Beta-Beams from the HERA facility at DESY

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Abstract
We present a conceptual layout of a beta-beam facility located at DESY. It makes maximal use of the existing HERA facility. For the investigation of CP violation in the neutrino sector a high intensity beam of muon neutrinos will be needed along with a beta-beam facility. The physics program requires these to be build at different sites. A location of the muon-neutrino beam at a future CERN SPL and the beta-beam facility at HERA gives an excellent solution.

1 Introduction

Within the EURISOL design study in the FP6 program a conceptual design of a beta-beam facility located at CERN has been studied. It was assumed, that radioactive ions will be produced with the isol method within a future EURISOL project at CERN. The accelerator chain includes the PS and the SPS as final acceleration before the ions are injected into a decay ring. This study was the first serious attempt to design a beta-beam facility. The exercises was extremely helpful in understanding the challenges of such a facility. To achieve the physics goals (CP violation) a high intensity beam of muon neutrinos is needed along with the beams of electron neutrinos from the beta-beam facility. The two beams should be produced at different baselines to the same detector and therefore cannot be located at the same site. For this reason we investigated different sites for the beta-beam facility. A location at DESY seems to be an excellent solution. The baseline is well within the required range. The HERA facility can be reused to accelerate the ions.

To study CP-violation in the neutrino sector one compares the oscillation probability of $\nu_e \to \nu_\mu$ with its CP conjugate $\overline{\nu}_e \to \overline{\nu}_\mu$. For T-violation one compares $\nu_e \to \nu_\mu$ with $\nu_\mu \to \nu_e$. The comparison of $\nu_e \to \nu_\mu$ against $\overline{\nu}_\mu \to \overline{\nu}_e$ tests CPT. To fully exploit these symmetries beams with two different flavors and beams of neutrinos and anti-neutrinos are needed. For the beta-beam concept $\nu_e/\overline{\nu}_e$ come from the beta-beams and $\nu_\mu/\overline{\nu}_\mu$ are produced in a conventional beam.

The neutrino beam is send from the beam facility to the detector through the crust of the earth. The propagation through the earth creates a fake CP effect. The atoms in the earth contain large numbers of electrons. The neutrinos interact with this medium elastically. This effects the oscillation probability. For ν_e the interaction is mediated by charged and neutral currents while for its anti-particle charged current is excluded. This creates an asymmetry which is proportional to the density integrated over the path to the detector. Unfortunately the density profile of the earth is not well enough known, to correct for this fake CP asymmetry. It has to be determined experimentally. For a low-energy beam one has a short optimal baseline. One should get the same true CP-asymmetry as in a high-energy beam, but the matter effect is much smaller. It is proportional to the baseline. Therefore we can separate matter effect and true CP-asymmetry by varying the baseline. We will need at least two different baselines.

2 Site Considerations

To fully exploit the physics program of a future neutrino facility we need beams of two different flavors, neutrino and anti-neutrino beams and we need two different baselines. A high intensity muon (anti-)neutrino beam can be build with minimal effort with a future SPL at CERN. A sufficient number of neutrinos can be produced with 10% of its intensity. A beam of electron (anti-)neutrinos will come from a beta-beam facility. The neutrino detector is a substantial fraction of the overall cost of the whole program. We assume that only one detector will be available. To realize two different baselines the beta-beam facility must then be located at a site different from CERN.

The CERN SPL will accelerate protons to energies between 1 and 4 GeV. With an OPERA-style target station a neutrino beam can be produced with an optimal baseline from approximately 130 km to a maximum of 600 km. The neutrino detector must be located within this range. The only location with an existing underground site in this range is the Laboratoire Souterrain de Modane in the Fréjus tunnel [1]. It is located 130 km from CERN. The beam of electron-neutrinos should then have a baseline at least twice as large. The beta-beam facility should be located at an existing accelerator laboratory. DESY is one possibility. The baseline from DESY to Fréjus is 960 km. To cover this baseline the ions need to be accelerated to a γ-factor of almost 500. The same accelerator would be capable of accelerating protons to approximately 1.4 TeV.

3 Beta-Beams at DESY

Here we present a first idea how a beta-beam facility can be build at DESY using as much as possible the existing infrastructure.

Ion source:

We adopt the idea of [2] for an ion source based on a low energy deuteron linac. A separate poster has been presented on the source and we refer to it [3].

Preaccelerator:

The ions must be accelerated from the source to ultra-relativistic energies. This is most easily achieved by a short linac followed by a rapid cycling synchrotron. The concept developed within the EURISOL design study is well-suited for DESY and we refer to it [4].

Accelerator:

In the next step the ions need to be accelerated from approximately 5 GeV to 110 GeV[1]. This can be achieved by a recycling linac based on the HERA arcs. The four straight sections of the current HERA accelerator would be replaced by TESLA-type linacs. 2 1/4 turns would be sufficient to bring the beam to 110 GeV. The arcs will run at fixed magnetic field. for the first four quarter turns the HERA electron ring can be used. A fifth quarter has to be build new. For the final four quarter turns the HERA proton ring can be used.

Decay Ring:

At approximately 110 GeV the ions are injected into an empty decay ring. This ring is partially located in the HERA tunnel on top of the existing accelerator. The HERA magnets cannot be used for this ring. The aperture is too small and they cannot be ramped fast enough. Instead a new ring has to be build. A decay section is introduced pointing to a detector in the Fréjus tunnel. Dipoles with relatively high fields are necessary to bend the beam into the decay section and out again. For 12 Tesla dipoles a straight section of 1.25 km can be achieved. For 8 Tesla it would be reduced to 850 m.

We have simulated the physics potential of this concept with respect to CP violation. Fig. 4 shows the range of the CP-violating phase δ for which CP-violation can be discovered. It depends on the still unknown mixing angle θ_{13}. The statistical power of our scenario is at least as good as that of a neutrino factory as long as θ_{13} is not too small. Systematic error have not been studied, yet.

4 Conclusion

DESY is a site well suited for a beta-beam facility. An initial layout of a facility shows that a substantial part of the HERA infrastructure might be reused. The major challenges are the ion source, the high field magnets in the decay ring and the design of an RF system. The physics case is very promising. We believe that this option should be pursued further.

[1] The energies given here are the equivalent energies a proton beam would reach in the same accelerator. The numbers correspond to ^{6}He. For $^{1}8Ne$ the requirements are somewhat reduced.

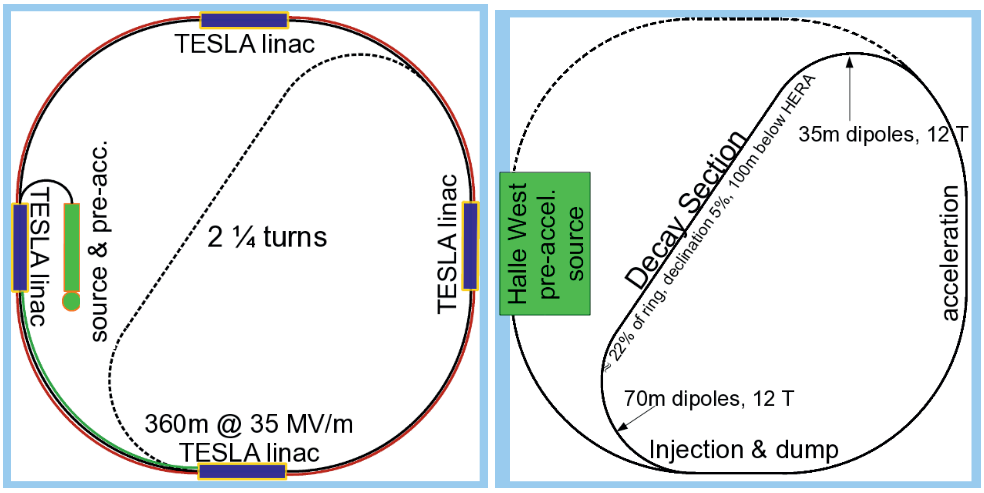

Fig. 1: Conceptional layout of a beta-beam facility in the HERA tunnel. The left plot shows the preaccelerator based on the HERA arcs. The right plot shows a decay ring with a straight section pointing to the Fréjus laboratory.

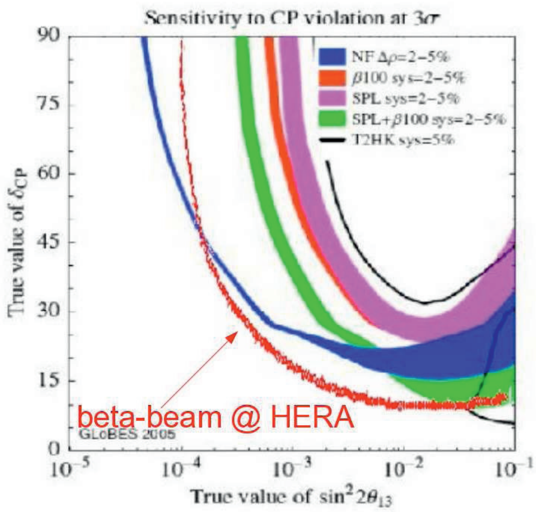

Fig. 2: Range of discovery of the CD-violating phase δ. In the parameter range above and to the right of the curves the value of the phase can be distinguished from 0 at the 3 σ level.

References

[1] See http://www-lsm.in2p3.fr/

[2] M Hass et al., *Light radio-isotopes for nuclear astrophysics and neutrino physics*, J.Phys. G: Nucl. Part. Phys., 35(1):014042, Feb 2008, http://www.iop.org/EJ/abstract/0954-3899/35/1/014042/.

[3] Markus Lauscher et al., *A He-6 Ion Source for Beta-Beam experiments*, poster presented at this workshop.

[4] See Task 12 on the EURISOL project: http://www.eurisol.org/ or directly http://www.eurisol.org/site02/beta-beam_aspects/.