DUNE
Near Detector Overview

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for the DUNE ND Design Group

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How to Measure Oscillations

- Oscillation probabilities

$$P_{\nu_\mu \to \nu_e}(E_\nu) = \frac{\phi_{\nu_e}^{far}(E_\nu)}{\phi_{\nu_\mu}^{far,no-osc}(E_\nu)} = \frac{\phi_{\nu_e}^{far}(E_\nu)}{\phi_{\nu_\mu}^{near}(E_\nu) * F_{far/near}\ (E_\nu)}$$

Well known (1-2%)

- Number of events/energy spectrum

$$\frac{dN_\nu^{det}}{dE_\nu} = \phi_{\nu_\mu}^{det}(E_\nu) * \sigma_{\nu_\mu}^{Ar}\ (E_\nu)$$

- In reality

$$\frac{dN_\nu^{det}}{dE_{rec}} = \int \phi_\nu^{det}(E_\nu) * \sigma_\nu^{target}\ (E_\nu) * T_{\nu_\mu}^{det}(E_\nu, E_{rec})\ dE_\nu$$

- Folding of detector effects
  - Prevents (easy) cancellations of many systematic effects
  - Needs unfolding

Are there cancellations?

- Oscillation signal

Small theo. uncertainty or measurement

$$\frac{dN^{far}_{\nu_e}}{dE_\nu} \Bigg/ \frac{dN^{near}_{\nu_\mu}}{dE_\nu} = P_{\nu_\mu \to \nu_e}(E_\nu) * \frac{\sigma^{Ar}_{\nu_e}(E_\nu)}{\sigma^{Ar}_{\nu_\mu}(E_\nu)} * F_{far/near}(E_\nu)$$

1-2% uncertainty

- Near muon/electron ratio

$$\frac{dN^{near}_{\nu_e}}{dE_\nu} \Bigg/ \frac{dN^{near}_{\nu_\mu}}{dE_\nu} = \frac{\sigma^{Ar}_{\nu_e}(E_\nu)}{\sigma^{Ar}_{\nu_\mu}(E_\nu)} * \frac{\phi^{near}_{\nu_e}(E_\nu)}{\phi^{near}_{\nu_\mu}(E_\nu)}$$

Not so small uncertainty

- Need to know
  - Flux & cross section ratios
  - Far/near extrapolation

But in Reality

$$\frac{\frac{dN_{\nu_e}^{far}}{dE_{rec}}}{\frac{dN_{\nu_\mu}^{near}}{dE_{rec}}} = \frac{\int P_{\nu_\mu \to \nu_e}(E_\nu) * \phi_{\nu_\mu}^{near}(E_\nu) * F_{far/near}(E_\nu) * \sigma_{\nu_e}^{Ar}(E_\nu) * T_{\nu_e}^{far}(E_\nu, E_{rec})\ dE_\nu}{\int \phi_{\nu_\mu}^{near}(E_\nu) * \sigma_{\nu_\mu}^{Ar}(E_\nu) * T_{\nu_\mu}^{near}(E_\nu, E_{rec})\ dE_\nu}$$

- No cancellations
  - Unless you unfold
- Need to understand especially
  - Detector effects in near and far detector
  - Relation of visible to neutrino energy
  - Cross section ratios
  - Near to far flux extrapolation
- Flux normalisation cancels
  - Shape is more important

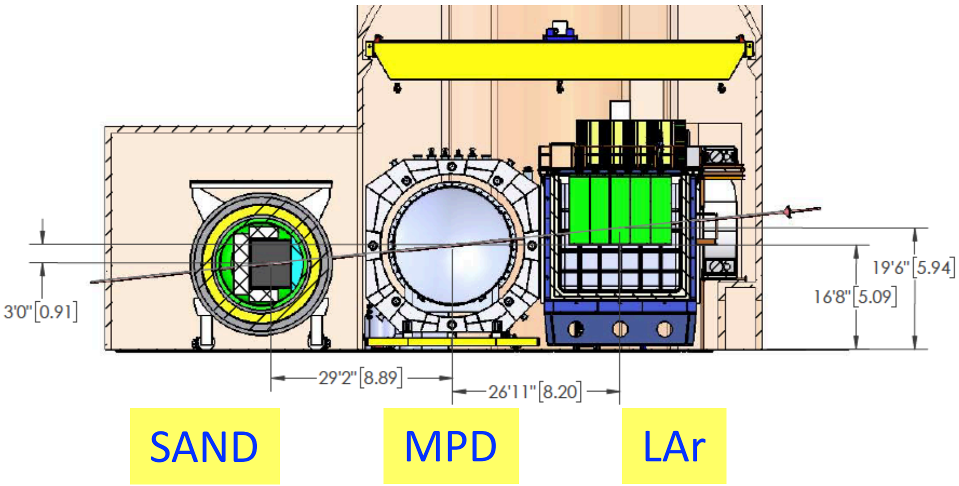
Overarching ND Requirements

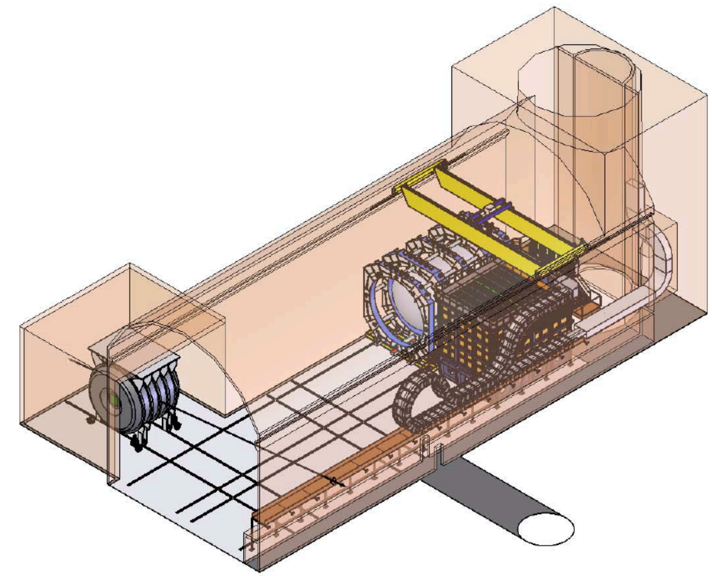
O0: Predict the neutrino spectrum at the FD: The Near Detector (ND) must measure neutrino events as a function of flavor and neutrino energy. This allows for neutrino cross-section measurements to be made and constrains the beam model and the extrapolation of neutrino energy event spectra from the ND to the FD.

O0.1	**Measure interactions on argon**	Measure neutrino interactions on argon, determine the neutrino flavor, and measure the full kinematic range of the interactions that will be seen at the FD.
O0.2	**Measure the neutrino energy**	Reconstruct the neutrino energy in CC events and control for any biases in energy scale or resolution.
O0.3	**Constrain the xsec model**	Measure neutrino cross-sections in order to constrain the cross section model used in the oscillation analysis.
O0.4	**Measure neutrino flux**	Measure neutrino fluxes as a function of flavor and neutrino energy.
O0.5	**Obtain data with different neutrino fluxes**	Measure neutrino interactions in different beam fluxes in order to disentangle flux and cross sections and verify the beam model. **(PRISM)**
O0.6	**Monitor the neutrino beam**	Monitor the neutrino beam energy spectrum with sufficient statistics to be sensitive to intentional or accidental changes in the beam on short timescales.

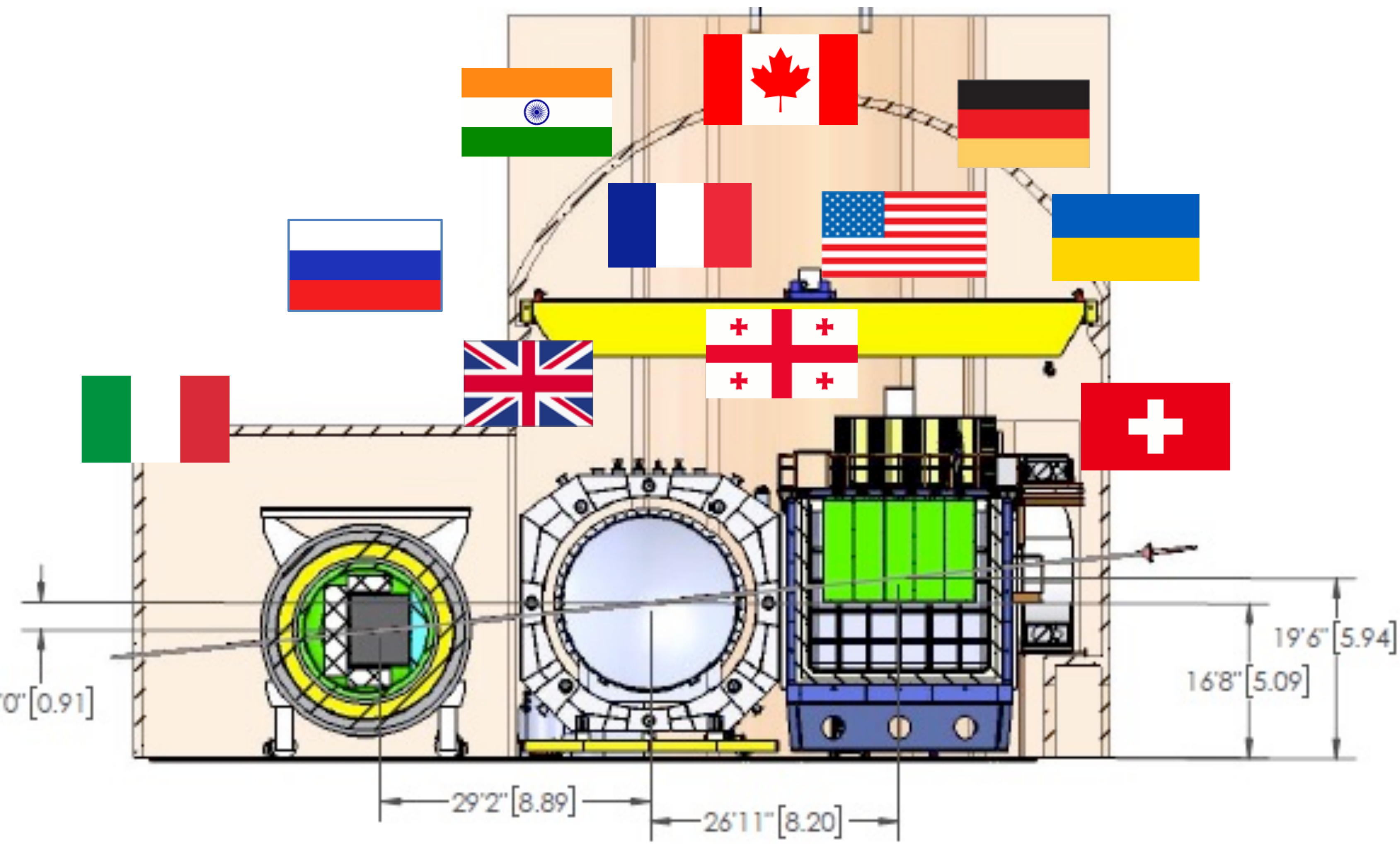
Near Detector Complex

- Four main components, working together:
  1. Liquid argon detector (ArgonCube)
  2. Downstream tracker with gaseous argon target (MPD)
  3. LAr and GAr systems can move off-axis (PRISM concept)
  4. **S**ystem for on-**A**xis **N**eutrino **D**etection (SAND)
- High statistics constrains
  - Cross section & neutrino flux





International Involvement



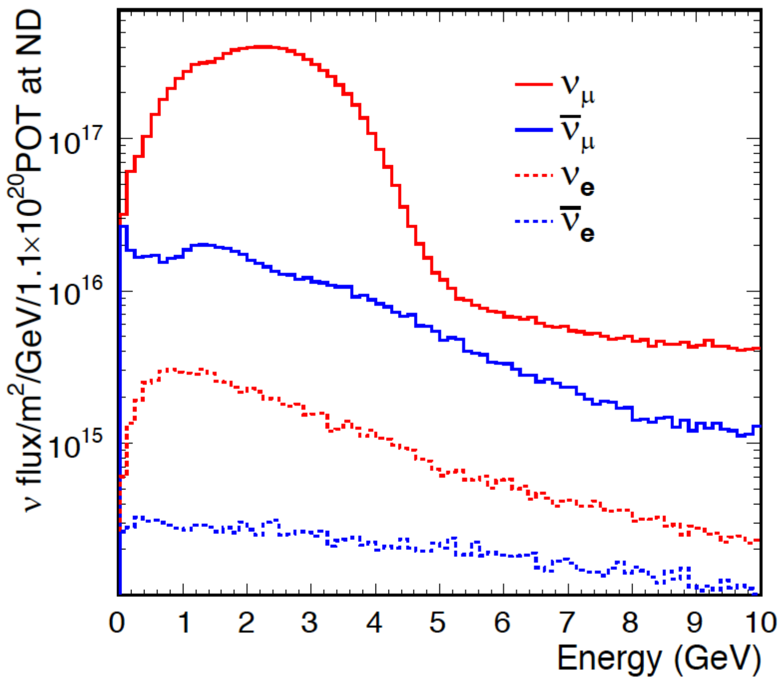
Detector Functionality

Multi-pronged approach with complementary approach leading to tremendous robustness:

- ν interactions on Ar
  - LAr provides ν-Ar interaction as seen by FD
  - MPD provides ν-Ar interactions with sign selection, very low thresholds, and minimal secondary interactions
- Integration
  - MPD is necessary to complete reconstruction of events in LAr detector
    - μ spectrometer
  - ECAL necessary to complete reconstruction of interactions in the HPgTPC (like collider detector)
  - Muon system to help with muon/pion separation
- Beyond interactions on Ar: Extend capability with SAND
  - provides detailed fixed, on-axis beam monitoring
  - provides look at ν-CH interactions with novel neutron detection capabilities

Flux & Event Rates @ ND570

Optimized CPV tune
FHC On-axis
1.25 MW



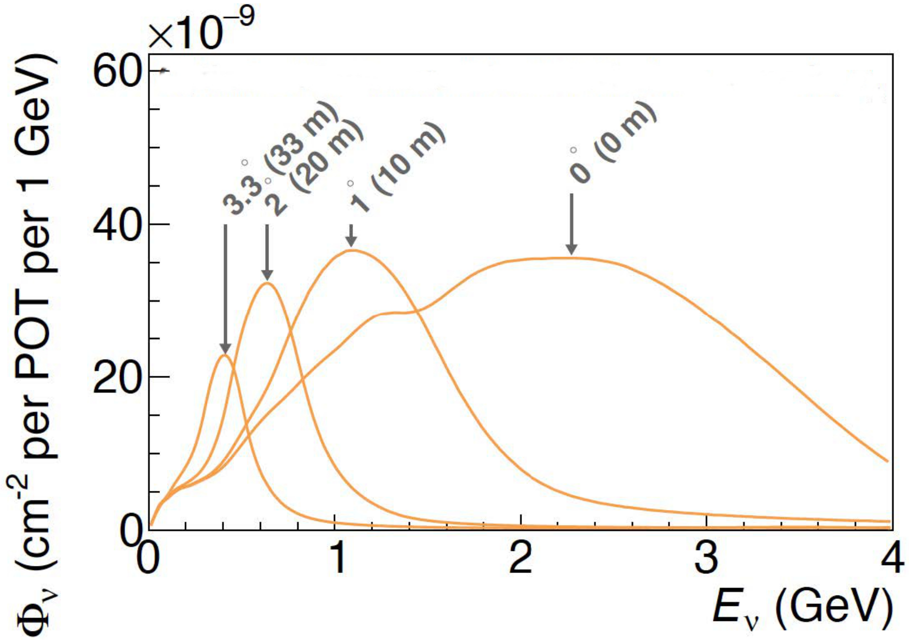
Events/year in Fiducial volume

Detector	Target (Fid. mass t)	# ν_μ CC ($X10^6$)
LAr	Ar (50)	80
HPgTPC	Ar (1)	1.5
SAND	CH (8)	12

Taking Data Off-axis

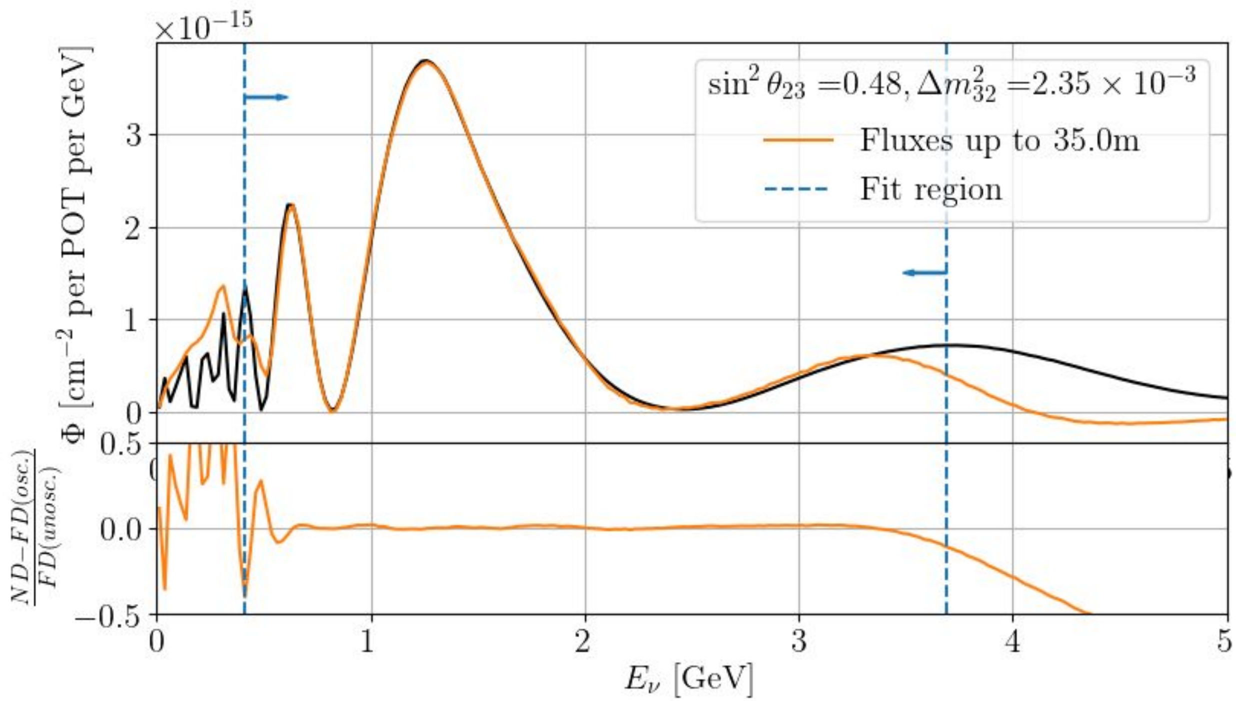
- The DUNE near detector complex will allow for off-axis running in order to accommodate the PRISM concept
  - Precision Reaction Independent Spectrum Measurement
- Flux varies as a function of detector transverse position

  - Pseudo-monochromatic beams can be formed by taking linear combinations of beam data at different off-axis positions
  - These can help in understanding of relationship between E_ν and E_{reco} and thus help deconvolve the flux and cross section uncertainties
  - Can predict oscillated neutrino event spectra at FD with reduced model dependence



PRISM

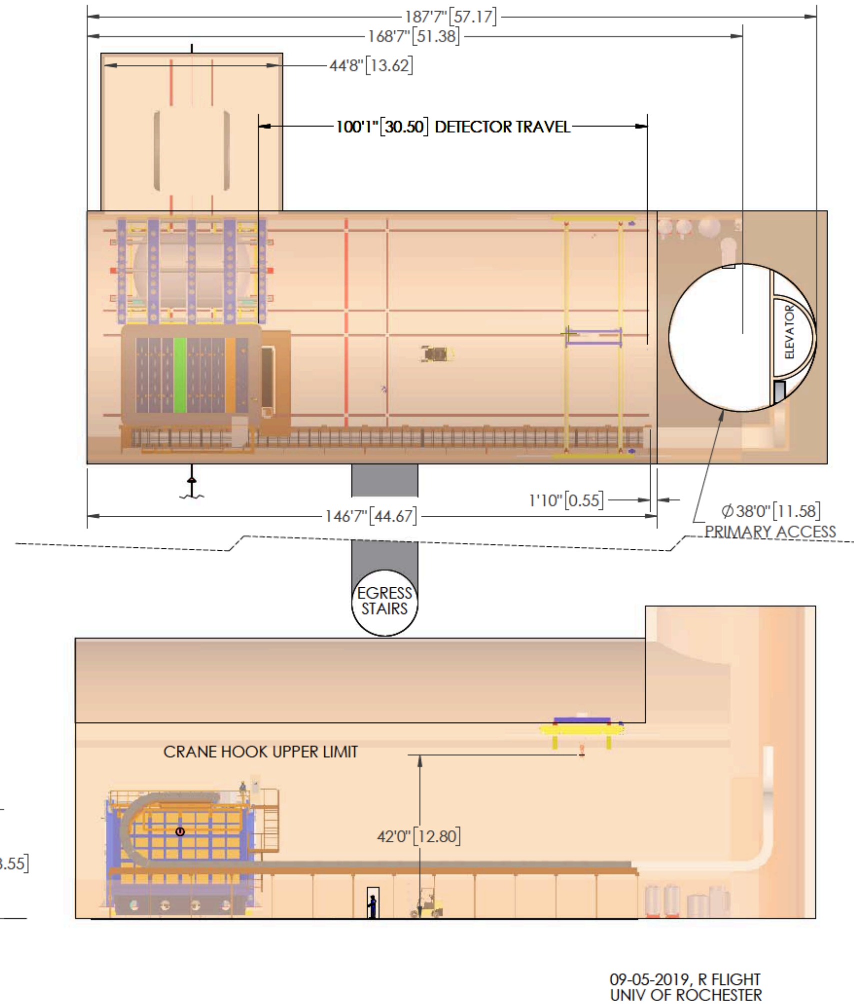
- Predict oscillated neutrino event spectra at FD with reduced model dependence
  - Form “oscillated” flux at near detector with linear combinations of off-axis data
  - Extrapolate to Far detector
  - Interaction model independent



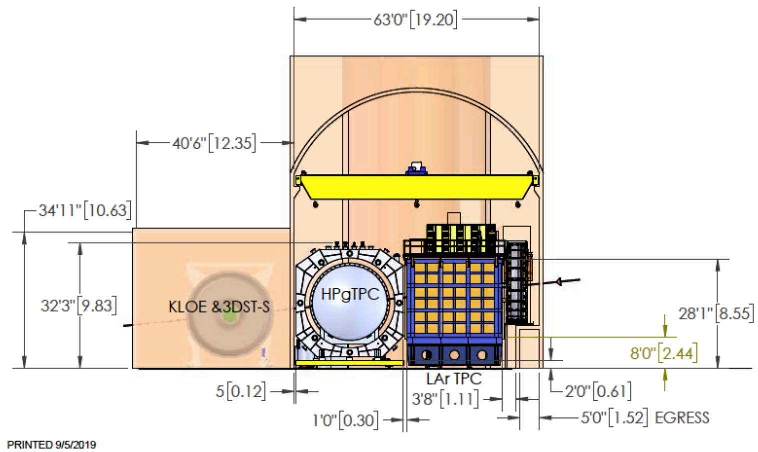
Near Detector Hall

- Design is progressing
- No show stoppers identified by engineering company
- Value engineering (cost savings) under discussion

~31 m (3.3°) travel

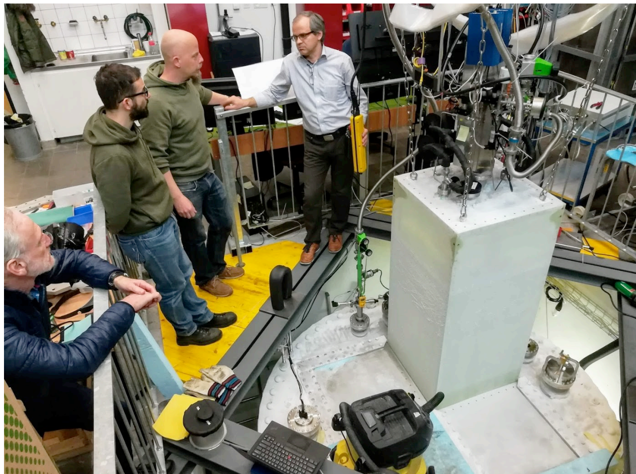


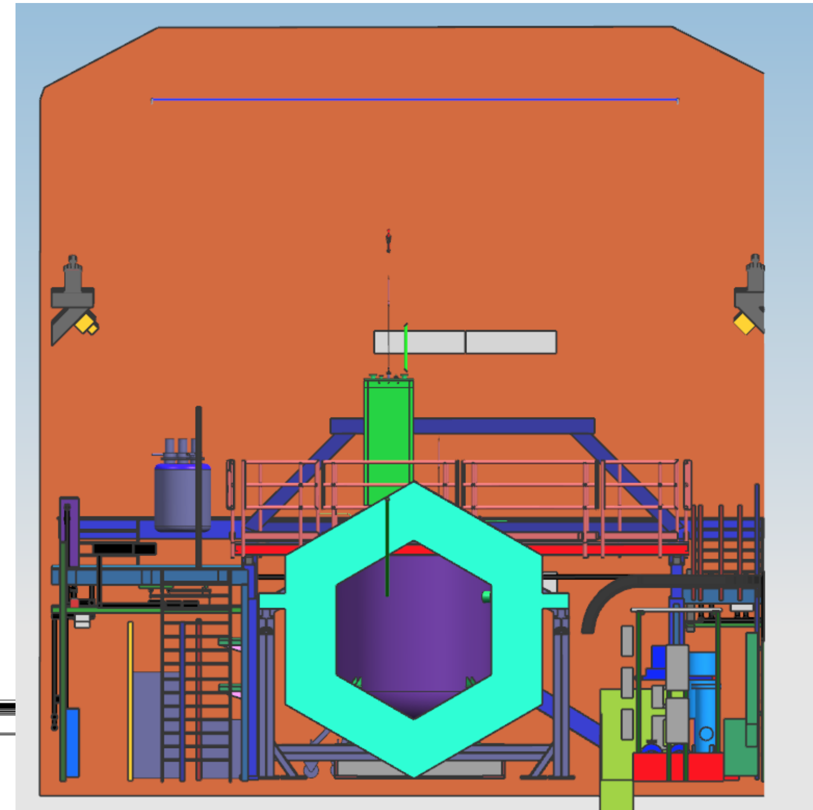
~19 m

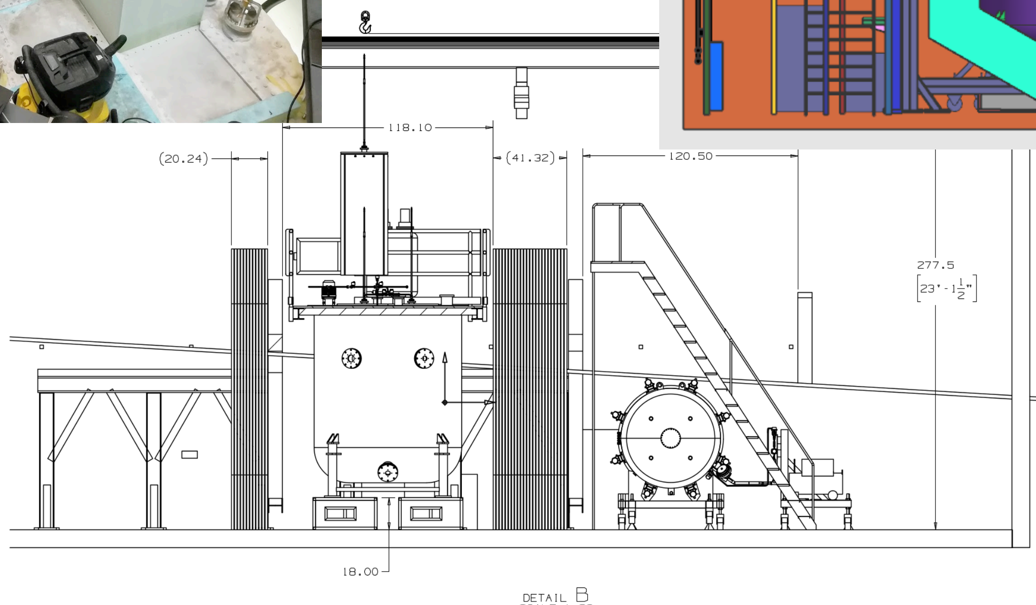


ProtoDUNE-ND

- ND prototypes in neutrino beam







Risk Mitigation Strategy

- Preparing for CD2/3B
- Most of ND is not in US DOE project scope
- What happens if international contributions fall behind?
- Define a minimal configuration to get started
  - LArTPC & cheap muon spectrometer
  - This configuration is included as risk in US DUNE project
- Goal of this configuration
  - pass CD2/3b, but never build it
- Ongoing work
  - Evaluate minimal performance requirements (just starting)
  - Cost minimal solution and add cost as US DOE project risk
- Possible Options (?)
  - Reuse MINOS planes
  - BabyMIND like detector (ala T2K)
  - SC Coils & planes of (scintillator) tracker

DESY WS

- Productive WS with large participation (~60)
- Wide engagement
  - ECAL, Magnet, TPC

End Note

- A lot of progress has been made
  - Hall design
  - CDR
  - technical details
  - Start forming consortia in preparation for interim design report
- This was a high level overview/introduction
- Details will follow in next presentations
  - ArgonCube/ProtoDUNE-ND
  - MPD
  - SAND
  - CDR/TDR Status