ePIC pfRICH prototyping R&D proposal

ePIC proximity focusing RICH
Detector Subsystem Collaboration*

July 7th, 2023 - Application for FY24†

Introduction

The ePIC Collaboration selected a proximity focusing Ring Imaging Cherenkov detector (pfRICH) for Particle Identification (PID) in the electron-going endcap after a review in March 2023 [1]. It was determined that this technology is more robust and bears less risk than an alternative solution of a modular RICH (mRICH). However, a fraction of the risks associated with the choice of aerogel, photosensors and readout electronics was essentially the same for both mRICH and pfRICH options. This proposal addresses a respective part of the EIC Project R&D Milestones as formulated in February 2023: *"Validate production readiness of a Ring-Imaging Cherenkov detector as matched with photosensors and readout electronics on the electron-side endcap of the EIC detector, including validation by prototypes that the EIC requirements can be met"*.

We propose to build a functional pfRICH prototype and test its performance at the Fermilab Test Beam Facility (FTBF) in early Summer 2024. This R&D effort will address a technical risk to the project, evaluating the convoluted effect of specific parameters of the main components of an ePIC Backward RICH detector on its performance:

- HRPPD photosensors by Incom Inc (quantum efficiency as a function of wave length, collection efficiency, gain, transit time spread, window transparency as a function of wave length, detector capacitance seen by the front end electronics);
- Aerogel tiles by Chiba Aerogel Factory (transparency, especially in a near UV wavelength range, homogeneity);
- Time-of-Arrival(ToA)/ADC based electronics of the EICROC family by OMEGA group (intrinsic noise, dynamic range, various sources of timing jitter).

In particular, we are going to confirm via direct measurements with a high energy particle beam that such a detector can simultaneously provide:

- π/K separation at a 3σ level up to 7 GeV/c via ring imaging of Cherenkov photons produced in aerogel;

*See Appendix for a full list of participating institutions, including those which formally are not part of this Detector Subsystem Collaboration (DSC)

†Contact Person: Alexander Kiselev, ayk@bnl.gov

- Single photoelectron timing resolution for Cherenkov photons produced in aerogel better than 50 ps;
- Multi-photon timing resolution O(10ps) for Cherenkov photon flashes produced by a high energy particle passing through the HRPPD window.

1 Prototype design

We are going to make use of a *full chain pfRICH prototype*, to be built in 2023/2024 using EIC Project Engineering & Design (PED) funding. This prototype will also use aerogel tiles and HRPPDs ordered by the EIC Project, and an HRPPD ASIC interface to be developed by the eRD110 Consortium in a collaboration with researchers from CNRS/IN2P3-Ecole Polytechnique (OMEGA group), Oak Ridge, Debrecen University and Jefferson Lab.

Therefore, the funding request of this proposal will be limited to ordering 3D printed enclosures and ASIC backplanes for the HRPPD tiles, AMD Kintex UltraScale FPGA evaluation boards, as well travel money for a test beam measurement at Fermilab.

1.1 Vessel

The full chain prototype will consist of a single light tight quadrant of a full size pfRICH vessel, with a subset of the side mirror segments and provisions to mount aerogel tile(s) on its upstream side and HRPPDs on the downstream side, see Fig. 1.

The vessel will be built in a LEGO style using molded reinforced carbon fiber building blocks as well as 3D printed parts, and will provide an opportunity to mount the five available HRPPDs in various configurations, required to evaluate the overall detector performance with and without Cherenkov light reflection off the side mirrors, see also Fig. 4.

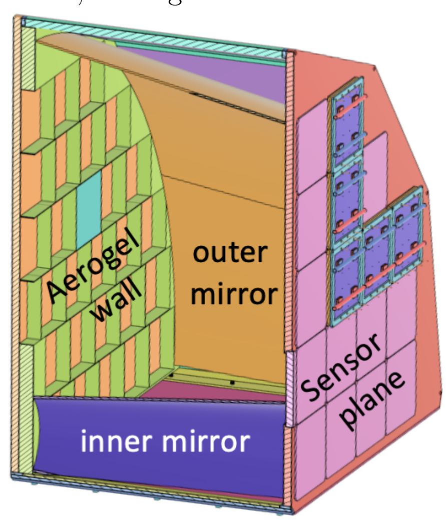

Figure 1: Schematic of the pfRICH vessel prototype in a configuration with five HRPPD sensors mounted close to the outer conical mirror.

1.2 Aerogel

2.5 cm thick square aerogel tiles with a refractive index n $\sim$ 1.045 and size $\sim$10 cm will be ordered by the EIC Project from Chiba Aerogel Factory in the second half of 2023. While engineering effort to consider various aerogel tile support and mounting schemes onto the pfRICH front vessel wall will be made as part of the respective PED program, for the purposes of this R&D effort, we will use a single aerogel tile and move it around the inner side of the vessel front wall (Fig. 1) matching the location of the HRPPD sensors in each particular configuration, see Fig. 4.

1.3 HRPPD photosensors

The EIC Project signed a PED contract with Incom in June 2023, according to which the company will finalize the sensor design by September 2023 (see Fig. 2 for the current layout as of July 2023) and produce five EIC HRPPDs [2] according to this design between October 2023 and March 2024.

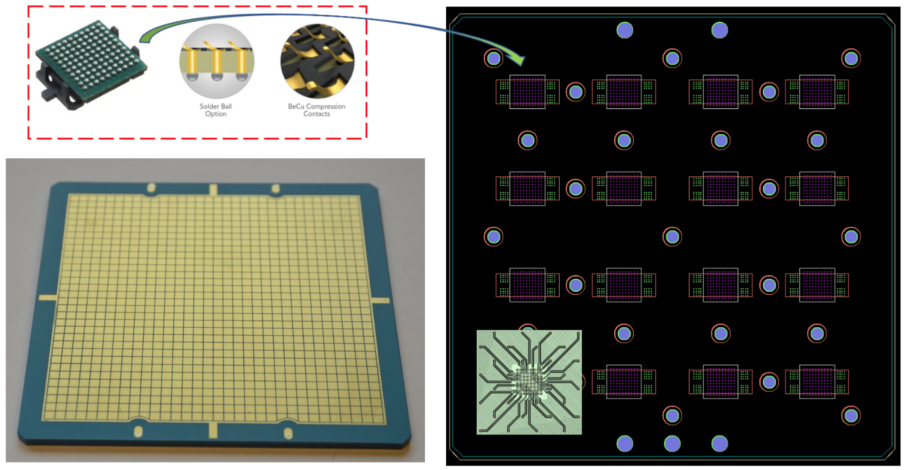

Figure 2: Left: EIC HRPPD ceramic anode base plate design, with a regular pixellation of the inner (vacuum) side into 32 x 32 square pads with a pitch of 3.25 mm. Right: layout of a matching ASIC readout backplane with smaller pitch interposer footprints on one PCB side shown in magenta, high-density HGCROC3 ASIC footprints on the other PCB side shown in green, and ceramic stack routing snapshot of one of the 8x8 pixel areas in the bottom left corner.

We are going to use these photosensors in a configuration with ASIC backplanes (see Section 2), after they get evaluated by the eRD110 Photosensor Consortium in the first half of 2024.

1.4 ASIC electronics interface and DAQ

We are going to make use of the collaborative effort between CNRS/IN2P3-Ecole Polytechnique (OMEGA group), ORNL, Debrecen University, JLAB and Brookhaven within the eRD110 Consortium activities in FY24 aimed at designing a 1024-channel readout backplane for the newly produced EIC HRPPD photosensors. This backplane will consist of sixteen 64-channel ASICs of the same family as EICROC [3] in the actual pfRICH detector (see Fig. 2), connected to AMD Kintex UltraScale FPGA KCU105 evaluation boards, for a total of five such sets (5120 channels). Manufacturing and acquisition costs are evaluated at [**$10k**] for the ASICs, [**$8k**] for the two missing KCU105 kits, [**$8k**] for the production and assembly of four more readout boards, and [**$2k**] for the 3D printed enclosures. We are planning to use the RCDAQ data acquisition system developed at BNL [4], with a custom developed user space driver for the KCU105 boards, working in a triggered mode and communicating with them via a well known FTDI USB interface.

1.5 Services

The full chain pfRICH prototype that will be constructed using PED funds (except for the ASIC interface described in Section 1.4) will include HV and LV subsystem elements sufficient to power five HRPPDs with the onboard electronics. In particular, stackable HV power supplies will be used. Concerning other services, we are going to use a simple but adequate cooling system (heat sinks and air blowing fans) to cool the ASICs, and a pair of inlet / outlet gas connectors to flush the vessel with a dry nitrogen.

2 Beam test setup

The setup will be installed in FTBF area MT6.2 [5] and will consist of the pfRICH quadrant prototype, trigger scintillators, available Photonis PF-16 and Hamamatsu R3809U-50 MCP-PMTs as a redundant timing reference, and a tracker consisting of four GEM chambers with a COMPASS 2D readout, see Fig. 3.

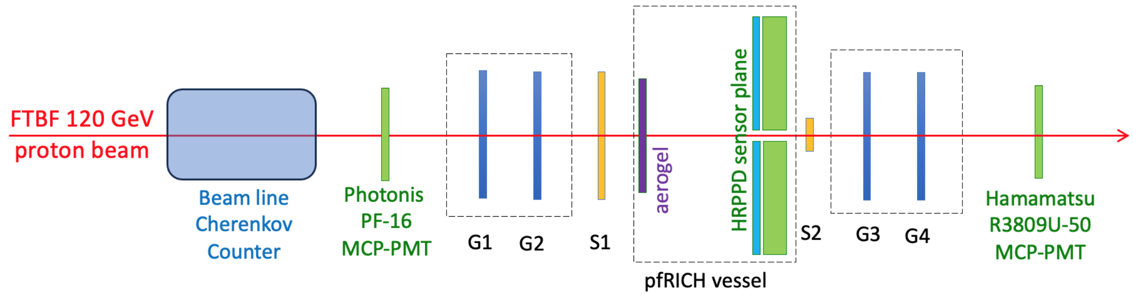

Figure 3: Schematics of the beam test setup (S1..S2 - scintillation counters, G1..G4 - GEM trackers).

A beam line Cherenkov counter will be used to identify particle types in the incoming beam. pfRICH timing performance will be typically evaluated using a primary 120 GeV proton beam. For ring imaging performance evaluation, we are going to use a low momentum and low intensity secondary hadron beam and directly measure π/K separation in the momentum range below 10 GeV/c. Should the kaon flux be too small in this momentum range, one can consider measuring π/p separation at $\sim$14 GeV/c. In this case, secondary protons are available in abundant quantities [6], and a gap in Cherenkov angle emission between these two particle hypotheses for an aerogel radiator with a refractive index n $\sim$ 1.045 is the same $\sim$7.4 mrad as between pions and kaons at 7 GeV/c.

The pfRICH performance evaluation will be based on two typical photosensor configurations, see Fig. 4. One of them will be sufficient to detect a fraction of a full size Cherenkov ring from the aerogel simultaneously with a flash from the sensor window, and be focused on evaluating timing performance (left configuration). The other (right configuration, using a partial light reflection off the conical side mirror) will be sufficient to fully contain the direct and reflected parts of an aerogel Cherenkov ring using the five available HRPPDs, and therefore be better suited for evaluation of the ring imaging performance, as well as provide data for tuning of the reconstruction algorithms.

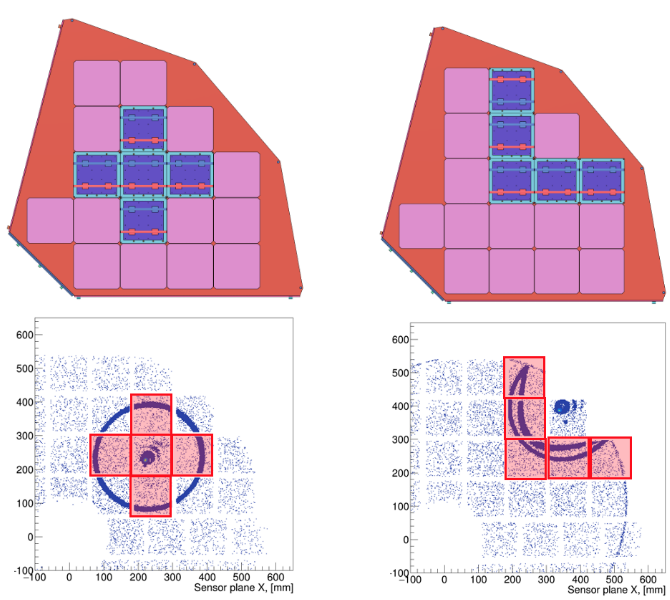

Figure 4: Two HRPPD configurations considered for the beam test. See text for more details.

The travel budget assumes the presence of seven people for two weeks of beam time, for a total of [**$35k**].

3 Deliverables and milestones

The final deliverables of this R&D effort are a simultaneous demonstration of a pfRICH prototype performance for π/K separation for particle momenta up to 7 GeV/c and an evaluation of the suitability of the pfRICH as a timing reference for the ePIC Time-of-Flight subsystems.

The PID separation performance will be determined by means of Cherenkov photon imaging. The suitability as a timing reference will be assessed by combining the single photon timing response of Cherenkov photons produced in the aerogel radiator with the multi-photon response of the Cherenkov photon flash produced in the HRPPD window.

The milestones below are given under the assumption that: the HRPPD delivery schedule (October 2023 - March 2024) follows the milestones of the EIC-Incom PED contract, the full chain pfRICH prototype PED funding becomes available in the second half of 2023, and that the HGCROC3 ASIC backplane interface gets developed as part of the eRD110 Consortium activities by the beginning of 2024. The milestones are:

- ASIC backplane interface design and procurement: March 2024;
- Prototype assembly at Stony Brook: May 2024;
- Beam test at Fermilab: June 2024;
- Data analysis and final report: by September 2024.

4 Institutional commitments

The prototype will be designed by JLAB and assembled at Stony Brook using 3D printed and molded parts produced by Purdue University. Mirror substrates will also be built by Purdue and aluminized at Stony Brook. Aerogel evaluation, handling and mounting procedures for the beam test will be performed by Temple University. HRPPD evaluation will be performed by BNL, INFN, Glasgow and Yale groups. BNL will also be contributing to the ASIC interface development, conducted in general by ORNL and Debrecen University, and its adaptation to the existing DAQ. Several groups will be participating in the actual beam test at Fermilab, subsequent data analysis and representation of the results for the ePIC Final Design Review in Fall 2024.

5 Budget request

The proposed budget breakdown is shown in Table. 1.

Four 3D printed HRPPD enclosures	$2k
80 HGCROC3 chips	$10k
Four readout backplane assemblies	$8k
Two KCU105 evaluation kits	$8k
Beam test travel	$35k
Total	**$63k**

Table 1: Requested funding for FY24.

M&S funds and respective orders will be dispatched via Brookhaven. Travel funds will be distributed over participating institutions once travel plans are finalized. As mentioned in Section 1, a full chain pfRICH vessel prototype will be built in 2023/2024 as part of the PED funding request.

Appendix

Full list of participating institutions

Argonne National Laboratory
Brookhaven National Laboratory
Chiba University
Debrecen University
Duke University
Istituto Nazionale di Fisica Nucleare, Genova
Istituto Nazionale di Fisica Nucleare, Trieste
Ljubljana University and J. Stefan Institute
Oak Ridge National Laboratory
Purdue University
Stony Brook University
Temple University
Thomas Jefferson National Accelerator Facility
University of Glasgow
Yale University

References

[1] ePIC Backward RICH Review, March 20-21, 2023

[2] A. Lyashenko, "Incom LAPPDs: status and plans", LAPPD Workshop, April 20, 2023

[3] Christophe de La Taille, "EICROC ASIC: architecture, status, applications and plans", EICROC ASIC evaluation for EIC HRPPD/MCP-PMT photosensors (zoom meeting), March 6, 2023

[4] RCDAQ, a lightweight yet powerful data acquisition system

[5] https://ftbf.fnal.gov/mtest-beam-areas

[6] Particle species composition of the FTBF MTest beam