L'attività italiana in EIC_NET: progetti di R&D

A. Celentano per la collaborazione “EIC Italia”

(con enorme contributo di tutti i colleghi impegnati in questa attivita’)

Introduction

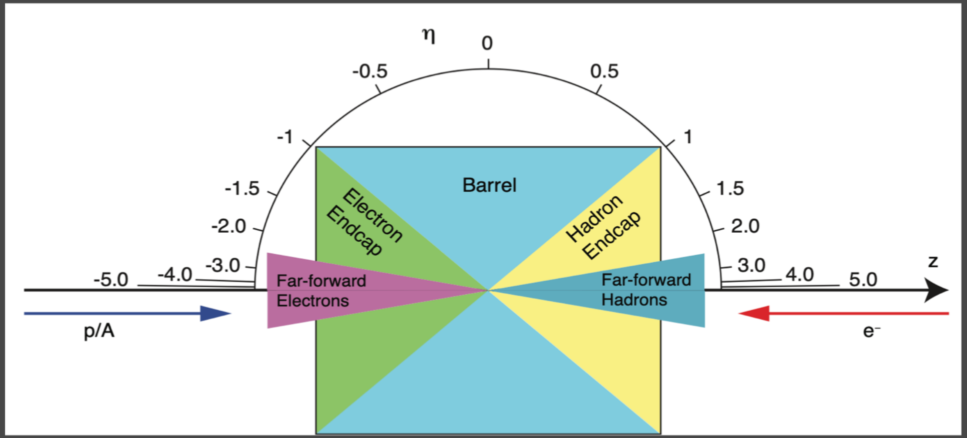
EIC_NET ongoing R&D activities are focusing on 3 main topics, all critical for a future EIC detector:

- Particle ID with RICH detector
  - High-momentum RICH: dual radiator / gas windowless
  - Modular RICH
- Triggerless readout system with a streaming architecture
- Electromagnetic calorimetry

All the activities benefit from the strong knowledge of the Italian groups, and are coordinated with the international EIC community within the US program for a generic EIC R&D

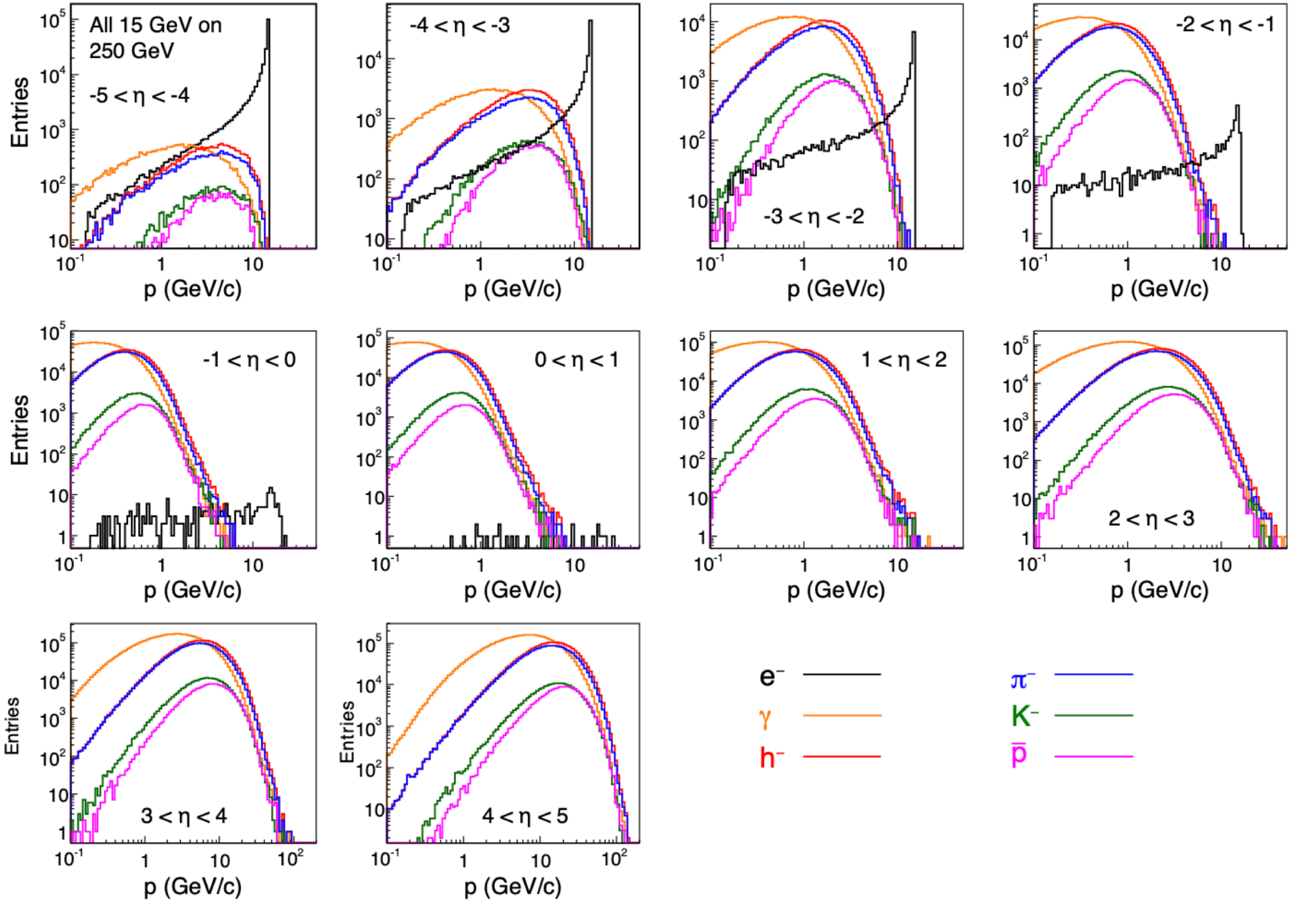
PID in EIC

PID is a crucial element for the future EIC detector



Rapidities / angles follow HERA convention

Expected particles distributions as a function of momentum for different rapidity intervals

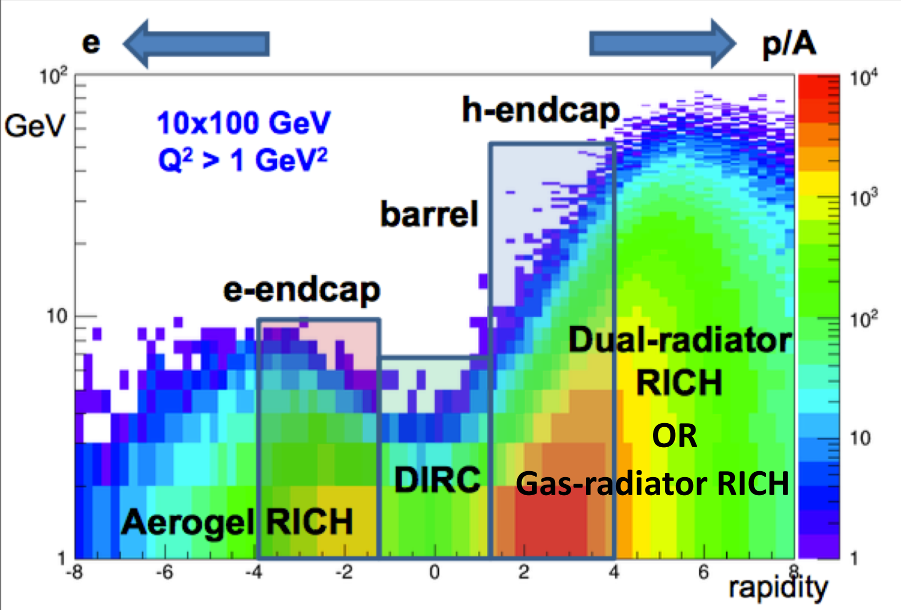


The large momentum range and the high particle multiplicities call for a **very strong PID efficiency and purity**, achievable only with complementary techniques depending on the kinematic range.

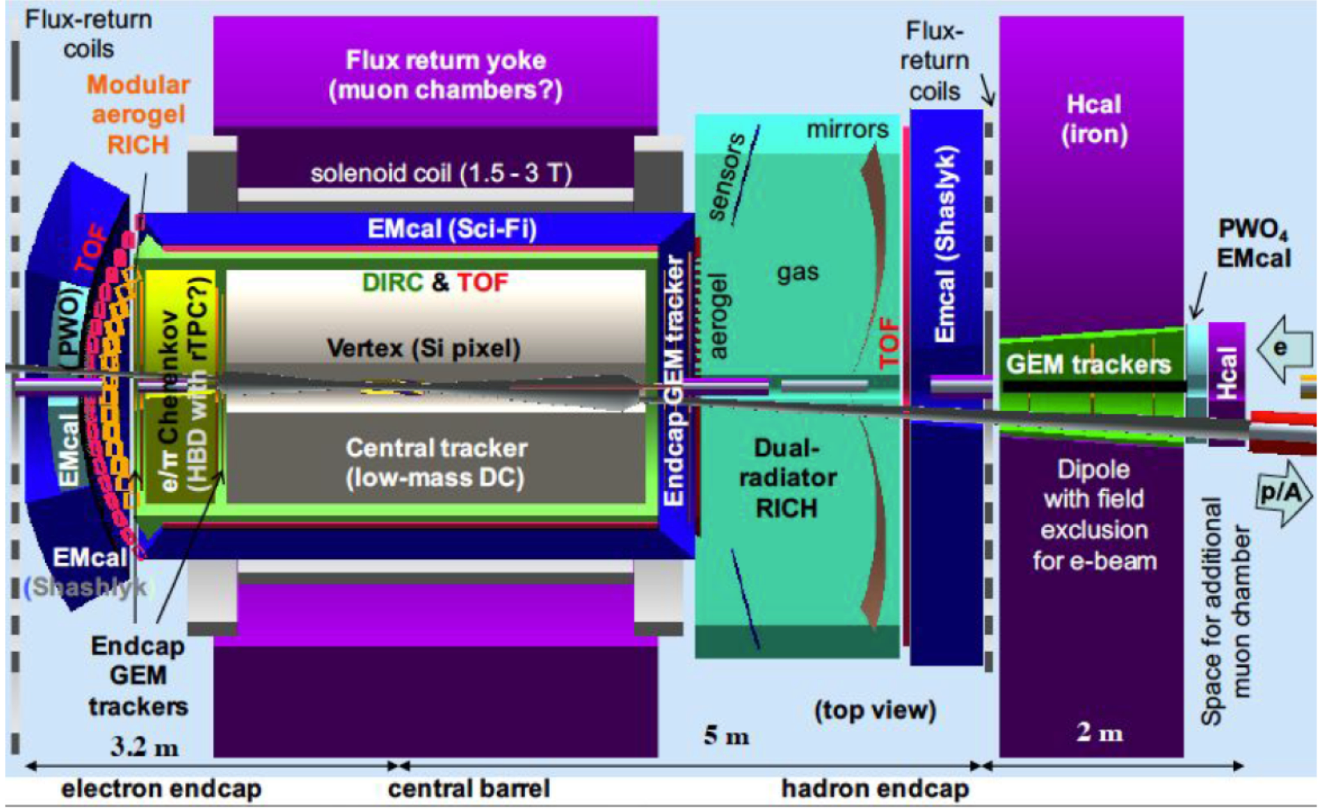
RICH detectors for PID in EIC

Three main approaches are foreseen, depending on the momentum range:

- Barrel, low momentum (< 6 GeV/c):
  - DIRC-approach
- Backward, low momentum (<10 GeV/c):
  - Modular-RICH approach
- Forward, high momentum (~ 50 GeV/c):
  - Dual-radiator RICH
  - Gas-radiator RICH with windowless readout



All proposed EIC detector concepts incorporate different RICH detectors for PID in almost all kinematic regions



JLAB-JLEIC

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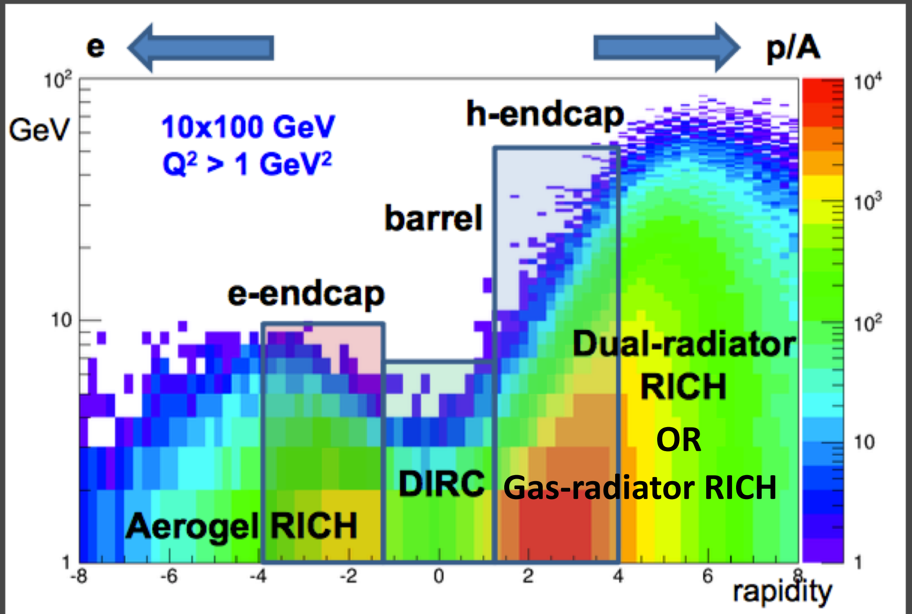

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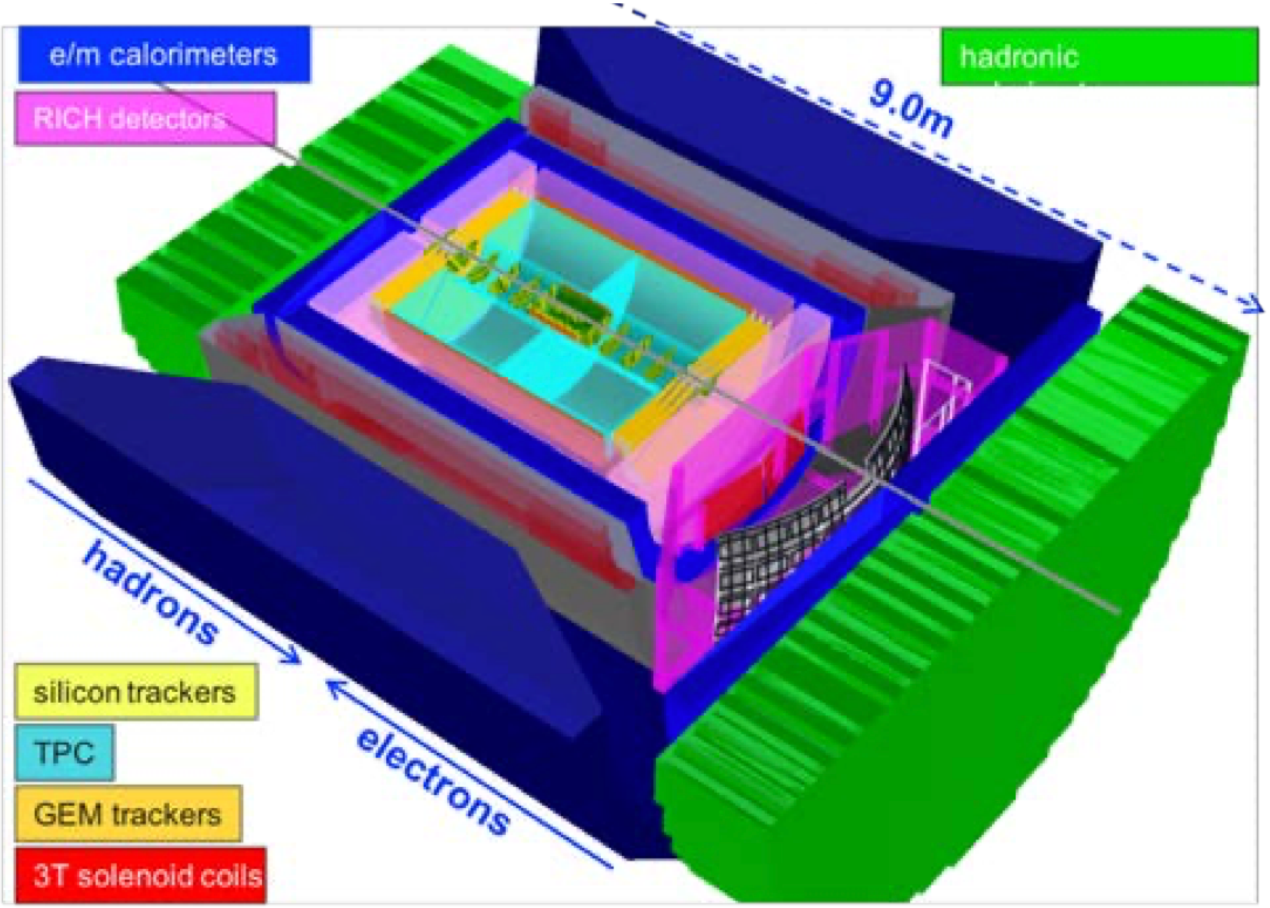

BNL - BEAST

RICH detectors for PID in EIC

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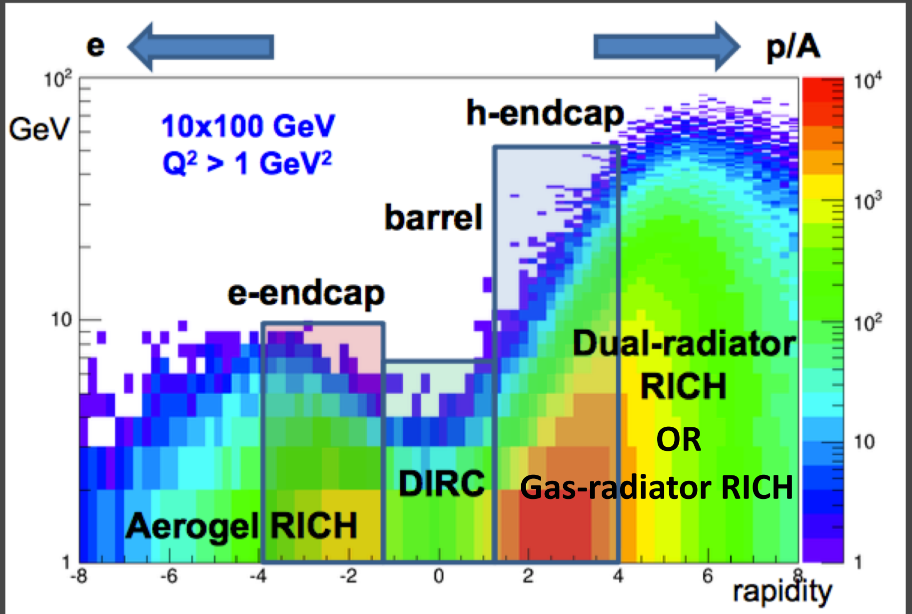

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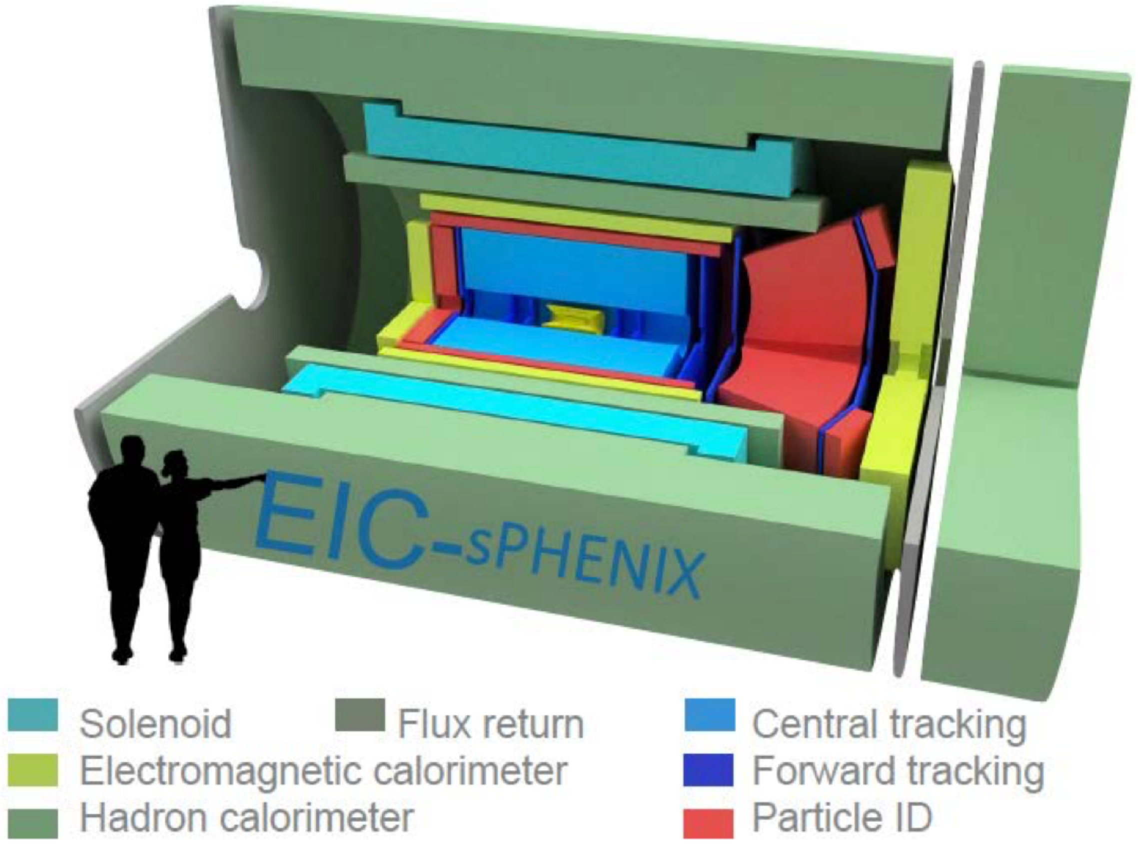

BNL – sPhenix EIC

RICH detectors for PID in EIC

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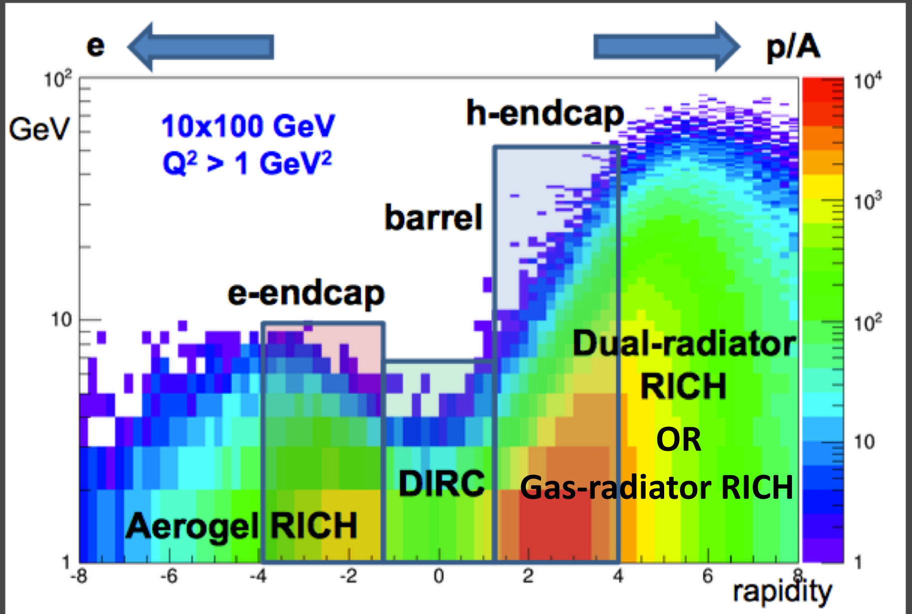

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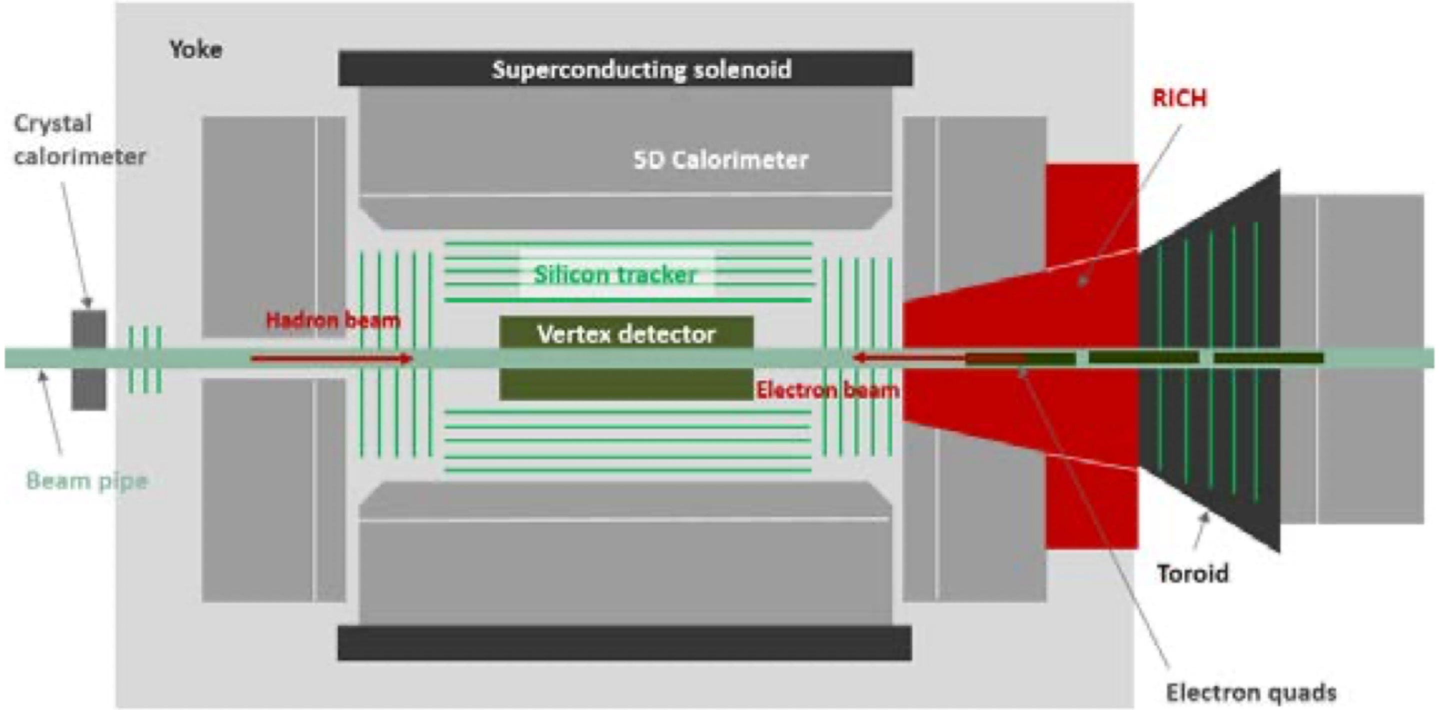


ARGONNE - TOPSiDE

INFN R&D activity: high-momentum RICH

The challenge: h-PID ad large momentum using known techniques (LHCb, COMPASS,...) requires both extended radiators and PMT-like photodetectors: critical for space requirements and operations in high B field

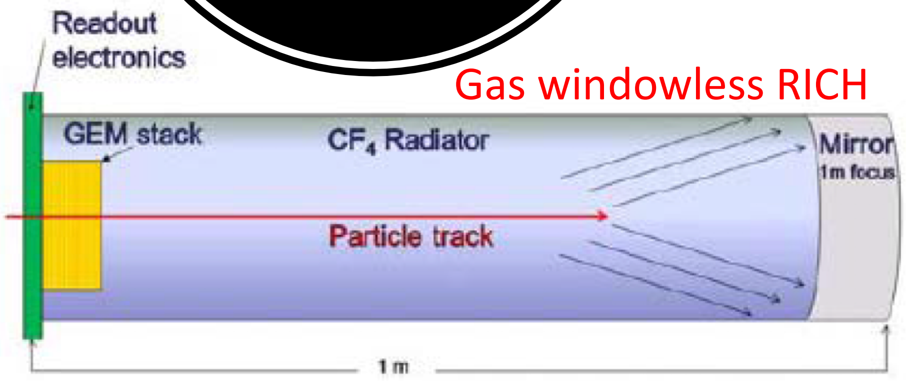
The possible solutions:

- *Visible-light dual-radiator RICH*
    - R&D required on photodetectors (LAPPD? SiPM?)
- *Far-UV RICH with windowless CsI-based gas photodetector*
    - Exploits the $1/\lambda^2$ number of photons
    - Use interferometric mirrors to select narrow λ range
    - R&D required on photodetectors

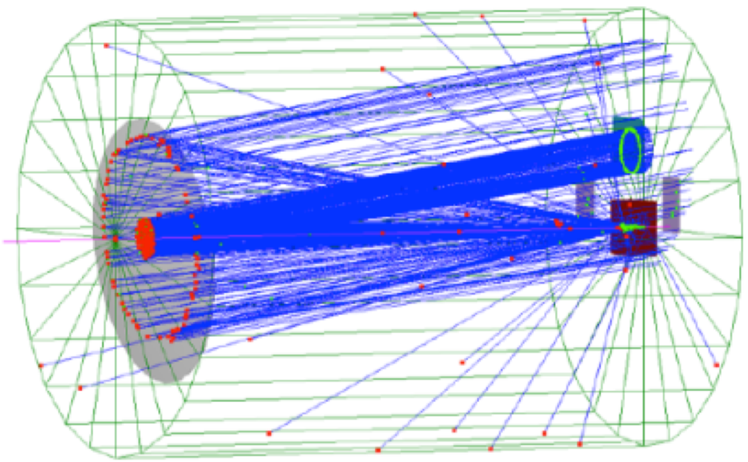
INFN activity exploiting both-options (within EIC R&D WP6 – particle ID):

- *Windowless gas RICH:*
    - Development of MPGD-based photo-detectors with a CsI photocatode, starting from the successful experience of COMPASS
    - MGPD properties optimization for EIC requirements: cells size, gain, …
    - Investigation of alternative approaches for photocathodes manufacturing: diamond powders ("blue sky investigation", INFN-CSN5, experiment "IDEA")
- *Dual-radiator RICH:*
    - Optimize design (radiators / dimensions) for wide momentum coverage
    - Investigating sector-based focusing to reduce photosensors area

Gas windowless RICH



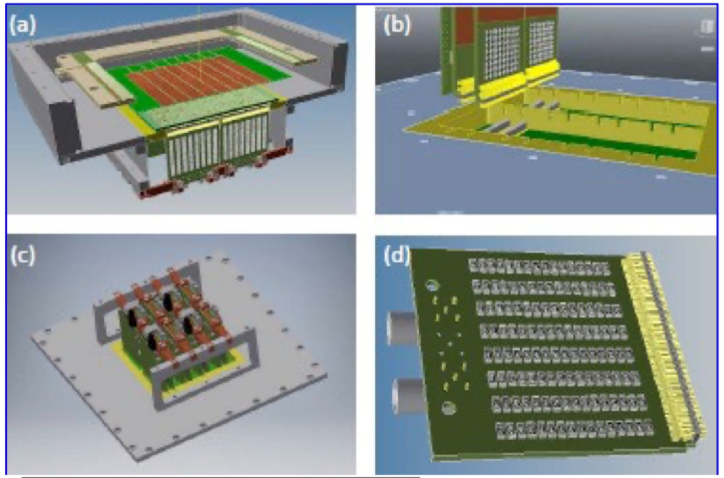
Dual-radiator RICH

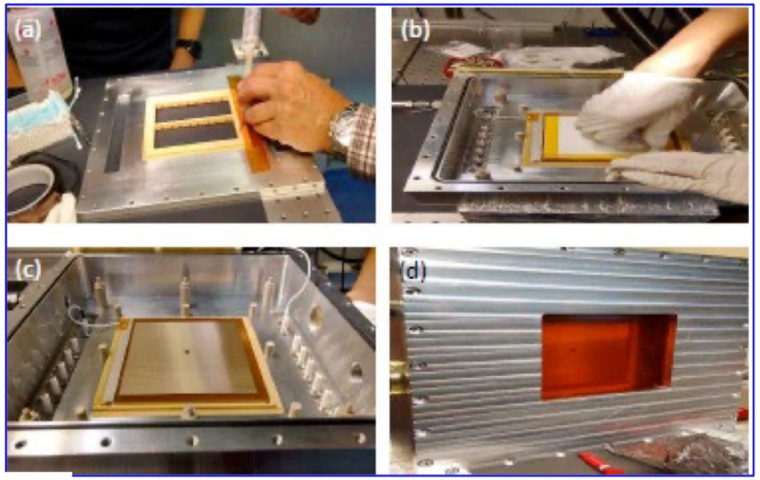


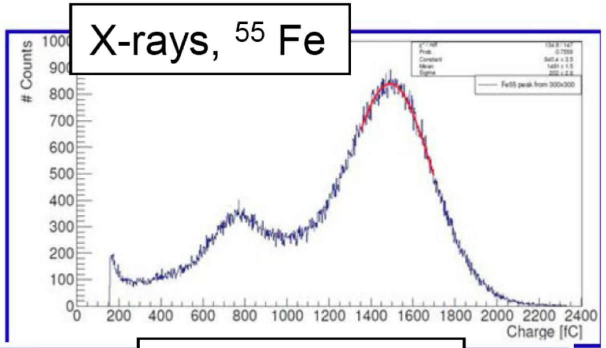
INFN R&D activity: gas RICH with windowless readout

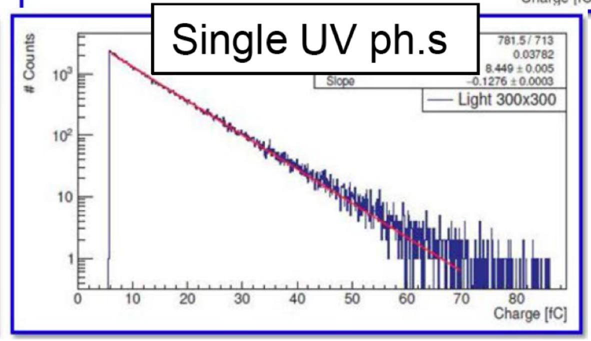
2017-2018: construction and characterization of a small-scale prototype with 3x3 mm^2 readout pads to investigate new MPGD solutions.

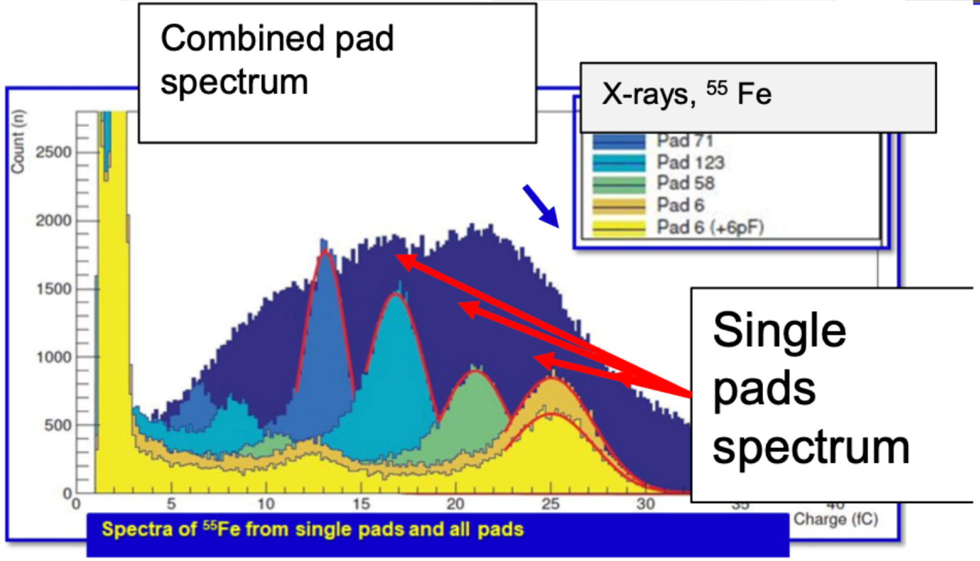
Hybrid MPGD: two-layers GEM + Micromegas readout by SRS(R&D51) with APV25 FE











Main results:

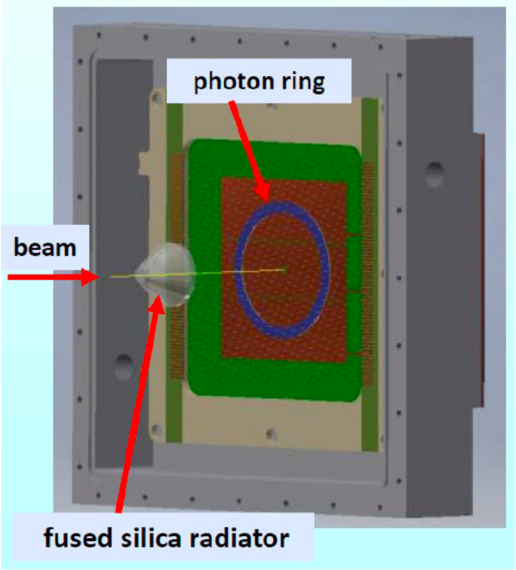
- Gain variation pad-to-pad at ~10% r.m.s.
- Parasitic capacitance of the read-out line to be equalized in a next prototype

INFN R&D activity: gas RICH with windowless readout

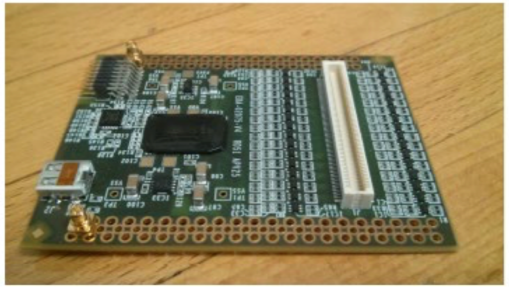
2018-2019: prototype characterization with test-beam @ CERN

Fused-silica radiator setup

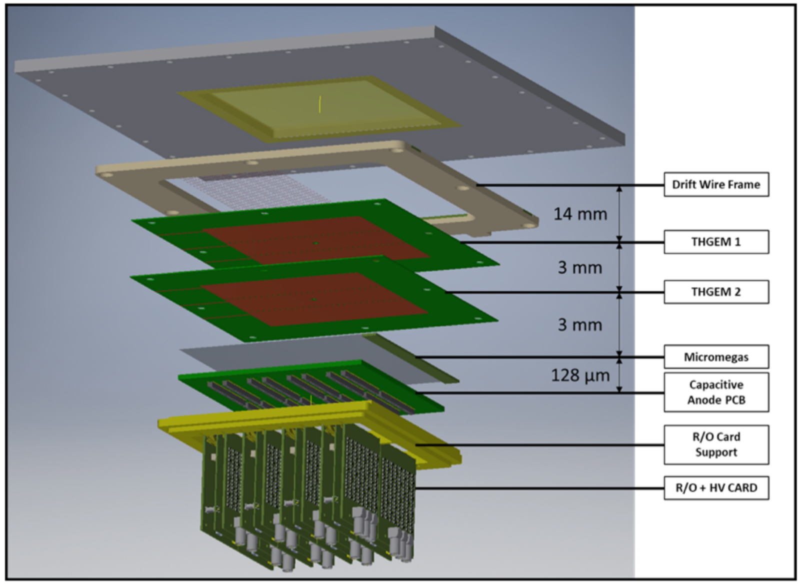
Fused-silica radiator



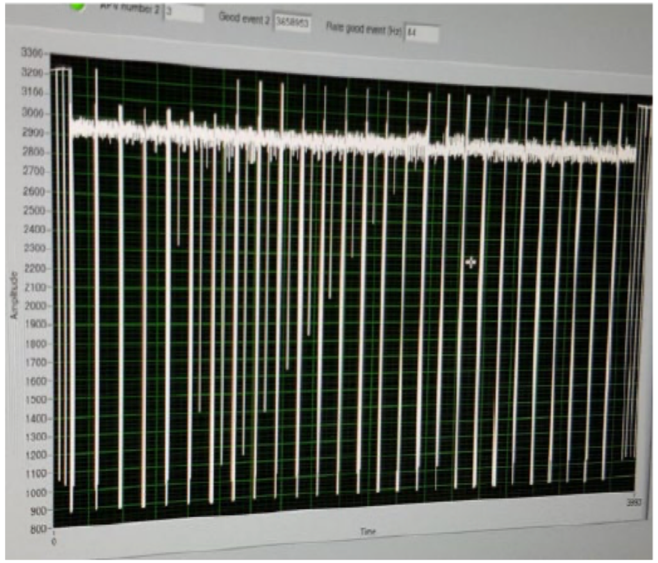
SRS is read-out by the new “RAVEN” DAQ-system designed to increase the acquisition rate and controlled via an user-friendly dedicated GUI



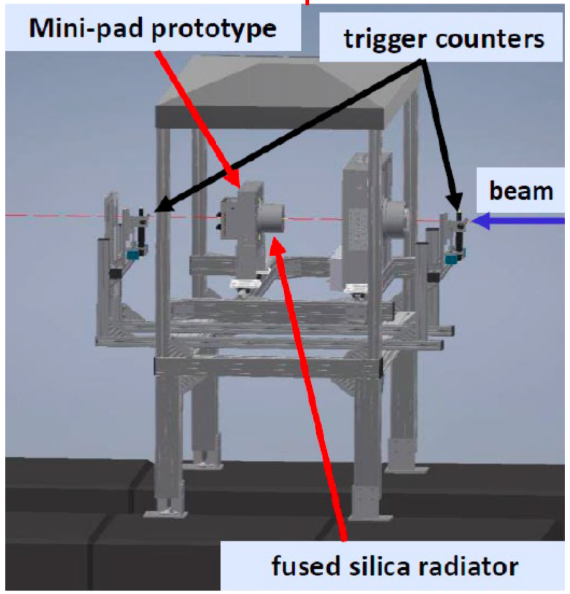
Prototype assembly



Signals from APV25 readout ASIC



Test-beam setup

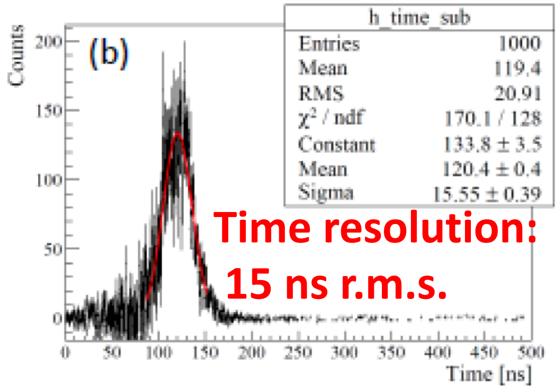


Reference: 1908.05052

INFN R&D activity: gas RICH with windowless readout

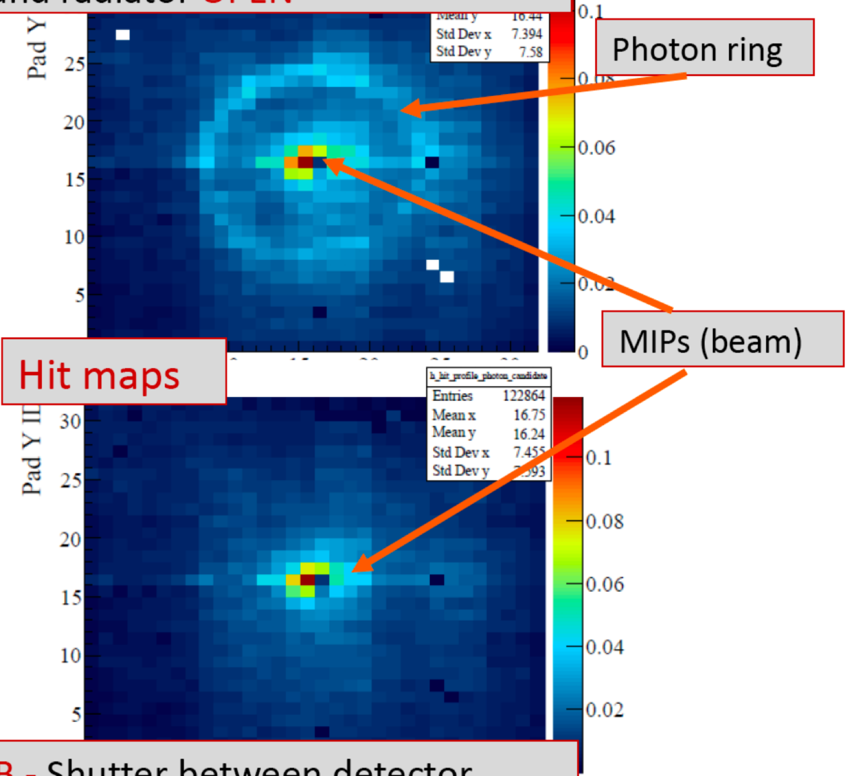
2018-2019: prototype characterization with test-beam @ CERN

Cherenkov ring well visible after direct-beam hit subtraction
On-going analysis to determine detector performances: detector gain, time resolution, cluster-size



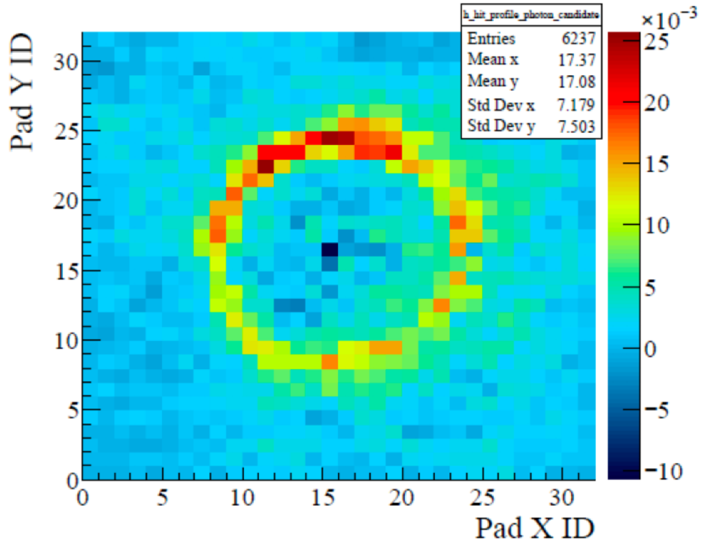
Time resolution: 15 ns r.m.s.

A - Shutter between detector and radiator OPEN

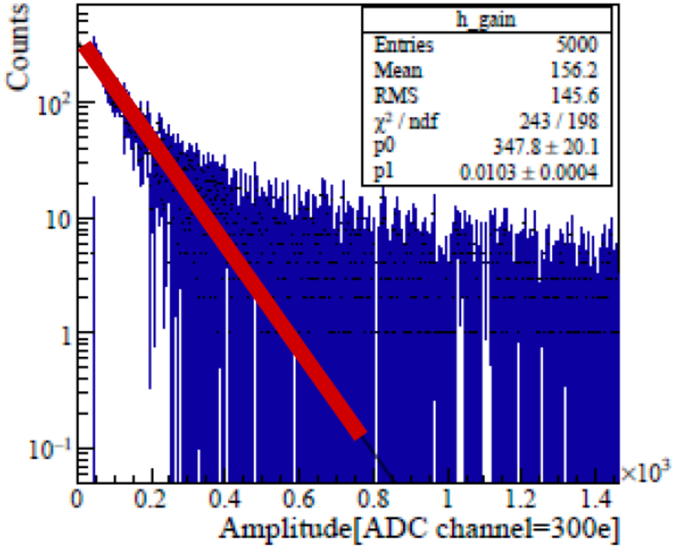


B - Shutter between detector and radiator CLOSED

A – B (properly normalized): only the photon ring remains !



Detector gain from single photon charge distribution slope: **30k**



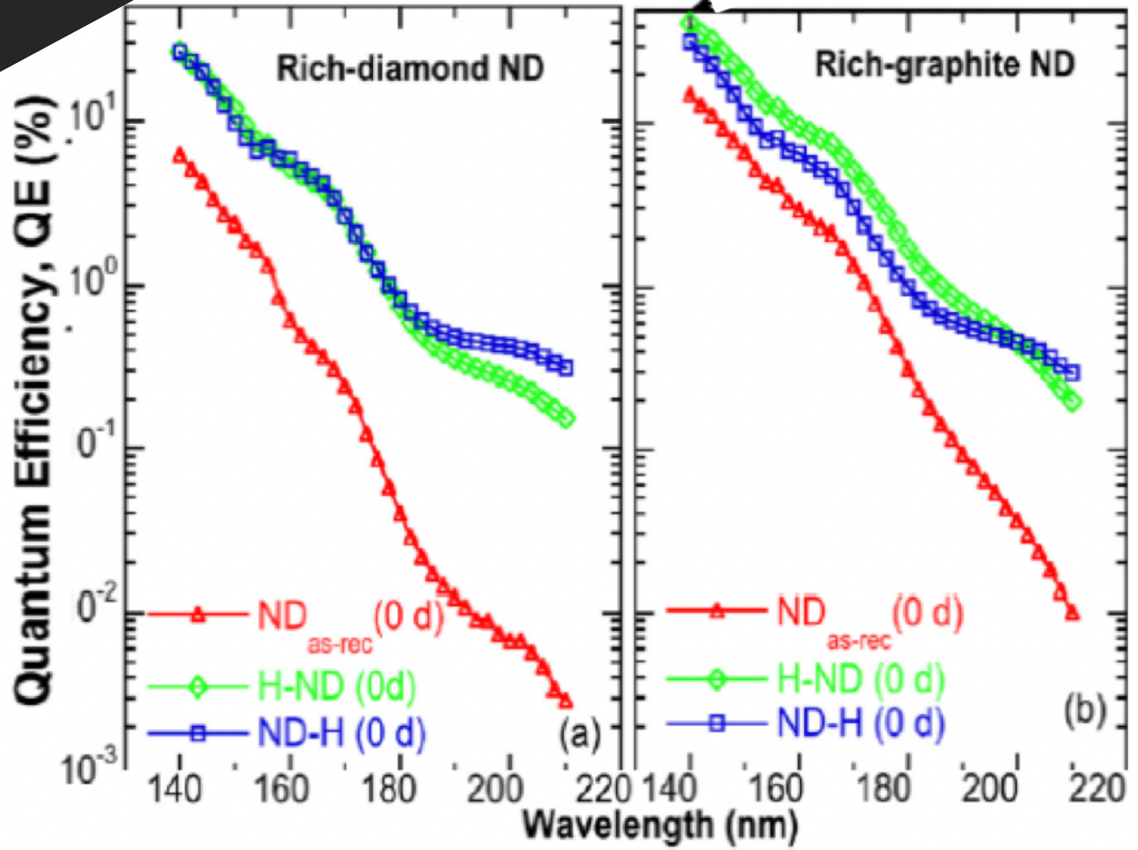
INFN R&D activity: nano-diamond powder photocatodes

Test of a nano-diamond powder based photocathode

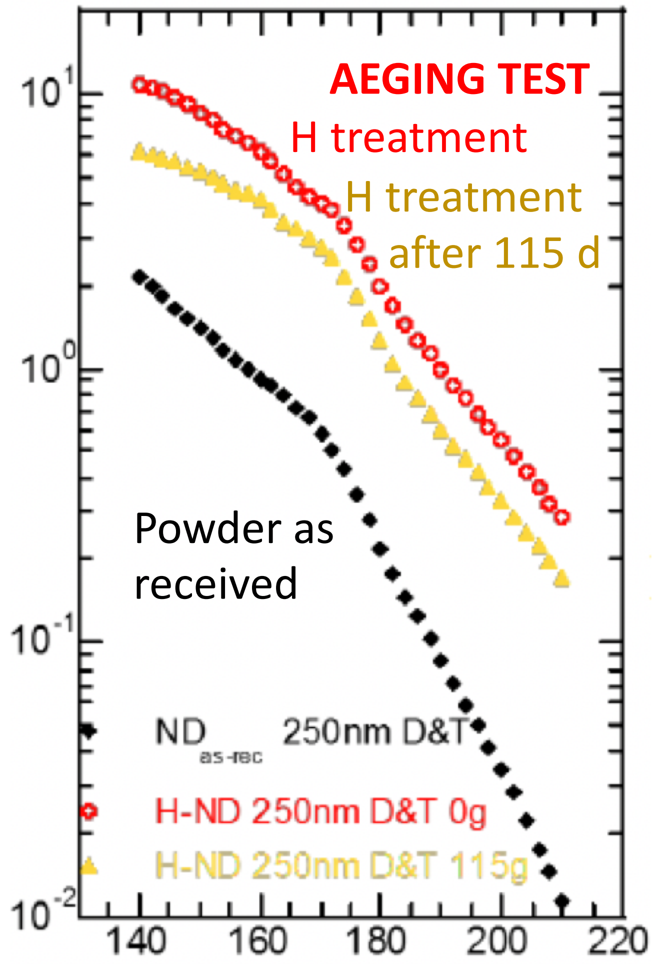
- Powder deposited with “spray” technique at low-T (120 degrees)
- Hydrogen plasm treatment to enhance QE

Quantum-efficiency measurement

- As-received
- Plasm treatment before deposition
- Plasm treatment after deposition



L.Velardi, A.Valentini, G.Cicala, Diamond & Related Materials 76 (2017) 1

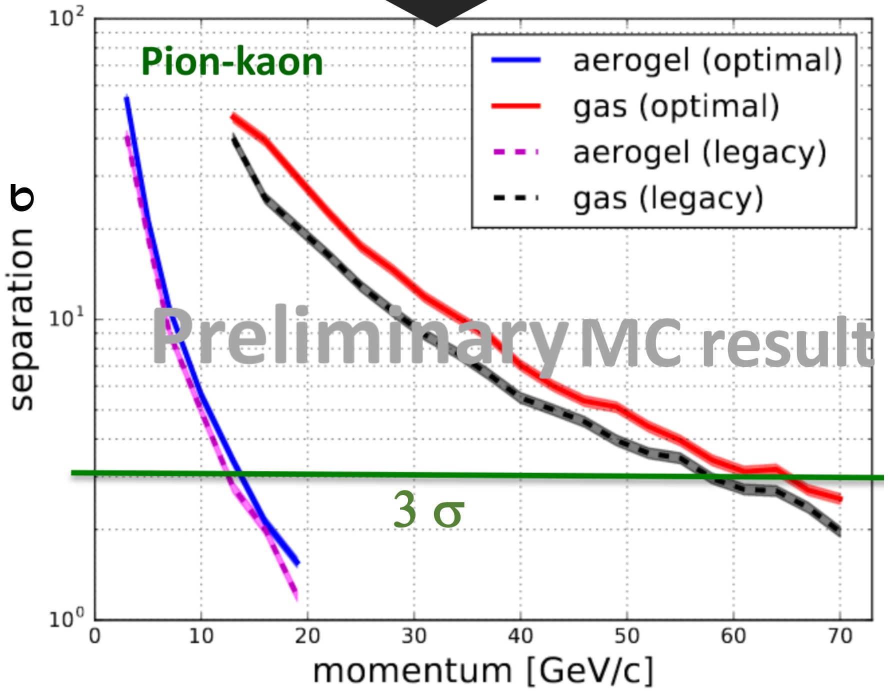


Significant powder quality (QE value) dependency on manufacturer. Call for a careful quality assessment

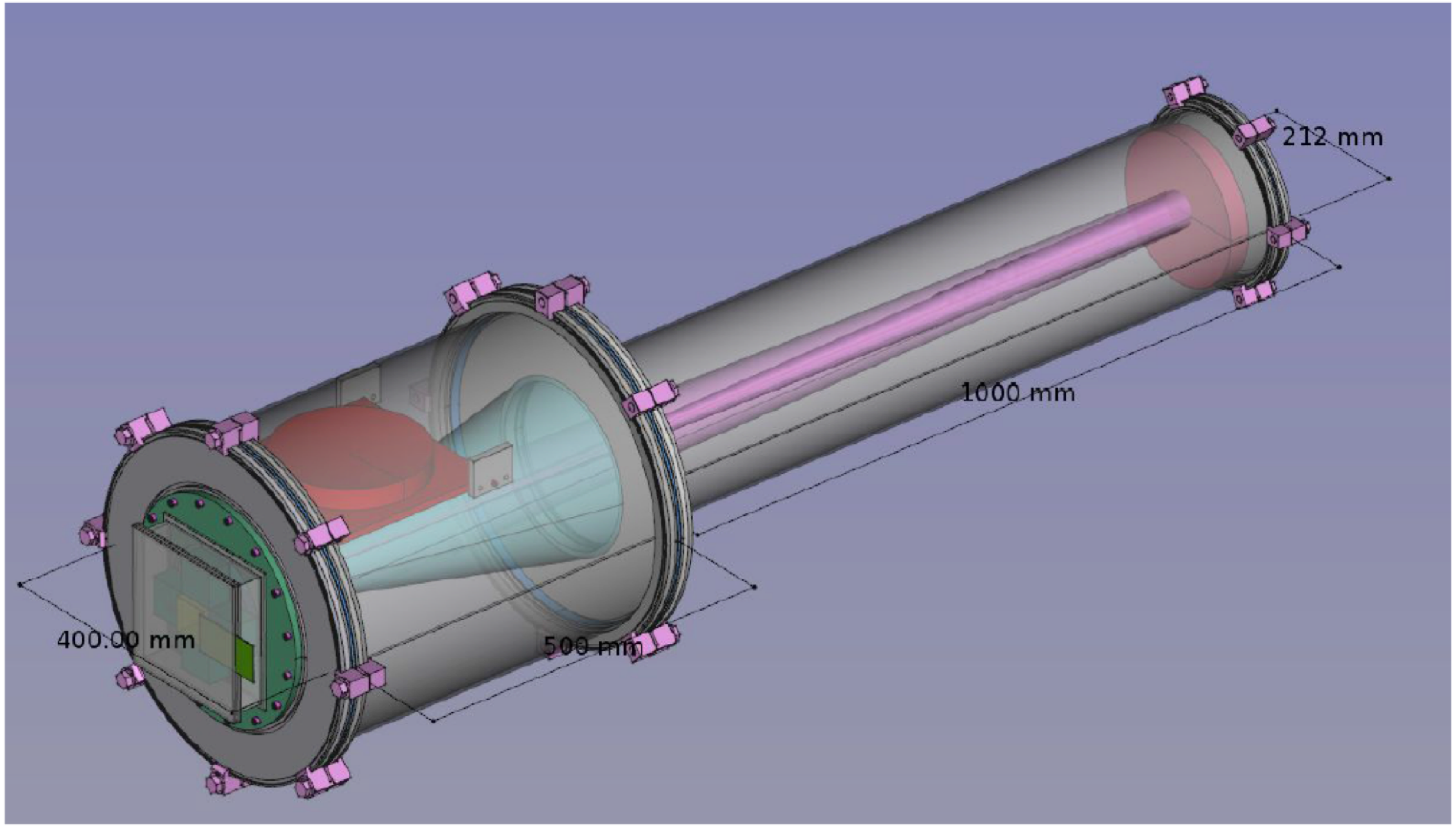
INFN R&D activity: dual-radiator RICH

Construction and characterization of a dRICH prototype: Aereogel + C_2F_6

- Prototype configuration optimized through Bayesian approach
- Almost overlapping Cherenkov rings to optimize photo-sensitive area
- Dual configuration with remote-controllable shutter



Prototype design



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Construction and characterization of a dRICH prototype: Aereogel + C_2F_6

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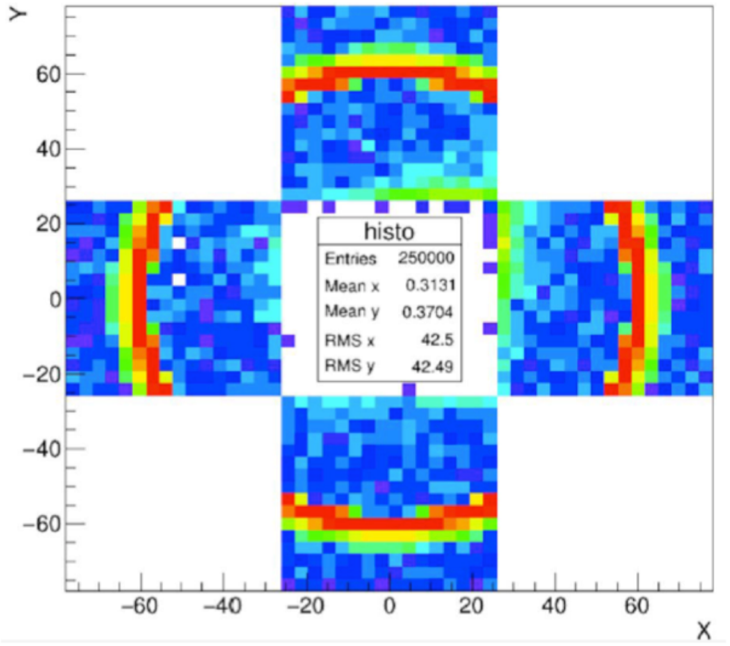
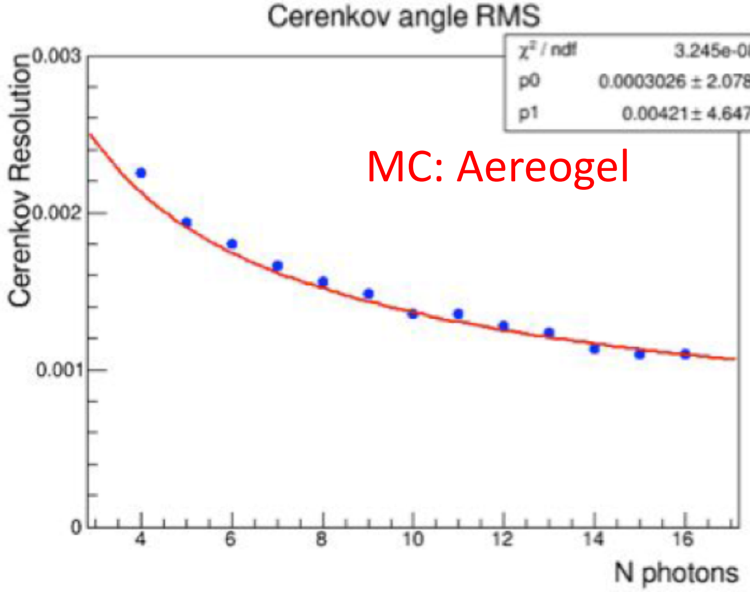
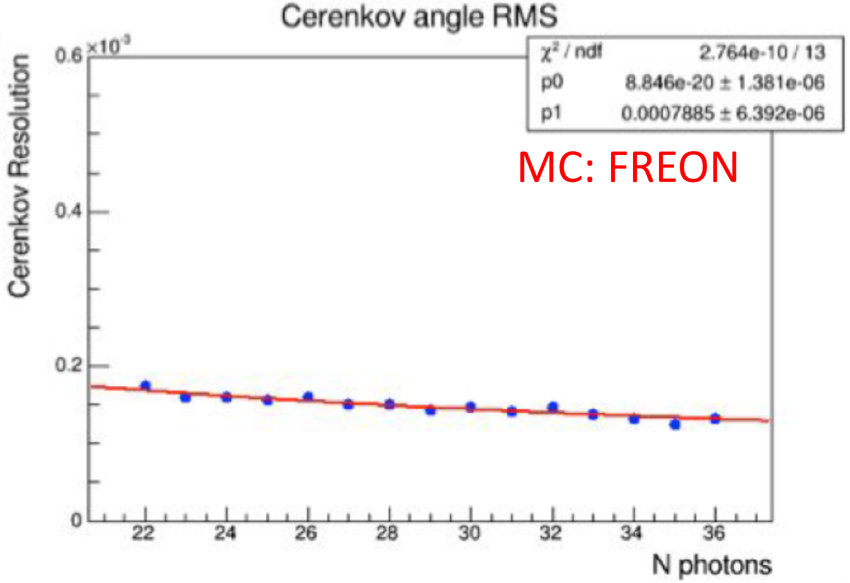
- Dual configuration with remote-controllable shutter

Results from MC simulation (Aereogel)







Contributions to the angular error (mrad)

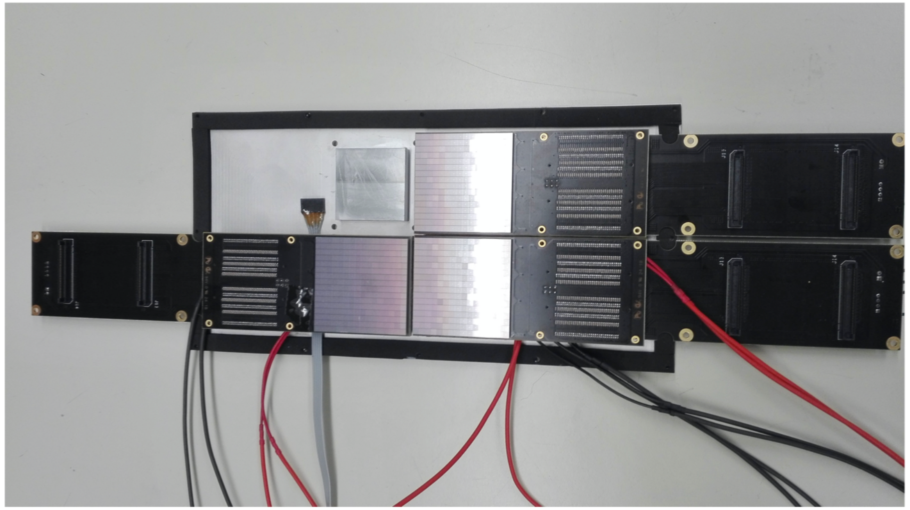
1 p.e. Error (mrad)	Aerogel	@EIC	C_2F_6 Gas	@EIC
Chromatic error	3.2	(2.9)	0.51	(0.8)
Emission	0.5	(0.5)	0.5	(1.2)
Pixel	2.5	(0.5)	0.42	(0.5)

INFN R&D activity: dual-radiator RICH

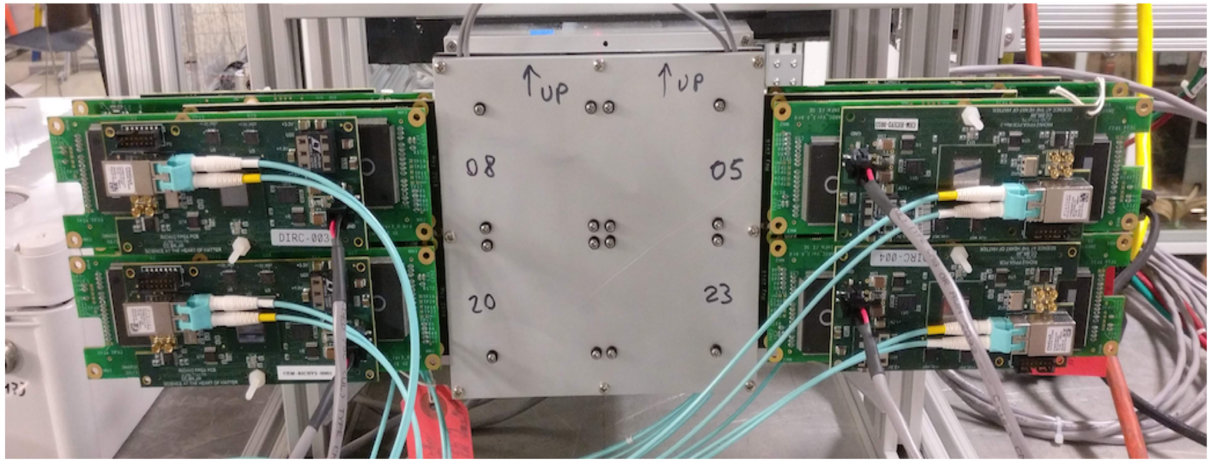
Construction and characterization of a dRICH prototype: Aereogel + C_2F_6

- Significant R&D activity on PD and associated readout electronics
  - MA-PMT
    - Well-known detectors (experience from CLAS12 RICH)
  - SiPM
    - Cheaper and more efficient solution
    - Critical item to be investigated: radiation hardness (neutron damage), possibly mitigated with low-T operations / annealing cycles
    - Challenge: cooling integrated into the sensitive readout
  - Readout electronics:
    - Investigating the use of different ASICS, using the well-known MAROC as a reference (for both MAPMT and SiPM)

SiPM readout box



MAPMT readout box



INFN R&D activity: modular RICH

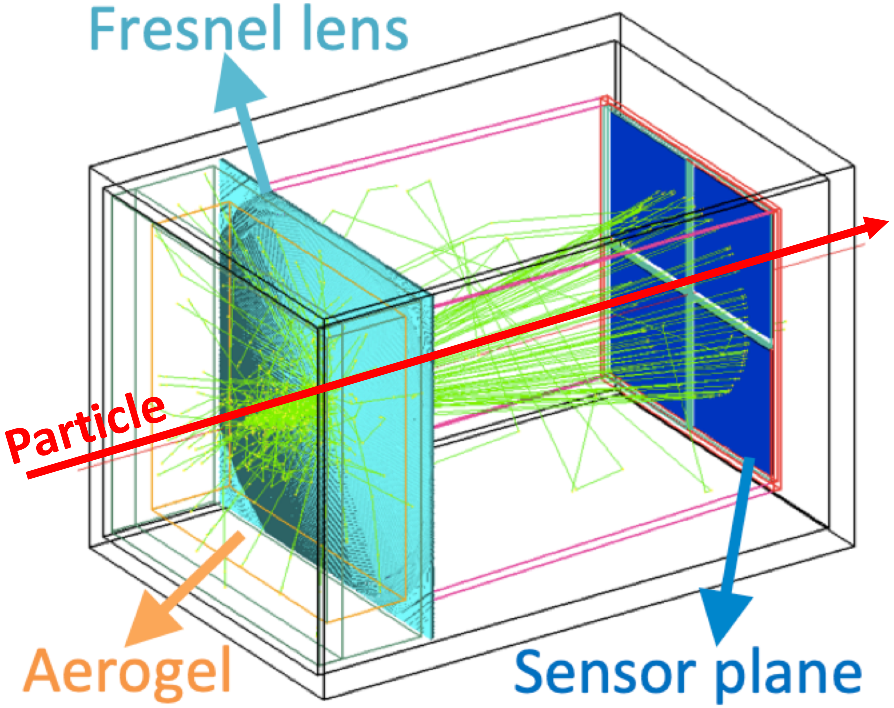
The challenge: PID in the backward region at intermediate momentum requires compact detectors (small radiation length)

The possible solution:

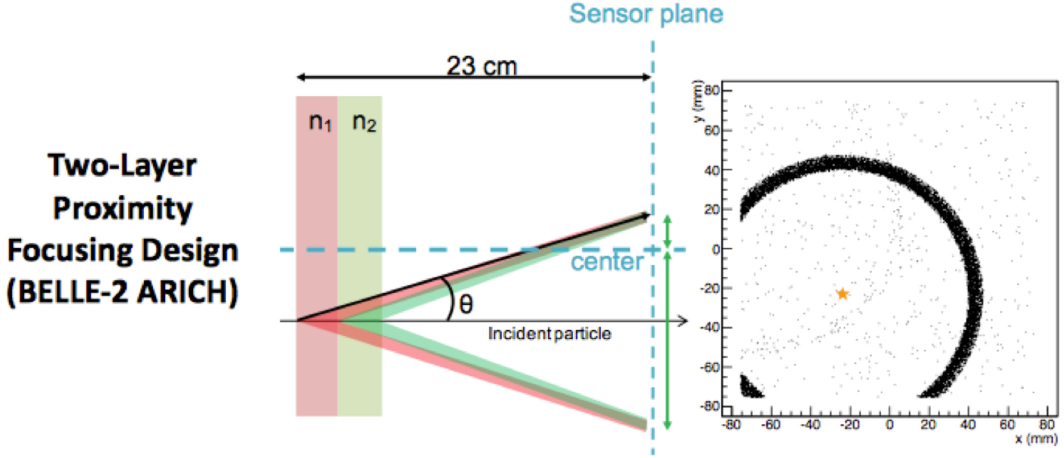
- Modular RICH with Aereogel radiator, made of independent modules
- Ring-centering of lens-based optics reduces sensors area

INFN activity:

- Investigate the use of Fresnel lens for ring focusing
- Study the performances obtained with different photo-detectors



Traditional approach – two layers proximity focusing



- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring is centered at point of incidence

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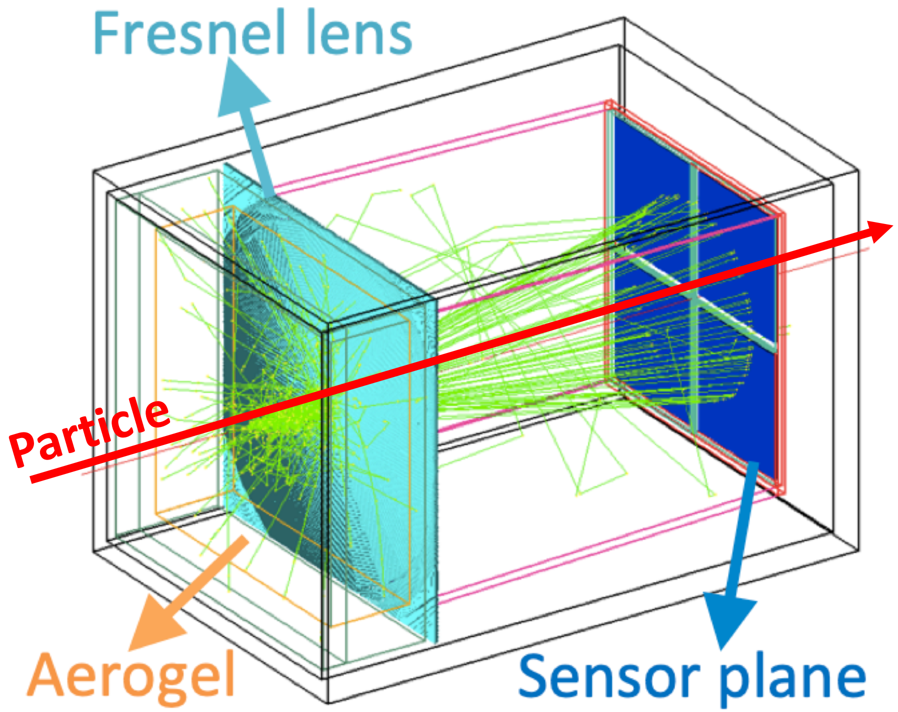
- Ring-centering of lens-based optics reduces sensors area

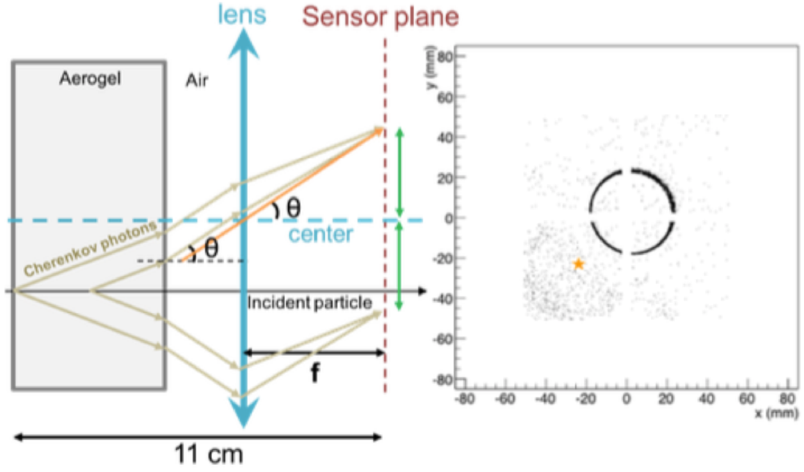
INFN activity:

- Investigate the use of Fresnel lens close to the Aerogel for ring focusing
- Study the performances obtained with different photo-detectors
- On-going MC studies to determine effect of mechanical structure (dead materials) on detector noise



New approach – lens focusing

Lens-Based mRICH Design

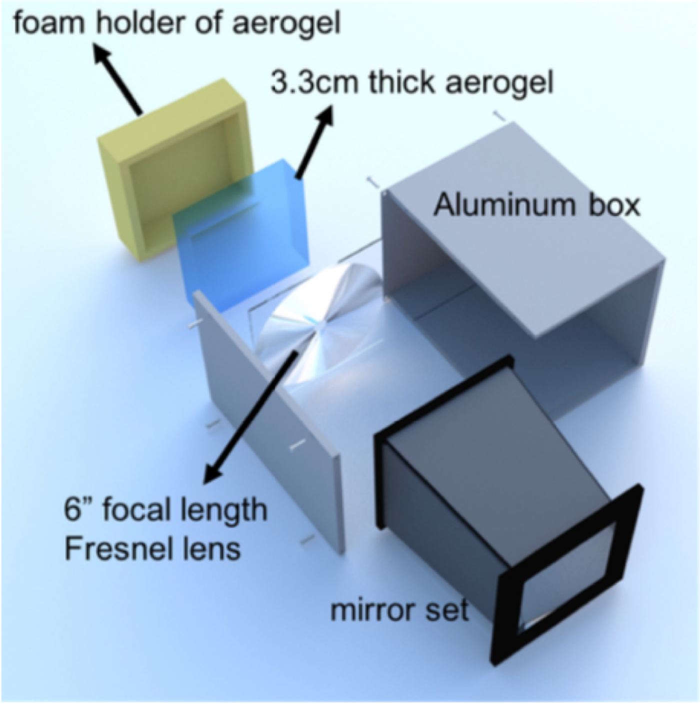


- 9 GeV/c pion beam incident at third quadrant (star) in simulation
- Ring image is **center** on the middle of the sensor plane

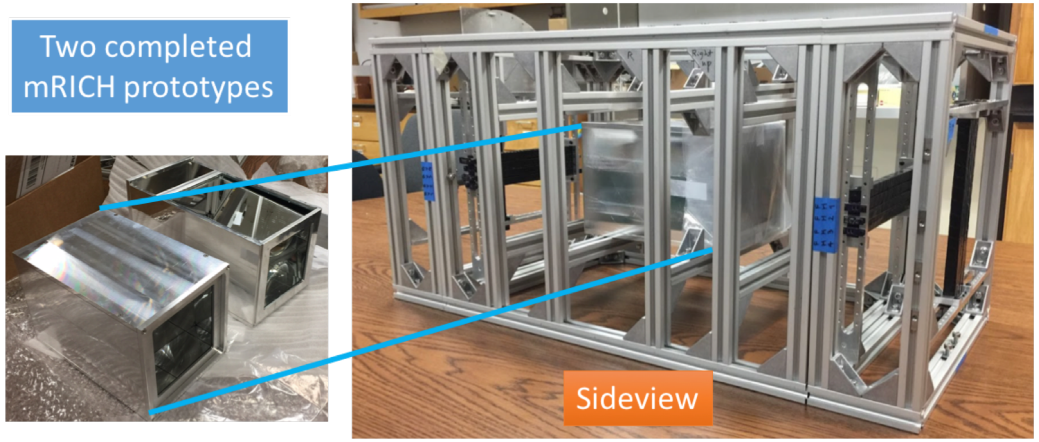
INFN R&D activity: modular RICH

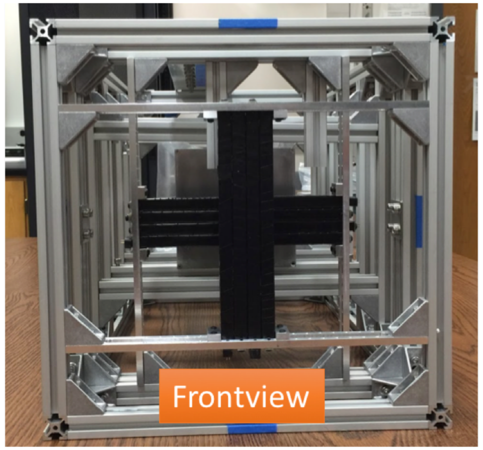
Construction and characterization of a modular prototype with Aereogel radiator

- Compact structure, that can be coupled to different photosensors



Two completed mRICH prototypes

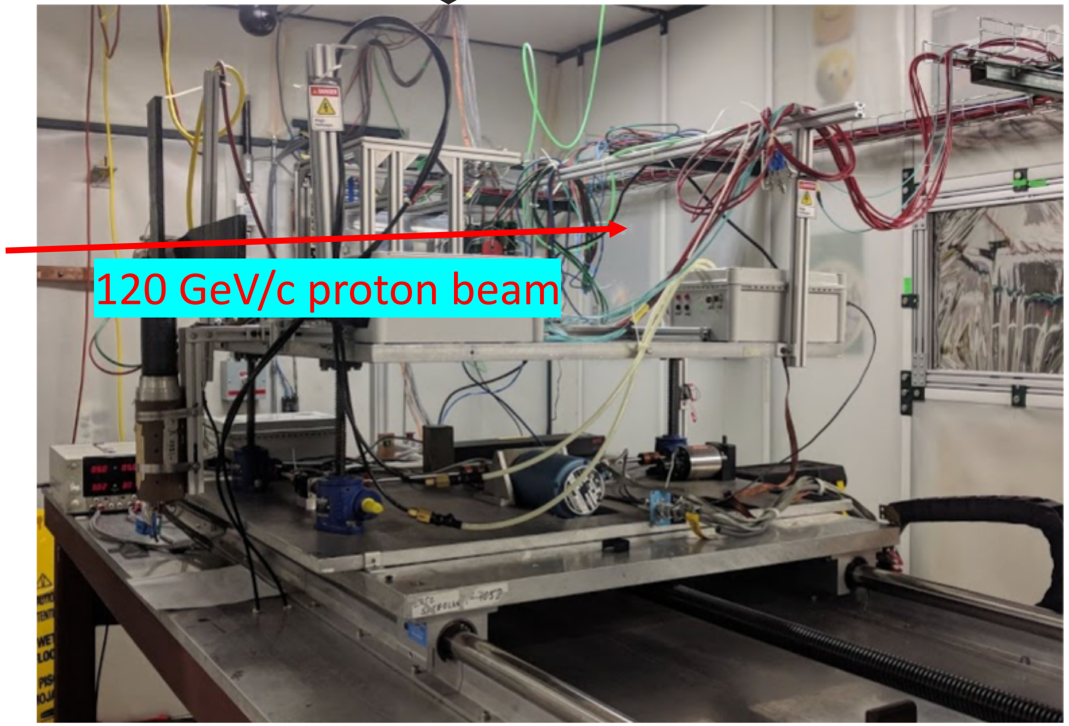




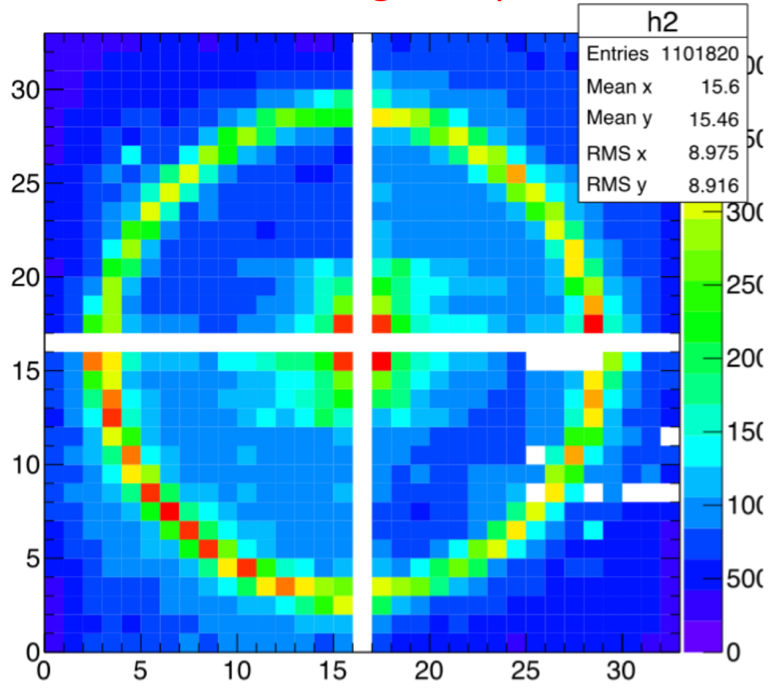
INFN R&D activity: modular RICH

Construction and characterization of a modular prototype with Aereogel radiator

- Beam test at Fermilab (Summer 2018)
  - Tests with both MAPMT and SiPM for readout



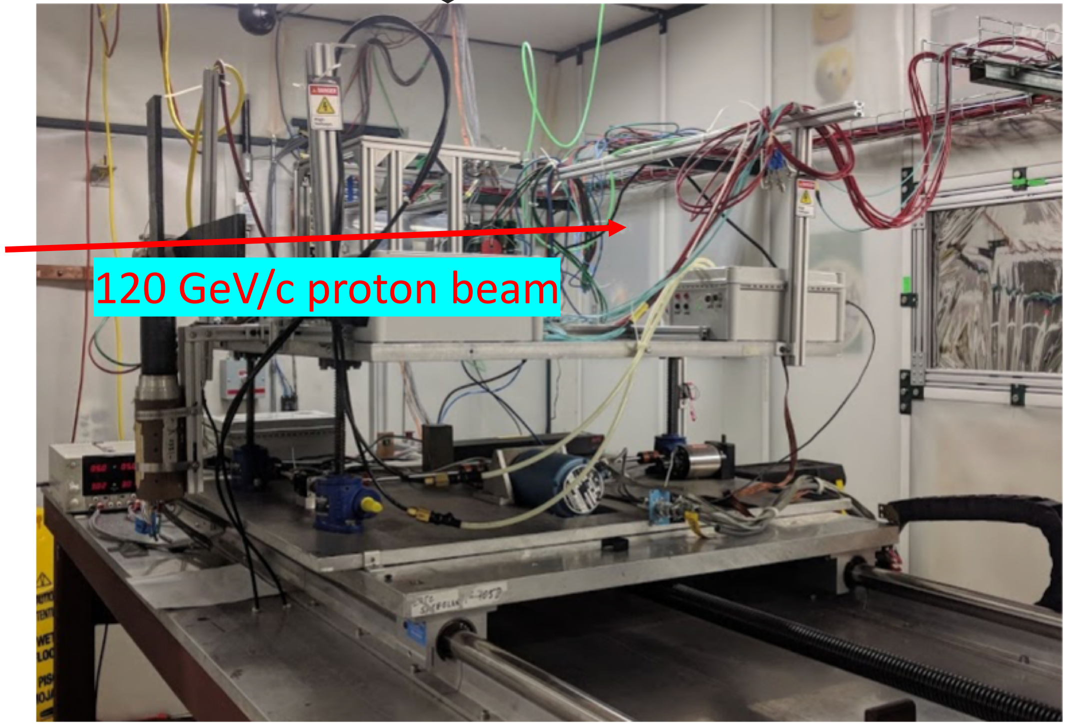
Cherenkov RING image for proton - MAPMT



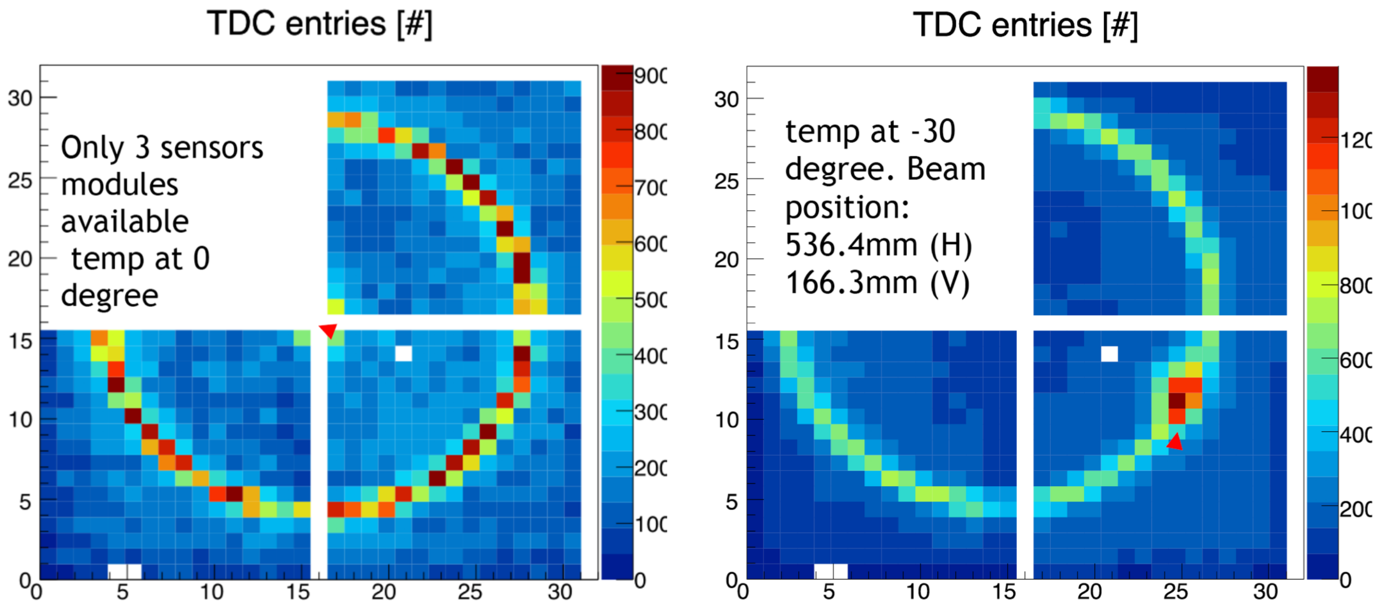
INFN R&D activity: modular RICH

Construction and characterization of a modular prototype with Aereogel radiator

- Beam test at Fermilab (Summer 2018)
  - Tests with both MAPMT and SiPM for readout
  - SiPM temperature was controlled with water-cooled Peltier cells



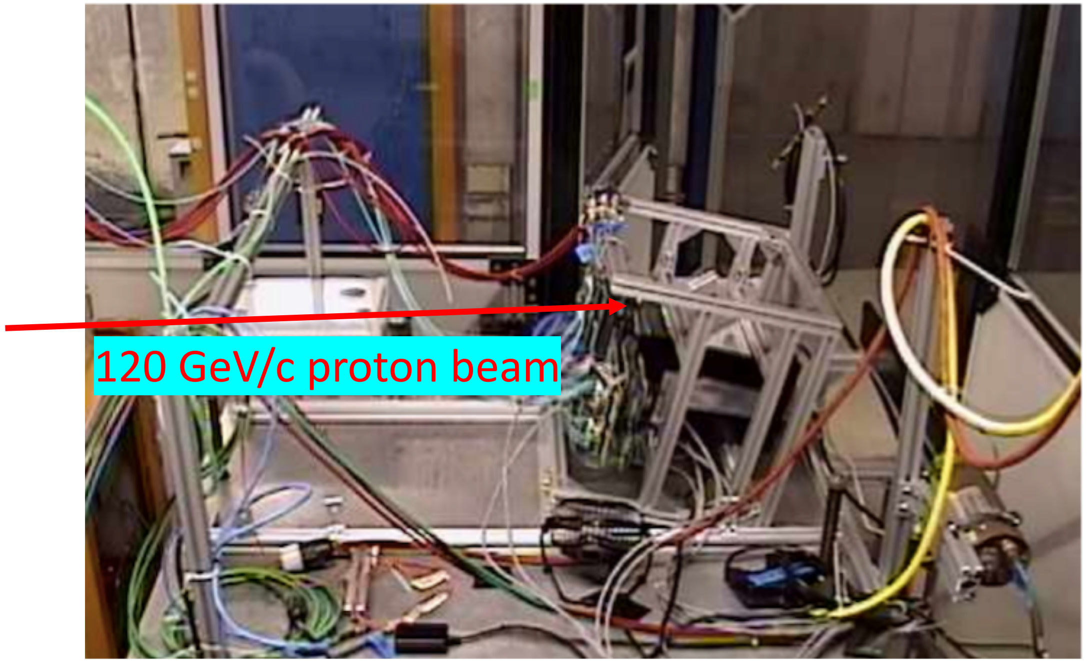
Cherenkov RING image for proton – SiPM
(only 3 SiPM matrixes available)



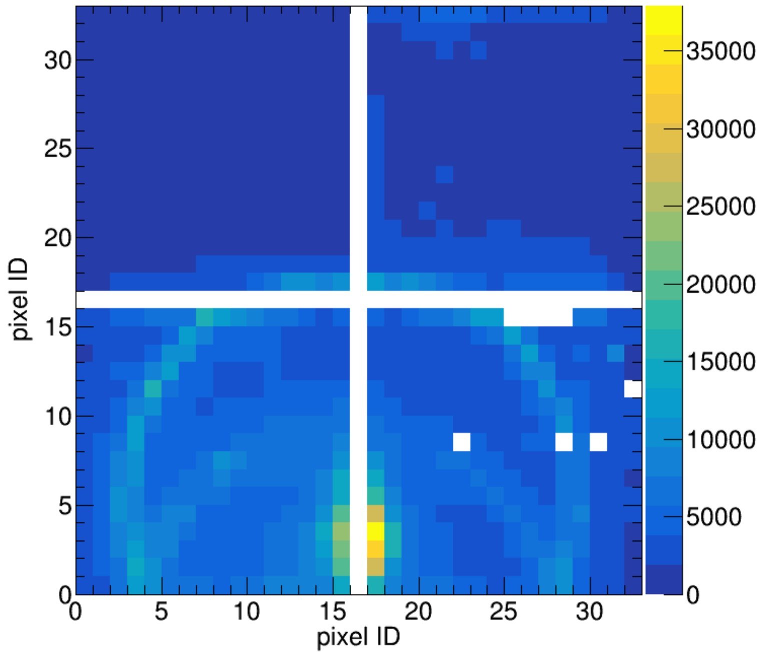
INFN R&D activity: modular RICH

Construction and characterization of a modular prototype with Aereogel radiator

- Beam test at Fermilab (Summer 2018)
    - Tests with both MAPMT and SIPM for readout
    - SiPM temperature was controlled with water-cooled Peltier cells
    - Tests with proton impinging at a tilted angle on the detector plane showed that the Cherenkov ring is visible also in this configuration



Cherenkov RING image for proton impinging at 11 degrees



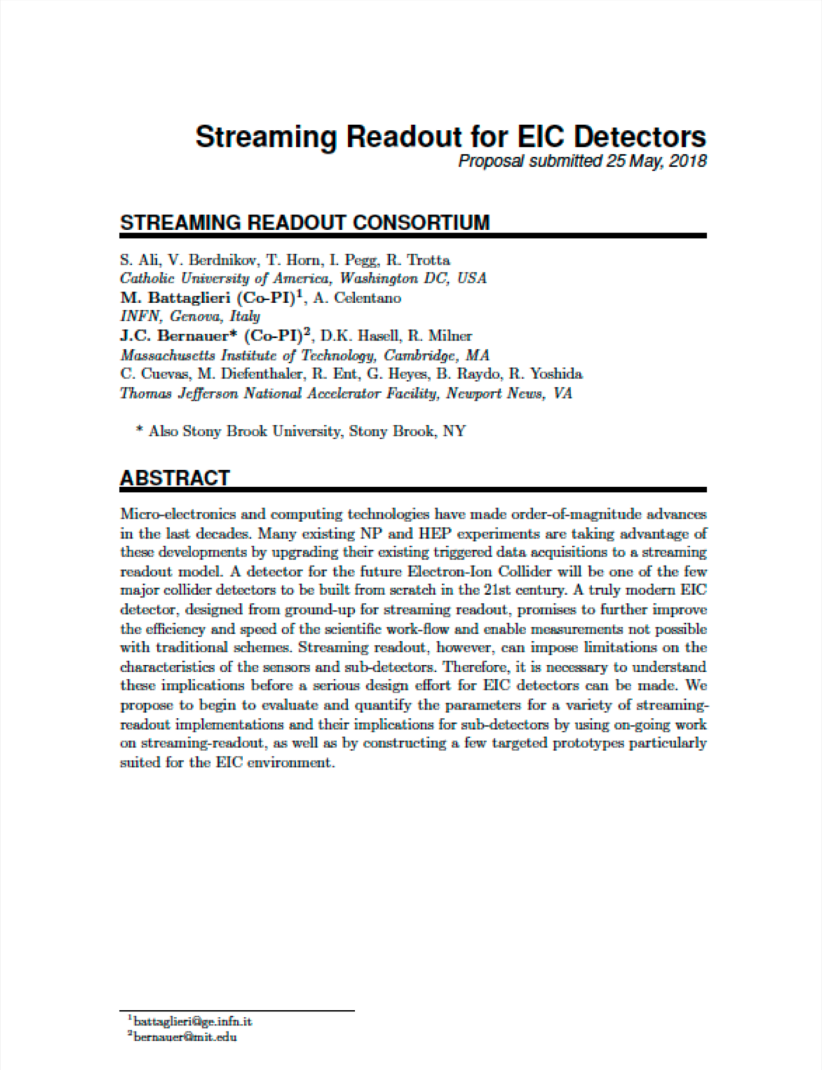
A streaming readout system for EIC

The challenge: design a modern TDAQ system for the EIC detector, exploiting the existing technological developments on computing / networking

The possible solution: a completely triggerless streaming readout system – no trigger decision is sent back from the TS to the DAQ

INFN activity:

- A new EIC R&D consortium has been formed in 2018, with strong INFN involvement (INFN co-PI)
- Focus on calorimetry as a starting point with new hardware and software solutions
- Specific emphasis on the physics validation of this new approach



Streaming Readout for EIC Detectors
Proposal submitted 25 May, 2018

STREAMING READOUT CONSORTIUM

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INFN, Genova, Italy
J.C. Bernauer* (Co-PI)[2], D.K. Hasell, R. Milner
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ABSTRACT

Micro-electronics and computing technologies have made order-of-magnitude advances in the last decades. Many existing NP and HEP experiments are taking advantage of these developments by upgrading their existing triggered data acquisitions to a streaming readout model. A detector for the future Electron-Ion Collider will be one of the few major collider detectors to be built from scratch in the 21st century. A truly modern EIC detector, designed from ground-up for streaming readout, promises to further improve the efficiency and speed of the scientific work-flow and enable measurements not possible with traditional schemes. Streaming readout, however, can impose limitations on the characteristics of the sensors and sub-detectors. Therefore, it is necessary to understand these implications before a serious design effort for EIC detectors can be made. We propose to begin to evaluate and quantify the parameters for a variety of streaming-readout implementations and their implications for sub-detectors by using on-going work on streaming-readout, as well as by constructing a few targeted prototypes particularly suited for the EIC environment.

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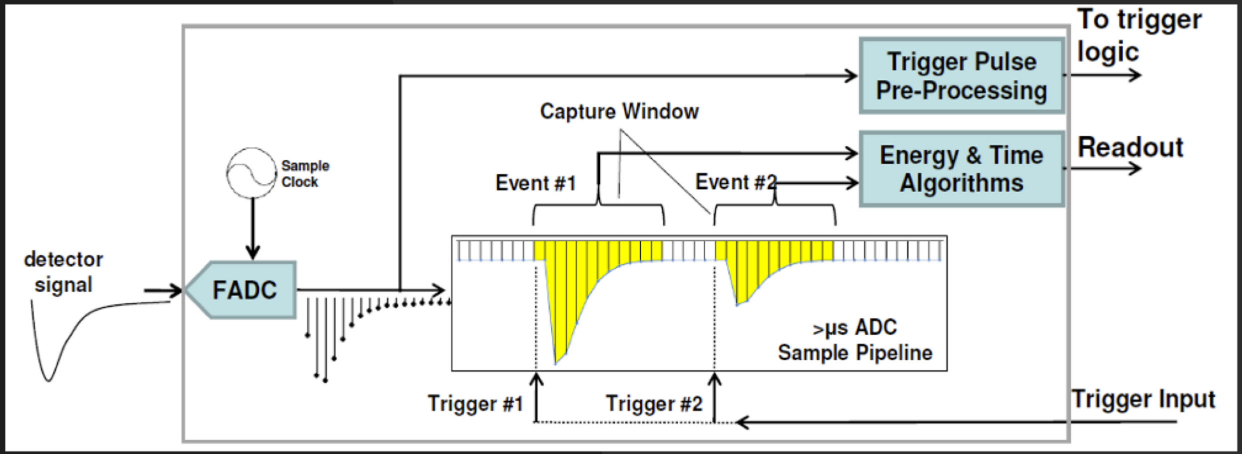
Streaming readout approach

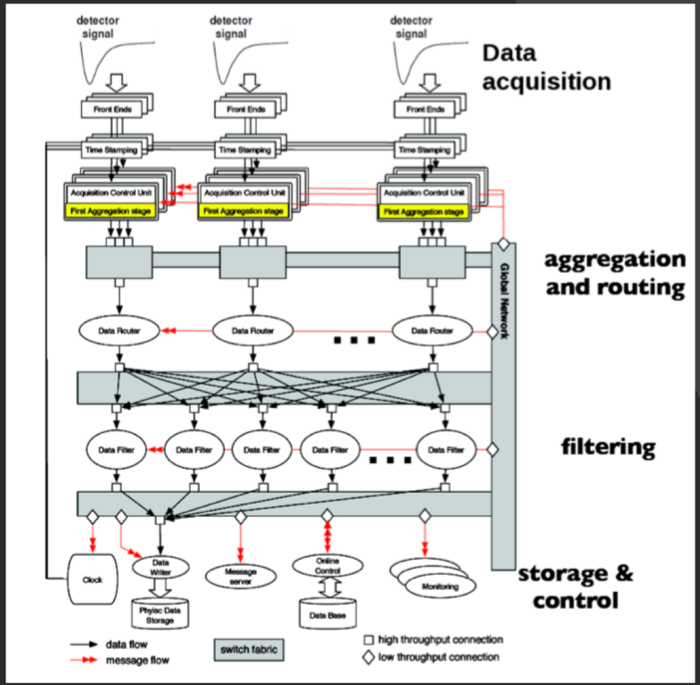
Triggered approach

- Data path *is different from* trigger path
- Trigger decision based on a *limited* information (“primitives”)
- Requires to re-send back trigger decision from TS to ROC
- “Event” defined at hardware level just after trigger decision – fixed window width

Triggerless approach

- Data path equal to trigger path
- Unidirectional data transmission from ROC
- Trigger decision based on complete detector information, possibly with the SAME offline reconstruction software used offline
- “Event” defined at software level – **maybe even not necessary: store (reconstructed) hits (high-level observables) with timestamp.**



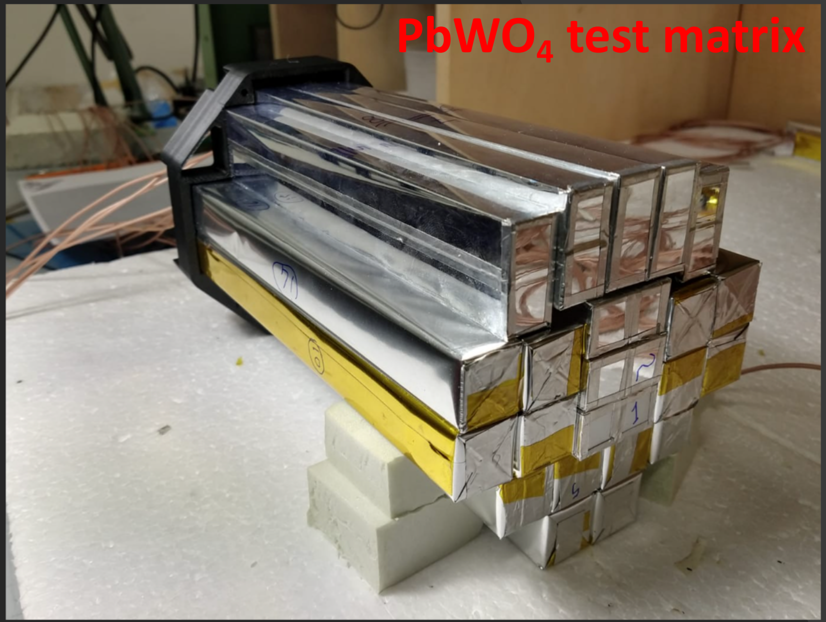


Streaming readout activity @ INFN

A key aspect of the consortium activity is the streaming readout approach **validation.**

2019: we characterized a matrix of $PbWO_4$ crystals with cosmic rays, comparing performances obtained from a full streaming readout system with those - for the same detector - from a triggered setup.

- Triggered system: CAEN v1730 digitizers + JLab trigger boards
- Streaming readout-system: Wave-Brd digitizer board + TriDAS software (adapted from KM3 experiment)



Preliminary results demonstrated the high performances of the system

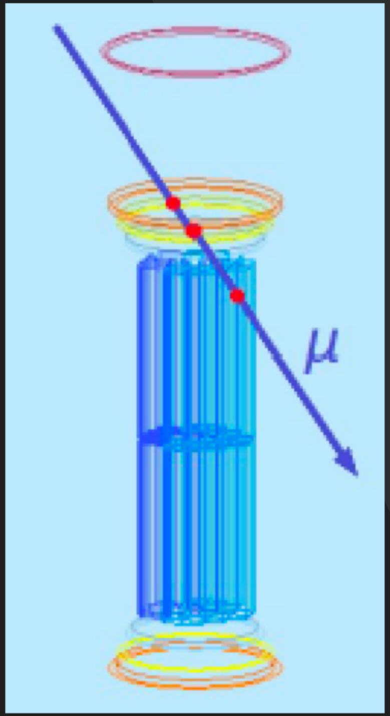
Next steps:

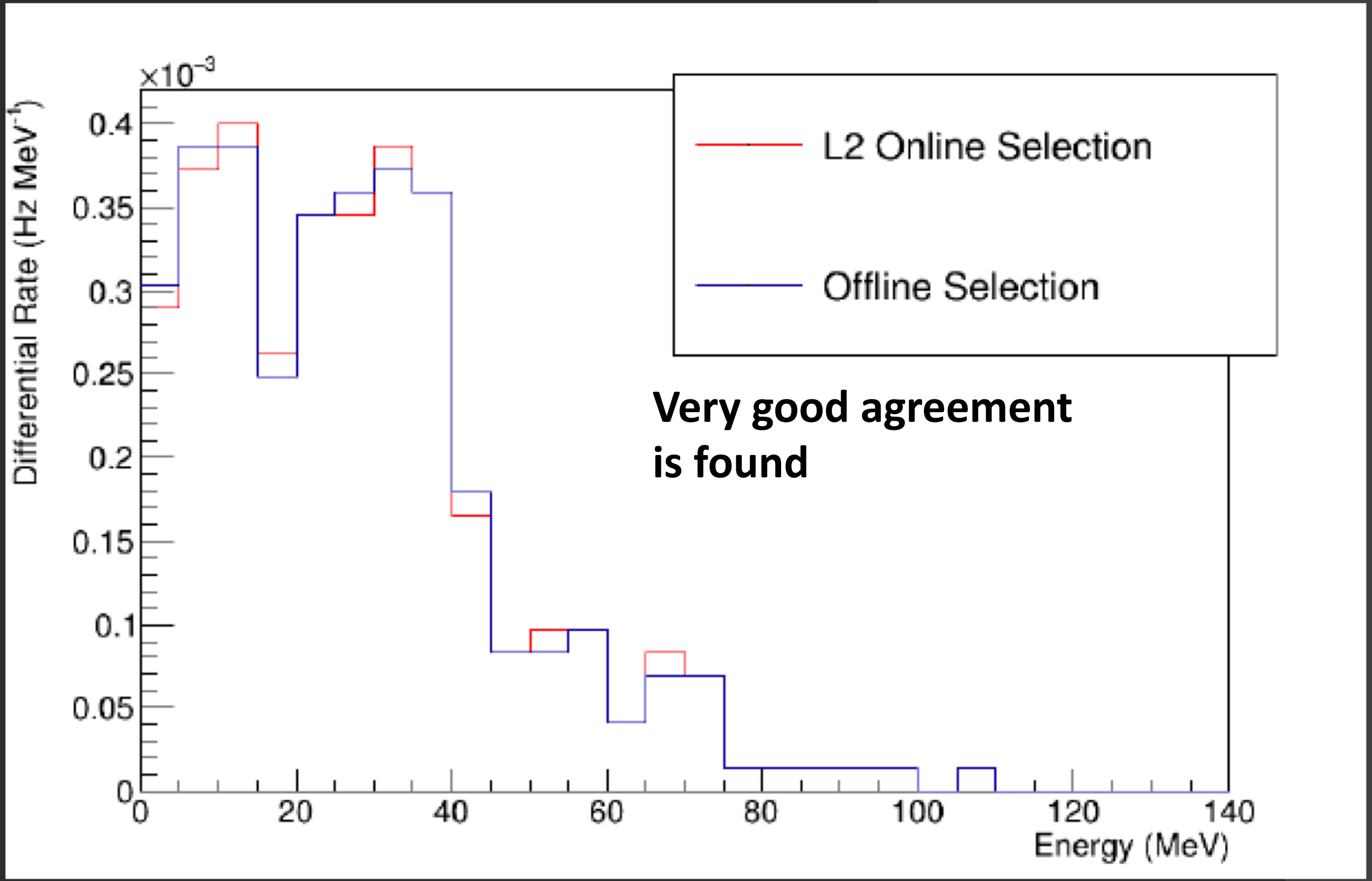
- Characterization of a small $PbWO_4$ calorimeter with e^- beam (sinergy with calorimetry activity)

DAQ comparison: online selection algorithms

Selecting events with hits in coincidence with external plastic scintillator counters can be used to identify cosmic muons trajectories.

- An online trajectory selection trigger was implemented
- Comparing online-selected events with same selection performed in offline reconstruction.





This test demonstrates the versatility of a triggerless streaming system: event-selection algorithms can be changed and tuned to each specific physics case

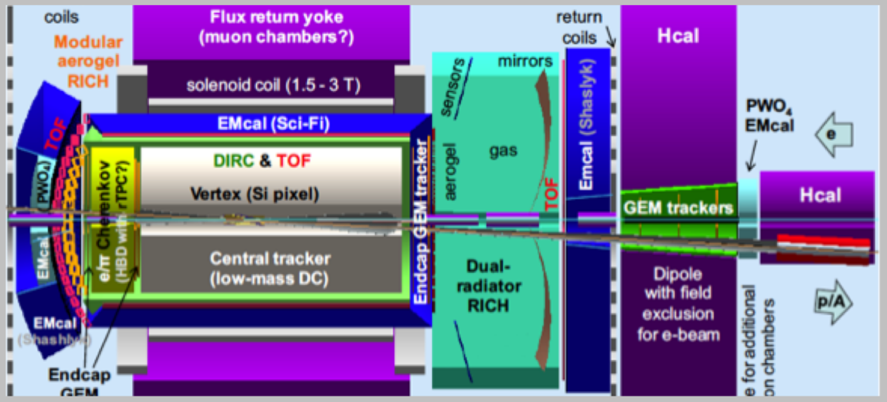
EM calorimetry in EIC

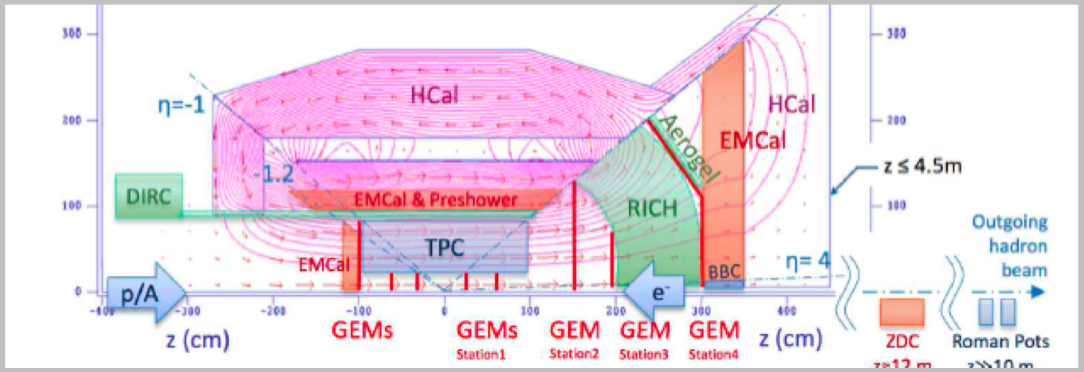
Motivation:

- ***Particle identification:*** important for discriminating single photons from π^0/η decay and for e-
- ***Particle Reconstruction***: driven by need to accurately reconstruct the 4-momentum of scattered electrons at small angles, where the momentum (or energy) resolution from the tracker is poor due to the low $\int Bdl$ value ($\eta < -2$ region)

Requirements:

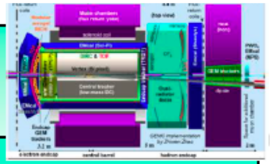
- Good resolution in angle to at least 1° to distinguish between clusters
- Energy resolution to a few % / $\sqrt{E}$ for measurements of cluster energy
- Ability to withstand radiation down to at least 1° wrt beam line





Calorimeters @ EIC

- Each kinematic region has different key physics observables and detector constraints, thus requiring a different technology
- Many on-going efforts:
  - *W/SciFi*
  - *W/Shashlik*
  - *Dual-readout Pb/Sc (HCAL)*
  - *Homogeneous Calorimetry*
- $PbWO_4$ is the leading option for homogeneus calorimetry, although new innovative materials are being tested



Regions and Physics Goals	Calorimeter Design
Lepton/backward: EM Cal o Resolution driven by need to determine (x, Q^2) kinematics from scattered electron measurement o Prefer 1.5%/√E + 0.5%	Inner EM Cal for for $\eta < -2$: ➢ Good resolution in angle to order 1 degree to distinguish between clusters ➢ Energy resolution to order (1.0-1.5 %/√E+0.5%) for measurements of the cluster energy ➢ Ability to withstand radiation down to at least 2-3 degree with respect to the beam line. Outer EM Cal for $-2 < \eta < 1$: ➢ Energy resolution to 7%/√E ➢ Compact readout without degrading energy resolution ➢ Readout segmentation depending on angle
Ion/forward: EM Cal o Resolution driven by deep exclusive measurement energy resolution with photon and neutral pion o Need to separate single-photon from two-photon events o Prefer 6-7%/√E and position resolution < 3 mm	
Barrel/mid: EM Cal o Resolution driven by need to measure photons from SIDIS and DES in range 0.5-5 GeV o To ensure reconstruction of neutral pion mass need: 8%/√E +1.5% (prefer 1%)	Barrel, EM calorimetry ➢ Compact design as space is limited ➢ Energy resolution of order 8%/√E +1.5%, and likely better
Ion/Forward: Hadron Cal o Driven by need for x-resolution in high-x measurements o Need Δx resolution better than 0.05 o For diffractive with ~50 GeV hadron energy, this means 40%/√E	Hadron endcap: ➢ Hadron energy resolution to order 40%/√E, ➢ EM energy resolution to < (2%/√E + 1%) ➢ Jet energy resolution < (50%/√E + 3%)

Summary of EIC R&D detector handbook, Calorimetry section

EIC calorimetry with crystals

$PbWO_4$ is the leading option for EIC calorimeters in backward direction ($\eta < -2$)

Requirements:

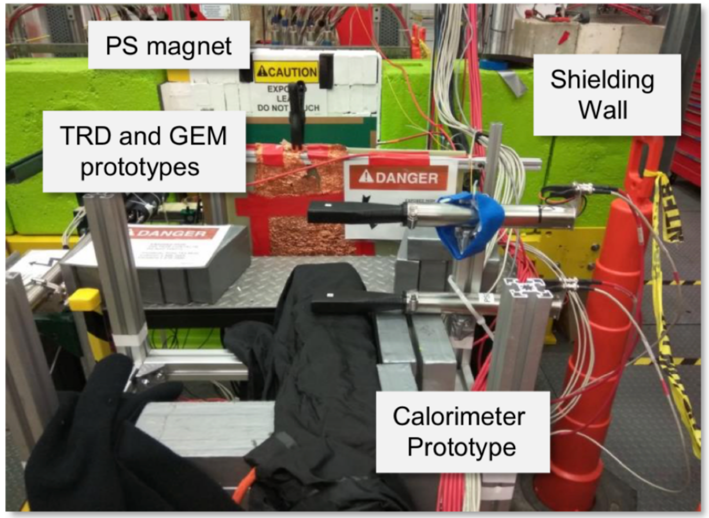
- Good ***angular resolution*** to at least 1 degree to distinguish between clusters
- ***Energy resolution*** < (1.0-1.5 %/$\sqrt{E}$+0.5%) for measurements of the cluster energy
- ***Time resolution*** to < 2ns
- Good radiation hardness

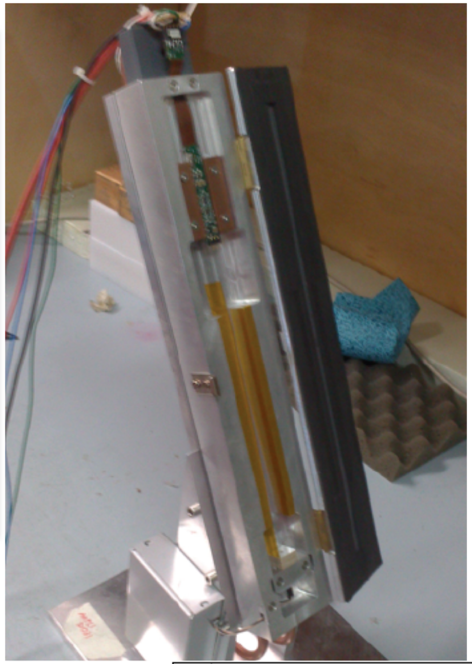
Challenges:

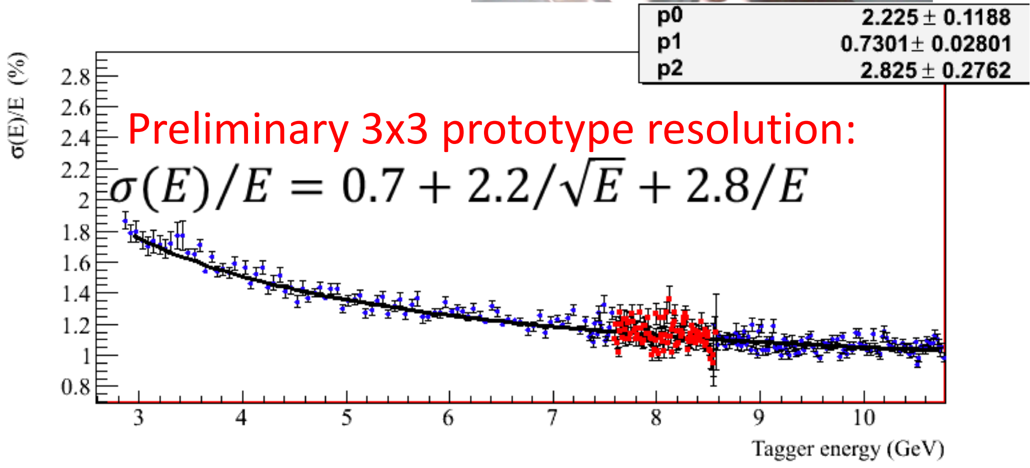
- Define a quality assurance protocol to be applied during crystals mass-production to meet above specifications
- Test crystals from different manufacturers and apply this protocol

INFN activity:

- Participate to crystals quality assurance measurements
- Participate to test-beam measurements to confirm crystal performances in a "real" environment

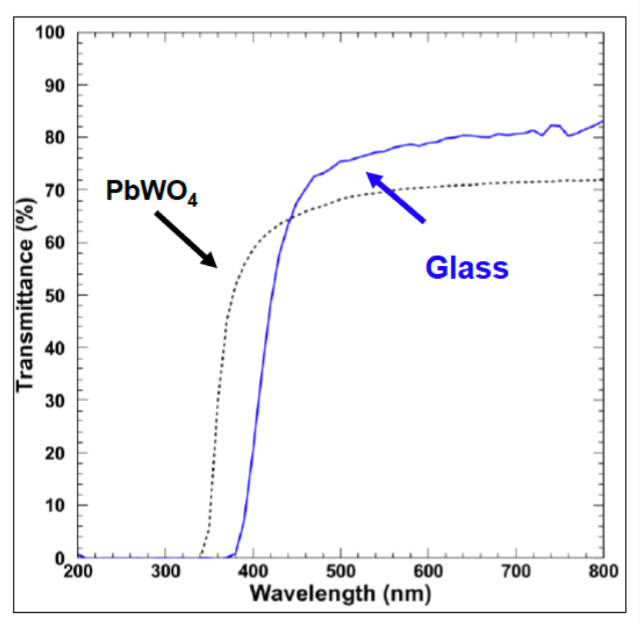






New materials for homogeneous calorimetry

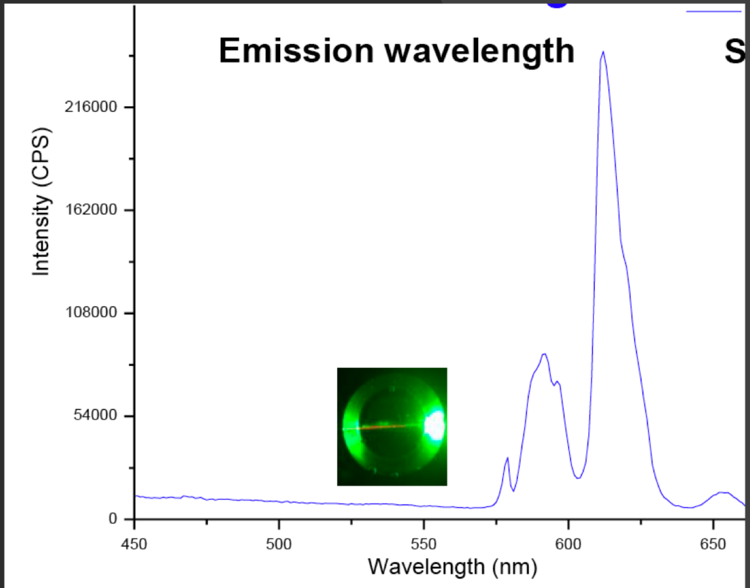
- $PbWO_4$ crystals are ideal, but also have limitations (light yield) and are expensive ($15-25/cm^3) – very large volume detectors are probably unaffordable
- Glass-based scintillators are a cost-effective alternative to crystals, in particular for regions with relaxed resolution requirements
- INFN is participating in this new R&D activity, together with CUA/VSL/Scintilex
- Our main involvement is the characterization of CUA-manufactured glass samples to extract the main parameters: LY / light transmission / timing



Preliminary results:

- Light transmission of small samples is equivalent or better than $PbWO_4$ crystals of same dimensions
- Light yield is higher
- Emission spectrum can be tuned with proper dopants
- Radiation hardness is demonstrated

A CSN-V young researchers grant has been proposed (M. Bondi', INFN-CT) concerning ceramic glasses characterization for high-energy calorimetry



Material/ Parameter	$PbWO_4$	Sample 1	Sample 2	Sample 3	Sample 4
Luminescence (nm)	420	440	440	440	440
Relative light output (compared to $PbWO_4$)	1	35	16	23	11

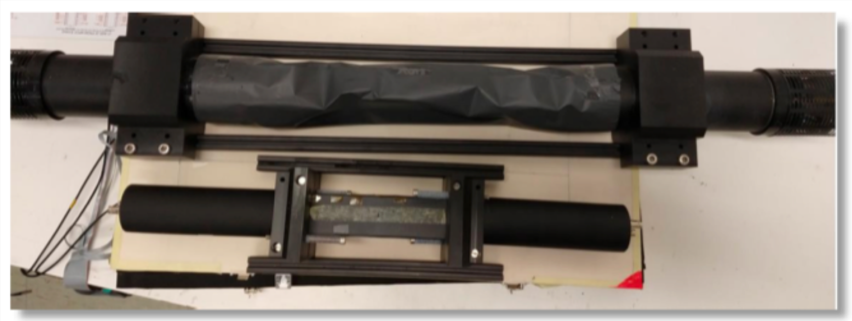
Scintillating glasses characterization @ INFN

Goal:

- Measure the main parameters of a large number of samples (light yield, rad. length, timing)
- Test different readout options

Infrastructure:

- Starting to assembly three Multi-gap Resistive Plate Chambers (80x160 cm^2) to map out material response over large area in short time – synergy with ALICE/EEE
- Using streaming readout boards developed at INFN for EIC streaming readout – compatible with PMT/SiPM/APD
  - Absolute time stamp from readout board allows to correlate hits with cosmic—rays tracks from chambers
- A smaller-scale cosmic ray telescope (including DAQ) is also available, for timing studies (resolution < 100 ps)



Summary and outlook

- INFN is strongly involved in the ongoing EIC R&D activities, focusing on selected topics of critical importance for this future effort
  - PID with RICH detectors
  - Readout system with streaming approach
  - Electromagnetic calorimetry
- All the activities benefit from the strong knowledge of the Italian groups, and are coordinated with the international EIC community within the US program for the generic EIC R&D
- We're looking forward into actively joining the EIC yellow reports preparation with an effective role in the editorial board

Streaming readout activity @ INFN: validation

“Technical validation” process: Compare between data acquired with “standard” (triggered) and “triggerless” DAQ system (coincidence rates, spectra...) – $PbWO_4$ matrix exposed to cosmic rays

Triggerless chain:

- Only signals over the wave-board hardware threshold are processed (Hits)
- Event definition and construction by Level 1 (L1) low level software selection algorithm (e.g. OR of crystals Hits)
- Event selection and tagging by Level 2 (L2) algorithm (e.g. clustering, trajectories selection)

Triggered DAQ Chain

- All channels are passed to discriminators
- Discriminator output passed to coincidence module for event definition (OR of crystals)
- All channels waveforms acquired and saved for each trigger – **no zero suppression**

DAQ comparison: rates

- For both DAQ systems, crystals were calibrated in energy comparing with MC simulations
- Single crystal energy distributions show good agreement above the “triggered” DAQ energy threshold
- Total energy distributions present slight discrepancy in shape due to the triggerless hit threshold