

Options for Tilting of the Magnetic Axis and the Mercury Jet in the CERN Target Experiment

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1 Introduction

Figure 21 of our CERN proposal [1] is reproduced below as Fig. 1. It shows the concept of tilting the proton beam and the mercury jet with respect to the magnetic axis, as has been foreseen for the proton beam target in the Neutrino Factory Feasibility Study 2 [2].

Better yield of low-energy pions (and hence also low-energy muons and neutrinos) is obtained from the mercury jet target if the proton beam and target are tilted with respect to the axis of the capture solenoid magnet. Monte Carlo simulations have indicated that a tilt angle of about 100 mrad between the mercury jet and the proton beam is optimal.

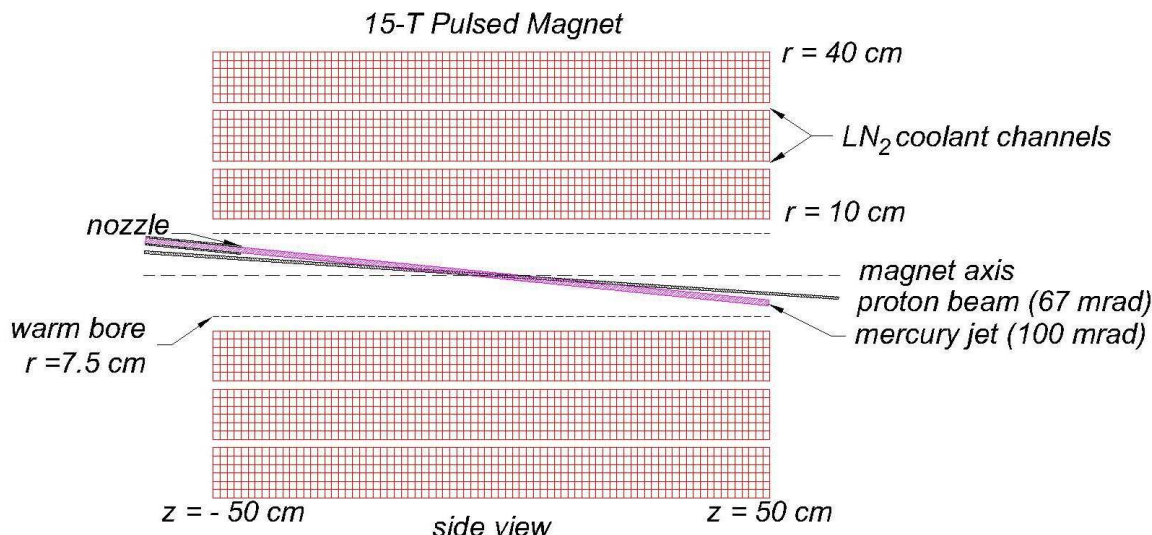


Figure 1: The geometry favored in Neutrino Factory Feasibility Study 2 [2] for the proton target system is that the mercury jet be tilted in a vertical plane by 100 mrad with respect to the axis of the capture solenoid magnet, and that the proton beam be tilted by 33 mrad in the vertical plane with respect to the mercury jet. Both the proton beam and the mercury jet move from left to right.

The nozzle of the mercury jet should be within the magnetic field to minimize eddy-current-induced deformations of the jet, but the nozzle should not intercept the proton beam. These requirements are met by a geometry in which the proton beam is tilted with respect to the mercury jet by 33 mrad, resulting in an interaction region about 60 cm long in case of a 1-cm-diameter mercury jet and a 1.5-mm- σ proton beam.

For use in a Neutrino Factory, the magnetic axis should be horizontal (as this is the axis of the desired secondary beam of π 's and μ 's) with the tilts of the mercury jet and the proton beam in the vertical plane (*i.e.*, the tilts are about a horizontal axis) so that the spent proton beam can be absorbed in a “dump” consisting of a pool of mercury that also collects the spent mercury jet.

We wish to demonstrate the concept of the tilted proton beam and mercury jet in the CERN Target Experiment. However, it will be simplest to implement this experiment in the TT2A beamline if the proton beam is horizontal.

This implies that the mercury jet should make a 33 mrad angle with respect to the proton beam axis in some direction, and that the magnetic axis should make an angle of 67 mrad with respect to the proton beam in a direction suitably correlated to the direction of the mercury jet.

Note that in the CERN Target Experiment the mercury will flow from the upstream end of the magnet to the downstream end of the magnet, as is also the case in the Study 2 concept. The spent mercury is to be collected in a sump at the downstream end of the magnet, and fed into the recirculating pump that feeds the nozzle at the upstream end of the magnet, as sketched in Fig. 2.

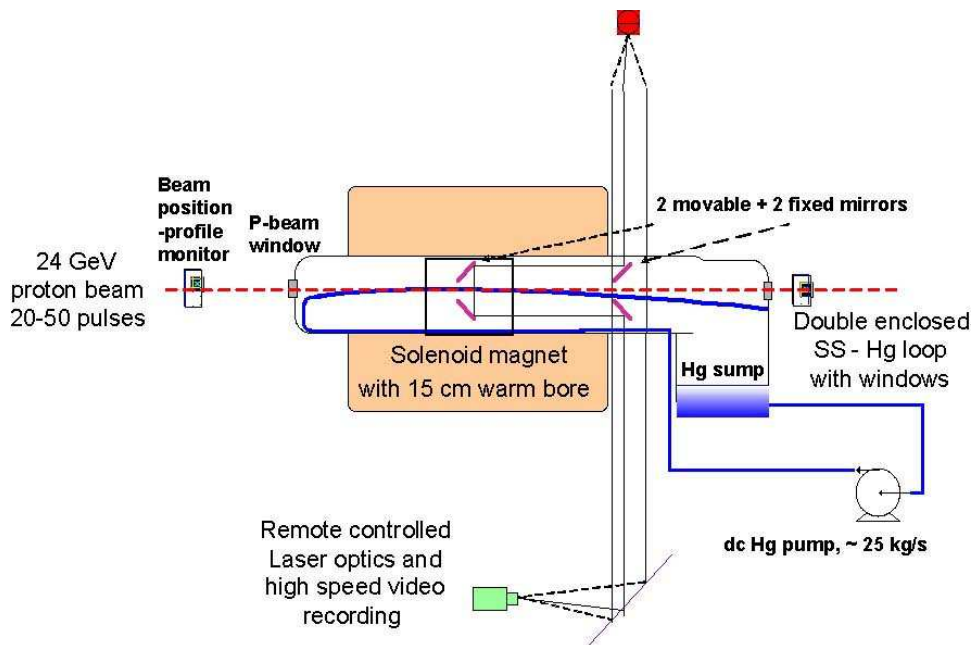


Figure 2: The 20-cm/s, 1-cm-diameter mercury jet flows inside a stainless steel containment vessel with windows for the proton beam and for optical diagnostics. Two sets of mirrors provide a folded optical path to view the mercury jet at the center of the solenoid magnet, where it interacts with the proton beam. A high-speed camera views the mercury jet via shadow photography based on illumination of the jet by a laser diode.

2 Option 1

It is not a good idea to rotate the configuration of Fig. 1 by 67 mrad about a horizontal axis, resulting in the configuration of Fig. 3. Some of the spent mercury would collect at the upstream end of the bore tube, flooding that tube to a depth of several cm before draining into the sump at the downstream end of the magnet.

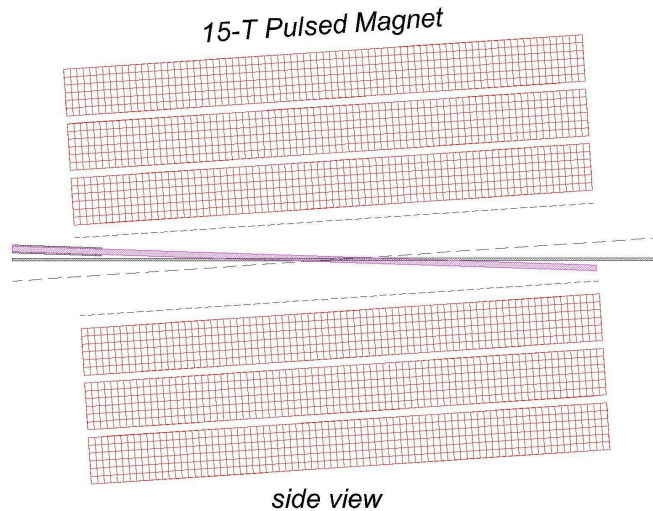


Figure 3: Option 1: Simply rotating the configuration of Fig. 1 by 67 mrad about a horizontal axis is a poor choice, because the mercury would collect at the upstream end of the magnet.

3 Option 2

We could instead rotate the configuration of Fig. 1 by 67 mrad about a horizontal axis, resulting in the configuration of Fig. 4. In this case any splashed mercury would be pulled by gravity into the sump at the downstream end of the magnet.

There are two disadvantages to this configuration.

1. The mercury jet ends up above the proton beam, so that when the mercury strikes the downstream end of the containment vessel, it will fall through the proton beam, increasing the activation of the mercury somewhat.
2. The flow of liquid nitrogen through the magnet during the cooling cycle is not ideal. Recall that we plan to inject the liquid nitrogen into the magnet coil from the downstream end. It would then have to flow uphill through the longitudinal channels. In practice, this would result in a pool of liquid nitrogen accumulating at the downstream end of the magnet, which we would then have to flush out somehow before the end of the cooling cycle.

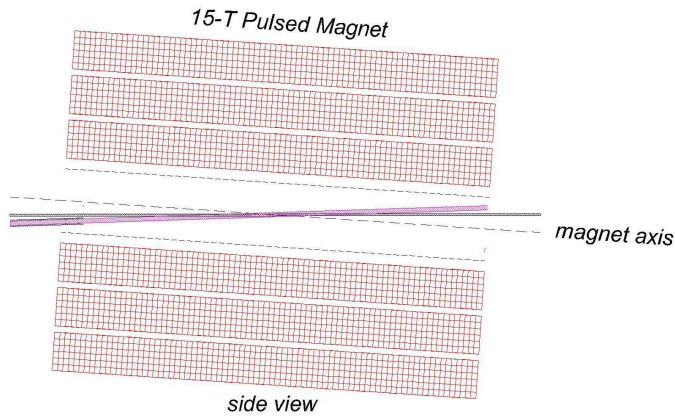


Figure 4: Option 2: Rotation of the configuration of Fig. 1 by 67 mrad about a horizontal axis, such that splashed mercury will drain into the sump at the downstream end of the magnet.

4 Option 3

The first problem of Option 2 could be addressed by directing the mercury jet across the proton beam as shown in Fig. 5. However, the mercury jet would then be nearly collinear with the magnetic axis, so the we would not be providing a full demonstration of the operation of the mercury jet at a significant angle (100 mrad). Hence, this option is disfavored as not meeting the physics goals of the experiment.

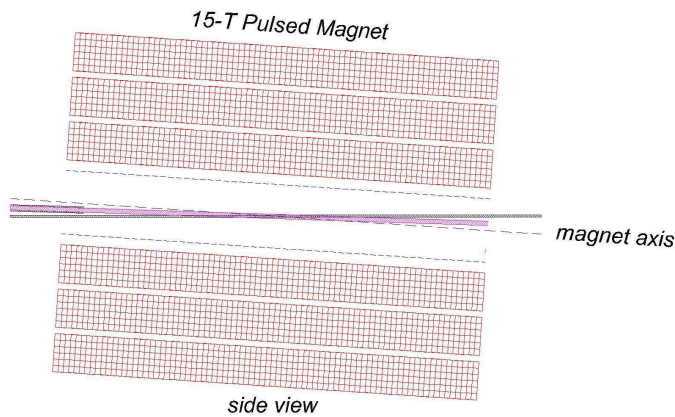


Figure 5: Option 3: If the mercury jet makes an angle of 33 mrad to the magnetic axis, it would cross the proton beam from high to low. However, this would not demonstrate successful operation of a jet at the ultimate goal of 100 mrad with respect to the magnetic axis.

5 Option 4

Both of the problems of Option 2 could be addressed by rotating the configuration of Fig. 4 by 90° about the beam axis, as shown in Fig. 6. In this case, the magnet has been rotated by 67 mrad with respect to the proton beam about a vertical axis. The mercury jet flows nominally in a horizontal plane, with gravity deflecting the jet into a shallow arc in the vertical plane.¹

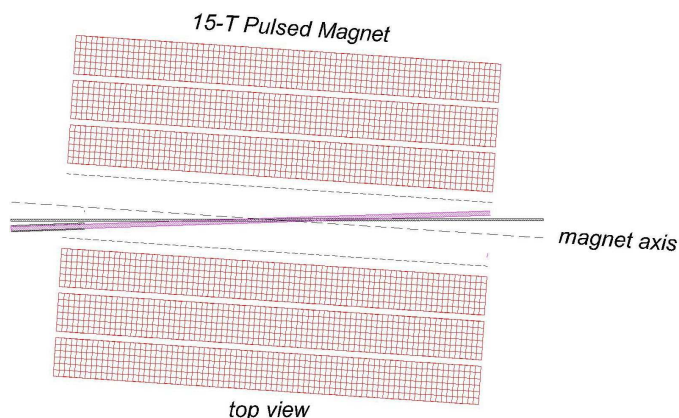


Figure 6: Option 4: Both of the difficulties of Option 2 can be avoided if the magnet is rotated by 67 mrad about a vertical axis, and the mercury jet flows in a horizontal plane.

6 Optical Diagnostics

There remains the issue of the configuration of the optical diagnostics to view the dispersal of the mercury jet by the proton beam (and the possible perturbation of the jet by the magnetic field). The concept of the diagnostics shown in Fig. 7 is more compatible with a mercury jet that flows in the vertical plane (Option 2) than in the horizontal plane (Option 4).²

If we only view the mercury jet close to the center of the magnet, the arrangement shown in Fig. 7 could work for both Options 2 and 4.

If we plan to view the mercury jet, say, close to the nozzle, then in Option 4 it would be best to rotate the scheme of Fig. 7 by 90° so that the optic axis crossed the mercury jet vertically. To keep mercury from collecting on the lower window of the optical system, that window (and perhaps the upper window as well) should be tilted slightly downwards from upstream to downstream.

¹If the jet is directed so as to be horizontal at the center of the magnet, it falls by only 1 mm over the ± 30 cm length of the interaction region when the jet velocity is 20 m/s.

²I believe that we should use rectangular mirrors rather than the elliptical mirrors shown in the figure.

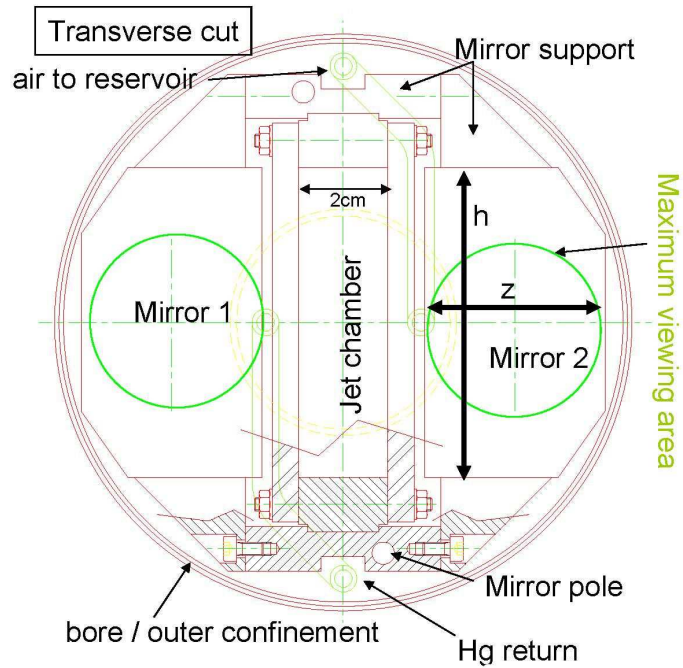


Figure 7: Sketch of a transverse cut through the mercury containment vessels near the center of the magnet. From [3].

7 References

- [1] R.J.R. Bennett *et al.*, *Studies of a Target System for a 4-MW, 24-GeV Proton Beam*, submitted to the CERN INTC (April 26, 2004), http://www.hep.princeton.edu/~mcdonald/mumu/target/cern_proposal.pdf
- [2] S. Ozaki *et al.* *Feasibility Study II of a Muon-Based Neutrino Source* (June 14, 2001), <http://www.cap.bnl.gov/mumu/studyii/FS2-report.html>
- [3] A. Fabich, *Particular Issues on the Experimental Layout* (Dec. 10, 2003), http://www.hep.princeton.edu/~mcdonald/mumu/target/fabich/fabich_121003.pdf