CEA-Saclay/Irfu (France) - Expression of Interest (EOI)

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Please indicate all institutions collectively involved in this submission of interest:

CEA/Irfu, Université Paris-Saclay, 91191 Gif-sur-Yvette, France

Please indicate the items of interest for potential equipment cooperation:

CEA/Irfu is strongly involved in hadron physics both on the theory and on the experimental side.

CEA/Irfu has decades of experience in the development of charged-particle tracking detectors, in particular based on Micro-Pattern Gaseous Detector technology (MPGD). These detectors have been successfully employed in a broad spectrum of experiments, from low-energy nuclear physics experiments, to long baseline neutrino experiments and of course, at CERN and Jefferson Lab.

The areas of possible involvement of CEA/Irfu in the EIC detector are:

- MPGDs for tracking detectors
- MPGDs for timing detectors
- Electronics
- Software

In addition, the hadron physics theory group at CEA/Irfu will contribute to the EIC software with the development of an exclusive process Monte Carlo event generator.

In the following sections, we give a brief overview of CEA/Irfu's experience and technologies that might be of interest for the EIC project.

MPGDs for tracking

The CEA/Irfu team is among the leaders in the development and deployment of MicroPattern Gaseous Detectors, in particular of the Micromegas technology. Detectors based on this technology have been successfully integrated in many experiments of nuclear, hadron and high-energy physics, among which MINOS, CLAS12, COMPASS, ATLAS. Some of these technologies and their ongoing developments might be considered as options for an EIC detector.

CEA/Irfu has been involved in the development of the readout detectors of the ILC TPC[1]. It is well known that TPCs operating at high rates suffer from local distortions of the drift field caused by back-flow of ions (IBF) produced in the amplification region. In collaboration with Yale University, CEA/Irfu has initiated an ongoing R&D program about **low IBF TPC readout based on a Micromegas/GEM hybrid detectors**. This R&D study is focusing on improving the trade-off between IBF and energy resolution with respect to the current TPC readout solutions (*i.e.* stack of GEMs). In addition, key points of this R&D are the detector stability and the minimisation of the material budget for an optimal momentum resolution, crucial for the scattered electron. For this reason, solutions for lowering the material budget also of the readout front-end electronics, like off-detector FEE, will be studied in synergy with the electronics department of CEA/Irfu.

The Barrel Micromegas Tracker (BMT)[2] integrated in the CLAS12 experiment showed that thin Micromegas can be curved to build **compact, low material-budget trackers**. Specifically, the CLAS12 BMT consists of six concentric layers of cylindrical resistive micromegas tiles, built to withstand luminosities up to 10^{35} $cm^{-2}s^{-1}$. Each tile has a spatial resolution of about 150 µm and its material budget is ~0.3% X/X_0. Recent studies performed for the EIC Yellow Report showed that a tracker based on MPGDs similar to the BMT tiles would have performance, both in momentum and angular resolutions, similar to a TPC, but with less total material budget[3]. An ongoing study at CEA/Irfu aims at lowering even more the material budget of each detector element and at simplifying the design and production of the detector elements.

In regions where the particle flux is high, up to 200 kHz/mm², MPGDs have shown outstanding capabilities, for example the COMPASS hybrid Micromegas detectors installed in 2015, and more recently the large area New Small Wheels for the ATLAS experiment upgrade. **Large area planar detectors** for tracking could also be used in the forward and backward regions of the EIC detector. Such planar trackers could also be considered as part of a pre-shower system to resolve close electromagnetic showers stemming from high-momentum $\boldsymbol{\pi}^0$ decay photons.

MPGDs for timing

High-resolution timing detectors are a new opportunity to help with particle identification (PiD) using Time Over Threshold (TOT), or to distinguish piled-up events in a high rate environment. For a TPC-based EIC detector, there is a gap in the particle momentum measurements between what the TPC would give via dE/dX and a RICH based detector, of ~2 to 7 GeV. This gap, both in the forward and barrel region could be complemented with TOF, requiring the instrumentation of a large area with fast timing detectors.

A new development emerged at CEA/Irfu with a Micromegas detector capable of reaching a time resolution of tens of picoseconds. The PICOSEC concept is a “two-stage” Micromegas detector coupled with a Cherenkov radiator, equipped with an appropriate photocathode (Figure 1). A prototype with MgF2 crystal as Cherenkov radiator and CsI as photocathode has reached a resolution of 24 ps in a muon beam test and 45 ps using a laser with one photo-electron.

However, the cost, the photo-cathode reliability as well as the time resolution must be confirmed before considering PICOSEC as a viable solution for an EIC detector. Diamond-like carbon coated kapton (DLC) is

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1 https://indico.in2p3.fr/event/18281/contributions/71244/

2 https://doi.org/10.1016/j.nima.2020.163423

3 https://indico.bnl.gov/event/7909/contributions/40878/attachments/30147/47096/EIC_MM_tracker_simulation_weekly_27082020-2.pdf

currently being studied as an alternative choice of photocathode, cheaper and more reliable than CsI. Ongoing studies at CEA/Irfu have demonstrated that Micromegas with DLC achieve a resolution of 40 ps given a large number of photons. To ensure such a large number of photons, several technical solutions could be considered such as installing PICOSEC as a pre-shower detector or directly in the calorimeter after a few radiation lengths. Finally, the development of a new front-end electronics is required to guarantee a time resolution of the entire system below 50 ps.
The maturity level of this technology might not be compatible with the time scale of the first EIC detector, but it could be considered for subsequent upgrades or for a second detector

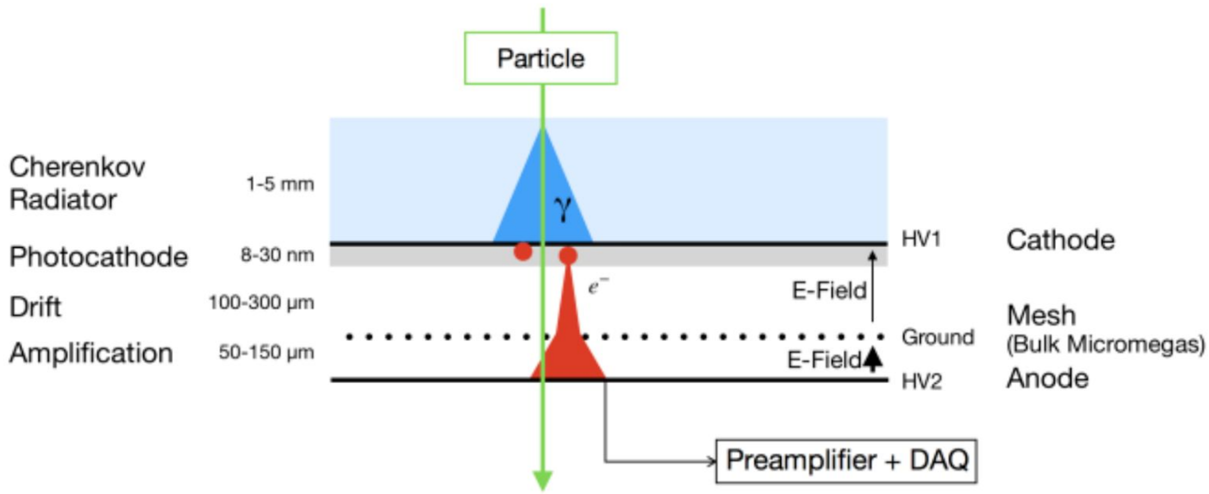

Figure 1: The PICOSEC detection concept. The passage of a charged particle through the Cherenkov radiator produces UV photons, which are then absorbed at the photocathode and partially converted into electrons. These electrons are subsequently preamplified and then amplified in the two high-field drift stages, and induce a signal which is measured between the anode and the mesh.

Electronics

Historically, CEA/Irfu has taken part in construction of the trigger / DAQ systems of a vast majority of leading High Energy Physics experiments worldwide. The extensive expertise unified within the detector, electronics and information technology division at CEA/Irfu allows for involvement at every level of the development of modern acquisition systems. The Micromegas Vertex Tracker can be cited as one of the recent implementations of a complete sub-detector integrated within the CLAS12 experiment at JLab. This includes the design and production of its innovative curved detectors and its readout, based on in-house developments such as the 64-channel frontend ASIC “DREAM” and a 512-channel versatile mixed analog-digital frontend board, as well as its real-time acquisition software.

Currently CEA/Irfu contributes to the collaborative developments of the readout ASICs and trigger/DAQ electronics of the particle physics experiments at LHC, within a harsh operational environment in terms of challenging data rates, stringent space, high magnetic field and radiation. The group take responsibilities for conception and large-scale production of:

A. complex on-detector trigger electronics such as, for instance, the Liquide Argon Trigger Digitizer Board for the Atlas phase-1 upgrade[4];
B. frontend ASICs such as, for instance, Catia trans-impedance amplifier chip for the phase-2 upgrade of the CMS electromagnetic calorimeter[5];
C. extremely sensitive parts within the radiation hardened multi-channel frontend ASICs such as, for instance, the IP blocks of on-chip jitter-cleaner and clock synthesizer PLL and of ~4ps precision TDCs integrated in the 78-channel HgRoc chip of the CMS high granularity calorimeter[6].

Other areas of expertise are developments of picosecond-level waveform analyzer ASICs, cryogenic electronics and the associated infrastructure.

Naturally, CEA/Irfu, with its wide-range experience in modern electronics, expresses an interest to participate in the definition of the readout architecture for the experiments at EIC and to the subsequent phases of the DAQ system development. The main EIC-related interest of the institute being gaseous tracking technologies, the most efficient involvement of its electronics group would be for the readout design for the corresponding tracking detectors. Such a "subsystem" approach could ensure the most optimized detector front-end interface, as well as production of the experimental equipment, its integration within the target EIC experiment and its subsequent maintenance. In this context, CEA/Irfu expresses its interest to:

1. Collaborate on the **development of a versatile multi-channel frontend ASIC**, with the capability of streaming readout, for micro-pattern gaseous detectors. A possible area of participation can be for a programmable very-front-end stage of the ASIC allowing the tuning of its gain and shaping time in order to achieve the highest possible signal to noise ratio for a wide range of detectors (i.e. GEM or Micromegas based TPCs and trackers). As it was the case in previous developments (i.e. CLAS12 MVT), the very-front-end stage can be made particularly well adapted to a large range of detector capacitances. This opens an opportunity for the development of very low material budget MPGDs with remote off-detector front-end electronics requiring no readout or cooling infrastructure within their vicinity. Contribution to other functionalities, such as on-chip digital signal processing in a form of intellectual property blocks, can also be envisaged.
2. Collaborate on the **development of a front-end ASIC for precision timing detectors**. The group can contribute with a TDC IP block based on the novel low power high speed architecture achieving ~4 ps precision for measurements of time of arrival signals. This is compatible with the tens of picosecond precision expected from an EIC timing detector. As a companion block, the group can contribute with a clock-synthesizer jitter-cleaner PLL IP block, ensuring the required clock quality needed for precision timing.
3. Collaborate on the development of front-end electronics with the capability of streaming readout, eventually based on new ASICs. A possible area of participation can include the design of front-end boards with high-speed serial links for data and control interface with upper layers of readout system. Yet another contribution can be the on-board programmable logic design (firmware) of the synchronous downlink (clock, commands) and of the streaming readout uplink. Within the common firmware framework, CEA/Irfu can also contribute to the local data formatting, event building, common mode noise subtraction, zero suppression and other blocks. These developments will be supported by the on-line (real-time) control software libraries and utilities to be integrated within the overall run control system of the experiment.

[4] https://arxiv.org/abs/1806.08046
[5] https://cds.cern.ch/record/2724948
[6] http://cds.cern.ch/record/2712269/files/CR2020_014.pdf

Software

Thanks to the long experience with MPGDs in several experiments, the CEA/Irfu team has become expert in the software packages needed for the reconstruction and the simulation of MPGD data. The team has taken part in the whole software chain. In simulation, particularly in the presence of magnetic field components that are orthogonal to the MPGD drift field, the detector response has to be carefully tuned taking into account the Lorentz angle effect. In reconstruction, the team has gained expertise in all the steps, from the decoding of the raw data to the track-finding, reconstruction, alignment algorithms. The team has experience in the deployment of tools for the monitoring of the detectors during the data taking.

MC event generator based on PARTONS

Exclusive processes, such as deeply virtual Compton scattering (DVCS) and deeply virtual meson production (DVMP), are among the most important channels that the EIC aims at studying. Therefore, it is crucial that their simulations are based on modern and state-of-the-art phenomenological frameworks.

The PARTONS software[7], mostly driven in Europe by CEA/Irfu in France and NCBJ in Poland, is one such frameworks. The PARTONS developers already started blueprinting the bases of an event generator that will benefit from the full stack of the framework. Such an event generator will give users access to the latest parameterizations. Thus it will be extremely important for the EIC community at the beginning for the detector design and then for the physics analyses. The PARTONS developers will work closely with the EIC software group to best integrate this event generator with the EIC software stack. The roadmap of the PARTONS software includes also the implementation of QCD evolution of GPDs and the integration of PDFs and TMDs libraries. These developments will make PARTONS an extremely useful framework that will allow the EIC users to evaluate the impact of future measurements and to extract from experimental data a comprehensive study of the 3D nucleon structure.

Please indicate what the level of potential contributions are for each item of interest:

The CEA/Irfu's contribution will consist in in-kind labor for the design, prototyping and testing of detectors and electronics. CEA/Irfu's staff will also contribute to in-kind labor from the detector production to the installation and commissioning. Software development will also be part of the in-kind labor contribution.

Depending on the technology choices and its priorities, CEA/Irfu will also consider in-kind contributions of experimental equipment at a significant level.

As an example, the CLAS12 Barrel Micromegas Tracker project has been a full in-kind contribution (both labor and experimental equipment) to the Jefferson Lab Hall B experiments.

The BMT consists of six layers of three curved tiles of resistive Micromegas detectors, for a total of 18 detectors (plus spares) and a total active area of about 2.7 m^2. It is equipped with 18k channels of front-end electronics, cables, holding structure and services (gas, LV and HV systems).

This project, not considering the R&D phase, involved about 65 FTEs integrated over a ten-year period, among which about 40 FTEs from technical staff and about 25 FTEs from staff scientists. The

[7] B. Berthou *et al.*, "*PARTONS: PARtonic Tomography Of Nucleon Software. A computing framework for the phenomenology of generalized parton distributions*", Eur. Phys. J. **C78** (2018) 478.

procurement costs of about 1 million Euros include detectors, FEE cards, and missions for detector integration.

Please indicate what, if any, assumptions you made as coming from the EIC Project or the labs for your items of interest:

CEA/Saclay assumes that, for a given detector, the integration operations and the detector services, such as gas, high and low voltages, will be provided by the EIC project. CEA/Irfu will closely collaborate with the EIC staff to facilitate the integration design.

Please indicate the labor contribution for the EIC experimental equipment activities:

The time commitment of members of the CEA/Irfu group in the EIC efforts described in this EoI is anticipated to be as follows:

Institution Name	Professor	Research Professor	Staff Scientist	Postdoc	Graduate Student	Undergrad. student	Engineer	Designer	Technician	Total Sum
CEA			1.8	1	1		2		2	7.8

NOTE: FTE in the above table represents the annual fractional full time equivalent (FTE).
NOTE: for a professor, full-time equivalent research time may be limited to 25% max, for a research professor (or a sabbatical) or a staff scientist limited to 50% max, for a postdoc maybe 100%, and for a grad. student perhaps 50% (on average). For an undergraduate student research time (on average) is limited to 20% max.

The quoted values from the table are annual FTEs. This commitment is valid for the next 2 years only for permanent staff positions. The number of graduate students and postdocs is based on the current situation and on the availability of external funding, and is valid for the next few years. It will increase significantly when data taking starts.

The Department of Nuclear Physics (DPhN) has 6 staff scientists working on experimental hadron physics, 2 staff scientists working on theoretical and phenomenological hadron physics. Since the EIC is among DPhN's priorities, **a plan to increase the number of staff scientists dedicated to EIC physics up to 5-7 by 2030 is already in place (corresponding to 3.5 FTE using the proposed metric)**. The theory group of DPhN will contribute to the software development of an MC event generator based on the PARTONS framework for exclusive processes with 0.2 FTE.

The technical departments commit to a minimum of 1 FTE engineer and 1 FTE technician on the detector development and 1 FTE engineer and 1 FTE technician on the electronics development. This is valid for the first phase of the project, *i.e.* the next two years. **Once the EIC project is better defined, CEA/Irfu foresees to increase the number of FTE depending on the technology choices.**

In addition to in-kind contributions, CEA/Irfu could make its infrastructures (clean room, etc.) and extra personnel available in exchange for financial contributions from the project.

Please indicate if there are timing constraints to your submission:

CEA/Irfu is heavily involved in a large number of hardware developments, particularly in the LHC detector upgrades. If there is no large delay related to the sanitary crisis, an increase of our technical in-kind labor can occur from mid-2022.

A major milestone for the development of PICOSEC Micromegas is the choice of the photocathode. For a usage with a large number of photons (pre-shower/Calorimeter), a 10x10cm^2 demonstrator is being built.

Please indicate any other information you feel will be helpful:

Irfu, the Institute for Research on the Fundamental Laws of the Universe, of the CEA's Directorate of Fundamental Research (DRF), brings together three scientific disciplines (astrophysics, nuclear physics and particle physics) as well as all the associated technological expertise. CEA/Irfu consists of about 1100 employees, 150 doctoral students and post-doctoral researchers.
In order to answer key questions concerning the elementary constituents of matter, the organization of nuclear matter, the structure and energy content of the Universe, CEA/Irfu is organized around scientific themes, to which are added technological themes related to gas pedals and superconducting magnets, detectors, microelectronic circuits and signal processing, as well as a theme related to algorithmic developments for scientific computing.

Several on site facilities allow CEA/Irfu to perform technological developments and the integration of the large instruments.

Some of the facilities are:

1. A 150m^2 clean room for detector assembly with high precision mechanical tooling
2. Versatile automated test stand for validation of medium to large scale ASIC production (several thousands to several tens of thousands)
3. Two wire-bonding machines BondTec 5632 and 5832 in a Class 100 000 clean room, for prototyping and large scale production respectively
4. On-site access to a “Pagure” gamma ray irradiator with several Cobalt 60 radioactive sources ensuring programmable fluxes within the 1 Gy/h - 25 kGy/h range
5. MPGD workshop, which allows one to build bulk and resistive Micromegas prototypes and to do small scale productions. This laboratory is equipped in particular with a micromesh stretching tool, a laminator, an UV insulator, a chemical detector, and a resistive paste applicator.

Among other facilities can be mentioned a flying probe tester, a 3D-imaging digital microscope and a precision timing lab equipped with high-end digital scopes, a phase noise analyzer and a set of low jitter clock sources.

More information can be found at: http://irfu.cea.fr/en/