EuPRAXIA@SPARC_LAB: TDR Review Report
November 21-23, 2023 Meeting

Review Committee Members:
Deepa Angal-Kalinin (UKRI STFC, UK)
Majed Chergui (EPFL, Switzerland)
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Siegfried Schreiber (DESY, Germany)
Luigi Scibile (CERN, Switzerland)

November 2023

The meeting was the sixth of its kind, and so is this report. The purpose of the review committee (RC) report is to review twice a year progress towards a technical design report (TDR) for the EuPRAXIA@SPARC_LAB facility. The meeting was attended in person (except S. S., remotely and D. A.-K., not attending). The RC welcomes at the review Sara Casalbuoni and Simone Dimitri as new representatives of the LNF MAC. They were invited and present for all the open and closed sessions. The agenda can be found at `https://agenda.infn.it/event/38578/timetable/` and the previous report at `https://www.overleaf.com/read/kxbkckqssdxq#9d5a48`. This report is based on presentations and discussions at the meeting. The seventh meeting is scheduled for June, 2024.

The RC congratulates the team on the progress since the last meeting, the project is advancing well. The RC congratulates the team on obtaining the building permit. However, the tendering might be delayed by six months (now mid-2024). A Project Office has been put in place. A cost and schedule review is scheduled for December 11; L. Scibile is the chair. SPARC_LAB continues playing its role as testbed for and R&D laboratory for the project TDR process.

The EuPRAXIA project is in its preparation phase and is progressing well. It is the general project EuPRAXIA@SPARC_LAB fits into, and LNF is expected to remain the HQ of the project despite the departure of one of the co-leaders, R. Assmann.

The main conclusion of the meeting is that urgent progress must be made on the text of the TDR document. The document presented at the meeting contains only a ToC. Progress with some topics is such that chapters, e.g., the ones on the building and facilities and the one on the X-band linac, can be written now and their format used as a template for all other chapters. For the next meeting, the Committee expects each chapter to have content following the format:

- table/list of parameters-goals

- current status
- next steps

It is important to nominate a small editorial team in order to ensure the consistency of the document writing.

The RC would like to have its role in the release process of the document defined soon. In particular, the depth of the review by the RC for that process needs to be established. The RC recommends that smaller reviews by more specialized review committees be organized for the major technical work packages of the TDR.

The lifetime of the capillary used for plasma production has clearly emerged as a major challenge to be met in the context of future operation of a facility (e.g., 400 Hz, 24/7). The RC strongly recommends that investigation in damage processes and more damage resistant materials be started very soon.

The RC notes that a different method to produce the drive-witness bunch train, the use of a masking technique is considered. Preliminary results on parameters and their sensitivity to variations from beam dynamics simulations are encouraging. The RC recommends this option to be thoroughly investigated through start to end simulations. The RC notes that the parameters of an number of components of the beam line are not yet determined.

Work on the X-ban linac is progressing well with tests of components and klystron at TEX, success with brazing of the X-band structure, and the procurement process for test klystrons and modulators.

The RC notes that the ARIA FEL line is not funded. The team may consider it as outside of the scope of the TDR and as an upgrade to the facility.

1 Specific comments

1.1 TDR/Project

The RC strongly recommends the following:
Allocate sufficient time to create a preliminary, but complete version of the Technical Design Report (TDR), focusing on establishing key parameters for consistency checks, and identifying areas that need attention before reaching the "TDR released" milestone. By complete, we mean that all chapters shall contain the list of target parameters and the expected performances that will be included in the final TDR version, as well as their current status and next steps. This approach will enable clearly outlining and prioritizing tasks for the upcoming year, scheduling detailed reviews on particular topics as needed, and preparing a progress report by June 2024, based on the early draft of the TDR. In detail, this recommendation can be broken down in five main objectives:

- Initial Drafting of TDR: This objective emphasizes the importance of creating an initial draft of the TDR. This step is crucial, as it sets the foundation for reaching the TDR milestones. By drafting the TDR, one can identify the main parameters and ensure coherence across different aspects of the project. This initial draft acts as a baseline for future developments.
- Identifying Gaps and Milestones: The process of drafting the TDR helps in identifying gaps that need to be addressed before reaching the TDR released milestone. This is a proactive approach to project management, allowing for the early detection of potential issues or areas that require more attention.
- Defining Priorities for the Next 12 Months: With the initial draft in place, it becomes easier to define priorities for the upcoming year. This involves determining which aspects of the TDR need more focus and resources, ensuring that the project stays on track and aligns with the overall objectives.
- Planning Reviews on Specific Topics: This objective suggests planning targeted reviews on specific topics. This is an effective way to deep-dive into particular areas of the TDR that might be complex or require additional expertise. These reviews can provide valuable insights and contribute to the refinement of the TDR. Status Report by June 2024 on Preliminary TDR.
- Finally, the recommendation proposes having a Status Report by June 2024 directly based on the preliminary TDR document. This deadline serves as a checkpoint to assess the progress made on the TDR. It ensures that the project is moving forward as planned and allows for adjustments if necessary.

Also, the process of release and approval of the TDR must be clarified.

1.2 SPARC_LAB results and next plans

SPARC_LAB continues its R&D contribution to EuPRAXIA@SPARC_LAB and remains a test bed for new ideas. There was an interesting attempt a using an APL-ACC-APL (APL=Active Plasma Lens, ACC=Accelerator) configuration, with APLs replacing problematic permanent magnet quadrupoles (PMQs). However, it is not clear how much was known about the e-beam parameters at the ACC entrance. It is not clear either how to optimize the system or to reach expected bunch parameters.

Interesting results were obtained with a bent capillary discharges, first as dispersion-free, compact bending element and, second, as a compact chicane with dispersion. Experiments with these new concepts fit very well in the general 'make it compact' concept of EuPRAXIA. It is however not clear that these are practical devices. These concepts need multipoles analysis to understand their usefulness beyond experimental curiosity. **The RC recommends that leadership makes sure that R&D for EuPRAXIA@SPARC_LAB takes precedent over 'nice to have' or 'fun' experiments.**

The FLAME laser was revived and reached almost original parameters. However, an upgrade will be necessary to reach parameters required for EuAPS. The RC notes that EuAPS is beyond the scope of its review.

1.3 Plasma Source

Development of plasma sources continues. The main challenge appears to be lifetime of the capillary for high-repetition-rate operation at a user facility. One needs to determine what processes lead to damage of the capillary. **The RC recommends that investigation of potential material(s) that could be more resistant to the plasma discharge be started as soon as possible. Since this is such an important part of the plasma-based program, the RC recommends determining how to include this 'challenge' in the TDR.**

1.4 Beam Dynamics

The assumption for the simulations of RF jitter parameters close to the state of the art (SwissFEL measurements), is giving encouraging results, but still too large for plasma acceleration, when using velocity bunching. In order to reduce the jitter between drive and witness bunch and improve the beam parameters (time separation, relative energy spread, ...), the team started studying a masking technique within the dispersive section of the compression chicane as alternative to a laser driven generation of the two bunche. The first simulation results are encouraging, indicating lower energy spread and jitter. The study has not yet produced a value for the emittance of the bunches. Using the masking technique rather than the velocity bunching one does not require changes to the machine layout, only the addition of the mask system. **The RC recommends pursuing the comparison between the two techniques as soon as computing resources will become available. The RC also recommends that optimization of the new scheme in S2E simulations be started as soon as possible. Since the masking technique requires absorption/scattering of electrons, an evaluation of the dose rate increase due to the utilization of a mask is required if pursuing this avenue. The RC notes that several the parameters of many beam line elements are not yet final: design of magnets, apertures, final optics, laser heater, ...** Beam dynamics is so central to the project that the RC recommends that it be reviewed and frozen (what needs to be) very soon.

1.5 X-Band Linac

The technical choices for modulator, klystron, wave-guide components, accelerating structures are mature for the TDR. The design of support systems for the structures was not presented at the meeting, but a technical solution exists (seen in the assembly workshop). The RC recommends implementing as soon as possible in

the TDR layouts and component parameters. The required performances and functionalities as well as the hardware strategy for the LLRF system are not yet defined. The development of these systems with respect to the required performances should not be underestimated. The goal for amplitude and phase jitters must be mentioned for the global system and distributed between LLRF, driver, modulator and klystron. It is essential to keep consistency of all parameters with the global machine goals.

1.6 Undulators and FEL

ARIA–Funding for the ARIA beam line is not secured. The question thus arises as whether to keep it in the TDR scope or handle this as an upgrade option. Parameters and mechanics to be modified with respect to the undulator of the FEL1 of Fermi to converge to the final device for ARIA must be determined.

AQUA–There are field differences between measurements and RADIA modeling results for the SABINA undulators. These were scaled for the AQUA undulator. Results look alright so far, but going from 55 mm to 18 mm period could enhance differences. This points at the importance of measurements and tuning in the technical realization. Also, strange behavior from the measurements on mechanical stress, asymmetry between the two ends, need further investigation. **The RC recommends that phase shifters be included in the technical concepts (AQUA and ARIA) as soon as possible.**

1.7 Next meeting

Dates (June 2024) and scope for the next meeting need to be fixed. The scope could be a review of all technical chapters of the TDR. **The RC requests that all presentations (as well as all technical chapters of the TDR) follow the format:**

- **table of parameters-goals**
- **current status**
- **next steps**

2 Material presented at the debriefing meeting, November 23, 2023

TDR-day minus 12 months!!!

For Committee: only two more meetings/opportunities

Good general progress ...

TDR/Project

Recommendation:

- Allocate sufficient time to create a preliminary, but complete version of the Technical Design Report (TDR), focusing on establishing key parameters for consistency checks, and identifying areas that need attention before reaching the "TDR released" milestone. By complete we mean that all chapters shall contain the list of target parameters and the expected performances that will be contained in the final TDR version and their current status and next steps. This approach will enable you to clearly outline and prioritize tasks for the upcoming year, to schedule detailed reviews on particular topics as needed and to prepare a progress report by June 2024, based on the early draft of the TDR. In details, this recommendation can be broken down in five main objectives:

- Initial Drafting of TDR: This objective emphasizes the importance of creating an initial draft of the TDR. This step is crucial as it sets the foundation for reaching the TDR milestone. By drafting the TDR, you can identify the main parameters and ensure coherence across different aspects of the project. This initial draft acts as a baseline for future developments.

- Identifying Gaps and Milestones: The process of drafting the TDR helps in identifying gaps that need to be addressed before reaching the TDR released milestone. This is a proactive approach to project management, allowing for the early detection of potential issues or areas that require more attention.

- Defining Priorities for the Next 12 Months: With the initial draft in place, it becomes easier to define priorities for the upcoming year. This involves determining which aspects of the TDR need more focus and resources, ensuring that the project stays on track and aligns with the overall objectives.

- Planning Reviews on Specific Subjects: This objective suggests planning targeted reviews on specific subjects. This is an effective way to deep dive into particular areas of the TDR that might be complex or require additional expertise. These reviews can provide valuable insights and contribute to the refinement of the TDR. Status Report by June 2024 on Preliminary TDR.

- Finally, the recommendation proposes having a status report by June 2024 directly based on the preliminary TDR document. This deadline serves as a checkpoint to assess the progress made on the TDR. It ensures that the project is moving forward as planned and allows for adjustments if necessary.

The process of release and approval of the TDR must be clarified.

EuPRAXIA

- EuPRAXIA in preparatory phase, progressing well

- Ralph leaving, need new co-leader ...

Beam Dynamics

- RF jitter parameters close to the state of the art (SwissFEL measurements) give encouraging results, but still too large beam jitter for plasma acceleration if using velocity bunching.
- Study use of a masking technique to improve bunch parameters and jitter (time separation, relative energy spread, ...).
- First results encouraging, lower energy spread and jitter, Q: emittance
- No change to the machine layout
- Need to pursue comparison as soon as computing resources will become available
- Optimization in S2E simulations
- An evaluation of the dose rate increase due to the utilization of a mask is required if pursuing this technique
- Several open points: design of magnets, apertures, final optics, laser heater, ...
- So central to the project, should be reviewed and frozen (what needs to be) very soon

SPARC_LAB results and next plans

- Continuing R&D contribution to EuPRAXIA@SPARC_LAB and testbed for new ideas.
- Interesting attempts a APL-ACC-APL (APL=Active Plasma Lens, ACC=Accelerator)
  - not clear how much is known about the beam at the ACC entrance
  - not clear how to optimize the system or to reach expected bunch parameters
- Interesting results with bent capillary discharge
- Fits very well in the 'make it compact' concept
- not clear that it is a practical device as a dispersion-free dipole or as a very compact chicane for compression
- need multipole analysis to understand usefulness of the concepts beyond the experimental curiosity
- Make sure that R&D for EuPRAXIA@SPARC_LAB takes precedent over 'fun' experiments
- FLAME laser revived and reached almost original parameters
- Upgrade will be necessary for EuAPS.
- May not deserve a chapter in TDR?

Plasma Source

- Continued development
- Main challenge appears to be lifetime of the capillary for high repetition rate operation at a facility
- Need to determine what processes damage the capillary
- Need to investigate potential material(s) that could be more resistant to the plasma discharge
- How to include this 'challenge' in the TDR?

Undulators and FEL

- ARIA
  - Some news about funding? If not do we keep it in the TDR?
  - What must be modified with respect to the undulator of the FEL1 of Fermi to converge to the final device for ARIA → to be described in the TDR?
- AQUA
  - Field difference between measured and RADIA model scaled for the AQUA undulator. Results looks so far OK, but going from 55 mm to 18 mm period could enhance differences → importance of measurements & tuning in the technical realization
  - Strange behavior from the measurements on mechanical stress need further investigation
- Phase shifters need to be included in the technical concept (AQUA and ARIA)

X-Band Linac(?)

- Maybe better title; RF Systems X-Band Linac?
- The technical choices for Modulator, Klystron, Wave-Guide components, Accelerating structures are mature for the TDR.
- The support systems of the structures where not presented but a technical solution exists (seen in the assembly workshop)
- Still to be defined LLRF system
- Layouts and component parameters can be implemented in the TDR
- Goal for amplitude and phase jitter must be mentioned for the global system and distributed between LLRF, driver, modulator+klystron
- Keep consistency with the global machine goals

Next meeting:

- Fix dates (June 2024) and scope
- All presentations need to follow:

  - review selected chapter of the TDR
  - review all chapters of the TDR

- All presentations need to follow:
  - table of parameters-goals
  - current status
  - next steps

Thank you to all the speakers for your contributions.
Thank you for the welcome and hospitality.