Dual-Readout with capillary tubes

status and prospects

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on behalf of the IDEA Dual-Readout calorimeter group

CALOR 2024 Tsukuba

AIDA innova

FUTURE CIRCULAR COLLIDER

INFN PAVIA

* INFN Pavia

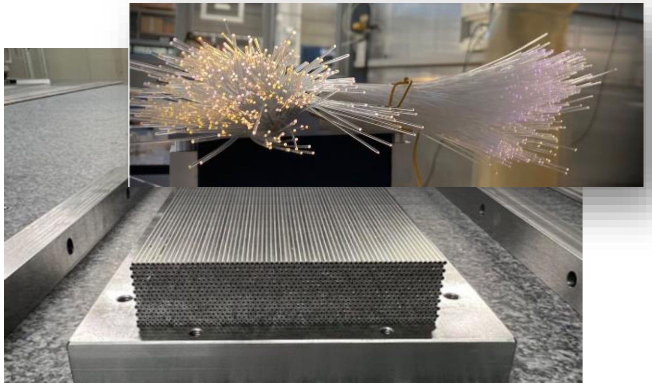
Capillary tubes - HiDRa

Dual-Readout technique reliability firmly established over 20 years of R&D (DREAM)

HiDRa(2021) - first prototype with EM-shower containment and SiPM readout

DESY (2021) and SPS (2021,23) beam tests

TODAY - HiDRa(2) assembly, the hadronic-shower prototype



2024 - SPS test beam

Completion of the 65 x 62 x 250 cm^3 demonstrator

EM shower-size prototype

Absorbers

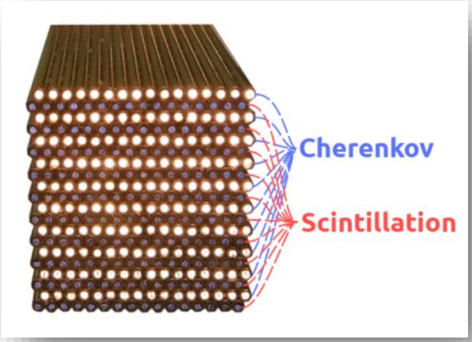
9 modules, 16x20 brass capillaries each

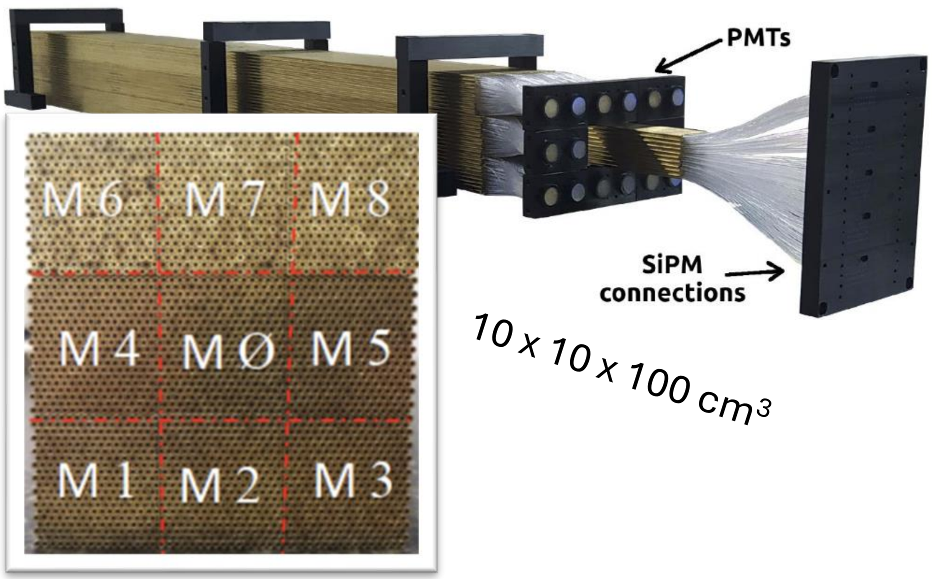
Diameter. Outer 2 mm; inner 1.1 mm

Light collection

Alternating rows of active plastic fibers:

- ‘Clear’ → Cherenkov light
- Doped → scintillation light





$10 \times 10 \times 100\ cm^3$

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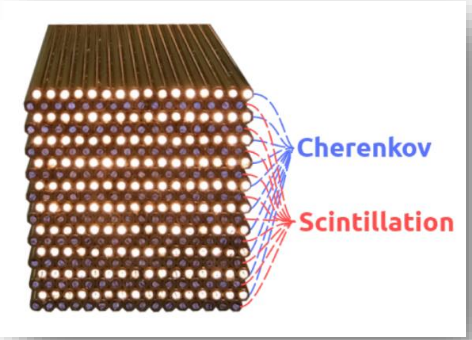
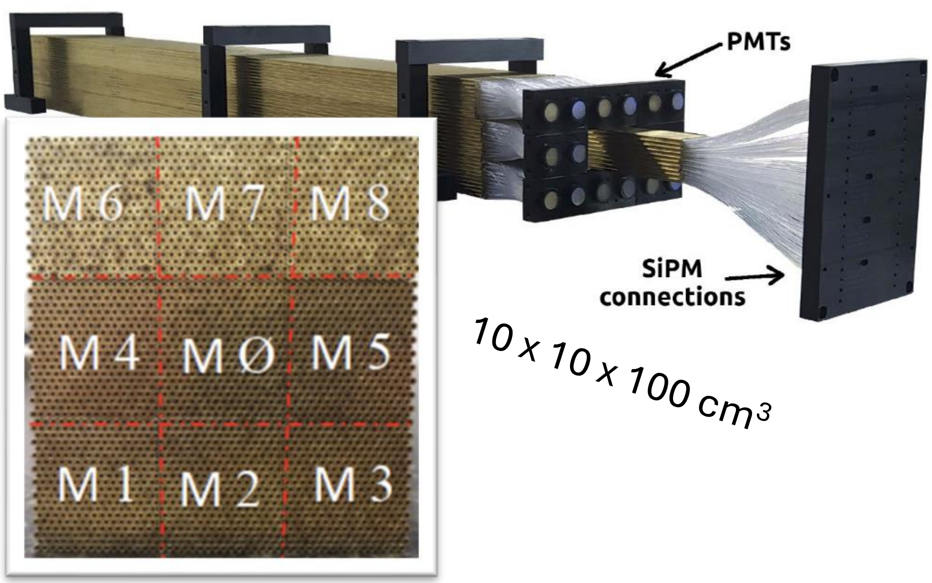




Readout

Central tower: single-fiber SiPM readout → High granularity

Pitch and cell size chosen to guarantee large dynamic range *

M1-M8 towers: PMT readout of scintillating/Cherenkov signal

Yellow filter to cut short wavelengths from scintillation **

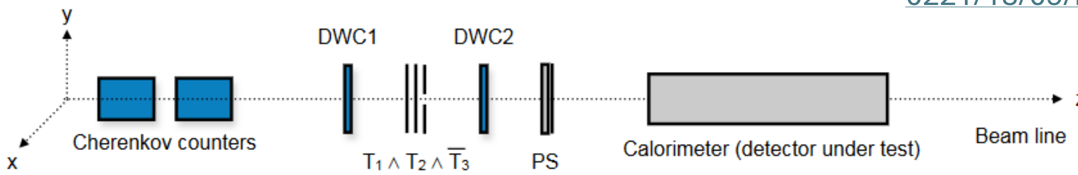
* 15 um pitch, 1.3x1.3 mm^2 sensitive area

** To make the signal less sensitive to the shower starting point

EM shower-size prototype

DOI 10.1088/1748-0221/18/09/P09021

SPS, CERN, 2021,
e^+ beam, 10 to 100 GeV

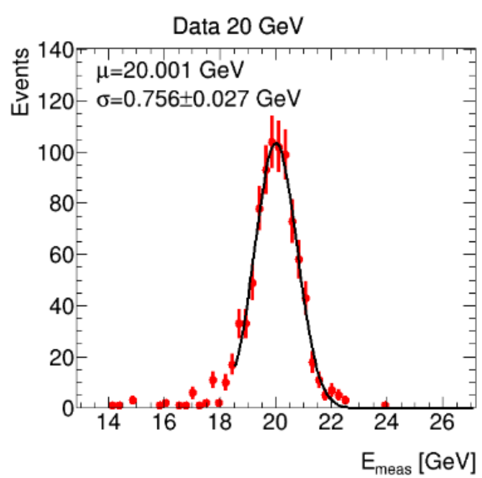


Large hadron contamination

- Purity selection with Cherenkov counters (energy < 30 GeV) + preshower auxiliary detector (far from the detector due to space constraint → increase of lateral leakage)

Full setup simulated in Geant4

Resolution highly affected by leakage induced by preshower...



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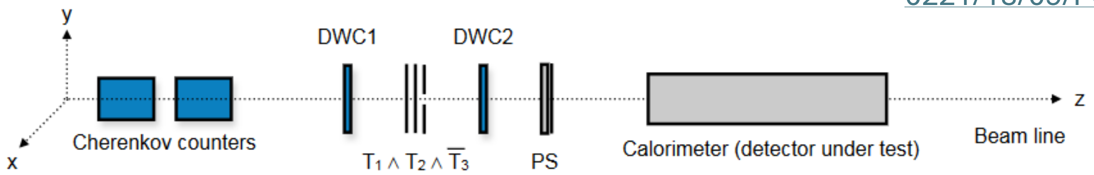

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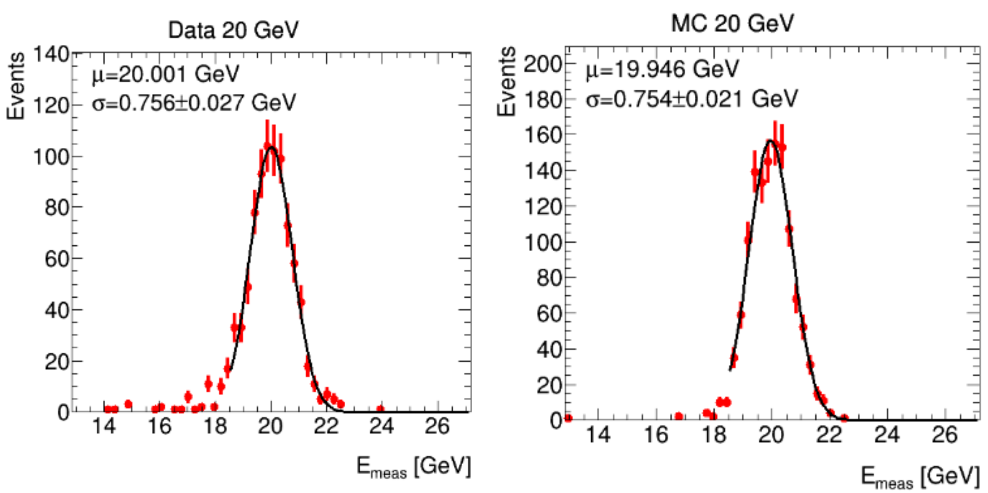

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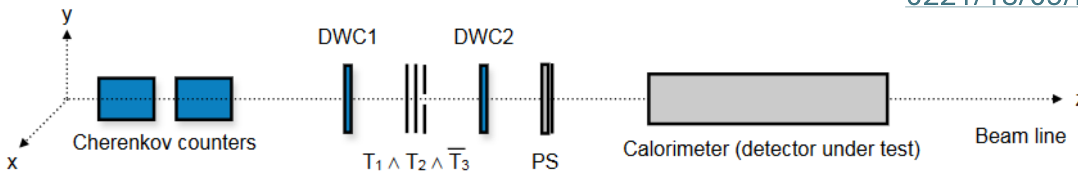

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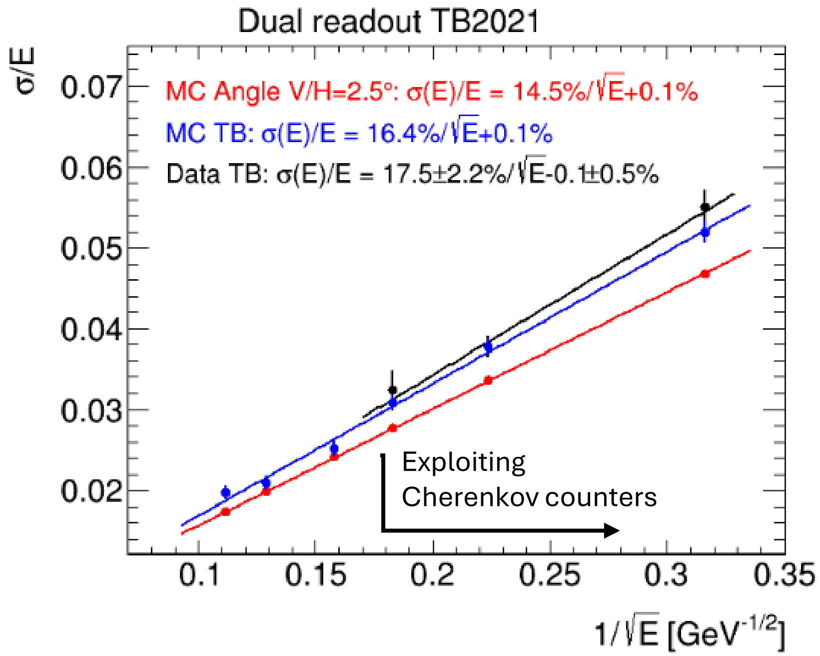

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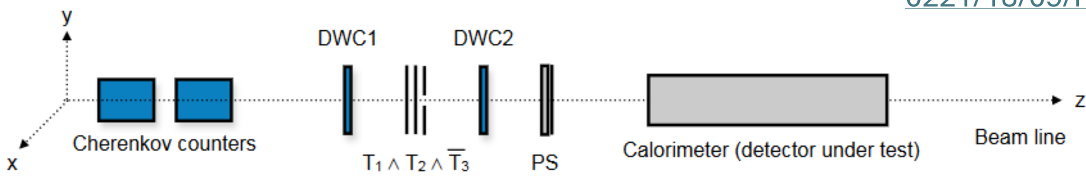

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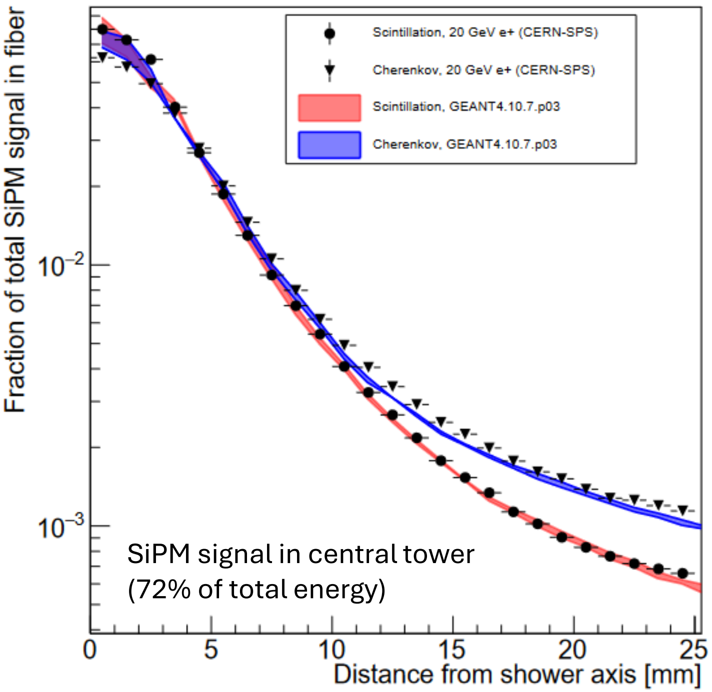
Shower shape and leakage well in agreement with Geant4



EM shower-size prototype

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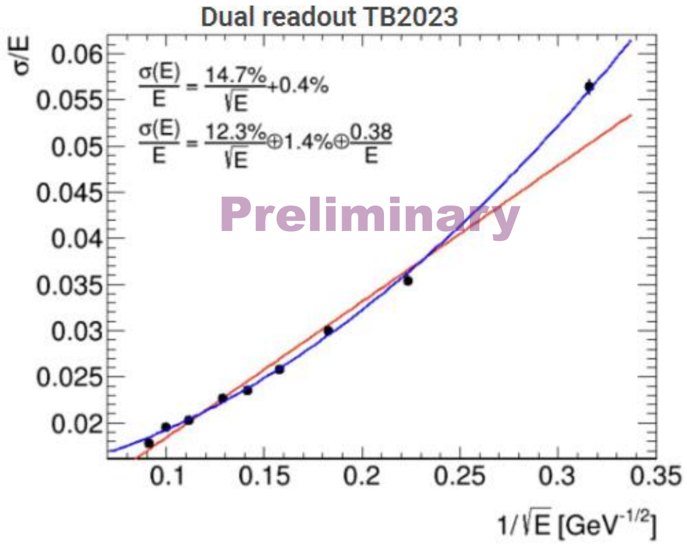
SPS, CERN, 2021,
e^+ beam, 10 to 100 GeV

Large hadron contamination
- Purity selection with Cherenkov counters (energy < 30 GeV) + preshower auxiliary detector (far from the detector → increase of lateral leakage)

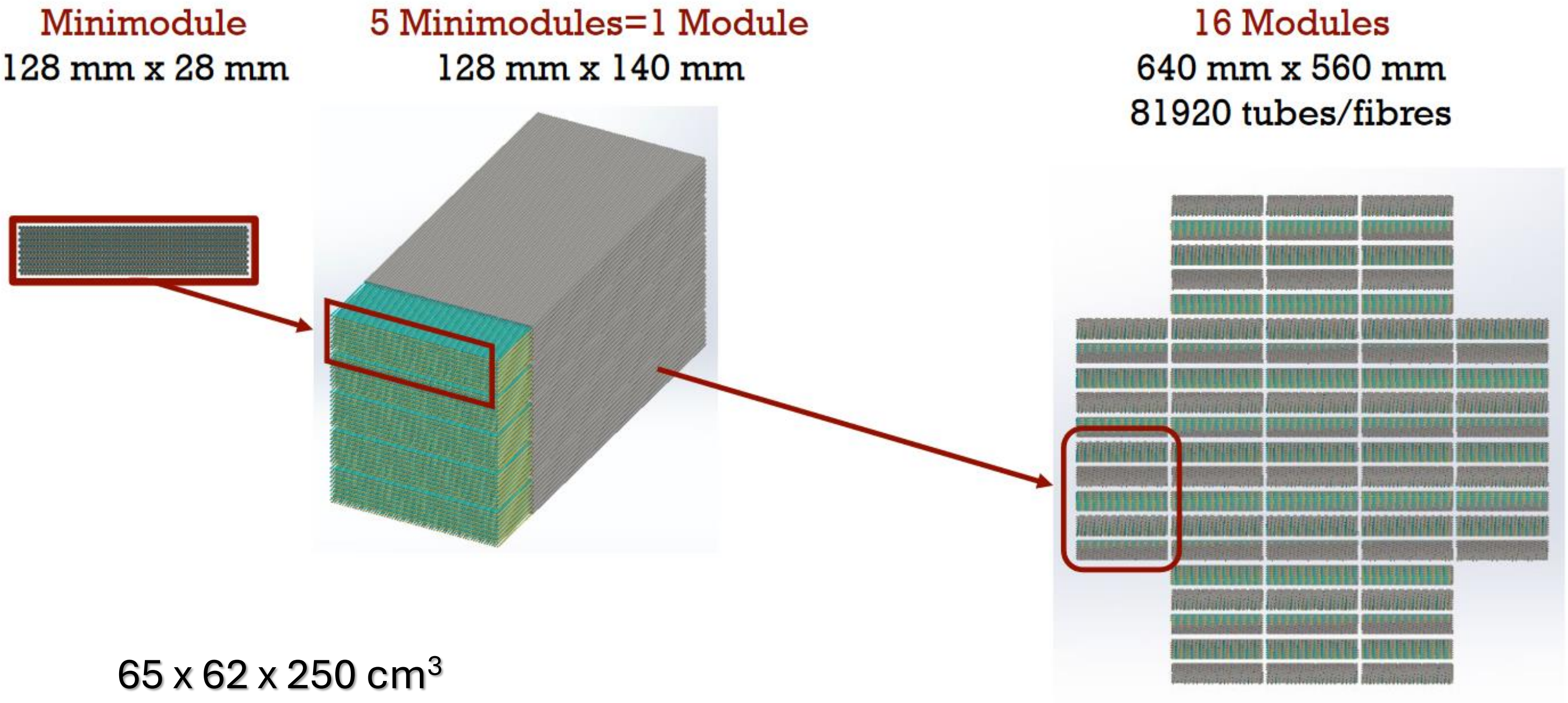
Further characterization of the detector on test beam in 2023 (SPS, CERN)

- Data with positron beams (energy scan, angular scan) as well as muon and pion beams have been taken
- Largely improved beam purity, better beam detector layout



The HiDRa demonstrator

Prototype large enough to (almost) fully contain hadron showers

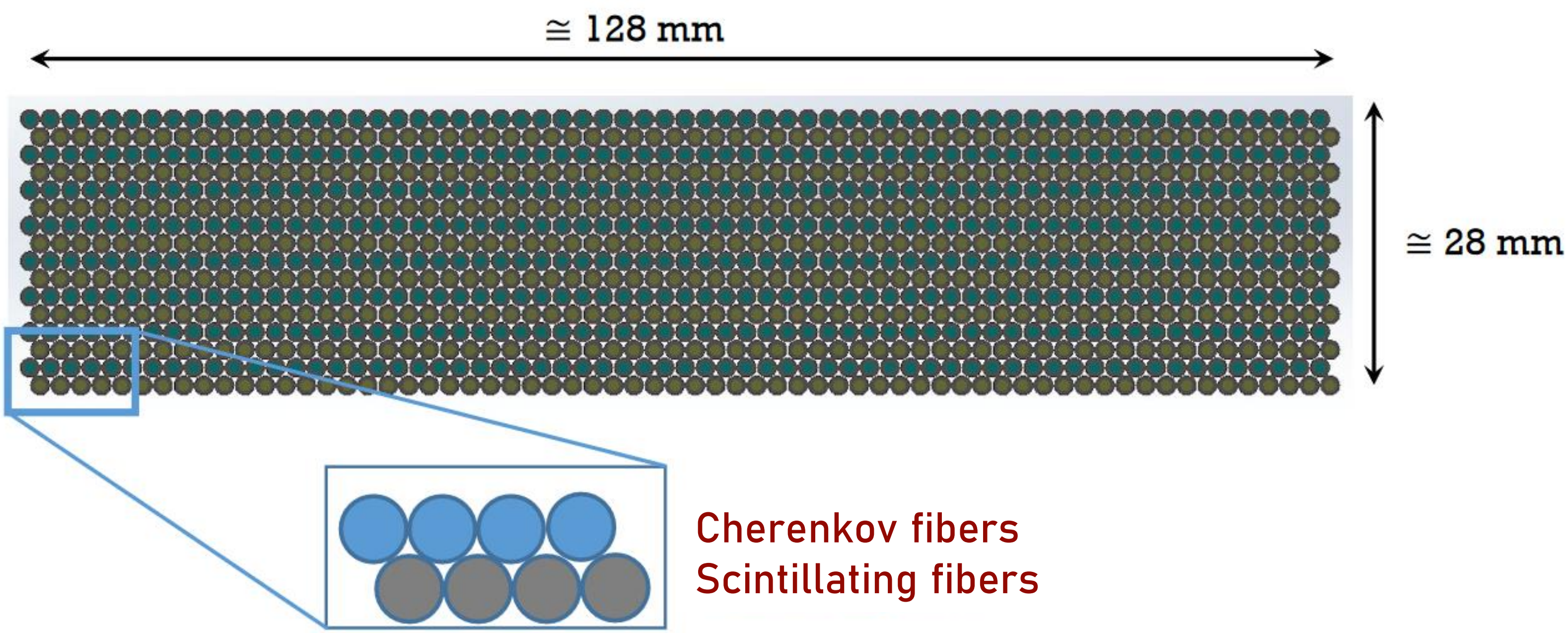


65 x 62 x 250 cm^3

The HiDRa demonstrator

HiDRa = 16x5 minimodules

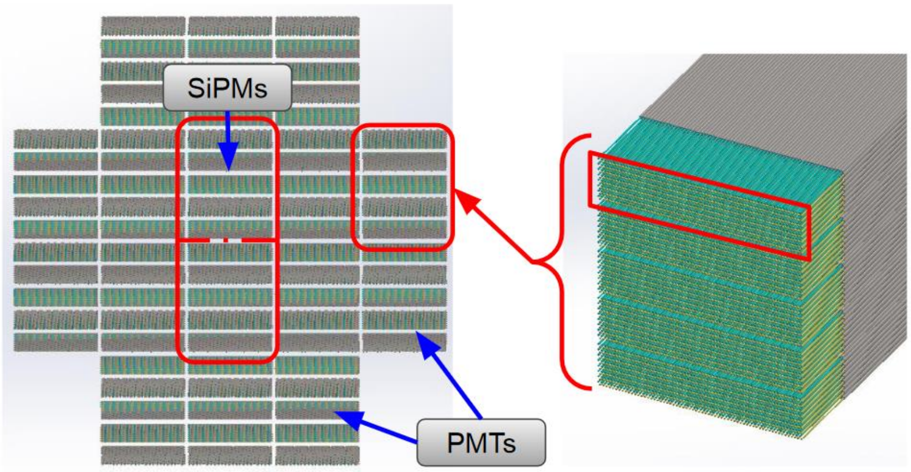
1 minimodule = 64x16 stainless steel capillary tubes
Alternating rows of scintillating / clear fibers



HiDRa - readout

Mixed SiPM / PMT readout

- Cost/performance optimization
- ➢ Significant increase in DAQ complexity



Outer shell

Two PMTs reading out each minimodule, for scintillating and Cherenkov fibers

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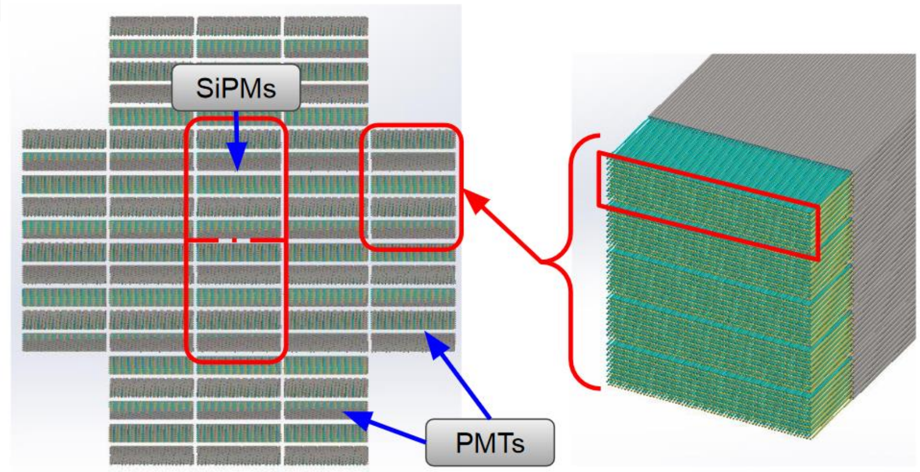
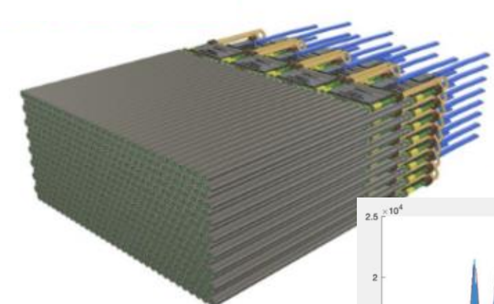


Central towers

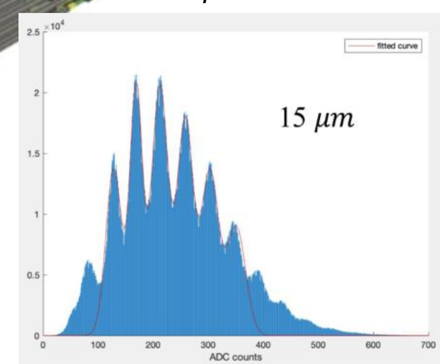
Two different SiPM models: *

10 μm pitch for scintillating fibers: better dynamic range

15 μm pitch for clear fibers: higher PDE compensating lower Cherenkov light yield



spectrum with LED source



* S16676 series from Hamamatsu

HiDRa – readout – SiPM integration

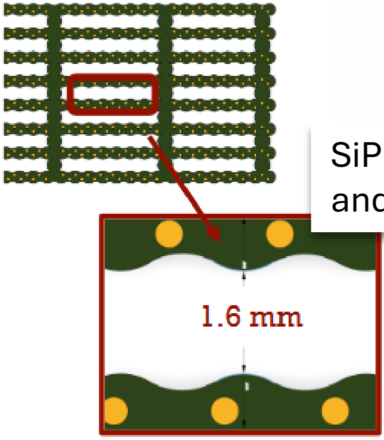
Challenging mechanical integration, to keep the system compact → needed for the future 4π-coverage geometry

10240 SiPMs

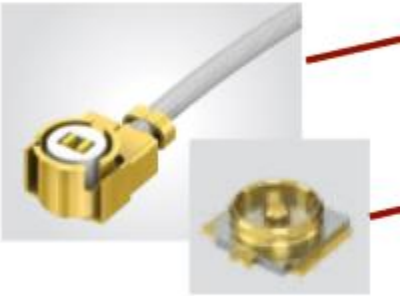
Grouping boards behind SiPMs make analog sum of 8 channels each *

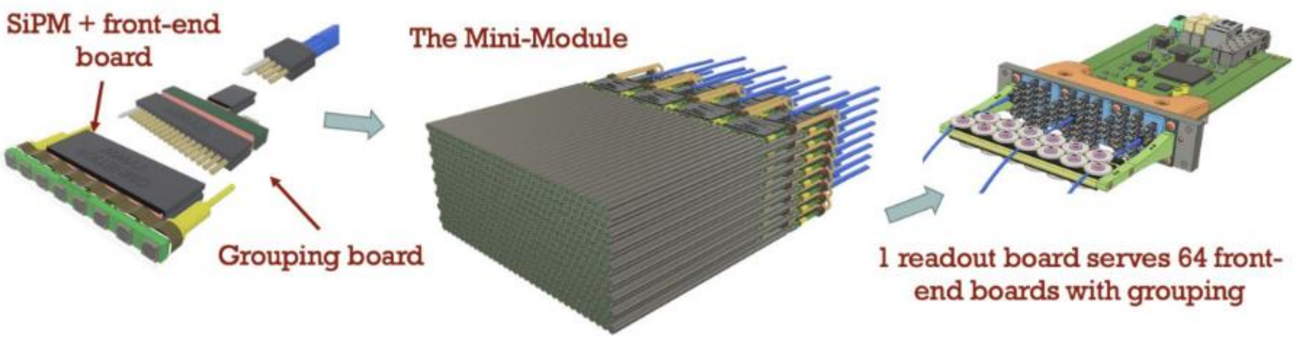
* 8 channel = 16 mm. Molière radius = O(25mm)

- 2 FERS operate 1 full minimodule
- 20 FERS operate high-granularity core of HiDRa prototype



SiPM bar mounted on the front and two-pin cable on the back

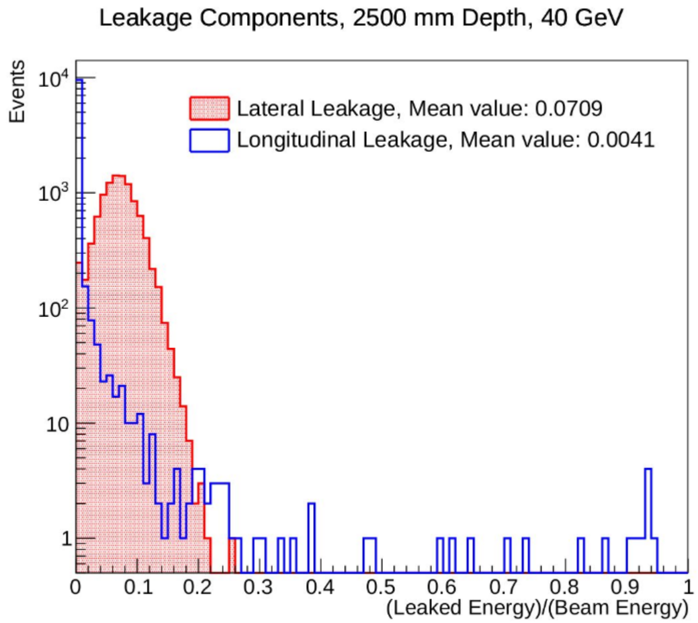




Simulation

HiDRa geometry simulated with Geant4
(response linearity, energy and spatial resolution, ...)

Fraction of energy leaking for a 40 GeV pion beam



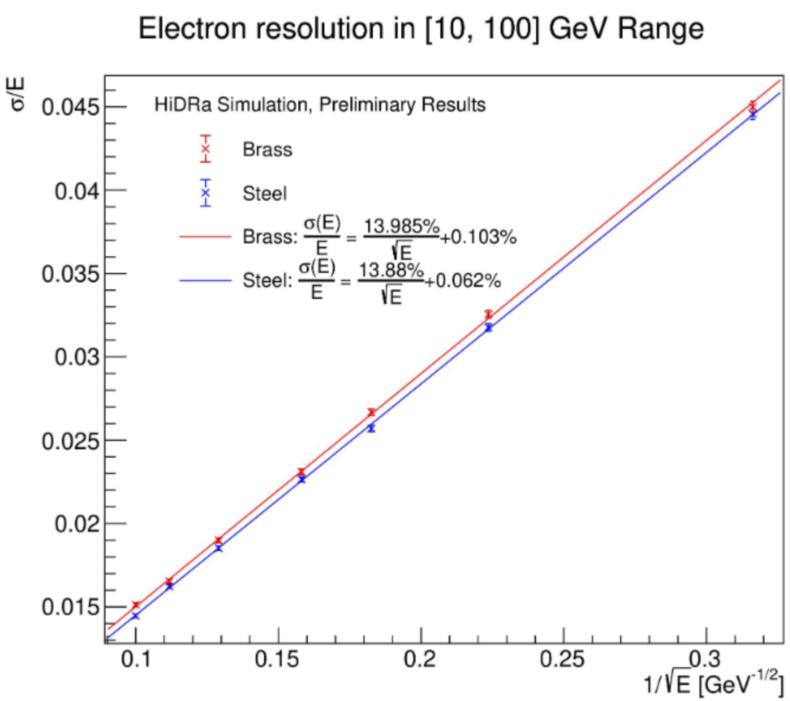
Longitudinal leakage leads to low-reconstructed-energy events

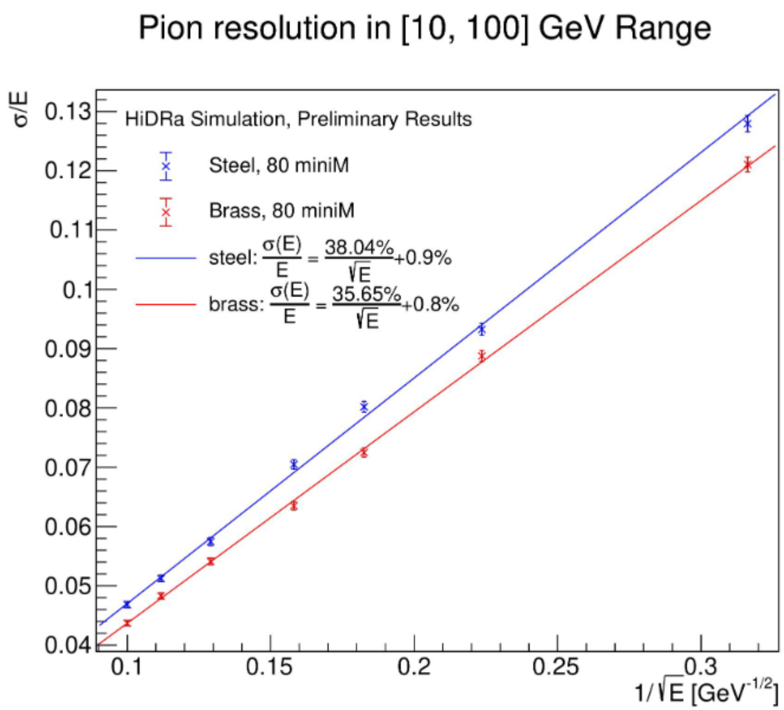
Lateral leakage has major impact on energy resolution

Simulation

HiDRa geometry simulated with Geant4
(response linearity, energy and spatial resolution, ...)

Energy resolution for electrons and pions:





Simulation

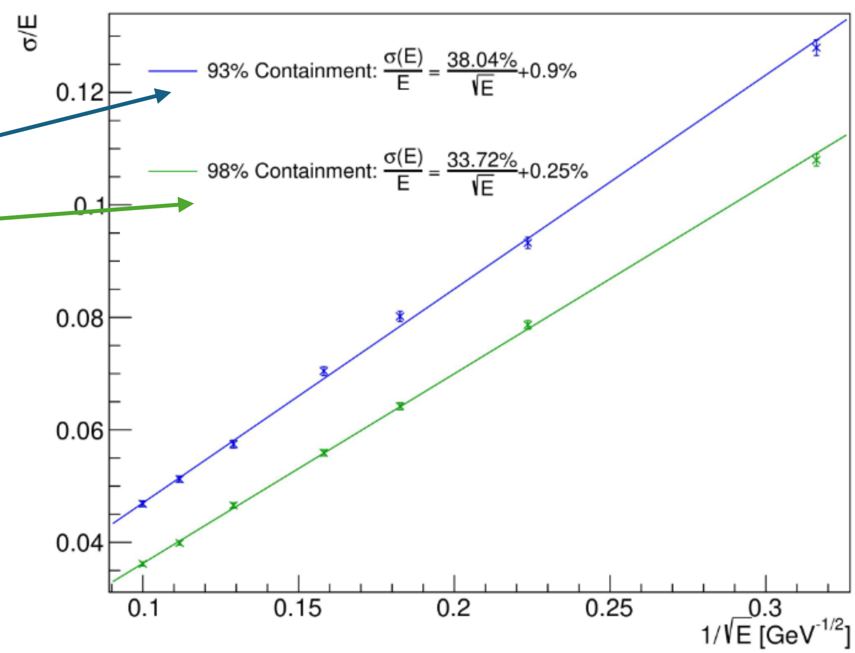
HiDRa geometry simulated with Geant4
(response linearity, energy and spatial resolution, ...)

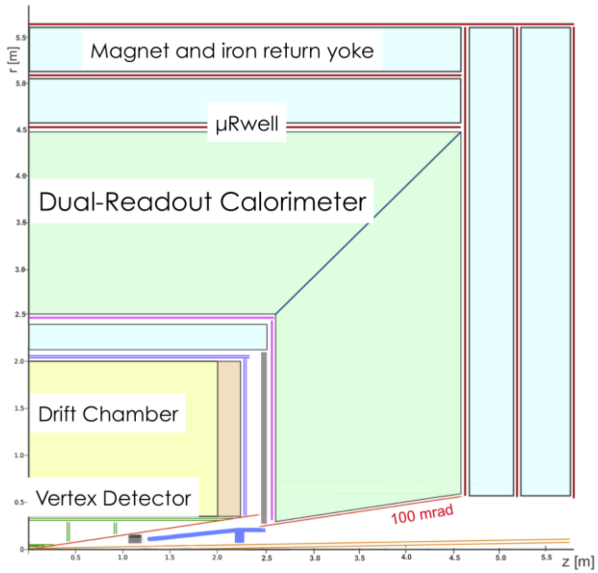
Probe 'IDEA' performance by increasing lateral dimensions

80 minimodules (HiDRa)

480 minimodules

Pion resolution in [10, 100] GeV Range



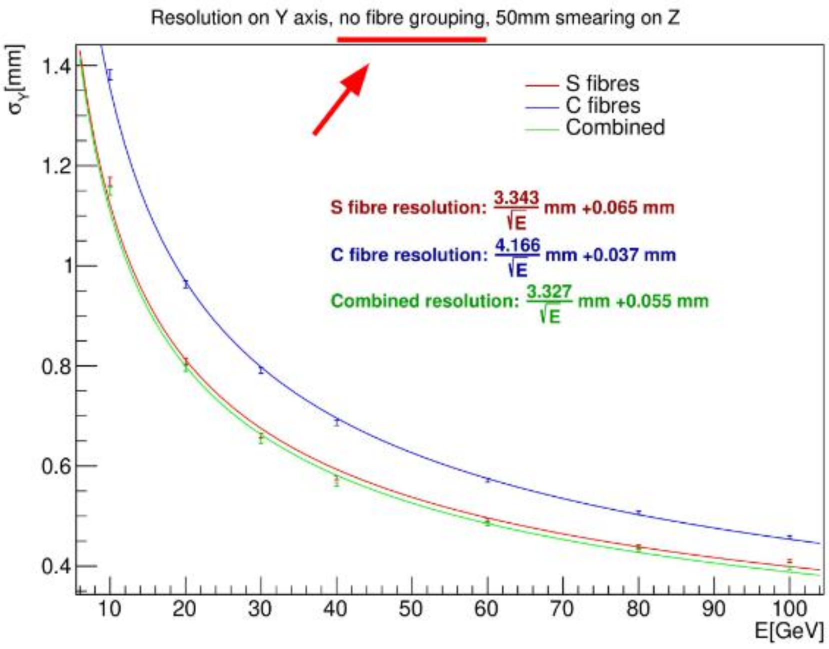


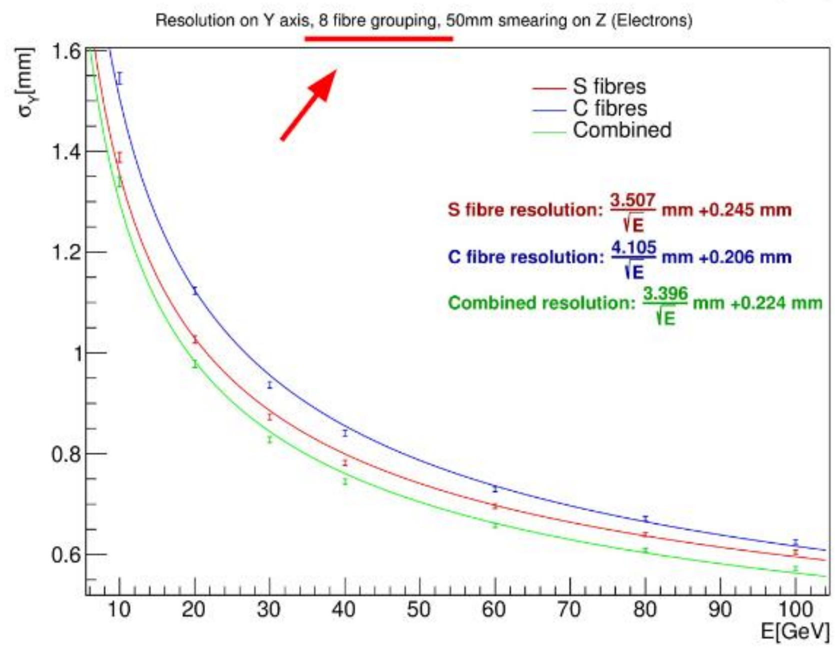
Layout of IDEA detector for FCCee

Simulation

HiDRa geometry simulated with Geant4
(response linearity, energy and spatial resolution, ...)

Grouping does not significantly worsen spatial resolution

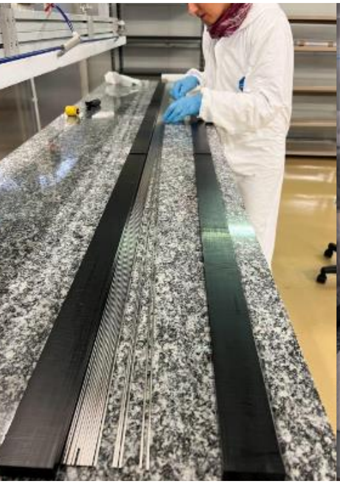




Assembly status

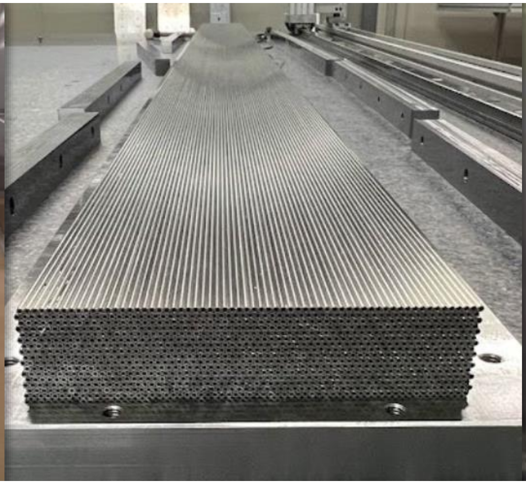
Tube gluing, fiber loading and QA/QC

Tubes alignment



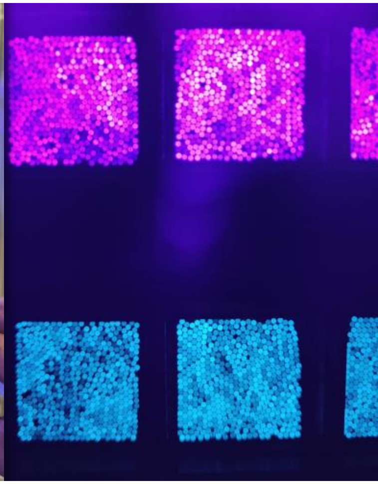
Glued, on the vacuum tool

One minimodule



Fibers loaded

*Ready for PMTs **

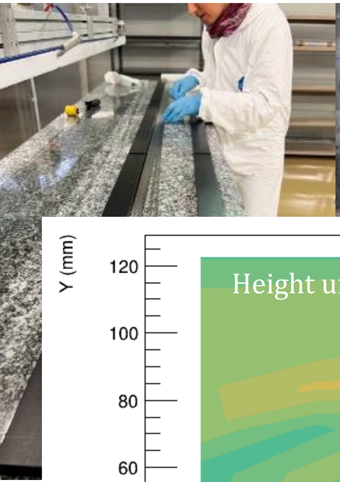


* Will be coupled with optical grease

Assembly status

Tube gluing, fiber loading and QA/QC

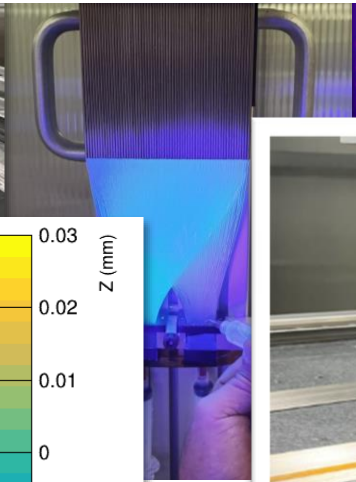
Tubes alignment



Glued, on the vacuum tool

One minimodule

Fibers loaded



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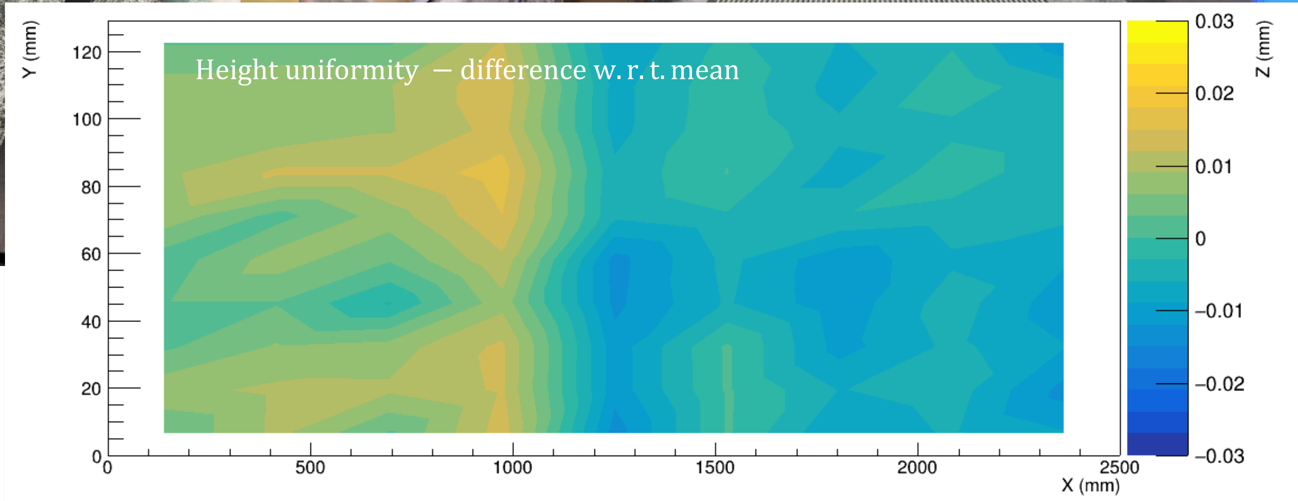


O (10 µm) precision on the minimodule height

Semi-automatic quality control of planarity

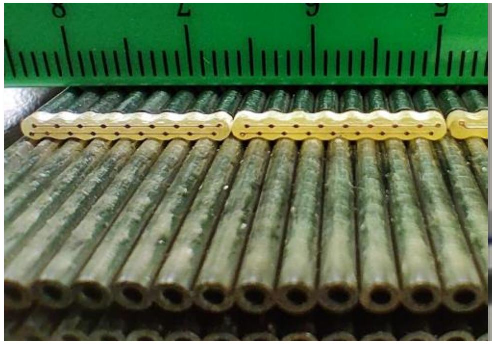
Assembly status – SiPM integration

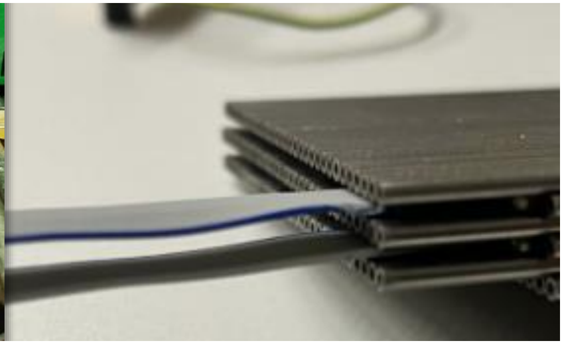
Bar of SiPM prototypes, characterization, studies on cabling and integration

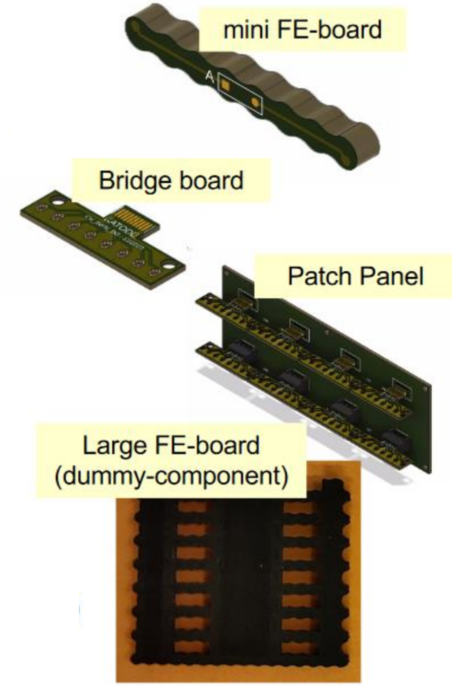
Design ready for bridge boards, patch panels, large and mini frontend boards

- ➢ Prototypes in production

FE-boards integration qualified with 3D-printed dummy prototypes







Status summary and prospects

- HiDRa assembly: **28 minimodules** completed
- Mixed SiPM (central tower) + PMT (outer shell) readout
    - PMTs available: gain curves measured and characterized
    - SiPM electronics and mechanics: design ready and partially tested with dummy prototypes
    - Fibers: quality assurance procedure for emission spectrum and attenuation length measurements developed and tested

- Physics simulation tools well advanced and validated with test beams on previous prototype

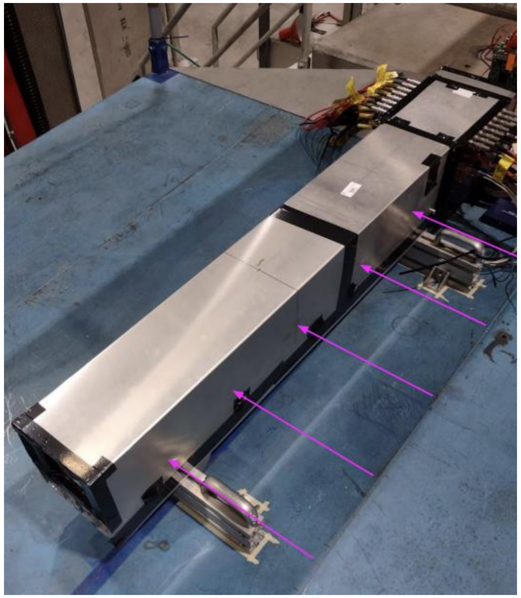
➢ Test Beam with 36 minimodules foreseen in 2024 (EM resolution, uniformity response, tuning of simulation, calibration, ...)
➢ Possibility to use RD52 modules to further contain the shower under discussion

This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under GA no 101004761

BACKUP

Fibers

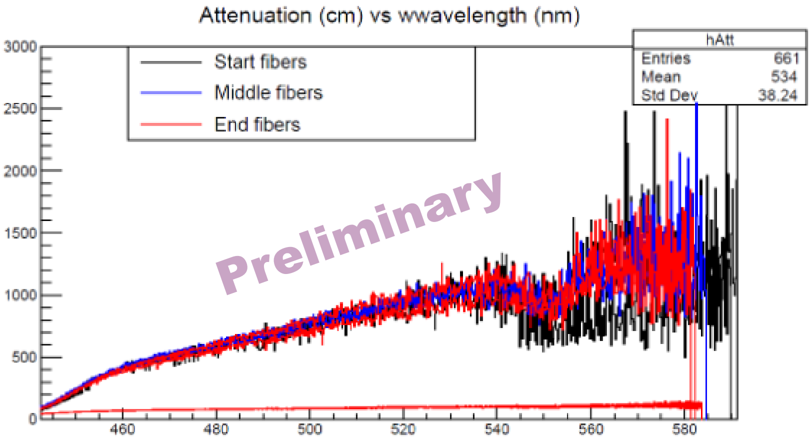
EM-shower-size prototype: SiPM signal with calorimeter rotated by 90 deg, 40 GeV electrons and 160 GeV muons



S fibres attenuation length:
~ 190 cm
C fibres attenuation length:
~ 390 cm

Preliminary

HiDRa components QAQC



FERS A502

Two Citiroc1A for reading out up to 64 SiPMs

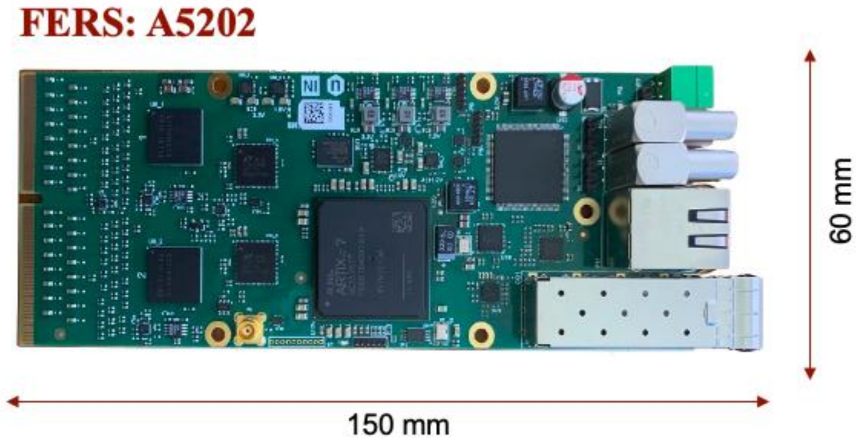
One (20 – 85V) HV power supply with temperature compensation

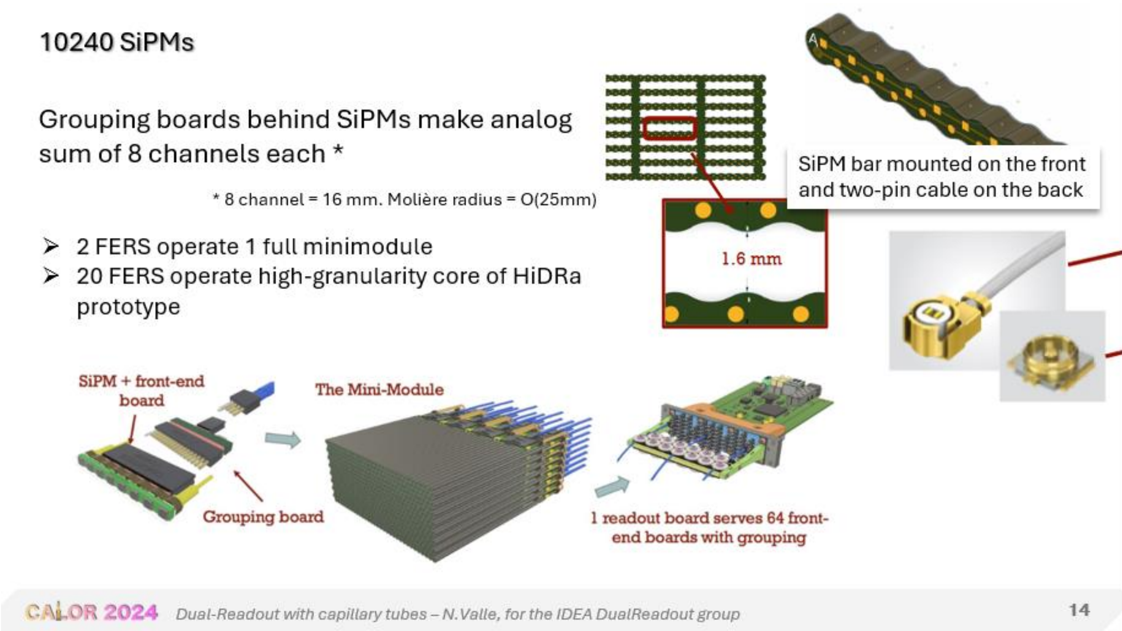
Two 12-bit ADCs to measure the charge in all channels

Timing measured with 64 TDCs implemented on FPGA (LSB = 500 ps)

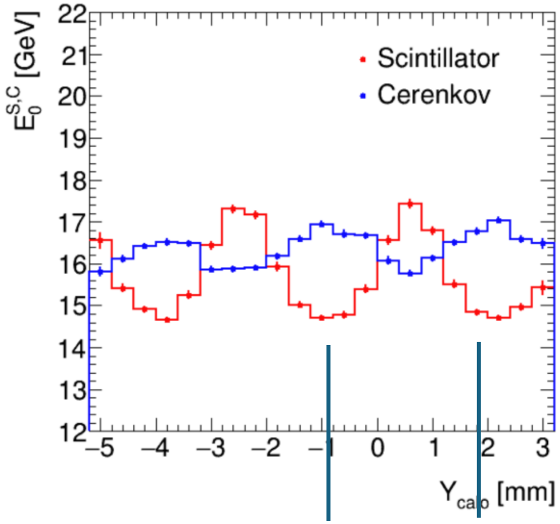
2 High resolution TDCs (LSB = 50 ps)

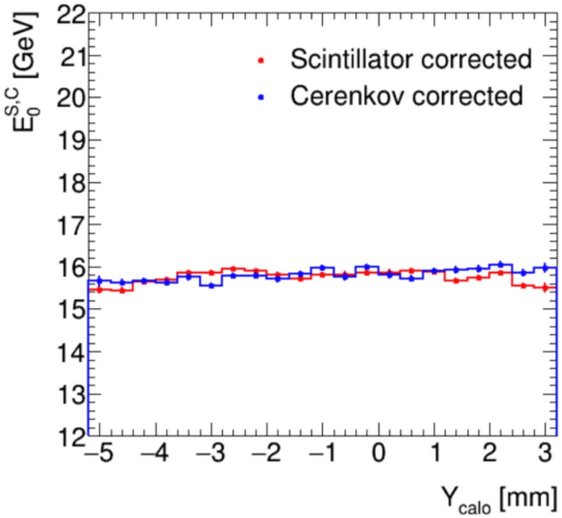
Optical link interface for readout (6.25 Gbit/s)





TB 2021 – correcting rotation angle





Distance between two rows of same-type fibres (TB 2021 data)

TB 2023 – purposes

Main objectives

Electrons:

- response linearity with energy
- energy resolution
- response modulation over impact point
- performance dependence over impact angle
- position resolution
- shower shape
- M0 tower uniformity

Muons:

- response dependence over impact angle and position
- (try) γ-radiation measurement
- (try) lepto-nuclear process probability

Pions:

- response to shower core
- Geant4 hadronic models validation