The dual-radiator RICH has been a common reference in the forward region since EIC Yellow Report
Moving from generic EIC R&D (eRD14) to targeted EIC R&D (eRD102, eRD110, eRD…)

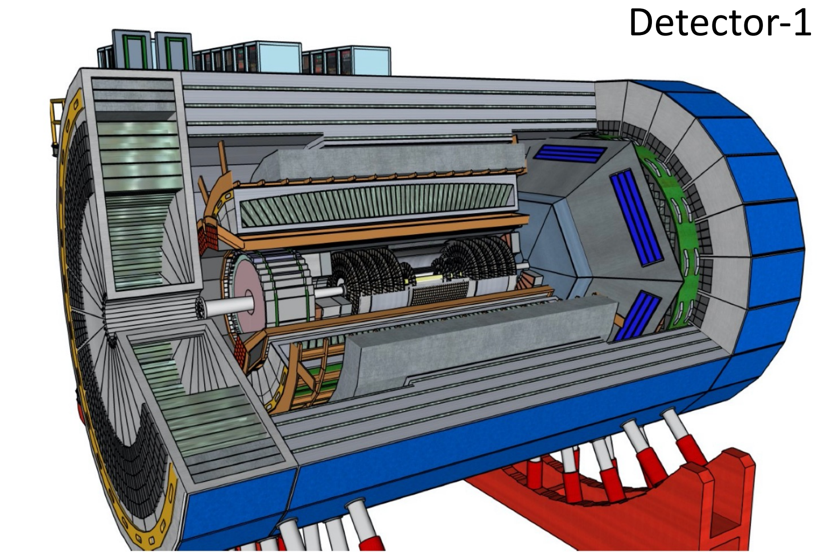
INFN

BO, CT, FE,

GE, LNF, LNS,

RM1, TO, TS

BA, CS, SA, CT



Duke University

NISER

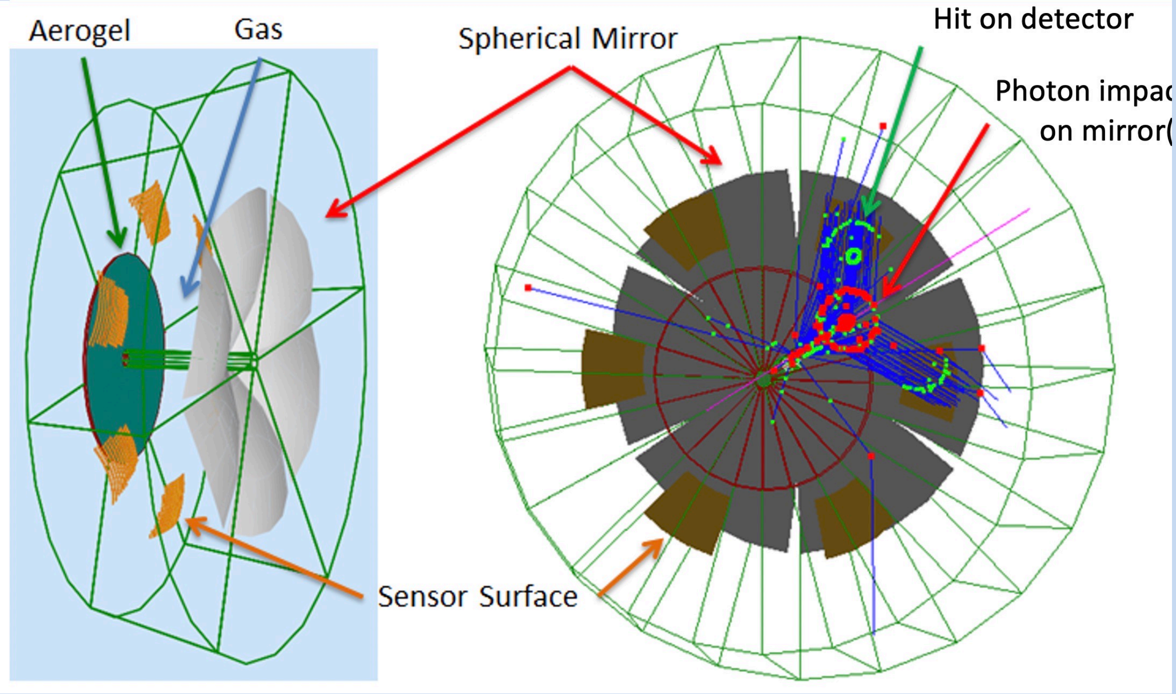
Georgia State University

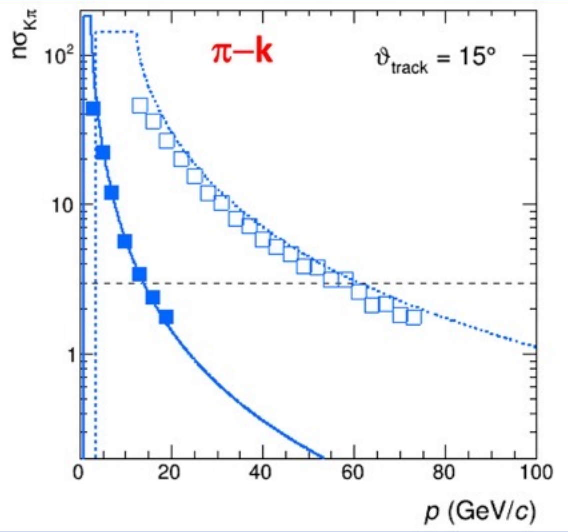
Stony Brook University

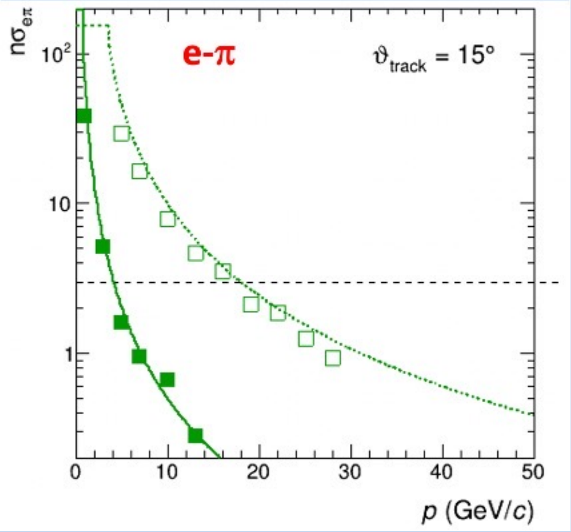
p: 41 GeV, 100 to 275 GeV	p/A beam →	← e beam	**e: 5 GeV to 18 GeV**

Contalbrigo Marco - INFN Ferrara

Two main challenges : **cover wide momentum range 3 - 60 GeV/c**
work in high (~ 1T) magnetic field







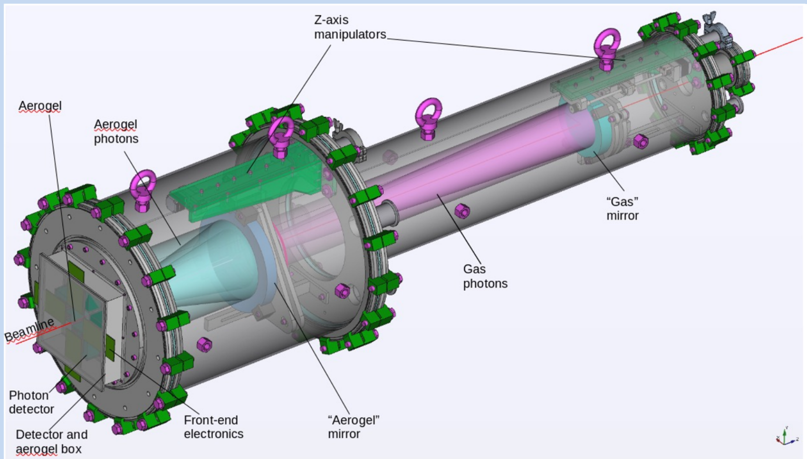
dRICH: effective solution, part of EIC reference detector

Radiators: Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6} ~ 1.0008)

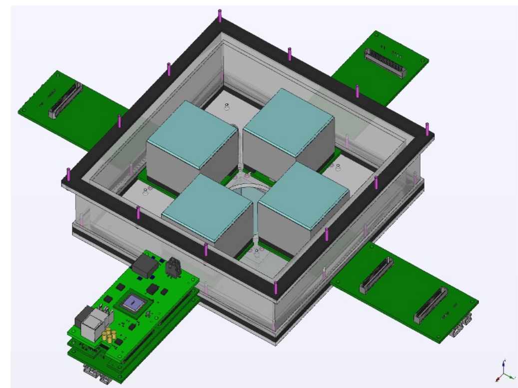
Detector: 0.5 m^2/sector , 3x3 mm^2 pixel. → SiPM option

Phase Space:
- Polar angle: 5-25 deg
- Momentum: 3-60 GeV/c

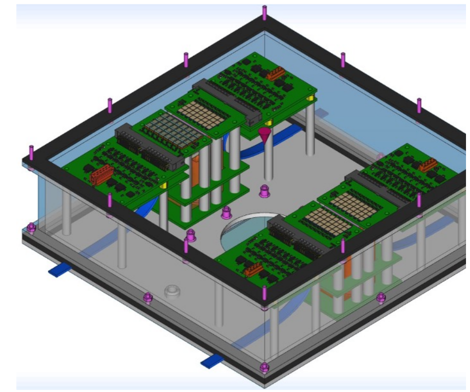
Prototipe to validate dual-radiator working principle,
optimize performance and define specifications for components

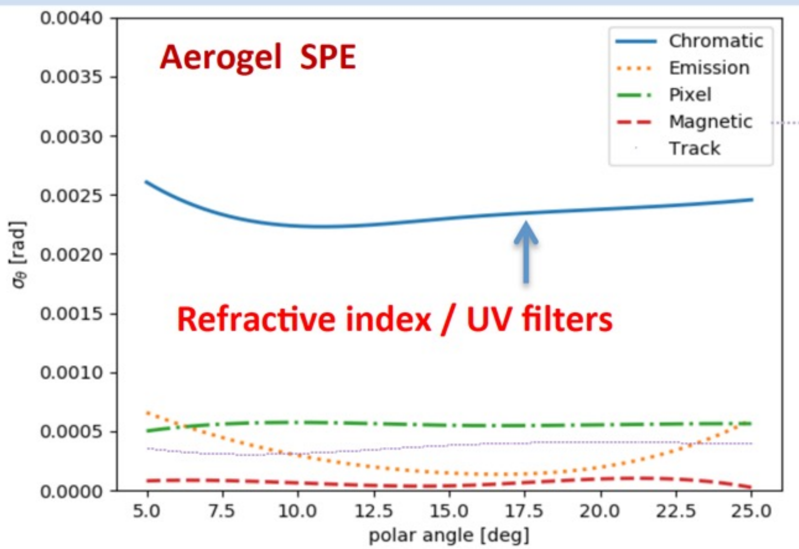


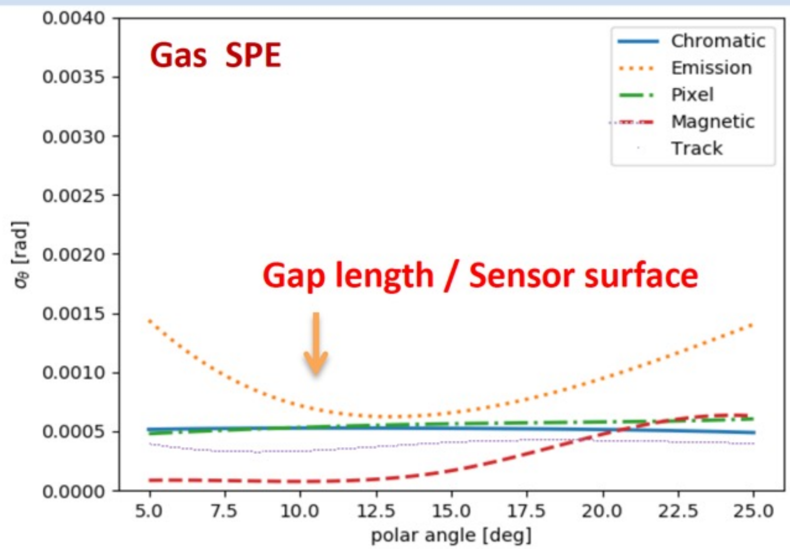
Reference detector



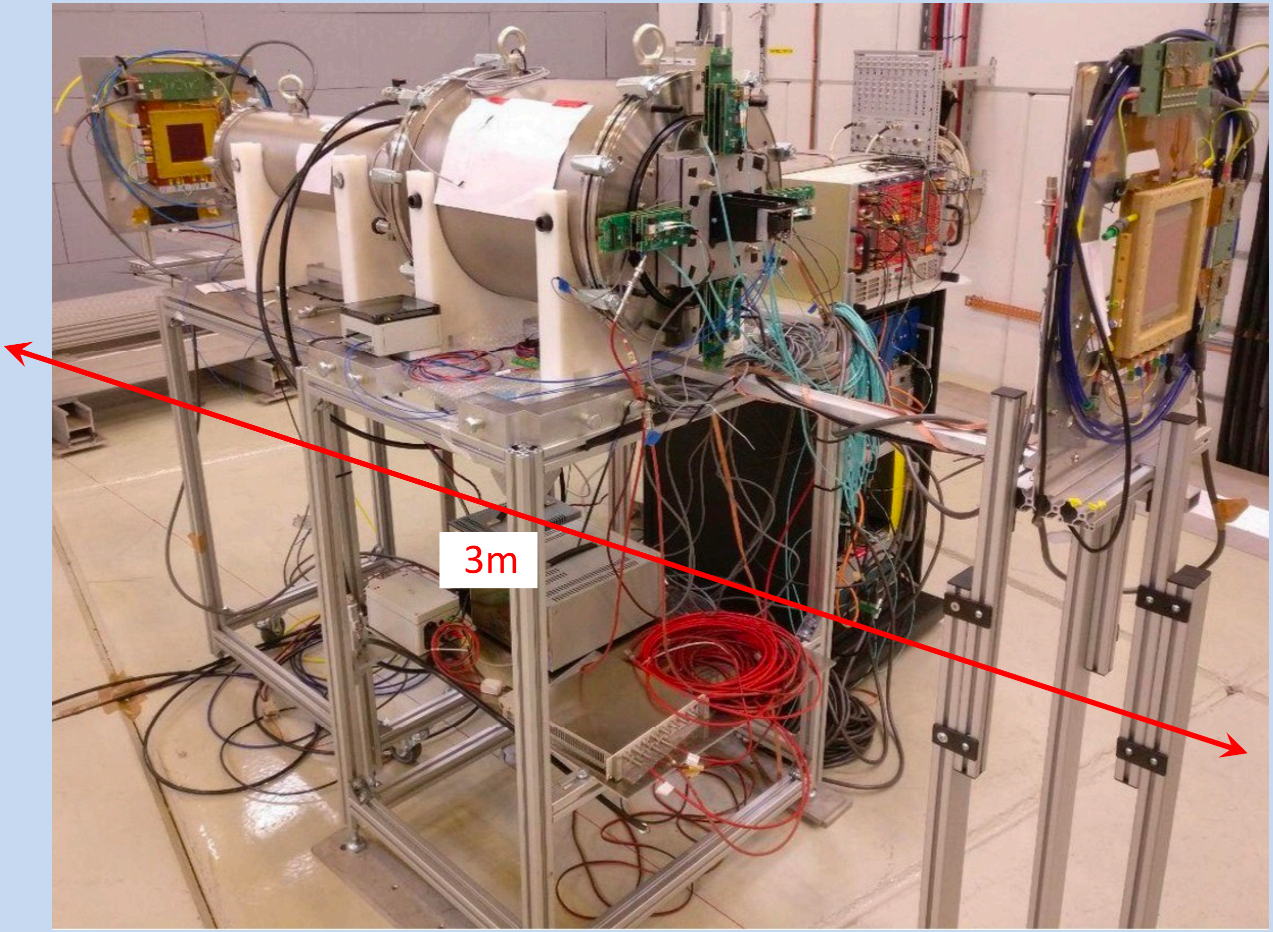
EIC driven detector







dRICH Prototype



Goals:

- Study dual radiator performance and interplay
- Study specifications and alternatives for optical components
- Test alternate single-photon detection systems
- Design parameters and optimization

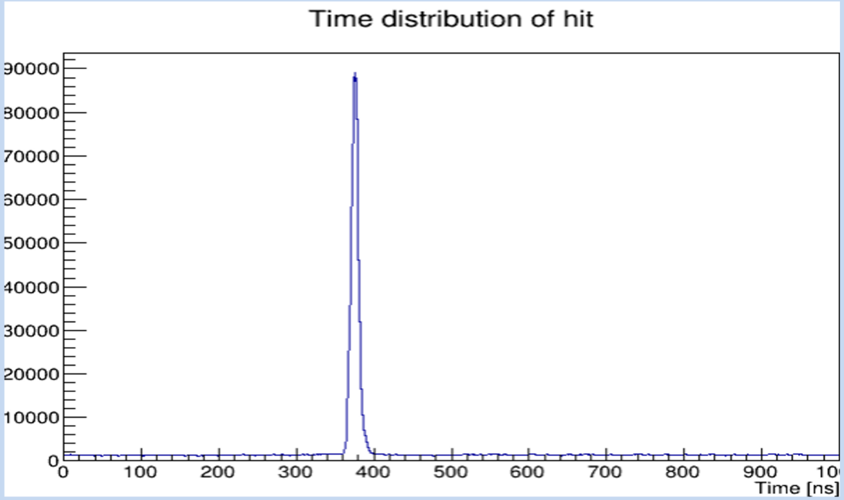
Basic system commissioned in 2021 runs

Prototype Signals

2021 beam time:

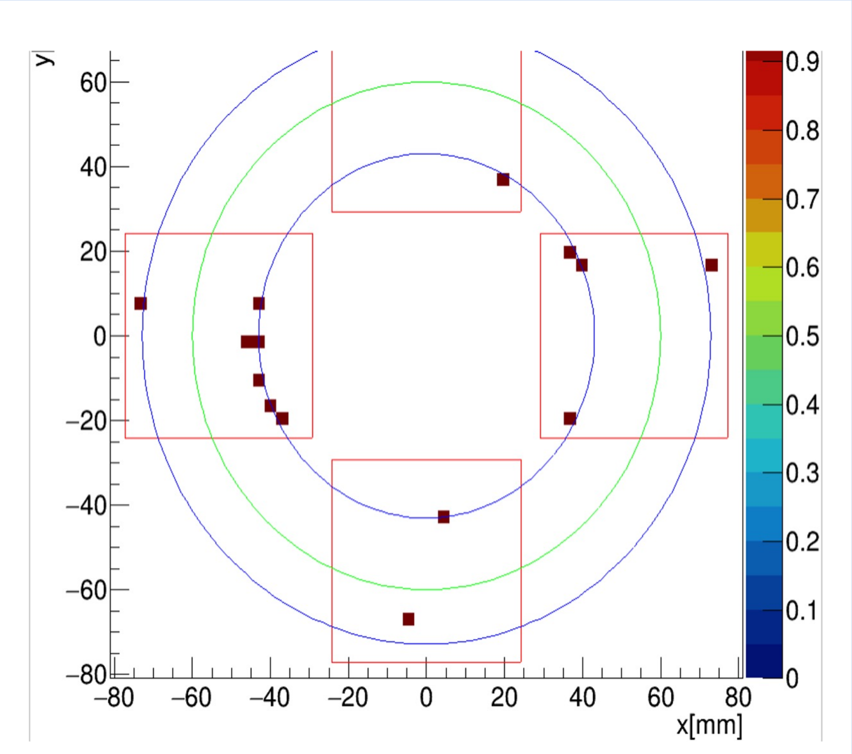
- Most of the time was parassitic
- Sensors + readout shared with eRD101
- Beam line still under commissioning

Prevented a detailed systematic study
Nevertheless preliminary performance study was possible



Example of event display

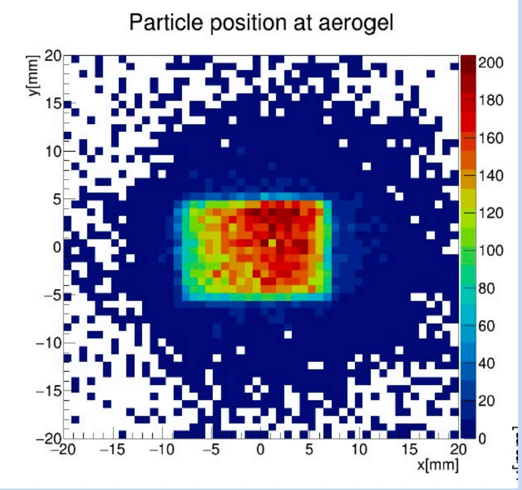
- Recorded hit
- Sensor
- Geometrical selection
- Gas and aerogel reconstructed rings

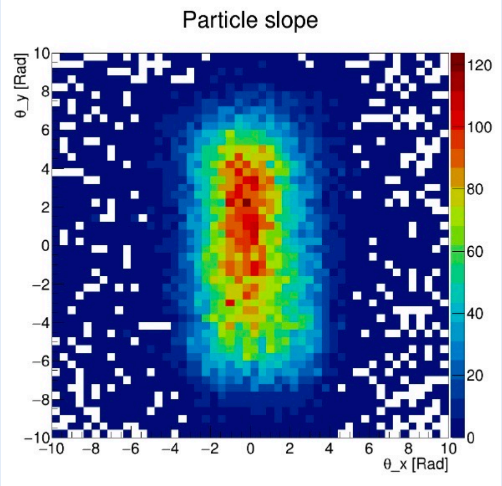


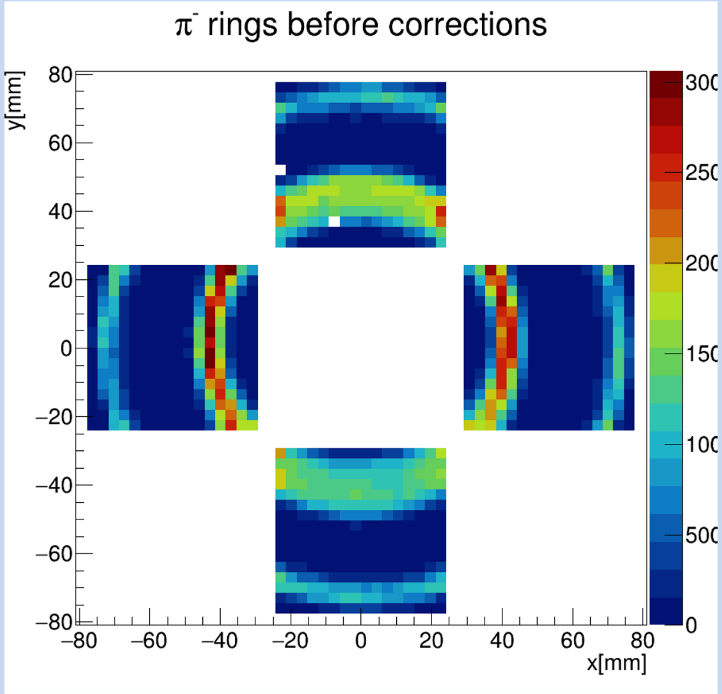
Cherenkov Rings

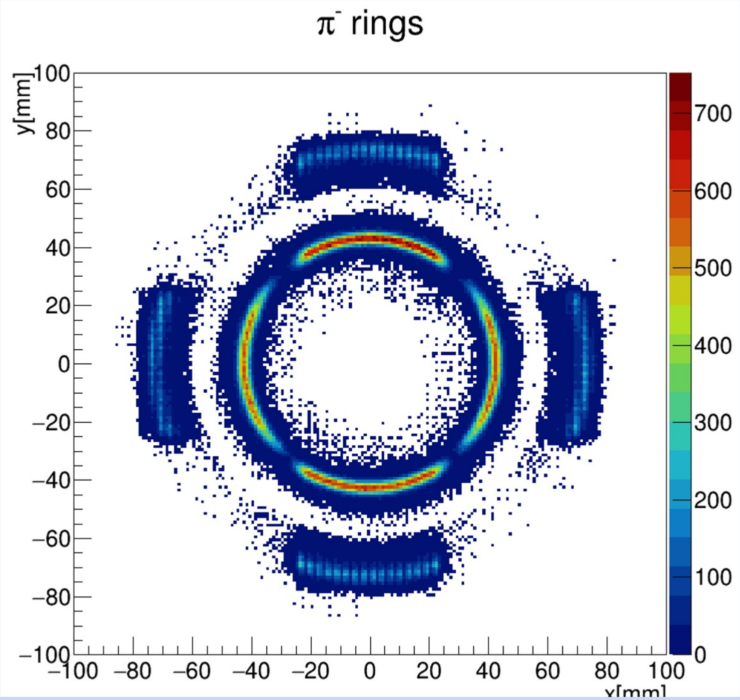
A tracking system based on two GEM detectors was used during the test beam to track the beam particles for measuring alignment and beam divergence.

The combination of the dRICH optical information and GEM track information allows to correct data on an event by event analysis.



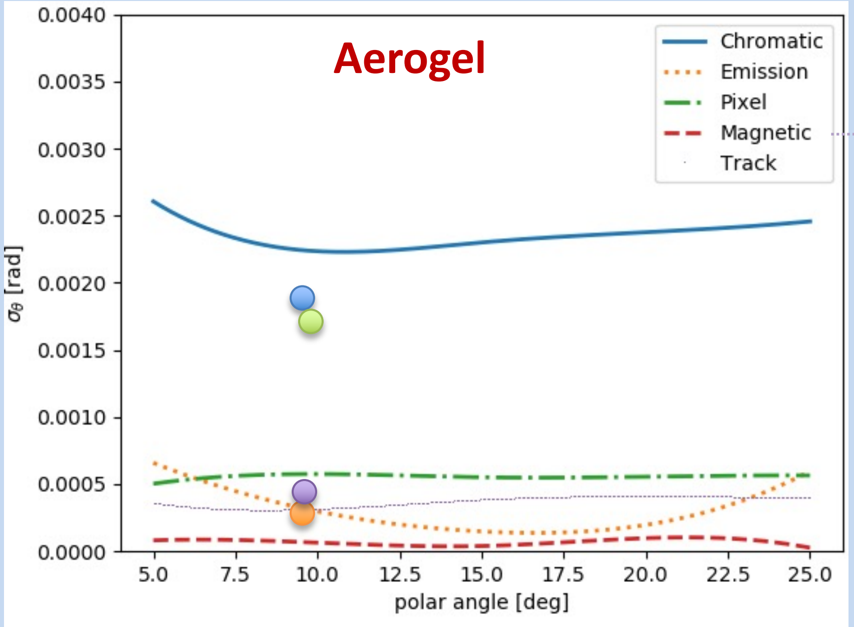


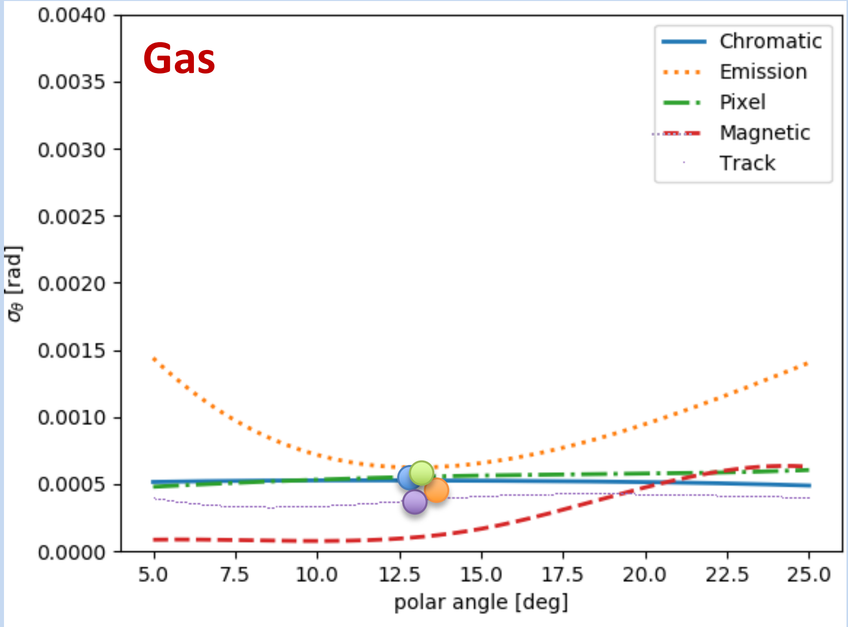




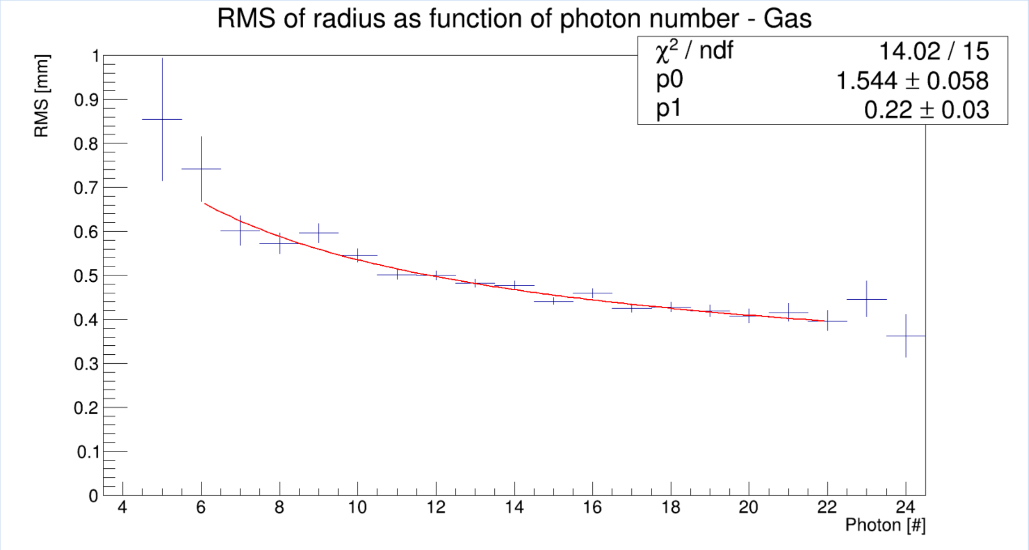
dRICH Resolution

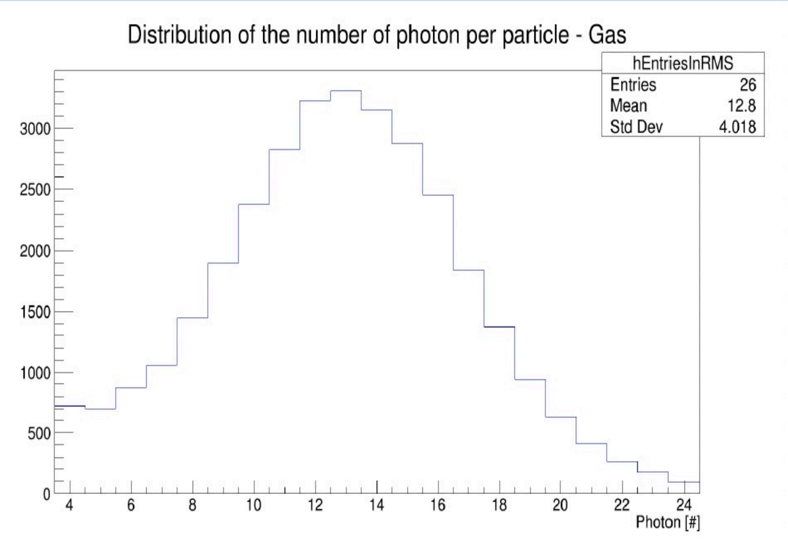
1 p.e. error (mrad)		Aerogel Demo	Aerogel dRICH	Gas Demo	Gas dRICH
Pixel	(3mm pixel)	1.9	(0.6)	0.6	(0.5)
Chromatic	(300 nm filter)	1.8	(2.2)	0.6	(0.5)
Emission	(1 cm out of focus)	0.3	(0.3)	0.4	(0.6)
Tracking	(0.5 mrad)	0.4	(0.3)	0.4	(0.4)
Total		3.0	(2.3)	1.1	(1.0)





Preliminary Performance: Gas





Fitting function: $$y = \sqrt{\frac{{p_0}^2}{x} + {p_1}^2}$$

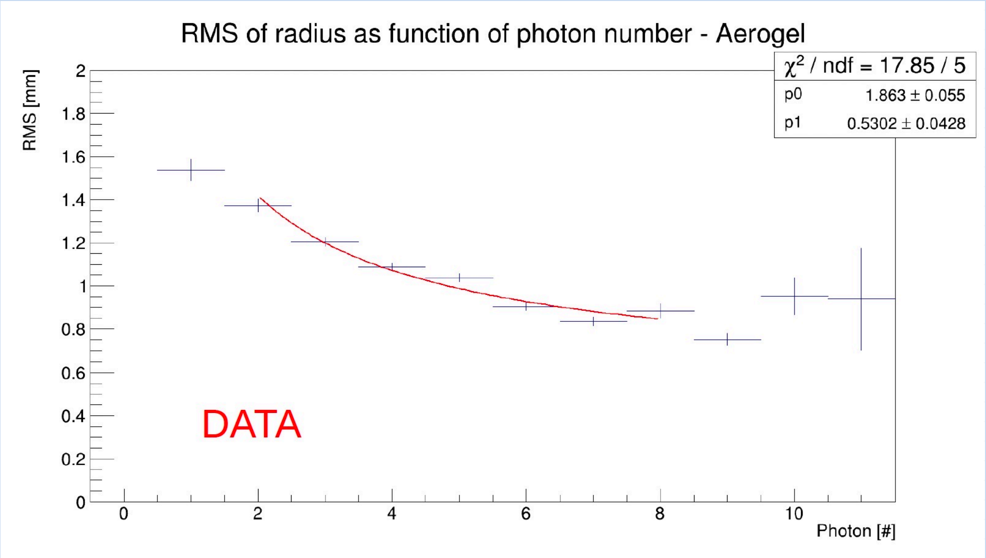
p_1 = single particle resolution constant term

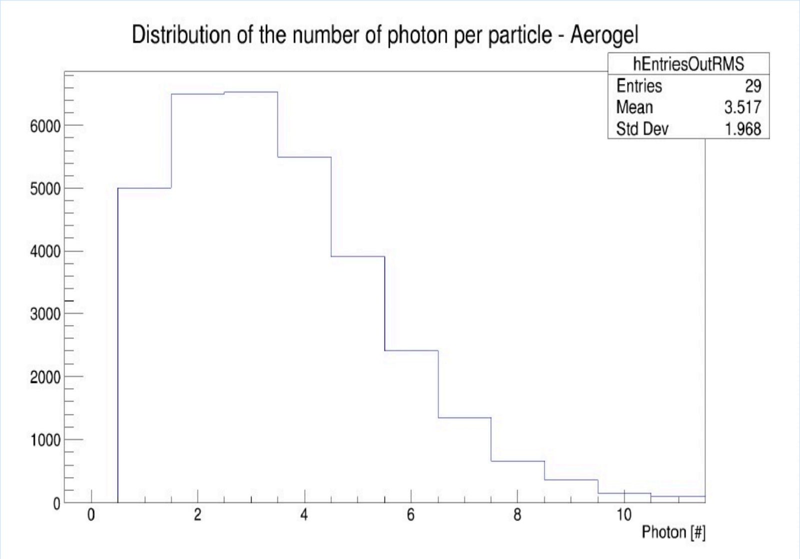
p_0 = single photon resolution

1.5 mm in radius
~ 1.2 mrad in angle (1.1 expected)
σ_{20} ~ 0.45 mrad

Gas	Data	Simulation
p_0 [mm]	1.5	1.1
p_1 [mm]	0.22	0.07
Avg photon	12.8	11.3

Preliminary Performance: Aerogel





Fitting function: $$y = \sqrt{\frac{{p_0}^2}{x} + {p_1}^2}$$

p_1 = single particle resolution constant term

p_0 = single photon resolution

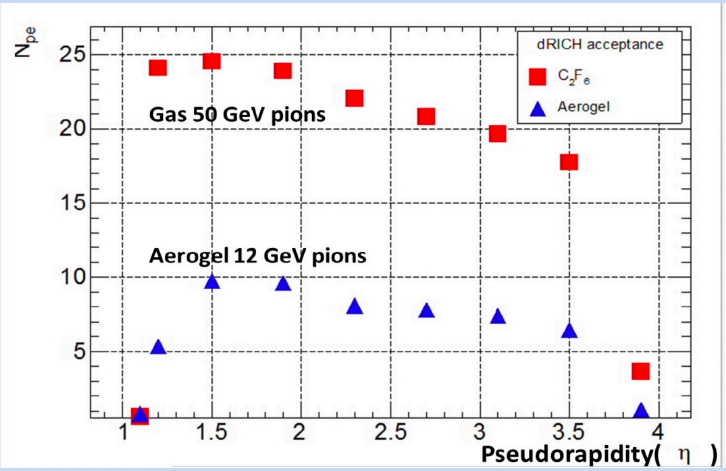
1.9 mm in radius

~ 5 mrad in angle (3 mrad expected)

σ_{10} ~ 1.5 mrad

Aerogel	Data	Simulation
p_0 [mm]	1.9	0.8
p_1 [mm]	0.53	0.26
Avg photon	3.5	3.5

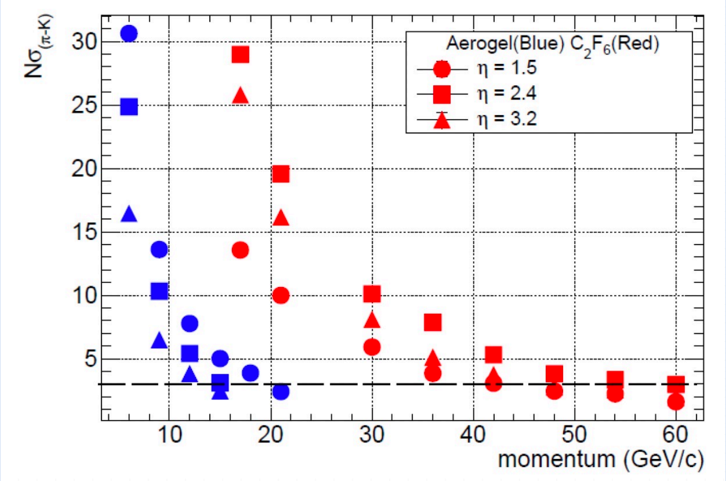
Progress with the analysis and simulation



Principle
- low-n (gas) radiator @ high-energy ○ long path for light yield
- resolution vs emission point ○ proper light focalization

Consequence
- extensive volume and not trivial geometry
- bending inside the magnetic field

Performance is strictly related to the Detector-1 global layout



Goal: study realistic implementation for Detector-1

compare with YR specifications

benchmark with prototype performance

dRICH for Detector-1

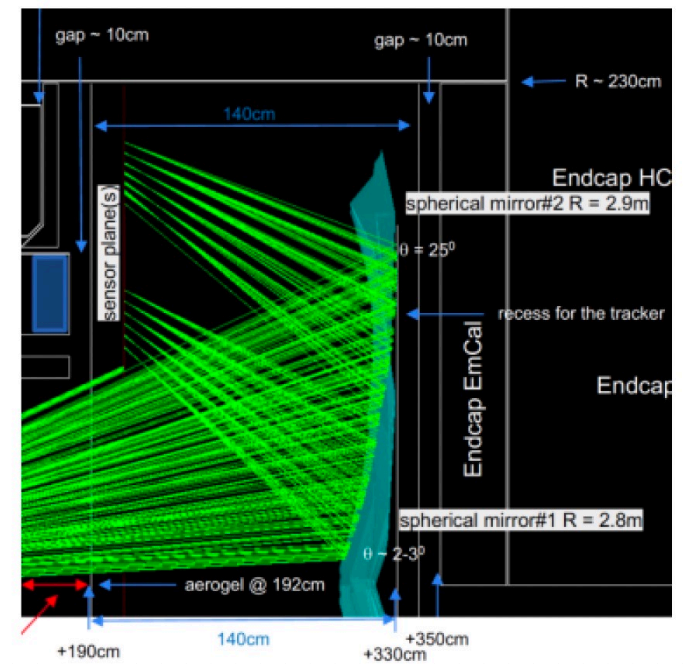
Study optics vs geometry constraints

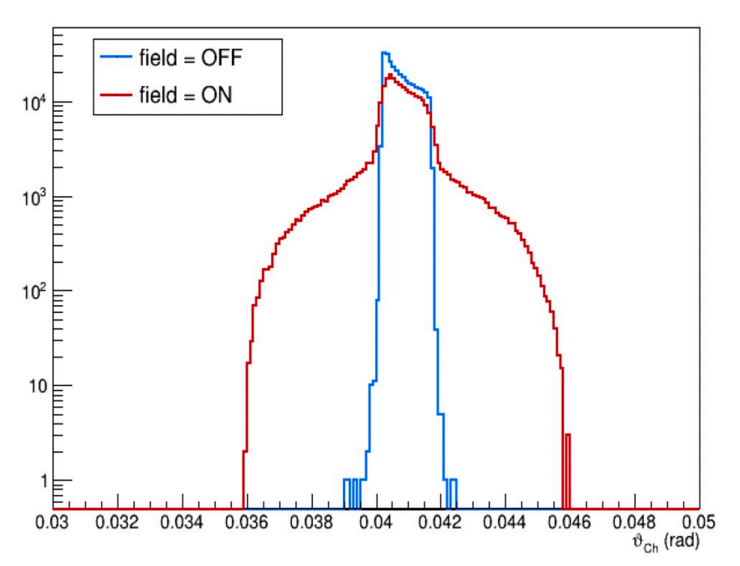
- radiator n vs thickness
- focal plane vs detector surface

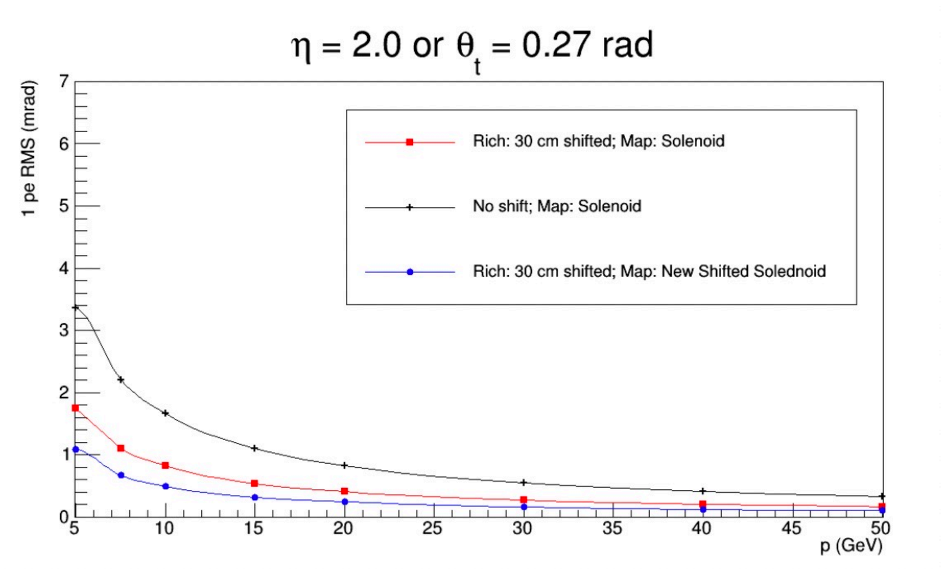
Study magnetic bending effect

.....

Chandra's talk





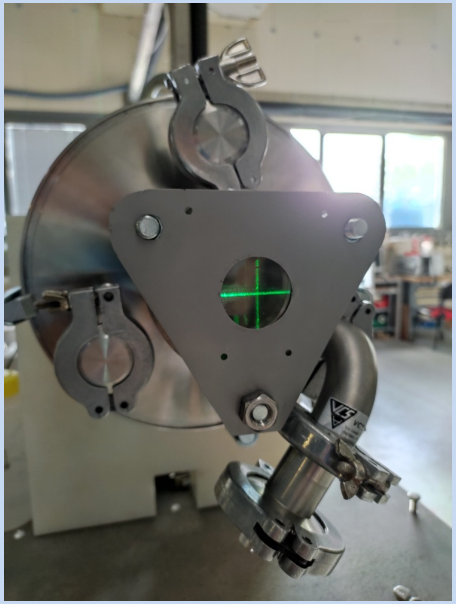


Next Steps: Prototype

Prepare for the next test-beam campaign (fall 2022)

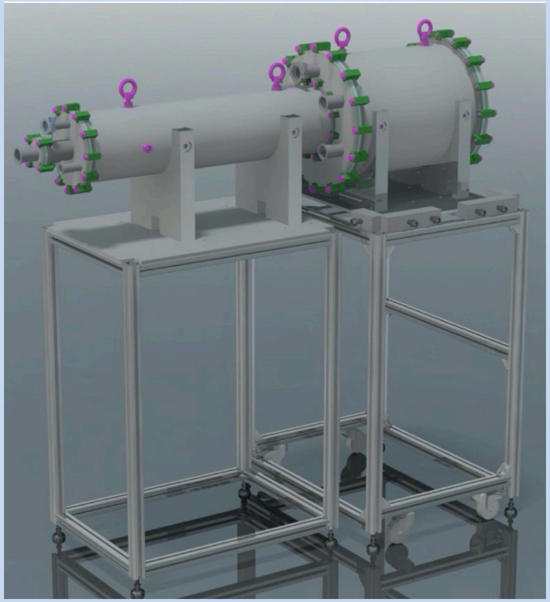
eRD102
MIlestone

Improved tools for alignment

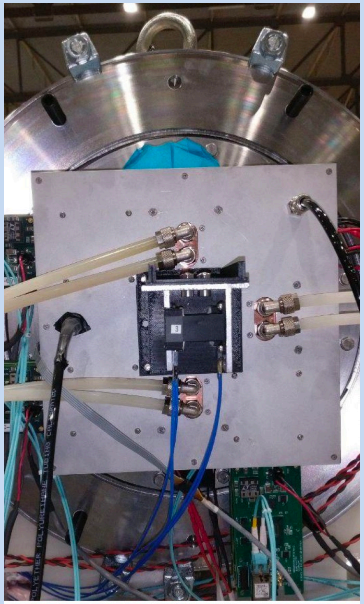


Time and gain calibration

Upgrade support structure



Improved trigger



Direct comparison between reference (MA-PMTs) and EIC-driven (SiPM)
Tagging of the beam particle

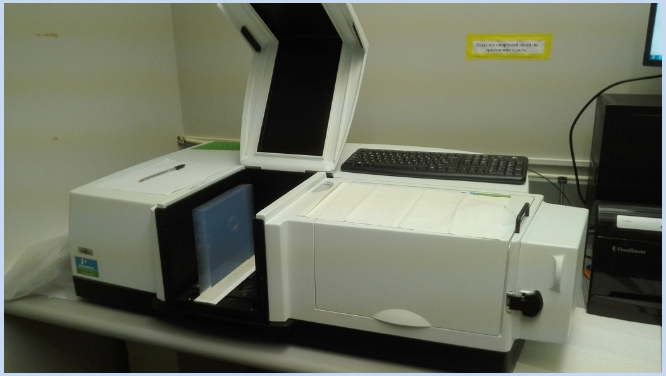
Simone's talk

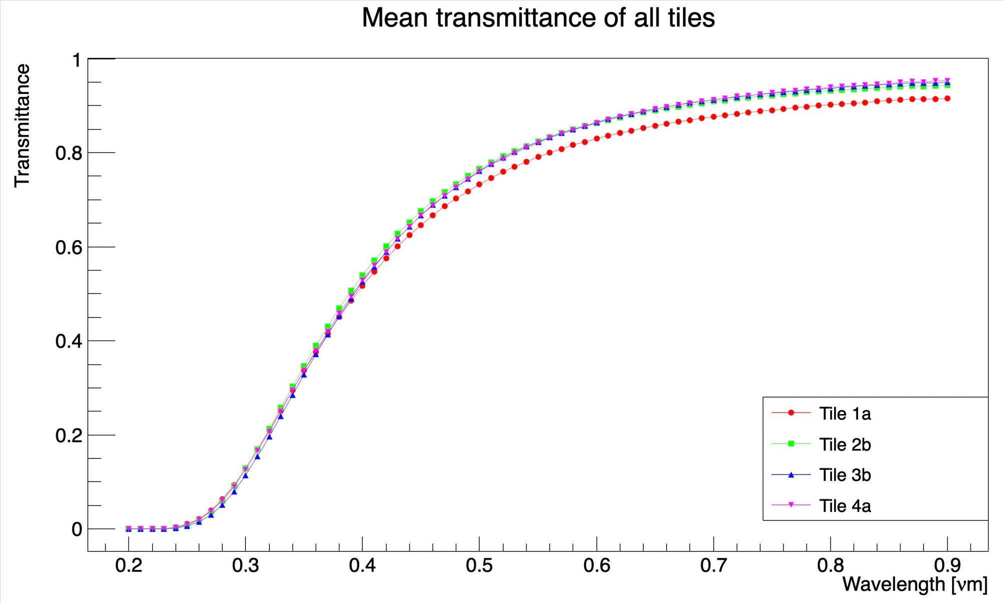
Next Steps: Radiators

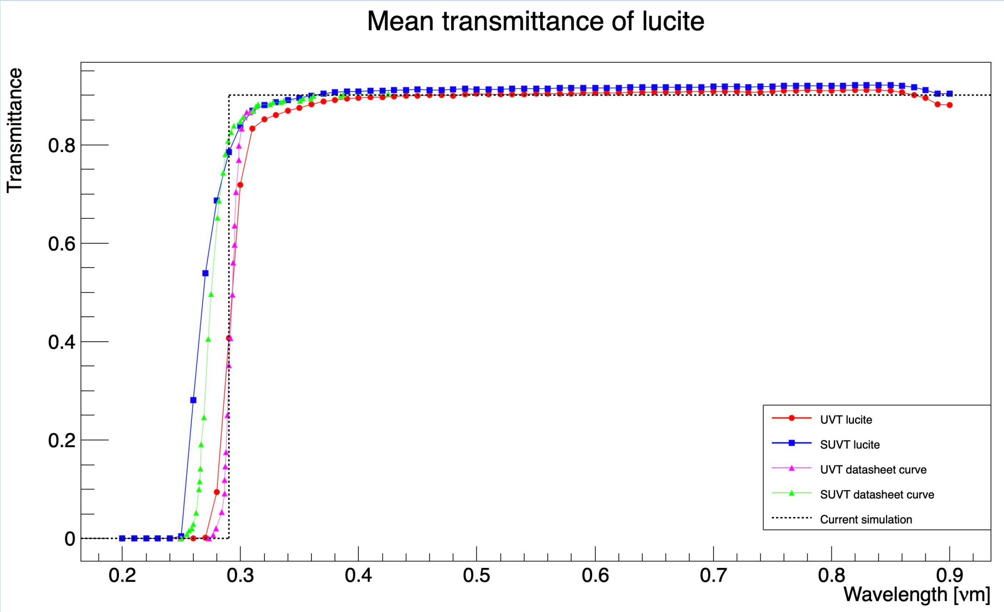
Existing facility to study detailed radiator optical properties and alternatives

Aerogel:
Safe handling and characterization (refractive index, surface planarity, forward scattering)

Interplay between radiators:
UV filters, refractive index optimization







Next Steps: Mirror & Mechanics

Existing facility to study detailed mirror optical properties and alternatives

Mirrors: Safe handling and characterization
(surface map, radius of curvature, reflectivity)

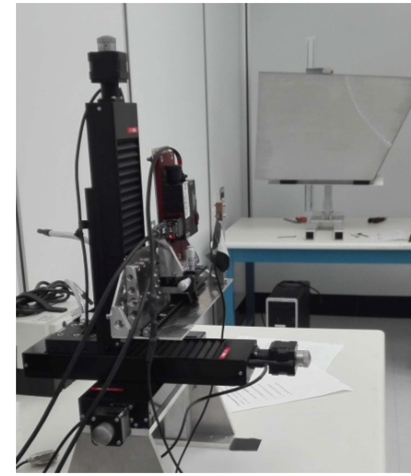
Carbon fiber (mature) vs glass skin (cost-effective)

Mechanics: Composite materials from aeronautics technology

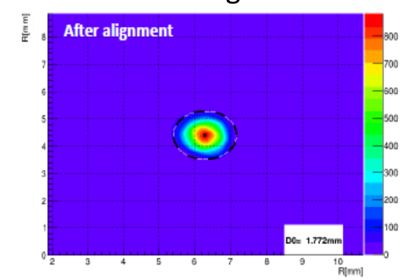
Stiff and light, supporting alignment

High-P A:r: Alternate of greenhouse gas

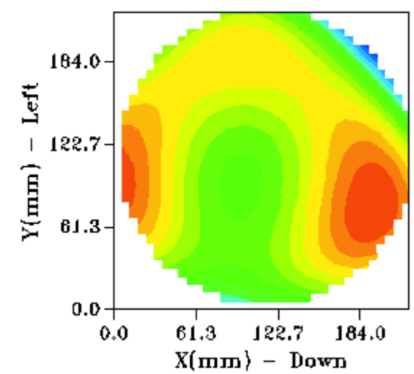
Surface Quality

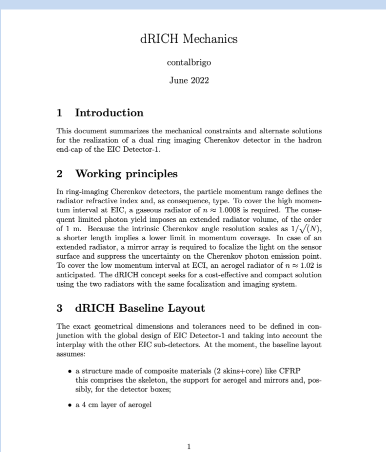


Pointlike source image



Shack-Hartmann sensor





dRICH Mechanics

contalbrigo

June 2022

1 Introduction

This document summarizes the mechanical constraints and alternate solutions for the realization of a dual ring imaging Cherenkov detector in the hadron end-cap of the EIC Detector-1.

2 Working principles

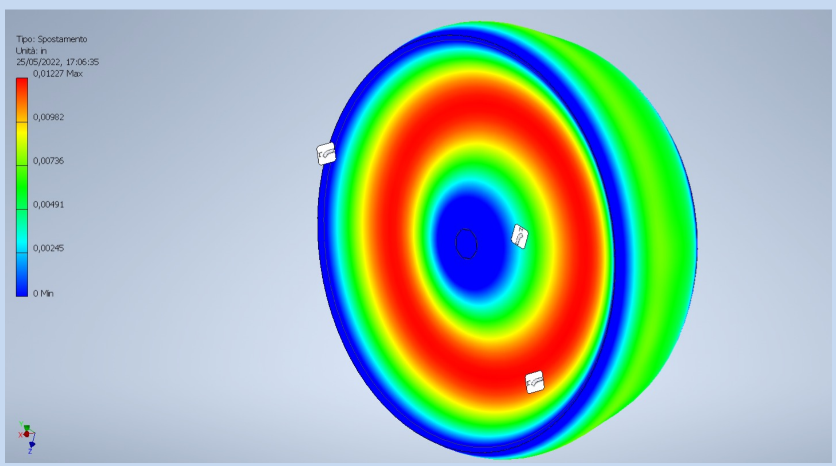
In ring-imaging Cherenkov detectors, the particle momentum range defines the radiator refractive index and, as consequence, type. To cover the high momentum interval at EIC, a gaseous radiator of $n \approx 1.0008$ is required. The consequent limited photon yield imposes an extended radiator volume, of the order of 1 m. Because the intrinsic Cherenkov angle resolution scales as $1/\sqrt(N)$, a shorter length implies a lower limit in momentum coverage. In case of an extended radiator, a mirror array is required to focalize the light on the sensor surface and suppress the uncertainty on the Cherenkov photon emission point. To cover the low momentum interval at ECI, an aerogel radiator of $n \approx 1.02$ is anticipated. The dRICH concept seeks for a cost-effective and compact solution using the two radiators with the same focalization and imaging system.

3 dRICH Baseline Layout

The exact geometrical dimensions and tolerances need to be defined in conjunction with the global design of EIC Detector-1 and taking into account the interplay with the other EIC sub-detectors. At the moment, the baseline layout assumes:

- a structure made of composite materials (2 skins+core) like CFRP this comprises the skeleton, the support for aerogel and mirrors and, possibly, for the detector boxes;
- a 4 cm layer of aerogel

1



Next Steps: Photosensor

Move from reference detectors (MAPMTs) towards EIC driven detector

- SiPM with dedicated streaming readout

eRD102
MIlestone

SiPM: evaluate radiation tolerance and mitigation procedures (annealing)

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

INFN BO/FE/TO

- LAPPD characterization

eRD110
MIlestones

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

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

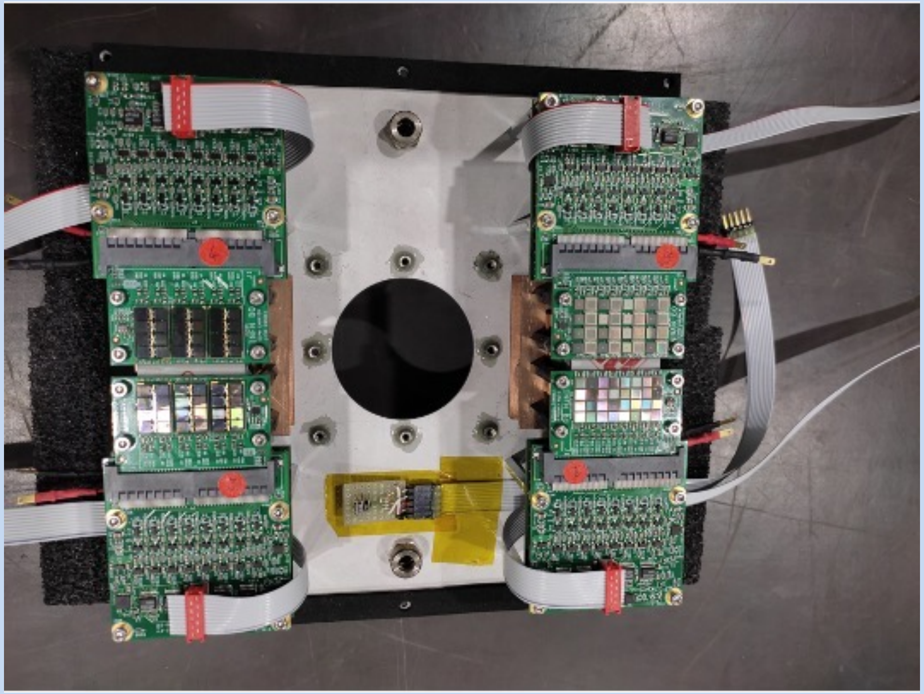
ANL – BNL – MSU – INFN TS/GE

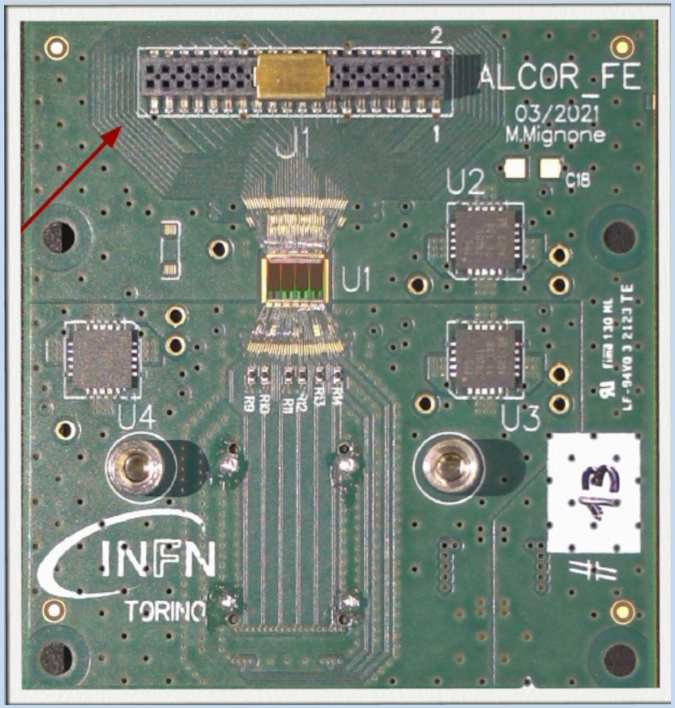
Test Cherenkov application for magnetic field insensitive sensor (SiPM)

Control SiPM high dark count to isolate single photon signal (same amplitude!)

Use a new ALCOR chip (high-rate ToT architecture) in streaming mode

50 ps time bin, > 500 kHz rate per channel, cryogenic compatible





Study performance of SiPM of various producers and types
(Hamamatsu, FBK, Bradcom, On Semiconductor)

ALCOR Chip

Towards a 3D a-SiPM

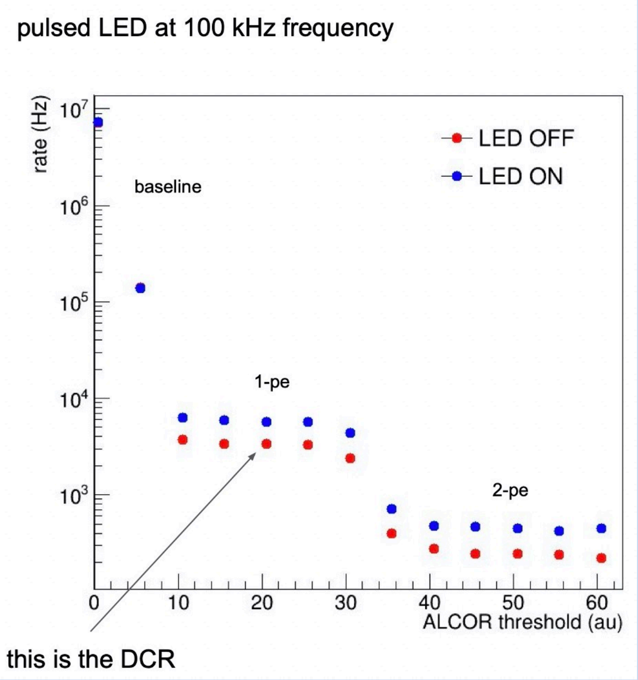
”digital tile” Developed by INFN (CSN2) for the readout of SiPMs at 77K, in the framework of Darkside

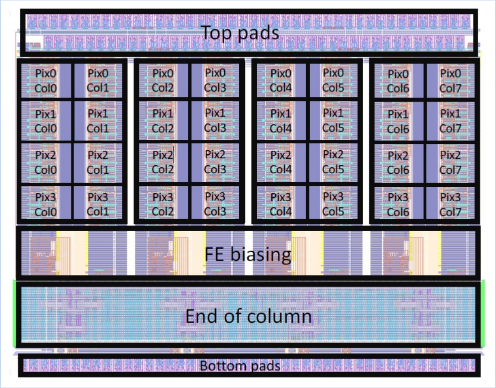
32-pixel (4x8 array) matrix mixed signal ASIC

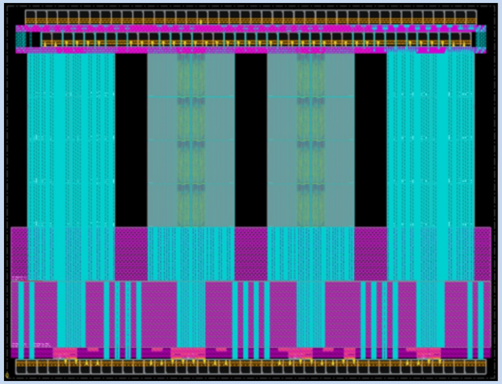
the chip performs amplification, signal conditioning and event digitisation, and features fully digital I/O Single-photon time tagging mode or time and charge measurement

4 LVDS TX data links, SPI configuration operation up to 320 MHz (TDC binning down to 50 ps)

64-bit (32-bit on time tagging mode) event and status data is generated on-pixel and propagated down the column end of Column collects digitised data from pixels and transmits it off-chip







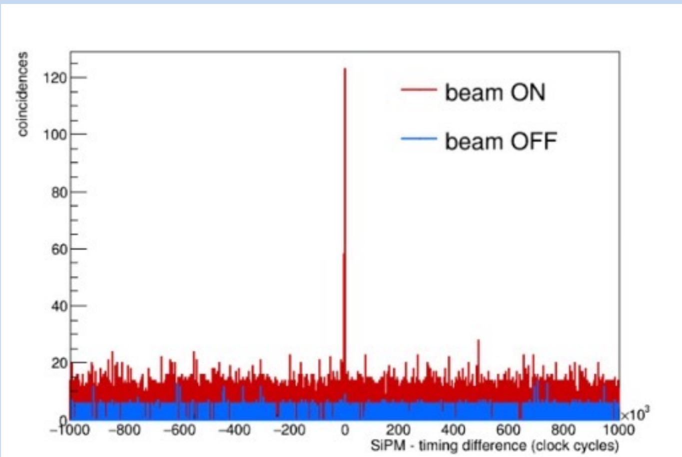
First Beam Test

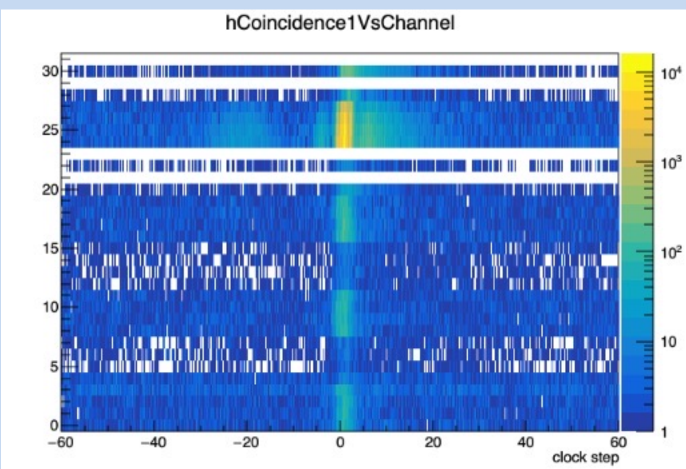
Test Cherenkov application for magnetic field insensitive sensor (SiPM)

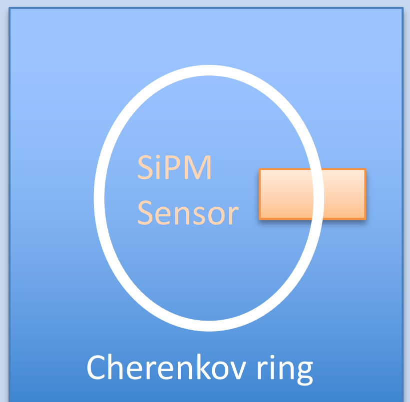
Control SiPM high dark count to isolate single photon signal (same amplitude!)

Use a new ALCOR chip (high-rate ToT architecture) in streaming mode

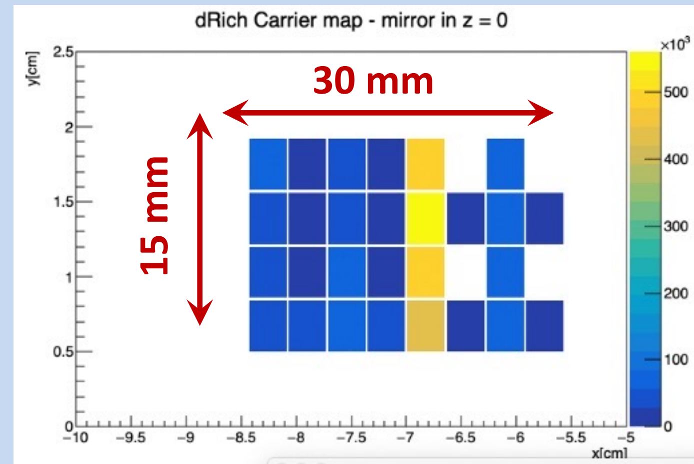
Time coincidence with beam particle

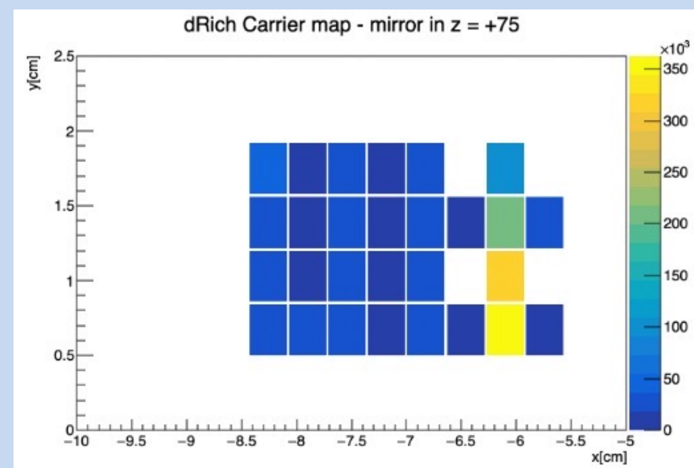






Reflected signal moves with mirror





ALCOR-v2 fro EIC applications

Optimised version ALCOR-EIC submitted at the end of May.

The new FE board has been designed and purchase order has been submitted

New Features:

Higher amplifier gain to optimise application with lower gain SiPM:
- one additional gain configuration (16/3) has been implemented
- the lower gain configuration (10/3) has also been maintained

The internal pulse generator has been modified to support both signal polarities

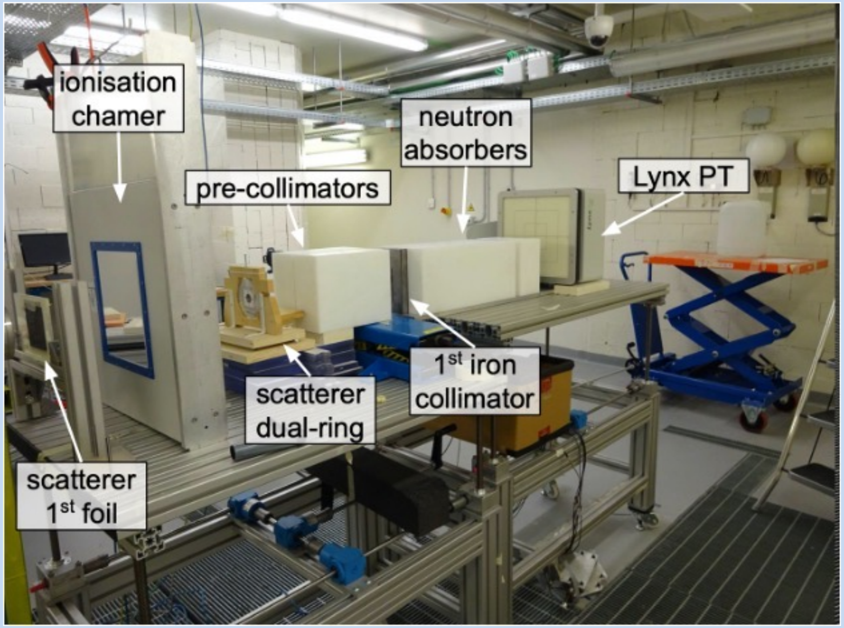
The front-end bias has been improved to reduce the noise level

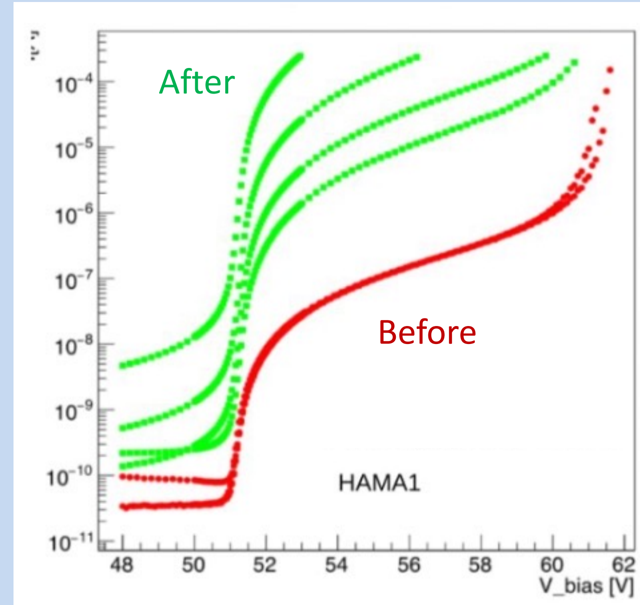
Fifo controllers have been rewritten, using gray counters, to avoid spike on FIFO enable signal

A new top level of the ASIC has been generated: the old one was not anymore compatible with the design kit. Maintained same size, pins, etc

SiPM Irradiation Campaign

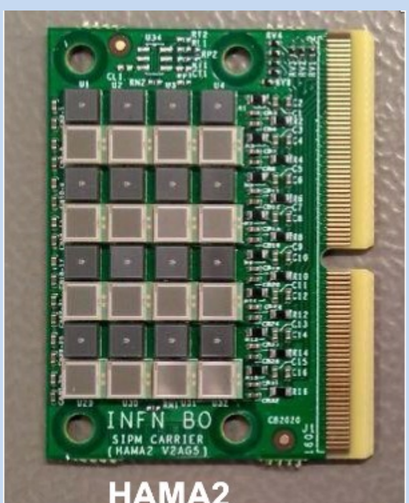
TIFPA
Proton
Beam
Facility

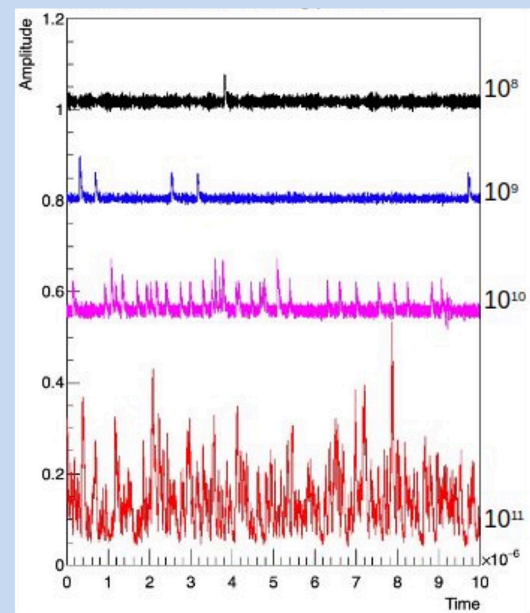




Collimated
Beam
10^9-10^{11} n_{eq}

Various SiPM

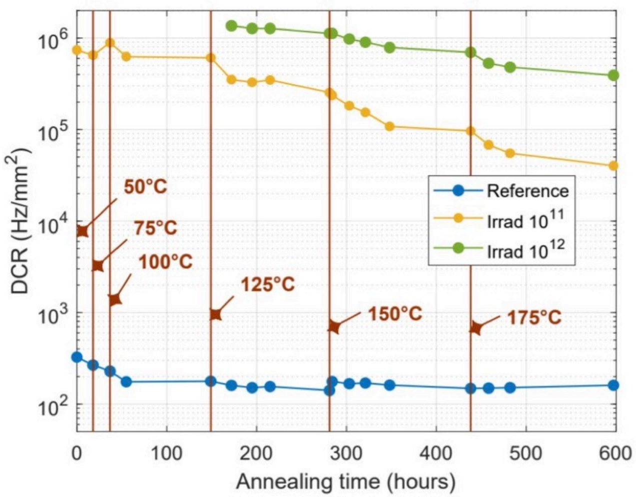


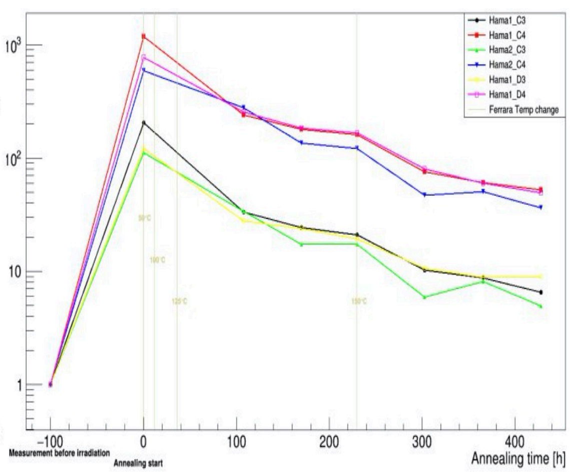


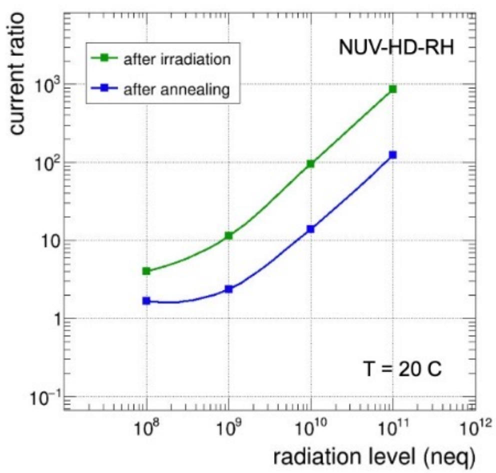
SiPM Annealing

Reproduce long-term high-T annealing (oven)

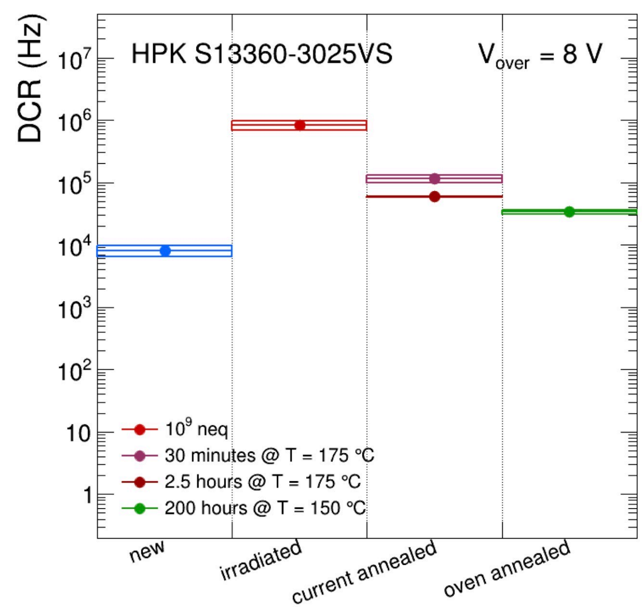
Calvi et al., NIMA 922 (2019) 243





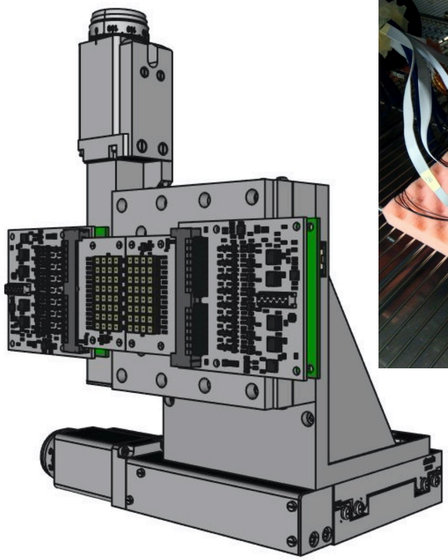


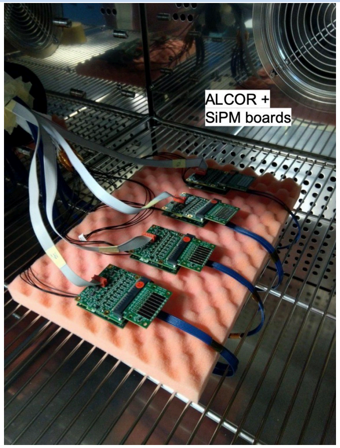
Study customized annealing (current shots)

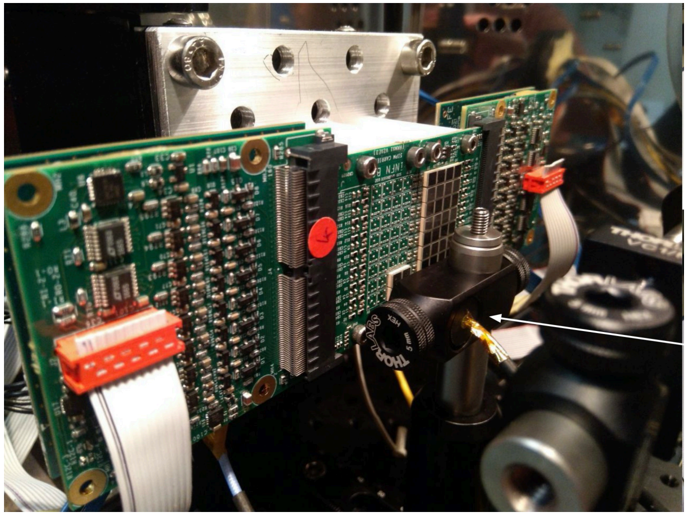


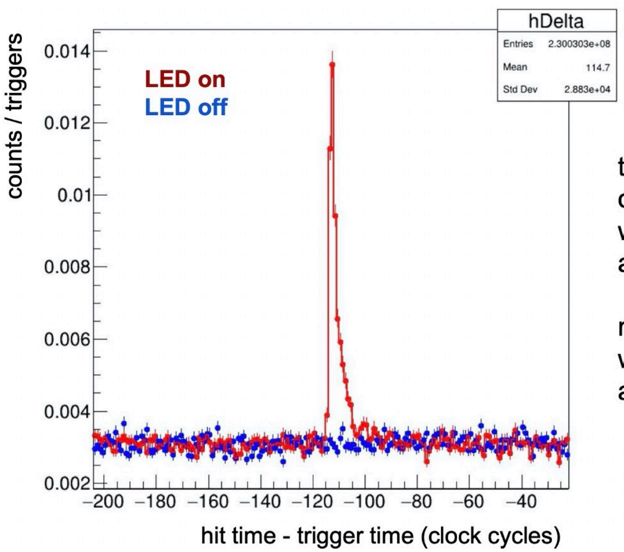
SiPM Characterization

- **use the complete electronics built in 2021 for laboratory tests**
  - SiPM carrier + adapter + ALCOR + readout
  - mount everything in the climatic chamber
  - with an LED / laser in front of the sensor
  - plus movimentation to inspect all sensors
- **study response of SiPM to pulsed light**
  - pulsed LED / laser
  - measure increase of rates
  - measure time coincidences
  - compare sensors with different NIEL
- **system is being setup in Bologna**
  - the goal is to have it as a permanent test bench
  - to be used to test SiPM response for 2022 irradiation plan
  - to be used to get ready for test beam (in case we want to)





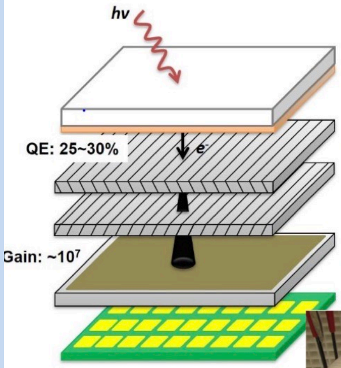




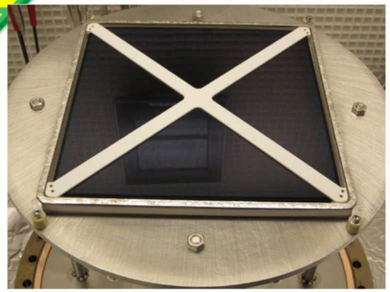
this is sensor C4
of the Hama1 irradiated board
which received NIEL = 10^{11}
and annealing at T = 150 C

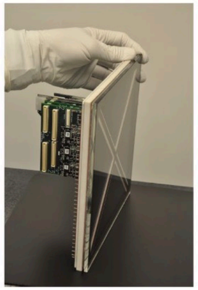
measured at T = -30 C
with Vbias = 51.3 V
and threshold for 1-pe detection

Luigi's talk

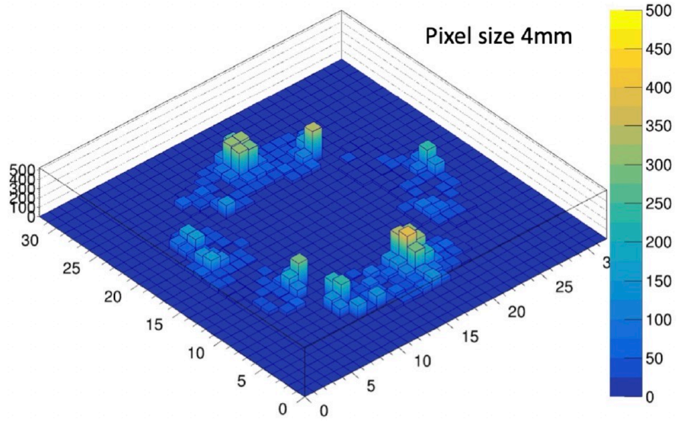


Large-area cost effective micro-channel plate detector



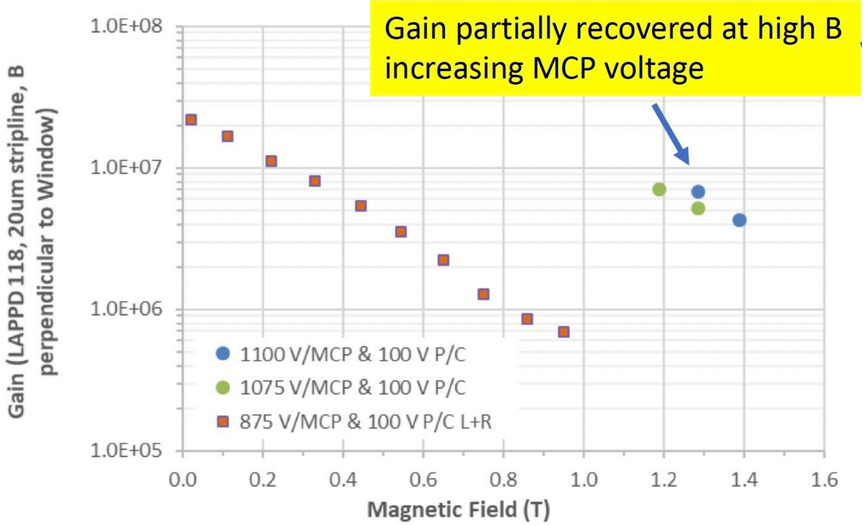


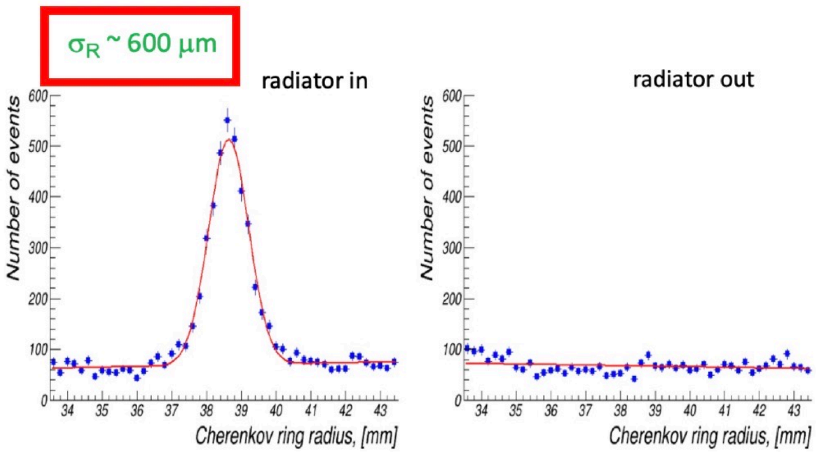
Test-beam at Fermliab (2021)



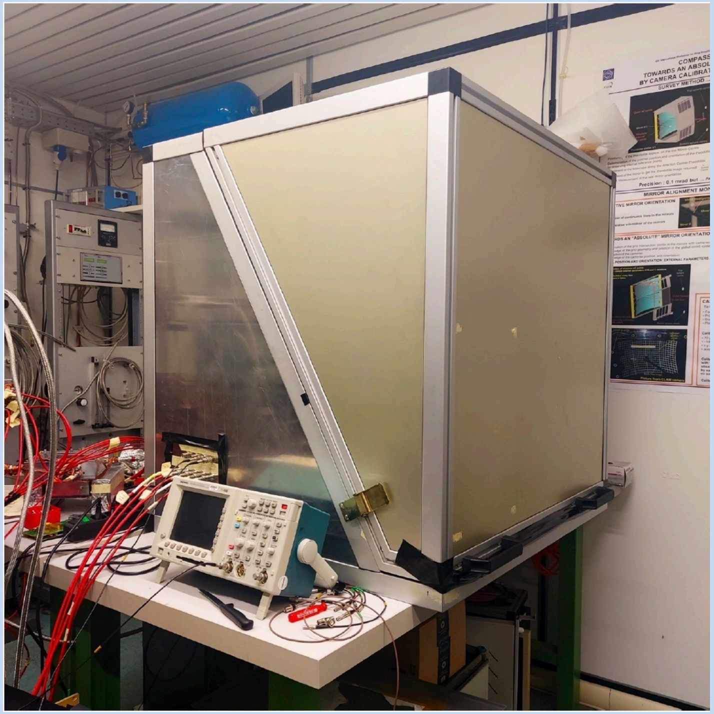
Single event with multiple photon clusters

Megnetic test at ANL (2022)

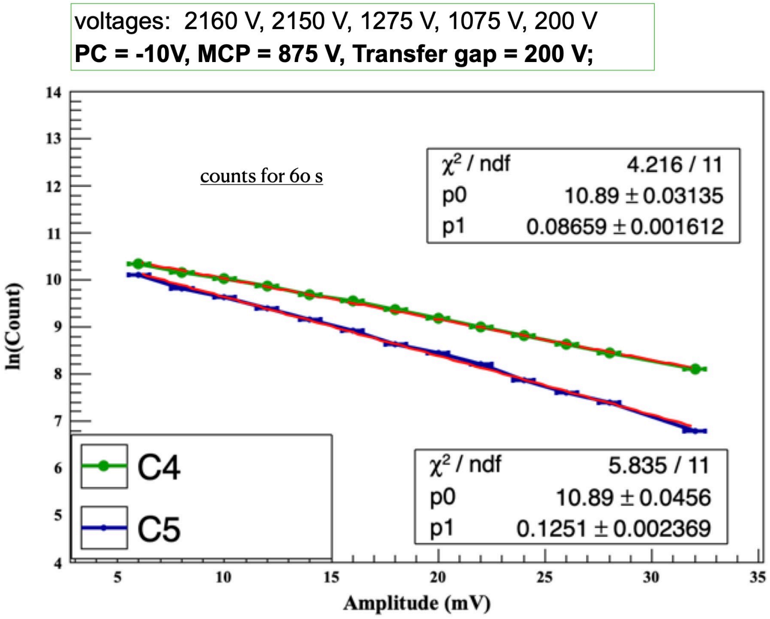


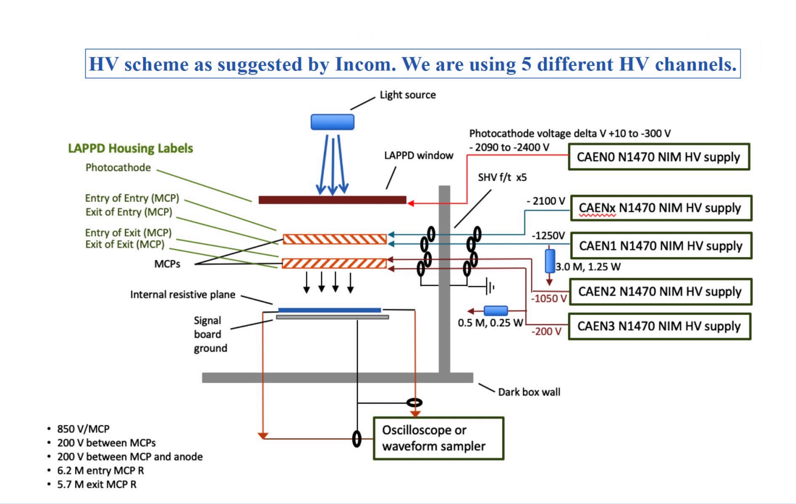


Single photon ring radius resolution

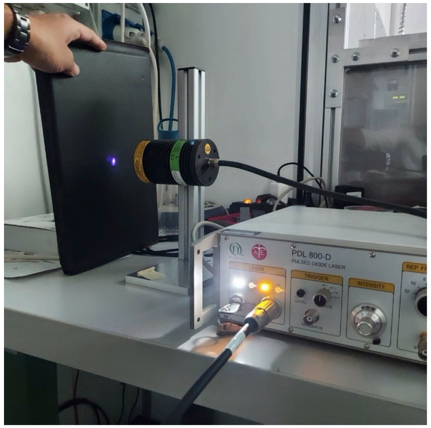


Measured dark rate: 140 Hz/m^2 at room temperature

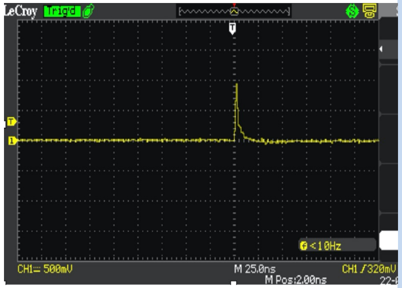




Preparing single-photon response characterization



Deb's talk



Conclusions

dRICH project aims to address **crucial PID aspects at EIC**

cost-effective compact solution for hadron PID in the forward region in a wide kinematic range

investigation of novel single-photon detector solution to be operated in high magnetic field

The dual-radiator RICH has been a **common reference** in the forward region since EIC Yellow Report

Moving from generic EIC R&D (eRD14) to **targeted EIC R&D** (eRD102, eRD110, eRD…)

INFN leading an international effort

Quite broad program (optics, sensors, electronics, mechanics, cooling, ….)

Many opportunities for contributions at the cutting edge of detector technology