Strategy Report on Research Infrastructures

ROADMAP 2026

ESFRI

Proposal Submission Questionnaire

8th October 2024

QUESTIONNAIRE FOR SUBMISSION OF PROPOSALS FOR ROADMAP 2026

In this document all answers to the questions asked that are provided by the ESSnuSB Consortium are written with Times New Roman font in order to help to distinguish the answers from the questions.

This questionnaire consists of three parts:

- PART A: GENERAL INFORMATION is used for the eligibility check by the EB and – if selected – for the public description of the Project in the Roadmap 2026.
- PART B: SCIENTIFIC CASE is used by the Strategy Working Group (SWGs) to evaluate the SCIENTIFIC CASE of the proposal.
- PART C: IMPLEMENTATION CASE is used by the Implementation Group (IG) to assess the IMPLEMENTATION CASE of the proposal.

Some questions require to tick a bullet, to fill a text section with a strictly limited number of characters or to upload supporting documents in PDF.

Only the electronic version of this questionnaire through the ESFRI MoS+ may be used to submit proposals for the Roadmap 2026 until **8th April 2025 at 17:00 CET.**

RESOURCE

- ROADMAP 2021 at https://roadmap2021.esfri.eu/
- ROADMAP 2026 Public Guidelines https://www.esfri.eu/roadmap-2026

SUPPORT

- General questions: national ESFRI Delegations – contact details available at https://www.esfri.eu/people?qt-people=1#qt-people
- Helpdesk for the Online Submission Form: roadmap@str-esfri.eu

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PART A: GENERAL INFORMATION

Fields marked with * are mandatory

SECTION 1: GENERAL DATA

*1.1 |NAME**

Provide the name of the RI

- FULL NAME* (maximum 200 characters with spacing) European Spallation Source neutrino Super Beam
-
ACRONYM* (maximum 20 characters with spacing) ESSnuSB

*1.2 |TYPE**

Identify the type of your RI

SINGLE-SITED

RI TYPE <DROPDOWN LIST FOR RI TYPE: SINGLE-SITED, DISTRIBUTED>

- Comment on your choice: TEXT (maximum 500 characters with spacing)

  The site of the infrastructure will be located at two separate locations, one in Lund and another one at Zinkgruvan, both in Sweden.

*1.3 |CLASS**

Indicate the class of your RI

NEW RESEARCH INFRASTRUCTURE

RI CLASS <DROPDOWN LIST FOR RI CLASS: NEW RESEARCH INFRASTRUCTURE, MAJOR UPGRADE OF AN EXISTING RI>

- Comment on your choice: TEXT (maximum 500 characters with spacing)

  ESSnuSB will make use of the ESS in Lund, Sweden. Its linac will be upgraded to produce an intense neutrino beam for long baseline measurements of neutrino oscillations. In addition, two new facilities will be built on the ESS site: a low energy muon storage ring (LEnuSTORM) and a low energy Monitored Neutrino Beam (LEMNB) for measurements of low energy neutrino cross sections and for R&D work towards a low energy Muon Collider. A large water Cherenkov detector will be installed in an underground site in Zinkgruvan 360 km north of Lund to detect the neutrino beam and perform other neutrino measurements, complemented with a near detector complex on the ESS site.

1.4 |GLOBAL DIMENSION

YES

GLOBAL DIMENSION <DROPDOWN LIST FOR GLOBAL DIMENSION: YES, NO>

- Comment on your choice: TEXT (maximum 500 characters with spacing)

The ESSnuSB will measure the Charge-Parity symmetry Violating (CPV) phase angle in the lepton sector to an unprecedented precision and, in this sense, will be a next, higher precision measurement (CPV-angle measurement error less than 8 degrees) which will supersede the measurements from the other two global experiments investigating CPV, DUNE in USA and Hyper-K in Japan. In addition, low energy neutrino cross sections, eagerly awaited from the neutrino community, will be measured.

|TIMELINE*

Indicate the timeline of the lifecycle of your RI

PHASE	FROM YEAR*	TO YEAR*	COMMENT
DESIGN*	2017	2026	Conceptual design
PREPARATION*	2027	2030	Technical Design
IMPLEMENTATION (CONSTRUCTION)*	2030	2038	Staged implementation of LEMNB by 2030, nuSTORM by 2034 and LBL ESSnuSB by 2038
OPERATION*	2033	2060	Staged operation of LEMNB (4y), nuSTORM (4y) and LBL ESSnuSB (20y)
TERMINATION*	2060	2070	Work to dismantle and transform

*1.5 |ESTIMATED COSTS**

Summarise the real or estimated costs for your RI

COST	Euro (€) *	COMMENT
TOTAL INVESTMENT*	2175 M€	
DESIGN*	10 M€	Already provided from two EC INFRADEV sequential grants and supplementary funding by the beneficiaries
PREPARATION*	5 M€	To be applied for to EC INFRADEV and ESSnuSB member countries
IMPLEMENTATION*	2000 M€	To be contributed from the ESSnuSB member countries

TERMINATION*	160 M€	To be contributed from the ESSnuSB member countries
AVERAGE ANNUAL OPERATION*	100 M€	To be contributed from the ESSnuSB member countries

*1.6 |HEADQUARTERS**

Indicate hosting institution of the Headquarters

- INSTITUTION NAME* (maximum 200 characters with spacing) European Spallation Source (ESS)

- INSTITUTION ADDRESS* **European Spallation Source ERIC, Box 176, SE-221 00 Lund, Sweden**

1.7 | WEBSITE

If available, provide the Internet address

- URL: (maximum 200 characters with spacing)
https://essnusb.eu/

1.8 | LOGO

Upload the logo of your RI

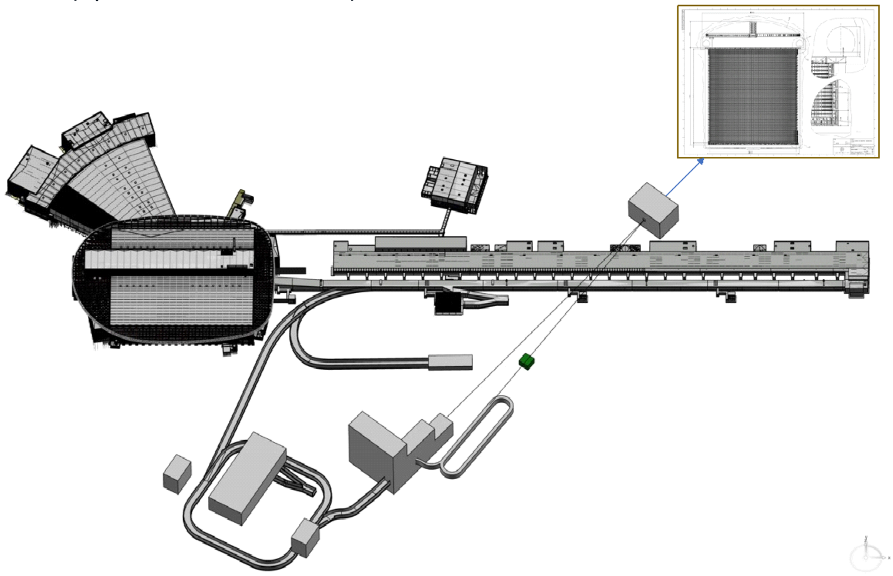
essνsb ESS NEUTRINO SUPER BEAM

- UPLOAD (upload with limit 1 MB)

1.9 | IMAGE

Upload an image which represents your RI

- UPLOAD (upload with limit 1 MB)



1.10 | DESCRIPTION*

Summarise the general characteristics and aim of your RI, including the impact on the quality and quantity of European research in the main field of action and the interdisciplinary aspects

- TEXT (maximum 1000 characters with spacing)

New neutrino long baseline projects are currently under construction in the US (DUNE) and Japan (Hyper-K) but not yet in Europe. Compared to the ESSnuSB project, these two projects can be seen as the first-generation neutrino Super Beams with proton beam power above 1 MW. But these experiments will not cover the full spectrum of outstanding questions at the required precision in neutrino physics, implying the need to plan for next generation experiments. As the preparation of these projects takes more than 20 years, the preparation of the next generation neutrino Super Beams, after DUNE and Hyper-Ke, must already start now. This is what we, with the support of the EU, are doing in the ESSnuSB consortium. The foreseen physics performance of our RI will surpass all earlier expectations by covering already after the first 10 years of data collection more than 70% of the range of possible CPV phase value (δ_{CP}) with a confidence level of more than 5 σ to reject the no-CPV hypothesis. The expected measurement precision of the value of δ_{CP} is better than 8° for all δ_{CP} values, making it the most precise proposed experiment by a large margin.

*1.11 |BACKGROUND**

Summarise the science background of your RI, the reference scientific community (-ies), the position in the current landscape, and the complementary or synergistic potential with other facilities.

TEXT (maximum 2000 characters with spacing)

The goal of the ESSnuSB project is to prepare the ground for observing and measuring leptonic CPV with unprecedented sensitivity.

A scientific fact that motivates our efforts in Europe is that neutrinos are presently the only elementary particles that have shown clear signs of physics beyond the Standard Model.

Another breakthrough would be the understanding of why mass remained in the Universe after the Big Bang and also why the fundamental particles of matter appear in generations and different flavours. The expectation is that the outcome of measurements to be made with the proposed ESS neutrino Super Beam RI will contribute to the corroboration of a new theory which can explain not only the results of these measurements but also other unexplained phenomena like Dark Matter and Dark Energy.

The aim is to measure with high precision the amplitude of CPV in the leptonic sector. The amount of leptonic CPV, once it has been measured, can be used to verify or falsify many Beyond-the-Standard-Model (BSM) theories that have been proposed. Naturally, the more precise the measurement of CP phase δ_{CP} will be, the more discriminative the identification of a possible BSM theory will be.

Muons from the pion decays are copiously produced together with neutrinos and can be used for other neutrino projects like low energy realisations of nuSTORM and the "Monitored Neutrino Beam" (the latter similar to the ENUBET project) or for R&D work for the Muon Collider. It is expected that with nuSTORM and LEMNB the muon neutrino and electron neutrino cross-sections will be measured with a precision of 2% or better. Such precise measurements are awaited by the neutrino community for a long time.

1.12 |STEPS TO IMPLEMENTATION*

Summarise the actions that led to the presentation to ESFRI, your plans for preparation and implementation in terms of schedules and milestones, including Preparatory Phase or other pre-implementation actions, acquisition of legal status

- TEXT (maximum 1000 characters with spacing)

The COST Action CA15139 “Combining forces for a novel European facility for CPV discovery” recognized the necessity to have at least one neutrino beam facility in Europe. Then, the ESSnuSB EU INFRADEV-01 H2020 Design Study (2018-2022 EU grant of 3 M€) pursued the goal to organize European physicists and accelerator engineers, in cooperation with the ESS Laboratory, to make a detailed design of ESSnuSB for CPV measurement at the second oscillation maximum. In Dec. 2022 a Conceptual Design Report for ESSnuSB was published, including a construction timeline and indicative capital costing. The results demonstrate that the physics performance of ESSnuSB goes beyond what could be achieved by the presently approved neutrino long baseline projects in the USA and Japan. A second EU INFRADEV- 01 design study project, ESSnuSB+, was approved by EU (2023-2026) to extend the project, in particular by making a design for precise neutrino cross-section measurements, and increase the synergies with other research activities like those that make use of intense muon beams.

1.13 |SCIENTIFIC DOMAIN*

Indicate which Strategy Working Group you believe to be the most suitable to evaluate the scientific case of your RI:

PHYSICAL SCIENCES & ENGINEERING

1.14 |OTHER RELEVANT DOMAIN

In case you believe that the scientific case of your RI should also be evaluated by one or more additional SWG, indicate which:

ENERGY and ENVIRONMENT

SECTION 2: POLITICAL SUPPORT

2.1 |LEGAL STATUS*

Indicate the current legal status of your RI:

In preparation

2.2 |POLITICAL SUPPORT – LEAD COUNTRY/ENTITY*

Identify the Member State (MS), Associated Country (AC) or the EIROforum Member, which leads the preparation of your RI

- LEAD COUNTRY/ENTITY NAME* <DROPDOWN LIST FOR MS/AC OR EIROFORUM> Sweden

Identify the authority from the LEAD MS/AC OR EIROFORUM OR OTHER ENTITY that has signed Expression of political Support (EoS) or provided a Council resolution

- AUTHORITY NAME*:
Swedish Research Council

Upload the Expression of political Support (EoS) of the Member State (MS) and Associated Country (AC); in the case of a EIROforum member, please upload the Council resolution

- UPLOAD EoS* (upload with limit 1 MB)

LEAD COUNTRY/ENTITY*	**AUTHORITY NAME***	**EoS***
DROPDOWN LIST FOR MS/AC OR EIROFORUM		UPLOAD

[1] Any legal entity from a MS, AC and third country that can take binding decisions to financially support the RI can submit an EoS. It may concern a regional or national government (agency), an umbrella organisation negotiating and redistributing funding on behalf of its members, a Research Funding Organisation (RFO) or a Research Performing Organisation (RPO).

[2] The ESFRI Delegation will validate such EoS

(allow for multiple entries)		

2.3 |POLITICAL SUPPORT – PROSPECTIVE MEMBER COUNTRY/ENTITY*

Identify at least two additional MS and AC – and any additional THIRD COUNTRY – which have submitted Expressions of political Support (EoS) signed by the national ministries responsible for RI, or other entities – such as EIROforum Member – whose mandated authorities have expressed interest to join the RI through a Council resolution

- PROSPECTIVE MEMBER COUNTRY/ENTITY NAME* <DROPDOWN LIST FOR MS/AC, THIRD COUNTRIES, EIROFORUM OR OTHER ENTITY>

Identify the authority[1] from the PROSPECTIVE MEMBER MS/AC OR EIROFORUM OR OTHER ENTITY that has signed Expression of political Support (EoS) or provided a Council resolution

- AUTHORITY NAME*

Upload the Expression of political Support (EoS) of the Member State (MS) and Associated Country (AC); in the case of any other entity – such as EIROforum Member – please upload the Council resolution

- UPLOAD EoS* (upload with limit 1 MB)

PROSPECTIVE MEMBER COUNTRY/ENTITY*	**AUTHORITY NAME***	**EoS***
DROPDOWN LIST FOR MS/AC, THIRD COUNTRIES, OR EIROFORUM OR OTHER ENTITY		UPLOAD
(allow for multiple entries)		

2.4 |POLITICAL SUPPORT – INCLUSION IN NATIONAL ROADMAPS

If applicable, identify the MS and AC which has (have) included your RI – or a preliminary form – in its (their) national RI roadmap (-s) or similar political document.

Please specify, per country, the amount of funds spent (in the past) or earmarked and allocated (for the future) to your RI in the framework of this (their) national RI roadmap (-s) or similar strategic document (in this case, please also provide reference of the relevant political document). Provide a clear link of the national level research infrastructure to the proposed ESFRI project: (maximum 1000 characters with spacing).

- COUNTRY NAME <DROPDOWN LIST FOR MS OR AC> <COMMENT>

NATIONAL ROADMAP COUNTRY	FUNDS EARMARKED OR ALLOCATED	RELEVANT POLITICAL DOCUMENT
DROPDOWN LIST FOR MS/AC	Contribution of typically one FTE per country as own contribution to the resources needed for the conceptual design work from 2018 till now	National inputs to the European Strategy for Particle Physics
(allow for multiple entries)		

SECTION 3: FINANCIAL COMMITMENT

*3.1 \|FINANCIAL COMMITMENT – LEAD COUNTRY/ENTITY**

Identify the MS/AC or the EIROforum Member, which is the LEAD COUNTRY/ENTITY

- LEAD COUNTRY/ENTITY NAME <DROPDOWN LIST FOR MS/AC OR EIROFORUM OR OTHER ENTITY>

Identify the authorities[3] from the LEAD COUNTRY/ENTITY that have signed Expression of financial Commitment (EoC) or provided a Council resolution to financially contribute to the Preparation and Implementation Phases of you RI

- NAME (maximum 200 characters with spacing)

- ADDRESS

- CONTACT PERSON (maximum 200 characters with spacing)

- EMAIL (email field)

- TELEPHONE (telephone field)

Upload the corresponding EoC or Council resolution

- UPLOAD EoC (upload with limit 1 MB)

[3] Any legal entity from a MS, AC and third country that can take binding decisions to financially support the RI can submit an EoC. It may concern a regional or national government (agency), an umbrella organisation negotiating and redistributing funding on behalf

of its members, a Research Funding Organisation (RFO) or a Research Performing Organisation (RPO).

LEAD COUNTRY/ENTITY*	AUTHORITY NAME*	ADDRESS*	CONTACT PERSON*	E-MAIL*	PHONE	EoC*
DROPDOWN LIST FOR MS/AC OR EIROFORUM Sweden						UPLOAD
(allow for multiple entries)						

3.2 |FINANCIAL COMMITMENT – PROSPECTIVE MEMBER COUNTRIES/ENTITIES*

Identify at least one additional MS and AC – and any additional THIRD COUNTRY – which have signed Expression of financial Commitment (EoC) or provided a Council resolution to financially contribute as prospective members to the Preparation and Implementation Phases of your RI.

- PROSPECTIVE MEMBER COUNTRY/ENTITY NAME <DROPDOWN LIST FOR MS/AC, THIRD COUNTRY, EIROFORUM OR OTHER ENTITY>

Identify the authorities[3] from each PROSPECTIVE MEMBER COUNTRIES that have signed Expression of financial Commitment (EoC) or provided a Council resolution to financially contribute to the Preparation and Implementation Phases of your RI.

- NAME (maximum 200 characters with spacing)

- ADDRESS

- CONTACT PERSON (maximum 200 characters with spacing)

- EMAIL (email field)

- TELEPHONE (telephone field)

Upload the corresponding EoC or Council resolution

- UPLOAD EoC (upload with limit 1 MB)

PROSPECTIVE MEMBER COUNTRY/ENTITY*	AUTHORITY NAME*	ADDRESS*	CONTACT PERSON*	E-MAIL*	PHONE	EoC*

DROPDOWN LIST FOR MS/AC, THIRD COUNTRY, EIROFORUM OR OTHER ENTITY Croatia						UPLOAD
(allow for multiple entries)						

*3.3 |FINANCIAL COMMITMENT – COVERAGE OF REAL AND ESTIMATED COSTS**

Specify the amounts that have already been financed or are fully agreed to be financed and specify the share of costs covered by the commitment (-s) for the real or estimated costs as reported in table 1.6:

COST	Euro (€)*	PERCENTAGE (%)*	COMMENT
TOTAL INVESTMENT*	10 000 000		
DESIGN*	10 000 000	100	Conceptual Design
PREPARATION*			Technical Design
IMPLEMENTATION*			Build-up at ESS and Zinkgruvan
TERMINATION*			Dismantling at ESS and Zinkgruvan
AVERAGE ANNUAL OPERATION COSTS*			Approximately 10% of the investment cost

SECTION 4: RESEARCH INFRASTRUCTURE CONSORTIUM

*4.1 |COORDINATOR**

Identify the Coordinator for the preparation of your RI

COUNTRY/ENTITY*	INSTITUTION NAME*	INSTITUTION ADDRESS*	CONTACT PERSON*	E-MAIL*	TELEPHONE

DROPDOWN LIST FOR MS/AC OR EIROFORUM	Uppsala University	Regementsvägen 1, Uppsala, Sweden	Tord Ekelöf	Tord.Ekelof@physics.uu.se	+46 70 4250210
(allow for multiple entries)					

*4.2 |PARTICIPANTS**

Identify the core partners – being research institutions – that have signed the inter-institutional and multi-lateral agreement and thus are formally involved in the consortium

COUNTRY/ENTITY* and INSTITUTION NAME’	INSTITUTION ADDRESS*	CONTACT PERSON*	E-MAIL*	TELEPHONE
Greece/ Aristotle U.	School of Physics, Faculty of Sciences, Aristotle University of Thessaloniki Campus, 54124 Thessaloniki, Greece	Spyros Tzamarias	tzamarias@auth.gr	+30 6936838393
IGO / CERN	CERN, Beams Department, CH 1211 Geneva 23	Ilias Efthymiopoulos	lias.Efthymiopoulos@cern.ch	+41 75 4113952
Turkiye/ Cukurova U.	University of Cukurova, Faculty of Science and Letters, Department of Physics, 01330 Adana,Türkiye	Aysel Kayis Topaksu	Aysel.Kayis@cern.ch	00 90 538 6201489
Greece/ Demokritos U	Institute of Nuclear and Particle Physics, NCSR Demokritos', 27 Neapoleos Str, 15341 Agia Paraskevi, Attiki, Greece	George Fanourakis	gfan@inp.demokritos.gr	+30 210 6503525
Spain/Consorcio ESS Bilbao	Parque Tecnológico de Bizkaia, Laida Bidea 207B, 48160 Derio - Spain	Fernando Sordo Balbin		+34 94 607 66 20
France/ IP2N3 Strasbourg	IPHC/CNRS 23, rue du Loess 67037 Strasbourg France	Elian Bouquerel	elian.bouquerel@iphc.cnrs.fr	+33 3 88 10 6137
Germany/ Hamburg U.	Institute for Experimental Physics, Hamburg	Tamer Tolba	tamer.tolba@uni-hamburg.de	+49 40-23952-6357

	University, 22761 Hamburg, Germany			
Sweden/KTH Stockholm	Department of Physics, KTH Royal Institute of Technology, Roslagstullsbacken 21, 106 91 Stockholm, Sweden	Tommy Olsson	tohlsson@kth.se	+46 8 790 82 61
Sweden/ Lulea U.	Luleå University of Technology, Laboratorievägen 14, SE-971 87 LULEÅ, SWEDEN	David Saiang	david.saiang@ltu.se	+46 920 49340
Sweden/ Lund U.	Lund University, Physics Department, Professorsgatan 1B, 223 64 Lund	Joakim Cederkall	joakim.cederkall@nuclear.lu.se	+46 73 8977187
ESS	European Spallation Source ERIC Box 176. SE-221 00, Lund	Hakan Danared	hakan.danared@ess.eu	+46 72 1792046
University Roma Tre/Rome	Department of Mathematics and Physics, University of Roma Tre, Via della Vasca Navale 84, 00146 Roma (Italy)	Davide Meloni	davide.meloni@uniroma3.it	+39 0657337035
Italy/ Milano Bicocca U. INFN	Dipartimento di Fisica "G. Occhialini", Università di Milano Bicocca Piazza della Scienza, 3, I-20126, Milano Italy	Francesco Terranova	francesco.terranova@unimib.it	+39 0264482328
Japan/Nagoya U.	Nagoya University Department of Physics, Graduate School of Science,	Tsutomu Fukuda	tfukuda@FLAB.PHYS.NAGOYA-U.AC.JP	

	School of Science, F-lab			
Italy/ Padova U. and INFN	Department of Physics and Astronomy of Padova University, via Marzolo n. 8, Padova	Fabio Pupilli	fabio.pupilli@pd.infn.it	
Croatia/ Ruder Boskovic Inst.	Ruđer Bošković Institute, Bijenička cesta 54, 10000 Zagreb, Croatia	Budimir Klicek	budimir.klicek@irb.hr	+385 1 456 0978
Bulgaria/ Sofia U.	Faculty of Physics, Sofia University St. Kliment Ohridski, 5 James Bourchier blvd., 1164 Sofia, Bulgaria	Mariyan Bogomilov	marian@phys.uni-sofia.bg	+359 28161409
Sweden/ Uppsala U.	Regementsvägen 1 Uppsala, Sweden	Maja Olvegaard	maja.olvegard@physics.uu.se	+46 72 9999627

Upload the corresponding inter-institutional and multilateral agreement, e.g. a Memorandum of Understanding (MoU)

- UPLOAD MoU (upload with limit 10 MB)

The ESSnuSB+ Consortium Agreement is available at the ESSnuSB home page by clicking on

ESSnuSBplus_CA_final_signed.pdf

PART B: SCIENTIFIC CASE

Fields marked with * are mandatory

SECTION 1: SCIENTIFIC EXCELLENCE*

1.1 Identify the scientific field (-s), including the scientific vision and mission and new frontiers, and - if applicable - the inter- or multidisciplinary scope (and potential impact on other fields) of your RI: (maximum 4000 characters with spacing).

It is believed that after the Big Bang, matter and antimatter were produced in equal quantities through transformation of the enormous energy released into massive particles. Observations show that today, however, there is a nearly total absence of antimatter in the Universe. The occurrence of Charge-Parity Violation (CPV) is a necessary condition for an explanation of this absence. CPV in the quark sector was discovered in 1964. However, the mixing of the quarks is by far too small for the quark CPV to explain the observed density of matter in the Universe. As the mixing of the neutrinos is much larger, the discovery and measurements of leptonic CPV could be of sufficient magnitude to explain the density of matter in the Universe. The discovery and measurement of CPV in neutrino oscillation phenomenon is thereby a task of primary importance in today's particle physics. The goal of the ESSnuSB project is to prepare the ground for discovering and measuring neutrino CPV with unprecedented sensitivity. The magnitude of leptonic CPV, once it has been measured, can be used to verify or falsify the many Beyond-the-Standard-Model (BSM) theories that have been proposed. Naturally, the more precise the measurement of CP phase δ_{CP} will be, the more discriminative the identification of a possible BSM theory will be.

Another breakthrough would be the understanding why the fundamental particles of matter – the quarks and the leptons – appear in generations and different flavours. A scientific fact of high significance that motivates our efforts in Europe is that in particle physics neutrinos are the only particles that have till now shown clear signs of physics beyond the Standard Model.

The current Standard Model of particles and forces and the General Theory of Gravity have no explanation for these phenomena. The expectation is that the outcome of measurements to be made with the proposed neutrino Super Beam research infrastructure will contribute to a formulation of a new theory which incorporates and goes beyond the two mentioned theories and which also can explain not only the results of these measurements but also other unexplained phenomena like Dark Matter and Dark Energy.

Muons from the pion decays are copiously produced together with neutrinos and can be used for other neutrino projects like low energy realisations of nuSTORM and the LEMNB (the latter similar to the ENUBET project) or for R&D work for the low energy Muon Collider. With the use of nuSTORM and LEMNB, we expect to be able to perform measurement of the muon neutrino and electron neutrino cross-sections with a precision of 2%. Such precise measurements are awaited from the neutrino community for a long time.

1.2 Describe how the scientific concept for the cutting-edge science of your RI was tested, that its innovations were found feasible and technically mature, and summarise the main findings concerning the scientific case from the design (and feasibility) study report (-ies): (maximum 3000 characters with spacing)

The ESSnuSB concept takes advantage of the construction in Europe of the European Spallation Source (ESS). The ESS linear proton accelerator will have a beam power of 5 MW, which is approximately a factor of 5 higher than any other currently existing or planned accelerator in the world. To obtain maximum sensitivity to CPV, and thereby be less affected by systematic uncertainties, the neutrino detector should be placed near the second neutrino oscillation maximum, attainable thanks to the uniquely high power of the ESS accelerator. The Zinkgruvan mine in Sweden, in which it is proposed to install the underground neutrino detector, is located at a distance from ESS that has been found optimal for the proposed measurements..

The European COST Action CA15139, "Combining forces for a novel European facility for neutrino-antineutrino symmetry-violation discovery", recognized the necessity to have at least one neutrino beam facility in Europe. Following this, the ESSnuSB EU INFRADEV-01 H2020 Design Study was approved in 2017 for the period 2018-2022 with an EU grant of 3 M€ (total cost 4.6 M€) and pursued the goal to organize European physicists and accelerator engineers, in cooperation with the ESS Laboratory, to make a detailed design of ESSnuSB. This study was successfully concluded with the publication in December 2022 of a Conceptual Design Report, (The European Spallation Source neutrino super-beam conceptual design report | The European Physical Journal Special Topics, [arXiv: 2206.01208] The European Spallation Source neutrino Super Beam Conceptual Design Report) for ESSnuSB, including a construction timeline and indicative capital costing. The results demonstrate that the physics performance of ESSnuSB goes beyond what could be achieved by the presently approved neutrino long baseline projects in USA and Japan. A second EU INFRADEV-01 design study project, ESSnuSB+, was approved by EU with a grant of 3 M€ in 2022 for the period 2023-2026 in order to enhance the possibilities shown by the first study and increase the synergies with other research activities that make use of intense muon beams. ESSnuSB+ will increase the motivation for realising this European neutrino project by making precision measurements of the neutrino cross-sections possible that are needed for a precise evaluation of the neutrino oscillation parameters, while at the same time performing important searches for sterile neutrinos.

1.3 Upload the design (and feasibility) study final report, if available: (upload with limit 1 MB; in case the document is longer than 30 pages, please also provide an executive summary of maximum 4 pages)

The ESSnuSB Conceptual Design Report is available at for (https://doi.org/10.1140/epjs/s11734-022-00664-w, https://arxiv.org/abs/2206.01208)

1.4 Describe any feedback from the identified user community (see Section 4, question 4.1) on the RI proposal: (maximum 2000 characters with spacing)

The current ESSnuSB consortium of more than 90 physicists and engineers is committed to design, build and operate the ESSnuSB research infrastructure and to make full use of it to make uniquely precise measurements of the leptonic CPV amplitude.. The number of ESSnuSB participants has been constantly growing since the start of the ESSnuSB design study. We are contributing to the process of forming a European Strategy for Particle Physics and have recently received expressions of interest in ESSnuSB from several new institutional groups. We are aiming at attaining an order of 500 participants by the time ESSnuSB long-baseline operation will start at the end of the 2030s. For our strategy on how to attain this number of participants please see section 4.3.

1.5 Describe the new services that the RI will offer to the scientific community and, if appropriate, to other user communities: (maximum 3000 characters with spacing)

The high intensity of the ESSnuSB low-energy neutrino-beam and the large volume of the far neutrino detector will make it possible for the community to make the highest precision measurements of the neutrino properties and interactions. In addition, measurements will be made of neutrinos from cosmic rays, from the Sun, from supernovae and from the Earth.

The primary aim of the ESSnuSB Design Study, financed by EU-H2020, was to demonstrate that the ESS linac could be effectively used to generate, concurrently with the spallation neutron production, an intense neutrino beam by doubling the average beam power of the linac**.** The ESSnuSB facility takes advantage of the fact that the linac's low duty cycle of only 4% can be increased to 8% by raising the pulse frequency from 14 Hz to 28 Hz.

During the ESSnuSB EU-H2020 Design Study, it became clear that other neutrino projects, like the Decay At Rest (DAR) and Coherent Scattering (CEvNS) neutrino experiments, could profit from the ca 3000 times shorter neutrino pulses from the ESSnuSB target as compared to those from the ESS spallation target, thereby drastically reducing the background and, opening new perspectives for these projects. Muons, from the pion decays, are copiously produced together with neutrinos and can be used for other neutrino projects like low energy realisations of nuSTORM and the Monitored Neutrino Beam (the latter similar to the ENUBET project) or for R&D work for the Muon Collider.

Potential users of the proposed neutrino super beam will have access to a research infrastructure with which unique research results can be achieved. The scientific community at large will learn about scientific results that will put their own research into a broader perspective. The European Technological Infrastructures will be trusted with the development of new technical designs and prototypes that will develop their competence further. The industrial companies will receive orders for components based on new technology which in many cases can be used for the development of other products of wide commercial interest. The funding agencies and governments will gain access to new scientific and technical information and international contacts that will be useful for the national and international planning of a few specific basic and applied research areas like fundamental physics and applied accelerator and instrument development, respectively. The students and the general public will widen their scientific knowledge in a research area which currently attracts great attention and interest in Society and which widens our culture.

With this, our aim has been to propose the ESSnuSB research infrastructure and its research program such that it shall fulfil the conditions for the ESFRI committee to support the project and decide that it can start its Preparatory Phase.

1.6 Identify the scientific leadership that was recruited to lead the preparation of your RI and elaborate how you will recruit and consolidate the scientific leadership and overall competences for the implementation and operation of the proposed RI: (maximum 2000 characters with spacing)

The ESSnuSB Consortium encompasses the necessary knowledge and skills to carry out the required work. The team is composed of acknowledged experts in their fields, with considerable experience and excellent contacts with laboratories and organisations of world-wide renown.

The main participants are as follows. A researcher from CNRS is the Consortium Coordinator while a professor from the UU is the Scientific Leader. ESS and LTU are leading the civil engineering studies at the ESS site and the Zinkgruvan site, respectively. CNRS/UNISTRA leads, together with UHH and ESSB, the target station design. Design of the low energy nuSTORM decay ring is led by UU which already designed the ESSnuSB accumulator, with the help of ESS, CERN and ESSB. The leading institute for Detectors and Physics reach is RBI which designed the Far Detectors for ESSnuSB and is leading the work to evaluate the ESSnuSB physics performance to which many of the ESSnuSB groups contribute, in particular KTH Stockholm. Low Energy Monitored Neutrino Beam is being led by UNIMIB with participants INFN, UNIPD, RBI, NCSRD and AUTH, all of which work also with the ENUBET project at CERN (high energy version of monitored neutrino beams).

ESSnuSB consortium members are affiliated to several of the major organisations in Europe undertaking R&D on accelerators for particle physics. The consortium contains the right balance of accelerator physicists, particle physicists, engineers and administrators to deliver the objectives of the Design Study. Most of the groups in the Consortium are members of broader scope projects and committees (e.g., ESS, ENUBET, TIARA, I.FAST, HITRI+) which provide important opportunities to meet and discuss plans for a major European neutrino facility.

SECTION 2: PAN-EUROPEAN RELEVANCE*

2.1 Position your RI in the RI landscape and describe how it addresses a gap, need or synergy in the current RI landscape in Europe (and beyond) and how it responds to needs of user communities, i.e. describe the `uniqueness` and the strategic added value of the RI.: (maximum 2000 characters with spacing).

ESSnuSB, the only long baseline neutrino experiment planned in Europe, will provide world-uniquely high precision measurement of leptonic CP violation. New neutrino projects are under construction only in the US and Japan. After the CERN political decision more than a decade ago to stop its neutrino activities, many of the European neutrino physicists that worked at neutrino long baseline beam infrastructures or with design studies of such in Europe have joined the DUNE project in the US and the Hyper-K project in Japan.

As a consequence, a significant fraction of the European neutrino community currently works on the preparation of the above two neutrino long baseline experiments. Compared to the ESSnuSB project, DUNE and Hyper-K can be seen as the next first-generation neutrino Super Beams, provided that their proton beam power will be made to exceed 1 MW, which is necessary for reaching a physics performance beyond the current generation of long baseline neutrino beams, NOvA in the US and T2K in Japan. Once the construction of the ESSnuSB project has been agreed by its member states the ESSnuSB project will offer these European neutrino physicists the opportunity to continue their research beyond DUNE and Hyper-K with a higher performance project in Europe. As the preparation of these projects, from the inception up to the realisation, takes more than 20 years, the preparation of the next second-generation neutrino Super Beams must already start now. This is what we, with the support of the EU, are doing in the ESSnuSB consortium.

In our CDR it is demonstrated that the foreseen physics performance of our RI will surpass all earlier expectations by covering, after 10 years of data collection, more than 70% of the range of possible CPV phase values (δCP) with a confidence level of more than 5 σ to reject the no-CPV hypothesis. The expected measurement precision of the value of δ_{CP} is better than 8° for all δ_{CP} values, making it the most precise proposed experiment by a large margin.

2.2 Indicate current RI or services that are operational and accessible for the relevant science communities, if any, and explain why they are not adequate: (maximum 3000 characters with spacing).

There is no other neutrino long-baseline experiment being designed in Europe. There are neutrino long-baseline experiments being constructed in Japan and the US, but they are not adequate for the high precision CP violation amplitude measurement.

2.3 Describe how your RI contributes to the enhancement and realisation of the European Research Area: (maximum 3000 characters with spacing)

The high intensity frontier programme at ESSnuSB at ESS will complement the high energy frontier programmes at HL-LHC and FCC at CERN in the European Research Area. The new technological developments that will be required for the unique ESSnuSB research infrastructure currently being designed will contribute to new advances in accelerator physics and technology, in radiation detection, in computational science, in underground geotechnical engineering and in other fields, all with applications in several other areas and activities in the Society. The current ESSnuSB+ project is driven by 20 participating research European institutes and groups. The creation of a world leading neutrino research facility in Europe will confirm Europe's position as a leading partner in the international field of fundamental research.

2.4 Describe how your RI will effectively (re-) orient resources from the relevant European science communities and stimulate `joint programming`, e.g. contributing complementary instrumentation, activating partnerships, training of young researchers in the relevant field (-s) of science: (maximum 2000 characters with spacing)

At the global level, new neutrino projects are currently under construction only in the US and Japan. After the CERN political decision more than a decade ago to stop its neutrino activities, many of the European neutrino physicists who worked at neutrino long baseline beam infrastructures or with design studies of such in Europe have joined the DUNE project in the US and the Hyper-K project in Japan. EU's DG fo Research and Innovation, on the other hand, has throughout continued to support the important and promising European neutrino long baseline design-studies through the INFRADEV feasibility studies CARE/BENE (FP7), EURONU (FP7), LAGUNA (FP7), LAGUNA-LBNO (FP7), EUCARD (FP7), COST Action CA15139, ESSnuSB (Horizon 2020) and currently ESSnuSB+ (Horizon Europe).

As a consequence of CERNs exclusive focus on high energy colliders, a significant fraction of the European neutrino community currently works on the preparation of the two neutrino long baseline experiments for leptonic CP violation discovery outside Europe, DUNE in the US and Hyper-K in Japan. Compared to the ESSnuSB project, these two projects can be seen as the next first-generation neutrino Super Beams, provided however that their proton beam power will be made to exceed 1 MW, which is necessary for reaching a physics performance beyond the current generation of long baseline neutrino beams, NOvA in the US and T2K in Japan. For the European neutrino physicists currently working in the US and Japan, ESSnuSB offers a long-term vision for what to do beyond DUNE and Hyper-K. As the preparation of these projects, from the inception up to the realisation, takes more than 20 years, the preparation of the next second-generation neutrino Super Beams must already start now. This is what we, with the support of the EU, are doing in the ESSnuSB consortium.

2.5 Describe the (potential) linkages between your RI and existing (European) platforms, networks and other (ESFRI) RI, e.g. European Technology Platforms (ETP), Joint Programming Initiatives (JPI), ERA-nets, Public-Private Partnerships (PPP), EU Missions and Framework Programme funded projects:
(maximum 3000 characters with spacing)

The ESSnuSB design study that was and is being financed by COST, Horizon 2020 and Horizon Europe, is making a crucial use of the investment in and the equipment of the ESS ERIC and will contribute to the enhancement of the ESS material science programme

We make use of and base the design of ESSnuSB on the results of a long series of earlier European neutrino long-baseline feasibility studies CARE/BENE (FP7), EURONU (FP7), LAGUNA (FP7), LAGUNA-LBNO (FP7), EUCARD (FP7), COST Action CA15139, ESSnuSB (Horizon 2020) and currently of ESSnuSB+ (Horizon Europe).

2.6 Describe how your RI will leverage European competitiveness in research and innovation, e.g. uniqueness of technical offer, advancement of technical standards, innovation in research process, base our impact on the innovation of research products and setting reference standards in data management:
(maximum 3000 characters with spacing)

ESSnuSB is advancing the performance of high intensity particle accelerators and high resolution detectors to new levels with applications in several other fields. The technical development of the proposed neutrino research infrastructure will impact other fields that plan to use very high intensity proton accelerators like

Accelerator Driven Systems (ADS) and hadron therapy. Among the technical developments that will have such effects are that of the high current, long pulse H^- ion source and of the target required to stand the impact of very short pulses of very high power. The development of the 500 000 m^3 underground Water Cherenkov detector equipped with an order of 100 000 high-resolution photon detectors will impact the photon-detector industry and modern rock engineering technology. It is expected that the industrial companies that will be contacted to investigate the feasibility of the industrial production of ESSnuSB components will see an economic and technical interest in engaging with the project. It is also expected that the realisation of the proposed project will improve societal conditions by its technological developments that will lead to a greener and safer world.

2.7 By testing your RI against the ESFRI pan-European *ex ante* indicators, identify which indicators your RI meets and describe how: (maximum 3000 characters with spacing)

The ESFRI pan-European *ex ante* indicators met by ESSnuSB

Background of new RI or Upgrade Project

Previous Design Study Project

We have successfully completed COST Action CA15139 (2016-2019), Horizon 2020 Design Study ESSnuSB (2018-2021) and work now within the Horizon Europe Design Study "ESSnuSBplus" (2023-2026). See The European Spallation Source neutrino super-beam conceptual design report | The European Physical Journal Special Topics This CDR demonstrates on the conceptual level that the ESSnuSB project is feasible.

Addressing new scientific challenges with unique /innovative approach strengthening European leadership

The ESSnuSB will measure the CPV phase angle to an unprecedented precision and, in this sense, will be a next, higher precision measurement (with CPV-angle measurement error less than 8 degrees) which could complement measurements from the other two global experiments investigating CPV, DUNE in USA and Hyper-K in Japan. In addition, low energy neutrino cross sections at low energy, eagerly awaited from the neutrino community, will be measured.

Upgrade of an existing operational RI to pan-European or Global RI

We will upgrade the power of the ESS linear accelerator from 5 MW to 10 MW.

Re-orientation of existing science sites to host new RI

We add a new RI (ESSnuSB) that makes use of an existing RI (ESS) in Sweden.

Re-orientation of existing science sites to host new RI

The ESS site will continue to host and operate a spallation neutron source with existing instruments. The long baseline neutrino beam with a near detector will be added and operated on the ESS site.

Landscape analysis of RI in the field and the territorial distribution of service points in Europe

The RI will be located in only one European country, Sweden

Membership Indicators

No. of MS/AC and global partners engaged with determined share to (a) construction and (b) operation. Mission statement from ownership

Currently there are more than 90 physicists and engineers in 20 member institutes in 13 countries. We foresee increasing those numbers by a factor of 5 in the construction and operation phases. The basic idea for the funding of construction costs as well as the operation costs is to divide between the countries proportionally to the Gross National Product like is done for e.g. CERN:

Maturity of international organization and structure of commitments to (a) construction and (b) operation/GBAORD

The current international organization and governance of the ESSnuSB consortium that has been in use for 6 years is described in section 10.2 . Our experience with this organization and governance model is that it works very well for the design study phase. Once the project will be in the preparatory and later implementation phase the organisation model will have to change, please see section 10.2.

User strategy Indicators

Fraction of possible users of the RI per country/ total no. of scientists per country (in the given field)

Currently, about 70-80% of the European particle physicists work at the LHC and other experiments at CERN and maybe 10-20% with Hyper-K and Dune. When ESSnuSB will be in operation we believe that 5 to 10% of the European particle physicists will be working with this experiment.

Data management and access structure

ESS itself has a Data Management and Software Centre (DMSC) located in Denmark which is responsible for Scientific Computing and Scientific Data Management at the ESS. One way would be to expand this center so that it can also deal with the ESSnuSB data. The data management will be organized by a dedicated working group within the consortium. Participation in the analysis will be open for all members of the ESSnuSB consortium, including new members as they arrive. The data will be processed and stored according to FAIR principles and will eventually be made available publicly. Please see also section 4.5

Networking Indicator

Number/size of users consortia willing / planning to contribute own resources to use the RI on contractual basis

In Particle Physics, the resources are usually provided by the governments and research councils of the participating countries and the user of ESSnuSB is on a contractual basis

Expected % of non-European users

We estimate 20-30%

Expressions of interest by diverse scientific communities

In addition to Particle Physicists: Astroparticle and Cosmology Physicists, Accelerator and Instrumentation Physicists, Rock Engineering and Geologist Physicists

Excellence Indicator

The uniquely high resolution of ESSnuSB will attract neutrino physicists from many institutions in Europe and the world. The fact that the plan is to double the power of the world's most powerful accelerator will attract leading accelerator physicists. The excavation of the huge underground far neutrino detector caverns already interest rock engineering researchers from countries other than Sweden; the use of these detectors will interest not only particle physicists but also astrophysicists, in particular in view of their use as detectors of supernova neutrinos.

Knowledge Transfer Indicator

PhD programme agreements with universities

Many of the groups in ESSnuSB already have PhD student supported by their universities to do their thesis project on the current design and performance evaluation of the ESSnuSB. Once ESSnuSB is in operation, the main work with the operation and simulation and analysis of the recorded data will be done by PhD students and Postdocs.

Industrial involvement in pre-procurement studies and in the construction phase, including IPR

Essentially all technology developments mentioned in section 8.4 will require collaboration with industry in the design phase, prototype phase and production phase. The high requirements that our project will place on its different components will require us to closely follow the development work in industry. In all collaboration with industrial companies, the Intellectual Property Rights will be carefully regulated in the contracts. See also section 8.5

SECTION 3: SOCIO-ECONOMIC IMPACT*

3.1. Describe the expected direct socio-economic impact of your RI, e.g. the economic impact from direct spending in the site and region hosting the facility or the headquarters and the nodes of a distributed RI: (maximum 3000 characters with spacing)

The technical development of the proposed neutrino research infrastructure will impact other fields that plan to use very high intensity proton accelerators like Accelerator Driven Systems (ADS) and hadron therapy. Among the technical developments that will have such effects are that of the high current, long pulse H^- ion source and of the target required to stand the impact of very short pulses of very high power. The development of the 500 000 m^3 underground Water Cherenkov detector equipped with the order of 100 000 high-resolution photon detectors will impact the photon-detector industry and modern rock engineering technology. It is expected that the industrial companies that will be contacted to investigate the feasibility of the industrial production of ESSnuSB components will see an economic and technical interest in engaging with the project. It is also expected that the realisation of the proposed project will improve societal conditions by its technological developments that will lead to a greener and safer world.

The ESSnuSB RI will include in its work programme publication of articles in popular science magazines and will seek to contribute to popular science TV programmes in all ESSnuSB member countries with the aim of informing about the latest progress in fundamental science research and the opportunities offered by the project to contribute with further advances. Special outreach events will be organised for the communities living near ESS in Lund and the mine in Zinkgruvan during which not only the scientific interest of the project will be explained but also the local impacts that the upgrade of the ESS research infrastructure will have in

Lund and the construction and operation of the neutrino detectors will have in Zinkgruvan. Examples of impacts are that engineers and scientists from other countries will come for longer and shorter stays and that the construction and the operation of ESSnuSB will bring new employment opportunities and service industries to Lund and Zinkgruvan. The population of Lund has increased from 95 000 in 2009, when the decision to locate ESS in Lund was taken, to 127 000 today. We are also aware that the non-academic commercial interest in such investments is not restricted to what might be called the scientifically literate but extends throughout the whole community from taxi drivers and hairdressers to restaurateurs and hotel owners encompassing real estate agents and school principals. The whole community is positively engaged. In a similar manner, the construction of ESS by in-kind contributions produces visible effects in all partner countries. ESSnuSB is not simply a scientific facility, it has far-reaching consequences for all the associated communities.

3.2. Describe the expected mid- and long-term socio-economic benefits of your RI, e.g. in terms of replacing/re-orientating costly infrastructures that are already in place or in terms of use and dissemination of generated data for support to public policy: (maximum 2000 characters with spacing)

The benefit of making use of the existing ESS linear accelerator and laboratory infrastructure and of the existing Zinkgruvan underground access and service facilities lies in creating and expanding a good business atmosphere in the region. For industrialists, economists and politicians, the primary interest lies in the technical applications that will inevitably emerge from fundamental experimental research like that of ESSnuSB. All the modern technology that so dominates our societal life today has originated from research, be it fundamental, applied or technological ones. The primary applications that arise from the research that ESSnuSB represents come from the development of the cutting-edge instruments and infrastructures that must be developed to enable the proposed kind of neutrino measurements that have not previously been possible to make. Many of these applications cover a wide variety of technological and societal sectors.

3.3. Estimate, if applicable, the impact on the innovation activity in the production of goods and services that will result from your RI, e.g. in terms of well-trained people, knowledge transfer, access programmes and services provided: (maximum 2000 characters with spacing)

An example of a service that will result from the project is the use of the large neutrino detectors in the Zinkgruvan mine for Muon Tomography, by which detecting of new metal ore within a wide area around the mine will be possible, demonstrating the increased sensitivity of the Muon Tomography when very large detectors are used. Another example is the use, after the decommissioning of ESSnuSB, of the large underground detector-caverns for Pumped-water energy storage that will be part of the ESSnuSB study.

All of the following areas will benefit from the RI: science, technology and innovation, education and training, political benefits and international relations, cultural effects, economy, employment, energy saving, environment protection, recycling and waste management, and many others. During the ESSnuSB construction and exploitation, awareness of all these areas will be emphasised, studied and evaluated and the results displayed in easily communicable dissemination material to be used in contacts and information meetings with European Research Councils as well as other funding agencies.

According to current planning, the operation of ESSnuSB project will not start earlier than 2040 and will continue for ~30-50 years, encompassing recurrent upgrades and additions. Many of the future initial users of the ESS neutrino Super Beam infrastructure are currently attending school and university science courses. It is thus important to inform this young generation about the opportunities for outstanding fundamental research that ESSnuSB represents. This will be done by organising outreach events at schools and universities in all ESSnuSB member countries at which ESSnuSB scientists will explain in open lectures the advancement of the design study and the research goals that will be pursued with the project. The material to be used for these outreach events will be produced in different languages, and a plan for the locations and dates of these events will be publicised.

[4] Please consider the Communication on A Reinforced European Research Area Partnership for Excellence and Growth COM (2012) 392.

3.4. Describe the potential and role of your RI in technological and social innovation: (maximum 2000 characters with spacing)

Potential technological developments resulting from ESSnuSB lie in material science at ESS by creating the possibility to produce shorter (order 100 microsecond instead of 3 ms long) spallation-neutron pulses, the development of a Muon Collider, in particular regarding tests of very high power, short pulses proton targets, ore searching using Muon Tomography and pumped-water energy-storage as already described in section 3.3. New technologies of both human communication and of data communication and storage, required for an international collaboration like ESSnuSB, once pioneered with innovation of the world wide web at CERN, is continuing to be developed and will soon enough find new applications also in the society at large.

3.5. Describe how your RI will attract innovation-oriented resources from business, industries and public services, e.g. as users or suppliers: (maximum 2000 characters with spacing)

Organization of collaboration with industrial companies for developing new photodetectors, large water cleaning systems, new methods for excavation in deep rock, new methods for data acquisition, communication, analysis and storage, muon tomography for ore and underground void detection, new methods for pumped-water energy storage will be undertaken.

3.6. Describe how your RI will contribute to tackling (grand) societal challenges: (maximum 2000 characters with spacing)

There is a possible use of ESSnuSB Muon Tomography to localize dangerous underground voids and, after project termination, of the detector caverns in Zinkgruvan for pumped-water energy-storage.

3.7 If available, upload a socio-economic *ex ante* impact study: (upload with limit 1 MB; in case the document is longer than 30 pages, please also provide an executive summary of maximum 4 pages)

Please, refer to point 2.7.

SECTION 4: USER STRATEGY & ACCESS POLICY*

4.1 Upload a table describing quantitatively (in estimated absolute figures as well as %) the targeted user community in terms of 1) scientific field (-s), 2) origin (i.e. local/regional, lead country, prospective member countries, participants, other European countries, other non-European third countries) and 3) sort (i.e. academia, business & industries, public services, other): (upload with limit 1 MB, maximum 30 pages)

Current community consists of 92 persons from 28 institutes in 14 countries. We aim at gathering a community of around 600 researchers and engineers in 1) intensity frontier physics, in particular neutrino physics, and astroparticle physics, 2) local region and lead country host country Sweden, all European countries, Japan, China, US and others, 3) particle physics academia 550, ESS staff 10, rock engineering academia 10, Zinkgruvan staff 10, industry staff 10 , public service staff 10.

4.2 Elaborate how your RI has verified the above-described expected user community and user needs, e.g. through a survey: (maximum 2000 characters with spacing)

The given overall number of staff is comparable to other large particle physics research infrastructures of similar nature (fixed target experiments) like e.g. Hyper-K, details of non-academic staff are rough estimates.

4.3 Describe your user strategy agreed and the possibilities to develop a reasonably sized user community considering costs and services based on identified user demands and needs: (maximum 3000 characters with spacing)

Already when the decision among the European states to finance and build ESS was taken in 2014 the unique opportunity offered by the ESS accelerator to produce an intense neutrino beam enabling measurements at the second oscillation maximum was publicly presented and a collaboration to explore this opportunity was formed. Collaborative work on the ESSnuSB design study was made possible by EU funding (COST, Horizon 2020, Horizon Europe) as from 2016 till now. Since 2016 the number of ESSnuSB collaborators has been constantly growing and the progress of the design study has been reported at European and international conferences on the average 4-8 times per year.

4.4 Describe how you have involved the above-described (potential) user community in the development of your RI proposal, e.g. in the definition of the scientific case and of the technical design specifications, in analysing costs versus benefits, in planning and funding (parts of) the RI: (maximum 1000 characters with spacing)

The work to design the intended research facility was divided up on Working Groups in which tasks were given to the participants. The reporting of the results was done in milestone reports and deliverables. The results of the first design study period 2018 to 2021 were collected in a Conceptual Design Report that was published in the European Physical Journal in 2022. The technical design and performance of the different parts of ESSnuSB research infrastructure, as well as ESSnuSB's global performance for physics, are detailed in this design study report and it has since been further developed and new components of the ESSnuSB infrastructure added. The arXiv version of the Conceptual Design Report (arXiv:2206.01208) contains a first estimate of the ESSnuSB investment cost.

4.5 Provide a quantitative and qualitative description of the services (including access modes and funding) which will be provided by your RI based on the user demands and needs: (upload with limit 1 MB; maximum 30 pages)

The ESSnuSB will produce data in different trigger streams, like neutrino beam data, atmospheric and cosmic neutrino data, solar neutrino data, supernovae neutrino data, proton decay data and muon tomography data. All these triggers can be run concurrently. Data analysis working groups will be created for each of these data streams. Participation in these working groups will be open for all members of the ESSnuSB consortium, including new members when they arrive. The data will be processed and stored according to FAIR principles and will eventually be made available publicly. Participation in the operation of the ESSnuSB infrastructure at ESS and and at Zinkgruvan during the running in of the experiment and the subsequent data taking will also be open for all members of the ESSnuSB consortium. The costs of the operation of ESSnuSB will be divided between the users in proportion to the GNP of their respective country.

4.6 Describe the envisaged (common) access policy of your RI in terms of access units, the access mode (-s), the conditions for access, the processes and interactions involved in the access and the support measures facilitating the access: (maximum 5000 characters with spacing)

All ESSnuSB members will have the access and participation rights described in 4.5. These rights presuppose that the institutes of the individual members provide their share of the funding of the operation costs.

SECTION 5: e-NEEDS & Data*

5.1. Outline the Data Management Plan (DMP) and data access policy of the RI. If applicable, describe how data would become accessible to the research community and the public (possible tools: https://dmponline.dcc.ac.uk/or this https://libraries.mit.edu/data-management/plan/write/): (maximum 3000 characters with spacing **6**)

The data access policy is outlined in 4.5 and 4.6 and will be adhered to the FAIR principles. ESSnuSB will make all data inter-operable, i.e., the data can be exchanged and reused between researchers and institutions. ESSnuSB will adhere to standard formats as much as possible, compliant with available open software applications and in particular facilitating re-combinations with different datasets from different origins. Concerning reusability, no data embargo and no licensing is foreseen. The data quality assurance procedures will be those of each institute. The data will be installed for re-use on publicly available servers to third parties during and after the project without restrictions. The data will remain re-usable for at least five years after the end of the project. Data produced and/or used in the project will be findable using metadata. Data will be identifiable and locatable using a standard identification mechanism with persistent and unique identifiers such as Digital Object Identifiers (DOI).

5.2. Describe and quantify what e-infrastructure services - e.g. resources for storage, computing, networking, tools for data management, security, access, remote analysis, etc. - your RI will need: (maximum 2000 characters with spacing).

Once in operation, the ESSnuSB will generate 100s of TB of data per year. The plan is to make use of the Worldwide LHC Grid for remote analysis. The required data analysis capacity is of order 10000 CPUs.

5.3. Describe how the e-infrastructure services needed by your RI will be implemented, specifying the human resources and the potential need of external e-infrastructure resources and the relations to external e-infrastructures: (maximum 2000 characters with spacing).

It is assumed that most of the collaboration ESSnuSB institutes will contribute e-infrastructure resources and manpower to the analysis effort. Once the data taking has started it is foreseen that that will be one of the dominant activities among the order 500 physicists of the ESSnuSB consortium.

5.4. Describe the compliance with the FAIR principles and how the RI will contribute to the development of the European and global e-infrastructure landscape at all levels (institutional, regional, national, international) - including e.g. the e-infastructure commons and the European Open Science Cloud (EOSC): (maximum 2000 characters with spacing).

Please, see section 5.1.

5.5. In case of a specific (non-horizontal) e-infrastructure, describe the interface with existing communication networks and technical design of your RI.

SECTION 6: ENVIRONMENTAL CONSIDERATIONS *

6.1. Indicate whether an (initial) environmental strategy addresses the potentially significant environmental issues that are considered relevant for the RI over the lifecycle, in particular for implementation, operation and decommissioning phases (cf. separate supporting checklist): (maximum 3000 characters with spacing)

The European Spallation Source will be one of the world's first sustainable research facilities[35]. The architecture of ESSnuSB reflects and contributes to the organisation's core values, i.e., excellence, collaboration, openness and sustainability. Many efforts are made to limit the energy consumption using the following concepts to which ESSnuSB+ will adhere:

• Responsible: monitor the electricity consumption to stay below a fixed level and to predict future operations to lower this as much as possible for the benefit of science.

• Renewable: ESSnuSB is committed to renewable power production in order to compensate for the increased power consumption caused by ESS. It is also vital that the cost of electricity for running the facility is competitive, stable and predictable.

• Recyclable: ESSnuSB is committed to recycle the surplus energy from its operations in a responsible way. The surplus energy consists of hot water that is a result of the cooling process in the facility. This hot water will be used by a district heating network and for heating the ESS buildings.

ESSnuSB is committed to certify the office buildings according to the internationally recognised environmental assessment method, BREEAM. During the ESSnuSB civil engineering studies, this same standard will be respected and all ESS rules for general and radiation safety will strictly be followed.

PART C: IMPLEMENTATION CASE

Fields marked with * are mandatory

SECTION 7: STAKEHOLDER COMMITMENT*

7.1 Complementing the identification of the lead country/entity, prospective member countries/entities, coordinator and participants from PART A, describe the envisaged final stakeholder community (scientific, funders, etc.) of your RI and elaborate on your strategies and plans on how your RI will obtain their commitment, including your plans to get listed in additional national RI roadmaps or alignment with similar strategic documents, National/Regional Research and Innovation Strategies for Smart Specialisation (RIS3) and Operational Programme (-s) from the European Structural and Investment Funds (ESIF): (maximum 3000 characters with spacing)

The envisaged scientific community of ESSnuSB are the neutrino long-baseline communities in European countries as well as outside Europe. Our reasons for believing that we will be able to attract a sufficient fraction of the world neutrino long-baseline community are outlined in section 4.3. Currently, the CERN management is arguing very strongly with good reasons for having as future project the Future Circular Collider (FCC) at CERN for which more than an order of magnitude more funding will be needed than for ESSnuSB. We argue that with the dominant FCC project there is a need for diversity in the European particle physics landscape, having the European CERN laboratory pursuing particle research at the high energy frontier with FCC and the European ESS laboratory, which has manifested a clear interest to widen its research scope to include particle physics at the high intensity frontier with, inter alia, ESSnuSB. Our third argument is that the existence of all hitherto discovered particles were predicted by the Standard Model (SM) theory, that there is no more particles predicted by the SM to discover, that there are many hypothetical particles predicted by other non-confirmed theories that have been search for without success since the discovery of the last remaining particle predicted in 2012 by the SM, i.e. the Higgs boson, and that there is, since the discovery of neutrino oscillations in 1998, a well-known particle that does not any longer fit in the SM, which is the neutrino. The neutrino therefore represents an important portal to new physics that ESSnuSB will pursue. These are the arguments we are making to the national science funding authorities in Europe, presently somewhat in the undeserved shadow of CERNs strong arguing for the FCC.

SECTION 8 & 9: PREPARATORY WORK & PLANNING*

|SECTION 8: PREPARATORY WORK

8.1 Elaborate on the prior work that led to this proposal: (maximum 1000 characters with spacing - **1326**).

The original idea for this proposal came in 2012 when measurements of the mixing angle Θ_{13} in the PMNS neutrino matrix found it to be about 8.5°. That implied a change in the optimal way to discover and measure leptonic CP violation (CPV) using neutrino flavour oscillations. With measured higher value of Θ_{13} the sensitivity at the second oscillation maximum is close to 3 times higher at the second maximum than at the first. In 2014 the construction of the ESS 5 MW linear accelerator was decided. A much higher intensity neutrino beam is required to reach sufficient event statistics at the 3 times more distant second maximum and the designed 5 MW power of the ESS linac offered for the first time a future opportunity to measure CPV at the second maximum. These facts attracted a number of particle physicists in Europe who formed a small consortium ESSnuSB which soon grew bigger and eventually in 2016 received a COST grant of 350 k€ that helped in forming a project and apply to Horizon 2020 for an INFRADEV grant of 3M€ to produce by 2022 a Conceptual Design Report.

8.2 Describe what type and level of assessment - including successful design and feasibility study (-ies) - your RI already has undergone: (maximum 1000 characters with spacing**1**).

The consortium ESSnuSB of European particle physics groups was first formed in 2015 and applied for a COST grant in 2016 allowing the common design work to start. In each of the years 2018 and 2022 the consortium received a Horizon 2020 grant of 3 M€. The work was organized in the following Work Packages: Management, Linac, Accumulator Ring, Target Station, Detectors and Physics Reach. In 2022 the results obtained were described and published in a ~200 pages Conceptual Design Report. In this it was shown to be possible to provide 5 MW beam for neutron spallation and a 5 MW beam for neutrino beam production concurrently, that the accelerator pulses can be compressed to 1.2 µ , that the designed neutrino production target can operate at 5 MW and that with the Far Detectors located at 360 km from the source the measurement error in the CPV phase angle will be no more than 8°, a close to 3 times higher resolution than for other long-base experiments now under construction in Japan and the US.

8.3 Describe how the implementation of your RI was tested and found feasible and summarise the main findings concerning the implementation from the design (or feasibility) study report (-s): (maximum 5000 characters with spacing).

The implementation and construction of ESSnuSB will be the objective of the ESSnuSB work in the implementation phase which we plan to start in 2027, leading up to the publication of a Technical Design Report in 2030.

8.4 Concerning the Technical Design Report (TDR), describe if all the relevant technologies are available or if and how much Research and Development (R&D) is needed in order to assess the full technical feasibility and draw a cost-book: (maximum 1000 characters with spacing).

There are a number of components building on new technologies that we will need to design and develop during the preparation phase 2027-2030 for the implementation phase starting 2030. Among those are: a high current H- source and a high power RFQ for the accelerator, laser electron stripping for the Accumulator ring at the injection, high power granular targets with focusing horns for the neutrino production, new rock engineering methods for the excavation an stabilization of the large Far Detector underground caverns, high time and spatial resolution photon detectors for the water Cherenkov neutrino detectors, mechanical support structure for the photon detectors, water cleaning and monitoring system, photodetection calibration and monitoring systems, Gadolinium admixture to the water, trigger and data acquisition electronics, data storage, physics analysis methods and long range and high precision Muon Tomography.

8.5 Describe whether the industrial capacity for the implementation (construction) and operation is already in place (EU or international market) or whether it needs to be developed in relation to your RI, e.g. spin off companies, joint ventures: (maximum 2000 characters with spacing).

Essentially all technology developments mentioned under point 8.4 will require collaboration with industry in the design phase, prototype phase and production phase. The high requirements that our project will place on its different components will require us to follow the development work in industry. One example of this is the development and provision of photodetectors. The the ca 20’000 50 cm diameter photomultipliers that have now been ordered from Hammamatsu in Japan for the Hyper-K experiment in Japan saturated the Hammamatsu production line capacity for several years. At this moment there are no more orders for that production line and it is not clear whether the production line could be maintained till when ESSnuSB will place its order for photodetectors. On the other hand, there are several new photodetector types that have been developed meanwhile providing higher time and spatial resolution, like e.g. the Large Area Picosecond Photodetectors (LAPPD) just to give one example. Currently the LAPPDs can be produced in small series by an US firm Income but not yet in the quantities and sizes required for ESSnuSB. We are also following other developments and hope to have, by the time when we will have to place the production order, an even more performing type of photodetector that will be available for series production. Another example is development of new rock engineering methods for the excavation and stabilization of the large Far Detector underground caverns. The two ESSnuSB underground caverns will be the largest in the world (270 000 cubic meters each) and have to be designed for the specific rock available near the Zinkgruvan mine. There are firms specialized in this technology for which the design of the ESSnuSB caverns will be an outstanding challenge and which will have several possible other applications in future.

8.6 Elaborate on the business case of your RI effectively linking the described scientific case, funding commitments, user strategy, access policy and Cost-Benefit Analysis (CBA) demonstrating the long-term sustainability of the operations of your RI and explain whether and how this business case has already been reviewed: (maximum 5000 characters with spacing).

The main goal of ESSnuSB is research in fundamental particle physics, which however in several ways is linked to applications in the Society through the advanced experimental equipment and instrumentation that needs to be developed to answer the fundamental scientific questions. One such application is the planned use of the large underground water Cherenkov detectors for Muon Tomography. By their large size and high spatial and temporal resolution for muon detection the two large detectors situated a few hundred meters apart can be used to map the underground far around the Zinkgruvan location by detecting cosmic ray muons generated in the atmosphere and incident from the sides, detecting the variations in the muon flux in different lateral directions caused by volumes of higher densities, like where there is metal ore, or lower densities, like where there are voids. This technique has already been successfully used with small-scale muon detectors. The large size and high precision of the ESSnuSB detectors will take this technology to new levels when it comes to searching new metal-ore veins and detection of newly created underground voids representing a risk for collapse of ground level buildings above, like has been the case for the city of Kiruna in Northern Sweden. The ESSnuSB consortium already disposes of a small, ca 15 m^3 volume, scintillator muon detector that it plans to install at an early stage in the Zinkgruvan mine to make a first pilot test and demonstration of the Muon Tomography technique there. Other technologies to be developed for ESSnuSB that have practical applications in Society are wide-area high-precision photon detectors, advanced high-capacity water-cleaning methods, and new large scale rock excavation methods. As to sustainability, when after 20-30 years ESSnuSB will be decommissioned, the large detector caverns can be used for pumped-water energy storage, generating electricity during night time by letting water fall down from ground level turning generators, and using solar power to pump the water up to ground level during daytime.

8.7 Describe your strategy for site selection and for siting. If your RI is single-sited, explain how the site was or will be chosen. If your RI is distributed, explain how you have (will) select the headquarters and (national) nodes: (maximum 1000 characters with spacing).

ESSnuSB has two sites, one at the ESS in Lund and the other at the premises of Zinkgruvan, 360 km north of Lund, both in Sweden. The selection of the ESS site was given at the outset of the project because the ESS linear accelerator is the only in the world that can provide a neutrino beam intense enough to record sufficient event statistics at the second neutrino oscillation maximum. For the Far Neutrino Detector site we planned to use the Garpenberg mine located at a distance 540 km from Lund and the Zinkgruvan mine at 360 km, which is a bit off the second maximum. Detailed Monte Carlo simulations eventually demonstrated that even if the CP violation discovery potential is about equal for the two sites, the spreading of the neutrinos by the divergence of the neutrino beam leads to that the number of neutrinos detected around the second maximum is about the same at the two locations. In the Zinkgruvan location some neutrinos in the first maximum were also detected providing additional information and it was found that the resolution in the CP-violation phase-angle is higher at the Zinkgruvan site.

8.8 Elaborate on the (prior) context of the site (-s) of your RI, e.g. a 'green-field', part of a broader plan of site development (including synergetic initiatives, installation in the premises of pre-existing facilities of similar or different scope) and the 'value' transferred to your new RI in terms of infrastructure, services and human resources: (maximum 1000 characters with spacing).

On the ESS site there are pre-existing facilities of similar use as for ESSnuSB, in particular the world-uniquely powerful proton linear accelerator. The possibility to use this accelerator for neutrino beam generation, concurrently with the generation of a high flux of spallation neutrons, represents a unique asset for ESSnuSB and a very significant saving in investment cost of ca 800 M€ and in expert personnel for maintaining and operating the accelerator. We are also investigating to develop further our technique for compressing the 2.86 ms long proton pulses from the accelerator to much shorter pulselength, which for the case of ESSnuSB is 1.2µs. For material science with spallation neutrons, there is a great interest in having pulses of length 50 to 100 µs. We already have a design for how to generate the 1.2 µs pulses and are working on how to achieve 50 µs to 100 µs pulses needed for material science measurements. For the Zinkgruvan site the possibility to use the ESnuSB underground detectors to search for new ore veins is discussed in point 8.6.

|SECTION 9: PLANNING

9.1. Describe the detailed planning for your RI as approved within the consortium complementing the timeline provided in PART A by specifying all phases, Work Breakdown Structure (WBS), deliverables and milestones, including investments decisions and possible updates and decommissioning: (maximum 5000 characters with spacing).

Below is shown the list of Work Packages, Deliverable and Milestones and a pie-chart of the distribution of the 5 M€ budget over time, type of personnel and work packages of our currently ongoing ESSnuSBplus Horizon Europe project that will be concluded in December 2026. Our plan is to continue during the period 2027 to 2030 with the preparation of the Technical Design Report. The planning of the early phase implementation that we will do during this preparatory phase is described further down in this section 9.

Table 3.1a: List of work packages

Work Package No	Work Package Title	Lead Participant No	Lead Participant Short Name	Person-Months	Start Month	End Month
1	Management	1	CNRS	64	1	48
2	Engineering and Infrastructure	7	ESS	54	1	48
3	Target Station and pion extraction	1	CNRS	131	1	48
4	Low Energy nuSTORM	5	UU	169	1	48
5	Detectors and physics reach	3	RBI	236	1	48
6	Low Energy Monitored Neutrino Beam	17	UNIMIB	108	1	48
	TOTAL			762		

3.1.4 List of Deliverables

Table 3.1c: List of Deliverables

Del. no.	Deliverable name	WP no.	Short name of lead part.	Type	Dissemination level	Delivery date (in months from the project start)
1.1	Data Management Plan.	1	CNRS	R	PU	6
1.2	Plan for dissemination and exploitation including communication activities	1	CNRS	R	PU	6
1.3	Initial facility parameters	1	CNRS	R	PU	8
3.1	Optimise the ESSvSB+ horn design and its pulse generator	3	UNISTRA	R	PU	18
5.1	Preliminary design of the LEnuSTORM/monitored beam near detector	5	RBI	R	PU	23
3.2	Design of the pion extraction and focusing systems	3	UNISTRA	R	PU	24
4.1	Review of the LEnuSTORM operation scheme	4	UU	R	PU	24
6.1	Design of the LEMNB transfer line	6	UNIMIB	R	PU	24
6.2	Completion of the LEMNB end-to-end simulation of the beamline	6	UNIMIB	R	PU	30
5.2	Sensitivity of ESSvSB far detectors to non-beam physics	5	RBI	R	PU	35
6.3	Physics performance of the monitored neutrino beam	6	UNIMIB	R	PU	36
4.2	Racetrack ring design	4	UU	R	PU	38
5.3	Performance of neutrino interaction cross-section measurement	5	RBI	R	PU	40
2.1	Conceptual study of civil works with indicative timeline for ESS Site related activities	2	ESS	R	PU	40
5.4	Sensitivity of END and LMND to sterile neutrinos and other new physics	5	RBI	R	PU	43
5.5	Effect of the ML approach on event reconstruction performance for ESSvSB and error analysis	5	ULUND	R	PU	43
2.2	Machine Conceptual Design & Mechanical Design of Linac, 2nd Target Station, near and far detectors, auxiliary systems and infrastructure	2	ESS	R	PU	44
4.3	Design of the LEnuSTORM transfer and injection systems	4	CNRS	R	PU	44
2.3	Deliverables for the far detector Civil Engineering Study including far detector site Feasibility Report and far detector Civil Engineering Study Report	2	LTU	R	PU	46
6.4	Update of LEMNB physics performance including the full systematic budget	6	UNIMIB	R	PU	46
3.3	Design of the Target Station	3	UNISTRA	R	PU	46

3.1.5.1 List of Milestones

Table 3.1d: **List of milestones** (all milestones will be accompanied by an internal note placed on DocDB)

No	Milestone Name	Related WP(s)	Due date (months)	Means of verification
1.1	Review of 1st year achievements, deliverables & costs	All	12	Report reviewed by GB
3.1	First design of the hadron collector	3	12	Report reviewed by external experts
5.1	Identification of requirements for LEnuSTORM / monitored beam near detector	4,5,6	12	Report reviewed by EC
6.1	Identification of the location and layout of the LINAC transfer line	6	12	Internal review
5.2	Identification of non-beam physics scenarios	5	17	Internal review
4.1	Evaluation of the LEnuSTORM requirements and parameter range	3,4,5	18	Report reviewed by external experts
6.2	Implementation of the static focusing system in MADX and G4beamline	6	18	Internal review
5.3	Identification of LEnuSTORM physics scenarios	5	22	Internal review
3.2	Preliminary design of the pion extraction and focusing system	3	24	Report qualified by external experts
5.4	MC simulation framework for all detectors is set up	5	24	Internal review
5.5	Development of ML approach finished and implemented for a data test sequence	5	24	Internal review
6.3	MC simulation framework for the tunnel instrumentation is set up	6	24	Internal review
1.2	Review on interim milestones, deliverables & costs	All	24	Report reviewed by GB
5.6	Update of the physics reach framework	5	27	Internal review
2.1	Conceptual report with indicative timeline for ESS site works	2	28	Report internal review
5.7	Preliminary estimation of cross-section measurement precision	5	29	Internal review
4.2	Preliminary racetrack ring lattice design	4	30	Report reviewed by external experts
6.4	Analysis framework for the evaluation of the systematics is set up	6	30	Internal review
6.5	Preliminary estimate of the neutrino flux in the monitored neutrino beam	5,6	30	Internal review
2.2	Conceptual Mechanical & Machine Design	2	34	Design internal review
4.3	First estimate of the neutrino flux from LEnuSTORM	4,5	33	Internal review
3.3	Final estimation of the pion beam	3	36	Report reviewed
1.3	Review of 3rd year milestones, deliverables & costs	All	36	Report reviewed by GB
3.4	Evaluation of the baseline design of the target station	3	42	Report reviewed by external experts
2.3	Civil engineering study for the far detector	2	46	Study internal review
4.4	Updated design of the linac, accumulator ring and transfer lines	4	42	Report reviewed by external experts
1.4	Cost and performance evaluation complete	All	48	Report reviewed by external experts

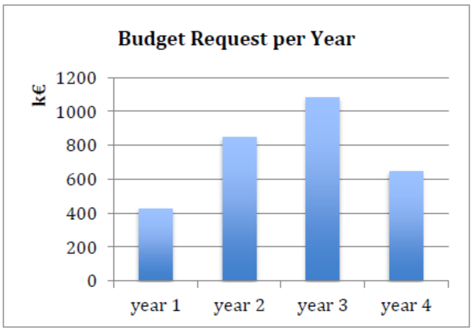


Figure 13: Expenditure profile of the EC requested budget per year.

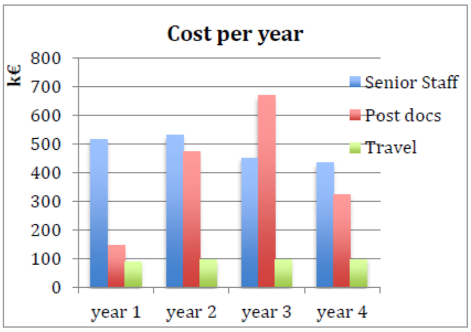


Figure 14: Cost per year for senior staff, postdocs and traveling.

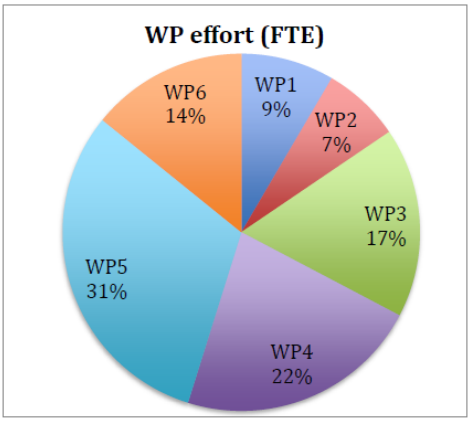


Figure 15: Fraction of manpower for each Work Package.

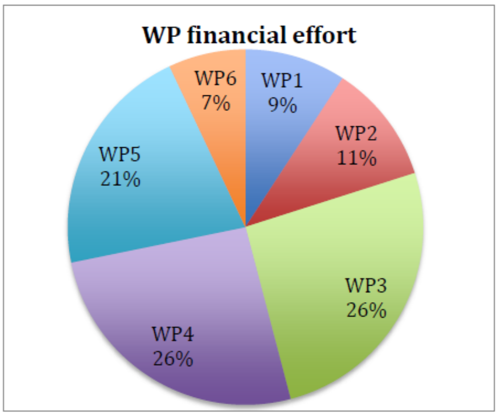
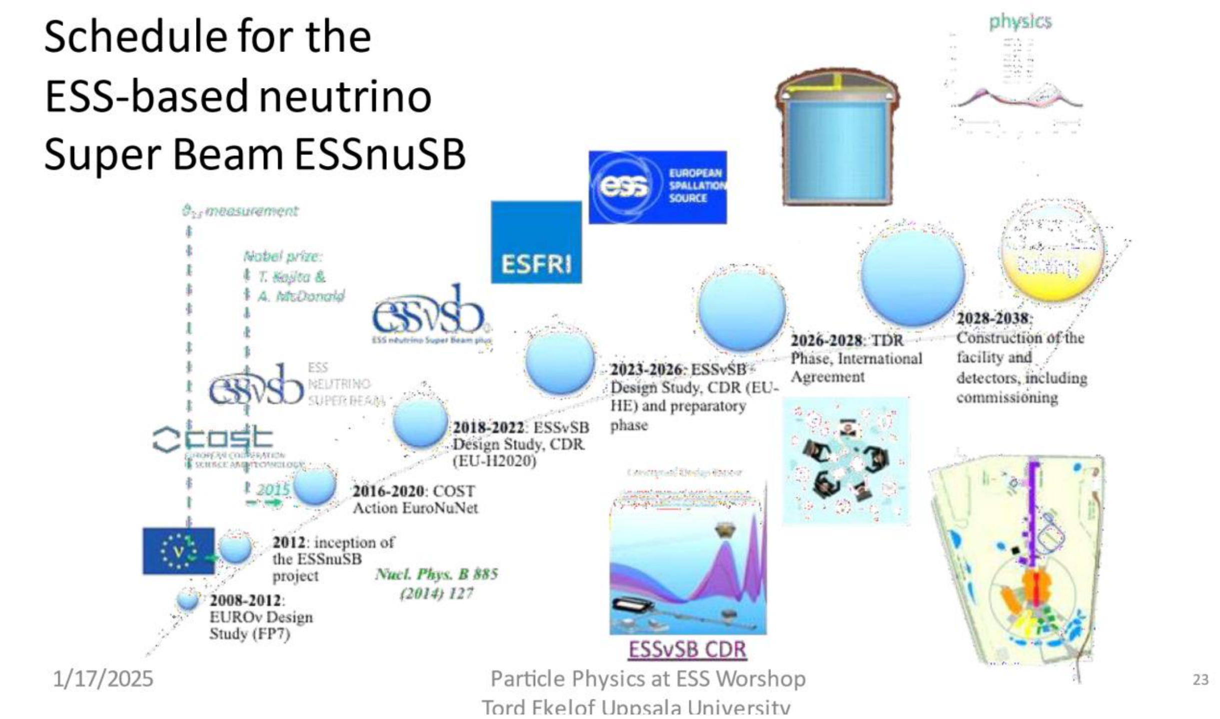


Figure 16: Fraction of manpower cost for each Work Package.

9.2 If available, upload a visual illustration of your planning: (upload with limit 1 MB).



9.3 Define the main objectives and tasks of your preparation phase and the aspects of readiness-to- implement within its 2-3 years reach.: (maximum 1000 characters with spacing).

A first goal to reach is the conclusion of the present second conceptual-design phase 2023-2026 and the publication in 2026 of the final Conceptual Design Report (a first ESSnuSB Conceptual Design Report was published in 2022). We are currently preparing two new projects for Horizon Europe, one to the already announced call "HORIZON-INFRA-2025-01-DEV-03: Consolidation of the Research Infrastructure landscape – Individual support for evolution, long term sustainability and emerging needs of pan-European research infrastructures" for performing a detailed design study of the ESSnuSB Far Detector in Zinkgruvan and one to the not yet announced call "HORIZON-INFRA-01-DEV-02: Early phase implementation of ESFRI Projects that entered the ESFRI Roadmap in 2026" for performing the preparation phase work 2027-2030 to produce the ESSnuSB Technical Design Report, on the basis of which ESSnuSB could start construction in 2030. These projects will have as main objectives to develop the design and technologies for the ESSnuSB components described in point 8.4.

9.4 Explain how your RI will reach the firm decisions for implementation by the involved stakeholders in the consortium within the lifetime on the ESFRI Roadmap, i.e. maximally ten years: (maximum 1000 characters with spacing).

Already now we are negotiating with a few of the Research Funding Authorities of the ESSnuSB EU member countries Bulgaria, Croatia, France, Germany, Greece, Italy, Spain and Sweden with the goal to have 3 of them provide letters of political and financial support in order for ESSnuSB to be eligible for introduction on the ESFRI Roadmap 2026. We will continue such negotiations with all the 8 current EU member countries during the preparatory phase 2027-2030. It is however only when we have published the Technical Design Report in 2030, which will contain a robust and precise investment cost estimate, that we intend to start negotiations to obtain firm decisions from the all ESSnuSB member countries on their financial contribution to the construction project, such that construction could start thereafter.

9.5 Describe a preliminary plan for decommissioning, if relevant

The ESSnuSB research infrastructure is estimated to have a lifetime of 30 to 40 years. It is not unlikely that the decommissioning of ESSnuSB will coincide more or less in time with that of ESS, which will provide synergy between the two decommissionings. Like for ESS, most of the ESSnuSB installations at the ESS site will be mostly underground and radioactively contaminated and will therefore require special handling and disposal of radioactive waste. This will not be valid for the decommissioning of the three ESSnuSB detectors on the ESS site as they will only have been exposed to neutrino beams. As to the Far Detector site, we will be studying how the two large underground detector halls and their service and access tunnels can find another use after the close-down of ESSnuSB. One such use is for Pumped Hydroelectric Energy Storage, using solar and wind energy to pump the 540 000 m^3 of water filling the underground halls up the 1000 m to ground level during daytime and letting the water fall down to the underground halls through electricity generating turbines during night-time.

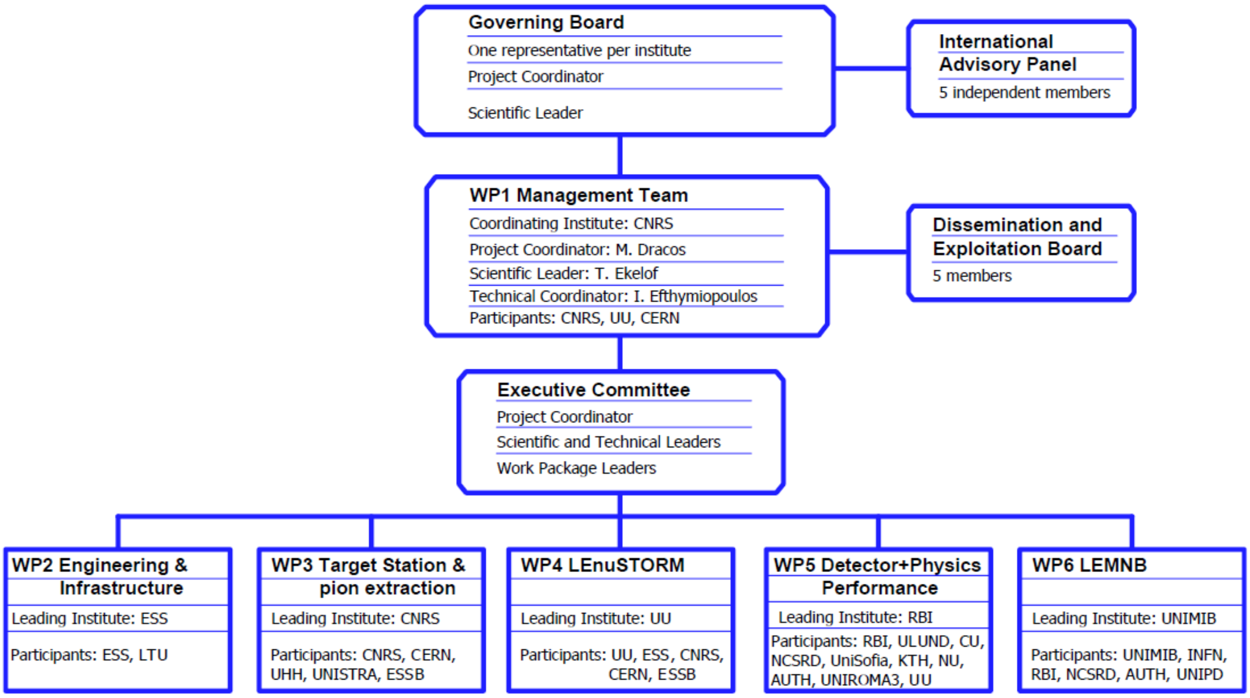
SECTION 10 & 11: GOVERNANCE, MANAGEMENT & HUMAN RESOURCES POLICY*

|SECTION 10: GOVERNANCE & MANAGEMENT

10.1 Describe the project organisation for the preparation and for the implementation of your RI as approved within your consortium: (maximum 1000 characters with spacing).

We refer to our answer under point 10.3 for this description.

10.2 Upload an organisation chart of the project organisation for the preparation and the foreseen implementation phase: (upload with limit 1 MB).



10.3 Outline the governance for operation with clearly defined responsibilities and reporting lines, including all bodies, senior managers, Supervisory and other Advisory Boards: (maximum 2000 characters with spacing - **1612**).

Answer to 10.2 and 10.3: The graph under point 10.2 shows the project organisation during the current design-study phase with a Governing Board advised by an International Advisory Panel, a Management Team linked with a Dissemination and Exploitation Board, an Executive Committee following and reporting to the Management Board the work in the 6 Working Groups, each of which is designing a well defined component of the ESSnuSB research infrastructure. We have more than 6 years of experience with this project organisation and have found that it is working very well for the design study phase. Entering the preparation phase, the previous design work will have to change into first phase of the preparation of engineering and fabrication drawings of the components and include a certain number of prototype tests as well as an international market search for industrial companies able to produce the ESSnuSB components, many of which will be series produced. The Working Groups will have to be restructured to carry out this kind of work. For the implementation phase the work of the Management Team, helped by the Dissemination and Exploitation Board, will have to focus on the contacts with the ESSnuSB members country research ministries to show the technical readiness of the project to be implemented and the reliability of the investment and operation cost estimates at that time with the goal to obtain contributions from the member state governments to the ESSnuSB investment budget and, on the basis of that, conclude an international agreement with the member states to start ESSnuSB construction.

10.4 Elaborate on the chosen or preferred legal structure, how you intend to implement it with particular attention to the transition from the project organisation to the (final) governance: (maximum 1000 characters with spacing).

The governance of ESSnuSB will need to have clear links with the management of the ESS laboratory. Following a presentation by ESSnuSB of the ESSnuSB status to the ESS Council in June 2024, a discussion followed in which a model with ESSnuSB as a “partner” to ESS was proposed by ESS. The ESS Council intends to further develop this model. As ESS already has a Council with governmental representatives of its member countries, and many of those member countries will also be member countries of ESSnuSB, one possibility is that the management of ESSnuSB, as a “partner” to ESS, will report to the ESS Council. These ideas are however very preliminary and the question of what legal structure ESSnuSB would have will require further work and negotiations with ESS and with the ESSnuSB member states.

10.5 Identify all measurable and credible Key Performance Indicators (KPI) for both the scientific case as well as the implementation case in all RI life cycle phases: (maximum 2000 characters with spacing).

For the scientific case:

1. Measurement of the muon neutrino and electron neutrino cross-sections with a precision of 2% using the Monitored Neutrino Beam and the nuSTORM
2. Operation of the ESS linear accelerator at 10 MW providing 5 MW proton beam for neutrino-beam production concurrently with 5 MW proton beam for spallation-neutron production.
3. Compression of the 2.86 ms long ESS Linac pulse to 1.2 microseconds using the Accumulator ring
4. Successful operation of the four 1.25 MW targets and the focussing horns to create the world’s

most intense neutrino beam

5. Measurement of neutrino oscillations with a systematic error not larger than 3% using the Far Detector
6. Measurement of the CP violation phase angle with an error not larger than 8 degrees
7. Measuring the proton lifetime with a reach up to 10^35 years
8. Measuring atmospheric and solar neutrinos with systematic error not larger than 5%

For the implementation case

1. Publication of a first Technical Design Report and firm cost estimate by 2030
2. Having established contacts with the research authorities in all ESSnuSB member countries
3. Having negotiated a generally accepted principle with the member countries by which the ESSnuSB investment costs will be divided between the ESSnuSB member countries, like proportionality to the relative Gross National Product between the countries, and on the maximum fraction of the investment that can be made with in-kind contributions
4. Having investigated all required licenses and other legal permissions that will be needed for the buildup of the ESSnuSB infrastructure on the ESS site and that at the Far Detector site
5. Having established agreements with the management of ESS and of the Far Detector site on the conditions under which the build-up and operation of the ESS infrastructure can be made.
6. Having agreed with the member states which in-kind contributions each member country will deliver.
7. Having identified and established relations with the industrial companies and consultants that will contribute to the ESSnuSB build-up and agreed on their costs for the components and services
8. Having appointed the management, section leaders, engineers and technicians and administrative personnel that will make up the organization that will execute the build-up of ESSnuSB

|SECTION 11: HUMAN RESOURCES POLICY

11.1 Describe how your RI will help European scientific communities' mobility and internationalisation, i.e. link your access policy - particularly the excellence-driven access mode - to your (scientific) human resources policy: (maximum 2000 characters with spacing).

The European ESSnuSB Consortium already comprises more than more than 90 scientists at more than 20 universities and research laboratories in 11 countries. New research groups are joining the Consortium every year with the goal to reach some 500 member scientists at the start of data taking operation around 2040. Research groups with interests in neutrino long-baseline research and/or any of the front-line technologies being developed and realized by ESSnuSB, like the technology of particle accelerators, of particle detectors, of high capacity computing and of rock and underground engineering are welcome to join the Consortium at any stage of the project. ESSnuSB already has relations to the Super- and Hyper-Kamiokande consortia which are providing ESSnuSB with their experience. There is participation from ESSnuSB in the current Water Cherenkov Test Experiment at CERN and the NINJA detector development in Japan, both projects essentially driven by Super- and Hyper-K groups. ESSnuSB will in particular be open to European scientists who are now part of the Japanese Super-K and US DUNE consortia and who will eventually like, after having contributed to these two projects, to continue their research by joining the second-generation, longer-term and higher-precision project ESSnuSB.

11.2 Describe the approved staffing plan for the preparation - and if possible for the implementation (construction) - of your RI, i.e. the skills and competences needed and how they will be recruited: (maximum 2000 characters with spacing).

In section 8.4 the main ESSnuSB components are listed, which all to a large extent build on new technologies. As mentioned in section 11.1, the conceptual design work will have to change by 2027 into the first stage of the preparation of engineering and fabrication drawings of the components and include a certain number of prototype tests as well as an international market search for industrial companies able to produce the ESSnuSB components, many of which will be series produced. Many of the scientists and engineers that are now preparing the final Conceptual Design Report to be published at the end of 2026 have competences also when it comes to preparing engineering drawings and working with industrial companies. Furthermore, most universities and laboratories have mechanical and electronic workshops with engineers that can be involved according to needs. We also intend to use external technical and legal consultancy firms as subcontractors for the study of certain specific tasks. As already mentioned in section 11.1, more groups are successively joining ESSnuSB and this provides opportunities to affiliate more technical and engineering expertise in areas where such is needed. One major component of ESSnuSB that will require a particular effort when it comes to engineering studies is the Far Detector, in particular more engineers will have to be recruited to study the rock engineering methods for the excavation and stabilization of the large Far Detector underground caverns. This recruitment is already under way with the Luleå Technical University Rock Engineering Department, already a member of the ESSnuSB consortium, establishing collaboration with the Technical Universities in Oulu in Finland and in Wroclaw in Poland, both of which have had a long activity in rock engineering.

11.3 Describe the managerial skills and competences – including scientific - needed for the preparation, implementation (construction), operation and termination of your RI and how you will recruit them: (maximum 1000 characters with spacing).

The current ESSnuSB Conceptual Design Study had a goal to provide a Conceptual Design. Most of the ESSnuSB groups have experience from being part of other international research infrastructures that have already passed all the stages from conceptual design, preparation, implementation to operation. ESS will soon be in its operational phase and therefore also has experience of building up the management of a large research infrastructure. All managers have been appointed by the ESSnuSB Governing Board, which has one representative per collaborating institute. This mode of operation will continue during the preparation phase. However, when the member states have agreed on an investment budget for ESSnuSB, the implementation phase will start and an ESSnuSB Legal Entity will be created. This Legal Entity, which will be governed by an international Council with governmental representatives, will recruit the ESSnuSB personnel. Experience shows that there are enough competent science and technology managers in Europe for such a process to be successful.

11.4 Outline the human resources policy for the operation of your RI, i.e. skills and competences needed, hiring, equal opportunities (including gender balance and diversity), secondments, education and training of staff and users: (maximum 2000 characters with spacing).

The procedure for hiring staff for the operation of ESSnuSB is described in section 11.3. An experience from the transition from the implementation to the operation of any accelerator research infrastructure, like e.g. ESS, is that the competencies and skills of the team needed for the implementation (construction) phase and those needed for the operation phase are different. As the implementation phase of ESSnuSB will follow after that of ESS, ESSnuSB may profit from already having a well trained implementation team employed by ESS that is well acquainted with the ESSinfrastructure. For the operation of the ESS accelerator at 10 MW as well as for that of the nuSTORM and Accumulator Rings, for which experience of accelerator operating is required, the personnel having already operated the ESS accelerator at 5 MW will be very well qualified. The ESSnuSB target station for neutrino-beam generation and the ESS target station for spallation-neutron generation are different in design but have several technical features in common and the operators of the ESS target station will also be well qualified for operating the ESSnuSB target station. As to the operation of neutrino detectors, on the ESS site and at the Far Detector site, there is no experience of that technology at ESS. The operation of the large particle detectors at CERN is to a large extent done by the particle physicists employed by the participating universities and laboratories, who also carry out the computer analysis and storage of data from the detectors. This model will be adopted also for ESSnuSB. Educating and training master and PhD students is already a prime component of the ESSnuSB activities and will remain so throughout the project. ESS is employing equal opportunities and gender balance and diversity policy when hiring personnel and ESSnuSB will employ the same policy.

SECTION 12: FINANCES*

12.1 Complementing the estimated costs as provided under PART A, describe the top-level breakdown of cost elements with overall order of magnitude estimates for all phases, including – in case of a distributed RI - for Central Hub, National Nodes and main upgrades. Please indicate the confidence levels of your estimates for each element. Please indicate if they are based on suppliers' quotations. (maximum 4000 characters with spacing). Please upload your cost models and cost-book analysis, if available: (upload with limit 5 MB).

A preliminary estimate of the investment cost of ESSnuSB was done for and published 2022 in the arXiv version of the ESSnuSB Conceptual Design Report https://arxiv.org/abs/2206.01208 on page 207:

Item	**Sub-item**	**Cost (M€)**	**Cost (%)**
Linac Upgrade	Ion Source and Low-Energy Beam Transport (LEBT)	5.00	0.36%
	Radio-Frequency Quadrupole	6.90	0.50 %
	Medium Energy Beam Transport (MEBT) Upgrade	3.00	0.22%
	Drift-Tube Linac with BPMs, BCMs	13.40	0.97%
	High-Beta Linac (HBL) Upgrade	10.40	0.75%
	33 Modulator Upgrades	3.50	0.25%
	8 New Modulators	9.00	0.65%
	15 Grid-Modulator Transformers	5.60	0.41%
	11 Grid-Modulator Transformers Retrofitted	0.50	0.04%
	26 Solid-State Spoke Amplifiers	26.00	1.88%
	New Klystrons for upgraded HBL	12.10	0.88%
	Remaining Klystron Refurbishment/Replacement	25.20	1.82%
	Cryogenics, Water Cooling, Civil Eng.	12.00	0.87%
	Total	**132.60**	**9.59%**
Accumulator	**Item**	**Cost (M€)**	**Cost (%)**
	DC Magnets and Power Supplies	50.00	3.62%
	Injection system	11.00	0.80%
	Extraction System	7.00	0.51%
	RF Systems	16.00	1.16%
	Collimation	8.00	0.58%
	Beam Instrumentation	19.00	1.37%
	Vacuum System	24.00	1.74%
	Control System	30.00	2.17%
	Total	**165.00**	**11.94%**
Target Station	**Item**	**Cost (M€)**	**Cost (%)**
	Target Station	32.00	2.32%
	Proton Beam Window System	5.20	0.38%
	PSU + Striplines	5.40	0.39%
	Target and Horn Exchange System	40.42	2.92%
	Facility Building Structure	26.60	1.92%
	General System and Services	21.80	1.58%
	Total	**131.42**	**9.51%**
Detectors	**Item**	**Cost (M€)**	**Cost (%)**
	Emulsion Detectors	2.00	0.14%
	Super Fine-Grained Detector	5.49	0.40%
	Near Water Cherenkov Detector	25.22	1.82%
	Far Water Detector	399.35	28.89%
	Underground Cavern Excavations	521.15	37.70%
	Total	**953.21**	**68.93%**
Grand Total		**1382.23**	**100.00%**

In this estimate the civil engineering cost on the ESS were not included. The Monitored Neutrino Beam and

the nuSTORM Ring are ESSnuSB infrastructures on the ESS site the conceptual design of which are being studied in the current ESSnuSB+ Horizon Europe design study to be concluded, including a cost estimate, in 2026. A very preliminary estimate made of the costs for ESS civil engineering and of these two additional infrastructures has resulted in a cost of order of 600 M€, implying a total ESSnuSB investment cost of ca 2 B€, which is close to the initial cost estimate for ESS.
As to the ESSnuSB operation costs, no study has been made. A rough rule of thumb for the operation costs of a research infrastructure is that it is of the order of 10% of the investment cost, i.e. ca 200 M€ per year in the case of ESSnuSB. The confidence level of this estimate is obviously low.

12.2 Describe the essence of your investment plan – in terms of current level of financial commitments, the (conditional) intentions to (co-) fund the implementation (construction) costs and access, site-premium and kind of formal investment commitments (in cash and/or in-kind), the plans to fund operating costs - and to what (sub-) set of stakeholders you have presented your investment plan: (maximum 2000 characters with spacing).

As we do not yet have a Technical Design Report with a final investment cost estimate, we do not have the basis for negotiating financial contributions, in particular their amounts, with the ESSnuSB member-state research-funding authorities. Our current baseline assumption is that the member state contributions shall be proportional to their relative Gross National Product (GNP), a scheme used e.g. by CERN. As to the site-premium, Sweden as the ESSnuSB host state, may be requested to contribute more than its GNP fraction. The ESSnuSB will be profiting from the already made investment in important technological parts of ESS, most of which have been delivered in-kind by the other ESS member countries, any site-premium for ESSnuSB should be based on other considerations. Anyhow, the contributions from the member states can only be the object of negotiations between the member states, which can only start once we have a firm cost estimate by 2030.

We intend to apply for funding from the foreseen but not yet published call "HORIZON-INFRA-2025-01-DEV-02: Early phase implementation of ESFRI Projects that entered the ESFRI Roadmap in 2026, that we expect to be announced in 2026, to finance our Technical Design Study 2027-2030, which will comprise a final investment and operation cost estimate. One of the reasons for submitting the present Questionnaire with our answers is to apply for being listed on the ESFRI Roadmap 2026 and thereby be eligible for applying for the early phase implementation grant as discussed here above. We have already started discussion with some of the ESSnuSB member state research-financing authorities to get some indication of their intention to contribute to the financing of the ESSnuSB investment costs and such letters from four member state authorities are, as required, attached to the present submission to ESFRI.

12.3 Indicate whether you intend to use other sources of funding like for example loans of the European

Investment Bank (EIB) or equivalent national credit systems: (maximum 3000 characters with spacing).

At the start of construction of ESSnuSB in 2030 a number of contracts will have to be signed with industrial companies, for staff employments and others, requiring a significant part of the total investment capital to be available for commitment. On the other hand, the payment by the member states of the contributions to the ESSnuSB investment fund need to be at a constant rate per year over the length of the construction period, estimated to be ca 8 years. There will therefore be too little capital available to the ESSnuSB management to sign all contracts required at start of construction. To compensate for this the ESSnuSB management will consider applying to the European Investment Bank for a loan according to the outcome of financial negotiations. The contracts signed with the ESSnuSB member states for the financing of the ESSnuSB construction will serve as guarantee for this loan.

SECTION 13: RISKS*

13.1 Describe the scientific developments or competing projects elsewhere that could affect the research outputs expected from your RI: (maximum 1000 characters with spacing).

There is little in the development of science that can decrease the advantage of ESSnuSB compared to other long base-line neutrino oscillation experiments under construction now. Unforeseen increases in the construction costs of Hyper-K and DUNE, which both are partially funded with European money, could delay the funding and thereby the construction of ESSnuSB. The same could be the case if and when the construction of the two orders of magnitude more costly FCC project would be decided. In such a situation it will be important to have the collective support of EU and the European research ministries for promoting a uniquely precise neutrino long-baseline experiment *in Europe* making measurements at the Particle Physics Intensity Frontier as a complementary to the measurements to be made at CERN. We are currently eagerly waiting for a sign of new physics beyond the Standard Model. The discovery in 1998 at the Intensity Frontier of that the neutrino has mass has increased the expectations that new physics will appear in the neutrino sector at the Intensity Frontier.

13.2 Identify the risks (scientific, technological, political, financial, research security, etc.) that your RI could face in the different phases and describe your mitigation strategies to tackle them: (maximum 3000 characters with spacing).

The political and financial risks were already discussed in section 13.1. As to the scientific and technological risks, these are not so much related to what new measurements and possibly discoveries by other experiments that can be made before ESSnuSB has gathered a sufficient amount of data to deliver its high precision results.

However there may be a risk of appearance of unexpected technological problems in increasing the power of the ESS linac, in the operation of the ESSnuSB specific high-power targets, in the operation of the ESSnuSB Monitored Neutrino Beam or nuSTORM and in the excavation and stabilisation of the very large underground caverns that will house the ESSnuSB Far Detectors. One possible mitigation action would be to somewhat decrease the beam power below 5 MW and/or to diminish somewhat the dimensions of the underground caverns to be excavated, both of which will somewhat decrease the precision in the measurements of the neutrino oscillation parameters, in particular the CP violation phase angle. Given the close to factor 3 higher sensitivity in the latter, the result obtained after such a decrease could still be of significantly higher precision than those of the other experiments.

13.3 From the risks identified in 13.2., describe more specifically the main risks that could delay, increase costs of or make the realisation of your RI impossible (maximum 1000 characters with spacing)

The main risks for delays or for decreased performance are already discussed in sections 13.1 and 13.2. Although the risks that could make the realisation of ESSnuSB impossible are small, they cannot be excluded. These risks are not of scientific nature but of economical and political nature. Excessive increases in the costs of European research infrastructures, also outside particle physics, that are already under construction could be so large, or the general political and economic situation in Europe could worsen so much, that it will be impossible to argue for investment in new research infrastructures by the time such investments will have to be negotiated as from 2030 with the European research ministries for ESSnuSB.

13.4 If available, upload a technical options analysis: (upload with limit 1 MB, maximum 30 pages).

Certain options for mitigating primarily technological risks have already been discussed in section 13.2.