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EMuS at CSNS Updated Target Studies

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In this article, the latest studies of the Experimental Muon Source (EMuS) target systems for muon production and capture are briefly presented. The EMuS is foreseen to be located at the China Spallation Neutron Source (CSNS) in Dongguan. It uses the proton driver of the neutron source and comprises of different target stations and beam lines for muons. EMuS will be a world class muon source especially competitive for muon Spin Resonance (μSR) experiments.

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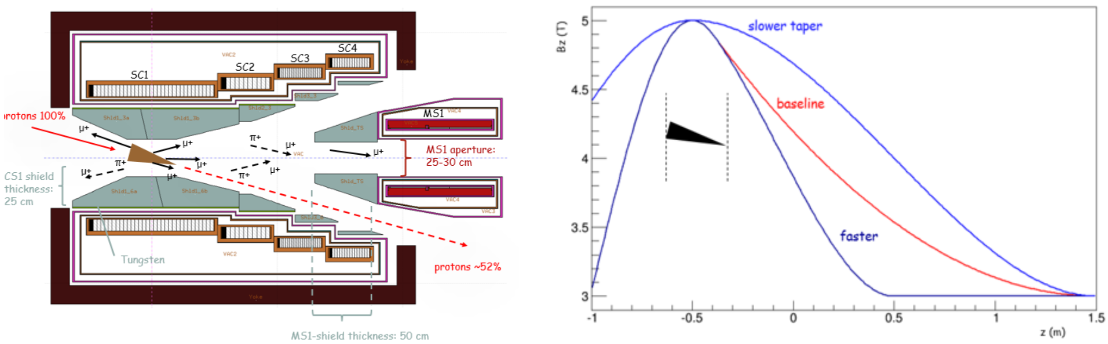

Figure 1: Left: EMuS capture solenoid as simulated in FLUKA. The four-coils/three-steps design and the matching solenoid can been seen. Right: Suggested 5 T to 3 T adiabatic tapers corresponding to "faster", "baseline" and "slower" decreases of the 5 T field.

1. EMuS at CSNS

EMuS is a newly proposed experiment in China and it is primarily intended for muon science, e.g. μSR techniques in matter physics. The EMuS ability to produce a neutrino beam is however also an option under investigation at CSNS [1, 2]. There are two muon beam schemes foreseen. The baseline scheme uses a target system composed of a superconducting solenoid with a graphite target inside the first coil. It has several independent modes: a) surface muon mode for μSR physics; b) decay muon mode, for higher energy μSR physics and muon imaging; c) an optional neutrino mode for low energy neutrino cross section measurements [3]. Downstream, pion and muon beamlines are being designed in order to allow the pions to decay into muons, and transport muons to detectors [4]. The second muon beam scheme is a conventional μSR experiment called "baby", where the surface muon capture is done by a quadrupole sideways at 90° from the proton-target interaction. The aim of the EMuS target stations is to collect a worldwide competitive number of muons for μSR applications, e.g. more than 10^6 or 10^7 μ^+/s for surface muons and higher ones for pions under selection criteria.

2. Baseline Scheme Target

The primary proton beam, with $E_{kin} = 1.6$ GeV and 5 MW power, is extracted from CSNS's rapid cycling synchrotron and is led to the target system. The superconducting capture solenoid, shown in Figure 1, has a length of 2.4 m and coils apertures from 1 m to 1.4 m. It is a unique four-coils/three-steps design with features as such as forward muon/pion capture and transportation, and spent-proton extraction. In addition, the proton beam and the target have a tilt of 15° with respect to the symmetry axis of the coils, which facilitates the extraction of spent-protons through the shielding of the capture and matching solenoids, and produces higher muon and pion rates. Furthermore, the solenoid is foreseen to operate with different adiabatic fields [5], from 1 T or 2.5 T down to 0.5 T (in surface muon mode), and from 5 T or 4.5 T down to 3 T or 2.5 T respectively (in decay muon mode) along its length, in order to capture, transport and reduce the divergences of highly polarized surface muons and pions. The target is positioned at the center of the first coil in order to maximize the particle capture and is made of graphite in order to produce

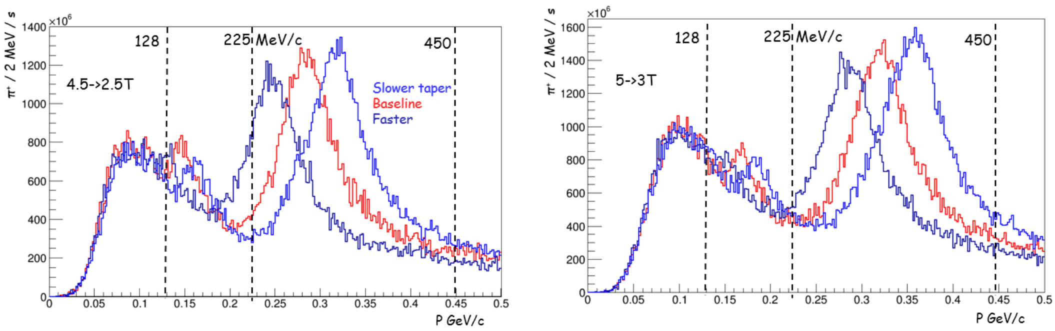

Figure 2: Momentum distributions of π^+s for different adiabatic fields values and shapes at the entrance of matching solenoid. There are three distributions in each plot, which are corresponding to a fast, baseline and slow decrease of a field as shown in Figure 1. Left: Using the 4.5 T to 2.5 T fields, pion capture at 225 MeV/c is maximized with the faster version (dark blue line) of the field. Righ: Using the 5 T to 3 T fields, pion capture at 128 and 450 MeV/c is maximized with the slower version (blue line) of the field.

low neutron radiation. It has a conical shape for higher surface muon production when compared to a cylindrical one, and has a short length of 30 *cm*. Pion production and capture are similar for both target shapes.

Surface muons rates, their polarizations and purities at the entrance of the matching solenoid are: 7×10^6 and 1.8×10^7 μ^+/s, -0.83 and -0.62, and 86% and 68% for the 1 T and 2.5 T adiabatic fields respectively. Those values are corresponding to a momentum range of $25 \leq P(MeV/c) \leq 29.8$ and emittance of 10000π *mm mrad* selections with 4% statistical errors. The rates are one order of magnitude higher without any emittance selection. Those rates are competitive worldwide while operating at such a low proton power of 5 MW, whereas the -0.83 polarization at 1 T is a unique result related to solenoidal capture [6].

Decay muons at detector are related to the pion capture and transportation from the target station. Pion momentum selection and charge separation are applied downstream of the capture and matching solenoids along the beamline [4]. For muon science and this study, π^+s with 128, 225 and 450 MeV/c within $\pm 10\%$ are required in order to produce μ^+s with central momentum of 60, 120 and 450 MeV/c respectively [7]. The pion momentum distribution at the entrance of the matching solenoid is highly related to the field shapes as shown in Figures 1 and 2. This is the result of the interaction between the helical trajectories of pions that are changing with different field shapes, and the shielding geometry of the solenoid. Therefore, the required momenta can be maximized by tuning the shapes of the adiabatic magnetic field. The π^+s rates are in order of $10^{10}\pi^+/s$ within a momentum range of $\pm$ 10% and emittance selection of 100000π *mm mrad*.

The main simulations are done using FLUKA monte-carlo [8]. Systematic differences in momentum distributions have been compared to GEANT4 [9]. FLUKA produces less or similar rates depending on the momentum range of surface muons and pions.

3. Baby Scheme Target

In the baby scheme, surface muons rates, their polarizations and purities are calculated at 90° sideways, 60 *cm* from the primary proton beam axis and proton-target interaction centre, and at a

Target $Height \times Width\ cm^2$	6x6	12x12	24x24
intensity (10^6) μ^+/s	2.9	3.3	3.4
polarization	-0.96	0.96	-0.94
surface muon purity (%)	98	97	96

Table 1: Baby scheme collection with different in size graphite target surfaces facing the collector.

target material	Gr	SiC	Be	Ti	Cu	W
intensity (10^6) μ^+/s	3.4	5.4	4.5	5.5	9.4	8.5
polarization	-0.94	0.94	-0.94	-0.94	-0.94	-0.92
surface muon purity (%)	96	96	96	96	97	96

Table 2: Baby scheme collection with different target materials.

circular surface of 16 *cm* radius. This calculation also considers an emittance of 4500π *mm mrad* that represents the collection by a quadrupole as discussed in [10]. The target is a graphite slab of $W \times H \times L = 4 \times 12 \times 12\ cm^3$, as it serves our purpose. The further enlarged dimensions of the target are not found to have improved the results due to low geometrical and angular acceptances of the quadrupole. The primary proton beam and target interaction is simulated along the length (L) of the target on the z coordinate. Best results are found with the configuration in which the dual-Gaussian proton beam spot, with $\sigma_x = \sigma_y = 0.5\ cm$, is allowed to hit the facing surface of the target, not exactly in the middle, but with the beam center placed sideways on the edge of the target surface closer to quadrupole, 0.5 *cm* inside from that edge. In this configuration, the proton beam is almost semi-interacting with the target. Tables 1 and 2 show the results for graphite targets with different surfaces, and for higher Z target materials, respectively. Results assume a momentum range $25 \leq P(MeV/c) \leq 29.8$ and emittance 4500π *mm mrad* selections with 2% statistical errors. SiC and Be targets might be considered in future. The higher Z target materials produce higher neutron rates and are not considered for our present study.

4. Conclusions

The EMuS experiment is a unique project considering μSR research due its different schemes and is competitive worldwide with similar muon experiments.

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