PAUL SCHERRER INSTITUT

Memorandum

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I shortly summaries an attempt to quantify the μ^+ asymmetry, $A_0P(t)$, for the EuS/Co experiment. Fig.1 shows the μ^+ stopping distribution for the sample measured in 2010. Question: has the thickness of the different layers been verified?

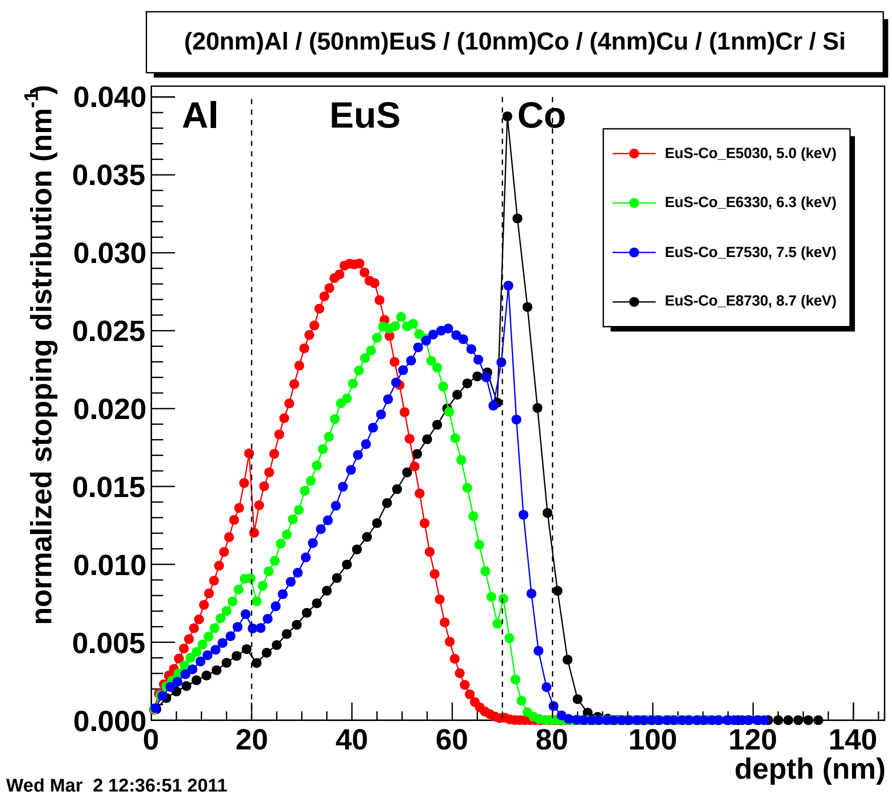

Figure 1: μ^+ stopping distribution for 20nm Al / 50nm EuS / 10nm Co / 4nm Cu / 1nm Cr on Si.

$A_0P(t)$ consists of

$$A_0P(t) = A_{\mathrm{Al}}(t) + A_{\mathrm{EuS}}(t) + A_{\mathrm{Co}}(t) + A_{\mathrm{bkg}}(t) \tag{1}$$

where the different terms are originating from: $A_{\mathrm{Al}}(t)$, $A_{\mathrm{EuS}}(t)$, $A_{\mathrm{Co}}(t)$ from μ^+ stopping in the Al, EuS, and Co layer, respectively. $A_{\mathrm{bkg}}(t)$ describes μ^+ stopping not on the sample but on the sample plate. Here a short discussion how these terms will look like, starting with the background term, which will have the form:

E (keV)	μ^+ prob. of stopping in the layer	asymmetry
5.03	0.153 [20nm Al]	0.0367
	0.847 [50nm EuS]	0.2033
	0.0 [10nm Co]	0.0
6.33	0.100 [20nm Al]	0.0241
	0.880 [50nm EuS]	0.2113
	0.019 [10nm Co]	0.0046
7.53	0.072 [20nm Al]	0.0172
	0.805 [50nm EuS]	0.1932
	0.122 [10nm Co]	0.0293
8.73	0.054 [20nm Al]	0.0130
	0.655 [50nm EuS]	0.1573
	0.262 [10nm Co]	0.0628

Table 1: Portions of μ^+ stopping in the individual layers (see also Fig.1). The corresponding asymmetries assume a total sample asymmetry $A_0 - A^0_{\rm bkg} = 0.24$.

$$A_{\rm bkg}(t) = A^0_{\rm bkg}\, e^{-\lambda_{\rm bkg} t} \tag{2}$$

with $A^0_{\rm bkg} \simeq 0.03$ and $\lambda_{\rm bkg} \simeq 0.05\,\mu{\rm s}^{-1}$. This we know from previous calibration experiments. The total asymmetry A_0 for the setup we use in the experiment is 0.27.

Lets go to the cobalt: In principle the ZF precession signal should be visible [see PRL **37**, 1644 (1976)] but we do not see anything of this ZF precession. This could be due to the disorder in the Co layer. This disorder will lead to a very strong dephasing and hence killing the asymmetry. For the data analysis I would treat $A_{\rm Co}(t)$ as lost asymmetry. *i.e.* $A_{\rm Co}(t) = 0.0$.

The μ^+ stopping in the aluminum will show an asymmetry as

$$\begin{aligned} A_{\rm Al}(t) &= A^0_{\rm Al}\, e^{-\lambda_{\rm Al} t} \\ A^0_{\rm Al} &= \int_0^{z_1} n(z)\ {\rm d}z \,/ \int_0^{\infty} n(z)\ {\rm d}z \end{aligned} \tag{3}$$

with $z_1 = 20\,$nm. $A^0_{\rm Al}$ is calculated from the μ^+ stopping distribution $n(z,E)$ (see Fig.1) and theses values are given in Table 1. The Co stray field damping $\lambda_{\rm Al}$ could be extracted from measurements $T \gg T_{\rm C}({\rm EuS})$. Unfortunately we do not have any measurements of muons stopping predominately in the Al layer, and therefore this needs to be fitted.

The EuS signal close to its $T_{\rm C}$ is the most complicated one. Close to $T \approx T_{\rm C}$, it will have a contribution of the Co stray field as well as one of the proximity effect. It can be written as:

$$\begin{aligned} A_{\rm EuS}(t) &= A^0_{\rm EuS}\, e^{-\lambda t} \int_{z_1}^{z_2} n(z) \cos(\gamma B(z) t + \phi)\ {\rm d}z \\ B(z) &= B_0 + B_1 \exp\left[-(z_2 - z)/\zeta\right] \\ A^0_{\rm EuS} &= \int_{z_1}^{z_2} n(z)\ {\rm d}z \,/ \int_0^{\infty} n(z)\ {\rm d}z \end{aligned} \tag{4}$$

where $z_2 = 70$ nm, $n(z,E)$ is given in Fig.1, and $A^0_{\rm EuS}$ is given in Table 1. This description should hold under the following assumptions:

- The Co stray field is just superimposing the proximity effect. Hence, λ can be extracted for each energy at $T \gg T_{\rm C}({\rm EuS})$, and then being fixed at lower temperature.
- The Co layer is close to full saturation, or at least the dominant portion of the magnetization is perpendicular to the muon spin.

- The form of $B(z)$ assumes that $B(z) \propto m$. This is not quite a trivial assumption since the field at the muon site is predominately of dipolar origin. In a lot of systems this is OK though.

Fitting strategy

I would try to do the following:

- keep the sample holder background fix according to Eq.(2).
- determine $\lambda(E)$ at $T \gg T_C$(EuS). And keep it fixed for the lower temperatures.
- fix the asymmetries according to Table 1. This assumes that the thickness of all the layers are OK.

I have setup a user-function for `musrfit` which takes into account Eq.(4). The syntax for this user-function is:

```
userFcn libPMagProximityFitter PMagProximityFitter 0 1 2 3 4 5 6
```

where the parameter 1–7 have the following meaning:

```
[0] energy (keV)
[1] z1 (nm)
[2] z2 (nm)
[3] B0 (G)
[4] B1 (G)
[5] zeta (nm)
[6] phase (deg)
```

An example file (`1492_test_mp.msr`) can be found on `pc8581` or `pc8372` under `/mnt/home/nemu/analysis/2010/EuS-Co/magProximity`. The theory part looks like:

```
FITPARAMETER
#       No Name         Value     Step        Pos_Error   Boundaries

# Common parameters for all runs

        1 zStart      20        0           none
        2 zEnd        70        0           none
        3 B0          0         0           none        0       none
        4 B1          40.0      3.6         none        0       none
        5 zeta        49.4      10.5        none        0       none
        6 phase       0         0           none
        7 asymBkg     0.03      0           none
        8 rateBkg     0.05      0           none
        9 rateAl      0.41      0.34        none        0       none

# Specific parameters for run 1492

       10 alpha1492   0.921     0.017       none        0       none
       11 asymAl1492  0.037     0           none        0       none
       12 asymEuS1492 0.203     0           none
       13 energy1492  5.03      0           none
       14 rate1492    2.73      0           none

###############################################################
THEORY
asymmetry     11
```

```
simplExpo      9          (rate)
+
asymmetry   12
userFcn  libPMagProximityFitter PMagProximityFitter 13 1 2 3 4 5 6
simplExpo   14          (rate)
+
asymmetry      7
simplExpo      8          (rate)
```

The first term describes the Al layer, and the last one the sample plate. The EuS layer is described by the term in the middle, and is formally given by Eq.(4).

Problems

I played a little bit around with this approach, but realized that the predominant portion of the damping λ is originating from the Co stray fields. The parameter B_1 is small ($\lessapprox$ 100 G) at $T \approx T_{\mathrm{C}}(\mathrm{EuS})$ since otherwise either oscillation should be visible or the damping is too strong (depending on ζ), and hence a fitting will be tough. B_0 has to be even smaller for the same reasons. I think the only hope could be when doing global fits, *i.e.* fitting all energies at the given temperature simultaneously using a minimal set of parameters. There is also such a template file available (`1492+global_zf_mp.msr`). What is the prediction of the model for $T < T_{\mathrm{C}}(\mathrm{EuS})$? Can the parameter ζ be estimated based on the model, PNR? From playing around with the user-function a can for sure say that ζ has to be short ($<$ 15 nm) otherwise there should be oscillations present.