Bungau, Adriana, Cywinski, R., Bungau, Cristian, King, Phlip and Lord, James

Material Studies for the ISIS Muon Target

MATERIAL STUDIES FOR THE ISIS MUON TARGET

Adriana Bungau, Robert Cywinski, University of Huddersfield, Huddersfield, UK
Cristian Bungau, Manchester University, Manchester, UK
Philip King, James Lord, STFC/RAL, Chilton, Didcot, Oxon, UK

Abstract

The ISIS neutron spallation source uses a separate muon target 20 m upstream of the neutron target for MuSR research. Because ISIS is primarily a neutron source, it imposes restrictions upon the muon target, which normally are not present at other muon facilities like PSI or TRIUMF. In particular it is not possible to use thicker targets and higher energy proton drivers because of the loss of neutrons and the increased background at neutron instruments. In this paper we investigate possible material choices for the ISIS muon target for increased muon yield.

THE ISIS FACILITY

ISIS is currently the worlds most intense source of pulsed muons. The pulsed muon channel of the ISIS facility at RAL has been successfully commissioned and operated for many years as a tool for μSR studies in condensed matter research. The accelerator starts with the ISIS ion source which creates negatively charged hydrogen ions which are accelerated in the linac. The ions are then transported to the synchrotron where they are stripped of their electrons by a thin foil, leaving the bare protons. The proton beam passes through a thin carbon target producing pions which decay with a mean lifetime of 26 ns into muons. The transmitted proton beam is sent then to the primary neutron target to produce neutrons. A separate beamline takes protons to the ISIS second neutron target station. This target is optimised for low energy neutrons providing greater capacity at ISIS and opening up new areas of research.

THE MUON TARGET

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 proton beam has an energy of 800 MeV with about 1 MeV energy spread. The nominal beam current is 200 μA, in double pulses at 50 Hz, so $2.5\,10^{13}$ protons per double pulse. The pions and muons are extracted into two beamlines each at 90 degrees with respect to the proton beam and these two beam lines are separated from the main proton beam and target vacuum vessel by a thin aluminium window. 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.

The specifications of an ideal target are firstly a high yield of pions, and hence of muons resulting from the pion decay, and a small production of unwanted particles such as electrons and positrons, neutrons, scattered protons, and gamma rays. Moreover the target should also generate little heat or dissipate heat easily, and have a low residual activity. An added bonus is that the pion target should be small, so that using electromagnetic optics, a small muon beam spot can be tailored to enable raster scanning of μSR samples, or the study of small single crystals. The muon production is limited because the geometry is constrained by the accelerators beam line parameters (90 degrees extraction and no worse proton beam losses - the proton beam loss is 96$\%$ at the moment).

GEANT4 SIMULATIONS

Because ISIS is primarily a neutron facility, little can be done to the energy of the proton driver to improve muon beam intensities. Substantial gain in intensity can be achieved through optimisation of the material target and target geometry. Computer simulations have been run with the Geant4 code [1] by sending a beam of 10^9 protons to the ISIS muon target. Two low-Z materials, graphite and beryllium were chosen for the target simulations because they have high melting points and the target is expected to run hot in vacuum (Table 1). Beryllium has also a high temperature stability and a low coefficient of expansion with temperature. Both graphite and beryllium have a low density therefore the proton beam passes through the target without significant interactions. Nickel was also considered as a potential high Z target material, but nickel may also be a suitable coating for conventional low Z targets.

Table 1: Material parameters.

Material	Density	Melting point
Graphite	2.26 g/cm^3	3800 K
Beryllium	1.85 g/cm^3	1560 K
Nickel	8.91 g/cm^3	1728 K

Because the muon facility runs in parallel with the neutron facility, the proton transmission through the muon target has to be taken into account for all target materials. A set of two collimators were implemented in the geometry model. 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 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 fraction of the transmitted protons after the second collimator represents the proton transmission and it must be kept at a reasonable level (usually above 96%). The proton transmission through different target materials is shown in Table 2.

Table 2: Proton transmission through target materials.

Material	Thickness	Transmission
Graphite	7 mm	96.79%
Beryllium	7 mm	96.57%
Nickel	1.6 mm	96.43%

ANGULAR DISTRIBUTION

The experimental measurements at the ISIS muon facility showed that there are 16,000 surface muons reaching the muon beam window for 2.5x10^{13} protons on target. In order to find the optimum target material with respect to the surface muon production we can consider the target being surrounded by a spherical shell detector for improved statistics. The validity of the results obtained with this configuration relies on the fact that the surface muons production is isotropic. This has been verified by measuring the forward-backward asymmetry in the surface muon production. Figure 1 shows the momentum distributions for the forward and backward muons and one can see that the distributions are almost identical. Similar results have been obtained for other angles.

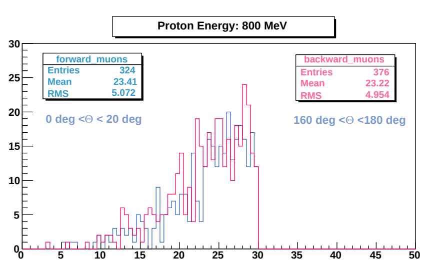

Figure 1: Momentum distribution for forward and backward muons.

MATERIAL TARGET

The spherical shell detector surrounding the target has an inner radius of 14 cm and an outer radius of 16 cm and is made of vacuum to avoid particle scattering. The shell detects all muons having the momentum in the range 0-100 MeV. Figures 2, 3, and 4 show the production rate for surface muons and muons coming from pions in flight for all three targets. One can see that the graphite target gives a higher surface muon yield than the beryllium and nickel targets for similar proton beam loss.

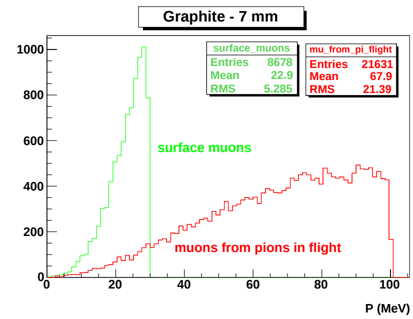

Figure 2: Total muon production for a 7 mm thick graphite target.

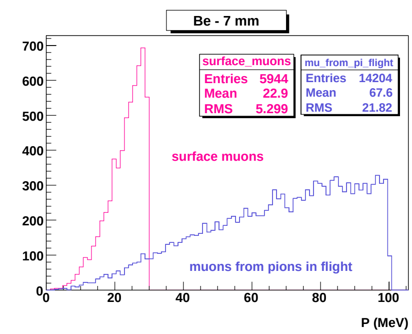

Figure 3: Total muon production for a 7 mm thick beryllium target.

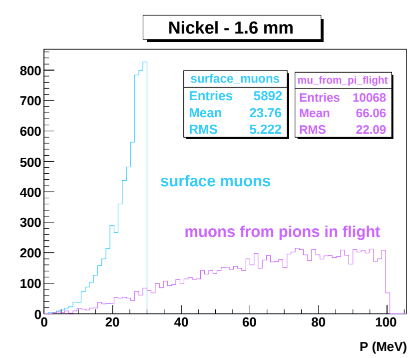

Figure 4: Total muon production for a 1.6 mm thick nickel target.

The surface muons have a momentum range 0-30 MeV in all three materials. However, if a cut is applied in practice at 30 MeV, the surface muons will be detected together with background muons (muons coming from pions in flight and having a momentum lower than 30 MeV). Figures 5, 6, and 7 show the rate of background muons passing the momentum cut for a graphite, beryllium and nickel target.

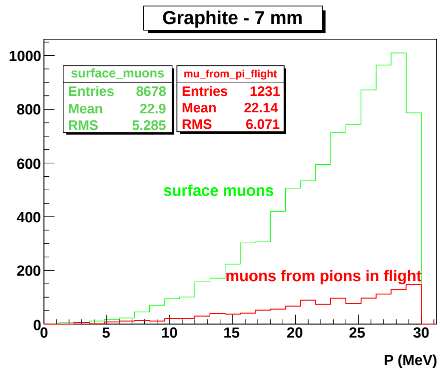

Figure 5: Surface and background muons passing the momentum cut for a graphite target.

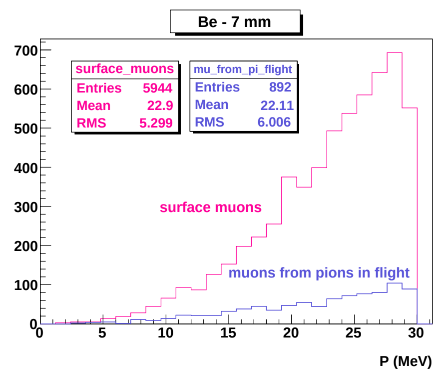

Figure 6: Surface and background muons passing the momentum cut for a beryllium target.

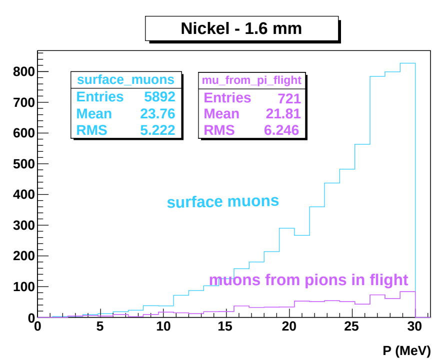

Figure 7: Surface and background muons passing the momentum cut for a nickel target.

COATED TARGET

Since graphite gives a higher surface muon yield for the same proton beam loss, the next step was to investigate the Be target in more detail. In practice the beryllium surface will be rough and a nickel coating will be required to prevent Be diffusing through. The Ni layer is non-uniform and the coating must be thick enough to ensure no holes even if handled roughly. Also, the thickness of Ni coating should be kept constant as it's required for protection, so the Be core should be make thinner to get an acceptable transmission. A beryllium target of 6 mm thickness coated with 0.5 mm Ni layer on all sides gives a proton transmission of 95.01%. A distribution of the surface muons vertex is shown in Fig. 8. Different colours represent the contribution of both materials to the pion production. The colour is chosen depending in which material the pion is produced, no matter in which material the pion is decaying.

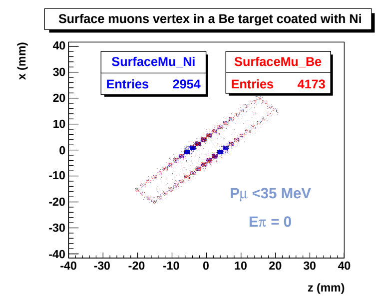

Figure 8: Distribution of surface muon vertex in a Be target coated with Ni.

A comparison between a plain and a coated beryllium target regarding surface and total muon production is presented in Table 3. For both muon production rates, the contribution of beryllium to the muon production is 59% while for nickel is 41%.

Table 3: Comparison between a plain and a coated target.

Muons	Plain Be	Be coated with Ni
		Be - Ni - Total
Total muons	7257	5107 - 3515 - 8622
Surface muons	6015	4173 - 2954 - 7127

CONCLUSION

Graphite, beryllium and nickel targets with similar proton transmissions are compared in this paper and the production rate for surface muons, muons coming from pions in flight and background muons is determined. The best material performance is for graphite. A comparison between a plain and a coated beryllium target is presented next. The muon production rates are higher in a coated Be target than in a plain one. The next stage is to look at the prformance of heavier elements with high melting points such as tungsten.

REFERENCES

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