TARGET OPTIMISATION STUDIES FOR MuSR APPLICATIONS

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

Abstract

Considering the ISIS muon target as a reference, Geant4 simulations have been performed to optimise the target parameters with respect to muon and pion yield. Previous studies suggested that the muon production can be optimised by using a thin graphite slab target with an incident proton energy significantly lower than initially considered. The current paper discusses a possible target design fully optimised for MuSR studies.

INTRODUCTION

MuSR is an experimental method in the condense matter, molecular and chemical science which requires intense beams of polarised positive muons to study the atomic and molecular properties of matter. Positively charged muons, polarized and of sufficient low energy to stop within a reasonable thickness of sample are implanted in a material where they come to rest and do not undergo any nuclear interactions apart from their natural decay. They couple to the local environment via their spin, this feature making them an extremely sensitive probe of magnetism. The evolution with time of the muon spin polarisation within a sample is detected via the muon decay positrons, providing information on the muons local atomic environment. The MuSR experiments are carried out at the continuous muon beam facilities at PSI (Switzerland) and TRIUMF (Canada) and the pulsed beam facilities at ISIS (UK) and J-PARC (Japan). The high cost related to accelerator construction and operation have resulted in the so-called multipurpose facilities where muon and neutron experiments are carried out all together, providing complementary information in a wide variety of science. It is therefore of technical interest to consider how muon production can be optimised. Considering the ISIS muon target as a reference, simulations have been performed to optimise the target parameters with respect to muon yield.

THE ISIS FACILITY

ISIS is a world-leading centre for research in the physical and life sciences at the Rutherford Appleton Laboratory, UK. Every year hundreds of experiments are performed at ISIS by visiting researchers from around the world in diverse science disciplines, from physics and chemistry, to earth science, pharmacology, environmental science and archeology. The range of science areas will continue to grow as use is made of the new ISIS Second Target Station, with instruments optimised for studies of soft condensed matter, biomolecular systems and advanced materials.

The muon target is a graphite plate with dimensions 50*50*7 mm, oriented at 45 degrees to the proton beam and giving an effective length of 10 mm along the beam. The proton beam has an energy of 800 MeV. 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 muon production is limited because the geometry is constrained by the accelerator beam line parameters (90 degrees extraction and no worse proton beam losses - the proton beam loss is 96% at the moment).

Previous simulation studies have shown that for this particular target geometry, graphite has the best material performance for surface muon production [1] [2]. A muon production peak at about 500 MeV incident protons suggests that this is the optimal energy for a muon facility [3]. Target geometry optimisation studies have shown that a double and triple slabs geometry can also improve the muon production. Having a two slab target design results in a higher surface muon yield, which can be increased by up to 20% with respect to the present target design configuration, for the optimum distance of 40 mm between the slices. Having a three slab target design results in a further increase 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 [4]. The GEANT4 code [5] was used for these simulations. Because ISIS is primarily a neutron facility, little that can be done to the energy of the proton driver to improve muon beam intensities. Therefore in the current simulations 10^9 protons having 800 MeV were sent to the muon target. A two and three slabs target geometry were used in simulations along with the original ISIS target. Graphite was used as a target material in all cases.

ANGLE DEPENDENCE

One way to increase the number of muons and pions captured at the beam window is to reduce the target angle. The surface muons are emitted isotropically [2] therefore by doing so the number of muons which reach the beam window is increased by reducing the target angle. Also the target becomes thicker in the beam direction leading to more proton interactions inside the target but to lower proton transmission. 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%).

In a stand alone muon facility these restrictions would not be imposed and the target can be oriented at even shallower angles.

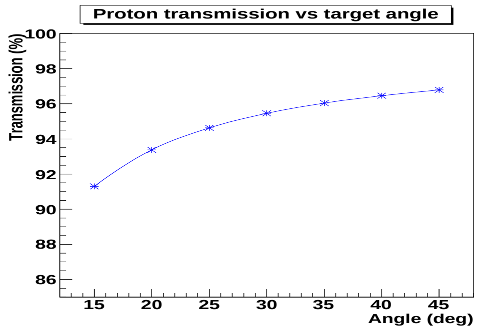

Figure 1: Proton transmission as a function of the target angle for the original target design.

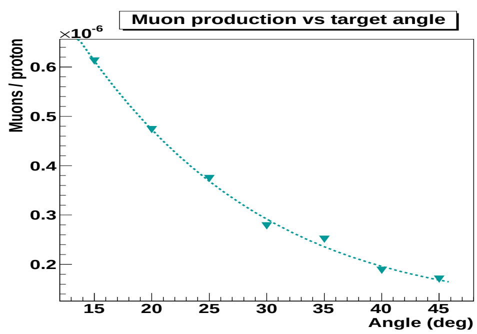

Figure 2: Muon production as a function of the target angle for the original ISIS target.

Figure 1 shows that the transmission can be kept above 90% for angles down to 15 degrees. The 96% transmission required at ISIS corresponds to target orientation angles of at least 35 degrees. Figure 2 shows that the number of surface muons reaching the ISIS beam window increases at shallower angles and at 35 degrees the number of muons is increased by 50% with a proton transmission still above 96%. Decreasing the angle even further to 15 degrees results in an increase of 260% in the number of surface muons reaching the beam window. The proton transmission will still be above 90%.

Two Slabs Target Geometry

Placing a set of slabs with a total thickness as the original target design in the proton beam path with variable distance between them will result in an increased muon production. The thickness of the slabs is constant in all these simulations. By varying the slabs orientation angle, different slab thicknesses will be presented in the beam path. As previously, the transmission is above 96% for angles larger than 35 degrees and above 90% for angles down to 15 degrees (Fig. 3).

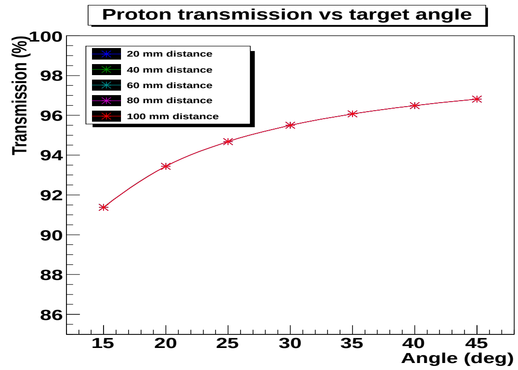

Figure 3: Proton transmission through a set of two slabs of variable orientation angle.

Figure 4 and Fig. 5 show that the surface muon production reaches a maximum for 40 mm distance between the slabs. As the angle gets smaller the muon yield increases. For a set of two slabs placed at 45 degrees and with the optimum distance between them of 40 mm, the muon yield is increased by 31% compared to the muon yield of the ordinal target. Decreasing this angle to 35 deg, the muon yield is improved with 82%. Decreasing the angle even further to 15 deg, the muon yield is increased by 391%.

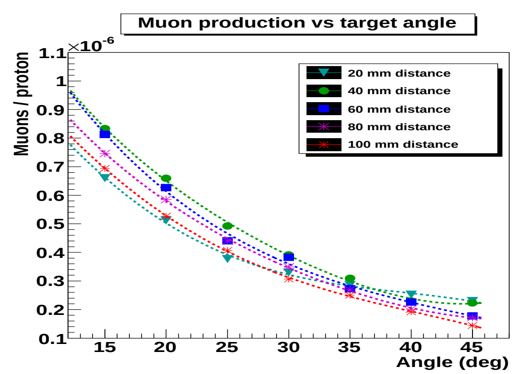

Figure 4: Muon production as a function of target angle for a set of two slabs.

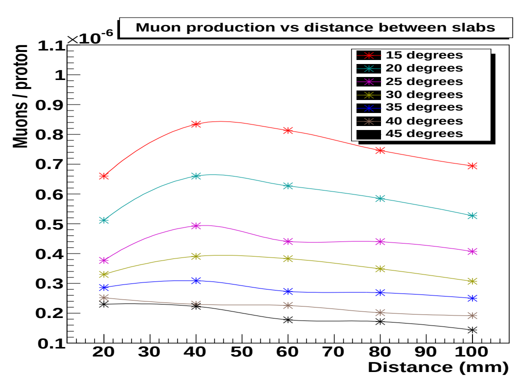

Figure 5: Muons production as a function of slabs distance.

Three Slabs Target Geometry

Since the total thickness of the slabs is always equal to the thickness of the original target, the proton transmission does not depend on the number of slabs or on the distance between them. It depends only on the angle made with the proton beam (Fig. 6).

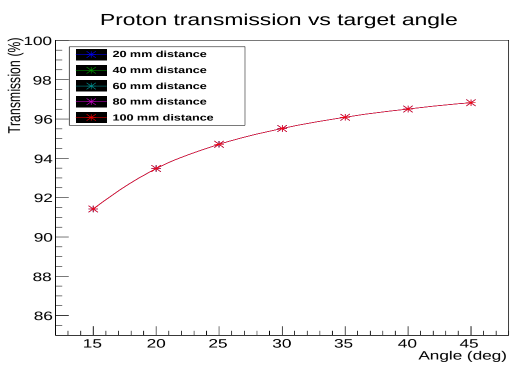

Figure 6: Proton transmission through a set of three slabs.

The study does not include angles smaller than 15 degrees as the transmission drops significantly. Also, at small angles and small distances between the slabs one slab could block the muons coming from the other slab. As in the case with two slabs, for the three slabs target geometry the optimum distance between them was found to be 40 mm. Tilting the slabs at 45 deg would increase the muon yield by 48% and at 35 degrees by 140%. For a shallow angle, the three slabs geometry would improve the muon yield by 431% (Fig. 7 and Fig. 8).

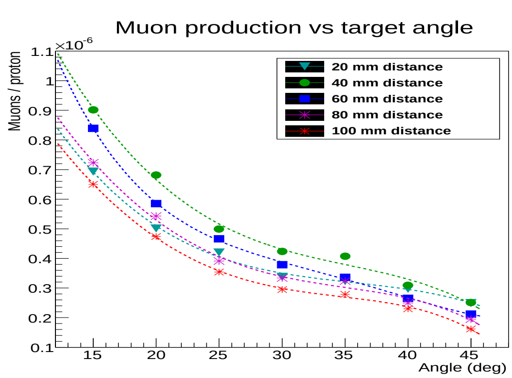

Figure 7: Muon production as a function of target angle for a set of three slabs.

CONCLUSION

The muon production can be increased by up to 48% by splitting the target into a set of parallel slabs. In addition to this, the muon production can also be optimised by tilting the target at smaller angles so that the proton transmission remains high enough and the muon yield increases further

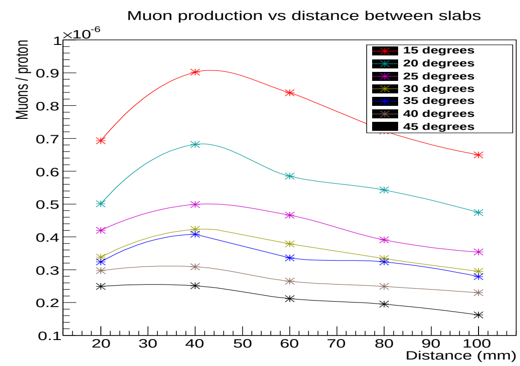

Figure 8: Muons production as a function of slabs distance for a three slabs target geometry.

by up to 140%. The optimum parameters were found to be 40 mm distance between the slabs and 35 degrees orientation angle with respect to the proton beam.

REFERENCES

[1] Adriana Bungau *et al.*, "Development and Optimisation of the Muon Target at the ISIS-RAL Muon Facility", PAC'09, Vancouver, May 2009, TU6PFP051, p. 1397 (2009), `http://www.JACoW.org`.

[2] Adriana Bungau *et al.*, "Material Studies for the ISIS Muon Target", IPAC'10, Kyoto, May 2010, MOPEA077, p. 253 (2010), `http://www.JACoW.org`.

[3] Adriana Bungau *et al.*, "Impact of the Energy of the Proton Driver on Muon Production", IPAC'10, Kyoto, May 2010, MOPEA079, p. 259 (2010), `http://www.JACoW.org`.

[4] Adriana Bungau *et al.*, "Geometry Optimisation of the ISIS Muon Target", IPAC'10, Kyoto, May 2010, MOPEA076, p. 250 (2010), `http://www.JACoW.org`.

[5] GEANT4 - a toolkit for simulation of the passage of particles through matter, version 4.9.3.p01, `http://geant4.cern.ch`.