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Z. Salman | LEM Group
54 57
WLGA / U119 | None
Zaher.Salman@psi.ch

Optimizing the asymmetry and detection solid angle for the new LEM APD detectors

Introduction

Geant4 simulations were used to implement the new APD detector setup, measure its solid angle for positron detection, and the its asymmetry for longitudinal field (LF) measurement. For this purpose muons were implanted into the sample plate and the emitted positrons were detected. The propagation of the muons throughout the full beamline was not considered. Muons we initialized only a 3.0 cm before the sample plate with a beam of randomly distributed rectangular shape with 20×20 mm cross section. All calculations were done in zero field. In the LF setup the muons' initial polarization was changed between $\pm z$ to take into consideration real muons asymmetry in a LF setup and the use of a spin rotator. Similarly, in the TF setup the muons' initial polarization was changed between $\pm x$.

LF Setup

The detectors geometry is shown in Fig. 1. We use a set of 16 segments in both the Forward/up

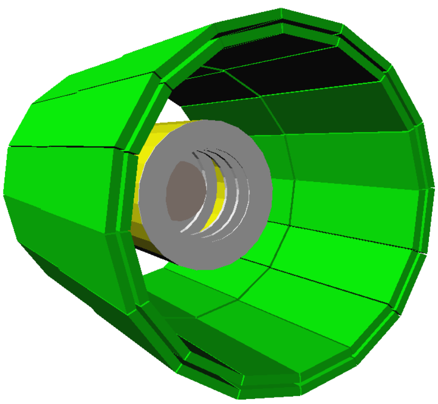

Figure 1: The new LEM APD detector setup. The detectors are divided into two groups, Forward/up stream (F detector) and Backward/down stream (B detector). The cryostat radiation shied and sample plate are also shown (yellow and gray).

stream (F) and Backward/down stream (B) detectors. Each segment consists of two coincidence counters, separated by 2 mm (along the radial direction). The gap between the 16 segments (along the circumference) in the F and B is set to 0.8 mm and the gap between the F and B detectors (along the beam direction) is 1 mm. All these dimensions are according to the final drawings from Hans-Peter from November 2009. Note, in all of these simulations I take coincidence between the inner and outer segments as well as an energy cut of 0.3 MeV to remove any background hits.

The first step in optimizing this setup was to find an appropriate division of F/B detector length which gives the highest F/B asymmetry in a LF setup. For this purpose I ran the simulation with the detector geometry but with varying length (D) of the F detector while maintaining a fixed total length of F+B. Although the gaps were fixed to the values of the final design, they have very little effect on the optimal value of D. However, these gaps do affect the solid angle of the detectors significantly.

The corrected asymmetry is defined as

$$A_{\mathrm{corr}} = \frac{F_+ - B_+}{F_+ + B_+} - \frac{F_- - B_-}{F_- + B_-} \tag{1}$$

where F_i/B_i correspond to the total number of counts in the F/B detector segments when the muon polarization is in the z_i direction. This correction eliminates any geometric (α) effects in the asymmetry. A_{corr} as a function of D is shown in Fig. 2. Here it is evident that the optimal value of D is

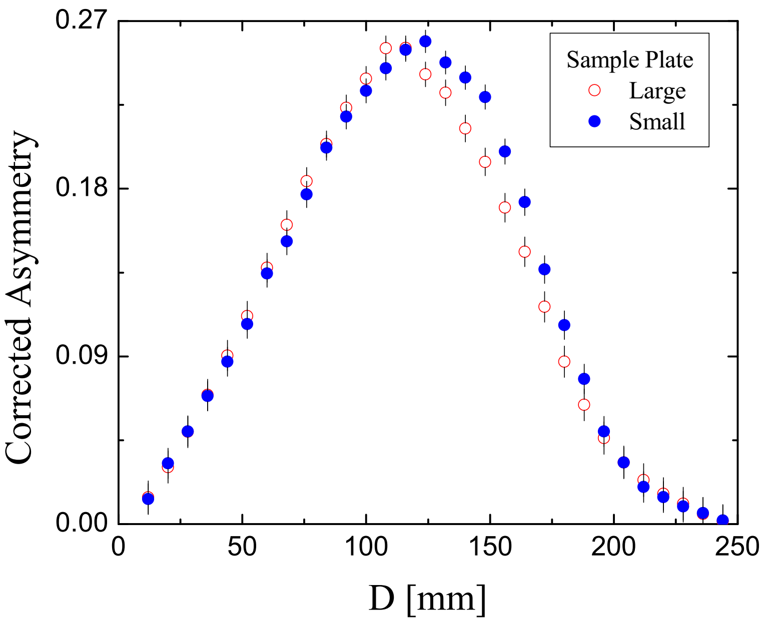

Figure 2: The corrected asymmetry as a function of D. Red squares and blue triangles are calculations with the large and small sample plates, respectively. Optimal D is ~ 120 mm.

120 mm for both a large and a small sample plates. At this optimal value we anticipate an asymmetry of ~ 0.26.

Next, I inspect the solid angle for the detector geometry described earlier. In order to calculate a realistic value of the solid angle, I calculate the total number of counts detected in both F and B detectors. In the simulation I implant into the sample equal number of muons with polarization in the $\pm z$ directions. The number of positron counts in the detectors is then divided by the total number of implanted muons. For example, the number of counts as a function of position z is shown in Fig. 3. In this case we consider only one long detector set, i.e. only F with length of 253 mm and

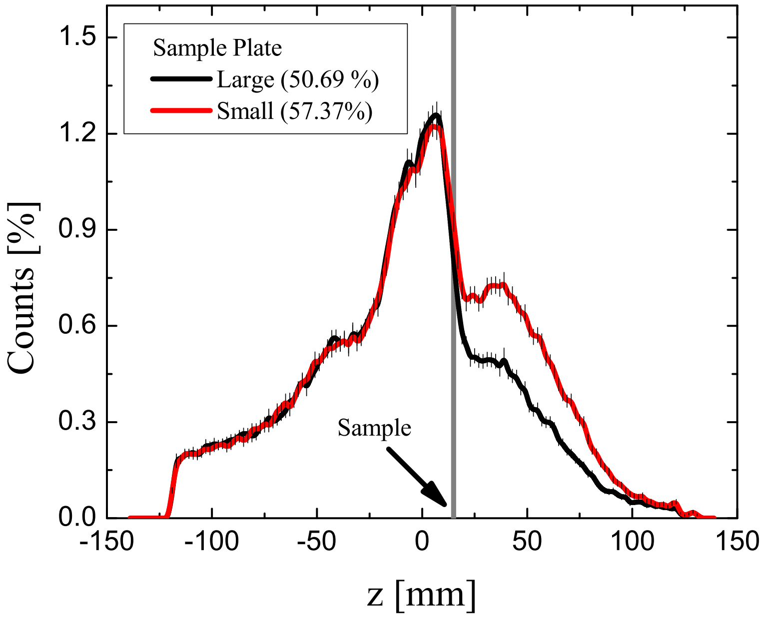

Figure 3: The total number of counts as a function of hit position z. The black and red lines represent counts measured with the small and large sample plates, respectively.

no B detector.

It is important to point out here that the solid angle when using the small sample plate is much larger than that with the large plate. As can be seen in Fig. 3, the main difference is in counts in the down stream B detectors due to attenuation of positrons in the Sapphire and base plate of the cryostat. The effect of this attenuation is also visible in the difference in the asymmetry calculated with the large and small plates. It is evident from Fig. 2 that the attenuated positrons contain high asymmetry information, i.e. they are emitted with a small angle relative to the initial muon polarization. The solid angle obtained from this simulation is $\sim 51\%$ and $\sim 57\%$ for large and small sample plates, respectively. These values are for detectors without any support vessel. They give an upper limit to the expected solid angle when the detector is split into F and B, since then we have a gap between them that will slightly reduce the solid angle.

The solid angle as a function of D is shown in Fig. 4. There are only small variations in the solid angle, but eventually in our current design we have summarised the values of the solid angle and asymmetry for the large and small sample plates in Table 1. Here we present values for different configurations:

1. Without any support material for the detectors.

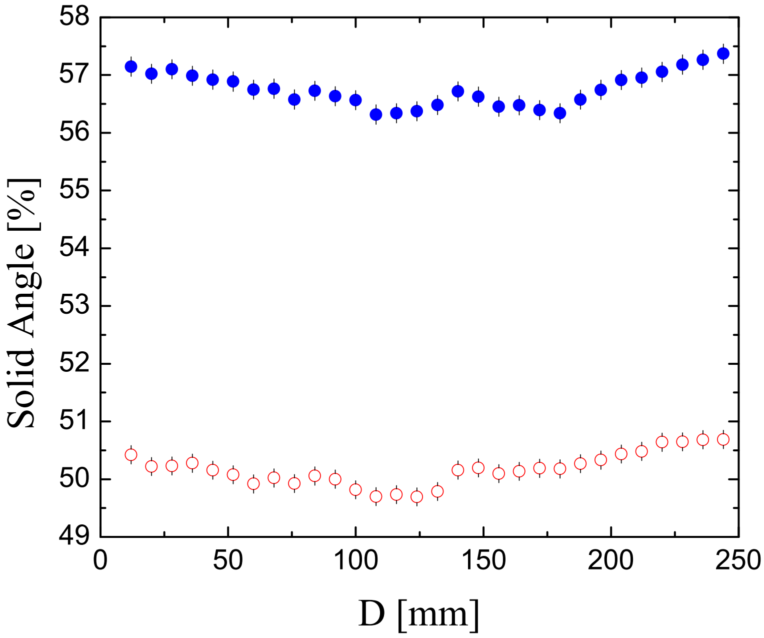

Figure 4: The solid angle as a function of D. At the optimal value of D the solid angle is 49.7% for the larges sample plate and 56.4% for the small plate.

2. With a support vessel - 5mm thick Al cylinder ($\rho = 2.699$ g/cm^3).
3. With a support vessel - 5mm thick plastic cylinder ($\rho = 1.032$ g/cm^3).
4. With a support vessel - 5mm thick plastic cylinder and replacing the sample chamber vacuum tube by plastic material instead of stainless steel ($\rho = 7.93$ g/cm^3). This is an extreme unrealistic situation.
5. With a support vessel - 5mm thick plastic cylinder and replacing the sample chamber vacuum tube by Ti ($\rho = 4.54$ g/cm^3) instead of stainless steel ($\rho = 7.93$ g/cm^3). This is a more realistic situation.

	Forward-Back Asymmetry	Solid Angle	Figure of Merit
Large Sample Plate			
no vacuum vessel (VV)	~ 0.251	49.7%	3.13
with 5mm VV	~ 0.251	44%	2.77
with 5mm plastic VV	~ 0.259	47.5%	3.19
with 5mm plastic VV and plastic sample tube	~ 0.247	56.8%	3.47
with 5mm plastic VV and 3mm Ti sample tube	~ 0.257	52.5%	3.47
with 3.5mm C fiber VV and 2mm Ti sample tube	~ 0.254	54.2%	3.50
Small Sample Plate			
no vacuum vessel (VV)	~ 0.257	56.5%	3.73
with 5mm VV	~ 0.265	50.9%	3.58
with 5mm plastic VV	~ 0.267	54.5%	3.89
with 5mm plastic VV and plastic sample tube	~ 0.255	63.1%	4.10
with 5mm plastic VV and 3mm Ti sample tube	~ 0.259	59.3%	3.98
with 3.5 mm C fiber VV and 2mm Ti sample tube	~ 0.257	61.0%	4.03

Table 1: Summary of the simulation results for LF geometry

TF Setup

Using the optimal values obtained for the LF setup we inspect the performance of this optimal geometry for TF setup (polarization in the x direction but zero applied field), i.e. D was fixed to its optimal value, 120 mm. I ran 4 different runs, changing the muons' polarization between $\pm x$ for both a small and a large sample plate. For all these I used 10E5 implanted muons.

To evaluate the performance of the detectors in TF geometry I gouped the detectors in 4 different groups: Top, Bottom, Left and Right. Each group consists of 8 segments, 4 from each of the F and B sets. Also here we take coincidences (after summation of innner and outer segments), with an energy cut of 0.3 MeV. The simulation was repeated for the same configurations tested in the LF geometry. The results show very good performance as summarised in Table 2.

	Left-Right Asymmetry	Solid Angle	Figure of Merit
Large Sample Plate			
no vacuum vessel (VV)	~ 0.298	49.8%	4.42
with 5mm VV	~ 0.315	44.4%	4.41
with 5mm plastic VV	~ 0.309	47.7%	4.55
with 5mm plastic VV and 3mm plastic sample tube	~ 0.284	57.1%	4.61
with 5mm plastic VV and 3mm Ti sample tube	~ 0.294	53.0%	4.58
with 3.5mm C fiber VV and 2mm Ti sample tube	~ 0.290	54.8%	4.61
Small Sample Plate			
no vacuum vessel (VV)	~ 0.289	57%	4.76
with 5mm VV	~ 0.305	51.4%	4.78
with 5mm plastic VV	~ 0.296	54.6%	4.78
with 5mm plastic VV and 3mm plastic sample tube	~ 0.280	63.6%	4.99
with 5mm plastic VV and 3mm Ti sample tube	~ 0.284	59.5%	4.80
with 3.5mm C fiber VV and 2mm Ti sample tube	~ 0.284	61.1%	4.93

Table 2: Summary of the simulation results for TF geometry