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# Simulations of pion production from water-cooled solid targets using MARS15

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Configurations of a solid pion production target for the neutrino factory that includes a water jacket are simulated in the hadron production code MARS15 [1]. The addition of water coolant and extension of the target into slices may introduce the effects of: yield degredation from pion reabsorption, additional heat load on the target, and increased scatter in arrival times. These three effects are quantified and used as figures of merit in a comparison of different target lengths and diameters, evaluated in the context of the neutrino factory front end requirements. Energy deposition is also broken down per component to quantify potential heat sources in the system.

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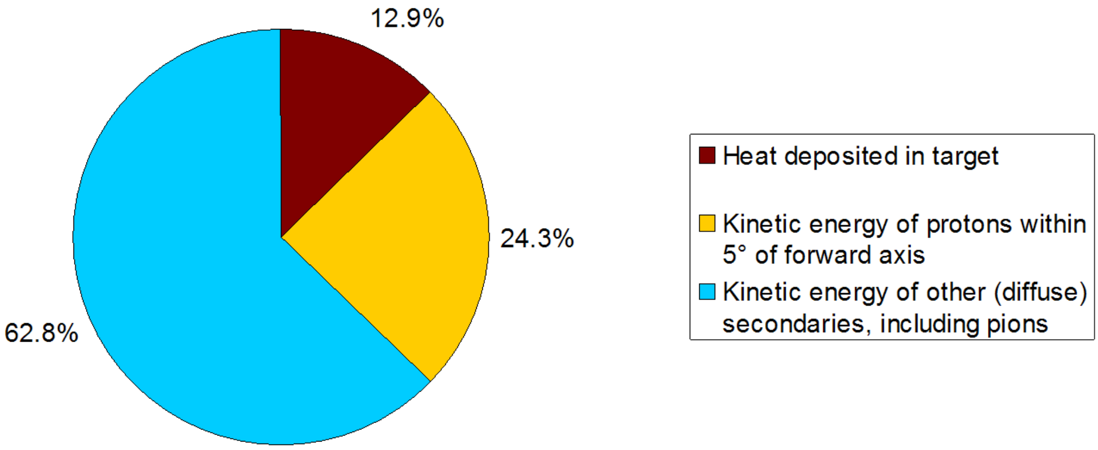

**Figure 1:** Proportions of the incoming power deposited when a 10 GeV proton beam hits a 20 cm long, 2 cm diameter tantalum rod target.

## 1. The UK Neutrino Factory Solid Target

The UK neutrino factory target group is evalulating a radiation cooled solid target [2] as an alternative to a liquid mercury jet [3]. A static solid target would be unable to dissipate the heat load via radiation alone without melting, so new material in the form of a new target bar is moved into the target station for each 50 Hz pulse of the facility via a chain or wheel mechanism. Currently the target is a tungsten bar of $\sim$20 cm length and $\sim$2 cm diameter.

## 2. Water Cooling

This paper examines the possibility of water cooling the target material for the neutrino factory, eliminating the need to change target for every pulse. Previously this had not been studied in the UK due to concerns that the extra water would absorb an unacceptable number of the pions produced and that the additional length of the target to include water would introduce too much time spread into the outgoing particles. In fact, tungsten has a density 19.2 times that of water, making water a minor absorber in comparison and the outgoing pions of interest around 250 MeV/c momentum have a speed of $\sim 0.87c$ compared to the $0.996c$ of the protons moving through the target, meaning only the small difference between these velocities causes real additional spread.

That a single water cooled bar can cope with 4 MW of incoming power may seem counter-intuitive. Figure 1 shows that in the neutrino factory case, as the secondaries are not thermalised, most of the incoming power is radiated as the kinetic energy of secondaries, mostly protons, neutrons and pions. This is a more favourable case than that of a stopping target for neutrons, which must absorb 100% of this power. A comparison in table 1 shows that despite a $> 20\times$ increase in beam power, the absorbed heat in the target is only 3–4$\times$ that of the existing ISIS neutron source.

A simple calculation shows that to dissipate 700 kW of heat in water with a $\Delta T$ of 50 K requires a flow rate of 3.34 kg/s, or 10.6 m/s in a 2 cm inner diameter pipe. Not an unfeasible number and roughly what is required to change the water for each pulse.

| **Proton accelerator** | **Beam power** | **Proton energy** | **Heating power** |
|---|---|---|---|
| ISS baseline neutrino factory [3] | 4 MW | 10 GeV | 514 kW |
| UK neutrino factory scenarios [4, 5] | 4 MW<br>5 MW<br>5 MW | 8 GeV<br>10 GeV<br>8 GeV | 512 kW<br>643 kW<br>640 kW |
| ISIS neutron source [6] | 169 kW | 800 MeV (211 $\mu$A) | 169 kW |

**Table 1:** Comparison of the heat load in neutrino factory solid targets with that of a stopping target in a neutron spallation source.

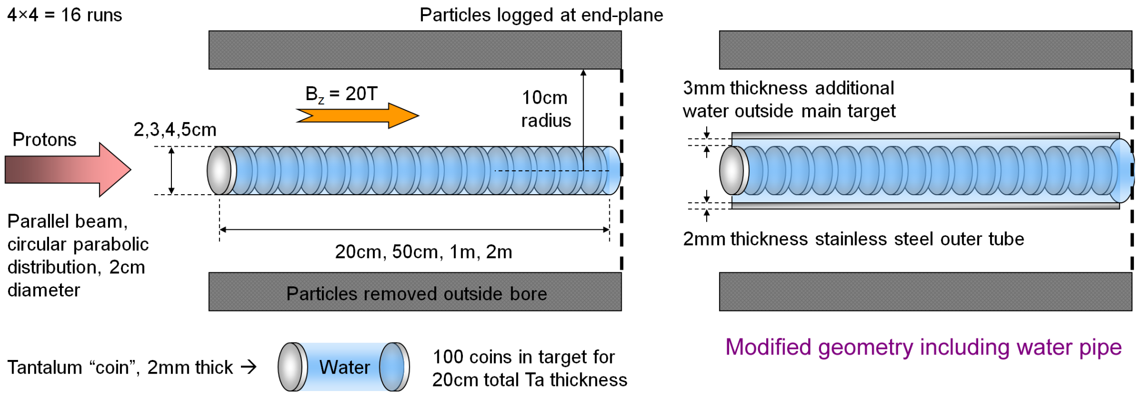

**Figure 2:** Target geometries used in the original (left) and modified (right) simulation.

## 3. Simulation and Figures of Merit

To investigate pion production in a water cooled target, two geometries were used as shown in figure 2. First the original tantalum bar was sliced into 100 2 mm slices and water inserted to extend the target to various lengths (including the original 20 cm without water). This does not include a water flow manifold, so for a more realistic case an enclosing water cylinder and outer steel tube were added to the simulation. The 2 mm slices could be replaced by thinner ones until heat transfer is ideal with little change to the results from the hadronic simulation. The neutrino factory target is mounted inside a solenoid, modelled by the 20 T constant field in the MARS simulation.

Pion production is counted at the end plane of the target and ‘useful’ pions selected by using a transmission probability map as used in [7]. Times of arrival may be logged in a similar manner and MARS outputs energy deposition in the `MARS.OUT` output file. The neutrino factory baseline [3] requires an RMS time spread of no more than 1–3 ns in the pions.

## 4. Results

Figure 3 highlights two target dimensions that retain over 90% of the yield of the solid target; the 50 cm length case does this even when the outer water manifold is included. These targets continue to compare well with the solid when heat load is considered in figure 4, staying around the 700 kW level with no more than 150 kW deposited directly in the water.

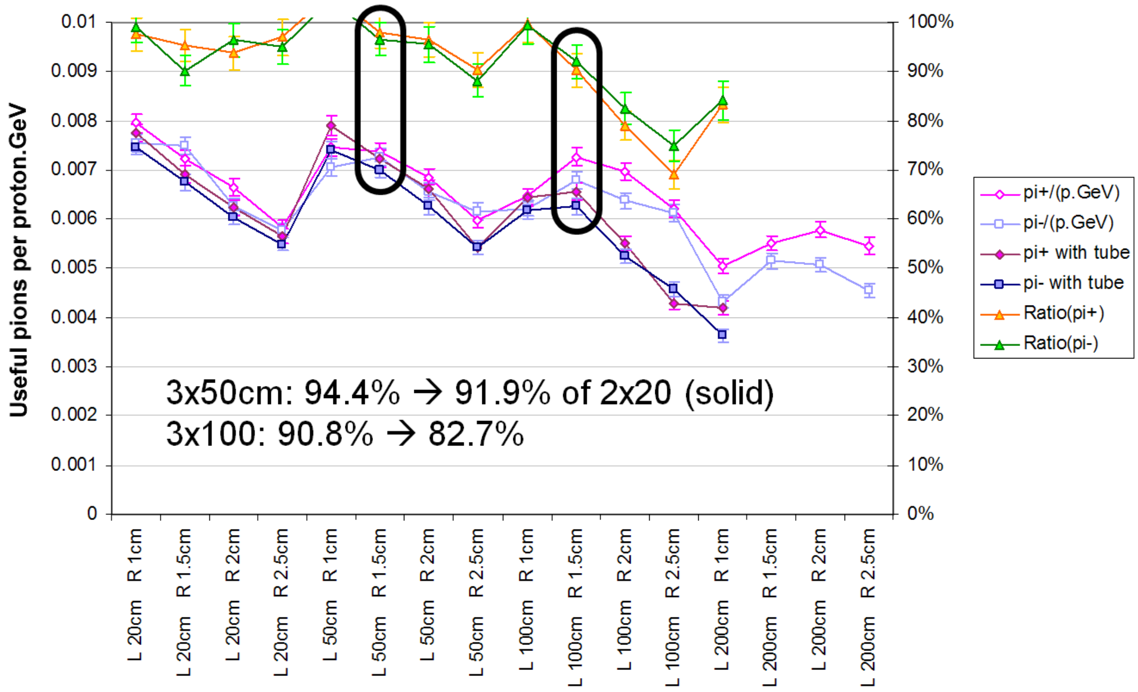

**Figure 3:** Usable pion yields for the two target geometries across permutations of length and radius. Hollow points are for the bare target; filled include the surrounding pipe; triangles are ratios of these (right axis) to show the extent of loss from the pipe.

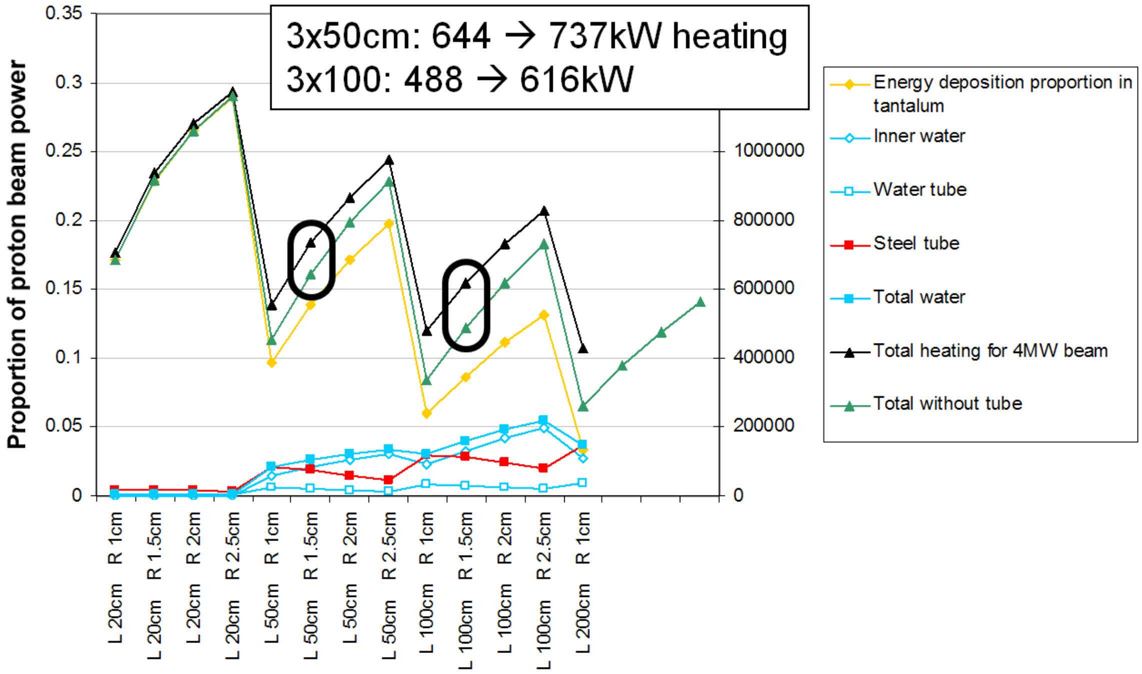

**Figure 4:** Breakdown of heating in the target including the outer tube, with the heating in the bare target included for comparison.

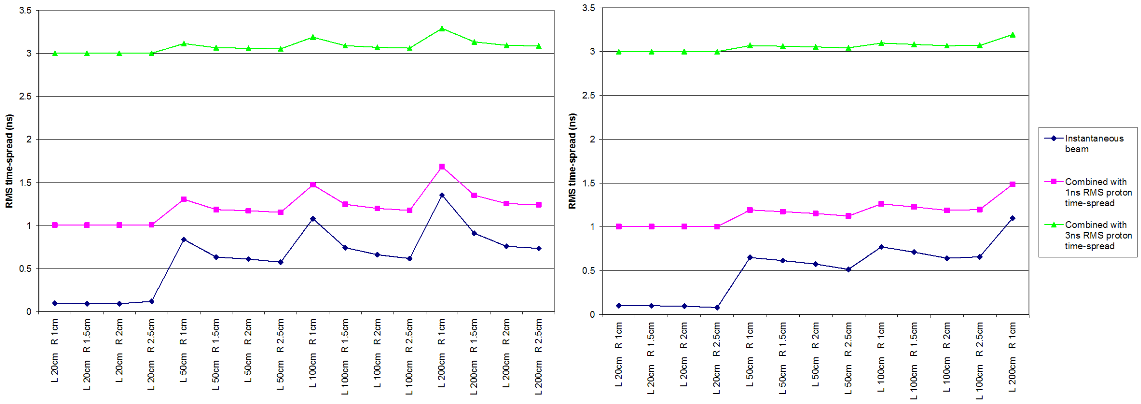

**Figure 5:** RMS spread of useful pion arrival times for the bare target geometry (left) and including the outer tube (right). The three plots use proton bunches of 0 ns (theoretical!), 1 ns and 3 ns RMS time spreads.

The arrival time spreads stay small for all target cases in figure 5, realistically the additional delay from the target will be swamped from that of the proton beam.

## 5. Conclusion

Time spread, reabsorption and heating may all be kept under control for a semi-realistic hadronic model of the design. Thus, the figures of merit examined in this paper do not preclude the use of a water cooled target in the neutrino factory. Mid–high-power examples of such targets already exist [6] and run for extended periods (years) at 50 Hz but at a somewhat lower power density. The energy deposited directly in the water may lead to a hammer effect from shock waves, so determining at what level this becomes problematic is the next issue to examine for the water cooled design.

## References

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[7] *Computed Pion Yields from a Tantalum Rod Target: Comparing MARS15 and GEANT4 Across Proton Energies*, S.J. Brooks and K.A. Walaron, Proc. NuFact’05.