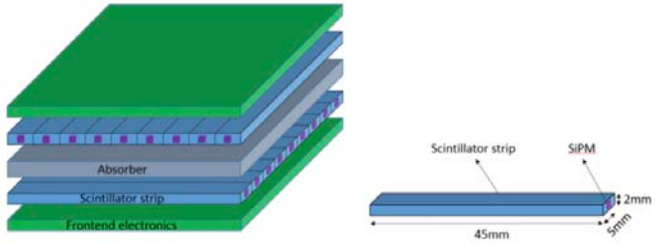
- Introduction
- Studies on CEPC Sci-ECAL sensitive cell
- CEPC Sci-ECAL prototype design and development
- Multi-EBUs commissioning and project schedule
- Summary

Introduction

- A fine-grained Sci+W calorimeter concept has been adopted as one of the CEPC ECAL options.
- There is a R&D program dedicated to the CEPC Sci-ECAL option that was started in 2016.
- The R&D goal is to build and characterize a technological Sci-ECAL prototype to validate the CEPC Sci-ECAL design.
- Collaborating with the Sci-ECAL effort in Japan to fully explore the synergy between CEPC and ILC in detector R&D.



CEPC detector concept



Strip Sci-ECAL concept for CEPC

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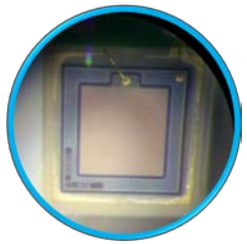
SiPM dark-count rate and cross-talk probability



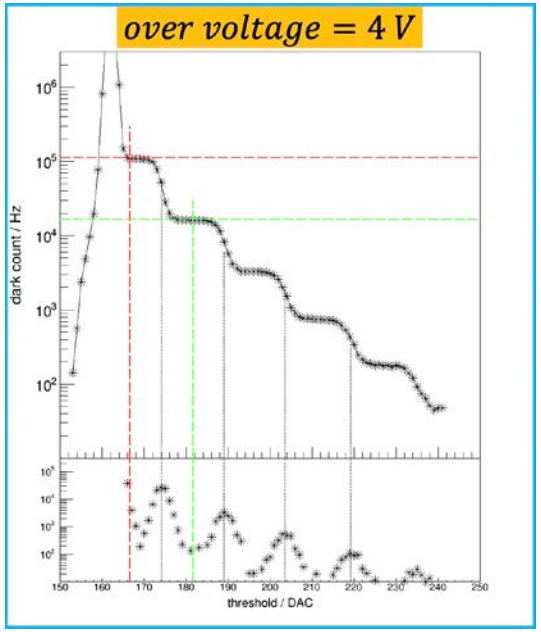
Baseline SiPM

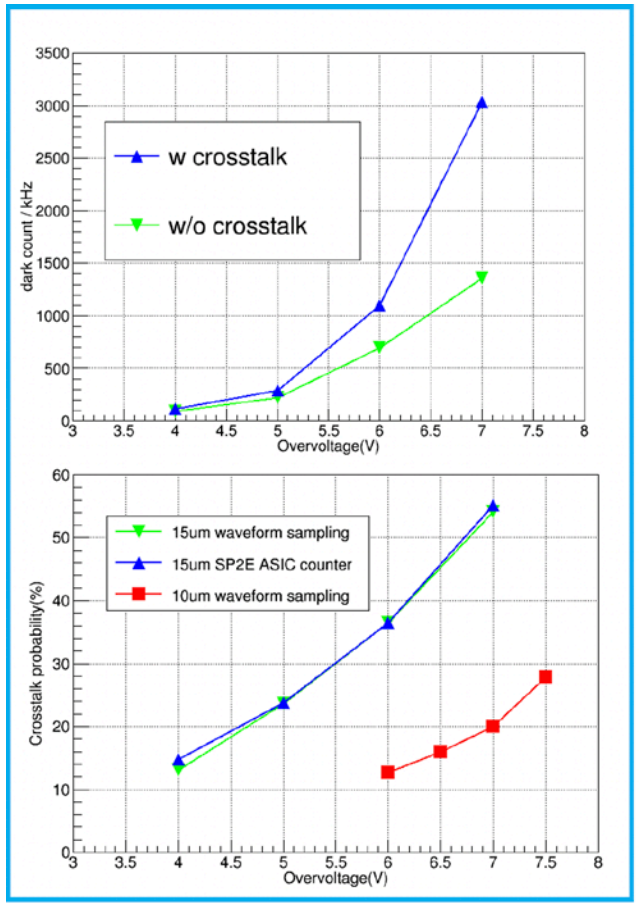
Hamamatsu S12571-010P

- size: $1mm \times 1mm$
- pitch: $10\mu m$
- number of pixels: 10K

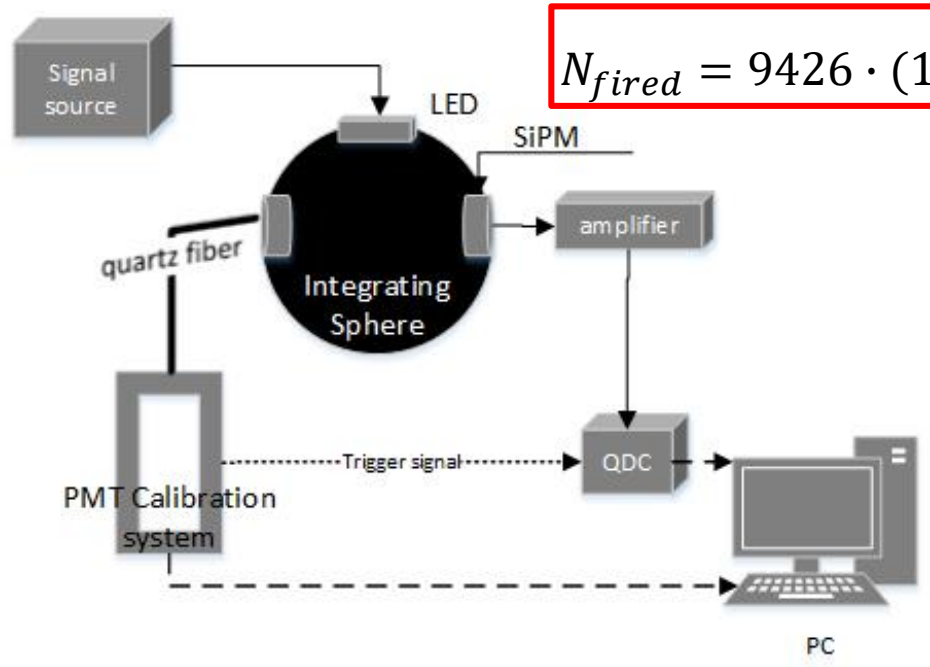
* Threshold for dark count: >0.5 p.e.
* Threshold for cross talk: >1.5 p.e.

- Dark count and cross talk are important aspects of SiPM performance
- Dark count rate is ~100kHz at normal operation voltage
- Cross-talk probability is ~15% for the SiPM with a 15-um pitch and 8% for the 10-um one.
- Dark count rate and cross-talk probability both increase rapidly with over-voltage.

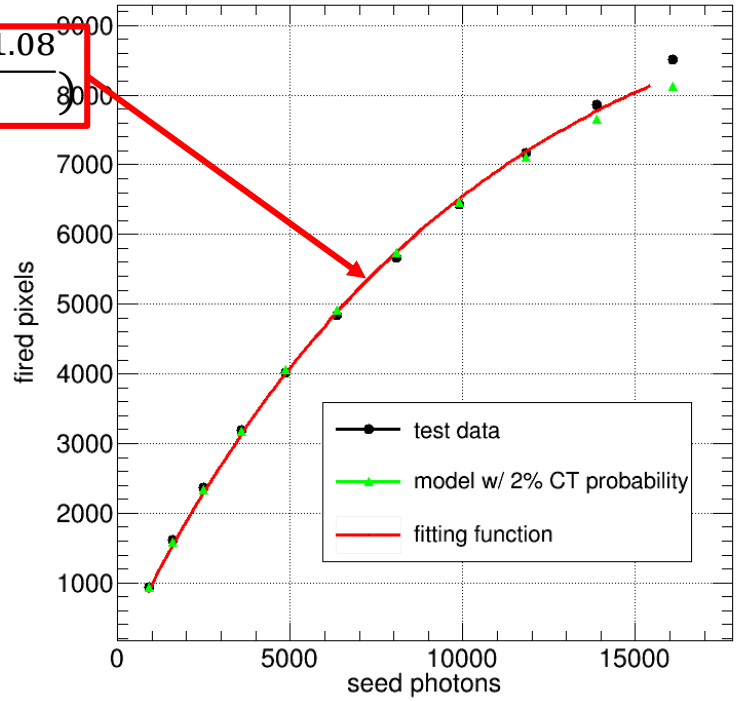




SiPM saturation effect

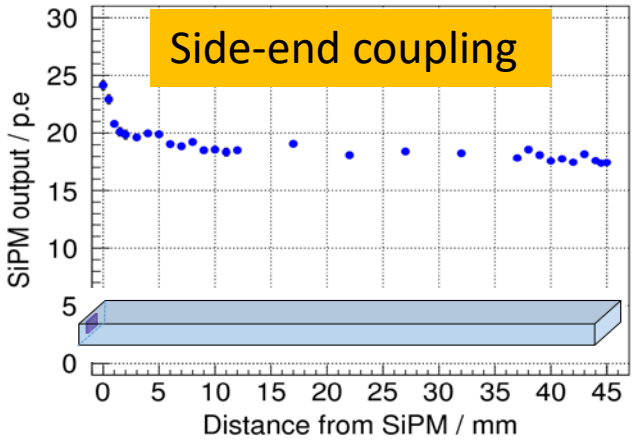


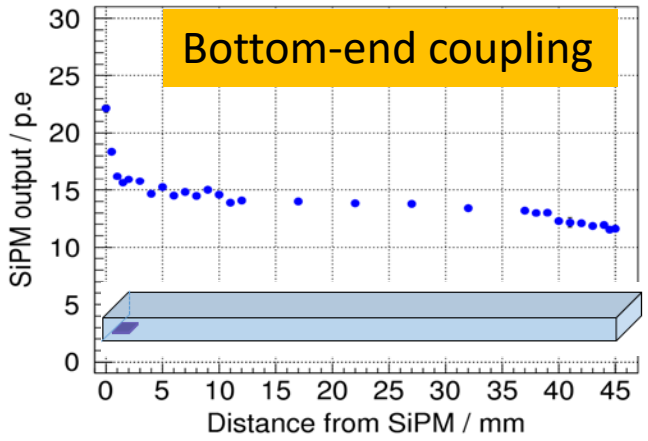
$$N_{fired} = 9426 \cdot (1 - e^{\frac{-N_{photon} \times 1.08}{9426}})$$

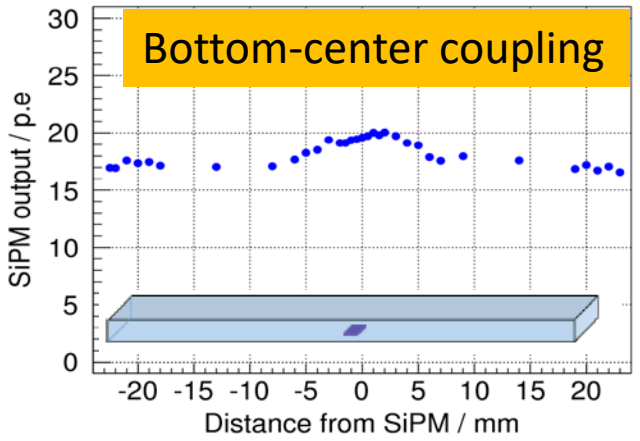


- SiPM would be subject to saturation at exposure of large amounts of light
- SiPM saturation behavior was tested and can be described very well with a function
- With corrections, the dynamic range of the S12571-010P SiPM can reach 15,000 photons within an uncertainty of 3%

Scintillator strip – SiPM coupling optimization

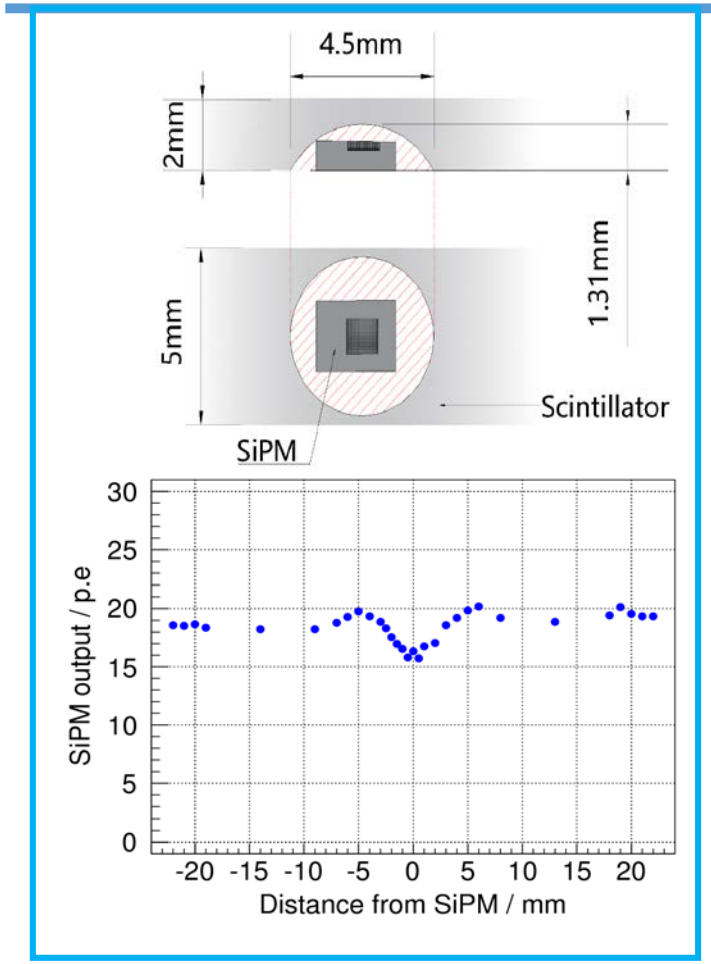


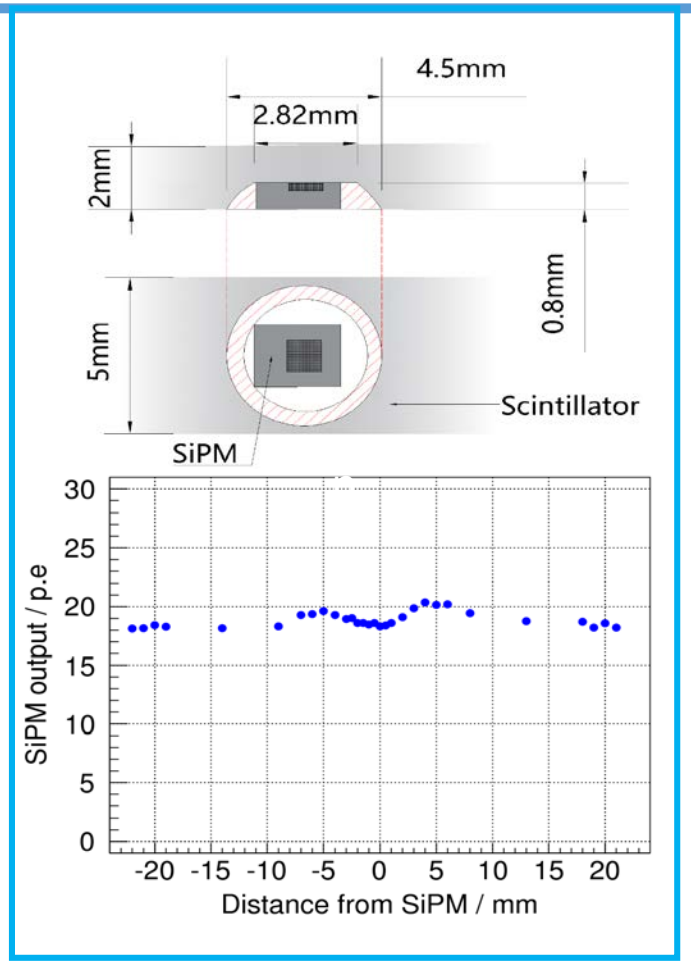


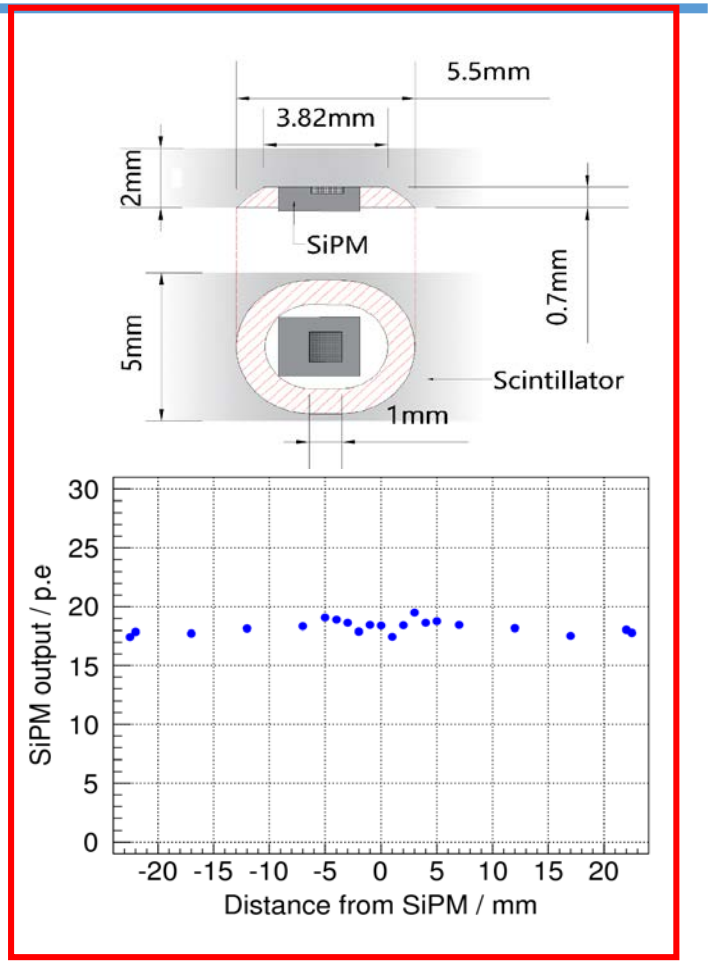


- Three coupling modes investigated: side-end, bottom-end and bottom-center
- Uniformity of light yield along the strip is important to the ECAL energy resolution
- Bottom-center coupling gives the best uniformity with additional advantages:
  - Avoiding the dead area between scintillators introducing by SiPMs
  - Simplifying sensitive layer assembling
  - Allowing for large-size SiPM for a large dynamic range

Design of the bottom-center coupling







- The uniformity of the sensitive cell with a racetrack-shaped dimple can reach 4%

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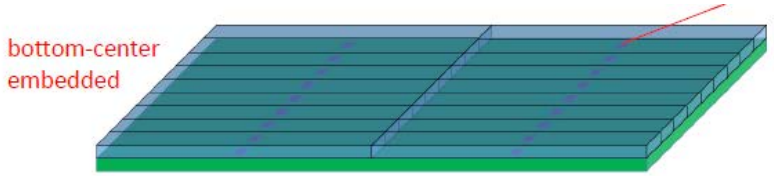
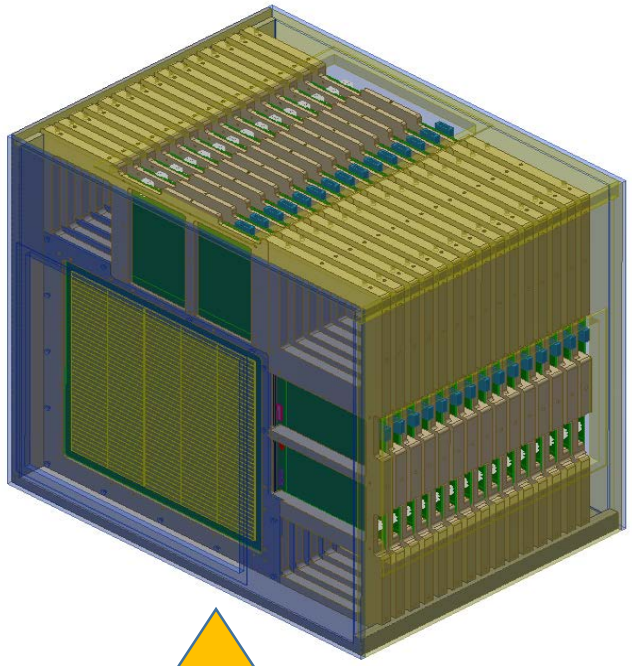
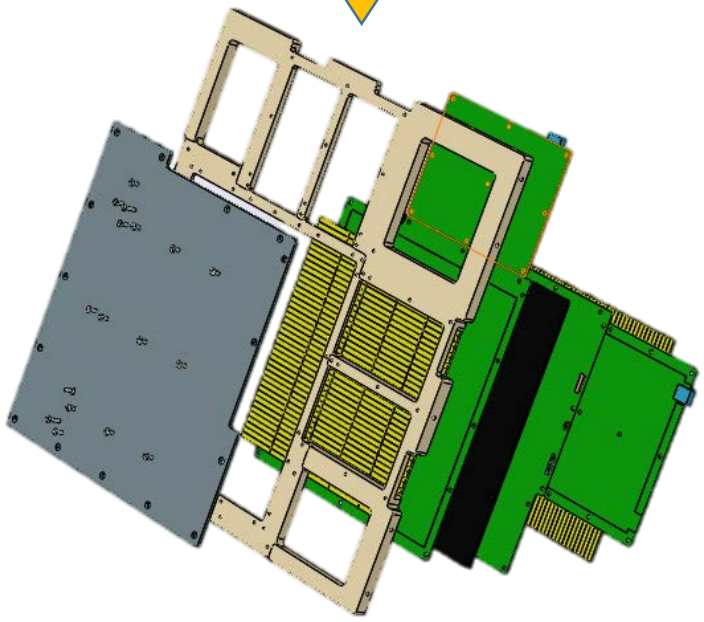
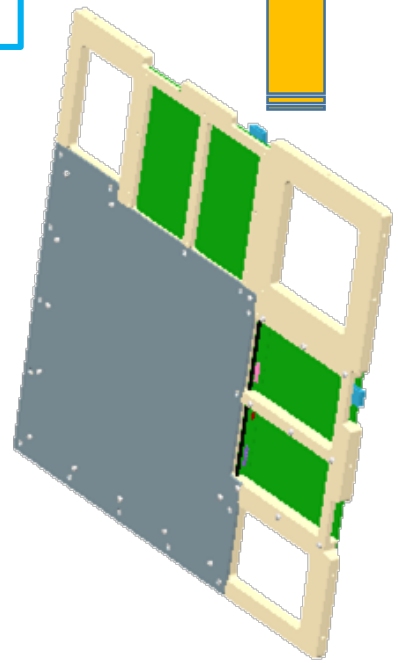
CEPC Sci-ECAL prototype design



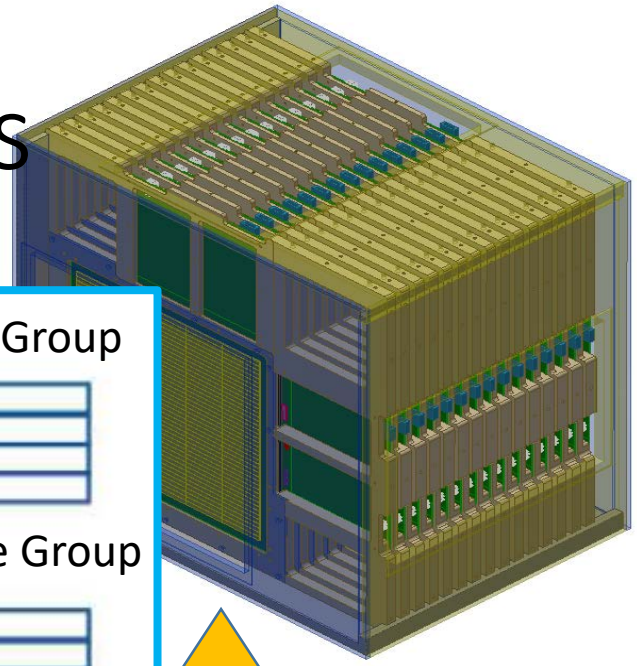
- 210 channels / EBU
- 30 EBUs + 30 DIFs
- 15 “super-layers”
- Full ECAL prototype



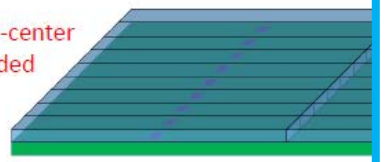




Contributions from Japanese groups

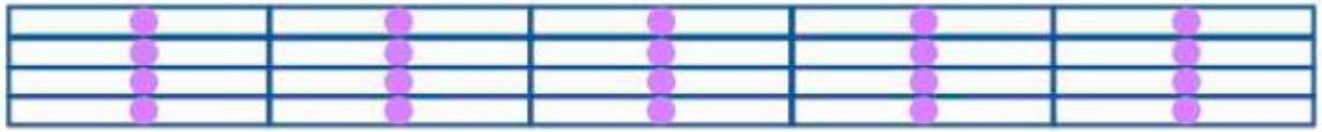


bottom-center embedded



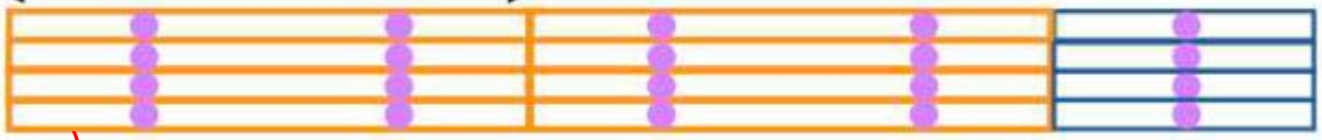
45mm

Single SiPM readout by Chinese Group



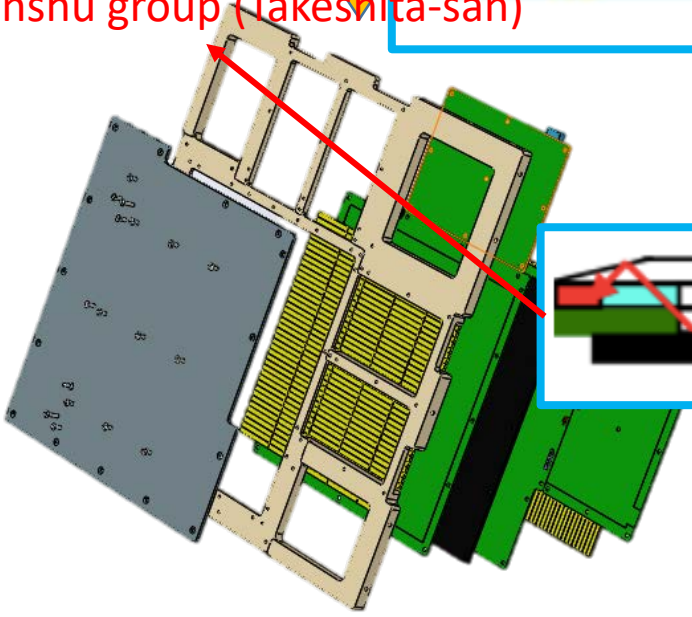
90mm

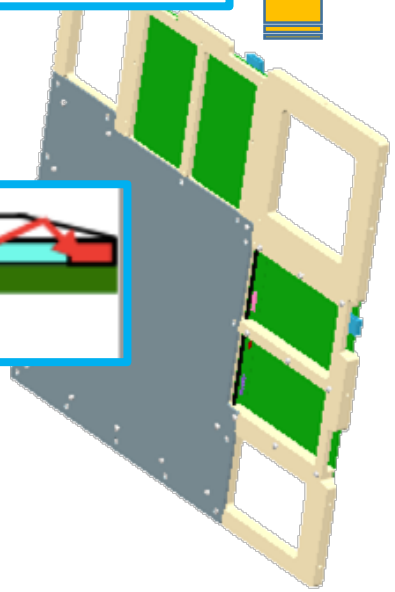
Double SiPM readout by Japanese Group



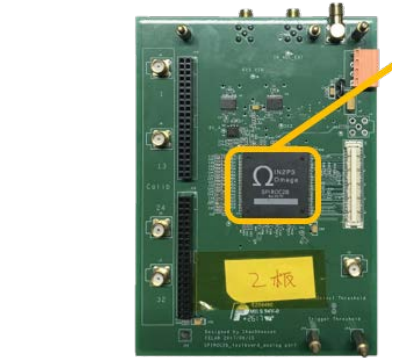
By Tokyo group (Wataru)

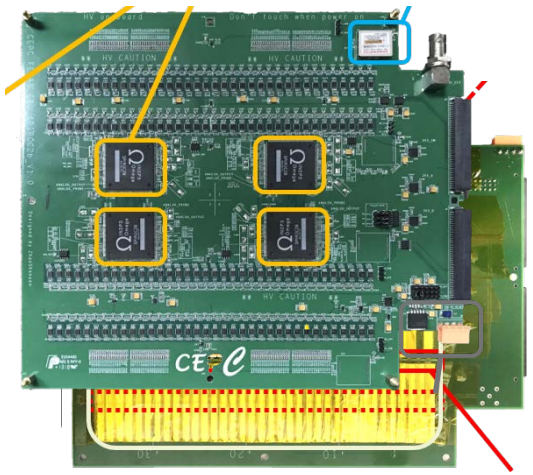
By Shinshu group (Takeshita-san)



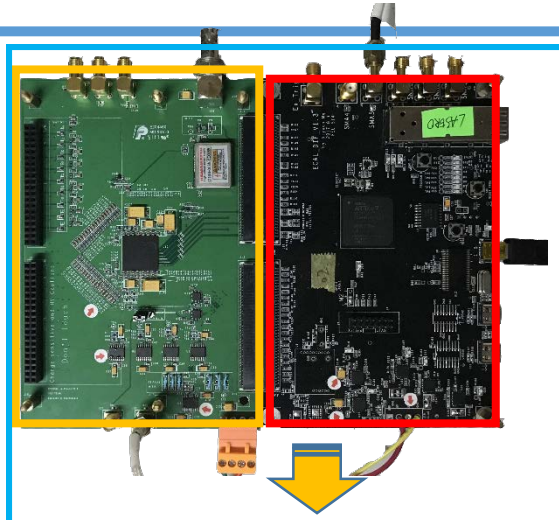


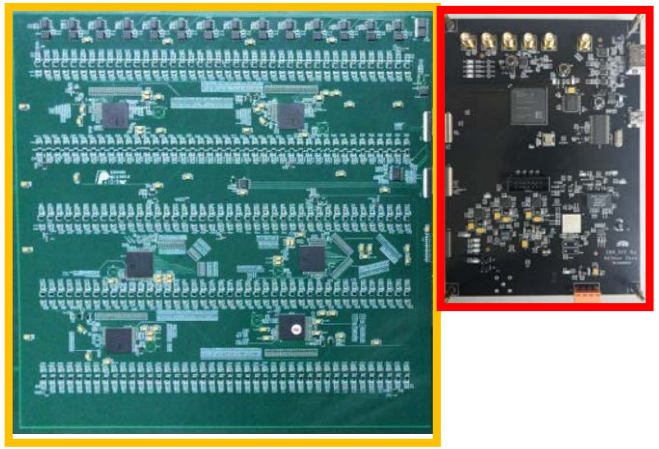
Readout electronics development history



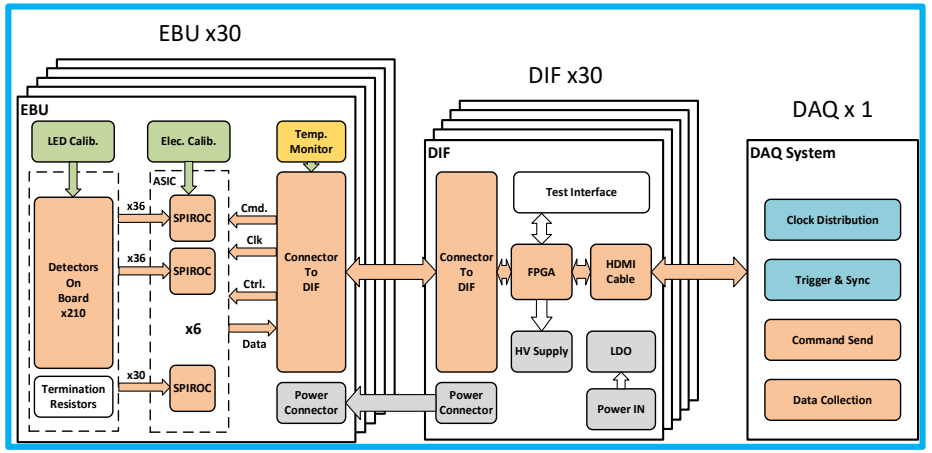


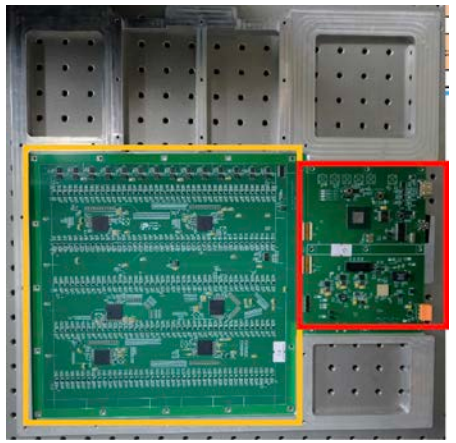
EBU with SP2b 144channels





EBU with SP2e 210channels





EBU with SP2e + DIF

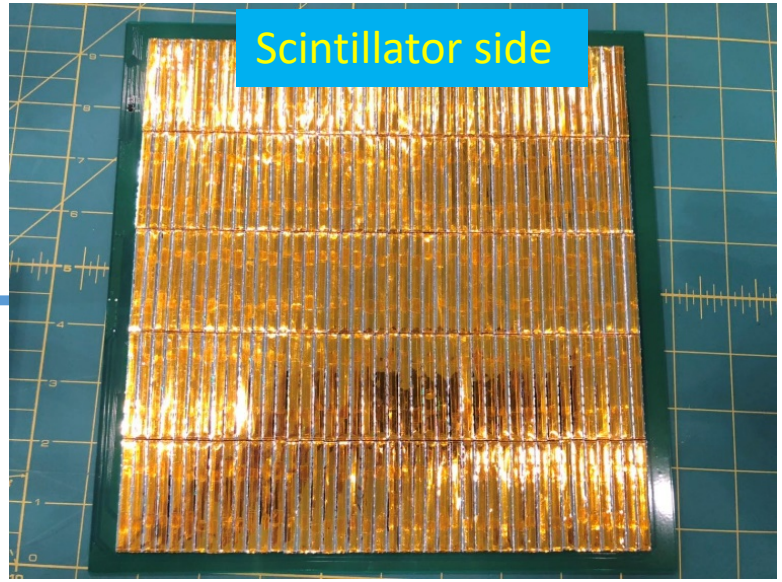
Electronics aging test

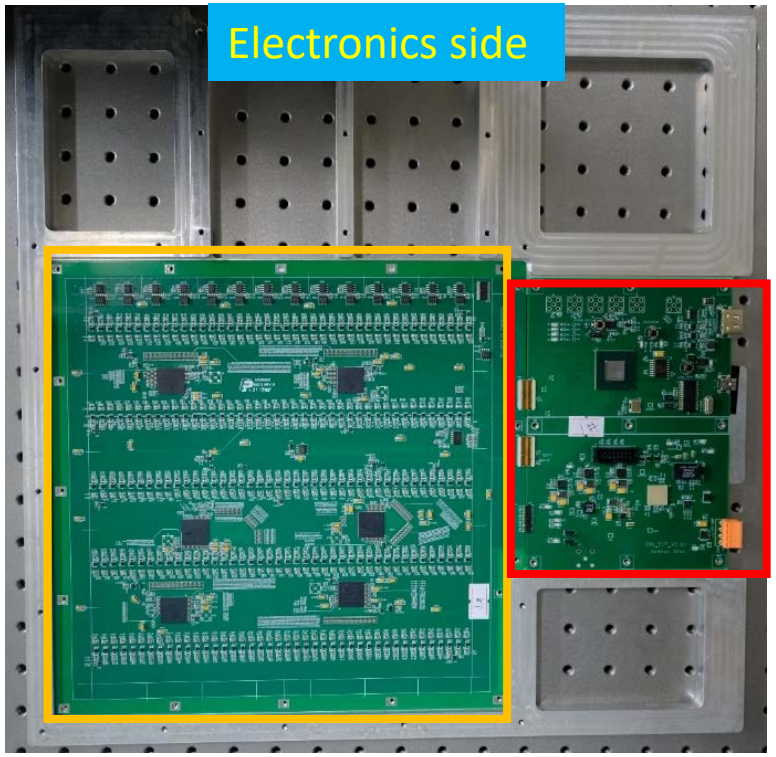
2019/12/26 ~ 2019/12/28

- Aging test for 48 hours with 50℃
- No high voltage applied on SiPM
- Recorded hourly the current passing through each layer
- Performed electronics calibration every 3 hours
- Powered down every 12 hours for a half hour down time

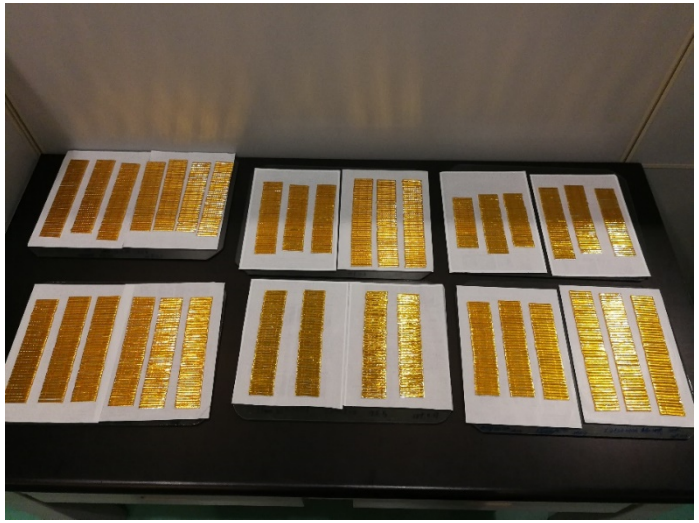
EBU design and development

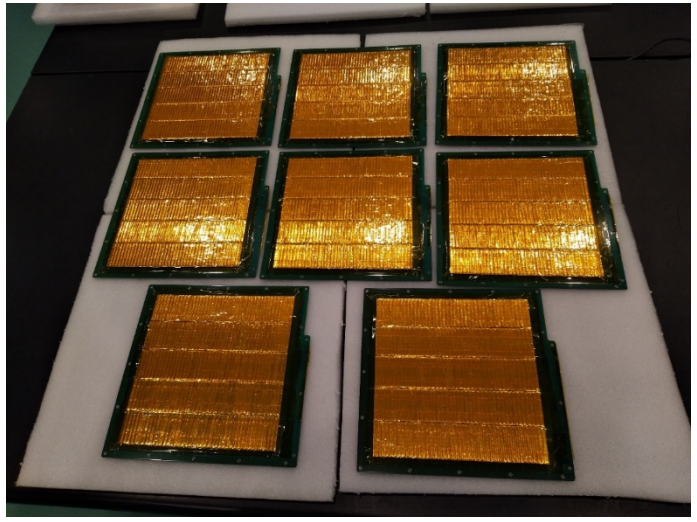
- 210 channels readout with 6 SP2E chips divided into 5 rows and 42 columns
- 24 layers of EBU with 10um SiPMs and 6 layers EBU with 15um SiPMs
- Total thickness is controlled under 6mm excluding DIF
- Electronics calibration and SiPM operation voltage adjustment realized
- LED calibration and temperature monitoring circuits under test.





Assembling of scintillator strips

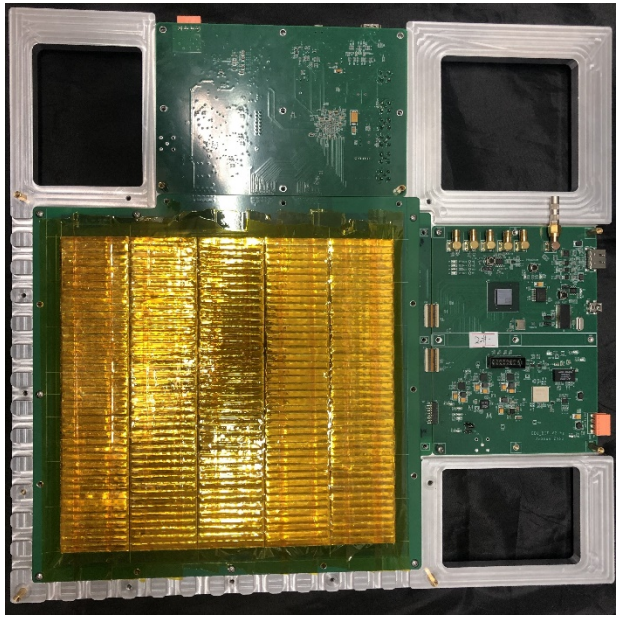


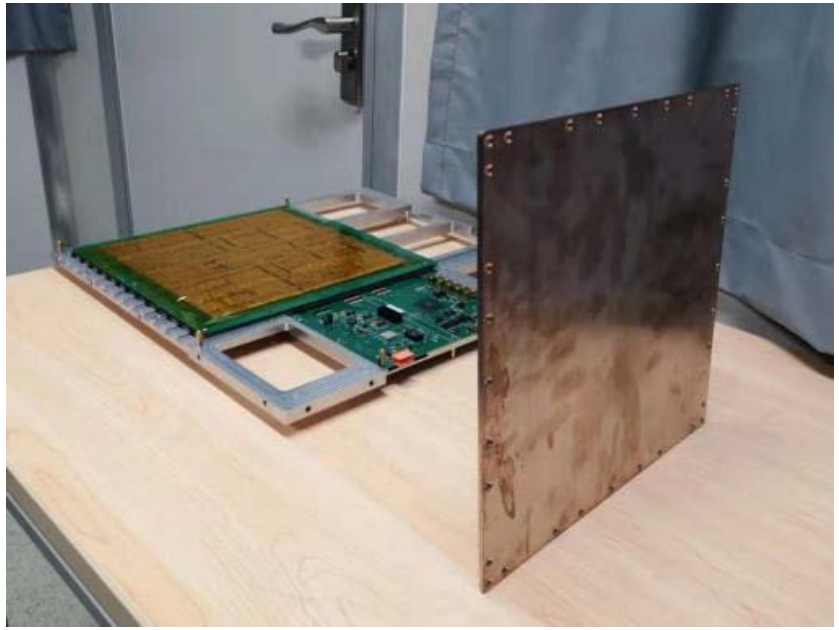


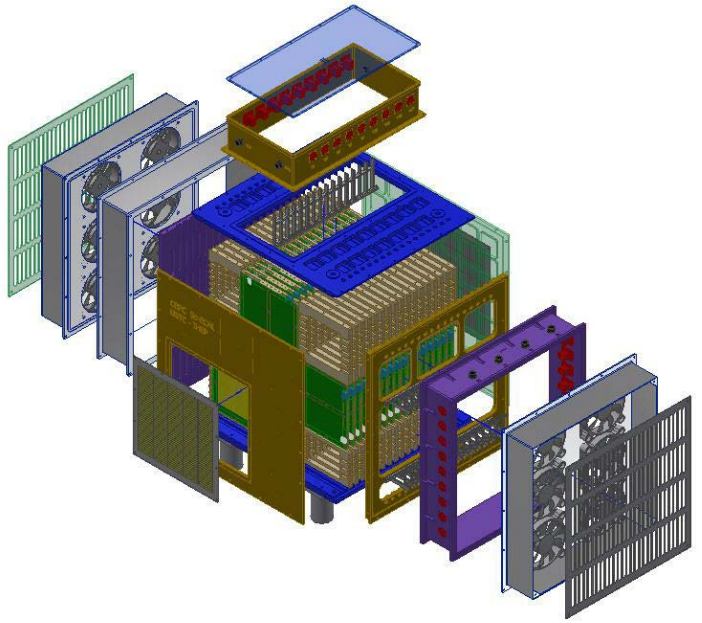
The scintillator strips were wrapped and assembled on EBU boards by Shanghai Institute of Ceramic

- 30 layers for Sci-ECAL finished
- 2 layers for DS by Japan will finish asap

Manufacturing of mechanical structure







- Supper-layer support structure produced and mounted with EBU and absorber
- Absorber layer: 3.2 mm 15%-85% Cu-W alloy
- Mechanical framework to be manufactured

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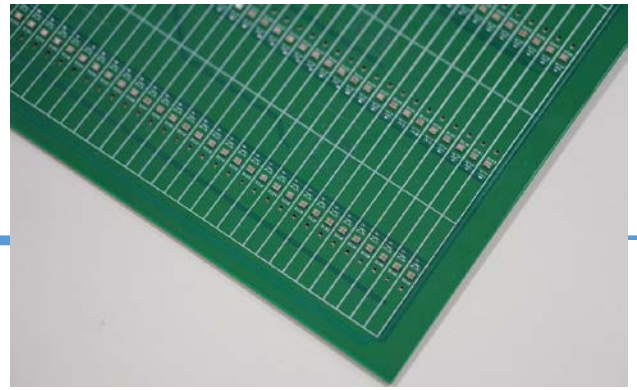
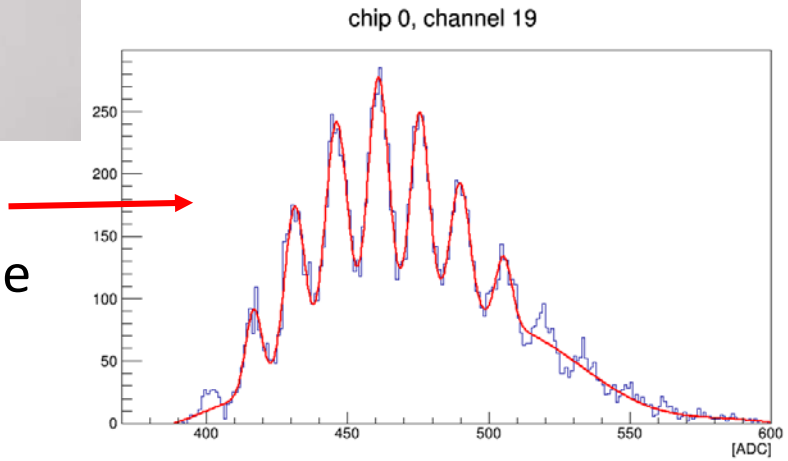
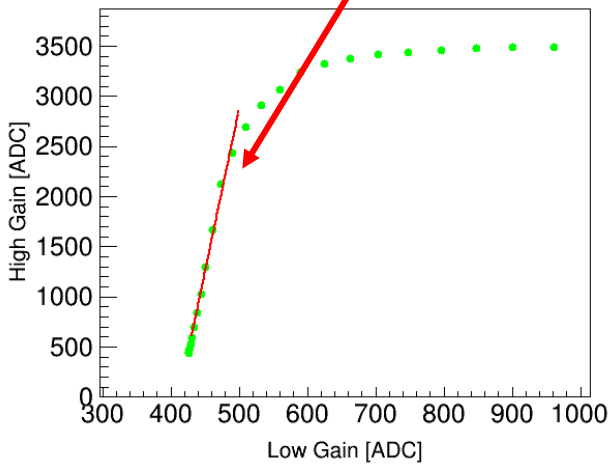
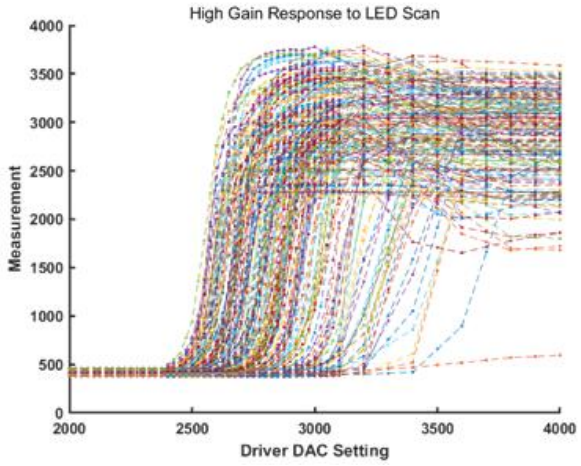
LED calibration

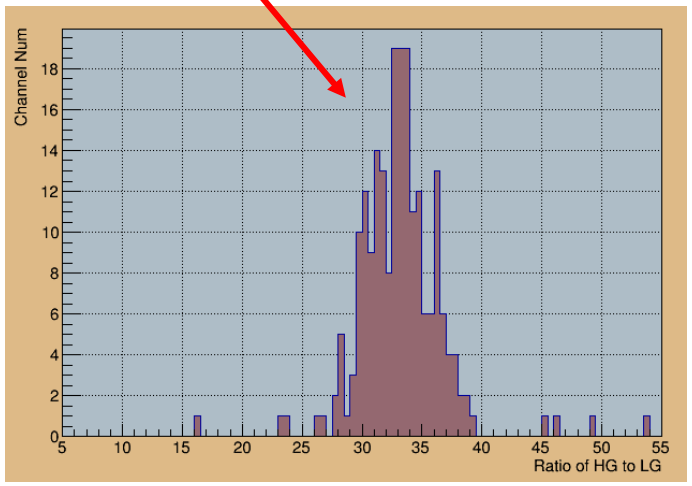


- > Tested SiPM response in all channels
- > Calibrated SiPM gain by single photon electron spectrum
- > Cross-calibrated the high gain and low gain modes of the electronics
- > Determined the linear range of the high gain mode

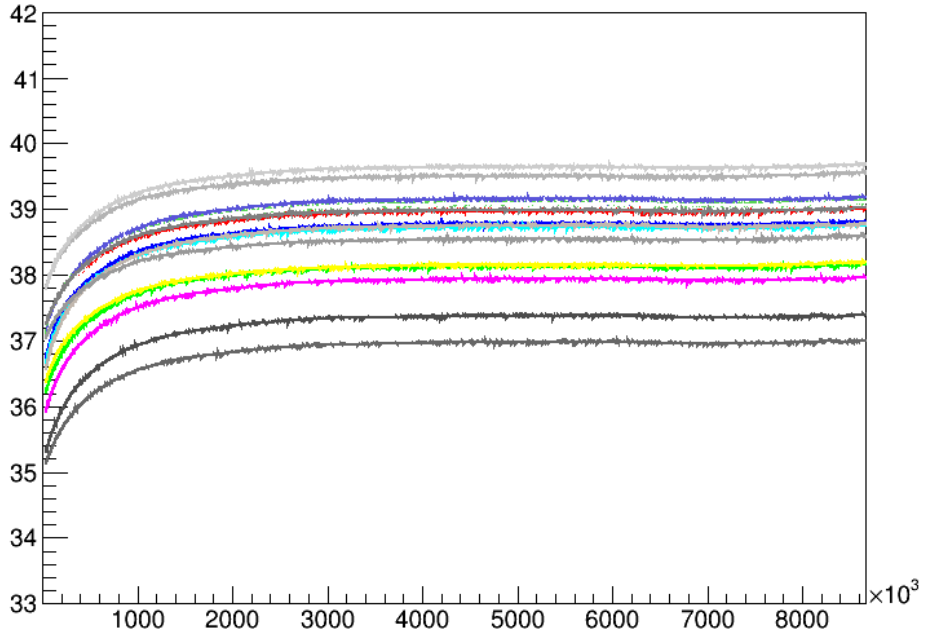


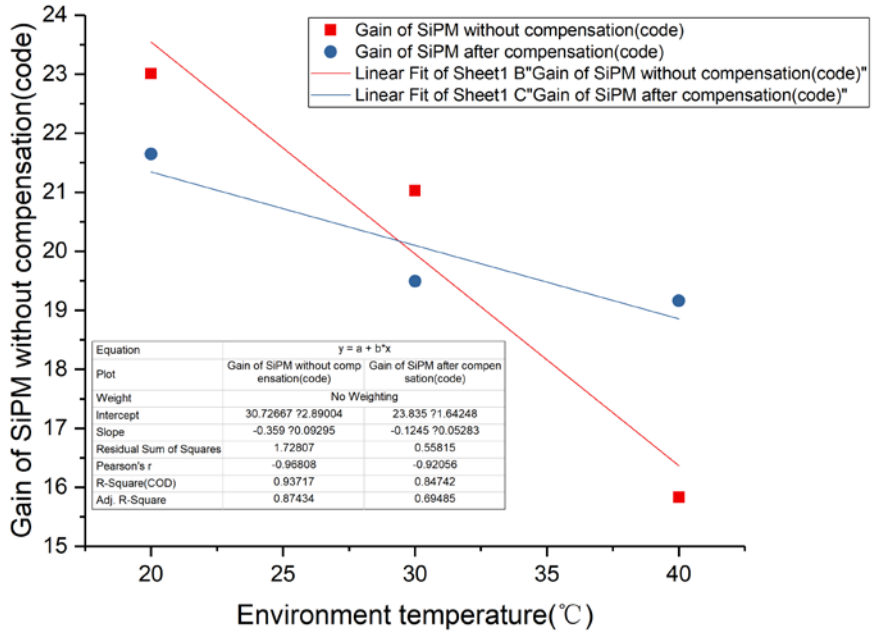






Temperature monitoring

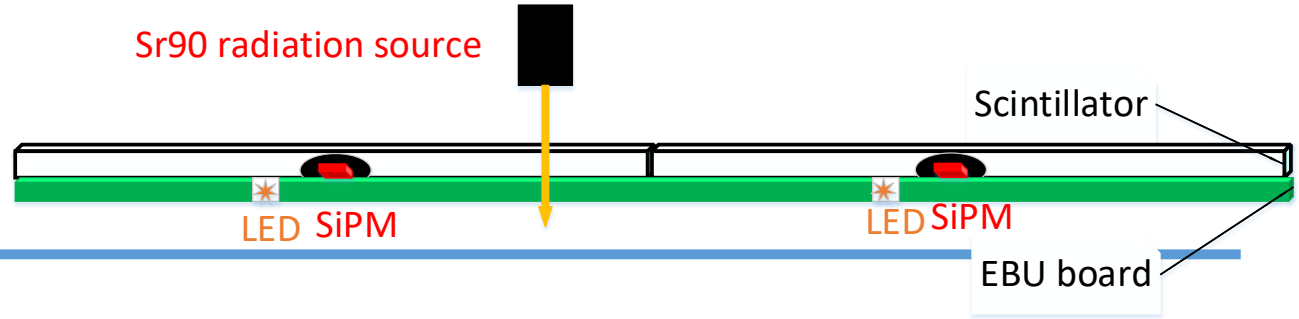




Equation	y = a + b*x	
Plot	Gain of SiPM without compensation(code)	Gain of SiPM after compensation(code)
Weight	No Weighting	
Intercept	30.72667 ?2.89004	23.835 ?1.64248
Slope	-0.359 ?0.09295	-0.1245 ?0.05283
Residual Sum of Squares	1.72807	0.55815
Pearson's r	-0.96808	-0.92056
R-Square(COD)	0.93717	0.84742
Adj. R-Square	0.87434	0.69485

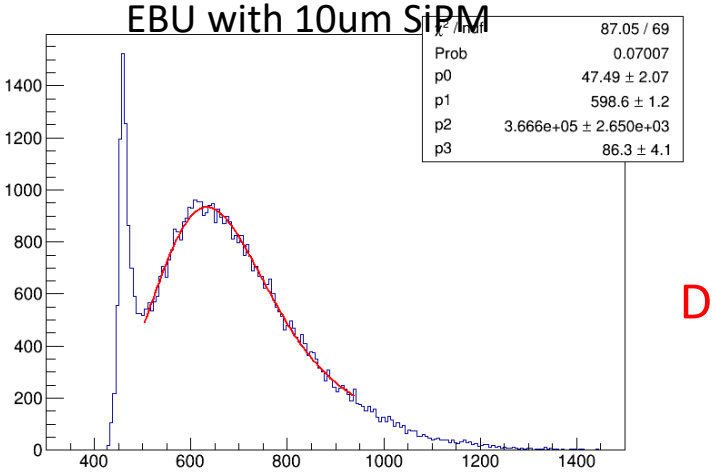
- 16 temperature sensors distributed on one EBU
- Temperature field reconstruction algorithm is needed
- Temperature compensation : expect to be implemented soon

MIP test with Sr90



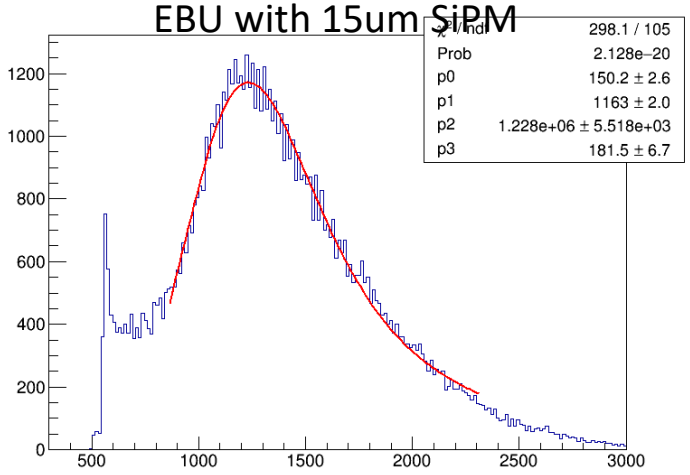
- Tested two layers of EBUs with 10um SiPM and 15um SiPM, respectively.

EBU with 10um SiPM



Distinct MIP signals in both cases

EBU with 15um SiPM

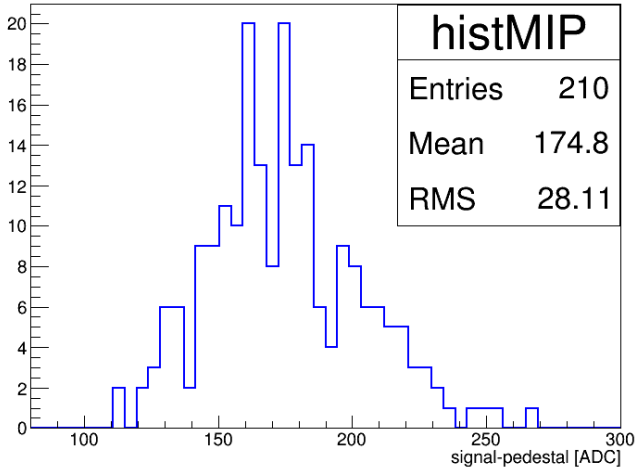


- 25ns shaping time for both 10um and 15um SiPM
- Self-trigger(auto-trigger) with 16 memory cells
- SiPM on recommended operation voltage
- Spectrum fit: $landau \otimes gaus$

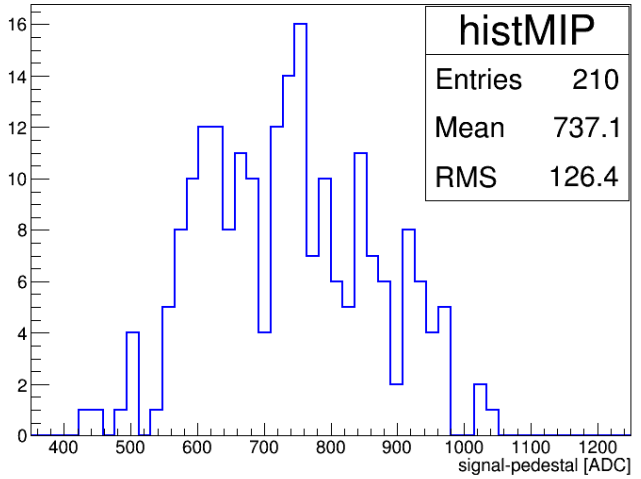
MIP signal amplitude

- MIP variation: RMS / MIP MPV ~ 16% for 10um and ~ 17% for 15um
- Signal over Noise Ratio: MIP MPV / Pedestal RMS ~ 35 for 10um and ~ 135 for 15um
- Negligible variation between 16 memory cells

Signal amplitude = landau peak – pedestal

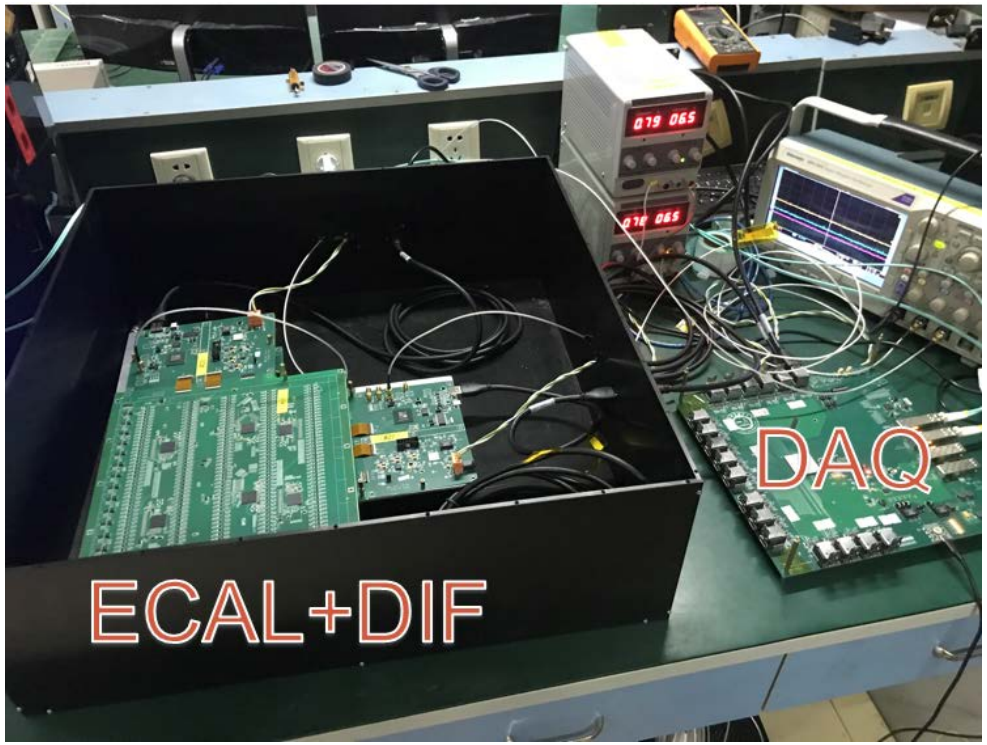


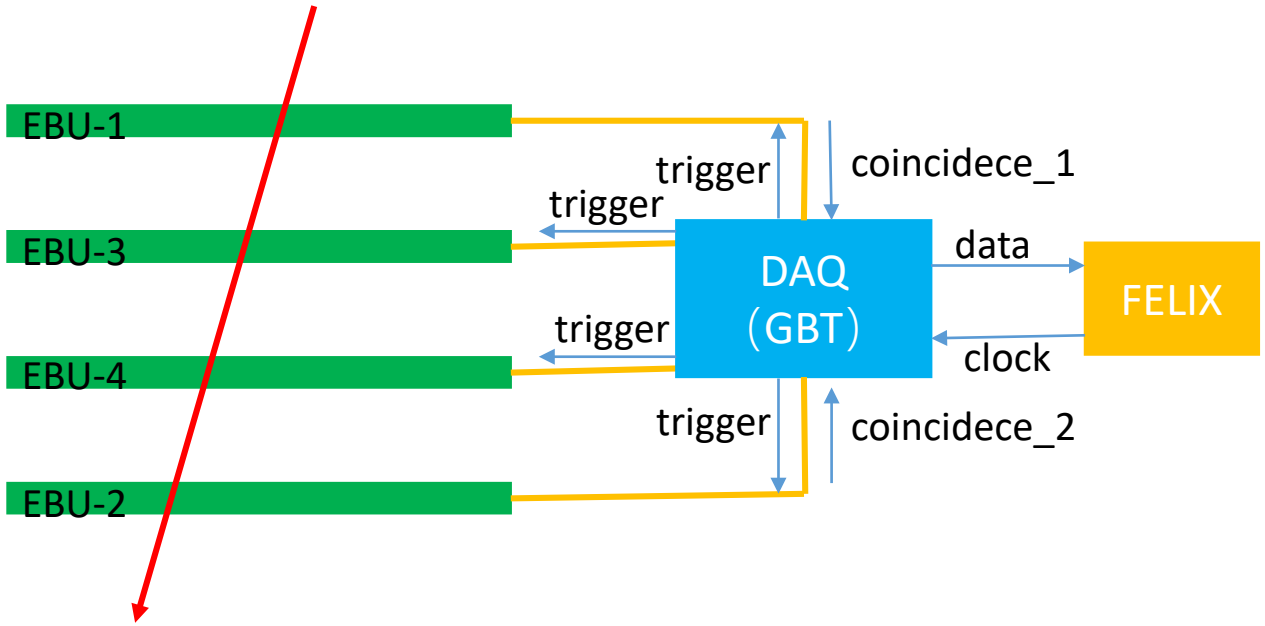
EBU with 10um SiPM (210 channels)



EBU with 15um SiPM (210 channels)

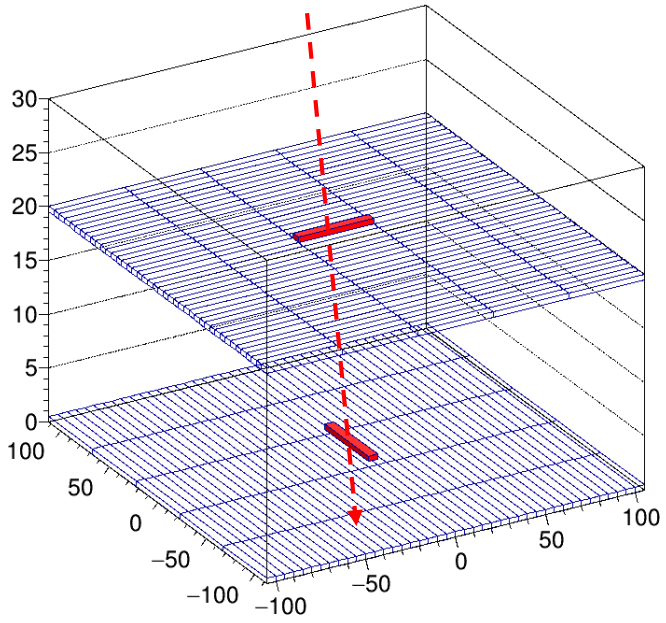
Combined test of multi-EBUs with DAQ



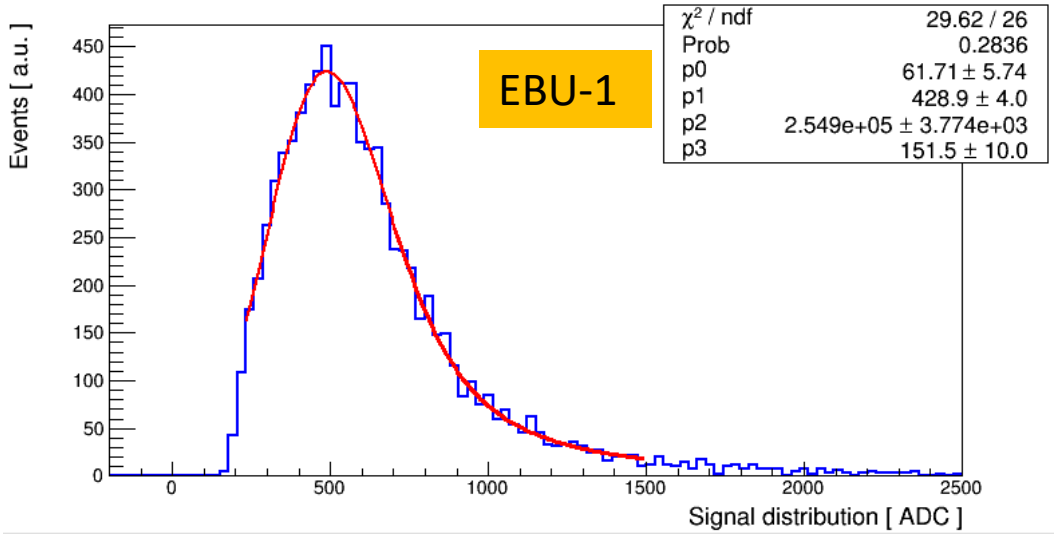


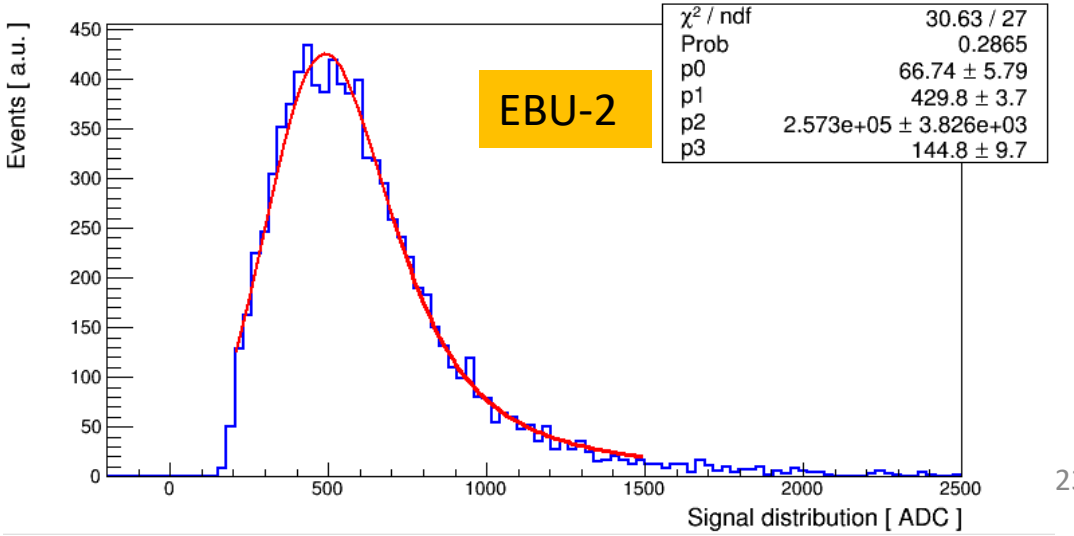
- The top and the bottom EBU coincidence as the external-trigger
- Additional two EBU work at validation mode, but don’t involved external-trigger

Results from the combined test



pedestal-subtracted signals with cosmic-rays

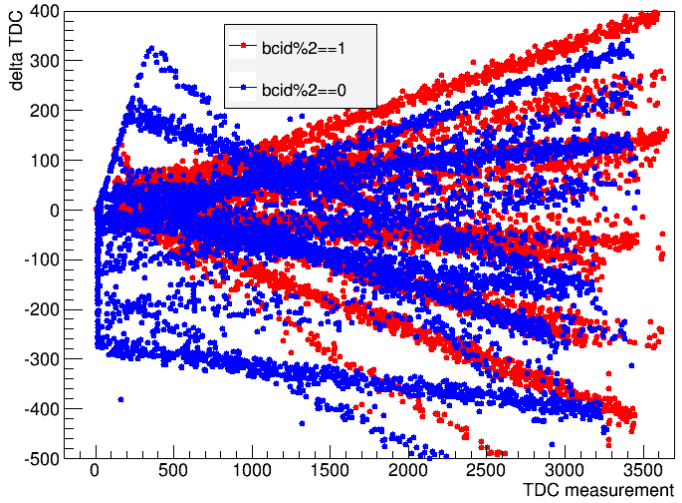




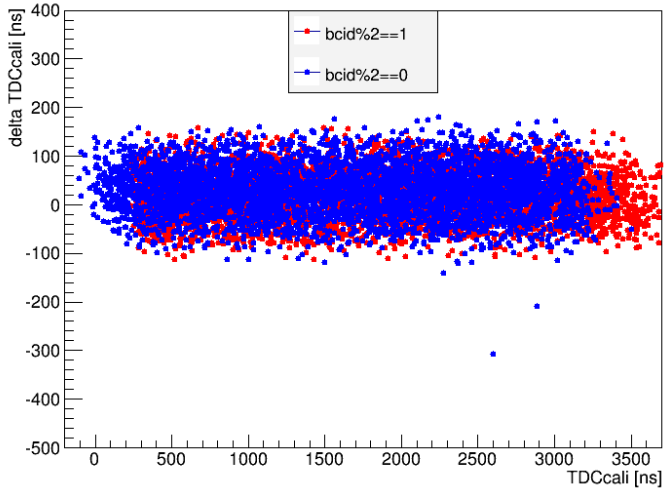
- The combined system worked properly !
  - Both EBUs functioned well
  - DAQ took data from the two EBUs successfully
  - The two EBUs were properly synchronized

Results from the combined test

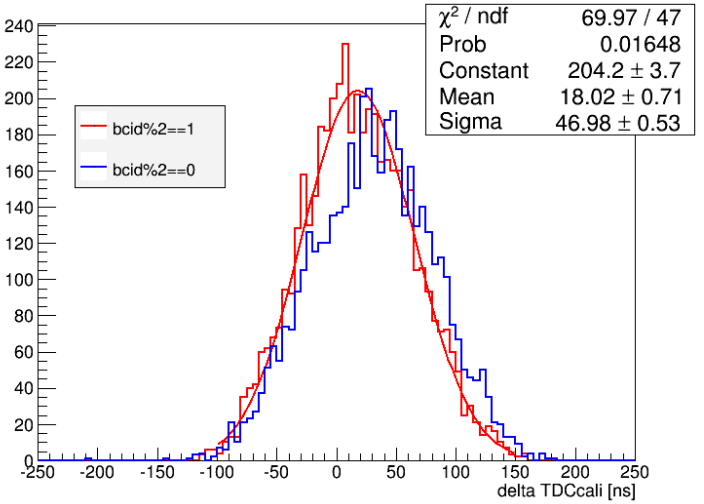
Raw TDC measurement



Calibration to time [ns]

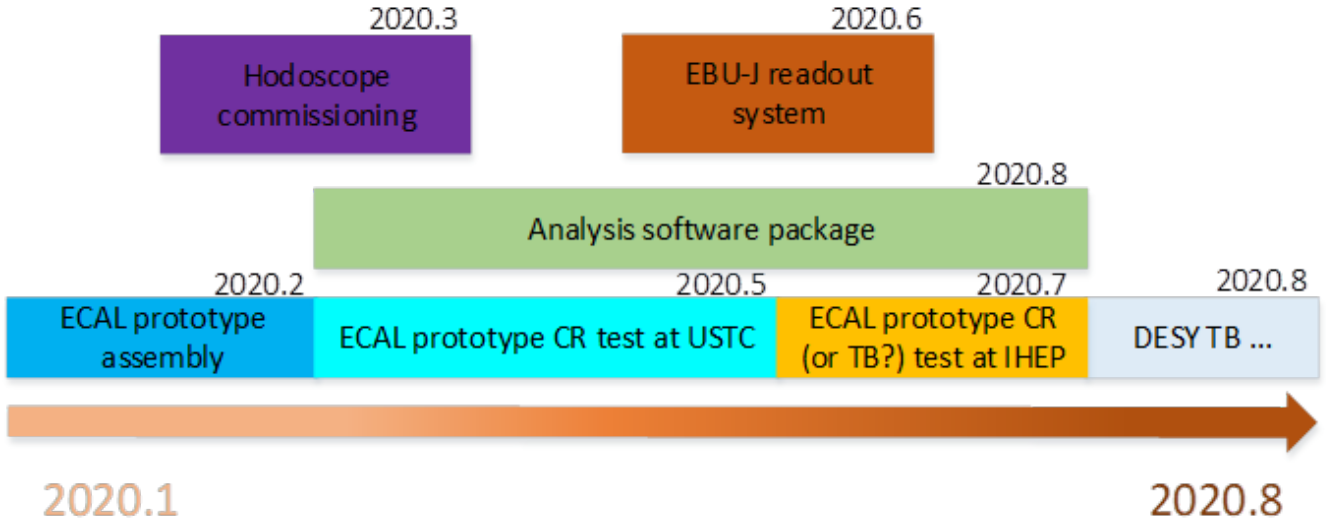


First preliminary CR result



- Raw TDC measurement need calibration and correction
- Preliminary CR result better than $47/\sqrt{2}\ ns$ time resolution can achieved

CEPC Sci-ECAL R&D project Schedule



Hold-off !!!

Target Aug.2020: perform test beam in DESY for full ECAL prototype

6-Jul-20										
13-Jul-20										
20-Jul-20										
27-Jul-20	31		BL4S	X	Belle-II PXD	X			AFP-TOF	
3-Aug-20	32		CMS OT 2S	X	Belle-II PXD	X	LCTPC-Pix	X		
10-Aug-20	33		MBI	X	Summer Students	X	LCTPC-Pix	X		
17-Aug-20	34		ATLAS-ITk-TJCMOS	X	CEPC-ECAL	X			CALICE AHCAL	X
24-Aug-20	35		CMS-Pixel-Phase2	X	CEPC-ECAL	X			CEPC-STCF	X
31-Aug-20	36		CMS-Pixel-Phase2	X	MUonE	X			CEPC-STCF	X
7-Sep-20	37		CLIC Pixel	X	ELAD	X			BCGS	X

Outline

- Introduction
- Studies on CEPC Sci-ECAL sensitive cell
- CEPC Sci-ECAL prototype design and development
- EBU commissioning and project schedule
- Summary

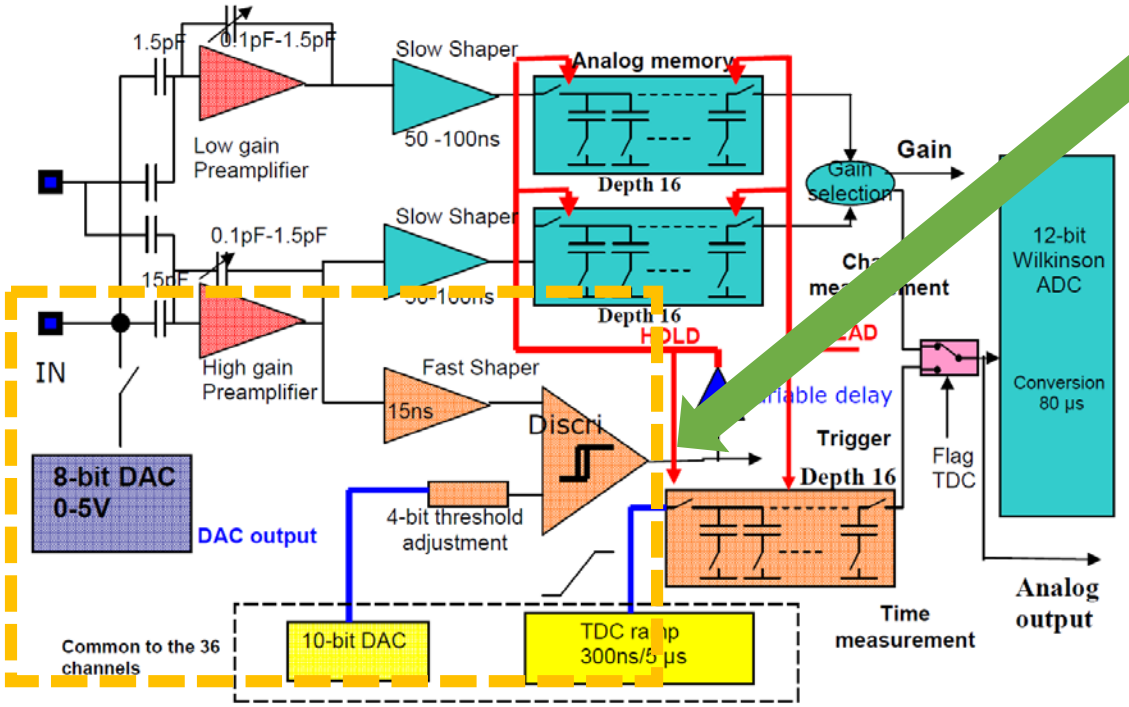
Summary

- CEPC Sci-W ECAL technological prototype is fast emerging
  - ✓ All of 30 layers EBUs have been produced for Sci-ECAL prototype
  - ✓ Mechanical structure has been manufactured and will be mounted
  - ✓ DAQ commissioned with multi-EBUs and the combined system worked well
- To do next
  - ✓ Cosmic ray test of all EBUs
  - ✓ Analysis of the cosmic ray measurement results
  - ✓ Commissioning of the cosmic-ray hodoscope from the Tokyo group to be ready for full commissioning of the ECAL prototype with cosmic rays

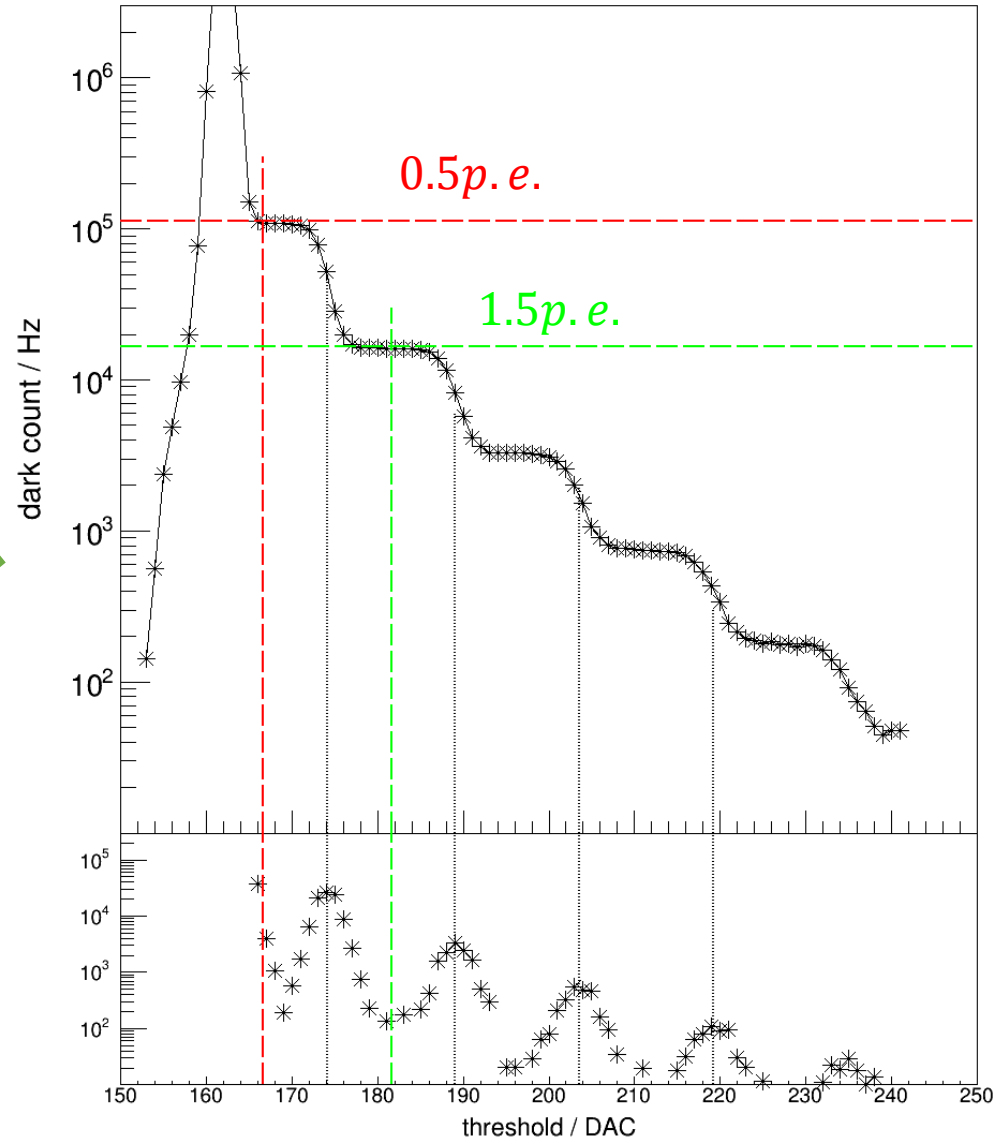
Additional

SP2e – 015P

- Shut down ADC portion
- Using DAC scan threshold and counter
  150ns dead time

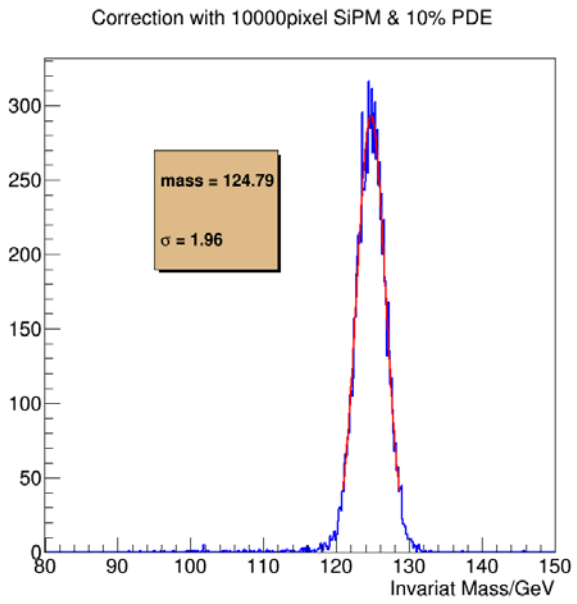


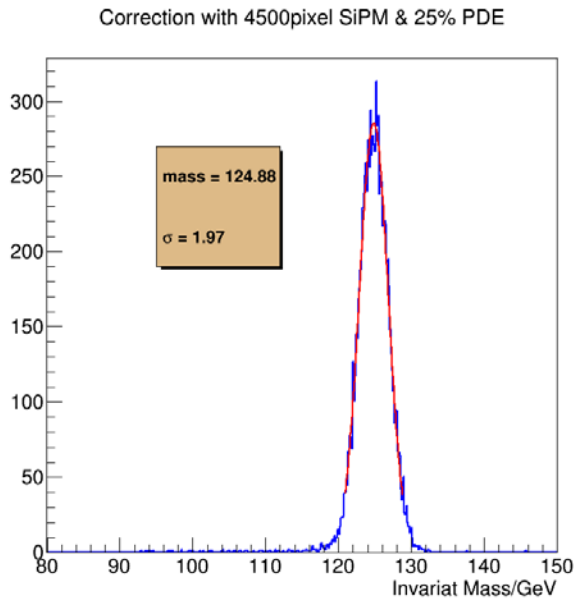
$over\ voltage = 4\ V$

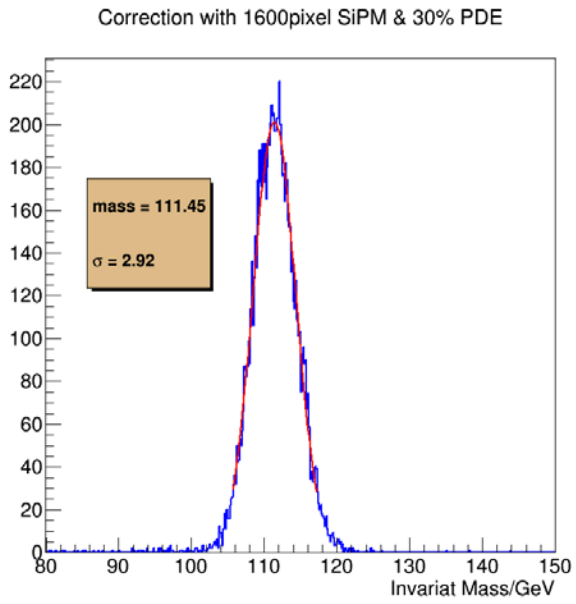


SiPM saturation correct

$Higgs \rightarrow \gamma\gamma$



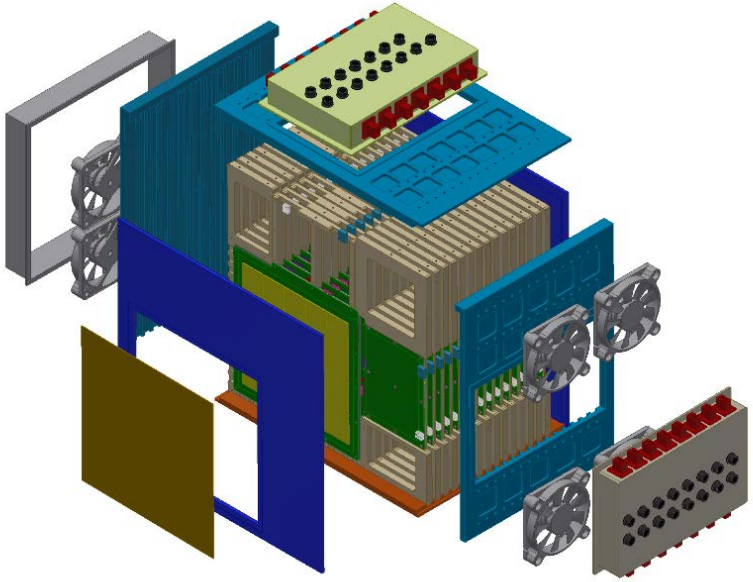


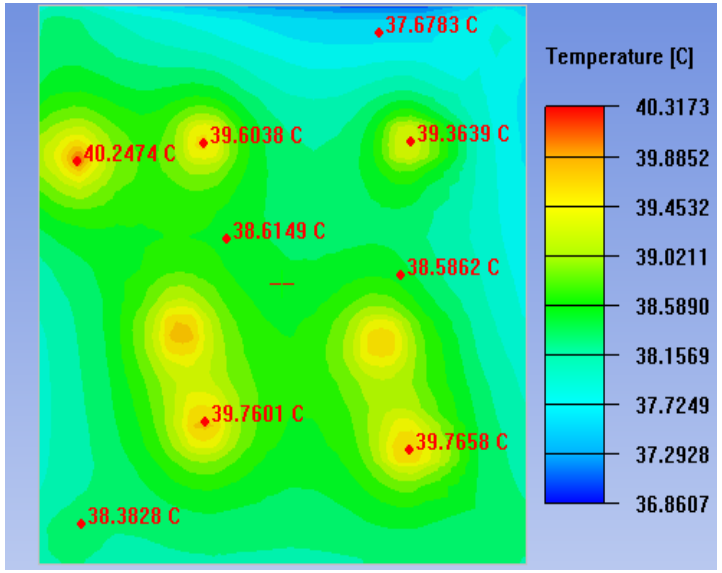


Pixel	10000	4500	1600
MIP LY / p.e.	20	50	60
PDE / %	10	25	30
Mean / GeV	124.79	124.88	111.45
$\sigma/Mean$	1.57%	1.58%	2.62%

- SiPM saturation effect can be corrected in very large range

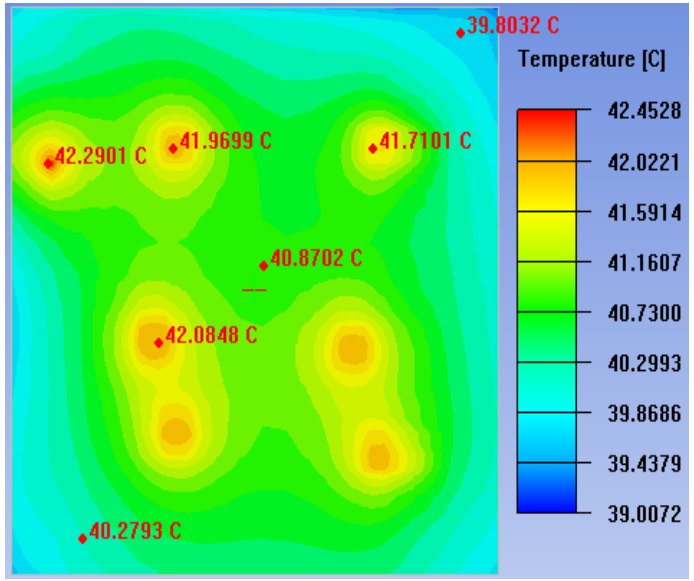
Cooling system





Layer 5

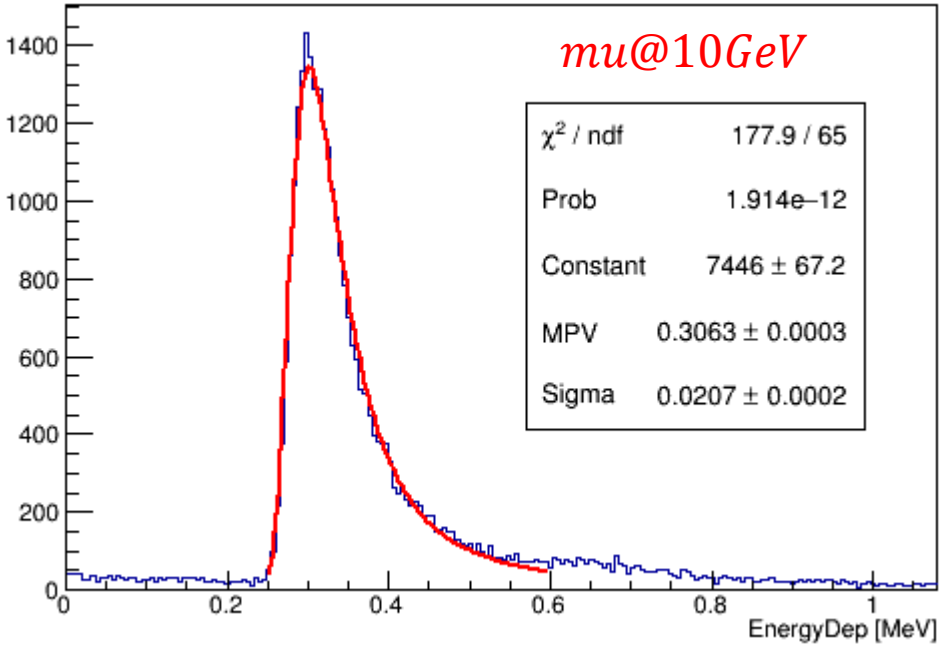
Object min:	36.8607	Std dev:	0.45	C
Object max:	40.3173	Area:	0.0617	m2

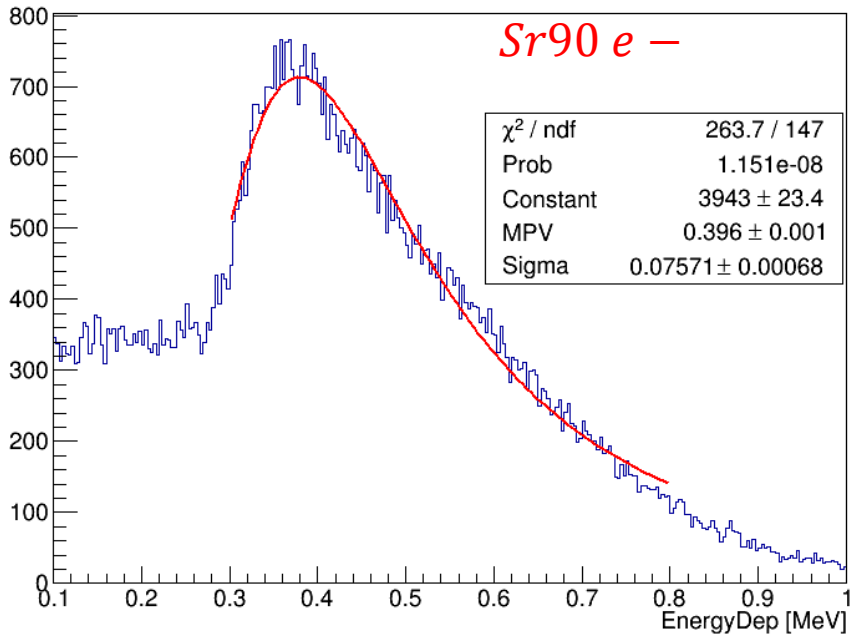


Layer 15

Object min:	39.0072	Std dev:	0.495	C
Object max:	42.4528	Area:	0.0617	m2

MIP response for mu- and e-





- “MIP” peak by Sr90 is about 1.3 times larger than by muon particle

TDC measurement vs. delay time