Beam commissioning at MuSIC : intensity and spin polarization measurement

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We have constructed a new DC muon beamline, MuSIC (MUon Science Innovative muon beam Channel) in the west experimental hall. The MuSIC beamline consists of the worlds' most efficient DC muon beam source using the first pion capture solenoid system [1], and successive muon beam transport magnets to the experimental port [2]. The 392 MeV, 20 nA primary proton beam is delivered to a pion production graphite target at 16.8 MHz. We have been already demonstrated that approximately 10^8 positive and 10^7 negative muons per second and per 1 μA primary proton beam (denoted count/(sec·1μA-proton)) were observed at the solenoid exit [3].

The beam intensity was measured at the experimental port by time-of-flight method separating $\mu^\pm$ from $e^\pm$ and $\pi^\pm$ as shown in Fig. 1 (a). The present beamline transports the positive or negative muon beam at momenta from 28 to 110 MeV/c from in-flight pion decay with a momentum bite of 10 %. Figures 1 (b) left and right show momentum dependence of negative and positive muon intensity produced by in-flight pion decay, where measured muon intensity is translated assuming that 1 μA proton beam is delivered to the target. Recently, we have been succeeded in transporting 3×10^4 count/(sec·1μA-proton) surface muons by changing a proper surface-muon beamline setting.

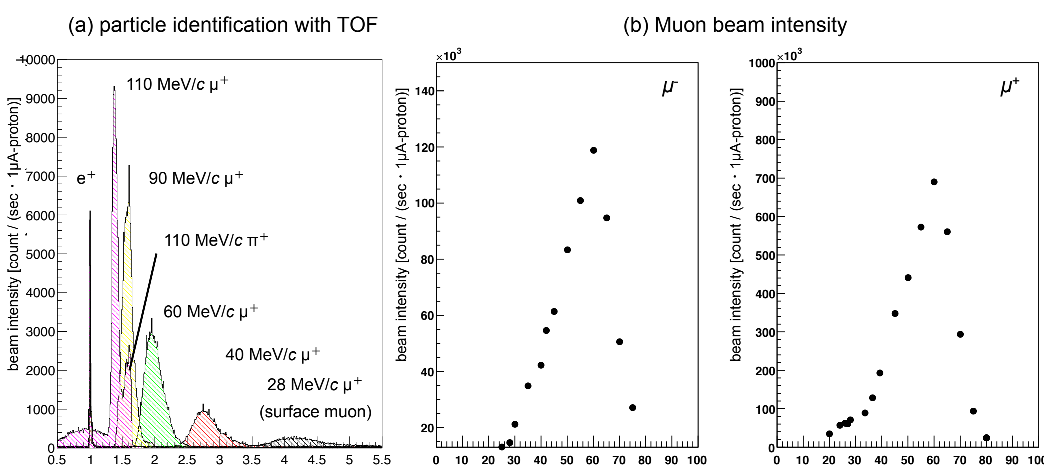

Figure 1: (a) Particle identification using $1/\beta$ for 28, 40, 60, 90, and 110 MeV/c e^+, μ^+ and π^+ peaks. (b) Measured muon intensity for negative (left) and positive (right) muons. The beam intensity falls above 60 MeV/c because an incident pion momentum is limited by the pion generation process using 392 MeV primary proton beam. Note that beam intensity in vertical axes are translated assuming that 1 μA primary proton beam is delivered to the muon production target.

Another important parameter is the muon spin polarization. In particular polarized muon beam is required in condensed matter physics and chemistry by the μSR (muon spin rotation, relaxation, resonance) method. Due to a specific feature of the MuSIC beamline: incident pion and successively decayed muon momenta cannot be controlled independently in the solenoid volume, forward-decay and backward-decay muons are mixed in some proportions. This suggests that degree of the spin polarization depends on a pion collection field and an outgoing muon momentum. The spin polarization for the positive muon is therefore directly measured at momenta of 28 MeV/c (surface) and 60 MeV/c (in-flight decay). Experimentally, muons were stopped at an aluminum target (10 cm×10 cm×5 mmt) and decay positrons were observed with upstream and downstream counters as shown in Fig. 2 (a). A magnetic field $B = 0.004$ T transverse to the muon spin at the muon stopping target was applied to precess the spin. Decay positron time spectra at upstream $N_U(t)$ and downstream $N_D(t)$ counters and a spin asymmetry function $A(t)$ are

$$N_{U/D}(t) = N_{0,U/D} \exp\left(-\frac{t}{\tau_\mu}\right) \left[1 \pm AP(0)G_x(t)\cos(\gamma_\mu Bt + \delta_0)\right], \quad (1)$$

$$A(t) = \frac{N_U(t) - \alpha N_D(t)}{N_U(t) + \alpha N_D(t)}, \quad (2)$$

where τ_μ, A, $P(0)$, γ_μ, and δ_0 denote the muon lifetime, an amplitude of asymmetry, an initial spin polarization, the gyromagnetic ratio for the muon and a incident spin precession phase, respectively. A function $G_x(t)$ denotes spin relaxation function (for the present aluminum target, $G_x(t) = 1$) and α denotes a correction factor to cancel solid angle difference between two counters. Figures 2 (b) and (c) show asymmetry spectra for (b) 28 MeV/c and (c) 60 MeV/c muons, respectively. We determined the α to be $A(t) \to 0$ $(t \to 0)$ and fit the spectrum (b) with Eq. 2. An observed spin asymmetry A_{obs} is ~ 0.08, whereas an expected spin asymmetry for a fully-polarized muon beam A_{full} is estimated to be ~ 0.14 considering the counter geometry. Muon spin polarization is then deduced to be ($A_{obs}/A_{full} \sim 0.57$) approximately 60 %, which is almost the same value in each spectrum in Figs. 2 (b) and (c). In addition, from the incident spin precession phase, both muon beams are polarized to the backward direction to the muon momentum. This indicates that forward-decay muons are dominant at these momenta.

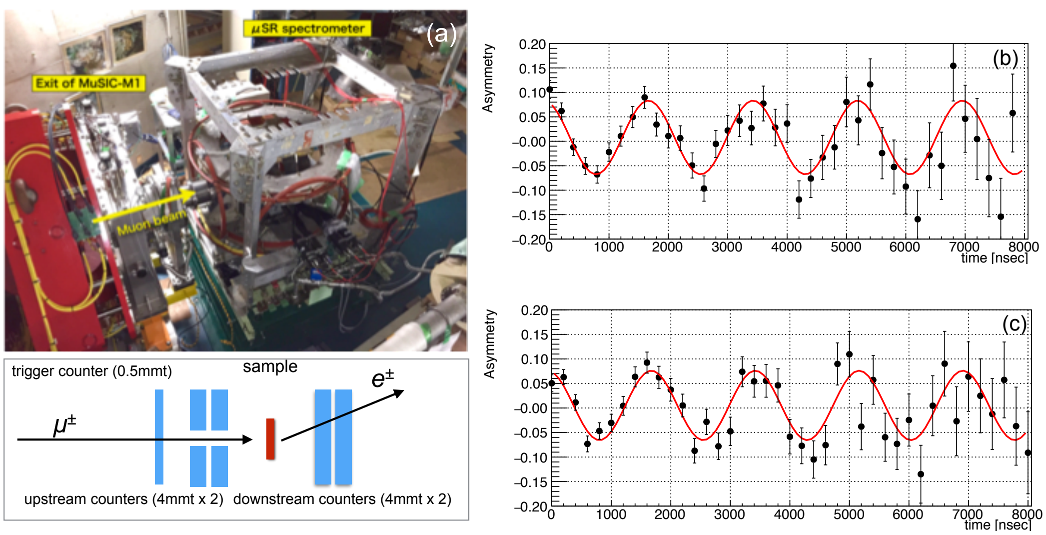

Figure 2: (a) Photograph of μSR spectrometer. A counter configuration is schematically described in the inset. (b, c) Measured asymmetry plots for 28 and 60 MeV/c muons, respectively. In the present analysis, the spin asymmetry function A(t) is calculated from counter hit timing data using Eq. 2. Measurement times are $\sim$ 60 and $\sim$ 25 min, respectively.

In 2016, we are planning to enforce radiation shields and install a remote control system around the muon production target. These upgrades will allow us to improve the primary proton beam to be 1 μA. Accordingly, the muon intensity is expected to be 50 times larger than the present value. After remaining beam commissioning works associating with the intense beam, we will be ready for variety of scientific programs within a reasonably shorter beam time, such as muonic X-ray measurements for nuclear physics, chemistry, and astrophysics, and μSR measurements for condensed matter physics.

References

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