Dual-Readout Calorimeter Test-Beam experience at CERN

DRD6 Collaboration Meeting
October 31, 2024

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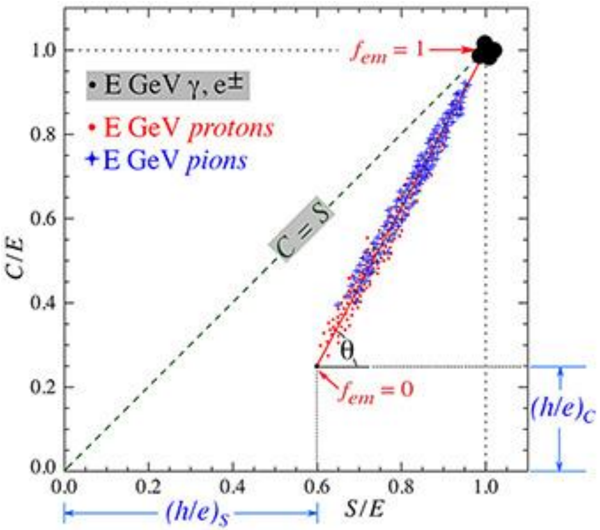
On behalf of the Korea Dual-Readout Calorimeter Team

Introduction

Korea DRC Test-Beam Experiments

DREAM FOR FUTURE



Nucl. Instrum. Meth. A 882 (2018)

- The dual-readout method **allows to measure f_{em} of single event**, by using complementary information from scintillation and Cherenkov light – different response ratio to EM and non-EM shower components (e/h)
- Dual-Readout Calorimeter (DRC) can offer **excellent energy resolution for hadron showers, even for EM showers** – in single detector.

Test Beam	2022	2023	2024
Location	SPS H8	PS T9	SPS H8
Module	Copper Plate	3D-Printing, SFHS, Lego-Like	SFHS, Copper Plate
Target Particle	High E EM	Low E EM	High E EM, Hadron

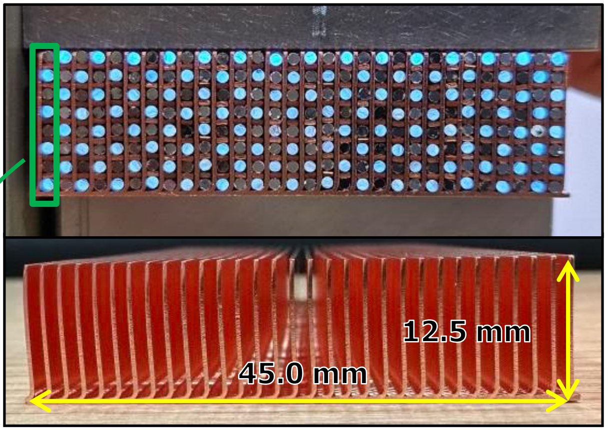
- Korea DRC R&D Collaboration has been **conducted test beam experiment** of prototype copper-based DRC modules, for the last few years @ CERN.

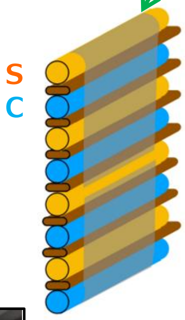
@CERN SPS H8, TB2024

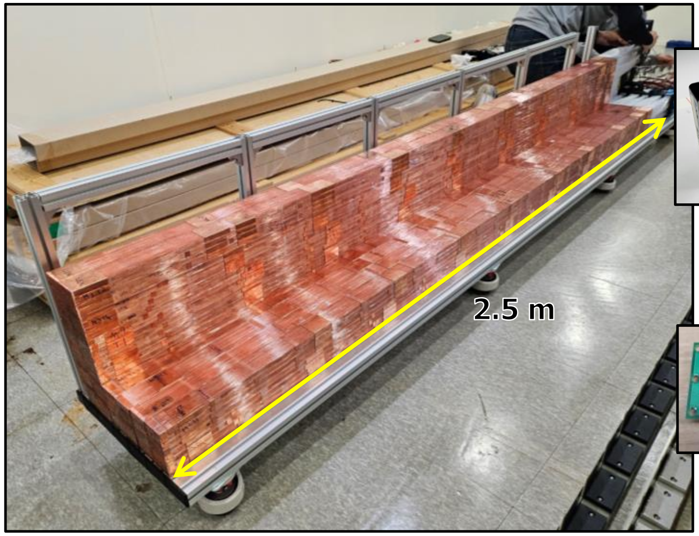
Test-Beam experiments at CERN

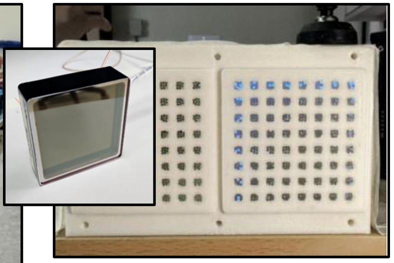
DRC R&D in Korea

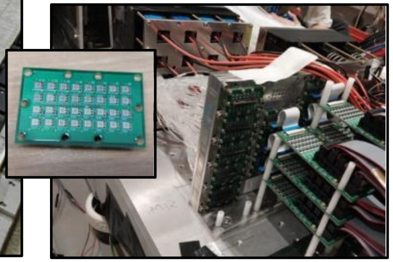
- Prototype DRC module building
  - ㄴ Copper Forming : Copper plate (Milling), 3D Metal Printing, Skiving HeatSink…
  - ㄴ High Granularity : MCP-PMT (128 ch), SiPM (400 ch)
- Customized DAQ system
  - ㄴ Fast Timing Resolution : Based on DRS4 chip
- Test-Beam for EM & Hadronic performance
  - ㄴ Energy, Timing, Position Resolution



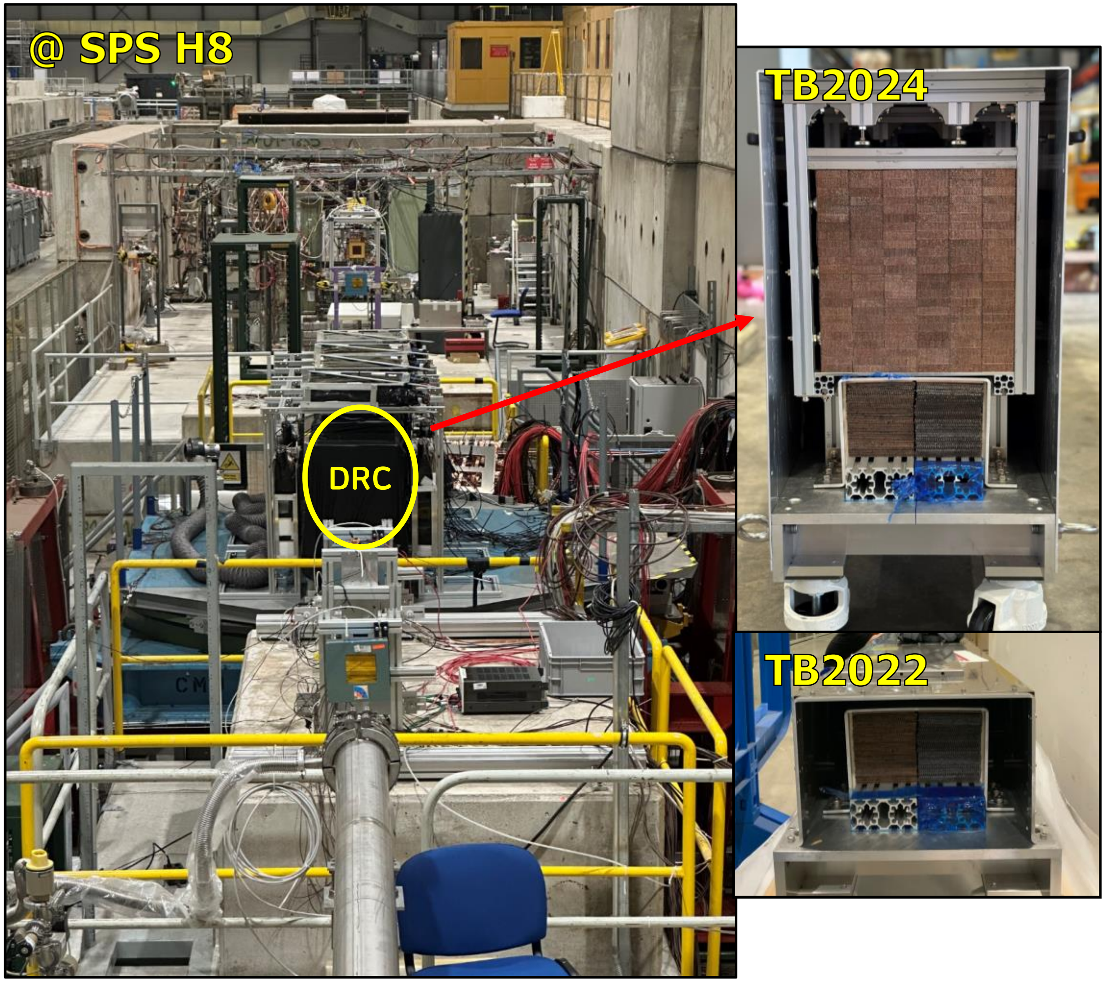








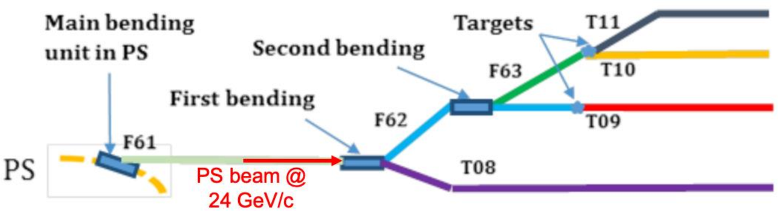
Test-Beam experiments at CERN
DRC Test-Beam

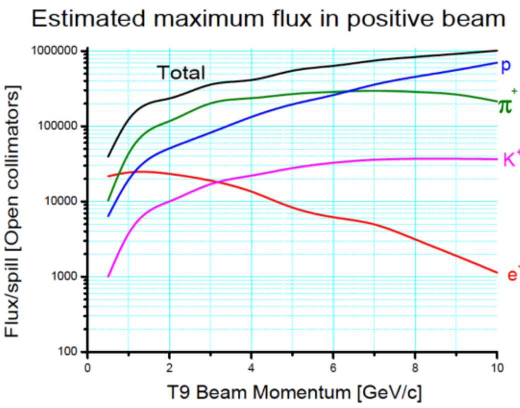


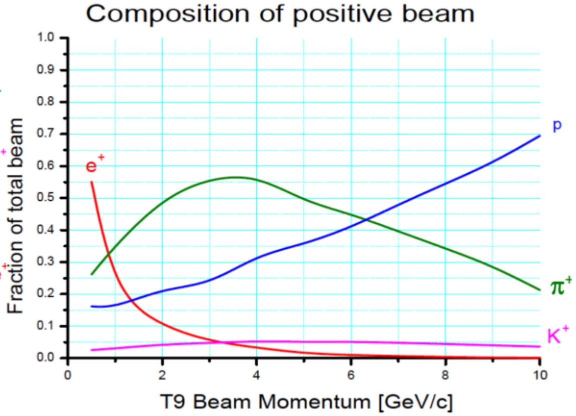
@ **SPS H8** Beamline (22, 24)

@ **PS T9** Beamline (23)

Test-Beam 2023
CERN East Area PS T9



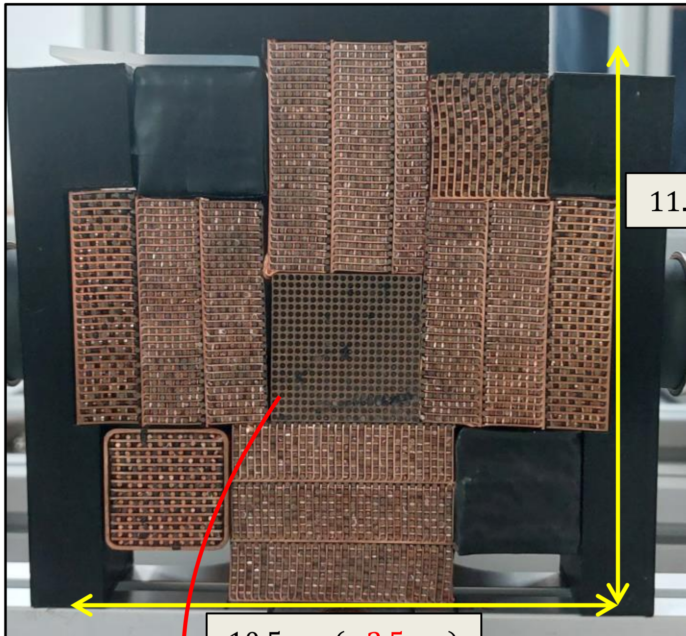


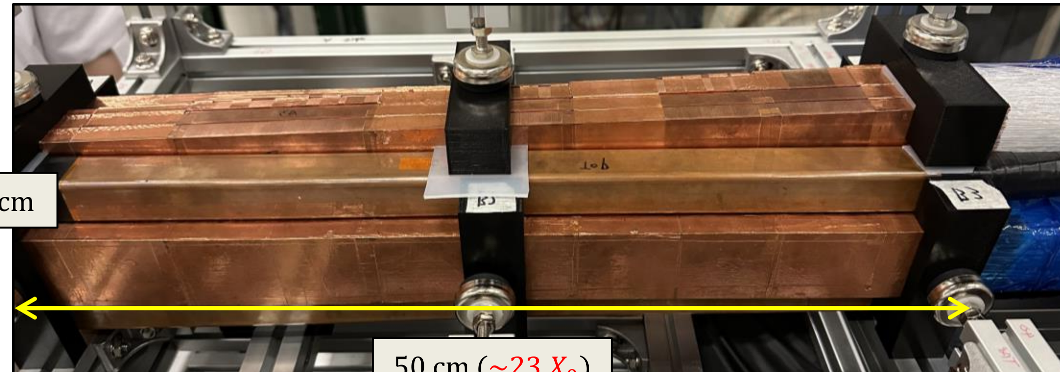


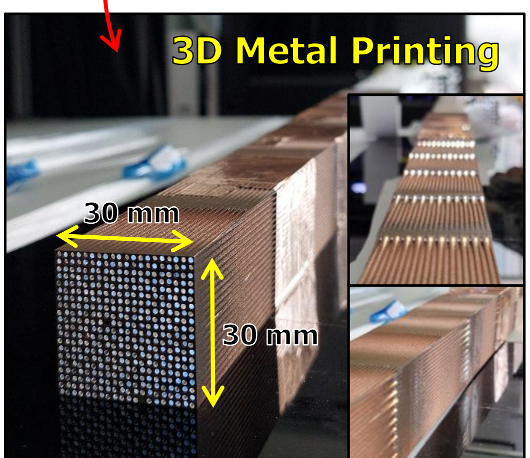
@CERN PS T9, TB2023

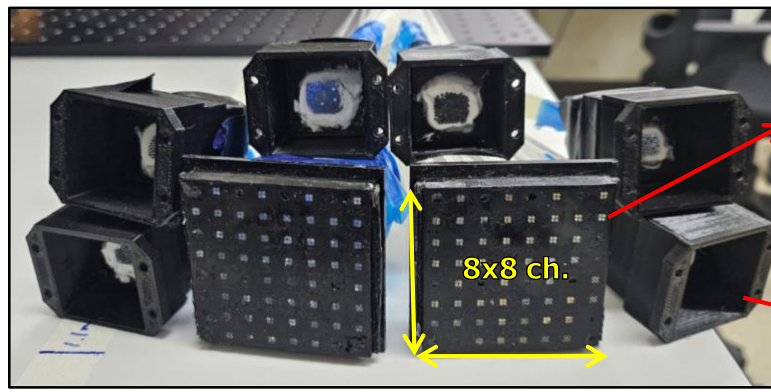
Test-Beam 2023

Module Setup

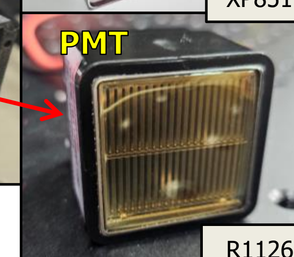








Readout of 3D-Printed Module



- Combination of different prototype modules, **projective geometry.**
- Aimed for **low energy EM particles**, >99% longitudinal shower contain, >95% shower lateral contain. (0.5~5 GeV e^+)

Test-Beam 2023
Experimental Setup

@ PS T9

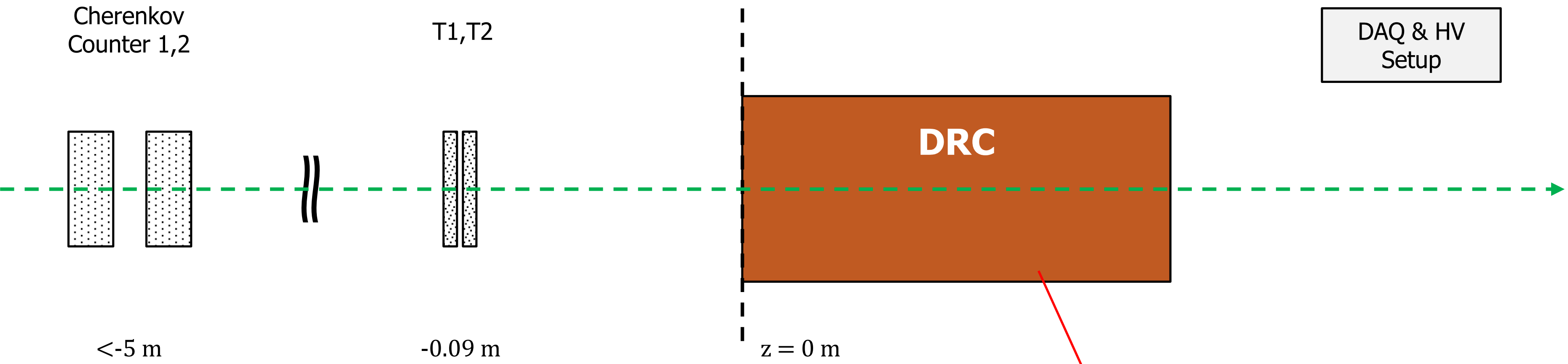
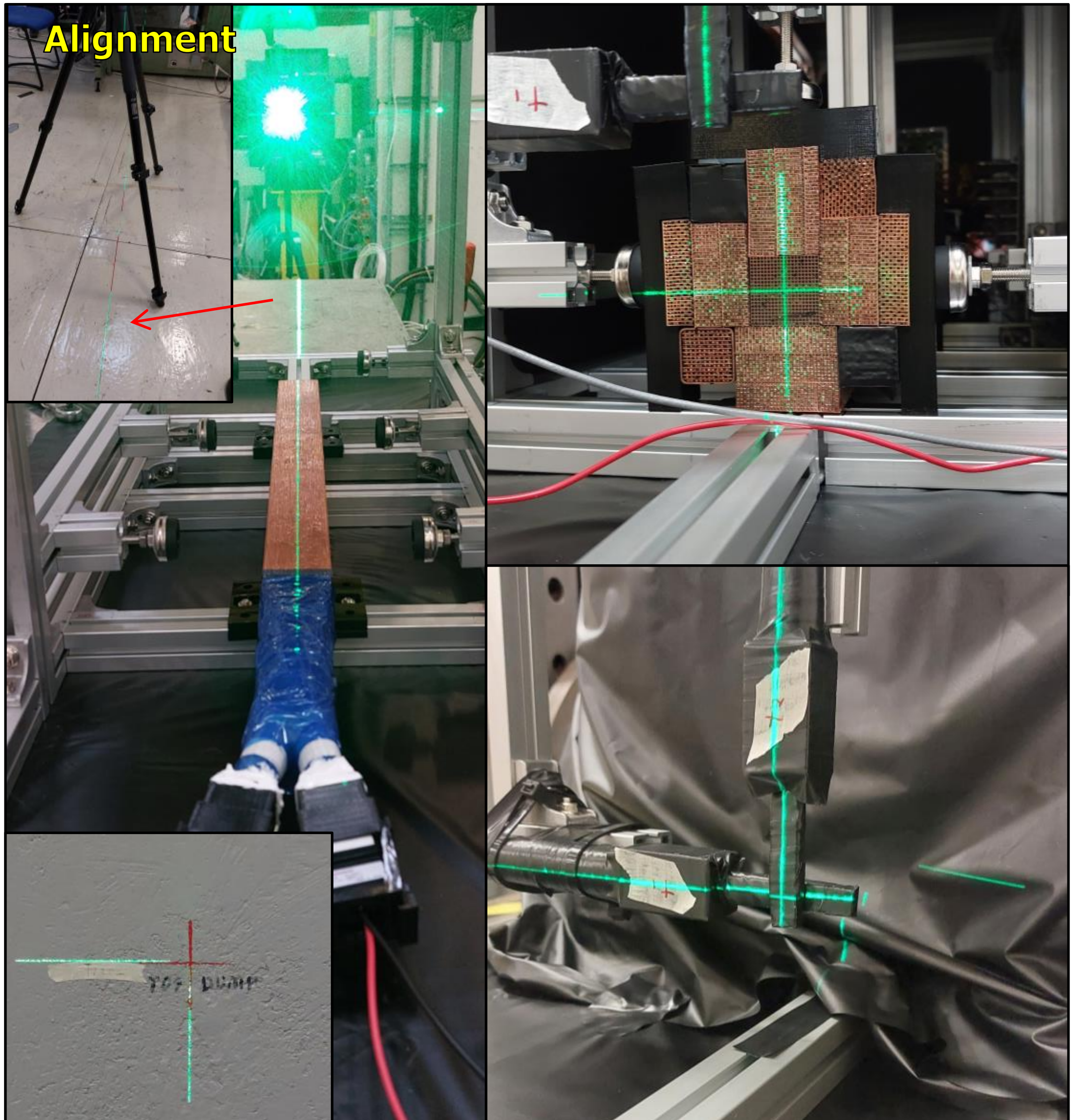
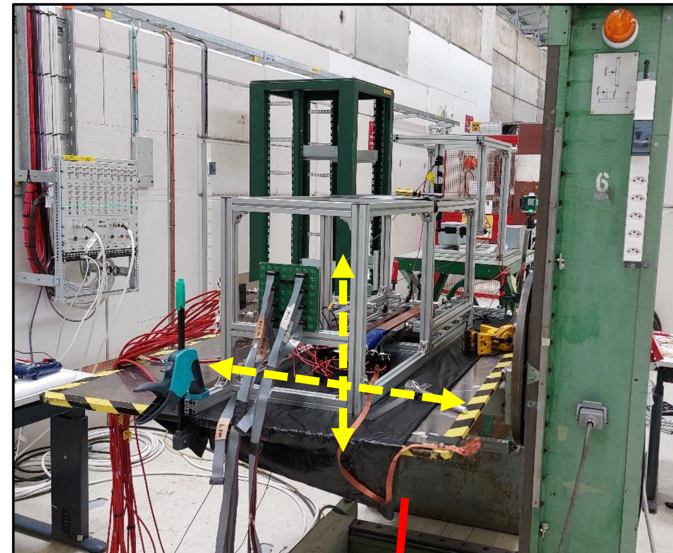


Fig. 4-30: Location of the new Cherenkov counters in the T09 and T10 beamlines.

Test-Beam 2023

Experimental Setup

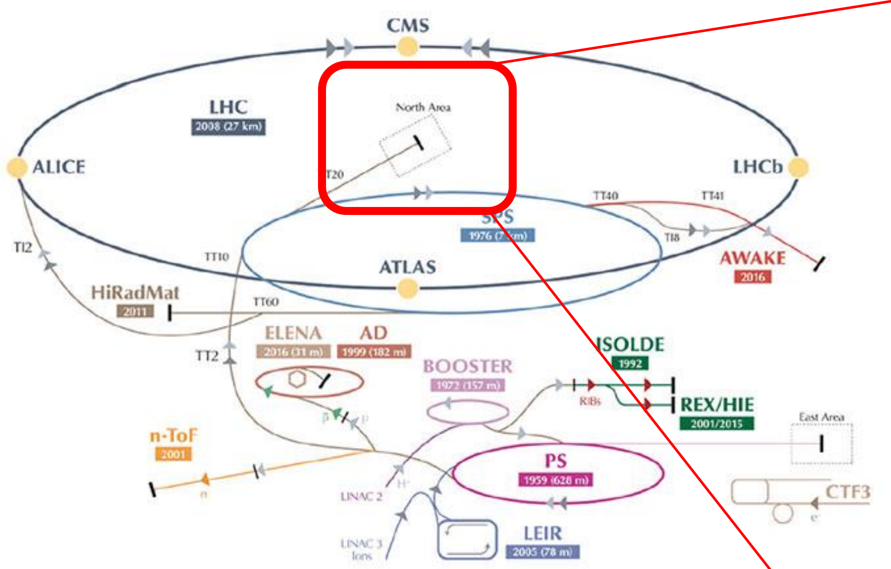


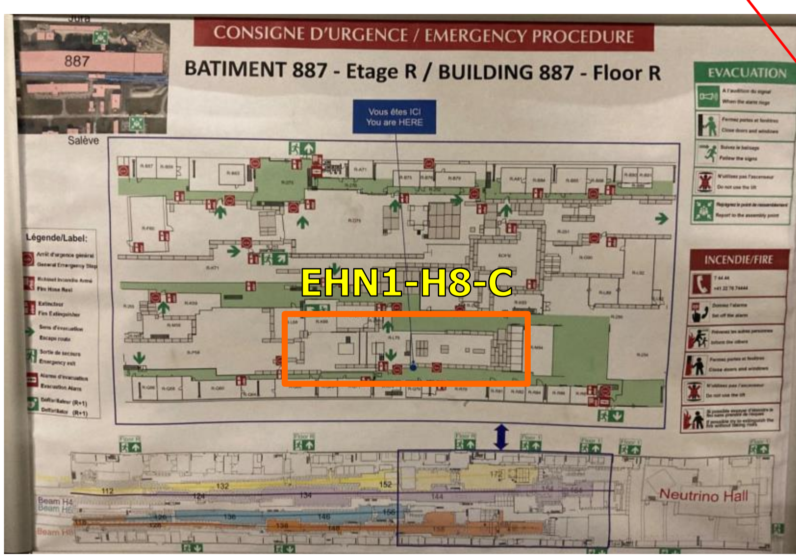


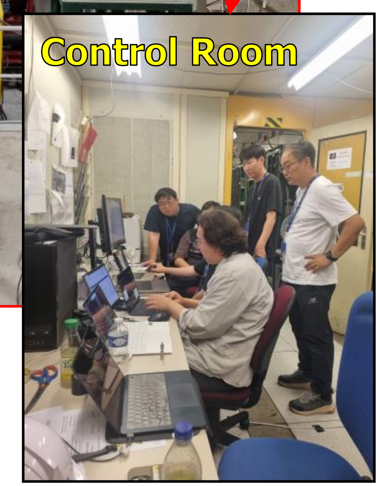
Test-Beam 2024

CERN North Area SPS H8

DREAM FOR FUTURE



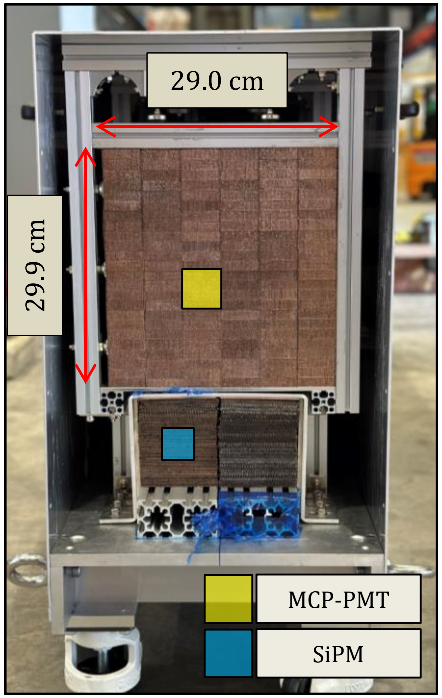


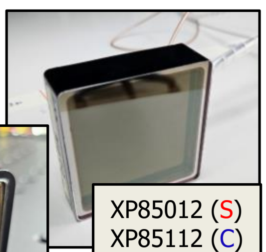


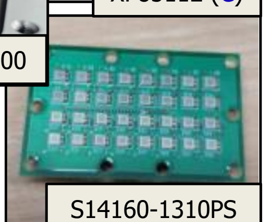
Experimental Hall View
@CERN North Area H8

Test-Beam 2024

Module Setup



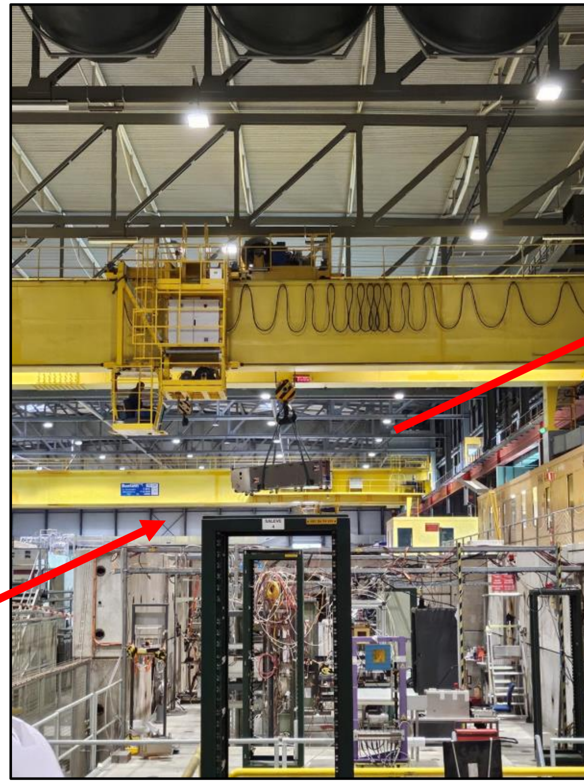




- **Largest prototype** Cu-based DRC module, assembled with TB2022 module setup.
- Aimed for test-beam of both EM & hadronic particles (10~100 GeV scale), so the module has **~90% lateral** deposit of hadronic shower and depth of **10 nuclear interaction length**.
- Tested high granularity – **MCP-PMT, SiPM** attached on center towers.

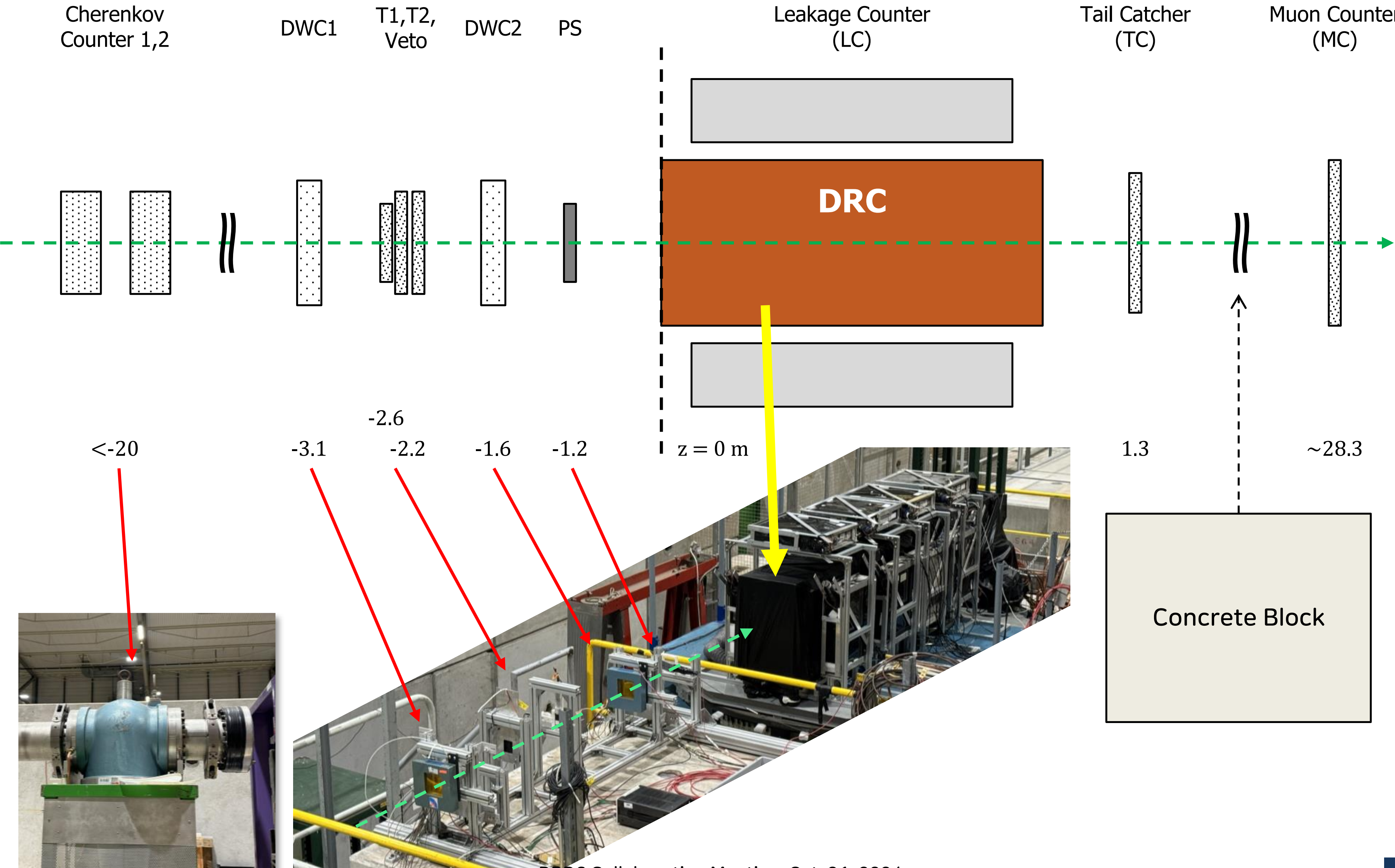
Test-Beam 2024

Module Installation



Test-Beam 2024
Experimental Setup

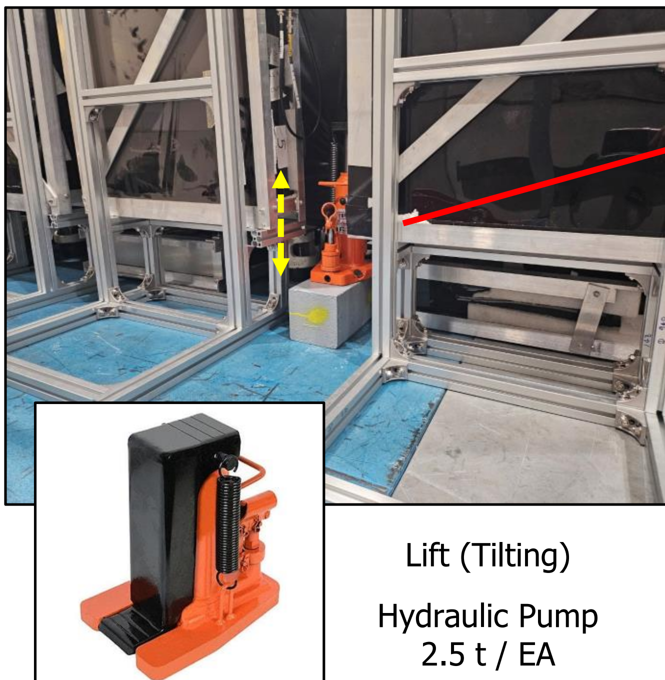
@ SPS H8



Test-Beam 2024
Sapphire Table – Moving & Rotation

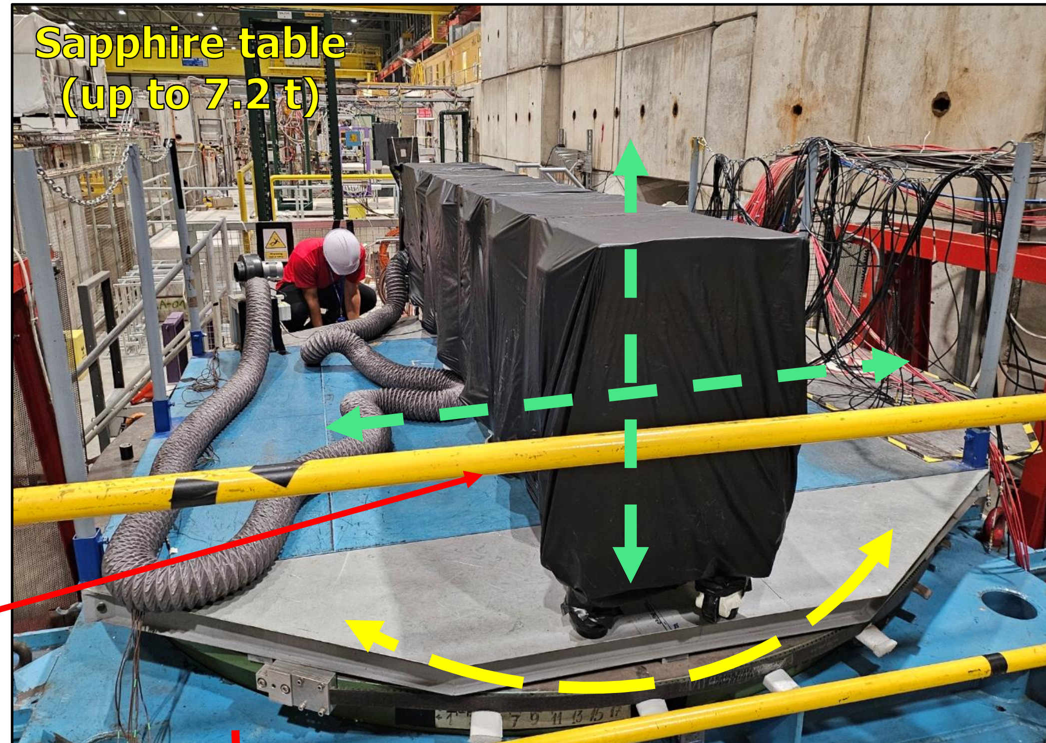
Rotation Controller

XY shift Controller



Lift (Tilting)

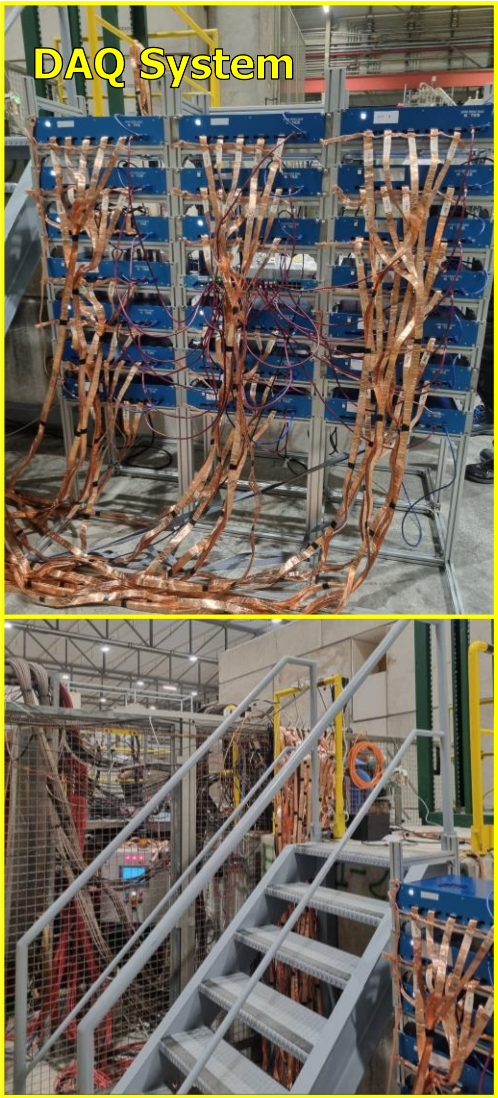
Hydraulic Pump
2.5 t / EA



Monitoring Cameras
under table

Test-Beam 2024

Readout Cabling

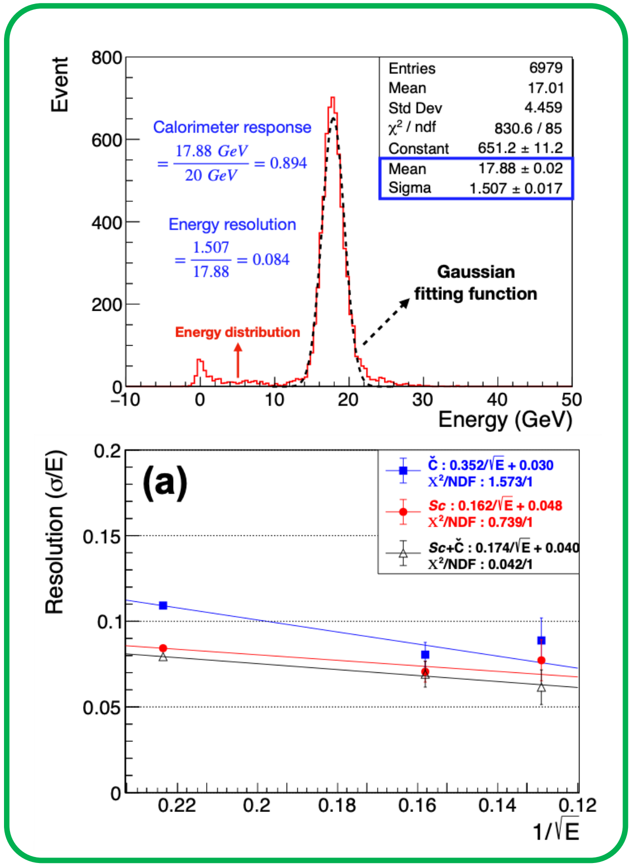


Test-Beam experiments at CERN

Results

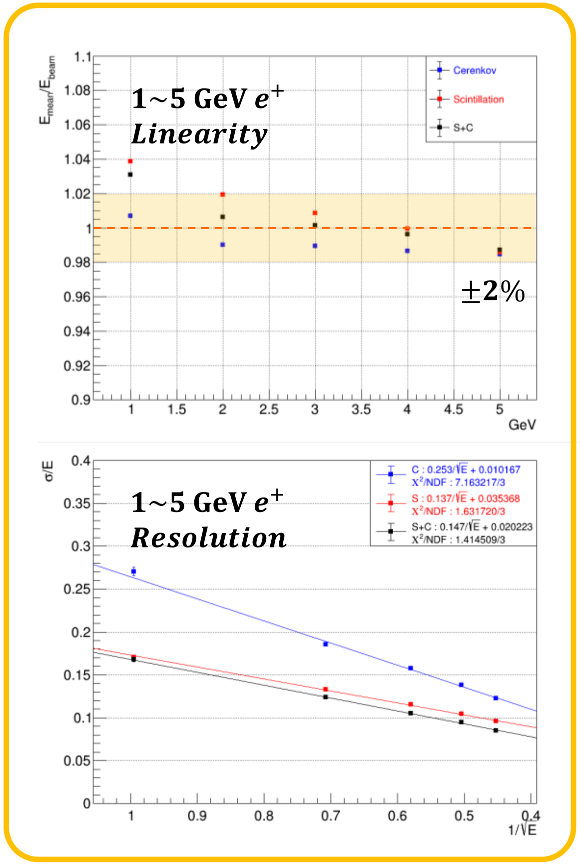
Test Beam	2022	2023	2024
Location	SPS H8	PS T9	SPS H8
Target Particle	High E EM	Low E EM	High E EM, Hadron

TB 2022



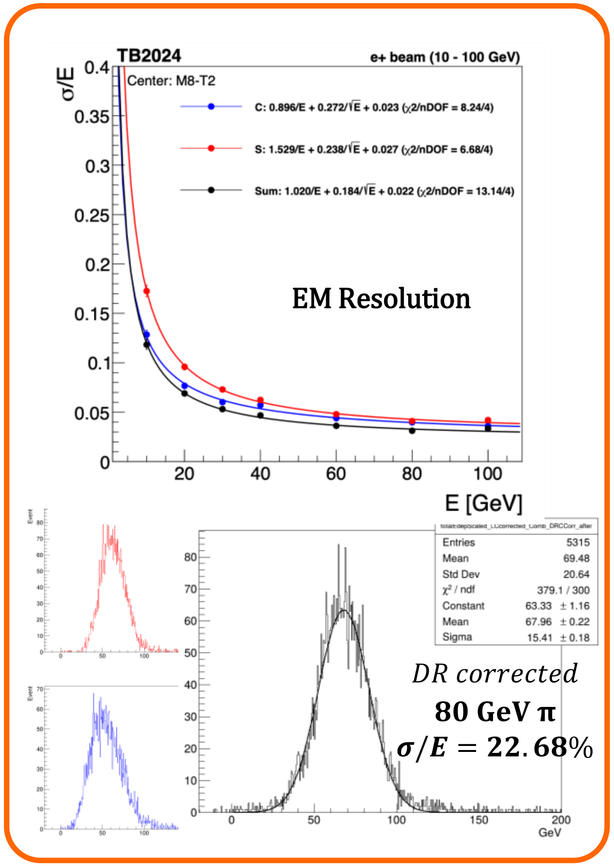
Submitted to Journal of Subatomic Particles and Cosmology (Elsevier)

TB 2023



Presented at CALOR2024

TB 2024



Very Preliminary Results, analysis ongoing

Summary

Korea DRC collaboration has conducted test beam experiment at CERN, for the last few years.

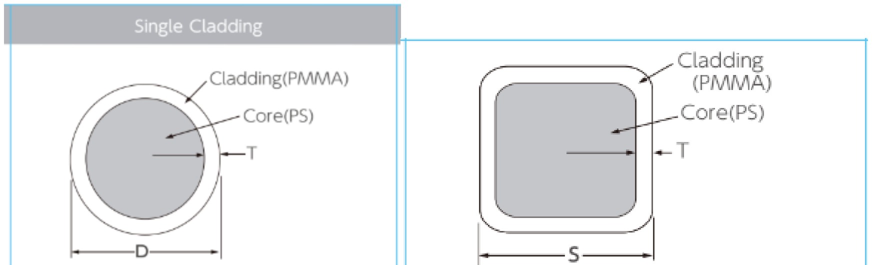
- At **SPS H8 & PS T9** beamline, data taken with prototype **DRC modules** with customized DAQ system.
- Taken data of **various physics programs**, low energy (PS) to high energy (SPS), EM & hadronic.

Location	PS T9	SPS H8
Test Beam	2023	2022, 2024
Module	Complex	SFHS, Cu Plate
Target Particle	$0.5 \sim 5$ GeV e^+	$10 \sim 120$ GeV e^+, hadrons
Feature	Accessibility Compact Setup	Wide area Applicable setup
Issue	-	Beam Purity (2022) Sapphire table

Backup

Optical Fiber Specification
Scintillating, Cerenkov Fiber

Scintillating Fiber (SCSF-78)



Cladding Thickness[1]: T=2% of D
Numerical Aperture: NA=0.55
Trapping Efficiency : 3.1%

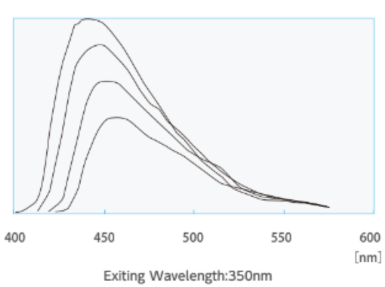
Cladding Thickness : T=2% of S
Numerical Aperture : NA=0.55
Trapping Efficiency : 4.2%

Core		Polystylene(PS)	n_D=1.59	1.05	C: 4.9x10[22] H: 4.9x10[22]
Cladding	for single cladding inner for multi-cladding	Polymethylmethacrylate (PMMA)	n_D=1.49	1.19	C: 3.6x10[22] H: 5.7x10[22] O: 1.4x10[22]

Description	Emission Color	Emission Spectra	Emission Peak[nm]	Decay Time [ns]	Att.Leng.[2] [m]
SCSF-78	blue	See the	450	2.8	>4.0

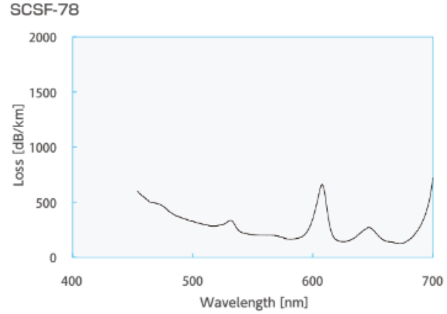
Emission Spectra

SCSF-78



Transmission Loss

SCSF-78

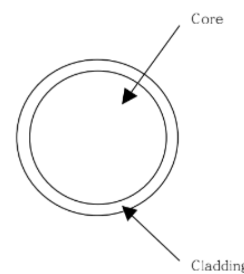


Cerenkov Fiber (SK-40)

Table 1

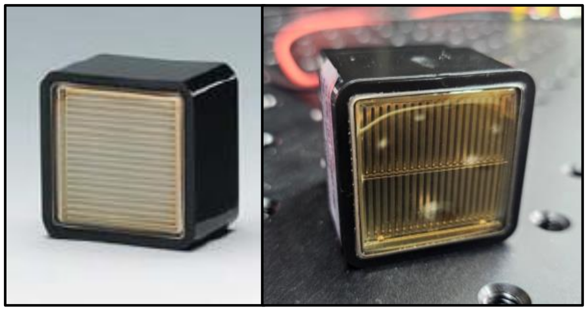
Item		SK-40 Specification Unit	Min.	Typ.	Max.
Optical Fiber 1	Core Material	–	Polymethyl-Methacrylate Resin		
	Cladding Material	–	Fluorinated Polymer		
	Core Refractive Index	–	1.49		
	Refractive Index Profile	–	Step Index		
	Numerical Aperture	–	0.5		
	Core Diameter	μm	920	980	1,040
	Cladding Diameter	μm	940	1,000	1,060
Approximate Weight		g/m	1		

Sectional View



Readout Detector Specification

Square PMT, MCP-PMT



Hamamatsu R11265U

PMT	Window Size	Max HV	Rise time
R11265-100	23x23 mm^2	1000 V	1.3 ns

Figure 1: Typical spectral response

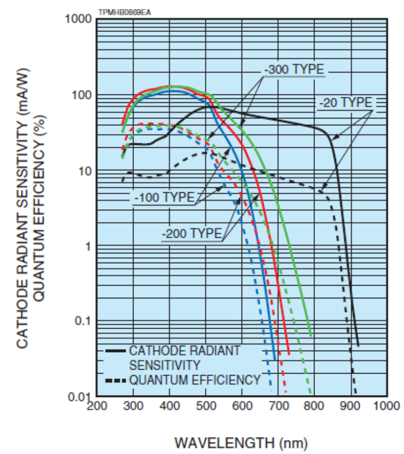
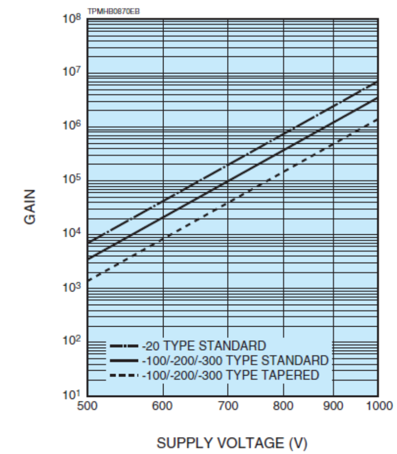
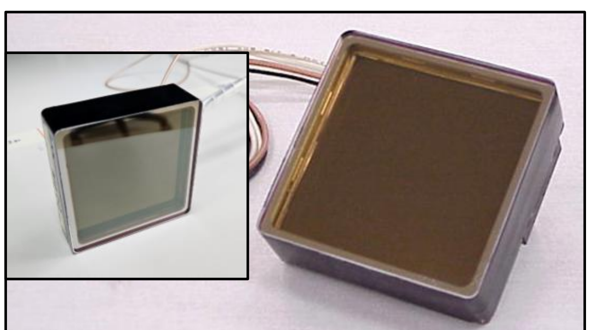


Figure 2: Typical gain

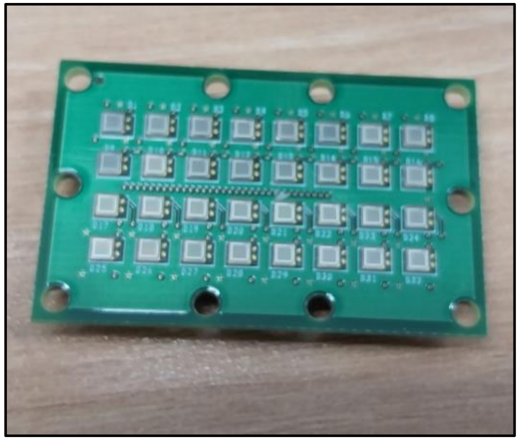




PLANACON XP85012, XP85112

PMT	Window Size	Max HV	Q.E (%)	Rise time
XP85012 (S)	53x53 mm^2	2400 V	~7% at 550nm	0.6 ns
XP85112 (C)		2800 V	~21% at 400nm	0.5 ns

Readout Detector Specification
SiPM



Hamamatsu S14160-1310PS

SiPM	Photosensitive Area (mm)	Pixel Pitch	# of pixels
S14160-1310ps	1.3 x 1.3	10 µm	16663