A new detector system for the ALC-spectrometer:

hardware solutions and simulations

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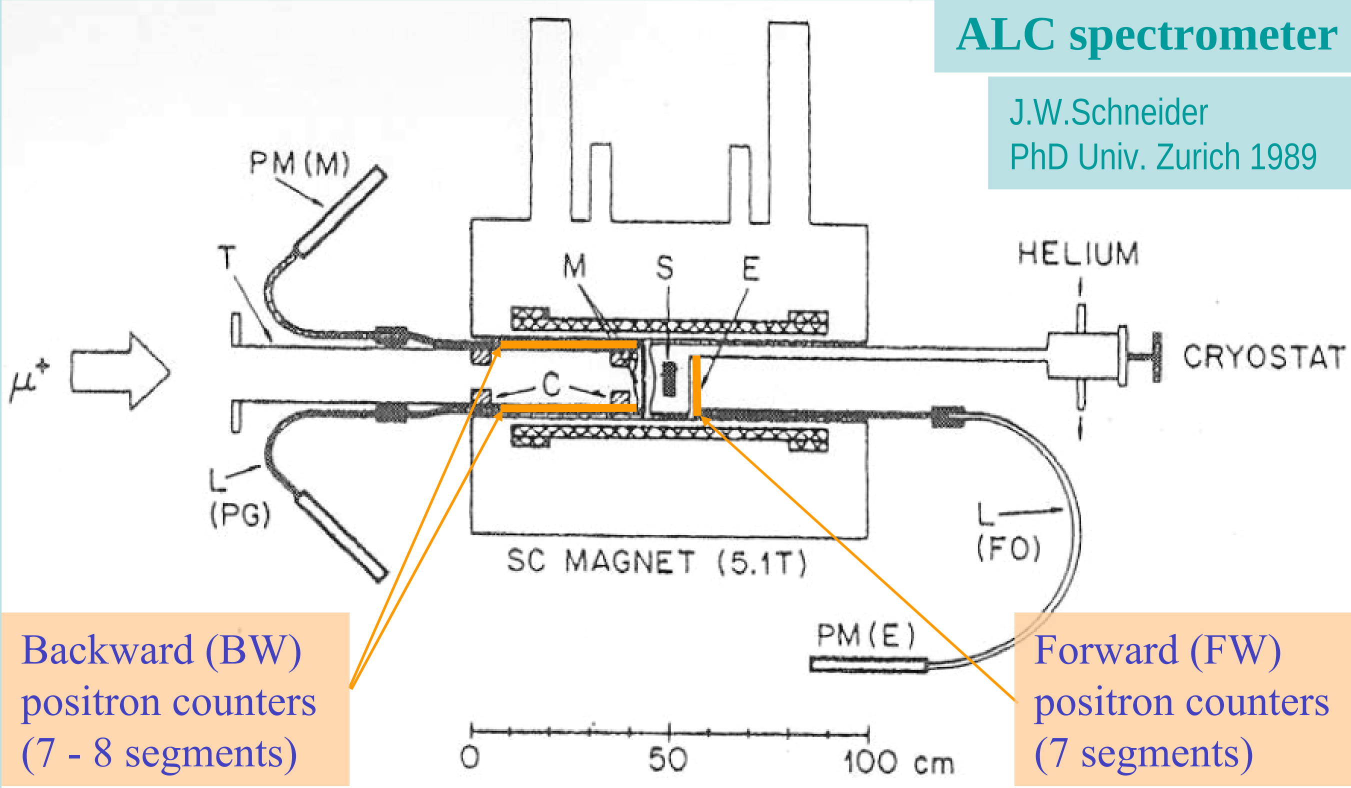
ALC spectrometer

J.W.Schneider
PhD Univ. Zurich 1989



Backward (BW) positron counters (7 - 8 segments)

Forward (FW) positron counters (7 segments)

<u>Time-integral mode</u>: $A(H) = (B - F) / (B + F)$

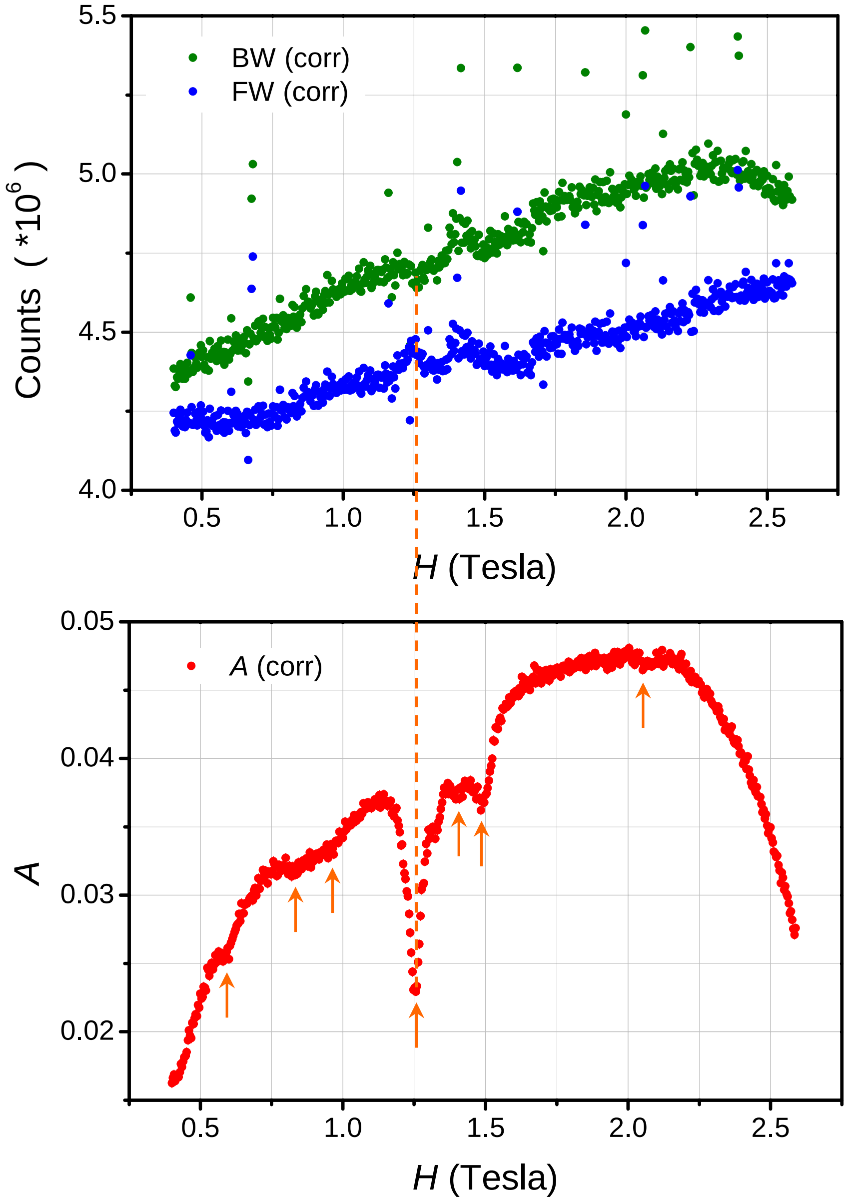
B, F – BW and FW integral positron counts;

A – measured asymmetry.

$H = H_r$ – resonant loss of integral muon spin polarization

$$B_r = B - \Delta B, \quad F_r = F + \Delta F \quad \Rightarrow \quad A_r = A - \Delta A$$

I.McKenzie: alc_06_2473.dat (sample: pyrrole; T = 350K; H = 0.4 - 2.6T, ΔH = 0.004T)



Different field dependencies of the positron count rates in BW and FW detectors

⇓

Base line with a field-dependent slope

⇓

Difficulties in assignment of resonances and in line shape analysis

Field dependence of ***B*** and ***F*** due to:

- gain variation of PMTs
- muon beam spot movement and oscillations
- variation of the counters solid angle due to altered positron trajectories

Goal:

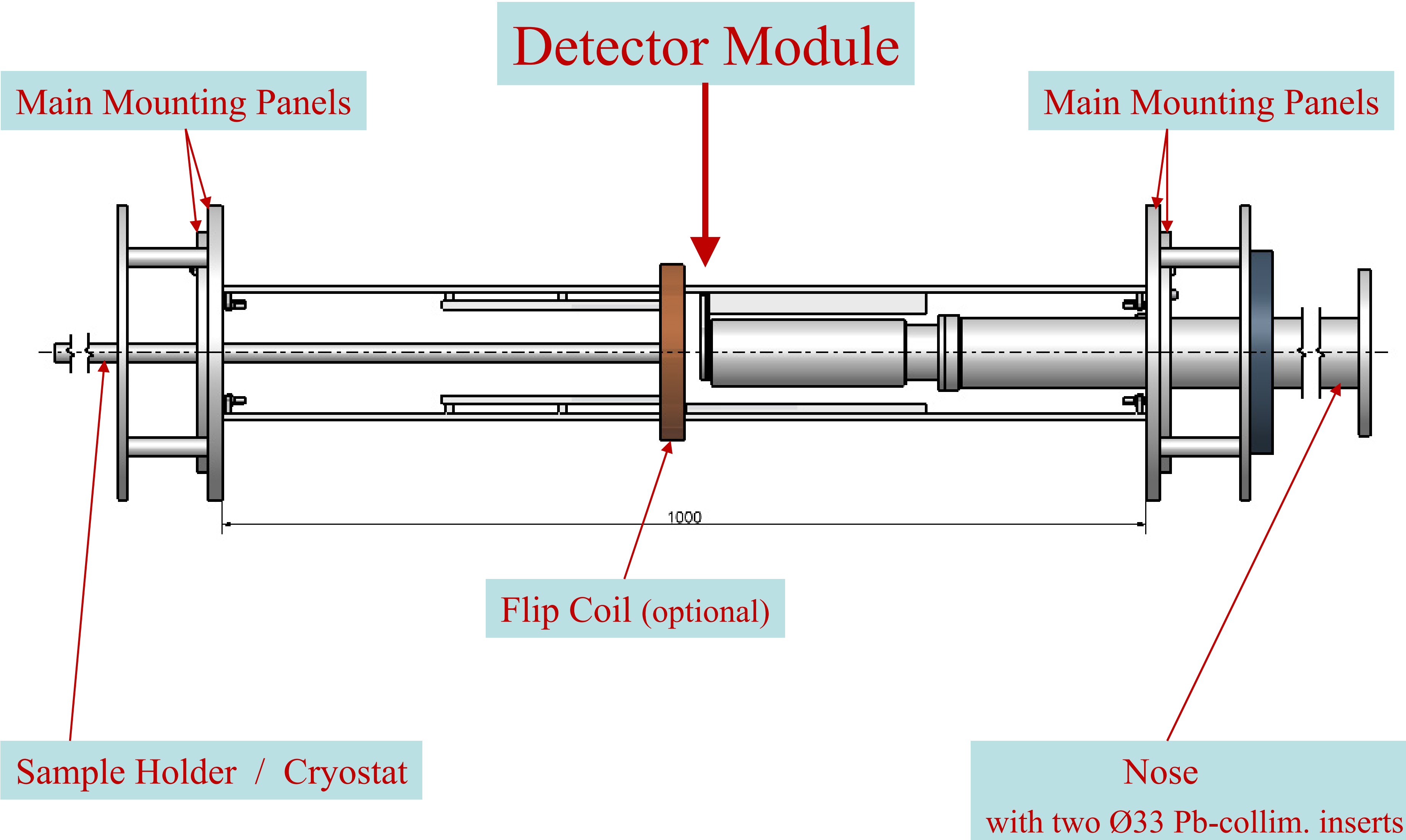
a new detector system with an optimized performance achieved by minimizing the effect of the above factors on the data quality

Realization → **G-APDs** instead of **PMTs**

- compactness and insensitivity to magnetic field;
- higher flexibility in the detector design;
- more possibilities for "tuning" the detector geometry, i.e optimization for a certain field range;
- low operation voltage (~ 50 V vs. 2 kV).

New ALC detector Design Assembly

New ALC detector | Design | Assembly

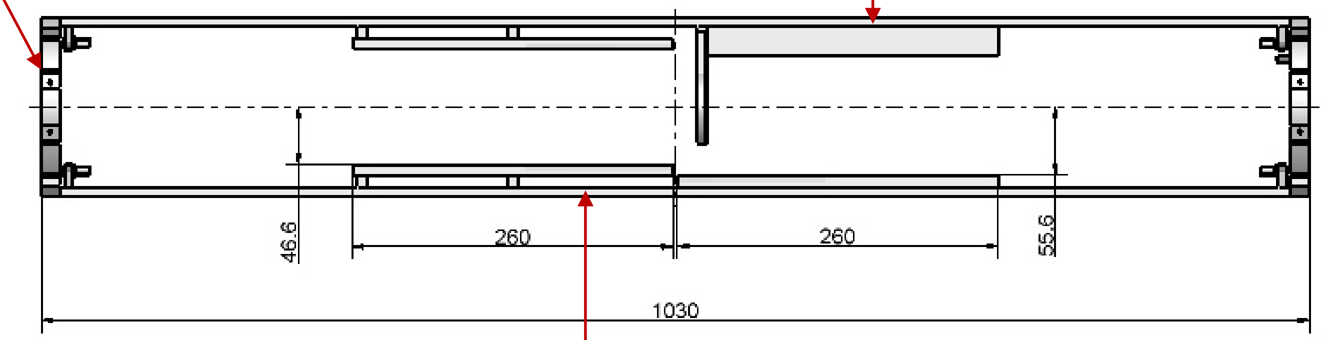


Detector Segment M

Positron Counter FW + Muon Counter

(optional: TD-LF, muon rate ~ 30 kHz)

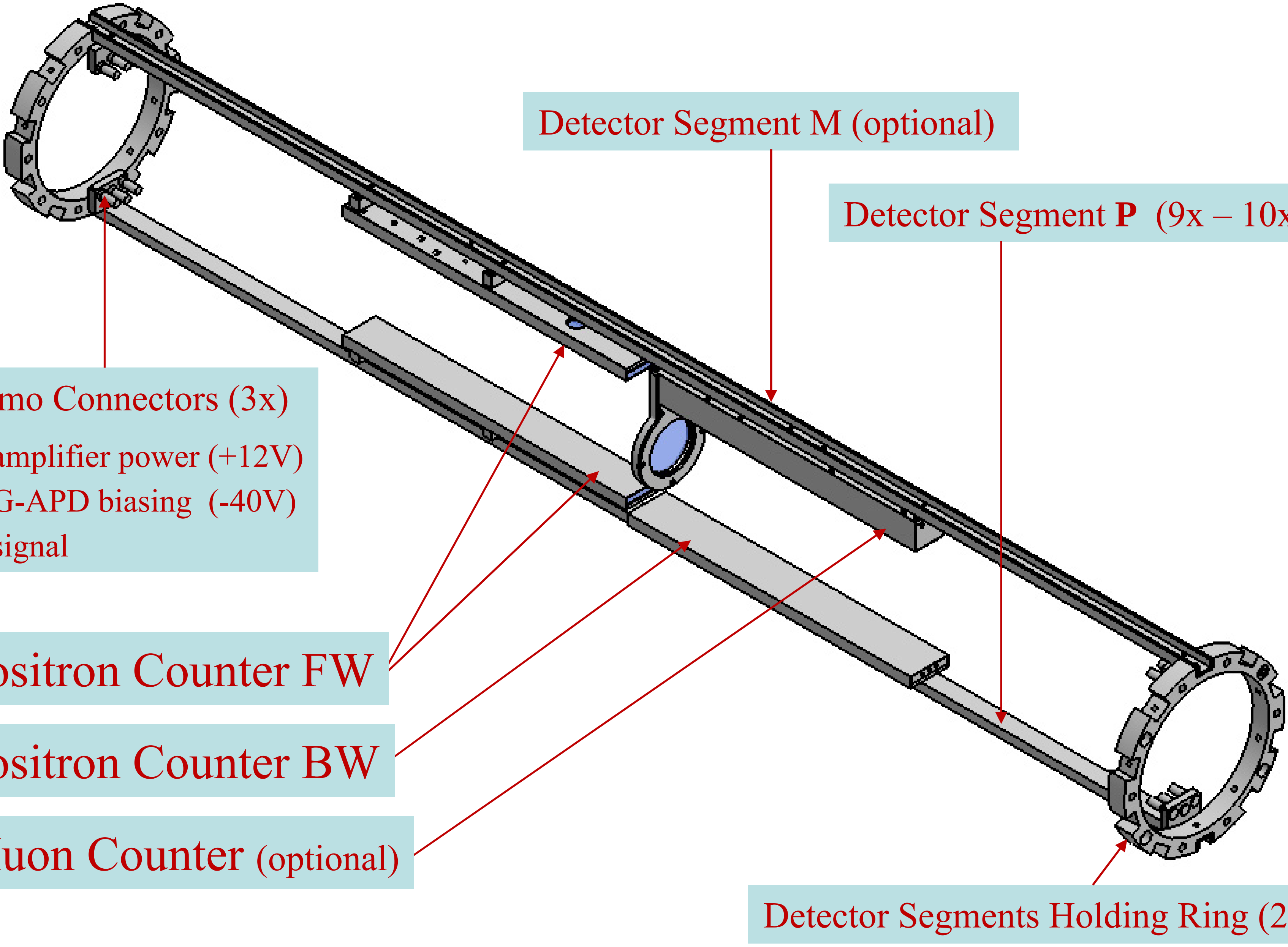
Detector Segments Holding Ring (2x)



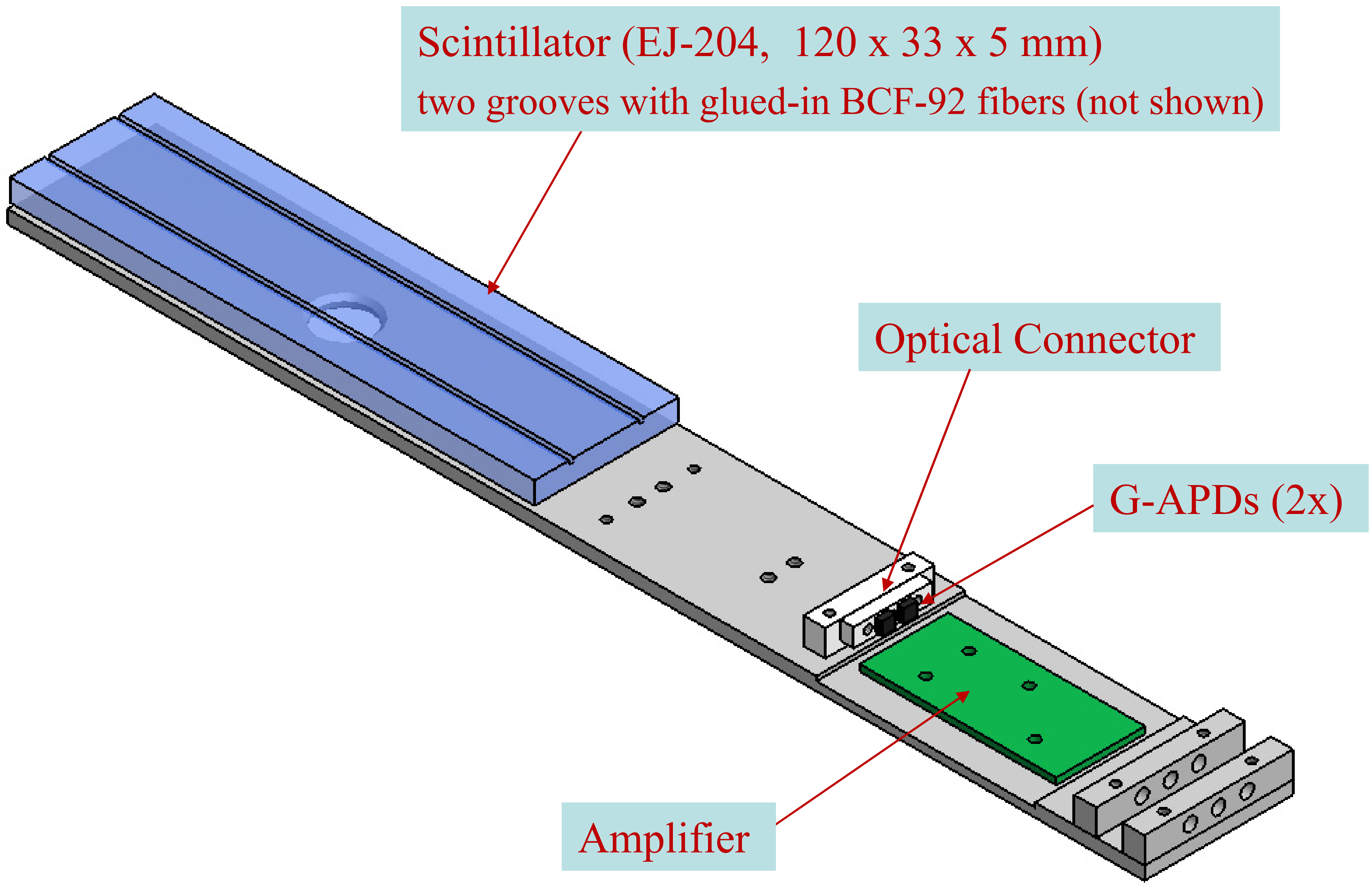
Detector Segment P (9x – 10x)

Positron Counter FW + Positron Counter BW

New ALC detector | Design | Detector Module



New ALC detector | Design | Positron Counter BW

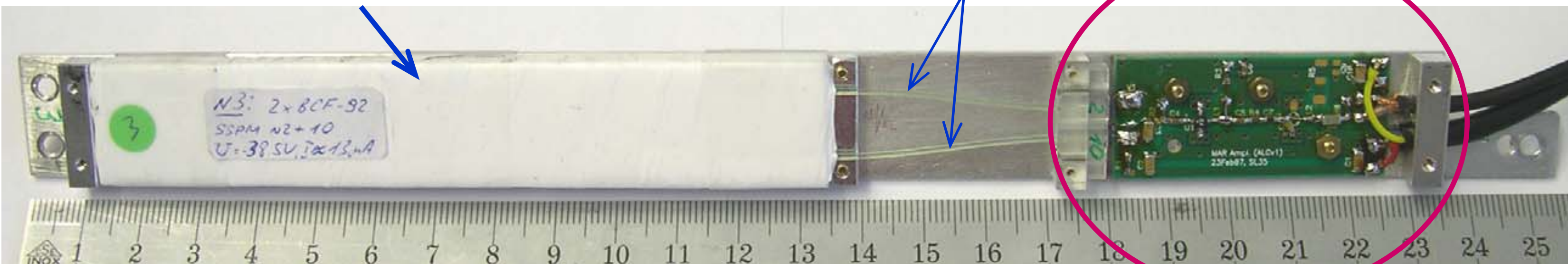


Positron Counter – **Prototype** (ALCv1)

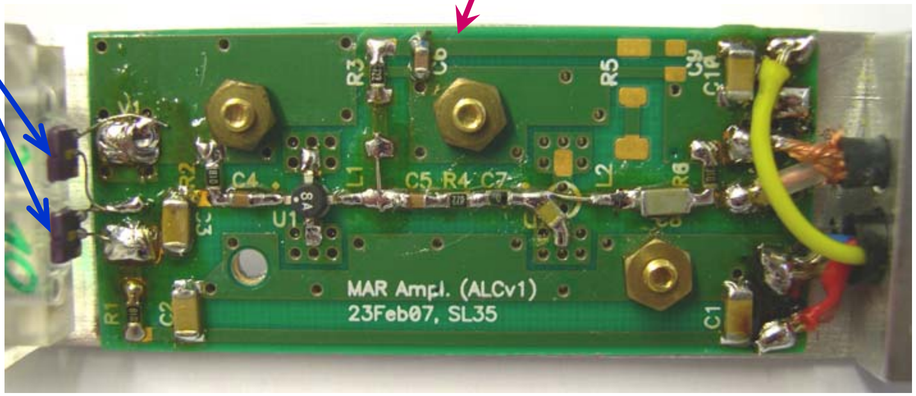
tests March – April 2007

EJ-204A (120 x 20 x 5 mm^3)

BCF-92

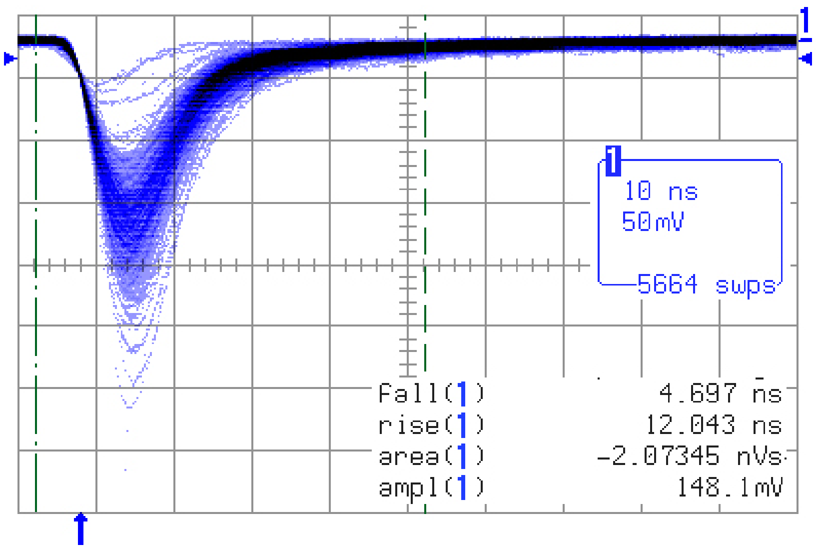


SSPM 0701BG

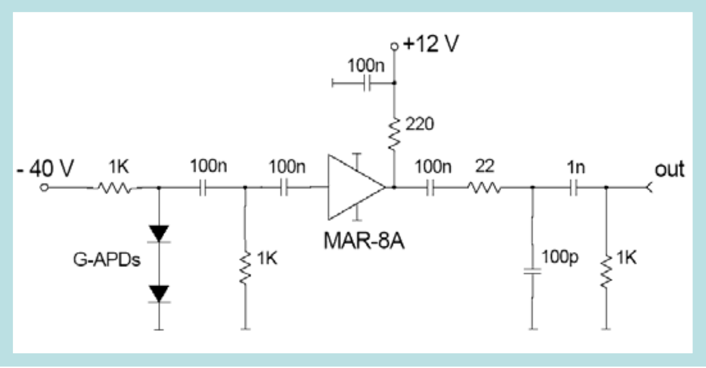


Detection of 28 MeV/c positrons

d5: $U = 20.0$ V, $I = 4.0$ μA, N_e = **2.3*10^3 s^{-1}**



Amplifier: gain ~ **20**, bw ~ **100 MHz**



The performance of a G-APD based positron counter satisfies the requirements of an ALC detector in terms of:

-- signal-to-noise ratio;

-- operation in high magnetic fields;

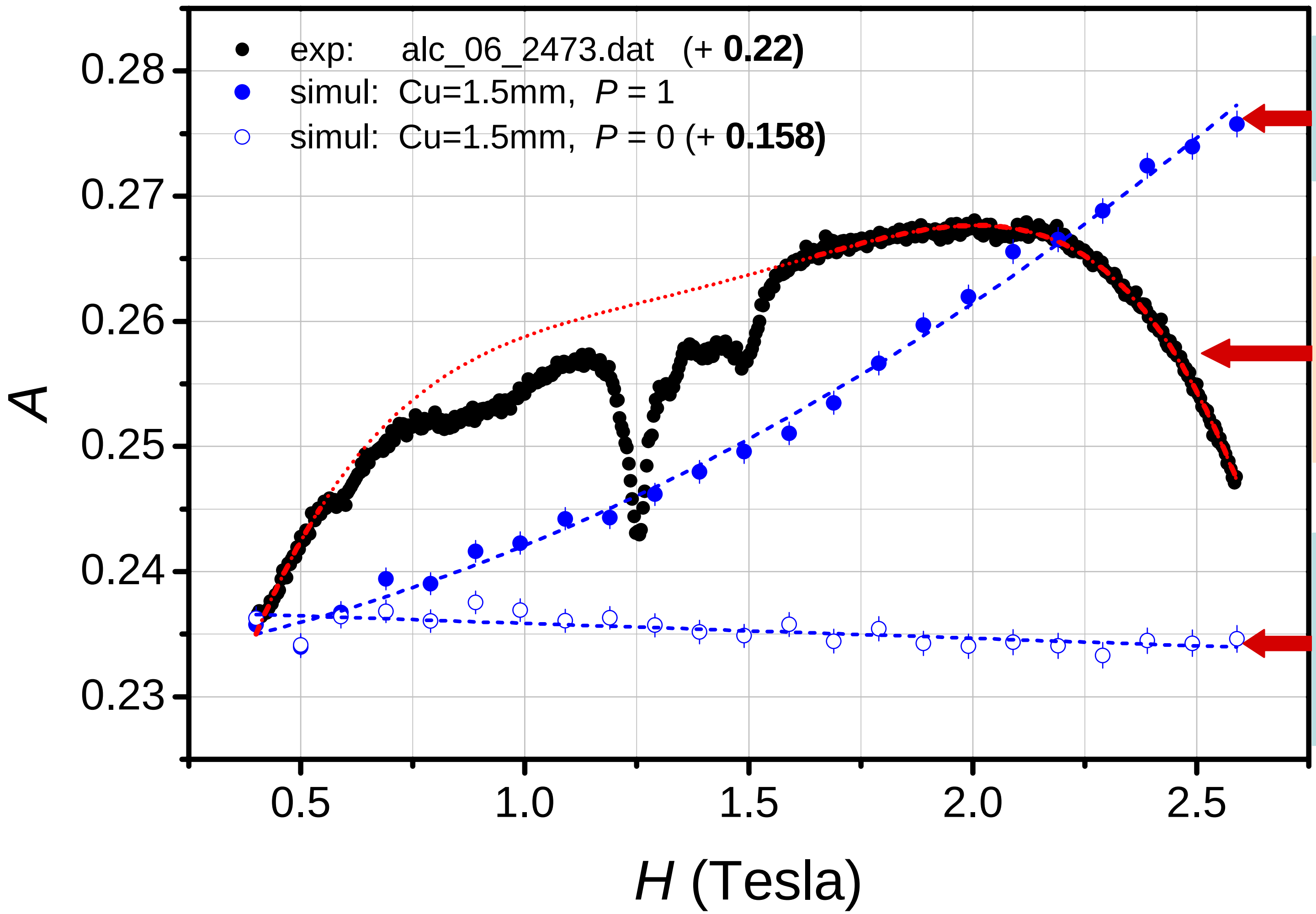
-- rate capabilities;

-- stability of the response vs. temperature variations;

-- long term stability and reliability.

Details see at: http://lmu.web.psi.ch/facilities/PSI-Detectors/APD_2007.pdf

New ALC detector Expected Performance (GEANT4 simulations)



New ALC
simul. $P = 1$

Present ALC
experiment
A + 0.22

New ALC
simul. $P = 0$
A + 0.158

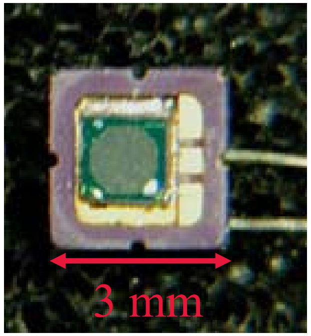
Simulations indicate the possibility to have a more simple shape of the base line

➔ **more reliable line-shape analysis**

Recent developments used in the new ALC-detector

Solid State Photo Multiplier

(Photonique SA, http://www.photonique.ch)



SSPM 0701BG		
PDE, at 490nm	--	25 %
Operating voltage	--	15V – 25V
Gain	--	$\leq 4 \cdot 10^5$
Temp. coeff. of Gain	--	< 1.0 %/C
Number of micro-cells	--	560

HV regulator module

(S.Ritt, R.Schmidt, LTP - PSI)

PHV8 – 600VLC		
Number of channels	--	8
Voltage	--	2V– 600V
Voltage accuracy	--	1mV
Current	--	200µA (max)
Current meas. accuracy	--	1nA
Control	--	MSCB-interface

Construction	–	November 2007
First tests	–	December 2007
Commissioning (LN_2 cryostat modified)	–	Spring 2008
New LHe cryostat	–	?

A new detector system for the ALC-spectrometer: hardware solutions and simulations

2^{nd} part, Kamil Sedlak

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 help us to 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 ?

- It 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.)
- Any GEANT4 application needs to develop its own specific components:
  - Specific detector geometry.
  - Specific signal treatment in the detector-sensitive volumes.
  - ...
- The μSR GEANT4 applications needed to extend the list of physics processes by the decay of the muon with spin and by the rotation of the muon spin in the magnetic field (more details will follow).

GEANT4 – why we have chosen it?

Why GEANT4 ?

- State of the art package (flagship in the particle detector simulation software).
- Continuously developed (by the scientific community).
- Extremely flexible (the trade-off for the need to write user-specific code).

Our Final Goal

- To have one common simulation package for all µSR devices (at least in PSI).

GEANT4 µSR simulations at PSI

- < 2004: Thomas Prokscha: GEANT 3 simulations for LEM spectrometer
- 2004/05: Taofiq Paraiso with support from Thomas Prokscha:
  - migration from GEANT3 (Fortran) to GEANT4 (c++).
  - inclusion of beamline components & magnetic field.

  Result: Simulations running; changes in GEANT4 package required.
- 2004: NMI3 / JRA8 WPZ: Toni Shiroka and Tom Lancaster:
  - position sensitive detectors; ALC; LEM (Toni).
  - High Field at ISIS and PSI (Tom).

  Idea: common development of the GEANT4 simulations for muon facilities.

  Result: Default GEANT4 code; all µSR specific code separated to a stand-alone package; private version of muon decay and spin rotation.
- 2006: Zaher Salman takes over the simulations for High Field at ISIS.
- 2006: Foko proposal “PSI High Field Project”: Kamil Sedlak.
  - 2 year postdoc (start in January 2007).

  Goal: design of the new High Field Instrument + continue the development towards the common µSR simulation package.

μSR GEANT4 code history

- Taofiq: ~ 50 classes, 22 000 lines of code
- Zaher: ~ 30 classes, 6 600 lines of code
- Now: ~ 21 classes, 5 600 lines of code

The main improvements done in 2007

- Replacing classes for the muon decay and for the muon spin rotation
- Output stored in the Root tree
- Generalisation of the simulation code for the different detector geometries
- Energy deposit treatment
- Thin layer simulation (G4CoulombScattering)

G4MuonDecayChannelWithSpin.cc

- The implementation of the muon decay with spin and spin rotation in magnetic field into GEANT4 was done by Taofiq and Thomas.
- At the same time, similar code was developed by T. MacPhail (TRIUMF ?):
  - uses NLO loop corrections for the muon decay.
  - successful implementation into the official GEANT4 package (17 August 2004).
- For historical reasons Taofiq implementation had been used at PSI till March 2007. Problems emerged when migrating to a new GEANT version (4.8.1) → segmentation faults.
- Finally we switched to the official GEANT4 routines of T. MacPhail in April 2007:
  - no segmentation faults.
  - Michel spectrum shifted to a little bit lower energies due to the NLO corrections.

Output in the Root tree

- Root is an analysis tool, originally developed for the high energy physics community. It allows us to analyse the simulated results and plot them as graphs. It is based on C++.
- The results of the simulation are now stored in a Root tree, which is a kind of table, in which we store all data relevant for the further analysis.
- All data are stored in just one tree (i.e. in one file) ➔ no problem to relate different quantities of the same event (e.g. the initial muon polarisation/position with the position of the decaying muon or emerging positron).
- It is very easy to store just the variables of interest for a given purpose (for the given problem or detector design under study).
- Automatic file compression.

Root tree - list of our variables

```
Int_t        runID;
Int_t        eventID;
Double_t     BFieldAtDecay_Bx;
Double_t     BFieldAtDecay_By;
Double_t     BFieldAtDecay_Bz;
Double_t     BFieldAtDecay_B3;
Double_t     BFieldAtDecay_B4;
Double_t     BFieldAtDecay_B5;
Double_t     muDecayPosX;
Double_t     muDecayPosY;
Double_t     muDecayPosZ;
Double_t     muDecayTime;
Double_t     muDecayPolX;
Double_t     muDecayPolY;
Double_t     muDecayPolZ;
```

```
Double_t     muTargetTime;
Double_t     muTargetPolX;
Double_t     muTargetPolY;
Double_t     muTargetPolZ;
Double_t     posIniMomX;
Double_t     posIniMomY;
Double_t     posIniMomZ;
Double_t     globalTime;
Double_t     fieldValue;
Int_t        det_n;
Int_t        det_ID[det_n]
Double_t     det_edep[det_n]
Double_t     det_edep_el[det_n]
Double_t     det_edep_pos[det_n]
Double_t     det_edep_gam[det_n]
Double_t     det_edep_mup[det_n]
Int_t        det_nsteps[det_n]
Double_t     det_length[det_n]
```

Generalisation of the code

- Usually each instrument has its own simulation code (executable)
  ➔ difficulties when maintaining the code e.g. when upgrading to the new GEANT4 version or improving some general-purpose routine.
- Therefore some generalisation of the simulation code was done such that I have just one code (i.e. one executable) for different instruments (e.g. the high field project and for the ALC project).
- 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, variables that will be saved into the output (Root) file, ...
- No need to recompile the simulation code when changing the instrument geometry (very useful for the instrument design optimisation) and even when switching between the different instruments.

Examples of the "steering" lines

- Example of a volume definition in the steering text file:

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

- Example of how to define whether a variable will be stored in the output file:

/musr/ignore rootOutput muIniMomX off

The code deals with the High Field and ALC projects, but it is not yet general enough to deal with the LEM due to the complications with combing many electric and magnetic fields together. This could be implemented in future.

Energy deposit treatment

- A primitive definition of the “hit” was used in the past:
  - The hit was recorded whenever a positron entered the sensitive detector volume.
  - Only the positron tracks were followed.
- Problems of this approach:
  - Positron causes hit regardless of it’s energy deposit inside the sensitive volume ➔ it is not possible to apply any energy thresholds (always done in a real experiment).
  - Background from particles other than positrons ignored.
  - “Double hit” in the simulation may not correspond to the “double hit” in a real detector, because the time separation between the subsequent hits is completely ignored in the simulation.

Energy deposit treatment

- The high-energy-physics rule nr. 1 for the detector simulation – always sum up all energy deposits inside the sensitive volumes of the detector! Otherwise the simulation will not describe a real detector behavior, and will probably depend on a technical parameters of the simulation (e.g. on cut-off parameters).
- The summation of energy deposits have therefore been implemented. Energy thresholds can be (and are) applied. Energy deposits of all particles are taken into account (not just positrons).
- Still room for further improvements. At the moment all the raw deposited energy is summed-up, while one could simulate its stochastic conversion into light in scintillators.

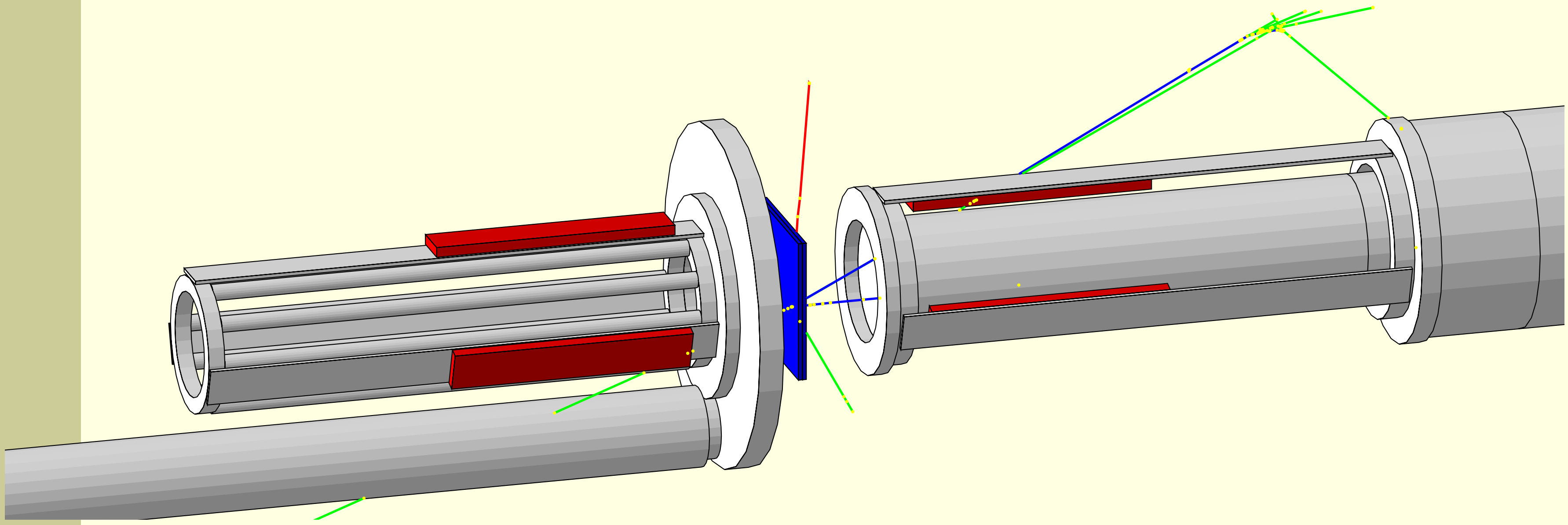
Thin layer simulation

- Traditionally, scattering of particles in a given material is simulated in GEANT4 by G4MultipleScattering, which combines together scattering on many atoms. This approximation is considered to be OK for materials thicker then 0.01*X_0 .   (X_0=radiation length).
- Recently, G4CoulombScattering process was implemented, which simulates the scattering on individual “atoms”.   This process aims to provide reliable predictions for materials of any thickness, however it is extremely computer-time demanding. Due to the slow calculation, it is in practice impossible to switch from G4MultipleScattering to G4CoulombScattering in µSR in all detector components.
- We made it possible to switch to G4CoulombScattering in just some critical parts of the detector, i.e. in the kapton foil at the end of the beam pipe, triggers and titanium foils on the cryostat window.

Simulation for the ALC

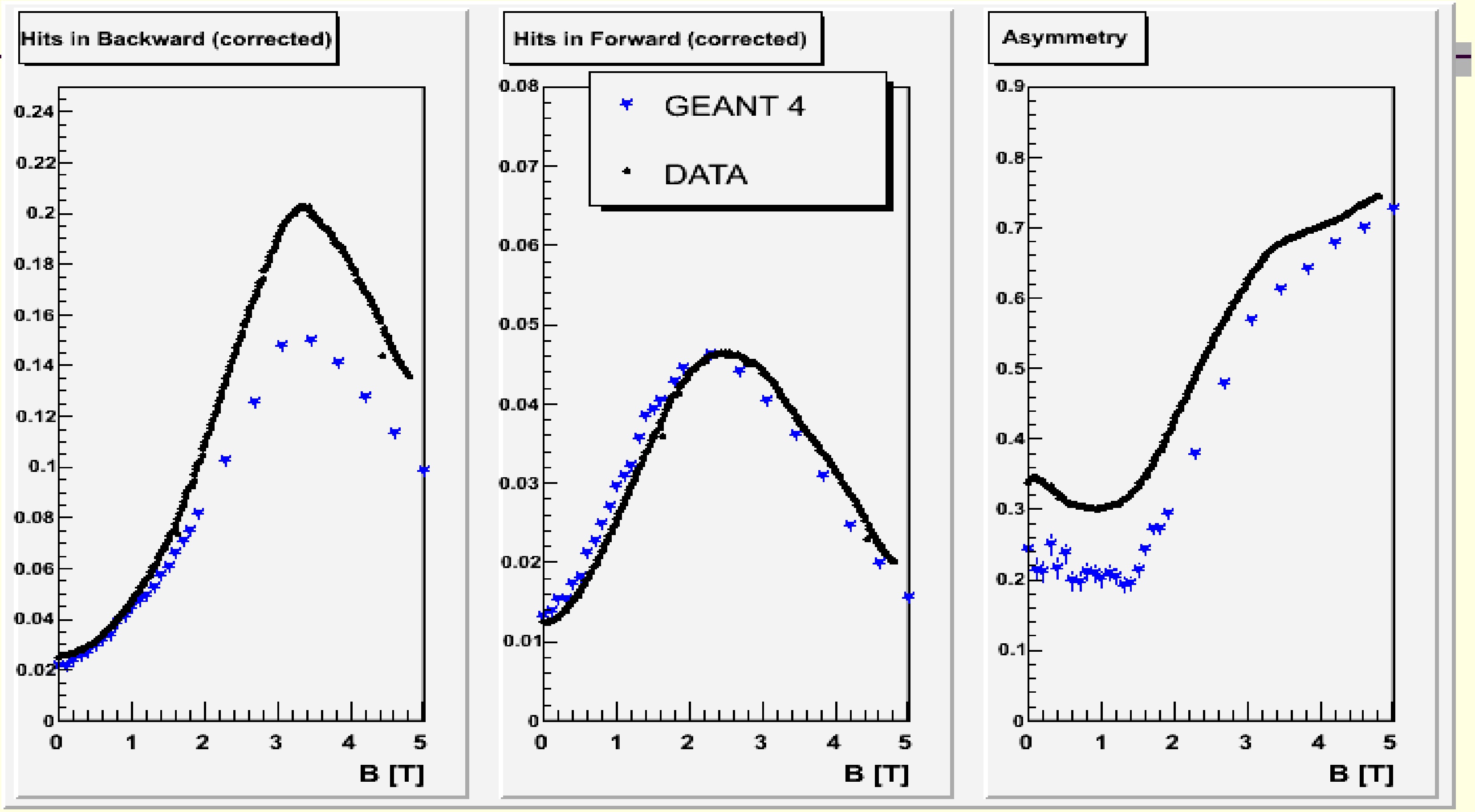
- My task at PSI – simulation of the planned high field μSR instrument.
- However, we felt we should test the simulation on some real experiment in order to:
  - check that there are no obvious bugs in the simulation.
  - find out the critical issues of the simulation.
  - check to what level of precision the simulated predictions match with the real data.
- The ALC simulations were done independently by Tony Shiroka and myself.

ALC test set-up



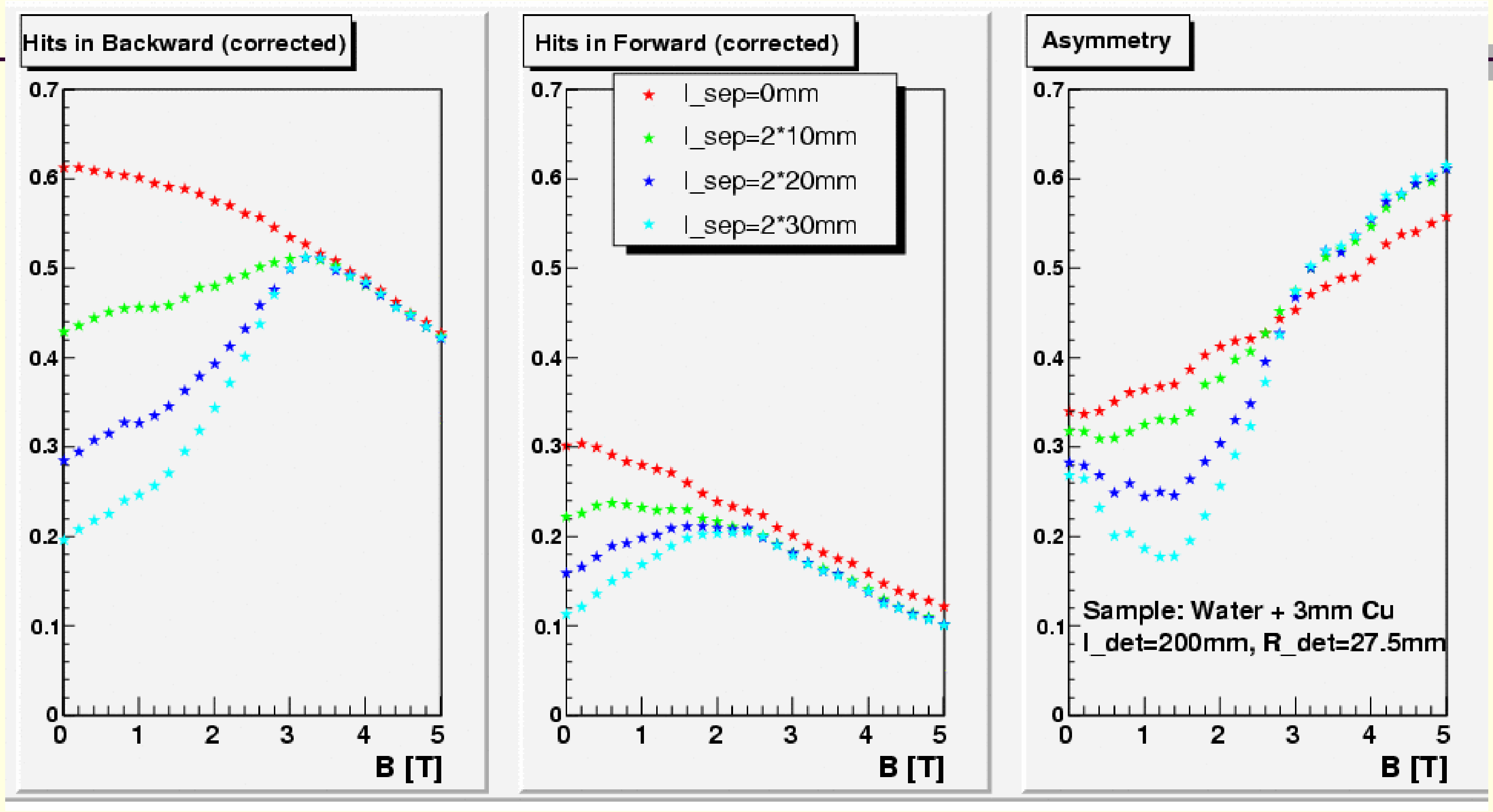
- An experimental test of the new ALC design was done in spring 2007.
- Motivation: To have as simple (flat) base-line of the asymmetry signal as possible.

ALC test set-up



- GEANT4 simulation describes the main features of the data, however the relative normalisation is far from perfect.
- Absolute normalisation of the data is not known.

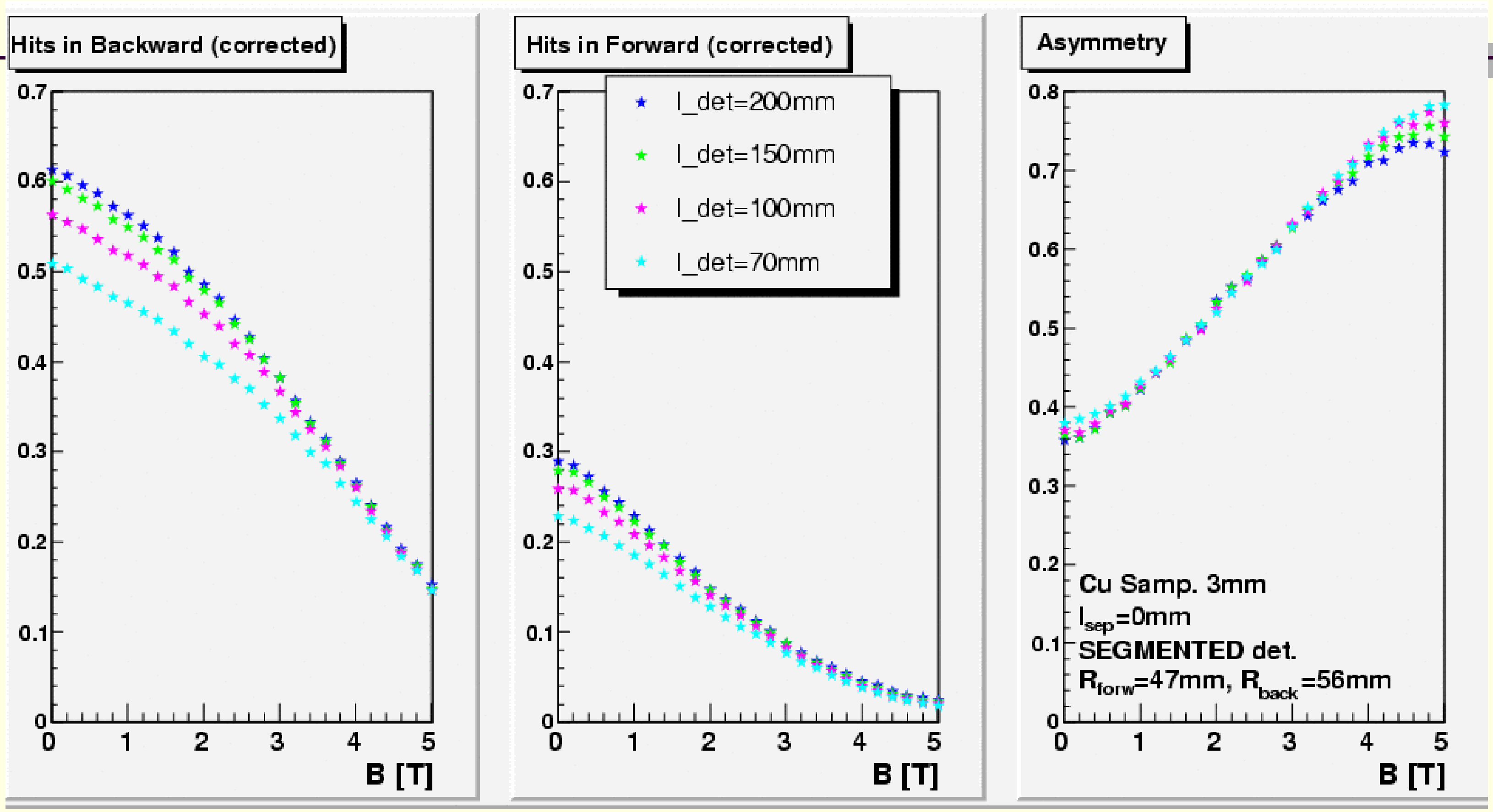
Gap between the B and F detectors



- The gap between the backward and forward detectors leads to the complicated shape of the asymmetry.

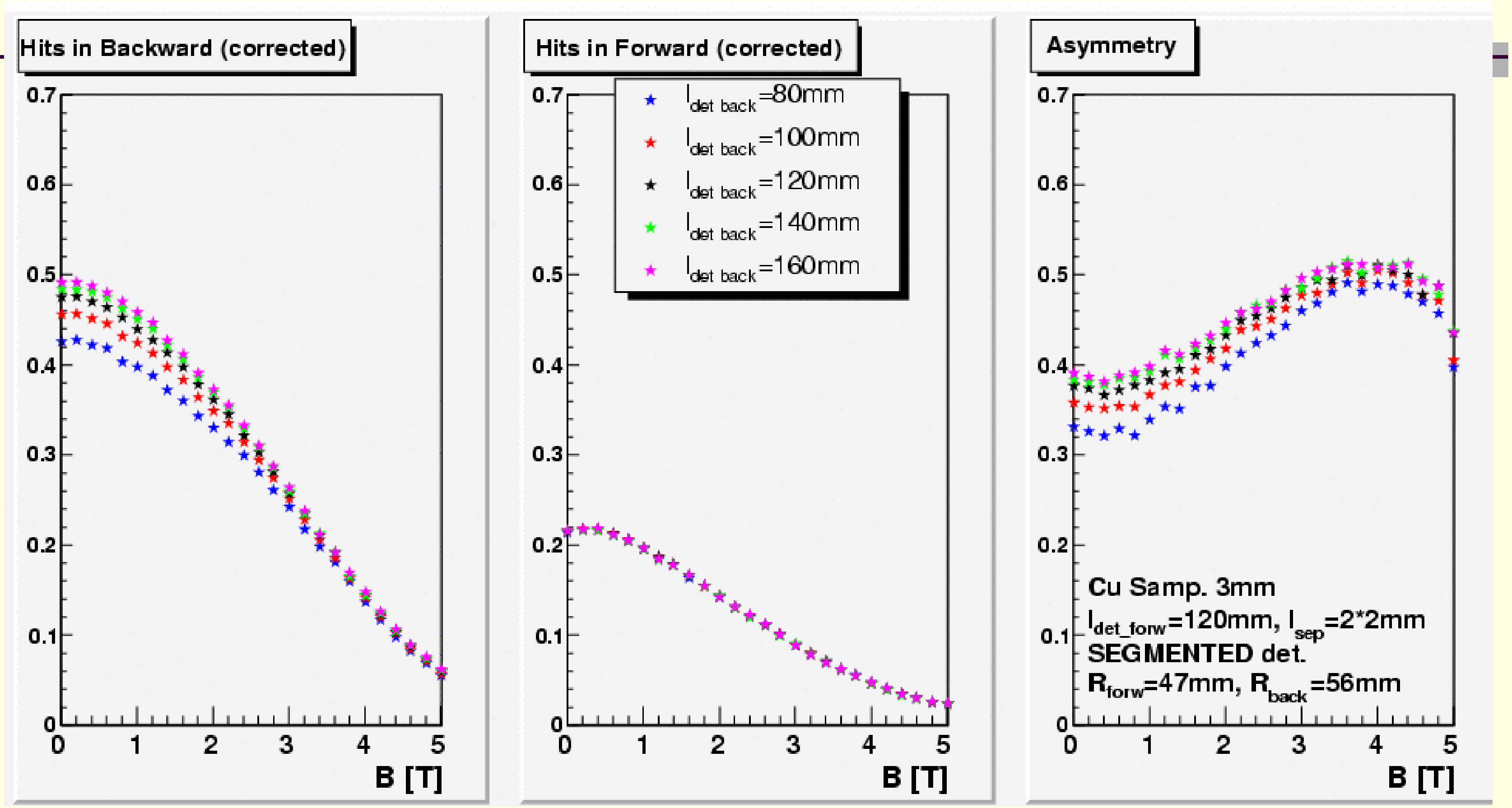
➔ The best shape seems to be achieved for zero gap between the detectors.

Length of the detectors



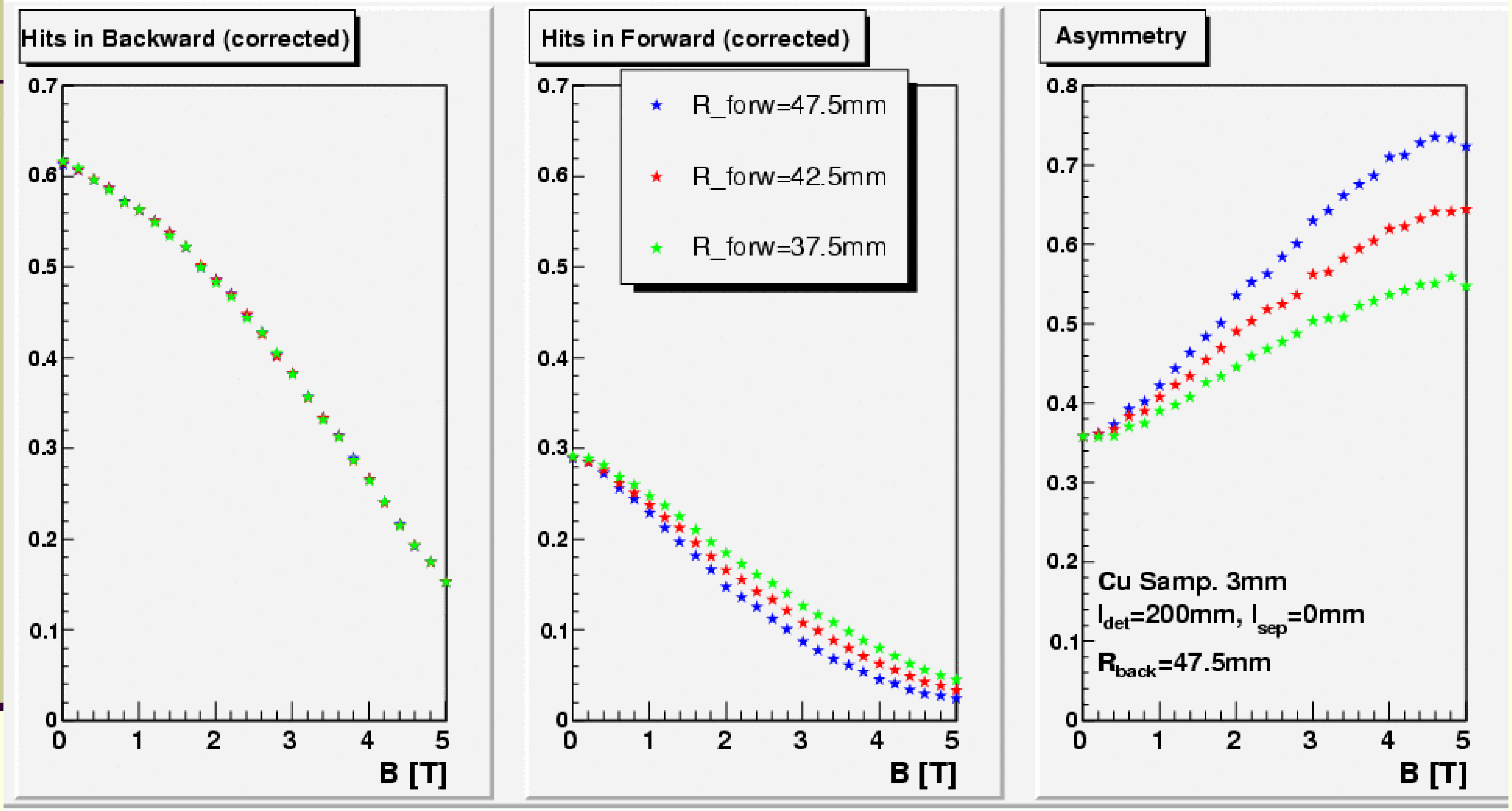
The length of the scintillator counters does not have a big effect on the asymmetry.

Length of the backward detector



Variation of the length of the scintillator counters just for the backward detector changes the absolute value of the asymmetry, however not the shape.

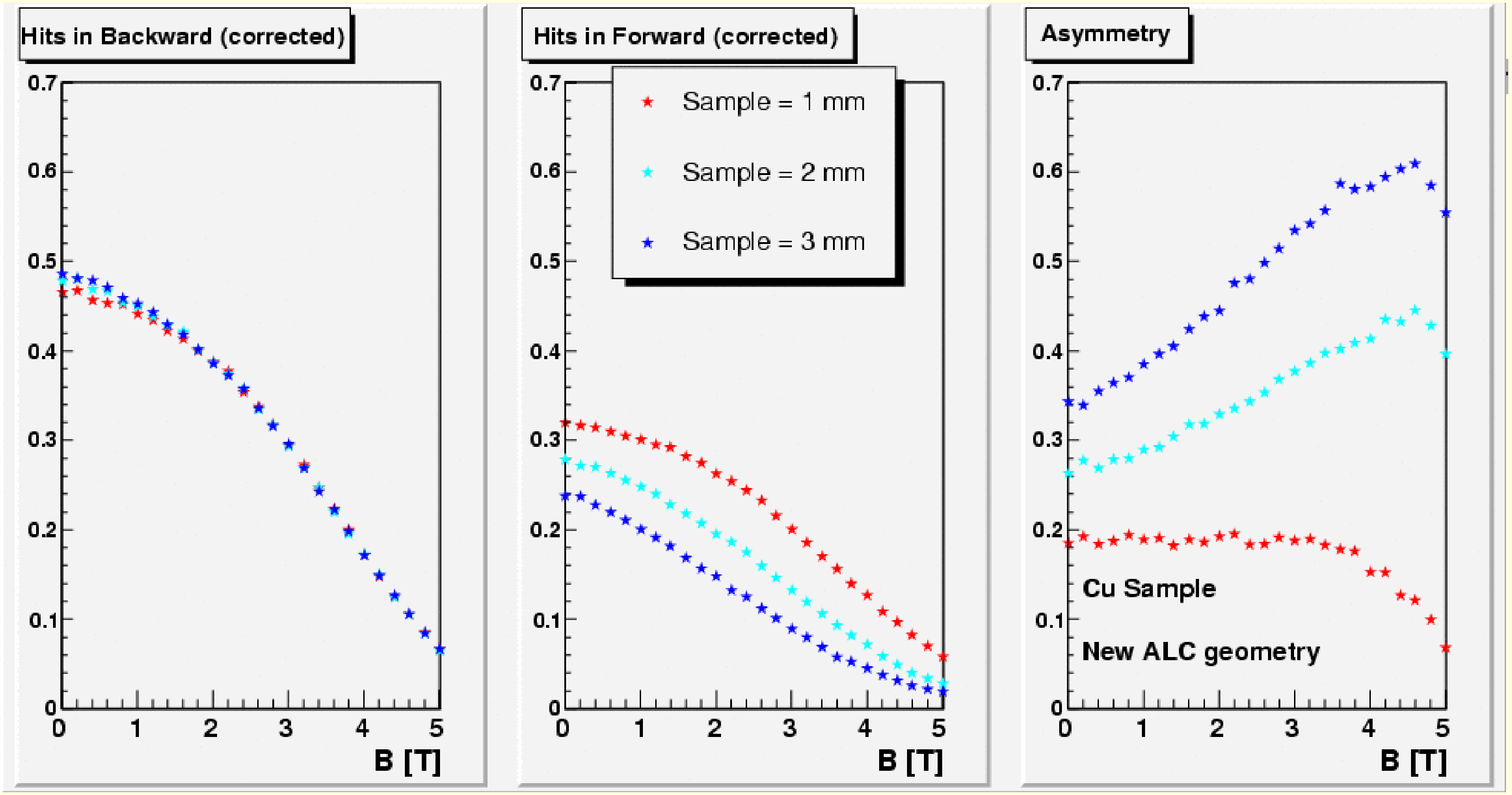
Radius of the forward detector



Variation of the radius of just one detector changes the slope of asymmetry (feature employed in our design).

Can we make the detector with flat constant base-line ?

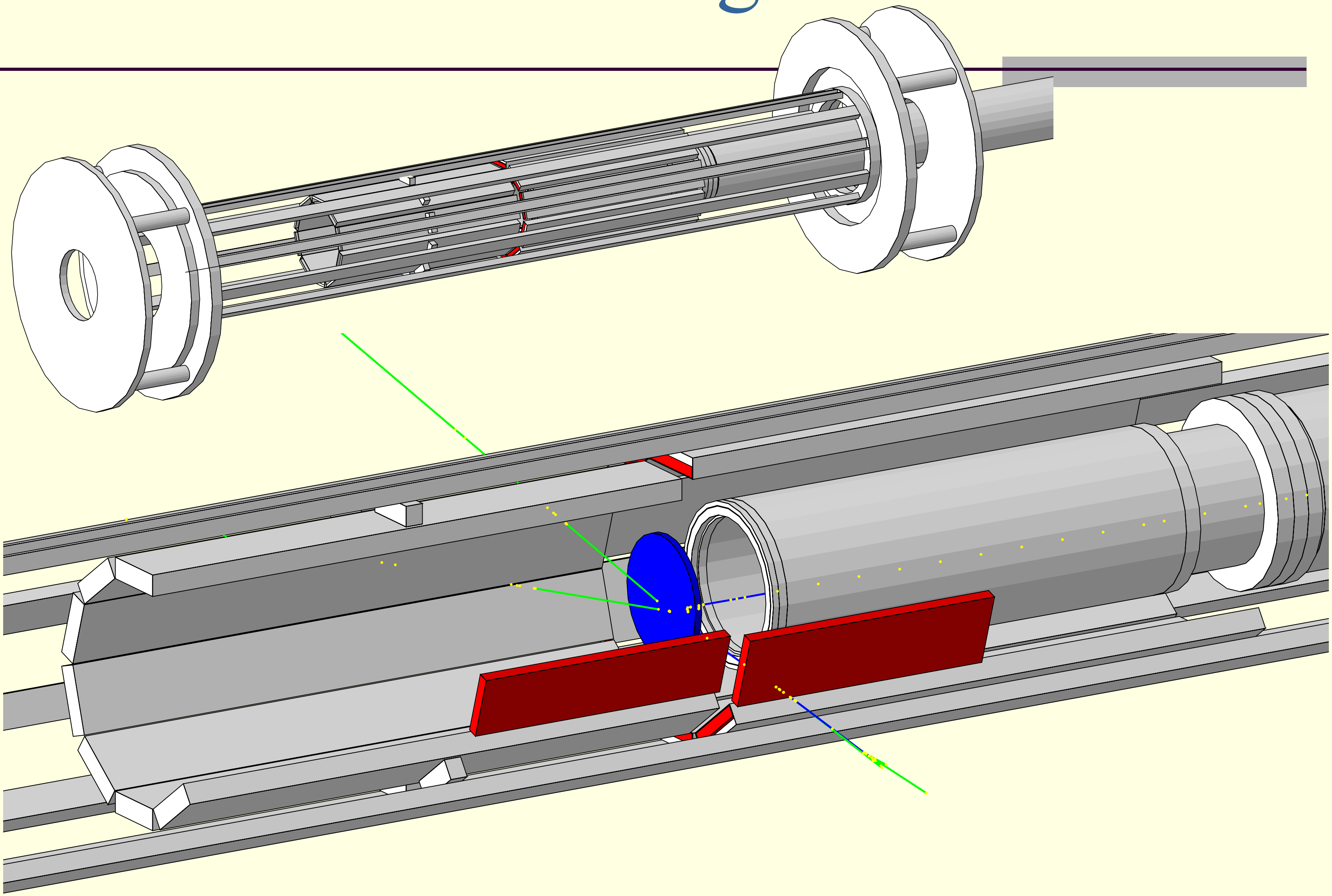
Target thickness



Target thickness strongly influences the slope of asymmetry.

➔ the slope of the asymmetry base-line will differ from sample to sample.

The final ALC design



Summary

- In the optimisation of the ALC design the following parameters were varied:
  - The gap between the backward and forward detectors
  - The length of the scintillator counters
  - The radius of the backward and forward detectors (independently)
  - The thickness of the sample
  - The thickness, radius and material of the supporting structure (which holds the detectors)
- Some critical aspects of the simulation reliability identified:
  - precision of the geometry description (e.g. the target thickness)
  - beam profile (e.g. asymmetry of the beam with respect to the z-axis; beam pitch; beam divergence)
  - detailed knowledge of the magnetic field

We are hoping to learn more from the data taken by the new ALC instrument.