COMITÉ NATIONAL DE LA RECHERCHE SCIENTIFIQUE

CONSEIL SCIENTIFIQUE D'INSTITUT

REPORT

Scientific Council of IN2P3

Session of October 21-22, 2024

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Speakers

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1 Introduction and framework

The meeting of the scientific council was held on 21 and 22 October 2024 at CNRS headquarters in Paris. The first day was dedicated to the presentation of the projects in an open session. The second day consisted of a closed session of the scientific council, including discussions with the project PIs, the invited external experts and the IN2P3 management.

The charge of the scientific council was to review the instrumental developments that were underway or being considered, in the context of the electron-ion collider (EIC) project at the Brookhaven National Laboratory (BNL).

The ultimate scientific motivation of these instrumental developments is to study the global structure and properties of the nucleon, including in particular the different contributions to its spin and to its mass, the dynamic distributions of quarks and gluons inside the nucleon, and insights into confinement processes and the quark and gluon plasma phase. These topics address the science driver #5 entitled "Understand the structure and the origin of the properties of hadrons (Hadrons)" in the IN2P3 Strategic Plan for French Nuclear, Particle and Astroparticle physics in the 2030 Horizon. For the accelerator developments, the envisaged contribution is in line with the future technological research programme described in the IN2P3 Strategic Plan, which aims to improve the performance of particle accelerators towards higher beam energies, intensities and luminosities.

IN2P3 teams have been showing interest in the EIC project since 2014 when they participated in the EIC White Paper writing. In 2021, they contributed to the EIC Conceptual Design Report. A DOE-IN2P3 statement of interest in the EIC project was signed in January 2024, and IN2P3 management is participating in the EIC Advisory Board and in the Resource Review Board. EIC-related activities at IN2P3 to date include the following accelerator and detector R&D developments, the latter in the framework of the ePIC detector proposal at the EIC:

- The design, construction and testing of superconducting radio-frequency cryomodule units for one of the subsystems of the accelerator complex, the Rapid Cycling Synchrotron (at IJCLab).
- The construction of a prototype of the backward endcap electromagnetic calorimeter (EEEMCal) based on lead tungstate (PWO) crystals and SiPMs, and performance studies with beams (at IJCLab and LLR).
- A contribution to the design and construction of the mechanical support of the EEEMCal (at IJCLab).
- A preliminary proposal to contribute to the design study of the cooling system of the roman pots detector, based on the AC-coupled Low Gain Avalanche Diode technology (at IJCLab).
- The design and production of two ASICs, CALOROC and EICROC, respectively for the readout of the EEEMCal and the roman pots (at IJCLab, LLR and OMEGA).

The calendar of the EIC is not yet firmly set. The current project timeline foresees the completion of the R&D phase by the end of 2025, when the second critical decision CD-2 is expected to be taken, followed by the start of construction in 2027 and the start of the early physics programme in 2034.

The instrumental developments presented in this session of the scientific council are at different stages of maturity, some of them very preliminary. Many uncertainties remain regarding the calendar, the organisation of the collaboration and the decision-making process for choosing between the various technical options under study. The IN2P3 management asked the scientific council to review EIC-related activities at this early stage in the particular context of the negotiations, led together with CEA/IRFU, of a very important budget from the Ministry in the form of an IR* (very large research infrastructure). The preliminary IN2P3 budget under discussion is of the order of 15 M€ for the accelerator part, and 6 M€ for the detector contributions.
More precisely, the scientific council was asked to evaluate and deliver recommendations to the management on the detector activities, while the accelerator activities are considered only for information purposes and to give a complete picture of the French contribution to the EIC. For the latter, the scientific council will give its thoughts but will not make any recommendations. The point of view of the scientific council is asked on the proposed contributions, as well as on the global strategy established by IN2P3 regarding EIC, including the objectives, the expected scientific impact in regards of the foreseen contributions, the resources allocated and their organisation.

Agenda of the session and material

Description of the projects under review, agenda, support files and videos of the oral presentations, report issued by the scientific council including recommendations, are archived publicly on the web site of the scientific council of IN2P3.

Indico time-table of the open session: see https://indico.in2p3.fr/event/33468/.

2 Detector developments

2.1 Introduction and highlights

The ePIC experiment will consist in a compact, cylindrical, asymmetric detector. It will contain a tracking system, particle identification detectors, electromagnetic and hadronic calorimeters and a 1.7 T magnetic field generated by a 2.8 m bore diameter superconducting solenoid magnet. In particular, the electromagnetic calorimeter will be composed of a barrel, a forward-endcap and a backward-endcap calorimeters. In addition, far detectors will complement the setup: a luminosity system, roman pots and a zero-degree calorimeter.
The proposal for the IN2P3 contribution consists of three contributions to the ePIC detector: to the backward-endcap electromagnetic calorimeter (EEEMCal), to the roman pots and to the electronic readout ASICs associated with these two sub-detectors, called CALOROC and EICROC, repectively.

- The EEEMCal will consist of nearly 3000 lead tungstate crystals, each crystal being read out by 16 SiPMs. It will play a key role to characterise the scattered electrons which are present in many physics channels. Within its pseudo-rapidity acceptance ($1 < \eta < 3.5$), the energy resolution is a must and requires homogeneous material such as crystals and glass. The physics simulations have already been carried out and documented, allowing the detector design and performance to be specified.

The IJCLab and LLR groups have already contributed to the simulation of the detector in terms of performance and thermal simulations, and have built a 5x5 crystal prototype including cooling plates. The proposed future involvement concerns the final design of the crystal support structure, as well as its construction and assembly. This support structure must minimise dead zones between the crystals and contribute to crystal temperature homogenisation. To achieve the energy resolution target of $2\%/\sqrt{E} \bigoplus 1\%$, the temperature must be kept stable at the $\pm 0.1\,^{\circ}\mathrm{C}$ level, which makes the cooling and the mechanics of the EEEMCal a very challenging task.

To reach the energy resolution goal, the linearity and the resolution of the readout electronics are also important ingredients. The proponents therefore propose to adapt HGCROC, the readout ASIC developed for the future electromagnetic calorimeter HGCAL in CMS, to the environment and requirements of the EIC. This new ASIC, called CALOROC, might be further considered for the readout of other ePIC calorimeters also using SiPMs, though they feature a much larger number of readout channels. The infrastructure for the mass testing available at LLR, as well as the experience and test software tools previously developed for CMS, will be reused.

- The roman pots will consist in far forward detectors placed $\sim 30\,\mathrm{m}$ away from the interaction point. They will play a crucial role to study exclusive reactions and diffractive processes. They will allow the detection of outgoing particles with very small polar angles ($\theta < 5.0$ mrad or $\eta > 6$), with a very good timing precision (~ 30 ps), good granularity (0.5×0.5 mm^2) and for a typical p_T resolution better than 10 MeV/c. To comply with these requirements, it is proposed to use a relatively new sensor technology: AC-coupled Low Gain Avalanche Diodes (AC-LGADs).

  The IJCLab's proposed contribution to the roman pots concerns the design of the AC-LGAD readout electronics, as well as the design of the modules and their cooling. These detection modules are located in vacuum and cannot be cooled by circulating fluid. Consequently the main constraint on the readout system is the need to reduce the power consumption per channel by a factor of ten, compared to what was measured on the first ASIC prototype. To date, the thermal and mechanical studies carried out at IJCLab for the roman pots have been mainly funded by the ANR and the Labex P2IO.

  It is proposed to develop a readout chip called EICROC, based on the existing ALTIROC ASIC previously developed by OMEGA for the ATLAS experiment. Fulfilling the specifications to read out the AC-LGAD signal of the ePIC roman pots will require a substantial modification of ALTIROC, in particular the replacement of the time-over-threshold with an ADC and drastically reduce the power consumption. Therefore, EICROC can almost be considered as a completely new ASIC development. A first prototype EICROC0 has already been designed by OMEGA. Several successive prototypes are planned for the future (EICROC0A/B, EICROC1, EICROC2, EICROC0_65nm). It is important to note that EICROC is the only readout option currently being developed for the roman pots in ePIC and more generally, for all detectors based on the pixelated AC-LGAD technology.

2.2 Comments

The link between the instrumental developments proposed at IN2P3 and the EIC physics programme is well established. Moreover, these developments match well the expertise available at IN2P3.

Obtaining an IR* funding would therefore be a very good opportunity to maintain the IN2P3 specific technical know-how, as well as the French community involved in nucleon structure physics in the long term. It will definitively enhance its visibility within the EIC collaboration. However, the size of the current physics community remains moderate (7 physicists at CNRS, 15 including IRFU), and the involvement of IN2P3 physicists will obviously become critical at the 2030 horizon. As far as the technical manpower is concerned, specifically for the mechanical aspects and for the design and testing of the two ASICs, resources also appear to be insufficient, based on the information provided for this review.

2.3 Recommendations

- The success of the proposed projects is in all likelihood linked to a growing involvement of the hadronic physics community in the EIC project and to the very significant support provided by IN2P3. As a first general recommendation, the growing support of IN2P3 for EIC and its impact on the other projects in the field of hadronic physics at IN2P3 should be carefully evaluated and clearly stated.

- Currently the manpower projection is only shown until 2028, whereas this should be planned at least until the EIC start-up phase in $\sim$ 2034. Moreover, we also recommend that the contributions of the main contributors already involved (physicists and engineers) should increase, closer to a 100% commitment.

- The EEEMCAL detector is well in line with the existing expertise at IN2P3. The proponents should include all the EEEMCal detector integration and maintenance tasks in their schedule. In addition, the interplay between mechanical and thermal aspects needs to be studied.

- The roman pots are an interesting project with potentially a very good visibility. However, a stronger support, particularly in terms of human resources, would be needed to achieve the claimed objectives, even if the schedule is less constrained than for the EEEMCAL contribution.

- The ASIC developments for the EIC detectors will provide a very good visibility and will allow to maintain and develop the expertise at OMEGA. We suggest seriously considering the added value of a "digital-on-top" approach coupled with extensive functional verification, while limiting the number of prototype iterations for the two ASICs. Meanwhile, these prototypes need to be designed with the detector integration and qualification aspects in mind. This will result in better and more complete prototypes that can be extensively tested and characterised, allowing potential problems to be identified before the next design iteration. A reinforcement of the digital expertise seems necessary for the project, either at OMEGA or from other IN2P3 laboratories. The latter would be more in line with a growing community joining the EIC project. In addition, system level considerations should be injected early in the ASIC design. In this perspective, the involvement of LLR in the front-end electronics could contribute to these aspects, provided that the team is closely linked to, or even involved in, data acquisition developments.

- It is strongly recommended to establish a clear schedule, with well-defined milestones and a clear decision process for the ASIC selection. This plan should obviously be established in agreement with the EIC collaboration. The main risk identified is that the R&D phase may not be completed in time for the CD-2/TDR deadline.

- We recommend that the developments planned for the 65 nm CMOS technology should only be considered if the 130 nm design results in a too large footprint, and moving to the 65 nm technology becomes mandatory to meet the requirements. In particular, in the context of limited resources for ASIC design, this would save resources that could be redirected to the design verification before tape-out, and to the test and characterisation phases as discussed above.

- The level of commitment of IN2P3 should be clearly stated to the collaboration, especially for EICROC which is a quite innovative and ambitious design. In addition, and for both ASICs, the amount of support that will need to be provided for use in other ePIC detectors should not be underestimated, in particular in the perspective of using CALOROC for several calorimeters.

- The difficulty of allocating the necessary resources can be identified as a risk, and we therefore recommend prioritising the different readout ASIC contributions, especially in the case of critical needs for the CALOROC project.

In conclusion, the scientific council underlines the opportunities offered by the proposed French contributions to the EIC. Assessing what level of resources is necessary and appropriate to achieve the stated objectives is rather difficult at the current stage of the projects, as some design decisions have not yet been made and other international contributions need to be clarified. We therefore recommend that a process be established to ensure that there is a match between the planned outcomes and the resources required to achieve them.

3 Accelerator developments

3.1 Introduction and highlights

The EIC accelerator complex will be built at the Brookhaven National Laboratory (BNL). It will accelerate a polarised electron beam from 400 MeV to a maximum energy of 18 GeV. The Rapid Cycling Synchrotron (RCS) will inject these electrons into the EIC electron storage ring. The ion beam will consist of protons (with energies from 41 to 275 GeV) and light or heavy ions (deuterons, helium, gold, uranium; with energies from 41 to 110 GeV).

An in-kind contribution from IN2P3 to the EIC accelerator is under discussion, with two international Cooperative Research and Development Agreements (iCRADA) being prepared to establish its framework: one between IN2P3 and the Jefferson laboratory JLAB, and another one between IN2P3 and BNL. The main objective is to procure, test and deliver to EIC a total of four SRF cryomodules for the EIC RCS. Each cryomodule is composed of one 591 MHz 5-cell SRF cavity equipped with its ancillary systems (high-order mode couplers, fundamental power coupler, tuning system, warm beam loss absorbers and a cold box). One of the four modules will be a designated spare.

The Supratech platform at IJCLab is necessary for such an in-kind contribution but would need to be upgraded.
IJCLab is an internationally renowned laboratory within the accelerator community and has provided major contributions to the construction of global accelerator facilities such as LHC in Switzerland, XFEL in Germany, SPIRAL2 in France, MYRRHA in Belgium, ESS in Sweden and PIP2 in the USA. In particular, more than 100 people spread across the Supratech platform, from both the Engineering and Accelerator divisions of the laboratory, have developed considerable expertise in large-scale SRF technology development and integrated system delivery. Capitalising on this valuable experience, IJCLab has been leading for many years an international collaboration which aims at building a new compact multi-MW Energy Recovery Linac (ERL), called PERLE, thanks to the funding from IN2P3 and enhanced synergies with the Innovate for Sustainable Accelerating Systems (iSAS) project of the European Commission.

For the scope of IJCLab's responsibility regarding the proposed RCS cryomodule provision for the EIC, the laboratory would be tasked with the following duties:

- The design of the tooling required for the assembly and testing of the cryomodules;
- The procurement and tracking of all components;
- The test of each critical component (SRF cavities, power couplers and tuning systems) before its assembly in the cryomodules;
- The cryomodule assembly;
- The final test of the cryomodules;
- The shipping of the cryomodules to BNL.

As was already done for the previous ESS spoke cavity cryomodules and currently for the PIP-II in-kind contribution from IJCLab, the plan is that approximately 40% of the project team will consist of non-permanent staff dedicated to specific operations (mainly technicians for the clean room and cryostating phases). More specifically for the EIC delivery scope, this would mean here a total of 546.9 person-months (45.6 FTE), including 220 person-months of non-permanent staff (18.3 FTE).

3.2 Comments

The IJCLab team has a well-established, long-standing and widely recognised expertise in building and testing cryomodules for a variety of projects. The EIC project provides an opportunity to keep the Supratech platform and cryogenics R&D expertise up to date and will create synergies with the PERLE and the iSAS projects, thereby opening up new avenues for research and development. This EIC project therefore looks strategically important for IN2P3, offering capability-building benefits for the specialised staff and enhanced infrastructure. These advancements are expected to ensure that IJCLab continues to deliver challenging, complex SRF systems for major national and international accelerator initiatives in the future. The Supratech SRF facility at IJCLab is already well aligned with the majority of the qualification and integration requirements anticipated for the EIC, placing the laboratory in an excellent position to leverage additional investments for the EIC, thereby further enhancing its impressive range of capabilities.

However, the present planning has been established without considering any contingency. In particular, it does not take into account any constraints arising from possible delays in obtaining relevant technical drawings or other related information. A comprehensive and in-depth risk analysis is deemed necessary, including the identification of measures to mitigate potential consequences. Only two primary risks were identified from the outset and raised by both the scientific council and by IJCLab members of EIC: the duration and human resources needed for the procurement phase, and the potential challenges in recruiting the large number of temporary staff that is required.
A certain number of concerns have been identified and so by appropriately addressing these issues, it would help further consolidate and strengthen IJCLab's plans for the proposed EIC project delivery. These are:

- A prototyping phase has not been clearly identified, which substantially weakens the critically important risk management provision of the project.
- The extent of possible delivery risks, their effective mitigation or the impact on schedule and cost have not been assessed.
- The spare hardware (such as cavities, power couplers, etc.), that is usually deemed necessary in case of failure or need for replacement, is missing. Moreover, if the proposed level of funding is indeed fixed, the possibility of re-scoping should be considered.
- A realistic cost model must be developed, including material cost escalation, inflation, VAT, customs, transportation, etc., if not already assumed and included.
- The potential difficulty of finding the necessary technical staff is only mentioned with very little anticipation.
- The sharing of design and testing responsibilities with EIC partners, in particular with JLAB, is not clarified.

In conclusion, although the project of IJCLab for the EIC accelerator is at a preliminary stage, the proposal represents a strong potential opportunity for IN2P3 to make a significant contribution to a major international project, such as the Electron Ion Collider at BNL, and thus to further enhance the international reputation and significant impact of IJCLab.