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GEANT4 as a simulation framework in μSR

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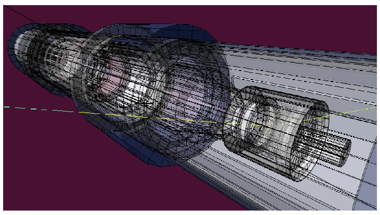


Numerical simulations in μSR

The increased use of numerical simulations in recent years has demonstrated the potential of Monte Carlo methods also for the μSR technique, where it has opened up new application possibilities by offering:

- New insights of the basics of μSR.
- A better understanding of the existing spectrometers, allowing a targeted performance improvement.
- Design and optimization of new instruments.

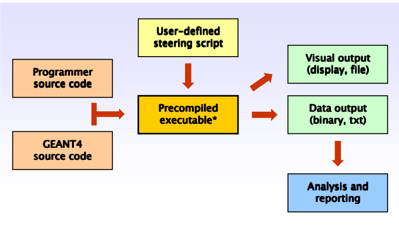


Fig. 1: Software architecture of the GEANT4-based μSR simulation platform, optimized for maximum flexibility and end-user friendliness.

GEANT4 as a simulation framework

GEANT4 is a Monte Carlo radiation transport toolkit which includes a complete range of functionalities required to build flexible simulation frameworks.
Taking advantage of its open architecture and object-oriented design, we could develop a new **software suite**, able to **model** and **simulate** μSR experiments and instrumentation:

- Any geometry and material (even complex)
- Any electromagnetic field:
  - From field map or constant field
  - 2D, 3D and axi-symmetric
  - Whatever field superposition
- Great user friendliness:
  - No C++ knowledge required
  - Not even the need to compile!
- Text or root format outputs
- Platform/version independent

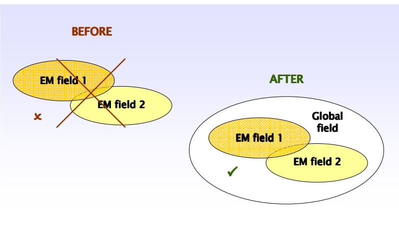


Fig. 2: The new electromagnetic field paradigm, developed for overcoming the G4 limits and to allow the overlap of multiple EM fields.

New insights on the basics of μSR

The versatility of the new tool has permitted the modelling of the incoming muon beam, the study of the outgoing positrons' behaviour, the investigation of the geometrical effects, etc.

Modelling muons' and ...

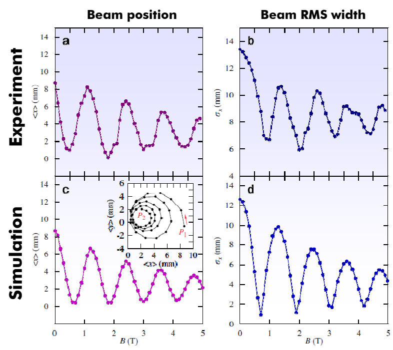


Fig. 3: Experimental characterisation (upper panels) and numerical simulation (lower panels) of the **muon beam spot** in the z = 0 plane as a function of the applied magnetic field. Both the measured (a) and simulated (c) average beam spot *position*, as well as the measured (b) and simulated (d) *RMS widths* of the muon intensity distribution all show a clear oscillatory behaviour.

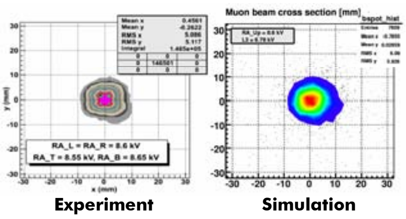


Fig. 4: Beam spot of a low-energy muon beam at z = 0.

... positrons' behaviour

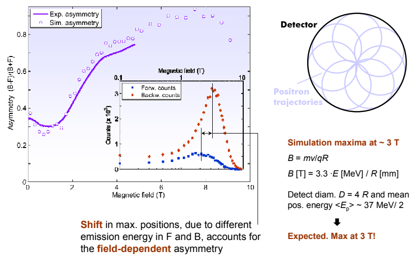
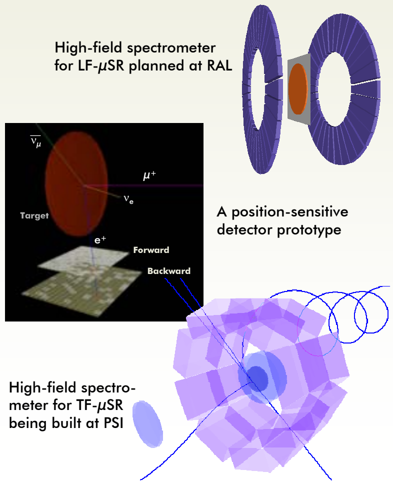


Fig. 5: Numerical simulations show that the field-dependent F-B asymmetry observed in ALC, is due to a shift in the count rate maxima, in turn reflecting the different positron emission energies in F and B.

Simulation-based instrument design

The new, high magnetic field instruments being built at RAL and PSI, whose design is entirely based on realistic Monte Carlo simulations, represent another example of the usefulness of numerical methods for the μSR technique.



Summary and future developments

- We could build a **complete simulation framework** dedicated to μSR applications, characterised by a high degree of **flexibility**, **modularity**, and a **simple** user interface.
- The reported examples show that numerical simulations carried out with the new platform
  - Provide a **deeper understanding** of the physics underlying the μSR experiment.
  - Are crucial in **designing** and **building** new, more sophisticated μSR instruments.
- Future uses of the developed platform could include also feasibility **analysis**, experiment **planning** and interactive **teaching** tools.

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