Future Circular Collider (FCC)
Dual Readout: a step closer to a scalable solution

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Step 1: The proposal of the Hidra-2 INFN project

Some Basics: Future ElectroWeaK factories require unprecedented highly granular jet calorimeters energy resolution. This goal appears to be achievable only with an imaging calorimeter it exploits particle flow algorithms or a fiber sampling **Dual Readout** (DR) calorimeter using scintillation and Cerenkov effects, the former produced by all ionising particles, the latter only by relativistic charged particles. In both cases, many problems are still open and R&D is needed to build a hadron-sized prototype and evaluate the performance. Finally, new digital devices as digital SiPMs, currently not in the schedule, could lead to a simpler and innovative readout architecture.

The **DR** features absorbers composed of stainless steel, and detectors which are composed of scintillating and clear fibers. The former are sensitive to all kind of charged particles, to measure the total deposited energy, the latter are sensitive to Cherenkov light to measure EM shower parameters.

The **Hidra-2** project aims to design, build and qualify prototype of fiber sampling granular DR calorimeter to evaluate:

a) a stand-alone hadronic resolution around 30%/√E or better, both for single hadrons and for jets, while maintain a resolution for isolated electromagnetic (em) showers close to 10%/√E;

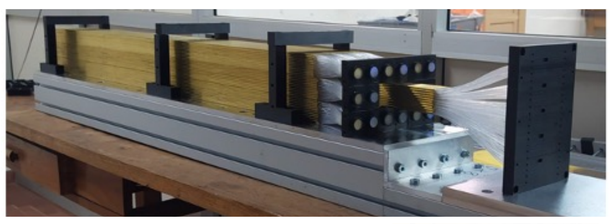
b) a transversal resolution of O(1 mrad)/√E;

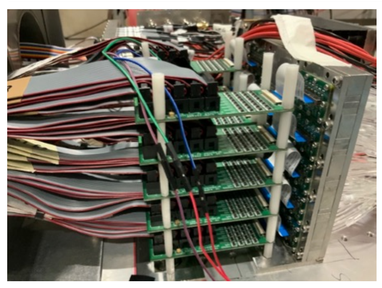
c) a longitudinal one of a few cm (by phasing);

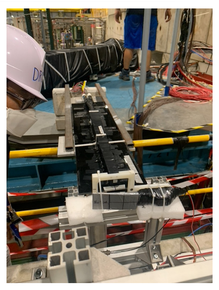
d) a modular and scalable construction technique;

e) an innovative reading architecture based on SiPM;

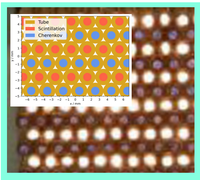
f) the performance of Deep Neural Network algorithms in exploiting such a large amount of (3D) information.







Examples of tests already performed by some collaborations to test the DR approach. The picture on the left shows the use of "bucatini" shape absorber and scintillating fibers as detectors.



Example of lines of "bucatini"-shaped absorber and fibers alternately lit to emphasize the capacity of different materials to play the role of Cerenkov or scintillating detector

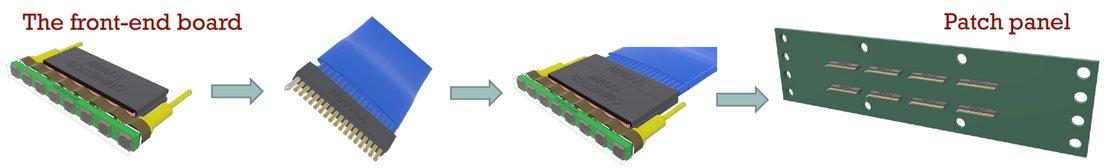
- **Test Beam lead by Korean team**
- **2022 test beam** at SPS with **different mechanics and readout options**
- Mechanical modules with **3D printed options**
- First time on beam - data taking was a big success - results to come

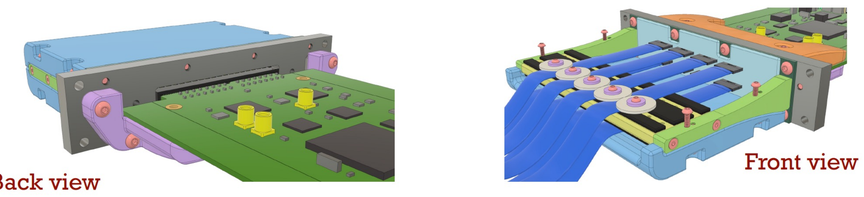
Already performed test beams in CERN/DESY at energies up to 6 GeV

Step 2: The Design of a scalable approach to group the fibers for an optimized readout

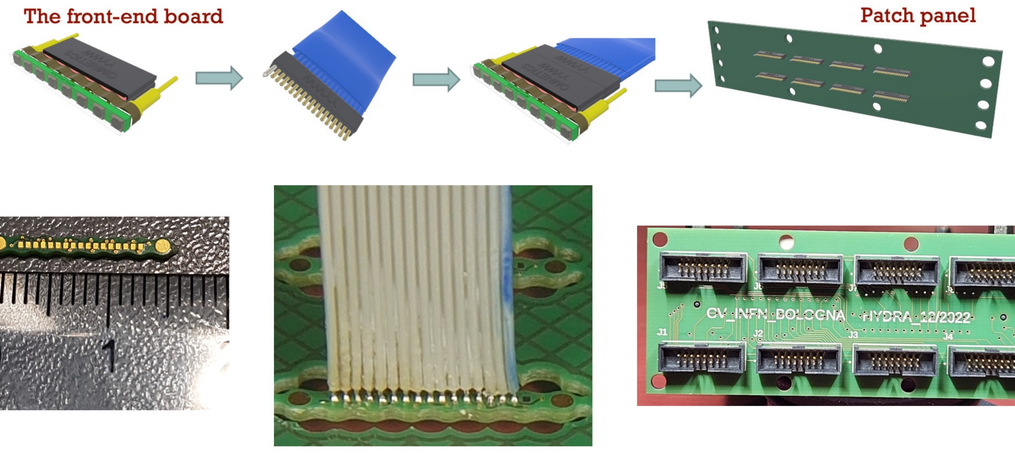
The operation of a large number of SiPMs poses a series of system integration challenges: the reduced space available on the back of the calorimeter, the number of channels and the costs. The optimal solution would be the custom design of a SiPM with on-board intelligence.
Channel grouping would allow us to save space and costs. We are considering a flexible design based on a dedicated board possibly compliant with future evolutions.

- Each SiPM is tested individually: crucial for the commissioning



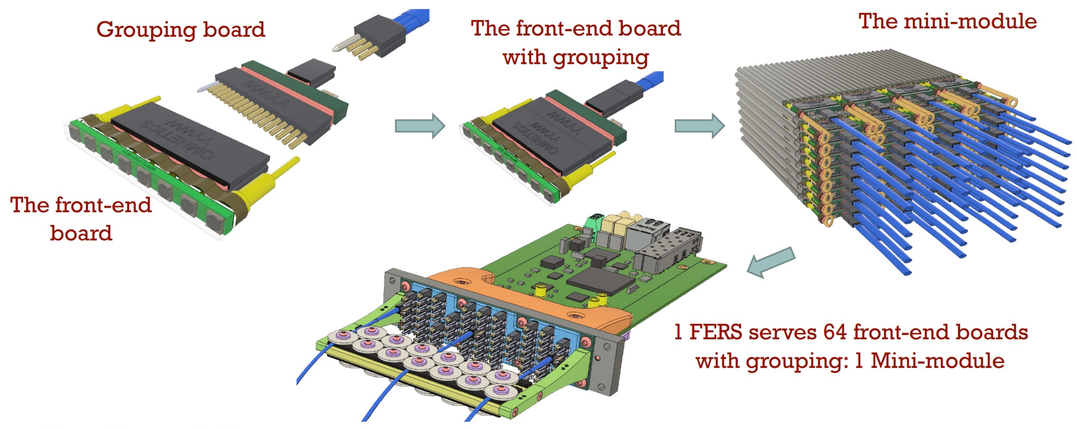


8 front-end boards
connected to 1 FERS



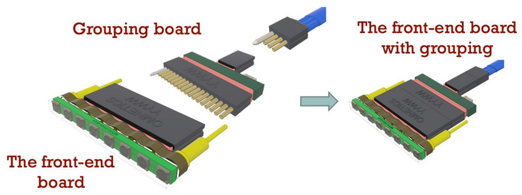
Step 3: An evolved scalable approach for the electronic readout

We use a CAEN Front-End Readout System (FERS) electronic cards designed to read out of **large arrays of detectors**.

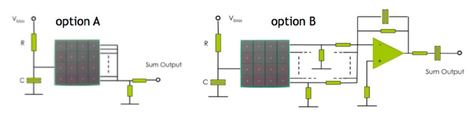


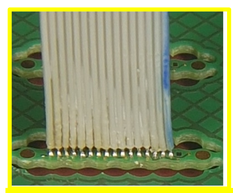
Baseline solution

- Each bar of SiPMs will be operated at the same voltage
- The signals from 8 SiPMs is summed up in the grouping board



We should do a sum of current at the tail of the cable (from 16 pins to 2 pins).
Ideas on how to proceed? What do we need?



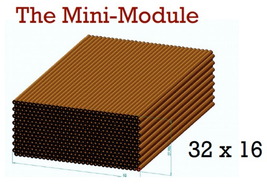


In the future we should redesign the patch panel (version II) so that can accommodate 64 grouping cards.
For this first phase, we need to carry out qualification tests and therefore it would be enough to have an actor to connect the grouping boards to the existing patch panel.
What do we need?

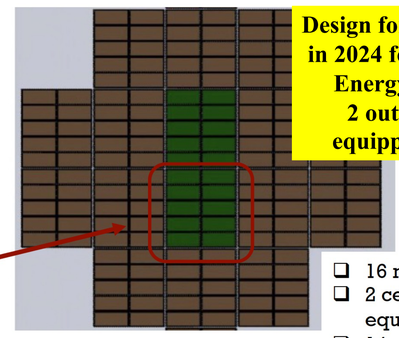
Test of mini-boards soldered to readout cables

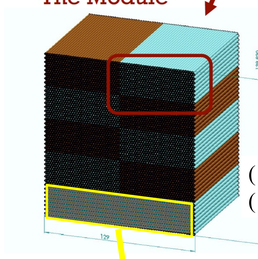
Step 4: Design for future Hidra-2 Hadronic Containment and DR integration

The hadronic prototype



Design for future test beam in 2024 for a 10k channels Energy up to 30 GeV 2 out of 16 module equipped with SiPMs





10 Mini-modules
~ 13 x 13 x 250 cm^3
(13 x 2.6) x 5 cm = 13 x 13 cm^2
(5 x 5) x (13 x 13) = 65 x 65 cm^2

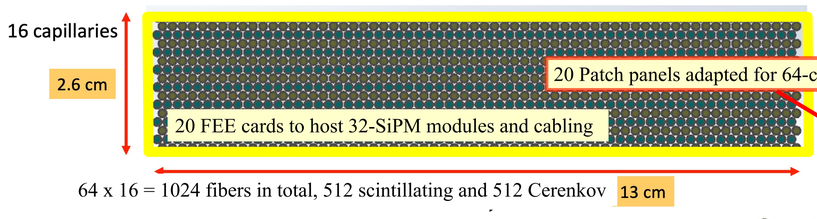
- 16 modules in total
- 2 central modules equipped with SiPMs
- 14 modules equipped with PMTs
- ~ 65 x 65 x 250 cm^3

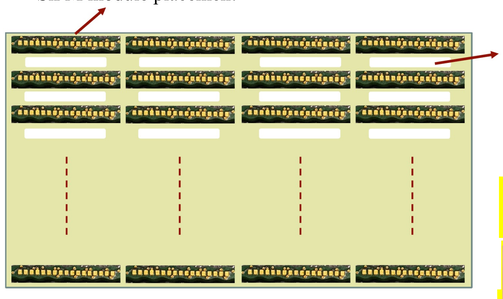
The challenge:

We have10240 SiPMs, fitting the back side of the detector, to be operated

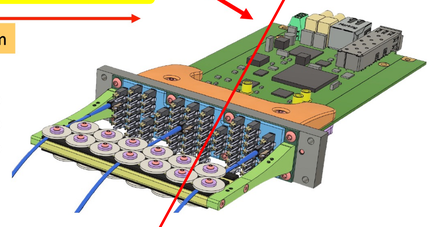
Modularity: 10240 SiPMs = 10 x 1024 fibers, grouped in 1280 x 8-SiPM modules

- 640 FEE mini-boards
  Equipped with cabling

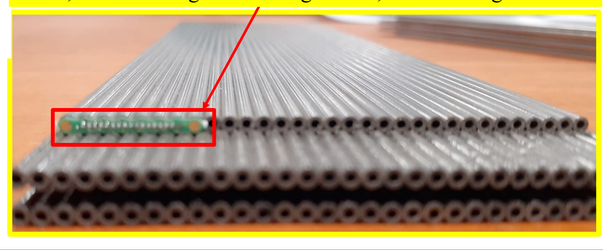




FEE card cable routing hole (needed to ensure there is clearance!



Example of lines of "bucatini"-shaped absorber and a mini-board, to host the light-collecting SiPMs, soldered together



Summary

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. The Hidra-2 project aims at testing a scalable solution using 10k channels in a "bucatini"-shaped absorber and detector hosting Cerenkov and scintillating fibers. A test-beam at 30 GeV is scheduled in 2024 to extend the previous test carried out by some international collaborations. The Hidra-2 project focuses on a 3-year study to build and test a hadronic-containment prototype which features a first (real) assessment of dual readout hadronic system. Today's main technical issues are related to the mechanical construction, and to the readout complexity