IDEA DR Calorimeter: readout electronics

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On behalf of the IDEA Dual-Readout calorimeter collaboration

The R&D strategy

- The R&D planned for the next years has 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

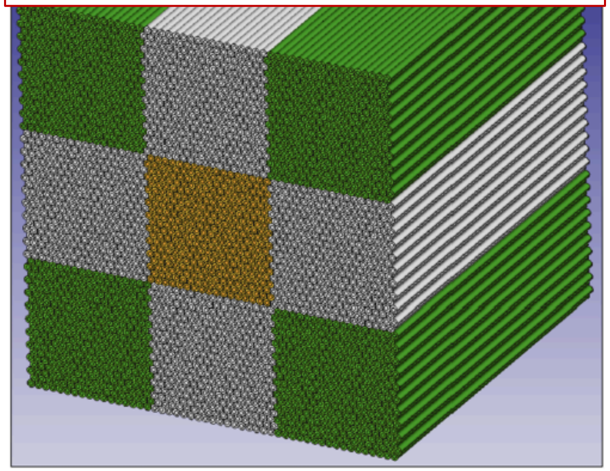
- The R&D planned for the next years has three main objectives:
  - Assess the EM performance of a dual-readout calorimeter module
  - Identify and test solutions at system level (i.e. mechanics/assembly, sensors, readout scheme, calibration etc.)
  - Demonstrate on beam the hadronic performance of the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

Outline

- Status of the short-term plan (2021):
  - Test beam preparation (planned for spring and / or Autumn 2021)
- R&D for the mid-term plan (2022-2025):
  - New module design
  - New readout scheme

Test beam: mechanics and assembly

See Gabri's talk for details



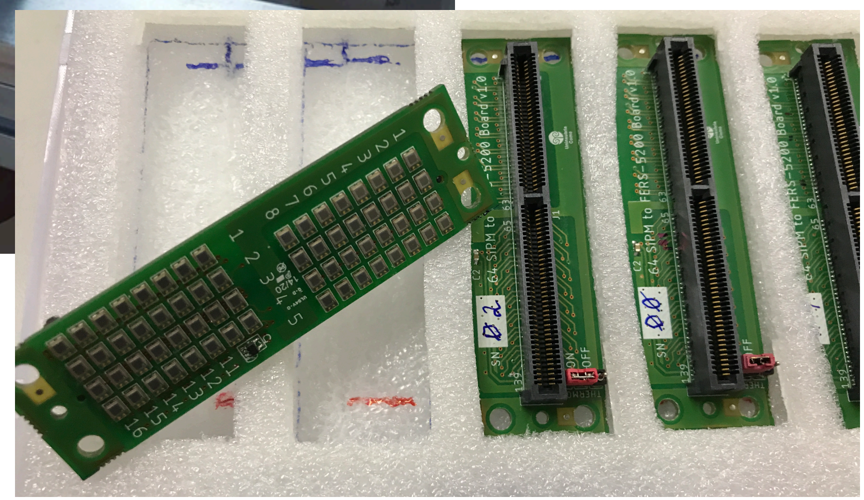
- EM-prototype (10x10x100 cm^3)
  - 9 modules made of 16 x 20 capillaries (160 C and 160 Sc)
  - Capillaries (brass): 2 mm outer diameter and 1.1 mm inner diameter
- EM-prototype readout
  - Each capillary of the central module is equipped with its own SiPM: highly granular readout
  - 8 surrounding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

Test beam: mechanics and assembly

See Gabri's talk for details

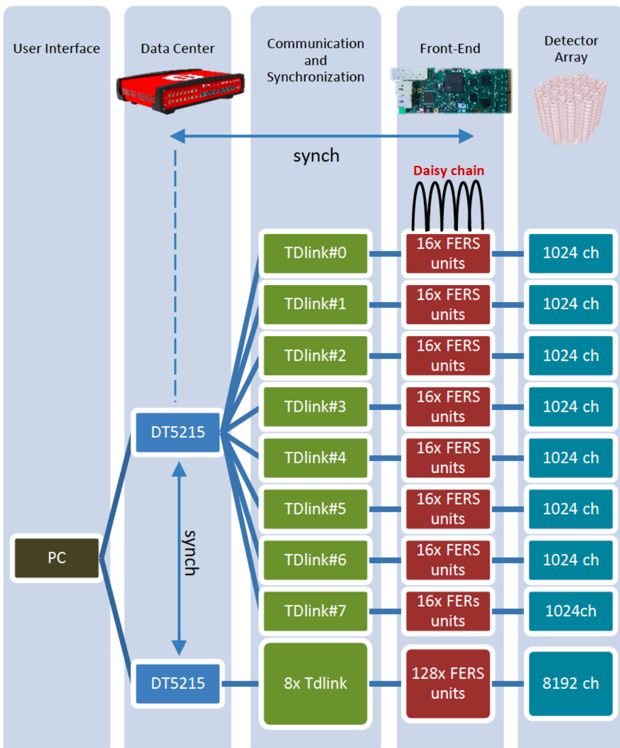
Readout Boars:
5 FERS - A5202



FEE – Boards
5 Boards (320 SiPMs)

Test beam: readout scheme

- The readout of the PMTs will is on Caen QDC (V862AC) and TDC (V775N) modules
- The readout of the highly granular module (320 SiPMs) is 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 units 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

Test beam: readout scheme

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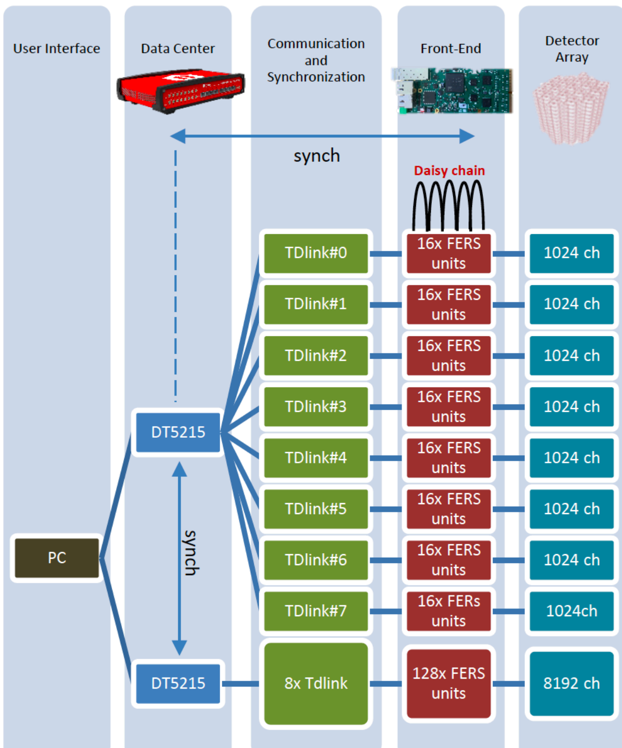
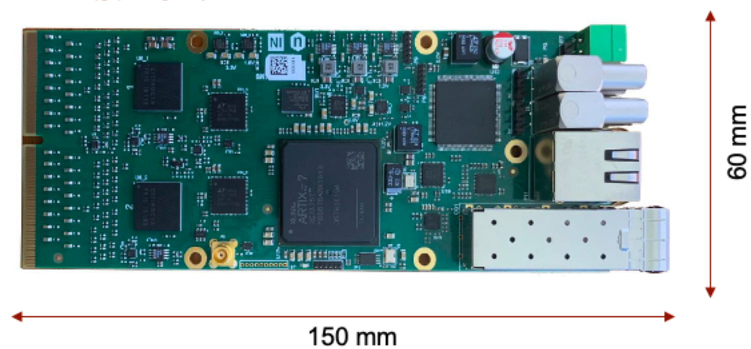


FERS: A5202



- Two Citiroc1A for reading out up to 64 SiPMs
- One (20 – 85V) HV power supply with temperature compensation
- Two 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)

Test beam: readout scheme

- The readout of the PMTs will is on Caen QDC (V792AC) and TDC (V775N) modules
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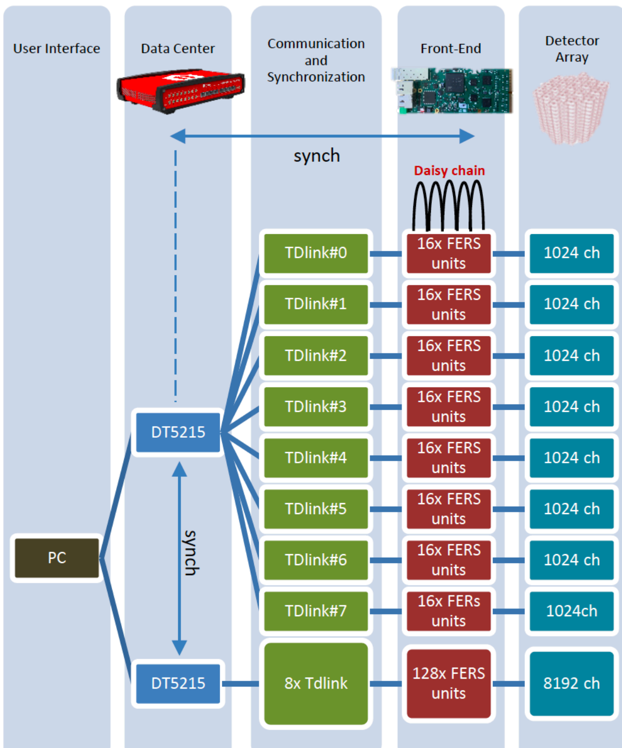

CITIROC 1A: specification

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

Test beam: readout scheme

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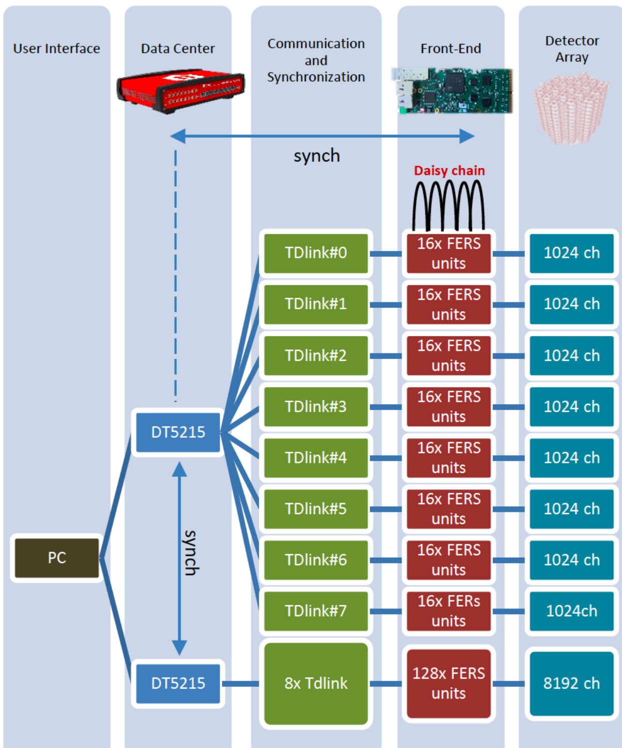
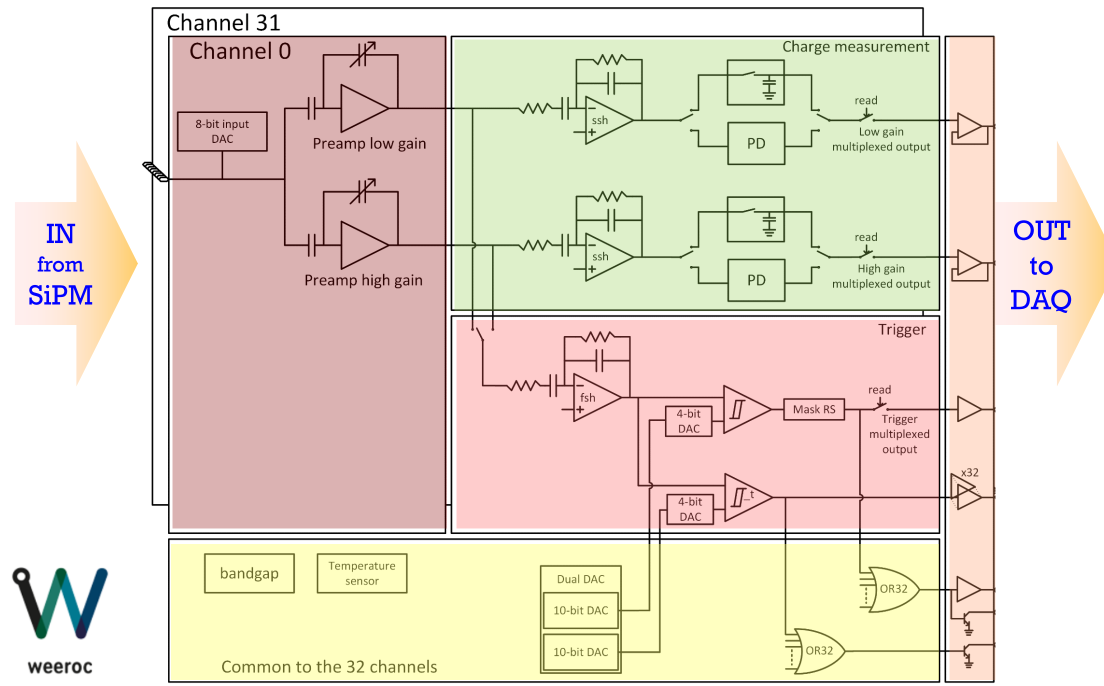


CITIROC 1A: block diagram



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

Test beam: readout scheme

Trigger Strategy

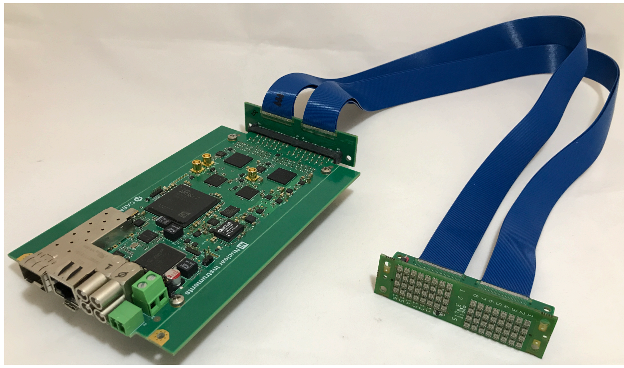
- The trigger is based on a majority logic at FERS (A5202) level
  - The majority is based on 64 Fast Shaper signals (1 per SiPM)
  - The threshold on the discriminator can be set at the level of single ph-e
- The majority signal activates the peak-search to measure the amplitude for all the SiPMs in the FERS
- The trigger from the test beam ancillary detectors is used as event-accept signal
- The Data concentrator synchronizes the FERS and makes the event building

Test beam: readout scheme

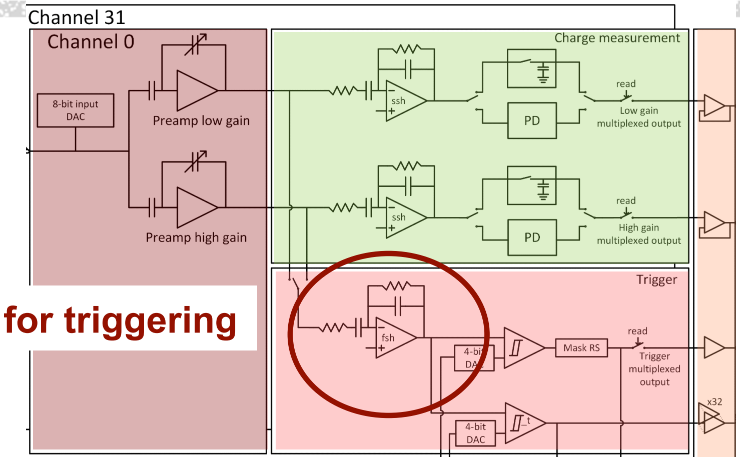
Timing Information

- Each FERS has 2 TDCs with high resolution (LSB=50 ps) and 64 TDCs (LowRes) coded on FPGA (LSB=500 ps)
- The LowRes TDCs can be used to measure:
  - The ToT for each SiPM
  - The ToA for each SiPM wrt the event-accept
- Two signals / FERS can be measured with HighRes TDCs: different options are possible:
  - 1^{st} option: majority and OR wrt the event-accept signal
  - 2^{nd} option: majority (cherekov) and majority (sc) wrt the event-accept signal
  - 3^{rd} option: OR (cherekov) and OR (sc) wrt the event-accept signal

Readout system qualification

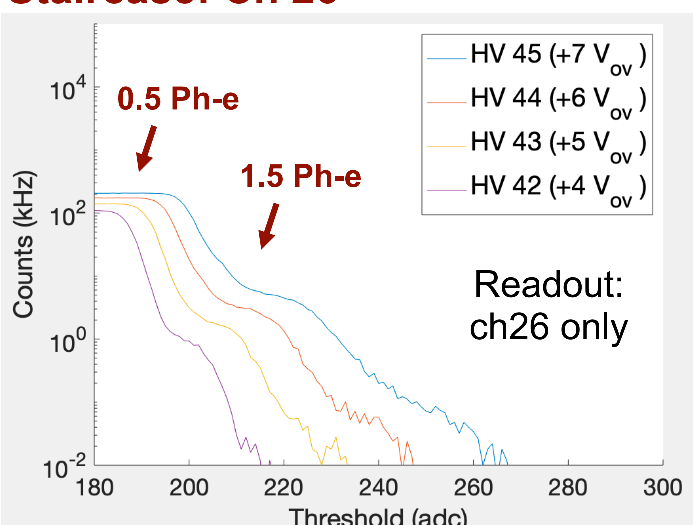


Hamamatsu SiPM: S14160-1315PS
Cell size $=15\mu m$



Fast shaper for triggering

Staircase: Ch 26



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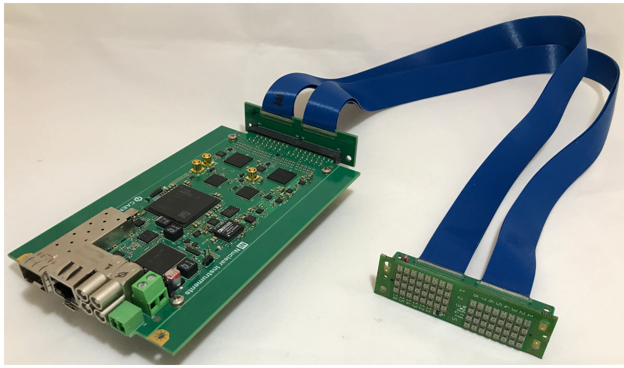
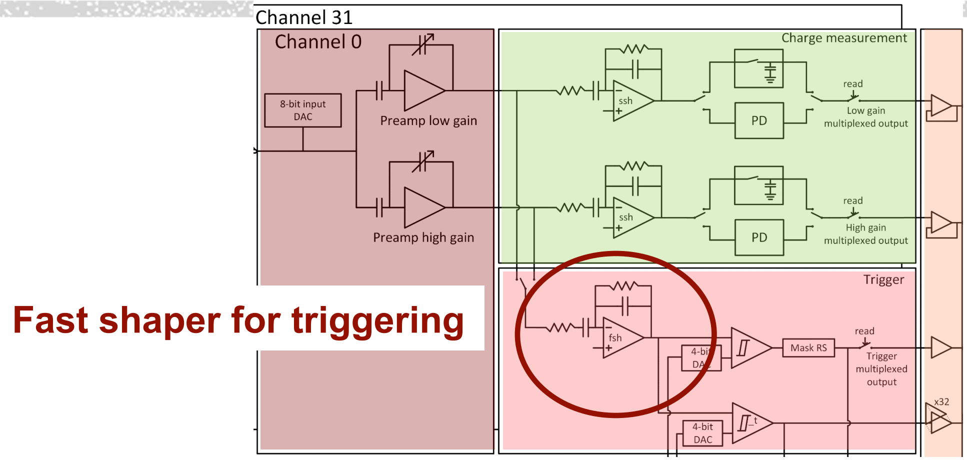
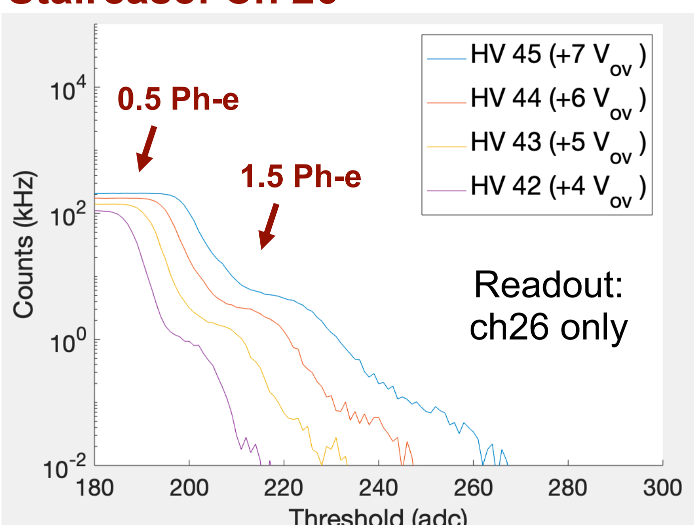




Hamamatsu SiPM: S14160-1315PS
Cell size =15μm

Staircase: Ch 26



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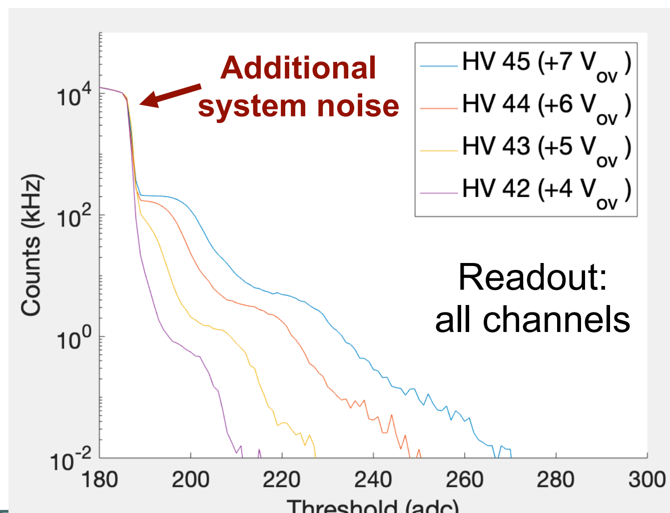
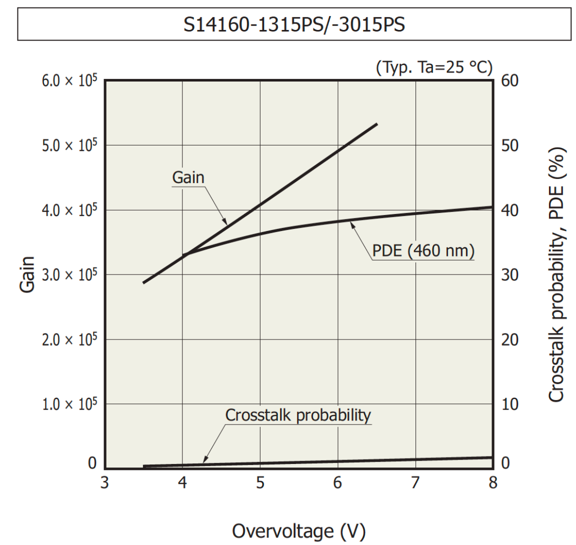
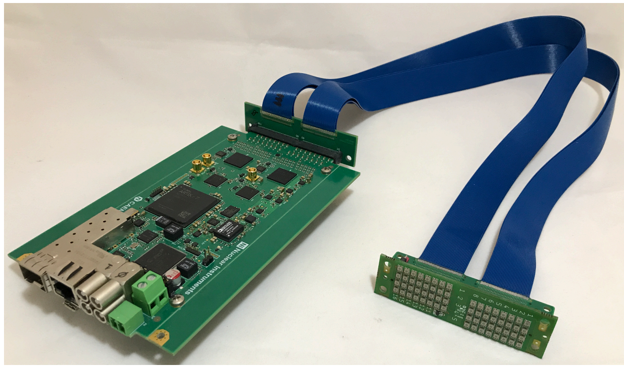
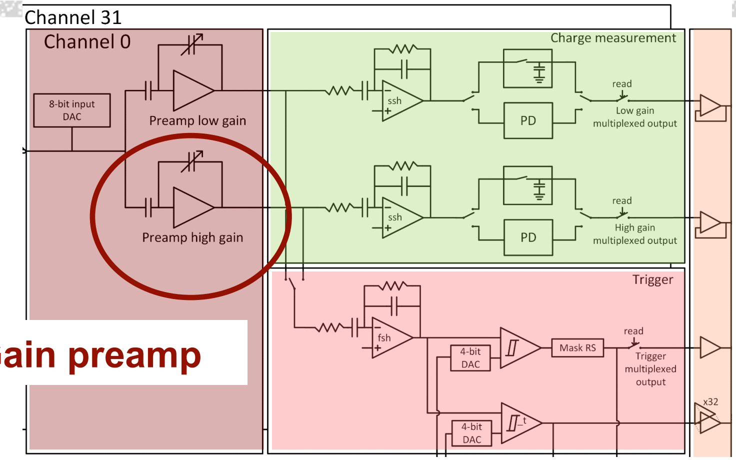




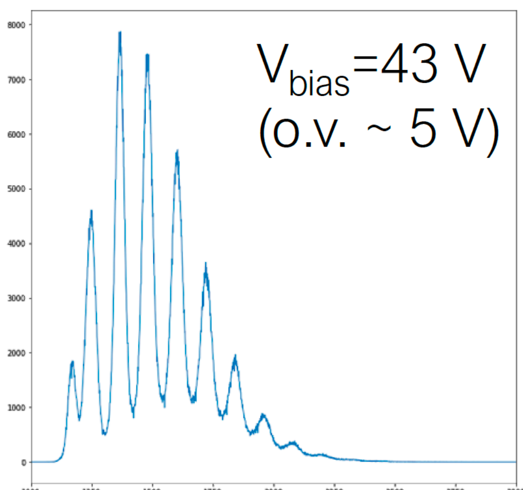
Readout system qualification

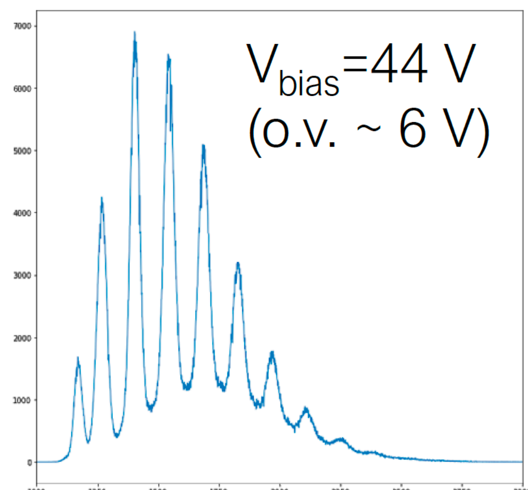


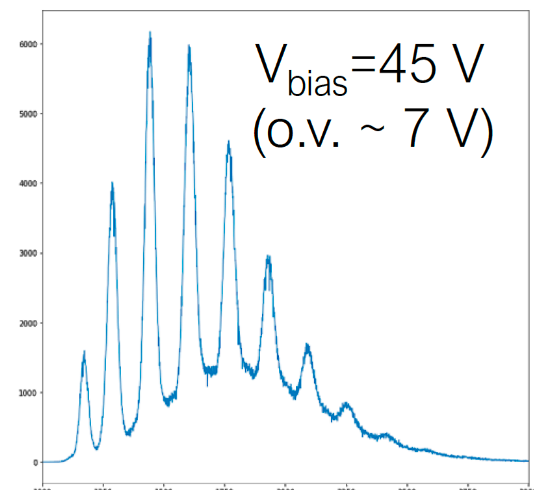
Hamamatsu SiPM: S14160-1315PS
Cell size =15μm



High Gain preamp

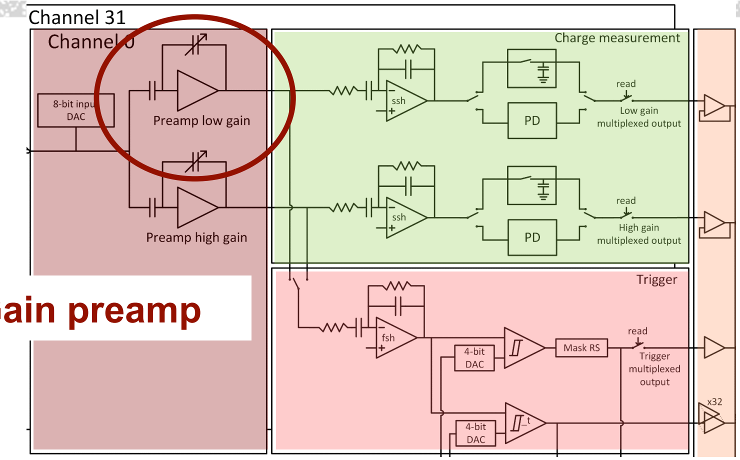






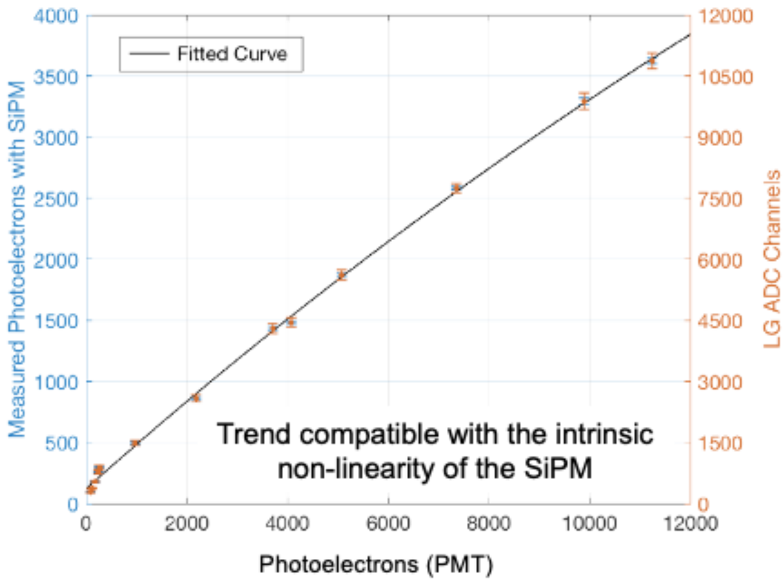
Citiroc1A: qualification

Measurement performed with the DT5550W evaluation board



Low Gain preamp

Dyn-range measured with the S14160-1315PS



Citiroc1A: qualification

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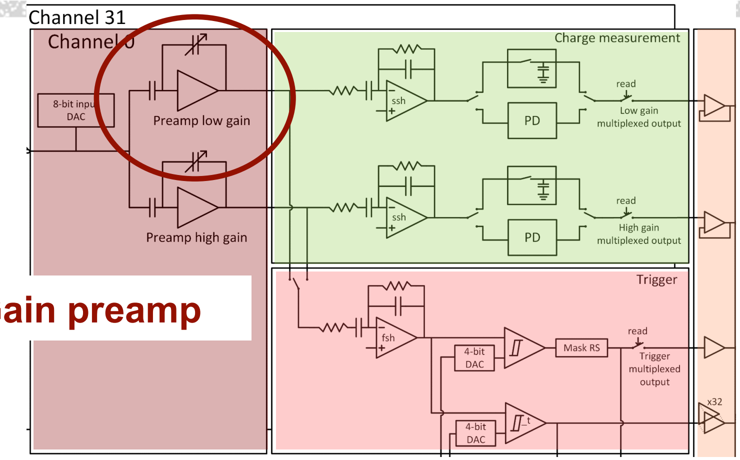

Low Gain preamp

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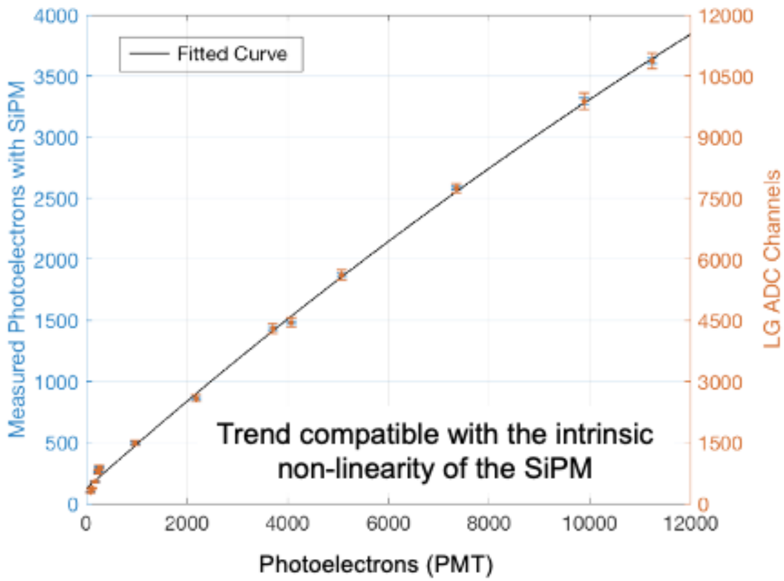
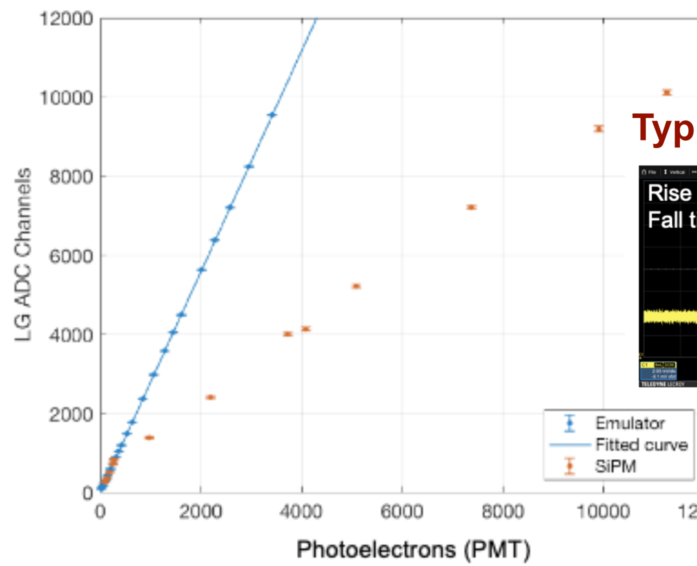
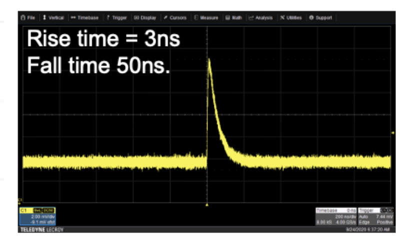


Linearity qualified with the detector emulator (DT5810 - Caen)



Typical injected signal



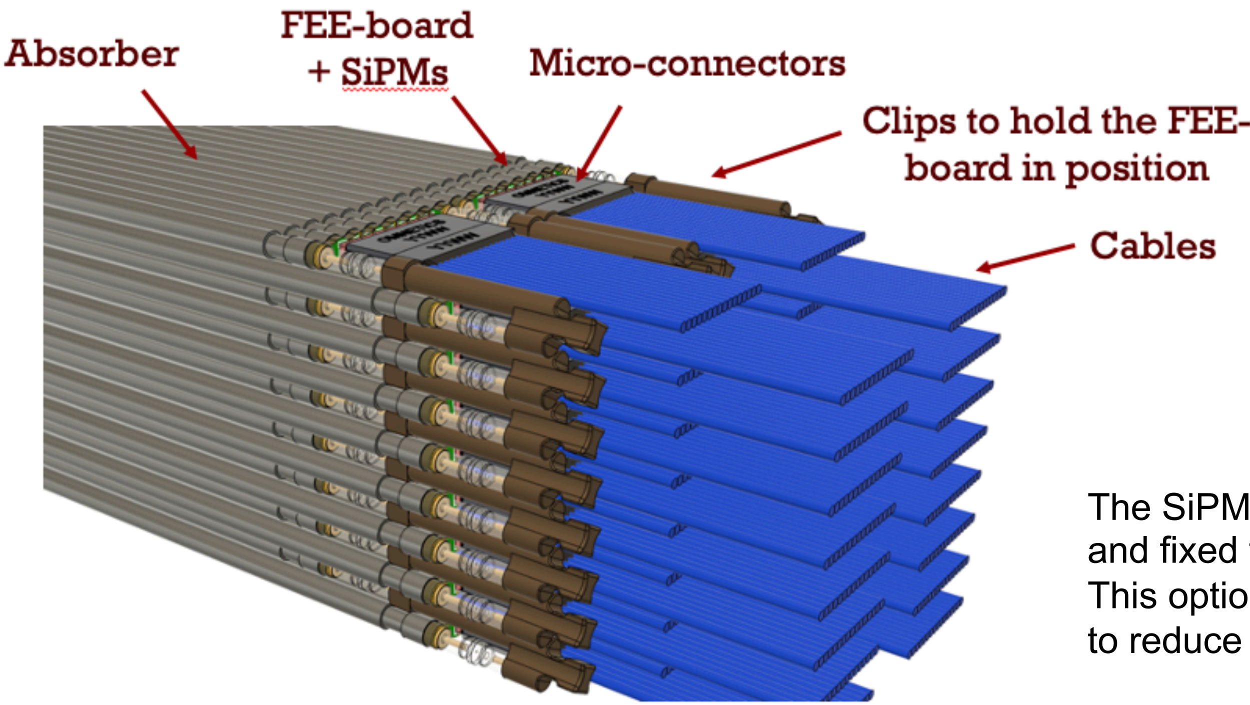
Outline

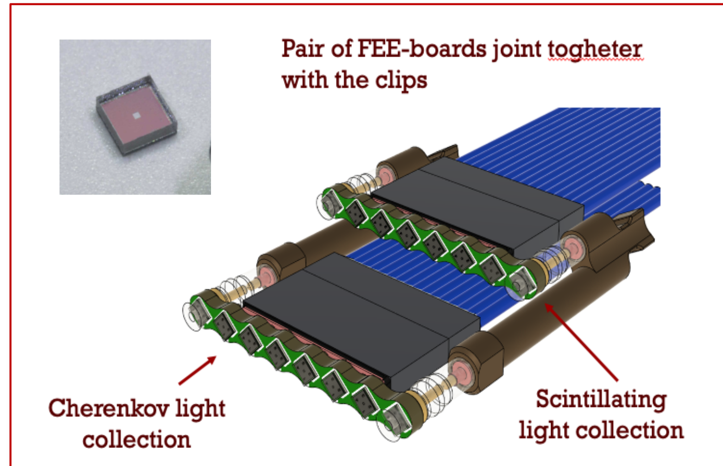
- Status of the short-term plan (2021):
  - Test beam preparation (planned for spring and / or Autumn 2021)
- R&D for the mid-term plan (2022-2025):
  - New module design
  - New readout scheme

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



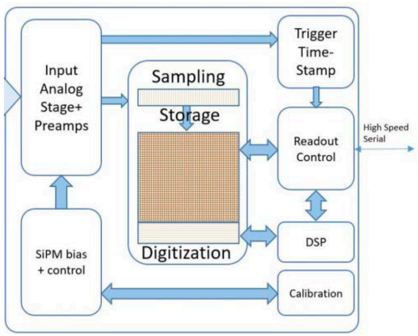


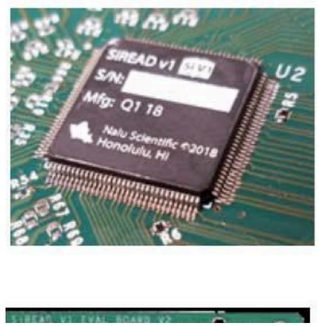
The SiPMs will be directly connected to the fibres and fixed to the absorber
This option will allow to group signals from 8 SiPMs to reduce the number of channels to be read out

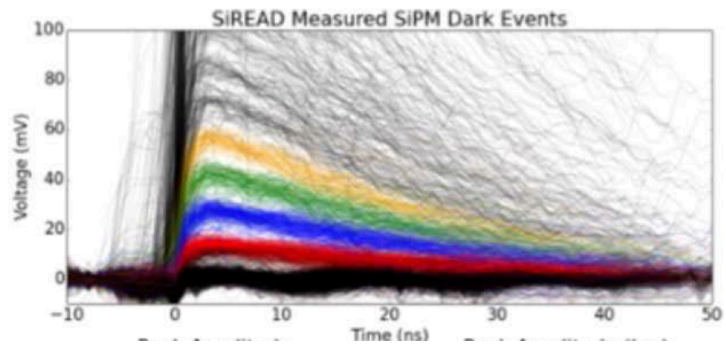
Readout scheme: an alternative approach

We are also considering waveform sampler ASICS with feature extraction

The SiREAD



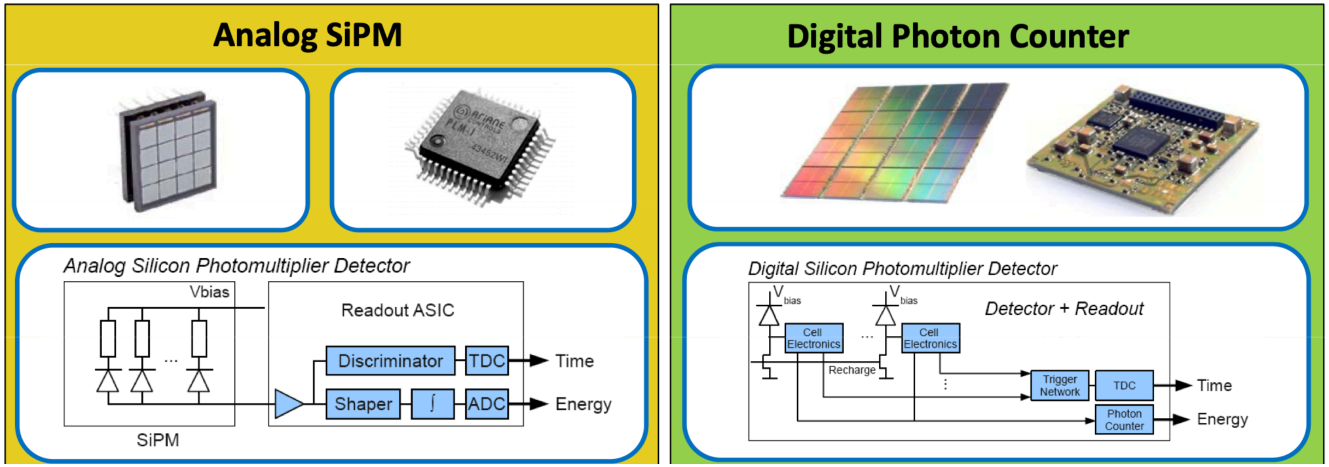




https://indico.bnl.gov/event/6351/contributions/29462/attachments/23682/34356/190709_Nalu_Scientific_-_Electronics_Update_for_EIC-PID_workshop_for_web.pdf

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

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 SiPMs. Nevertheless they are rapidly improving
- This R&D 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 from different sensors

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

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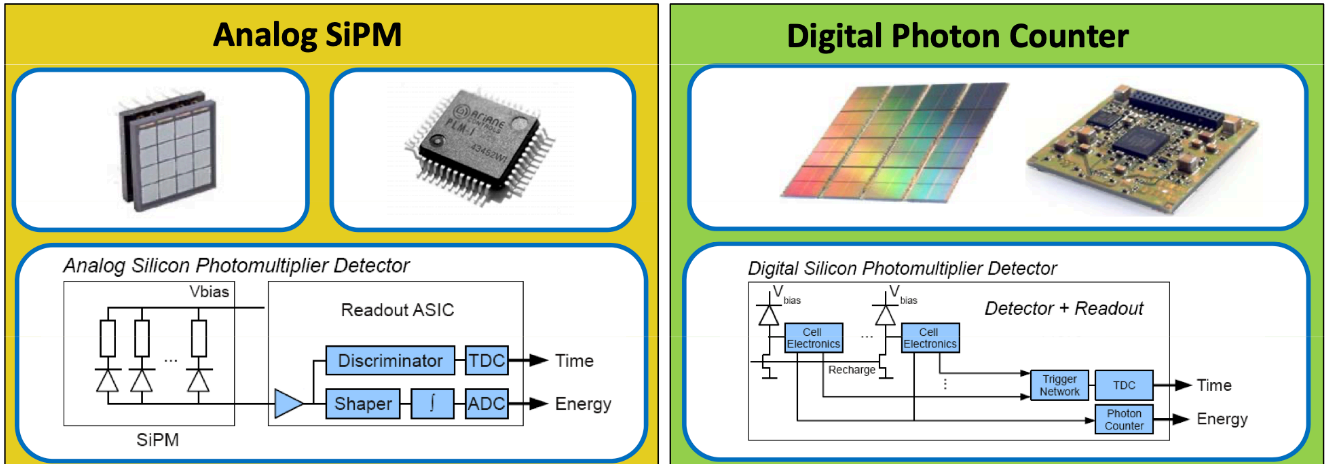

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  - Simplified readout system
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Two proposals have been submitted for grants on this topic
- CSNV call in 2020 (well evaluated but not funded)
- PRIN – 2021 (just submitted)

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

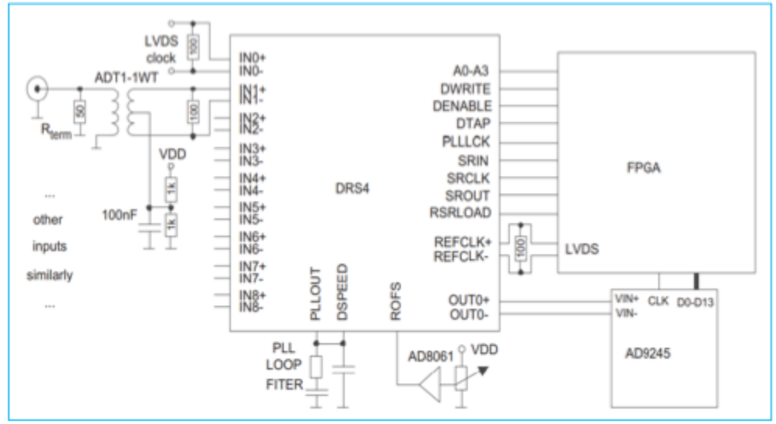
Readout System R&D (in Korea)

DRS chip

DRS chip can help us to reach our R&D goals of readout system.

Typical operation mode - NIM A 623 (2010) 86, Stefan Ritt et al.

Specification of DRS chip
- DRS (Domino Ring Sampler) based on SCA (Switched Capacitor Arrays)
- Channel number of input and trigger: 8 + 1 ch
- Sampling frequency: 1~5 GSPS (1 ns ~ 200 ps/sampling depth)
- Number of sampling depth: 10 bit
- Power consumption: max. ~40 mW/channel
  [ex] ~40 mV/ch * 480 ch = 19.2 W for 60 DRS chips



According to the user's comments, the **time resolution of DRS** can be expected ~10% of one sampling depth.
[ex] If we open ~300 ns gate with one sampling bucket is ~300 ps, then ~30 ps can be reached.

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https://indico.cern.ch/event/992076/contributions/4181022/attachments/2170249/3664295/20210113-KFC-TB2021_ReadoutSystem-mryu.pdf

Readout System R&D (in Korea)

Introduction of NOTICE Korea

http://www.noticekorea.com/

NOTICE

NOTICE
Nuclear physics and optical test instrument and communication equipment
=
Nuclear physics and
+
Optical
+
Test
+
Instrument and
+
Communication
+
Equipment

NOTICE Korea is a domestic company that has been **developing and supplying a front-end electronics (FEE) and readout system** for high-energy experiments and other application fields.

40 CHANNEL TRIGGER & CLOCK MODULE
TCB 40 channel trigger and clock module generates clock and trigger signals for NKFADC500 and M64ADC.

ECL COLLECTOR BOARD
N-CB-2-12 ECL Collector board is a electronic board for **Belle experiment in KEK laboratory**.

SHAPER AND DIGITIZER BOARD
SDB-2012 shaper and digitizer board is a electronic board for **Belle experiment in KEK laboratory**.

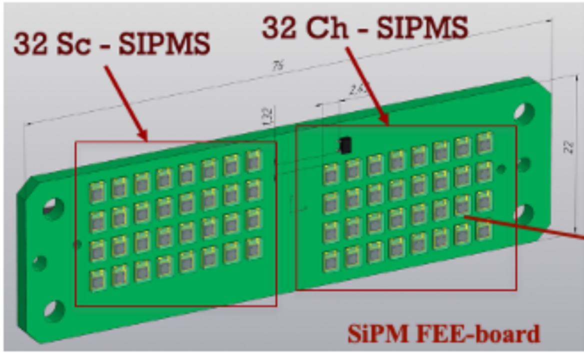
Min Sang RYU (Univ. of Seoul)
https://indico.cern.ch/event/992076/contributions/4181022/attachments/2170249/3664295/20210113-KFC-TB2021_ReadoutSystem-mryu.pdf

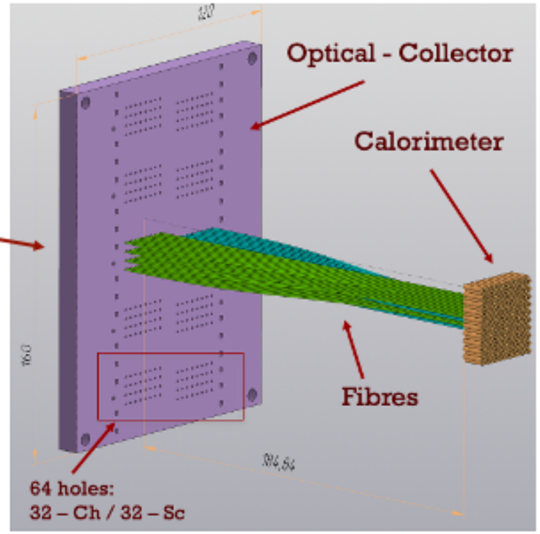
Summary

- The preparation of the next test beam is well progressing even if with some delay due to the pandemic
  - In these days we are commissioning the readout system
  - We received 3/5 FERS
  - The data concentrator is still missing but we have a backup solution for the test beam in case of further delay
- We are also considering alternative approaches:
  - Waveform sampler with data extraction
  - Digital SiPM: option of great interest for future R&D

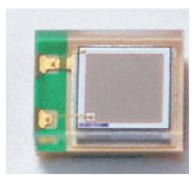
Backup

Test beam: assembly



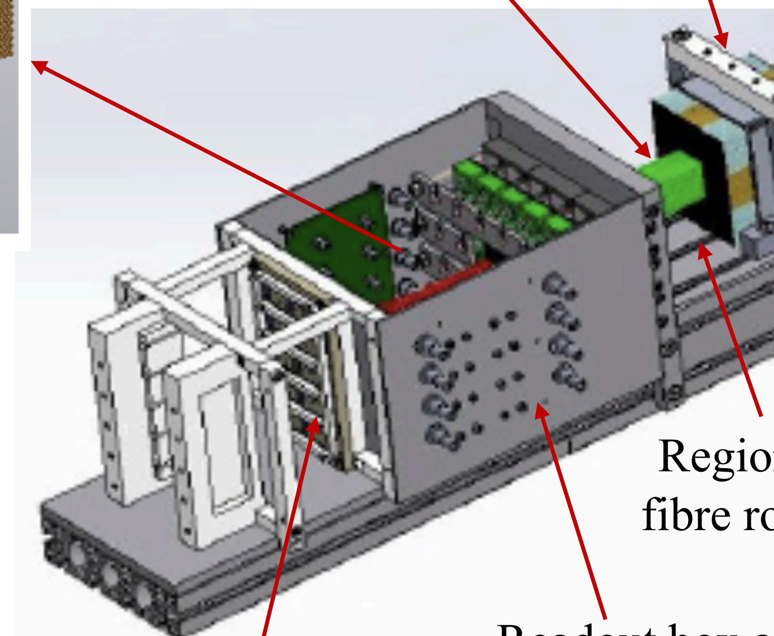


S14160-1315PS		
Effective Area	1.3x1.3	mm^2
Cell pitch	15	μm
Number of cells	7296	
Geometrical factor	49	%
Vbd	38+-3	V
Gain	$3.6*10^5$	
PDE	32	%
Xtalk	<1	%
DCR (Typical)	120	kHz



Central module (read out by SiPM)

Prototype rear-end



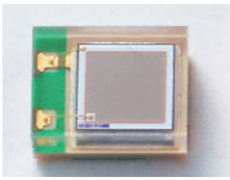
Region for fibre routing

Readout box and patch-panel for SiPMs

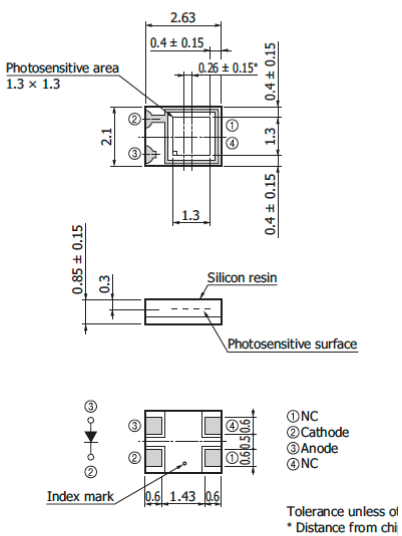
Readout box and patch-panel for PMTs

New SiPM under test

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



Parameter	Symbol	S14160 -1310PS	S14160 -3010PS	S14160 -1315PS	S14160 -3015PS	Unit
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				-

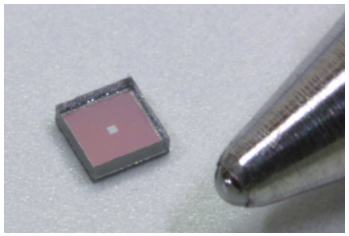


Parameter		Symbol	S14160 -1310PS	S14160 -3010PS	S14160 -1315PS	S14160 -3015PS	Unit
Spectral response range		λ	290 to 900				nm
Peak sensitivity wavelength		λp	460				nm
Photon detection efficiency at λp*2		PDE	18		32		%
Breakdown voltage*3		V_{BR}	38±3				V
Recommended operating voltage*3		Vop	Vbr + 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

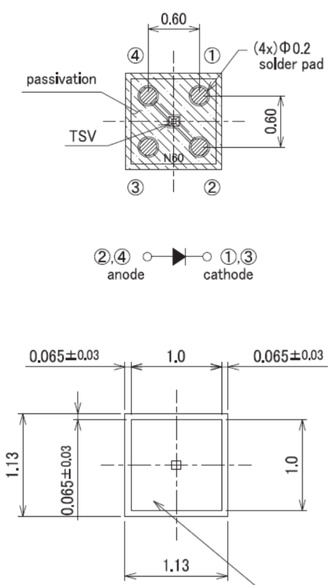
*2: Photon detection efficiency does not include crosstalk and afterpulses.
*3: Refer to the data attached for each product.
*4: Threshold=0.5 p.e.

The SiPM used in the previous test beams

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



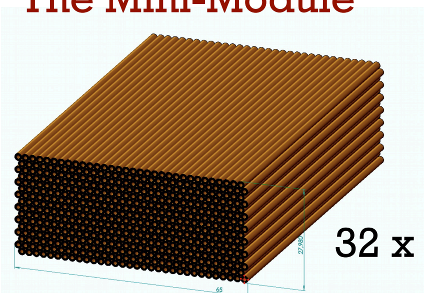
Parameters	S13615 -1025	S13615 -1050	Unit
Effective photosensitive area	1.0x1.0		mm^2
Pixel pitch	25	50	µm
Number of pixels / channel	1584	396	-
Geometrical fill factor	47	74	%



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	-

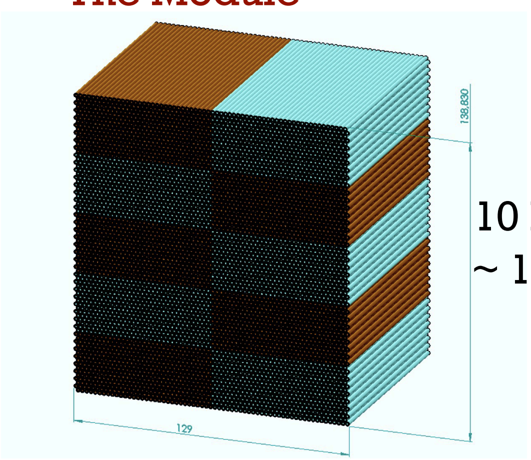
Prototype with hadronic containment

The Mini-Module



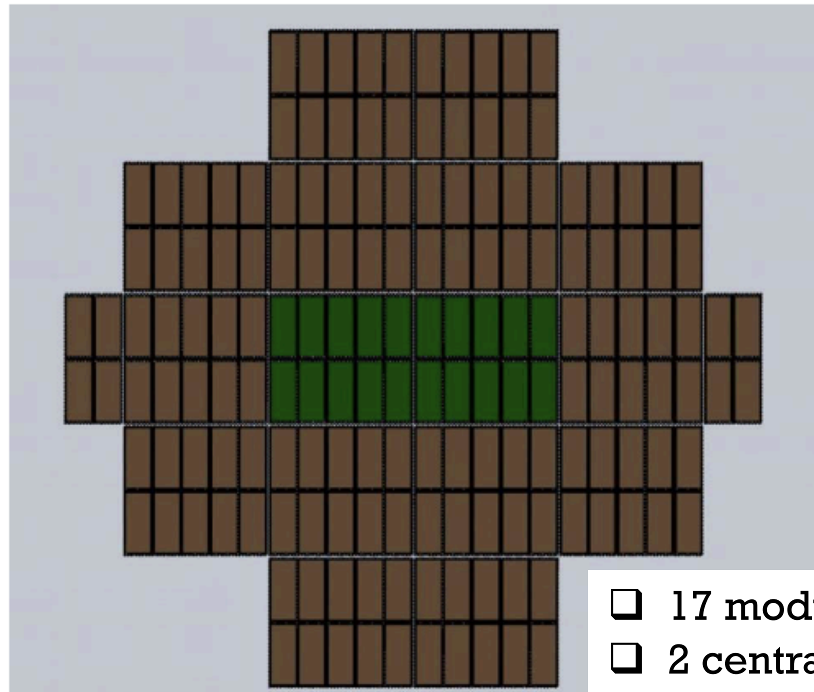
32 x 16 capillaries

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