66rd MEETING OF THE LNF SCIENTIFIC Committee – 8-9/11/2023

The Scientific Committee (SC) met at the *Laboratori Nazionali di Frascati* (LNF) for its fall session on the 8-9 November 2023. Besides the Open Session, the committee visited various facilities in the laboratory for LHC-detector upgrades, 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/35533/timetable/#20230504.detailed

The director of LNF, Fabio Bossi, welcomed the committee.

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.

1. Director's Report

Findings:

- After successfully accumulating data during the first part of the year, the 2nd half will be dedicated to SIDDHARTA-2 data taking as well as the first semester of 2024. This will conclude the SIDDHARTA-2 data taking, while PADME is pursuing the analysis work.
- 2024-2025 will be a challenging year concerning the various construction and installation projects (EuPRAXIA, Computing Center, SABINA…) A cost and schedule revie of Eupraxia foreseen in December 2023, with the main concern being the hiring of technical staff and delivery within schedule of PNRR (National Recovery and Resilience Plan) financed projects.

- Despite an increase of the number of employees, after several years of decrease, hiring qualified technical personal remains a challenge.

Recommendation:

- *The committee congratulates LNF for the successful running of DAFNE and the Siddharta-2 data taking. Discussion have started in order to define the future of DAFNE, and the committee expects one or several resources loaded scenarios to be presented at the Spring 2024 session. In order to elaborate those, we recommend to set up a project management bureau for the laboratory.*
- *The 2024-2025 period several construction projects will have to be carried out in time and on budget due to their funding scheme. The utmost vigilance of the laboratory management is required to identify early on any possible difficulties and mitigate the risks: review and reporting mechanisms need to be in place and followed up.*
- *We encourage the laboratory management to continue the efforts in hiring qualified work force, and envisage to expand the connection to the relevant school.*

2. LINAC-BTF and DAΦNE

Findings LINAC-BTF:

- The LINAC has been operated for BTF2 and DAΦNE since the las Scientific Committee Meeting in May except during the summer stop. It has suffered from a series of faults (cooling tower, modulator B, dipole chicane, water leak on a klystron solenoid) significantly impacting BTF2 and DAΦNE availability. Out of the 4 weeks of scheduled beam time lost, 3 could be rescheduled.
- PADME is presently installed in BTF1 and for that reason BTF1 is not available for the users' community. Requests for beam time for HL-LHC detector tests at BTF might increase in the future, in particular in the period 2026-2027, as a consequence of the forthcoming long shut-down of the SPS North Area and the possible construction of PETRA IV at DESY.
- The committee was reminded that the specifications for the consolidation of the power converter of the switching magnet DHPTB101 depend on the future of DAΦNE operation.

Findings DAΦNE:

- DAΦNE was stopped on 24 July for the summer break after 81 days of run. Operation in June and July suffered once more from poor reproducibility of the machine due to the high external temperatures. DAΦNE has restarted operation on September 15 and collisions have resumed by 25 September. The accumulated electron and positron currents and peak luminosity achieved in spring 2023 have been regularly obtained with the exception of a period where electron beam instabilities and higher backgrounds have been observed. These instabilities have been traced back to ion accumulation on the electron beam resulting from a vacuum leak. A reduction of the number of bunches with an increase of the bunch population has mitigated the impact on

performance. The vacuum leak could be identified and fixed by 23 October. Since then, the machine performance has been recovered.

- The major source of downtime has been the LINAC (431 h), followed by Ring RF plant (265 h) and magnets and power supplies (193 h). A significant fraction of time was also lost for interventions on the SIDDHARTA-2 detector. The machine availability since the start of the 2023 run has been 68% (excluding the machine stops required by the experiment).
- Approximately 350 pb^{-1} (including the luminosity accumulated during injection) have been collected in 2023 by the time of the Scientific Committee and it is expected that additional 150-200 pb^{-1} could be delivered by the end of the 2023 run, planned for 21 December, assuming the average production rate (4-5 pb^{-1}/day) and the machine availability achieved so far. Operation in 2024 until the end of June should allow DAΦNE to deliver the required total luminosity in K-d mode (800 pb^{-1}) and additional 100-150 pb^{-1} for calibration purposes.
- The lack of technical personnel, exacerbated by the forthcoming retirements, is an issue to guarantee DAΦNE regular operation. DAΦNE operation requires 2 technicians on shift in addition to the 2 technicians required for the LINAC-BTF operation. The technicians are drawn from equipment and technical infrastructure groups and therefore machine operation competes for resources with accelerator and infrastructure maintenance and consolidation or with the execution of other accelerator projects.

Comments LINAC/BTF:

- The Committee congratulates the LINAC/BTF team for the dedication and commitment in the repair of the HW faults affecting the machine and for the efficient rescheduling of the BTF user shifts to minimize their impact.
- The recent faults highlight the necessity for a consolidation of the LINAC systems and its technical infrastructure considering that the LINAC and the associated BTF user facility are a pillar of the long-term strategy of the Laboratory.

Comments DAΦNE:

- The Committee congratulates the DAΦNE team for the identification of the origin of the instabilities observed during the run and for its cure, as well as for maintaining the performance of the machine at the levels achieved in spring.
- The possibility of using DAΦNE as test-facility for accelerator physics experiments has been once more ventilated but no concrete program and no resource requirements or resources allocation from interested partners have been presented.

Comments on LINAC-BTF/ DAΦNE strategy:

- The LNF director has stressed that the Laboratory has a series of commitments in the near future (particularly in 2024-2025). These include the completion of the EuAPS betatron radiation line, the SABINA THz line and the High-Performance Computing facility as well as the installation of the ELI-NP Linac in Magurele, Romania. These

activities are critically relying on technical manpower. Replacement of the retirements is hampered by the extremely competitive job market.

- A program of consolidation of the LINAC is also critical in view of the long-term aspirations of the Laboratory.
- The Committee has not been presented with a resource-loaded medium-term plan for the operation (and consolidation) of the LNF accelerator facilities.

Recommendation on LINAC-BTF/ DAΦNE strategy:

- *The committee encourages the LNF management to define a resource-loaded medium-term plan for the operation and corresponding required consolidation of the LNF accelerator facilities as well as for the execution of the projects above mentioned and in particular of EUPRAXIA according to the presently known commitments. Some **indicative** scenarios are suggested, e.g.:*
    - *interleaved operation of PADME and of DAΦNE for EXCALIBUR according to the plans proposed by the respective collaborations in parallel to BTF2 operation; the possibility of operating DAΦNE as accelerator physics testbed for future colliders could be included;*
    - *operation of DAΦNE as accelerator physics testbed for future colliders in parallel to BTF2 and interleaved with PADME operation according to the plan presented by the collaboration after June 2024;*
    - *exclusive operation of the LINAC for BTF2 and PADME according to the plan presented by the collaboration after June 2024;*
    - *exclusive operation of the LINAC for BTF1 and BTF2 after June 2024.*

  A possible long shutdown of some/all of the LNF accelerator facilities could be included as part of the above scenarios.

  The scenarios including operation of DAΦNE as accelerator physics testbed should include a detailed program as well as the resources required at the Laboratory and those expected to be realistically committed by the participating Laboratories.

  An analysis of the expected BTF user beam time requirements should be included.

  The results of the above analysis should be presented at the next Scientific Committee meeting.

3. SIDDHARTA-2 and PADME

Findings SIDDHARTA-2:

- Since the last SC meeting in May 2023 the collaboration reports the publication of their simultaneous analysis of $K^-p \rightarrow \Sigma^0\pi^0$ and $K^-p \rightarrow \Lambda\pi^0$ [1], of a pionization method

[1] Phys. Rev. C108 (2023) 055201.

to study the nuclear surface[2], their findings on potentialities of CdZnTe detectors[3], the KAMEO proposal to investigate the effects of the E2 resonance in kaonic atoms[4] and two reviews about kaonic atoms and kaon-nucleus/nuclei interactions[5,6].

- The collaboration also highlights its publications of 2022 data analyses. Namely, the submission[7] of the first measurement of M-transitions in K-^{4}He, relevant for cascade models and the publication[8] of their study on the density dependence of the K-^{4}He Lα transition.
- Concerning the K-Ne data collected in early 2023, they report the remarkable precision (<1eV) of their first-ever measurement X-ray transitions, which they are preparing for publication. In addition, these data have allowed for a preliminary determination of the charged-kaon mass, of interest given the ∼5σ discrepancy between the two most precise previous experiments. The collaboration has developed a machine-learning method that could improve the systematic uncertainty and could allow for high-precision results, published (online)[9].
- In addition, the study of their Veto-2 system has been accepted by JINST. Finally, they inform of several publications of contributions to conferences and workshops, submissions to journals, as well as the completion of one PhD and two Master theses.
- Since the last SC, SIDDHARTA-2 has used the optimized setup to measure kaonic deuterium. The first run started in May and was completed in July, collecting an integrated luminosity of ∼200 pb^{-1}, including injection time (∼70 pb^{-1}). Run2 began on 25 September and, until 8 November, provided another ∼100 pb^{-1}, also including injections. They expect to collect at least ∼100 pb^{-1} more by the end of the year, totaling at least ∼400 pb^{-1} in 2023, plus another ∼400 pb^{-1} in Run3 from January until June 2024.
- The collaboration presented a very preliminary analysis of the Kd Run1 data. They found a promising but inconclusive accumulation of events in the region of interest (ROI) around 7 keV. More importantly, the findings of this analysis have been relevant in two ways:
    - To reduce nearby peaks very close to the ROI. They correspond to the KN6→5 (7595 eV) and CuK$_\alpha$ (8041 eV) transitions. Consequently, to remove or suppress these peaks, during the summer stop, the collaboration has redesigned the support structures and replaced a scintillator, some screws behind the SDD holders with new ones made of titanium, and the vacuum chamber's

[2] Phys. Rev. C108 (2023) 014313.
[3] Sensors 23 (2023) 17, 7328.
[4] Nuovo. Cim. 46 (2023) 3, 59.
[5] Front. in Phys. 11 (2023) 1240250
[6] Front. in Phys. (2023) 1237644
[7] J. Phys. G: Nucl. Part. Phys.
[8] Nucl. Phys. A, 1029, 122567.
[9] Meas. Sci. Technol. 35 (2024) 025501.

entrance window with a new one made of Mylar. These improvements are being checked in the ongoing Run2 data analysis.

  - To assess the quality of the data collected during injection. Setting a simple threshold of 0.5 in the Kaon/SDD rate, so that the background does not increase more than a factor of 2, it appears that more than 50 pb^{-1} out of about 70 pb^{-1} could be usable. The final assessment is still under evaluation.

- Completing the Run1 preliminary analysis requires the inclusion of all the calibrations, the use of the 1 and 3 veto systems, and the selection of injection data.
- The collaboration also informs of the K-Pb measurement using the satellite HPGe detector. They have acquired ~110 pb^{-1} in June-July and ~118 pb^{-1} from the end of September until early November. The preliminary analysis of the data collected before the summer stop has already allowed for the identification of three transition lines. The analysis is in progress, and a publication will be submitted soon.
- In addition, SIDDHARTA-2 has been running the first test of the CdZnTe detectors mounted at DAΦNE, now covering 8 cm^2. They have confirmed a high efficiency in the 20-100 keV region and a reasonable one up to 300 keV, as well as a very good resolution (~%) and fast response (<50ns). Two publications related to these detectors have appeared this year[10,.11]. A second module with another 8 cm^2 is being installed to measure kaonic carbon and aluminum atoms in the next run.
- The collaboration reiterates the request for an extension after the Kd runs, profiting from the post-calibration runs, to measure light kaonic atoms (e.g. Li, Be, B), using solid targets and 1 mm SDDs. With 150 pb^{-1} they expect to achieve a precision of 2-3 MeV.
- The collaboration also restated the EXCALIBUR proposal to measure with precision kaonic-atom spectroscopy along the periodic table. They emphasized the modular character of the proposal, as already presented to the SC65, that could extend from 400 to 1500 pb^{-1}. Each module could be executed over a few months per year in the next 2-3 years. This provides the opportunity to extend the SIDDHARTA/DAΦNE physics program, taking advantage of the studies performed by SIDDHARTA-2 on solid targets as well as CdZnTe, HPGe and 1mm SDD detectors. They reiterated their availability for discussions and to reschedule their plans, depending on machine and beam time availability.

Comments for SIDDHARTA-2:

- The SC commends the members of the SIDDHARTA-2 collaboration for their new publications and the results obtained on K-^{4}He, KNe, and KPb atoms, as well as the remarkable results in their tests of CdZNTe detector.

[10] Sensors 23 (2023) 17, 7328.
[11] Eur. Phys. J. Spec. Top. 232, 1487–1492 (2023).

- The committee also praises the collaboration for their fast preliminary analysis of the kaonic deuterium Run1 200 pb^{-1} and their rapid actions toward identifying and replacing components deemed responsible for emission peaks that could increase the background in the region of interest.
- The SC also appreciates the promising study of the usability of data collected during injections.

Recommendations for SIDDHARTA-2:

- *The SC endorses the current plan to continue running the DAΦNE/ SIDDHARTA-2 setup, completing a second run by the end of 2023 and a third one before the summer of 2024. Thus, it encourages the SIDDHARTA-2 collaboration to continue decisively with their kaonic deuterium data-taking, with the aim of collecting 800-900 pb^{-1} in total.*
- *To complete the ongoing evaluation of the usability of the data recorded during injection time.*
- *If the 800-900 pb^{-1} goal on deuterium is successfully achieved before the end of June, the SC considers it appropriate to still extend Run 3 until the end of June 2024, so that the collaboration can measure light kaonic atoms, partly profiting from the post-calibration run.*
- *To continue during runs 2 and 3 with the satellite HPGe and CdZnTe detectors, but always minimizing their interference with the Kd data taking.*
- *Finally, the SC recommends the submission, before the next SC meeting in May 2024, of a detailed proposal of the first module of the EXCALIBUR proposal. This should include a calendar for installation, commissioning, and operation, integrated luminosity needs, and details on what parts of the main and satellite detectors could be operative at what times as well as the specific kaonic atoms to be measured.*

4. PADME

Findings

- PADME Run II analysis proceeds. The collaboration is working on an ML technique applied to the ECAL giving a better time resolution.
- A further experiment has strengthened case for PADME Run III:
    - IPC experiment repeated by Hanoi University using a pelletron accelerator with a 2 arm spectrometer like the one used by ATOMKI on the giant resonance 12C and 8Be tested at different bombarding energies. The anomaly was confirmed in both 8Be and 12C, as presented in talk given at ISMD 2023
- PADME Run III analysis: First look into the “far side-bands”.
- Expected sensitivity update taking into account new information
    - Actual number of POT and energy point from Run III (real data)

    - MC simulations of the energy resolution energy by energy (full Geant4)
    - MC driven estimates of the total background and acceptance (ToyMC)
- Two publications for Run III by PADME collaboration, LNF theory and BTF staff in preparation (expected December 2024)
    - "Characterization of the PADME beam for the X17 run": Describing measurements and simulations of the beam parameters
    - "Status of X17 search at PADME": Providing analysis strategy, PADME sensitivity in off resonance regions, and projected sensitivity in the signal regions.
- Expect a result on the X17 signal region by summer 2024.
- PADME will ask for ~120 days of running in 2024, if a significant fluctuation is
    - observed in the 17 MeV region on Run III data, the collaboration wants to repeat the mass scan in a limited region around the fluctuation
    - not observed, the collaboration would like to explore visible decays scenarios in an expanded mass region from 14-23 MeV. This would require up to 300 scan energy points.

Recommendations

- *The committee is pleased to see the two publications in an advanced state. These will be important before unblinding the analysis.*
- *Even in the absence of a signal the current Run III statistics is too low and a statistical fluctuation is likely. The collaboration should plan for additional running to collect more statistics around the 17 MeV mass region. This run should be scheduled after the SIDDHARTA-2 run is completed.*
- *The scientific case for an expanded mass region scan of 14-23 MeV should be strengthened.*

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

KLOE-2

We discussed with Antonio Di Domenico the status of the activities. The new strong group from the University of Liverpool (3 staff, 2 post-doc, 2 students- including theorists) has been trained to work to complete the MC production and to start reprocessing and analyzing data on the hadronic cross-section contribution to muon anomaly. Many positive progresses, on analysis and published or close to be published results: direct tests of T, CP, CPT symmetries in transitions of neutral K mesons[12]. An editorial team is concentrating on publishing, one at the time, results on $\eta \to \pi^0\gamma\gamma$ analysis of KLOE-2 data.

[12] Physics Letters B 845 (2023) 138164.

On $\gamma\gamma \rightarrow \pi^0$ with High Energy Tagger (HET) a test beam at BTF has been performed dedicated to study HET response to validate Bhabha acceptance. The analysis on B-boson search has started.

The critical point remains the computing and the old library maintenance, where we recommend to preserve at best the data copy, and possibly support the dedicated expert.

DUNE

The yoke, coil and e.m. calorimeter of KLOE2 should still be dismounted, both requiring refurbishments. The ECAL requires an adequate working space to store the disassembled modules and install the new electronic read-out chain, which is close to finalized. The procurement for the new joke power supply and cryo interface are placed. Tests must be completed before dismounting and shipping the magnet to FNAL in 2025.

HL-LHC experiment upgrades

The Committee visited the laboratories where activities are on-going at different stages:

- ALICE: the ITS module construction was completed with success, also testing sensors at the BTF;
- LHCb: work is in progress on $\mu RWELL$ R&D;
- CMS: LNF is a production site for the GE2/1 chambers: 15 assembled on the 45 total expected;
- ATLAS is finalizing the cleanroom space and preparing the infrastructures for the assembly and commissioning of one outer pixel endcap.

The work ahead for ATLAS is significant and requires detailed planning and dedicated experts, with good technical support from the LNF.

6. SPARC_LAB and EuPRAXIA@SPARC_LAB

Findings SPARC_LAB:

- SPARC operated in 2023 for about 4 months in total, with approximately one third of the operation used for experiments.
- First experiments with the "all-in-one" configuration, combining two plasma lenses (instead of PM-Magnet triplets) and the plasma wakefield accelerator in an integrated capillary configuration were performed. Acceleration with this set-up was demonstrated but fell short of expectations. The present interpretation is, that non-linearities of the radial dependence of the plasma lens focusing strength is the cause.
- In a recent experiment at SPARC_LAB a 4° bending of an electron beam by a plasma lens with a curved capillary was demonstrated. This experiment demonstrates an idea of R. Pompili, see AIP Advances 8.1 (2018): 015326.
- The new set of PM focusing triplets has been delivered to LNF. First checks of magnetic field indicate that their field quality is better than the previous triplets.

- The administrative procedures for early procurement of two EuPRAXIA@SPARC_LAB solid-state klystron modulators for a first use in SPARC_LAB have been launched. Delivery is expected for 2025.
- All three undulators for SABINA have been delivered to LNF
- During 2024 major installations for EuAPS and SABINA will take place, which limits the time available for plasma acceleration and focusing experiments. The experiment program for 2024 has still to be defined.
- First laser plasma acceleration experiments with the FLAME laser system demonstrated acceleration up to 250MeV with a very large energy spread. Furthermore, were X-ray photons from betatron radiation observed.

Comments SPARC_LAB:

- The SC appreciates that the SPARC_LAB team took the recommendations from the last report into account and reported on the progress of the related items.
- The results of the first tests with the all-in-one configuration underlines the importance of the R&D and experiments in SPARC_LAB for focusing and plasma acceleration system. This is essential for a successful realization of EuPRAXIA@SPARC_LAB.
- The SC commends the SPARC_LAB team for the successful demonstration of beam bending with a curved capillary plasma lens. This is based on an idea developed at LNF and it is the first experimental demonstration of this scheme. SC recommends publishing these results soon.

Recommendations SPARC_LAB:

- *Assure that further R&D and experiments with the focusing and PWFA systems get sufficient effort and beamtime in 2024 despite of EuAPS and SABINA installations.*
- *Continue studies and explore possible applications of curved capillaries, in particular applications as a novel source of synchrotron radiation could be attractive.*

Findings EuPRAXIA:

- The Eupraxia effort at LNF is not only the realization of EuPRAXIA@SPARC_LAB but LNF is also the headquarter of the overarching European EuPRAXIA effort.
- The schedule for EuPRAXIA@SPARC_LAB facility implementation foresees completion by end 2027.
- Formal authorization for the EuPRAXIA@SPARC_LAB building has recently been received.
- The TEX facility for testing of EuPRAXIA@SPARC_LAB RF components has successfully started the testing of components.
- Design and prototyping of various components made good progress. The injector design has been frozen, a prototype RF structure is in production and designs for both undulator types made very good progress.

- Facility layout, schedule planning and cost estimate are progressing well. Due to inflation and addition of a second FEL line the estimate of total cost has increased since 2019 from 108M€ to 125M€. A cost review with external experts is scheduled on 11.12.2023.

Comments EuPRAXIA:

- The SC commends the EuPRAXIA@SPARC_LAB team for obtaining the building permit. With this a major milestone has been achieved.
- The Eupraxia naming conventions and the multitude of EuPRAXIA subprojects makes it difficult to give the key challenge for LNF, the realization of the EuPRAXIA @SPARC_LAB user facility, sufficient prominence and visibility.
- The SC would like to see a summary of the cost review results at the next SC meeting.

Recommendations EuPRAXIA:

- *The SC re-iterates its recommendation from the last two reports that radiation levels and shielding dimensions for the drive beam collimator 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 construction starts!*
- *The SC recommends to carefully analyze the implementation phase of EuPRAXIA@SPARC_LAB in 2027. The present approach is to install the facility by LNF personal in parallel with building and infrastructure completion by the contractor. This scheme bears several technical and legal risks, which could be avoided by extending the installation period beyond 2027.*

7. Coldlab

Findings

FLASH

- FINUDA magnet almost ready for the cooling / energizing test (planned between December and January)
- CDR for FLASH published in Physics of the Dark Universe

Axion searches

- QUAX:
    - 8.5 GHz tunable cavity run almost ready to start the cooling (end of November);
    - SC magnet has been repaired (current leads) and is now operating at nominal field (9 T);
    - Publication of "Search for galactic axions with a traveling wave parametric amplifier" in Phys.Rev.D 108 (2023) 6, 062005, performed at INFN Legnaro.

- First tests of a Cu/ReBCO (HTSC) tape RF cavity (f = 17.8 GHz (TM110)) measured a loaded Q factor of 1.65×10^5, somewhat below the expectations, but good enough to reach nearly KSVZ sensitivity

Recommendations

- *"Ceterum censeo"*

  If no show stoppers are found,

  - *INFN procedure towards establishing the experiment should start*
  - *FLASH "interest group" should head to found the FLASH collaboration.*

  COLD Lab would profit from more lab space and from more PhD students.

8. Committee matters

The committee would like to thank LNF for the excellent organization of the meeting and everyone involved in the visit of the upgrade construction facilities of the LHC experiments. This meeting was also the last one of Patrick Decowski, who served over the last six years as a committee member, in particular reviewing the Padme activities. We would like to express our appreciation of all of his contributions and thank him for his engagement in the committee and propose to allow him to follow the PADME presentation at our next meeting, as the first results are expected.

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

9. Next Meetings

The next meeting will be held on the 27-28 May 2024 and the fall-meeting is envisaged on the 6-7 November 2024.

Appendix:

Members:

U. Bassler (Chair)

H. Braun (SPARC_LAB and EuPRAXIA@SPARC_LAB)

P. Decowski (PADME)

N. Pastrone (KLOE-2 and DUNE)

G. Arduini (LINAC/BTF and DAΦNE),

A. Ringwald (COLDLab)

J. Pelaez (SIDDHARTA-2)