THE μ SR FACILITIES AT PSI

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The μ SR Facility Instruments presently available at PSI and the envisaged medium- and long-term developments are presented. The plans focus on further upgrades of the existing instruments and the development of new techniques using the very high fluxes becoming available at PSI, in particular the setup of a beamline with a fast kicker for 'muons on request' (MORE) and the development of very low energy muon beams.

1. Introduction

In 1989 the PSI management decided to initiate the development of a μ SR *User Facility* with dedicated beamlines and instruments by the formation of an in-house μ SR group. Operation of the newly commissioned facility instruments began in 1991 after completion of the extensive accelerator and target upgrades designed to increase the proton-beam intensity up to 2 mA [1].

At present four facility instruments are available for a wide range of μ SR applications: Two *General-Purpose* instruments (*GPD* for decay-channel muons and *GPS* for surface muons), a *Low Temperature Facility* (*LTF*), and an *Avoided Level-Crossing Resonance* (*ALC*) instrument. The facilities are maintained and supported by the PSI μ SR group (five physicists and a technician), a computing expert, and the beam-development group.

2. The μ SR Facility Instruments

At PSI positive and negative muons which may be used for μ SR experiments are available on the beamlines μ E1, μ E4, π E1, π E3, π E5, and π M3 [2] (Fig. 1). The superconducting decay channels in the μ E1 and μ E4 beamlines provide a muon momentum range of 30 – 115 MeV/c whereas π E1, π E3, π E5, and π M3 are designed for pions, for positive muons emerging from the production targets (surface and sub-surface μ^+ , momentum 5 – 30 MeV/c),

Fig. 1. The beamlines and μ SR facility instruments at PSI. The *General-Purpose Surface-Muon* instrument (GPS) and the *Low Temperature Facility* (LTF) are permanently installed on the dedicated π M3 beamline, whereas the *General-Purpose Decay-Channel-Muon* (GPD) and *Avoided Level-Crossing* (ALC) instruments have to share the appropriate beamlines with other experiments.

and for negative ‘cloud’ muons (momentum 5 – 300 MeV/c) from π^- decaying just outside the targets.

In 1989 the only surface- μ^+ beamline at PSI which is equipped with a crossed-field electromagnetic separator / spin rotator, π M3, has for the first time been entirely dedicated to μ SR research, thus laying the grounds for the *permanent installation* of facility instruments. The other beamlines have to be shared with particle-physics experiments.

2.1. THE GPS AND LTF INSTRUMENTS

These are the most frequently used instruments of the facility. They are both permanently installed on the π M3 beamline providing a high-quality μ^+ beam of typically 28 MeV/c momentum (range ≈ 150 mg/cm² in CH₂). The beam may be switched between *GPS* and *LTF* by means of a

bending magnet (ASK33). Both instruments are equipped with a *variable external collimator* at an intermediate focus downstream of ASK33 which is imaged onto a 0.2 mm thick scintillation muon detector in front of the sample chamber by means of a quadrupole-triplet lens.

In *GPS* the decay positrons are detected by five scintillation-counter telescopes which may be mounted in two configurations: 'forward', 'backward', 'up', 'down', 'right' when using a cryostat with horizontal access or 'forward', 'backward', 'left', 'right', 'down' for vertical cryostats, the directions referring to the direction of the muon momentum. The detector arrangement of *LTF* consists of single scintillators in the 'forward', 'left', and 'right' directions and a split 'backward' detector. The polarization of the incoming muons may be rotated out of the direction of the muon momentum by up to 90° .

The main magnetic field of the instruments is parallel to the muon beam. In *GPS* it is generated by a pair of Helmholtz-type air-core coils (0–0.6 T), in *LTF* by a split-coil superconducting magnet (0–3 T). For zero-field measurements three orthogonal pairs of compensation coils are provided. *LTF* is further equipped with air-core coils for small transverse magnetic fields up to 10 mT.

The temperature ranges covered by the cryostats available for *GPS* are 2.5–350 K with a continuous-flow ^4He evaporator or 11–350 K with a closed-cycle refrigerator. The base temperature of the Oxford Instruments $^3\text{He}/^4\text{He}$ dilution refrigerator in *LTF* is about 10 mK. In *GPS* the cryostats can be rotated by $\pm 90^\circ$ around an axis perpendicular to the muon momentum for measurements of orientation-dependent effects in single crystals.

GPS and *LTF* share the same data acquisition electronics, making it very easy to switch between them and hence use one instrument during short breaks (e.g. sample changes) in the other one.

2.2. THE GPD INSTRUMENT

This instrument is designed for the use of higher energy muons as provided by one of the superconducting decay channels μE1 or μE4 . In its standard setup it can be used with μ^+ or μ^- of momentum 65–115 MeV/c (range 2–10 g/cm² in CH₂). It is equipped with a conventional air-core magnet (0–0.5 T) which can be rotated by 90° so that longitudinal- or transverse-field experiments are possible.

The detector arrangement consists of four positron(electron)-counter telescopes ('forward', 'backward', 'up', 'down') and two muon detectors. The incoming muons pass through a lead collimator (standard dia. 14 mm) and a variable polyethylene degrader (0–24 mm in steps of 1 mm).

Four different cryostats are presently available: a simple nitrogen flow cryostat for large samples (up to 35 mm dia., temperature range 77–350 K, mostly used for chemistry experiments), a closed-cycle refrigerator as in *GPS*, a ^4He evaporator (4–350 K), and an Oxford Instruments ^3He cryostat (base temperature 0.5 K), the latter two being provided by the University of Braunschweig, Germany.

2.3. THE ALC INSTRUMENT

The Avoided Level-Crossing Resonance Instrument is based on a 1 m long superconducting solenoid (0–5 T parallel to the beam). Since the *ALC* method is based on *integral* counting, the instrument can make full use of the highest-intensity surface-muon beams, $\pi\text{E}3$ or $\pi\text{E}5$, when equipped with an electromagnetic separator.

The forward-backward decay asymmetry is measured by two detector rings consisting of eight scintillators each. For time-differential measurements a thin muon detector is available. A simple flow cryostat and a vacuum furnace cover the temperature range 40–800 K.

3. Future Developments

The plans for further improvements of the facilities include three main objectives: (i) upgrades to the existing instruments, (ii) better exploitation of the very high muon fluxes becoming available in the near future, and (iii) development of new techniques and beams, in particular extremely low-energy muon beams.

3.1. UPGRADES OF EXISTING INSTRUMENTS

The improvement program of the existing instruments aims mainly at making them more user-friendly and including new features such as in-situ NMR field measurement, automatic angular scans, and new ‘top-loading’ cryostats allowing faster sample changes. The planned upgrades of *GPD* and *ALC* include extensions of the available sample-temperature ranges towards lower temperatures.

3.2. EFFICIENT USE OF HIGH INTENSITIES

One disadvantage of the quasi-continuous beams at PSI is the *rate limitation* due to muon pileup in time-differential μSR experiments, thus rejecting a very large fraction of the available muons (at a proton-beam current of 500 μA , e.g. only about 2 % of the surface μ^+ in the $\pi\text{M}3$ beamline can

be used by *GPS*. An obvious and simple improvement is the use of variable collimators in an intermediate focus of the beamline as implemented in *GPS* and *LTF*, resulting in less background and making measurements on smaller samples feasible.

A more efficient way to make use of very high muon fluxes is the extraction of *one muon at a time* on request of a μ SR instrument by means of a *fast beam deflector* ('kicker'), thus getting rid of the muon pileup problem and gaining up to a factor of 5 in counting rate. Moreover, there would still be plenty of muons left in the original beam for simultaneous use by other instruments. Such concepts have been proposed for kicked surface muon beams at TRIUMF and KAON [3]. The first practical realization of a chopped muon beam has been achieved at LAMPF [4].

At PSI a modification of the π M3 beamline is currently being designed which will be equipped with a fast triggered electrostatic deflector followed by a septum magnet, feeding two instruments – one with muons on request (*MORE*) and a conventional one – simultaneously. In a first stage, it is planned to use *GPS* as *MORE* instrument while *LTF* will get the rest of the beam. On medium terms, a second general-purpose instrument is supposed to share the remaining beam with *LTF*.

In the present design the kicker consists of two plates 50 cm long, 20 cm apart. The 30 kV deflecting pulses (rise time <100 ns) will be triggered by a thin muon detector in the beamline. The low- and high-field regions of the septum magnet will be separated by a 5–10 mm thick iron plate. The modification of the π M3 beamline is planned to start during the next accelerator shut-down period in September 1993.

3.3. NEW BEAMS AND TECHNIQUES

Interesting new materials in solid state research are often difficult to produce in large quantities, let alone to grow big single crystals from them. This may lead to severe background problems in a μ SR experiment. As long as the samples can be made sufficiently thicker than the range width of the muon beam (~ 50 mg/cm² for surface μ^+), this problem could be solved by a position-sensitive muon detector allowing to reject muons which would not hit the sample. In a collaboration with R. Horisberger of PSI the development of such a detector, based on the technique of silicon micro-strip detectors [5], has been initiated.

The study of very thin samples or surfaces, however, requires very low energy muon beams of sufficient intensity and polarization. At PSI, several approaches to produce μ^+ and μ^- at very low energies are currently under

investigation [6]– [9]. While the most efficient way to produce lowest-energy μ^- beams is still a subject of discussion [6], the solution for μ^+ beams is to use surface muons which are available at very high luminosity. At present the most advanced approach to produce lowest-energy μ^+ seems to be the moderation of surface muons by solid rare gases: Using solid Ar a moderation efficiency of 10^{-4} has been obtained [7], which at a proton current of 1 mA would result in a source flux of $\sim 10^4$ slow μ^+ per second in π E5. But there are other methods which still look promising, e.g., the extraction of slow muons from superfluid liquid helium [8].

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