PAUL SCHERRER INSTITUT

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Geant4 Simulation of the High Field µSR Instrument

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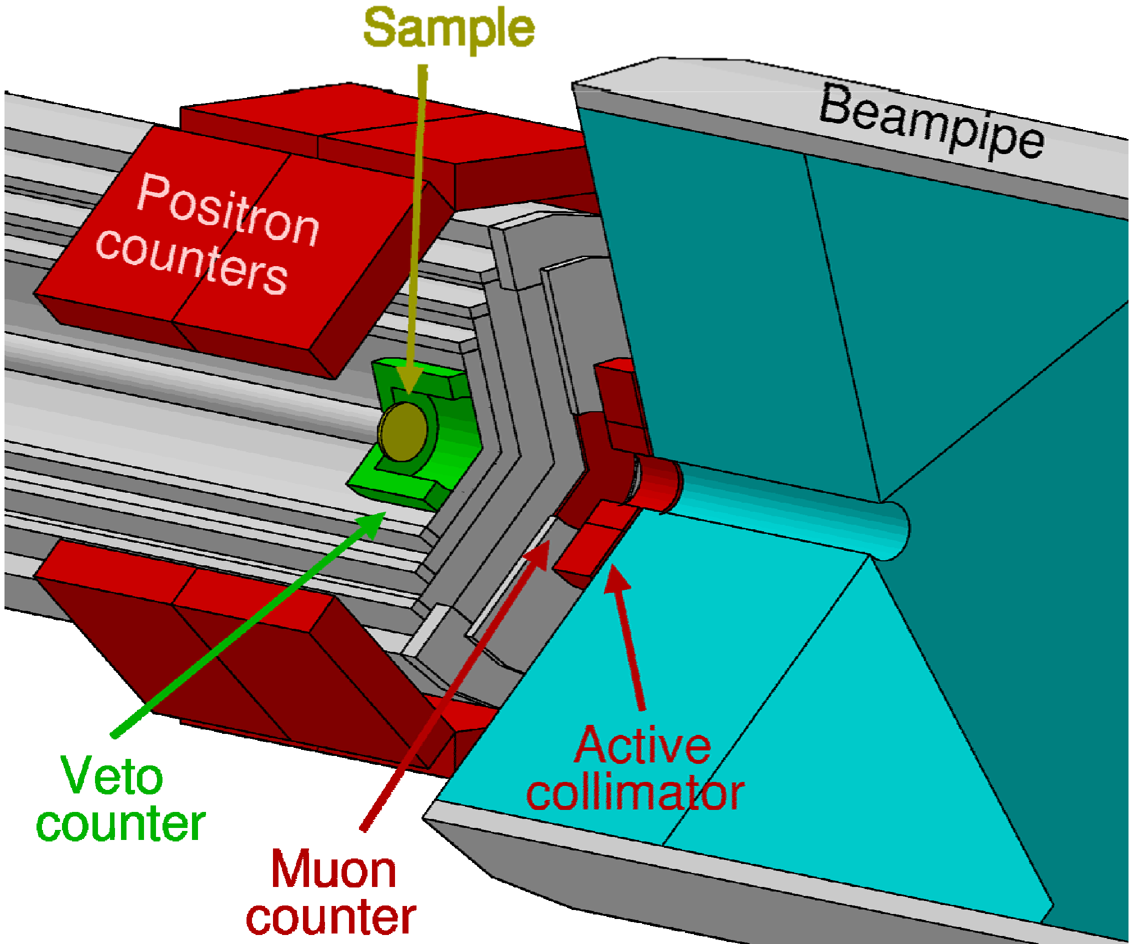
musrSim program

- *Geant 4*
  - standard tool to simulate passage of particles through matter, and the corresponding response of detectors.
  - developed and used mainly by particle physicists.

- *musrSim*
  - simulation program designed specifically for the simulation of μSR instruments.
  - based on Geant4.
  - based on the previous simulation programs done at PSI and ISIS by Thomas Prokscha, Taofiq Paraiso, Tom Lancaster, Zaher Salman, Toni Shiroka (and perhaps others).
  - general – the detector geometry and the muon beam are specified in a text input file ➔ different μSR instruments have different text input files, but share the same *musrSim* executable.

High Field detector geometry (with dilution fridge)



Sample diameter: 5 mm
Positron counter: 18 x 18 x 4 mm
Outer cryostat diameter: 42 mm

Main facts:

- Realistic detector geometry
- Realistic magnetic field (field maps calculated using the program OPERA).
- Realistic muon beam (first 24 meters of the beam-line calculated using TURTLE, last 100 cm using Geant4).
- Thresholds are applied on the energy deposited in the counters (scintillators) in a similar way as they are applied in discriminators in a real experiment.

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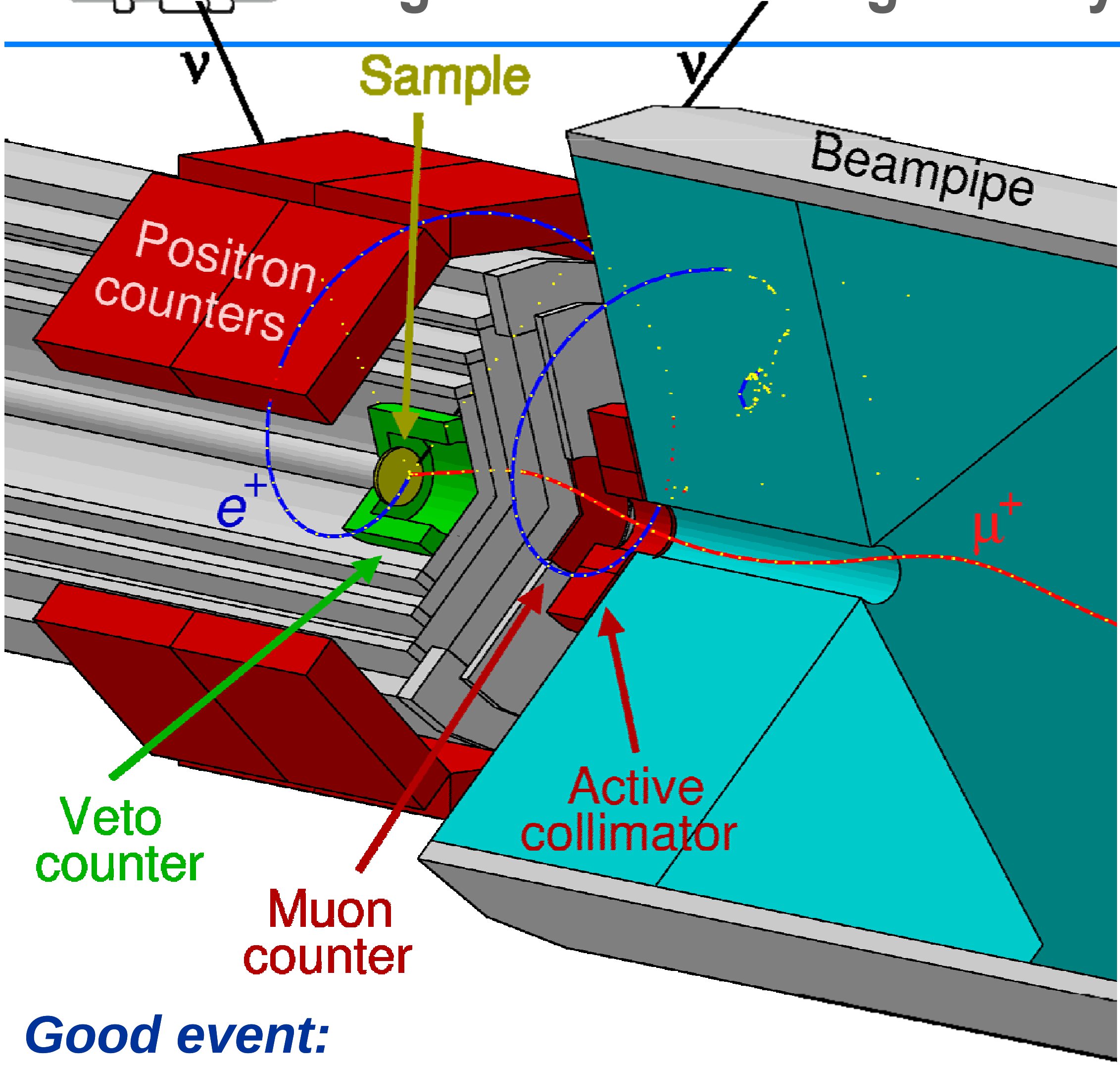

Good event:

muon passes through the muon counter
& positron hits pos. counter
& not rejected (pileup, veto, active collim.)

Advantages of the simulation:

- Easy to compare different detector designs (magnets, cryostats, ...).
- Easy to disentangle effects of one particular change in the design (detector inner radius, muon counter thickness, design of the veto counter, ...).
- Easy to relate the "generated" variables with the "observation" ("detected" signal) → we always know whether the measured signal comes from the muon in sample or from elsewhere (background).

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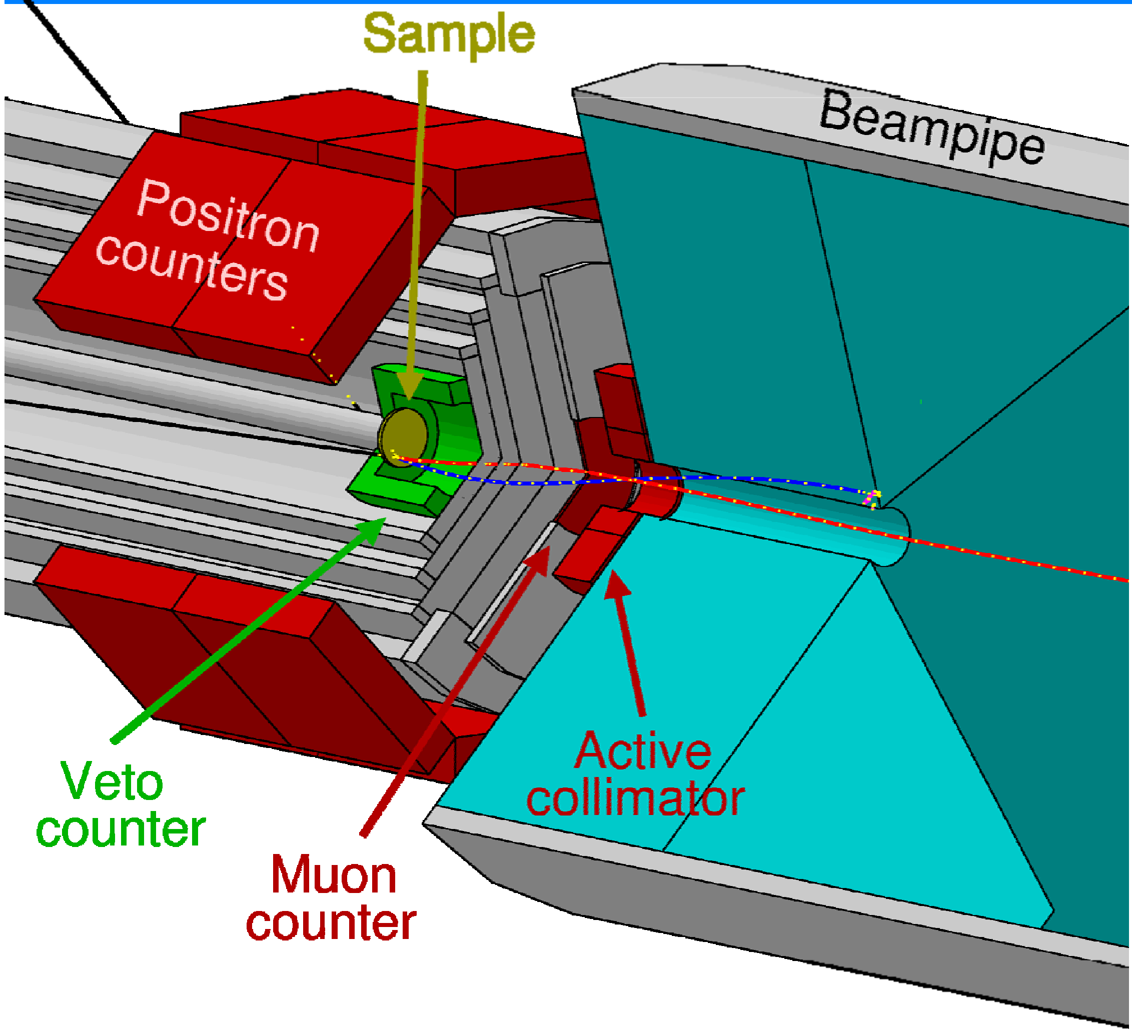


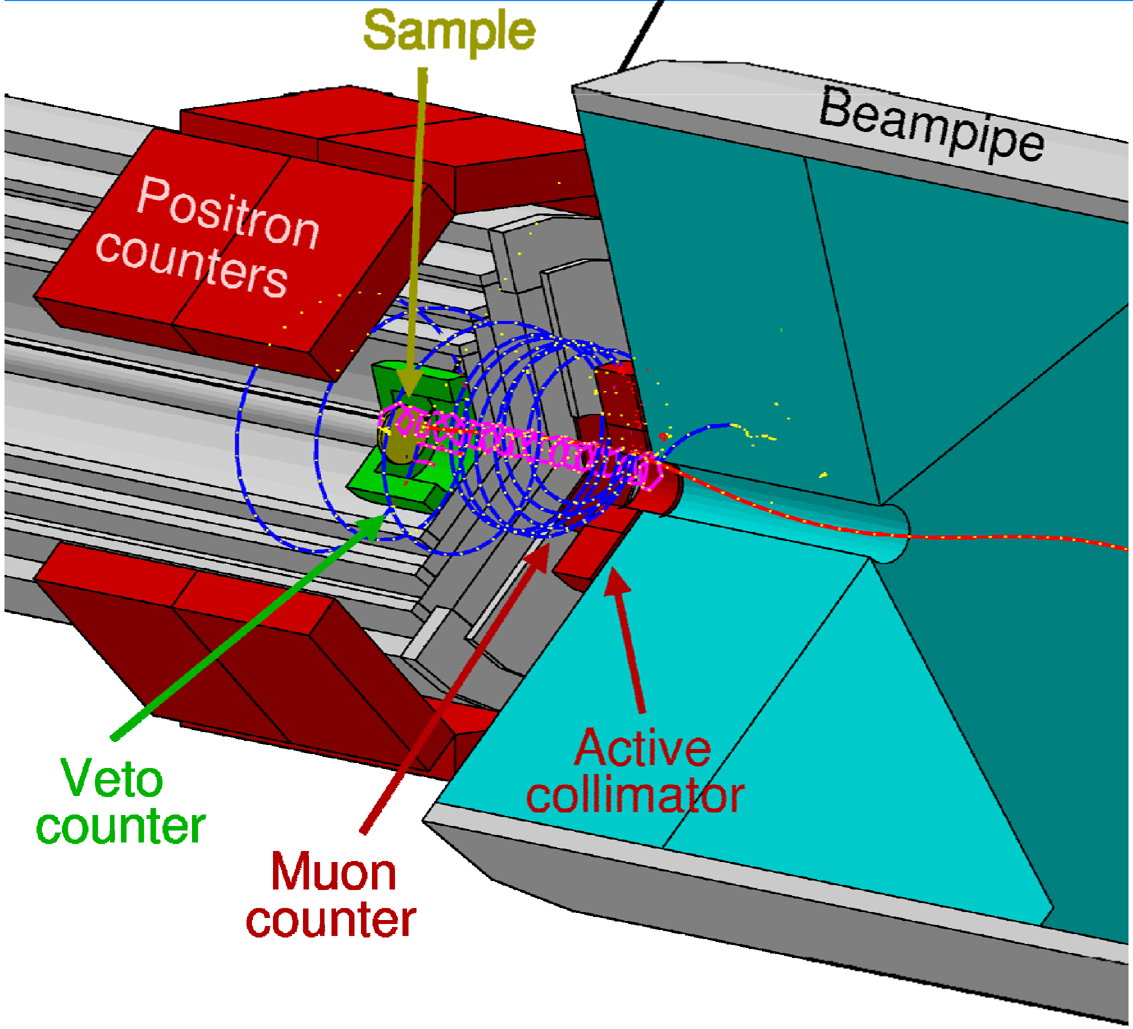
Advantages of the simulation:

- Possibility to investigate the pileup background (muon of one event starts the clock, positron of other event hits the positron counter within 10 μs).

Potential pile-up event:

muon passes through the muon counter (clock started)
& data gate on positron counters opened for background

High Field detector geometry (with dilution fridge)



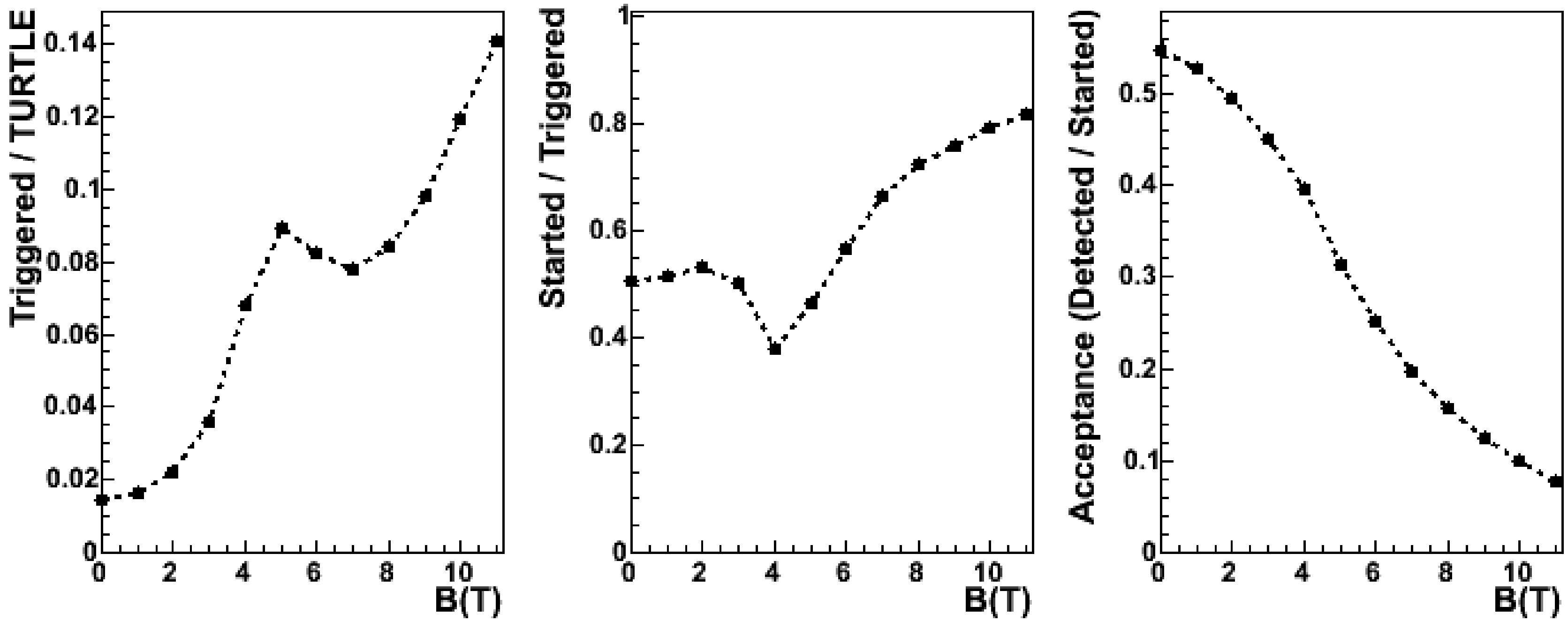
Limitations of the simulation:

- Simulation is much slower than real measurements (1 million of "good" and "bad" events at 10 tesla takes ~10 hours of computing time on an ordinary PC).

Messy event (again potential pile-up):

muon passes through the muon counter (clock started)
& positron and electron spiral out undetected

Trigger rate and detector acceptance



- Number of triggered muons increases with field (focusing effect of the High Field magnet). However, only ~30 000 μ/second are wanted for the time-differential μSR.
- "Started" = Trigger & NOT (active collim. at T_0) & NOT (veto counter at T_0).
- Acceptance = (# of events with a good hit in positron counter) / (# started)
  It is decreasing due to the bending of electron trajectories at high fields.

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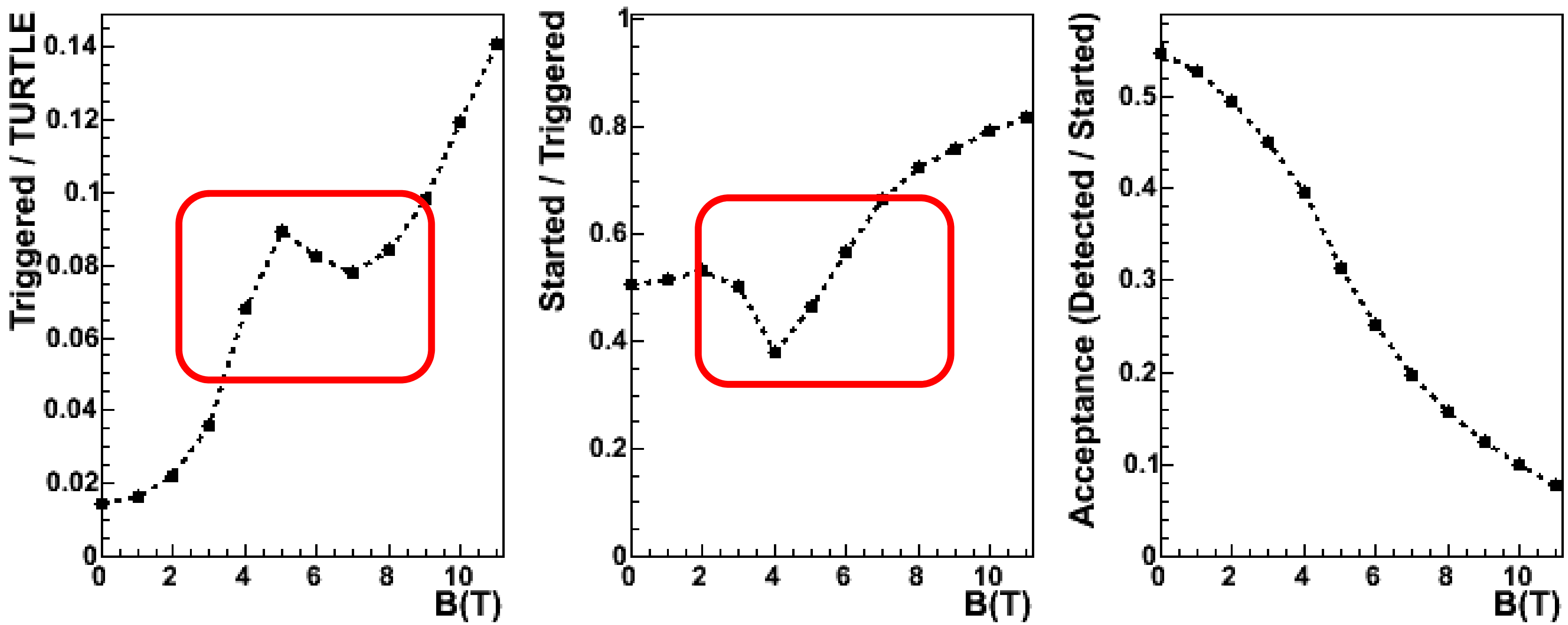

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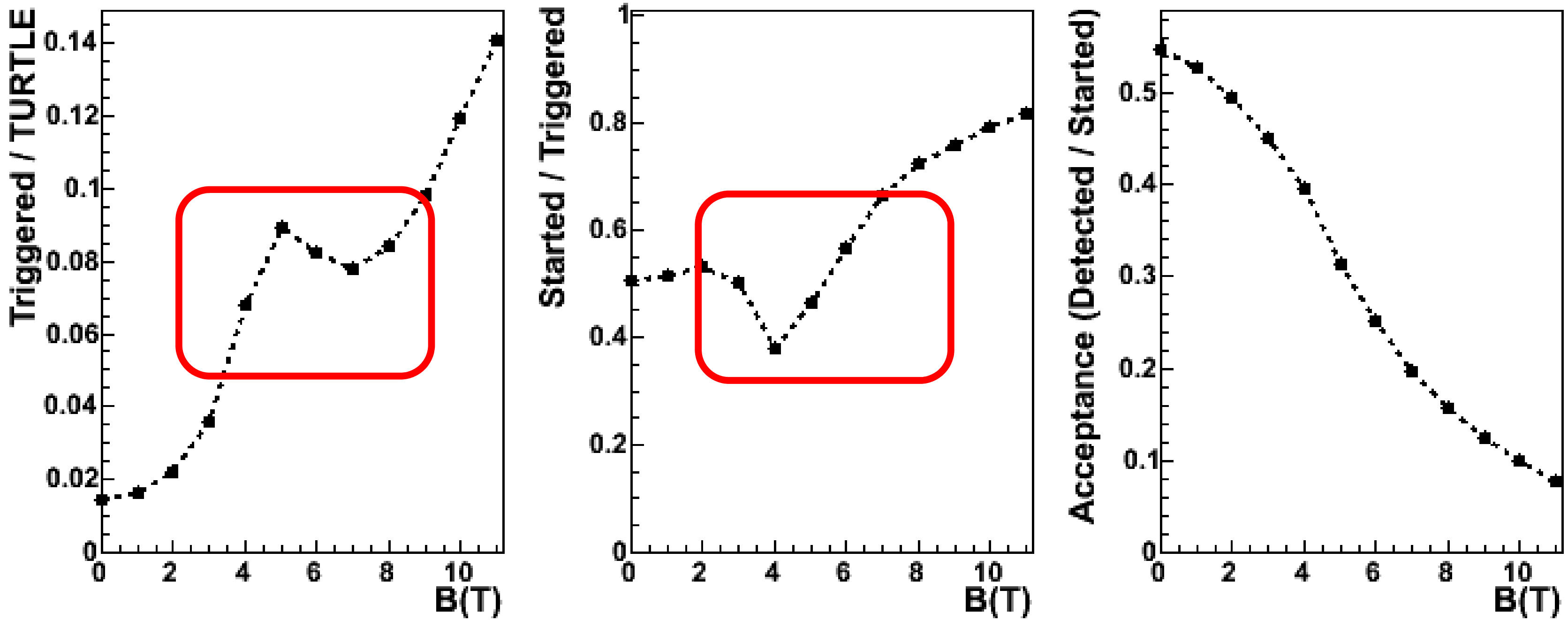

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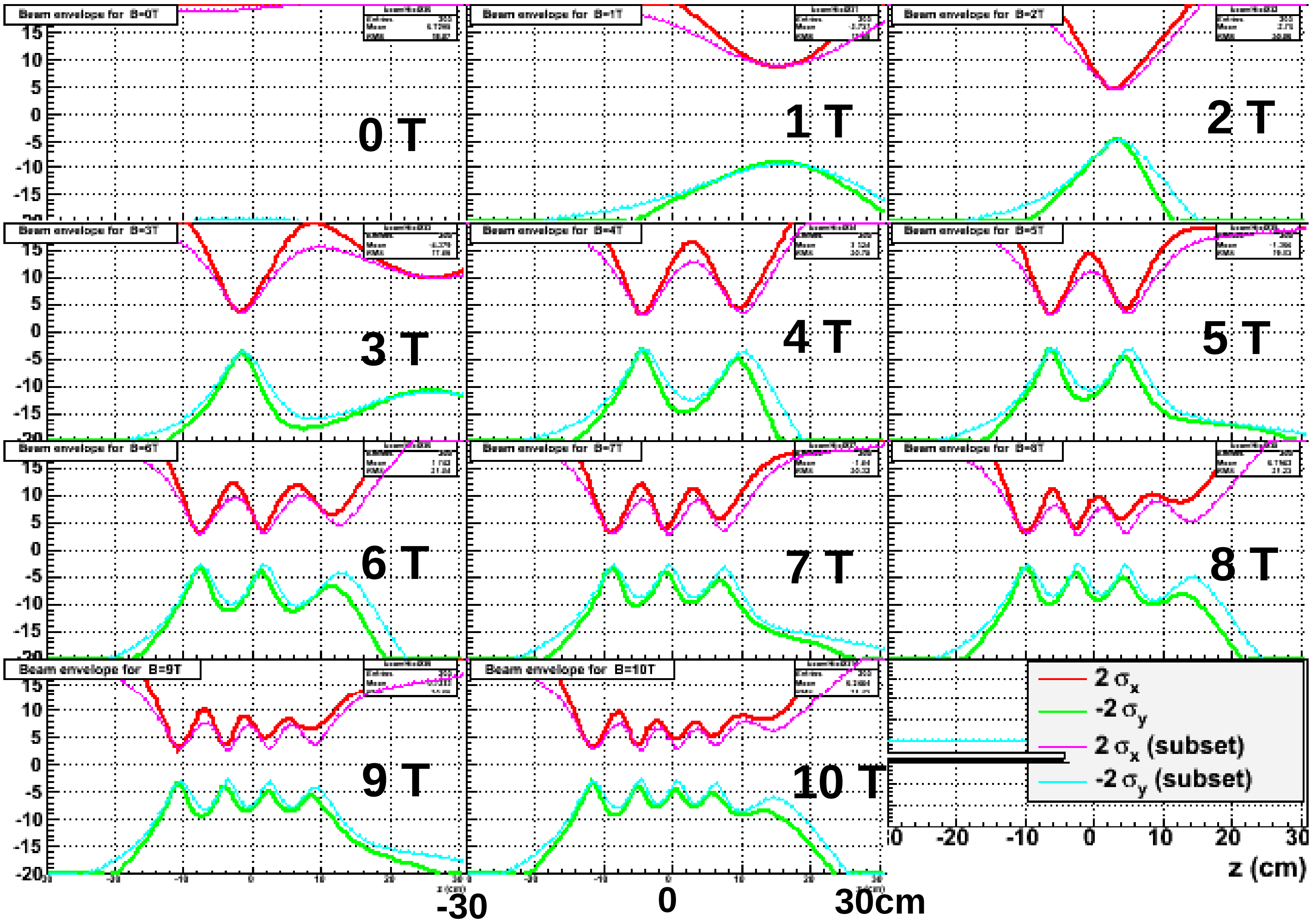
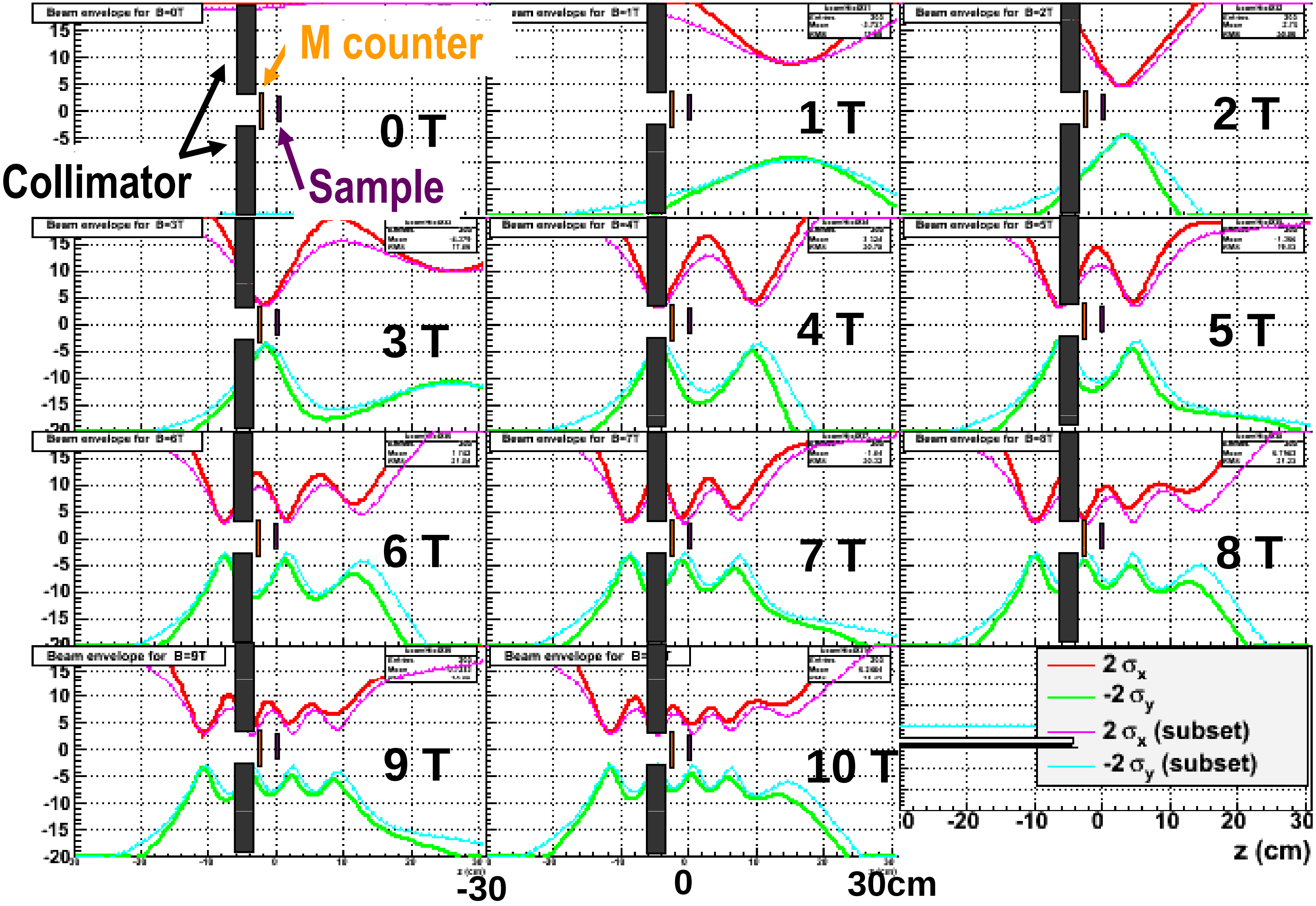
- **Why there are strange peaks at 4 – 5 tesla?**

  ➔ Oscillations of the muon beam envelope in the High Field magnet.

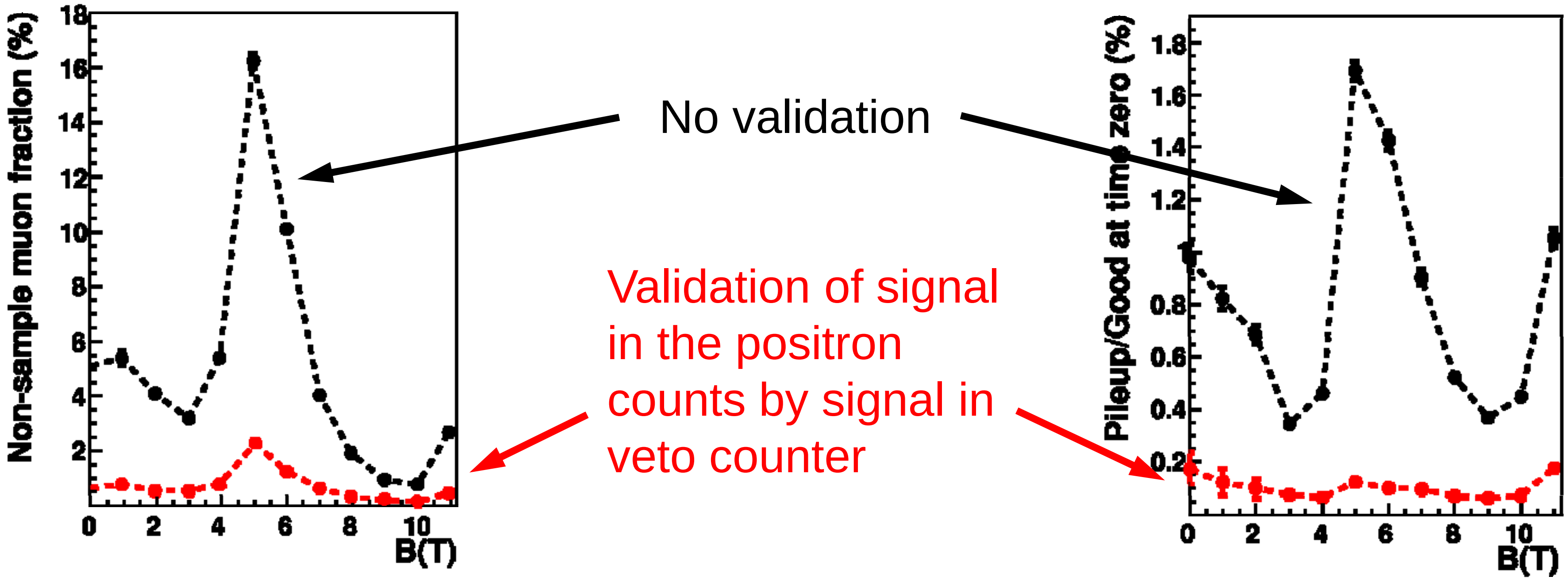
Muon beam envelope



Muon beam envelope



Background



Non-sample muon fraction:

- due to good looking events, in which muon stops outside the sample.

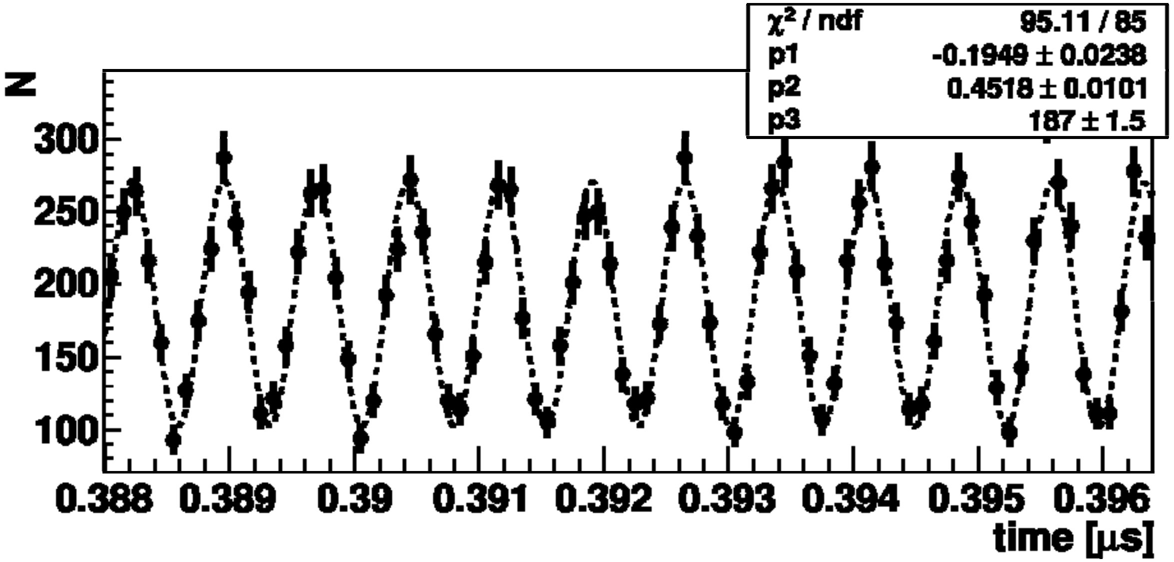
Pileup/Good at time zero: (assumed 30 000 triggered muons/second)

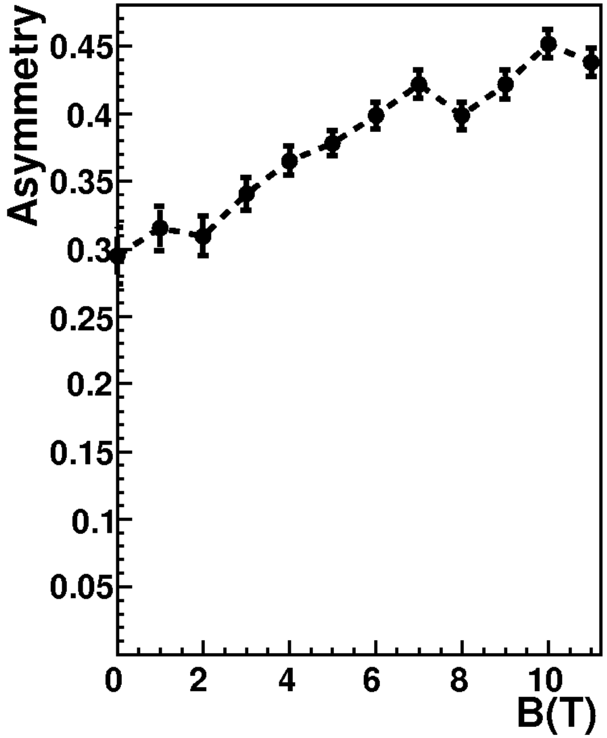
- trigger initiated in event nr. “N”, positron counter hit comes from event M≠N.

Validation of the positron signal:

- veto detector acts as veto for m-counter signal around t_0, and simultaneously as a coincidence detector (perhaps with a lower threshold) around t_1.
- Reduces background significantly, but spoils the measurement around t_0.

Effects on asymmetry at high fields





Other potential effects on asymmetry at high fields:

+ Escape of low energy positrons on a helical trajectory
- Dephasing of the muon polarisation before muons reach the sample
- Different bending angles of positrons with different energies
- Detection of secondary particles (electron, gamma)
- Multiple scattering of positrons on cryostat walls

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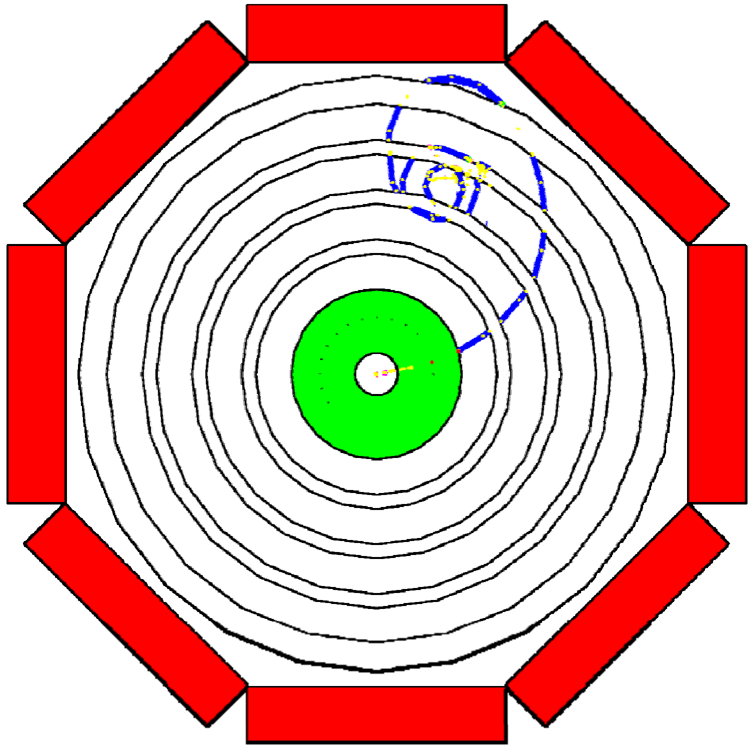

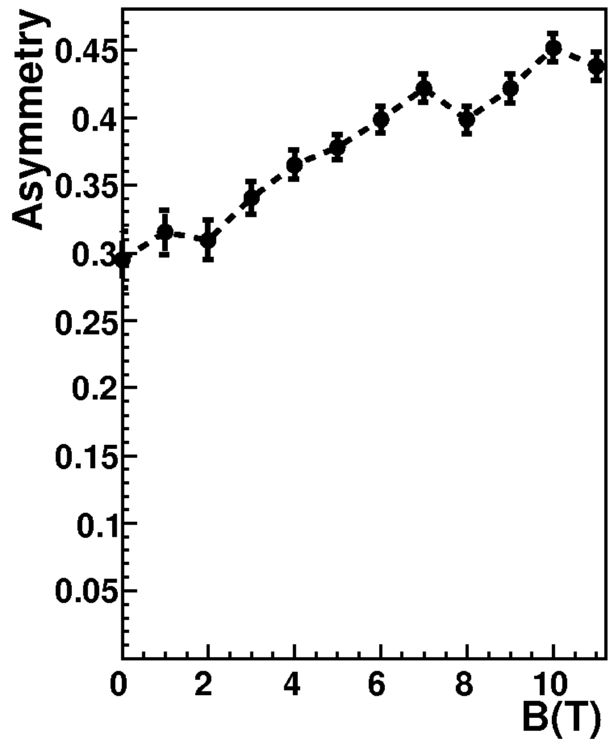

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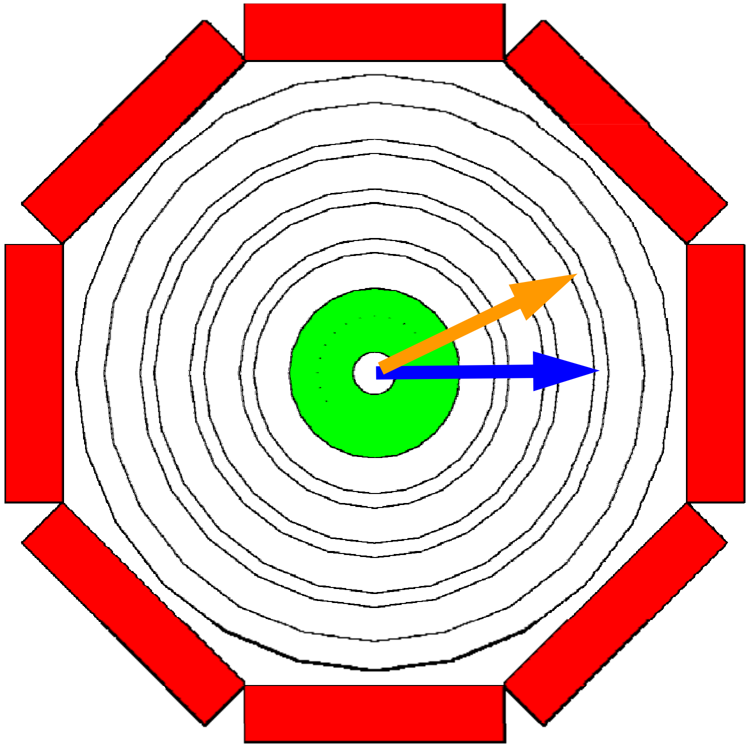

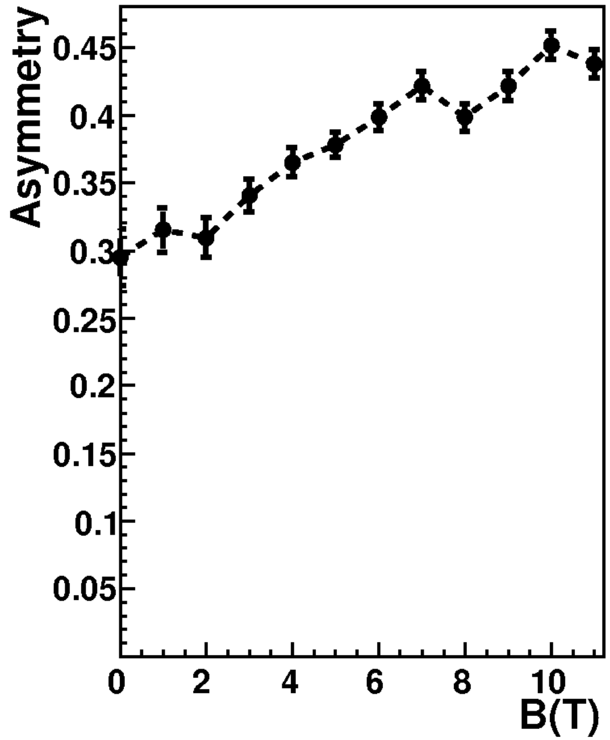

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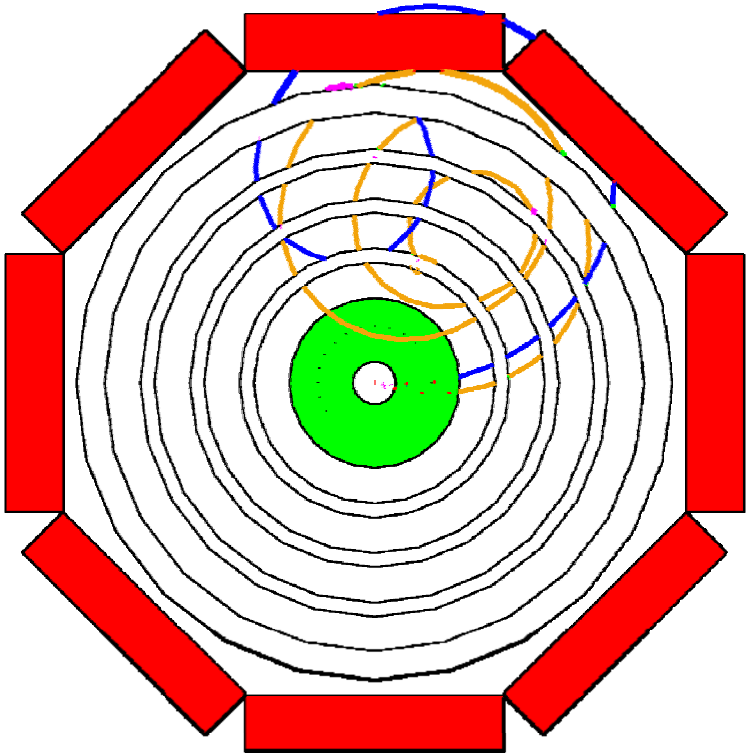

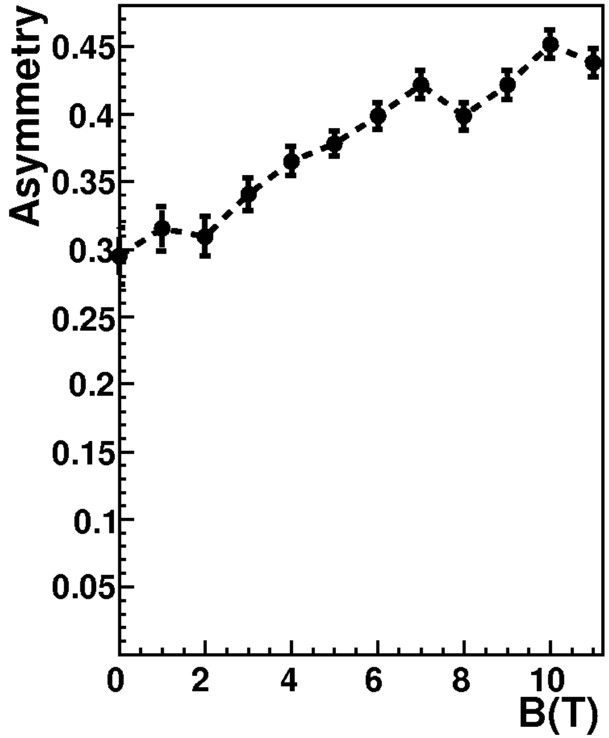

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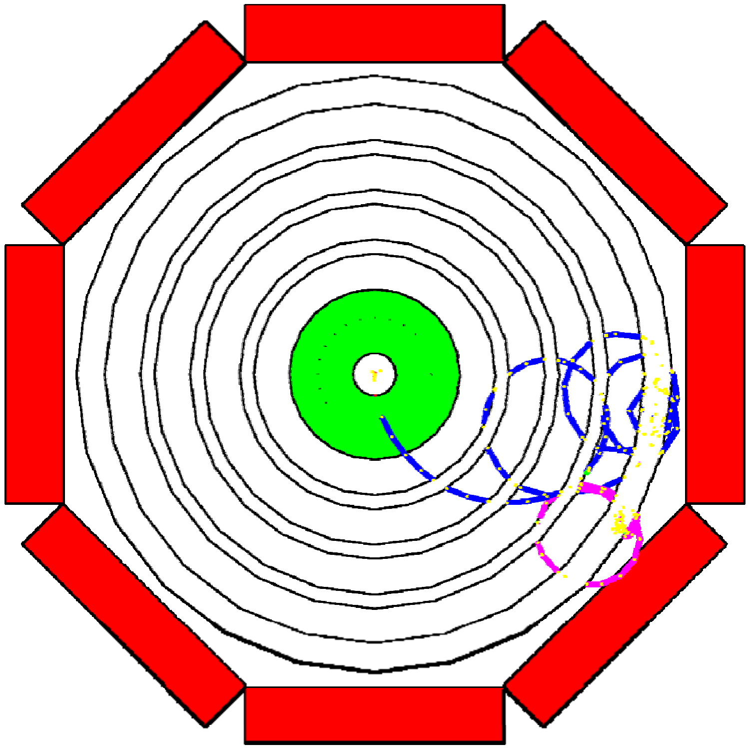

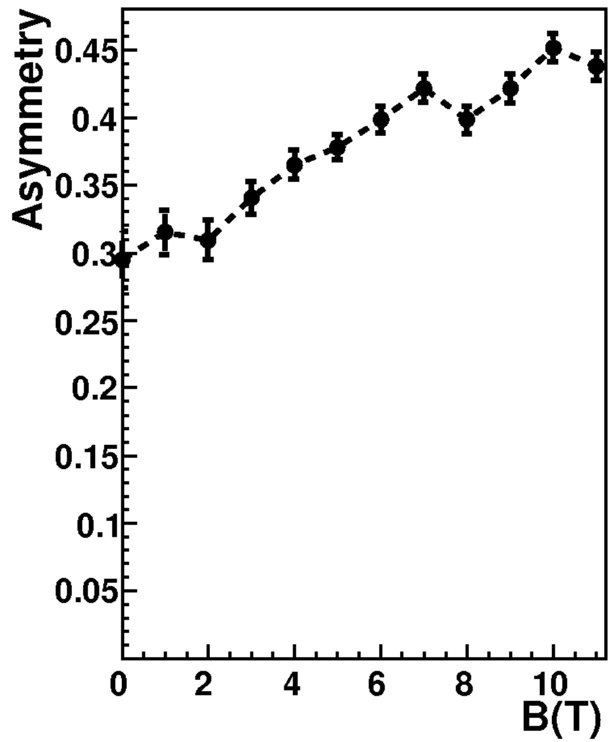

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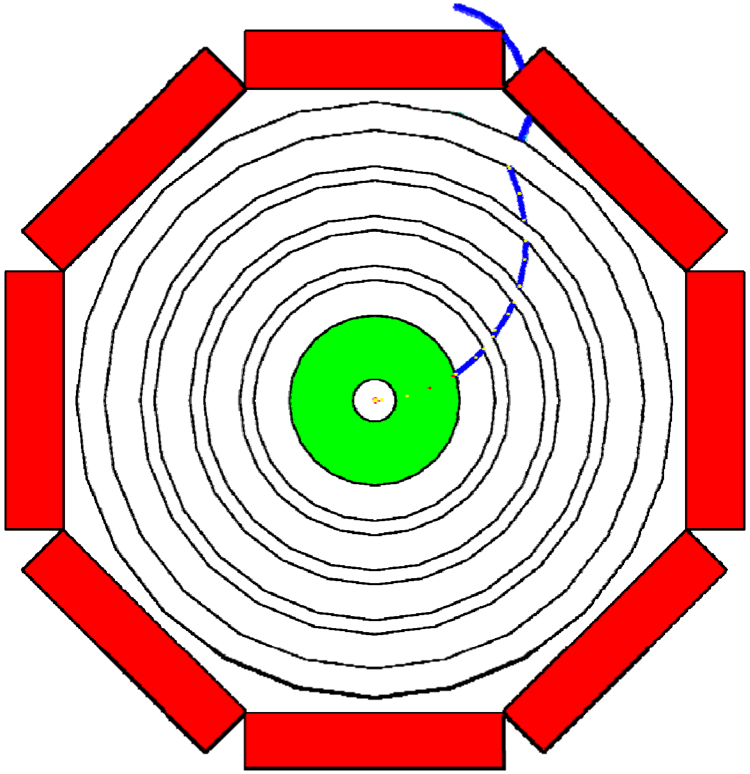

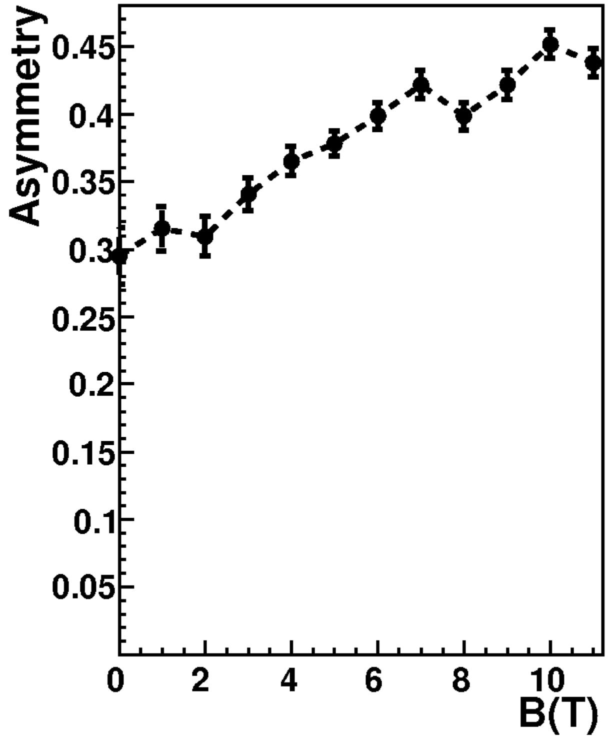

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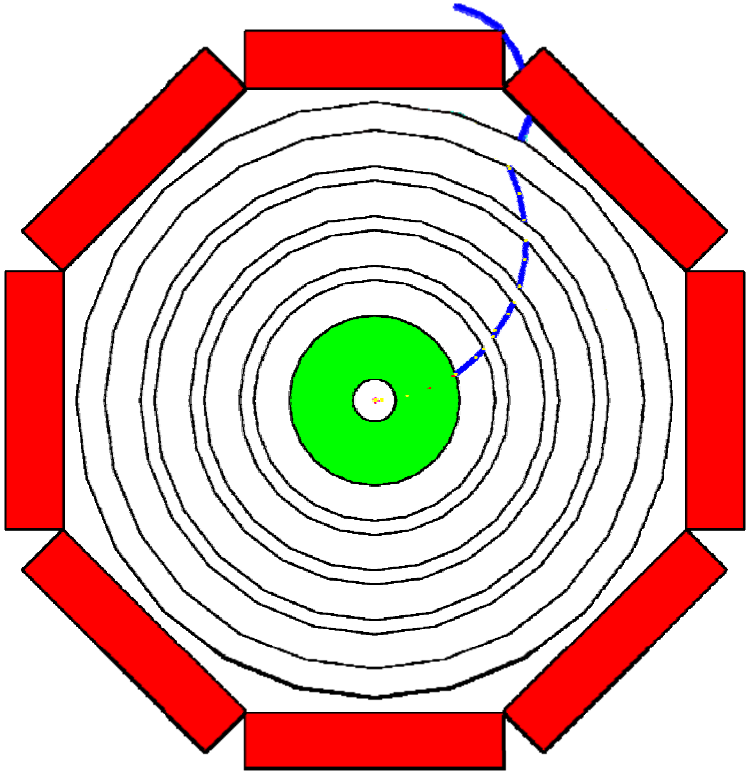
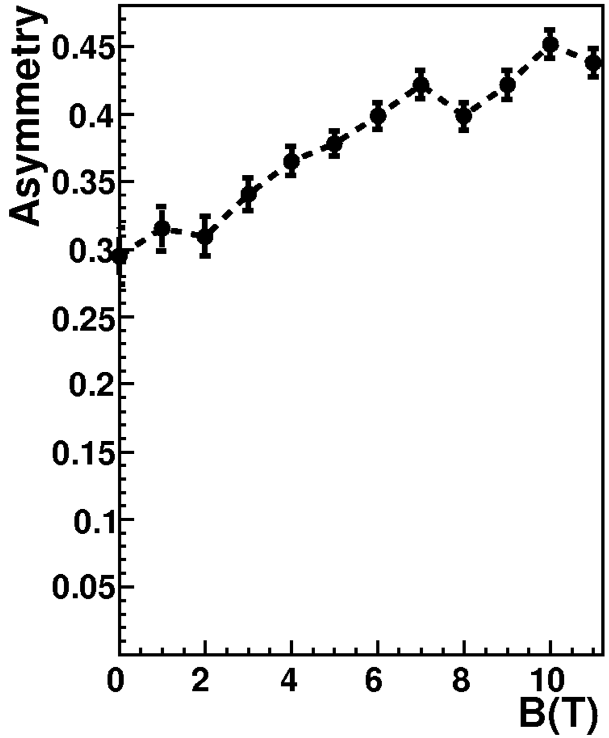




Other potential effects on asymmetry at high fields:

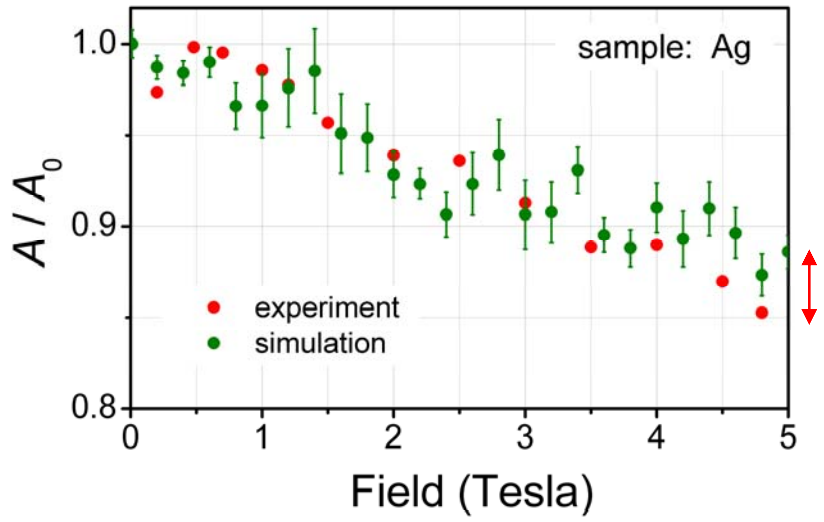
...

...

...

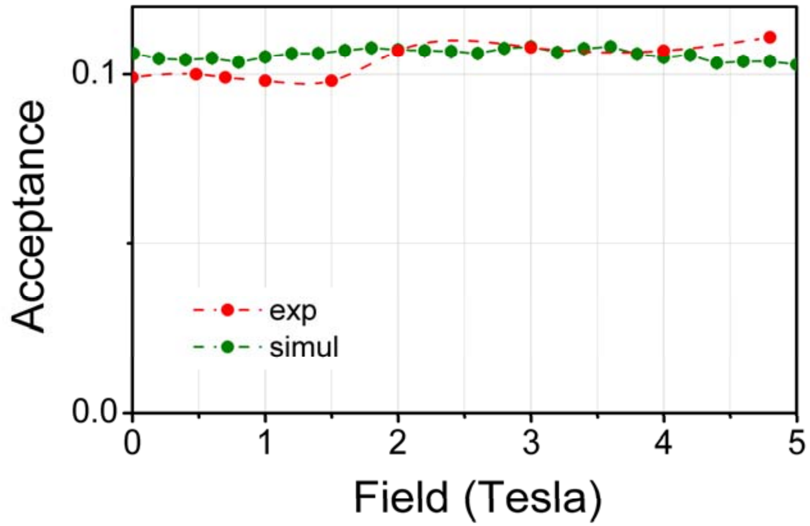
(and the finite time resolution of the TDC, finite bin-widths, ...)

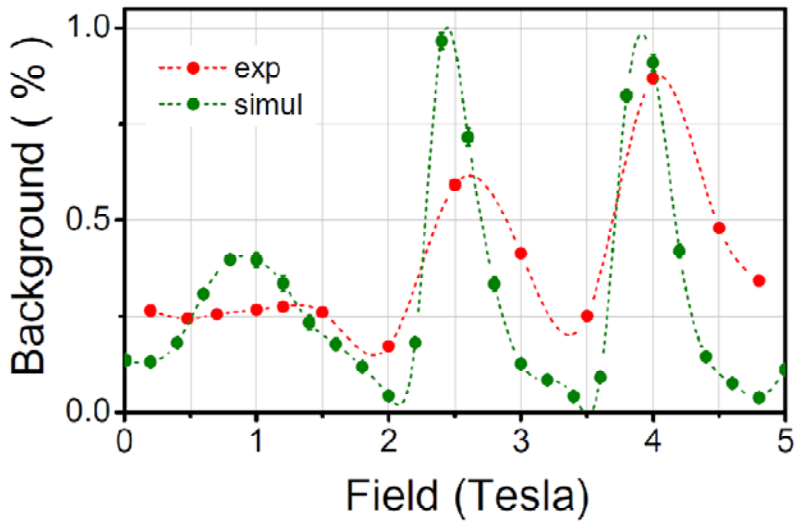
December 2009 tests



Relative change of asymmetry **~0.05** at 4.8T is consistent with the time resolution of **~90 ps** , which is not considered in the simulation.

Pile-up background – very sensitive to the incoming muon beam (beam tilt, offset, ...) – known with just a limited precision.





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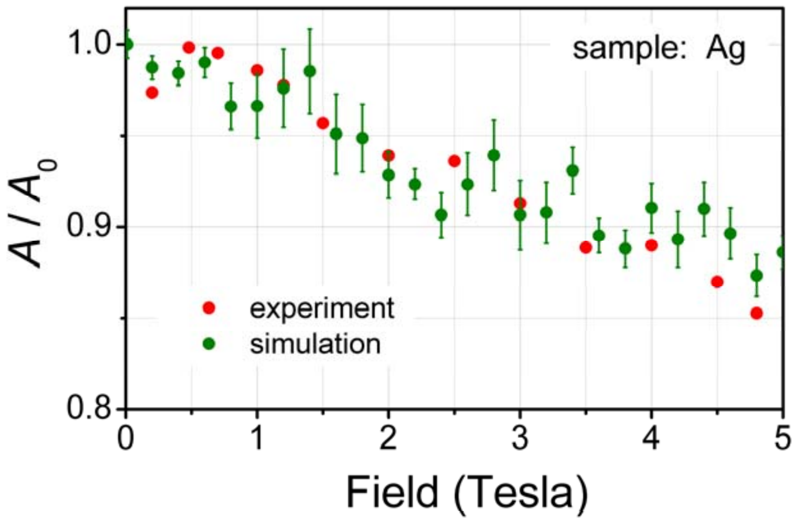
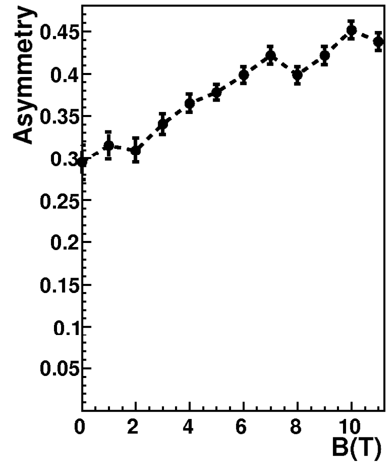
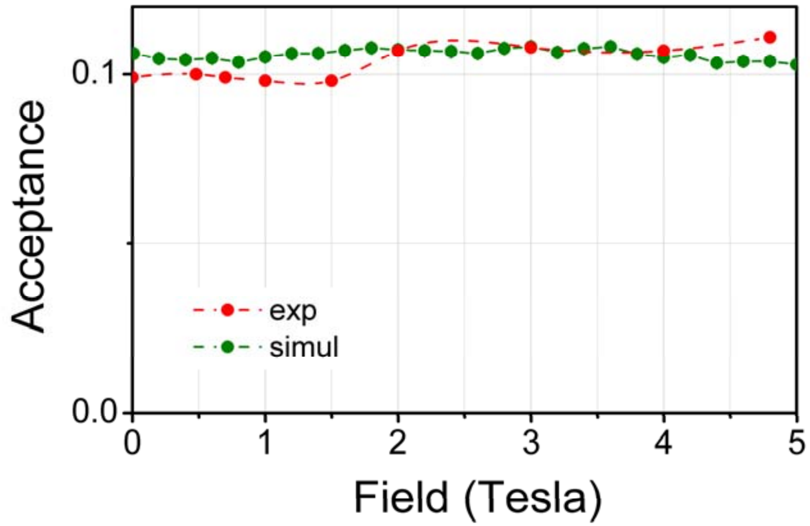
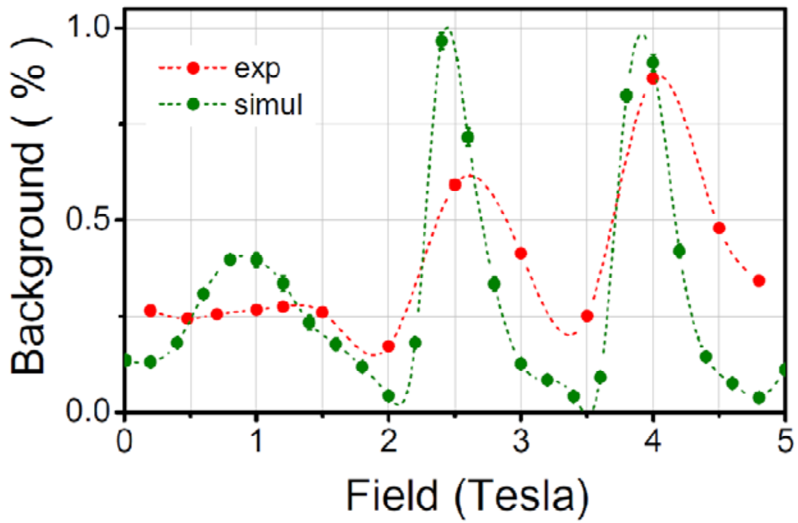


Why A/A_0 is decreasing while it was increasing on the previous slides?







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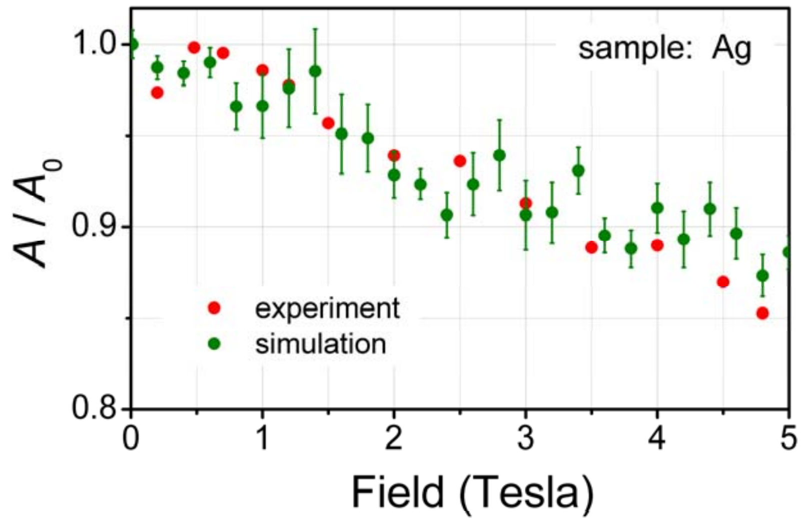
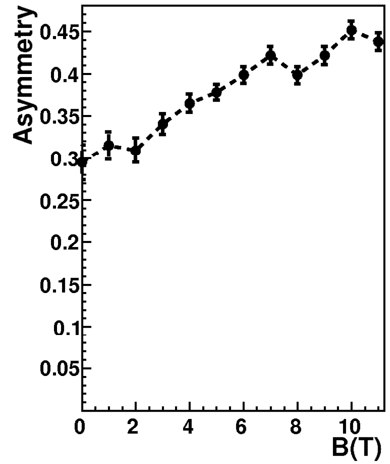
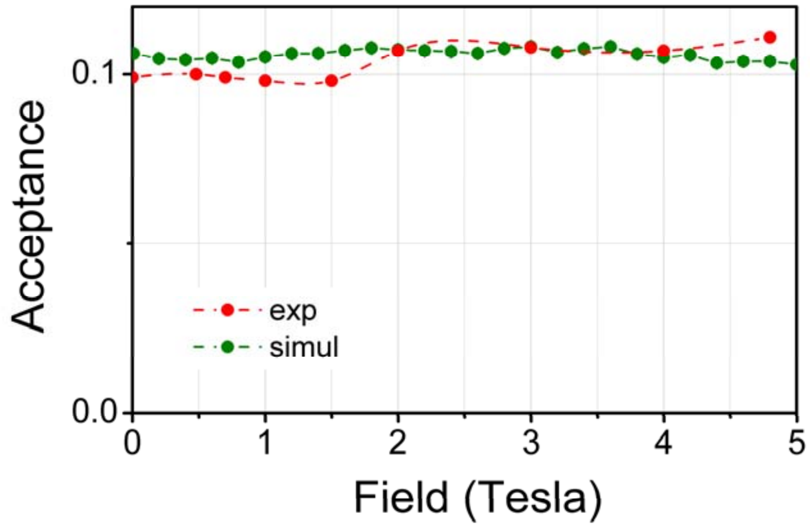
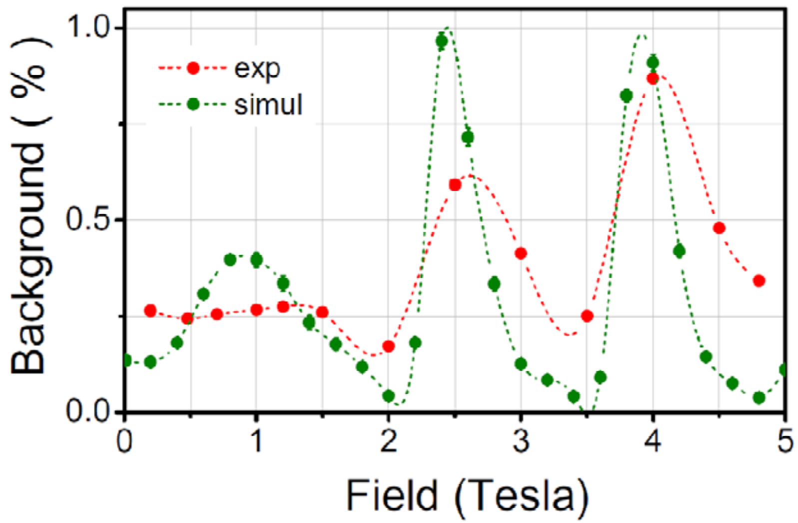


Why A/A_0 is decreasing while it was increasing on the previous slides?

Because ALC magnet used in this test is very long ➔ big field integral ➔ big initial muon spin dephasing (before muon reaches the sample).

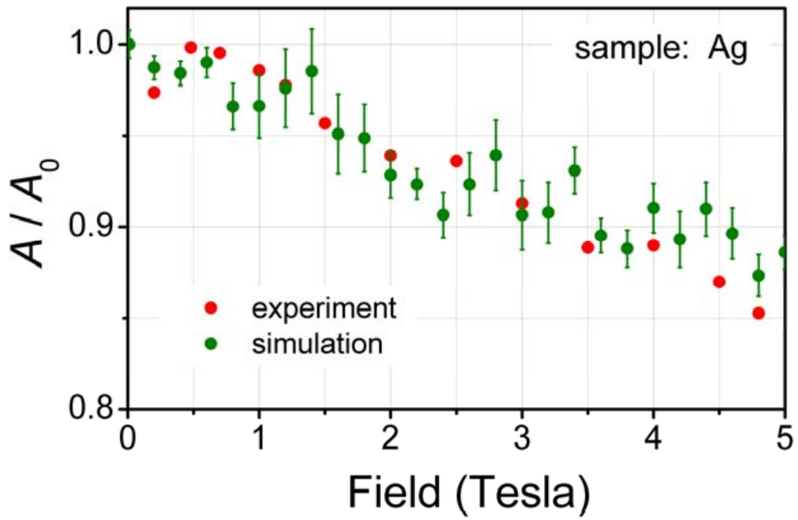


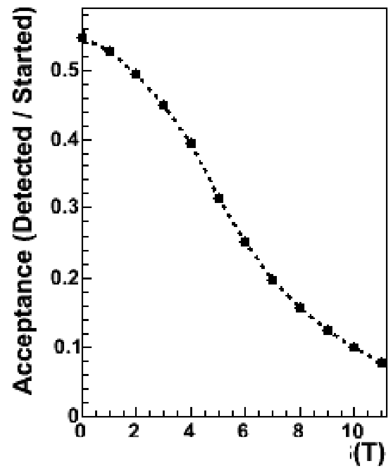


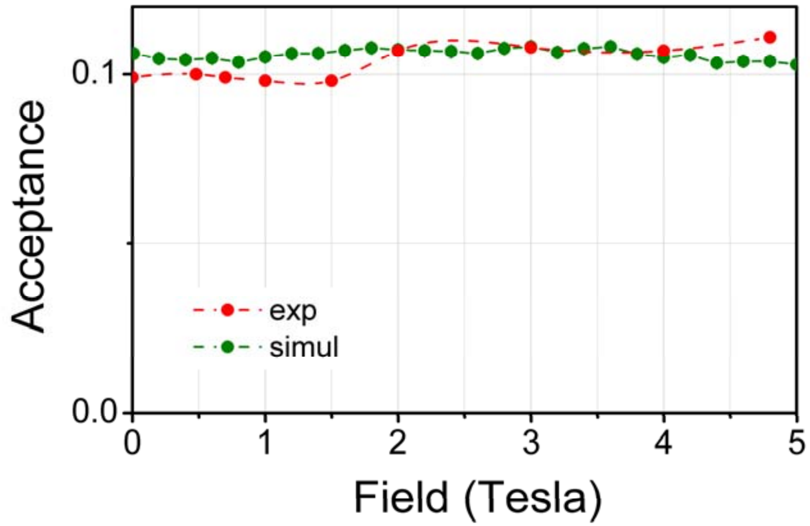


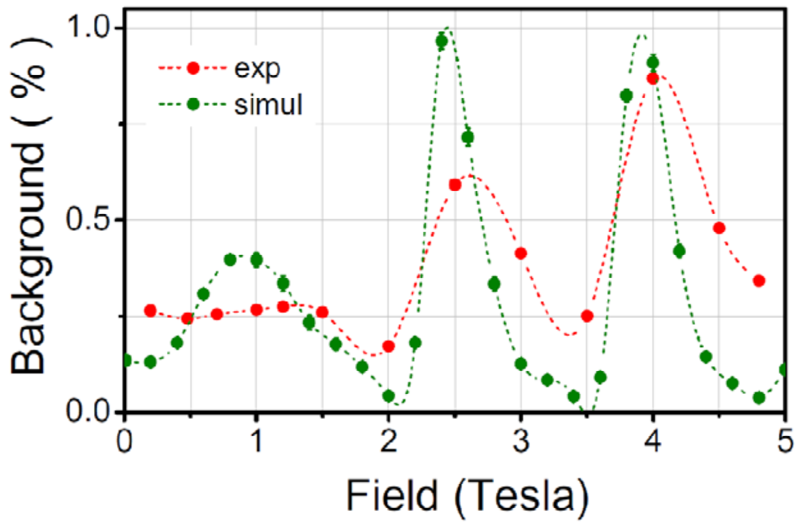
December 2009 tests

Why acceptance is constant while it was decreasing on some previous slide?









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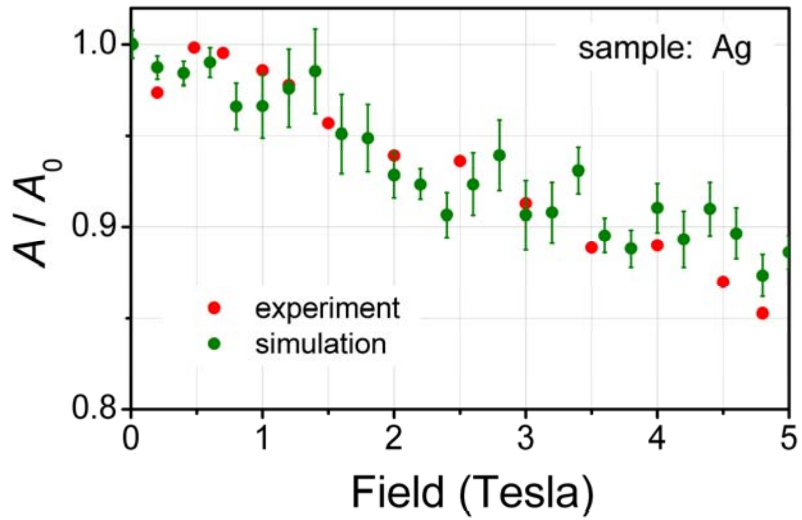
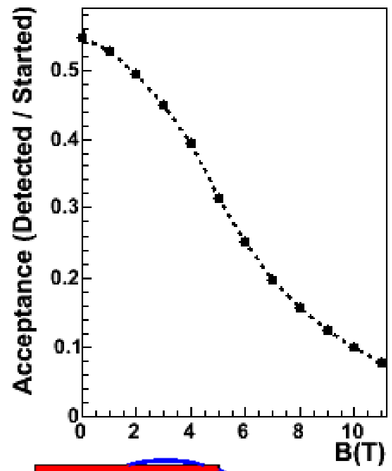
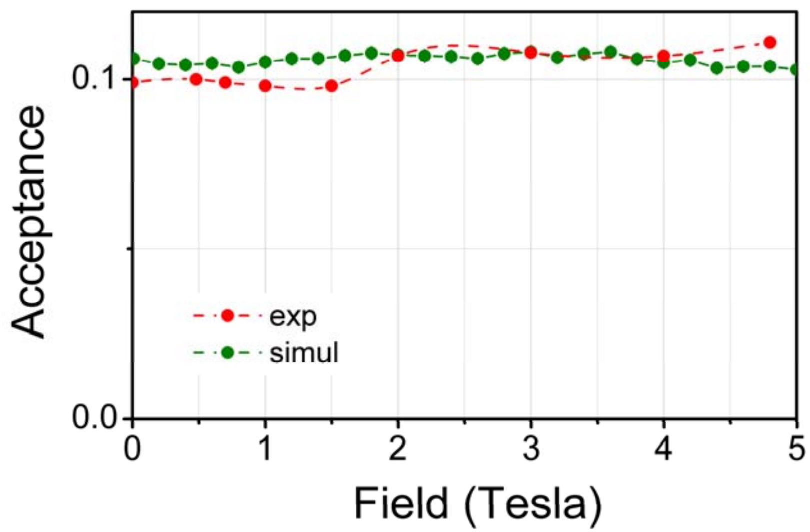
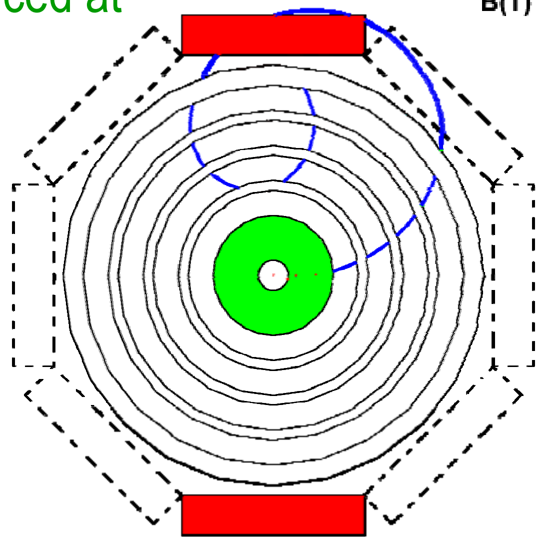


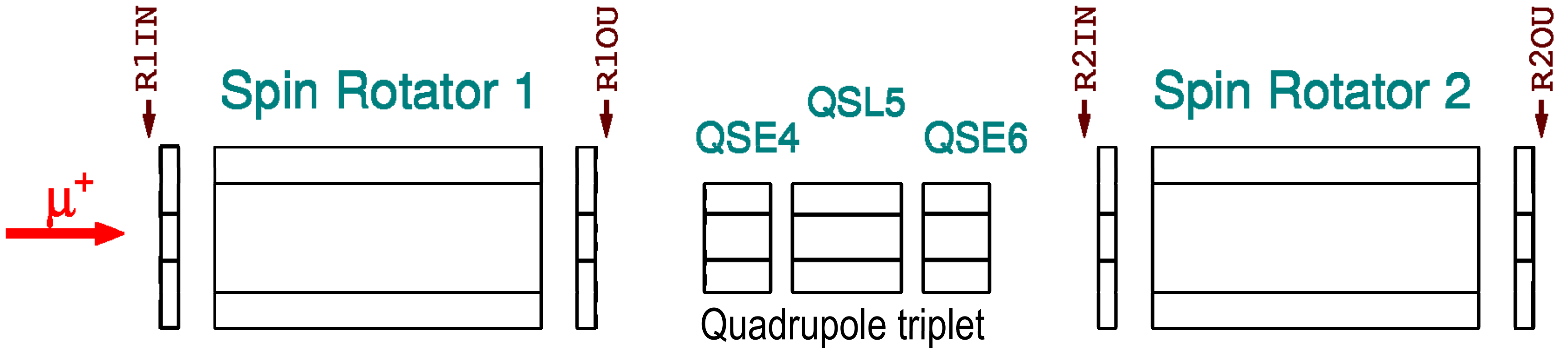
Because there were only two opposite counters in the test (instead of eight in the default High Field geometry) ➔ number of double hits (which are rejected from the analysis) was significantly reduced at high fields







Spin Rotator (under development at PSI)



Spin Rotator – rotates the muon spin from “longitudinal” to “transverse” direction

	Single spin rotator	2 spin rotators + quadrupole triplet
Transmission for realistic beam	89%	56% (37%)
RMS of μ momentum bite (initial value was 3.5%)	2.8%	4.3% (1.3%)
Spin rotation ± RMS	45°±1.5°	90°± 6.4° (90°± 1.6°)

➔ Spin rotators should perform well

Potential further development of the μSR simulation

- Simulation program is general (for any μSR instrument), but the analysis of the simulation is not (different logic of coincidences between detectors)

  ➔ development of an analysis program that would be general enough.

- At the moment only the energy deposited in a counter is summed up

  ➔ simulation of the light yield in the scintillator and WL shifters ?

- Presently there is no "solid state physics" in the sample (i.e. magnetic field in the sample is equal to the externally applied field only)

  ➔ some models for the field distribution/evolution in the sample could be added ?

Conclusions

- *musrSim*
  - Simulation became a reliable tool to describe existing μSR instruments, and to predict (design) the performance of the future ones.

- *High Field Project:*
  - Dec 2009 tests well reproduced by the simulation.
  - Trigger rates, detector acceptance and measured asymmetry should meet expectations.
  - Veto detector would reduce the background significantly.
  - Spin rotator that is being developed at PSI should perform very well.

- *Founding from NMI3:*

RII3-CT-2003-505925 (FP6)
CP-CSA_INFRA-2008-1.1.1 Number 226507-NMI3 (FP7)