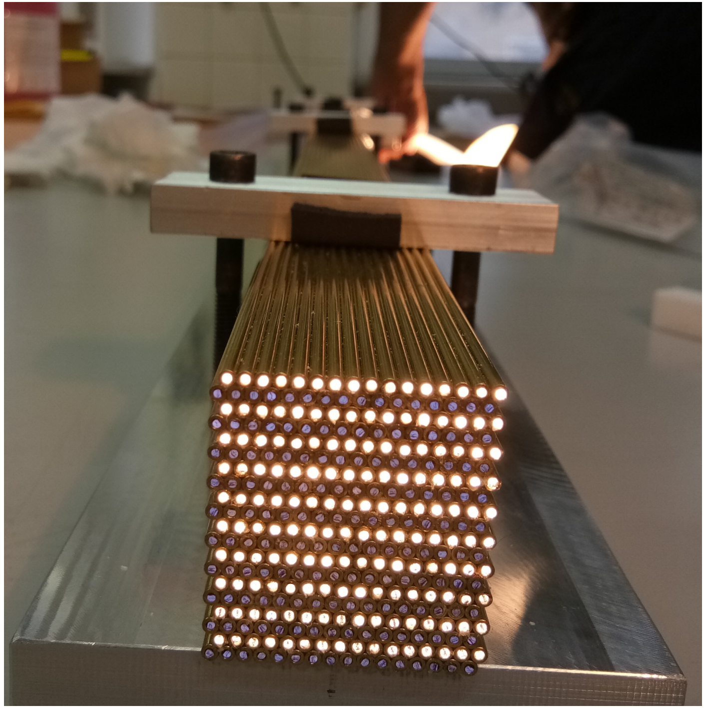
IDEA Dual-readout calorimeter: mechanics

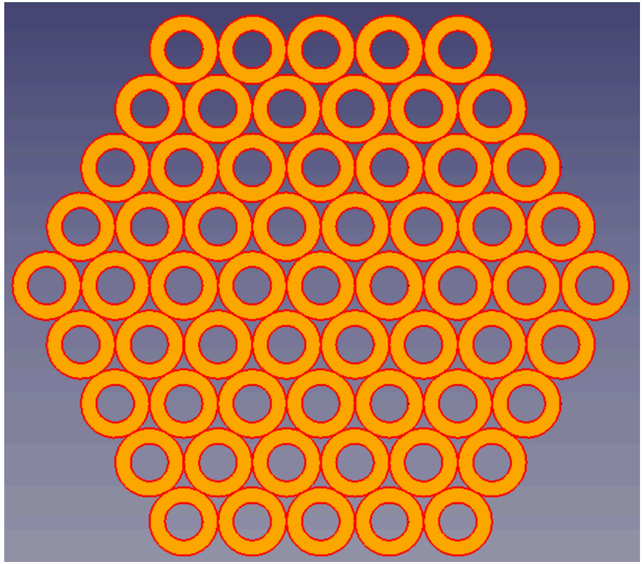


Gabriella Gaudio
on behalf of the IDEA Dual-Readout Calorimeter Collaboration
February, 16th 2021

Outline

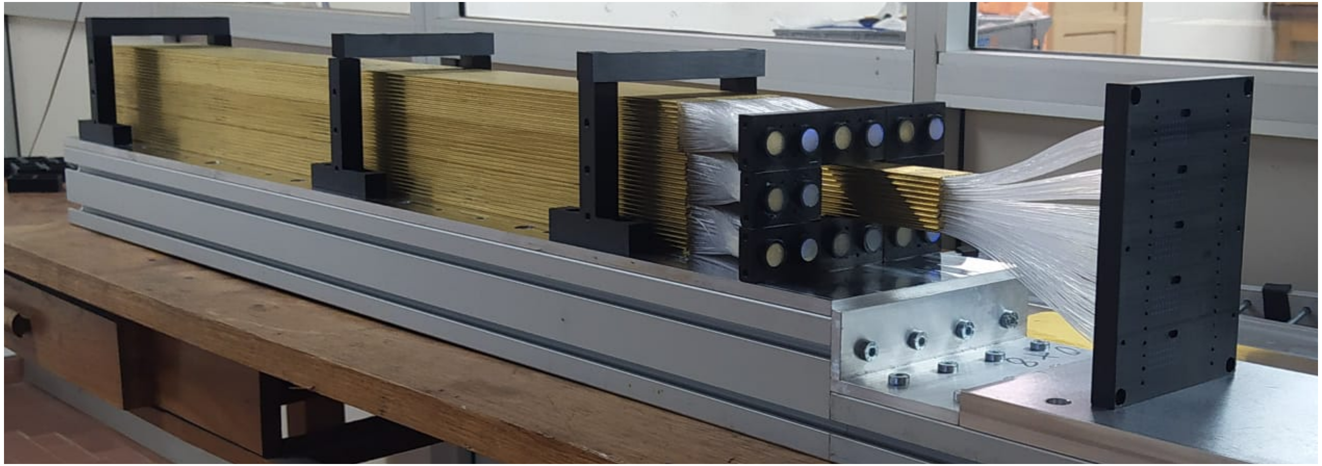
Proposal from RBI

https://agenda.infn.it/event/19360/contributions/95824/attachments/64280/77719/Capillary_tube_RBI_Proposal.pdf



- "EM-size" calorimeter prototype
- Activities 2021:
  - CSN1, AIDAInnova
- Outlook

Capillary-tube based Prototype

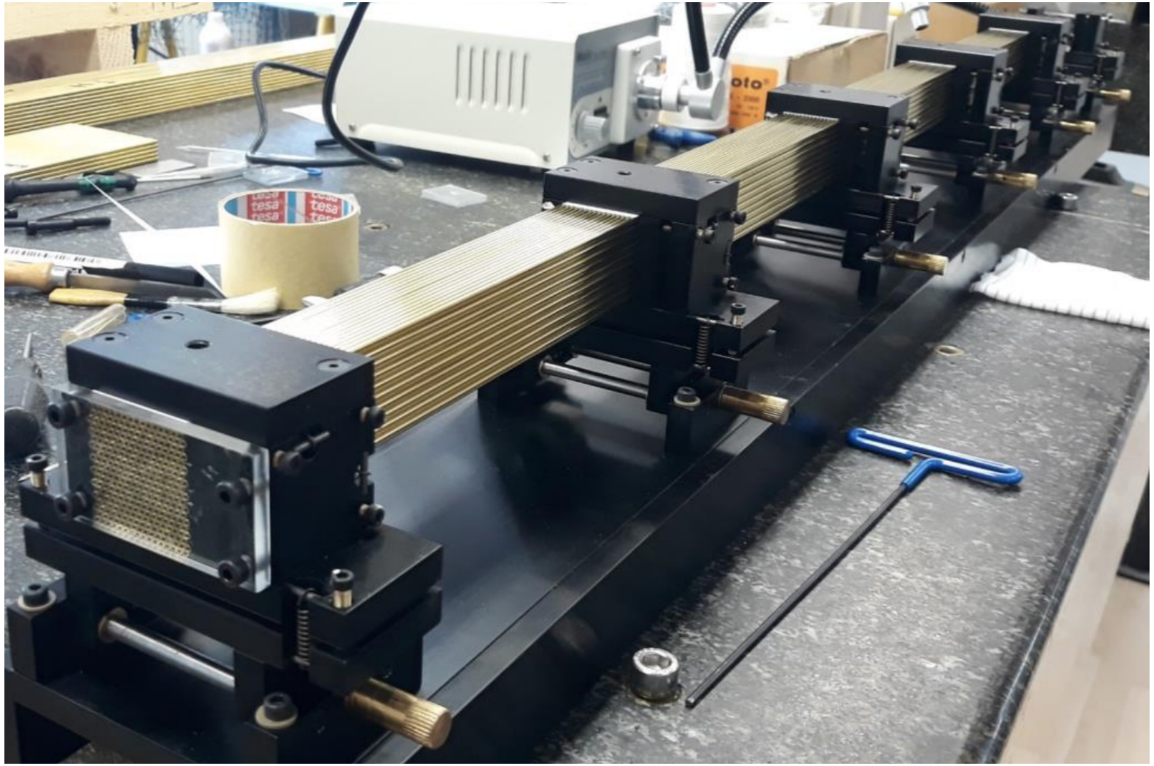


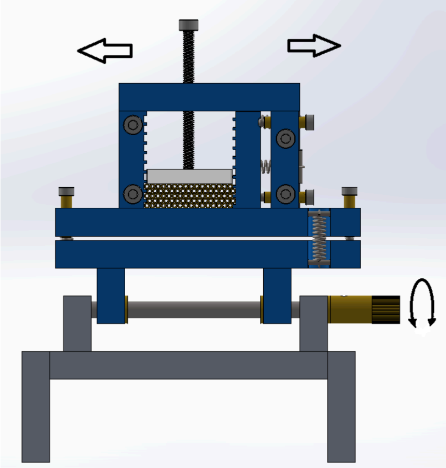
10x10 cm^2 divided in 9 towers, 1m long
16x20 capillary each (160 C + 160 S)

Capillary:
2mm outer diameter, 1mm inner diameter
Material: brass CuZn37

Readout:
- 1 central tower read out by SiPMs
- 8 surrounding towers read out by PMTs (à la RD_52)

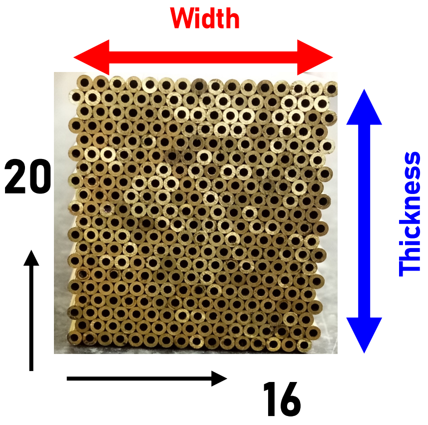
Assembly system





6 adjustable stands for packing capillaries to correct position. Alignment of stations through micrometric screws

Tower measurements



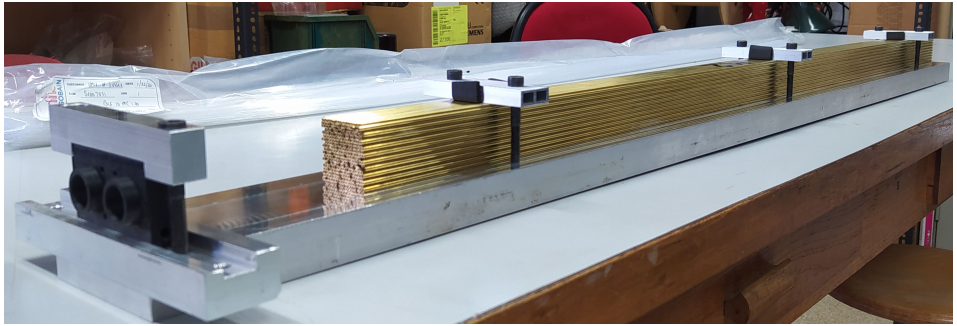
Measured in Pavia with high-performance Height Gauge

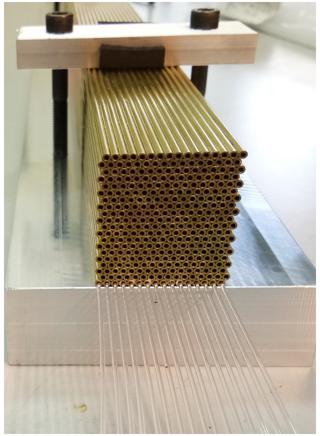
48 points per tower

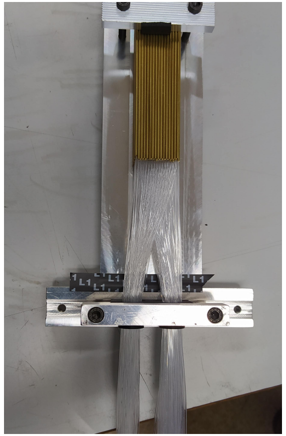
Thickness (in mm)		
Module/ Tower	Mean	RMS
M0	34.95	0.05
M1	35.00	0.05
M2	34.98	0.04
M3	34.96	0.04
M4	34.92	0.05
M5	34.95	0.05
M6	35.08	0.04
M7	35.08	0.03
M8	35.14	0.05

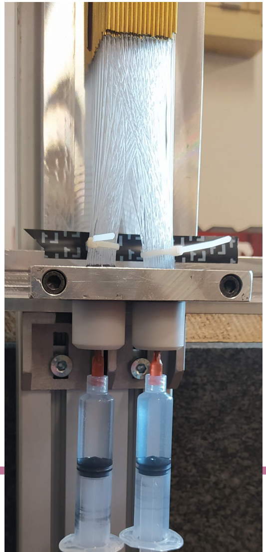
Width (in mm)		
Module/ Tower	Mean	RMS
M0	33.01	0.03
M1	33.07	0.02
M2	33.07	0.04
M3	33.06	0.02
M4	33.25	0.05
M5	33.23	0.10
M6	33.18	0.04
M7	33.19	0.04
M8	33.21	0.05

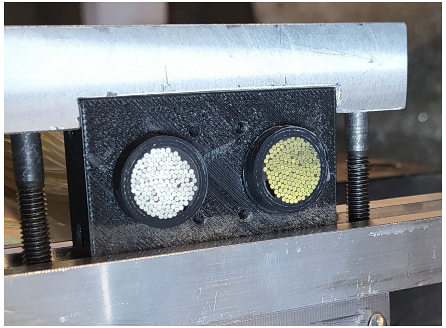
Fiber Loading for PMT readout





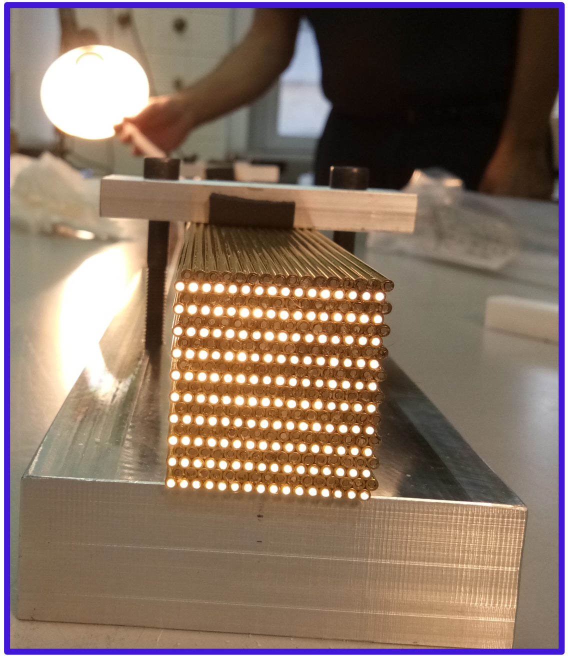




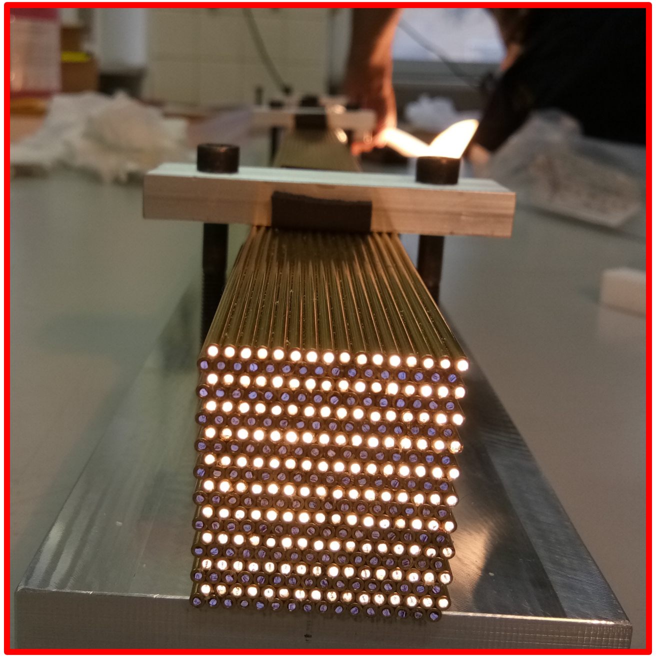


Fibers loaded in a tower

Fibers illuminated from rear end

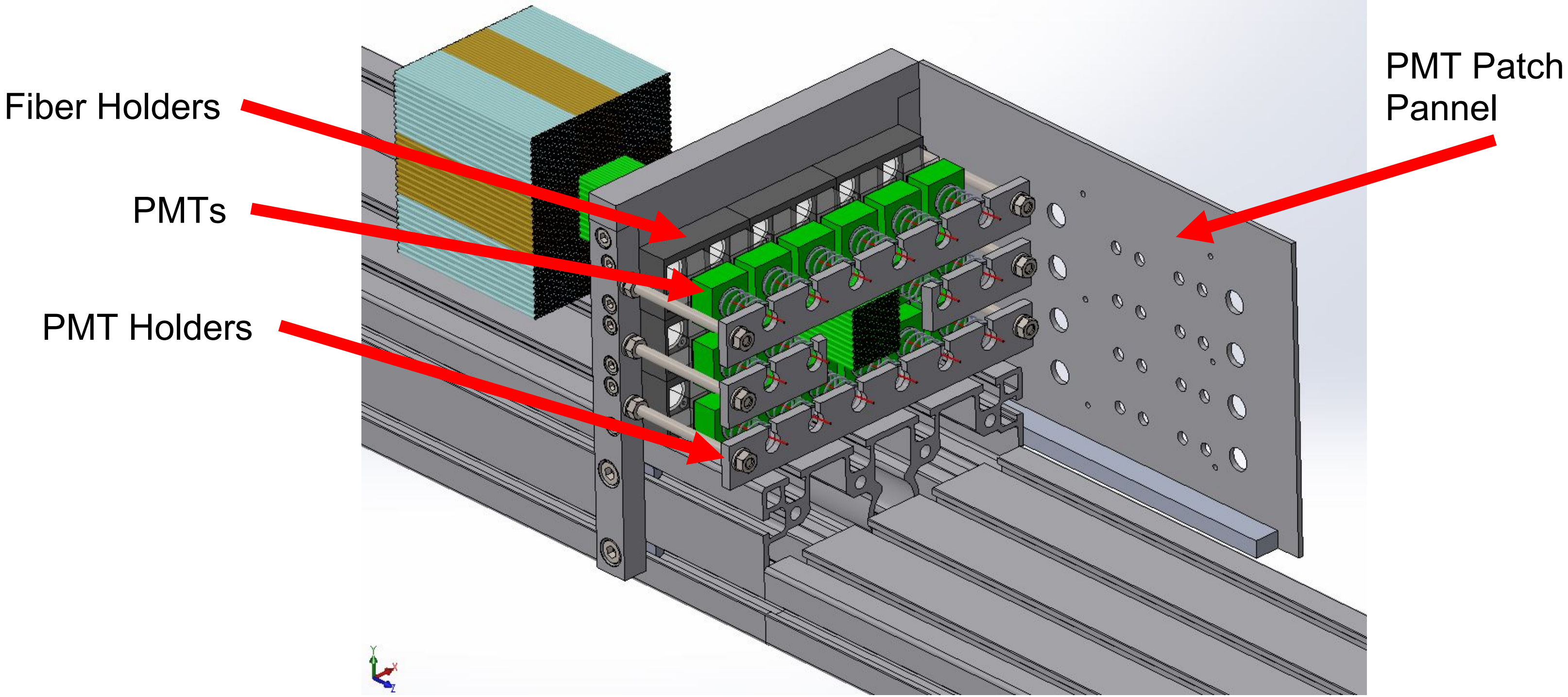


Scintillation fibers

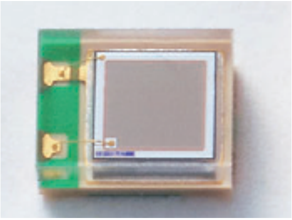


Cherenkov fibers

Fiber connection to PMTs



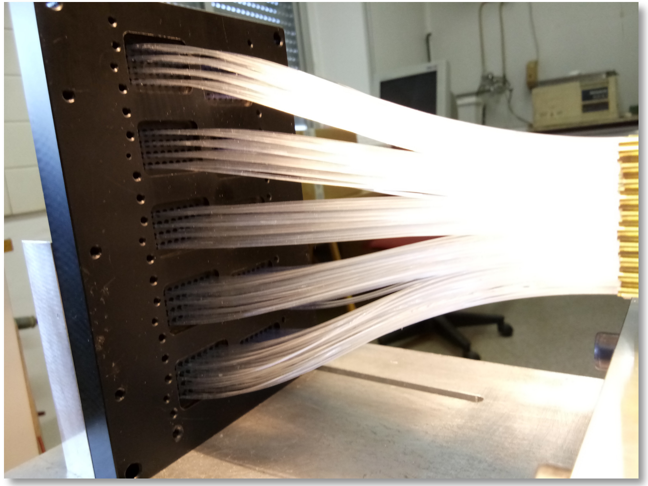
Fibers for SiPMs readout

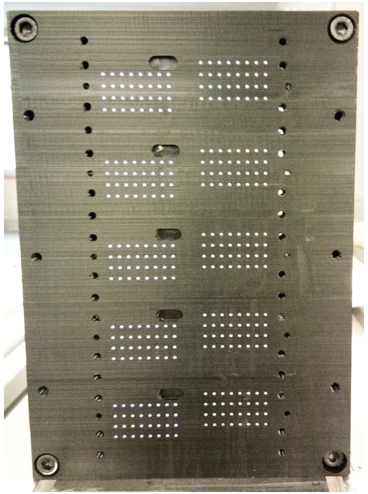


SiPM: S14160-1315PS from Hamamatsu
Cell size: 15 μm

Sensor packaging not compatible with absorber structure: using a SiPM interface

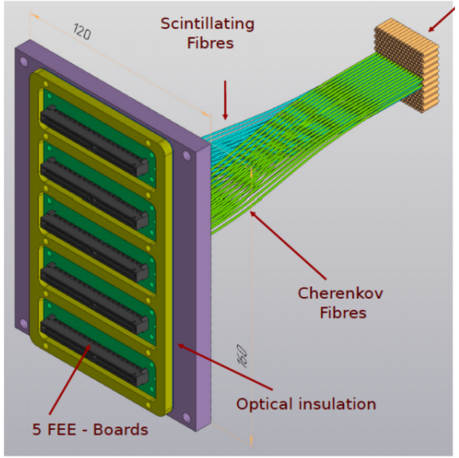
See Romualdo's presentation





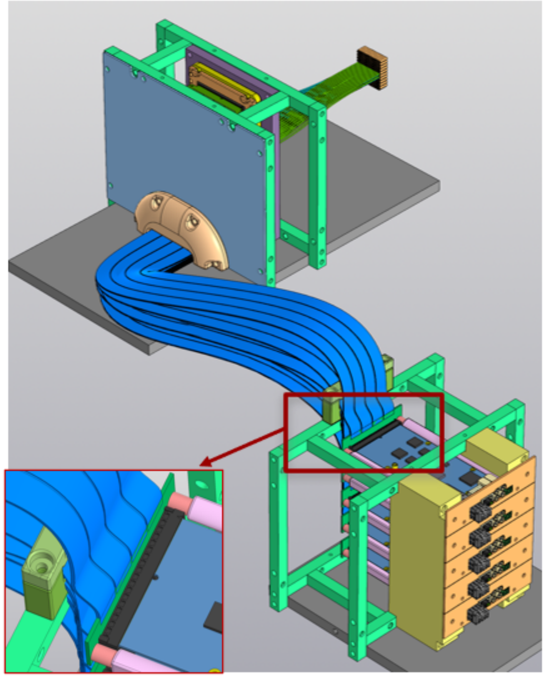
Sample SiPM board attached

Readout chain

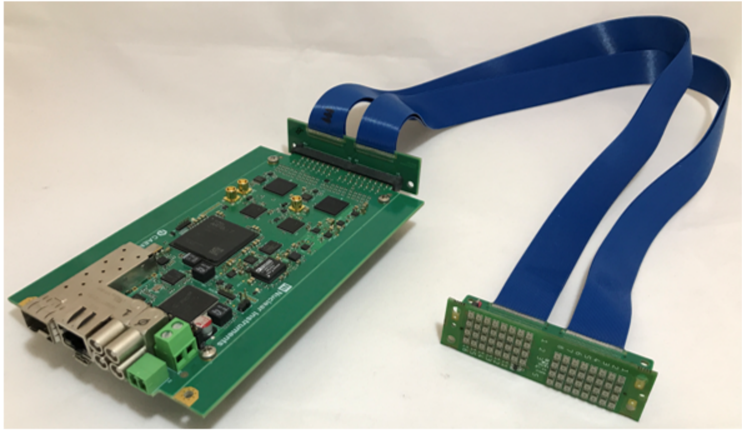


5 FEE-boards

Each board—> 64 SiPMs (32 S +32 C) to FERS board



Readout Boards:
5 FERS - A5202
1 FERS - A5202 (spare)



FEE – Boards
5 Boards (320 SiPMs)

See Romualdo's presentation

“Short-term” activities on prototype

- Final mounting of the PMTs and mechanical supports
- SiPM and readout-boards final test and integration (see Romualdo’s presentation)
- Testbeam
  - DESY slot moved from Nov. ‘20 to Feb. 21, and now foreseen sometime in spring
  - Request for test beam at CERN NA submitted
- Setting up of test in the lab
  - Radioactive source
  - Cosmic stand

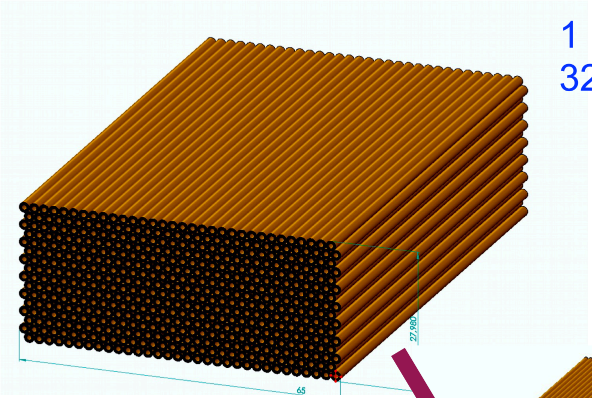
  under development

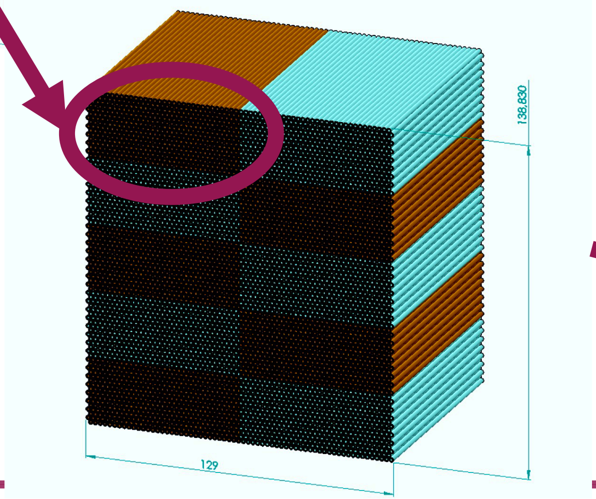
2021 program

From HiDRa project for CSNV

Capillary-tube based calo

1 Mini-Module (MM):
32 x 16 channel (512 ch)

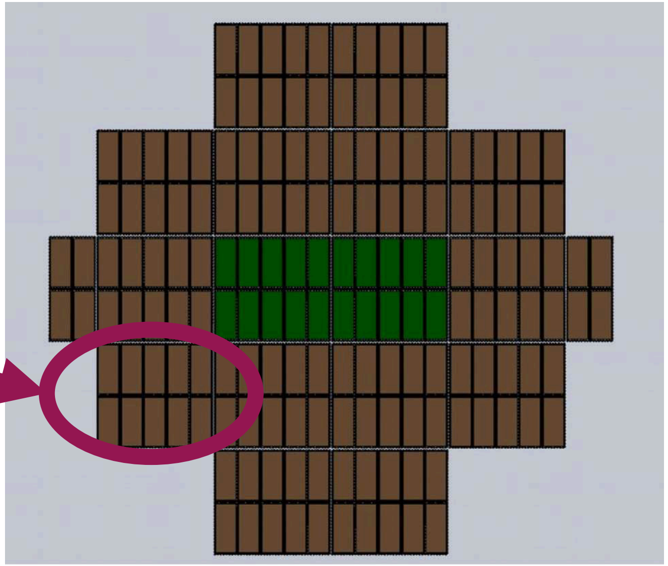




1 Module:
2 x 5 MMs
→ 10 FEE boards
(8-channel grouping)
~ 13 x13 x 200 cm^3

17 modules, ~ 65 x 65 x 200 cm^3

- 2 central modules with SiPMs
  → ~ 10 k SiPMs, ~ 20 FEE boards
- all others with PMTs
  → ~ 150 PMTs



Scientific Program: mechanical development

Improve and define baseline options for the construction of a capillary-tube calorimeter

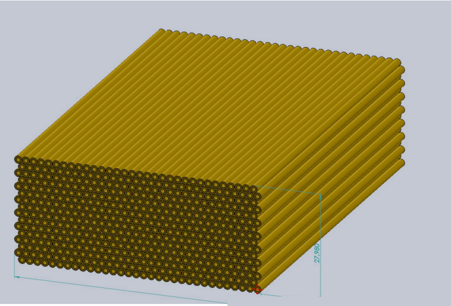
- CAPILLARY TUBE (PV, RBI):
  - Absorber material choice, optimal tolerances
  - Quality on larger production sets, comparison of different producers

- FIBERS (PI, SUSSEX):
  - Test of different producers to find optimal characteristics for DR calorimeter
  - Qualification of fibers: definition of procedure and setup

- CALORIMETER ASSEMBLY (PV, PI, RBI):
  - Definition of optimal dimensions for coupling to readout
  - Definition of assembly procedure and tools
  - Automatization of some assembly procedures (e.g. gluing)
  - QAQC procedure and criteria

- FIBER INSERTION IN THE TUBE AND COUPLING TO SENSORS (PV,PI, Como)
  - Fiber in Metal Tube products already on the market: are they suitable?
  - PMTs for external ring in large size calorimeter: choice and test

Scientific Program: mechanical development



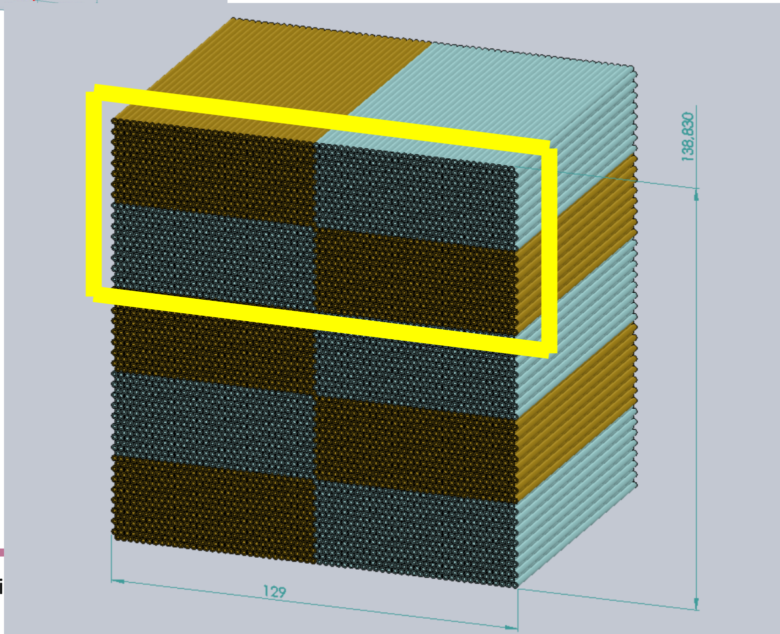
1 MINIMODULE:
32 x 16 channel (512 ch)

Construction of a few MINIMODULEs to study:

- Assembly procedure
- Reproducibility of assembled modules
- Mechanical supports

At least 4 MINIMODULEs are needed
(HiDRA design: 10 minimodules = 1 module)

+ Material to assess material choice and baseline choice
(cost equivalent to 1 MINIMODULE)



We had 2+1 minimodules funded by CSN1

Research program (synergic to CSN1 – RD_FCC)

WP 8.4.2

Development of highly-granular dual-readout fiber-sampling calorimeters

(INFN-PV, INFN-MI, INFN-PI, INFN-BO, University of Sussex, ~~RBI,~~ CAEN) + INFN-CT + INFN –RM1

- The production and mechanical assembly of the detector elements, the readout of $O(10^8)$ channels with an optimised scalable system, and the possibility to discriminate photon and electron showers from hadrons by time measurements will be investigated.
- The readout system will be developed in collaboration with CAEN in order to equip several 10×10 cm^2, 2 m long, prototypes to be qualified with test beams.

Deliverable:
D8.4 : Construction and qualification with beam of 10×10 cm^2, 2 m long, prototypes [46]

A large-scale prototype of a dual-readout calorimeter that allows for extrapolation to a full system will be constructed and operated. Its performance will be documented in a report (Task 8.4)

Budget

Istituto Nazionale di Fisica Nucleare

Full costs budget per Task

Beneficiary short name	Person-months	Monthly personnel cost	Personnel costs	Travel	Equipment and consumables	Other direct costs	Sub-contracting	Material direct costs	Total direct costs	EC requested funding (without overheads)	EC requested funding (including overheads)
Task 8.1	**Management**										
INFN	4,0	5.000,0	20.000,00	4.000,00				4.000,00	24.000,00	4.000,00	5.000,00
Task 8.4.2	**Dual readout calorimetry for future particle physics experiments**										
INFN	20,0	5.000,00	100.000,00	10.000,00	10.000,00			20.000,00	120.000,00	40.000,00	50.000,00
Total	**24,0**		**120.000,00**	**14.000,00**	**10.000,00**	**0,00**	**0,00**	**24.000,00**	**144.000,00**	**44.000,00**	**55.000,00**

Total funds INFN: 120 k€

40k€ from EU: 2y of PostDoc position (possibly 4 if we cofunded by INFN/Phys. Department)
80k€ cofunded by INFN: Personnel time + Travel and equipment (20k€)

Other partners in the task:

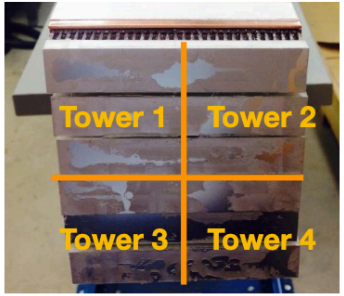
Univ. of Sussex (120k€)
CAEN (Total 60 k€ : 30k€ from EU + 30 k€ cofunded by the company): aim at development of RO boards for DRC

Meanwhile ….

in the world

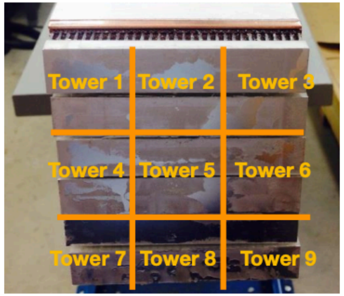
Plate-based (+3D printing) calo

Module #1 (2x2)

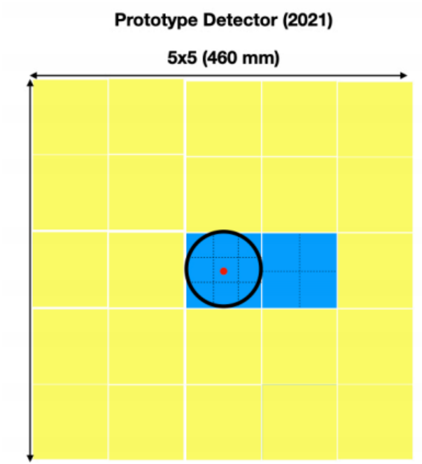


Tower#1	Tower#2
Tower#3	Tower#4

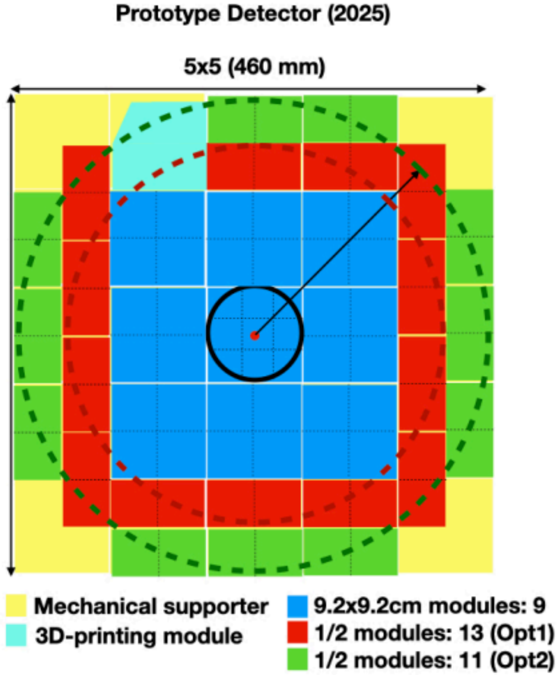
Module #2 (3x3)



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



Building more and more modules 2022-2025

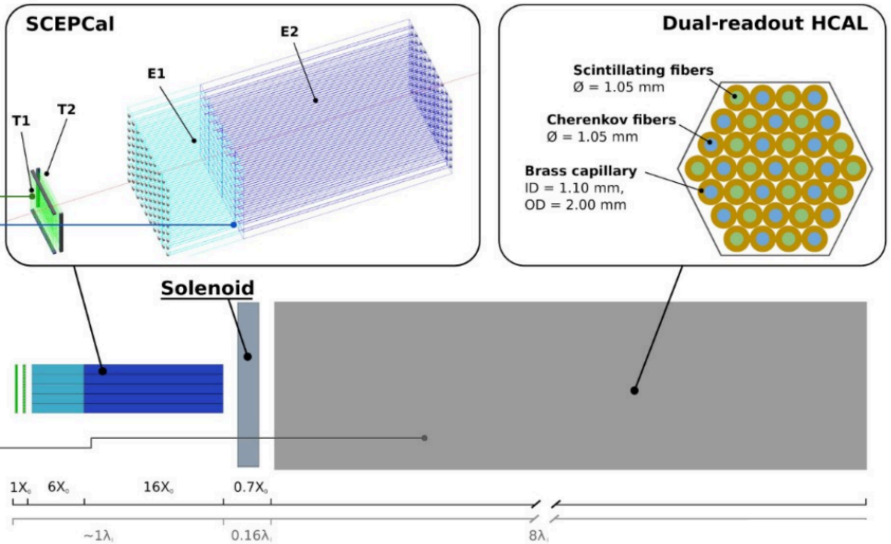


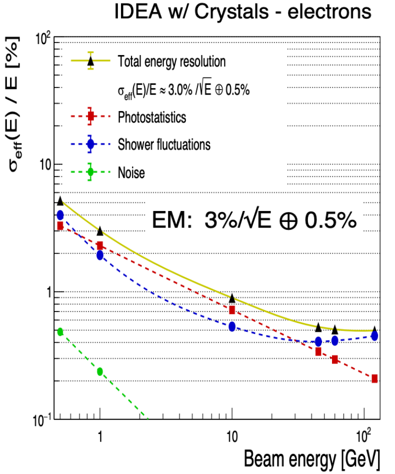
Crystal calorimeter option

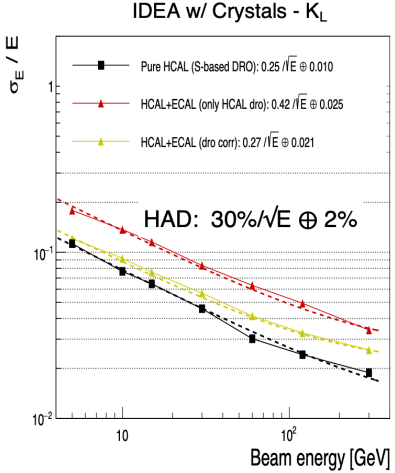
Layout overview

- **Transverse and longitudinal segmentations** optimized for particle identification and particle flow algorithms
- Exploiting **SiPM readout** for contained cost and power budget

- **Timing layers** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals (~$1X_0$)
  - 3x3x60 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layers** — $\sigma^{EM}_E/E \sim 3\%/\sqrt{E}$
  - PWO crystals
  - Front segment (~$6X_0$)
  - Rear segment (~$16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)
- **Ultra-thin IDEA solenoid**
  - ~$0.7X_0$
- **HCAL layer** — $\sigma^{HAD}_E/E \sim 27\%/\sqrt{E}$
  - Scintillating and quartz fibers inserted in brass capillaries
  - (similar to prototypes in





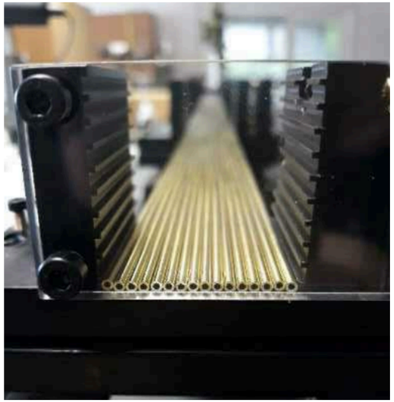


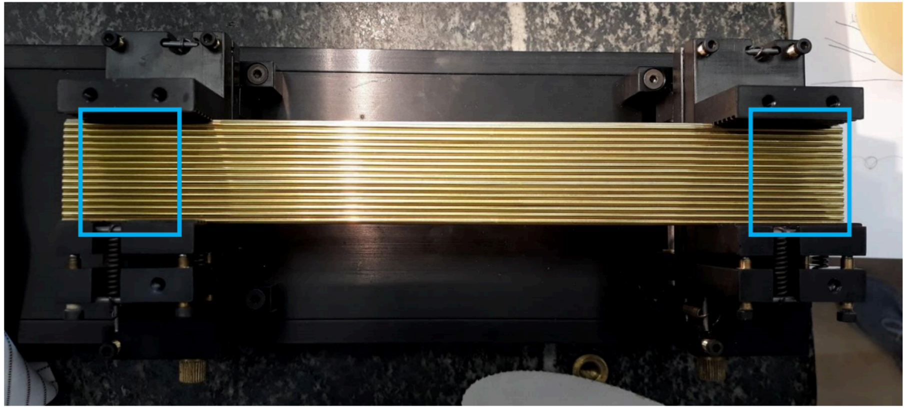
Outlook

- 2020 "EM-size" module was delayed due to Covid-19 spread, both from construction and testing point of view
  - Aiming at finishing it in a month-scale period and start testing (cosmic, radioactive source)
- Starting activities for CSN1-RD_FCC project and AIDAInnova task 8.4.2 program
- Submitted many EOIs to SNOWMASS project
- Recently submitted a PRIN (see Romualdo's talk for details)
- Planning to re-submit call in CSNV this year

Additional Material

Construction Method

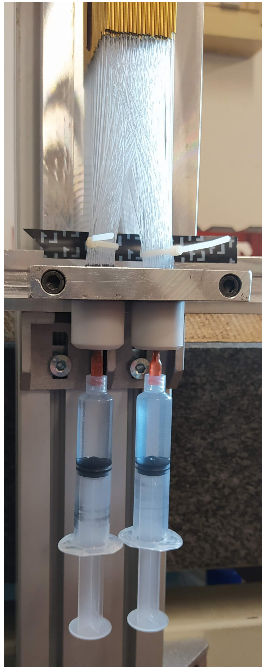




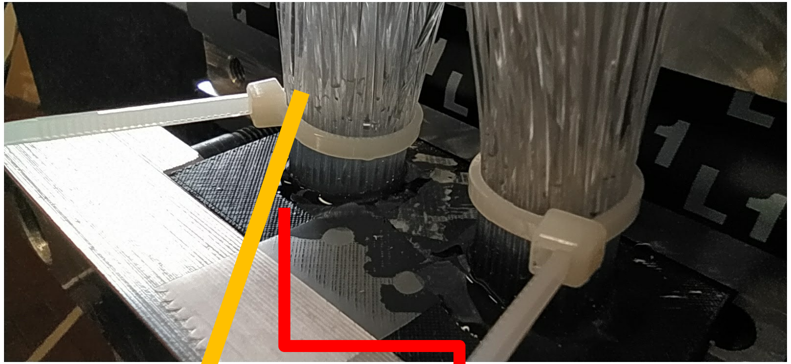
- Capillaries are positioned layer by layer
- Dry run with all tubes for each tower (~3x3 cm^2) is performed and measurements are checked
- If all ok, capillaries removed and repositioned distributing glue at each layer
- Full tower left to cure overnight
- Measurement (external dimensions) done after removal from assembly stations

Gluing fibers for PMTs

Cut edges of bunch of fibers inserted in a Teflon Container



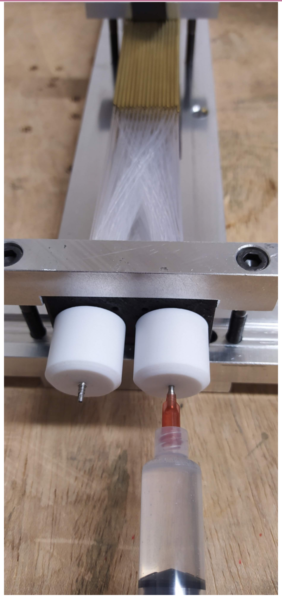
Adhesive pushed in containers with syringes



Due to viscosity glue rises above 3d printed black holder

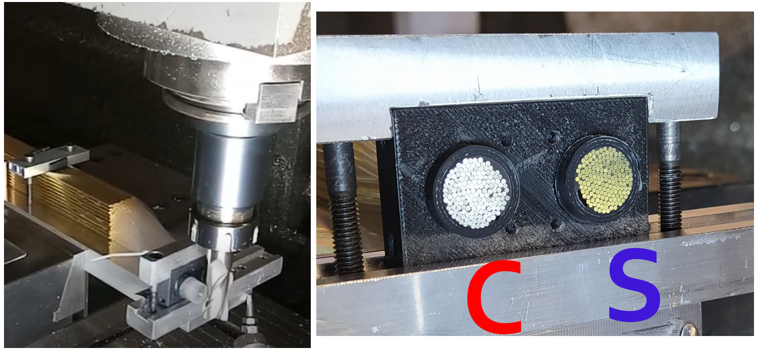
Glue set in 24 hours

Fibers machining



Syringe removed

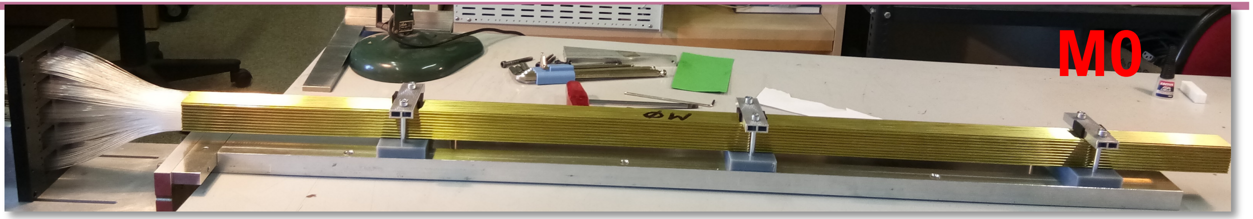
Teflon containers removed

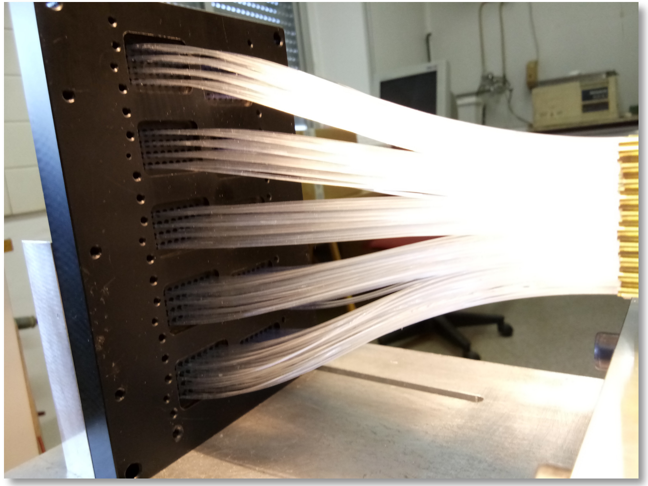


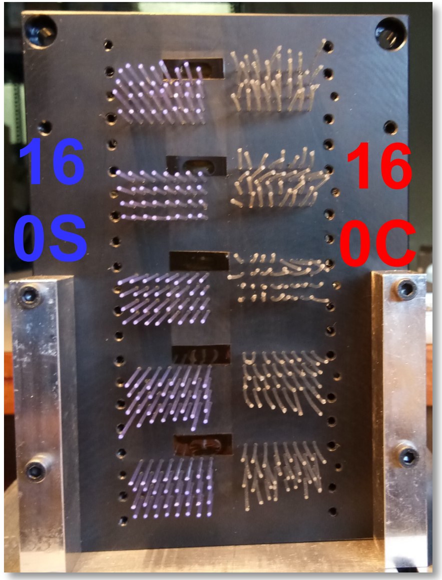
Grouped glued fibers outside 3d printed holder are cut off by milling machine

Fibers for SiPM readout

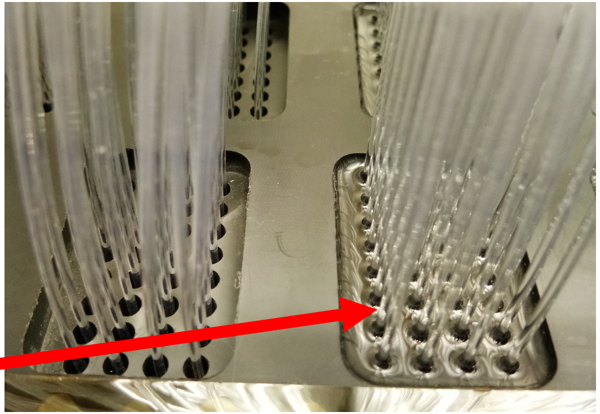
- Central tower loaded with fibers







Fibers for SiPM readout



At back side of the interface

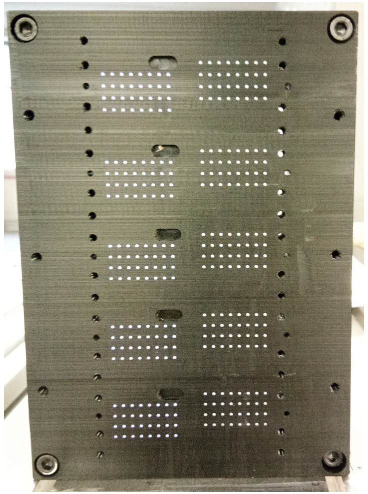
- White frames to be filled with glue
- 24 hours to set

At front side of the interface

- Deeps are filled with glue (BC 600 optical cement)
- 24 hours to set

Machining Fibers for SiPMs

- Back side of the interface milled upto the level of surface and polished

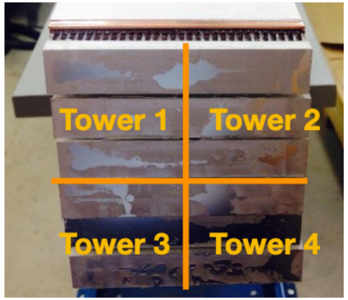


Fine polished

Sample SiPM board attached

Plate-based prototype: fiber and readout config

Module #1 (2x2)

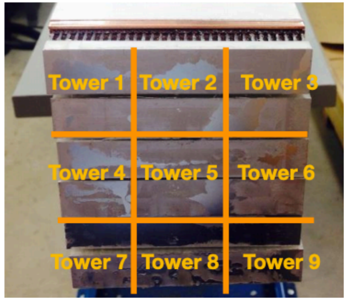


Tower#1	Tower#2
Tower#3	Tower#4

Combination of fibers for Module#1

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

Module #2 (3x3)

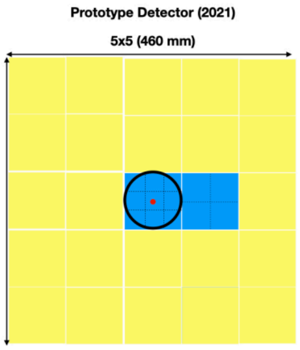


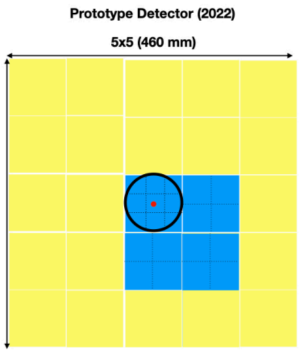
Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

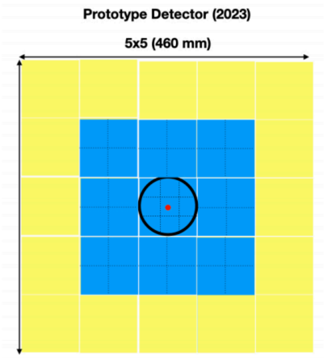
Combination of fibers for Module#2

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

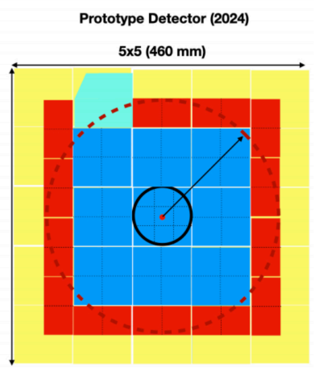
Plate-based prototype – roadmap to full containment

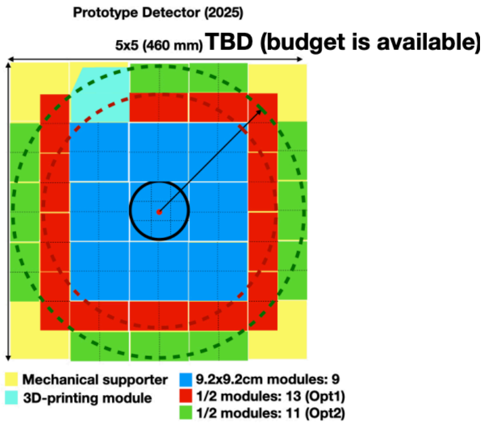






Aim to assemble the modules at CERN and do test beam every year





EOI-77 Project Description

Present project aims at developing a solution for a cost-effective construction of a realistic calorimeter based on dual-readout method. In particular:

Synergic to CSN1

1. choice of the absorber material, brass, lead and iron being the options on the table (each of them has pros and cons);
2. definition of the production procedure for the absorber (capillary production being the baseline solution, at present);
3. definition of the fiber optical properties (light spectrum, light yield, attenuation length, numerical aperture);
4. definition of an assembly method and material (e.g. glue) for 10×10 cm2, 2 m long, modules;
5. building and test of several of the above modules;
6. design of a realistic, engineering solution for the 4π **calorimeter** of the IDEA detector;
7. definition of a planning for the IDEA 4π **calorimeter construction and assembly**.

EOI-77 - Work plan

INFN Istituto Nazionale di Fisica Nucleare

- Material Choice
  - brass, copper, (lead), … find out best compromise between performance and technological achievement
  - clear and scintillation fibers characteristics: optimization and characterization of fibers
- Detector Assembly Technique
  - Definition of allowed mechanical tolerance and way to cope to them
  - Glue choice and gluing technique
  - Projective module construction
  - Module handling for detector mounting on the experiment
- Fiber Handling
  - Fiber insertion in the tubes: mass production approach
  - Definition of connection technique of fiber and SiPM: QAQC
- Simulation and Performance
  - detector achievable performances and layout optimization
  - detector realistic simulation
- Technical documentation
  - Engineering drawing for 4π calorimeter

Investigation of some of these technological problems will start during test-module construction

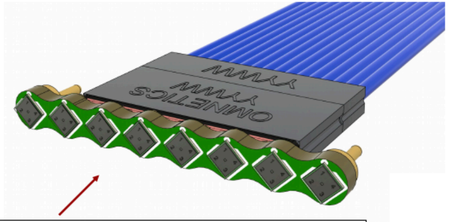
EOI-27 work plan

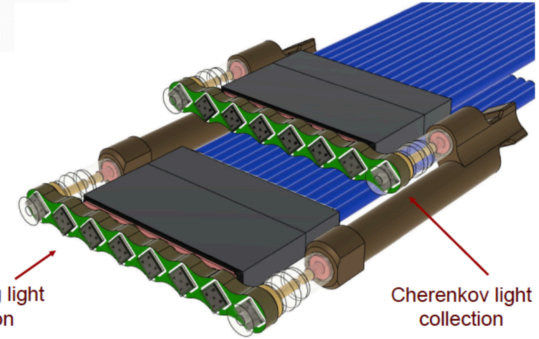
Synergic to CSN1

- **Particle discrimination: photons/electrons vs hadron induced showers**
  - Detailed study based on a full simulation which integrates both the geometry of the calorimeter and the detector response
  - Impact of the signal shape, transversal segmentation and longitudinal segmentation using the time stamp to the particle discrimination
- **Experimental qualification of existing front-end ASIC**
  - We have already identified the Citiroc1A as a potential solution, but still has to be fully qualified. Alternatives will be also considered
  - The qualification will be based on:
    - Lab measurements using evaluation boards
    - Test beam measurements using compact and scalable systems
- **Linearity response of the detector**
  - SiPMs with increased dynamic range in a compact packaging
  - Filters optimization
- **Grouping to reduce the number of channels to be readout and the costs**
  - Solutions under discussion are based on optical or electrical grouping
- **Development of an intelligent back-end system**
  - Scalable system to readout a large number of SiPMs
  - Requirements definition (i.e. charge, time, TOT and whatever information could be of interest for machine learning techniques)

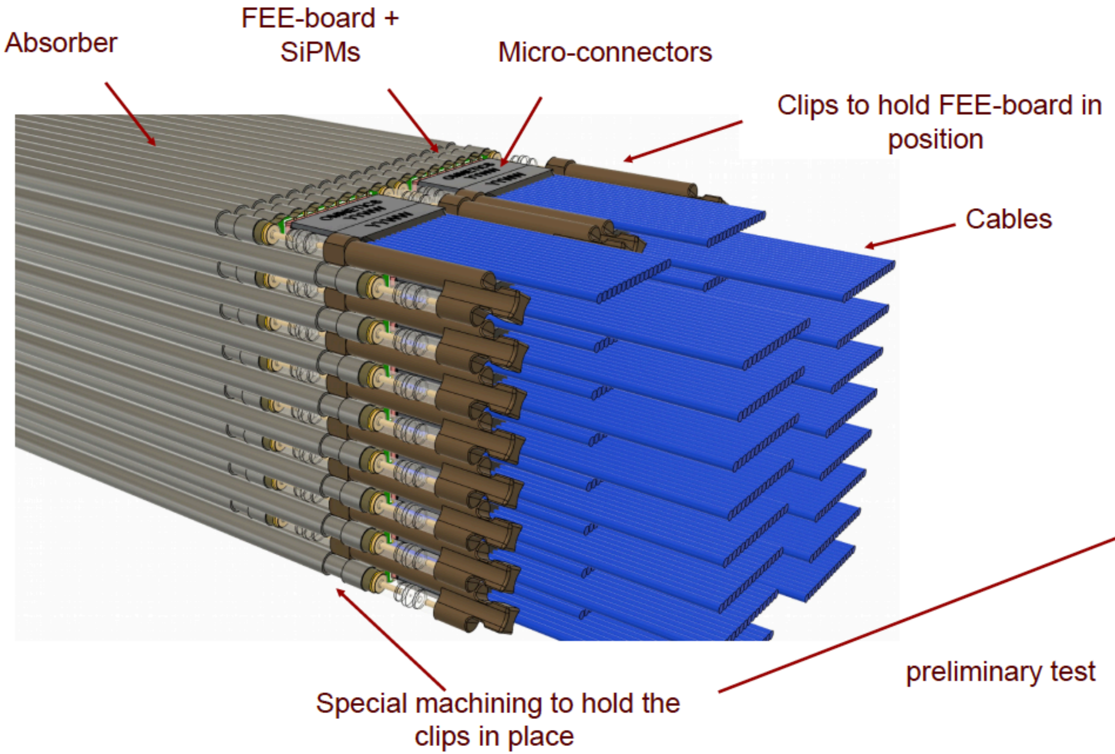
Scientific Program: FEE-board

- Mini FEE Boards (8 ch) equipped with SiPMs and micro connectors.
  - Costs are dominated by PCB printing area
- Qualification of single signals and signal grouping
- Qualification of power supply for SiPM
- After preliminary studies, signal caracterization with ASIC under evaluation





New concept for a true scalable module



Scientific Program: ASIC evaluation

Evaluation of an ASIC with digitizer and feature extraction capability, produced by Nalu

- CAEN is planning to implement it on FERS platform.
- If available in 2021, we plan to verify that its characteristics are consistent with our needs.
  - Studies from electrical point of view
  - Test readout SiPM of choice (small area with large dynRange)
  - Use with multiple SiPMs arrays.
- Interest of Catania and Bologna groups to collaborate on these activities to spread knowledge and support work load.
- We propose to put the request sj at ASIC availabily

Richieste e assegnazioni

Descrizione	Richiesta	Sede	Capitolo	
acquisto capillari	5	Pavia	Consumo	9.5 k€ (aggiornamento costo + taglio)
Colla	0,5	Pavia	Consumo	1 k€
sistema di costruzione meccanico	15	Pavia	Consumo	5k€
sistema di test meccanica	2	Pavia	Inventario	Ok
fibre scintillanti	12	Pisa	Consumo	7 k€ (per riduzione moduli)
fibre chiare	1,5	Pisa	Consumo	1 k€ (per riduzione moduli)
componenti per sistema di test fibre	5	Pisa	Consumo	Ok
fotomoltiplicatori	5	Pisa	Inventario	3 k€ (per riduzione moduli)
SiPM	3	Como (MI)	Consumo	2 k€ (per riduzione moduli)
produzione mini-FEB	7	Como (MI)	Consumo	Aggiornato a 8.5 ok
micro cavi coassiali	3	Como (MI)	Consumo	
board di qualifica ASIC SiREAD	6	Como (MI)	Inventario	Ok
~~board di qualifica ASIC SiREAD~~	~~6~~	~~Bologna~~	~~Inventario~~	
metabolismo di laboratorio	2	Catania	Consumo	Ok
Sum	73			

ONLY 2+1 module financed