The INFN in-kind contribution to the dRICH detector

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INFN - Ferrara

Giornate Nazionali EIC_NET, Bologna, June 28th 2024

dRICH Collaboration

Compact cost-effective solution for particle identification in the high-energy endcap at EIC

dRICH

INFN — BA, BO, CS, CT, FE , GE, LNS, RM1, RM2, SA, TO, TS

Jefferson Lab

Duke University

Ramaiah University of Applied Sciences

NISER

हरियाणा केंद्रीय विश्वविद्यालय
CENTRAL UNIVERSITY OF HARYANA
NAAC ACCREDITED 'A' GRADE UNIVERSITY

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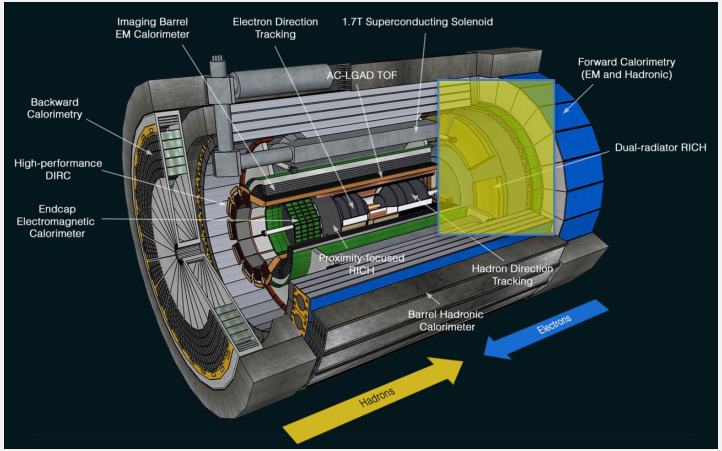
EPIC



EIC RICH Consortium

Brookhaven National Laboratory

Stony Brook University

Purdue University

Temple University

Univerza v Ljubljani

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Forward particle detection

Hadron ID in the extended 3-50 GeV/c interval

Support electron ID up to 15 GeV/c

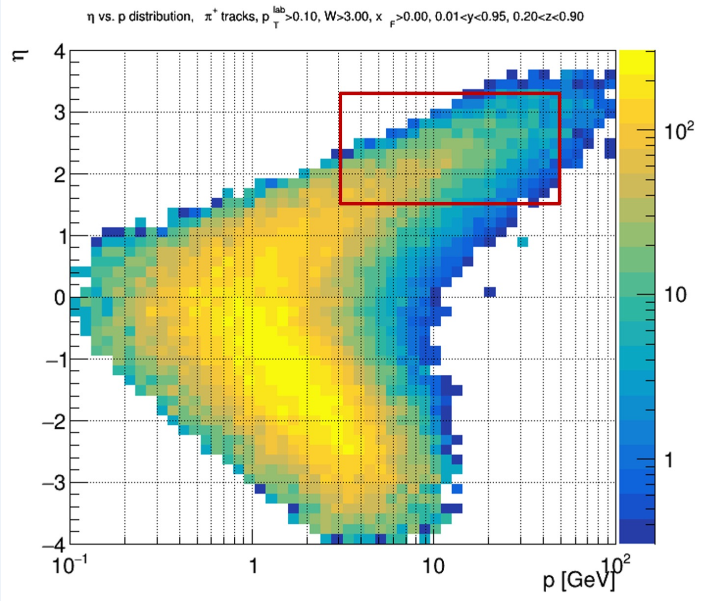
Main challenges:

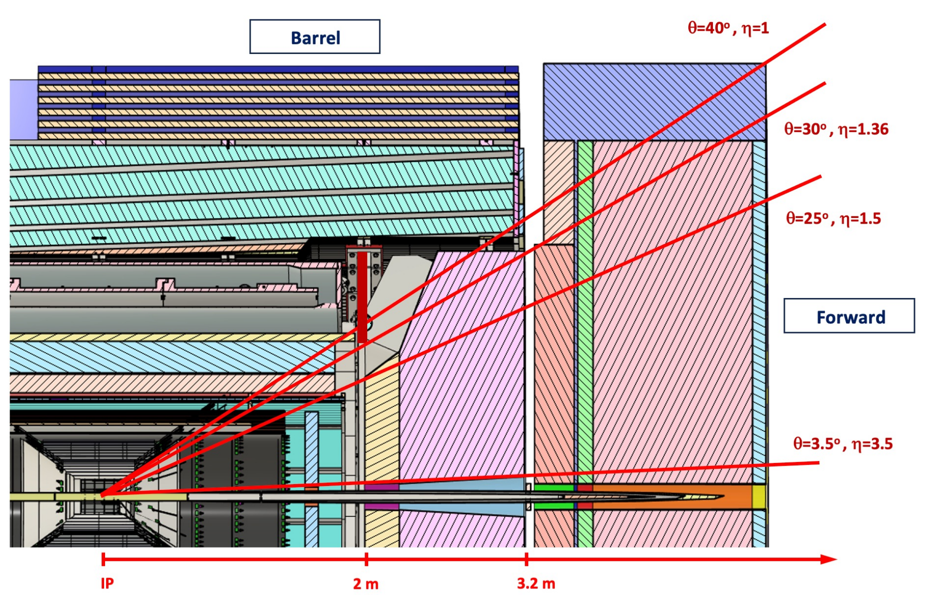
Cover wide momentum range 3 - 50 GeV/c -> dual radiator
Work in high (~ 1T) magnetic field -> SiPM
Fit in a quite limited (for a gas RICH) space -> curved detector

Essential for semi-inclusive physics due to

absence of kinematics constraints at event-level

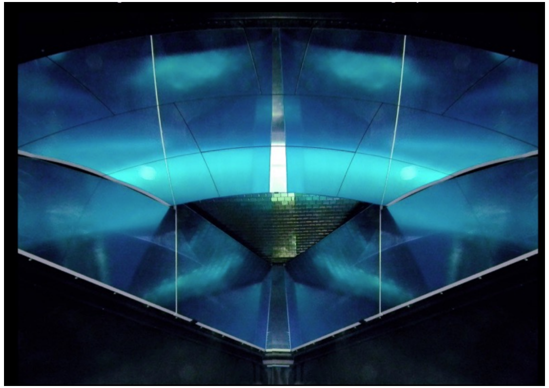
η	Nomenclature	Electrons and Photons			π/K/p	
		Resolution σ_E/E	PID	Min E Photon	p-Range	Separation
1.0 to 1.5	Forward Detectors	2%/E ⊕ (4*-12)%/√E ⊕ 2%	3σ e/π up to 15 GeV/c	50 MeV	≤ 50 GeV/c	≥ 3σ
1.5 to 2.0						
2.0 to 2.5						
2.5 to 3.0						
3.0 to 3.5						



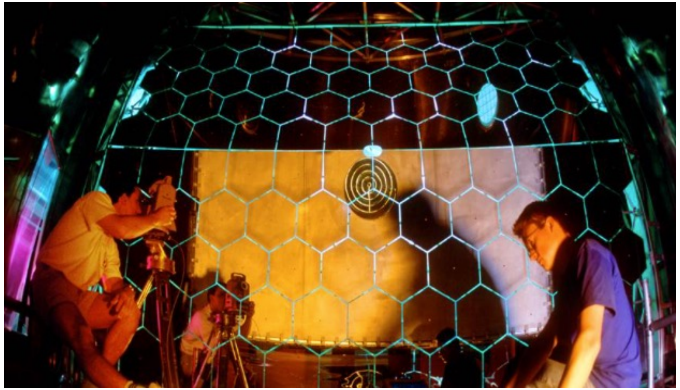


INFN Background

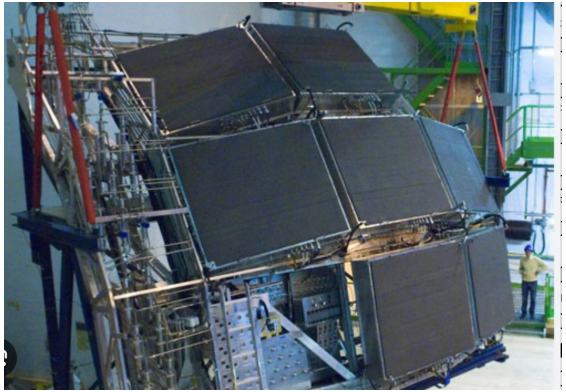
CLAS12 RICH



COMPASS RICH

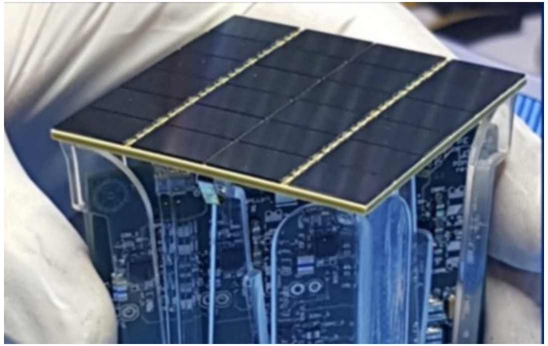


ALICE HMPID

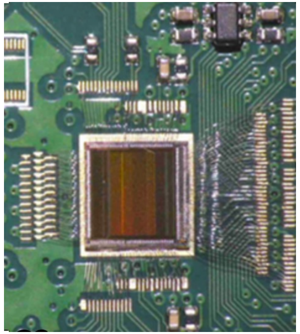


HERMES RICH

DARKSIDE



ALCOR



dRICH Sub-System Organization

6.10.04 Particle Identification	Level-3	CAM from Project
6.10.04.03 dRICH	Level-4	CAM from Project + DSTC from EPIC (**M. Contalbrigo**)

Work packages lead from EPIC

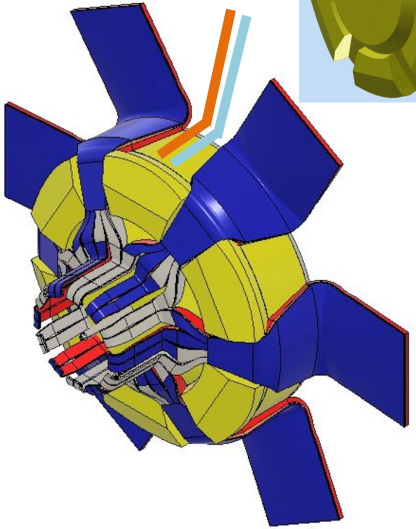
Photo-Detector	Level-5	**R. Preghenella**, INFN-BO, INFN-FE, INFN-CS, INFN-SA, INFN-CT, INFN-TS, NISER
Front-end Asics	Level-5	**F. Cossio**, INFN-TO, INFN-BO
Data-acquisition	Level-5	**P. Antonioli**, INFN-BO, INFN-FE
Mechanics	Level-5	**A. Saputi**, INFN-FE, INFN-CT, INFN-TS, JLAB, BNL
Gas radiator	Level-5	**F. Tessarotto**, INFN-TS, BNL
Mirror	Level-5	**A. Vossen**, DUKE, JLAB, NFN-FE, RICH Consortium
Aerogel Radiator	Level-5	**G. Volpe**, INFN-BA, INFN-FE, RICH Consortium
High-Pressure	Level-5	**S. Dalla Torre**, INFN-TS, INFN-FE, INFN-LNS
Simulation		**C. Chatterjee**, INFN-TS, DUKE, INFN-FE, RICH Consort.

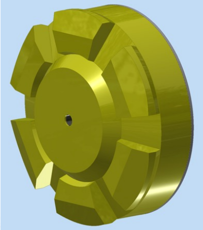
Possible work packages not yet active

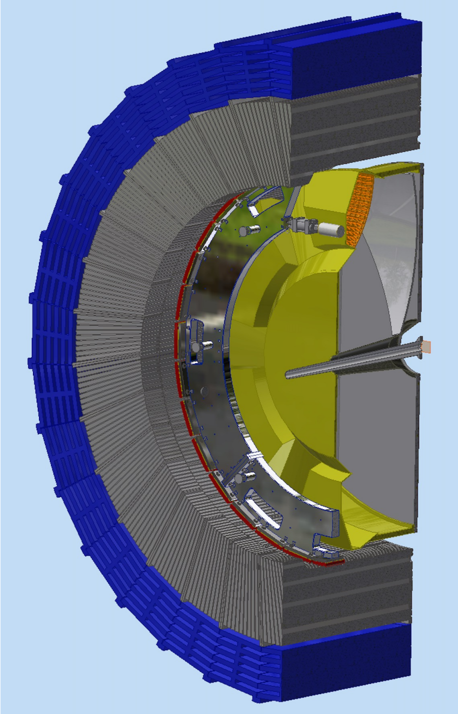
Detector box	Level-5
Gas purging	Level-5
Cooling	Level-5
Slow Control	Level-5
Interlock	Level-5
Alignment	Level-5
Power Supply	Level-5
……	Level-5

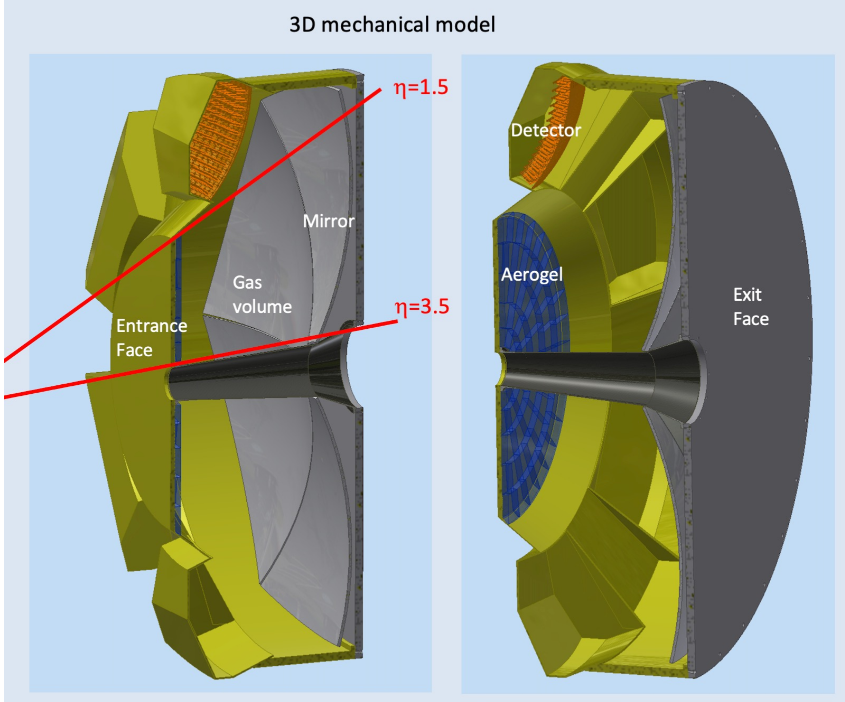
ePIC dRICH

- Φ3600 mm x L1200 mm
- Operating pressure up to 200 Pa
- Operating temperature of 22 °C









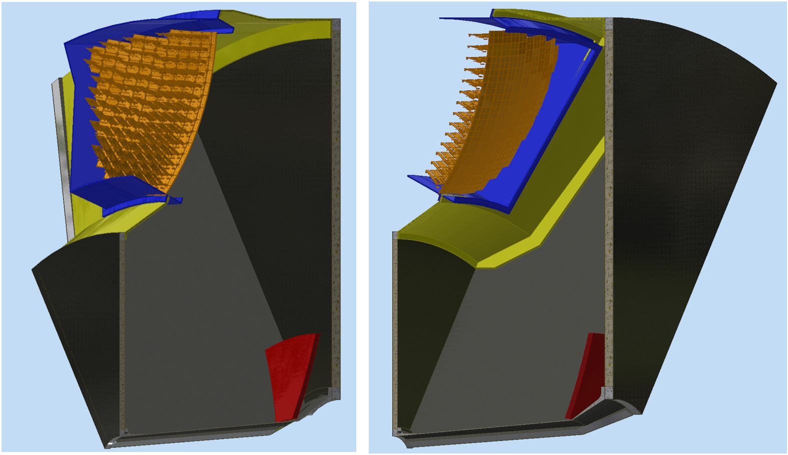
Acceptance: defined by pipe and barrel ecal
minimize material budget with the use of composite materials

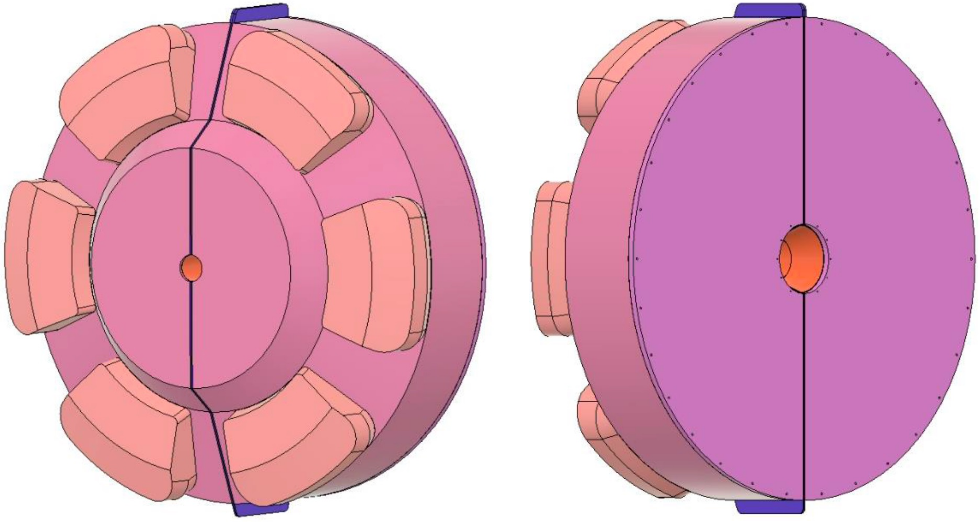
Interferences: material budget concentrated beheind the barrel ecal and its support ring
readout electronics design in order to minimize the detector box volume

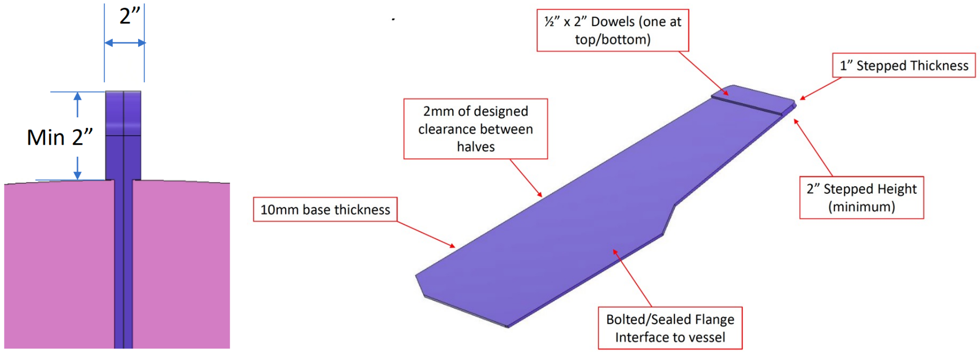
Real scale prototype

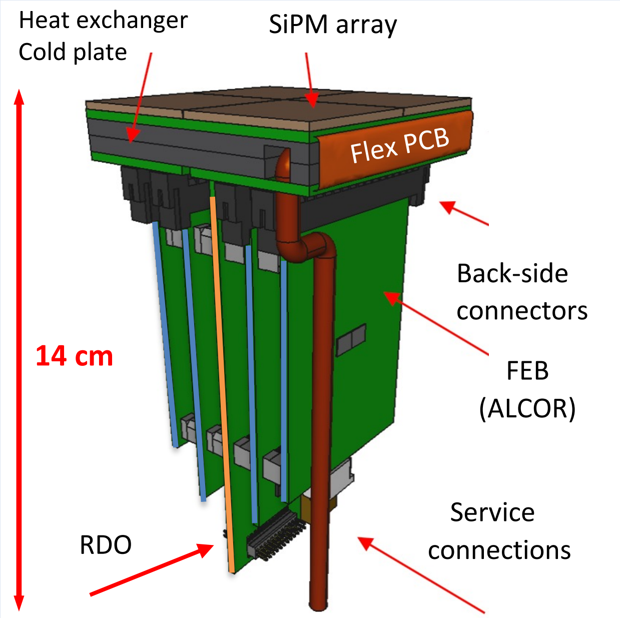
Detector box integration

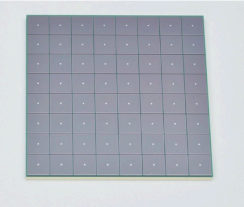
dRICH split model

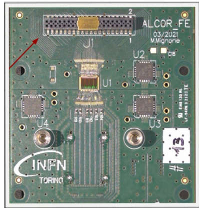









SiPM array



ALCOR chip

Photon Detector Unit (PDU):

Compact to minimize space

4x Hamamatsu S13361-3050HS SiPM arrays

4x Front-End Boards (FEB)

4x ALCOR chip (ToT discrimination)

4 x Annealing Circuitry

1x Read-Out Board (RDO)

1x Cooling plate (< -30 C)

Active area is shaped to resemble the focal surface and best exploits the focalization

Detector box:

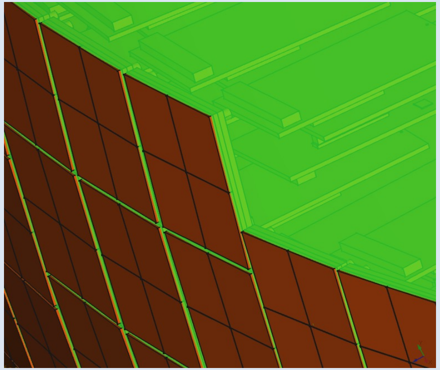
Shaped to fit the space

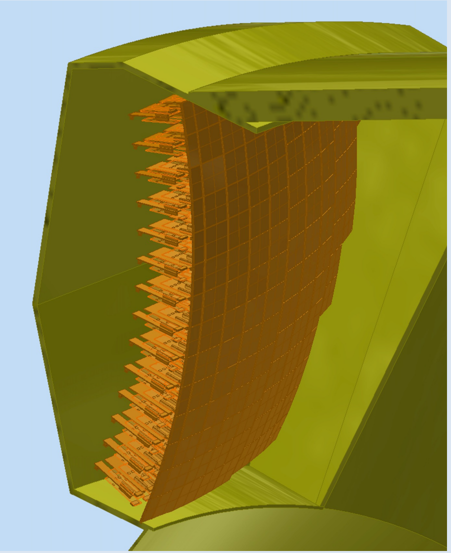
Quartz window

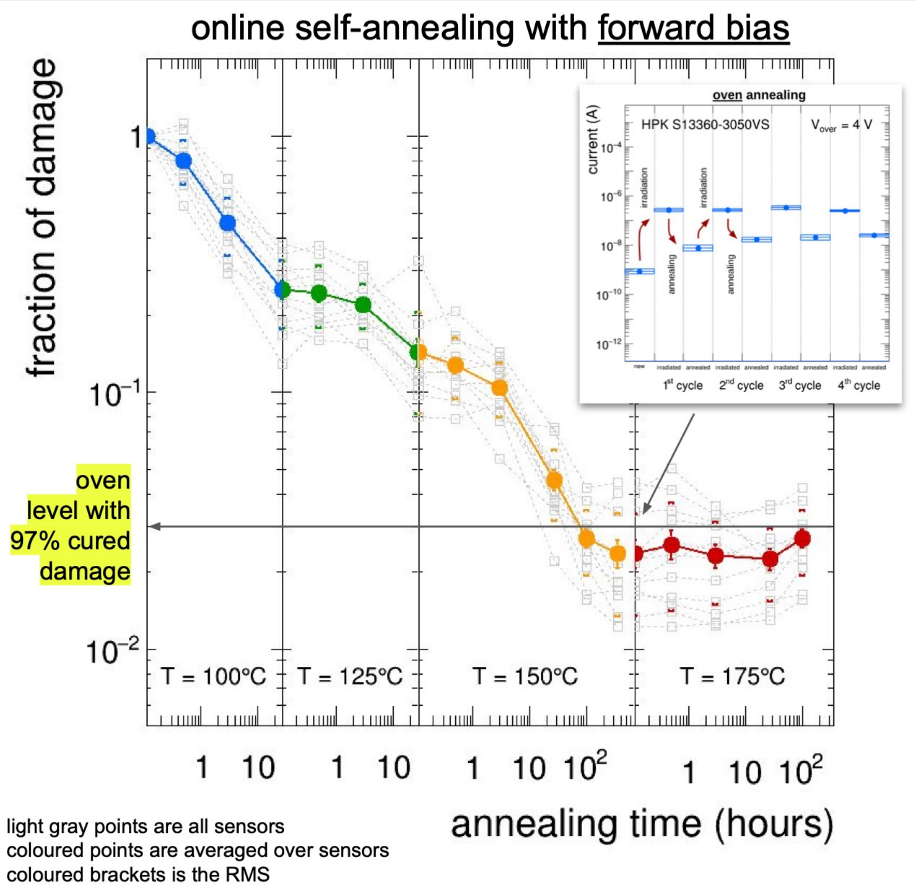
Cooling for sensors and electronics

Power distributing patch panel

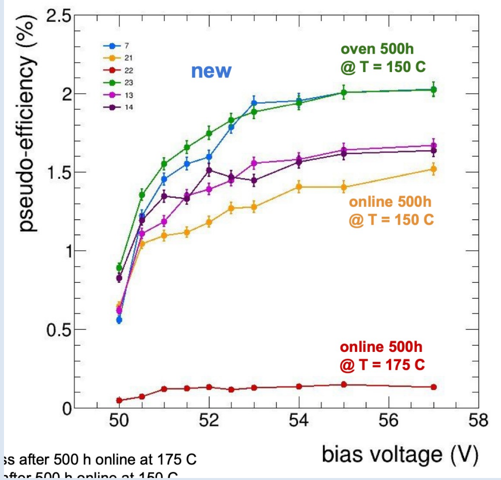
Heat insulation





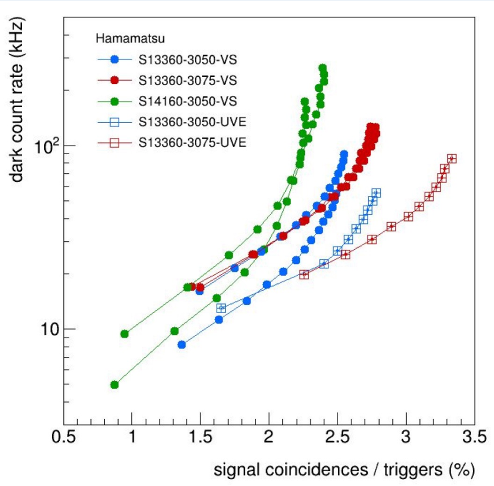


Hamamatsu sensors
oven vs ob-board annealing

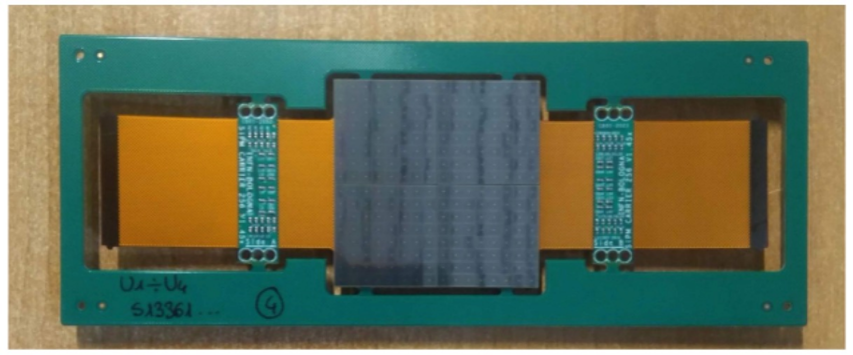


Hamamatsu sensors
- 10^9 neq
- oven annealing

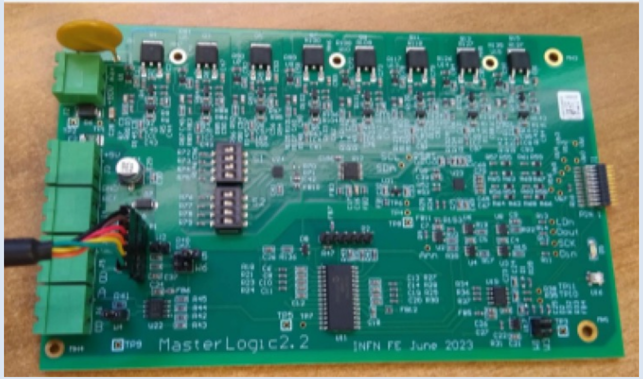
Luigi



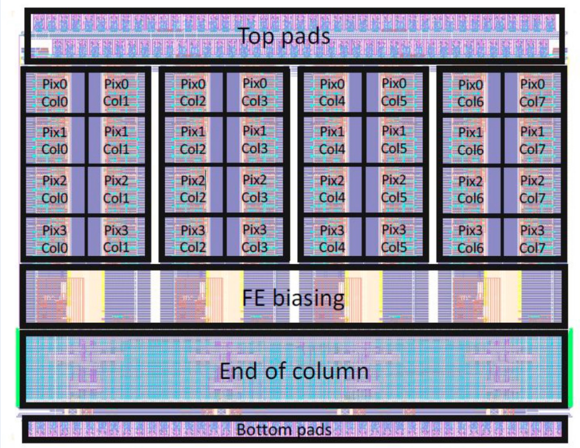
SiPM **carrier board** with 256 channels and flex connector circuits.

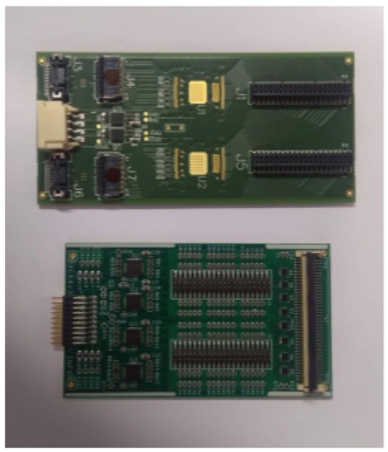


MasterLogic card to control SiPM bias voltage & monitoring service



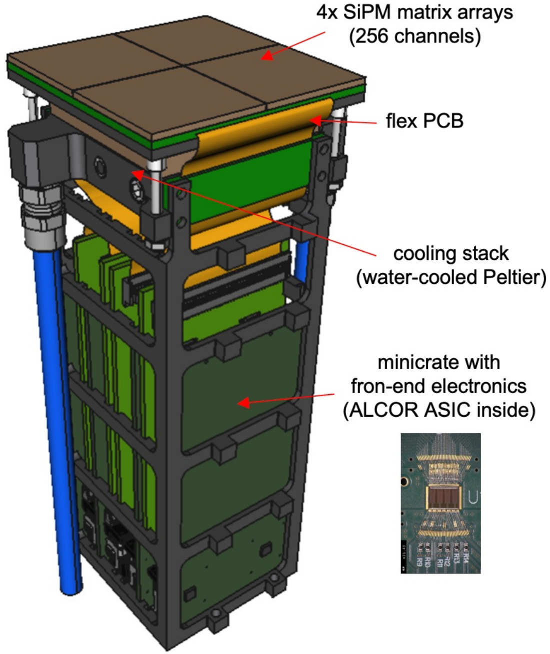
2x **ALCOR front-end card** and the **adapter board**



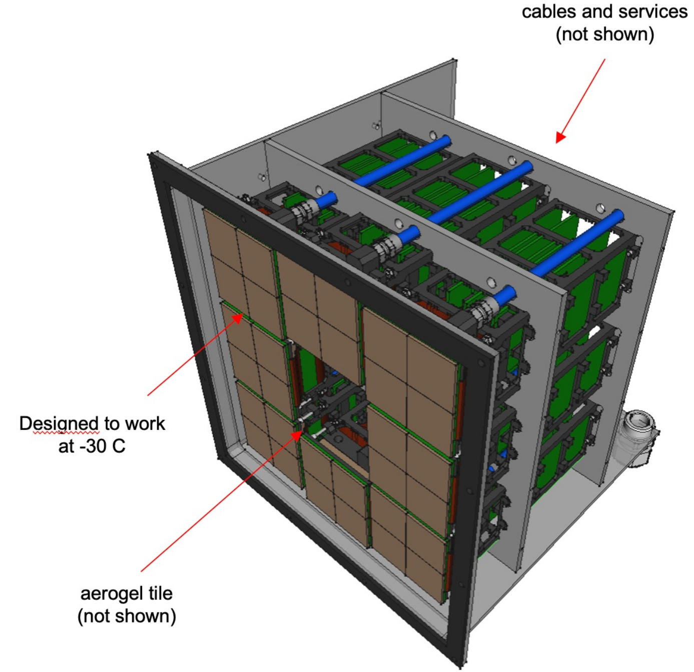


SiPM Detection Plane

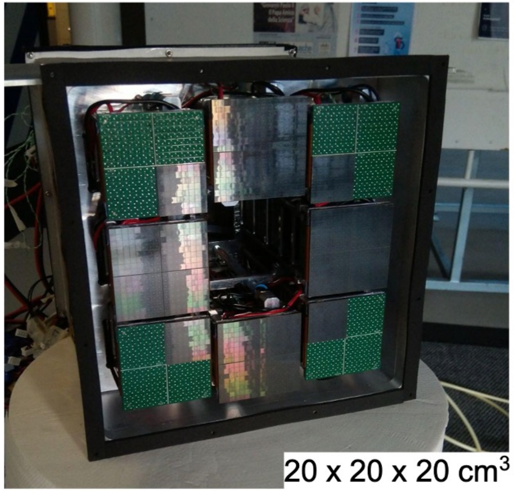
Photon Detection Unit
Streaming readout mode

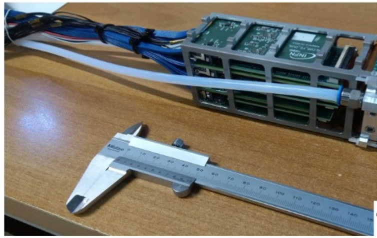


Readout Box
8 PDUs, 2048 channels

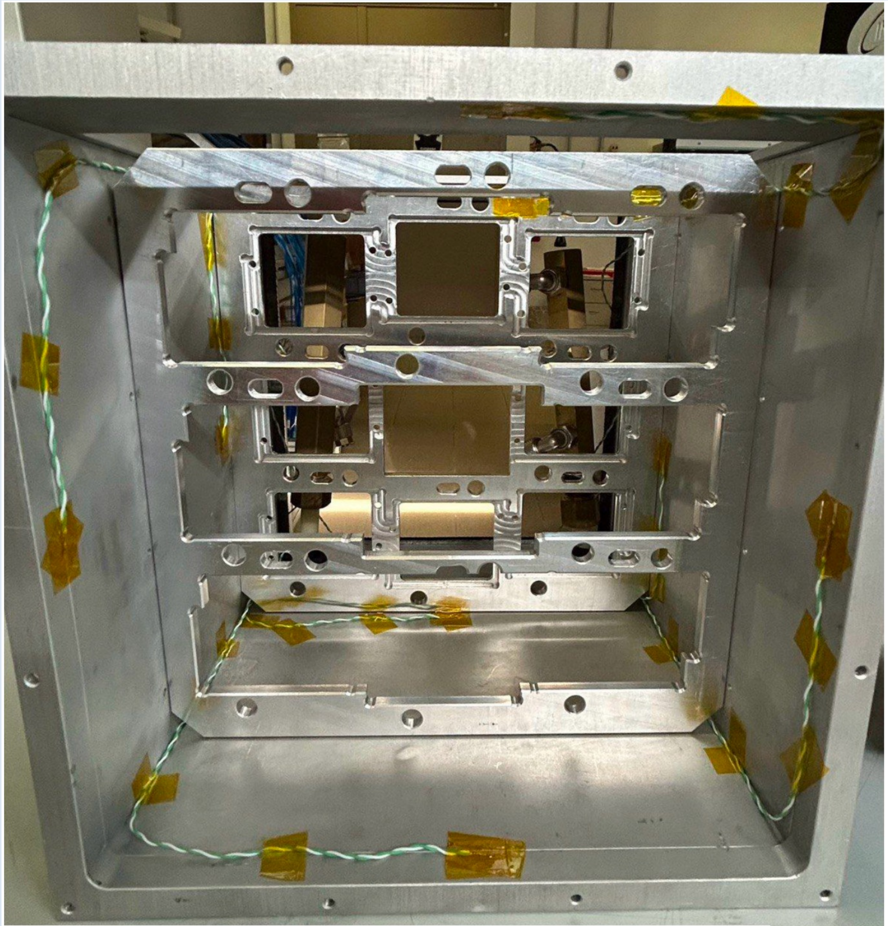


Prototype
Working Pooint -40:-20 C

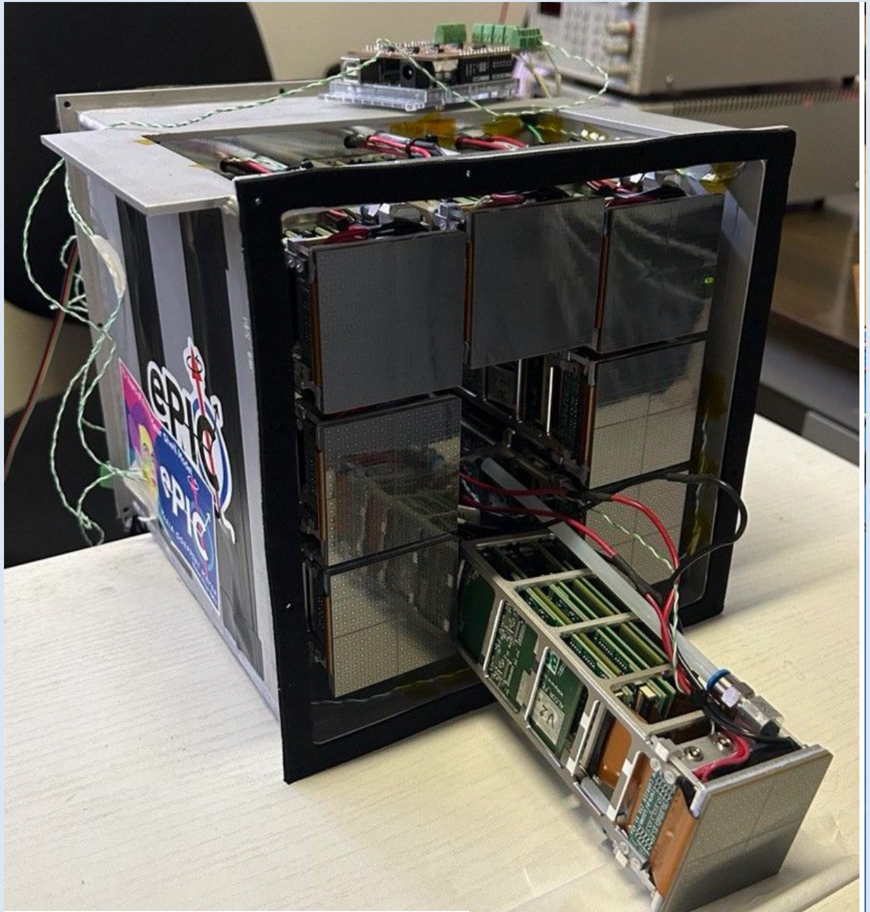

20 x 20 x 20 cm^3


14 cm long

Detector Prototype



empty readout box with PDU housing and monitor thermocouples

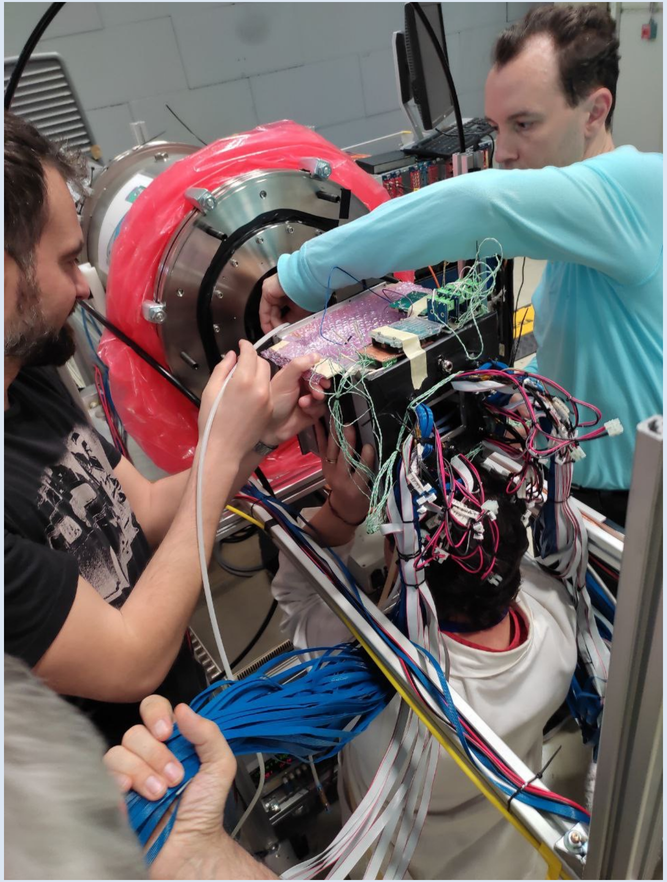


Photon Detection Unit Insertion

May 2024 Test-beam

SiPM Detector

Detector Mounting



Tracking GEM+SciFi

Successful campaign:

Mixed hadron beam 2-11 GeV/c

Various aerogel samples (1.020-1.026)

Two gas radiators (C_2F_6, C_4F_{10})

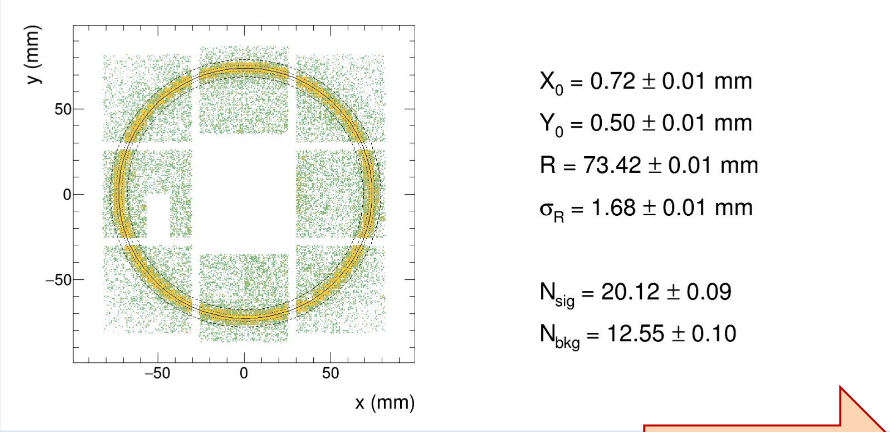
Two SiPM working points (-40 C and -20 C)

Two tracking systems (GEM & SciFi)

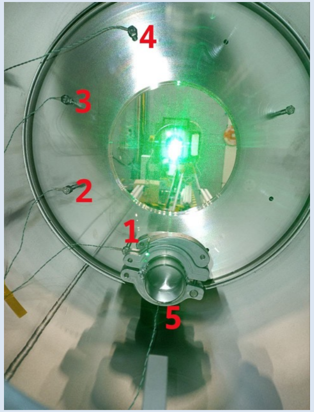
Many optical fiters

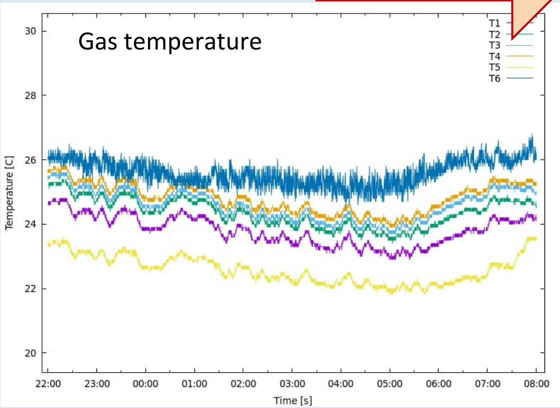
Beam line Cherenkov tagging

Temperature monitor

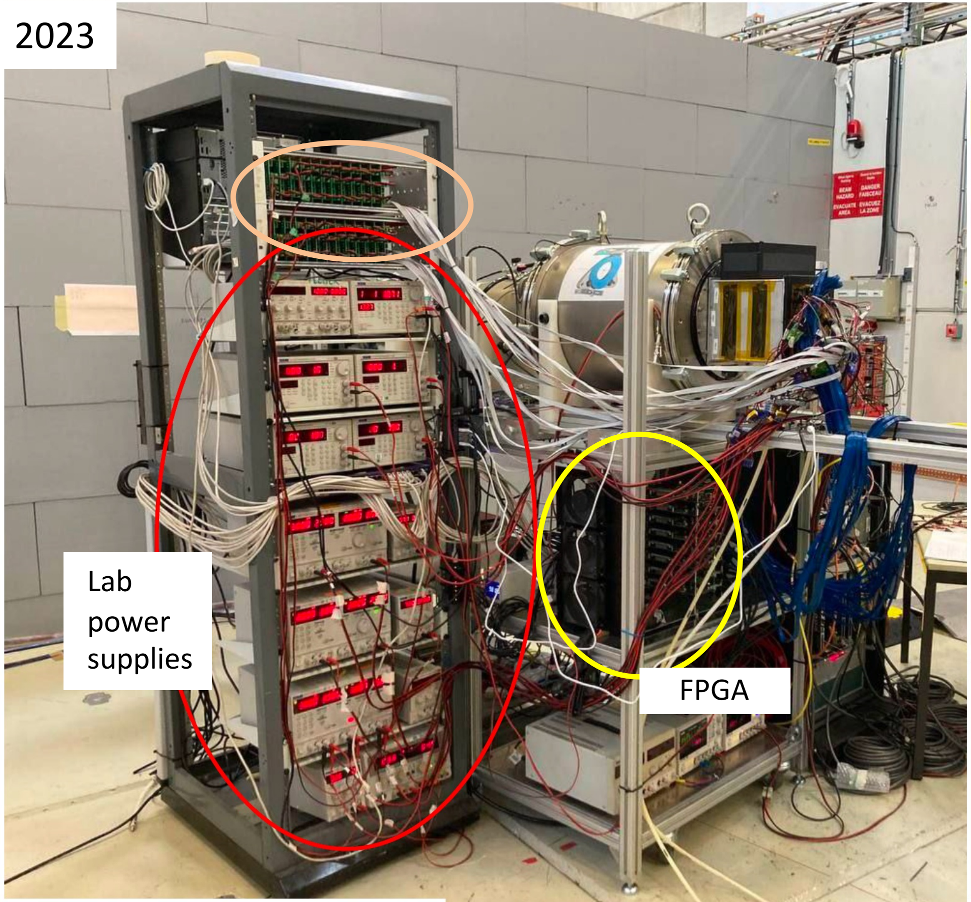


Nicola

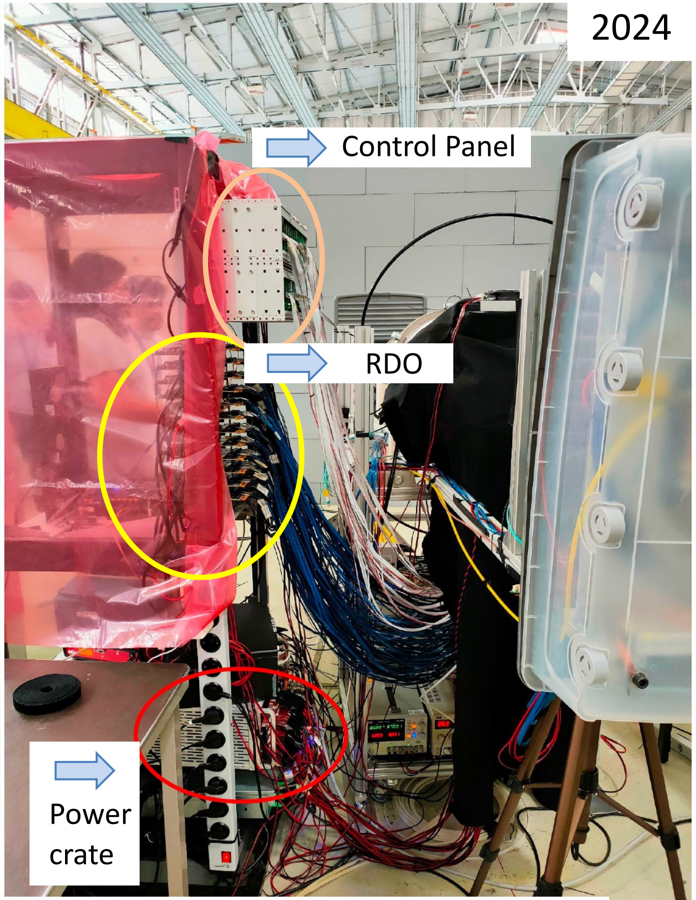




Detector Readout

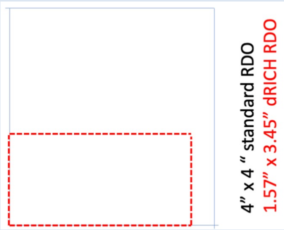


many table-top power supplies in 2023



experiment-oriented CAEN power-supply unit in 2024

Space challenge



1 SEU every 4.3x10^5 s/FPGA

↓

1 SEU every 3.5x10^2 s/dRICH

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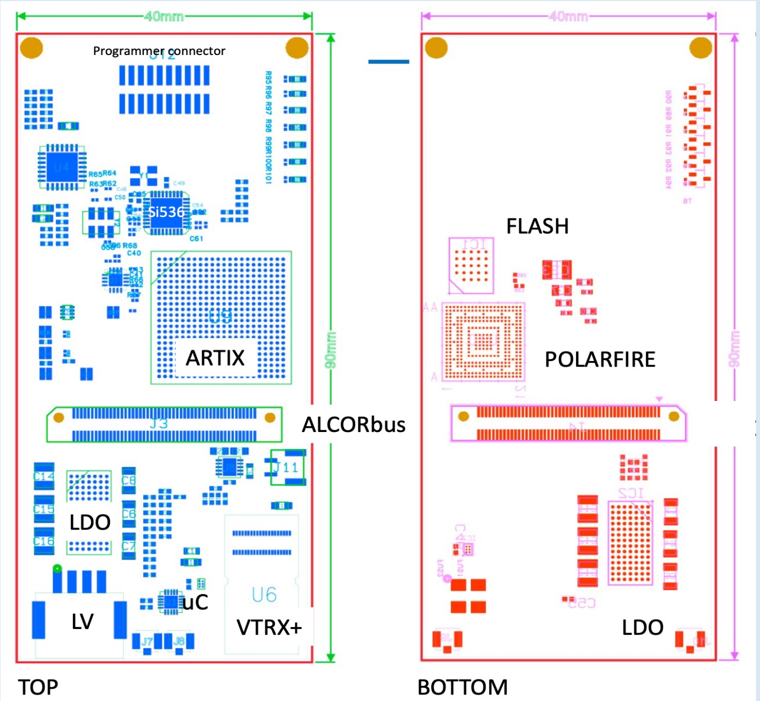
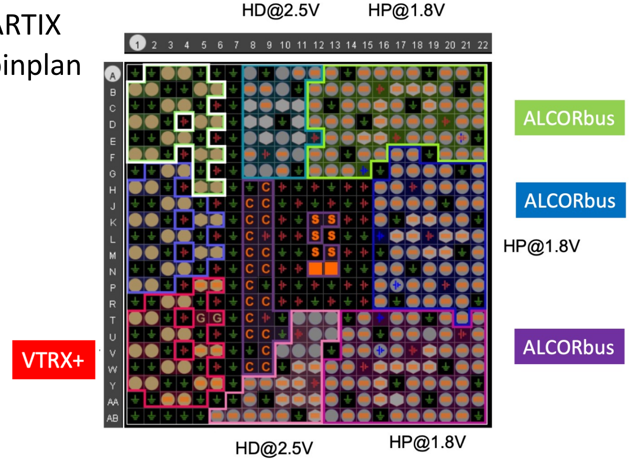
1 SEU **every 6 minutes** in whole dRICH

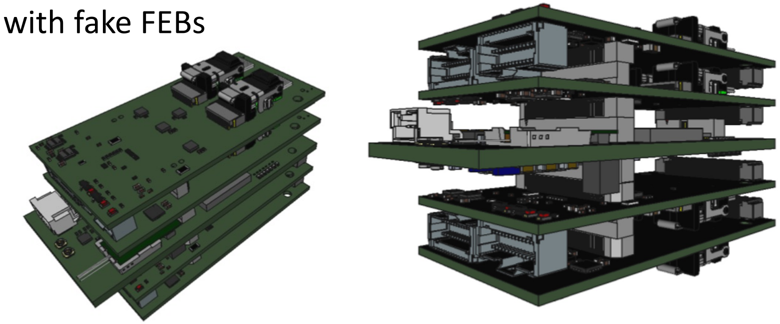
Radiation challenge



ARTIX pinplan



RDO stack with fake FEBs



Requirements for ePIC

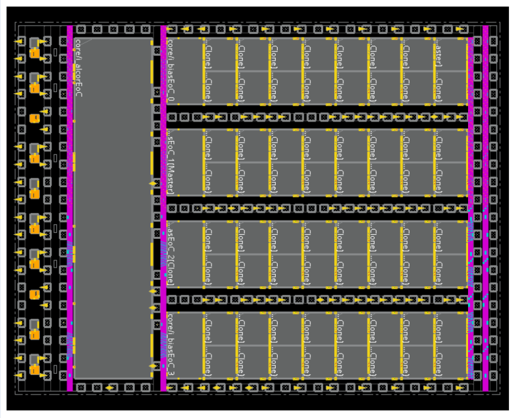
Component function	QTY	Baseline option/producer	V	Comments/hyperlinks to datasheets
Main FPGA	1	Xilinx AU15P-SBVB484	0.85, 0.9, 1.2, 1.8 , 2.5	Artix Ultrascale+ Overview
Scrubber FPGA	1	Microchip MPF050T-FCSG325	1.0 1.2 1.8	Polarfire overview
QSPI Flash	1	MT25QU01	1.7 - 2.0 V	package W9 6x8 mm Datasheet
VTRX+	1	CERN	1.2V, 2.5V	https://edms.cern.ch/ui/file/2149674/1/VTRxPlusApplicationNote.pdf
ALCORbus connector	2	Samtec ERF5-050-05.0-L-DV-K-TR	N/A	
uC power manager	1	ATtiny416	VDH	Watchdog on current monitor for RDO and FEB Datasheet
LDO	2	LTM4709	VDH VDL	6x12 mm Datasheet link, Demo board link
Step-Up Charge Pump	1	LTC3203	VDH	Provides VBIAS to LDO from VDH Datasheet
Temperature sensors	2	TMP119NAIDRVT	2.5	Close to LDO and VTRX datasheet
Clock multiplier/ jitter cleaner	1	SkyWorks SI5326	1.8 or 2.5 V	6x6 mm, 2 input - 2 output Family Datasheet and Si5326 Datasheet
3OT Crystal for Si5236	1	Abracon ABM8 -114_255MHZ-D2X-T	N/A	3.2 x 2.5 mm SkyWorks guidance
Crystal oscillator	1	SkyWorks 511JCA40N0000BAG	1.8	A 40 MHz crystal + an additional one for VTRx

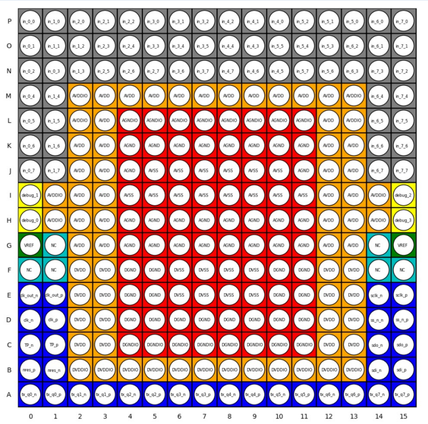
FPGA (+ SEU protection + remote programming) requirements

Power management, SEL protection, slow control requirements

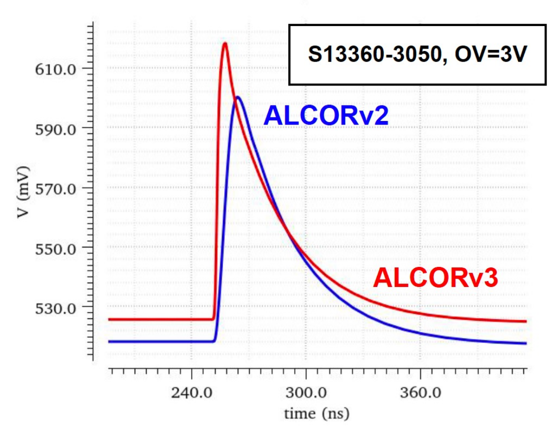
Clock requirements

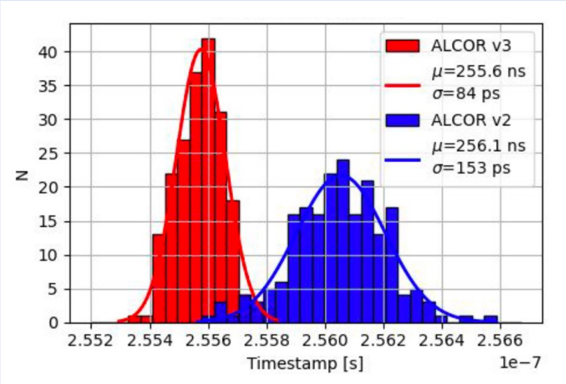
ALCORv64 digitazing chip



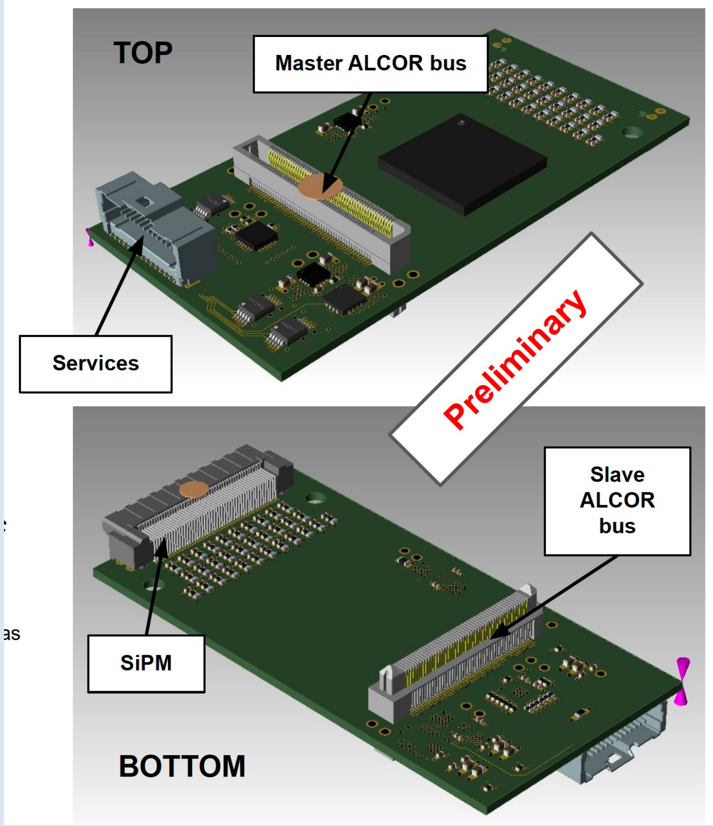


Improvements





Font-End Board



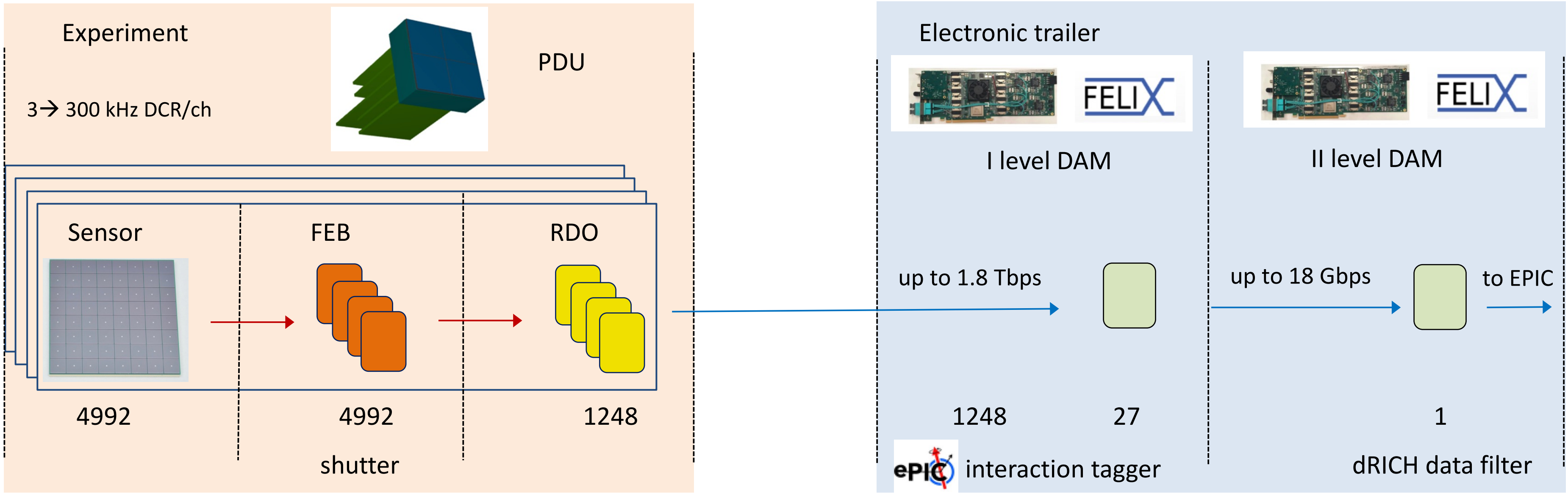
Requirements for ePIC

ePIC streaming data acquisition system (no traditional hardware trigger)

- **Digital shutter**: “inhibit” pixel digital logic to suppress out-of-gate DCR hits and **reduce data throughput**
- ~10.2 ns bunch crossing, ~300 ps bunch length, select **2-3 ns time window** → **3x-5x data reduction** before ALCOR digitization
- Asynchronous digital shutter implemented in ALCOR v3 pixel logic using external test-pulse signal
- **Programmable delay chain**: 4 configuration bits at channel-level (LSB ≃ 350 ps) and at the chip periphery (LSB ≃ 100 ps) to adjust offsets between different pixels and columns
- Shutter needed only when DCR becomes higher due to SiPMs taking radiation damage over time → use first period of ePIC data taking to optimize **shutter calibration**

Operation of ALCOR at multiple of **EIC clock frequency** (98.52 MHz)

- Nominal ALCOR v3 clock frequency: 98.52 MHz x 4 = **394.08 MHz**
- Digital logic, TDCs and serializers/drivers re-implemented and verified at 394.08 MHz



Goals: **Maximise modularity** (detector shaping) and **capability** (data stream)

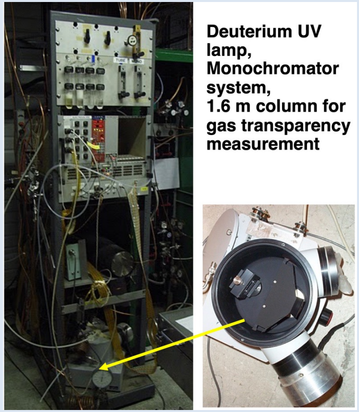
DAM Hierarchy: Maximum data rate capability till DAM-L1
Big data reduction at DAM-L1 with external input (2 μs latency interaction tagger)
DAM-L2 data aggregation allows for effective data-reduction algorithms

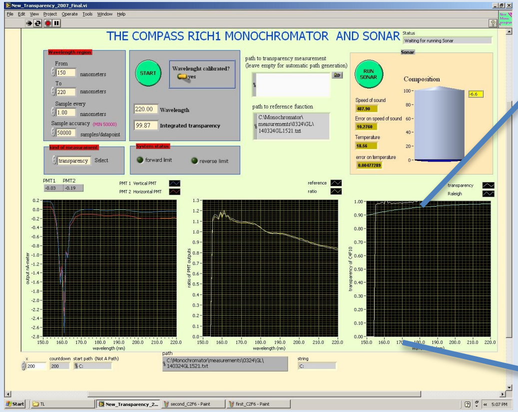
Opportunity for online ML applications (involving INFN specific expertise)

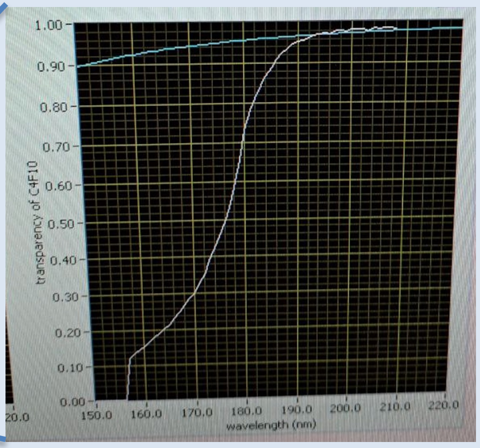
Simone

Alessandro

Gas characterizaiton & optimization (synergy with AMBER/CERN)

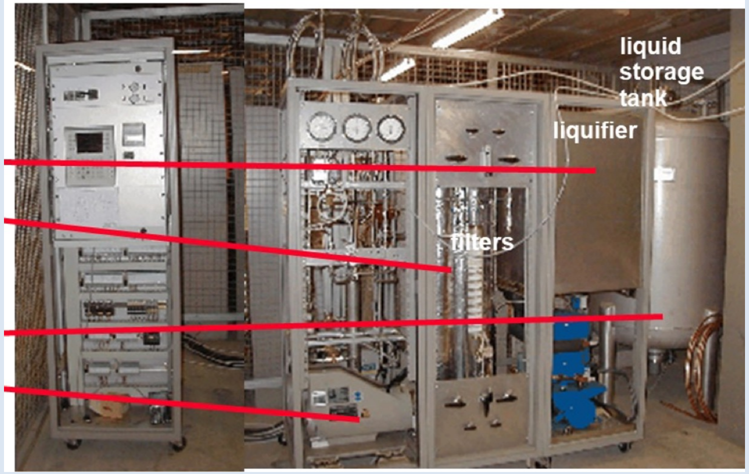


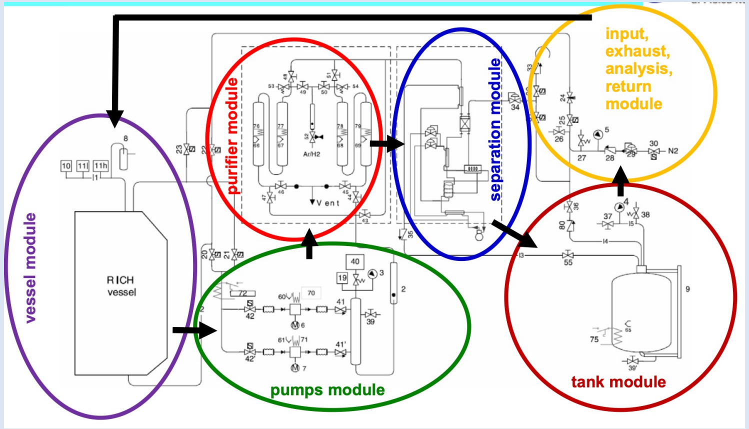




Fulvio

Gas system





Aerogel Radiator

Refractive index (density)

Transmission, absorption, diffusion

Rayleigh and forward scattering

Chromatic dispersion (λ dependence)

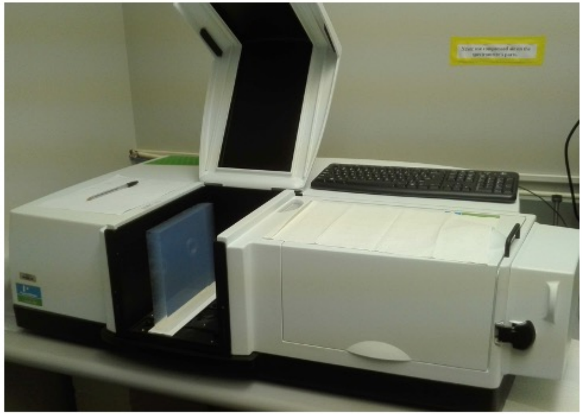
Tile shaping precision

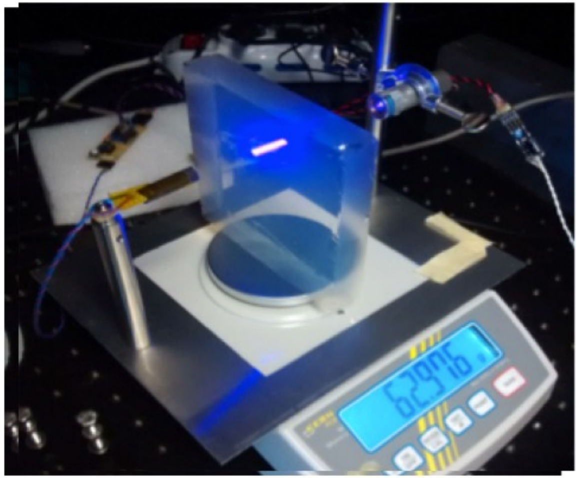
Visual integrity

Surface planarity

Uniformity & dimensions

……

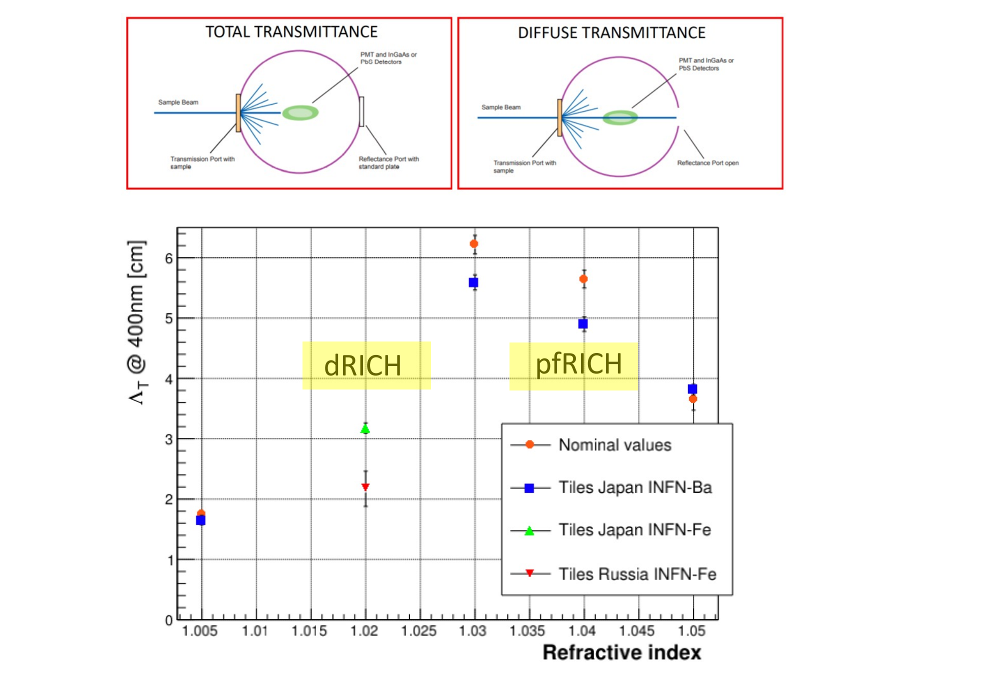




Synergies: ALICE

Spectrometer: Transmission & Absorption

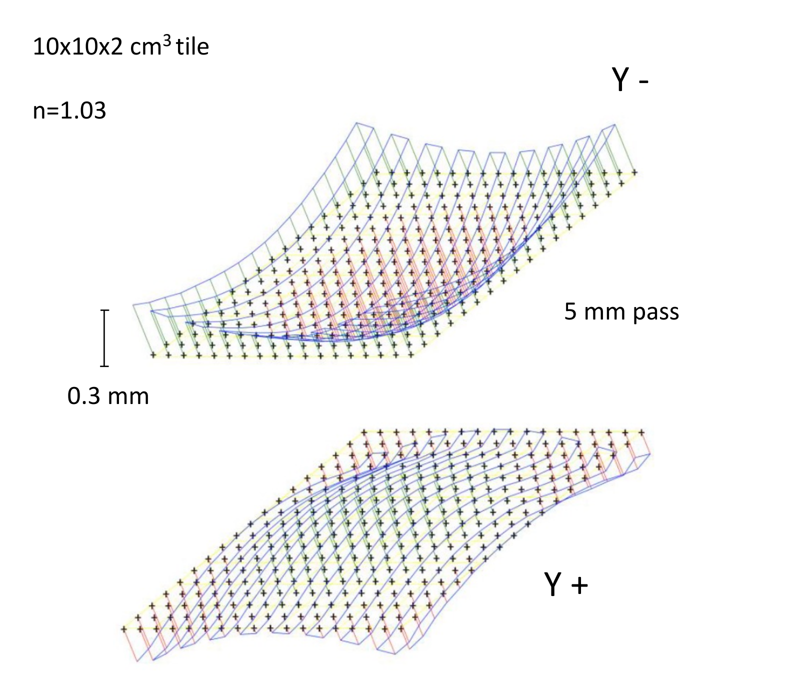
Perkin Elmer spectrometer @ CERN
Agilent Cary 4000 spectrometer @ INFN - BA



Typical best optical performance at n=1.03

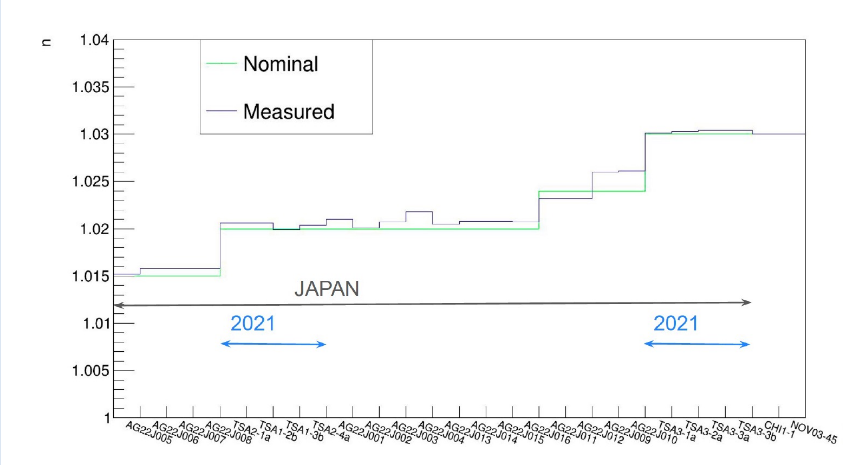
Touch Probe: Planarity and thickness

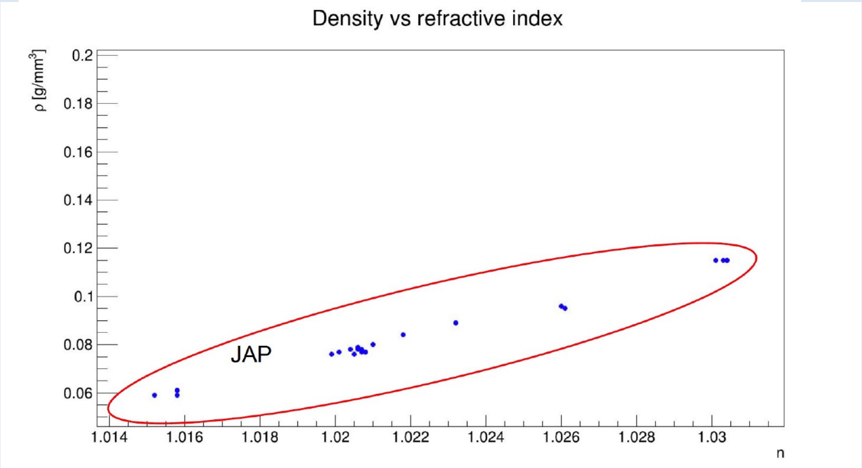
LEITZ PPMC @ CERN 0.3 mm precision
2 gr force touch probe

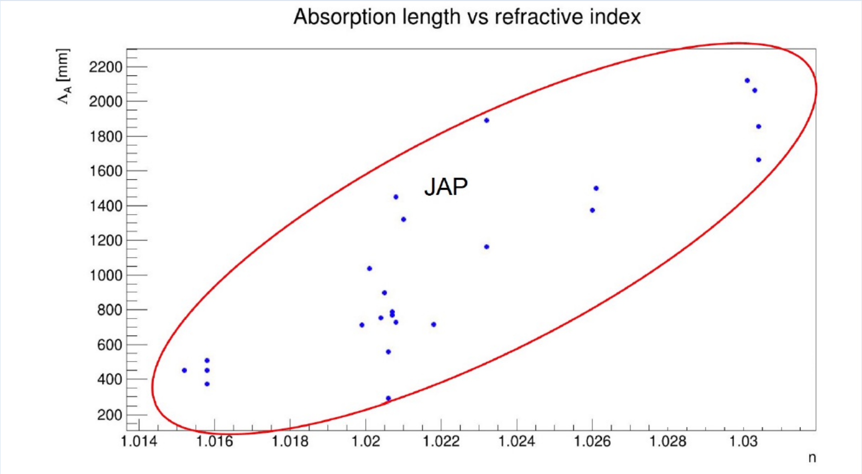


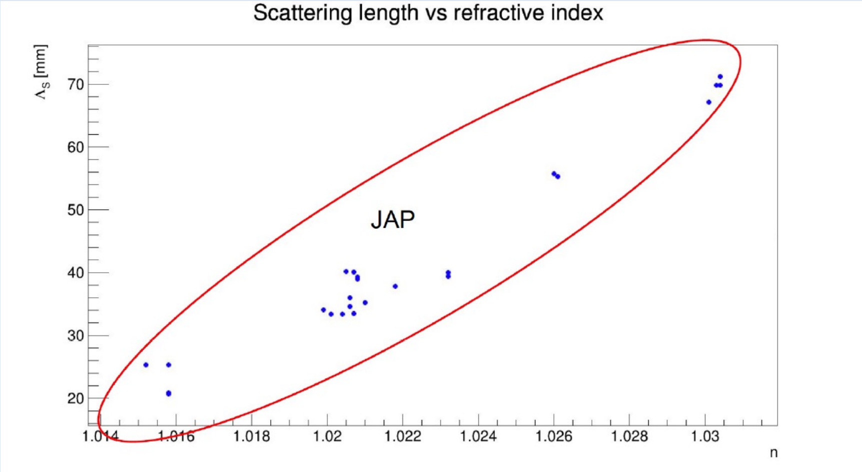
Typical cup shape with a meniscus on the edges

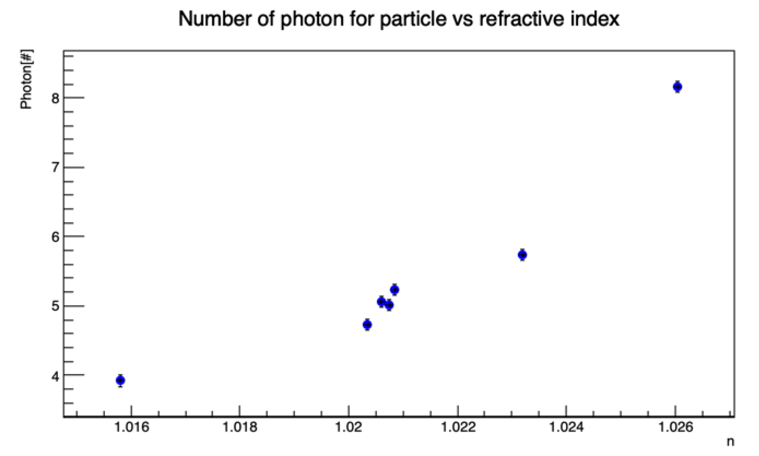
dRICH Samples

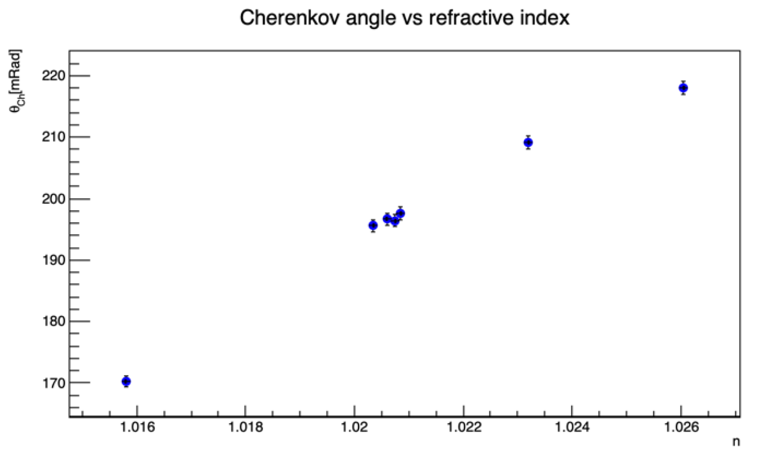


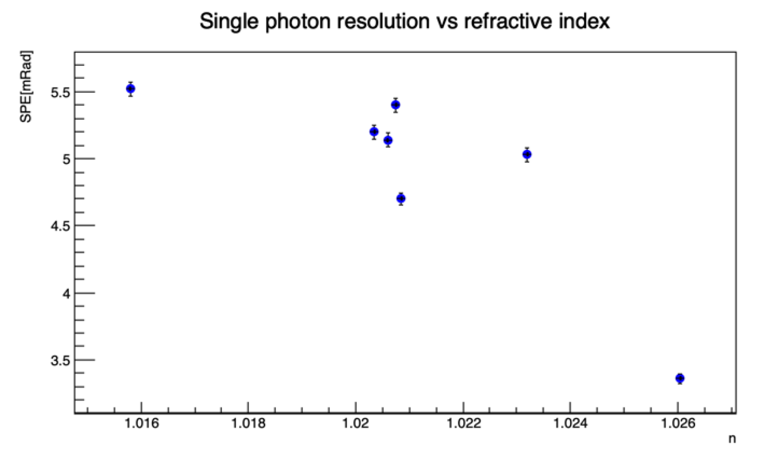


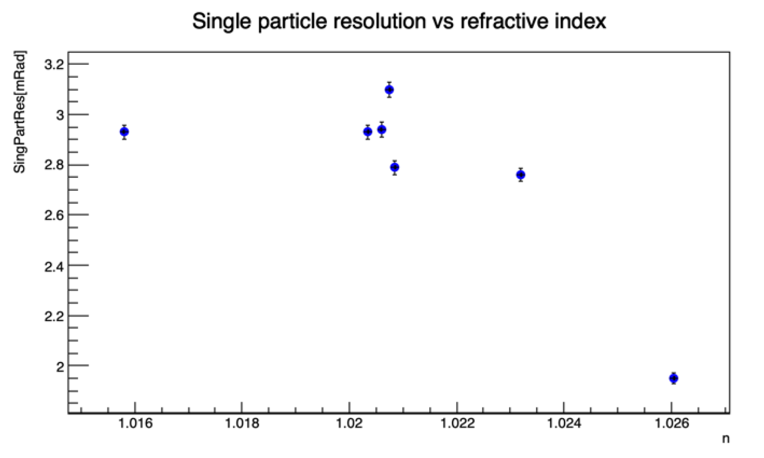




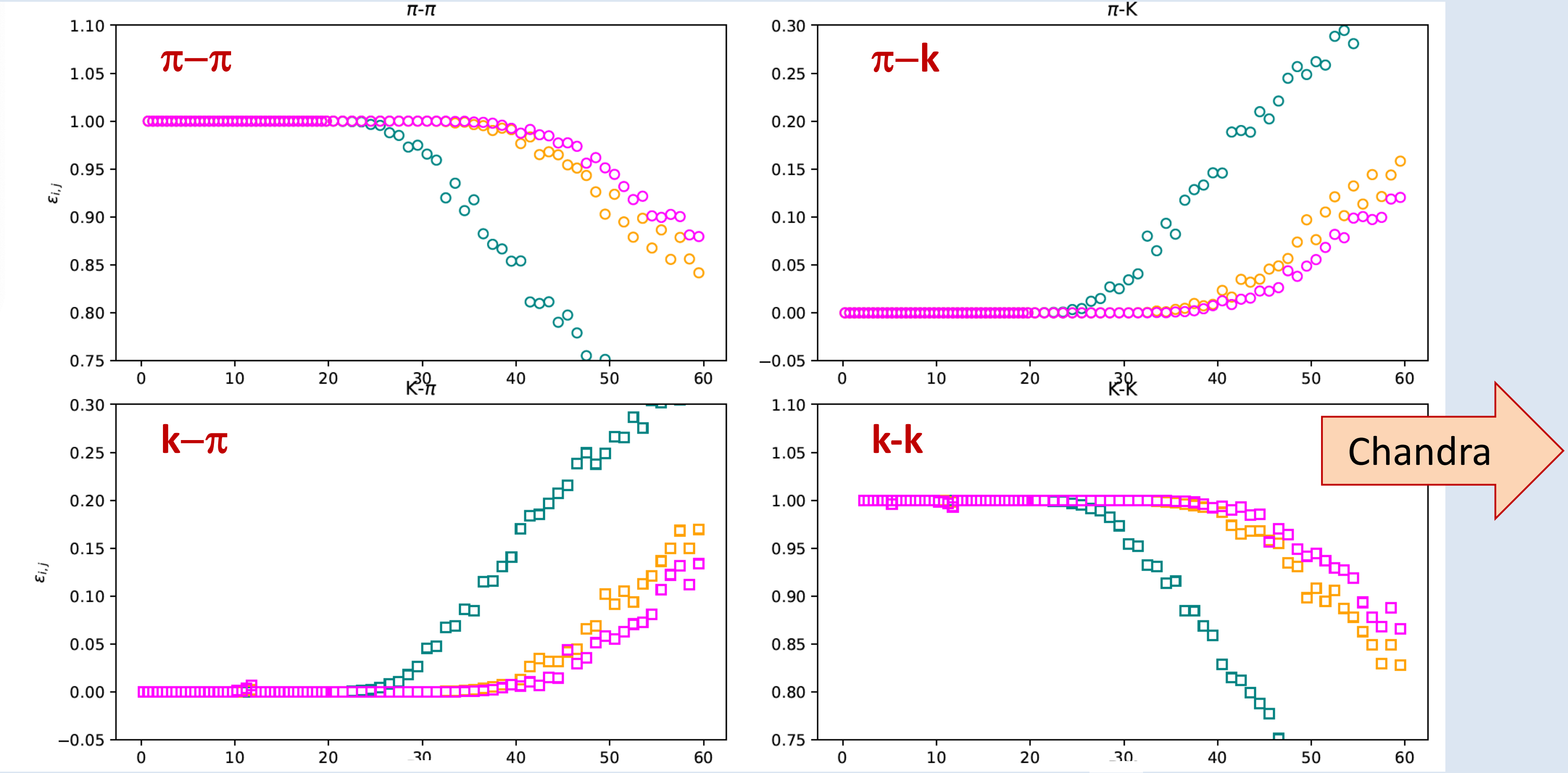

Number of photon for particle vs refractive index
Photon[#]
8
7
6
5
4
1.016
1.018
1.02
1.022
1.024
1.026
n


Cherenkov angle vs refractive index
θCh[mRad]
220
210
200
190
180
170
1.016
1.018
1.02
1.022
1.024
1.026
n


Single photon resolution vs refractive index
SPE[mRad]
5.5
5
4.5
4
3.5
1.016
1.018
1.02
1.022
1.024
1.026
n


Single particle resolution vs refractive index
SingPartRes[mRad]
3.2
3
2.8
2.6
2.4
2.2
2
1.016
1.018
1.02
1.022
1.024
1.026
n

dRICH performance is studied within the ePIC simulation framework (with tracking resolution and magnetic bending)



dRICH Construction Items

	INFN	Shared	DOE
Mechanics	Detector box (FE, LNS)	Vessel (FE, LNS) Insulation (TS)	Aerogel & mirror supports (JLab) Installation tools (JLab/BNL
Photo-detector	Sensors (BO,CS,SA,CT,TS) PDU (cool plate) (BO)		
Readout	ALCOR (TO) FEB (TO) Master Panel (FE)		
DAQ	RDO (BO)	Data stream (GE, RM1, RM2)	DAM (BNL)
Radiators	Aerogel (BA)		Gas (BNL) Aerogel QA (Temple, BNL)
Mirror			Mirror (JLab/Duke) Coating (Duke)
Services			Gas Plant (BNL) Cooling Plant (BNL) Power Plant (BNL)
Monitors	Gas monitor (TS)	Slow Control/Interlock LED+Laser	

INFN Engagement

BO: new space under discussion (ex Tier1) & elec. + mech. support

CS: lab (+new) space

TS: lab space & tech. support

TO: micro-electronic workshop

LNS & CT: tech. support

RM1 & RM2: tech support

BA: lab (+new) space & tech. support

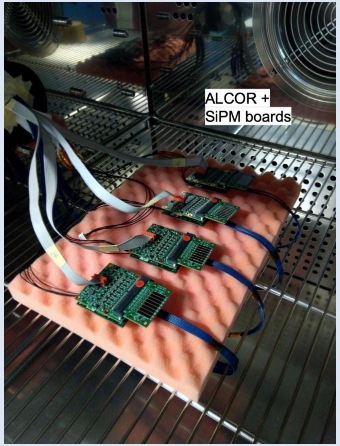
GE: lab space & electr. support

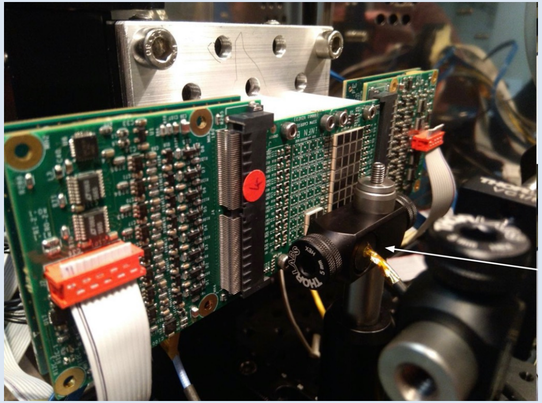
SA: lab (+new) space & tech. support

FE: lab space, clean room & elec. + mech. support

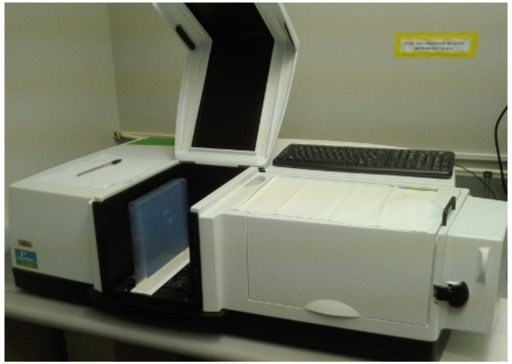
Quality Assurance

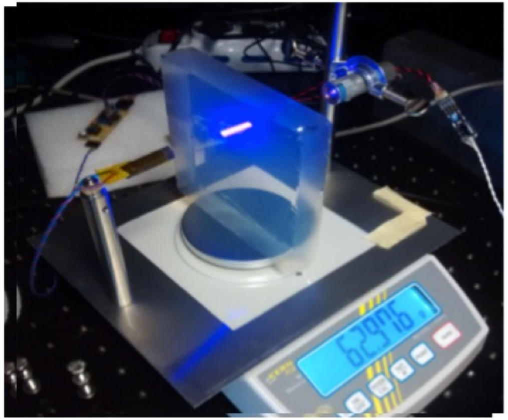
Sensors: INFN (CS/SA/CT) – TS – BO



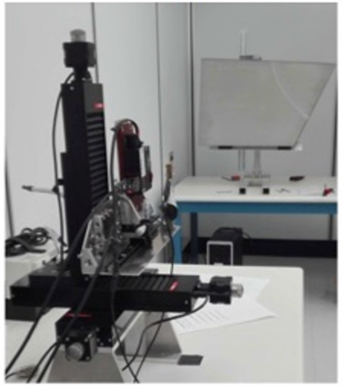


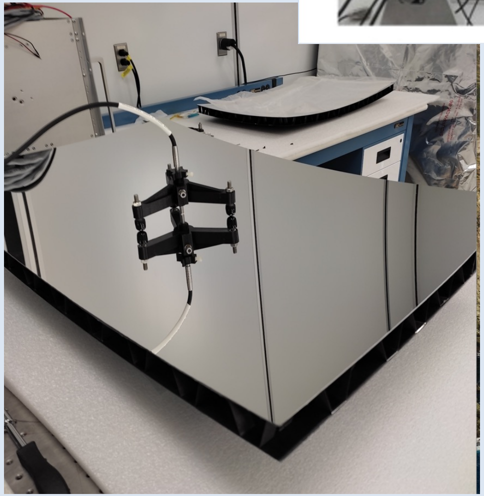
Aerogel: Temple - BNL – INFN (BA)





Mirror: JLab – Duke – INFN (FE)





INFN Funding Profile

DOE granted the EIC dRICH R&D program (eRD102) about 150 keu/yr in the last three years

Assumptions: - 6 months delay of CD3 (now on spring 2026)
- no delay of installation (now on Oct 30: unlikely)
- possibility to split the major procurements in batches/years