Status and plans for Dual-Readout Calorimetry R&D

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On behalf of the IDEA detector concept group

Pagina successiva

The R&D strategy

- The R&D planned for the next years have three main objectives:
  - Assess the EM performance of a dual-readout calorimeter module
  - Identify and test solutions at system level (i.e. mechanics/assembly, sensors, readout scheme, calibration etc.)
  - Demonstrate on beam the hadronic performance of the dual-readout technique

The R&D strategy

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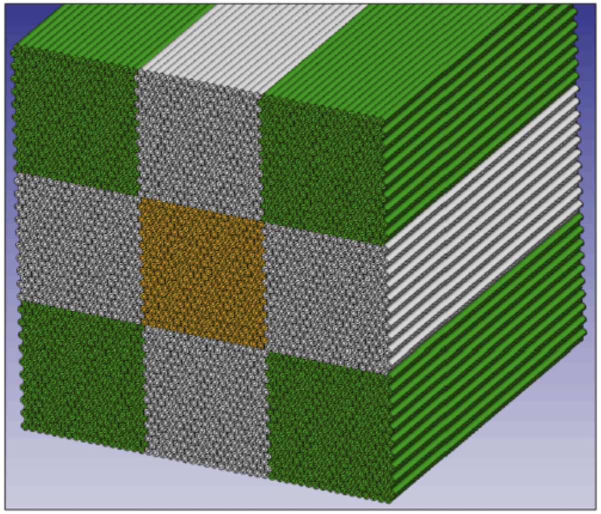
  - Assess the EM performance of a dual-readout calorimeter module
  - Identify and test solutions at system level (i.e. mechanics/assembly, sensors, readout scheme, calibration etc.)
  - Demonstrate on beam the hadronic performance of the dual-readout technique
- To achieve these objectives we have a two-step plan:
  - Short-term plan: build and test on beam a module with EM shower containment (10x10x100 cm^3) and a highly granular core (3.5x3.2x100 cm^3) equipped with SiPMs
  - Mid-term plan: design, build & qualify on beam a scalable system with hadronic containment, partially equipped with SiPM for cost/performance optimisation
- During the Mid-term R&D, the input from the simulation will be crucial to define the requirements and to guide the R&D in the proper direction

Outline

- Status of the short-term plan (2020-2021):
  - The test beam preparation (scheduled for mid-Feb. 2021)
- R&D for the mid-term plan (2021-2025):
  - New module design
  - New readout scheme

Test beam: mechanics and assembly

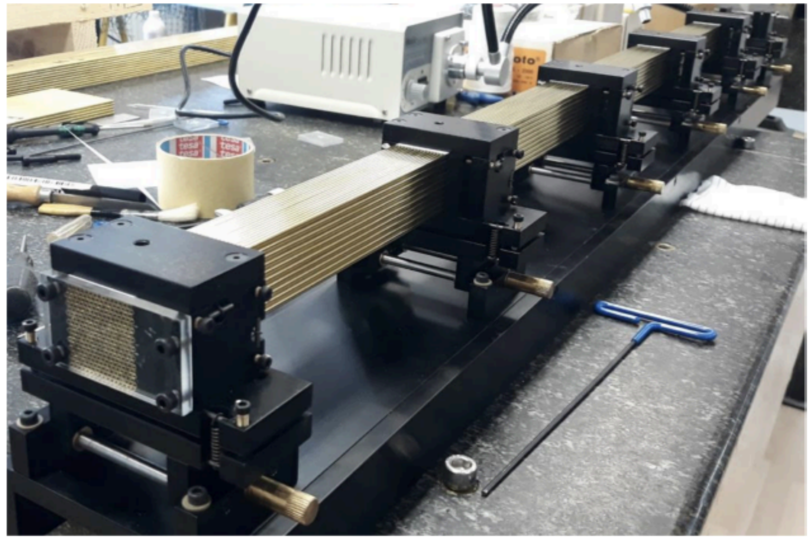


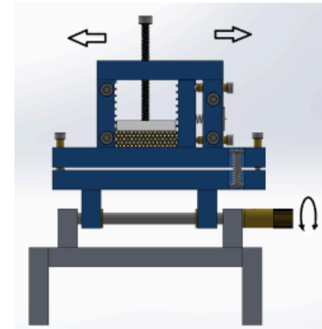
- EM-prototype (10x10x100 cm^3)
  - 9 modules made of 16 x 20 capillaries (160 C and 160 Sc)
  - Capillaries (brass): 2 mm outer diameter and 1.1 mm inner diameter
- EM-prototype readout
  - Each capillary of the central module is equipped with its own SiPM: highly granular readout
  - 8 surrounding modules equipped with PMTs (each module will use 1 PMT for C and 1 PMT for Sc fibres)

- Capillaries have been produced by Albion Alloys and the quality was in line with the specification: OD 2.0 (+ 0.1 / - 0.0) mm, ID 1.1 (+ 0.1 / - 0.0) mm
- The inner diameter is defined by the fibres but the outer diameter can be either increased or reduced (performance has to be carefully evaluated)
- Even if there are alternatives under study, this option could be almost considered ready for large production

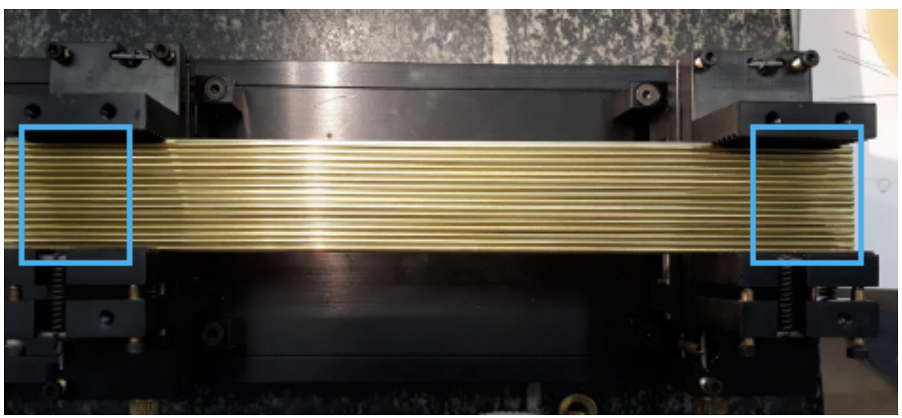
Test beam: mechanics and assembly

The Assembly station





6 adjustable stations for packing capillaries to correct position. Alignment of stations through micrometric screws

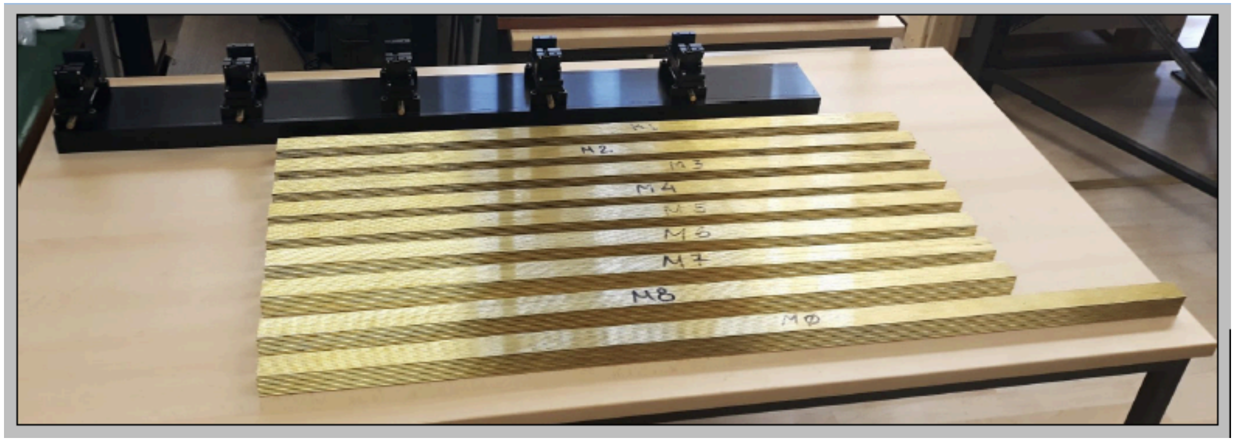


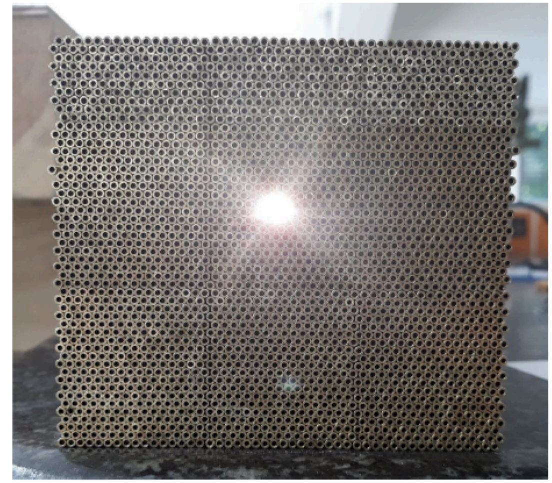
The capillaries are placed and glued layer by layer. The glue is applied only in the marked regions with a hypodermic needle.

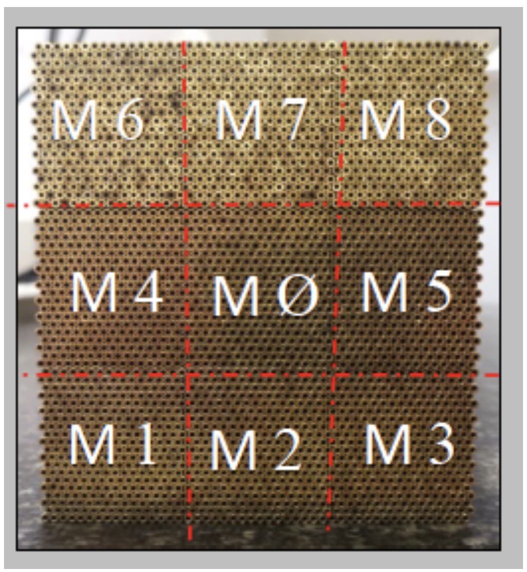
This procedure has demonstrated good results

Horizon 2020
European Union Funding for Research & Innovation
Grant Agreement No 669014

Test beam: mechanics and assembly







- Time to produce a module is ≈1.5 day
- The modules nicely fit close to each other
- The width and the height of the modules have a std < 80μm with a maximum difference < 200μm

Horizon 2020
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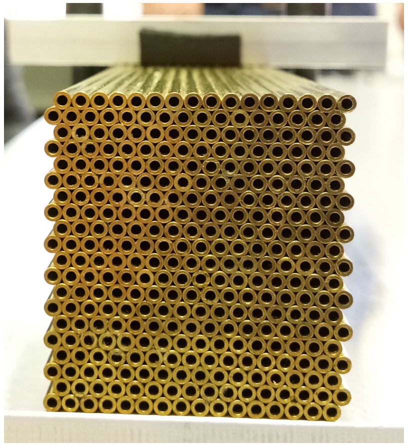
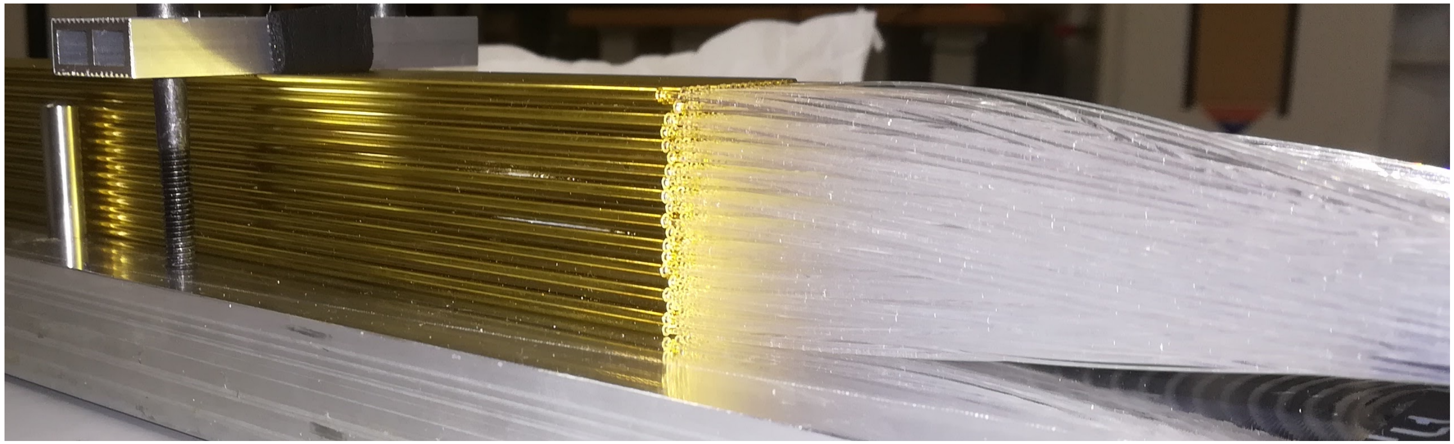
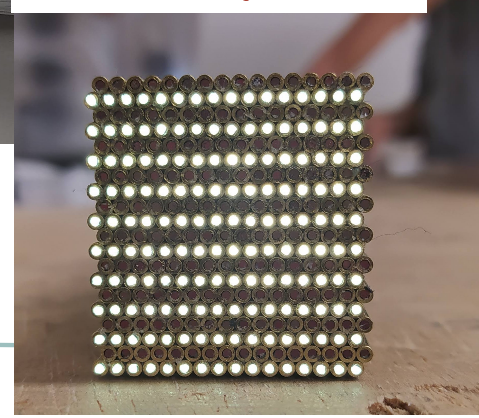
Test beam: mechanics and assembly



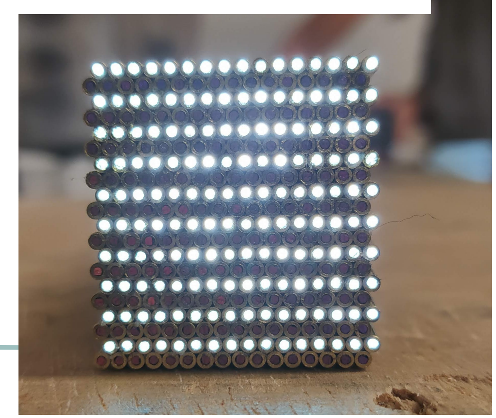


A module equipped with PMTs

Scintillating fibres



Cherenkov fibres



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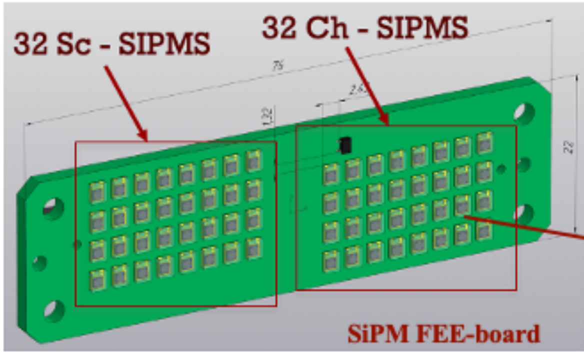
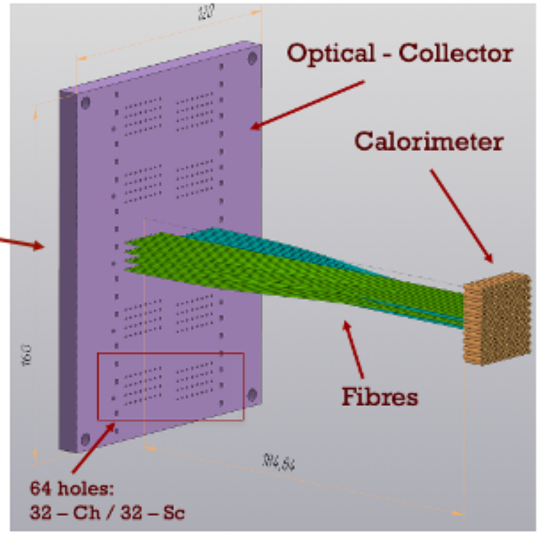
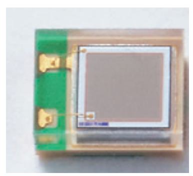
Test beam: assembly



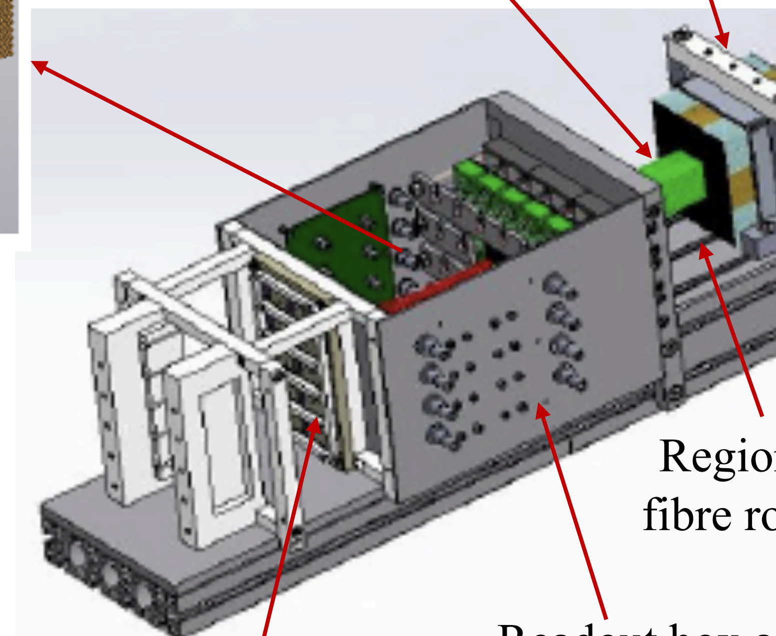


S14160-1315PS		
Effective Area	1.3x1.3	mm^2
Cell pitch	15	μm
Number of cells	7296	
Geometrical factor	49	%
Vbd	38+-3	V
Gain	$3.6*10^5$	
PDE	32	%
Xtalk	<1	%
DCR (Typical)	120	kHz



Central module (read out by SiPM)

Prototype rear-end



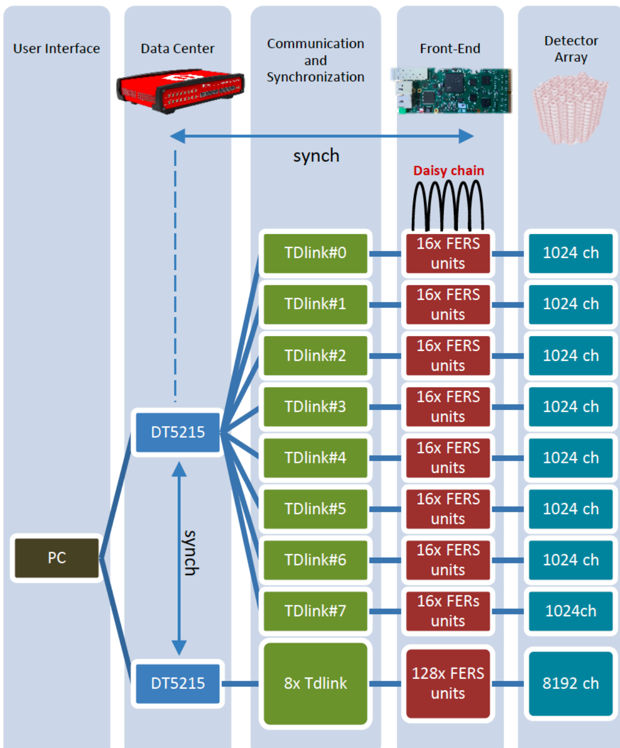
Region for fibre routing

Readout box and patch-panel for SiPMs

Readout box and patch-panel for PMTs

Test beam: readout scheme

- The readout of the PMTs will be based on Caen QDC (V862AC) and TDC (V775N) modules
- The readout of the highly granular module (320 SiPMs) will be based on the Caen FERS system (5200) using 5 readout boards (A5202)



FERS-system

- FERS unit can be used in standalone or connected to the system
- Up to 16 FERS unit can be connected in daisy chain (FERSnet)
- The FERSnet communicates to the concentrator board DT5215 via TDlink (6.25 Gbit/s) optical link
- A DT5215 houses 8 high-speed optical links (TDLink) to read out up to 8192 channels (SiPMs)
- The DT5215 has an embedded ARM processor (Quad Core) running Linux for data processing / data compression
- The connection to the host PC is performed over a 10 Gbit ethernet
- Further scalability can be reached synchronizing more concentrator boards

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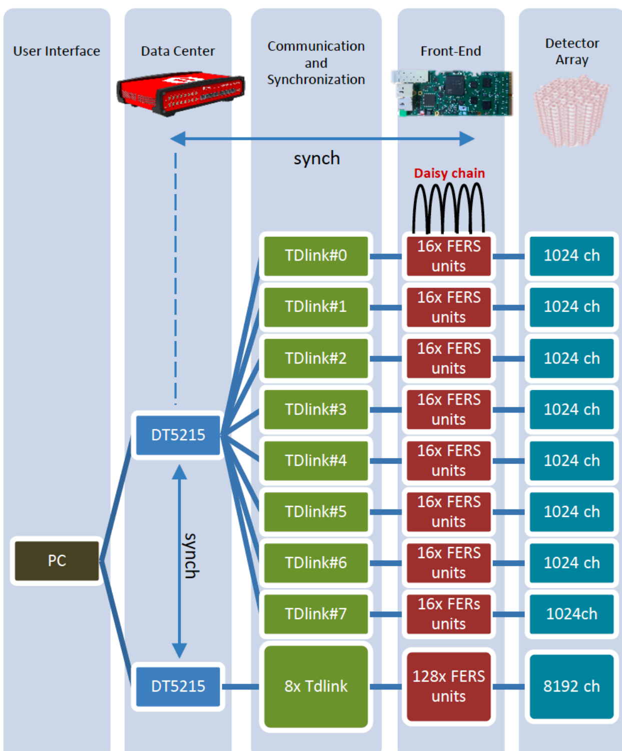
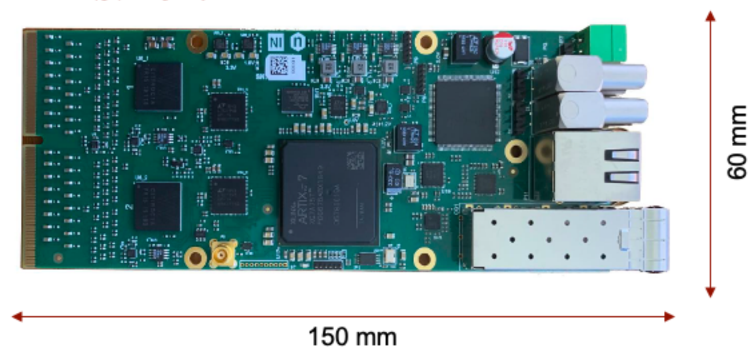


FERS: A5202



- Two Citiroc1A for reading out up to 64 SiPMs
- One (20 – 85V) HV power supply with temperature compensation
- Two 13-bit ADCs to measure the charge in all channels
- Timing measured with 64 TDCs implemented on FPGA (time resolution ≈ 200 ps)
- Optical link interface for readout (6.25 Gbit/s)

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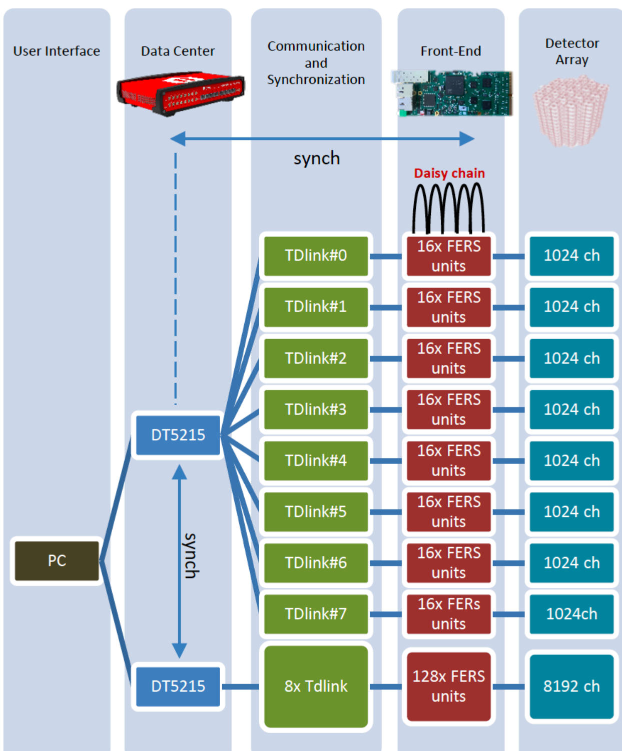

CITIROC 1A: specification

Detector Read-Out	SiPM, SiPM array
Number of Channels	**32**
Signal Polarity	Positive
Sensitivity	Trigger on **1/3 of photo-electron**
Timing Resolution	Better than **100 ps RMS** on single photo-electron
Dynamic Range	0-400 pC i.e. 2500 photo-electrons @ 10^6 SIPM gain
Packaging & Dimension	TQFP160-TFBGA353
Power Consumption	225mW - Supply voltage: 3.3V
Inputs	32 voltage **inputs with independent SiPM HV adjustments**
Outputs	**32 digital outputs (for timing)** **2** multiplexed **charge output, 1** multiplexed **hit register and 2 trigger outputs**
Internal Program. Features	32 HV adjustment for SiPM (32x8bits), Trigger Threshold Adjustment, channel by channel gain tuning, 32 Trigger Masks, Trigger Latch, internal temperature sensor

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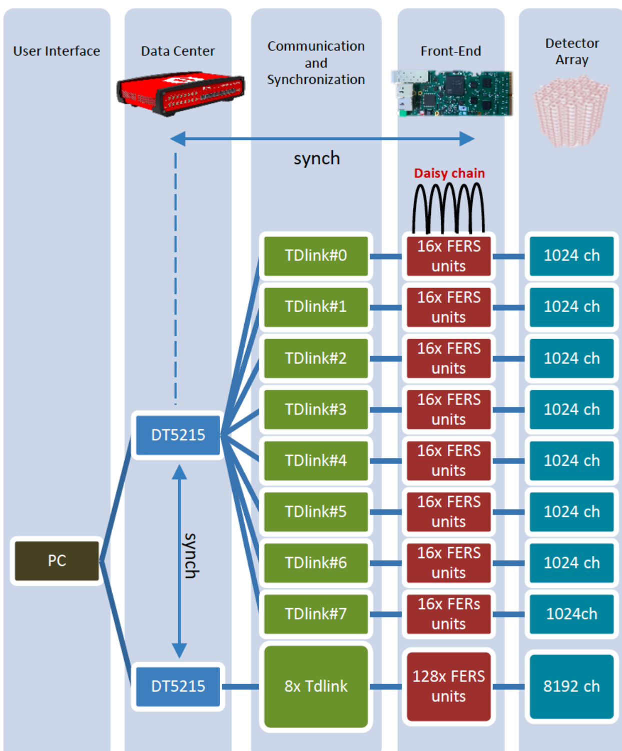
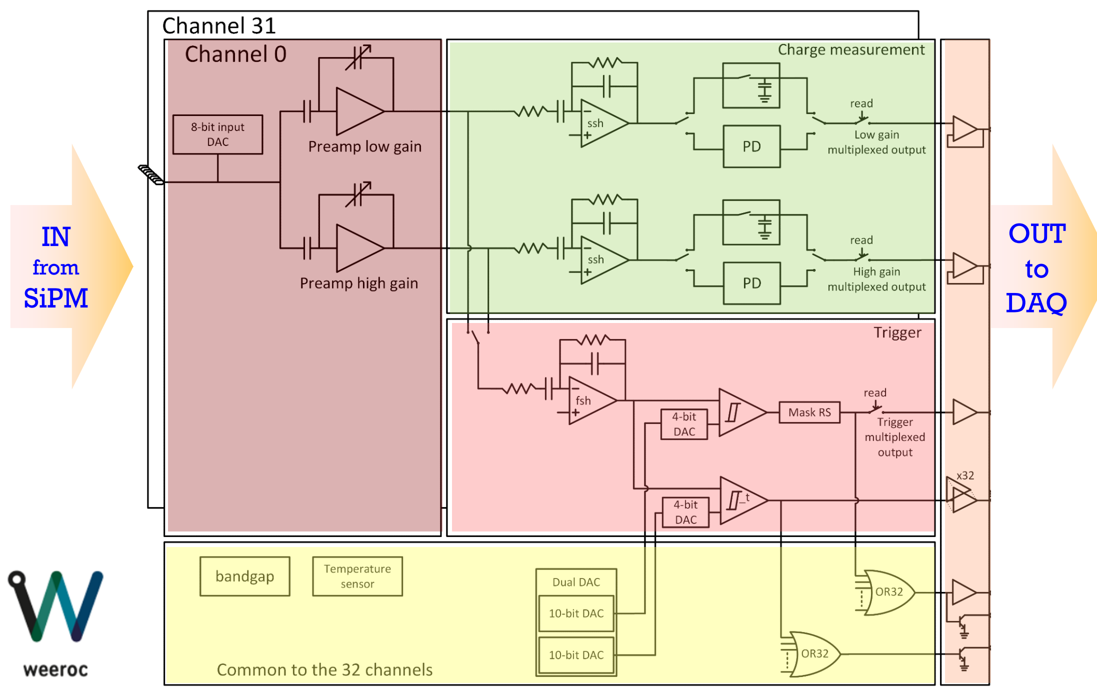


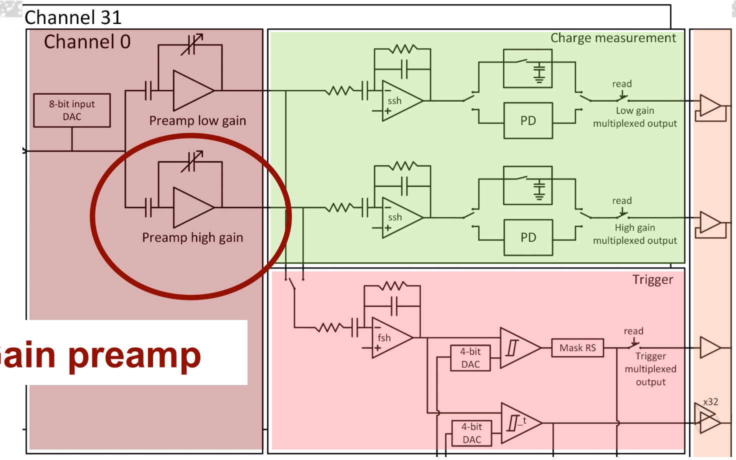
CITIROC 1A: block diagram



https://www.weeroc.com/my-weeroc/download-center/citiroc-1a/16-citiroc1a-datasheet-v2-5/file

Citiroc1A qualification

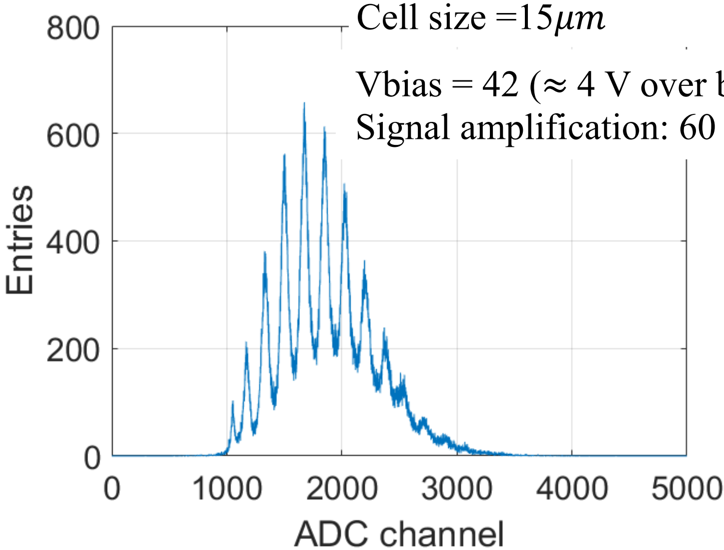
Since the FERS system is not yet available we started the Citiroc qualification using an evaluation board (DT5550W)



High Gain preamp

Sensor: S14160-1315PS
Cell size $=15\mu m$

Vbias = 42 (≈ 4 V over breakdown)
Signal amplification: 60 a.u.



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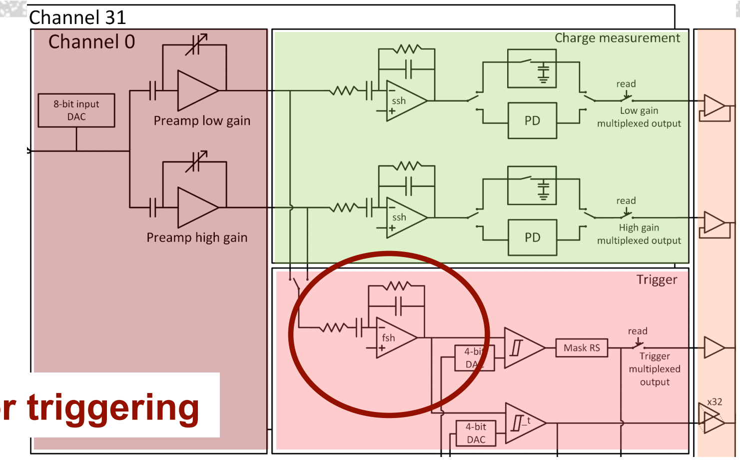
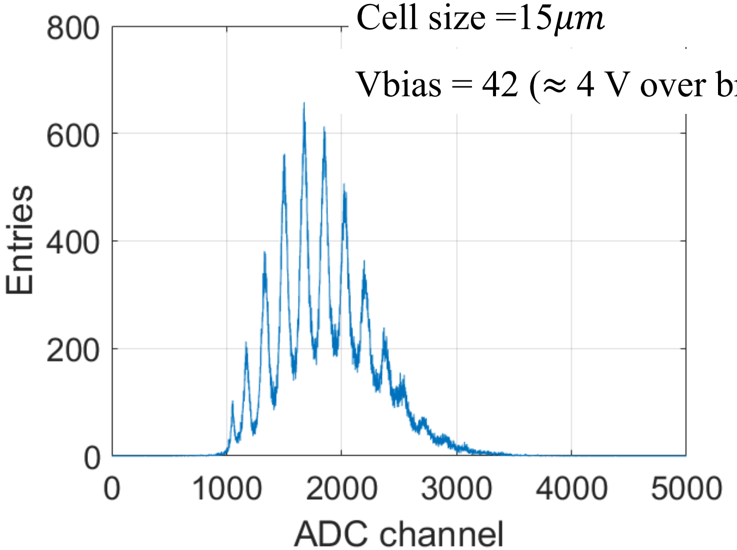
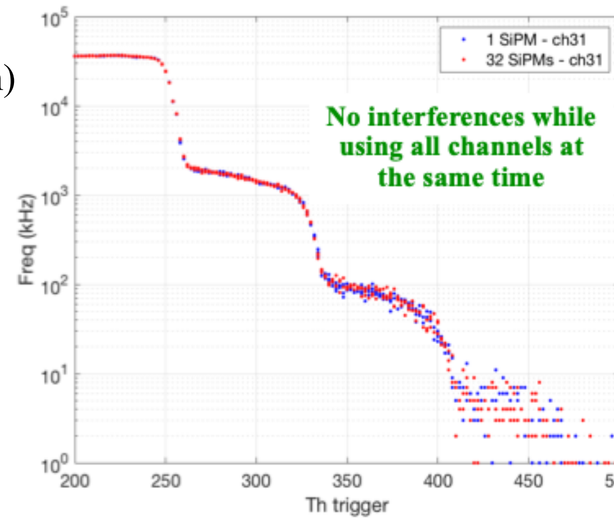


Fast shaper for triggering

Sensor: S14160-1315PS
Cell size $=15\mu m$

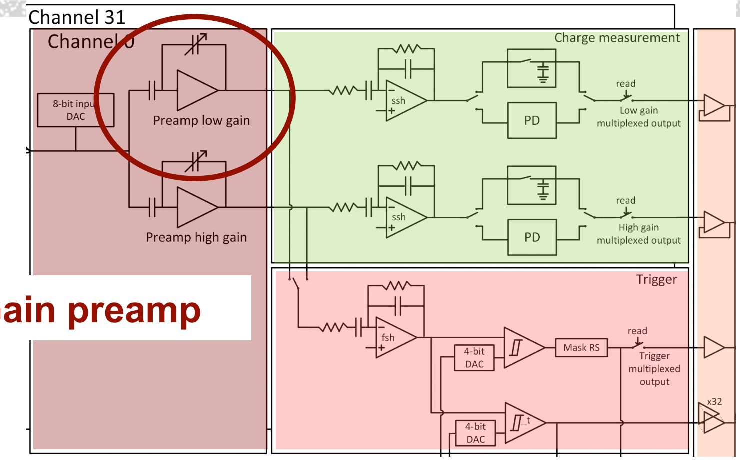
Vbias = 42 (≈ 4 V over breakdown)





The system has demonstrated good quality down to the single p-e level

Citiroc1A qualification



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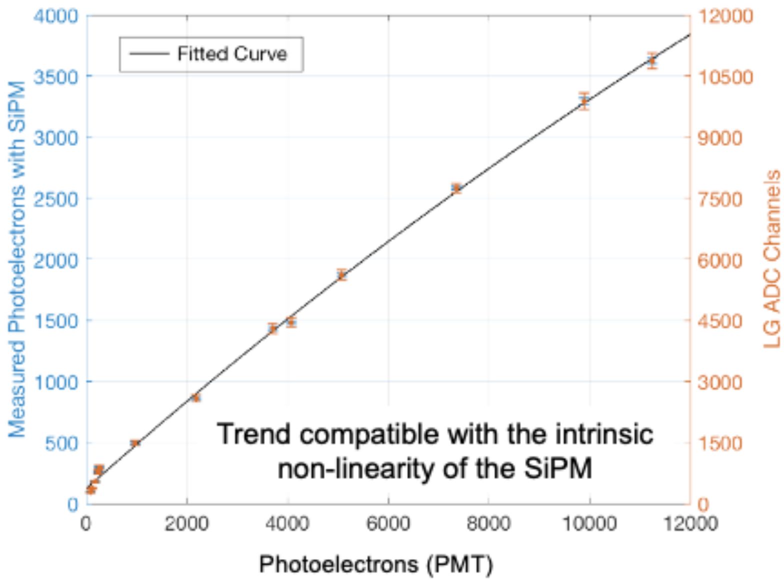
Low Gain preamp

Dyn-range in response to the S14160-1315PS



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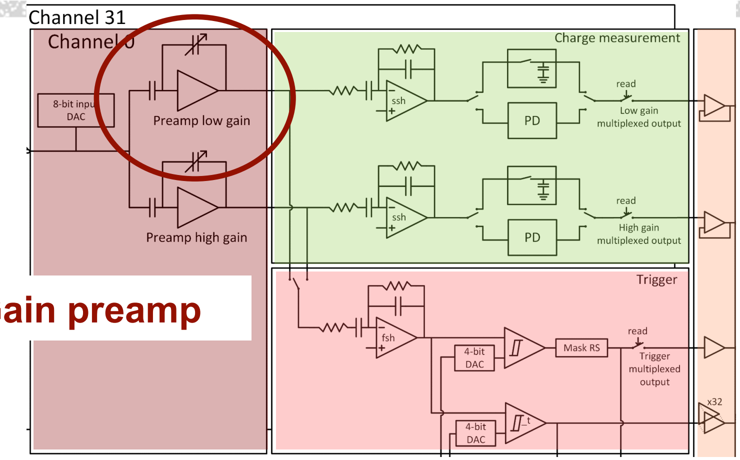

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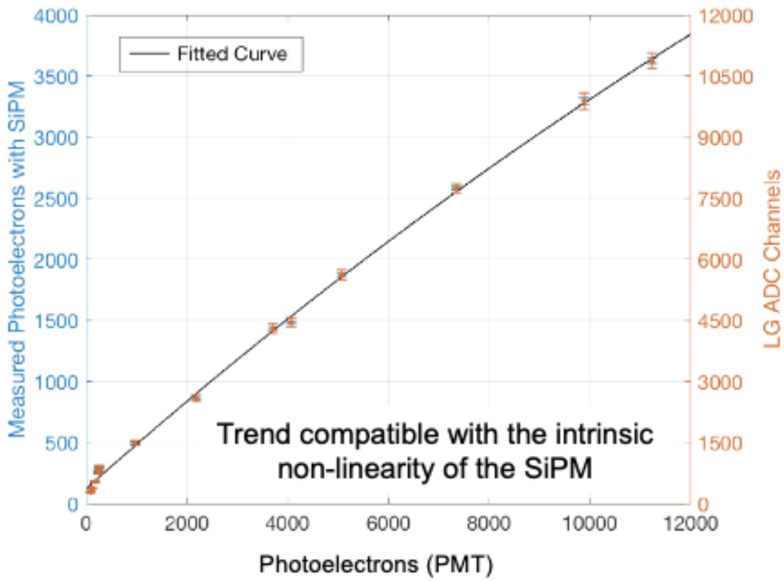
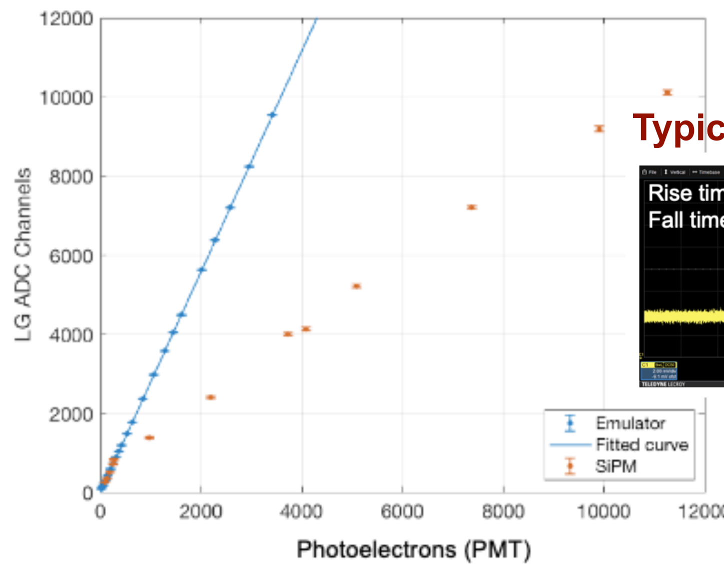
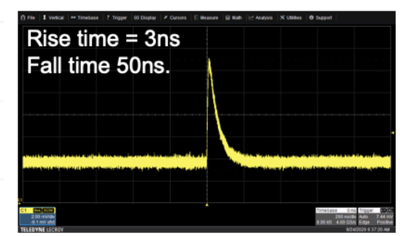


Linearity qualified with the detector emulator (DT5810 - Caen)



Typical injected signal



Test beam preparation: in short

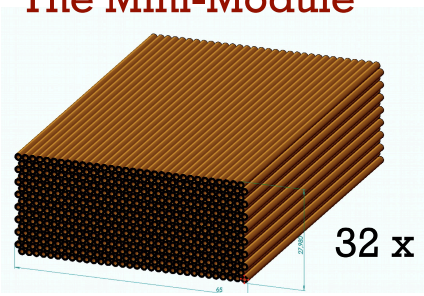
- The absorber of all the modules has been assembled
- All fibres have been delivered and the insertion in the modules has just started
- Front-end boards delivered (to be tested)
- FERS system expected to be delivered at the beginning of December
- System commissioning expected in January 2021

Outline

- Status of the short-term plan (2020-2021):
  - The test beam preparation (scheduled for mid-Feb. 2021)
- R&D for the mid-term plan (2021-2025):
  - New module design
  - New readout scheme

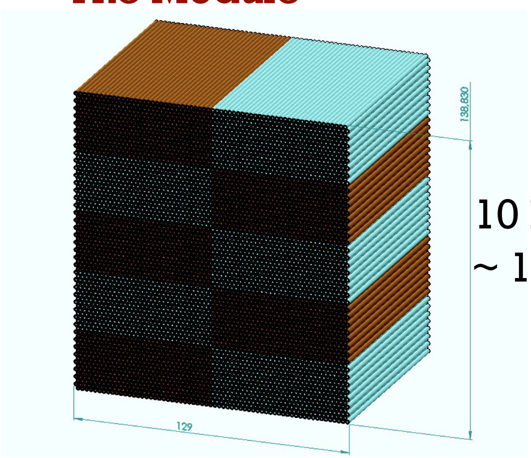
Prototype with hadronic containment

The Mini-Module



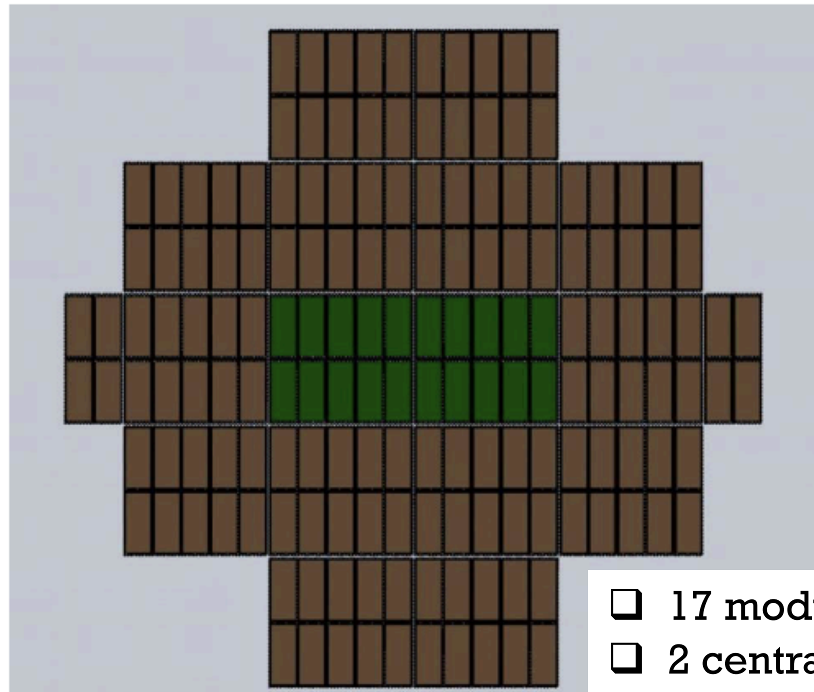
32 x 16 capillaries

The Module



10 Mini-modules
~ 13 x 13 x 200 cm^3

The hadronic prototype

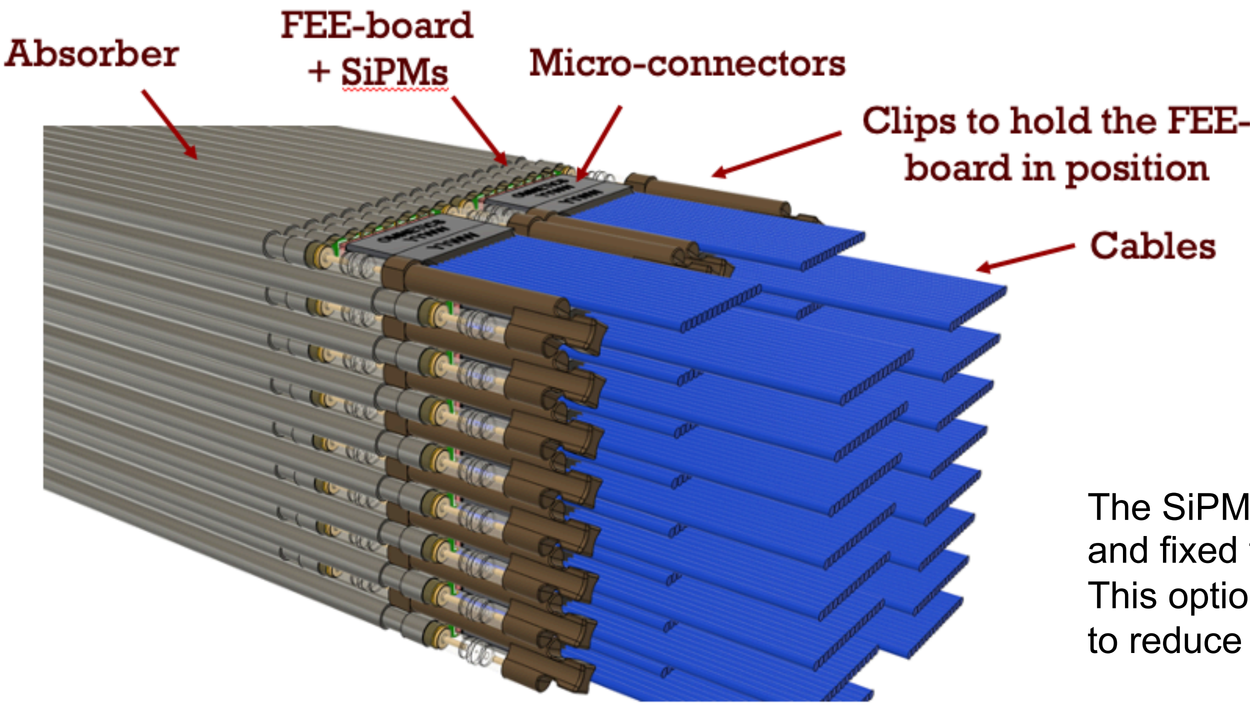


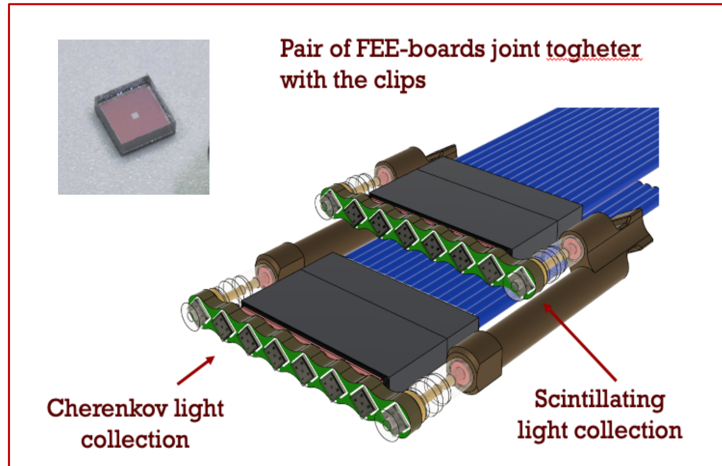
- ❑ 17 modules in total
- ❑ 2 central modules read out with SiPMs
- ❑ 15 modules read out with PMTs
- ❑ ~ 65 x 65 x 200 cm^3

New module design

For the new design we are investigating scalable options which would guarantee the possibility to build large and projective modules.

Option based on capillaries





The SiPMs will be directly connected to the fibres and fixed to the absorber
This option will allow to group signals from 8 SiPMs to reduce the number of channels to be read out

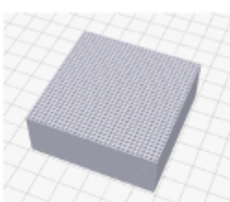
New module design

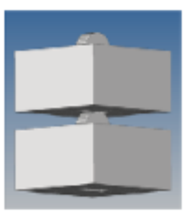
For the new design we are investigating scalable options which would guarantee the possibility to build large and projective modules.

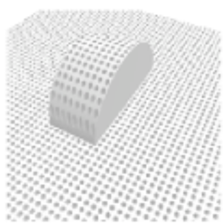
Alternatives based on 3D-printing techniques are under study

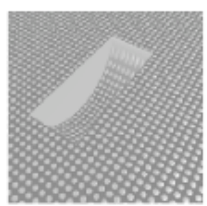
Process still to be optimized:

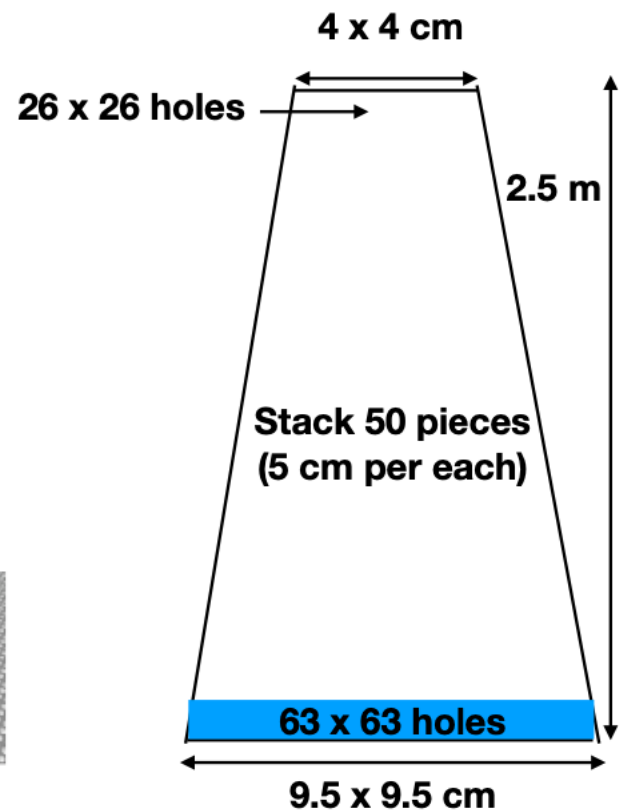
- Copper with different densities (from 95 to 99.5%)
- Different parameters of the 3D printer
- Holes diameter: 1.3 mm
- Pitch: 0.7 mm











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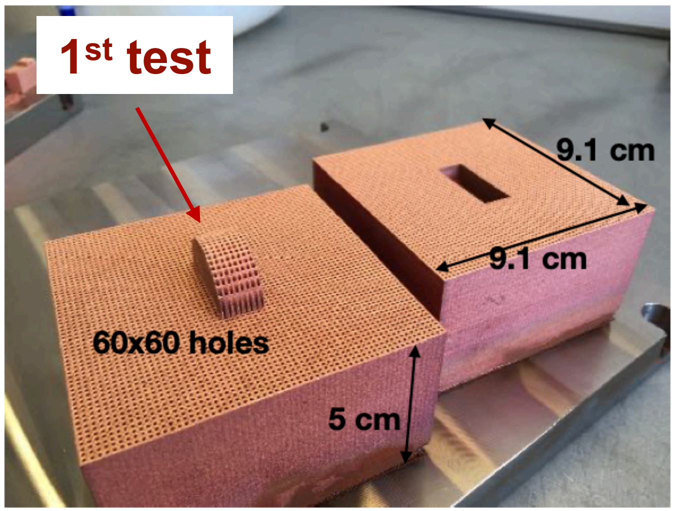
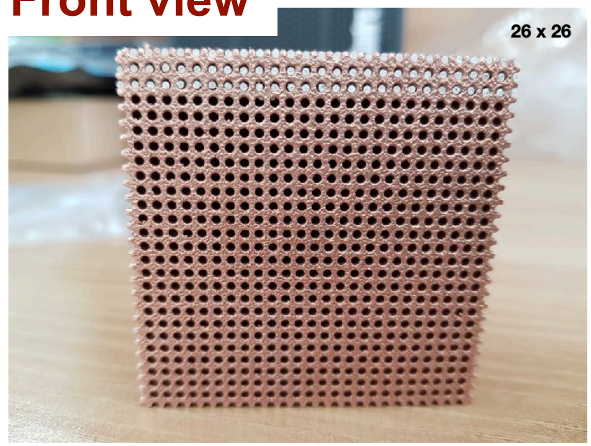
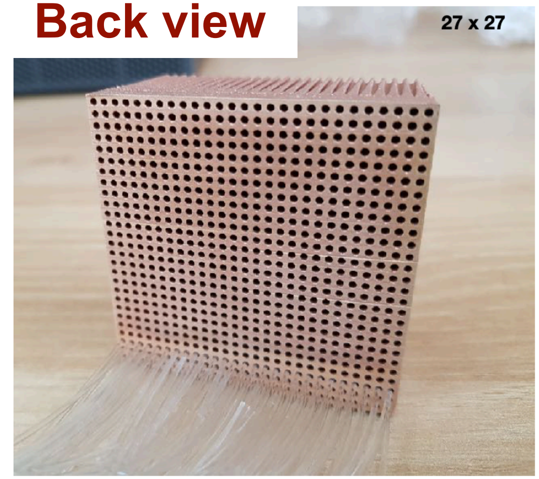


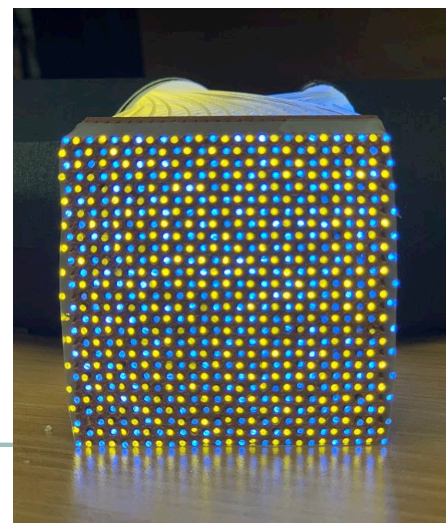
Results not yet optimal, but it looks manageable

Front view



Back view





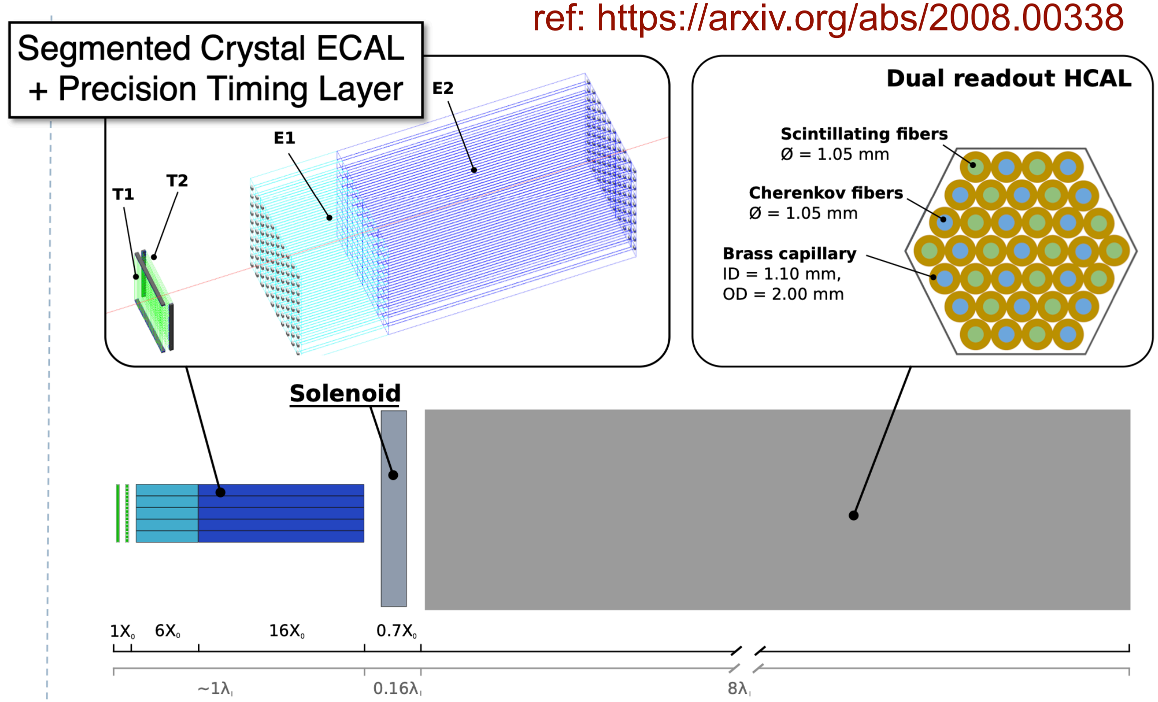
Segmented Crystal EM option

The option with a segmented EM detector before the solenoid is also under discussion

- ***SCEPCAL:*** a **S**egmented **C**rystal **E**lectromagnetic **P**recision **C**alorimeter
- **Transverse and longitudinal segmentations** optimized for particle identification, shower separation and performance/cost
- Exploiting **SiPM readout** for contained cost and power budget

ref: https://arxiv.org/abs/2008.00338

- **Timing layer** — $\sigma_t \sim 20$ ps
  - LYSO:Ce crystals ($\sim 1X_0$)
  - 3x3x54 mm³ active cell
  - 3x3 mm² SiPMs (15-20 um)
- **ECAL layer** — $\sigma_E/E \sim 3\%/\sqrt{E}$
  - PbWO crystals
  - Front segment ($\sim 6X_0$)
  - Rear segment ($\sim 16X_0$)
  - 10x10x200 mm³ crystal
  - 5x5 mm² SiPMs (10-15 um)

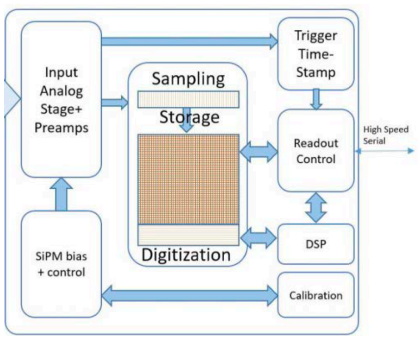


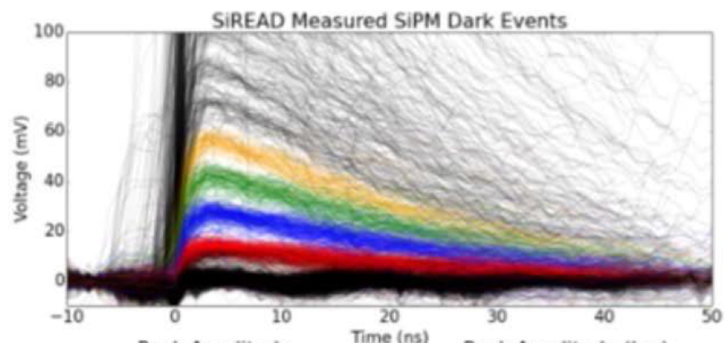
For details see also:
Sarah Eno's talk (calorimetry session)
Chris Tully' talk (performance session)

Readout scheme: an alternative approach

Together with an ASIC that reads signal amplitude and time, we are also considering waveform sampler with feature extraction

The SiREAD

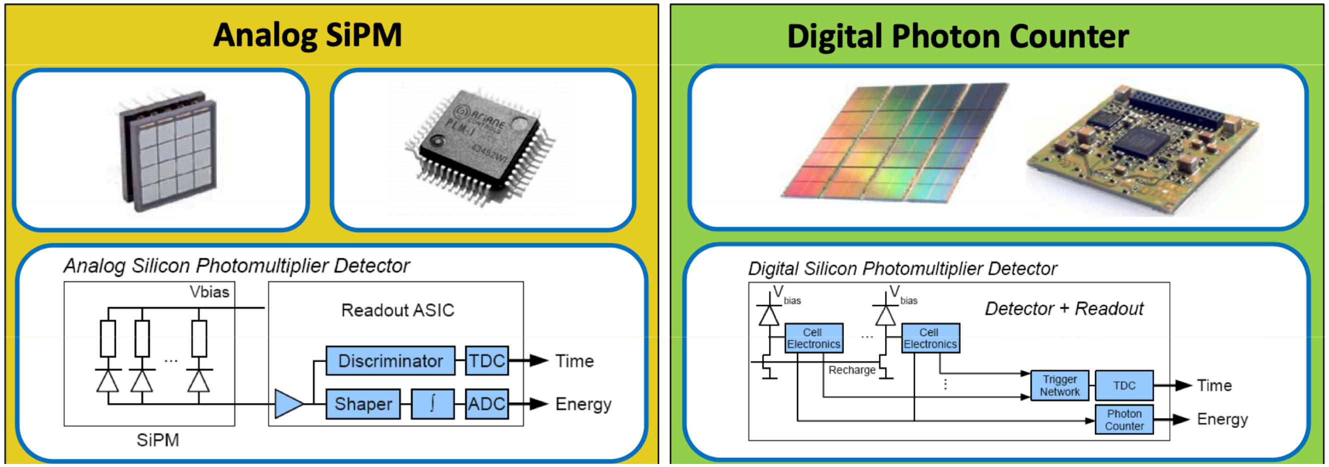




https://indico.bnl.gov/event/6351/contributions/29462/attachments/23682/34356/190709_Nalu_Scientific_-_Electronics_Update_for_EIC-PID_workshop_for_web.pdf

- Produced by Nalu Scientific
- The SiREAD has been replaced by new ASICS (HDSOC, ASOC)
- Next year we could have a demo board for preliminary tests and qualification

Readout scheme: 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

- The technology is not yet consolidated and the performance is not yet at the level of the standard SiPMs. Nevertheless they are rapidly improving
- This R&D is very important because it could bring to a series of advantages:
  - Custom sensor design with reduced cost for mass production
  - Simplified readout system
  - Improved timing performance
  - The non-linearity could be corrected before merging the information among different sensors

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

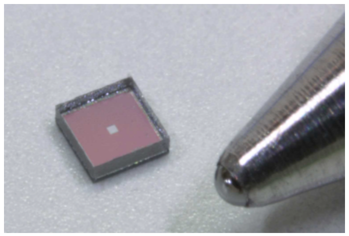
Summary

- The preparation of the next test beam, scheduled for mid-Feb. 2021, is well advanced
- The design of a scalable module is progressing well: different options have been identified and discussed
- The mid-term goal is to build a demonstrator with hadronic containment, partially equipped with SiPM, to assess the hadronic performance on beam

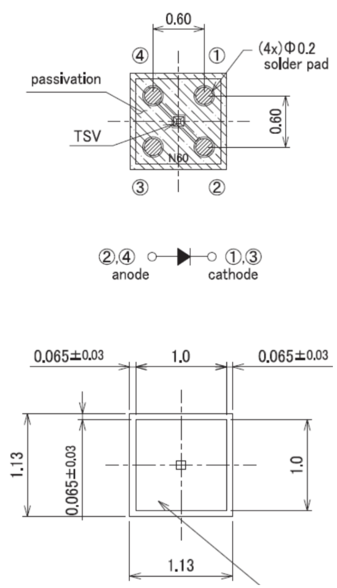
Backup

The SiPM used in the previous test beams

The sensors used were 25 µm cell pitch (S13615-1025)



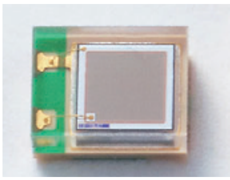
Parameters	S13615 -1025	S13615 -1050	Unit
Effective photosensitive area	1.0x1.0		mm^2
Pixel pitch	25	50	µm
Number of pixels / channel	1584	396	-
Geometrical fill factor	47	74	%



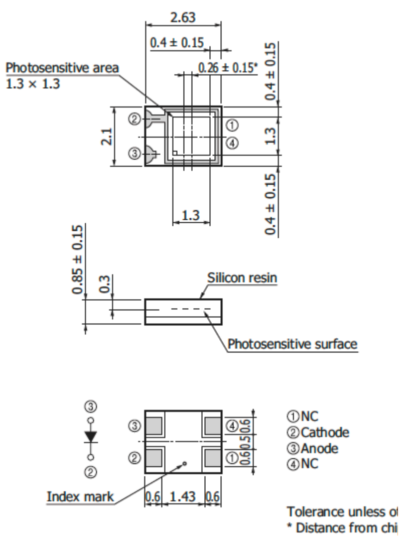
Parameters		Symbol	S13615 -1025	S13615 -1050	Unit
Spectral response range		λ	320 to 900		nm
Peak sensitivity wavelength		λp	450		nm
Photon detection efficiency at λp*3		PDE	25	40	%
Breakdown voltage		V_{BR}	53 ±5		V
Recommended operating voltage*4		V_{op}	V_{BR} + 5	V_{BR} + 3	V
Dark Count	Typ.	-	50		kcps
	Max.		150		
Crosstalk probability	Typ.	-	1	3	%
Terminal capacitance		Ct	40		pF
Gain*5		M	7.0×10^5	1.7×10^6	-

New SiPM under test

New sensors: S14160-1310PS / S14160-1315PS



Parameter	Symbol	S14160				Unit
		-1310PS	-3010PS	-1315PS	-3015PS	
Effective photosensitive area	-	1.3 × 1.3	3 × 3	1.3 × 1.3	3 × 3	mm
Pixel pitch	-	10		15		μm
Number of pixels	-	16675	90000	7296	40000	-
Geometrical fill factor	-	31		49		%
Package	-	Surface mount type				-
Window	-	Silicone resin				-
Window refractive index	-	1.57				-



Parameter		Symbol	S14160				Unit
			-1310PS	-3010PS	-1315PS	-3015PS	
Spectral response range		λ	290 to 900				nm
Peak sensitivity wavelength		λp	460				nm
Photon detection efficiency at λp*2		PDE	18		32		%
Breakdown voltage*3		VBR	38±3				V
Recommended operating voltage*3		Vop	Vbr + 5		Vbr + 4		V
Vop variation within a reel		-	±0.1				V
Dark count rate*4	typ.	DCR	120	700	120	700	kcps
	max.		360	2100	360	2100	
Direct crosstalk probability		Pct	< 1				%
Terminal capacitance at Vop		Ct	100	530	100	530	pF
Gain		M	1.8×10^5		3.6×10^5		-
Temperature coefficient of Vop		ΔTVop	34				mV/°C

*2: Photon detection efficiency does not include crosstalk and afterpulses.
*3: Refer to the data attached for each product.
*4: Threshold=0.5 p.e.