The suggested MuLAN muon transport guide as positron scatterer and muon stopper

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1 Objectives

In this document I try to show how much scattering is introduced by mounting a muon transport beam pipe into the MuLAN ball. This pipe connects the beam vacuum directly to the AK3 target, omitting the EMC and the Helium bag. The beam window (100 μm Mylar) was left in for vacuum safety reasons, but we might decide to abolish it too and so have even less scattering. Shown are the effects of scattering on the decay positron distribution in a simplified detector, which is displayed as phi-theta plane, as I do not have the MuLAN ball segmentation introduced in my simulation. Also the stopping distribution of the beam muons in the pipe material is shown. This is an important parameter to design the thickness of the pipe and its cover material. As this study does sensitively depend on the assumed beam parameters, we take those rather conservatively. I think that for the real beam we have less spread in both, beam momentum and divergence.

This study is also triggered by the fact that I have not found a company yet which provides a thin flexible magnet sheet which fits our needs. I checked specifically with the AK3 engineers at Arnold engineering. Typically flexible magnets and thin AK3 foils cannot be polarized with a single pole on the flat surface. We would also need a external field of at least a 30 Gauss extending for 1 mm into the Al material of the pipe. Standard magnetic sheets are all multi-pole polarized and thus have zero-field crossings over the plane, which makes them unusable for our case.

2 Simulation

2.1 Monte Carlo Setup

The Monte Carlo setup is shown in Fig.1. The studies were done using various setups for the muon transport beam pipe. It was assumed to be made out of 2 mm aluminum and in additional runs covered inside with either 100μm or 200μm of AK3. As normalization for our study we look at the setup without a muon transport pipe. The AK3 target is fully contained within the muon transport pipe.

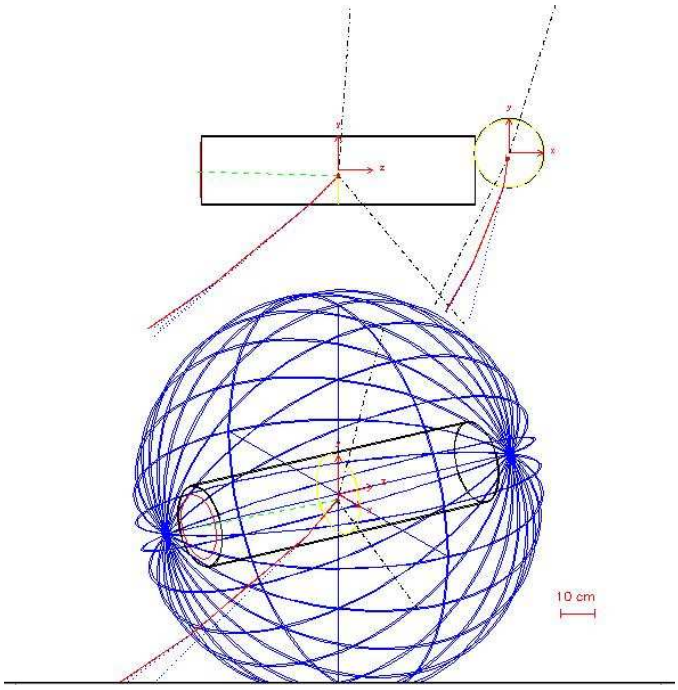


Figure 1: Sketch of the MuLAN Monte Carlo setup (3D-view and projections in yz and yx planes): The muon transport beampipe, the AK3 target with 18 mil thickness. The detector is a full 4π ball, which is not segmented. the muon beam actually start within the ball, therefore one does not need to cut a hole in there.

2.2 Input beam

2.2.1 Conservative standard beam, dp/p = 5%

Fig.2 shows the used muon beam momentum distribution. The used beam parameters were momentum = 28.6 MeV/c, dp/p = 5%, beam origin spread σ_x=1.0 cm,σ_y=1.7 cm, divergence(x) = 5 mrad, divergence(y) = 10.4 mrad. These numbers were derived from some distribution of Gercons provides some time ago.. In comparison we can use beam parameters which are derived from Dan's analysis, which have a smaller beam-spread of dp/p = 2.5% 3.

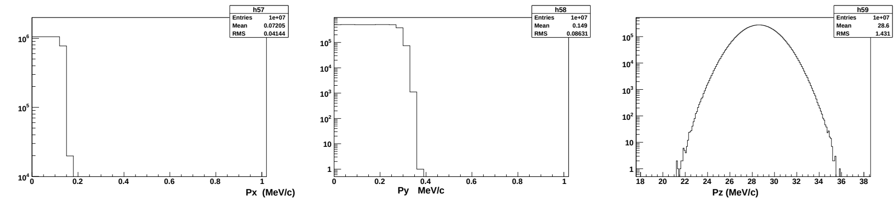


Figure 2: Input beam momentum for the simulation is 28.6 MeV/c with a σ of dp/p = 5%.

2.2.2 dp/p = 2.5 %

This momentum spread was taken from Dan's analysis and probably is closer to reality.

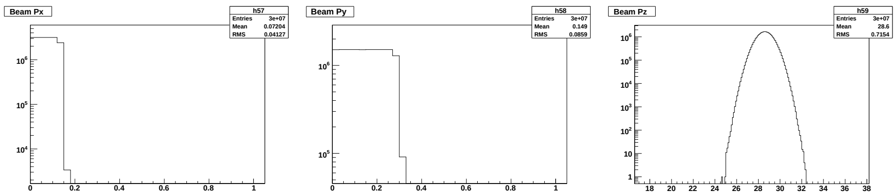


Figure 3: Input beam momentum for the simulation is 28.6 MeV/c with a σ of dp/p = 2.5%.

3 Comparison of scattering

3.1 No muon transport pipe

The distribution of positron hits in the phi-theta plane of the MuLAN detector. Phi describes the horizontal angle (0-2π), theta the vertical angle ($-\pi/2$-$\pi/2$).

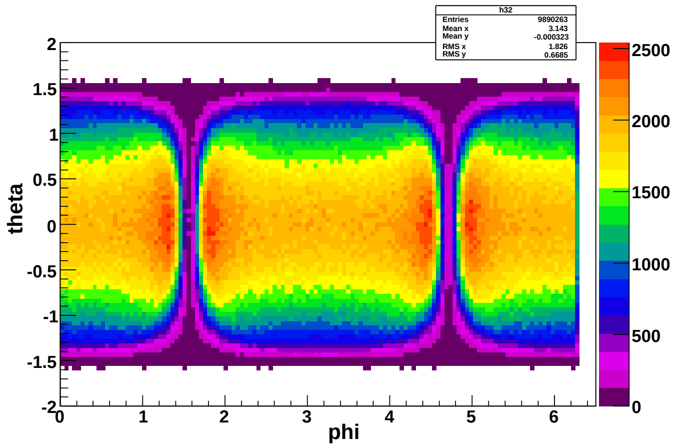


Figure 4: Hits in the phi-theta plane of the Mulan detector without a muon transport pipe. The dominant feature is the scattering of decay positrons in the AK3 target itself which creates the deprived stripes in the target plane. This is our normalization distribution.

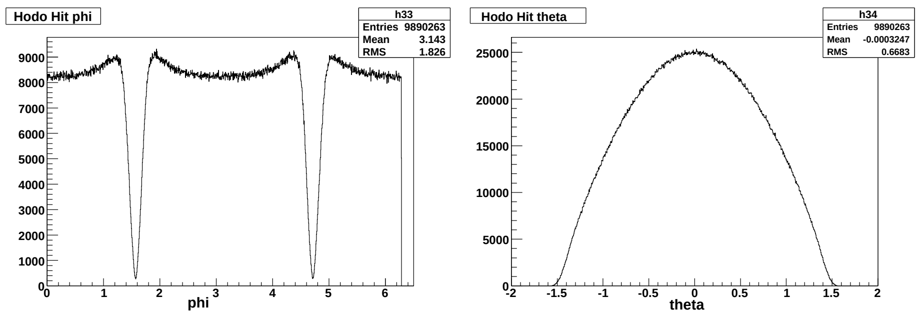


Figure 5: Projections of Fig.4.

3.2 Pipe = 2 mm aluminum

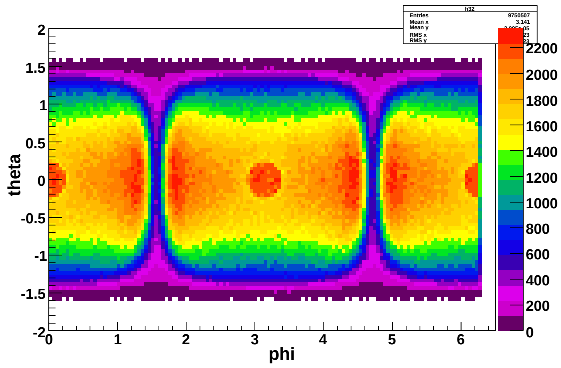


Figure 6: Hits in the phi-theta plane of the Mulan detector with a muon transport pipe made of 2 mm thick aluminum. The dominant features are the scattering in the target plane and the red spot which refers to a larger unscattered positron intensity inside the vacuum pipe.

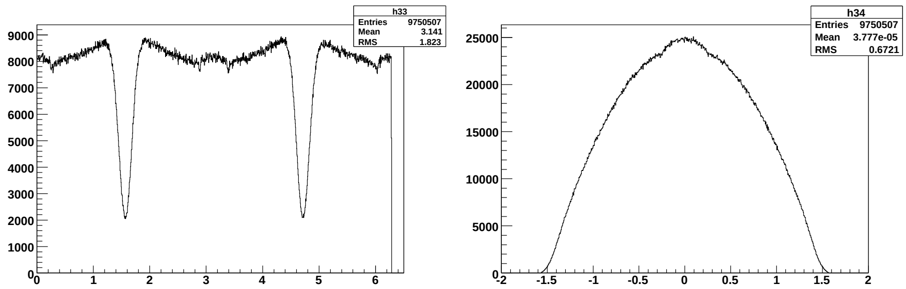


Figure 7: Projections of Fig.6. The little bump in the center shows the unscattered positrons in the vacuum.

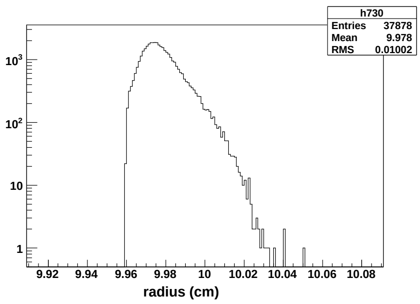


Figure 8: Radius of muon stopping in the muon transport pipe. The Al pipe starts at 9.96 cm. A fraction of 3.8 $\times 10^{-3}$ muons stop in the pipe material.

3.3 Pipe = 2 mm aluminum + 100 μm AK3

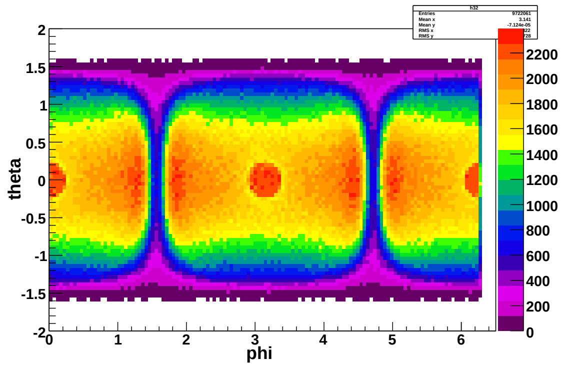


Figure 9: Hits in the phi-theta plane of the Mulan detector Pipe made of 2 mm thick aluminum and additional 100 μm of AK3 inside the pipe. The dominant features are the scattering in the target plane and the red spot which shows the unscattered positron intensity inside the vacuum pipe.

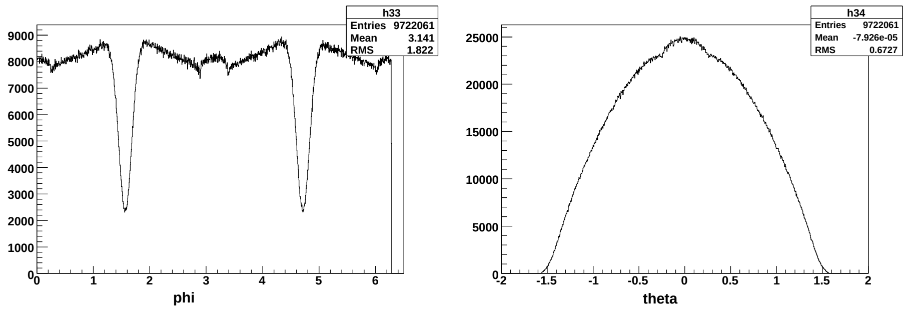


Figure 10: Projections of Fig.9. The little bump in the center shows the unscattered positrons in the vacuum.

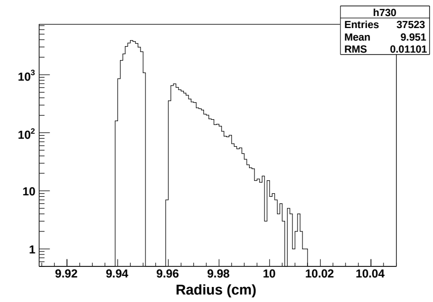


Figure 11: Radius of muon stopping in the muon transport pipe. The Al pipe starts at 9.96 cm, the 100 μm thick AK3 foil at 9.94 cm A fraction of 3.8 $\times 10^{-3}$ muons stop in the pipe, with 78% in the AK3 and 22% in the Al.

3.4 Pipe = 2 mm aluminum + 200 μm AK3

Most (99%) of the muons stop in the AK3 of 200μm thickness. The muon stops in the pipe linearly increase along the beam axis. Most muons stop in the target center.

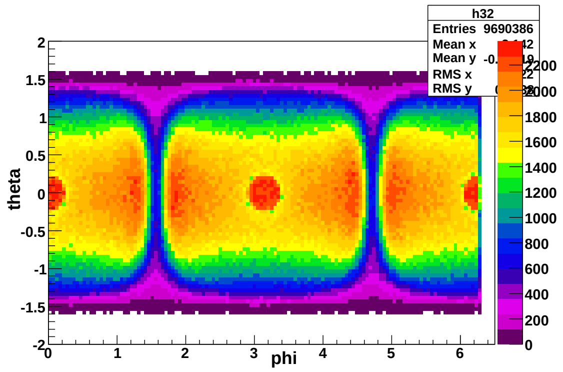


Figure 12: Hits in the phi-theta plane of the Mulan detector Pipe made of 2 mm thick aluminum and additional 200 μm of AK3 inside the pipe. The dominant features are the scattering in the target plane and the red spot which shows the unscattered positron intensity inside the vacuum pipe.

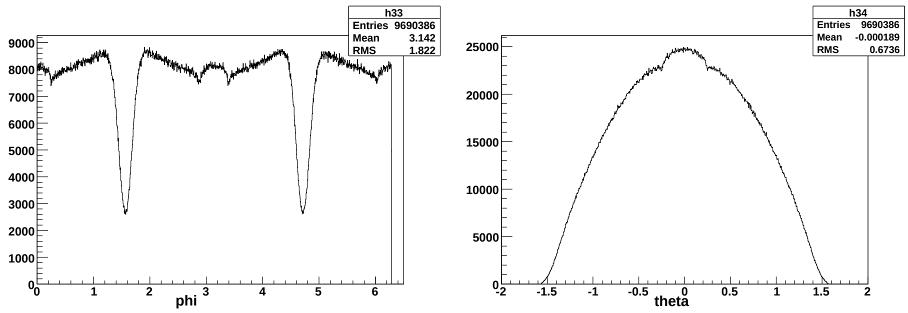


Figure 13: Projections of Fig.12. The little bump in the center shows the unscattered positrons in the vacuum.

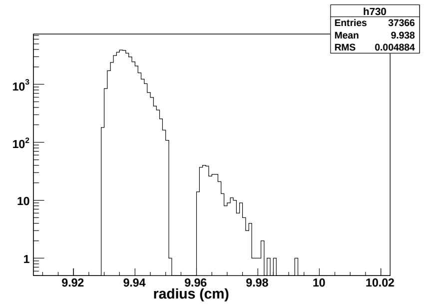


Figure 14: Radius of muon stopping in the muon transport pipe. The Al pipe starts at 9.96 cm, the 100 μm thick AK3 foil at 9.94 cm A fraction of 3.8 $\times 10^{-3}$ muons stop in the pipe, with 99.1% in the AK3 and 0.9% in the Al.

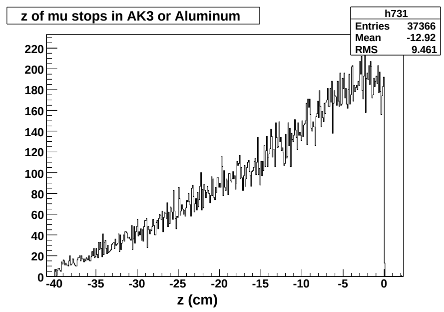


Figure 15: Beam axis position (z) of muon stopping in the muon transport pipe. Negative numbers are upstream, the target is at 0.

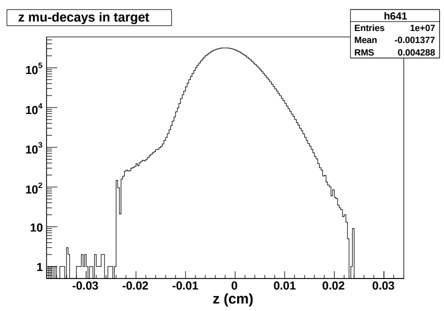


Figure 16: Beam axis position (z) of muons stopping in the target. Negative numbers are upstream, the target is at 0. One sees that the bulk of the muons stop around 0, meaning that the typical stopping depth is around 200 μm for the used beam conditions,but 18 mil are not enough to stop the highest muon momenta.

3.5 Pipe = 2 mm aluminum + 200 μm AK3 dp/p = 2.5%

Using a momentum spread of the beam of only 2.5%, as is suggested by Dan's analysis to be more realistic, does not actually change a lot for the observed scattering distributions.

Most (99.4%) of the muons stop in the AK3 of 200μm thickness. The muon stops in the pipe linearly increase along the beam axis. Most muons stop in the target center. While the distribution of positrons looks identical as the above one, we observe two changes: 1) the stopping position in the target is smaller and all muons contained within the AK3 disc. 2) the fraction of muons stops in the pipe aluminum, passing through the AK3 is half in comparison to the beam with dp/p = 5.5%.

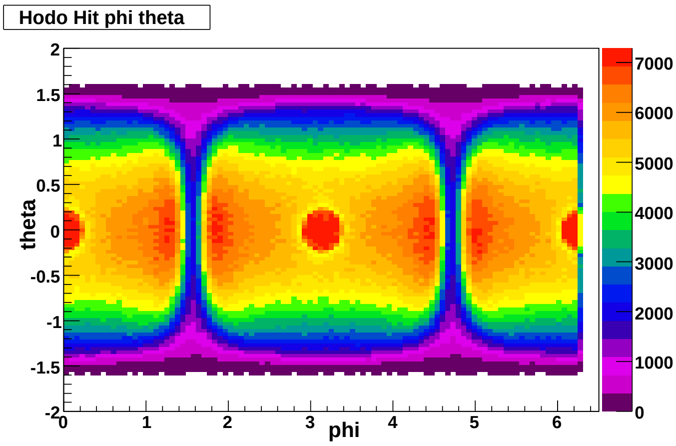


Figure 17: Hits in the phi-theta plane of the Mulan detector Pipe made of 2 mm thick aluminum and additional 200 μm of AK3 inside the pipe. Beam with momentum spread of 2.5 % only. The dominant features are the scattering in the target plane and the red spot which shows the unscattered positron intensity inside the vacuum pipe.

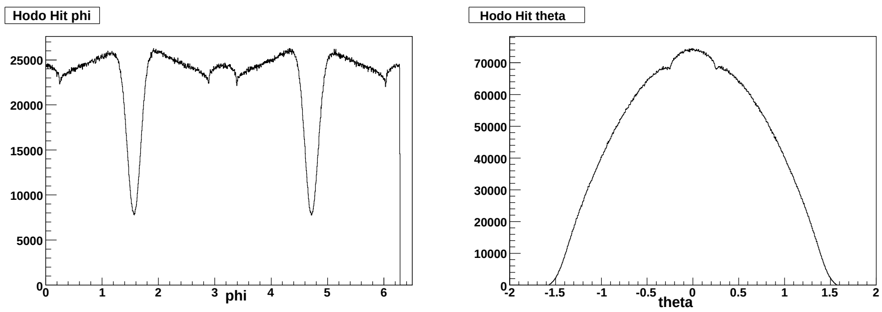


Figure 18: Projections of Fig.17.

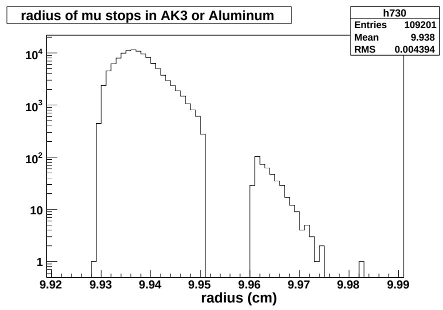


Figure 19: Radius of muon stopping in the muon transport pipe. The Al pipe starts at 9.96 cm, the 200 μm thick AK3 foil at 9.94 cm A fraction of 3.6 $\times 10^{-3}$ muons stop in the pipe, with 99.6% in the AK3 and 0.4% in the Al.

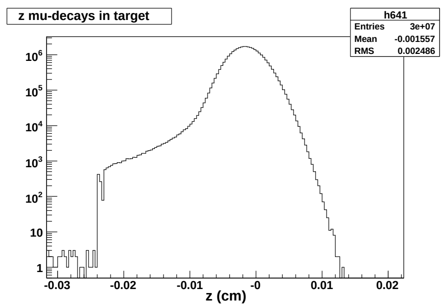


Figure 20: Beam axis position (z) of muons stopping in the target. Negative numbers are upstream, the target is at 0. One sees that the bulk of the muons stop around 0, meaning that the typical stopping depth is around 200 μm for the used beam conditions,but 18 mil are not enough to stop the highest muon momenta.

3.6 Pipe = 2 mm aluminum + 300 μm AK3 dp/p = 2.5%

Using the more realistic beam with dp/p = 2.5 % we can see that in a 300 μm thick Ak3 layer all of teh muons which hit the pipe are stopped within the magnetic material, actually stopping before the end at 9.95 cm.

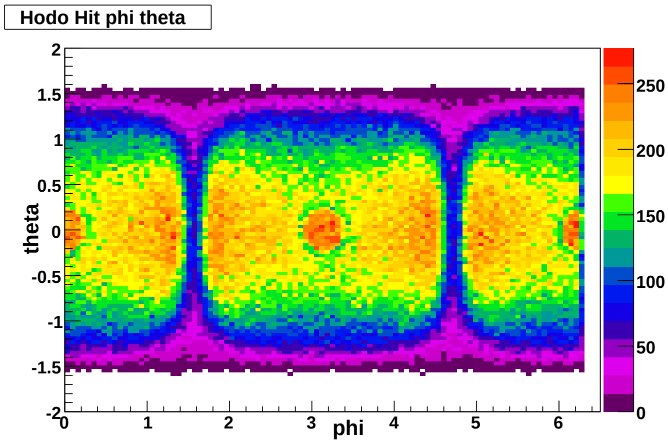


Figure 21: Hits in the phi-theta plane of the Mulan detector Pipe made of 2 mm thick aluminum and additional 300 μm of AK3 inside the pipe. Beam with momentum spread of 2.5 % only. The dominant features are the scattering in the target plane and the red spot which shows the unscattered positron intensity inside the vacuum pipe.

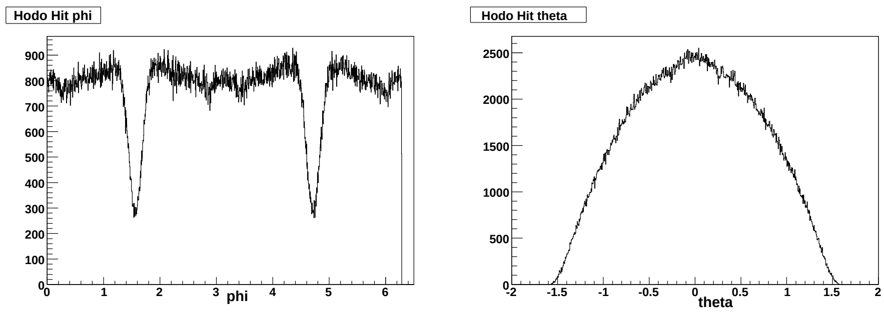


Figure 22: Projections of Fig.21.

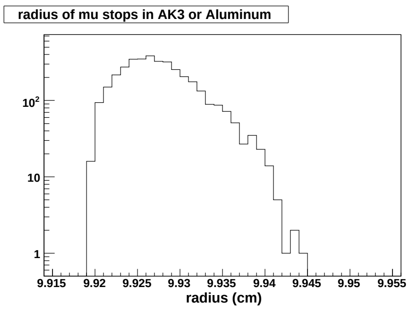


Figure 23: Radius of muon stopping in the muon transport pipe. The Al pipe starts at 9.96 cm, the 300 μm thick AK3 foil at 9.92 cm A fraction of 3.6 $\times 10^{-3}$ muons stop in the pipe all of them in the AK3.

4 Comparison of muon stops in the muon transport pipe

4.1 No pipe versus 2 mm Al + 200μm AK3

In order to see the effect of scattering more pronounced we compare the hit distribution of the setup without a pipe with the one using 2 mm Al and 200μm AK3 (Al+Ak3 minus vacuum file). Figs.?? show the respective distributions obtained by subtraction of the 2 runs. Negative numbers show the regions where scattering causes losses of uniformity with respect to the no pipe setup.

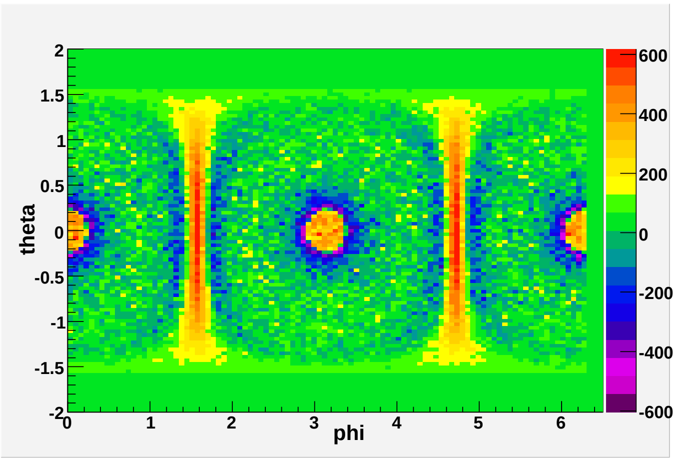
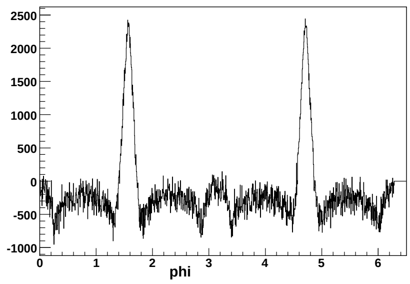


Figure 24: Phi-theta scattering distribution of the setup with Al and 200μm AK3 pipe minus the setup with no pipe. One sees the blue region where events are missing (scattered out) into the red region with the largest surplus on events. The dominant green shows that there is not too much change. One looses events which are scattered into the beam pipe. The target plane gains events, as with the beam pipe there some events are scattered into a region which was almost empty before.



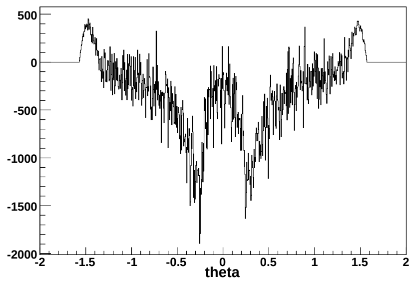


Figure 25: Projections of Fig.24. Clearly observable is the decrease of events due to scattering around the beam pipe.

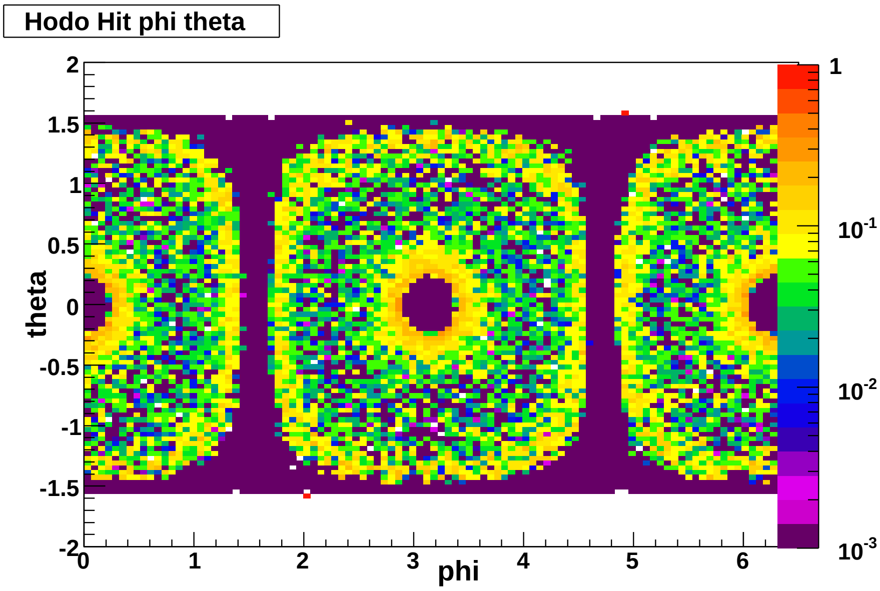


Figure 26: Relative phi-theta scattering distribution of the setup with Al pipe minus no pipe, divided by the latter. One sees that largest change in positron hits is, as expected, around the beampipe and also close to the target plane.

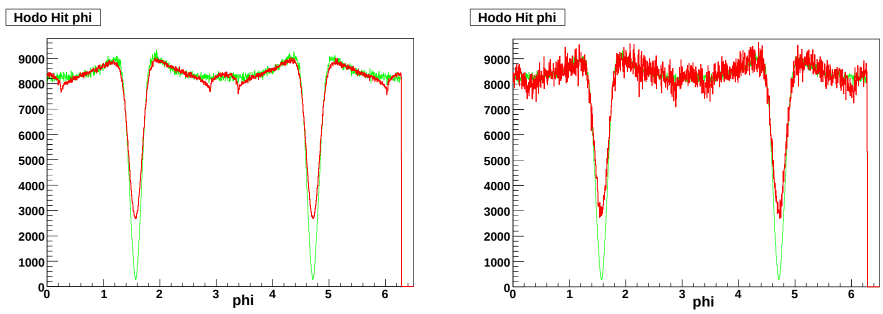


Figure 27: Projections of the two individual phi and theta distributions with (red) and without (green) a beam pipe. It looks identical for all simulated different beam pipe thicknesses.

4.2 2 mm Al versus 2 mm Al + 200μm AK3

In order to evaluate the scattering caused by the addition of 200μm of AK3 material, we compare the covered and uncovered pipe versions. The observed difference is fairly small.

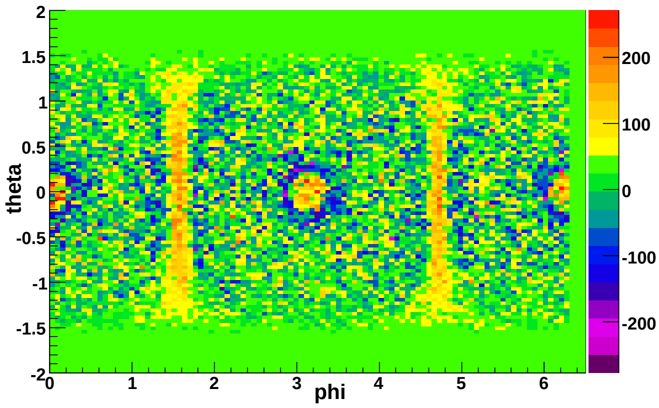


Figure 28: Phi-theta scattering distribution of the setup with Al pipe with 200μm AK3 coating minus Al pipe alone . One sees the blue region where events are missing (scattered out) into the red region with the largest surplus on events. The dominant green shows that there is not too much change. One looses events which are scattered into the beam pipe.

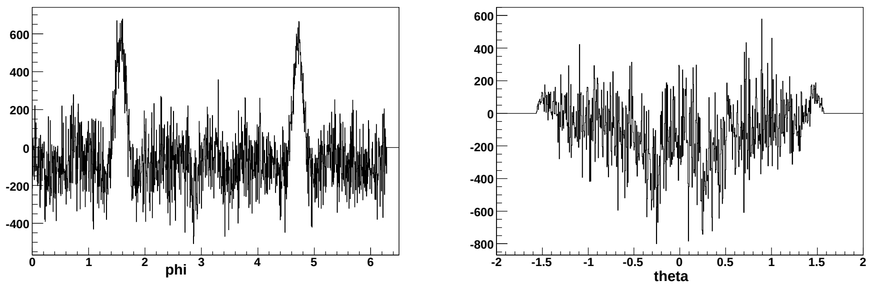


Figure 29: Projections of Fig.28. Still observable is the decrease of events due to scattering around the beam pipe, but now this is much less pronounced.

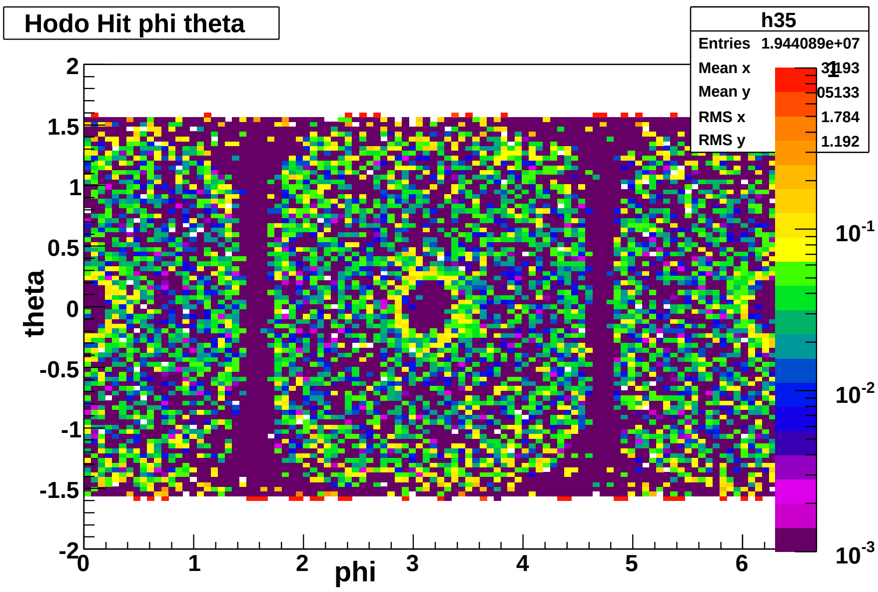


Figure 30: Relative phi-theta scattering distribution of the setup with Al pipe with 200μm AK3 coating minus Al pipe alone, divided by the latter. One sees that largest change in positron hits is, as expected, around the beampipe.

5 Summary

At this stage there is no spin-tracking of the muon decay and hence no corresponding lifetime change in the Monte-Carlo program, which limits the content of this study. However, the decision on hardware manufacturing has to be taken now in order to be ready for the 2006 run, and this study should contribute to this.

I believe MuLAN has decided to incorporate an evacuated muon transport pipe into the next stage setup. In order to control the μSR behavior of muons stopped in this pipe we need a magnetic field. An inside shielding with AK3 to provide a high field stopping environment seems to be most attractive to me as this avoids any handling of an extra magnet which needs power and cooling.

A 2 mm Al pipe is thick enough to stop all beam muons thus eliminating the need of a μSR field outside the pipe. We do not observe a significant scattering difference between the setup with the Al pipe and the one with additional 200 μm of AK3. An AK3 layer of 200 μm is sufficient to stop at least 99 % of the fraction of muons stopping in the pipe inside the AK3 layer.

One could decide to add a total of 300 μm of Ak3 as a 3 layered sandwich inside the Al pipe. With dp/p = 2.5 %, all muons out of 10^6 stop in the AK3. 300 μm would therefore be very save.

As a design suggestions, I would go ahead in constructing the muon transport pipe as suggeted from 2 mm aluminum. I would also order additional three AK3 layers of 4 mil (101 μm) each. The AK3 then should be bent and cover the whole inside of the transport pipe and probably be cut in half to cover the front and the back side of the target separately. We could then finally decide to put in one, two or three AK3 layers.