*First experience with **G-APDs** in **μSR** instrumentation*

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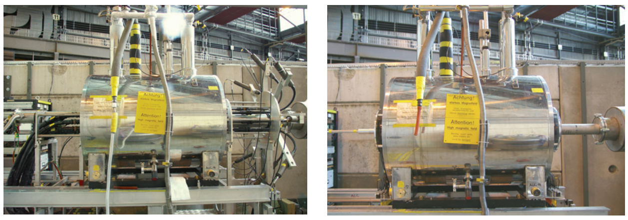
*Muon spin spectroscopy (**μSR**) is an experimental technique which utilizes the muon as fully polarized probe to study the properties of condensed matter. The operation of a μSR spectrometer is based on the detection of muons entering the sample and the corresponding decay positrons. For this purpose traditionally scintillation detectors based on photomultiplier tubes (PMTs) are used.*

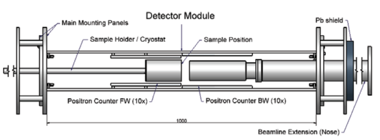
*In this work we demonstrate the potential of the detectors based on Geiger-mode Avalanche Photodiodes (G-APDs) for the development of the μSR technique. For the 5 Tesla Avoided Level Crossing (**ALC**) instrument located at the Swiss Muon Source (SμS) of PSI we build a completely new detector system using as a basic element a tile-fiber scintillation counter with a G-APD readout. For the planned 10 Tesla High Magnetic Field (**HMF**) spectrometer we carry out feasibility tests aiming at the highest possible time resolution.*

ALC spectrometer:

Based on a 5 Tesla superconducting solenoid (1m long, room-temperature bore 20cm). The muons are stopped in the sample positioned at the solenoid center. The decay positrons emitted in the forward (FW) and backward (BW) directions with respect to the initial muon momentum are detected by two sets of scintillation counters. *Time-integral operation mode*: per each set value of the magnetic field the integral number of e^+ counts in BW and FW detector sets is recorded within a predefined time interval and then used to calculate the muon decay asymmetry.

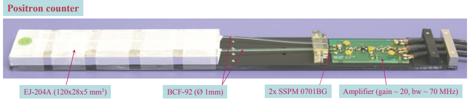


ALC spectrometer equipped with the "old" PMT-based detector system (left) and the new G-APD based detector (right) in the πE3 experimental area of SμS (muon beam comes from the right).



New ALC detector: mounting of the detector module in the warm bore of the solenoid (left); detector module – view along the muon beam direction (right).

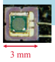
Positron counter



SSPM 0701BG

PDE, at 490nm	-- 25 %
Operating voltage	-- 15V – 25V
Gain	-- ≤ 4·10⁵
Temp. coeff. of Gain	-- < 1.0 %/C
Number of micro-cells	-- 560
Active area	-- Ø1.1 mm

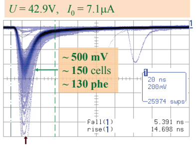
Photonique SA
http://www.photonique.ch



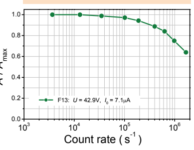
The main requirements on the performance are:

-- small variation of the efficiency with changing ambient temperature;
-- ability to handle count rates up to 1 MHz.

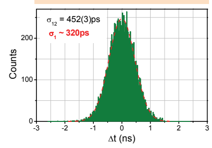
Detection of mips (normal incidence)
$U = 42.9$V, $I_0 = 7.1$μA



Signal Amplitude vs. Rate



Time resolution

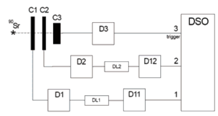


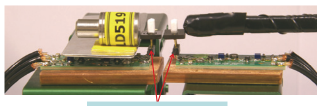
HMF spectrometer: detector feasibility tests

10 Tesla μSR instrument planned at SμS. *Time-differential mode of operation*: correlation between the muon implantation and the decay times is measured.

Muon and positron counters. Dimensions about 1cm² (1cm is the characteristic spiraling radius of the decay positrons in 10 T). Energy deposition range 0.3 – 1 MeV.

Main requirement: time resolution better than 90ps (σ) per counter. Such time resolution is needed in order to detect muon-spin precession with its Larmor frequency of 1.35 GHz in a field of 10 T with approx. half its low field amplitude.





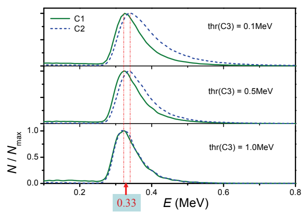
MPPC S10362-33-050C
Hamamatsu Photonics

Experimental setup for the time resolution measurements:

C1, C2 – identical detectors under test:

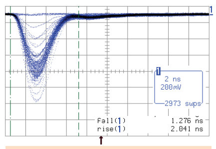
G-APD: **MPPC 33-050** (3x3 mm², $I_0 = 1$μA, $U \approx 70$V); **Scintillator**: BC422 (4.5x4.0x2 mm³);
Amplifier: gain = 13, bw ~ 600 MHz

C3 – trigger detector; **D1-D2** – CFDs PSI VME CFD-950; **DSO** – LeCroy WavePro 960



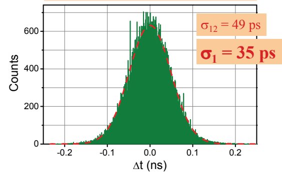
GEANT4 simulations of the energy losses of ^{90}Sr electrons in C1 and C2 for different energy thresholds in the trigger detector C3. The actual threshold in C3 is ~0.3 MeV. The most probable value for the energy losses in C1 (C2) is about 0.33 MeV.

The detection threshold in C1 and C2 is set at ~1/3 of the most probable amplitude of their signals.



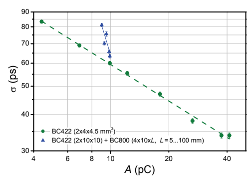
Detection of ^{90}Sr electrons in C1 (trig = C2)

Time difference C1-C2 (trigger = C3)



(Circles): Time resolution of the counter C1 vs. the signal amplitude. The dashed line a dependence $\sigma \sim A^q$ with $q = 0.42$.

(Triangles): The effect of a light guide (BC-800 UVT plastic, cross-section 4x10 mm², length L = 5, 15, 30, 50, 100 mm) used between a 10x10x2 mm³ BC-422 scintillator and the G-APD on the time resolution of the counter. As the length of the light guide increases, the signal amplitude remains practically constant while the time resolution degrades.



*We used G-APDs to build a new detector system for the 5T **ALC** μSR spectrometer. The new detector is compact, insensitive to the magnetic field and is operated at voltages below 50V. To the best of our knowledge this is the first operating μSR apparatus dispensing with photomultiplier tubes.*

*With a small G-APD based scintillation counter we demonstrate the time resolution of **σ = 35 ps**, i.e. about the best results achieved so far with PMTs. In contrast to PMTs, however, such time resolution should be possible to achieve also in the presence of high magnetic fields.*

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