# Contribution aux exercices de prospective nationale 2020-2030

## *Accélérateurs et instrumentation associée*

## ESSnuSB (European spallation source neutrino super beam)

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## Informations générales

**Titre : European Spallation Source Neutrino Super Beam**

**Acronyme :** *ESSnuSB*

**Résumé** *(max. 600 caractères espaces compris)*

The goal of the ESSnuSB (European Spallation Source neutrino Super Beam) project is to discover and measure neutrino CP violation with unprecedented sensitivity. The construction in Europe of the European Spallation Source, ESS, the world's most intense proton source, with a beam power which is significantly higher than any other accelerator can deliver (5 MW) represents an outstanding opportunity for such project to take place.

***Préciser le domaine de recherche*** *(plusieurs choix possibles)*

- *Physique des accélérateurs (nouveaux concepts machines, optique et dynamique des faisceaux…)*
- *Sources de particules (électrons, positrons, muons, protons, ions lourds stables, ions radioactifs…) et cibles associées*
- *Supraconductivité accélérateur (aimants fort champ, cavités SRF…)*
- *Accélération plasma (électrons, ions…) et interaction lasers/faisceaux*
- *Technologies RF innovantes (structures haut gradients, alimentations RF…)*
- *Diagnostics faisceau, instrumentation et contrôle intelligent*
- *Développement durable de la discipline (infrastructures technologiques, efficacité énergétique, fiabilité…)*
- *Autre R&D spécifique : (préciser)*

***Préciser la motivation principale visée par la contribution :***

- *Accélérateurs pour la physique nucléaire*
- *Accélérateurs pour la physique des particules*
- *Accélérateurs pour les sources de lumière ou de neutrons*
- *Accélérateurs pour les applications sociétales (santé, énergie, industrie…)*
- *Autre : (préciser)*

# 1. Description des objectifs scientifiques et techniques
## *(2 pages max incl. figures)*

*Décrire les objectifs scientifiques et/ou techniques de la contribution proposée en en précisant les motivations.*
*Préciser comment ces objectifs se situent par rapport à l'état de l'art et au contexte international (ex : est-ce une contribution visant un développement théorique ou expérimental ? Est-elle dans la continuité de concepts ou technologies actuelles, ou bien est-ce une nouvelle approche conceptuelle ? )*
*Préciser les liens éventuels avec d'autres projets nationaux ou internationaux existants ou envisagés.*

## 1.1 OBJECTIVES

### 1.1.1 THE PRECISION MEASUREMENT OF THE CP VIOLATING ANGLE

The implications of the discovery and precise measurement of the CP violating parameter $\delta_{CP}$ are far reaching, leading to the inference that neutrino interactions may in fact be responsible for that a small residual fraction of matter survived the massive annihilation of the matter and antimatter created in the Big Bang, a residual that is what presently makes up the matter of the Universe. The neutrino may also have played a crucial role in the birth and evolution of the Universe itself, in view of its enormous abundance. An understanding of the contribution of neutrinos in these areas requires precise measurements of the parameters governing neutrino oscillations, in particular $\delta_{CP}$.

A measurement of $\delta_{CP}$ could also imply the discovery of a completely new source of CP violation. The quark mixing matrix provides a consistent description of the quark CP violation amount observed so far, which can be encoded in the reduced Jarlskog invariant $J = (3.0 \pm 0.2)\cdot 10^{-5}$. This value has been shown to be far too small to account for the observed Baryon Asymmetry of the Universe (BAU). The recent measurement of $\theta_{13}$ indicates that the corresponding quantity in the neutrino sector $J=0.3\cdot\sin\delta_{CP}$ is potentially four orders of magnitude larger. A measurement of $\delta_{CP}$ could thus, as already discussed, provide very illuminating information on the origin of the BAU.

### 1.1.2 THE MEASUREMENT OF SUPERNOVA NEUTRINOS AND SEARCH FOR PROTON DECAY

The MEMPHYS detector, which will be used for CP violation observation using the ESS neutrino Super Beam, can also be used simultaneously for astroparticle physics. In 1987, 12 neutrinos emitted from a supernova explosion in the Large Magellan Cloud near our galaxy were detected by the Kamiokande detector. Such detection helps to understand the supernova explosion mechanism. With its 500 kton large fiducial mass, the MEMPHYS detector will record about $5\text{x}10^4$ neutrinos from a supernova explosion at 10 kiloparsec distance in our galaxy which would provide very detailed and highly interesting information on the mechanism of the explosion.

The MEMPHYS detector can also be used for proton lifetime measurements. Proton decay is not allowed by the Standard Model (SM). On the other hand, Grand Unified Theories (GUT) predict proton decay. Its discovery would once again reveal the existence of a more fundamental theory beyond the SM. The present lower limit of the half-life for the decay $p\rightarrow\pi^0e^+$ is $1.6\text{x}10^{34}$ years set by Super-Kamiokande employing the same Water Cherenkov detector technique as ESSnuSB is planning to use, but with a detector volume 20 times smaller than MEMPHYS. If the proton life-time is below $10^{35}$ years, then proton decays would be observed after 10 years of data taking with MEMPHYS. If not, on the other hand, no proton decays would be observed, this would impose a stringent limit on GUT.

## 1.2 METHODOLOGY

### 1.2.1 THE ESS LINAC UPGRADE REQUIRED TO DELIVER A 2X5 MW BEAM

In order to achieve a sufficiently intense neutrino beam a proton beam of about 5 MW average power will be required. The ESS linac will be used to accelerate protons to the energy of 2 GeV in 2.86 ms long pulses at 14 Hz pulse frequency to be used for spallation neutron production. The low duty cycle of 4% of the ESS linac makes it possible to accelerate additional pulses of $H^-$ ions, interleaved with the proton pulses, to be used for the proposed production of a uniquely high-intensity neutrino beam.

The modifications that will have to be undertaken to increase the ESS linac power from 5 MW to 10 MW, have been studied by F. Gerigk and E. Montesinos and documented in a CERN report[1]. The conclusion of the authors is that "*no show stoppers have been identified for a possible future addition of the capability of a 5 MW $H^-$ beam to the 5 MW $H^+$ beam of the ESS linac built as presently foreseen*." The proposed modifications are studied now in more detail by the current Design Study.

### 1.2.2 THE DEVELOPMENT OF AN ACCUMULATOR RING

The very high current (350 kA) pulse needed in the hadron collector (magnetic horn) that focuses the produced pions in the forward direction causes a high heat dissipation in the thin walls of the hadron collector. The flat top of the current pulse can for this reason not be longer than the order of a few µs. The 2.86 ms length of the pulses from the ESS linac will therefore be compressed by about three orders of magnitude to about 1.3 µs using a 400 m circumference accumulator ring.

As a first step in the design of this ring, the magnetic lattice of the accumulator ring of the US Spallation Neutron Source (SNS) in Oak Ridge, USA, has been adapted to the higher energy of the ESS beam, using simulations to study different $H^-$ stripping schemes and the accumulator beam stability including space charge effects. The beam transfer line from the linac to the accumulator, the multi-turn injection, including the $H^-$ stripping system and the extraction kicker for single turn ejection, will be developed.

Spallation neutron users of the ESS have expressed a keen interest in having pulses significantly shorter than 2.86 ms, like 100 µs long pulses. Such pulse could be achieved with the proposed accumulator ring using slow extraction, an option that will be included in the present Design Study. The synergy between the two uses opens up the perspective of sharing the investment and operation costs for the $H^-$ beam and the accumulator with the neutron users.

### 1.2.3 THE TARGET STATION FOR A 5 MW PROTON BEAM FOR NEUTRINO PRODUCTION

The Target Station includes the proton target itself, the hadron collector, the decay tunnel and the beam dump. The design of a target for neutrino production capable of withstanding the heat load of a 5 MW beam seems not feasible. In order to reduce the heat-load there will be four targets, which will be hit in sequence by the proton pulses, thereby reducing the beam power hitting each target to 1.25 MW. Following the EUROv studies, a packed bed of titanium spheres cooled with helium gas has become the baseline design for a Super Beam based on a 2-5 GeV proton beam with a power of up to 1.3 MW per target.

The Target Station includes a ca 25 m long decay tunnel and a beam dump. Particular care will be taken in the design of these elements to preserve a possible future utilisation of muons produced at the same time as the neutrinos for other facilities such as low-energy nuSTORM, a Neutrino Factory and/or a muon collider R&D.

### 1.2.4 THE NEAR AND FAR DETECTORS

A Near Detector located in the beam a few hundred meters downstream from the target station is required to monitor the neutrino flux, to measure neutrino cross sections and to study background channels. For ESSνSB the study of cross sections will be particularly important as there are till now very few such measurements for the relatively low neutrino energies 0.2-0.6 GeV of the ESSνSB beam. The relatively high beam flux of the ESSνSB beam at the level of the Near Detector will make high statistics measurement of the neutrino cross-sections feasible.

The Far Detector shall detect and identify the $\nu_\mu$ and, in particular, the $\nu_e$ and provide a measurement of their energy with an as large as possible fiducial target mass. The starting point for the ESSνSB Far Detector design is the detailed MEMPHYS detector designed and evaluated by the EUROν and LAGUNA EU projects. This detector has 500 kt fiducial mass divided up on two cylindrical detector volumes, 65 m in diameter and 100 m high.

## Développements associés, calendrier et budget indicatifs *(1 page max. incl. figures)*

*Préciser les travaux envisagés pour mener à bien les objectifs décrits (étude conceptuelle, expérience, prototypage, construction…) ainsi que les résultats espérés et leur échéance, en précisant si possible les partenaires potentiels.*
*Si possible, évaluer grossièrement l'ordre de grandeur du financement nécessaire pour mener le développement envisagé (coût complet, en distinguant équipements, consommables et ressources humaines).*

ESSnuSB is led by IPHC/CNRS and is currently supported by the COST Action CA15139 "Combining forces for a novel European facility for neutrino-antineutrino symmetry-violation discovery" (EuroNuNet).

In 2017, it was positively evaluated by the TIARA council and received funding for a 4-year Design Study the following year from the European Union's Horizon 2020 research and innovation programme under grant agreement No 777419.

A Preparatory phase is aimed to start after this Design Study from 2022 (Fig.1). Several European institutes have already shown their interest in contributing to the next phases of the project: University of Uppsala, ESS, CERN, INFN, AGH…

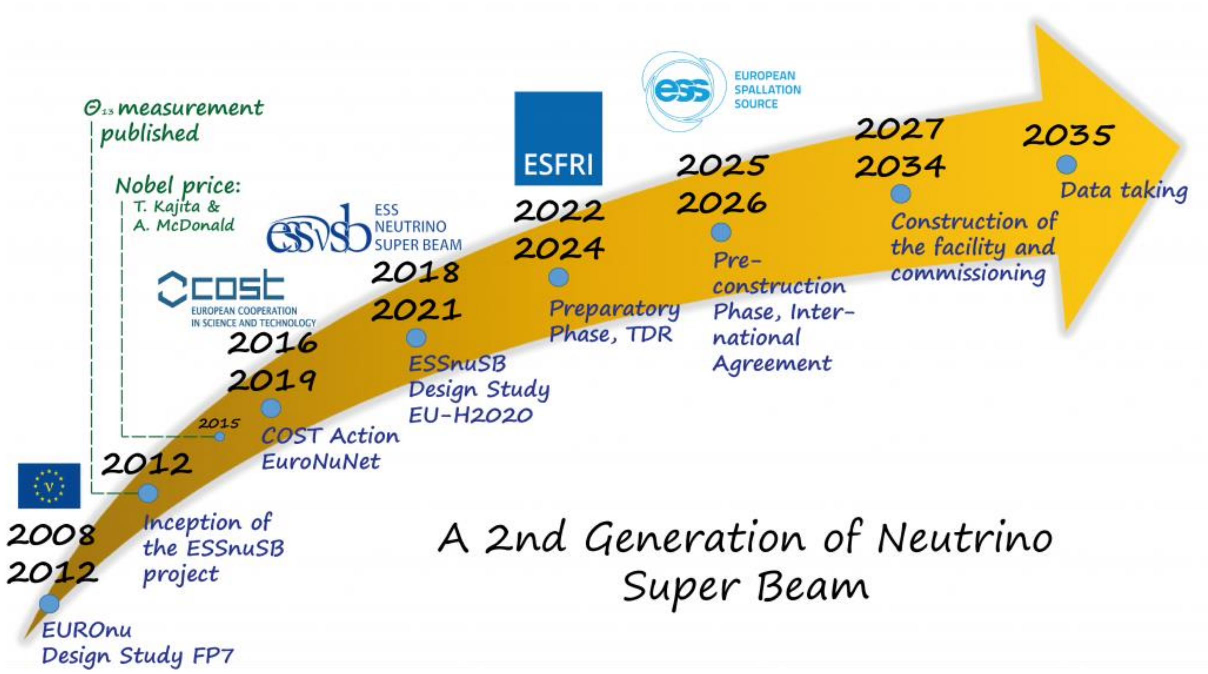


Figure 1: ESSnuSB Timeline

## 2. Impact
*(0.5 page max.)*

*Décrire les retombées espérées pour le développement de futures installations de recherche basées sur des accélérateurs ou pour d'autres applications sociétales.*
*Le cas échéant, préciser les partenariats industriels envisageables.*

### 2.1 Comparison with other initiatives and impact on particle physics research

In the USA, the LBNF/DUNE project using a large Liquid Argon detector has been proposed and some initial funding has been approved. The upgrade of the Fermilab accelerator complex above 1 MW and the use of extremely large (tens of kilotons scale) Liquid Argon neutrino detector modules represents significant technical risks. Conditionally, in Japan, the T2HK project based on the use of an upgrade J-PARC proton driver and a megaton Water Cherenkov detector, is proposed as a continuation of the T2K experiment. This project is now about to be approved. Also, for this project it is not sure that the necessary proton beam power will be reached.

Both DUNE and T2HK have their far neutrino detectors placed at the first neutrino oscillation maximum and will therefore have to reach a systematic uncertainties level of order 2-3 % (a real challenge) in order to have a significant coverage for the discovery of CP violation. ESSvSB, having its detector located at the second oscillation maximum where the signal is three times more pronounced than at the first maximum, systematic uncertainties on the signal of the order of 5% will suffice (T2K, after 10 years data taking has reached systematic errors of the order of 6-7%). **Erreur ! Source du renvoi introuvable.** shows clearly that the ESS Neutrino Super Beam has a higher physics performance for CP violation discovery and measurement than the previously proposed projects, although ESSvSB has not been yet optimised as it's the case of the two other projects. Irrespectively of how the American and the Japanese projects will progress, with ESSvSB Europe will thus be in a position to propose a very competitive project with high potentiality.

By 2020 the CERN Council Strategy Group will make a new assessment of the future of European Particle Physics. By that time, the Higgs boson will have been explored with more precision. However, if there will have been no new particles or other new phenomena discovered at LHC by 2020 it will be even more important to explore the potentiality of neutrino physics to discover further evidence of new physics. It is therefore of paramount interest that a plan in the form of a Conceptual Design Report for a European accelerator-based neutrino project exists at that time.

The ESSvSB project would, when realised, be an implementation of a multi-national infrastructure on a topic under the CERN Council's coordination responsibility, located outside the CERN laboratory campus, to the benefit of High Energy Physics and the European Research Area. The accumulated experience and expertise of the CERN laboratory will clearly represent an important asset for the project.

## Références


- A Very Intense Neutrino Super Beam Experiment for Leptonic CP Violation Discovery based on the European Spallation Source Linac, Nuclear Physics B, Vol 885, Aug 2014, 127-149, http://dx.doi.org/10.1016/j.nuclphysbps.2015.09.278
- ESsnuSB website, https://essnusb.eu/about-us/