Upgrading the PSI Muon Facility

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Abstract. A new project was initiated at PSI to replace the existing μ E4 decay channel with a new beam line delivering surface/cloud beams of highest luminosities. This goal will be accomplished by installing a solenoidal lens system at the main production target E and then transporting the muons with conventional beamline elements of very big apertures to a greatly enlarged experimental floor. Several slit systems and an electrostatic separator will be available to control the beam shape and reduce the electrons and other background.

Particle fluxes up to $5 \times 10^8 \mu^+/s$ and $10^7 \mu^-/s$ can be expected at 28 MeV/c beam momentum, using the 600 MeV primary proton beam of 1.7 mA. The operation of the channel will be limited to a maximum momentum of 40 MeV/c. The beam line has been specially designed to provide highest flux to the ultra-slow μ^+ beam (LEM).

Key words: muon beam, low energy muons.

1. Introduction

Since 1975 PSI has provided intense low momentum muon beams suitable for physics experiments with stopped muons at 100% duty cycle [1]. Beams of high luminosity are generated in two superconducting solenoid channels working on the principle of backward $\pi \rightarrow \mu$ decay [2] delivering pure muon beams with extremely low π or e background. In addition, even more luminous surface μ^+ beams were developed at PSI collecting the muons directly from pions stopping and decaying near the surface of the primary proton target. The state of the art is documented in [3] and can also be viewed on the internet [4]. Some characteristics and intensities of low momentum muon beams presently available at PSI are shown in Table I.

2. Development of the low energy μ^+ facility

A very important extension of our large μ SR research program at PSI was achieved by the recent development of the “LEM” facility producing ultra slow μ^+ particles which can be implanted at very small and controllable depths in the nm scale below the surface of a sample [5, 6]. Figure 1 gives a layout of this new beam-

Table I. Characteristics of low momentum muon beams available at the 600 MeV accelerator of PSI (proton current 1.7 mA)

Beam area	Channel type	Particle	p MeV/c	$\Delta p/p$	Beamspace $x \cdot y$ (cm ²)	Fluxes sec ⁻¹	Remarks
π M3	surface	μ^+	28	3%	0.9×1.4	5×10^6	with spin rotator
π E1	surface	μ^+	28	8%	1.8×1.0	5×10^6	
π E3	surface	μ^+	28	8%	1.5×3.0	5×10^7	
π E5	cloud	μ^-	15	10%	1.5×2.0	6×10^6	Z-version
μ E4	supercond.	μ^+	40	4%	6×4	1.2×10^6	backw. decay μ
	channel	μ^-	40	4%	6×4	3×10^5	chromatic mode

line transporting the muons in ultra-high vacuum onto a tertiary target with μ SR spectrometer.

Surface μ^+ of 4 MeV are slowed down using a specially designed moderator of a solid noble gas or nitrogen. The large electronic excitation energy of such material leads to the generation and escape into vacuum of 100% polarized muons at epithermal energies (~ 15 eV). These particles are then accelerated, filtered and focused by an electrostatic beam transport system, and implanted in a sample at a tunable energy between 0.5 and 30 keV. This allows all the advantages of the μ SR technique to be obtained in thin samples, near surfaces, and as a function of depth below and above surfaces. The spectrum of possible applications of this new magnetic microprobe is very broad, including superconducting thin films and multilayers, nanostructured materials, quasi two-dimensional magnetic systems and new materials which can only be prepared in thin film form.

The LEM apparatus is now already in operation at the π E3 beam of PSI which delivers at 28 MeV/c fluxes of up to $5 \times 10^7 \mu^+$ /s. About 350 ultra-slow μ^+ /s can be stopped in thin targets today. This intensity is already sufficient for doing μ SR research near surface regions and on thin films [7], however one order of magnitude increase in intensity would allow the exploitation of the full potential of this technique.

For this reason a proposal [8] was presented to PSI and received approval to construct a new surface μ^+ (cloud μ^-) beam line with the highest possible luminosities replacing the existing μ E4 channel.

3. The upgraded μ E4 low energy muon beam channel

The layout of the new μ E4 beam line is shown in Figure 2. It takes off at 90° from the main pion production target “E” which is a slowly rotating carbon wheel intersecting the primary 600 MeV proton beam over a length of 4–6 cm.

Figure 1. Layout of the low energy muon beam and μ SR spectrometer (LEM) at PSI. 4 MeV surface muons stopping in a kryogenic moderator (e.g., solid argon) are extracted and transported by electrostatic devices (lenses and mirrors) onto the tertiary target. The triggering at ultra low energies is done via multi channel plates MCP1 and MCP2.

The beamline elements consist of a special solenoidal lens system followed by three short bending magnets with triplets of large aperture quadrupoles in between and with two more quadrupole triplets at the end embedding an electrostatic separator.

The crucial innovation in this system is the first beam element, a double solenoid lens ($l = 1$ m, $d = 30$ cm, $B = 4$ kGauss) which can accept muons from the proton target in a solid angle of 150 msr. Because of geometric constraints it was not possible to solve the demand for a large solid angle acceptance with conventional quadrupoles. As a reference, the accepted solid angle of the π E3 beam on the other side of proton target E is about ten times smaller!

In order to maintain a large beam phase space transported through the system of conventional beam focusing elements, special short quadrupole lenses are used (length $l_{\text{eff}} \sim 40$ cm) equipped with extra large apertures ($a = \pm 25$ cm). Correspondingly, the three bending magnets of type “ASK” are also short ($l_{\text{eff}} \sim 75$ cm) and exhibit large gaps of 24 cm.

Table II. Calculated design and performance parameters of the new μ E4 beam assuming a 1.7 mA primary p-beam hitting a 6 cm C-target

Parameter	Unit	Value	Remarks
accepted solid angle	msr	150	full beam
channel length	m	17.3	incl. separator
full momentum band		$\pm 3\%$	FWHM
x - y beam spot	cm^2	3.5×2.1	FWHM
μ^+ flux	μ^+/s	5×10^8	28 MeV/c
μ^- flux	μ^-/s	$\sim 10^7$	28 MeV/c
(e^+/μ^+) -ratio		7%	after separator

The system is equipped with three slit systems to curb the phase space and intensities. One of them is placed inside the second bending magnet, assigned to cut the momentum acceptance.

The electrostatic separator is designed to eliminate totally the electrons (positrons) originating in the proton target. The calculations – based on a useful beam spot of $3 \times 3 \text{ cm}^2$ at the low energy muon moderator – indicate an electron suppression factor of ~ 100 .

Table II lists the parameters and expected performances as they were determined in the design phase.

4. Outlook

The new upgraded μ E4 beamline described in this paper was approved in spring 2001 by the PSI research committee and receives substantial financial contributions from the German BMBF, the UK EPSRC as well as Swiss Universities. The facility is now in full design stage. Construction and implementation of the new beam line is planned for the years 2003/2004. PSI expects to develop with this upgrade an important and highly demanded facility for present and future research in new fields of applied and fundamental muon physics.

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