eRD110 – Photosensors for EIC

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eRD110: LAPPD R&D
FY22 Report and FY23 Proposal

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Brookhaven National Laboratory
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Mississippi State University
Thomas Jefferson National Accelerator Facility
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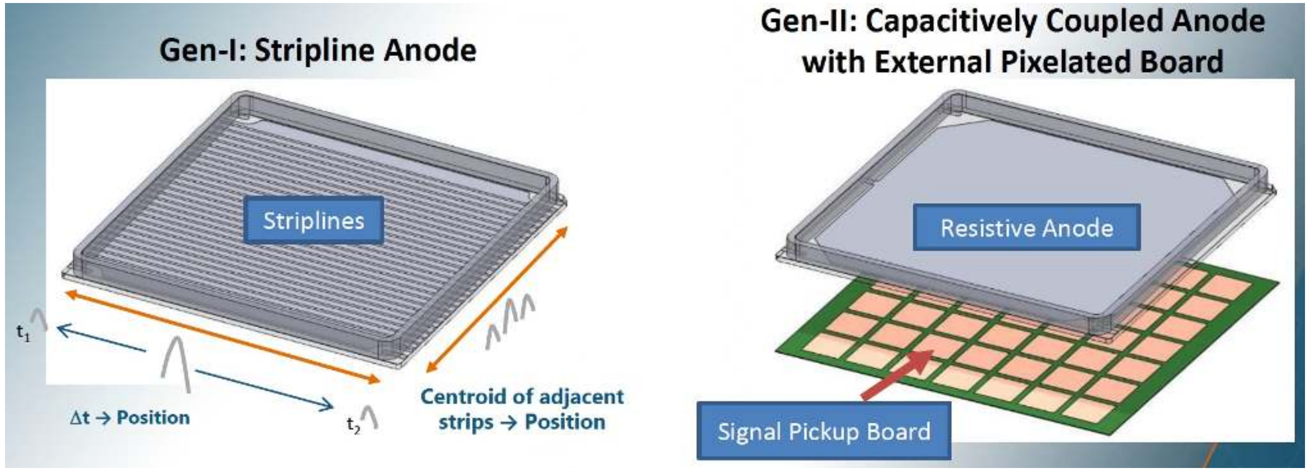
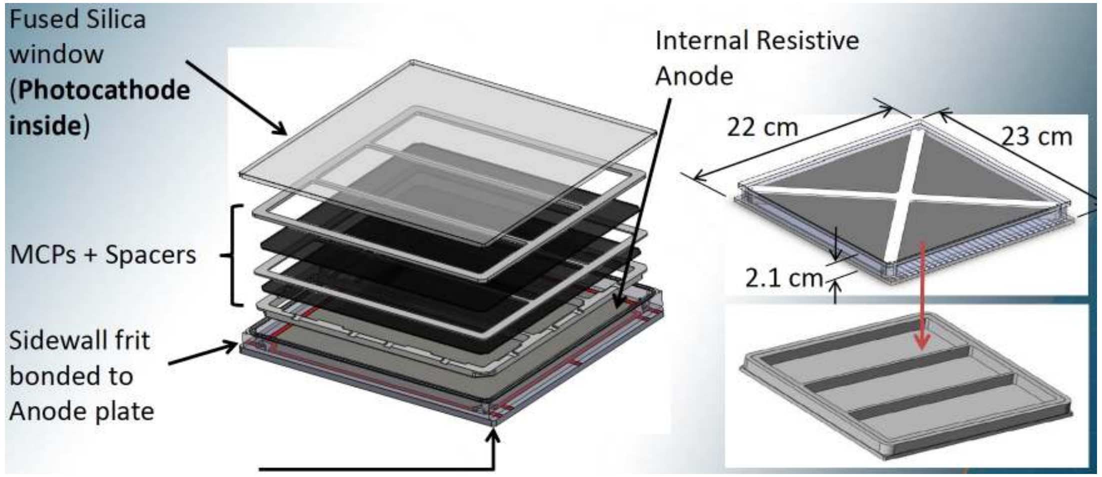
EIC Detector Advisory Committee Meeting, October 19-21, 2022

Introduction

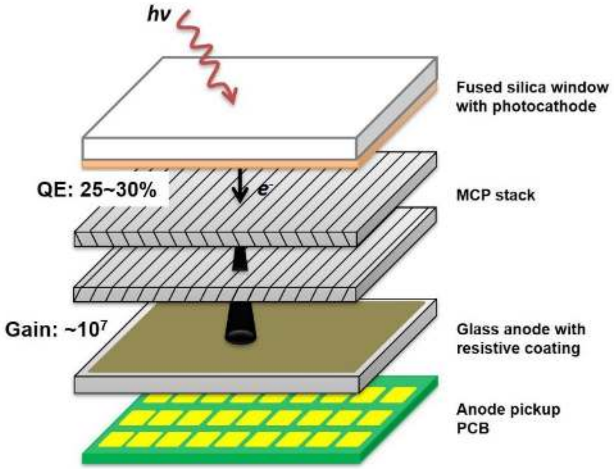
Incom LAPPDs



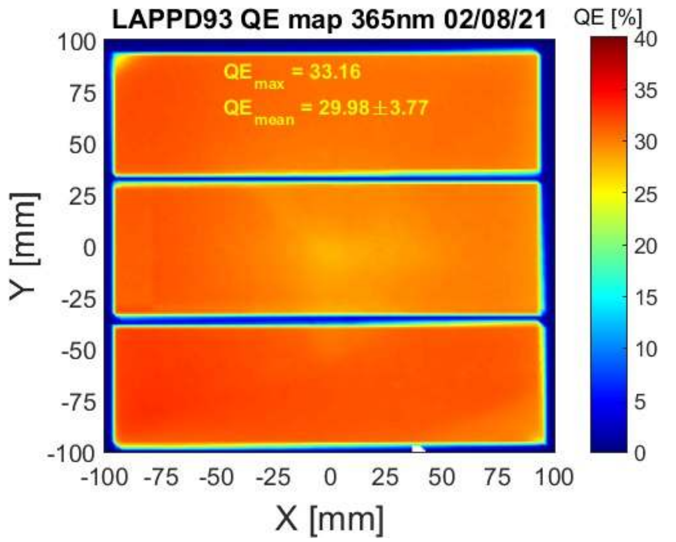


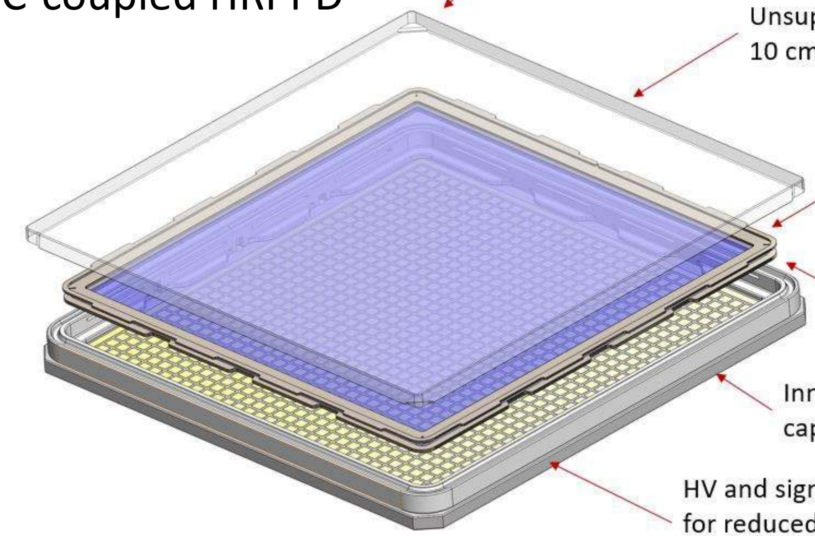
- An affordable large area (finely pixelated) vacuum photosensor
- Originally developed by LAPPD collaboration; now commercialized and produced by Incom Inc.
  - 10x10 cm^2 or 20x20 cm^2 active area
  - DC- (Gen I) or capacitively (Gen II) coupled species
  - DC-coupled strips or 2D pixellation
  - Expected to be (very) cost efficient in mass production
  - High enough quantum efficiency and uniform high gain up to ~10^7
  - Sub-mm spatial resolution for finely pixelated tiles
  - Single-photon timing resolution on a ~50ps level or higher

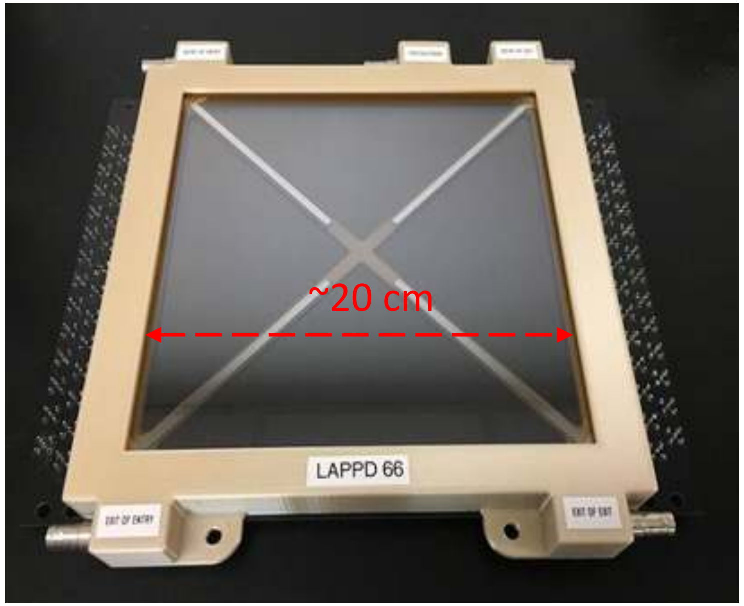
Gen II variety



Incom LAPPDs







- ePIC PID detector applications:
  - mRICH / pfRICH: low dark noise, Time of Flight capability (vs SiPMs)
  - DIRC: expected to be more cost-efficient (vs other MCP-PMTs)
  - dRICH: problematic, because of the magnetic field orientation
- Preferred variety:

mRICH	either DC-coupled or Gen II, 10cm formfactor
pfRICH	Gen II, either 10cm or 20cm
DIRC	DC-coupled, 10cm

Open R&D questions before CD-3

- In brief, we need to come up with a detailed assessment of the current state of the art and projected LAPPD photosensor performance, evaluate their potential use in various EIC PID detector subsystems, and assist Incom in modifying their existing product line to meet EIC requirements
  - Spatial resolution for Cherenkov imaging applications in a variety of fine pixellation schemes
  - Timing resolution in a single photon mode, for a selected subset of pixellation scenarios
  - Timing resolution for Time-of-Flight purposes
  - Performance in a strong (inhomogeneous) magnetic field

  - QE spectrum tuning and evaluation for ePIC detectors
  - Overall PDE and gain uniformity tuning and measurement
  - Geometric formfactor optimization

  - Prospects of integration in particular ePIC detector subsystems (together with the respective groups and / or consortia), as well as the on-board electronics integration (together with eRD109 and ASIC manufacturer candidates)

FY22 activities

- LAPPD characterization in the magnetic field
- Beam tests (with a focus on LAPPD timing resolution)
  - Fermilab: June 2022
  - CERN: October 2022
- DC-coupled HRPPD interfacing

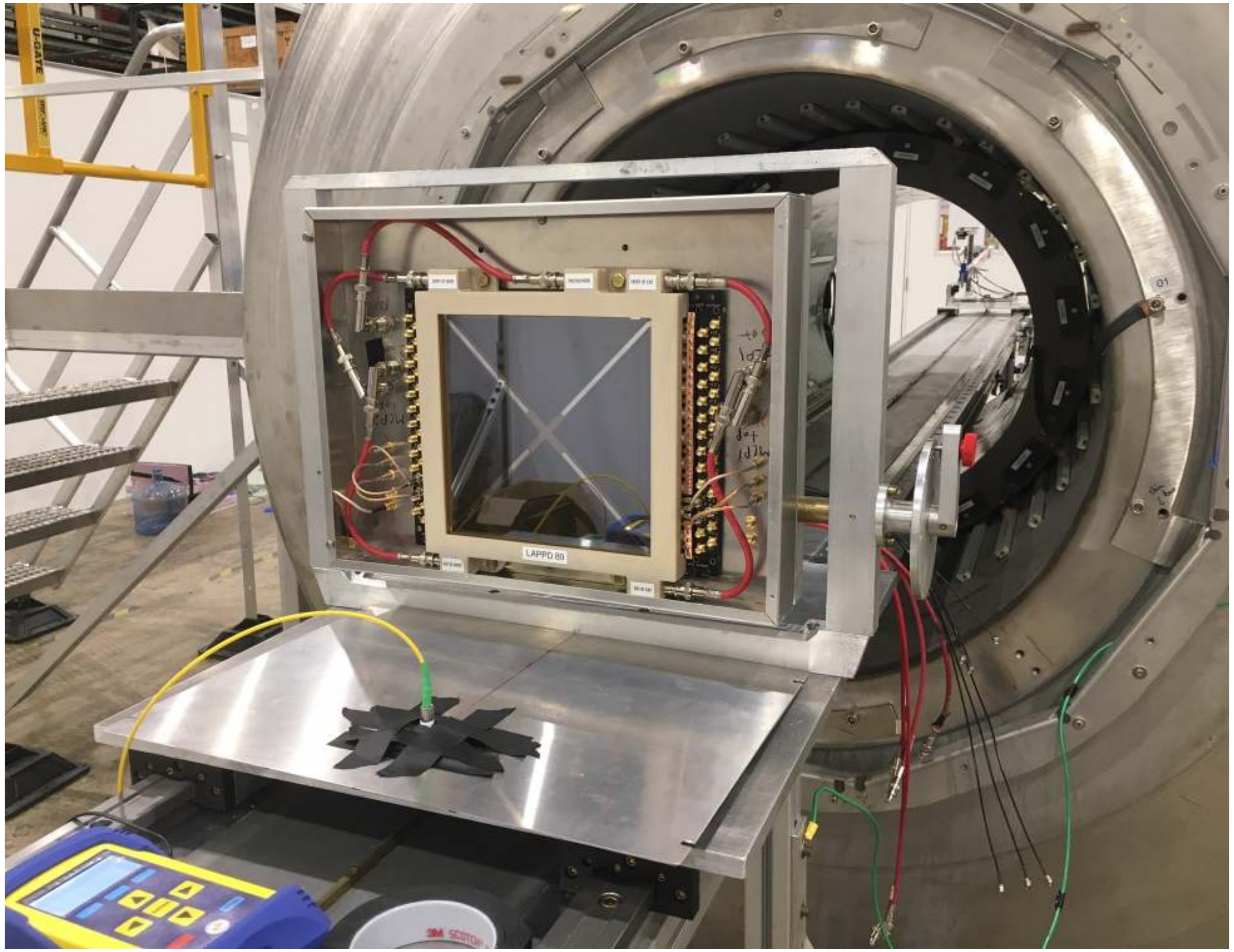
- Work in a (very) close contact with the manufacturer
  - Participation in SBIR proposals
  - Regular discussions of technical nature
  - Beam tests and other measurements with Incom experts present
- Organization of LAPPD workshop(s)
- Synergistic activities in the field of medical imaging
  - Share designs and equipment

Magnetic field tolerance measurements at Argonne in 2022

(Argonne, Incom Inc.)

LAPPDs at g-2 solenoid magnet

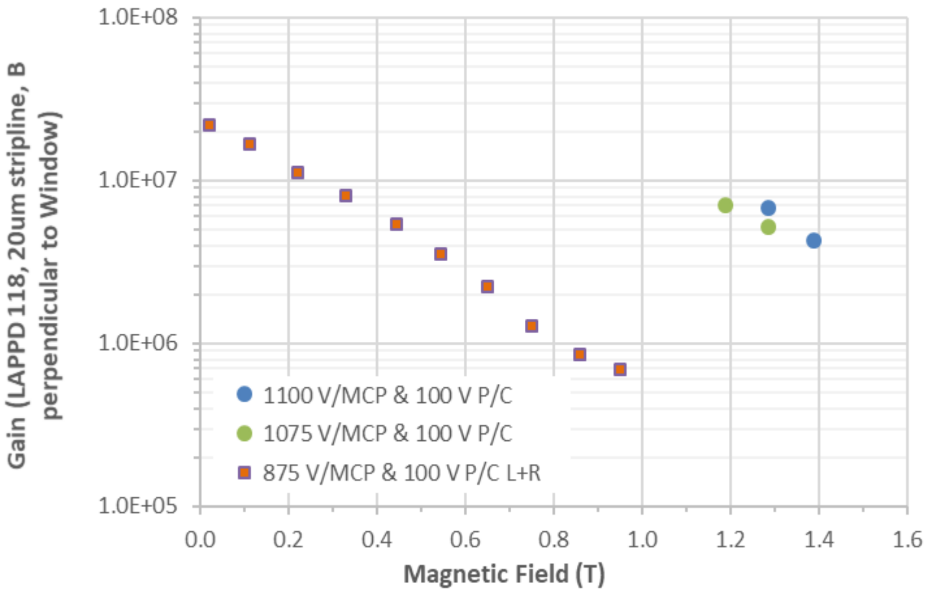
- Two stripline LAPPDs received:
  - # 118, 20 um MCP pore size (completed)
  - # 89, 10 um MCP pore size (data under analysis)
- One capacitively-coupled LAPPD received:
  - # 126, 20 um MCP pore size (readout electronics does not work inside magnet field, no data was taken)
- Magnetic field strength: 0.02 T to 1.4 T
- Dark box
  - Aluminum case
  - Laser input fixed in the center near the bottom – on the centerline of the solenoid when the LAPPD is vertical.
- Rotation in the magnetic field:
  - LAPPD tips into or out of the region of stronger magnetic field
  - Move the LAPPD in or out at each angle to compensate for the change in field strength

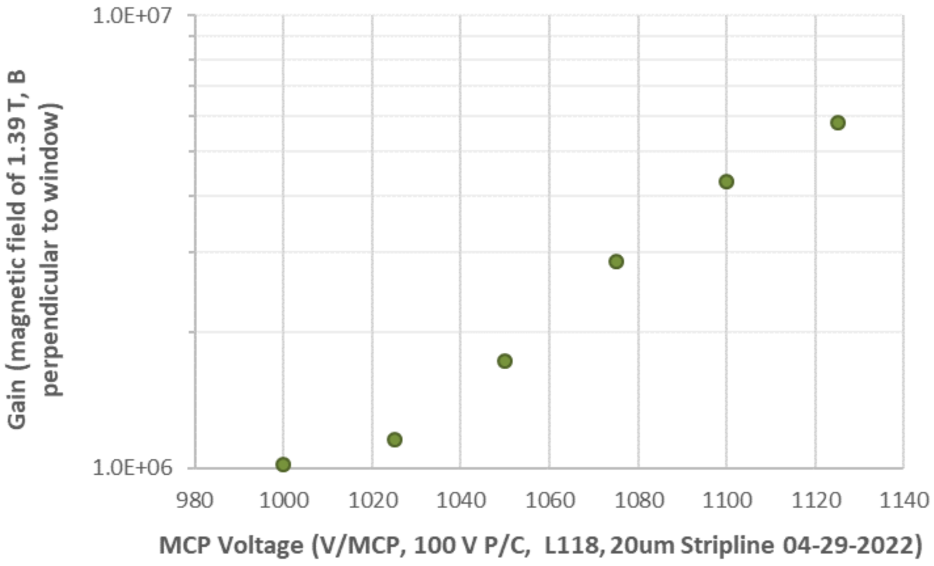


Gain vs magnetic field normal to the tile surface

- LAPPD shows similar behavior trends as R&D MCP-PMT
  - Went down from over $2x10^7$ to ~$7x10^5$ as the field strength was increased from 0.02 T to ~0.9 T.

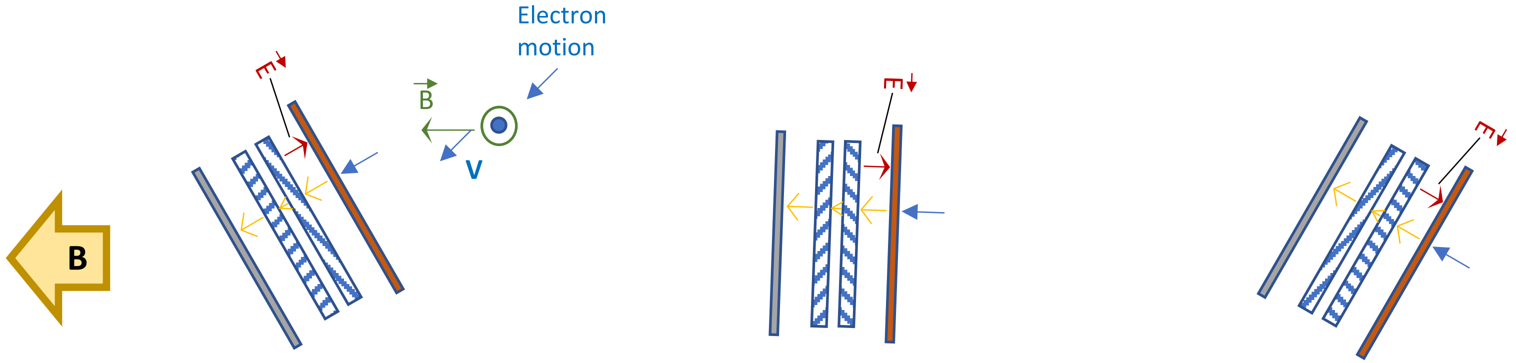
- At a field strength of 1.39 T, the gain was recovered to $6x10^6$ by significantly increasing the MCP voltages.





Gain vs rotation angle in a small field

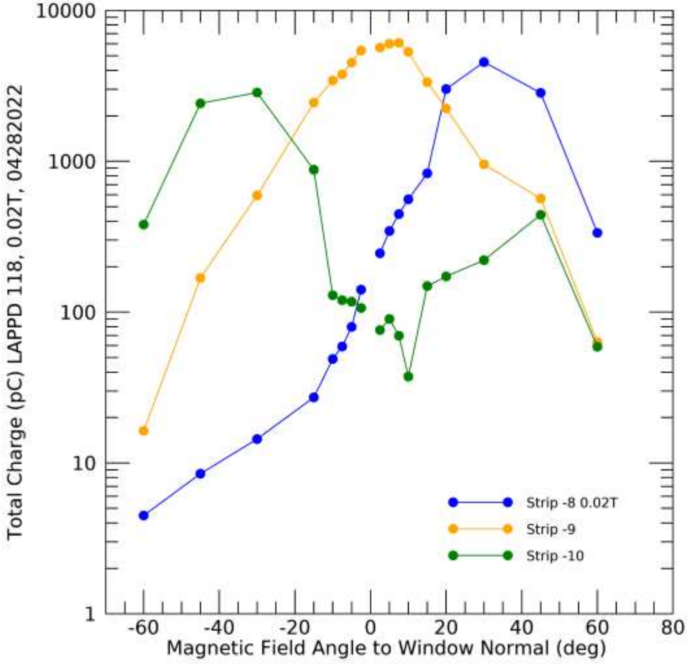
- Pulse height distributions show motion of electrons from one strip to another
- Striplines are in and out of the page
- Motion of electrons appears to be perpendicular to strips, instead of parallel to strip

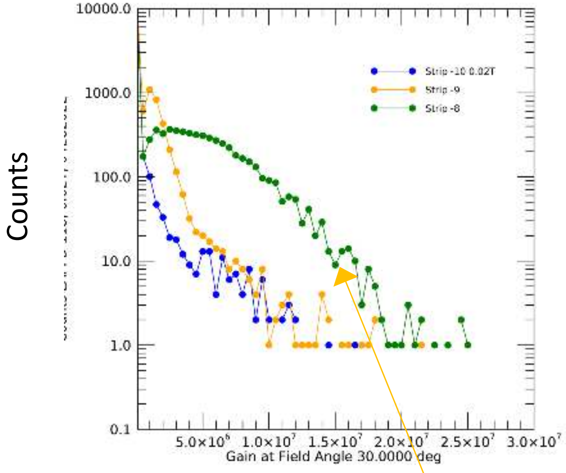


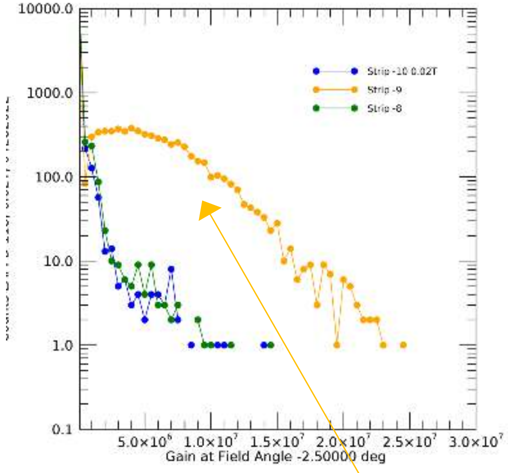
30 deg: top of LAPPD toward magnet

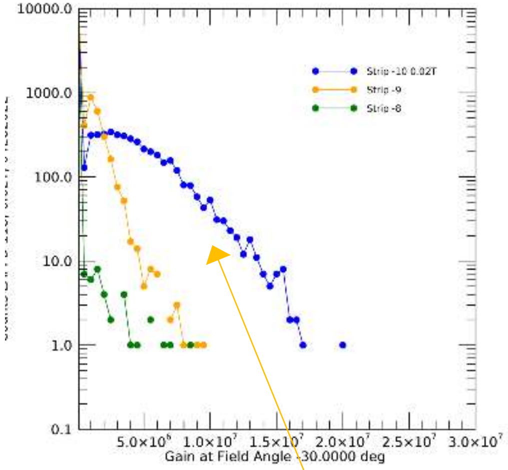
-2.5 deg: LAPPD ~ vertical

-30 deg: top of LAPPD away from magnet





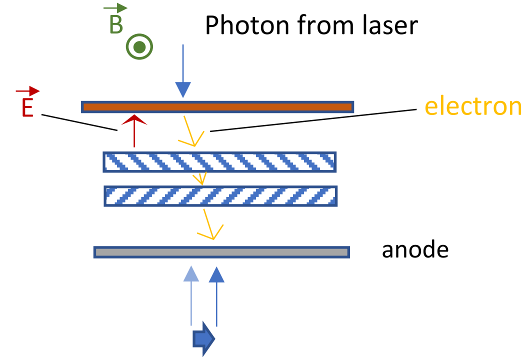




Adjacent strip on one side (-8)

Center strip (-9)

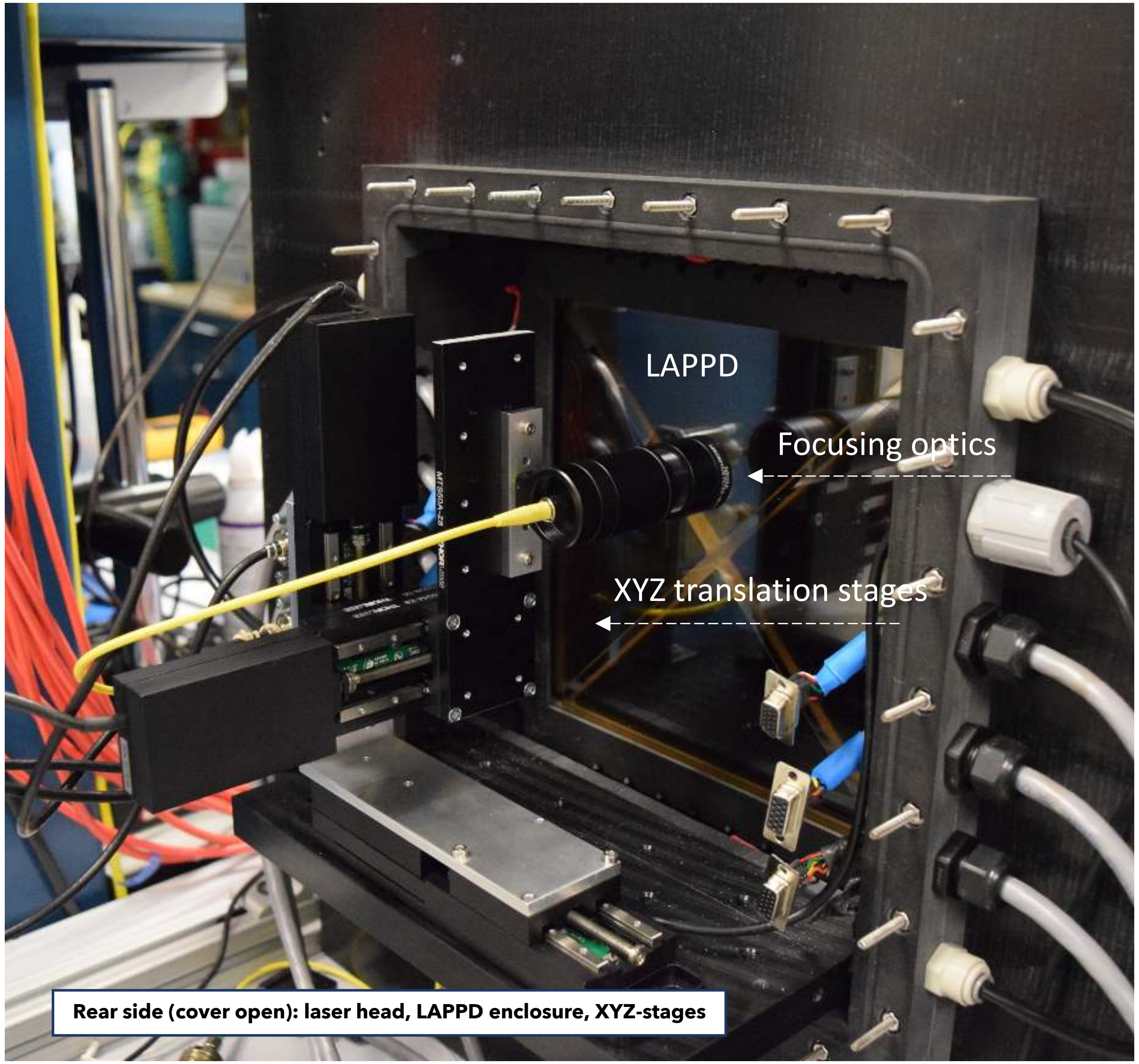
Adjacent strip on the other side (-10)



Beam test at Fermilab in June 2022

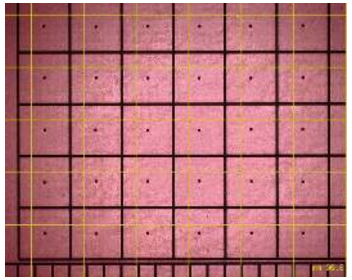
(BNL, Incom Inc., Argonne, MSU, INFN Trieste)

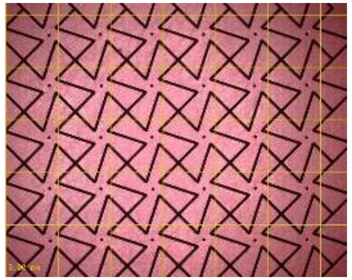
Equipment

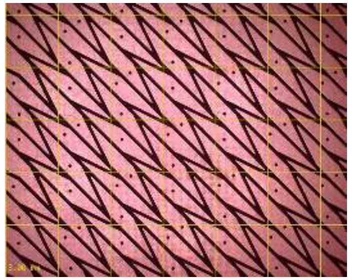


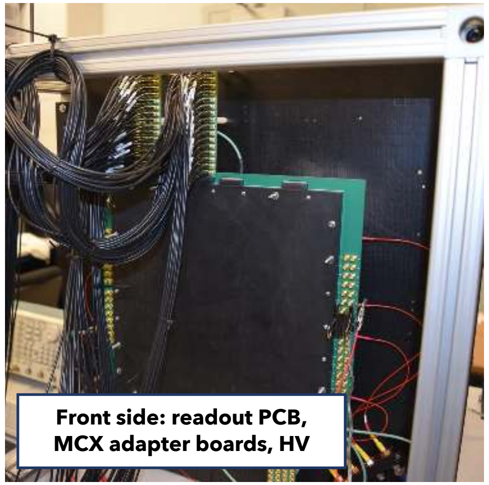
Rear side (cover open): laser head, LAPPD enclosure, XYZ-stages

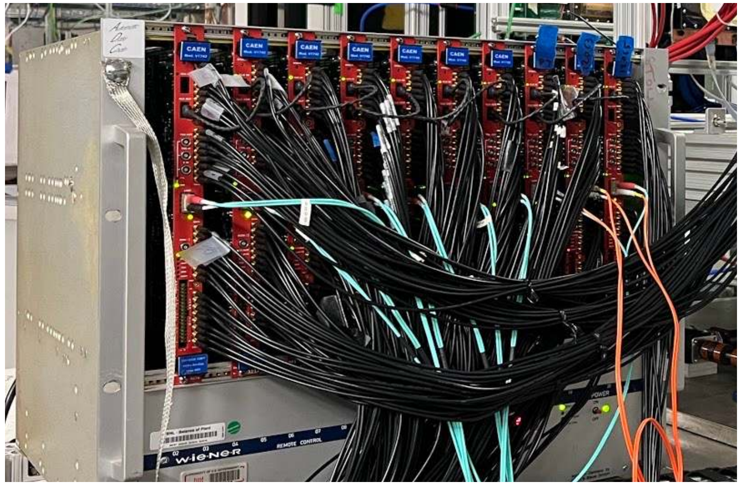
- Picosecond PiLas laser
- Compact light-tight enclosure
- 320 (soon 512) DRS4 channels (V1742 digitizers)
- MCX to high-density Samtec adapter cards
- A variety of finely pixelated readout boards







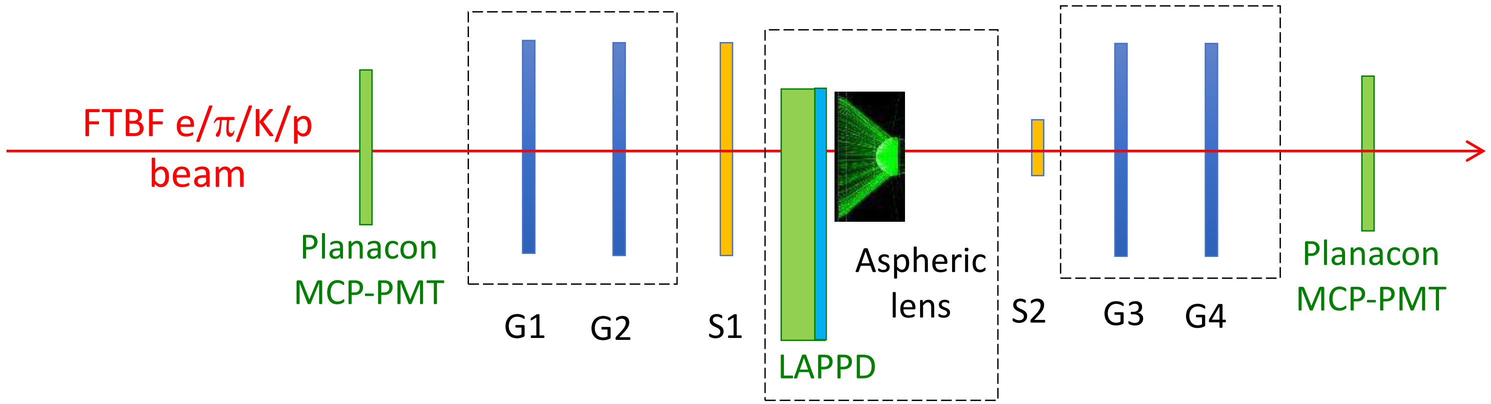

Front side: readout PCB, MCX adapter boards, HV

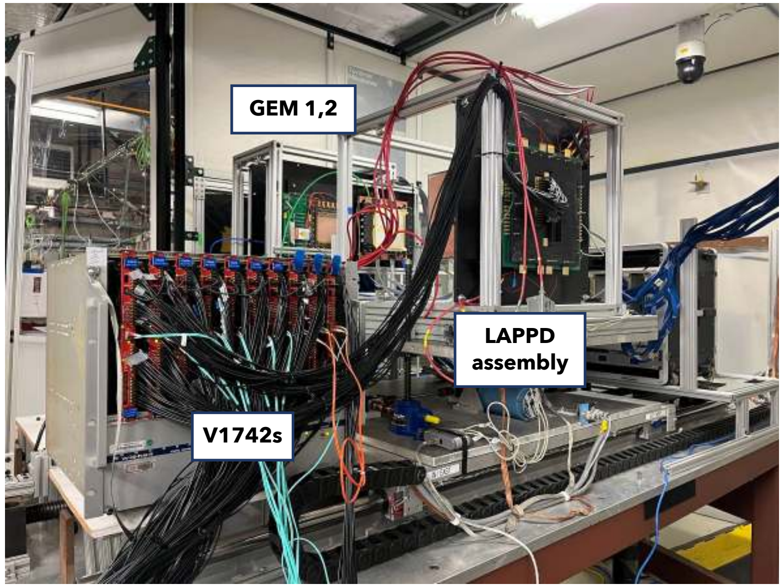


Modular setup: it takes one only half an hour to exchange (or rotate) the readout board

Experimental setup at Fermilab

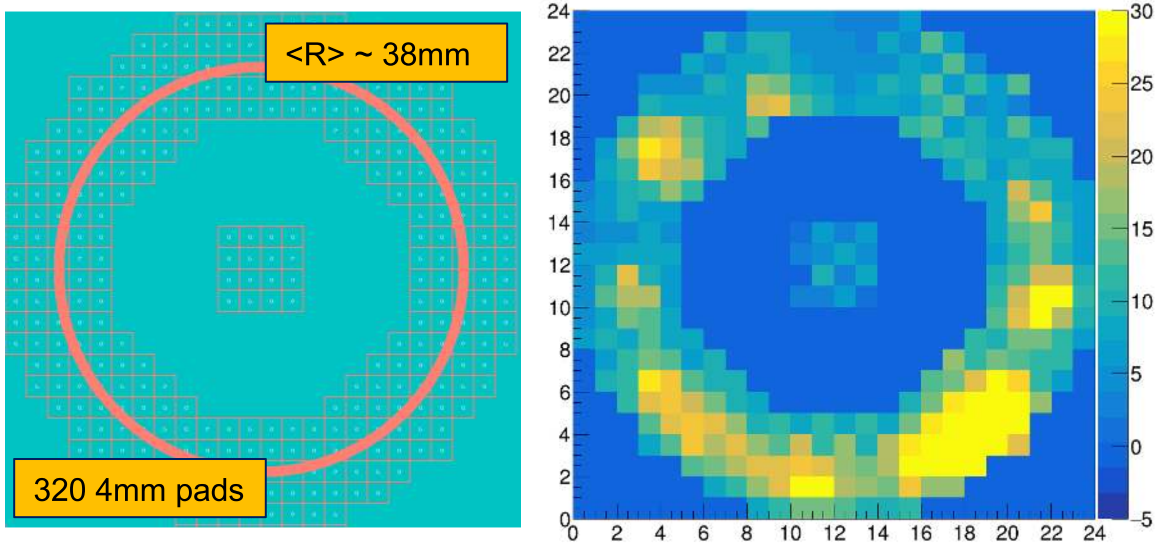
- G1 .. G4 – COMPASS GEM reference tracker
- S1 .. S2 – trigger scintillator counters





- A new 20 cm Gen II LAPPD tile 136
  - 10 μm pore MCPs
  - Full glass body (implies 5 mm thick anode base plate)
  - Window material -> UV grade quartz
- GEM reference tracker
- New set of the pixelated readout boards
- A pair of Planacon MCP-PMTs as a timing reference

Aspheric lens as a source of coherent Cherenkov photons

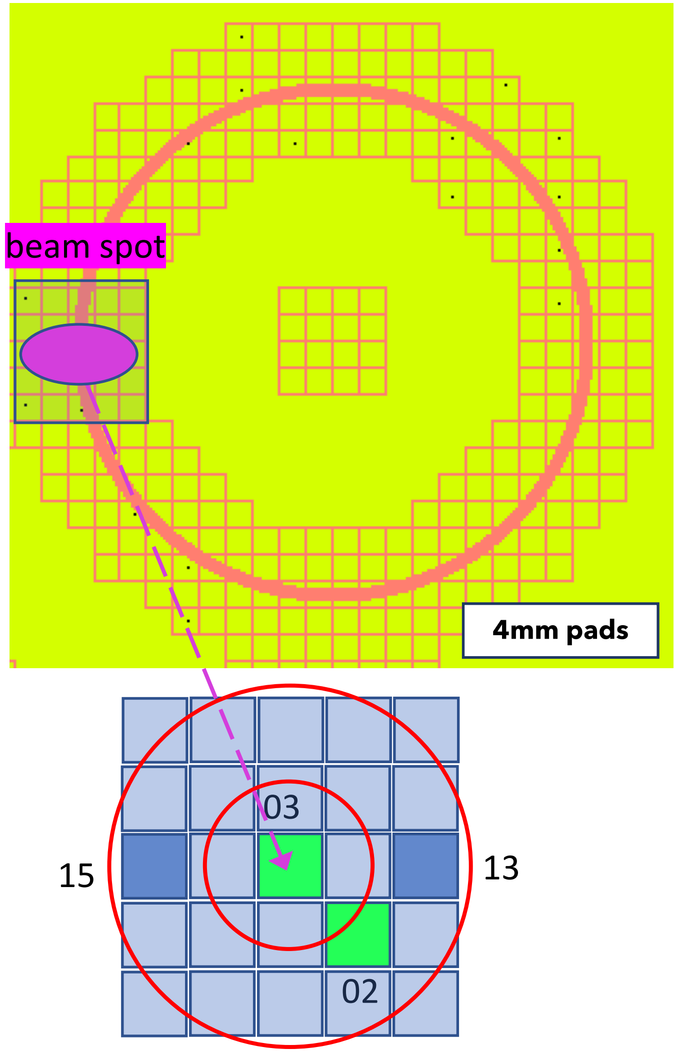


Single event, [mV] units

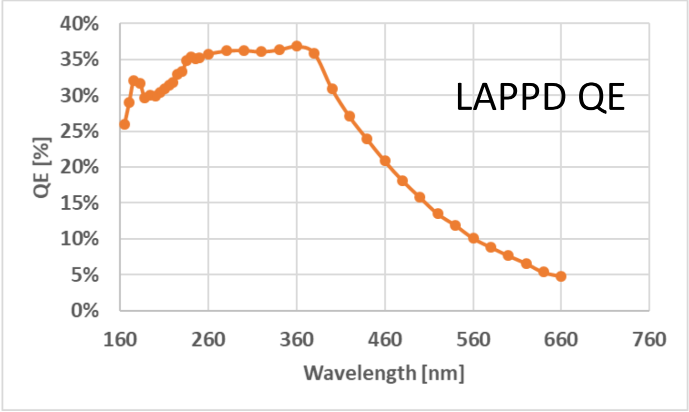
Enough data on tape to quantify **single-photon** timing resolution

Timing for Time-of-Flight applications

LAPPD quartz window as a Cherenkov radiator

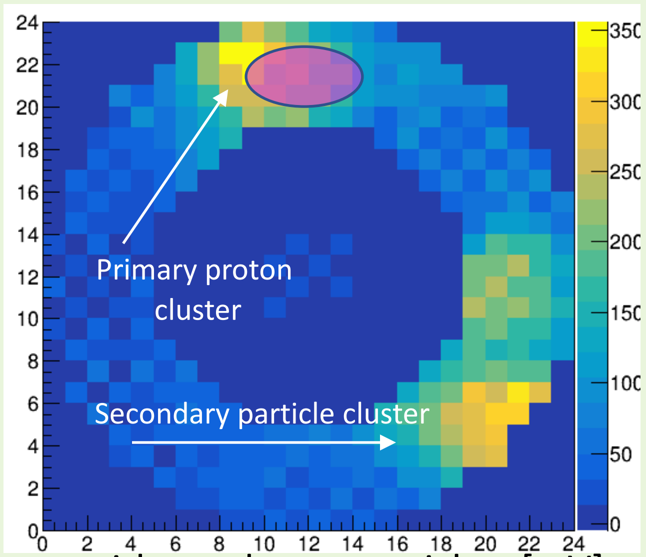


Due to the TIR, photons only hit the PC in a radial band ~[5.5 .. 12.0] mm

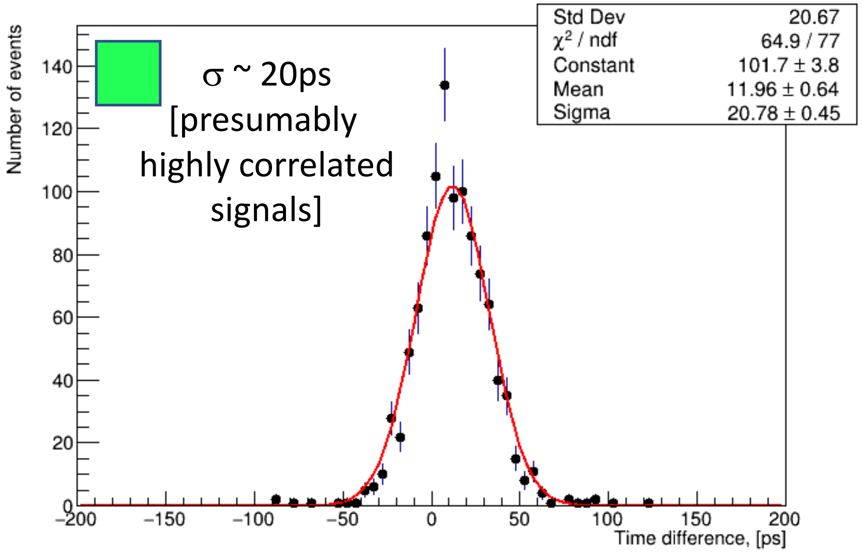


- *Single* photon TTS ~50 ps
- UV grade quartz window: a 120 GeV proton produces a **blob of ~100 p.e.'s**

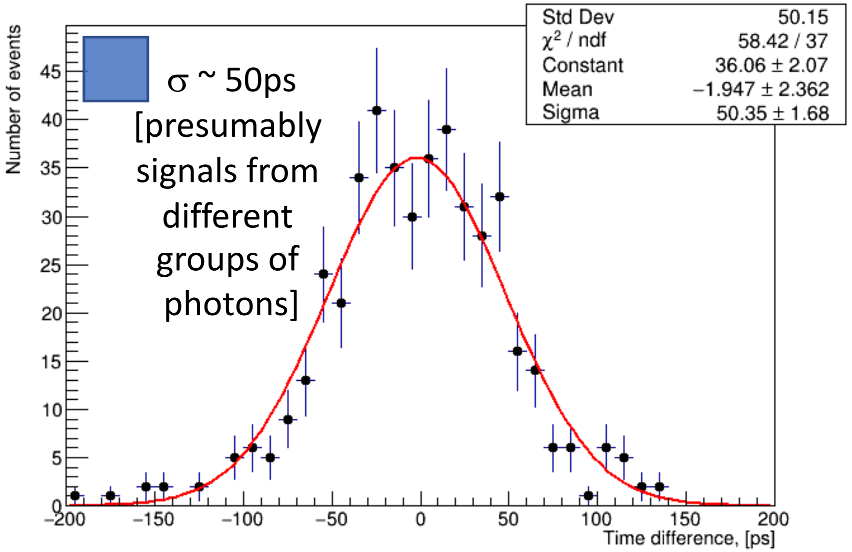
Future work: how to circumvent the missing high precision t_0 timing reference?



Single event with two beam particles; [mV] units



DRS4 chip#0: time(ch#03) – time(ch#02)

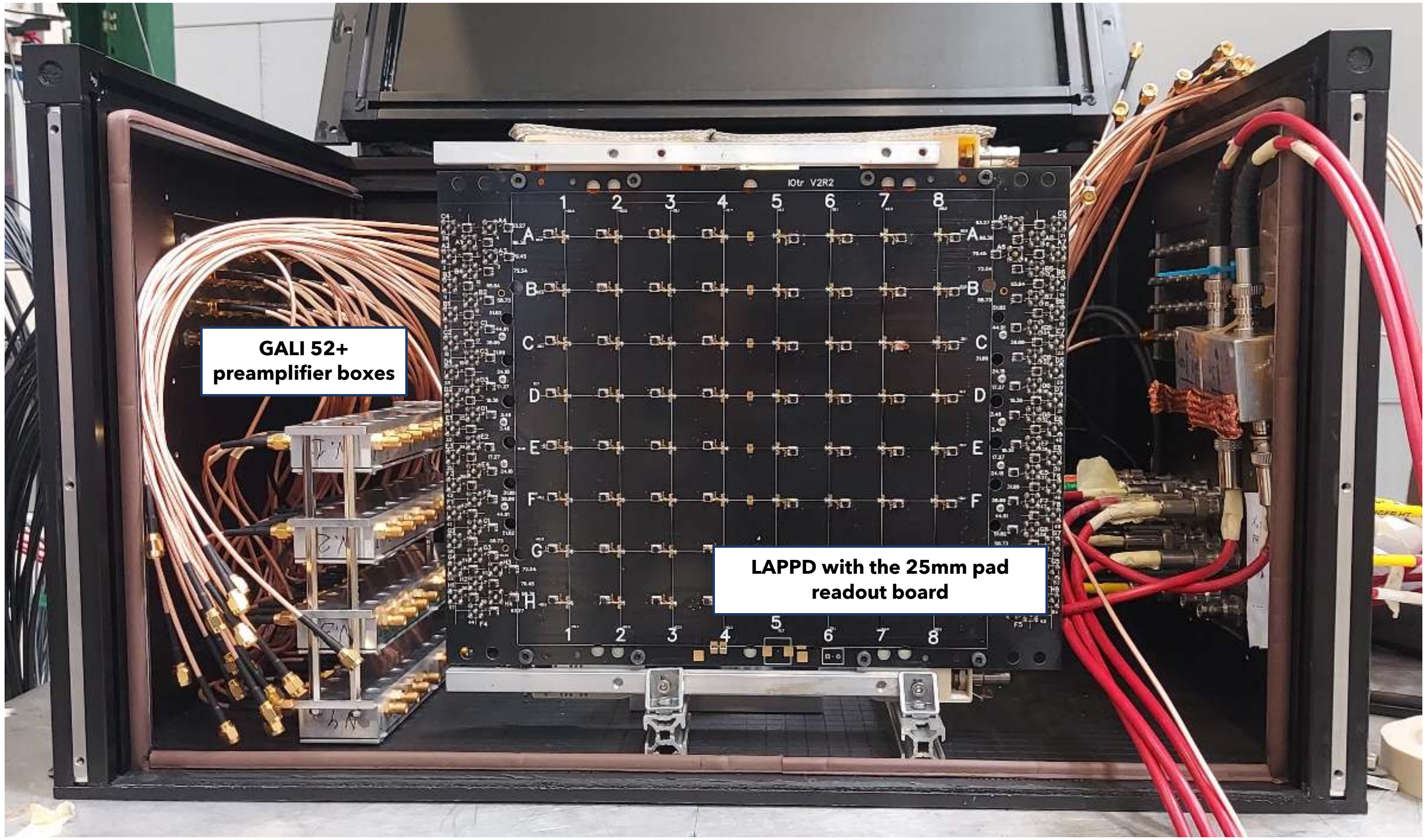


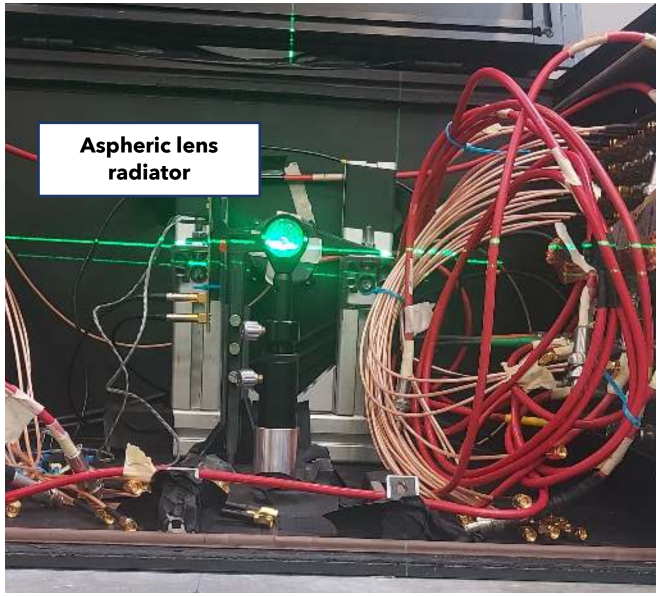
DRS4 chip#1: time(ch#15) – time(ch#13)

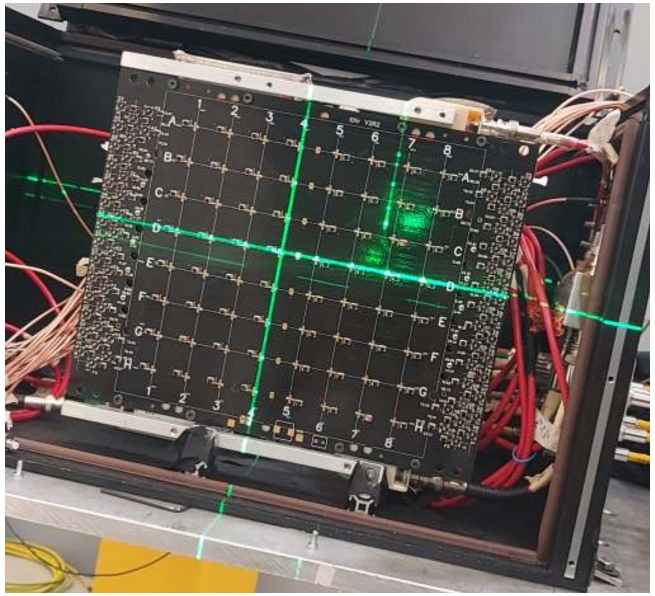
Beam test at CERN in October 2022

(INFN Trieste, INFN Genova, BNL)

Experimental setup

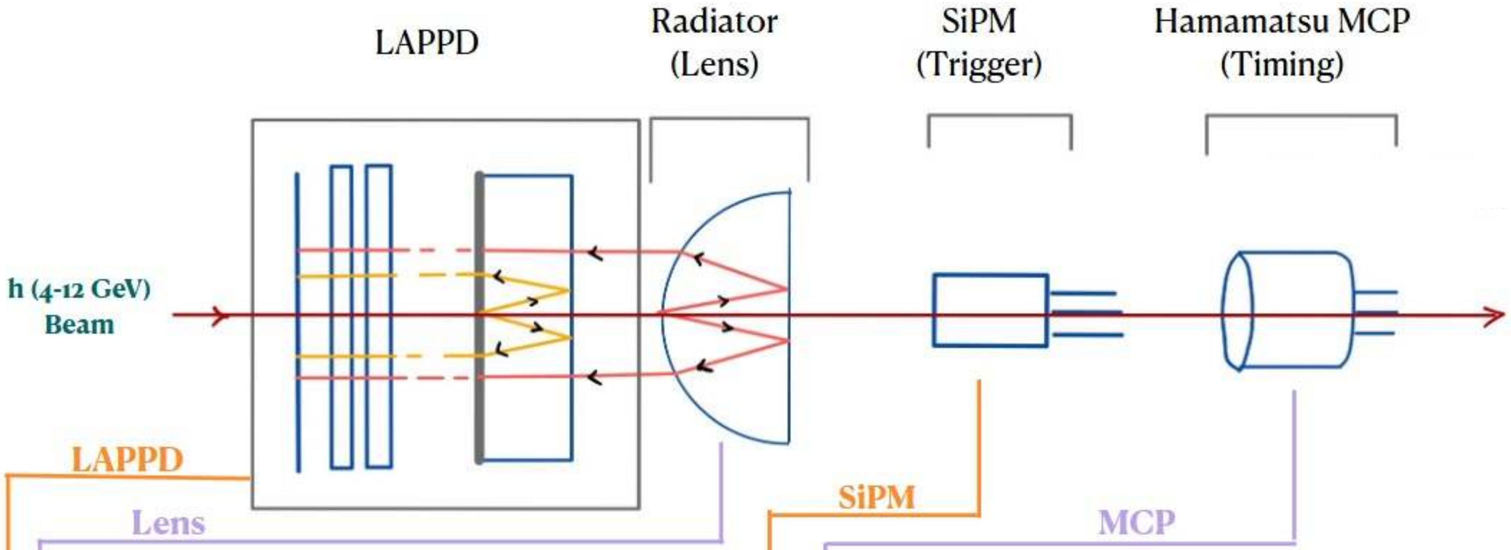






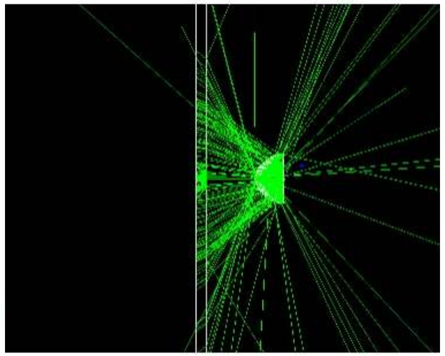
- A standard 20 cm Gen II LAPPD tile 124 with 20 μm pore MCPs
- Incom's own 8x8 pad board
- x10 amplifier boards
- Hamamatsu R3809U-50 MCP-PMT as a timing reference

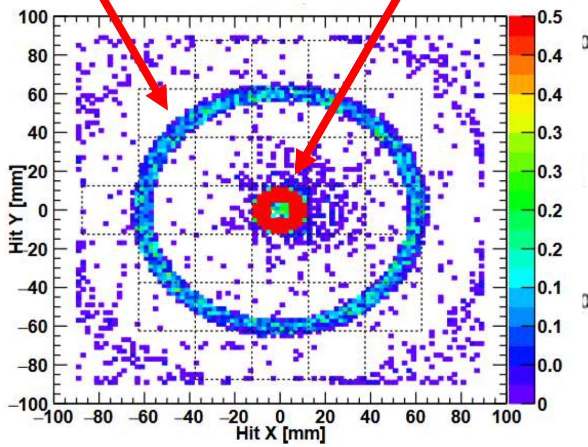
Experimental setup & G4 modeling

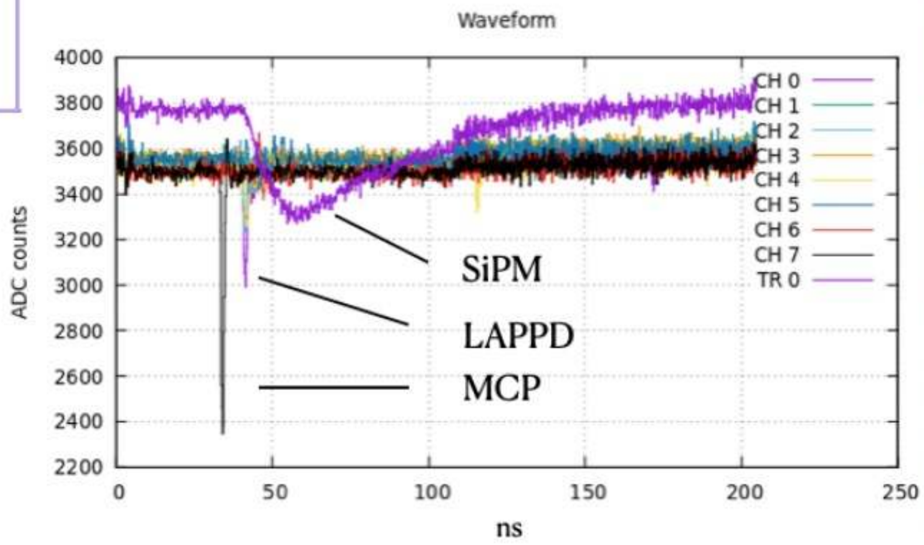


Setup inside the dark-box

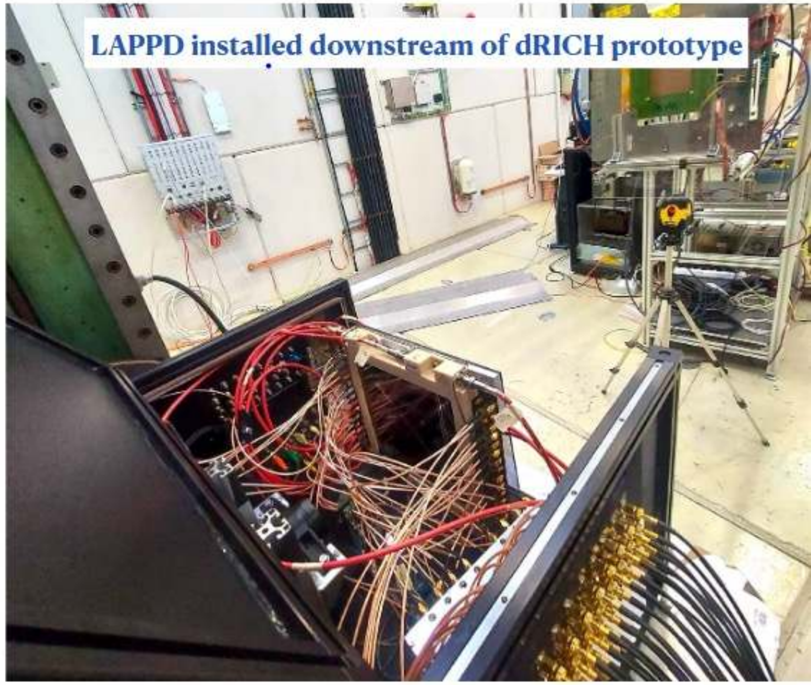
Simulation studies





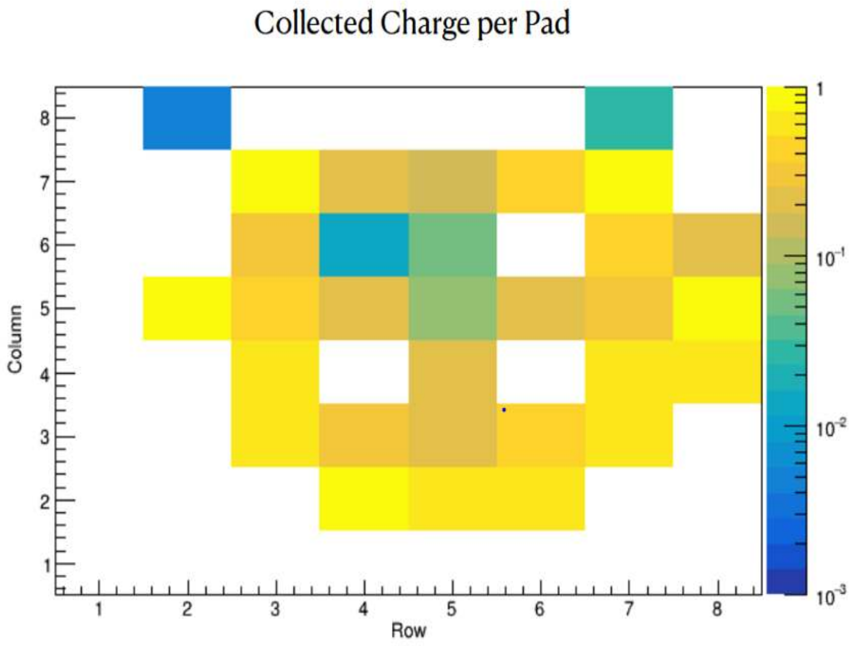


Online Signals

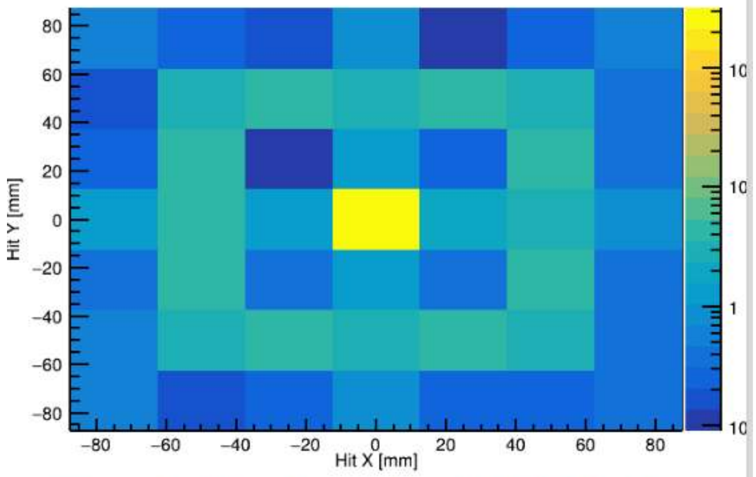


First results from the online data analysis

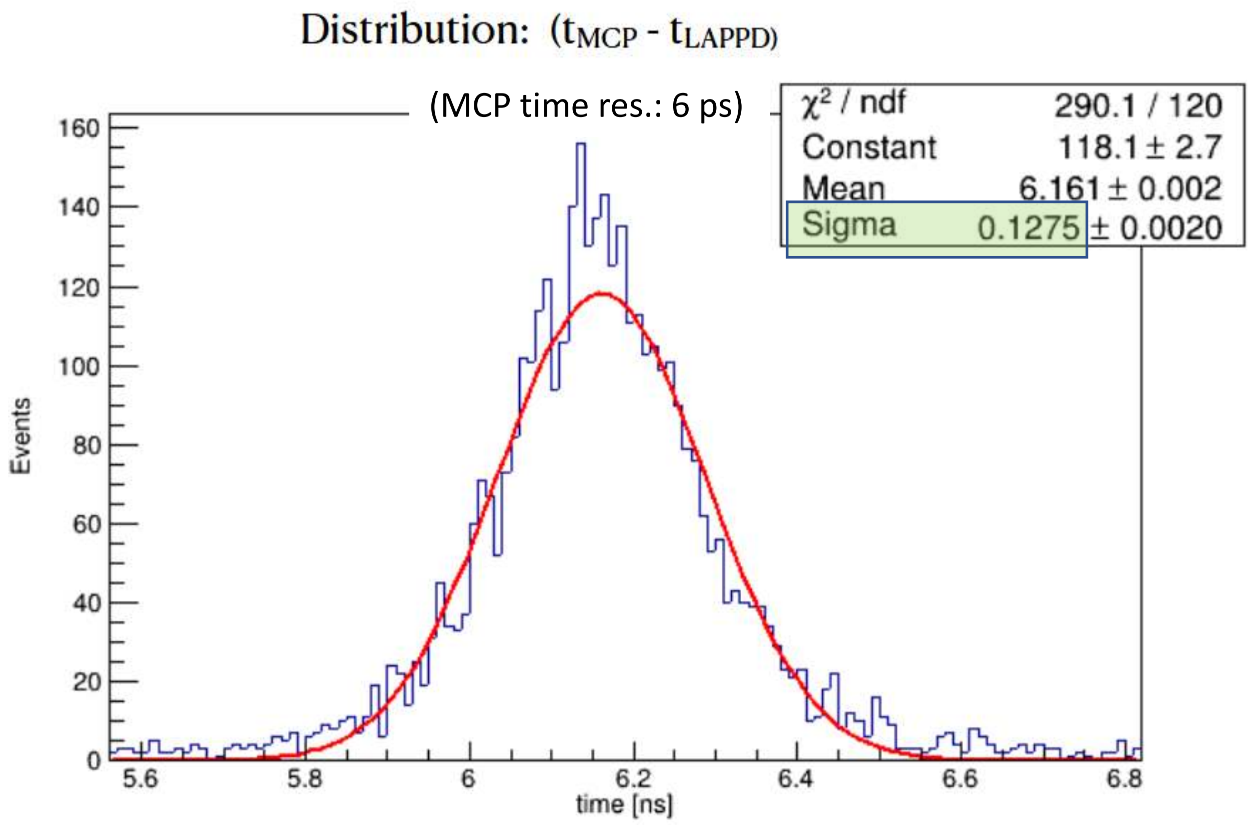
Data



Simulation



Hit map of a Cherenkov ring from GEANT4 simulation

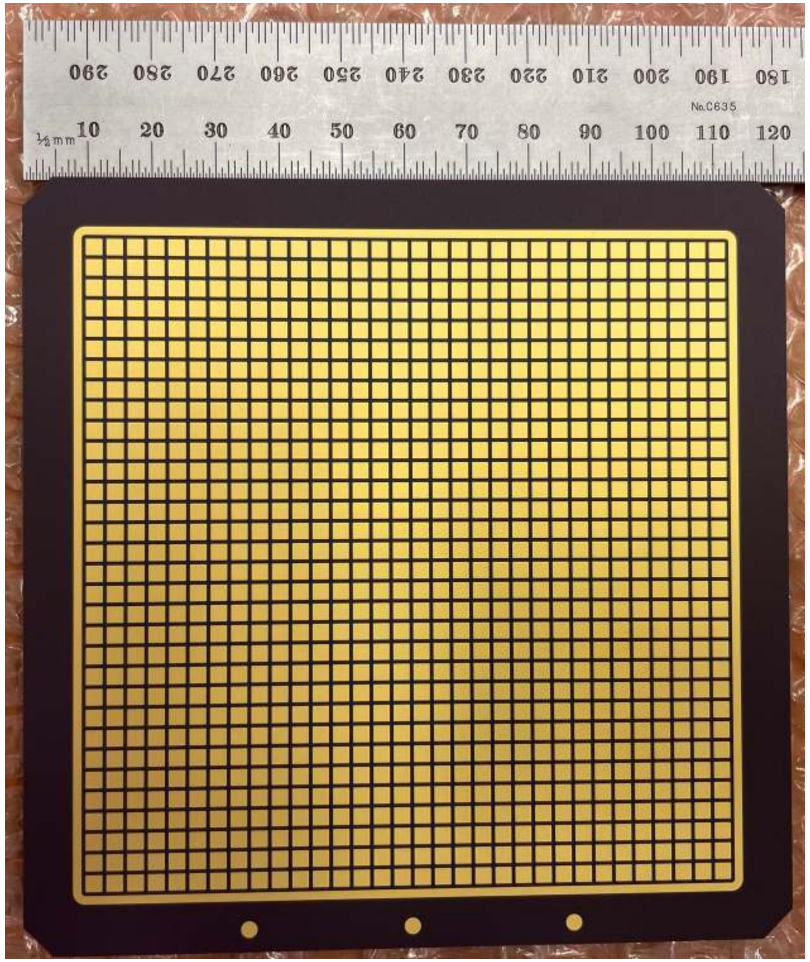


- The standard INCOM readout board is not optimized for multi-hit measurements (also 25mm pad size is too coarse)
- Time resolution spectrum is very preliminary (raw data shown)
- A novel DRS4 calibration procedure is being developed
- Detailed data analysis is required (test beam ended on 10/19, 2022)

DC-coupled HRPPD interface

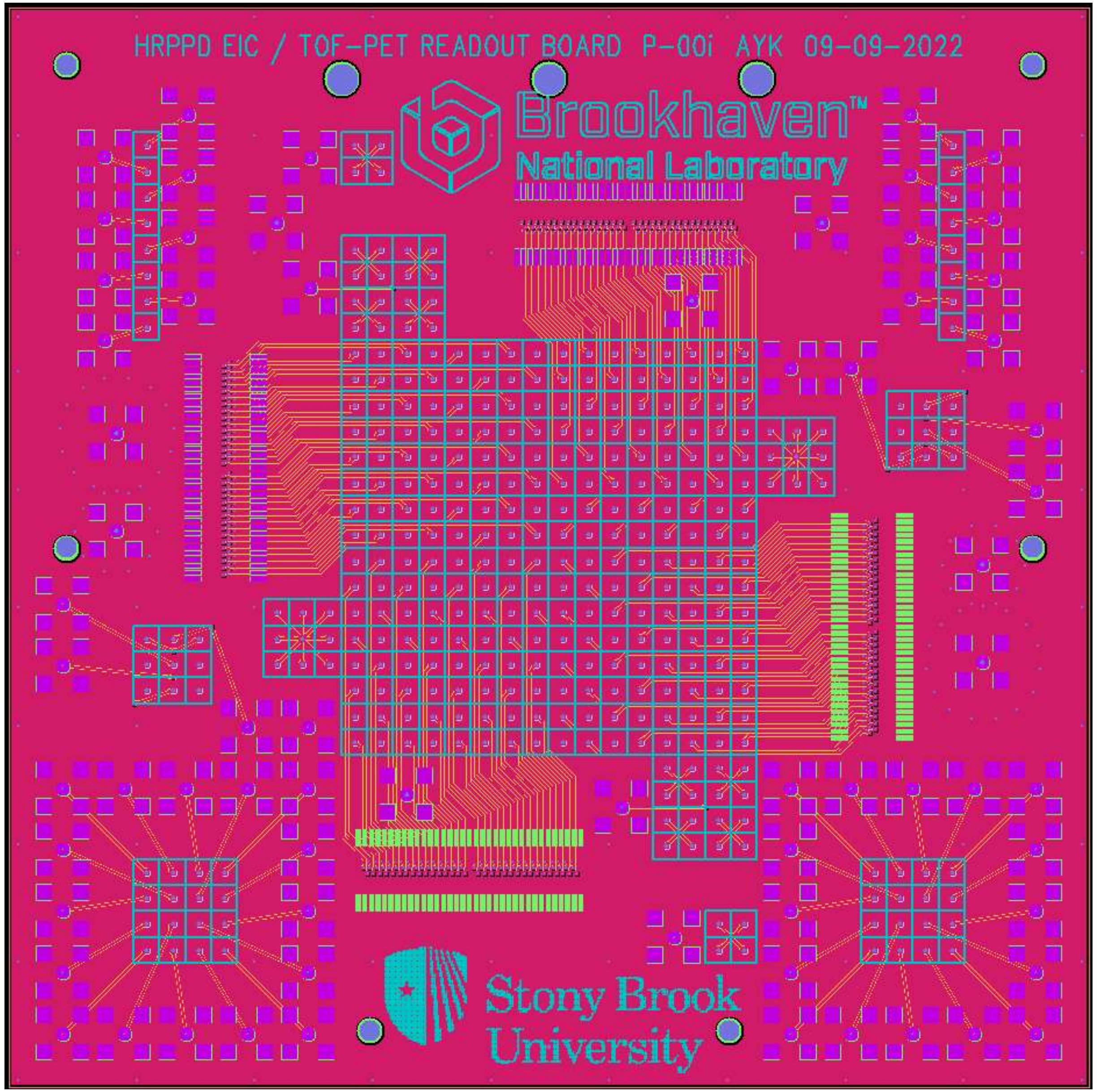
DC-coupled HRPPD

Tile #4 delivered to BNL beginning of October



- ~120 x 120 mm^2 footprint; ~100x100 mm^2 unobscured active area
- 1024 pads, hermetic through vias, 1/8” (~3.2 mm) pitch
- Short MCP stack with 5mm thick quartz window and 3mm thick ceramic base plate

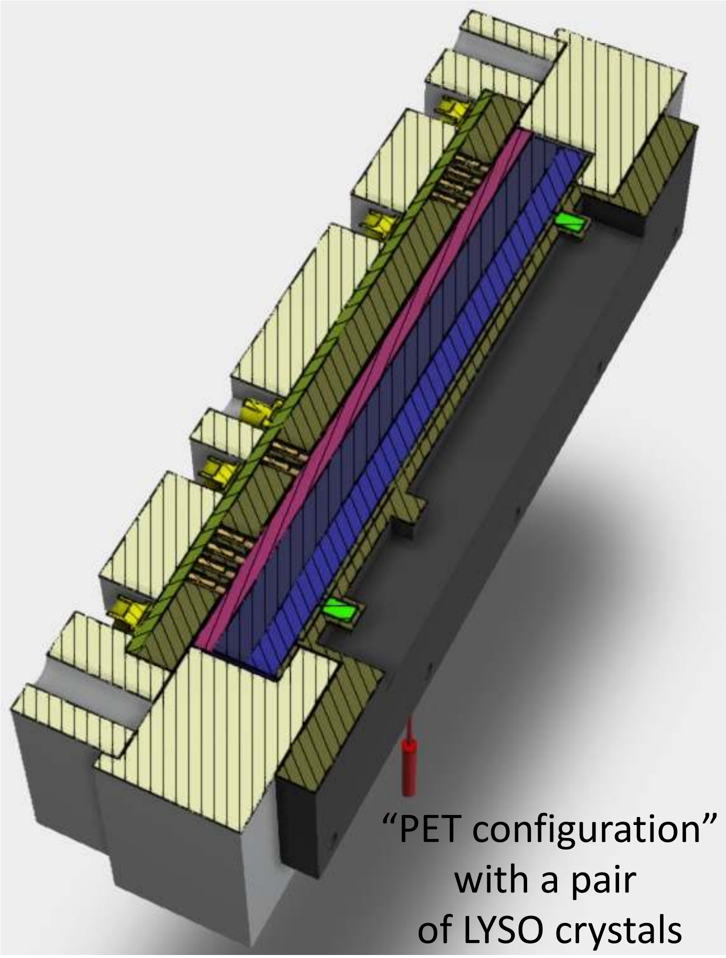
Dual purpose readout PCB

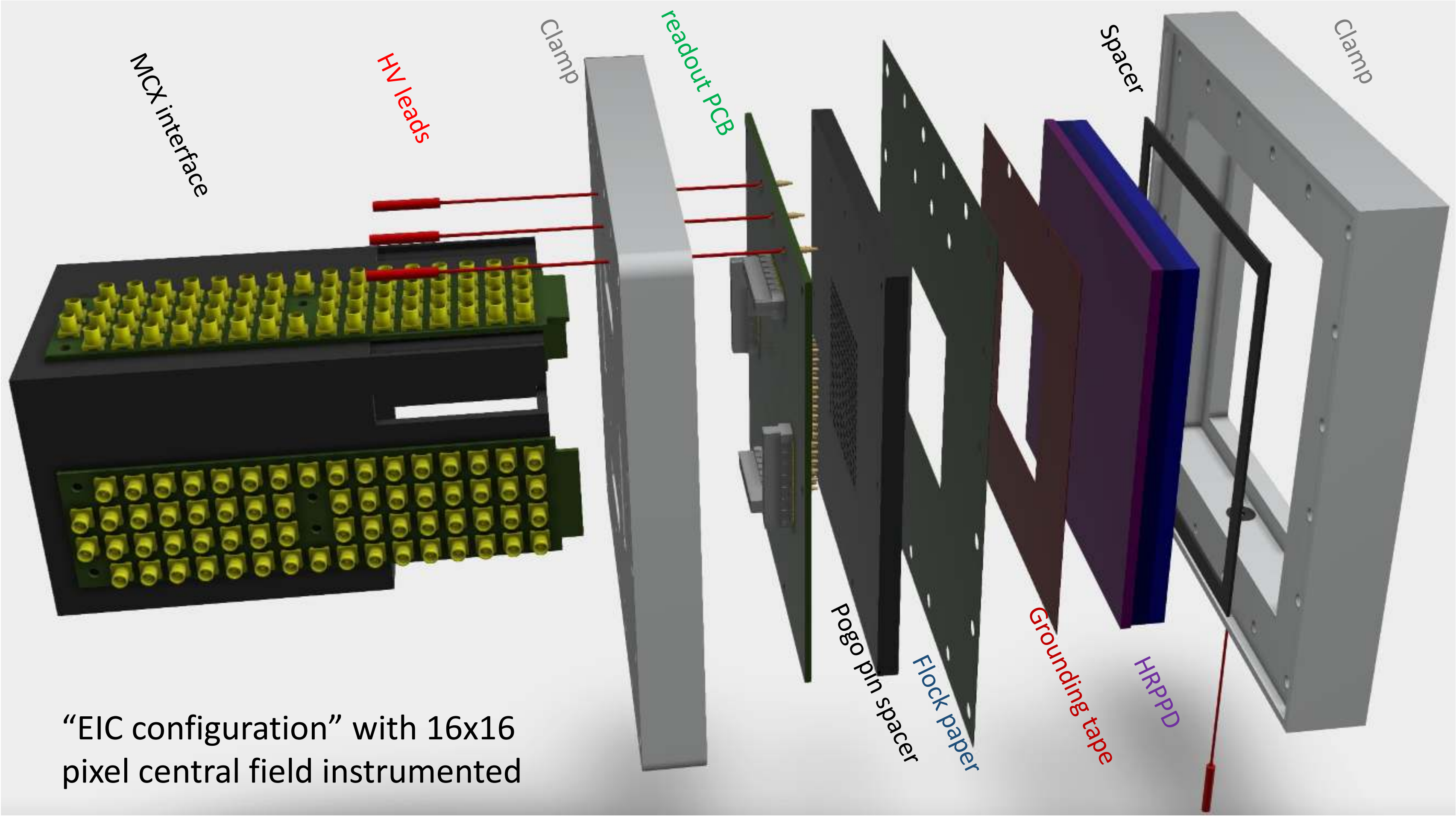


- A compact universal 132 x 132 mm^2 board
- Pixellation follows ~3.2mm HRPPD pad pitch
- Two "main" instrumentation options:
  - A 16x16 pad field in the center
  - Pairs of individual pad fields for systematic studies
- Connectivity via either MCX->MCX cables or Samtec->MCX adapters
- Can be used for the DC-coupled HRPPDs (assembly with the pogo pins), as well as for the capacitively coupled HRPPDs / LAPPDs (assembly without the pogo pins)
- Can also be used in a coincidence setup with a picosecond laser

Bare boards are on their way from HK to BNL

3D integration model(s) for the evaluation studies





- Parts are being machined and 3D printed as we speak **(to be ready first half of November)**
- The "final" integration design (LGA or ZIF sockets, dead area minimization) will require more work

FY23 work plan & budget request

FY23 R&D plan & proposed milestones

Despite the late start in FY22, all planned test beam and test facility measurements were performed by now (reports mostly expected by the end of 2022)

Task	Details	Timeline
LAPPD / HRPPD characterization in the magnetic field	At least one state of the art Gen II and one DC-coupled tile, as pre-selected by the spatial and timing resolution studies; gain dependency on the field-to-normal angle and feasibility of gain recovery by the HV settings tuning	September 2023
DC-coupled HRPPD interface feasibility study	Limitations of the DC-coupled interface in terms of the tile footprint increase, and pad density per cm^2 unless using custom low insertion force sockets	May 2023
Report on a simultaneous spatial and timing performance optimization for a selected subset of Gen II and DC-coupled tiles	Cluster size, spatial and timing single photon resolution evaluation for pixel sizes anticipated for ePIC mRICH/pfRICH and DIRC detectors	September 2023
Report on a "routine" Q&A characterization of a selected subset of tiles	Gain and QE uniformity	September 2023

FY23 budget request

	Argonne	INFN GE/TS	MSU	BNL	JLab	USC		Grand Total
B-field facility maintenance	$10k							**$10k**
Staff effort support	$18k							**$18k**
Engineering / technical support	$15k			$5k				**$20k**
Consumables for the B-field studies		$6k						**$6k**
Postdoc support @ 50%		$20k						**$20k**
Travel to test beams & facilities		$20k	$12k	$15k	$5k	$4k		**$56k**
LAPPD / HRPPD rentals		$24k		$24k				**$48k**
HRPPD interface				$5k				**$5k**
PHOTONIS reference MCP-PMT				$12k				**$12k**
Readout (and preamp) boards				$5k				**$5k**
Test stand equipment				$3k				**$3k**
Total	**$43k**	**$70k**	**$12k**	**$69k**	**$5k**	**$4k**		**$203k**

eRD110 – SiPM

for RICH

INFN-Bologna	P.Antonioli, R.Preghenella, L.Rignanese
INFN-Cosenza	M.Capua, S.Fazio
INFN-Ferrara	L.Barion, M.Contalbrigo

for Calorimeters

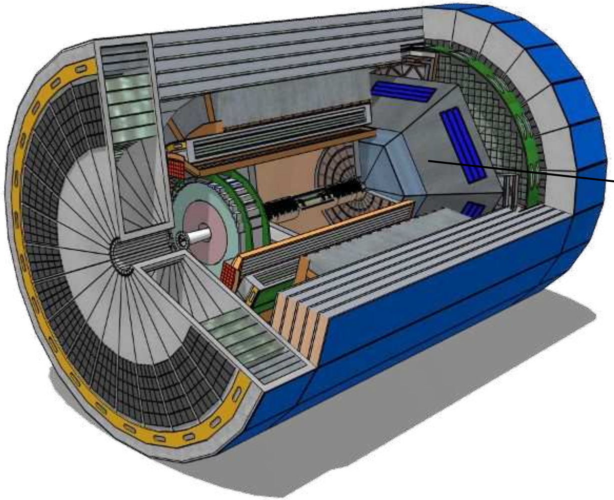
UCLA	O.Tsai
UCR	M.Arratia

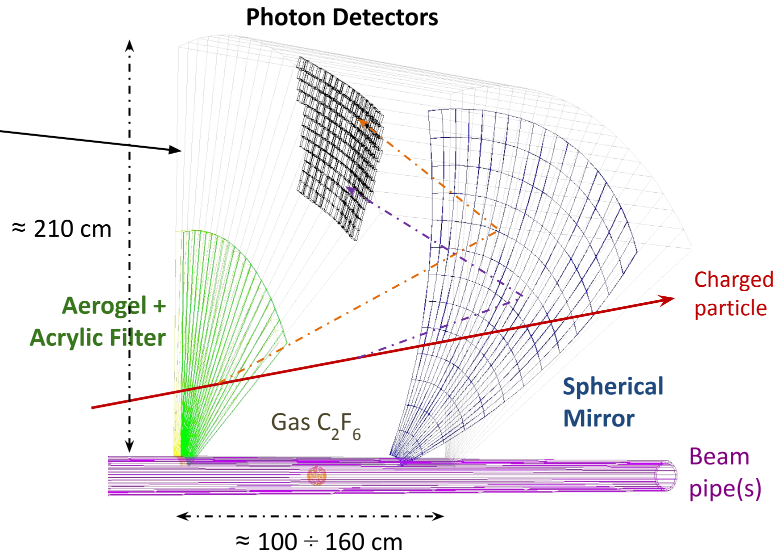
The dual-radiator (dRICH) for forward PID

eRD 102

compact and cost-effective solution for broad momentum coverage at forward rapidity

3-60 GeV/c
$1.5 < \eta < 3.5$





- **radiators:** aerogel (n ~ 1.02) and C_2F_6 (n ~ 1.0008)
- **mirrors:** large outward-reflecting, 6 open sectors
- **sensors:** 3x3 mm^2 pixel, 0.5 m^2 / sector
  - ~ 3m^2 surface with photosensors (~ 300 k channels)
  - single-photon detection inside high B field (~ 1 T)
  - outside of acceptance, reduced constraints

SiPM readout option

SiPM option for RICH optical readout

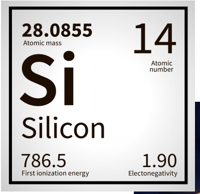
- **pros**
  - cheap
  - high photon efficiency
  - excellent time resolution
  - insensitive to magnetic field

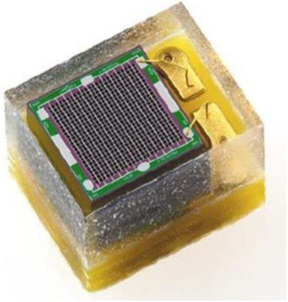
- **cons**

large dark count rates

not radiation tolerant

R&D focus on risk-mitigation strategies





Open R&D questions before CD-3

- **sensor cooling**
  - mitigation of high DCR
  - decide type of cooling approach
    - thermoelectric
    - liquid / hybrid
  - critical for layout of detector plane
    - cooling / electronics on the back
    - dead area between sensor modules
  - also critical for engineering
    - material budget
    - space and services
- **high-temperature annealing**
  - mitigation of radiation damage
  - definition of annealing protocol
    - in-situ approaches
    - oven annealing needs unmounting
  - critical for engineering
    - services for Joule annealing (power)
    -
- **high data-rate readout**
  - mitigation of required bandwidth
  - usage of dedicated electronics
    - fast bunch-crossing gating / inhibit
    - online data reduction / interaction tagger (~ trigger)

R&D status

INFN

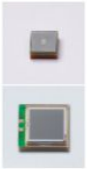
Milestones FY 2022

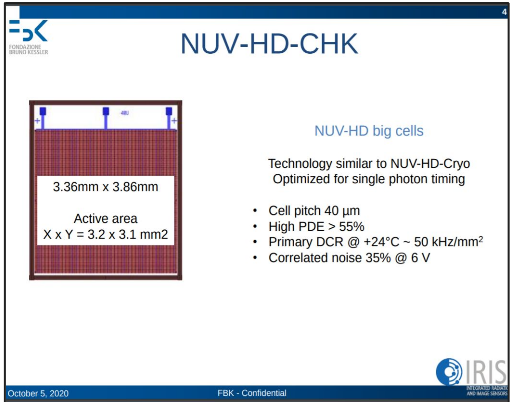
- **[COMPLETED]** automated setup for SiPM characterization in climatic chamber (9/2022)
- **[PARTIAL]** Comparative assessment of commercial (and prototypes not yet available on the market) of SiPM performance after irradiation (2/2023)
- **[PARTIAL]** Definition of an annealing protocol (2/2023)

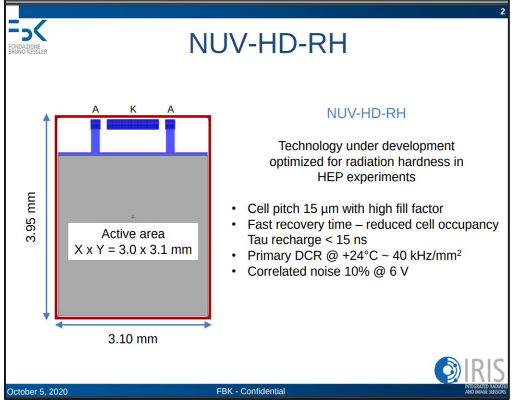
- **acquired SiPM samples**
  - from different manufacturers
  - and of different types
- **developed electronic boards**
  - SiPM carrier boards
  - adapter boards
  - ASIC readout board
- **irradiation campaign(s)**
  - with proton beams
  - increasing NIEL: 10^9 10^{10} and 10^{11} neq
- **high-temperature annealing**
  - with industrial oven
  - up to T = 150 C
  - exploring alternative solutions
- **characterisation and operation**
  - low temperature operation
  - I-V characterisation
  - DCR and signal sampling
  - readout with ALCOR ASIC
  - pulsed LED light response

Commercial SiPM sensors and FBK prototypes

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







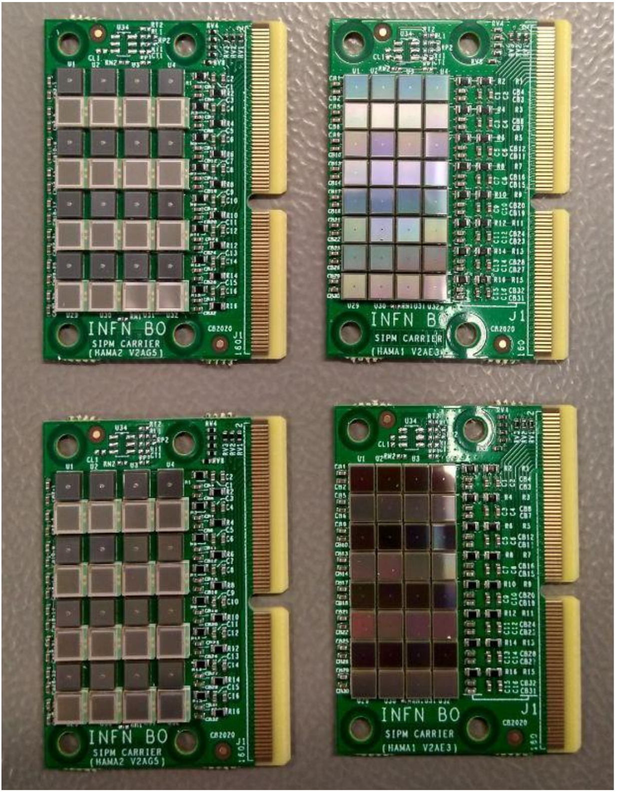
multiple producers: different technologies, SPAD dimensions, V_{bd}, electric field …

in collaboration with FBK since inception

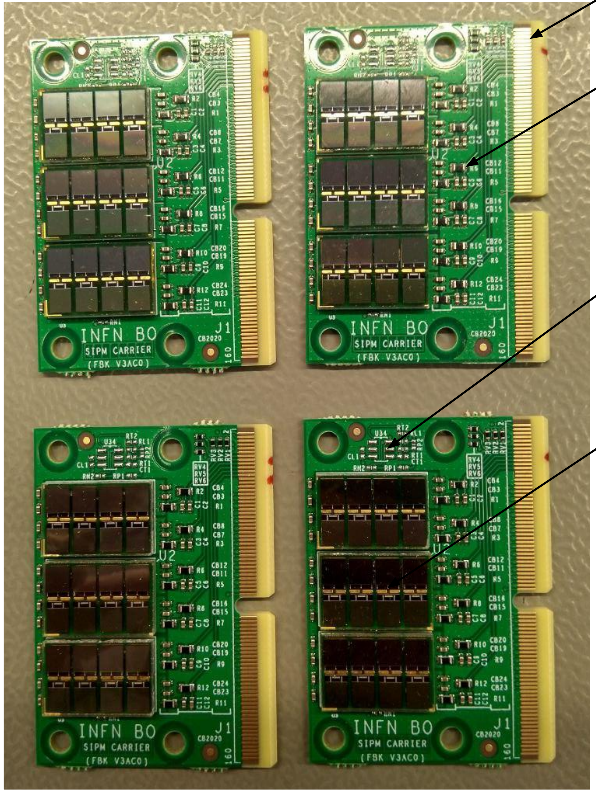
SiPM custom carrier boards

milestone FY 2022

8x4 matrices with commercial Hamamatsu



6x4 matrices with prototype FBK sensors



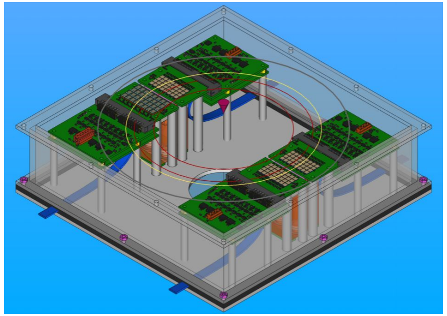
high-density edge connect

high-T grade FR4 for annealing up to 180 °C

temperature sensor for
operation with Peltier cooling

many metallic vias for heat conductivity
(Peltier cooling from the back)

prototype SiPM readout box

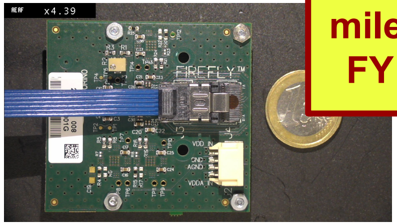


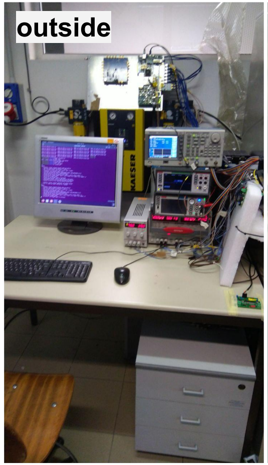
withstand irradiation, high-T annealing and low-T operation in form-factor usable for imaging in beam tests

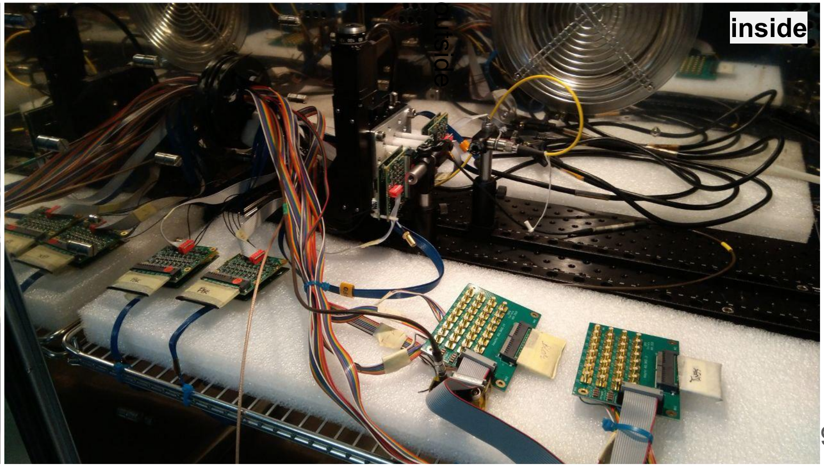
Characterisation setup

- **climatic chamber**
  low-temperature operation
- **2x 40-channel multiplexers**
  source meter
- **ALCOR-based front-end chain**
  FPGA (Xilinx) readout
  automatic measurement of 2x SiPM boards (64 channels)

milestone FY 2022

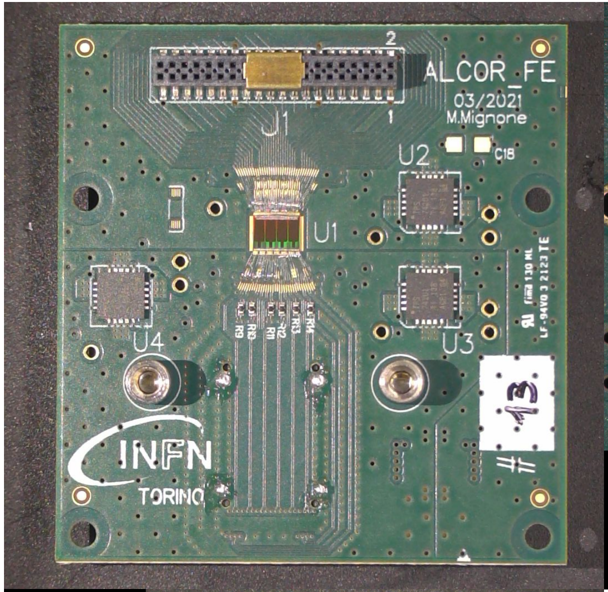


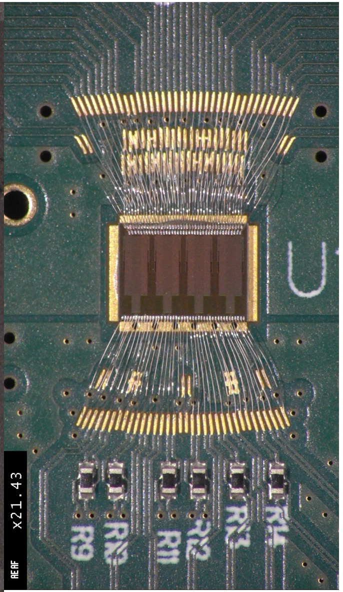


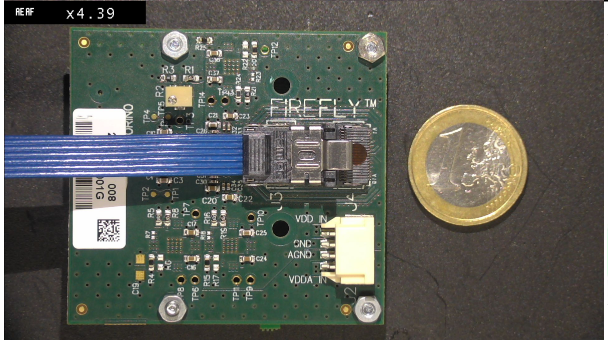


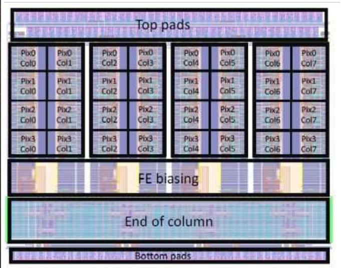
ALCOR: A Low Power Chip for Optical sensor Read

eRD 109







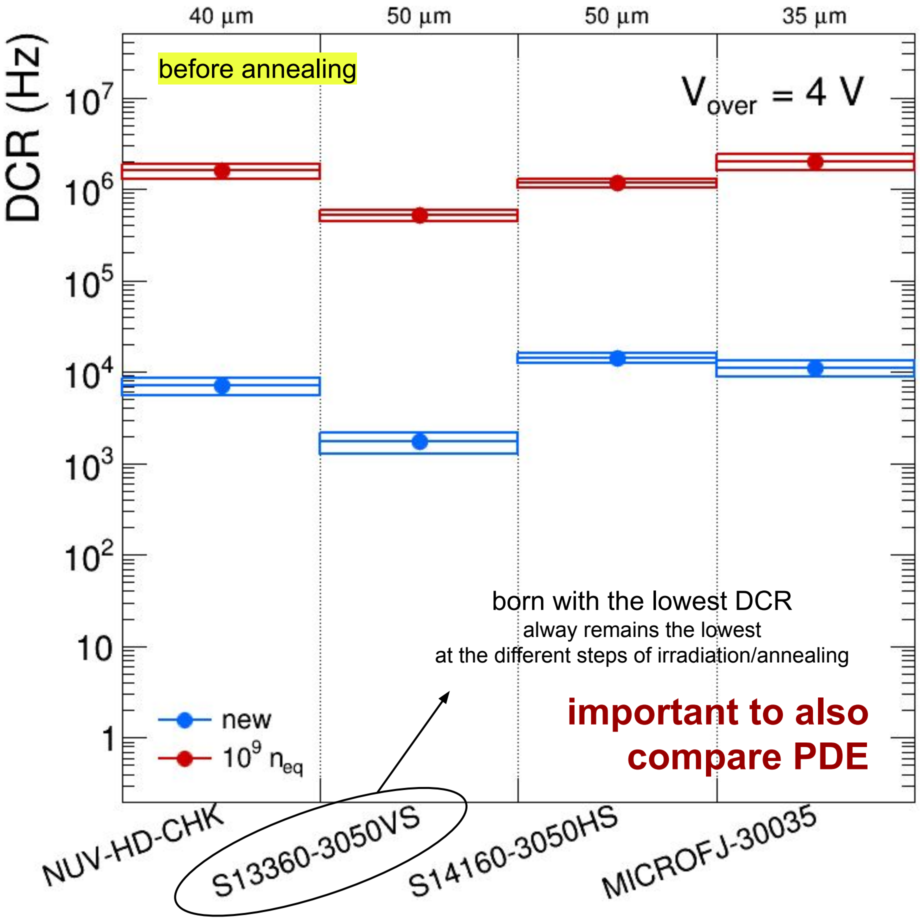


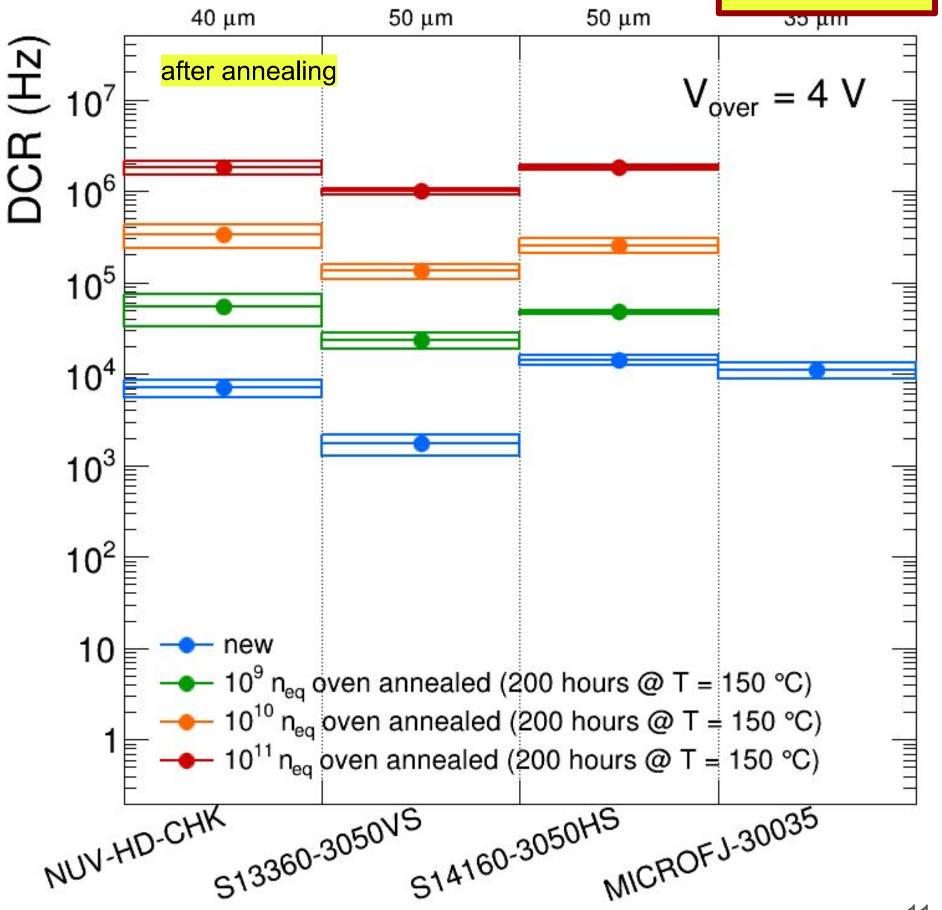
developed by INFN-TO for DarkSide

- 32-pixel matrix mixed-signal ASIC
- the chip performs
  - signal amplification
  - conditioning and event digitisation
- each pixel features
  - dual-polarity front-end amplifier
    - low input impedance
    - 4 programmable gain settings
  - 2 leading-edge discriminators
  - 4 TDCs based on analogue interpolation
    - 50 ps LSB (@ 320 MHz)
- single-photon time-tagging mode
  - also with Time-Over-Threshold
- fully digital output
  - 4 LVDS TX data links

DCR after irradiation and annealing

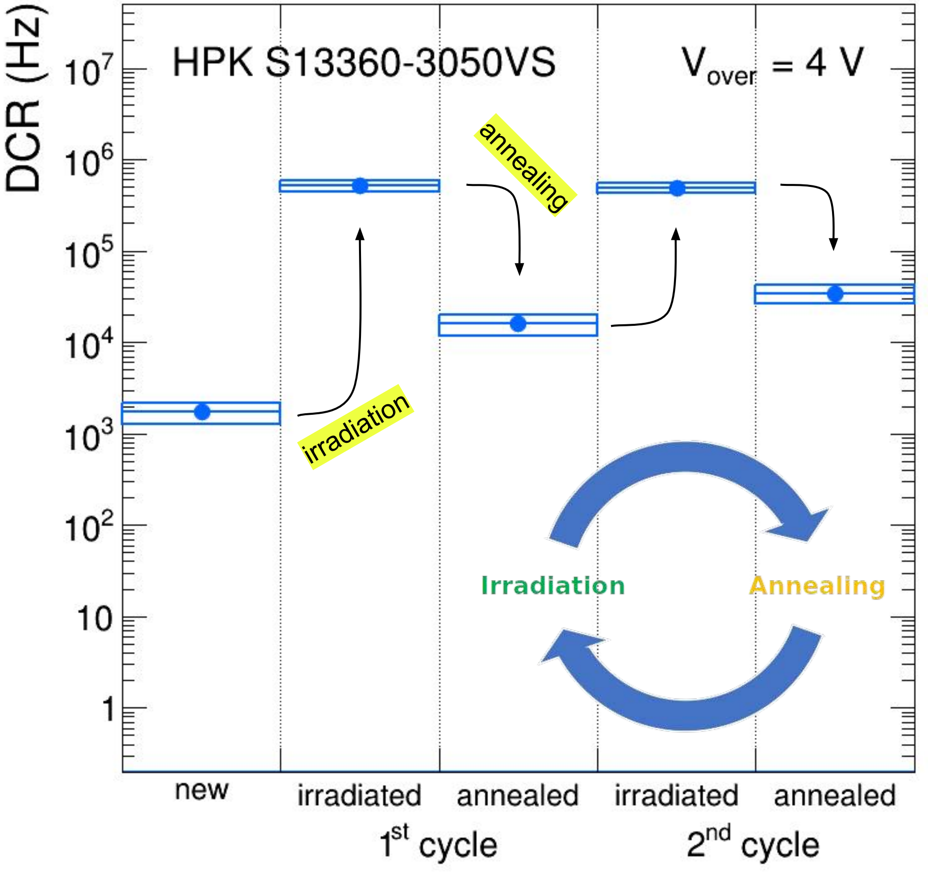
milestone FY 2022





Repeated irradiation-annealing cycles

milestone FY 2022



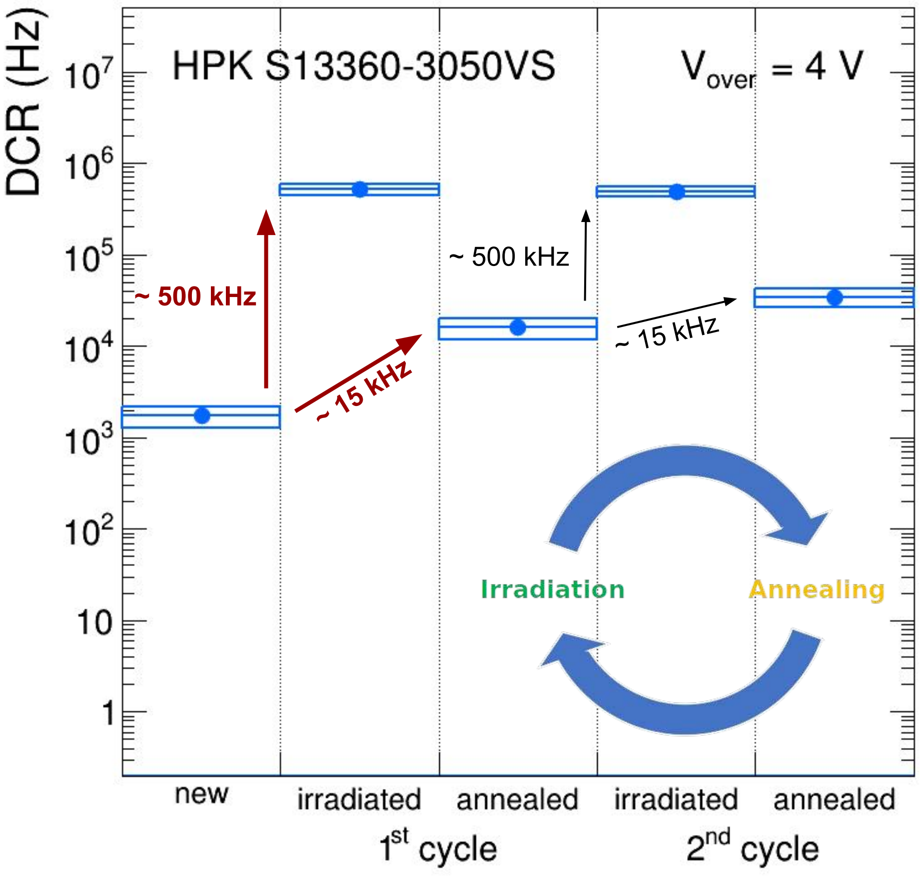
test reproducibility of repeated irradiation-annealing cycles

simulate a realistic experimental situation

- campaign is ongoing
  - partial results reported here
- 2 cycles performed so far
  - irradiation fluence/cycle of 10^9 n_{eq}
  - annealing in oven for 150 hours at 150 °C
- interleaved with full characterisation
  - new
  - after each irradiation
  - after each annealing

Repeated irradiation-annealing cycles

milestone
FY 2022



test reproducibility of repeated irradiation-annealing cycles

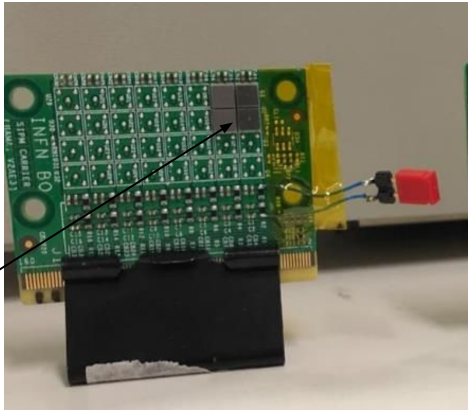
simulate a realistic experimental situation

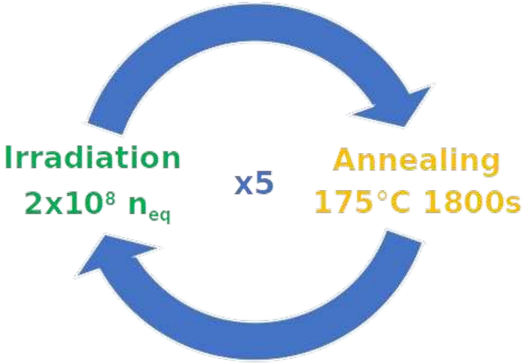
- consistent irradiation damage
  - DCR increases by ~ 500 kHz (@ Vover = 4)
  - after each shot of 10^9 n_{eq}
- consistent residual damage
  - ~ 15 kHz (@ Vover = 4) of residual DCR
  - builds up after each irradiation-annealing

annealing cures same fraction of newly-produced damage

~ 97% for HPK S13360-3050 sensors

Online annealing

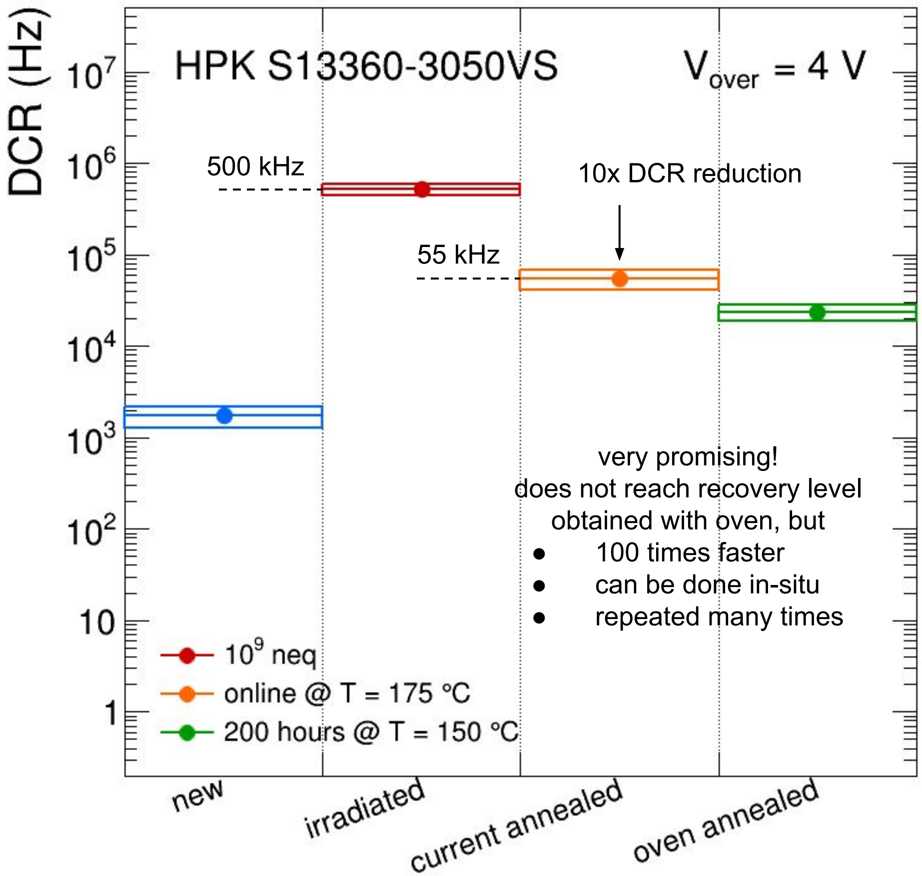




explore solutions for in-situ annealing

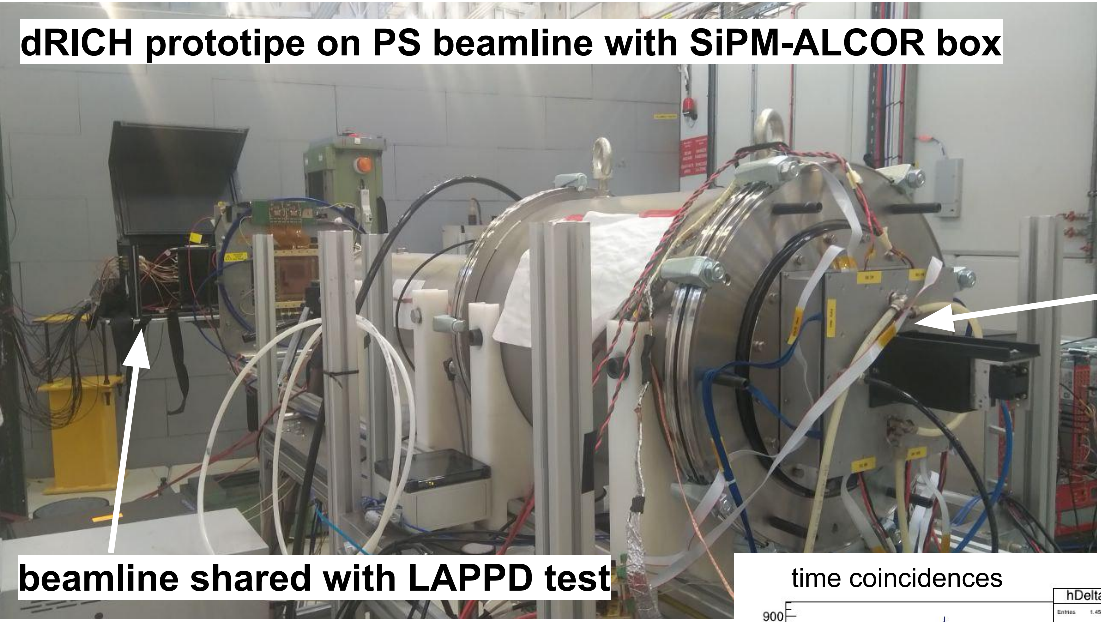
- total fluence of 10^9 n_{eq}
  - delivered in 5 chunks
  - each of 2 10^8 n_{eq}
- interleave by annealing
  - forward bias, ~ 1 W / sensor
  - T = 175 °C, thermal camera
  - 30 minutes
- preliminary tests
  - Hamamatsu S13360-3050

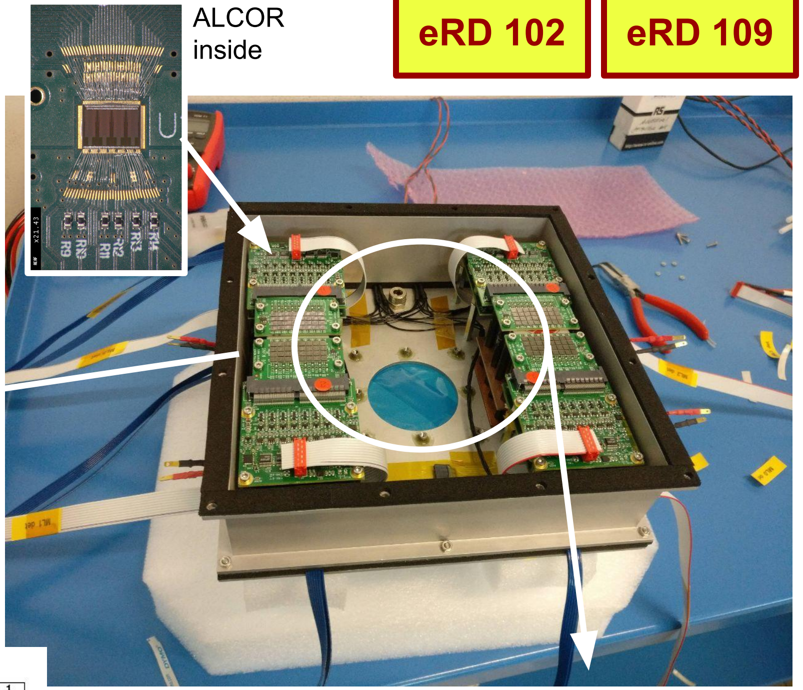
Online annealing

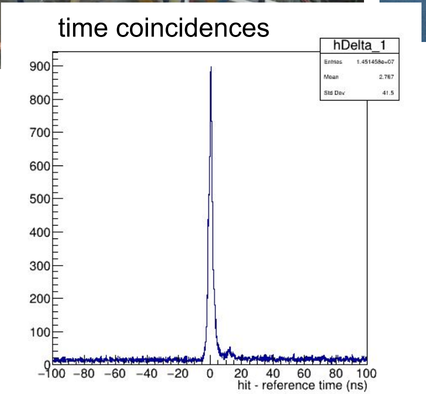


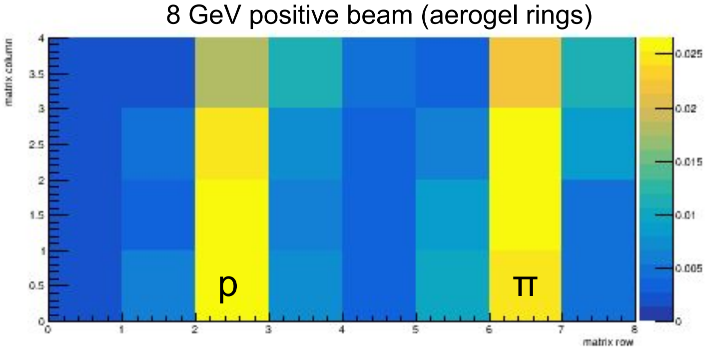
Test beam at CERN just concluded

eRD 102 **eRD 109**









successful operation of SiPM

- all sensors were irradiated (up to 10^{10}) and annealed (oven)
- complete prototype readout chain based on ALCOR-v1

Plans for FY 2023

Milestones FY 2023

critical results for pre-TDR

- Timing measurement of irradiated (and annealed) sensors (6/2023)
- Comparison of the results achieved with proton and neutron irradiation sources (8/2023)
- Study of annealing in-situ technique with a proposed model selected as baseline for the pre-TDR (9/2023)

- **single-photon time resolution**
  - of full SiPM-ALCOR readout chain
    - no capacity to measure it so far
  - critical to set performance simulation
- **alternative annealing solutions**
  - so far done with industrial oven (days)
  - address ideas for faster / in-situ recovery
    - exploration started, promising
    - critical to become structured R&D
- **irradiation campaigns**
  - so far only with 150 MeV protons
  - critical to test neutron damage
    - might be topologically different
    - effectiveness of annealing
    - test NIEL damage hypothesis
  - irradiation needed to test new annealings
- **operation at low temperature**
  - so far characterisation in climatic chamber
    - compare results with TEC (Peltier) cooling
  - explore alternative solution to TEC
    - liquid, hybrid (liquid + TEC) approaches
- **development of new sensors**
  - within INFN-FBK collaboration agreement
    - critical for procurement risk mitigation
  - reduction of DCR
    - field / thickness optimisation
    - exploration of advanced microlensing
  - development of “monolithic” SiPM sensor array
    - wire bonded, cost reduction

Financial requests for FY2023

- **SiPM R&D program benefits from significant INFN in-kind contribution**
  - infrastructures
  - access to irradiation facilities (TIFPA proton, LENA reactor)
  - laboratory equipment (power supplies, climatic chamber, …)
  - procurement of new sensors and electronics
  - engineering run with FBK
- **complementary characterisation setup in Cosenza**

  - most of the equipment funded by INFN
  - request eRD110 support for FPGA eval. board (ALCOR readout) [7.5 k$]
- **other financial requests**
  - partial support for irradiation costs [14 k$]
  - laser equipment for time resolution measurements [20 k$]
  - partial support to cover the cost of the FBK engineering run [20 k$]
- **manpower**
  - 6 researcher and several technicians available
    - one post-doc ending contract in early 2023
  - request eRD110 support for co-funding of two post-docs [40 k$]
    - critically required given the extent of the R&D program

fruitful collaboration with FBK
- since the inception
- prototype sensors

great perspective for joint R&D

SiPM for calorimetry applications: R&D plan FY23

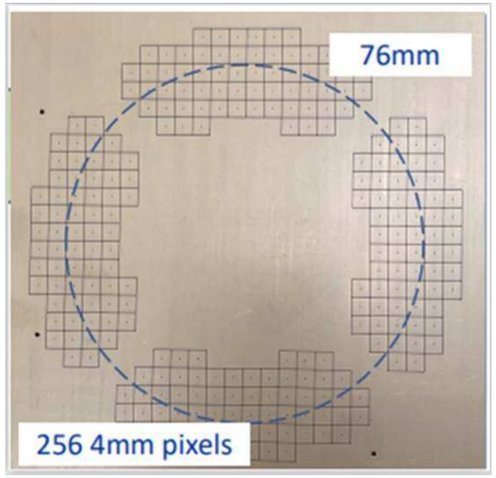
- **HPK SiPMs for calorimetry applications**
  - were extensively studied during generic EIC R&D program since 2016 (eRD1 consortium)
  - large samples irradiated with sources and at RHIC (up to few 10^{11} n/cm^2)
- **degradation effects well understood and characterized**
  - SNR
  - degradation of energy resolution for ECals
- **large sample of ~10k HPK SiPMs used at STAR**
  - Forward Calorimeter system in Run 22 pp 500 GeV
  - neutron fluxes similar to high luminosity EIC, noise increases as expected
- **HPK sensors are present baseline sensors for all ePIC calorimeters**

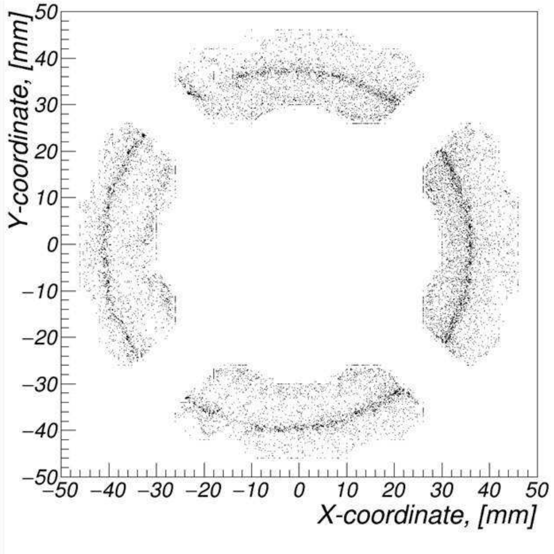
- **there is need for sensors with large area, small pixels size and good PDE**
  - NDL SiPMs on paper are very good (6x6 mm^2, 15 μm pixels size, 45% PDE)
  - different technology than HPK
- **in FY23 perform comparison studies of HPK and NDL sensors under exposure**
  - program similar to one of done for generic R&D
  - will use Berkeley 88-inch Cyclotron, 50 MeV (10^9 – 10^{12} n/cm^2)
  - RHIC Run 23 (AuAu) is not useful for such studies
- **determination of SNR as a function of overvoltage and exposure**
  - main objective for these studies

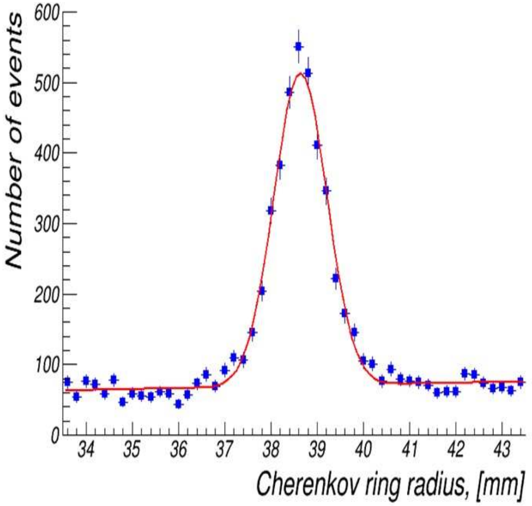
Backup

Sensor pixellation

- Input considerations (assume n ~ 1.02 aerogel):
  - Cherenkov saturation angle ~200 mrad times ~40 cm expansion volume -> ~160 mm diameter rings
  - $\langle n_{pe} \rangle \sim 10$, on a good day
  - We have beam data showing 4 mm pixellation is good enough to achieve single photon ring radius resolution ~600 μm, even without signal pre-amplification

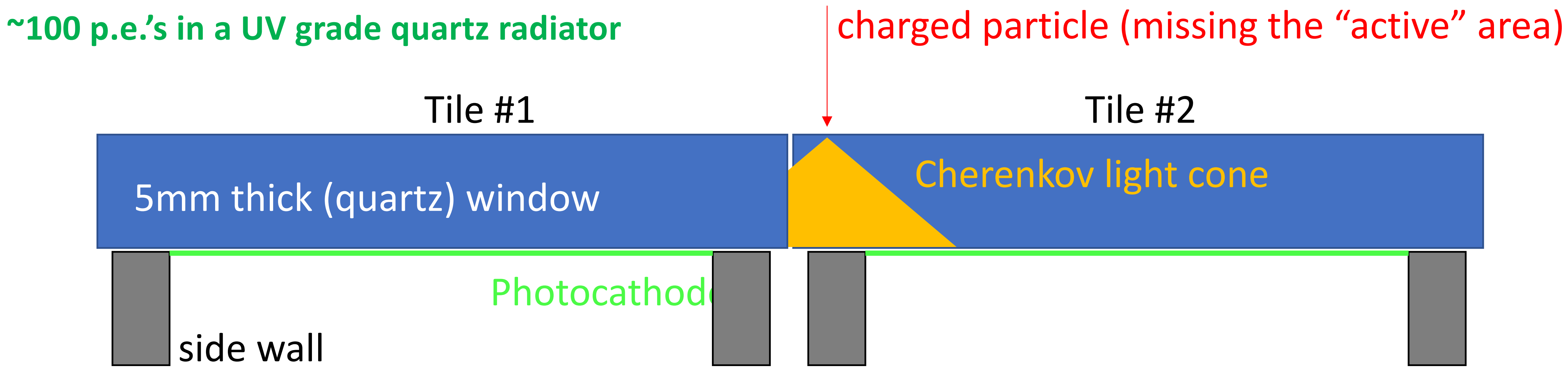






Let's assume occupancy is not a problem for ~4 mm pixels

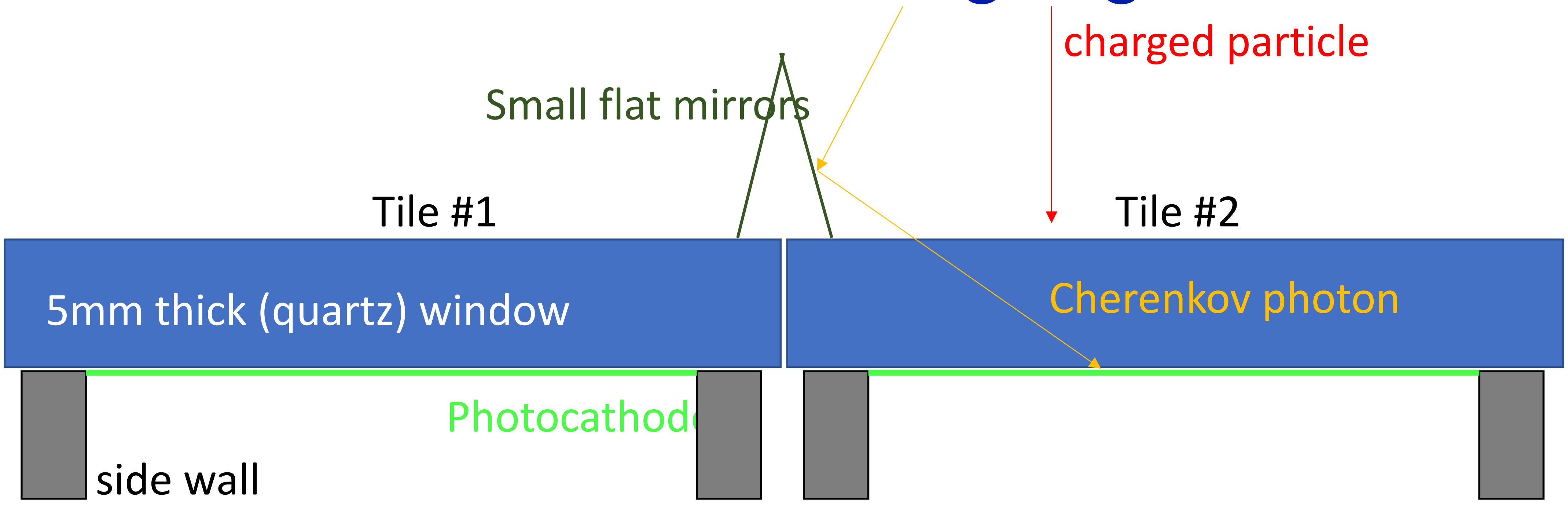
Towards ~100% time-of-flight geom. efficiency



- Even that the HRPPD active area (the photocathode and the MCP stack) is much smaller than the tile footprint, the Cherenkov light cone spot in a 5 mm thick quartz window has a base of ~11 mm diameter
  - By making the edge area reflective (or perhaps just relying on a TIR) one should be able to gain timing performance over the whole surface, even though with a degraded resolution towards the tile edges, apparently

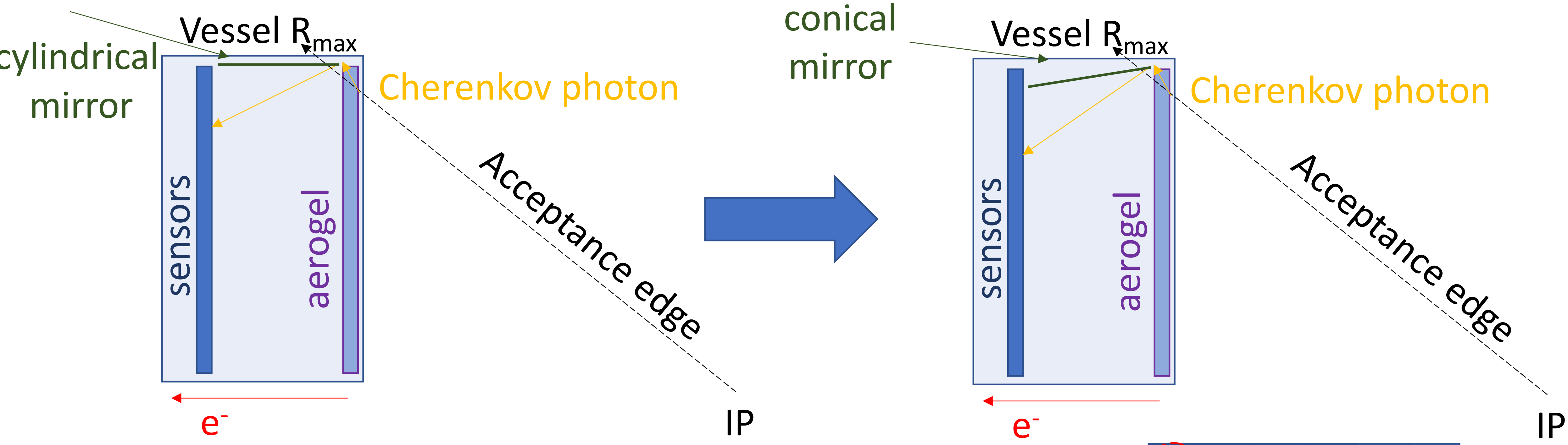
Tiling a flat sensor surface without gaps is a clear benefit

Towards ~100% Cherenkov light geom. efficiency



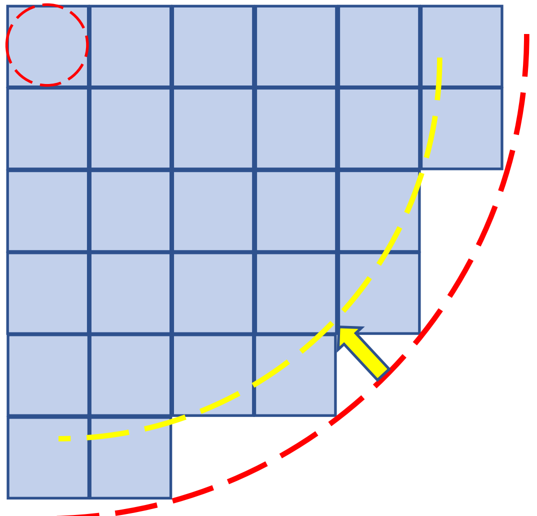
- One should seemingly be able to “save” the Cherenkov photons, which would otherwise miss the photocathode, by funneling them away from the dead area
  - The reconstruction procedure can certainly be adjusted to handle such cases
  - Requires geometry optimization

Acceptance at the DIRC inner radius, cont'd



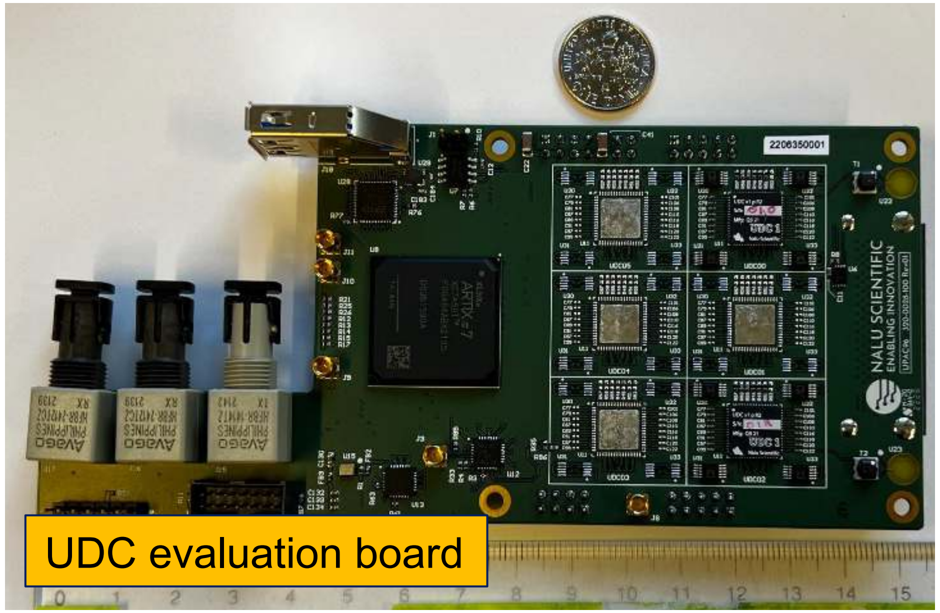
- No reason to lose this acceptance *on the sensor plane* either
  - Use a conical (or a piece-wise flat *tilted*) mirror at $\sim R_{max}$

- Use the same trick around the beam pipe?

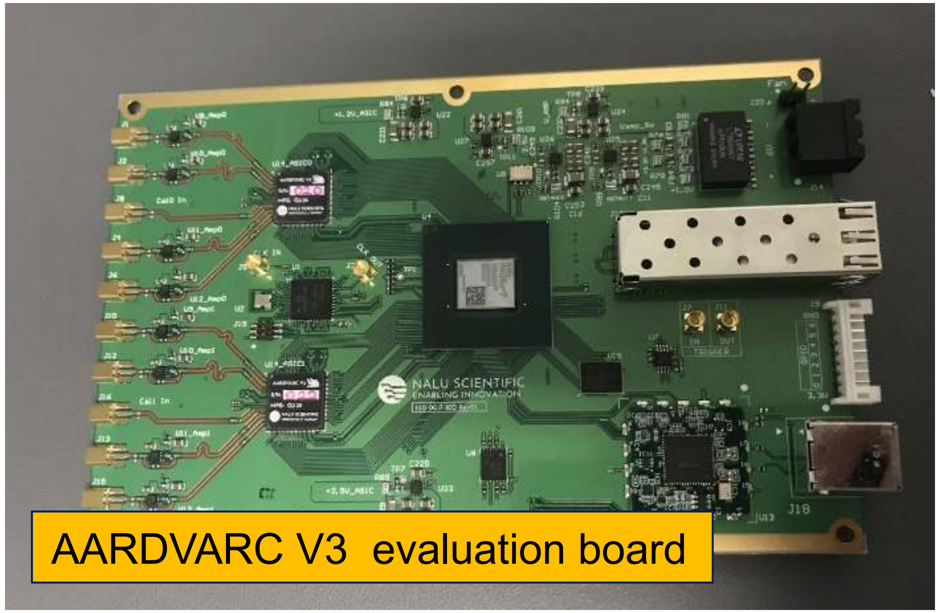


pfRICH readout electronics solution

- Assume 24x24 pixellation suffices (~4.2mm pads) -> 576 pixels per 12x12 cm^2 footprint
- A hybrid of Nalu Scientific UDC and AARDVARC v4 chips as a “reference ASIC”
  - 16-channel ASICs (would be better to have 32- or 64-channel ones, of course) -> defines the layout!
  - 20 dB preamplifier on die (~6mW additional power per channel)
  - ~10GS/s digitizer, ~2GHz ABW, feature extraction, streaming capability (whatever it means), etc.
  - Few kW of power dissipation for the whole system seems to be a real-life estimate

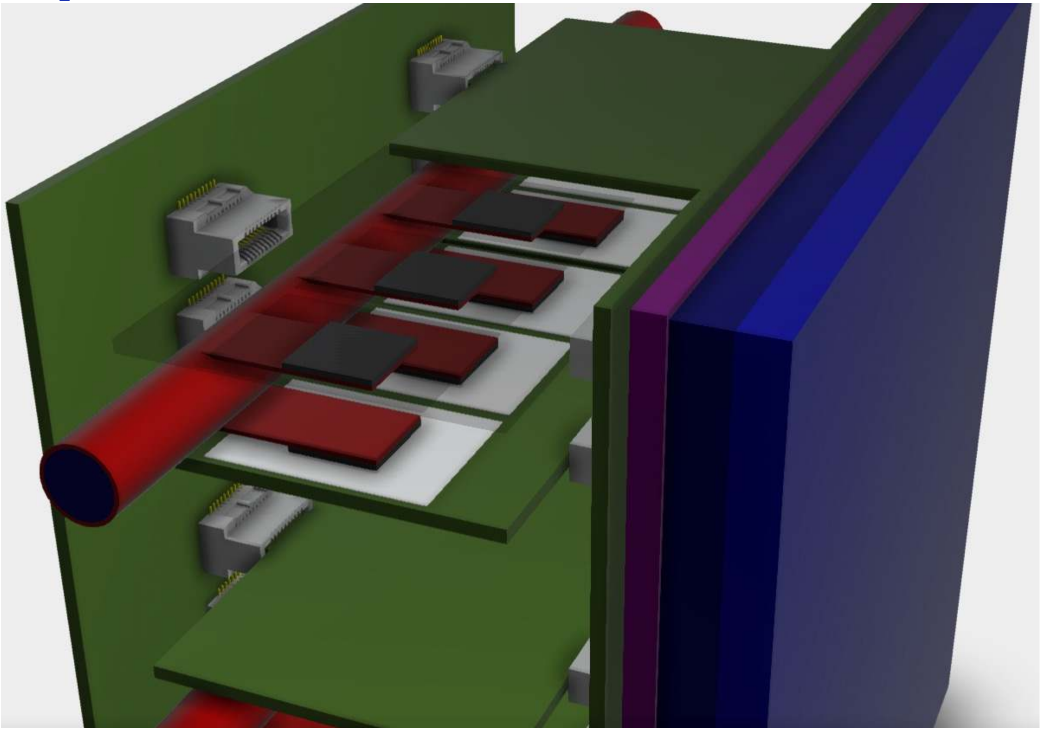


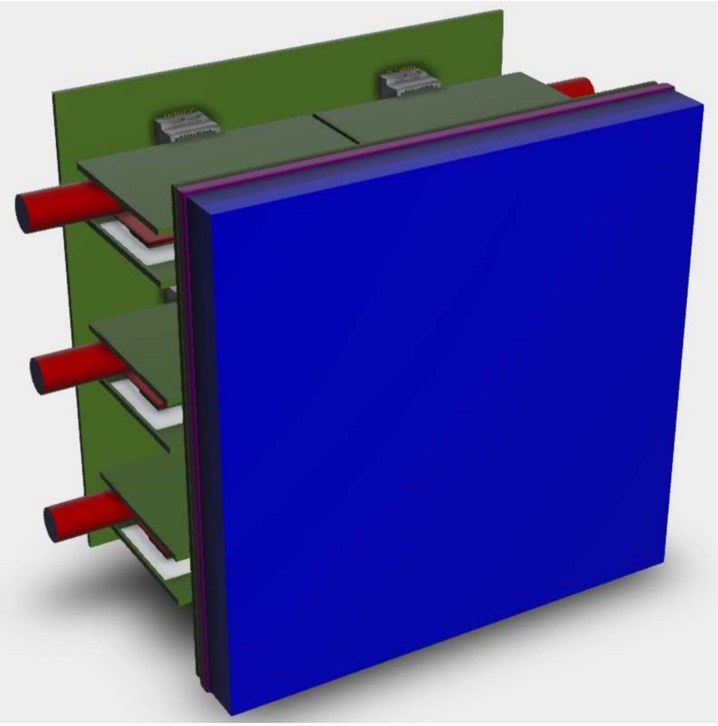
UDC evaluation board

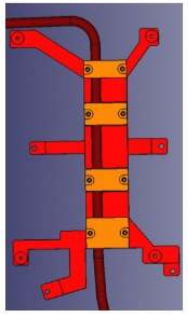


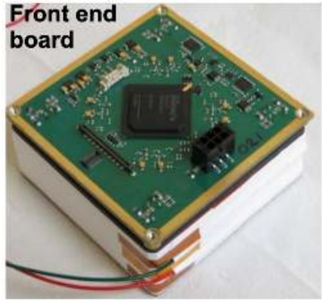
AARDVARC V3 evaluation board

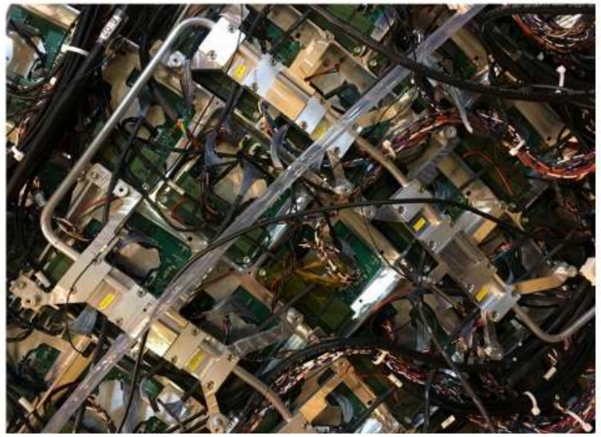
pfRICH readout electronics solution

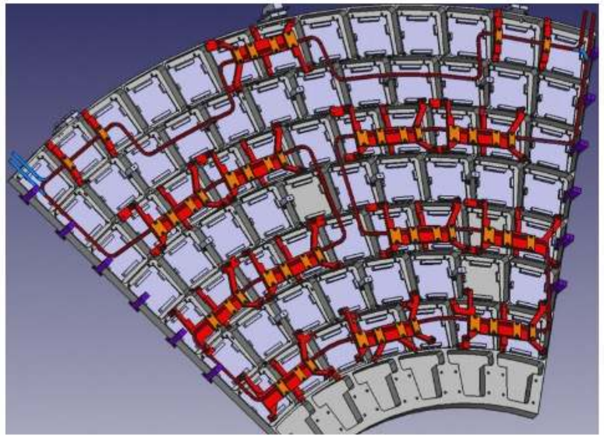












Belle II ARICH

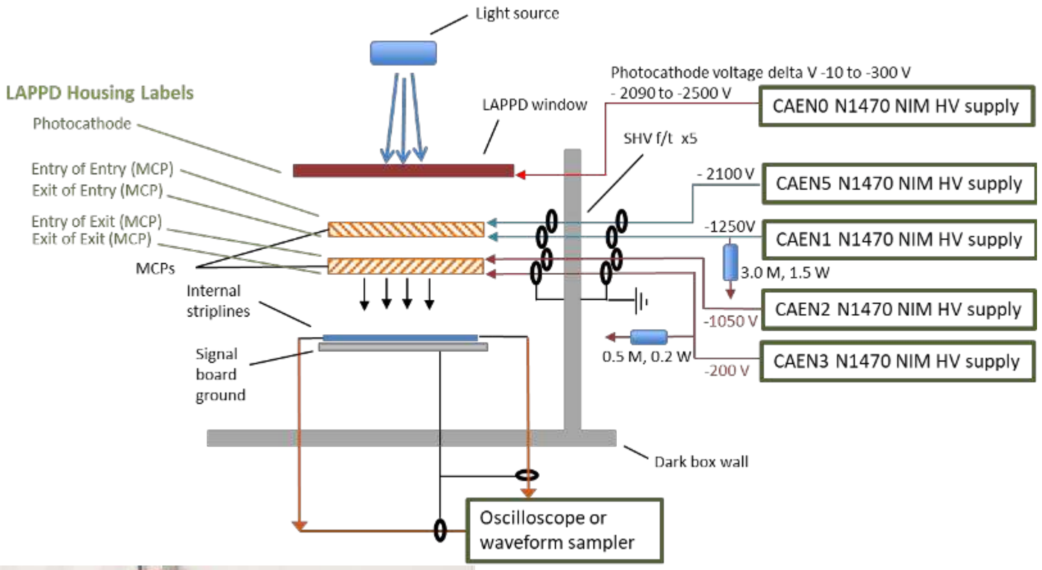
This suffices to estimate material budget, cooling needs and (most importantly) space remaining for the expansion volume

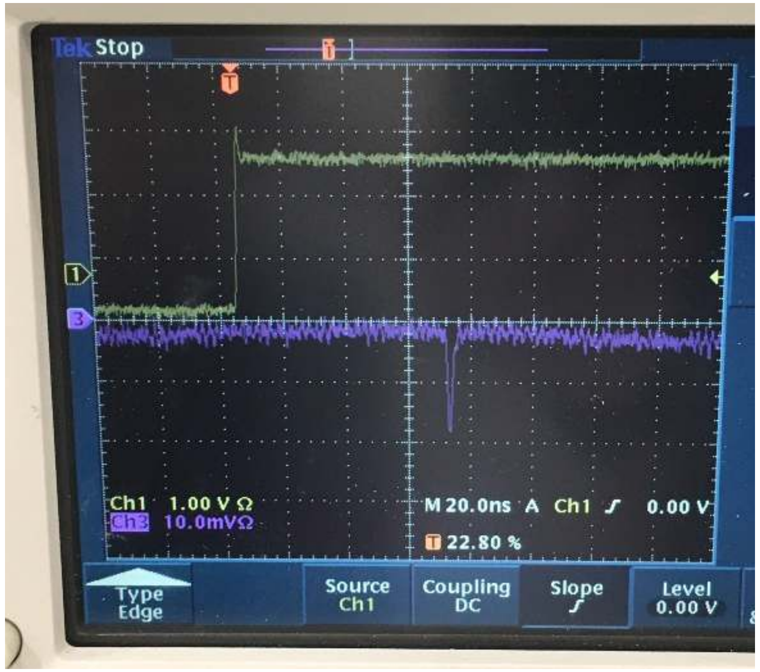
- Should fit into <10 cm space behind the LAPPD anode base plate
- Real estate conservatively assumes 16-channel UDC chips
- Cooling can seemingly be integrated in the same space

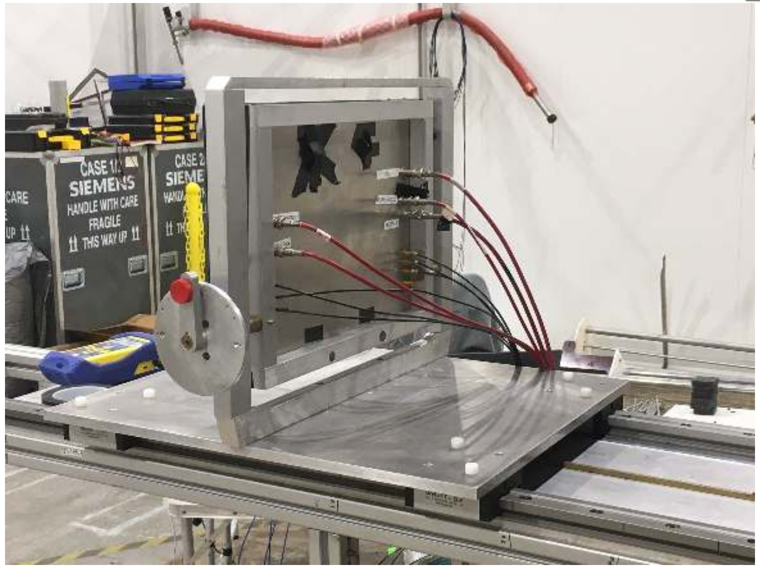
Or should one aim at a planar configuration a la Belle II from the start?

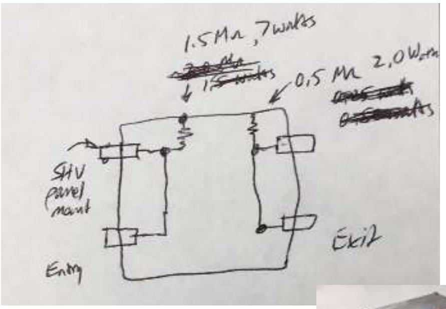
High Voltage and Signal Connections

- Three strips, both ends were brought out to a Caen DT5742 DRS_4 waveform sampler.
- Five high voltages were brought in.
    - Two separate MCP current circuits
    - Maximum current delivery
- Excellent pulse waveforms from the stripline LAPPDs.



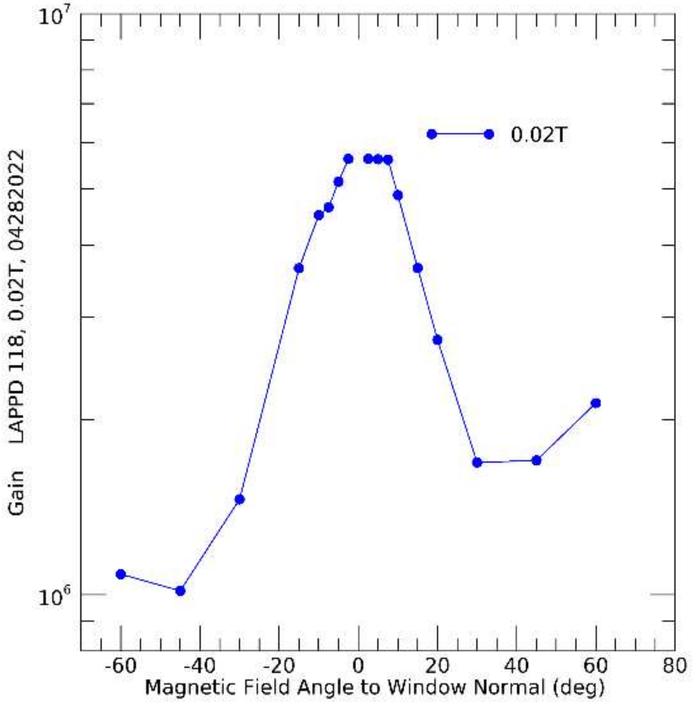




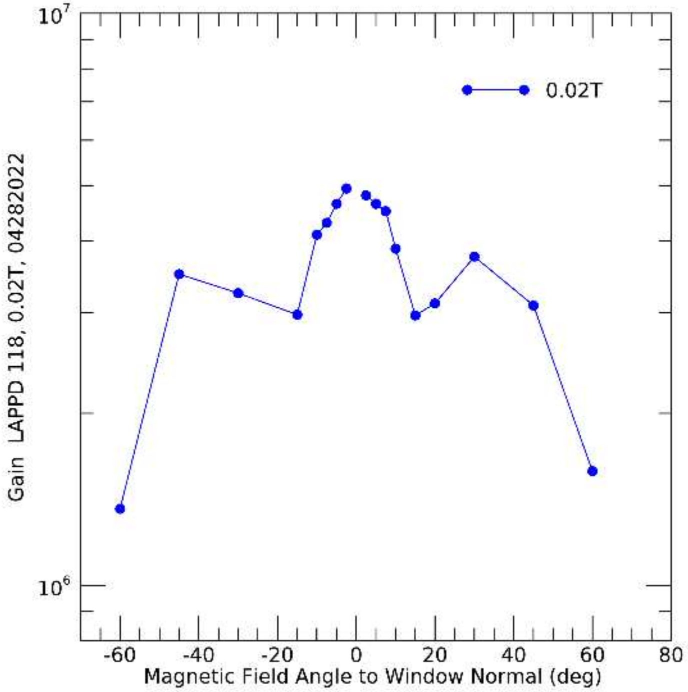


Gain vs. Rotation Angle: LAPPD 118

Middle strip only



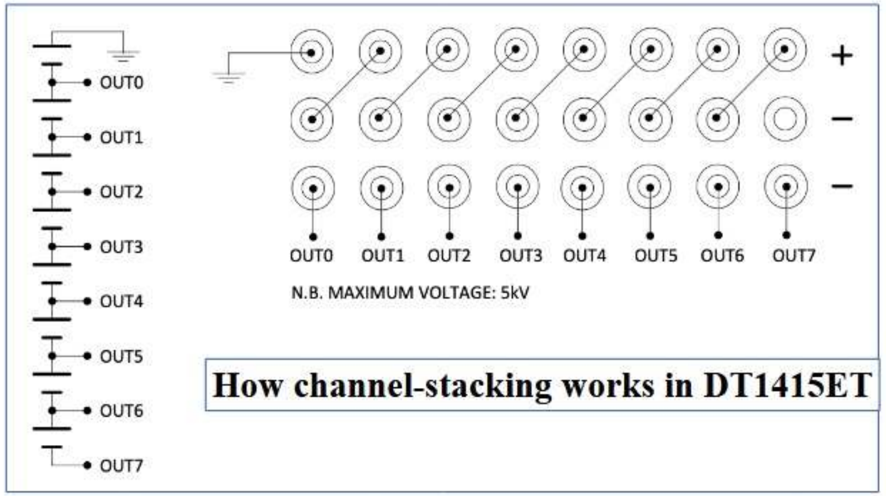
Three adjacent strips summed



- Gain decreases as the LAPPD is rotated
- B field is no longer parallel to photoelectron motion
- Signal electron cluster landing zone on the anode **moves** with relative B angles

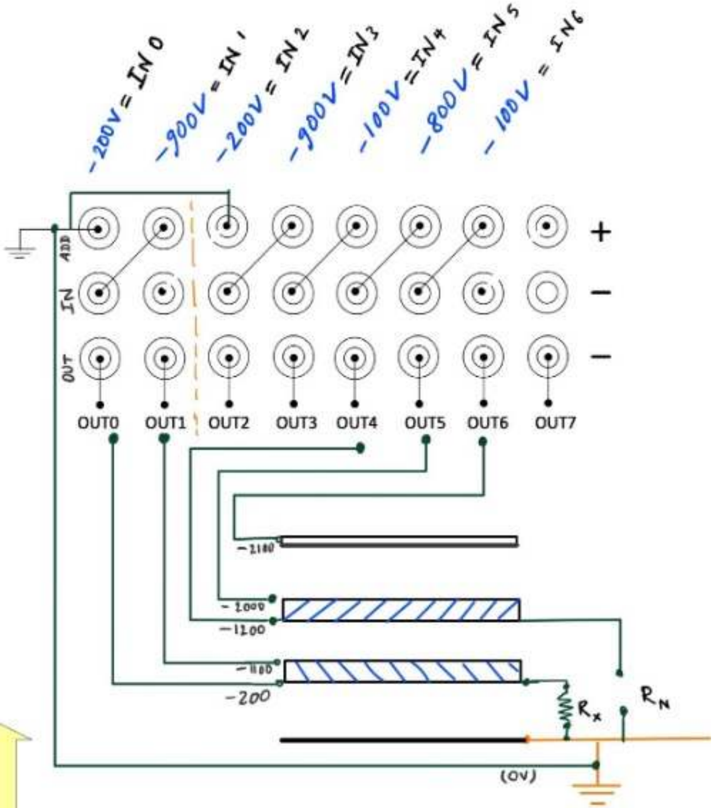
The main equipments:

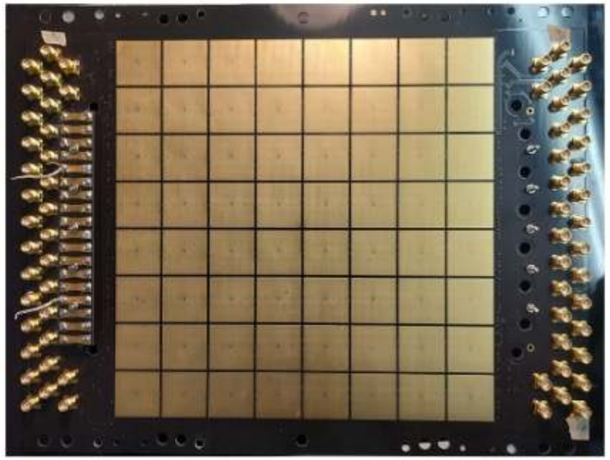
CAEN DT1415ET Floating HV supply



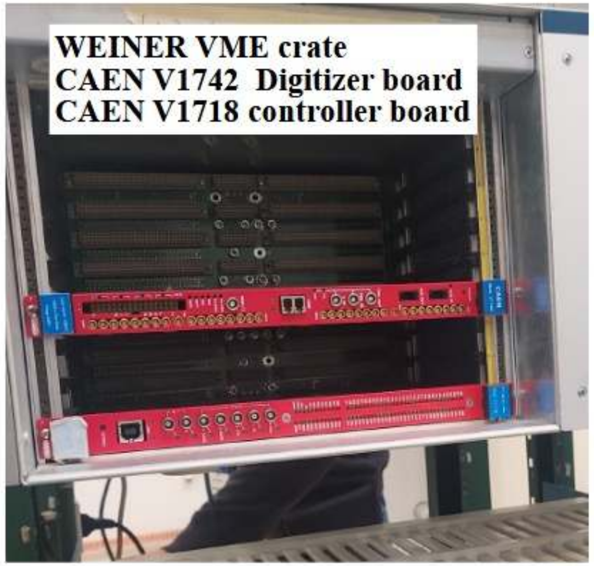
How channel-stacking works in DT1415ET

How we used it: An example set of voltages

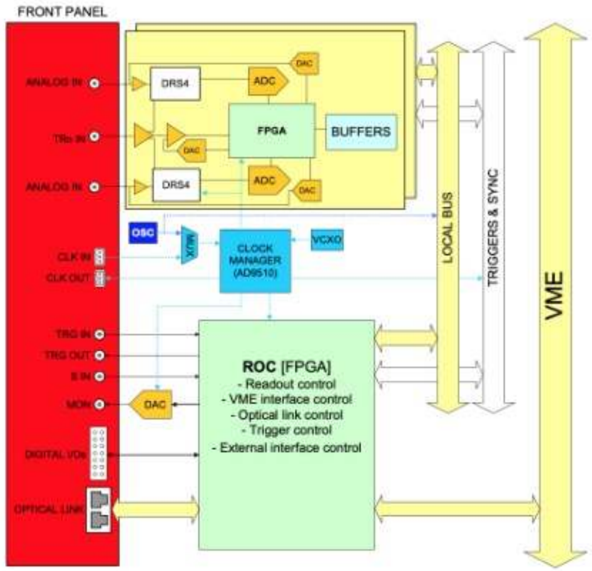




INCOM LAPPD #124
INCOM readout PCB



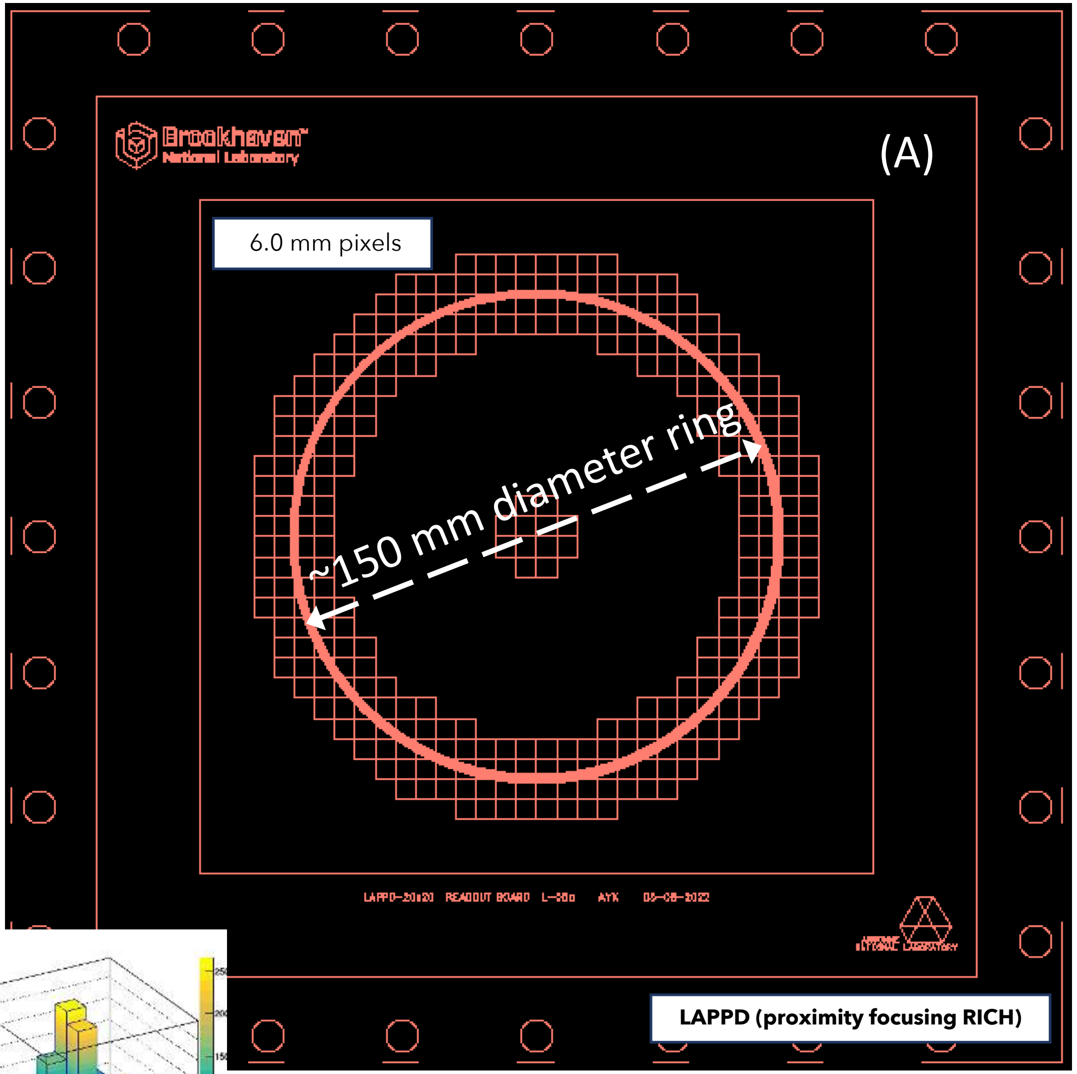
WEINER VME crate
CAEN V1742 Digitizer board
CAEN V1718 controller board

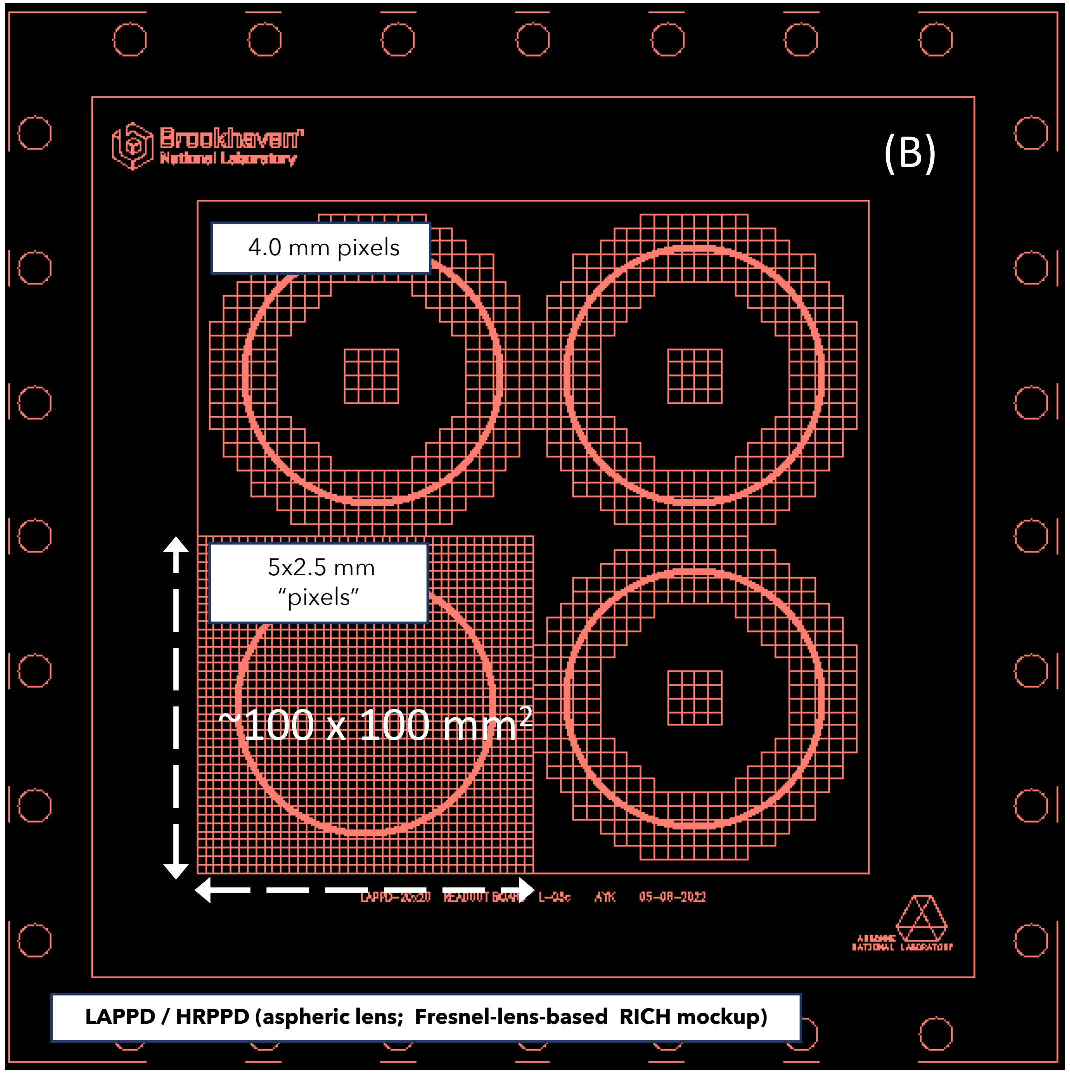


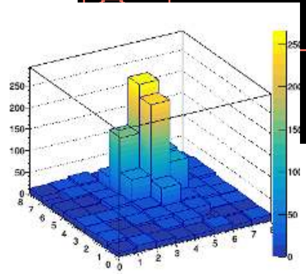
V1742 Board:

> 4 DRS chips
> 32 Analog channels
> 2 fast triggers (1 global trigger)
> each channel has 1024 SCA (Cells)
> one 12 bit ADC in each chip

New readout boards







6mm pixels

SiPM spare slides

SiPM radiation damage and mitigation strategies

Radiation damages increase currents, affects V_{bd} and increase DCR
With very high radiation loads can bring to baseline loss, but…
does not seem to be a problem up to 10^{11} n_{eq}/cm^2 (if cooled, T = -30 C)

If the baseline is healthy, single-photon signals can be be detected one can work on reducing the DCR with following mitigation strategies:

- Reduce operating temperatures (**cooling**)
- Use **timing**
- High-temperature **annealing** cycles

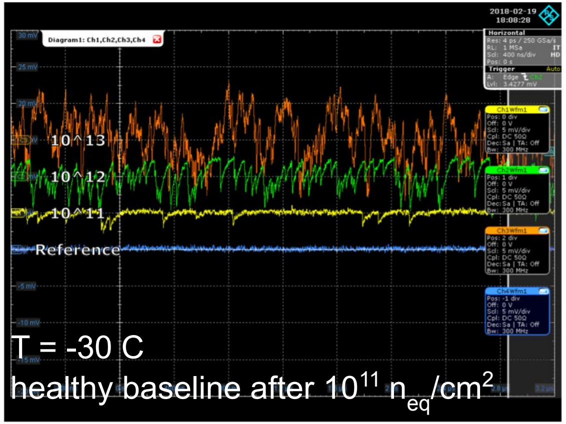
Key point for R&D on RICH optical readout with SiPM:

- demonstrate capability to measure Single Photon
- keep DCR under control (ring imaging background)

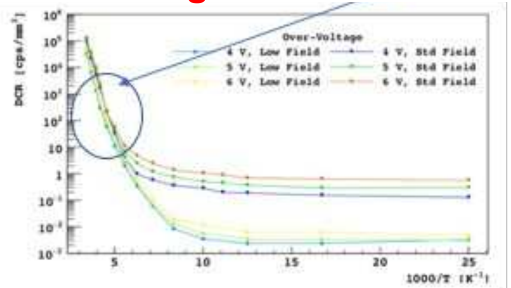
despite radiation damages

Calvi, NIM A 922 (2019) 243

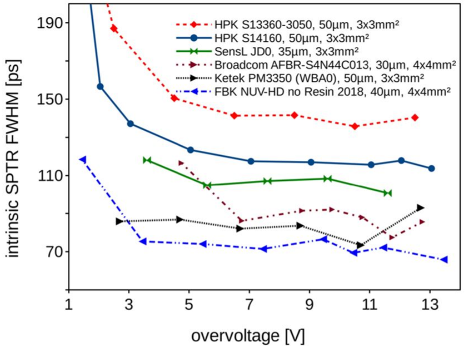
10^{11}

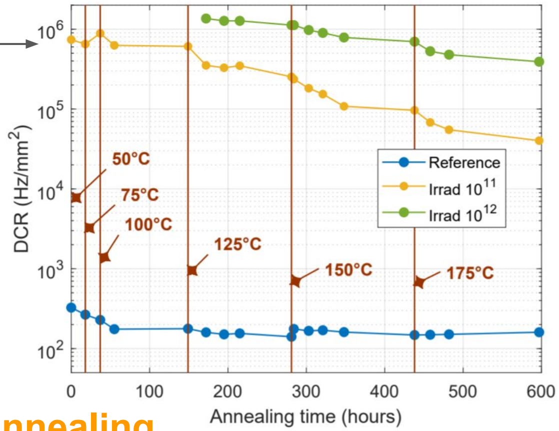


cooling



timing

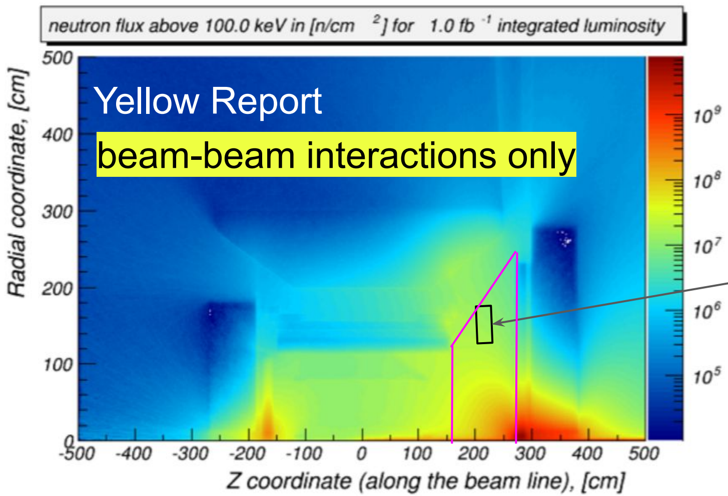


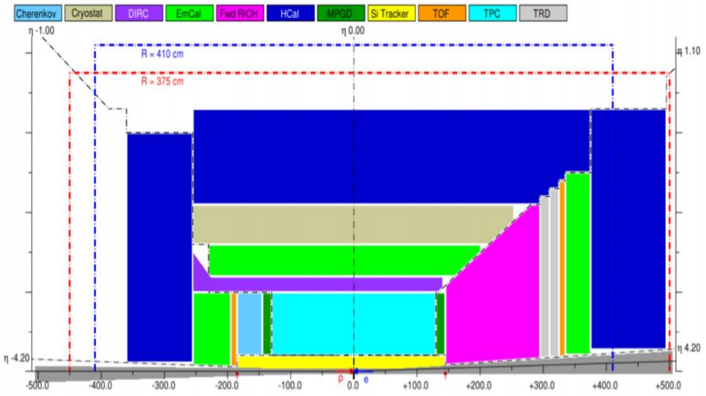


20x less DCR

annealing

Neutron fluxes and SiPM radiation damage





> Most of the key physics topics discussed in the EIC White Paper [2] are achievable with an integrated luminosity of 10 fb^{-1} corresponding to 30 weeks of operations. One notable exception is studying the spatial distributions of quarks and gluons in the proton with polarized beams. These measurements require an integrated luminosity of up to 100 fb^{-1} and would therefore benefit from an increased luminosity of $10^{34} cm^{-2} sec^{-1}$.

possible location of dRICH photosensors
neutron fluence for 1 fb^{-1} → 1-5 10^7 n/cm^2 (> 100 keV ~ 1 MeV n_{eq})

- radiation level is moderate
- magnetic field is high(ish)

R&D on SiPM as potential photodetector for dRICH, main goal
study SiPM usability for Cherenkov up to 10^{11} 1-MeV n_{eq}/cm^2

notice that 10^{11} n_{eq}/cm^2 would correspond to 2000-10000 fb^{-1} integrated $\mathcal{L}$
quite a long time of EIC running before we reach there, if ever
it would be between 6-30 years of continuous running at $\mathcal{L} = 10^{34}\ s^{-1}\ cm^{-2}$

→ better do study in smaller steps of radiation load

10^9 1-MeV n_{eq}/cm^2	*most of the key physics topics*
10^{10} 1-MeV n_{eq}/cm^2	*should cover most demanding measurements*
10^{11} 1-MeV n_{eq}/cm^2	*possibly never reached*

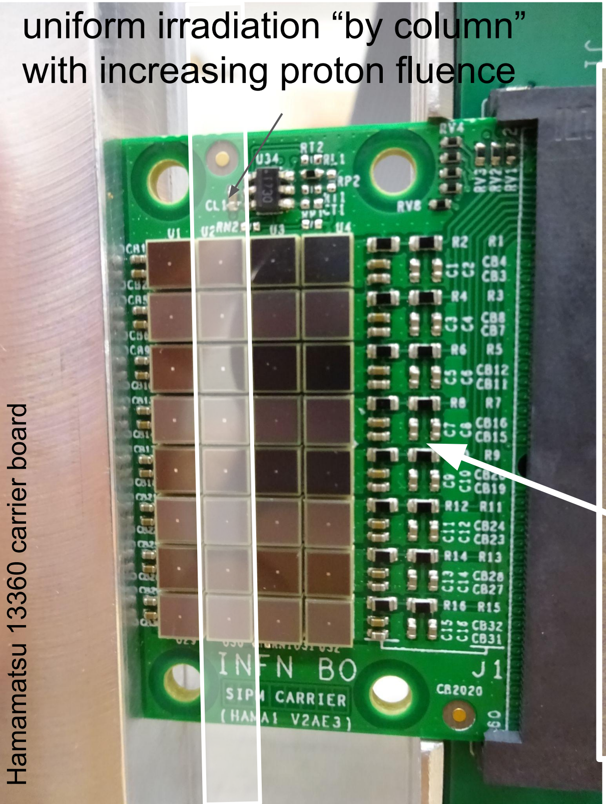
Irradiation at Trento Proton-Therapy hall (TIFPA)

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

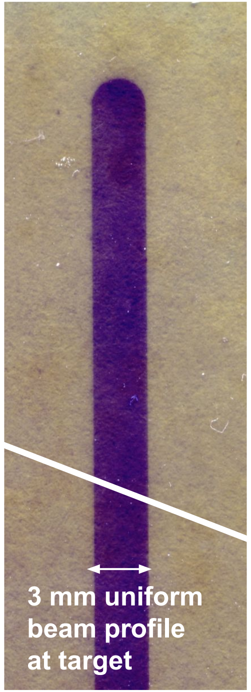
multiple types of SiPM: **Hamamatsu** commercial (13360 and 14160)
FBK prototypes (rad.hard and timing optimised)

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

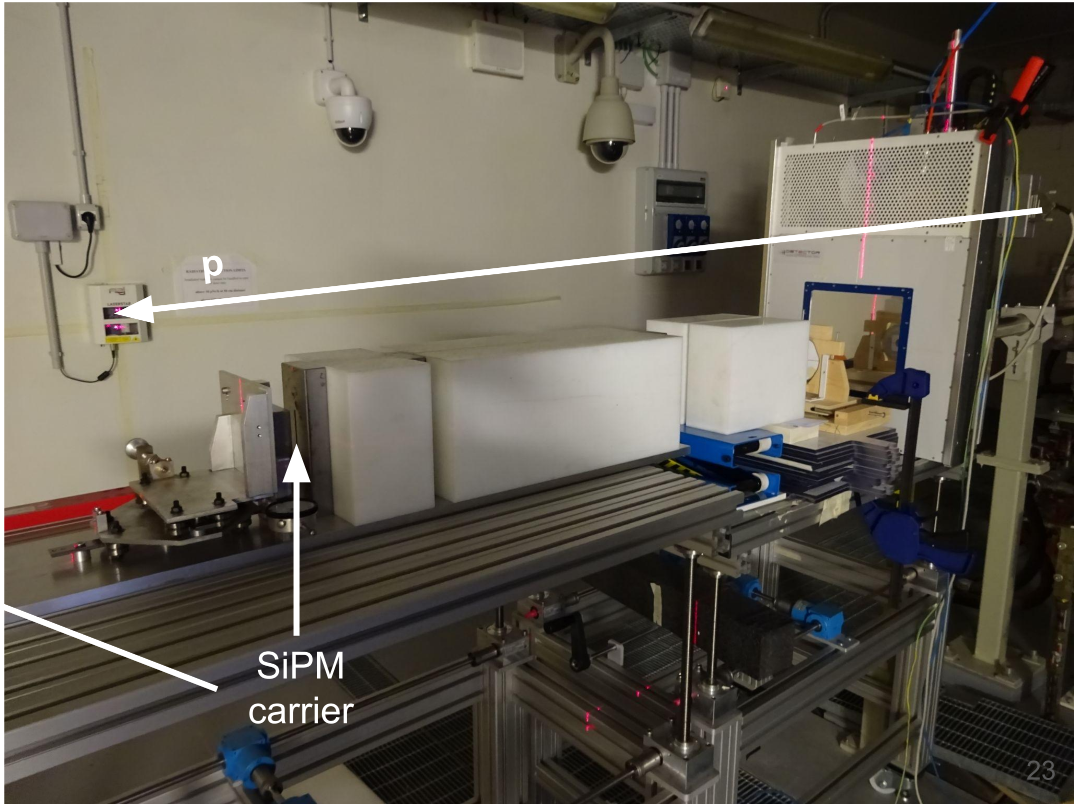
uniform irradiation “by column”
with increasing proton fluence



Hamamatsu 13360 carrier board



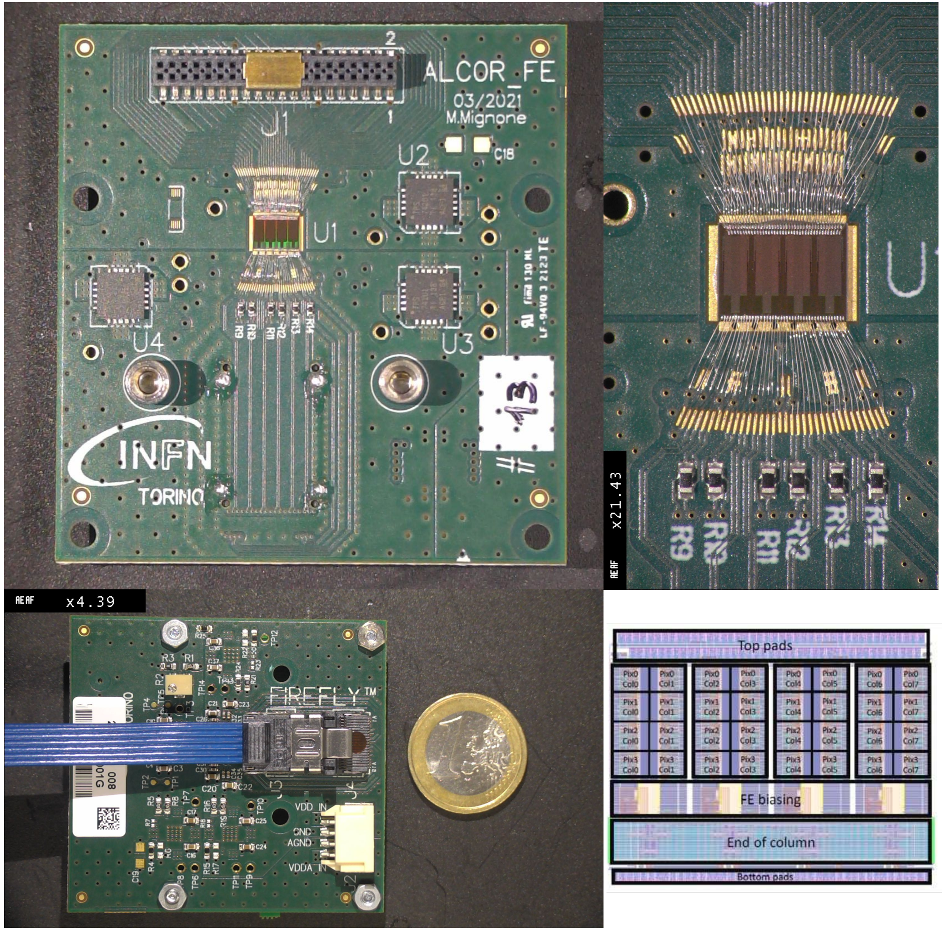
3 mm uniform beam profile at target

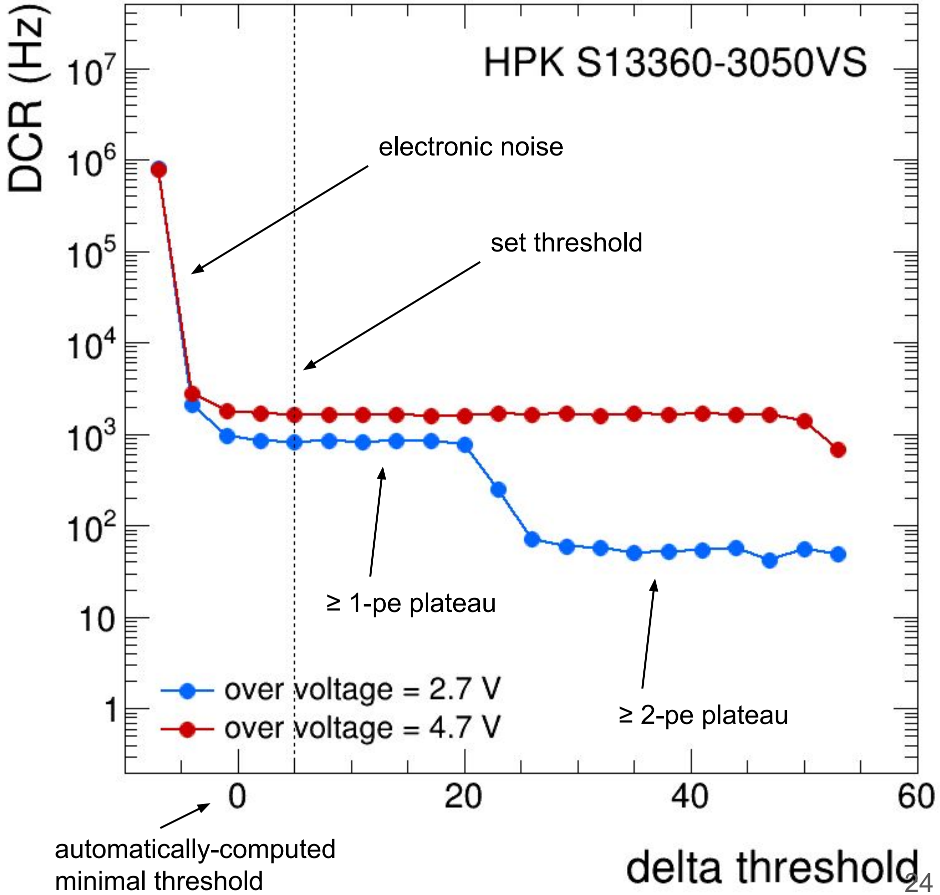


SiPM carrier

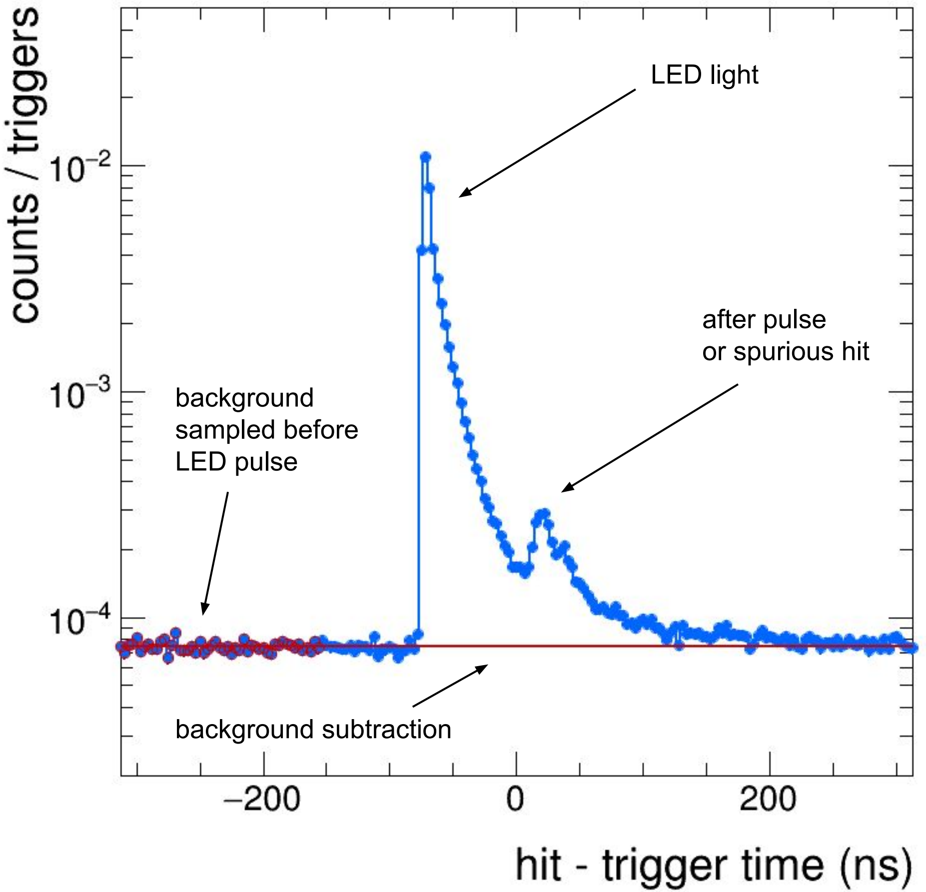
Photon counting with ALCOR

eRD 109

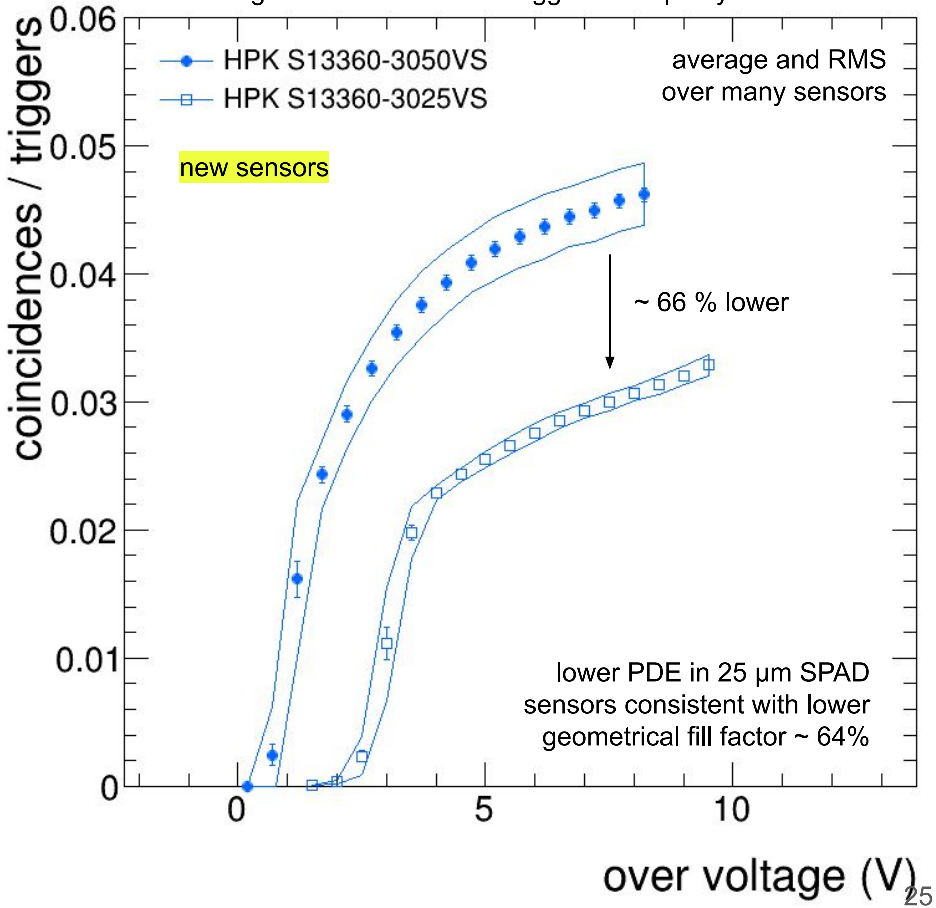




Light response with pulsed LED



integrated coincidences / triggers as a proxy for PDE



Light response after irradiation and annealing