GEOMETRY OPTIMIZATION OF THE ISIS MUON TARGET

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Abstract

ISIS is the world's most successful pulsed spallation neutron source that provides beams of neutrons and muons that enable scientists to study the properties of the matter at the atomic level. Restrictions are imposed on the muon target regarding thickness as this will affect the proton transmission to the second neutron target. However, it could be possible to improve the muon production by optimizing the target geometry. Currently the muon target is a 7 mm thick graphite plate oriented at 45 degrees with respect to the proton beam. A set of slices placed at variable distance is proposed instead of the 7 mm thick graphite target. The performance of the set of slices is examined in this paper.

THE ISIS MUON FACILITY

The requirement for MuSR science is to make available intense beams of polarised muons. The principal continuous muon sources are at TRIUMF and PSI while the pulsed facilities are at KEK and ISIS. The ISIS accelerator produces intense pulses of high energy protons for neutron production by the spallation process and muon production through pion creation. The ion source produces negative hydrogen ions which are sent to the Radiation Frequency Quadrupole accelerator. Intense RF electric fields are used to focus, bunch and accelerate particles before they are passed to the linac where they are accelerated to 70 MeV. Final acceleration of the beam occurs in the synchrotron where the bunches are accelerated to 800 MeV. The acceleration process is repeated 50 times per second, so a mean current of 200 μA is delivered to the targets. The muon target is an edge water cooled plate made of graphite with dimensions (50x50x7) mm, oriented at 45 degrees to the proton beam (rotated about a vertical axis) giving an effective length of 10 mm along the beam. The pions and muons are extracted into two beamlines each at 90 degrees with respect to the proton beam. The muons are collected using a thin aluminium beam window situated at 15 cm from the target centre and having a diameter of 8 cm. The muons emerge from the target within a vertical acceptance of $\pm$5 mm and a horizontal acceptance of $\pm$30 mm, with a divergence of 35 mrad in the horizontal direction and 180 mrad in the vertical direction and a momentum in the range 25-27 MeV/c per unit charge. The muon beam is fully polarised and this polarisation is maintained as the beam is transported to the muon spectrometers. As the muon facility runs in parallel with the neutron facility, the proton transmission through the muon target must be kept at the required level (usually above 96%). The target is followed by a set of two collimators. The collimators are angled cones of 40 cm length and are made of Cu . The first collimator has an inner radius of 37.5 mm and an outer radius of 54.15 mm and the second collimator has an inner radius of 51 mm and an outer radius of 61.4 mm. The interaction of the protons in the graphite target produces intense pulses of pions with a wide energy spectrum. The low energy pions come to rest and decay in the muon target. These muons have low energy and the only ones with sufficient range to escape the target are those that stop near or at the surface of the target. These are surface muons and are 100% polarised in any chosen direction of emission from the target. In order to improve the surface muon production, substantial gain in intensity can be achieved through optimisation of the target geometry as there is very little that can be done to the energy of the proton driver to improve muon beam intensities. A target geometry optimisation is presented next in this paper.

GEANT4 SIMULATIONS

The Monte Carlo code GEANT4 [1] was used for these simulations. GEANT4 is a toolkit used to simulate particle interactions in matter and it supports a flexible framework of hadronic models. The Bertini Cascade physics model was used in the current study because it performs well for incident protons and is validated up to 10 GeV incident energy. In this model, the target nucleus is treated as an average nuclear medium to which excitons (particle-hole states) are added after each collision. The path lengths of nucleons in the nucleus are sampled according to the local density and free nucleon-nucleon cross sections. At the end of the cascade the excited nucleus is represented as a sum of particle-hole states which is then decayed by pre-equilibrium, fission and evaporation methods [1].

Slice Target Geometry

In the computer simulations the ISIS 7 mm graphite target is split along the proton beamline into two and three slices, such that the total thickness will still be 7 mm. The distance between the slices is then varied gradually. The surface muons are detected by the ISIS beam window and in parallel by a spherical shell of inner radius of 14 cm and an outer radius of 16 mm surrounding the target. The spherical shell is made of vacuum to avoid particle scattering. In order to have a good statistics for surface muons detected by the ISIS beam window, 10^9 protons were sent to the graphite slices. When the spherical shell was used for detection, only 10^8 protons were simulated. The validity of the results obtained with the spherical shell configuration relies on the fact that the surface muons production is isotropic [2].

The distribution of suface muon vertices was simulated for the present design of the ISIS muon target, and also for the alternative slices target geometry, for different distances between the slices. Fig. 1 shows the distribution of the vertices of the surface muons detected by the ISIS beam window and by the spherical shell surounding the target.

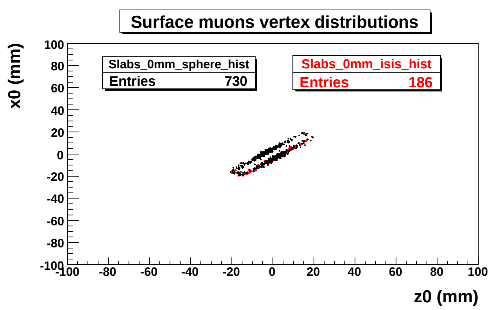

Figure 1: Surface muons vertex distributions for the present ISIS muon target design detected by the spherical shell and also by the ISIS beam window.

Taking into acount the factor of 10 difference in the number of protons simulated in these two cases, one can conclude that the ISIS beam window is detecting ~2% of the total number of surface muons produced in the target. This result is to be expected since the solid angle to the beam window is $\Omega = 0.073\pi$ and the surface muon production is isotropic. The distribution of the vertices for the surface muons detected by the spherical shell also indicate the whole contour of the ISIS target. The ISIS target was split next into two slices, each 3.5 mm thick and rotated at 45 degrees with respect to the proton beam axis. The muon vertex distributions are shown in Fig. 2, 3 and 4, for 20, 40 and 80 mm, respectively, between the slices.

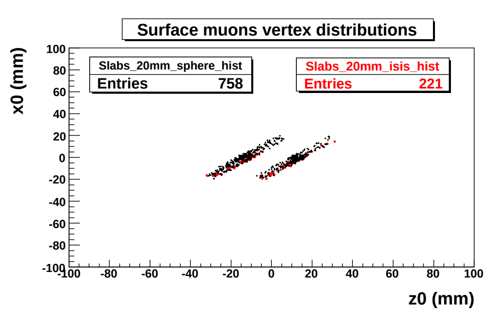

Figure 2: Surface muons vertex distributions for a 2 slices muon target design and 20 mm between the slices.

Having a two slices target design results in a higher surface muon yield, which can be increased by up to 20% with

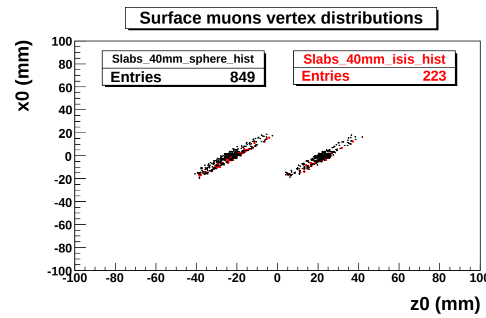

Figure 3: Surface muons vertex distributions for a 2 slices muon target design and 40 mm between the slices.

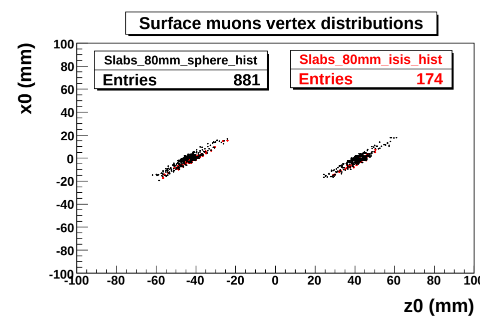

Figure 4: Surface muons vertex distributions for a 2 slices muon target design and 80 mm between the slices.

respect to the present target design configuration, for the optimum distance of 20-30 mm between the slices.

Similar simulations have been performed for a 3 slices target design, each slice being 2.33 mm thick and rotated at 45 degrees with respect to the proton beam. The muon vertex distributions are shown in Fig. 5, 6 and 7, for 20, 40 and 80 mm, respectively, between the slices. Having a three slices target design results in a further incease in the surface muon yield, increased by up to 37% with respect to the present target design configuration, for the optimum distance of 20 mm between the slices. Also the fraction of surface muons which are detected by the ISIS beam window for this new configuration has increased to 3.3%.

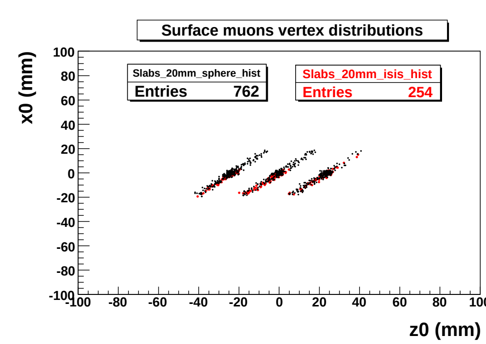

Figure 5: Surface muons vertex distributions for a 3 slices muon target design and 20 mm between the slices.

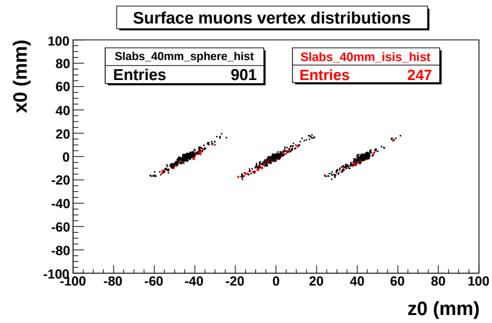

Figure 6: Surface muons vertex distributions for a 3 slices muon target design and 40 mm between the slices.

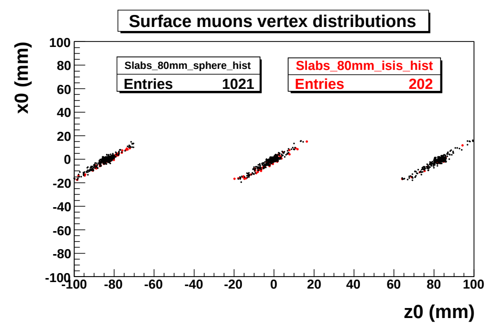

Figure 7: Surface muons vertex distributions for a 3 slices muon target design and 80 mm between the slices.

Variation with Distance

The muon production rate variation with the distance between slices was studied next. The muons were detected in both detectors, the spherical shell and the ISIS beam window. When the slices are too close, a fraction of the surface muons does not reach the detectors because of channeling between the slices. As we increase the distance between slices, the muon production rate is increasing. For the spherical shell, the muon production rate is increasing and flatens after some distance as all the muons produced in the target reach the detector (Fig. 8).

Regarding the surface muons reaching the ISIS beam window, the muons entering under large angles must be excluded because they will not even enter the first quadrupole and cannot be transmitted. In order to get the usable yield, one must apply the angular cut appropriate to the muon beam line, which accepts muons with a divergence of 35 mrad in the horizontal direction and 180 mrad in the vertical direction. As a consequence, a surface muon produced inside a target slice which is more than ∼50 mm from the central position, will not pass the angular selection cuts, and cannot be used in the experiment.

For a two slice geometry there is an increase in the muon production rate but after ∼40 mm, which seems to be the optimum distance, the rate starts to decrease (Figure 9). For a three slices geometry the rate increases initially with the distance but when the distance between the slices is greater than ∼50 mm, the only surface muons collected by the beam window are those produced in the central slice, and the muon rate becomes constant.

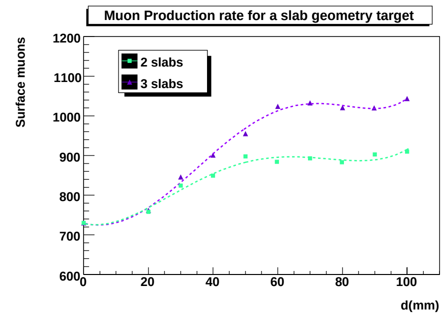

Figure 8: Variation of the number of surface muons detected with the distance between the slices for the spherical shell.

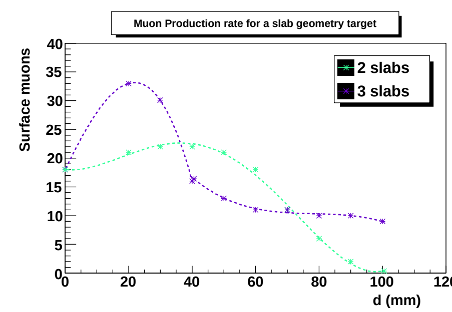

Figure 9: Variation of the number of surface muons detected with the distance between the slices for the ISIS beam window.

CONCLUSION

A target geometry optimisation for an increased surface muon yield was presented in this paper. The performances of the double and triple slice geometries were compared. It was found that for the three slices target the muon yield is higher than for the two slices geometry. The variation of the muon production rate with the distance between the slices shows the optimum value for the surface muon detection in the ISIS beam window being at about 40 mm for two slices and 20 mm for three slices target geometry.

REFERENCES

[1] Geant4 - a toolkit for simulation of the passage of particles through matter, version 4.9.3.p01, `http://geant4.cern.ch`.

[2] A.Bungau *et al.*, "Material Studies for the ISIS Muon Target", MOPEA077, IPAC 2010, Japan.