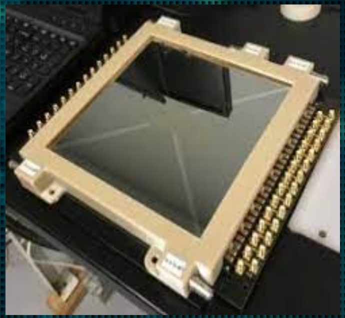
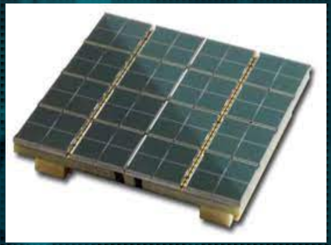
eRD110





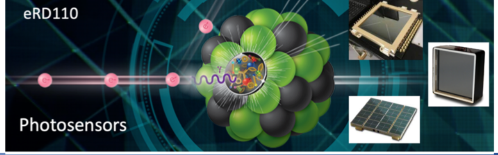
Photosensors

P. Antonioli – INFN Bologna

Istituto Nazionale di Fisica Nucleare

on behalf of the EIC Project Detector eRD110 - Photosensors

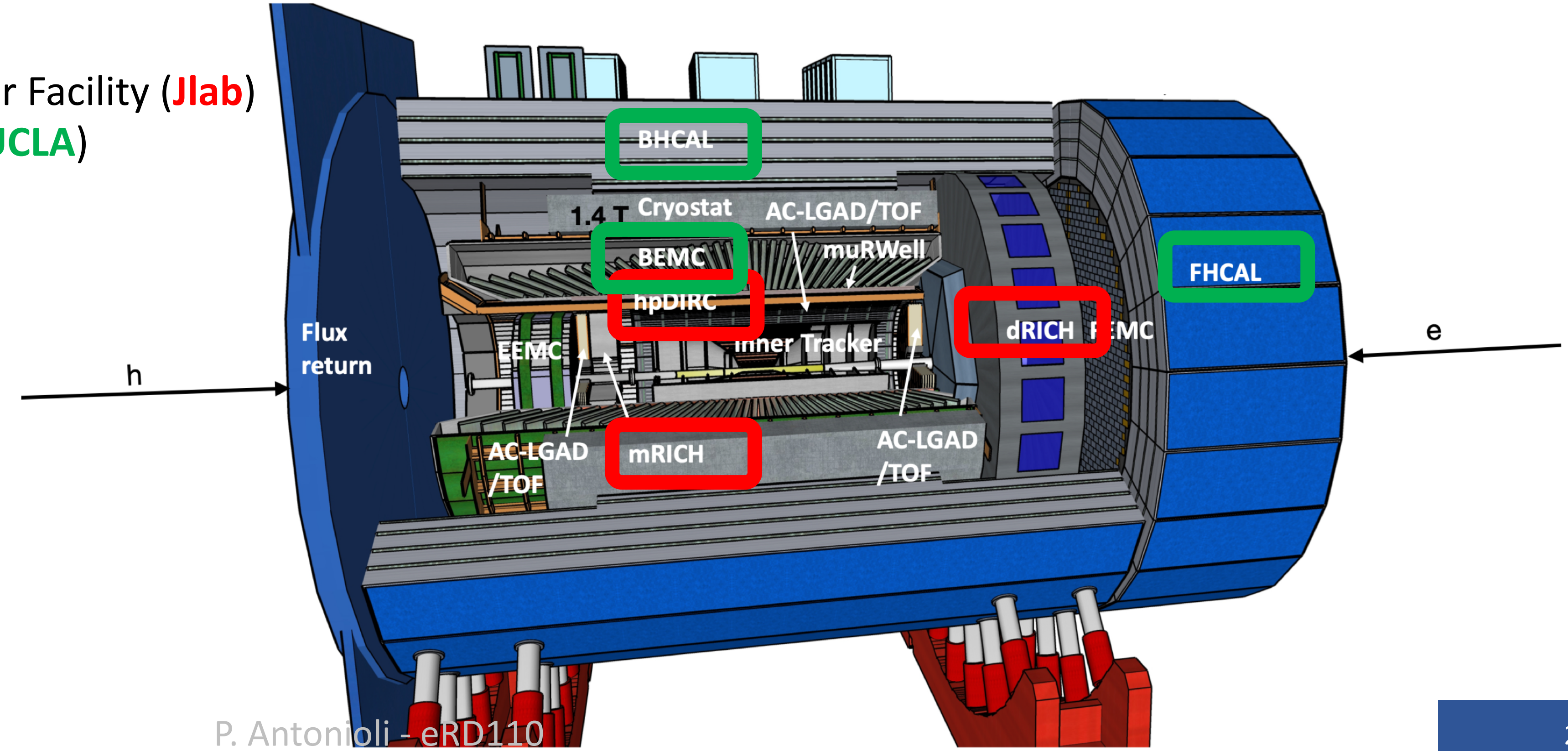
The eRD110 consortium



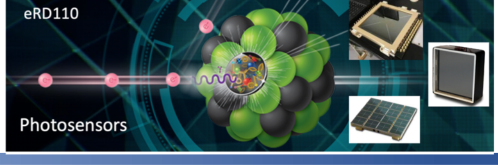
Applied for FY22+ for SiPM, LAPPD and MCP-PMT (**DIRC** and **RICHs**)

Planned application since FY23 for **calorimeters** readout via SiPM

Argonne National Laboratory (**ANL**)
Brookhaven National Laboratory (**BNL**)
Catholic University of America (**CUA**)
Friedrich-Alexander-Universit¨at Erlangen-N¨urnberg (**FAU**)
GSI Helmholtzzentrum f¨ur Schwerionenforschung (**GSI**)
Istituto Nazionale di Fisica Nucleare (**INFN**) (Bologna, Ferrara, Genoa, Trieste, Turin)
Mississippi State University (**MSU**)
Stony Brook University (**SBU**)
Thomas Jefferson National Accelerator Facility (**Jlab**)
University of California Los Angeles (**UCLA**)
University of South Carolina (**USC**)



Outline

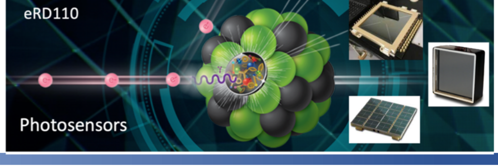


- Motivations
- Results from 2021 and plans/activities in 2022
- The long term: toward EIC Detector 1 CD 2/3a and CD 3

From eRD110 proposal

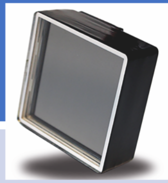
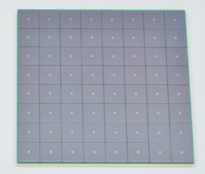
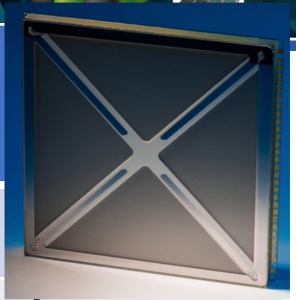
*"The objective of the R&D effort presented here is to **mitigate technical, cost, and schedule risk related to readout sensors of EIC Cherenkov detectors and Calorimeters.** The call for this proposal requests that this R&D effort comes to a clear and well-informed decision for a baseline sensor solution for each PID detector in FY22. Our common consensus is that R&D effort beyond FY22 is absolutely necessary in order to be able to form a decision that capitalizes on all state-of-the-art tech- nologies to mitigate all of the risks specified above".*

The table of requirements



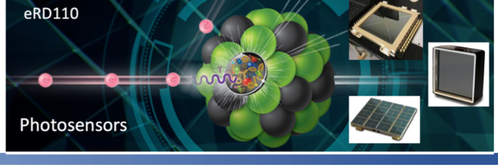
Parameter	hpDIRC	dRICH – mRICH/pfRICH
Gain	$\sim 10^6$	$\sim 10^6$
Timing resolution	$\leq 100\ ps$	$\leq 300\ ps$
Pixel size	2– 3 mm	$\leq$ 3 mm
Dark noise	$\leq$ 1 kHz/cm^2	$\leq$ 1 MHz/cm^2
Radiation tolerance @ 10^{11} 1 MeV-neq	NEEDED	NEEDED
Single-photon mode	REQUIRED	REQUIRED
Magnetic field immunity	NEEDED (0.7-1.5 T)	NEEDED (0.7-1.5 T)
Photon Detection Efficiency	$\geq 20\%$	$\geq 20\%$

The table of candidate photosensors

	MCP-PMT/Planacon 	SiPM 	LAPPD 
Area	5x5 cm^2	Tiles available 5.76 cm^2	20x20 cm^2
Pixel		3x3 mm^2	25 x 25 mm available → 3x3 mm in future?
Magnetic field	Seen drop in collection efficiency at angle > 10 deg	insensitive	0.7 T on 20 μm MC seems ok, depending orientation. Smaller MCP's for larger field
Radiation	insensitive	neeeds test + assess mitigation protocol (annealing)	No data, but reasonable to expect not a problem
Availabteyility	In stock*	In stock*	"In-stock" for 20 μm
Manufacturers	Photonis/Photek	many (HPK, OnSemi, FBK/L-Foundry, Ketek/Boradcom)	Incom
Price	$ 15-20 k$ each (few units)	1 k$ /(8x8 tile 3x3 mm)	$25-50K each LAPPD (20x20 cm^2 or 10x10 cm^2 similar price)
Unit price	16 k$/25 cm^2 = 600 $/$cm^2$	≈50-100 $/$cm^2$	62.5-500 $/$cm^2$
Concerns	cost	DCR increase with radiation	Cross talk, integration, availability
Risks	None	None if mitigation of DCR increase "manageable"	Achievable with risk, time schedule challenging

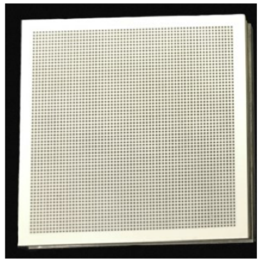
R&D program in a slide

(FY22)



MCP PMTs: Photonis xp85122-s-HiCE and Photek MAPMT253

→ check collection efficiency with B
→ evaluate Photek MAPMT253
→ full characterization
→ adapt NALU ASIC for custom readout



Not funded by EIC project for FY22

USC – CUA – SBU - JLab

LAPPD/HRPPD: evaluation of Incom "Gen-II"

→ Gen-II == capacitively coupled → pixelation
→ 10 micron pore size/reduced stack height → improved tolerance to B
→ characterize sensors and test them on beam conditions

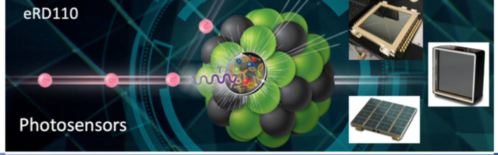
ANL – BNL – MSU – INFN TS/GE

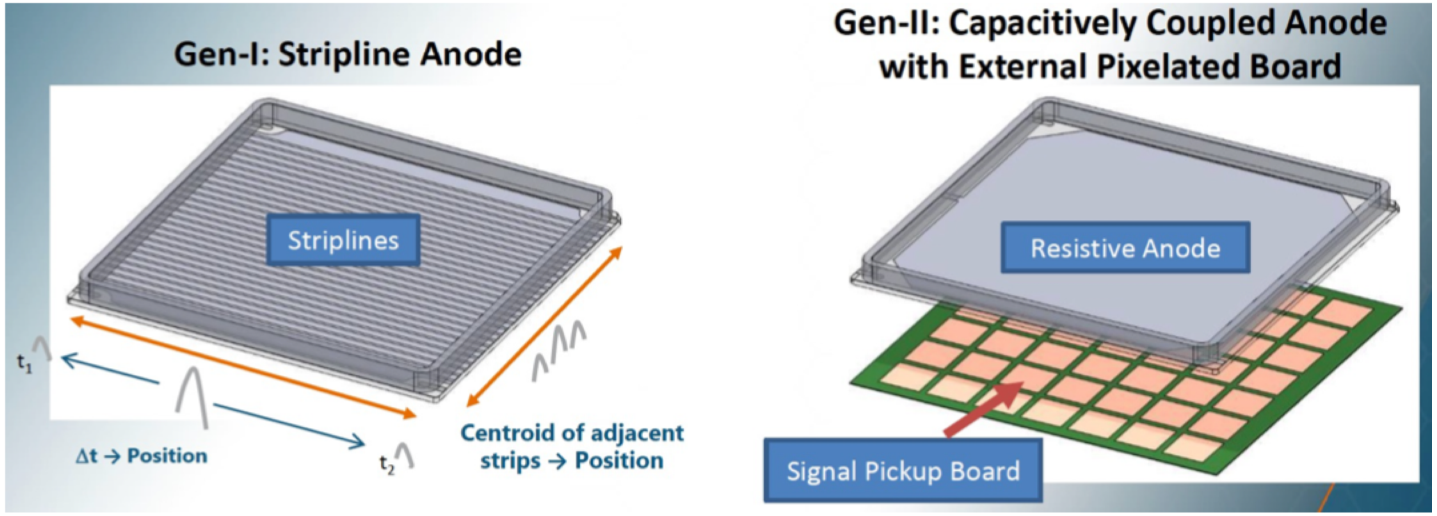
SiPM: evaluate radiation tolerance and mitigation procedures (annealing)

→ test large O(10-100) samples of commercial (HPK/OnSemi) and prototypes (FBK)
→ establish annealing protocol, evaluate DCR after repeated annealing cycles
→ characterize sensors and test them on beam conditions
→ realistic readout with ALCOR ASIC

INFN BO/FE/TO

LAPPD R&D highlights

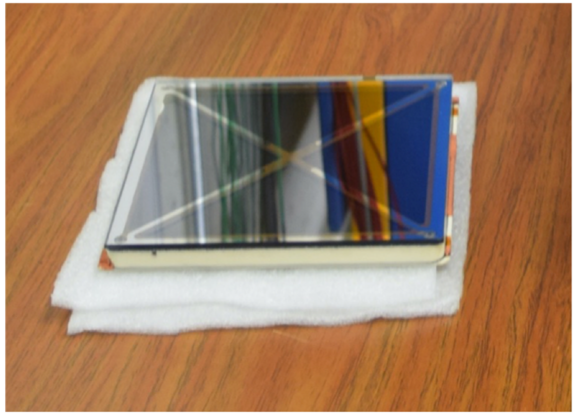


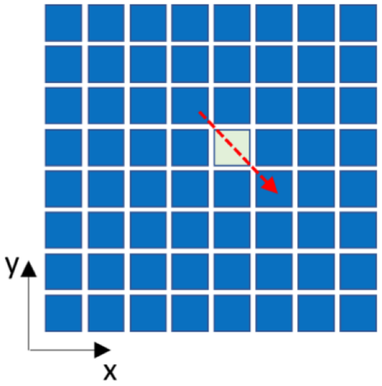


capacitively coupled allow user flexibility for pixelation
better spatial resolution expected
timing resolution preserved

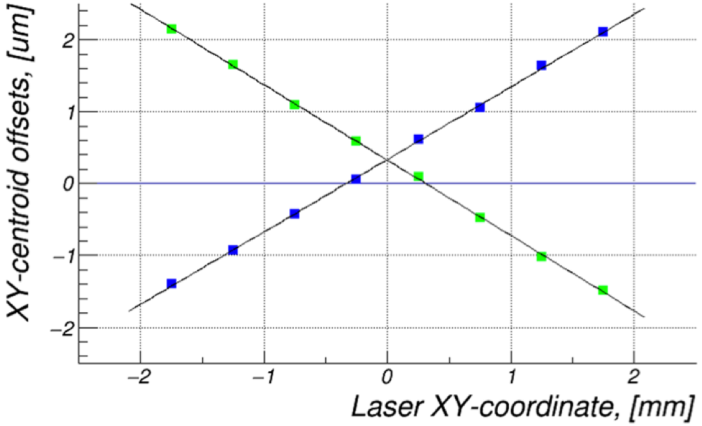
"from one photon – one hit to a multi-pixel cluster"

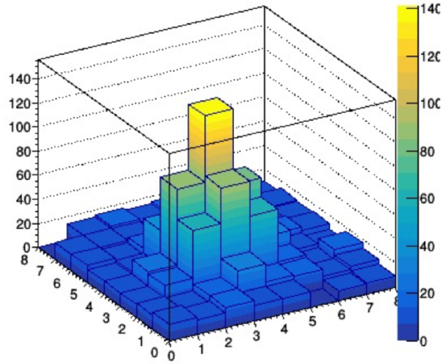
laser scan @ BNL





3x3 mm field

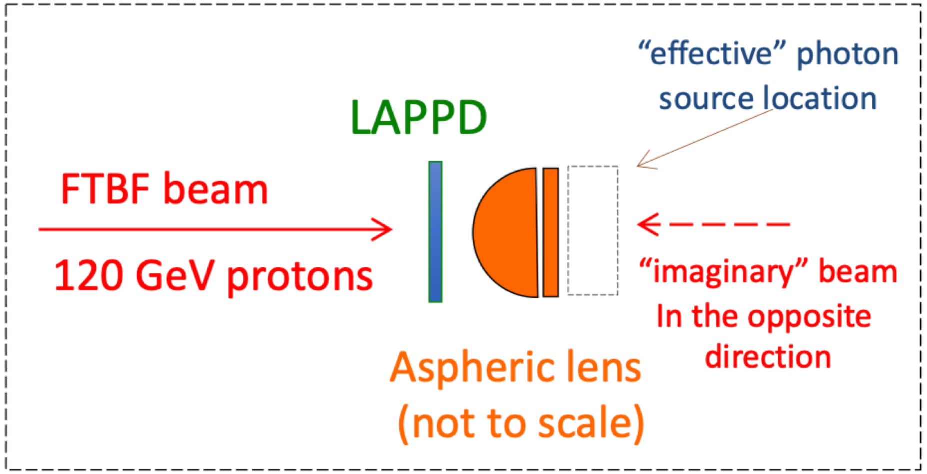


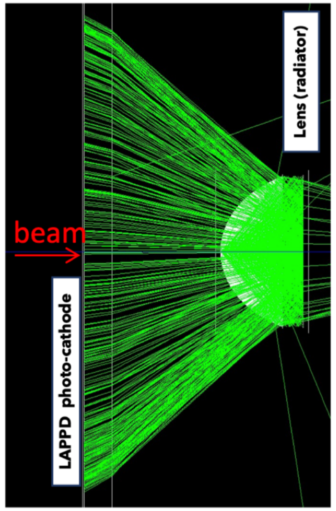


Typical single photon cluster has RMS ~ 3.5 mm

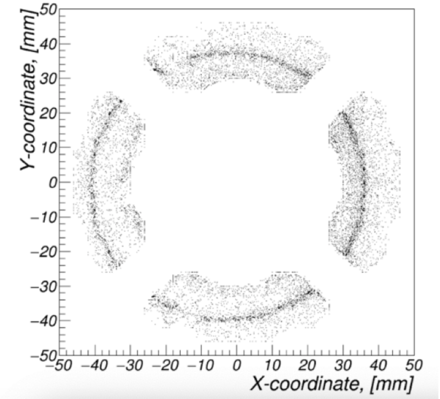
(see for more info the recent talk at 15th Pisa Meeting on Advanced Detectors May 22-28, 2022, La Biodola – Isola d'Elba (Italy)
https://agenda.infn.it/event/22092/contributions/167345/attachments/91232/123760/ayk-2022-05-23-pisa-lappd-pixellation.v00.pdf

Beam tests in 2021 (FNAL)



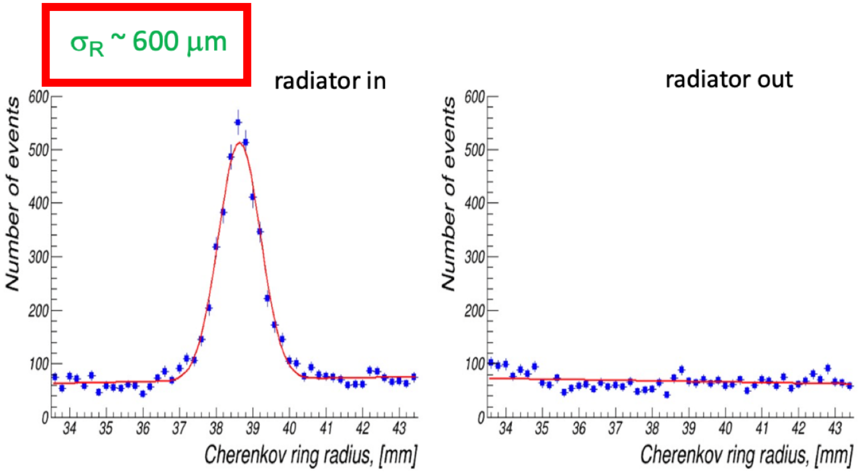


thick aspheric lens as controlled Cherenkov ring producer

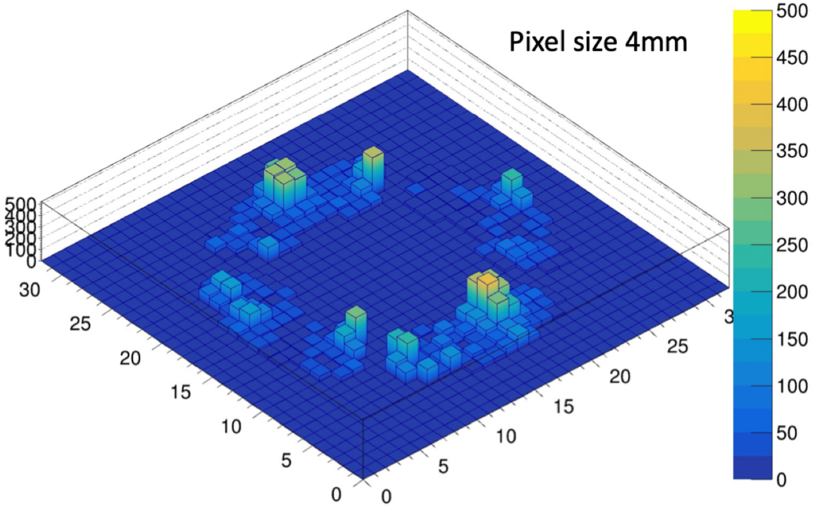


accumulated pixel hits

Cherenkov ring radius resolution



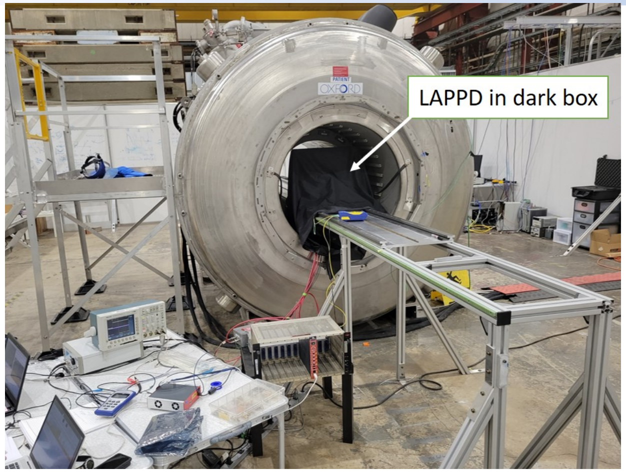
Single photon ring radius resolution

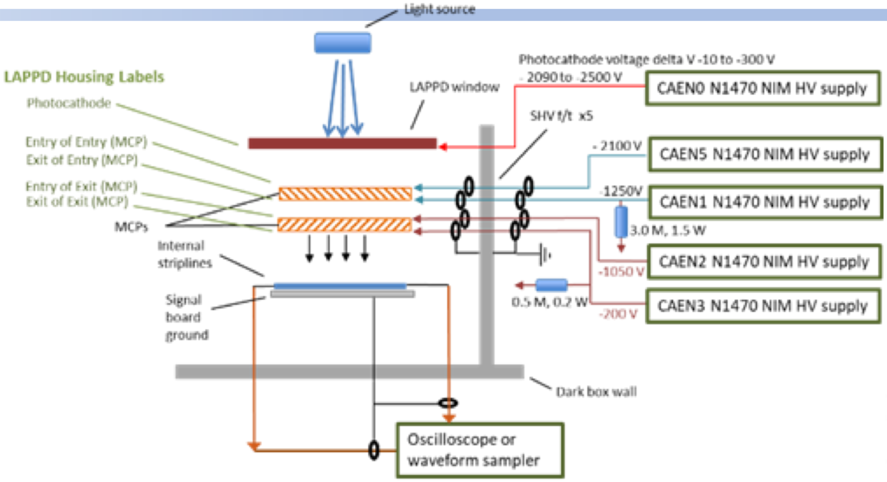


Single event with multiple photon clusters

single Cherenkov photon detection with sub-mm resolution!

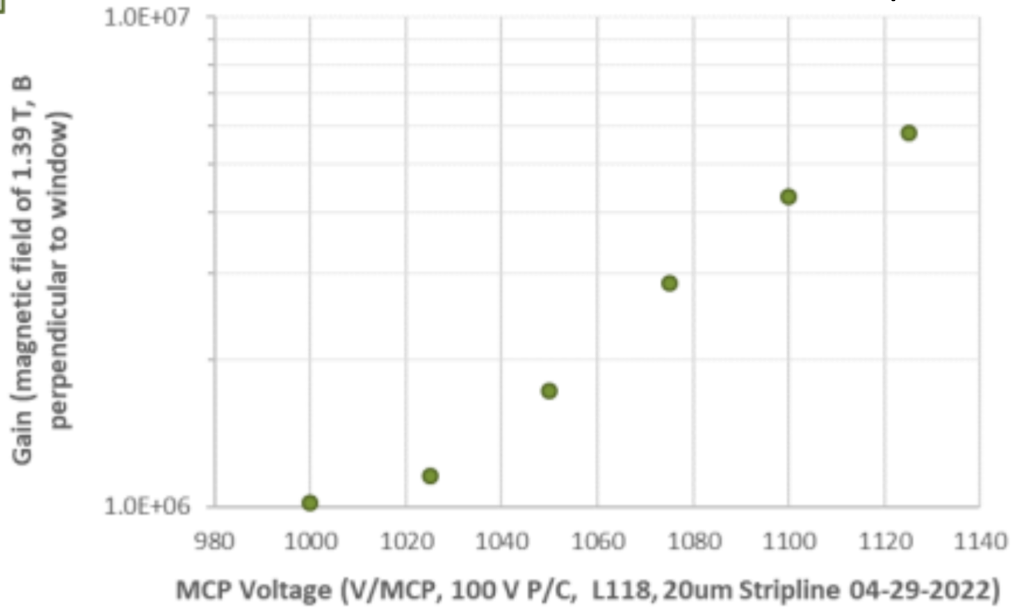
Magnetic test @ ANL – 2022



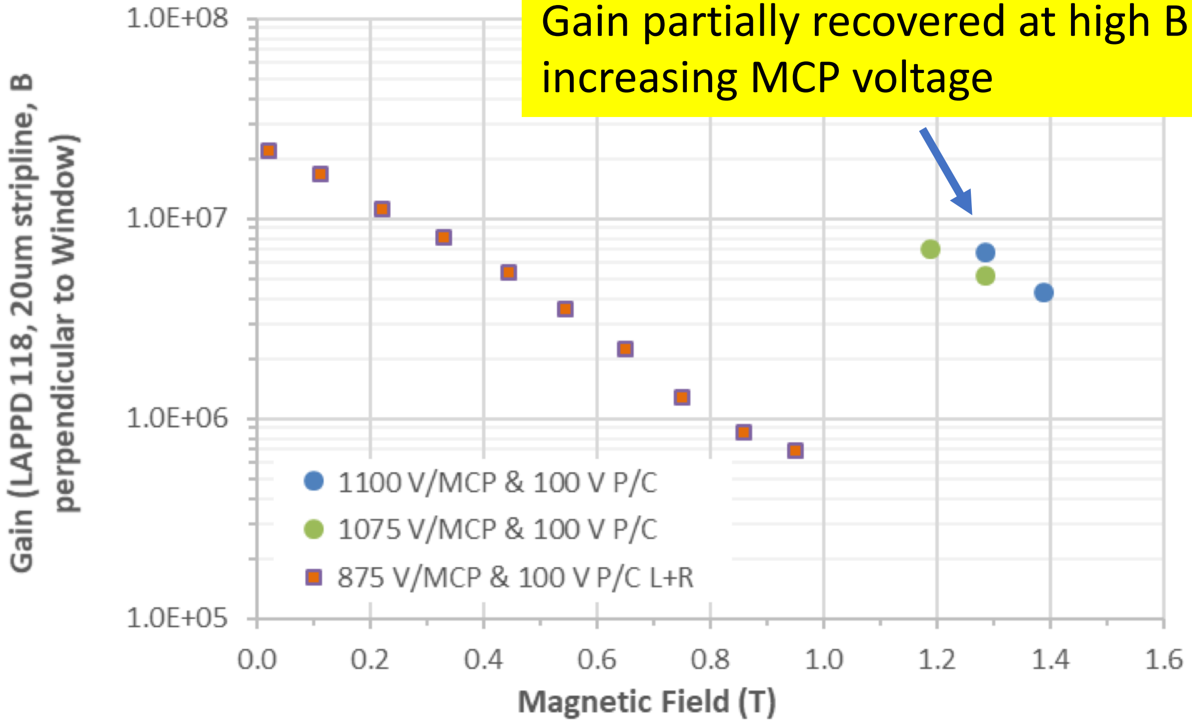


credits: Junqie X.
see also J. Xie et al., JINST 15 (2020) C0438

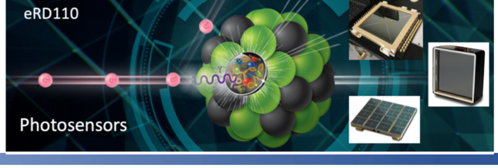
abstract submitted to IEEE NSS-MIC/2022

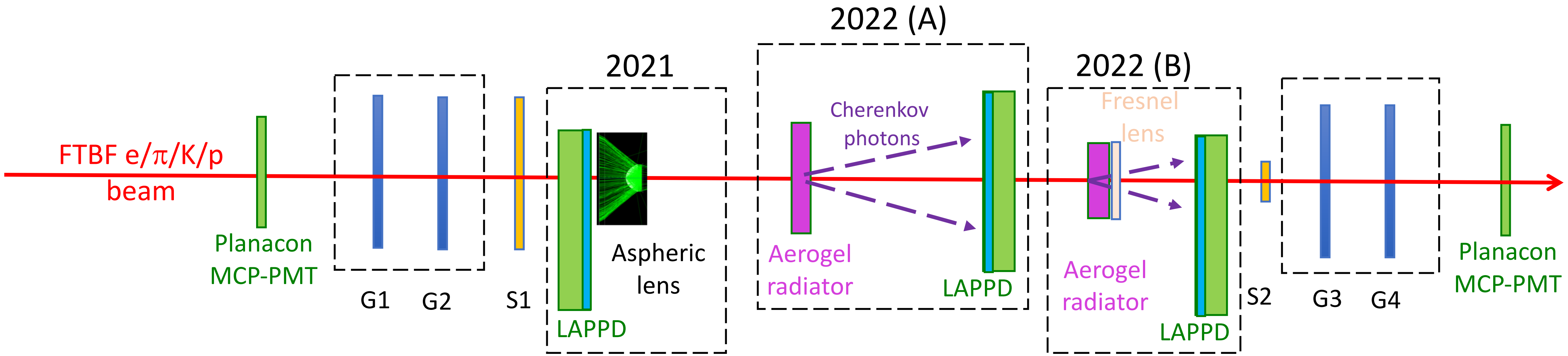


Gain partially recovered at high B increasing MCP voltage



LAPPD – 2022 plans

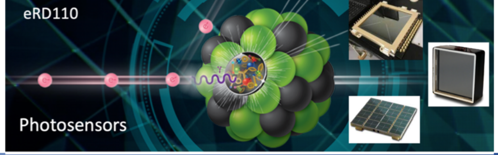




- Rent state-of-the-art Gen II 20cm LAPPD and 10cm HRPPD tiles
  - 10 μm pore MCPs
  - 2 mm thin ceramic base plate and short ceramic walls
- Quantify expected reduction of the induced signal spread, spatial and timing resolution, gain uniformity and PDE
- Work on Gen I HRPPD readout interface

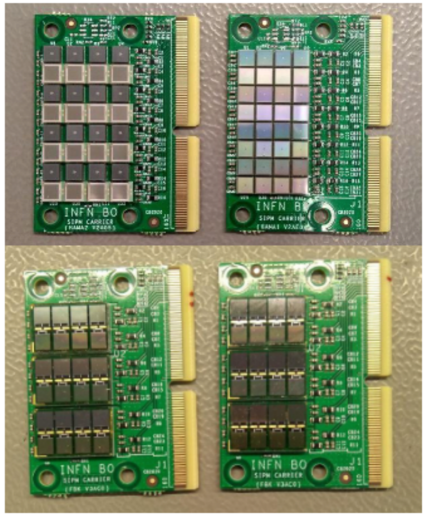
- Beam test at Fermilab June 13-26
  - Verify single photon and "TOF blob" timing resolution, as well as Cherenkov ring radius resolution
  - Provide a first direct π/K separation measurement, potentially using both Cherenkov imaging and time-of-flight technique
  - Configuration(s): mRICH mockup and / or pfRICH geometry

SiPM R&D highlights @ INFN



SiPM carriers

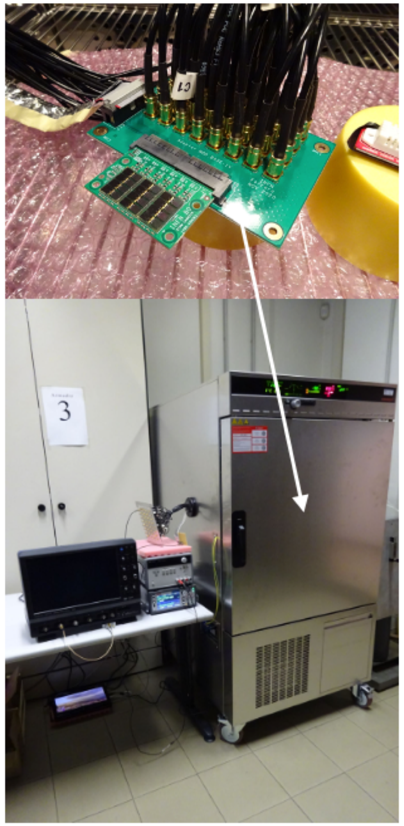
commercial Hamamatsu



FBK prototypes

3x3 mm² SiPM

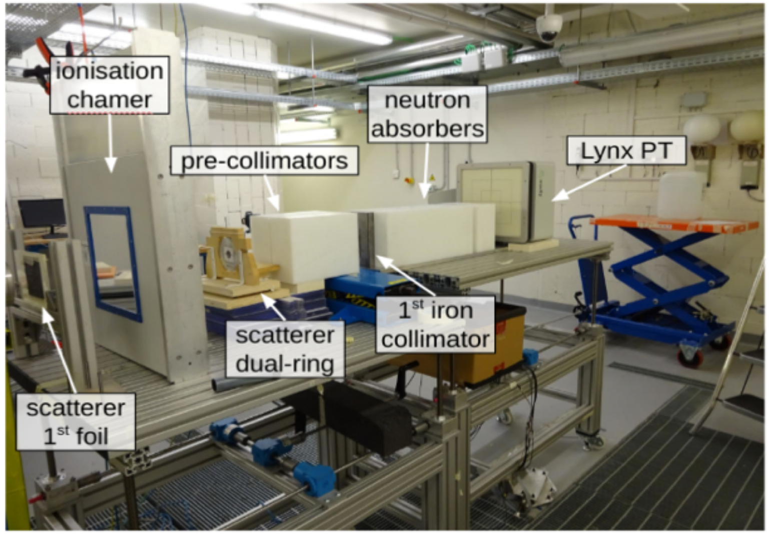
characterisation in lab @ BO/FE

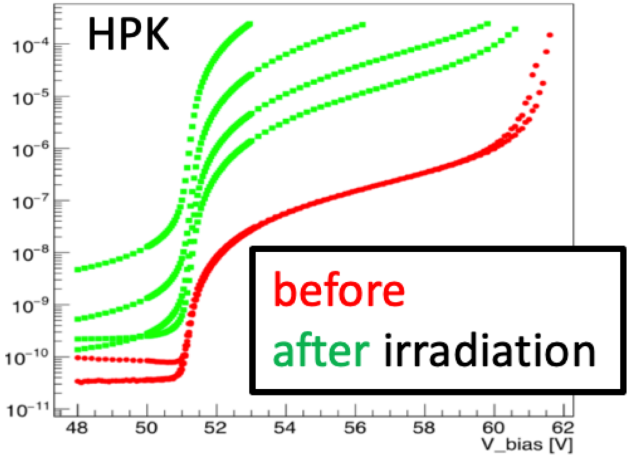


climatic chamber, low-T operation

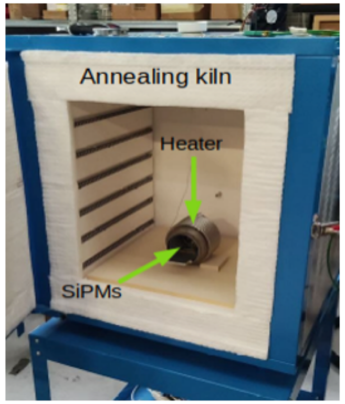
irradiation tests at Centro di Protonterapia at TN

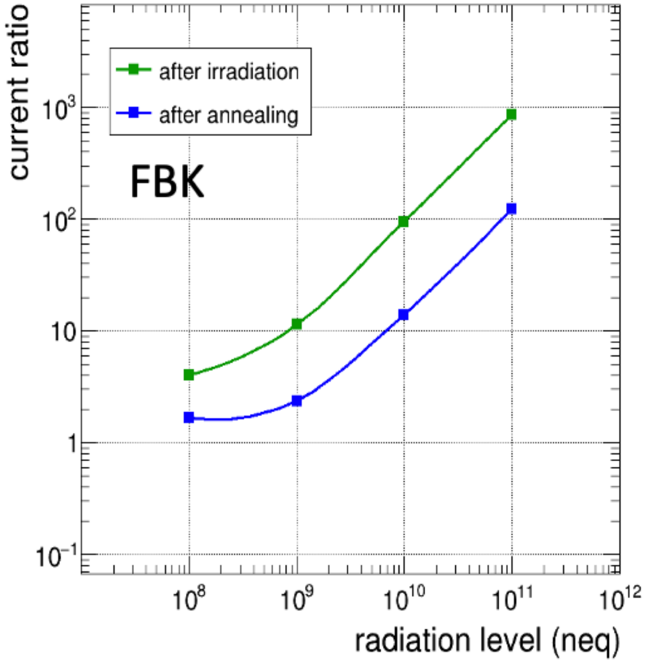
$10^8 – 10^{11}$ 1-MeV neq/cm² fluences





high-T annealing (FE)





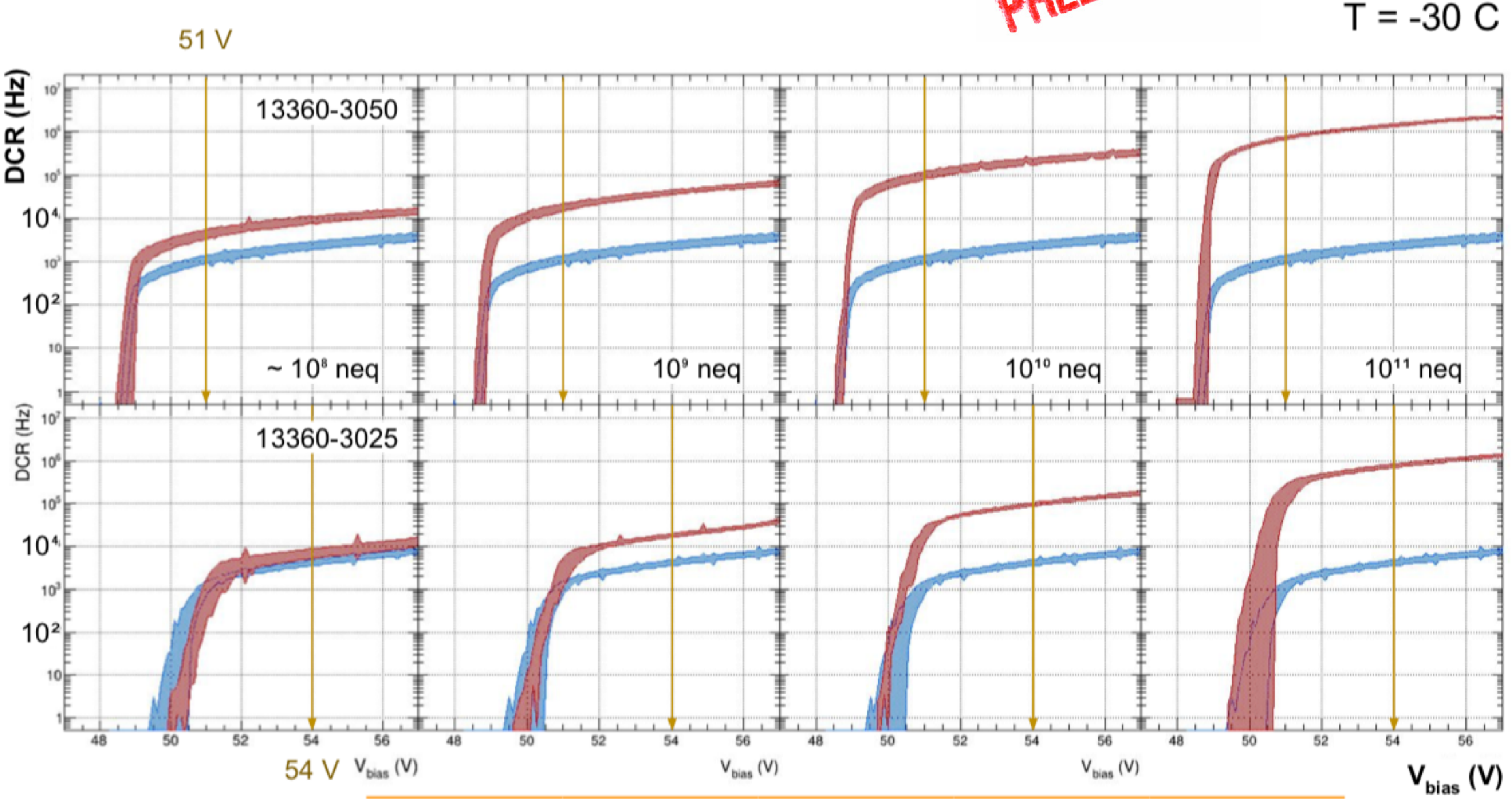
HAMA1 new/after annealing

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

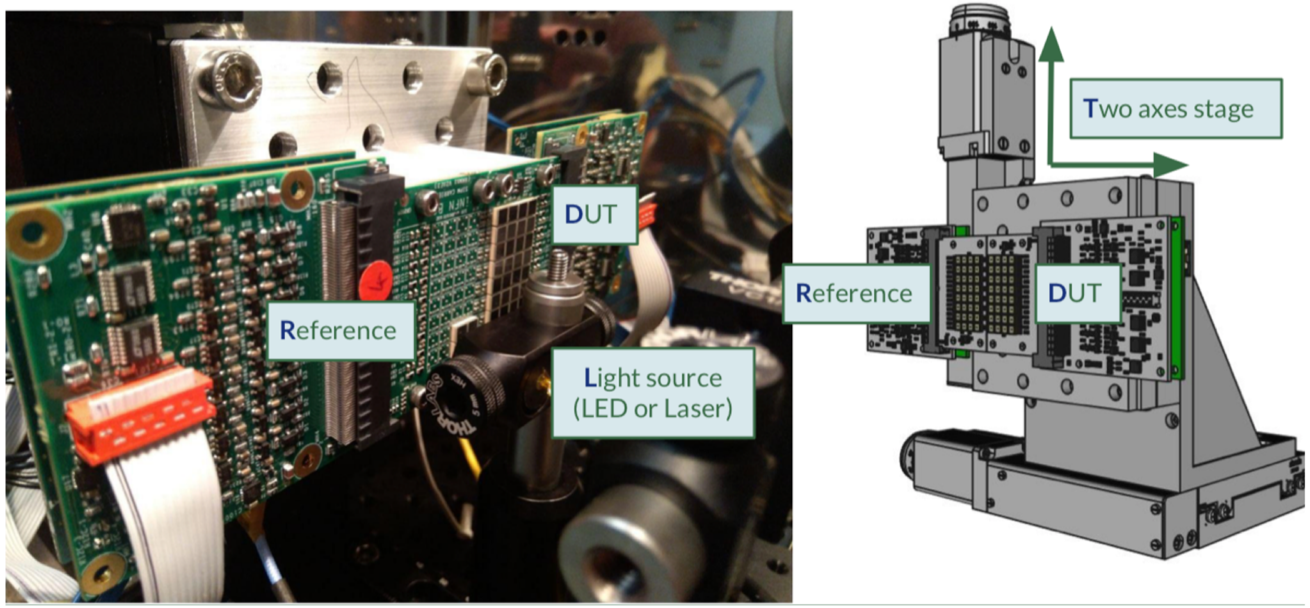
SPAD cell size doesn't seem to make big difference, fill-factor might be other element to choose best SiPM sensor for RICH application

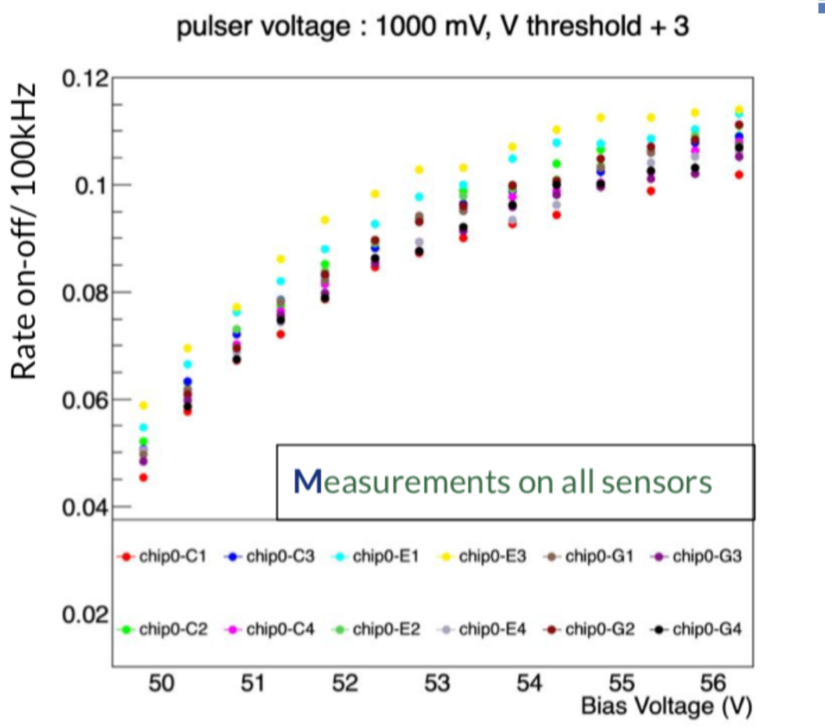
not irradiated board / new
after annealing



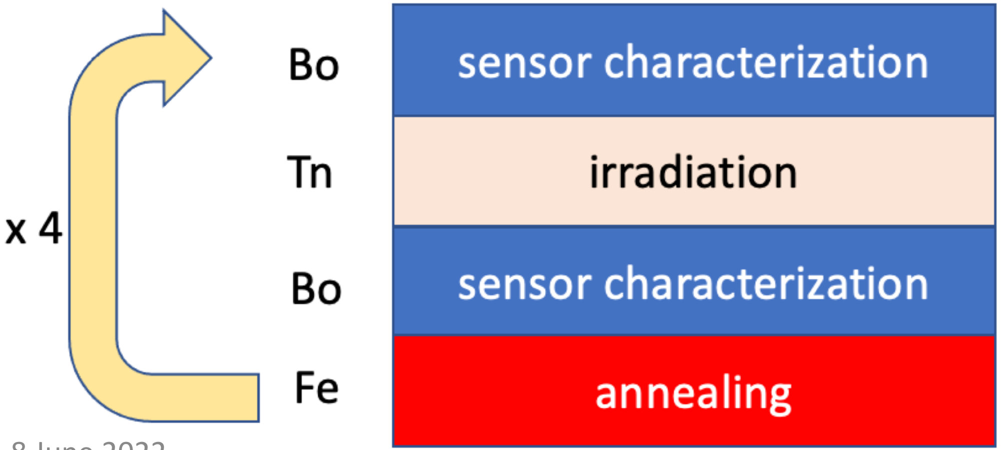
SiPM 2022 plans

improved setup for characterization in Bologna



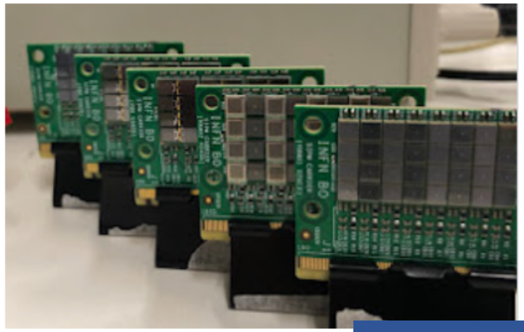


repeated irradiation-annealing cycles to prove the "mitigation strategy"

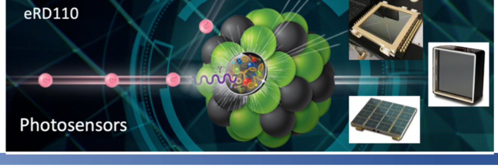


- 1 x 10^9 cm^2 1 MeV-n_{eq} → 4/6/2022
- 2 x 10^9 cm^2 1 MeV-n_{eq} → 16/7/2022
- 3 x 10^9 cm^2 1 MeV-n_{eq} → end of August
- 4 x 10^9 cm^2 1 MeV-n_{eq} → December

Five brand new SiPM carriers (134 sensors)
HAMA1, HAMA2, FBK (2), OnSemi



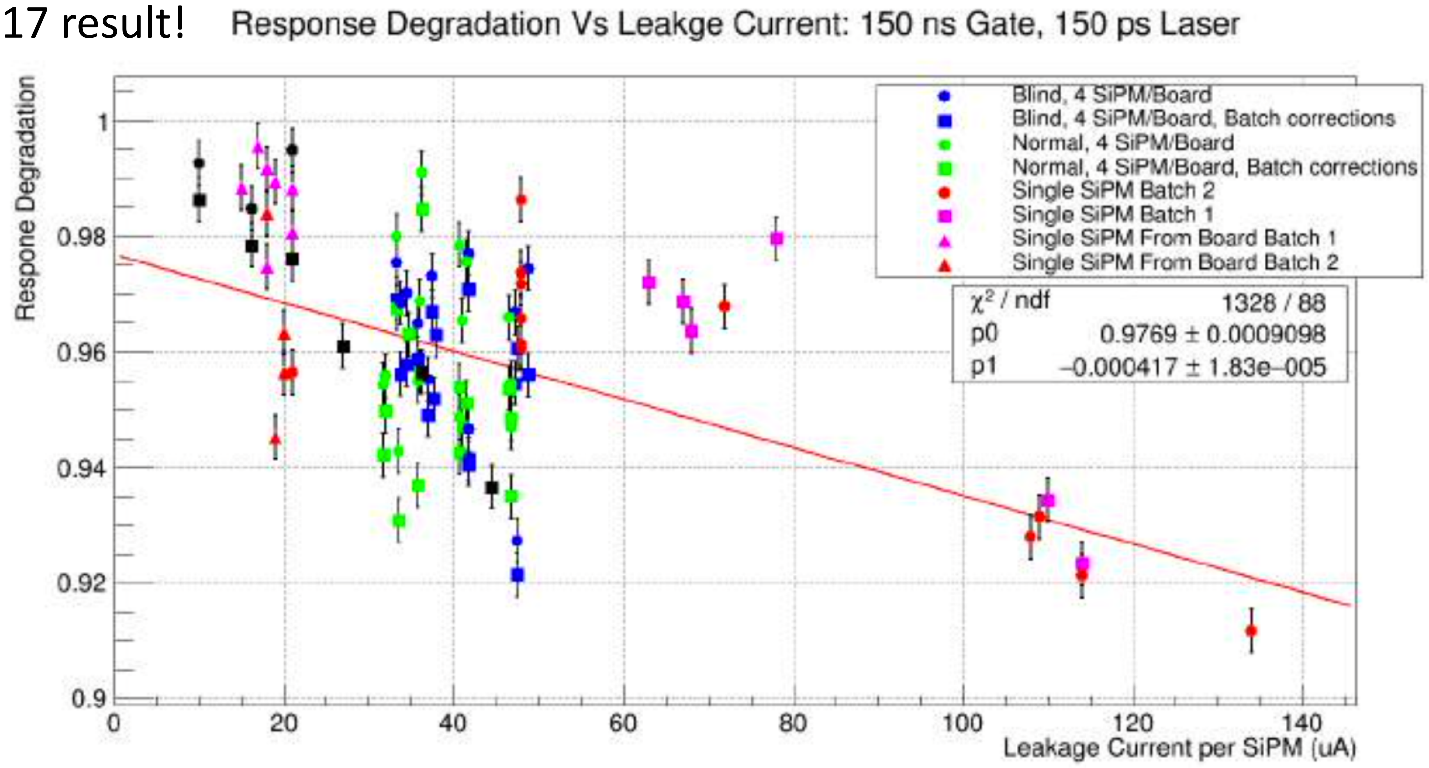
SiPM for calorimeters (I)



- very different context: no single-photon requirements
- very consolidated experience: SiPM made possible STAR Forward Calorimeter System (> 10^4 SiPM from HPK) + sPHENIX (>10^5)
- operated with no cooling @STAR
- use of SiPM foreseen in EIC Detector 1 Calorimeters

For calo eRD please check eRD105 and eRD106/7 presentations today

2017 result!

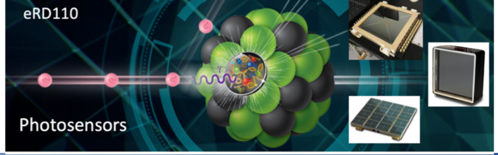


Irradiation of a large sample of SiPM (152) showed different degradation at equal irradiation, traced then to heating (due to leakage current) in the avalanche region
→ fixed with current requirements on SiPM operated in the FCS

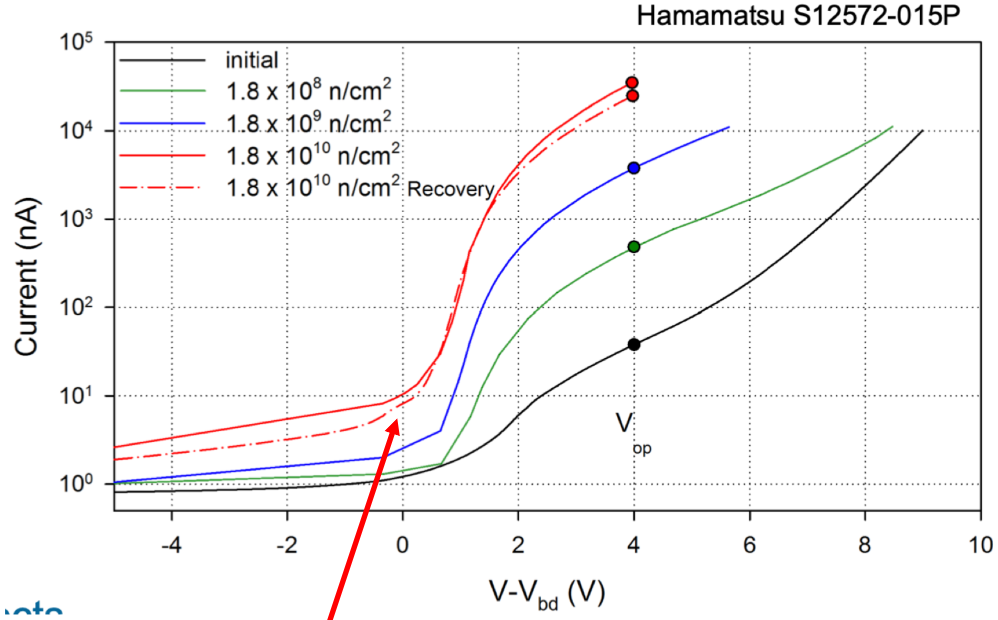
Note: for EIC applications need to move **from 3x3 to 6x6** noise may reach 20 MeV (or cooling needed)

Use 2022 to develop FEE board for 6x6 (under eRD106) and apply to eRD110 in FY23 to buy SiPM

SiPM for calorimeters (II)



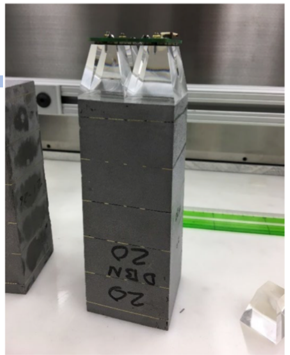
- SiPMs @sPHENIX will receive a dose ~ 10^{11} n/cm^2 over the currently 3 yr lifetime
- sPHENIX uses cooling system



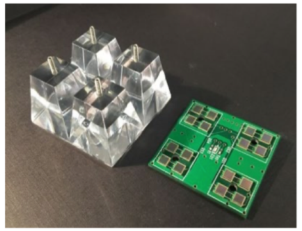
small recovery at room temperatur

credits: Craig W.
see his talk at SiPM meeting for more details

sPHENIX



6144 Modules (24,576 towers)



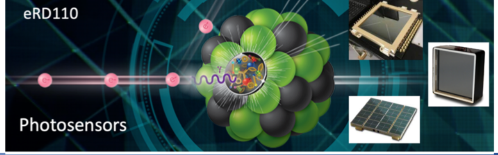
Readout with light guides and SiPMs

(~ 100K SiPMs)

R&D Issues for SiPMs for EIC calorimeters

- Need for large area (≧ 6 x 6 mm^2) SiPMs with small pixel size (10-15 μm) at low cost. *Issue for manufacturers.*
- Shashlik calorimeters will have high segmentation with an individual readout for each fiber. This will require low-cost small area (~ 2 x 2 mm^2) SiPMs with small pixel size. *However, due to high channel count, cost of readout electronics will be an issue.*
- While radiation exposures at EIC are expected to be much less than at LHC or in RHIC HI running, devices with less susceptibility to radiation damage (particularly neutrons) would enhance long term stability and performance.
- SiPMs with less temperature dependence would also improve long term stability and performance.
- Lower noise would be extremely beneficial for RICH applications.

Some recent meetings to get more info



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

Meeting on SiPM Use and Needs at EIC

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

February meeting convened by Patrizia and Thomas

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...

More info on SiPM calorimeter program in eRD110 (not covered too much in this talk)

https://indico.bnl.gov/event/15059/

LAPPD Workshop

Monday 21 Mar 2022, 08:00 → 12:00 US/Eastern

March meeting convened by eRD110 -LAPPD

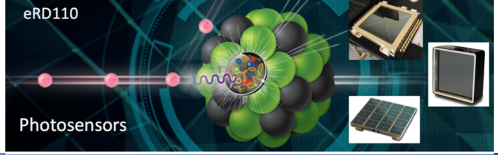
Description Organizers: Silvia Dalla Torre (INFN), Alexander Kiselev (BNL), Deb Sankar Bhattacharya (INFN), Junqi Xie (ANL)

Hosted by CFNS: https://stonybrook.zoom.us/j/98025752609?pwd=WTlicTlwTmxkNE9wODlOZEx2NU1sUT09

Zoom recording: link (Passcode: 5^vvb*3W)

Argonne National Laboratory — Brookhaven National Laboratory — INFN — Center for Frontiers in Nuclear Science

Note talks from NALU, Incom and many other groups (behind EIC) + R&D at ANL (including magnetic fiield tests)



Summary and outlook

LAPPD:

- Proof of principle measurements confirming feasibility of Gen II LAPPD use for single photon detection in Cherenkov imaging applications → results presented at La Biodola workshop (May 2022)
- Readout board optimization on-going (spatial resolution performance, cross talk suppression and instrumented channel count optimization) → upcoming test beam @FNAL June 2022
- Magnetic field tests submitted to IEEE NSS-MIC

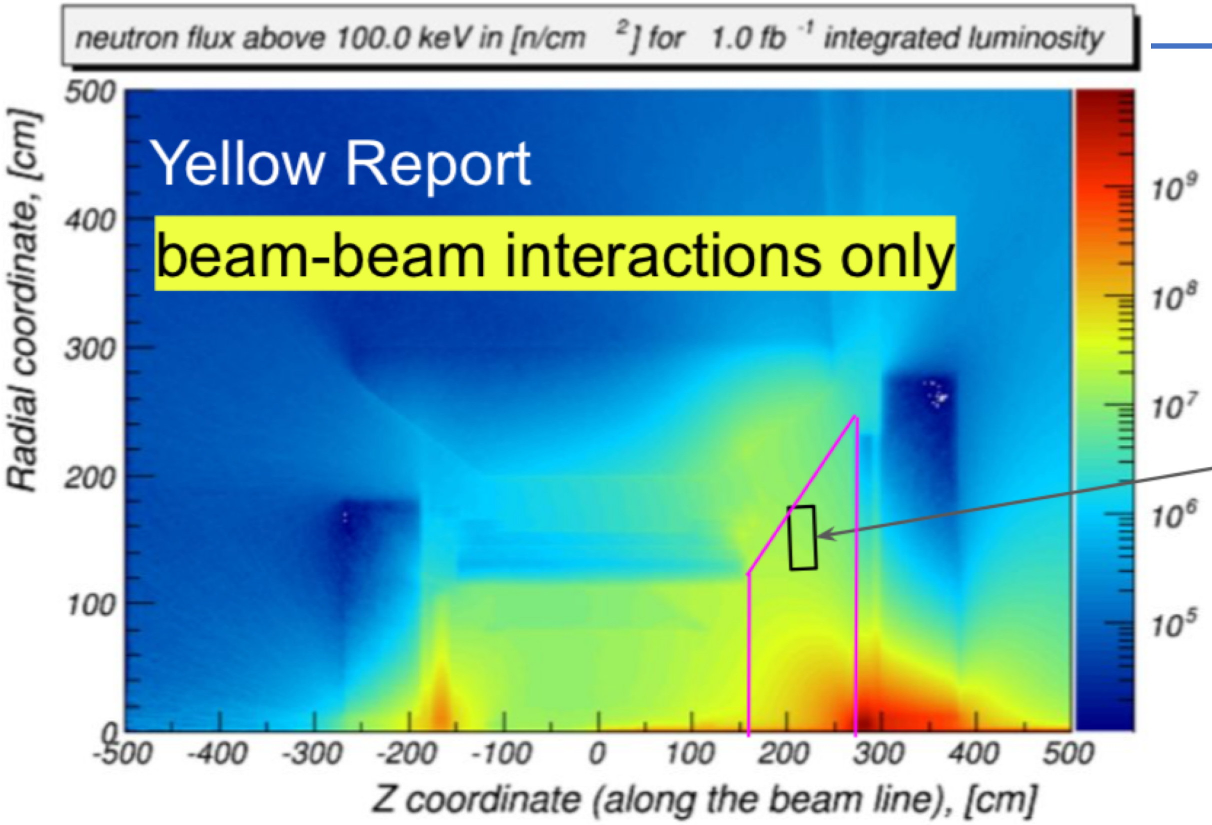
SiPM:

- Results of 2021 campaign to be presented at NDIP2022 in Troyes
- 2022 irradiation campaign will establish if annealing strategy/protocol holds → next step move to "cooling/heating" challenges + integrated dRICH tiles (256 SiPM with 4 8x8 tiles)
- for calorimeters: larger (6x6 mm^2) SiPM with small cell (15 μm) one of the topics to be investigated in 2023
- summing up know-how and expertise from "RICH & CALO people" we can build a really nice SiPM-EIC team!

Many thanks to many eRD110 colleagues for material and input, including:
Y. Ilieva, A. Kiselev, R. Preghenella, C. Woody, J. Xie.

Additional info

EIC and radiation levels



having as target 100 fb^{-1} (several years at maximum luminosity) this brings

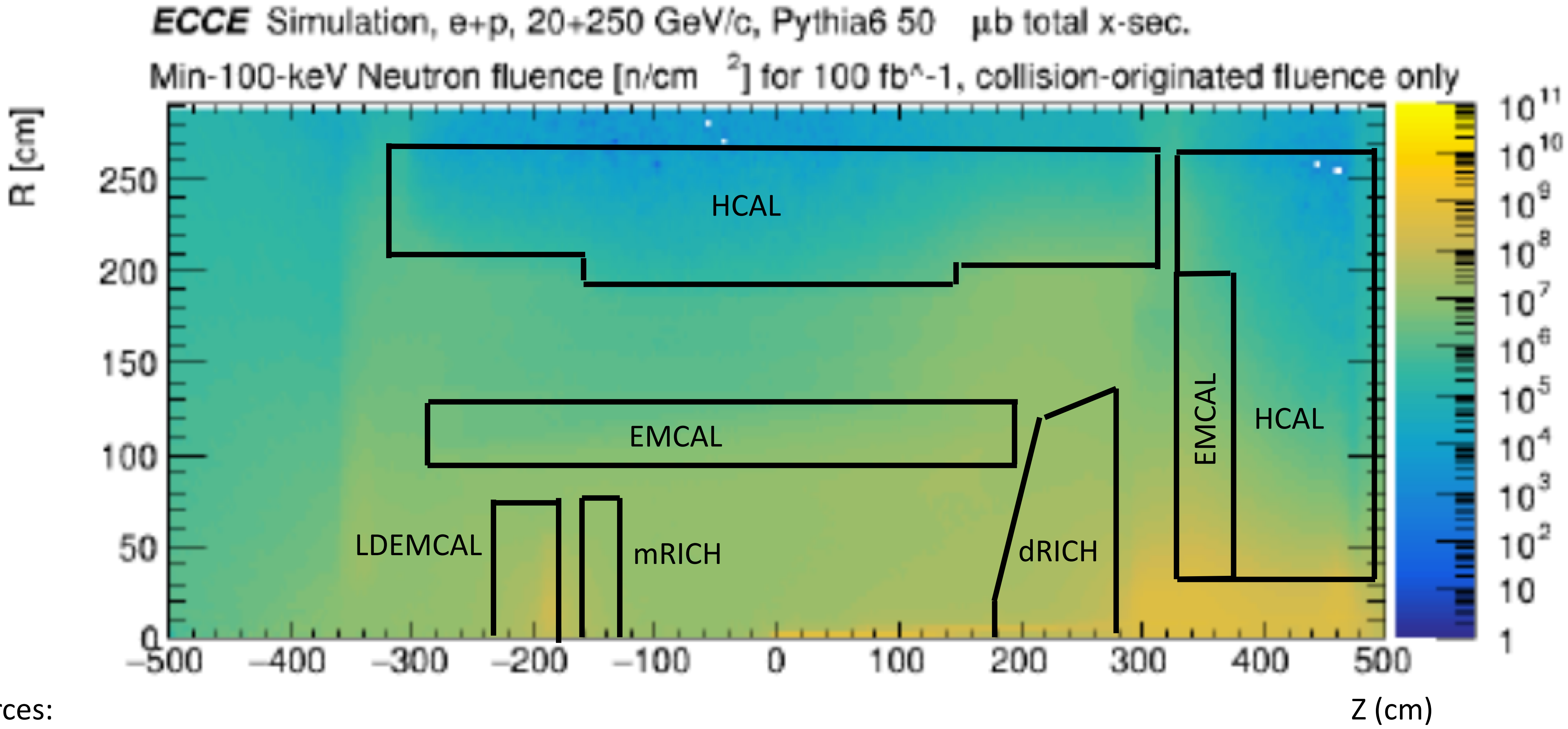
10^{11} n/cm^2 1 MeV-neq as "maximum"

- 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

ECCE radiation levels

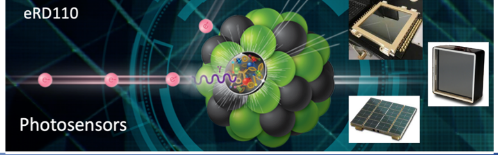


Sources:

ECCE radiation levels: https://indico.bnl.gov/event/14715/contributions/59782/attachments/39682/65822/SiPMs%20for%20EIC%202-4-2022.pdf

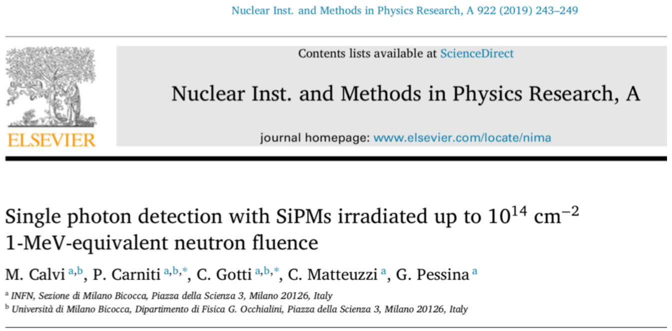
Detector positions: https://physdiv.jlab.org/EIC/Menagerie/docs/DetectorParameterTable.pdf

SiPM and radiation damages



Comprehensive (2018) review on radiation damages on SiPM from E. Garutti and Y. Musienko

NIM A 926 (2019) 69-84
https://doi.org/10.1016/j.nima.2018.10.191


Nuclear Inst. and Methods in Physics Research, A 922 (2019) 243–249

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journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Single photon detection with SiPMs irradiated up to 10^{14} cm^{-2} 1-MeV-equivalent neutron fluence

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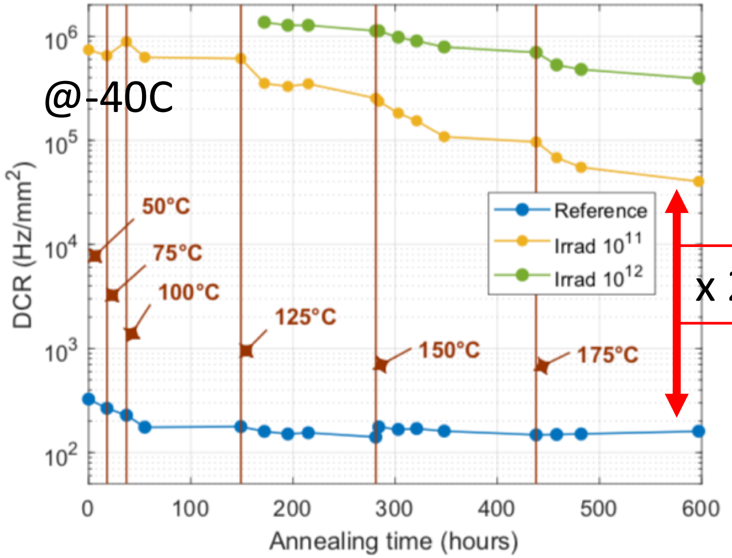
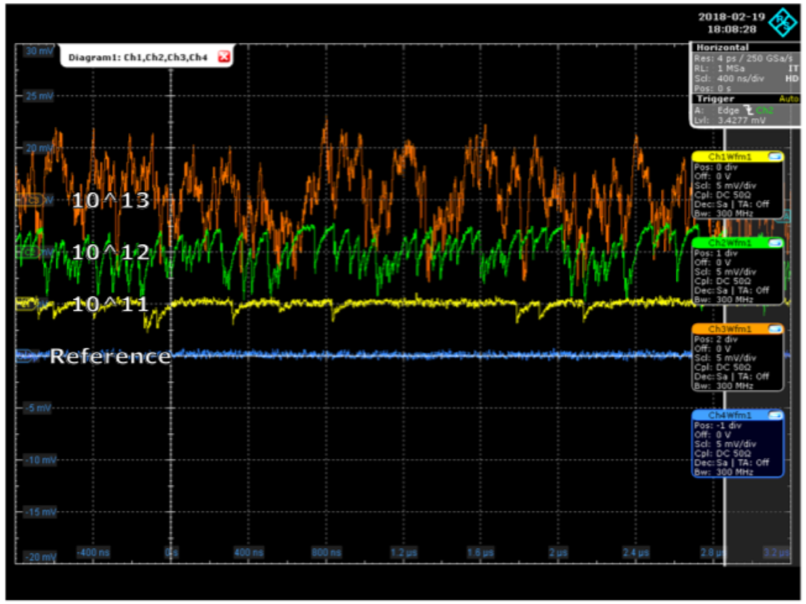
https://doi.org/10.1016/j.nima.2019.01.013

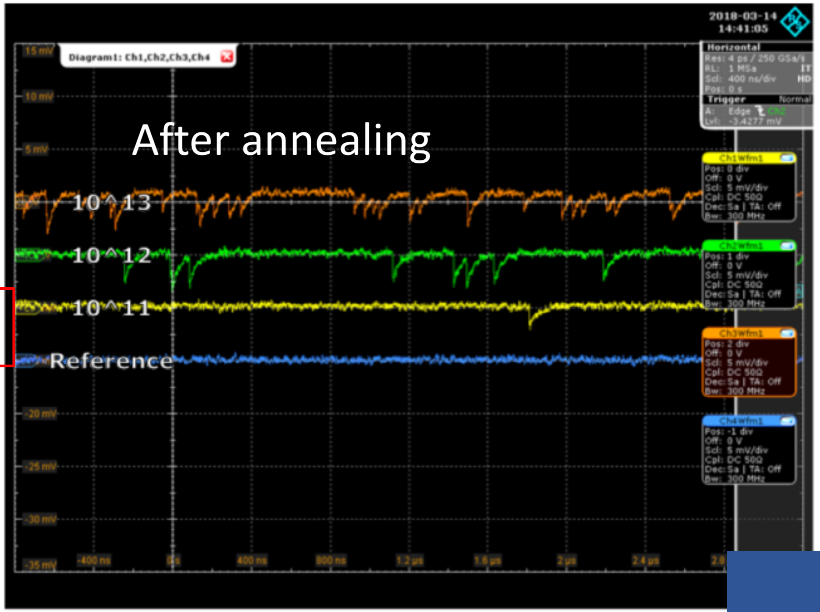
Hamamatsu S13360-1325CS (1.3x1.3 mm^2)
Hamamatsu S13360-1350CS (1.3x13 mm^2)



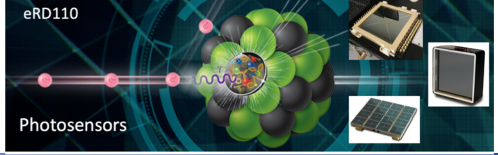
x 200

- 30 C: DCR





How often to do annealing?



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

EXAMPLE

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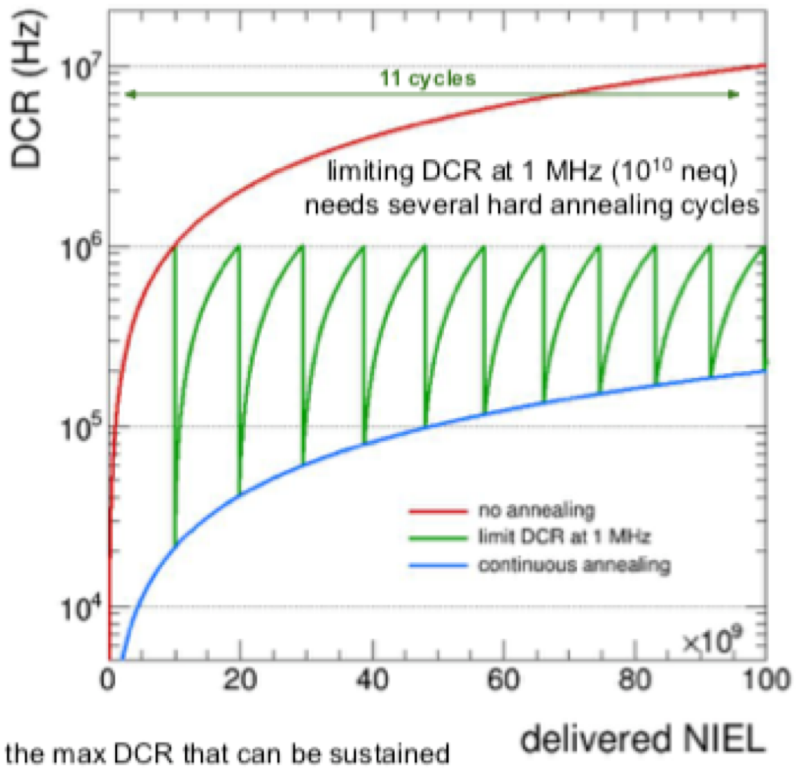
assumptions

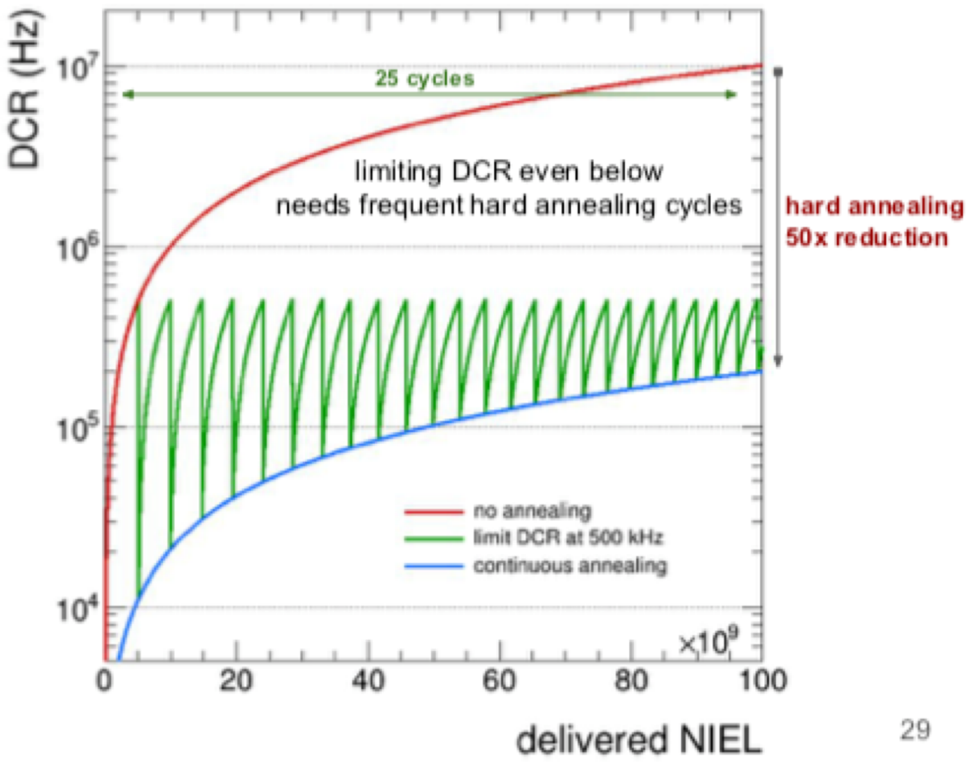
- NIEL = 10^{11} neq/cm^2 ⇒ DCR = 10 MHz
- DCR increases proportionally to NIEL
- annealing always cures same fraction of damage caused by NIEL
  - constant fraction of new damage, regardless total damage

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



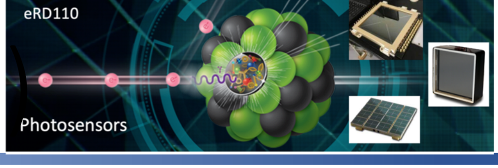


29

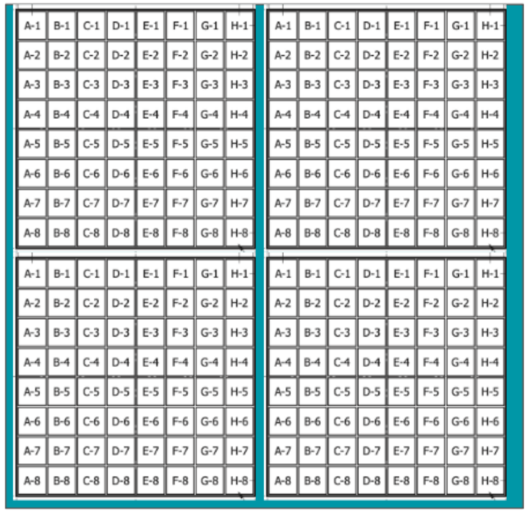
it depends on the max DCR that can be sustained

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

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



dRICH tile



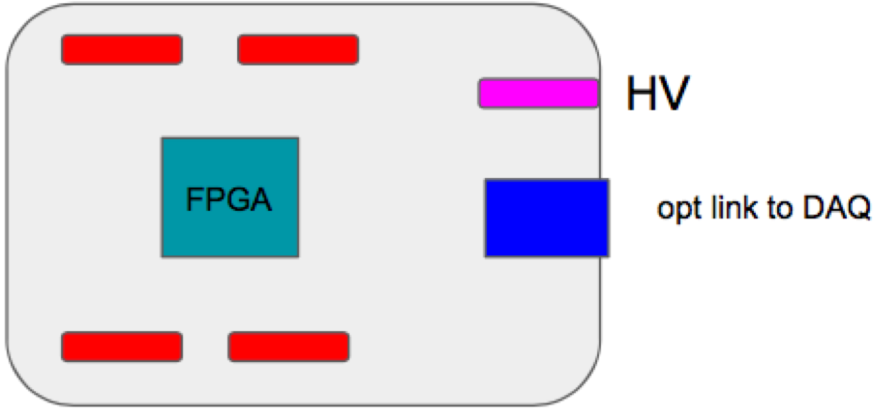
x 1240

dRICH tile 5.6 x 5.6 cm^2

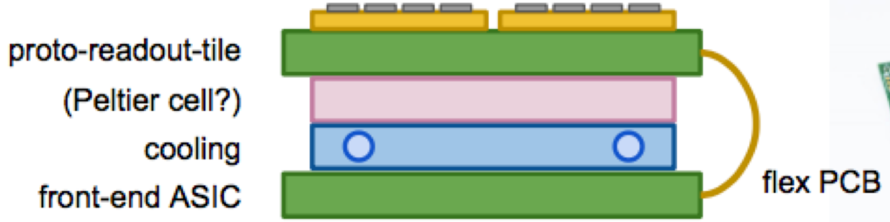
dRICH FEB (front-end board)

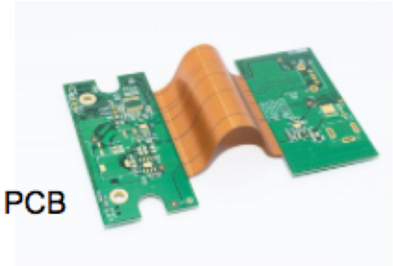
x 1240

dRICH ROB (readout board)



x 310

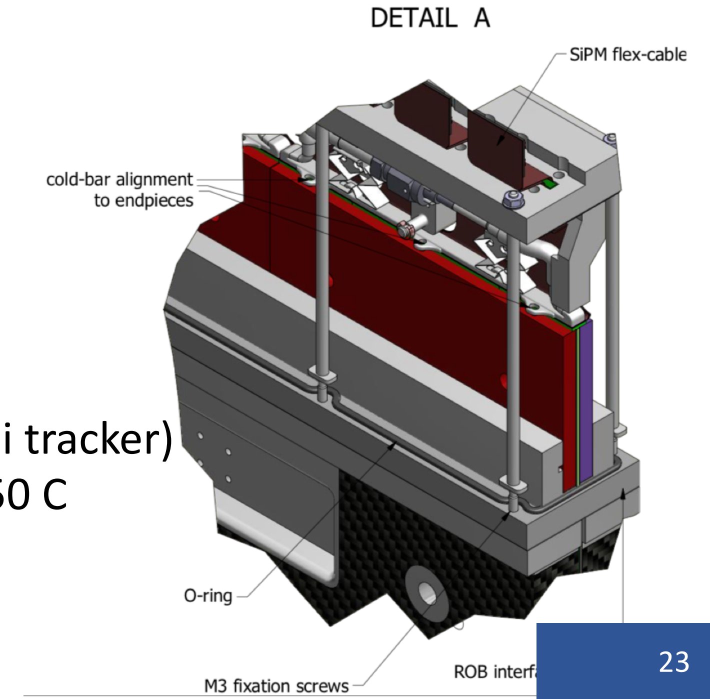




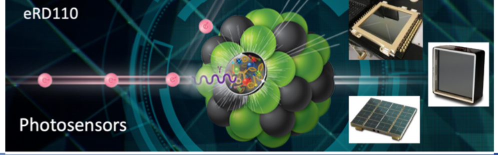
- SiPM selection
- ASIC development
- annealing protocol
- cooling (& annealing *in situ*)

a lot of R&D ahead of us!

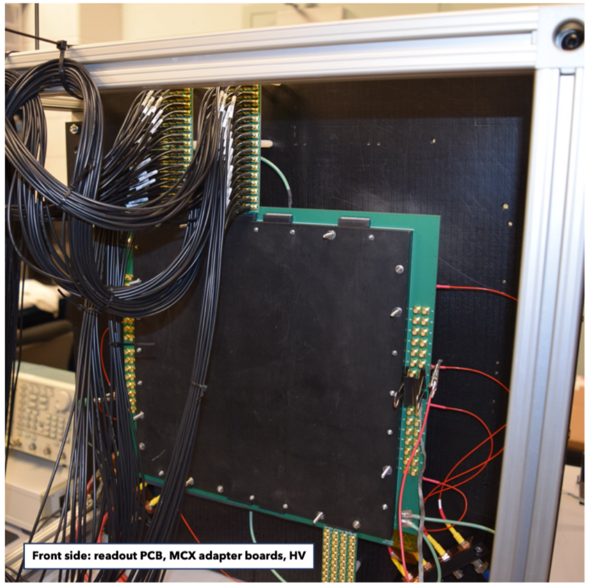
Cooling system from LCHb (SciFi tracker) for SiPM expected to work at -50 C
LHCb-PUB-2015-008



LAPPD readout details



Test setup

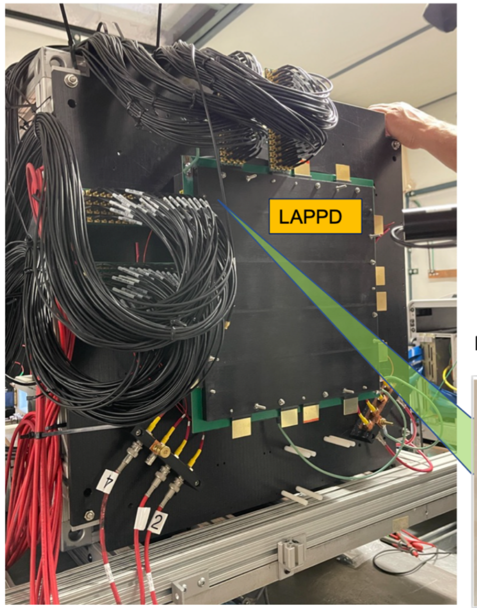


- Light-tight enclosure
- Up to 320 DRS4 channels (V1742 digitizers)
- MCX to high-density Samtec adapter cards

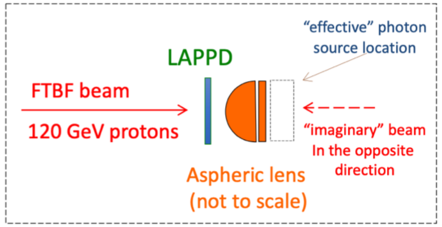
Modular setup: it takes one only half an hour to exchange (or rotate) the readout board

credits: Alexander K.
see his talk at Elba meeting for more details

Experimental setup (Fermilab Test Beam Facility)



- The same setup as in the lab, but instead of laser use *a thick aspheric lens* as a well controlled Cherenkov light source



- Off-the-shelf component
- (Almost) no stray photons
- To first order no need in tracking
- The used model (Edmund Optics #67-265, EFL 20.0mm) produces a crisp ~76mm diameter ring at the focal plane

Pixel pattern & accumulated single photon XY-coordinates