From Overleaf LhARA-Gov-PMB-2022-02:

2. Response to feedback

2.2 Review of LhARA collaboration's R&D proposal for the Preliminary Activity Phase – Report Accelerator and Technology Session

2.2.2 Assess in depth possible challenges and limitations of the Gabor lens in addition to the required electron density and plasma transverse size as the required focusing linearity and, in turn, electron density homogeneity and possible beam pollution by other species.

A natural consequence of the thermalised, low temperature, non-neutral plasma to be formed as part of the Gabor lens is a uniform density (see e.g. Dubin and O'Niel [1]) which is ubiquitously observed in various systems. In addition, perturbations to this density distribution, typically called plasma modes or oscillations with amplitudes <<1% of that of the plasma itself, can be observed under a multitude of conditions and are well understood for well confined plasma [see e.g. ref.'s 2-6].

As discussed within the report and during the associated WP3 presentation, many of the individual parameters expected for the final plasma (e.g. size or density) have largely been obtained in systems elsewhere, but perhaps insufficient emphasis was made during the review of the fact that many of these previous plasmas also have the highly uniform density characteristics required for a Gabor lens. Much of the current experimental program has focussed upon other parameters, such as 'size' or 'lifetime', as these are intrinsically linked to the density: for instance, under 'poor' conditions, deleterious plasma modes will develop and if unchecked grow which will lead to an unstable plasma that is ultimately destroyed through expansion.

However, it is the expectation (and requirement) of the test bench to study plasmas, at various scales towards that expected for the final design, to confirm the expected density behaviours as multiple parameters are scaled simultaneously. As part of these studies (and final deployment), diagnostics which rely upon various density perturbations are envisaged to provide real time knowledge of the plasma, potentially allowing feedback to damp deleterious modes before they become an issue, and possibly provide important shot-to-shot information.

The catalyst for the development of density perturbations is often 'pollution', whether by other species within the plasma (such as background gases) or the quality (e.g. homogeneity and static nature) of external fields. It is expected that ion-beam pollutants, such as multiple ion species, within the capture system will influence the trapped plasma, although without knowing details of their distributions from preliminary source experiments yet to occur, detailed responses are unavailable. However, current estimates suggest the various timescales involved are sufficiently disparate to result in minimal impact on individual shots, and when operating the system at 10 Hz, there is significant time for plasma preparation (e.g. damping of induced density perturbations) between shots, if needed.

As highlighted several times during this review process, resources are currently very limited so extensive use of in-depth simulations will be made to ensure the formation of suitable size and density plasmas is indeed possible, and the conditions necessary for the development of deleterious density perturbations within our parameter space are clearly identified (so they can be avoided). The first step towards this is obviously to confirm the suitability of the numerical code to capture the relevant physics (and its disparate timescales).

Thus, while challenges are expected along the route to for the formation of a suitable Gabor lens plasma, and are highlighted in the risk register, the experimental limitations (such as wall-to-plasma radius, or fraction of the Brillouin limit) are reasonably well identified and mitigating engineering solutions are expected to be implemented within the testbench. Further studies of new literature, extended computation, and possibly experimentation within existing apparatus, will be performed as resources become available. This will provide further understanding of the limitations and avoidance, or alternative mitigation, schemes can be implemented.

2.3 Other comments

2.3.2 Work package 3

Work Package 3 is very appreciative of the reviewers' comments with respect to the Gabor lens, and their overall support for the proposed campaign.

At this point, we take the opportunity to clarify text under section 2.8 (located on page 8). We note that the ALPHA Penning traps containing electron plasmas, while of similar design to those proposed here, are not used as particle or Gabor lenses as envisaged in this project. (Their purpose is to cool antiprotons, whose wide kinetic energy spread in the presence of a strong magnetic field masks any lensing effects.)

References

[1] Dubin & O'Neil - Trapped nonneutral plasmas, liquids, and crystals (the thermal equilibrium states) - Rev. Mod. Phys **71** 87 (1999)

[2] Bernstein et al - Exact Nonlinear Plasma Oscillations - Phys. Rev. Lett. **108** 546 (1957)

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[4] Fine & Driscoll - The finite length dicotron mode - Phys. Plasma **5** 601 (1998)

[5] Hisabeck and O'Niel - Finite Length Diocotron modes – Phys. Plasmas **8** 407 (2001)

[6] Trivelpiece & Gould - Space Charge Waves in Plasmas – J. Appl. Phys **30** 1784 (1959)