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LEM Group

None

LEM Beamline

Introduction

GEANT4 simulations were used to introduce the new spin rotator (SR) into the existing LEM beamline. For this purpose muons were initialized at the entry point of the first Einzel lens (L1) with a beam of circular shape with a Gaussian cross section of 6.83 mm RMS. The muons were then propagated through the beamline until the sample position. All the simulations discussed here were carried out with 15 keV beam energy and in zero magnetic field at the sample. The initial polarization of the muons was along the $+x$ direction and the spin rotator (SR) was tuned to rotate the spins by 90^o, to obtain muons with polarization along the $+z$ direction.

In order to make space for the SR in the current beam line, the second Einzel lens (L2) and the spacer chamber after the trigger detector are removed and the SR is inserted in its place. The trigger detector (TD) chamber is moved downstream and positioned just before the ring anode (RA). The arrangement of the beamline elements is envisaged to be as shown in Fig. 1.

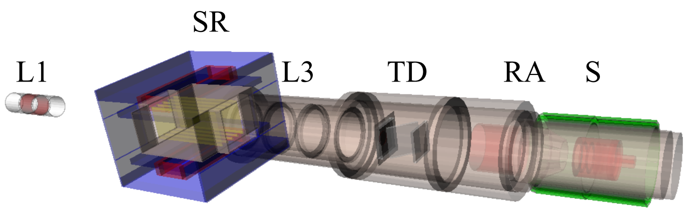

Figure 1: The new rearrangement of beam line elements incorporating the SR.

Tuning the SR

A first step in testing the SR is to tune its magnetic (B) and electric (E) fields. In an ideal case of uniform fields this task is quite simple, as one maintains $v = E/B$. However, in the case of non-uniform realistic fields a correct tuning can be done by adjusting the ratio E/B to minimize the deflection of the beam as it goes through the SR, while achieving 90^o rotation of the spin. Once the exact magnetic and electric field maps are know, this can be done numerically, however, it is just as easily achieved iteratively in the simulations.

Initially, I tune the SR using a parallel beam, whose energy is 15 keV and has a circular shape with a

Gaussian cross section of 6.83 mm RMS. At this stage, both L1 and L3 are still off, and I propagate the beam from the entrance of L1 to the center of L3. Examples of the initial and final beam spots for electric field plates at different lengths are shown in Fig. 2. Note that for an initially parallel

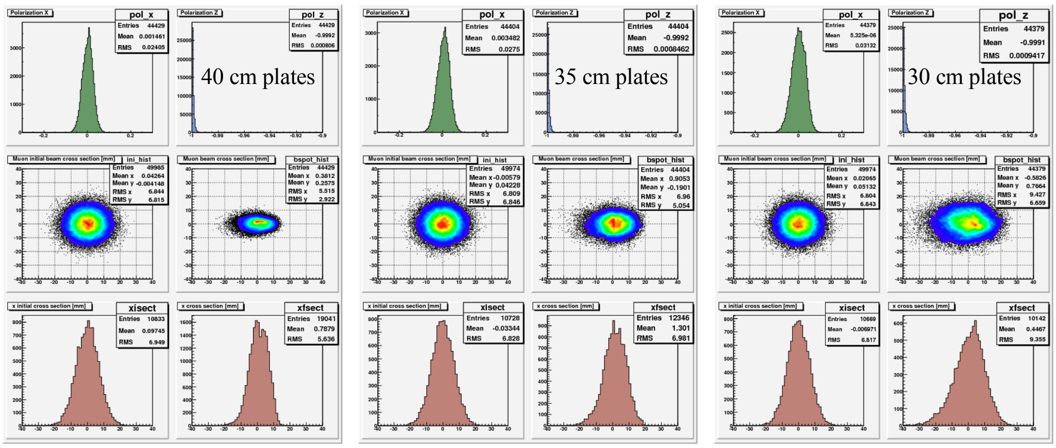

Figure 2: The beam properties as it goes through the SR for different capacitor plate lengths. The longer the capacitor plate the stronger the effective focusing of the SR.

beam the SR does not act as a simple drift chamber. Instead there is some focusing effect, especially in the x direction, i.e. the direction of the electric field or the main direction of the forces. This can be understood by considering the magnetic field direction away from the center of the SR. As can be seen in Fig. 3 when the beam is deflected away from the center of the SR (due to the slight missmatch between E and B), the magnetic forces will have contributions also in the y direction, helping in focusing the beam in this direction. In addition, the gradient of the magnetic field along the x direction will produce forces in the same direction that increase as one goes further from the center. Eventually, this gradient produces a focusing effect on the beam, since portions of the beam with larger deflection experience larger forces towards the center of the SR.

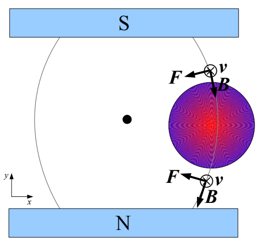

Figure 3: The direction of the forces acting on the beam as it passes through the SR.

These focusing effects along x and y produce an asymmetric beam spot. Therefore, in order to correct for this asymmetry one may require asymmetric focusing elements after the SR. One option, for example, is using the RA. Alternatively, one may split the L3 into top-bottom and left-right anode sets, each at a different voltage. The advantage of this option is that it will also be usable in high magnetic fields on the sample, however, its feasibility is still under consideration.

Tuning the beam line

The next stage in testing the SR is testing its compatibility with the whole LEM beamline. This is to ensure maximum transmission throughout the beamline and minimize the beam-spot size at the sample. For this purpose, I followed a step by step tuning procedure:

1. Tune L1 to maximize transmission at the center of L3.
2. Tune L3 to minimize the beam envelope at the carbon foil in the TD.
3. Tune RA to minimize the size of the beam spot on the sample.

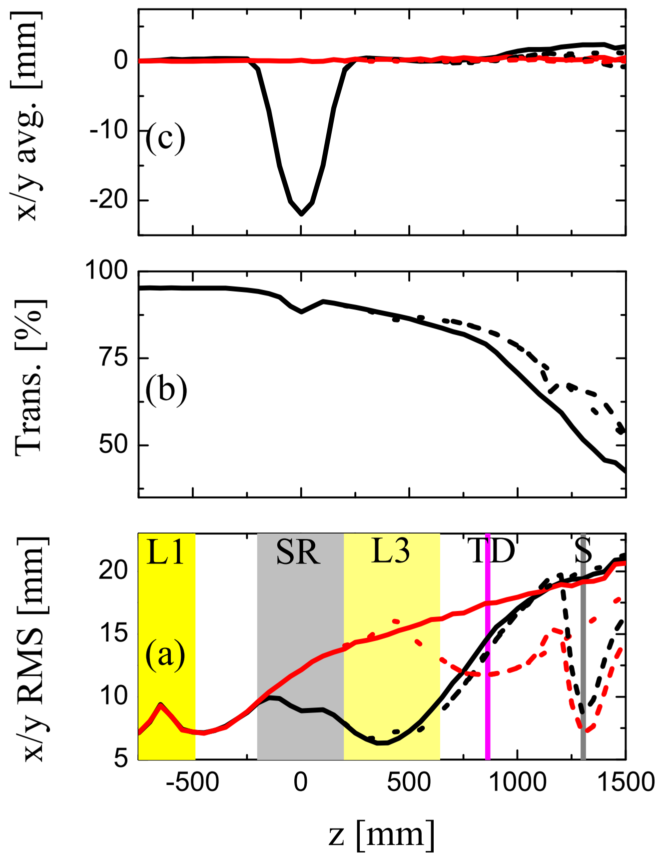

Figure 4: (a) The RMS of the beam envelope in the x and y, (b) the transmission of the beamline and (c) the position of the center of the beam as a function of z. The solid, dashed and dotted lines represent the beam with L3 and RA off, L3 on and RA off, and both L3 and RA on, respectively.

Fig. 4 shows (a) the RMS in the x and y directions, (b) the percentage of transmitted beam and

(c) the average position of the beam in the x and y directions. The solid, dashed and dotted lines correspond to the simulation results after step (1), (2) and (3), respectively, with black showing the x direction parameters and red for y direction.

I would like to point out here a few important points:

- The beam envelope (or RMS) at the sample position is comparable to the initial values before L1. This is a very encouraging fact suggesting that the divergence of the beam in the SR can be corrected for by subsequent beam line elements.
- The transmission through the beamline until the sample is $\sim$ 65%, quite reasonable and slightly larger than the current transmission in the beamline. This may be slightly optimistic since we do not take losses in the grids into consideration. The increased transmission compared to the current setup could be due to the fact that since the TD is closer to the sample, with the RA just after it, we avoid many of the beam losses in this region.
- The beam spot at the sample is slightly asymmetric. In low magnetic fields (at the sample), this may be corrected by applying different voltage to the top-bottom and left-right ring anodes. However, a better and more useful correction may be possible by splitting L3 into a top-bottom and right-left sets, allowing for different focusing powers in the x and y directions.

Finally, for visualization purposes, Fig. 5 shows the initial (before L1) and final (at the sample position) beam spot images and their corresponding properties.

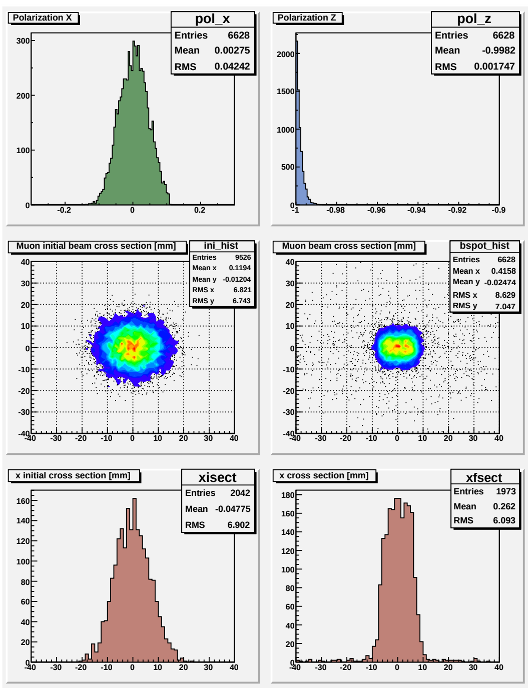

Figure 5: The beam properties before L1 and at the sample position once the beam line is fully tuned.