HiDRa2:
High-Resolution Highly Granular Dual-Readout Demonstrator

PI: Roberto Ferrari, INFN Pavia
Research units: INFN Bologna, Catania, Milano, Pavia, Pisa, Roma I, TIFPA
Time frame: 2022 – 2023 - 2024

Francesco Chiapponi, **Davide Falchieri**, Alessandro Gabrielli, Paolo Giacomelli, Carlo Veri, Mirco Zuffa
University & INFN, Bologna

Assemblea di Sezione – 20 Marzo 2023

Project organization

PI: Roberto Ferrari (PV)

WP1: Mechanics and fiber characterisation (MI, PI, PV)
Responsible: G. Gaudio (PV)

WP2: Light sensors (analog and digital SiPMs) (**BO**, CT, MI, TIFPA)
Responsible: M. Caccia (MI)

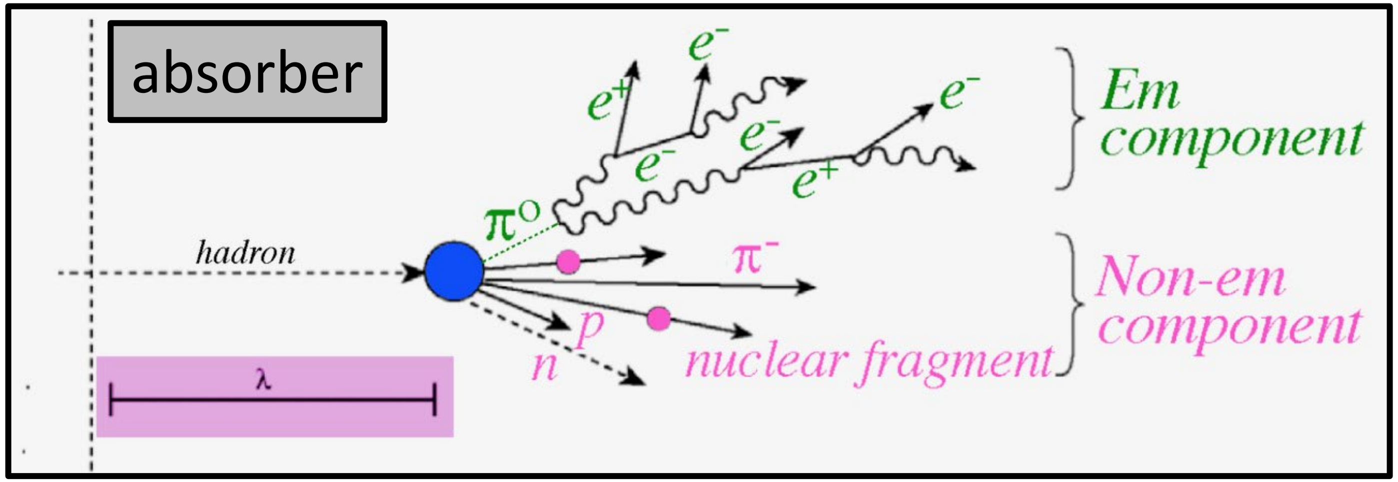
WP3: FEE and DAQ development (**BO**, CT, MI, PV, TIFPA)
Responsible: R. Santoro (MI)*

WP4: Performance assessment (MI, PV, RM1)
Responsible: G. Polesello (PV)

Thanks to Hidra2, we have co-financed a PhD scholarship for **Francesco Chiapponi**, who is working on DAQ activities and will also work on microelectronics design

Hidra2 will build a calorimeter

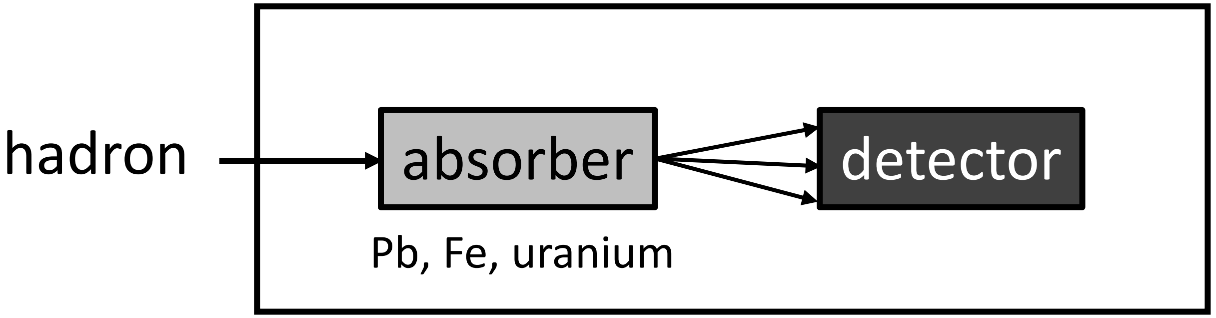
A **calorimeter** is a piece of material which is instrumented as to provide a signal which is proportional to the energy of the crossing particles. When segmented and with fine granularity, it can also provide information on the type of crossing particles, the position and the crossing angle.



from neutral meson (π^0, η) decays

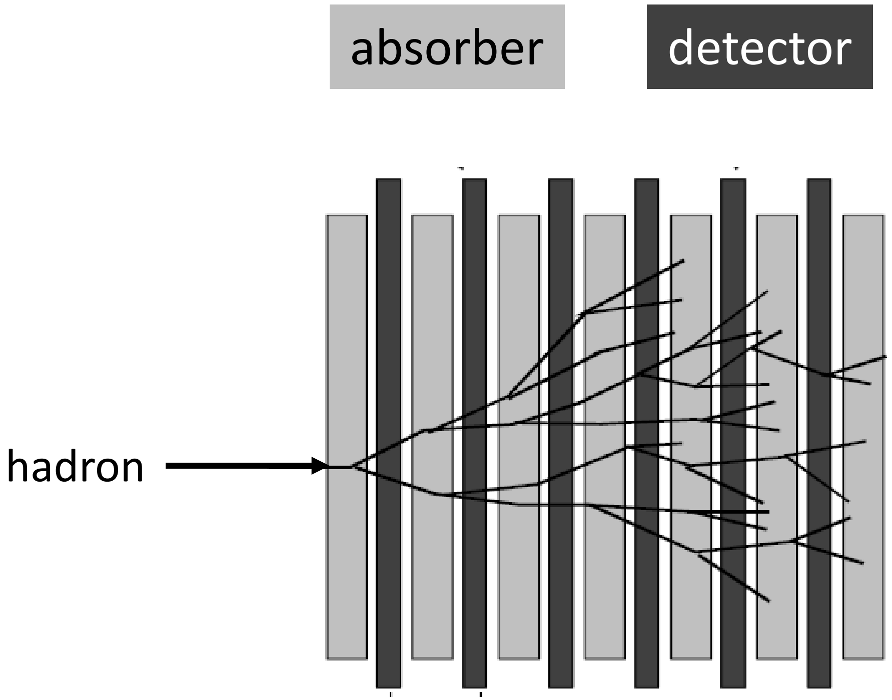
charge hadrons $\pi^\pm$, $K^\pm$ (20%)
nuclear fragments, p (25%)
n, soft γ's (15%)
break-up of nuclei (invisible energy) (40%)

For hadronic showers, the energy resolution is normally dominated by the event-by-event fluctuations of the *em* component



scintillators
scintillating fibers
silicon detectors
…

Hidra2 is a dual readout calorimeter



It features:

- **absorbers**: stainless steel
- **detectors**: scintillating fibers (sensitive to all kind of particles) → total deposited energy
  + clear fibers (sensitive to Cherenkov light) → EM shower component

dual readout technique

Hidra2's goals

The goal of the project is to build and qualify with beam **a calorimeter** which exploits the dual readout technique to measure the electromagnetic (EM) part of hadronic showers event by event. This measure allows to get a better energy resolution of the shower.

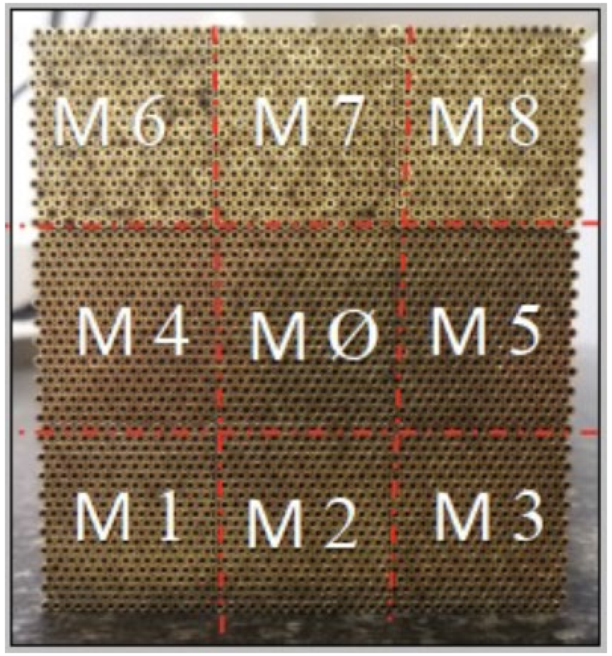
This calorimetric technique has already been studied in previous projects, even if the hadronic resolution has never been proved on beam, since the demonstrator was not big enough as to contain all the released energy.

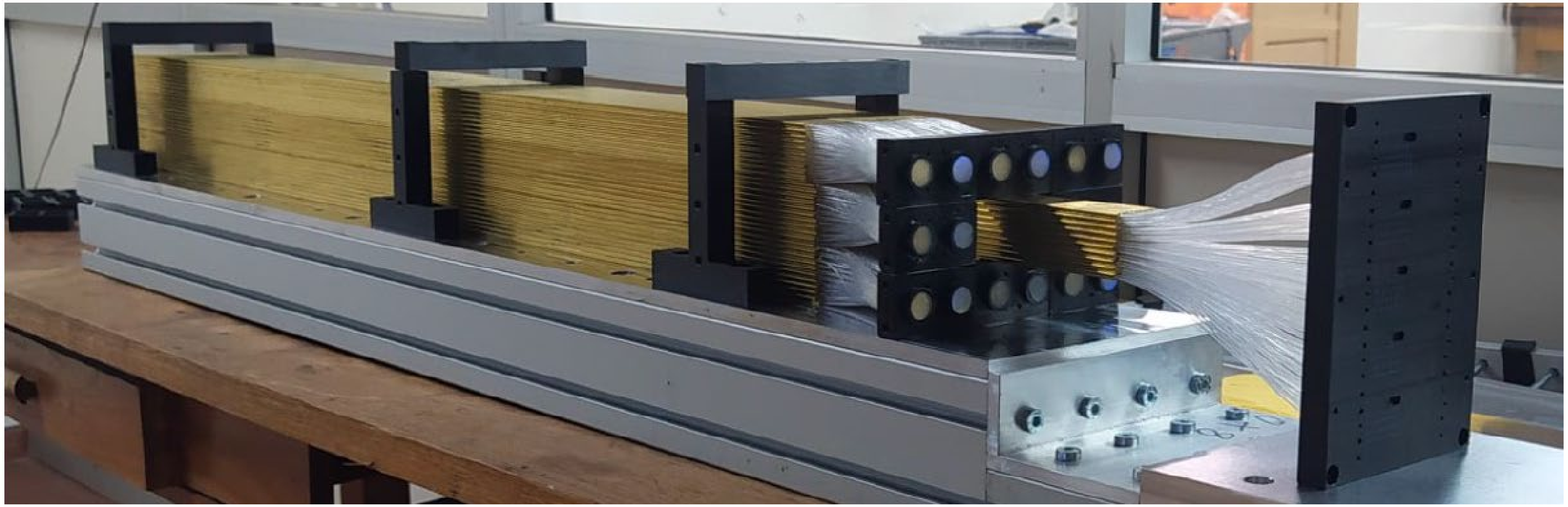
Declared goals of the project:

- a stand-alone **hadronic resolution** around $30\%/\sqrt{E}$ or better, for both single hadrons and jets, while maintaining a resolution for isolated EM showers close to $10\%/\sqrt{E}$
- a transverse resolution of $O(1\ \mathrm{mrad})/\sqrt{E}$
- a longitudinal resolution of a few cm (through timing)
- a modular and **scalable** construction technique
- an innovative readout architecture based on SiPMs

For the future → **FCC_ee** (Future Circular Collider@ CERN)
→ **CePC** (Circular Electron Positron Collider @ China)

Before Hidra2





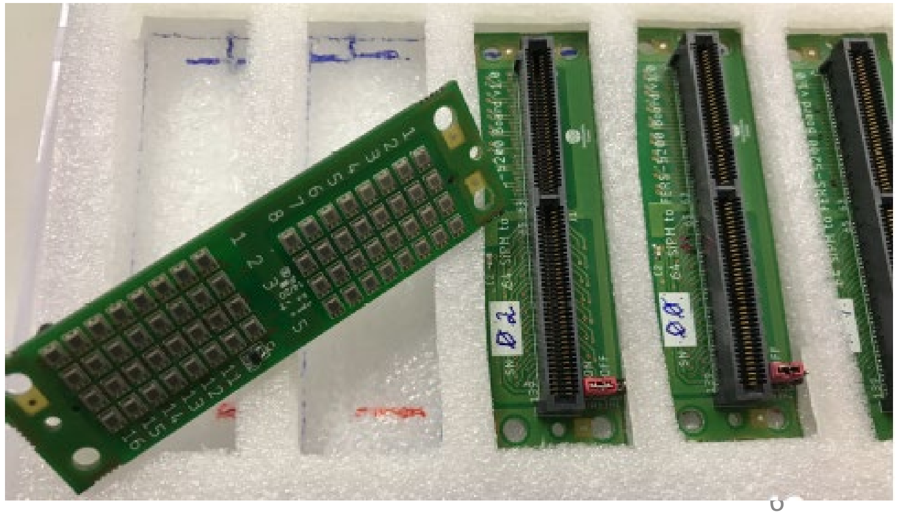
EM prototype (10x10x100 cm^3)

- 9 modules made of 16 x 20 capillaries (160 C and 160 S)
- capillaries (brass): 2 mm outer diameter and 1.1 mm inner diameter

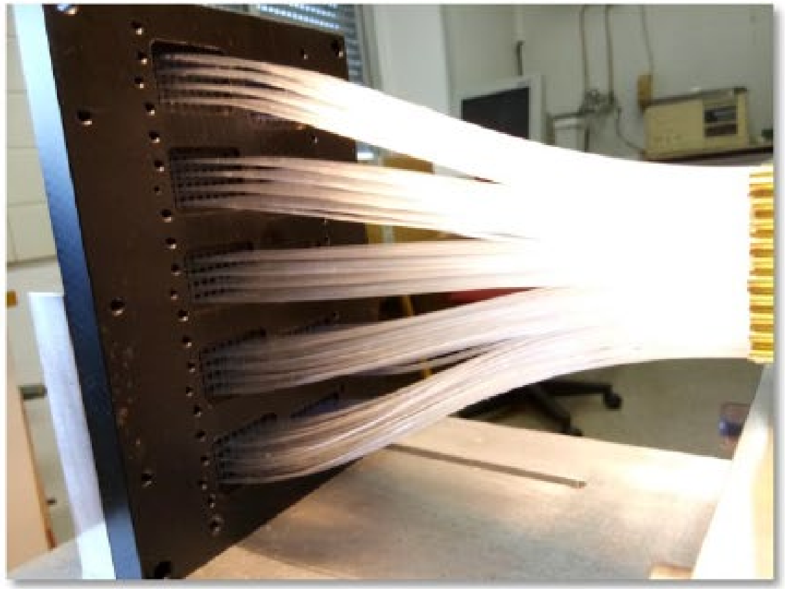
EM prototype readout:

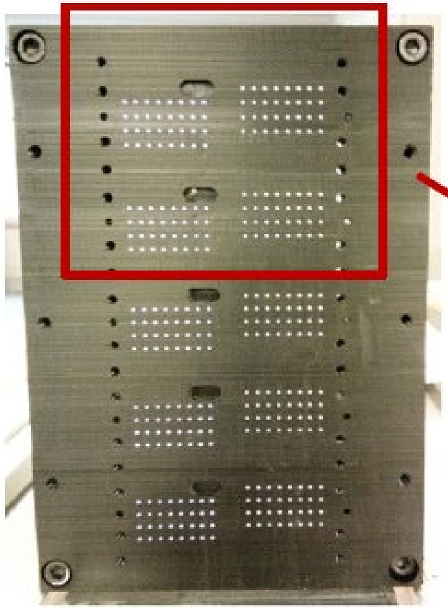
- each capillary of the central module is equipped with its own SiPM: highly granular readout
- 8 surrounding modules equipped with PMTs (each module uses 1 PMT for C and 1 PMT for S fibers)

front-end boards with SiPMs

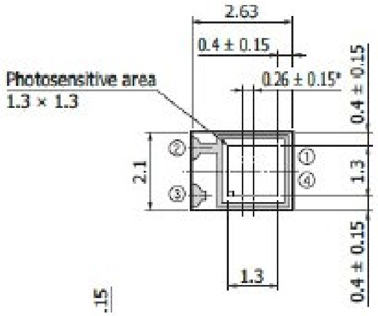


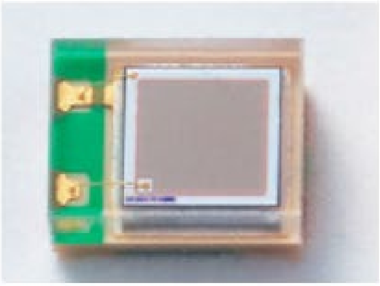
Before Hidra2





Dummy SiPM FEE board

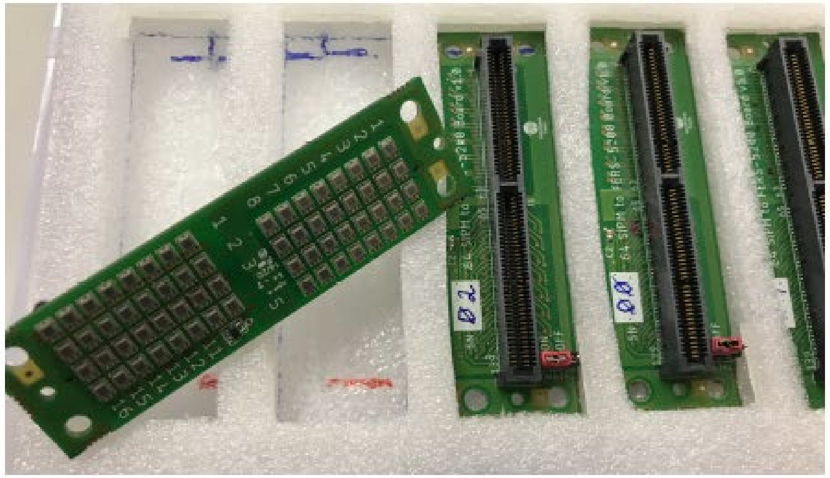




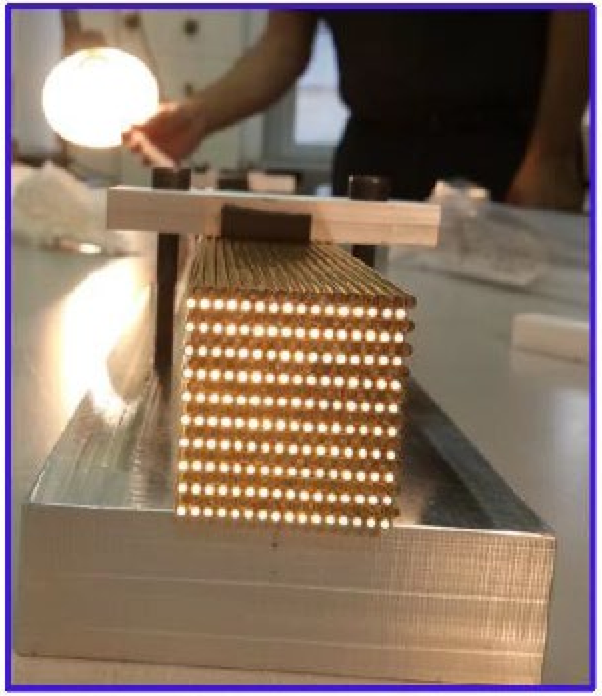
Hamamatsu SiPM: S14160-1315 PS

Cell size: 15 μm

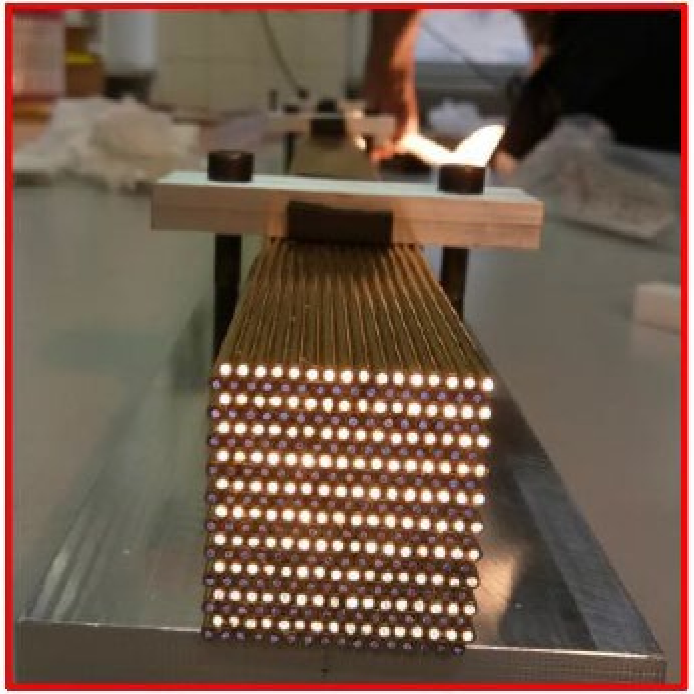
5 FEE Boards (320 SiPMs)



Before Hidra2

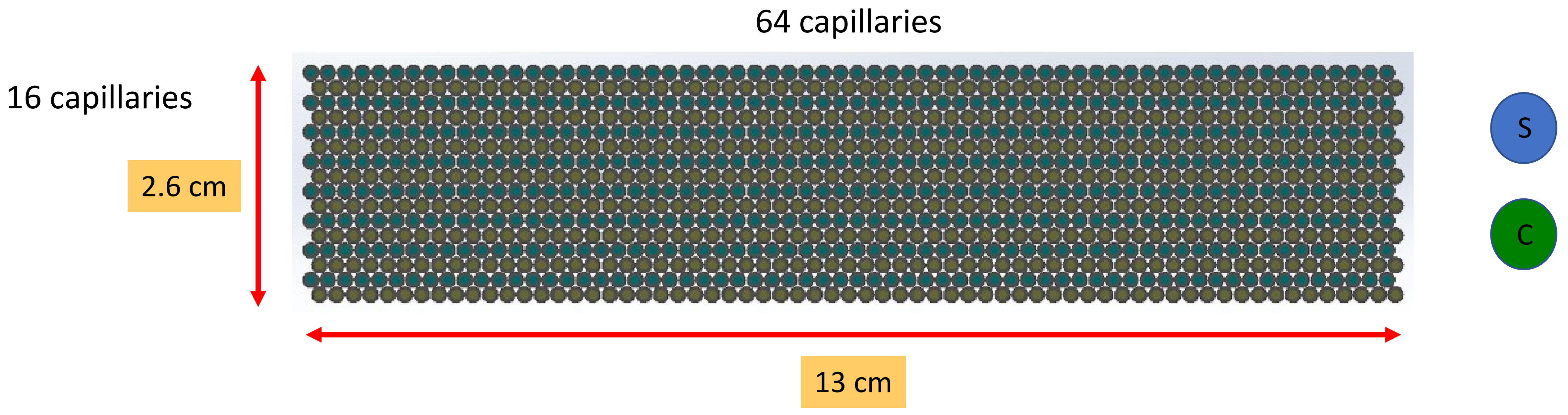


scintillation fibers



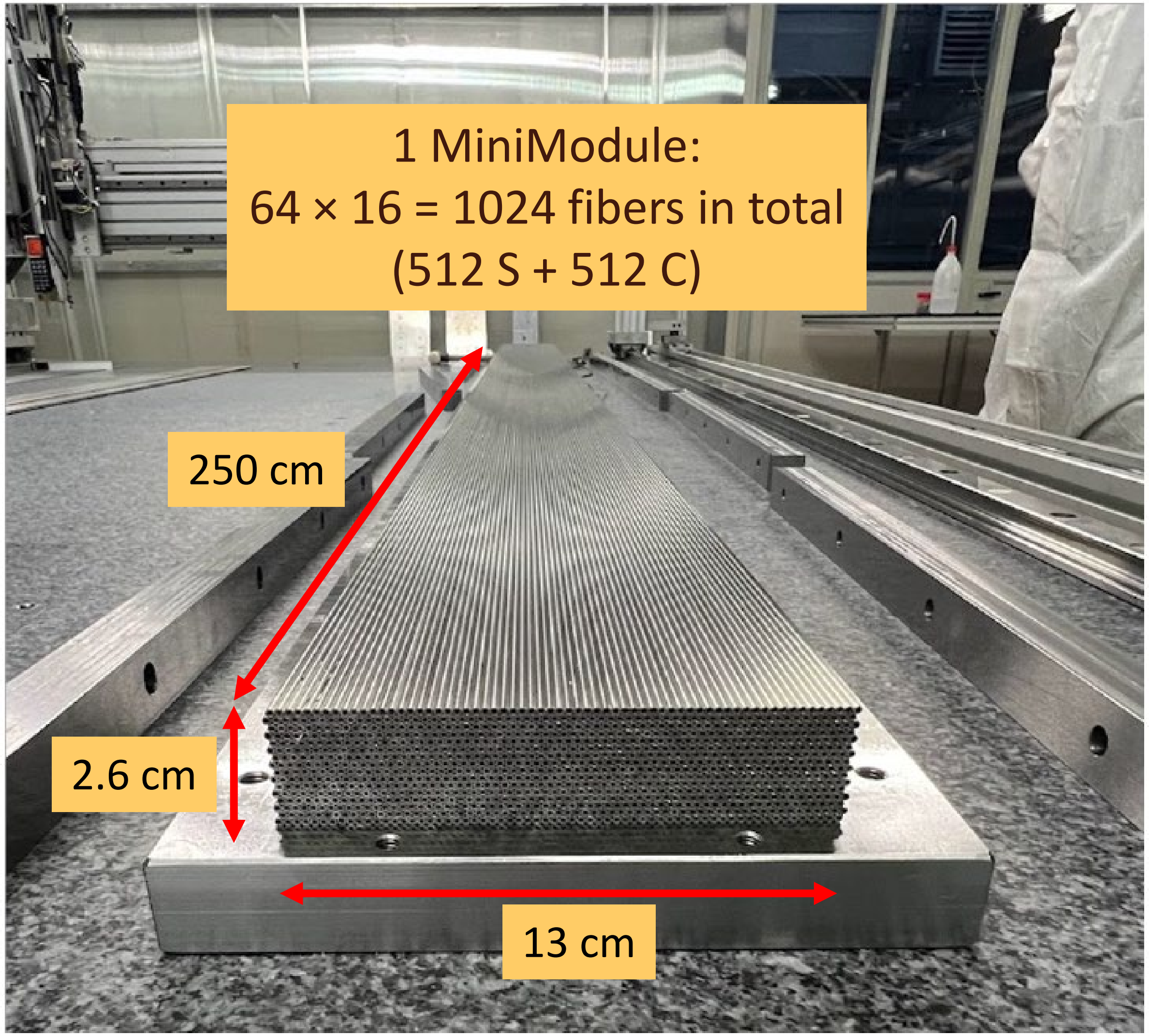
Cherenkov fibers

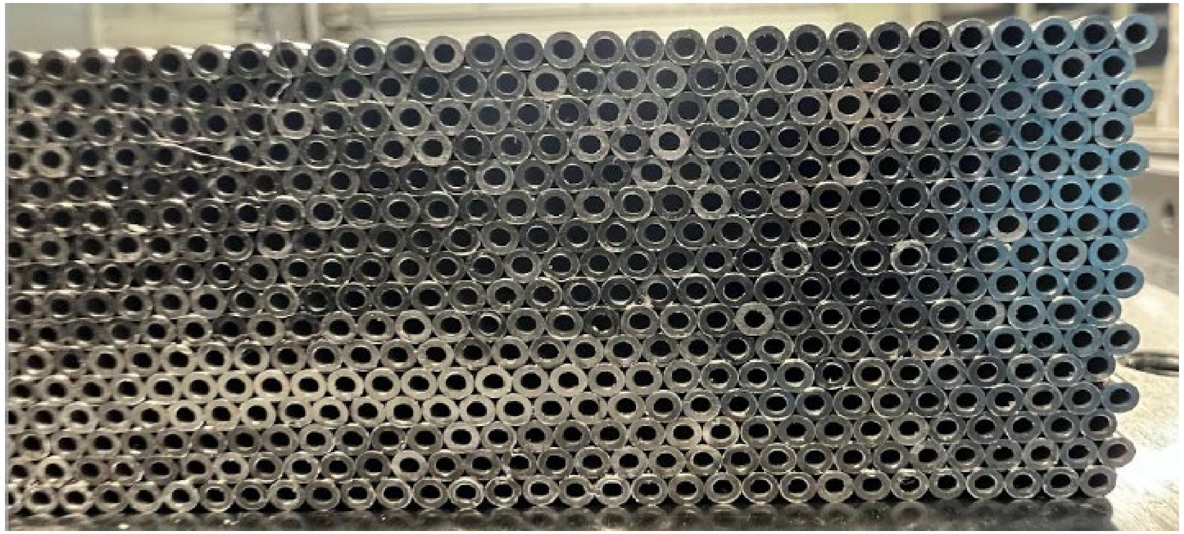
Towards Hidra2: the MiniModule



64 x 16 = 1024 fibers in total (512 S + 512 C)

Towards Hidra2: MiniModule 0



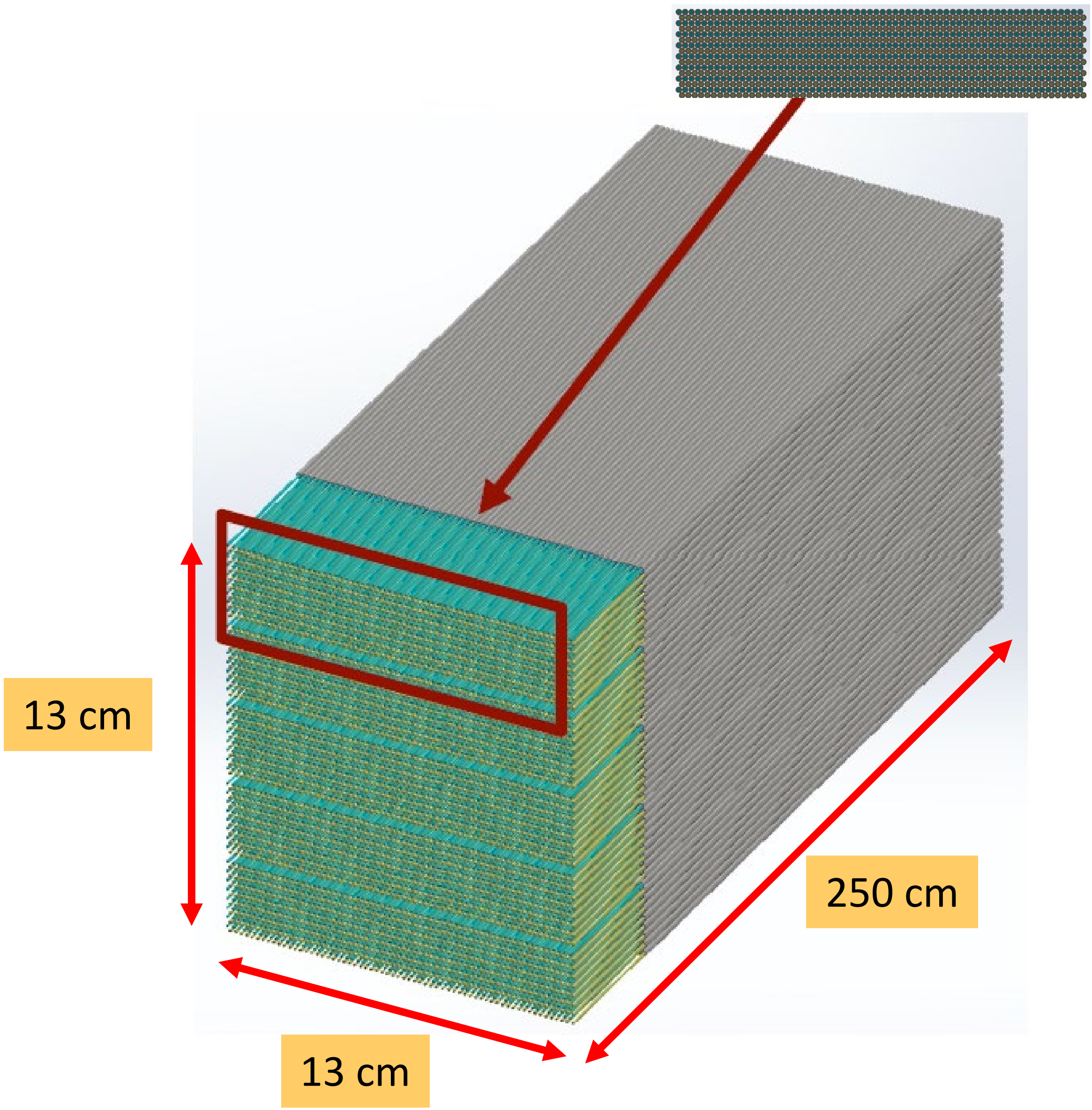


Capillaries:

- external diameter: 2 (± 0.050) mm
- internal diameter: 1.1 (-0 +0.1) mm
- length: 2.5 m

Material: stainless steel 304 (cheaper than brass, comparable performance)

Towards Hidra2: one module

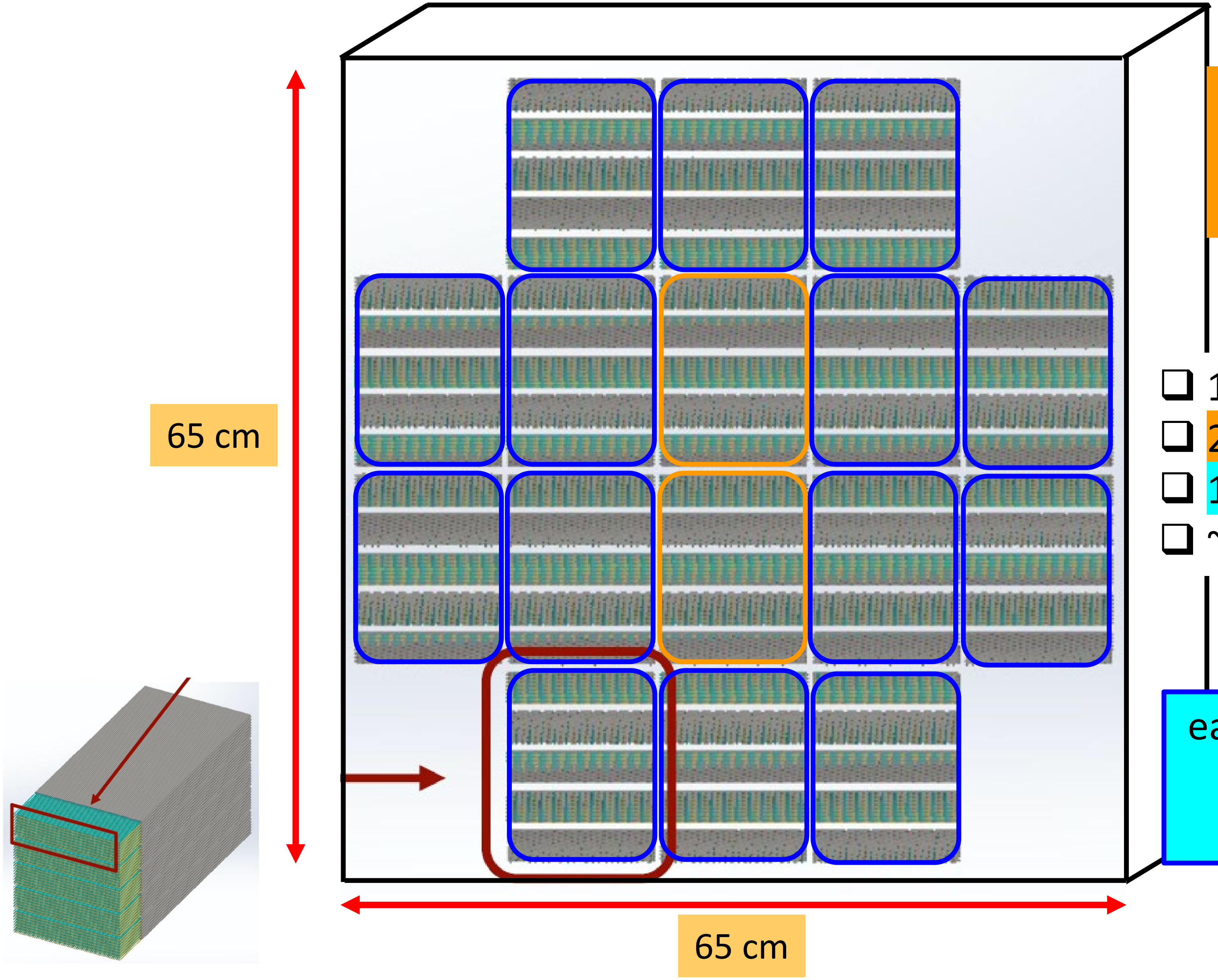


1 **Module** = 5 MiniModules

~ 13 × 13 x 250 cm^3

5120 fibers

The complete Hidra2 demonstrator

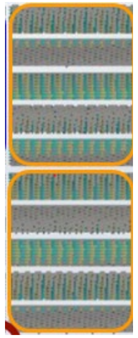


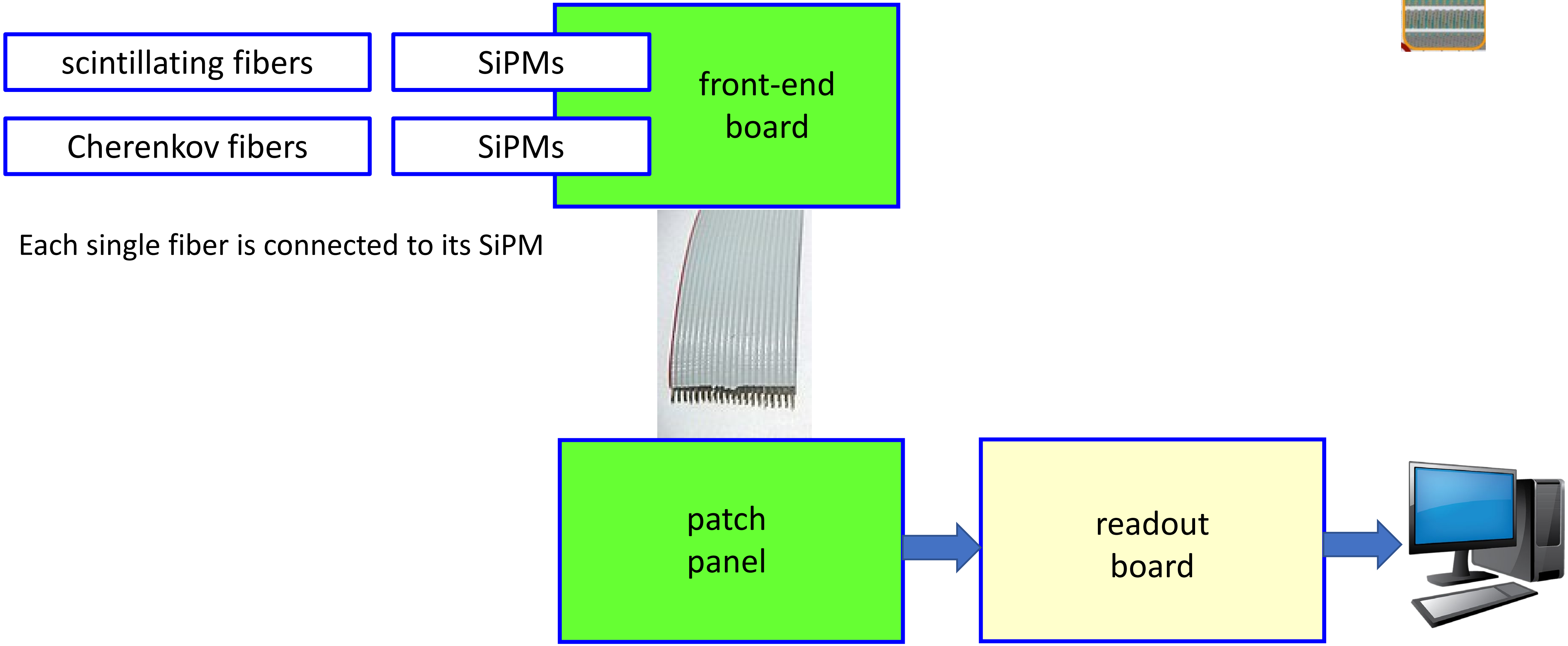
high-granularity core:
fibers individually read-out by SiPMs

- 16 modules in total (=81920 fibers)
- 2 central modules equipped with SiPMs
- 14 modules equipped with PMTs
- ~65 x 65 x 250 cm^3

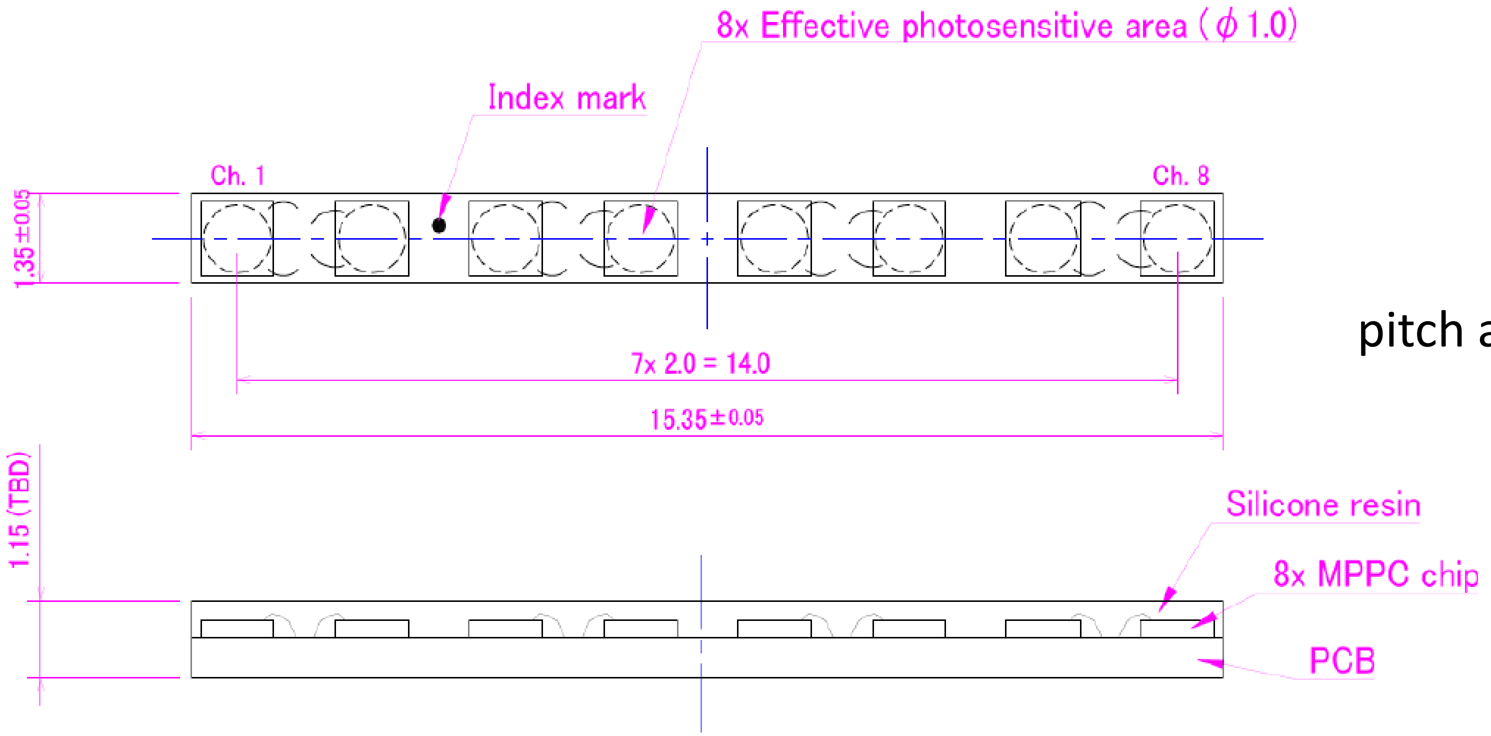
each minimodule is readout by 2 PMTs (1 for Cherenkov and one for scintillation)

Readout scheme for the two central modules





Custom SiPMs from Hamamatsu

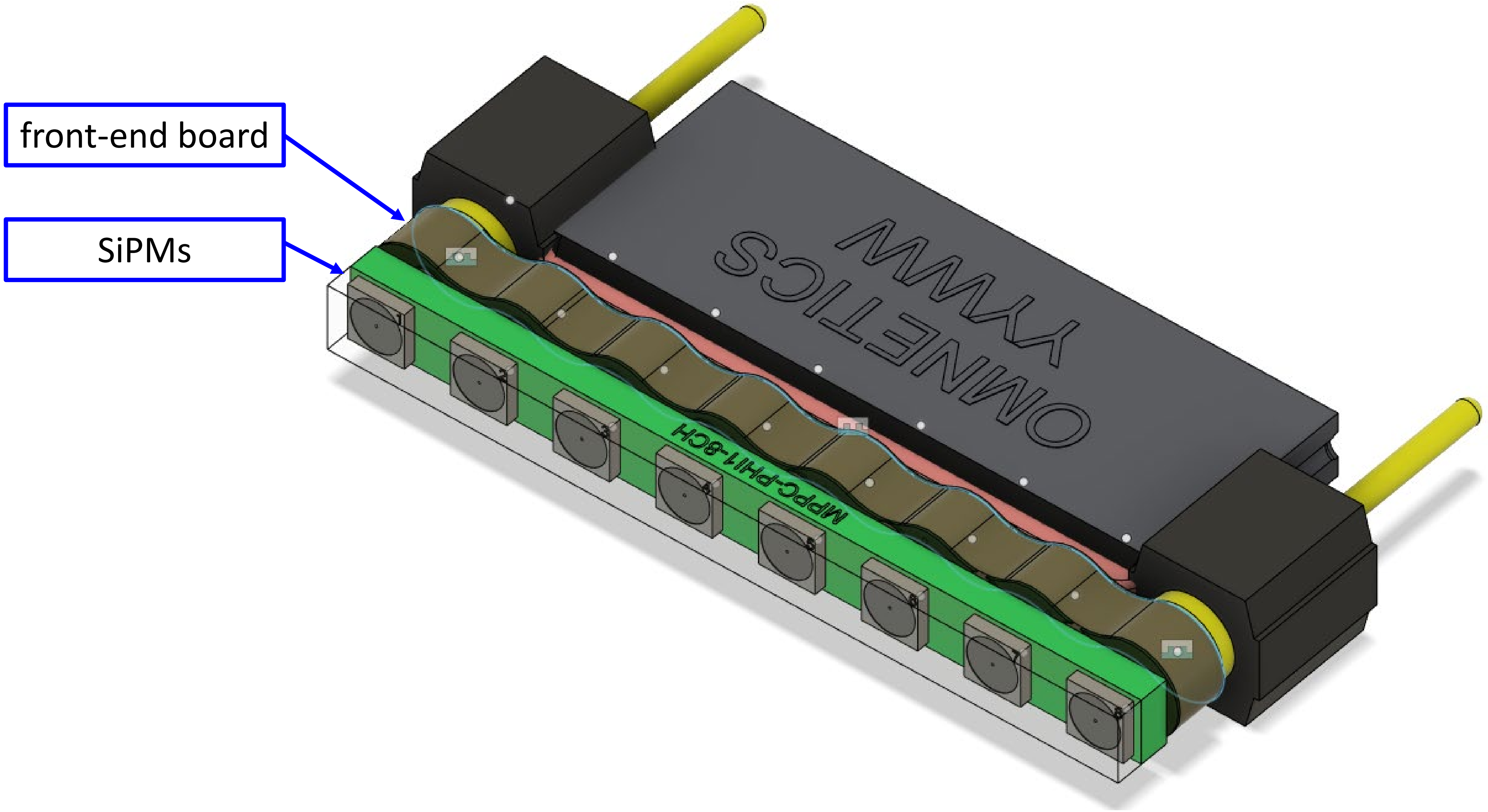


8 1-mm^2 SiPMs

pitch among 2 SiPMs: 2 mm

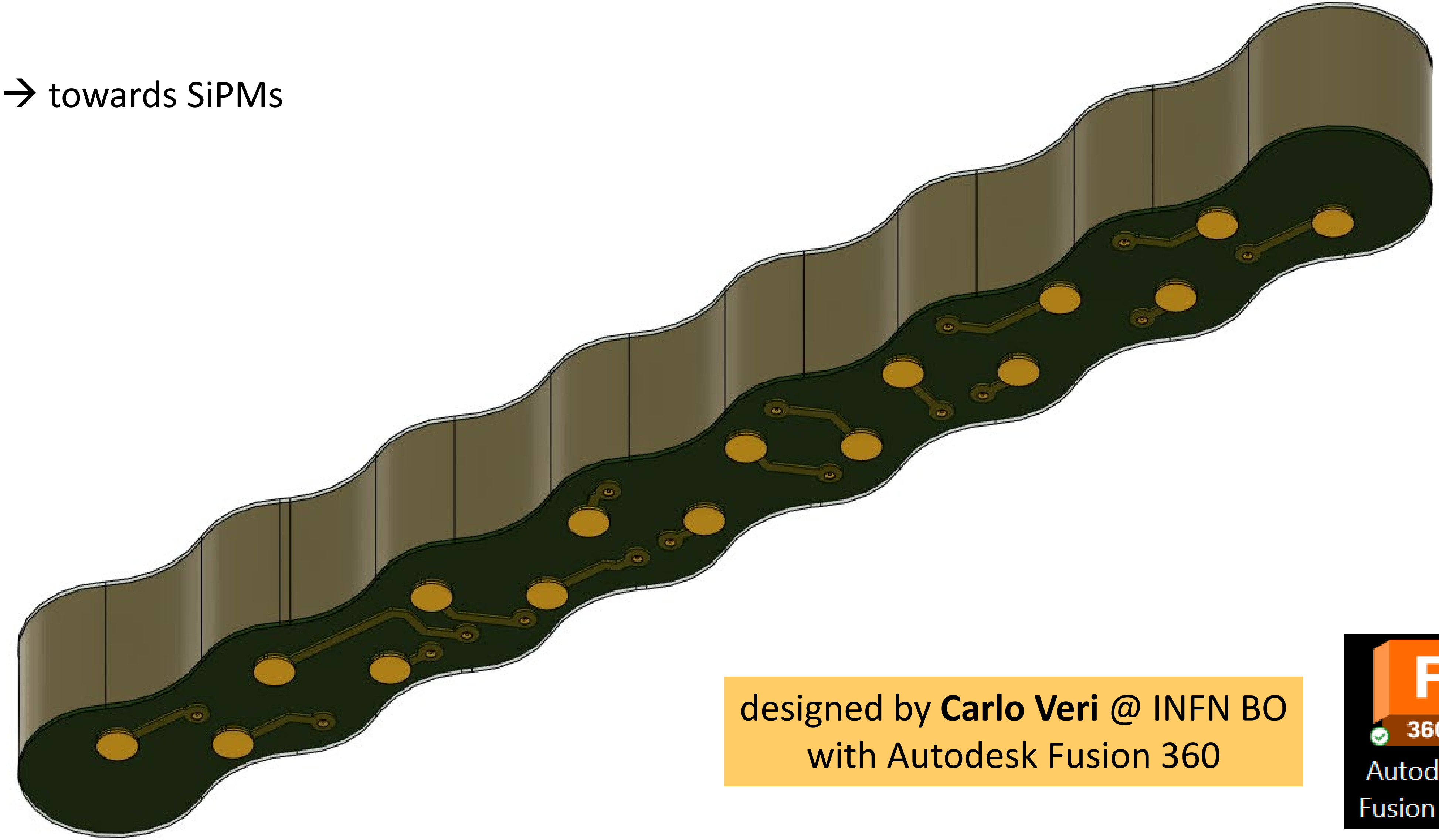
- 20 of these custom SiPMs have been delivered by Hamamatsu:
  - 10 modules with 10-µm SiPMs (S16676-10)
  - 10 modules with 15-µm SiPMs (S16676-15)

SiPM + FE board



Front-end board

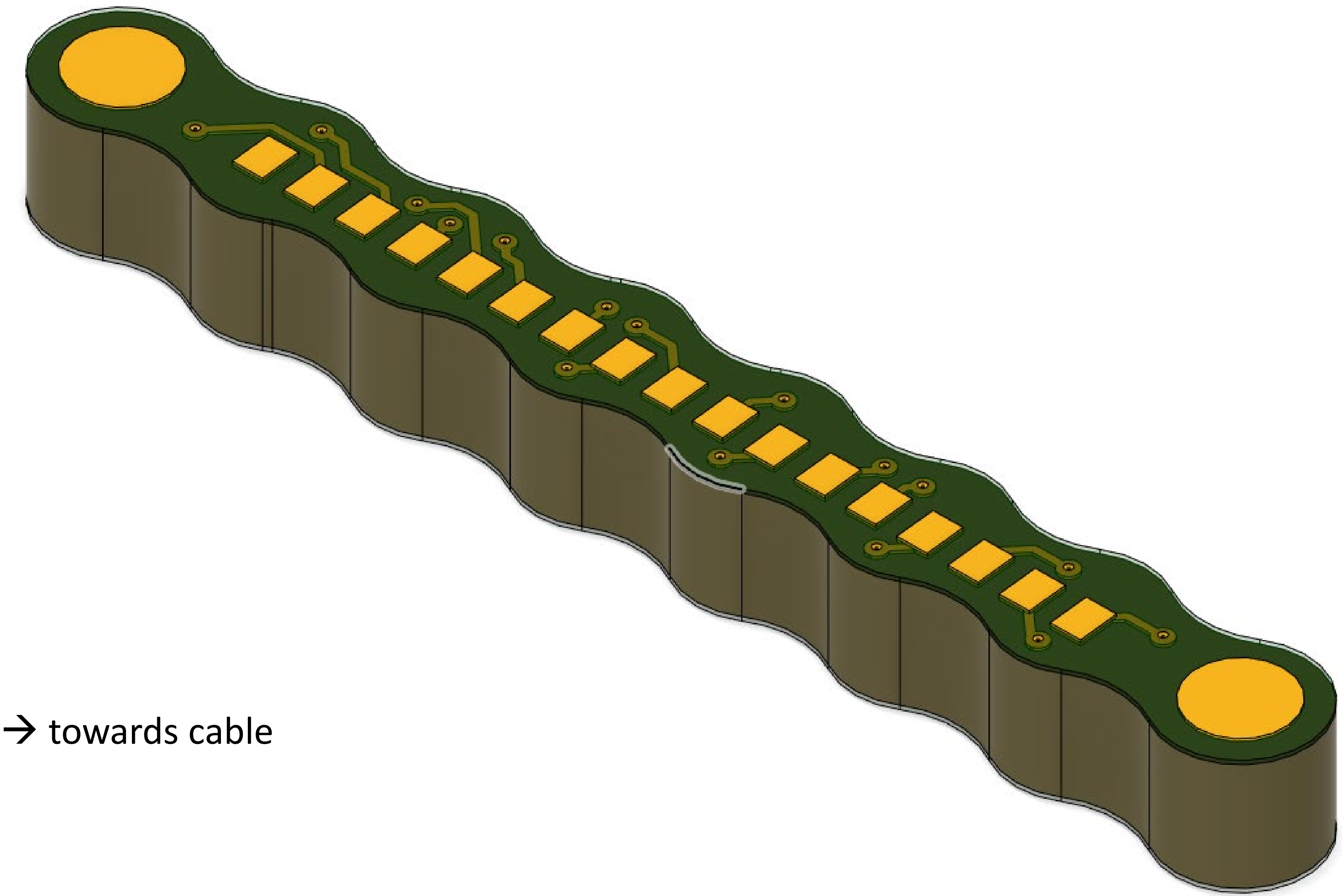
front side → towards SiPMs



designed by **Carlo Veri** @ INFN BO
with Autodesk Fusion 360

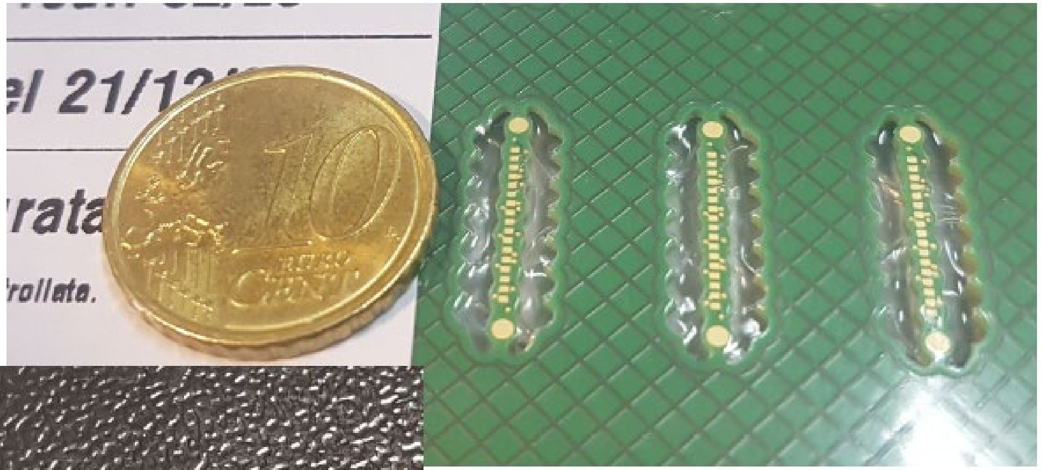
Autodesk
Fusion 360

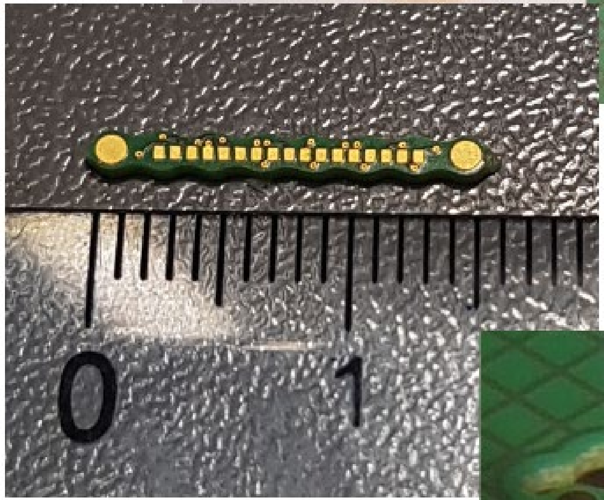
Front-end board



back view → towards cable

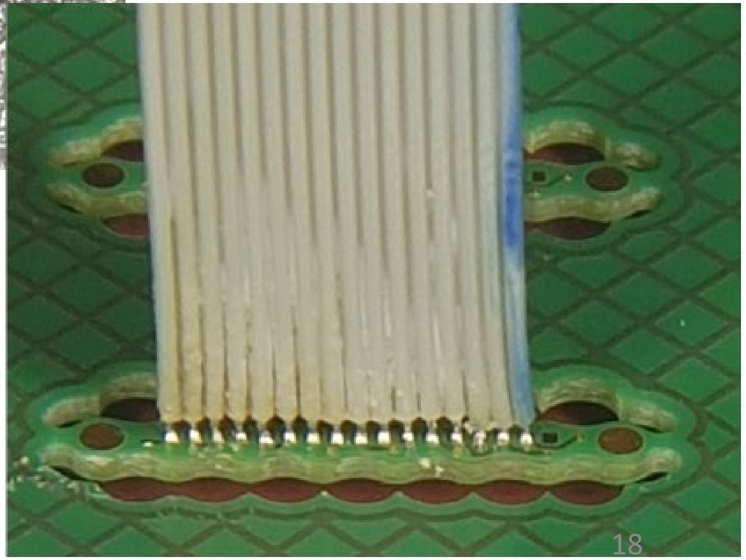
Front-end board





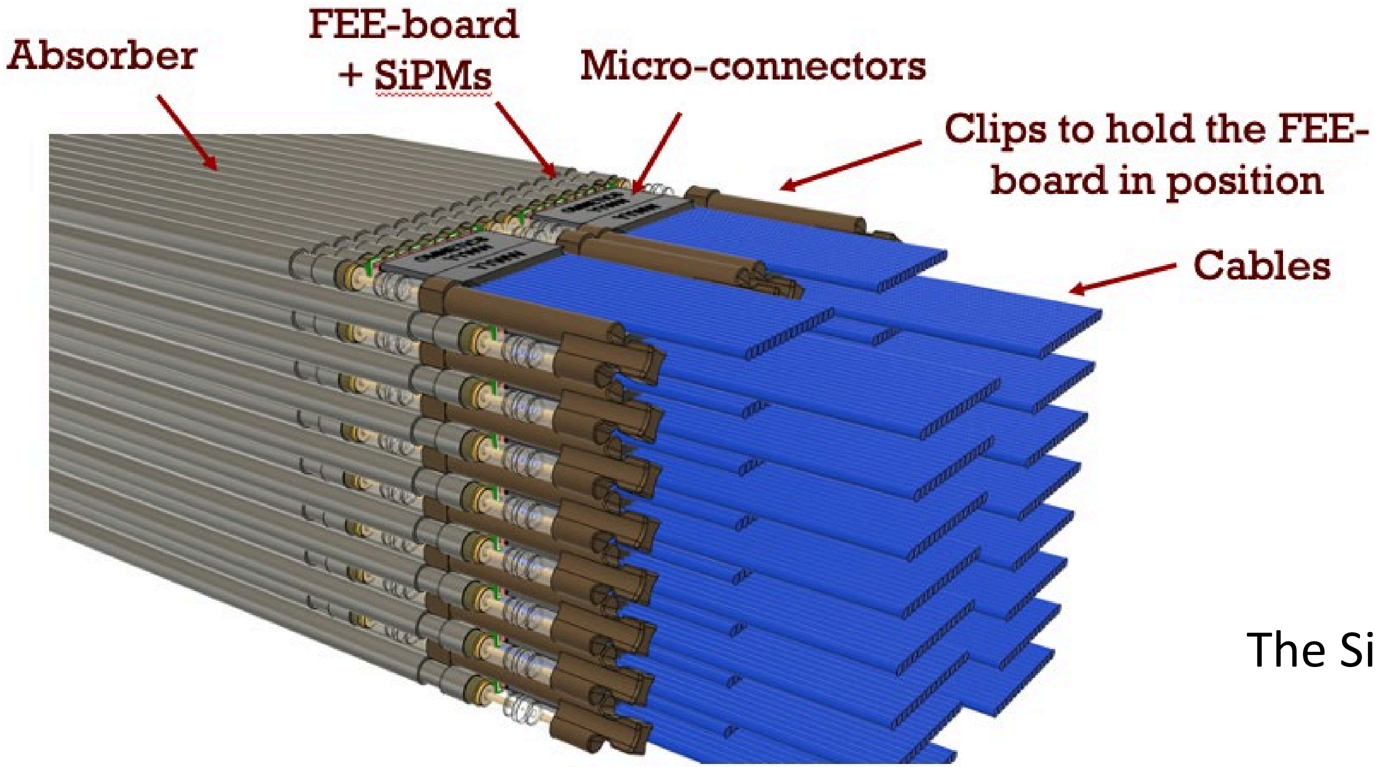
- 20 front-end boards prototypes have been realized
- waiting for SiPM mounting + cable soldering
- as a test, on one front-end board the cable has been soldered directly

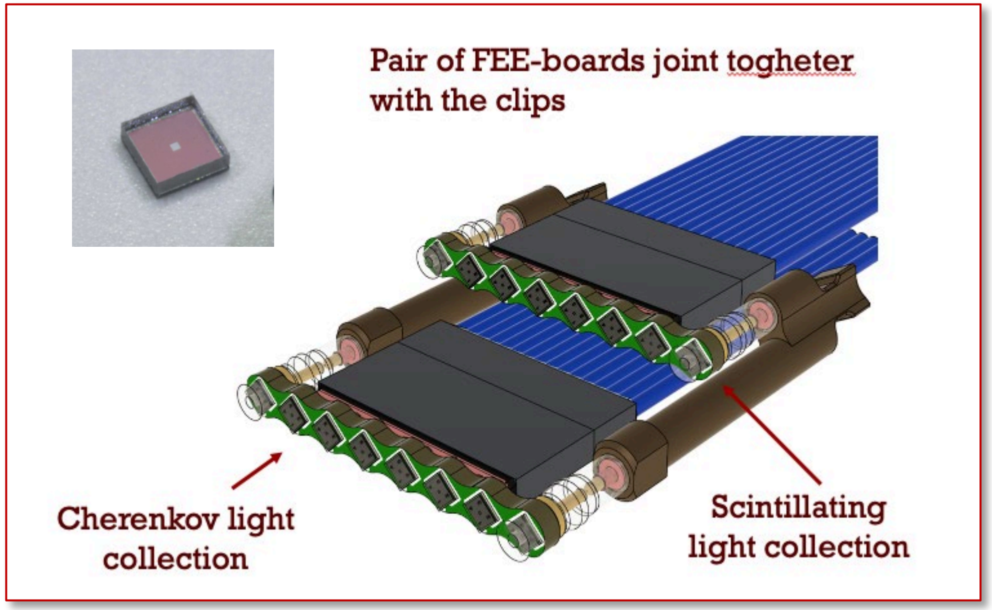
cable soldered by
Mirco Zuffa @ INFN BO



Module design

We are investigating scalable options which would guarantee the possibility to build large and projective modules

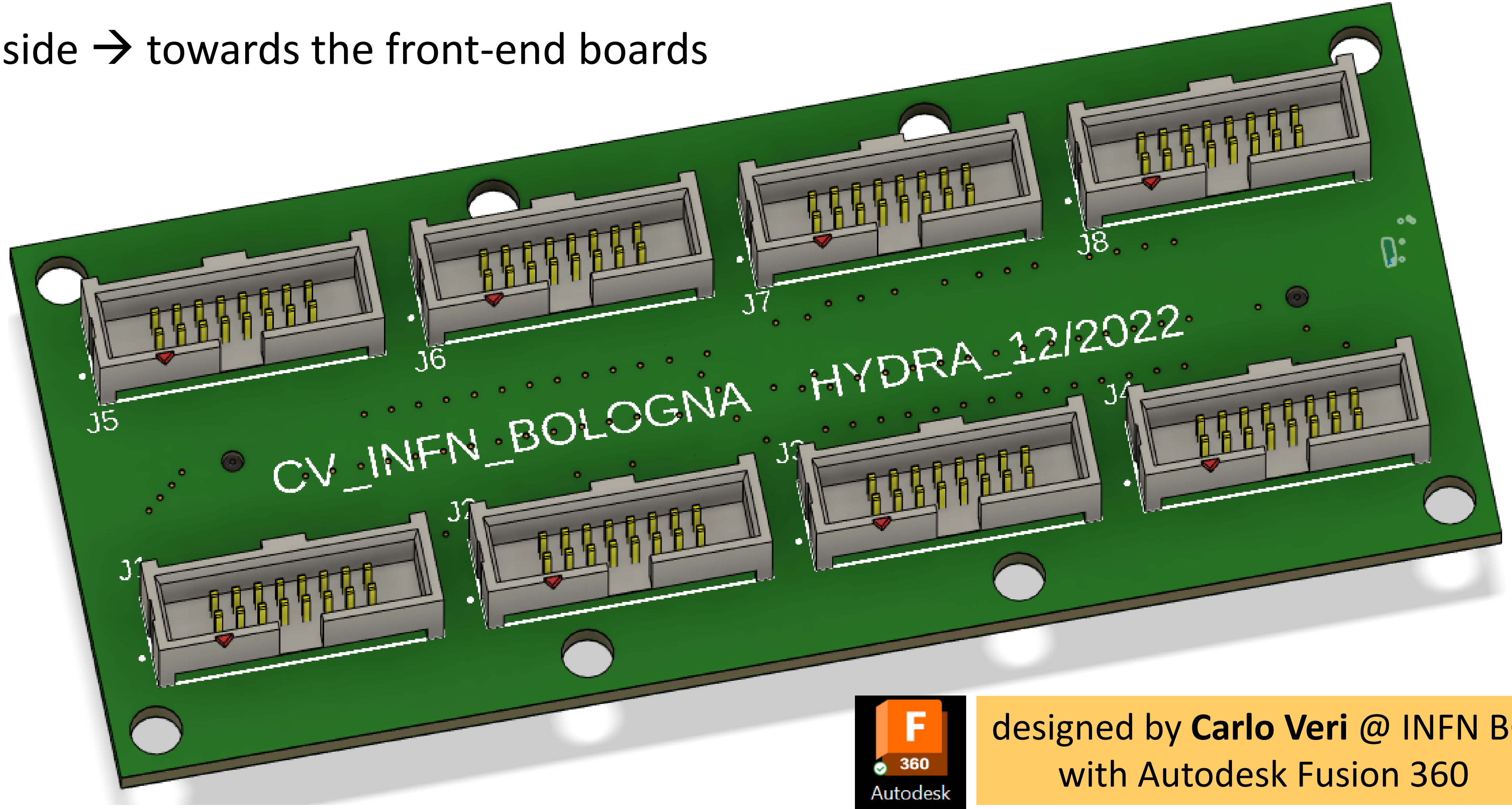




The SiPMs will be directly connected to the fibers and fixed to the absorber

Patch-panel

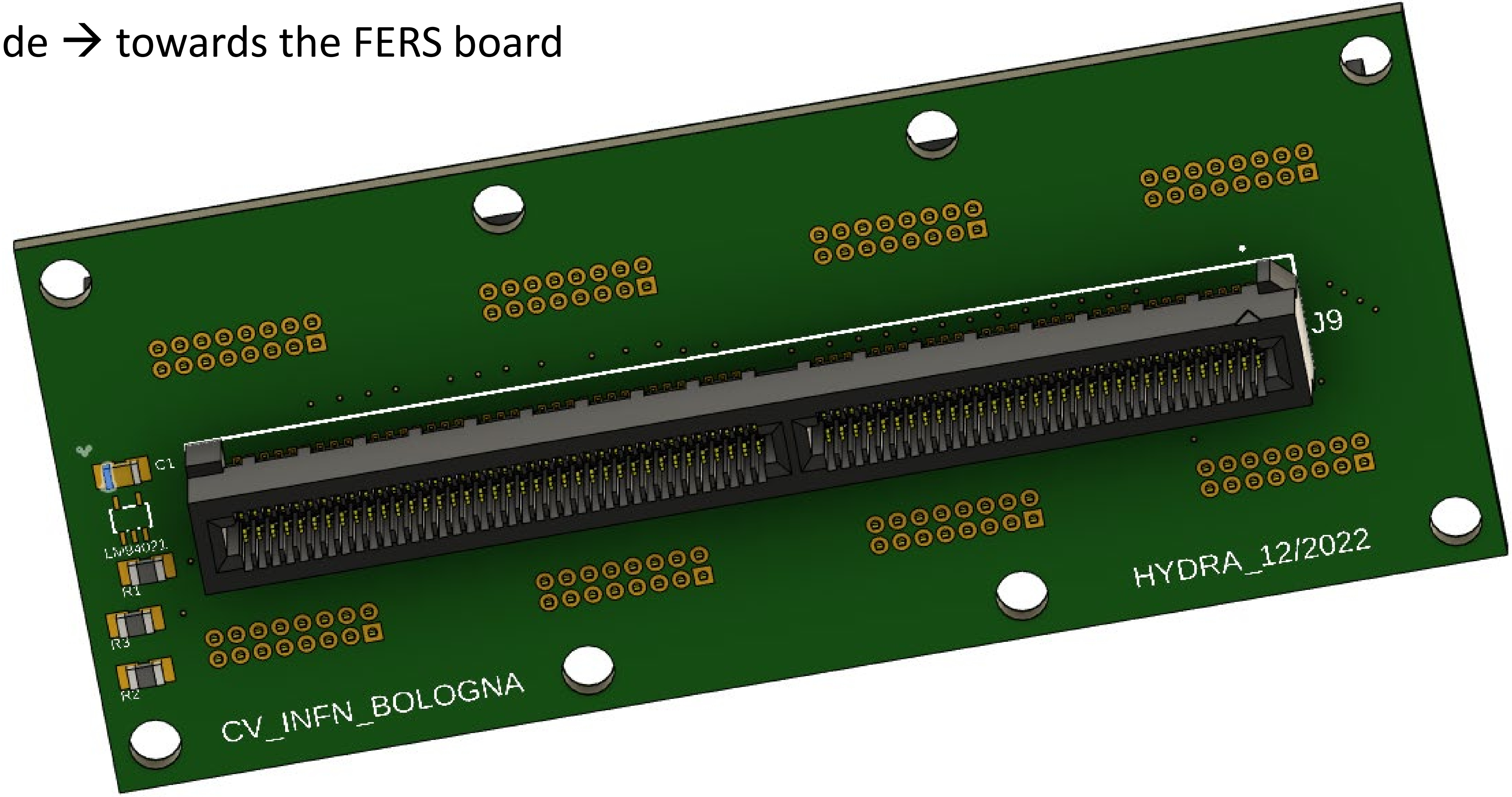
front side → towards the front-end boards



designed by **Carlo Veri** @ INFN BO
with Autodesk Fusion 360

Patch-panel

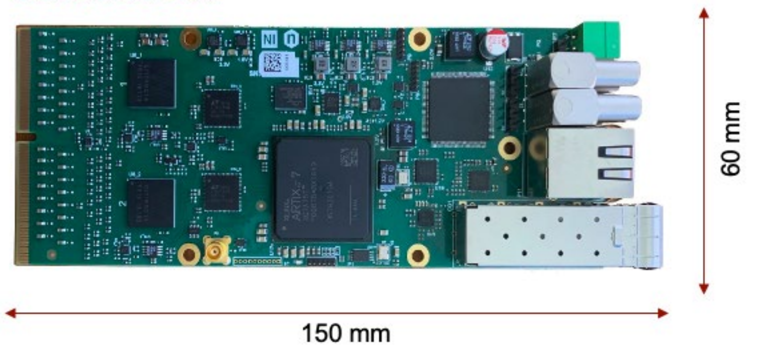
back side → towards the FERS board



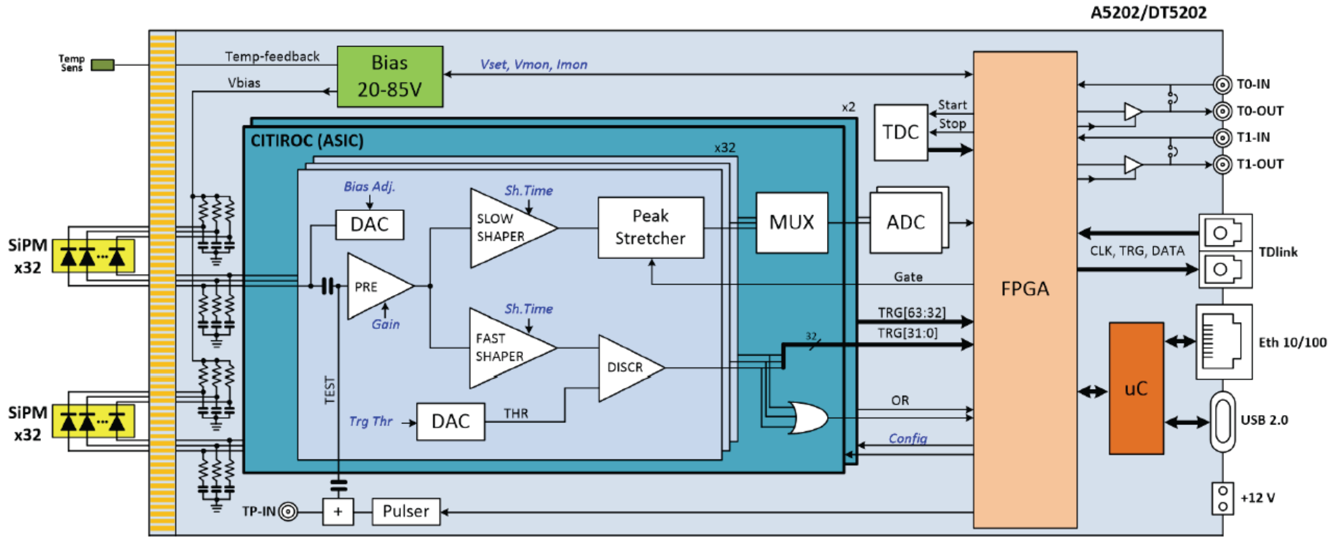
Readout scheme

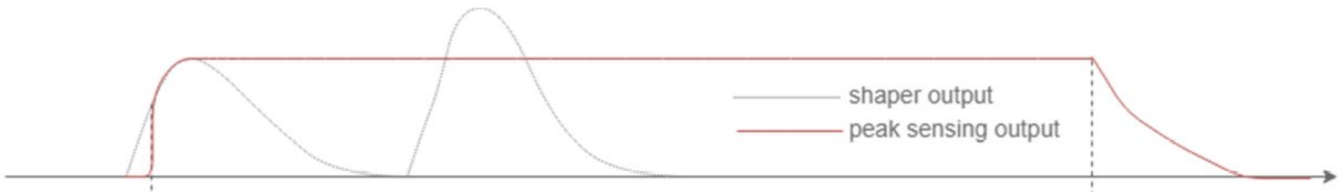
- The readout of the PMTs could use QDC (V792AC) and TDC (V775N) modules
- The readout of the highly granular modules could be based on the Caen **FERS** system (5202) using 10 readout boards (A5202) and a grouping technique to sum the signals from 8 SiPMs

FERS: A5202

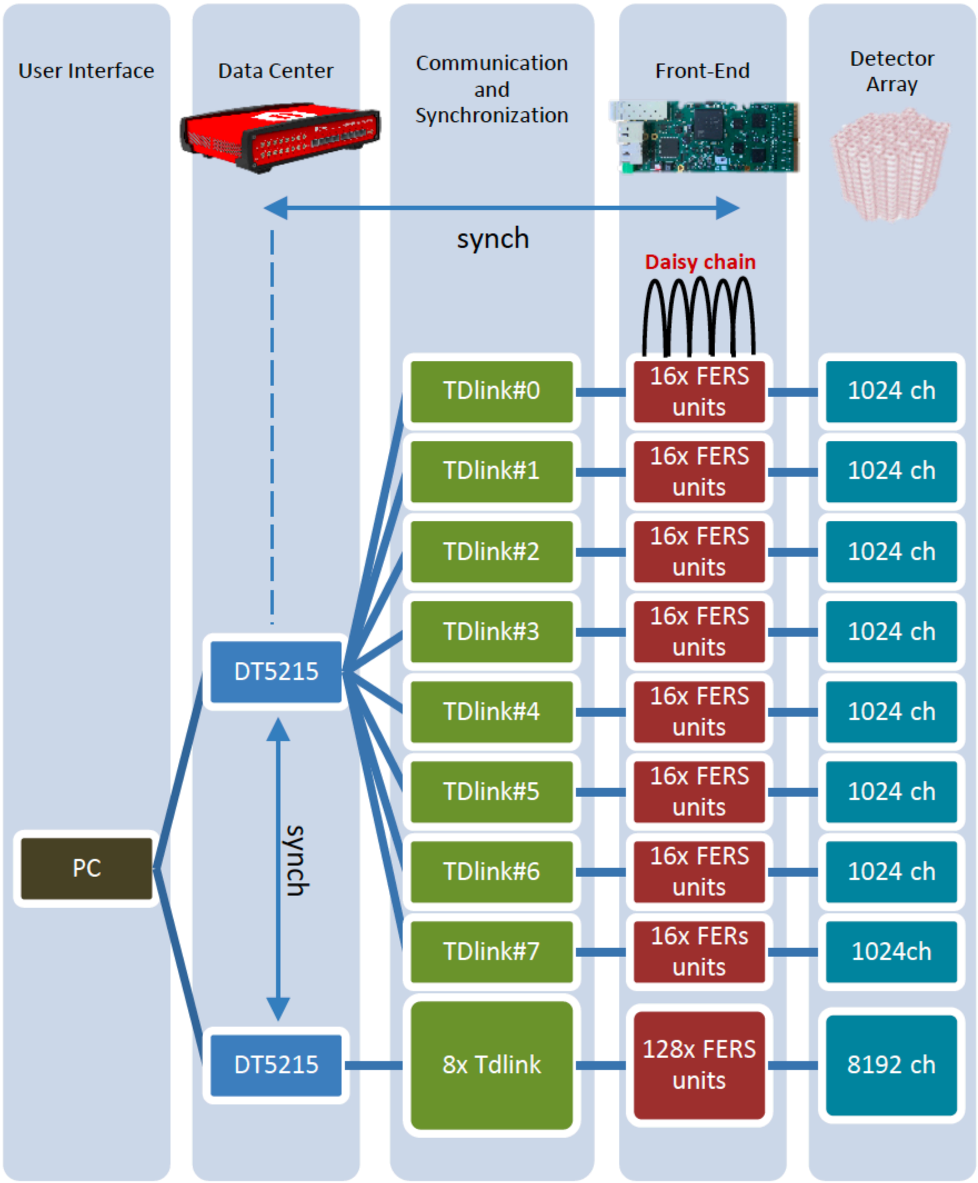


- Two Citiroc1A for reading out up to 64 SiPMs
- One (20 – 85V) HV power supply with temperature compensation
- Two 12-bit ADCs to measure the charge in all channels
- Timing measured with 64 TDCs implemented on FPGA (LSB = 500 ps)
- 2 High resolution TDCs (LSB = 50 ps)
- Optical link interface for readout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





Readout scheme



One **DT5215 (FERS Data Concentrator)** can manage up to 8 TDlinks, each connected to 16 FERS units in daisy chain: it makes **8192 readout channels**. The Data Concentrator is connected to the Host computer through 1/10 Gb Ethernet or USB 3.0. Multiple concentrator boards can be synchronized in order to further extend the total number of channels.

Conclusions

Highly granular dual readout calorimetry is one of the most promising technologies for future collider experiments: R&D is needed to assess dual readout performance and reach “production” maturity

3 years to build and test the hadronic-containment prototype:

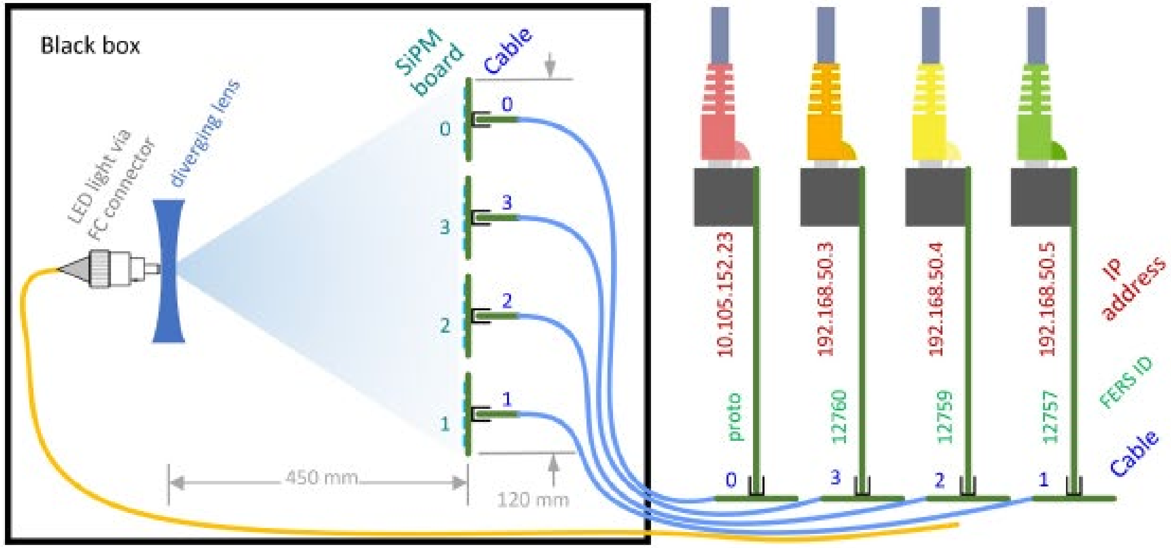
→ first (real) assessment of dual readout hadronic performance

Main technical issues:

- mechanical construction
- readout complexity

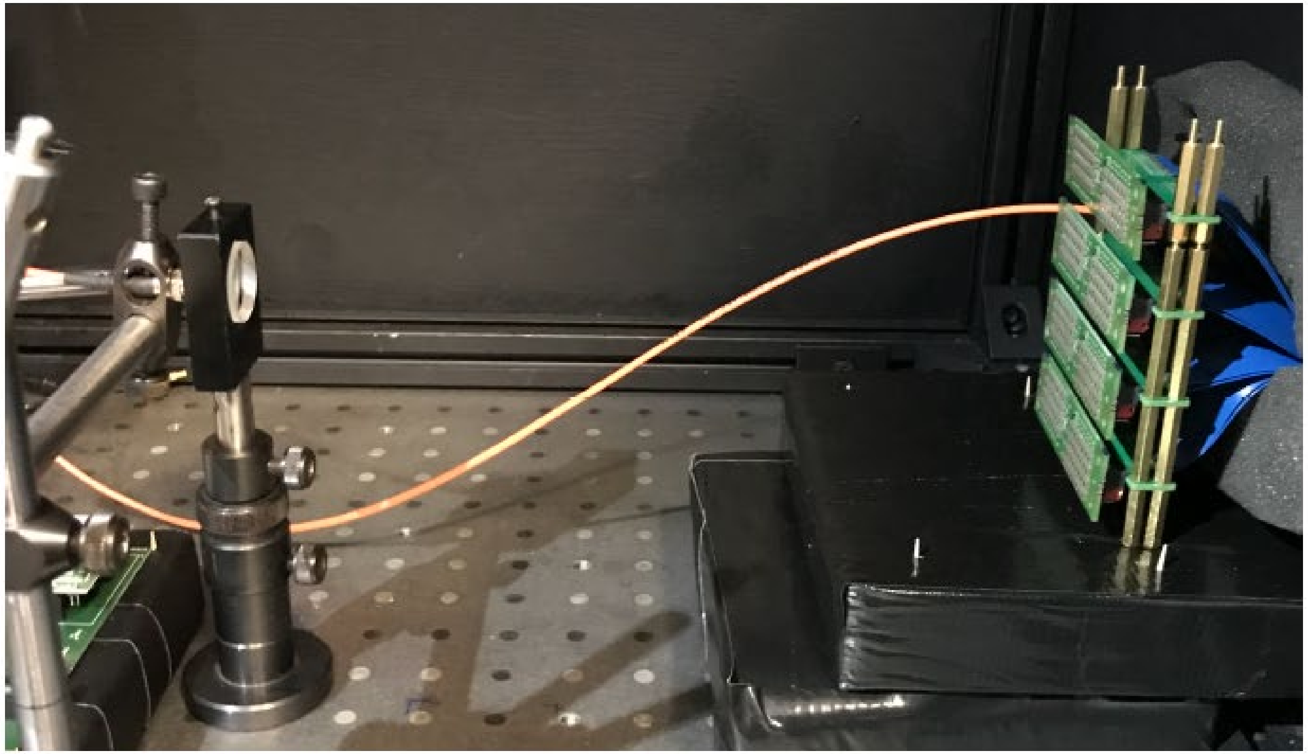
Thanks to all the persons who are giving a contribution to the construction of Hidra2 !!!

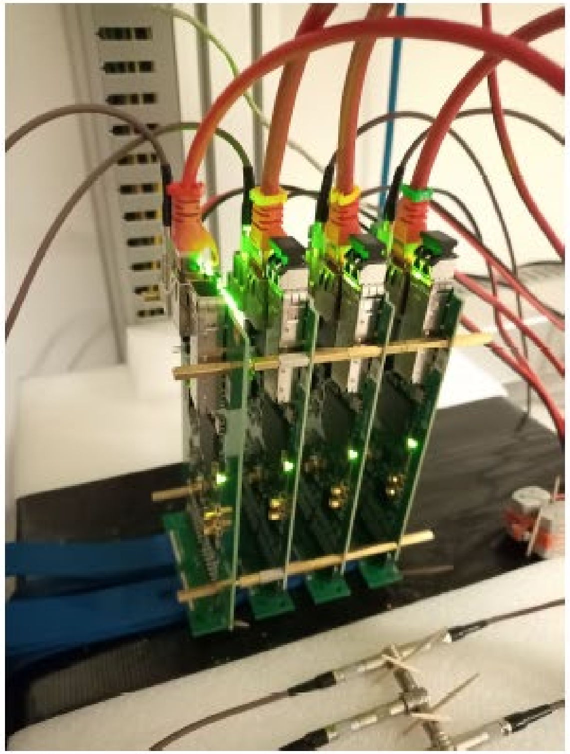
Backup

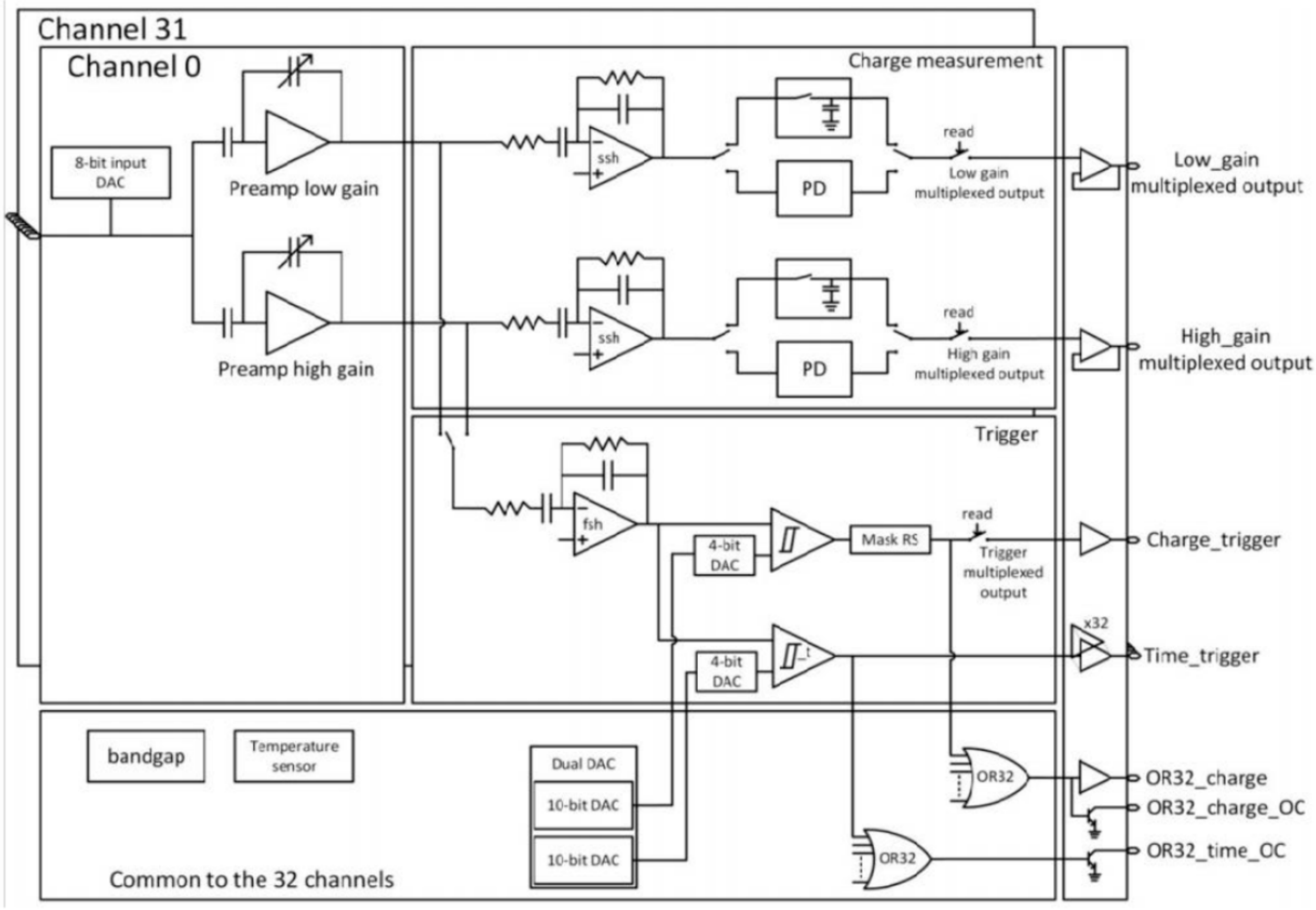


- FE-boards: 3/5 fully qualified (the other 2 are under test)
- FERS: 3/5 fully qualified (the other two will be delivered today)
- Data-concentrator: soon

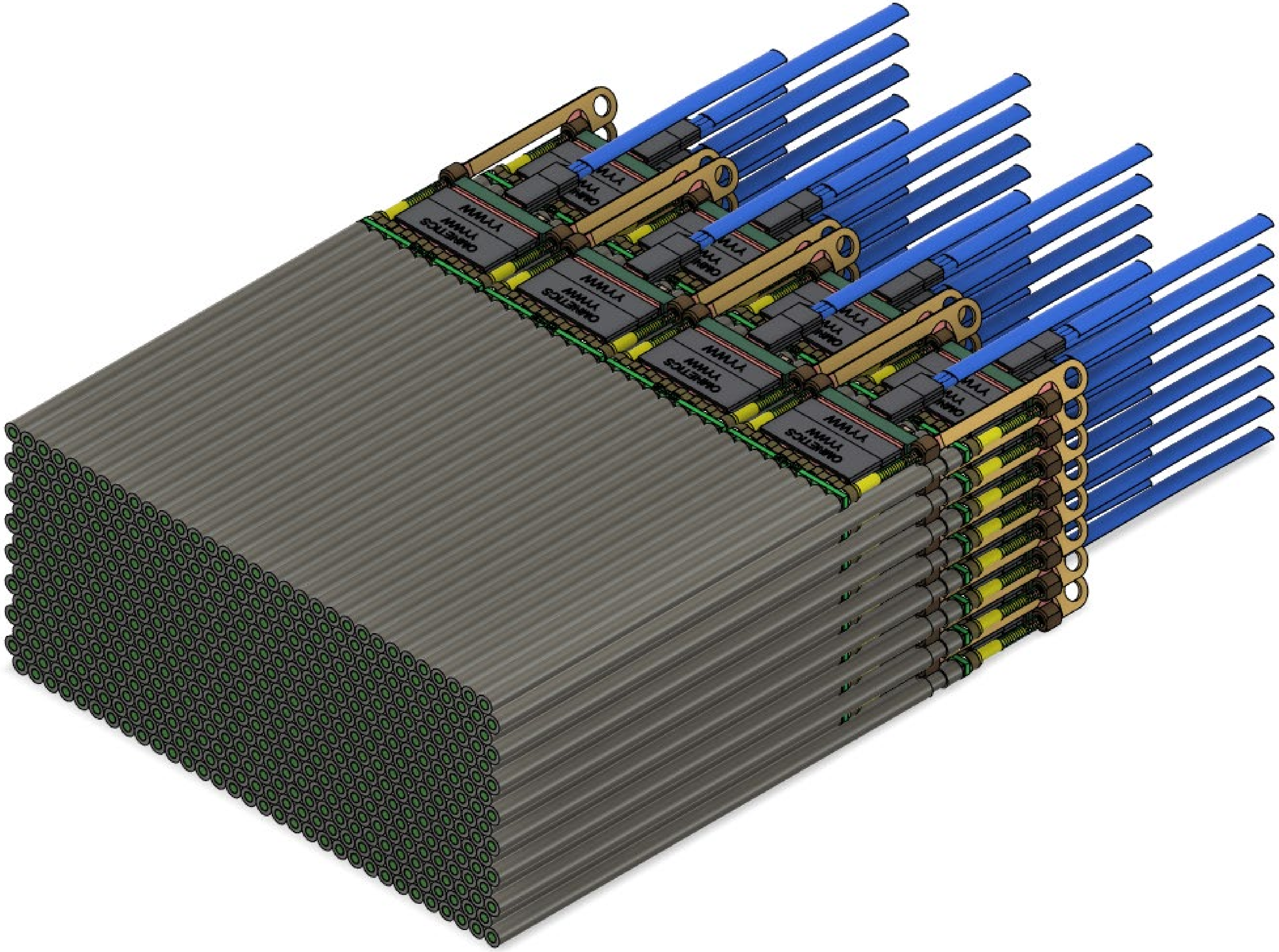
@ Como







Citiroc 1A schematic diagram



Hadronic showers

- The main fluctuations in the event-to-event calorimeter response are due to:
  - large, non-gaussian fluctuations in energy sharing EM / non-EM
  - large, non-gaussian fluctuations in “invisible” energy losses
  - increase of EM component with energy
- The calorimetric performance at collider experiments has always been spoiled by the problem of non-compensation, arising from the dual nature of hadronic showers