The dual Ring Imaging Cherenkov detector for the Electron-Ion Collider

Simone Vallarino

May 10, 2022

EIC_NET
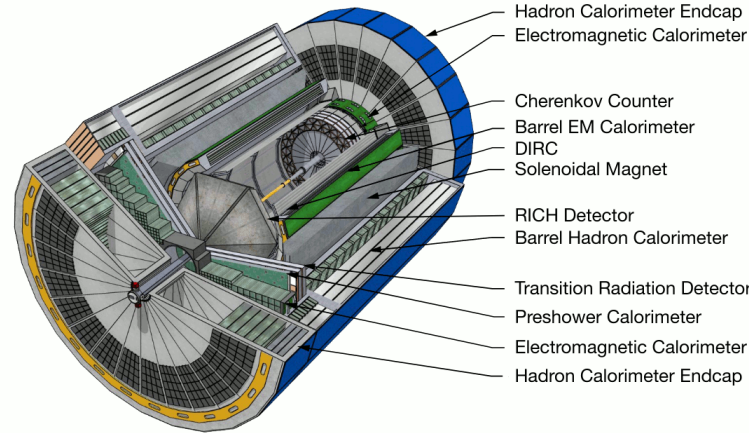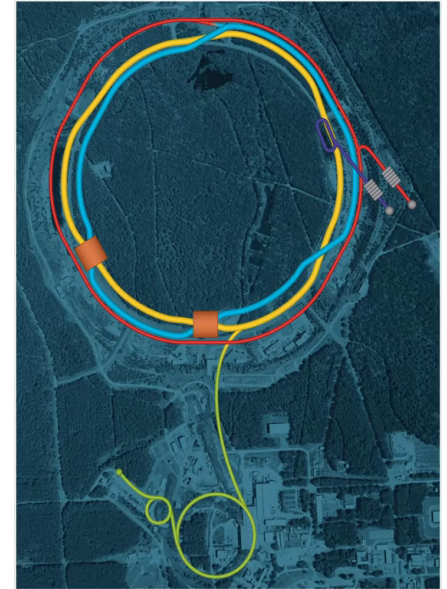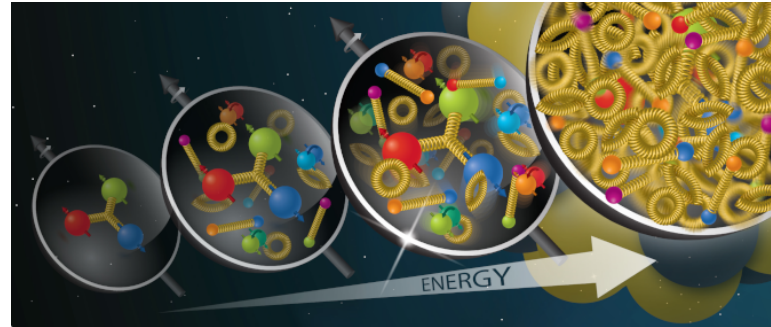
INFN – Sezione di Ferrara

Università degli Studi di Ferrara

- Highly polarized electron (~70%) and proton (~70%) beams
- Availability of ion beam from deuterons to heavy nuclei
- $e+p$ center-of-mass energy up to 100 GeV
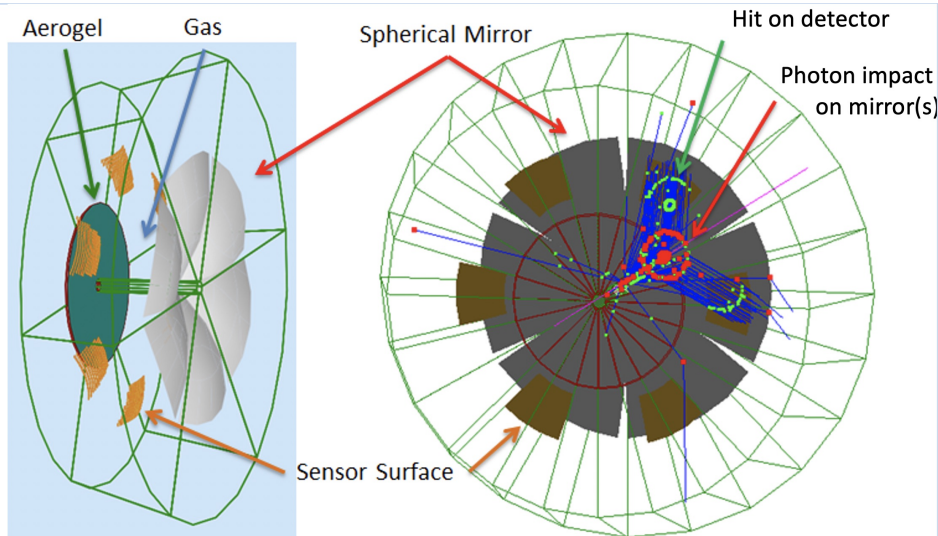- High luminosity (up to 10^{34} cm^{-2}s^{-1})

Hadron Calorimeter Endcap
Electromagnetic Calorimeter

Cherenkov Counter
Barrel EM Calorimeter
DIRC
Solenoidal Magnet

RICH Detector
Barrel Hadron Calorimeter

Transition Radiation Detector
Preshower Calorimeter
Electromagnetic Calorimeter
Hadron Calorimeter Endcap

The dRICH at EIC

Challenges:

- **cover wide momentum range 3-60 GeV**
- **work in high (~1 T) magnetic field**

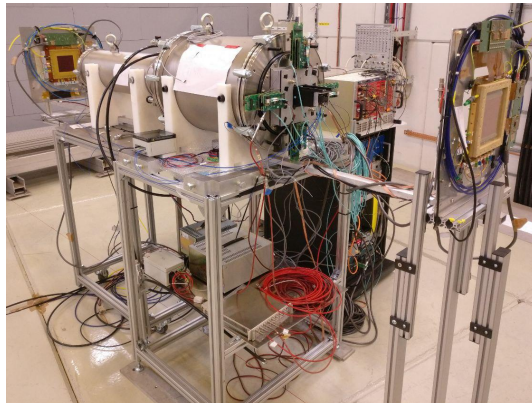Aerogel   Gas   Spherical Mirror

Hit on detector

Photon impact on mirror(s)

Sensor Surface

Effective solutions, part of EIC reference detector
Radiators: aerogel (n_{aero} ~1.02) + gas C2F6 (n_{gas} ~1.0008)
Detector: 0.5 m^2/sector, 3x3 mm^2 pixel, SiPM option

Magnetic field

dRICH sensor

SiPM option

~$10^{11} n_{eq}$/cm^2

neutron flux above 100.0 keV in [n/cm^2] for 1.0 fb^{-1} integrated luminosity

Neutron flux (Courtesy of A. Kiselev)

Radial coordinate, [cm]

Z coordinate (along the beam line), [cm]

Study on radiation mitigation on SiPM

INFN
Istituto Nazionale di Fisica Nucleare

Università degli Studi di Ferrara
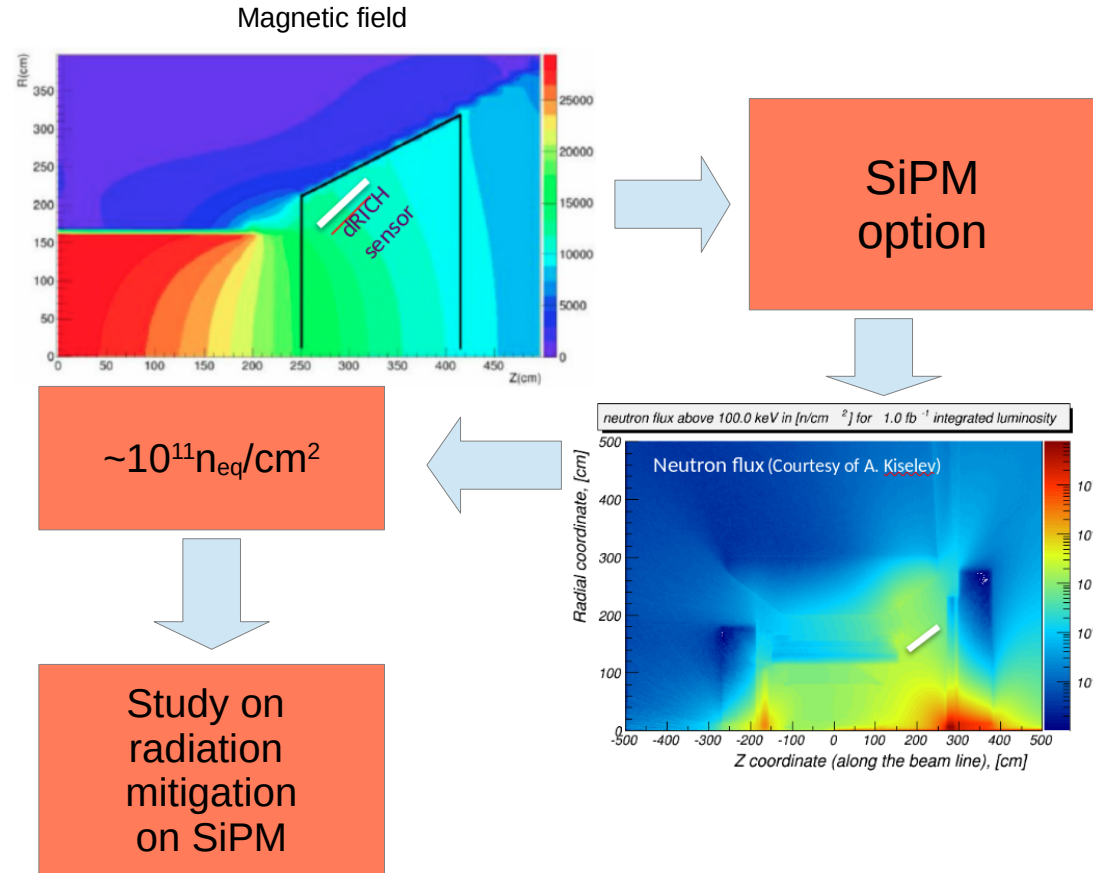
The dRICH prototype 2021 test beams
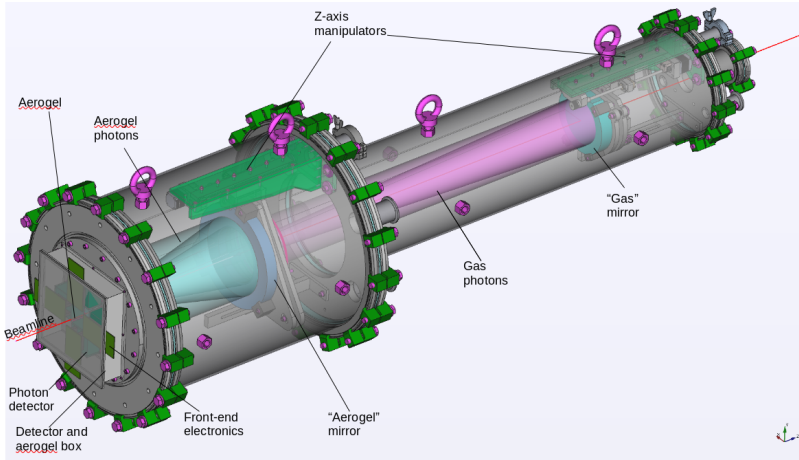
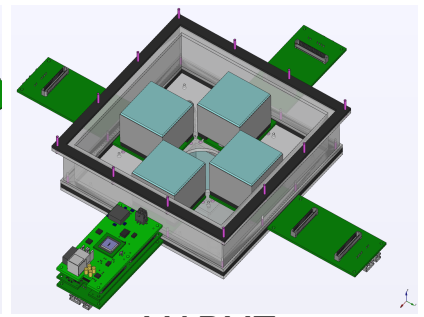| Test	Cherenkov medium	Energy [GeV]	Beam	Photon detector and DAQ
September at SPS	Aerogel	40÷120	π^+ π^-	SiPM and ALCOR
October parasitic runs at SPS	Aerogel	120	μ^- π^-	MPPC and MAROC
October at PS	Aerogel and Gas (C_2F_6)	4÷12	p and π^+ π^-	MAPMT and MAROC

The dRICH setup at PS
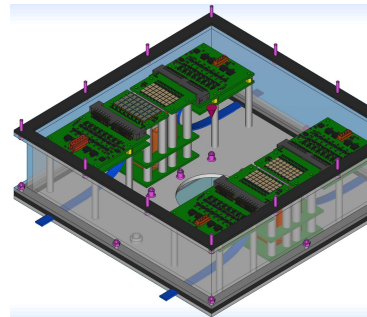
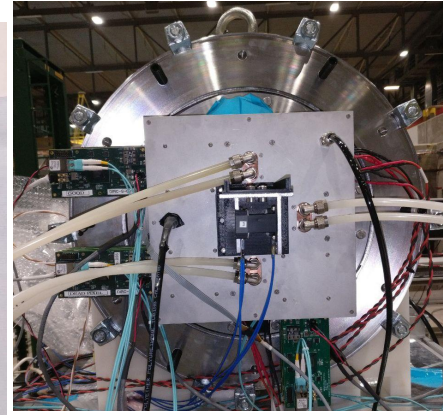SiPM   MPPC   MAPMT

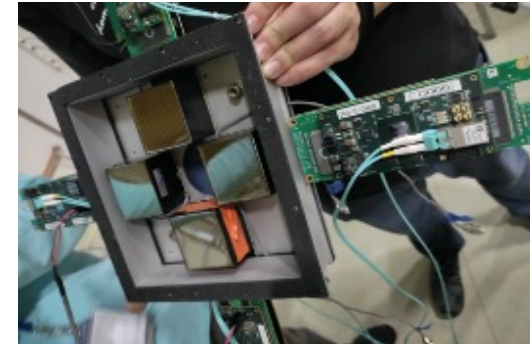dRICH for EIC   May 10, 2022   4
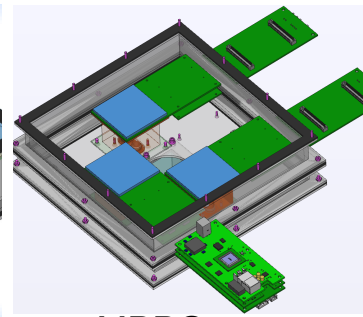
The dRICH prototype components

dRICH chamber

Gas mirror

Frontal view

Aerogel mirror

Support

MAPMT detector box

INFN — Istituto Nazionale di Fisica Nucleare

Università degli Studi di Ferrara
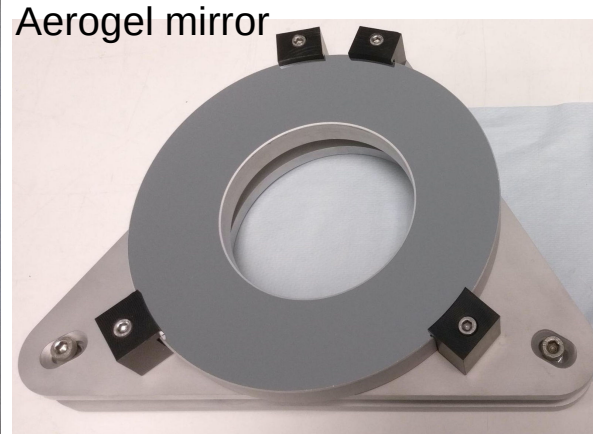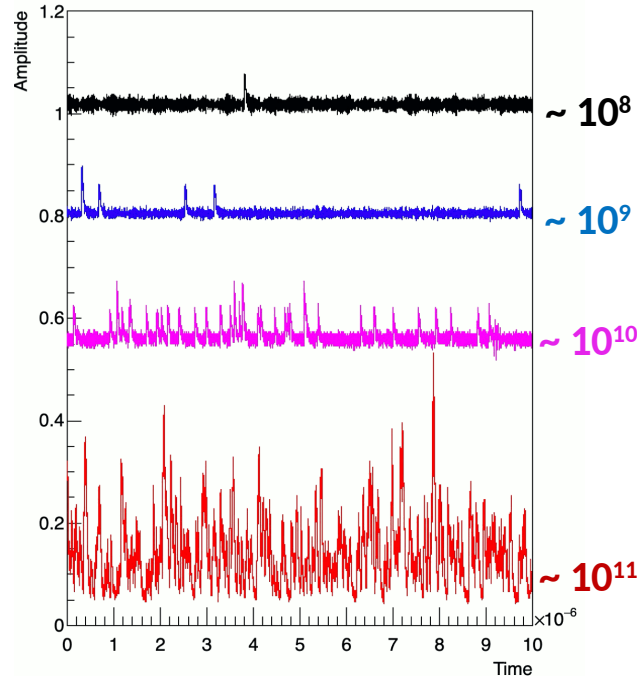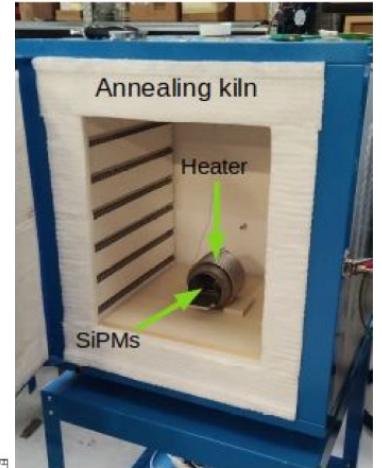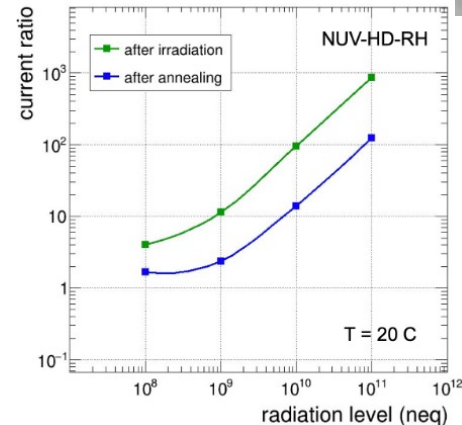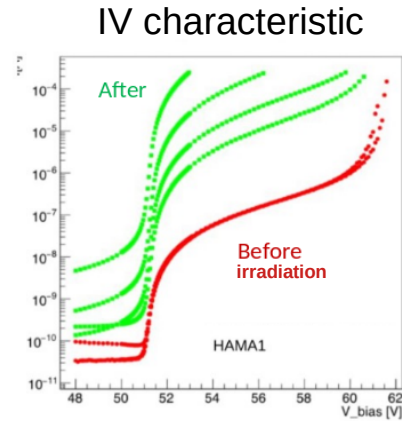
SiPM study

A study of radiation effects on SiPM and recover by annealing is ongoing. We developed custom carriers for SiPMs of several producers, which can bear the high temperature (up to 170°C) of the annealing process.

HAMA2

Some carriers were irradiated in May at TIFPA (Trento) and in the following months underwent annealing at Bologna and Ferrara

~ 10^8

~ 10^9

~ 10^{10}

~ 10^{11}

IV characteristic

After

Before irradiation

HAMA1

NUV-HD-RH
after irradiation
after annealing
T = 20 C

Annealing kiln
Heater
SiPMs

In just one week of annealing the SiPMs recovered one order of magnitude in dark current (or neutron dose).

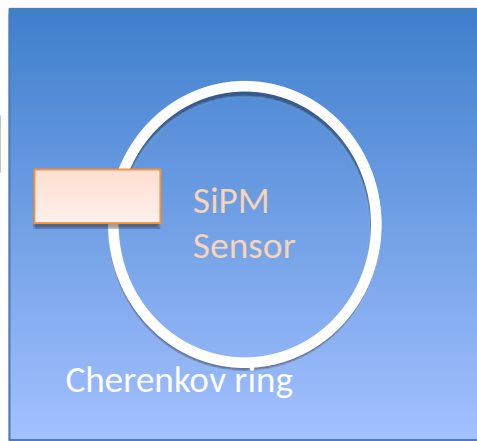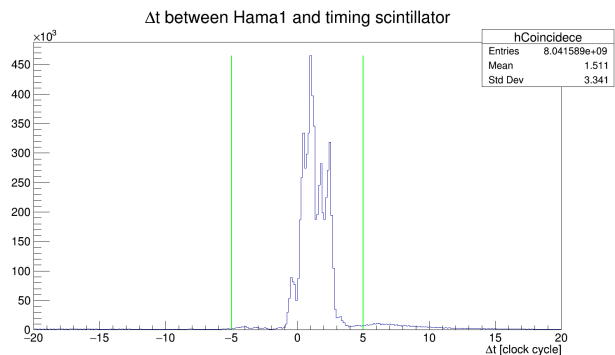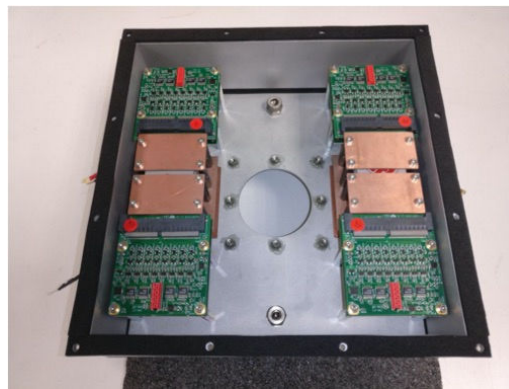The september test main goal was to implement the readout chain based on ALCOR (with not irradiated SiPMs)

The ALCOR chip and ARCADIA DAQ are INFN developments designed to readout SiPM with precise time resolution (50 ps time binning) and at high rate (up to 500 kHz per channel).

The plot shows the coincidence peak between the SiPM signal of dRICH and the timing and trigger scintillators.

dRich Carrier map - mirror in z = 0

30 mm

15 mm

Δt between Hama1 and timing scintillator

hCoincidece	
Entries	8.041589e+09
Mean	1.511
Std Dev	3.341

Δt [clock cycle]

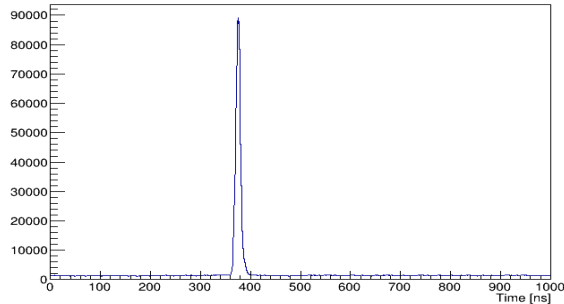SiPM Sensor

Cherenkov ring

dRich Carrier map - mirror in z = +75
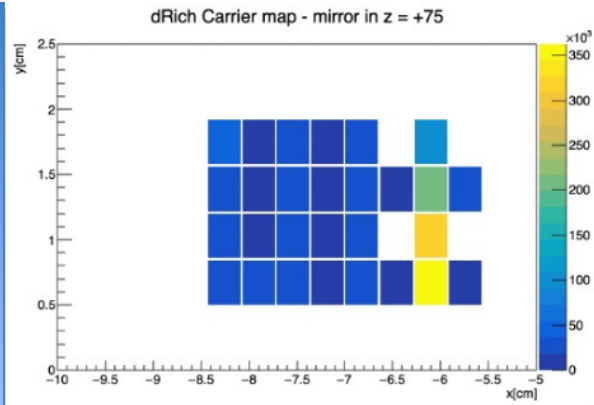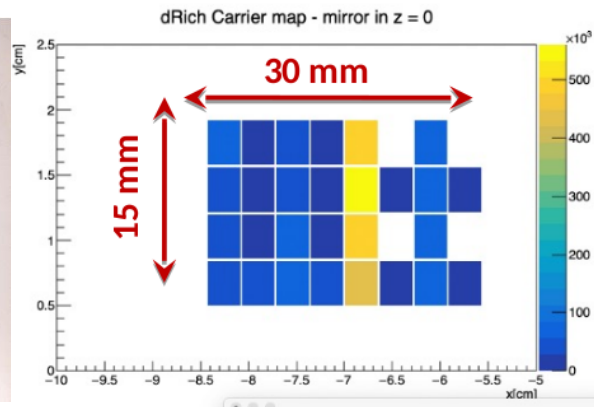
Goals:
- To operate the dual RICH by using both aerogel and gas;
- preliminary study the performance of the dRICH.

Difficulties:
- Sensors came late due to an overlap with another test beam;
- the renovated beam line was not completely commissioned;
- most of the time was parasitic.

Time distribution of hit

Distribution of hit time, the coincidence with the trigger time is clearly visible.

The right plot shows one event measured at PS.

Legend:
- Little red square, a pixel of the MAPMTs turned on by a photon.
- Red line, edge of MAPMTs.
- Green, geometrical cut applied to distinguish gas (inner) and aerogel (outer) photon.
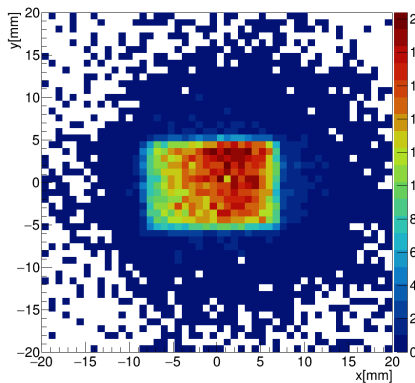- Blue, gas and aerogel rings reconstructed.
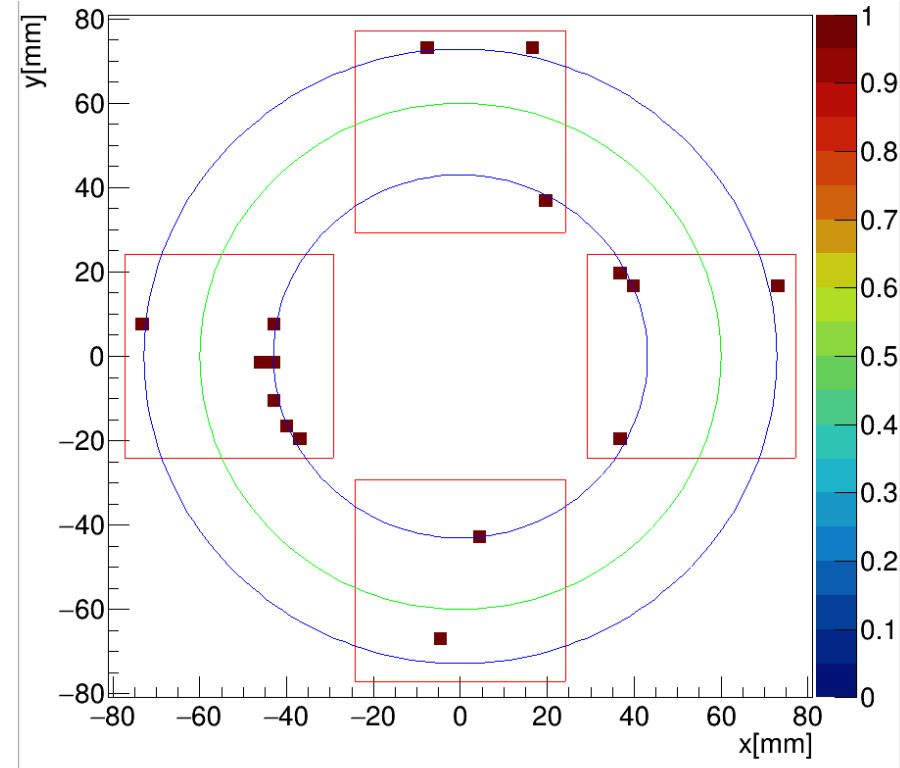
dRICH alignment & data corrections
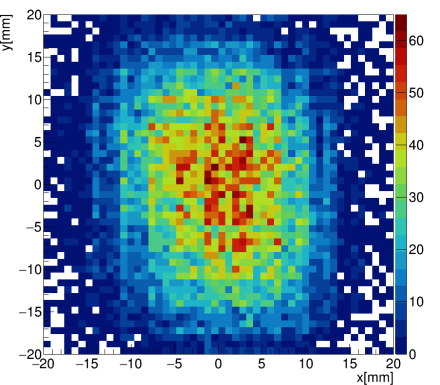

Particle position on upstream GEM

Particle position at aerogel

Particle position on downstream GEM
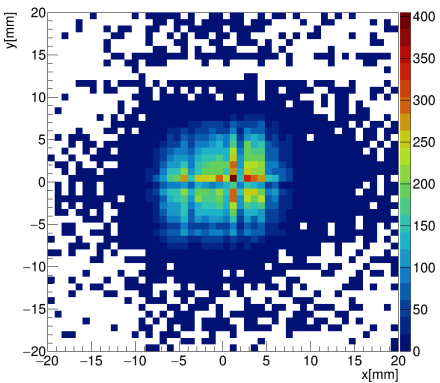
Particle slope

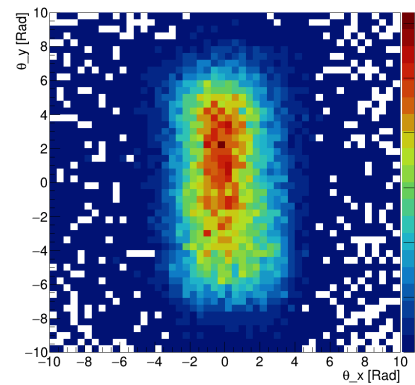A tracking system based on two GEM detectors was used during the test beams to track the beam particles for misalignment and beam divergence,
The combination of the dRICH optical information and GEM track information allows to correct data on a event by event data.
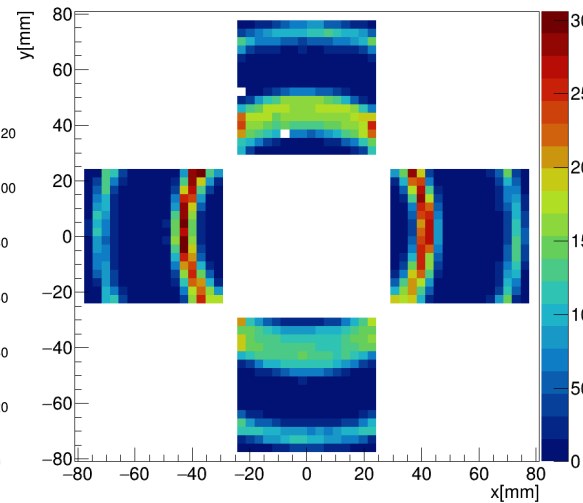

π^- rings before corrections

π^- rings

INFN
Istituto Nazionale di Fisica Nucleare

Università degli Studi di Ferrara

Radius of single particle

χ^2 / ndf	177.6 / 11
Constant	3602 ± 28.6
Mean	42.82 ± 0.00
Sigma	0.4852 ± 0.0031

Radius of single particle

χ^2 / ndf = 81.69 / 18	
Constant	2071 ± 16.8
Mean	72.66 ± 0.01
Sigma	1.146 ± 0.009
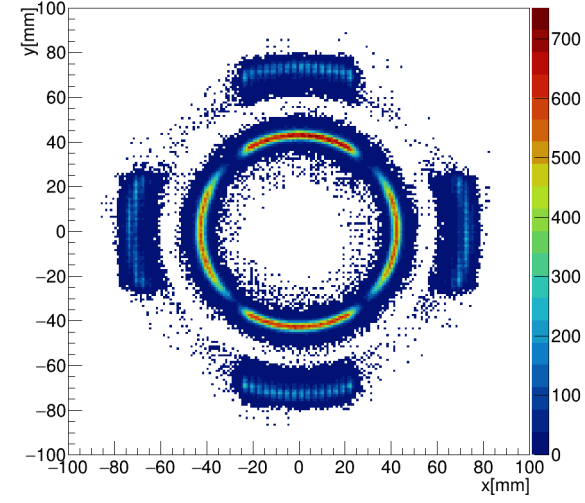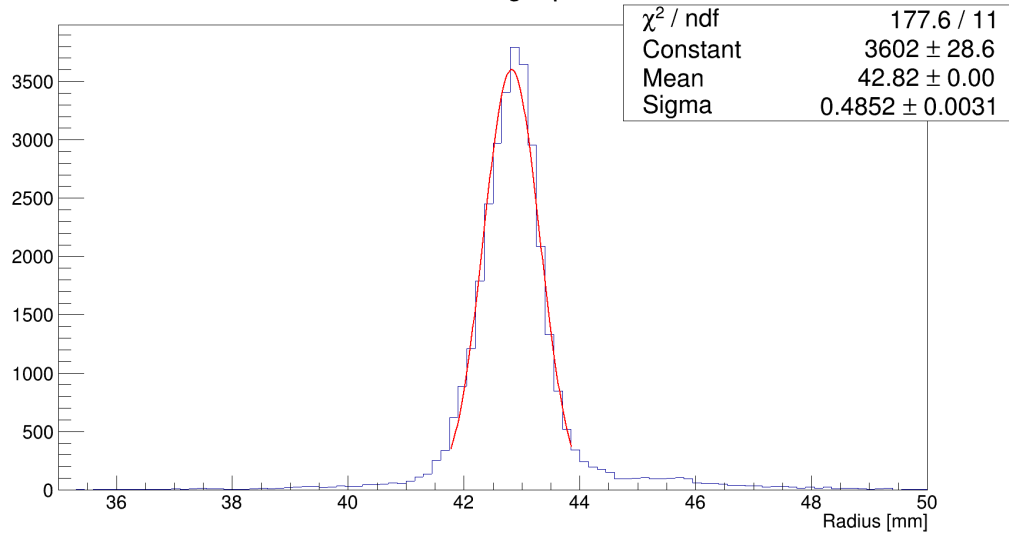
Radius of ring produced from 12 GeV π⁻ by crossing the gas
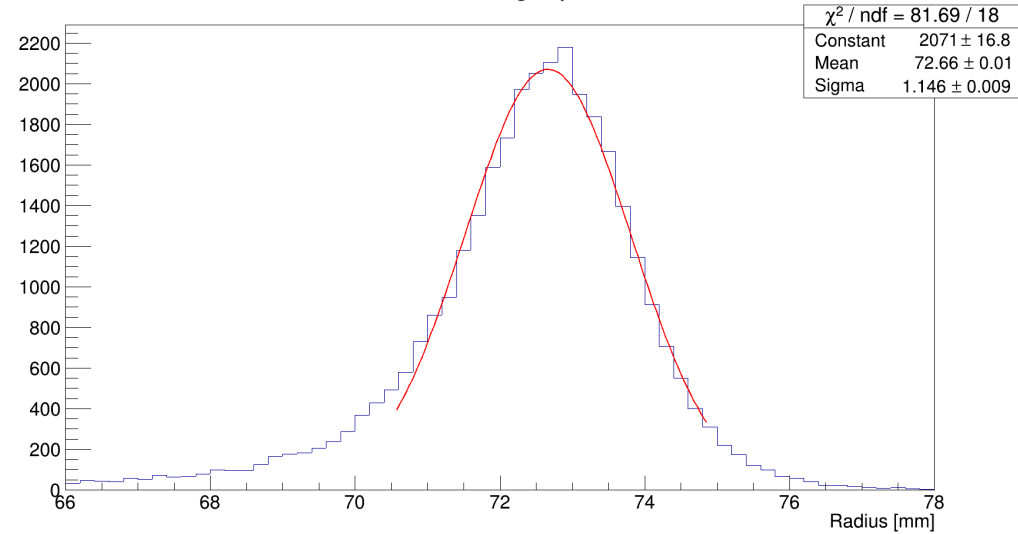
Radius of ring produced from 12 GeV π⁻ by crossing the aerogel

RMS of radius as function of photon number - Gas

χ^2 / ndf	14.02 / 15
p0	1.544 ± 0.058
p1	0.22 ± 0.03

DATA

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

p_0 = single photon resolution
p_1 = single particle resolution constant term

p_1 is not compatible with zero, so there is some residual systematic effect
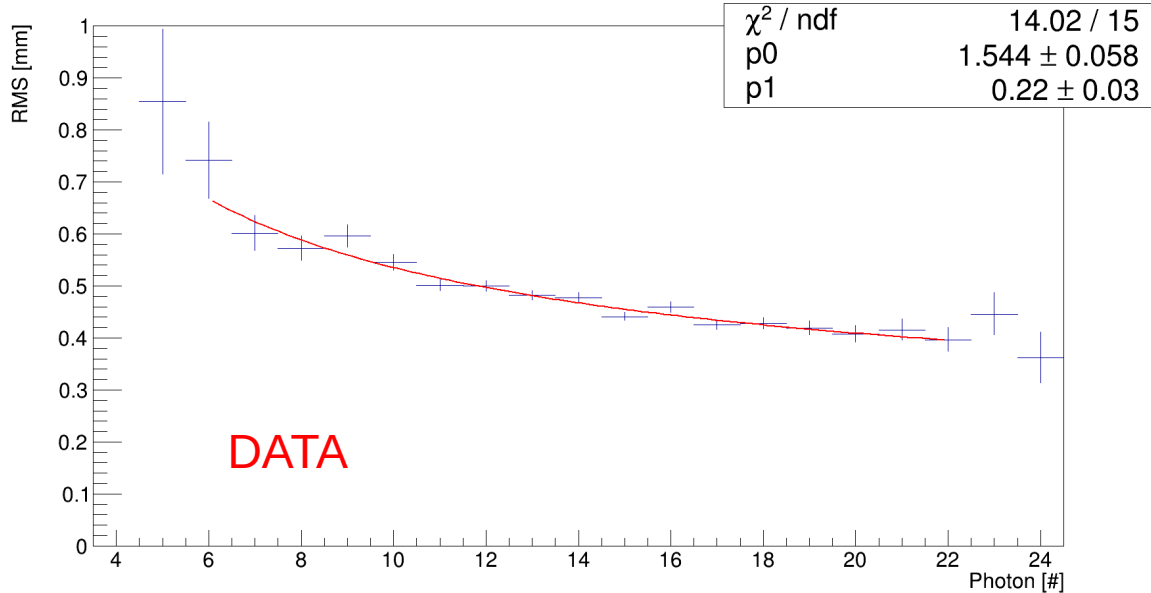
Distribution of the number of photon per particle - Gas

hEntriesInRMS	
Entries	26
Mean	12.8
Std Dev	4.018

RMS of radius as function of photon number - Gas - Simulation

χ^2 / ndf	12.74 / 11
p0	1.101 ± 0.041
p1	0.06961 ± 0.05186

MC

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

Distribution of the number of photon per particle - Gas - Simulation
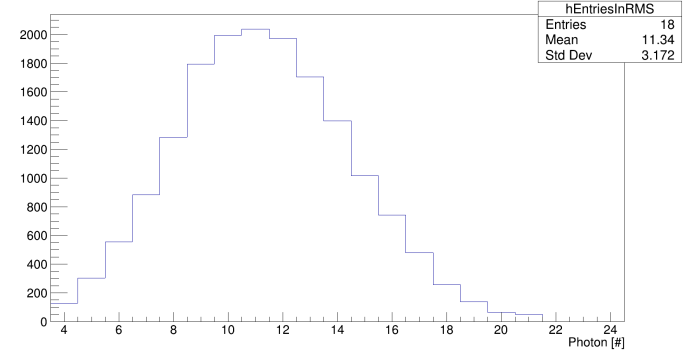
hEntriesInRMS	
Entries	18
Mean	11.34
Std Dev	3.172

dRICH for EIC

May 10, 2022

12

RMS of radius as function of photon number - Aerogel

χ^2 / ndf	= 17.85 / 5
p0	1.863 ± 0.055
p1	0.5302 ± 0.0428

DATA

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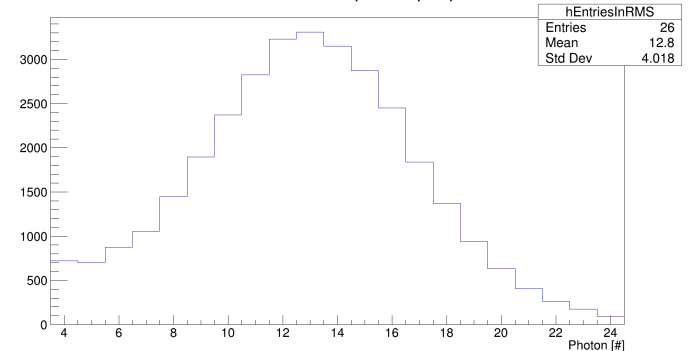
$$y=\sqrt{\frac{p_0{}^2}{x}+p_1{}^2}$$

p_0 = single photon resolution
p_1 = single particle resolution constant term

p_1 is not compatible with zero, so there is some residual systematic effect
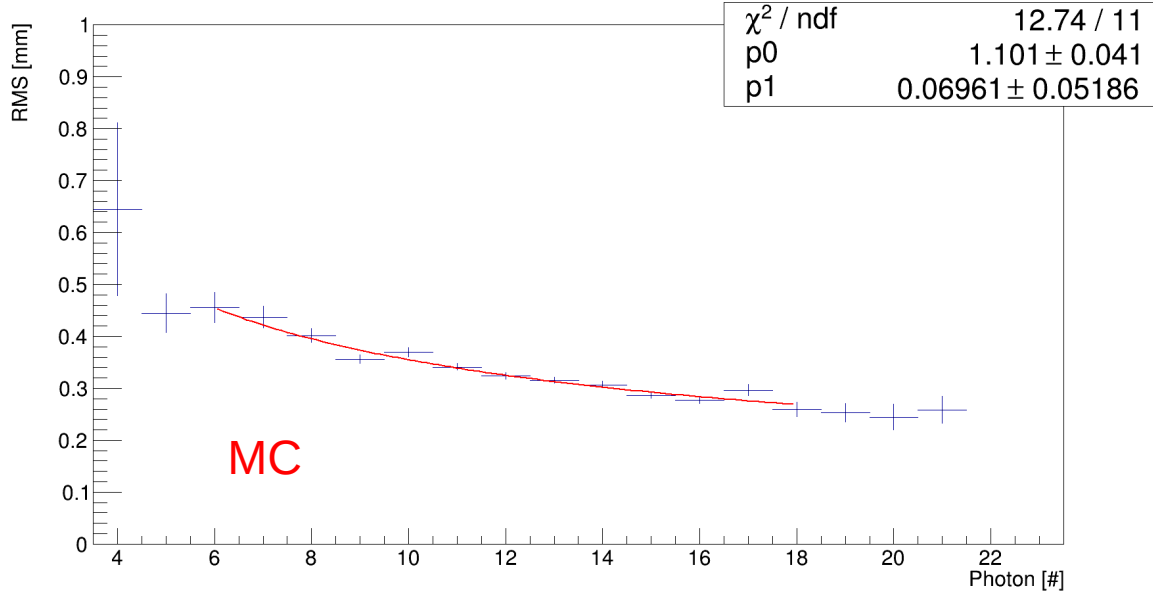
Distribution of the number of photon per particle - Aerogel

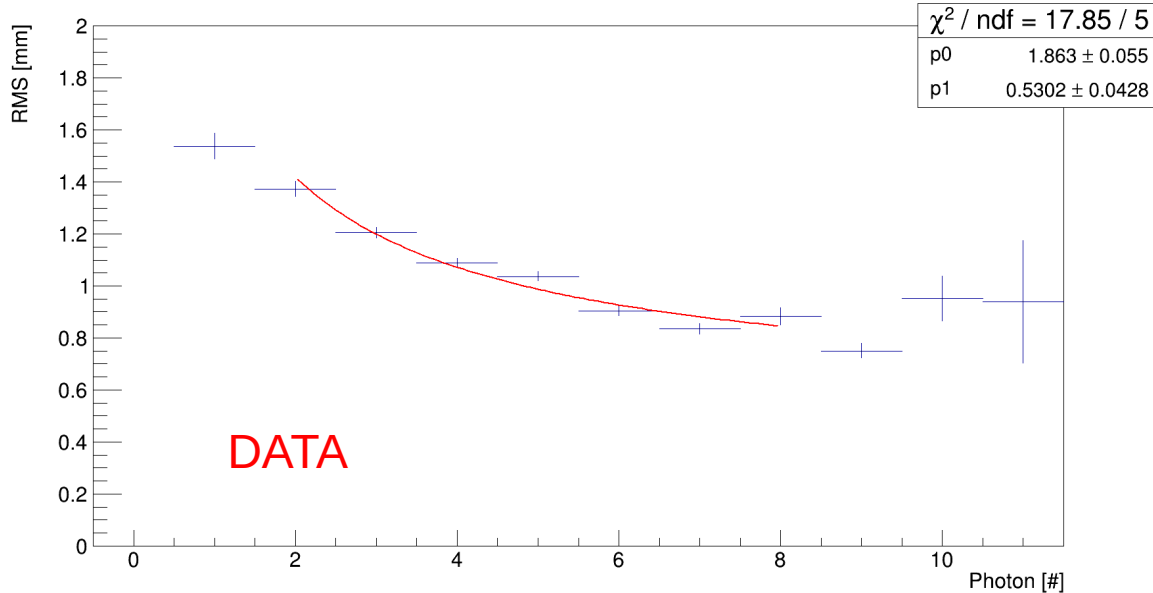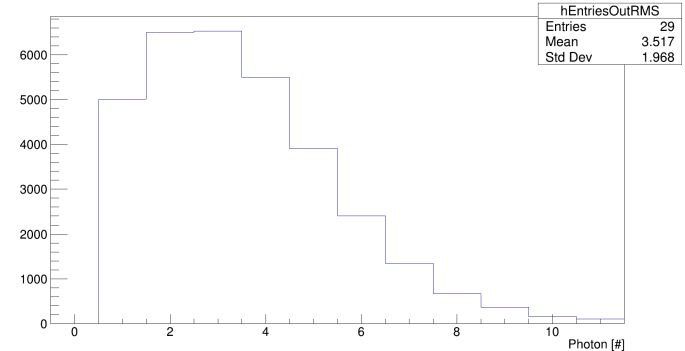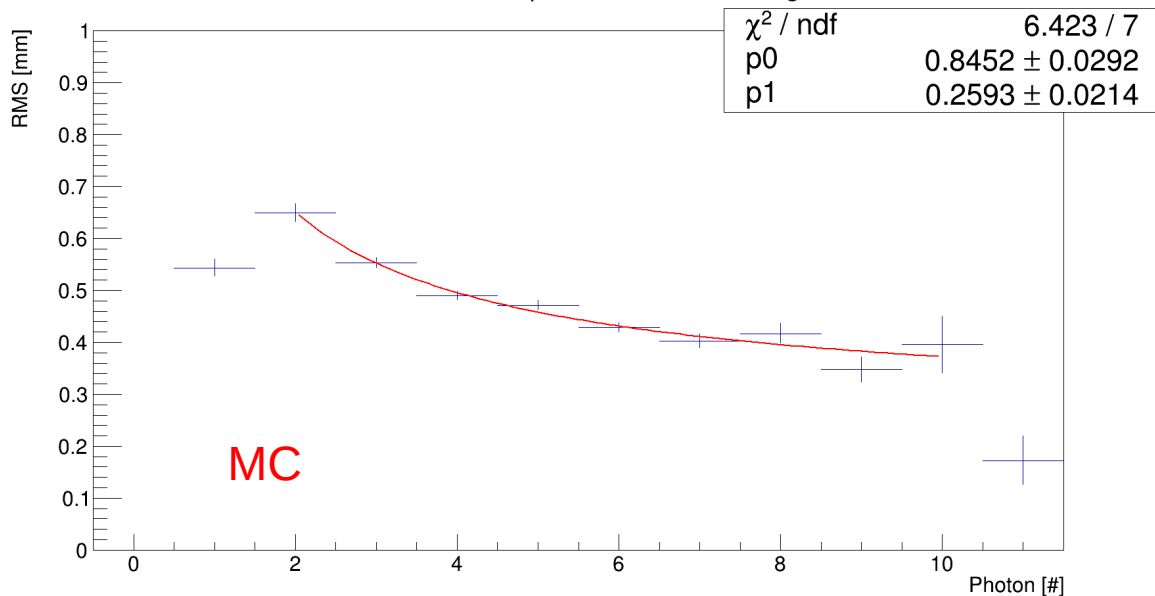| hEntriesOutRMS	
Entries	29
Mean	3.517
Std Dev	1.968

RMS of radius as function of photon number - Aerogel - Simulation

χ^2 / ndf	6.423 / 7
p0	0.8452 ± 0.0292
p1	0.2593 ± 0.0214

MC

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

Distribution of the number of photon per particle - Aerogel - Simulation

hEntriesOutRMS	
Entries	17
Mean	3.546
Std Dev	1.859

dRICH for EIC

May 10, 2022

14

Università degli Studi di Ferrara

INFN
Istituto Nazionale di Fisica Nucleare
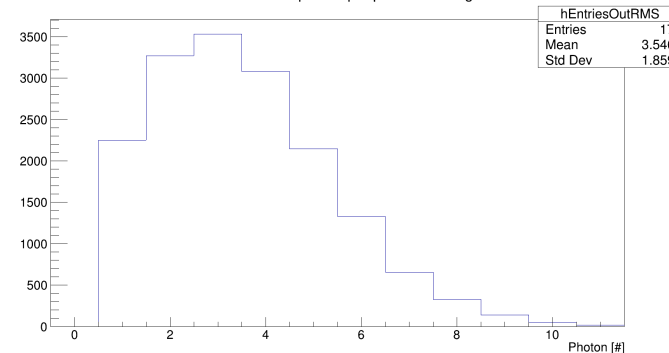
Conclusions and future perspectives

- We develop a dRICH prototype and SiPM program to address the challenges of PID at the future EIC.

- We operated the dRICH prototype and all its subsystems, collecting a good set of data to compare with simulations.

- The obtained results are promising, but the expected resolution in not yet achieved.

- A larger amount of data will be acquired in the new test beams in fall 2022, making it possible to carry out systematic studies on the dRICH performance towards the design resolution.

- A new version of the reconstruction and analysis software is under development, which will allow an improved resolution and online monitoring.

- An improvement of the simulations is on going, based on the ongoing optical characterization of the dRICH components.
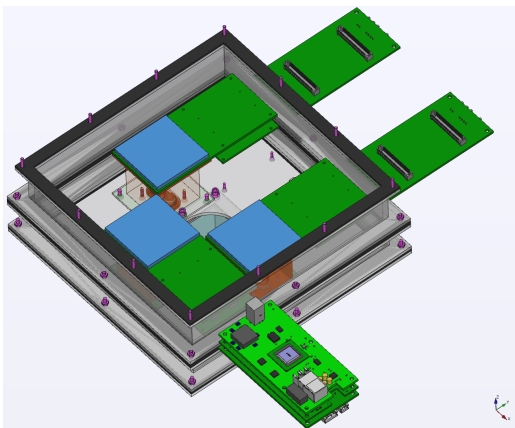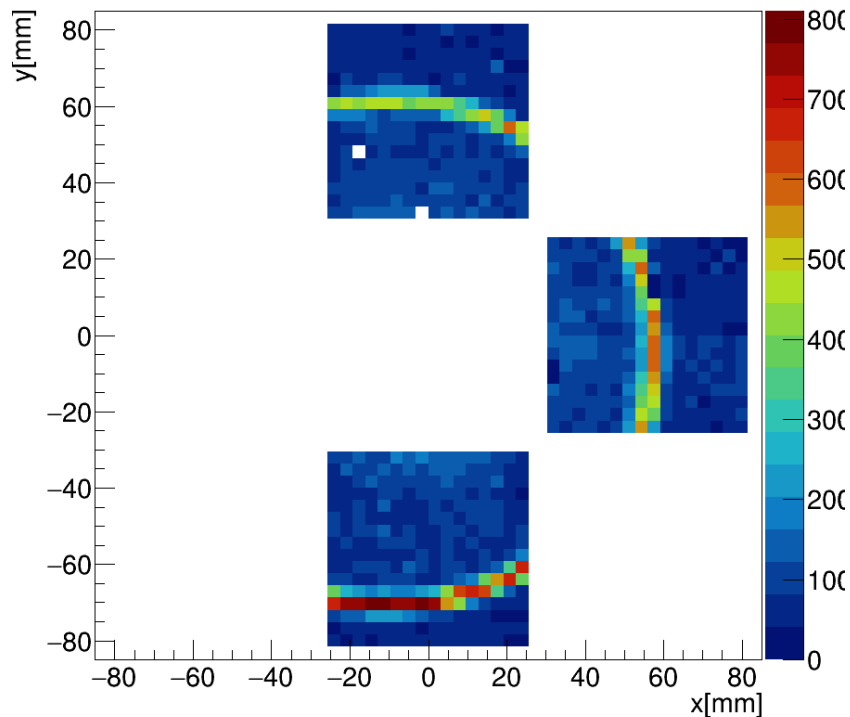
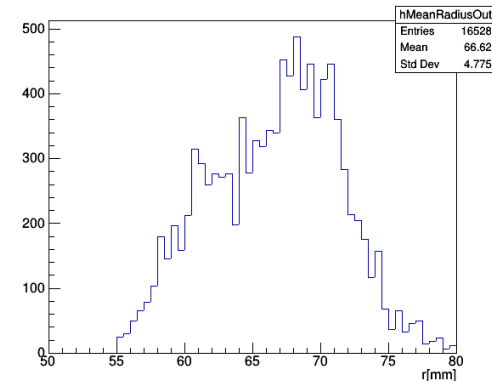Thanks for your attention

Backup slides

The MPPC detectors were used.
Data analysis is ongoing, but the different geometry requires a partially new data analysis which is under development.
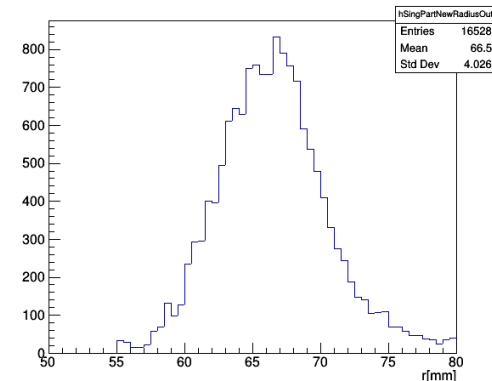

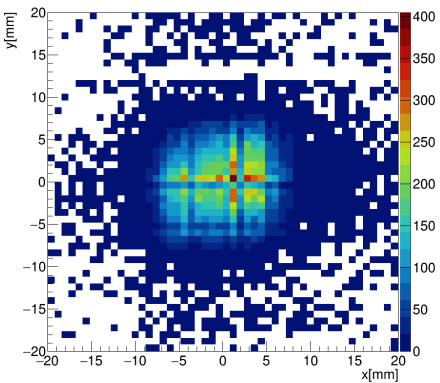Rings without correction

Outer mean radius - North and South

hMeanRadiusOut	
Entries	16528
Mean	66.62
Std Dev	4.775

Outer mean radius - Corrected - North and South

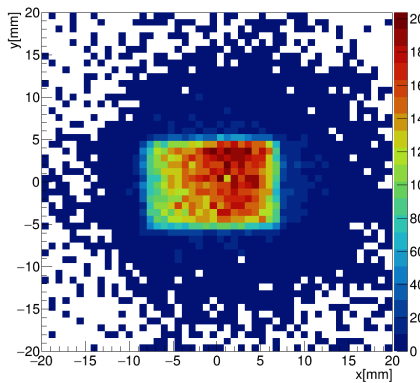| hSingPartNewRadiusOut	
Entries	16528
Mean	66.5
Std Dev	4.026

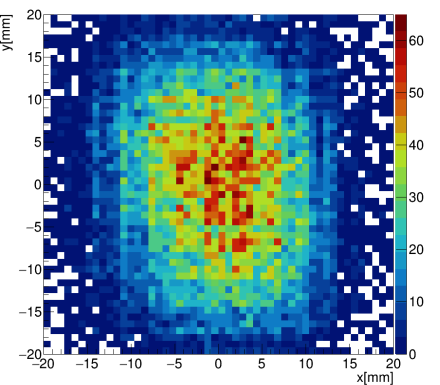dRICH for EIC   May 10, 2022   18
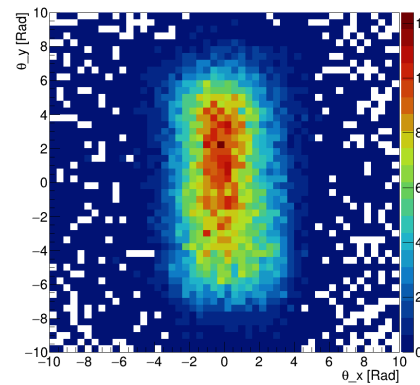
Particle position on upstream GEM

Particle position at aerogel

Particle position on downstream GEM

Particle slope

The GEMs provide the track of each event.
In this run, only the GEMs and the frontal scintillator were used as trigger.
We found a correlation between the semi-difference of the radius measured from two opposite MAPMTs and the particle slope provided by GEMs.

Semi difference of north-south PMT vs Aerogel θ y - Inner ring
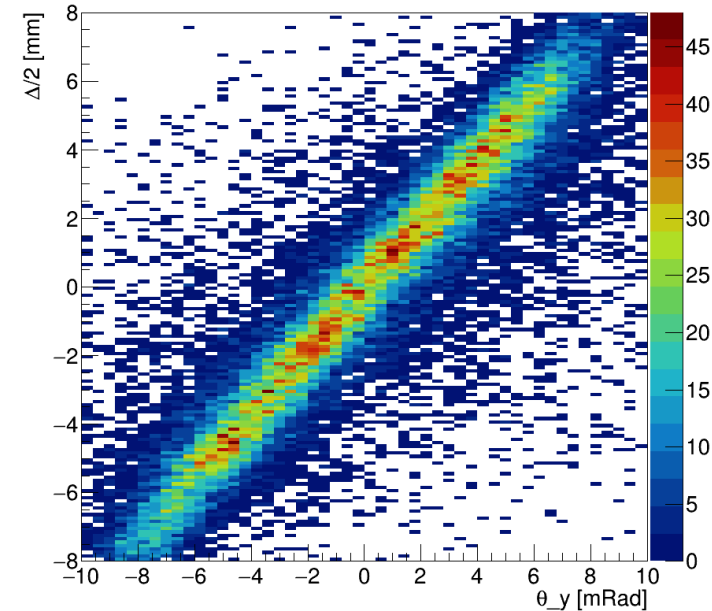
Computing the dRICH alignment

We define the coordinate of the dRICH-optical center as the mean value of the semi-difference between the radius measured in two opposite PMTs, evaluated by using only small angle events (slope < 1 mRad). This is a dRICH optical property, and the values are the same for each run (unless change on the mirrors orientation).
The coordinates of the single event center are provided by the sum of the optical center and the product of particle slope and length of path inside dRICH.

Gas ring optical center, Y coordinate

χ² / ndf	124.1 / 50
Constant	170.2 ± 4.8
Mean	1.784 ± 0.027
Sigma	1.198 ± 0.021

π⁻ rings before corrections

π⁻ rings