A Flexible Geometry Simulation for the DUNE Near Detector Hall

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Neutrino Mixing

- Neutrinos interact in flavor eigenstates and propagate in mass eigenstates
  - Mixing of flavor eigenstates and mass eigenstates described by PMNS matrix
- Consequence: probability of measuring neutrino to be of certain flavor eigenstate oscillates as neutrino propagates
- Can obtain elements of PMNS matrix by studying this phenomena
- For more in-depth review, see PDG's 2019 review of neutrino masses, mixing, and oscillations

$$\begin{bmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{bmatrix}$$

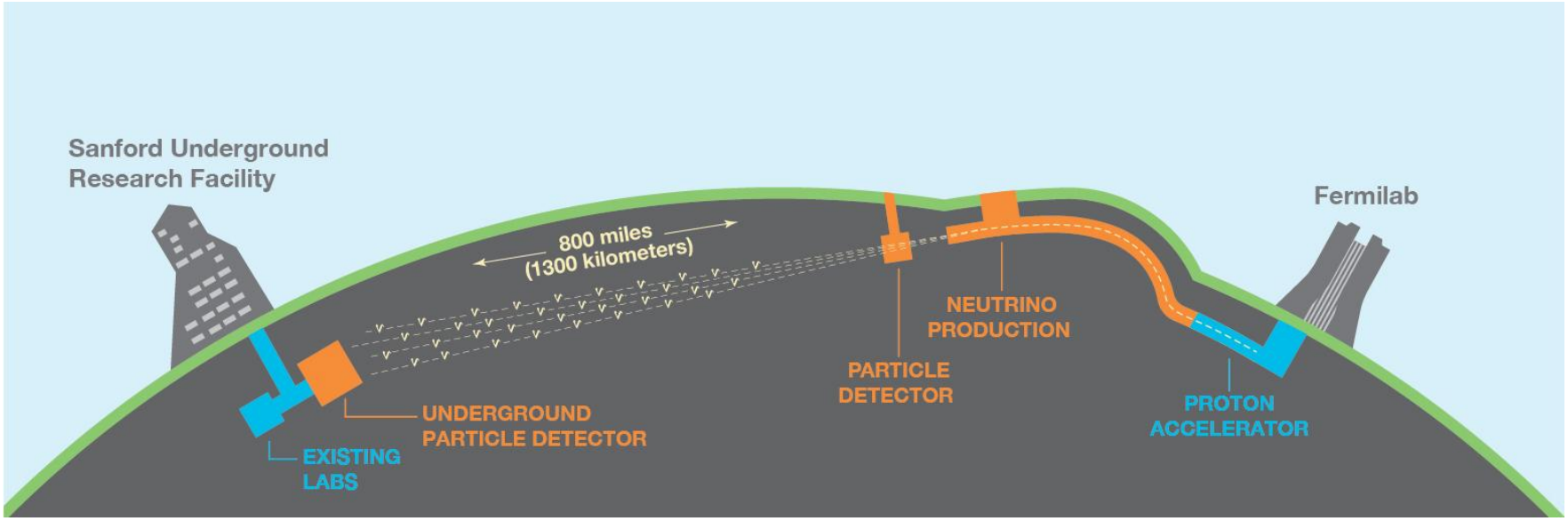
$S_{ij} = \sin(\theta_{ij})$

$C_{ij} = \cos(\theta_{ij})$

$$\begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{\mathrm{CP}}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{\mathrm{CP}}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{\mathrm{CP}}} & s_{23}c_{13} \\ s_{12}s_{23} - c_{12}c_{23}s_{13}e^{i\delta_{\mathrm{CP}}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{\mathrm{CP}}} & c_{23}c_{13} \end{bmatrix}$$

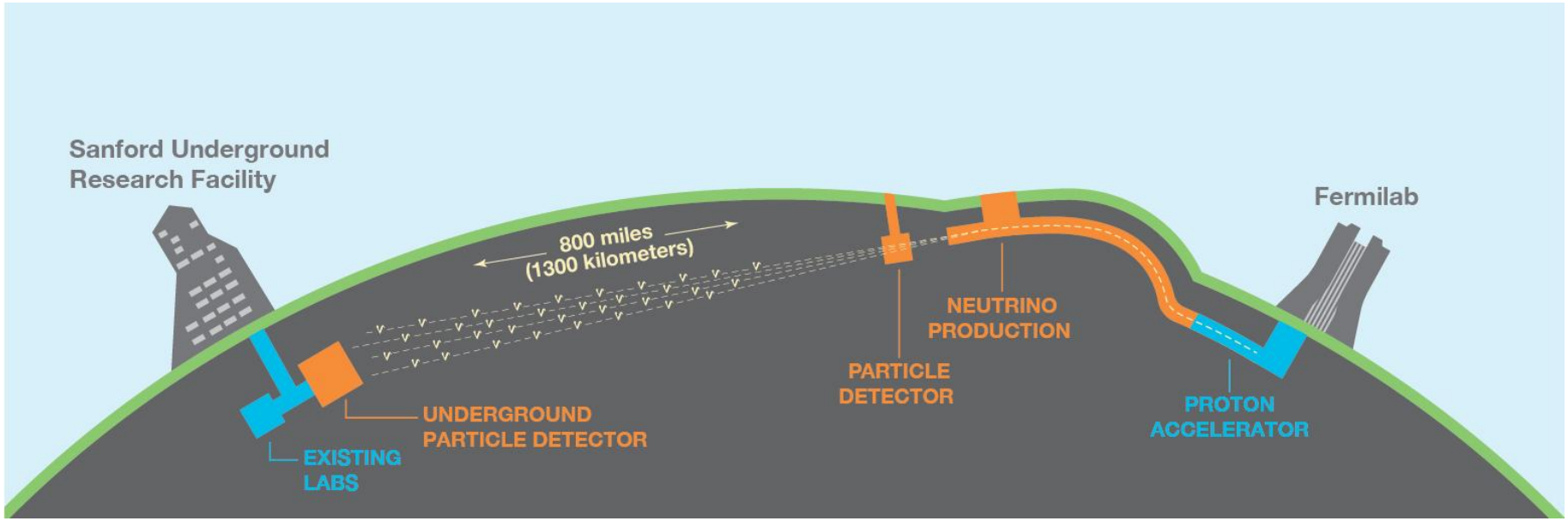
The Deep Underground Neutrino Experiment (DUNE)

- A next-generation long-baseline neutrino experiment
- Over 1000 collaborators from over 190 institutions in over 30 countries plus CERN
- Includes:
  - 1.2 MW neutrino beam from Fermilab's Long Baseline Neutrino Facility
  - Beam has wide energy spectrum, allowing detection of multiple oscillation patterns
  - 40 kt liquid argon TPC Far Detector at the Sanford Underground Research Facility
  - Near Detector 575 m downstream of beam production target



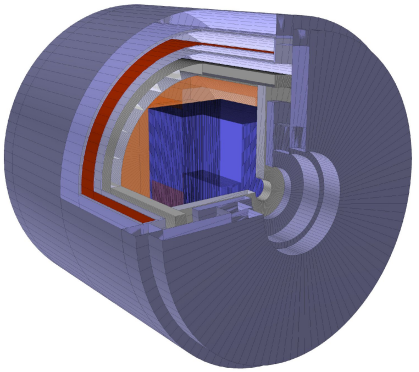
DUNE Goals

- Answer fundamental questions in particle physics
  - Measure δ_{CP} violation phase in lepton sector
  - Search for evidence of proton decay
- Further our understanding of neutrinos
- Further our understanding of supernovae



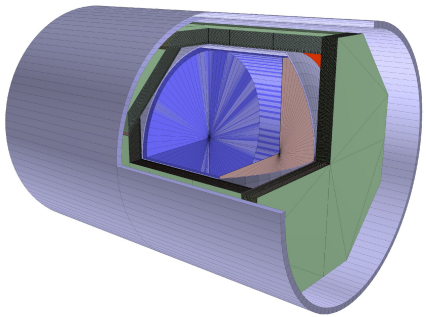
DUNE Near Detector (ND)

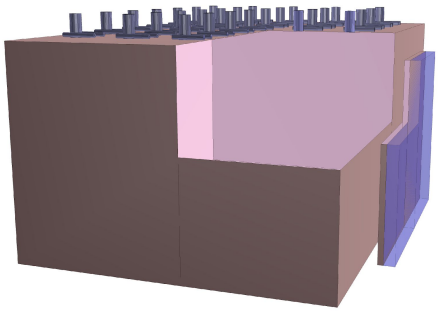
- Primary role is to control systematic uncertainties, including:
  - Beam flux
  - Cross sections
  - Detection and component background
- In long-baseline experiments, allows one to compare initial beam with beam after propagation
- 575m downstream of beam production target
- Detectors:
  - Liquid Argon TPC (LAr)
  - Multi-Purpose Detector (MPD)
  - System for on-Axis Neutrino Detection (SAND)



SAND

MPD





LAr

Near Detector Hall Engineering Design

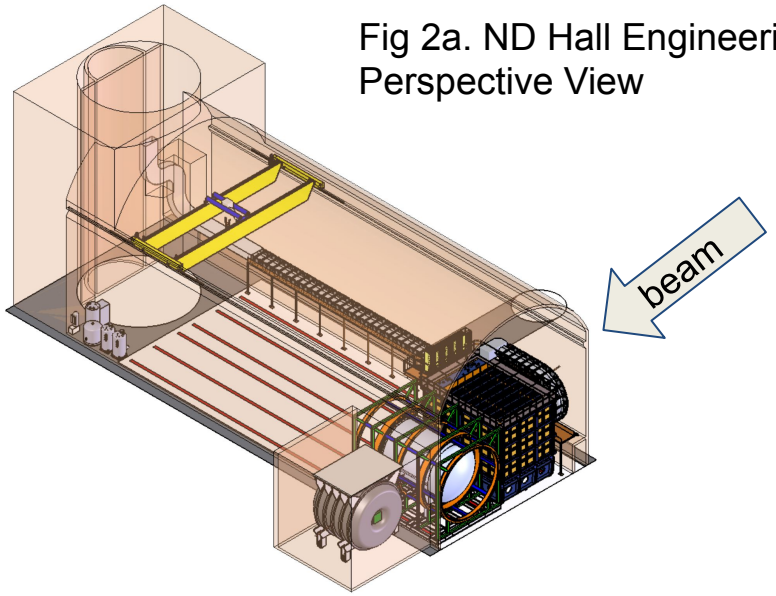


Fig 2a. ND Hall Engineering Design
Perspective View

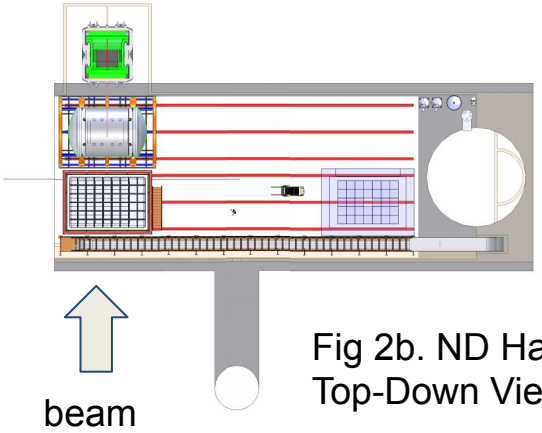
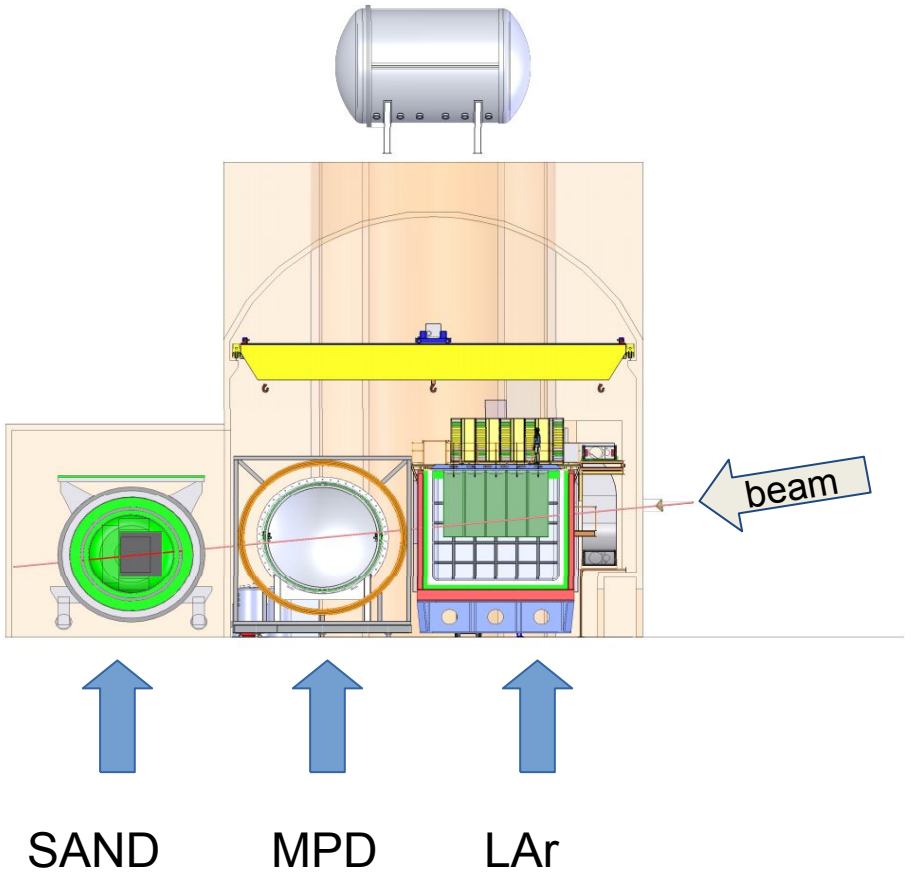


Fig 2b. ND Hall Engineering Design
Top-Down View

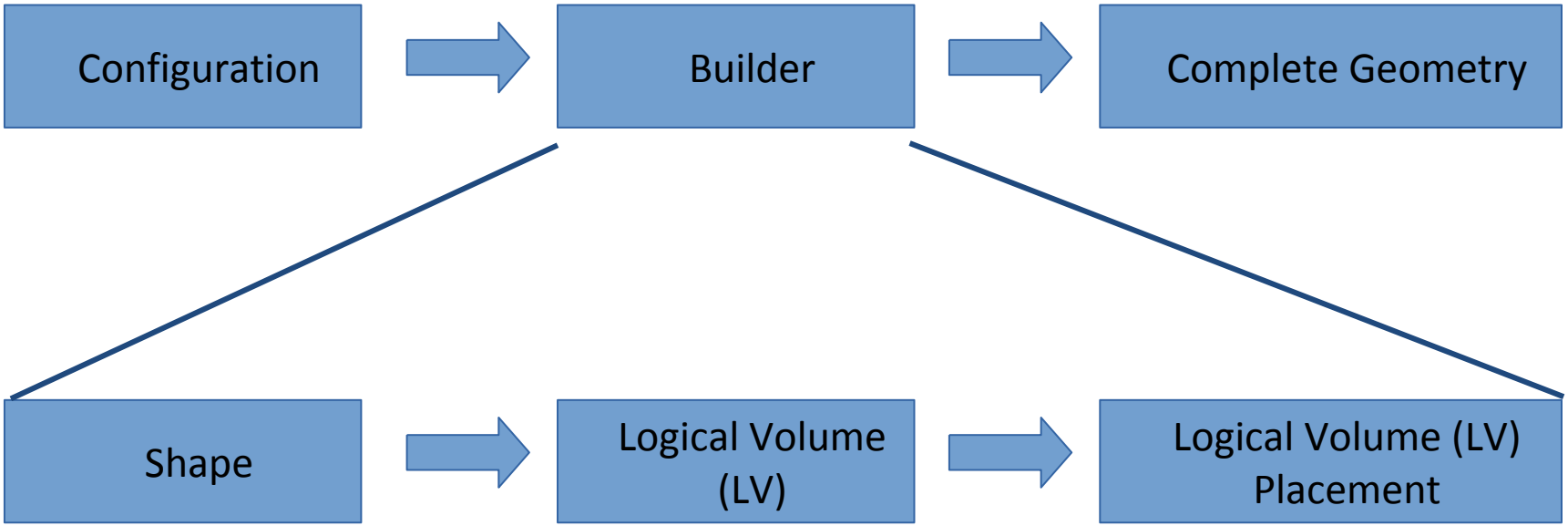
Fig 2c. ND Hall Engineering
Design Front View



DUNENDGGD

- Designed to provide convenient tool to design and configure the DUNE ND Geometry
- Based on GeGeDe package (B. Viren, BNL)
    - Generates constructive solid geometry
    - Made to work with Geant4 or ROOT
    - Built with Python
    - Github URL: https://github.com/brettviren/gegede

Standard process for geometry creation in DUNENDGGD



DUNENDGGD Example

- Building 3DST + TPC geometry

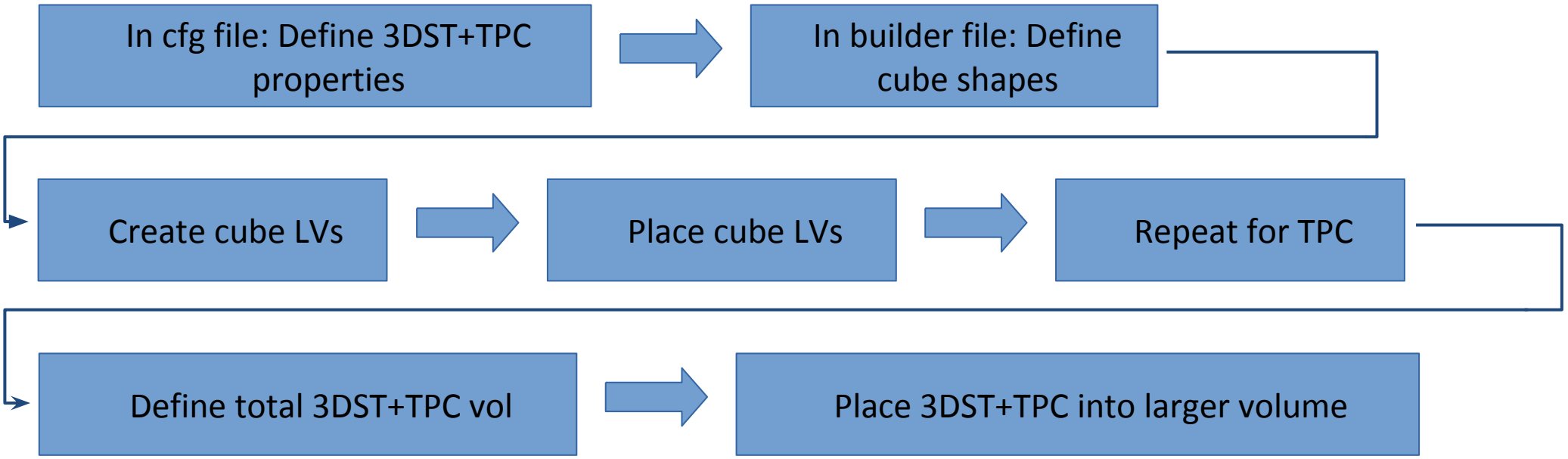
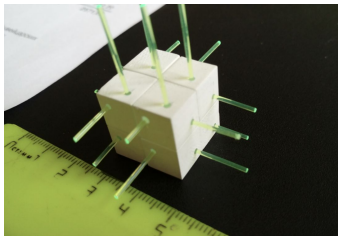
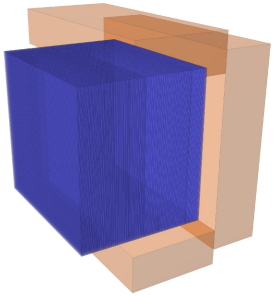


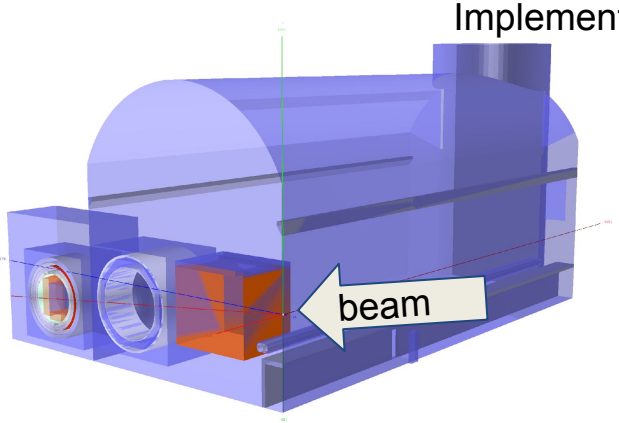
fig 3.
Left: 3DST Scintillator with Fibers
Right: 3DST+TPC Geometry





Near Detector Hall Implemented using DUNENDGGD

Fig 4a. ND DUNENDGGD Implementation Perspective View



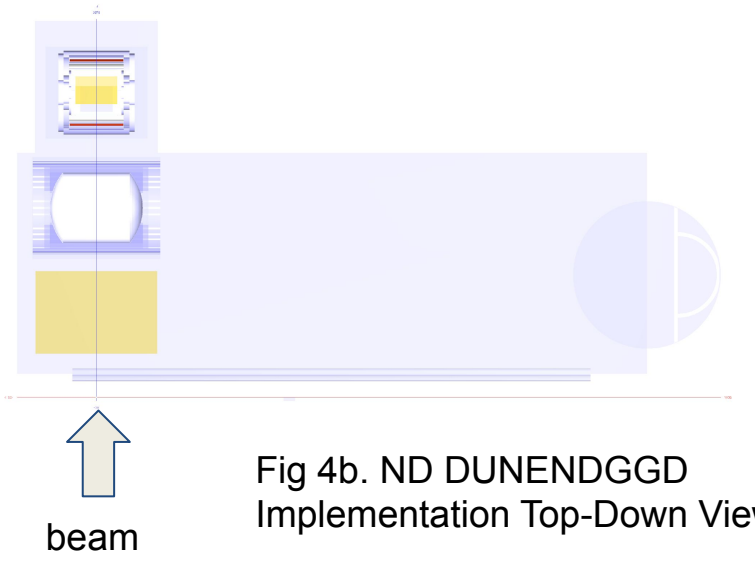
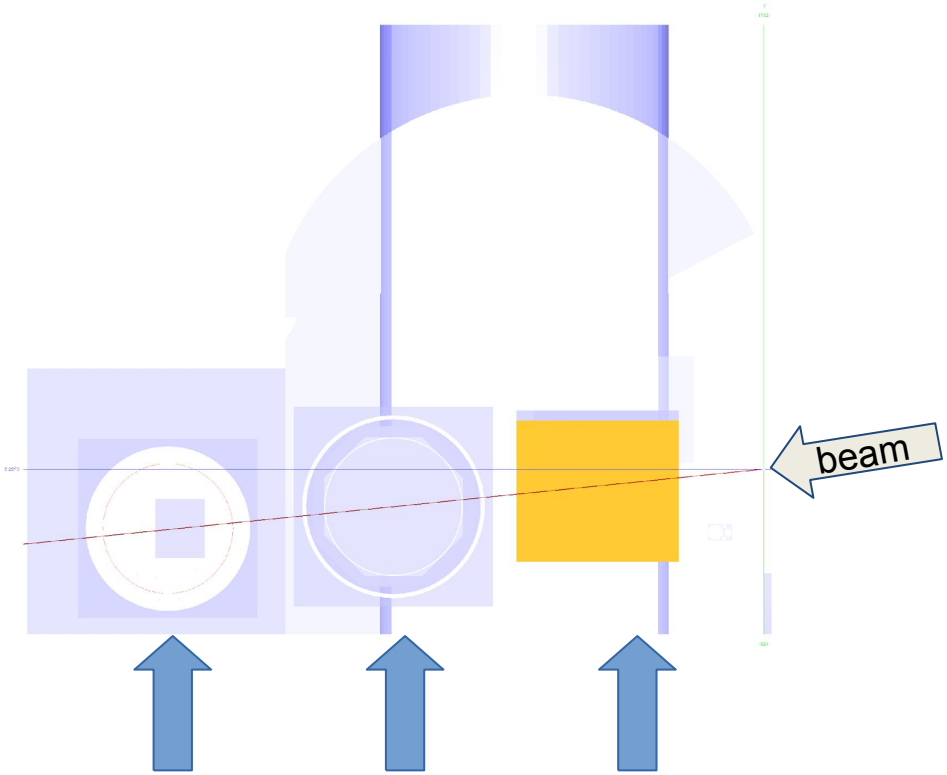
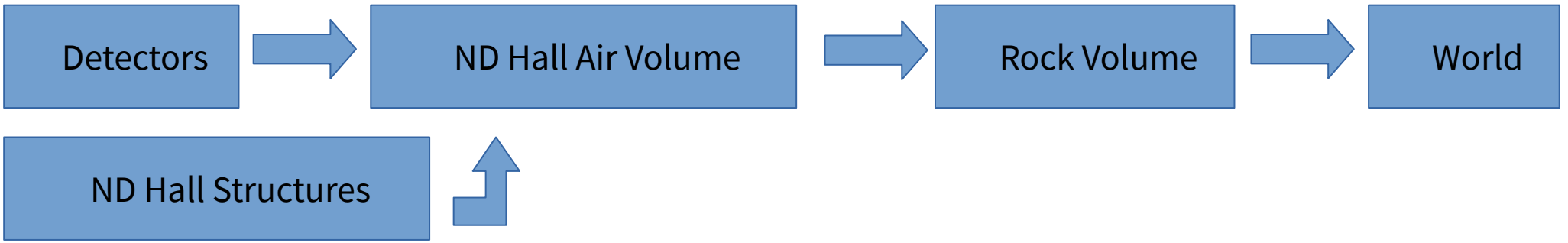


Fig 4b. ND DUNENDGGD Implementation Top-Down View

Fig 4c. ND DUNENDGGD Implementation Front View



Structure in DUNENDGGD



- Logical Volumes placed inside each other using sub-builders
- Arrows indicate DUNENDGGD sub-builders to higher level builders

Rock Volume

- Two versions:
  - 5 m of rock upstream of hall
  - 250 m of rock upstream of hall
- Simple to transition between each version

Fig 5a. ND DUNENDGGD Implementation - 5 m of rock upstream

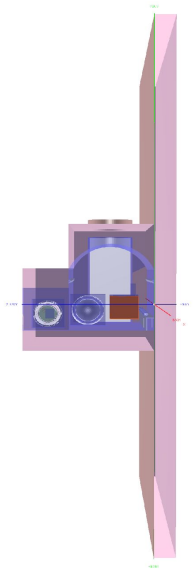
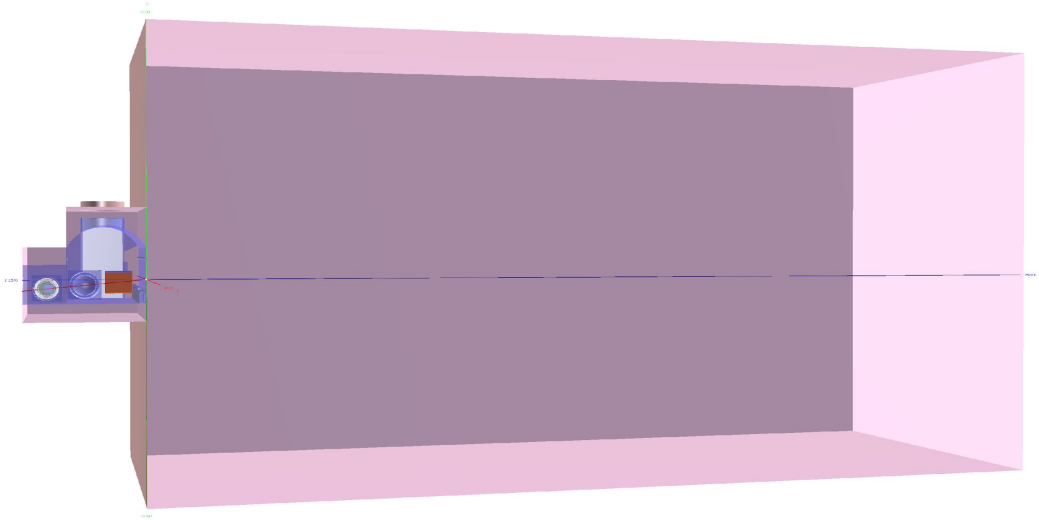
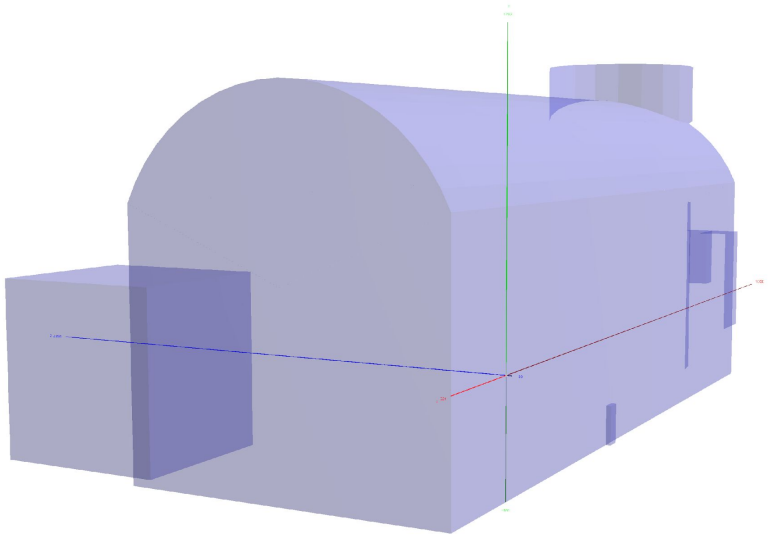


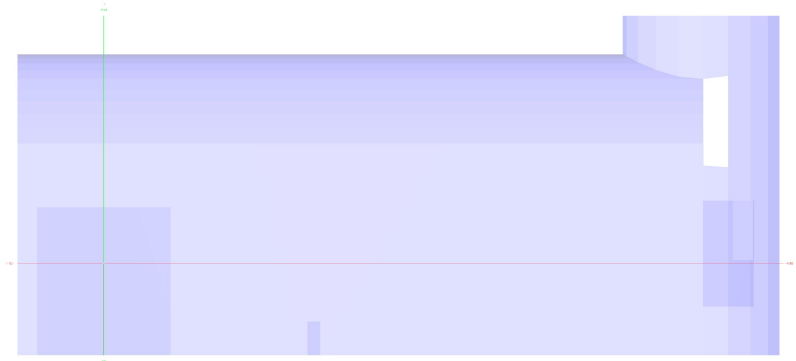
Fig 5b. ND DUNENDGGD Implementation - 250 m of rock upstream

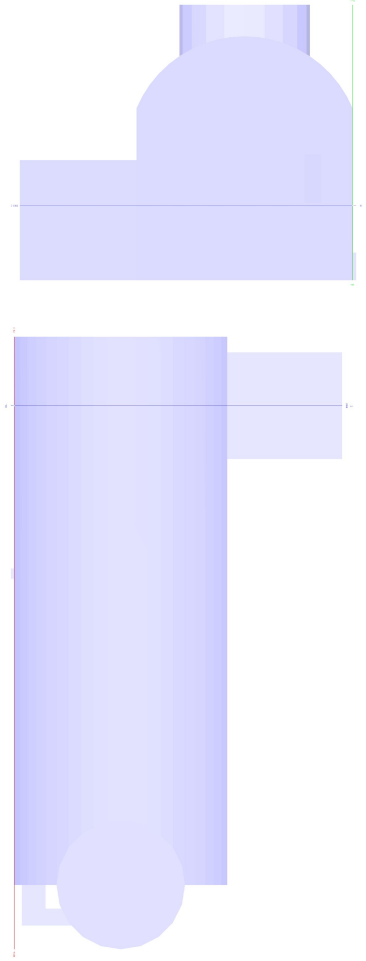


Air Volumes

Fig 6. ND DUNENDGGD Implementation Air Volumes
Bottom Left: Perspective View
Bottom Middle: Side View
Bottom Right: Top-Down View
Top Right: Front View







Detectors

- DUNENDGGD allows simple construction of complicated detectors

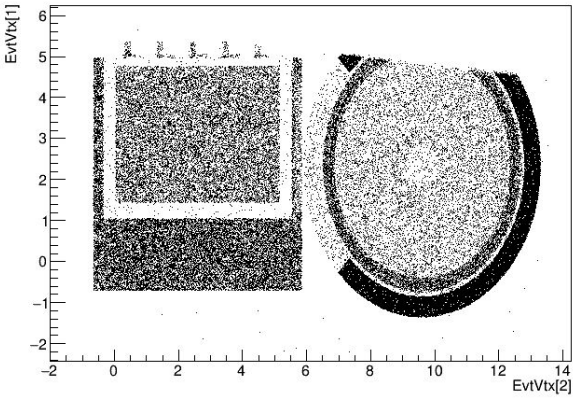
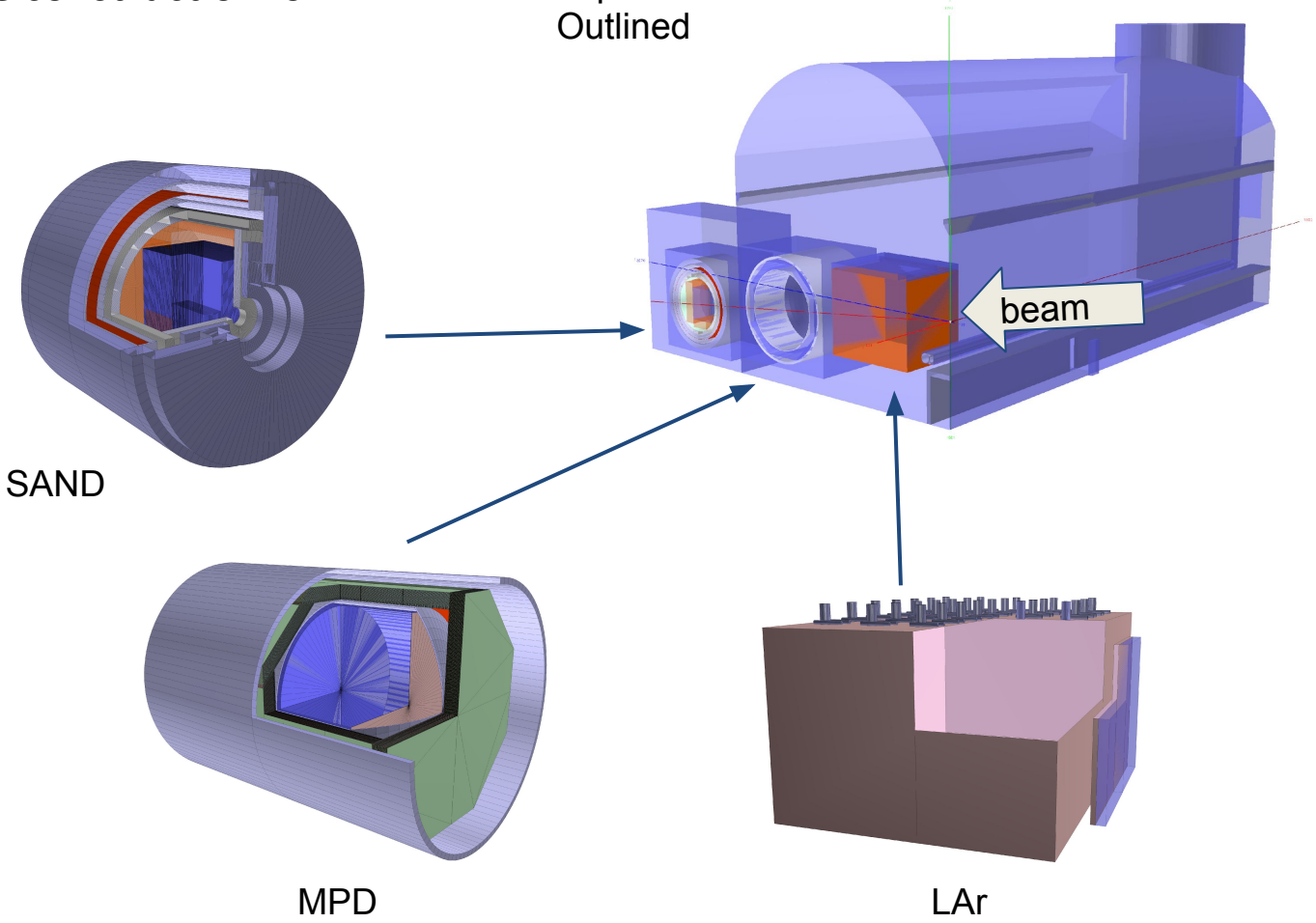


fig 7. GENIE Neutrino Interaction Vertices in LAr and MPD - Z vs. Y

fig 8. ND DUNENDGGD Implementation with Detectors Outlined



ND Hall Structures

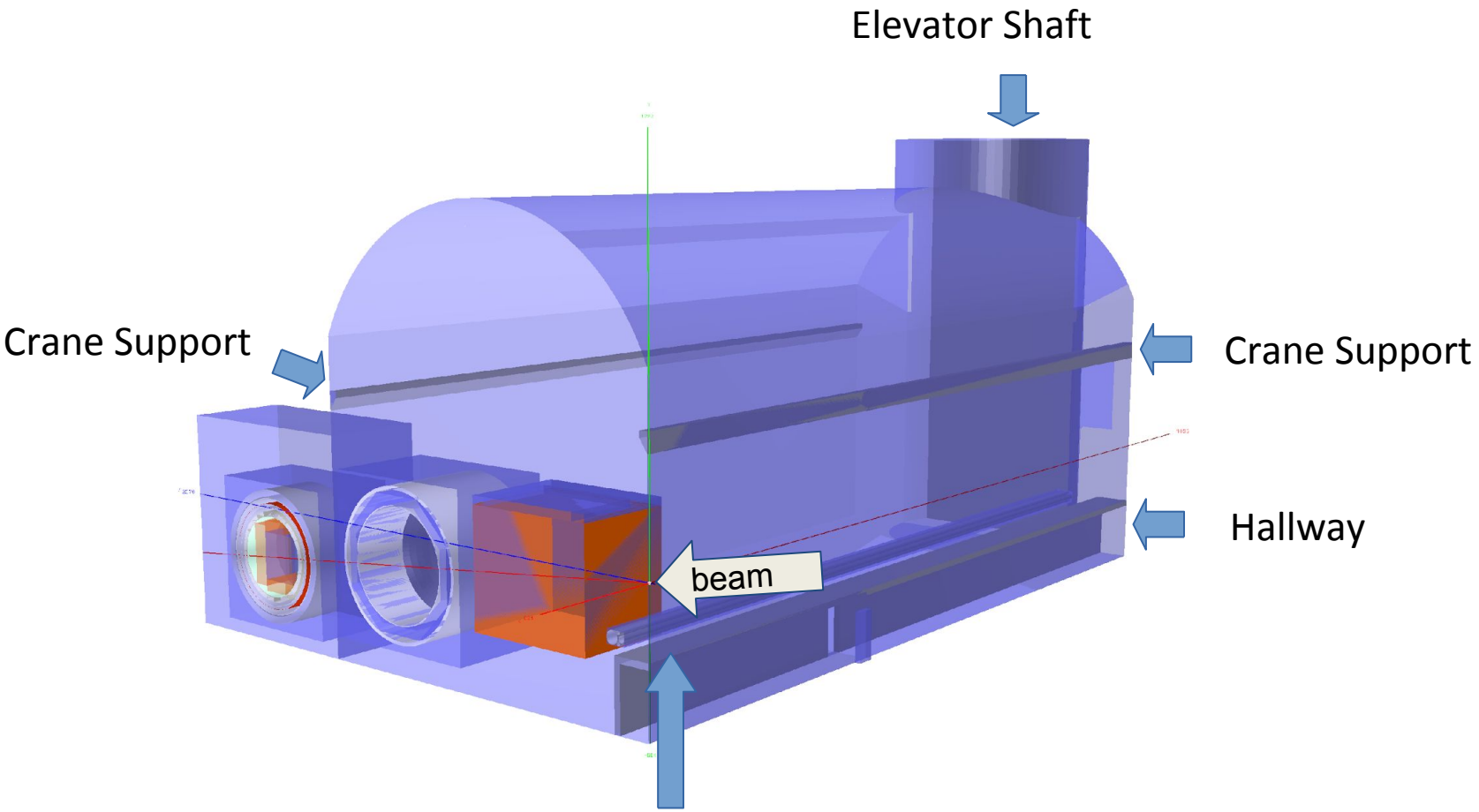
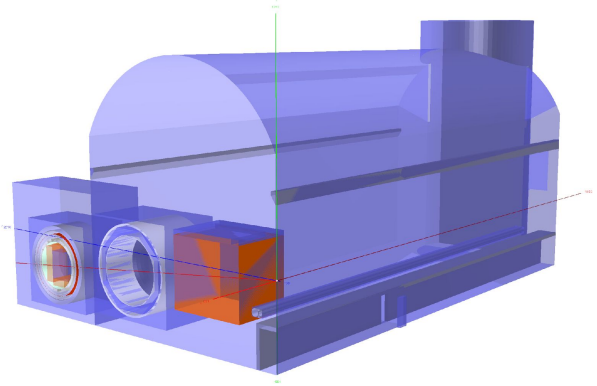
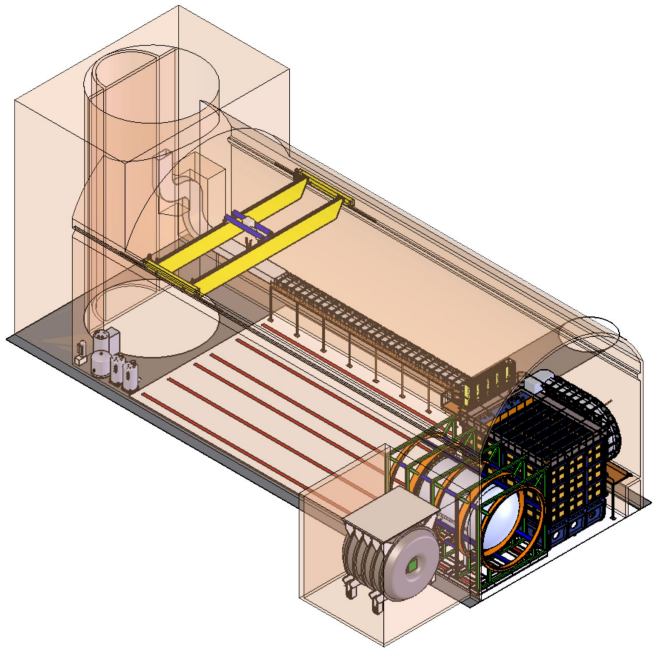


fig 9. ND DUNENDGGD Implementation with Hall Structured Outlined

Summary

- A full DUNE Near Detector geometry generated with DUNENDGGD is being officially used in the DUNE ND Software Integration Group
- Each component can be modified independently





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Thank You