INFN
Istituto Nazionale
di Fisica Nucleare

# *Call HiDRa(2)*

*CdS Pavia - 7 luglio 2021*

*Roberto*

# CSN 5 Call – HiDRa (refurbished)

High-Resolution Highly Granular Dual-Readout Demonstrator

Goals:

direct demonstration of hadronic resolution:

~ 30% / √E [ em ~ 10% / √E ]

→ need “hadronic size” → ~ 65×65×200 $cm^3$

identify and assess a scalable solution (in all aspects)

work out all critical issues for physics at future leptonic Higgs factories

validate/tune GEANT4 hadronic (and em) shower models

# CSN 5 Call – Ingredients

Mechanics:

identify and assess a scalable construction method
(material, assembly, QAQC)

Sensors (SiPMs):

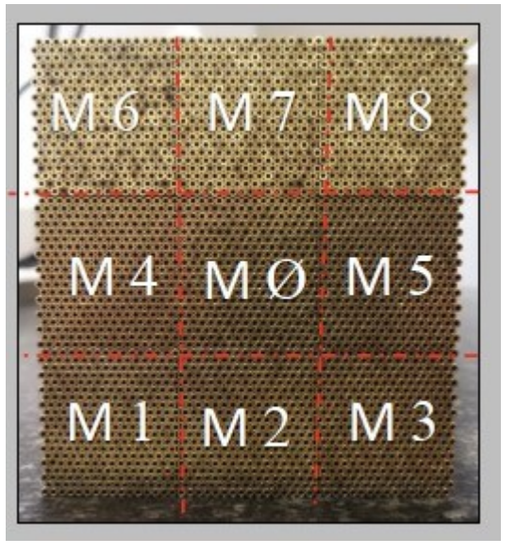
high transverse granularity O(2 mm)
timing information O(100 ps) → shower depth O(5 cm)

FEE: test/qualify commercial ASIC
→ charge integrators, waveform samplers, MUSIC(?)

digital SiPMs: highly prospective R&D

Simulations, data analysis … deep learning algorithms …
→ validate/tune GEANT4 simulations

# The 10×10 cm$^2$ 2020 prototype




1 m long, 10×10 cm$^2$, module divided in 9 towers

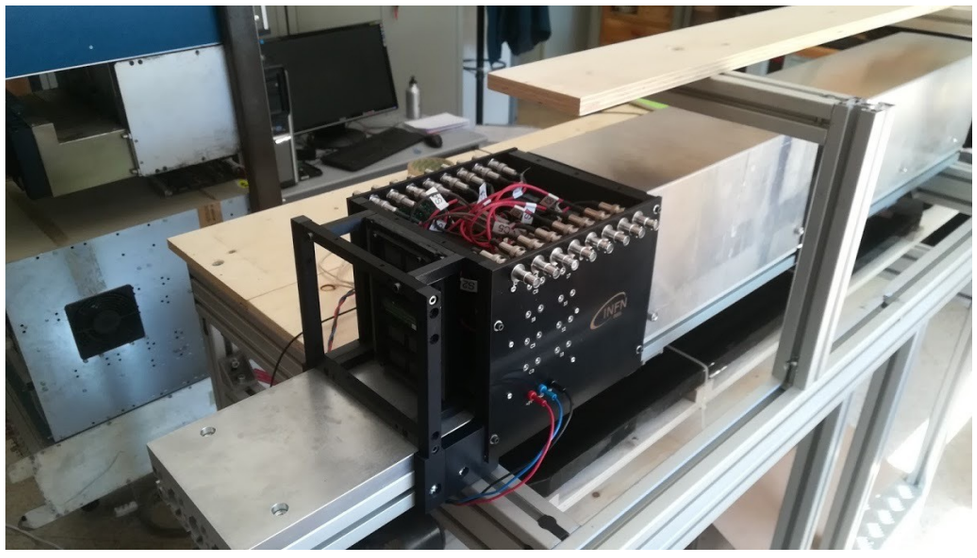
each tower: 16×20 capillary tubes (160 C + 160 S fibres)

each tube: 2 mm Ø, 1 m long, brass

Readout:

central tower with SiPMs

8 external towers with PMTs (à la RD52)

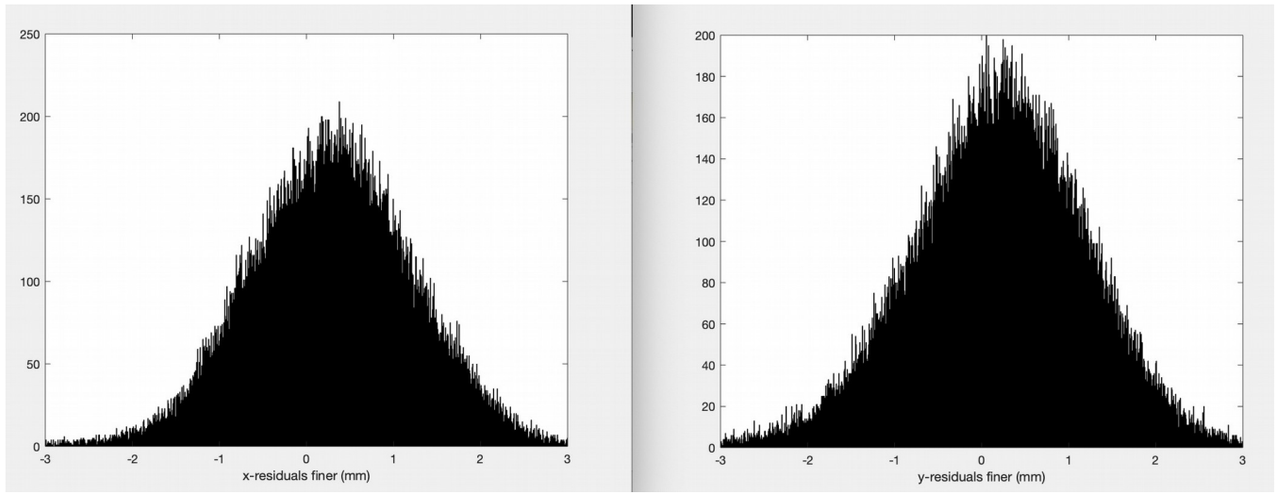


# Testbeam @ DESY

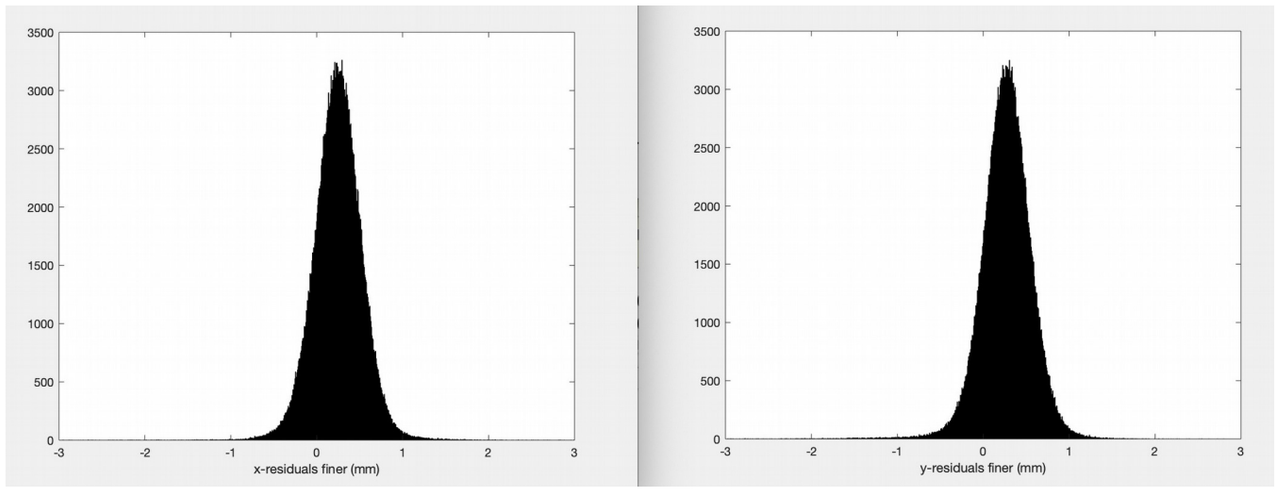
1-6 GeV electron beams
- many datasets acquired
- 3 (initially 2) independent DAQ systems running in parallel

Beam position difference (SiPM – PMT reconstruction)

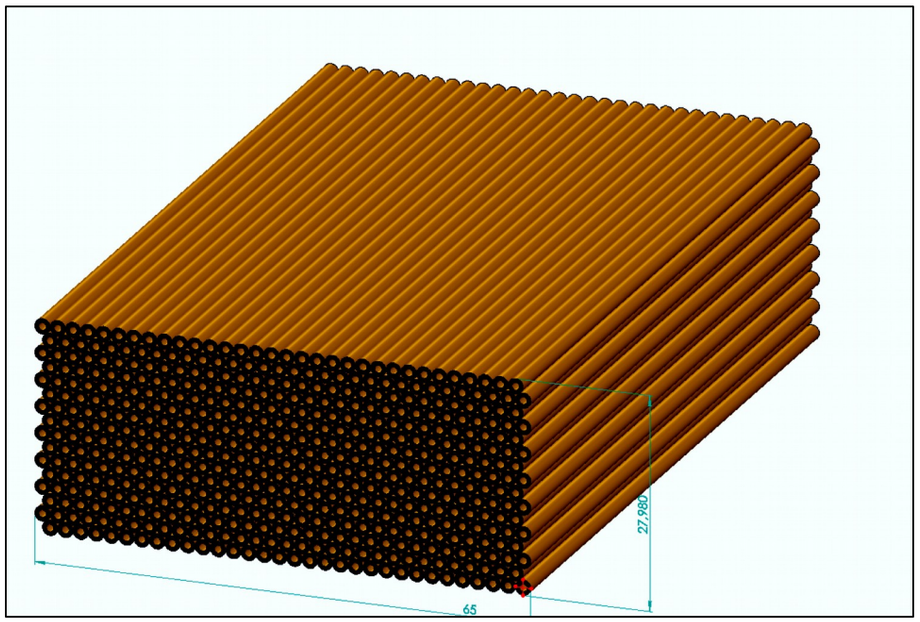
for independent events →




for correlated events
(i.e. the same) →

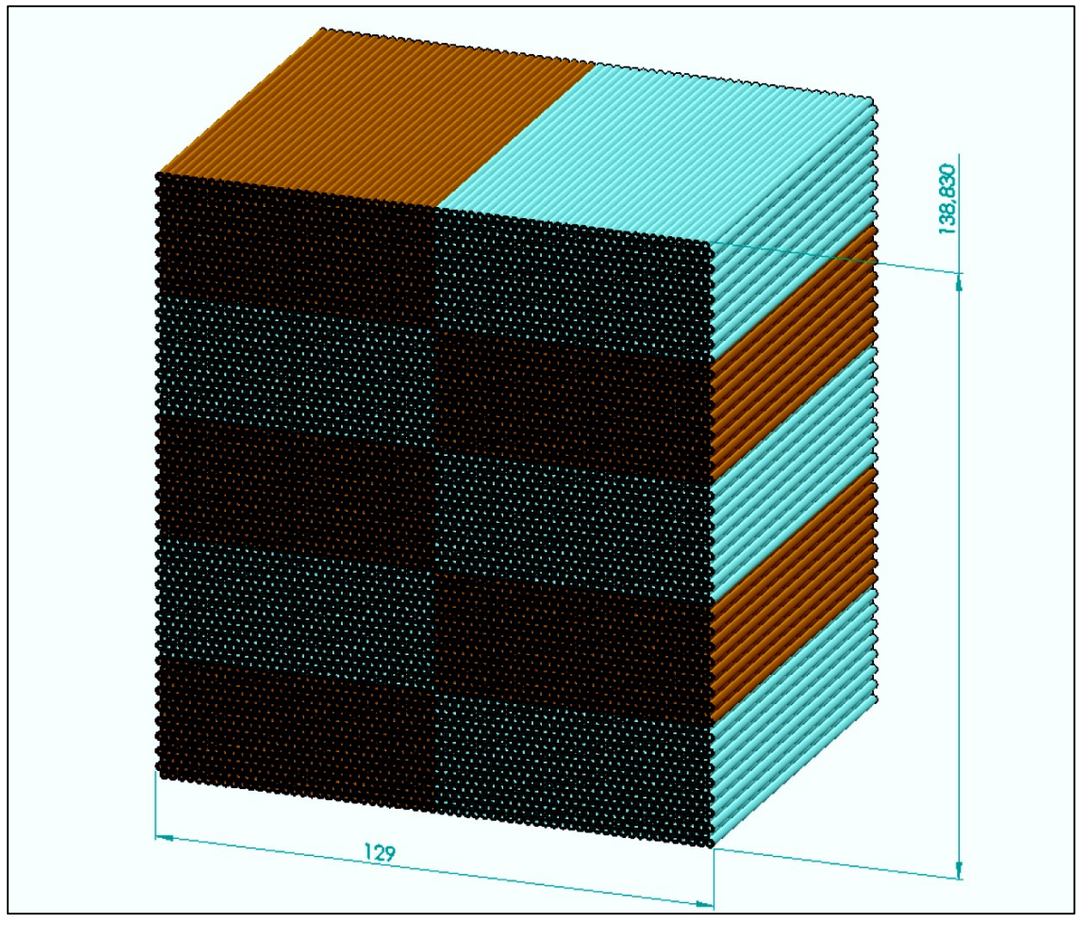


# HiDRa detector design




1 Mini-Module (MM):

32 × 16 channel ( 512 ch )




1 Module:

2 × 5 MMs
→ 10 FEE boards
(8-channel grouping)

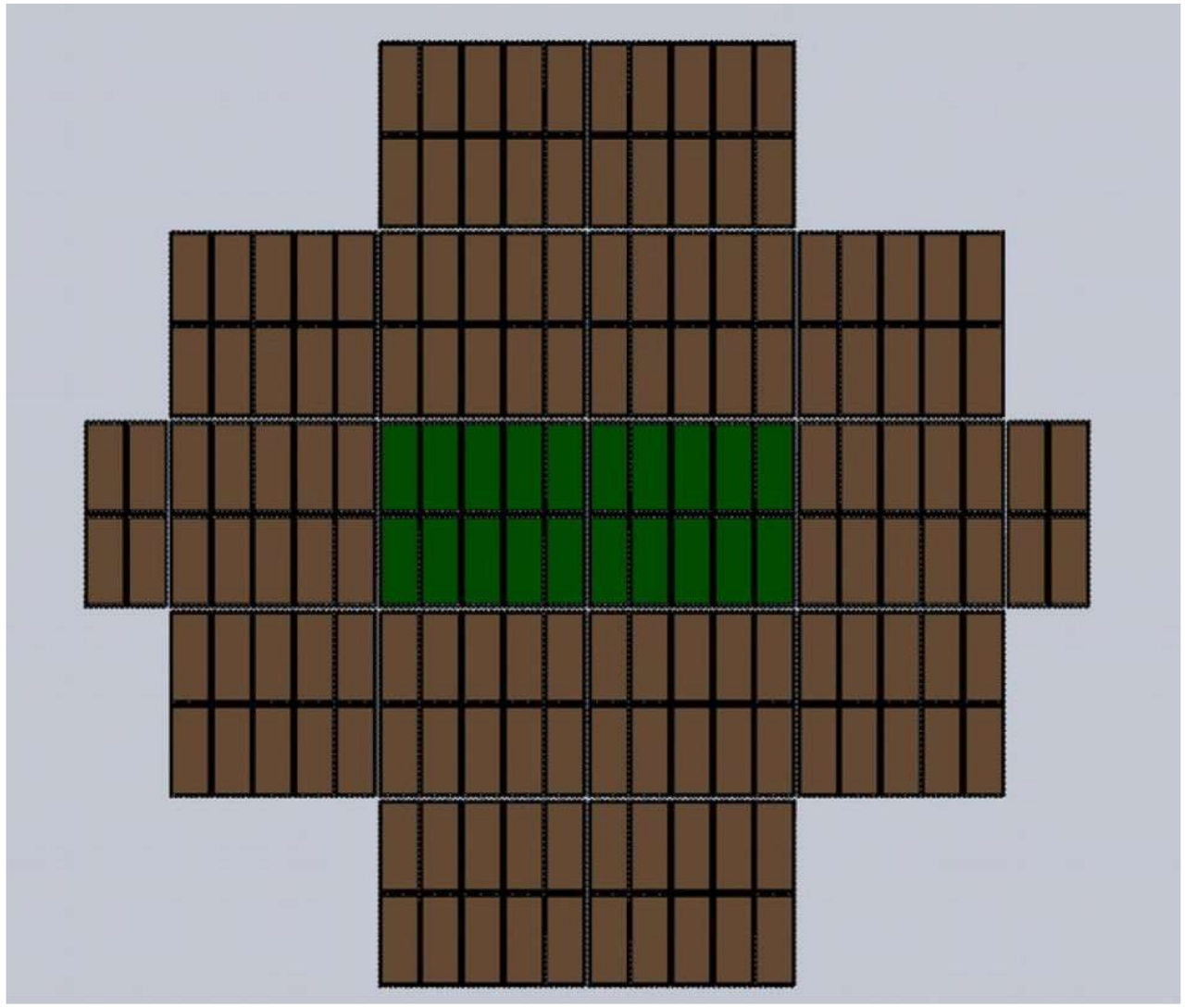
~ 13 × 13 × 200 $cm^3$

# Main deliverables

~16 modules:

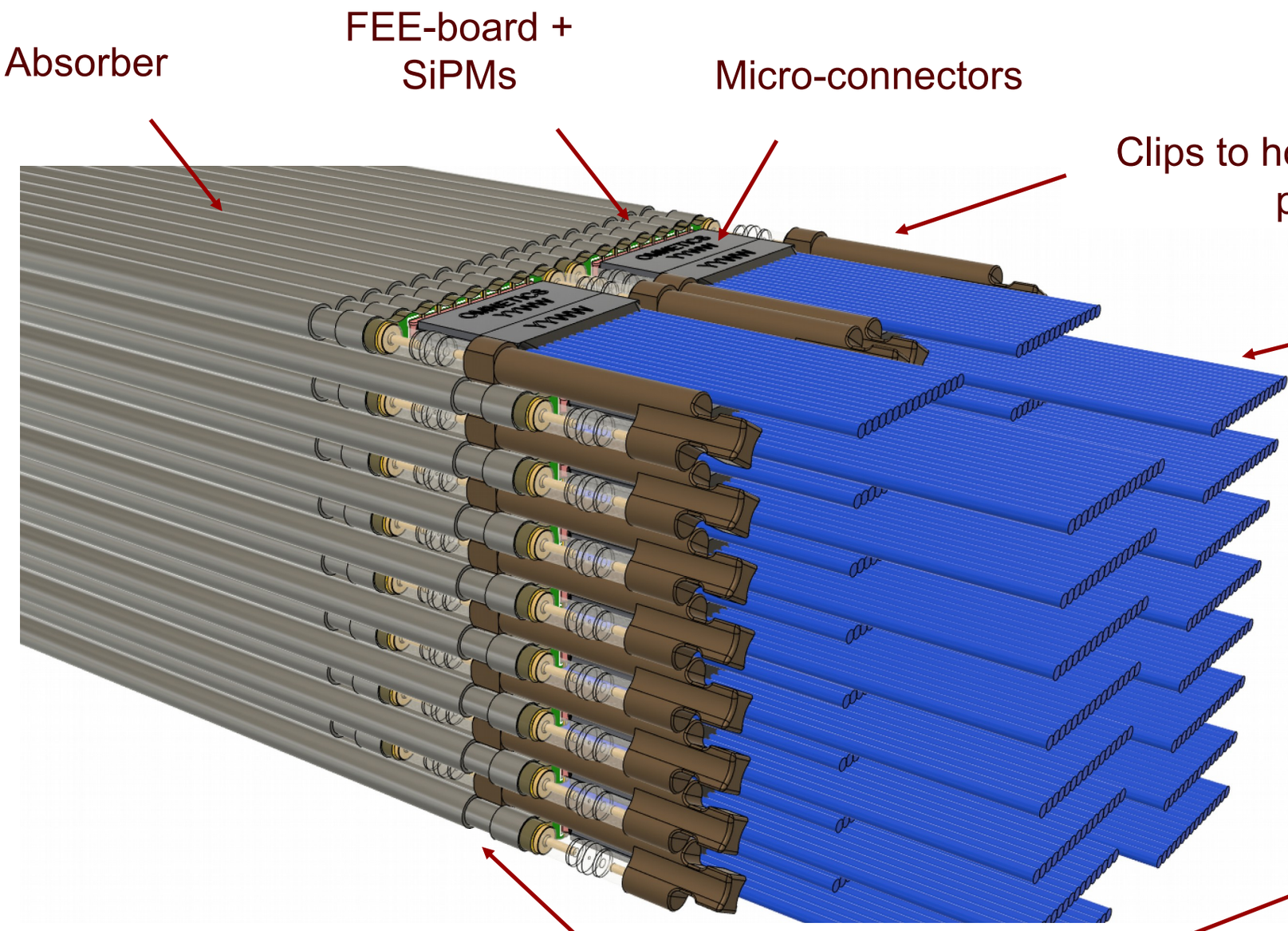
- 2 central ones with SiPMs
  → ~ 10 k SiPMs
  → ~ 20 FEE boards

- all others with PMTs
  → ~ 150 PMTs

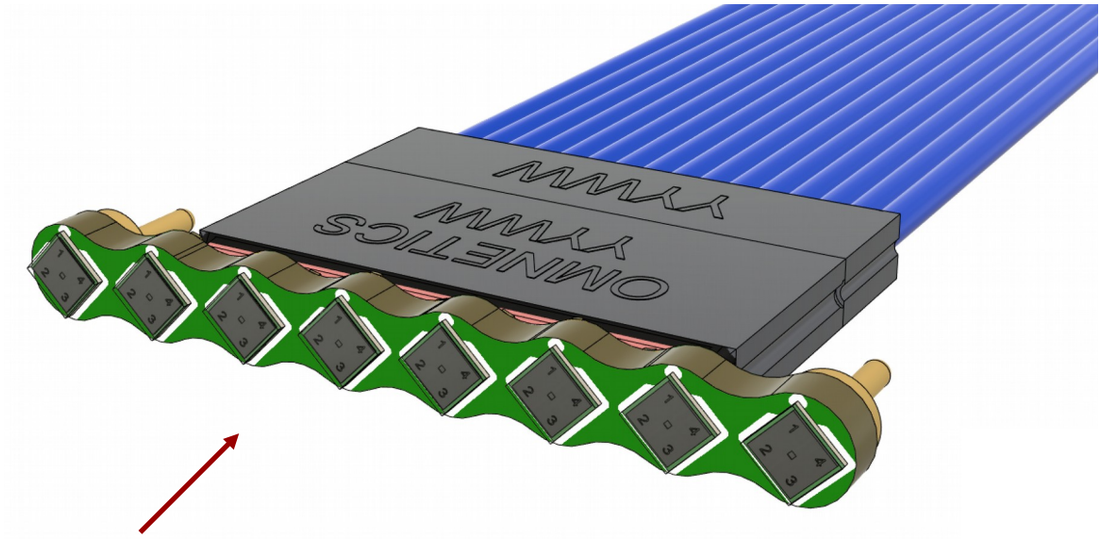


d-SiPMs: small 64-channel demonstrator
~ 1 × 1 × 100 $cm^3$

# New concept for a true scalable module (I)

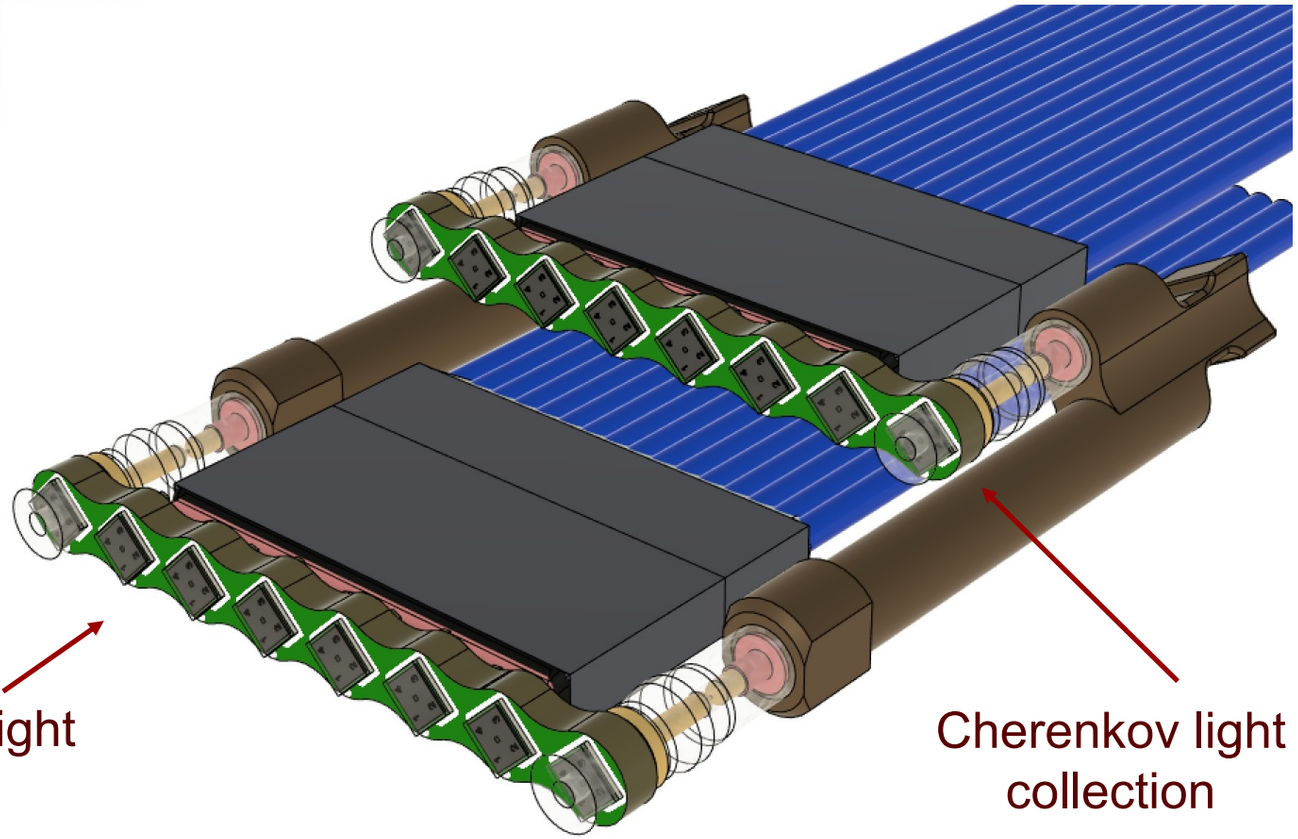


# New concept for a true scalable module (II)



FEE-board + SiPMs
Segmentation optimised to exploit grouping

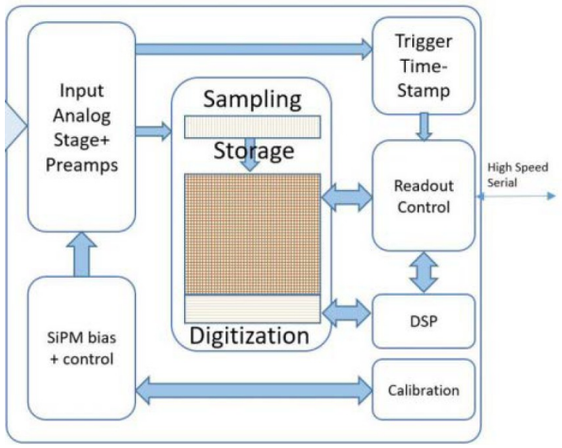
Pair of FEE-boards joint together with clips



Scintillating light collection

Cherenkov light collection

# Waveform sampler (alternative readout ASIC)




System-on-Chip with

a) built-in SiPM biasing, calibration and digitisation control (analog side)

b) feature extraction and digital signal processing (digital side)

HDSoC: Produced by Nalu Scientific

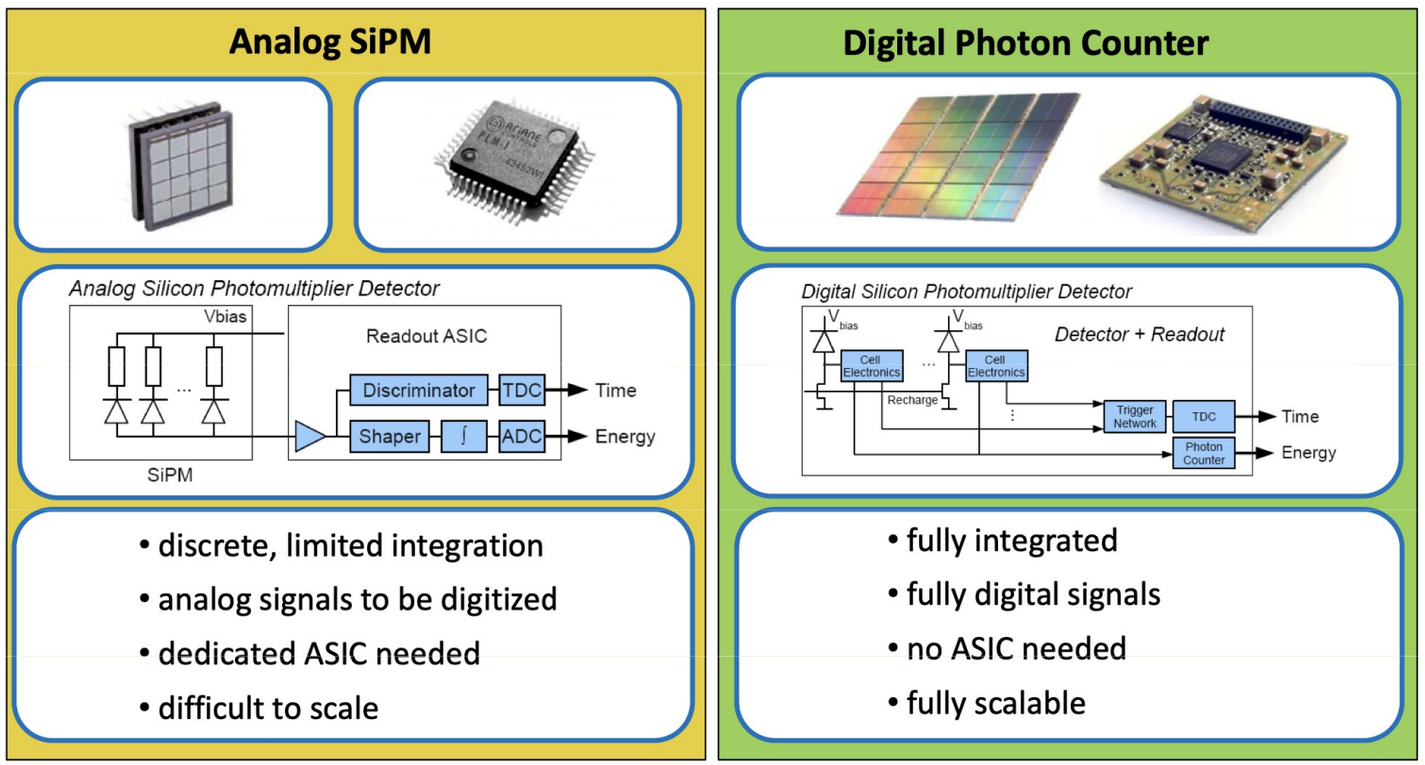
Possibly integrated into the FERS readout system (CAEN)

Next year, demo board could be available for preliminary tests and qualification

| Parameter | Spec |
|---|---|
| Sampling Rate | 1-2 GSa/s |
| ABW | > 600MHz |
| Depth | 2k Sa |
| Trigger Buffer | ~3 us* |
| Deadtime | 0** |
| Channels | 64 |
| Supply/Range | 2.5 |
| ADC bits | 12 |
| Timing accuracy | 80-120ps |
| Technology | 250 nm CMOS |
| Power | TBD |

- On chip calibration
- Serial interface
- On chip feature extraction
- Virtually dead-timeless
- 32 ch proto chip fabricated
- Phase II SBIR awaiting award
- Next steps: packaging and eval

# Do we really want to be Analogue ?




https://indico.cern.ch/event/192695/contributions/353376/attachments/277251/387863/TIPP2014_Amsterdam_lecture_Philips_Haemisch_pub.pdf

- Not yet consolidated technology but strategic R&D in terms of cost production and system complexity
- Performance not yet at SiPM level but rapidly improving
- Good expertise, in simulation and design, at FBK and in few INFN groups
- Non-linearity corrected before summing information
- Timing performance more straightforward

Interesting review-paper: NIM-A, 809 (2016), 31-52

# SW and performance

Lot of work in progress for:

a) integration in FCCSW (DD4HEP, EDM, digitisation, …)

b) integration with other detectors (drift chamber and preshower)

c) development of calibration and correction procedures for single particles (e, γ, μ, single hadrons, jets)

d) exploiting timing information

e) developing deep learning algorithms for event selection and reconstruction

f) crystal option for high-res em measurements

g) validation of GEANT4 predictions/modelling

Many people contributing (or planning to do) from INFN, UK, S. Korea, US, … Chile, CERN, ...

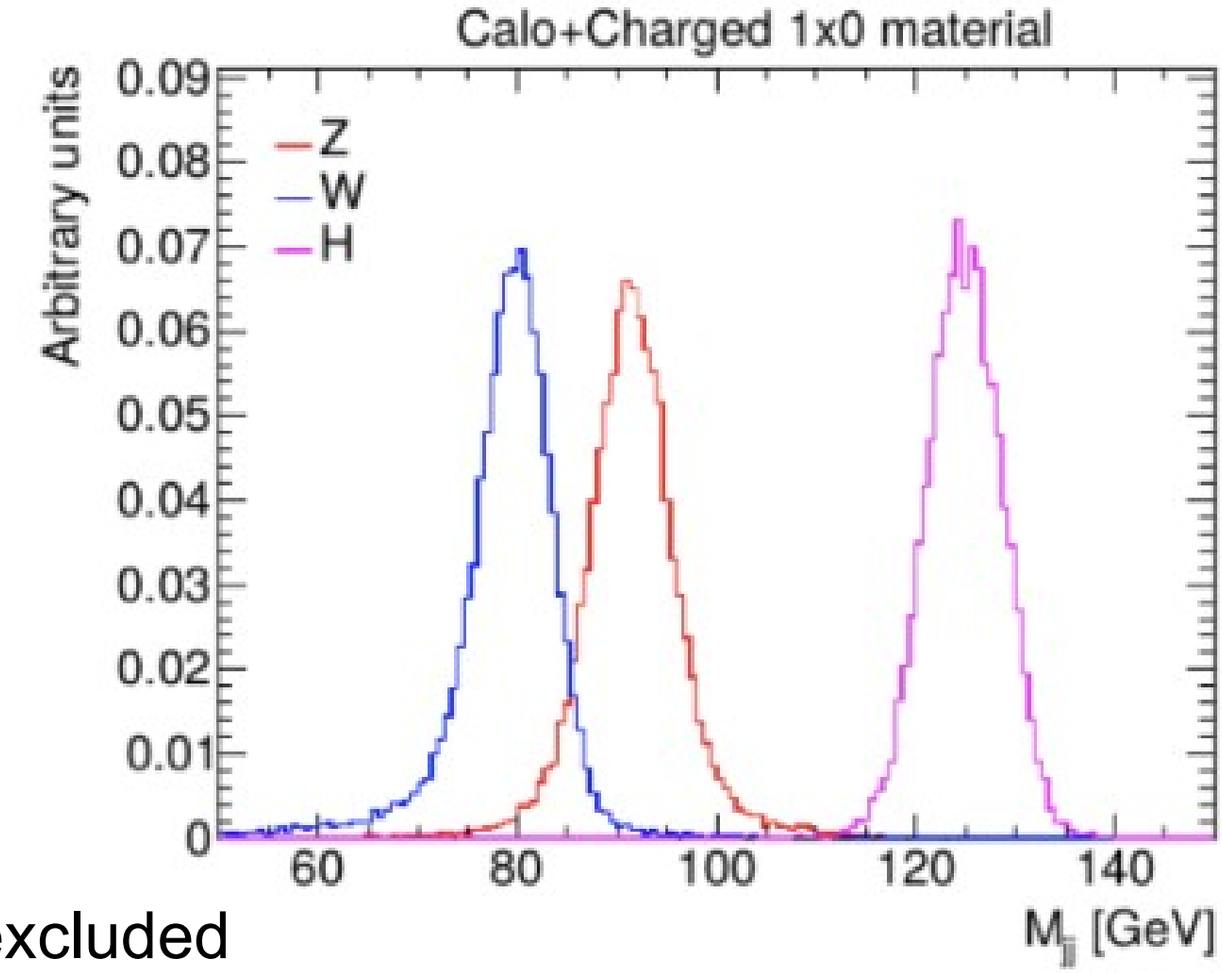
# Commercial information

Physics benchmarks: 2-jet final states

$$e^+e^- \to HZ \to \tilde{\chi}^0\tilde{\chi}^0 jj$$

$$e^+e^- \to WW \to \nu_\mu \mu jj$$

$$e^+e^- \to HZ \to bb\nu\nu$$




semi-leptonic decays of heavy quarks excluded

# Project organisation

P.I.: Roberto Ferrari (PV)

WP 1: Mechanics and fibre characterisation (MI, PI, PV)
Responsible: G. Gaudio (PV)

WP 2: Light sensors (analog and digital SiPMs) (BO, CT, MI, TIFPA)
Responsible: M. Caccia (MI)

WP 3: FEE and DAQ development (BO, CT, MI, PV, TIFPA)
Responsible: R. Santoro (MI)

WP 4: Performance assessment (MI, PV, RM1)
Responsible: G. Polesello (PV)

# Groups and personpower

7 INFN departments (BO, CT, MI, PI, PV, RM1, TIFPA)

External firms: CAEN, FBK

| RU | FTE and Number of people (without AdR requests) | | | | | | FTE and Number of people (with AdR requests) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2022 | | 2023 | | 2024 | | 2022 | | 2023 | | 2024 | |
| | FTE | People | FTE | People | FTE | People | FTE | People | FTE | People | FTE | People |
| **Bologna** | 1,3 | 5 | 1,3 | 5 | 1,3 | 5 | 2,3 | 6 | 2,3 | 6 | 1,3 | 5 |
| **Catania** | 0,7 | 3 | 0,7 | 3 | 0,7 | 3 | 0,7 | 3 | 1,7 | 4 | 0,7 | 3 |
| **Milano** | 1 | 3 | 1 | 3 | 1 | 3 | 1 | 3 | 2 | 4 | 2 | 4 |
| **Pavia** | 3,3 | 9 | 3,3 | 9 | 3,3 | 9 | 3,8 | 9,5 | 4,3 | 10 | 3,8 | 9,6 |
| **Pisa** | 0,8 | 4 | 0,8 | 4 | 0,8 | 4 | 0,8 | 4 | 1,8 | 5 | 1,8 | 5 |
| **Roma 1** | 0,2 | 1 | 0,2 | 1 | 0,2 | 1 | 1,2 | 2 | 1,2 | 2 | 0,2 | 1 |
| **TIFPA** | 1,2 | 3 | 1,2 | 3 | 1,2 | 3 | 1,2 | 3 | 1,2 | 3 | 1,2 | 3 |
| **Total** | 8,5 | 28 | 8,5 | 28 | 8,5 | 28 | 11 | 30,5 | 14,5 | 34 | 11 | 30,6 |

Table 1.3.1. Summary of FTE per each RU during the 3 years of the project.

# International collaborators

Already (or just starting) collaborating:

UK: University of Sussex

S. Korea: Kyungpook National Univ., Seoul National Univ, Univ. of Seoul, Yonsei Univ.

Chile: Univ. Tecnica Federico Santa Maria (Valparaiso)

US: Univ. of Maryland, Texas Tech Univ., Princeton Univ.

GEANT4 Collaboration

Crystal Clear Collaboration

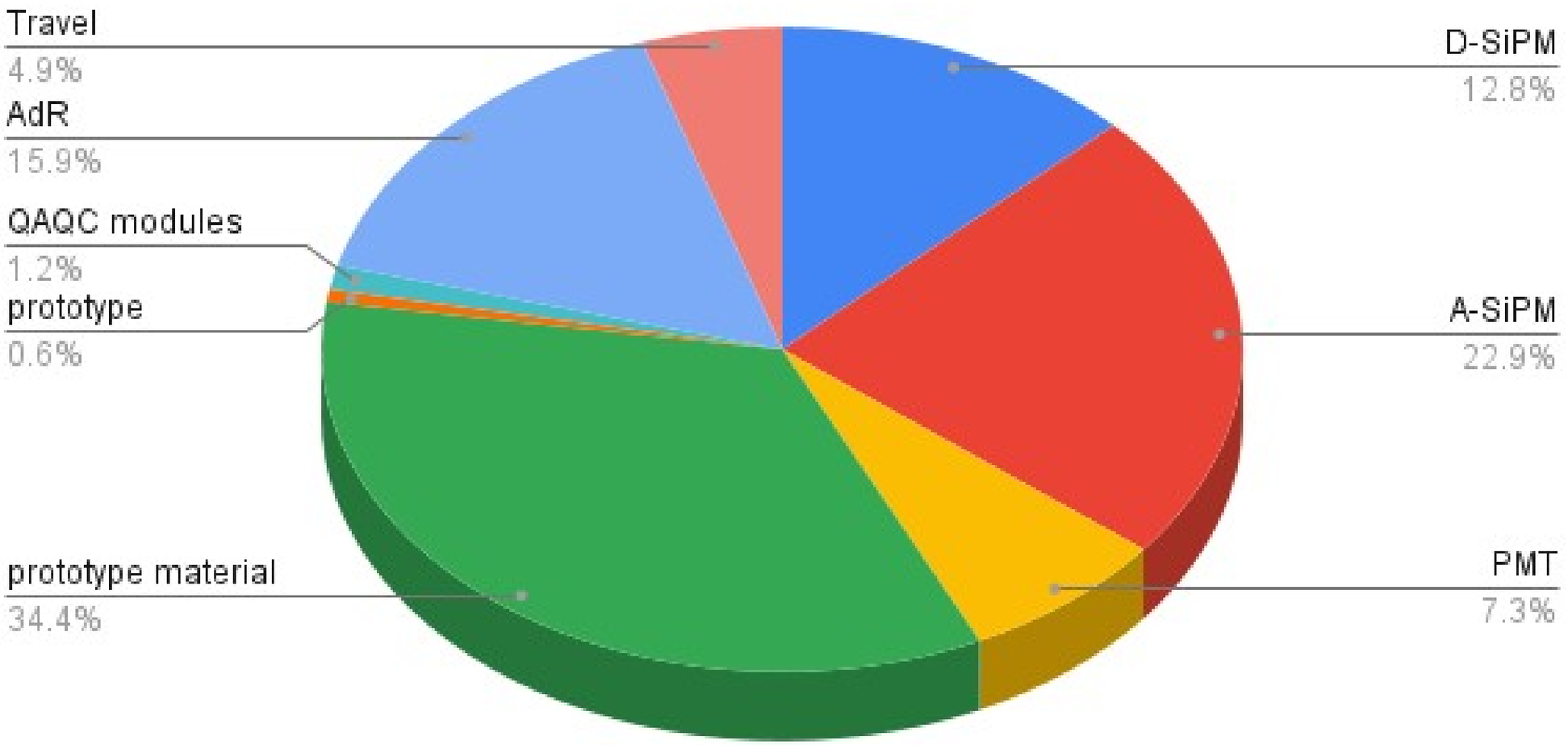
Interested for LHC upgrades: ALICE FOCAL group, LHCb calo group

# Pavia group

| Researcher | RU | FTE |
|---|---|---|
| G. Gaudio | PV | 20% |
| J. Agarwala | PV | 30% |
| R. Ferrari | PV | 50% |
| A. Negri | PV | 10% |
| G. Polesello | PV | 20% |
| S. Sottocornola | PV | 20% |
| L. Ratti | PV | 30% |
| C. Vacchi | PV | 50% |
| G. Torilla | PV | 100% |
| AdR (50% on project funds) | PV | 67% |
| | FTE | 4 |

# Funding requests

## Total request: 985.5 k€ (dominated by M&S)



# Funding requests

Total request: 985.5 k€ (dominated by M&S)

| | | BO | CT | MI | PV | PI | RM1 | TIFPA | Total |
|---|---|---|---|---|---|---|---|---|---|
| 2022 | M&S | 35 | 10 | 88.3 | 19 | 45 | | 38 | 235.3 |
| | PostDoc | 12.5 | | | 7.5 | | 12.5 | | 32.5 |
| | Travel | 1 | 0.9 | 1 | 5 | 0.8 | 0.3 | 1.2 | 10.2 |
| 2023 | M&S | 40 | | 73 | 76 | 152 | | 28 | 369 |
| | PostDoc | 12.5 | 12.5 | 19 | 16 | 12.5 | 12.5 | | 85 |
| | Travel | 1.4 | 0.9 | 1 | 5 | 0.8 | 0.3 | 1.2 | 10.6 |
| 2024 | M&S | 35 | | 4 | 43.6 | 93.6 | | | 176.2 |
| | PostDoc | | | 19 | 7.5 | 12.5 | | | 39 |
| | Travel | 4.1 | 1.7 | 3 | 12.5 | 2.4 | 0.4 | 3.6 | 27.7 |
| Total | M&S | 110 | 10 | 165.3 | 138.6 | 290.6 | 0 | 66 | 780.5 |
| | PostDoc | 25 | 12.5 | 38 | 31 | 25 | 25 | 0 | 156.5 |
| | Travel | 6.5 | 3.5 | 5 | 22.5 | 4 | 1 | 6 | 48.5 |
| Grand total | | 141.5 | 26 | 208.3 | 192.1 | 319.6 | 26 | 72 | 985.5 |

# External funding

AIDAinnova proposal

40 k€ → PV
30 k€ → CAEN
40 k€ → Sussex University

mainly for hiring people (post-doc)

S. Korea: large funding for a 5-year project (projective hadronic prototype)

US: (minimal) starting grant approved

Funding requests submitted in Chile and in UK

# Very rough time profile

Y 1 : R&D → identify solutions

Y 2 & 3 : prototype construction and (finally) qualification with beam

# Richieste servizi (Pavia)

Officina meccanica: 5 m.u. / anno

Elettronica: 5 m.u. / anno

# Summary

R&D still needed to assess DR performance and reach a "production level" maturity

3 years to build and test a hadronic-containment prototype

Main technical issues:
- mechanical construction
- readout complexity

Highly prospective R&D on digital SiPMs

Collaboration growing (including DR crystal option) …

Plan B: continue R&D within RD_FCC & AIDAinnova in CSN I
(but dropping dSiPM package)