Presentation of the preliminary LINAC4 ion source review report

D. Bollinger, U. Fantz, M. Stockli, O. Tarvainen, A. Ueno
CERN
October 23, 2018
General observations

CERN impresses us through the progress it has made in the past five years since the last review.

Assessing the 25 mA requirement was found to be easy and all reviewers agreed on virtually everything.

Assessing the 45 mA requirement turned out to be challenging.

The RFQ box is a very good tool to translate the test stand results to "tunnel reality".

The committee appreciates the effort put into understanding the ion source and related physics but with the given time constraints a streamlined project plan is required.

The plasma in the extraction aperture region should be the focus of any additional source physics studies.
Q1:
From 2020 to 2023 – The source must provide a 600us long 25mA pulses at 1.2s rep rate at the exit of the RFQ, with an availability of 99% (in addition to specifications for pulse flatness and reproducibility). Is the CERN programme of the low energy stage in position to reach this?

Yes.
A concern is the stability (flatness) of the RF amplifier affecting the beam current flatness.
The committee thinks this can be reached in both, volume and caesiated modes of operation, but it is strongly recommended to implement the caesiated mode already at this stage.
Q1: 25 mA at 1.2s rep rate at the exit of the RFQ with 99% availability

Are the technical choices and hardware adequate to deliver the specified beam and reliable operation?

The majority of the technical choices as presented are adequate. Technically the plan is sound. The RF amplifier is a concern (reliability and stability). The cusp-free source is likely to allow operation at lower RF power and mitigate the electron burst related to the plasma ignition and should therefore be pursued.

Management has to be prepared to have some unexpected setbacks in the beginning in terms of reliability.

A spare for the caesium oven is required for the caesiated source (JL says it exists).
Q1: 25 mA at 1.2s rep rate at the exit of the RFQ with 99% availability

Is the schedule clear, with sufficient detail and milestones, and is it sound?

The schedule and plan for the test stand is reasonable and the expected output will definitely guide the development effort to reach the goal. The committee strongly encourages to study beam optics in volume and caesiated sources for different bore diameters. **Continuous caesiation experiment should have high priority.** This is seen important especially for reliability of the 25 mA beam and the ultimate goal of 45 mA.

**Experiments with caesium, however, need long-term runs (>> 1 week) at the test stand with different bore sizes for example. The test stand program should be adopted to that.** There is sufficient back up in the test stand program (summer 2019) to prolong the experiments planned for late 2018.

The test stand is the correct place to run experiments with the volume source. These experiments help to understand the extraction system.

The plan for the tunnel after the **first decision point clearly is in favour of the volume source.** This however **needs to be revised** as only one change at the time (bore diameter) would be more adequate. The caesiation should be continued through the reliability run.
Q1: 25 mA at 1.2s rep rate at the exit of the RFQ with 99% availability

Are the relevant issues addressed?

25 mA is a safe value.

**Autopilot (or similar) should have a priority** to make recovery from incidents faster. The reviewers are not in a position to fully understand the programming philosophy of the proposed autopilot.

RF-amplifier is a concern. It is recommended to investigate the root-cause of high voltage and RF malfunctions. Preventive measures should be taken if the cause is systematic.
Q1: 25 mA at 1.2s rep rate at the exit of the RFQ with 99% availability

What are the main risks for operation, are there mitigations in place and what could be added?

The committee is worried about reaching 25 mA reliably with the volume source because there is not much margin. Also the high electron current could be a risk.

The risks are mitigated with a caesiated source.
Q1: 25 mA at 1.2s rep rate at the exit of the RFQ with 99% availability

Are the impacts of any baseline changes (e.g. on downstream equipment/operation) understood and mitigated?

Baseline changes were not presented or discussed.

The transmission efficiency of the RFQ seems low and should be understood including the effect of the RFQ on the space charge compensation in the LEBT because this affects the requirements of the source.
Q1: 25 mA at 1.2s rep rate at the exit of the RFQ with 99% availability

Are the resources adequate?

Yes for 25 mA. *Investment on a new RF amplifier is encouraged.*
Q1: 25 mA at 1.2s rep rate at the exit of the RFQ with 99% availability

Can any further improvements be proposed?

Consider operation with some margin of the current of the ion source.

Investigate if the hydrogen pressure injection can be made less sensitive to small variations in timing and pressure.
Q2:
Development of the source and low energy stage should continue with an objective to reach 45mA reliably out of the RFQ in 2023, after demonstration on the test stand in 2022.

This has **not been demonstrated** yet and no clear path to reach the goal has been presented. Significant changes may be required to reach this target.

With the current resources (as presented) the RF source should have the highest priority.

Reliability cannot be assessed at the present stage.

With the current resources the committee does not see a chance of having the magnetron as a back-up solution by 2023.

The magnetron is unlikely to solve the problem in the transmission.
Open questions on the magnetron: Pulse-to-pulse stability and beam current flatness? Find answers from other labs.

Is the magnetron even a possible solution? Beam within the RFQ total acceptance?

From the source physics point-of-view the magnetron discharge is completely different. It is a caesium discharge. This concerns the caesium consumption/management and the reliability of the source.

With this schedule the magnetron should have its own test stand (learning curve expected) which requires investment in adequate hardware and manpower.

With the present resources and time constraints we recommend to let the magnetron development rest because all resources are required for the RF source and LEBT.
Q2: 45 mA reliably out of the RFQ in 2023 after demonstration in 2022

Are the technical choices and hardware adequate to deliver the specified beam and reliable operation?

The cusp-free RF source has delivered 75 mA measured with the BCT. However, this appears to be “a single shot result”. We think this should be adequate to obtain 56 mA at the entrance of the RFQ within the total acceptance of the RFQ. We find the provided data set confusing.

We encourage to obtain a consistent data set at the test stand trying to reach 75 mA from the source and then measure the emittance and the current from the RFQ box (mask). The transmission efficiency into the box should be monitored whereas the emittance measurement should be done only at the highest beam current. This should have a priority immediately after the continuous caesiation experiment at the test stand.
Q2: 45 mA reliably out of the RFQ in 2023 after demonstration in 2022

Is the schedule clear, with sufficient detail and milestones, and is it sound?

No.
Q2: 45 mA reliably out of the RFQ in 2023 after demonstration in 2022

Are the relevant issues addressed?

We recommend to focus on long-term experiments with the highest possible current having the RFQ box as a monitor after 2019.

Now is not the time to try radical changes.

We recommend to concentrate on mastering the caesium delivery process (occasional caesiation vs. continuous caesiation) and caesium consumption / leakage during these experiments.
Q2: 45 mA reliably out of the RFQ in 2023 after demonstration in 2022

What are the main risks for operation, are there mitigations in place and what could be added?

At this point it is unclear whether or not 45 mA can be reached in 2023.

This question should be re-assessed after test stand experiments at the highest possible beam current and monitoring the transmission into the RFQ box.
Q2: 45 mA reliably out of the RFQ in 2023 after demonstration in 2022

Are the impacts of any baseline changes (e.g. on downstream equipment/operation) understood and mitigated?

See the comments on the LEBT and RFQ transmission above.
Q2: 45 mA reliably out of the RFQ in 2023 after demonstration in 2022

Are the resources adequate?

No. In-house expertise is required for beam formation physics. Also an additional source expert overlapping with JL from 2020 is highly recommended. These two people could share the on-call duties when the source is operating.
Q2: 45 mA reliably out of the RFQ in 2023 after demonstration in 2022

Can any further improvements be proposed?

The experiments at the test stand should focus on reaching the beam current goal already by the end of 2019 and the reliability by 2020 (end). If not achieved, concept changes should be reconsidered at this point. This includes the extraction system, caesium supply etc.

When is the opportunity for the demonstration? It is not scheduled in the tunnel? A staged approach is recommended. Push towards higher current in the tunnel between 2020 and 2023 if allowed by operations.
General comments

The reviewers are concerned about the emittance growth (simulated) in the extraction system and subsequent losses in the LEBT. If the experiments at the test stand by the end of 2019 do not demonstrate 45 mA delivered into the RFQ mask, construction of a new extraction system and LEBT should be seriously considered. This is because failing to meet the goal of 45 mA is seen as a serious roadblock potentially affecting the ISOLDE physics program. The J-PARC extraction system and 2-solenoid LEBT is an example of a working system.
CERN additional questions

• Is the level of resources on the RF source plus extraction for beam formation and tests, and operation running sufficient. If not, what is missing.

See above.
CERN additional questions

• Are we too optimistic to bet on this RF source reaching 45mA out of the RFQ (including stability requirements)? But does another source type (magnetron) have a significantly better chance?

Betting on the source is ok for 45 mA. Comments to magnetron see above.

The committee sees that the source might be a bottle neck but transmission is a real issue and needs to be understood and possibly addressed.
CERN additional questions

• What do you think are necessary resources to develop the magnetron to meet 2022 proof at the test stand? If we continue on two lines, would this need another test zone, and what would be the resources needed for that?

A new test stand with additional manpower allocations, hardware and additional support from the support team(s) starting from now on.
CERN additional questions

• Does the continuous caesiation experiment require study of the filter fields interplay with the caesiation process (Akira brought this point up). What study exactly?

The priority of optimizing the filter field is not high. Caesium management has a higher priority and should be studied first at the test stand.

Changing the filter field concept affects the extraction (electron dumping) and thus requires significant effort.
These comments and recommendations were formed after 1.5 intense days.

We will provide detailed scientific arguments behind these comments and recommendations in the written report to be submitted by November 16th.
Take Home Priorities From the Reviewers

• 25mA
  • cesiated source with constant cesiation.
• 45mA
  • Autopilot
  • 2MHz RF Ion Source (not magnetron)
  • High current operation, with emittance data set.

• No Radical Changes until the high current data is available.