The dRICH Project

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,

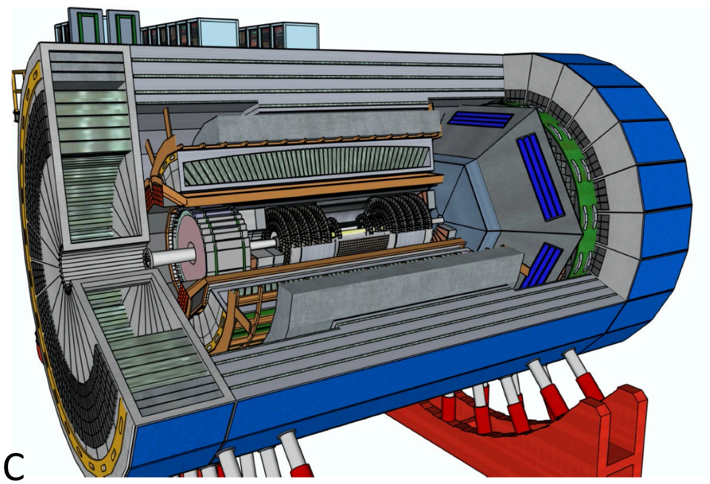
GE, LNF, LNS,

RM1, TO, TS

BA, CS, SA, CT

Jefferson Lab

Brookhaven National Laboratory



EPIC

Duke University

NISER

Georgia State University

Stony Brook University

p: 41 GeV, 100 to 275 GeV

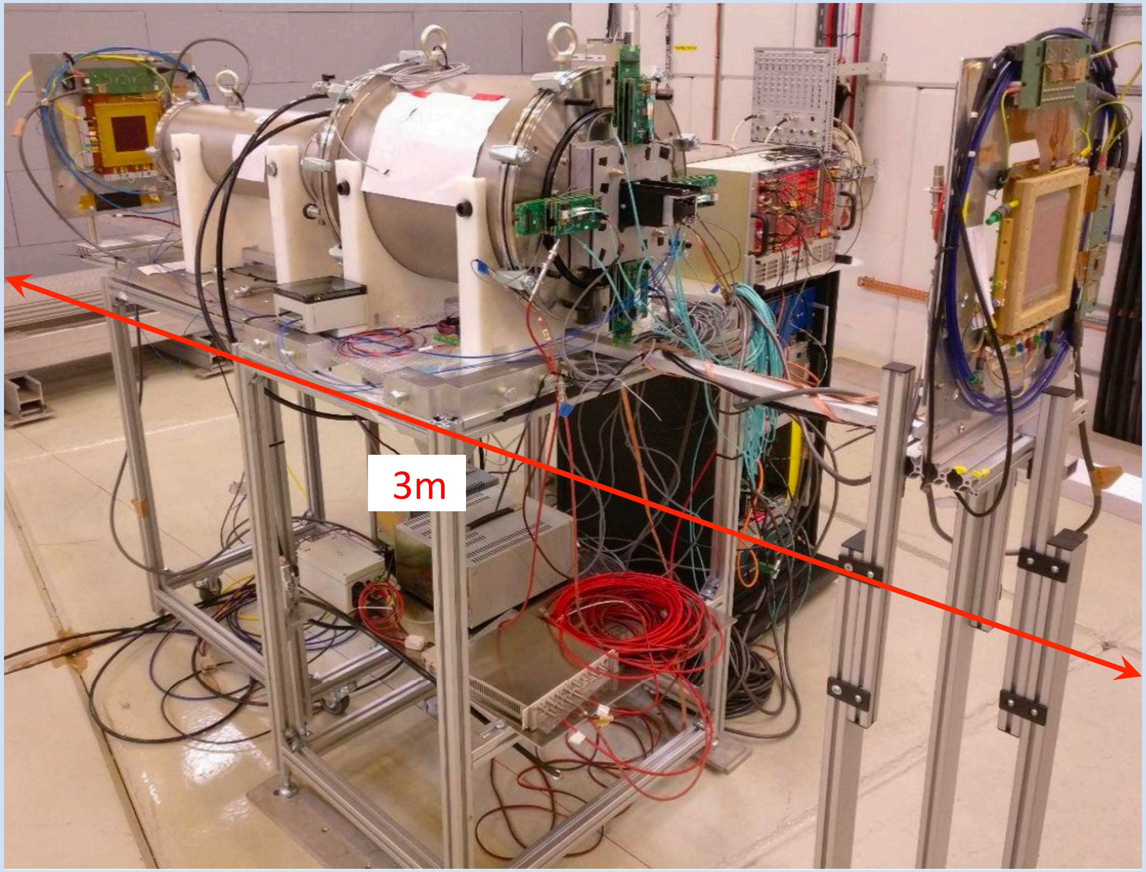
p/A beam →

← e beam

e: 5 GeV to 18 GeV

dRICH Prototype

Based on experience from previous realizations (HERMES, COMPASS, CLAS12, Hall-A)



Goals:

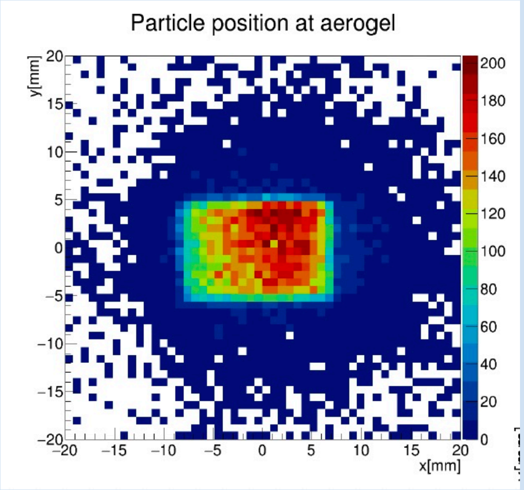
- Study dual radiator performance and interplay
- Study specifications and alternatives for optical components
- Test alternate single-photon detection systems
- Design parameters and optimization

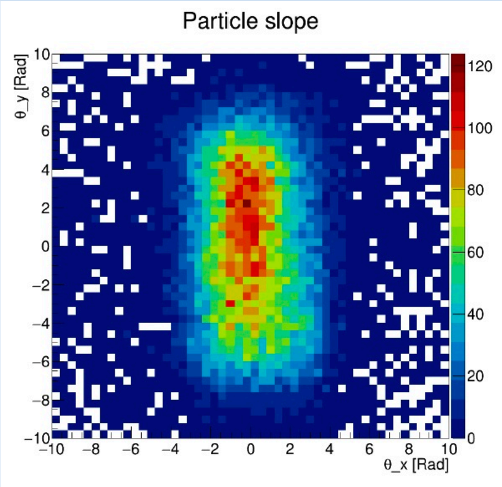
Basic system commissioned in 2021 runs

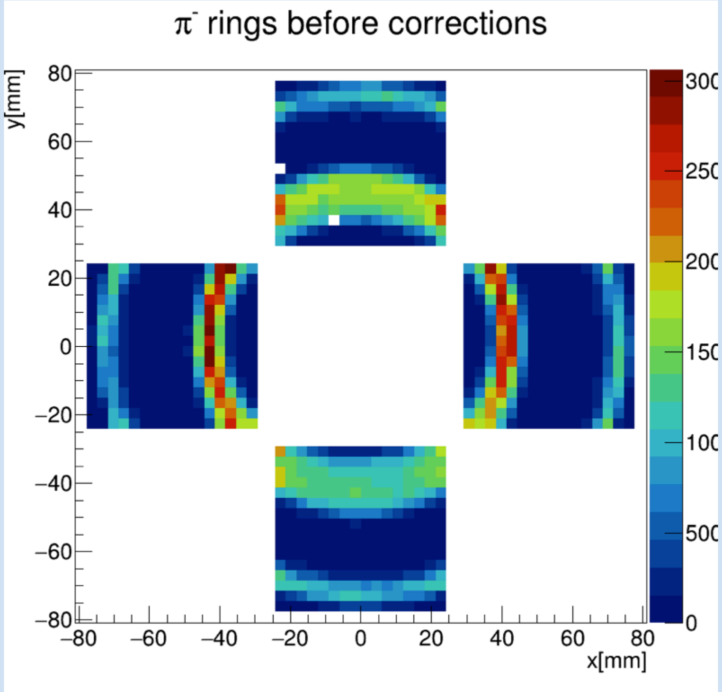
dRICH Cherenkov Rings

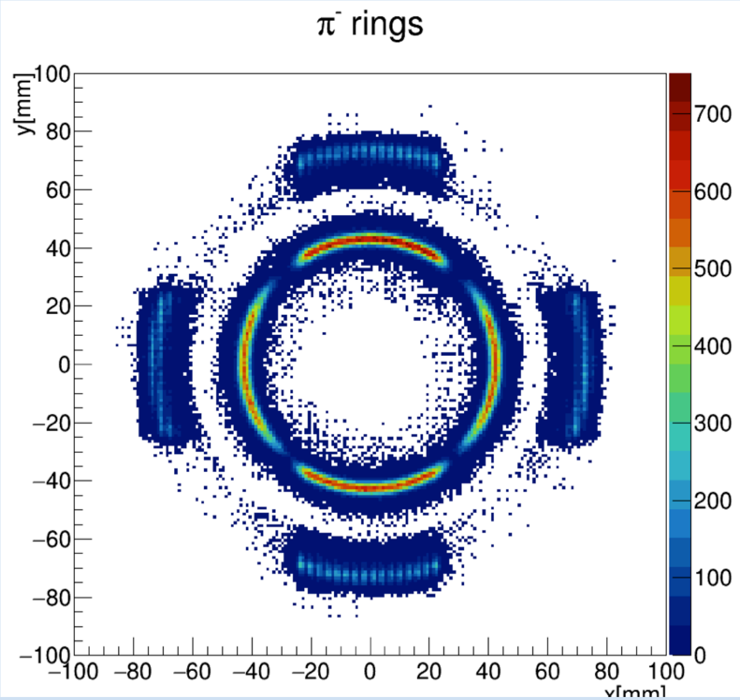
A tracking system based on two GEM detectors was used during the test beam to track the beam particles for measuring alignment and beam divergence.

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







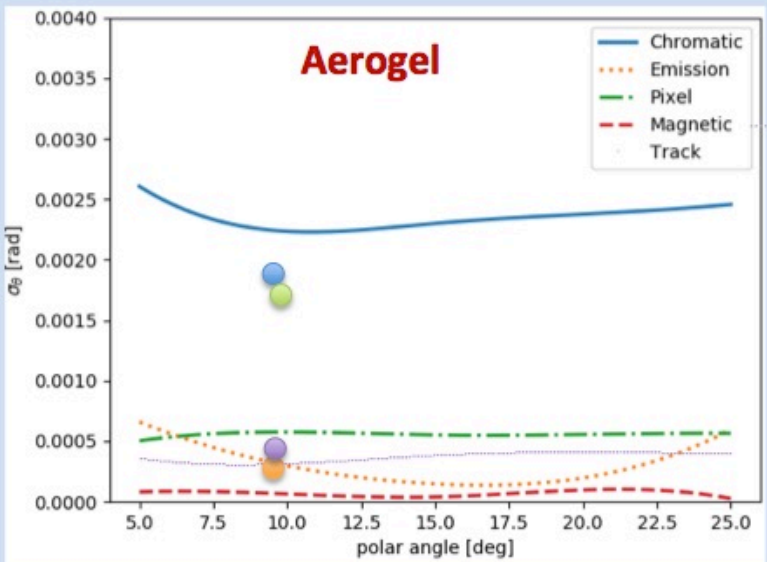


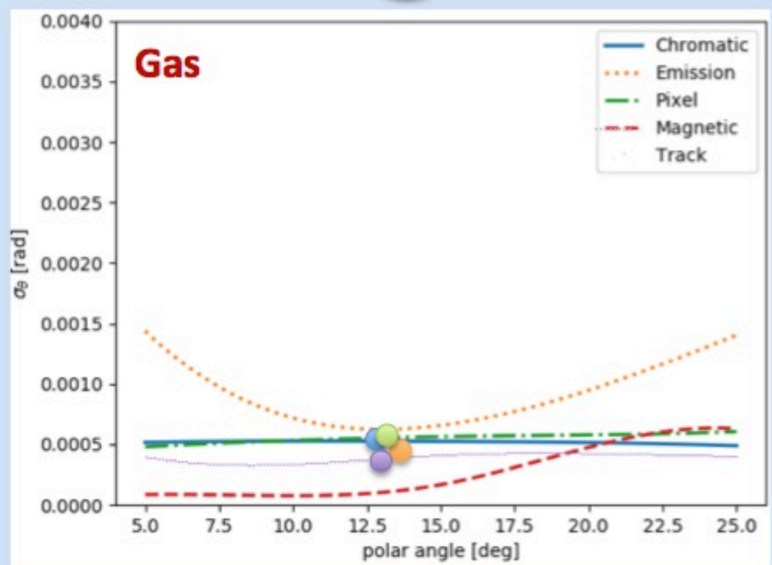
dRICH Resolution

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)

5

1.2



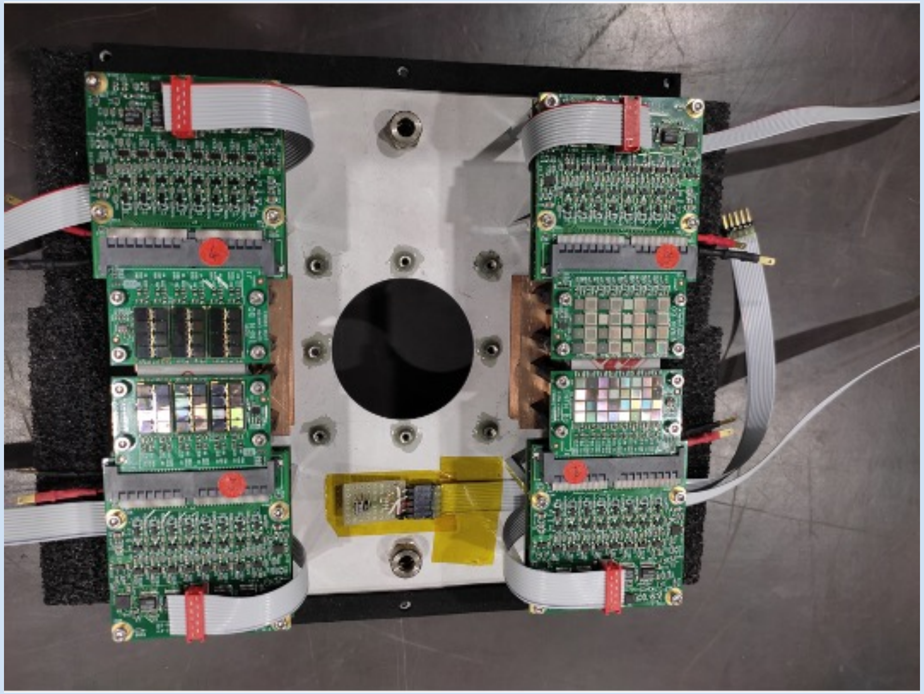


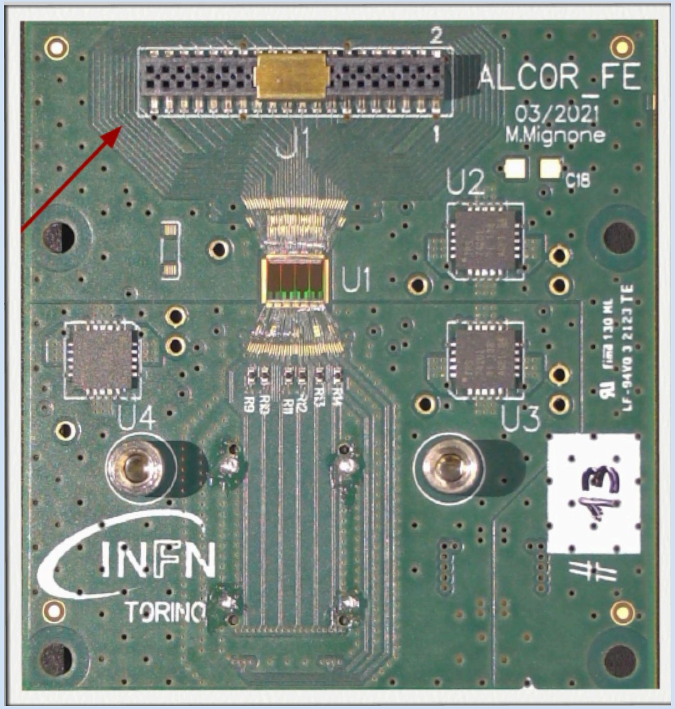
Preparing the prototype for the next test beam campaign (fall 2022)

The SiPM Program

Based on previous R&D (CLAS12), INFN developments (DARKSIDE, ALCOR, ARCADIA) and local facilities (development at FBK, production at Lfoundry)

Control SiPM high dark count rate and radiation damage to isolate single photon signal
Use a new ALCOR chip (high-rate ToT architecture) in streaming mode
(50 ps time bin, > 500 kHz rate per channel, cryogenic compatible)



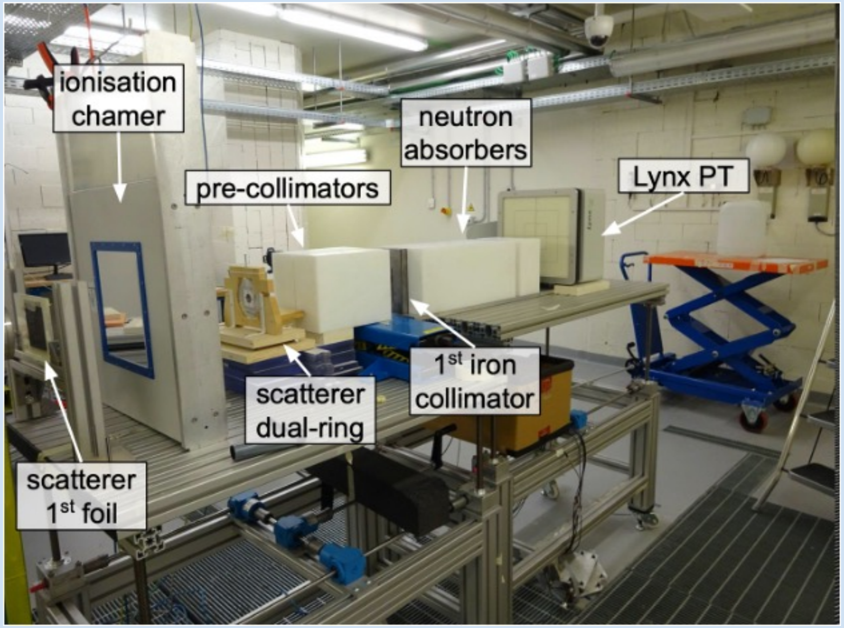


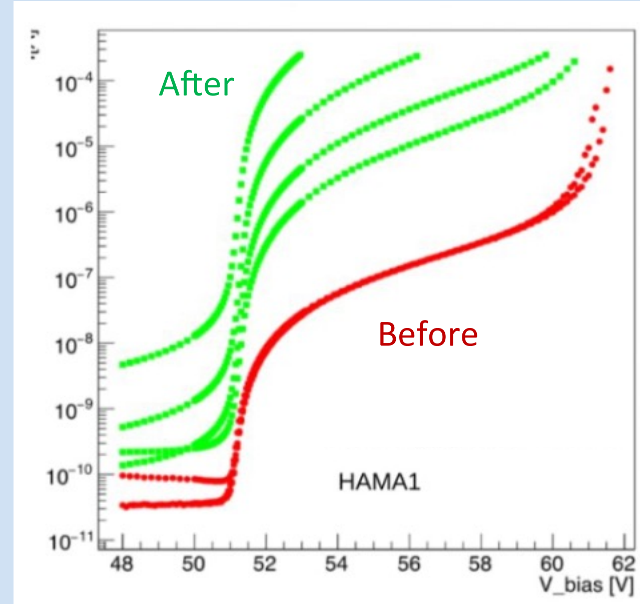
Study SiPM performance of various producers and types (Hamamatsu, FBK, Bradcom, On Semiconductor)

SiPM Irradiation Campaign

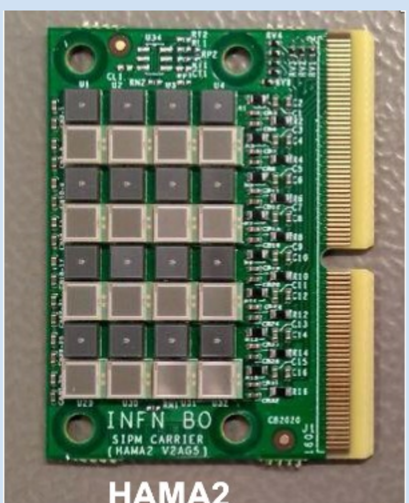
TIFPA
Proton
Beam
Facility

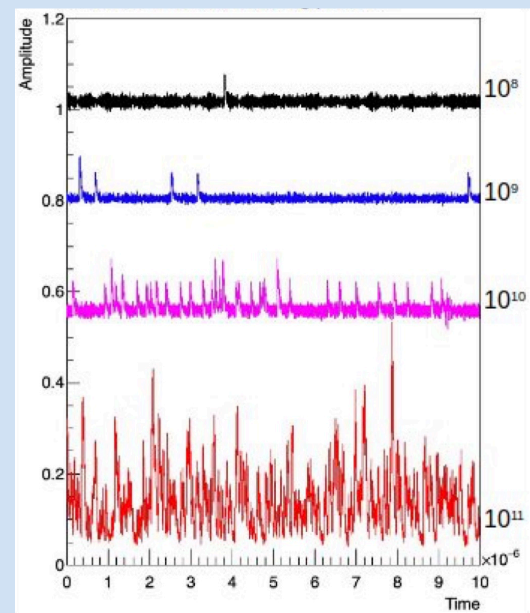
Collimated
Beam
10^{9}-10^{11} n_{eq}





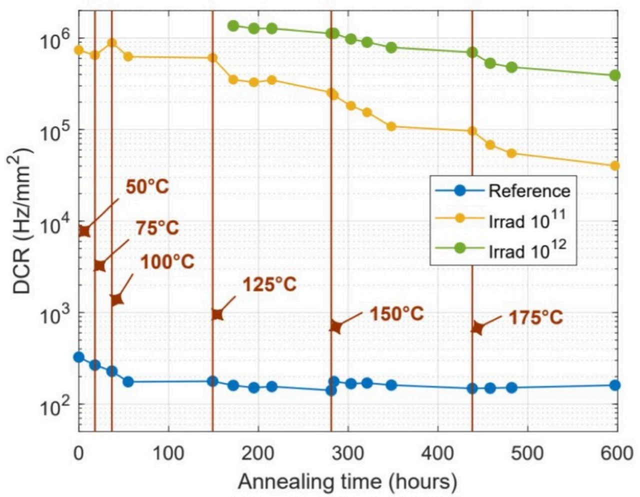
Various SiPM

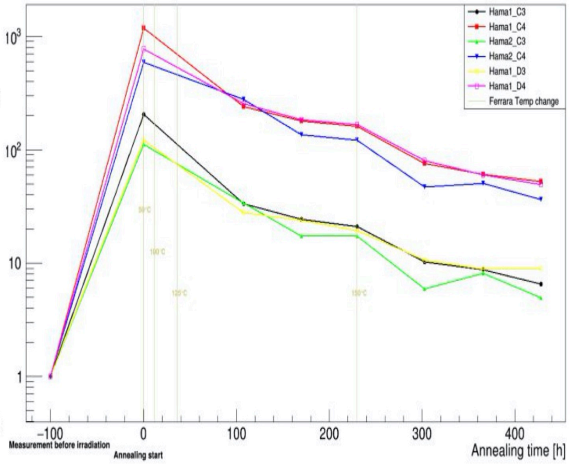


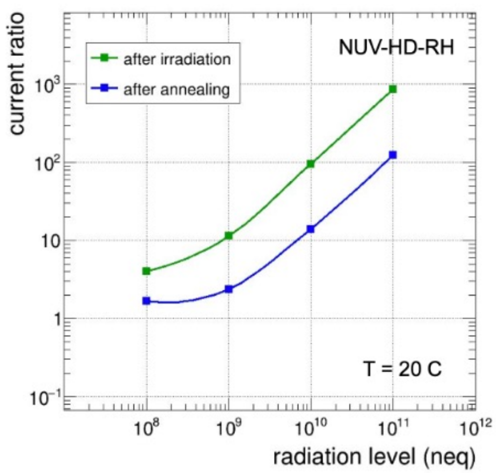


Reproduce long-term high-T annealing (oven)

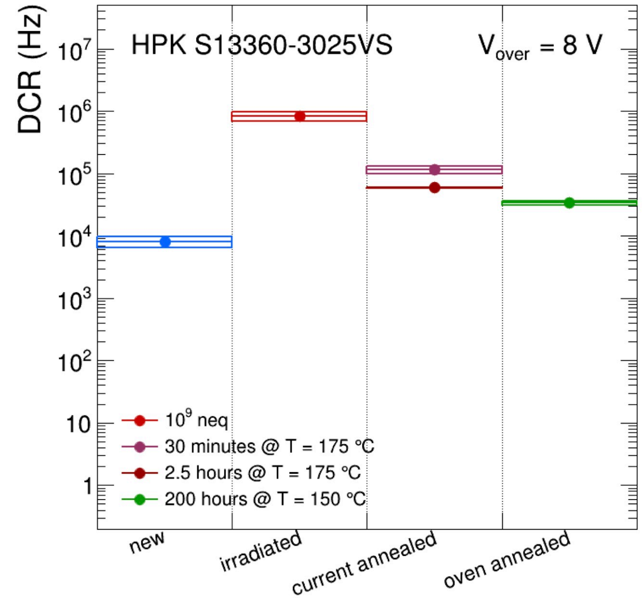
Calvi et al., NIMA 922 (2019) 243







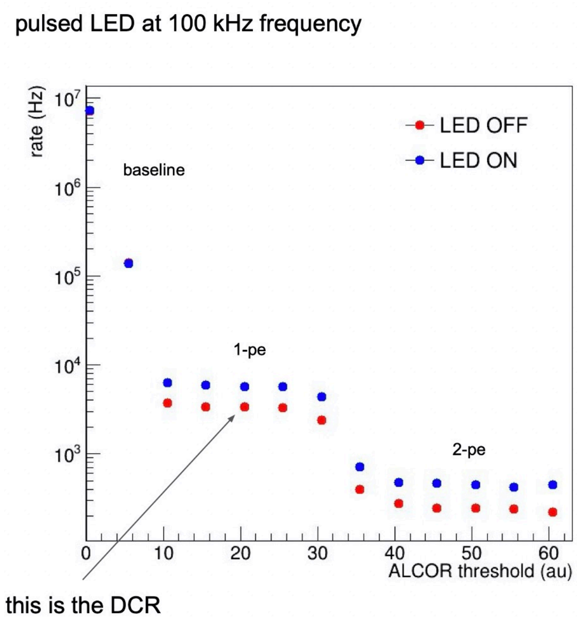
Study customized annealing (current shots)



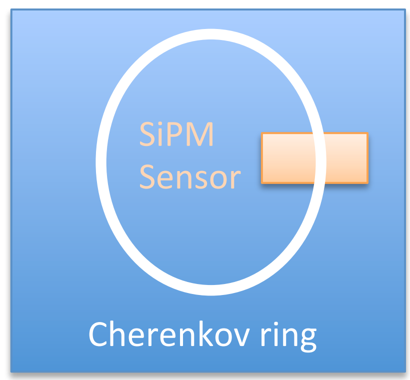
First Beam Test

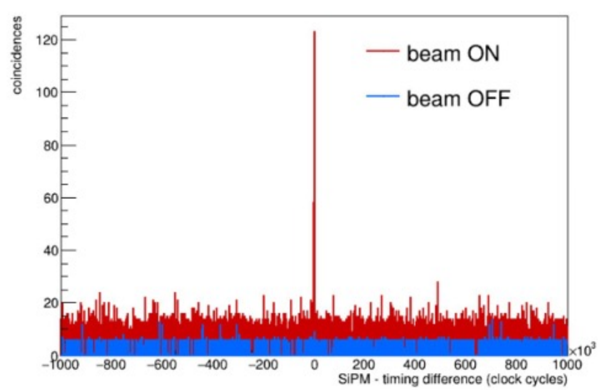
Test Cherenkov application for magnetic field insensitive sensor (SiPM)
Control SiPM high dark count to isolate single photon signal (same amplitude!)
Use a new ALCOR chip (high-rate ToT architecture) in streaming mode

Single photon detection

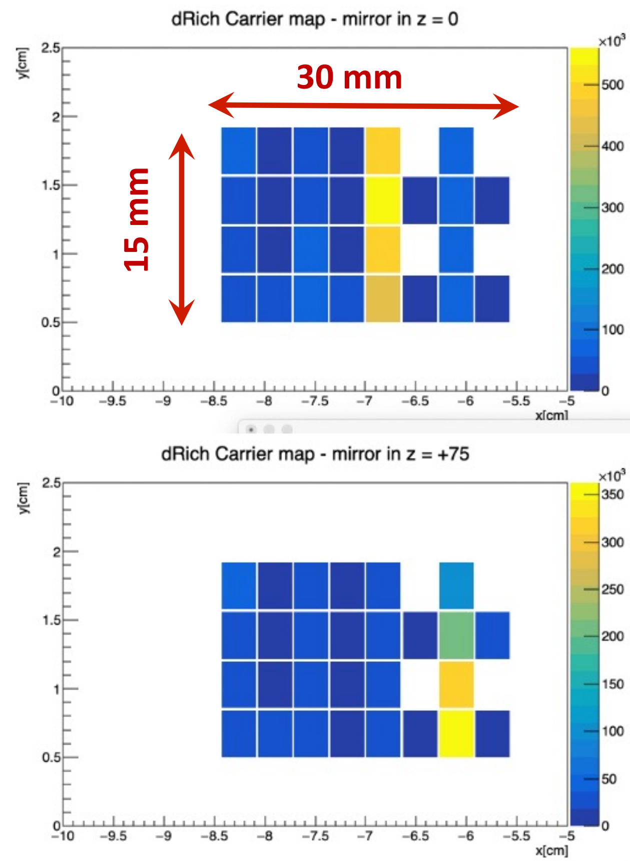


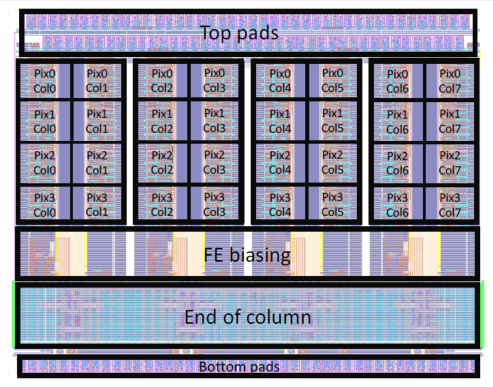
Time coincidence with beam particle

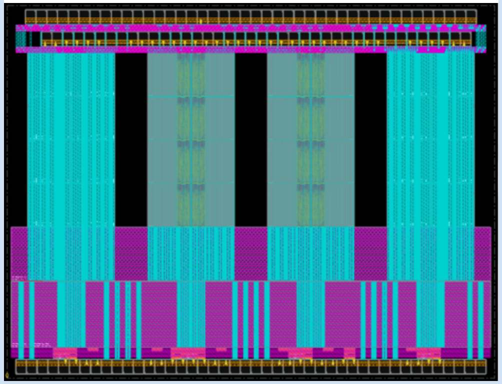




Reflected signal linked to mirror







ALCOR-v2 fro EIC applications

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

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

dRICH DAQ

Based on preliminary studies in synergy with JLab

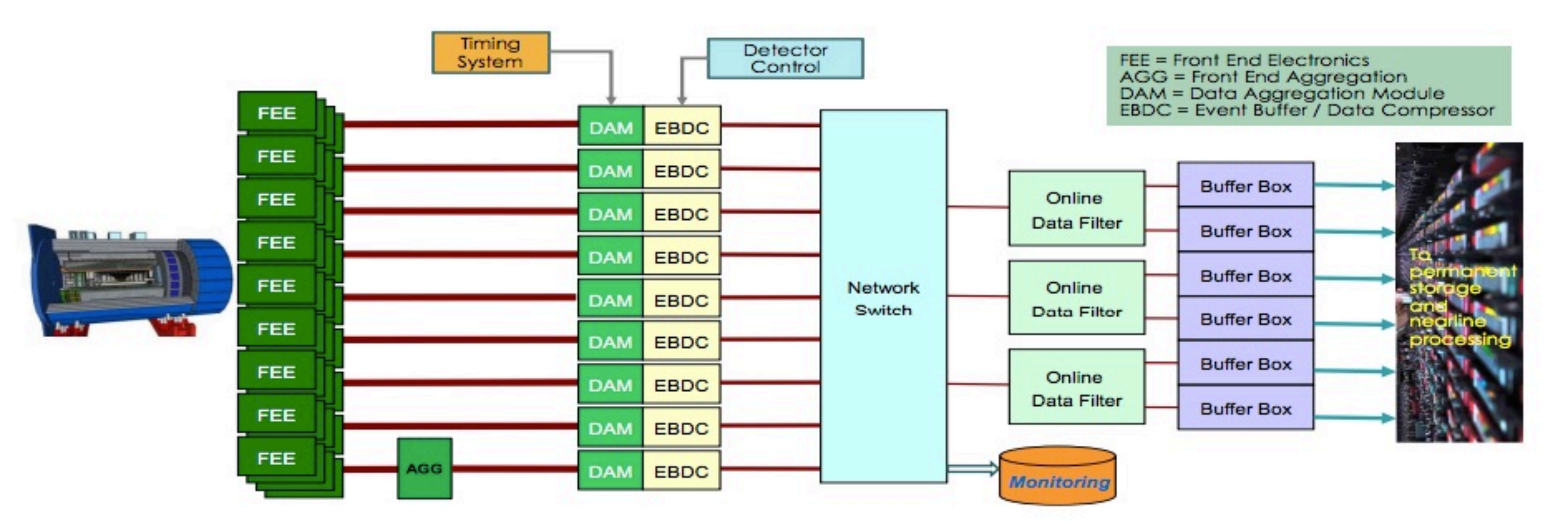
Needs smart solutions to deal with large data volume and to migrate towards consolidated architecture

This was computed assuming an average 300 kHz DCR per pixel before moving to annealing cycles and a factor 3 reduction due to timing selection (it might be 5)

ALCOR: 64 bit per hit (TOT)

Table 2.5: Maximum data volume by detector.

Detector	Channels	DAQ Input (Gbps)	DAQ Output (Gbps)
B0 Si	400M	<1	<1
B0 AC-LGAD	500k	<1	<1
RP+OMD+ZDC	700k	<1	<1
FB Cal	4k	80	1
ECal	34k	5	5
HCal	39k	5.5	5.5
Imaging bECal	619M	4	4
Si Tracking	60B	5	5
Micromegas Tracking	66k	2.6	.6
GEM Tracking	28k	2.4	.5
uRWELL Tracking	50k	2.4	.5
dRICH	300k	1830	14
pfRICH	225k	1380	12
DIRC	100k	11	11
TOF	332k	3	.8
Total		3334	62.9



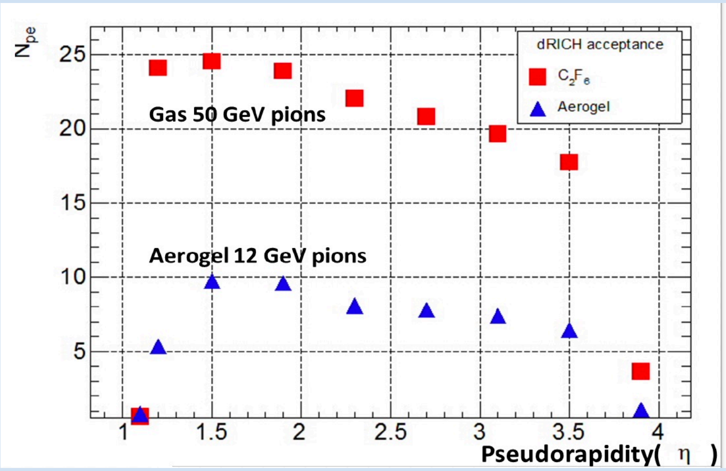
dRICH Simulations

Excellent team at work, but facing limited time availability and fast evolving framework
Dedicated manpower would be crucial to meet project CD deadlines

dRICH performance is strictly related to the EPIC global layout

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

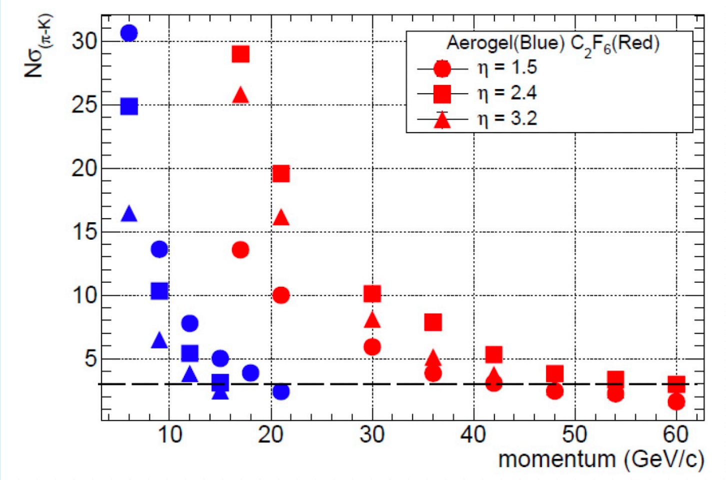
Consequence
- extensive volume and not trivial geometry
- bending inside the magnetic field



Goal: study realistic implementation for EPIC

compare with YR specifications

benchmark with prototype performance



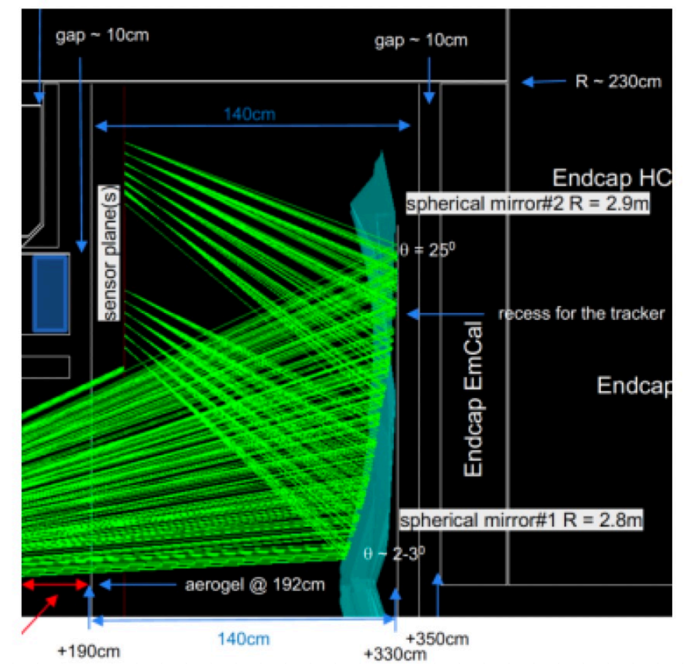
dRICH for EPIC

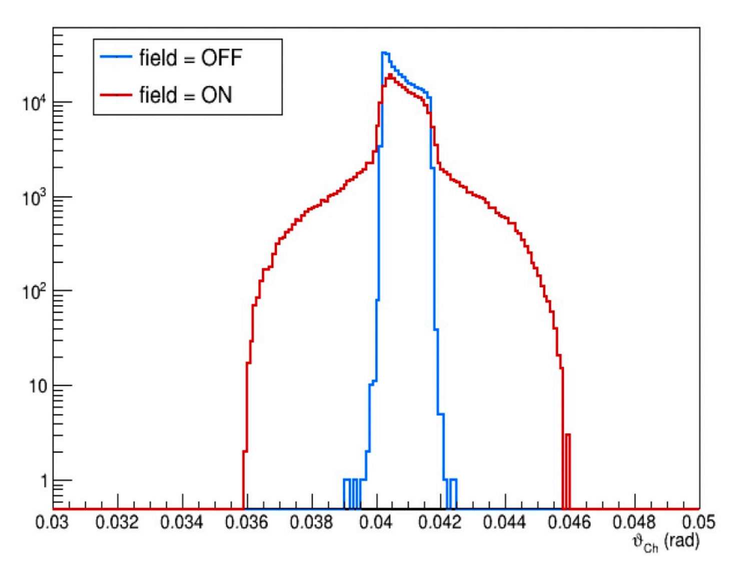
Study optics vs geometry constraints

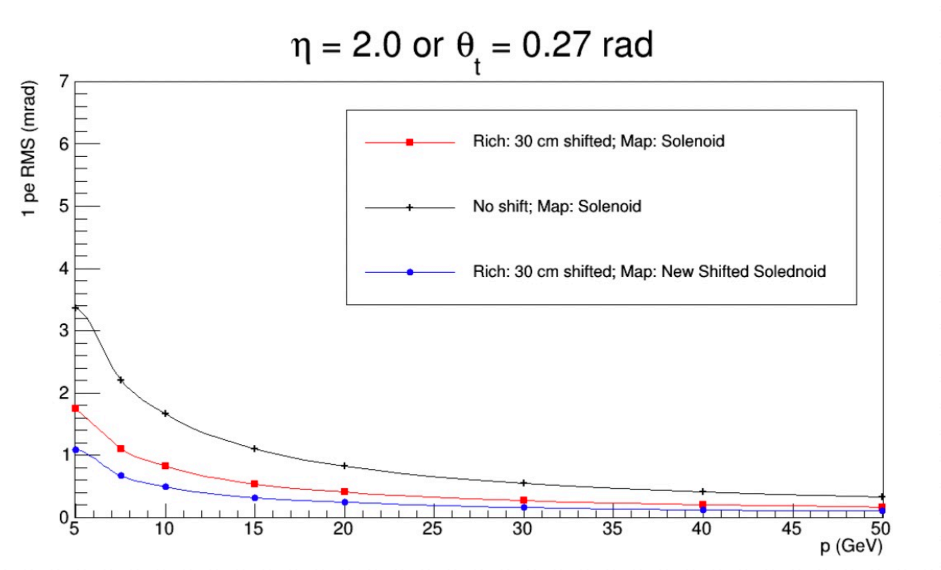
- radiator n vs thickness
- focal plane vs detector surface

Study magnetic bending effect

…..



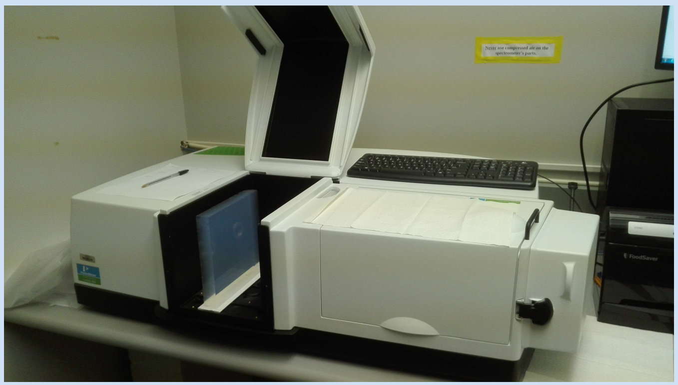


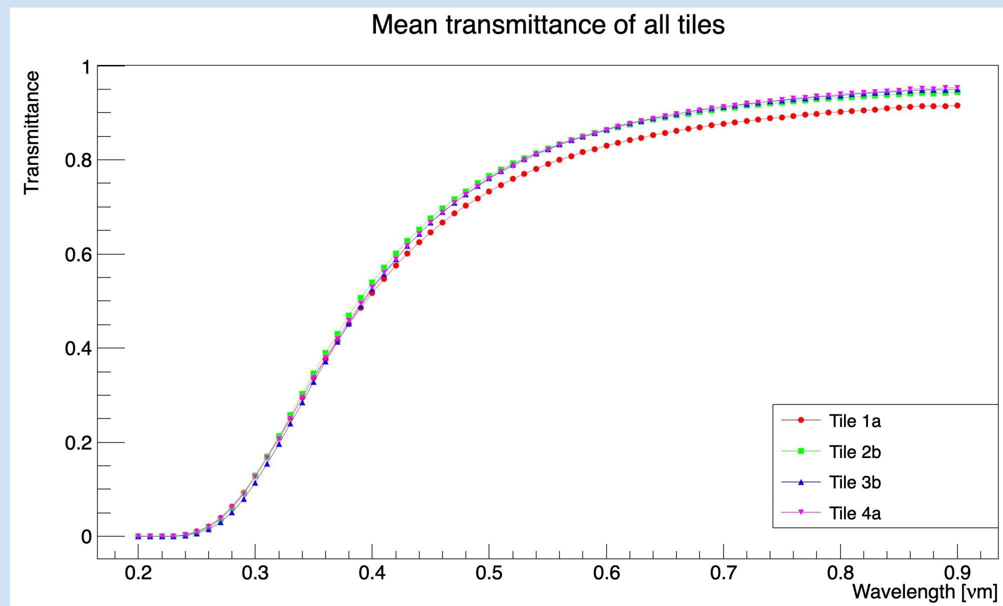


Existing facility to study detailed radiator optical properties and alternatives

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

Budker Institute - Russia: not accessible
Aerogel Factory - Japan: good quality, working on dimensions (in collaboration with ALICE3)
ASPEN – USA: promising quality for n=1.02, awaiting validation (in collaboration with CUA)





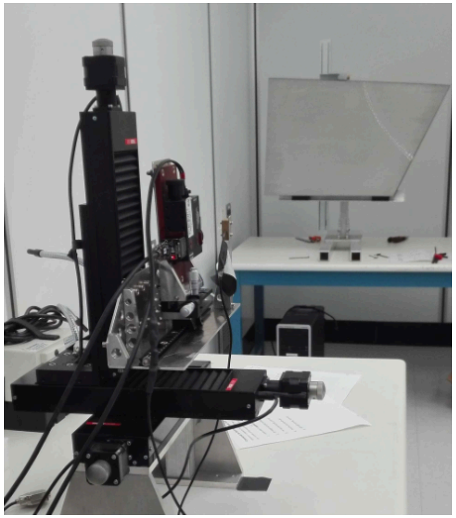
Existing facility to study detailed mirror optical properties and alternatives

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

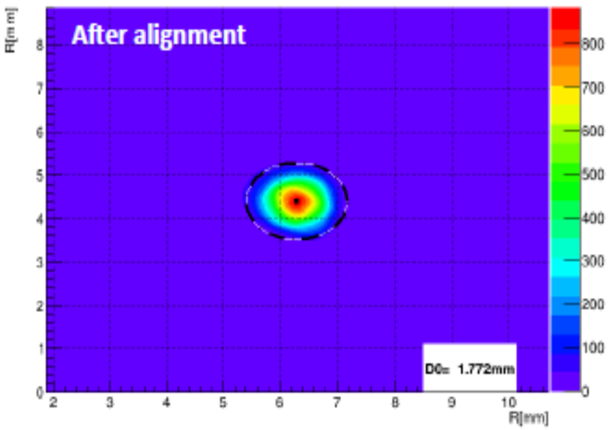
CMA - USA: Carbon fiber (HERMES, AMS, LHCb, CLAS12)
requires validation for EIC (2023)

Media-Lario: Glass skin (cost-effective)
requires specific R&D

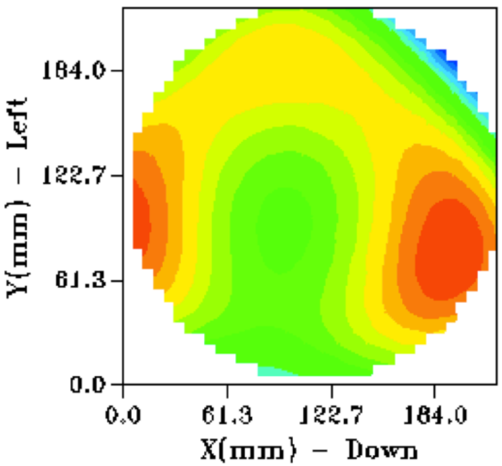
Surface Quality



Pointlike source image



Shack-Hartmann sensor



Mechanics

Assuming composite materials from aeronautics technology

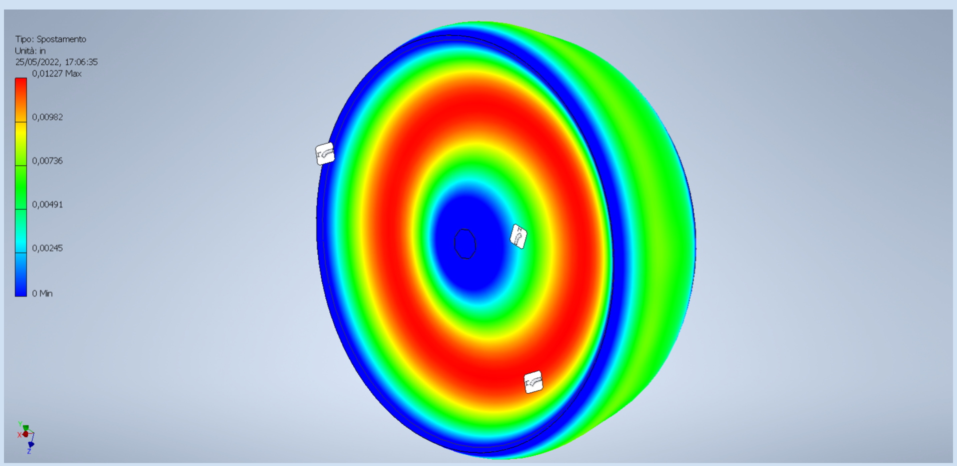
Stiff and light, with a skeleton supporting alignment elements

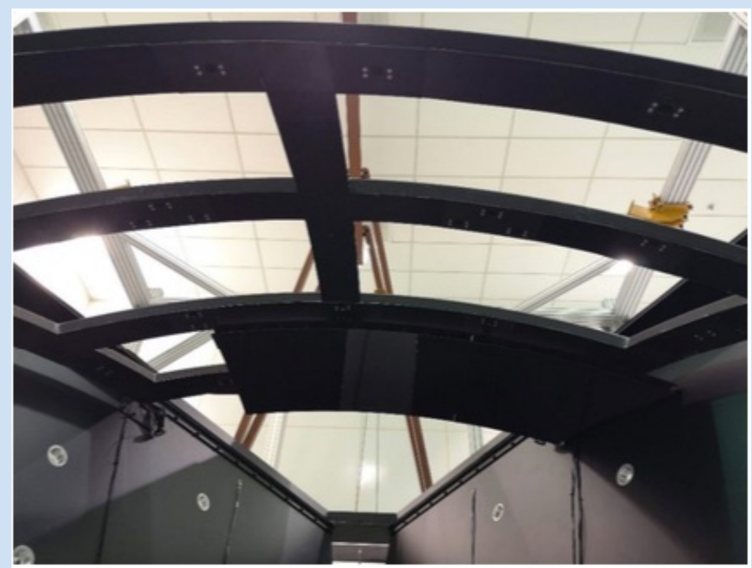
Need guidance to select alternatives and define specifications

High-P Ar: Alternate of greenhouse gas

Dedicated R&D planned to start in fall 2022

stage 1: simple cylinder of candidate material(s)
stage 2: prototype on scale





dRICH Status and Plans

- ✔ Proto: baseline existing
  Systematics studies after proof-of-principle to benchmark design resolution

- ✔ SiPM: local facilities (FBK for development, Lfundry for production)
  Well structured R&D ongoing
  LAPPDs as alternative

- ✔ F-E: ALCOR chip
  INFN started R&D awaiting eR109

- ✔ DAQ: streaming readout ?
  Investigating online data selection (correlations with other detectors, off-bunch inhibit)

- ✔ Simulations: consolidate framework, natural entry point for new collaborators

- ✔ Aerogel: R&D ongoing based on experience, characterization laboratories
  Aerogel Factory: R&D on size
  ASPEN: open new R&D with US groups ?

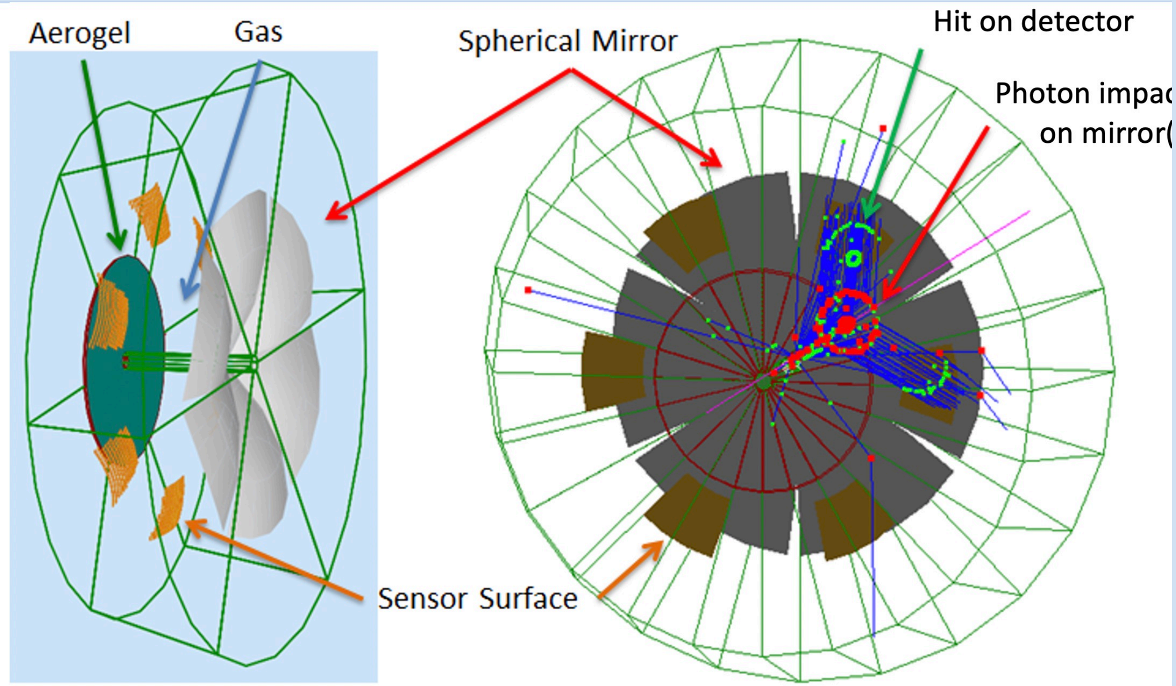
- ✔ Mirrors: experience, characterization laboratories
  World leading manufacturer based in USA (CMA)
  R&D planned in 2023

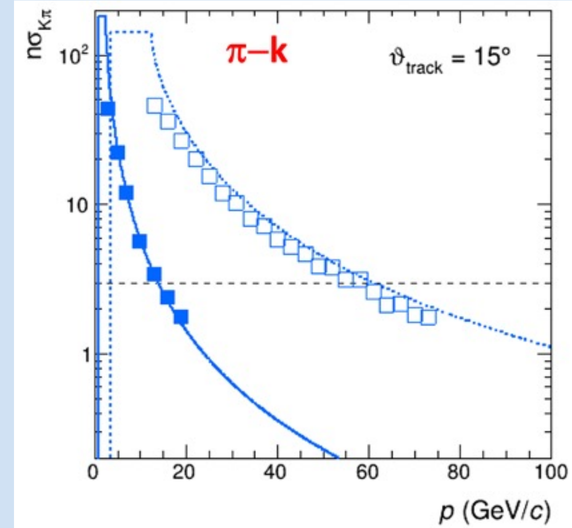
- ✔ Mechanics: initiating a dedicated task force, high-pressure option to be validated with BNL/JLab
  R&D planned to start in fall 2022

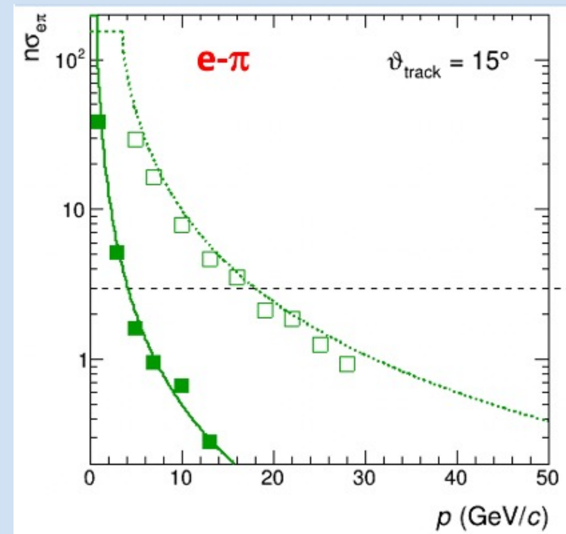
Backups

Dual Radiator RICH @ EIC

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

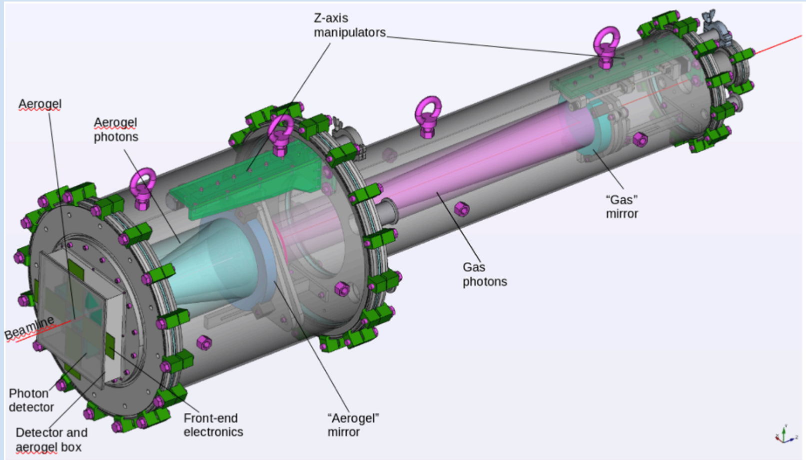
Radiators: Aerogel (n_{AERO}~1.02) + Gas (n_{C2F6} ~ 1.0008)

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

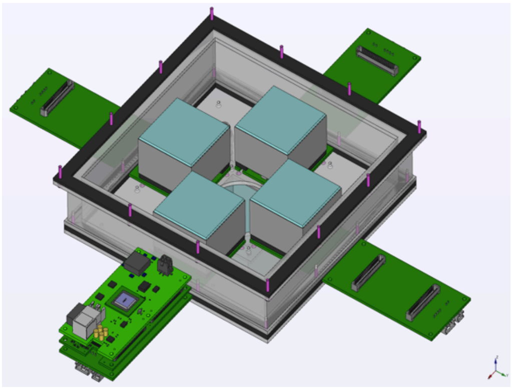
Phase Space:
- Polar angle: 5-25 deg
- Momentum: 3-60 GeV/c

Targeted R&D eRD102

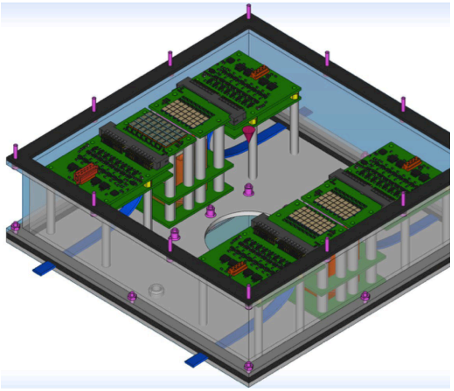
Prototipe to validate dual-radiator working principle,
optimize performance and define specifications for components

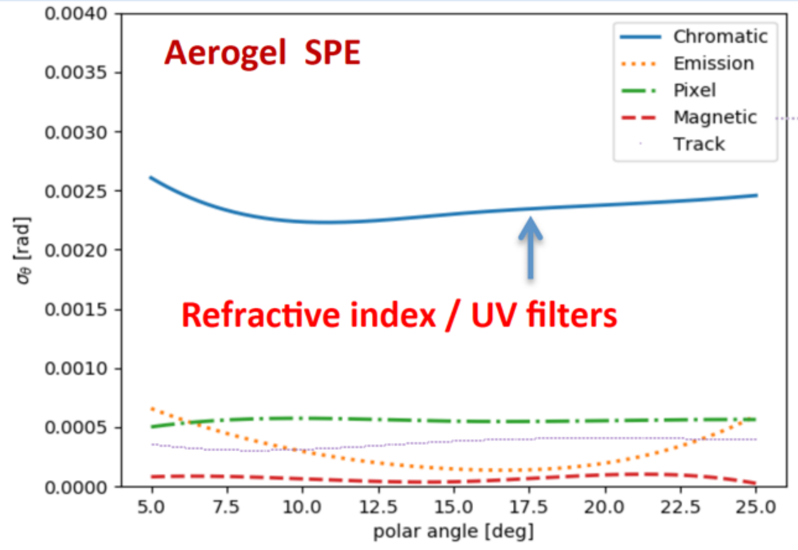


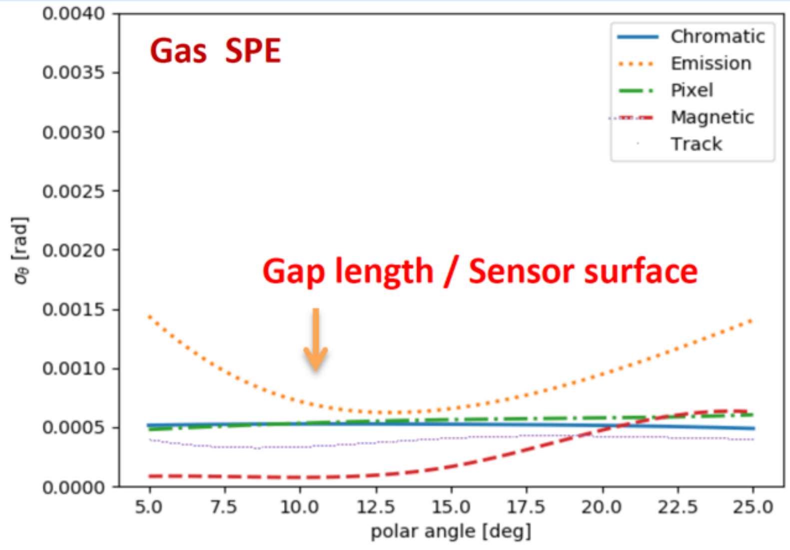
Reference detector



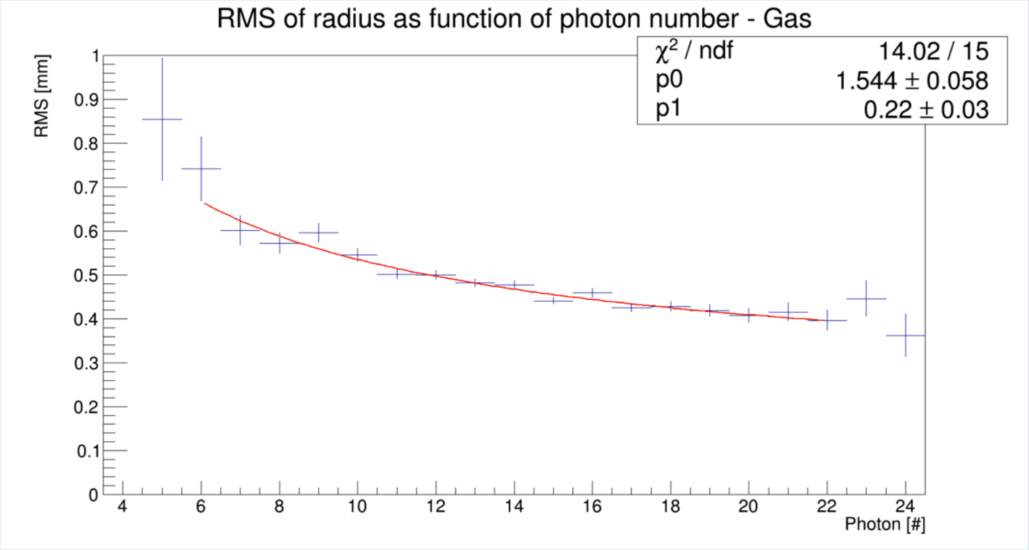
EIC driven detector

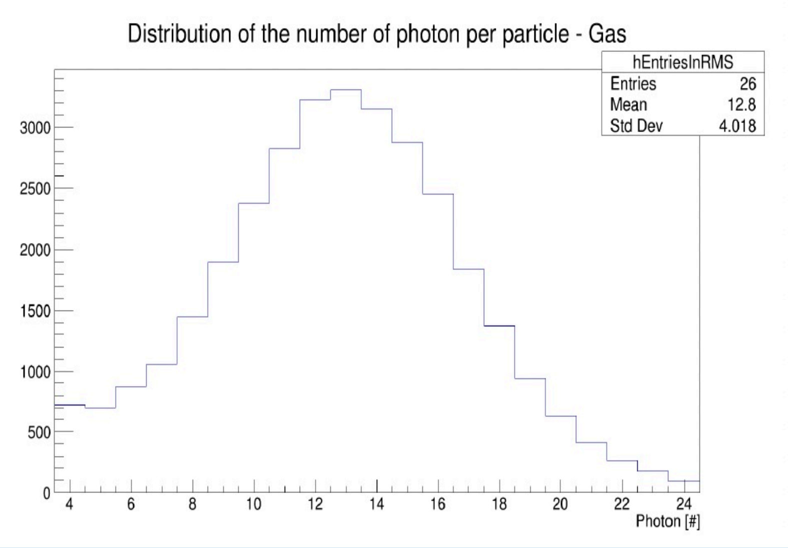






Preliminary Performance: Gas





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

p_1 = single particle resolution constant term

p_0 = single photon resolution

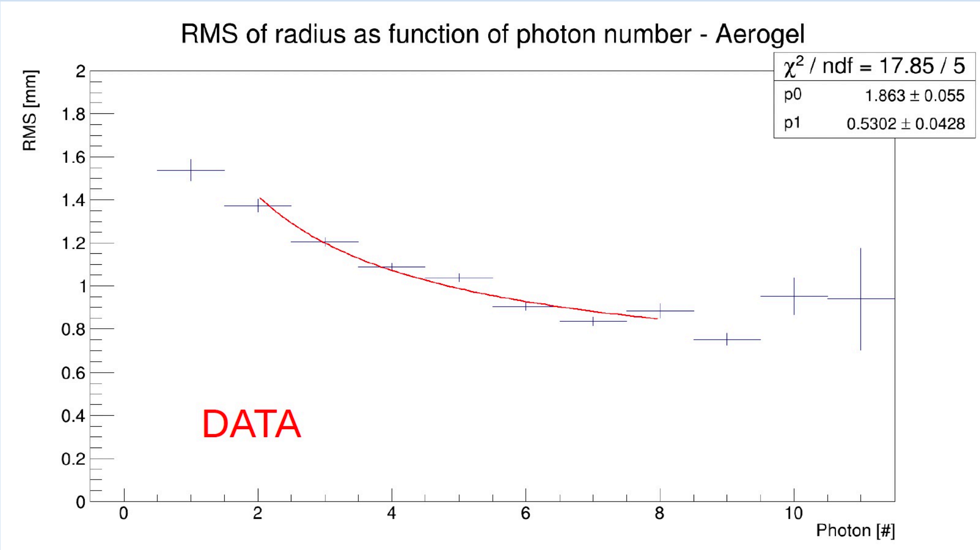
1.5 mm in radius

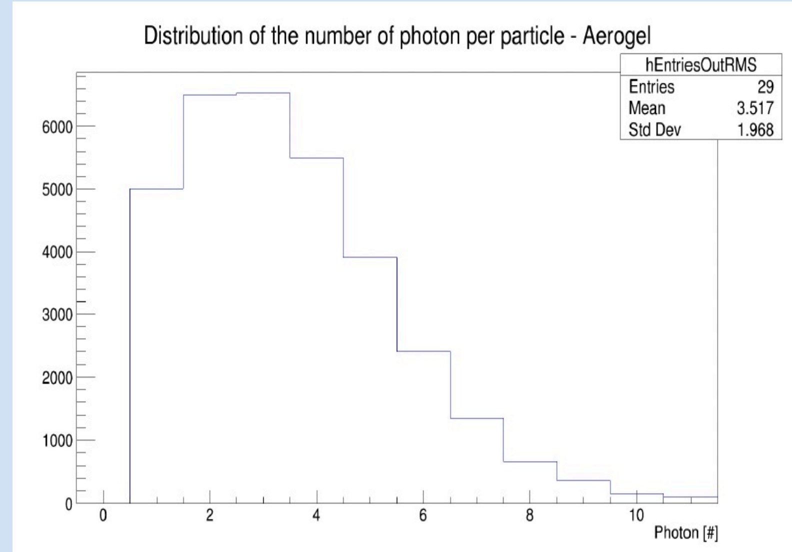
~ 1.2 mrad in angle (1.1 expected)

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: $y=\sqrt{p_0^2/x+p_1^2}$

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

ALCOR Chip

Towards a 3D a-SiPM

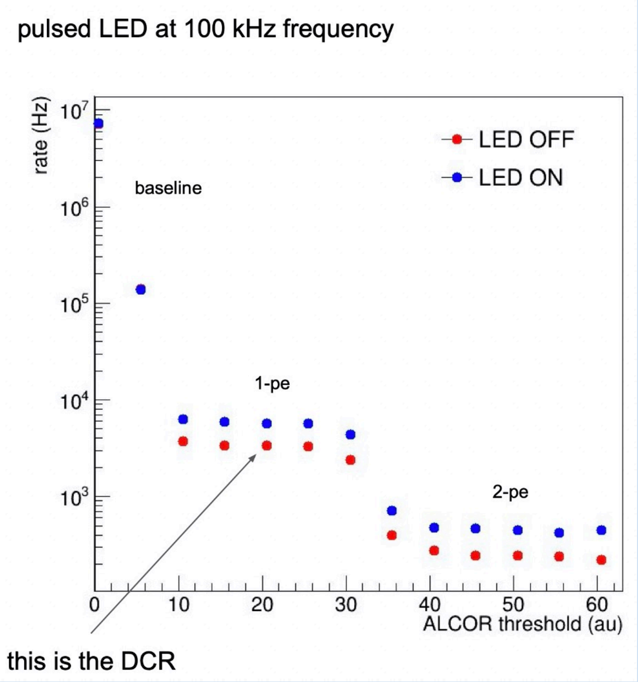
”digital tile” Developed by INFN (CSN2) for the readout of SiPMs at 77K, in the framework of Darkside

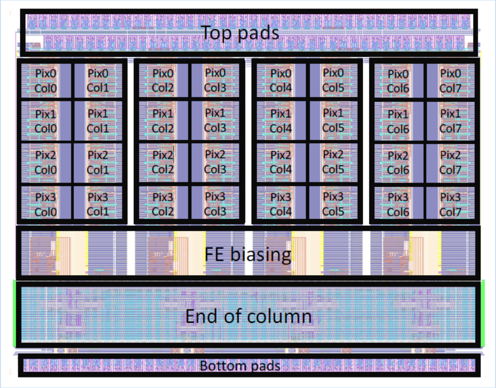
32-pixel (4x8 array) matrix mixed signal ASIC

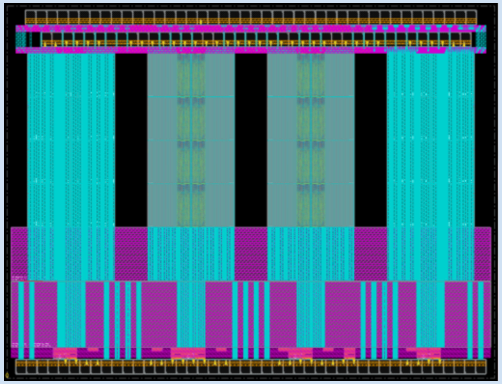
the chip performs amplification, signal conditioning and event digitisation, and features fully digital I/O Single-photon time tagging mode or time and charge measurement

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

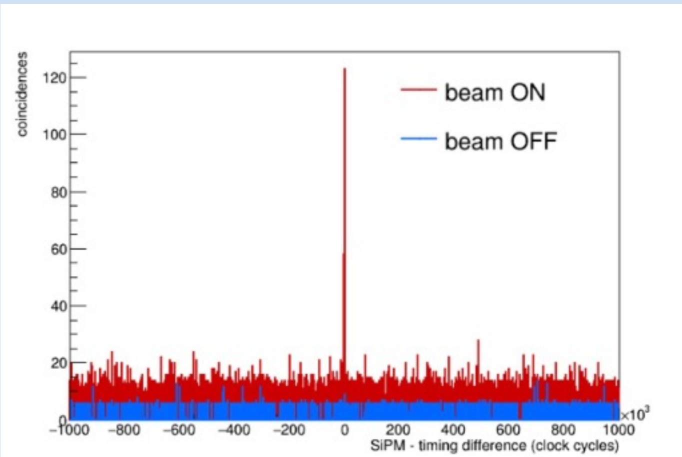


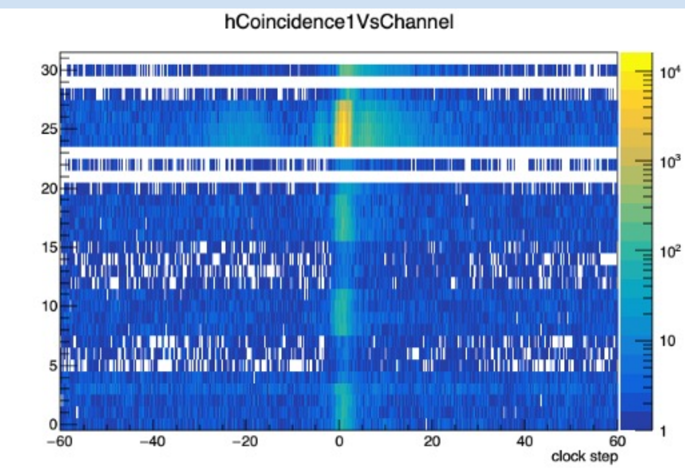


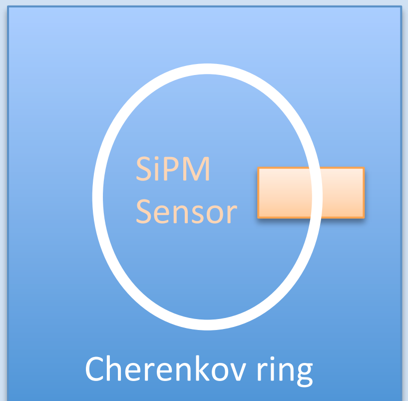


Test Cherenkov application for magnetic field insensitive sensor (SiPM)
Control SiPM high dark count to isolate single photon signal (same amplitude!)
Use a new ALCOR chip (high-rate ToT architecture) in streaming mode

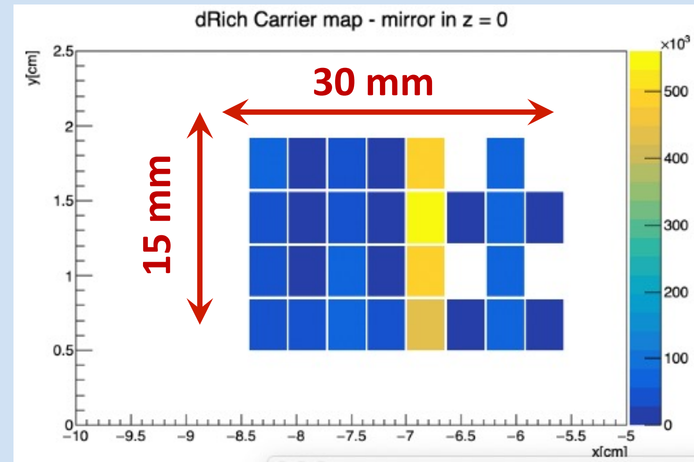
Time coincidence with beam particle

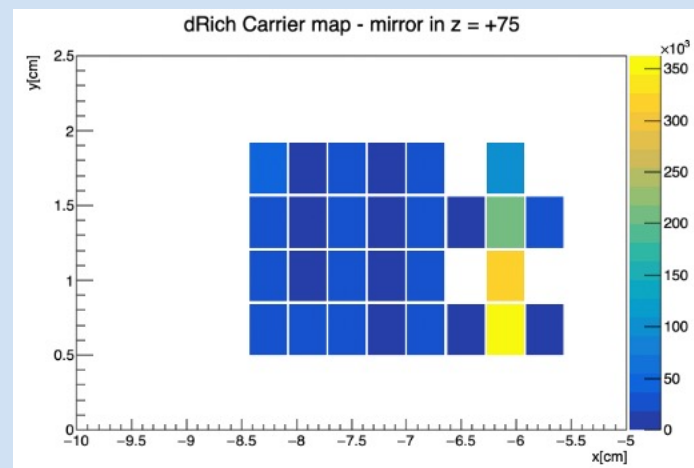






Reflected signal moves with mirror



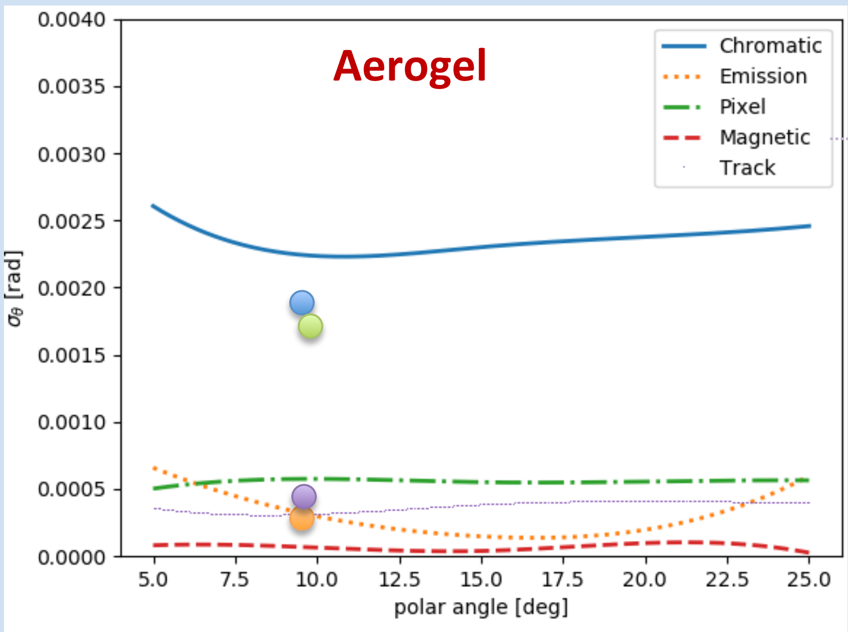


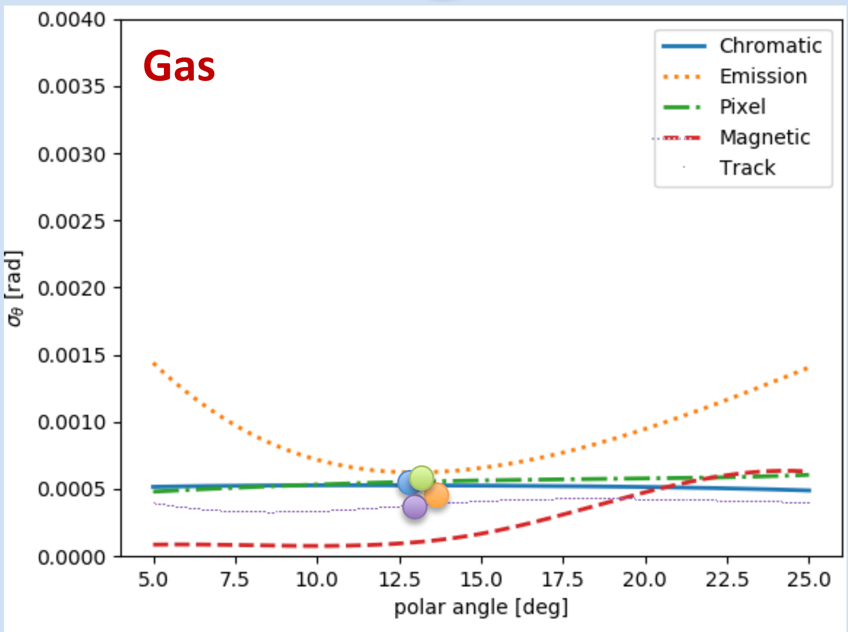
dRICH Resolution

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)

5

1.2

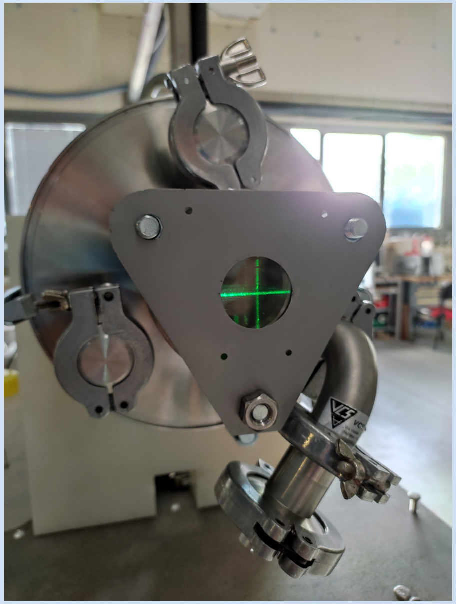




Next Steps for Prototype

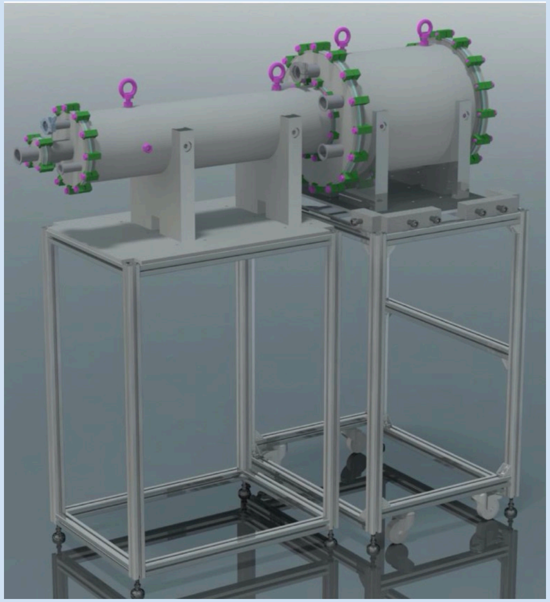
Prepare for the next test-beam campaign (fall 2022)

Improved tools for alignment

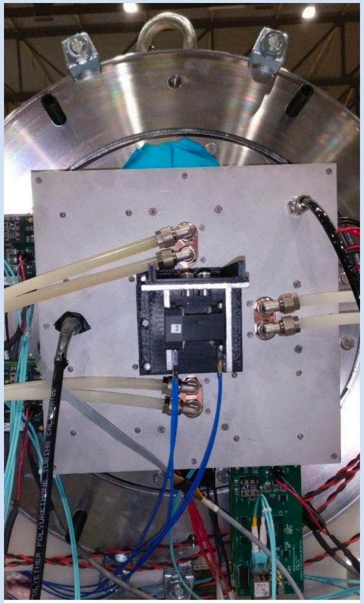


Time and gain calibration

Upgrade support structure



Improved trigger



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