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**THE EURONu PROJECT: A HIGH INTENSITY NEUTRINO  
OSCILLATION FACILITY IN EUROPE**

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EURONu is a European Commission funded FP7 Design Study investigating three possible options for a future high intensity neutrino oscillation facility in Europe. These options are a CERN to Fréjus Super-Beam, a Neutrino Factory and a Beta Beam. The aims of the project are to undertake the crucial R&D on each of the accelerator facilities and determine their performance and relative cost, including the baseline detectors for each facility. A comparison will then be made and the results reported to the CERN Council as part of the CERN Strategy Review.



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## INTRODUCTION

EURO $\nu$  is a Design Study within the European Commission Seventh Framework Programme, Research Infrastructures. It is investigating the three possible options for a future, high intensity neutrino oscillation facilities in Europe. The aim is compare the physics performance and cost of the facilities and present the results to the appropriate decision making bodies in Europe, in particular the CERN council. The work is being undertaken by the EURO $\nu$  consortium, consisting of 15 partners and a further 15 associate partners [1]. The project started on 1<sup>st</sup> of September 2008 and is due to finish on 30<sup>th</sup> of August 2012. The status of the work so far is described in the following sections. As well as looking at the accelerator facilities, EURO $\nu$  is also determining the performance and cost of the baseline detectors and the physics reach of each facility.

## THE SUPER BEAM

A Super Beam creates neutrinos by impinging a high power proton beam onto a target and focussing the pions produced towards a far detector using a magnetic horn. The neutrino beam comes from the pion decay (Fig. 1). EURO $\nu$  is studying the CERN to Fréjus Super Beam, using the High Power Superconducting Proton Linac (HP-SPL) [2] as the proton driver, producing a 4 MW beam. The baseline is 130 km and the planned far detector is the 440 kT fiducial mass MEMPHYS water Cherenkov detector [3]. The main activities have been proton beam optimization, designing and testing candidate targets and magnetic horns and determining the characteristics of the resulting neutrino beam for physics simulations.

Given the difficulty in producing a target and horn able to work in a 4 MW beam, the option taken in EURO $\nu$  is to use results from existing targets such as CNGS and T2K by employing four targets and horns, rather than one. The beam will be steered on to each target in turn, so that they

all run at 12.5 rather than 50 Hz. The baseline design for the target is a pebble bed, consisting of 3 mm diameter spheres of titanium or beryllium in a canister. These are cooled by flowing helium gas through vents in the canister. Offline tests of the cooling, using a coil to heat the target, are planned. A test target will also be subjected to a beam of the correct energy density using the HiRadMat facility in CERN.

The horns have been designed based on the existing MiniBooNE horn. They will need to be pulsed at least 300 kA resulting in significant heating from both the current and the beam corresponding to a maximum of 12 kW on the surface closest to the target. Modelling suggests that this can be removed with sufficient cooling. The thermal stresses in the target material are 18 MPa maximum: prototype tests will be required to determine what the lifetime will be due to fatigue and radiation damage. Finally, a prototype pulsing circuit has been designed and will be built and tested.

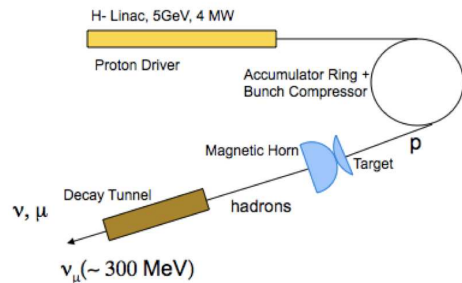


Figure 1: Layout of the CERN to Fréjus Super Beam.

## THE BETA BEAM

Production of (anti-)neutrinos from beta decay of radioactive isotopes circulating in a race track shaped storage ring was proposed in 2002 [4]. Beta Beams produce pure  $\nu_e$  or  $\bar{\nu}_e$  beams, depending on whether the accelerated isotope is a  $\beta^+$  or a  $\beta^-$  emitter. The “Beta Beam facility” is based on CERN’s infrastructure and the fact that some existing accelerators can be re-used will reduce the cost, though it will constrain the performance (see Fig. 2). The isotope pair that was first studied for neutrino production, and is now the baseline, is  $^6\text{He}$  and  $^{18}\text{Ne}$ , accelerated to  $\gamma = 100$  in the SPS and stored in the Decay Ring [5]. The lack of available isotope production for one of the isotopes,  $^{18}\text{Ne}$ , is one of the main issues to solve within the EURO $\nu$  program and is being addressed in two ways. One is the

use of a production ring (12 m circumference) with an internal gas jet target [6] to make  ${}^8\text{Li}$  and  ${}^8\text{B}$ . A 25 MeV beam of  ${}^7\text{Li}$  and  ${}^6\text{B}$  is injected over a gas jet target of  $\text{d}$  or  ${}^3\text{He}$ , respectively. The associated research tasks (cross section measurements for the reactions and the device for collection of the produced isotopes) are presently analyzing experimental data. Studies show that the required target gas-flow would be very challenging. As a result, research on a novel  ${}^{18}\text{Ne}$ -production method, using a molten salt loop (NaF) by the reaction  ${}^{19}\text{F}(p,2n){}^{18}\text{Ne}$ , is currently being undertaken.

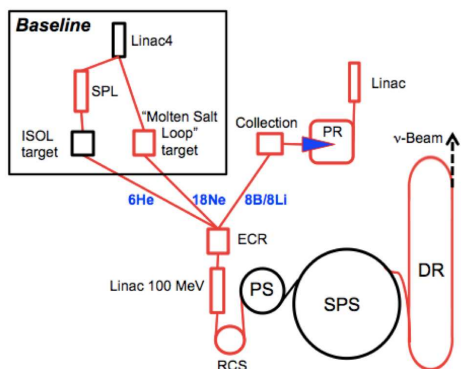


Figure 2: Layout of the CERN Beta Beam.

Research and development of a 60 GHz pulsed ECR source are continuing within EURO $\nu$ , and successful magnetic tests will be followed by tests with the gyrotron. Compatibility and possible integration of Beta Beams in the upgrade program for LHC is essential and is closely followed. Requirements to have very short and intense bunches in the Decay Ring (due to signal/noise in the detector) favours beam instabilities for which solutions will be found by re-optimizing the bunch structure over the accelerator cycle.

The baseline isotopes could use the MEMPHYS detector [3]. For the  ${}^8\text{Li}$  and  ${}^8\text{B}$  option a detector some 700 km away would be needed.

## THE NEUTRINO FACTORY

In a Neutrino Factory, the neutrinos are produced from the decay of muons in a storage ring. The muons are produced by impinging a 4 MW proton beam on to a heavy metal target and focussing the pions produced in to a decay channel using a super-conducting solenoid. The muons from the pion decay are captured, bunched, phase rotated and finally cooled in the muon front-end, before being accelerated using a linac, two re-circulating linear accelerators (RLAs) and a non-scaling Fixed Field Alternating Gradient accelerator (ns-FFAG) to 0.9 GeV, 3.6 GeV, 12.6 GeV and 25 GeV, respectively (see Fig. 3). The muons are then injected in to two storage rings, to produce beams of neutrinos and anti-neutrinos to two far detectors.

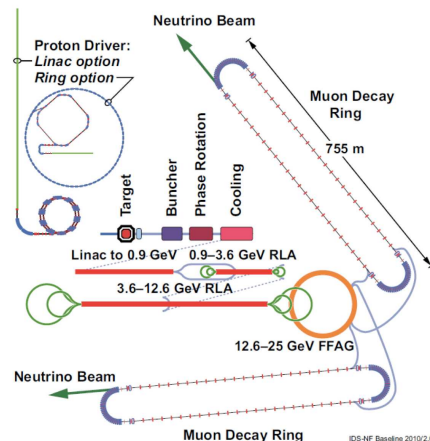


Figure 3: Layout of the Neutrino Factory

The work in this project is being done in close collaboration with the International Design Study for a Neutrino Factory (IDS-NF) [7]. However, EURO $\nu$  is focussing on the section from the pion production target to the muon acceleration system. The baseline target is a liquid mercury jet, but the calculated heat load in the first super-conducting solenoid is too big, around 50 kW. As a result, solid targets with lower atomic number, which meet the tensile strength, high enough melting point and resistance to radiation damage requirements are now under consideration.

A related issue is the transmission of secondaries in to the muon front-end. As well as the required large flux of muons, there are also still many protons, pions and electrons. The front-end is being re-designed in EURO $\nu$  to include a chicane to remove the unwanted particles in a controlled way. In the baseline cooling channel, the RF cavities are in a large magnetic field. Measurements suggest this could limit the accelerating gradient. Alternative cooling lattices are considered that reduce the magnetic field at the cavities, while maintaining the same performance.

The design of the acceleration system is well-advanced, though full 6-D tracking still needs to be done. For the ns-FFAG, a proof-of-principle machine called EMMA [8] has been constructed and recently demonstrated that many of the novel features of the muon accelerator, in particular serpentine acceleration and multiple resonance crossings. The full EMMA experimental programme is now starting.

## DETECTORS

The focus of EURO $\nu$  is on the accelerator facilities. Nevertheless, to make a genuine comparison between physics performance and cost, it is also important to include the neutrino detectors in the study. Thus, the project includes the baseline detectors for each facility, with the aim of determining their performance in detecting neutrinos and the cost of construction.

The baseline for the Neutrino Factory are Magne-

tised Iron Neutrino Detectors (MIND). These are iron-scintillator calorimeters, with alternating planes of 3 cm thick iron and 2 cm thick solid scintillator. Two detectors are planned, one of 100 kT at 2000-4000 km and a second of 50 kT at 7500 km. Each detector will have a transverse size of around 15 by 15 m. The baseline for both the Super Beam and Beta Beam facilities is the MEMPHYS detector [3] in the Fréjus tunnel. This will be a 440 kT fiducial mass water Cherenkov detector. Near detectors are also being investigated for all three facilities.

## EURO $\nu$ PHYSICS

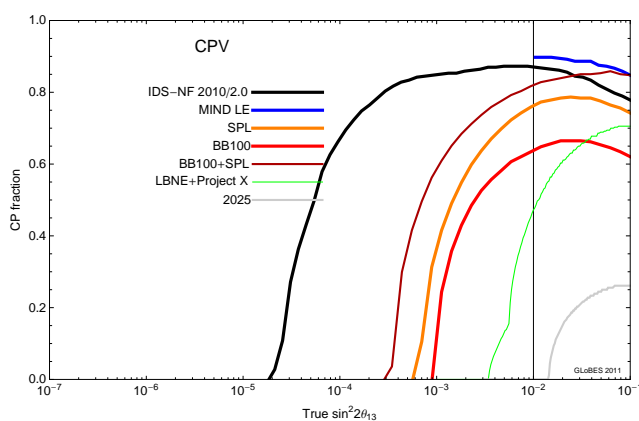


Figure 4: Physics reach comparison, courtesy P. Huber

The physics group in EURO $\nu$  determines the physics reach of each facility and combination of facilities using the parameters provided for the accelerators and detectors. They also assess and include the corresponding systematic errors in a uniform way and optimize performance based on information from other experiments. Recent indication of a difference between neutrinos and anti-neutrinos in Mini-BooNE and MINOS [9] and an indication from T2K that  $\theta_{13}$  is large, with a best fit value of  $\sin^2(2\theta_{13})$  of 0.11 [10] has been included.

A recent comparison in sensitivity to CP-violation for a number of facilities, including the three studied in EURO $\nu$  and the combination of the Super Beam and Beta Beam, are shown in Fig. 4. It should be noted that these are with standard parameters and an optimisation is likely to be required for all three facilities if  $\theta_{13}$  does turn out to be large.

## COSTING AND SAFETY

The EURO $\nu$  comparative costing is based on the three facilities being located at CERN using similar assumptions and a common costing tool produced by CERN. This is all being overseen by a costing panel. To complement this, major safety aspects and technical risks are assessed. As only limited resources are available, the emphasis in costing is to achieve the best relative precision between the facilities. The same principle is being applied for the safety

assessment. It will use existing experience, where that exists. The technical risks will be assessed by the facilities at the end of the Design Study.

## OUTLOOK

EURO $\nu$  is completing its third year out of four. Due to its important nature, it will be playing a leading role in the preparation of a single input to the CERN Strategy Review for Particle Physics [11] for future neutrino oscillation facilities in Europe over the next year. Further, there is a desire to continue EURO $\nu$  after the completion of the Design Study and discussions are taking place to determine how to do this.

If it is confirmed that  $\theta_{13}$  is large, this will have an important influence over which of the facilities will be the most attractive to build. The Neutrino Factory has the best sensitivity to CP-violation, for example, at small values, but this is less clear at large values, where it is likely that systematic errors will be the limiting factor. A study within EURO $\nu$  will be required to optimize the parameters of the facilities and to assess the corresponding systematic errors to allow a comparison. It is likely that the Super Beam will have the smallest cost and the Neutrino Factory the largest, though this has to be confirmed. While the Beta Beam is unique to CERN, there is much interest in Super Beams in Japan and the US, as well as at CERN. In addition, the Super Beam requires a 4 MW target, which will be a challenge on the CERN site, while the Beta Beam does not. It is possible to conclude from this discussion that if  $\theta_{13}$  is large, there is a case for increased studies of the Beta Beam option at CERN.

## ACKNOWLEDGMENTS

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