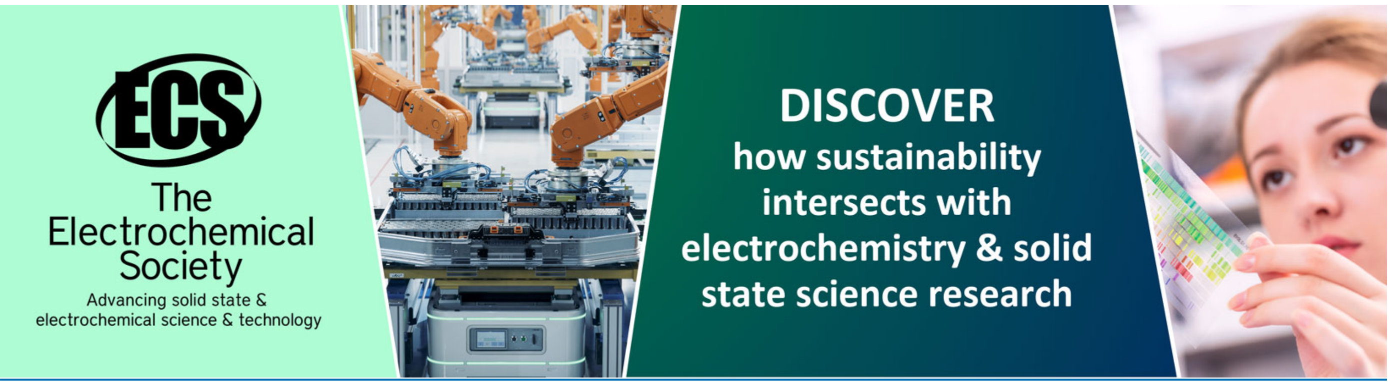
Journal of Physics: Conference Series

Beamline design of EMuS - the first Experimental Muon Source in China

To cite this article: Yu Bao *et al* 2018 *J. Phys.: Conf. Ser.* **1067** 042006



IOP Conf. Series: Journal of Physics: Conf. Series **1067** (2018) 042006 doi:10.1088/1742-6596/1067/4/042006

Beamline design of EMuS - the first Experimental Muon Source in China

Yu Bao, Jingyu Tang, Hantao Jing, Yingpeng Song, Yukai Chen, Luping Zhou, Ye Yuan, Nikos Vassilopoulos, Guang Zhao, Zhilong Hou
Institute of High Energy Physics, Beijing, China

Abstract. We report the beamline design of the Experimental Muon Source (EMuS) project in China. Based on the 1.6 GeV/100 kW proton accelerator at the Chinese Spallation Neutron Source (CSNS), EMuS will extract one bunch from every 10 double-bunch proton pulses to hit a stand-alone target sitting in a superconducting solenoid, and the secondary muons/pions are guided to the experimental area. The beamline is designed to provide both a surface muon beam and a decay muon beam, so that various experiments such as muSR applications and particle/nuclear physics experiments can be conducted. In this work we present the conceptual design and simulation of the beamlines, and discuss the future aspects of the project.

1. Introduction

Muons are elementary particles, and decay in 2.2 µs. As a charged lepton, the muon is a great tool to test the V-A structure in the weak interaction [1]. The Micheal decay of muons are used to precisely measure important constants to test the Standard Model [2]; the rare decay of muons are used in experiments to search for new physics [3].

When the muon decays it emits a fast decay positron (electron) preferentially along the direction of its spin due to the parity violating decay. Based on the Muon Spin Rotation (muSR) technique, muons are widely used in studying the electromagnetic characteristics of materials. As an exquisitely sensitive local probe, the muons can tackle fundamental problems in condensed matter physics and chemistry [4].

Muons are produced by protons hitting targets. Most of the muon facilities around the world are based on powerful proton accelerators. Muon experiments and applications have widely extended the application of proton accelerators. The Chinese Spallation Neutron Source (CSNS) at Dongguan, China hosts a 100 kW proton accelerator with a beam energy of 1.6 GeV and a repetition rate of 25 Hz [5]. As the CSNS project is completing, the construction of muon sources becomes an important expansion of the CSNS platform. The Experimental Muon Source (EMuS) project will provide both a low-energy surface muon beam and a high-energy decay muon beam. The beam momentum is tunable and covers a wide range from 30 MeV/c up to 600 MeV/c, which makes various experiments feasible at EMuS.

In this paper we report the conceptual design of the EMuS beamlines, including the target station, the surface muon beamline and the decay muon beamline. We simulate the target station and the beamlines in G4beamline [6].

2. EMuS beamline design

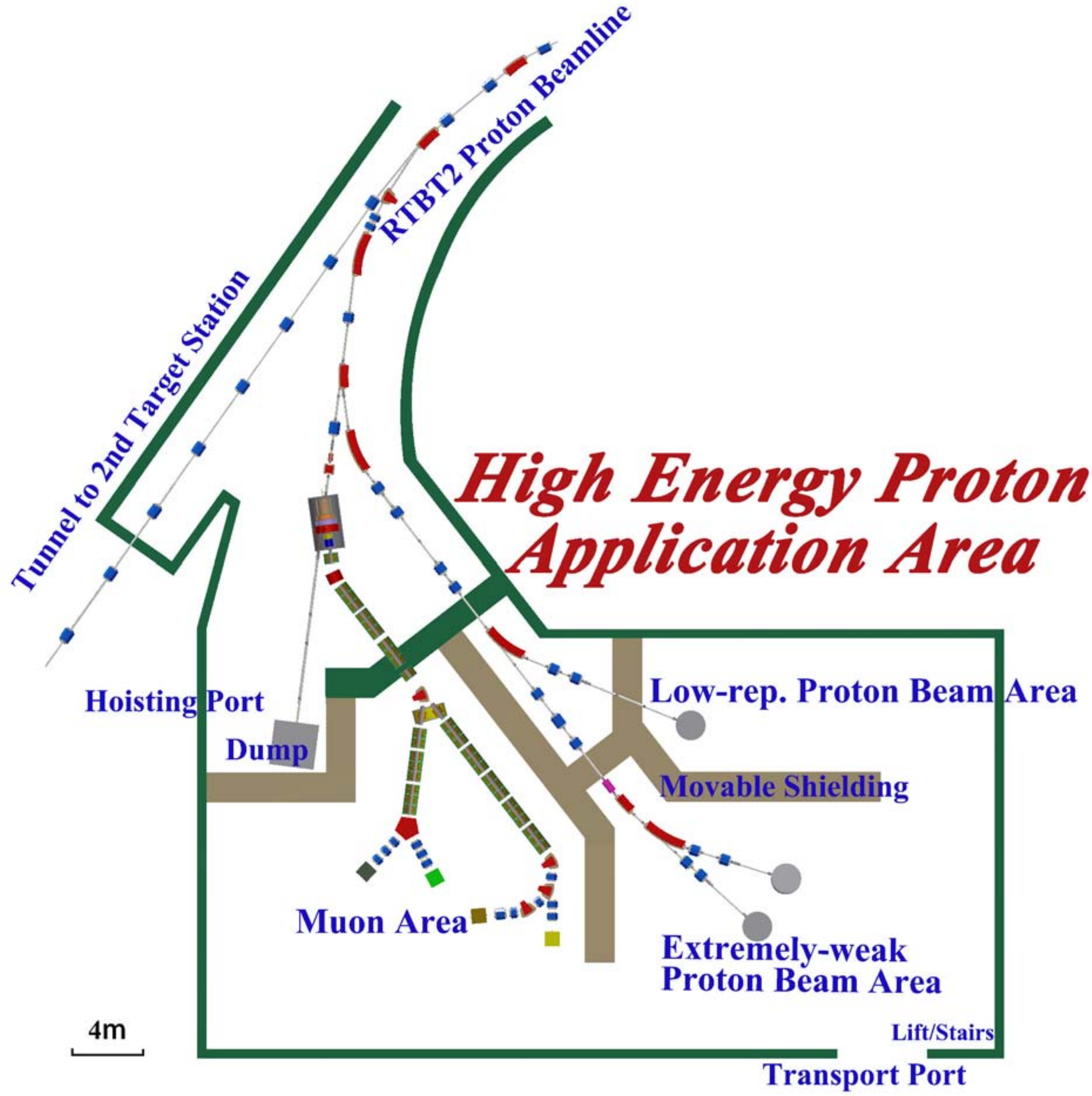


Figure 1. Schematic layout of the high-energy proton application area including the EMuS beamlines at the CSNS campus.

The proton beam has a double-parabolic bunch structure in time within each pulse. One bunch in every 10 pulses is extracted from the main proton beam and guided to the proton application area, as shown in Fig. 1. A very small fraction of the protons are used at the Low-repetition Proton Beam Area for proton radiography or extracted to Extremely-weak Proton Beam Area for detector calibration and radiation effect study. The majority of the bunch is led to hit a 30-cm long carbon target, which sits inside a superconducting solenoid with a magnetic field up to 5T. The muon beam line will work at two different modes: a low-energy surface muon mode and a high-energy decay muon mode. Depending on different experiment requirements, the beamline will be adjusted to select muons/pions with the specific energy.

2.1. Target station

The proton beam spot at the target is about 5.7 mm in rms radius. The protons are injected into the solenoid with an angle of about 16 degree, and the solenoidal field slightly changes the direction of the 1.6 GeV proton beam. The target sits at the center of the major solenoid. Various materials for the target have been investigated. Although carbon produces relatively less muons compared to high-Z materials, it produces lower radiation on the cryostat and scatters the proton beam less so that the proton beam dump is less complicated.

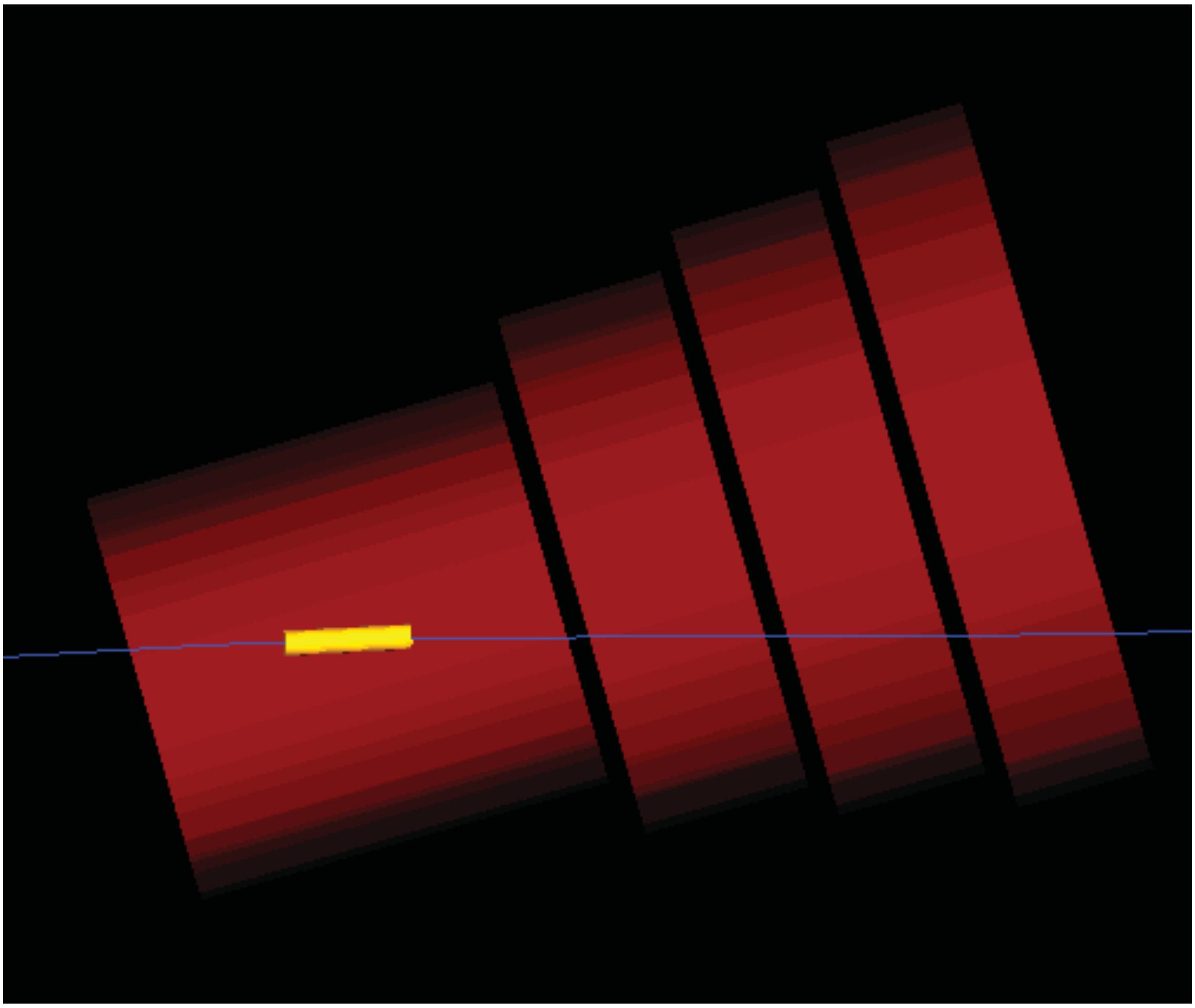


Figure 2. Schematic layout of the target station. The target (yellow) sits at the center of the first coil with an angle of 16° and the protons (blue line) hit the target and get through the target station to the downstream beam dump.

The capture solenoid (shown in Fig. 2) is a high field magnet with a graded solenoidal field varying smoothly from a high field up to 5 T to a relatively low field. The gradient is formed by 4 axial coils with increasing aperture from 800 mm to 1480 mm. This gradient forms an adiabatic tapered field to reduce the large angular spread of the muons/pions, and it is optimized for different beam momentum. The total length of the capture solenoid is about 2.5 m.

IOP Conf. Series: Journal of Physics: Conf. Series **1067** (2018) 042006 doi:10.1088/1742-6596/1067/4/042006

2.2. Surface muon beam

After the capture solenoid, two matching solenoids are used to match the beam to the straight section. A 30-degree bending dipole magnet is placed between the matching solenoids in order to select the required momentum. In order to reduce the chromatic effect, the muon beam passes the bending magnet with a large beta function, so the aperture of the dipole magnet is large.

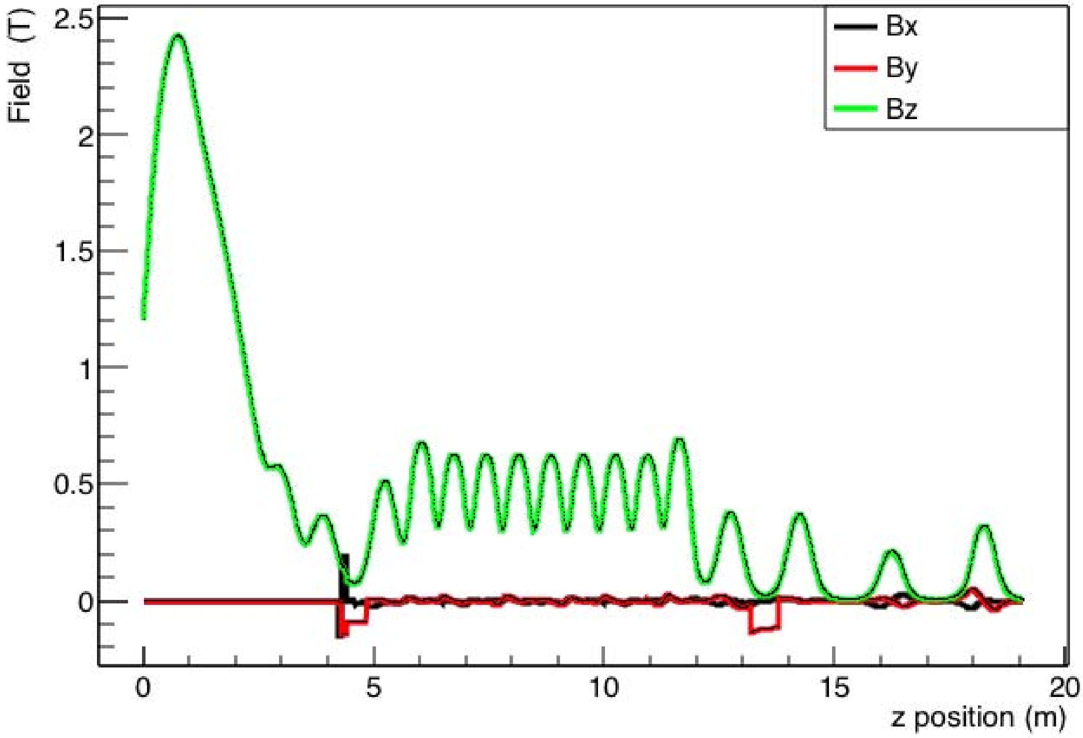


Figure 3. Magnetic field along the surface muon beamline. The green line is Bz field representing the solenoids, and the red line is By field indicating the positions of the bending magnets.

The straight section is a 5.6 m long superconducting solenoid with an aperture of 300 mm. This long solenoid consists of 8 coils with lengths of 0.5 m each, and separated by 0.2 m for vacuum vessel and thermal shielding. This straight section is shared with the high-energy decay muon beamline.

Another dipole magnet is placed after the straight channel to separate the surface muon beamline from the decay muon beamline and to guide the surface muons to the muSR application area. This dipole magnet also has a bending angle of 30 degree. Because the long straight section brings a large amount of muons with wide momentum spread, this second bending magnet also filters out the unwanted muons, especially the cloud muon that reduces the polarization of the beam.

Two matching solenoids are designed to match the beam to the final focusing section. Another two solenoids are used to focus the surface muons to the sample area.

Figure 3 shows the magnetic field along the surface muon beamline, where $z = 0$ defines as the entrance of the capture solenoid. When working in the surface muon mode, the capture solenoid is tuned to 2.5 T and optimized to reach the largest $I * Pol^2$, where I is the intensity of the muons and Pol is the polarization of the beam. The fluctuation of the magnetic field in the straight section is due to the gaps between coils. The sample area is about 0.8 m from the last focusing magnet. Shielding of the field will be designed in future works to reduce the fringe field at the sample area.

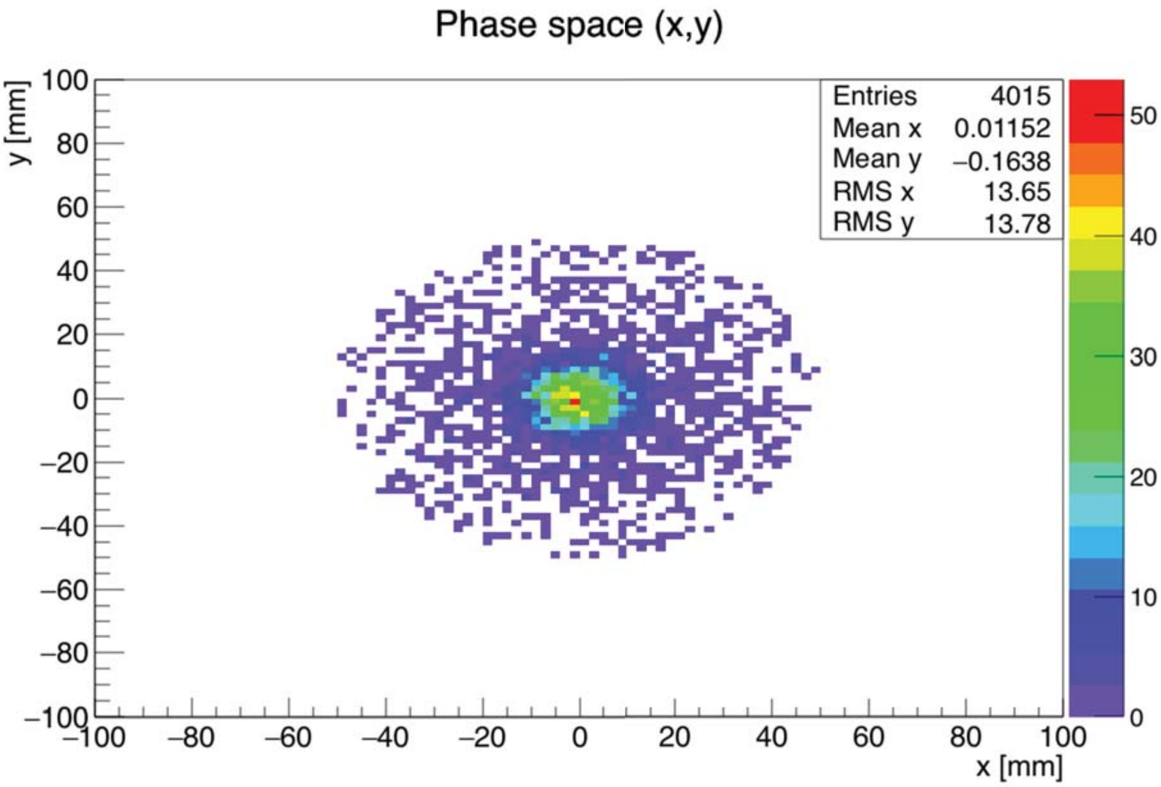


Figure 4. Beam spot at the sample area after collimating the beam by a size of 50 mm in radius.

Figure 4 shows the beam spot at the sample area. The intensity of the muons in a spot radius of 50 mm is $1.1 * 10^7/s$ based on 5 kW proton beam power, and the polarization of the beam is about 80%.

2.3. Decay muon beam

The decay muon beam provides high-energy muons for muSR applications on thick samples. It shares the same target station and part of the beamline with the surface muon beam. Instead of collecting muons, the capture solenoid is optimized to collect pions in the decay muon mode. Because of the relatively high momenta of the pions, the capture solenoid is set to 5 T when working in the decay muon mode. Figure 5 shows the pion and muon momentum distributions at the end of the collecting solenoid, which is optimized to collect pions with momentum of 230 MeV/c as an example. The spectrum covers a wide range of momentum with a large peak at 230 MeV/c, and another smaller peak around 110 MeV/c also comes along and will be filtered out in the downstream beamline.

Figure 6 shows the magnetic field along the decay muon beamline. After a selecting dipole magnet, the pions are matched to a 18 m-long straight channel with a magnetic field up to 2 T. In this straight solenoidal channel the pions decay and produce secondary muons. We then

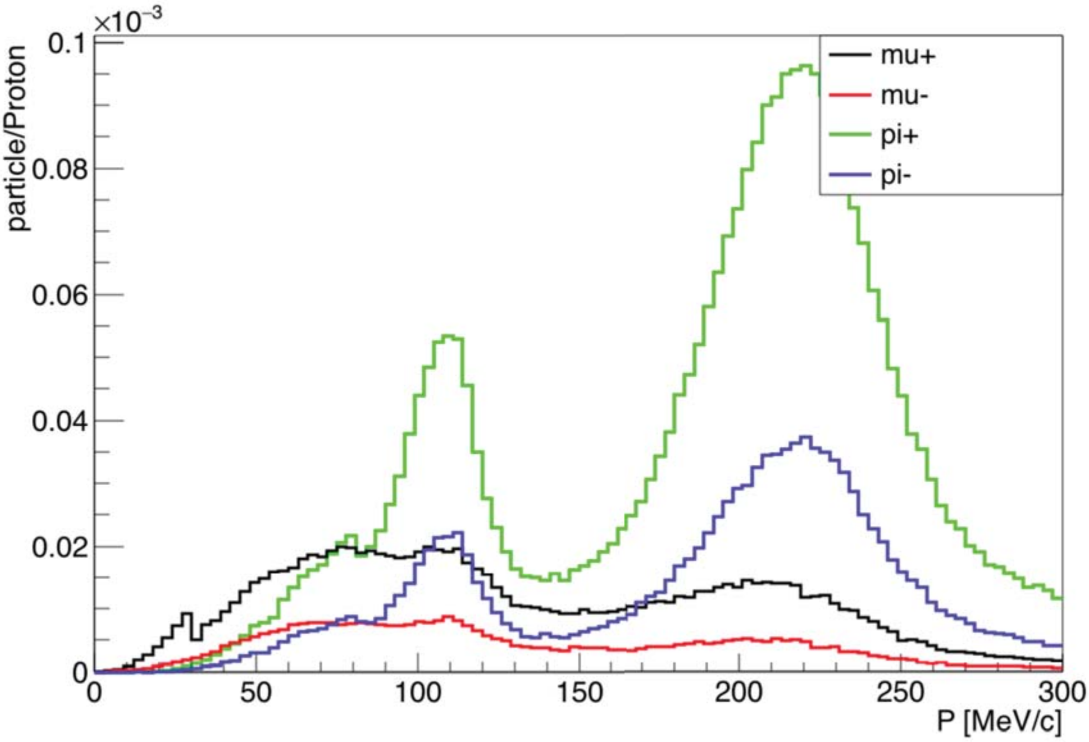


Figure 5. Momentum distributions of the muons and pions at the end of the capture solenoid. The solenoid is optimized to capture pions with momenta of 230 MeV/c.

select muons with momenta around 130 MeV/c with another bending magnet after the straight section. The muons are then focused to the sample area.

The rms width of the momentum spectrum of the decay muon beam relative to the beam momentum ($\Delta p/p$) is about 10%. The intensity of the beam can reach $10^9/s$ and the polarization of the beam is about 40%. The relatively low polarization is due to the low-energy muons coming into the strong solenoidal field. Further study will be carried out to filter out these low-energy muons.

3. Summary and future aspects

In this paper we report the status of the conceptual design of the EMuS beamline. Three groups are working on the proton beamline, the target station and the muon beamlines respectively. Both the surface muon beamline and the decay muon beamline are designed, and more details need to be studied in the future.

The polarization of both the surface muon beam and the decay muon beam is relatively low. Further study on containment of unwanted muons is needed.

Currently the positrons are not tracked in the simulations. Wien filters will be implemented into simulations to study the content of positrons in the muon beam.

As many of the muSR applications require low magnetic field, the stray field of the final focusing magnet needs to be shielded. Feasibility studies need to be carried out on magnetic field shielding.

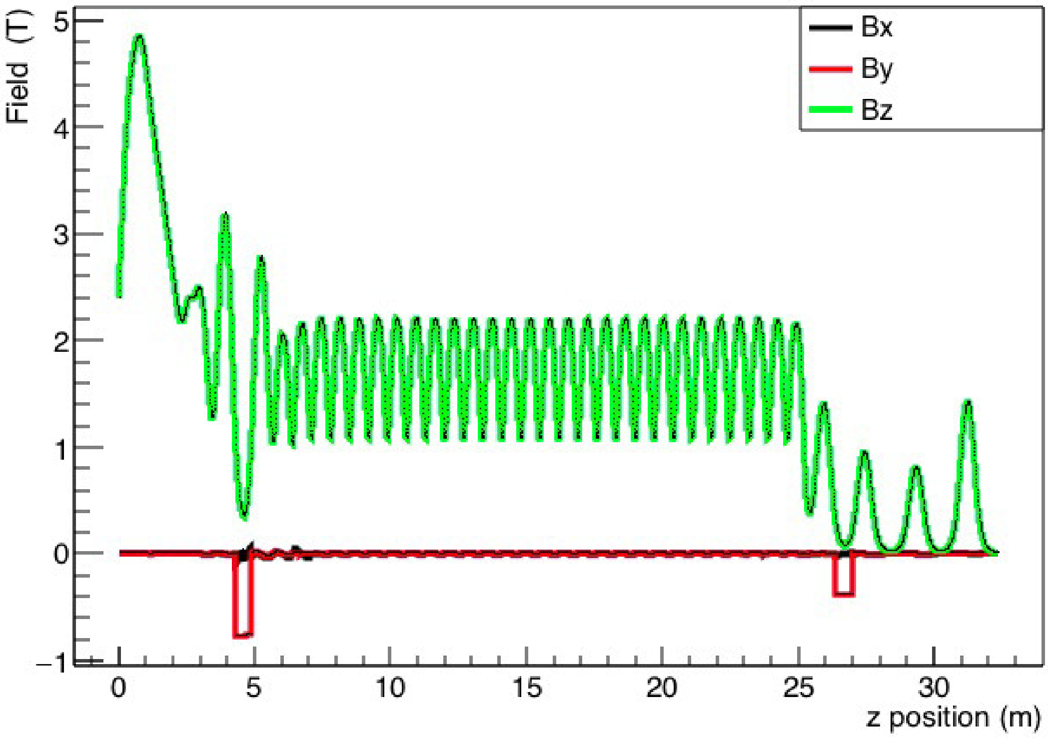


Figure 6. Magnetic field along the decay muon beamline.

4. Acknowledgement
The authors thank James Lord and Thomas Prokscha for helpful discussions on muon beamlines. This work is supported by the National Natural Science Foundation of China under Grants 11575217 and 11527811. Yu Bao thanks the support from Hundred Talents Program (Outstanding Technician) of Chinese Academy of Science.

5. References
[1] K. Kirch, The Virtue of Precision Particle Physics, Proceeding of 2nd International Symposium on Science at JPARC, JPS Conference Proceedings 8, 001003, 2015

[2] J. R. Musser, et al, Measurement of the Michel Parameter rho in Muon Decay, Physical Review Letters, 2005, 94, 101805

[3] Y. Kuno and Y. Okada, Muon Decay and Physics Beyond the Standard Model, Review of Modern Physics, 1999, 73 (1) :151-202

[4] P. Bakule and E. Morenzoni, Generation and Application of Slow Polarized muons, Contemporary Physics, 2004, 45 (3): 203-225

[5] J. Wei, et al, China Spallation Neutron Source Design, Proceeding of APAC 2007, Indore, India

[6] G4beamline, http://g4beamline.muonsinc.com