**Synergies on detector R&D activities between INFN groups working on ALICE-ITS3/ALICE3, EIC_NET and NA60+ initiatives and ALICE Italy**

**Scope and introduction**

This document details a list of R&D collaborations/joint projects in place between several INFN groups working in ITS3/ALICE3 (R&D projects within the ALICE Collaboration) and in EIC_NET and NA60+ initiatives, recognizing the important level of potential synergies related to these three experiments also given the significant overlap among INFN groups working on these three research programs.

Upon request of EIC_NET groups a workshop in July 2021 was hosted by the ALICE Collaboration (https://indico.cern.ch/event/1059080/). This document is a further development based on the outcomes of the discussion there and including the NA60+ initiative.

As of May 2022, 10 INFN units are part of the ALICE experiment, the large part of them since many years and some of them since the presentation of its initial Letter of Intent, almost thirty years ago.

The ALICE experiment is now entering into LHC Run3 Data Taking with a further substantive programme of upgrades being proposed for the existing detector in the forthcoming Long Shutdown 3 (a forward calorimeter and an improved central tracker "ITS3") and with an entirely new detector to be installed during LS4 ("ALICE3").

All the ALICE INFN groups have signed the Letter of Intent of the ALICE3 proposal clearly indicating the long-term commitment to the experiment and its scientific goals. At the same time, some of these INFN groups are part of other initiatives as EIC_NET (for a general-purpose detector at the approved Electron-Ion Collider at Brookhaven National Laboratories in US) and NA60+ (a proposal for a fixed target experiment devoted to a study of the QCD phase diagram at high $\mu_B$ at the CERN SPS).

While there is a partial overlap among INFN groups and people involved in these three initiatives ("sigle" of INFN Commissione Scientifica Nazionale 3 – CSN3 – devoted to Nuclear Physics), there are also INFN groups or individuals belonging to only one of them, further expanding the potential network of INFN researchers/groups for potential R&D synergies for these three projects.

This document maps the areas of common interest where a mutual benefit is foreseen from expanding the already present exchange of information and/or common activities. The aim is to maximize the impact of INFN investments in R&D spending during the coming years. On the other hand, an INFN finance investment assigned formally to just one initiative (to avoid duplication) will be valorized by all INFN groups in their respective international collaborations, globally helping an optimal positioning of INFN in all three projects.

This document is therefore limited in scope to a description of the synergies among INFN groups and the ALICE Collaboration, even if we are aware of other existing levels of collaborations for R&D, led by EIC Project and CERN management (see for example special EIC session on CERN R&D Days 2021 https://indico.cern.ch/event/1063927/) or under the JENAS Expression of Interest (https://indico.ph.tum.de/event/7004/ ). Similarly, formal agreements for the use of specific technology (namely TowerJazz 65 nm process for MAPS) are subject to agreements being negotiated at a higher level not discussed here.

According to the currently approved (or under discussion) schedules, the time-overlap among the different projects is reported in Fig. 1.

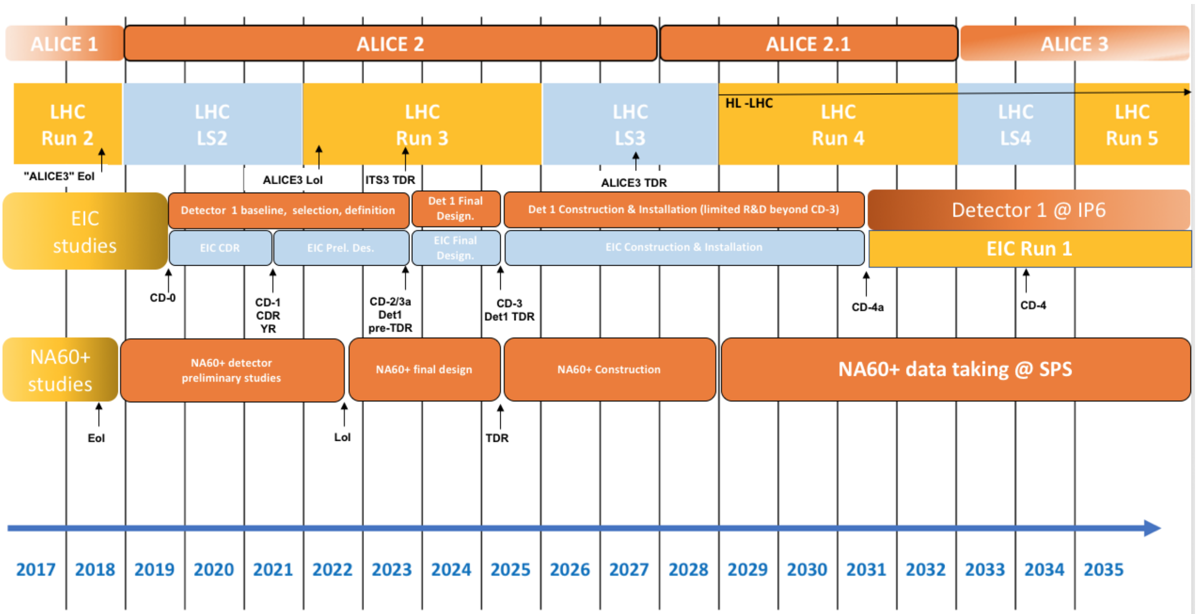


*Fig. 1: current timeline foreseen for the different projects. Some of the dates are not yet formally approved but were reported in recent talks by CERN DG (Jan 2022) or EIC Project Leadership (May 2022).*

Given the current timelines a reasonable scenario is to see the result of the R&D performed by ALICE preparing for Run4 ("ITS3") as a baseline choice for EIC detector 1 and for NA60+. On the other hand, R&D from EIC groups might inform and be used in designing the ALICE3 apparatus. In turn, some of the innovative technologies anticipated for ALICE3 (and certainly needing a long R&D being some of them not available on the market as the Digital SiPM) might be an option for some upgrades of EIC Detector 1 in the second half of the next decade.

Clearly, R&D for detectors, sensors and electronics could be intensively shared across these projects, which have, luckily enough, slightly staggered schedules as visible from the above figure. It is also clear that the maintenance and operations of the current ALICE detector up to 2032 will take a considerable amount of human and financial resources (INFN groups are currently in leading roles in the following ALICE detector projects: ITS, TOF, ZDC, MUON and HMPID).

**INFN Units involvement**

As of 2022 INFN "books" (preventivi 2022) the following ALICE INFN groups are also involved in EIC_NET and NA60+ initiatives:

EIC_NET: BA, BO, PD, TS (there are also EIC_NET groups active at CT, LNF, LNS, CS (gruppo collegato to LNF) and TO but as of preventivi 2022 without any overlap with the ALICE groups present in these units).

Globally EIC_NET has groups from 12 INFN Units (FE, RM1 and RM2 are units where ALICE groups are not present).

NA60+: TO, CA, PD. Globally NA60+ has groups from these 3 INFN units.

The total number of researchers and technologists participating in ALICE is respectively 141 and 40 for a total of 127,1 FTE. Unsurprisingly given they are just proposed experiments these numbers are quite different for EIC_NET (56 researchers and 8 technologists, for a total of 15,5 FTE) and NA60+ (20 researchers and 4 technologists, for a total of 3,95 FTE). The total number of researchers from ALICE contributing also to EIC_NET and NA60+ is respectively 11 (20%) and 20 (100%).

The EIC_NET initiative also involves INFN groups from FE, RM1, RM2, GE, LNS, CS and the COMPASS/AMBER experimental groups in TS and TO. All these groups are expected to be working on the dRICH, even if a potential contribution is expected from GE and RM1 to the general DAQ “streaming readout” model, that is like the continuous readout scheme currently implemented in ALICE. It is expected that significant expertise will arise from ALICE in this area during Run3 and Run4.

**Common R&D areas**

In the following we list several R&D developments there are relevant for all the projects.

- The development of **MAPS sensors** for tracking and vertexing detectors. These sensors will be based on 65 nm technology thanks to the experience gained via ALPIDE chip for ALICE ITS2. The 65 nm technology, under development for ALICE ITS3, has been selected both by EIC and NA60+ as the preferred option for their vertex detector. An EIC Silicon Consortium has been setup where INFN groups are active members (BA, TS). The Consortium is going to negotiate with CERN/ALICE a specific agreement of collaboration for the use of this technology that is developed with TowerJazz foundry. Many INFN groups (BO, BA, CT, PD, CA, TO, TS) are currently involved in the ITS3 effort, and some of them also in their “EIC” or “NA60+” capacity. During 2021, the 65 nm TowerJazz technology was tested on small scale pixel matrices in the lab and in test beams. The results are very encouraging. The design of the first stitched sensor prototype, with the aim to study the yield of the process, was launched in 2021 and the first prototypes are expected in 2022. On the long run the expected EIC specific development of large area MAPS in 65 nm technology with EIC-optimized operations and a modified stitching plan with respect to what is foreseen in ITS3 will be certainly beneficial to inform the preparation of ALICE3 TDR. For NA60+ the use of stitching technology for large area sensors is crucial as well. The vertex spectrometer will be formed by 5 to 10 planes. Each plane will be formed by 4 stitched MAPS of 15x15 cm2 each. In addition to INFN contributions, it is worth to note that a funded project by Italian Ministry of Research (Progetto di Ricerca di Interesse Nazionale) granted to University of Cagliari about physics to be studied by NA60+ and ALICE will directly contribute to 65 nm MAPS technology development.
- The **aerogel** developed by Chiba University (Japan) could be an interesting replacement of the one produced by the Budker and Boreskov Catalysis Institutes of Novosibirsk (Russia) and used by JLab CLAS12 RICH. The identification of a different reliable producer is even more urgent given the overly complicated situation with Russia at the time of writing this MoU due to the Ukraine-Russia war. The assessment of optical properties of aerogel is a common interest of

ALICE and EIC_NET groups. EIC_NET groups not belonging to ALICE (INFN FE) have facility and consolidated expertise on this respect to offer.

- Silicon Photomultipliers (**SiPM**) are the candidate photosensors for the forward dRICH detector at EIC, where INFN is expected to give a substantive in-kind contribution for the construction. An advanced assessment of radiation tolerance (and radiation damage mitigation techniques as annealing) is under way, led by EIC_NET BO and FE groups. EIC_NET TO is actively working together with INFN TO Microelectronics Lab for the development and testing of an ASIC for SiPM readout (pre-amplification, discrimination, and digitalization with 50 ps LSB; ALCOR).
- These two research streams could be factorized when shaping the more ambitious ALICE3 RICH design that currently foresees the development of digital SiPM in CMOS Image Sensor technology. In turn, if this ALICE3 R&D would succeed, it might become a valid option for a potential upgrade of the EIC_NET dRICH photosensors after several years of operations.
- The INFN ALICE3 groups (BO, BA) are also investigating the option of using **the SiPM as a charged particle sensor,** with promising test beam results and tests of prototypes from several companies (FBK and HPK) being under way. While this approach is not relevant for the dRICH (sensors are placed off-axis) it could be an interesting option to be considered by the mRICH in the backward region. Among EIC groups in detector 1, a high degree of collaboration between the dRICH and mRICH groups is expected, even if a direct INFN contribution to mRICH is not foreseen at this time.
- Two EIC_NET groups (GE, TS) are following closely R&D efforts led by US groups (ANL, BNL, MSU) together with Incom company about the development of Gen2 **LAPPD** pixelated. At this stage it is unclear if this promising technology could be advisable for a RICH detector given its initial stages of development, but it is currently considered as a "plan B" option if the SiPM R&D would give negative outcomes. LHCb groups (including INFN BO) are also investigating the LAPPD option, reporting extremely good timing resolutions (for a summary see the recent workshop: https://indico.bnl.gov/event/15059/). Such an option does not seem to have been considered so far by ALICE groups and an exchange of information about the first R&D results would be beneficial. EIC_NET INFN groups are expected to investigate the effect of magnetic field on LAPPD efficiency and quantify time resolution.
- Finally, the experience gained within ALICE under O2 computing model implementing a **triggerless DAQ** for many detectors could be factorized in the design of the expected EIC DAQ model (so-called "streaming readout" in EIC and "continuous readout" in ALICE). INFN Genova and INFN Roma2 (two groups not part of ALICE) are currently leading this effort as part of the EIC_NET INFN groups. The implementation of the $O^2$ computing model could be of interest also for NA60+ which is considering a triggerless data taking approach with a high intensity Pb beam at the SPS.

**Common commitments**

With this document the different parties assume a shared and common commitment to maximize the synergies described above in the interest of the INFN groups involved. Given the ALICE crucial role (collaboration with the largest number of FTE and individuals from INFN among the three experiments and its immediate leading role in the development of the MAPS 65 nm technology) it is also signed by the ALICE Spokesperson, in the understanding that the ALICE Collaboration will benefit as well of this enhanced collaboration among these INFN groups.

The three INFN sigle (ALICE, EIC_NET, NA60+) commit to:

- frequent exchanges of information, with one or two specialized meetings/year organized for the purpose of reviewing progress in the common areas of interest.
- a common planning of test-beam campaigns at CERN, namely at CERN PS and SPS, to the extent this will be feasible and productive (examples: maximize beam time, share trigger, trackers or DAQ facilities, share front-end electronics minimize mission costs);
- submit funding requests to INFN CSN3 for these R&D common streams of work, with the explicit aim of avoiding any duplication of costs. Specific R&D requests will be submitted just on one of the three “sigle”, explicitly noting the synergy in place, and properly noted vis à vis all the three international Collaborations as appropriate. This implies a specific coordination to be in place, via the RNs, at the time of the annual budget submissions (“preventivi”) specifically.
- keep informed the ALICE Upgrade Coordination about significant R&D progresses in these areas even if not carried out directly by the ALICE INFN groups and about significant changes in the schedule of the corresponding projects
- explore with CSN3 the possibility to finance INFN-CERN similfellow grants shared across the three projects, similarly to what has been recently decided by CSN1 regarding HL-LHC and FCC R&D
- explore with ALICE Management scope and plans of specific R&D projects as listed above

For the sigle INFN: ALICE, EIC_NET, NA60+:

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