SiPM e ALCOR

2 settembre 2021 -- incontro EIC_NET con i referee INFN

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a nome del gruppo **sipm4eic-elettronica**

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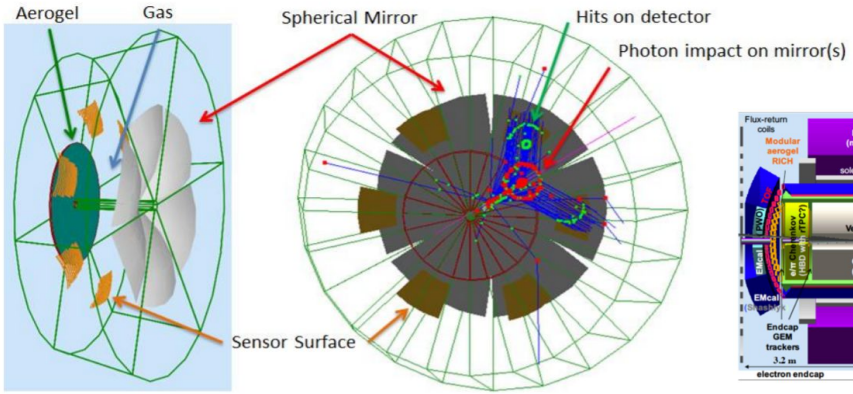
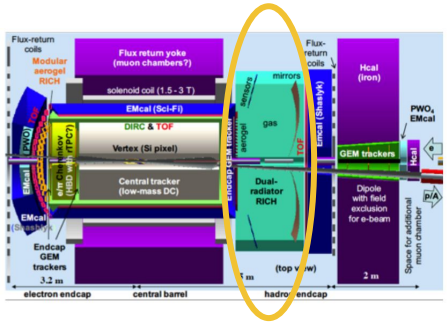
SiPM R&D program

- **born within the forward RICH proposal for EIC**
  - proof of feasibility of SiPM for Cherenkov application at colliders, this requires
    - single-photon counting capabilities (SiPM can do it)
    - reasonable dark-count rates (low-temperature operation, time resolution)
    - radiation tolerance (small SPAD cells, high-temperature annealing)
  - SiPM readout with dedicated readout electronics
    - ALCOR front-end ASIC (Torino)
    - streaming (aka continuous) readout DAQ
- **two main phases in 2021**
  - characterisation of the sensors before and after irradiation
  - use of the sensors (with/without irradiation) in dRICH prototype at test beam
- **can have direct applications in multiple cases, i.e.**
  - other EIC detectors looking for B-tolerant photon counters
  - the Aerogel-RICH proposal for ALICE3

this R&D is 100% synergic with ALICE3

dRICH proposal for forward PID

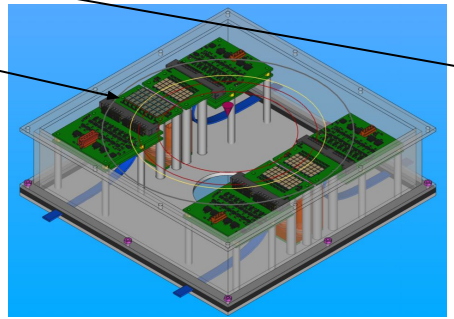


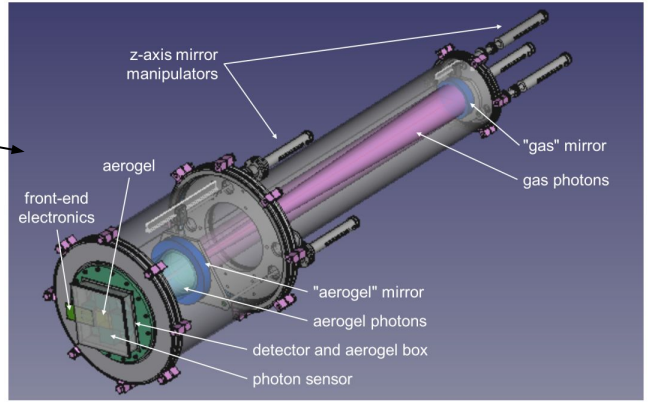


- **dual-radiator RICH (dRICH)**
  - aerogel (n ~ 1.02) + gas (n ~ 1.0008)
  - for PID in the hadronic endcap
    - $3 < p < 50$ GeV/c
    - $1.5 < \eta < 3.5$
  - 6 sectors x 0.5 m^2/sector photosensors
    - ~ 1 T magnetic field
    - sensors out of acceptance

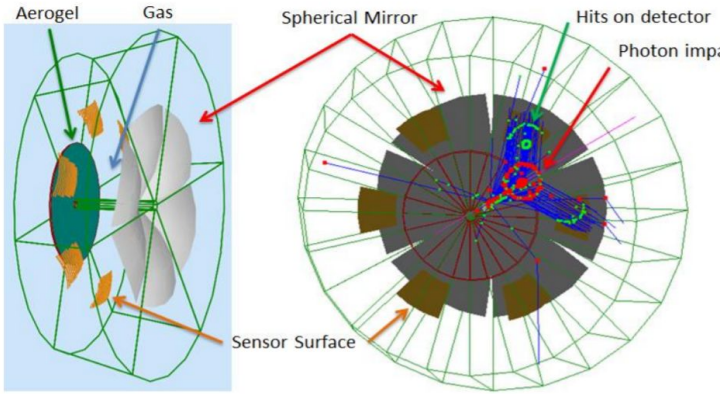
explore SiPM readout option

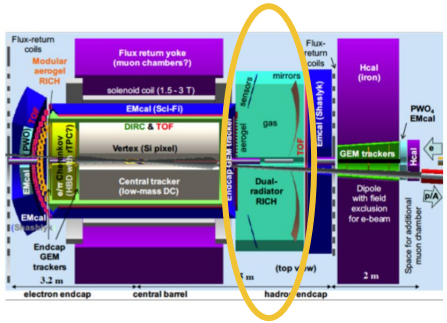
- **realisation of dRICH prototype, test beam in 2021**
  - design of electronics boards
  - SiPM studies
    - irradiation tests (@ Trento)
    - annealing at high T ~ 170°
    - operation at low T ~ −40°
  - DAQ for front-end readout
    - front-end based on ALCOR





dRICH proposal for forward PID





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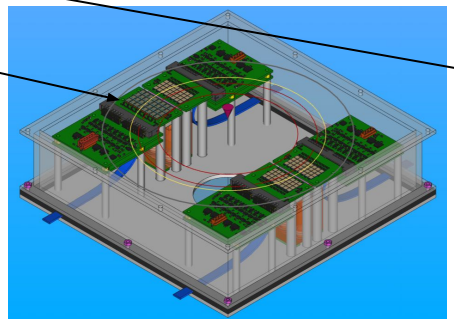
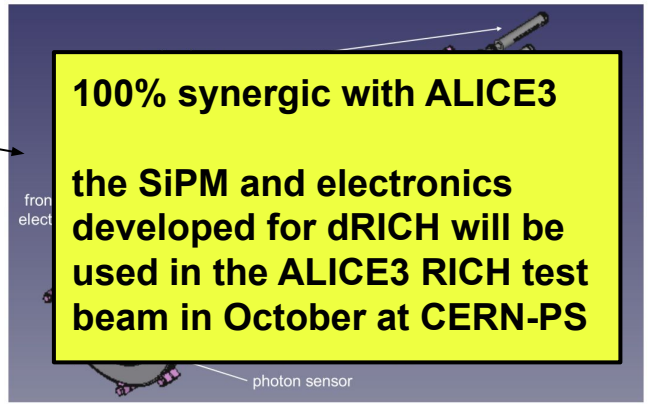




100% synergic with ALICE3

the SiPM and electronics developed for dRICH will be used in the ALICE3 RICH test beam in October at CERN-PS

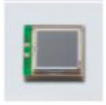
Electronics equipment

acquisition of commercial and prototype (FBK) SiPM sensors
design and production of dedicated electronics boards

- **SiPM carrier boards (BO)**
  - host SiPM matrix: designed with irradiation, annealing and testbeam in mind
  - one form factor, different layout for different SiPM family
- **SiPM adapter boards (FE)**
  - couples the SiPM carrier board with readout system (oscilloscope, ALCOR)
    - IV-base adapter (for SiPM IV and DCR characterisation)
    - mini-adapter (for ALCOR-TEST board)
    - adapter-CA (for ALCOR-FE board)
- **ALCOR FrontEnd board (TO)**
  - hosts ALCOR frontend ASIC
- **FireFly breakout board (ARCADIA)**
  - links ALCOR I/O to FPGA
    - ALCOR configuration and readout

the list does not stop here, these are the main equipment boards

Commercial SiPM sensors



board	sensor	uCell (μm)	V_{bd} (V)	PDE (%)	DCR (kHz/mm^2)	window	notes
HAMA1	S13360 3050VS	50	53	40	55	silicone	legacy model Calvi et. al
	S13360 3025VS	25	53	25	44	silicone	legacy model smaller SPAD
HAMA2	S14160 3050HS	50	38	50		silicone	newer model lower V_{bd}
	S14160 3015PS	15	38	32	78	silicone	smaller SPADs radiation hardness
SENSL	MICROFJ 30035	35	24.5	38	50	glass	different producer and lower V_{bd}
	MICROFJ 30020	20	24.5	30	50	glass	the smaller SPAD version
BCOM	AFBR S4N33C013	30	27	43	111	glass	commercially available FBK-NUVHD

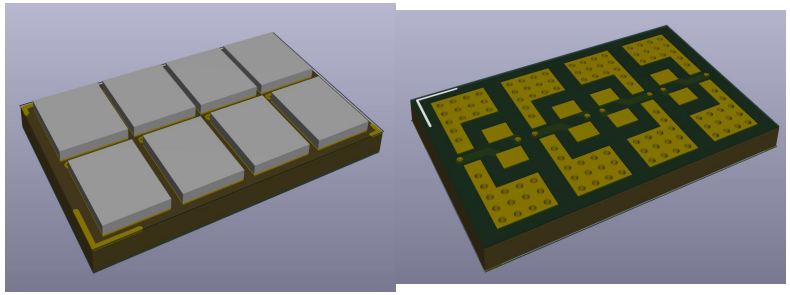
HAMAMATSU
PHOTON IS OUR BUSINESS

ON Semiconductor

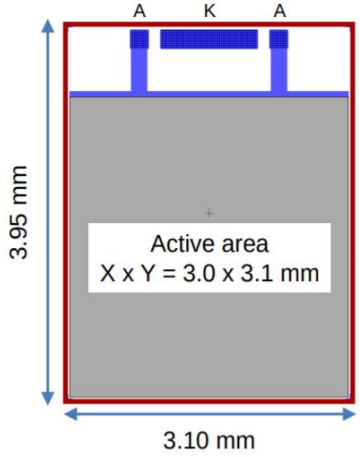
BROADCOM

and FBK prototype sensors wire bonded on custom mini-tiles

FBK has developed for us custom mini-tiles hosting 2x4 prototypes each



NUV-HD-RH

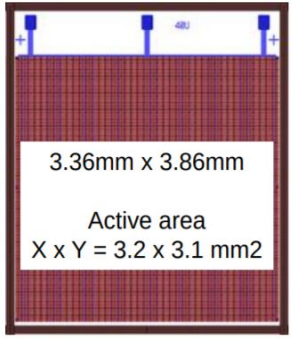


NUV-HD-RH

Technology under development optimized for radiation hardness in HEP experiments

- Cell pitch 15 µm with high fill factor
- Fast recovery time – reduced cell occupancy Tau recharge < 15 ns
- Primary DCR @ +24°C ~ 40 kHz/mm^2
- Correlated noise 10% @ 6 V

NUV-HD-CHK



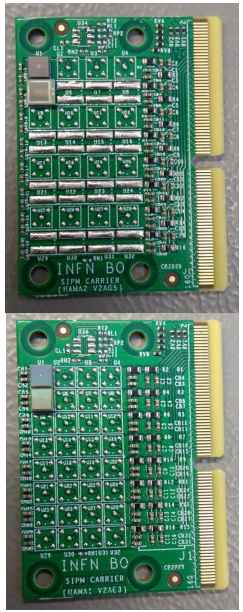
NUV-HD big cells

Technology similar to NUV-HD-Cryo Optimized for single photon timing

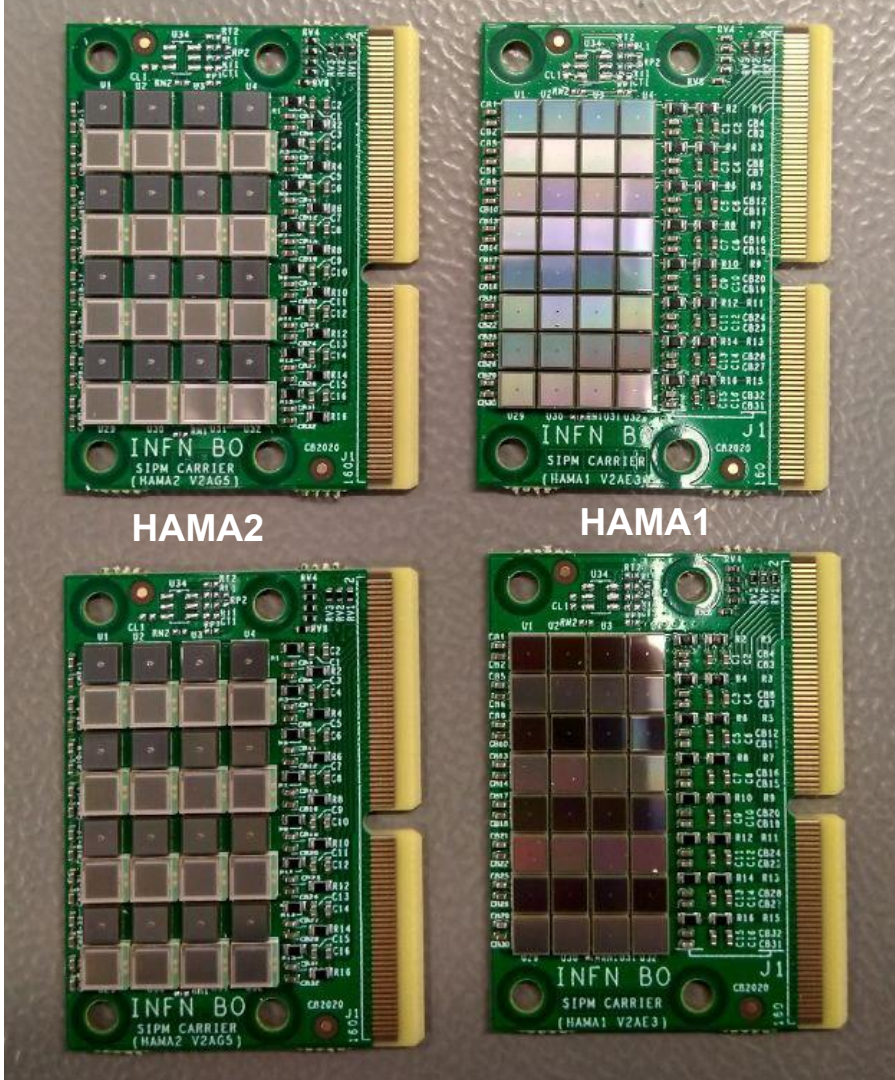
- Cell pitch 40 µm
- High PDE > 55%
- Primary DCR @ +24°C ~ 50 kHz/mm^2
- Correlated noise 35% @ 6 V

Schede SiPM carrier

- **SENSL**
  - 2 schede FULL
  - 3 schede LIGHT
- **BCOM**
  - 4 schede FULL
  - 2 schede LIGHT
- **HAMA1**
  - 2 schede FULL
  - 3 schede LIGHT
- **HAMA2**
  - 2 schede FULL
  - 3 schede LIGHT
- **FBK**
  - 4 schede FULL



schede LIGHT



schede FULL

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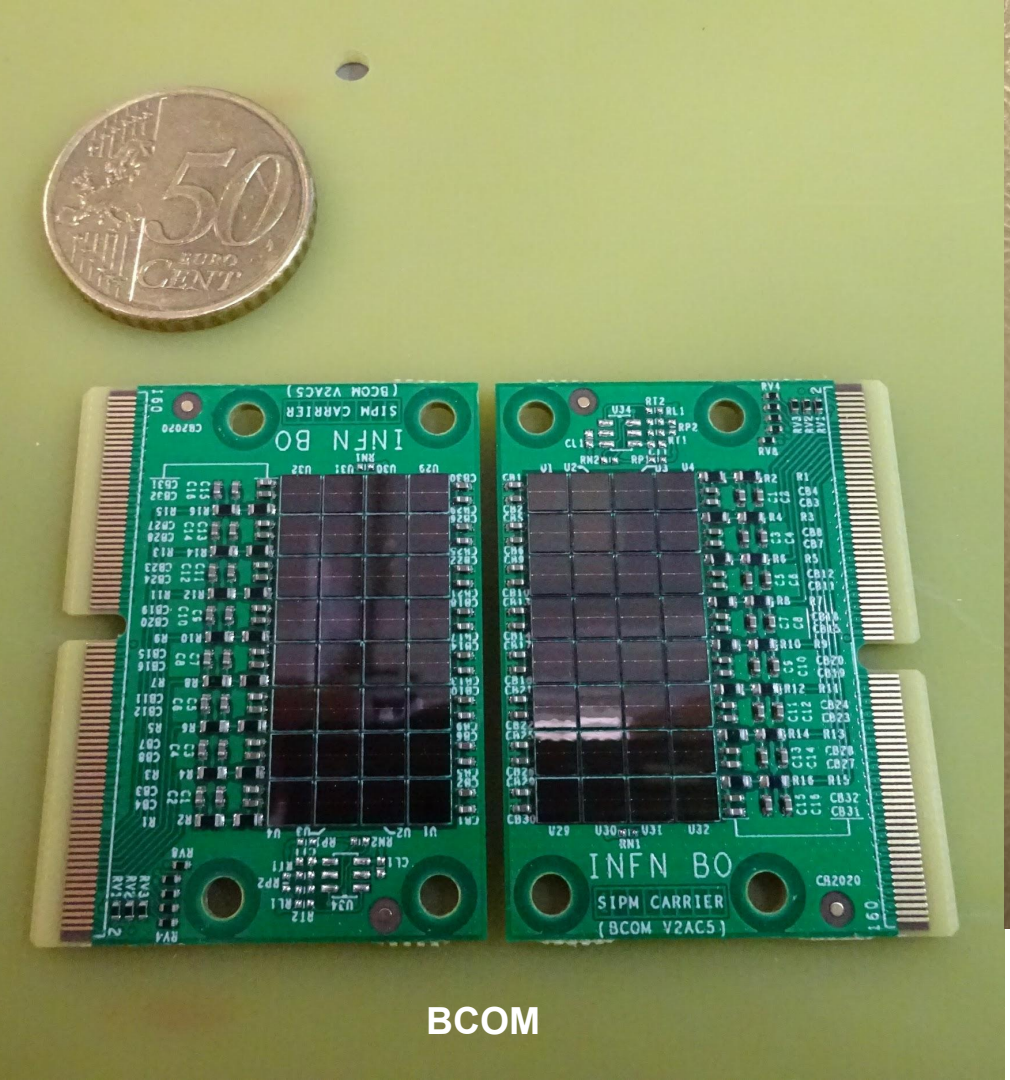
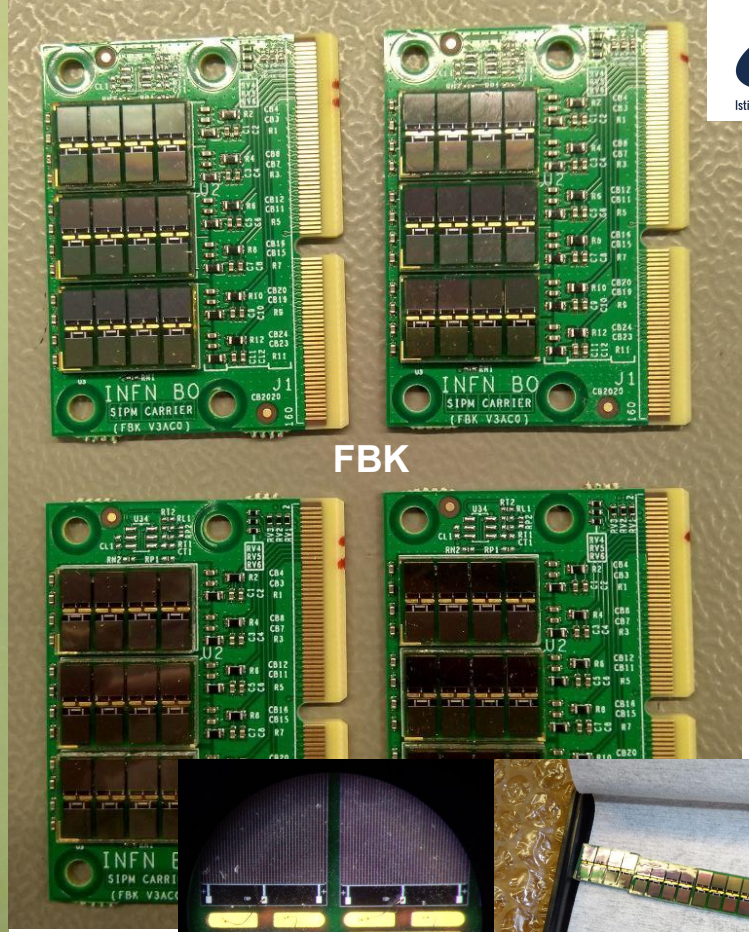
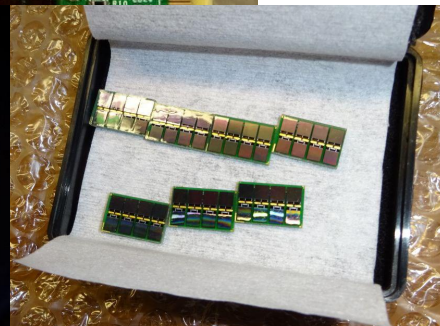


BCOM



FBK



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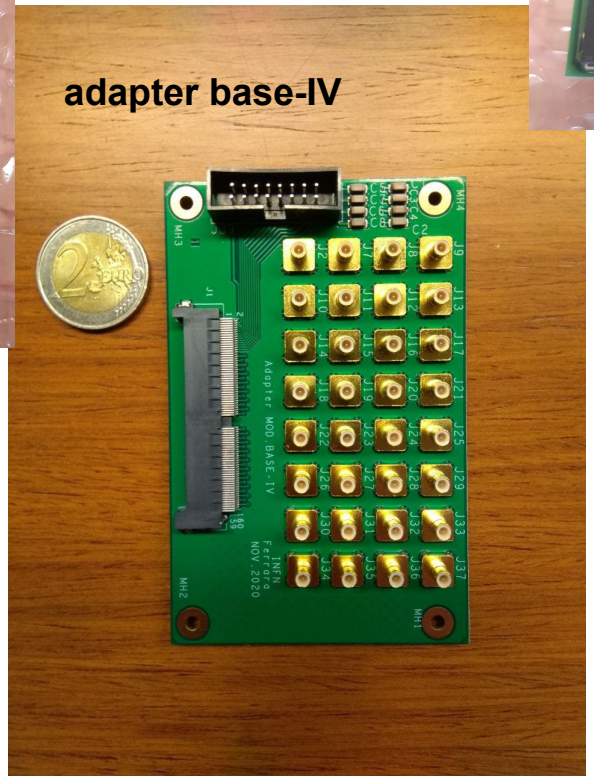
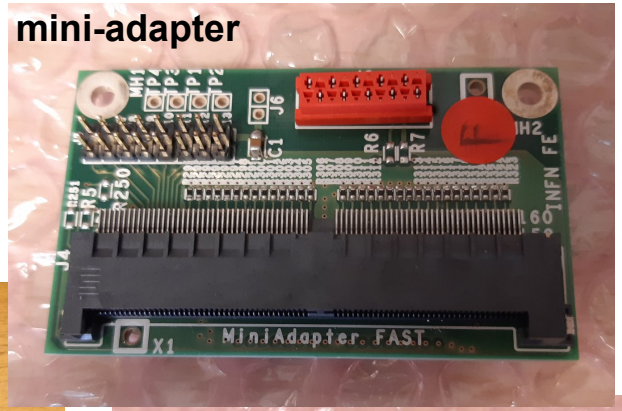
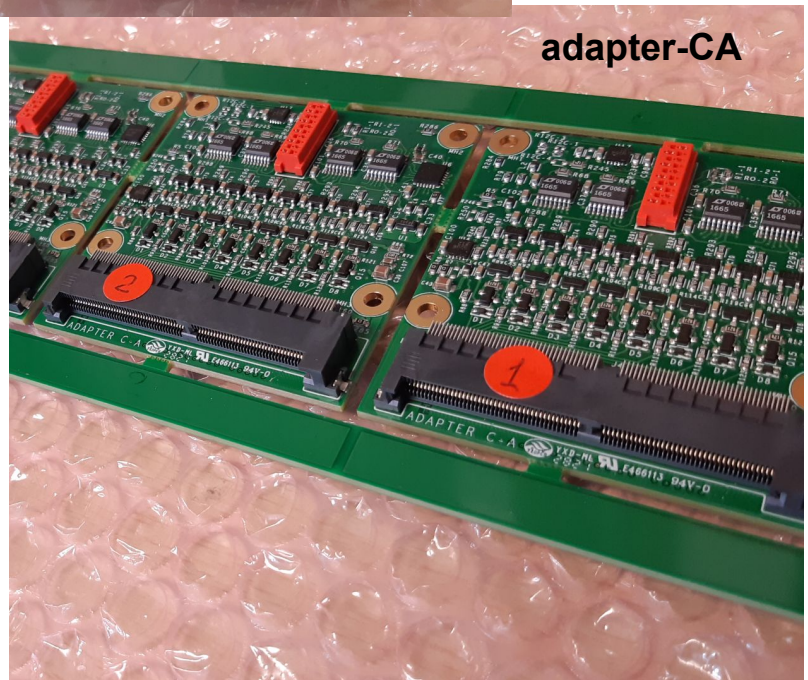
Schede adapter





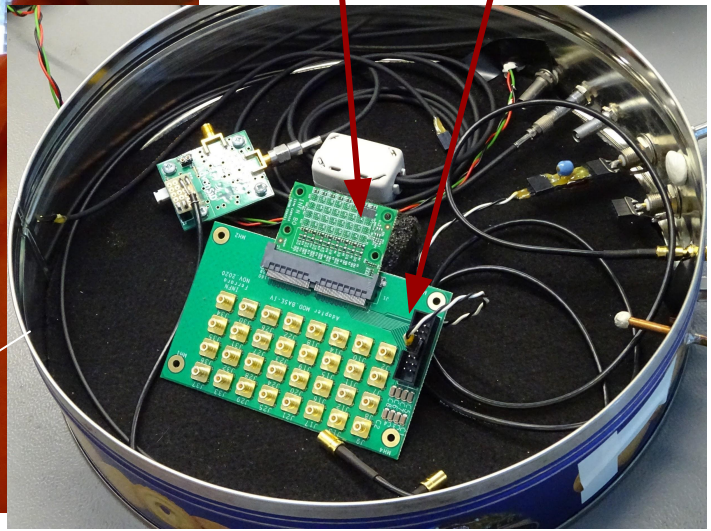


in azienda durante produzione schede SiPM

segnali dai SiPM !

SiPM carrier LIGHT

SiPM adapter Base-IV



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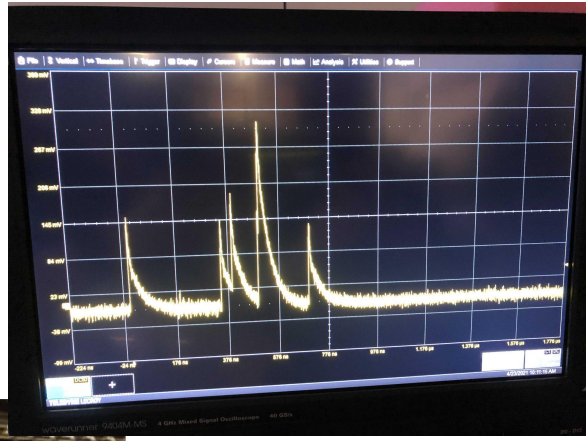
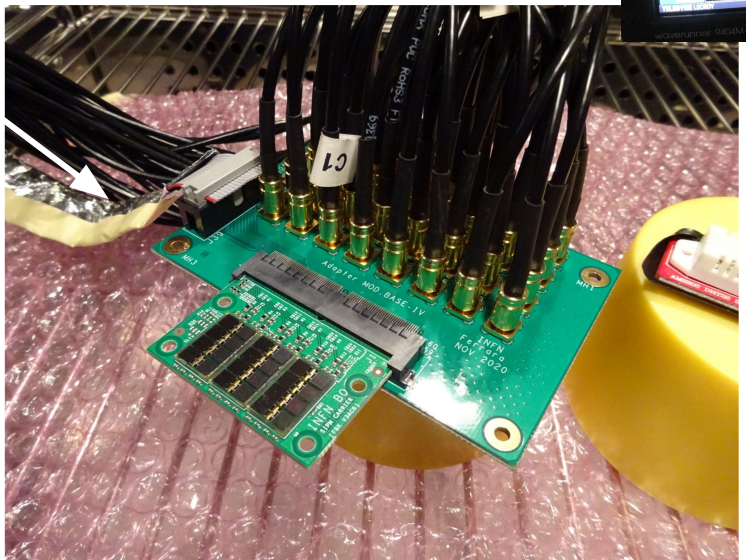
SiPM characterisation @ BO

I-V curves and DCR
at different temperatures

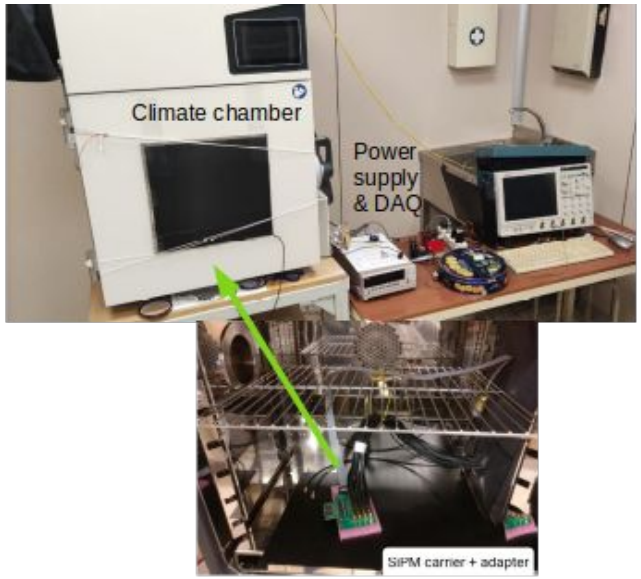
+20 C −10 C −30 C

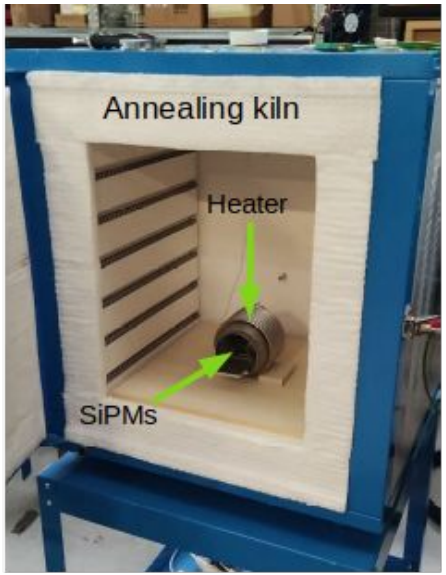
- Memmert climatic chamber
- Keithley source meter
- Keysight power supply
- Cividec amplifier
- Lecroy oscilloscope



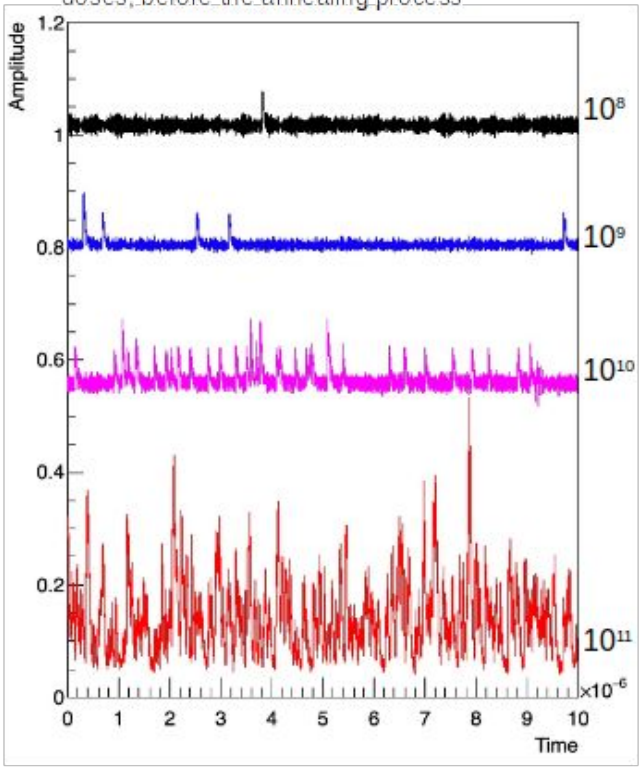


SiPM characterisation @ FE

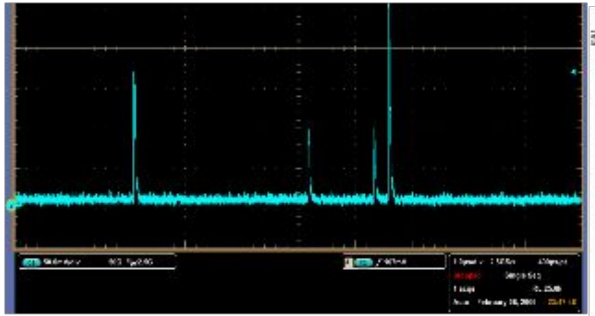


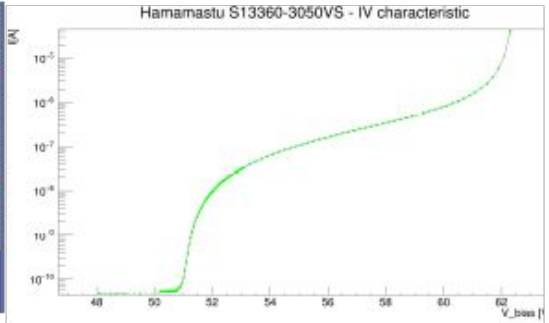


Signals of SiPMs irradiated with different doses, before the annealing process



Not irradiated SiPMs, room temperature, signal and IV characteristic



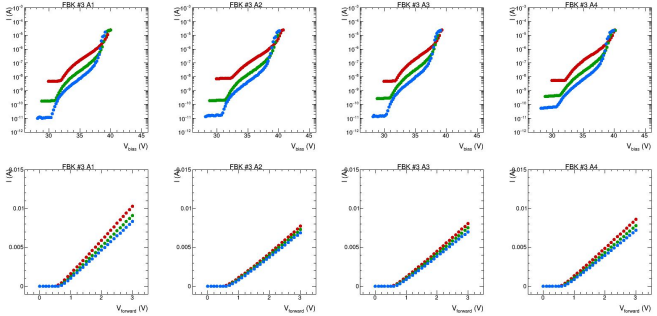


SiPM characterisation

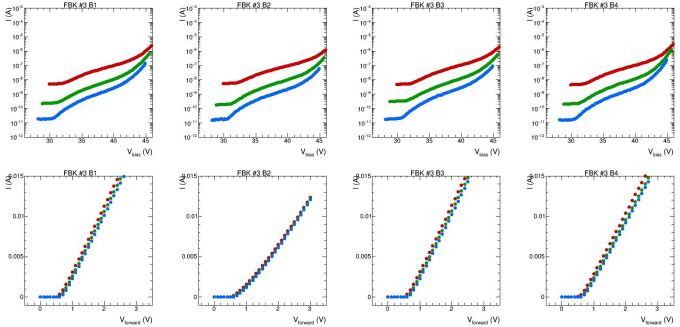
IV characteristics at different T

+20 C
−10 C
−30 C

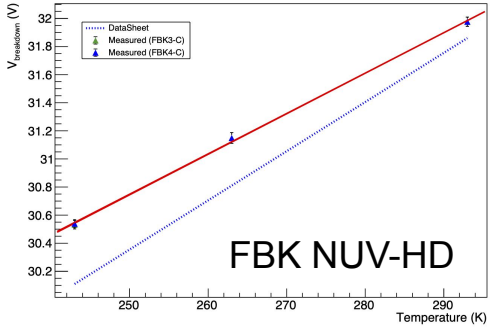
FBK NUV-HD-CHK

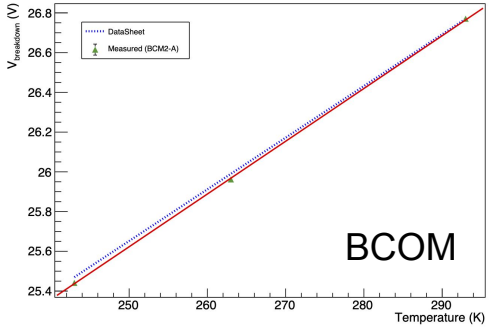


FBK NUV-HD-RH

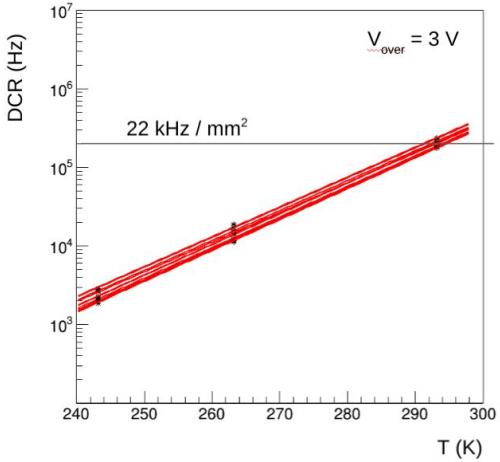


breakdown voltage vs. temperature





dark count rate vs. temperature



only a little fraction of the large amount of data collected shown

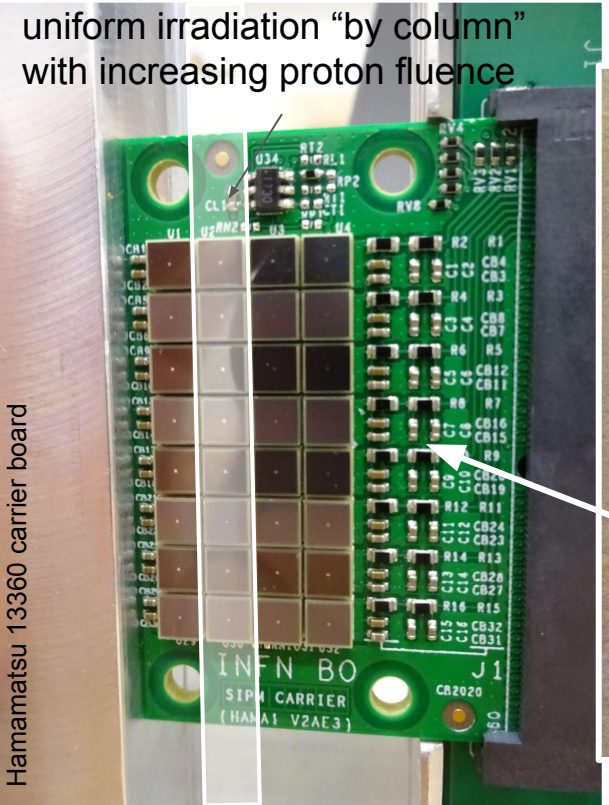
1st irradiation round in May

3x3 mm^2 SiPM sensors
4x8 “matrix” (carrier board)

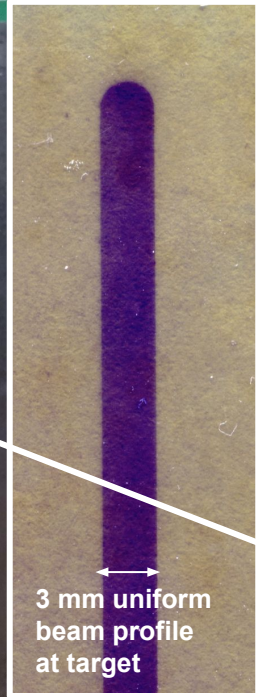
multiple types of SiPM: **Hamamatsu** commercial (13360 and 14160)
FBK prototypes (rad.hard and timing optimised)

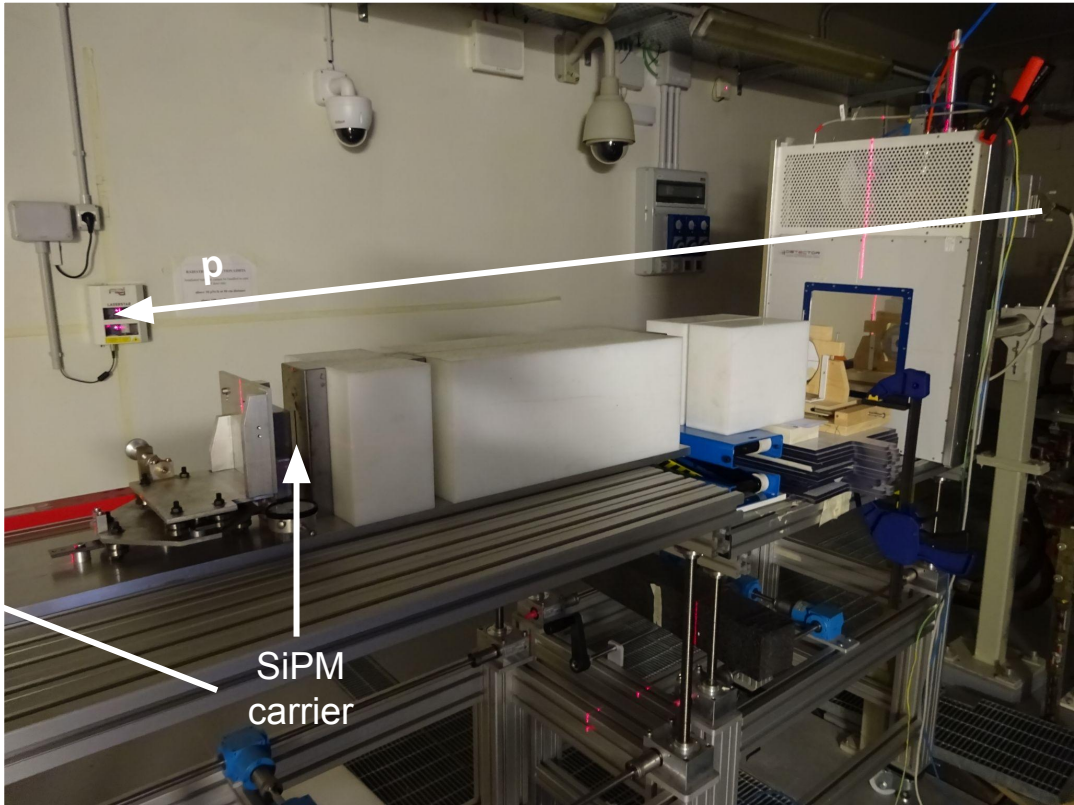
148 MeV protons → scattering system → collimation system → carrier board

uniform irradiation “by column”
with increasing proton fluence

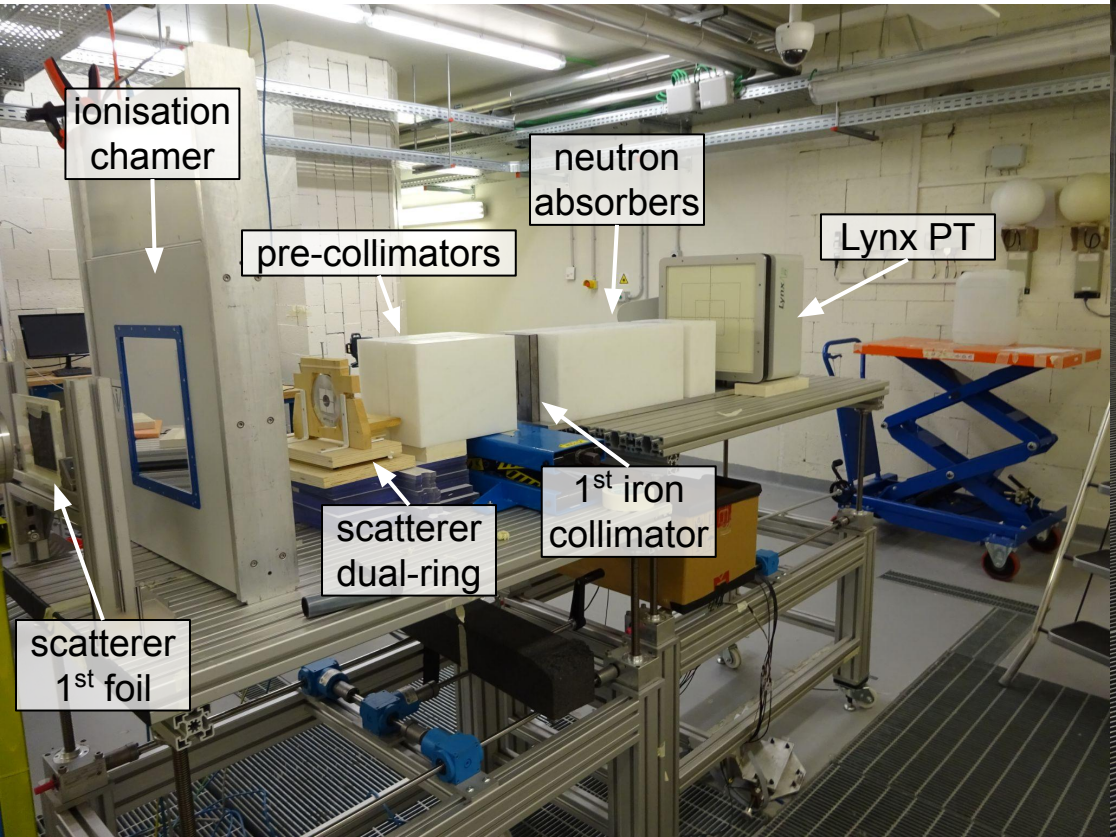


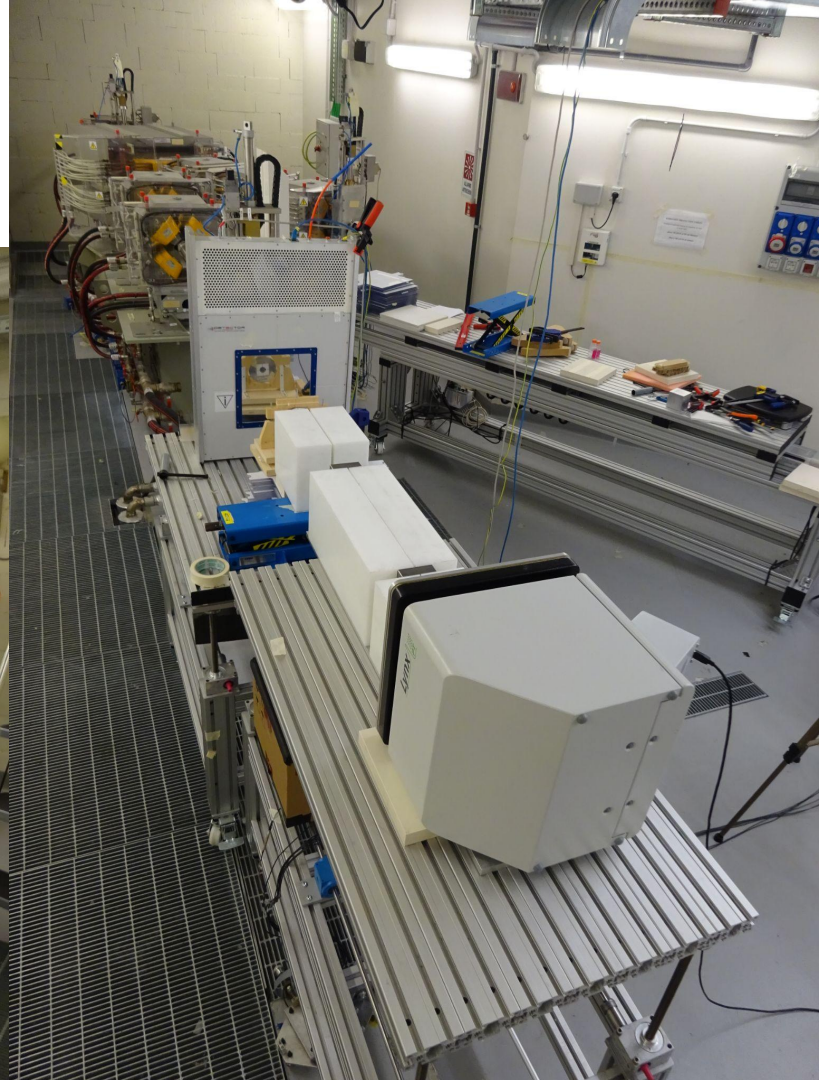
Hamamatsu 13360 carrier board





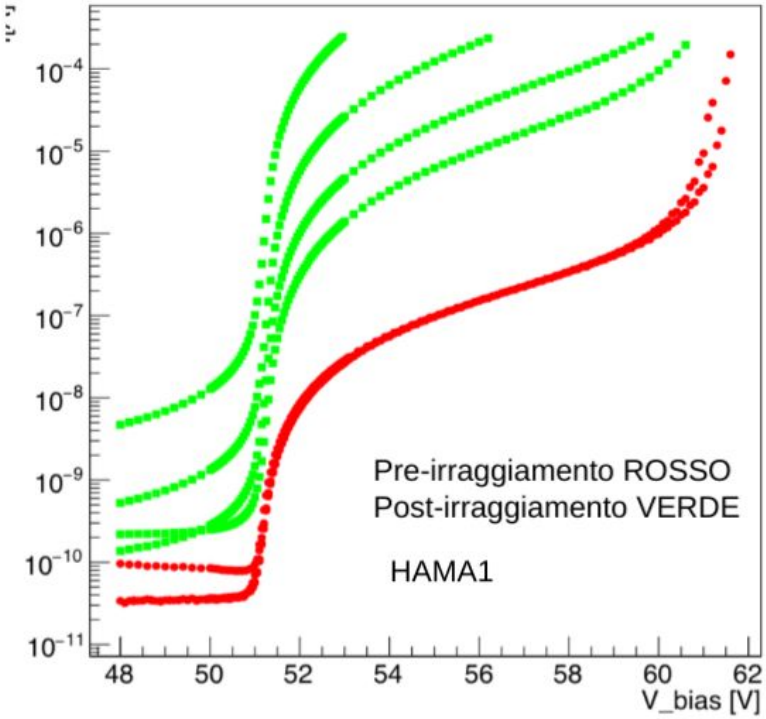
Collimator setup: intensity calibration

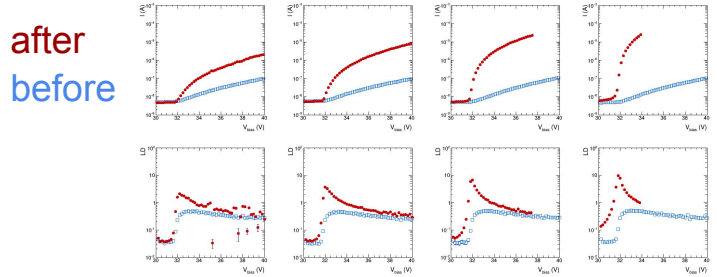


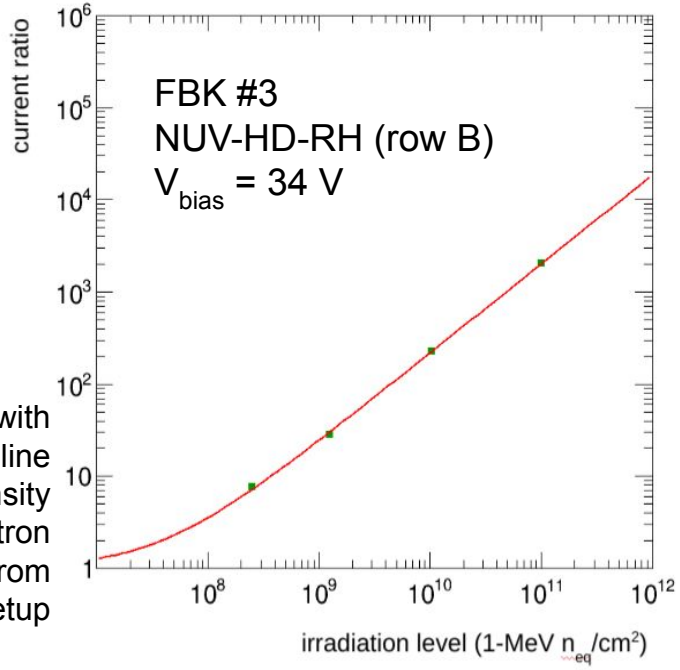


Post-irradiation characterisation

measured also right after irradiation in TIFPA bunker and ~10 days later when TIFPA released the SiPM

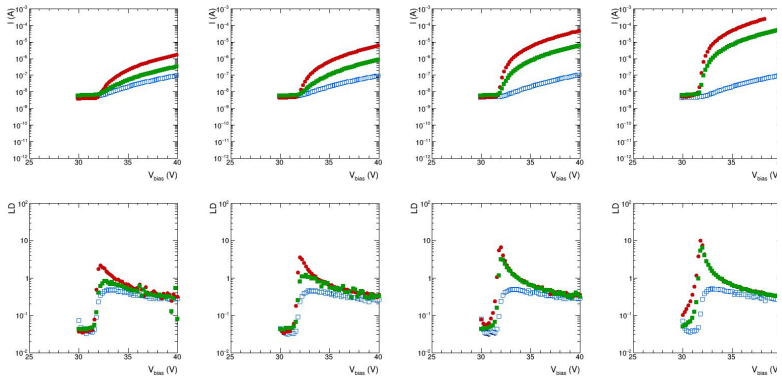




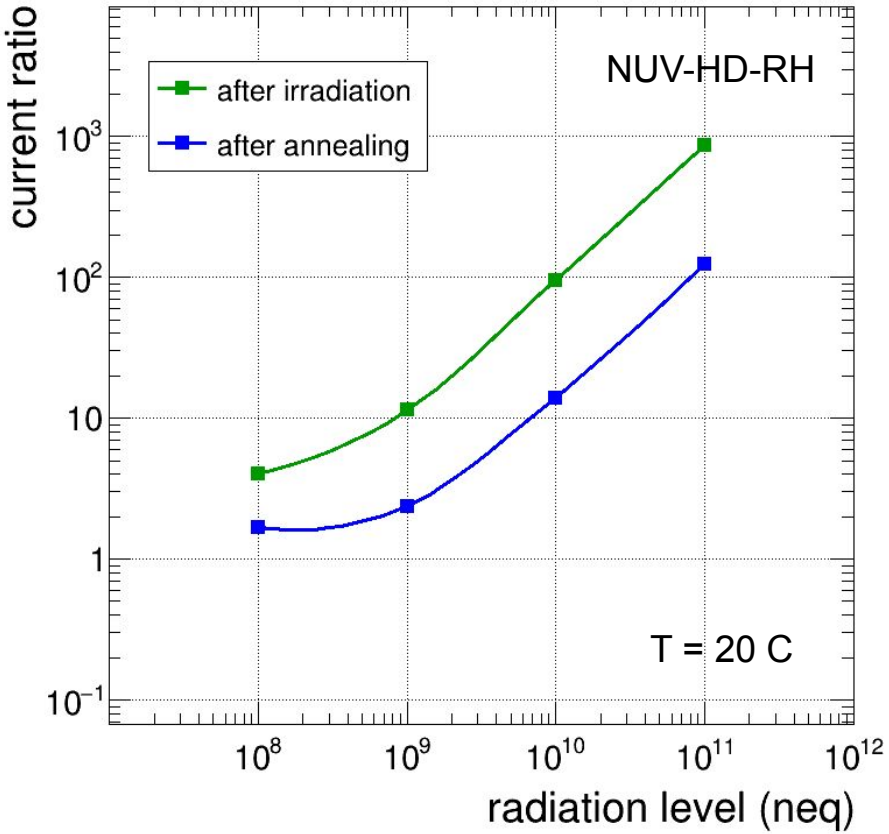


current increases with irradiation level in line with proton intensity calibration + neutron background from simulations of the setup

FBK characterisation after 1 week of annealing at T = 125 C



new
irradiated
annealed



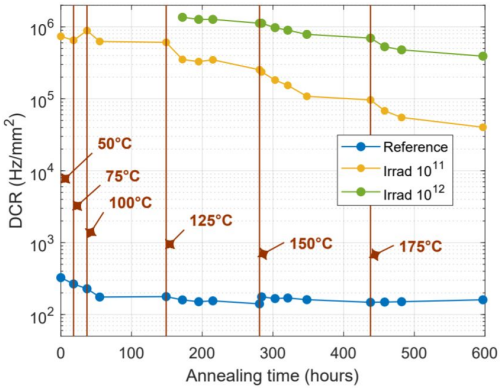
annealing reduced dark current by a factor of ~5-10, in line with expectations

SiPM irradiated up to 10^{11} now behave like if they were irradiated by 10^{10}

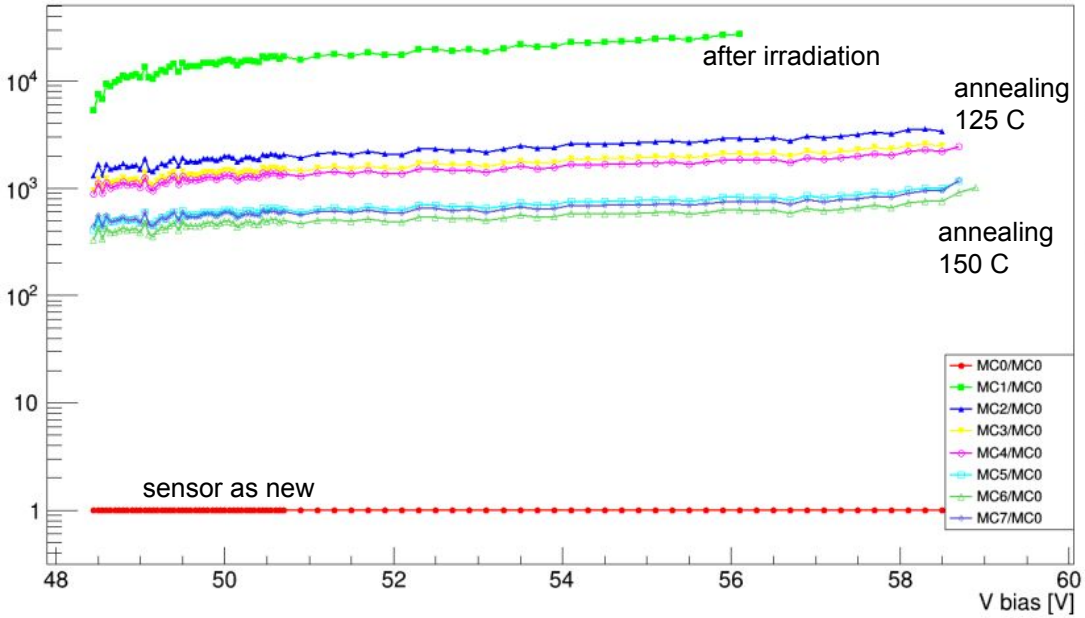
FBK annealing stops at 125 C for the time being
little issue related to the solder paste used during assembly (T = 138 C) does not allow to reach T = 175
→ needs reworking of the carriers
→ will be done after test beam

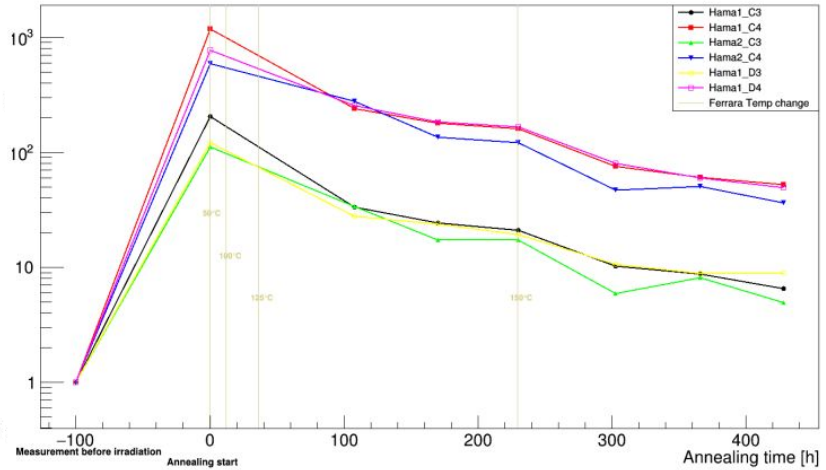
Hamamatsu annealing up to T = 150 C completed

behaviour in line with literature (Calvi et al)



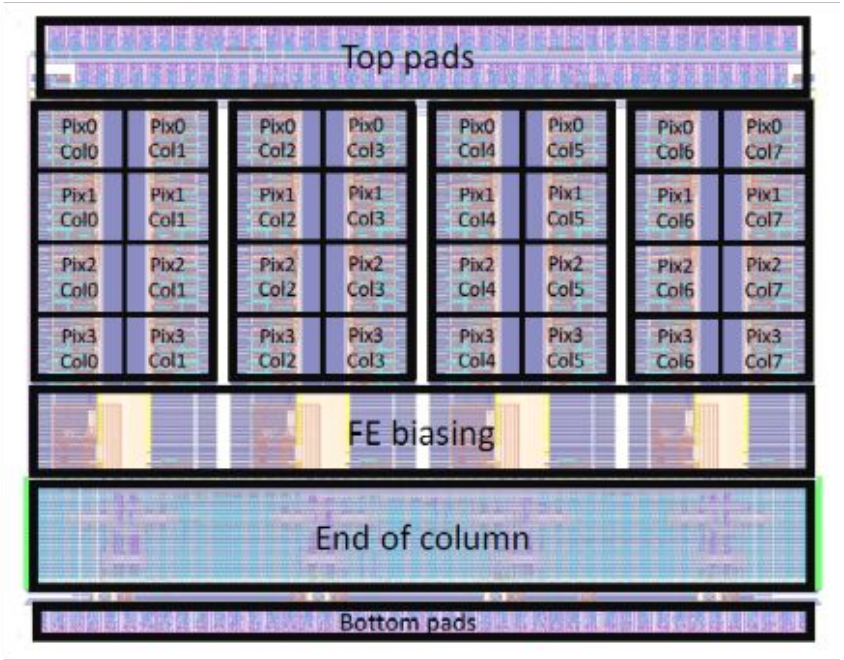
current ratio wrt. before irradiation





ALCOR – A Low Power Chip for Optical sensor Readout

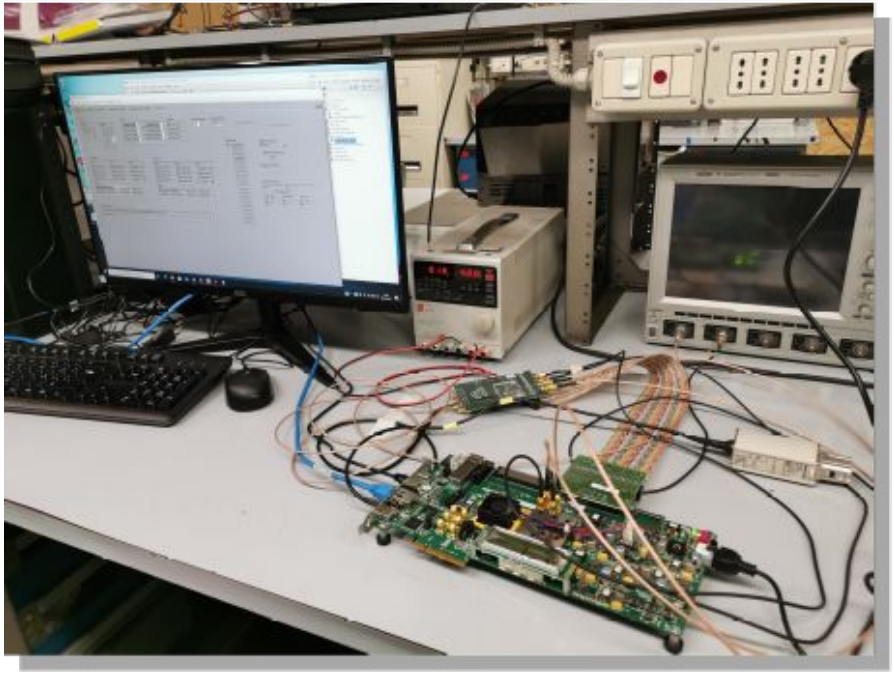
- 32-pixel matrix mixed-signal ASIC
- The chip performs signal amplification and conditioning and event digitization
- Each pixel features:
  - Dual-polarity front-end amplifier with low input impedance (10-20 Ω) and 4 programmable gain settings
  - 2 leading edge discriminators for events selection
  - 4 TDCs based on analogue interpolation: time binning≈50ps (@320 MHz clock frequency)
- Single-photon time tagging mode or time and charge measurement (Time-over-Threshold)
- Fully digital output (4 LVDS TX data links)

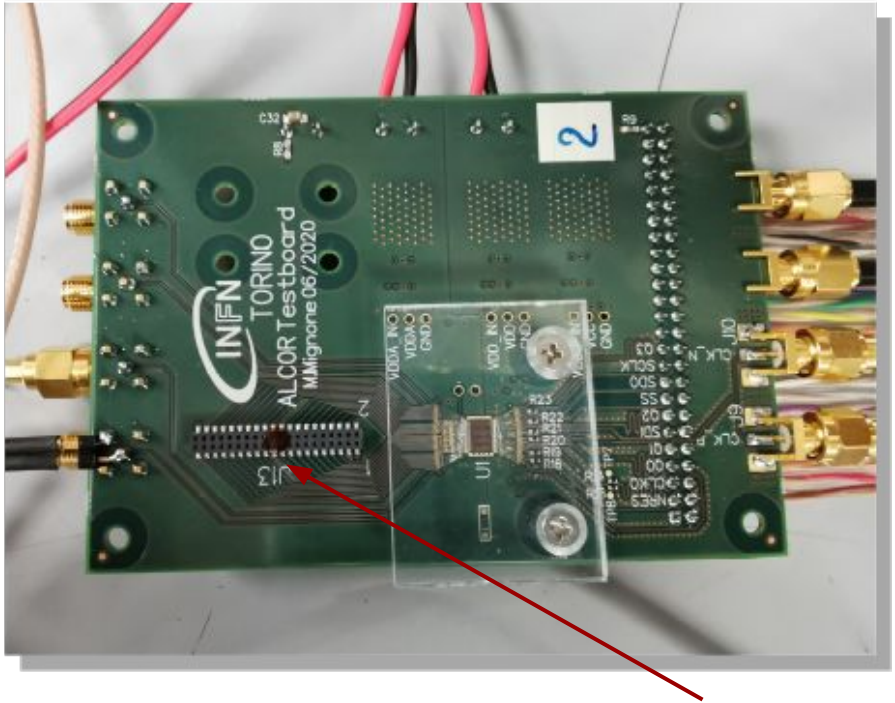


developed by TO for Darkside
2022: ALCOR++ optimised for RICH

ALCOR test-bench setup in Torino

for characterisation of the ALCOR chip with a test board and first look at signal from SiPM carriers



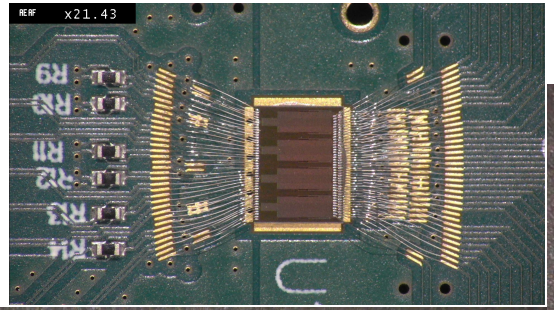


ALCOR test board not designed within EIC_NET R&D
utilised with EIC_NET SIPM boards via dedicated mini-adapter board

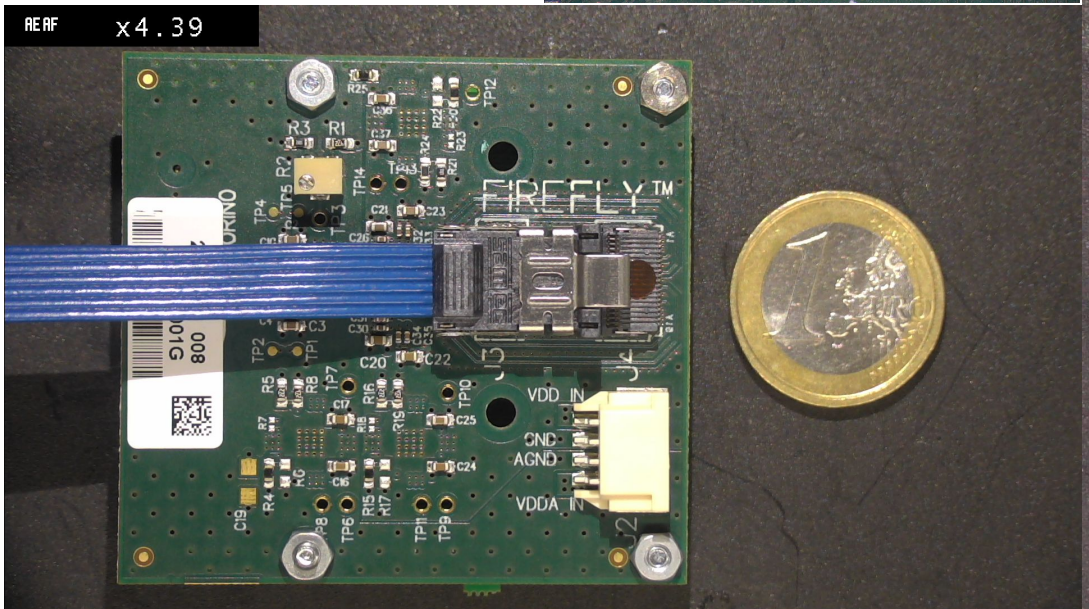
connector to mini-adapter board

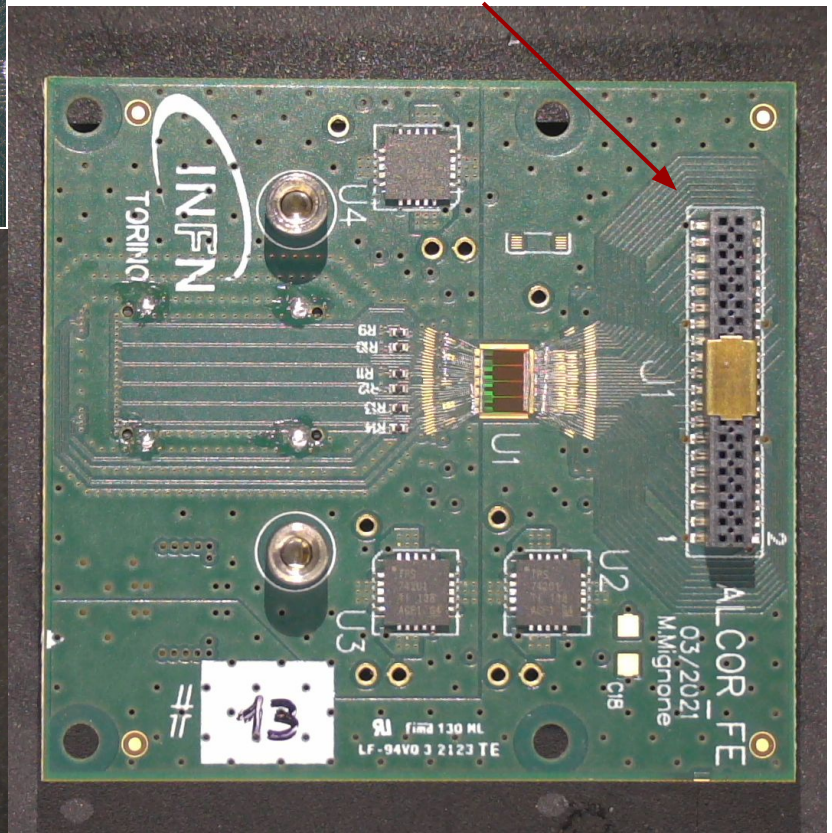
ALCOR – A Low Power Chip for Optical sensor Readout

ALCOR-FE frontend board for testbeam with bonded ALCOR chip and FireFly cable



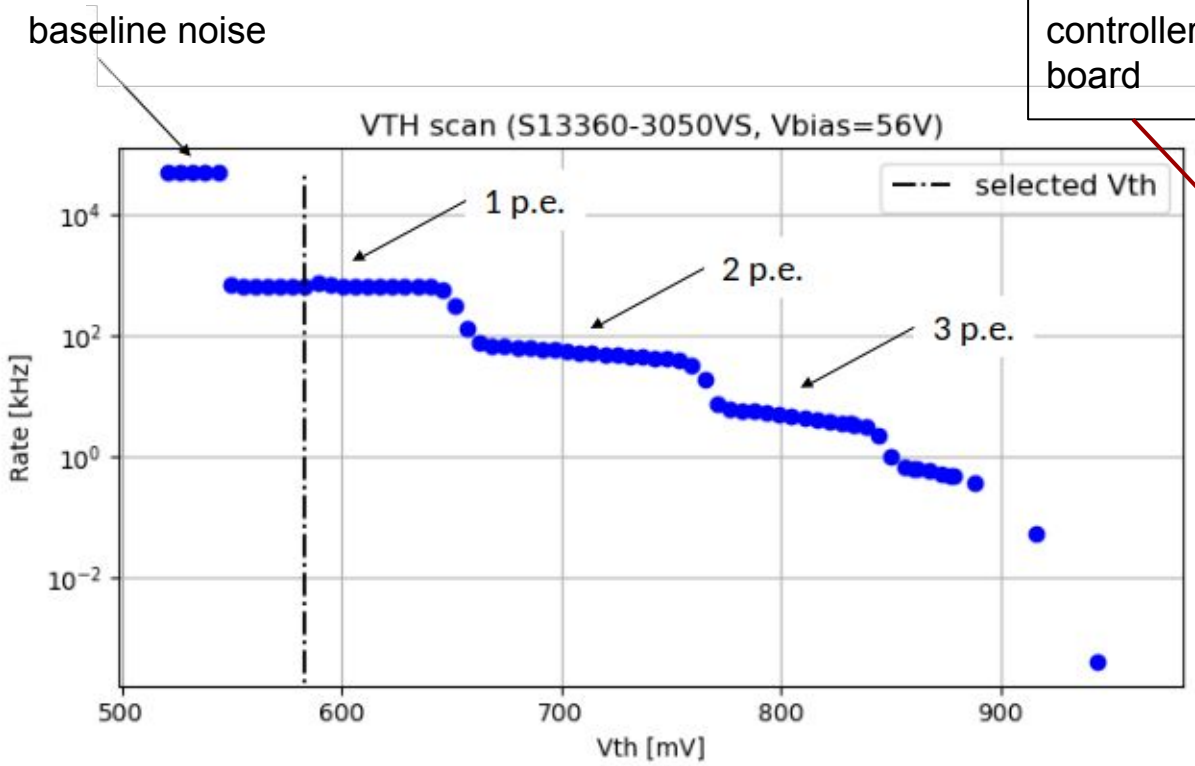
connector to adapter-CA board

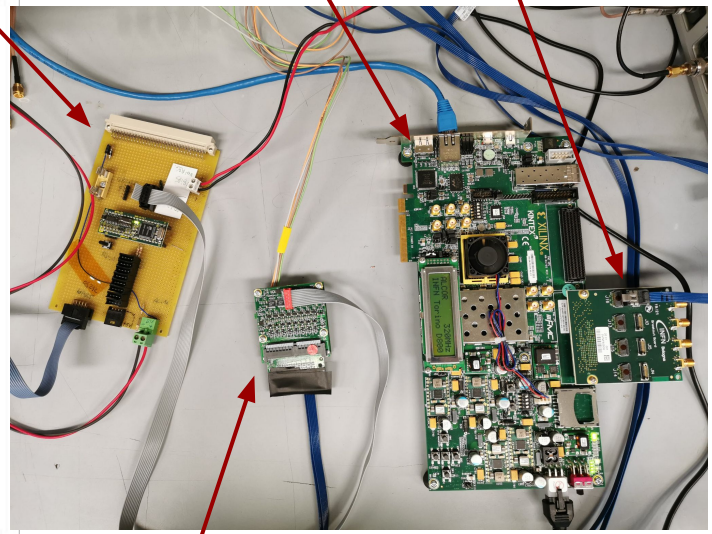




ALCOR threshold scan

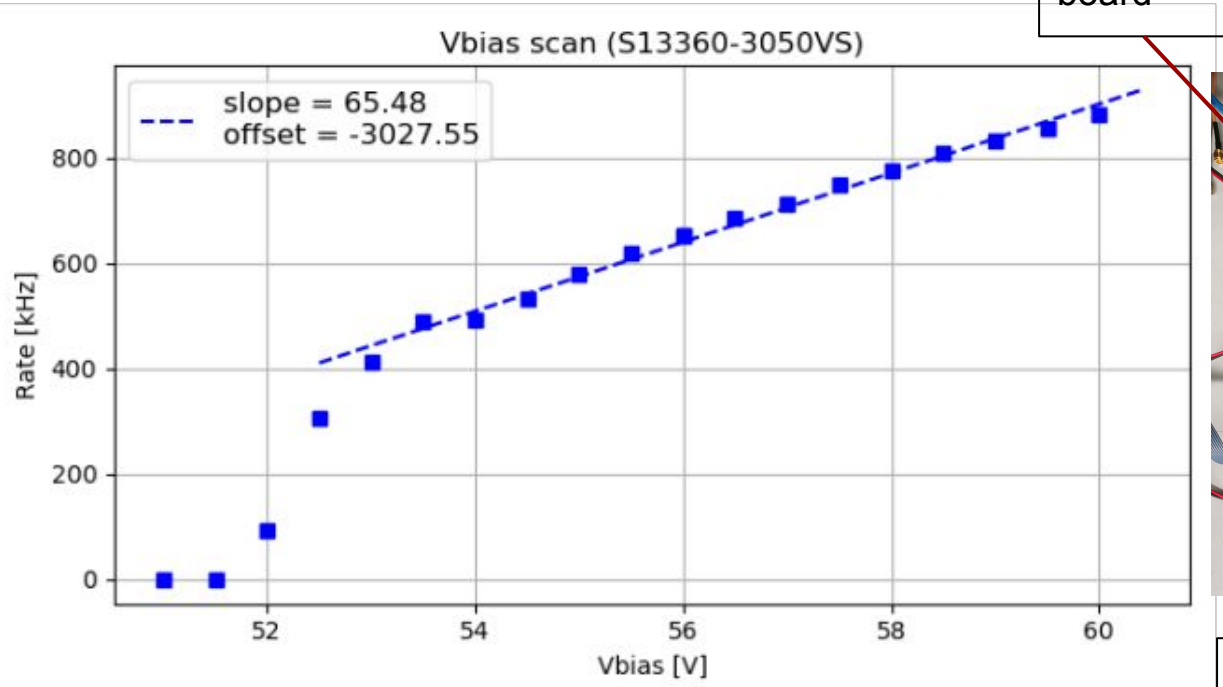
final electronics setup during functional tests in Torino





SiPM Vbias scan

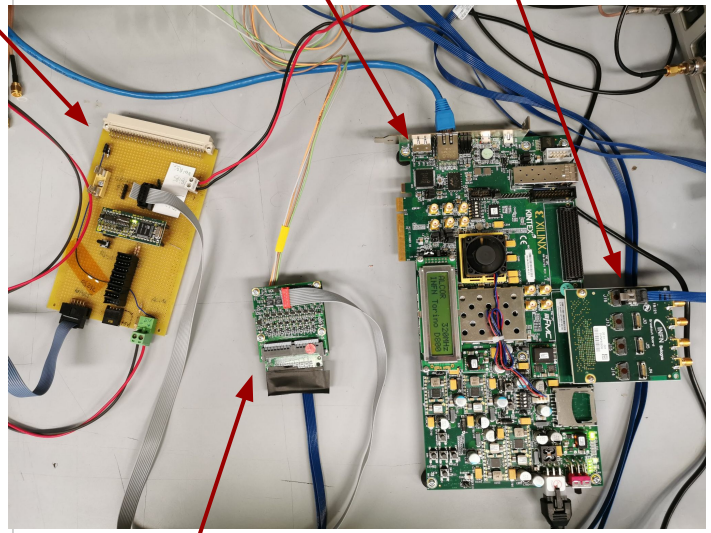
final electronics setup during functional tests in Torino



SiPM HV controller board

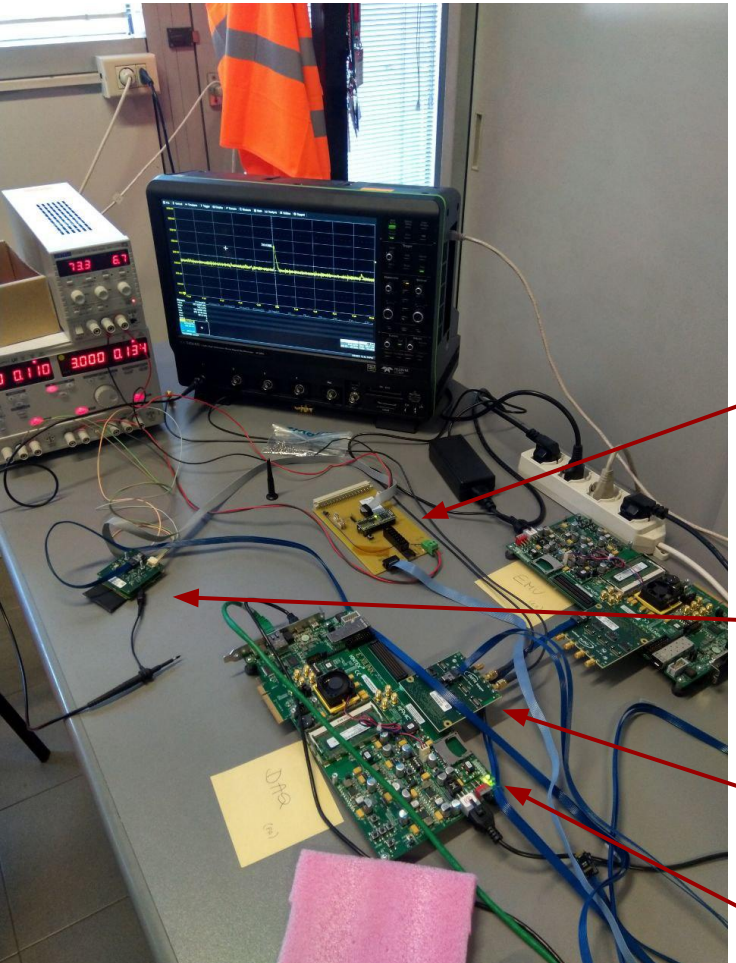
FireFly breakout board

Xilinx FPGA board



SiPM carrier + adapter + ALCOR-FE

DAQ tests for ALCOR readout in Bologna

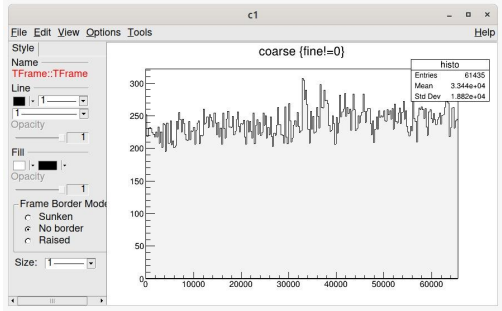


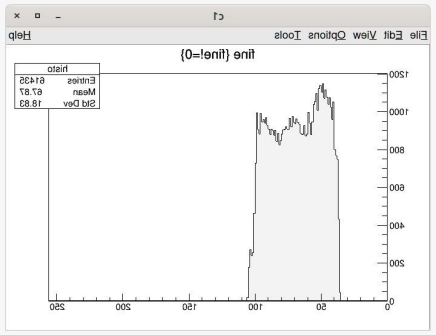
SiPM HV controller board

SiPM carrier + adapter + ALCOR-FE

FireFly breakout board

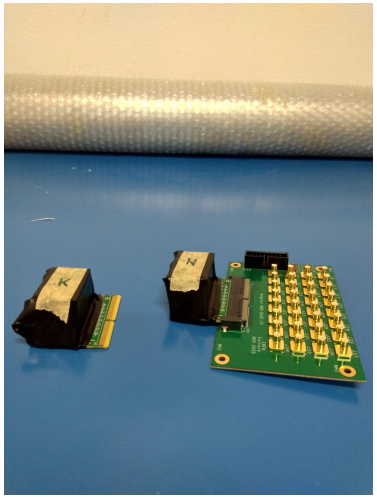
Xilinx FPGA board

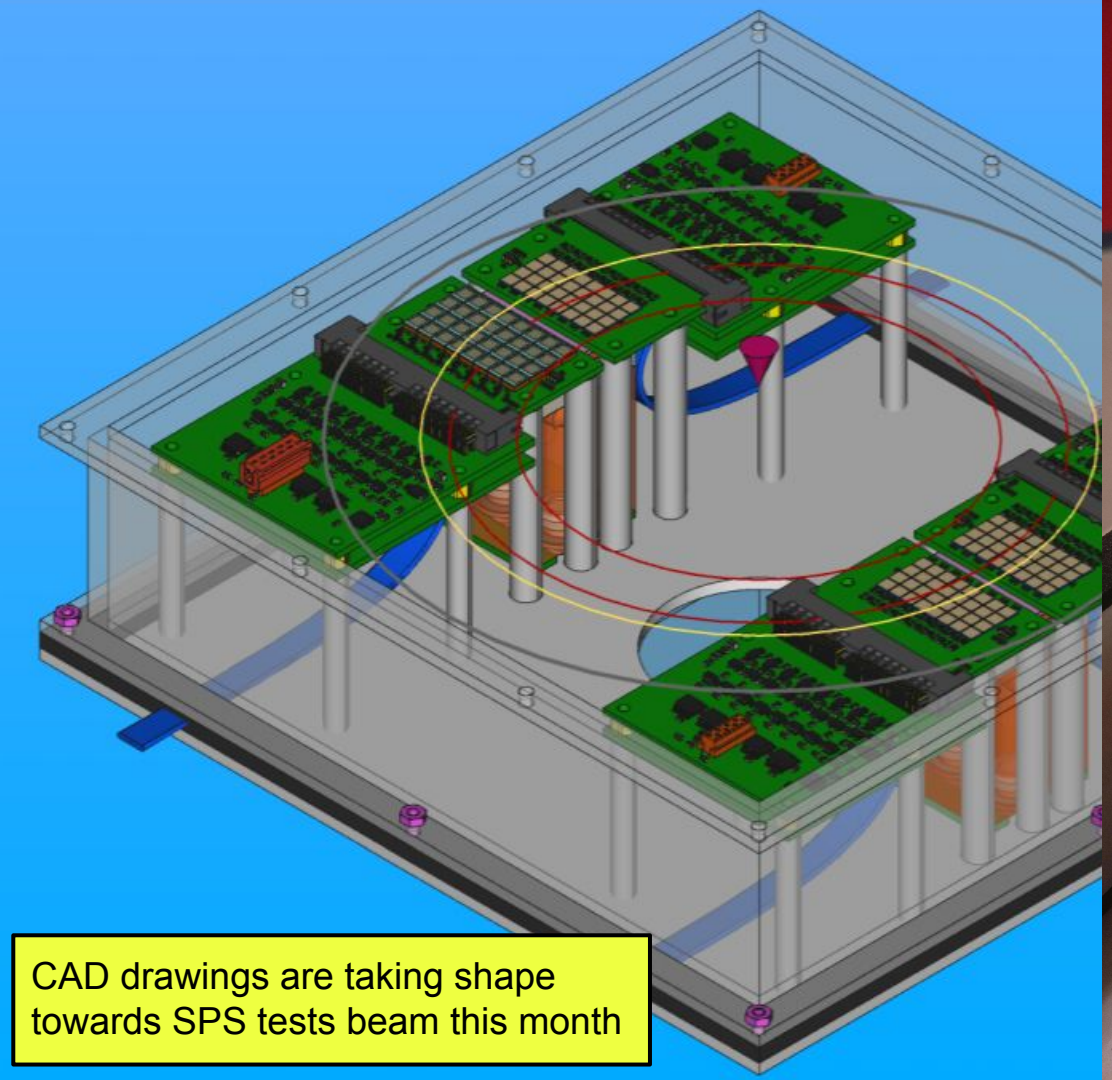




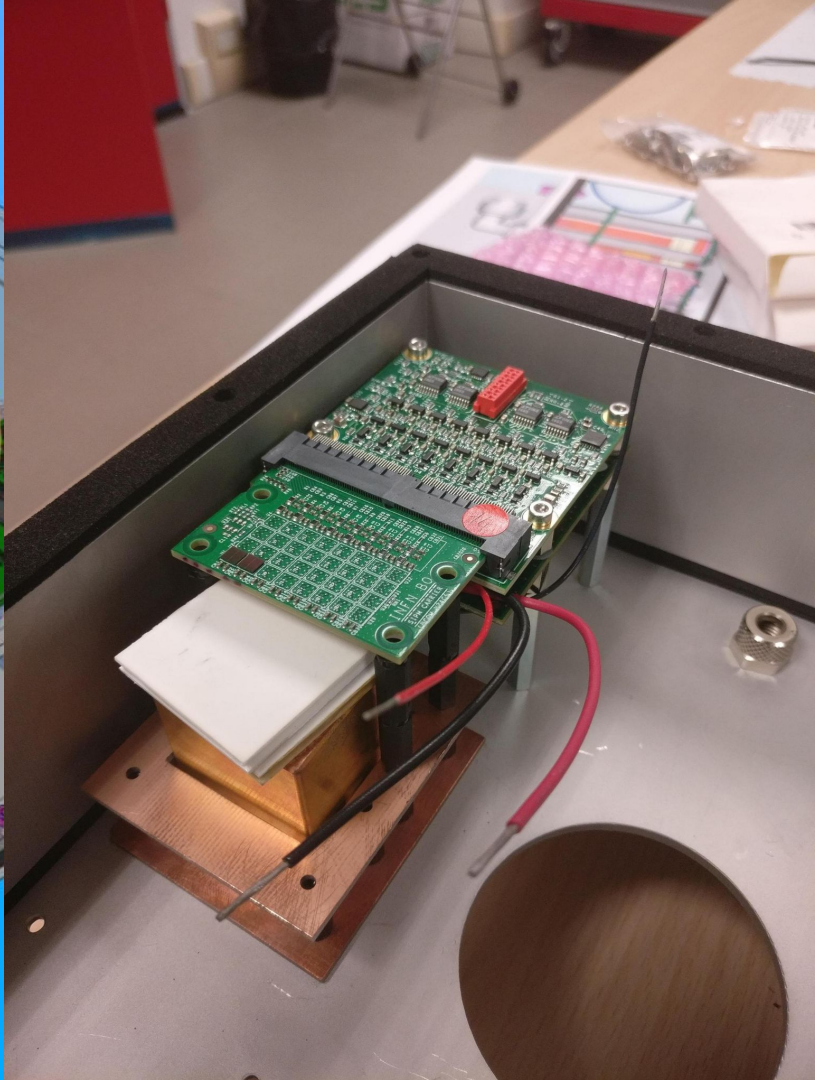
so far only noise rates

soon cosmic rays (with scintillators coupled to SiPM matrices)

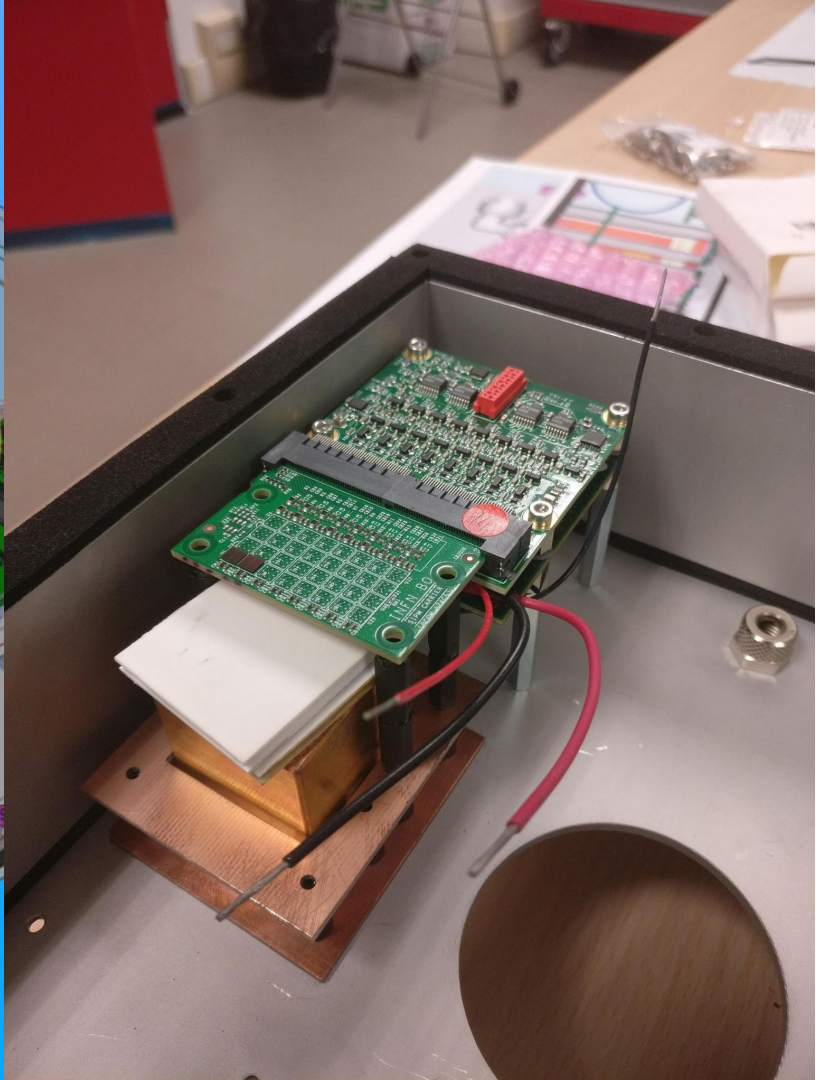




CAD drawings are taking shape towards SPS tests beam this month



thanks to all the people who worked hard to come till so far !!!



qualche slide extra sulle attività / richieste 2022

Matrici proto-readout-tile RICH (SiPM FBK)

in sinergia con ALICE 3 RICH

CORPO DEL DOCUMENTO														
Linea	Cod.	Tipo C/P	Descrizione	Q.ta	Val. Unit.	Scont / Magg.	Val.Tot.	IVA (%)	Ritenuta	Natura	Dal	Al	Rif. Amm.	Altro
1			FBK SiPM mini-tiles 4x2 Ordine di acquisto n. 6166 del 03-DIC-20 CIG: Z4C2ECD620	3.00UN	470.00		1410.00	22.00						

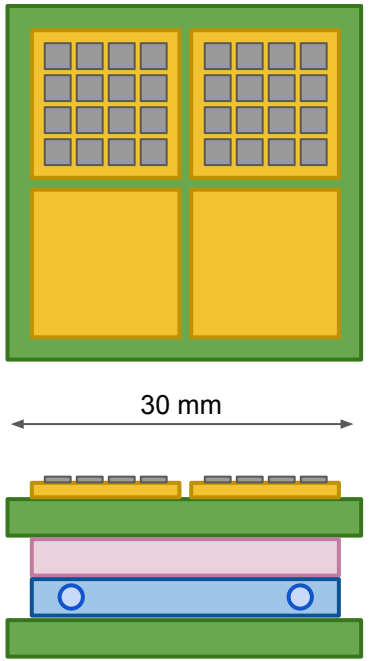
ordine nel 2020 acquisto sensori SiPM FBK: tile 4x2, costo unitario 0.5 kEUR
previsione per tile 4x4, costo unitario 1 k EUR

preventivo per sviluppo in collaborazione con FBK di unità proto-readout-tile per radiazione Cherenkov: dettagli specifici da definire, contatto con FBK iniziato per discussione interesse e possibili soluzioni

stima costi proto-readout-tile composta di 4 mini-tiles SiPM FBK 4x4
realizzazione di 4 unità proto-readout-tile, non complete (2 mini-tile + 2 dummy)

- 8x mini-tiles SiPM FBK 4x4 = 8 kEUR
- 4x celle Peltier = 0.5 kEUR
- water-cooling = officina meccanica
- extra costi (connettori, assemblaggio, …) = 1.5 kEUR

TOTALE richiesto = 10 kEUR (consumo)



Irraggiamento presso Centro ProtonTerapia (TIFPA)

Con la presente ci pregiamo ordinarvi quanto segue, alle condizioni sottoindicate:

Descrizione sintetica:

QUANTITA'	DESCRIZIONE	SCONTO	%	PREZZO UNITARIO	IMPORTO
1,0	costo fascio protoni per irraggiamento SiPM presso Centro di Protonterapia di Trento il 13 -14-15 Maggio 2021 -- Rilascio documenti di riconsegna come da normativa vigente	0,00	0	2.000,00	2.000,00

ordine 2021 un accesso fascio protoni (2 sere, una mattina, totale 8 ore) = 2.5 EUR

TOTALE EUR : 2.000,00

TOTALE EUR **(Ivato):** 2.440,00

IVA AL 22% EUR 440,00

previsti due accessi fascio nel 2022

- 1 accesso per irraggiamento SiPM Broadcom e SENSL = 2.5 k EUR
  - non irraggiati nel 2021 causa rallentamenti dovuti ad attivazione in area controllata
- 1 accesso per seconda fase studi R&D su danni radiazione SiPM = 2.5 kEUR
  - danno da radiazione integrato in diverse fasi nel tempo (come da esperimento)
  - sensore nuovo → irraggiamento → annealing → irraggiamento → annealing

in sinergia con ALICE 3 RICH

TOTALE richiesto = 5 kEUR (consumo)

Schede elettronica per caratterizzazione SiPM

Con la presente ci pregiamo ordinarvi quanto segue, alle condizioni sottoindicate:

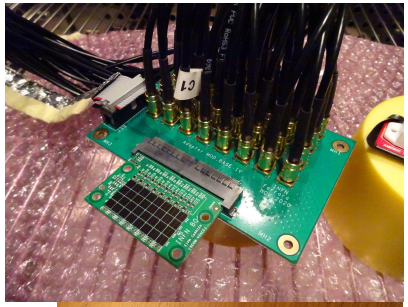
Descrizione sintetica:

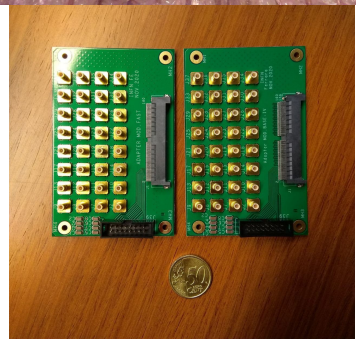
QUANTITA'	DESCRIZIONE	SCONTO	%	PREZZO UNITARIO	IMPORTO
1,0	Produzione PCB e assemblaggio schede SiPM Adapter SMB	0,00	0	2.550,00	2.550,00

nel 2021 schede adapter SMB per caratterizzazione IV SiPM = 3.0 kEUR
di cui connettori SMB forniti in conto/lavorazione = 1.0 kEUR
e corrispondenti cavi e adattatori per effettuare misure = 1.0 kEUR

TOTALE EUR : 2.550,00
TOTALE EUR **(Ivato):** 3.111,00

IVA AL 22% EUR 561,00





supportare necessità sviluppo schede per continuamento attività R&D e caratterizzazione SiPM, di cui i dettagli non ancora ancora sviluppati

- break-out / adapter board ottimizzata per PDE e SPTR
- break-out / adapter board per interfaccia con multiplexer (automatizzazione misure caratterizzazione)

più necessità supporto metabilismo R&D, acquisto compomenti, cavi
più supporto necessità specifiche all'attività sinergica per il RICH di ALICE 3

in sinergia con ALICE 3 RICH

TOTALE richiesto = 5 kEUR (consumo) + 5 kEUR sj. (sottomissione LoI ALICE 3)

Evoluzione ALCOR++ chip ottimizzato per RICH

ALCOR:
• Developed by INFN Torino originally for a Darkside application
• Optimized for cryo operation
• An ALCOR++ optimised for RICH application will be next step

The microelectronics group at TO will design a second version of ALCOR featuring:

- bug fixes to the pixel control logic, problems observed during experimental characterisation and post-layout simulations occur when the TDCs operate at very
high data rate

- a new and optimised very front-end, implementing a pole-zero cancellation circuit, suitable for the readout of SiPMs with high DCR