Dual-Readout Calorimeter for future e+e- collider

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On behalf of the Dual-Readout Calorimeter Collaboration

Supported by

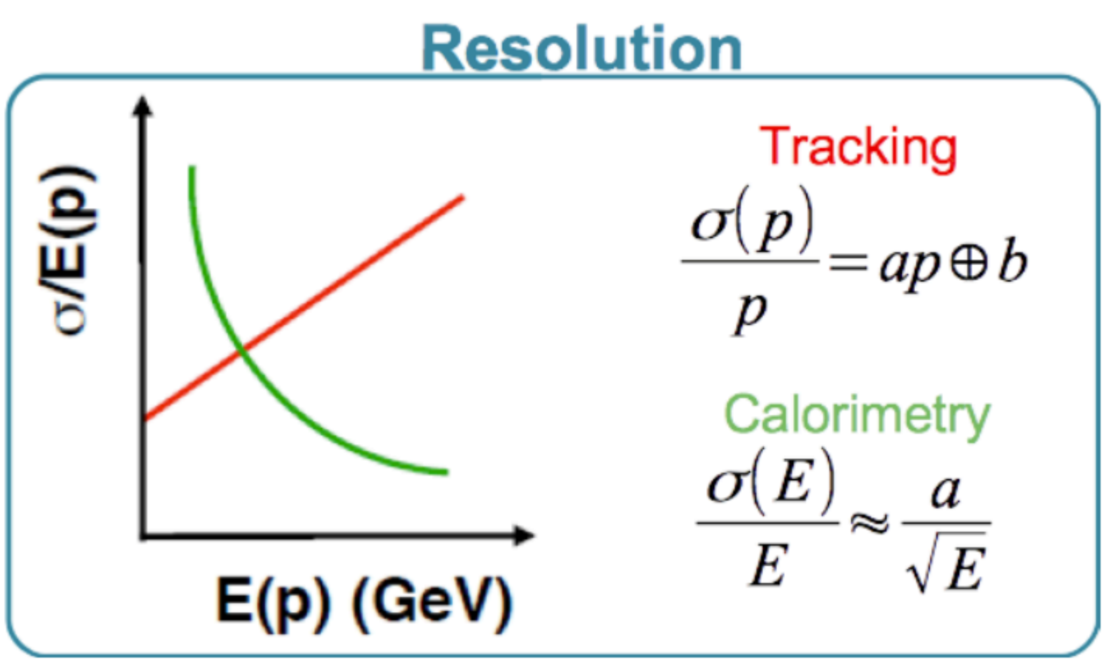
Calorimeter in HEP

- In HEP calorimetry is the detection of particles through total absorption in a block of matter
  - Most particles end their journey in calorimeters

- Calorimeters can **measure both charged and neutrals** (calorimeters are sensitive to all types of particles)
  - They can even provide indirect detection of neutrinos and their energy through a measurement of the event missing energy

- Relative resolution improves with energy

- Complementary to tracking detectors
  - Trackers measures charged particle bending
  - Calorimeters measure absorbed energy



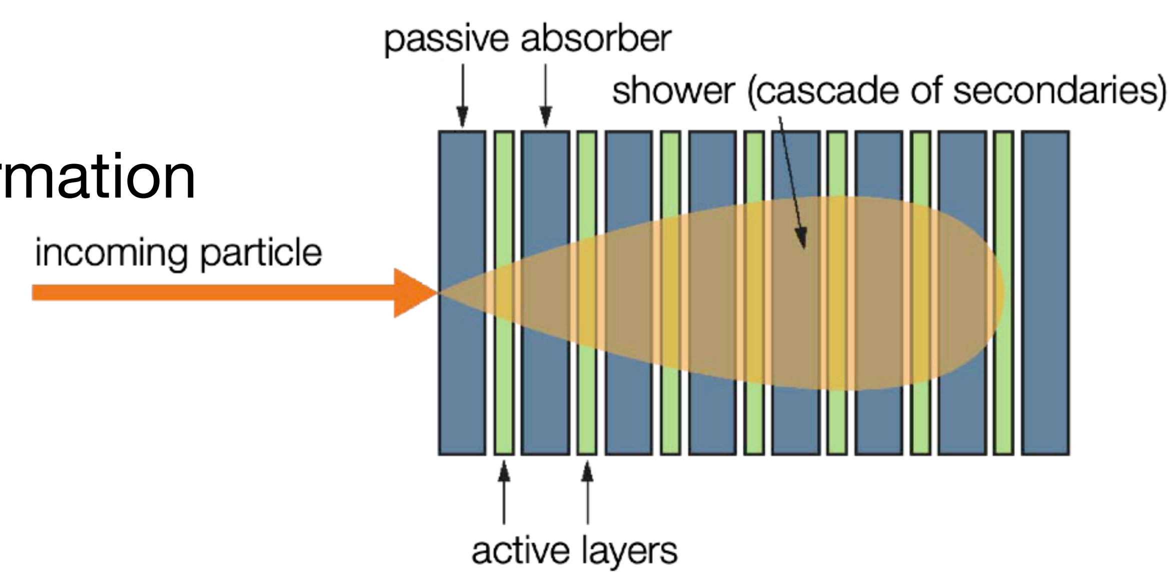
Calorimeter Types

- Homogeneous calorimeter

  - Single medium development (dense material)
  - It has good energy resolution (all energy deposited is collected)
  - But, it has limited spatial resolution
  - Usually (very) expensive
  - ex) CMS ECal

- Sampling calorimeter

  - Shower is sampled by layers of **active medium** **(low-Z)** alternated with **dense radiator (high-Z, passive medium)** material
  - It has limited energy resolution
  - However, it allows detailed shower shape information
  - it is cheaper than homogeneous calorimeters
  - Dual readout calorimeter



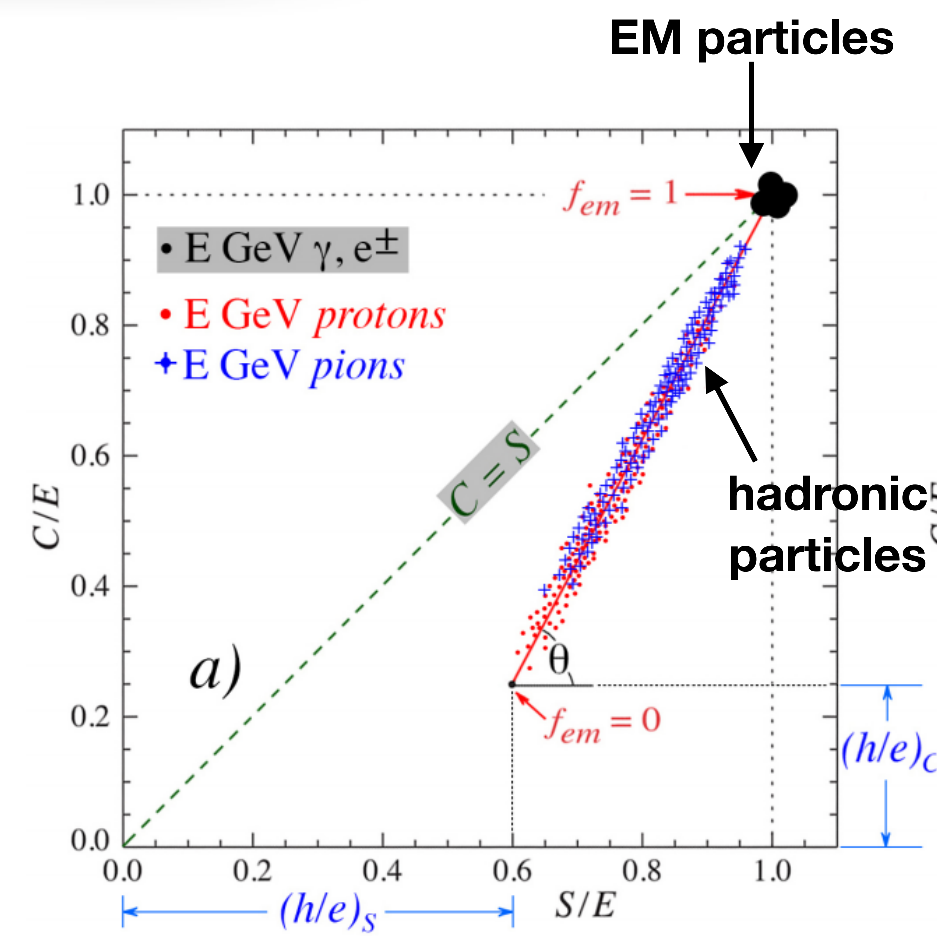
Dual Readout Calorimeter

- The major difficulty of measuring energy of hadronic shower comes from the fluctuation of EM fraction of shower, f_em

- f_em can be measured by implementing two different channels with different h/e response in a calorimeter

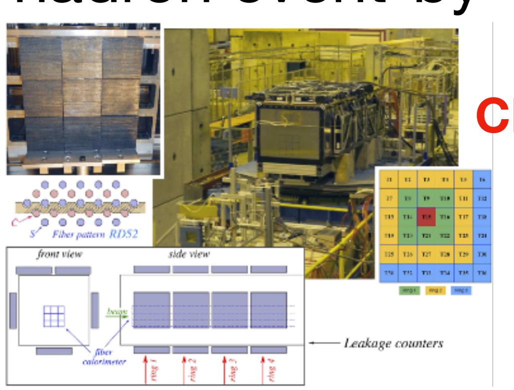
$$f_{\rm em} = \frac{(h/e)_C - (C/S)(h/e)_S}{(C/S)[1-(h/e)_S] - [1-(h/e)_C]} \qquad \cot\theta = \frac{1-(h/e)_S}{1-(h/e)_C} = \chi$$

$$S = E\left[f_{\rm em} + \frac{1}{(e/h)_S}(1-f_{\rm em})\right]$$
$$C = E\left[f_{\rm em} + \frac{1}{(e/h)_C}(1-f_{\rm em})\right] \qquad E = \frac{S-\chi C}{1-\chi}$$

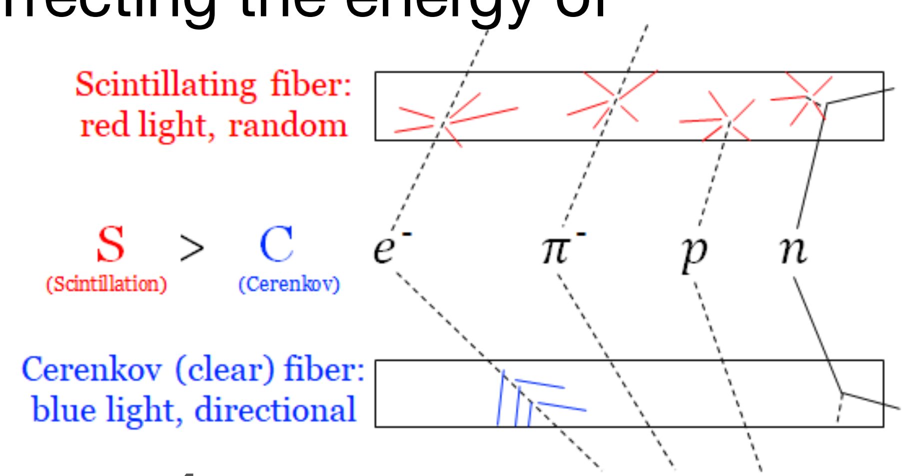


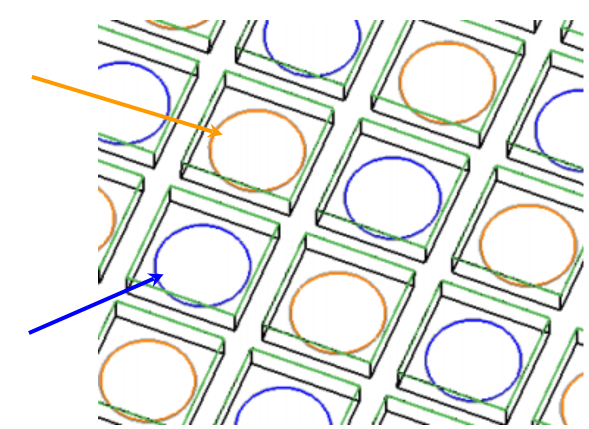
- **Dual-readout calorimeter offers high-quality energy measurement for both EM particles and hadrons**

- **Excellent energy resolution** for hadrons can be achieved by measuring f_em and correcting the energy of hadron event-by-event.



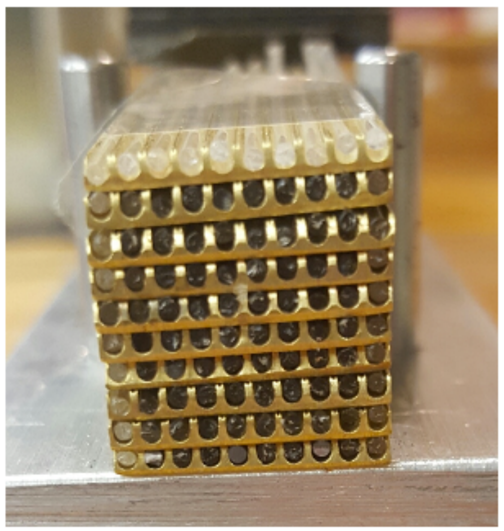
CERN RD52 experiment

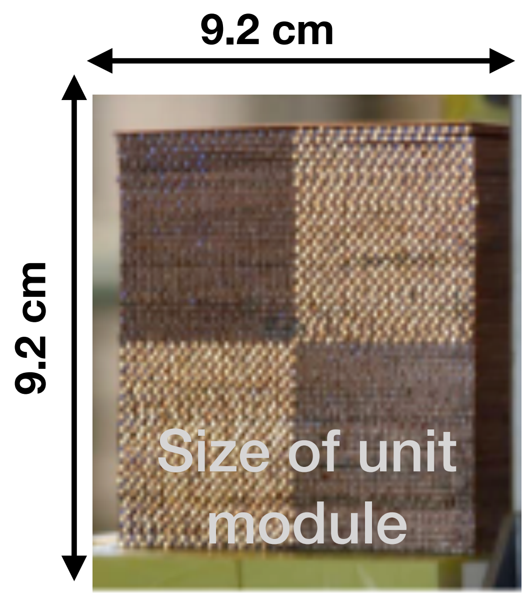


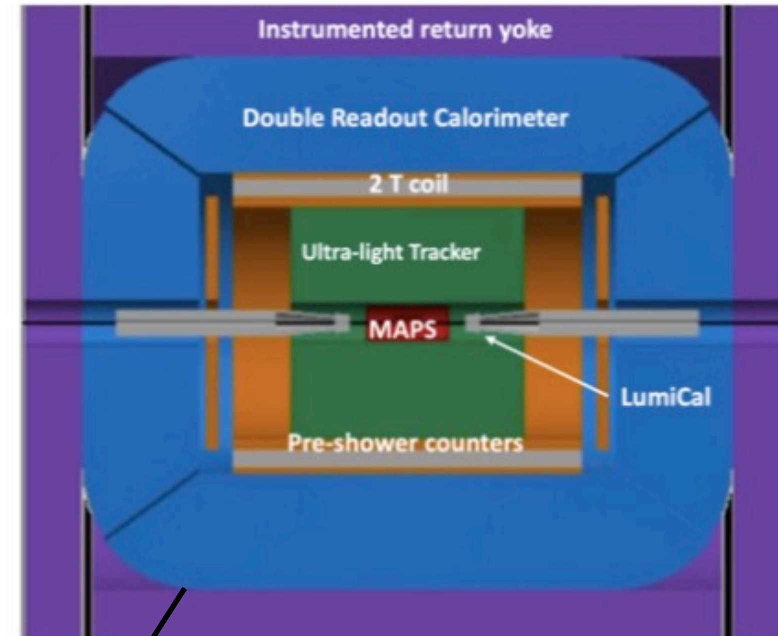


DRC Geometry and Module

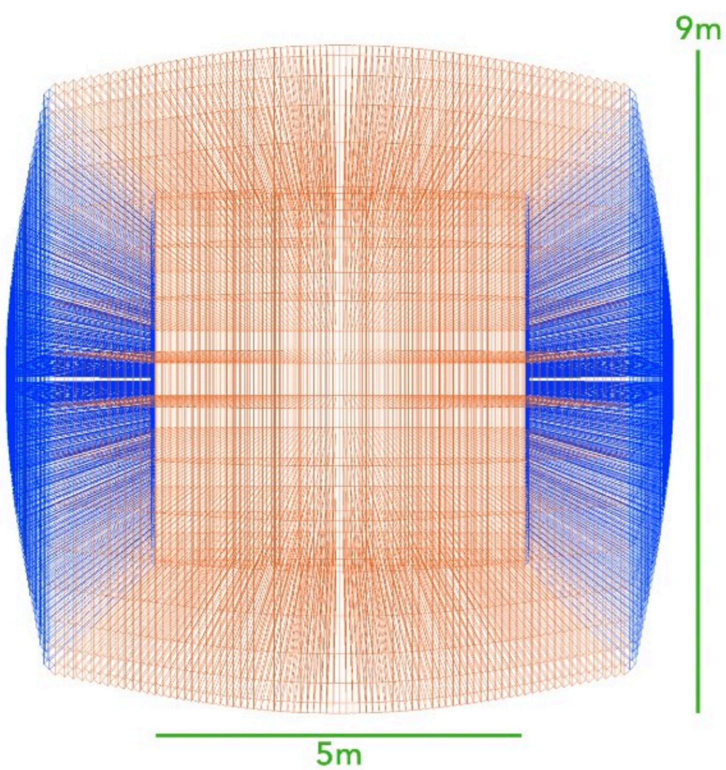
- The design of the Dual-Readout Calorimeter (DRC) for IDEA detector is included in the **CDRs** of both **FCC-ee** and **CEPC**, published at the end of 2018

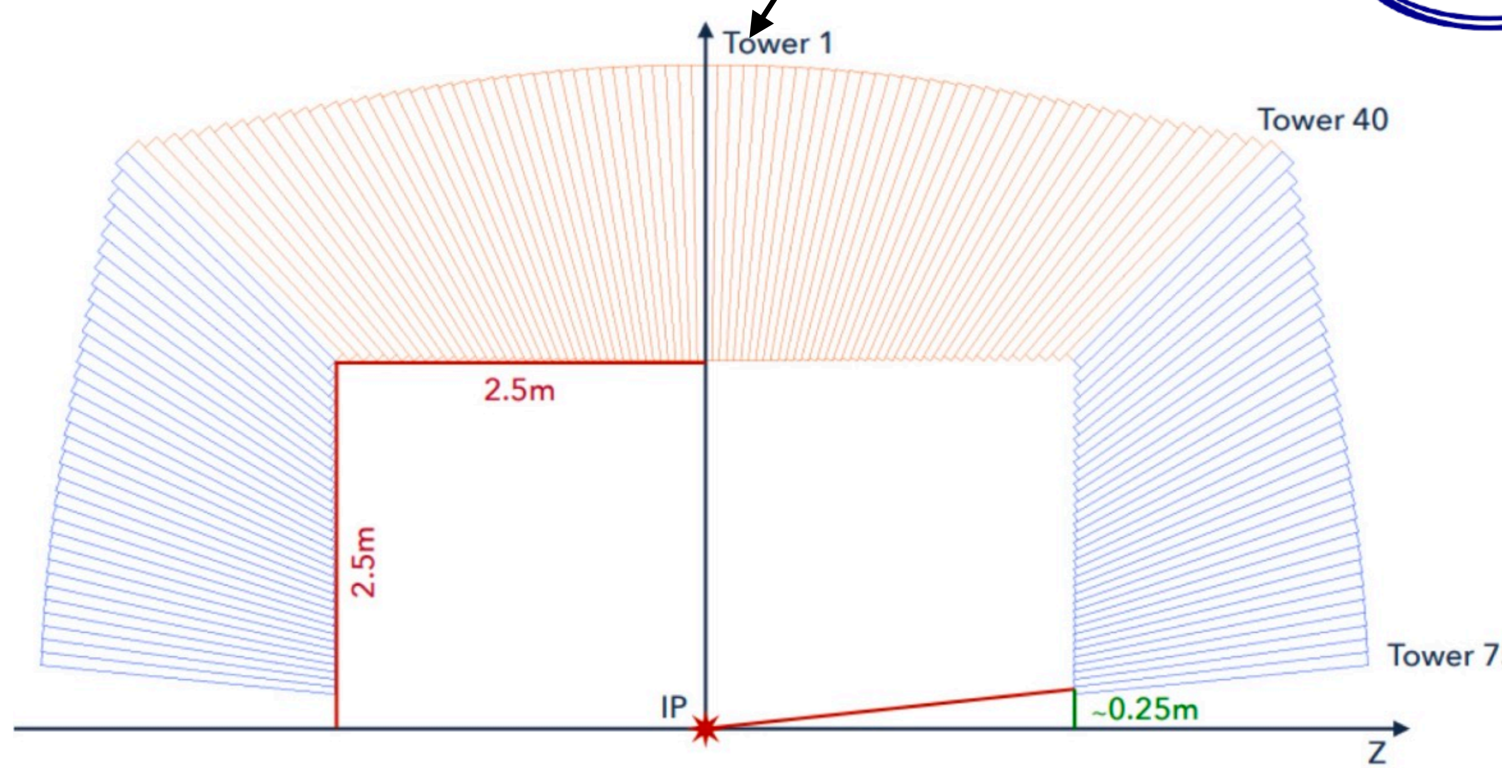






IDEA





Intro: DRC International Collaboration

DREAM FOR FUTURE

Korea

Prof. Hyonsuk Jo (KNU)
Prof. Yongsun Kim (Sejong U.)
Prof. Jason Lee (UoS)
Prof. Sehwook Lee (KNU)
Prof. Sanghoon Lim (PNU)
Prof. Hwidong Yoo (YU)
Prof. Suyong Choi (KU)
Prof. Byunggu Cheon (HU)
Prof. Minsuk Kim (GWNU)
Prof. Beomkyu Kim (SKKU)

Taiwan

Prof. Rong-Shyang Lu
Prof. Chia Ming Kuo

Japan

Prof. Yuji Enari
(Active from 2021)

USA

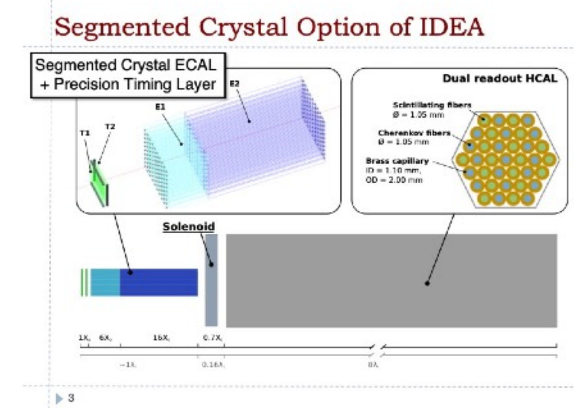
Prof. Sarah Eno
Prof. Chris Tully
Prof. Richard Wigmans
Prof. Nural Akchurin
Prof. John Hauptman

Europe

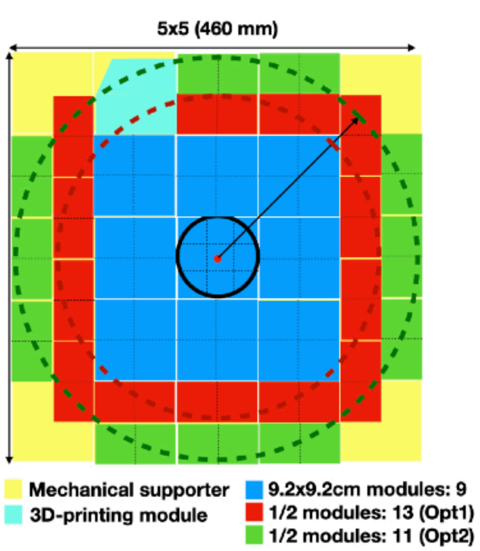
Prof. Paolo Giacomelli (Bologna)
Prof. Romualdo Santoro (Insubria)
Prof. Roberto Ferrari (Pavia)
Prof. Franco Bedeschi (Pisa)
Prof. Iacopo Vivarelli

FCC · DREAM FOR FUTURE · CEPC

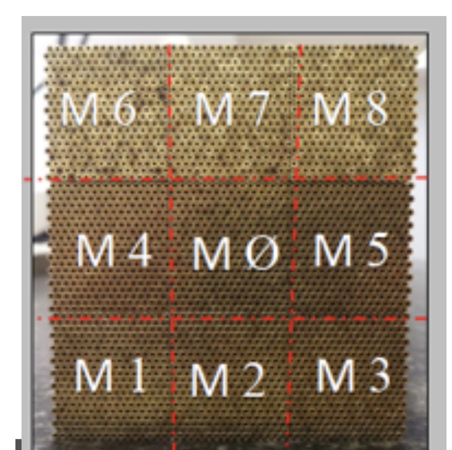
DRC with crystal



Full-size prototype detector



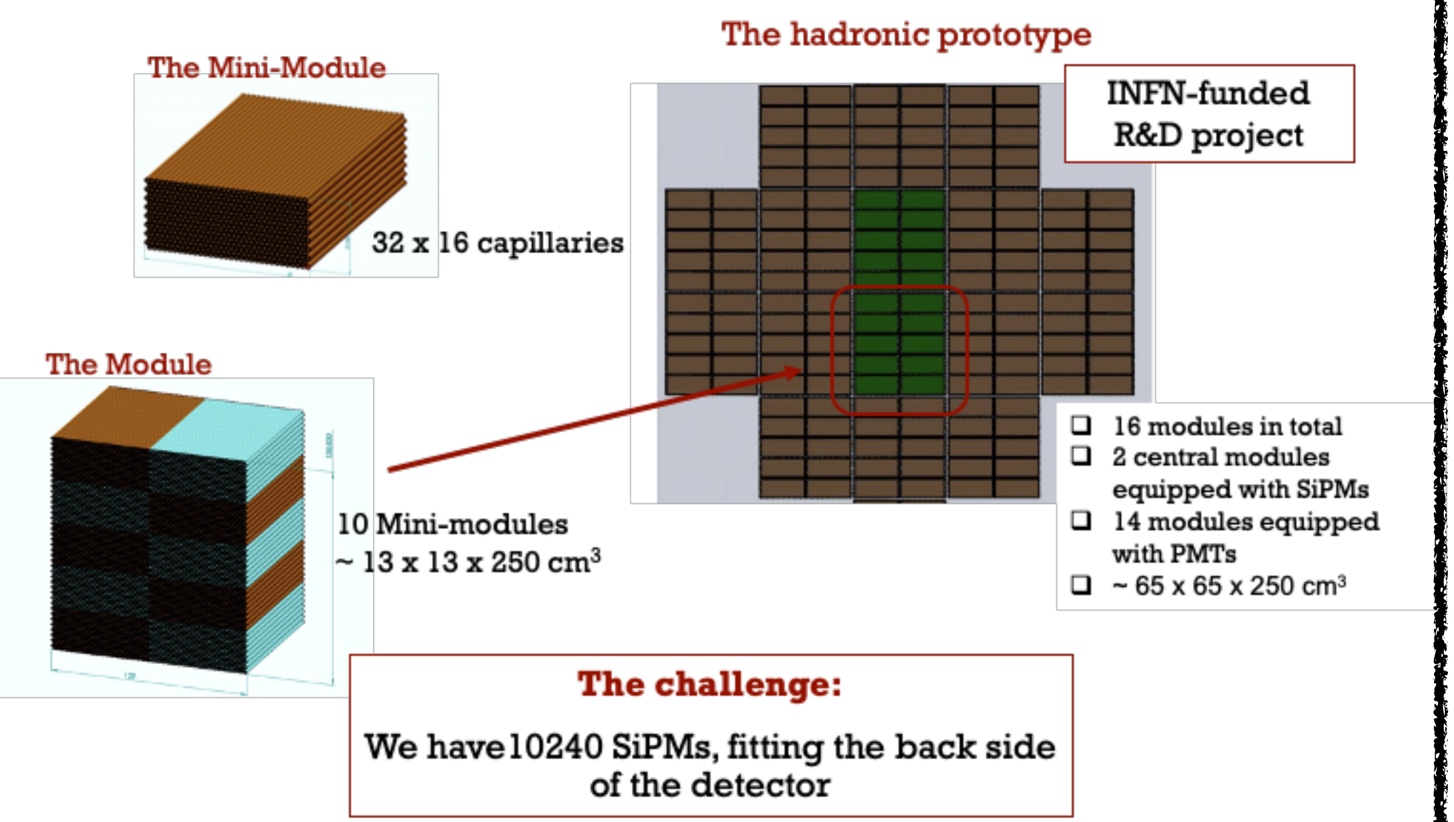
Bucatini prototype



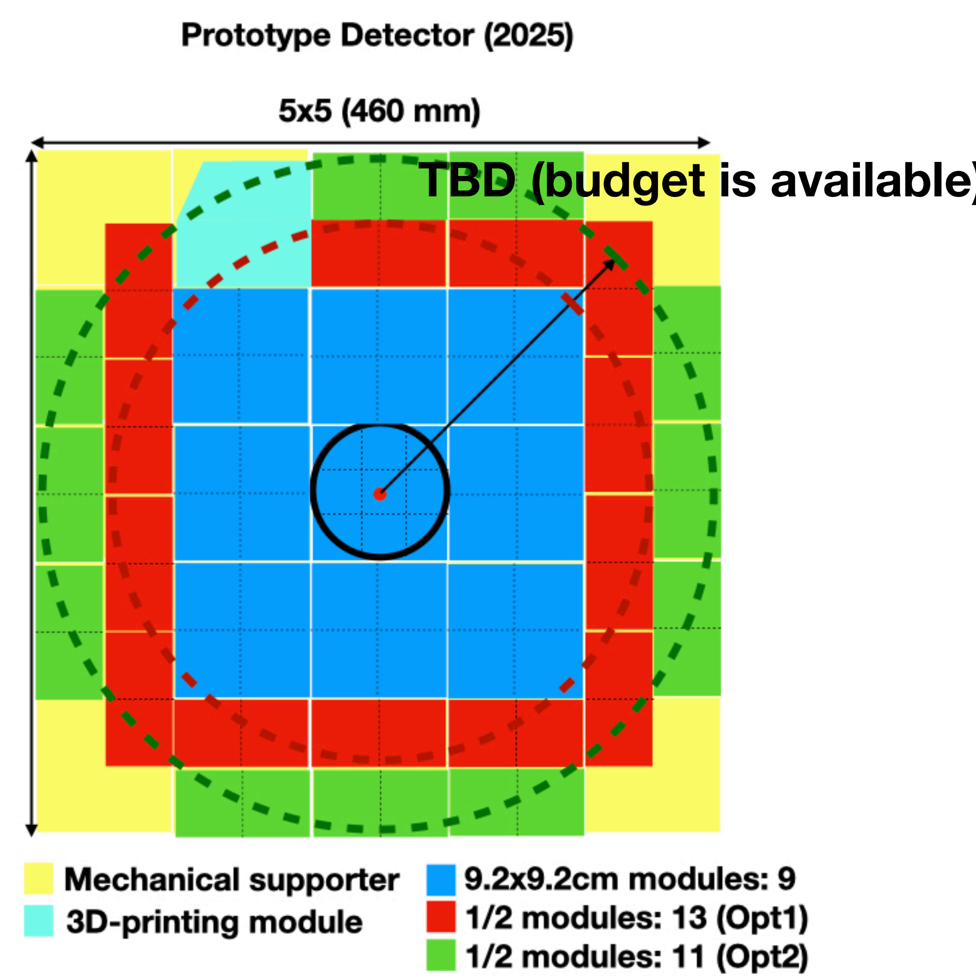
Toward TDR!

- **In order to move on to TDR, we need to demonstrate feasibility of the 4pi detector construction**
  - we will produce more modules! (**Contain almost (97.5%) full hadronic shower energy**)

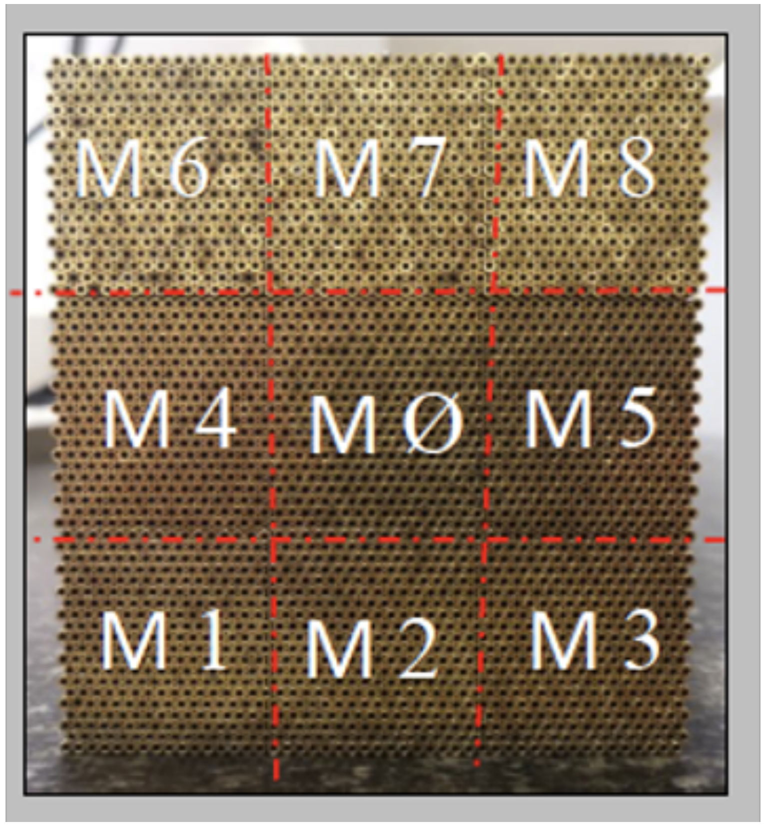
HiDRa prototype (capillary based)



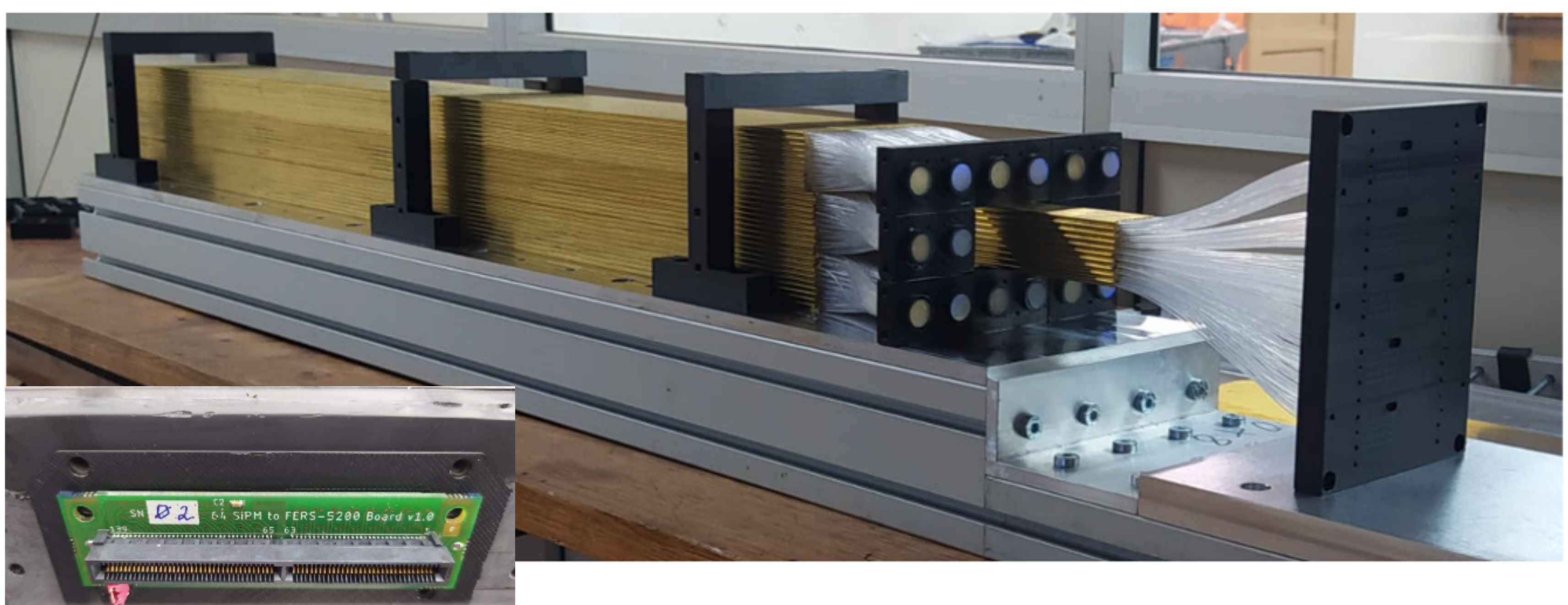
Cu Plates (Korea)

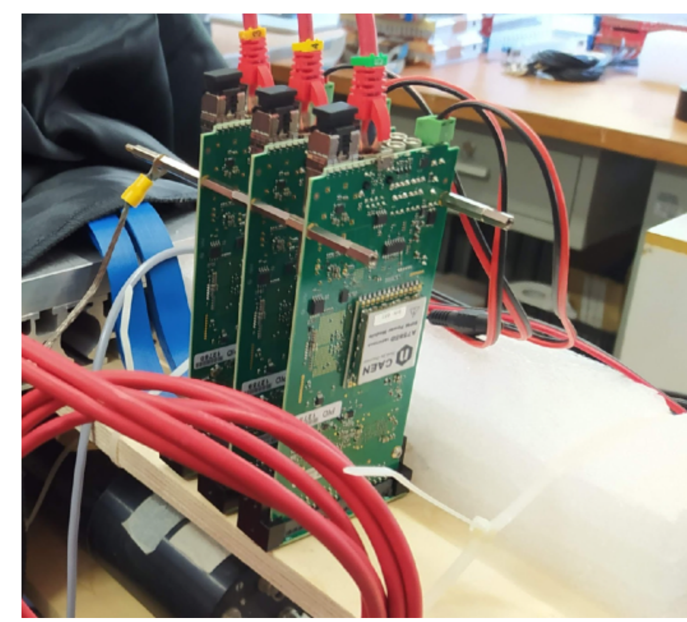


2021 Test Beam (Bucatini Calorimeter)



- Basic calorimeter unit: **one brass capillary tube** of 2 mm **external diameter hosting a fiber (1 mm diameter)**
  - Electromagnetic dimensions of **10x10x100 cm^3**
  - 9 towers containing 16x20 capillaries each (160 C and 160 S)
  - **Capillary tube with outer diameter of 2 mm and inner diameter of 1.1 mm. 1-mm-thick fibers**
- Goal: millimetric 2-dimensional shower-shape reconstruction in dual-readout calorimeters





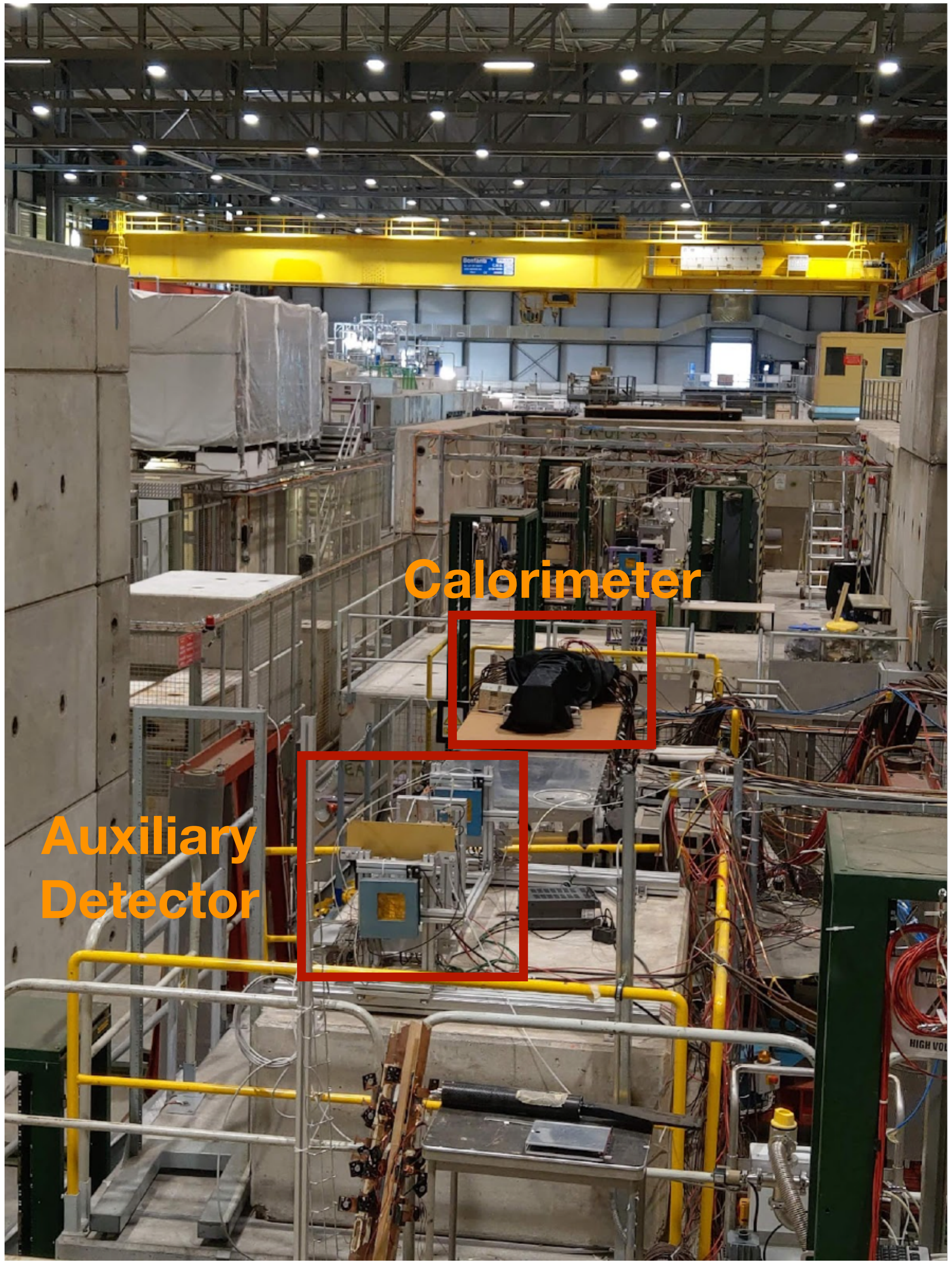
2021 Test Beam (Bucatini Calorimeter)

- **At DESY (June 2021)**

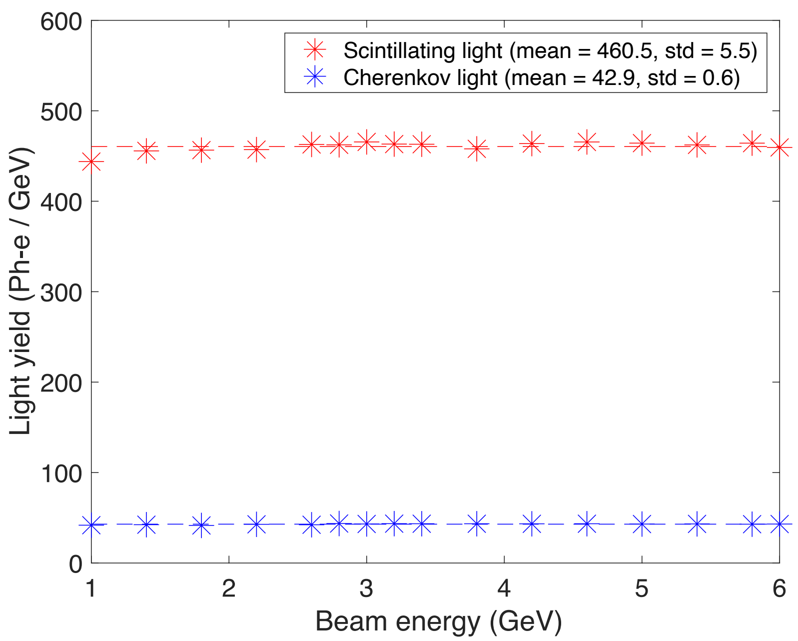
  - e^- with energy range 1-6 GeV
  - Energy scan both with and without yellow filters on Scintillating fibers
  - Scan over multiple points at the calorimeter surface to check the dependency of the response on the position

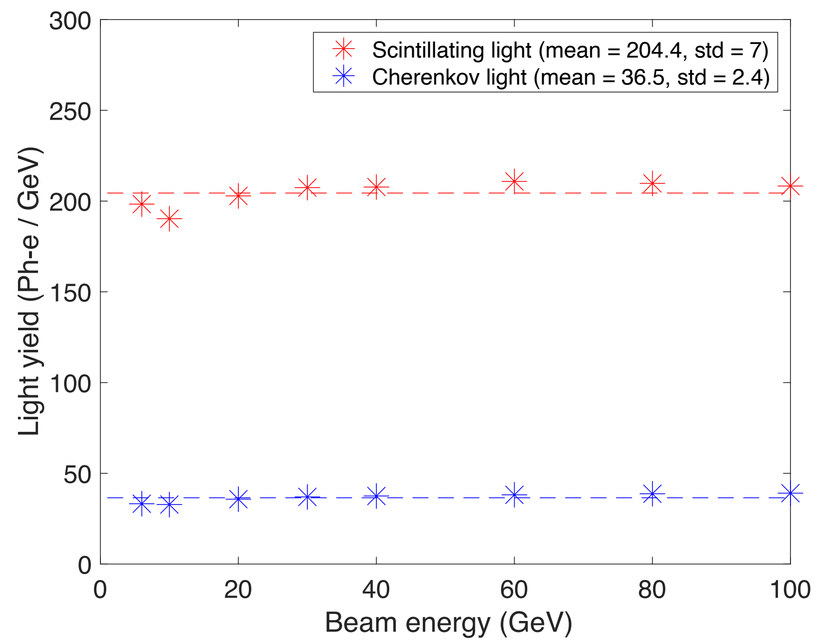
- **At CERN-SPS H8 beam line (August 2021)**

  - e+ with energy range 10-125 GeV
  - Energy and position scan
  - e+ beams highly affected by π+ 2% contamination
  -μ+ in non-monochromatic beams



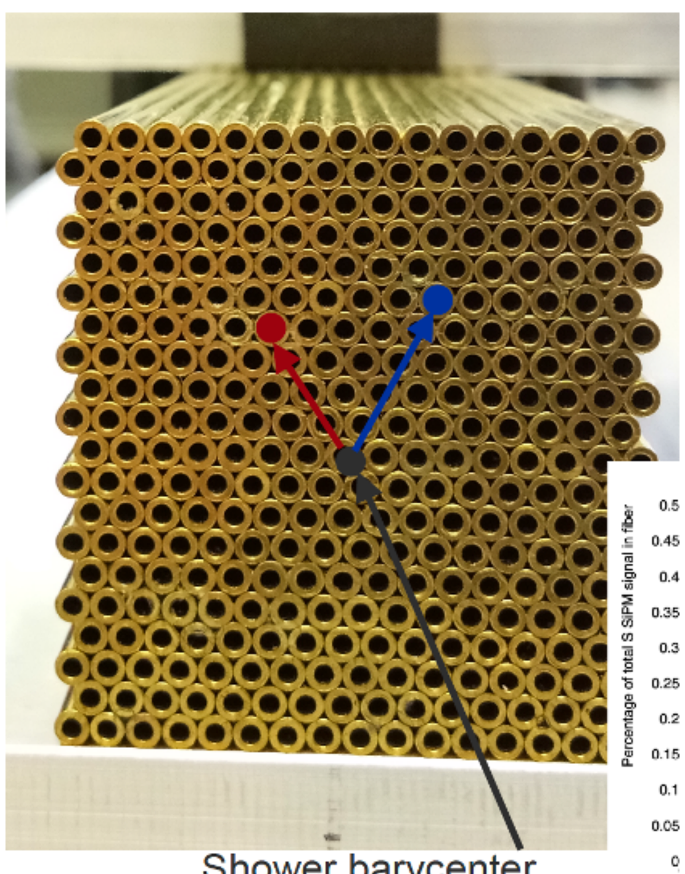
2021 Test Beam (Bucatini Calorimeter)



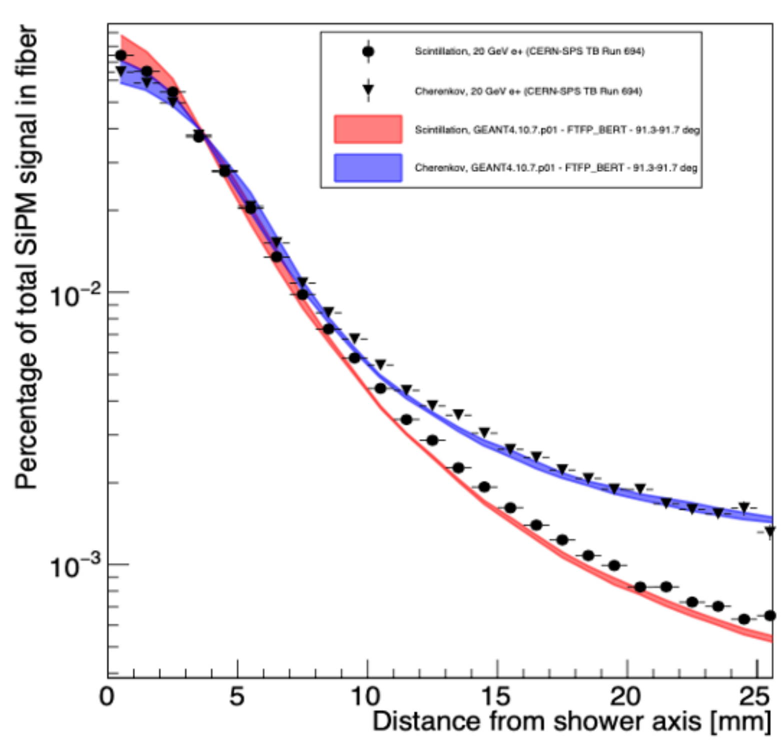


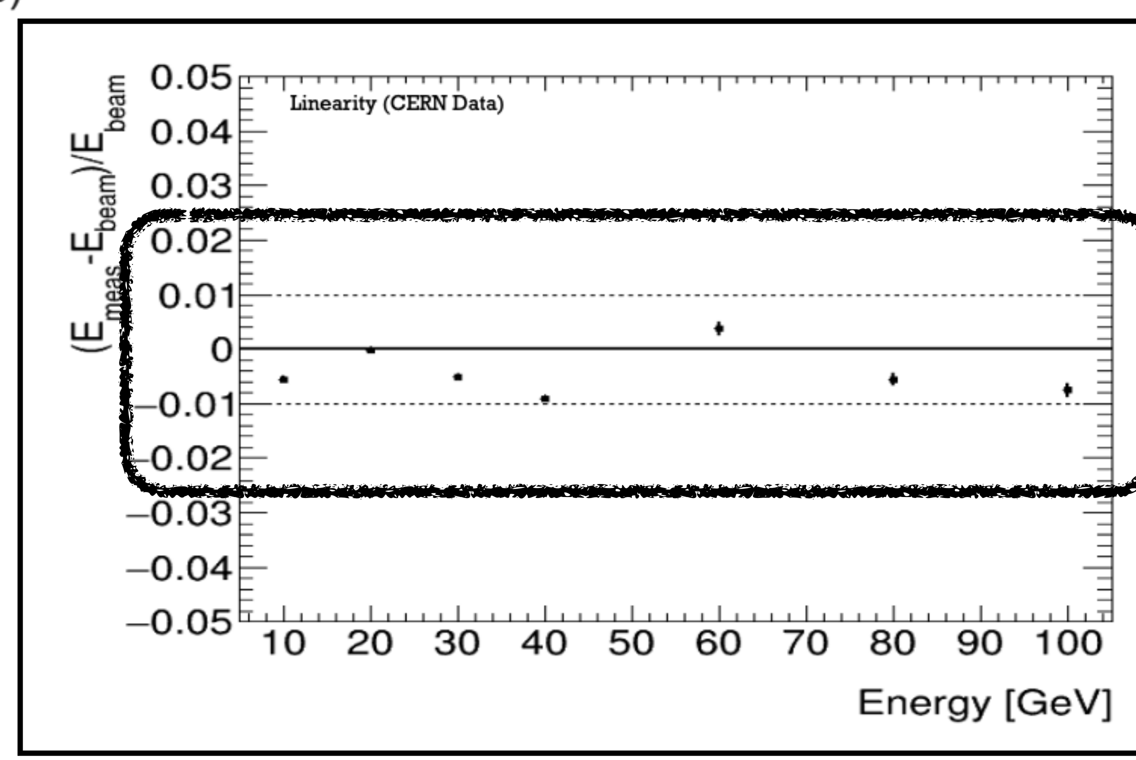
After Calibration with electrons, linearity within 1% over a wide range of enegies

Excellent **lateral shower shape development** measurements



CERN SPS 20 GeV e^+ - GEANT4 (log scale)



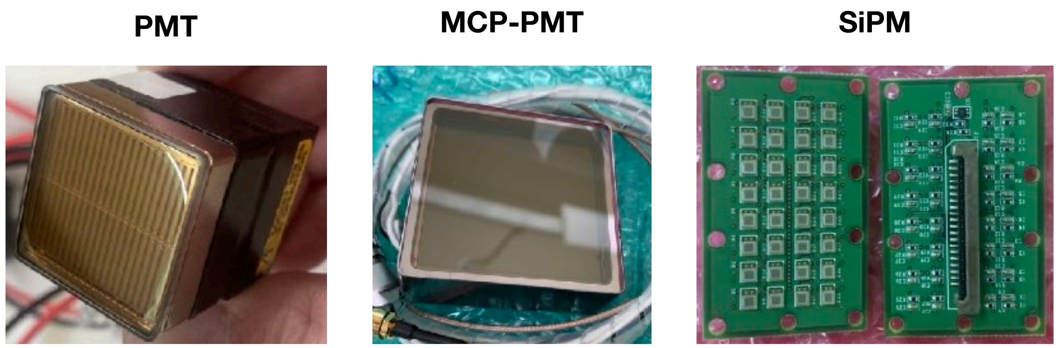


2022 Test Beam (Korea)

- **Duration : Aug. 4th ~ 24th**
- **Location : CERN North area (H8)**
- **Measurement Goal**

Module 1	- Shower depth - Longitudinal shower profile - Light attenuation length
Module 2	- Position resolution - Lateral shower profile - EM energy resolution - Uniformity study

- **R&D Goal**
  - Readout system test (MCP-PMT & SiPM)
  - Study of various type of optical fibers (scintillation)



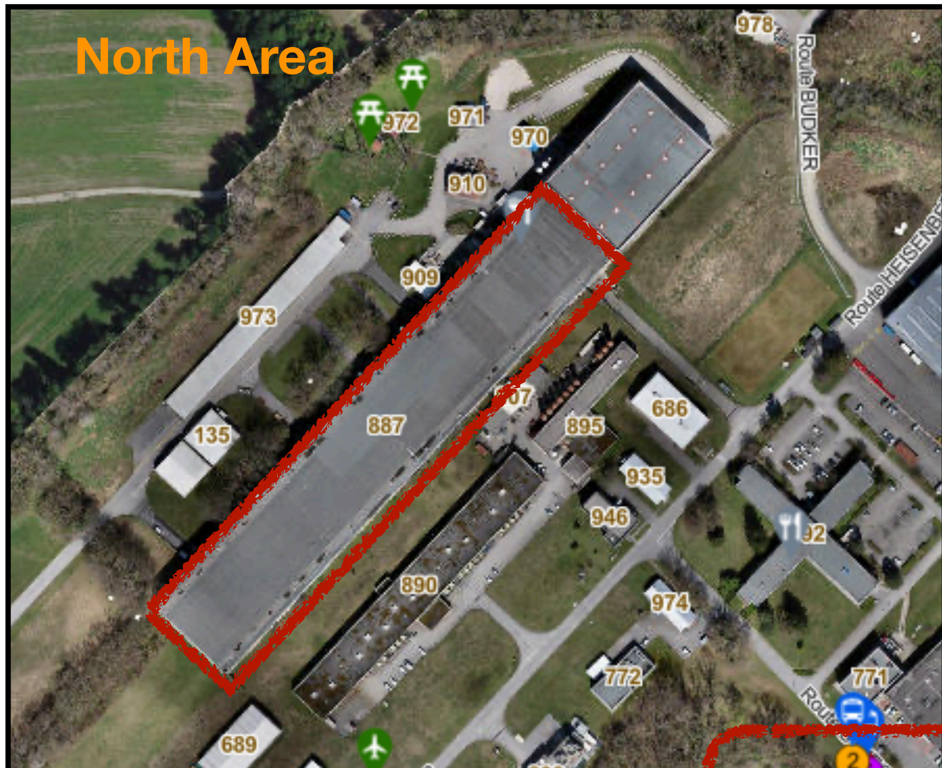
- Training Goal
  - Training next generation experts for DRC HW

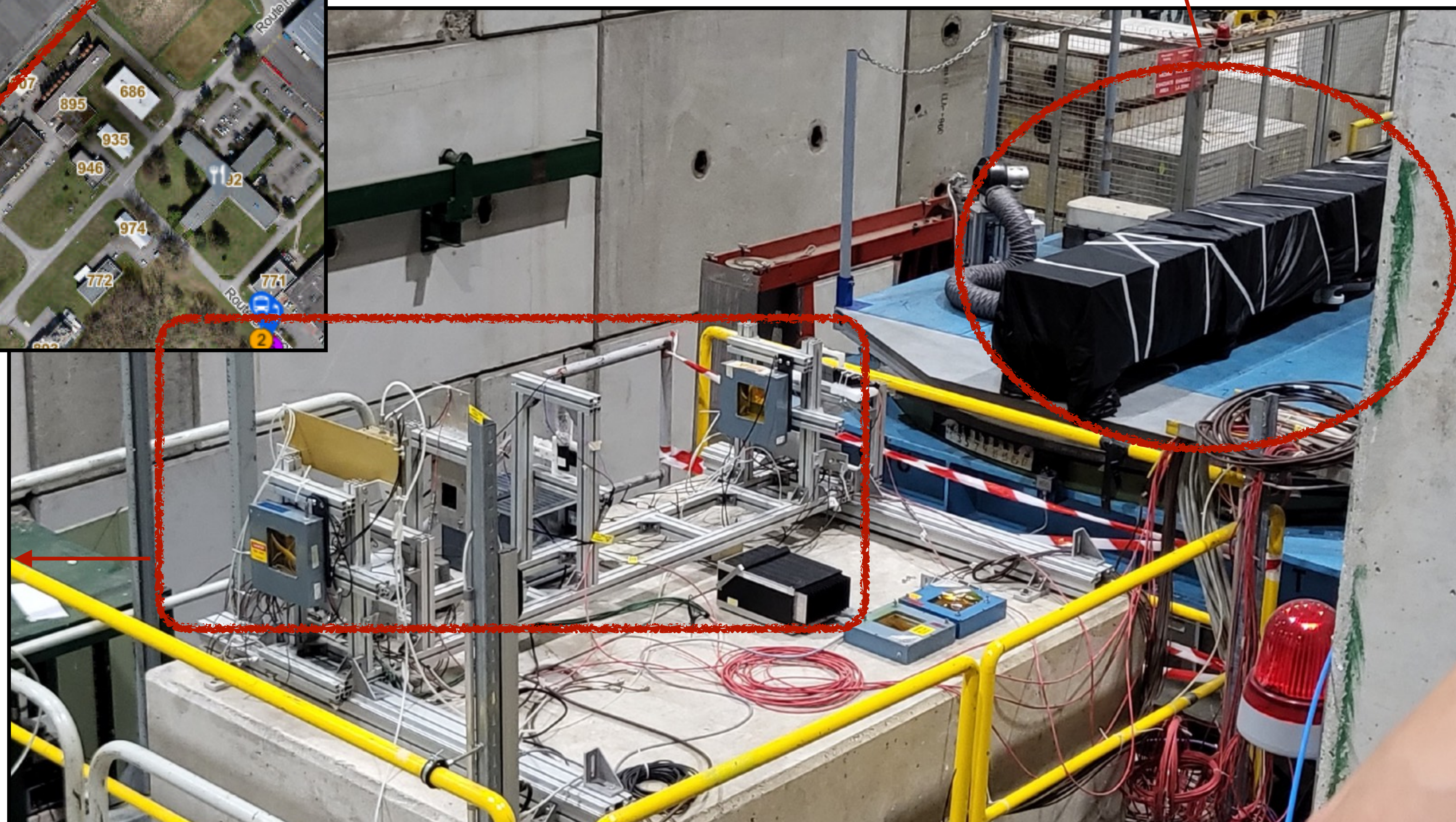
- **Schedule of test beam**

Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug		
Module	Building Module (fiber+Cu)		Attach readout			Test Commissioning	Packing/ Shipping	Install @ CERN(H8)	-	
DAQ	Test Mutichannel operation						Packing/ Shipping	Install @ CERN(H8)	-	
Test beam							Packing/ Shipping	8/3 ~ install	Preparation & commissioning @ cern (~8.16)	Taking test beam (8.17~8.24)

2022 Test Beam (Korea)

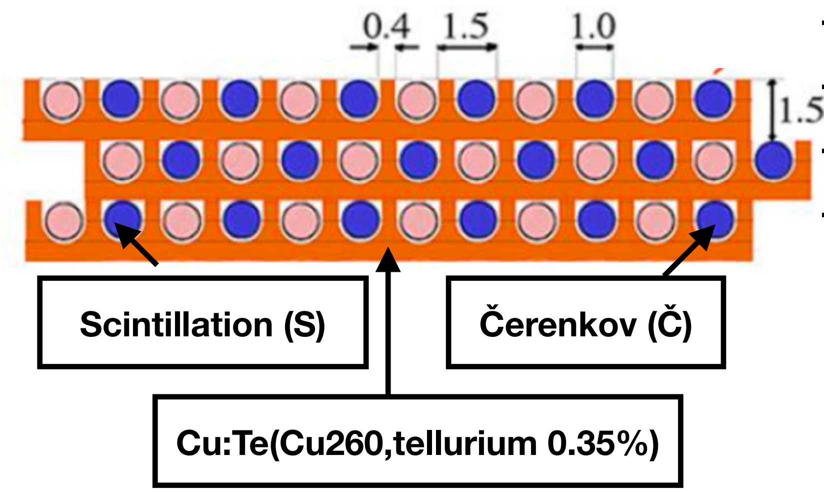
- **Experimental hall**
  - During test beam, our experiments conducted at T4-H8 @ North Area





2022 Test Beam (Korea) : 2 Modules

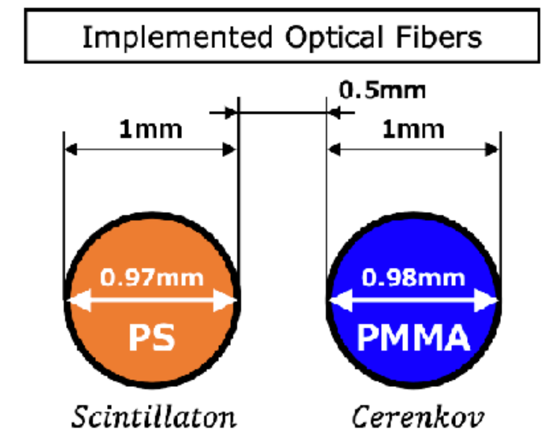
- **Copper Plate & Fibers**



- Copper plate (60)
- Width : 10 cm
- Length : 2.5 m
- Thickness : ~1.6 mm
- Hole : 1 mm (diameter)
- Distance between hole : ~ 0.63 mm

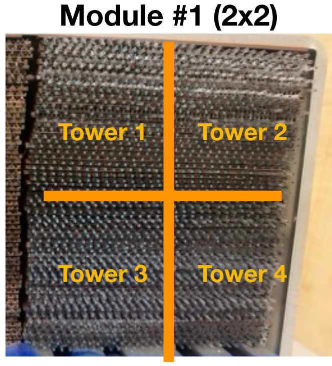
61 hole on the each copper plate
- Odd layer : 31 Sc fibers & 30 Ck fibers
- Even layer : 30 Sc fibers & 31 Ck fibers

- Optical fibers
- Scintillation fibers & Cerenkov fibers

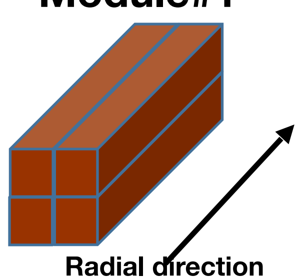


- **Configuration of Fibers & Readout detector for Test Beam**

Module #1 (2x2)



Module#1



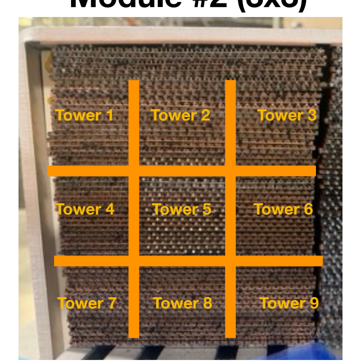
Module#1

Tower#1	Tower#2
Tower#3	Tower#4

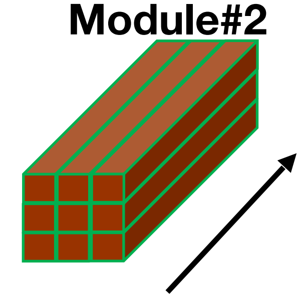
Combination of fibers for Module#1

	Tower #1	Tower #2	Tower #3	Tower #4
Scintillation fibers	Round / Single cladding	Round / Double cladding	Round / Single cladding	Square / Single cladding
Cherenkov fibers	Round / Single cladding	Round / Single cladding	Round / Single cladding	Round / Single cladding
Readout detector (2*4 ch)	2 PMTs	2 PMTs	2 MCP-PMTs	2 PMTs

Module #2 (3x3)



Module#2



Module#2

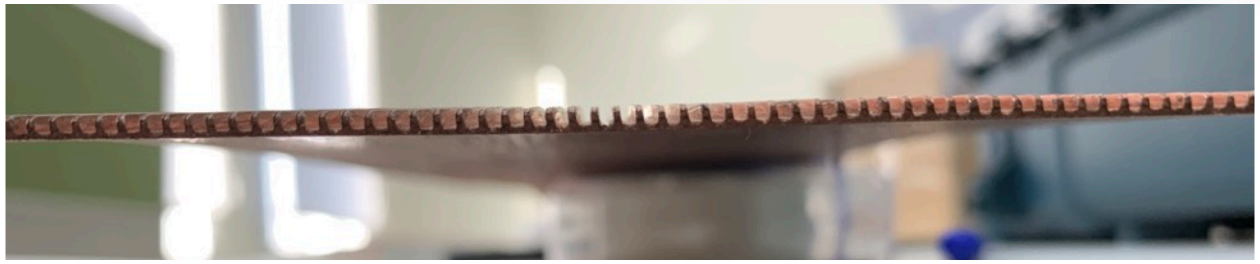
Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

Combination of fibers for Module#2

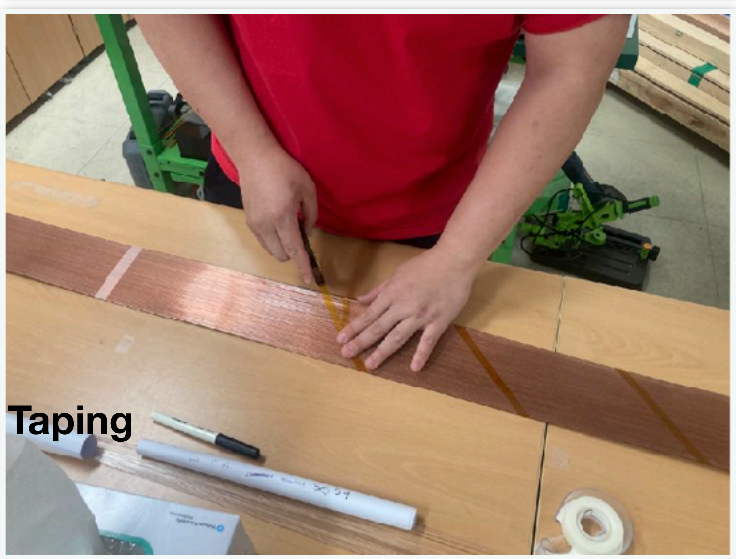
	Tower #1~4 and #6~9	Tower #5
Scintillation fibers	Round / Single cladding	Round / Single cladding
Cherenkov fibers	Round / Single cladding	Round / Single cladding
Readout detector (400+16 ch)	16 PMTs	400 SiPMs

In the G1.03 CHO Guk and G1.04 KIM Dongwoon, details will be presented

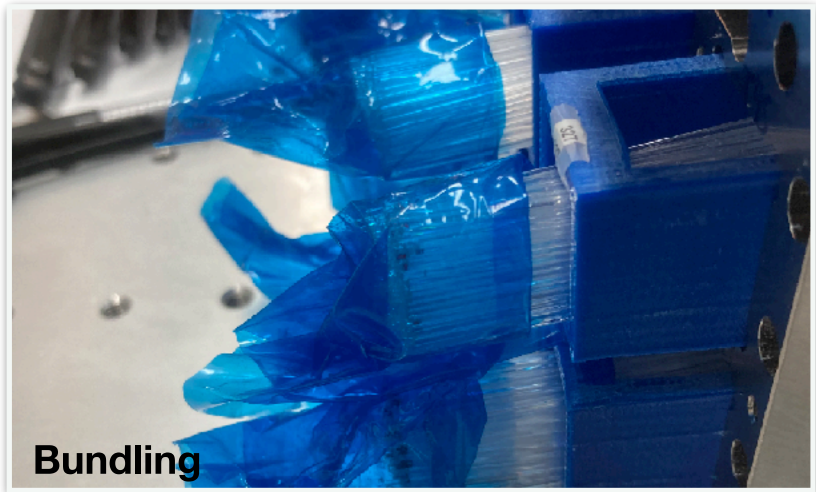
2022 Test Beam (Korea) : 2 Modules

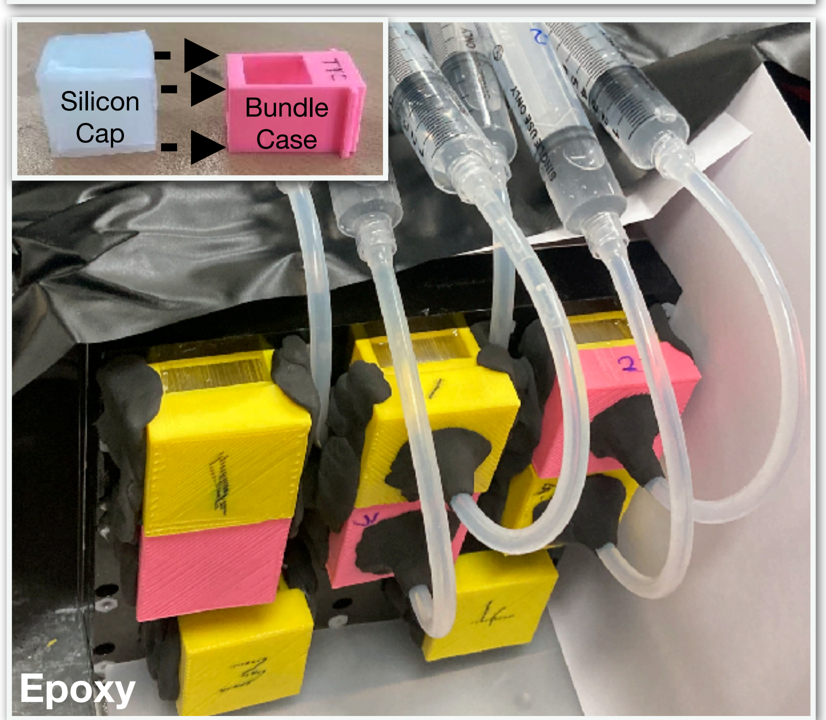


Assembly

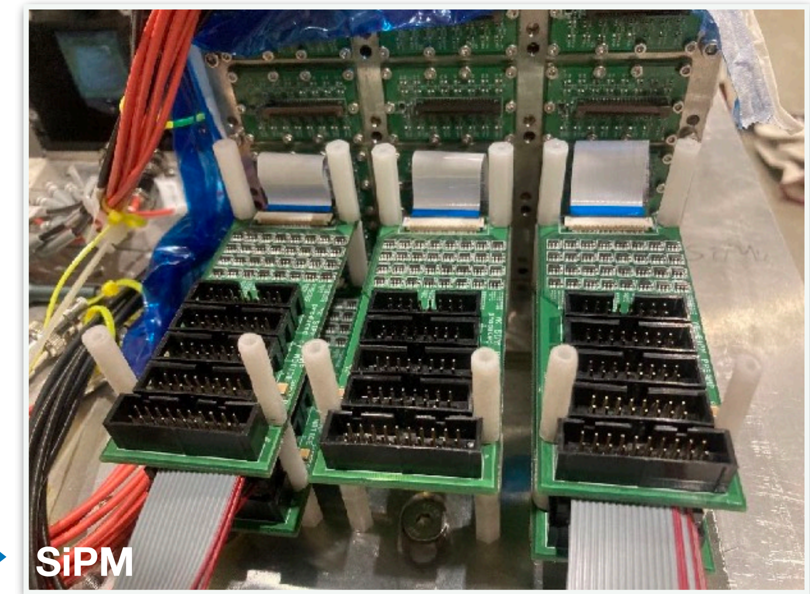


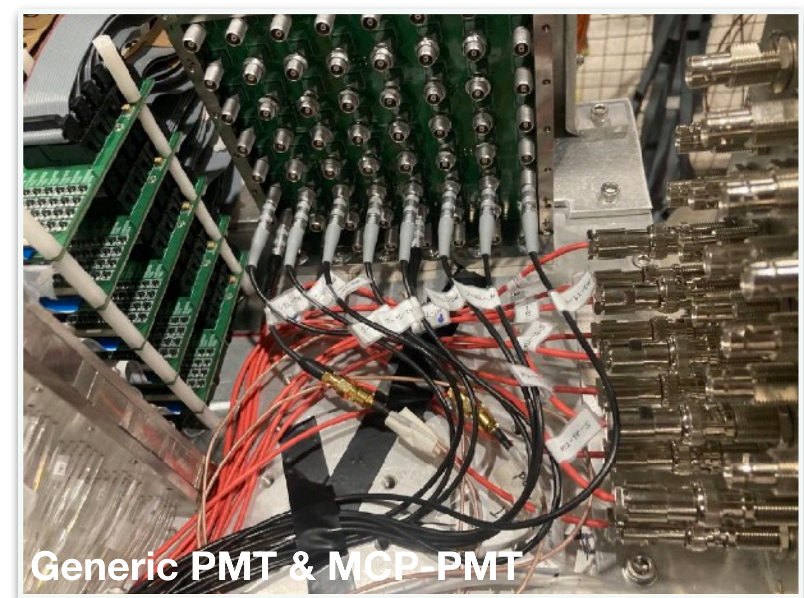
Bundling & Epoxy





PMT Installation & Reflector

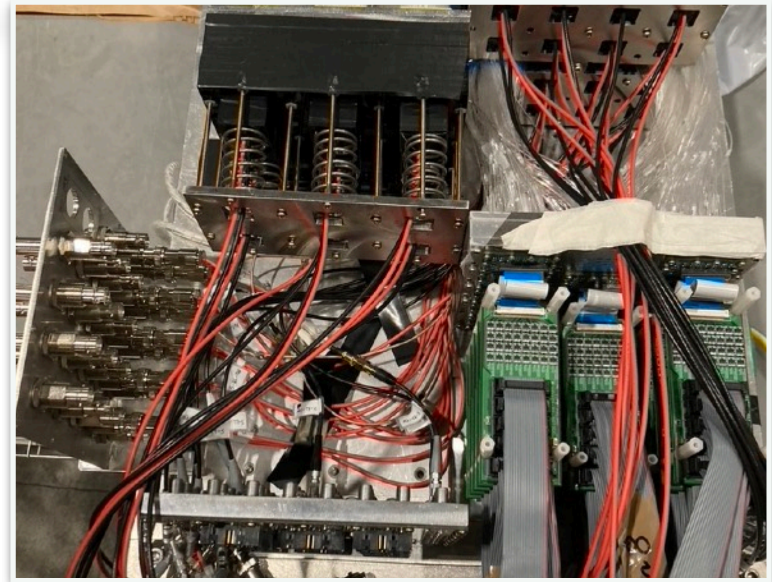


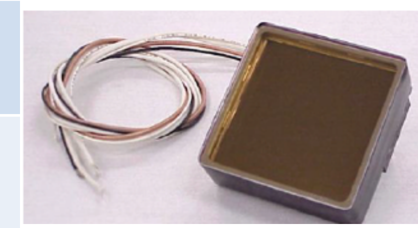


2022 Test Beam (Korea) : Readout System

- Module 1
  - Read out information
    PMT (6ch) + MCP-PMT (2ch)

- Module 2
  - Read out information
    PMT (16ch) + SiPM (416ch, T.5)



MCP-PMT	Window size	light	Quantum Efficinecy (Q.E.)	max. HV (V)	Rise time (ns)	Pulse width (ns)	photo
PLANACON XP85012	53x53 mm²	scintillation	~7% at 550 nm	2400	0.6	1.8	
PLANACON XP85112		Cerenkov	~21% at 400 nm	2800	0.5	0.7	

PMT	Window size	Q.E. for Ck.	Q.E. for Sc.	max. HV (V)	Time response (ns)			photo
					anode pulse rise time	electron transit time	Transit time spread (FWHM)	
R8900 series (old)	23.5x23.5 mm²	35% at 420 nm	~7% at 550 nm	1000	2.2	11.9	0.75	
R11265-100 (new)	**23x23 mm²**	**~35% at 400 nm**	**~7% at 550 nm**		**1.3**	**5.8**	**0.27**	

SiPM	photosensitive area	photo detection efficiency (PDE)		operating voltage	Gain at V_{BD}+5V	Linearity of Q.E.	number of pixels	geo. Fill factor
S14160-1310PS	**1.3x1.3 (1.69 mm²)**	**~15% at 400 nm**	**~17% at 550 nm**	**$V_{breaking\ Down}$ + 5 V**	**~1.75x10^5**	**~2x10^{10}/sec as incident photons**	**16675**	**31 % (0.524 mm²)**
fiber (Φ1 mm)	**0.785 mm²**						**~7745 (effectively)**	

2022 Test Beam (Korea) : DAQ System

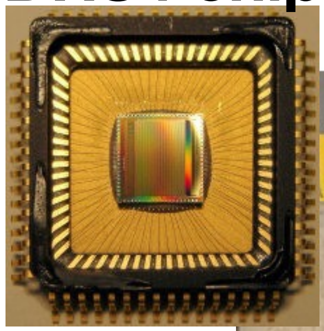
- **DAQ System**
  - 15 DAQ Board + 1 TCB Board

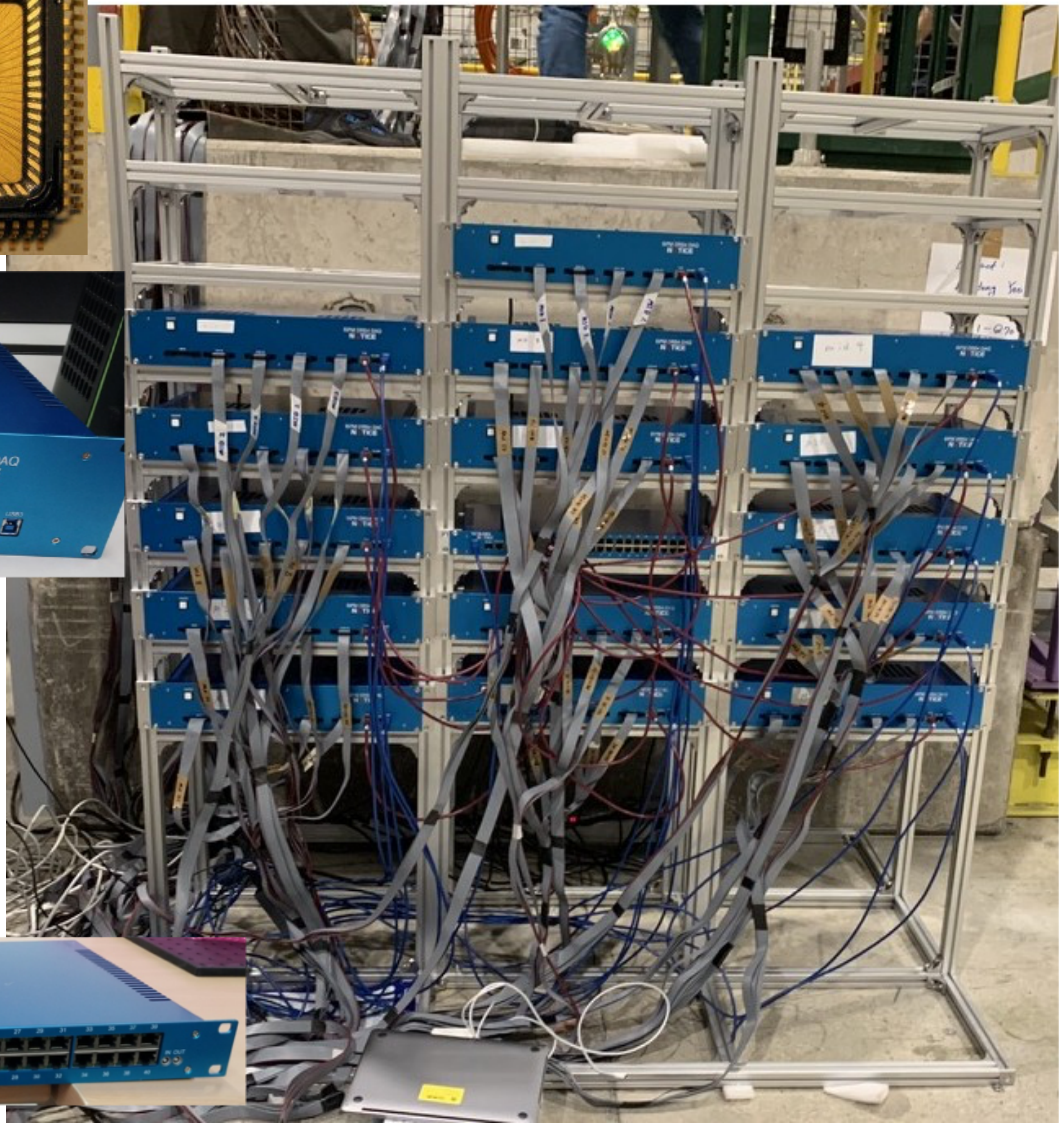
  - DAQ Board
    - One board can cover 32 channels
    - DRS4 chip
    - 16 pin Ribbon cable

  - TCB Board
    - Control the setting value of DAQ boards and the trigger system
    - Connect DAQ boards with TCP/IP cable, cover 40 ch DAQ

  - All boards connected with PC using USB3 line

DRS4 chip



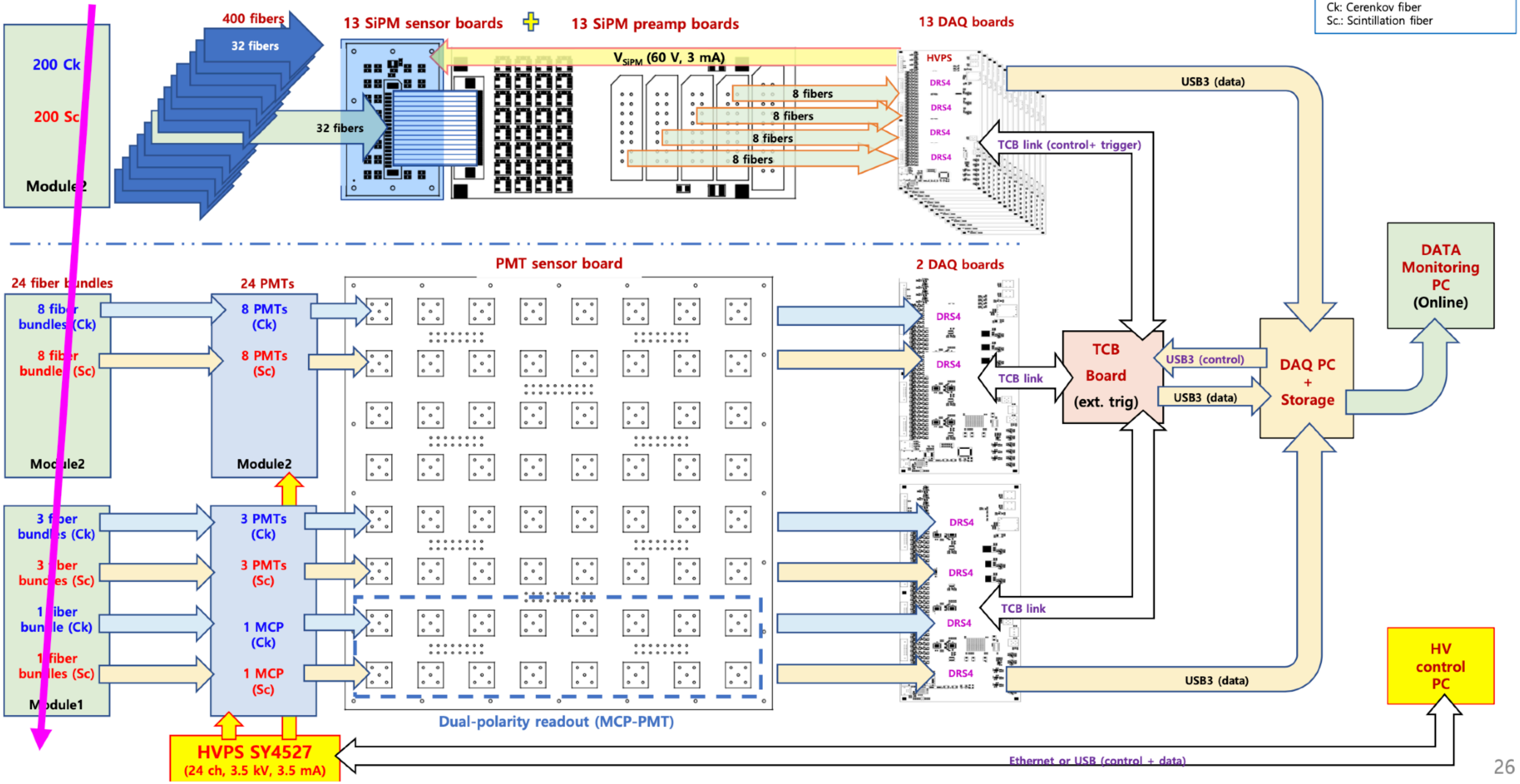


	PMT	MCP-PMT	Auxilary detector	SiPM
channels	22	4	11	400
DAQ	2			13

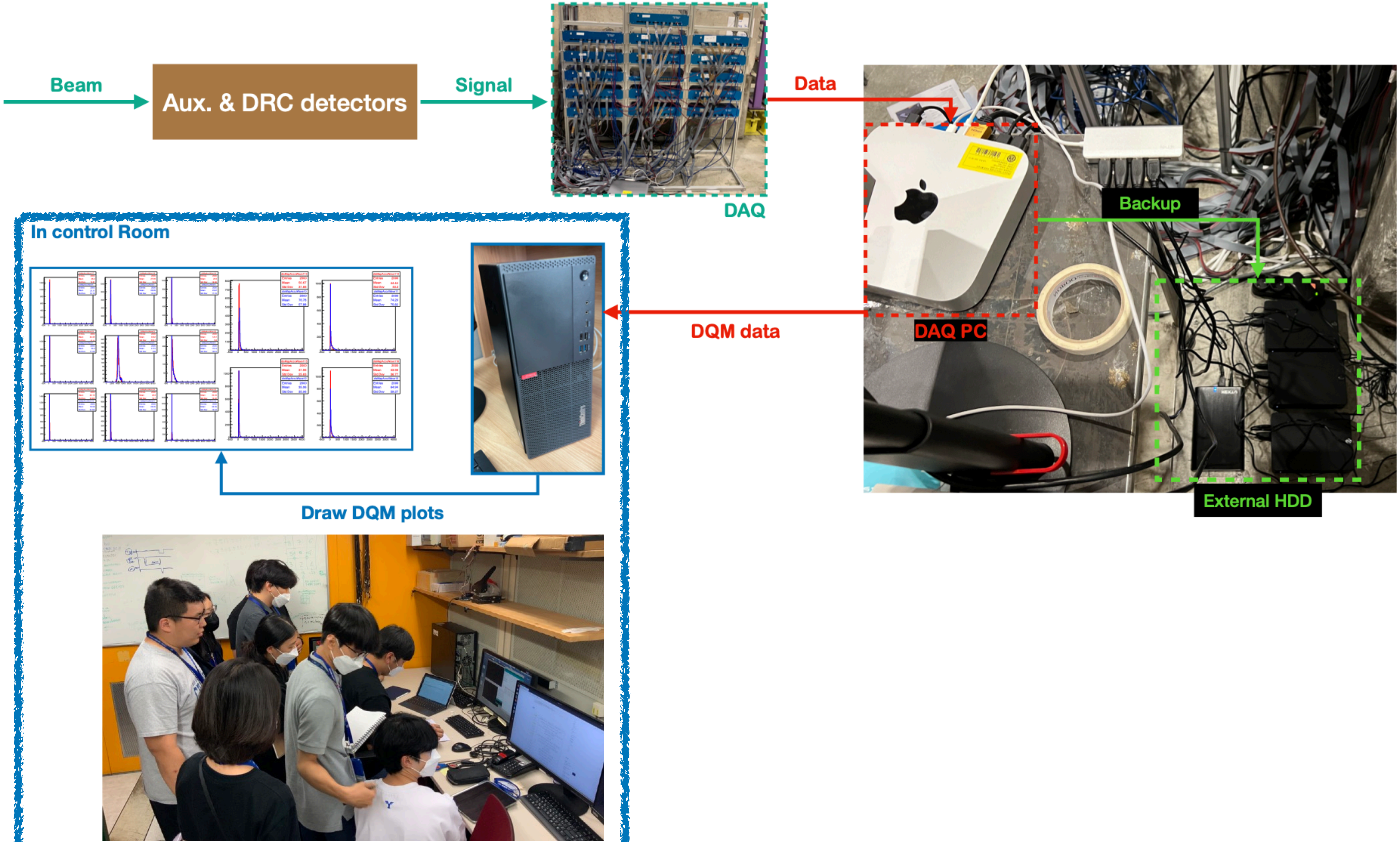
2022 Test Beam (Korea) : DAQ System

DAQ: Full Data Flow

TCB: Task Control Block
USB: Universal Serial Bus
HVPS: High Voltage Power Supply
DRS: Domino Ring Sampler
DAQ: Data Acquisition
Ck: Cerenkov fiber
Sc.: Scintillation fiber

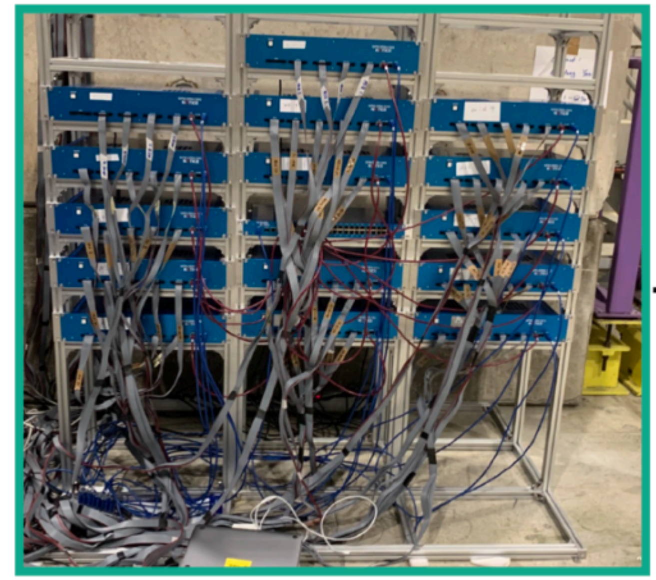


2022 Test Beam (Korea) : DQM System

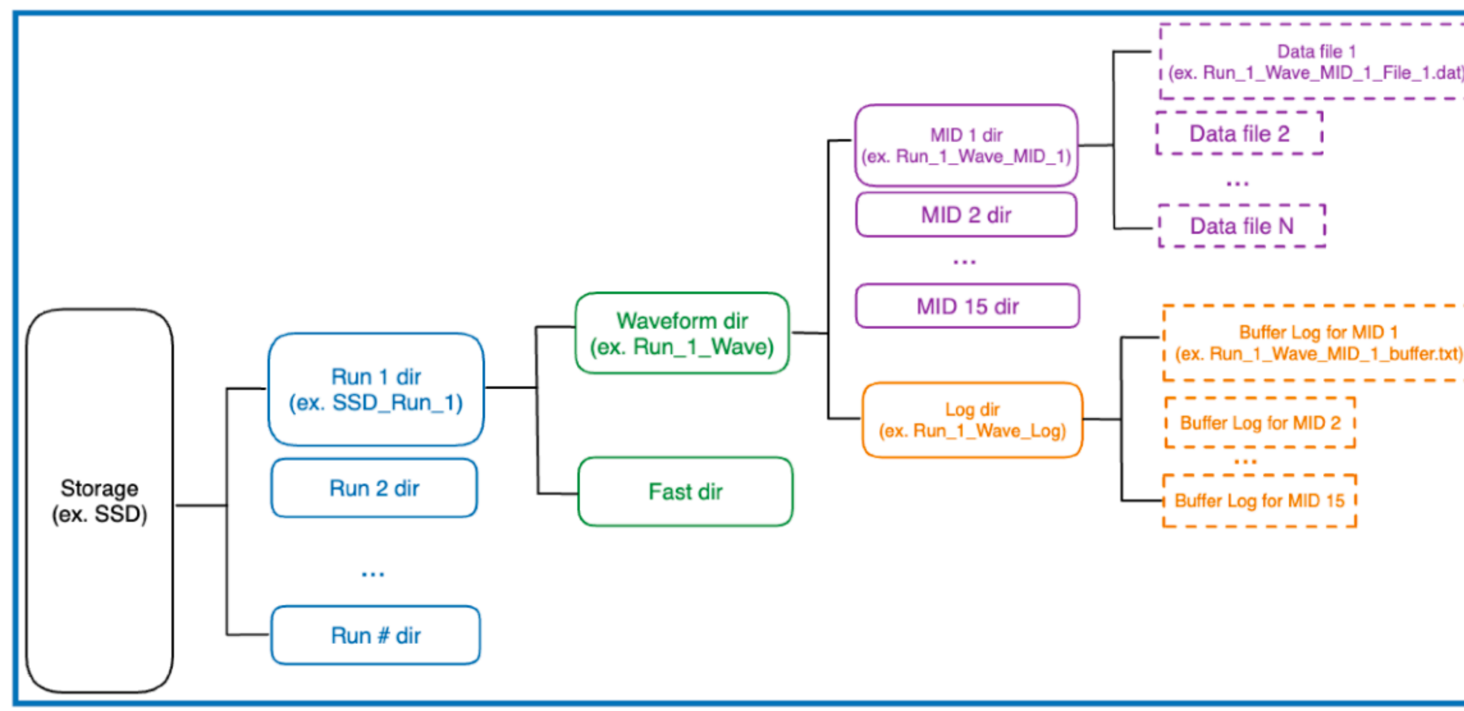


2022 Test Beam (Korea) : DQM System

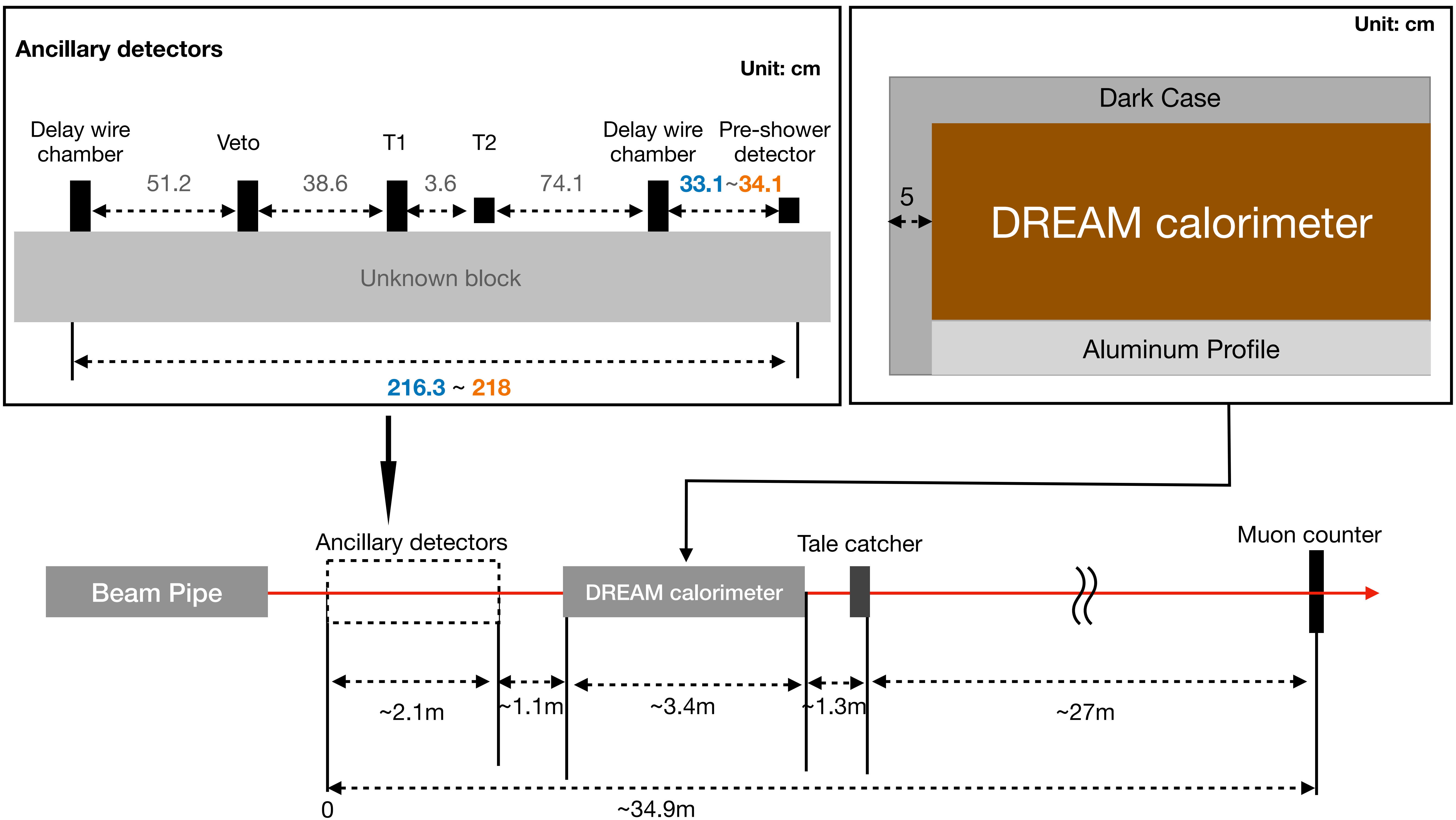
- Each **DAQ** created its own data file, and save it on **DAQ PC**
- Data saved with **fixed directory structure** for efficient data management
- **100k events** stored in **single file**
- **15 files** created for each record (Run)
- Average **beam rate** for 20GeV e+ : **~20 Hz**
- **Data size : ~92GB** per **1.3 hours**



	Wave	Fast	Sum
Size / evt (KB)	64	0.25	**64.25**
Size / 15 files (GB)	91.55	0.36	**91.91**



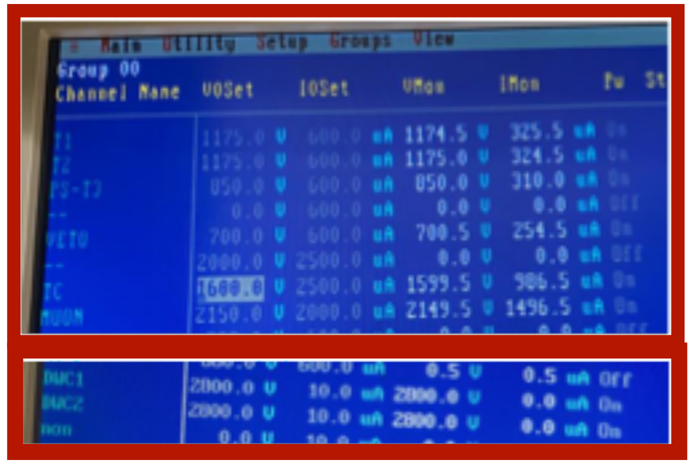
2022 Test Beam (Korea) : Geometry Setup



2022 Test Beam (Korea) : Experimental Setup

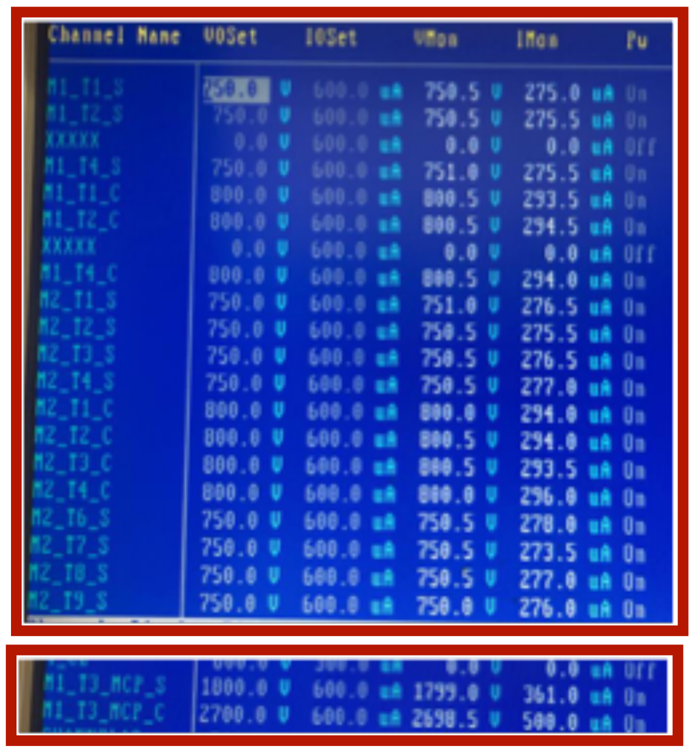
HV System

HV monitor for ancillary detectors



Group 00

Channel Name	V0Set	I0Set	VMon	IMon	Pw
T1	1175.0 V	600.0 uA	1174.5 V	325.5 uA	On
T2	1175.0 V	600.0 uA	1175.0 V	324.5 uA	On
PS-T3	050.0 V	600.0 uA	050.0 V	310.0 uA	On
--	0.0 V	600.0 uA	0.0 V	0.0 uA	Off
VETO	700.0 V	600.0 uA	700.5 V	254.5 uA	On
--	2000.0 V	2500.0 uA	0.0 V	0.0 uA	Off
TC	1600.0 V	2500.0 uA	1599.5 V	906.5 uA	On
MUON	2150.0 V	2000.0 uA	2149.5 V	1496.5 uA	On
DWC1	2800.0 V	10.0 uA	2800.0 V	0.0 uA	On
DWC2	2800.0 V	10.0 uA	2800.0 V	0.0 uA	On

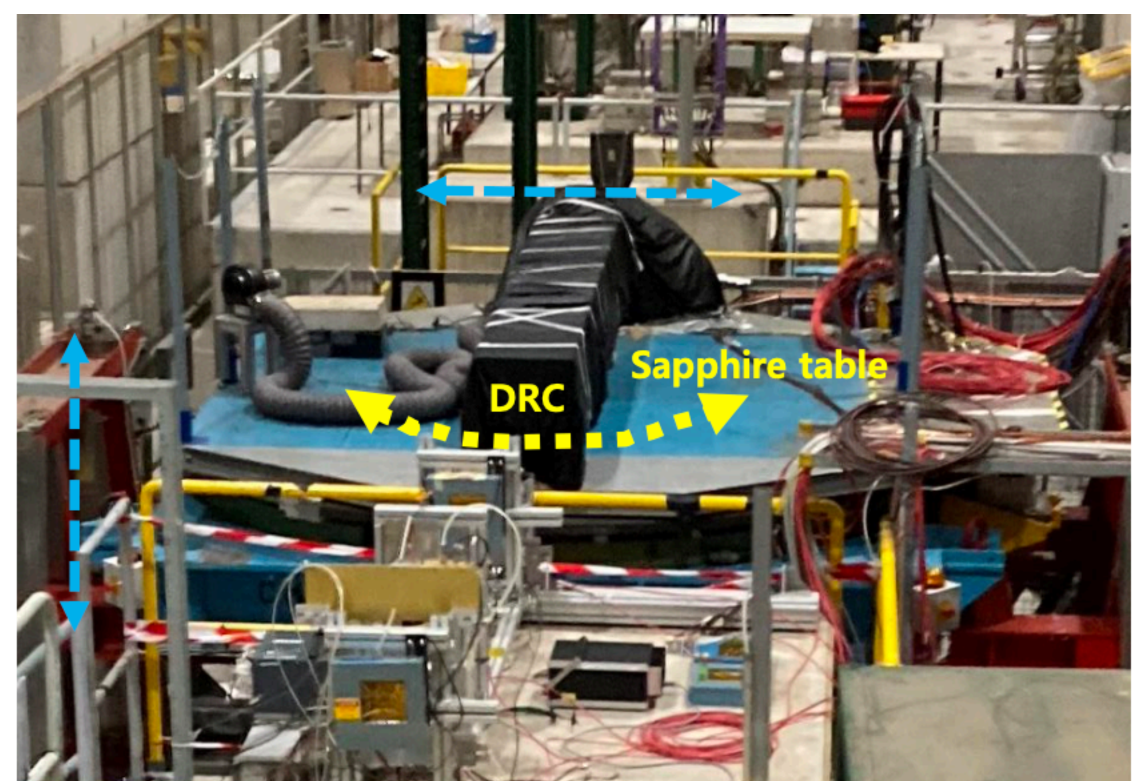


Channel Name	V0Set	I0Set	VMon	IMon	Pw
M1_T1_S	750.0 V	600.0 uA	750.5 V	275.0 uA	On
M1_T2_S	750.0 V	600.0 uA	750.5 V	275.5 uA	On
XXXXX	0.0 V	600.0 uA	0.0 V	0.0 uA	Off
M1_T4_S	750.0 V	600.0 uA	751.0 V	275.5 uA	On
M1_T1_C	800.0 V	600.0 uA	800.5 V	293.5 uA	On
M1_T2_C	800.0 V	600.0 uA	800.5 V	294.5 uA	On
XXXXX	0.0 V	600.0 uA	0.0 V	0.0 uA	Off
M1_T4_C	800.0 V	600.0 uA	800.5 V	294.0 uA	On
M2_T1_S	750.0 V	600.0 uA	751.0 V	276.5 uA	On
M2_T2_S	750.0 V	600.0 uA	750.5 V	275.5 uA	On
M2_T3_S	750.0 V	600.0 uA	750.5 V	276.5 uA	On
M2_T4_S	750.0 V	600.0 uA	750.5 V	277.0 uA	On
M2_T1_C	800.0 V	600.0 uA	800.0 V	294.0 uA	On
M2_T2_C	800.0 V	600.0 uA	800.5 V	294.0 uA	On
M2_T3_C	800.0 V	600.0 uA	800.5 V	293.5 uA	On
M2_T4_C	800.0 V	600.0 uA	800.0 V	296.0 uA	On
M2_T6_S	750.0 V	600.0 uA	750.5 V	278.0 uA	On
M2_T7_S	750.0 V	600.0 uA	750.5 V	273.5 uA	On
M2_T8_S	750.0 V	600.0 uA	750.5 V	277.0 uA	On
M2_T9_S	750.0 V	600.0 uA	750.0 V	276.0 uA	On
M1_T3_MCP_S	1000.0 V	600.0 uA	1799.0 V	361.0 uA	On
M1_T3_MCP_C	2700.0 V	600.0 uA	2698.5 V	500.0 uA	On

CAEN SY1527LC Universal Multichannel Power Supply System

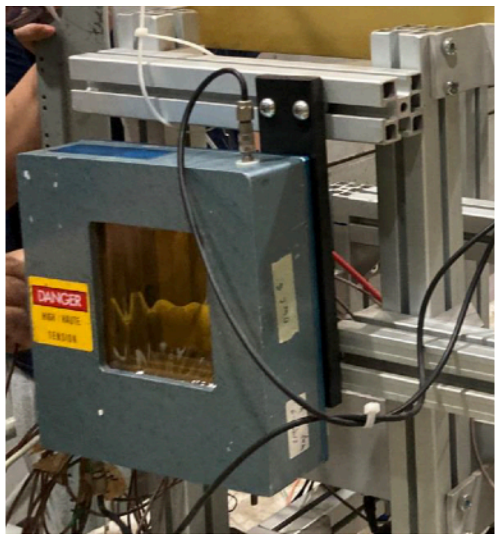
- PSU (A1532, 750 W)
- CPU (A1531, 316 W)
- HV board (A1535SN, 24 ch., -3.5 kV, 3 mA, 8 W/ch.)

Movement System

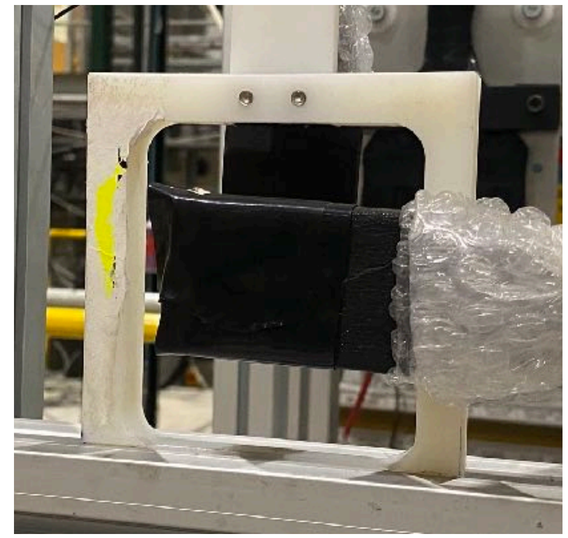


2022 Test Beam (Korea) : Ancillary Setup

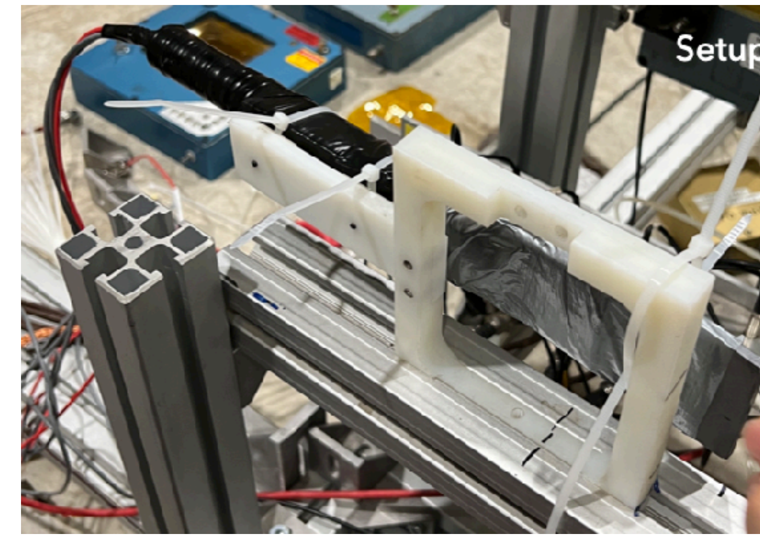
- **Delay wire chamber: x,y position measurement**

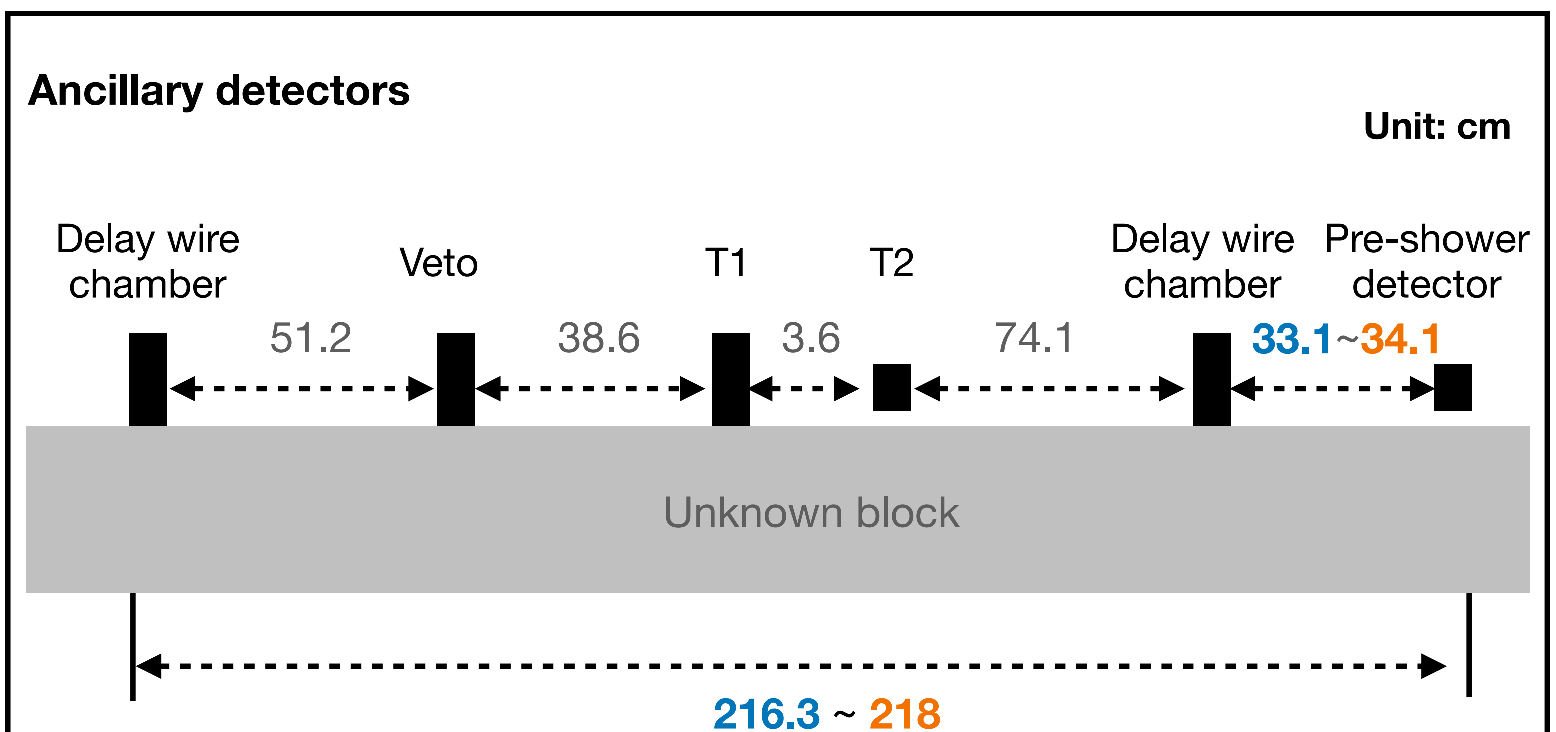


- **T1T2+veto: trigger**

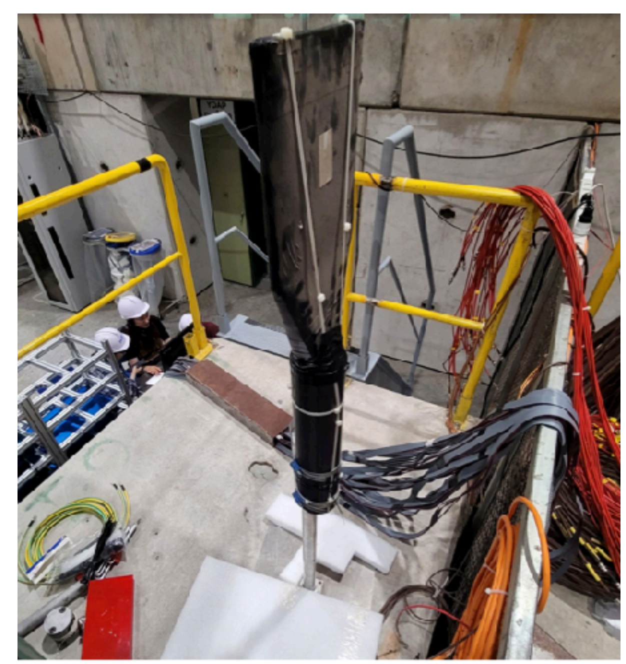


- **Pre-shower detector: for obtaining various types of particles by shower**





- **Tale catcher: to detect particles that are through the DRC**



- **Muon counter: to detect muon**

2022 Test Beam (Korea) : Programs

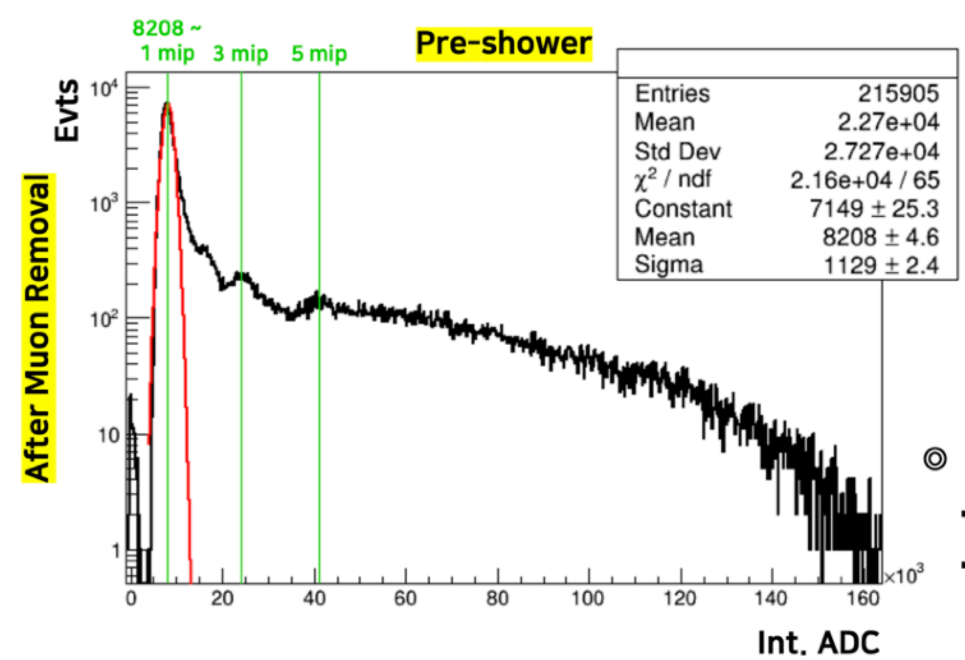
Aim	Module	Description
Finding towers (scanning tower position)	M1, M2	- Using positron beam (20 GeV) - 1cm vertical & horizontal scan - Find boundary of tower!
Gain tests	M1, M2	- Check signal level w.r.t. HV
Calibration	M1, M2	- Using 20 GeV positrons, equalized the responses of the scintillation and Cerenkov channels
Resolution	M2	- Energy resolution (6, 10, 20, 30, 40, 60, 80, 100 GeV positrons) - Position resolution (6, 10, 20, 30, 40, 60, 80, 100 GeV positrons) - Time resolution using SiPM channels (Module 2) and tower equipped with MCP-PMT (Module 1)
3D shower reconstruction	M2	- Using muons and pions steered to the tower equipped with 400 SiPM
Cerenkov channel response	M1	- Using position 20 GeV, rotating & moving module
Longitudinal shower profile	M1	- Using position 20 GeV, variated lead blocks (variation of radiation length)

2022 Test Beam (Korea) : Runs & Results

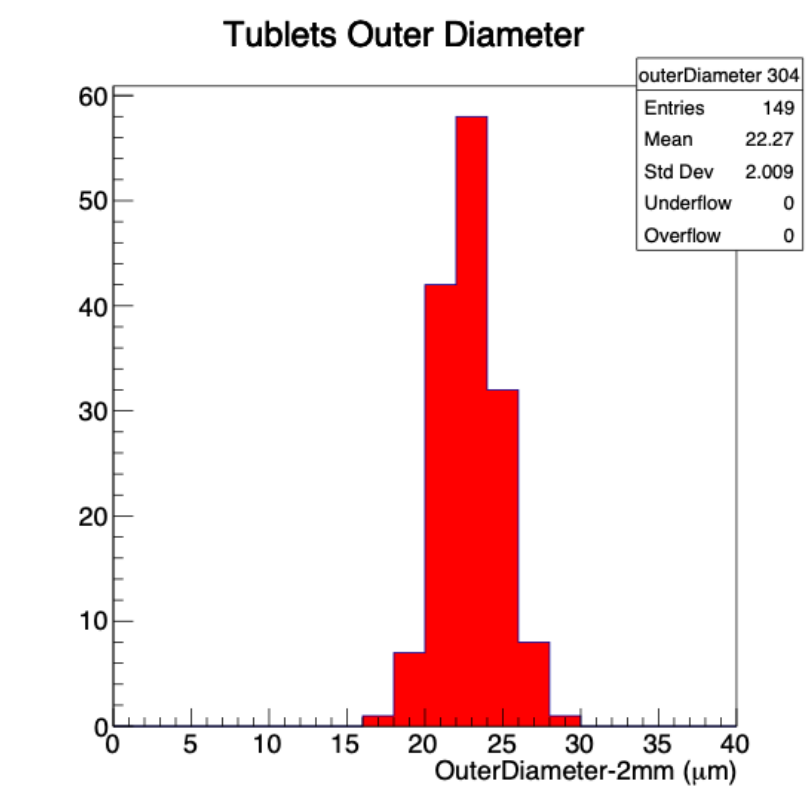
- During the test beam, we took data 84hours, and ~23M events were taken as fast mode and 4.6M events as waveform mode!

Total wave	Total Fast	Total Time (min)	Total Time (hour)
4,657,849	23,248,704	5,046	84

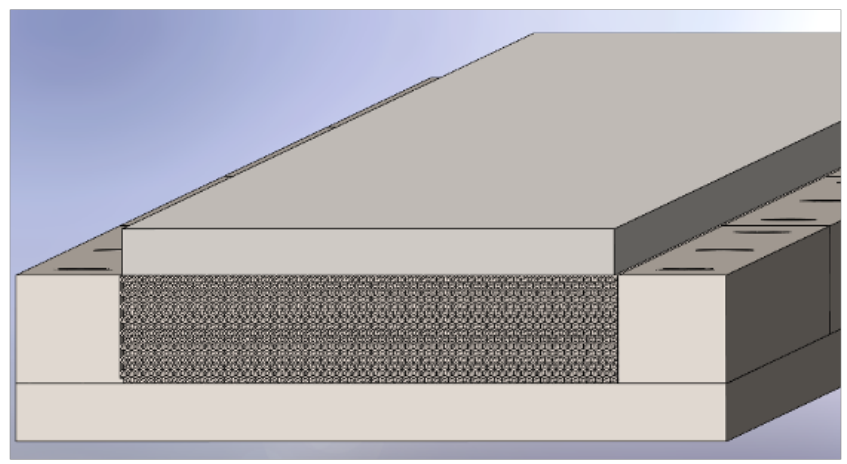
- The biggest data set is used for prompt analysis
  - To do PID, we used auxiliary detector
    - DWC : Selection on beam position and angle
    - Muon counter : Selection on muon signal
    - Pre-shower : Discrimination on b.g. vs electrons



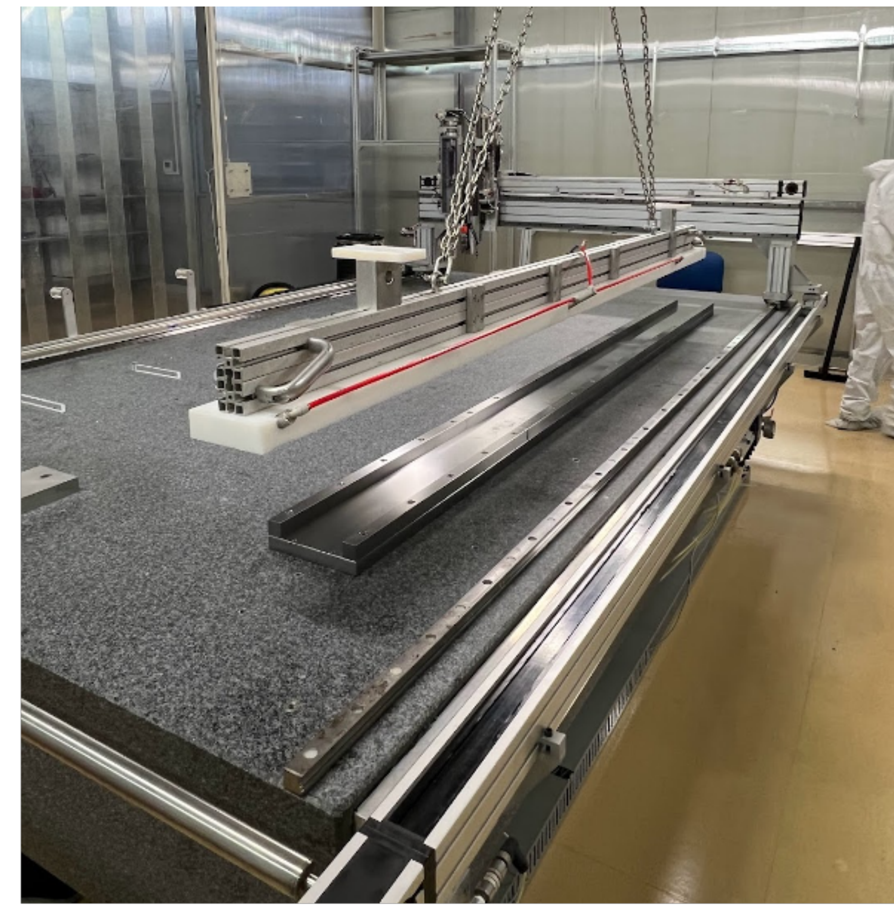
R&D : HiDRa (Construction)



Quality of capillary is very good
This allow for simplified construction tool



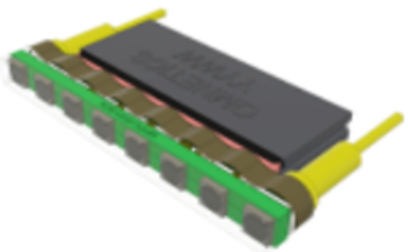
building-block: double mini-module (64x16 channels, 2.5 m long)

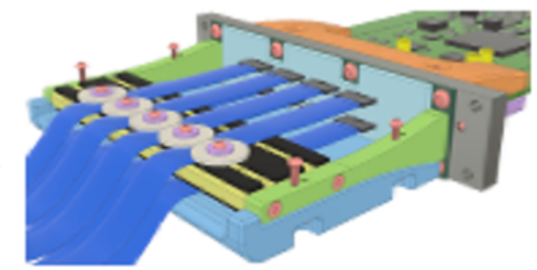


Assembly system and capillary handling tools install in the clean room (assembly facility)

R&D : HiDRa
(SiPM readout – a scalable solution)

The front-end board



8 front-end boards connected to 1 FERS

- Each SiPM is individually qualified: crucial for the system commissioning

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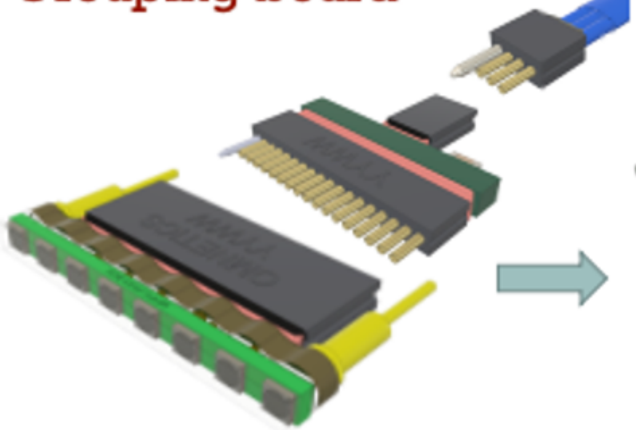
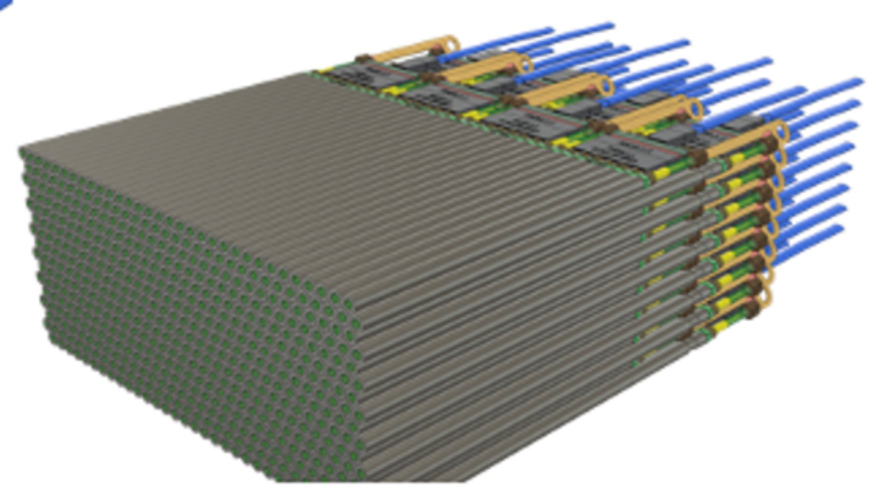
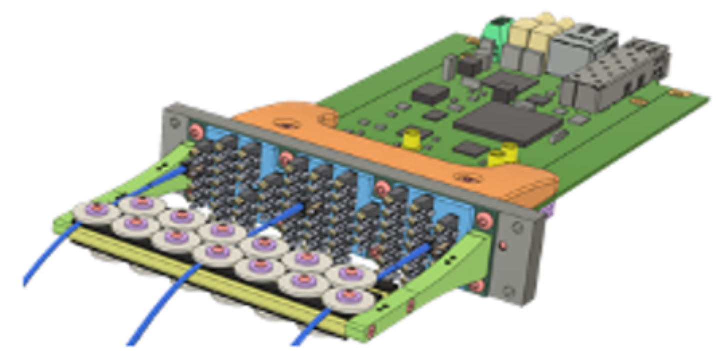
Grouping board



The Mini-Module

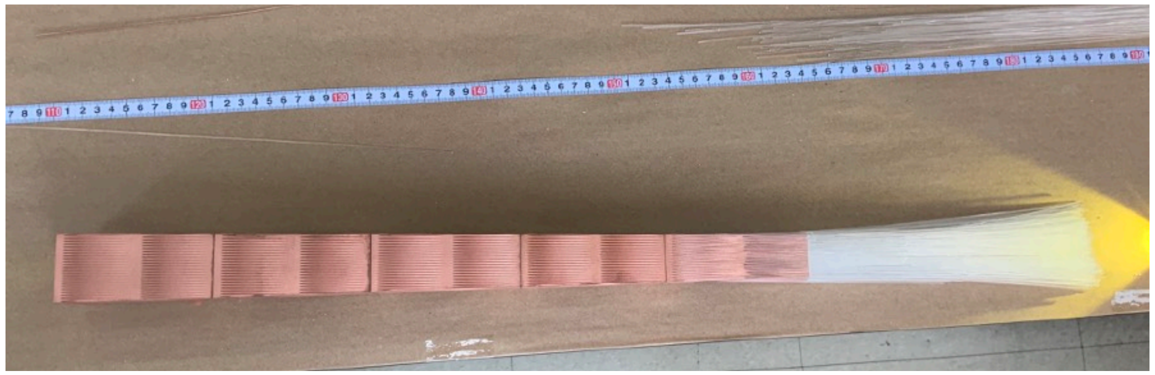



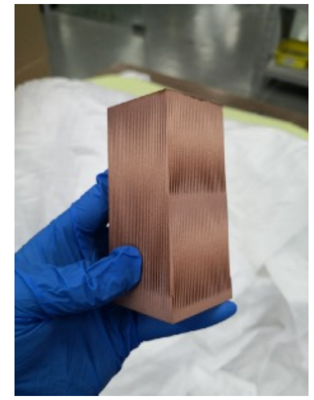
1 FERS serves 64 front-end boards with grouping

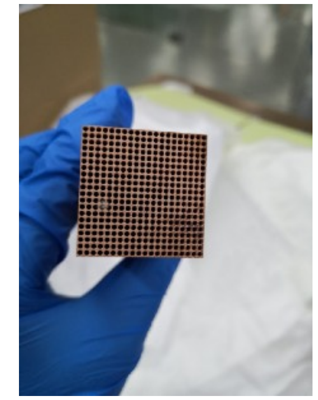
- Each bar of SiPMs will be operated at the same voltage (ΔV_{bd}<0.15V)
- The signals from 8 SiPMs are summed up in the grouping board

R&D : Cu Forming

- **3D printing**

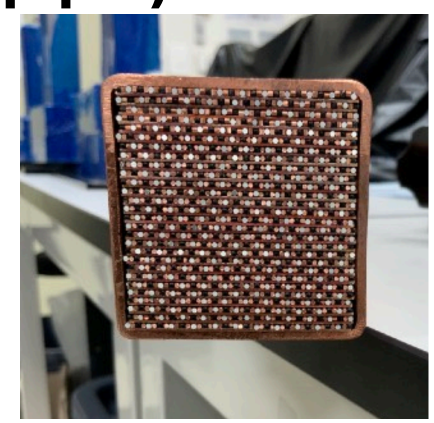






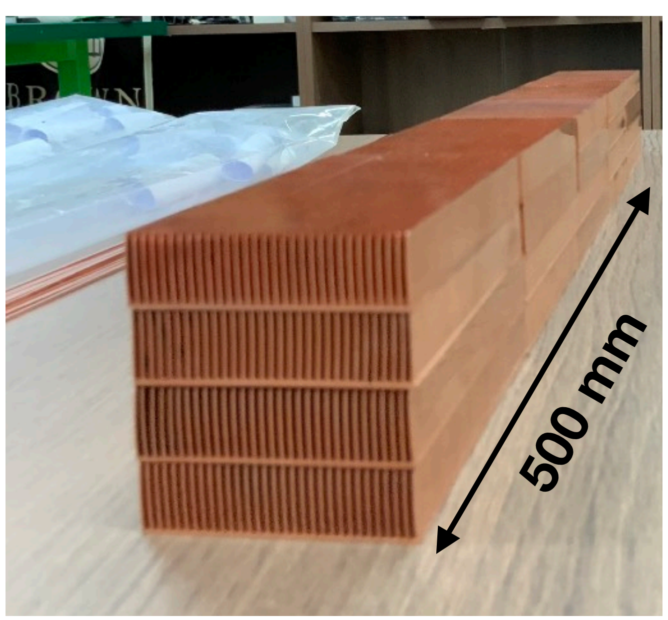
It has very perfect accuracy, but the cost is very high

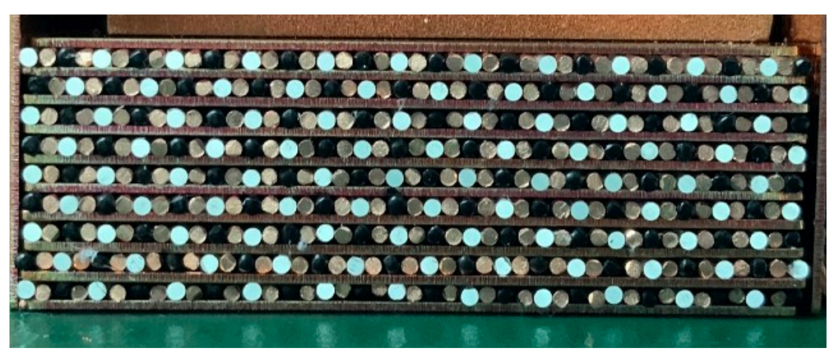
- **LEGO-like (Copper pipe)**

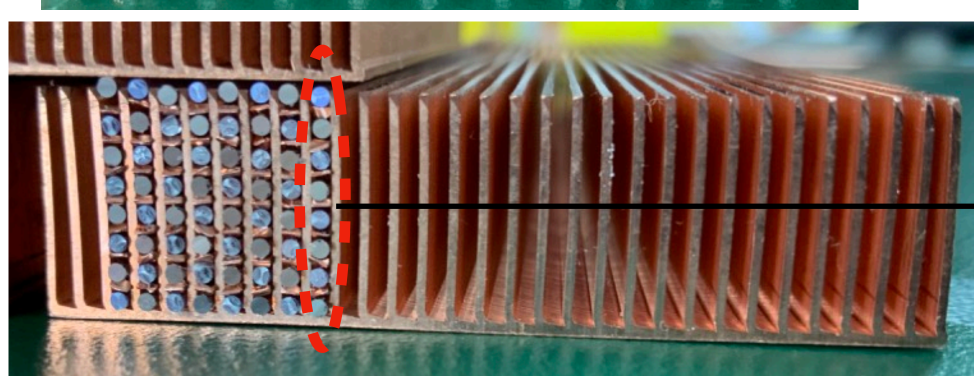


It has very good accuracy, and pretty low cost

- **SF Heatsink**







It has very excellent accuracy, and cost is low

Possibility for mass production!

Summary

- Dual-readout calorimeter R&D are very active!

- Two different types of DRC were tested
  - Bucatini type is tested (2021 DESY & CERN)
    - Excellent lateral shower shape development measurements
    - allowed to validate construction method and SiPM readout (scaling up in the number of channels)
  - Plated based two modules (Korea) have test beam 2022
    - Analysis using TB data is on going

- Please Stay tune our activities !!!

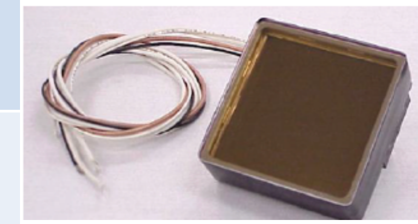
Backup

Test Beam

- Duration : Aug. 4th ~ 24th
- Location : CERN North area
- Schedule of test beam

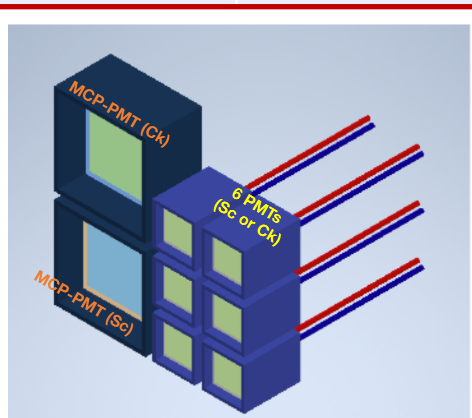
Date	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug		
Module	Building Module (fiber+Cu)		Attach readout			Test Commissioning	Packing/ Shipping	Install @ CERN(H8)	-	
DAQ	Test Mutichannel operation						Packing/ Shipping	Install @ CERN(H8)	-	
Test beam							Packing/ Shipping	8/3 ~ install	Preparation & commissioning @ cern (~8.16)	Taking test beam (8.17~8.24)

Readout Detectors

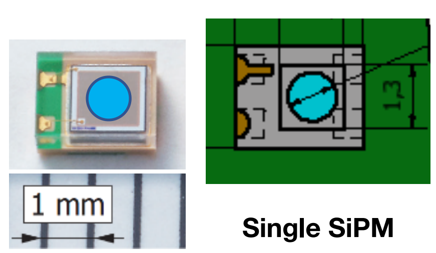
MCP-PMT	Window size	light	Quantum Efficiency (Q.E.)	max. HV (V)	Rise time (ns)	Pulse width (ns)	photo
PLANACON XP85012	53x53 mm^2	scintillation	~7% at 550 nm	2400	0.6	1.8	
PLANACON XP85112		Cerenkov	~21% at 400 nm	2800	0.5	0.7	

PMT	Window size	Q.E. for Ck.	Q.E. for Sc.	max. HV (V)	Time response (ns)			photo
					anode pulse rise time	electron transit time	Transit time spread (FWHM)	
R8900 series (old)	23.5x23.5 mm^2	35% at 420 nm	~7% at 550 nm	1000	2.2	11.9	0.75	
R11265-100 (new)	**23x23 mm^2**	**~35% at 400 nm**	**~7% at 550 nm**		**1.3**	**5.8**	**0.27**	

SiPM	photosensitive area	photo detection efficiency (PDE)		operating voltage	Gain at V_{BD}+5V	Linearity of Q.E.	number of pixels	geo. Fill factor
S14160-1310PS	1.3x1.3 (1.69 mm^2)	~15% at 400 nm	~17% at 550 nm	$V_{breaking\ Down}$ + 5 V	~1.75x10^5	~2x10^{10}/sec as incident photons	16675	31 % (0.524 mm^2)
fiber (Φ1 mm)	0.785 mm^2						~7745 (effectively)	

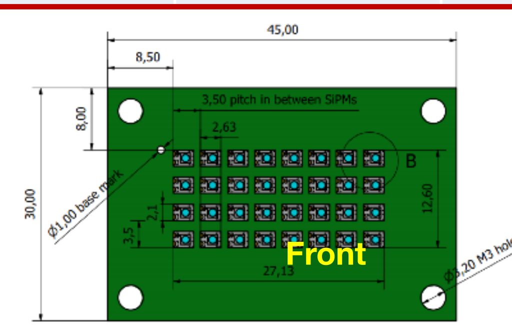


Design
in real size (Module 1)

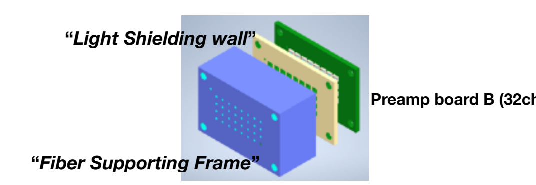


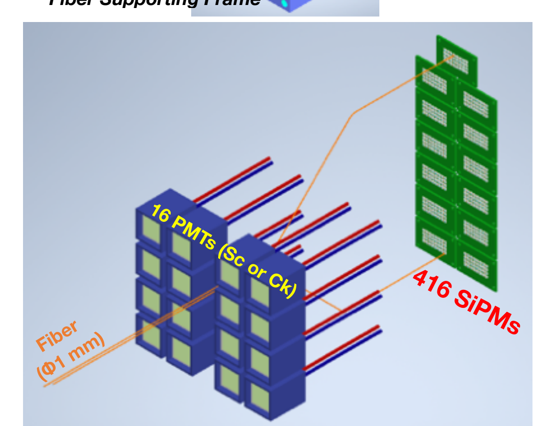
Single SiPM

Design
in real size (Module 2)



Preamp board B (32 ch)





Programs

- **Beam Information**
  - positron beam : 6, 10, 20, 30, 40, 60, 80, 100, and 125 GeV
  - pion beam : 20, 60, 80, 180 GeV

- **Detailed TB Programs**

  - Finding tower (scanning tower)

  - Gain tests

  - Calibration

  - Resolution

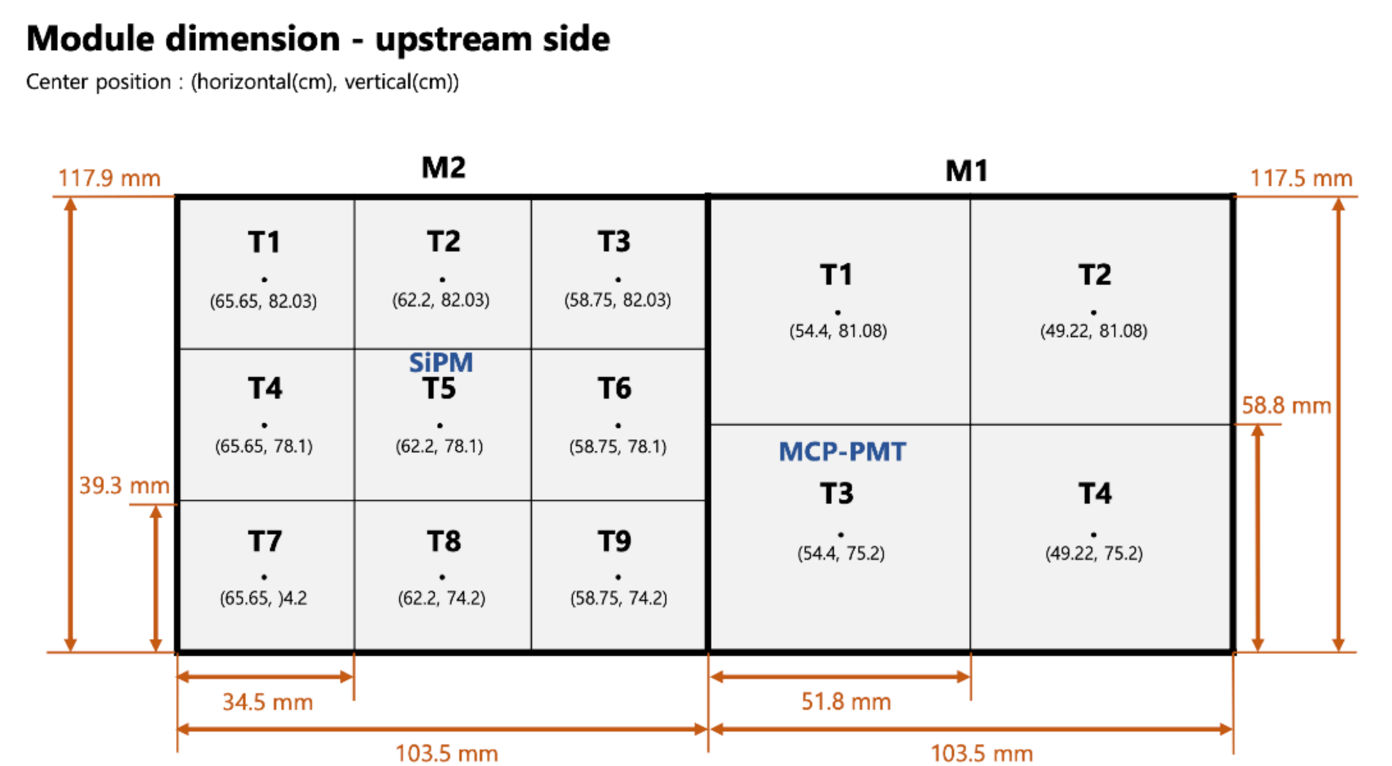
  - 3D reconstruction (Pion)

  - Cherenkov channel response

  - Longitudinal Shower profile

  - 3D printing module

Finding tower (scanning tower)
- Using positron beam (20 GeV)
- 1cm vertical & horizontal scan
- Find boundary of tower!



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- Using positron beam (20 GeV)
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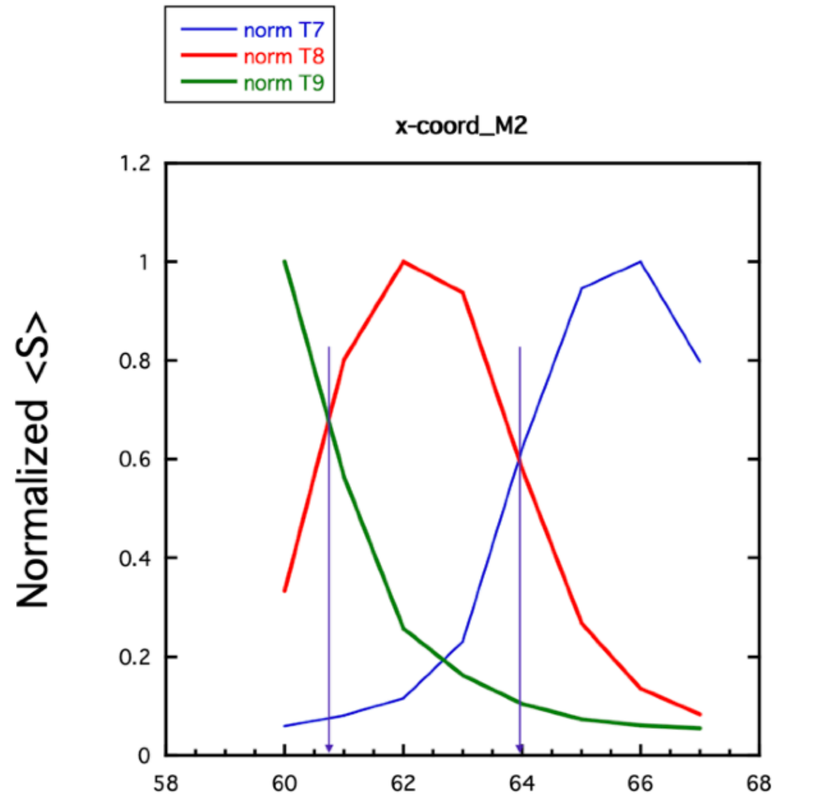
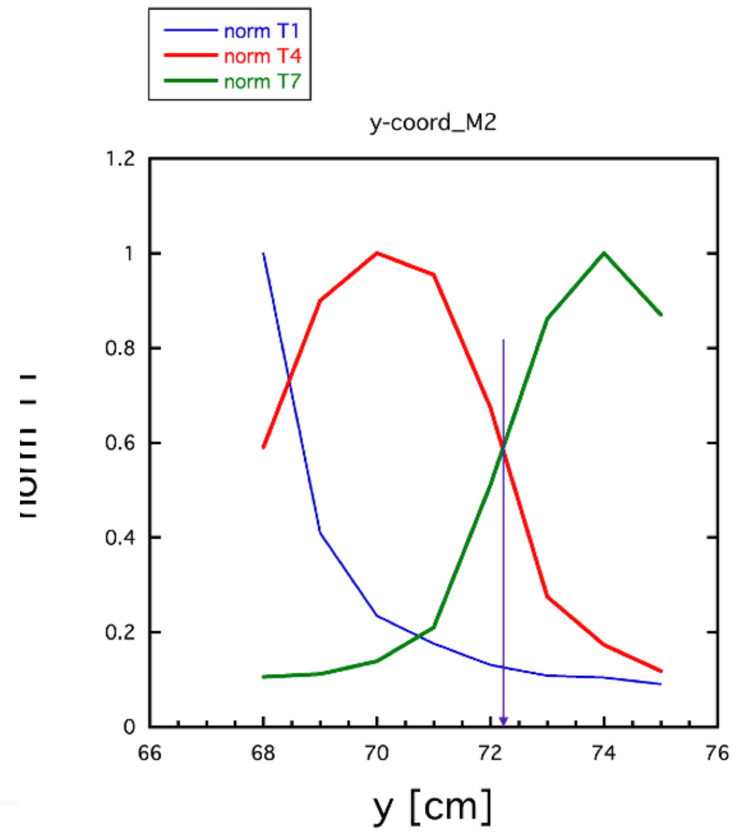


X-axis



Y-axis

Programs

- **Beam Information**
  - positron beam : 6, 10, 20, 30, 40, 60, 80, 100, and 125 GeV
  - pion beam : 20, 60, 80, 180 GeV

- **Detailed TB Programs**

  - Finding tower (scanning tower)

  - Gain tests

  - Calibration

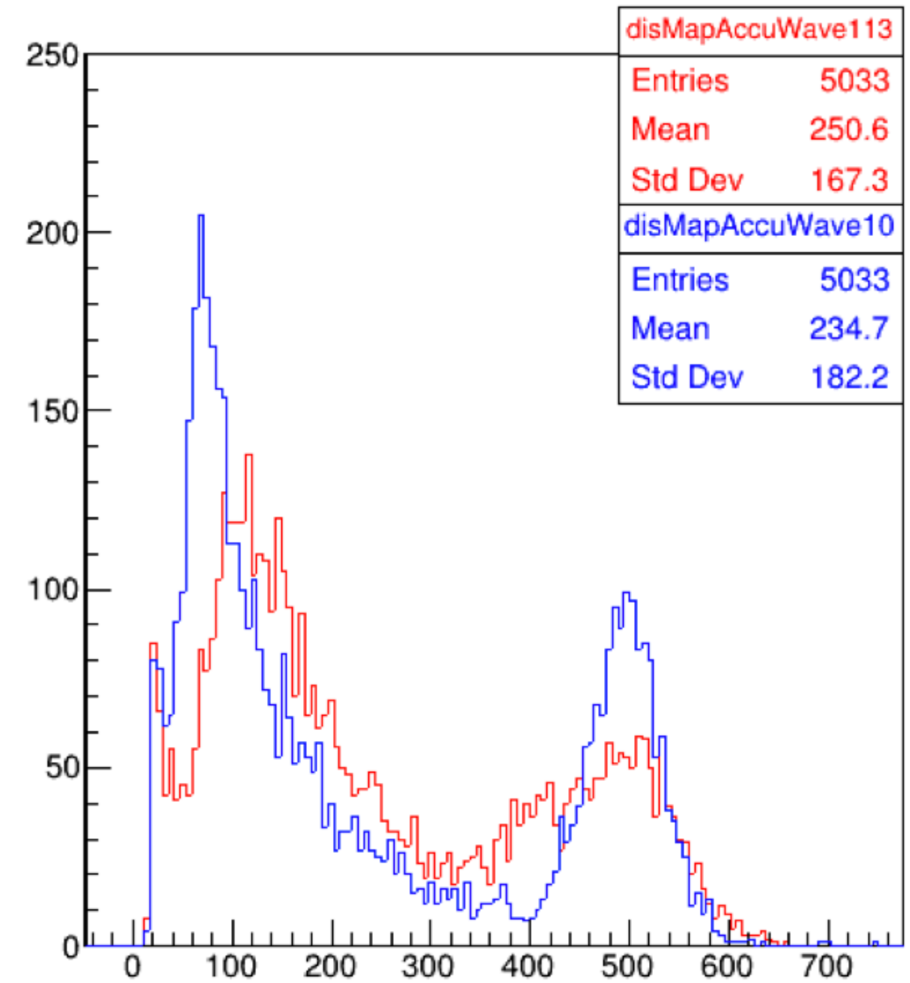
  - Resolution

  - Cherenkov channel response

  - Longitudinal Shower profile

  - 3D printing module

- Using positron beam (20 GeV)
- Check up the signals w.r.t. HV (50V interval)



Programs

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  - positron beam : 6, 10, 20, 30, 40, 60, 80, 100, and 125 GeV
  - pion beam : 20, 60, 80, 180 GeV

- **Detailed TB Programs**

  - Finding tower (scanning tower)

  - Gain tests

  - Calibration

  - Resolution

  - Cherenkov channel response

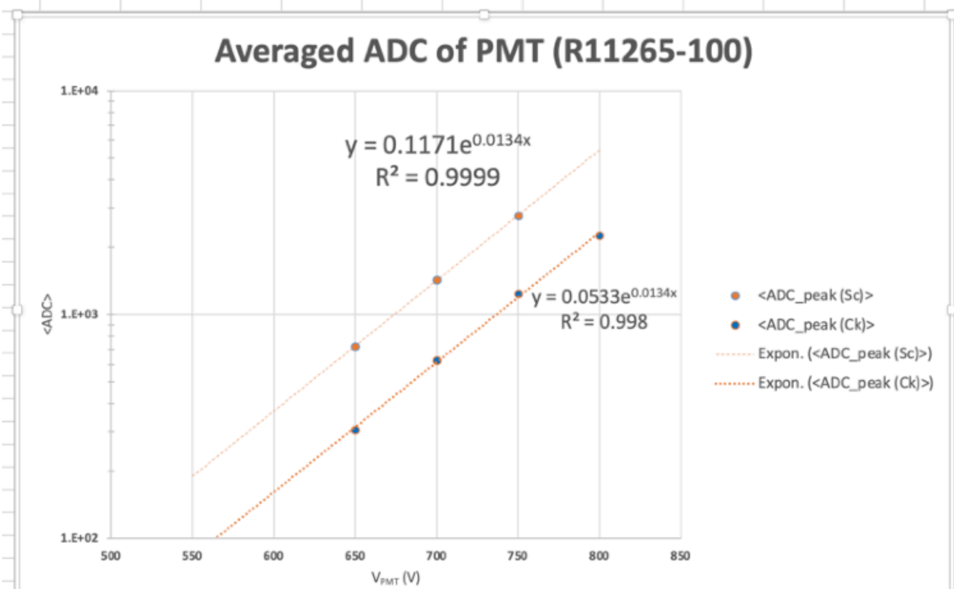
  - Longitudinal Shower profile

  - 3D printing module

- Using positron beam (20 GeV)
- Check up the signals w.r.t. HV (50V interval)

Ex) module 2 & tower 4

module2 - tower4		
V_PMT (V)	<ADC_peak (Sc)>	<ADC_peak (Ck)>
550		
600		
650	722	305.9
700	1427	625.5
750	2766	1239
800		2256



Programs

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  - pion beam : 20, 60, 80, 180 GeV

- **Detailed TB Programs**

  - Finding tower (scanning tower)

  - Gain tests

  - Calibration

  - Resolution

  - Cherenkov channel response

  - Longitudinal Shower profile

  - 3D printing module

Calibration HV (at 500 ADC)

		voltage [V]		current [uA]	
		S	C	S	C
M1	T1	654	629	240	231
	T2	633	650	232.5	239.5
	T3 (MCP)	1808	2680	363	494.5
	T4	676	688	248.5	243
M2	T1	619	715	228	262.5
	T2	669	682	246	250.5
	T3	609	672	225	246.5
	T4	624	684	230.5	253.5
	T5 (SiPM)				
	T6	683	653	253.5	240
	T7	664	664	242	244.5
	T8	614	667	227.5	248
	T9	669	674	246	248

Programs

- **Beam Information**
  - positron beam : 6, 10, 20, 30, 40, 60, 80, 100, and 125 GeV
  - pion beam : 20, 60, 80, 180 GeV

- **Detailed TB Programs**

  - Finding tower (scanning tower)

  - Gain tests

  - Calibration

  - Resolution

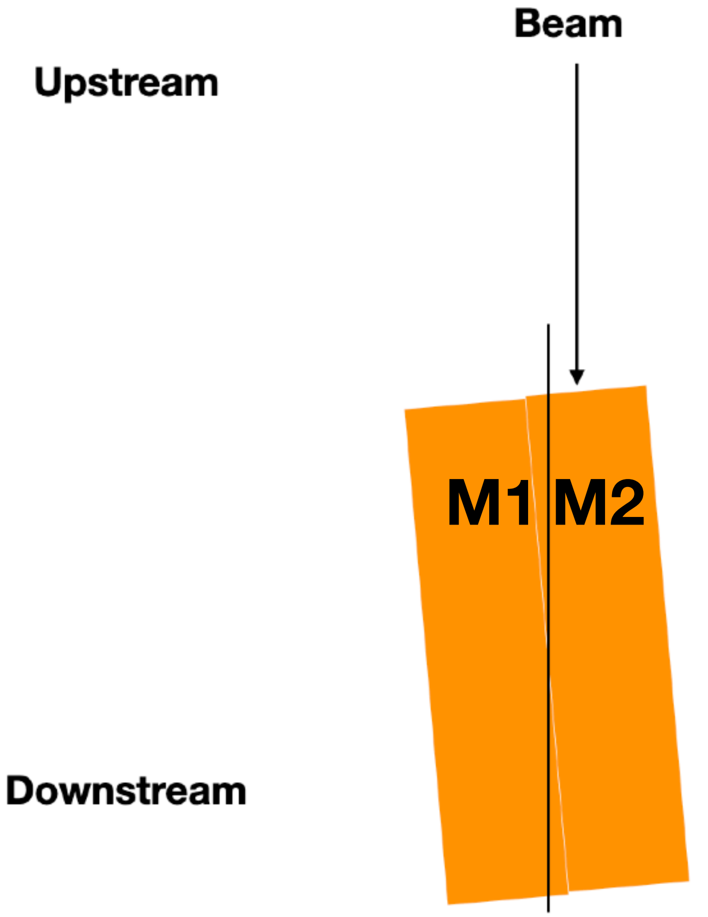
  - 3D reconstruction (Pion)

  - Cherenkov channel response

  - Longitudinal Shower profile

  - 3D printing module

- **Rated module to measure resultion (energy, position)**
  - rotated 1.5 degree (r*sin(1.5) ~ 4.2 cm)
  - electron (positron) beam



Programs

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  - positron beam : 6, 10, 20, 30, 40, 60, 80, 100, and 125 GeV
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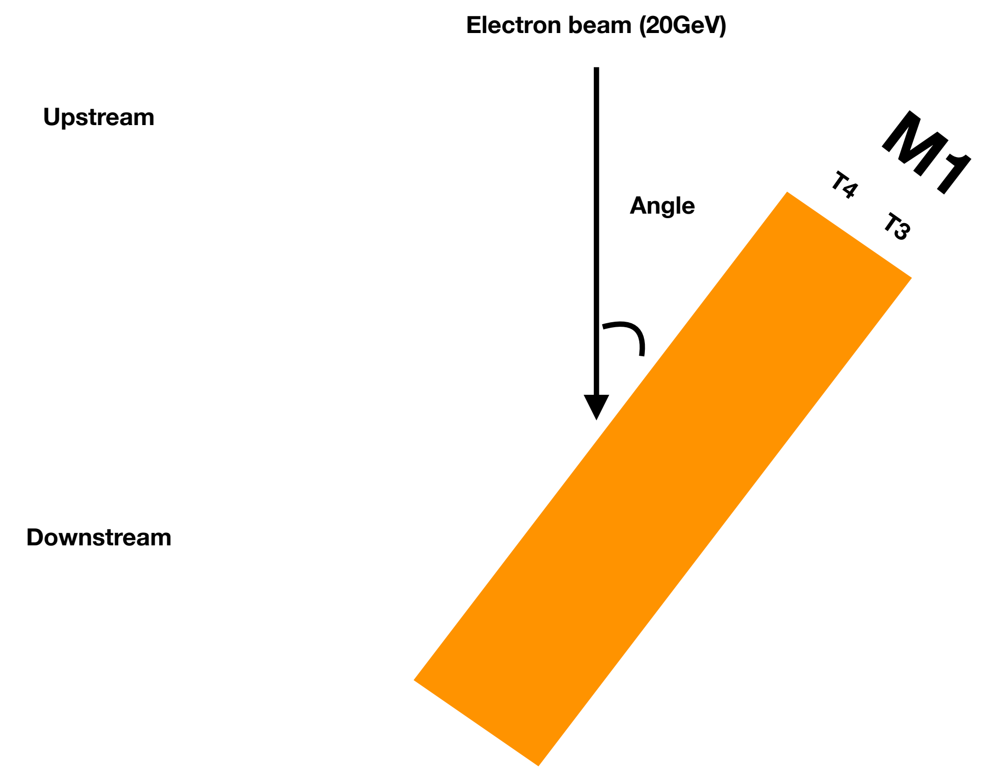
  - Longitudinal Shower profile

  - 3D printing module



Angle (degree)	36	30	25	20	15	10	5
Horizontal (cm)	53.4	53.7	53.9	54.1	54.4	54.5	54.8
Target events	30k	30k	30k	30k	30k	30k	30k

Programs

- **Beam Information**
  - positron beam : 6, 10, 20, 30, 40, 60, 80, 100, and 125 GeV
  - pion beam : 20, 60, 80, 180 GeV

- **Detailed TB Programs**

  - Finding tower (scanning tower)

  - Gain tests

  - Calibration

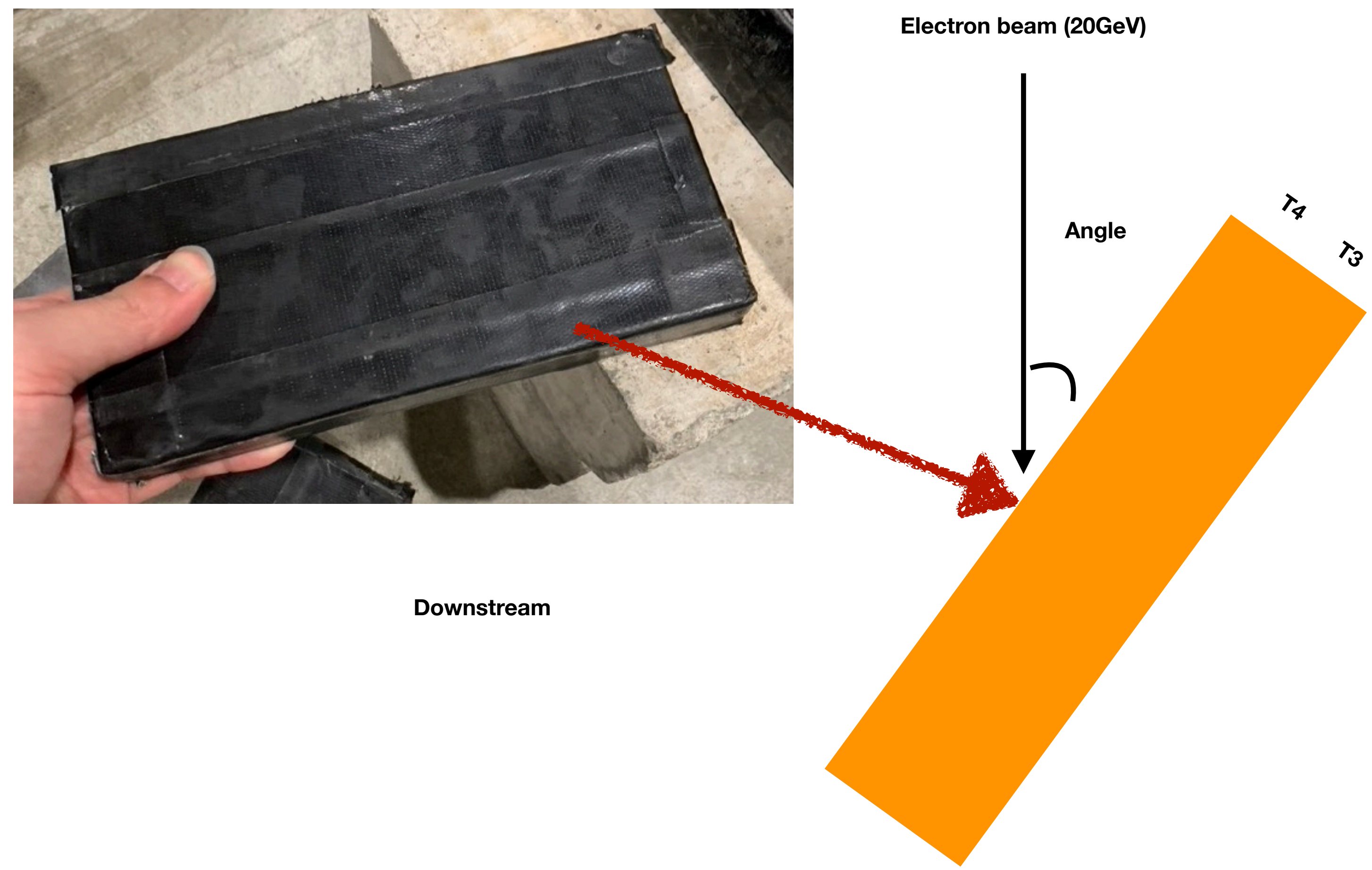
  - Resolution

  - 3D reconstruction (Pion)

  - Cherenkov channel response

  - Longitudinal Shower profile

  - 3D printing module



Xo	None	1Xo	2Xo	4Xo	5Xo	7Xo	9Xo	12Xo
Target events	20k	20k	20k	20k	20k	20k	20k	20k

Total Run & Events

- **During 84hours, we took ~23M events as fast mode and 4.6M events as waveform mode**

Total wave	Total Fast	Total Time (min)	Total Time (hour)
4,657,849	23,248,704	5,046	84

GeV	Total wave e+/e-	Total fast e+/e-	Total wave pion	Total fast pion	Total wave mu	Total fast mu	Total wave	Total fast
20	3,014,502	3,044,800	141,339	471,424	-	-	3,155,841	3,516,224
30	111,453	111,360	-	-	-	-	111,453	111,360
40	181,690	181,504	-	-	-	-	181,690	181,504
60	150,952	571,584	109,825	439,232	-	-	260,777	1,010,816
80	471,194	1,451,968	110,209	220,416	-	-	581,403	1,672,384
100	110,317	882,496	-	-	-	-	110,317	882,496
125	100,060	800,448	-	-	-	-	100,060	800,448
160	-	-	-	-	30,966	30,848	30,966	30,848
180	-	-	125,342	15,042,624	-	-	125,342	15,042,624
SUM	4,140,168	7,044,160	486,715	16,173,696	30,966	30,848		

North Area Beam characteristics

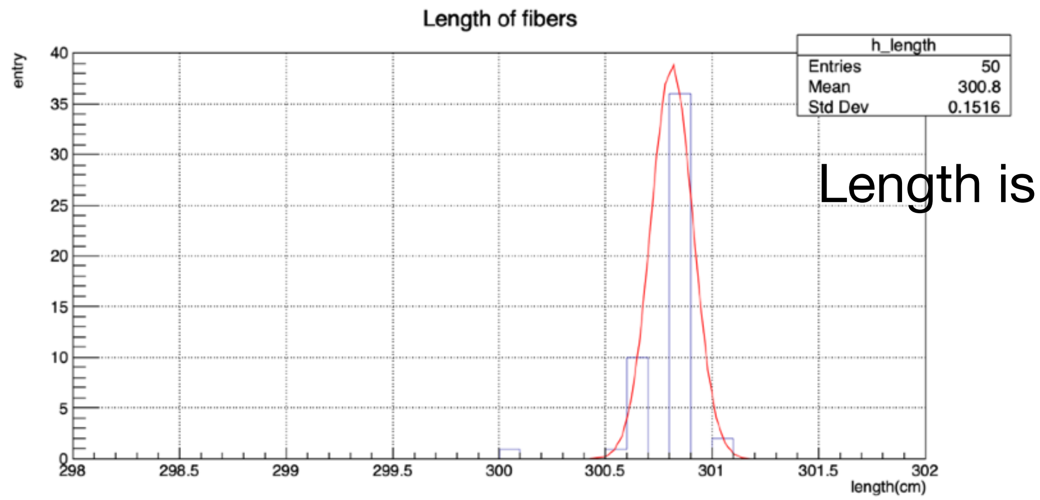
Parameters	T2		T4	
Beam Line	H2	H4	H6	H8
Maximum Momentum [GeV/c]	400 / 380	400 /380	- / 205	400 / 360
Maximum Acceptance [uSr]	1.5	1.5	2	2.5
Maximum Δp/p [%]	± 2.0%	± 1.4 %	±1.5%	±1.5%
Maximum Intensity / spill * (Hadrons / Electrons)	$10^7/10^5$	$10^7/10^7$	10^7 **/10^5	10^7 **/10^5
Available Particle Types	Primary protons*** OR electrons OR muons OR mixed hadrons (pions, protons, kaons)			
Other / Special requests	sba-physicists@cern.ch & sps.coordinator@cern.ch			

* Imposed by Radiation Protection, and not available to every zone
** In some zones can be elevated up to 10^8 subject to certain restrictions
*** Not available in H6

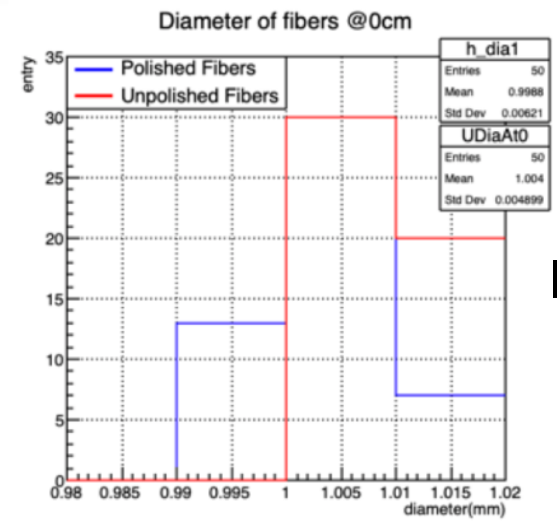
Nota Bene : The particle momenta in H2/H4 and in H6/H8 are coupled. Send your beam request and discuss in advance with the SPS coordinator and the responsible liaison physicists.

Quality Check of Cerenkov fibers

- **Dimension of fibers**



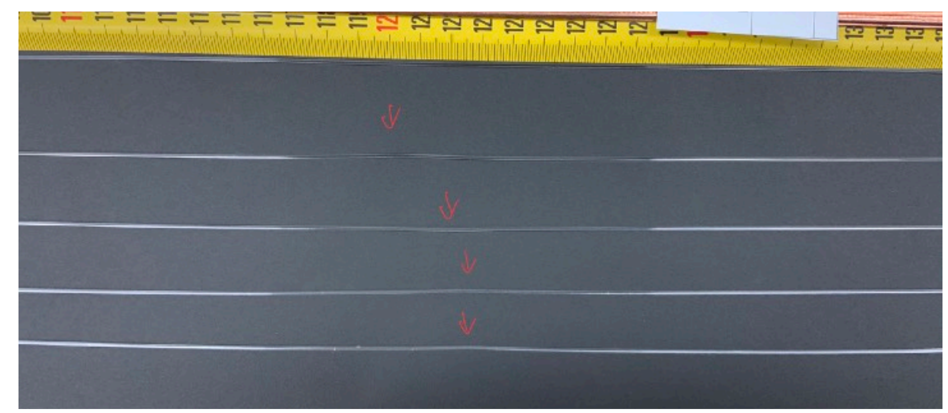
Length is ~ 3m



Diameter is ~ 1mm

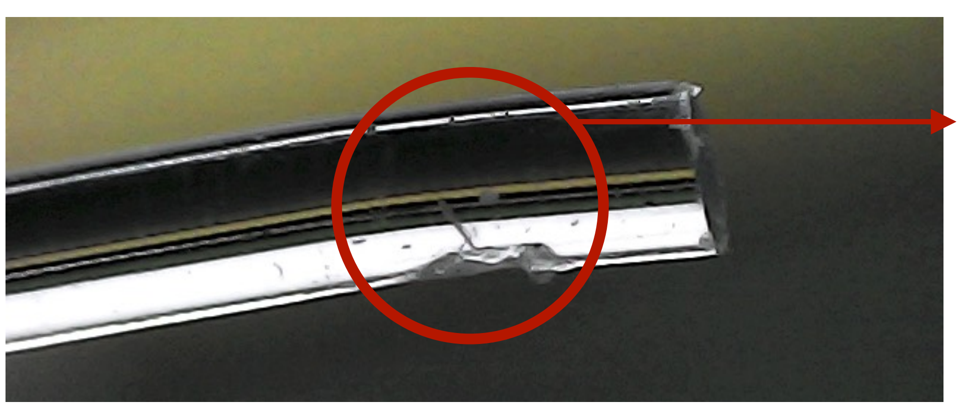
- **Straightness of fibers**

Fibers are slightly curved



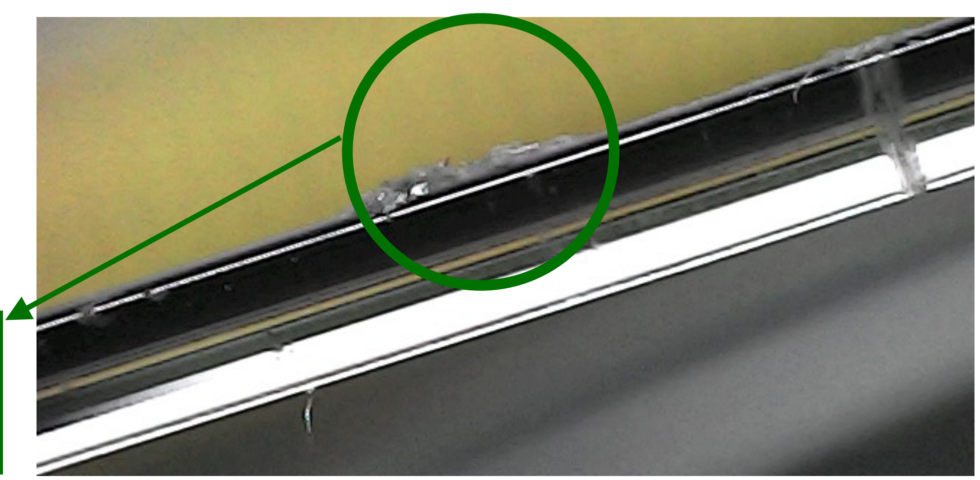
We are checking which points are curved

- **Defect on the fibers**



Most cracks were found at both ends of fibers

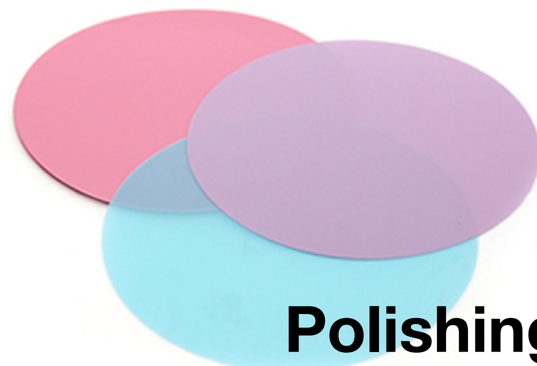
Tape residue remains.



- **We have been checking status of fibers**

Procedure of Polishing Fibers

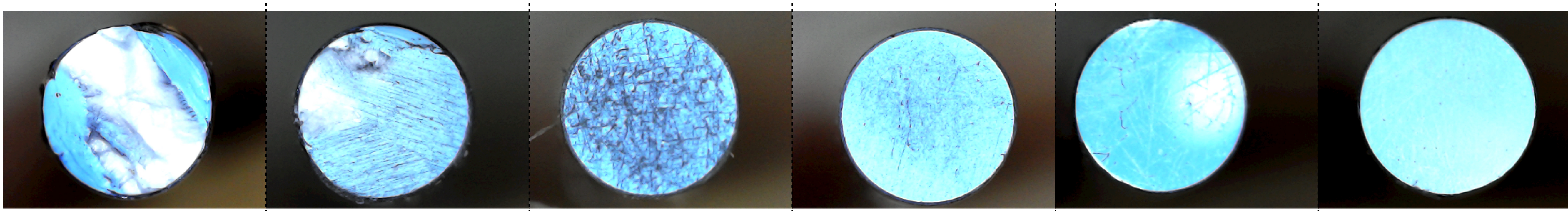
- **How to polish a fiber manually**
  - Using sandpaper and polishing a fiber, we can polish the fibers



Polishing film

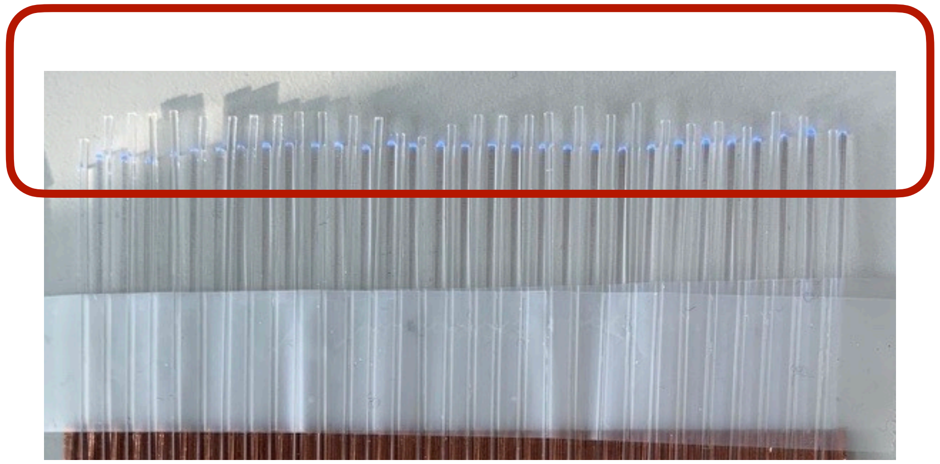
- **Result of polishing fiber for each step**

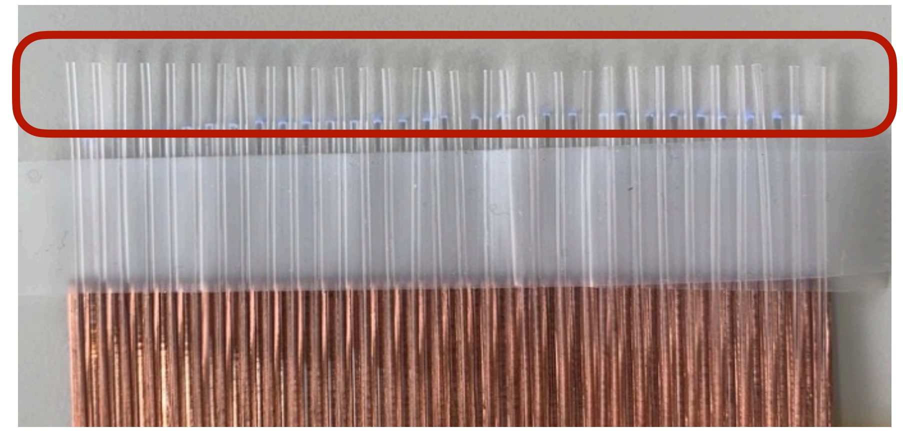
Before Polishing	Step1	Step2	Step3	Step4	Step5
-	**Sandpaper**	$9\mu m$ **Film**	$3\mu m$ **Film**	$1\mu m$ **Film**	**Final Film**



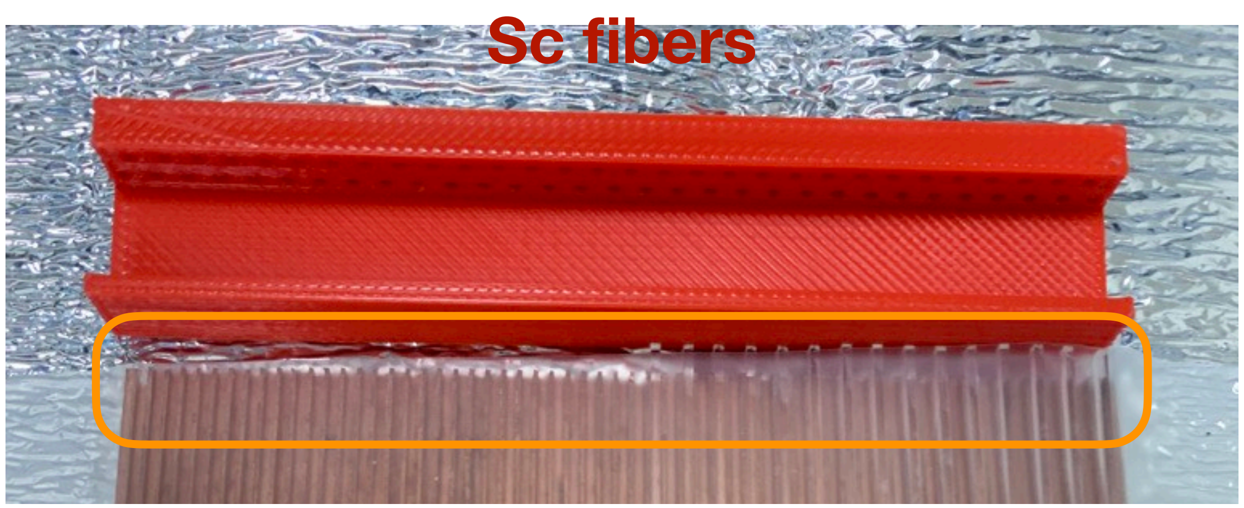
Preparing procedure : Tools & Reflector

- **Since it is not easy to align the end of fibers, we need some tools**





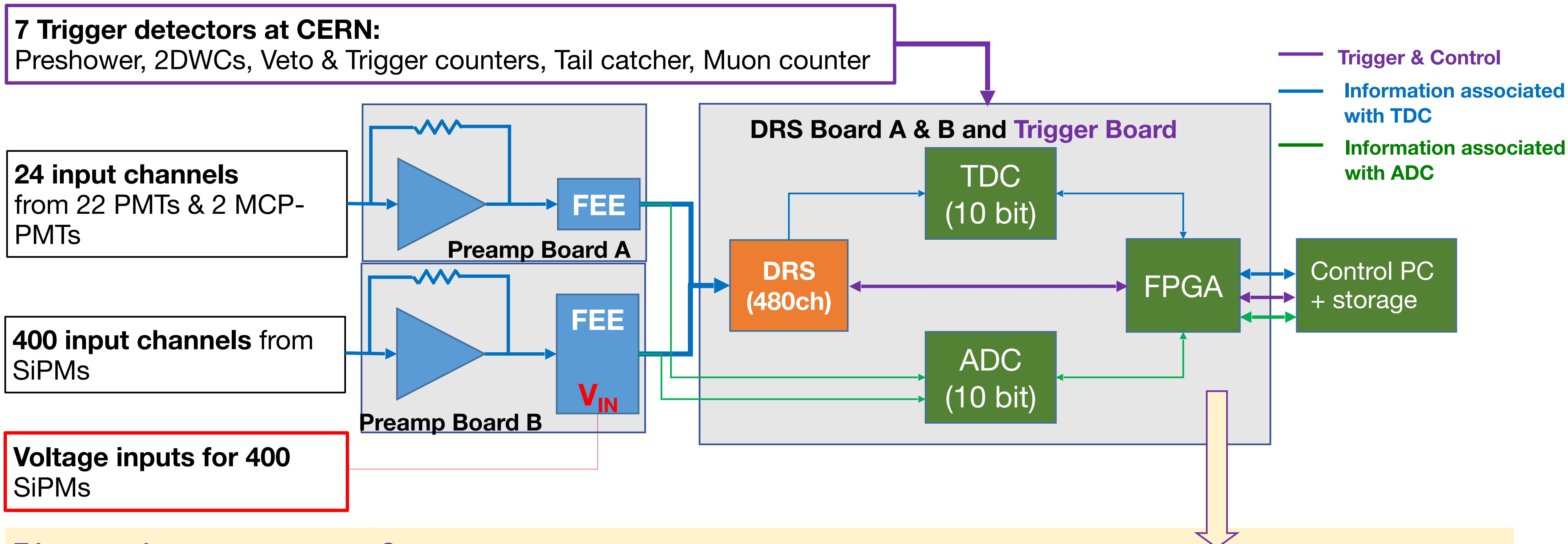
- **To make wall with gap, we can align the fibers easily**



- **Supporter for attaching reflector**
  - To easily and strongly attach the reflector (aluminum) to holder

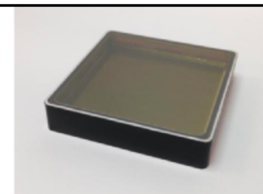
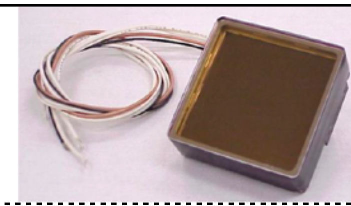
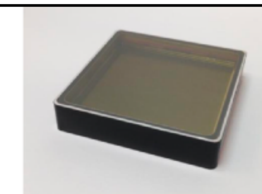
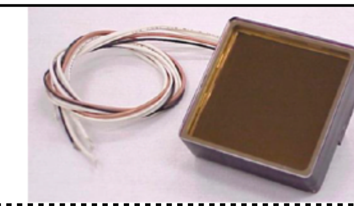
DAQ scheme with two Trigger modes

- **Initial requirement of readout system**
  - need ≤ 50 ps to achieve lower than 1% position precision toward the radial direction
  - need good energy resolution (26%)



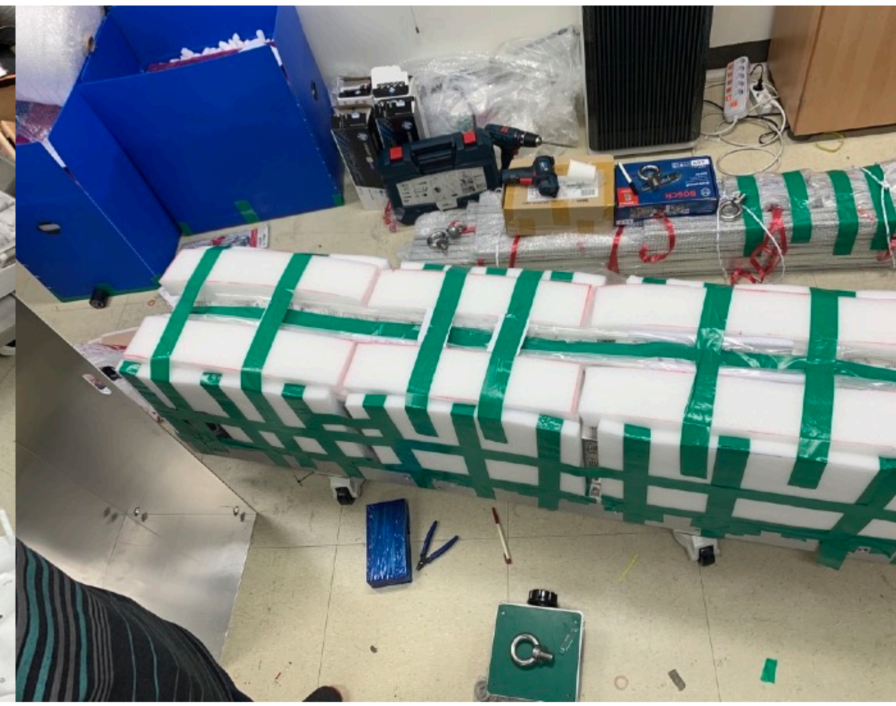
Trigger mode	Contents
Fast DAQ & Bin event modes (digitized data)	Data type: **ADC peak and its time values** while over the threshold Memory: DRAM Data size: 8 Bytes per channel (256 or 2^8 Bytes/32ch) Control bus: USB3 (expectation speed ~1 GBps) **Trigger rate: ~25 kHz** (while **15 DRS boards** are controlled by a single DAQ pc with USB3 communication)
Waveform & Bin event modes (digitized data + waveform)	Data type: **ADC peak and its time values** while over the threshold + **waveform data** during gate open Memory: two RAM (one for ADC peak value and another one for waveform data) Data size: 2048 Bytes per channel (2^{16} Bytes/32ch) Control bus: USB3 (expectation speed ~1 GBps) **Trigger rate: ~0.1 kHz** (while 15 DRS boards are controlled by a single DAQ pc with USB3 communication)
Bin event mode	DAQ mode for taking data during periods in between beam spills

MCP-PMT

	XP85122	XP85112	XP85022	XP85012
Exterior				
MCP	10μm MCP-PMT	10μm MCP-PMT	25μm MCP-PMT	25μm MCP-PMT
Active area	53x53 mm	53x53 mm	53x53 mm	53x53 mm
Anode	32x32 array, 1.1 / 1.6 mm (size / pitch)	8x8 array, 5.9 / 6.5 mm (size / pitch)	32x32 array, 1.1 / 1.6 mm (size / pitch)	8x8 array, 5.9 / 6.5 mm (size / pitch)
Quantum Efficiency	22% (Typ)	22% (Typ) 18% (Min)	22% (Typ)	22% (Typ)
Transit Time Spread	< 30 ps	35 ps (Typ) 60 ps (Max)	< 40 ps	< 40 ps
Additional Info.		- Superior Magnetic Field Immunity - Enhanced Timing Performance		

Packing Module

- **We completed packing the module (Jul. 21) and we shipped our module to CERN**


Arrived Module & DAQ

- **Our two modules and DAQ systems arrived at Bldg. 887 area**

Module

DAQ & etc…

Module Setup