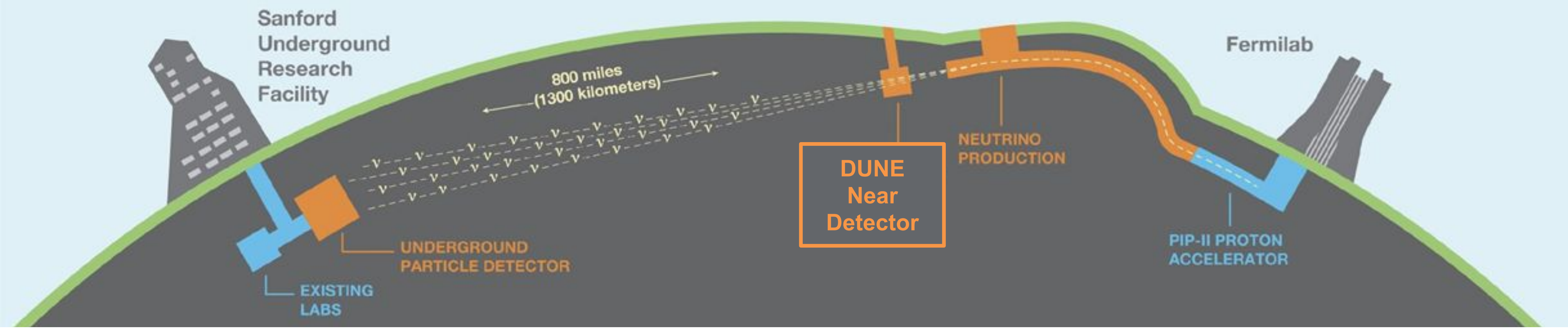
DUNE-ND PRISM Movement System Introduction

DUNE ND PRISM Team
PRISM Design Assessment
November 19th, 2024

Assessment Agenda

- 01 Introduction (This Talk)
  - Project overview (DUNE Near Detector)
  - Assessment goals
  - Overview of our design (Hilman rollers)
  - Interfaces (cavern/rails & detector)
  - Additional information
    - Movement system controls
    - Safety and monitoring systems
    - Alternatives considered
- 02 Requirements
  - Flowdown requirements
  - System tolerance requirements due to cavern rail system
  - Description of each key requirement
- 03 Integrated Design and Interfaces
  - Detector design details
  - Roller/detector interface (fabric pads)
  - Movement system design details
    - Meeting requirements set by cavern rail tolerances
      - Fabric pad performance
    - Setting and achieving coefficient of friction targets
- 04 Risks and Prototype Testing
  - Primary PRISM risks
  - PRISM prototyping and testing plan

DUNE (Deep Underground Neutrino Experiment)



- DUNE is a 3rd generation long-baseline neutrino oscillation experiment
  - A beam of neutrinos is produced at Fermilab, measured by a Near Detector (ND) at Fermilab, and measured again by a Far Detector (FD) at the Sanford Underground Research Facility in Lead, SD
- The ND is used to measure the properties of the neutrino beam before the neutrinos have had a chance to oscillate
  - It is also used to determine how the energy deposited in the detector is related to the incoming neutrino energy (a critical parameter to determine neutrino oscillation parameters)
- These ND measurements play an essential role in extracting the fundamental physics parameters from the neutrinos measured at the far detector

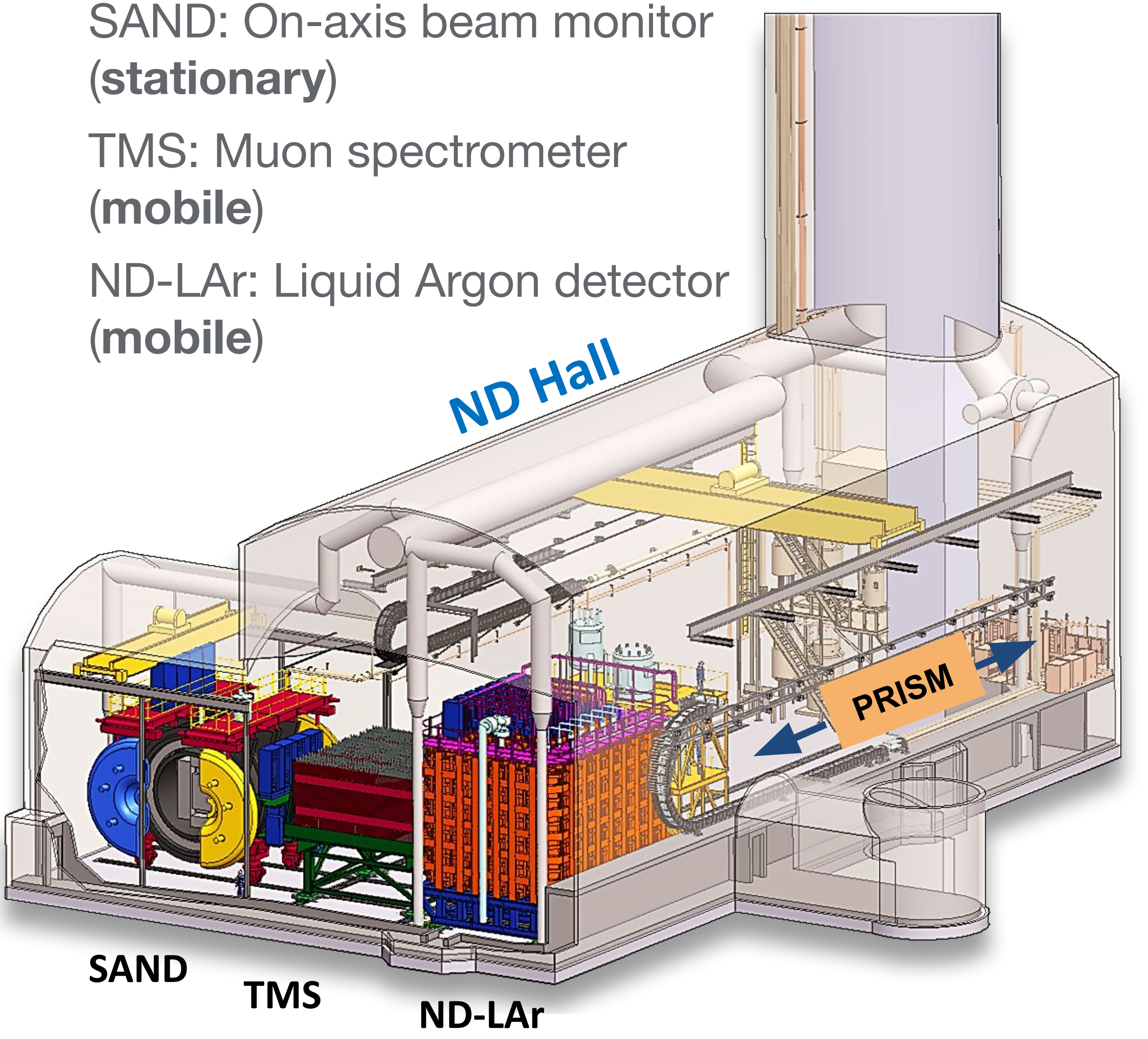
The DUNE Near Detector Complex (Fermilab)

- Neutrino beams are produced by particle decays, so the transverse beam size is very broad
  - This is very different from proton, electron, or laser beams, which have a small, controlled spot size
- When viewed from increasing off-axis angles, the neutrino beam energy decreases
  - DUNE will be the first experiment to take advantage of this phenomenon, and measure the beam across a variety off-axis positions
- This will allow DUNE to calibrate the measured energy in the detector to the true neutrino energy

SAND: On-axis beam monitor (**stationary**)

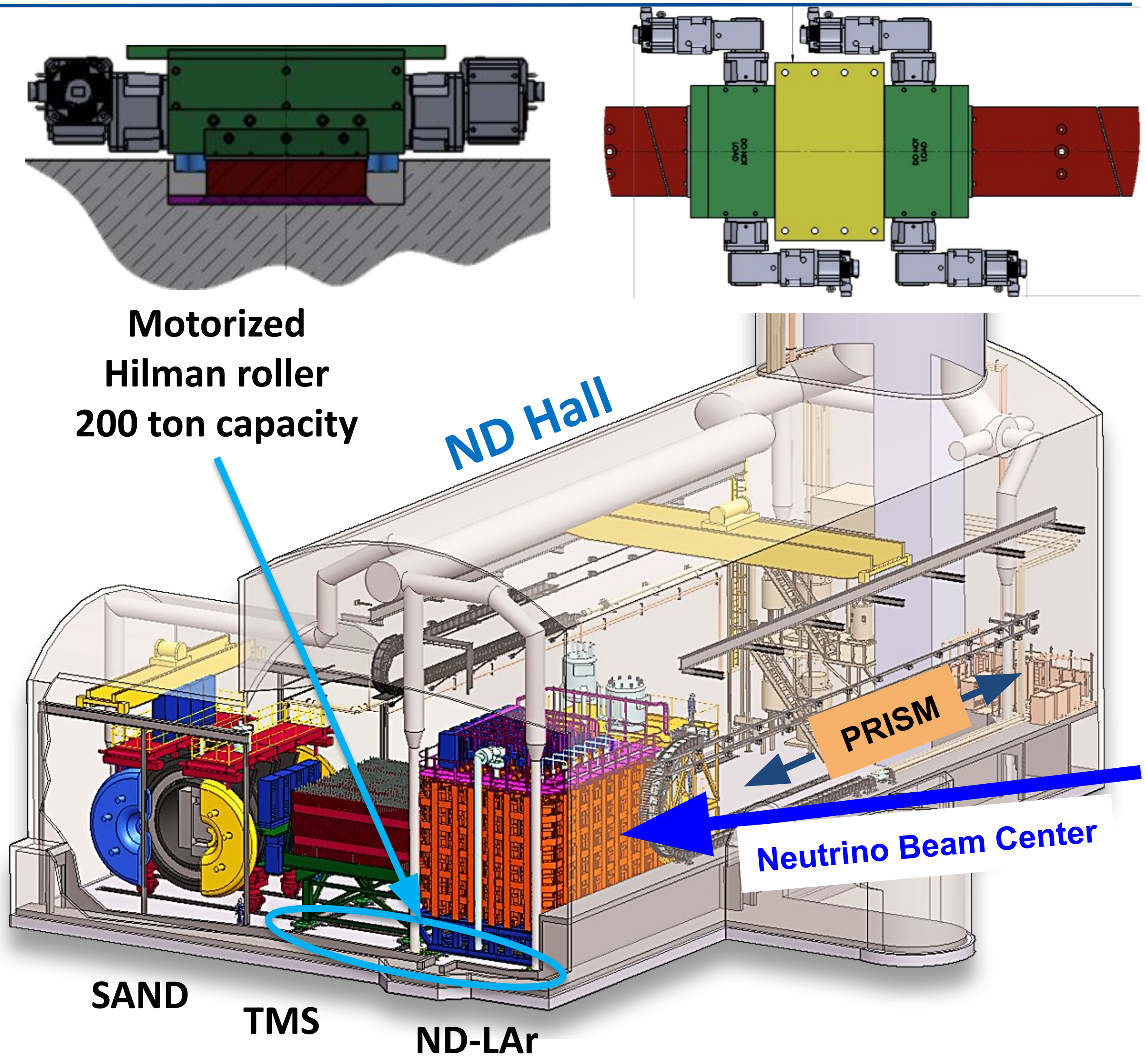
TMS: Muon spectrometer (**mobile**)

ND-LAr: Liquid Argon detector (**mobile**)



The DUNE-PRISM Detector Movement System

- Two of the 3 DUNE NDs (ND-LAr and TMS) are designed to move up to 30 m off-axis from the neutrino beam center
  - This is the **PRISM** Movement System
  - PRISM: Precision Reaction Independent Spectrum Measurement
- ND-LAr is the primary neutrino target
  - Most of the particles produced in a neutrino interaction are contained and measured within ND-LAr
  - However, muons will often escape out of the back of ND-LAr
- TMS (The Muon Spectrometer) measures the particles that escape ND-LAr
- During normal running, ND-LAr and TMS will move together

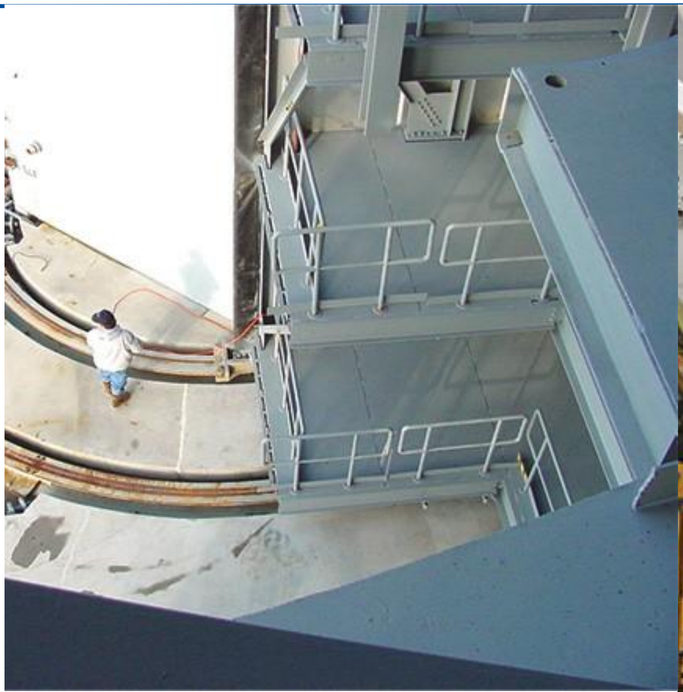


PRISM Design Assessment

- The purpose of this PRISM Design Assessment is to evaluate whether our choice of movement system technology (motorized Hilman rollers) will be able to meet our requirements
  - Many factors contributed to this technology choice (cost, R&D required, complexity, risk, etc.)
  - Rather than presenting all of this background material and asking the reviewers to determine whether we made the best technology choice, we would instead like to limit the scope of this assessment to whether the choice we made will work sufficiently well for our application
- Summary of charge questions:
  - Requirements: Well defined? Reasonable? Sufficiently complete to design the system?
  - Design: Meets requirements? Have all relevant operational scenarios been considered? Does our solution accommodate all of the key tolerances?
  - Risks and Test plans: Are we missing any important risks? Does our baseline testing plan sufficiently address existing risks?
    - We have developed additional testing plans that are not currently in our baseline plan. How important are these tests, and should we push the project for the additional funding that would be required for these tests?

Hilman, Inc.

- 70+ years of designing roller systems for moving heavy objects
- Used extensively at major research labs (Fermilab, BNL, JLAB, etc.)
- NASA, Shipyards, bridges, off-shore rigs, Stadium Roofs (Florida Marlins)
- https://www.hilmanrollers.com/about-us/projects/



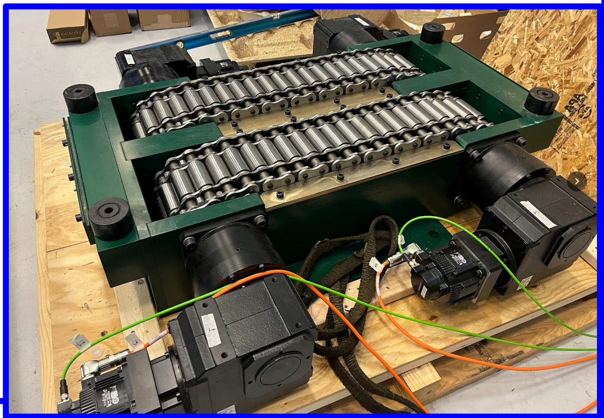
Hilman Motorized Rollers

- Newer product (patent is 10 years old)
- Each Hilman roller is powered by servo motors that is controlled by a manufacturer-supplied control unit
  - The control system allows for custom control of the detector speed, acceleration, and jerk
  - A built-in encoder is used to determine the instantaneous position within the cavern and initiate motion changes to reach any specified target location
- The existing application that most closely resembles our application is at a nuclear waste removal site in Loveland, CO
  - 6 100-ton powered rollers

Motorized Rollers

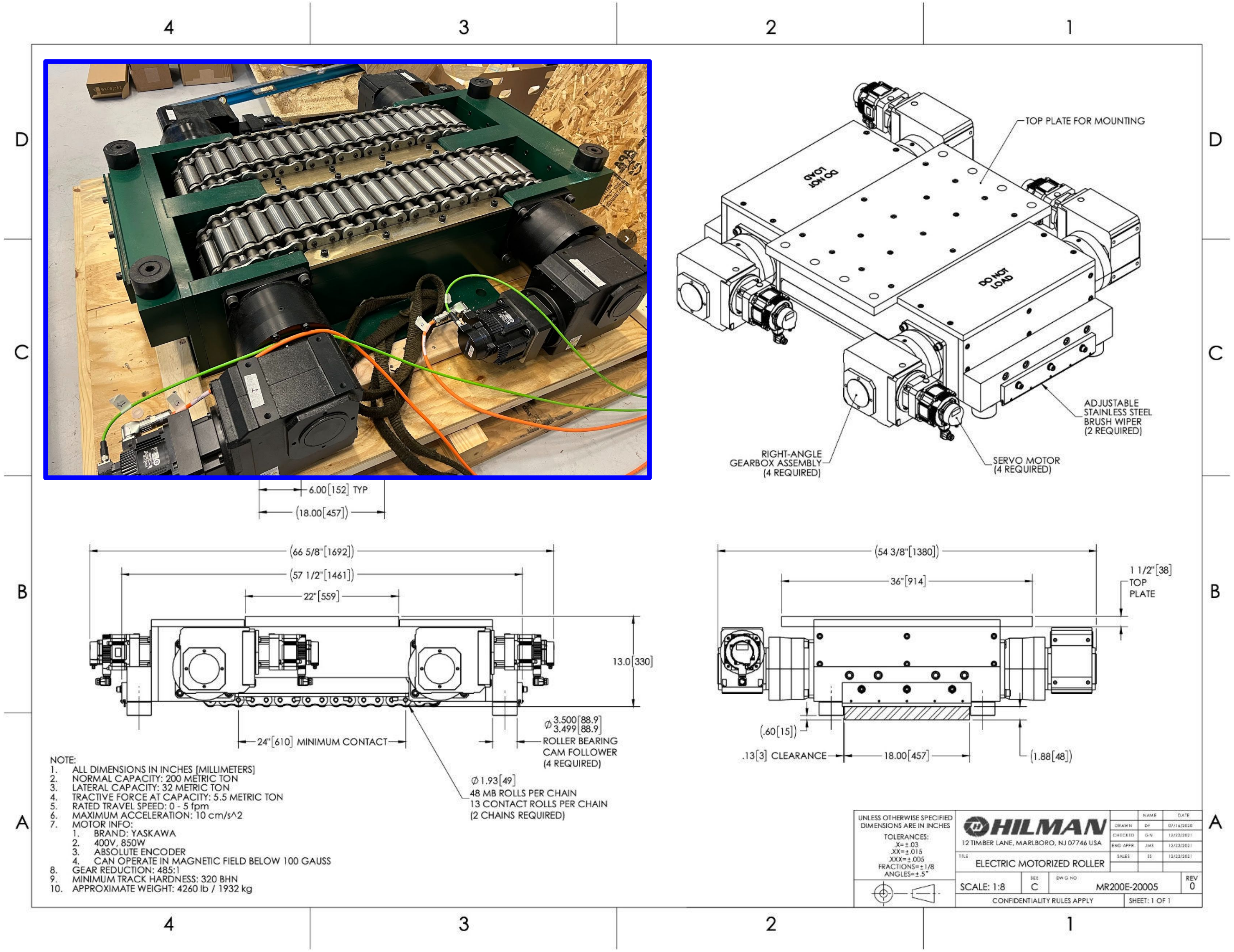
The Hilman Motorized Roller is a low-profile, high-capacity solution for permanent, repetitive movement of heavy objects.

Patent No. US8672063B2 United States, EP2636579B1 Europe, CN103303637B China, NO2844637T3 Norway



The PRISM 200 Ton Motorized Roller

- Our rollers have 2 side-by-side chains, with 48 rolls per chain (13 contact rolls per chain)
- Each chain is driven by 2 servo motors
- A 90° gearbox (485:1) connects the servos to the sprockets that move the chain
- 4 cam followers are placed at the corners of the roller to ensure the roller remains on its rail
  - Designed for the 18" wide rails in the DUNE ND cavern



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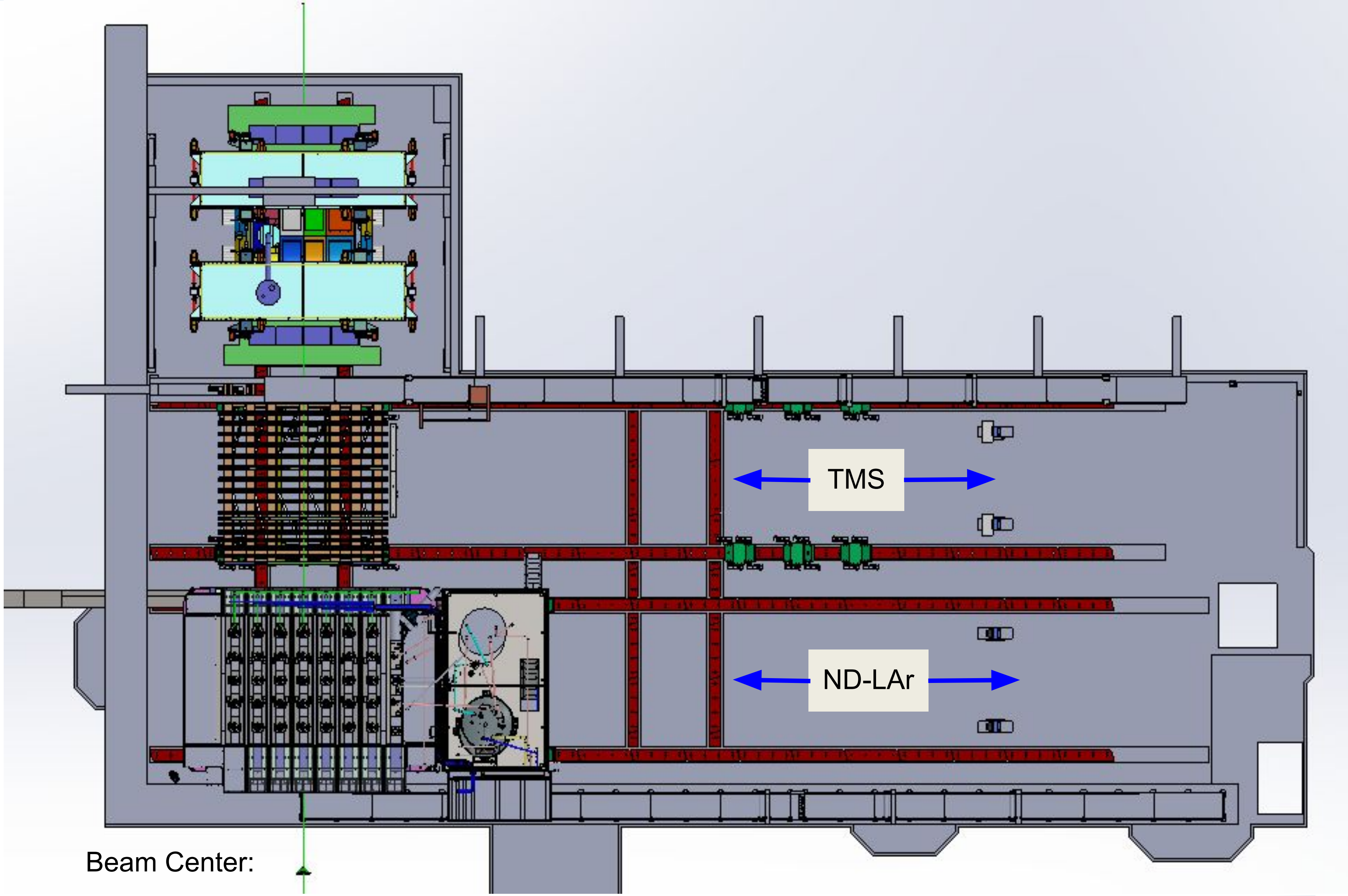
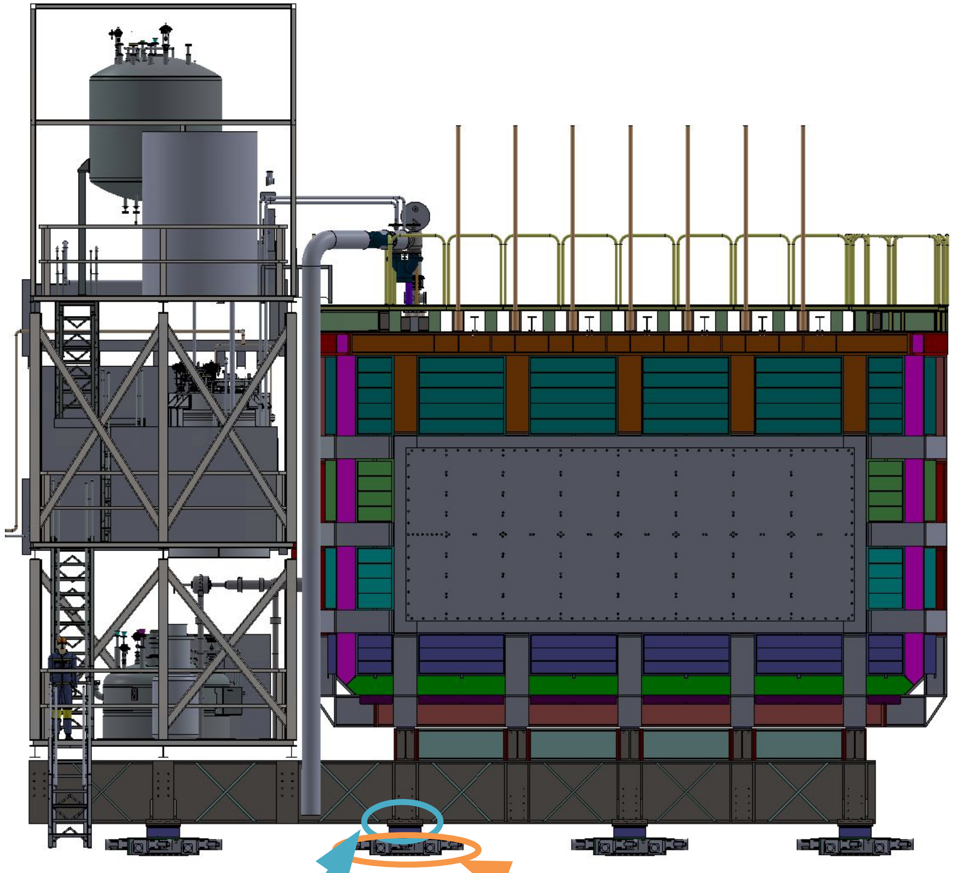
Near Detector Cavern Layout

- Near Site Conventional Facilities (NSCF) provides the ND cavern
  - Rail requirements were specified by the PRISM team
- ND-LAr and TMS each have their own set of 2 rails
  - These detectors cannot move between rails
- 2 sets of cross rails used only by SAND
  - SAND uses all rails
  - Very infrequently

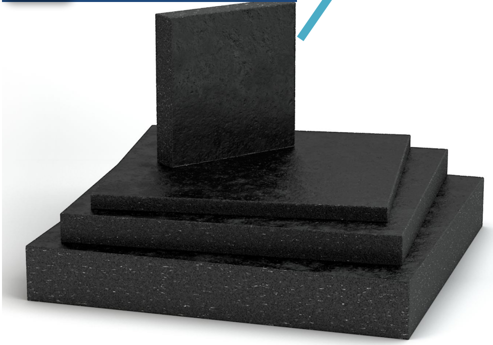


ND-LAr/PRISM Interface

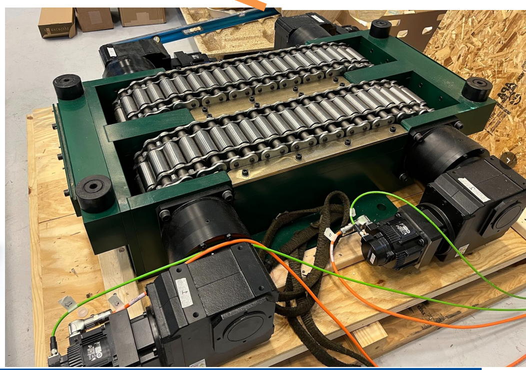
- For this assessment, we will focus on the PRISM system for ND-LAr
  - (We expect that nearly the same system will be used for TMS)
- The ND-LAr cryostat team is responsible for designing the support frame for ND-LAr
- PRISM team supplies the movement system, including the compressible pads that couples the rollers to the frame
  - These pads provide vertical compliance to allow the system to adapt to variations in the rail height (i.e. pads are the suspension system for the detector)
- Hilman has a long-standing relationship with Fabreeka (https://www.fabreeka.com/)
  - Several pads are under consideration for our force/compression requirements (presentation 03)



FABREEKA
A STABILUS COMPANY



HILMAN



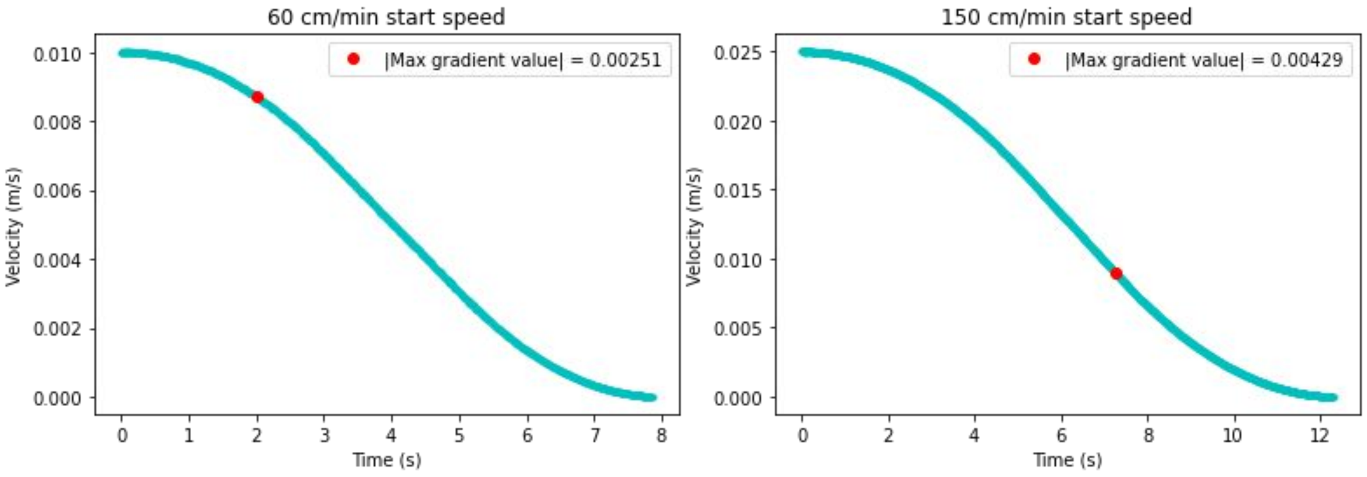
Additional Information

- The following slide present additional system details to provide context for the full, integrated system

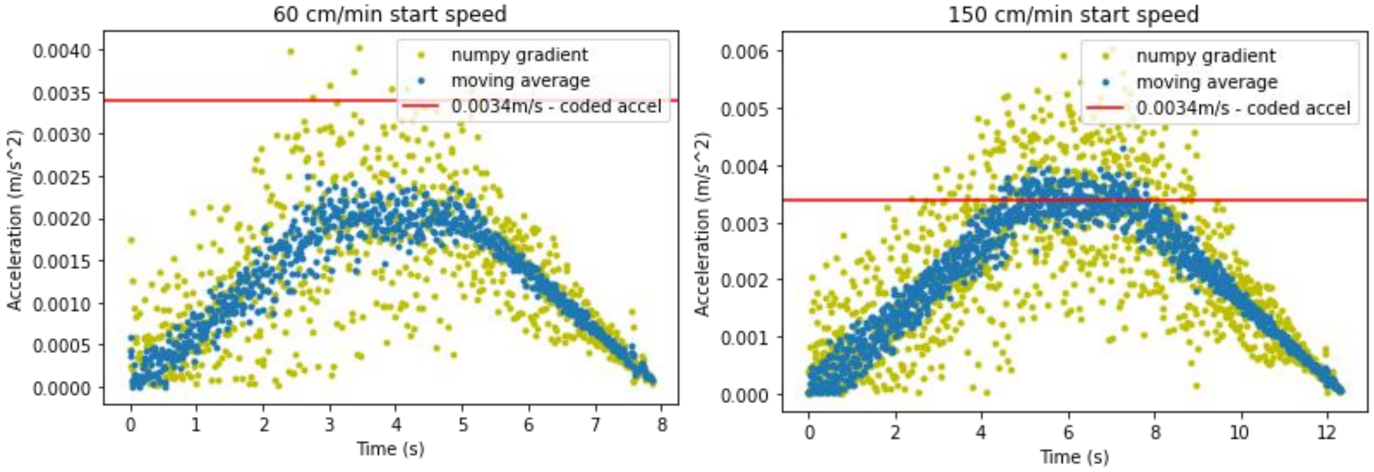
Movement System Controls

- Hilman provides a fully integrated system, including movement controls
- Acceleration is linearly ramped up/down to start/stop motion (constant jerk)
  - Very smooth motion
- At U of Minnesota, a motion system GUI has been built in Ignition
  - Ignition is the slow control system used by the DUNE FDs, the ND cryogenic systems, and ND “2x2” prototype detector, and other experiments
- More details regarding prototyping and development plans will be provided in presentation 04

Stopping Velocity vs Time



Stopping Acceleration vs Time



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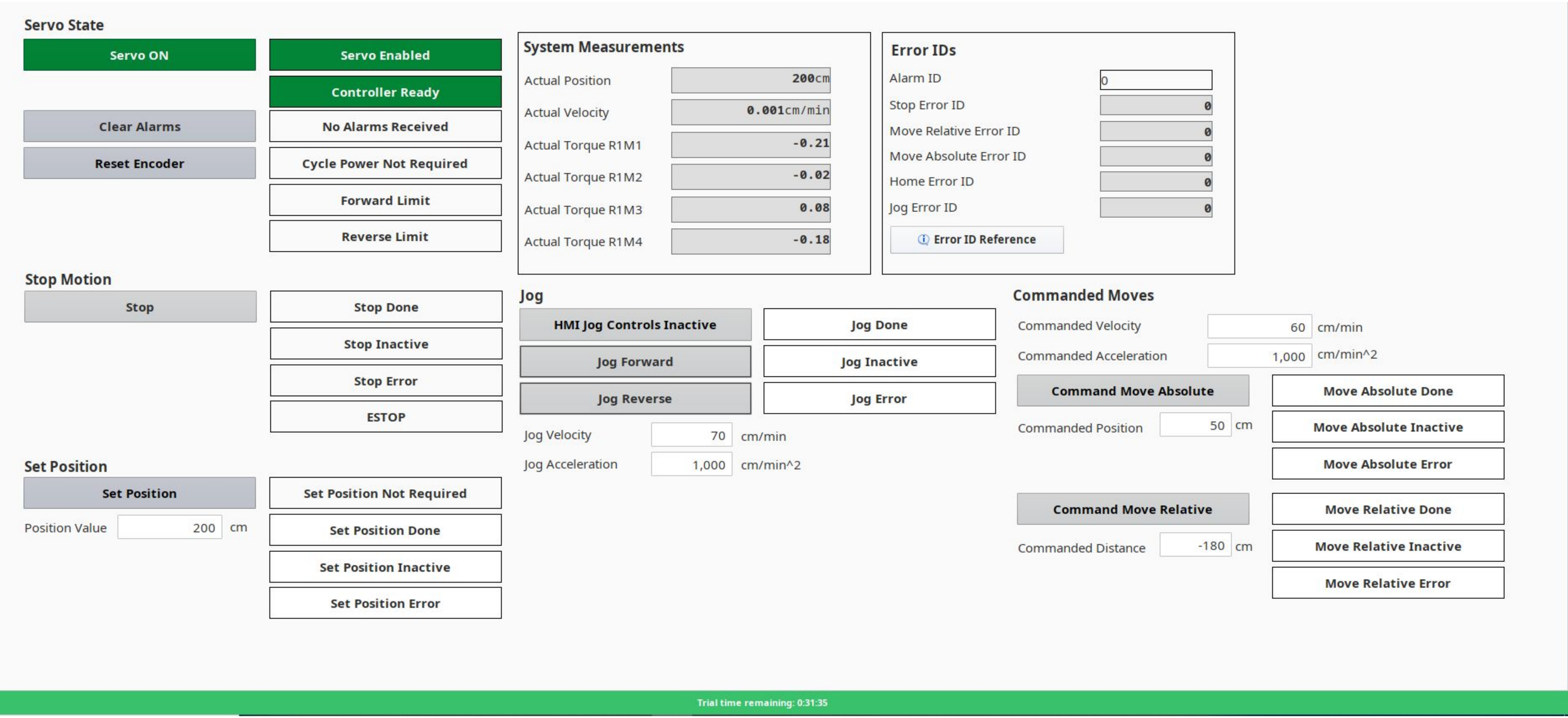
Controls GUI (Integrated into Ignition)



Monitoring and Safety Systems

- Position monitoring uses a laser system (distance to target on cavern wall)
- Vibrations/accelerations are monitored via a triaxial accelerometer
- Each rail is monitored with an area scan camera
- Safety systems:
  - PSC unit that integrates with movement system electronics
  - limit switches to prevent over-travel
  - emergency stop buttons

Position monitoring

Safety PLC

PSC1-C-100

Vibration / acceleration monitoring

Limit switches

PS315

Area scan cameras

e-stop buttons

BDF100

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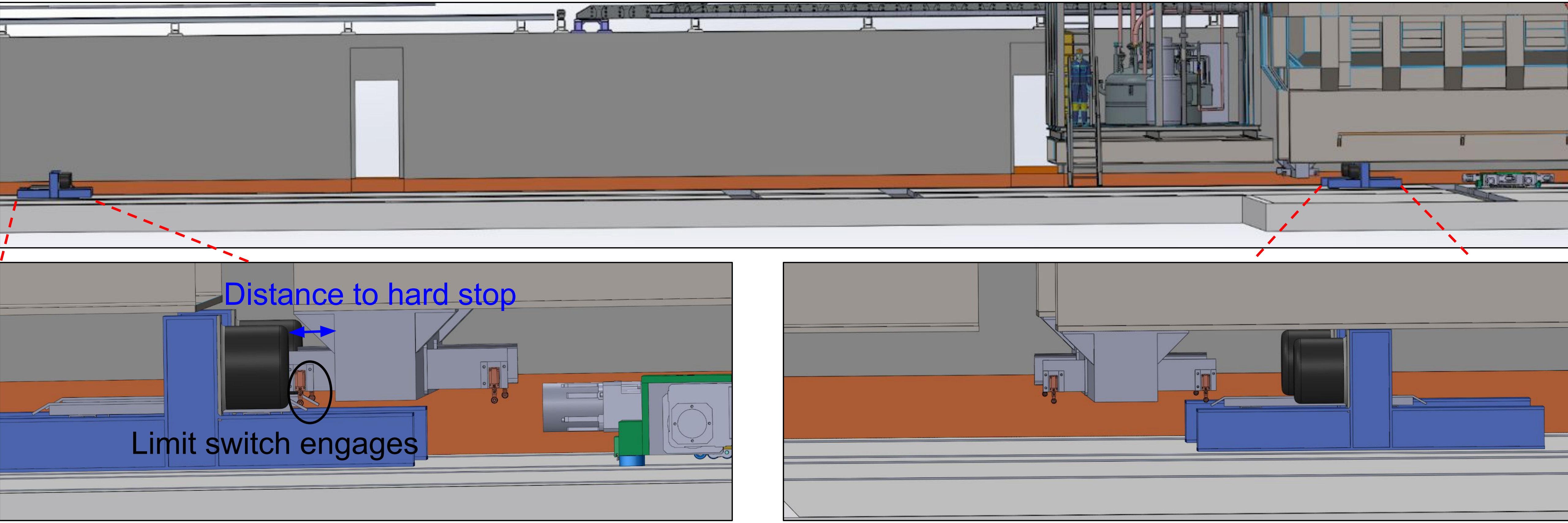
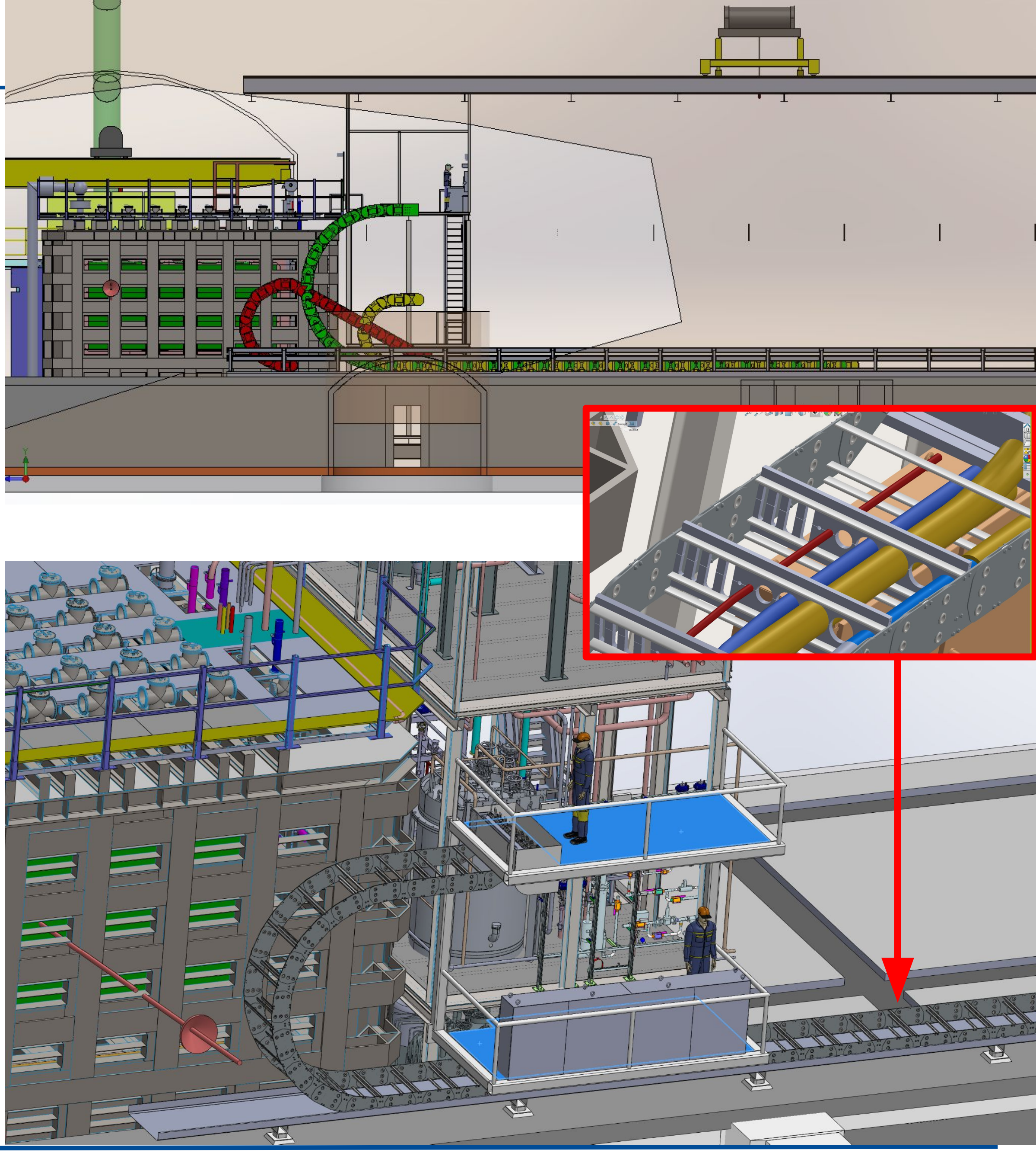
Detector Stopping Redundancy

- Movement system is programmed with predefined maximum travel distances
  - Additional levels of redundancy are needed in the event of the software malfunctioning
- 3 stages of stopping: (1) software stop, (2) limit switch engages, (3) hard stop
  - Goal is to only every use (1), and (2) ensures that (3) is never used
- Powered Hilmans interface nicely with limit switches (hard stops needed for any technology)



Energy Chain (ND-LAr)

- All detector utilities are carried through an “energy chain” that curls/uncurls as the detector moves
  - Allows for arbitrary positioning of the detector
- We use a “C-shape” design (**green** option) to avoid any local maxima in the chain
  - This causes a hot spot in the cryogenic lines that causes phase separation, which makes flow rates difficult to control
- Energy chain attachment balcony allows for routing of cryogenic piping
- Lower balcony holds the PRISM control cabinet
  - Reduces difficulties associated with different grounding for the mezzanine and the cryostat

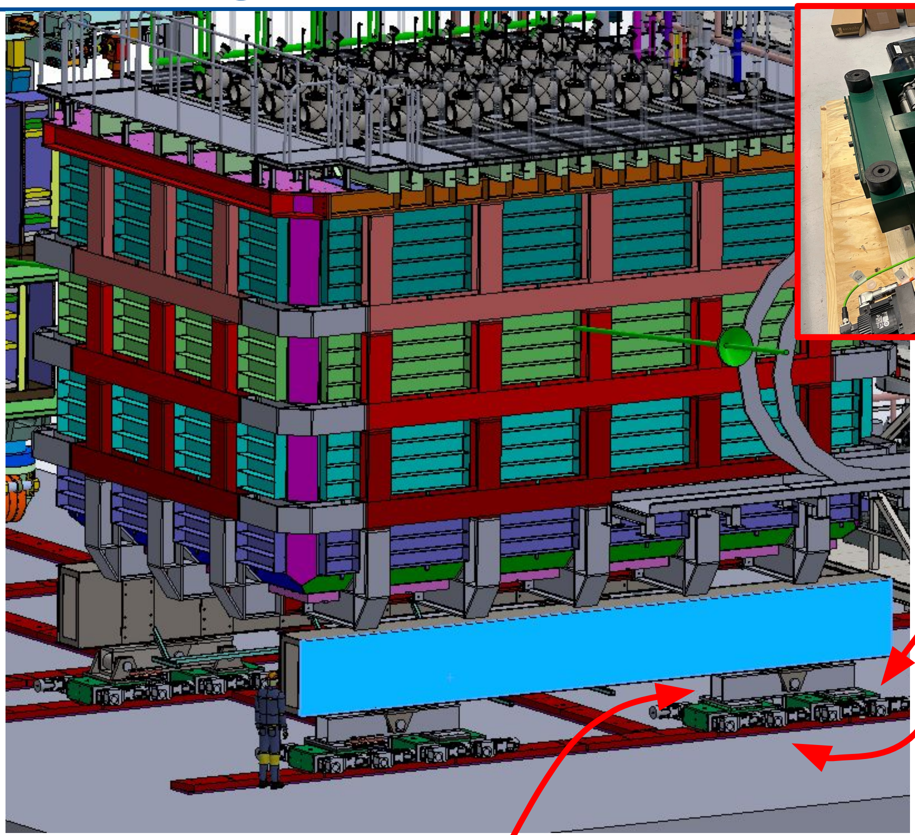


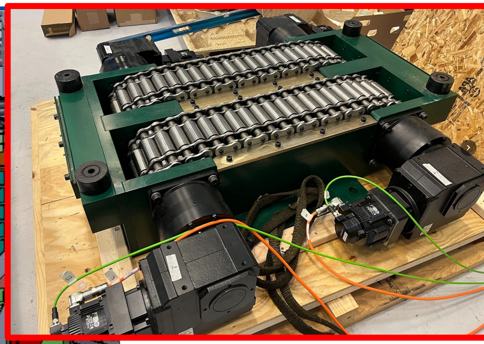
Alternatives Analysis

- The primary goal of this assessment is to determine whether our chosen system can adequately move the DUNE near detectors
- However, for completeness, the following slides show some alternative options we considered, and why they weren't chosen for our application

Alternative 1: Powered Hilmans + Bogie

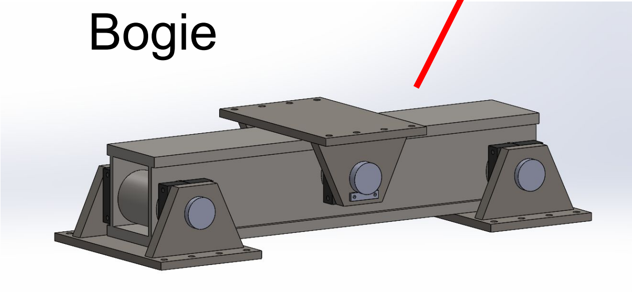
- A bogie connects 2 rollers to a single pivot point
  - If the elevation of the rail changes, a bogie will naturally distribute the load evenly between the 2 rollers
- If there are 2 bogies per rail, the load will be distributed evenly between all 8 rollers, regardless of the elevation change on each rail
  - (provided the 2 main frame beams can twist relative to each other)
- Hilman has produced 300 ton motorized bogies for a different customer
- However, bogies significantly increase the complexity of the design
  - If adequate suspension can be achieved via pads, they are a much simpler solution





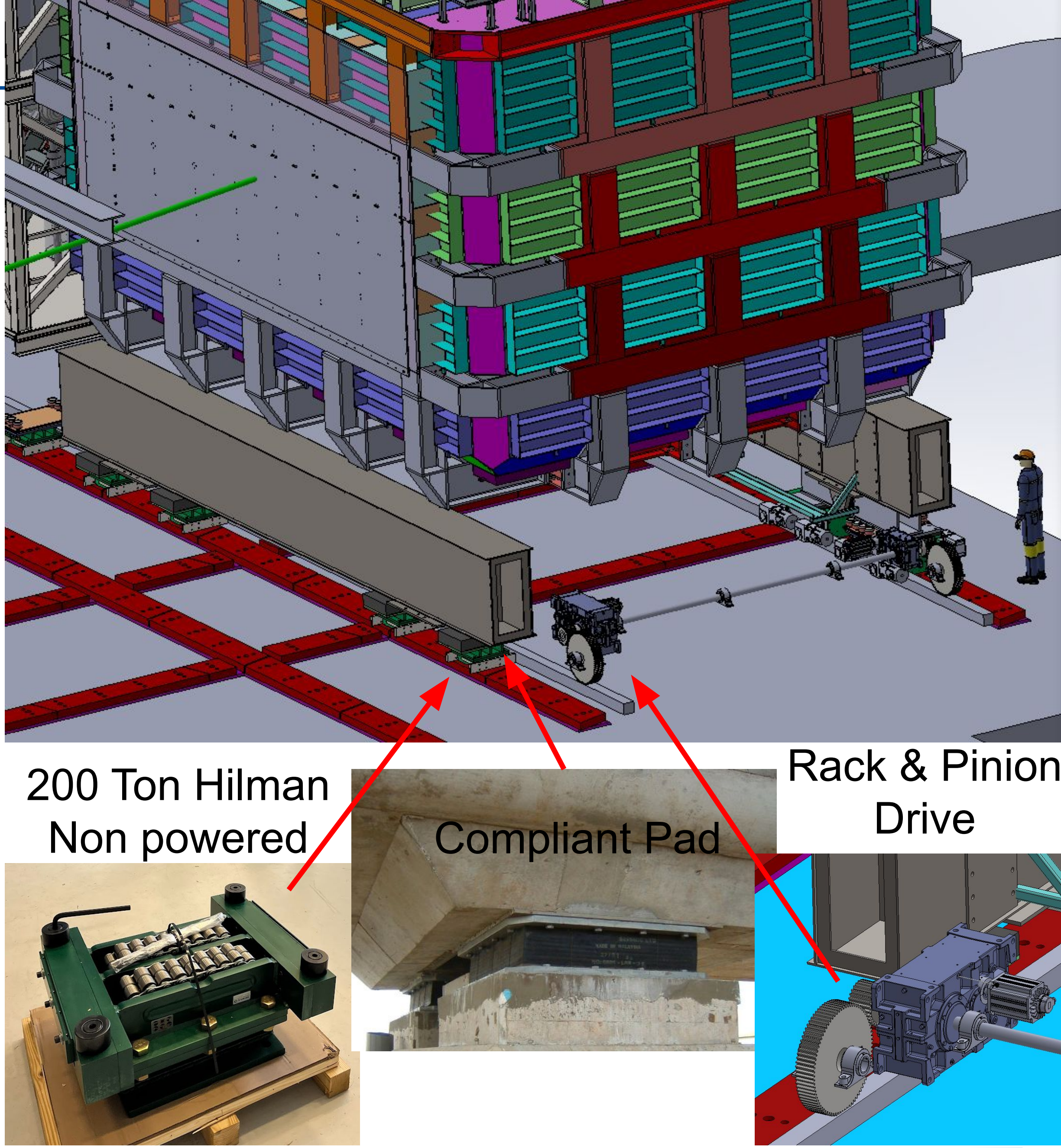
200 Ton Powered Hilmans

Bogie



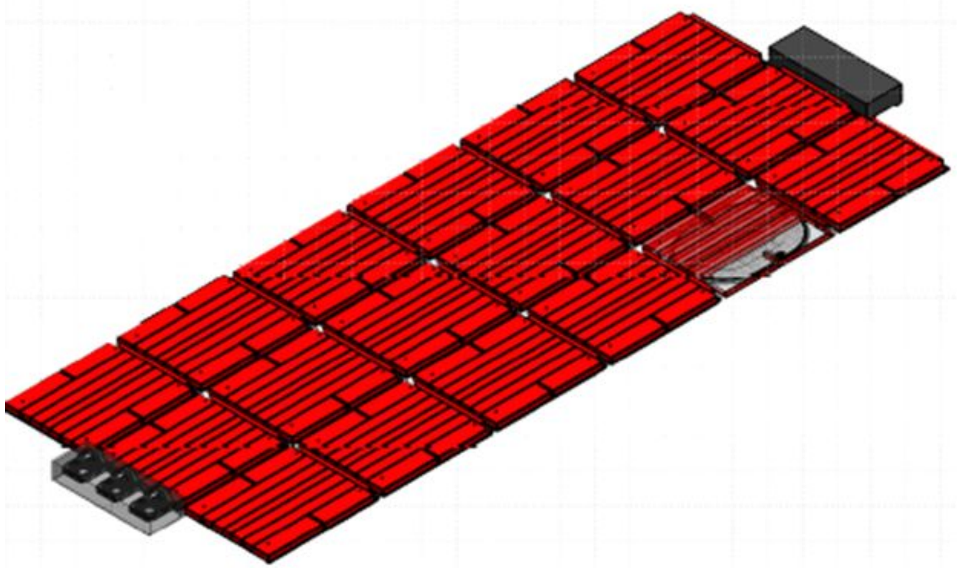
Alternative 2: Rack and Pinion

- The powered Hilman rollers must remain adequately loaded to provide traction force without slipping
- A rack and pinion system allows the detectors to be moved without requiring a minimum load on each roller
  - With or without powered rollers, the maximum capacity of the roller cannot be exceeded
- The rack and pinion system significantly increases the complexity of the system
  - Unlike the powered roller system, which Hilman delivers as a complete solution, only rack and pinion parts are available, and we would have to engineer the whole system
  - The pinion must remain engaged with the rack to some precision, which introduces a new, vertical tolerances
- If compliant pads can provide the minimum load required to maintain traction with powered rollers, this is a much simpler solution



Alternative 3: Air Pads

- Detectors can be lifted on air pads and then slid along the cavern floor
  - Requires a custom guidance system
    - steering, start/stop location precision, etc.
  - Requires a leveling system to ensure uniform elevation change during inflation (avoid sloshing)
  - Bottom surface likely requires lubrication
  - Extra floor space and heat load dissipation required for the compressor system
- Spoke with Jim Grudzinski, ATLAS engineer
  - Lubrication produces an oil mist in the cavern
  - Powered Hilmans weren't available when ATLAS was built
    - If they were available, ATLAS likely would have used them
    - He agreed powered Hilmans were a better choice for DUNE



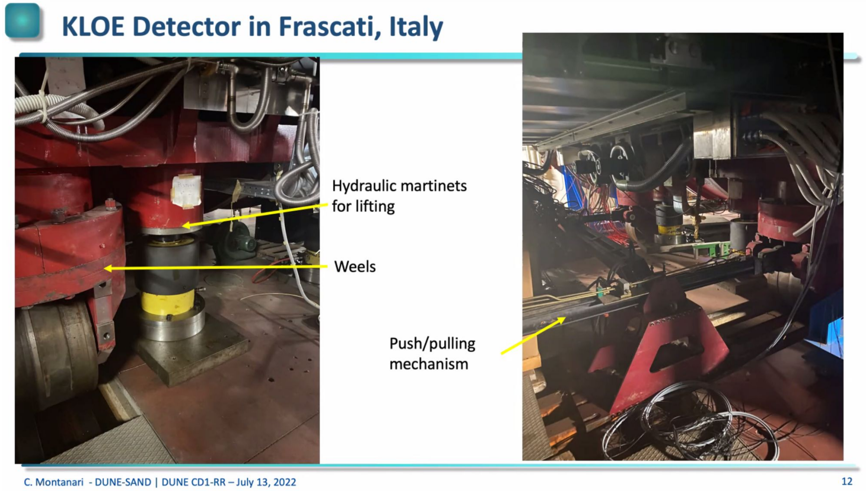
Alternatives 4,5,6,7,8,9

4. Cable push pull -

Double winch needed to pull on both sides or
Single drum winch mounted on the frame
20-50 Tons pushing pulling force will need multiple cables and pulleys
Possibility for the cables to become tangled, therefore less reliable.
High stored energy in cable increase personnel and equipment damage risk

5. Hydraulic Push pull system-

Inch worming.
Not automated
Movement limited to stroke of cylinder and the system needs to be repositioned.
Jerky movement.
Hard to do on a weekly basis.



Alternatives 4,5,6,7,8,9

6. Crane rail drive -

34 Wheels @30 tons per wheel for 1000 tons
50 Wheels @20 tons per wheel

Multiple Bogies needed for load distribution

Space constraints

3000 Ton Ship crane, 104 wheels

7. SPMT - Self Propelled Modular Transporter

64 wheels @ 1000 tons as per example
Large wheels needed
Space constraints

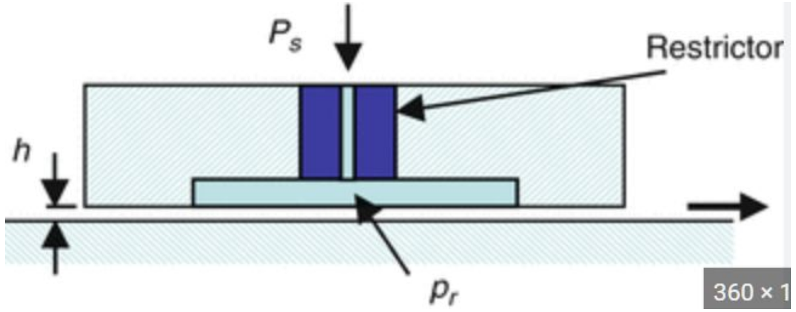
1000 ton Wheeled transporter

Alternatives 4,5,6,7,8,9

8. Hydraulic load leveling -

More complex vs rubber pads.
Need maintenance for hydraulic system.
Leveling control needed

9. Hydrostatic Bearing-



High tolerance continuous rails needed.
Need to maintain rail perfectly clean.
Need maintenance for the hydraulic system.
Scratches/ Imperfections/ rust on rail surface will make the system problematic
Separate tractive system needed.
Oil mist in air possible problem.

Summary

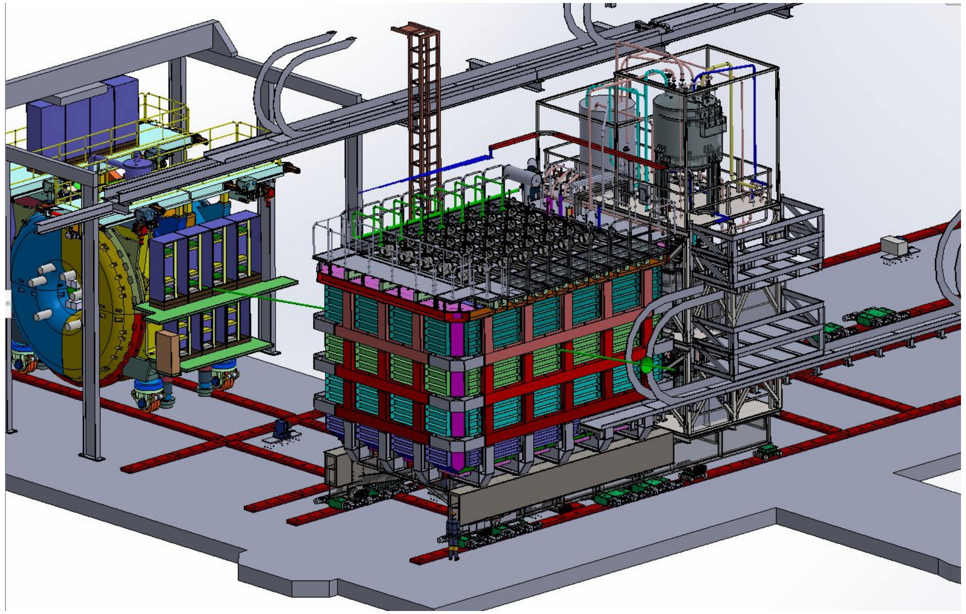
- The PRISM movement system will enable a fundamentally new way to use neutrino beams to constrain the most important systematic uncertainties for DUNE
  - This requires moving the detectors each week to sample a different portion of the beam
  - The movement system must be robust and simple to operate to achieve and sustain weekly movements throughout the life of the project
- The purpose of this assessment is to evaluate whether our chosen system will achieve these goals
  - Are the requirements sufficient to design a robust system?
  - Does the design meet the requirements, and do you foresee any technical technical, reliability, or operational challenges?
  - Does the baseline prototyping/testing plan adequately address the identified risks?
    - Should the additional tests (described in presentation 04) be performed to further mitigate risk?
    - Are there other important risks that should be considered?

Backup

2. PRISM Movement System

NDLAR and TMS detector movement system:

• Location:	Underground cavern, possible high humidity
• Load capacity:	1000 US Tons
• Travel length:	30 m
• Travel time:	at most 4 hours
• Number of cycles:	1 cycle/week
• Life:	25 years
• Movement Accuracy:	3 cm



High Level Description

The DUNE-PRISM rail system within the near detector cavern is shown. The 2 sets of rails for the TMS and ND-LAr run the length of the hall, and 2 sets of cross rails allow the SAND detector to cross between sets of primary rails and enter the SAND alcove.

Each of the 2 mobile detectors will have an independent roller + control system, which will move in unison during normal operating conditions