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Performance Assessment of Plastic Scintillator Bars for the ALICE-3 Muon Identifier

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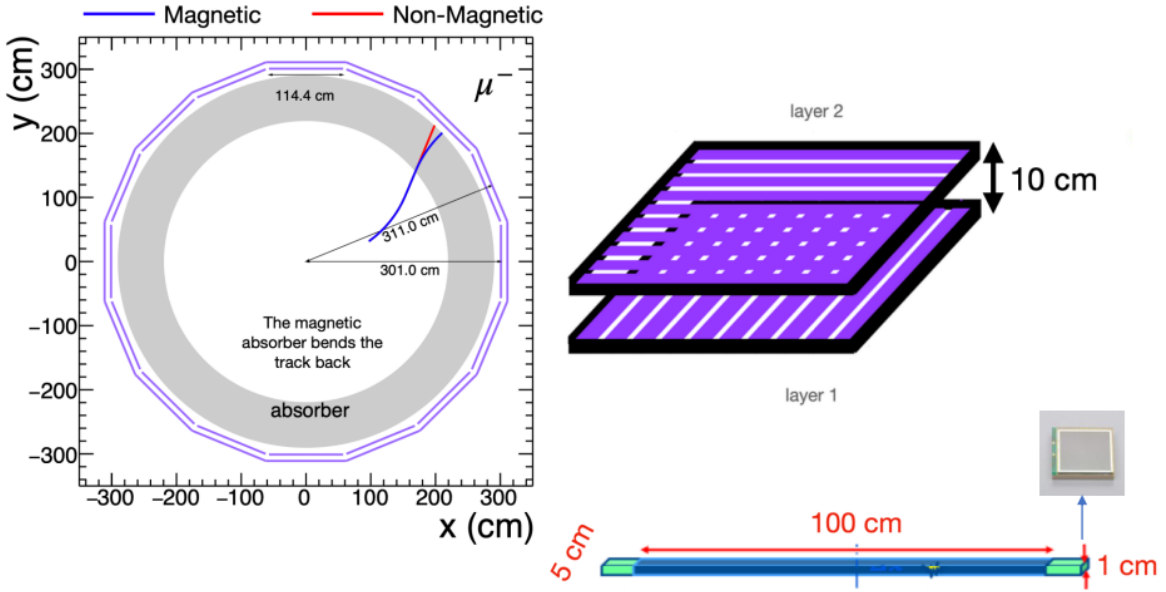
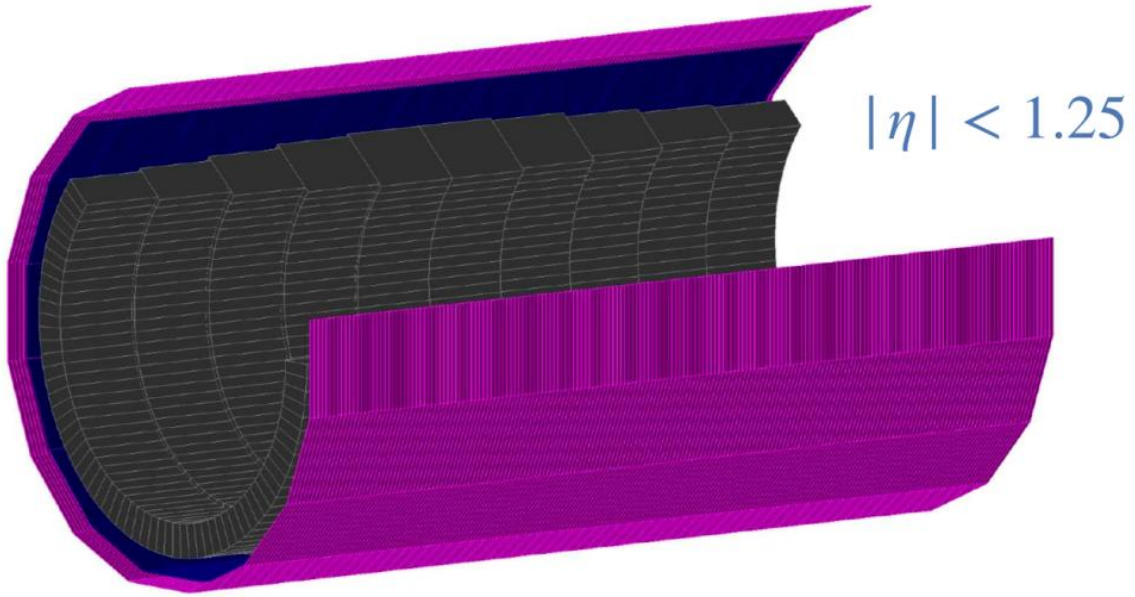
Outline

- Muon Identifier
- Cosmics Rays Tests
- Test Beam 2023
- Test Beam 2024
- Test Beam 2025
- Plans

Muon Identifier – Plastic Scintillator Option



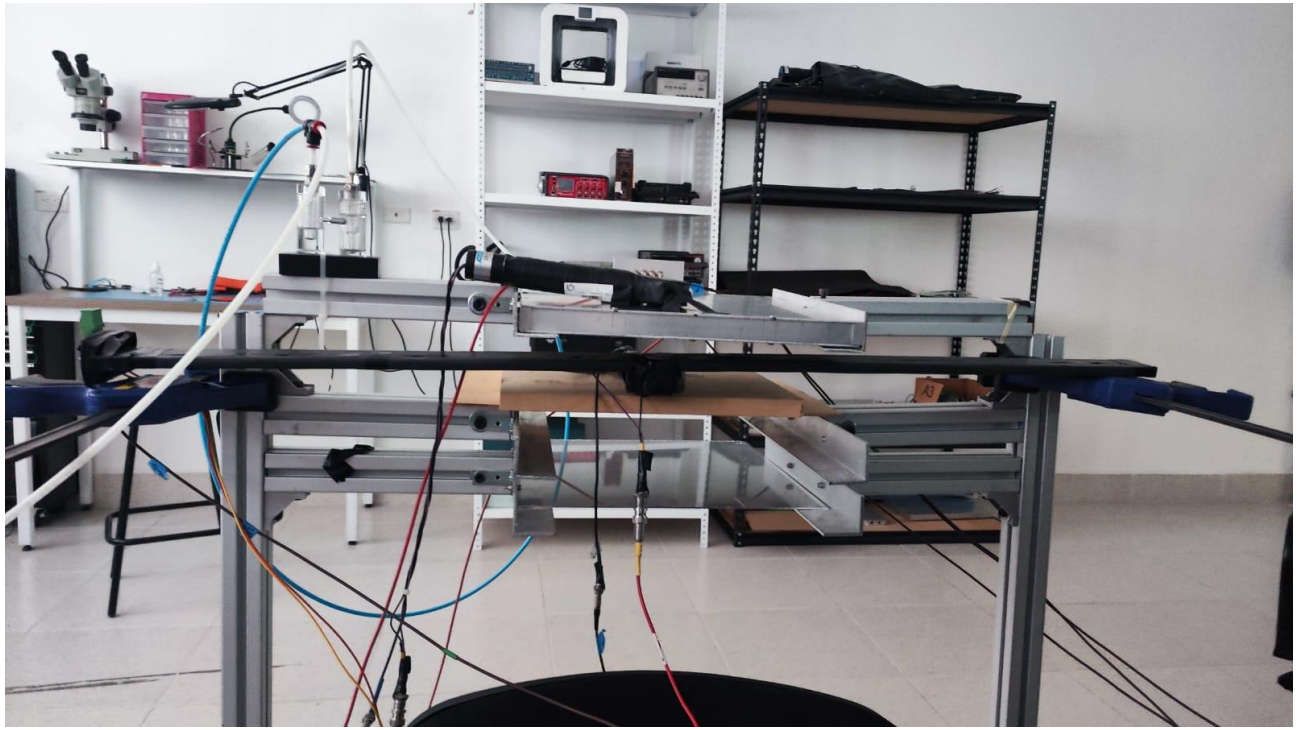


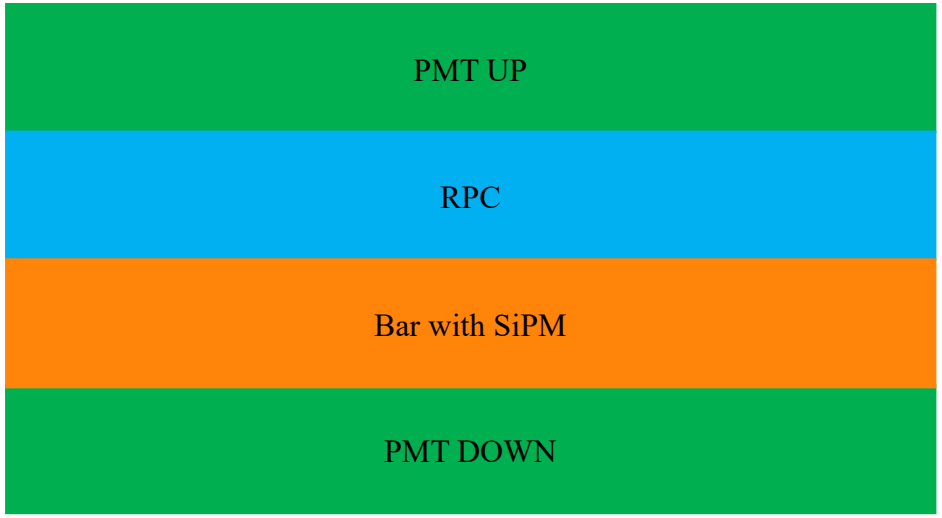
The ALICE-3 Letter of Intent (LoI) [1] considers the use of scintillator bars equipped with wavelength-shifting (WLS) fibers and silicon photomultiplier (SiPM) readout as the baseline option. This design includes two layers of crossed scintillator paddles, each 100 cm long, 5 cm wide, and 1 cm thick, with a 10 cm gap between the layers [2].

Assumptions:

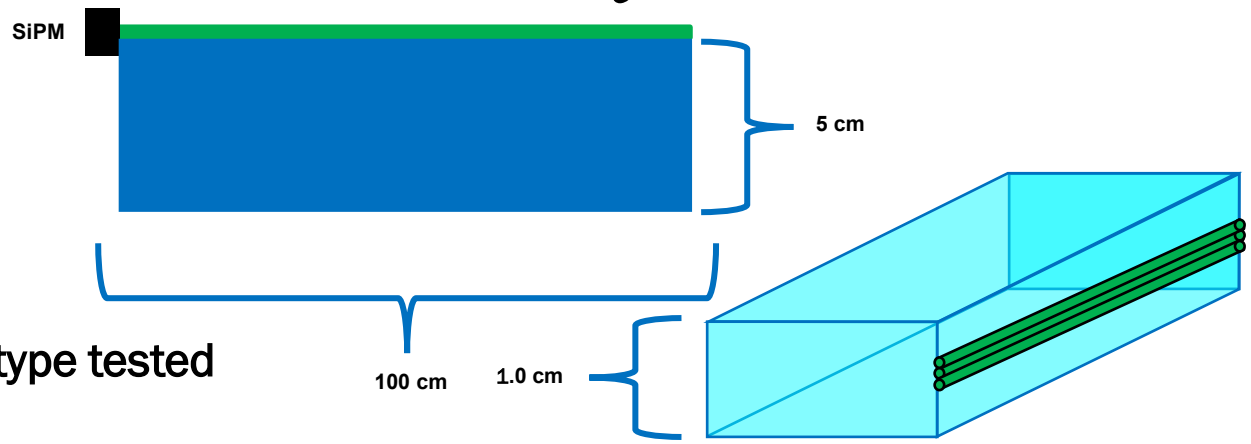
- 10 rings
- 16 segments per ring
- 1 chamber per segment
- 40 channels per chamber
- 6400 channels in total

Cosmic Rays Tests – Setup

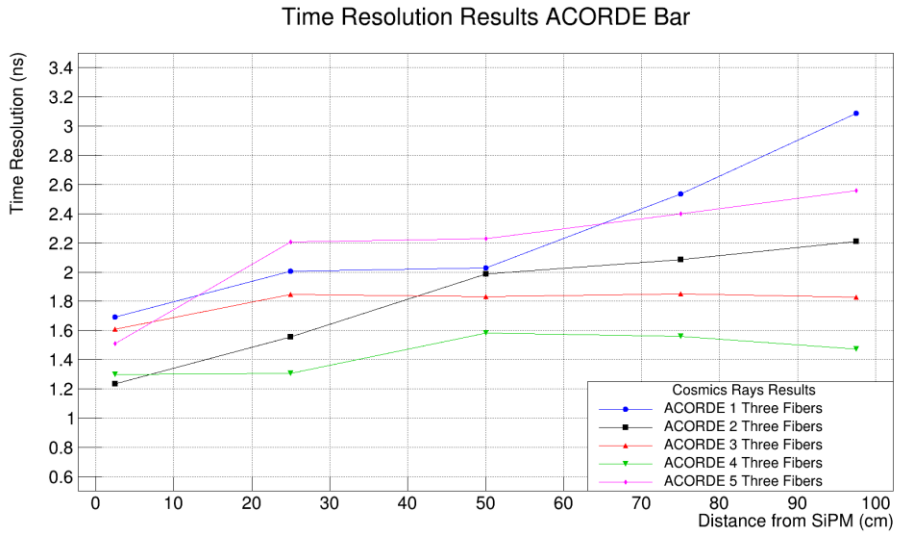


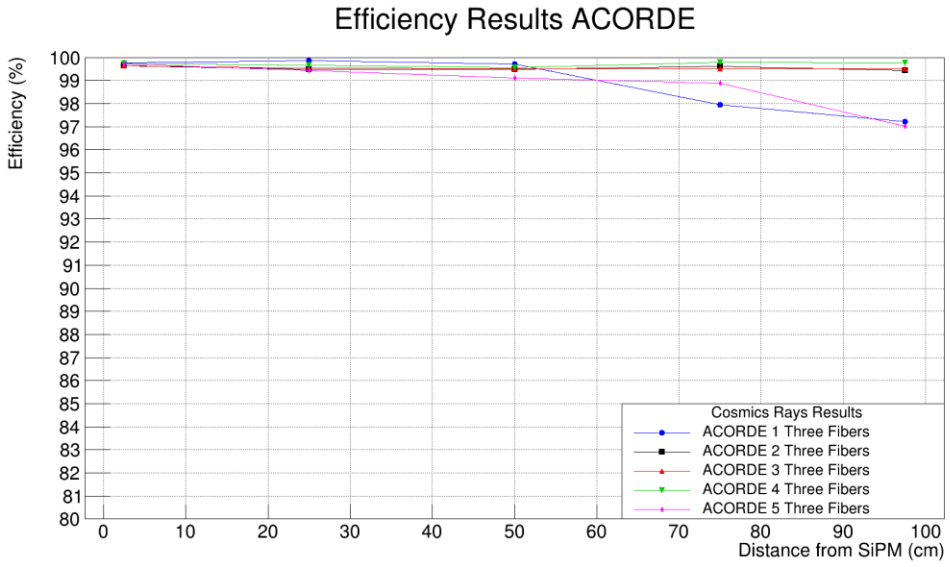


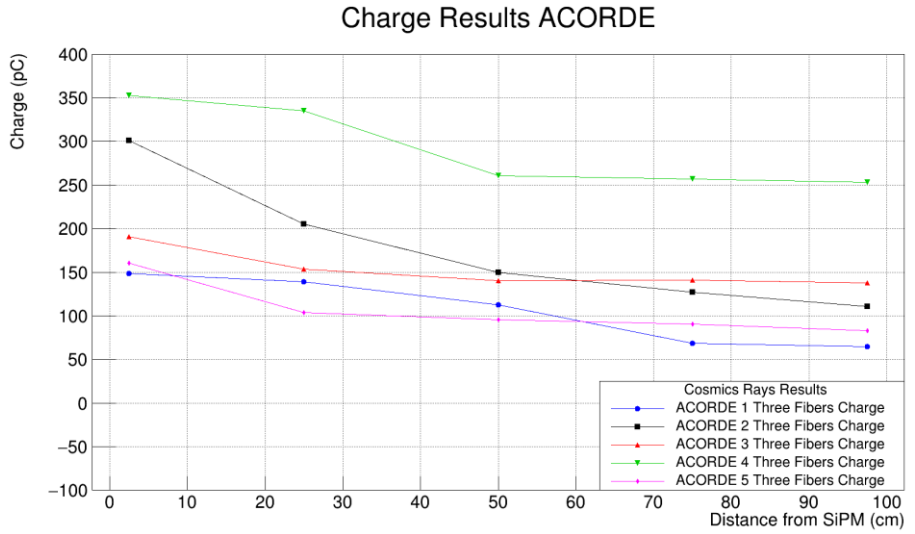
Cosmic Rays Tests



Prototype tested







Cosmic Rays Tests

ACORDE bars efficiency and time resolution results with three WLS fibers

Distance from SiPM (cm)	ACORDE 1		ACORDE 2		ACORDE 3		ACORDE 4		ACORDE 5	
	Efficiency (%)	Time Resolution (ns)	Efficiency (%)	Time Resolution (ns)	Efficiency (%)	Time Resolution (ns)	Efficiency (%)	Time Resolution (ns)	Efficiency (%)	Time Resolution (ns)
2.5	99.76	1.7 ± 0.1	99.64	1.2± 0.1	99.64	1.6 ± 0.1	99.75	1.3 ± 0.1	99.72	1.5 ± 0.1
25	99.87	2.0 ± 0.1	99.50	1.5± 0.1	99.55	1.8 ± 0.1	99.67	1.3 ± 0.1	99.43	2.2 ± 0.1
50	99.71	2.0 ± 0.1	99.49	2.0± 0.1	99.51	1.8 ± 0.1	99.56	1.6 ± 0.1	99.12	2.2 ± 0.1
75	97.94	2.5 ± 0.1	99.62	2.1± 0.1	99.52	1.8 ± 0.1	99.80	1.6 ± 0.1	98.88	2.4 ± 0.1
97.5	97.22	3.1 ± 0.1	99.43	2.2 ± 0.1	99.51	1.8 ± 0.1	99.77	1.5 ± 0.1	97.02	2.6 ± 0.1

Efficiency: ≈ 99%

Time resolution: 1.2 – 3.0 ns

Cosmic Rays Tests

ACORDE bars amplitude and charge results with three WLS fibers

Distance from SiPM (cm)	ACORDE 1		ACORDE 2		ACORDE 3		ACORDE 4		ACORDE 5	
	Amplitude (mV)	Charge (pC)	Amplitude (mV)	Charge (pC)	Amplitude (mV)	Charge (pC)	Amplitude (mV)	Charge (pC)	Amplitude (mV)	Charge (pC)
2.5	34.39 ± 0.13	148.6 ± 1.9	60.30 ± 0.20	300.6 ± 1.8	44.27 ± 0.16	190.4 ± 2.5	72.26 ± 0.26	352.3 ± 3.9	34.08 ± 0.16	160.2 ± 2.1
25	34.14 ± 0.12	138.7 ± 1.6	43.89 ± 0.15	205.2 ± 1.6	35.43 ± 0.12	153.5 ± 1.8	70.17 ± 0.23	335.0 ± 2.0	22.30 ± 0.10	103.56 ± 1.3
50	29.43 ± 0.12	112.5 ± 1.8	32.04 ± 0.11	149.7 ± 1.7	34.22 ± 0.13	140.0 ± 1.6	56.57 ± 0.24	260.8 ± 2.1	20.84 ± 0.07	95.79 ± 1.2
75	16.63 ± 0.05	68.68 ± 1.08	30.51 ± 0.10	127.2 ± 1.8	34.20 ± 0.10	140.9 ± 1.6	55.41 ± 0.21	256.5 ± 2.1	19.71 ± 0.06	90.37 ± 1.2
97.5	16.03 ± 0.07	64.72 ± 1.06	26.92 ± 0.11	110.9 ± 1.7	31.82 ± 0.12	137.4 ± 1.6	52.33 ± 0.19	252.9 ± 2.3	18.23 ± 0.08	82.63 ± 1.2

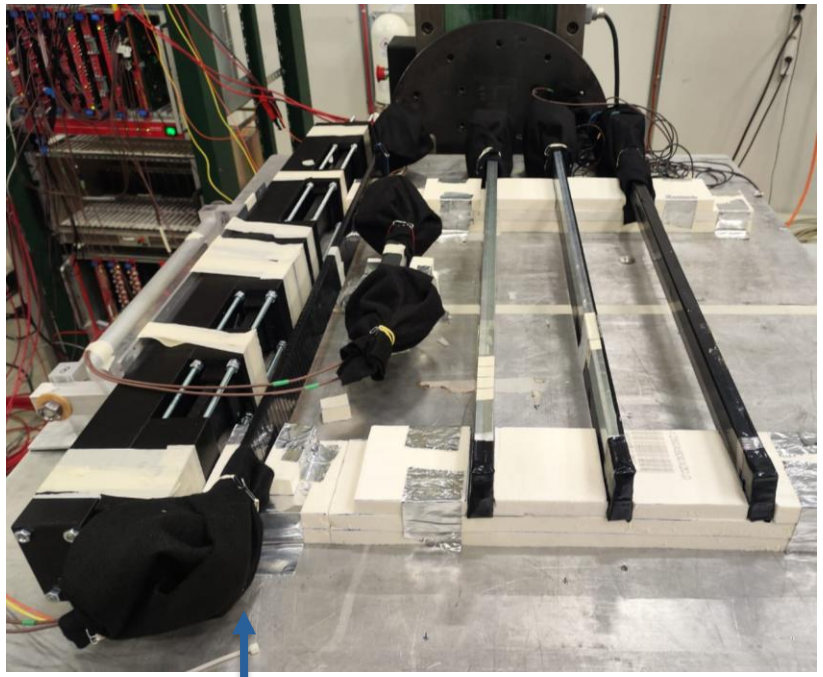
Cosmic Rays Tests

ACORDE bars charge and number of photons results with three WLS fibers

Distance from SiPM (cm)	ACORDE 1		ACORDE 2		ACORDE 3		ACORDE 4		ACORDE 5	
	Charge (pC)	Photons (γ)	Charge (pC)	Photons (γ)	Charge (pC)	Photons (γ)	Charge (pC)	Photons (γ)	Charge (pC)	Photons (γ)
2.5	148.6 ± 1.9	≈ 32.96	300.6 ± 1.8	≈ 68.09	190.4 ± 2.5	≈ 45.51	352.3 ± 3.9	≈ 83.58	160.2 ± 2.1	≈ 35.54
25	138.7 ± 1.6	≈ 30.76	205.2 ± 1.6	≈ 46.48	153.5 ± 1.8	≈ 36.69	335.0 ± 2.0	≈ 79.48	103.56 ± 1.3	≈ 22.97
50	112.5 ± 1.8	≈ 24.96	149.7 ± 1.7	≈ 33.91	140.0 ± 1.6	≈ 33.46	260.8 ± 2.1	≈ 61.87	95.79 ± 1.2	≈ 21.25
75	68.68 ± 1.08	≈ 15.24	127.2 ± 1.8	≈ 28.81	140.9 ± 1.6	≈ 33.67	256.5 ± 2.1	≈ 60.85	90.37 ± 1.2	≈ 20.05
97.5	64.72 ± 1.06	≈ 14.36	110.9 ± 1.7	≈ 25.11	137.4 ± 1.6	≈ 32.84	252.9 ± 2.3	≈ 60.01	82.63 ± 1.2	≈ 18.33

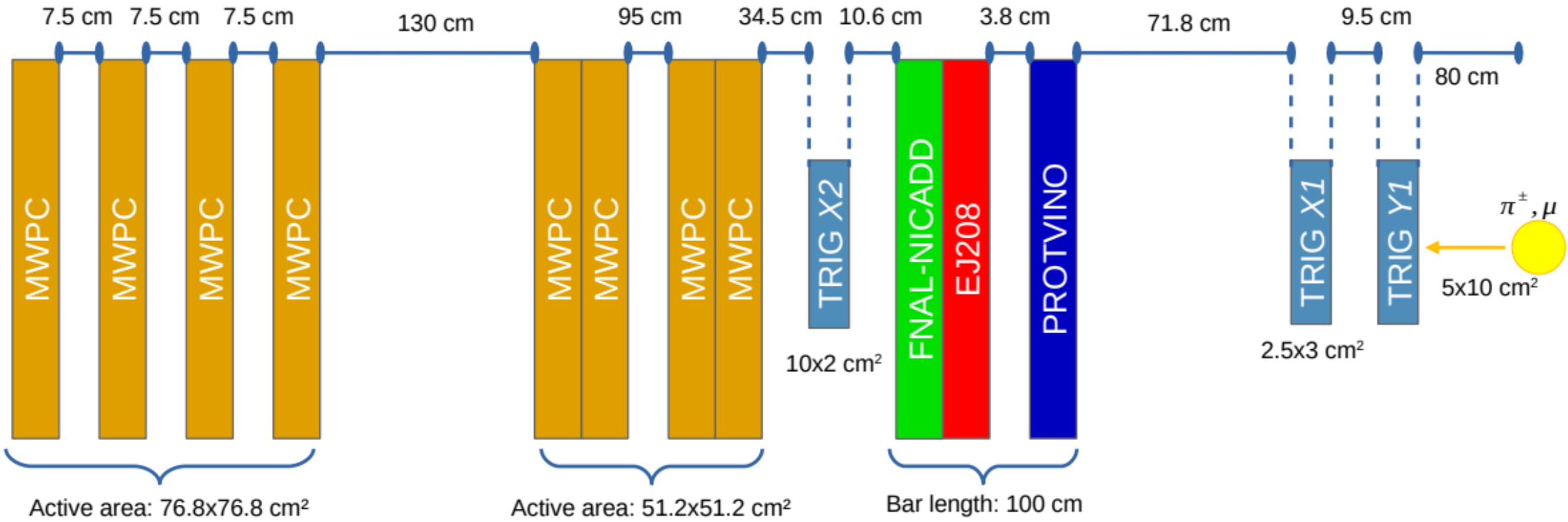
Average number of photons (γ): ≈ 40

Test Beam 2023 – Setup

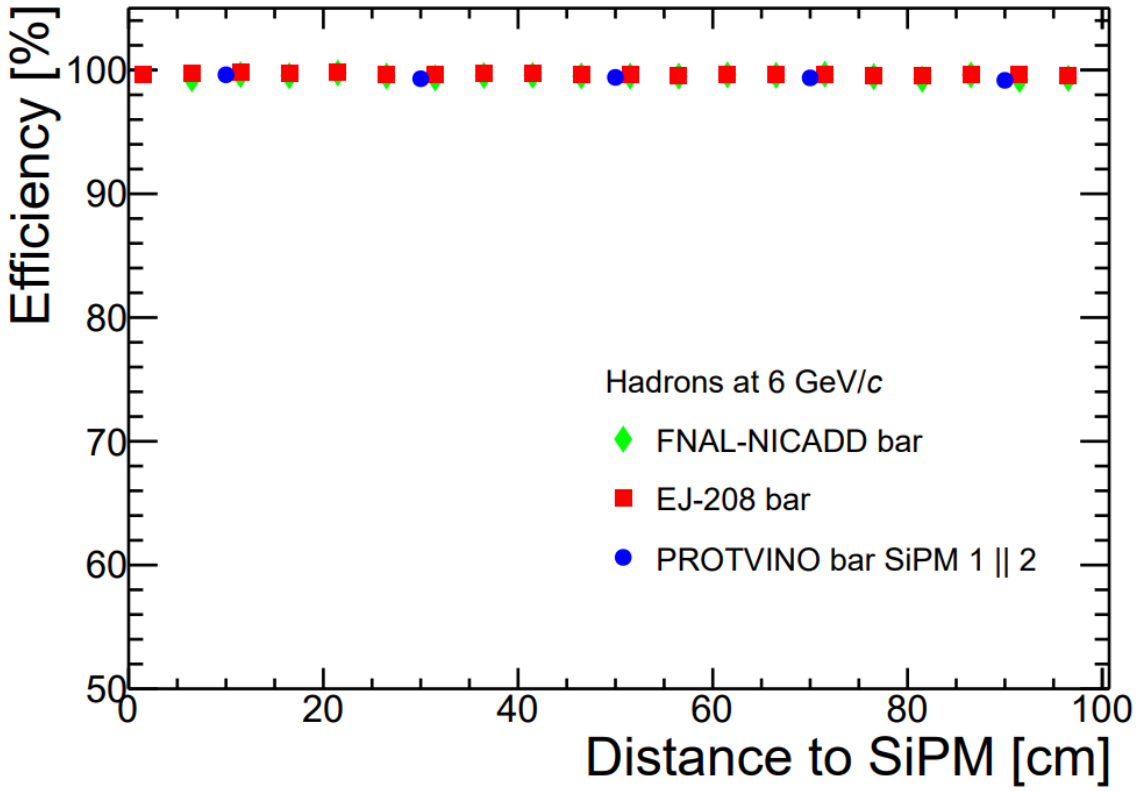


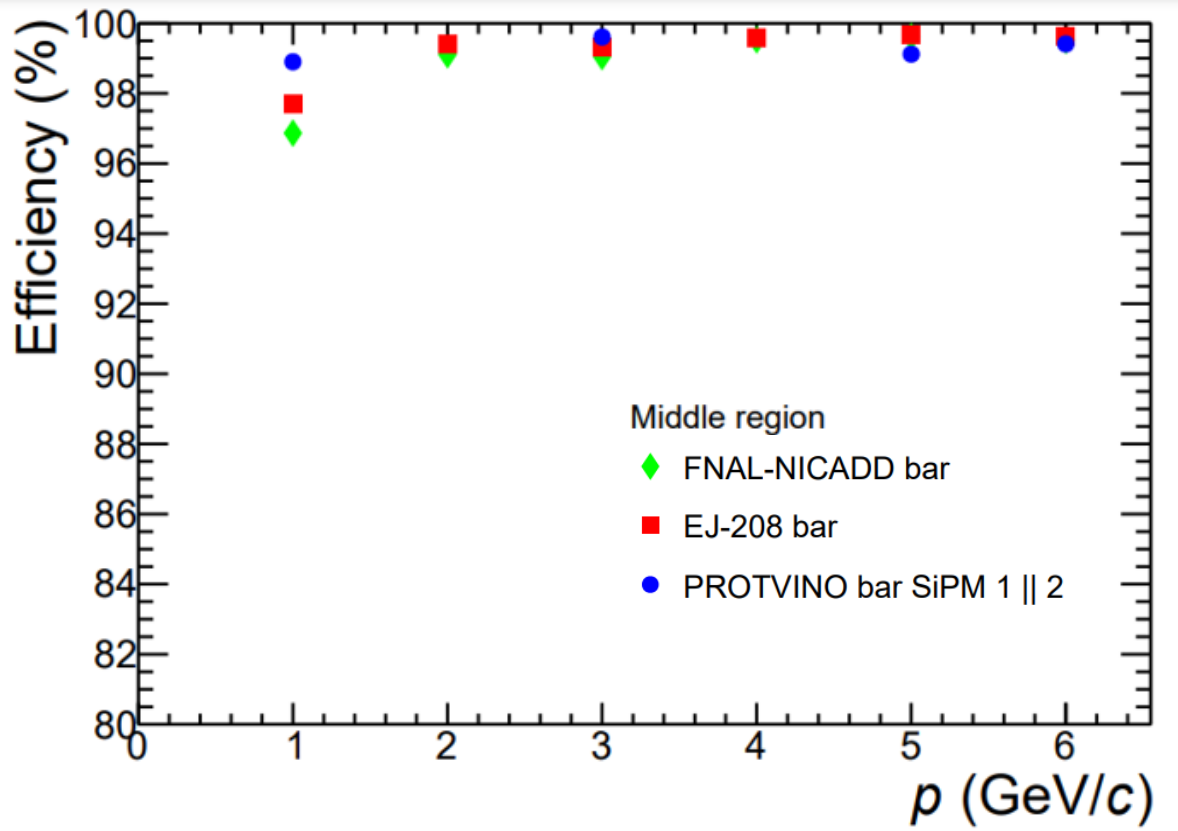
ACORDE

Test Beam 2023 – Setup



Test Beam 2023 – Paper results





Ruben Alfaro et al 2024 JINST 19 T04006 **[3]**

Test Beam 2024

Period: October 9 to October 16, 2024

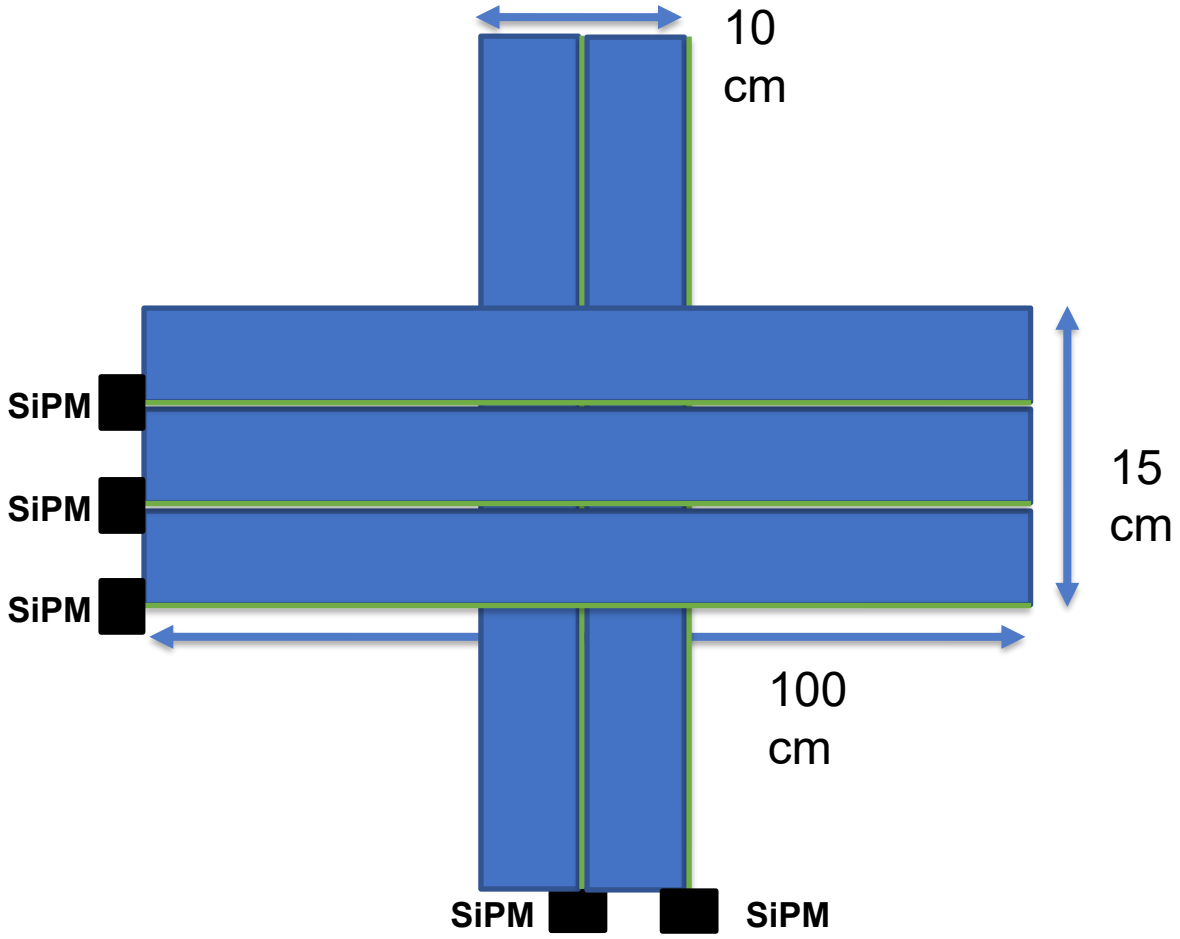
Location: T10 beamline at the CERN PS facility

Prototype:

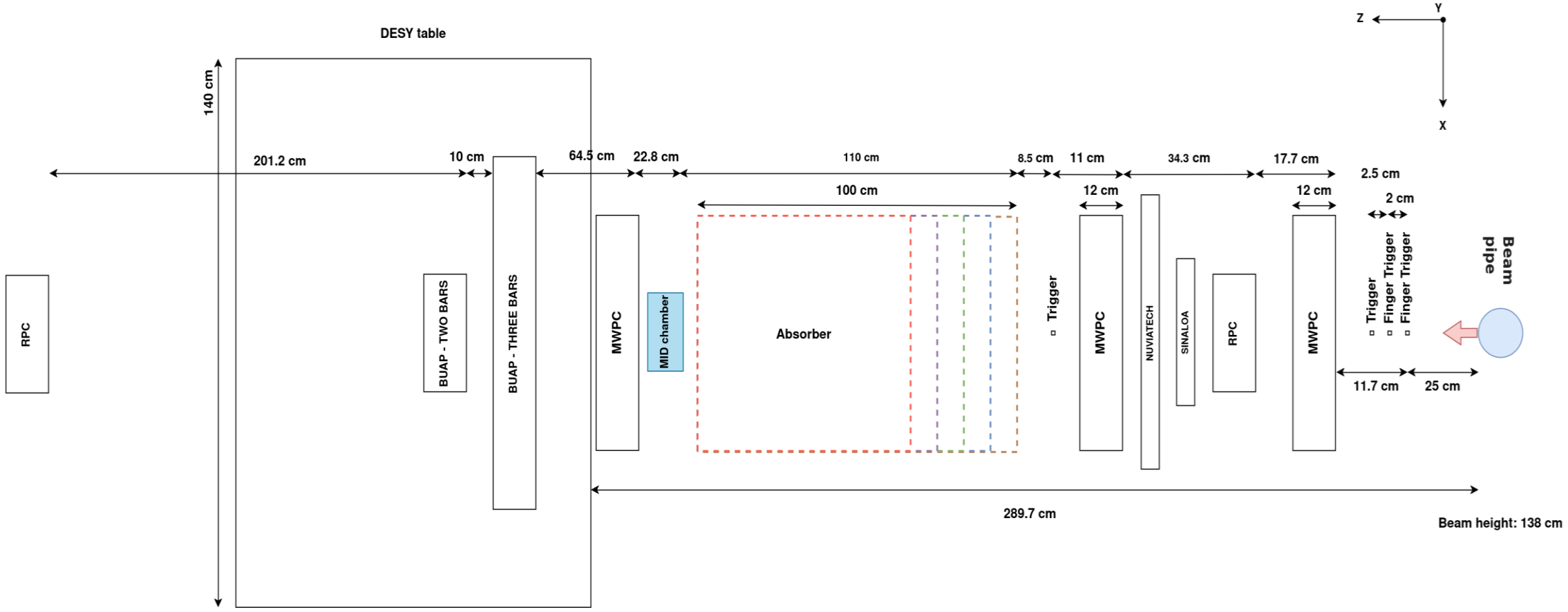
- Five plastic scintillator bars. First layer with three bars and second layer with two bars.
- Bar dimensions: 100 × 5 × 1 cm³
- SiPMs: SensL C-series 6×6 mm².
- One SiPM per bar
- Three Kuraray Y-11(200) WLS fibers per bar

Goals:

- Evaluate detector performance with the absorber scan and energy scan
- Optimize light collection and electronics integration
- Validate the prototype design for the MuonID system



Test Beam 2024 – Setup



Test Beam 2024 – Setup

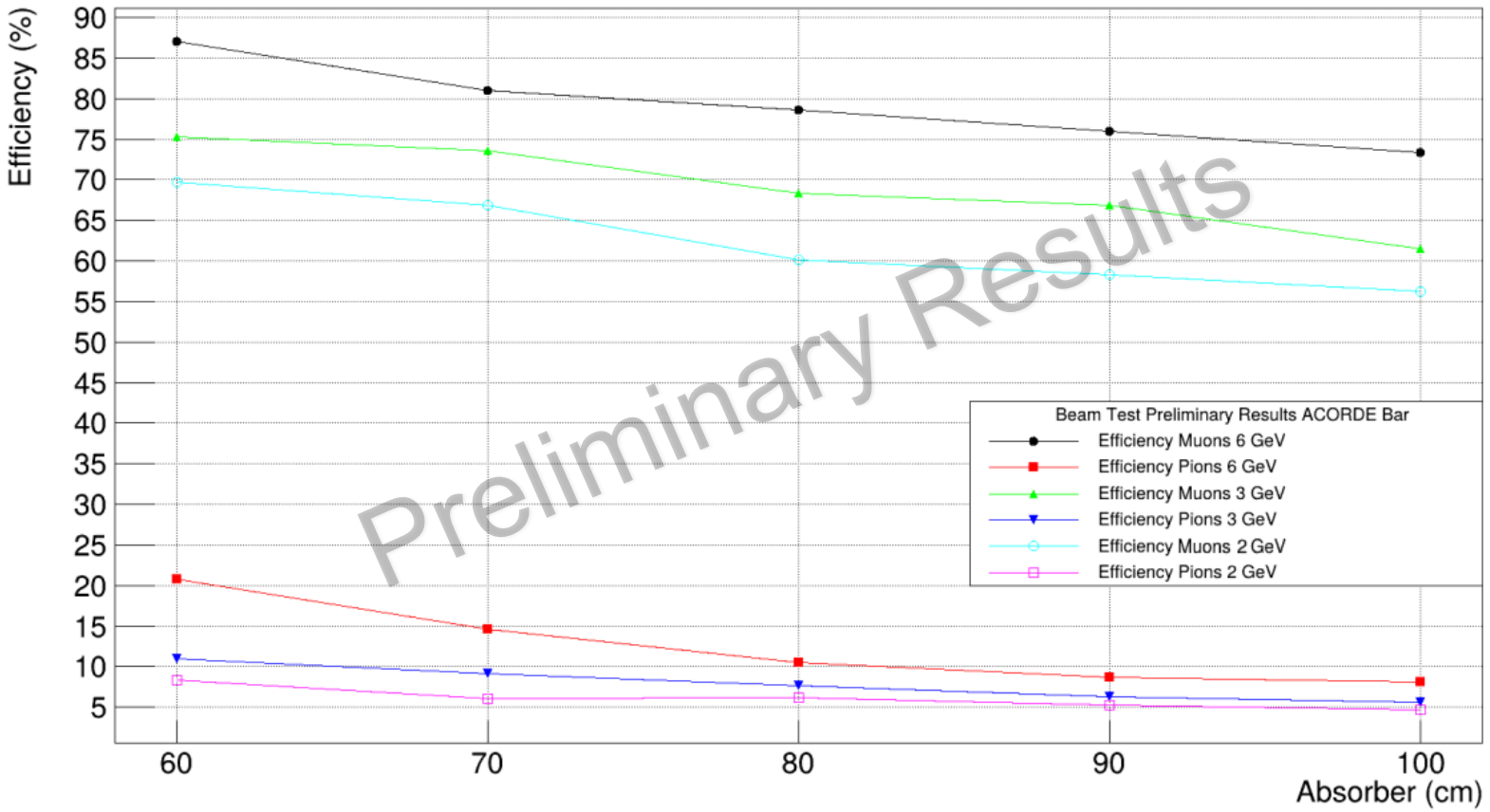
ACORDE

Test Beam 2024 – Preliminary Results

For pions, the efficiency is notably low and decreases further with increasing absorber length, which reduces the number of particles passing through.

In contrast, muons show higher efficiency; however, as the energy increases, the beam composition exhibits greater pion contamination.

Determining the acceptance factor for our module remains an open task, and we are actively working on corresponding simulations.



Test Beam 2025

Period: July 30 to August 13, 2025

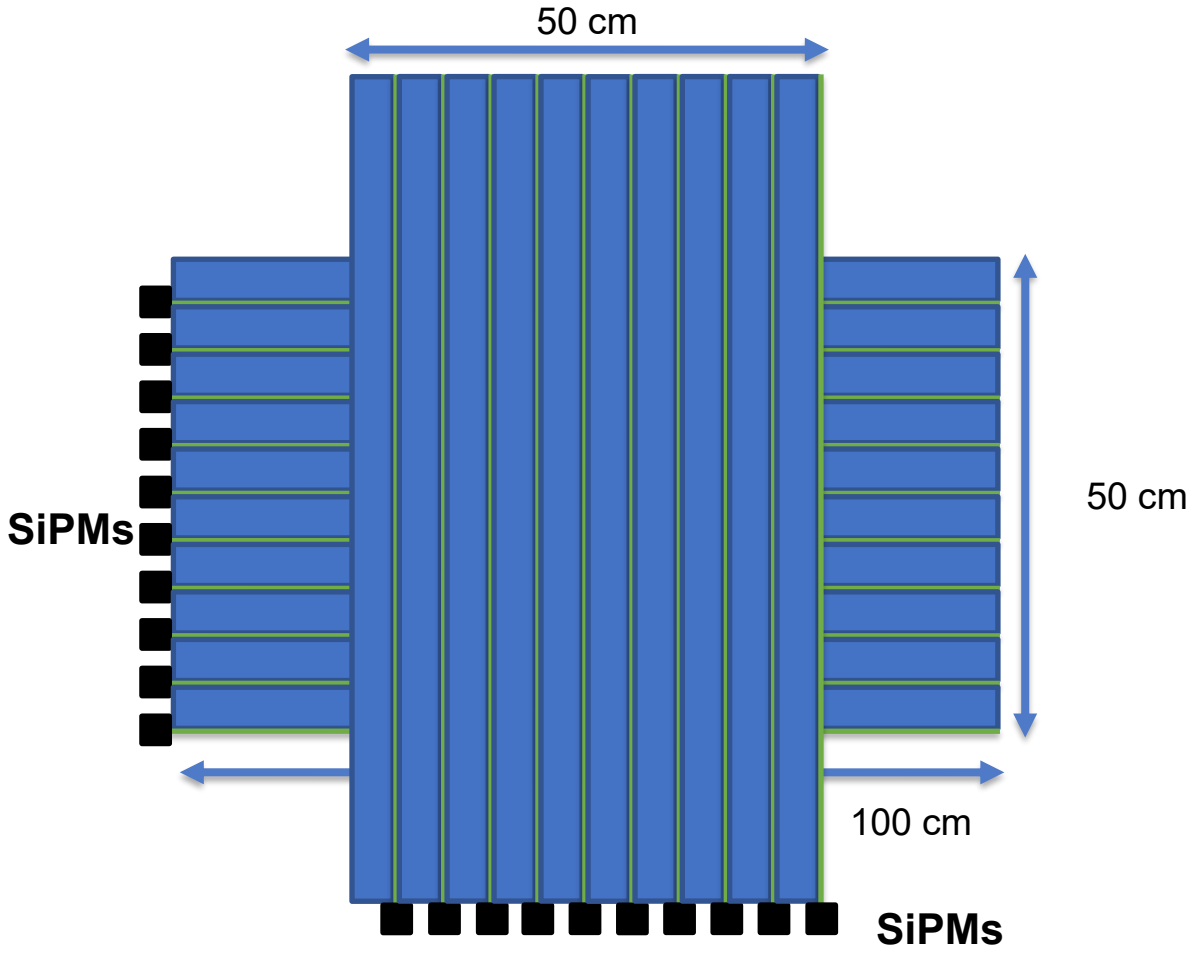
Location: T10 beamline at the CERN PS facility

Prototype:

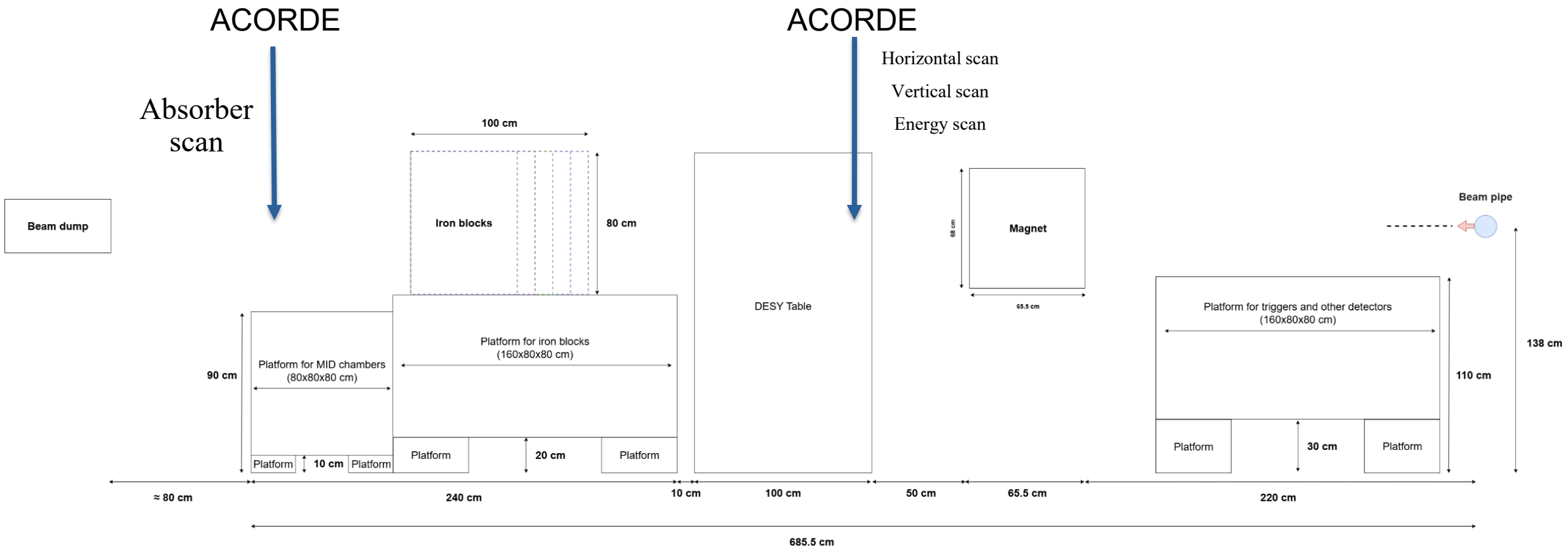
- Two layers of ten plastic scintillator bars each
- Bar dimensions: 100 × 5 × 1 cm³
- SiPMs: SensL C-series, both 6×6 mm² and 3×3 mm²
- One SiPM per bar
- Three Kuraray Y-11(200) WLS fibers per bar

Tests performed:

- Efficiency and energy scan in two orientations: vertical, and horizontal
- Efficiency and energy scan in different sectors in the arrangement.
- Absorber scan with pions and muons at different beam energies



Test Beam 2025 – Setup



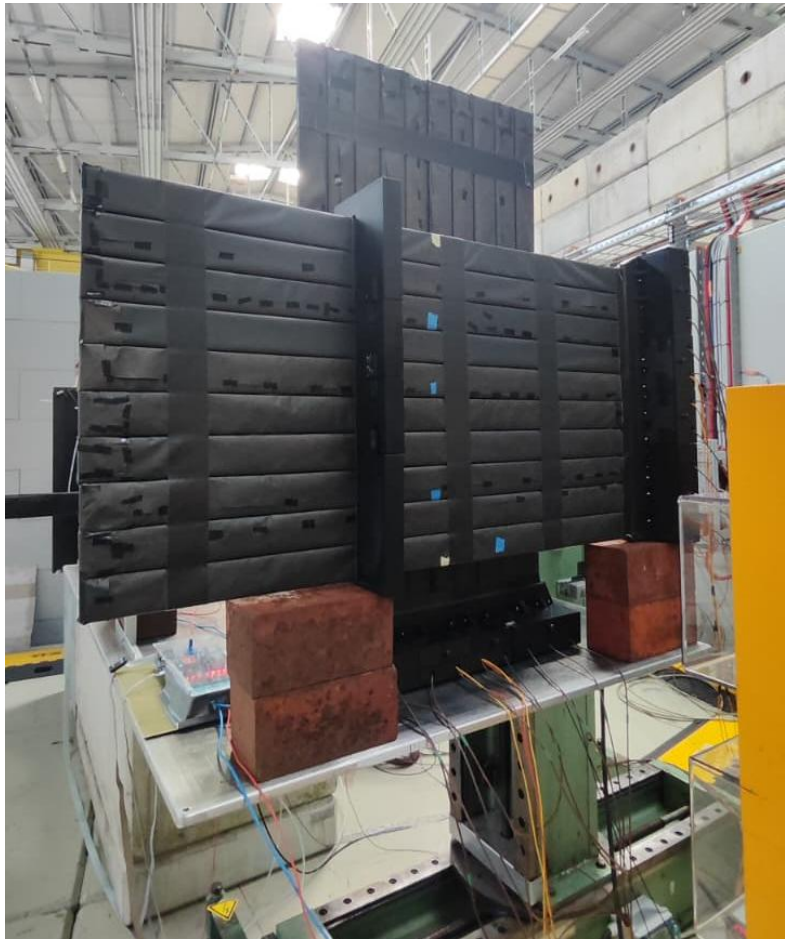
Test Beam 2025 – Setup

ACORDE

ACORDE

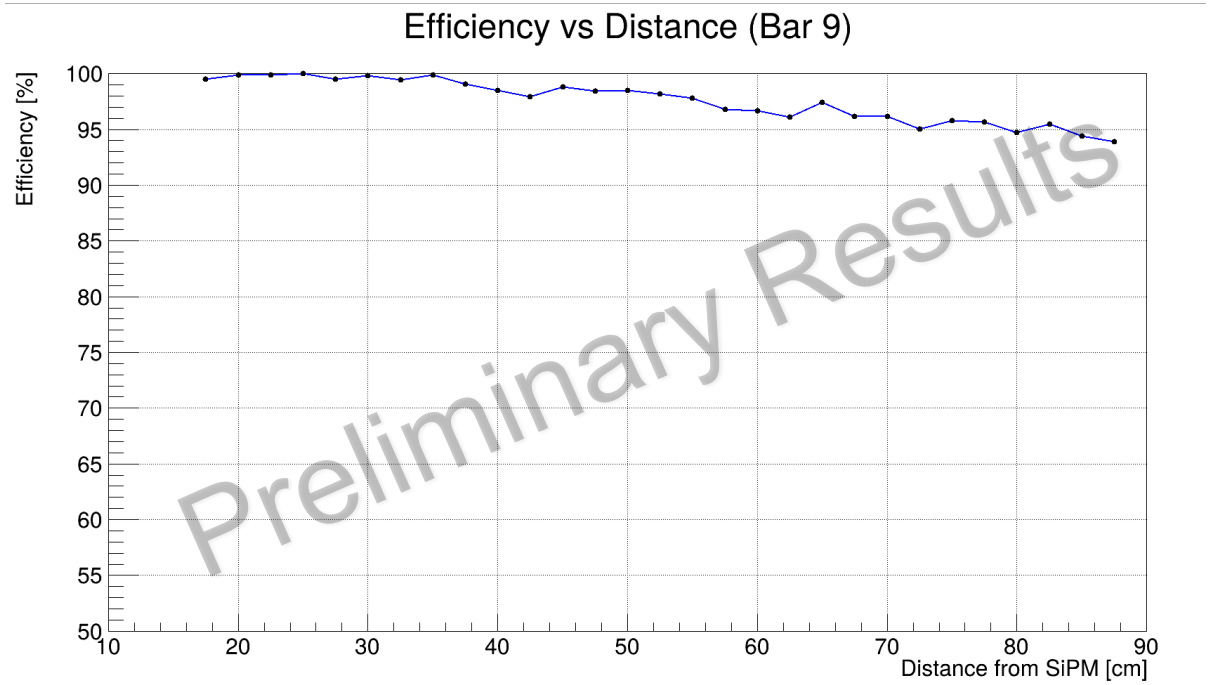
Test Beam 2025 – Setup

Prototype installed on the DESY table



Prototype installed behind the absorber

Test Beam 2025 – Preliminary Results

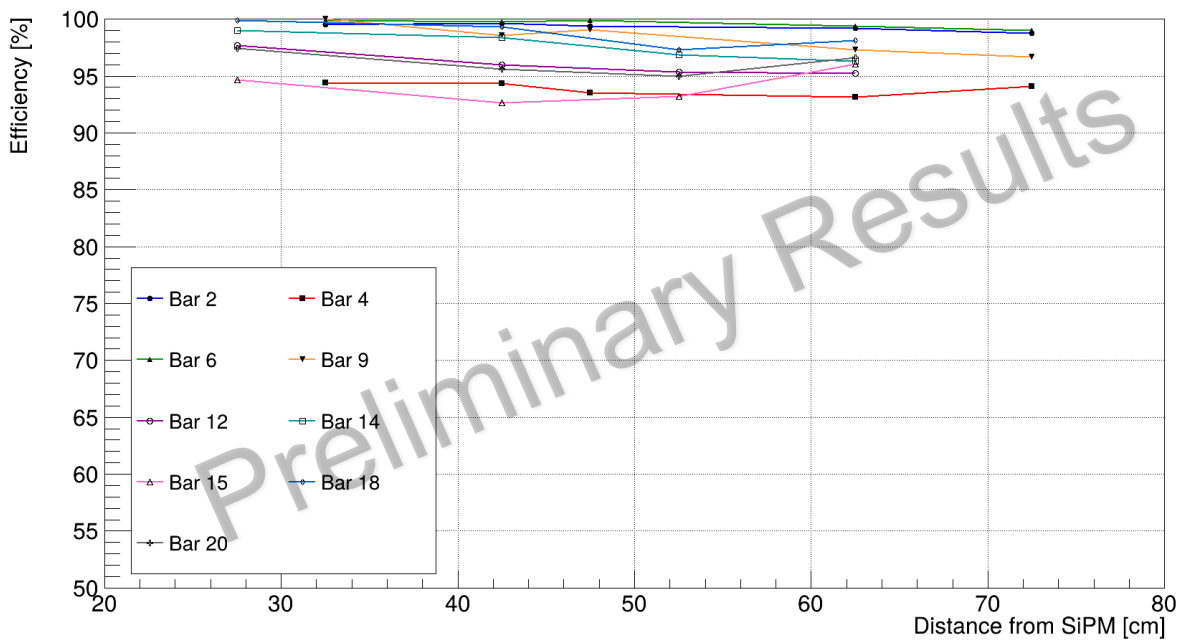


Horizontal Scan with Pions @ 6 GeV

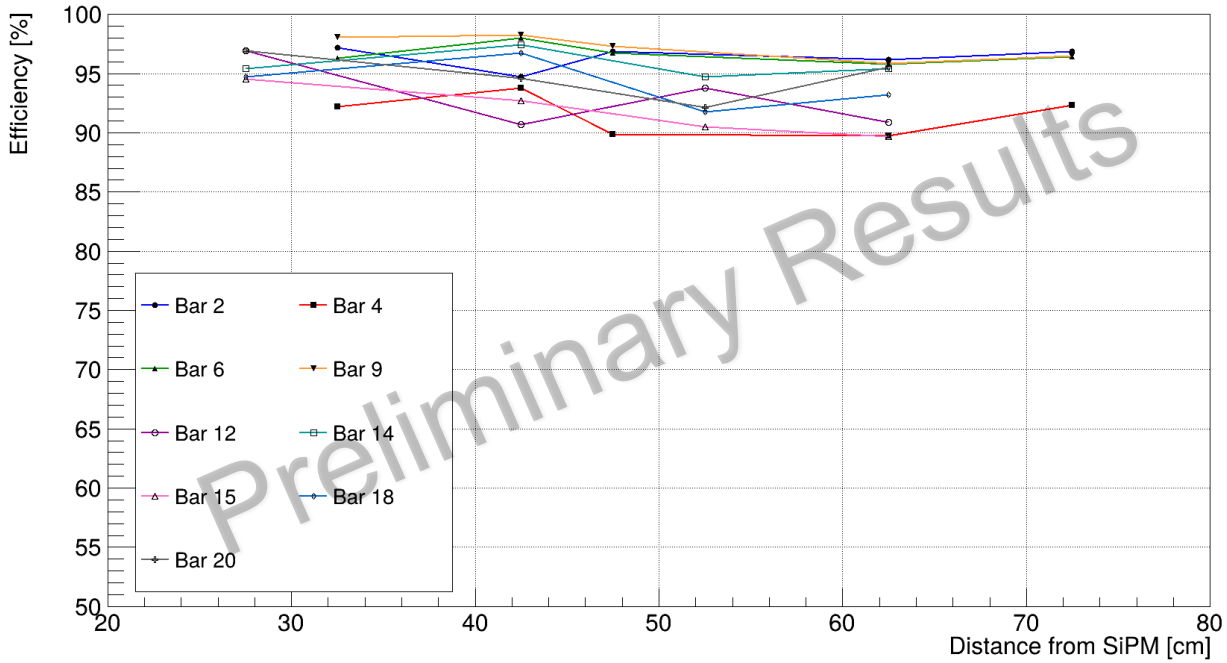
Vertical Scan with Pions @ 6 GeV

In the horizontal scan, the efficiency slightly decreases with distance. In the vertical scan, however, the efficiency drops in the middle of the bar and then increases again. This behavior might be related to coupling issues between the SiPMs and the WLS fibers. We are currently working on improving the assembly method to minimize human errors during coupling.

Test Beam 2025 – Preliminary Results



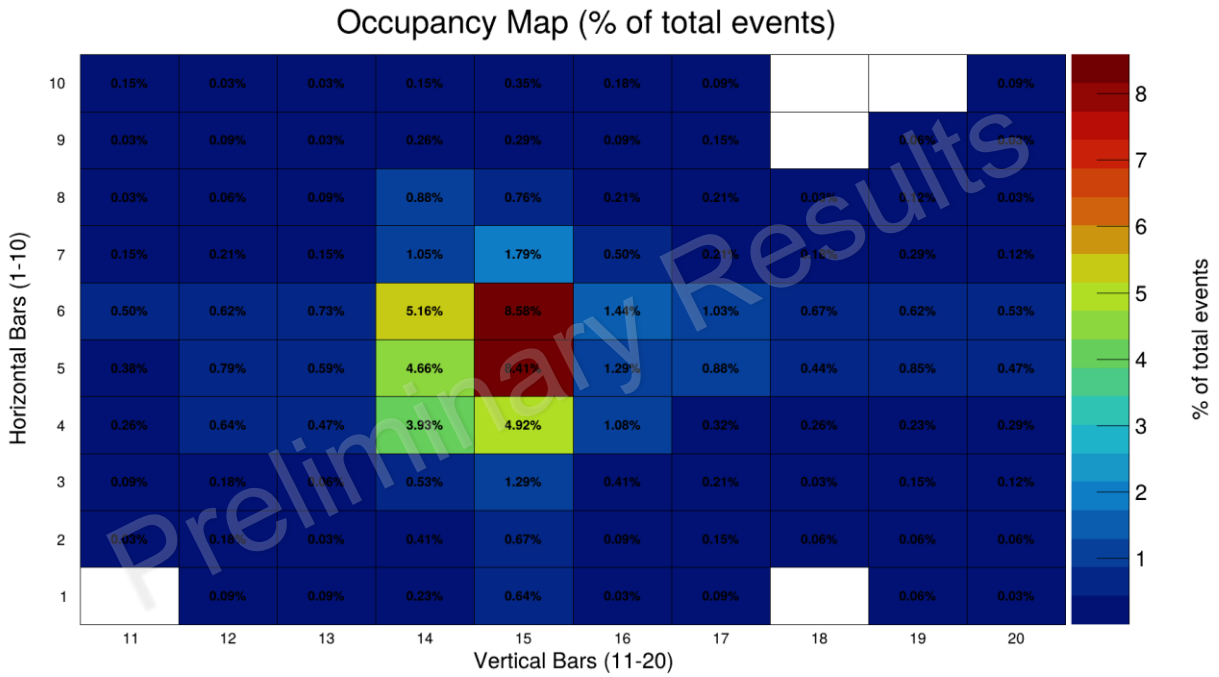
Efficiency with Pions @ 6 GeV

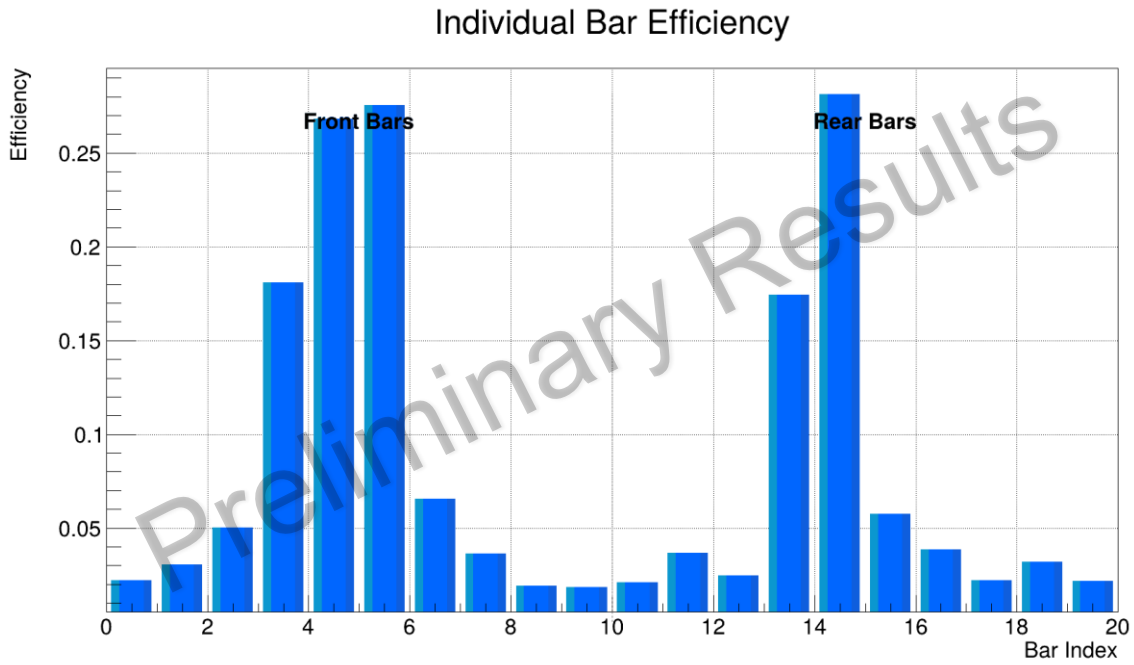


Efficiency with Pions @ 3 GeV

The efficiency of each bar is different, indicating that the coupling was not performed uniformly across all bars. This will be improved in the next prototypes. Another source of error is that the trigger behind the bars was wider than the bar itself. For this reason, the efficiency decreases at lower energies, as the beam spot becomes wider. This effect can be corrected through simulations, and we are currently working on it.

Test Beam 2025 – Preliminary Results



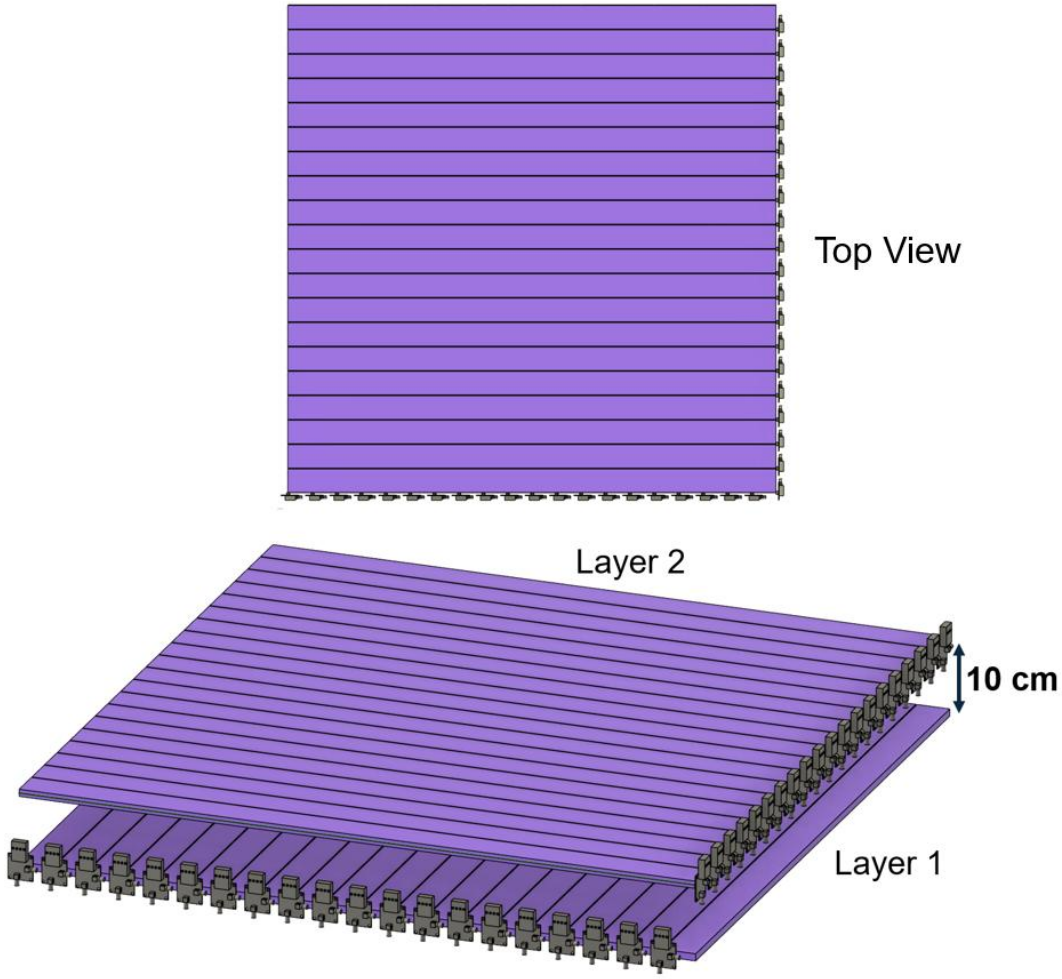


The beam was centered between bars 14 and 15 horizontally, and bars 4, 5, and 6 vertically.

Data analysis of the absorber scan is still in progress.

Plans

- Finalize data analysis of this year's test beam.
- Compare the data with simulations and determine detector acceptance.
- Test this year's test beam prototype with cosmics rays.
- Improve the coupling of the SiPMs with the WLS fibers.
- Desing and construct a robust mechanical structure.
- Assemble the full MID module (40 bars, 20 in each layer)



Thank you!

Questions or comments?

Bibliography

[1]. ALICE Collaboration. Letter of intent for ALICE 3: A next generation heavy-ion experiment at the LHC. Technical report, CERN, Geneva, Mar 2022.

[2]. A. Ortíz Velázquez. MID WP: Summary. 3rd ALICE Upgrade Week. Technical report, CERN, Geneva. May, 2023.

[3]. R. Alfaro et al. Characterisation of plastic scintillator paddles and lightweight MWPCs for the MID subsystem of ALICE 3. JINST 19(04):T04006, 2024.

Backup

Test Beam 2023 – Results

Distance from SiPM (cm)	Efficiency (%)
	SiPM1 || SIPM 2
10	99.62
30	99.30
50	99.41
70	99.37
90	99.17

Momentum (GeV/c)	Efficiency (%)
	SiPM1 || SIPM 2
1	98.90
3	99.61
5	99.12
6	99.41
10	99.03

Assembling

Assembly components:

- Three WLS fibers attached to one of the edges of each bar.
- One layer of Mylar reflective film.
- Two layers of Tyvek black paper.

Mechanical structure:

- 3D-printed housing
- Protects the SiPMs from external light.
- Allows alignment of the SiPMs with the ends of the WLS fibers.
- Gap between the bars of ≈ 2 mm

Test Beam 2024 – Preliminary Results

Absorber (cm)	6 GeV		3 GeV		2 GeV	
	Muon Efficiency (%)	Pion Efficiency (%)	Muon Efficiency (%)	Pion Efficiency (%)	Muon Efficiency (%)	Pion Efficiency (%)
60	87.01 ± 0.19	20.75 ± 0.27	75.31 ± 0.31	10.91 ± 0.12	69.69 ± 0.17	8.33 ± 0.10
70	81.03 ± 0.11	14.58 ± 0.16	73.54 ± 0.20	9.11 ± 0.09	68.88 ± 0.30	6.03 ± 0.07
80	78.59 ± 0.23	10.51 ± 0.09	68.30 ± 0.22	7.68 ± 0.08	60.10 ± 0.36	6.17 ± 0.08
90	75.93 ± 0.27	6.33 ± 0.08	66.81 ± 0.18	6.33 ± 0.07	58.35 ± 0.32	5.23 ± 0.07
100	73.39 ± 0.22	5.55 ± 0.07	61.45 ± 0.17	5.55 ± 0.06	56.24 ± 0.29	4.71 ± 0.05

Assembling

Assembly components:

- Three WLS fibers attached to one of the edges of each bar.
- One layer of Mylar reflective film.
- Three layers of Tyvek black paper.

Mechanical structure:

- 3D-printed housing
- Protects the SiPMs from external light.
- Allows alignment of the SiPMs with the ends of the WLS fibers.
- Gap between the bars of ≈ 2.5 mm

Test Beam 2025 – Preliminary Results

Scans Performed

Vertical Scan
Horizontal Scan
Energy Scan

							(0, 66.5)	(5, 66.5)							SiPMs
				(-25, 61.5)	(-20, 61.5)	(-15, 61.5)	(-10, 61.5)	(-5, 61.5)	(0, 61.5)	(5, 61.5)	(10, 61.5)	(15, 61.5)	(20, 61.5)		Bar 1
				(-25, 56.5)	(-20, 56.5)	(-15, 56.5)	(-10, 56.5)	(-5, 56.5)	(0, 56.5)	(5, 56.5)	(10, 56.5)	(15, 56.5)	(20, 56.5)		Bar 2
				(-25, 51.5)	(-20, 51.5)	(-15, 51.5)	(-10, 51.5)	(-5, 51.5)	(0, 51.5)	(5, 51.5)	(10, 51.5)	(15, 51.5)	(20, 51.5)		Bar 3
				(-25, 46.5)	(-20, 46.5)	(-15, 46.5)	(-10, 46.5)	(-5, 46.5)	(0, 46.5)	(5, 46.5)	(10, 46.5)	(15, 46.5)	(20, 46.5)		Bar 4
				(-25, 41.5)	(-20, 41.5)	(-15, 41.5)	(-10, 41.5)	(-5, 41.5)	(0, 41.5)	(5, 41.5)	(10, 41.5)	(15, 41.5)	(20, 41.5)		Bar 5
				(-25, 36.5)	(-20, 36.5)	(-15, 36.5)	(-10, 36.5)	(-5, 36.5)	(0, 36.5)	(5, 36.5)	(10, 36.5)	(15, 36.5)	(20, 36.5)		Bar 6
				(-25, 31.5)	(-20, 31.5)	(-15, 31.5)	(-10, 31.5)	(-5, 31.5)	(0, 31.5)	(5, 31.5)	(10, 31.5)	(15, 31.5)	(20, 31.5)		Bar 7
				(-25, 26.5)	(-20, 26.5)	(-15, 26.5)	(-10, 26.5)	(-5, 26.5)	(0, 26.5)	(5, 26.5)	(10, 26.5)	(15, 26.5)	(20, 26.5)		Bar 8
(-45, 21.5)	(-40, 21.5)	(-35, 21.5)	(-30, 21,5)	(-25, 21.5)	(-20, 21.5)	(-15, 21.5)	(-10, 21.5)	(-5, 21.5)	(0, 21.5)	(5, 21.5)	(10, 21.5)	(15, 21.5)	(20, 21.5)	(25, 21.5)	(30, 21.5)				Bar 9
				(-25, 16.5)	(-20, 16.5)	(-15, 16.5)	(-10, 16.5)	(-5, 16.5)	(0, 16.5)	(5, 16.5)	(10, 16.5)	(15, 16.5)	(20, 16.5)						Bar 10
									(0, 11.5)	(5, 11.5)					
									(0, 6.5)	(5, 6.5)					
				Bar 20	Bar 19	Bar 18	Bar 17	Bar 16	Bar 15	Bar 14	Bar 13	Bar 12	Bar 11	SiPMs	

Horizontal scan was performed on bar 9.

Vertical scan was performed on bar 14.

Energy scan was performed on the sectors marked in green.