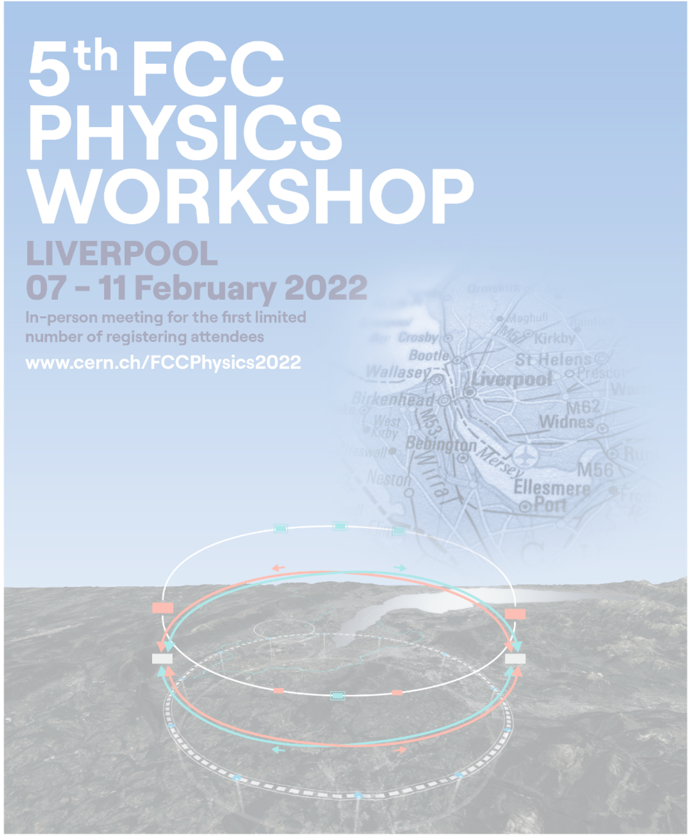
Credits: H. Yoo, L.Pezzotti, G. Polesello, R. Santoro,

Istituto Nazionale di Fisica Nucleare



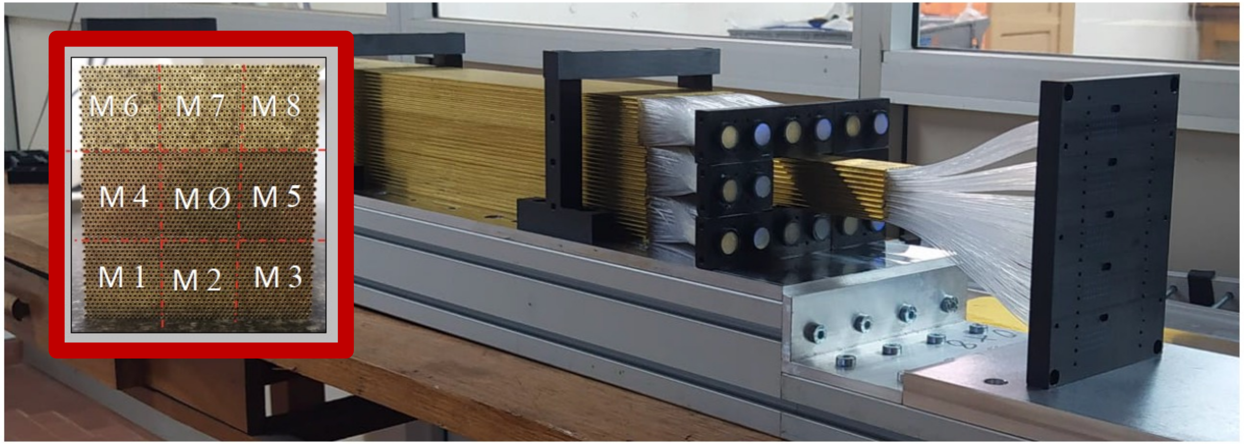
Test Beam Results and R&D Programme for a Highly Granular Fibre-Sampling Dual-Readout Calorimeter

Gabriella Gaudio

on behalf of the IDEA Dual-Readout Calorimeter Collaboration

February, 8th 2022

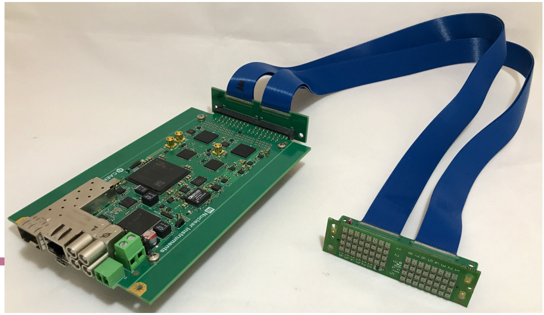
The 2021 test beam prototype



10x10 cm^2 divided in 9 towers, 1m long
16x20 capillary each (160 C + 160 S fibres)

Capillary:
2mm OD, 1.1 mm ID
Material: Brass

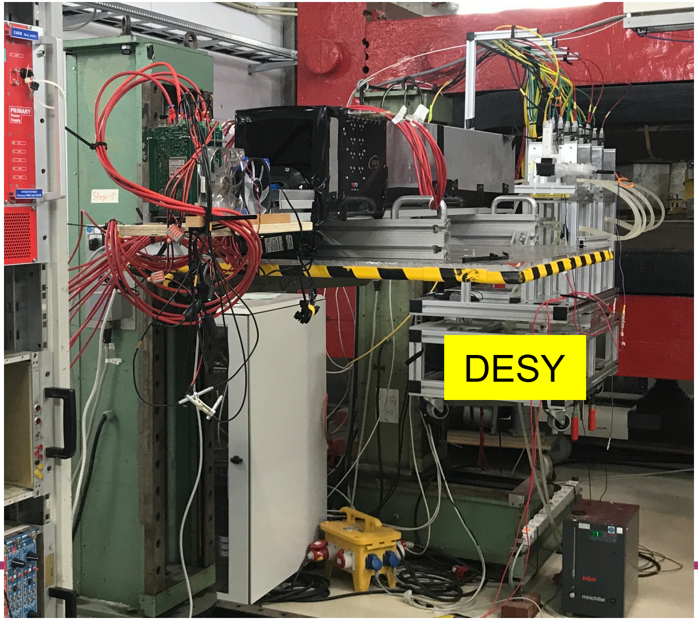
- Hi-quality commercially available capillary tubes
- Quite easy and fast assembly system
- Test the viability of this mechanical solution

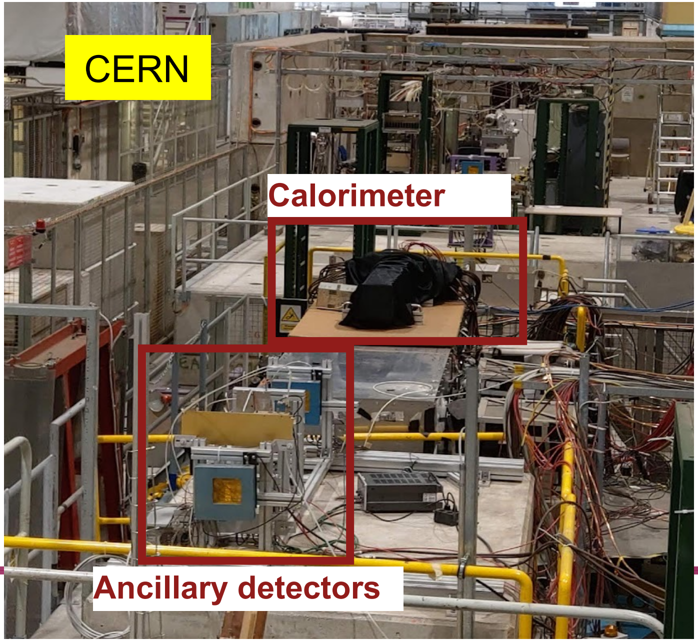


2021: DESY and CERN SPS beam test

- Energy and position scans 1-6 GeV e-
- Geant4 validation
- Timing information with large angle measurements

- e^+ with energy range 10 -125 GeV
  - Energy and position scan
  - e^+ beams highly affected by π contamination
- μ^+ in non-monochromatic beams





Data Handling and workflow

Indipendent acquisitions for SiPM and PMTs (+ auxiliaries)

Raw Data Handling

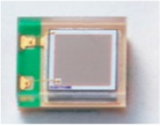
Raw ASCII Data as DAQ Output
for PMTs and auxiliaries

↓

Rootified raw data output
for PMTs and auxiliaries

Rootified raw data output for SiPMs

↑



.dat files as raw data output for SiPMs

Data Merging

Stored events from the two DAQs are synchronized by taking into account the random pedestal events and stored in a dedicated root merged file.

→

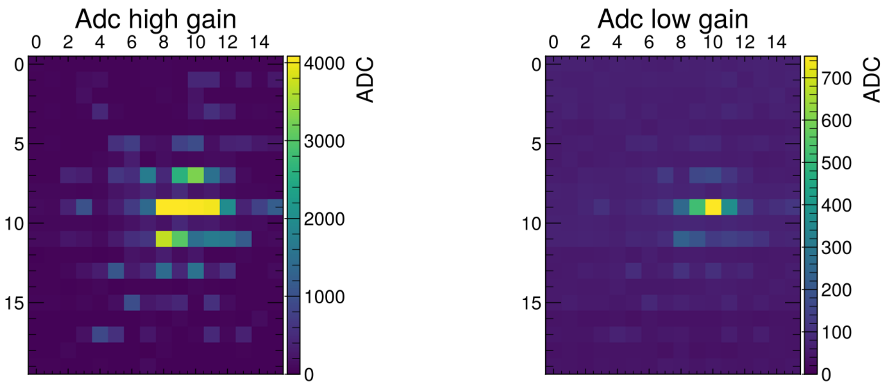
Calibration and High-Level Abstraction

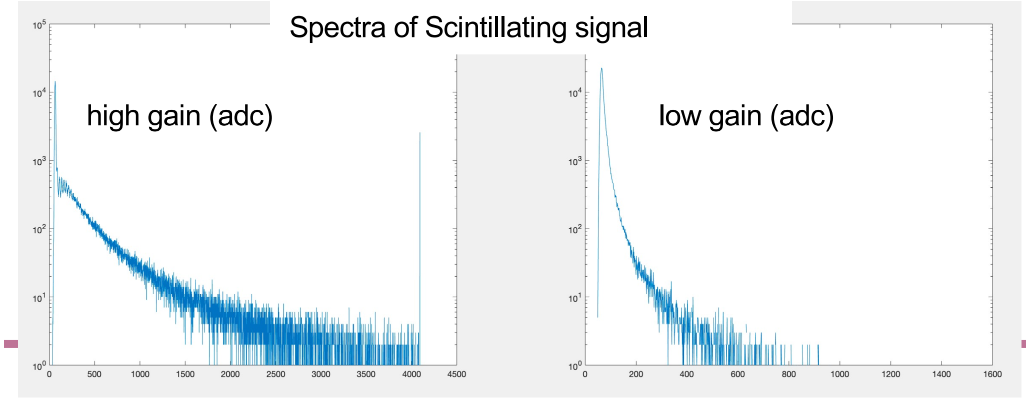
Calibration constants are applied for ADC to GeV conversion, final information is saved in a high-level-object (class) ready for analysis.

https://github.com/lopezzot/DREMTubes

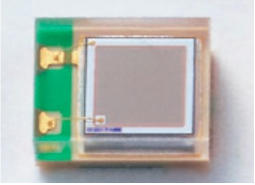
The impact of high granularity

(DESY) Beam @ 6GeV centered on the SiPM tower

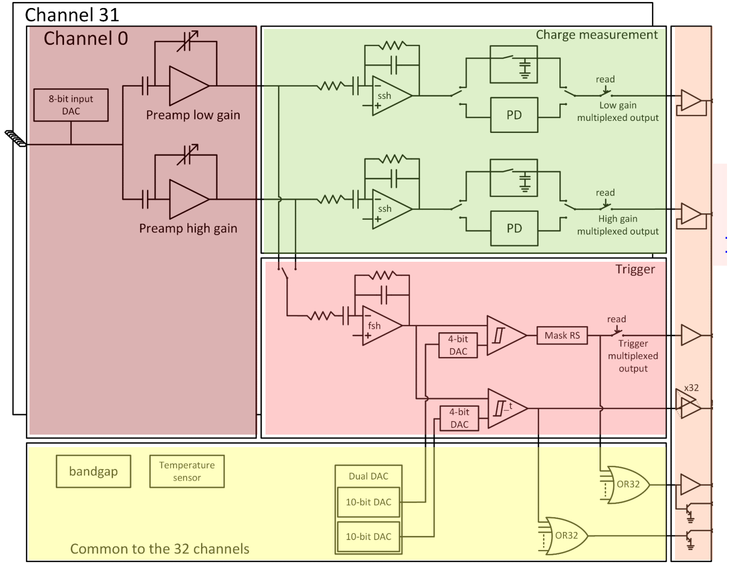




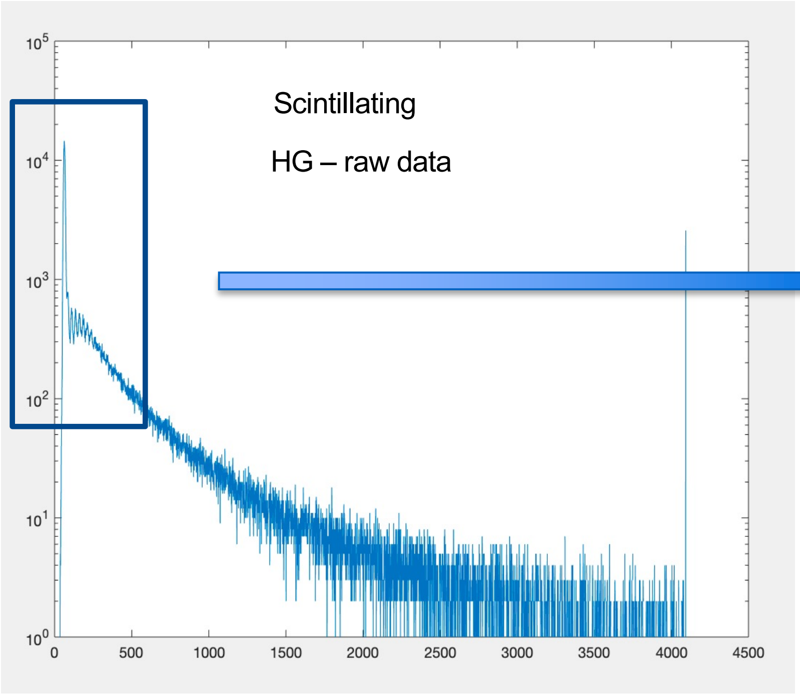
Hamamatsu SiPM:
S14160-1315 PS
Cell size: 15 μm

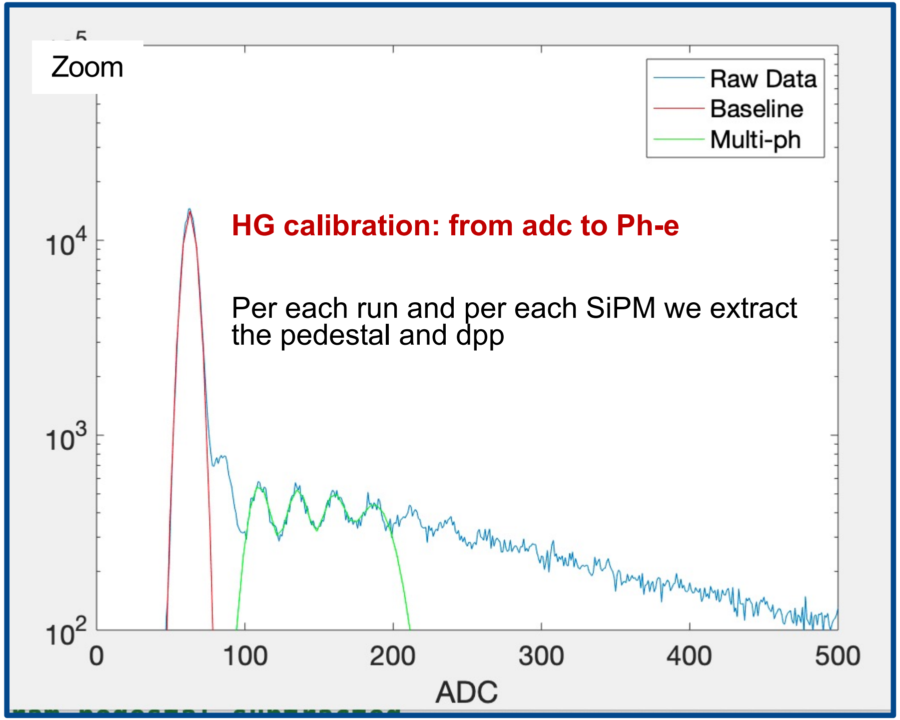


CITIROC 1A: block diagram



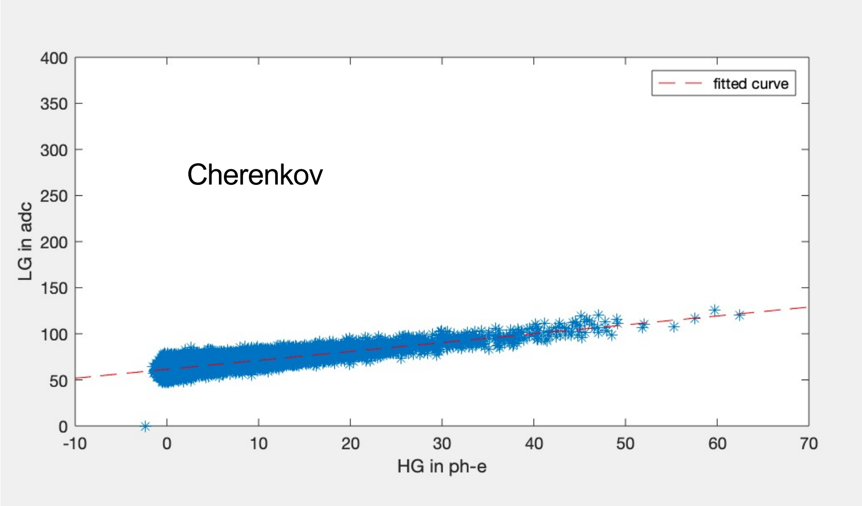
SiPM calibration – High Gain

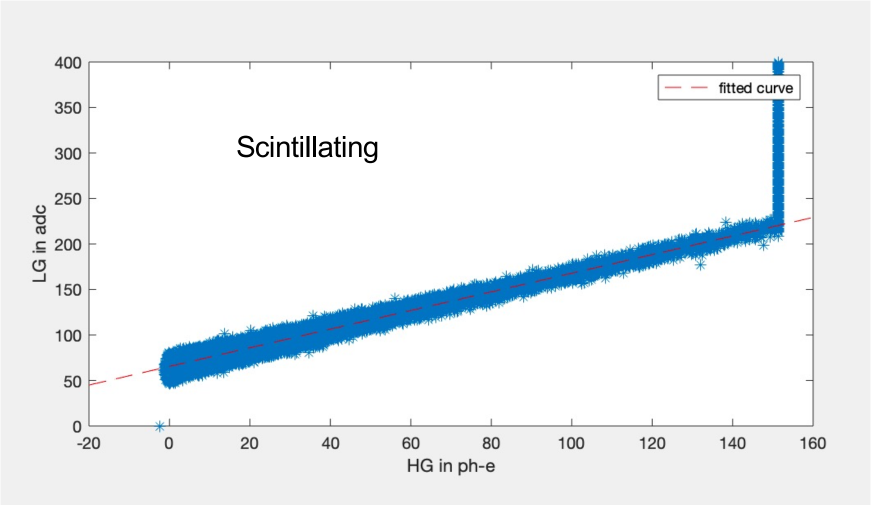




SiPM calibration (Low Gain)

Low gain calibration using the HG - LG correlation plots





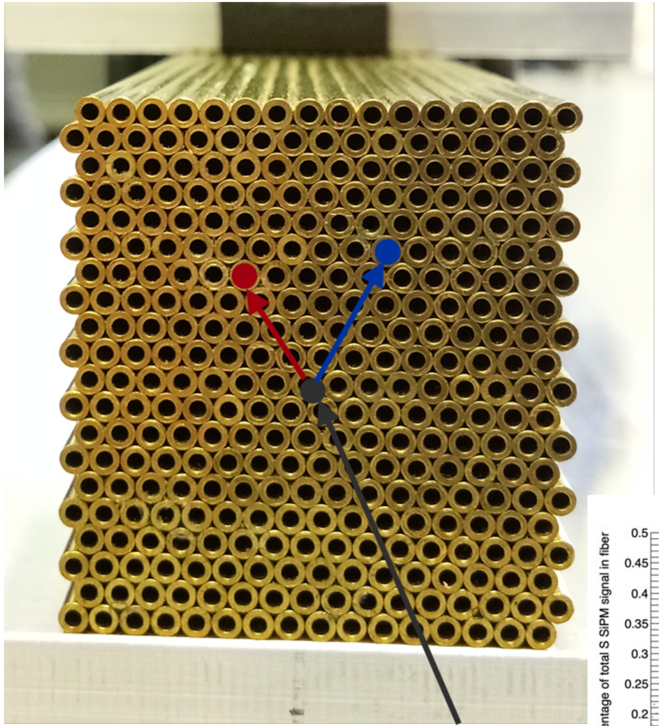
we get the calibration for the low gain (ADC - phe) for each run and each SiPM

Shower shape measurement

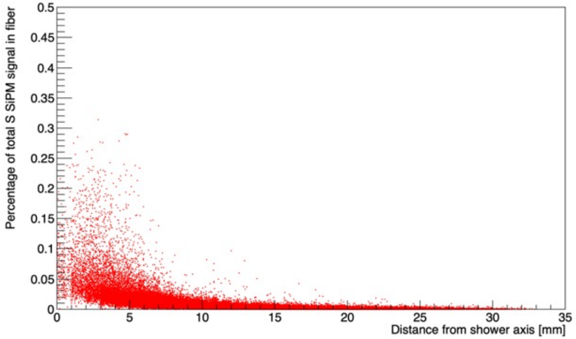
Lateral profile: the average signal carried by a fiber located at a distance from the shower barycenter

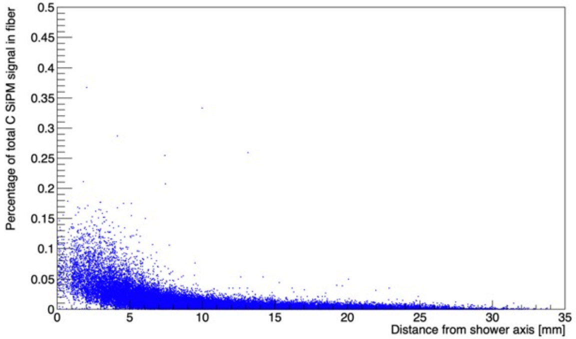
Measurement:

- For every event, and for every fiber, we populate a scatter plot (signal vs. distance)
- Lateral profiles are extracted as average values for every x-bin



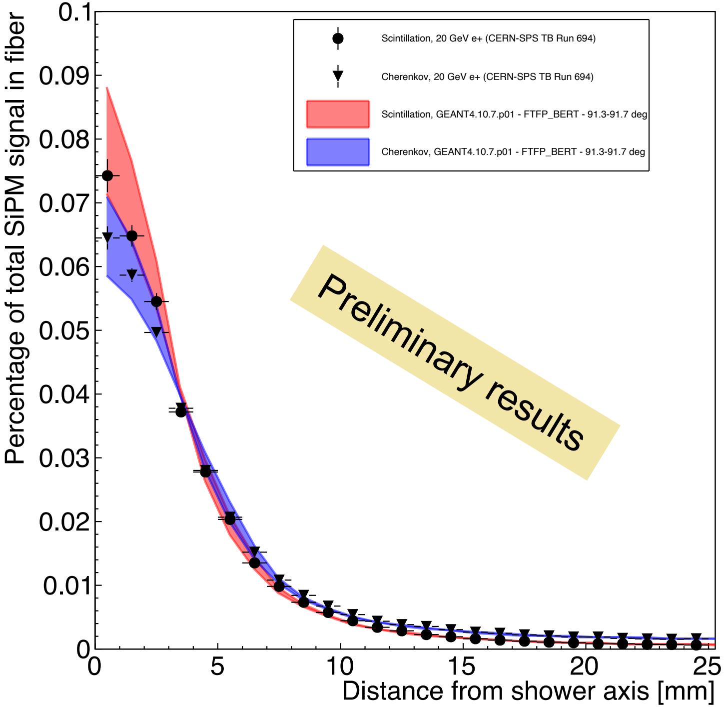
Shower barycenter





Shower shape measurements

CERN SPS 20 GeV e^- - GEANT4

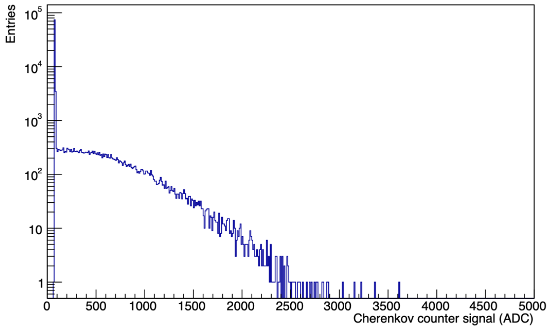


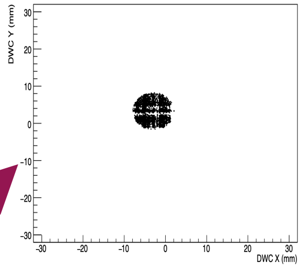
Data - Geant4 comparison

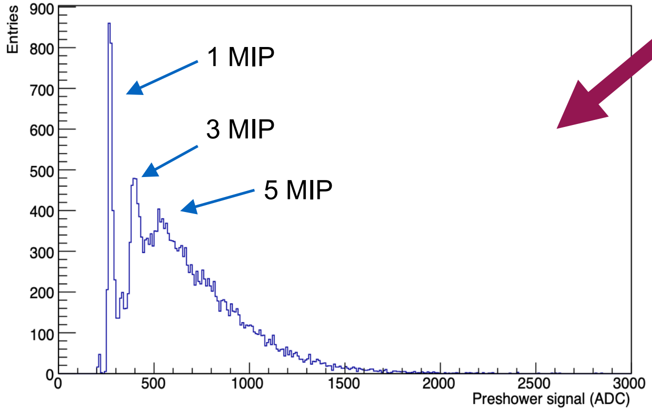
- Non negligible dependence of the shower shape on the impinging angle
- Good agreement at 20 GeV when including a systematic error on the impinging angle (±0.2°)
  - Both shower "core" and "tails" properly reconstructed

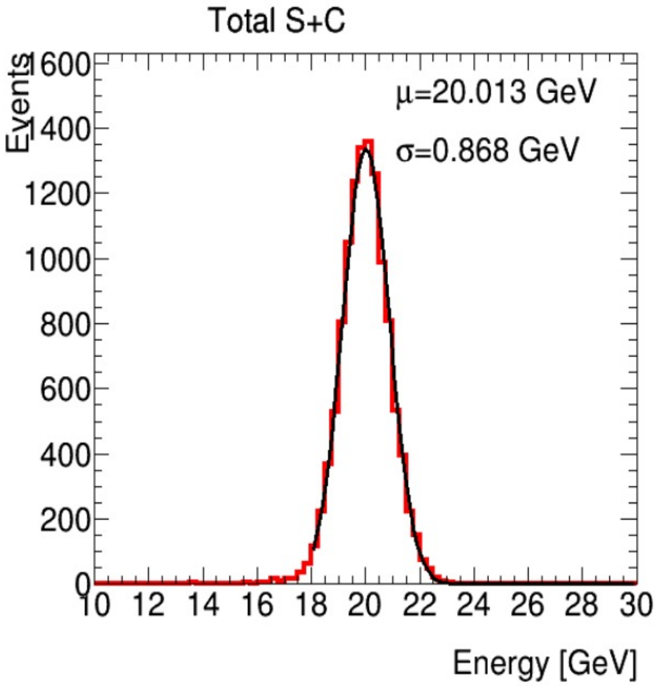
- Sensible differences found between the scintillation and Cherenkov signals at any energy scale

Energy Resolution @SPS





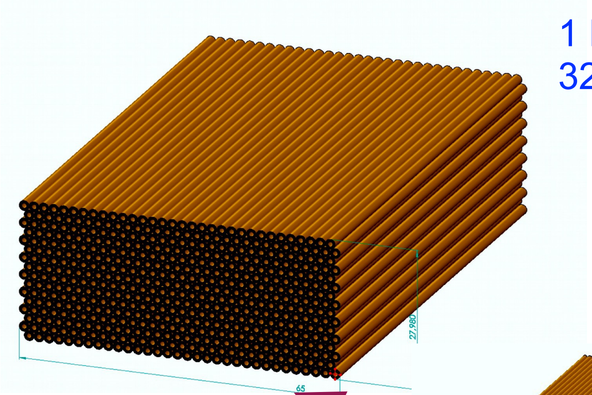




Preliminary results

CERN SPS 20 GeV e^-

HiDRa2 – Hadronic Full containment DR Calo

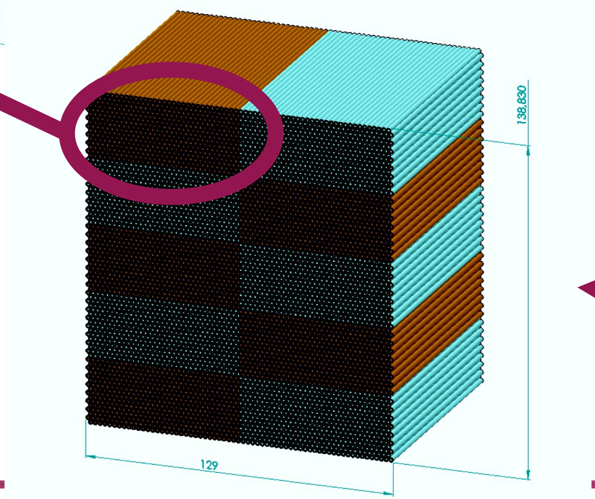


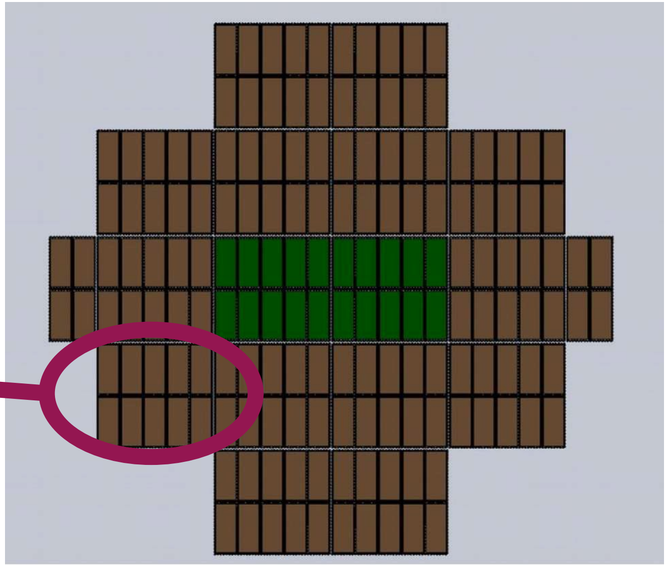
1 Mini-Module (MM):
32 x 16 channel (512 ch)

HiDRa2 project funded by INFN CSNV

16 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





1 Module:
2 x 5 MMs
→ 10 FEE boards
(8-channel grouping)
~ 13 x13 x 200 cm^3

The design of a scalable solution

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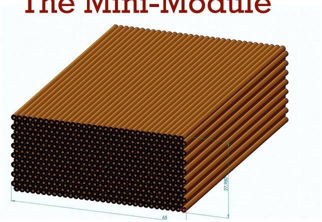
The challenge:

The Mini-Module

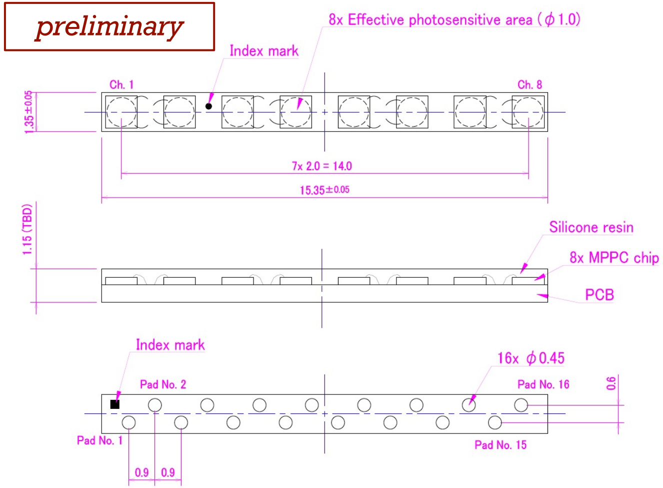


32 x 16 capillaries
1 capillary: (2mm OD and 1.1mm ID)

- 1 SiPM per Fibre: compact package
- SiPM with high Dyn-Range: 10μm pitch
- No contamination between Cherenkov and scintillating light

SiPM module from Hamamatsu

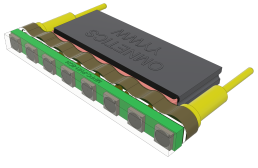
preliminary

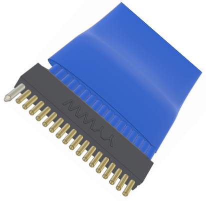


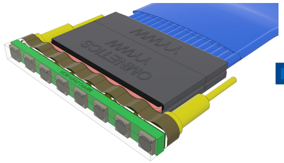
- Custom designed module with 8 SiPMs (1x1mm^2)
- SiPM interspace: 2mm
- Two options under study: 10 and 15 μm pitch

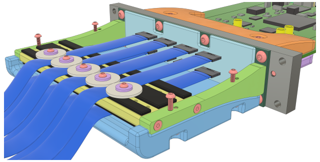
The design of a scalable solution

The front-end board





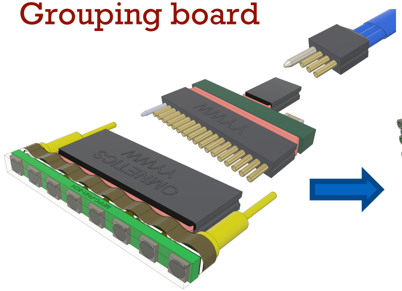




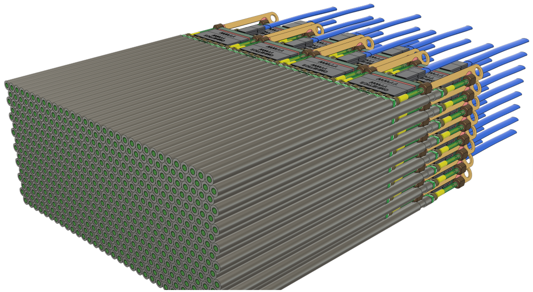
8 front-end boards connected to 1 FERS

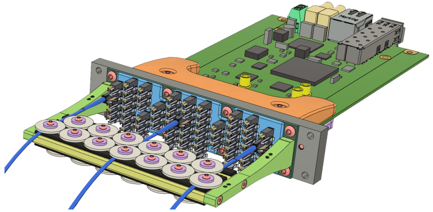
Each SiPM is individually qualified: crucial for the system commissioning

Grouping board



The Mini-Module





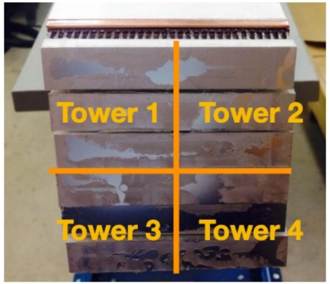
1 FERS serves 64 front-end boards with grouping

- Each bar of SiPMs will be operated at the same voltage (ΔV_{bd}<0.15V)
- The signals from 8 SiPMs are summed up in the grouping board

Plate-based (+3D printing) calo (Korea)

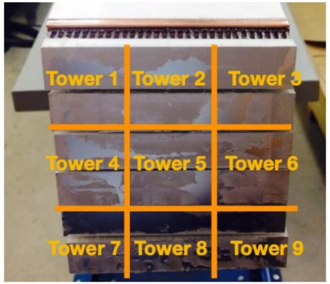
"Short-term plan"

Module #1 (2x2)

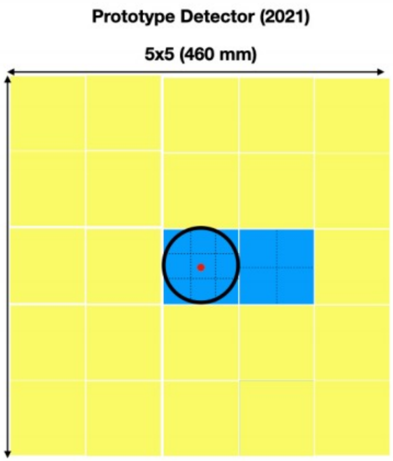


Tower#1	Tower#2
Tower#3	Tower#4

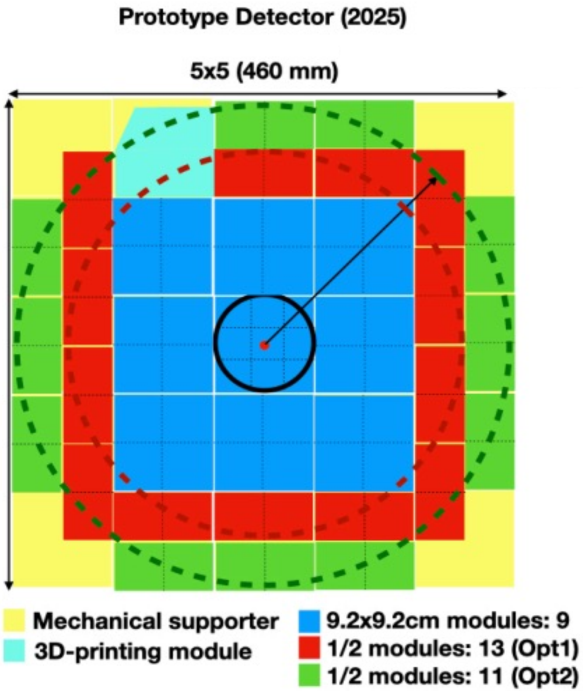
Module #2 (3x3)



Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9



"Mid-term plan"



Building more and more modules in 2022-2025

Refurbishing Cu Plates

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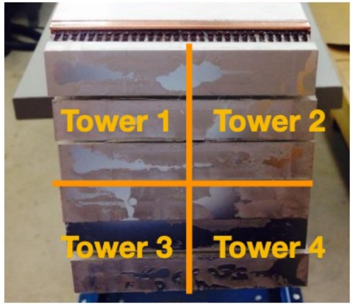
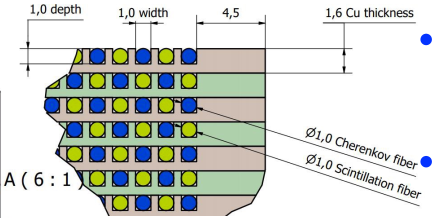
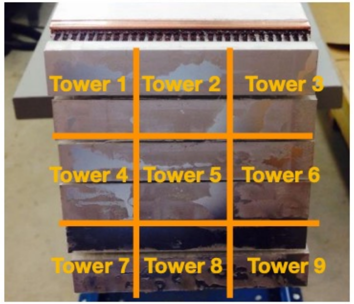
Module #1 (2x2)



Tower#1	Tower#2
Tower#3	Tower#4



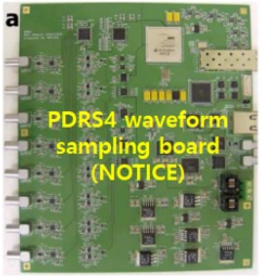
Module #2 (3x3)



Tower#1	Tower#2	Tower#3
Tower#4	Tower#5	Tower#6
Tower#7	Tower#8	Tower#9

92x92mm^2, 2.5 m long

Preamp board based on DRS4



NIM A830 (2016) 119 H. Kim et al.

- Two modules has been prepared meant for 2021 Test Beam at SPS (postponed to 2022)
- Reusing two RD52 Cu module
  - disassemble, recuperate Cu plates
  - new fibers
- R&D Goal
  - Different light sensors under study (MPT, MCP-PMT and SiPM)
  - Study of various type of optical fibers (scintillation)
  - Time resolution (100 ps processing)

Status and Perspective

- "EM-size" DR module has been built and tested at DESY and CERN TB
  - Study mechanical solution
  - Scale-up number of SiPMs
  - Electromagnetic performance
- Funded projects in both INFN and Korea will allow to build and exploit hadronic scale prototypes
  - Study scalable solution toward TDR
  - Assess hadronic performance

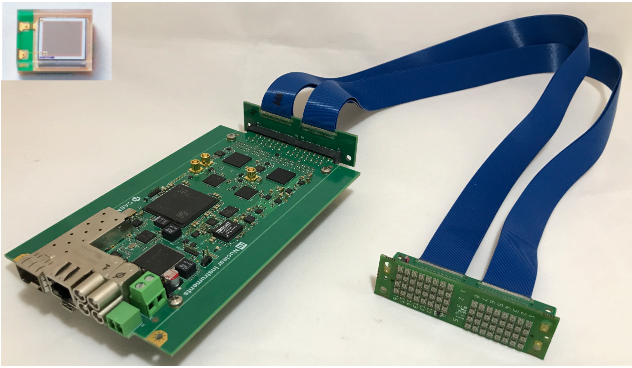
Additional Material

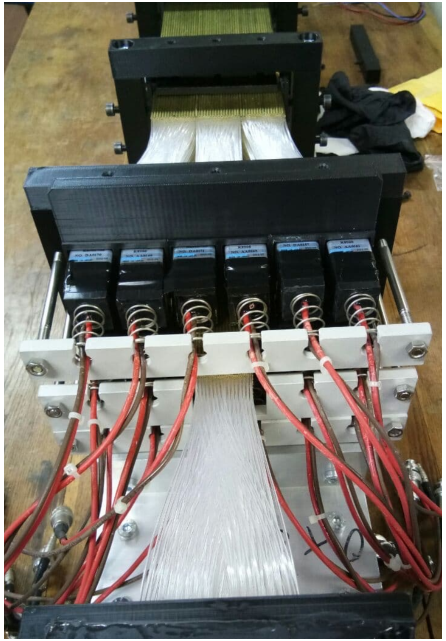
The 2021 test-beam prototype

Readout:

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

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





PMT readout: Hamamatsu
Cherenkov: R8900-100
Scintillation: R8900

Plate-based calo sensors: SiPM, PMT, MCP-PMT

MCP-PMT: excellent timing performance

MCP-PMT	Window size	Light / pour size	Q.E. (Bialkali)	max. HV (V)	Rise time (ns)	photo
PLANACON XP85012	53x53 mm^2	scintillation / 25 um	~7% at 550 nm	2400	0.6	
PLANACON XP85112		Cerenkov / 10 um	~21% at 400 nm	2800	0.5	

https://www.photonis.com/products/planacon

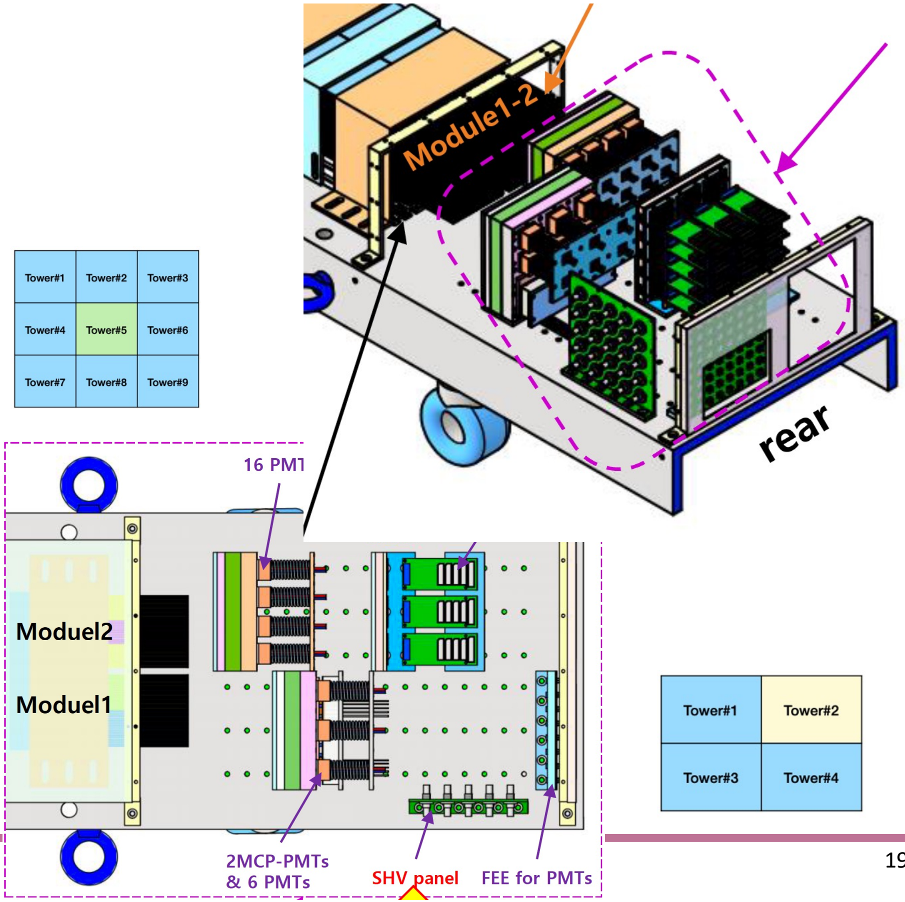
PMT: window size and timing performance

PMT	Window size	Q.E. (Super bialkali, SBA)		max. HV (V)	rise time (ns)	photo
		Ck.	Sc.			
R11265-100	23x23 mm^2	~35% at 400 nm	~7% at 550 nm	1000	1.3	

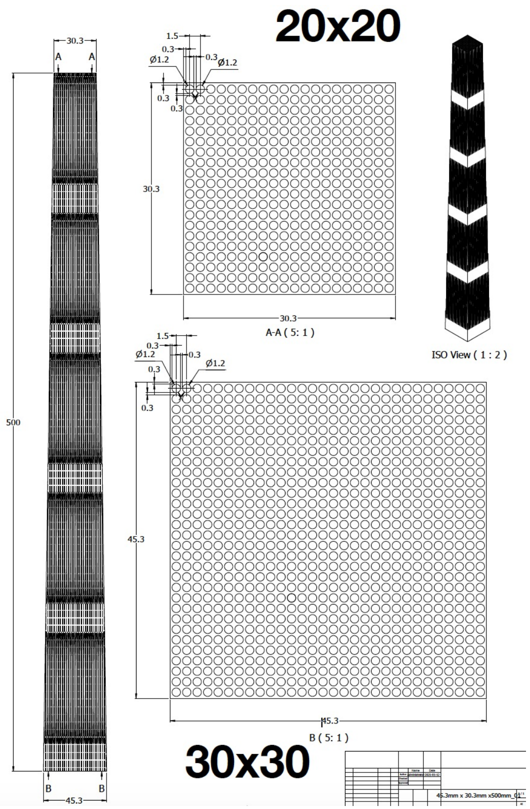
https://www.hamamatsu.com

The biggest number of pixels (16675) have been chosen
to avoid the saturation effect of photon counting for the scintillation lights.

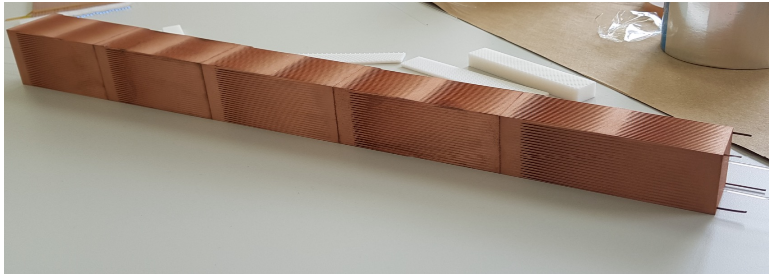
SiPM	Photo-sensitive area	pixel size	Photo detection eff. (Silicone resin)		number of pixels	photo
S14160-1310PS	1.3x1.3 (1.69 mm^2)	10 μm	~15% at 400 nm	~17% at 550 nm	16675	

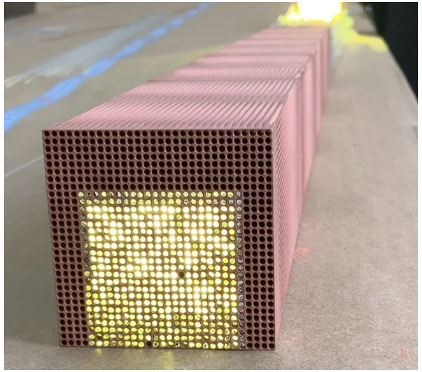


Cu 3D printing



- Exploiting 3D printing technique to obtain desired shape
  - 5 tiles 30.3 x 30.3 mm^2 (front), 45.3x45.4 mm^2 (back), 100 mm long
- 1st projective module
- Easy alignment of the tiles and fiber insertion
- Ultra-high cost





Cu Lego Module

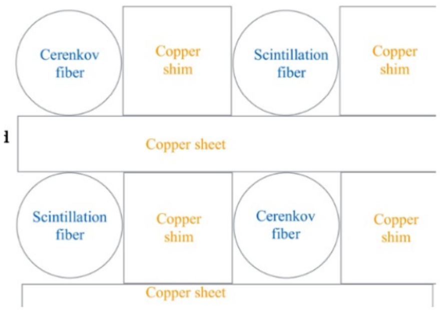


Figure 27: Direct stacking of copper shims and fibers. The shims bear the load.

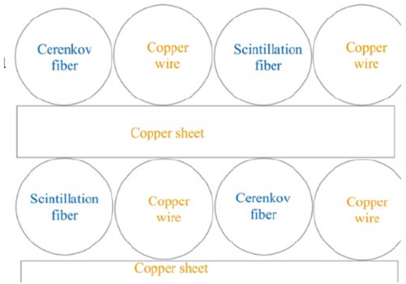
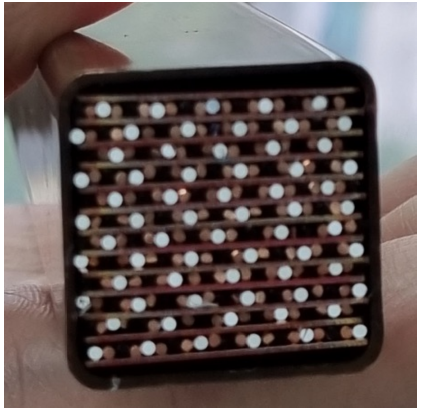
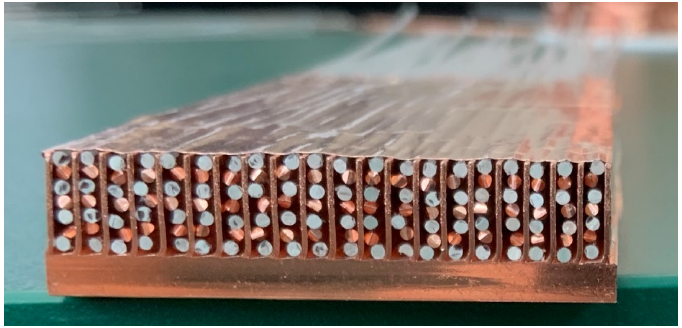


Figure 28: Direct stacking of copper wires (1.05mm diameter) and fibers on 0.5mm copper sheets. The slightly oversized copper wires carry the load.

- Ingredients: housing, copper wall, copper plate
- Use ingredients available in a market as much as possible
  - housing (copper pipes)
  - structure/wall: copper wire or plates, skiving fin heatsink

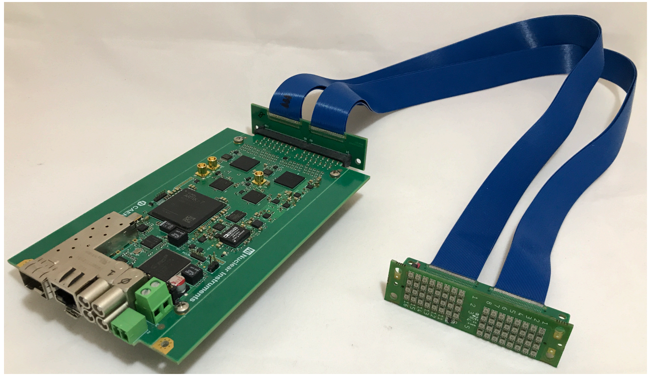


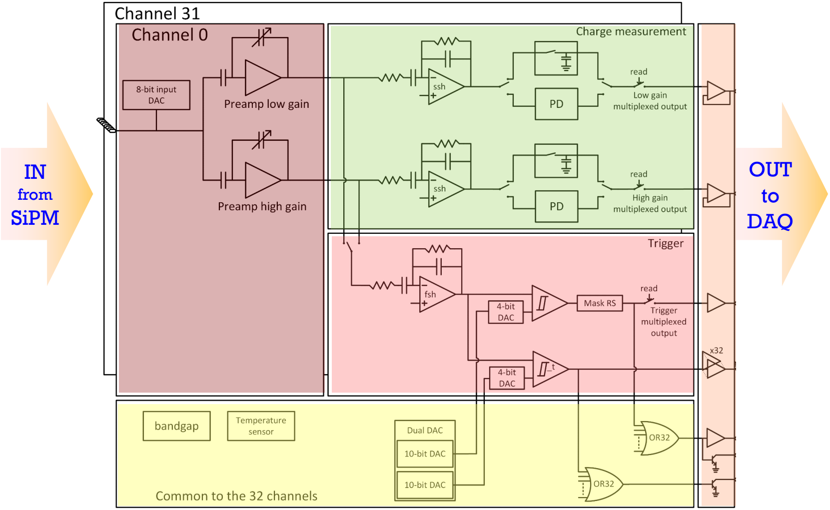
45x45 mm^2, 50 cm long



Citiroc1A based readout

- 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)





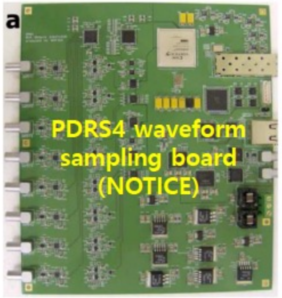
DRS based readout

DRS4

Specification of DRS4 chip NIM A 623 (2010) 86, Stefan Ritt et al.

- DRS (Domino Ring Sampler) based on SCA (Switched Capacitor Arrays)
- Number of channel (input + trigger): 8 + 1 ch
- Sampling frequency: 1~5 GS/S (1 ns ~ 200 ps/sampling depth)
- Number of sampling depth: 10 bits
- Power consumption: max. ~40 mW/ch
  max. 19.2 W for 60 DRS chips (480 ch)

Preamp board based on DRS4



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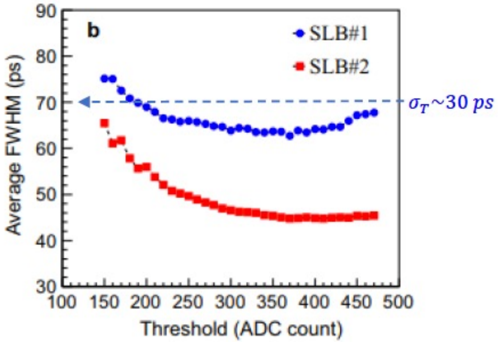
Average FWHM with DRS4 & SiPMs



Operation Mode

Trigger mode	Data Type	Data Size	Control Bus	Expected Trigger Rate (kHz)
Waveform & **Bin event modes**	**Waveform data** during gate open and **ADC peak and its time values** over the threshold	16 bits per channel (64 kBytes/32ch)	USB3 (~1 GBps)	**~0.1 kHz**
Fast DAQ & **Bin event modes**	**ADC peak and its time values** over the threshold	8 bits per channel (256 Bytes/32ch)	USB3 (~1 GBps)	**~25 kHz**
Bin event mode	**Pedestal data** during periods in between beam spills (**pedestal trigger mode (every 1 ms)** with external beam trigger)			

AARDVARC based readout

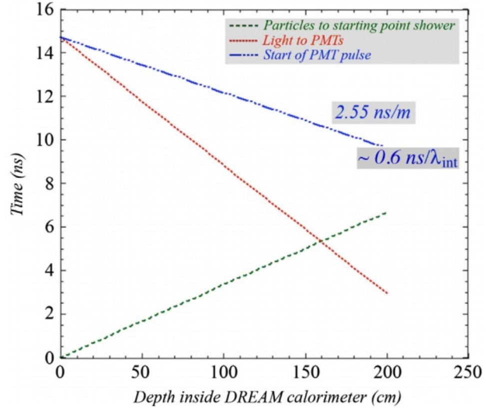
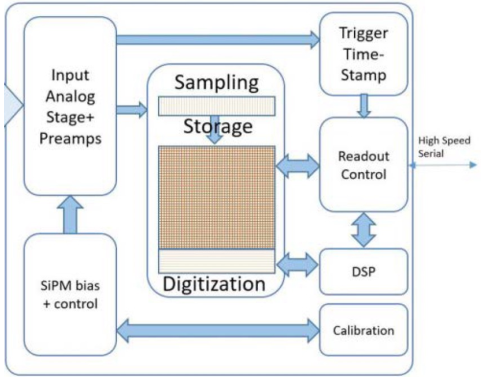


Fig. 8. Dependence of the starting time of the PMT signals on the average depth (z) inside the calorimeter where the light is produced (the dash-dotted line). This time is measured with respect to the moment the particles entered the calorimeter. Also shown are the time it takes the particles to travel to z (the dashed line) and the time it takes the light to travel from z to the PMT (the dotted line).



HDSCoC
Produced by Nalu Scientific

System on Chip with a built in SiPM biasing

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

Timing information is a key element for PID in a longitudinally unsegmented fiber calorimeter