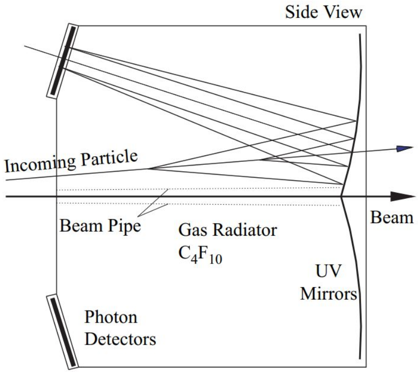
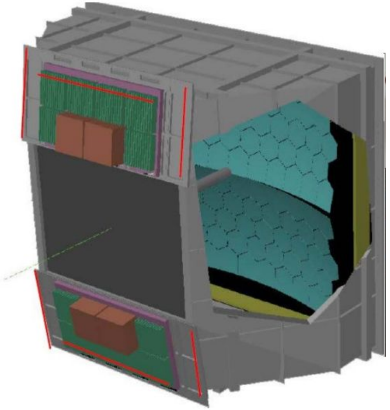
Istituto Nazionale di Fisica Nucleare

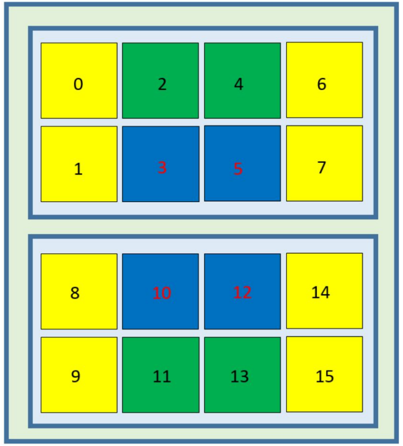
R&D on particle identification and photon detection

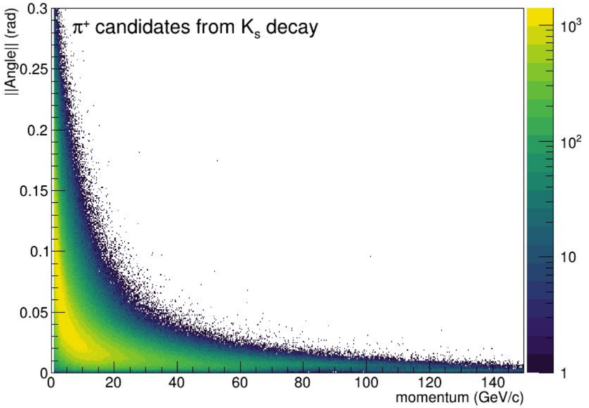
Chandradoy Chatterjee

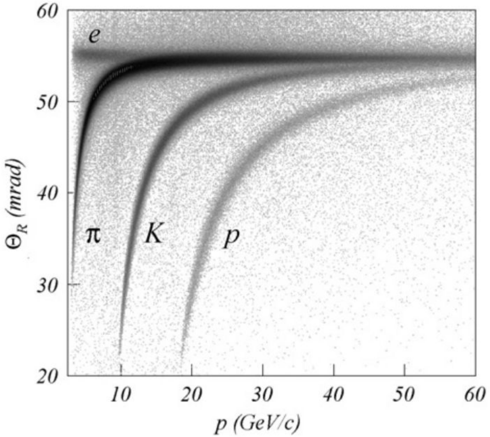
COMPASS RICH-1

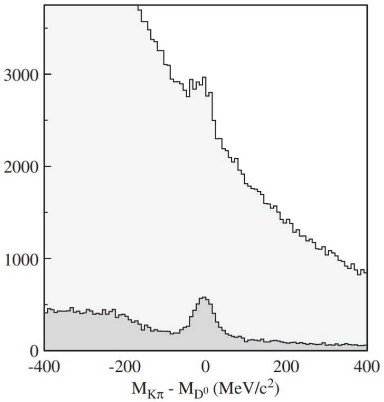


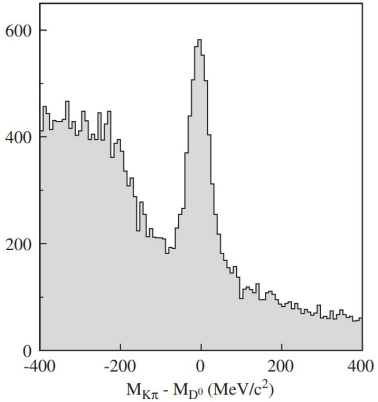






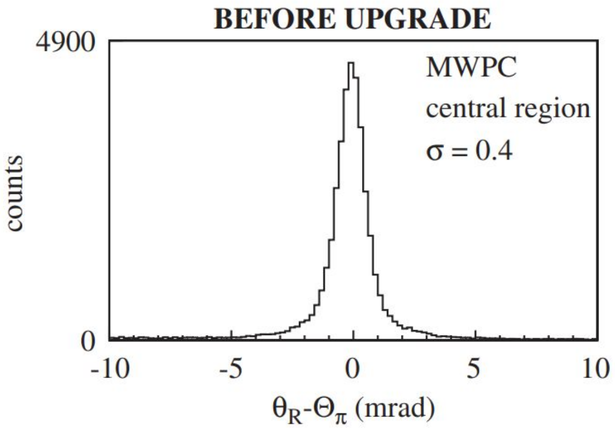


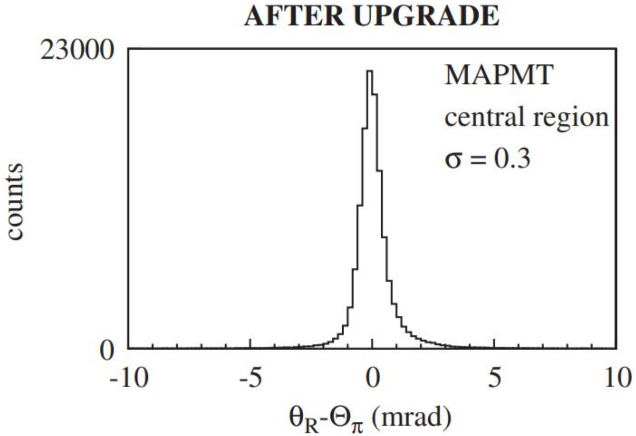


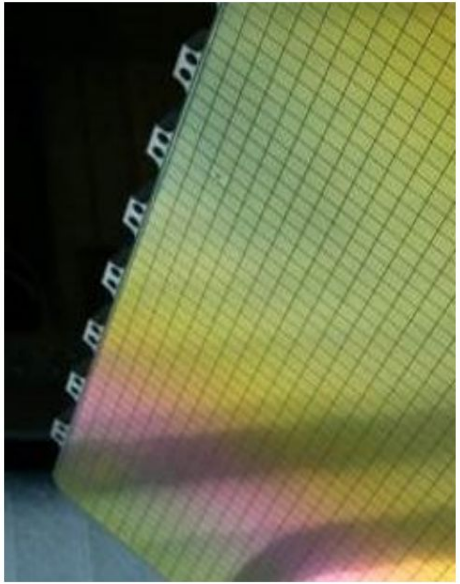


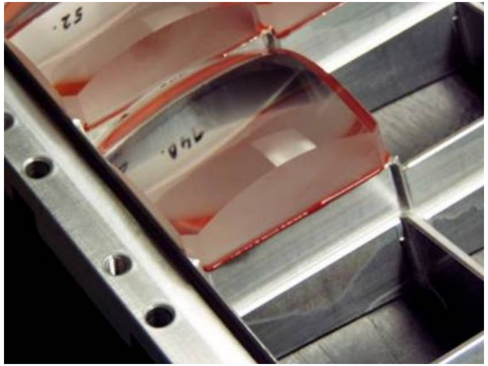
- High momentum PID pi/K/P separation upto 60 GeV/c. Wide acceptance (+- 250 mrad).
- A large gaseous RICH (3m radiator) with C_4F_{10} is used to serve the PID.
- INFN TS has played the leadership role in the R&D, construction, and successful operations for **TWO DECADES!**
- Sophisticated reconstruction software, upgrades with cutting edge technologies are outcome of the INFN TS endeavor.

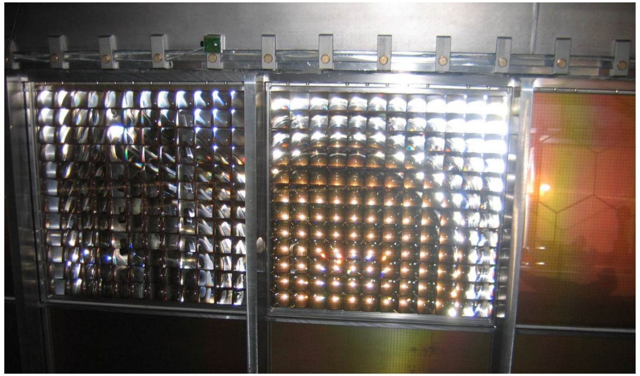
COMPASS RICH-1



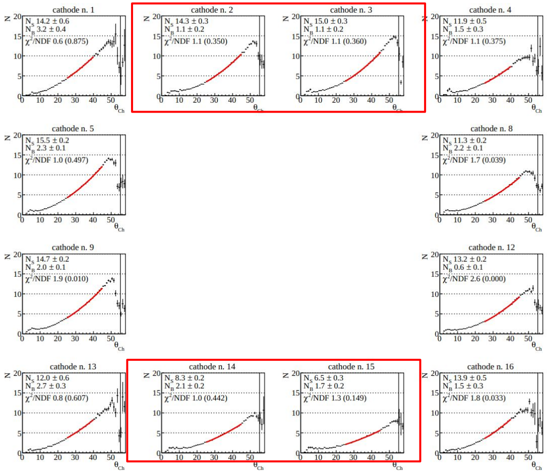


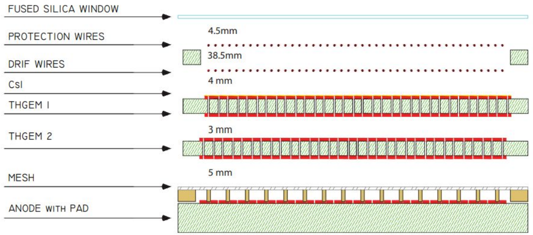


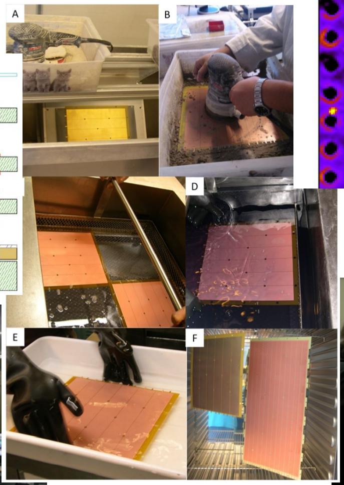


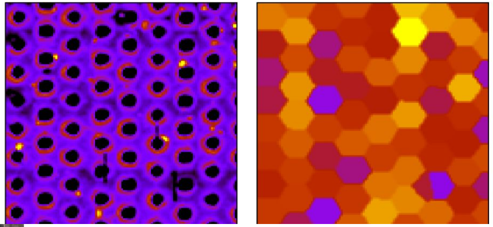


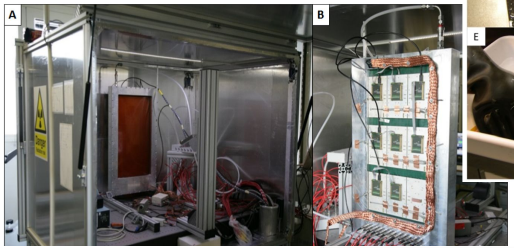
COMPASS RICH-1: 2016 Upgrade

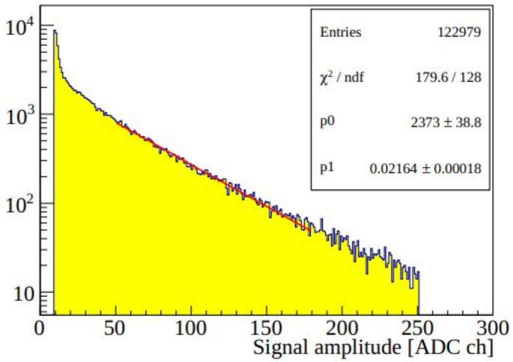


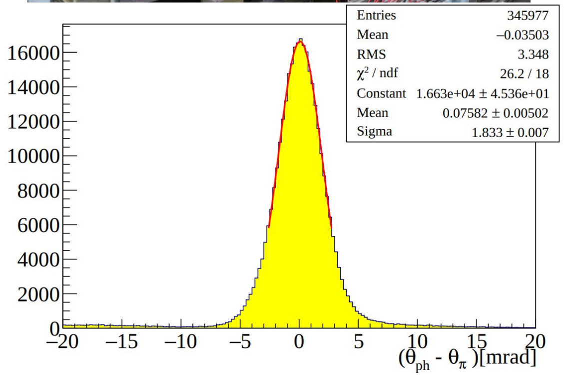


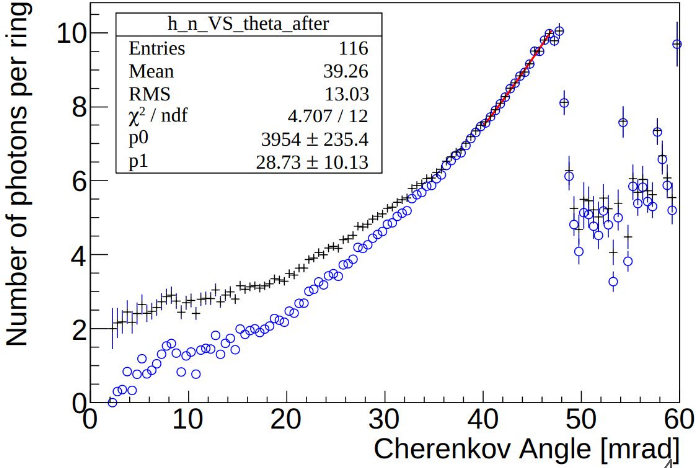






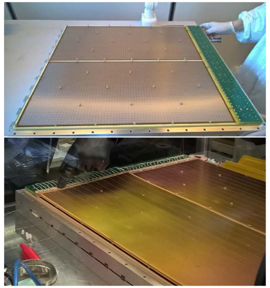


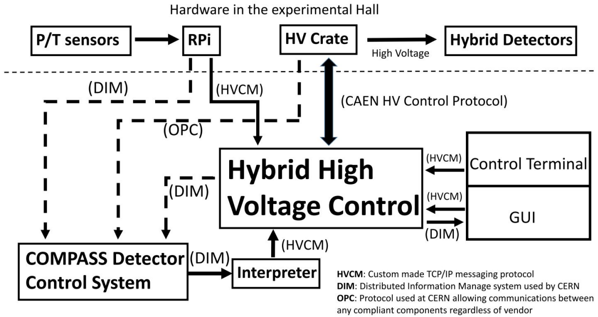


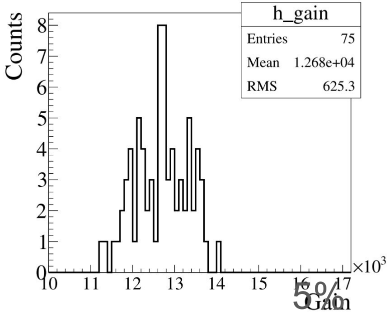


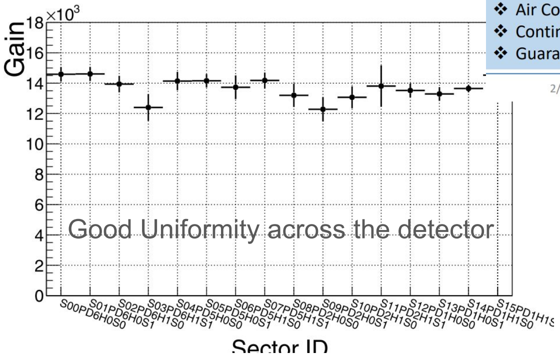
Eight year long R&D, came with promising results!

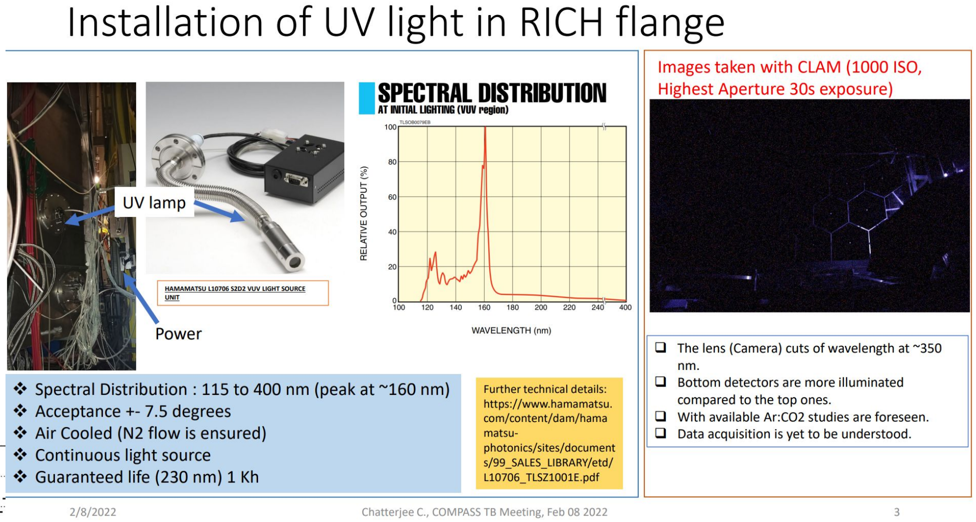
Gaseous detectors HV system and monitoring

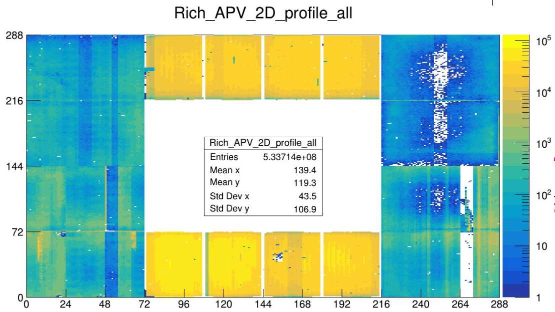


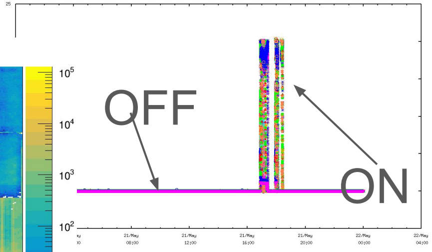










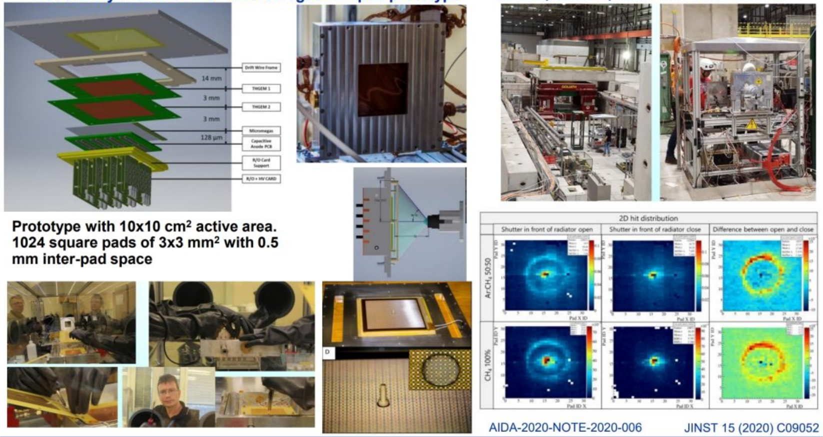


The high voltage system with pressure and temperature corrections for the novel MPGD-based photon detectors of COMPASS RICH-1, J Agarwala et al.; https://doi.org/10.1016/j.nima.2019.162378

R&D effort for EIC RICH

- COMPASS RICH upgrade motivated MPGD based photon detectors for future RICH applications.
- Two streams of R&D
  - To couple modular hybrid THGEMs + Micromegas with smaller size readout pads (3mmX3mm)
  - To study performances of the MPGD based detectors coupled with alternative photocathodes.

Modular Hybrid THGEMs + Micromegas Minipad prototype *"after the positive experience with COMPASS RICH"*

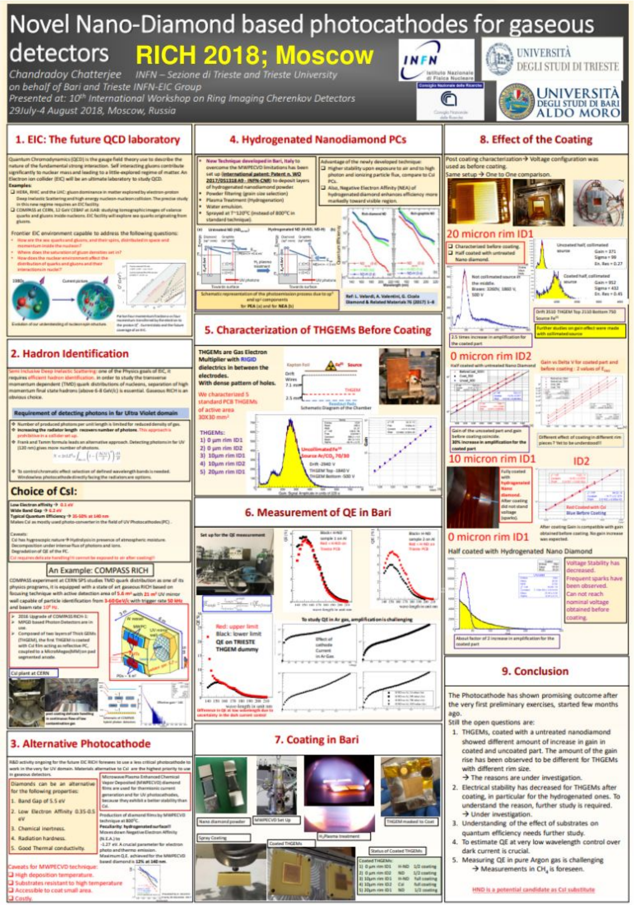


AIDA-2020-NOTE-2020-006 JINST 15 (2020) C09052

A modular mini-pad photon detector prototype for RICH application at the Electron Ion Collider; J. Agarwala et al 2020 J. Phys.: Conf. Ser. **1498** 012007

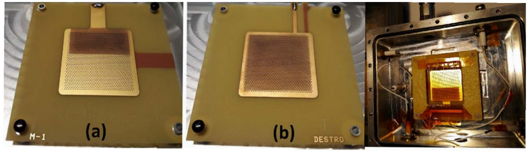
DOI 10.1088/1742-6596/1498/1/012007

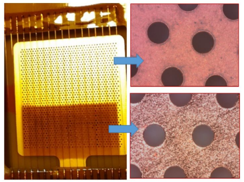
Chandradoy Chatterjee, MPGD 2022, December 15th, 2022

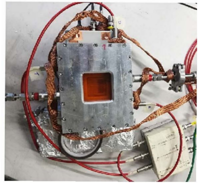


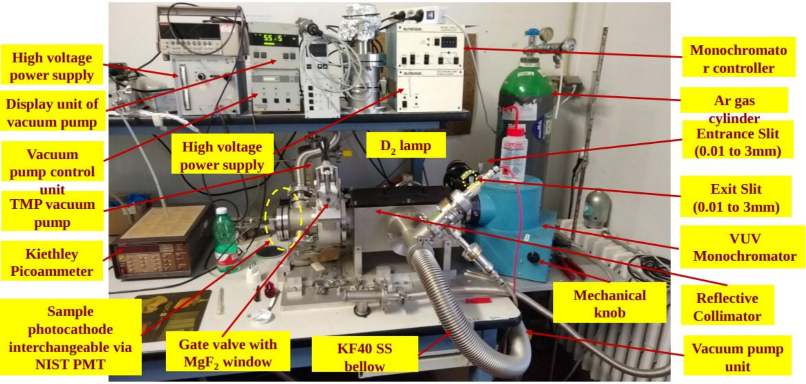
Trends in particle and nuclei identification techniques in nuclear physics experiments Open access Published: 08 March 2022 Volume 45, pages 189–276, (2022)

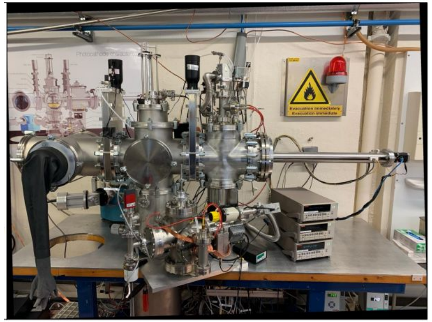
Nanodiamond

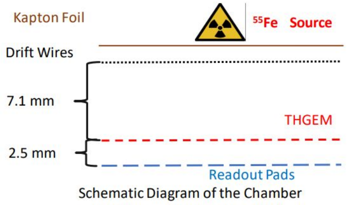


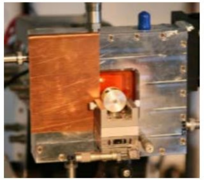


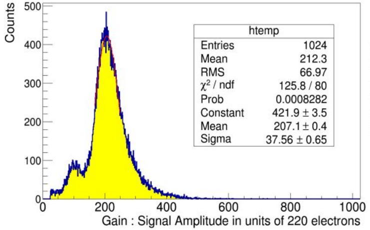


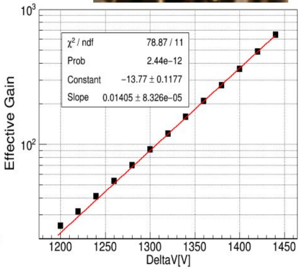


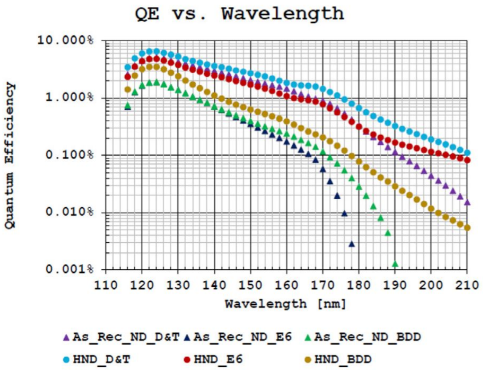


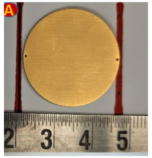


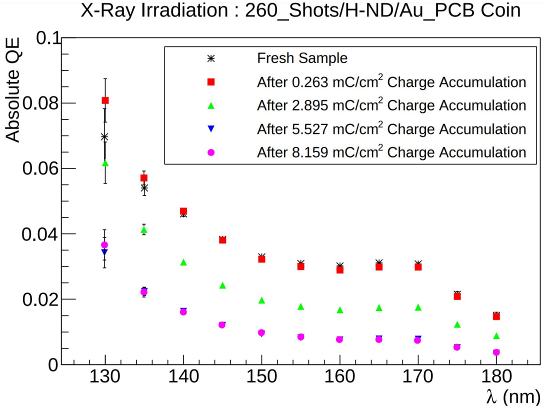






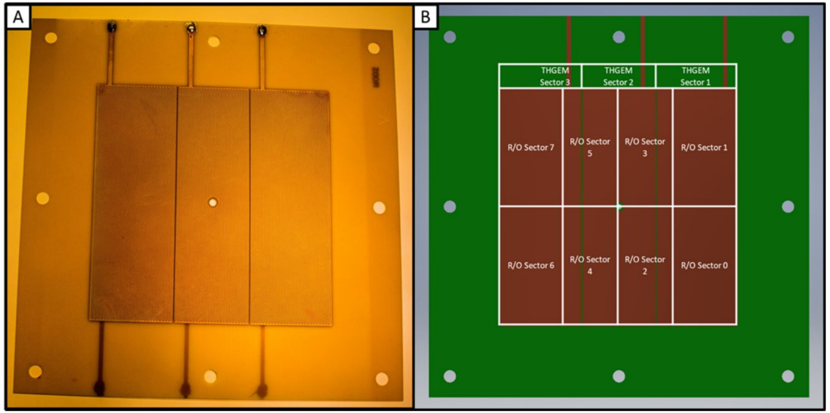


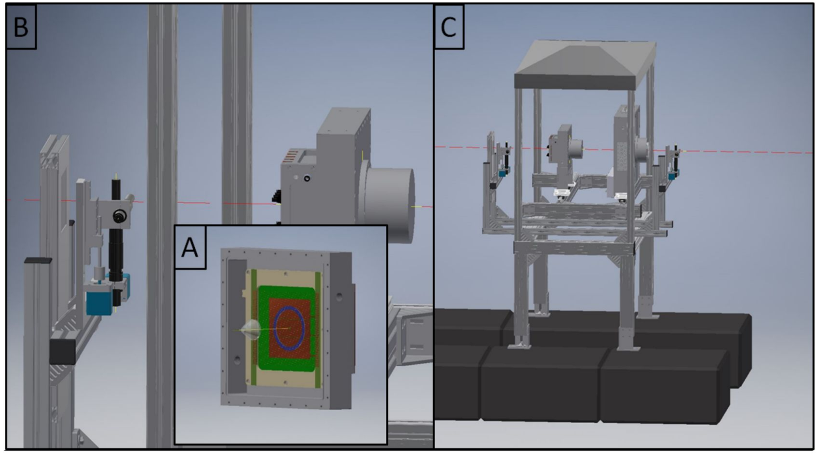


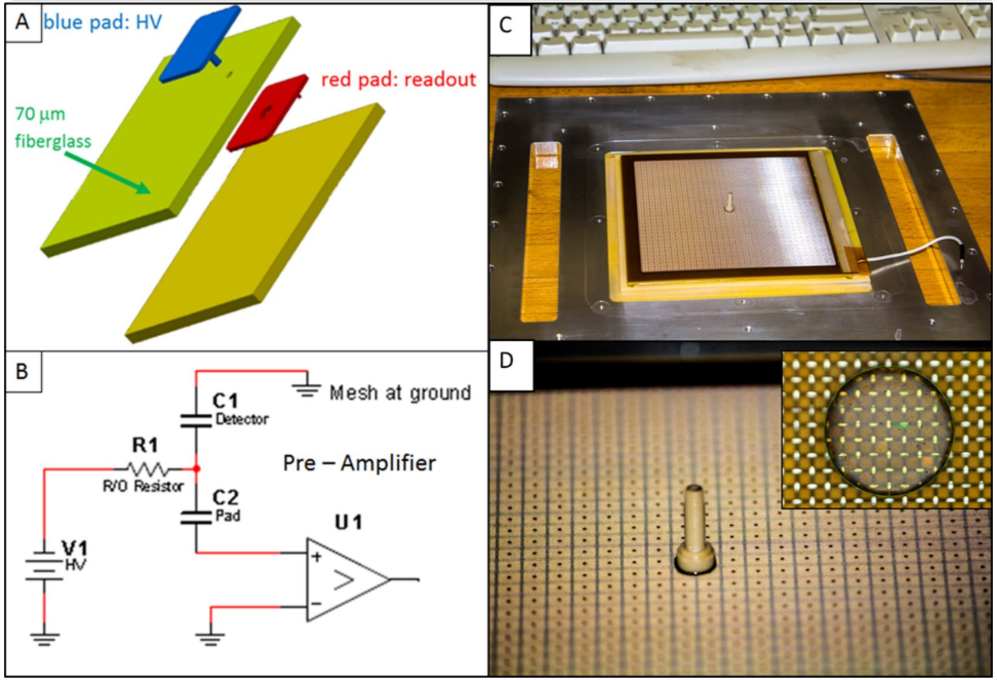


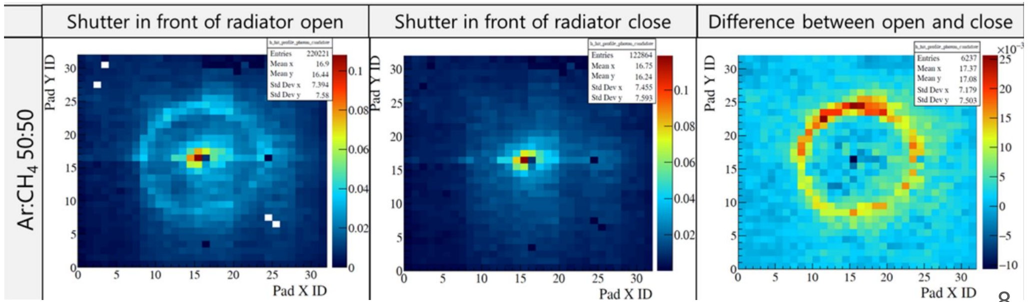
- After extensive R&D we understood that hydrogenated nanodiamond based photo cathode does not provide reproducible QE for RICH application.
- However, the have DLC like QE and it is more robust as compared to CsI. Possible application for timing detectors coupled to MPGDs.
- For a dual Radiator RICH or pfRICH we also don’t want large photon yield in the far UV.
- Important lessons for QE and aging measurements.

Minipad

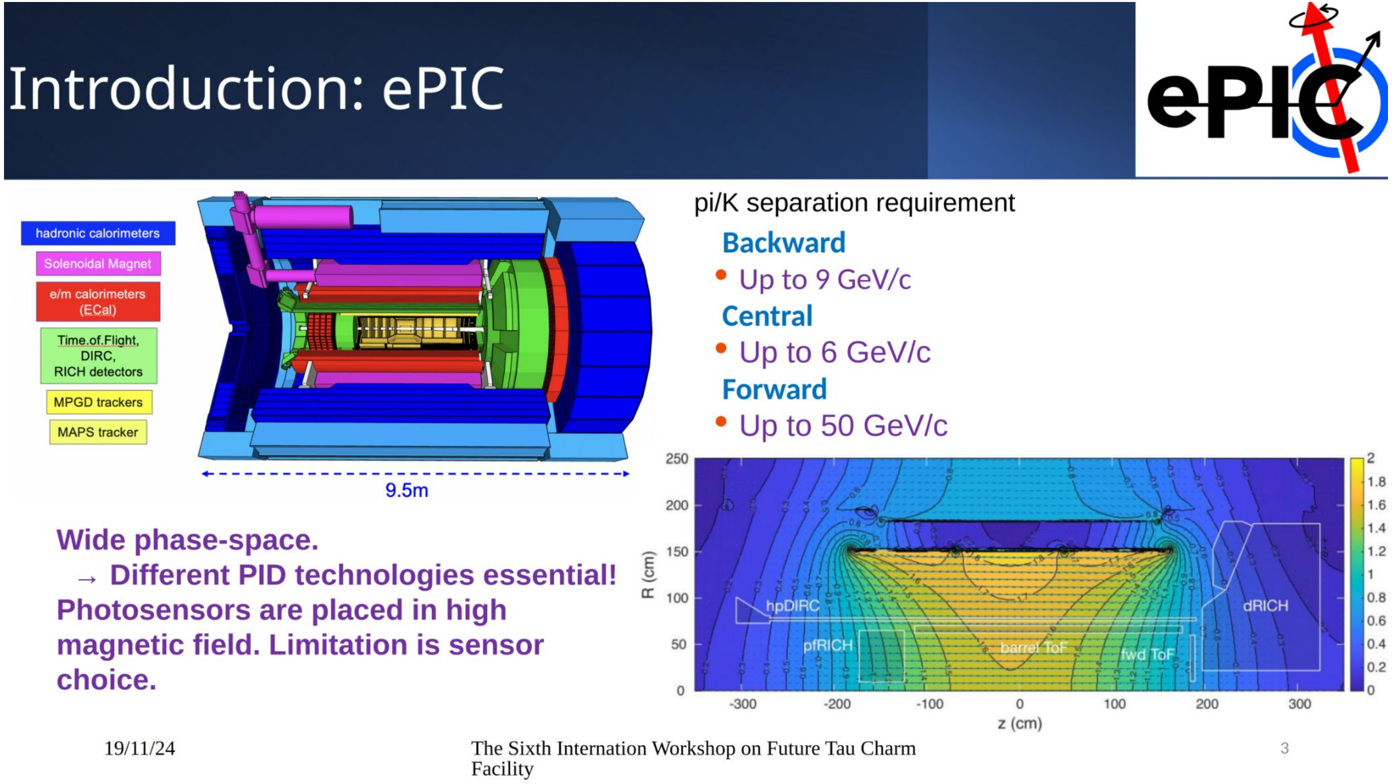

A
B
THGEM Sector 3
THGEM Sector 2
THGEM Sector 1
R/O Sector 7
R/O Sector 5
R/O Sector 3
R/O Sector 1
R/O Sector 6
R/O Sector 4
R/O Sector 2
R/O Sector 0

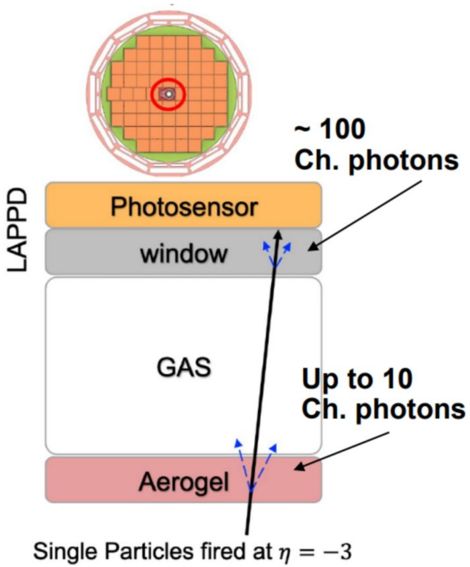

B
C
A


A
blue pad: HV
red pad: readout
70 μm fiberglass
B
C1 Detector
Mesh at ground
R1
R/O Resistor
C2 Pad
Pre – Amplifier
U1
V1 HV
C
D


Shutter in front of radiator open
Shutter in front of radiator close
Difference between open and close
Ar:CH4 50:50
Pad Y ID
Pad X ID

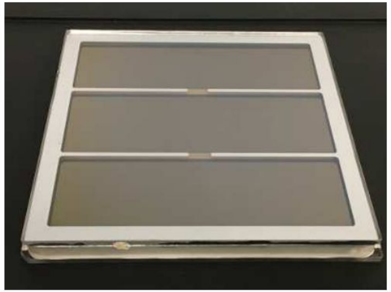
ePIC PID requirements

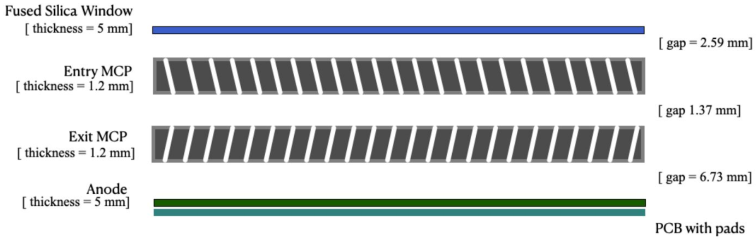


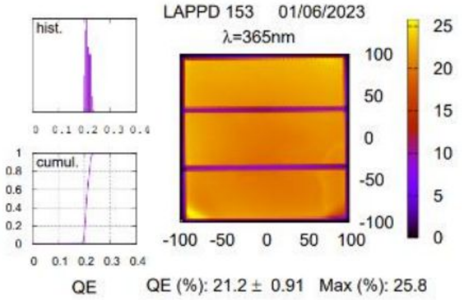


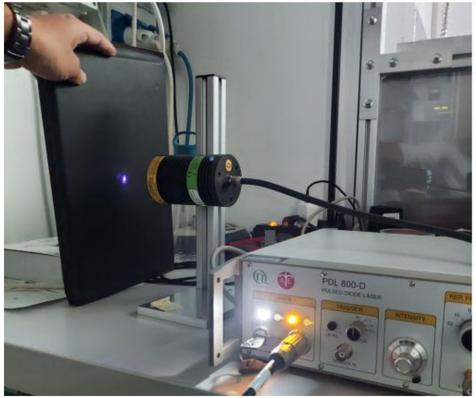
Challenging PID.
LAPPD/HRPPD based sensors to provide time-of-flight to perform low momentum PID.
Less than 100 ps time resolution for single photo-electron is required!

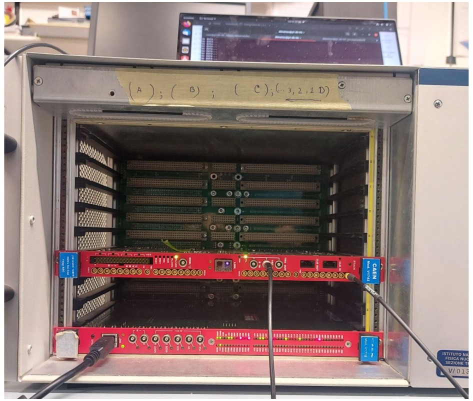
LAPPD activities in TS

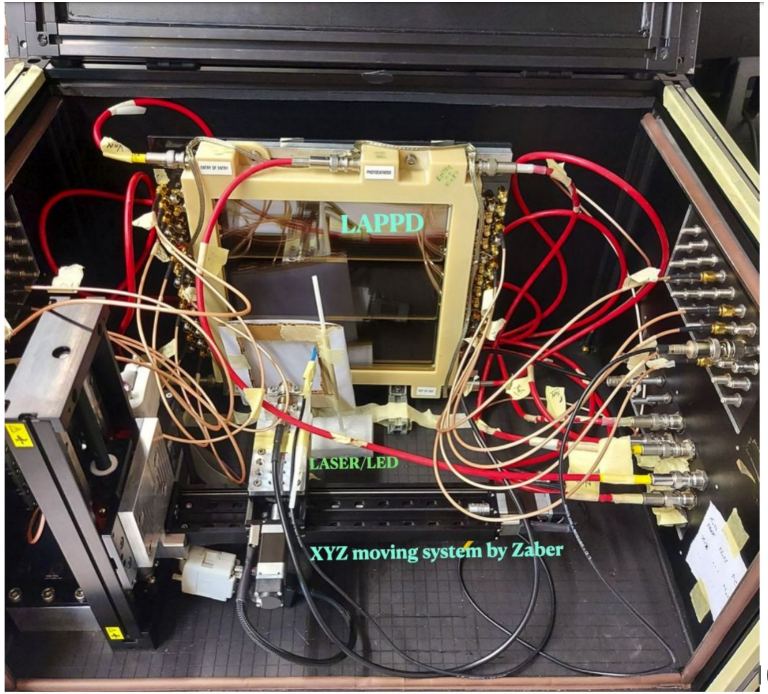






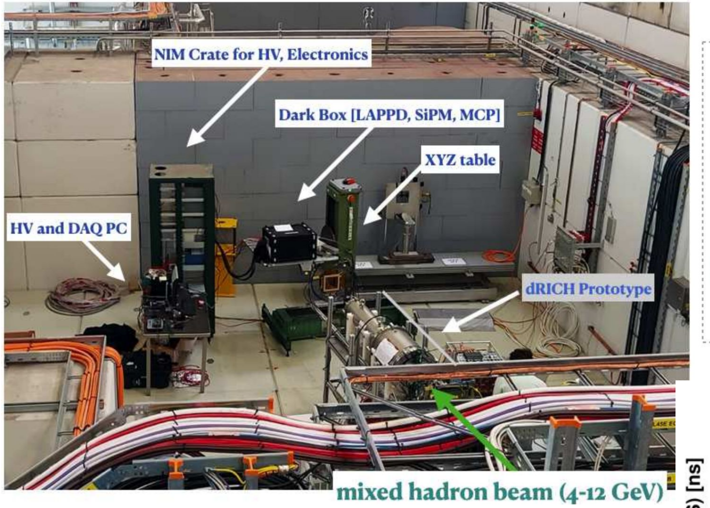


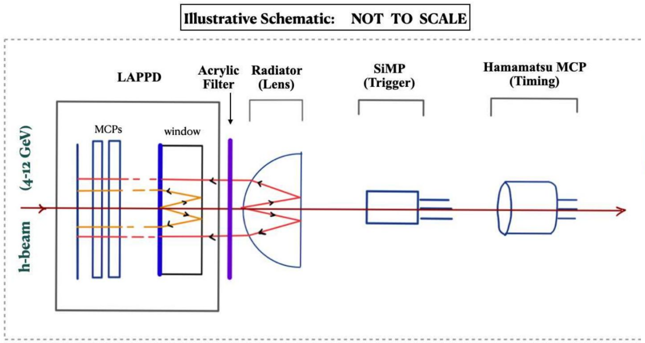


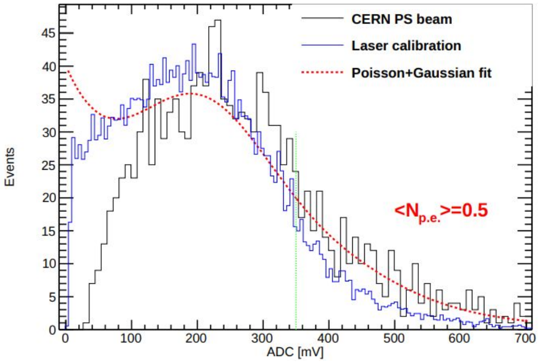


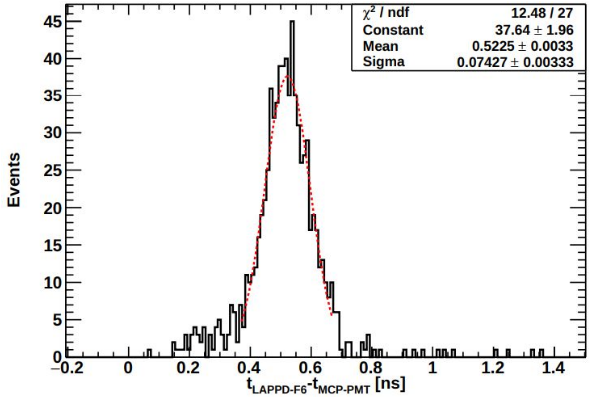
Thorough characterization of the LAPPD in INFN TS lab

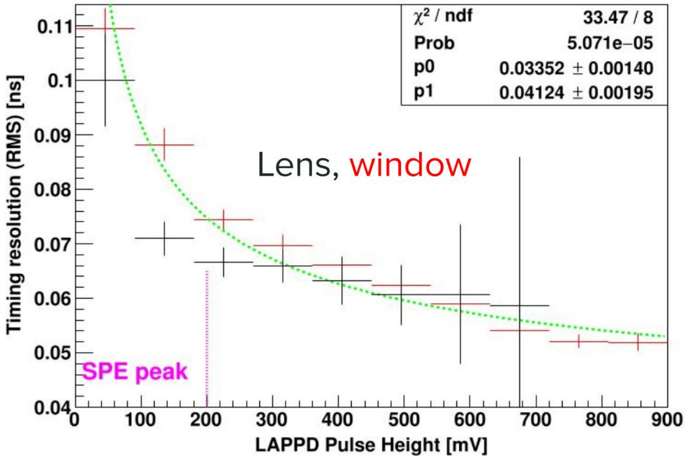
LAPPD in CERN test beam









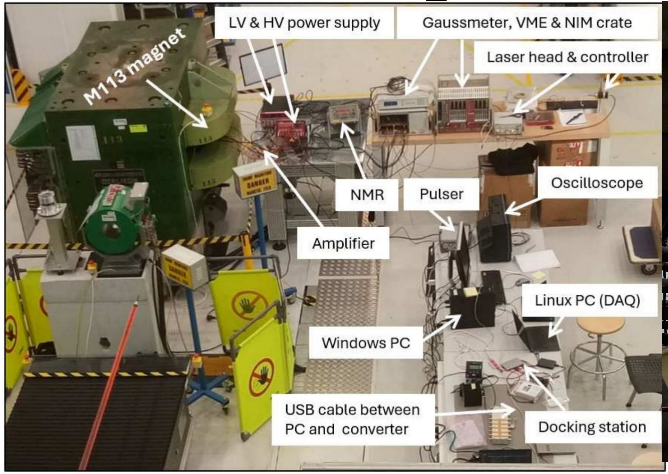


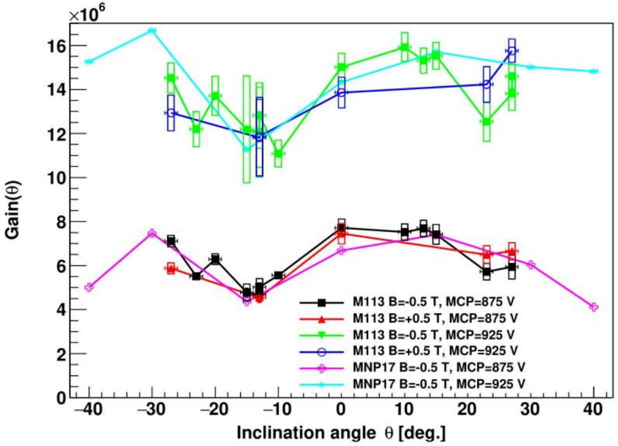
Characterization of LAPPD timing at CERN PS testbeam; D.S.Bhattacharya et al. DOI: https://doi.org/10.1016/j.nima.2023.168937

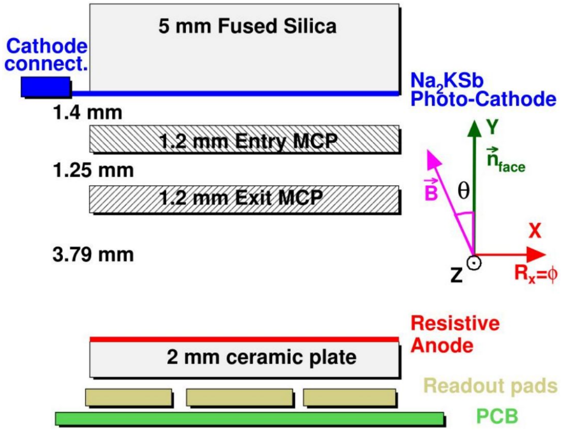
The beam test demonstrated that LAPPD like MCP PMTs can provide ~80 ps time resolution for Single photo-electrons.

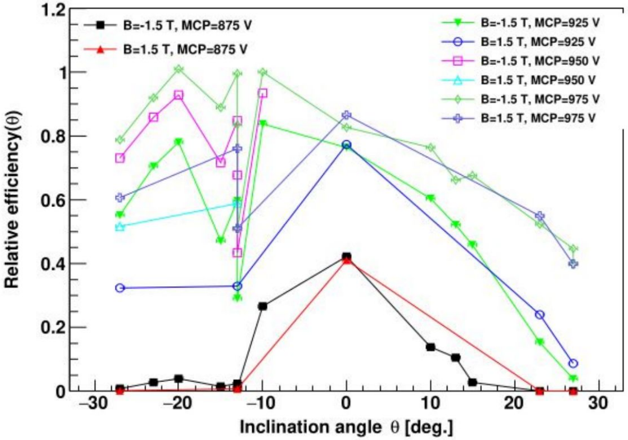
Critical inputs for EIC requirements have been pointed out.

LAPPD in magnetic field









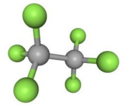
Gain and efficiency to detect single photo electrons has been studied in the magnetic field. All components were checked at INFN-TS before inserting to the magnet.

The loss in the gain and efficiency due to magnetic field can be improved by increased by increasing the MCP voltage. However, the right voltage configuration is object depended. Has to be tuned sensor by sensor.

Submitted to NIMA

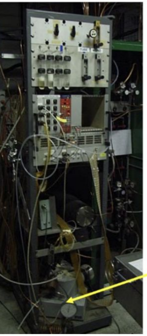
ePIC dRICH gas radiator

VUV Trasparency of C_2F_6

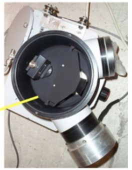


Exafluoroethane 5.0 at CERN

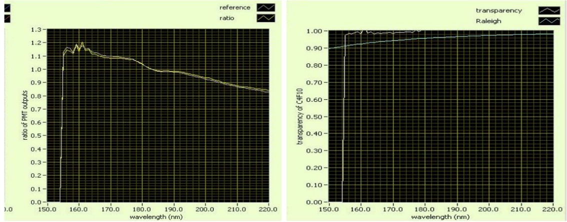
Used for a test-beam



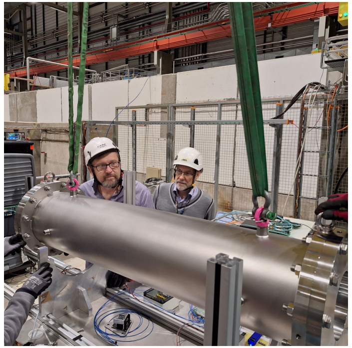
Deuterium UV lamp, Monochromator system, 1.6 m column for gas transparency measurement

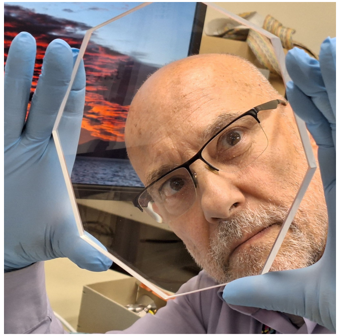


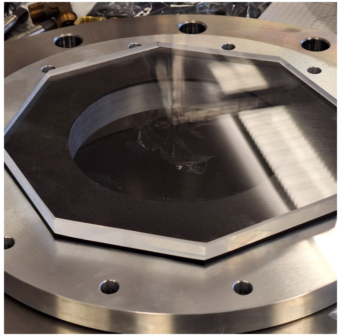
Measured in the COMPASS setup



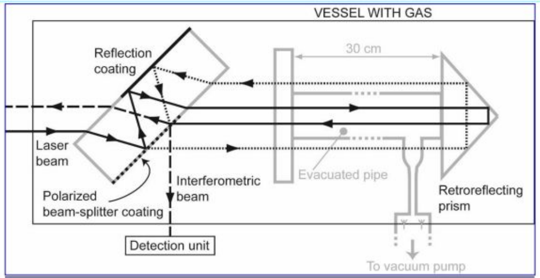
transparency > 98%
for 170 nm < λ < 220 nm







The system already existing for COMPASS gas system is used for the measurement of transparency C_2F_6 (baseline for dRICH)
INFN TS designed the mechanical system, assembly and beam test with a pressurized dRICH.

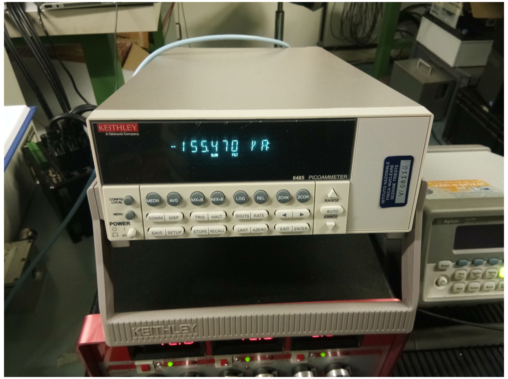


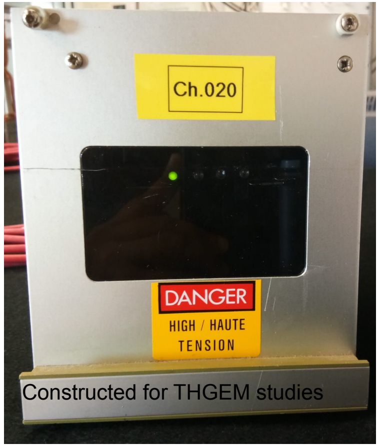
Using a Raspberry Pi and a USB oscilloscope Digilent Analog Discovery 3, 8kHz sampling

One fringe (360°) corresponds to 1 ppm variation of the refractive index

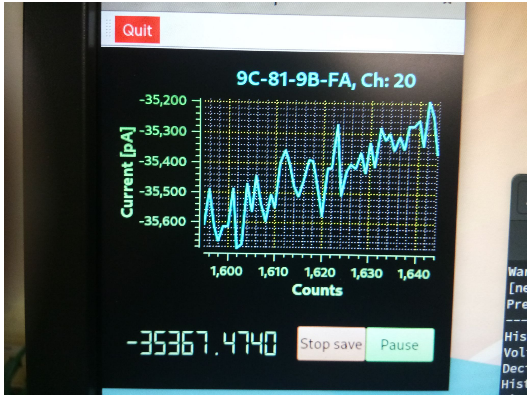
A set up for measuring precise refractive index of the gas radiator is procured and tested. With a simple readout is made. Studying refractive index <10 ppb is feasible.

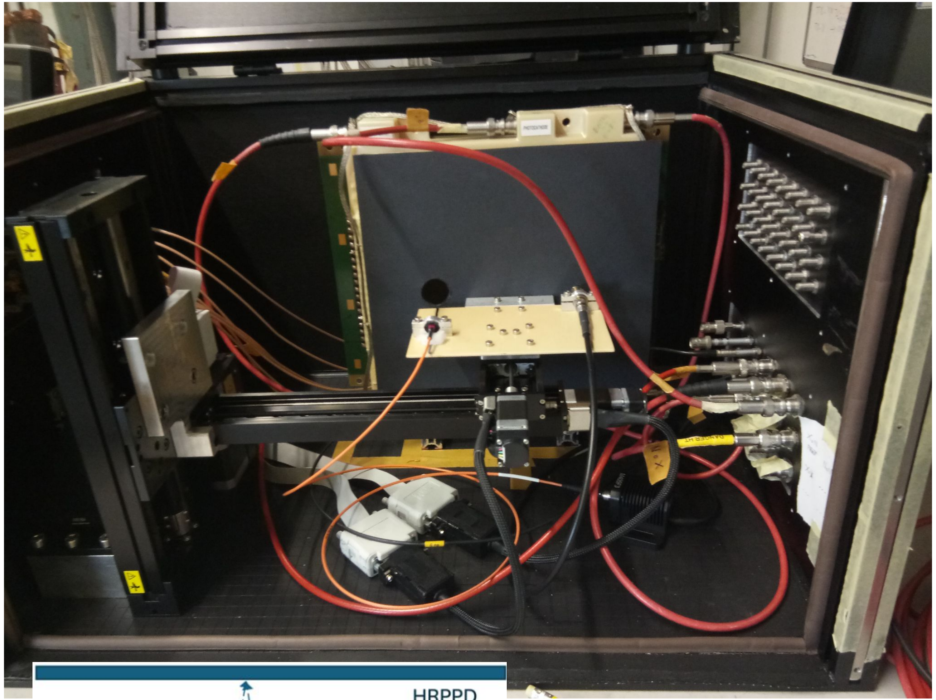
LAPPD Aging studies in TS

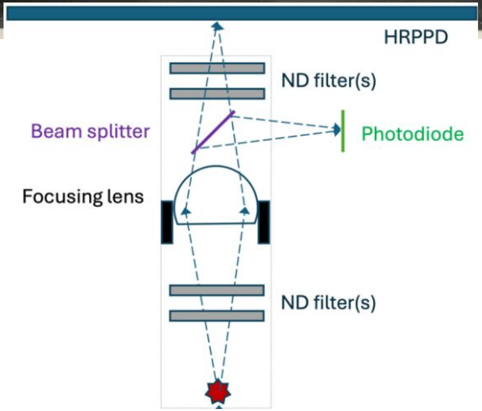




Aging study aims to quantify the change in the performance of the detector components (PC, MCP) with light illumination.
Critical aspect to monitor currents in different electrodes.







Procurement for optics is ongoing

Soon arriving…

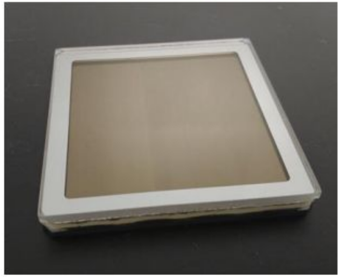
HRPPD – High Rate Picosecond Photodetector

- 10 cm x 10 cm MCP-PMT
  Chevron pair GCA-ALD-MCPs (10 μm)
  Ceramic package
  Capacitive (CC) or Direct (DC) Coupling
  100 cm^2 active area

- High Gain ($5*10^6$)
  Dark Rates: <10kHz/cm^2

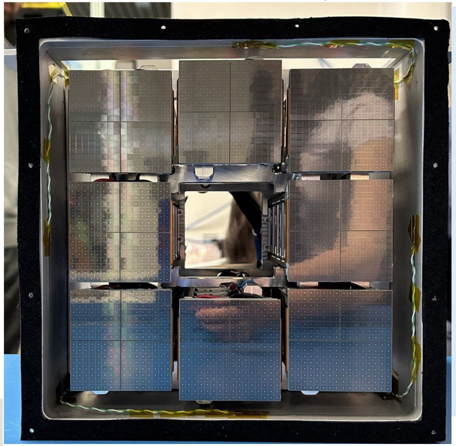
- Photocathode Na_2KSb
  - >20% QE at 365 nm
  - >80% spatial uniformity

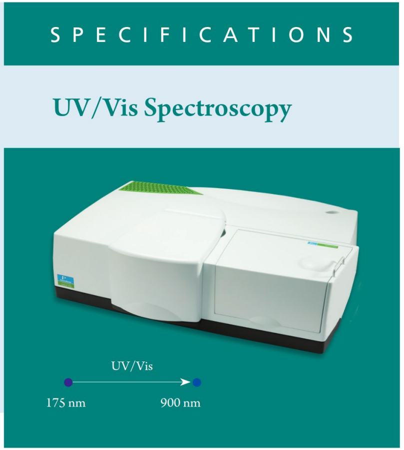
- Timing Resolution
  - SPE: <50 psec
- Position Resolution (TBD)



5/19/2023 An Update on HRPPD/LAPPD Application Specific Developments for EIC

Hamamatsu S13360-3050/3075 8x8 MPPC arrays

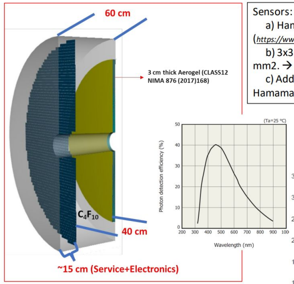




Similar characterization for HRPPD is foreseen.
Preparation to characterize the SiPM based photosensors for dRICH is ongoing.
To characterize the radiator gas for dRICH in the interesting wavelength region will be made in INFN-TS.

Simulation studies (pfRICH)

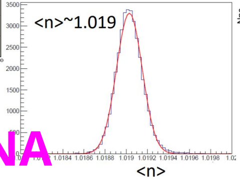
Geometry of pfRICH



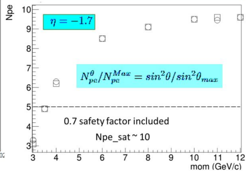
Sensors:
a) Hamamatsu S13361-3050AE-08 8x8 SiPM panels (https://www.hamamatsu.com/us/en/product/type/S13361-3050AE-08/index.html)
b) 3x3 mm² single SiPM with 8X8 pixels in each sensor. Sensor full size = 25.8x25.8 mm2. → 0.85 geometric efficiency.
c) Additional safety factor of 0.7 on top of Photo Detection Efficiency provided by Hamamatsu.

Aerogel (3 cm) Example:
Absorption length->@ 400 nm 157 mm
Rayleigh->@ 400 nm ~40 mm
R_{index}->@ 400 nm 1.01933

Consistency found from RICH Cherenkov angle reconstruction



N_{pe} : open box Exp Open Circle Obtained from simulation



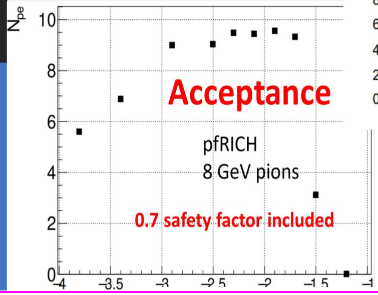
C_4F_{10} parameters:
NIMA 510(2003) 262

ATHENA

5/10/2022 Chatterjee INFN 2022 9

Performance plot

YR requirement achievable



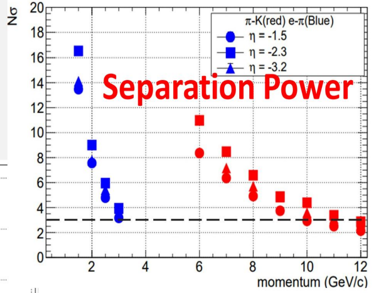


Figure 4.11: N_σ separation

Yellow Report requirement: hadron PID in the electron-going endcap: better than 3σ π/K separation either (1) to 7 GeV/c (pp. 21) (2) up to 10 GeV/c [table 3.1]
We consider the later as a reference!

ePIC

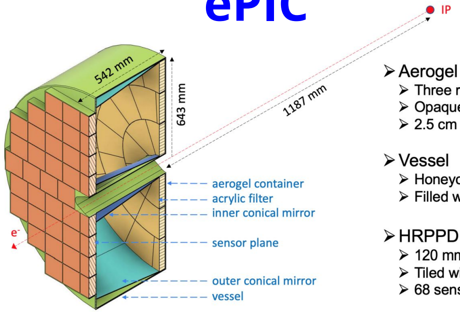
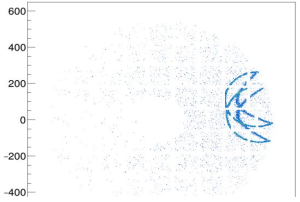
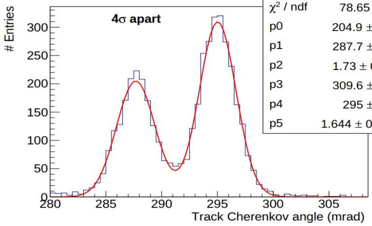


Figure 1.4: The proposed pfRICH detector. See the text for more details.

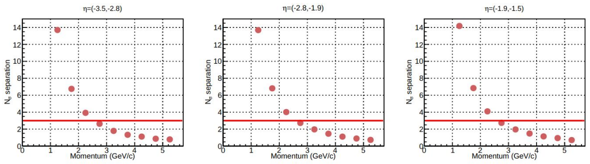
- Aerogel
  - Three radial bands
  - Opaque dividers
  - 2.5 cm thick, 42 tiles total
- Vessel
  - Honeycomb carbon fiber sandwich
  - Filled with nitrogen
- HRPPD photosensors
  - 120 mm size
  - Tiled with a 1.5mm gap
  - 68 sensors total



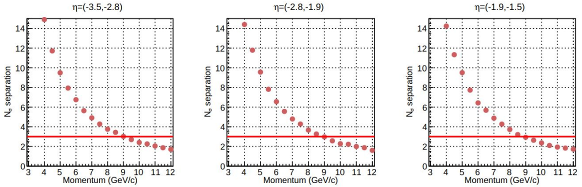
Momentum Vs Cherenkov angle (track)



χ^2 / ndf	78.65 / 46
p0	204.9 ± 6.5
p1	287.7 ± 0.0
p2	1.73 ± 0.04
p3	309.6 ± 8.0
p4	295 ± 0.0
p5	1.644 ± 0.031

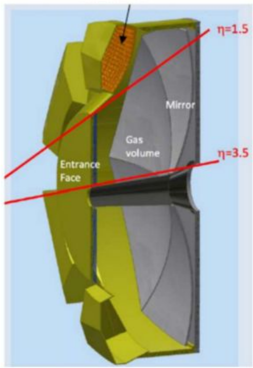


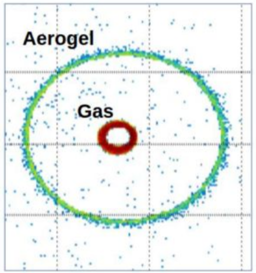
(a) N_σ separation between the electron an pion hypotheses as a function of momentum for different bins of pseudo-rapidity.

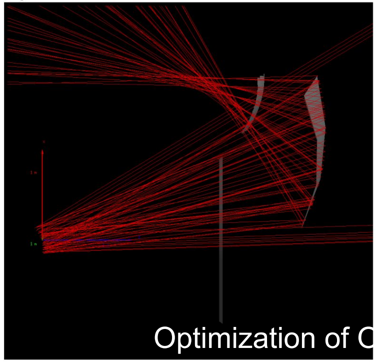


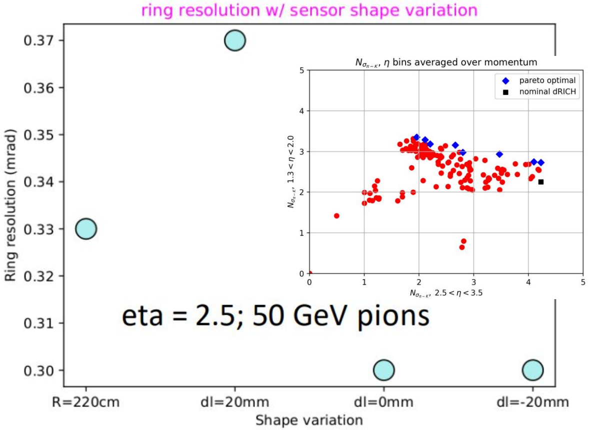
(b) N_σ separation between the pion and kaon hypotheses as a function of momentum for different bins of pseudo-rapidity.

Simulation studies (dRICH optimization)







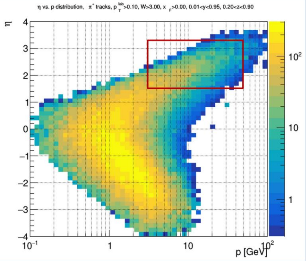


Main challenges:

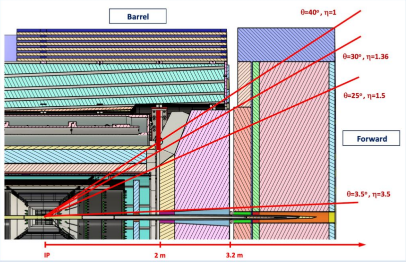
- Cover wide momentum range 3 - 50 GeV/c -> dual radiator
- Work in high (~ 1T) magnetic field -> SiPM
- Fit in a quite limited (for a gas RICH) space -> curved detector

η	Nomenclature	Electrons and Photons			π/K/p	
		Resolution σ_E/E	PID	Min E Photon	p-Range	Separation
1.0 to 1.5	Forward Detectors	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c	≥ 3σ
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0						
3.0 to 3.5						

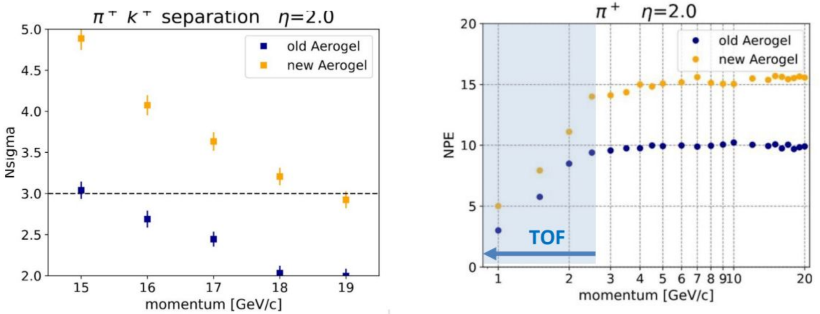
Essential for semi-inclusive physics due to absence of kinematics constraints at event-level



Acceptance in oseudo-rapidity defined by barrel and beam pipe



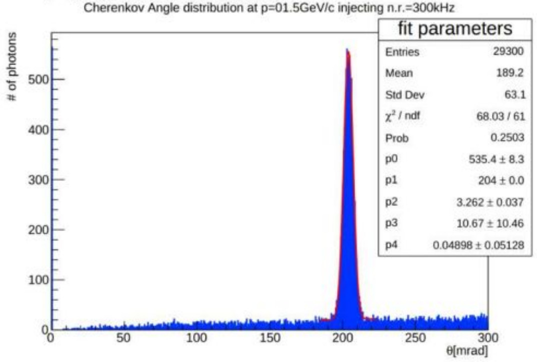
ePIC simulations

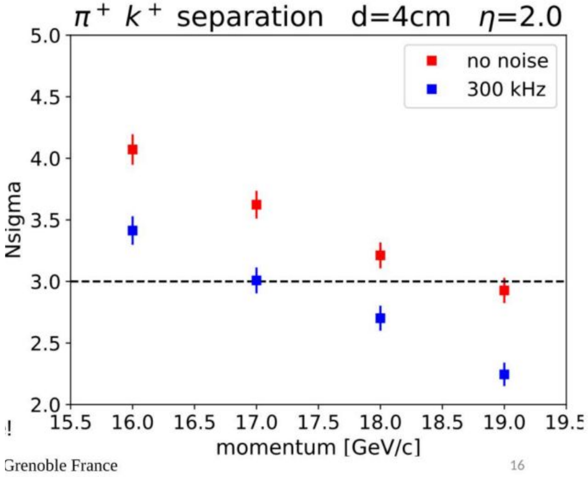


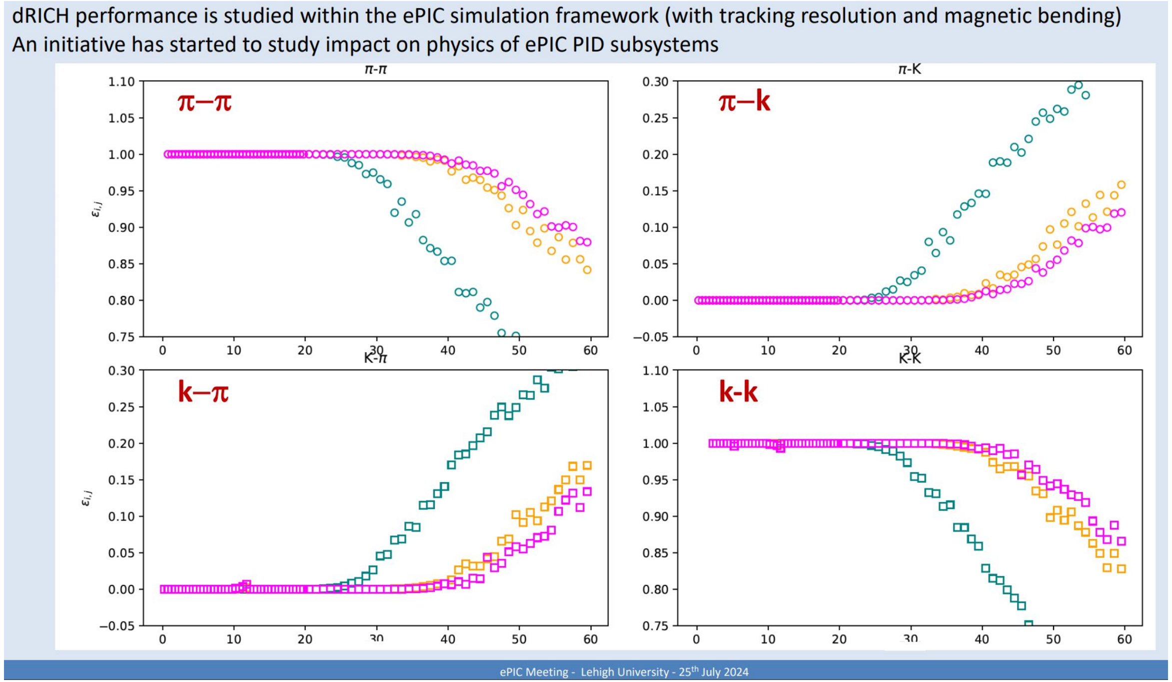
Simulation studies (dRICH performance)

Intrinsic noise of SiPM

- → 300 kHZ of noise
- → 1ns time window





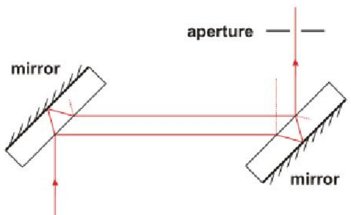


Detailed simulation studies have been made. This is an ongoing effort. A potential synergy between pfRICH and dRICH.

Particle Identification with the ePIC detector at the EIC; DOI: https://doi.org/10.48550/arXiv.2410.20410

Thank you!

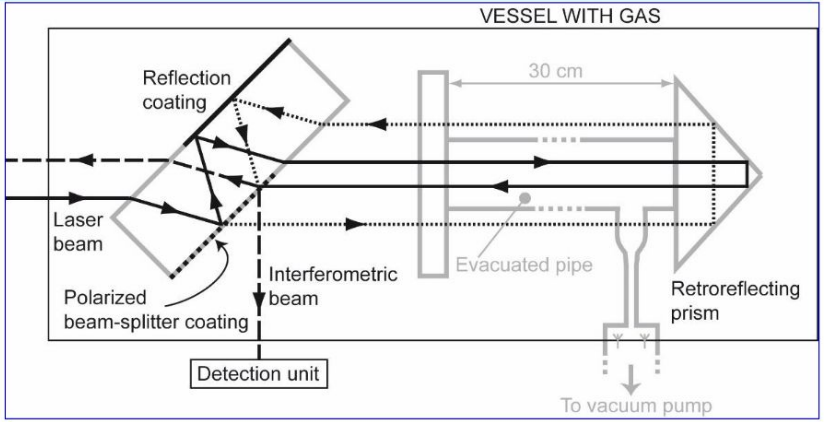
Jamin Interferometer



Jamin interferometer (1856)

Jamin interferometer:

- classical interferometer for gas refractive index measurement
- insensitive to rotation and translation of its two optical elements.

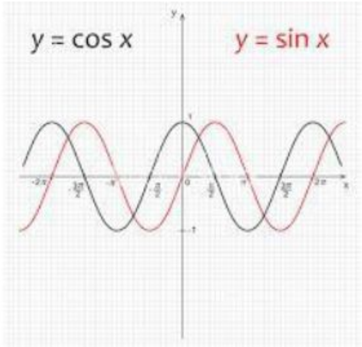


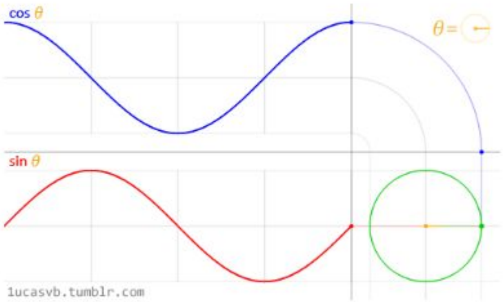
$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\Delta\phi(t)$$

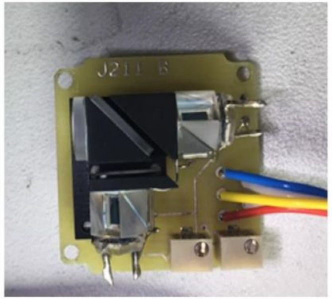
$$\Delta\phi(t) = \left(2\pi\ell/\lambda\right)\Delta n(t)$$

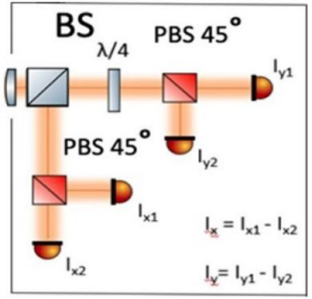
$\ell/\lambda = 10^6$ ➔ 1 fringe = 1 ppm Δn

- ❑ Input of the quadrature detector is the interference signal, composed from two linearly polarized beams, with orthogonal polarization with respect to each other
- ❑ In the detector both beams are splitted to X and Y component, giving final electrical output of two sinus signals (shifted by $\pi/2$ with respect to each other)
- ❑ Adding both of the signals digitally on 2D imaging plane gives a circle
- ❑ Advantage of quadrature detection lies in giving information of the direction of circulating → the change of refractive index δ is positive or negative





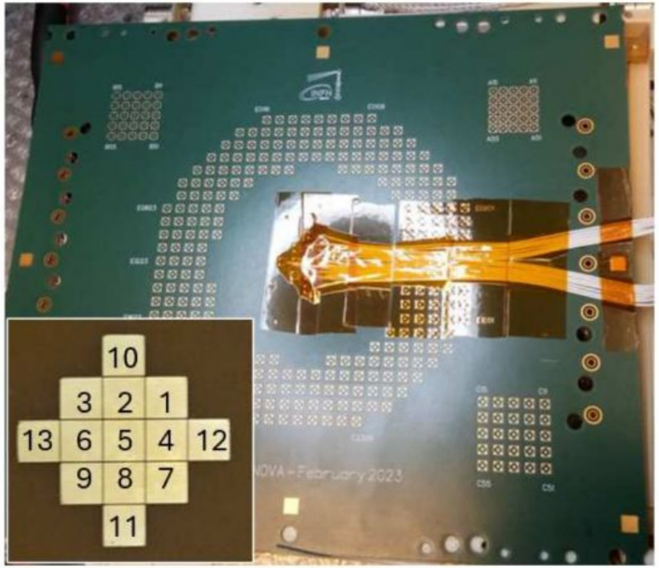


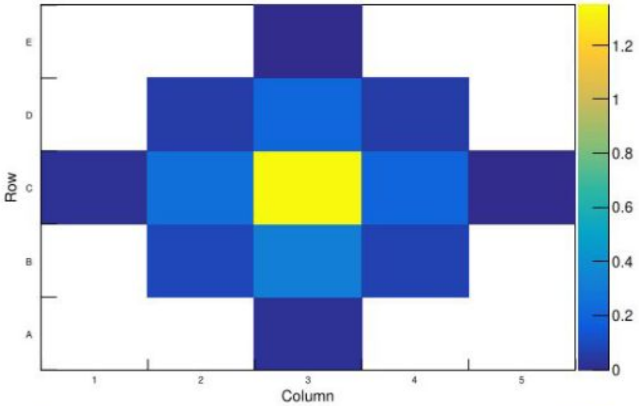


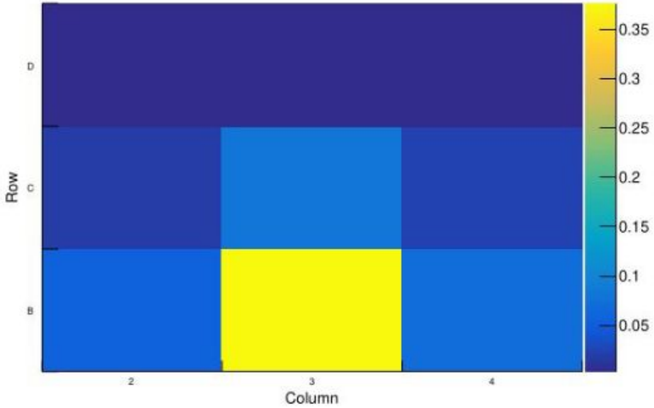
LAPPD in Magnetic field

LAPPD in Magnetic Field: Changes compared to beam test

LAPPD 153 used in magnetic test has 10 micro pore diameter.
Readout pads are 6mmX6mm

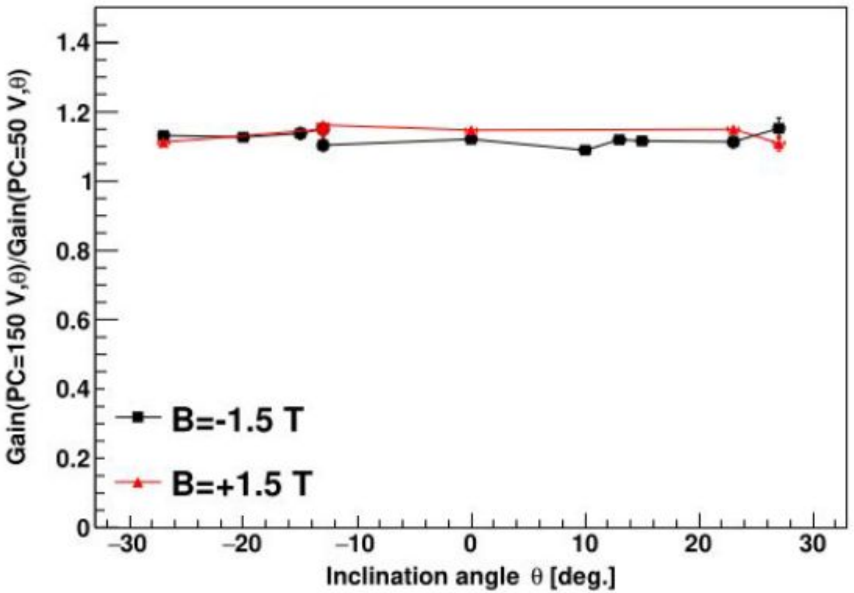


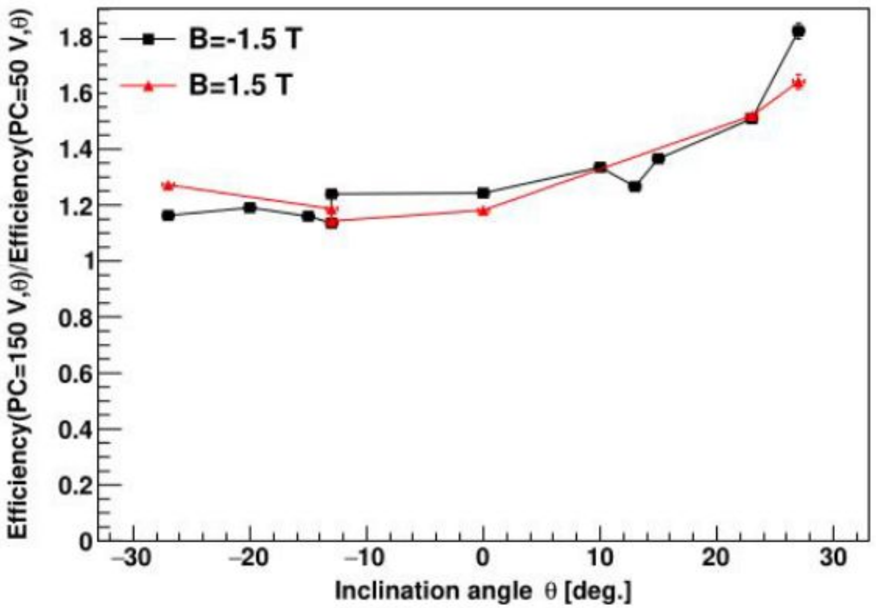




LAPPD in Magnetic field

LAPPD in Magnetic Field: Effect of Photocathode Voltage

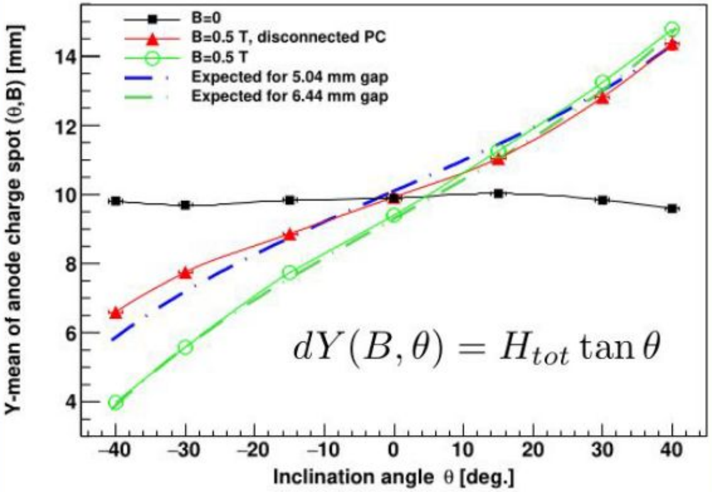




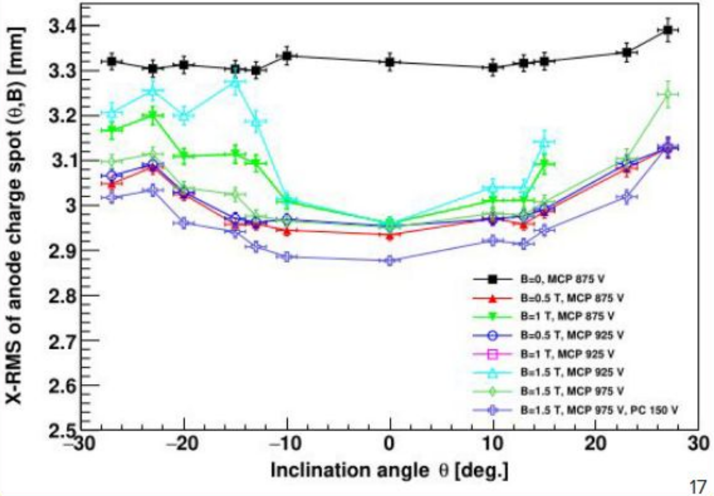
LAPPD in Magnetic field

LAPPD in Magnetic Field : Geometric effects

1) Photo-electrons follow Electric field (normal to surface) in absence of magnetic field.
2) In Magnetic field (not normal to surface) they drift along field in helical path.
3) An offset is expected to mean spot position as a function of the angle of inclination.
4) W/ and W/O photocathode photoelectron drift path (H_tot) os different.

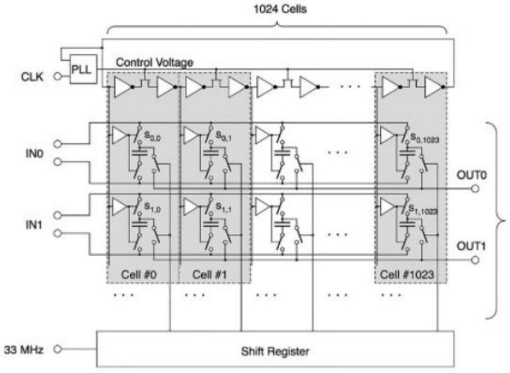


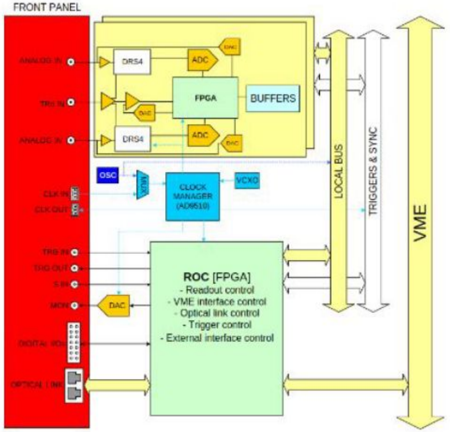
1) Magnetic field focalizes the charge spot.
2) The focalization is almost independent of Magnetic field intensity.
3) About 12% decreased RMS for field intensity larger than 0.5T.
4) Small improvement with increased photocathode voltage.

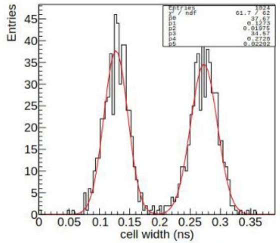


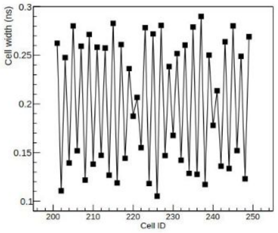
17

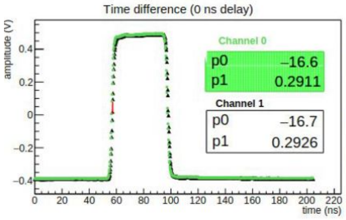
LAPPD in Digitizer

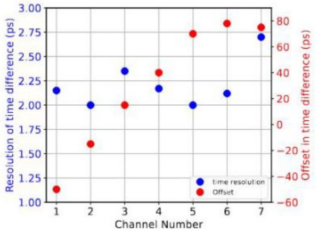


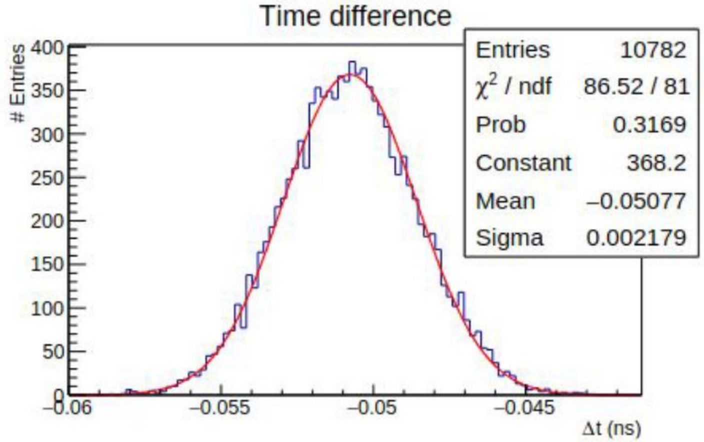


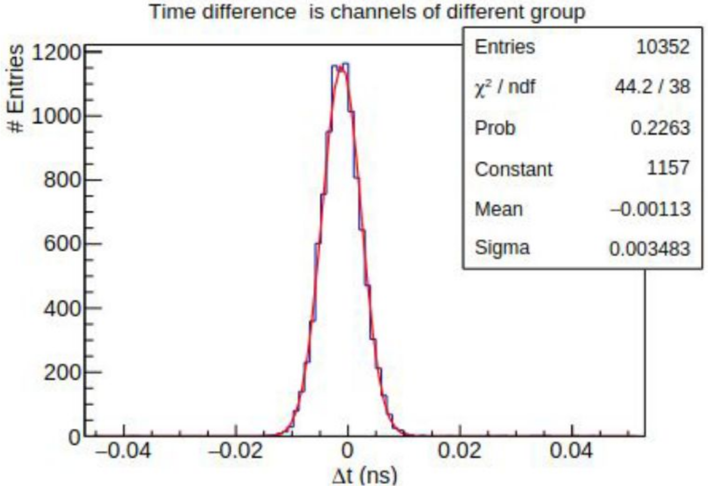




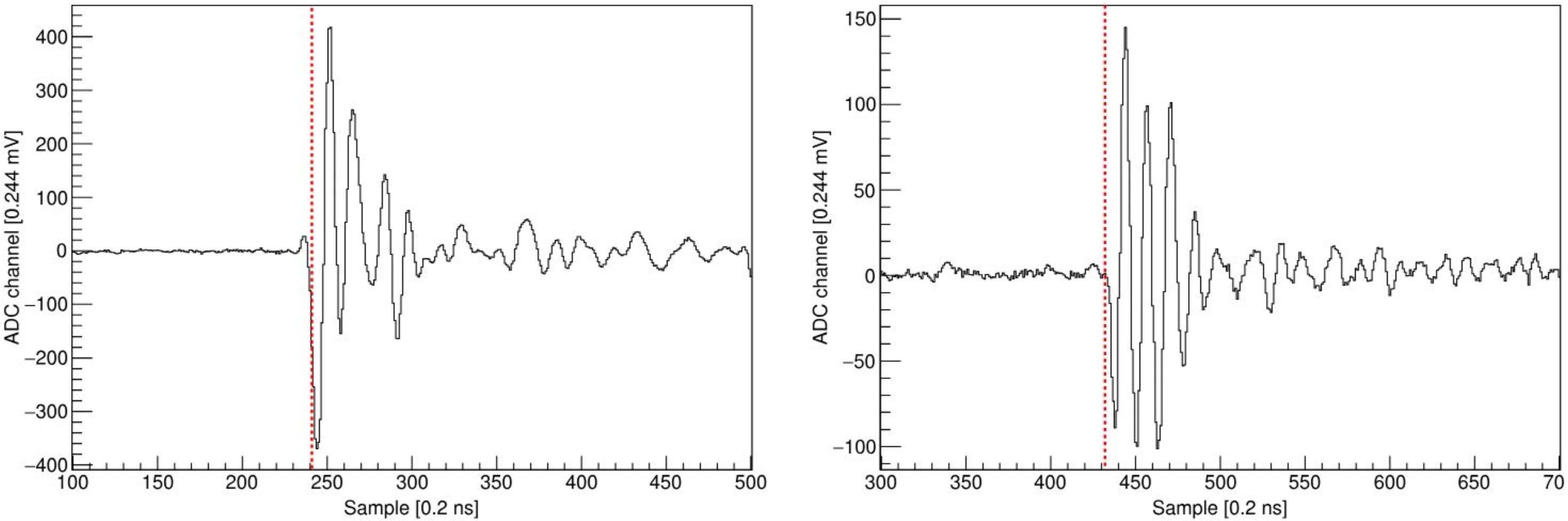






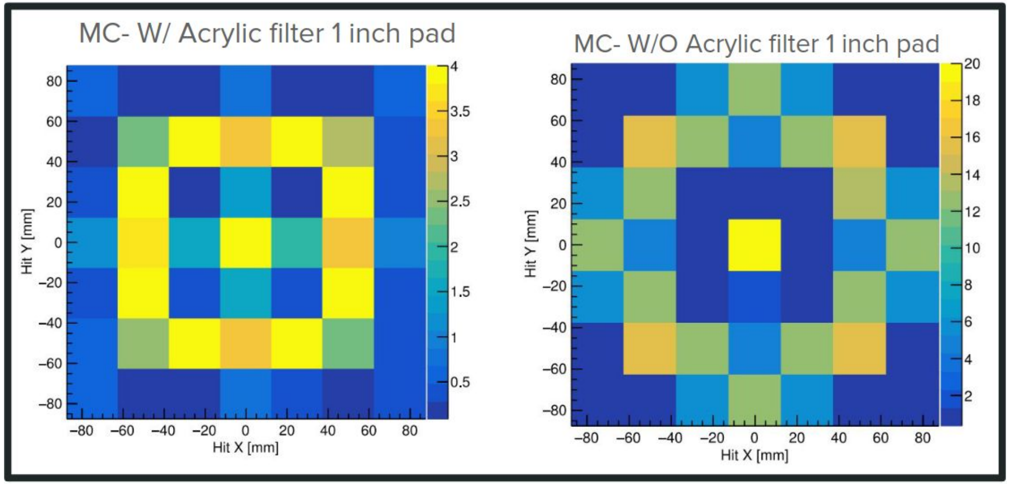


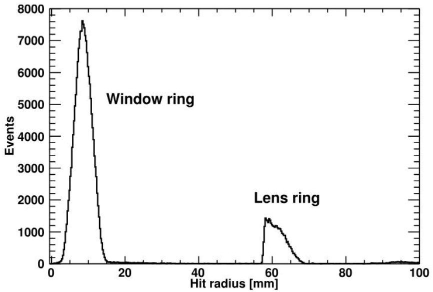
LAPPD cross-talk

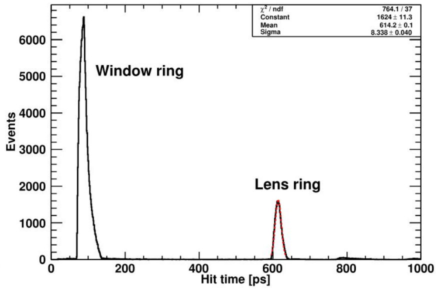


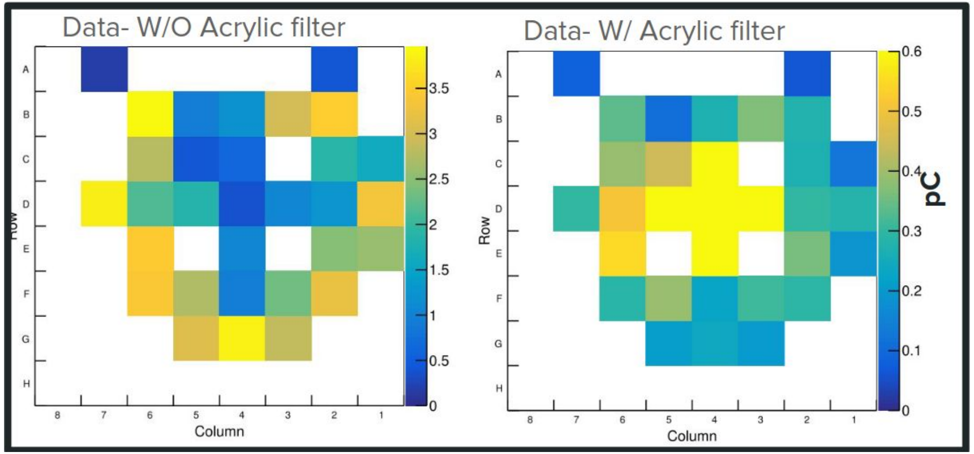
Oscillatory signal observed when beam spot is larger and small Cherenkov signal. A Directly coupled readout will be better! HRPPDs are designed for ePIC are directly coupled

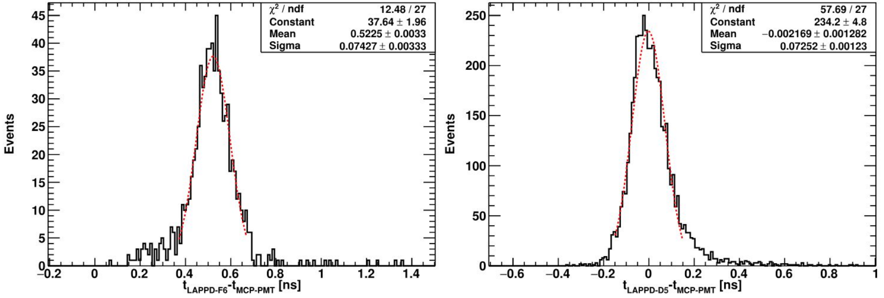
Beam test with LAPPD







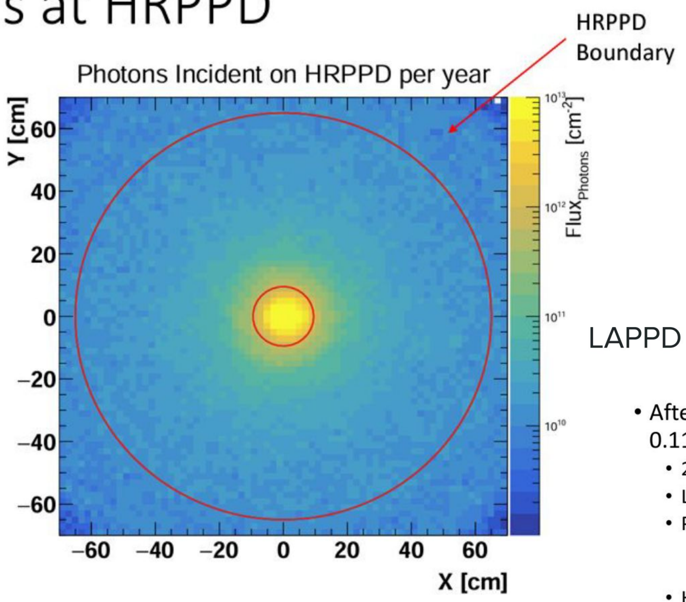




LAPPD Ageing

Total Flux of photons at HRPPD

- Scale total per second flux by 26 weeks in seconds
- Add together both contributions, and scale to 100 photons/particle at window at 10 photons/particle at aerogel
- Assuming all photons travel straight ahead (naïve assumption for now)
- Total photons incident on HRPPD in one year of running



LAPPD Ageing

- After 10 years of running, would accumulate charge of approximately 0.11 C/cm^2 at gain of 10^5
  - 26 weeks of 24hr running
  - Luminosity of 1 x $10^{34} cm^{-2} s^{-1}$
  - Photons Produced per Cherenkov inducing particle (factors in quantum eff.)
    - Window: 100
    - Aerogel: 10
  - HRPPD Gain of 10^5
- At maximal gain of 10^7, would slightly exceed benchmark of 10 C/cm^2