Muon energy deposit in target counter / Work-log

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January 27, 2006

1 Micro-size simulation with the MuLAN experiment being a factor 100 smaller

The principal setup to simulate MuLAN on a micro-scale includes the following items: a 2 cm thick target scintillation counter, the standard 75 μm thick beam exit window, and tungsten wires which are 25 × 25 micron box shaped, or the full EMC materials budget. While the extensions were shrunk by a factor 100, the thicknesses in beam direction stayed real size.

The muon momentum is set to 28.5 MeV/c and dp/p = 0, with no spread of origin or divergence.

The GEANT step-size is set to STEMAX = 0.0002 for tungsten and STEMAX = 0.001 for Mylar, and all materials STEMAX=0.1, STMIN = 0.000001. Important is also that the energy cut for muons is set to 100 keV as all other cuts.

The positioning of the items are beam origin at -0.42 cm, beam window -0.41 cm, tungsten wire 1 -0.2 cm, target counter at +1 cm (half its width)

The following plots show the total energy deposit of muons in the target counter. The strategy is to put in one material item at the time. Experiment in vacuum and muon counter. add beam window, 1 wire, 2 wires.

The maximum kinetic energy deposit of the muon is relativistically calculated by GEANT with:

$$p_\mu = 28.8\ Mev/c, m_\mu = 105.658\ MeV/c^2, \tag{1}$$

$$E_{kin} = (p^2 + m^2) - m_\mu = 3.77\ MeV. \tag{2}$$

Reducing the energy cut-off for all GEANT processes down to 100 keV – the lowest limit allowed by GPHYSI – results in an energy spread in one 10 keV bin and we get a final energy spectra shown in Figure1. This looks identical with all GEANT processes but the E-loss switched on or off. Typically the spectra below contain 100000 generated muons. One should also realize that every muons starts in the center with no angle spread, therefore it hits the positioned wire.

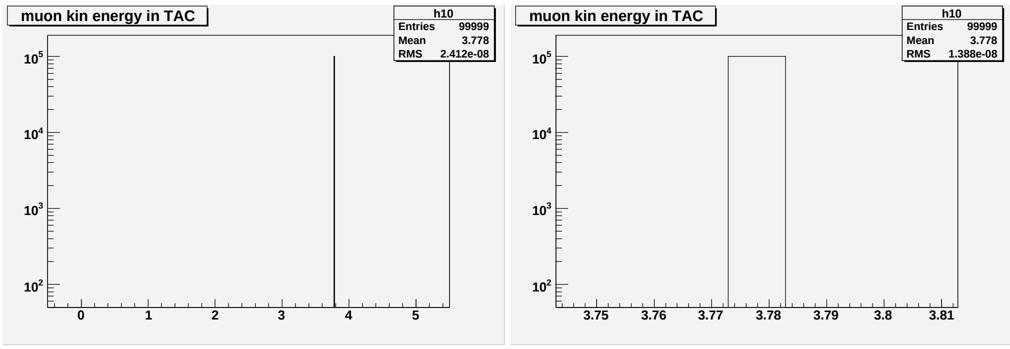

Figure 1: Energy deposition of muons in target counter.. Setup: Experiment in vacuum, muon counter 2 cm scintillator All energy cuts on 100keV.

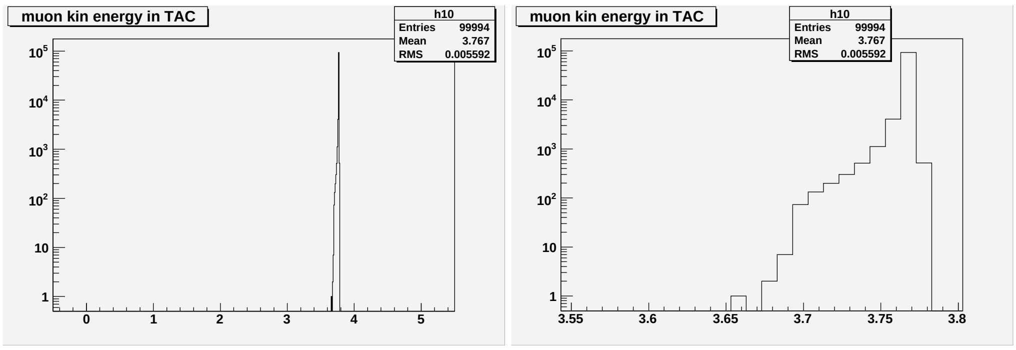

Figure 2: Energy deposition of muons in target counter.. Setup: Experiment in air, muon counter 2 cm scintillator

The micro-model simulation of the simplified setup clearly shows the effect of the tungsten wire at a size, that it could be the cause of the low energy tails in our muon energy distribution.

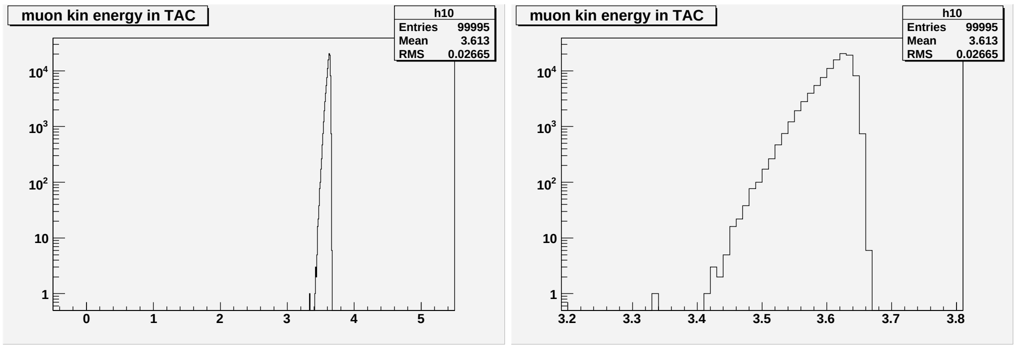

Figure 3: Energy deposition of muons in target counter. Setup: Experiment in air, 70μm Mylar beam window, muon counter 2 cm scintillator.

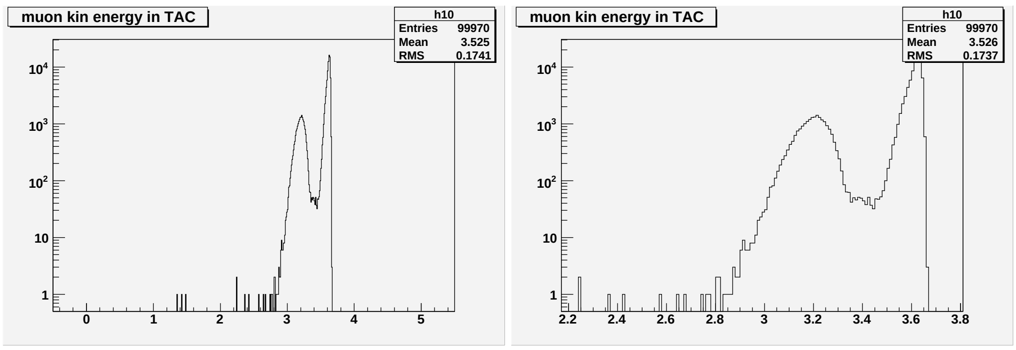

Figure 4: Energy deposition of muons in target counter. Setup: Experiment in air, 70μm Mylar beam window, 1 tungsten wire box-shaped with 25 $\mu m\times$ 25μm cross-section and 3 cm length, muon counter 2 cm scintillator. Clearly we see a peak due to the single wire scattering.

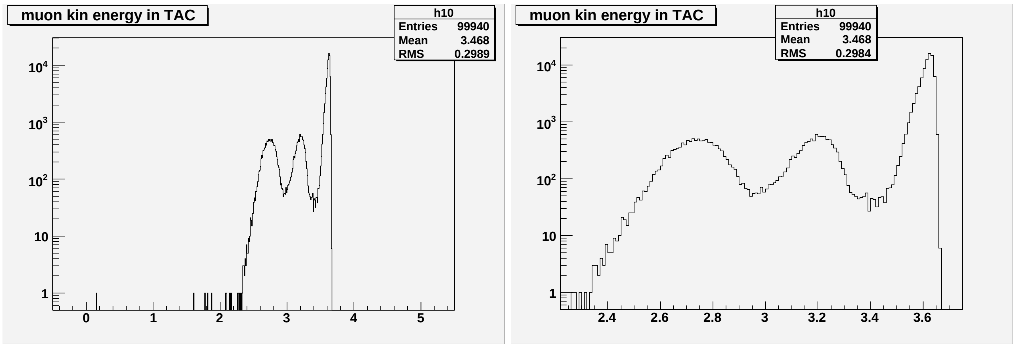

Figure 5: Energy deposition of muons in target counter. Setup: Experiment in air, 70μm Mylar beam window, 2 tungsten wires, box-shaped with 25 $\mu m\times$ 25μm cross-section and 3 cm length, muon counter 2 cm scintillator. Clearly we see a peak due to the single wire scattering. Every muon passes the wires unless it is scattered out of this direction already in wire 1.

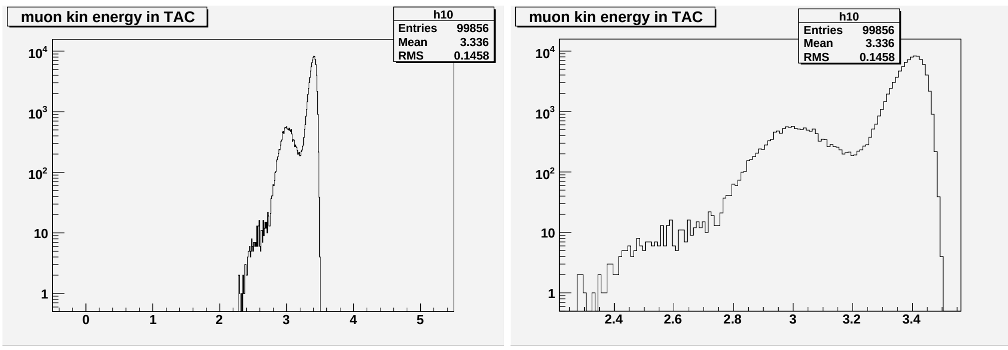

Figure 6: Energy deposition of muons in target counter. Setup: Experiment in air, 70μm Mylar beam window, a realistic EMC model with tube-shaped 25 μm radius wires on two crossed planes, 25 mm of chamber gas, 70 μm of aluminum representing windows and cathodes, 90 μm of Mylar foil, muon counter 2 cm scintillator.

2 Real size model

2.1 Muon energy deposit

This simulation is now a real scale model of the MuLAN setup with: the experiment being in air, a 70μm Mylar beam window, a realistic EMC model with tube-shaped 25 μm radius wires on two crossed planes with 1 mm wire spacing, a 25 mm volume of chamber gas, 70 μm of aluminum representing windows and cathodes, 90 μm of Mylar foil, a helium balloon of 36 cm length, made from 50 μm thick Mylar and filled with 1 bar helium, a muon counter which is a 2 cm thick scintillator to record the muon energy.

Using a still monoenergetic and straight beam one still observes a structure due to wire hits Fig.9. But when using more realistic beam parameters (Fig.8), one broadens the energy spread and the structure vanishes (Fig.10-12).

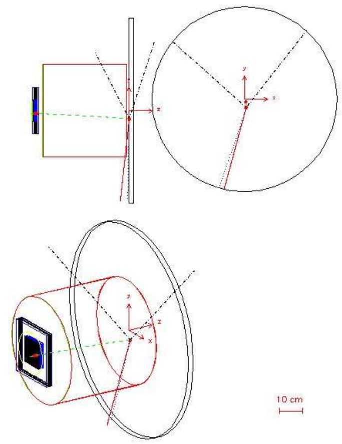

Figure 7: Sketch of the GEANT setup as used for the full scale simulation. Showing: the yellow beam window, the EMC, the round helium bag, the black large muon counter.

Fig.10 shows the muon energy in the target counter with a realistic setup and realistic beam parameters. Clearly we observe a large low-energy tail.

If we remove the EMC, we can improve this situation to the one shown in Fig.11 with the helium balloon still in place, but extending it to the beam pipe window.

The only way to get better is replacing the helium with vacuum. However, one then has to carefully study how many muons stop in the beam pipe. This results in what we see in Fig.12. The energy spread is mainly caused by the simulated 3% beam momentum spread.

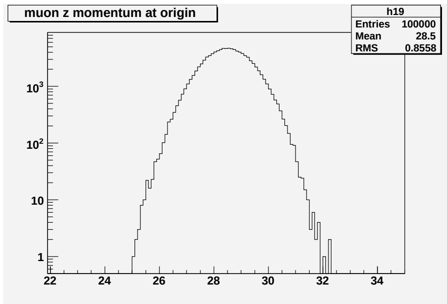

Figure 8: z-momentum distribution of muons at origin with the given parameters of p = 28.5 MeV/c and dp/p($\sigma = \pm 3\%$. Is this distribution going too low ? It is based on some old Gercons file.

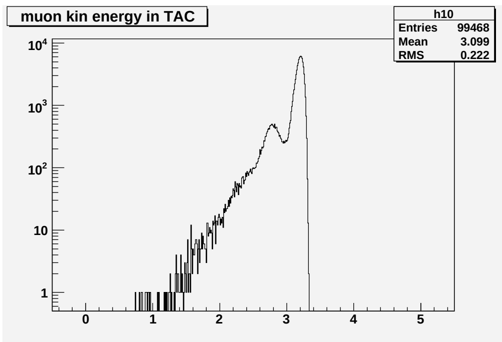

Figure 9: Energy deposition of muons in target counter. Realistic Mulan setup as described in the text. Beam parameters: $p_m u = 28.5 + -0\%, \sigma x_y = 0, divxy = 0$. Muons hit for sure 1 wire of the EMC.

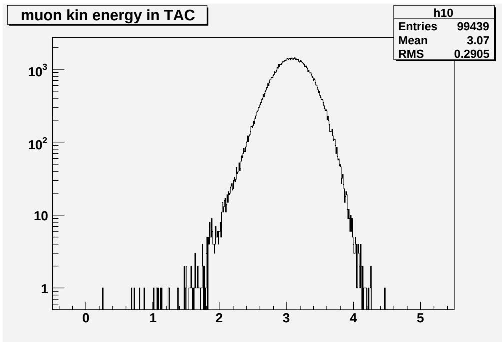

Figure 10: Energy deposition of muons in target counter. Realistic Mulan setup as described in the text. Beam parameters: $p_m u = 28.5 MeV/c \pm 3\%, \sigma x = 1.0 \sigma y = 1.7, divx = 5, divy = 15.4$.

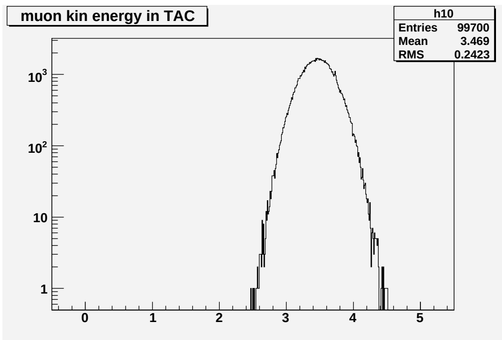

Figure 11: Energy deposition of muons in target counter. Realistic Mulan setup as described in the text. Beam parameters: $p_m u = 28.5 MeV/c \pm 3\%, \sigma x = 1.0 \sigma y = 1.7, divx = 5, divy = 15.4$. EMC removed and helium ballon extended.

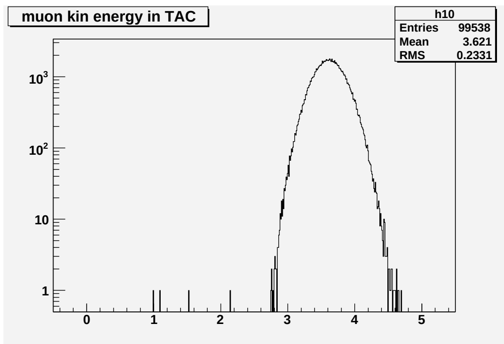

Figure 12: Energy deposition of muons in target counter. Realistic Mulan setup as described in the text. Beam parameters: $p_mu = 28.5MeV/c \pm \sigma(dp/p) = 3\%, \sigma x = 1.0\sigma y = 1.7, divx = 5, divy = 15.4$. No EMC and helim balloon, vaccum pipe all the way through to the target.

2.2 Muon stop positions

It is not clear what's going on with GEANT here

Next we would like to observe where the muons really stop in the setup. This is problematic, as there is a large difference in GEANT 3.1 when turning on and off the muon decay in flight. I do not really understand what GEANT 3.1 is doing with the decay-in-flight parameter DCAY as it turns off all muon decays not only the ones in flight.

If one selects muon stops via the tracking ISTOP parameter, desribing internally a particle has stopped, then one obtaines a very much smaller fraction of muons stopped before the target in comparison with selecting the muon decay position with decay in flight on.

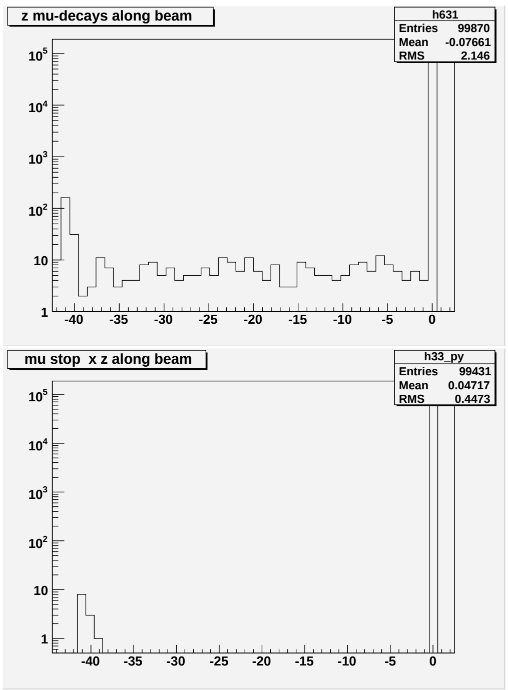

Figure 13: Position of muon decays along the beam axis z with full setup EMC + balloon.
a) position of muon decays including in flight decays;
b) position of stopped muons (ISTOP 0).

Fig.13 compares this behavior for the full setup simulation. This is not understandable for me at this time, as clearly Fig.13a) shows a peak in the position of the beamwindow and EMC, where more stops are expected. Removing the EMC (Fig.15) removes this peak. So the question why does a material there enhance the decay probability. A possible explanantion could be that GEANT just recaculates more often a particle decay probability if the stepsize within a tracking material is smaller. The real answer I do not know.

If one calculates the fraction of muons which decay within the first 3 ns equivalent to the beam-target distance, the calculation agrees approximately with the GEANT simulation of decayed particles.

The difference between the 2 situations however is striking 2 order of magnitude. Either one observes 10^{-5} stops (ISTOP =1 or =2) before the target (with DCAY = 0 off) or 2×10^{-4} (with DCAY = 1 on), or 10^{-3} muons decay before the target (DCAY on).

Out of 1 Million muons not a single one stopped in the helium balloon. For MuLAN operating in kicked mode, the muon decays in flight should be irrelevant, as those decay positrons would be outside the observation interval. In DC mode however they would be observed. The higher number however is close to what was speculated after the fall05 run to stop in the non-field region. Estimating the cross section of two crossed 25 μm wires every square mm results in a fraction of 0.6×10^{-3} roughly consistent with aboves run05 estimation and the number from simulation with decays.

Looking closer to the simulations with decay on: With a realistic setup and realistic beam parameters and muon-decay-in-flight allowed, (Fig.14) we observe that roughly a fraction of 0.0043 of all muons decay before reaching the target, a fraction of 0.0019 in or around the EMC, and a fraction of 0.0024 in the helium bag.

If we remove the EMC, we change this situation to the one shown in 15, with the helium balloon still in place, but extending it to the beampipe window. This decreases the fraction of muons decaying before the target inside the helium to 0.0026 . Fig.16 shows the decay positions obtained with a vacuum pipe all the way to the target, which does not improve the situation further.

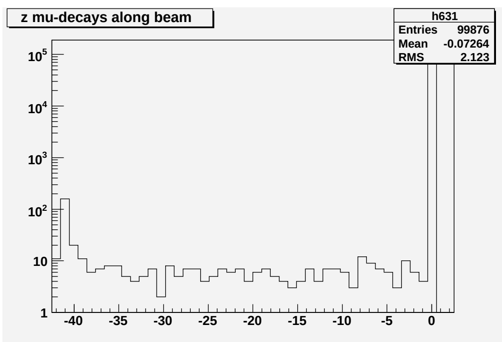

Figure 14: Position of muon decays along the beam axis z. One clearly observes a peak at the EMC location in the left bins.

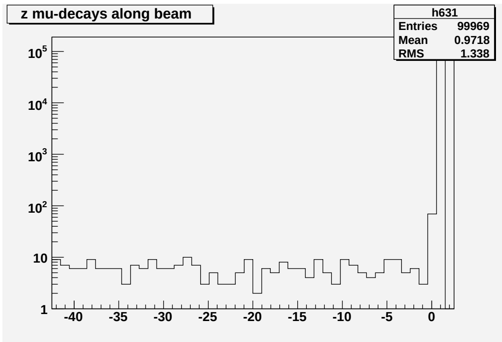

Figure 15: Position of muon decays along the beam axis z. EMC removed and helium ballon extended.

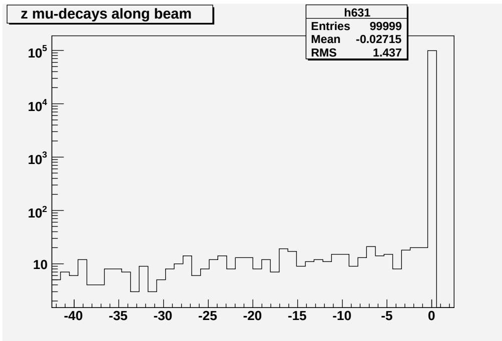

Figure 16: Position of muon decays along the beam axis z. No EMC and Helium balloon, vacuum pipe to the target. There is not much change to the previous picture.

3 Summary

Tuned to small stepsizes a simulation of the MuLAN setup clearly shows that the muon energy spread at the target position goes down to very low momentum. A feature which was observed in the air-scans performed in fall05. These low energy tails can clearly be explained by wires in the EMC and other materials present. More work has to be done to understand what the DCAY parameter and the muon stop versus decay position really means.