2nd Report of the

ESSnuSB International Advisory Panel

(preliminary)

tbd	WP2 (Civil engineering)
Yong Joong Lee (ORNL)	WP3 (Target)
Shinji Machida (RAL)	WP4 (Accelerator)
Teppei Katori (KCL)	WP5/6
Livia Ludhova (GSI Darmstadt & RWTH JGU Mainz)	WP5/6

Hamburg, Germany, September 26h, 2024

ESS neutrino Super Beam plus

Thank you!

- We IAP members sincerely thank to the entire organizing team for the seamless coordination, insightful discussions, and the collaborative spirit that prevailed throughout the meeting.
  We had great time with you in Hamburg!
- Thank you for providing detailed answers to our recommendations from the last year.
- We provide our further recommendations in this report.
  Your answers and comments to these questions will be highly appreciated.

General remarks

- **IAP members**
  - **WP2** is currently without a dedicated reviewer
  - We suggest identifying also a new reviewer with expertise for **WP6.**

- **Schedule of the meeting, we suggest**
  - **Broadening the topics of the 1st day plenary session.** In particular, a general overview of the project, including its design and physics goals, as well as main updates from the last year could be highlighted. It might be beneficial not only for the IAP members, but also for the multidisciplinary team of collaboration members.
  - Allowing IAP members to participate remotely to the introductory plenary sessions and to the parallel sessions of different WP.
  - **Dedicated session for IAP,** in the 2nd half of the week. Presentations by the WP conveners summarizing status of the WP and answering questions from the past review. Plan broad time for discussion in person. Session open to the whole collaboration.
  - **IAP report** on the last day to be eventually planned as the first talk in order to allow your collaboration for a free discussion about our report.

General remarks

- **<u>Any need to improve communication with ESS?</u>**
  - We lacked information about the status of the communication with ESS. We believe an analysis about how the whole project as well as each WP depend on the ESS decisions would be beneficial for the project.

- **<u>Need for cost evaluation of different phases</u>**
  - Phase-I: LBMNB target station
  - Phase-II: LEnuSTORM target station
  - Phase-III: ESSnuSB
  - Gd-doping in parallel with the ongoing physics goal evaluation

- **<u>Limited resources covering a wide range of physics and engineering disciplines</u>**
  - Clarify the physics goals of each phase.
  - Select key strategic areas to focus that will help continued funding of this state-of-the-art neutrino facility.
  - Make the focus areas of physics and engineering such that chosen system will be developed to a maturer design with better positioned physics cases.
  - By elaborating on the strategic focus areas, the available limited resources could be optimally used.

Physics goals

And now at the 2nd year of ESSνSB+

ESS neutrino Super Beam plus

- **EU Design Study** has been submitted end of April (HORIZON-INFRA2022-DEV-01)
  - **Title of Proposal**: **Study of the use of the ESS facility to accurately measure the neutrino cross-sections for ESSνSB leptonic CP violation measurements and to perform sterile neutrino searches and astroparticle physics**

From Monojit's plenary talk

- Done: Scalar NSI and Decoherence papers has been published
- Ongoing: Progress has been made in atmospheric, supernova and sterile
- Initiated: Work on solar neutrinos and long range force has been initiated
- Long-term: Reactor and Geo for future

Congratulations!

We appreciate the progress here!

Physics goals

- **Cross sections: the main goal**
  - No specific presentation, we suggest an explicit discussion and definition of the goals regarding the cross-section measurements.

- **Sterile neutrinos**
  - Nice progress regarding sensitivity in the plane of Δm^2_41 vs $\sin^2 2\theta_{e\mu}$ compared to MicroBooNE results.
  - In addition to the presented future plan, we suggest to consider in more detail different systematic effects.
  - Consider in the comparison the current sterile neutrino limits from other experiments, including reactor based.

- **New physics search**
  - Explore models and scenarios in which ESSnuSB+ provides the best results in the world, including long-range force.
  - To study new physics, consider to use properties of LEnuSTORM and LEMNB beyond the energy spectrum. For example, production points of LEMNB could be a useful parameter to explore new physics otherwise impossible.

Physics goals

- **Solar neutrinos**
  - The physics goals are well identified: they regard B8 and *hep* solar neutrinos
  - Consider background evaluation.
    - cosmogenic background is critical - what is the design of the muon veto?
    - 206Tl at 2.6 MeV - what is the required radiopurity of water?

- **Atmospheric neutrinos**
  - Study synergy with the CP violation measurement with beam neutrinos.
  - Define required precision for energy, baseline, and flavour reconstructions
  - Consider evaluation of the potential in terms of neutrino Earth tomography - as for example, electron density contrast between the metallic core and silicate mantle.

- **Supernovae neutrinos**
  - ESSNuSB+ could see a large amount of SN events due its size - certainly very interesting for validation of different models.
  - Any discovery potential for extra-galactic SN enutrinos?
  - Define detector requirements needed for the detection of the huge event rate in a short time window.

Working Package 5

Findings:

Many progresses in new aspects such as far detector scientific cases, ML and likelihood reconstruction comparison, and detector visualization.

Astroparticle physics goals rely on data from the **far detector.** The presented studies are purely phenomenological and lack evaluation of the detector performance.

Recommendations:

Study a realistic design of LEMMOND and build simulation so that the collaboration can explore the physics potential including the cross-section measurements.

Explore full potentials of LEnuSTORM and LEMNB and use them to study physics cases. This includes not only energy spectrums, but also divergence, flavor, and timing.

While we understand that the design of the far detector was part of the ESSNuSB project, enlarging the physics goals and lowering the energy range, might require changes, as for example the Gd-loading. Additionally, event reconstruction performance at lower energy scale is not known from the ESSNuSB. Therefore, we strongly encourage to

- study the dependence of evaluated sensitivities on detector and event reconstruction performances
- define better the plan for the inclusion of the far detector in the simulation framework

Working Package 6

Findings:

Strong program thanks to ENUBET, and WP6 is moving to a realistic design for this (pion transport, picosecond micromegas, monitoring detector design).

Recommendations:

Continue to study new technologies in this project, including picsec micromegas.

Provide a realistic flux simulation for the LEMMOND. This may be 4-momentum neutrino vectors because the distance of production to detection is close O(50m) and the beam may not be parallel to the beam axis.

Physics case of the monitoring neutrino beam is still unknown. Good communication with WP5 to study what kind of physics one can explore with LEMNB. 2 priorities, first, as the stage one project, LEMNB can take advantage of time scale and physics exploitation consider this. Second, explore physics only possible by LEMNB, for example neutrino cross-section with energy-momentum transfer reconstruction.

Work Package 2: Civil Engineering

- LEMNB target station
  - New target station with dedicated beam dump is a big additional cost driver
    - Several 100 kW power class target station and beam dump requires massive shielding
    - It also requires to be equipped with dedicated remote handling capability
    - If the linac should be upgraded to 28 Hz rep rate, it will also play as a major cost driver
  - Recommendations:
    - Study the feasibility of using LEnuSTORM target station with extended proton transport line utilizing the site reserved for accumulation ring
    - Reach out to ESS management and neutron scattering community to find out way forward between extracting fraction of the beam pulses or increasing the linac source rep rate to 28 Hz
    - Optimize overall cost of the project and the level of required investment for important physics

Work Package 2: Civil Engineering

- LEnuSTORM target station
  - The accumulator ring will need two beam dumps
    - As charge stripping will happen in the beam injection area, a beam dump is foreseen in the downstream region of the beam inject point.
    - In the beam extraction region, a tuning dump is foreseen.
    - Each beam dump should be shielded by massive steel and concrete structure, which is a big cost driver
- Check whether the project proposal should include an evaluation decommissioning cost
    - For the ESS project an estimate of decommissioning cost was required as the the facility concept is based on full recovery of green fields after the facility endlife.

Work Package 3: Target

- LBMNB Target Station:
  - Presented graphite target parameters are optimized for high pion/muon yields
  - Beam optics magnet components are close to target
- Recommendations:
  - Develop a cooling concept of the graphite target
    - Determine a baseline beam profile on the target. As there could be a correlation between the beam profile and pion/muon yields, check the sensitivity of different beam profiles on particle yields.
    - Active water cooling might not be an option. Consider active gaseous helium cooling or passive radiative cooling. Depending on the heat loads in peripheral devices, water cooling might be required for these devices.
    - Based on the determined cooling concept, perform thermal analysis to check the temperature in the target. The temperature should be kept below the temperature above which considerable graphite sublimation incurs.
    - Based on the temperature data, perform mechanical analysis to ensure that the target keeps its structural integrity during the its lifetime from stress, fatigue and radiation damage viewpoints
  - Assess the dose in the insulating materials of magnets
    - For example, kapton is a commonly used insulating material in magnets. Kapton is known have a typical dose limit of 1 MGy at a high dose rate irradiation tests, which translates to about 200 kGy dose limit in operating environment. Check whether the integrated dose in kapton during the lifetime of the magnets exceed 200 kGy. If it is a case, mitigation measures should be taken into consideration like applying upstream shielding or move the magnets further into downstream region. This might affect the overall neutrino yield.

Work Package 3: Target

- LEnuSTORM Target Station:
  - The target baseline is helium cooled granular titanium target
  - Downstream bending magnet is close to target
- Recommendations:
  - Elaborate on predicting the helium flow pressure drops across the granular target area
    - Build a partial model with the details of Ti sphere geometry to estimate the pressure drop
    - Design ETHEL experiment to measure the correlation between the flow rate and pressure drop
  - With estimated pressure drop, study the availability of helium compressors/blowers on the market that can provide the desired flow parameters. The cost and availability of helium compressor/blower is mainly dependent on the ratio of pressure drop to inlet pressure
  - Perform literature study on radiation damage of titanium and titanium alloys
    - Many metals suffer from radiation induced void swelling at above a third of melting point, which is 374 C for the case of pure titanium.
    - Look for literatures reporting data on radiation hardening, helium embrittlement, radiation induced thermal diffusivity decrease, and fatigue limit of Ti and Ti-alloys
    - The radiation damage and fatigue are the two major factors that determine the survivability and lifetime of the target
  - As planned, elaborate on analysing dynamic response of beam intercepting components to short pulse beam, which will be used to assess the survivability and lifetime of the target
  - Assess the dose in the insulating materials of magnets
    - See related comments on LEMNB target in WP2

Work Package 3: Target

- LEnuSTORM Target Station:
  - FLUKA simulations have been made to optimize the horn geometry for optimal pion yields in desired energy range
    - FLUKA simulation is smartly coupled with optimization algorithm
  - There is no cooling requirement and concept presented for the downstream beam dump
  - There is no cooling requirement and concept presented for the horn
- Recommendations:
  - The presented FLUKA data are recommended to be reported with errors to ensure that simulated physics converged well.
  - Calculate energy depositions in the horn, beam dump and shielding to define cooling requirements
    - The contribution of ohmic heating should also be taken into account in the thermal analysis of the horn system

Work Package 3: Target

- LEnuSTORM Target Station:
  - Design concept of horn power supply unit was presented
  - Lab scale concept for a helium loop based target gas flow dynamics teststand was presented
- Recommendations:
  - Estimate the magnetic field perturbation due to electric pulses to the horn system
  - Make a mitigation plan for helium flow tests if constraints on complexity in flow diagnostics and budget realizes
    - Experiments with cold flow could also produce useful data if achieving desired heating becomes a challenge
    - Experiments with air flow could be considered if helium circulation based test becomes technically and budgetically challenging. For airflow case, the dimensionless flow parameters should be set according to desired helium flow conditions

Working Package 4 (General)

- (general comment) Despite the difficulty of filling the advertised posts and, therefore, the shortage of workforce, the work has been carried out efficiently by the current members, especially the PhD student and the postdoc. We are pleased to see that the first version of the LEnuStorm design is almost completed, which is the primary task of the WP4, and that there is steady progress on the other topics as well. We expect a few iterations will follow to match the detailed requirements from the other parts of the facility design and to incorporate the practicality of the hardware design. However, we do not have any concerns at the moment about finishing the deliverables.

Working Package 4 (LEnuStorm ring design)

- (finding) The pion momentum is chosen at 700 MeV/c to accumulate muons at a momentum of 400 MeV/c. Choices of other parameters like the arc length, straight length, optics of the ring and magnet aperture are shown with clear reasonings. The full ring design was shown based on those optimized parameters. The design is no longer a simple scaled-down model of the previous nuStorm designs elsewhere, and is now more specific to the ESSnuSB requirements.

- (recommendation) Having a linear optics design is a good start to further optimise the parameters to increase the neutrino flux. We could follow several techniques which were considered in the previous design of nuStorm at CERN and Fermilab. Partial correction of chromaticity, introduction of different optics for two straight sections, use of FFA optics (or a few lower order multipoles) are among them. It is also important to understand the mechanism of beam loss, other than the decay of muons. Although the total turn number of circulation is a few 10s, the stability of particle orbits with a large momentum spread of more than 10% and a large transverse amplitude is an interesting problem that other conventional ring accelerators did not have.

Working Package 4 (Pion beam transport)

- (finding) Beam transport line of the pion beams is designed from the exit of the horn to the injection point of the ring. Almost independently, the dipole magnet design was made and critical radiation issues are presented.

- (recommendation) Creating a version of the complete pion beam transport line is a good start with a linear optics approximation. Since the momentum acceptance has to be large, more than 10%, and the transverse emittance is also large, chromaticity (optics depending on momentum) and off-axis magnetic fields are not negligible. Those effects affect the design more strongly than in the case of more conventional beam transport. That does not mean, however, requirements of the detailed tracking with the 3D magnet fields. Since the design parameters keep changing at least for the next several months, it is important to create a methodology of evaluating the beam line performance quickly with reasonable accuracy.

- (recommendation) The design of the beam transport line also very much depends on the ionizing radiation considerations, not only the optics, especially right after the horn. Optics design and hardware considerations with radiation should be more integrated together.

Working Package 4 (Injection into LEnuStorm)

- (finding) Neutrino flux estimation is given by taking into account of all the process although some of the numbers seem merely an order of magnitude estimation.

- (recommendation) In order to estimate the number of stored muons and the neutrino flux from the LEnuStorm, a consistent estimation or numerical simulation from the target to the circulation of stored muons in the ring is necessary. That is to say the end to end simulation of the LEnuStorm. A consistent figure of the first half before the nuStorm ring injection has been shown and the second half after the injection was given separately. A very crucial missing part is the connecting point of two studies, that is the injection of pions into the ring. Stochastic injection which has been proposed in the previous nuStorm design is the obvious candidate. That may be the only possible way to inject such a huge beam both in longitudinal and transverse space. Establishing a design of stochastic injection is the immediate next step before further optimization of the beam transport and the ring design.

Working Package 4 (Injection into LEnuStorm)

•(recommendation) During the summary talk, the possibility of injecting 700 MeV/c pion beams and accumulating 700 (690) MeV/c muons was discussed. That needs an alternative injection scheme other than stochastic injection. Although it is not clear whether alternative injection scheme, for example more conventional injection with septum and kicker magnets, can be used for such a huge emittance beam, if that is the requirement from physics, the team should investigate the feasibility.

Working Package 4 (RFQ)

•(finding) Increasing the linac duty factor as twice as much is essential. Simulation on the RFQ has been presented and it shows feasible with some extra care. That is encouraging but the study is somehow isolated from the current ESS commissioning activities.

•(recommendation) More could be done if the team consider more integration of the study into the current ESS commissioning activities. Analysis of RFQ in the extreme conditions must be very helpful to understand the current operation of the ESS, especially when they find some mysterious behaviour. Proactive participation of the ESSnuSB+ team in the ESS commissioning efforts with all analysis they have done should be beneficial to both the ESS commissnining and the ESSnuSB+ design..

Working Package 4 (Others)

- Proton beam line: Optics for collimation, proper phase advance, etc.
- Accumulator ring: Sustainability consideration, smaller circumference, use of permanent magnets, etc

Thank you

and see you next year!