Simulation and Optimisation of the planned High-Field μSR Spectrometer at PSI.

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GEANT4

- Package for the simulation of the passage of particles through matter.
- Originally developed for the high energy physics detectors, nowadays extended to the applications in nuclear and accelerator physics, medicine and space science.

Why GEANT4 is interesting for μSR ?

- It allows us to test new μSR apparatus before they are actually built, and to optimise their design for the best performance.
- It can predict the impact of the modifications of the present μSR devices on the measurements.
- It can help us to better understand the measured results, (e.g. sources of background, it's dependence on the magnetic field, ...)

GEANT4 – what it is ?

- Geant4 is a framework (library) for developing the simulation code for a specific detector/apparatus rather then a ready-to-use toolkit. (There is some analogy to the concept of LABVIEW – the final simulation program is build-up from ready-to-use components as well as from user-developed specific objects.)
- The μSR applications needed to extend the list of standard GEANT4 physics processes by the decay of the muon with spin and by the muon spin precession in the magnetic field (done by P.Gumplinger and T.MacPhail, TRIUMF).
- There is a close collaboration between ISIS and PSI simulation teams:
  - ISIS: T. Lancaster, Z. Salman
  - PSI: T. Prokscha, T. Paraiso, T. Shiroka, K. Sedlak
- Input also from P.Gumplinger (TRIUMF)

Output data stored in a Root tree.

- Polarisation, momentum, time and coordinates of the muon at the moment when:
  - muon is created
  - muon enteres the sample
  - muon decays
- Magnetic field at the location where the muon decays
- Initial momentum of the decay positron
- Information from the muon and positron counters, active collimator, ...:
  - counter (detector) ID
  - deposited energy
  - time and coorinates of the first hit belonging to the given signal in a counter

Generalisation of our program

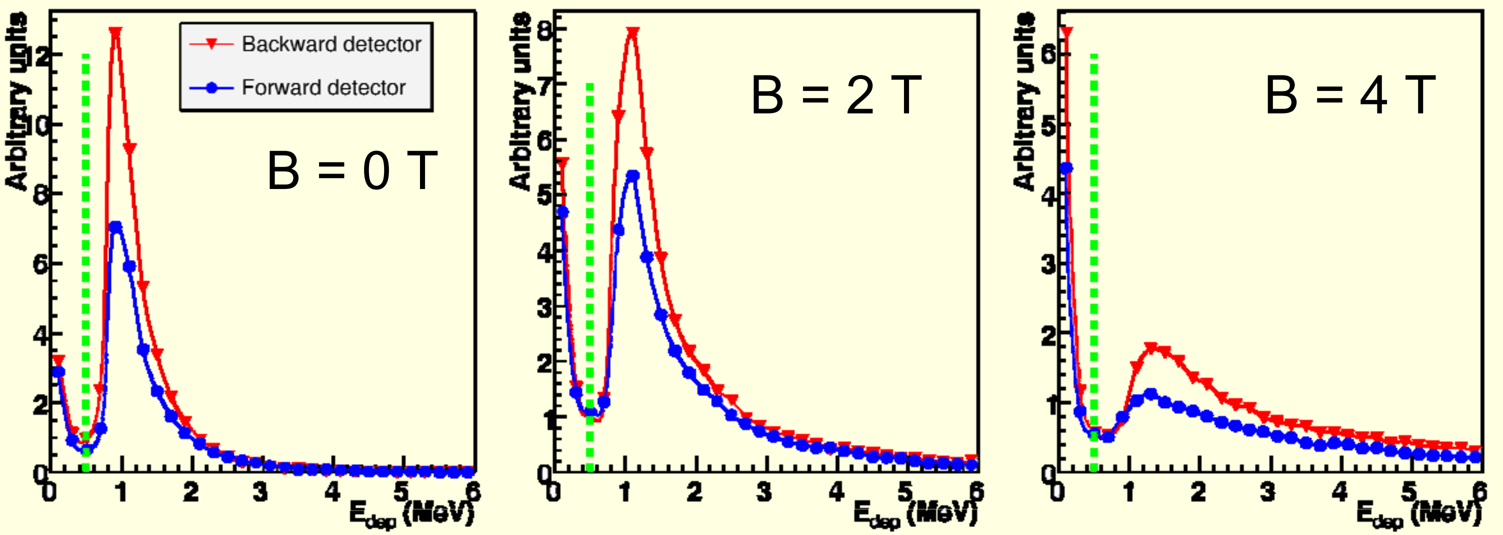
- In the past, each instrument had its own simulation code (executable)
  ➔ difficulties when maintaining the code
- Therefore some generalisation of the simulation code was done such that ideally we have just one common code (i.e. one executable) for different µSR instruments. (This goal is not yet fully achieved.)
- Switching between different detector setups is done via “steering files”, which are just text files that include all the details of the detector geometry, sensitive volumes, magnetic field, variables that will be saved into the output (Root) file, ...

/musr/com construct box pannelA 14 2.5 60 G4_Al 0 49.5 62 log_World norot dead 11

- No need to recompile the simulation code when changing the instrument geometry (very useful for the instrument design optimisation).

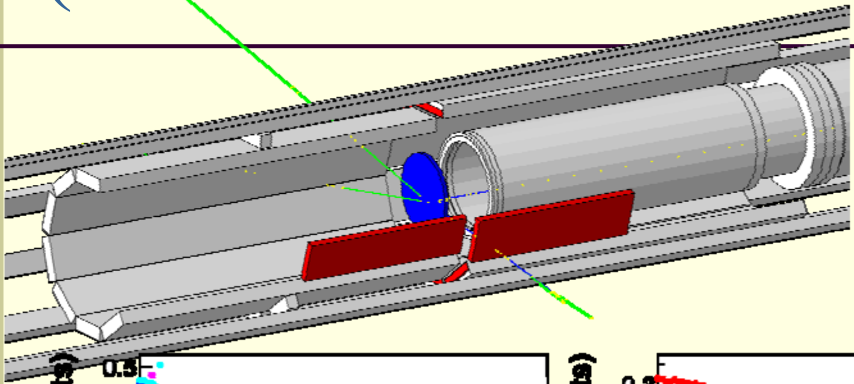
Energy deposited in a counter

- The energy deposited in a given detector module (e.g. in a positron or muon counter) during some time interval is summed up.

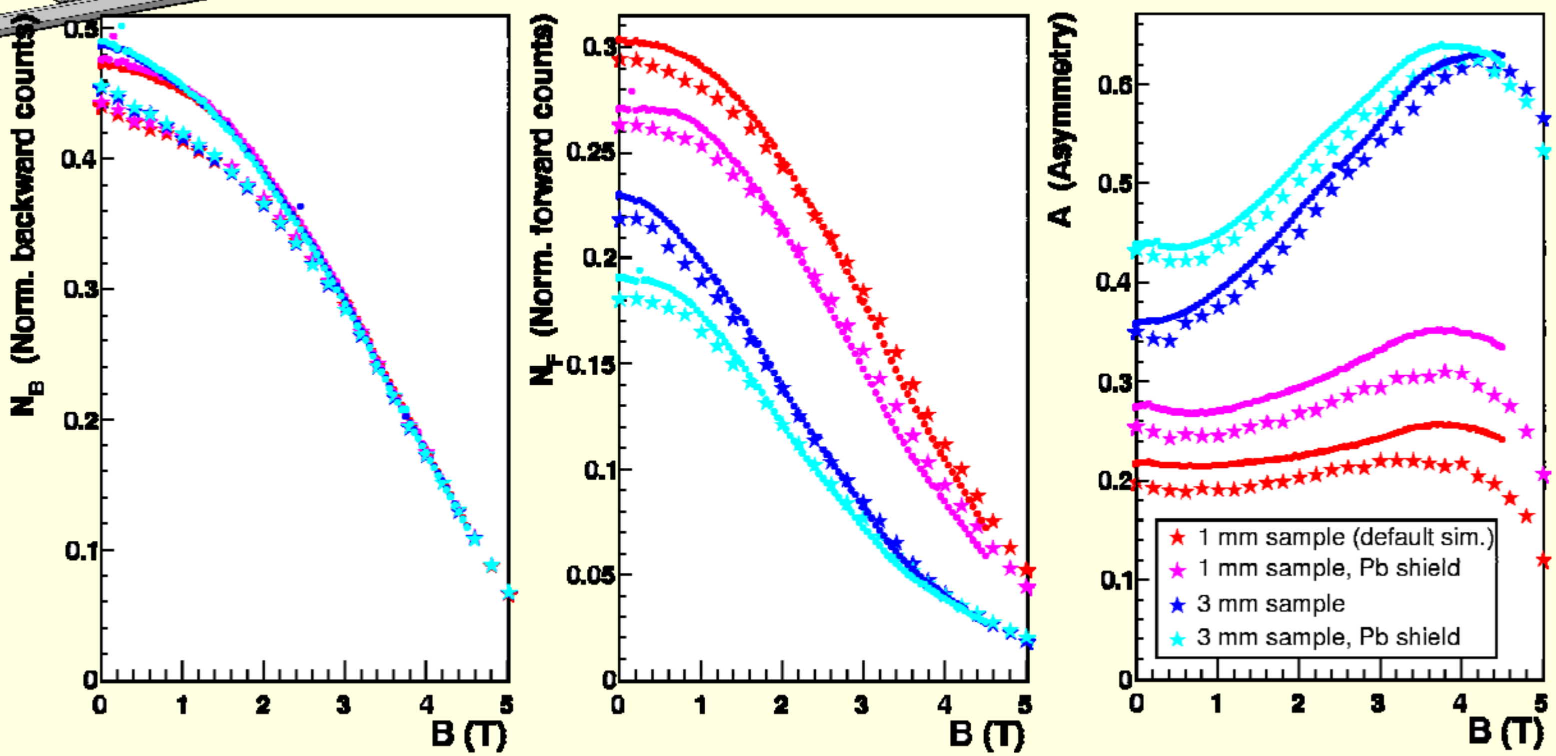


- Energy thresholds can be (and are) applied.
- Energy deposits of all particles (e^+, e^-, γ, μ^+) are taken into account (not just positrons).

Can we trust the simulation program? (Simulation of an existing µSR detector)



Example simulation of an existing µSR spectrometer in a time integral mode (details in a poster about the ALC spectrometer simulation).

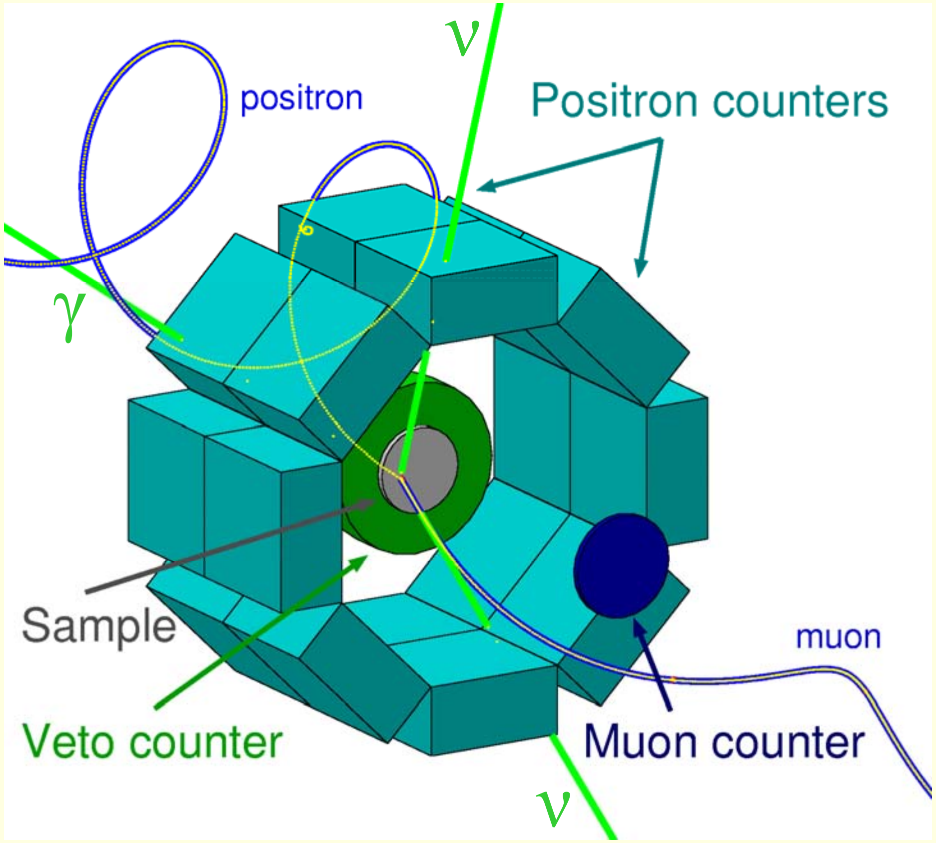


High Field Instrument

10 Tesla field

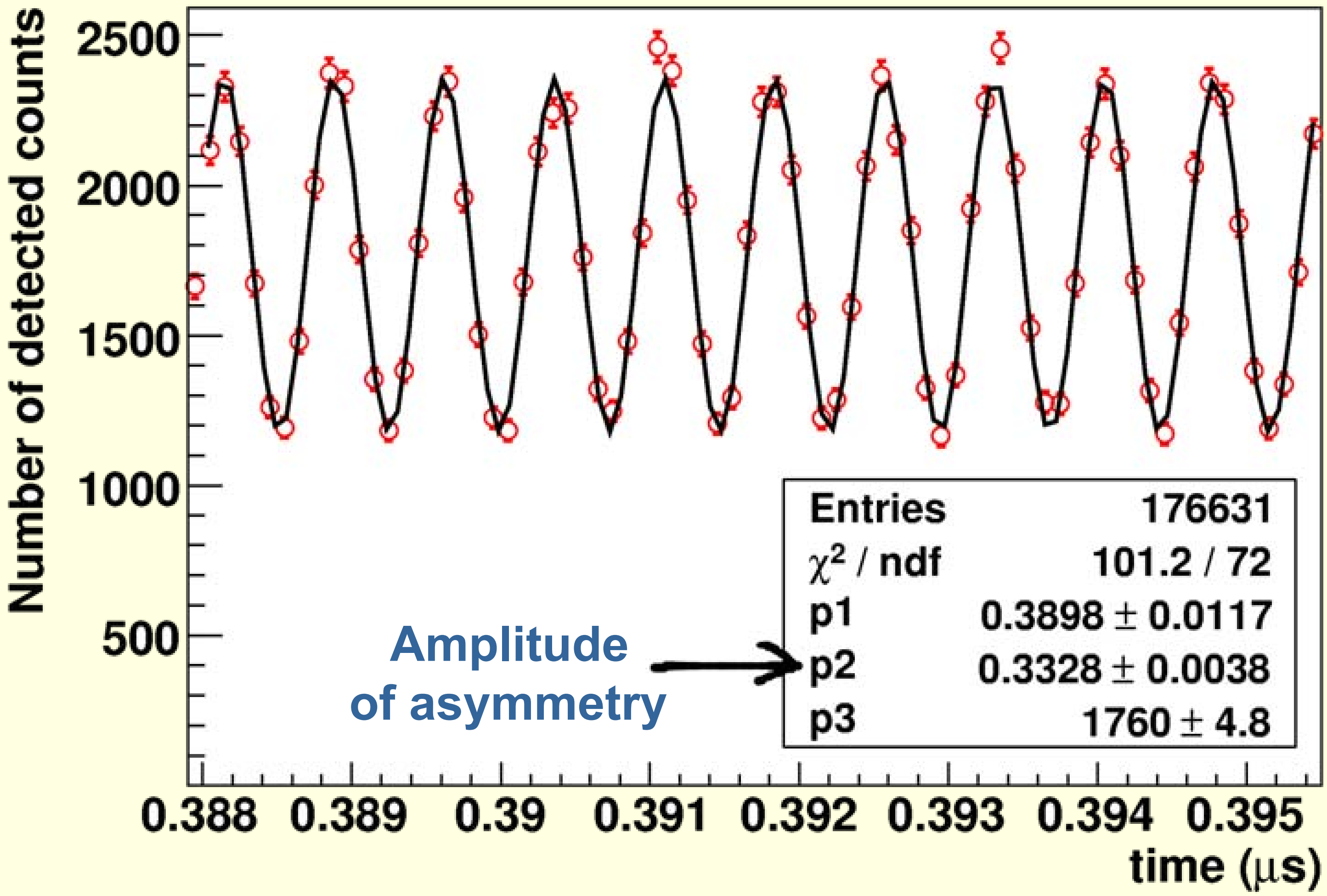
The detector has to be:

- small (due to the small e^+ bending radius in 10 Tesla field).
- very fast: σ(timing)=150ps
- insensitive to magnetic field ➔ using G-APDs instead of PMTs.

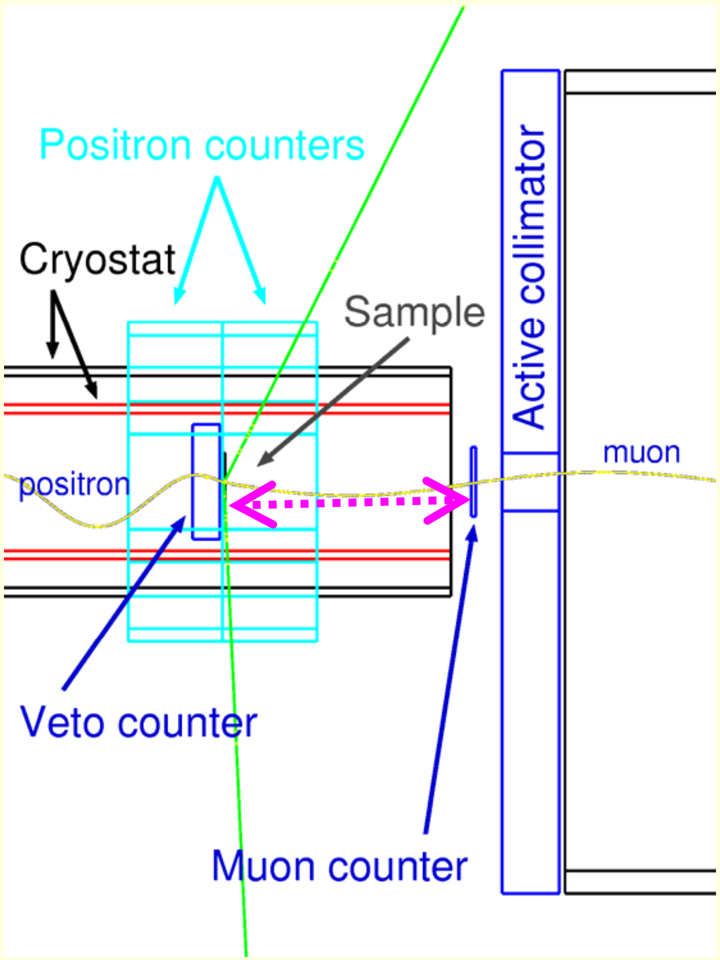


Magnetic field of the solenoid has to be very homogeneous, ΔH/H < 10 ppm over sample volume

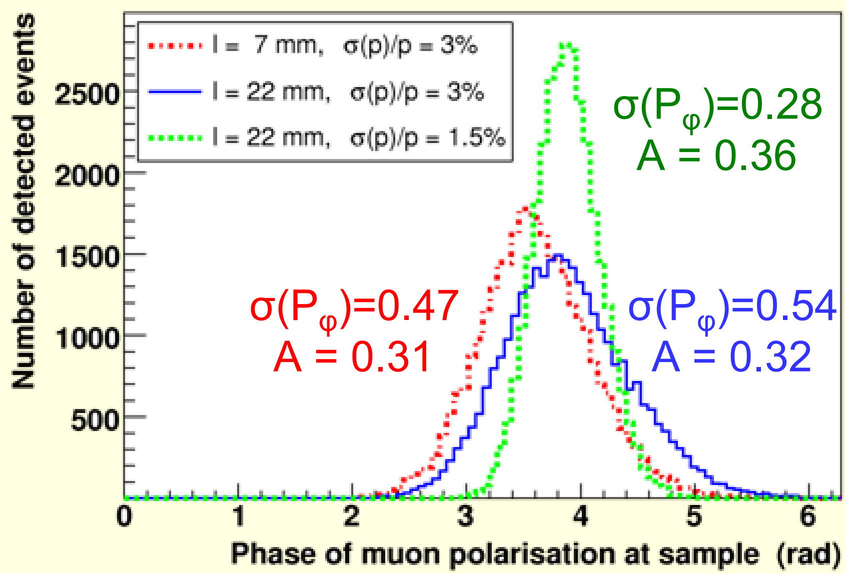
Asymmetry at 10 Tesla



Example of optimisation no. 1



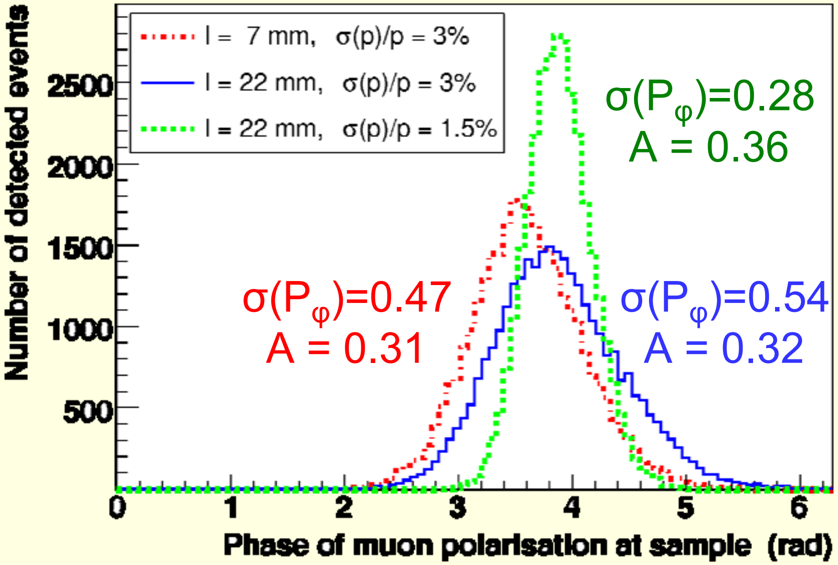
- What is the effect of the length between the muon counter and the sample on the muon spin dephasing (and subsequently on the measured asymmetry)?



Example of optimisation no. 1

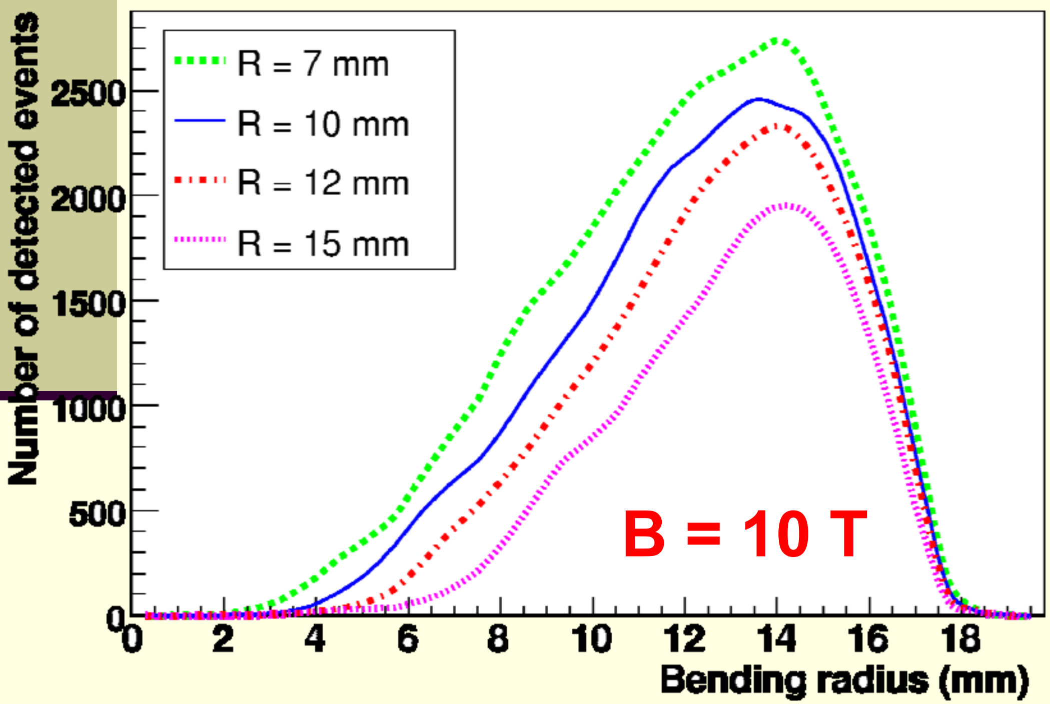
- Varying the distance between the muon counter and the sample from 7 to 22 mm has only negligible effect on the muon spin dephasing (asymmetry amplitude).
- Reducing momentum bite from 3% to 1.5% would help significantly.

- What is the effect of the length between the muon counter and the sample on the muon spin dephasing (and subsequently on the measured asymmetry)?

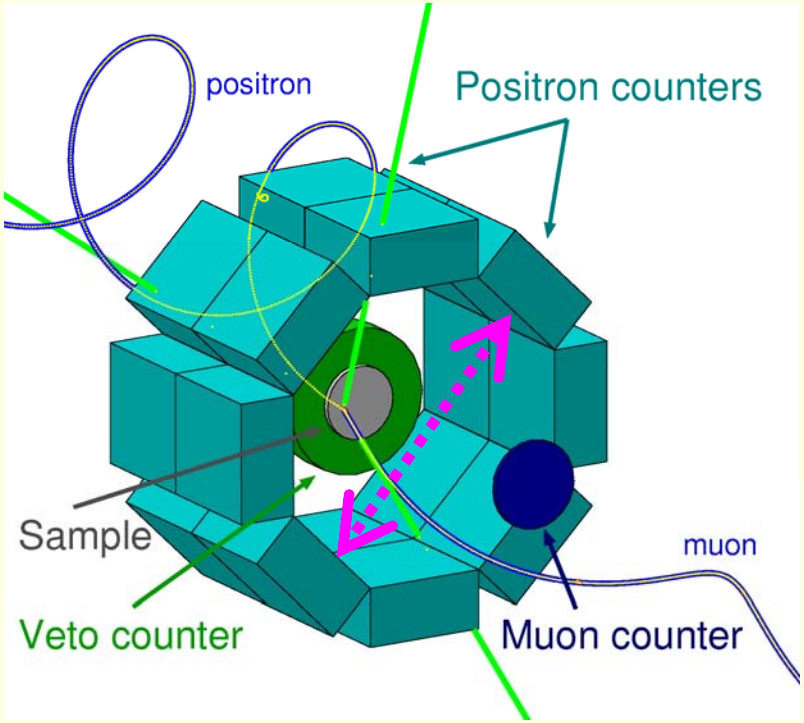


Example of optimisation no. 2

- What is the effect of the inner detector radius on the measurement of asymmetry?



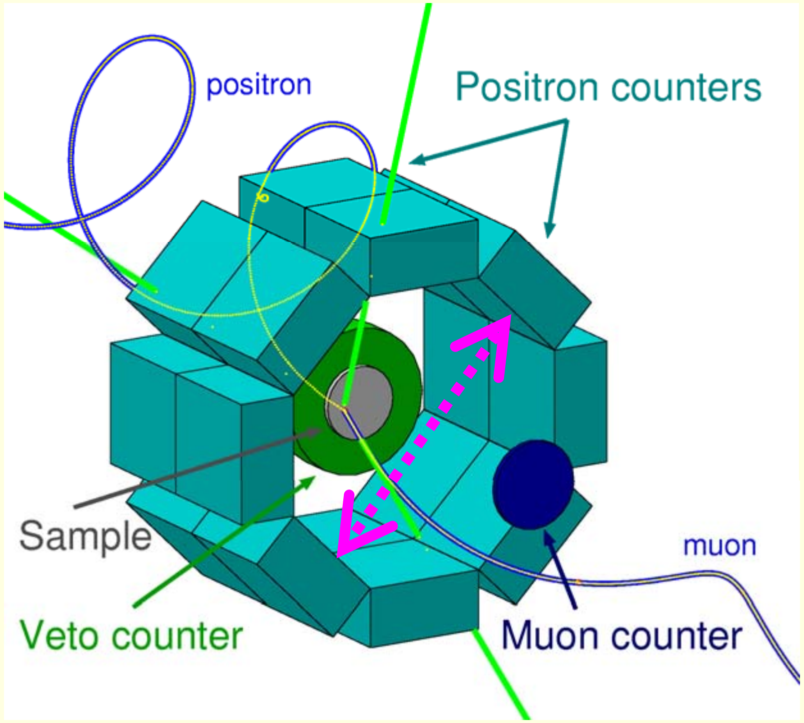
$= p_T/eB$



Example of optimisation no. 2

- What is the effect of the inner detector radius on the measurement of asymmetry?

R(mm)	N	A	$A\sqrt{N}$
7	36 400	0.31 ± 0.01	58.6
10	30 800	0.33 ± 0.01	56.3
12	26 300	0.34 ± 0.01	55.4
15	19 900	0.38 ± 0.01	53.7

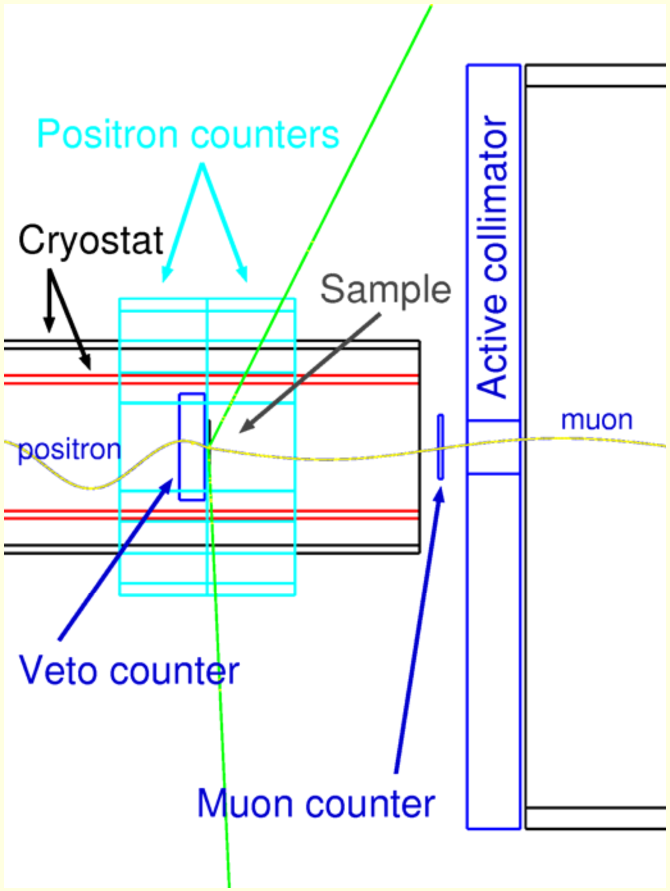


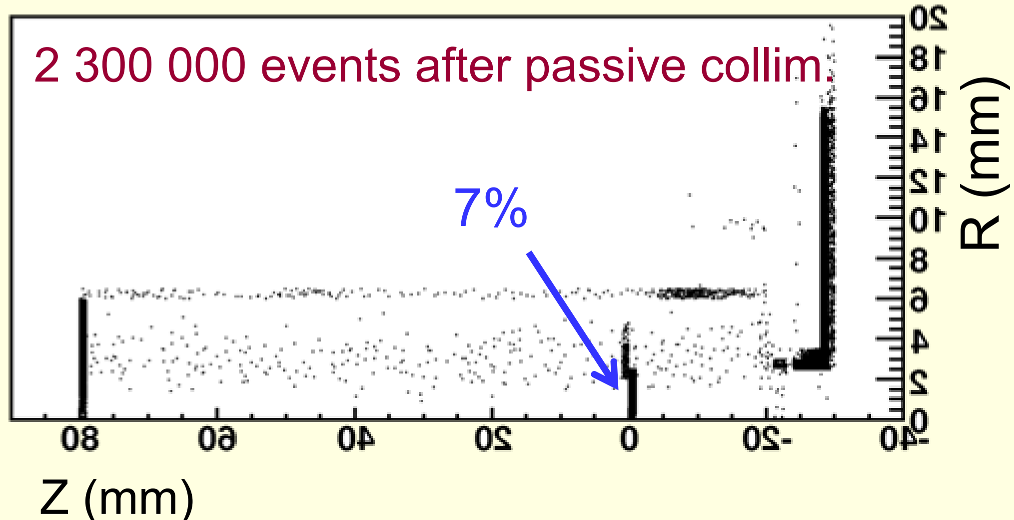
There are two competing effects for increasing detector radius R

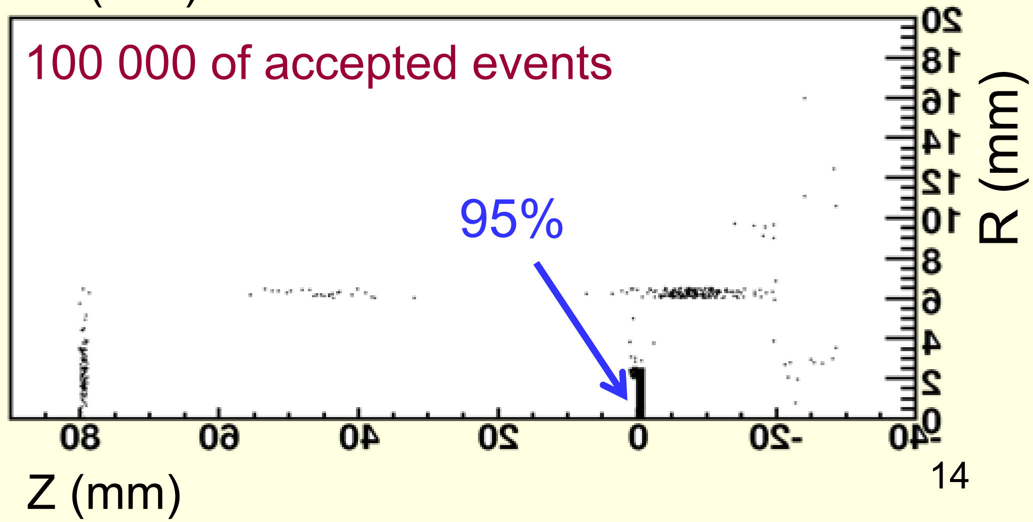
1. number of detected positrons decreases.
2. amplitude of asymmetry increases.

➔ The "figure of merit" ($A\sqrt{N}$) depends only weekly on R

Muon decay map







Summary

- Geant 4 simulations are becoming a standard tool for the instrument development at PSI.
- The simulation of the High Field instrument shows that:
  - We do not need to insist on a minimum possible distance between muon counter and the sample ➔ 22 mm is OK.
  - We do not loose too much (in terms of figure of merit $A\sqrt{N}$) when increasing the inner detector radius ➔ $R \approx 15$ mm is OK.
  - The quality of the measurements would clearly benefit from smaller momentum bite of the incoming muon beam (at present $\sigma(p)/p = \sim 3$ %).
- Further studies of the background signal and different options for the cryostat and magnets will be performed.

The simulations together with the tests of the fast positron and muon counters based on the Geiger-mode avalanche photodiods provide us confidence in the feasibility of the ~10 T field μSR instrument.