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Beta beam R&D status

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EURISOL (European Isotope Separation On-Line Radioactive Ion Beam Facility) Design Study is a Project funded by the Europeean Community (EC) within the 6th Framework Programme (FP6). The "EURISOL Beta Beam design study" is part of the EURISOL study. The four year duration of FP6 is coming to an end in 2009. New funding has been allocated to beta beam studies within the European Commission Framework Programme 7 (FP7), "A High Intensity Neutrino Oscillation Facility for Europe". In the beta beam task of this collaborative project, different accelerator and target setups to produce neutrinos will be evaluated for an optimal production of neutrinos for physics.

The present study is based on the acceleration of ^{6}He and ^{18}Ne ions to produce the neutrino beam using the existing CERN infrastructure for acceleration of the ions. The ion production needed for the physics experiments could not, up to now, be reasonably satisfied. Very encouraging research shows ways to overcome the shortfall in production. Studies of alternative beta emitters, ^{8}Li and ^{8}B, with properties interesting for physics reach will be in focus. New promising production methods have been proposed for these ions, for example a small storage ring where the beam traverses a target, creating the ^{8}Li and ^{8}B isotopes that will be collected and further accelerated.

Considerable efforts have been put into radiation safety aspects and equipment protection and will continue throughout the FP7 programme. Greenfield beta beams are of interest for comparison.

In this paper we present the status of the work achieved and an overview of ongoing and planned activities to make the beta beam project a solid proposal for neutrino production within the EUROnu project.

Keywords: Beta Beams, Neutrino Physics

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[1] Speaker

1. Introduction

The beta-beam concept for the generation of an electron (anti-)neutrino beam was proposed by Piero Zucchelli (CERN) in 2002 [1]. A first study of the possibility of using the existing CERN machines for the acceleration for radioactive ions to a relativistic gamma of roughly 100, for later storage in a new decay ring of about 7 km circumference, was made in the same year [2]. In 2004 it was decided to incorporate a design study for the CERN based beta-beam facility within the EURISOL DS proposal within the 6th European Framework Programme. EURISOL is a project name for a next-generation radioactive beam facility based on the ISOL method for the production of intense radioactive beams for nuclear physics, astrophysics and other applications. The proposal was accepted with the beta-beam task as an integral part. The four year design study officially started in 2005 and is now entering the phase of editing a conceptual design report for a beta-beam facility.

The design is based on the assumption that the beta emitters chosen for this application, ^{6}He and ^{18}Ne, can be produced in sufficient quantities to satisfy the needs for physics. To complement the study, research and experimentation is needed to get realistic rates for production of the chosen species. In addition, in depth studies of all security issues related to the intrinsic losses of the child ions in beam pipes, magnets, absorber systems and dumps are needed. The deployment of superconducting magnet technology implies special requirements on the heat that can be deposited in magnet coils from decaying ions. Material resistance in the accelerator equipment has to be evaluated. Alternative ion species, ^{8}Li and ^{8}B, for different physics reach and interesting production methods, have been proposed and will be studied. The continuation of the work is now supported within the EUROnu part of the 7th European Framework Programme.

In this presentation we will describe the status of the work on the EURISOL beta beam facility and bridge over to the imminent continuation of the R&D and the development within the EUROnu framework.

2. The EURISOL beta beam facility

The study is based on the CERN infrastructure which means that we will use the ISOL facility foreseen for radioactive ion production, the PS (or a possible replacement for the now 60 year old Proton Synchrotron, the PS) and the SPS in the acceleration chain. A new source and a new LINAC for bunching and first acceleration, an RCS and the final ring for production, the Decay Ring, will have to be implemented. See Figure 1. The ion species chosen for (anti-) neutrino production are ^{6}He and ^{18}Ne based on their decay times, decay products and availability.

The relativistic gamma of the decay ring is 100 for both species; this is based on the requests and optimization from the physics community and on the possible gamma values reachable with the existing machines.

Important is also the fact that we can, commonly with other experiments, use a Mton water Cherenkov detector housed in the Frejus tunnel, situated 130 km from the CERN.

The optimised parameter set assumes the same stored ions, but at $\gamma = 350$, illuminating a 500 kT water Cherenkov at a baseline of 730 km. Using other ions with higher Q-values may allow this alternative within the baseline option.

The required annual neutrino rate is $2.9{\cdot}10^{18}$ anti-neutrinos from ^{6}He and $1.1{\cdot}10^{18}$ neutrinos from ^{18}Ne.

The EURISOL study will be used as a baseline scenario for our future studies; the performances with the ion species ^{8}Li and ^{8}B, produced in a dedicated production ring as proposed within FP7 (high Q-value beta beams), will be studied using the same baseline for reference.

So called "greenfield" beta beams, where other infrastructures than what will exist at CERN, will also be looked at within the collaborative FP7 project [3]. More options exist: low energy beta beams (Lorentz gamma < 20) and monochromatic electron capture beta beams may also be of interest for physics [4].

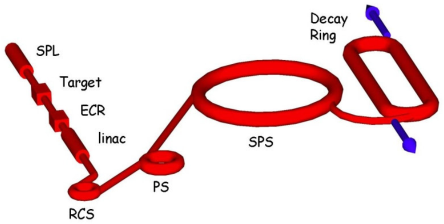

Figure 1: The EURISOL Beta Beam Scenario based on the CERN infrastructure.

2.1 The ion production

The present production limits for the ions can be summarized as below, using present simulations and limited experiments:

- *ISOL method at 1-2 GeV (200 kW),* studied within the EURISOL program
  - $>1{\cdot}10^{13}$ ^{6}He per second
  - $<8{\cdot}10^{11}$ ^{18}Ne per second

- *Direct production,* presently studied at LLN, Soreq, WI and GANIL[1]
  - $>1{\cdot}10^{13}$ ^{6}He per second
  - $1{\cdot}10^{13}$ ^{18}Ne per second

We see that to achieve the ion production rates that correspond to the required annual neutrino rates, $2{\cdot}10^{13}$ ions/s from ^{6}He and $2{\cdot}10^{13}$ ions/s from ^{18}Ne, needs continued research. New results for production have been presented and related work will be continued in the context of the FP7.

Converter technology, i.e. the use of neutrons produced on a primary, water cooled, W/Pb spallation target, is an alternative to direct irradiation of for example BeO. The heat transfer and efficient cooling of the converter target heated by the beam, allows in this case higher power

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[1] GANIL (Grand Accelerateur National d´Ions Lourds, common laboratory DSM/CEA-IN2P3/CNRS, France), LLN (Louvain la Neuve, Belgium), CRC (Centre de Recherche du Cyclotron, Louvain la Neuve), Soreq Nuclear Research Center (Israeli Nuclear Energy Commission, Israel),WI (Weizmann Institute of Science, Israel)

compared to irradiation of insulating BeO. Using projection of measured cross sections, ^{6}He production rate is ~2·10^{13} ions/s (dc) for ~200 kW on target [5][6].

To produce 1·10^{13} ^{18}Ne/s could be possible with a beam power of 2MW (~130mA of a15 MeV ^{3}He beam) on a 60 cm diameter MgO target. The extraction efficiencies, the optimum beam energy, target cooling, the high intensity ion source and LINAC are subjects for ongoing studies [12].

The reactions ^{9}Be(n,α)^{6}He, ^{11}B(n,α)^{8}Li have been studied using a 2 mA, 40 MeV deuteron beam on a two stage target setup [7]. The upper limit for the ^{6}He production rate is ~6·10^{13} atoms per second.

3. The Production Ring

A new concept of ion production has been proposed by C. Rubbia, et al. [8], see Figure 2. ^{7}Li and ^{6}Li are injected into a storage ring, the “production ring”. This setup should allow to produce 1·10^{14} ^{8}Li /s and >1·10^{13} ^{8}B/s from ^{7}Li and ^{6}Li on a gas target and a stripper from the reactions ^{7}Li(d,p)^{8}Li and ^{6}Li(He,n)^{8}B.

In the production scenario described in [8] a wedge shaped gas target is used in a dispersive region of the ring which adds longitudinal cooling as particles with higher energy can be made to pass through a thicker part of the target compared to those that have lower energy. The straggling and energy loss at each passage is compensated for by the RF system and a net beam cooling is expected. A gas target permits high beam power on the target. The produced ions are collected with a second target consisting of e.g. tantalum foils contained in a box with a hole through the centre in which the circulating beam can pass the target without interacting with the foils. A Fixed Field Alternating Gradient (FFAG) accelerator with large longitudinal acceptance can be used to manage the beam without any longitudinal cooling [9]. For both machines the beam is injected partially stripped and the energy of the circulating ions is kept high enough to ensure that the beam is fully stripped after target traversal.

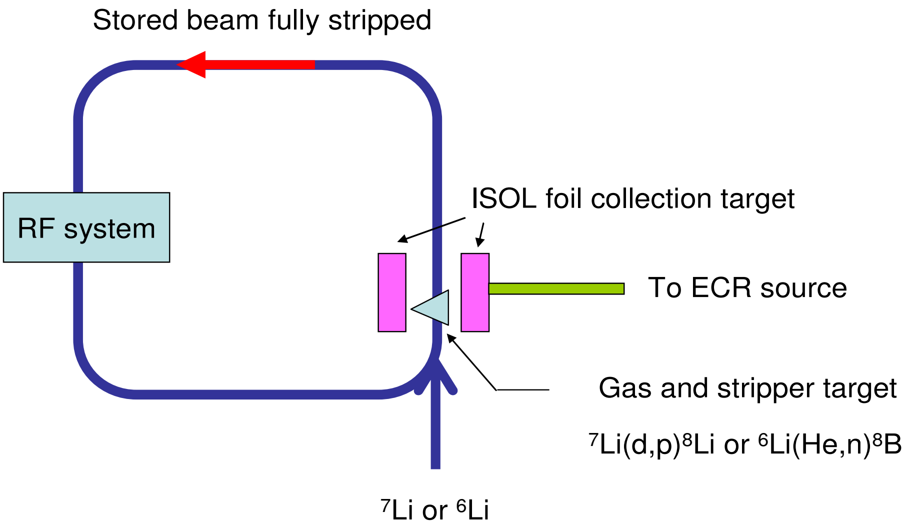

Figure 2: Basic configuration of the ^{8}Li- and ^{8}B-Production Ring proposed by C. Rubbia et al.

The cooling efficiency [10] and the reactivity of B with the foil material are points that need special attention. The generation of a pulsed ion beam in a 60 GHz ECR source is studies at present [11].

A large proportion of beam particles (^{6}Li) will be scattered into the collection device. The scattered primary beam intensity could be up to a factor of 100 larger than the produced radioactive ion beam intensity within 5-13 degrees using a Rutherford scattering approximation for the scattered primary beam particles [12]. The ^{8}B with the energy of 12 MeV±4 MeV ions are produced in a cone of 13 degrees using 20 MeV 6Li ions (~30% variation).

4. Decay products: safety and equipment protection

Radiation safety for staff making interventions and maintenance at the target, bunching stage, accelerators and decay ring are of outmost importance and this subject requires thorough attention. 88% of 18Ne and 75% of 6He ions are lost between source and injection into the Decay Ring for the present beta beam scenario. Detailed studies on RCS shielding (4.5 m concrete), airborne activity (in tunnel/released in environment) and residual dose have shown that safety requirements are respected [13]. The PS is heavily activated (bunched beam during 1 s flat bottom). For the present layout of the PS we have preliminary results showing that the situation can be handled and that damage on magnet coil insulation can be mastered by shielding systems [14]. Safe collimation in the decay ring during stacking and dumping of decayed ions, where ~1 MJ beam energy/cycle injected has to be removed, see Figure 3, is ongoing [15][16][17].

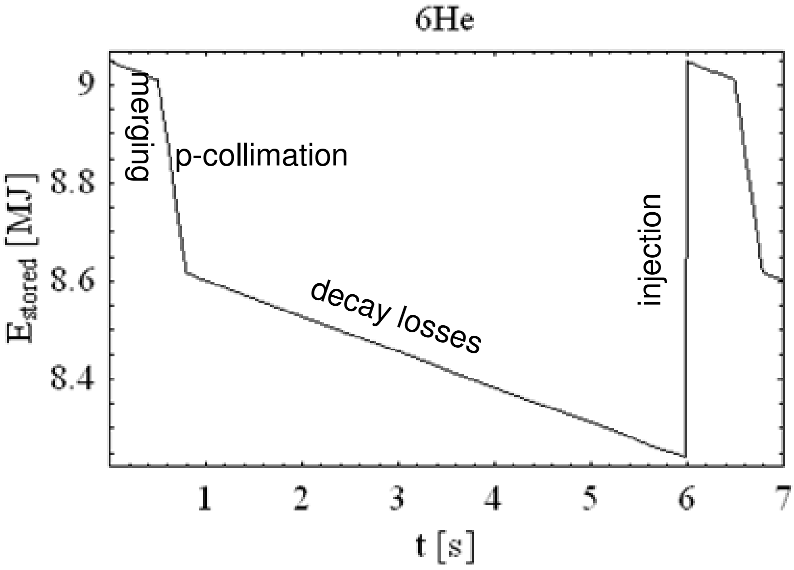

Figure 3: Illustration of the distribution of the losses in the decay ring for the He cycle

Heat deposition studies for the superconducting magnets in the decay ring [18] have shown that an open mid-plane magnet design would be needed to safely operate those magnets [19]; in Figure 4 the sharp energy distribution in the mid-plane of the decay ring dipole is illustrated.

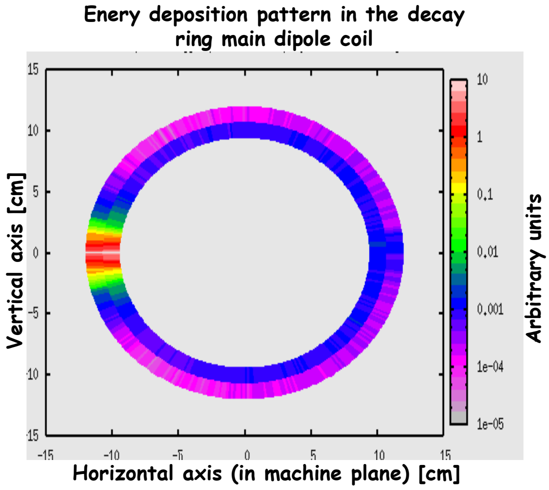

Figure 4: Illustration of the sharp distribution of the deposited energy in the decay ring dipole coil for He ions (transverse cut, projection over the whole magnet).

Studies on dynamic vacuum in the PS will be studied in more detail for the layout of a new CERN PS machine that is presently under study. Tritium and Sodium production in the ground water around the decay ring needs to be studied in more detail [20]. Important for doing this is to know the construction site of the decay ring (geological conditions and water contents).

5. Further improvements

The EURISOL beta-beam study is aiming for a production of 10^{18} (anti-)neutrinos per year. Can this production be increased to10^{19} (anti-)neutrinos per year? This can only be clarified by detailed and site specific studies of ion production, bunching, radiation protection issues including studies on cooling down times for interventions tritium and sodium production in ground water.

Multiple charge state acceleration in the LINAC [21] will improve the number of ions injected in the RCS by accelerating several selected charge states of the produced ions, extracted from the source.

The low duty cycle needed due to the background of atmospheric neutrinos in the detector and the low number of efficient stacking cycles in the decay ring (see Figure 5) can be overcome by using other ion species, for example ^{8}Li and ^{8}B and permit increase longitudinal bunch size, which will make the bunch shortening and the resulting losses at momentum collimation not necessary.

The long ramping time of the PS can be used to accumulate produced ions in an accumulation ring, for later injection [22].

Magnet R&D may give the possibility to use high field magnets to shorten the decay ring arcs and limit the decay wasted in these decay ring regions.

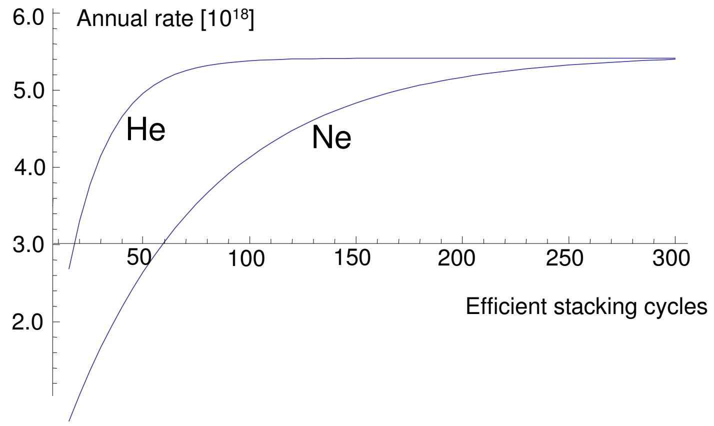

Figure 5: The dependence on annual production rate of the number of efficient stacking cycles (presently 15 for He and 20 for Ne)

6. Conclusions

The EURISOL beta-beam conceptual design report will be presented in second half of 2009 and is the first coherent study of a beta-beam facility. Results from the study made within the EURISOL programme have shown that the production of ^{6}He and ^{18}Ne ions cannot, for the time being, satisfy requirements for physics reach. Ongoing research and new proposals for ion production will therefore be integrated in the continuation of the beta beam studies within the FP7 framework. The use of new ions species, ^{8}Li and ^{8}B, may also relax the constraints for efficient ion accumulation in the decay ring and increase the duty factor for higher neutrino production rates. First results on the neutrino production from the CERN beta beam accelerator complex using ^{8}Li and ^{8}B will come from the beta beam task in the EUROnu DS (starting fall 2008).

7. Acknowledgements

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