Low-pressure characterizations of the mini-eTPC detector

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1 Physics motivations

As part of nuclear physics research prospects with the high-brilliance Gamma Beam System (GBS) at the ELI-NP facility, the GBS-TDR4 Technical Design Report [1] proposed the development of an electronic-readout Time Projection Chamber (ELITPC, e-TPC) for charged-particle emitting photonuclear reactions studies. The e-TPC scientific program incorporates forefront research topics in nuclear structure and nuclear astrophysics, encompassing: (i) investigations of near-threshold alpha-clustering in light nuclei, (ii) measurements of key photo-dissociation reactions to constrain problematic stellar hydrogen and helium burning rates. Independent pair reviews of the GBS-TDR4, including the Nuclear Physics European Collaboration Committee (NuPECC) 2016-2017 long-range plan [2], have emphasized the importance of the e-TPC research program and further recommended that the project be given priority.

2 The mini-eTPC detector development

The development of the e-TPC instrument has been carried out in the framework of Memorandums of Understandings and Collaborative R&D Agreement Contracts concluded between ELI-NP and the University of Warsaw, Poland. Laboratory research and development activities completed between 2014 and 2016 delivered a small-scale detector functioning at atmospheric gas pressure, named *mini-eTPC*, as a proof-of-concept precursor to the design of ELITPC [3, 4].

The gas volume filling mini-eTPC acts simultaneously as an extended target material and detection medium. In this operation mode, the detector is referred to as an active target AT-TPC. Several research collaborations worldwide, e.g., in the GANIL (France) and NSCL (USA) laboratories, have recently commissioned similar instruments for nuclear reaction spectroscopy applications with radioactive isotope beams. The mini-eTPC's active section consists of a 20-cm drift cage immersed in a uniform electric field. The passage of a charged particle in the active e-TPC volume causes gas electrons ionization. Drifting charges are then amplified in a stack of hole-type Gas Electron Multipliers, GEM foils [5]. The position and time sensitivity of the detector are ensured by a 3-coordinate (schematically, U-V-W strips) planar electronic circuit board, called the *readout PCB*. The readout signals collected from 256 independent channels (72U+92V+92W) are processed by the GET digital electronics [6].

3 Proposal goals

The current milestone in the ELITPC project implementation pertains to the upgrade of the mini-eTPC detector for lower-than atmospheric gas pressure operation. A compressed gas target ensures that photonuclear reaction products are tracked, together with a stable detector response; yielding thereby a performance that meets the project goals. Reference [7] provides an overview of – and a glimpse into – the growing popularity of GEM-based tracking detectors for a breadth of applications, expanding to microdosimetry and space

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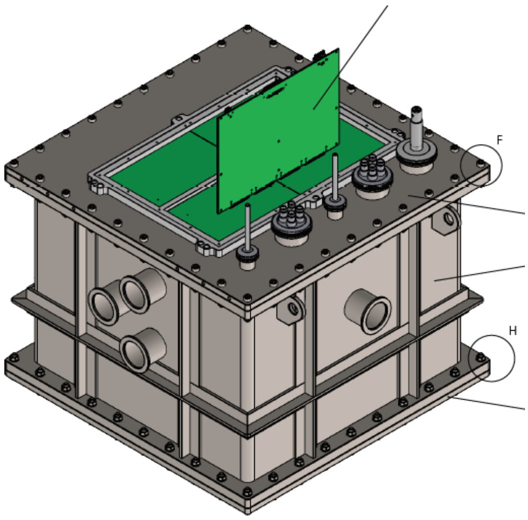

Figure 1: CAD design of the mini-eTPC detector reaction chamber in stainless steel. The gas stream inlet and outlet ports are located on the top end-cap cover. The standalone lateral port is the beam entrance point.

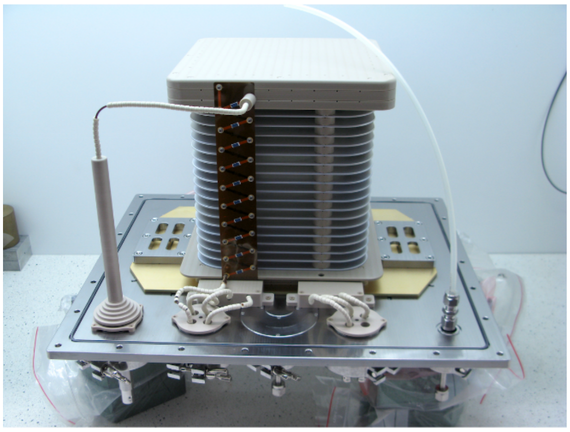

Figure 2: Upsade-down view of the internal structure of the mini-eTPC detector, consisting of the drift cage, GEMs amplification stage, and the readout PCB (in yellow color).

sciences. It should be noted, however, that data on multiple stage amplification, as achieved by the GEM technology, in the pressure regime of interest to ELITPC (∼50-200 mbar) and with a dominant non-noble gas target composition is scarce. Among high-priority experiments with ELITPC at the ELI-NP-GBS facility are the crucial photo-dissociation $^{16}O(\gamma,\alpha)^{12}C$ and $^{19}F(\gamma,p)^{18}O$ astrophysical reactions, which will employ CO_2 and CF4 gases respectively. Hence, it is important to demonstrate the low-pressure scaling of mini-eTPC before any further developments can be undertaken. Moreover, the proposed low-pressure characterizations of mini-eTPC at the IFIN-HH Institute will contribute a body of new experimental data and knowledge to the community.

For the low-pressure upgrade, a vacuum-compatible reaction chamber in stainless steel – shown in Figure 1 – has been manufactured to house the internal structure of the mini-eTPC detector (c.f., Figure 2). The reaction chamber's top end-cap cover accommodates for the gas stream inlet and outlet, high-voltage supply ports, and the readout PCB connectivity to the GET electronics board. Thin Mylar films placed on the beam entrance and exit ports, of an ISO-KF, DN-40 vacuum standard size, gas-seal the chamber.

The choice of a low-energy stable isotope beam for the characterizations is predominantly motivated by the well-defined direction of the beam ions with reference to the mini-eTPC's readout plane. Mapping of the detector's response, i.e., readout tracks, would be studied in conjunction with the charged particles ranges and track orientation. Furthermore, interactions of the beam ions with the sealing windows and the most-central drift electrodes would provide suitable conditions to study and qualify the effects of the background on the e-TPC performance.

4 Experiment beam time request

The ELITPC collaboration requests 14 calendar days of a low-intensity ^4He beam delivered from the IFIN-HH 3-MV Tandem Accelerator at incident energies in the [3.0-9.0] MeV range. The beam energies will allow detailed characterizations of the mini-eTPC detector employing various gas composition and pressure combinations. The experiment shifts will be partly allocated for setting up the detector's configuration. Consequently, the actual beam-on-target and data collection time would be less than 42 shifts. The beam intensity will be reduced to a fewer 100 part./s hitting the detector entrance window. The experiment will aim in hindsight to infer optimal detector operation parameters from:

- Gas medium and mixture proportion (Ar, CO_2, CF4, He)
- Gas pressure
- GEMs and drift voltages.

Support for running of the experiment will include masks to reduce the primary ^4He beam intensity and beam diagnostic ancillaries. The diagnostics equipment will be used to profile the beam energy distribution and count rate. These characteristics can be inferred from a plastic scintillator with reliability, provided the count rate does not exceed 10^4 part./s.

The gas stream will be supplied from standard cylinders of compressed CO_2, He, Ar, and CF4 high-purity gases of grade 5.0 or better. The gas handling system will be the responsibility of the ELITPC working group.

The beam time and experiment scheduling request would be for the April - May 2018 period.

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