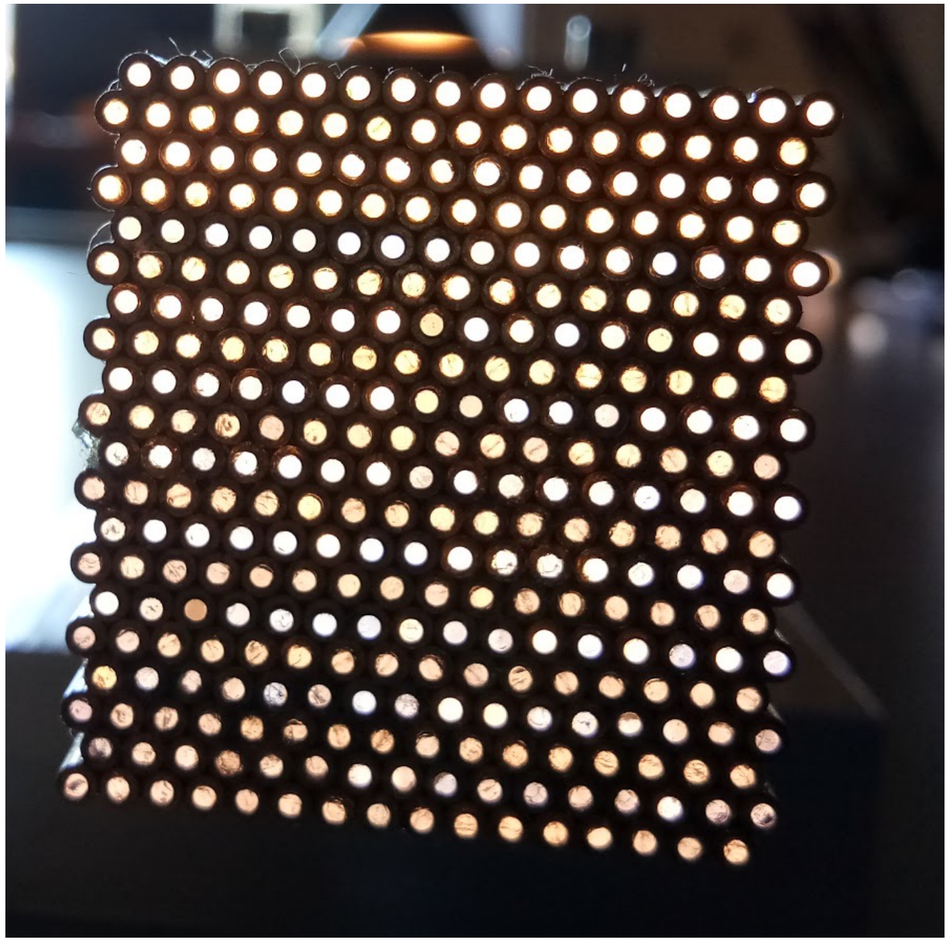
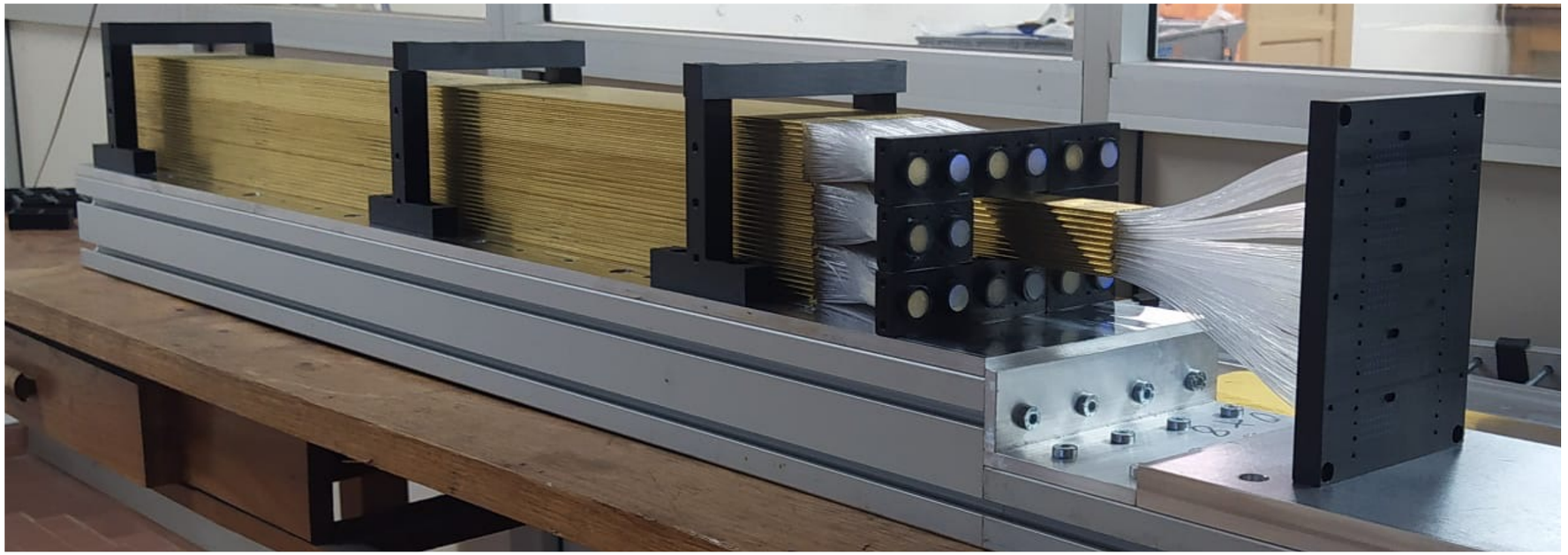


IDEA Dual-readout calorimeter

Gabriella Gaudio
on behalf of the IDEA Dual-Readout Calorimeter Collaboration
June, 3rd 2021

- Update on 2020-prototype
- Development for Had-prototype
- Synergies
- (a lot of details in the "additional material" section)

Capillary-tube based Prototype



10x10 cm^2 divided in
9 towers, 1m long

16x20 capillary each
(160 C + 160 S)

Capillary:

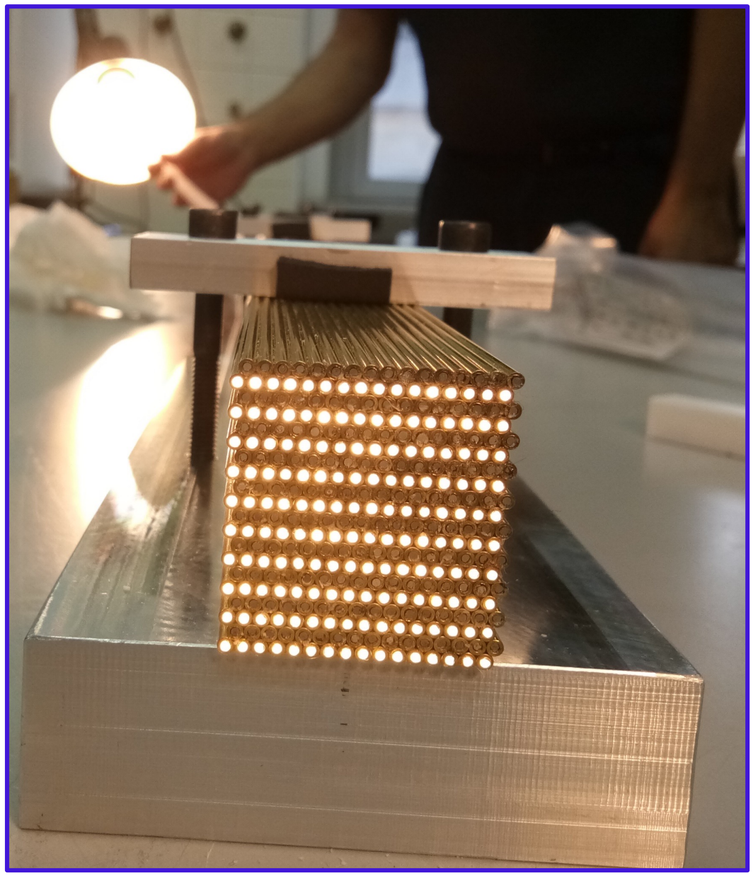
- 2mm outer diameter, 1mm inner diameter
- Material: brass CuZn37
- Absorber structure assembled in RBI (Zagreb)

Readout:

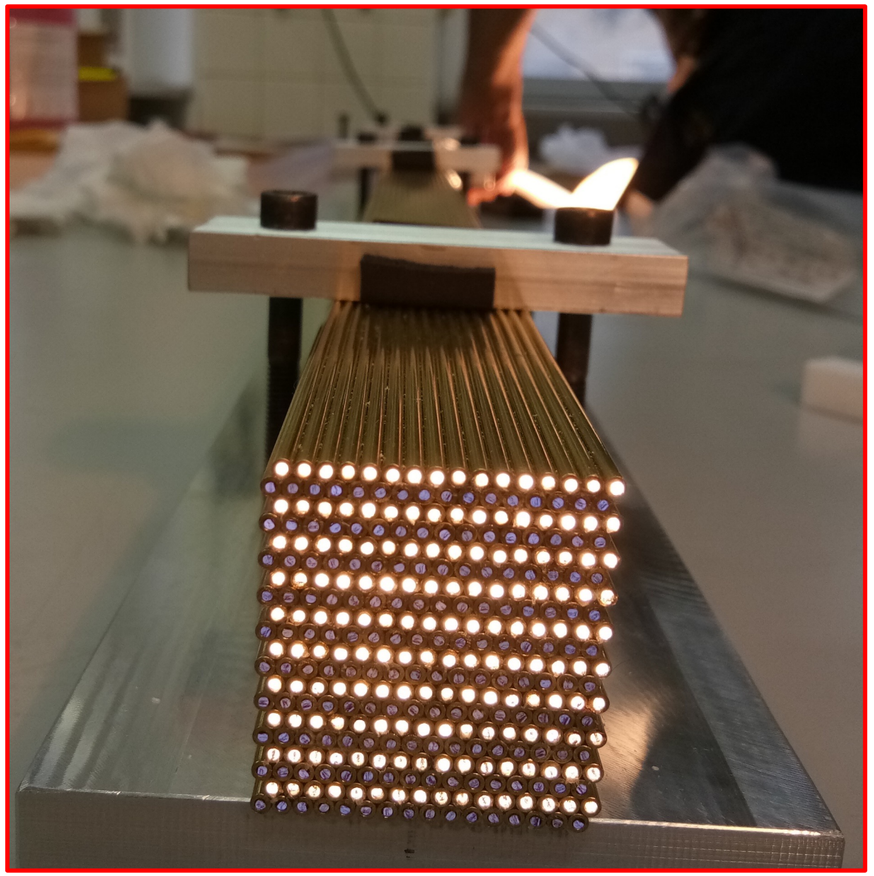
- 1 central tower read out by SiPMs
- 8 surrounding towers read out by PMTs (à la RD_52)

Fibers loaded in a tower

Fibers illuminated from rear end



Scintillation fibers

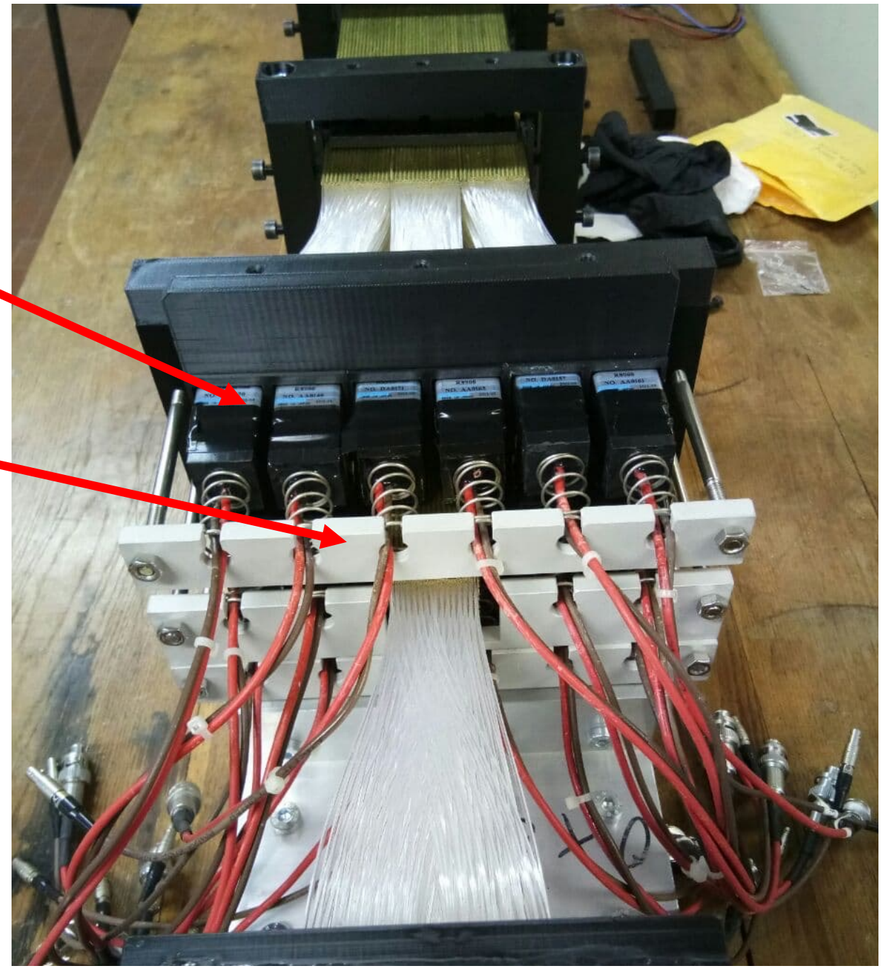


Cherenkov fibers

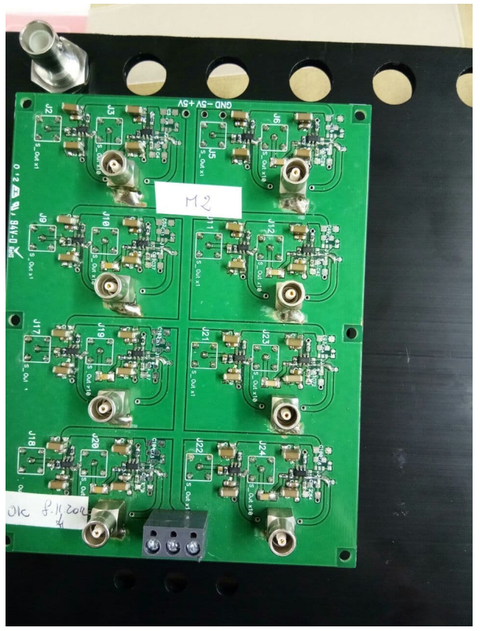
PMTs readout of external towers

PMTs

PMT Holders



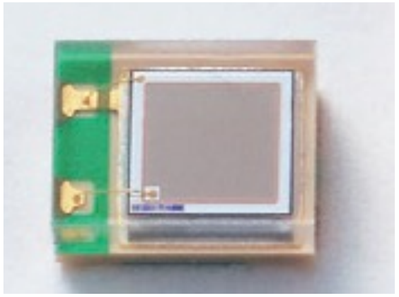
PMT: Hamamatsu R8900 (S), R8900-100 (C)
Custom made tapered base



Preamp board for the PMTs

The readout of the PMTs is based on Caen QDC (V792AC)

SiPMs readout of central tower

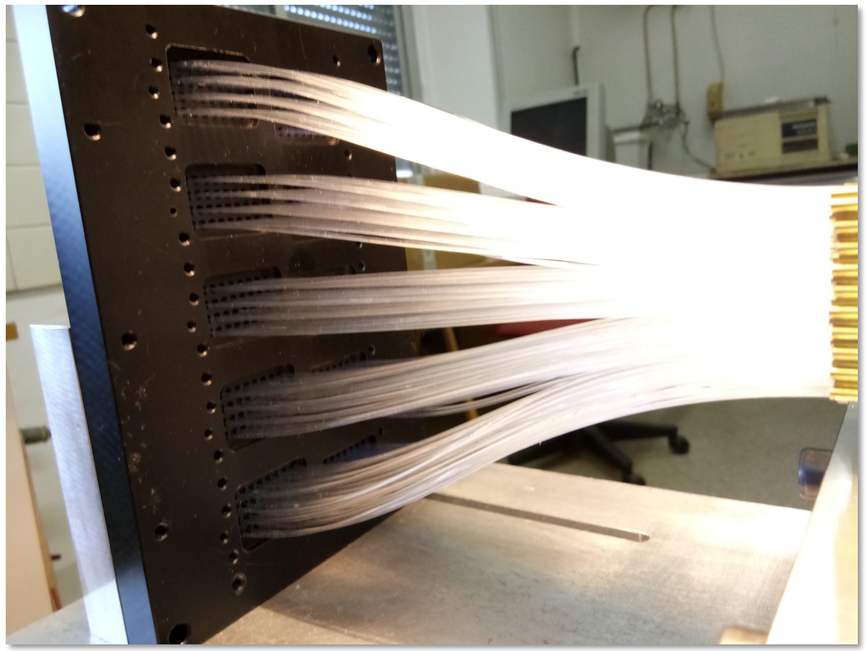


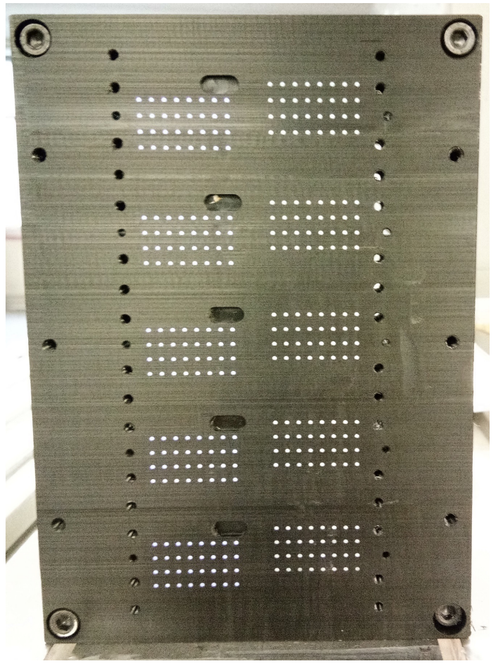
SiPM: S14160-1315PS from Hamamatsu
Cell size: 15 μm

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

FEE – Boards
5 Boards (320 SiPMs)

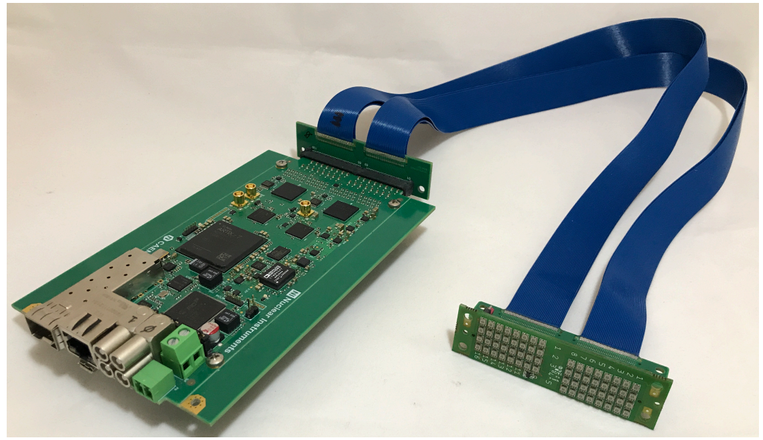
Each board—> 64 SiPMs
(32 S +32 C) to FERS board

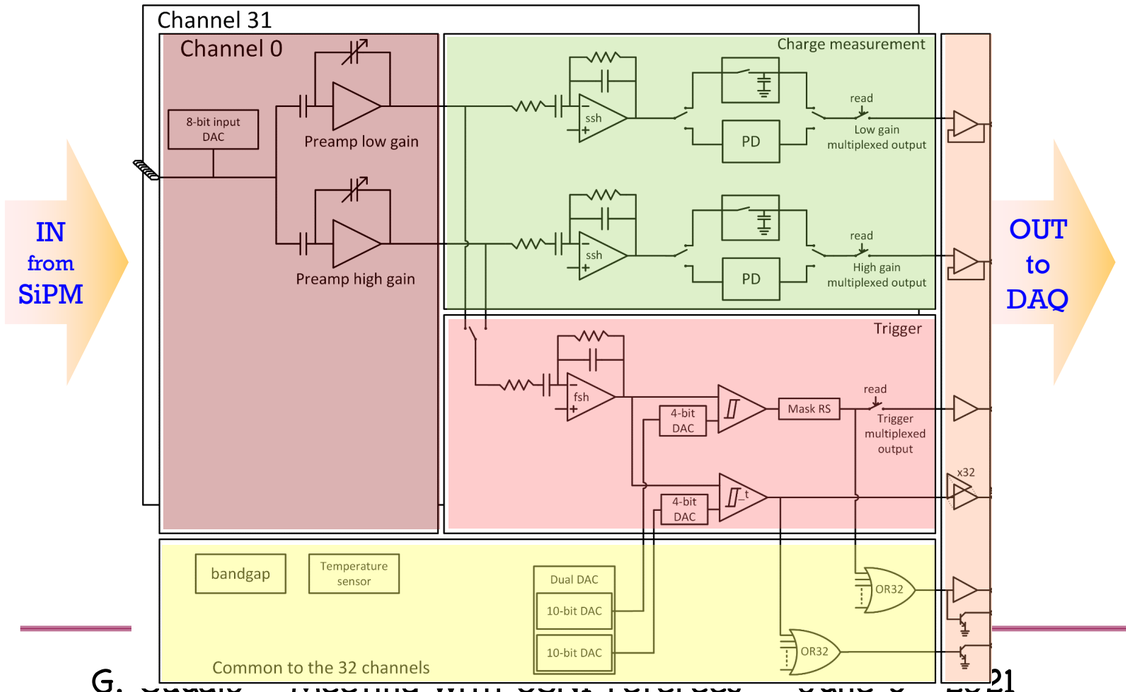




S C

SiPMs readout of central tower



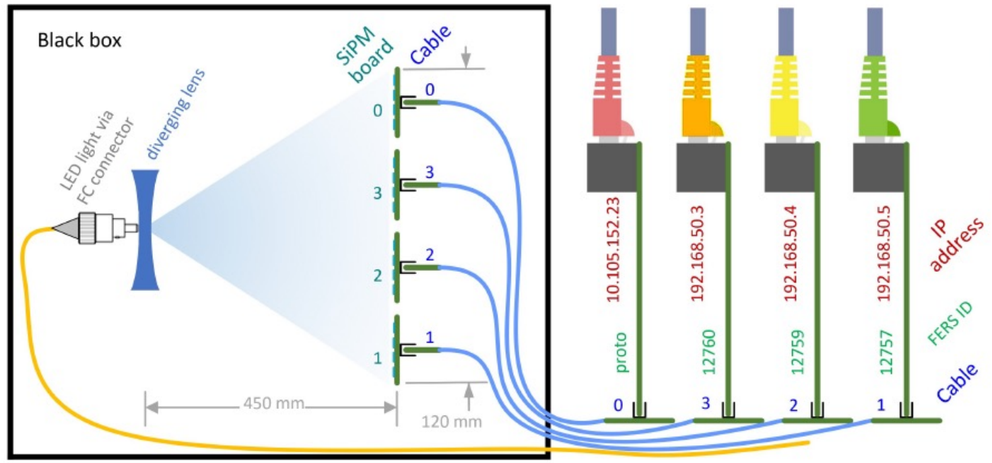


The readout of the highly granular module (320 SiPMs) is based on the Caen FERS system (A5202)

5 boards required

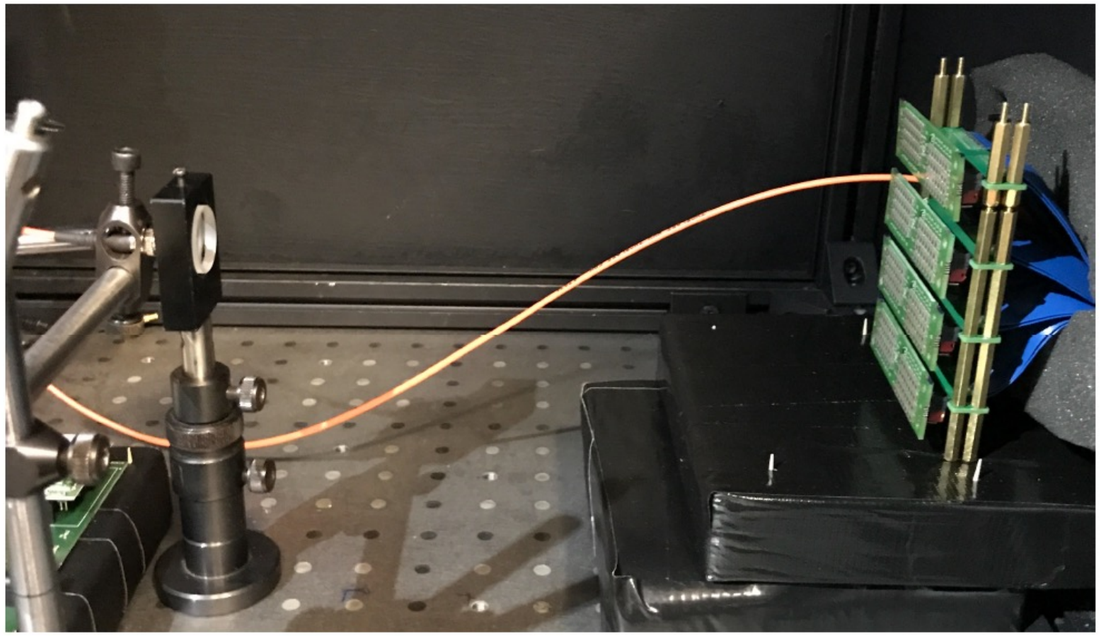
- Two Citiroc1A for reading out up to 64 SiPMs
- One (20 – 85V) HV power supply with temperature compensation
- Two 12-bit ADCs to measure the charge in all channels
- Timing measured with 64 TDCs implemented on FPGA (LSB = 500 ps)
- 2 High resolution TDCs (LSB = 50 ps)
- Optical link interface for readout (6.25 Gbit/s)

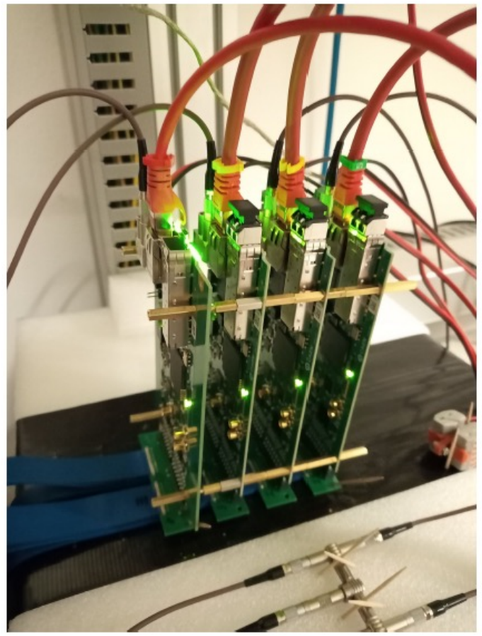
SiPM & FERS system under test



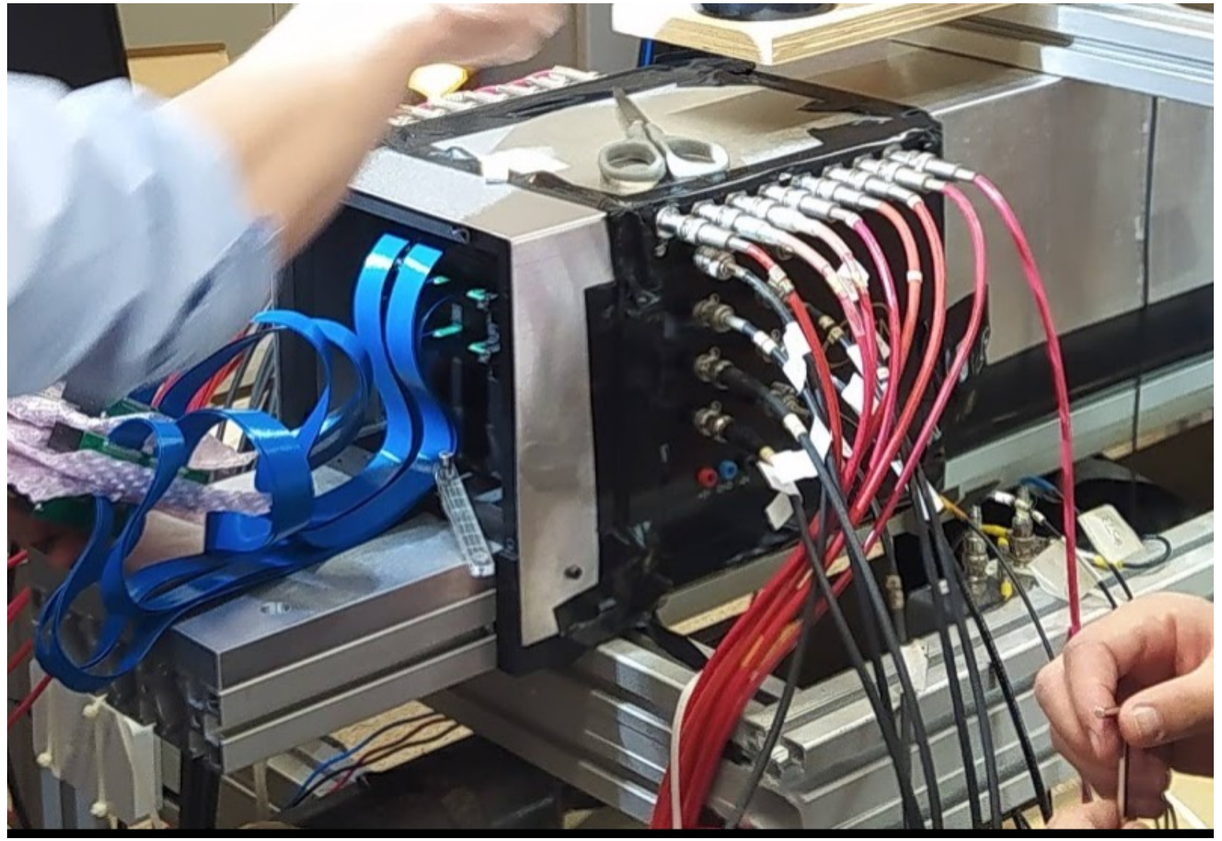
- FE-boards 5/5 qualified
- FERS 5/5 qualified
- Data Concentrator: soon

- Channel equalization based on an automatic 3-steps procedure. Found set of optimal operational parameters





2020-prototype integration



- Integration of FEB boards, FEB + FERS system testing
- Check equalization by stimulation single fibre with a pulser
- Integration in the cosmic ray stand ongoing

Testbeam Program

- DESY: 14-27.6
  - 1- 6 GeV electrons
- CERN: 18-25.8 (possibility to run parasitically in the previous week under evaluation)
  - 6-180 GeV electrons and muons

- Measurement programs
  - Main goal in DESY is system integration and working assessment + low energy measurements
  - CERN measurements will allow to focus on position, angular, energy scans
  - Timing measurements

Prototype 2021

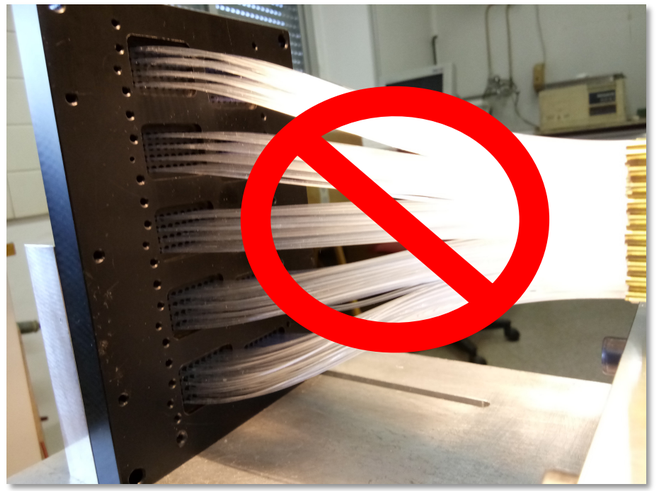
2021-plans

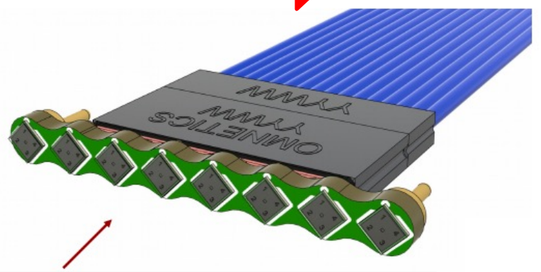
Construction of a few MINIMODULEs to study:

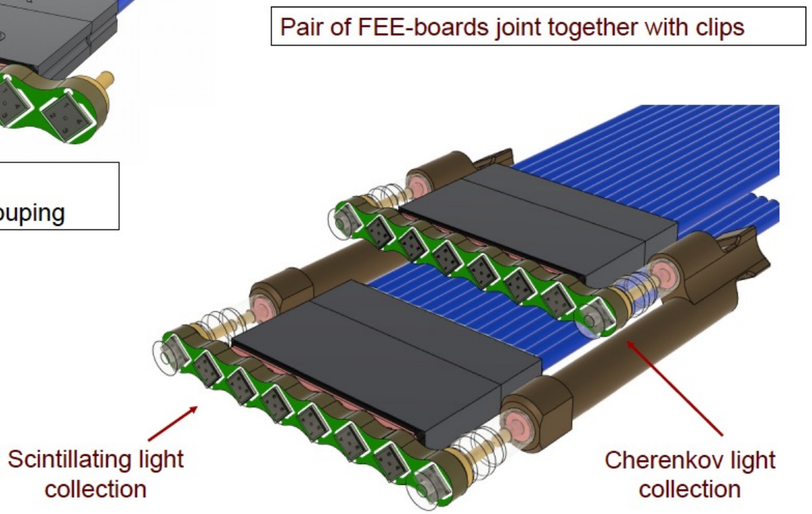
- Assembly procedure
- Reproducibility of assembled modules
- Mechanical supports

+ Material to assess material choice and baseline choice

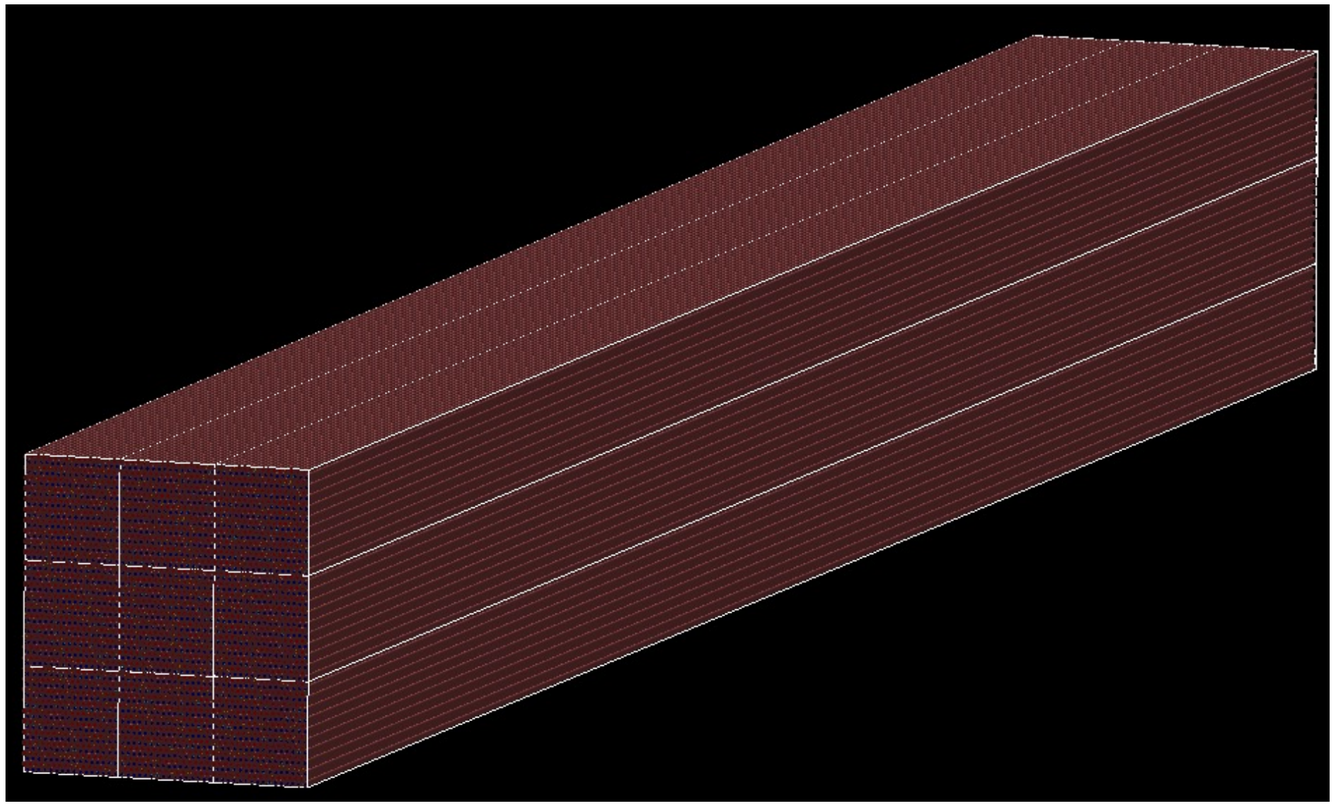
- ✦ Mini FEE Boards (8 ch) equipped with SiPMs and micro connectors.
  - ✦ Costs are dominated by PCB printing area
- ✦ Qualification of single signals and signal grouping
- ✦ Qualification of power supply for SiPM
- ✦ After preliminary studies, signal caracterization with ASIC under evaluation

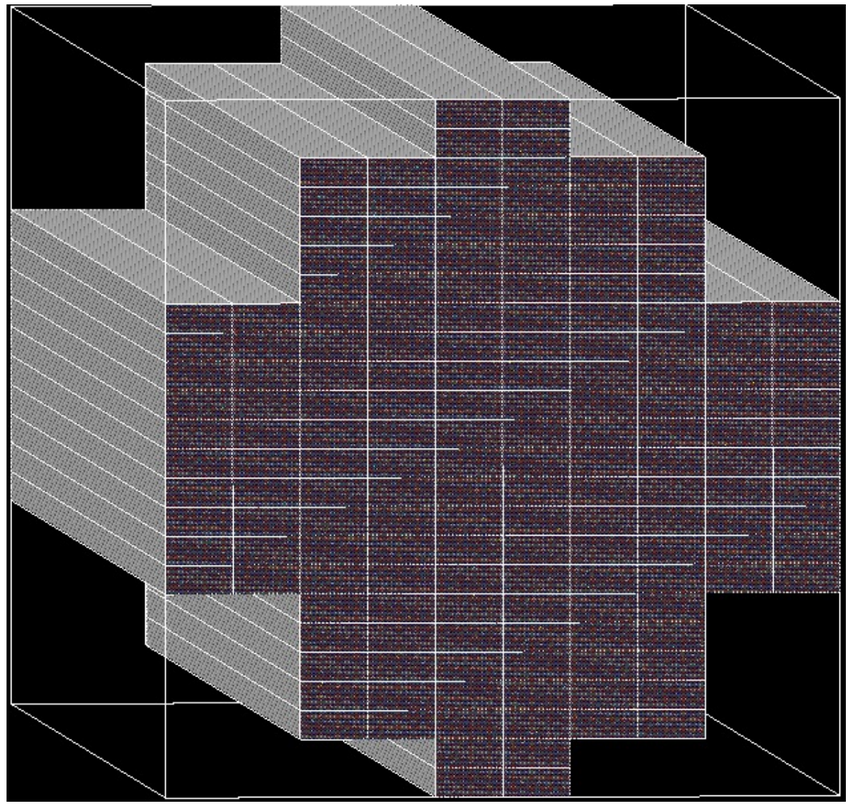






Prototype G4 Simulation





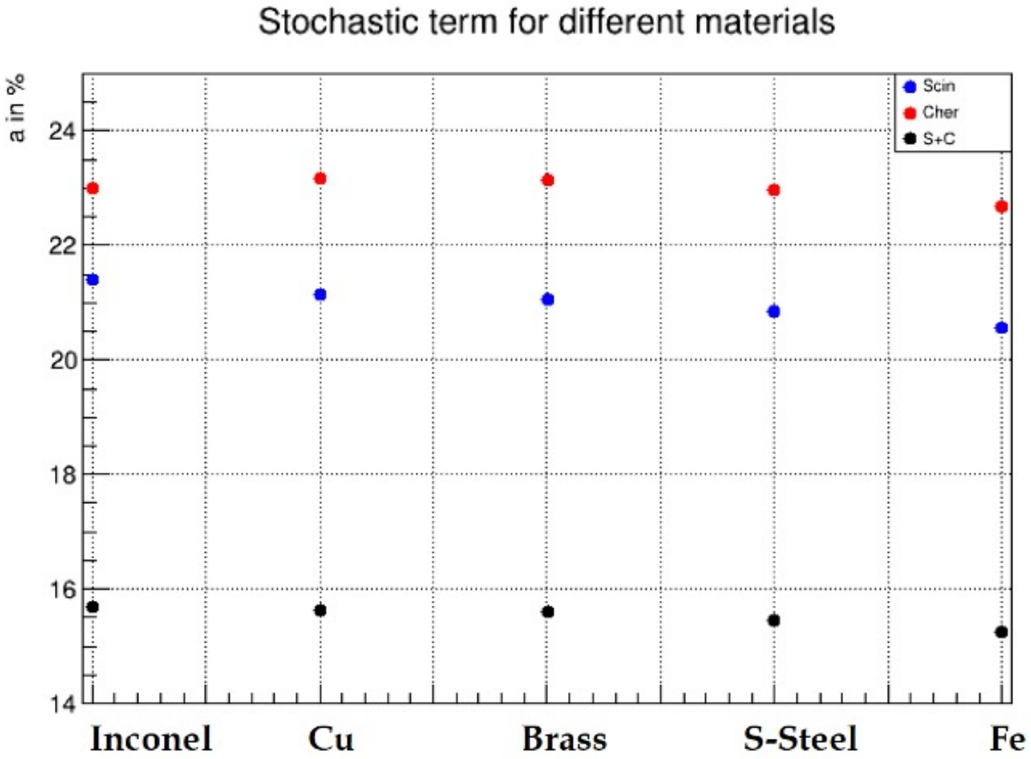
"em-prototype":

- realistic geometry and readout
- comparison with TB data

"Hadronic-size prototype":

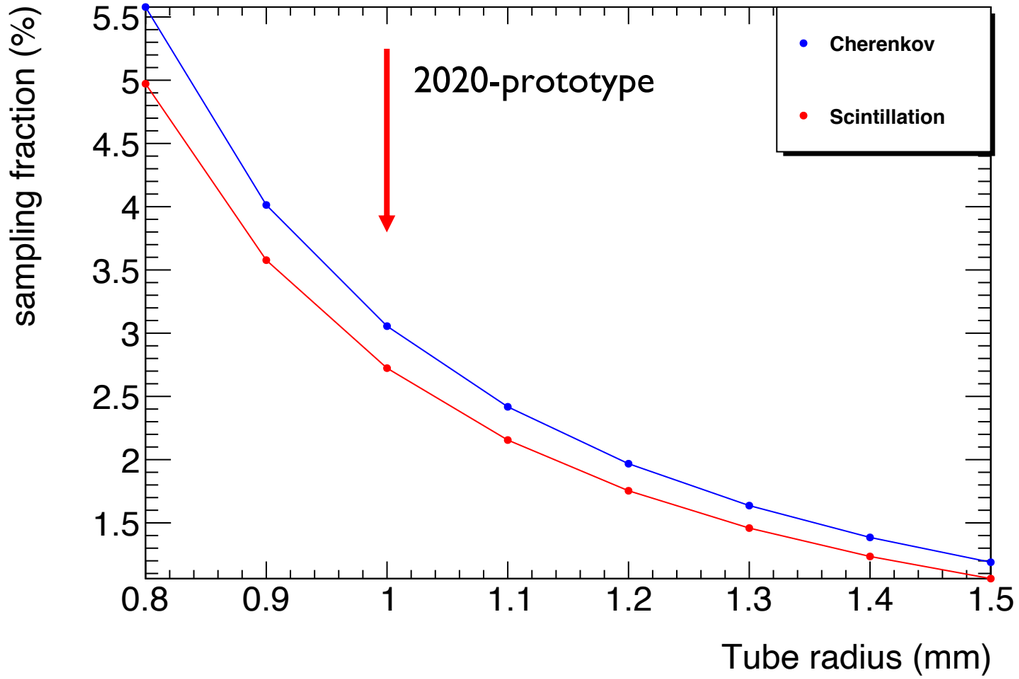
- study performance as support for technical choice

Choice of material and dimensions



GEANT4 simulation of 2020-prototype

$$\frac{\sigma}{E} = 2.7\% \frac{\sqrt{d/f_{samp}}}{\sqrt{E}}$$



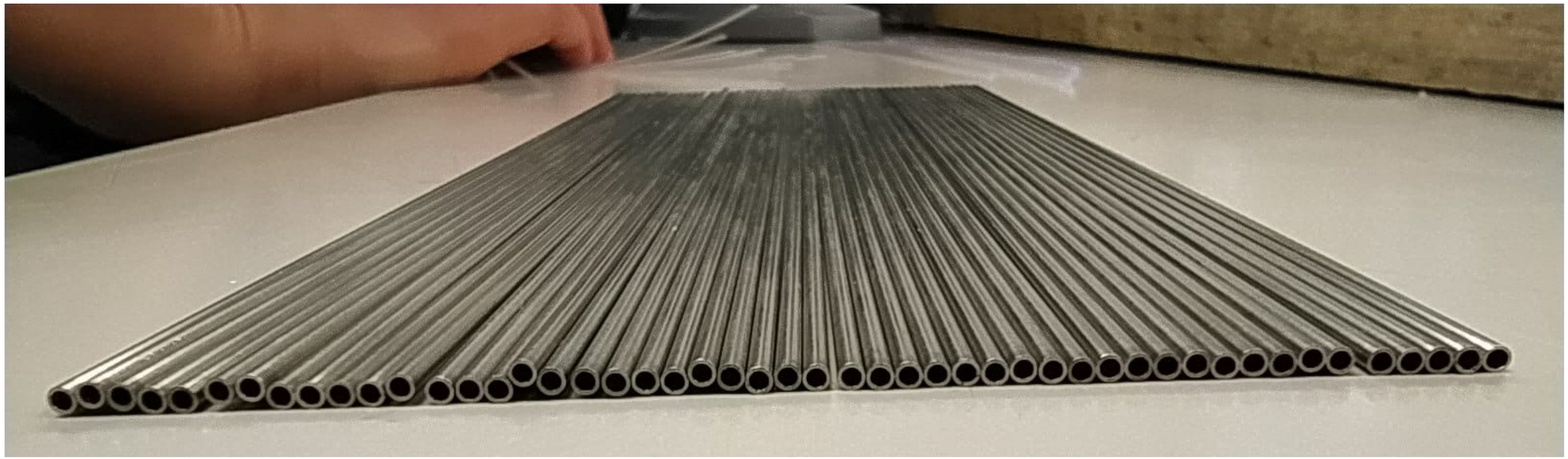
Calculation

capillary for 2021-modules

Company	OD (mm)	ID (mm)	toll. length (mm)	Material	cost per tube	total	cost per tube	total
					1200x 2m		~ 90k x 2m	
Rigamonti	1.6 +/- 0.020	1.1 -0 +0.1	0.1-0.2	AISI 316L EU	1.406	1687	1.334	120000
Albion Alloys	1.6 -0 +0.01	1.1 -0 +0.03		CuZn37	3.65	5474	3.09	278000
	2.0 -0 +0.03	1.1 -0 +0.04		CuZn37	3.73	5595	3.15	283000

- Other 3 companies contacted, but either non available or costs too high
- Albion Alloys (same for 2020-prototype) could send only sample of 2mm OD, 1m long
- Sampling from Rigamonti tested in Pavia:
  - 50 tubes 20-cm long
  - 10 tubes 2m-long

Stainless-steel tubes

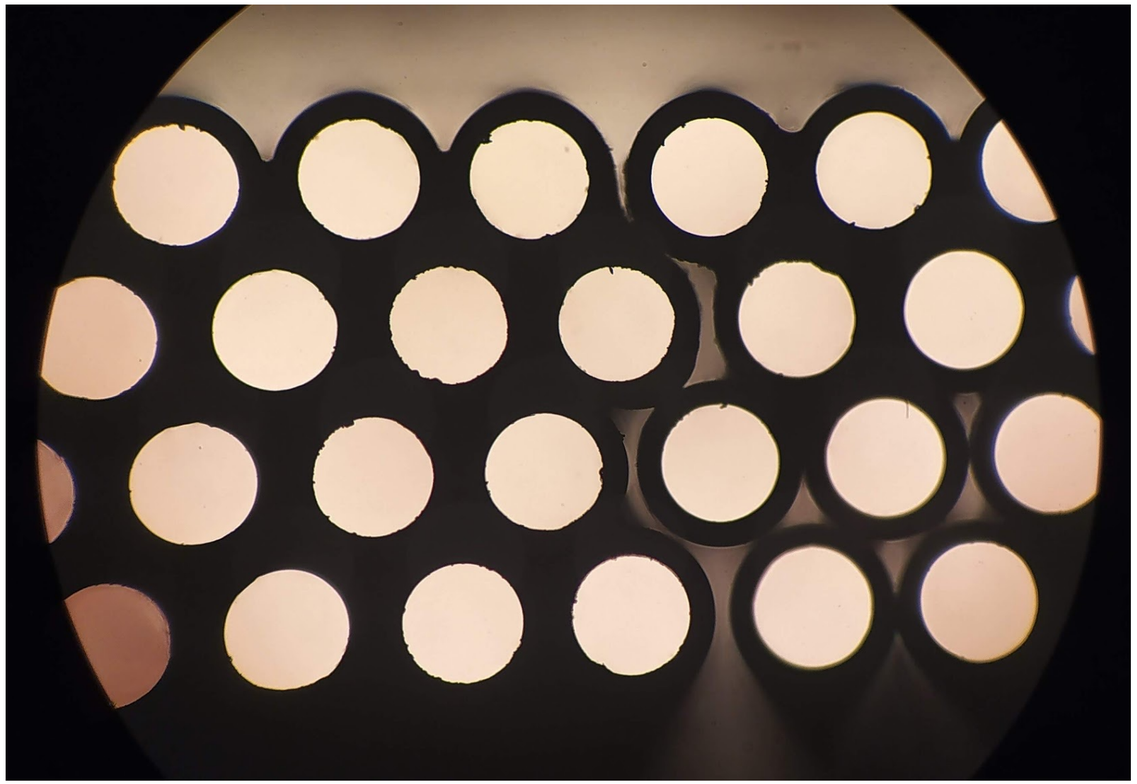


AISI 316L EU (diamagnetic)
electro-welded
1.6 mm OD
1.6 to 2.0 mm OD also available

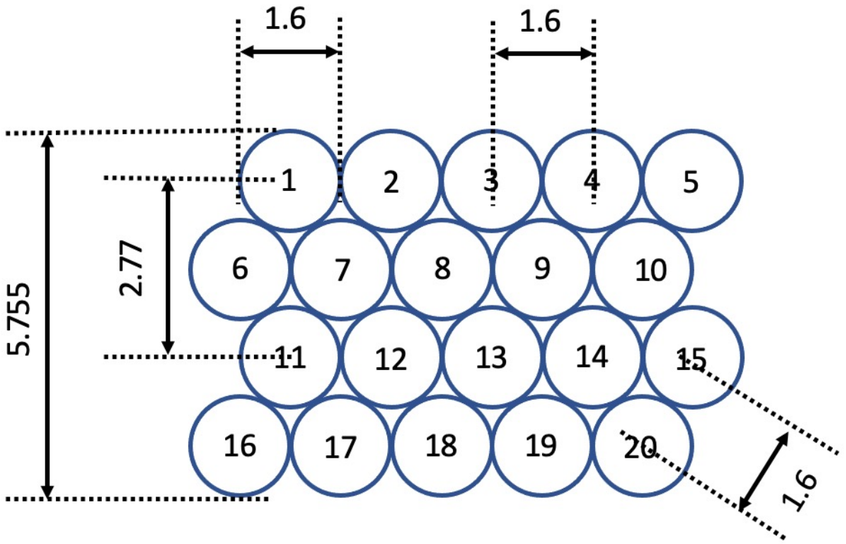
In all the tubes a scintillating fibre was passed

- 40/50 good
- 10/50 good after a quick cleaning with a drill-bit

Assembly tool for testing



produced sample tested for stiffness
and measured with a microscope



Obtained distributions for center-to-center distances with RMS ~ 20 μm

Quality of the tube (OD: RMS 2 μm; ID RMS 6 μm) seems to be sufficient to guarantee good quality of the assembled array

Great simplification on the assembly tools

Budget update

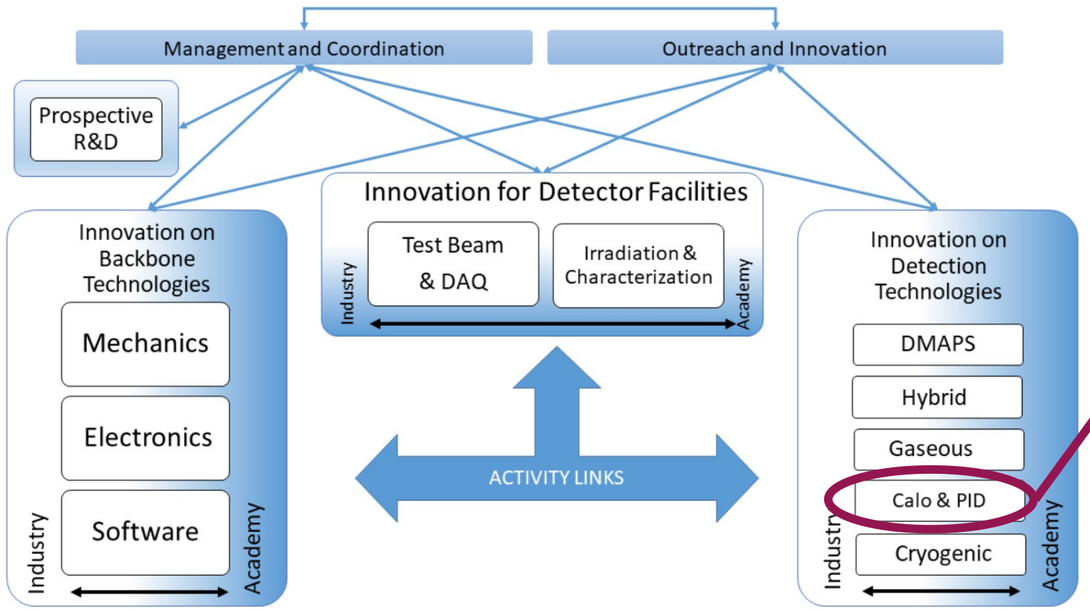
- Order for material to construct modules not yet done
  - finalization of dimension of tube and circuitry for mini-FEB ongoing
  - fibre chosen
  - acquire 2 new PMTs from Hamamatsu (new type)
  - SiPM: choice under finalization
- Design of mechanical assembly system
  - under development (finalization with tube dimensions)
- Test system for mechanical test and fiber test – to be developed
- Board to qualify ASIC SiREAD
  - The evolution of the SiRead is the HDSOC, but the evaluation board is not yet available. For this reason we are considering to delay this activity at the next year

Left: R11265U series, Right:

- borosilicate window, UBA (-200)
- UV glass window (extended to 185nm) UBA (-203)

Synergies

AIDAInnova



AIDAInnova Program
Start: April 1st, 2021
Duration: 4 years

WP 8.4.2: Development of highly-granular dual-readout fiber-sampling calorimeters

INFN-BO, INFN-MI, INFN-PI, INFN-PV, U. Sussex, ~~RBI,~~ CAEN + INFN-CT + INFN-RM1

Deliverable:
D8.4 : Construction and qualification with beam of 10×10 cm^2, 2 m long, prototypes [M46]

Total founds INFN: 120 k€

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

Other partner in the task:

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

ECFA R&D Detectors

Rich program of symposia: https://indico.cern.ch/event/957057/program

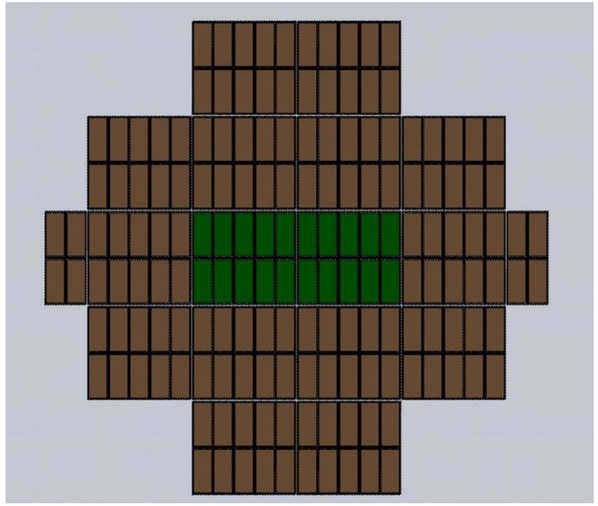
https://indico.cern.ch/event/999820/

- A talk specific on "R&D for Dual-Readout fibre-sampling calorimetry"
- Dual-readout mentioned in other talks

Call GR5 & PRIN

Re-submitted project to CSN5 call

- BO, CT, MI, PI, PV, RM1, TIPFA
- Updated wrt work done in 2021
- Large number of supportive letters



PRIN Project: MonSiPh

- R&D on dSiPMs
- target applications in biophysics and particle physics
- Uni. Insubria (PI Massimo Caccia), Uni. Piemonte Orientale, Uni. Padova, Uni. Pavia, INFN

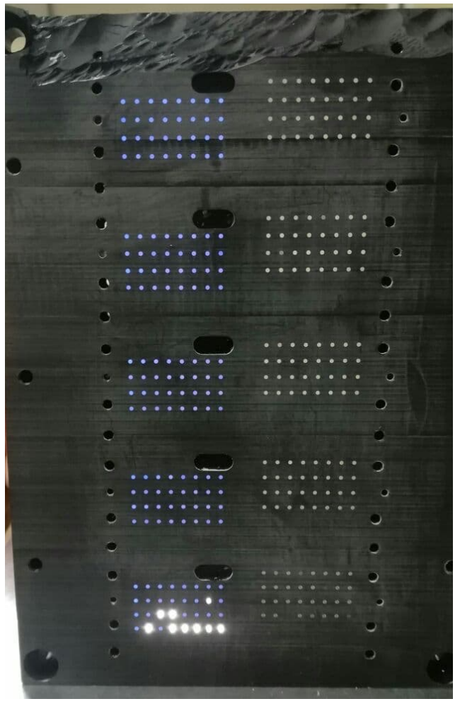
Additional Material

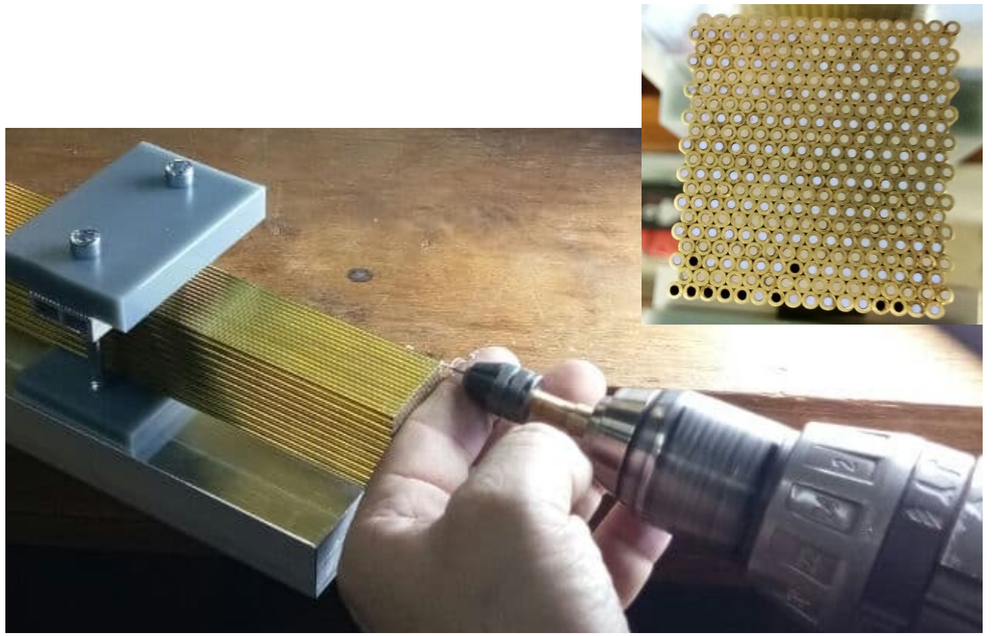
Reloading fibers

While milling the SiPM interface surface , the machine stopped, hitting the surface itself

10 S fibers broken between module and interface

- Fibers reloaded
- Glued
- Damages Recovered





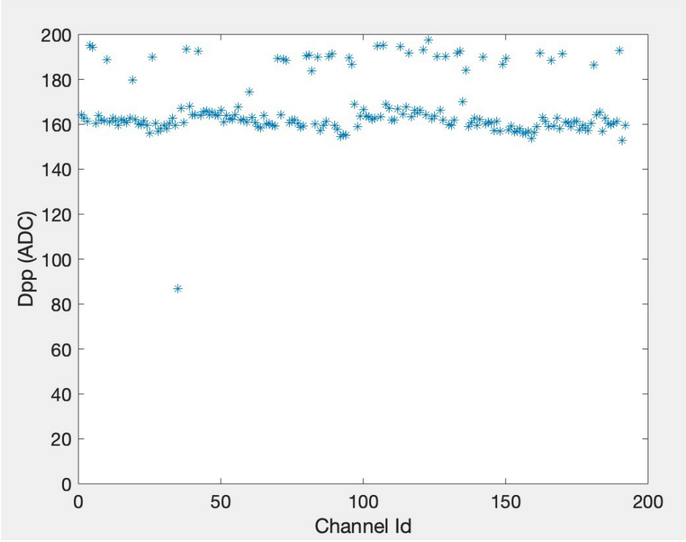
Drilling

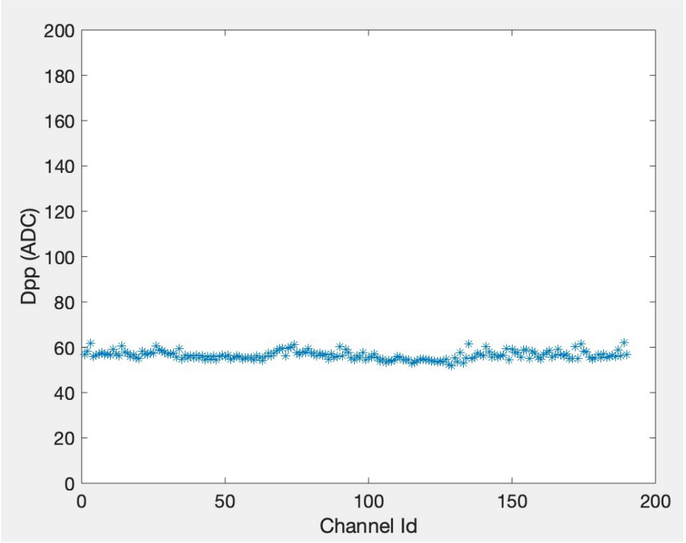
Precise Drilling

SiPM equalization

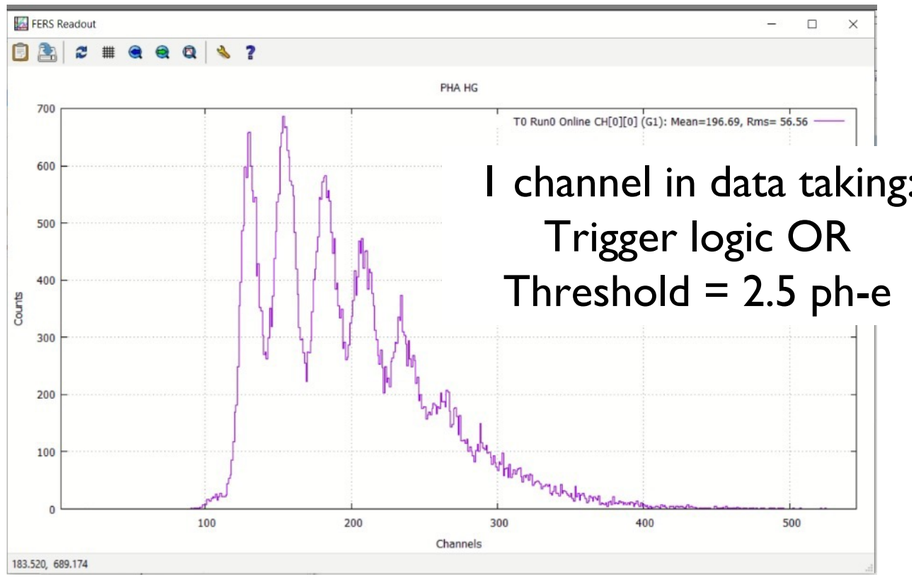
- Channel equalization is based on an automatic 3-steps procedure:
  - HV scan to measure the Breakdown voltage (all SiPMs will be operated at the same V_over)
  - HV-Adjust DAC scan:
    - This procedure will allow to calibrate the HV-Adjust DAC for all channels and the fits are used to get the proper settings
  - High Gain DAC scan
    - This procedure will allow to calibrate the High Gain DAC for all channels
- The threshold used for the trigger is defined at the end of the procedure (2.5 or 3.5 ph-e)

HG = 40 and LG = 0 : enough overlap for the LG calibration and we should cover up to the 60% of the SiPM occupancy

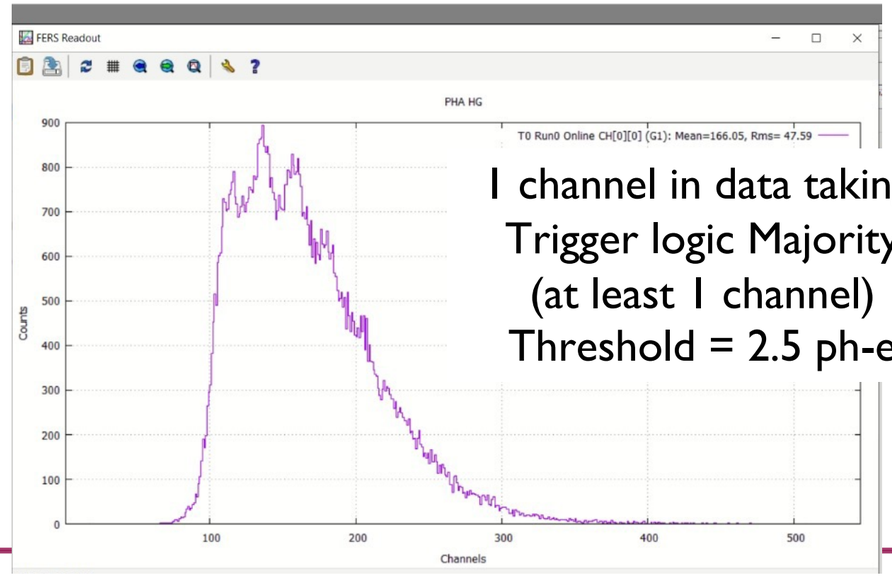




System qualification



1 channel in data taking:
Trigger logic OR
Threshold = 2.5 ph-e

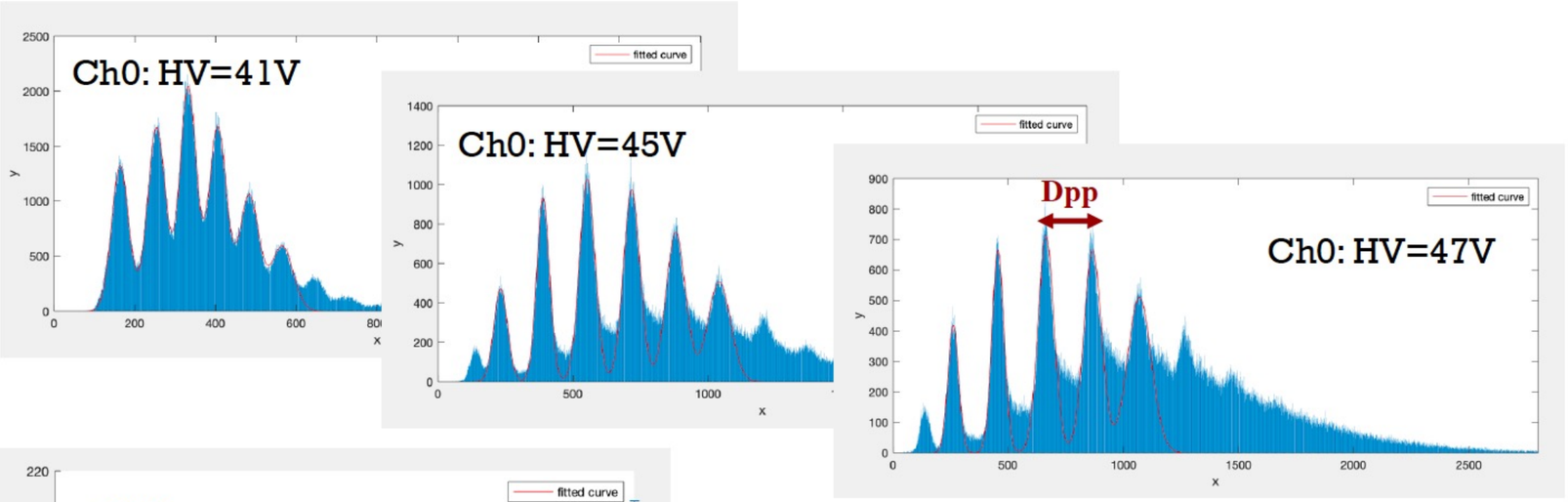


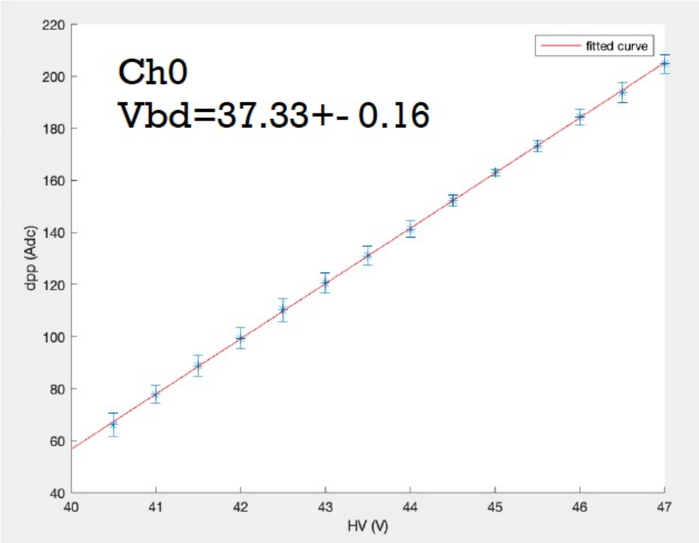
1 channel in data taking:
Trigger logic Majority
(at least 1 channel)
Threshold = 2.5 ph-e

- Readout system qualification (Multi-board schema– without data concentrator): well advanced
  - Data concentrator is not yet available (Caen is finalizing the firmware)
  - too risky to use it at the test beam in DESY
- Event accept works as expected (latency < 200 ns)
- The majority must be improved (it probably comes too late). In case of problems we can still use alternatives:
  - The OR logic with a threshold at 3.5phe + event accept (Dark rate measured at the Hz level)
  - The OR32_AND2 with a threshold at 2.5/3.5 phe + event accept (to be checked)

Breakdown Voltage

FEE Board1_FERS12757



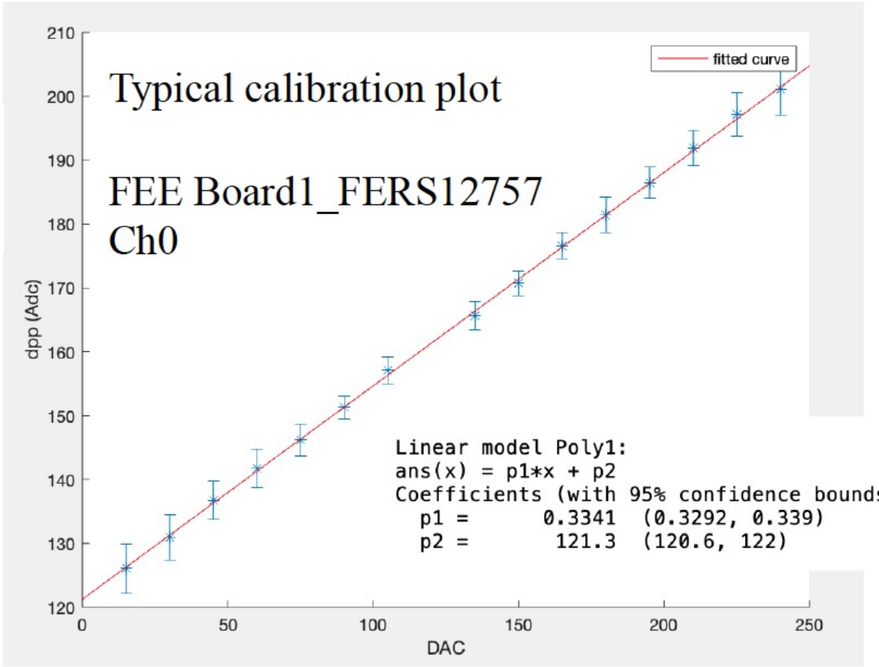


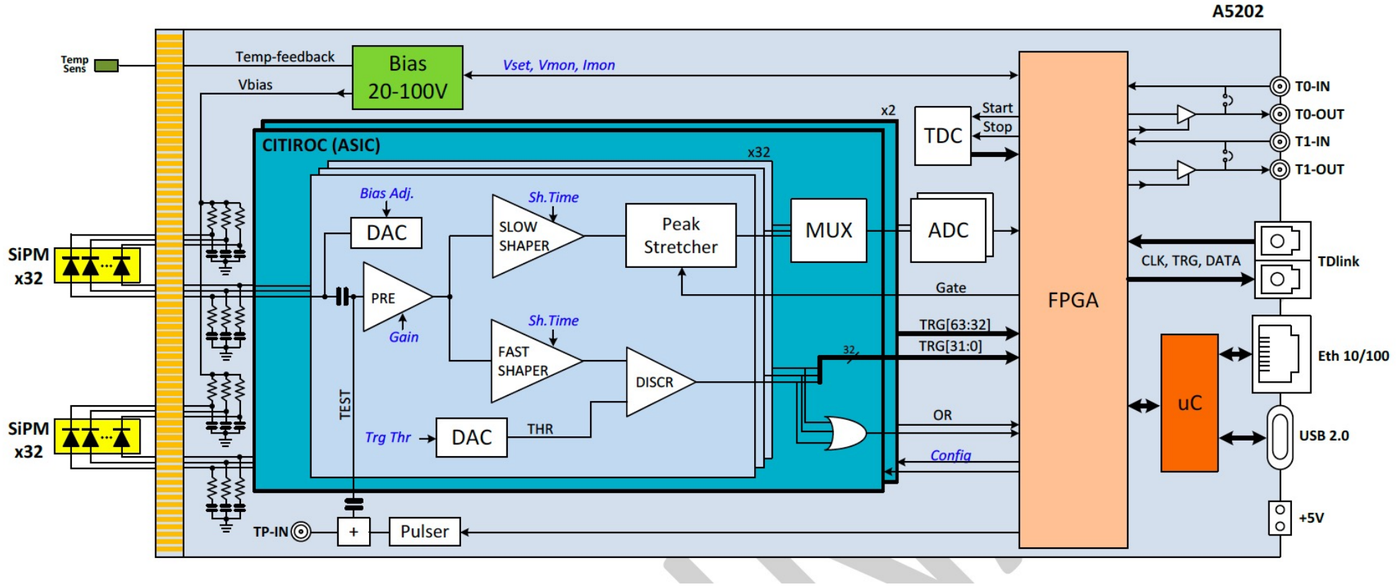
This is one of the standard procedures used to measure the SiPM breakdown voltage

Setup	Vbd (V)
Board1_FERS12757	37.27+- 0.14
Board2_FERS12759	37.37+- 0.19
Board3_FERS12760	37.41+- 0.25

HV-DAC: calibration

The FERS provides the same HV to all channels, but it can be adjusted using 64 DACs (one per SiPM)

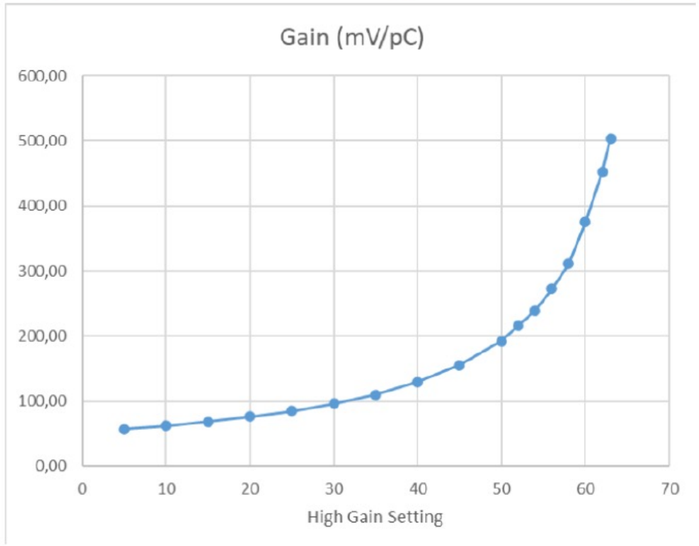




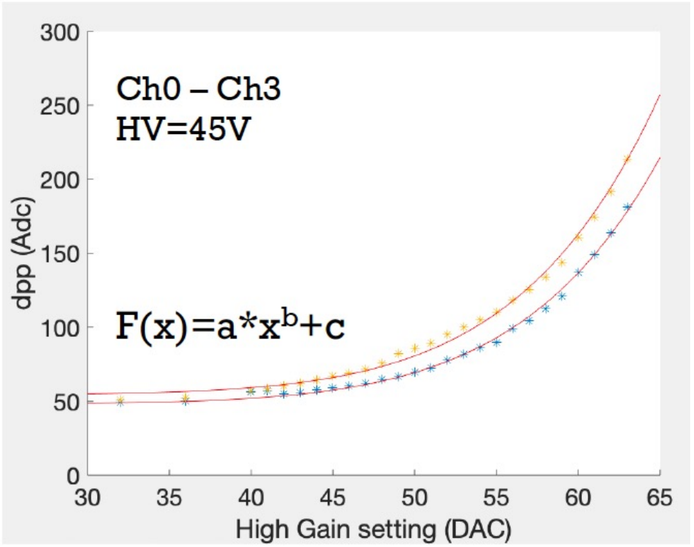
Setup	DAC –Dpp calibration
Board1_FERS12757	0.3353+- 0.0085
Board2_FERS12759	0.3312+- 0.0093
Board3_FERS12760	0.3301+- 0.0126

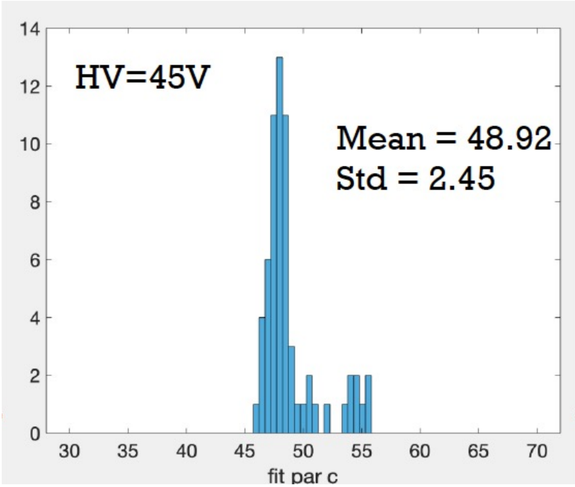
High Gain calibration

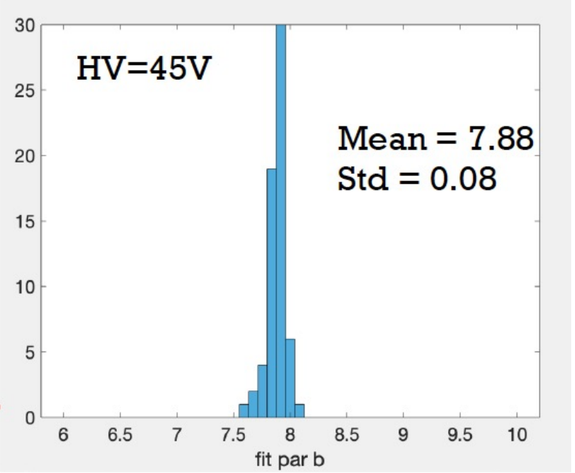
High Gain calibration (From CAEN)



FEE Board3_ FERS12760

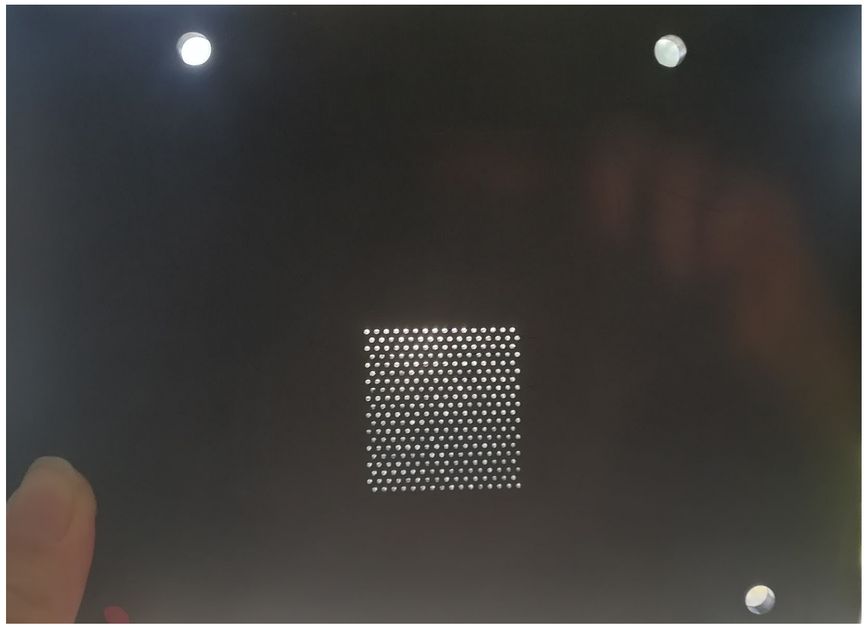


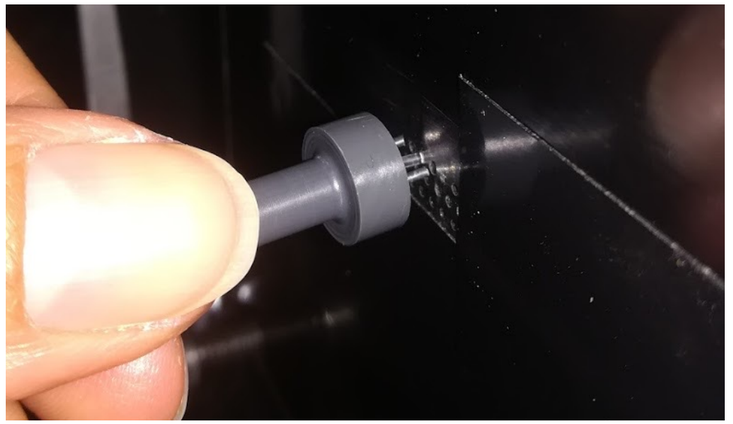




Integrated system test

- Extra entrance window for single SiPM test
- Single fiber stimulated with a pulser
- Check equalization (work started, to be finished in next days)





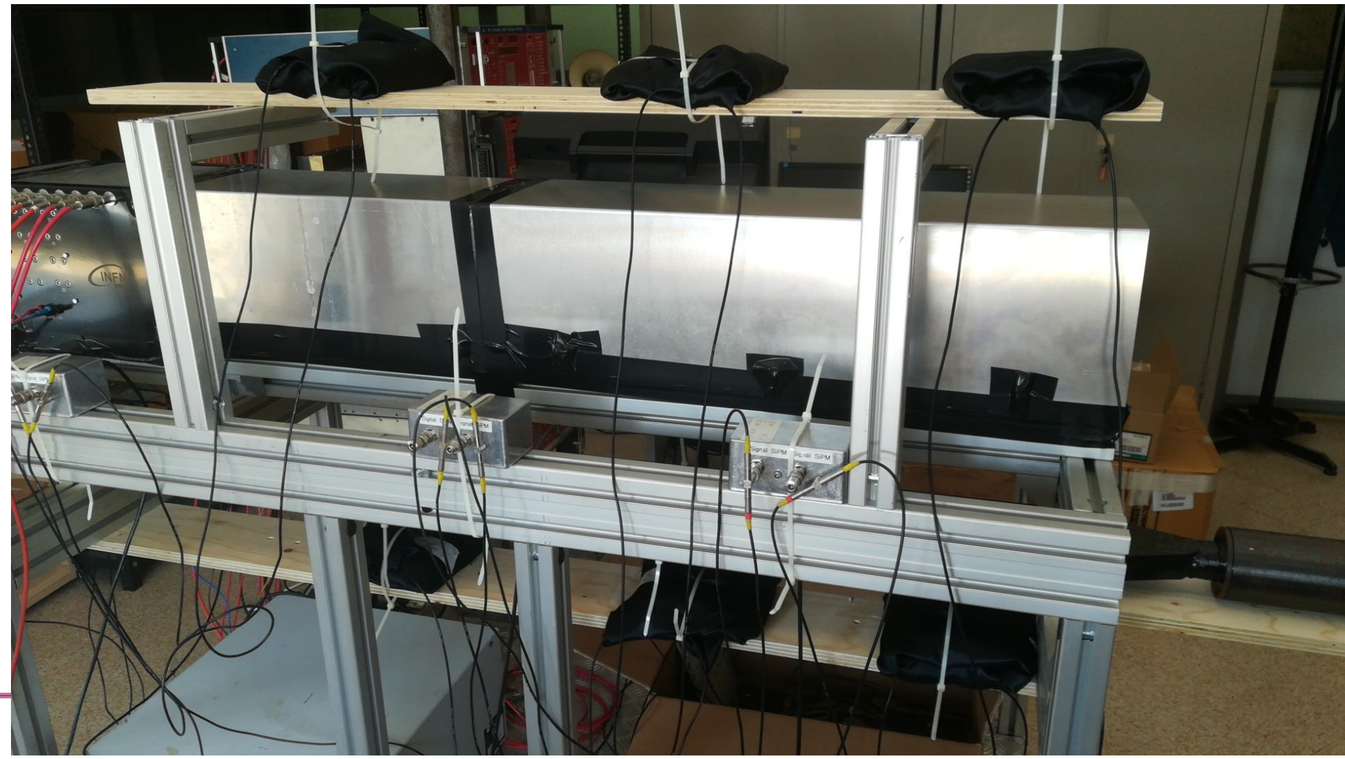
Cosmic-Ray test stand

Scintillator (NE110) slab :

120x12x2 cm^3
2PMTs XP2020 Philips

6 Scintillator tiles:
BC422 from MEG, 10x15x2.1 cm^3

SiPM S14160 – 50 μm cell size 3x3 mm or 6x6 mm
parallel of 8-14 SiPM (3% of lateral surface)

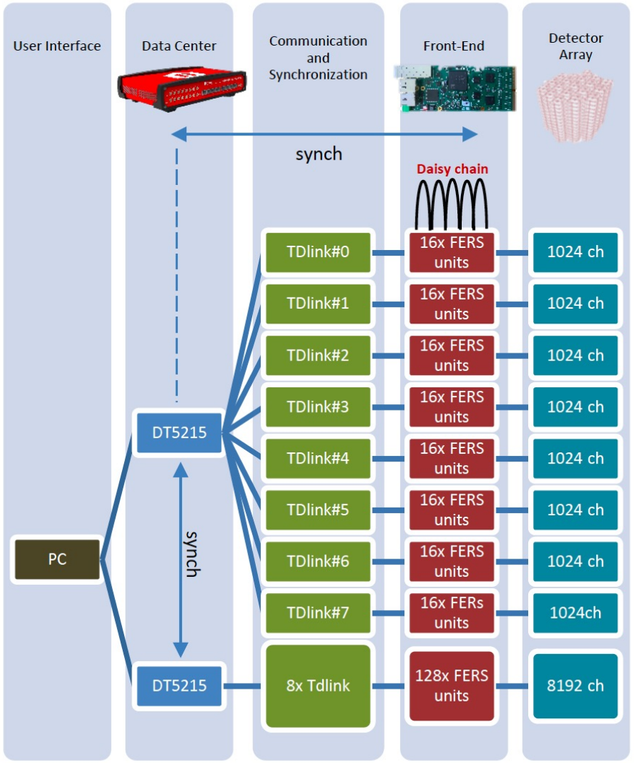


3 towers to select evt at different depth
Very low light from muon cosmic rays

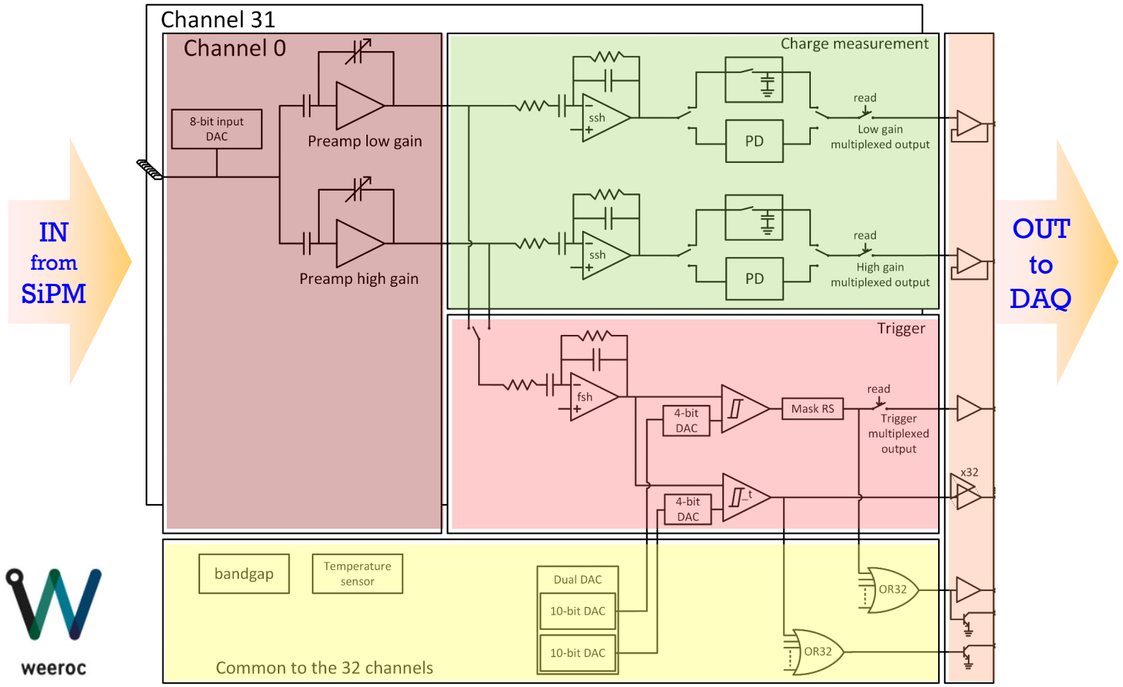
Analisys ongoing

Test beam: readout scheme

- The readout of the PMTs will is on Caen QDC (V792AC) and TDC (V775N) modules
- The readout of the highly granular module (320 SiPMs) is based on the Caen FERS system (5200) using 5 readout boards (A5202)



CITIROC 1A: block diagram



https://www.weeroc.com/my-weeroc/download-center/citiroc-1a/16-citiroc1a-datasheet-v2-5/file

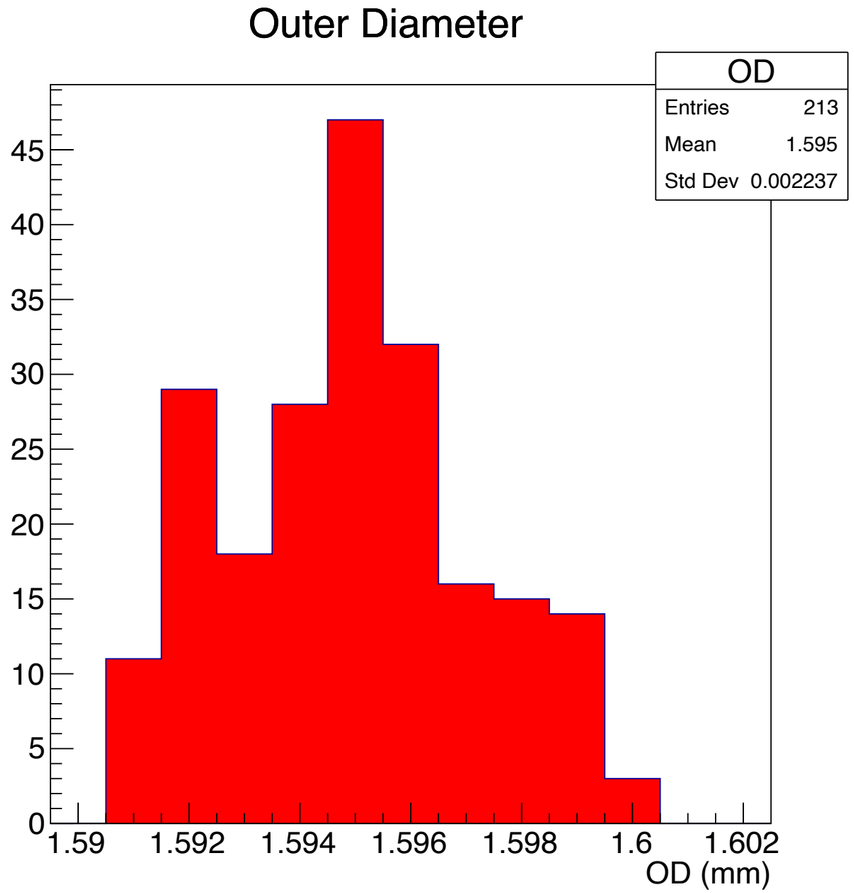
Test beam: timing information

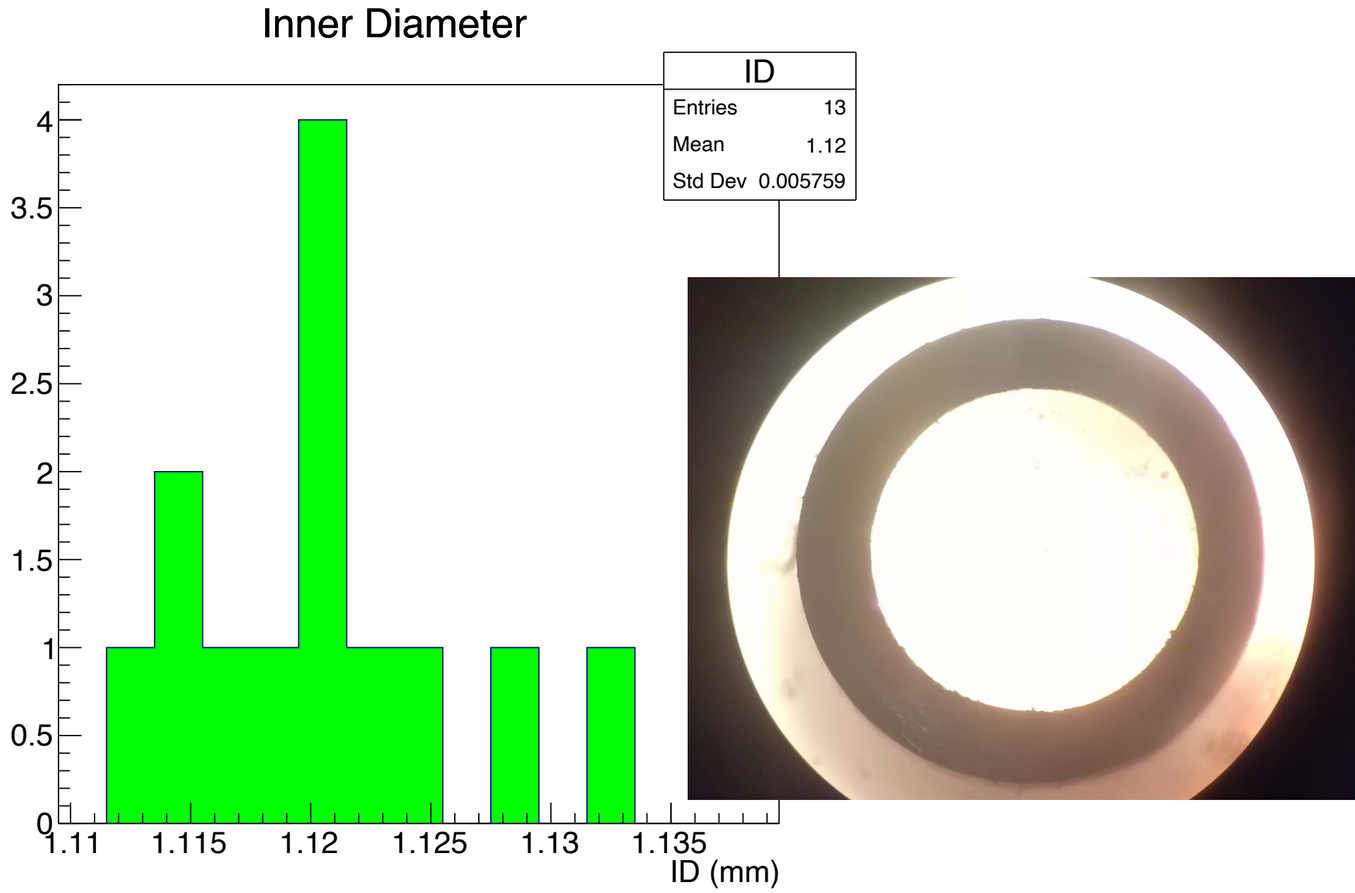
- Timing is an important feature for a longitudinally unsegmented fiber calorimeter
- Each FERS has 2 TDCs with high resolution (LSB=50 ps) and 64 TDCs (LowRes) coded on FPGA (LSB=500 ps)
- The LowRes TDCs can be used to measure:
  - The ToT for each SiPM
  - The ToA for each SiPM wrt the event-accept
- Two signals / FERS can be measured with HighRes TDCs: different options are possible:
  - 1st option: majority and OR wrt the event-accept signal
  - 2nd option: majority (cherekov) and majority (sc) wrt the event-accept signal
  - 3rd option: OR (cherekov) and OR (sc) wrt the event-accept signal

Material Properties

Properties	Copper	PMMA (Cherenkov)	Polystyrene (Scintillanting)
% in Calo	65%	17,5%	17.5%
Z	29	H,C,0 1,6,8	H,C 1,6
Density (g/cm^3)	8.96	1.19	1.06
MIP($MeV\ g^{-1}\ cm^2$) MIP ($MeV\ cm^{-1}$)	1.403 12.57	1.929 2.296	1.936 2.052
Radiation Length (cm)	1.436	34.07	41.31
Moliere radius (cm)	1.568	8.422	9.409

Tube quality control

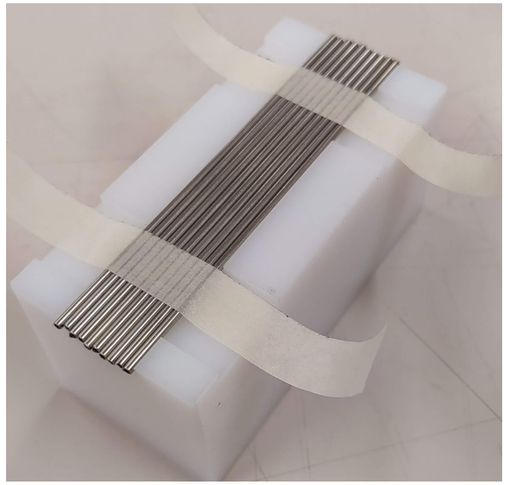




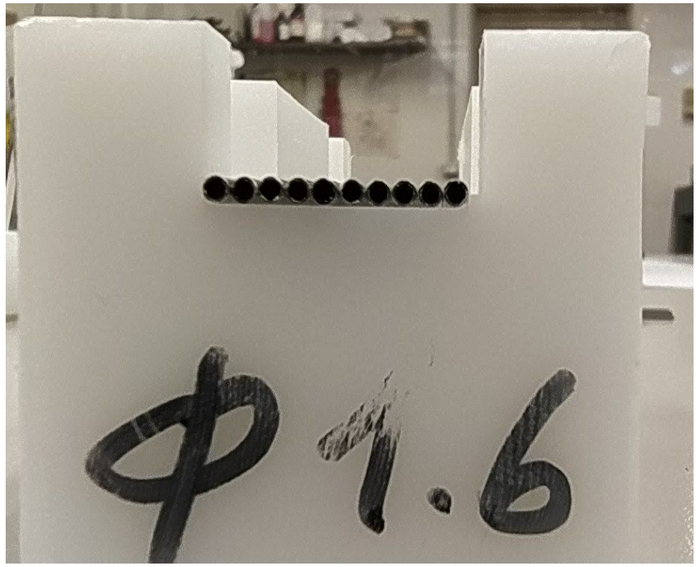
micrometer measurements

microscope measurements

Assembly tool for testing



1 - Preparation of 10 tubes ~10 cm long



3 - positioning of the tube in the maquette of the assembly station

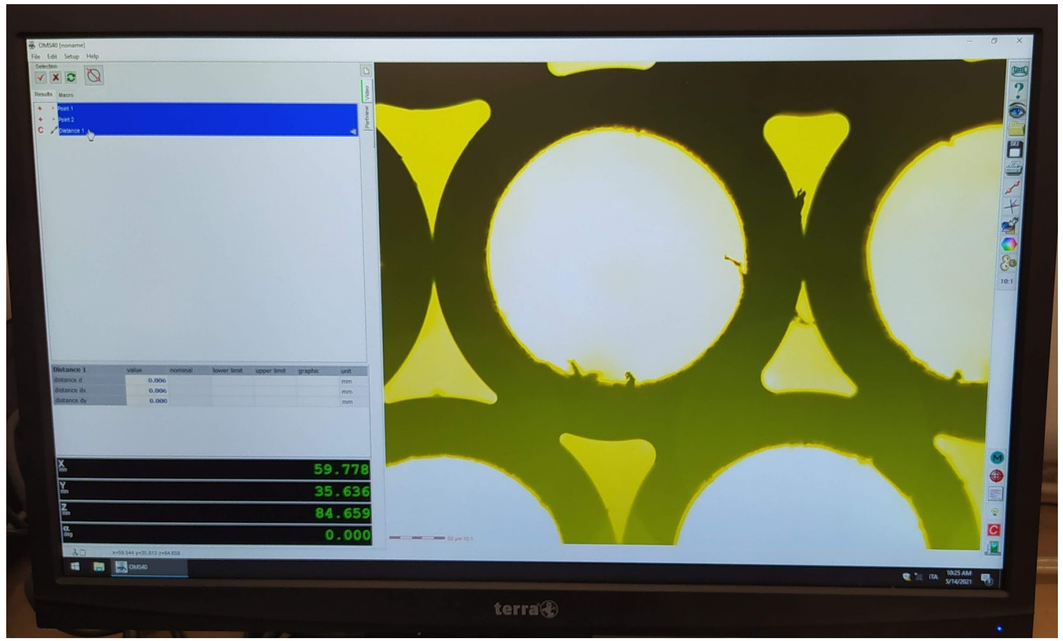
2 - glue in mixed and distributed on the tube with a small roller

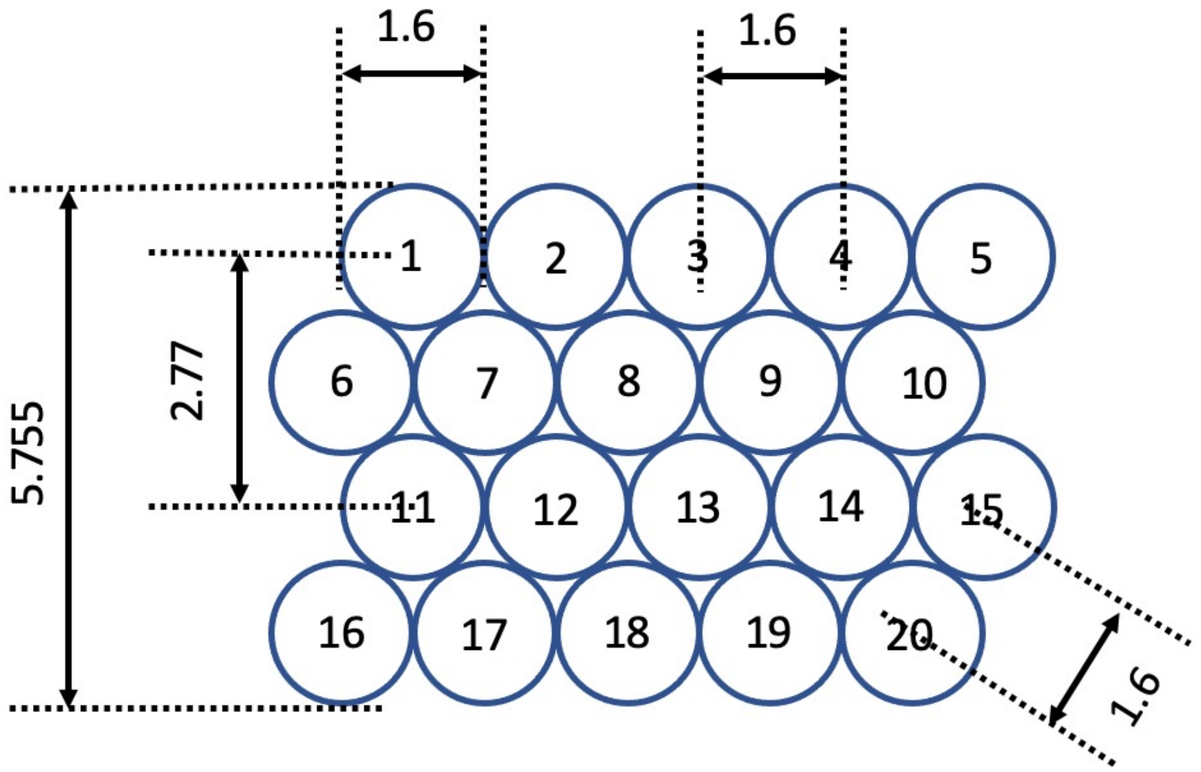
4 - glue left to set overnight weights apply on the top

Assembly test – glue choice

- Purpose was to check different glue types and how distribute them on the tube
  - DP270
  - DP190
  - DP490
  - Araldite 2011
- We tested also ideas for assembly technique
  - Teflon tool (avoid gluing of pieces) – true one will be rectified stainless steel
  - Small maquette to test how glue is distributed
  - Microscope measurements of the assembly

Microscope measurements

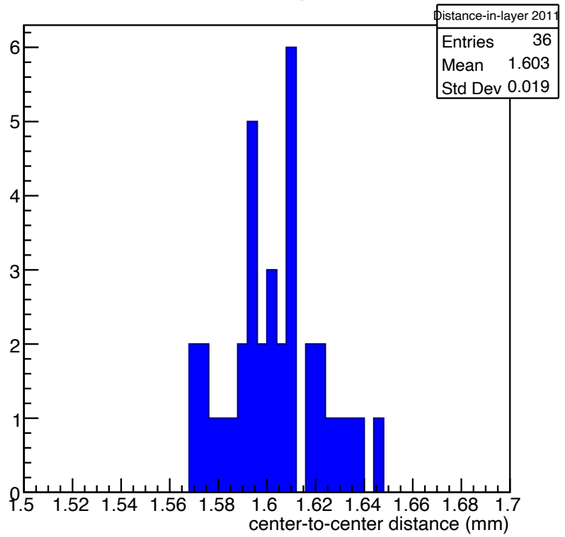




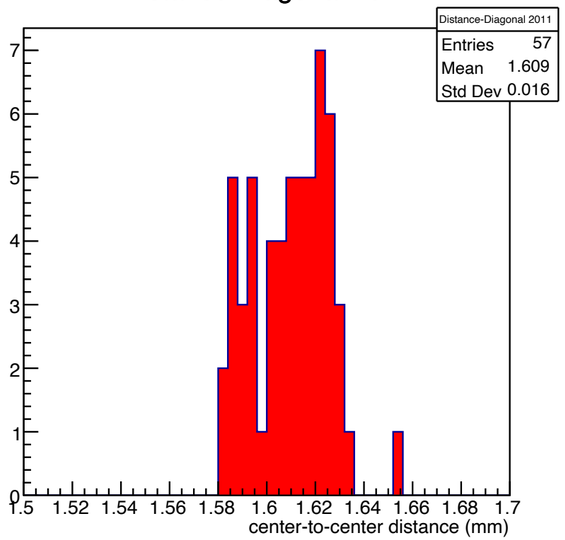
Identify the circle (inner diameter)
with transmitted light
measure center-to-center distance

Araldite 2011 and DP190

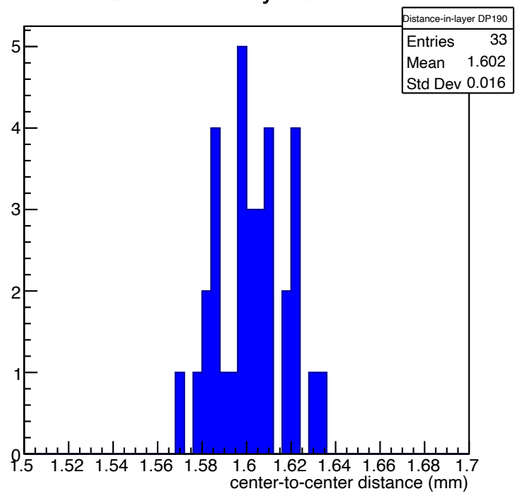
Distance-in-layer 2011



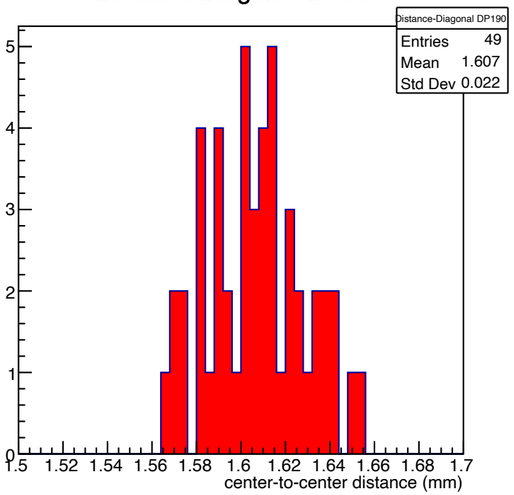
Distance Diagonal 2011



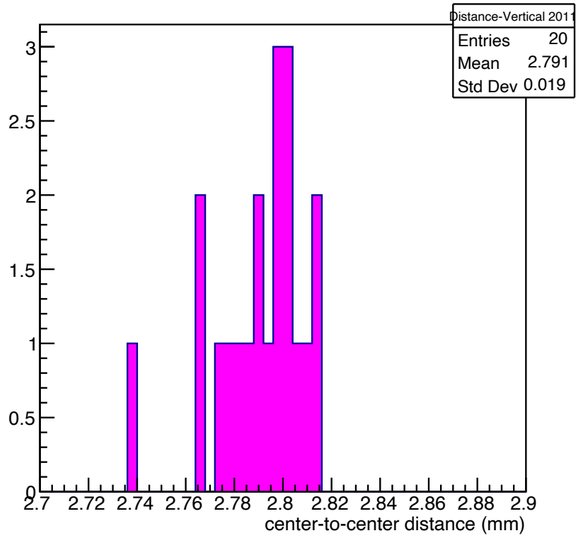
Distance-in-layer DP190

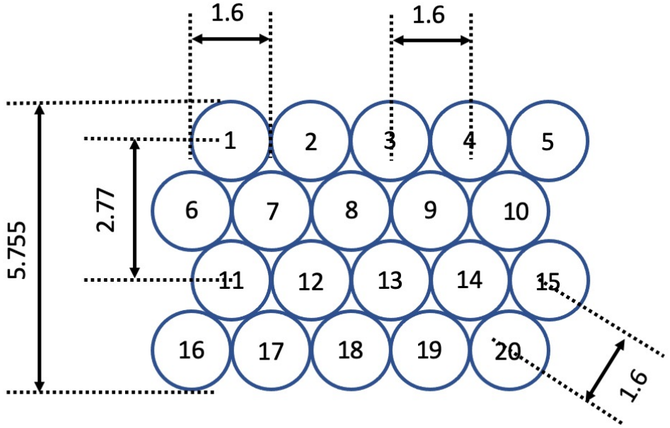


Distance Diagonal DP190

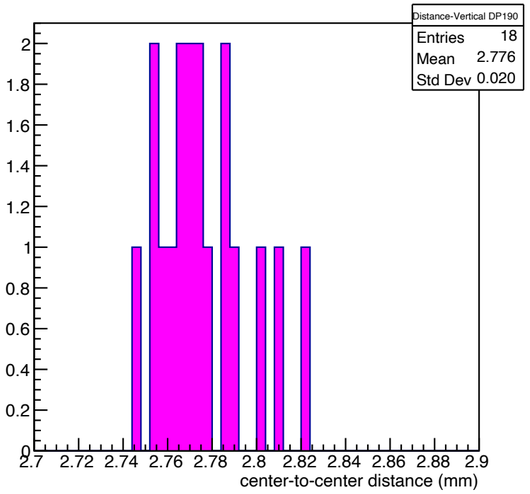


Distance-Vertical 2011



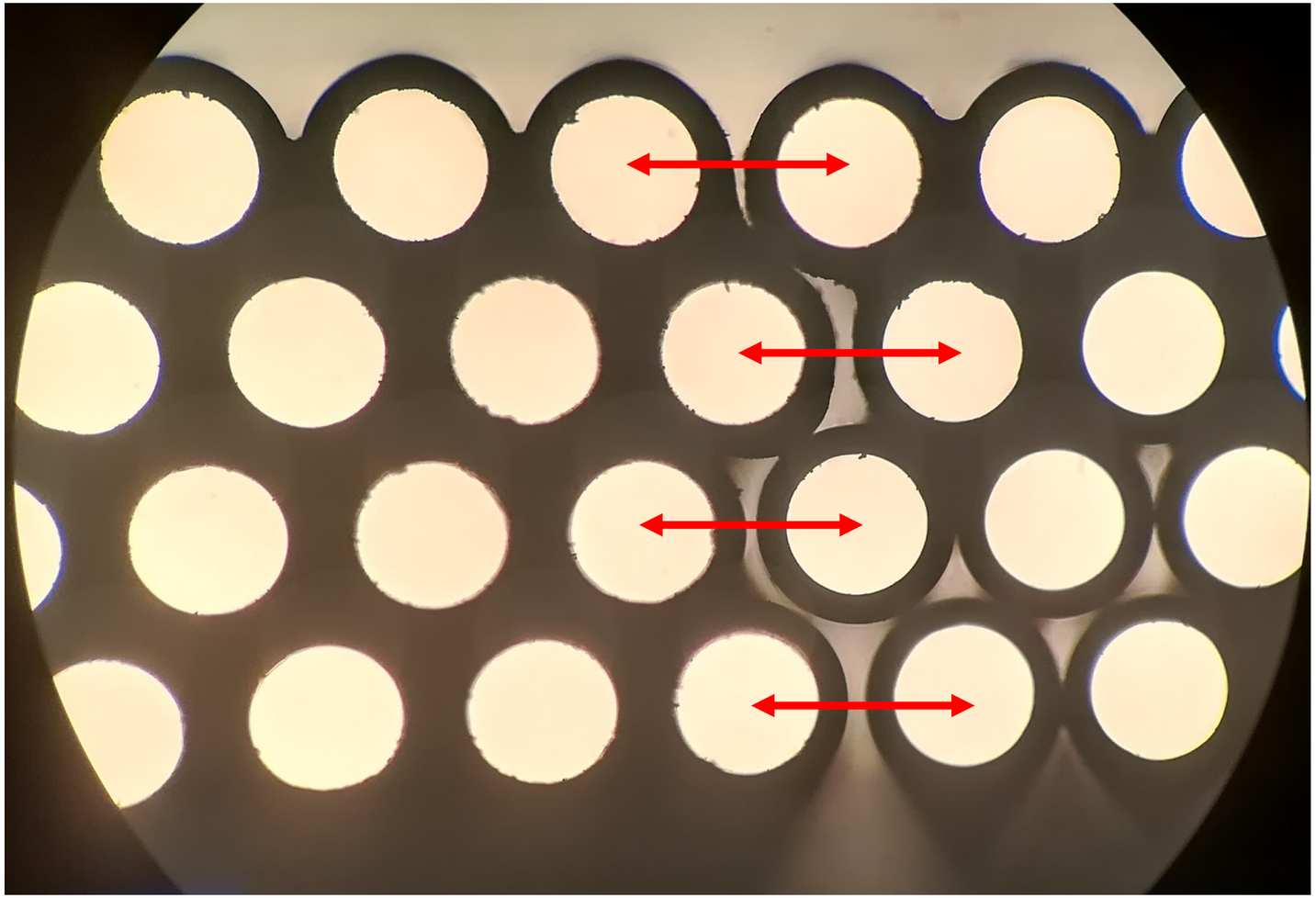


Distance-Vertical DP190



Just for fun

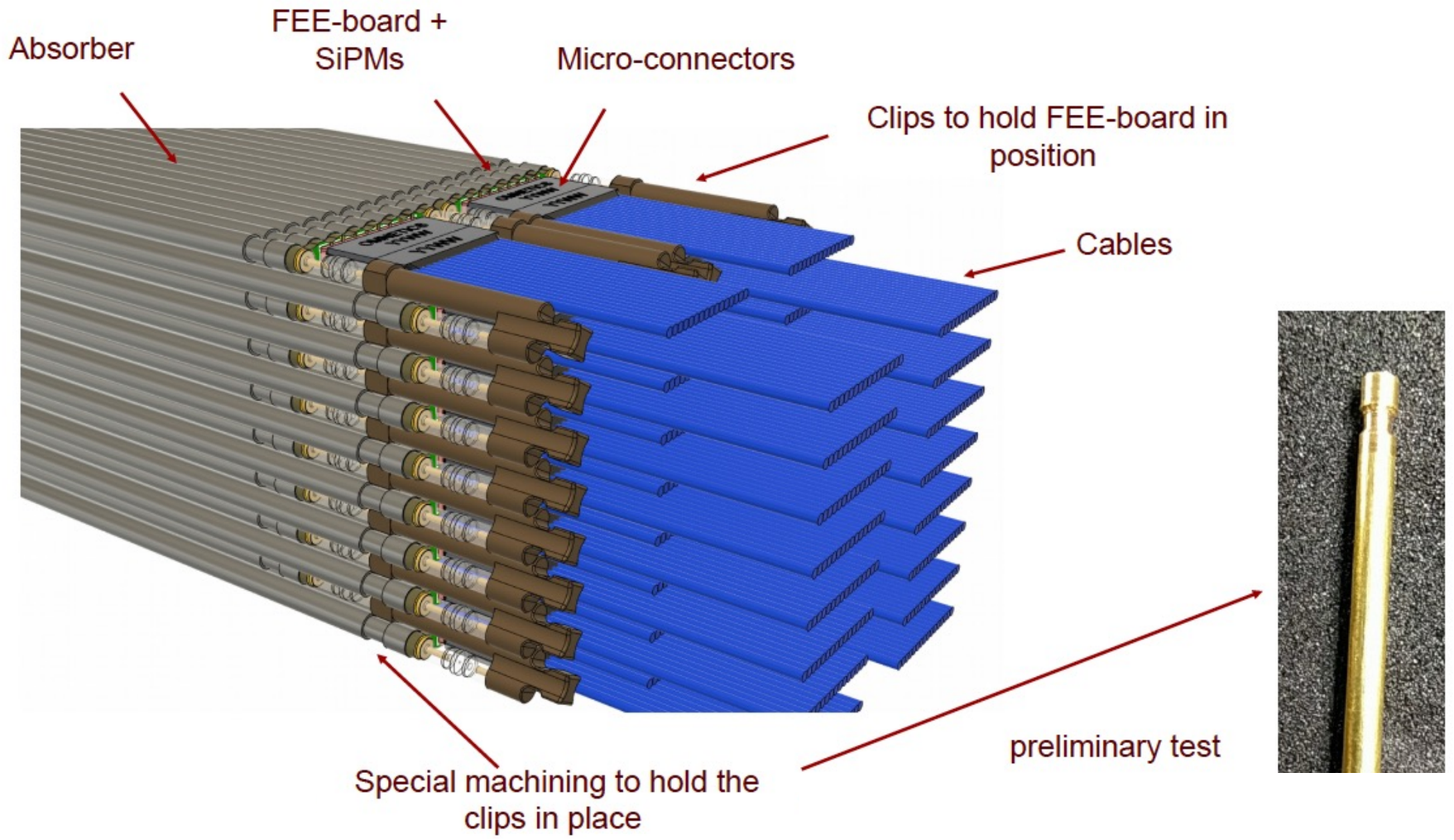
1,719 - 1,723 - 1,701 - 1,758



The Teflon tool was not meant to guarantee mechanical precision, just for glue test

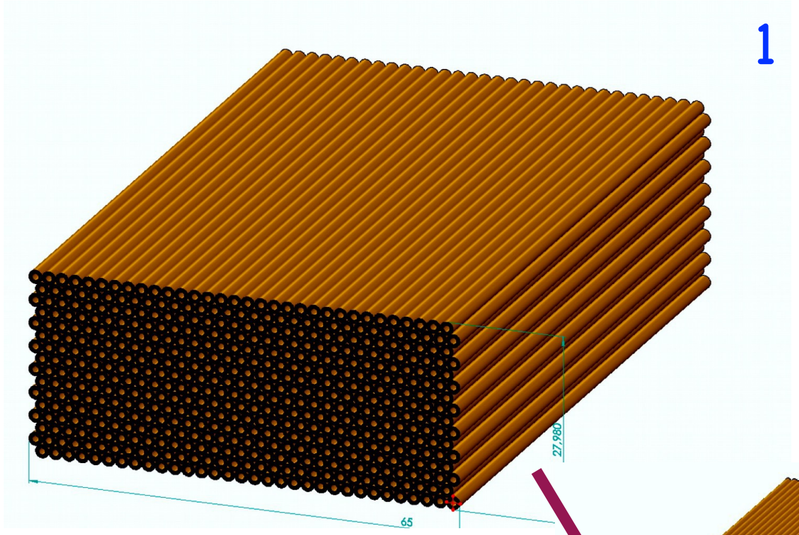
On the other hand, already this has allowed to produce small reproducible assembled arrays

New concept for a true scalable module

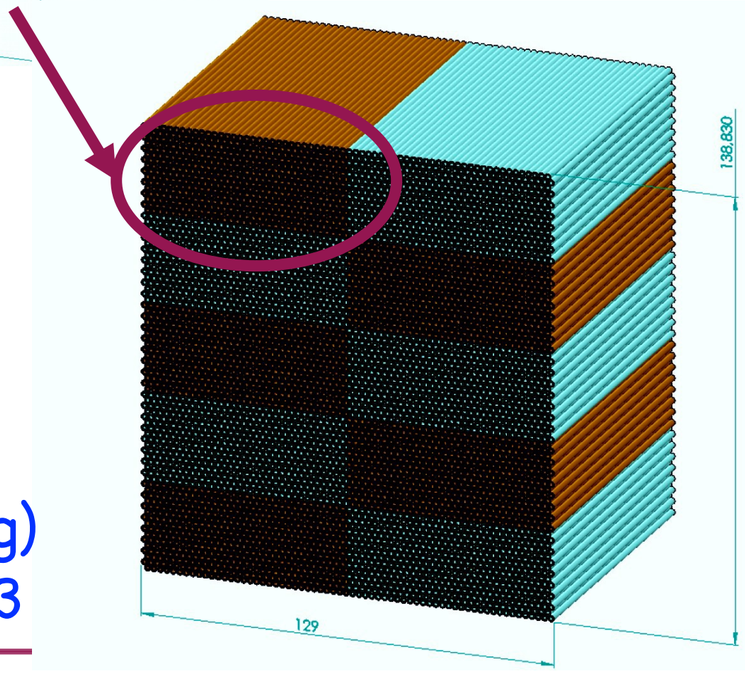


rom HiDRa project for CSNV

Mid-term plans



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 cm3

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