PROCEEDINGS OF SCIENCE

EMuS at CSNS-II

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Experimental muon source (EMuS) at China's spallation neutron source (CSNS) is a multidisciplinary project intended mainly for μSR, muon induced x-ray emission and imaging applications, and is envisaged for muonium to antimuonium conversion physics or neutrino cross sections measurements. These goals are achieved by intense beams of surface and decay muons produced by pions decaying at rest or in flight respectively, and neutrinos. At EMuS, pions are produced when a target of graphite is interacting with a 25 kW primary proton beam provided from the rapid cycling synchrotron (RCS) of CSNS at phase-II. Two schemes of EMuS are being studied. The main scheme is called baseline and is operating in surface or decay muons modes and secondary for neutrinos. It is employing a target station with a superconducting capture solenoid and a conical target of graphite for the capture and collection of surface muons or charged pions, a long superconducting line for the transport of surface muons or the decay of charged pions, and shorter beamlines with which extracted surface or decay muons are led to μSR, muon induced x-ray emission and imaging experiments. In addition, upstream from the superconducting target station, a vertical μSR beamline of quadrupoles is foreseen to run in parallel, employing a thin slab of graphite for the production of surface muons with high polarization. The secondary scheme is called simplified and operating for surface muons and possibly for muon induced x-ray emission experiments. It is employing a conventional rotated thick slab of graphite located sideways from a quadrupole triplet collector, a dipole and a beamline of quadrupoles for the selection and transport of surface muons respectively to μSR experiments. In this proceedings, the different layouts of target stations and beamlines are discussed.

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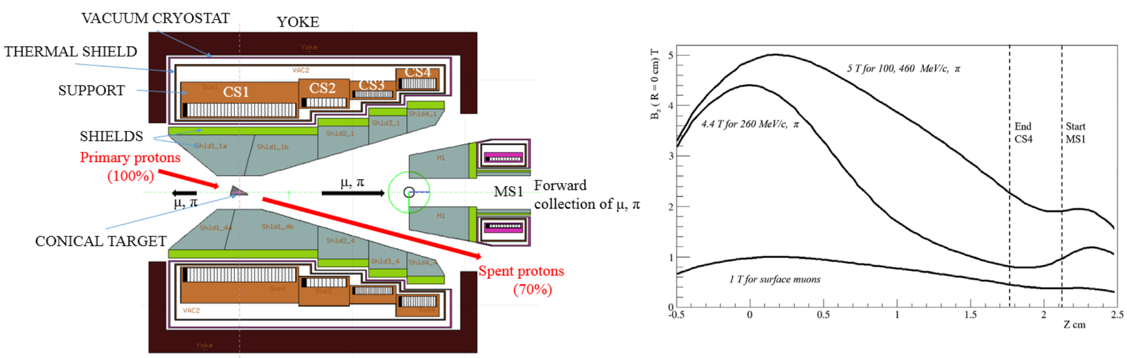
1. Introduction

EMuS was foreseen initially to take place at China Spallation Neutron Source phase-I and then at phase-II (CSNS-II) [1,2]. At CSNS-II, the total proton beam power available for the spallation target and the EMuS project is increased from 100 kW to 500 kW and from 5 kW to 25 kW, respectively. That is important because EMuS was initially studied for CSNS phase-I, and the increased power at CSNS-II forced the re-optimization of the project, due to higher muon rates and also the additional radiation at the target stations. In this article, a brief description of the two schemes of EMuS that are independent of each other, the Baseline and the Simplified ones, is presented. Especially, for the beamlines, a detailed discription is presented in [3] at NuFact21. While EMuS was foreseen to be a part of CSNS-II, an alternative study was decided to take its place during the second half of 2021. However, EMuS could be applied to any high-power proton accelerator in China, for example, at China initiative Accelerator Driven System (CiADS) [4].

2. The Baseline Scheme

The Baseline scheme has two running modes, the surface and decay muons ones. It is employing: (i) A target station with a superconducting capture solenoid and a conical target of graphite for the production and collection of surface muons and charged pions. (ii) A long superconducting line for the transport of surface muons or the decay of pions. (iii) Shorter beamlines where the extracted surface or decay muons are directed to μSR, muon induced x-ray emission and imaging experiments.



(a) (b)

Figure 1: (a) The superconducting capture solenoid, conical target and first matching solenoid as simulated in FLUKA and visualized with FLAIR. (b) The adiabatic fields produced by tuning the current of the four coils in order to optimize the capture of surface muons and pions.

2.1 The Main Target Station

Figure 1(a) shows the latest layout of the capture solenoid, the target and the first matching solenoid as simulated and visualized with FLUKA and FLAIR, respectively [5, 6]. The changes of the capture solenoid in order to operate at 25 kW are: (i) while the four coils in the stepped arrangement made of NbTi-Aluminum superconducting cable remain the same, the apertures of the coils are now higher because of the thicker shielding. (ii) New hybrid shields of tungsten with B4C endings are applied with a maximum thickness of about 43 cm at the first coil. (iii) Re-optimized adiabatic tapers with a maximum intensity at 1 T and 4.4 T or 5 T for surface muons and charged pions, respectively, as shown in Figure 1(b). (iv) The tilted by 15^0 conical target of

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graphite is shorter, its length is reduced from 30 cm to 15 cm, in order to reduce the radiation to the coils and consequently in order for them to have lifetimes of 30 years.

The target and the shielding optimizations are necessary because of the increase of power at 25 kW, the location of the conical target at the first coil, and the forward collection of particles. Also, the first matching solenoid is relocated downstream at an increased distance from the target than the 5 kW design, in order to use a thicker upstream shield and consequently in order to have a lifetime of 23 years.

The physics performance of the capture solenoid at the exit of the first matching solenoid is: (i) For the surface muon mode, 2.1×10^8 $\mu+$ / sec in total and 4.6×10^7 $\mu+$ / sec with an average polarization of 79% within a transverse emittance of 10000 π mm mrad are predicted by FLUKA. (ii) For the decay muon mode, the rates of pions ($\pi^\pm$ / sec) are predicted to be of the order of 10^{10} within a large transverse emittance of 100000 π mm mrad, making EMuS the most intense pion source worldwide. In that mode, different 4.4 T or 5 T adiabatic tapers are used in order to maximize the capture of pions with momentum of 260 MeV or 450 MeV/c respectively as presented in NuFact18 [7].

(a)

(b)

Figure 2: (a) Prototype of the conical target of graphite (Photo courtesy of Donghui Zhu / IHEP). (b) Prototype coil of a 5 T with six layers of NbTi-Al cable (Photo courtesy of Zhilong Hou and Zian Zhou / IHEP).

During the past years, a R&D program for EMuS was performed, that included the construction of prototypes for the support of the capture solenoid and conical target, and also prototypes of the conical target and a 5 T superconducting NbTi-Al magnet. Figure 2(a) shows the prototype conical target of graphite design for the 5 kW design of EMuS. The target support is assembled by three rings. The larger ring suspends the conical target by six spokes that are attached to the other two rings, and the larger ring is attached to a small plate. Figure 2(b) shows the prototype coil with 6 layers of NbTi-Al superconducting cable for the 5 T magnet. The NbTi-Al superconducting cable was fabricated in China.

2.2 The Muon Beamlines

In the surface muons mode, a muon beamline of superconducting solenoids, superferric dipoles and room temperature magnets has been designed. The momentum selection for the surface muons is done by the first selection dipole after the target station, which is tuned for 28 MeV/c. Then, the surface muons are directed to the μSR or the low energy muon areas by using a dipole magnet. In the former case, the surface muon beam is split by an electrostatic separator into three branches towards three muon spectrometers. In the decay muon mode, the selection dipole is tuned for 260 MeV or 450 MeV/c momentum for the charged pions. Then, the pions are decaying into muons along a long superconducting beamline (the trunk line). A second selection dipole is used at the end of the trunk line in order to select polarized muons and extract them towards the decay muon beamline, in which, the muons are directed into one of the (high-energy) μSR or muon induced x-ray emission or imaging experiments.

2.3 Additional Thin Target and Vertical Beamline

Upstream from the superconducting target station, a secondary target station is foreseen in order to provide surface muons with a high polarization to a vertical quadrupole triplet collector and a μSR beamline of quadrupoles on an upper floor. The target station is employing a rotated thin slab of graphite with an effective length of proton and target interaction of 1 cm. The slab can provide at the entrance of the quadrupole-triplet collector 3.84×10^6 μ+ / sec with an average polarization of 96% within a transverse emittance of 4500 π mm mrad.

3. The Simplified Scheme

The Simplified and is foreseen for μSR and possible muon induced x-ray emission experiments. It is employing a conventional rotated thick slab of graphite, with an effective length of proton and target interaction of 12 cm, which is located sideways at 90^0 from a quadrupole triplet collector. At the entrance of the collector, rates of 1.7×10^7 μ+ / sec with an average polarization of 95% within an emittance of 4500 π mm mrad are predicted by FLUKA.

After the quadrupole triplet collector, the surface muon beamline goes through an electrostatic separator and is split on the horizontal-plane into two branches, and then, along each branch surface muons are directed to two muon spectrometers by kicker magnets. A total of four muon spectrometers can operate at the same time in the Simplified scheme.

4. Summary

A high performance muon source is a very important platform for multidisciplinary research, and EMuS could be the first muon instrument in China. The EMuS project proposes two different schemes with intense muon beams, in which, μSR, muon induced x-ray emission and imaging experiments could be executed at a high-power proton accelerator facility in China.

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