Development of 1-MW Target and Beam Detector for NuMI

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Abstract

The Neutrinos at the Main Injector (NuMI) facility produces a wideband neutrino beam that is used in three neutrino experiments looking for physics beyond the Standard Model. The accelerator improvement plan at Fermilab proposes increasing the beam power delivered to the NuMI beamline from 700 kW to 1 MW to make a more intense neutrino beam, meaning a better chance of neutrino detection. However, with this beam power, the detector components must be modified to handle a 1-MW beam power. This project consisted of improving two components of the NuMI beamline: the graphite target and the hadron monitor. Simulations were ran with G4Beamline to find the most optimal configuration of the target, while preparation for a beam test for a newly designed hadron monitor was ongoing.

NuMI Diagram

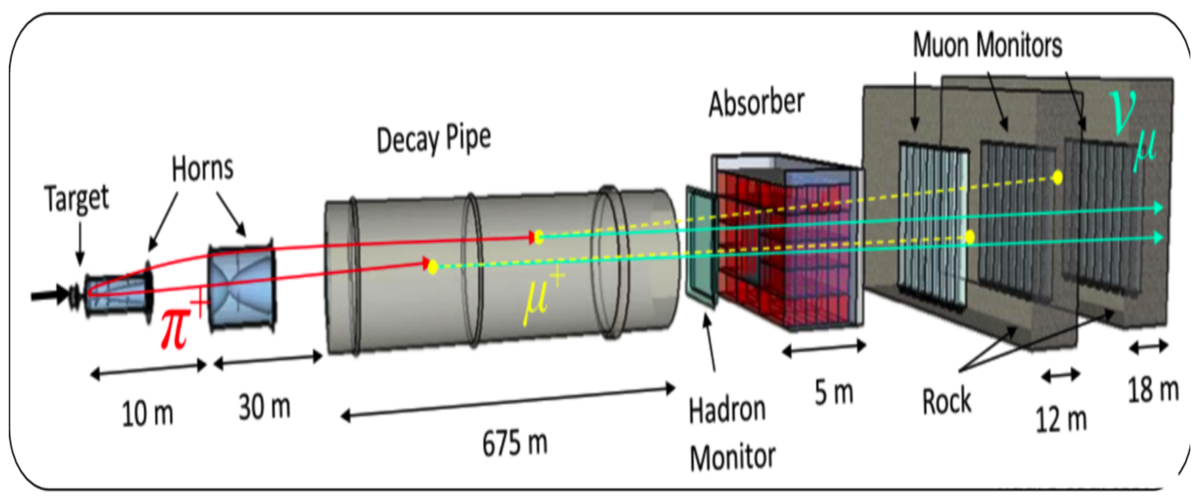

Figure 1: Overview of NuMI beamline components.

Figure 1 shows a 120 GeV proton beam from the main injector smashing into a graphite target.

- Pions are produced, which go on to decay into neutrinos.
  - **Goal is to maximize pion yield.**
- A hadron monitor is set up to detect any residual charged particles in the beam after traveling through the decay pipe.
  - **A new radiation robust hadron monitor will be tested for handling a 1-MW beam power.**

Target Simulation

The current target (length = 1200 mm) consists of 48 graphite fins (24 mm thick pieces)

- A target with a winged fin structure is proposed for a 1-MW beam power to prevent damage from accidental beam.
- Need to determine the optimal size, position, and number of winged fins in the target.

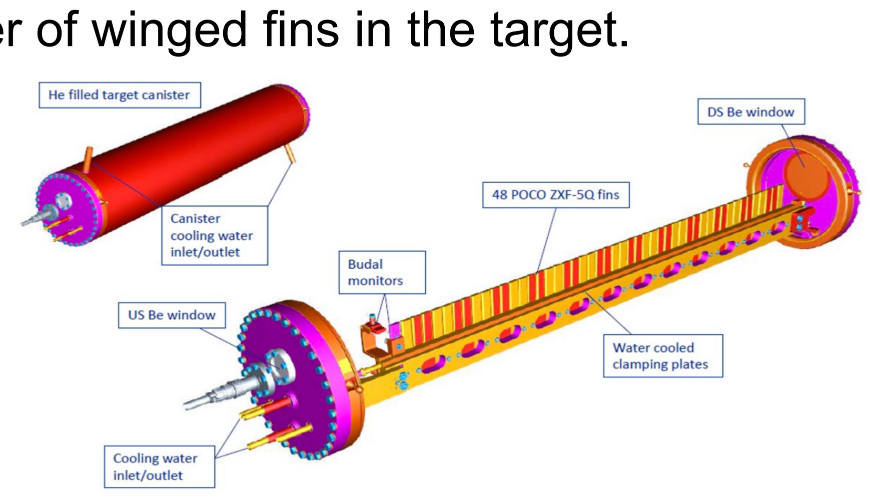

Figure 2: Current NuMI target.

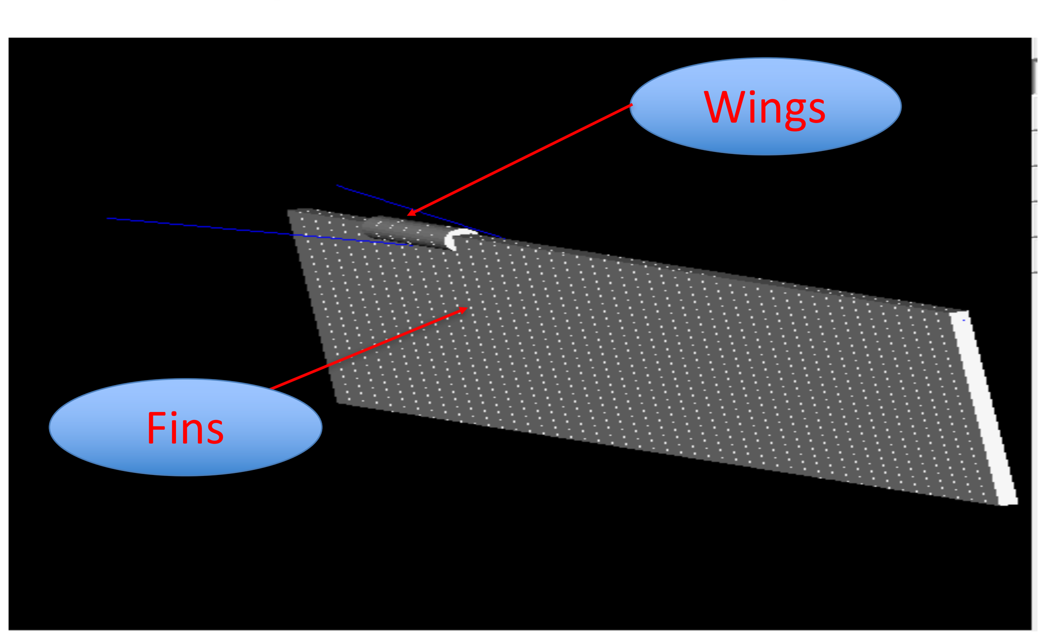

Figure 3: Simulation of Downstream Winged Fins.

Target Simulation Methods and Results

- G4Beamline simulations were used to alter the target parameters and target configuration, which included:
  - Addition of winged fins at multiple positions.
  - Variation of fin width.
- **Winged Fin Addition Simulation:** Winged fins were placed in the current 48 fin target both at upstream (z = 0 mm) and downstream (z = 900 mm) locations.

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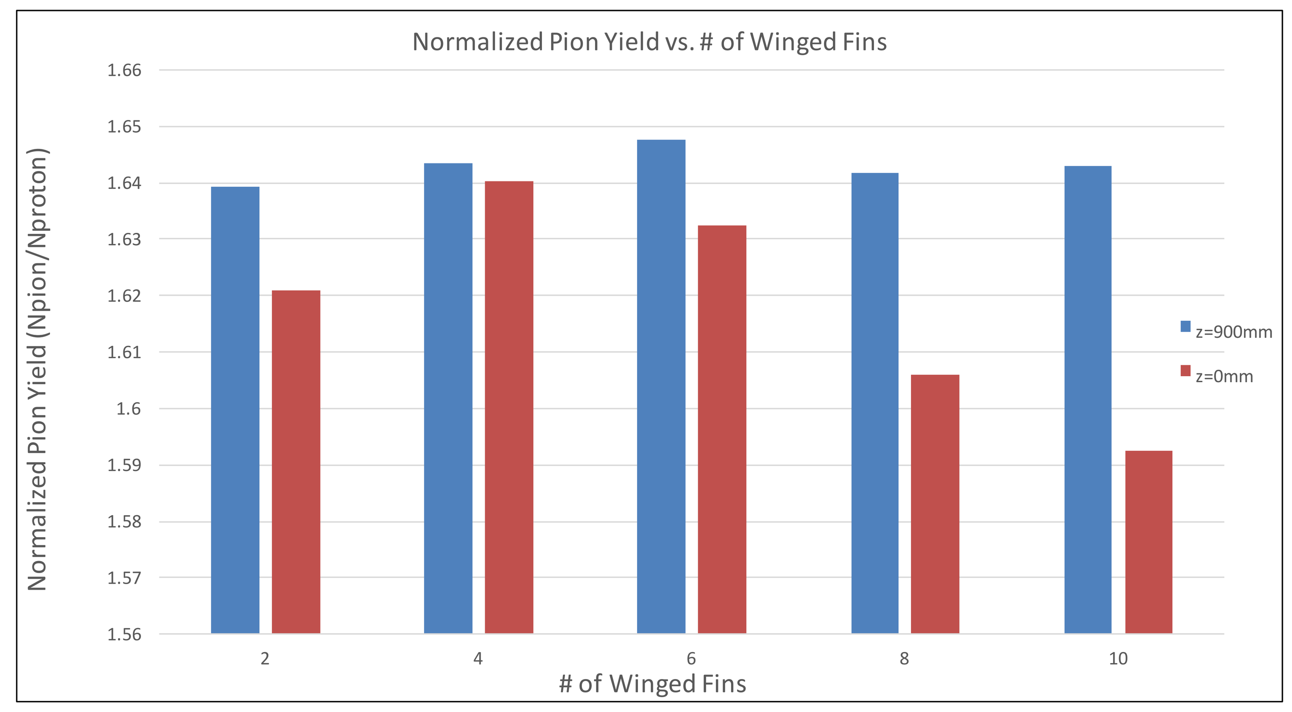

Figure 4: Normalized pion yield as a function of the number of winged fins at both z = 0 mm and z = 900 mm.

- Figure 4 illustrates the location and number of winged fins giving the highest pion yield of six winged fins at z = 900 mm.
- **Fin Width Verification:** As shown in Figure 5, simulations for the three different target configurations (no wings, front wings, and back wings) were performed for various fin widths.

Figure 5: Normalized pion yield as a function of width.

- Figure 5 shows the highest pion yield was seen at widths slightly larger or smaller than 9 mm.
  - 1% deviation level
  - Possible variance in the simulation
- **Updated Target:** Based on results from a full NuMI beamline (shows neutrino yield) simulation, a 40 fin target is the most optimal configuration.
- Figure 6 illustrates the pion yield for winged fins at multiple locations of a 40 fin target configuration.

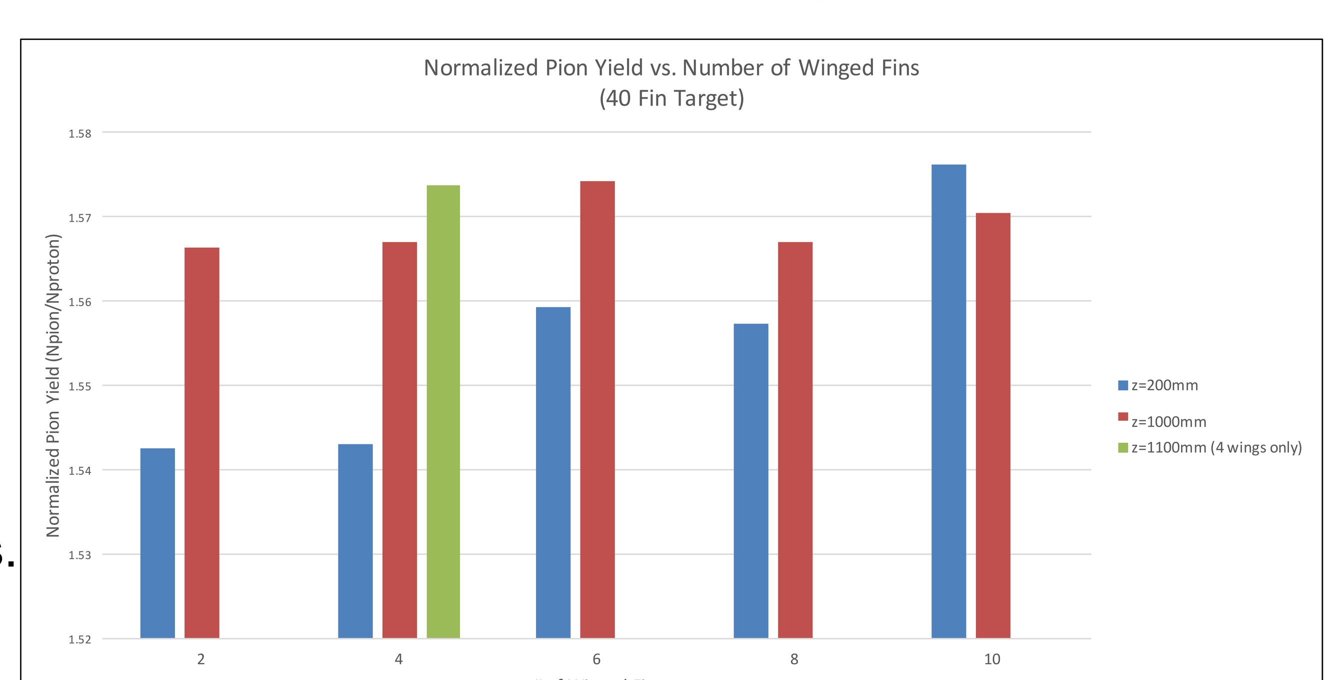

Figure 6: Normalized pion yield as a function of the number of winged fins at z = 200 mm, z = 1000 mm, and z = 1100 mm (40 fin target).

Hadron Monitor Improvements

- A new design for a radiation robust hadron monitor is being implemented.
  - Gas-filled RF cavity-based detector with an aluminum alloy body
  - Measures residual charge by detecting the permittivity shift of ionized gas
  - Preparing for a beam test in the MI-40 abort line area with a 120 GeV proton beam
- For this test, FLUKA-based simulations were run to look at residual dose on this detector compared to that of an iron-based detector, as shown in Figures 7 and 8.

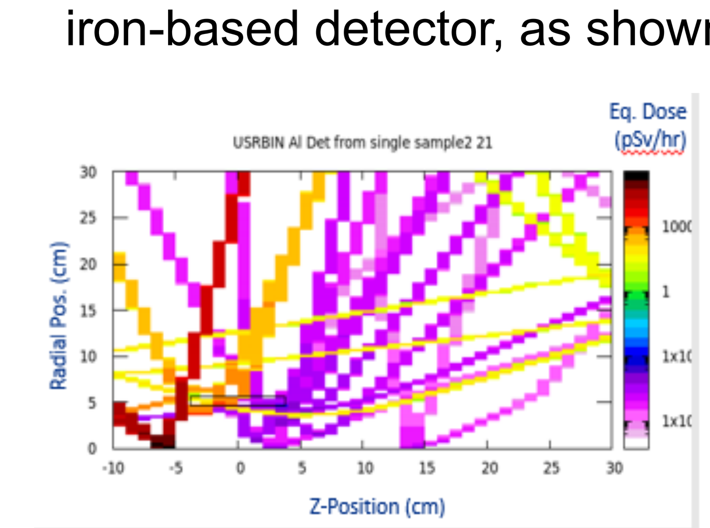

Figure 7: Aluminum detector equivalent dose.

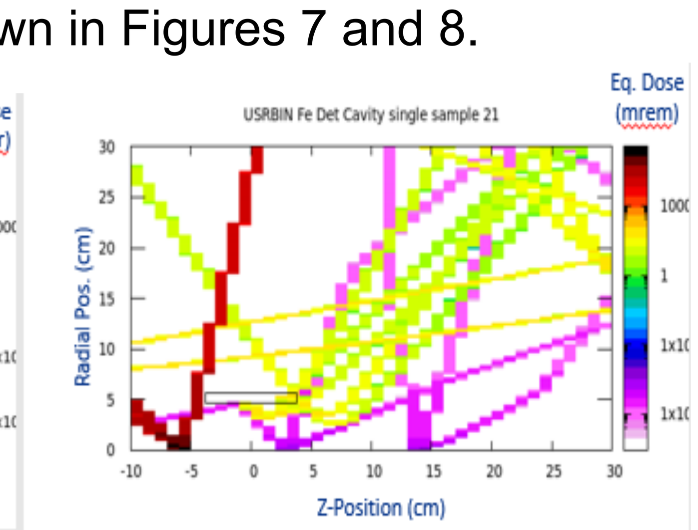

Figure 8: Iron detector equivalent dose.

- Based on these figures, the iron detector has higher equivalent dose regions than aluminum.
- For implementing the detector into the beam test area, a new support structure was necessary to place the detector in the test area.
- Preliminary design is shown in Figure 9:

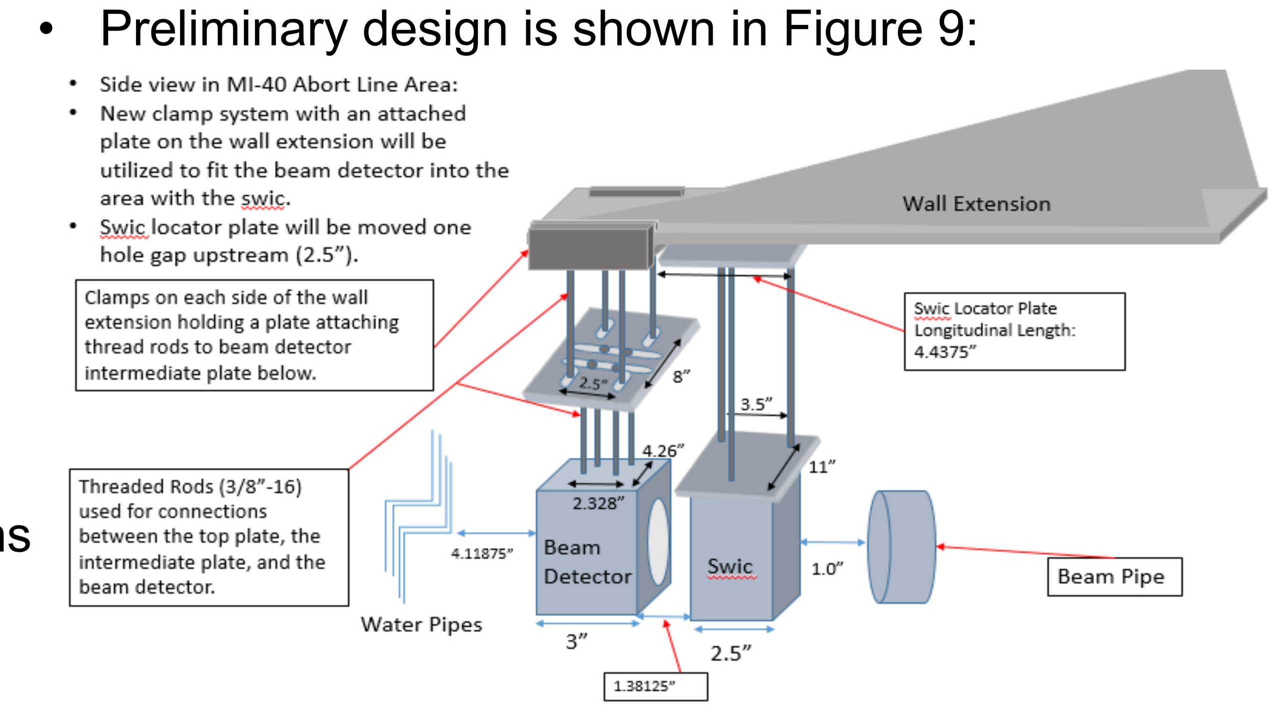

Figure 9: Test area diagram with beam detector included.

- Design allows for shifting of the detector in each direction, and it takes into account the previous detector still in the test area.

Conclusions

- Simulation results show a downstream winged fin target configuration provides an alternative option.
  - This configuration is now proposed to be put into a full NuMI beamline simulation.
- Aluminum RF cavity-based detector is more radiation robust than that of a steel detector.
- The design of the support structure is being modified based on updates received from MI engineers for what changes can be made in that area.

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