INVESTIGATION ON THE STRUCTURAL DYNAMICS OF THE DECAY VESSEL FOR THE SHiP EXPERIMENT

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INTRODUCTION

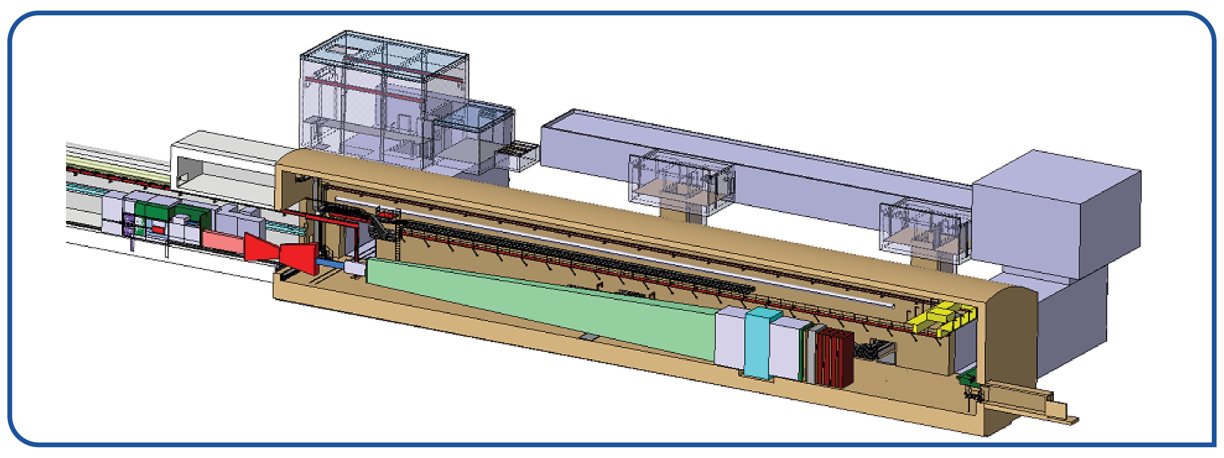
The Search for Hidden Particles (SHiP) experiment aims to explore the realm of dark matter and investigate hidden particles beyond the Standard Model of particle physics. Planned to be launched at the Super Proton Synchrotron (SPS), SHIP aims to detect hidden particles, such as heavy neutral leptons and other long-lived exotic particles, which could provide clues about the universe's missing mass and the nature of dark matter.

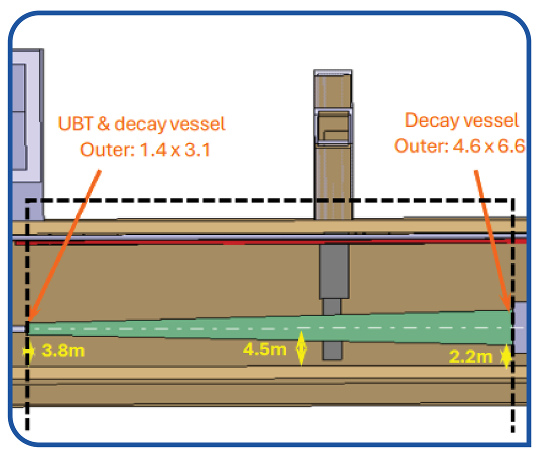
The experiment involves directing a high-intensity beam of protons at a fixed target to produce a large number of particles. SHIP's sophisticated detector system, positioned downstream from the target, is designed to capture and identify the signatures of these rare particles. The experiment will operate in an extremely low-background environment, crucial for distinguishing the signals of hidden particles from the plethora of other particle interactions.

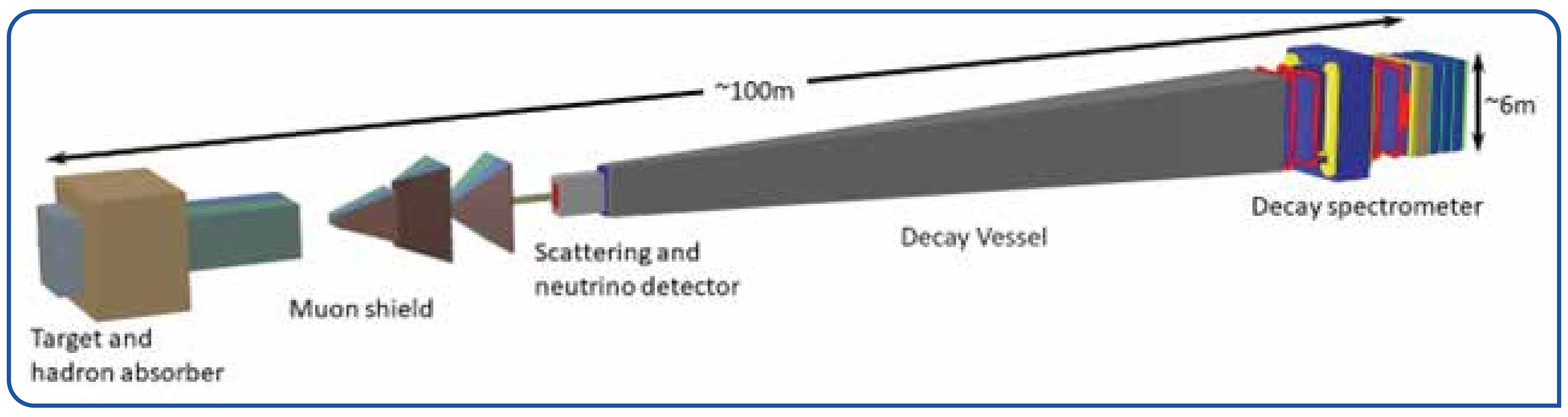
One of the critical components of this experiment is the decay vessel, where particles decay into measurable products. This vessel is a 50m elongated, shielded chamber positioned downstream of the proton target, designed to provide a low-background environment for detecting particle decays. The vessel is surrounded by a series of detectors, including tracking devices and calorimeters, which capture the decay products' trajectories and energy signatures.

OBJECTIVE

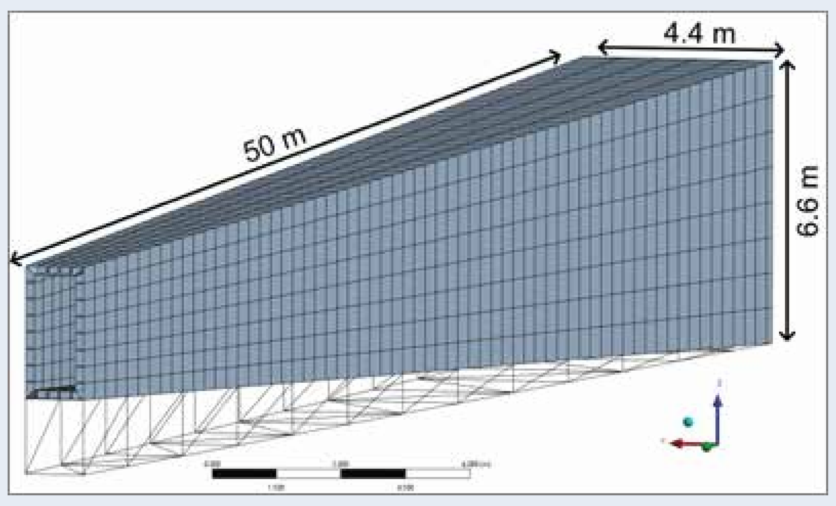
Creation of the optimized decay vessel design using computer-aided design (CAD) software, and performing modal analysis to obtain dispersion curves useful for seismic analysis and non-destructive testing.



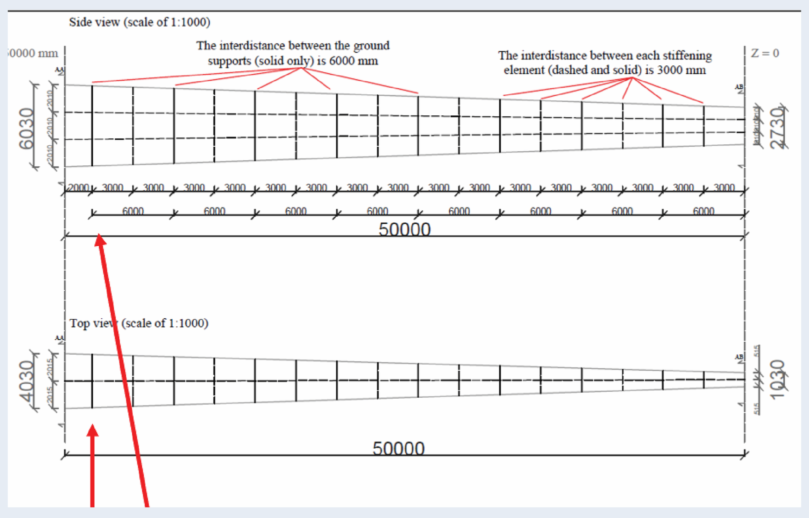




OPTIMISED DESIGN

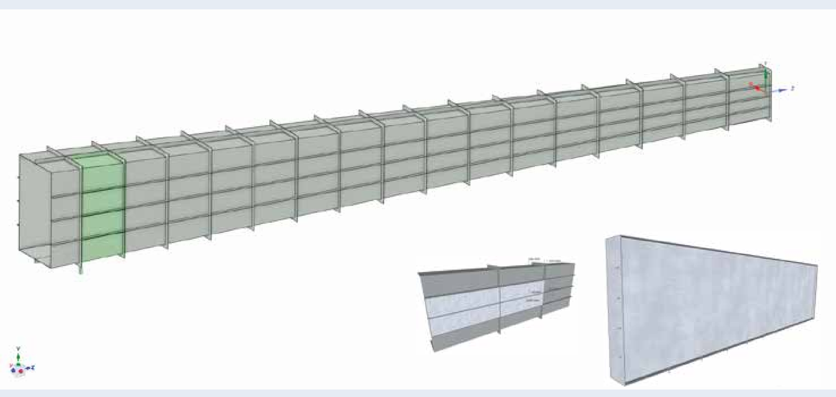


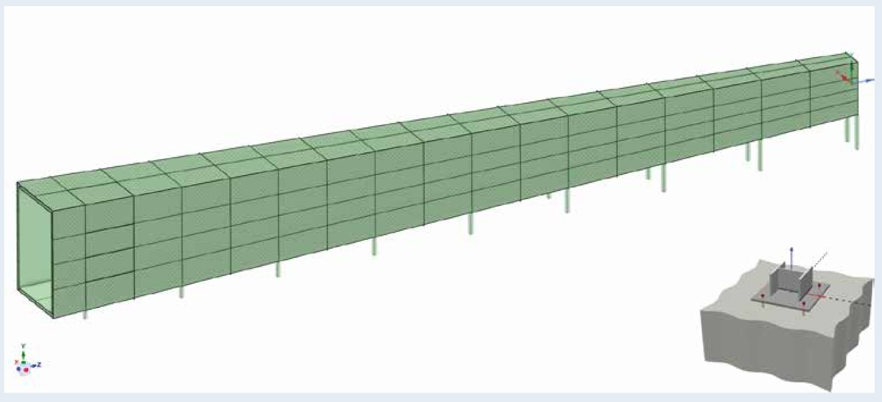
Previous design



Geometrical config. of the new design

The optimized design reduces the weight of the decay vessel from approximately 300 tons to 200 tons, a substantial reduction of about 30%. These values do not consider the weight of the liquid scintillator.





Optimised design modelled in ANSYS Spaceclaim

The optimized decay vessel has fewer stiffening members. Structural integrity is ensured by using a different steel material (S355). It also utilizes detachable aluminum liquid scintillator containers with an HE-A (specifically HE 200A) profile column for support, enhancing ease of maintenance and accessibility.

MODAL ANALYSIS

Modal analysis is a technique used in structural dynamics to determine the natural frequencies, mode shapes, and damping characteristics of a structure. In the context of making dispersion curves, modal analysis plays a crucial role by analyzing how different modes of vibration propagate through a structure.

$$M\ddot{u} + C\dot{u} + Ku = F$$

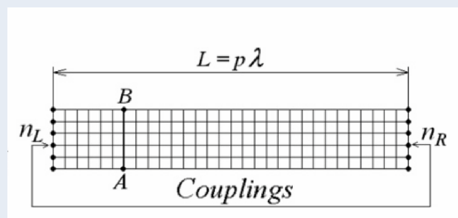
$$\left(\begin{bmatrix}K_{11}&K_{1i}&K_{12}\\K_{1i}^T&K_{ii}&K_{i2}\\K_{12}^T&K_{i2}^T&K_{22}\end{bmatrix} - \omega^2\begin{bmatrix}M_{11}&M_{1i}&M_{12}\\M_{1i}^T&M_{ii}&M_{i2}\\M_{12}^T&M_{i2}^T&M_{22}\end{bmatrix}\right)\begin{Bmatrix}U_1\\U_i\\U_2\end{Bmatrix}=\begin{Bmatrix}F_1\\F_i\\F_2\end{Bmatrix}$$

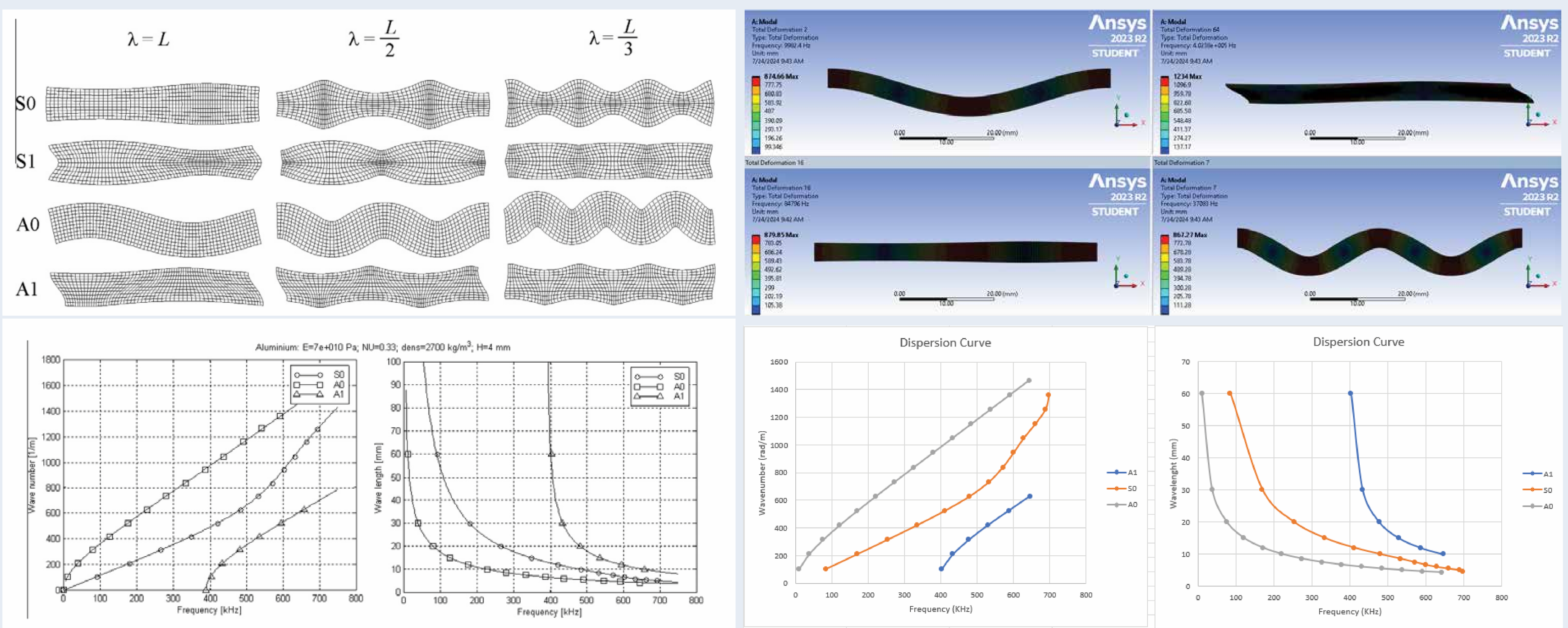
$$\begin{bmatrix}K_{11}+2K_{12}+K_{22} & K_{1i}+K_{i2}\\ K_{1i}+K_{i2} & K_{ii}\end{bmatrix}\begin{Bmatrix}U_1\\U_i\end{Bmatrix} = \omega^2\begin{bmatrix}M_{11}+2M_{12}+M_{22} & M_{1i}+M_{i2}\\ M_{1i}+M_{i2} & M_{ii}\end{bmatrix}\begin{Bmatrix}U_1\\U_i\end{Bmatrix}$$

Finite element formulation for the propagative waves

Test Case

Using the methodologies outlined in the [1] for extracting dispersion curves, the first step was to replicate their analysis using ANSYS to compare results. This was done before proceeding to carry out the same analysis on the decay vessel.

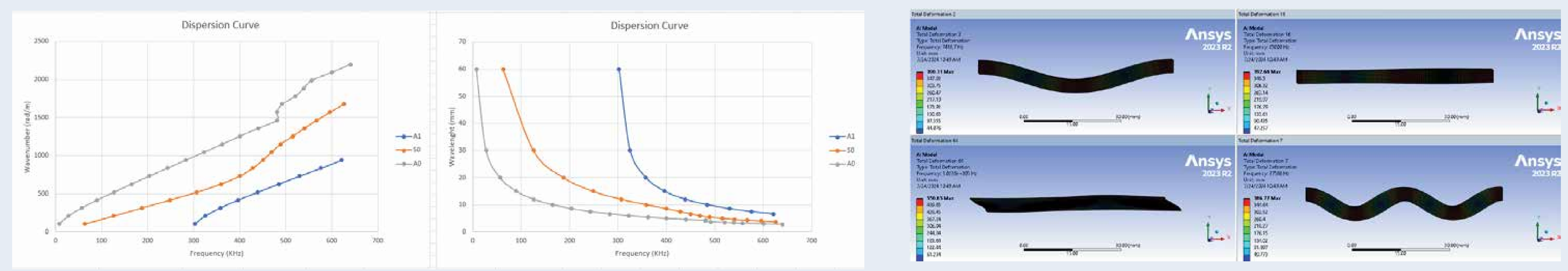




Comparing the mode shapes and dispersion curves obtained with [1].

Decay Vessel Approximate Case

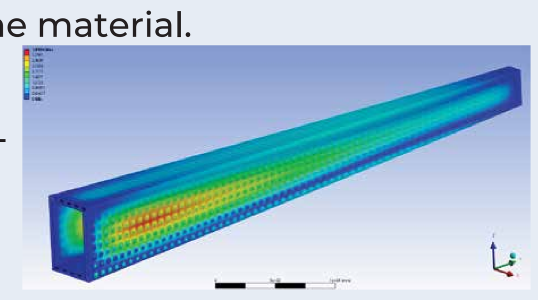
An approximate cross section of the decay vessel was used for the analysis to simplify the modeling process. This approach allows for a more manageable and efficient analysis



CONCLUSION

In summary, the modal analysis (frequency domain approach) was used to determine the vibrational characteristics of the decay vessel, these characteristics are then used to generate dispersion curves that describe how these vibrations propagate through the material.

What's Next



- Carrying out same analysis for more detailed cross sections (considering the stiffening members and changing cross-sections)
- Using the results for further analysis (Seismic, NDT)
- Investigating the fluid-structure interactions

REFERENCES

1. Sorohan, Ștefan, et al. "Extraction of Dispersion Curves for Waves Propagating in Free Complex Waveguides by Standard Finite Element Codes." University Politehnica of Bucharest, Laboratory for Integrity Evaluation of Composite Structures, Bucharest, Romania, 2012.
2. Bonnes, Felix, et al. "Seismic Risk of Non-Conforming Steel Structures — Preliminary Assessment of the Ship Decay Vessel at CERN." CERN – European Organization for Nuclear Research, Meyrin, Switzerland, 2023.

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