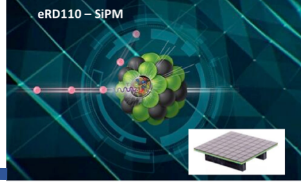
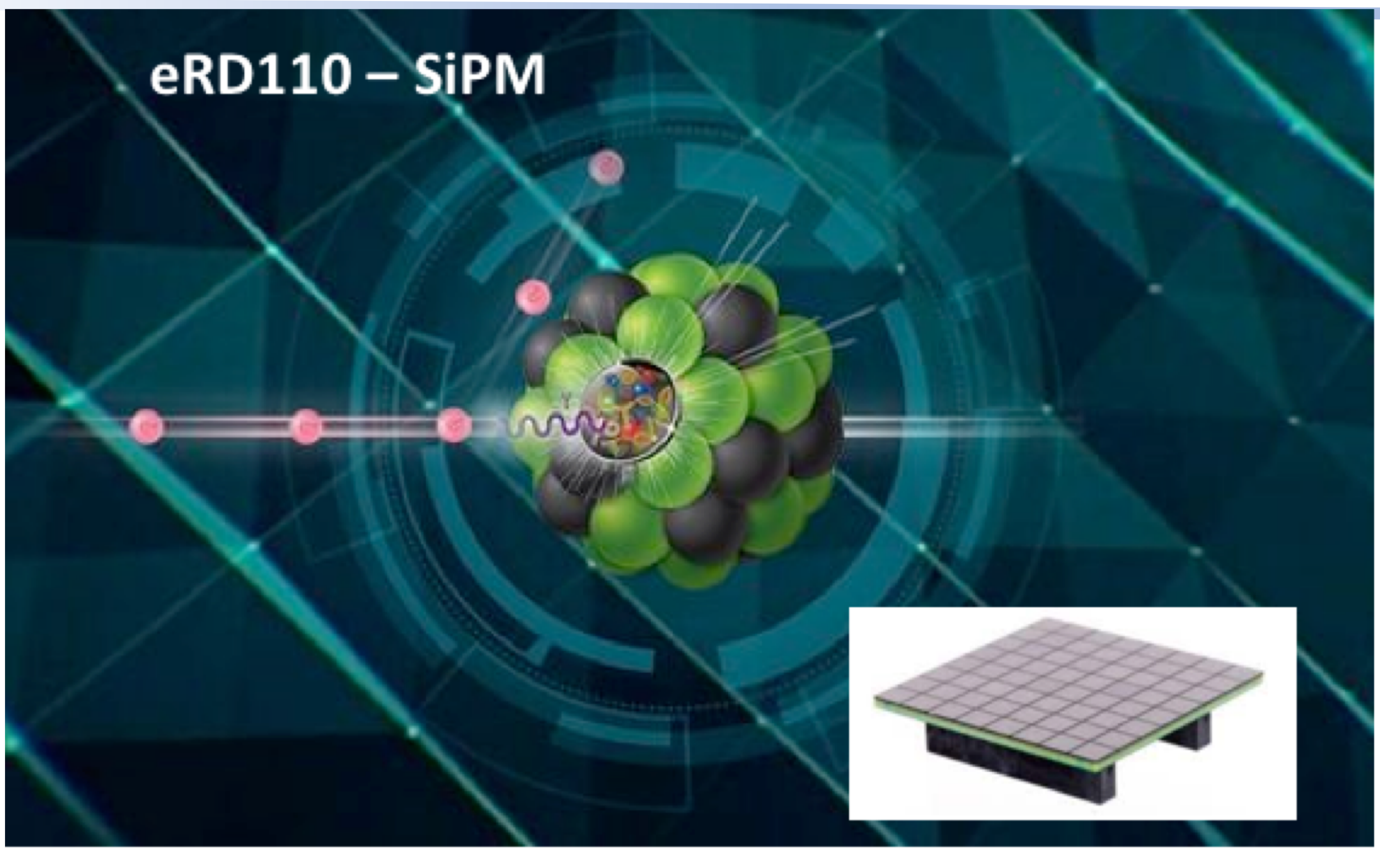
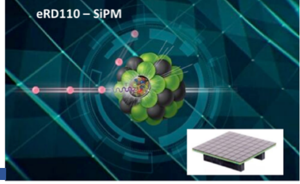




P. Antonioli – INFN Bologna
on behalf of eRD110-SiPM INFN effort
(INFN BO/FE/TO for FY22)



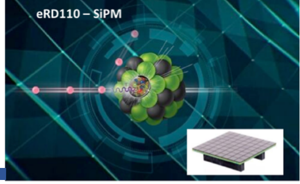
Outline

- Motivations
- Sensors and irradiation campaign in 2021
- eRD110 application
- 2022 program, plans and current status

DISCLAIMER / not covered today:

- what is inside eRD110 from calorimeters colleagues (plans are for FY23)
- Front-End electonics (ALCOR) / DAQ considerations
- test beams in 2021

Motivations



SiPM good candidates as photosensors@EIC (for RICHes and not only)

- sensitivity to single photon
- very good timing performance (< 100 ps)
- cheap
- insensitive to magnetic field

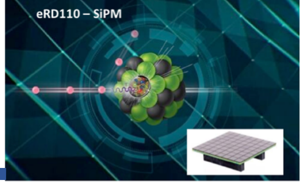
BUT:

with the need to operate at single photon threshold (RICH-specific)

- high DCR O(100 kHz-1 MHz) at room temperature → the **coooling** challenge
- no radiation immune → the **annealing** challenge
- higher DCR after irradiation/annealing → the **data** challenge

Front-end electronics & DAQ is part of the challenge (and of the solution)

Where we are? (I)



https://indico.bnl.gov/event/14715/

Meeting on SiPM Use and Needs at EIC

Friday 4 Feb 2022, 08:00 → 10:00 US/Eastern

08:00 → 08:05 **Introduction**
Speakers: Patrizia Rossi (Jefferson Lab) , Thomas Ullrich (BNL)

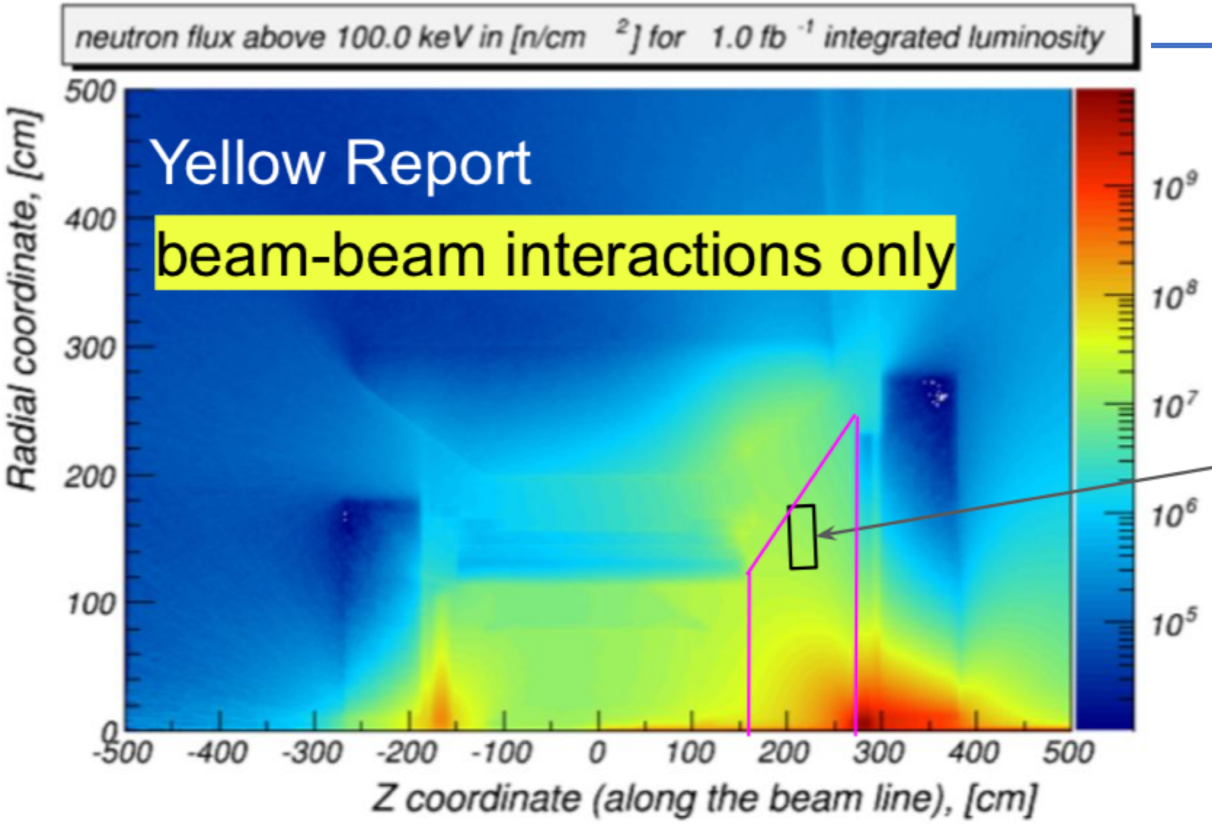
08:05 → 08:35 **SiPMs for RICH detectors**
Each talk should focus on what we have already highlighted in our e-mail, i.e.
where we are
where the technology has to improve
what the prospects are
where we can benefit from synergies
what we need to focus on
Speaker: Roberto Preghenella (INFN Bologna)
[20220204][EIC][SiP...

08:35 → 09:05 **SiPMs for calorimeters**
Each talk should focus on what we have already highlighted in our e-mail, i.e.
where we are
where the technology has to improve
what the prospects are
where we can benefit from synergies
what we need to focus on
Speakers: Craig Woody (BNL) , oleg tsai (ucla)
SiPMs_calor_0204... SiPMs for EIC 2-4-2...

February meeting convened by Patrizia and Thomas,
at the time US budget still locked in continuing resolution

In Roberto's and Craig's talks more detailed information than in this presentation. In the following here a quick recap.

EIC and radiation levels



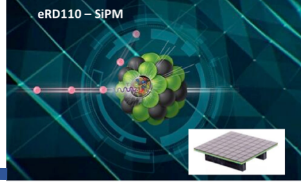
having as target 100 fb^{-1} (several years at maximum luminosity) this brings
10^{11} n/cm^2 1 MeV-neq as "maximum"

- 10 fb^{-1} in 30 weeks of operations at 10^{34} $s^{-1}cm^2$
- 100 fb^{-1} in 10 years → 1.5 10^9 n/cm^2

potential location of sensors in ATHENA design. To be revised in ECCE (180<z<280) but order of magnitude will not change.
≈ 1.5 10^7 n/cm^2 (100 keV ≈1 MeV-eq) every 1 fb^{-1}

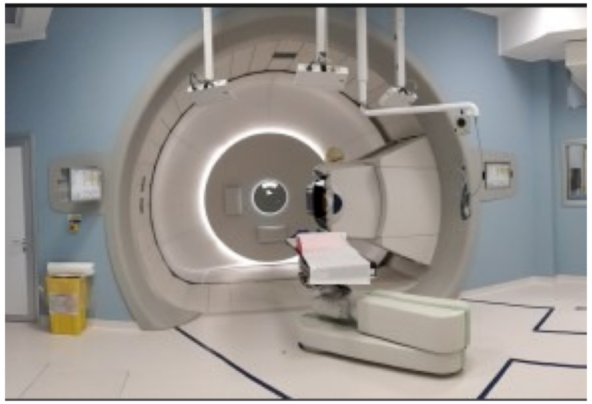
Foreseen radiation levels allow one to consider solutions already available on the market
\+ strategy to mitigate the radiation damages

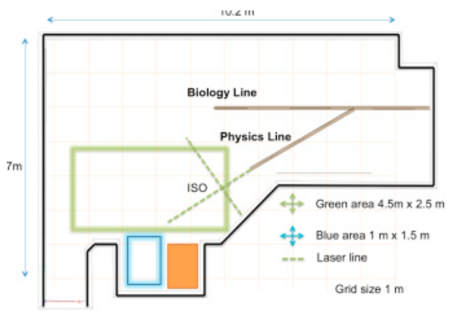
R&D program at INFN



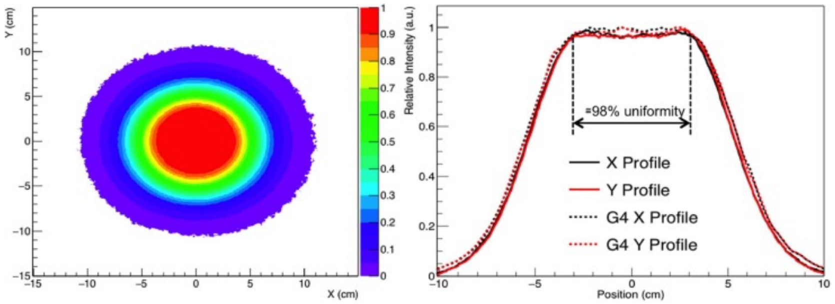
- first meetings in early 2020, proposing SiPM studies with target October 2021. In 2020 we submitted an application as part of eRD14. Program partly delayed due to pandemic + a lot of expertise built in the meantime!

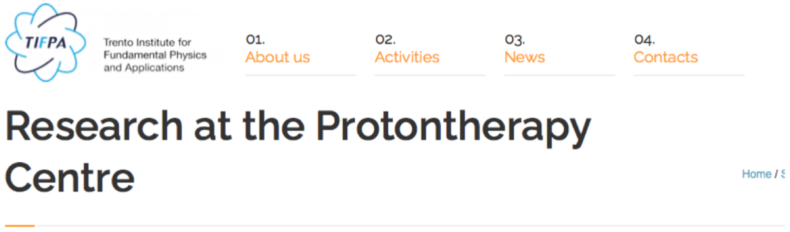
- achieved so far:
  - ✓ selection of SiPM candidates (HPK, FBK, OnSemi, Broadcom)
  - ✓ carrier boards for SiPM "matrix"
  - ✓ readout electronics based on ALCOR chip (developed at INFN-TO)
  - ✓ tests and characterization in climate chamber (mainly at INFN-BO)
  - ✓ irradiation at Centro di Protonterapia in Trento
  - ✓ annihilation at INFN-FE/BO





Max proton beam at 228 MeV
Biology line setup allow "large spot"
https://doi.org/10.1016/j.ejmp.2019.02.001



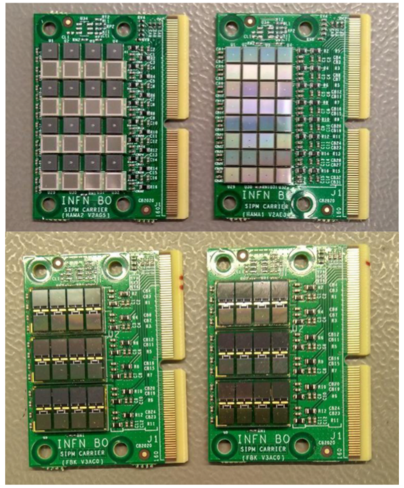


The two beamlines in the Trento Protontherapy Centre research room.

A quick look at 2021 operations (I)

SiPM carriers

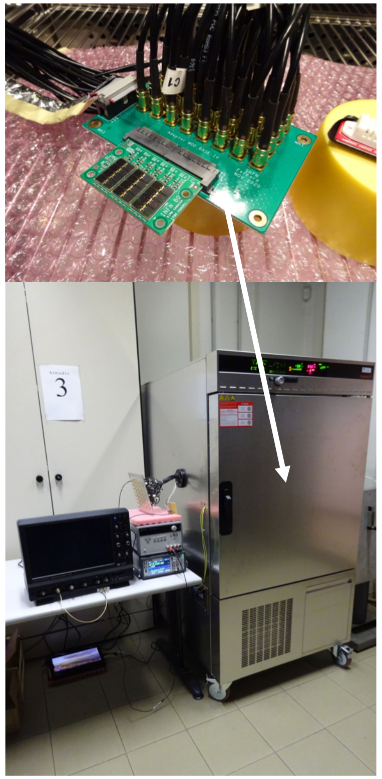
commercial Hamamatsu



FBK prototypes

3x3 mm^2 SiPM

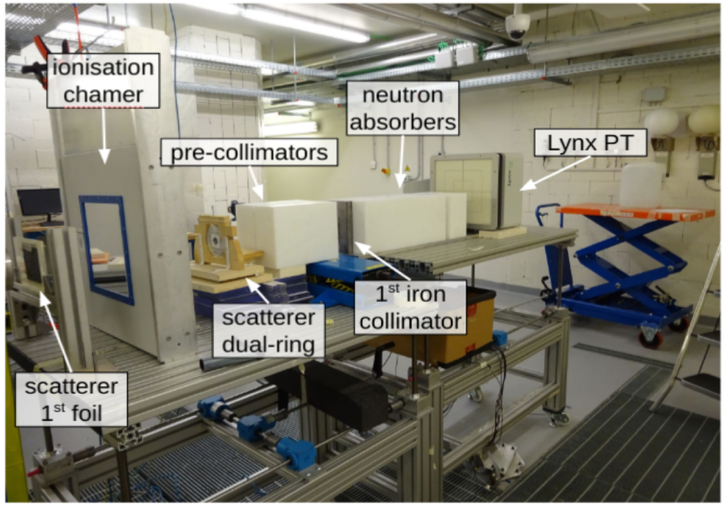
characterisation in lab @ BO/FE

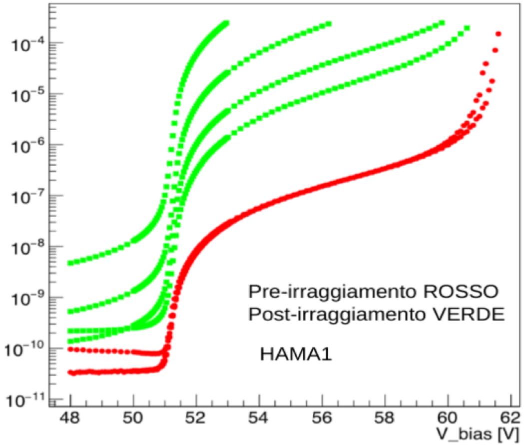


climatic chamber, low-T operation

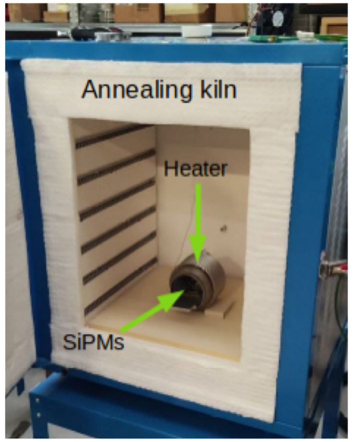
irradiation tests at Centro di Protonterapia at TN (with TIFPA)

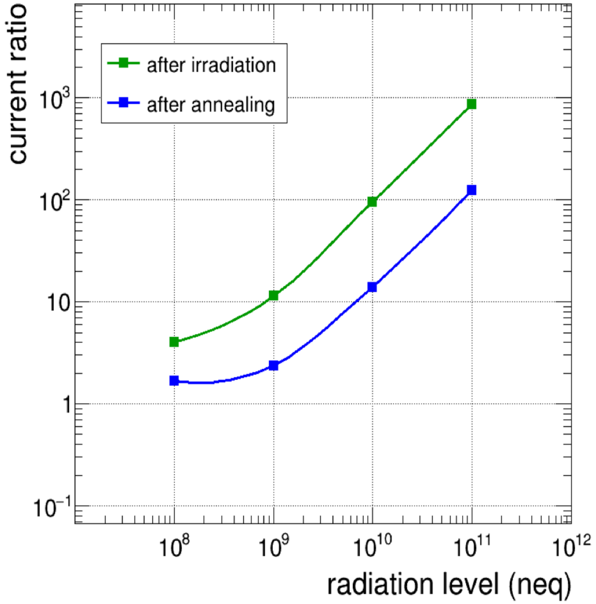
$10^8 - 10^{11}$ 1-MeV neq/cm^2 fluences





high-T annealing (FE)





A quick look at 2021 operations (II)

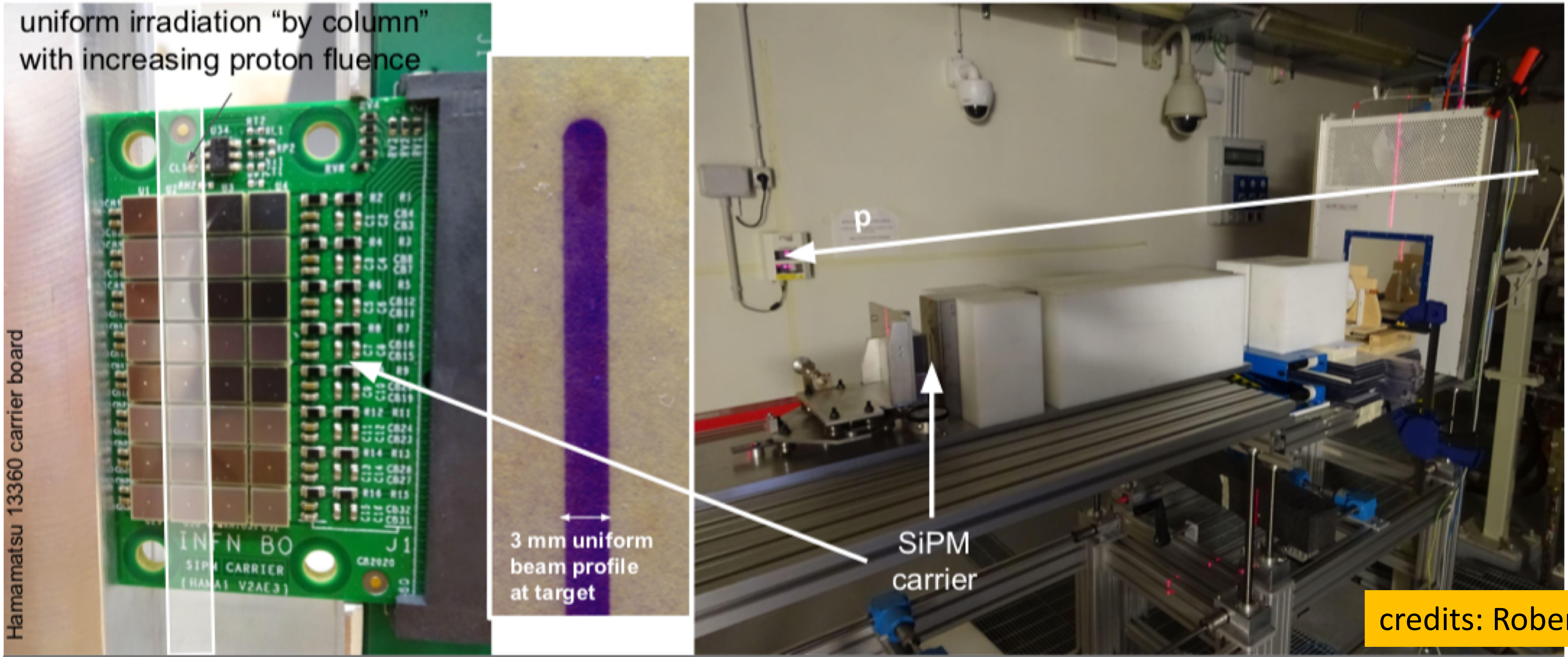
1st irradiation round in May

INFN
Istituto Nazionale di Fisica Nucleare

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

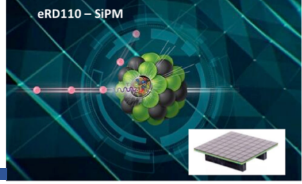
multiple types of SiPM: **Hamamatsu** commercial (13360 and 14160)
FBK prototypes (rad.hard and timing optimised)

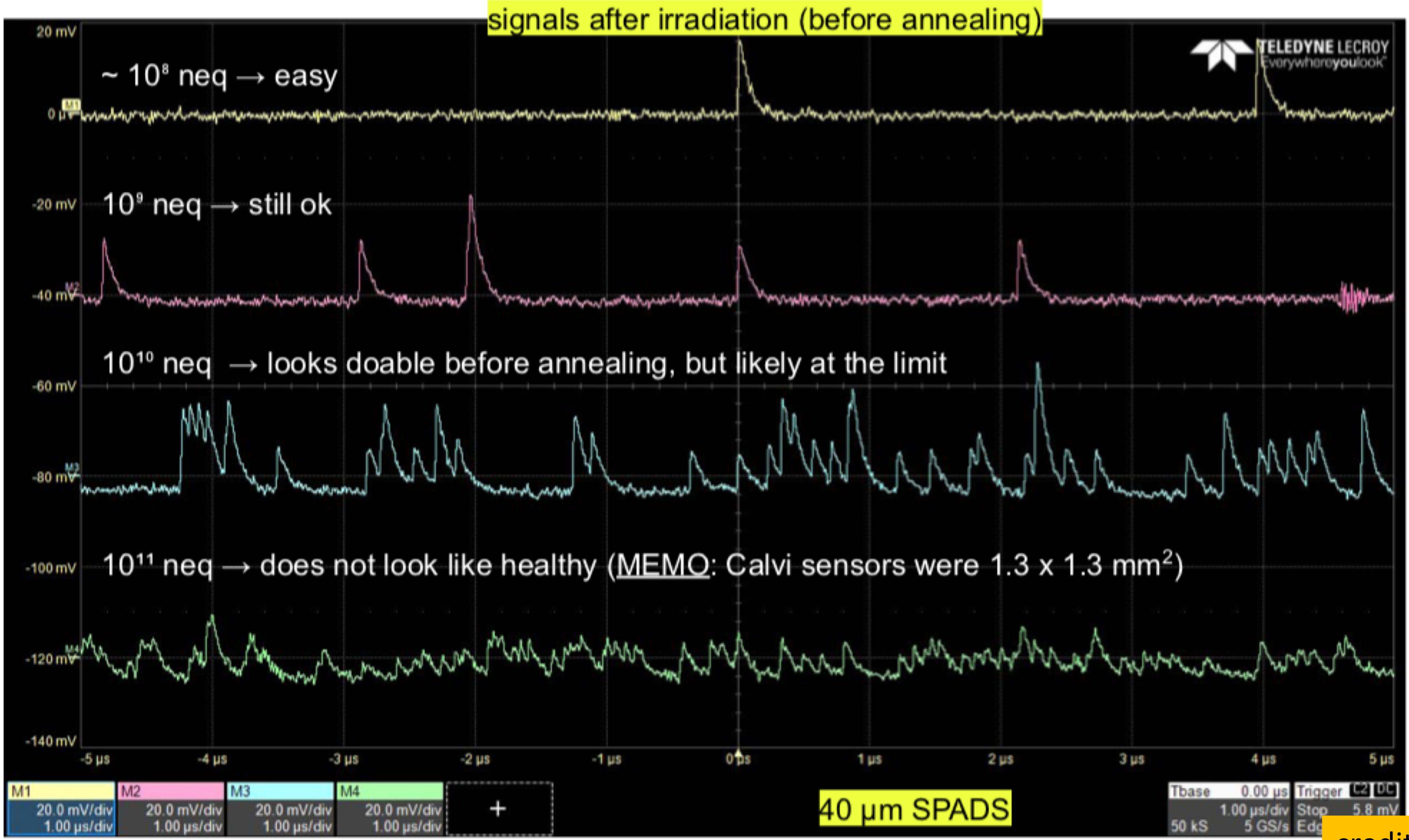
148 MeV protons → scattering system → collimation system → carrier board



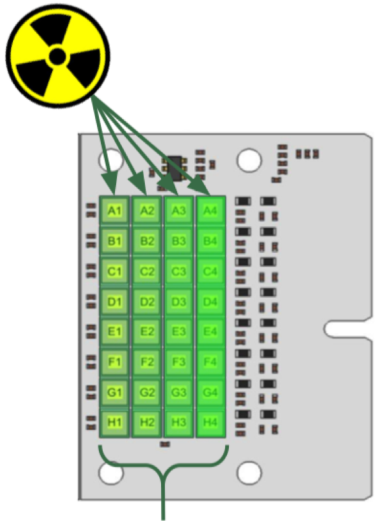
credits: Roberto P.

A quick look at 2021 operations (II)



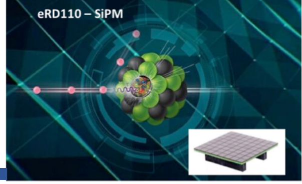


FBK #3 (T = -30 C)
NUV-HD-CHK (row A)

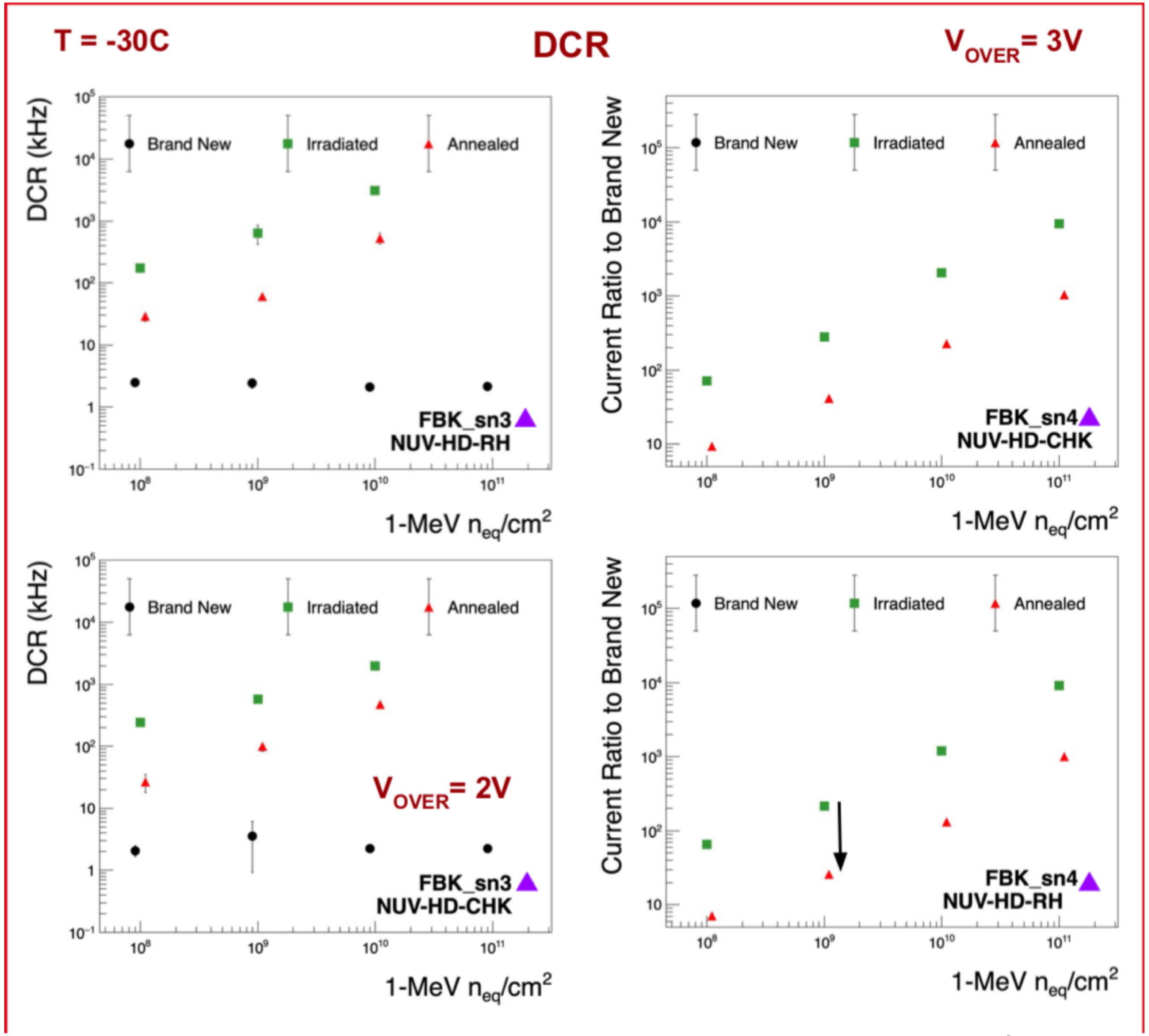


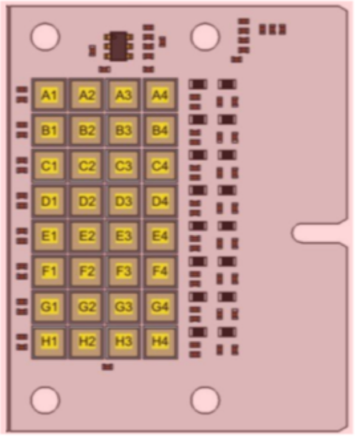
Different levels of dose administered

credits: Roberto P.

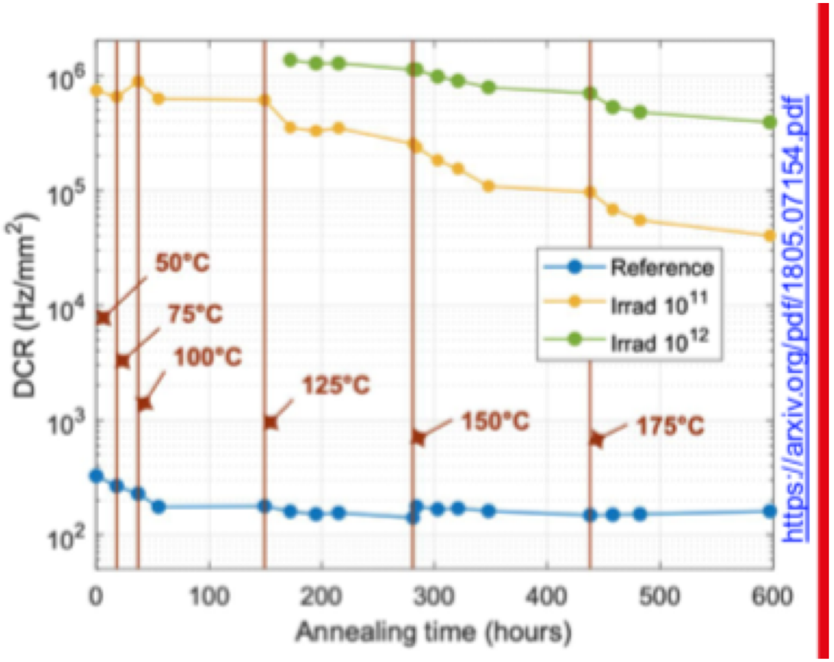


and after annealing (FBK)





annealing cycle done up to 150 C so far
results consistent with Calvi et al.



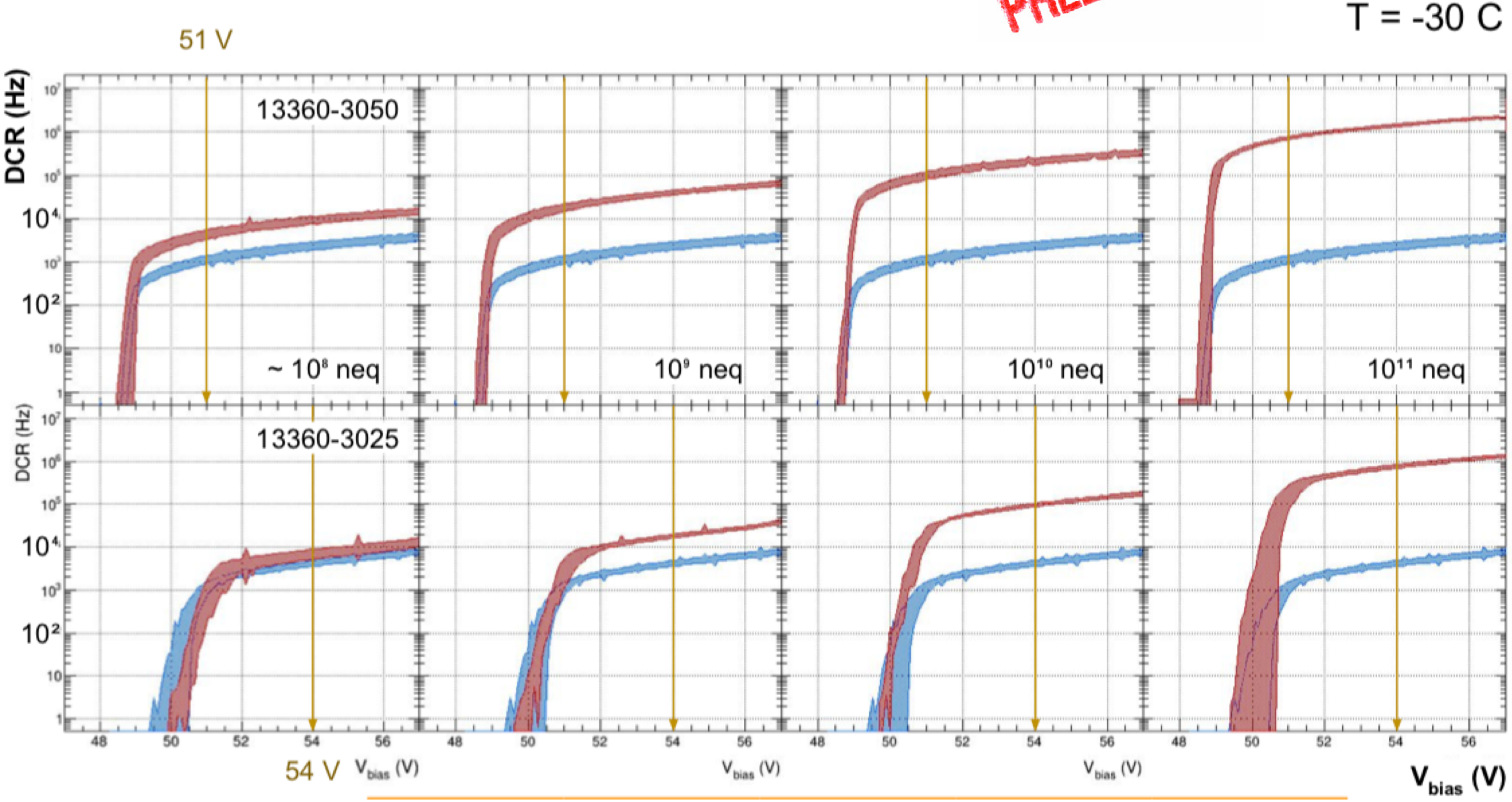
HAMA1 new/after annealing

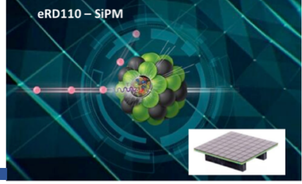
envelope represents
variations over tested sensors
(8 x column at given radiation level)

Fluence (1 MeV-neq)	DCR (kHz) 50 μm	DCR (kHz) 25 μm
new	1.1	2.4
~ 10^8	4.4	7.0
10^9	18	18
10^{10}	100	95
10^{11}	730	770

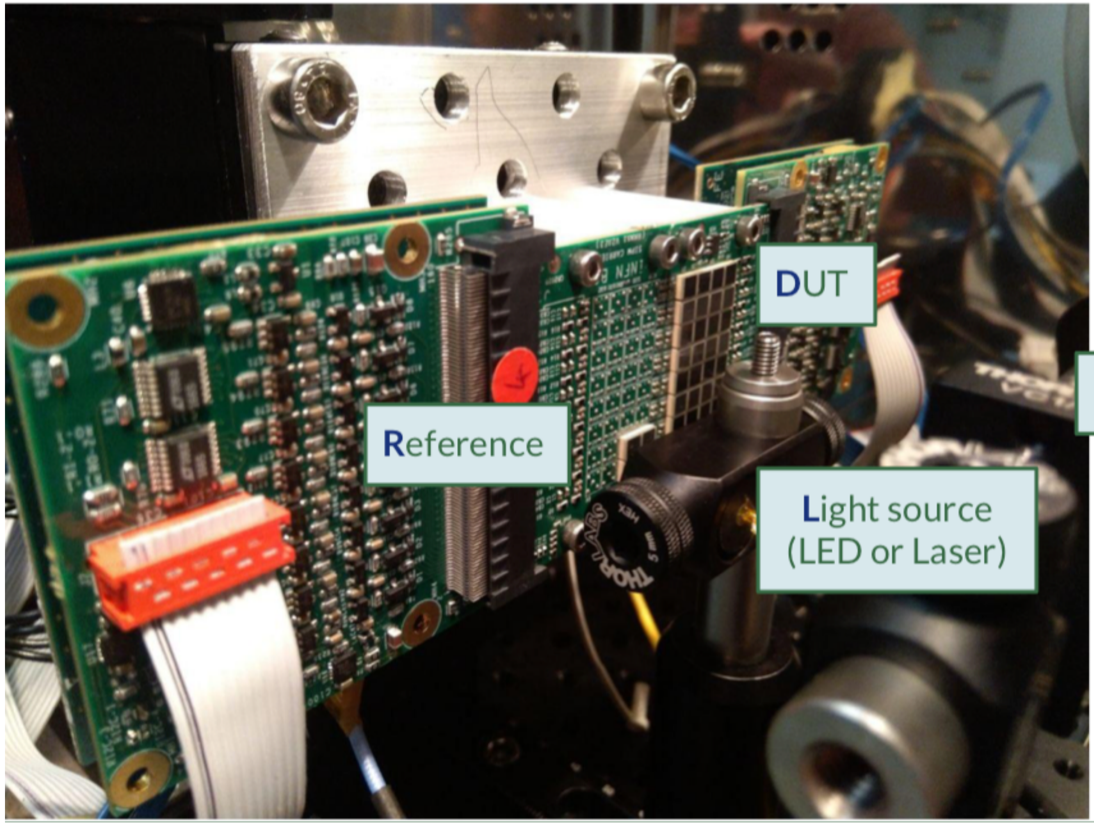
SPAD cell size doesn't seem to make big difference, fill-factor might be other element to choose best SiPM sensor for RICH application

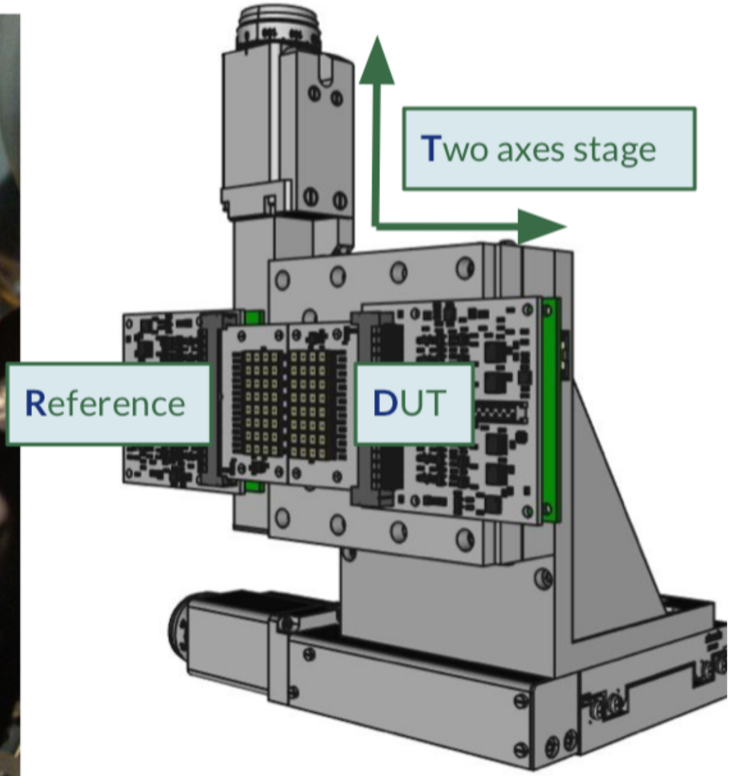
not irradiated board / new
after annealing

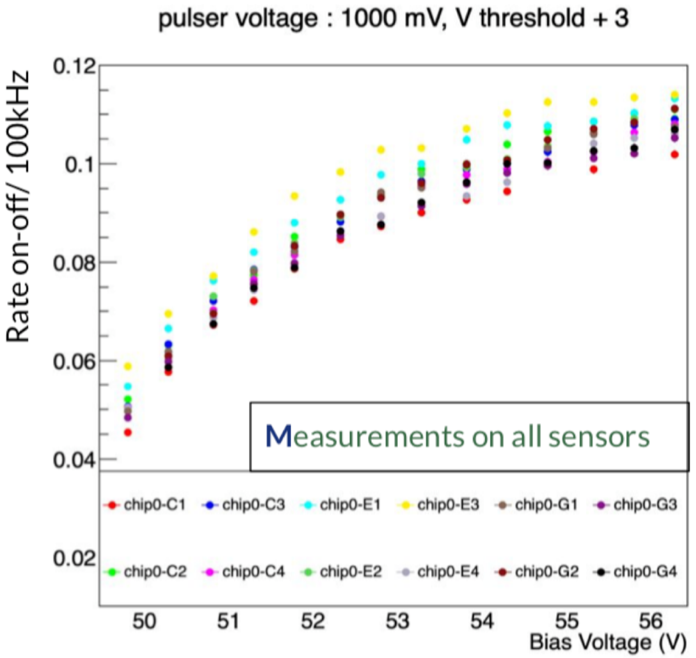




Improving test setup for characterization







- using pulser + LED we proved sensibility or the tool (rate on – rate off)
- setup to be improved: motor stage able to work at low temperature
- setup to be improved: from LED to laser

How often to do annealing?

credits: Roberto P.
see his talk at SiPM meeting for more details

EXAMPLE

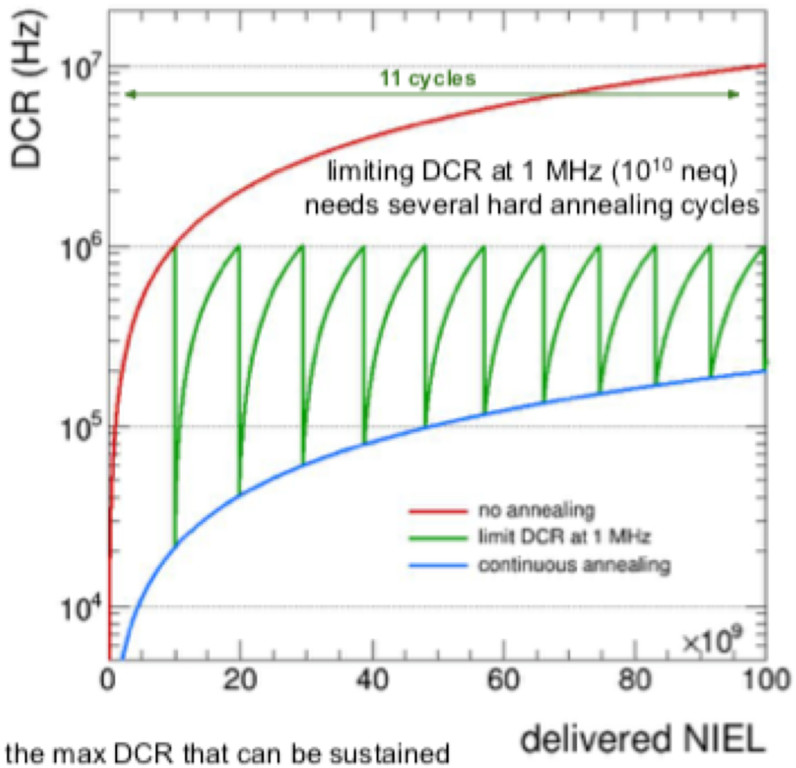
assumptions

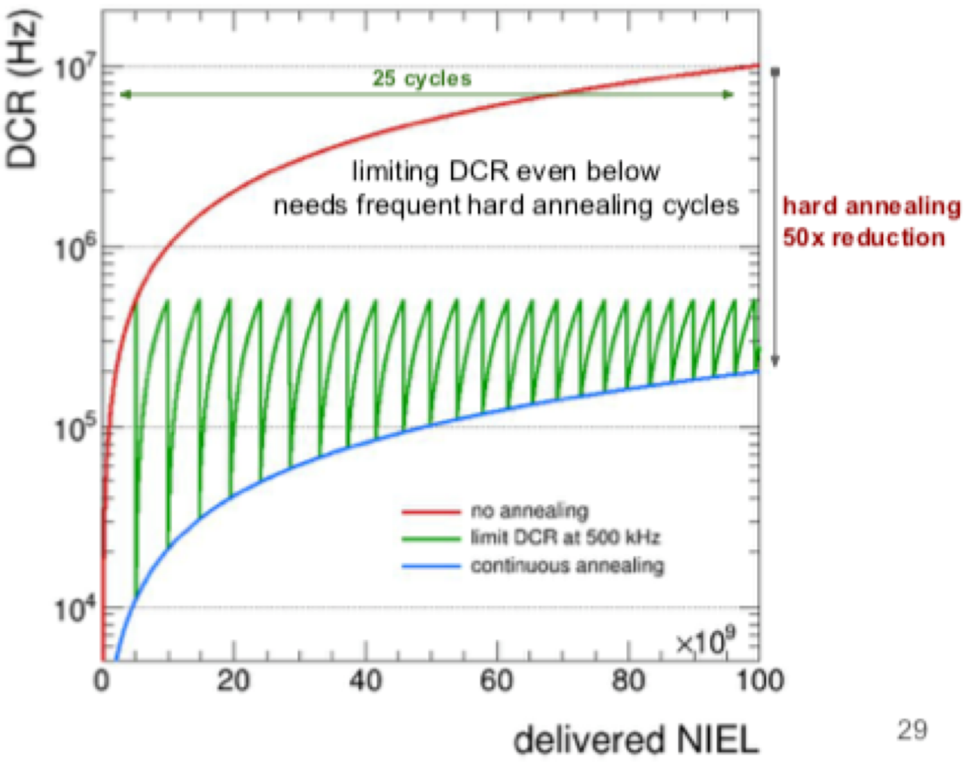
- NIEL = 10^{11} neq/cm^2 ⇒ DCR = 10 MHz
- DCR increases proportionally to NIEL
- annealing always cures same fraction of damage caused by NIEL
  - constant fraction of new damage, regardless total damage

example

- delivered 10^{10} ⇒ DCR = 1 MHz
- annealing, cures 90% of damage ⇒ DCR = 0.1 MHz
- delivered another 10^{10} ⇒ DCR = 1.1 MHz
- annealing, cures 90% of new damage ⇒ DCR = 0.2 MHz

10^{10} neq



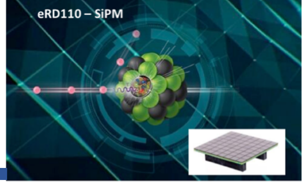


29

it depends on the max DCR that can be sustained

key point: we need to test the effect of iteration of radiation/annealing cycles

eRD110 application



Milestones for FY22:

1. Comparative assessment of commercial (and prototypes not yet available on the market) of SiPM performance after irradiation. Prototypes were made already available to INFN.

2. Definition of an annealing protocol

Timeline: We plan a new irradiation campaign by end of June 2022 and the start of custom developments during summer 2022.

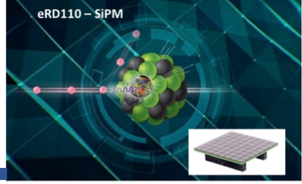
What we had to delay:

- irradiation campaign → from Q1/Q2 2022 to Q3/Q4 2022
- test setup in Bologna
- are eRD110 funds coming?

delay in convention renewal between INFN and local Health Authority in Trento

two months stop due to failure in climatic chamber

decision on eRD funding April 2022



eRD110: the plan

- try to mimic the irradiation – annealing cycle at the experiment
- 4 irradiation campaigns:

Bo — sensor characterization
Tn — irradiation
Bo — sensor characterization
Fe — annealing
Bo — sensor characterization

- 1 x 10^9 cm^2 1 MeV-n_{eq}
- 2 x 10^9 cm^2 1 MeV-n_{eq}
- 4 x 10^9 cm^2 1 MeV-n_{eq}
- 8 (or 4) x 10^9 cm^2 1 MeV-n_{eq}

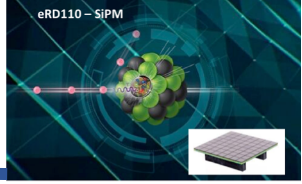
→ 4/6/2022
→ 16/7/2022
→ end of August
→ December

We will use 5 brand new SiPM carrier:
HAMA1, HAMA2, FBK (2), OnSemi

- use led/laser characterization on a subset of sensors
- annealing at 175 C

Possibly use irradiated and annealed sensors at PS@CERN test beam (aspherical lens to get photons à la LAPPD?) in October

a little bit of management....



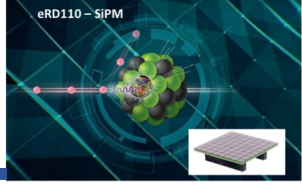
consumables:

1. 5 k$: half of irradiation costs at Trento (the other half is covered by INFN)
2. 5 k$: half of costs of a moving stage able to operate at low temperature (-30C) inside the climatic chamber. This tool will reduce dramatically scan time needed for the full characterization of an irradiated SiPM matrix
3. 10 k$: pulsed laser (the laser currently used in the lab is not property of the EIC group and is shared)
4. 5 k$: oven for annealing. Currently the annealing is done in Ferrara where an oven is available. Having such tool in Bologna aims to equip the lab as a full-fledged SiPM lab for characterization and annealing studies, where other INFN units personnel might also involved
5. 5 k$: additional sensors (FBK) for additional tests

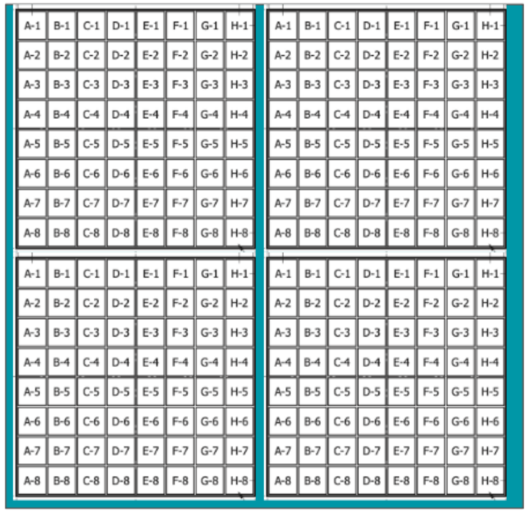
personnel

1. 30 k$ covering ex-post partial funding of a post-doc position in Bologna and a PhD in Bologna

How a dRICH "tile" could look like (toward FY23)



dRICH tile



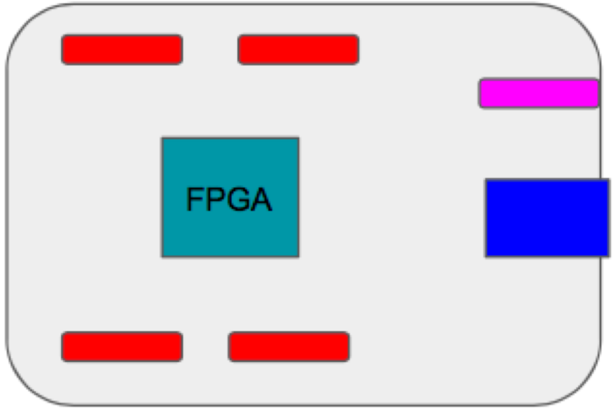
x 1240

dRICH tile 5.6 x 5.6 cm^2

dRICH FEB (front-end board)

x 1240

dRICH ROB (readout board)



HV

opt link to DAQ

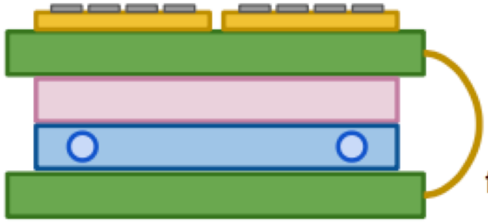
x 310

proto-readout-tile

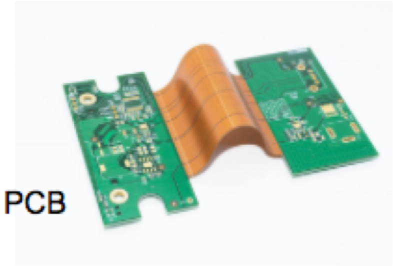
(Peltier cell?)

cooling

front-end ASIC



flex PCB

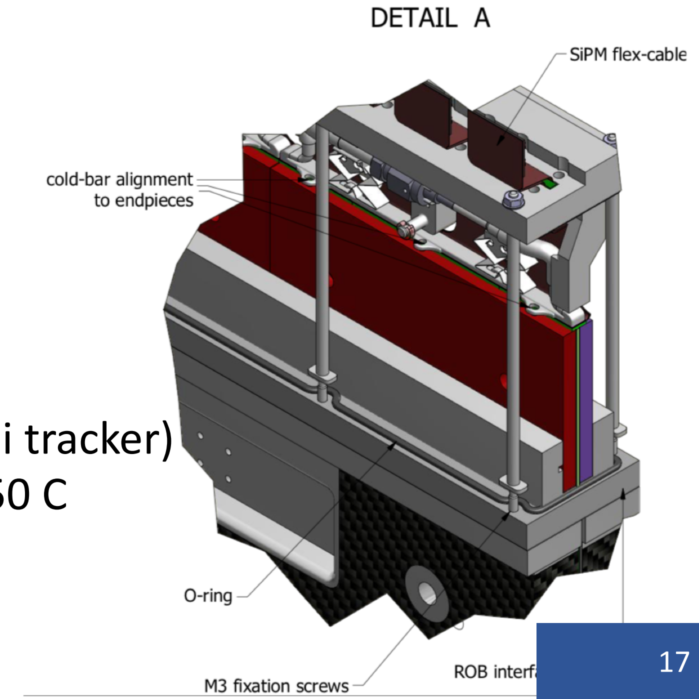


- SiPM selection
- ASIC development
- annealing protocol
- cooling (& annealing *in situ*)

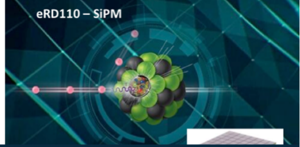
a lot of R&D ahead of us!

Cooling system from LCHb (SciFi tracker) for SiPM expected to work at -50 C

LHCb-PUB-2015-008



Plans & outlook



Results of 2021 campaign (and partially 2022 if everything goes well) to be presented at NDIP2020 (that will be in 2022) (+ RICH2022: abstract submitted)

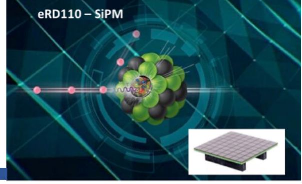
Intense program of irradiation campaign + measurement / data analysis

We aim to fulfill milestones by March 2023 at the latest. Possibly in February.

Application for FY23 will aim to build small scale final prototype of the tile unit.

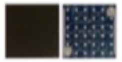
Many thanks to colleagues for a lot of material, especially R. Preghenella, L. Rignanese and N. Rubini

Backup



Sensors under test






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

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