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OPTIMIZATION STUDIES OF RADIATION SHIELDING FOR PIP-II PROJECT AT FERMILAB

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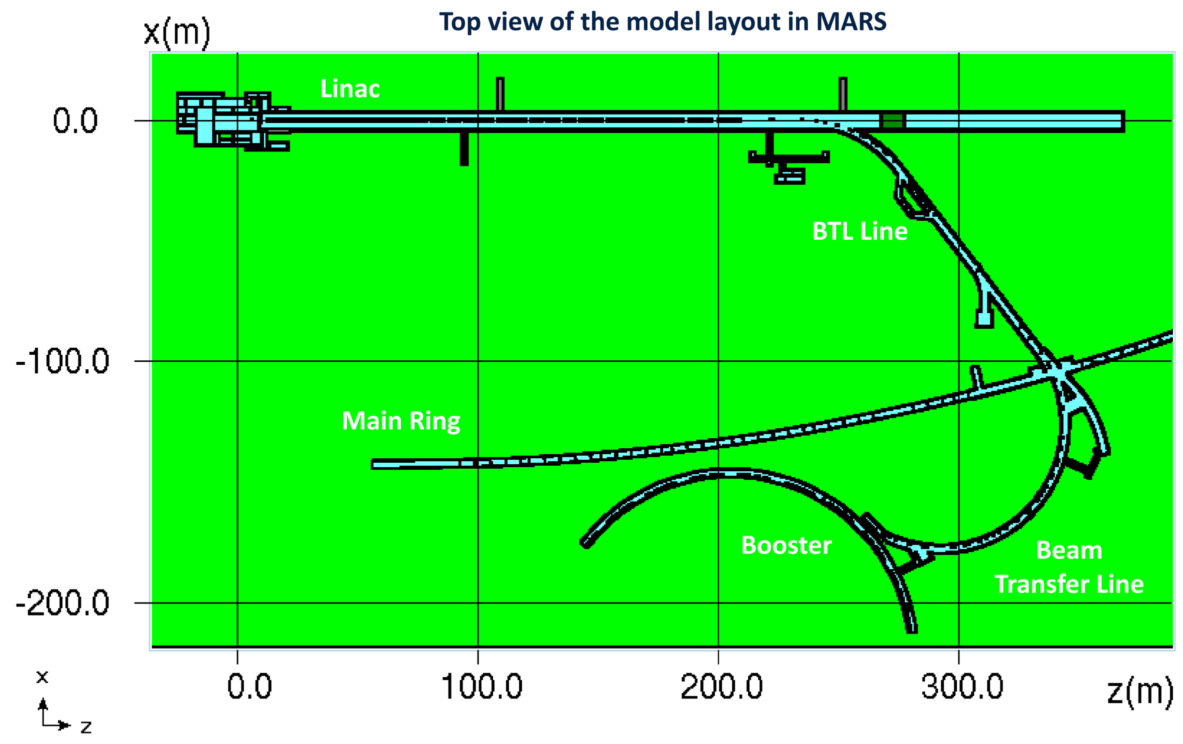
Introduction

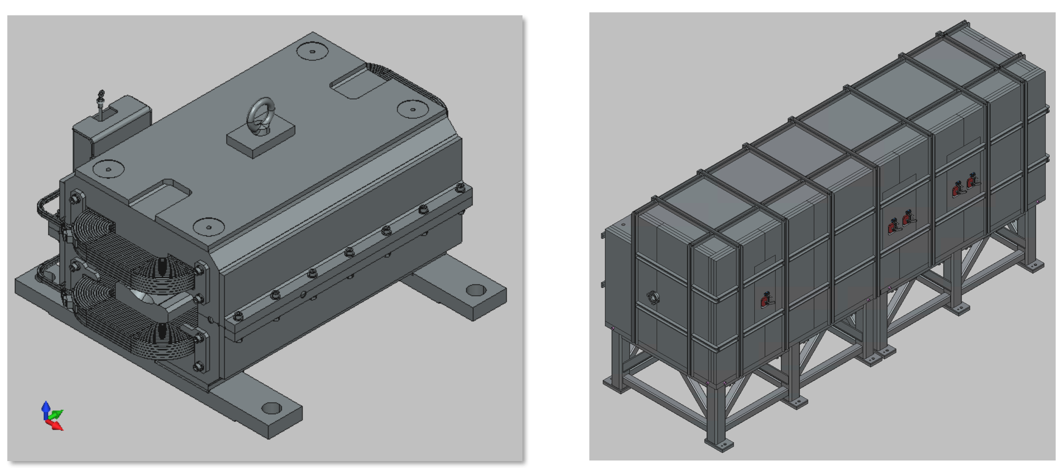
The Proton Improvement Plan-II (PIP-II) at Fermilab represents a significant advancement in the quest to answer some of the most profound questions about our universe using the world's most intense high-energy neutrino beam. The project requires the construction of a new addition to the Fermilab accelerator complex – an 800-MeV high-intensity superconducting linear accelerator. Ensuring the safety and regulatory compliance of this ambitious project is paramount, necessitating thorough dose rate assessments under both normal operational and accidental scenarios to align with the Fermilab Radiological Control Manual (FRCM) standards.

Top view of the model layout in MARS



3D view of the Fast Kicker Dipole (left) and the horizontal PIP-II collimator (right) CAD model

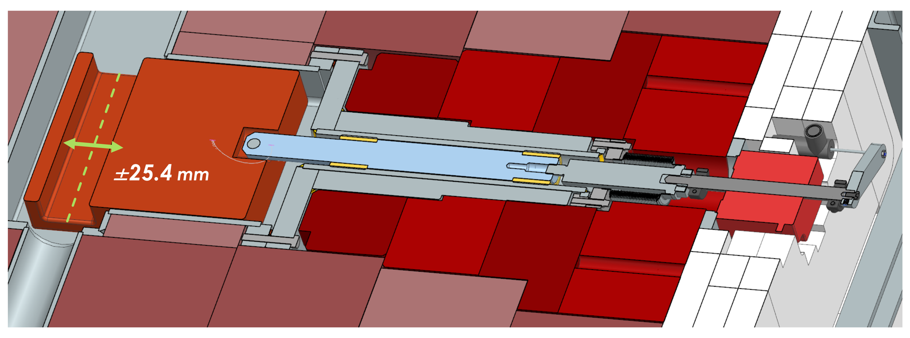
Our approach included a shielding optimization used for the simulations with the Monte Carlo code MARS [1,2,3] to incorporate new magnet and collimator designs, essential for reflecting the current state of PIP-II infrastructure.



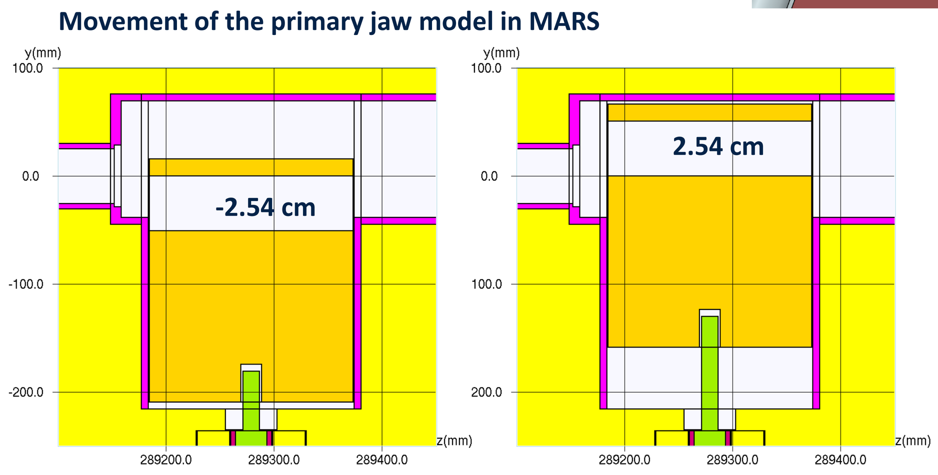
Implementation of Parametric Geometry

The primary jaw of the horizontal and vertical PIP-II collimators can shift ±25.4 mm from its nominal centered location, with a "hard stop" safeguard to prevent contact with the vacuum chamber.

Primary jaw (copper)

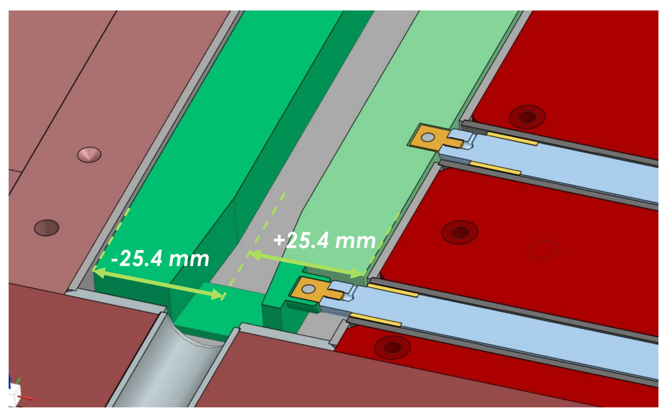


Movement of the primary jaw model in MARS



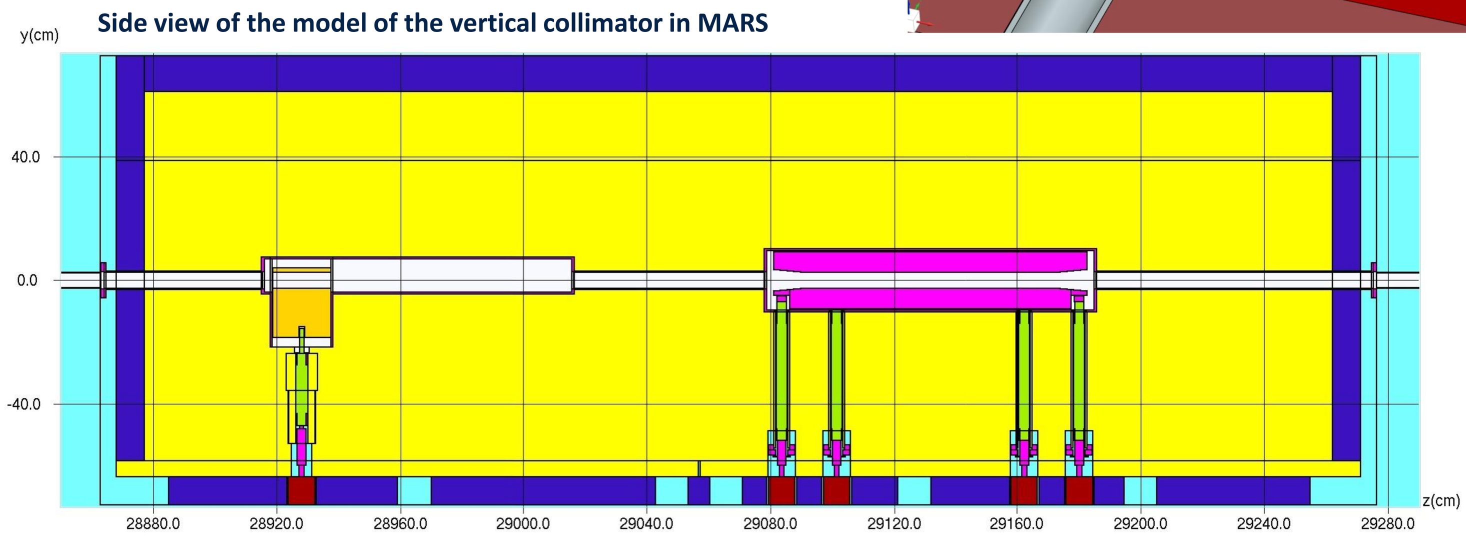
Using features provided by ROOT TGeo (https://root.cern.ch), the primary and secondary jaws and their surroundings were designed to allow parametrized movement of the jaws, supporting various operational and accidental conditions.

Secondary jaw (stainless steel, SS-304)



For the secondary jaw, both sides operate independently, moving 25.4 mm inward but not outward from their nominal positions.

Side view of the model of the vertical collimator in MARS

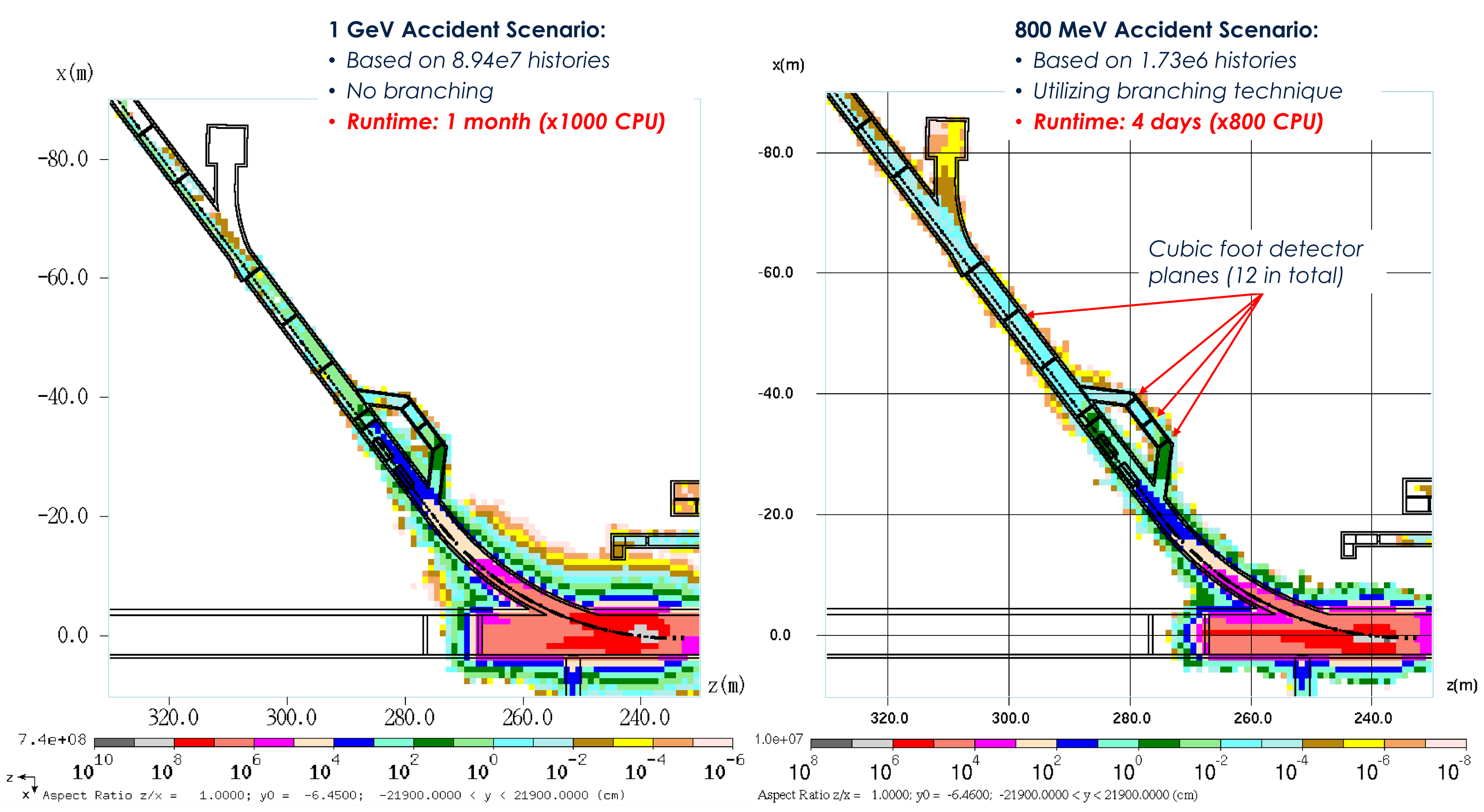


Application of Importance-Based Splitting Technique

At the request of the ESH group, we added several planes across the tunnel populated with cubic foot-sized air cells, acting as detectors, to obtain high-resolution results on a spatial scale comparable to an actual dose monitor. Despite their computational demands, the implementation of these high-resolution detector planes enabled us to obtain crucial radiation field data crucial for optimizing shielding configurations.

- To overcome the significant computational demands, we implemented a well-known branching technique that drastically reduced simulation runtimes while maintaining statistical integrity.
- This was achieved through particle splitting and the application of Russian Roulette techniques, tailored to prioritize regions of interest based on predefined importances and weight limits.

Comparison of runtime through simulations for the PIP-II Linac Shielding Assessment:
Dose rate is given in mrem/accident for the maps



- *Incident (3 s): Full Linac beam at 1 GeV is lost*
- *Power: 2000 kW = 2 MW*
- *Flux: 1.25e16 H-/sec * 3 = 3.75e16 H-/accident*

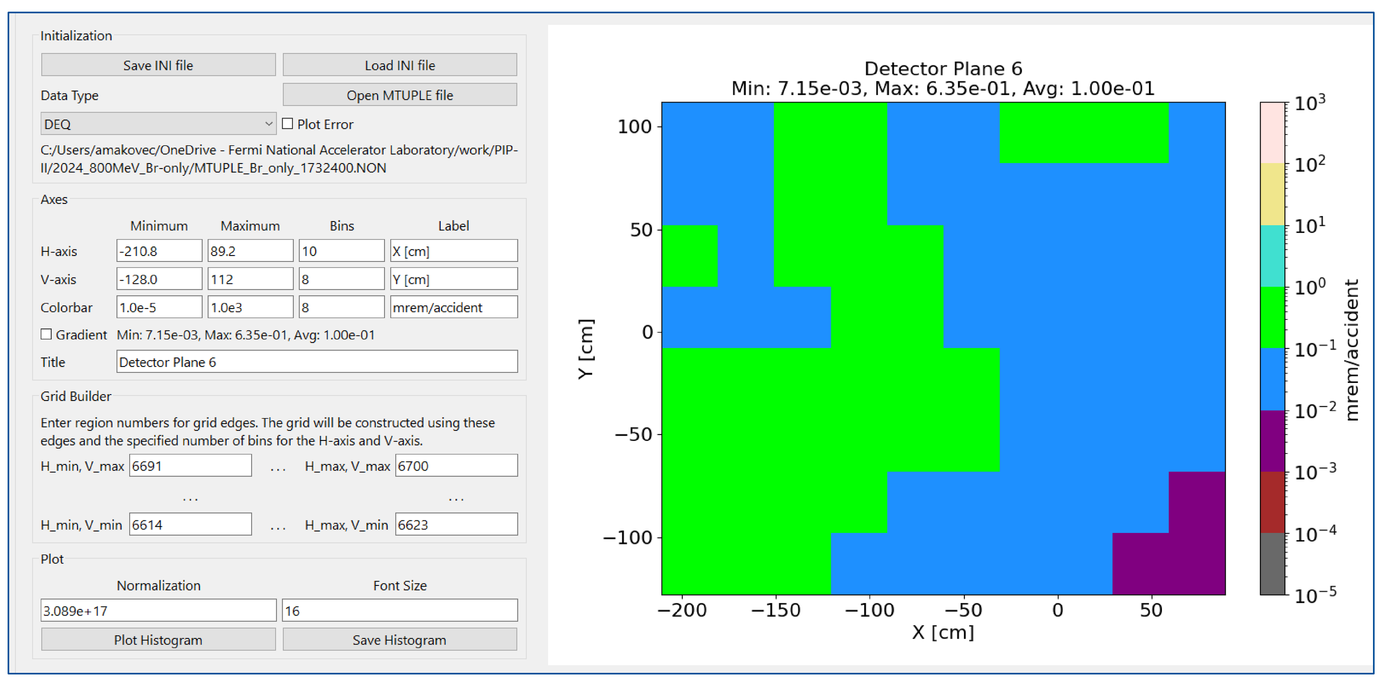
- *Incident (3 s): Full Linac beam at 800 MeV is lost*
- *Power: 17.6 kW*
- *Flux: 1.37e14 H-/sec * 3 = 4.12e14 H-/accident*

Auxiliary Graphical Tools for Data Processing and Visualization

We have started the development of a new, more user-friendly GUI for MARS. As part of this project, we created a tool to visualize the detailed radiation field data scored by the high-resolution detector planes.

- The MTUPLE Grid Visualizer tool can generate the necessary region numbers to locate corresponding data reported in the MTUPLE simulation output file by inputting the four region numbers at the edges of the detector plane, along with the number of bins along the horizontal and vertical axes.
- The visualization can be customized by altering several parameters.

MTUPLE Grid Visualizer tool in action



Conclusion

The PIP-II Linac Shielding Assessment project at Fermilab necessitated rigorous radiation shielding optimization. Through our comprehensive update of the geometry model and the incorporation of high-resolution detector planes, we have obtained crucial radiation field data essential for this optimization. The development of our importance-based branching code has dramatically reduced simulation runtimes while maintaining statistical integrity, allowing us to efficiently model complex radiation environments. Furthermore, the creation of the MTUPLE Grid Visualizer tool enhances our ability to analyze and interpret detector plane scoring results, making the data more accessible. Overall, our methodologies and tools have significantly improved the efficiency and accuracy of radiation dose assessments for the PIP-II project.

References

[1] N.V. Mokhov and C.C. James, "The Mars Code System User's Guide, Version 15 (2016)", Fermilab-FN-1058-APC, (2017) https://mars.fnal.gov

[2] N.V. Mokhov et al., "MARS15 Code Developments Driven by the Intensity Frontier Needs ", Prog. Nucl. Sci. Technol., 4, pp. 496-501 (2014)

[3] N.V. Mokhov, "Status of MARS Code", Fermilab-Conf-03/053 (2003)

Acknowledgement

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