# Pressurized RICH

**Contact Person**: M. Contalbrigo *

**Project Members**:

INFN Ferrara and University of Ferrara (contact: M. Contalbrigo)

INFN Laboratori del Sud (contact: F. Noto)

INFN Trieste and University of Trieste (contact: S. Dalla Torre)

July 14, 2023

**Abstract**

A generic R&D program is proposed to mitigate the risk associated with the long-term usage of fluorocarbon gasses in ring-imaging Cherenkov detectors, for the hadron identification in the high momentum range of the hadron end-cap of the experiments at EIC. Greenhouse gasses with high global warming power as $C_2F_6$ might encounter unexpected restrictions or shortage causing potential market instabilities and cost increase. The alternate use of pressurized inert gasses like Argon could offer a solution with comparable optical performance and reliable long-term availability, while minimizing the environmental impact.

*e-mail: contalbrigo@fe.infn.it

# 1 Introduction

Hadron Particle IDentification (PID) at high momenta in a wide phase space range, typically for pseudo-rapidity $(\eta) > 1.5$, is requested for the physics scope of EIC. This proposal aims to develop a novel approach to accomplish this mission.

RICHes with gaseous radiators still represent the only option for hadron PID at high momenta. The choice of fluorocarbon gasses are privileged because they offer high Cherenkov photon yield and low chromaticity. These two characteristics are both relevant to obtain fine resolution in the Cherenkov angle measurement and, therefore, in determining the momentum upper limit for effective PID.

Fluorocarbons are characterized by huge-values of their Global Warming Power (GWP). This fact poses ethical, procurement and authorization issues for their use in future devices. Therefore, alternative approaches can ensure the operation of gaseous RICH detectors is future experimental programs and can represent a risk mitigation for projects that assume the use of fluorocarbons as baseline option.

Any potential alternative to the use of fluorocarbons as gas radiators in Cherenkov imaging application should match the following requirements: similar refractive index in the high value range for gasses, in order to guarantee a good rate of produced Cherenkov photons, and limited chromaticity to preserve the high resolution, being the chromatic dispersion the irreducible component of the Cherenkov angle dispersion. An option is offered by pressurized noble gasses, which have limited chromaticity. Helium and Neon would require severe high pressure to obtain refractive indexes in the fluorocarbon range. Argon and Xenon can mimic fluorocarbon refractive indexes at moderate pressure (see Table 1). The chromatic dispersion varies with the quantum efficiency spectrum of the photosensors. The chromatic dispersion of three fluorocarbon gasses, assuming three possible photosensors with different spectral response, are provided in Table 2 in comparison with the one of Argon and Xenon. The chromatic dispersion of Argon is similar to that of fluorocarbons, in particular to the one of $C_4F_{10}$, both in the visible and UV domain. Xenon chromatic dispersion is acceptable in the visible and near UV domain, offering the advantage that lower gas pressure is required to mimic the fluorocarbons. On the other hand, cost considerations suggest to regard pressurized Argon as the most natural choice to provide an alternative to fluorocarbons for hadron PID at high momenta.

We propose to advance in three basic ingredients needed to qualify the use of pressurized Ar for hadron PID at EIC:

- establish the performance of a RICH with pressurized Argon in comparison with the performance provided using $C_2F_6$ at atmospheric pressure;
- design a vessel of low material budget adequate for a pressurized RICH up to an absolute pressure-value of 3 bar;
- validate the compatibility of aerogel tiles with a pressurized inert environment.

| Fluorocarbon | Ar, Pressure (bar) | Xe, Pressure (bar) |
|---|---|---|
| $CF_4$ | 1.7 | |
| $C_2F_6$ | 2.9 | 1.2 |
| $C_4F_{10}$ | 4.6 | 1.9 |

Table 1: Argon and Xenon absolute pressure required to mimic the refractive indexes of three fluorocarbons typically used in gaseous RICHes. Fluorocarbon are assumed to work at atmospheric pressure.

# 2 R&D Activity

The goals of the proposed generic R&D activity is to reduce the risk associated with the long-term usage of a greenhouse gas of high global warming power as $C_2F_6$. The alternate use of pressurized inert gasses like Argon could offer a solution with comparable optical performance in conjunction with important benefits. The first is to reduce the environmental impact. The second is to decouple from the potential market instabilities, due to unexpected restrictions or shortage of fluorocarbon gases and possible related cost increase.

| photosensor | MAPMT | SiPM-14520 | SiPM-13615 |
|---|---|---|---|
| Wavelength range (nm) | 200-700 | 270-900 | 320-900 |
| $\sigma_\theta/\theta$ ($CF_4$) | 2.3 | 1.2 | 0.8 |
| $\sigma_\theta/\theta$ ($C_2F_6$) | 2.5 | 1.3 | 0.9 |
| $\sigma_\theta/\theta$ ($C_4F_{10}$) | 3.3 | 1.7 | 1.1 |
| $\sigma_\theta/\theta$ (Ar) | 3.3 | 1.7 | 1.5 |
| $\sigma_\theta/\theta$ (Xe) | 7.9 | 3.2 | 2.3 |

Table 2: Chromatic dispersion of three fluorocarbons in comparison to Argon and Xenon, assuming the following photosensors: MAPMT type R7600-03-M16 by Hamamatsu, with UV extended glass window,; SiPM-14520 by Hamamatsu; SiPM-13615 by Hamamatsu.

## 2.1 Design of the vessel for a pressurized RICH

The feasibility of a light material vessel capable to support a 2 bar relative pressure and designed to preserve a safe and effective interface of the radiator gas volume with the aerogel and the photosensors can be studied by working on a realistic case: the ePIC dRICH is assumed as the relevant case of study, see Fig. 1.

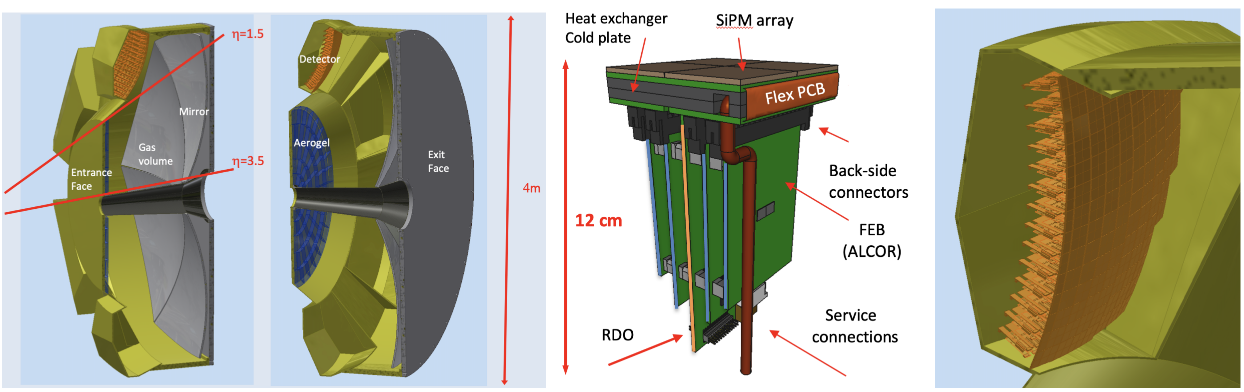


Figure 1: dRICH 3D mechanical model (left). Details of the dRICH photon detection unit (center). dRICH readout plane shaped to best match the mirror focalization surface (right).

The dRICH structure could be ideally divided in three main pieces with different requirements: The aerogel volume, the gas volume and the detector-box. Aerogel requires a minimal support structure, assumed to mimic the BELLE-II solution, and may require an insulation window. Mirrors require a support with an integrated alignment system. The detector boxes should provide support and thermal insulation for sensor, electronics, integrate services and cooling, and mount a transparent window to separate the gas volume from the sensor and electronics volume. The standard solution for a pressurized vessel, i.e. a thick metal structure (few cm of Al or steel) is not well-suited for an EIC spectrometer, as would introduce too much material budget for the detectors (typically calorimeters) downstream. Composite materials could offer a workable solution, because allow to develop large structures with excellent properties of lightness and stiffness. These can be made by layers of carbon fiber reinforced polymer (CFRP), metallic materials (like Aluminum) or a composition of the two. For simplicity, we will refer in the following to CFRP. Each of the dRICH structures could be ideally realized by a skeleton of ribs connected by laminated planes. To minimize the material budget in the EIC forward acceptance, it is assumed to use skin-core-skin sandwiches for the entrance and exit faces, and a possible bulk structure for the inner pipe and external cylindrical shell.

A preliminary study of a possible pressurized vessel has been initiated at INFN, with mockups of simple geometry (1:10 scale) to test promising materials like CFRP, and to verify corresponding finite element method (FEM) analyses. A first CFRP mockup has been realized and successfully tested for gas tightness under water, shoving no evident leaks at +50 mbar over-pressures, see Fig. 2.

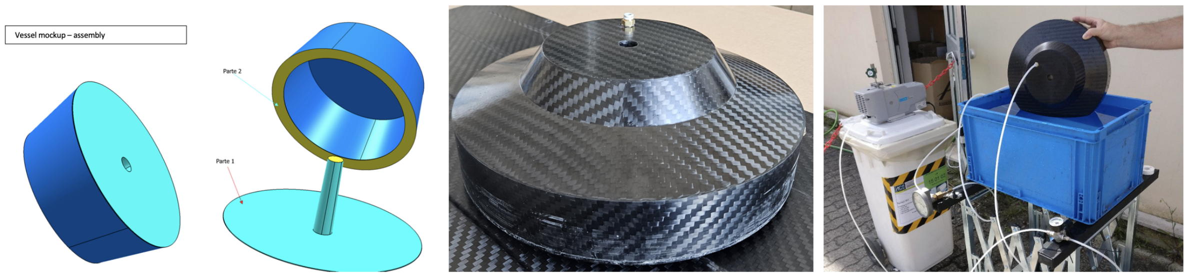


Figure 2: Concept design of the RICH vessel mockup (left). First mockup realized in CFRP, with one of the gas inlets visible (center). Water leak test (rigth).

The complete study foresees leak checks with Helium and stress tests with deformation measurements at various pressures up to at least 3 bar absolute. The mockup is a good starting point, as allows a preliminary assessment of the material properties and basic construction principles. However it presents also significant limitations. First: it is produced as a single piece (two halves glued together) without flanges to access the inner volume. In a real detector, openings to instrument the inner volume are unavoidable, could act as weak structural or leak points and therefore require careful design and testing. Second: Because of the reduced size, the mockup does not allow to layer a realistic structure and can only be used as benchmark for the pure material modeling. Indeed, it is not possible to freely downscale the structure sandwich as can be done for the inner volume, because the CFRP layers have a finite thickness. The only way is to remove some of the layers, resulting in a different (i.e. not uniform) stiffness and structural resistance.

During the three R&D years, realistic sizes and mechanical details (opening and connections) can be progressively introduced for the most promising materials and solutions with the following provisional sequence. First year: material study with simple mockups and FEM analyses. Second year: realistic components for gas vessel, aerogel and detector supporting structures. Third year: real-scale prototype integrating all the subsystems. The design activity requires a close collaboration between INFN with BNL and JLab engineers to comply with the safety regulations and EIC installation and integration aspects. INFN technical workforce is an in-kind contribution but US technical support is requested from the EIC project.

## 2.2 Performance using pressurized Argon as gas radiator

The principle of a RICH with pressurized Argon can be consolidated comparing the performance obtained with pressurized Argon in comparison with those obtained using $C_2F_6$ at atmospheric pressure. The existing dRICH prototype, developed within the EIC eRD102 R&D program, can be used for this comparative study during dedicated test-beams, see Fig. 3.

The prototype has been designed to study the simultaneous imaging capability of aerogel and gas in a dual-radiator concept, with realistic radiator and photo-sensor demonstrators, see Fig. 4. The prototype essentially comprises a gas volume and a detector-box, separated by a transparent window. The detector-box (in front of the gas vessel) houses the photo-sensors, the readout electronics, and provides support for the aerogel bricks in a volume physically separated from the gas radiator. The gas vessel mounts supports for two inner mirrors, one for each radiator, designed to provide optimized imaging within the limited active surface. Depending on the longitudinal position of the mirrors, the Cherenkov cones generated by either the aerogel, or the gas, or both radiators can be imaged.

The gas vessel is a cylinder made of vacuum standard pipes and flanges to contain the cost and support pressures different from atmospheric one. This choice was made to simplify the mechanical aspects and allow for efficient gas exchange (before circulating a new gas, the previous gas is evacuated). This structure in principle allows adjustment of the refractive index and consequent flexibility in the gas choice, in support of the search for alternatives to greenhouse gasses, and can be upgraded to work at 2 bar relative pressure to support the study of the Argon case. The required modifications concentrate on the sealing gaskets and fixing clamps, in addition to some feed-troughs. The pressure control and interlock systems should be complemented with high-pressure gauges. The remotely-controlled motor system, used for real-time translation of the mirrors along the beam axis (to adjust focalisation

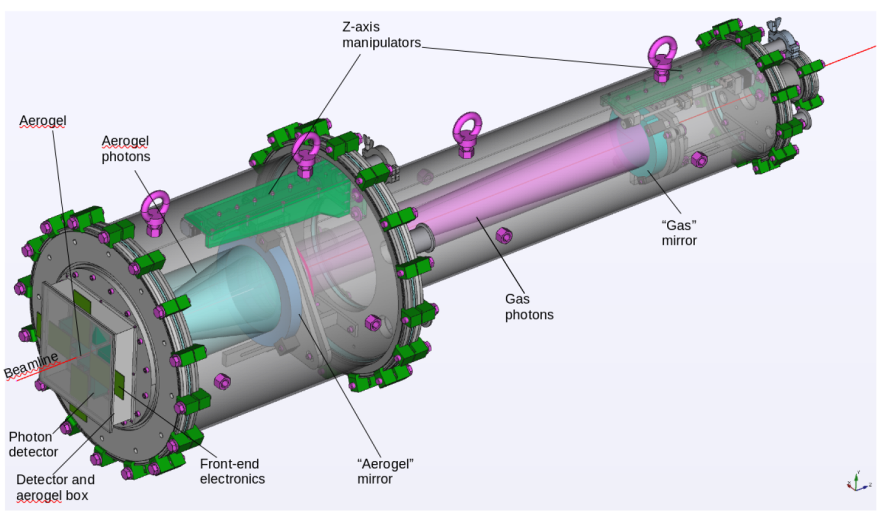


Figure 3: 3D model of the baseline dRICH prototype. Highlighted are the Cherenkov photon paths from aerogel (cyan) and gas (magenta).

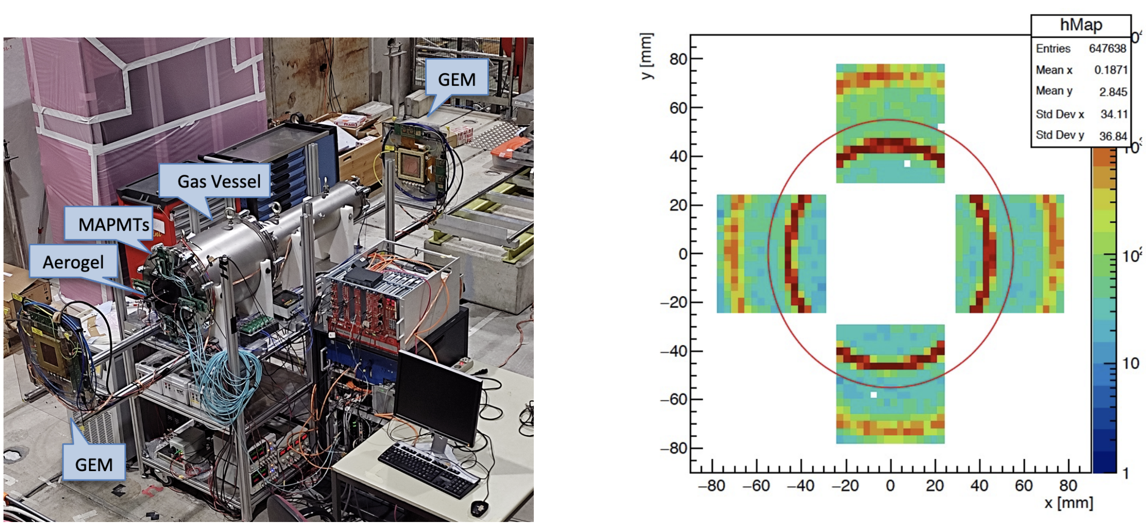


Figure 4: dRICH baseline prototype at the SPS beam line in October '22, complemented with a GEM tracking system (left). Imaging of the two radiators with the reference photon-detector based on MA-PMTs and MAROC3 chip, the gas ring being the brighter one at smaller radius (right).

or to move the mirror outside acceptance) should be validated for the usage while the prototype is pressurized. This should allow to simplify the prototype operations during the tests and to challenge the photon pattern reconstruction with a realistic occupancy.

On the contrary, the current acrylic window that interfaces the vessel and the detector-box cannot stand significant over-pressure. As a first step, the window could be made thicker, in order to study the Argon performance in the same conditions of $C_2F_6$ and allow any photon detector, e..g. the reference eRD14 one using multi-anode photo-multipliers (MAPMTs) and MAROC electronics. On a longer term, this obstacle can be overcome operating the photosensors in a volume at the same pressure of the gas radiator. In this case the photon detector is assumed to be made of the EIC-driven units under development, based on silicon photomultipliers and ALCOR chip, see Fig. 5. A gas-tight container capable to stand 2 bar relative pressure should be realized to house the photosensors and their readout, with special attention to the connections to the external services. The box shall be mechanically interfaced to the gas radiator vessel, with a gas-line connection to limit the maximum pressure difference at the two faces of the transparent window within a safe margin. This configuration will be likely used only with inert and cost-effective gases like Argon. The same box could be finally interfaced with the real-scale prototype made in composite materials, and developed within the vessel work-package of the present R&D program.

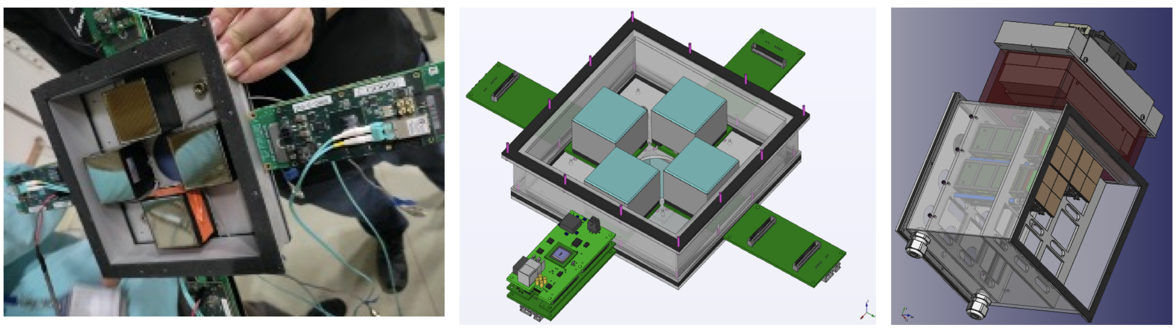

Figure 5: Example of available detector box with multi-anode photo-tubes (left and center). Novel EIC-driven detector box under development with compact readout units based on SiPM arrays (rigth).

In order to interpret the prototype data and project performance at EIC, a realistic description should be implemented into the simulation framework, taking into account the measurements done during laboratory characterization and beam-test campaigns. For a pressurized vessel, the structural elements could be relevant and need to be properly described to account for the material budget. The simulations will necessarily evolve following the developments of the mechanics and the characterization of the optical components, and need to be integrated within the general EIC detector model to provide a complete information.

During the three R&D years, the pressurized Argon case can be studied in stages of increasing level of complexity moving towards a realistic technical solution. First year: usage of the current dRICH prototype with minimal upgrades to sustain the 2 bar gas over-pressure. Second year: development of a detector-box compatible with the 2 bar over-pressure. Third year: realistic prototype in composite materials integrating all the subsystems.

## 2.3 Compatibility of aerogel with a pressurized atmosphere

The extension of the effective momentum range of a gaseous RICH is obtained using a couple of suitable radiators. Aerogel and gas radiators have been paired for the RICHes at HERMES, LHCb and for the ePIC forward RICH. Therefore, exploring the possibility to couple the novel gas approach with the aerogel radiator is a a very natural complement of the pressurized RICH development.

Aerogels are a class of synthetic porous ultralight material derived from a gel, in which the liquid component for the gel has been replaced with a gas, without significant collapse of the gel structure. Depending on the production process, aerogel could manifest hydrophobic or hydrophilic properties, and present the tendency to adsorb contaminants. Past experience suggests to preserve aerogel in inert and purged atmospheres, and to keep it separated from the gas radiator. In a pressurized RICH, this approach would imply a thick transparent window of large area, with severe implications for mechanical stability and light propagation. An interesting alternative would be to keep the aerogel volume at the same pressure of the gas radiator, to relax the pressure stress on the window and restore the standard solution. Being Argon an inert gas, it may even allow to avoid such a window.

We propose to verify the compatibility of aerogel samples of interest for RICH applications with high pressure. The samples will be optically characterized before exposing them for a period of the order of several weeks to an increasing relative pressure up to 2 bar. The optical characterization will be repeated at each step, to trace possible modifications of the optical performance of the samples, see Fig. 6.

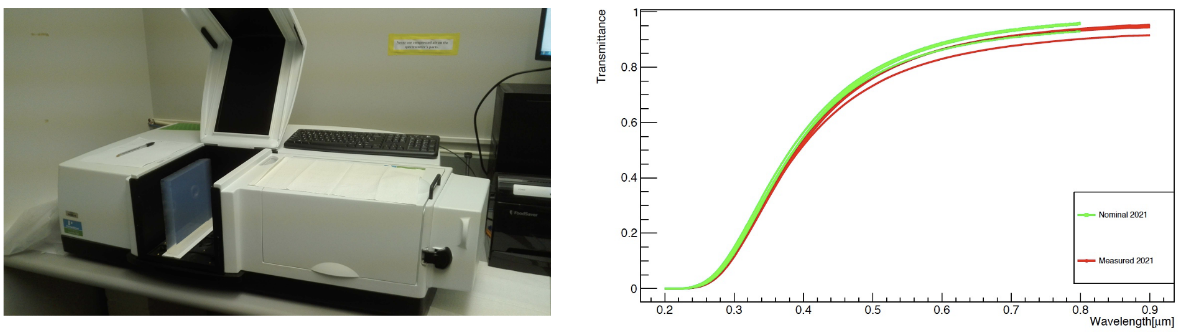


Figure 6: Existing spectro-photometer for aerogel characterization (left). Comparison between measured (red curves) and declared (green curves) characteristic light transmission as a function of the wavelength (right).

The study will be performed during three R&D years. First year: development of a high-pressure test-station for aerogel, with tests performed at progressive increasing pressure. Second year: upgrade of the station with a purging gas system, long-term tests. Third year: beam-test with a real-scale prototype integrating all the subsystems.

## 3 R&D Plan

The proposed plan develops over three years. The main technical goals of the first year of R&D (FY24) is to establish the proof-of-principle of a pressurized gas RICH for hadron PID at EIC. This is performed by separately pursuing three key ingredients: the study of over-pressure capability of composite material, the first assessment of pressurized Argon performance with an upgraded dRICH prototype, and initial tests of the stability of aerogel under a pressurized inert atmosphere. This step will be instrumental to consolidate the pressurized RICH concept. In the following year of R&D (FY25), assuming a positive outcome of the initial studies, the three developing activity will be completed by the realization of a high-pressure detector box, the study of realistic structural components of a pressurized RICH, and the long-term stability test of pressurized aerogel. During the last year of R&D (FY26), all the elements will be combined in a prototype for the final validation of the concept by beam test characterization.

**Manpower:** Within the EIC R&D program, various INFN activities have been targeted to possible application at the forward RICH (eRD102, eRD109, eRD110). The proposed generic R&D program builds upon a consolidate experience and infrastructure already present at INFN, in addition to all the developments so far achieved within the targeted R&D. High-level expertise is available among the collaborating units covering all the aspects described above. Among the proponents, there is a clear complementarity: INFN-TS is specialised in gaseous RICH (COMPASS), INFN-FE in aerogel RICH (CLAS12) and mechanics (LHCb) and INFN-LNS offers a laboratory infrastructure. INFN can count on 3 researchers (about 0.1 FTE each) as manpower directly involved. EIC funds would be crucial to co-fund young researcher positions and ensure dedicated manpower with long-term perspective.

**Milestones:** (1) First pressure test of a RICH mockup based on light composite materials (March '24); (2) Realization of a test station for pressurized aerogel (June '24); (3) Preliminary assessment of the pressurized Argon optical performance (October '24). The estimated timeline is subject to funds availability, as outlined in Table 4.

**Funding profile:** The project could count on a significant INFN in-kind contribution in infrastructures, expertise and synergistic developments (e.g. dRICH prototype and ALCOR), technical and scientific manpower plus about a 25 k$/yr budget covering the basic development, but relies on EIC project funds to mitigate the technological risk. Dedicated personnel can only be co-funded at this stage of the project. Financial support from the EIC generic R&D program of post-doc positions to work on hardware as well as on software aspects is crucial. The proposed funding profile is outlined in Table 3, where years beyond FY24 should be considered projections subject to possible revisions following the actual progresses. The requested baseline, 80% and 60% budget scenarios with associated milestones are presented in Table 4.

The request corresponds to 0.5 FTE for a post-doc (at INFN-TS) and a contribution for a PhD program (at INFN-FE) to support the developments as described above, and their integration in a realistic prototype. Dedicated manpower will be crucial for the laboratory characterization of components, the analysis of the test-beam data, and the update of the dRICH and prototype simulation model. Travel funds are requested to support the beam-tests at the CERN facility. It is planned to redirect efforts of locally co-funded personnel, such that the employment of the early career scientist is not necessarily dependent on the future continuation of the R&D funds.

| | vessel | gas radiator | aerogel radiator | personnel | travel | total |
|---|---|---|---|---|---|---|
| FY24 | 15 | 15 | 10 | 30 | 5 | 75 |
| FY25* | 20 | 20 | 20 | 30 | 5 | 95 |
| FY26* | 40 | 5 | 5 | 30 | 5 | 85 |

**Table 3:** Proposed EIC project funding profile in k$. The anticipated 25 k$/yr of INFN in-kind contribution is in addition and covers part of the costs described in the text. Personnel funds request takes into account hardware and software needs and assume co-funding. * Projected costs.

| FY24 budget | vessel | gas radiator | aerogel radiator | personnel | travel | total | milestones |
|---|---|---|---|---|---|---|---|
| baseline | 15 | 15 | 10 | 30 | 5 | 75 | 1,2,3 |
| 80% | 15 | 15 | | 30 | | 60 | 1, 3 |
| 60% | | 15 | | 30 | | 45 | 3 |

**Table 4:** Proposed EIC project FY24 funding scenarios with corresponding activity and achievable milestones.