64rd MEETING OF THE LNF SCIENTIFIC Committee – 14-15/11/2022

The Scientific Committee (SC) met at the *Laboratori Nazionali di Frascati* (LNF) for its fall session on the 14-15 November. Besides the Open Session, the committee 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/33111/timetable/#20221114.detailed

The director of LNF, Fabio Bossi, welcomed the committee, in particular its new members and chair: J.R. Pelaez, who took over from À. Ramos, N. Pastrone as successor of B. Heinemann and U. Bassler, who succeeded G. Dissertori as SC chairperson. This meeting would be the last of A. Polosa. However, to ensure a smooth transition, we would like to invite A. Polosa to the next meeting of 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, once more, clearly addressed

1. Director's Report

The LNF director Fabio Bossi emphasized the need to discuss with and obtain advice from the SC regarding the current energy crises and the possible impact on the 2023 operations plan for DAΦNE and LINAC/BTF, in order to serve the two main ongoing experiments SIDDHARTA-2 and PADME.

Findings:

- Three scenarios have been envisaged, with an energy consumption of
  - 15.4 GWh (Full DAΦNE and BTF running);

- 10.2 GWh with DAΦNE running in spring and summer and only BTF in autumn;
- 9.1 GWh with no beam in fall.

Recommendation:

- *In the current volatile situation, planning must remain as flexible as possible. As all three scenarios foresee data taking in Spring/Summer by DAΦNE, a decision point should be determined in late Spring concerning the plans for Fall in order to communicate with the experiments in due time. Priority should be given to the DAΦNE/SIDDHARTA-2 program, yet, if the energy prizes do not allow for running in Fall, an extended PADME run should be supported.*
- *Evaluate the possibility of running DAΦNE in spring and autumn, extending the summer stop, to minimize sources of unavailability and possibly profiting of lower energy costs.*

2. LINAC-BTF and DAΦNE

Findings LINAC-BTF:

- After the initial issues with the start-up following the winter stop, already presented during the last SC meeting, the LINAC has been running with good availability as DAΦNE injector. The availability for the BTF users has been close to 100%. The ERAD run, testing radiation resistance for aerospace components funded by the Lazio region, could be completed successfully. Following some tests, the LINAC and PADME team have agreed to operate the experiment with primary positron beams. This has required extended setting-up effort but has allowed reducing the background to the experiment. The availability for the dedicated runs searching for the X17 boson (X17 run) has been close to 94% until 11/11. Unfortunately, an intervention on the external electrical network has required a stop of the whole accelerator complex since then.
- An intervention is planned on Klystron C during the next winter stop allowing for the operation of the LINAC at 50 Hz and halving the injection time in DAΦNE.

Comments LINAC/BTF:

- We congratulate the LINAC/BTF team for the completion of the ERAD programme and for the efficient running for the PADME X17 experiment, the latter requiring an impressive number of machine configurations. The LINAC is one of the major assets of the laboratory and it is important to continue the hardware consolidation effort to maintain and possibly improve its availability.

Findings DAΦNE:

- In 2022 DAΦNE was operated from 8 April to 11 July and it has delivered to SIDDARTHA-2 ~45 pb^{-1} with the helium target (K-^{4}He run), ~35 pb^{-1} with the deuterium target (K-d run) and ~5 pb^{-1} with helium target for post-run calibration. The average machine uptime was 72% with major stops due to the LINAC (mostly at the beginning of the run), magnets and power supplies and electrical network perturbations. The analysis of the downtime distribution during the DAΦNE run

indicates a lower availability during the summer when more frequent perturbations on the network were observed and the equipment operational conditions were harsher due to the high temperatures.

- The maximum luminosity production rate has exceeded slightly 2.5 pb^{-1} per day, while the average rate was 2.1 pb^{-1}/day. The average ration between the Kaon trigger rate and the Silicon Drift Detector rate has been improved from 13% to more than 20% but it remains lower than the best achieved during the SIDDHARTINO run when it was exceeding 30%.
- The positron beam intensity is presently limited to about 600-650 mA while 800 mA could be achieved during the SIDDHARTINO run. Betatron coupling as well as positron intensity limitation and emittance blow-up both due to electron cloud were identified as sources of the lower luminosity reached. Whereas the betatron coupling for the positron beam has been corrected, the main contribution to electron cloud density comes from the wiggler magnets. Clearing electrodes that were used in the past to suppress electron cloud build-up in the wigglers are no more operational and interventions to repair would entail significant risks (e.g., venting and loss of conditioning). The DAΦNE team is confident that an optimization of the parameters of the transverse feedback could allow to increase the stored positron current to 800 mA. Crab-waist sextupoles are not fully powered and their beam-based realignment would be required to re-establish nominal currents of these elements, as misalignments induce undesired feed-down effects (tune shifts or coupling) that increase with increasing operating current of the sextupoles. Re-establishing nominal crab-waist sextupole currents could help to reduce background to the experiment and/or luminosity. No machine time has been allocated to address the above points, so far. The sudden loss on the electron beam reported during the last SC meeting was understood and corrected.
- At present, injection of each beam takes approximately 6 mins and 3 mins are taken to switch from the injection of one beam to the other. During this time (15 mins) SIDDHARTA-2 cannot take data due to the high background. The optimum "stable beam" time is ~24 mins. The injection time is mostly determined by the repetition rate of the LINAC which is presently limited to 25 Hz due to a faulty vacuum window in Klystron C.
- At least 500 pb^{-1} are required to complete the SIDDHARTA-2 physics programme. At least at 200 days of operation will be necessary to achieve that goal at the present rate of luminosity production. The proposed actions for reducing the injection time, conducting the beam-based alignment of the crab-waist sextupoles and tuning of the transverse feedback to increase the positron current appear to be a worthwhile investment (in particular if implemented early in the run).
- During the years the power consumption of DAΦNE has been reduced significantly and additional energy-saving measures have been implemented recently: wigglers and main dipoles have been switched off when machine stops exceeding 4-5 hours were expected. According to the DAΦNE team this has affected machine reproducibility and therefore performance, though no quantitative estimate of that has been provided. Further energy saving measures have been studied: a potential reduction of the power consumption by 7% could be achieved by lowering the powering of the damping ring and injection transfer lines between injection periods,

but this could entail thermal excursions on the magnets and reduce further reproducibility.

Comments DAΦNE:

- The Committee commends the effort made by the DAΦNE accelerator team to improve the performance of the machine and to envisage means to reduce power consumption.

Recommendations LINAC/BTF and DAΦNE:

- *Operate the LINAC at 50 Hz, provided a repair of Klystron C is successful, to reduce injection time. Optimum "stable beam" duration should be adapted accordingly considering luminosity lifetime.*
- *Prioritize and assign sufficient DAΦNE machine development time to recover the performance reached during the SIDDHARTINO run. This appears to be a good investment given the expected duration of the SIDDHARTA-2 run.*
- *Evaluate quantitatively (by means of an analysis of past operation and of dedicated tests) the impact of actions taken or proposed for reducing the DAΦNE complex power consumption on machine reproducibility and integrated performance. Determine the effectiveness of these measures in reducing the energy consumption per unit of produced luminosity before implementing them in operation.*
- *Continue the analysis effort for the identification of the sources of LINAC down-time and of the elements that might require consolidation for long-term operation of the accelerator in view of maintaining and possibly increasing reliability.*

3. SIDDHARTA-2 and PADME

Findings SIDDHARTA-2:

- Since the last SC meeting in May 2022 the collaboration reports the publication of the K-^{4}He L-series measured with SIDDHARTINO, their investigation of KKK low-energy interactions with light nuclei at AMADEUS, and the imminent submission to EPJA of the results on K-atom transitions from solid targets performed at SIDDARTA-2. They also report several publications of contributions to conferences and workshops, as well as four more articles already submitted and awaiting reports together with 4 more in preparation.
- In the May-July 2022 period, they report a total of 45 pb^{-1} collected for the optimization K-He run, about 35 pb^{-1} for their first K-deuterium run, and about 5 pb^{-1} for a post-calibration run with K-He again. This is only slightly less integrated luminosity than the 100 pb^{-1} goal recommended in the previous 63rd SC, due to major stops and other external adverse circumstances suffered by DAΦNE. The possibility of acquiring additional integrated luminosity in September, whose consideration was recommended by the 63rd SC in case the PADME set up had to be performed in September, finally did not take place.
- During these runs they have developed and tested a calibration method of the full 384-SDD apparatus (six-times more SDDs than SIDDHARTINO) operating under the real background conditions of the DAΦNE collider, showing stable performances

during the data taking period. The resulting spectra analysis shows that, provided the required integrated luminosity (around 500 pb^{-1}, and not less than 500 pb^{-1}) is delivered, with this method they will be able to accomplish the K-deuterium measurement with systematic errors at the level of 2-3 eV, required to disentangle the strong present controversy about low-energy K-N interactions.

- They have also installed the veto-1 and veto-2 systems, improving their K-deuterium background rejection factor down to $1.6x10^{-5}$. However, with 35 pb^{-1} a mere 1σ effect is to be expected and thus no significant K-d signal is observed yet. The first SIDDHARTA-2 K-d run has thus had a predominant technical character.
- Concerning K-^{4}He run in gas, they have completed their data taking, achieving a sub-eV precision, observing also many transitions from solid targets. Surprisingly they have been able to perform the first measurement of M-line transitions and the coincidence with L-lines. They have improved the S/B ratio by a factor larger than 30, which constitutes a positive test for the feasibility of future kaonic atom measurements. All these results should give raise to several publications, some of them of technical character.
- However, both DAΦNE and SIDDHARTA reported that the kaon trigger versus SDD normalized rate is still about 30% lower than the value attained during the SIDDHARTINO run. Apart from the consolidation plan advanced by DAΦNE, the SIDDHARTA collaboration is proposing several actions to optimize this performance. This will be carried out between September 2022 and February 2023, before the start of the next data run. These actions include: the use of new material for the entrance windows to eliminate contamination from spurious signatures like N and O transitions, reinforcing the setup lateral shielding, and the addition of a third veto system below the setup. This optimization aims at reducing the background up to a factor of four.
- Concerning the parasitic HPGe detector, aiming at the precise determination of the charged kaon mass from heavy kaonic atom outer transitions, the collaboration has shown its first measured spectrum, for which they plan a technical publication, as well as the K-Pb measurements, which analyses are still ongoing,
- The collaboration also ran the first ever test of a CdZnTe detector on a collider. These detectors are of interest for the study of the spectroscopy of intermediate mass kaonic atoms. The prototype was installed in June 2022 and operated for three days under standard collider conditions. The expected good resolutions were confirmed, although a small worsening due to the configuration of some DAΦNE cables was observed. It will be modified before the next spring run.
- Finally, the collaboration put forward a proposal to measure kaonic atom transitions for solid targets with the SIDDHARTA setup after the K-deuterium run and an *Ex*tensive *K*aonic *A*toms research program comprising *LI*thium, *B*erylium and *U*ranium (acronym: *EXCALIBUR*), that would take place over a three to five-year period.

Comments SIDDHARTA-2:

- The SC congratulates the collaboration for their precise and surprising new results in K-He, their observation of kaonic atoms from solid targets, for completing the installation of the SIDDHARTA-2 setup and their development of the full apparatus

calibration method, as well as the confirmation of the feasibility of future measurements with HPGe and CdZnTe detectors. The committee also commends the collaboration for its achievements in testing and calibrating the main setup and parasitic detectors as well as for its continuous efforts to conceive additional actions to improve the detector performance and reduce the background.

Recommendations SIDDHARTA-2/DAFNE/BTF:

- *The SC encourages collaboration and coordination with DAΦNE in their mending plan to reduce background and improve the Kaon/SDD ratio.*
- *To continue their planned optimization activities: shielding reinforcement, veto3 system and installation of new entrance window. These should be completed before the end of February 2023, thus ready for the spring H-deuterium run1.*
- *To complete the proposed setup tests and installation of the parasitic HPGe and CdZnTe parasitic detectors with the aim of acquiring data during the 2023 runs.*

Findings PADME:

- The PADME collaboration submitted the manuscript detailing the gamma-gamma cross section measurement.
- The dark photon analysis from Run-2 is hampered by a newly discovered background ("Beam crash background") that is difficult to identify and might jeopardize the analysis. The collaboration is currently studying new reconstruction methods such as developing a shower discriminator to help identify this background. In addition, the "no target" runs taken during Run-2 may help in studying the background.
- The X17 run, with an energy scan around the resonance expected for a 17 MeV boson, is currently ongoing. The PADME collaboration studied the beams in the summer and settled on the primary beam to do this scan. The beam quality and energy resolution are very good.
- The collaboration is proposing a further extension of the energy scan to higher and lower energies to cover a wider part of the parameter space, beyond the X17 study, essentially covering any resonance between 11 and 21 MeV.
- Three new PhDs started in the collaboration.

Comments PADME:

- The SC acknowledges the submission of the paper on the gamma-gamma analysis and commends the start of the new PhDs.

Recommendations PADME:

- *The newly discovered background in the dark photon analysis is challenging and the collaboration will need some time to address it. The SC would like to see a report on this issue at the next SC meeting.*
- *The X17 run is going well and the SC hopes that data will be analyzed soon. The claim from the ATOMKI group requires a careful and unbiased analysis and techniques, such as a blinding strategy, should be adopted.*
- *Extending the energy scan beyond the X17 scan might be interesting but there is a general consensus that these should not be prioritized over SIDDHARTA-2 running.*

4. KLOE-2

Findings KLOE-2:

- Recent results include three papers on kaons: one published, two submitted to journals; two analyses at final stage, with a draft paper expected by the end of the year. Results have been presented in all major and topical conferences and workshops.
- The final data reconstruction is completed as well as MC production (DBV-40) with the main phi decays and a Luminosity Scale Factor = 1 corresponding to 4.7/fb.
- The ROOT KLOE-2 data output production, now available for 4.1/fb (to be completed) allows fast access to reconstructed data on four different streams: Charged Kaons, Neutral Kaons, Rho-Pi and Radiative. The aim is to facilitate new collaborators to join and contribute, even proposing new analyses. The plan for the next year is now to continue with the production of the KLOE2 MC sample and then follow with the KLOE data and MC production. 400 TB were purchased to keep all ROOT files on disk allowing faster accessibility.
- Despite the nice results and the great value of the KLOE-2 data, few peoples are really involved in data analysis and many results and activities are single-manned. The list of new interesting analyses proposed would still require new collaborators.
- Additional efforts are needed to guarantee data access and preservation according to the FAIR principles.

Comments KLOE-2:

- The SC comments the good progress done by collaboration in publishing and spreading results at conferences and underlines the great value of the KLOE-2 data, which deserves proper data-preservation.

Recommendation KLOE-2:

- *The collaboration should stay engaged and promote possible new analysis and search for new collaborators.*
- *The data preservation program is a positive initiative and the root output represent a good compromise to spread the access toward external collaborators keeping the effort at the collaboration scale. For real open-data access additional support is needed and should be provided by Data-Professionals. Possible synergies with other groups/experiments have to be investigated in order to profit of their expertise.*
- *For future SC, we would suggest to have a discussion with the KLOE-2 project leaders upfront of the meeting and to free up the current referee to be assigned to a different project.*

5. SPARC_LAB and EuPRAXIA@SPARC_LAB

Findings SPARC_LAB:

- The new permanent magnet quadrupole triplet did not perform as expected. The minimum electron beam spot size achieved was 35 μm x 35 μm, which is insufficient for beam driven plasma acceleration. After this problem had manifested the new triplet was removed and the old triplet re-installed for further plasma acceleration tests. First magnetic measurements of the removed triplet indicate a large sextupole like error component.
- With the re-installed old triplet, a plasma wake field acceleration of 35-42 MeV corresponding to an accelerating field of 1.0-1.2 GeV/m was achieved. This was possible because of the increased charge capability of the recently installed new RF gun. This value is a factor 3-4 higher than the values achieved before in SPARC_LAB. However, the quality and matching of the witness bunch after plasma acceleration was not suitable for FEL experiments.
- During the coming month a new photo-cathode laser system will be installed. Therefore, probably no further beam experiments are performed before the May'23 SC meeting.
- Progress was made on improving RF phase stability by improving LLRF feed-back and feed-forward systems. But the achieved stability in the order of 50 fs does not yet correspond to cutting-edge systems elsewhere. The main limitation is the voltage stability of the old style PFN high voltage modulator driving the klystrons.
- Studies of performance of glass and sapphire plasma capillaries as function of repetition rate have begun.
- With the EuAPS project funding for a short pulse X-ray source based on betatron radiation from laser plasma accelerated electrons was secured.

Comments SPARC_LAB:

- The SC commends the publication in PRL of "Stable operation of a free-electron laser driven by a plasma accelerator", describing seeded FEL operation with SPARC_LAB and showing that SPARC_LAB results continue to provide high impact publications underlining the success of this LNF activity.
- The SC appreciates again that the SPARC_LAB team has considered all recommendations from the 63nd SC meeting report and given competent response to the recommendations.
- Though the EuAPS project opens opportunities to get first users for short pulse X-rays to LNF, the X-ray generation method is very different from the SPARC_LAB and EuPRAXIA@SPARC_LAB ones.

Recommendations SPARC_LAB:

- *Perform an in-depth study of the permanent magnet quadrupole triplet including magnetic measurements, particle tracing and a redesign of the magnet assembly, possibly with additional features for field corrections.*
- *Establish improved quality control procedures for all critical components before installation.*

- *Consider an anticipated procurement of a solid-state S-Band klystron modulator of EuPRAXIA@SPARC_LAB for replacement of the present K2. This would allow early tests of a complete RF system for EuPRAXIA in realistic conditions and improve stability for SPARC_LAB experiments.*

Findings EuPRAXIA:

- TDR work made good progress. In particular beamline layout and RF system layout have matured.
- X-band structure mechanical prototype are completed; RF prototype work is progressing.
- The present inflation and supply chain problems worldwide may require an updated cost-estimate and spending profile.
- Substantial funding has been secured for the PNRR project EuAPS.

Comments EuPRAXIA:

- The SC commends the good progress on many design aspects including beam-dynamics, RF systems, beam instrumentation and plasma capillary.
- The SC re-iterates that further clarifications of the long-term schedule and resource needs of all LNF accelerators are a boundary condition for a successful EuPRAXIA@SPARC_LAB project execution.
- Though EuAPS can be a door opener for future EuPRAXIA@SPARC_LAB users, it bears the risk that some of the already scarce resources for EuPRAXIA@SPARC_LAB preparation are diverted to EuAPS realization. EuAPS uses a very different approach to X-ray generation and is therefore of limited relevance for the technical progress of EuPRAXIA@SPARC_LAB.
- The idea to use plasma lenses for re-matching is certainly tempting, but approaches that are more conservative should not be excluded before the feasibility of stable long-term operation and beam-dynamics issues like nonlinearities and gas scattering in the plasma lenses have been fully investigated.

Recommendations EuPRAXIA:

- *An anticipated procurement of one of the S-band modulators and installation in SPARC_LAB K2 slot would provide early RF system tests.*
- *The recent experience with the SPARC_LAB triplet emphasizes the need of well-established quality control procedures for all critical components of EuPRAXIA@SPARC_LAB.*
- *Continue with the two-pronged approach for X-band klystrons, and monitor progress with both companies closely. This is probably the most time critical procurement item for EuPRAXIA@SPARC_LAB.*
- *Compute radiation levels and shielding dimensions for the drive beam collimator. 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.*
- *Engage with the LEAPS-Innov collaborative R&D for novel undulators. These developments may open attractive design options for the EuPRAXIA@SPARC_LAB FELs.*

6. ColdLab

The SC received a report from on the ongoing activities of the ColdLab. However, no referee has been assigned and no referee session has been scheduled, therefore no recommendations have been formulated. Once committee member is appointed as referee for ColdLab, we would suggest a visit of that facility by the SC.

7. Committee matters

During this meeting the SC discussed possible evolutions of its mode of operation and received clarifications on the mandate of the SC, in particular to focus strongly on the in-house research at LNF, not being evaluated elsewhere. Nonetheless, the SC suggested an overall presentation of the activities of the laboratory at the Spring Session, in order to have a broader vision on the activities in the laboratory, the available resources, expertise and competences.

For the committee members to get a better insight on the projects carried out in Frascati, another suggestion was to organize turning visits to an experiment or an infrastructure during the meeting. In order to keep a reasonable schedule, the meeting between the referees and the project leaders could be shorten to one hour.

The construction of EuPRAXIA is a major effort for LNF and should be the highest priority. This implies a careful planning of the DAPHNE activities to come, in order to take into account, the expertise and manpower available. As decisions will also have to be taken in the not so far future on the evolution of DAPHNE, a presentation on different possible scenarios would also be appreciated in due time. We would like to suggest, that such a presentation would be accompanied by a visit of the DAPHNE infrastructure by the committee.

8. Next Meetings

The next meeting will be held on 4/5 May 2023, and after an offline doodle poll the autumn meeting is scheduled for 8/9 November.

Appendix:

Members:

U. Bassler (Chair)
H. Braun (SPARC_LAB and EuPRAXIA@SPARC_LAB)
P. Decowski (PADME)
N. Pastrone (KLOE-2)
G. Arduini (LINAC/BTF and DAΦNE),
A. Polosa (PADME)
J. Pelaez (SIDDHARTA-2)