HRPPD as a photosensor of the EIC Cherenkov Particle Identification Detectors

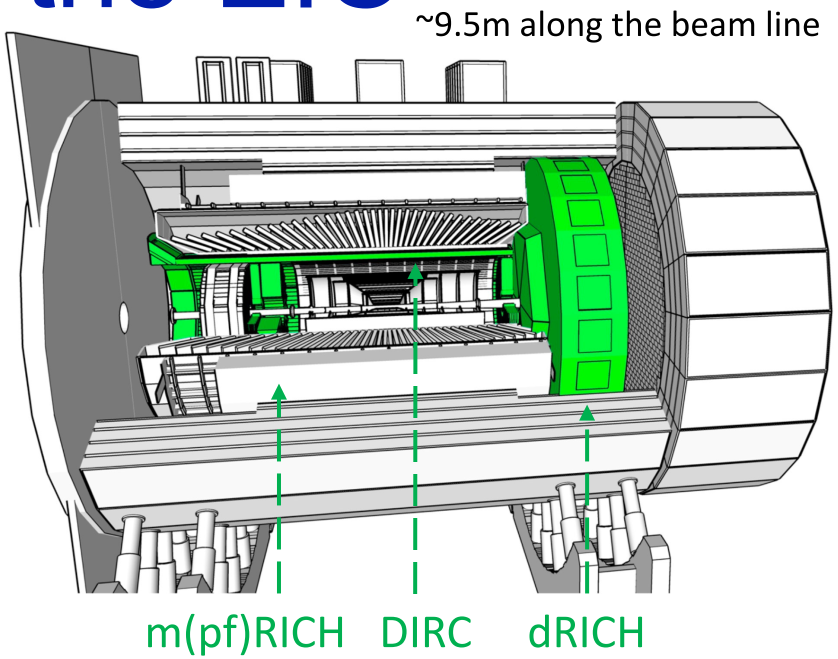
Alexander Kiselev (BNL)

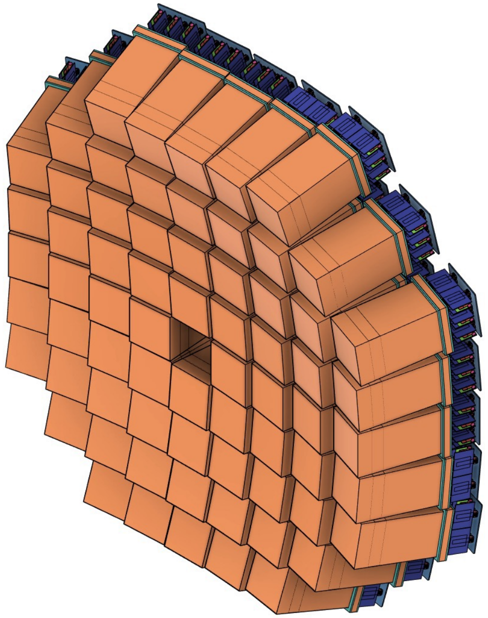
EIC leadership meeting with Incom Inc., Charlton MA, January 12, 2023

Possible LAPPD applications for the EIC

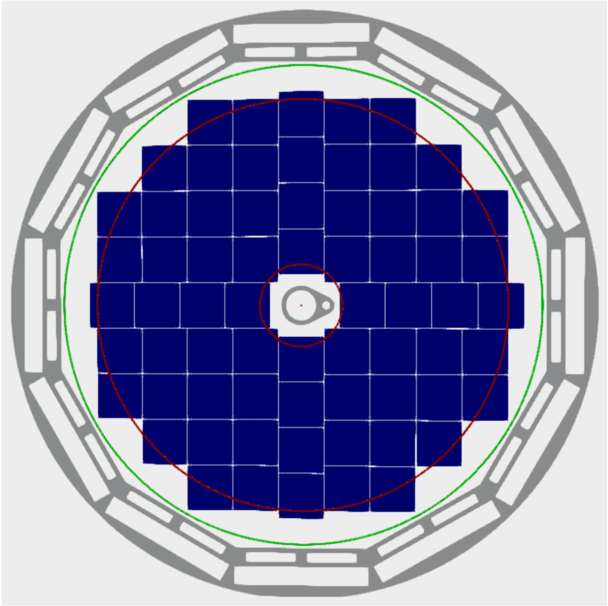
- mRICH / pfRICH: low dark noise, ToF capability (vs SiPMs)
- DIRC: expected to be more cost-efficient (vs other MCP-PMTs)
- dRICH: problematic, because of the magnetic field orientation

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

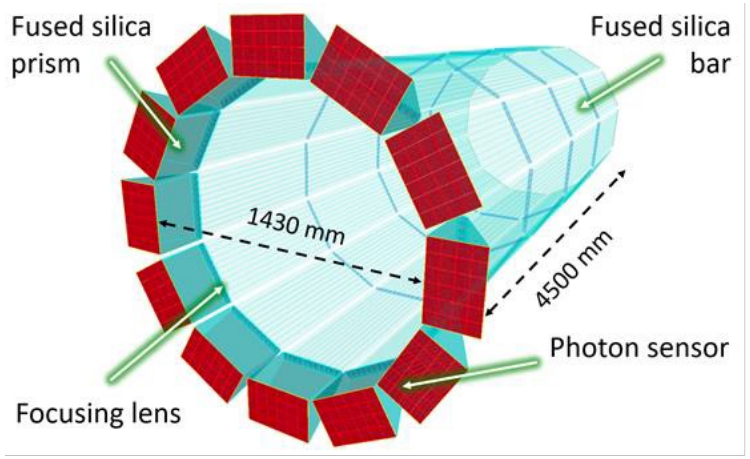




mRICH: 68 HRPPDs total



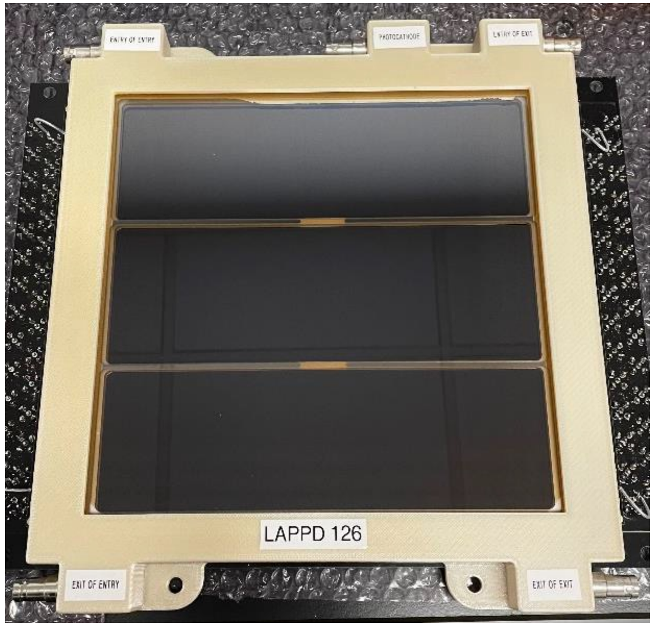
pfRICH sensor plane: 68 HRPPDs total



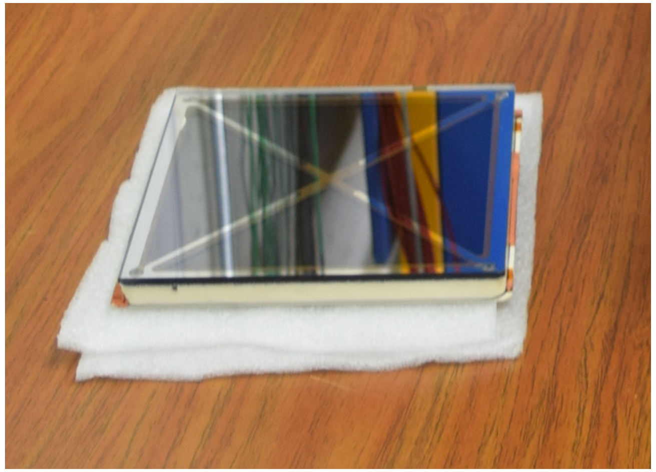
DIRC: 12*3*2 = 72 HRPPDs total

EIC requirement highlights

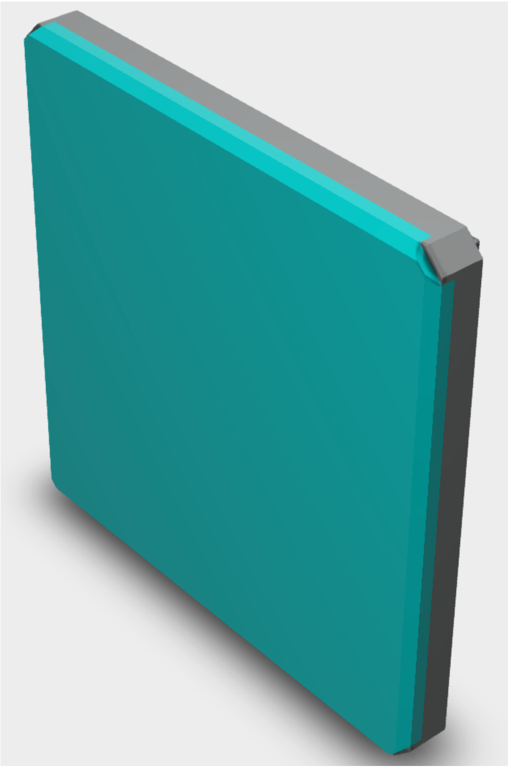
Formfactor & geometric acceptance

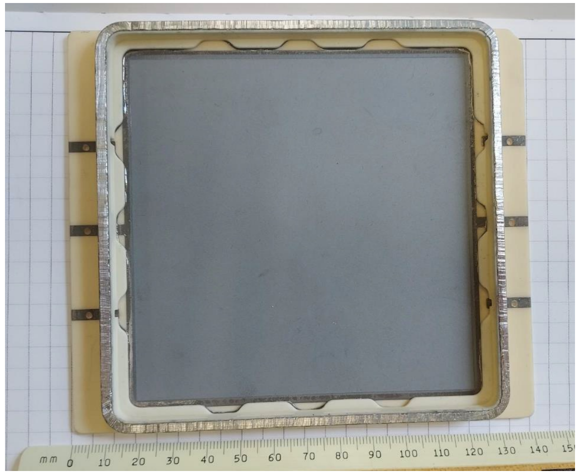


Capacitively coupled 20cm LAPPD



DC-coupled 10cm HRPPD

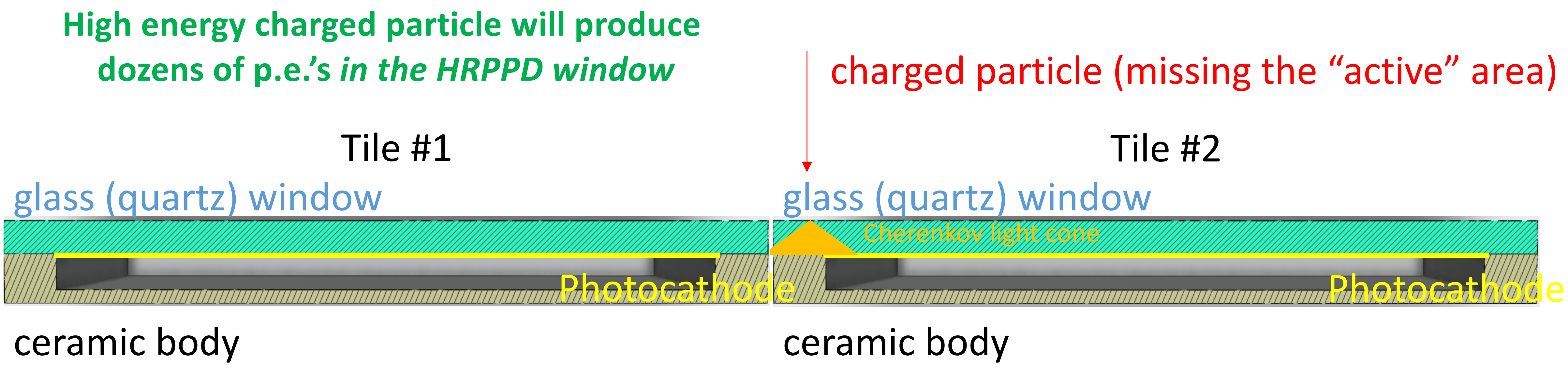




Capacitively coupled 10cm HRPPD

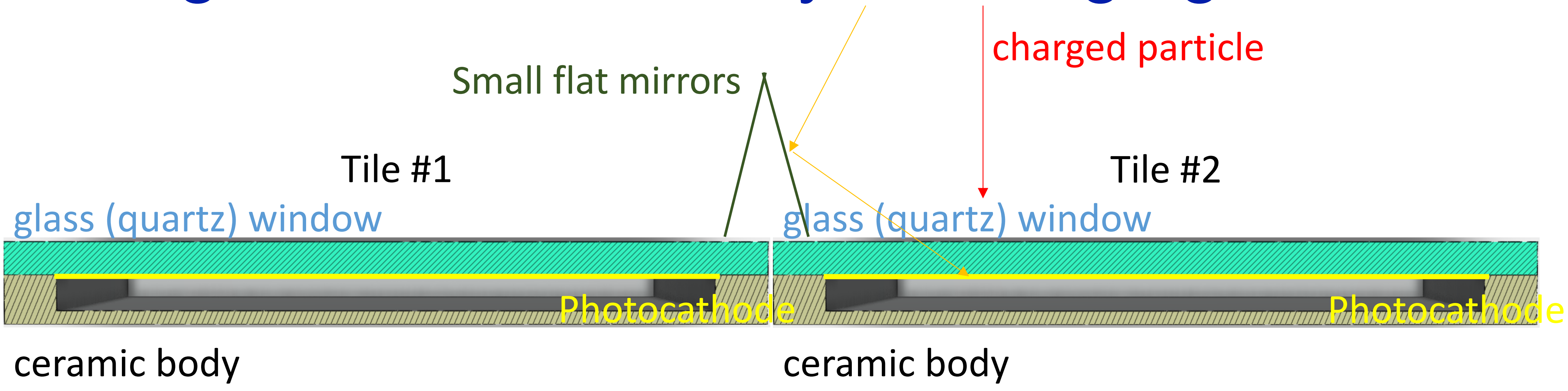
- None of them was initially designed for high geometric acceptance efficiency
- Need to fix this for EIC:
  - Wall area width minimized
  - HV connections on the rear side
  - Tileability without gaps

OAR: geometric efficiency for a t_0 reference



- 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 and / or tapered and / 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

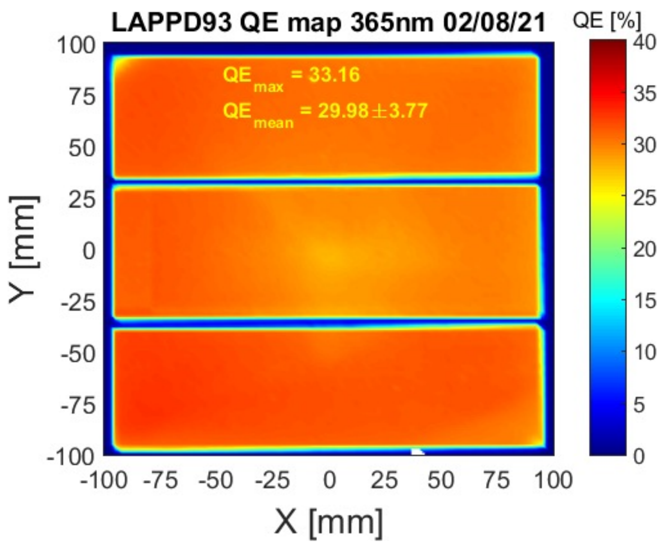
OAR: geometric efficiency for imaging



- *If really needed*, one should be able to "save" the Cherenkov photons, which would otherwise miss the photocathode, by funneling them away from the sensor dead area

-> 80% active area (108mm x 108mm in a 120mm x 120mm footprint) suffices

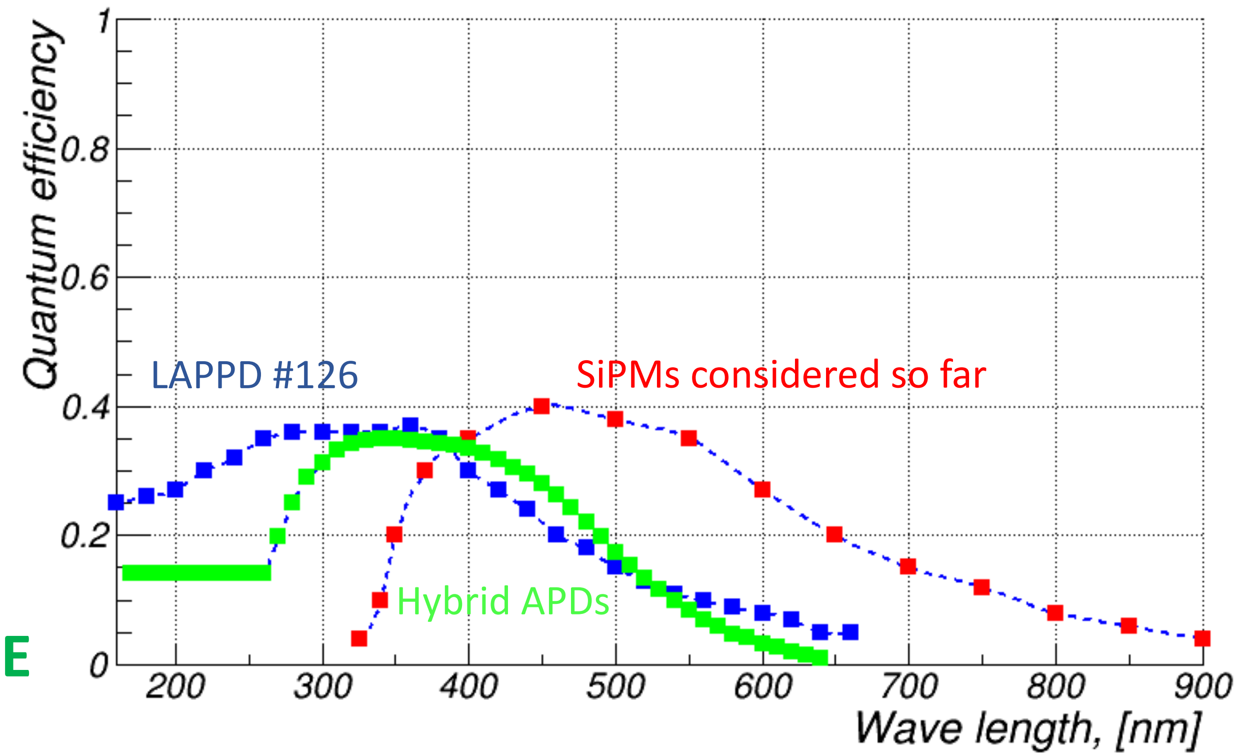
Quantum Efficiency & PDE



- Essentially, the QE shift to ~450nm would only be required for the mRICH, which natively filters out the UV light because of the Fresnel lens

- This proposed SBIR would bring LAPPD PC QE to 30% at 450 nm
  - At best PDE=QE
  - Measure this value
- Steps to improve LAPPD PDE
  - Higher QE
  - Funnel-shaped MCP Pores
  - Electron Steering

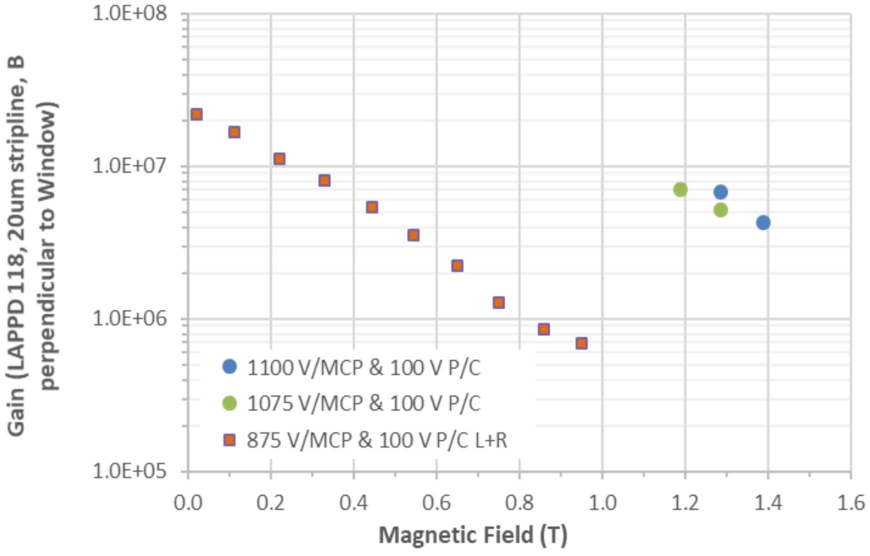
- Consider simplifying the strategy in case of a pfRICH:
  - Abandon the <350nm UV filter
  - Use ultra-transparent aerogel and stick to the near UV wavelength range



-> focus on maximizing the overall HRPPD PDE and the uniformity over the active area

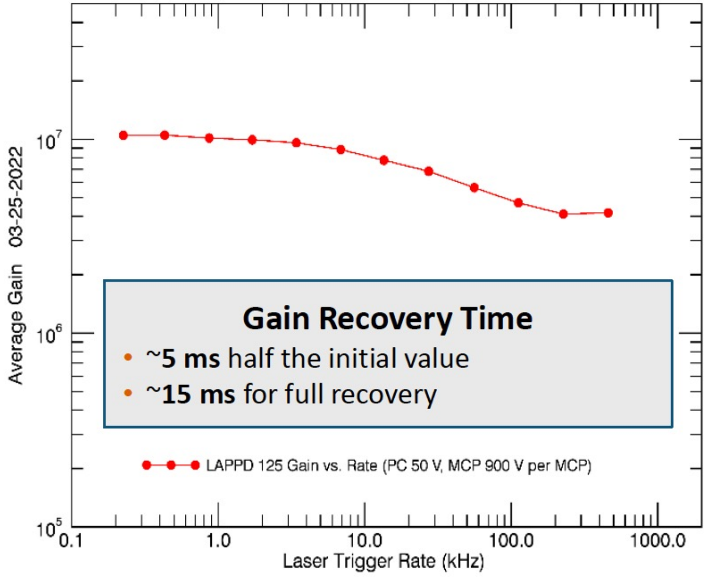
Operating voltage settings

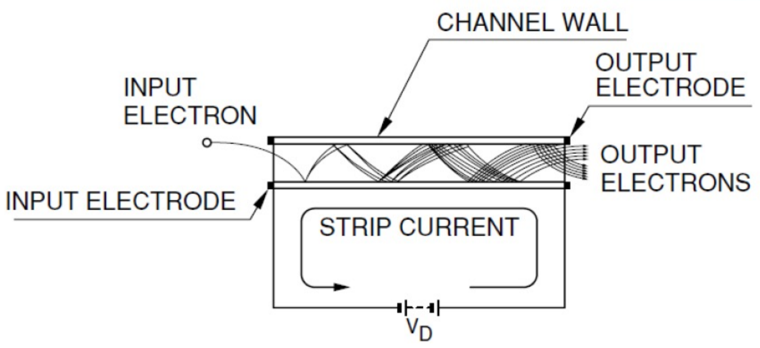
- We prefer safe operating mode as a default
  - moderate gain ~10^6 + configurable preamplification
- Reasoning:
  - Have enough headroom for tuning (in the magnetic field)
  - Increase lifetime (surprisingly enough, in mRICH / pfRICH we may reach ~C/cm^2 in the area close to beam pipe) if run with ~10^7 gain
  - Minimize dark count rates



-> Gain recovery time issue needs to be addressed!

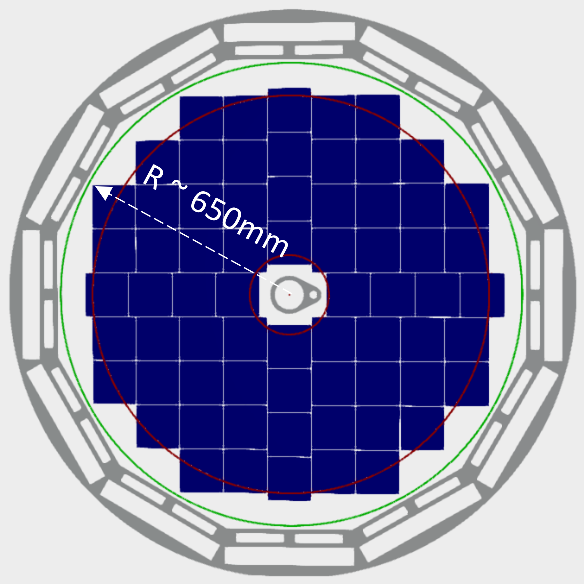
- MCP stacking may be not a bad idea in this scenario
- Radiation hardness needs to be confirmed



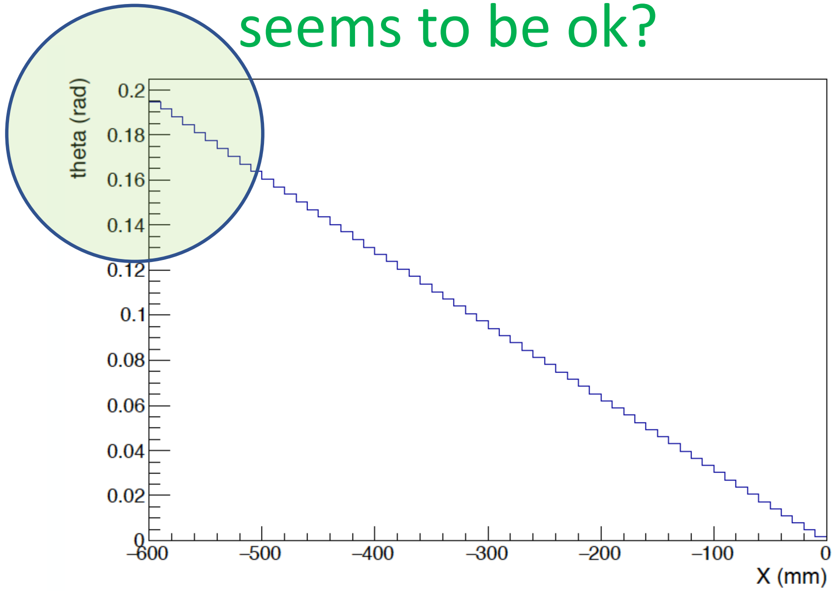


$$\tau_{dead} = \frac{Q_{out}}{I_{strip}}$$

Magnetic field @ m(pf)RICH HRPPD location



seems to be ok?



pfRICH: field-to-sensor-normal angle

- Oba et al., 1981

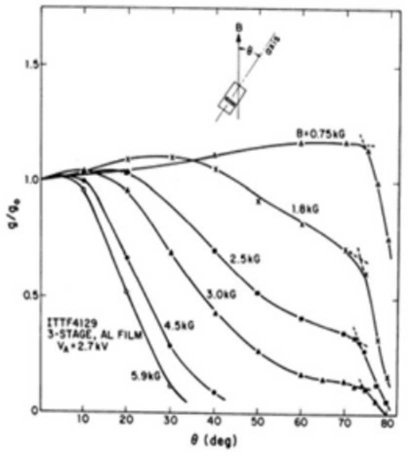


Fig. 11. Dependency of the output degradation in F4129 on the off-axis magnetic field.

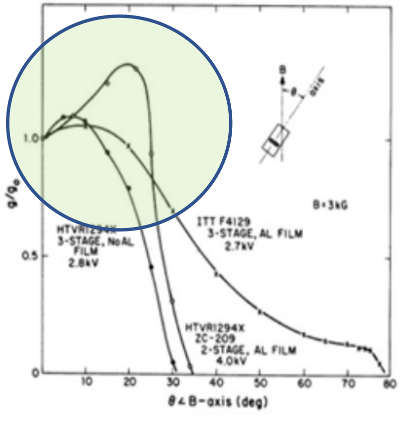
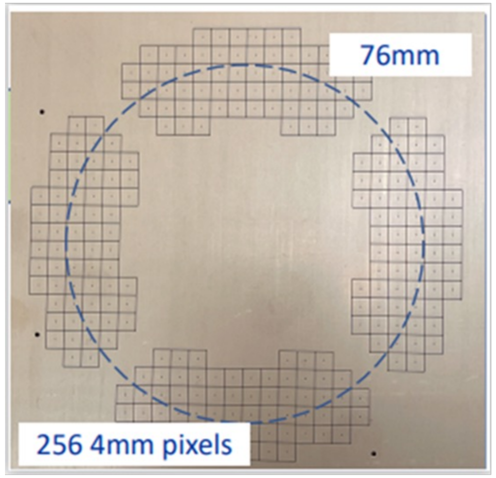


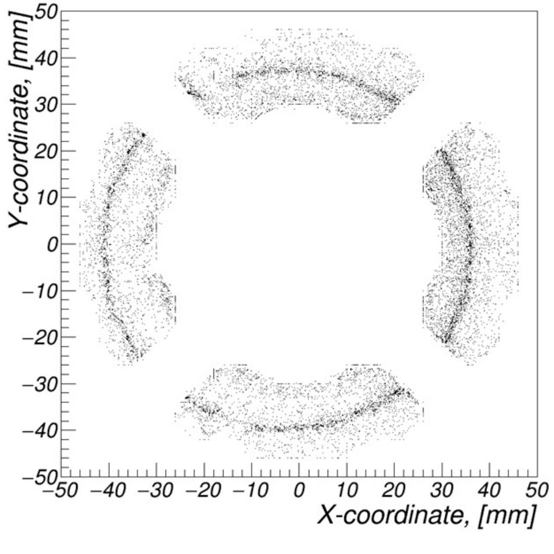
Fig. 10. Output degradation in three MCP-PMTs in the off-axis field.

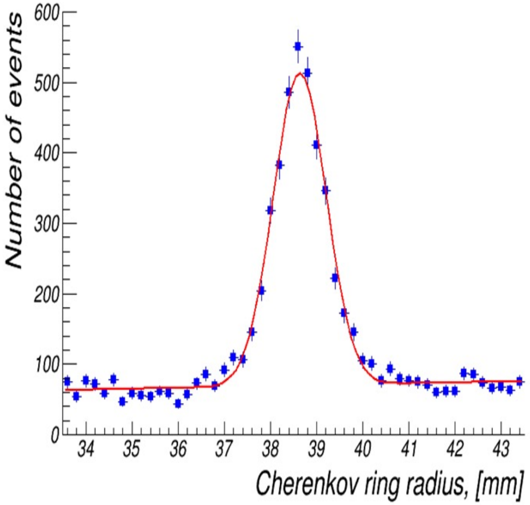
- Extreme point at R_{max} ~ 650mm will be at ~1.7T and ~10^0 to normal for either pfRICH (flat sensor plane) or mRICH (projective geometry)
- DIRC seems to be safe

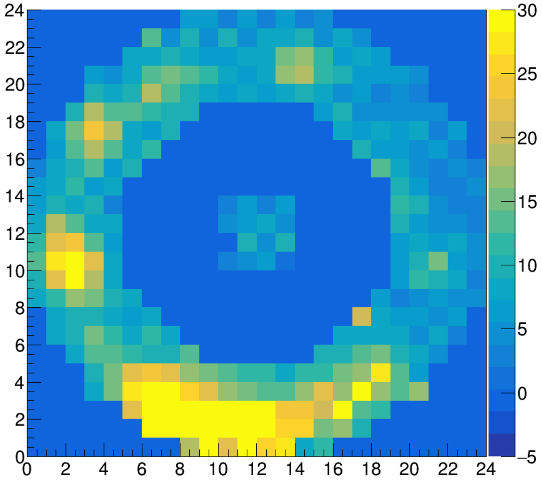
-> Direct measurements at Argonne and / or CERN should be performed

Pixellation, spatial resolution, charge sharing





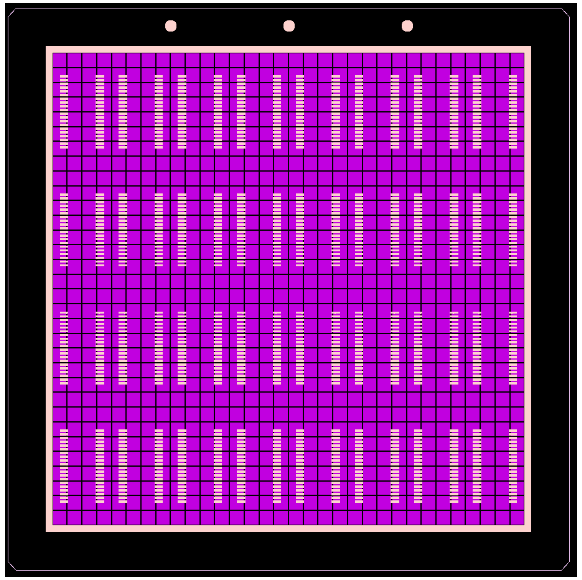




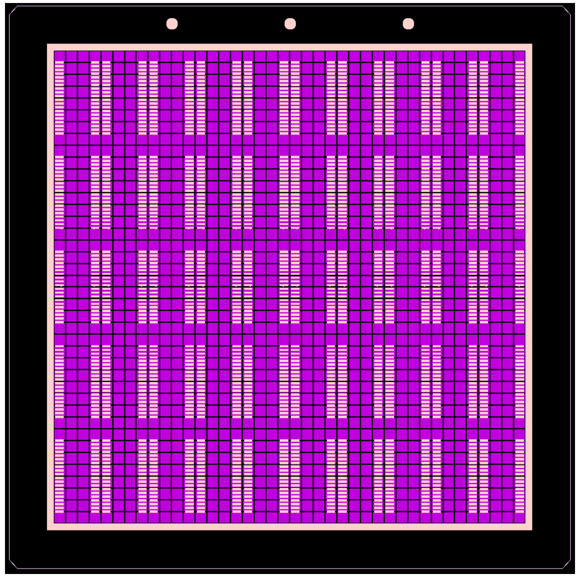
- m(pf)RICH: Capacitively coupled LAPPDs with 4 mm pixellation are good enough to achieve single photon ring radius resolution ~600 μm (beam test data), even without signal pre-amplification
- DIRC: DC-coupled HRPPD with minimal charge sharing and 3mm pixels would suffice

-> We will make an effort to converge to a single (DC-coupled) HRPPD design

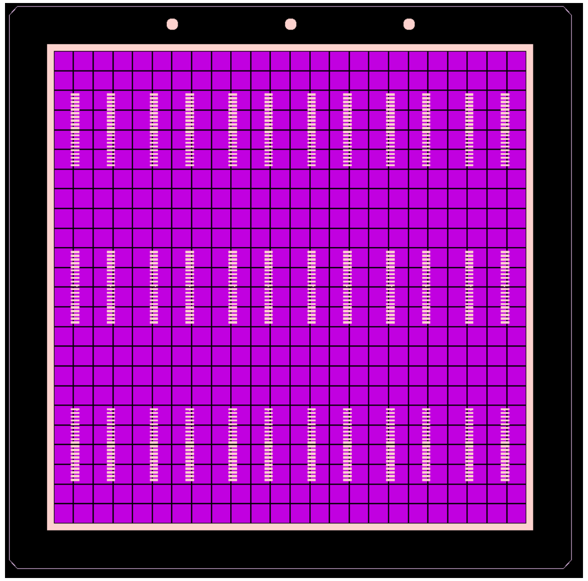
Pixellation for m(pf)RICH and DIRC



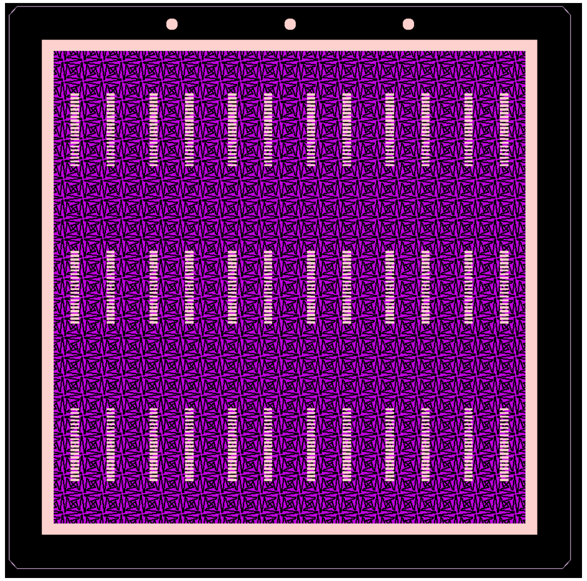
32 x 32 square pads (present layout)



40 x 40 square pads (DIRC)



24 x 24 square pads (pfRICH)



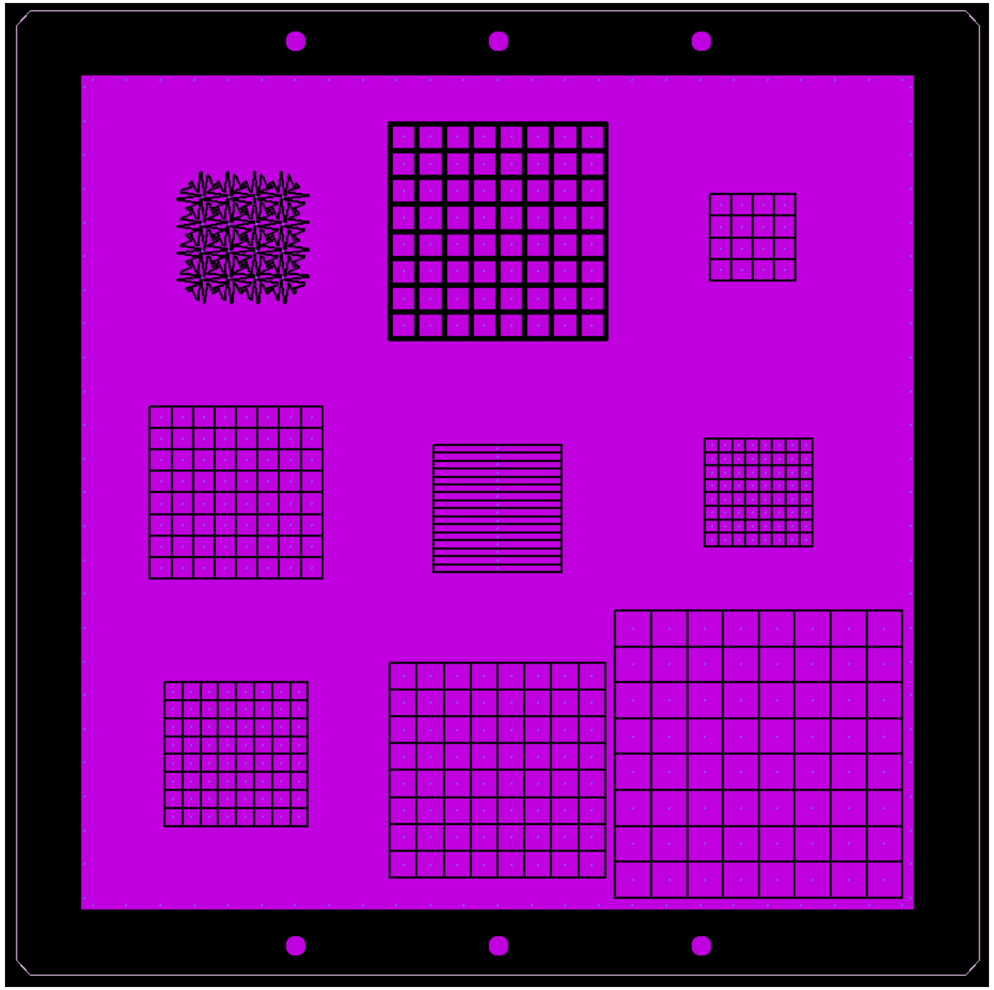
24 x 24 charge sharing pads (pfRICH)

- Polish ceramic manufacturer (Techtra) can produce such layouts in house
- First iteration will be a test bench HRPPD tile with a mixed layout, to test them all at once
  - Tooling and fabrication will take 2-3 months

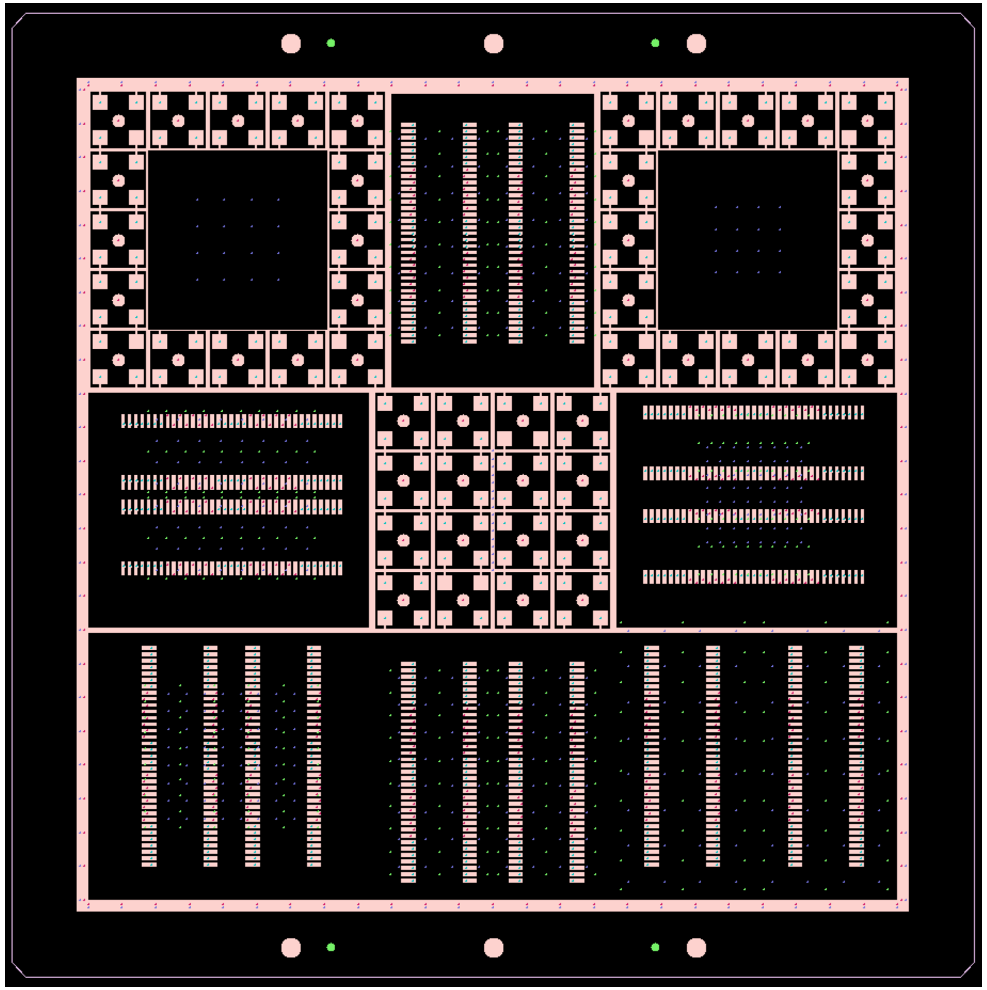
-> The hope is that pixellation will be the only difference between m(pf)RICH & DIRC HRPPDs

Pixellation test bench for m(pf)RICH and DIRC

pad (inner) size

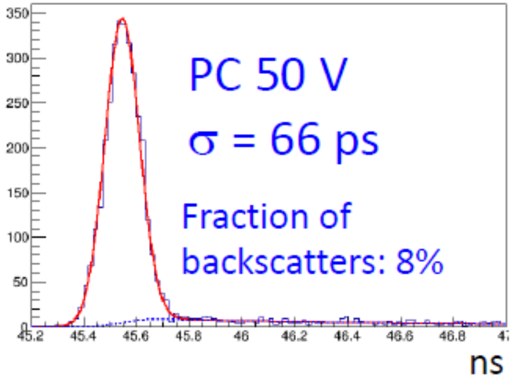


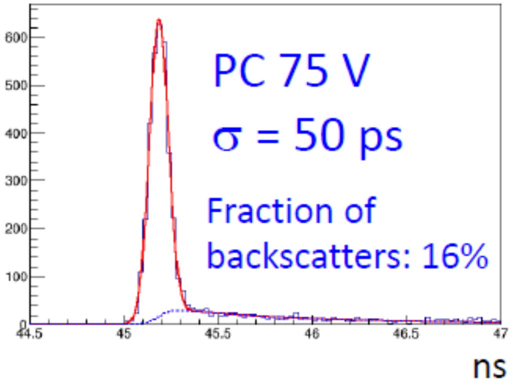
connector (outer) side

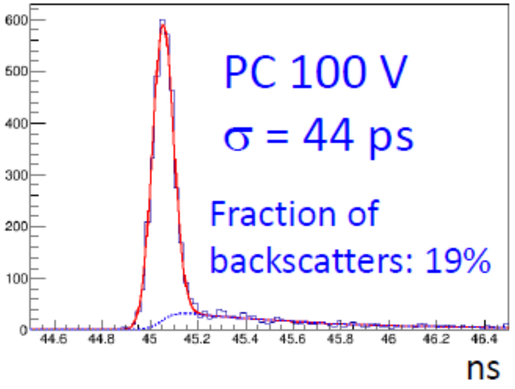


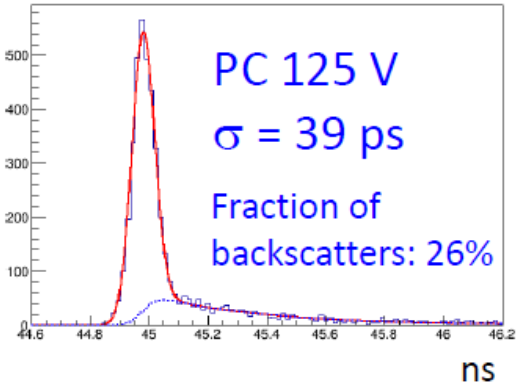
- Will use existing side walls / windows; pad size tuned to the new active area size of 108 mm
  - Pixellation patterns 24x24, 32x32, 40x40, 48x48, 64x64 + 1D charge cloud profiling field

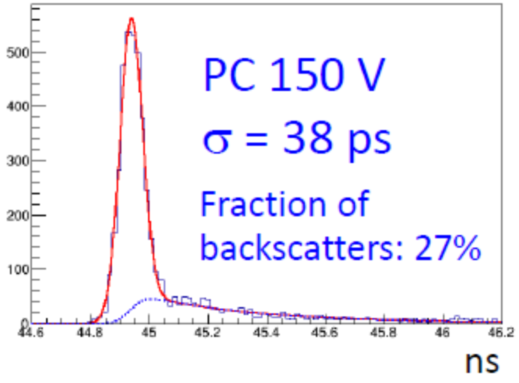
Single photon timing resolution

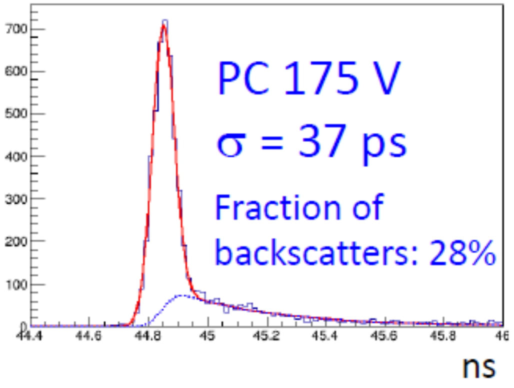


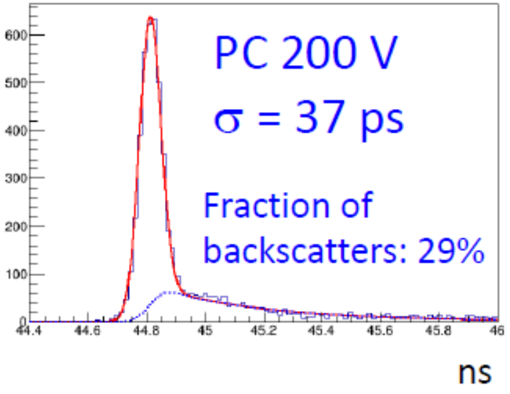












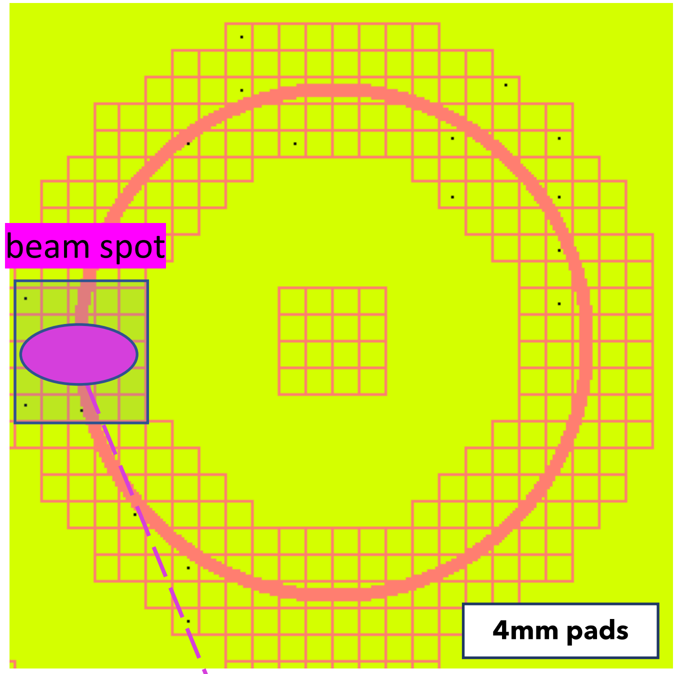
Data: V. Vagnoni (INFN Bologna)

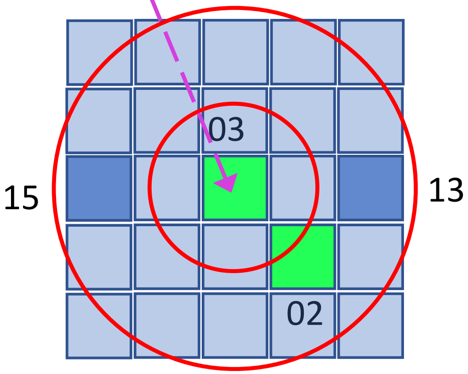
- DIRC will likely require moderate resolution, but small tails
- m(pf)RICH will likely benefit from the best possible resolution, and deal with the tails in data analysis

Recent activities

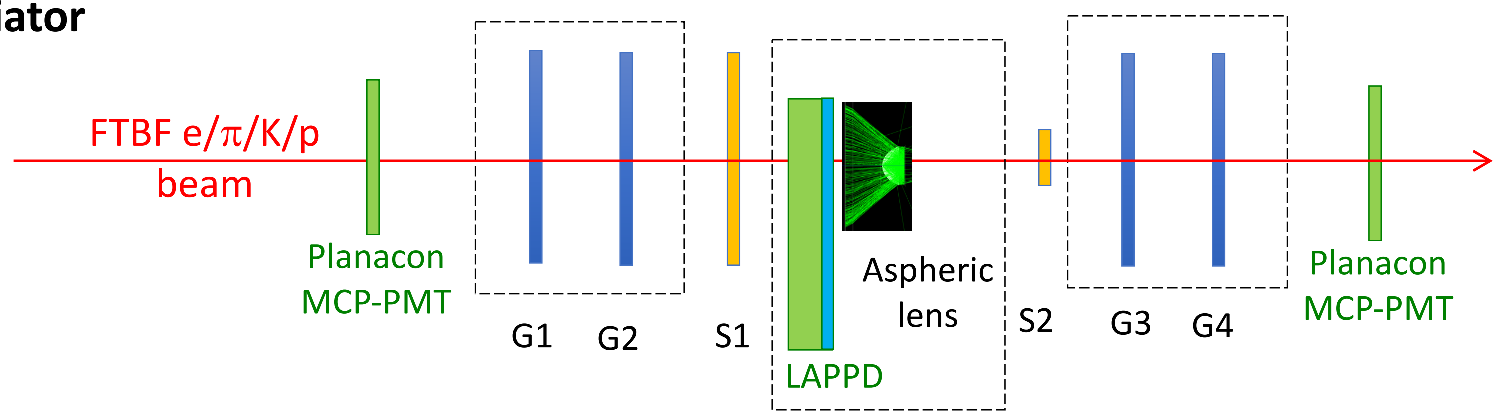
Beam test at Fermilab, June 2022

LAPPD quartz window as a Cherenkov radiator

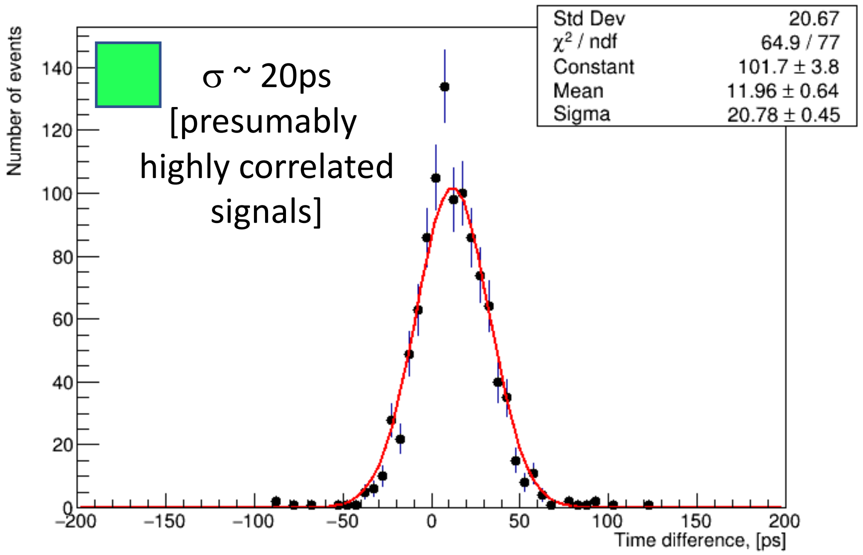




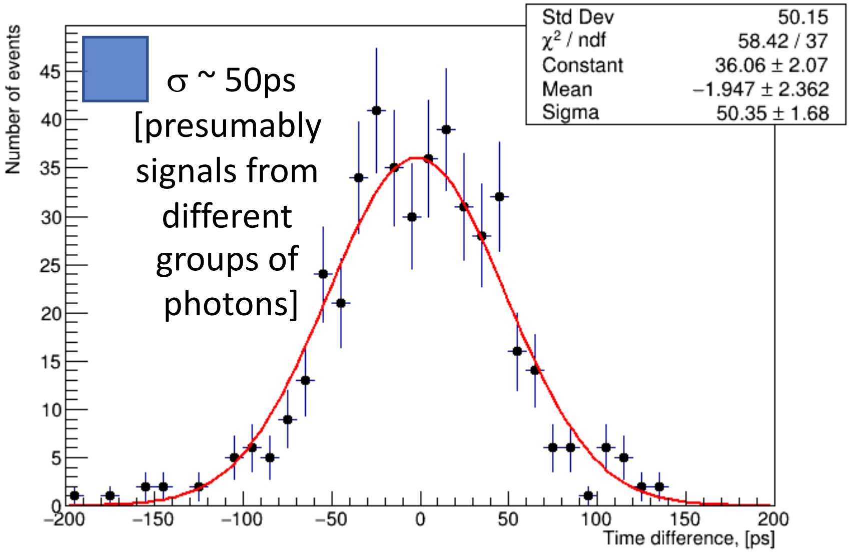
Due to the TIR, photons only hit the PC in a radial band ~[5.5 .. 12.0] mm



- A new 20 cm Gen II LAPPD tile 136
- GEM reference tracker
- New set of the pixelated readout boards

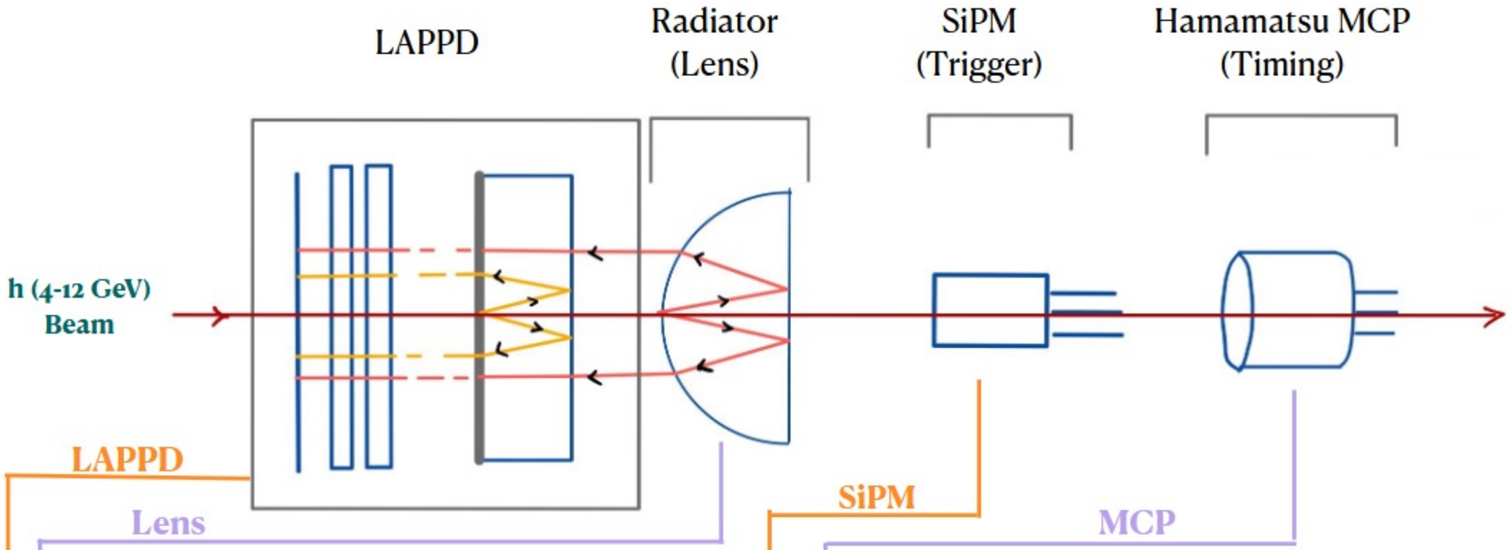


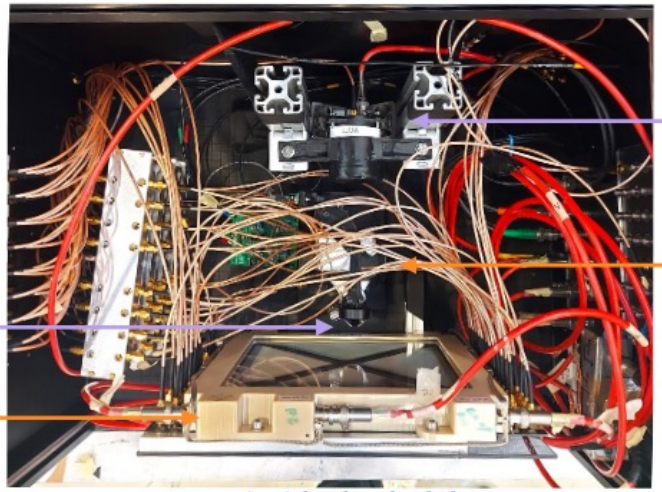
DRS4 chip#0: time(ch#03) – time(ch#02)



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

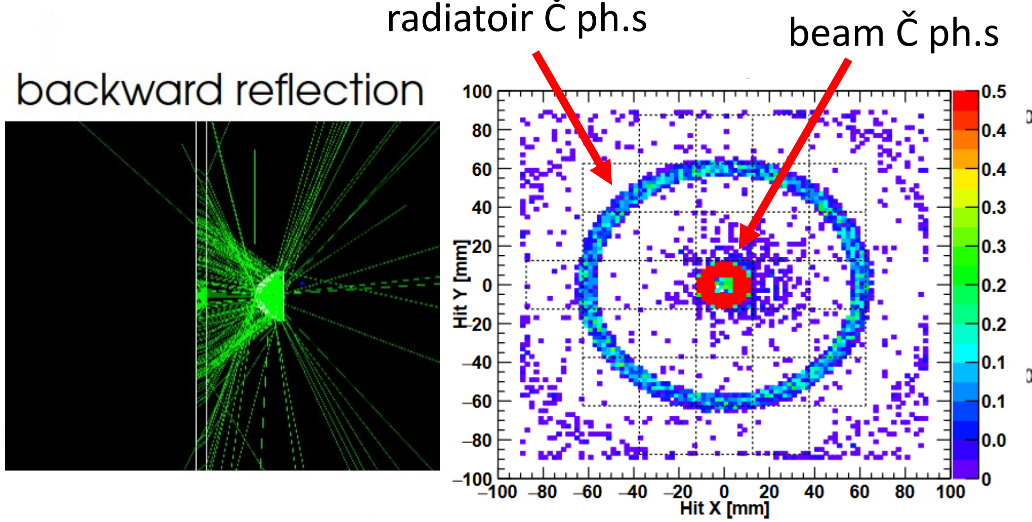
Beam test at CERN, October 2022

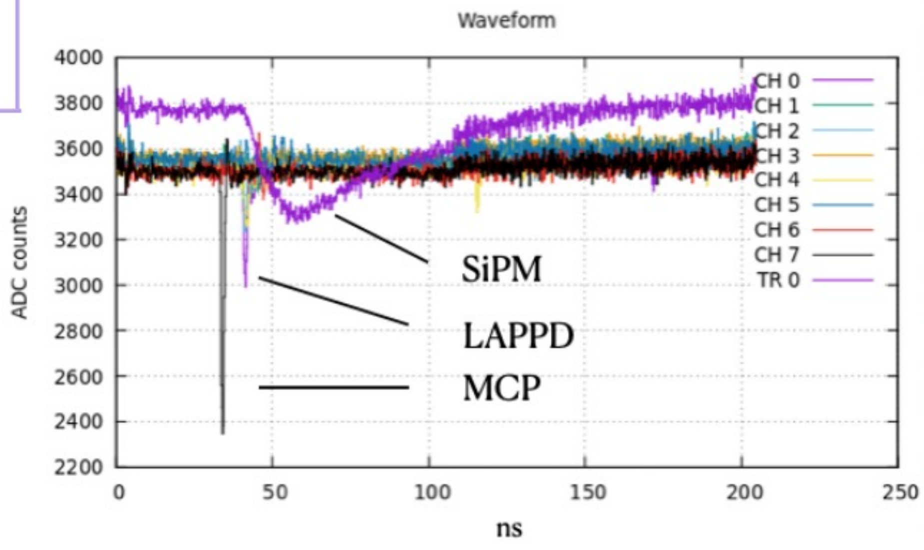




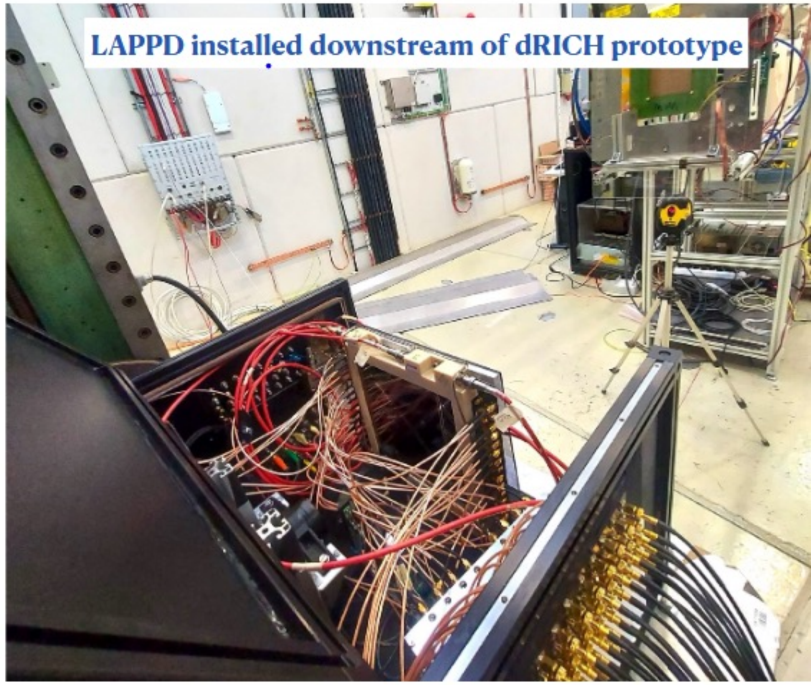
Setup inside the dark-box

Simulation studies

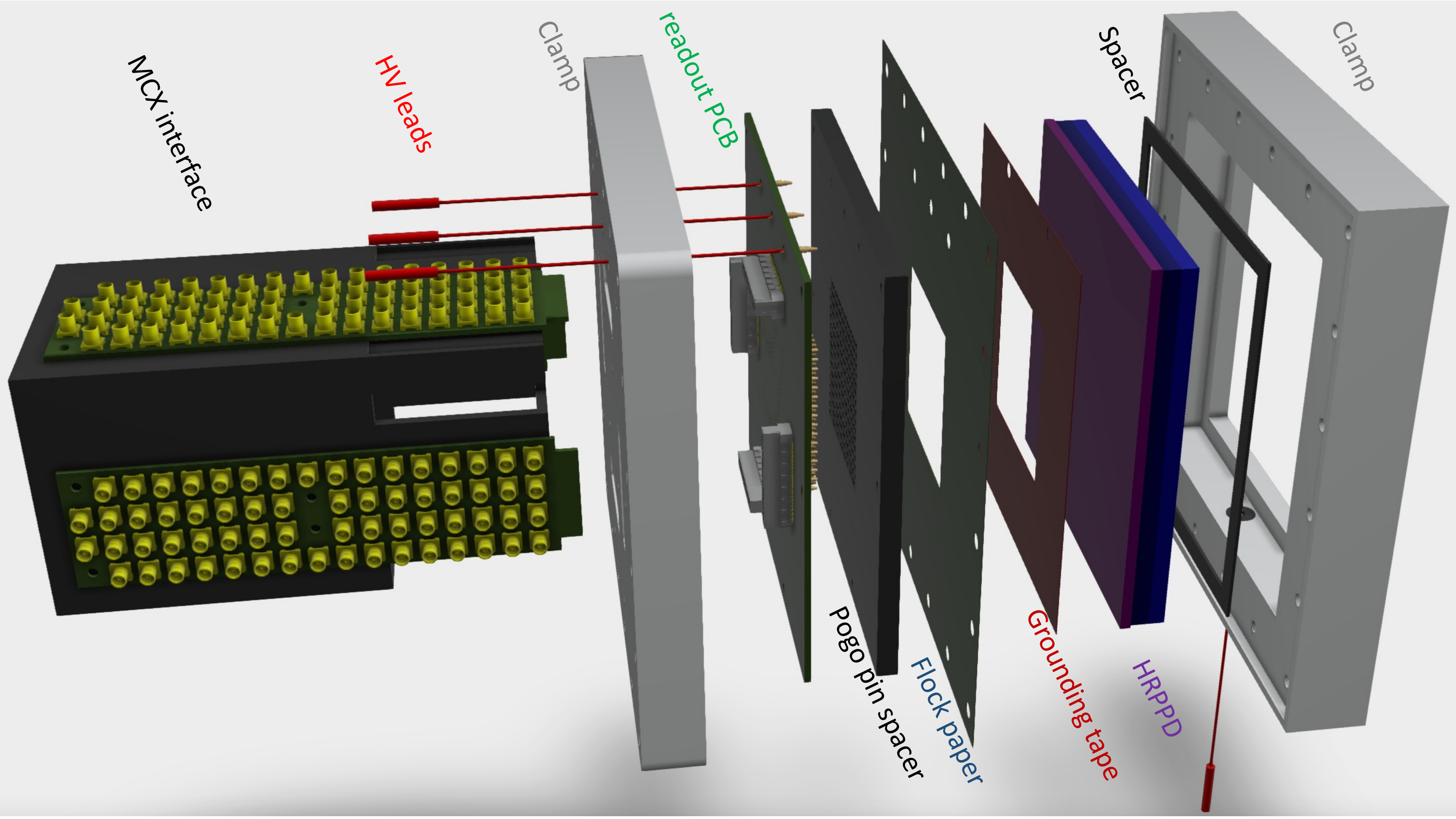


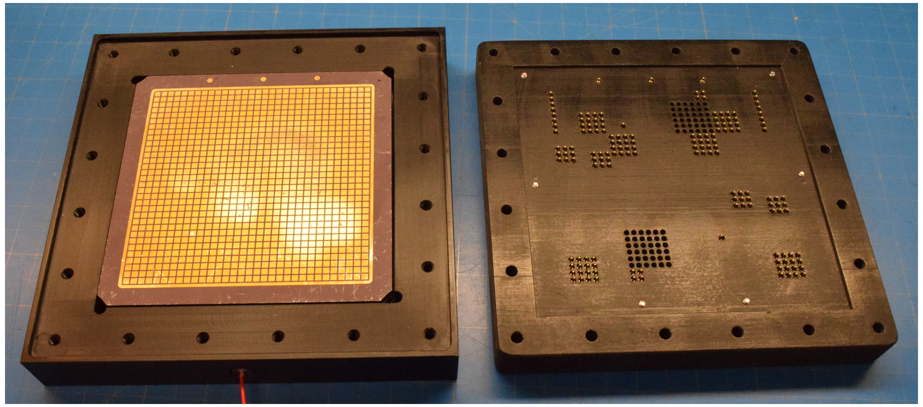


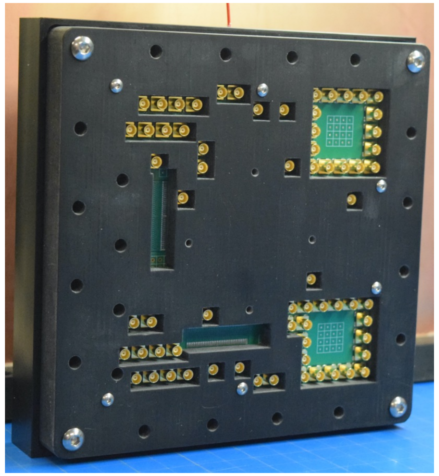
Online Signals

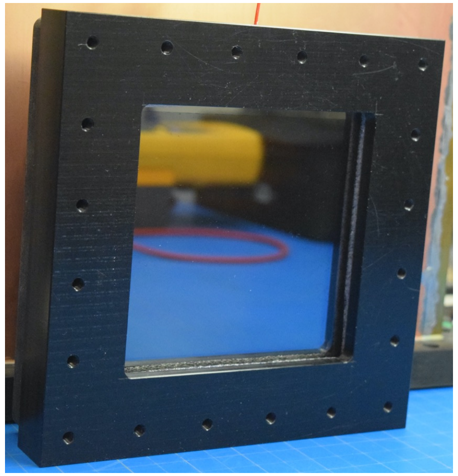


DC-coupled HRPPD evaluation





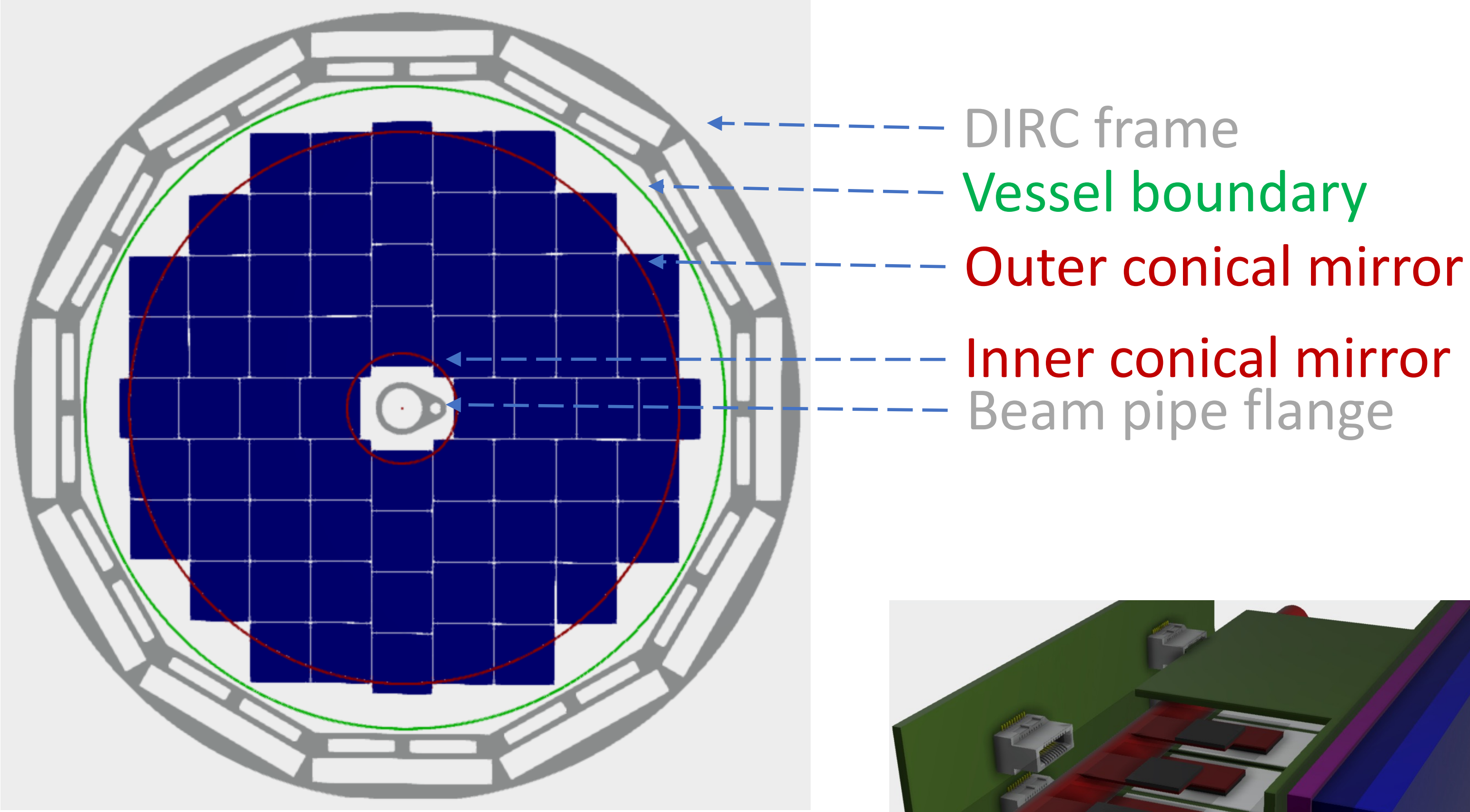


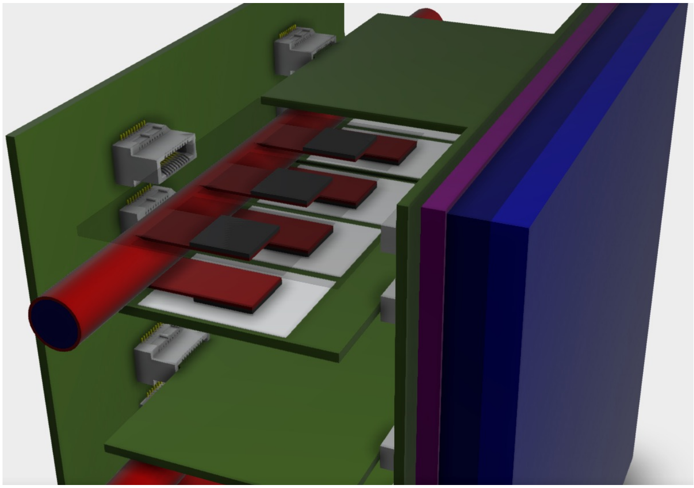


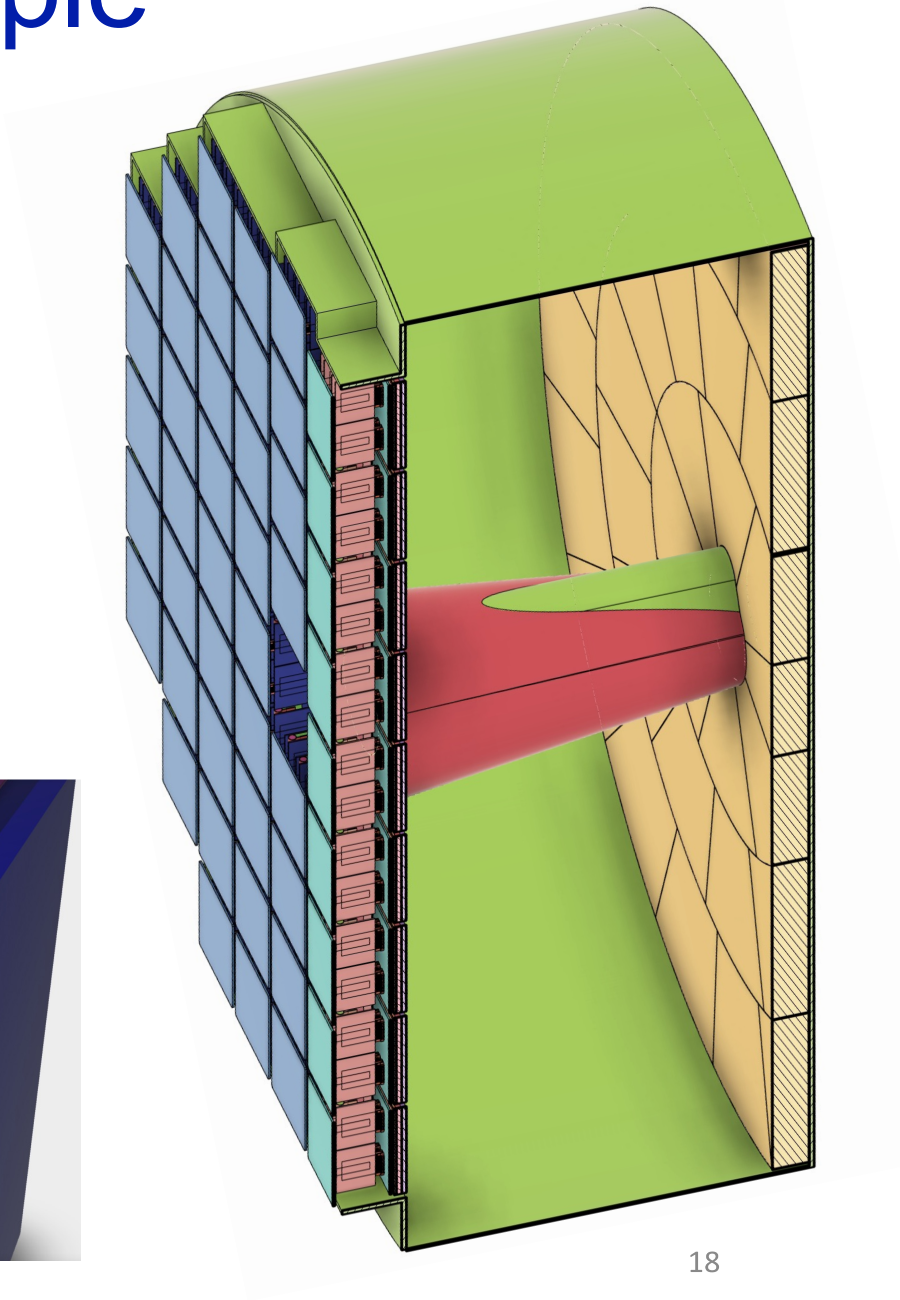
- Setup is fully functional, commissioned mid December with Mark's help

pfRICH integration model example

sensor plane tiling scheme







- Detailed HRPPD-based pf(m)RICH CAD models exist

R&D plans and funding sources

SBIR proposals

- Phase I, with a specific focus on EIC-related tuning ☹
- Phase IIA, with several topics relevant for EIC application

Topic / subtopic: **C55-24. A2 Advances in Detector and Spectrometer Technology, 2. Cherenkov detectors**
DOE Opportunity # **DE-FOA-0002783** Application Type: **Phase I SBIR**

"LAPPD & HRPPD: Fast Photosensors for EIC and other Particle Physics Applications"

Critical LAPPD / HRPPD developments to optimize performance customized for EIC

1) **Photocathode and PDE Optimized for Aerogel Cherenkov Signals** – EIC RICH will use a silica aerogel Cherenkov radiator with a useable wavelength range above ~350 nm. The LAPPD PC will be modified to improve PDE in this range. Program objectives include PC QE ≥ 30% and PDE ≥ 20% for λ ≥400 nm, to be met as follows:
   a) **Photocathode Peak and QE** – 20% QE at 450 nm was previously (DE-SC0019821) achieved by modifying the chemistry of Incom's Na_2KSb bialkali photocathodes. This work will be extended to achieve ≥ 30% QE at >400nm.
   b) **Photon Detection Efficiency** – Incom will establish (for the first time) the ability to measure PDE. In addition to red shifting QE, PDE ≥ 20% for λ ≥400 nm, to be achieved by developing ALD-MCPs with higher OAR.
2) **Timing Optimization** - Optimize timing performance of LAPPD / HRPPD with regard to requirements for DIRC, which are more stringent than the RICH detectors.
3) **Sensor Readout** - Tests on LAPPD and HRPPD with fully populated readout to optimize pixel shape, size, and number, including for the availability, cost and performance of recommended electronics.
4) **Sensor Form Factor** - Modify LAPPD/ HRPPD dimensions for optimal lay out and tiling of sensors.
5) **Confirmation of Device Lifetime** – Measured 5 C/cm^2 extracted charge with no deterioration of gain. These results will be confirmed, extended, and validated replicating specific EIC RICH and DIRC conditions, and for the specific photocathode and tile configuration selected.

eRD110: FY23 R&D plan & proposed milestones

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

slide from the EIC Detector Advisory Committee review in October 2022

eRD110: open R&D questions before CD-3

- 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)

slide from the EIC Detector Advisory Committee review in October 2022

eRD110 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**

Funded in full!

Other sources

- SBU/BNL Seed Grant proposal *"LAPPDs for TOF PET: a breakthrough in ultra-high sensitivity Positron Emission Tomography using fast affordable Micro-Channel Plate photomultipliers"*

  Small funding, but can evolve in a substantial follow up proposal

- EIC Generic Detector R&D Program?

  Possible, but not really suited to "fill the gap" in the next two years

- A contract between EIC and Incom Inc.?
  - Well-defined and documented set of requirements
  - Focused "remaining R&D" plan for ~half a year
  - Purchase of 4-5 HRPPDs in 2023
  - Bench test (also for DIRC purposes) and m(pf)RICH prototype beam test in spring 2024

TILES ORDERED	TILE COST	LAPPD Cost / cm^2	CUSTOMER SERVICES	SELLING PRICE	TOTAL SALES
1	$35,000	$92.11	$15,000	$50,000	$ 50,000
3	$28,440	$74.84	$15,000	$43,440	$ 130,319
5	$25,111	$66.08	$15,000	$40,111	$ 200,557
7	$23,284	$61.27	$15,000	$38,284	$ 267,988
10	$21,540	$56.68	$15,000	$36,540	$ 365,398