IDEA Dual Readout Calorimetry

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on behalf of the IDEA Dualreadout Calorimeter Group

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The HiDRa2 Dual readout Calorimeter

"Traditional" Calorimetry

- ❖ Response of EM and non-EM components is different ($e/h \neq 1$)
- ❖ The energy fraction of the EM component (f_{em}) has a non Gaussian distribution and it increases with energy.
- ❖ Fluctuations are large
- ❖ The response is not linear with energy
- ❖ Compensation ($e/h = 1$) solves a part of the problems but it requires small sampling fraction ⇒ poor EM resolution

High-resolution EM and high-resolution Hadronic calorimetry are mutually exclusive

The dual readout strategy in fibre sampling calorimeters

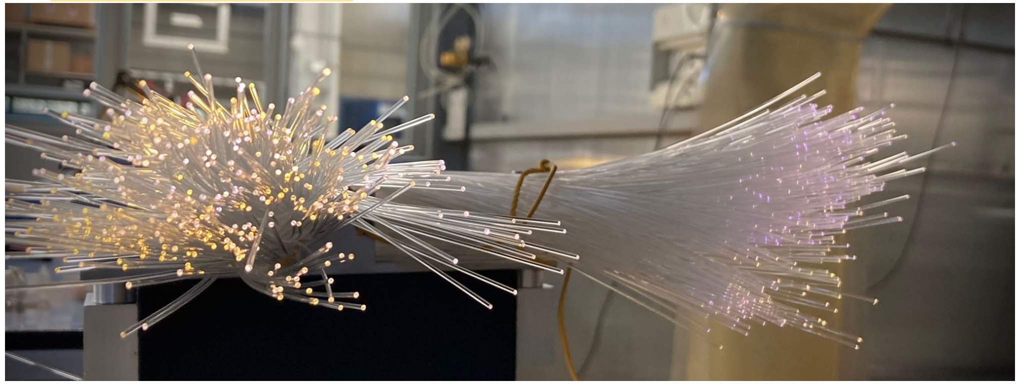
It is possible to measure, event by event, f_{em} by means of two signals:

- ❑ Cherenkov light produced by relativistic particles, dominated by EM components ("clear" fibres)
- ❑ Scintillation light produced by "dE/dx" (scintillating fibres)

The HiDRa2 Dual readout Calorimeter

- **Absorbers:** stainless steel capillaries
  2 mm O.D. - 1.1 mm I.D.

- **Detectors**
  - Scintillating Ø 1 mm fibres (sensitivity to all particles) → Total dep. energy
  - "Clear" Ø 1 mm fibres (sensitivity to Cherenkov light) → EM shower

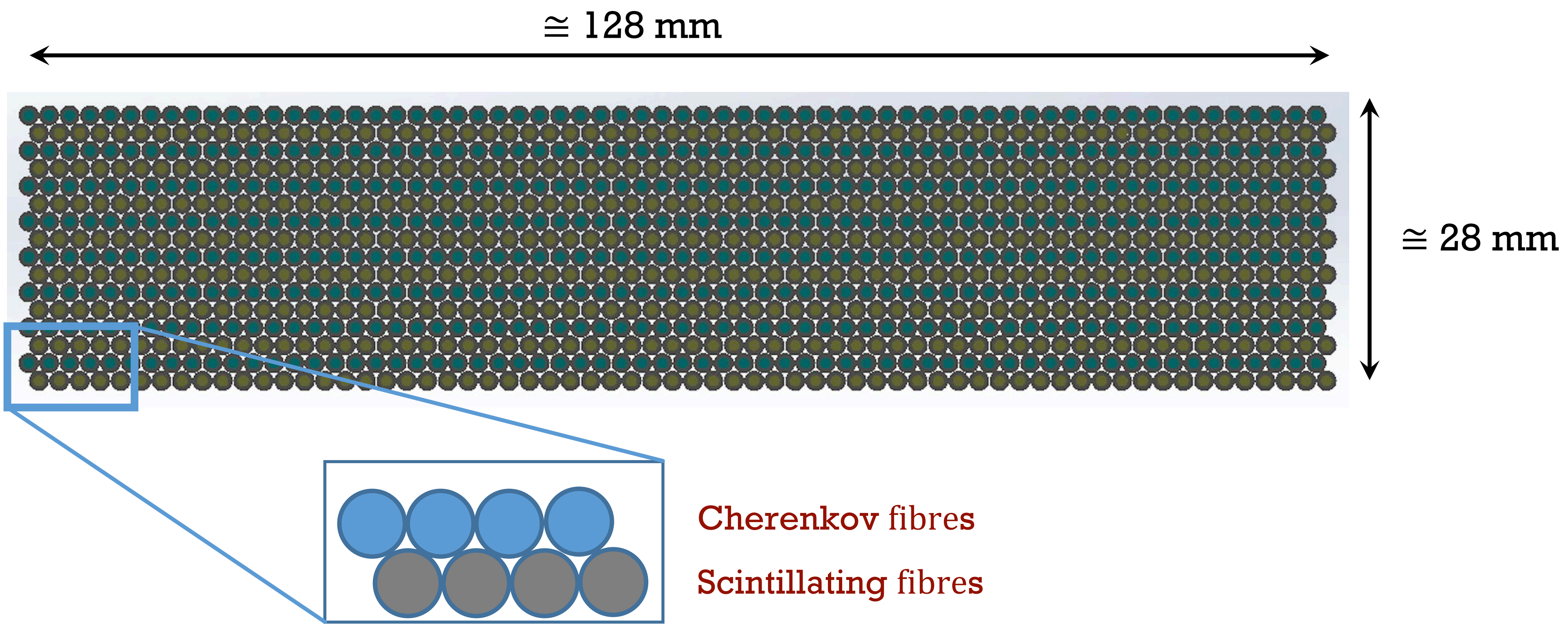


Requirements/goals

- Hadronic resolution $\lesssim \frac{30\%}{\sqrt{E}}$
- EM resolution $\cong \frac{10\%}{\sqrt{E}}$

Geometry of the HiDRa2 Calorimeter

The Minimodule 64 x 16 capillaries: 128 mm x 28 mm x 2.5 m



Geometry of the HiDRa2 Calorimeter

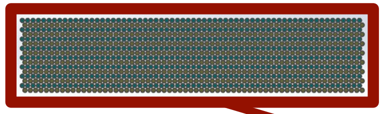
The Minimodule 64 x 16 capillaries: 128 mm x 28 mm x 2.5 m

Pavia

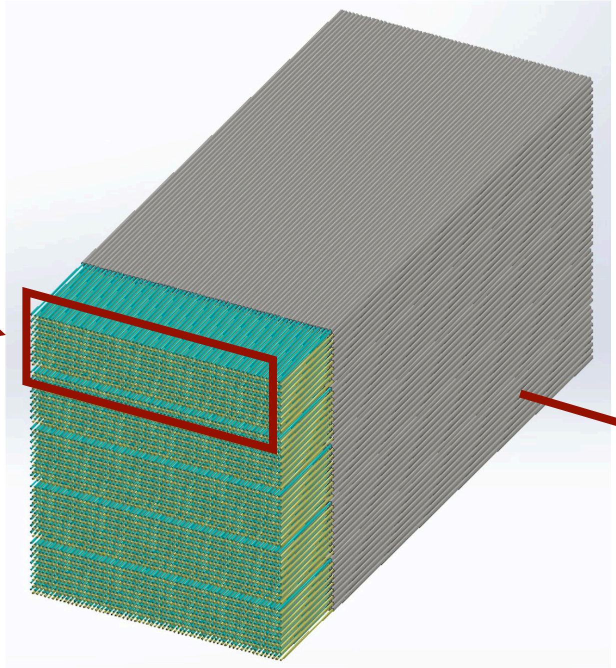
- Assembly
- QAQC
- Preliminary tests
- Mechanics

Geometry of the HiDRa2 Calorimeter

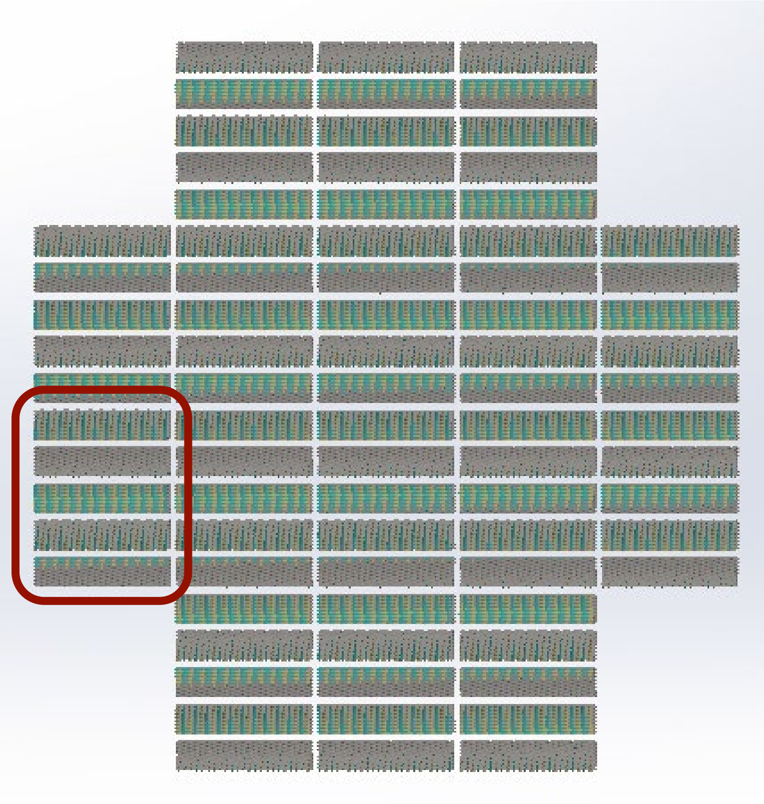
Minimodule
128 mm x 28 mm



5 Minimodules=1 Module
128 mm x 140 mm



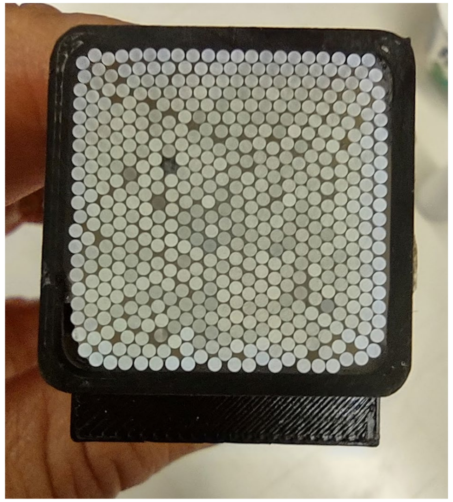
16 Modules
640 mm x 560 mm
81920 tubes/fibres



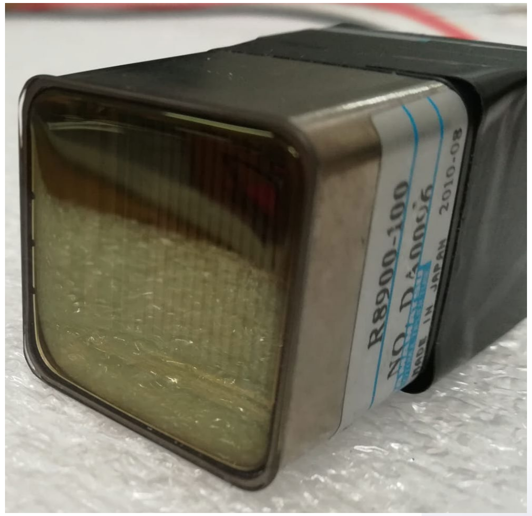
Photodetectors

Outer shell: Each Minimodule is readout by 2 **PMTs** (one for Cherenkov and one for scintillation)
Bundle of fibres 23 x 23 mm

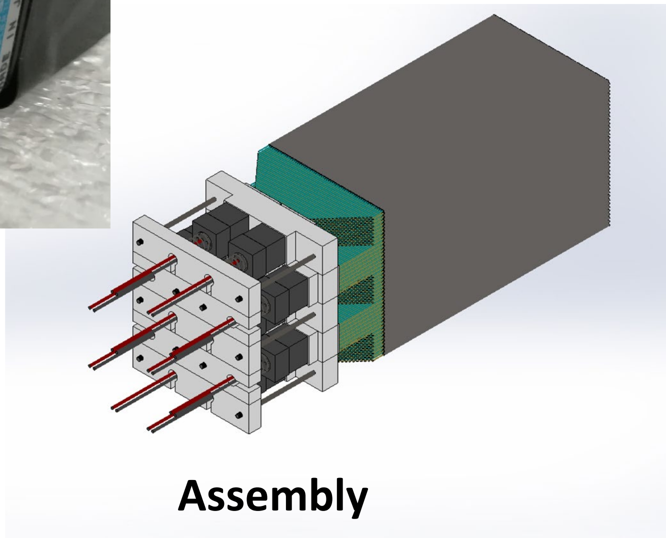
High granularity core: fibres individually readout by **SiPMs**



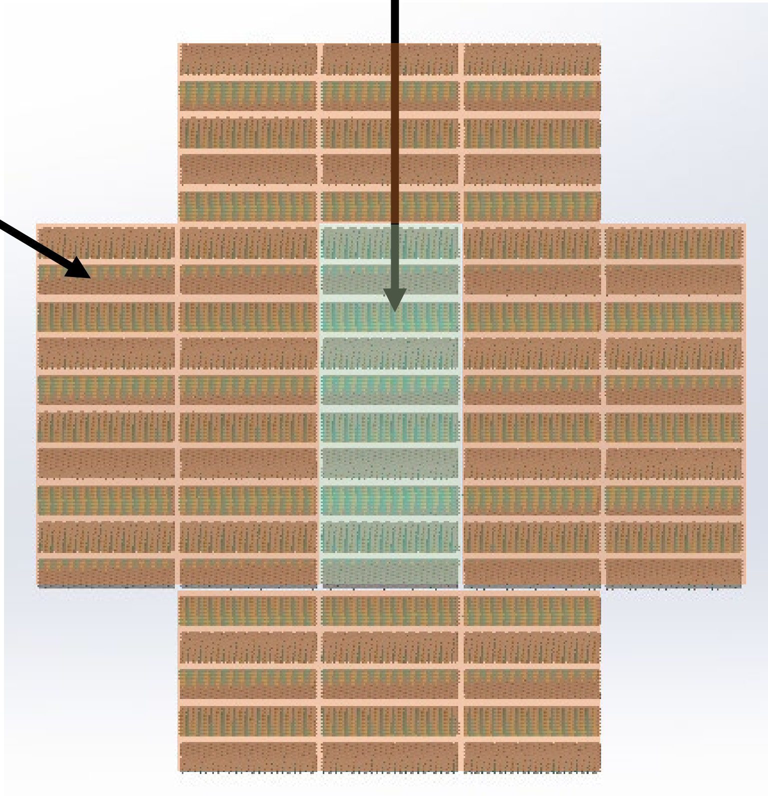
Bundle



PMT



Assembly



Photodetectors/PMTs

INFN Istituto Nazionale di Fisica Nucleare

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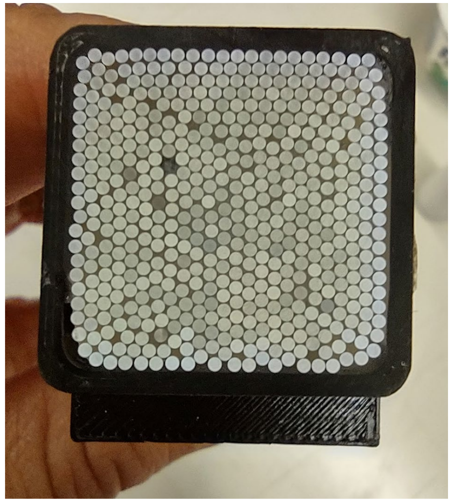

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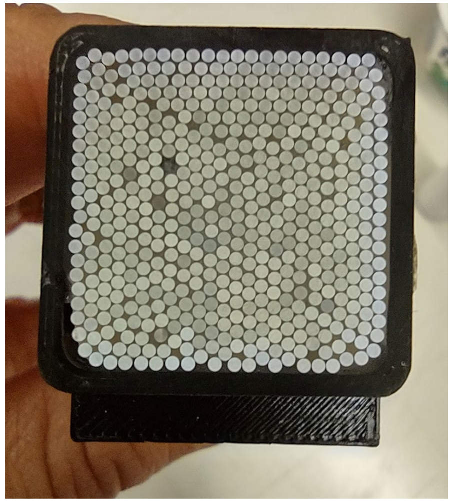
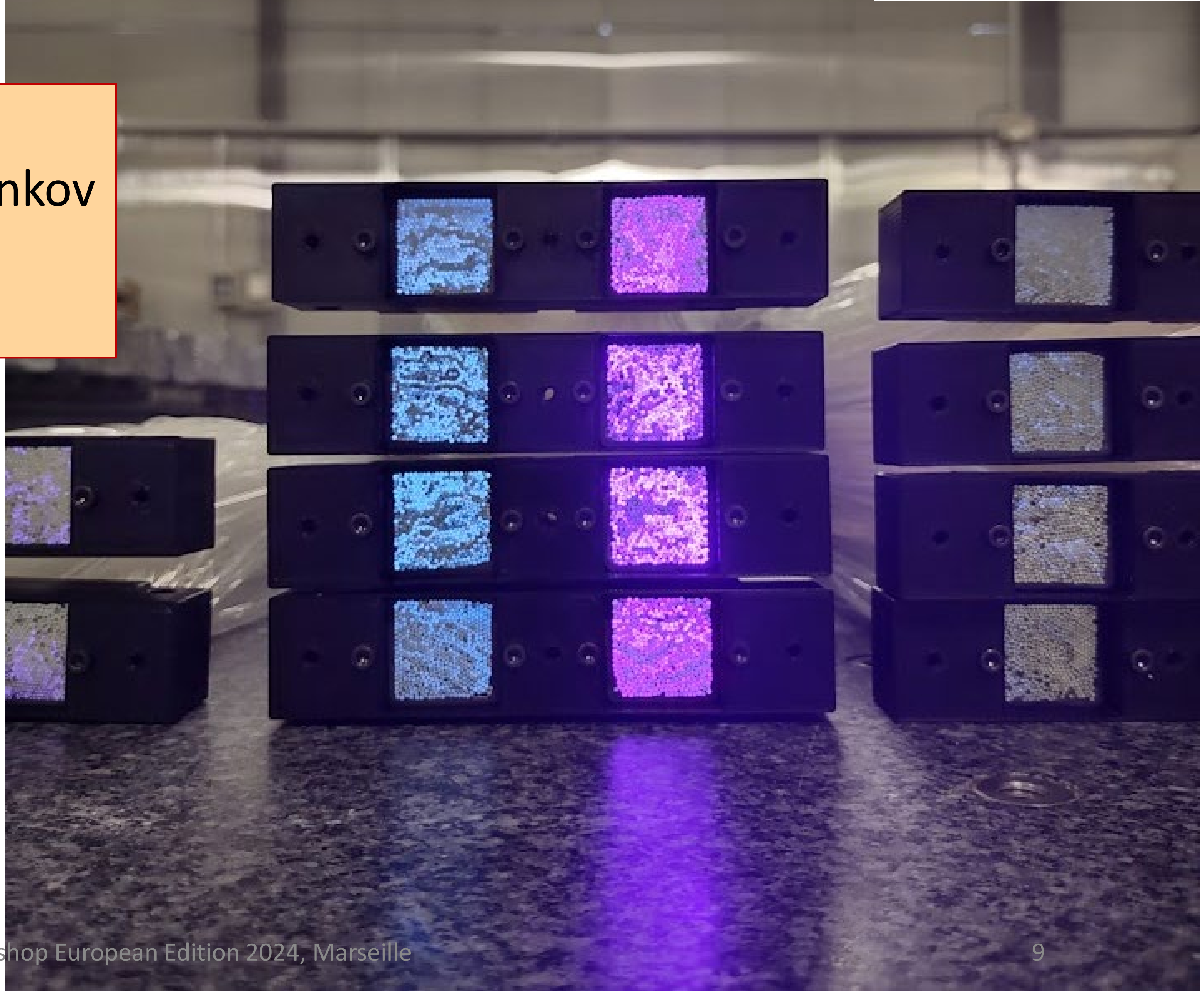
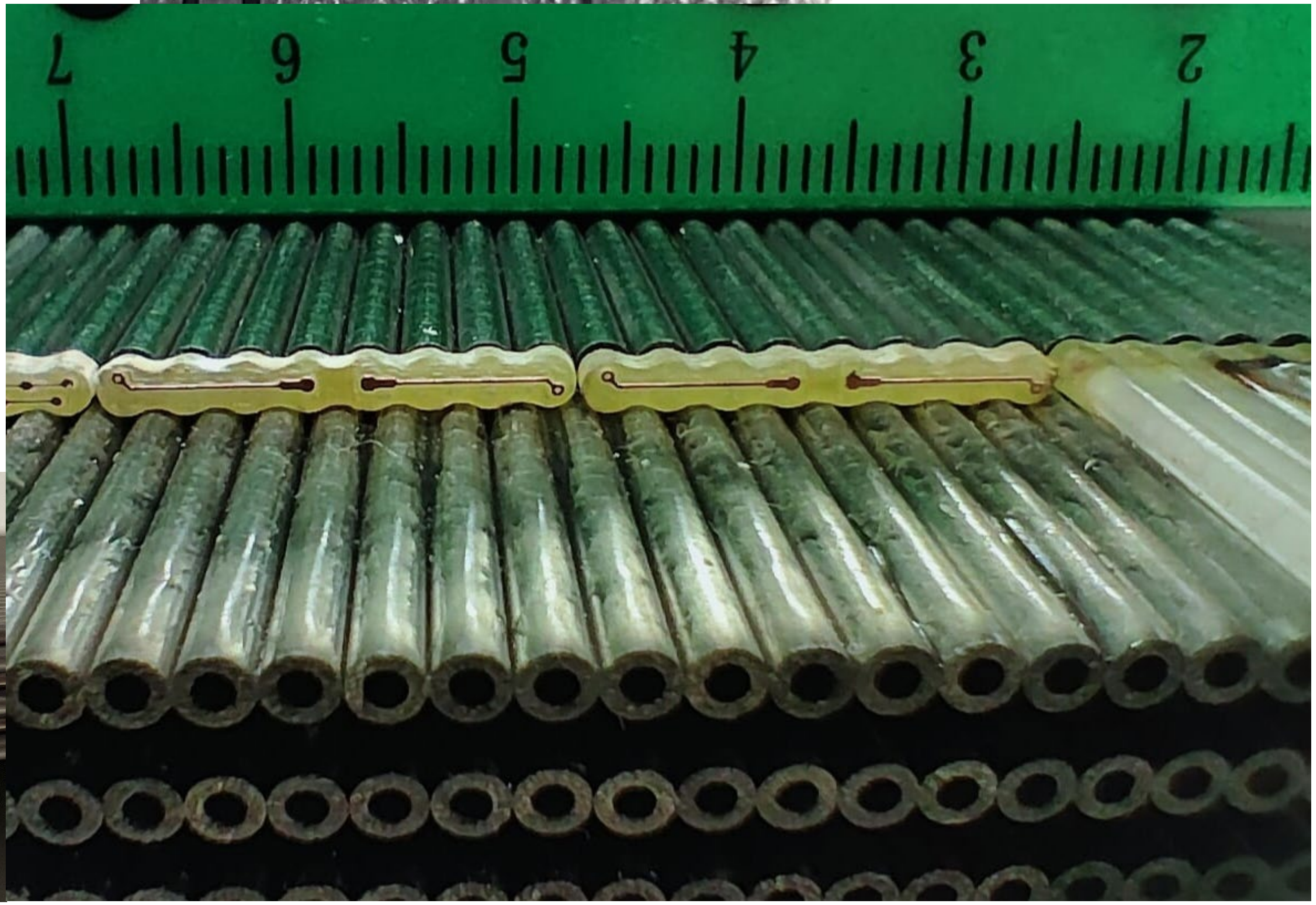
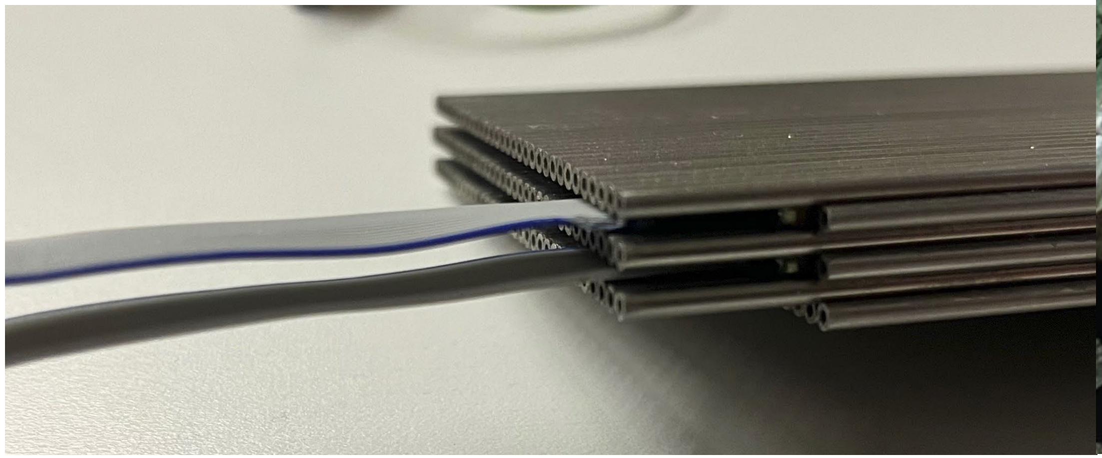




Photodetectors/SiPMs

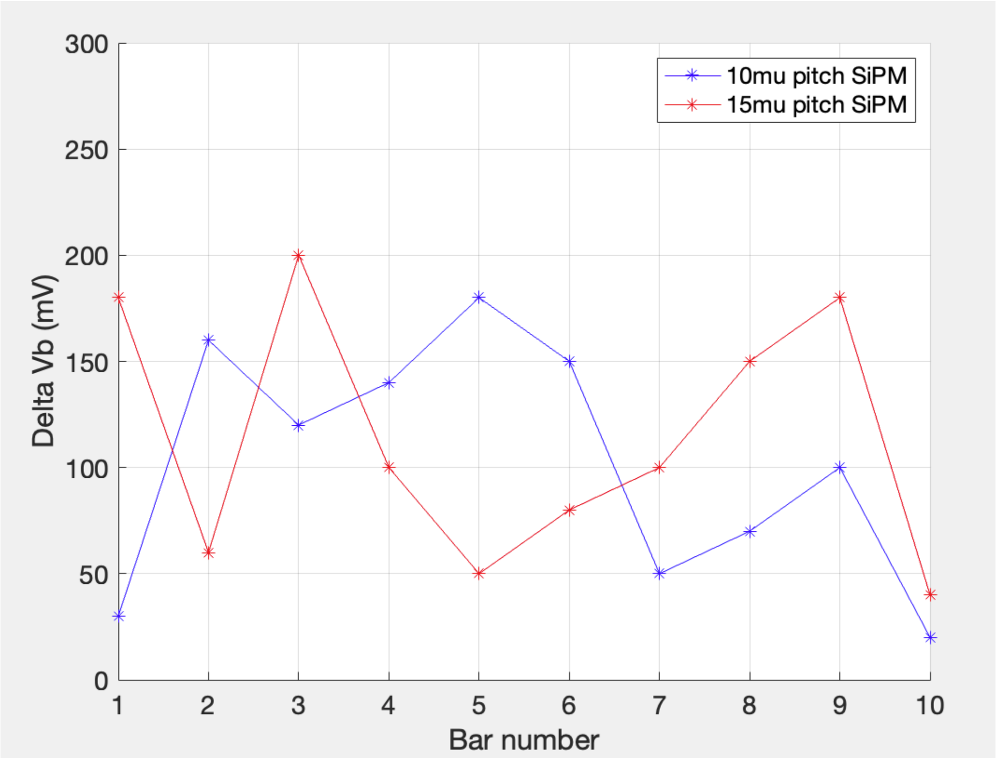
INFN Milano (UniMi & UnInsubria)

- Bar of SiPMs, prototype characterization
- Grouping
- Studies on cabling and integration

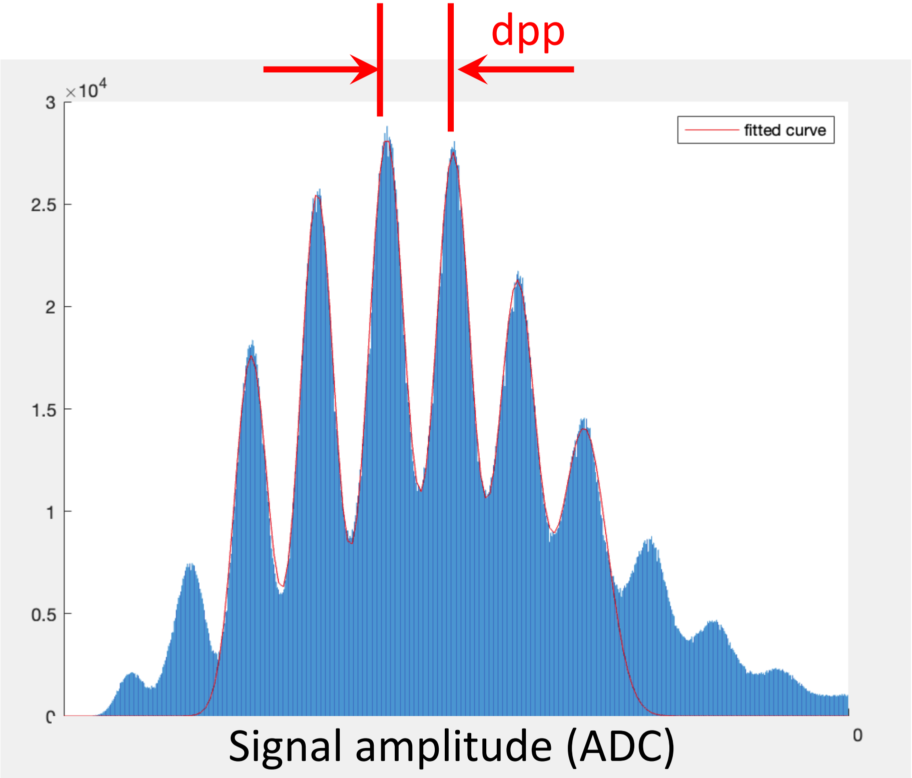




Photodetectors/SiPMs

- **Bar of SiPMs**, delivered by Hamamatsu
  - 10 μm pitch for scintillating fibres (better dynamic range)
  - 15 μm pitch for Cherenkov fibres (higher PDE compensates lower light yield)
  - $\Delta V_b < 200$ mV



ΔV_b for different SiPM bars



Typical SiPM spectrum with LED source
15 μm pitch , V_b=43 V

High precision EM calorimetry: the crystal option

Milano Bicocca, Napoli, CERN, IN2P3-IP2I, CALVISION

- **Context**
  - High EM energy resolution improves event reconstruction and expands the physics studies at e^+e^- colliders
  - Actual EM resolution $\begin{cases} 1-3\%/\sqrt{E} & \text{(homogeneous)} \\ 10-15\%/\sqrt{E} & \text{(sampling)} \end{cases}$

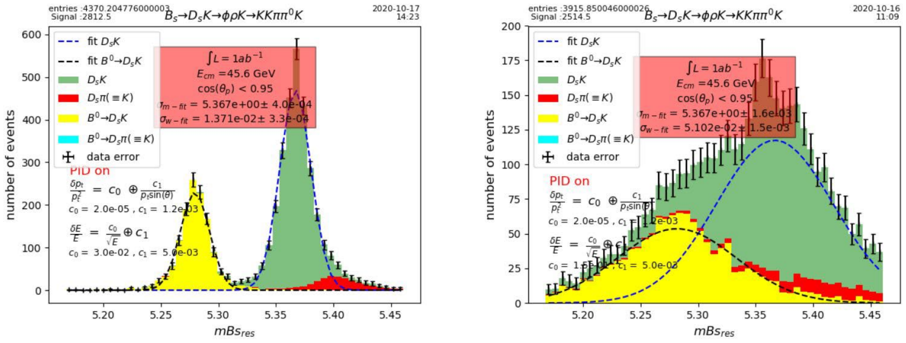
Adding high density crystals with dual readout:

1. boosts EM resolution at $3\%/\sqrt{E}$
2. preserves hadronic resolution

M. Lucchini et al [1] and [2]

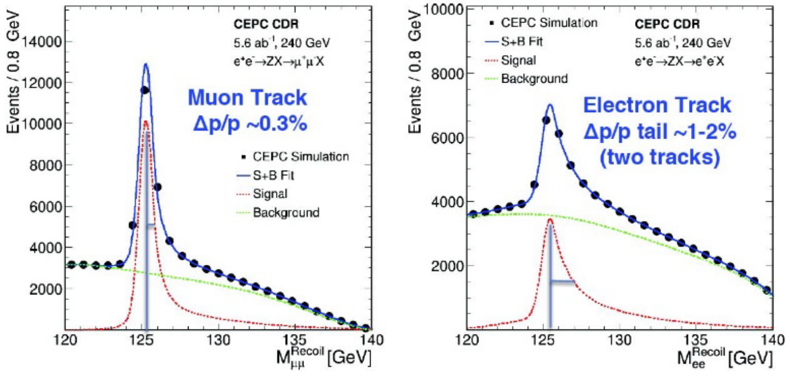
CP violation studies with B_s decay

$\frac{\delta E}{E} = \frac{0.03}{\sqrt{E}} \oplus 0.005$ $\qquad$ $\frac{\delta E}{E} = \frac{0.15}{\sqrt{E}} \oplus 0.005$



Improve the resolution of the recoil mass signal from Z→ee decays

- Z→μ+μ− Recoil
- Z→e+e− Recoil



High precision EM calorimetry: the crystal option

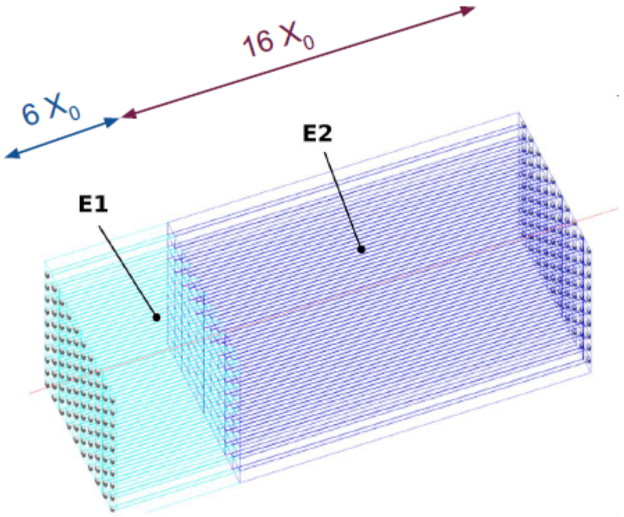
M. Lucchini

Istituto Nazionale di Fisica Nucleare

Conceptual layout:
key design features

Crystal candidates specs:

- good cherenkov radiators for dual-readout
- good calorimetric properties for compact shower development



PWO as baseline
density is comparable to iron / brass!

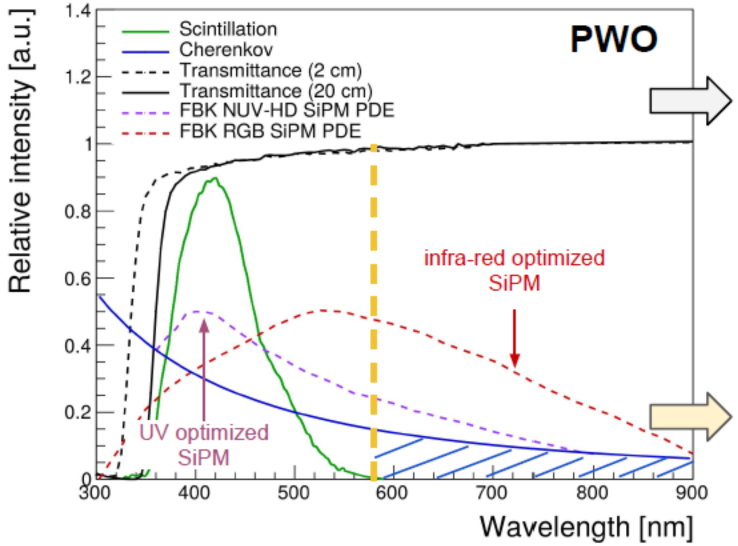
Crystal candidates								
Crystal	Density g/cm³	λ_I cm	X_0 cm	R_M cm	Total crystal length for $22X_0$	Refractive index, n	Relative LY @ RT	Decay time ns
PWO	8.3	20.9	0.89	2.00	19.6 cm	2.2	1	10
BGO	7.1	22.7	1.12	2.23	24.6 cm	2.15	70	300
BSO	6.8	23.4	1.15	2.33	25.3 cm	2.15	14	100

High precision EM calorimetry: the crystal option

M. Lucchini

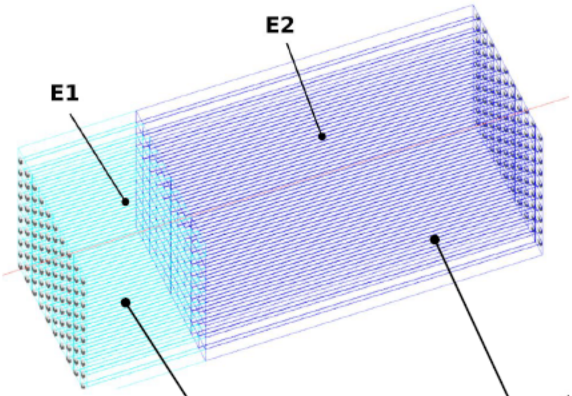
Conceptual layout:
key design features

<u>Dual-readout implementation</u>
Cost-effective SiPM readout
Optical filters for separation of
Cherenkov and scintillation signal from
the same active elements

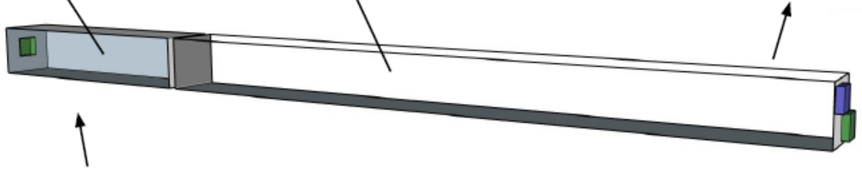


Estimated:
- >2000 phe/GeV for scintillation photons [dyn. range: 100-120,000 phe]
- >100 phe/GeV for Cherenkov photons [dyn. range: 10-10,000 phe]

Cherenkov photons above scintillation peak are much less affected by elf-absorption



Rear crystal ECAL segment:
Two 4x4 mm² SiPMs with optical filters optimized for scintillation (10 µm cell size) and Cherenkov (40 µm cell size) detection



Front crystal ECAL segment:
Single 5x5 mm² SiPM per crystal optimized for scintillation light detection (10 µm cell size)

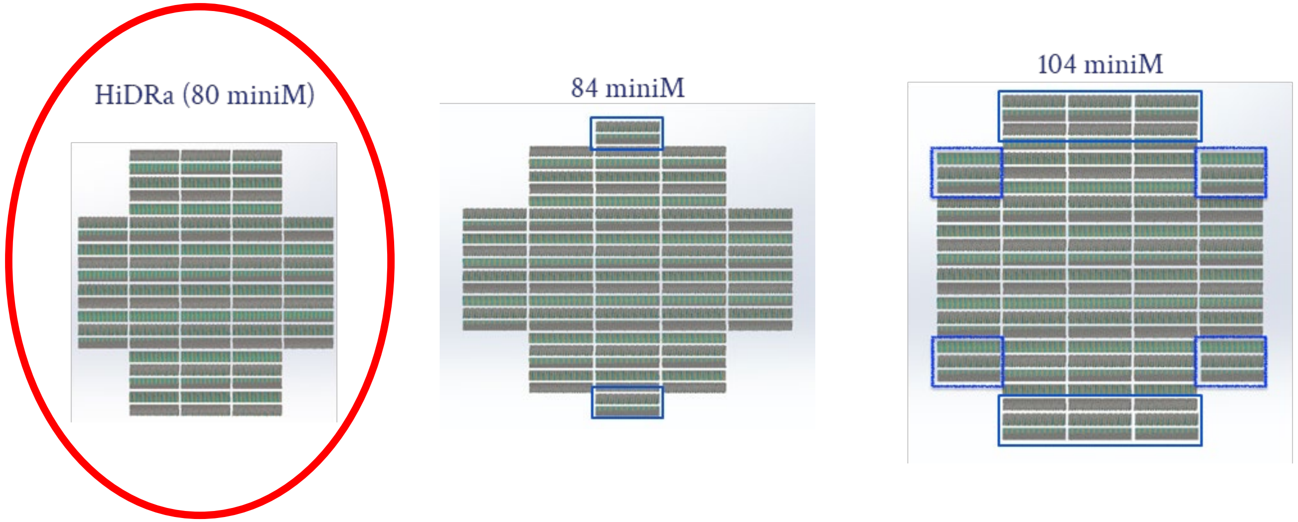
Simulations and Physics studies

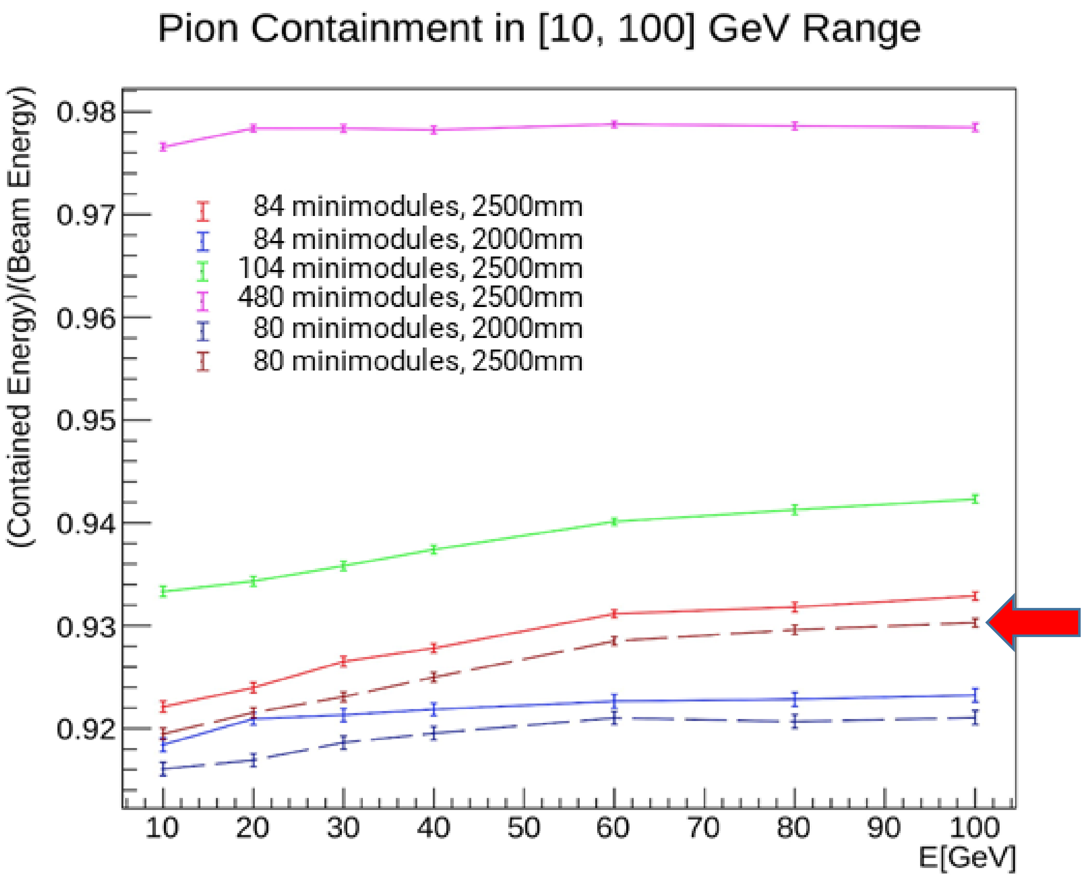
- Detector simulations
  - Optimization of the design, containment
  - Performances: linearity, energy and spatial resolution
  - Crystal option

Simulations and Physics studies

- Detector simulations (Pavia)
  - Optimization of the design, containment

Change number of mini modules and their length in the simulation to study the energy leakage outside detector volume



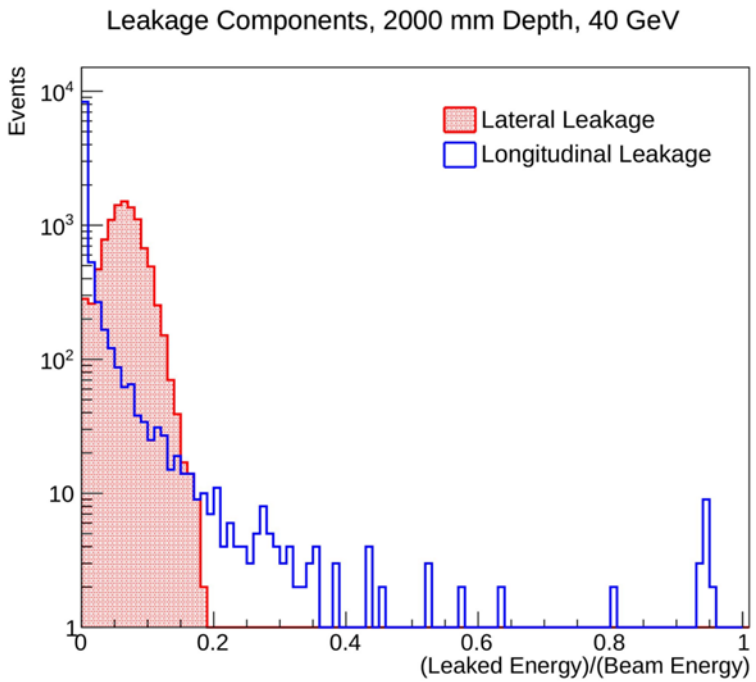


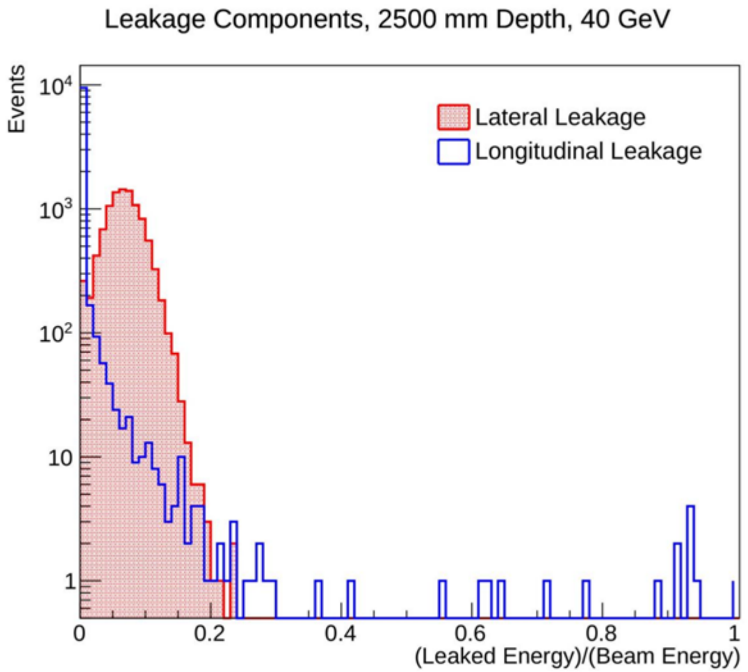
Simulations and Physics studies

- **Detector simulations** (Pavia)
  - Optimization of the design, containment

Change number of mini modules and their length in the simulation to study the energy leakage outside detector volume

- Lateral leakage has major impact on energy resolution
- Longitudinal leakage leads to low-reconstructed-energy events





Simulations and Physics studies

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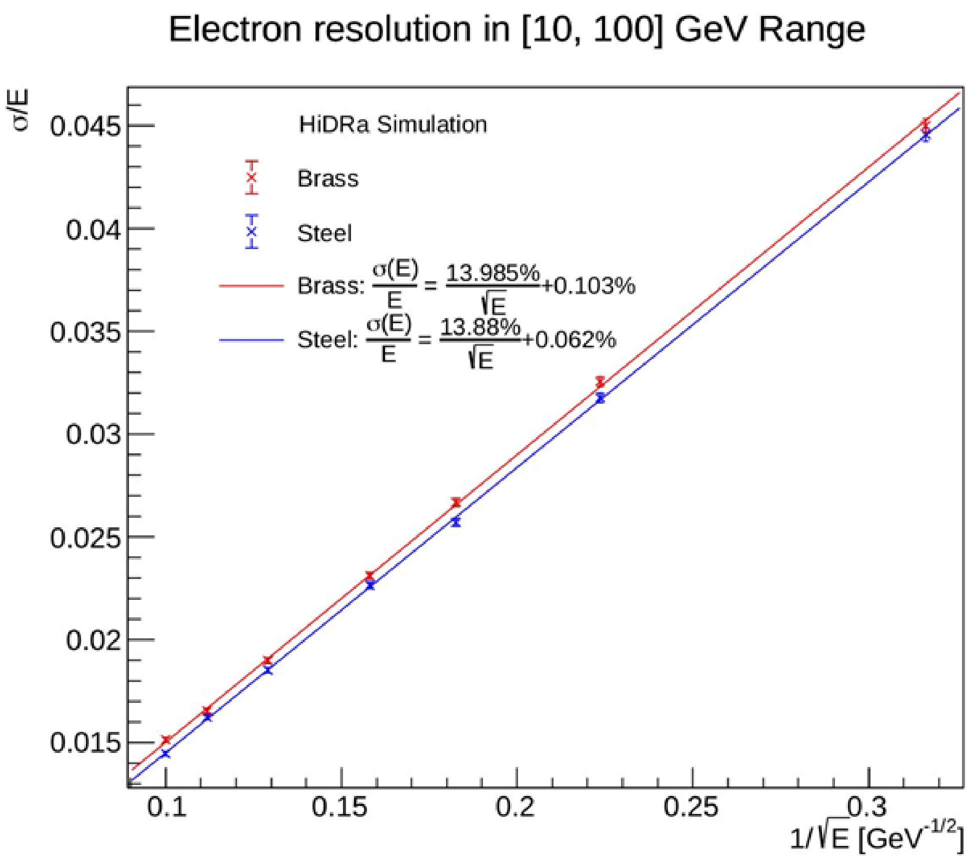
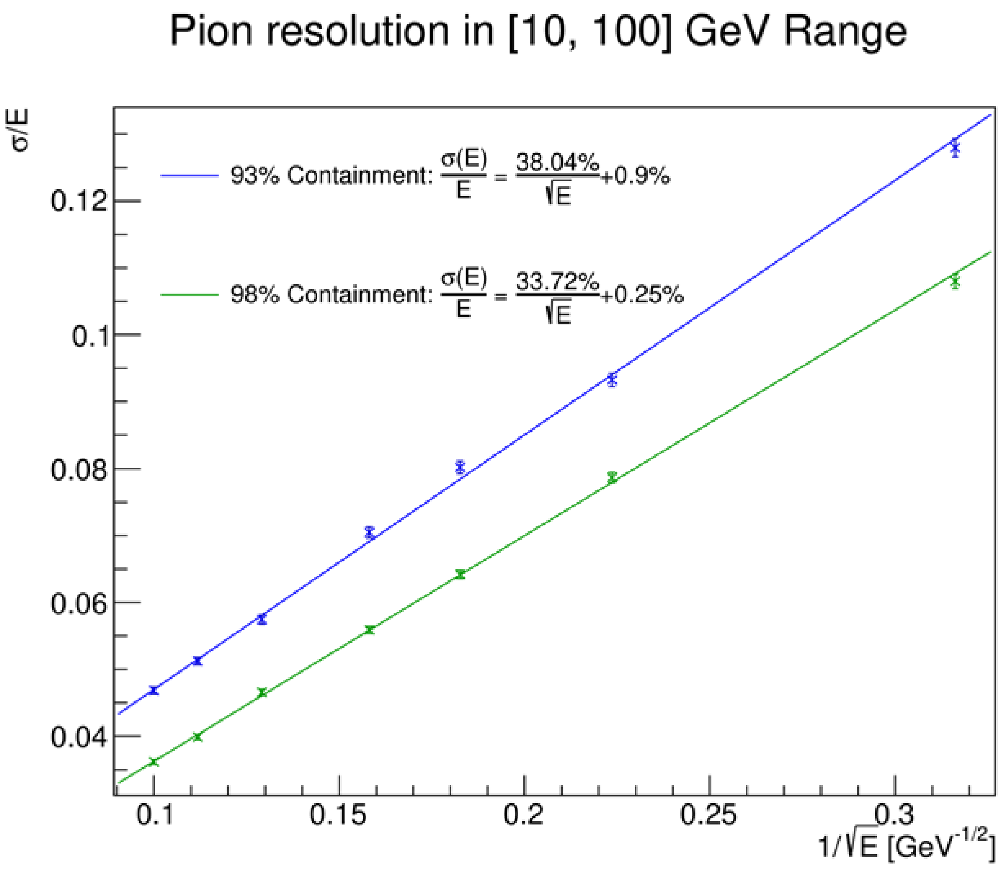
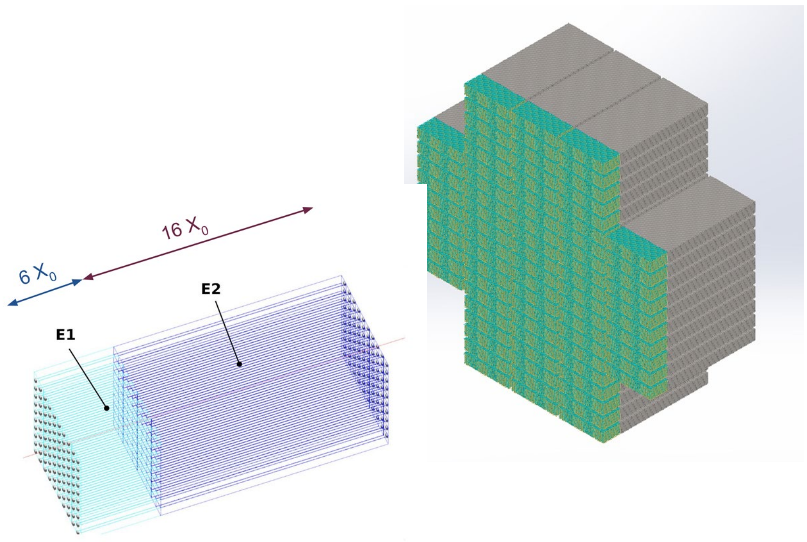


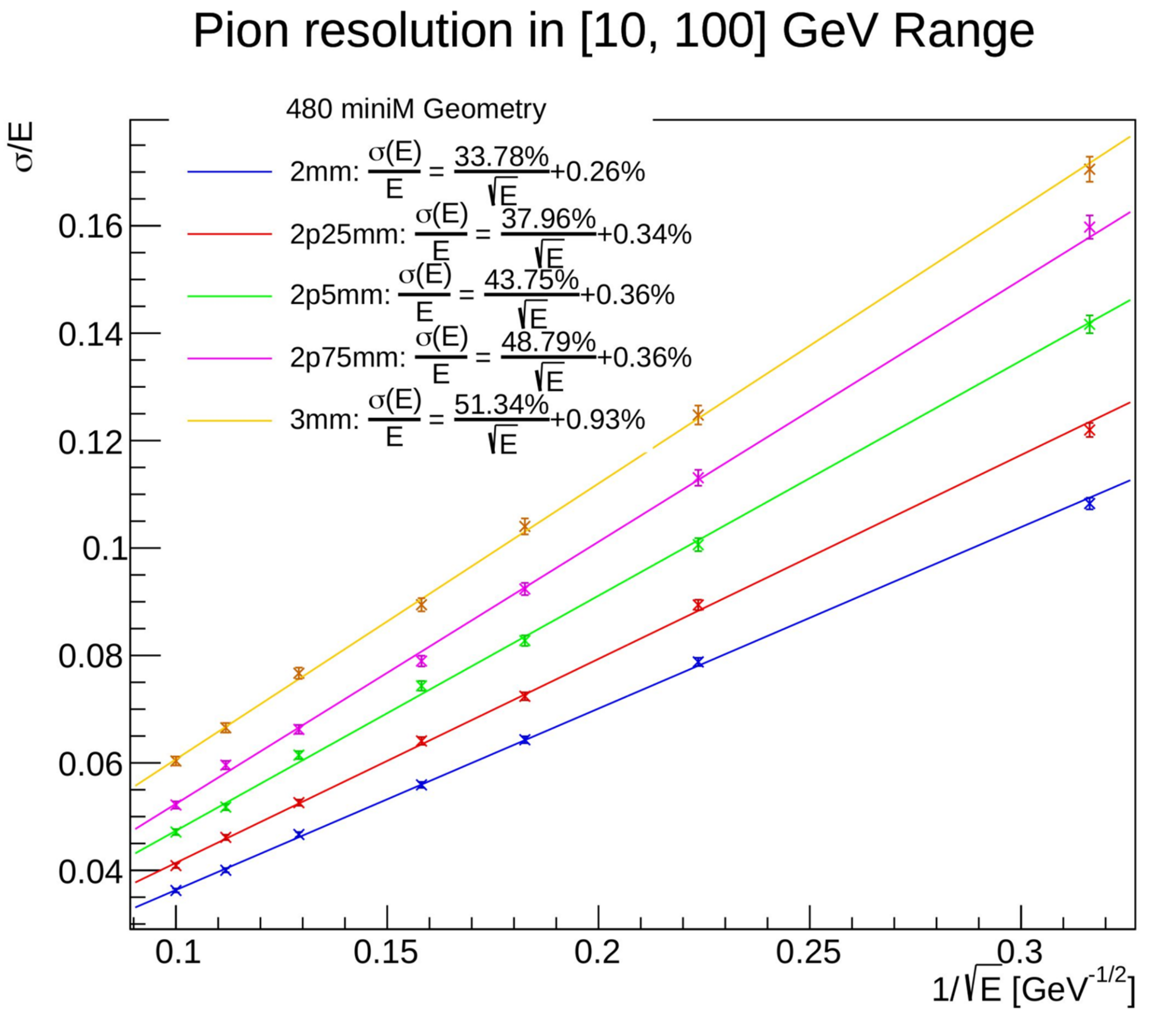


Simulations and Physics studies

- Detector simulations
  - Crystal option

Reduce number of fibres and channels to reduce cost
Increase capillary tubes outer diameter (2mm → 3mm)





Summary and activity 2024

A lot of progress both in hardware and simulation

- ❑ 20 out of 80 Mini modules have been assembled up to now
- ❑ Several simulations are ongoing
- ❑ Studies for SiPMs prototyping and integration are underway
- ❑ Studies for the crystal option are underway
- ❑ A test beam at CERN with ≈ half detector is foreseen in the summer