67rd MEETING OF THE LNF SCIENTIFIC Committee – 27-28/05/2024

The Scientific Committee (SC) met at the *Laboratori Nazionali di Frascati* (LNF) for its spring 2024 session on the 27-28 May 2024. Besides the Open Session, the committee visited the SPARCLab-facility, discussed with the project leaders and the directorate in closed meetings and presented its findings. These exchanges between the SC and the LNF colleagues were highly appreciated. The presentations of the open session can be found at this indico page:

https://agenda.infn.it/event/41331/timetable/#20240527.detailed

The SC commends the lab for several achievements made in the recent months and thanks all people involved for the clear presentations during the open session and for the constructive discussions during the closed meetings. The SC appreciated very much that the recommendations from the last report were directly addressed.

The Scientific Committee expresses its condolences as to the recent passing away of Prof. Carlo Guaraldo as one of an highly esteemed colleague, who has been instrumental in the establishment of the kaonic atoms program at Frascati.

This meeting is the last meeting with Dr Fabio Bossi as director of the Frascati Laboratory. The Committee expresses its warmest gratitude to Dr Bossi for the collegial work and for the welcome it always received, and in particular the committee congratulated Fabio Bossi for all the achievements and impressive scientific results produced at Frascati during his mandate.

Findings:

- DAΦNE delivered and SIDDHARTA-2 acquired all the necessary statistics for the Kaon-deuterium measurements: still to come are some calibration runs to be taken by SIDDHARTA-2 and machine studies with DAΦNE.

- Analysis of PADME data slower as expected, due to some additional systematic effect to be taken into account. After the results to be presented at the summer conferences this year, additional data should be taken with an improved detector.
- A new proposed experiment (FIREBALL) gave a first presentation.
- FINUDA magnet test have been successful and FLASH experiment is in preparation.
- Installation at SPARCLab of the SABINA beam-line (financial contribution from the Lazio region) and EuAPS (PNRR funding) are ongoing.
- Preparative work for the construction of the new HPC Center (PNRR funding) is ongoing.
- EuPRAXIA preparation ongoing, but slip in scheduling.
- Installation work for ELI-NP in Romania has to be realized in 2026.

Comments:

- The committee congratulates LNF for the successful running of DAΦNE and the SIDDHARRTA-2 data taking; the BTF running and the fundamental progress made in the PADME data analysis; the progress made with the SPARCLab installations; the successful test of the FINUDA magnet.
- The committee expresses some concern about the EuPRAXIA schedule, the overall work-load on the acceleration division, in view of the additional installation work at ELI-NP.

Recommendation:

- *With a delay in the EuPRAXIA schedule, it is mandatory for the laboratory to clarify its priority in terms of accelerator operations and running experiments over the next 5-10 years. As already recommended in the previous session, a project management office should be put in place for the laboratory, which should elaborate resource loaded scenarios for the upcoming years and identify associated risks in particular concerning potential delays in schedule and increase of cost.*
- *In particular, the future operation of DAΦNE has to be clarified, which is linked to the proposed EXKALIBUR extension of the SIDDHARTA-2 experiment, the running of the FLASH experiment, the delivery of soft X-rays for material science, the use of DAΦNE as test facility for FCC-ee, as well as a received preliminary experimental proposal for an experiment in K-He laser spectroscopy.*
- *In the planning exercise, particular attention should be given to the commitments in 2025/2026 where various installation programs will have to be finalized (EuAPS, HPC Center with PNRR funding, Sabina beam-line with regional funding, ELI-NP and EuPRAXIA building CFT) and which could lead to a tension in technical manpower.*
- *The first presentation of the FIREBALL experiment has been given, but needs to be more detailed and articulated with the necessary additional running of PADME.*
- *We encourage also the laboratory to continue the preparation of EuPRAXIA becoming a user facility with exercising all the necessary structures on existing user facilities at LNF and search active contact with the Photon-Science community.*

1. LINAC-BTF and DAΦNE

Findings LINAC-BTF:

- The LINAC has been operated for BTFEH2 and DAΦNE since the last Scientific Committee Meeting in November except during the winter stop.
- More than 80% of the beam time at BTFEH2 is dedicated for detector tests for high energy physics. PADME, installed in BTFEH1, has not been running.
- The committee was presented with:
    - a proposal for an additional run of PADME in 2025 (February-July) and a limited number of short test-runs in fall 2024.
    - a preliminary proposal for an experiment (FIREBALL) to be conducted at the BTF1 experimental hall at the earliest in 2026.
- The committee was reminded that consolidation of the LINAC and of the lines to the experimental halls is necessary to guarantee a good availability for the users. The consolidation work would require extra-budget (in addition to that available for regular maintenance) but it could be conducted with the available resources.

Findings DAΦNE:

- DAΦNE availability and, in particular, performance have been remarkable. The integrated luminosity targets for SIDDHARTA-2 have been exceeded. LINAC (276 h), power supplies (275 h), wiggler magnets (173 h) and ring RF (156 h) have been the major sources of downtime. Significant progress has been made in the minimization of the background, also during injection, allowing to collect high-quality data.
- The machine team has presented a request for conducting a series of machine studies to qualify and document DAΦNE machine performance and its limitations.
- The committee was presented with:
    - the proposal of a first module of a programme for kaonic-atom spectroscopy along the periodic table requiring operation of DAΦNE. The full programme would require operation of DAΦNE for 2 to 3 years. The first module would require the accumulation of an integrated luminosity of 500 pb^{-1}.
    - the DAΦNE-light INFN-LNF synchrotron radiation facility activities covering a wide range of photon energies from infrared to soft X-rays. Soft X-rays are available only when DAΦNE is operating while conventional sources can cover the remaining energies when DAΦNE is not operating.
    - a letter written by world-renown accelerator experts and directed to the INFN and INFN-LNF management in support of the operation of DAΦNE as a facility to test new hardware and advanced accelerator physics concepts for future circular lepton colliders.
- Reliable operation of DAΦNE in the second half of the 2020s would require an important consolidation programme, with significant budget and personnel requirements, competing for manpower with other approved programmes.

Comments LINAC/BTF:

- The Committee congratulates the LINAC/BTF team for the continued support for the user community at the BTFEH2 and for the remarkable performance of the LINAC serving the above community and DAΦNE.
- The beam parameters required by the FIREBALL experiment are achievable with the available hardware. The installation of the FIREBALL experiment would require the dismantling of PADME in BTFEH1, but it would allow accommodating another user in the same Experimental Hall. Interleaved operation of BTFEH1 and BTFEH2 would be possible. Operation of DAΦNE would be possible in parallel.

Comments DAΦNE:

- The Committee congratulates the DAΦNE team for the excellent performance of the machine exceeding the expectations.
- The committee acknowledges the potential of DAΦNE to serve as an extremely valuable facility to train accelerator physicists and engineers for performance improvement and design of present and future circular lepton colliders world-wide, as well as to test hardware prototypes and new accelerator physics concepts. No detailed experimental programme and required resources have been presented supporting this vision.
- A stop of the DAΦNE accelerator might prevent to continue the material science programme with soft X-rays in particular for small samples.
- The installation (and possibly operation) of the FLASH experiment in the FINUDA magnet in the DAΦNE hall is incompatible with DAΦNE operation.

Recommendations on DAΦNE short term plan:

- *The Committee recommends dedicating a sufficient amount of time for conducting machine studies before the end of the 2024 run, as requested by the DAΦNE accelerator team. Involvement of partners from other accelerator laboratories might be desirable in view of defining a possible future experimental program for DAΦNE as test-facility for present and future circular lepton colliders (e.g., SuperKEKb, FCC-ee, CEPC, Super Tau-Charm factory).*

Recommendations on the laboratory accelerator complex strategy:

- *The committee encourages the LNF management to study various realistic scenarios for the execution of the current projects and for operation and consolidation of the LNF accelerator facilities (including the options of running* DAΦNE*), taking into account the latest EUPRAXIA schedule, and to determine the corresponding required resources.*
- *An assessment of the photon science user community that would benefit from the future (EUPRAXIA@SPARCLAB, SABINA and EuAPS) and existing accelerator-driven photon sources at INFN-LNF and of its needs would be desirable in order to define the operational model of these facilities and the manpower required for operation and beamline support. This could provide input to the definition of the long-term ambitions of the laboratory and for the medium-term programme and succession planning.*

2. SIDDHARTA-2

The Scientific Committee extends its condolences to the members of the SIDDHARTA-2 collaboration for the recent passing away of Prof. Carlo Guaraldo, a truly inspiring colleague and one of the main driving forces for the establishment of the LNF kaonic atoms program.

Findings SIDDHARTA-2:

- In particular, with the invaluable work of the DAΦNE team, the SIDDHARTA-2 collaboration has more than achieved their integrated luminosity goal, by collecting 779 pb^{-1} during Run 2 (October-December 2023: 276 pb^{-1}) and 3 (February-April 2024: 375 pb^{-1}). With Run 1, this adds up to 975 pb^{-1} on a deuterium target.
- They have also completed their evaluation of the usability of data recorded during injection time and determined that an optimal S/B quality threshold of 0.6, which translates into 60% of the injection data being usable for physics (50 out of 82 pb^{-1}). All in all, this amounts to 815 pb^{-1} usable for the Kaon-deuterium (K-d) data analysis.
- The collaboration also presented the preliminary data analysis of the K-d Run 1, including the use of a veto-1 time window to reduce background. This system, optimized using a previous K-He run, provides evidence that the signal in the energy region of interest is coming from the target gas. Their preliminary result provides the shift and width of the 1s K-d energy level, with a statistical uncertainty of about 50 and 270 eV, respectively. Systematic effects lie at the eV level. Moreover, the analysis including Runs 2 and 3 is ongoing and it should improve the statistical uncertainty by a factor of approximately two. Such an accuracy will definitely solve the most acute and longstanding problem in kaon physics.
- After the K-d Run 3, the collaboration completed a calibration run on K-H (April-May: 150 pb^{-1}), to check the performance of detectors and veto system, for further constraining the background in the K-d analysis.
- Since the end of May 2024 and until the end of June, the collaboration is collecting data on a "low-density" K-d target. The goal is to collect 200 pb^{-1} to disentangle the controversy between cascade models that predict different density behaviors of the K-d yields.
- Since the last SC, the collaboration has published 2 articles (J. Phys. G: Nucl. Part. Phys. 51 055103 and Nuclear Instruments and Methods in Physics 1060, 2024, 169060) and about a dozen proceedings in several international workshops and conferences. They have also submitted two new articles to international journals.
- Finally, a detailed proposal of the first module of the EXKALIBUR scientific program was presented to the committee. It includes a calendar for installation, commissioning, and operation, an account of the integrated luminosity needs, and details on what parts of the main and satellite detectors should be modified, when they could be operative, as well as the specific kaonic atoms to be measured. In brief, the module has three goals with the following needs:

i) Measuring the charged kaon mass with sub-eV precision, using a gaseous Ne target and about 300 pb^{-1} (approx. 8 weeks).

ii) Measuring, using solid targets, the spectrum of selected light atoms (Li, B, Be), of interest for studying kaon interactions with a few nucleons, strange matter and the $\Lambda(1405)$. This will require about 200 pb^{-1} (approx. 6 weeks).
iii) Study of intermediate-mass kaonic atoms (O, Al, S) with satellite CdZnTe detectors. This program will run in parallel with the other two and has no extra luminosity requirements.

Goals i) and ii) do not have to be carried out consecutively. All three objectives could be achieved with minimal additions and modifications to the SIDDHARTA-2 present setup, which are well documented in the proposal. In addition, in the collaboration presentation it was argued why such measurements are not feasible in other existing or planned facilities in the foreseeable future. The collaboration claims it could be ready to start this module as soon as January 2025.

Comments SIDDHARTA-2:

- The Scientific Committee congratulates the members of the collaboration for their remarkable work, which has allowed them to obtain the - still preliminary - *first ever measurement of kaonic deuterium X-ray transition to the 1s ground state.*
- The committee praises the members of the collaboration for their results on the satellite detectors during runs 2 and 3. On the one hand, they have been able to measure the first kaonic atoms spectrum with CdZnT detectors and demonstrate their very good "in-beam" performance, supporting their suitability to study intermediate-mass kaonic atoms. On the other hand, they have completed the analysis of three transitions of the K-Pb spectrum measured with their satellite high purity Germanium detector

Recommandations for SIDDHARTA-2:

- *The Scientific Committee considers that the first measurement of a transition to the 1s kaonic deuterium is a very remarkable and long-awaited achievement. The expected level of accuracy of the full analysis will have deep implications in our understanding of kaon physics. Hence, the collaboration is recommended to aim for a very high-impact physics journal for the publication of their full results.*
- *The Scientific Committee considers that the first module of the EXKALIBUR experiment is a very interesting scientific proposal of great value and merit, although its final realization depends, of course, on the operational situation of DAΦNE. Our recommendation is that it may be worth studying whether there is a possibility to carry out the first part of the module (8 weeks of dedication on gaseous Ne target) after the PADME Run IV are completed and in compatibility with other construction activities.*

3. PADME SC

Findings

- X17 analysis of Run III data ongoing:
    - Beam flux and beam geometry are understood and a corresponding paper is on arXiv and submitted to JHEP.
    - Signal acceptance and background estimation are under control with systematics O(1%).

    - Theorists from LNF (+ theorists from outside) have calculated the line shape modification due to the electron motion in the target atoms and validated their calculations with available data (arXiv and accepted for publication in PRL): Peak height decreases, width increases, Signal/Background decreases.
    - This effect has been neglected before in the sensitivity estimates of Run III. It is now implemented in the analysis chain.
- A common theory-experimental paper on the unblinding strategy is in preparation is expected to be submitted end of June to the arXiv and JHEP.
- PADME aims to open the box from Run III for the summer conferences.
- The line shape modification due to electron motion in the target leads to the fact that the expected sensitivity of Run III data covers only half of the region of interest in the coupling versus mass plane.
- To probe the full region of interest, PADME has worked out a new strategy:
    - Less scan points due to the widening of the X17 lineshape because of the electronic motion, with more statistics per point.
    - Building a new detector in front of the electromagnetic calorimeter due to rate limitations of present tracker: MICROMEGAS tracker developed by LNF ATLAS group will allow precise electron-positron / gamma-gamma discrimination.
- PADME proposes a detailed plan to prepare a Run IV aiming to cover the remaining parameter space after Run III:
    - Installation of MICROMEGAS tracker proposed for autumn 2024
    - PADME Run IV proposed from Feb to July 2025
        - Profit from present understanding of the systematic limitations of Run III data taking.
        - Better control on beam geometry, especially at ECal plane and at the downstream beam monitoring detectors.

Comments:

- The committee welcomes all the progress made in understanding the PADME data and experimental setup.
- The committee appreciate in particular the tight cooperation of PADME with theorists from LNF+ and outside, which should be continued.

Recommendations

- *Common PADME + Theorists Paper on unblinding strategy should really appear reasonably in time before box is opened. Ideally, the box should be opened after this paper is accepted for publication in a journal*
- *The preparation and the execution of run IV should get full support from the lab*
- *The collaboration should prepare for the next SC meeting a statement, why and how long after Run IV the experiment should be kept at its position in the BTF premises (Similar statement is required from the Fireball experiment).*

4. KLOE-2, DUNE and HL-LHC upgrades

KLOE-2

Discussion with Antonio Di Domenico the status of the activities took place before the Session of the Scientific Committee.

The new Liverpool group with new PhD students and post-docs started the analysis on $\pi^+\pi^-\gamma$ data and is rapidly progressing, with advances also on MC simulation. The analyses at an advanced or final stage are also progressing:

- $\gamma\gamma \to \pi^0$ with High Energy Tagger (HET), the first completed with KLOE-2 data. The analysis of the data collected at the BTF test beam to study HET response and to validate Bhabha acceptance is completed and a technical paper is in preparation;
- $\eta \to \pi^0\,\gamma\gamma$ and B-boson search: are in the final review stage, almost ready to be submitted for publication.

The critical point remains the computing. The valuable support of the dedicated expert is crucial to complete data migration and data consolidation operations, facing old library problems.

DUNE

The 24 barrel-modules of the electromagnetic calorimeter of KLOE2 were all successfully extracted, and now are under refurbishment. The endcaps-dismounting work is in preparation.
The new yoke power supply will be delivered in 12 months. The design of the magnet cryostat extraction tools is completed. Work is progressing.

HL-LHC experiment upgrades

The Committee will review these activities during one of the next meetings.

ATLAS cleanroom, completed with dry air system will be commissioned before summer. The 28 m^3 climatic room is ready and part of the facility. CO_2 cooling plant is already in operation to test first prototypes, before final installation to be used in the cleanroom by end of 2024.

5. SPARC_LAB and EuPRAXIA@SPARC_LAB

Findings SPARC_LAB:

- SPARC_LAB operation continued after the last SC meeting in November for another 3 weeks. Experiments in this period concentrated on plasma beam interaction, namely: beam bending with a curved capillary; focusing and acceleration and refocusing in a common capillary; wakefield studies in combinations of plasma and dielectric structures.
- Since then, SPARC_LAB is in shutdown for installation work, comprising the SABINA THz Undulator line, new solenoids for the accelerating structures and a new Low-Level Radiofrequency (LLRF) system.

- Experimental activities will resume in July with focus on: the new RF photo-injector; further plasma/beam interaction experiments; test of the new PM focusing quadrupole triplet. This run is planned to continue until end 2024.
- The first half of 2025 will be used for EuAPS installations, which have to be finalised in 2025 because of PNRR funding rules.
- Promising preparatory test for EuAPS utilizing the FLAME laser were performed

Comments SPARC_LAB:

- The SC appreciates again that the SPARC_LAB team took the recommendations from the last report into account and reported on the progress of the related items.
- The SC applauds publication of "Guiding of Charged Particle Beams in Curved Plasma-Discharge Capillaries" in PRL.
- The experimental demonstration of tunable dispersion with curved plasma capillaries is another impressive result of SPARC_LAB.

Recommendations SPARC_LAB:

- *Assure that sufficient effort and time is put on experiments relevant for finalising EuPraxia@SPARCLAB design.*
  In particular
    - *Demonstration of robust plasma capillaries suitable for long term, high repetition rate operation*
    - *Comparison of PM magnet vs. plasma focusing*
    - *Studies of timing/bunching/energy stability with velocity bunching. These tests are decisive for the choice velocity bunching vs. magnetic bunching and have substantial impact on the EuPRaxia@Sparclab concepts and design finalisation.*
- *Accelerate procurement and installation of a solid-state klystron modulator for the velocity bunching section of the injector. A high stability RF power source at this position is imperative for demonstrating the stability of timing/bunching/energy mentioned above.*
- *Continue studies and explore the application potential of curved capillaries.*

Findings EuPRAXIA:

- On March 8th P. Campana was appointed EuPRAXIA project leader following R. Assmann in this role.
- Since the last SC meeting the milestone for building completion has shifted by two years, from 2027 to 2029, The milestone for TDR completion has shifted by about half a year to end of 2025.
- A recent EuPRAXIA@SPARCLAB cost review revealed that the budget is short of about 20M€, even if the project scope is reduced from two to one FEL line. For this estimate an annual cost increase due to inflation of 2% is assumed.
- Two key design decisions have to be taken before the TDR can be finalized
    - Velocity or magnetic bunching for electron bunch compression
    - Drive bunch dump mechanism and location including related radiation shielding design.

Comments EuPRAXIA:

- The building delay is partly explained by the lack of support for civil engineering inside LNF, because LNF's experts are occupied with the preparation for the new computing center building. Therefore, the call for tender preparations didn't proceed as planned.
- The recent cost review, although pointing to a very significant budget issue, was an important step to get a better understanding of the financial risks of EuPRAXIA@SPARCLAB.

Recommendations EuPRAXIA:

- *The delays of EuPRAXIA@SPARCLAB have to be taken into account for the overall strategy for research activities at LNF, since a sufficient portfolio of other scientific activities has to be maintained until the science program at EuPRAXIA@SPARCLAB starts. This has to be kept in balance with sufficient technical resources for EuPRAXIA@SPARCLAB design and project execution.*
- *The SC re-iterates its recommendation from the last three reports that radiation levels and shielding dimensions for the drive bunch collimation and/or dump need to be computed. At a beam energy of more than 1 GeV and a mean beam current in the order of 0.1 μA this shielding may need considerable space and has to be known before building specifications are frozen!*
- *To avoid further delays the open design question for the TDR need to be solved with high priority by studies, simulations and appropriate experiments in SPARCLAB.*
- *Component procurement should start as soon as the TDR is finalized, otherwise inflation will drive the overall cost even higher.*
- *The LNF and EuPRAXIA management has to develop a strategy how to cope with the cost overrun. Either additional financial resources have to be found, or a project descoping, or a phased approach has to be decided.*

6. COLDlab

Findings

- QUAX@LNF
  - First physics run established upper limit on axion photon coupling about an order of magnitude above Kim-Shifman-Vainshtein-Zakharov (KSVZ) axion prediction in a small mass region around 36.5 micro-eV (published in arXiv and submitted to PRD)
  - Developed program for next runs to reach KSVZ sensitivity
- Quantum Superconducting Devices (QSD)
  - Start to have the building blocks to produce QSD
    - Quantum amplifier JPA (Josephson Parametric Amplifier) with good performance fabricated at FBK (Fondazione Bruno Kessler)
    - Qubit design, fabrication and characterization ongoing
- FLASH
  - Successful test of the FINUDA magnet
  - Collaboration forming proceeds

    - FLASH CDR almost ready; FLASH TDR in preparation
    - Ongoing discussion with Physics Beyond Collider Study Group at CERN for support on cryostat design
- Since last SC meeting and as suggested by the latter, many young researchers and students have been hired
- To carry forward all the three projects above, more permanent staff scientists is needed.

Comments

- The committee is pleased to see remarkable progress in all three sub-projects
- It congratulates QUAX@LNF to be now on the world-wide map of established axion haloscopes, sensitive in a mass region which has not been probed before.
- It appreciates that the Quantum Superconducting Devices (QSD) sub-project has now acquired the knowledge to produce in fact QSDs.
- It congratulates for the successful test of the FINUDA magnet. Happy that indeed no show-stoppers towards FLASH have been fund and that, as recommended by the report of the last SC meeting, the INFN procedure towards establishing the experiment and the collaboration forming process have started.

Recommendations

- *Looking forward to the results of the next QUAX@LNF runs with improved detector which are projected to probe the predictions from vanilla axion models.*
- *To carry forward all the three sub-projects above one needs more permanent staff scientists. There are already experienced post-docs at COLDlab who are possible candidates for those positions.*

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7. Committee matters

The committee would like to thank LNF for the excellent organization of the meeting and everyone involved in the visit of SPARC_LAB and the various beamlines under construction.

In view of the decisions that will need to be taken concerning the evolution of DAΦNE, the committee would appreciate to visit the facility at the next meeting.

8. Next Meetings

After the meeting of the Scientific committee, the dates for the November 2024 meeting have been shifted and the meeting will take place 20-21 November 2024. Further meetings will then be scheduled with the incoming director.

Members:

U. Bassler (Chair)
G. Arduini (LINAC/BTF and DAΦNE),

H. Braun (SPARC_LAB and EuPRAXIA@SPARC_LAB)
N. Pastrone (KLOE-2, DUNE and HL-LHC upgrades)
J. Pelaez (SIDDHARTA-2)
A. Ringwald (PADME, COLDLab)