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DECAY MUON BEAMLINE DESIGN FOR EMUS*

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Abstract

The beamline design philosophies and simulation results of the decay muon on Experimental Muon Source (EMuS) are reported in this paper. The trunk of the beamline is mainly composed of solenoids to keep a large acceptance, and has been optimized for 45, 150 and 450 MeV/c decay muons respectively according to the π spectra optimization results from the target station. Three spectrometers are planed for decay muons, corresponding to μSR application, muon imaging and muonic application respectively. Decay muons from 45 to 150 MeV/c with polarization above 75% are designed for μSR applications, and high momentum muons up to 450 MeV/c are designed for muon imaging. Negative decay muons from 45 to 150 MeV/c are designed for muonic applications. The momentum of the decay muons is tuneable between 45 and 450 MeV/c.

INTRODUCTION

The China Spallation Neutron Source (CSNS) [1] is a multidiscipline research platform based on a high power proton beam with a kinetic energy of 1.6 GeV. The designed power is 100 kW at Phase-I, and will be upgraded to 500 kW at Phase-II. CSNS has been commissioning since March 2018, the configuration of CSNS complex is shown in Fig. 1. EMuS is proposed to build a muon source based on CSNS. To extend the application of EMuS, different running modes are designed: surface muon mode can offer surface muon for μSR (muon Spin Rotation, Relaxation and Resonance) application, also ultra-slow muon application is considered; decay muon mode can offer both positive decay muon for μSR application and negative muon for muonic application (e.g. X-ray element analysis), also high momentum pion/muon for neutrino cross-section measurement and muon imaging. Muon targets are placed upstream of the neutron target at all but one (TRIUMF/CMMS [2] is the exception) existing muon facilities (J-PARC/MUSE [3], ISIS muon source [4] and PSI/SμS [5]), which requires the high proton transmission (usually above 90%) through the muon target to guarantee the neutron yield, which put a strict restriction on material and thickness choices of the muon target. In EMuS, beam with about 5% of total CSNS proton power is extracted to produce muons, the proton power for the muon source will be 25 kW at Phase-II. After hitting the muon target, the spent proton will be extracted to the beam dump. The stand-alone muon facility makes the much longer target practical.

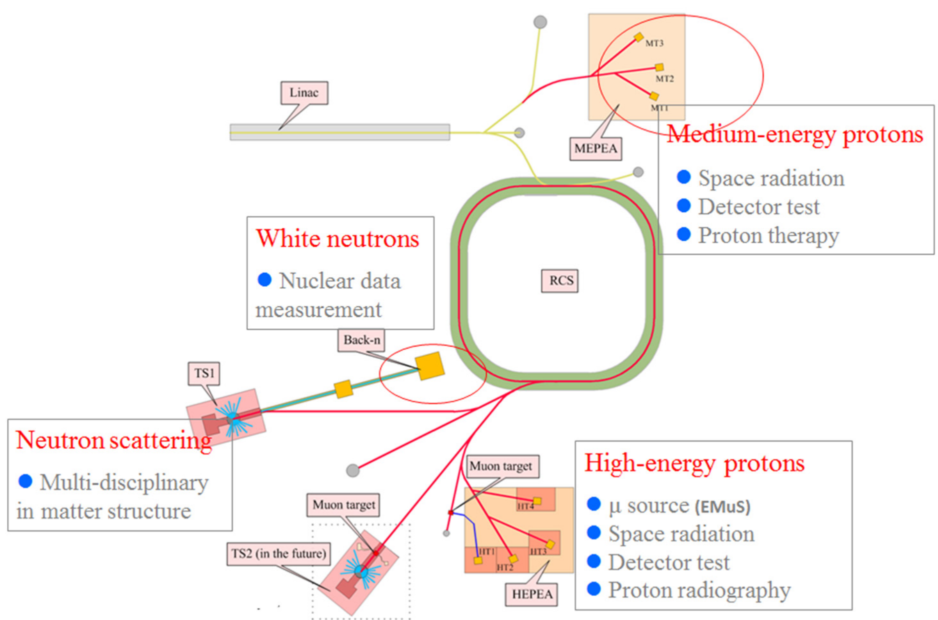

Figure 1: Layout of the CSNS and its extended beam application areas, EMuS is located in High-energy Proton Experiment Area (HEPEA).

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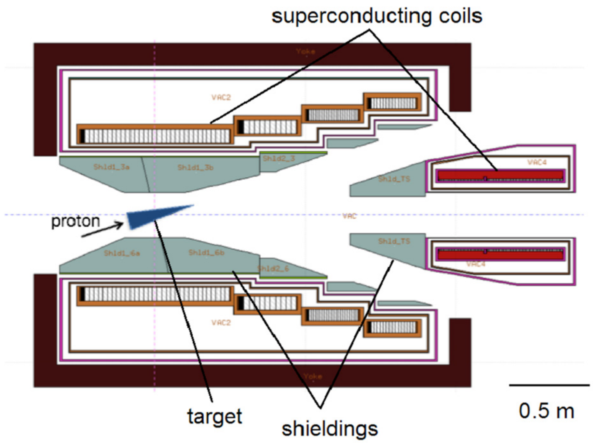


Figure 2: Layout of the target station.

A conical graphite target with a length of 300 mm and front/rear radius of 45/2.5 mm is adopted in EMuS. To improve the pion/muon capturing efficiency, the target was placed in the superconducting solenoid as shown in Fig. 2, which has been proposed in MUSIC [6] and COMET [7]. The capturing section comprises four solenoids with independent power supply, which makes sure the magnetic field is adjustable for the optimization of the collecting system for different operation modes. The surface muon mode prefers lower peak field about 1 T and decay muon mode for higher field about 5 T, so only one mode can run at one time.

BEAMLINE DESIGN AND SIMULATION

The layout of the EMuS beamline is shown in Fig. 3. Following the capturing section, a dipole with a bending angle of 30° was placed for charge selection and preliminary momentum selection, and one solenoid at each side to match the beam to downstream beamline. The long decay channel adopts periodical solenoid-focusing structure, which used for both surface and decay muon modes. Each solenoid is 500 mm long with an aperture of 300 mm, and 200 mm space is kept in between. The surface muon will be extracted from the decay channel at around 12 m from the target, and then split into three beams for μSR applications by an electrostatic separator. At the end of the decay channel, decay muon beams will be delivered to spectrometers by beamlines consisting quadrupole/dipole.

EMuS decay muon beamlines are designed to offer decay muons with momentum continuously tuneable from 45 to 150 MeV/s, which the corresponding pion momentum is from 100 to 260 MeV/c. Two sets of field map in capturing section are optimized for decay muon mode, one is for 45 MeV/c decay muon and high-momentum muon, the other is for 150 MeV/c decay muon. The optics design for beamline is divided into two parts. The first part is from the end of the capturing section to the end of the decay channel, in which the magnetic field of adjacent elements is heavily overlapped and the matrix optics is not suitable in this case. G4Beamline [8] is applied to optimize parameters of beamline elements in this part. The optics for the rest beamline is done by TRANSPORT [9].

To get high-polarized decay muon beams, narrow momentum bite pion beams are necessary [10]. By using solenoid magnets we gain in the high intensity beams, while it also brings difficulty in increasing the polarization of the beam due to large momentum acceptance. The dipole magnet with the adjacent matching solenoids helps in selecting a pion beam with narrow momentum bite into the long decay channel. Collimators are also placed before and after the dipole for momentum selection. For 45 MeV/c decay muon, the solenoids strength in decay channel can be set at the value which makes the stop-band locate around 70 MeV/c, so the transmission for both 45 MeV/c decay muon and 100 MeV/c pion will not be affected, while transmission for pion with momentum from 60 to 80 MeV/c can be reduced, then the polarization for decay muon around 45 MeV/c can reach around 75%. Setting the strength of the dipole higher than the reference momentum can restrain the transmission of low momentum beams, which helps in obtaining high-polarized decay muons.

To distribute three spectrometers practically in the hall, three dipoles are used in beamline after the decay channel, with bending angle of 60° for each one, and triplets for focusing. The envelopes of beamlines are shown in Fig. 4. Different beams can be delivered to different spectrometers by adjusting the bending direction of the last dipole. Spectrometer in 60° direction is for μSR application, 0° for muon imaging and -60° for muonic application. Collimators are placed along the beamlines for beam spot collimation.

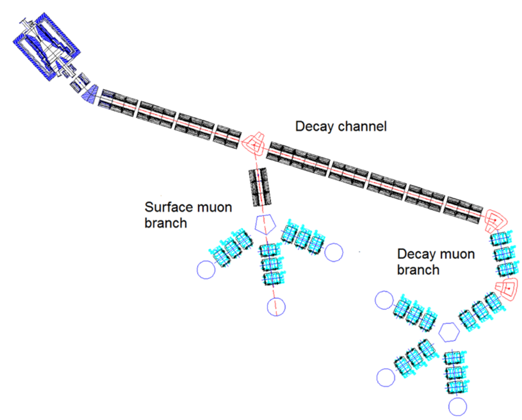
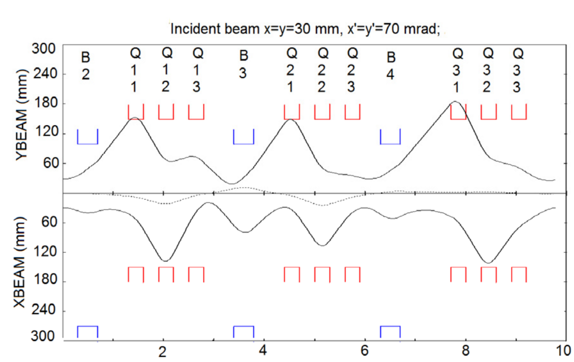


Figure 3: Layout of the EMuS beamline.



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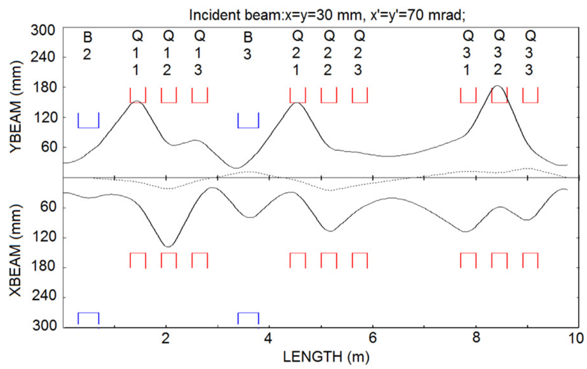

Figure 4: Beam envelopes of the beamlines after decay channel, top leading to ±60° spectrometers, and bottom to 0° spectrometer.

END-TO-END SIMULATION

Since the beamline design work has been done for each section, an End-to-end simulation is carried out to check the performance of the beamline. Following are the proton beam and target settings for End-to-end simulation:

- Proton beam: σ_x=σ_y=5.7 mm, $\sigma_{x'}$=$\sigma_{y'}$=0 mrad, 1.6 GeV, 1×10^9 POT (Proton on target).
- Conical target: L=300 mm, r_1=45 mm, r_2=2.5 mm, graphite.

The sample locates 0.6 m away from the end of the last quadruple. All intensities are calculated based on 25 kW proton power on muon target. With Full-Width-Half-Maximum (FWHM) value on x and y around 30 mm and momentum spread about 7% with respect to the reference momentum, the intensity for 45 and 150 MeV/c decay muon is 4.0×10^5/s and 5.9×10^6/s respectively, with polarization of 81% and 82%. The beam spot and momentum spectrum for 45 MeV/c is shown in Fig. 5. With the same beam spot and momentum spread selection as decay muon, the plot of intensity of negative muon as a function of muon momentum is shown in Fig. 6. For high momentum muon around 450 MeV/c, the intensity can reach 1.0×10^8/s in large beam spot.

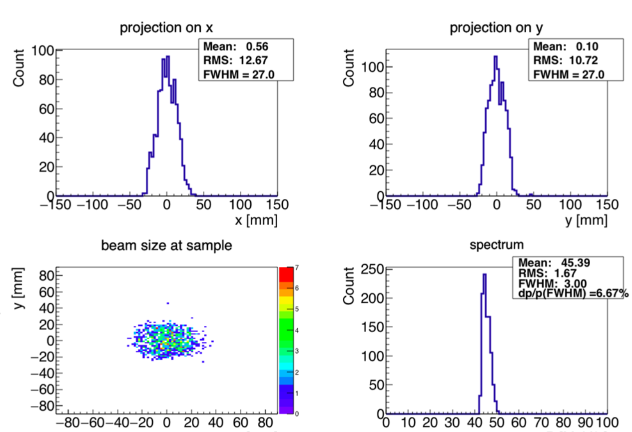

Figure 5: Decay muon beam spot and momentum distribution at sample place for 45 MeV/c.

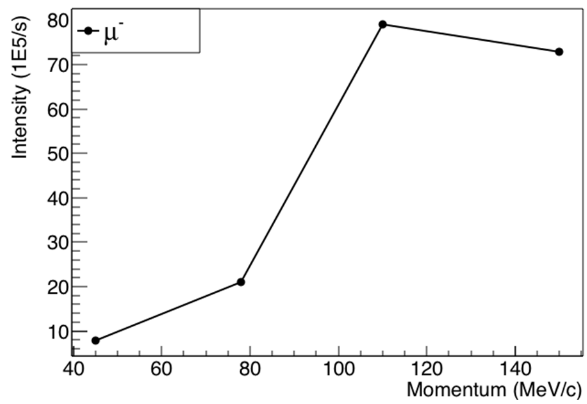

Figure 6: Negative muon intensities calculated with FWHM values on x and y around 30 mm, and momentum spread around 7%.

SUMMARY

The beamline design and multi-particle simulations for decay muon beamline of EMuS have been carried out. Compared with traditional muon sources, a stand-alone muon facility can improve the pion/muon yield and capturing efficiency by nesting long target in the superconducting solenoid. The simulation results show that the decay muon quality of EMuS fulfills the requirement for μSR application.

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