EIC_NET
2022 Annual Report

The EIC_NET Collaboration
July 2022

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1. Introduction

1.1 The Electron Ion Collider and the CSN3 EIC_NET initiative

The EIC_NET CSN3 initiative covers preparatory activities for the future experiments at the USA Electron Ion Collider (EIC) aiming to shape INFN participation to the experiment foreseen in this new collider machine, devoted to the study of the hadron structure, via DIS on proton and nuclei, with availability of polarized beams (electrons, protons and light ions).

The activities include: establishing a national and international network to support the EIC project and to form international collaborations for the experiments at EIC; performing physics studies, simulations and detector R&D for the future experiments at EIC; shaping the future INFN contribution for specific detectors.

The Italian community interested in the project is based on a variety of groups arising from experiments at JLAB, CERN/SPS (COMPASS now AMBER), BNL (STAR), and LHC (ATLAS, CMS and ALICE) as well as CNS5 initiatives as IDEA. Unsurprisingly some of the members worked previously at HERA (ZEUS and HERMES). EIC_NET was approved by CSN3 in June 2018 and started its activity in 2019.

Following approval of the so-called “Critical Decision 0” and site selection at BNL by the US Department of Energy (DOE), the program had consequently an acceleration and therefore the networking work. At the time of writing this report, the project is at a critical juncture with the first Collaboration meeting for the construction of the so-called “Detector 1” to happen at the end of July.

The EIC_NET Collaboration, a networking initiative, will still operate as such in 2023, but it is clear now that time has matured to plan its transformation in a full-fledged experiment “sigla”. As it is evident in the activity program presented for next year, many Italian groups are exiting from simple “networking mode” and are taking progressive responsibilities in the future detector. In parallel the Collaboration is taking shape and the next challenge will be to have full recognition for the INFN contribution and build the key international collaborations with other institutions.

This report presents the status of the Collaboration, an updated activity report (covering from January 2021 to June 2022) and activity plans for 2023.

1.2 The international project

The international project is progressing rapidly with relatively small delay with respect to the announced schedule at the time of project inception. According to last estimates and taking into account the delayed approval of the US budget for FY2022, detectors are expected to be completed in 2030 with first beam operations in 2031 and the accelerator delivering at design luminosity in 2034. During the period reported here, the project went through several important steps (here listed in chronological order):

- The EIC User Group community in March 2021 completed the Yellow Report effort ("Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report" https://arxiv.org/abs/2103.05419) . Despite the difficulties due to the pandemic, this was a one-year (March 2020-March 2021) community-led concerted thorough effort to delineate the detector requirements to achieve the EIC science physics program. A baseline design for an EIC experiment and its subsystems was consequently elaborated and partially tested. There were, indeed, no full simulations as well as not specific detector technologies chosen, etc.
- Immediately after the release of the YR, in March 2021, the EIC project management released a Call for Collaboration Proposals for Detectors to be located at the Electron-Ion Collider (https://www.bnl.gov/eic/cfc.php) with dead-line on 1 December 2021.
- In June 2021 the project reached CD1 approval (Critical Decision 1: project ready for design phase). The main preparatory document that made this step possible is the Conceptual Design Report (CDR, https://doi.org/10.2172/1765663) of the new accelerator facility, released in February 2021.
- Following the call for collaboration the community clustered around proto-collaborations for the preparation of the proposals. Two of them aimed at the design of a setup able to cover the complete EIC physics program: ATHENA , characterized by the use of a new solenoid with up to 3 T field, and ECCE planning to re-use the 1.5 T BABAR magnet. A third collaboration, CORE, designed a smaller size set-up.
- In the second part of the year, the BNL and JLab laboratories appointed the EIC Detector Proposal Advisory Panel (DPAP) (https://www.bnl.gov/dpapanelmeeting/), a scientific-technical committee of renowned and independent experts, with the mandate to advise BNL and JLab on how to realize an optimal set of experimental equipments at the EIC capable of addressing the science case of the EIC White Paper and NAS Report, based on the identified YR report recommendations.

- All the three proto-collaborations submitted their detector proposals that were subsequently subject to the DPAP scrutiny in December 2021 and January 2022. The final DPAP report was then released in March 2022.
- The DPAP report :
  - indicates that both ATHENA and ECCE designs fulfil the physics requirements set by the Yellow Report and congratulates both the proto-collaborations for the hard preparatory work achieved in such a small amount of time;
  - selects the ECCE detector as reference design. The main impact is the selection of the "BABAR magnet", with a lower magnet field (1.4 T with respect to 3.0 T in ATHENA) and a smaller bore diameter;
  - encourages all the community to converge on a single Collaboration being clear that, in terms of institutions and funding agencies no one of the two proto-collaborations has enough capacity to build the detector;
  - emphasizes the importance of a second detector, as general good practice for big facilities as the EIC.
- Under the leadership of the EIC project, it was then initiated the process of merging of the proto-collaborations. Given the unhelpful tone of the DPAP report (that was surprising in many respects) this path was/is not easy, but the community is willing to stay united and converge in a single, solid, project. The first meeting of the new Collaboration was convened on 27th April and it is formally taking shape at the time of writing this report, with new "merged" working groups and review of the design. The ECCE design is assumed as reference design (in particular the constraints imposed by the magnet), but clearly the ideas, choices and frameworks arising from the work of the two main proto-collaborations are debated and - slowly - "merging".
- The upcoming EICUG meeting (26-31 July in Stony Brook) will also include the first meeting of the new Collaboration. In addition to obviously selecting a more attractive name than "Detector 1", there are plans to draft and approve a Charter soon, and elect a new leadership by October. The Collaboration is *ad-interim* coordinated by a Steering Committee (3 persons from ECCE, 2 from ATHENA) arising from the leadership of the previous proto-collaborations.

In March-April, the RN kept updated both the INFN Giunta Esecutiva and the chair of CSN3, as well as the EIC_NET referees about these important developments. It appears the DPAP evaluation - certainly disappointing and concerning for several reasons - was driven mainly by cost reduction and risk mitigation considerations. The point made by the DPAP about "a second detector" seems to be taken into consideration by the EIC management, but a potential decision to include funding for such a second detector is not expected before CD-3 (2025) and - if positive -, it means that such a detector would start operations 3 years and half (minimum) after Detector 1.

1.3 The EIC_NET contribution to the international project

As detailed in 2020 and 2021 activity reports ("consuntivi"), the INFN community contributed substantially to the Yellow Report, with one INFN staff as co-editor, several INFN staff serving as conveners in different working groups, and 57 of 414 authors as INFN staff or associated personnel. Two INFN authors contributed to the CDR document too.

In Spring 2021, the EIC NET collaboration decided to join the ATHENA proto-collaboration (https://sites.temple.edu/eicatip6/). As per the detector proposal submitted document, the proto-collaboration included groups from 94 Institutions. In the initial phases the proto-collaboration was steered by a Coordination Committee, Silvia Dalla Torre (INFN-TS) being a member of. The detector proposal preparation activity was performed within 12 Working Groups (WG), one dedicated to software and computing, four following the different sectors of the EIC physics and seven dedicated to the subdetector sectors. A Proposal Committee was responsible for the proposal preparation, including cost estimates.

Members of the EIC_NET initiative took active part in ATHENA during 2021: as detailed below, besides one of the apical coordinating positions, INFN had five conveners in different working groups (computing, tracking, PID, semi-inclusive and exclusive/tagging), as well as in the Charter preparation and Election committees. Remarkably, in September 2021 Silvia Dalla Torre (TS) was elected spokesperson of the ATHENA Collaboration with Bernd Surrow (Temple University) as her deputy. Besides the convenership roles, many people from INFN contributed to the proposal, including working on Monte Carlo simulations, physics performance, detector design and the budgeting and cost estimates for detectors (dRICH and tracker). In agreeement with INFN management, the foreseen in-kind level of engagement by INFN (not binding) was expressed in line with what stated in the 2020 Expression of Interest by INFN (see 2020 activity report).

In summary, thanks to the important contribution of the EIC NET groups in the YR context and thanks also to the rich and exhaustive EoI by the INFN groups, the following INFN physicists were selected for relevant roles in ATHENA

- spokesperson (S. Dalla Torre, TS) (and before election 1 over 8 members of the Coordination Committee);
- 4 over 37 WG conveners (A. Bressan, TS; D. Elia, BA; S. Fazio, CS; R. Preghenella, BO), while M. Radici, PV from NINPHA-CSN4 at that time was convener in the semi-inclusive phyics WG;
- 1 over 14 members of the Charter Committee (M. Ruspa, TO);
- 1 over 6 members of the Nomination and Election Committee (P. Antonioli, BO);

- 1 over 13 members of the Proposal Committee (S. Dalla Torre, TS);
- 2 over 7 members of the EIC Silicon Consortium Coordination Board (G. Contin, TS; D. Elia, BA);
- in addition the 13 RL of INFN units were members of the Institution Board of the Collaboration.

In her capacity of spokesperson, S. Dalla Torre presented and defended the ATHENA proposal during the DPAP scrutiny, in particular at the DPAP December meeting (13-15 December 2021). She also presented the ATHENA proposal at the Pisa Detector Meeting (22-28 May 2022).

All together, these efforts and contributions from the INFN EIC_NET community found their finalisation with the presentation of the ATHENA detector proposal. As a documentation of this collective effort the ATHENA proposal has been recently approved for publication on JINST (ref. no: JINST_063P_0522).

Moving to “Detector 1 Collaboration” some reorganization was needed (less positions available) and currently INFN has:

- 1 over 5 members of the interim Steering Committee (S. Dalla Torre, TS)
- 4 over 60 WG conveners (A. Bressan, TS; S. Dalla Torre, TS; R. Preghenella, BO; M. Radici, PV)
- in addition the 15 RL of INFN units are members of the Institution Board of the Collaboration, that has been convened for the first time on mid July 2022

Upon INFN initiative, a special meeting was convened to start the full development of simulation and reconstruction software inviting other interested institutions (NISER (India), BNL, Duke University, MIT, SBU) coming from both ATHENA and ECCE. As a result a dRICH Software group (at Detector 1 Collaboration - level) was formed, with C. Chatterjee (TS) as one of the co-conveners (together with scientists from Duke University and BNL).

In August 2021 several INFN groups applied for the EIC targeted R&D programs. This is a significant move from the traditional “generic EIC R&D program”, active since 2011. The answer from US DoE arrived very late (April 2022) due to the delayed approval of the Federal US Budget by the US Congress. The outcome was, however, very positive, with three projects where INFN researchers are now among the contact persons/PI and three projects that granted funds to INFN for a total of 265 k$ (these funds are technically allocated to US FY2022, but they will be delivered to INFN in three instalments by April 2023). A summary of the projects is available at: https://wiki.bnl.gov/conferences/index.php/ProjectRandDFY22
The projects where INFN has co-P.I roles are:

- eRD102: (dRICH): M. Contalbrigo (FE) and E. Cisbani (RM1)
- eRD110: (photosensors): P. Antonioli (BO)
- eRD111: (Si-Vertex) D. Elia (BA), G. Contin (TS)

Each eRD project corresponds to a group of different institutions (“consortium” in the DOE language) and the consortia are expected to coalesce the group of institutions that will contribute to specific projects (sub-detectors) in Detector 1. Funds were granted to INFN under projects eRD102 (dRICH), eRD105 (Streaming readout for calorimeters) and eRD110 (SiPM and LAPPD). INFN Board of Directors (CD) approved the relevant act to enact the transfer of funds in July 2021.

In terms of INFN visibility, remarkably, G. Contin (TS) was tasked to organize as co-convener the EIC Detector session at AGS/RHIC users meeting held 7-10 June 2022 (https://indico.bnl.gov/event/15479/), where eRD102 and eRD110 consortia selected respectively M. Contalbrigo (FE) and P. Antonioli (BO) to report on these projects. Similarly, at the recent (20-21 June) Kick-off meeting on synergies between EIC and LHC (https://indico.ph.tum.de/event/7014/), S. Dalla Torre (TS) was tasked to report on EIC detector status and R&D projects. M. Ruspa (TO) co-convened and organized CFNS Ad-hoc Workshop “Target fragmentation and diffraction physics with novel processes: Ultraperipheral, electron-ion, and hadron collisions”, held online last 9/11 February 2022 (https://indico.bnl.gov/event/14009/).

Finally, all EIC_NET members are also EICUG members. The representatives of each of the EIC_NET groups are members of the EICUG Institutional Board and the vice-chair of this body is from EIC_NET (A. Bressan, TS). The governing board of the EICUG is the Steering Committee (SC), where an EIC_NET member (S. Dalla Torre, TS) has served since the beginning of 2021. M. Ruspa (TO) has been chair of the EICUG Elections and Nominating Committee until September 2021, M. Chiosso (TO) is member of the EICUG Conference and Talks Committee. It is worth mentioning that M. Radici (NINPHA-CNS4) from PV is also a member of the EICUG SC since its formation in 2017, and in August 2021 he was elected vice-chair. SInce 2023 M. Radici and INFN PV will join the EIC_NET initiative.

1.4 INFN EIC_NET Collaboration: status and responsibilities

The EIC_NET collaboration, formed mainly by INFN physicists active in the projects ALICE (CSN3), COMPASS (CSN1), JLAB12 (CSN3), ATLAS (CSN1), CMS (CSN1), and IDEA (CSN5) is constantly growing (Table 1) in parallel with the consolidation and approval steps of the EIC project, as reported in Table 1.

year	researchers	FTE
2019	45	6.20
2020	46	6.80
2021	48	9.05
2022	62	15.50
2023	85	20.0

Table 1: researchers (including technologists) and FTE in EIC_NET since the creation of the initiative.

The increasing trend holds also for INFN units/institutions: in 2022 a new group at CS (gruppo collegato to LNF) joined EIC_NET. In 2022 13 INFN units were part of EIC_NET, and they will be 14 in 2023: while the RM1 group is exiting from EIC_NET due to CSN3 rules (the only remaining person wants to keep a 100% FTE on JLAB), INFN SA (gruppo collegato to NA) with an experienced group of faculty staff (S. De Pasquale, D. De Gruttola, A. De Caro, A. Calivà) working in ALICE joins EIC_NET. The group has experience in ALICE TOF detector, including in heavy-flavour and UPC analyses. Also INFN PV is joining EIC_NET. Following consultation with CSN3 and CSN4 chairs, we decided to "institutionalize" participation of M. Radici in Detector 1, given his role as convener of the semi-inclusive physics WG .

S. Dalla Torre (TS) served her last year as RN in 2021. Pietro Antonioli (BO) took office on 1st November 2021 for a three-year term.

The situation of the Collaboration for 2023 is summarised in Table 2. Having reached a dimension greater than 1 FTE, the following units move to "sigla" (instead of being under "Dotazioni") in 2023: SA (directly), TO, PD, RM2.

Group	Local Responsible	Researchers	FTE
BA	D. Elia	10	2.4
BO	R. Preghenella	11	2.75
CS.DTZ	S. Fazio	3	0.8
CT.DTZ	C. Tuvé	4	0.7
FE.DTZ	M. Contalbrigo	2	0.5
GE	M. Osipenko	7	1
LNF.DTZ	M. Mirazita	2	0.1
LNS	F. Noto	4	1.7
PD	R. Turrisi	6	1.35
PV.DTZ	M. Radici	1	0.1
RM2	A. D'Angelo	7	1.0
SA	D. De Gruttola	9	1.5
TO	M. Ruspa	7	1.1
TS	A. Bressan	11	4.8
Resp. Nazionale: P. Antonioli	**Totali:**	85	20.0

Table 2: list of EIC_NET groups in 2023, with local responsibles and dimension of the groups. The number of FTE includes percentages from synergistic initiatives (STRONG2020, AIDAInnova) in few units: BA (0.2), BO (0.25), TS (1.0). Researchers here include technologists. In addition a CTER position is funded 100% at INFN FE for the project.

1.5 EIC governance / relevant contacts within INFN

The RN in 2021 and 2022 maintained frequent contacts with INFN Giunta Esecutiva for mutual exchange of relevant information, in particular with respect to the relationship with US Department of Energy, but also in occasion of GE high-level meeting with IN2P3/CEA (to update on the expected contribution of French funding agencies to the EIC).

The EIC governance, following high-level meetings with key funding agencies, is gradually morphing toward a governance model more similar to CERN. There will be an EIC Advisory Board (with evidently less power than the CERN Council, but where top management representatives of funding agencies will sit and a mandate oriented to the construction of the facility) and Resource Review Board (*à la CERN,* and a mandate oriented to the scrutiny and funding of the detectors). These two bodies are expected to start operations by the end of 2022 with INFN representatives in both of them.

The INFN GE (D. Bettoni) repeatedly stated the willingness of the INFN to contribute also to the accelerator part: the LNF Research Division was tasked by BNL to contribute to the SEY (Secondary Electron Yield) materials characterization, a matter of concern in particular for the hadron ring. The "EIC opportunity" was stressed by CSN3 chair and detailed by Alessandro Gallo, in their respective talks at INFN Acceleratori workshop held in Milan 7-8 April 2022 (https://agenda.infn.it/event/29704/timetable/#20220407) with the potential of the realization - as INFN in-kind - of the design, engineering and construction of hadron ring inserts (for a 3.8 km ring!) to curb SEY. Final decisions on this matter are evidently within the exclusive remit of INFN Giunta Esecutiva.

P. Antonioli, as EIC_NET RN, led the process to detail in a document the synergistic activities among three CSN3 sigle: ALICE, EIC_NET and NA60+. The process was initiated in July 2021 with a devoted meeting (https://indico.cern.ch/event/1059080/). Given the expected timeline of R&D and constructions (ALICE 2.1 ITS3 → EIC/NA60+ → ALICE3 TOF/RICH), the three experiments will work in enhanced coordination for the R&D requests during the upcoming years. The document was finalized in June 2022 and circulated to CSN3, referees and GE (D. Bettoni). It is available here: https://cernbox.cern.ch/index.php/s/C7QUuny57ibvmxJ

1.6 Internal organization and Giornate Nazionali 2021 and 2022

Despite the pandemic, the EIC_NET community in 2021 was finally able to meet again in presence in Turin (20-21 December: https://agenda.infn.it/event/28762/). The meeting had around 60 participants with half of them in presence (the meeting was run in hybrid mode). As usual the first part of the meeting was open to the wider community with several non-EIC_NET members getting closer to the project (from Turin, Salerno, PV and LNF). There were also talks discussing the potential INFN contribution for the accelerator part and a talk by Elke-Caroline Aschenauer, Co-Associate Director for the EIC Experimental Program.

In addition to the Giornata Nazionale a growing number of meetings happened in 2021 given the increasingly inter-connected R&D activity (especially for dRICH test beams preparation, see next section). Regular meetings were held for the simulation and among Comitato EIC_NET Italia, made of RN and RL. In addition, it is important to say that, in the second half of the year 2021, for coordination purposes many meetings were "naturally subsumed" by the corresponding one in the ATHENA Collaboration while preparing the detector proposal.

In 2022 the Collaboration started to scale up operations and coordination in Italy.

National (online) meetings are held every three months: the first two were held 31st January and 28th March. In the latter the community met for the first time after the release of the DPAP report, and it emerged clearly the willingness to work on Detector 1, under the projects selected since some time (dRICH, Si-vertex, streaming readout, software and computing) with no interest for the second detector. Next national meetings will be next October 3rd and December 5th.

The 2022 Giornate Nazionali were held in Catania, 30 June-1st July, with an extended agenda (1.5 day instead of 1 day). The talks are available at: https://agenda.infn.it/event/30932/. The meeting was attended by 56 participants (with just few connected online, the rest in presence). It was also a meeting to start more closed R&D collaboration among groups in the preparation of 2023 budget and activities. It is visible the increased R&D activity by different groups as well as the progressive focusing on key activities where the INFN is expecting to contribute more on Detector 1.

In the day-by-day operations there are now three main coordination groups:

- dRICH, convened by M. Contalbrigo (FE)
- Simulation and Physics Performance, convened by A. Mastroserio (BA) and S. Fazio (CS)
- Si-vertex, convened by D. Elia (BA) and G. Contin (TS)

Bi-weekly meetings are held every Monday (in alternate weeks, so every week there is a meeting) for the dRICH and Simulation groups, while the Si-vertex group meets via the regular EIC Silicon Consortium meetings.

A full repository of EIC_NET meetings is available at: https://agenda.infn.it/category/1147/

Since July 2022 it was established a Coordination Group that includes, besides the RN and leading coordinators of activities listed above (and M. Battaglieri (GE) for streaming readout and A. Bressan (TS) for computing), all the INFN persons currently having management or convenership roles in "Detector 1" Collaboration (and listed in section 1.3). Interestingly such a decision marks the on-going organizational transition from a model "network-oriented" to an enhanced coordination of the groups now "experiment-oriented".

2. EIC_NET R&D activities (Jan 2021 - June 2022)

2.1 Physics and software/computing coordination

2.1.1 Spectroscopy programme at the EIC (GE, RM2)

A renewed interest in the field comes from many unexpected observations of exotic hadrons in the heavy quark sector including the proliferation of non-standard multi-quark mesons, the so-called XYZ states, the observation of charmed penta-quark Pc baryons and meson-gluon hybrids. While these discoveries came from e+e− colliders and b-hadron decays at LHCb, it is now recognized that they can be studied in alternative processes such as photo- and electro-production. Experimental groups from Rome2 and Genoa are involved in fixed target experiments using CLAS at the Jefferson Laboratory, which provide access to the light-quark regime, including hybrid baryons and s-channel production of Pc. The 12 GeV electron beam however is not enough to produce XYZ states via t-channel exchange. JLab leadership and the user community are currently discussing a 24 GeV upgrade of the CEBAF accelerator to extend the current program to the charm sector. If it will happen, the hadron spectroscopy program at EIC will benefit by the natural extension to higher energies. The ability to study heavy quarkonia through photoproduction in ep collisions has been proved at HERA while the COMPASS collaboration has studied muon production of the J/Ψ final state finding an indication of a new X(3872) state. The high luminosity expected at EIC, coupled with a detector having high acceptance for exclusive processes, opens the possibility to access the most relevant topics in hadron spectroscopy. The main physics interests in ep processes are:

- exclusive production of XYZ states via coupling of the quarkonia to intermediate light mesons in the t-channel ;
- production of XYZ in semi-inclusive e J/Ψ nπ processes;
- search for Pc heavy pentaquarks with hidden charm in the s-channel production of J/Ψ, where the signature is given by deviations of the cross- section s dependence from the quark counting rule;;
- search for Pb heavy pentaquarks with hidden bottom Pb in the s-channel production of Υ(nS);
- J/Ψ and Υ production via odderon (3 gluons) exchange;
- study of proton-resonance transition GPDs from hard exclusive electro-production of photons and mesons (π,ρ,φ,ω..),providing insight on the quark and gluon content of the excited states of the nucleon.

The access to e-A processes allows one to study the effect of medium propagation of exotic hadrons in cold matter and nuclear transparency. Relevant topics of interests might include: X(3872) and other exotic hadrons propagation in cold nuclear matter. An additional open heavy flavor process of interest is the study of transition GPDs in $\Lambda_c D^0$ associate charm production.

In 2022 the GE and RM2 groups identified some of the above mentioned reactions accessible at the EIC using the initial available luminosity. Based on cross-section estimates provided by M.Albaladejo et al. (Phys. Rev. D102 (2020) 114010) and assuming a reference luminosity of 10^{33} $cm^{-2}s^{-1}$ and an effective parametrization of the EIC detector, a detailed analysis of the reaction gamma $\gamma\ p \rightarrow e'\ Z_c(3900)^+$ (with $Z_c \rightarrow J\backslash\psi\ \pi^+$ and J/ψ to e^+e^-) provided yield estimates for different beam energiy configurations. Assuming a 10 GeV-100 GeV center-of-mass energy the exclusive Z_c detection yield is expected to be in the range of ~150k events (~10k with the scattered electron in coincidence) in six months. A similar study, performed on Y(4260) and X(3872) show a detection yield of ~100k and ~500k events, respectively. From this study, we concluded that reasonable statistics could be collected in the first year of operations allowing the study of the XYZ exotic states at EIC.

2.1.2 Exclusive Processes: partonic imaging in coordinate space (CS)

The main goal of this program is paving the way to the extraction of generalized parton distribution functions (GPDs) from measurements of hard exclusive processes in electron+nucleon scattering at the EIC. GPDs describe the quark-gluon structure of nucleons in longitudinal momentum and transverse position and thus allow one to create tomographic images of the partonic structure. In addition, GPDs provide access to the energy momentum tensor describing the distribution of mechanical forces inside the nucleon. Observing the change of the spatial gluon distribution from low to high Bjorken-x might give us a hint on the underlying mechanism of saturation.

Innovative analysis techniques combining the use of neural networks and recently developed next-to-leading (NLO) models can now be applied to extract information on GPDs by global fits of combined deeply virtual Compton scattering (DVCS), Time-like Compton scattering (TCS) and hard exclusive meson production (HEMP) measurements. The creation of a novel GPD-based Monte Carlo and a common software platform is key in evaluating the requirements - in terms of kinematic reach and luminosity - for a precise extraction of flavor-separated GPDs at the EIC. This assessment is of the utmost importance in driving the complementarity in design of EIC detectors and the two interaction regions and should therefore be performed with high priority. These studies include the evaluation of the physics impact of an unpolarized positron beam, discussed as a facility upgrade to the current EIC base design having only an electron beam.

The CS group led the way by initiating close collaborations with colleagues from theory and experiment, with the aim to develop common software platforms and simulation tools that will enable us to perform next-generation studies of partonic spatial imaging. We have established a collaboration with key international partners from BNL, Stony Brook, CEA-Saclay, NCBJ-Warsaw, Mainz and Zagreb Universities.

During the year 2022 the first version [arXiv:2205.01762] was released. It is a unique Monte Carlo generator for hard exclusive processes, called EpIC, initially capable of simulating DVCS, TCS, π^0, based on available GPD models (GK, KM20), and featuring a state-of-the-art simulation of the initial- and final-state radiative effects. The EpIC paper has also been submitted for journal publication.

2.1.3 Radiative correction effects at the EIC (TS)

The study of radiative effects in the lepton-nucleon scattering and the determination of Radiative Corrections (RC) is an essential ingredient for the physics of the EIC (as well as for JLAB and COMPASS). The TS group is in continuous contact with the main author of DJANGOH, Hubert Spiesberger, for improving the code and the last version was installed in July 2021. An important aspect for these codes is the validation of the results over existing data; the use of COMPASS data for this purpose results particularly important. Non-polarized events with Djangoh were simulated and kinematic distributions reconstructed (including TDM variables). We aimed to compare Djangoh with radiative effects introduced in PYTHIA 8.3, i.e. a modern, full purpose, MCEG, but there are delays in the implementation of inclusive RC effects (radiative tails, elastic and semi-elastic and therefore a full comparison between PYTHIA and Djangoh is still to be performed).

2.1.4 Software and computing coordination

Coordination of the EICUG Software Working Group:
The EIC SWG has strongly contributed to the tools used for the studies included in the Yellow Report. The group has prepared a single entry point for all the software tools from the web page eic.github.io. Here are stored all the Monte Carlo Event Generators used to simulate all the processes of interest at an eA collider, i.e. PYTHIA6 (PYTHIA8 is under evaluation), BeAGLE, DJANGOH, MILOU, RAPGAP etc; all the codes for fast and full detectors simulation and the singularities for job submission. Regular weekly meeting to monitor the activities and organize the work are held.

In the spring of 2021, the Conveners of the EIC-SWG, have started a new Software Project called eAST (eA Simulation Toolkit) with Makoto Asai, the former spokesperson of the GEANT4 Collaboration as Project Leader. The scope of the project is to prepare a modern, GEANT4 based, code, capable of exploiting all the new features of GEANT, that will be used both for full and fast simulations. We have outlined the following requirements:

- ability to reuse existing simulation work
- ease of switching detector options
- ease of switching between detailed and coarse detector descriptions
- ease of leveraging new and rapidly evolving technologies (e.g., Artificial Intelligence and Machine learning, AI/ML), computing hardware (e.g.,heterogeneous architectures)

Meetings to share the work and shape the different aspects of the project were started at the beginning of June 2021 and continued regularly on weekly basis (Developing Project eAST). An indirect support to this initiative from INFN comes from the test of the program MRADSIM Converter, which is a tool to convert STEP format CAD files to GDML format on Linux operating systems. The development of such program was started within the MC-INFN GR V initiative. The developers are very supportive and promptly fulfil our needs for modifications. A MoU for the use of the code was requested by MRADSIM developers. This information was passed to our JLab colleagues, but it is taking some time due to the legal aspects which have to be review by the legal department of JLab.

Presently both by BNL and JLAB are making available computing resources for the EICUG community via the OSG . To participate in this effort, the INFN Groups have made available resource via OSG. Contacts are maintained with CNAF-Support in order to prepare for this. The configuration used by the EICUG on OSG was being prepared at CNAF and then used for the 2021 summer simulations (as part of the detector proposals campaign) S3 storage is available at BNL and the jobs included a task to transfer there the outputs.

EIC Computing Coordination Group:
In order to deal with the computing needs of the proto-collaborations the Steering Committee have formed, in June 2021, the EIC Computing Coordination Group; members of this group are laboratory representatives (Graham Heyes for JLab and Jerome Lauret for BNL), a representative from the EIC Software Working Group (Andrea Bressan, TS) and representatives from the proto-collaborations. This group has been reshaped after the formation of the Detector 1 collaboration. The core components were not changed (Jerome, Graham and Andrea) but instead of representatives from the proto collaboration now we have two representatives from Detector 1 software conveners (Wouter Deconinck and David Lawrence). The group is meeting once per month and, if needed, on short notice to discuss urgent needs in case of simulation campaigns.

2.2 Detector Simulation (BA, BO, Roma1, TS)

In 2021 the detector simulation activity has been focused at the beginning of the year finalizing the contribution to the Yellow Report preparation and later to the detector simulation within the ATHENA proto-collaboration. The DPAP report and the merging of the proto-collaboration inevitably delayed this process, given there is a need to make uniform choices between the software frameworks adopted (in short the software “stack” selected by ATHENA is pretty complex but very modern and a clear investment for the future, the one used in ECCE is more basic but more easy to deploy).

D. Elia (BA) has served as convener of the Tracking Working Group for the YR up to its finalization and then as convener of the Tracking for the ATHENA proto-collaboration and the corresponding preparation of the Detector Proposal due by the end of 2021. The contribution to the Tracking WG by the BA group has been mainly devoted to study the performance for the central silicon vertex layers in combination with different configurations of outer (gaseous detector based) layers and sets of silicon disks at large pseudorapidity in the backward/forward regions. The relative momentum resolution and the pointing resolution to the vertex have been studied as a function of momentum/transverse momentum for different detector configurations. Results have been first analytically estimated via a fast simulation tool already used in the past for the ALICE inner tracking system upgrade (years 2011-2014) and then further improved in a more realistic environment using one of the full simulation packages available from the EIC Software WG (EicRoot).

Such studies have been functional to the definition of the two baseline central tracking systems included in the Yellow Report, namely a more compact full silicon tracker and a vertex tracker complemented with gaseous detectors at larger radii. The contribution to the ATHENA Tracking WG was initially devoted to the migration of the simulation tools from EicRoot to Fun4All environment. The BA group contributed to the full validation in Fun4All of the performance for the different configurations identified by the ATHENA Tracking WG, with work based on single-particle event simulations (charged pions or electrons) for the study of momentum and pointing resolution in different momentum and pseudorapidity ranges. Tracking performances were also checked against different magnetic field maps (with central top strength of 3 T), based on the outcome of the first preliminary magnet design attempts within the proto-collaboration. Results for the final selected tracking configuration, fully studied in Fun4All in the initial stages, were finally compared with the corresponding ones from the full integrated simulation, where the same tracking system configuration have been implemented (together with the other ATHENA detectorsub-systems) by the Software Working Group in the DD4Hep framework.

Since few months, with the EIC project moving to the “Detector 1” collaboration mode, the Tracking WG is dealing with the optimization of a reference design starting from the ECCE and ATHENA tracking configurations. In this context, the BA group is continuing the contribution and support to testing the performance of the ECCE tracking system with different variations (eg including additional material budget for the support structures and varying the radial position of the sagitta layers) via two fast simulation tools. The first one is the already mentioned fast tool for the ATHENA which was validated for ECCE geometry by means of the full simulation results provided by Fun4All. The second one was developed in a completely analytical approach and it introduces the possibility to disentangle detector resolution effects from multiple scattering effects in both momentum resolution and transverse pointing resolution in any configuration of barrel layers.

Multiple contributions to Monte Carlo simulation studies for the Particle Identification have been given by various groups within the EIC NET community (BA, BO, Roma1, TS). The main focus was on the study of RICH performance for particle identification in the forward hadronic direction at the EIC, within the framework of the Yellow Report effort of the EIC User Group in 2020. The studies have extended in the year 2021 following the organisation of the work and the formation of proto-collaborations towards the preparation of the Detector Proposals. One member of these groups (R. Preghenella BO) served as co-convener of the PID Working Group of the ATHENA proto-collaboration and it has been then appointed (in April 2022) as co-convener of the newly established Cerenkov-PID working group (covering the RICHes - back and forward - and the hpDIRC).

The INFN community contribution to the simulation activities was characterized by multiple actions:

- the porting of the dual-radiator RICH (dRICH) simulation code from the original implementation in the GEMC Geant4 Monte Carlo simulation framework into the Fun4All and Escalate Monte Carlo simulation frameworks developed by the Software Working Group of the EIC User Group. The definition of the dRICH geometry, materials and their optical properties have been adjusted to fit into a generic software library that can be easily interfaced and used by multiple Geant4 simulation frameworks; in this context, also the backward PID device introduced by the ATHENA Collaboration, namely the Proximity Focusing RICH (pfRICH) has been introduced and simulated;
- work to implement the simulation of the dRICH within the DD4Hep Monte Carlo framework adopted by the ATHENA proto-collaboration;
- studies for the optimisation of the dRICH configuration and adjustments to its geometry and optics to fit the detector into the allocated volume as defined by the current specifications of the ATHENA detector;
- further improvements toward improved performance and larger portability, of the inverse ray tracing Cherenkov based angle reconstruction and

performance analysis code originally developed for the characterization and optimization of the EIC-baseline dRICH detector and for a computationally efficient PID algorithm;
- studies on the impact of a realistic magnetic field on the particle-identification performance of the forward RICH detector (these studies were performed within a standalone Geant4 framework with simplified version of the forward RICH using two possible configurations of realistic magnetic field maps)
- the fast simulation of a focusing RICH for high-momenta, with an innovative eco-friendly solution based on pressurized Argon as Cherenkov radiator. Preliminary performance studies have been made available and need to be further improved with a realistic description in the full simulation framework;
- R&D studies of a Cherenkov detector based on an aerogel radiator in a proximity-focusing configuration in collaboration with ALICE studies for an upgraded heavy-ion experiment at the LHC. Preliminary, even if already detailed simulation results were obtained and the performance has been encoded in the fast simulation tools and presented at the ATHENA PID meeting as well. The results will be complemented by further simulation studies of a prototype system to be tested with beams.

As mentioned before, all these studies contributed to the presentation of the ATHENA detector proposal.

The EIC project is moving now to a Detector 1 proposal arising mainly from the ECCE and ATHENA designs: all these simulation studies are expected to be further refined during 2022 (and 2023). As part of this process the INFN EIC_NET dRICH community organized a meeting of different experts from RICH experiments (HERMES, COMPASS, ALICE-HMPID, LHCb. CLAS12/JLAB). The meeting was convened by M. Contalbrigo (FE): https://agenda.infn.it/event/30966/ .

Being EIC_NET a networking initiative, it is worth to note that some of all these studies were done in strict collaboration with non-INFN groups, as from Duke University, and BNL, somehow starting to coalesce the potential pool of institutions that will support the dRICH detector.

2.3 Detector R&D: dual RICH activities (BA, BO, CT, FE, LNF, LNS, RM1, TO, TS)

2.3.1 dRICH prototype (CT, FE, LNF, LNS, RM1)

The dual Ring Imaging Cerenkov (dRICH) detector is part of the reference detector for EIC. It is under design and development to provide full hadron identification from

3 GeV/c up to 60 GeV/c in the ion-side endcap. It also offers a remarkable electron and positron identification from a few hundred MeV/c up to about 15 GeV/c. In addition to the extended momentum coverage, dRICH needs to operate single-photon detection inside the strong (about 1 T) magnetic field of the EIC solenoid. The main technical goals for the reporting period have been preparation of the dRICH prototype test-beam and SiPM irradiation campaign. In the year 2021 important accomplishments were achieved: dRICH baseline prototype realization, initial SiPM irradiation campaign, and first beam test. All groups (including the ones working on SiPM) contributed to the test beams activities with different involvements.

Details of the prototype design were finalized (FE, RM1, LNF and LNS), including: the cylindrical vessel made of standard vacuum parts to support pressures different from atmospheric one, the mechanical support, the mirror system and alignment, the ancillary systems (tracking, trigger, gas and slow control). Despite difficulties in the procurement of all components, the goal to have the prototype ready for the test-beams planned in Fall 2021 was reached. The proposed prototype configuration has been modelled and simulated in gemc/Geant4. The prototype design resolutions are close to those expected in EIC, except for the pixel size contribution with the aerogel radiator due to the adapted focal length of the corresponding mirror.

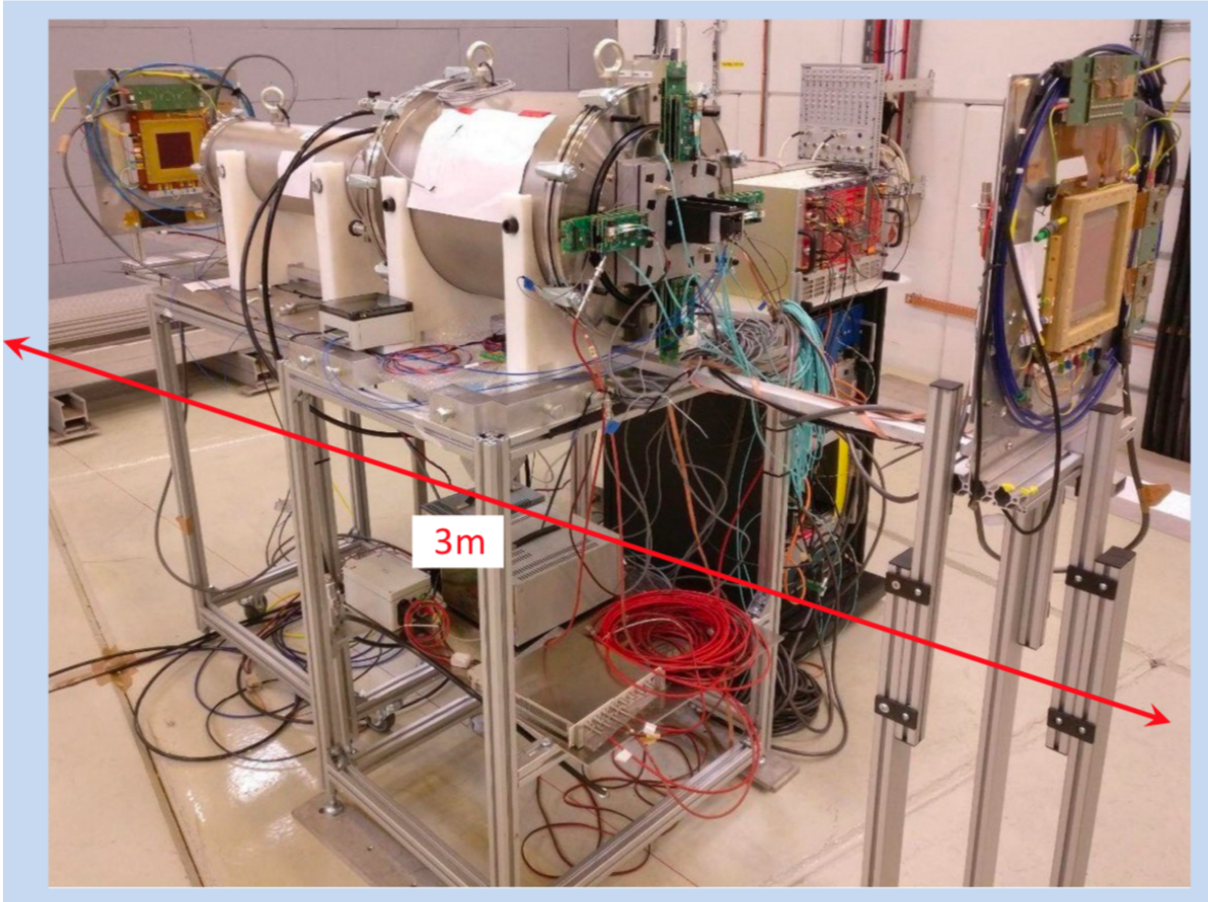

Fig. 1. The dRICH prototype at PS T10 in October 2021. The two GEM layers for tracking (provided by INFN RM1) are also visible, as well as the detector box (here with PMT from HPK and CLAS12 readout electronics) mounted on the front face of the prototype (beam from right).

Custom detector boxes to mount diverse sensors at the dRICH entrance window (separating gas and aerogel) were produced. Large area sensors (borrowed from the EIC eRD equipment) were used in conjunction with the CLAS12 readout electronics to test the optical performance of the prototype: Hamamatsu H13700 photo-multipliers were used as reference, S12642-1616PA MPPC matrices were used to practice with magnetic tolerant devices. Small custom-made matrices of state-of-the-art SiPM were also used with dedicated ALCOR readout electronics as detailed below. The detector box was designed to control in temperature the SiPM sensors, down to -30 Celsius degrees, to mitigate the high dark count rate.

In September 2021, the dRICH prototype was for the first time tested at the CERN H6 SPS beam line, using the proton pencil beam at 120 GeV/c and mesons with momenta between 20 GeV/c and 60 GeV/c. Subsequently, in October 2021 the setup was moved at the CERN T10 PS beam line where a test was done in synergy with ALICE using mesons with momenta below 15 GeV/c. During the beam time all the dRICH prototype subsystems were successfully commissioned, the first double-ring images were obtained, and various working configurations were tested, making use of Russian and Japanese aerogel and C_2F_6 gas. The beam conditions were not optimal, without a tagging-particle detector provided by CERN, and machine parameters not completely under control: it was literally the first test beam at PS after the LS2, the pandemic and the overdue refurbishment of all PS halls.

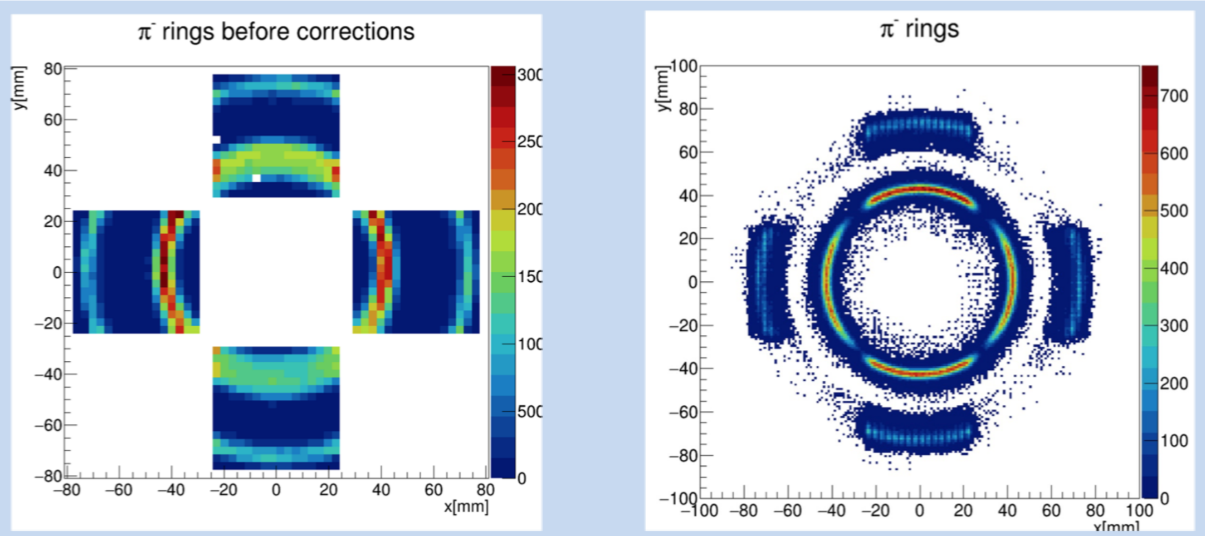

Fig. 2. Double ring images obtained with pions, before tracking correction (left) and after tracking correction (right)

This R&D activity is synergistic with developments of the proposed RICH for ALICE3 (where an aerogel radiator is also foreseen) and got additional funding via EIC-eRD102 project.

Preliminary results of the test beams were discussed at Giornata Nazionale EIC in December and presented at INFN2022 Workshop (S. Vallarino, FE), and accepted as a poster at RICH2022 conference (September 2022). Further analysis of the data is ongoing to detail the optical performance, tune the simulations and prepare the next test-beam (September and October 2022). A considerable effort has been done improving tools for alignment, time and gain calibration, as well as upgrading the support structure and trigger.

2.3.2 SiPM studies and readout electronics (BO FE TO)

In 2020 a collaboration has been initiated among several INFN groups interested in the application of SiPM for Cerenkov imaging, to pursue a systematic investigation of the SiPM use for RICH detectors at EIC.

After a wide-range survey of the available SiPM candidates, a selection of the most interesting state-of-the-art devices has been acquired from Hamamatsu, Broadcom, OnSemi-conductors and Bruno Kessler Foundation. Carrier boards were designed to carry groups of 4×8 SiPMs, support the irradiation and annealing cycles and provide direct access to each sensor for laboratory characterization. Such configuration allows one to test SiPMs from different producers and at different levels of irradiation, up to 10^{11} equivalent 1-MeV neutrons per cm^2 (the maximum expected at EIC).

The SiPM sensors have been characterized with laboratory instruments (BO and FE): current versus voltage and dark count measurements have been performed at various temperatures, from 20 down to -30 Celsius, with the help of climate chambers. A first SiPM irradiation campaign, with Hamamatsu and FBK sensors, was performed at the TIFPA INFN facility at Centro di Protonterapia in Trento, Italy, in May 2021. Several samples of four types of sensors have been irradiated at levels ranging from 10^8 up to 10^{11} equivalent 1-MeV neutrons per cm^2. After irradiation, the sensor characterization was repeated before and after annealing at increasing temperatures, from 50 up to 150 Celsius.

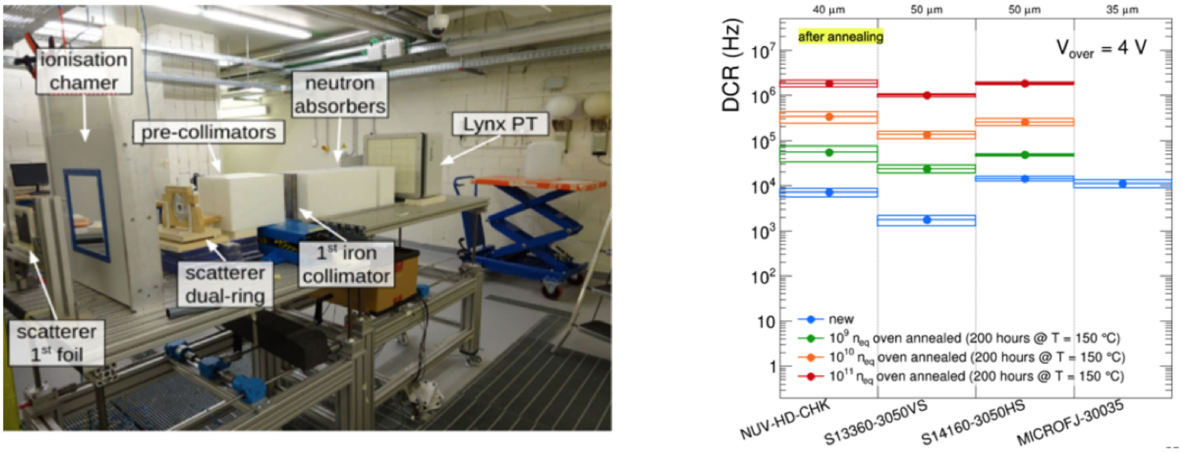

Fig. 3. The setup used at Centro di Protonterapia in Trento to collimate the beam on different sensors (left) and DCR after annealing for different sensors (right)

Results are encouraging, with a reduction of the DCR after annealing by a factor 50, depending on the sensor. Annealing by applying a direct bias (to heat the sensor via Joule effect) is also under study.

The 2022 campaign aims to test the reproducibility of repeated irradiation - annealing cycles on the same sensors at increasing radiation load. First irradiations took place at Trento on 4th June and 16th July, with two other irradiation sessions scheduled by the end of the year.

During the first semester 2022 a full-fledged characterization setup for the SiPM was developed in Bologna, allowing simultaneous measurements on different sensors in the climatic chamber of I-V, DCR and relative PDE (using a LED and a motor stage). The readout is made via the ALCOR chip (INFN TO), with the bias distribution system provided by INFN FE and readout via FPGA from INFN BO.

This R&D activity is synergistic with developments of the proposed RICH for ALICE3 (where a SiPM readout is foreseen) and with AIDAinnova (WP 7 – Task 7.5.1: Photon detectors for hadron particle identification at high momenta) and got additional funding via EIC-eRD110 project.

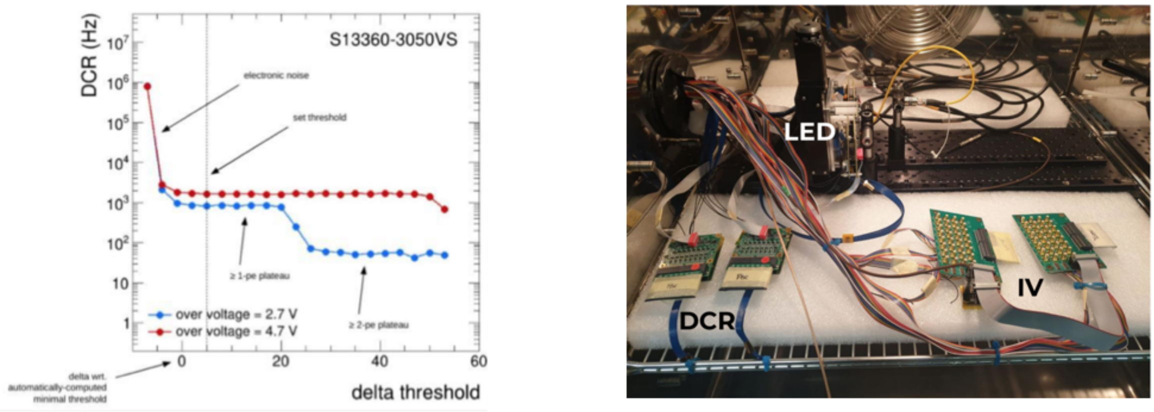

Fig. 4. An example of a I-V characterization using the ALCOR chip (left) and an image of the climatic chamber in Bologna with the different SiPM carrier boards under different tests.

The development of a dedicated readout electronics compatible with the SiPM temperature treatment has been planned based on the ALCOR chip and ARCADIA DAQ, two in-house INFN developments. Designed for cryogenic applications, the ALCOR chip applies a time-over-threshold analysis of the discriminated signals and can be evolved following the dRICH specifications. With a proper readout chain, the chip could provide 50 ps bin timing and sustain a rate up to 500 kHz per channel.

The first version of the ALCOR chip (TO) became available in the early months of 2021, mounted on specifically designed readout bords interfaced with the SiPM matrix. The DAQ, based on IPBUS implemented on a Xilinx Evaluation Board (BO), was successfully deployed during test beams in September (SPS) and October (PS). A second version of the ALCOR chip was submitted in May 2022 and it is expected to be available by October 2022. The second version implements a fix in the digital readout logic and an improved gain in the amplification stages (for SiPM with small signals). Moreover the internal pulse generator has been modified to support both signal polarities and the front-end bias has been improved to reduce the noise level. A third version of the chip should foresee 64 channels, AC-coupling tailored to the chosen sensor and possibly improved bandwidth. This work is led by INFN TO.

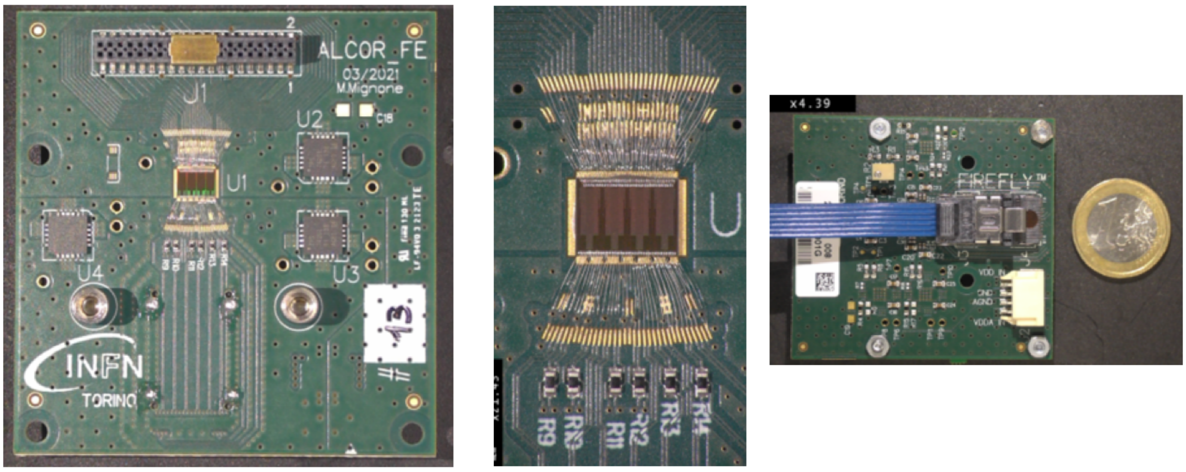

Fig. 5. The ALCOR readout board realized for EIC SiPM readout (left), the detail of the wire-bonding connection of the ALCOR (center) and the card with the FireFly cable (databus toward the FPGA)

Results of the SiPM campaign were presented, besides at internal meetings including the ones with EIC management, at INFN2022 CNS3 Workshop (N. Rubini - BO), at the ICHEP2022 Conference (L. Rignanese - BO) and at “New Developments in Photodetectors” conference (4th-8th July 2022) (R. Preghenella - BO). A talk was accepted at RICH2022 conference in September.

2.3.3 LAPPD studies (GE TS)

LAPPDs are large-size (200×200 mm^2) MicroChannel Plates (MCP) with photon converter by bialkali, covering the visible range, and are an interesting alternative to SiPM, even if, in spite of the long R&D path of the project, the technology is not yet fully mature. The long lasting development, performed in a combined effort by academia (Argonne National Laboratory, University of Chicago) and industry (INCOM), aims at providing what the commercially available MCP devices do not offer, namely large size and moderate cost per unit area.

LAPPD, generation 1, is now commercially available. The QE-values are the typical ones for bialkali photocathodes and the homogeneity over the large surface is satisfactory. Generation 1 anode is segmented in strips, namely not adequate for single photon detection. LAPPD, generation 2, is at prototype level. It is characterized by a resistive anode by a thin Cr film. The read-out elements are faced to the external anode face and the signals are capacitively collected. Test-beam results at BNL in 2021 indicate that, using a read-out plane segmented in small pads (~ 4×4 mm^2), sub millimetric space resolution can be obtained.

This R&D activity is synergistic with developments for an aerogel RICH in AMBER (RICH0) and with AIDAinnova, WP7, task 7.5.1 and got additional funding via eRD110 project.

After key networking and establishment of needed industrial and scientific contacts in 2021 and securing a post-doc position to this aim in TS, the activity started in 2022. Equipping the Trieste laboratory took longer than foreseen due to the delayed delivery of the purchased equipment, a global feature experienced worldwide in 2022. As planned, the initial phase of the studies was performed in TS, where pulsed light, which can be operated in single detected photon mode, are availables. The GE team contributed with the realization of signal preamplifiers and visiting TS for common work in the laboratory. A digital scope with data storage options is being used for the very first exercises. The multiple read-out (32 channels) system based on the front-end ASIC DRS4, embedded in the V1742 VME 32-channel module financed in 2022, has been put in operation with the support of INFN GE. The electronic chain will support more advanced characterization. A very encouraging rate DCR of 140 Hz/cm^2 was measured at room temperature.

Measure	P1:rise2080(C4)	P2:fall8020(C4)	P3:pkpk(C4)	P4:pkpk(C4)	P5:- - -	P6:area(C4)
value	350 ps	629 ps	13 mV	384 mV		
mean	< 277.13 ps	< 612.79 ps	18.00 mV	> 395.05 mV		
min	< 89 ps	< 120 ps	4 mV	> 150 mV		
max	< 567 ps	< 913 ps	278 mV	> 928 mV		
sdev	< 122.74 ps	< 88.98 ps	19.51 mV	> 120.66 mV		
num	597	1.473e+3	1.477e+3	1.477e+3		
status	[illegible]	✓	✓	✓		

Fig. 6 The dark-box realized in TS to house the LAPPD (left) and the signal shape output from the LAPPD using an Agilent 33220A (right). A time time resolution of 35 ps was preliminary estimated.

A more accurate measurement of the time response of the LAPPD can only be obtained in a test beam. A first measurement is planned in October 2022 using in parasitic mode the second test beam slot at CERN assured for the dRICH studies. A quartz lens will be used as Cherenkov radiator and time resolution will be extracted comparing the response of the detector to isochronous Cherenkov photons generated by a same particle crossing the radiator.

The characterization of an LAPPD prototype in magnetic field is postponed to 2023, after consolidating the laboratory characterization studies.

A very successfull LAPPD workshop was organized on 21 March 2022 by INFN TS (S. Dalla Torre and D. Sankar Bhattacharya), Brookhaven and Argonne National Laboratories (https://indico.bnl.gov/event/15059/). The goal of the workshop was to promote world-wide synergies in establishing LAPPDs as suitable sensors for Cherenkov detectors, as requested by several future projects also beyond the EIC detector.

2.3.4 High pressure Argon as gaseous radiator (LNS, TS)

RICH detectors with particle identification capability in the high momentum range must use gaseous radiators. Fluorocarbon gasses are largely used thanks to their high density at atmospheric pressure, but fluorocarbons exhibit extremely large Global Warming Power (GWP) and they also destroy ozone. More and more restrictions are imposed on their use: gas recovery increases the complexity of the gas circulation systems, fluorocarbons commercial availability is compromised and results in increased costs. As noted in activity plan 2021, argon at a few bar pressure can reproduce the fluorocarbon gas features for what concerns both the Cherenkov photon yield and the chromatic dispersion. According to the desired refractive index, the absolute pressure can be selected in the range 2 - 4 bar. Argon is not harmful to the environment, has a moderate cost and it can be commercially available with good purity figures.

The design of a RICH with a gas vessel with a few-bar pressure capability and with limited material budget is a mechanical engineering challenge and requires selection of adequate options for the vessel wall. The mechanical requirements were initially defined in 2021 as preparatory actions for the 2022 activity. A few promising options are being considered as carbon-fiber foils and carbon-fiber honeycomb structures or aluminium composite (foils + honeycomb). Their capabilities will first be tested with finite element method (FEM) calculations. This approach is particularly suitable when the domain is variable, when the accuracy required of the solution is not homogeneous on the domain and when the solution sought lacks regularity. The solver we intend to use for the development of the forward RICH is COMSOL Multiphysics which, in addition to having its purely mechanical module, is also able to couple the fluid dynamics, that is fundamental for the optimization of the gas volumes inside the detector. Such simulations will allow us a thorough and detailed study of the detector.

Limited progresses were made in the first semester of 2022, given the general slow-down in these tasks, produced by the merging of the proto-collaborations and the consequent uncertainties on exact dimensions of the vessel/detectors. Initial contacts were put in place with BNL and JLab engineers with critical input needed about US safety regulations. The realisation of a full prototype is now foreseen for 2023, while in late 2022 a simplified vessel to check deformations of candidate materials will be tested.

2.3.6 Aerogel studies (BA, FE, RM1)

INFN BA and FE units are working on aerogel characterization, an activity synergistic with ALICE 3, in particular for the evaluation of the Japanese provider Aerogel Factory, a spin-off company from the Chiba University and the aerogel developer for the BELLE-II experiment. This would be an interesting alternative to the aerogel 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 report due to the Ukraine-Russia war. The assessment and optimization of aerogel optical properties is a common interest of ALICE and EIC_NET groups. EIC_NET groups not belonging to ALICE (INFN FE) have facility and consolidated expertise in this respect to offer.

In addition to the results collected during test beams (already with “Japanese” aerogel), a systematic characterization is started with the spectrophotometer available in FE, measuring the transmittance as a function of wavelength for various aerogel samples. Similar instrumentation is available in BA. Metrology measurements on Japanese aerogel samples are being carried out by BA.

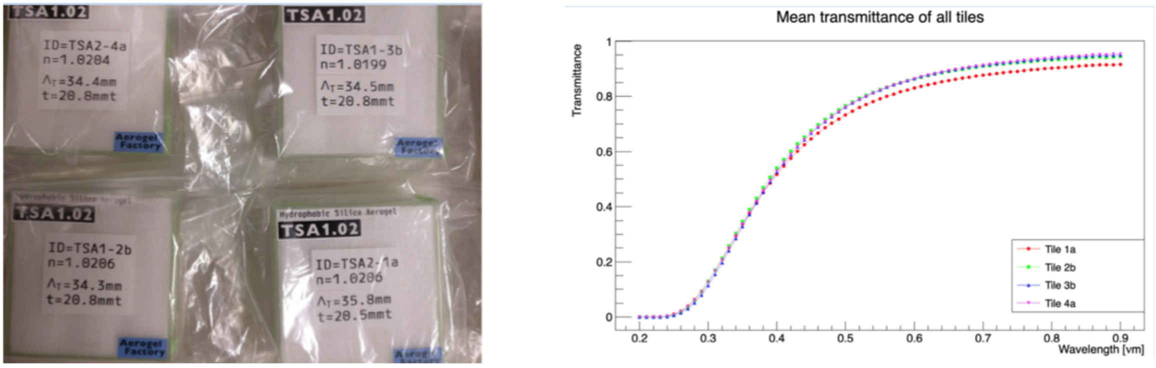

Fig. 7: Aerogel tiles samples obtained by Aerogel Factory (JP) and typical transmittance measurements (INFN FE)

The members of the RM1 group were also involved in a fiber reinforced aerogel project, aiming at the development and realization of low refractive index aerogel (1.02) with adequate mechanical robustness; this activity is clearly related and may have a significant impact on the dRICH component selection and realization. A Finite Element Method simulation has been consolidated and preliminarily validated on real data; the simulation is used as preliminary test of potential solutions and as realistic data generator for an automated AI based optimizer (similar approach used in the dRICH baseline design). Even if software is basically ready, due to lack of manpower in RM1 group this activity was suspended.

2.3.6 Gaseous single photon detectors for Cherenkov applications (BA, TS)

This activity relates to previous R&D, before selecting SiPM as the baseline option for photosensors of the RICHes at EIC. This work, indeed, already started before 2019 (EIC_NET creation) in the context of the Consortium eRD6 supported by the ”Generic R&D for the EIC” programme and of the INFN experiment RD FA (CSN 1) and intended to develop adequate gaseous photon detectors for a windowless RICH. This work was not brought to a conclusion in 2020/2021 due to all the disruption and limitations due to the pandemic. As a closure for all these activities, the studies will be documented in a coming PhD thesis and, for what concerns the novel photoconverter by hydrogenated nanodiamond powder, in a publication. The activity will be completed by 2022, while the completion of the documentation is foreseen by mid 2023.

a) Gaseous single photon detectors based on MicroPattern Gaseous Detector technologies

A high-momentum RICH counter at EIC, requires establishing the concept of a compact RICH imposing a short gaseous radiator and the detection of a large number of photoelectrons per radiator unit length, together with fine space granularity of the Photon Detectors (PD) because the shorter radiator implies shorter lever arm. One of the promising approaches was therefore a ”windowless RICH” with gaseous PD operated with the radiator gas itself and enlarging the number of produced photons by moving the detection window to extremely VUV photon. The completion of the construction and test of the second foreseen prototype in 2020 was not possible due to the pandemic (no access to the lab) and has been complete in the first part of 2022.

A different read-out electronics is coupled to the detector prototype. A different read-out system is based on the VMM3 front-end chip and the stand-alone VMM read-out board MMFE; both VMM3 and MMFE have been developed in the context of the ATLAS NSW project. VMM3 has been selected because of its low noise figure also when coupled to detectors with relevant capacitance, as it is the case for MPGDs, and its architecture is compatible with a streaming read-out DAQ approach. The prototype is now readout with the VMM3 front-end ASIC and its characterization with this readout approach will be completed by 2022.

b) Development of novel photoconverters for gaseous single photon detectors

The development of novel photoconverters compatible with the operation in gaseous photon detectors is complementary to this work. This activity is developed within the IDEA experiment (CSN 5). So far, CsI is the only photoconverter successfully used in gaseous detectors. It is fragile due to its chemical reactivity to water vapor and because the bombardment of the ions created in the multiplication process degrades the Quantum Efficiency (QE). The proposed novel photoconverter by Hydrogenated NanoDiamond (H-ND) powder is expected to be more robust, as confirmed by the initial studies. The development aims at establishing the use of photoconverters by H-ND in gaseous detectors and determining the key parameter of ND powders to obtain maximum and reproducible QE.

The identification of the key parameters for high and reproducible QE of the ND powder is at an initial stage and this development was fully based on laboratory activities, in 2020 and 2021 severely affected by the restrictions imposed by the pandemic emergency (as well as BA and TS campaigns of measurements and the access to the facility ASSET at CERN).

The study of the QE properties of the H-ND powder (line i), namely the selection of the best powder among those commercially available and the identification of the powder parameters that affect the QE is performed coating small disc-shaped substrates. The compatibility of the H-ND powder with THGEMs as photocathode substrate is pursued in order to prove that this novel photoconverter can be successfully coupled with MPGDs (line ii). A portable gas mixing system in view of well-controlled and reproducible measurements of the effective QE in different gas atmospheres has been realized.

Twenty new THGEMs have been produced by industry and then submitted to the refinement protocol in TS, previously developed for the COMPASS RICH upgrade. These fully characterized THGEM were therefore ready for coating with the photoconverter film. The next step of the construction of a small prototype of photon detector, including all the required MPGD stages, which will be equipped with a THGEM coated with H-ND film, is also beneficial to the development line (ii). the prototype has been equipped with the H-ND coated THGEMs and characterized
in its complete configuration.

A complementary exercise is ongoing aiming at a precise comparison of the effective QE of the novel HND photocathodes and photocathodes by CsI. For this purpose, a set of disk-shaped substrates have been mounted on an appropriate support adequate for coating the substrate samples with CsI in the CsI coating setup at CERN. In the CERN setup, the QE of the photocathodes is measured inside the coating setup itself immediately after coating. This measurement provides relative information about the QE, even if no absolute values can be obtained. In fact, no calibration of the response is available. Coated samples whose QE has been measured in the coating setup have been obtained. This measurement campaign has been completed in 2022 measuring QE in different gas atmospheres.

2.4 Detector R&D: Si-Vertex (BA TS)

The EIC will require a well-integrated, large acceptance tracking and vertexing system with high spatial resolution and low mass that exceeds the current capabilities of any existing highly granular pixel detectors. The Monolithic Active Pixel Sensors (MAPS) technology has been identified as the only sensor technology that can meet in the available time frame the particular requirements the EIC imposes on pixelation, power consumption, and material budget.

Some of the EIC_NET INFN groups (BA,TS) are involved in the development of a new-generation MAPS in 65 nm CMOS imaging technology for the ALICE ITS3 project, whose sensor specifications and development timescale are largely compatible with those of the EIC. Within the ALICE ITS3 R&D activities, the EIC_NET INFN groups worked on bending, thinning and interconnecting single-reticle sensors and large-size MAPS chips, and on characterizing them in flat and curved geometry. The results of this R&D activity, published in https://doi.org/10.1016/j.nima.2021.166280, demonstrated that curved MAPS sensors maintain their performance when bent, and that they can be used for the construction of the EIC innermost vertexing layers with truly cylindrical geometry. The INFN groups have also been involved in the design and production of the test system for the characterization of the first test structures designed and fabricated in 65 nm CMOS imaging technology. These prototypes will be exploited for the design of the EIC silicon tracker system. The first 65 nm structures produced in the MLR1 (multiple layer per reticle) production in 2021 are currently being characterized in laboratory measurements and beam test campaigns, while the design specs for the first engineering run (ER1) have been just submitted. An illustration of the stitching design for the ITS3 sensor is reported in Fig.xy.

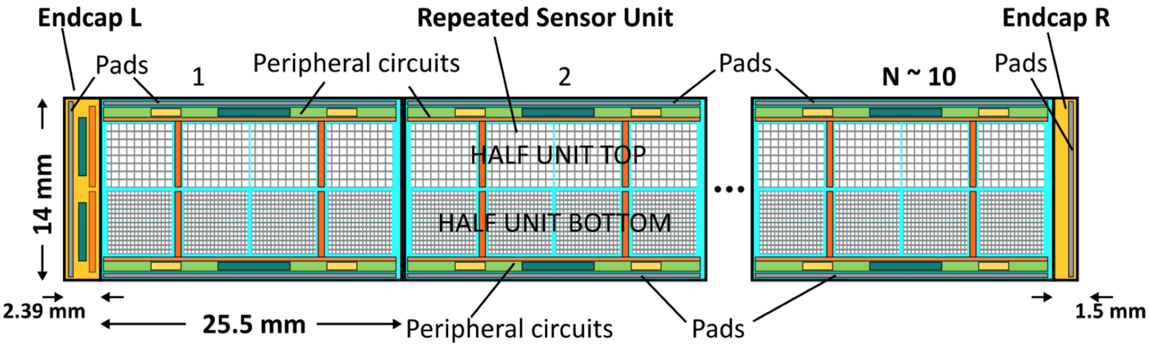

Fig. 8. Example of stitching design for the ALICE ITS3 sensors.

The reticle size is not yet fixed, although the best value for the ITS3 radii targets overall sensor dimensions of 18.85 mm x 30 mm that could be also suitably adapted to the EIC innermost layers. The impact on the detector configuration and performance of this option and alternative stitching plans are currently being investigated within the Detector 1 Tracking WG.

In the last years, the INFN BA and TS groups joined the effort started within the eRD25 program, built upon the prior work of eRD16 and eRD18, and culminated in the EIC Silicon Consortium (EIC SC), to develop a dedicated MAPS sensor with associated powering, cooling, support structures, control and ancillary parts suited for integration in the EIC central tracking system. G. Contin (TS) and D. Elia (BA) contribute to the EIC SC coordination.

The EIC SC activity progressed regularly in 2021-2022 with weekly Coordination Meetings and occasional Workshops, where the EIC groups were asked to report their capabilities and to express their interest in joining the R&D towards the silicon tracker for EIC. As members of the Consortium, the INFN groups submitted a proposal to the FY22 Detector R&D projects call, and are now active in the eRD111 (Silicon Vertex) project. Intellectual work on the different topics started immediately. INFN BA and INFN TS are specifically engaged in the task "Forming modules from stitched sensors", and coordinating the participation of the other EIC groups in the ITS3 sensor testing activities. A general framework to regulate the collaboration between EIC SC and ALICE ITS3 is being set up as part of a larger agreement between DoE-EIC and CERN.

2.5 Detector R&D: streaming readout (GE, RM2, BO)

During 2021 the contribution to the development of the streaming readout concept continued for the EIC (see 2020 activity report), with activities synergistic with on-going efforts at JLab as “proof of concept” facility. A. Celentano (INFN-GE) served as co-convener of the Electronic and DAQ Working Group for the Yellow Report, contributing to its finalisation up to March 2021. Following 2020 activity, the group made a proposal within the R&D group toward the development of a second version of the online streaming readout software, to incorporate TriDAS (KM3net software developed in BO) and JANA2 (JLab-based) in a single high-performance framework based on the CLAS12 re-construction micro-service platform ”CLARA”. The results of the 2020 campaign were published in 2021 on EPJ Conf. (https://arxiv.org/abs/2104.11388).

This R&D activity was pursued in the contest of the ”Streaming Readout” EIC R&D consortium. Results were presented and discussed within the group during the ”Streaming Readout IX” (December 2021) remote workshop and then finalized in a publication submitted in early 2022 (https://arxiv.org/pdf/2202.03085.pdf). The involved groups maintain a presence in the relevant community, as visible in the program of the Streaming Readout X workshop (May 2022) where M. Battaglieri gave the introductory talk ((https://indico.jlab.org/event/519/overview).

This activity in 2022 got additional funding under eRD105 project (calorimeters: but the two INFN groups work on the streaming readout implementation). Previously it was supported via funds obtained via MAECI (with a participation of some CNAF staff too).

3. 2023 Activity planning

3.1 EIC_NET requests for 2023

The EIC_NET requests for 2023 reflect the on-going transition from networking-mode to experiment-mode.

On one side several units are clustering on specific hardware items.

This is the case, in particular for the CS-CT-SA units joining the SiPM initiative. While they will start working actively on characterization of sensors (an activity so far carried out by BO and FE), they represent a first step towards future distributed centres of qualification / production that will be crucial at the time the detectors will be built.

A similar path is visible with PD unit, that increases substantially FTE in 2023 and it is joining BA and TS in activities related to the Si-Vertex. These three groups are expected to sustain the main effort (as EIC_NET) of the INFN contribution to that detector.

On the other side all the other planned activities are now very much focused on the pre-TDR requested by October 2023 by the DoE as part of the EIC project timeline. The requests for R&D activities are mainly related to dRICH and Si-Vertex, with the R&D for the dRICH narrowing down the technologies for photosensors to just two (SiPM as baseline, LAPPD as plan B). The choice of the technology is expected at the time of the pre-TDR release.

The proposed networking activities are also morphing: we expect meetings of the Collaboration for Detector 1 or at least of some of the people having more responsibilities, as well as an increased level of intra-groups (within Italy) missions: between Bologna and Southern Italy groups to sustain the effort for SiPM, between GE and TS for LAPPD etc. We no longer have a single unit working in isolation on a single task but the groups are clustering under the main tasks. A key effort toward the attraction of young generations to the project is then represented by the proposal of an EIC School, for last year master students, graduate students and PhD.

3.2 Networking activities

Following several observations by local INFN directors we recommend CSN3 referees and CSN3 to avoid concentration of missions in specific INFN units, but to stick as much as possible to the proposed local programming. If the problem is the risk of not collecting efficiently unused resources, we commit to then go with internal transfers from INFN units to another (“storni”) in the second half of the year to manage effectively the residual resources (if any).

The financial requests are based on four typologies of networks:

- **The EIC community at large**. In 2023 the in-person EICUG meeting (likely during Summer) is scheduled to be held in Europe, possibly in Warsaw. There is also the possibility (as in 2022) that the Detector 1 Collaboration meeting will be encapsulated within the EICUG meeting. A request of 2 k€ for each participant is made, with one or more (depending on FTE of the unit) being requested.

- **The Collaboration Detector 1**. We don’t know yet if there are plans for meetings of the Collaboration (in addition to the EICUG meeting). It is predictable, however, a certain amount of key meetings happening, with some INFN staff needed to attend depending on his/her role in the Collaboration. Sub-judice requests in the US (2.5 k€) are made on certain units, depending on the actual calendar of meetings (not yet available given the early stages in the life-cycle of the Collaboration).

- **The intra-Italy networking**. As described above the relations and projects are consolidating among certain clusters of units and this creates the need for certain trips across Italy more than in the past. On top of that we plan as usual the organization of one “Giornate Nazionali” as it happened since 2019 (0.5 k€ for each participant).

- **The EIC School**. We are working on the organization of a first School on Electron-Ion Collider physics. Intended for master students (close to the degree), graduate students and PhD we aim to attract young generations. From the current INFN units, but not only, given the possibility to attend it as part of PhD requested schools. Several sites are taken into considerations: Frascati, Maratea, Bertinoro, Vieste for a residential school. The mix of lectures will include theoretical introduction to hadron physics (and structure of the nucleon in particular), DIS physics, EIC detector, etc. as well as hands on sessions on Monte Carlo simulation. We will ask local support and possibly sponsors. Centrally we ask a contribution **[5 k€ BO, under RN]** in missions to ease some trips. The target period being considered is late Spring (May - June).

3.3 Physics, software and simulation activities

3.3.1 Semi-inclusive DIS (PV)

M.Radici (working also in NINPHA-CSN4) in PV is co-convener of the semi-inclusive DIS (SIDIS) WG. The main short-term strategy of this working group is:

- In collaboration with the DIS WG, continue studying the kinematic resolution of DIS variables for different reconstruction methods
- Check impact on resolution as detector configurations change and improve, optimizing the reconstruction
- In collaboration with the Jet/heavy-flavor WG, explore ML techniques in hadron and jet reconstruction
- Study the longitudinal double-spin asymmetry ALL in SIDIS to use the detected final hadron as a flavor analyzer of various parton helicities contributing to the nucleon spin sum rule
- Determine the feasibility of 3D imaging studies of partons inside the hadrons in momentum space through the Sivers and Collins effects and the measurement of transverse-momentum dependent multiplicities
- Estimate the precision on the proton tensor charge that can be extracted by the Collins effect or by the inclusive detection of di-hadrons (and related studies of properties of Di-hadron Fragmentation Functions - DiFF)
- Explore the potential to probe gluon saturation by measuring gluon-induced high-pT di-jets or di-hadrons in electron-proton and electron-ion collisions.

M.Radici (PV) is directly involved in providing theory support to simulations on 3D imaging and on the extraction of the tensor charge via the first Mellin moment of the chiral-odd transversity parton distribution function.

On a longer term, the SIDIS WG is engaged in realizing a proper treatment of radiative effects, estimating their impact of physics results, and in studying systematic uncertainties, including the theoretical ones connected to the use of different generators and different parton distribution parametrizations in the simulation studies.

Given the relevance of the dRICH detector for the SIDIS analyses (critical information about the PID of the hadron in the forward region) we expect to gradually involve students from the experimental groups in phenomenological and physics performance studies linked to the use of the dRICH, as part of the preparatory work of the INFN contribution to Detector 1. Supporting requests are for missions **[5 k€ PV].**

3.3.2 Diffractive physics - Partonic imaging in coordinate space (CS TO)

The activities foreseen in 2023 in this area are the natural continuation of the work developed in 2022 (see section 2.1.2).

Furthermore the EpIC generator tool is now used to quantify the impact of the EIC in constraining GPDs, disentangle contributions from different partonic flavors, and evaluate the model-dependence of the procedure. We have already started this study at the generator level by simulating a mix of DVCS and BH events. We have evaluated the main detector and forward proton acceptance, as well as detector resolution effects using a fast smearer. The next, awaited phase will be to pass the data through a full simulation of EIC Detector 1. After this stage, a full analysis including an accurate event reconstruction and particle identification will be performed, which shall yield pseudo-data to be used in global fits together with world data. We will perform this exercise with data simulated according to two different state-of-the-art GPD models (KM20 and GK).

Not less relevant than GPDs are the diffractive parton distribution functions (dPDFs) which were first extracted in e-p scattering at HERA where they are the equivalent to the parton distribution function (PDF) when the proton is probed diffractively. The dPDFs can be interpreted as conditional probabilities of finding partons in the proton in a diffractive interaction. The several extractions of dPDFs available from the inclusive diffractive HERA data (with the addition in some cases of diffractive dijet data) are based on collinear factorization and DGLAP evolution and to a further factorization assumption, usually referred to as proton vertex factorization (Ingelman-Schlein). The popular physical interpretation of such factorization is that the diffractive exchange is a colorless object with a partonic structure (referred to as the Pomeron). The analysis of the experimental data often shows the need of a sub-leading term (referred to as the Reggeon).

Evaluating the impact of the EIC in disentangling to which extent this factorization holds is the goal of this program as far as the study of inclusive diffractive processes is concerned.

Likewise for the study of exclusive processes outlined above, we will contemplate the understanding of the detector acceptance for inclusive diffractive processes and later on the realization of a full chain with Monte Carlo events passed through a full simulation of the EIC Detector 1. Pseudodata will be used in dPDFs fits, with the possibility to include also previous HERA (ZEUS) data.

Specific requests for critical scientific mobility to support all this work are made **[2.5 k CS]**.

3.3.3. EIC software coordination and computing (TS BA CT CS)

The Software Group of Detector 1, together with the community and in coordination with the SWG of the EICUG is reviewing and taking decisions on software common tools to be used by the Detector 1 collaboration. Every Wednesday (at the same time of the regular SWG meetings), the case for different options available are presented and discussed. The result of this review will be presented at the forthcoming end of July Meeting and, if endorsed, it will be implemented aiming to have the full software stack in place for the October simulation campaign. Planes B, in case of delays, are also implemented. The aim is to have a common software ready for the simulation campaign in preparation of the pre-TDR which is due for next year.

Even if the decision process is not over yet, we agreed to use most of the simulation chain of ATHENA (DD4Hep, CI tools), an important aspect, also for the INFN community which was using those tools. The year 2023 will be devoted to the simulation for the TDR and all the coordination and development activities will be devoted to that.

For the Computing, we do expect that the computing model of the Detector 1 collaboration will be defined. This will also help us to shape the INFN contribution to computing. If a TIER like structure is put forward, we will try to shape our contribution accordingly, with resources available only at TIER1 but also at TIER2 and 3. Yet, we don’t expect this to happen next year, and therefore we don’t ask for anything more than what we already have at CNAF. We do expect to start in 2023 the negotiation process. CT and CS groups, given their expertise (and resources available locally) are also joining this portion of work.

3.3.4 Detector simulation (BA TS LNS SA)

For the tracking simulation, the work foreseen for the coming months and in 2023 will be in continuity with the activity already ongoing in the Tracking WG by the BA group. The first phase will be connected to finalize the optimization studies on the reference detector configuration starting from the ECCE baseline: this is already being carried out using both the ECCE full simulation framework (Fun4All) and the fast simulation tool developed in Bari for ATHENA, both properly adapted to the new configurations under investigation.

Input from the BA group to the Tracking activities are currently coming also from the link with the EIC Silicon Consortium and the need to fold in technology constraints in defining the optimal detector configuration. Additional simulation studies will be needed also in connection to eventual limitations/issues coming from the sensor design stitching plan finally defined (likely the same for ITS3): for instance checks on the impact on the tracking performance from a reduced longitudinal length of the innermost (vertex) layers and/or from the need of handling a larger number of stitched sensors (4/8 instead of 2 as in the ITS3 concept currently assumed) will likely require careful investigation at simulation level.

At a later stage in 2023, possibly with a well defined detector configuration and simulation framework and in view of the preparation of the pre-TDR, the plan is to contribute to the study of physics performances on some benchmark signals (eg measurement of HF decays) via dedicated centrally simulated samples. Some effort to increasingly exploit resources from the national computing infrastructure will be also pursued.

In the dRICH simulation sector, the work, foreseen in the year 2023, can be categorized into two main branches: (A) optimization of the forward dual radiator RICH (dRICH) geometry and optimization and (B) adaption of the single photon Cherenkov angle reconstruction software in the main electron-ion-collider Detector 1 software framework. However, the two branches go hand in hand to check the effect of any changes made in the dRICH description.

A. The optimization of the geometry includes the placement of the dRICH in the central detector layout, where the effect of the magnetic field is minimal for the Cherenkov angle resolution and in gaining (if possible) some extra space to increase the dRICH radiator length, this will increase the number of Cherenkov photons and improve the available lever-arm to obtain better focalization, dictated by principles of geometrical optics. Any movement of the dRICH in the central detector enforces repositioning and tuning the reflective mirrors and sensor planes. A further detailed description of the photon sensors; including material, noise rate, and photon detection efficiency to be described in the simulation description. In addition, we also foresee improving the focalization of the reflected photons by two reflective mirrors of different focal lengths. Some of these activities have been already initiated and are under regular discussion for moving towards consolidation in global integration.
B. The existing reconstruction software, which had been built for the ATHENA detector proposal submission can be foreseen to be used in the EIC Detector 1 reconstruction framework. This, however, requires further refactoring of the existing software to deal with the modifications made upstream of the software chain. In the beginning, the plan is to make a minimal software chain. The process is already initiated, and it will extend to 2023 to adopt all changes in the main software frames, foreseen to come in the end part of the current year. The goal of the software is to check the effect of any modifications to the dRICH description almost in real-time. By mid-2023, when

the software framework is much more understood and the geometrical optimization of the dRICH is near to consolidation, the reconstruction software can be enhanced to perform particle identification based on some robust particle identification algorithms to check the effect of the different geometries in physics performance. This requires the initial design of the software to be open enough, to easily adopt further sophisticated algorithms namely the global likelihood method or neural network-driven particle identification for detailed physics analysis and characterization of the dRICH from reconstructed decay channel samples. This ensures that by the end of 2023 we will be capable of obtaining an optimized geometry that is consistent with the global integration by using if any space is available in the placeholder. In parallel, the optimization is supported by a constant and unbiased evaluation by the reconstruction software. The above-mentioned works are to be done with dRICH enthusiasts of different institutes under the umbrella of the EIC Detector 1 international collaboration.

The resources need for the simulation activity are traveling support for networking and computer resources from the national computer infrastructure.

The groups of SA and LNS will join simulation efforts in 2023.

3.4 Detector R&D: dRICH

3.4.1 dRICH prototype (BA CT FE LNF LNS RM1 TS)

The main goals for the next year are: assessment of the prototype design performance and validation of optical components, coupling of the prototype with a EIC driven photon detection plane, realisation of a prototype for the high-pressure gas alternative and aerogel characterisation.

During the 2021 test-beam campaign, all the baseline dRICH prototype components were commissioned and a first set of data was collected to provide a basic proof-of-principle of the dual radiator concept. The prototype is now being prepared for a second test beam campaign, scheduled in fall 2022, to benchmark the design performance and perform a systematic study of the various contributions to the Cherenkov angle resolution (chromatic dispersion, pixel size, emission point among others). The measurements on beam will be complemented by a **detailed characterization in laboratory**. The latter will be based on sophisticated instruments like spectrophotometers to measure the transmittance, diffusion and reflection of light by the dRICH optical elements, but also custom test stations with laser and CMOS cameras to study local light scattering and refraction, and map surface defects [**10 k€ FE**]. The collected information will be used as input to the simulation in creating a realistic model of the dRICH detector and performance.

Realistic solutions for the optical components should be validated. New samples of the **Aerogel** Factory producer will be acquired with same refractive index, to verify reproducibility, with slightly varing refractive index, to compare optical performance, and wide area, to check uniformity **[10 k€ FE, 5 k€ BA]**.

The dRICH prototype currently mounts glass **mirror**. They have high optical quality, but are not suitable for a real experiment due to the massive body. Composite materials (foils+core) could offer a light and stiff solution, but tipically feature a worse optical quality due to the not uniform material. CMA in Tucson is a world-leading manufacturer of carbon fiber mirrors. Their technique has evolved in time seeking for reduction in material budget and costs but with varying quality. A demonstrator will be realized to validate the technology **[12 k€ FE].**

The dRICH prototype utilises a reference detector that provides the wanted spatial resolution but is not adequate for EIC, being assembled with obsolete or magnetic field sensitive photo sensors. The readout electronics, borrowed from the CLAS12 RICH, can not be evolved following the EIC specifications. A suitable **detector plane**, based on the state-of-the-art SiPM and the ALCOR readout chip, will be realised to move towards EIC needs. Such a plane is assumed to use the most promising SiPM identified with the ongoing irradiation campaign and the improved version-2 of ALCOR, to cover an area adequate for imaging and implement a realistic cooling system. DoE funds will contribute critically to this activity.

The current **vessel** of the dRICH prototype uses vacuum components that could in principle sustain pressures different from the atmospheric one, for example, during the gas exchange operations. Although it could be in principle upgraded to sustain high pressures, it can not offer a solution for EIC due to the massive steel structure. The development of a realistic dRICH mechanics is being pursued through the study of a sandwich of composite materials, i.e. a honeycomb core and a double layer of light material as carbon fiber or aluminum. This solution could guarantee the required specifications of lightness and stiffness. The prototype is being designed using COMSOL, Inventor Mechanical Desktop, ANSYS software with corresponding request on software licenses **[5.5 k€ LNS]**.

After checking in 2022 tolerances and deformations of candidate materials with a simplfied vessel, a full (in scale) prototype in 2023 will be pursued **[20+3 k€ LNS]**, waiting for exact definition of dimensions (and other mechanical details and constraints) as emerging from Detector 1 Collaboration discussions.

3.4.2 SiPM and electronics (BO, TO, FE, CT, CS, SA)

The R&D activity on SiPM and related electronics continues in 2023 with the inclusion of the units of CT, CS and SA. Thanks to the large amount of work and developments carried out so far in this topic, the new units can benefit from the available experience and the added manpower can therefore be put in a position to promptly contribute to the research activity in the most active and collaborative way. Proper financial means are necessary to allow the collaboration to be as fruitful as possible, which requires an adequate degree of travelling resources to be allocated for this purpose **[2 k€ BO, 3 k€ CS, 3 k€ CT, 1.5 k€ SA]**.

It has to be stressed that within the SiPM R&D activity for the EIC dRICH there is still a substantial amount of work and studies that have to be carried out, as it will be discussed in the following. The addition of the new units will help in increasing the manpower that can be allocated to the R&D items to be followed in the upcoming months. Nonetheless, the foreseen R&D activity for the year 2023 requires proper financial resources to match also the increase in the available manpower. At the current level, the sensors acquired and the electronics produced so far are sufficient only to conclude the studies carried out in the years 2021 and 2022. The continuation of the activity with the goals discussed in the following requires acquiring new SiPM sensors **[10 K€ BO]** and corresponding boards **[30 K€ BO]**, ensuring the availability of the needed instrumentation and developing the required custom electronics, that will be distributed to INFN units involved. Other consumables and “inventario” requests are made by the different units **[3.5 k€ BO, 7 k€ CS, 7 k€ CT, 8 k€ SA]**, in particular by CS CT and SA to start operations.

The main activities planned to be carried out in the year 2023 are briefly described in the following.

- **studies of recovery from radiation damage** have so far only been performed heating up irradiated sensors at high-temperature by means of an industrial oven for long (days) thermal annealing cycles. It is necessary to explore alternative recovery solutions which can allow one to partially recover the sensors in shorter time-scales and without intervention on the detector. Preliminary studies performed in 2022 show that heating the sensors with direct current exploiting the Joule effect is an effective way to achieve significant recovery factors (10x) in short time-scales (30 minutes). This approach needs to be followed up in a systematic way with a structured R&D program where different heating strategies with direct current and Joule effect are tested (direct forward bias, inverse bias in dark, inverse bias with light, …) in irradiated sensors. A sample of new sensors will be acquired and new boards will be produced and irradiated to be eventually systematically recovered with alternative annealing strategies.

- **studies of radiation damage in irradiated SiPM** have been performed so far only with proton source. The literature shows that at very high doses (much higher than the ones expected at EIC) the damage caused by neutrons might be topologically different from the damage caused by protons. Studies at radiation levels expected at the EIC must be performed also with neutron sources. It is necessary to establish whether the degree of damage and recovery from annealing observed in the proton irradiation campaigns performed so far is in line with the damage and recovery of the damage induced by neutrons. It is in any case important that data from both types of sources of radiation damage is collected to provide the necessary input to future simulations in support of the work in preparation of the pre-TDR. In the year 2023 more irradiation campaigns with protons **[10 K€ BO]** will be performed to consolidate the acquired knowledge on SiPM damage and recovery at EIC levels and to support the exploration of alternative annealing recovery strategies and operation cooling modes. A first irradiation campaign with neutrons **[4 K€ BO]** will be performed to collect also neutron-damage-related data. On top of studying the effect of radiation damage caused by hadronic sources we believe it would be wise to foresee already for the year 2023 an irradiation campaign with high-energy photon sources (gamma). Literature is not clear about the effect on SiPM of high energy photon radiation, with reports on increase of the leakage current and possible decrease of detection efficiency. It is therefore important to carry out a study with the expected gamma fluxes at the EIC as an initial baseline.

- **a new version of the ALCOR front-end ASIC chip** has been submitted for production in the year 2022 with a few additional features especially requested for EIC in the amplification circuitry. The new ASIC will be intensively characterised (TO) and its performance will be studied in detail with a special emphasis on the best matching between the SiPM and ASIC circuits with a special emphasis on the best matching between the SiPM and ASIC circuit. In particular, signal shaping with passive (capacitors) components in the SiPM circuits will be studied to find the optimal input to the ASIC depending on the specific SiPM device in order to retain as much as possible the amplitude of the fast component of the signal while at the same time reducing the slow component and therefore the probability of signal pileup in case of high count rates. Studies of SiPM-ALCOR coupling will guide the future developments on a potential ALCOR version tailored for the SiPM selected for the EIC dRICH detector and on-chip signal shaping features. In parallel the design studies of the new packaging and of the bandwidth optimisation will start, in view of the next ALCOR version (Cadence and LabView license **[2 k€ TO]).**

- **the excellent SiPM time resolution for single-photon tagging** is a major ally to counter the high dark count rate of the devices, which degrades with increasing radiation damage. The SiPM-ALCOR readout system is expected to provide photon tagging with very good time resolution (< 200 ps RMS), nonetheless there was no capacity within the groups involved in this R&D to perform studies on this topic so far. It is crucial to advance the studies with a preliminary measurement of the time resolution of the system and provide guidance for simulations of the performance. A specialised measurement setup has to be equipped with a low-photon yield high-precision light source (ie. a picosecond / femto laser [**15 K€ BO**]) and studies to be carried out on sensors before irradiation, after irradiation and after annealing.

- **SiPM are operated at low temperature to reduce their intrinsic DCR**, which reduces by about a factor of 2 every 10 degrees of temperature decrease. Studies have been so far performed using climatic chambers where low temperature is achieved in a controlled way. The SiPM readout of the dRICH prototype employs ThermoElectrics Coolers (TEC, Peltier cells) to achieve sub zero (down to -30 degree C) operation temperatures, which are an effective but inefficient way to achieve the goal in the experiment. In the year 2023 it will be studied if the use of TEC can provide the same performance as the one measured within the controlled environment provided by the climatic chamber. A direct comparison of the IV characteristics of SiPM and DCR curves measured at -30 degree C in the climatic chamber and in an experimental-like environment with TEC will be performed. It is important to stress that while TEC can be an effective way to achieve very low temperatures, it is not clear it is a viable and efficient way in terms of electric power in the experiment. Alternative solutions will be explored like the use of a cooling system with liquid coolant circulating at very low temperature (-20 -40 degree C) on top of a moderate use of a TEC component, with funds requests made accordingly **[11.5 K€ BO]**.

- **the EIC DAQ system has to cope with the high data-rate injected by the SiPM** sensors. While it is not clear yet whether there really is a limitation caused by the fact the foreseen EIC DAQ system is based on a streaming triggerless paradigm, it is a concern that the SiPM dark count rate might reach too high values and flood the system with background data. The current ALCOR design already includes some features that allow one to deploy countermeasures that effectively can reduce the SiPM data flux to the DAQ by inhibiting the discriminator circuits on demand by means of a dedicated ALCOR input signal. It has yet to be proven whether this strategy can be utilised at high frequency, by inhibiting the ALCOR digital electronics “outside” of the EIC bunch-crossing. In the year 2023 this approach will be tested and studied in detail with inhibition gates at up to 100 MHz rate at various inhibition widths. The optimal inhibition width depends on the optimal gate where SiPM signals from physics events are expected to arrive owing to colliding bunches and can be as small as 1 ns, depending on many details that can be acquired from precision simulations of the detector and physics collisions. A full characterisation of a system based on this ALCOR-inhibit paradigm is of major importance to be able to provide a data reduction that can be up to 10x within the streaming triggerless EIC DAQ scenario. To perform this test a dedicated setup has to be equipped with one Kintex-7 FPGA KC705 and an extremely stable clock generator, which is critical in the testing of the digital component **[8.5 k€ TO**]). In the year 2023 it will also be investigated the use of physical trigger signals and staging memories (in the front-end or at the DAQ receiving end) to provide a very large reduction factor of the dataload of a SiPM based optical readout of the dRICH to the DAQ. Bunch crossings at the EIC will happen at 100 MHz, whereas at th highest luminosity the interaction rate will peak at 500 kHz: the data payload could be reduced by a factor 200.

From the inception of the SiPM R&D program a **collaboration with FBK** (Fondazione Bruno Kessler) was put in place and several prototype sensors have been provided tested for their use for Cherenkov application at the EIC. Two types of sensors from the "Low Field" development branched from the DarkSide application in the FBK NUV-HD technology have been tested, one being optimised for fast-timing and one optimised for radiation-tolerant calorimetry. Recent discussions with FBK together with our findings on commercial sensors with different breakdown voltage values give a good perspective towards a joint R&D within the INFN-FBK collaboration agreement framework ("convenzione"). Diifferent values of electric field in the gain region as well as its thickness can studied to eventually obtain the optimal DCR for new sensors and sensors after radiation damage. Furthermore, an aspect that has a large impact on both the DCR of the sensor and of its radiation tolerance is the size of the avalanche multiplication region (both in transverse and longitudinal dimension). While the longitudinal dimension can be optimised with different values of doping profiles and corresponding applied field without significantly affecting the detection efficiency (PDE), the size of the transverse dimension (normally matching the SiPM entrance window area) has direct implications on both the PDE and the DCR, being both directly proportional to the transverse dimension. A significant advance in the SiPM technology might come from devices designed such that a small transverse active area is complemented with a focusing medium that directs onto it the photons impinging on a larger surface. This would effectively give a large acceptance over a small active area, which in turns maintains the PDE approximately constant while effectively reducing the DCR by the ratio of the two areas. Different approaches can be studied (so-called "micro-lensing" obtained with different layers of metal-oxydes). Such approach could be tested in the proposed FBK joint engineering run [**25 k€ BO**] together with the studies on different field levels. Within the same R&D program we also plan to design monolithic SiPM sensor arrays which will allow the sensor active surface to cover as much silicon as possible while at the same time retain functionality features to efficiently wire-bond the sensors onto PCBs.

3.4.3 LAPPD (GE TS)

In 2023 the characterization of LAPPD detectors will progress in collaboration between Genova and Trieste. Therefore, travelling resources for the cooperative efforts between the two INFN units are requested.

Four major exercises are planned in 2023.

A. A magnet with adequate magnetic field and large bore has to be identified and two options are being considered, one at CERN and a second one at Desy. The choice will be based on logistic aspects and availability. Correspondingly, travelling resources have been requested. The main goal is measuring the variation in gain and efficiency of LAPPD in intense (up to 1-1.5 T) magnetic field with different field orientation. The preparatory exercise will consist in modifying those setup elements that are not compatible with operation in intense magnetic field (costs included in the request of consumable for the laboratory).
B. This is a laboratory study that can be performed using the pulsed diode laser source properly collimated by scanning with small step size (50-100 um) the LAPPD surface. Resources to acquire a motorized 3-axis translation system 3-D have been requested **[17 k€ TS]**. The third axis has a shorter range and is used to focus the light onto the detector entrance window.
C. So far, a 20 x 20 cm^2 prototype is being used and characterized; in particular, the present prototype has 20 um pore diameter. Next year, when the characterization protocols will be better tuned, we plan to rent for a few months a more advanced prototype with 10 um pore diameter. Resources **[7 k€ TS]** are requested to be matched with equivalent resources requested within the AMBER experiment (CSN1). In fact, the characterization of LAPPDs for single photon detection is synergetic between EIC_NET and AMBER.
D. Pico TDC development – Another key development towards implementation of LAPPDs as RICH photo-sensors is readout electronics. The superior timing resolution featured by LAPPDs allows to improve Cherenkov angle reconstruction by the correction for light emission point, which can be obtained from the hit time with few mm resolution. Moreover, the timing of charged tracks crossing the LAPPD surface in proximity focusing RICH can be used simultaneously as a part of ToF system for hadrons with the energy below 6 GeV. To exploit fully this property of LAPPDs we will study new high precision TDC electronics, in particular, the picoTDC chip. This is a 64 channels TDC chip featuring 3 ps bins, well matched to LAPPD timing resolution. However, it requires a frontend stage for which NINO and FastIC ASICs will be tested. A test of LAPPD readout with picoTDC will be performed to understand feasibility of this approach **[19.5 k€ GE]**.

3.4.4 Streaming readout (GE RM2)

The SRO activity in 2023 will be performed by Genova and Roma-TV INFN units in collaboration with CUA, BNL, and JLab, continuing the development of a SRO prototype for the EIC and related on-beam tests. Part of this activity will be coordinated with CUA as part of the eRD105 R&D program.
Among the other activities we expect to work on the following items:

- Development of the TriDAS backend as a part of the ERSAP framework (JLab)
- Interface of the ERSAP-TRIDAS systems with GEANT4 simulations of EIC detectors;
- Characterization of scintillating glass crystals with the facility installed at INFN-GE (attenuation length, LY, and other optical properties;
- Off-beam test (cosmic rays) of a 3x3 PbWO calorimeter readout by sipm implementing SRO algorithms;
- contribution to the prototype commissioning for on-beam tests.

As a perspective the SRO effort will be finalized in support of the dRICH DAQ, being the detector with the highest expected throughput. Simulated dRICH data (including noise due to the increase of DCR) will be simulated, encoded and then sent to an FPGA where AI algorithms will be tested for pattern recognition and noise reduction. Requests of funds are done accordingly **[6 k€ GE, 4.5 RM2 k€]**.

3.5 Detector R&D: Si-vertex (BA PD TS)

The R&D activity on the silicon vertex will continue in the coming months and in 2023 along the lines of the current involvement of the INFN groups in ALICE ITS3 and EIC eRD111 projects and in close connection with the EIC Silicon Consortium. Starting from the year 2023 the PD group will join BA and TS in this common effort.

The main task for the INFN groups in the eRD111 project planning is devoted to "Forming modules from stitched sensors". In general the effort for this task deals with the process of "taking sensor reticles (even stitched sensor reticles) and integrating them into building block units that are compatible with detector size requirements, electrically and mechanically integrated units, and can be joined together to propagate power and signal lines." The sizes and compositions of the module type(s) together with the reticle size (and number stitched together) dictate a set of possible configurations that need to be evaluated with respect to suitability for forming staves and discs out of these module type(s).

Large area sensor bending and testing, together with wire-bonding on curved sensors have been already exercised at the INFN sites along the last year, with the smaller (and more challenging) ITS3 radii. Next steps will be connected to adapt to the EIC radii (once defined) and optimize the bending and interconnection procedure correspondingly. Characterization studies on the new prototypes in 65 nm will allow to estimate the yield which is expected for the final sensor and optimize the stitched sensor dimension for the Detector 1 tracker. In addition to this, studies on how to include the sensor in the module unit will be also addressed.

The planned activities will be carried out in the local labs of the three INFN groups involved in the Si-vertex project (BA, PD and TS) as well as at CERN, in particular for the participation in beam test phases and continuing synergies with ALICE ITS3. Dedicated funding requests on EIC_NET, besides those submitted by the same groups for ALICE in the framework of the agreed synergies, have been focused on supporting the in-person participation to the EIC SC coordination (in US) and the link between the EIC SC and the ALICE ITS3 project (both in US and at CERN).

Appendix A: Synergies with other INFN initiatives

As in annual report 2021 we present a map of the synergies in place with other INFN initiatives for 2023 and where funding is requested directly through EIC_NET requests.

EIC_NET R&D	EIC_NET groups	Synergistic to	Supported within
MAPSs 65 nm technology	BA PD TS	ALICE ITS3 / NA60+ (CSN3)	ALICE
Aerogel studies	BA FE	ALICE3 RICH (CSN3)	EIC_NET
SiPM for Cherenkov app.	BO CT CS FE SA TO	ALICE3 RICH (CSN3)	EIC_NET
LAPPD	GE TS	AMBER (CSN1)	EIC_NET and AMBER
Pressurized gaseous RICH	LNS TS	AMBER (CSN1)	EIC_NET

Table 3. Synergies in place with other INFN initiatives

As mentioned before, a full discussion of the synergies in place with ALICE and NA60+ is available here https://cernbox.cern.ch/index.php/s/C7QUuny57ibvmxJ

Appendix B: External financial support

In year 2022, the EIC_NET groups have made use of the financial support external to INFN from a variety of different sources, as presented in Table 4.

Project/source	**group**	**Amount**	**period**	**usage**
eRD102/DoE	FE	165 k$	2022-2023	C+M
eRD105/DoE	GE-RM2	20 k$	2022-2023	C
eRD110/DoE	BO	60 k$	2022-2023	C+M
STRONG2020/UE	FE	30 k€	2019-2022	M
STRONG2020/UE	BA	26.5 k€	2019-2022	M
STRONG2020/UE	LNF	17 k€	2019-2022	M
STRONG2020/UE	TS	54.5 k€	2019-2022	M
AIDAInnova/UE	TS	60 k€	2021-2024	M
AIDAInnova/UE	BA	25 k€	2021-2024	M
AIDAInnova/UE	BO	25 k€	2021-2024	M

Table 4. External funds used by EIC_NET groups

Appendix C: Milestones

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Date due	Description
31 July 2023	Sottomissione su rivista di risultati ottenuti in campagna di irraggiamento SiPM
30 Nov 2023	Realizzazione di una ampia superficie di rivelatori SiPM per la lettura ottica del prototipo dRICH basata su readout ALCOR
31 Dic 2023	Misura della resa di produzione e ottimizzazione delle dimensioni dei sensori CMOS 65 nm stitched per Detector 1 tracker
31 Dic 2023	Contributo a simulazioni Detector 1 (in particolare per Si-Vertex e dRICH) per pre-TDR
31 Dic 2023	Contributo a studi di physics performance per Detector 1 nei canali esclusivi attraverso EpIC generator
31 Dic 2023	Organizzazione giornate nazionali EIC

Table 5. Proposed milestones for 2023

Date due	Description	Completeness at 1/7/2022 and comments
30/11/2022	Giornate nazionali EIC	100%
15/12/2022	Completamento documentazione per CD2 EIC	N/A: The deadline for CD2/3A documents was moved by the project to 10/2023
30/6/2022	Implementazione simulazione dRICH nel detector per IP6 a EIC	N/A: Following DPAP process this activity had to wait deliberations of new Collaboration. Could be now declared fulfilled likely by 12/2022.
31/07/2022	dRICH con SiPM: prototipo aggiornato per test beams	90% - On target
31/10/2022	Caratterizzazione in laboratorio di LAPPD per rivelazione di singolo fotone	60% - On target

Table 6: Updates at 1/7/2022 on 2022 Milestones

Appendix D: Note on missions budgeting

Requests for EICUG meeting are requested at 2 k€ /participant. Being the meeting in Europe (Warsaw not confirmed yet, pending the difficult situation about Russia-Ukraine conflict) we used “France” as parameter (same per-diem as Poland, but listed in CSN3 table).

As per CSN3 tables, France cost is 4600 €/month with per diem at 120 €. This means CSN3 estimates a travel cost of 4600 - 30*120 = 1100 € that seems quite high for France. We suggest CSN3 to revise its table. Anyway this is our estimate for an EICUG meeting in Europe: 800 € (travel) + 90 €/day (hotel) * 5 days + 60 € (per-diem/2)*6 + 200 € (EICUG fee 2022 is 200 €) ≅ 2 k€.

Requests for meetings in US are listed at 2.5 k€/participant assuming a five days meeting, and 7 days out, but with 5 nights in hotel.

As per CSN3 tables, US cost is 5300 /month, with per-diem at 130 €. This means CSN3 estimates a travel cost of 5300 - 30*130 = 1400 €, that is quite difficult to achieve these days, especially if directors approve missions very late (given the pandemic). To try to compress costs we foresee:

- 1000 € (travel, quite optimistic) + 150 € * 5 (hotel, optimistic) = 1750 €
- Per-diem/2 * 7 = 65 € * 7 = 455 €
- ESTA: 20 €
- Conference fee: 200 €
- AIG Insurance (mandatory): 100 €

This brings to a quite optimistic ≅ 2.5 k€ that is what was quoted. The location plays an additional burden (to reach BNL there is the need to rent a car). We would like just to point out that our estimate is very conservative, and simply dividing by 4 the cost/month provided by CSN3 gives a totally insufficient 1325 €.

We suggest CSN3 to avoid providing cost/month given the “normal” mission is typically one week and how things have to be exactly computed can be difficult (or varying a lot among experiments). We used as reference document the guidance available here: INFN-CSN3-QA-51