MusrSim(Ana) – Simulation Tools for the µSR Instruments

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The programs *musrSim* and *musrSimAna*

The simulation of µSR instruments is performed in two steps:

- *musrSim* – Geant4 simulation of the detector response, very demanding on CPU.
- *musrSimAna* – analysis of the simulated results, much quicker than the first step.

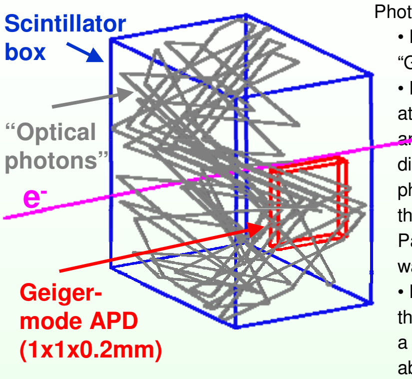
Typically, musrSimAna is run repeatedly for one musrSim run.

Both programs are tailored to the needs of µSR instruments, however the *musrSim* can be (and was) used also for other purposes, e.g. for simulation of particles passing through the spin rotators and quadrupole magnets, or to simulate the response of a simple test setup detecting electrons emitted by a Sr source.

An important advantage of *musrSim* and *musrSimAna* is the possibility to define virtually all relevant parameters like detector geometry, muon beam properties, coincidences and anticoincidencies between different counters, etc. in text steering files, and therefore the users (in an ideal case) do not have to modify the source code of the programs.

Simulation of the light transportation in *musrSim*

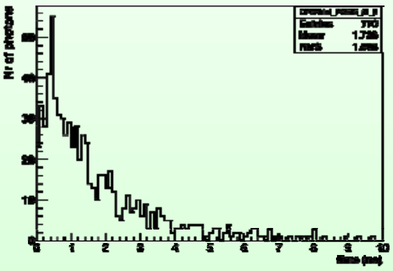
The program musrSim has been presented already at the µSR conference in Tsukuba (2008). Since then, we improved the program, and added some new functionalities. The latest one is the possibility to simulate light signals generated in scintillators.

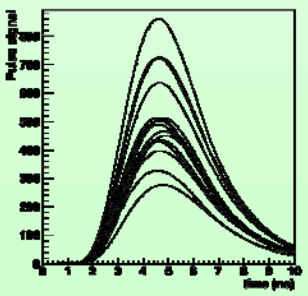


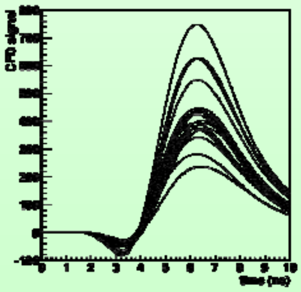
Photons:

- Photons are implemented as "G4OpticalPhotons" of Geant4.
- Effects of scintillation, light attenuation, reflection, absorption and detection can be controlled by different parameters, like e.g. photon yield, rise and decay times in the scintillator, refractive index, ... Parameters can often be set wavelength dependent.
- Example on the left – just a few of the photons reflected on the walls of a scintillator box and finally absorbed in a Geiger-mode APD are shown.

Histogram on the right shows the time distribution of photons "detected" in the G-APD in an event similar to the above one (this time all simulated photons are shown). The rise and decay times of the light emission in the scintillator are set to 0.175 ns and 1.6 ns, respectively. Detection efficiency of the G-APD was set to 25%.







In the end, the individual photon counts shown in the histogram can be replaced by a G-APD response function, and summed together. This way we obtain a "pulse signal". Left plot shows pulse signals for 15 different events. Right plot shows signals after further shaping corresponding to the constant fraction discriminator (CFD) processing. We can determine the time when a given CFD signal crosses zero, and use it in the analysis – this way the fast timing counters to be used in the High-field µSR instrument at PSI were investigated in detail.

musrSimAna

The output of musrSim is stored in a Root tree, but sometimes it is not trivial to analyse it (especially when "event mixing" is required). The program musrSimAna was developed to be a general analysis tool for any µSR instrument. Presently, however, only continuous muon beam facilities are supported. The aim of the musrSimAna development is to define all the necessary parameters and the detector logic (i.e. which counters are the M- and P-counters, what are (anti)coincidencies between counters, ...) in the text setup file, so that the user does not have to modify the c++ source code. An example of the steering file:

```
RESOLUTION=100              . . . one TDC bin corresponds to 100 ps
MCOINCIDENCEW=50            . . . time interval (in TDC bins) to find coincidences with M-counter
PCOINCIDENCEW=50            . . . time interval (in TDC bins) to find coincidences with P-counter
VCOINCIDENCEW=100           . . . time interval (in TDC bins) to find anti-coincidences
MUONRATEFACTOR=0.089        . . .will be described in section 3
DATAWINDOWMIN=-2.0          . . . data interval (in µs) in which positrons are detected
DATAWINDOWMAX=10.0
PILEUPWINDOWMIN=-10.0       . . . the pileup interval (in µs) for muons
PILEUPWINDOWMAX=10.0

102;  "M up";         M;  0.4;  2005;  -401;                                        . . .  M-counter
1;    "B1";           P;  0.4;  2005;  21 -401; B1; 1485; 1515; 50995;              . . .  positron counter
2;    "B2";           P;  0.4;  2005;  22 -401; B2; 1485; 1515; 50995;              . . . (coincidence with 22)
11;   "F1";           P;  0.4;  2005;  -401 -21 -22; F11; 1485; 1515; 50995;        . . . (anticoincidence with 401)
12;   "F2";           P;  0.4;  2005;  -401 -21 -22; F12; 1485; 1515; 50995;        . . . (threshold on dep. E =0.4 MeV)
13;   "F3";           P;  0.4;  2005;  -401 -21 -22; F13; 1485; 1515; 50995;        . . . (saved in histogram "F13")
21;   "Coinc B1"      K;  0.4;  2005;                                               . . . counter used in coincidence
22;   "Coinc B2"      K;  0.4;  2005;
401;  "Active Veto"   V;  0.1;  2005;                                               . . . counter used in anti-coincidence

musrTH1D hMuDecayPosZ "Where the muons stop;z[mm];N" 100 -5. 5. muDecayPosZ     . . . defines a histogram

condition 1 oncePerEvent                 . . . true exactly once for every event (irrespective of number of detected hits)
condition 2 muonDecayedInSample gen      . . . true in those events, where muon decayed in the sample
condition 4 muonTriggered det            . . . true if a good muon was detected in the M-counter
condition 6 goodEvent det                . . . true if a good hit detected in the M-counter and a good hit det. in a pos. counter
condition 9 pileupEvent                  . . . true for time-independent background event (µ uncorrelated with positron hit)
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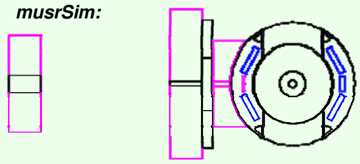
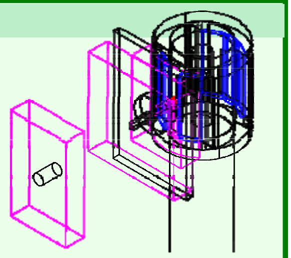
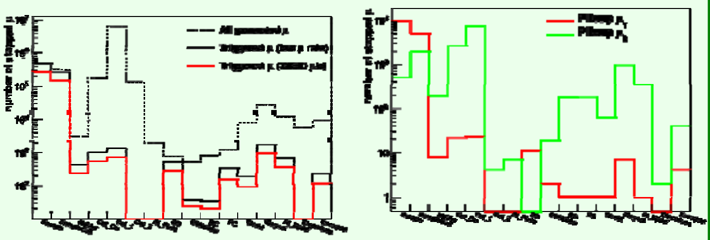
Example – GPD instrument at PSI

musrSim:



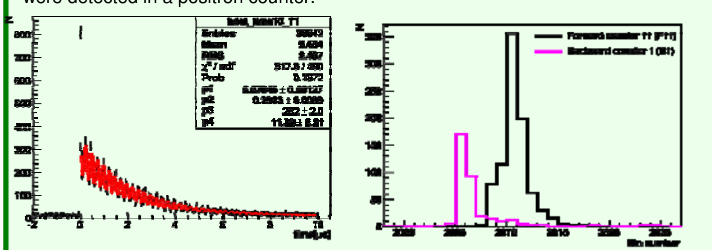


musrSimAna:



Left – illustration of where the muons stop and decay. Majority of them stops in collimators (dashed line), however only few of such events give rise to the signal in the M-counter (full lines), mainly due to the decay positron passing through the M.

Right – muons causing time-independent background. Here μ_1 stands for the muons that triggered the M-counter, and μ_2 are muons, whose (mainly) decay positrons were detected in a positron counter.



Left – µSR signal detected in backward counters. There is the time-independent background at times $t < 0$, prompt peak around $t = 0$, and a fitted oscillating signal (B=300G) at times $0 < t < 10$ µs.

Right – details of the prompt peaks in TDC bin units in one backward and one forward histograms.

Conclusions

We believe that musrSim and musrSimAna could be useful to many scientists in the µSR community. Some modifications might be necessary for the pulsed beam facilities. The programs including a documentation and some examples can be downloaded from http://lmu.web.psi.ch/simulation/index.html .

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