Characterization of a Compact 16×16 Interleaved Scintillating Bar Detector

Experimental heritage and a compact detector path toward close-range muography

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Experimental heritage from NA64

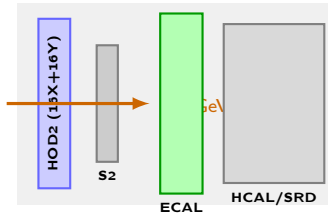
Experiment: NA64, fixed-target at the CERN SPS H4 beamline.

- 100 GeV electron beam; search for dark sector mediators.
- **Hod2018 (HOD2):** 16 X + 16 Y MPPC-scintillator strips for beam tracking.
- Built by the Chilean team (P. Ulloa et al.).
- Beam-test characterization of a compact scintillating-bar hodoscope.

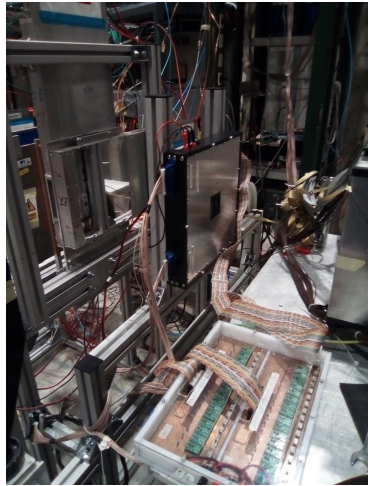
Role in this talk: HOD2 data provide a controlled beam-test baseline for the detector technology later adapted toward muography.

[EXPERIMENTAL] Data: NA64 Collaboration, 2018 H4 test beam, CERN SPS.
Analysis: R. Carrera, 25 May 2026.
[ONGOING] Same detector lineage; exact unit identity/evolution is being checked.

H4 beamline (schematic)



HOD2 in the NA64 H4 beam area [EXPERIMENTAL]



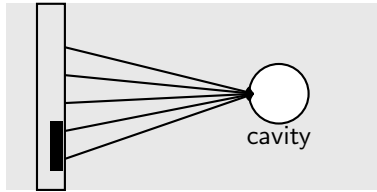
HOD2 installed in the NA64 fixed-target setup, CERN SPS H4 beamline (2018 test beam). Same MPPC + scintillating-bar technology used as the muography baseline.

Why compact muography?

Motivation: compact instruments make geometry characterization important.

- Mining targets: veins, cavities, stopes, and pillars.
- Boreholes and galleries demand compact, deployable telescopes.
- Smaller apertures increase the value of controlled alignment and acceptance studies.

Consequence: detector response and geometry both matter along the path toward field validation.



Beam-test system efficiency: 99.28% [EXPERIMENTAL]

Beam-test system efficiency, run 3661:

$$\varepsilon = 99.28\%$$

Definition:

$$\frac{N(\mathrm{S2} \wedge \mathrm{HOD2})}{N(\mathrm{S2})}$$

- 126 307 total events.
- 100 GeV e^-, CERN H4, near-normal incidence.
- S2 $>$ 700 ADC.
- HOD2 hit $\equiv$ any X-strip $\wedge$ Y-strip $>$ 50 ADC.
- Robust response under controlled NA64 beam conditions.

Caveat

This is a beam-test system efficiency, not a cosmic-muon efficiency.
[FUTURE WORK] A dedicated cosmic-muon measurement is still required for the final muography configuration.

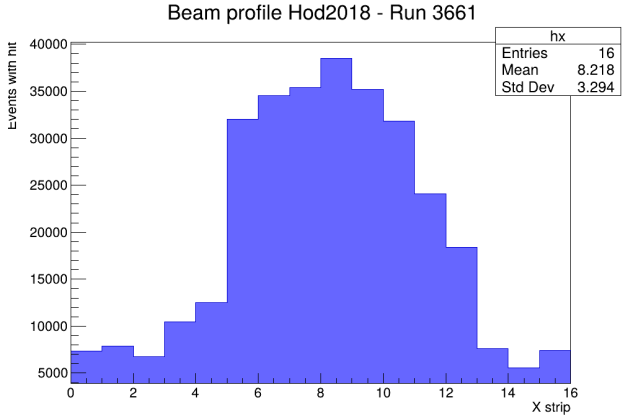
Relative response across active channels [EXPERIMENTAL]

Run 3661 channel response:

- Mean amplitude (raw SADC):
  - HOD2X: 62 ± 86 ADC
  - HOD2Y: 67 ± 60 ADC
- All 16 X + 16 Y channels active.
- Entries (X): 1 277 597; (Y): 1 192 842.

Interpretation

Relative response characterization across channels, not a complete absolute SiPM calibration.



[EXPERIMENTAL] Beam profile: hits per X-strip (amp $>$ 50 ADC).
Beam centred at strip $\sim$8 ($\approx$16–17 mm).
Credit: R. Carrera; P. Ulloa et al.; NA64.

2D hit map: active-area imaging [EXPERIMENTAL]

Experimental result: the compact active area reconstructs the beam impact distribution.

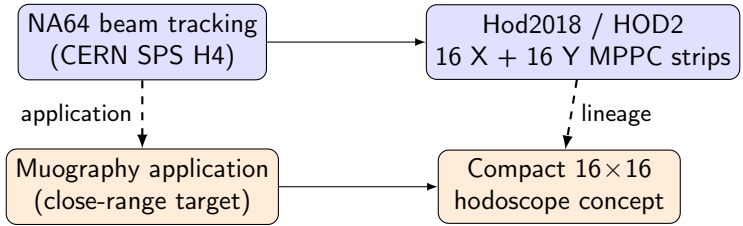
- Active area: $\approx 33 \times 33$ mm^2 (design).
- Beam spot mean: (16.8, 15.3) mm.
- Beam spot Std Dev: (5.0, 5.7) mm.
  This is beam width, not spatial resolution.
- 117 700 reconstructed 2D hits.
- Position algorithm: nearest-neighbour on port 3 strips (2 mm pitch, 16 strips).

Reconstruction note

Two physically offset layers (port 3 + port 5, 2 mm pitch each) provide a design effective granularity of 1 mm over 31 bins. **This map uses port 3 only.** [ONGOING] Combined dual-port reconstruction is a follow-up check.

[EXPERIMENTAL] HOD2 2D hit map, run 3661, port 3.
Axes: position [mm]; colour: entries/bin.
Analysis: R. Carrera, 25 May 2026.
Detector: P. Ulloa et al. (Chilean team), NA64.
Data: NA64 Collaboration, 2018 H4, CERN SPS.

From NA64 heritage to a muography detector concept



Inherited technology: MPPC readout, interleaved strip geometry, compact active area, WLS fibers.

New validation regime: cosmic muons, geological targets, deployment constraints, and dedicated laboratory characterization.

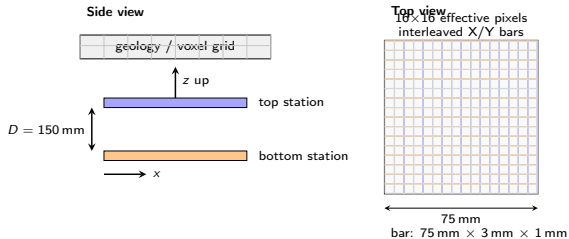
[DESIGN] Same detector lineage; exact unit identity/evolution remains under confirmation.

Compact interleaved hodoscope geometry [DESIGN]

Design relation: D trades angular granularity against acceptance.

- Two stations, interleaved 16×16 pixel readout.
- Active bars: **75 mm** length $\times$ 3 mm width $\times$ 1 mm thickness.
- Active area $\approx 33 \times 33$ mm^2; 1 mm bar overlap.
- $D = 150$ mm gives $d/D \simeq 20$ mrad angular pitch.
- Larger D improves angle but lowers Ω.

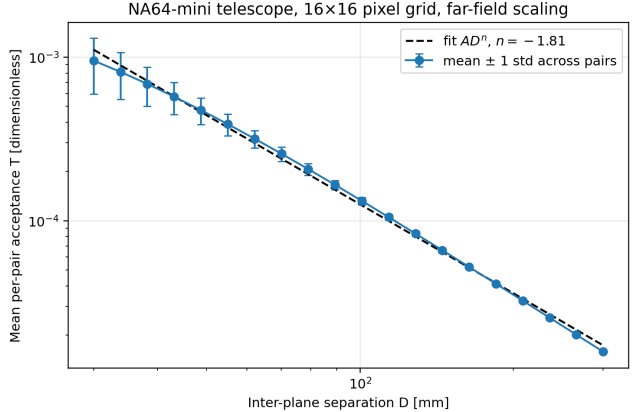
Consequence: the target and deployment constraints guide the useful geometry.



Frame convention and active-area schematic.

Geometry sets the muography exposure [SIMULATION]

- The inter-plane separation D trades angular granularity against acceptance.
- Far field: acceptance $\sim d^2/D^2$ ($1/D^2$ scaling, simulated).
- In a suitable D, this compact geometry is relevant for close-range muography.



[SIMULATION] Phase A: acceptance scan vs. inter-plane separation D.

Current characterization status

[EXPERIMENTAL] Measured in NA64 beam data

- Beam-test system efficiency: 99.28%, run 3661.
- All 16 X + 16 Y channels responsive.
- Relative mean amplitudes: 62 ADC (X), 67 ADC (Y).
- 2D beam-impact distribution reconstructed.

[SIMULATION] Demonstrated in simulation

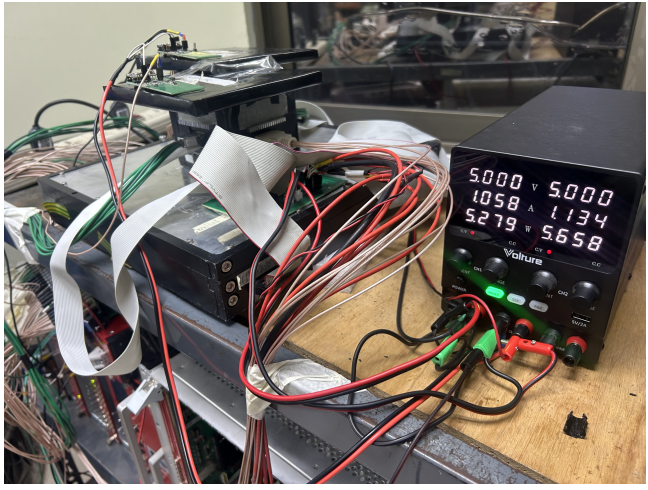
- Geometry/acceptance scan relevant to muography exposure.

[ONGOING] Dedicated follow-up

- SiPM bench: V_{br}, gain, DCR, optical crosstalk, and PDE.
- Cosmic-muon efficiency for the final configuration.
- Spatial and timing resolution measurements.
- Physical-assembly metrology.
- Shared-grid reconstruction and posterior uncertainty.
- Exact HOD2 / prototype unit identity confirmation.

Cosmic-Muon Characterization

ULS cosmic bench setup (2026) [EXPERIMENTAL]

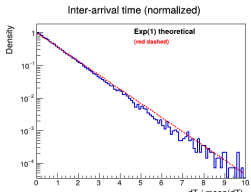


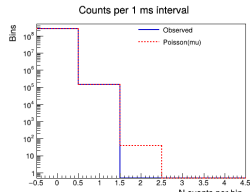
Current ULS bench: hod2018 + hod2019 stack read out with the cosmic trigger. The two scintillator trigger paddles (T1, T2) forming the T1∧T2 coincidence are visible; front-end powered at 5 V.

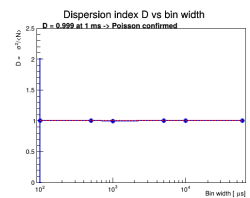
Cosmic operation verified: Poisson trigger statistics

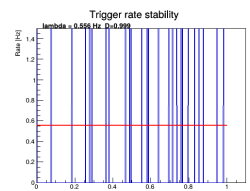
[EXPERIMENTAL]

- Trigger T1∧T2 operated stably during cosmic acquisition
- Inter-arrival times: Poisson-distributed
- Rate: $\lambda = 0.57$ Hz
- Dispersion index: $D = 0.999$ (Poisson-consistent)
- Dead time: $\tau_{\mathrm{dead}} = 1.12$ ms





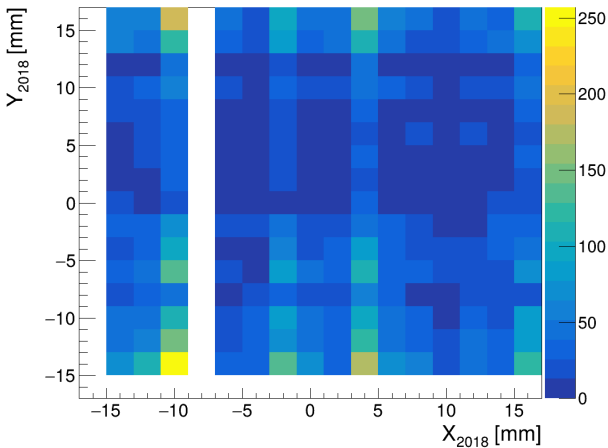




hod2018 cosmic-muon 2D impact map

[EXPERIMENTAL]

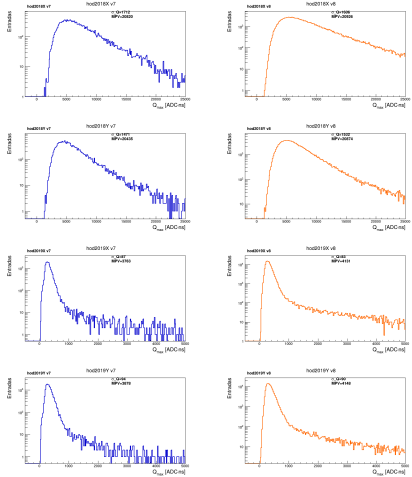
Dense cosmic-muon impact map (8073 events):



hod2018 cosmic-muon MIP spectrum (Landau)

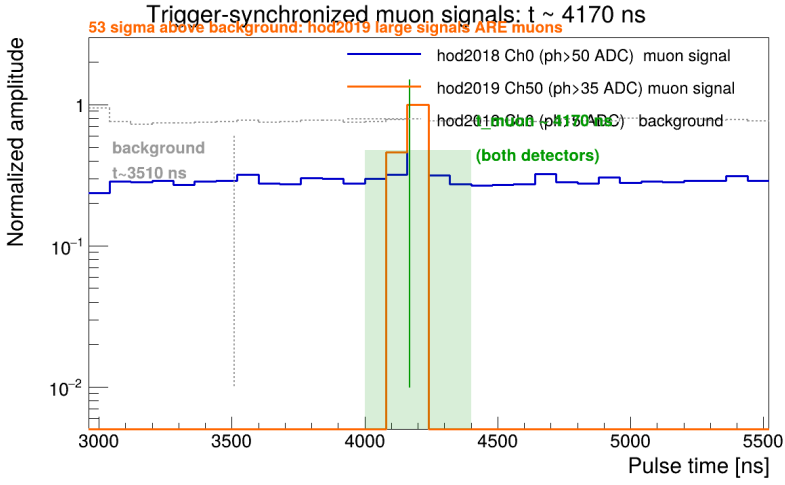
[EXPERIMENTAL]

Charge spectrum showing clear MIP (minimum ionizing particle) peak:



Muons confirmed in both hodoscopes: time-synchronization test

[EXPERIMENTAL]

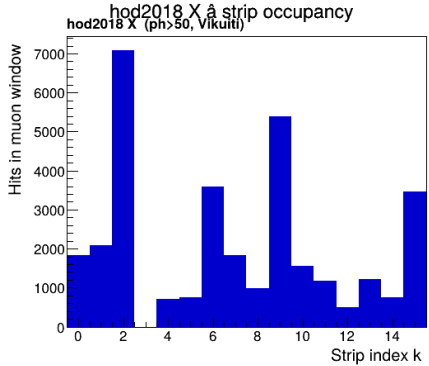


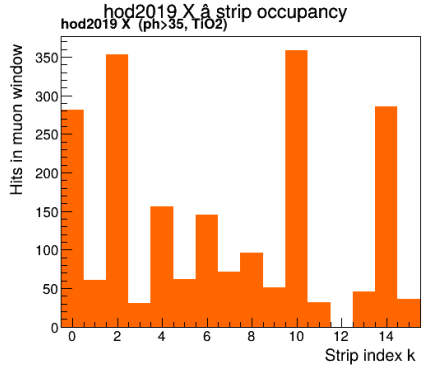
Both hod2018 and hod2019 detect the muon at the same time: $t = 4170$ ns, 53σ above background.

hod2019 efficiency is non-uniform: light-yield limitation

[EXPERIMENTAL]

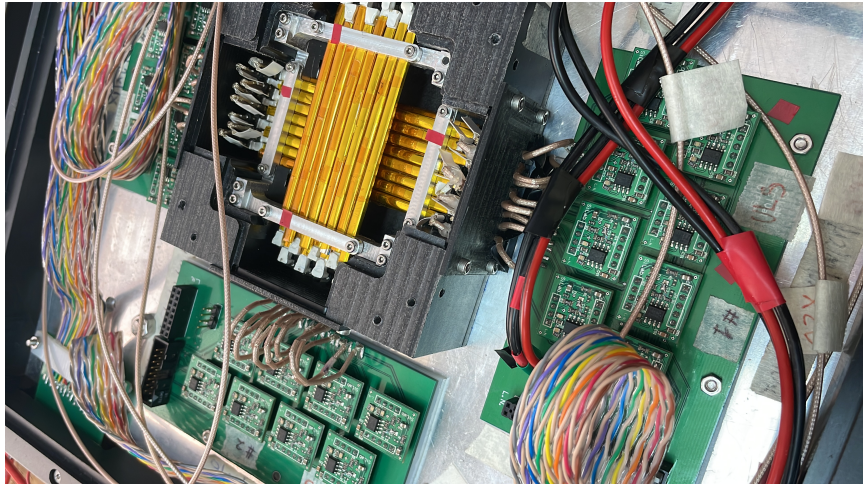
Strip occupancy comparison (hod2018 vs hod2019):





- hod2018X: 13/16 strips active (Vikuiti reflector)
- hod2019X: 4/16 strips active (TiO_2 + epoxy, insufficient light yield)
- Root cause: reflector optical coupling to MPPC

hod2018: Vikuiti-wrapped bars and custom front-end [EXPERIMENTAL]



hod2018 active bars wrapped with Vikuiti specular reflector (bright wrapping visible); custom MPPC front-end boards around the frame. Higher light yield $\Rightarrow$ 13/16 active strips.

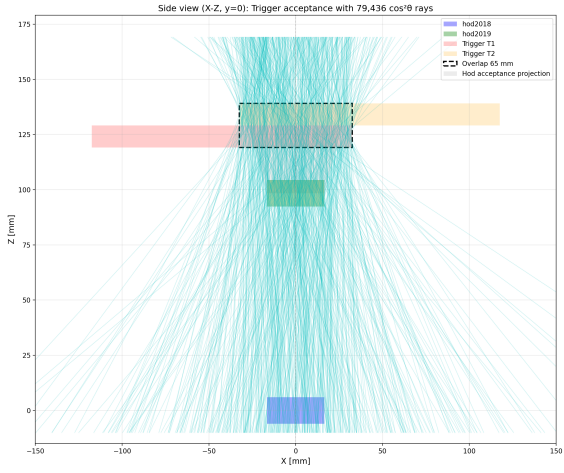
hod2019: TiO_2-painted bars [EXPERIMENTAL]

hod2019 bars finished with TiO_2 + epoxy (white coating visible). Lower light yield than Vikuiti is the root cause of the 4/16 active-strip limitation.

Geometric acceptance: trigger vs. telescope (side view)

[DESIGN] [EXPERIMENTAL]

Monte Carlo (3M cosmic rays, $\cos^2\theta$ distribution):

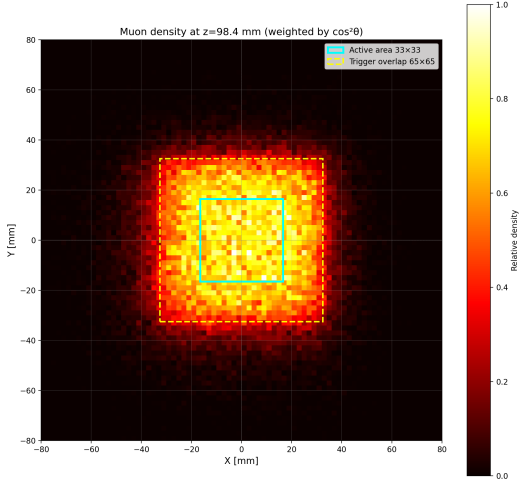


$f_{\text{both}} = 1.27\%$ of trigger rays cross both active areas simultaneously.

Muon density at z=98.4 mm (hod2019 plane)

[DESIGN] [EXPERIMENTAL]

Weighted by $\cos^2\theta$ (flux distribution):



Tracking attempt: diagnosis and corrective action

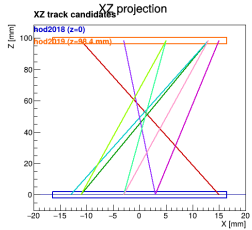
[EXPERIMENTAL]

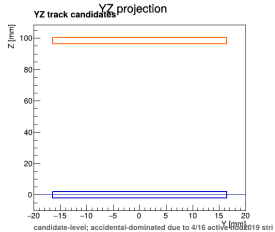
With corrected time window: $N_{3D} = 1$ track in v8 data.

Root causes:

(1) Non-uniform hod2019 efficiency (4/16 strips) ⇒ missing X∧Y coincidences

(2) Geometric constraint: $f_{\mathrm{both}} = 1.27\%$ ⇒ few simultaneous impacts





Scenario	N_{3D}	**Corr.**	**Status**
Previous (wrong window)	9	$r \approx -0.01$	Artifact
Corrected (muon window)	1	$r \approx -0.03$	Expected
With Vikuiti (proj.)	∼1480	$r > 0.5$	Viable

Take-home messages

[EXPERIMENTAL] Experimental achievements

- NA64 beam-test lineage for a compact MPPC-scintillator hodoscope.
- Beam-test system efficiency: 99.28% for run 3661.
- 16 X + 16 Y active channels; relative response means of 62/67 ADC.
- 2D beam-impact map with an explicit beam-width caveat.

[SIMULATION] Simulation and analysis achievements

- Geometry/acceptance scan ($1/D^2$ scaling) simulated; tomographic inversion is future work.

[FUTURE WORK] Next measurements and work in progress: SiPM bench, cosmic-muon efficiency, spatial/timing resolution, metrology.

Thanks to P. Ulloa, O. Soto, J. C. Helo, R. Carrera, and Universidad de La Serena.

Backup

Backup: SiPM bench characterization plan [FUTURE WORK]

Dedicated SiPM bench measurements are ongoing/planned:

- Breakdown voltage V_{br} and gain versus over-voltage.
- Dark count rate (DCR).
- Optical crosstalk.
- Photon-detection efficiency (PDE) at the WLS-sensitive wavelength.

These component-level quantities are distinct from the closed HOD2 beam-test system-efficiency result. Numerical bench results are intentionally omitted until the DAQ export is available.

Backup: parameters and provenance I

Parameter	Value
D	150 mm
Bar width d	3 mm
Bar length	75 mm (corrected; abstract had typo)
n_{channels}	16