DUNE Near Detectors

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Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro
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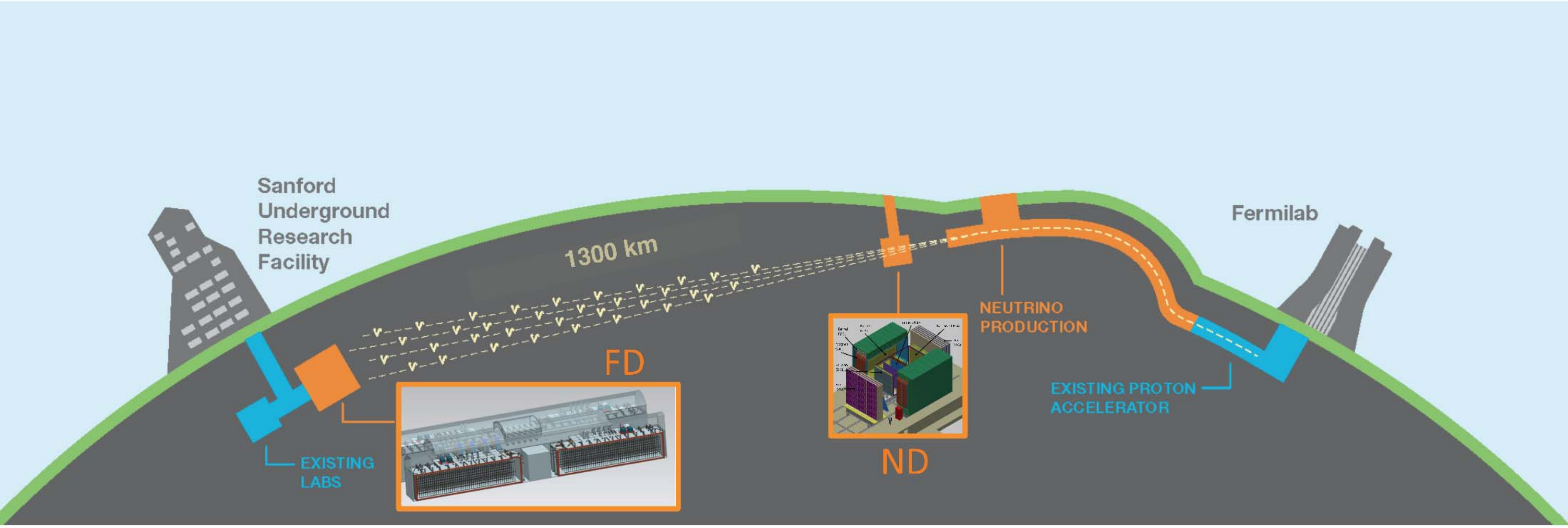
Compiled from the LBNF/DUNE DOE CD-1 Refresh Review (July 14, 2015)
https://web.fnal.gov/project/LBNF/ReviewsAndAssessments/LBNF_DUNE%20DOE%20CD-1%20Refresh%20Review/SitePages/Agenda.aspx

LBL Oscillation Strategy

Measure neutrino spectra at 1300 km in a wide-band beam

- Determine MH and θ_{23} octant, probe CPV, test 3-flavor paradigm and search for ν NSI in a <u>single experiment</u>



- **Near Detector at Fermilab:** measurements of unoscillated beam
- **Far Detector at SURF:** measure oscillated neutrino spectra

DUNE Near Detector Strategy

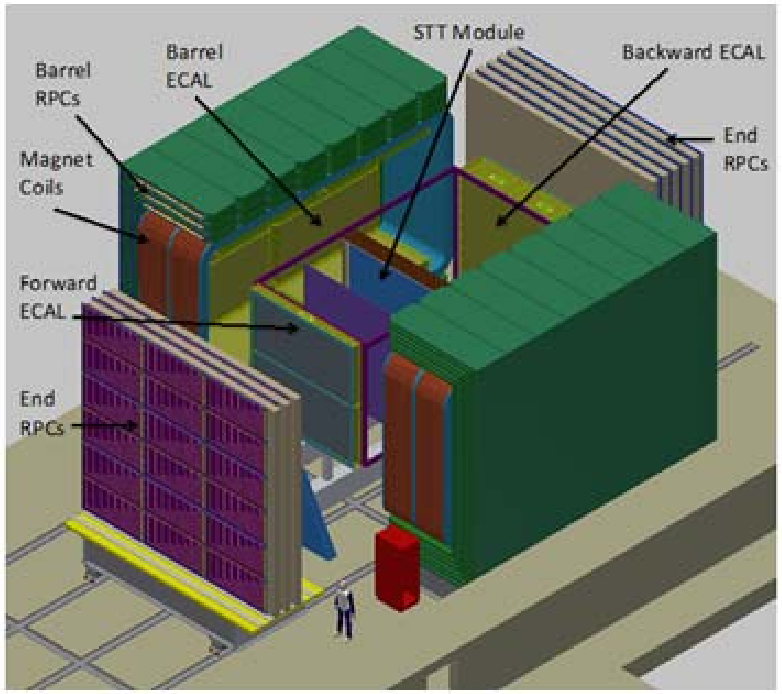
- **Top-level Requirements**
  - Ability to constrain systematic uncertainties for the DUNE oscillation analysis
  - Drives the design and implies the capability to precisely measure exclusive neutrino interactions

  ⇨ Naturally results in a self-contained non-oscillation neutrino physics program
    - Exploiting the intense LBNF neutrino beam
- **International context**
  - The proposed contribution of Indian institutions to the design and construction of the DUNE near detector is a central part of the DUNE strategy for the construction of the experiment

Near Detector Reference Design

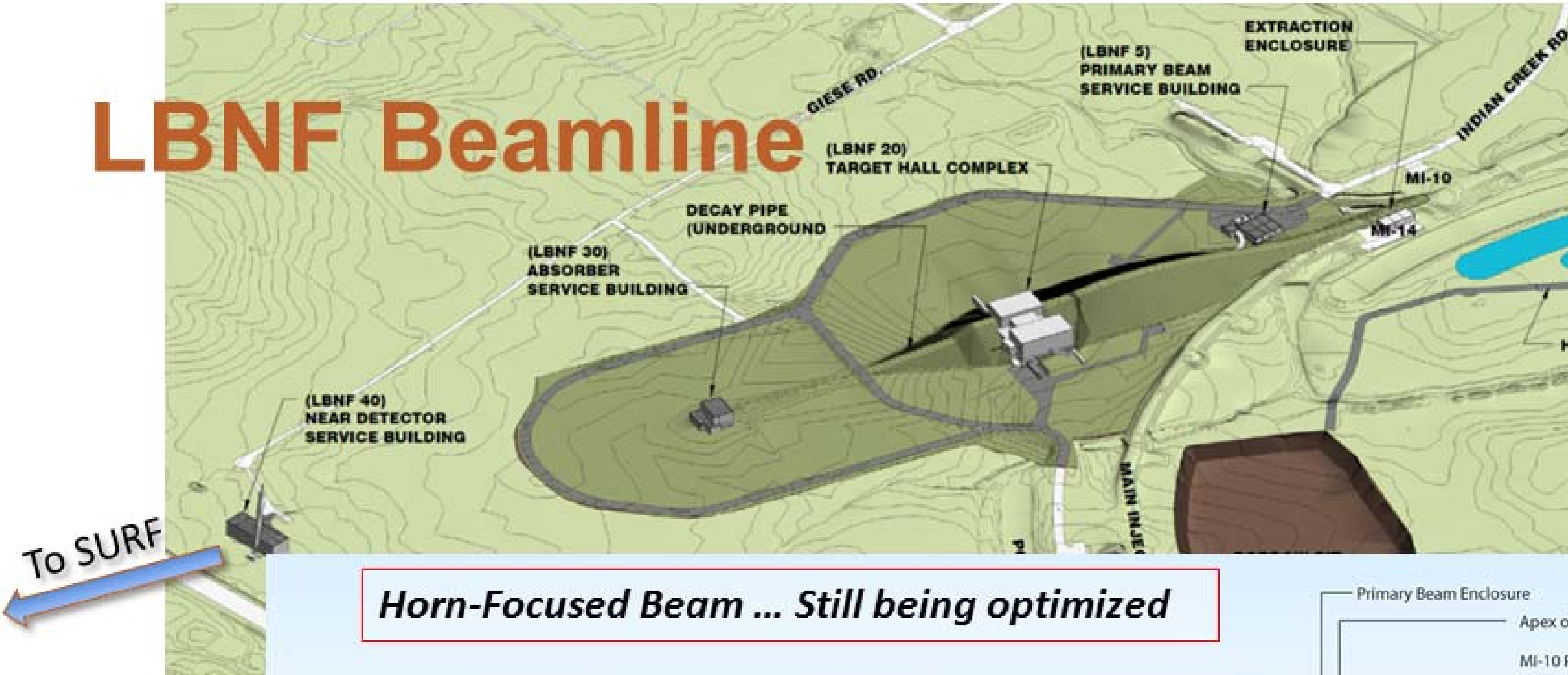
The NOMAD-inspired Fine-Grained Tracker (FGT)

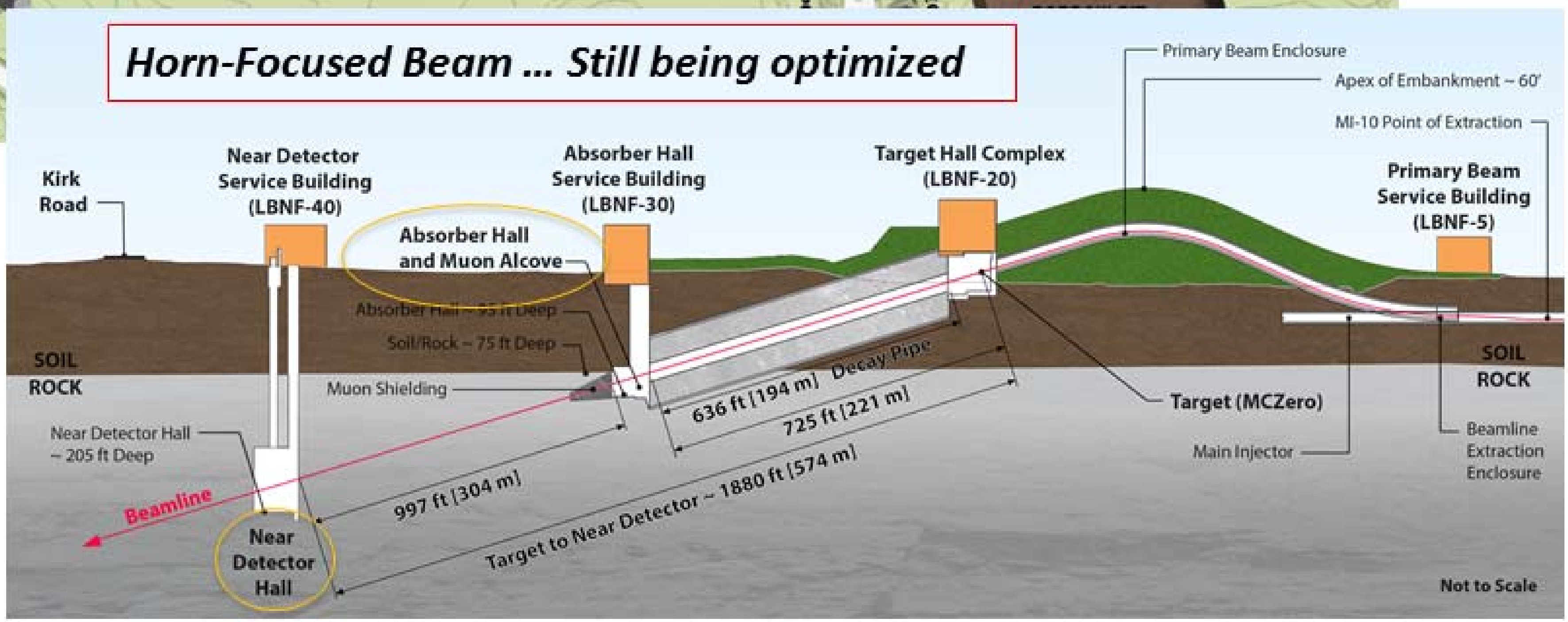
- **It consists of:**
  - Central straw-tube tracking system
  - Lead-scintillator sampling ECAL
  - Large-bore warm dipole magnet
  - RPC-based muon tracking systems



- **It provides:**
  - Constraints on cross sections and the neutrino flux
  - A rich self-contained non-oscillation neutrino physics program
- **DUNE has set up a ND task force**
  - End-to-end physics study of FGT measurements and LBL analysis
  - Quantifying the benefits of augmenting the ref. design with a LArTPC or high-pressure gaseous argon TPC

LBNF Beamline

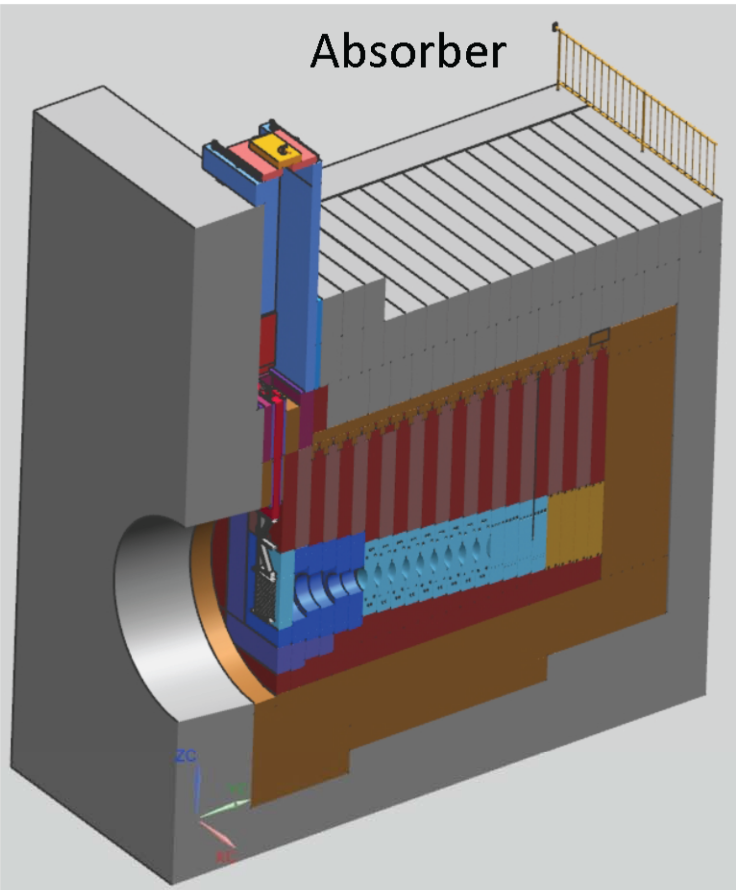


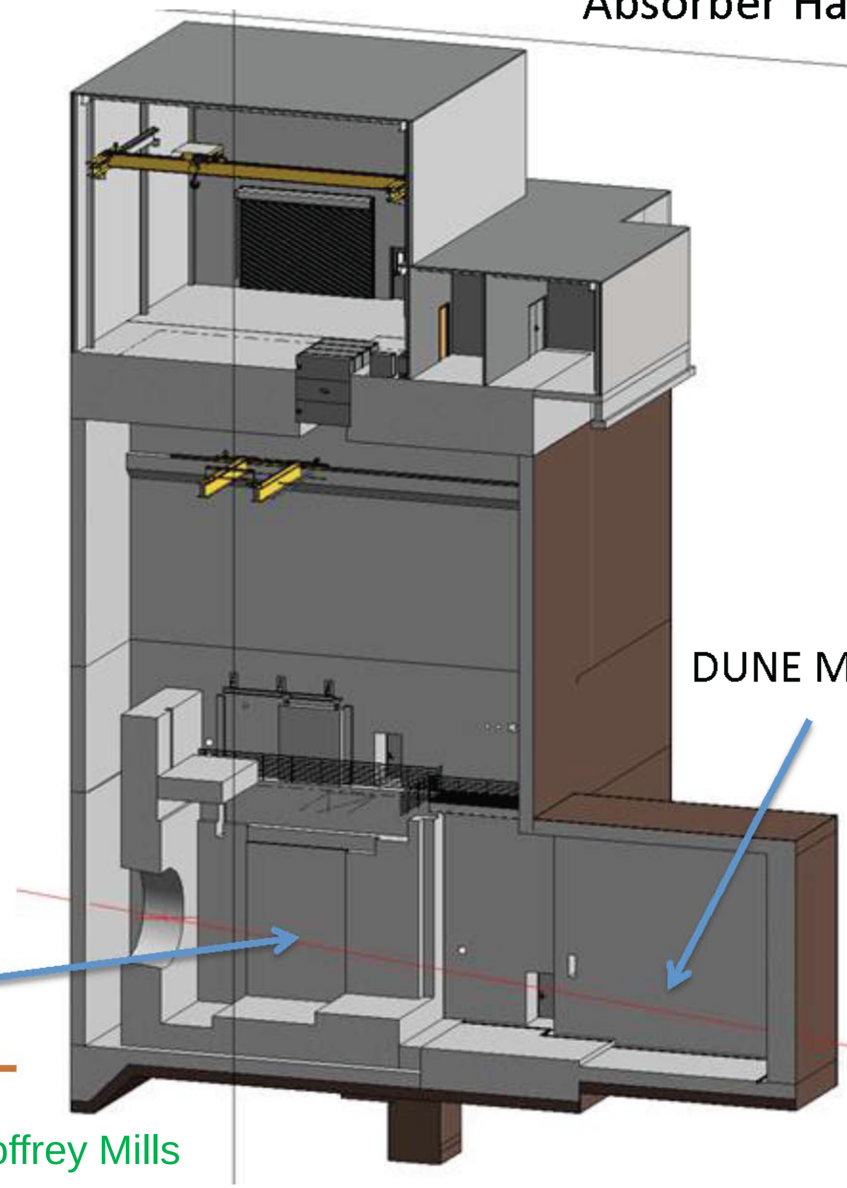


Details in talk in WG3, Friday at 15:00

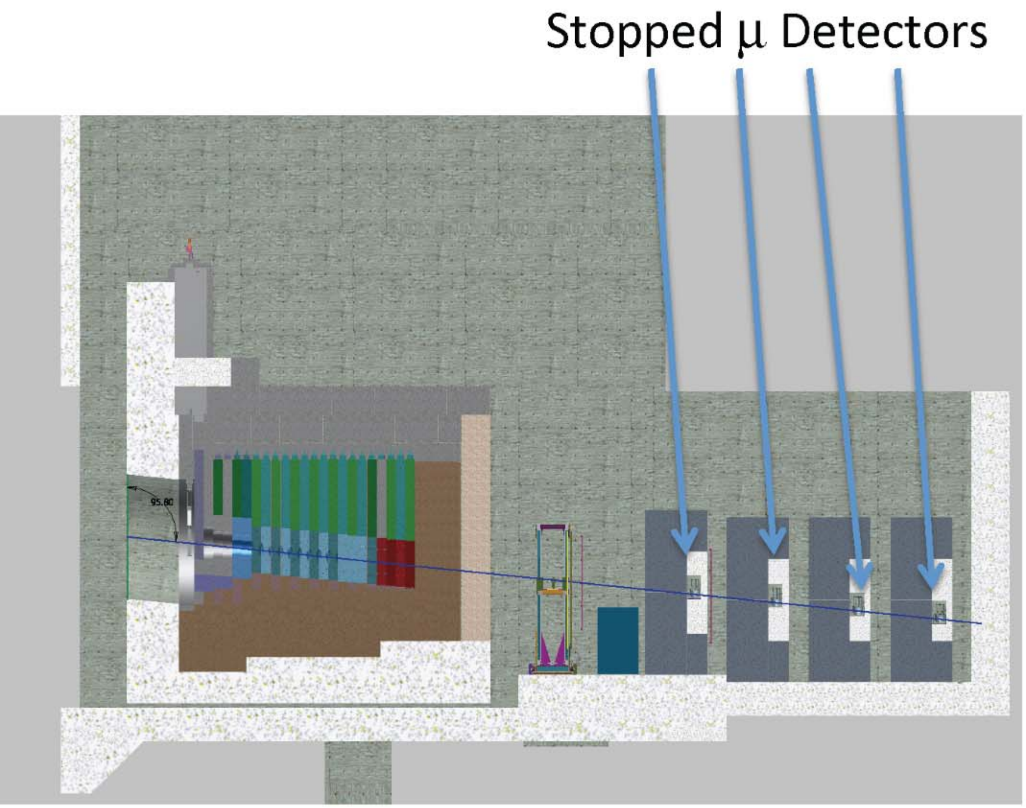
Beam Line Muon Detectors Will Be Placed Downstream of Absorber

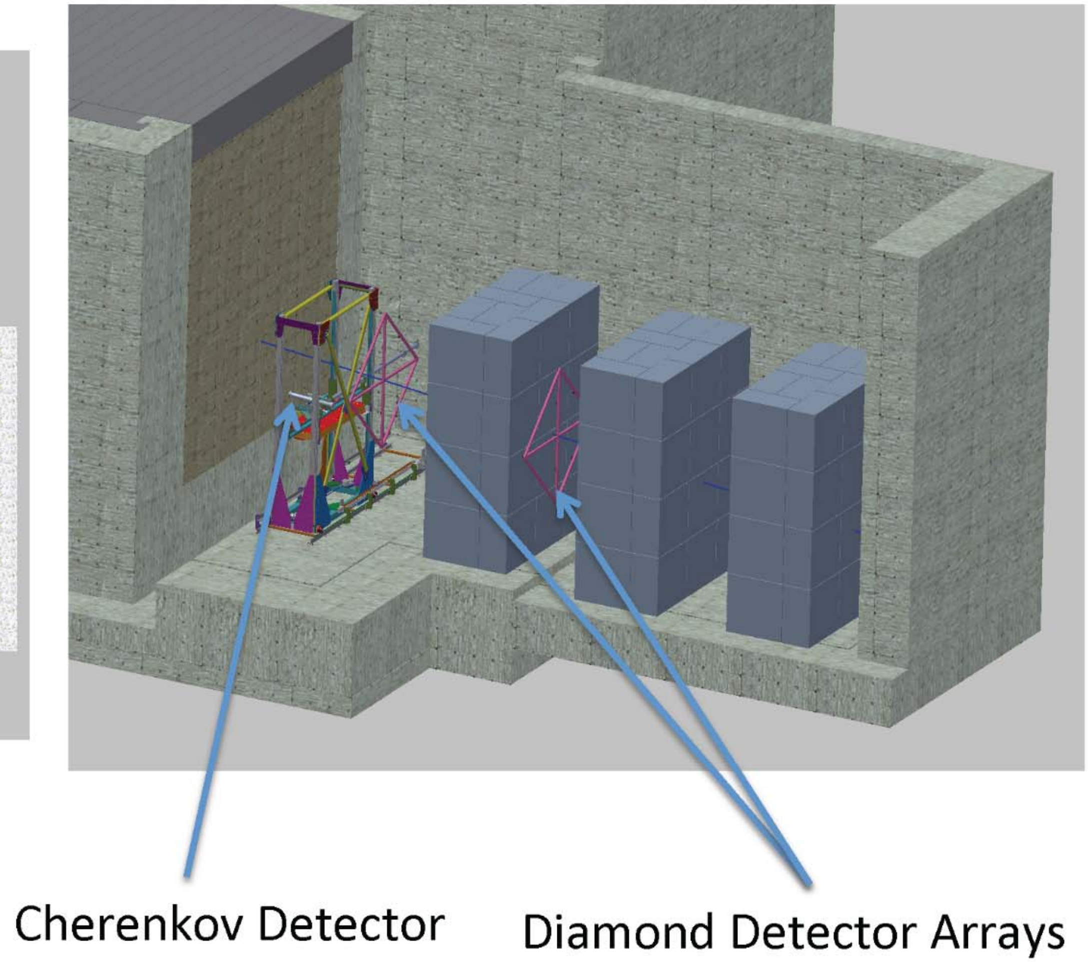
Aluminum absorber core provides window to low energy muons





Beamline Muon Detectors Layout



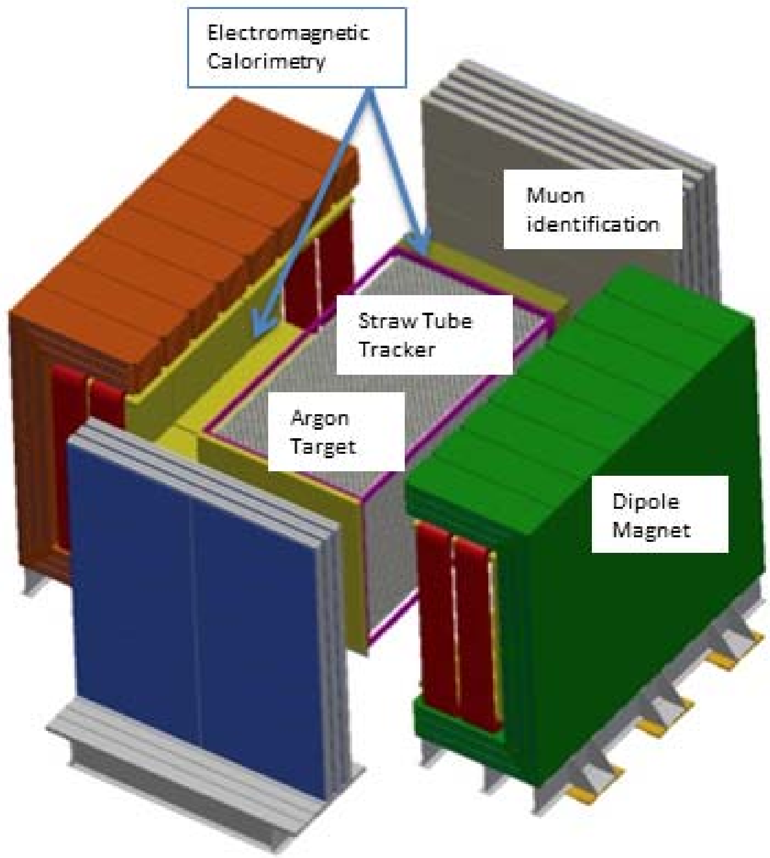


1-3 Cherenkov Detectors
10-20 Stopped μ Detectors
20-25 Diamond Detectors

DUNE Near Detector Scope

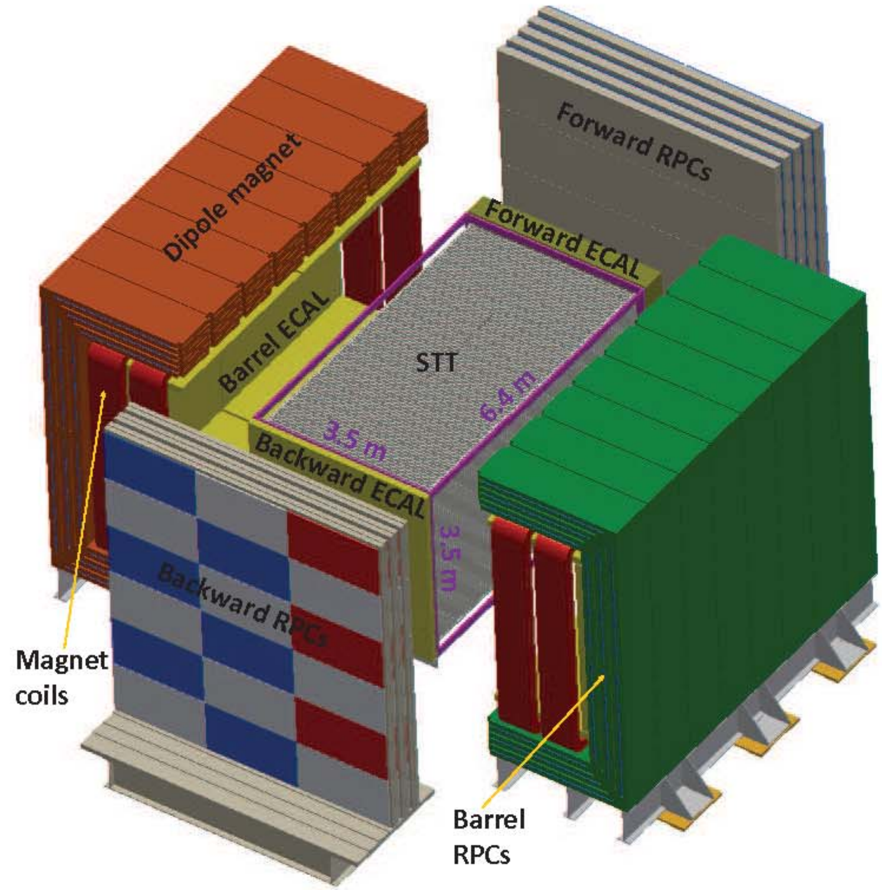
- Active detector: dipole magnet, targets, straw tube tracker, electromagnetic calorimetry, muon ID detectors, readout electronics, DAQ, installation, and integration

- Parameters
  - 3.5 m x 3.5 m x 7 m Straw Tube Tracker
  - 4π electromagnetic calorimetry and muon ID in dipole B field (0.4T)
  - Pressurized Argon Target



THE DUNE ND CONCEPT

- *Evolution from the NOMAD experiment*
- *High resolution spectrometer*
  $B = 0.4$ T
- *Low density "transparent" tracking*
  $\rho \sim 0.1 g/cm^3 \quad X_0 \sim 5m$
- *Combined particle ID & tracking for precise reconstruction of 4-momenta*
  - Transition Radiation $\Longrightarrow e^-/e^+$ ID, γ
  - $dE/dx \Longrightarrow$ Proton ID, $\pi^{+/-}$, $K^{+/-}$
- *Tunable thin target(s) spread over entire tracking volume* $\Longrightarrow$ *target mass* $\sim$ 7t
- 4π ECAL in dipole B field
- 4π μ-Detector (RPC) $\Longrightarrow \mu^+/\mu^-$



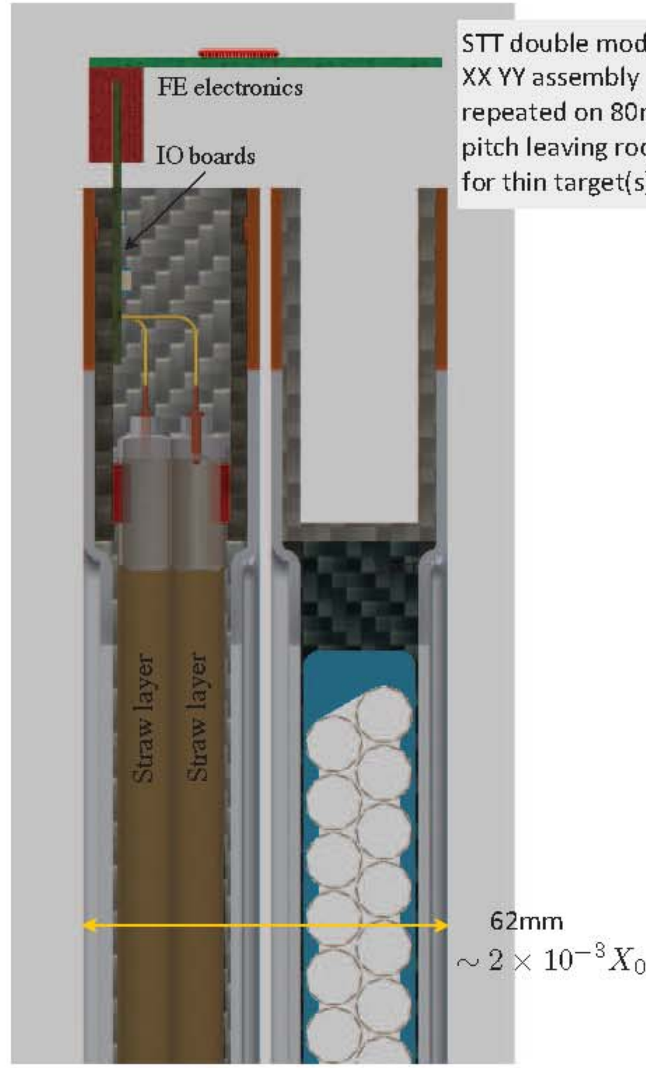
"ELECTRONIC BUBBLE CHAMBER" WITH $\mathcal{O}(10^8)$ EVENTS

THE STRAW TUBE TRACKER

- *Main parameters of the STT design:*
  - *Straw inner diameter* 9.530 ± 0.005 *mm;*
  - *Straw walls* $70 \pm 5\mu m$ *Kapton 160XC370/100HN* ($\rho = 1.42$, $X_0 = 28.6cm$, *each straw* $< 5 \times 10^{-4} X_0$);
  - *Wire W gold plated* $20\mu m$ *diameter;*
  - *Wire tension around 50g;*
  - *Operate with 70%/30% Xe/*CO_2 *gas mixture.*
  - *Straws are arranged in double layers of 336 straws glued together (epoxy glue) inserted in C-fiber composite frames;*
  - *Double module assembly (XX+YY) with FE electronics (each XX+YY tracking module* $\sim 2 \times 10^{-3} X_0$);
  - *Readout at both ends of straws (IO & FE boards on all sides of each XX+YY STT module);*
  - *160 modules arranged into 80 double modules over* ~ 6.4 *m (total 107,520 straws).*

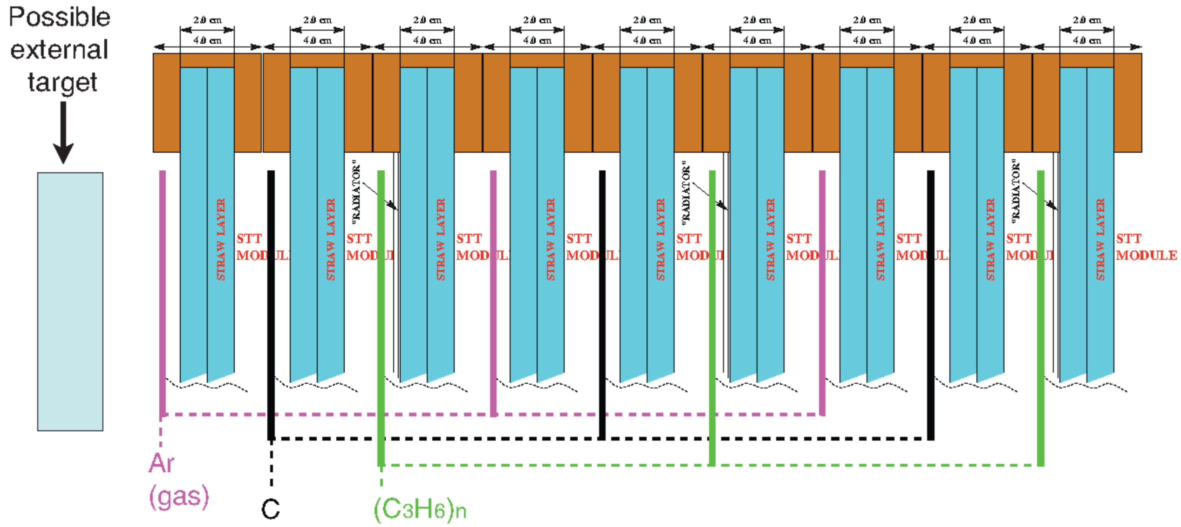
  $\Longrightarrow$ *Total tracking length* $\sim 0.3 X_0$

- *Add dedicated (anti)neutrino thin target(s)* to each STT double module keeping the average STT density ~ 0.1 g/cm^3 for required target mass.



STT double module XX YY assembly repeated on 80mm pitch leaving room for thin target(s)

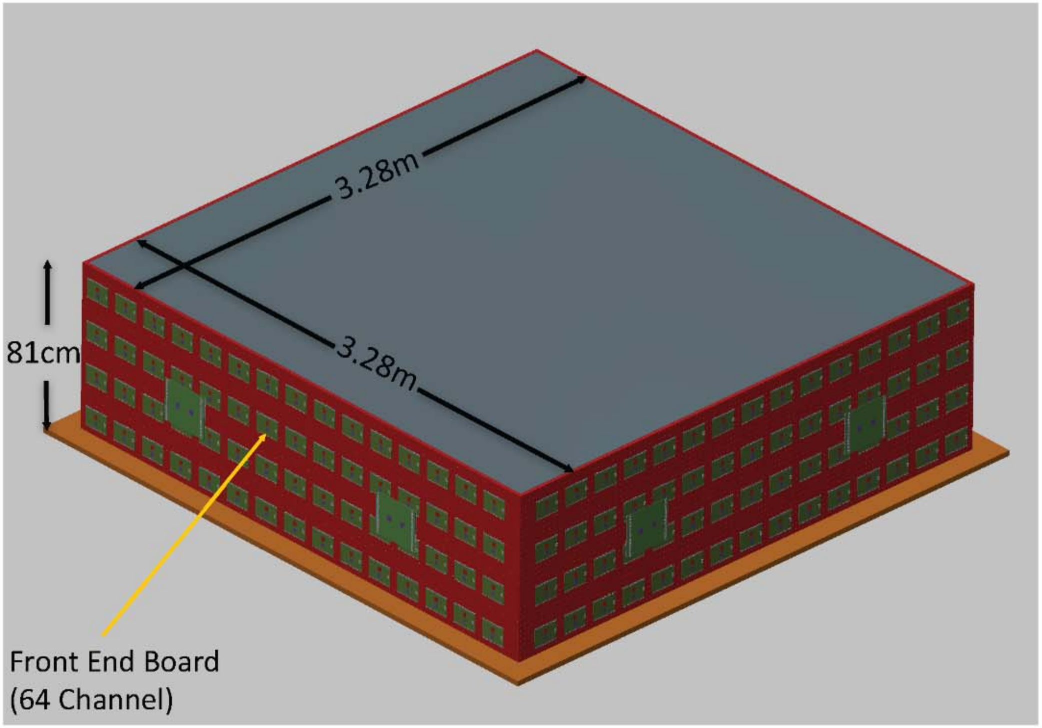
NUCLEAR TARGETS

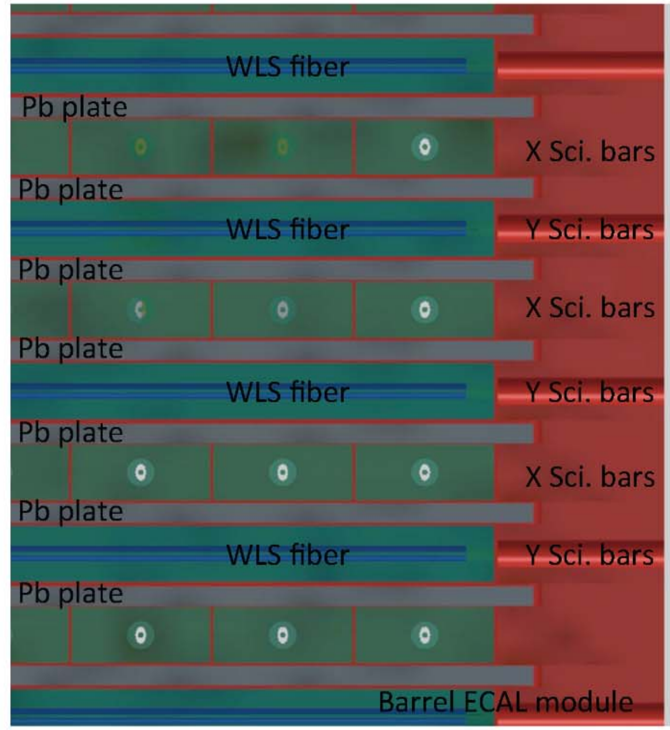


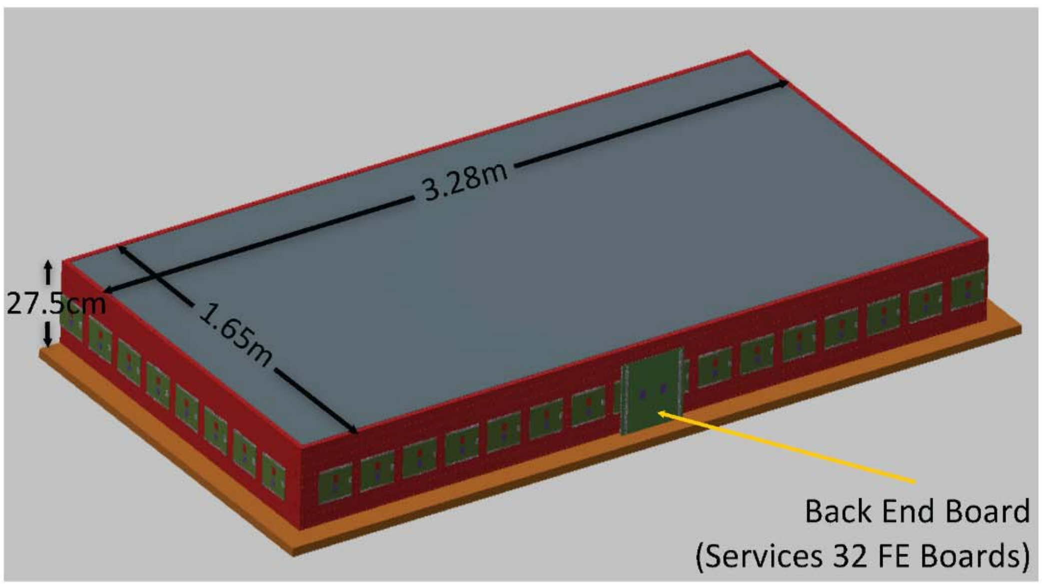
MAIN target $(C_3H_6)_n$ radiators: mass $\sim 5t$

- *Multiple nuclear targets in STT: $(C_3H_6)_n$ radiators, C, Ar gas, Ca, Fe, H_2O, D_2O, etc.*
  $\Longrightarrow$ *Separation from excellent vertex ($\sim 100 \mu m$) and angular (< 2 mrad) resolutions*
- *Subtraction of* C TARGET *(0.5 tons) from polypropylene* $(C_3H_6)_n$ RADIATORS
  provides $5.0(1.5) \times 10^6 \pm 13(6.6) \times 10^3 (sub.)$ $\nu(\bar{\nu})$ *CC interactions on free proton*
  $\Longrightarrow$ *Absolute $\bar{\nu}_\mu$ flux from QE*
  $\Longrightarrow$ *Model-independent measurement of nuclear effects and FSI from RATIOS A/H*
- *Pressurized* Ar GAS *target ($\sim$ 140 atm) inside SS/C tubes and solid* Ca TARGET
  (more compact & effective) provide detailed understanding of the FD $A = 40$ target
  $\Longrightarrow$ *Collect $\times 10$ unoscillated FD statistics on Ar target*, i.e., ~10^5 of the ~10^8 ND ν events
  $\Longrightarrow$ *Study of flavor dependence & isospin physics*

THE ELECTROMAGNETIC CALORIMETER







Forward ECAL
mass 21.7 tons

Barrel ECAL Module
(16 Barrel, 2 Backward ECAL)
mass 4.9 tons

THE MUON DETECTOR

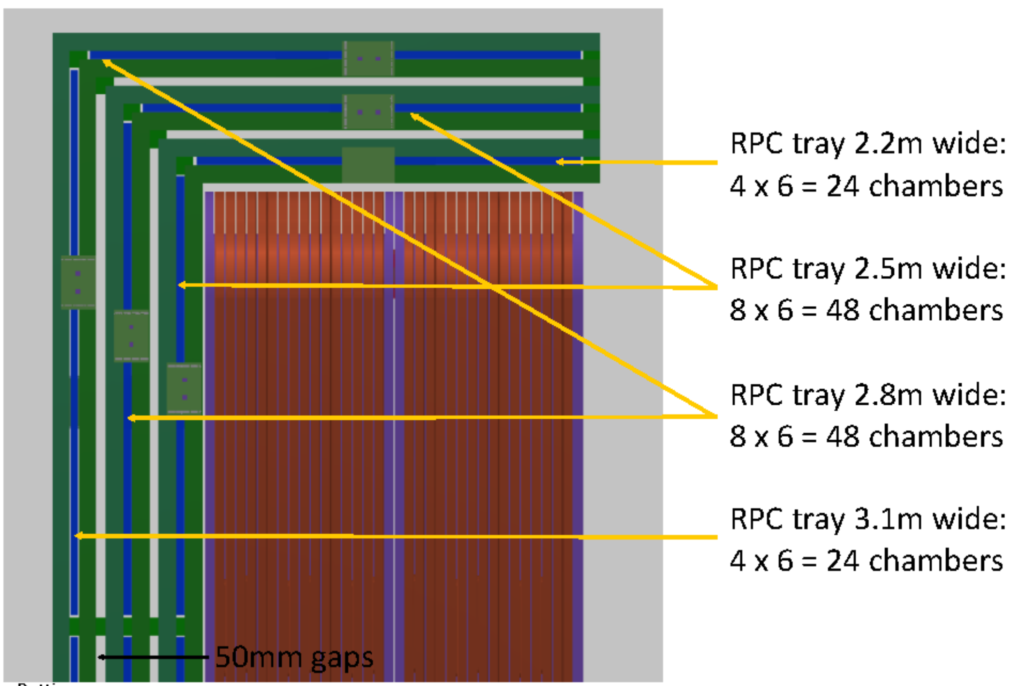
- Glo-Sci-51 *measure absolute and relative ν_μ and $\bar{\nu}_\mu$ spectra separately.*
  Glo-Sci-52 *measure NC and CC cross-sections separately vs. hadronic energy*

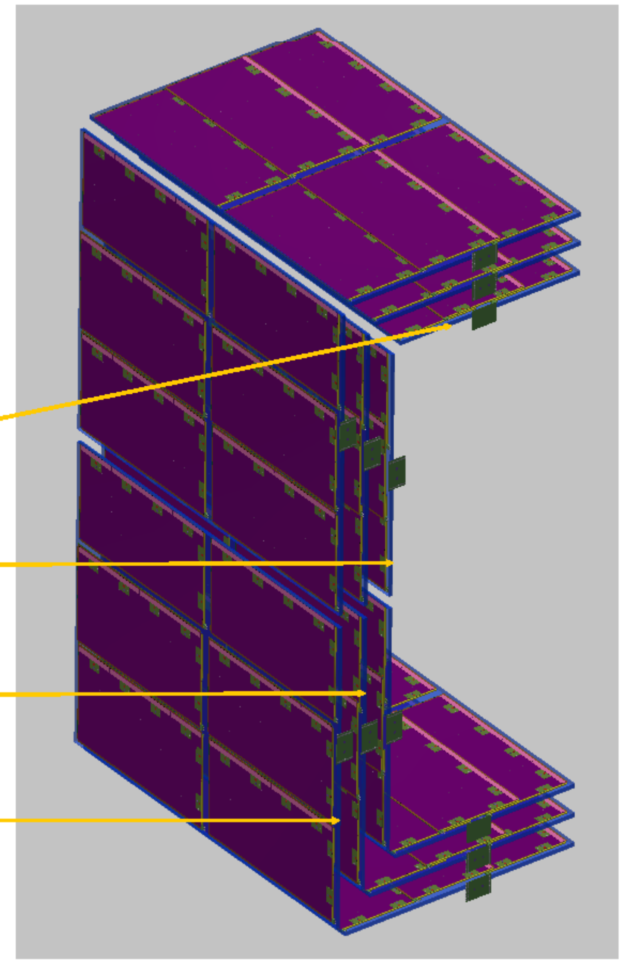
  $\Longrightarrow$ *identify muons exiting the tracking volume* NDC-L2-34,35

  $\Longrightarrow$ *4π muon detector with < 1 mm space resolution*

- *Bakelite RPC chambers 2m $\times$ 1m (432 in total) with 7.65 (7.5) mm X (Y) strips in avalanche or streamer mode*

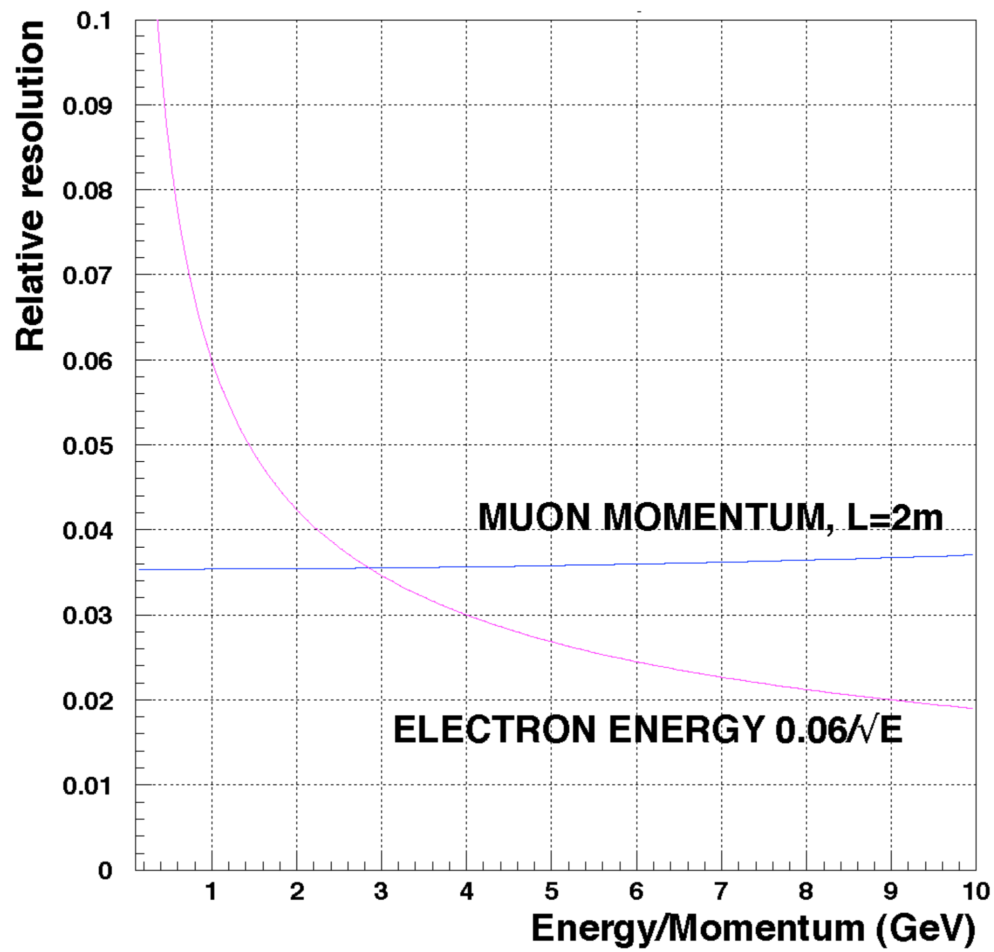
- *Instrument magnet yoke (3 planes), and downstream (5 planes) and upstream (3 planes) stations*





EXPECTED PERFORMANCE

- *Single hit resolution* $\simeq 200\mu m$
- *Time resolution* $\simeq 1ns$
- *CC-Events Vertex:* $\Delta(X, Y, Z) \simeq \mathcal{O}(100\mu m)$
- *Angular resolution:* ~ 2 *mrad*
- *Momentum res.* (ρ=0.1g/cm^3, B=0.4T)
  - *Multiple scattering term* 0.05 *for* $L = 1m$
  - *Measurement error term* 0.006 *for* $L = 1m$ *and* $p = 1$ *GeV/c* ($N = 50$)
- *Downstream-ECAL res.* $\simeq 6\%/\sqrt{E}$
- e^+/e^- *down to 80 MeV from curvature*
- *Protons down to* $\sim$ *200 MeV/c*
- π^0 *with at least 1 converted* γ ($\sim 50\%$)



$\Longrightarrow$ *Design resolutions match the global science and L2 requirements for ND*

Key ND Detector Performance Metrics

Performance Metric	FGT
Dipole magnetic field	0.4 T
Average target/tracker density	$\rho \sim 0.1$ g/cm^3
Target/tracker Volume	3.5m x 3.5m x 6.4m
Target/tracker Mass	8 t
Vertex Resolution	0.1 mm
Angular Resolution	2 mrad
E_e Resolution	5%
E_μ Resolution	5%
$\nu_\mu/\bar{\nu}_\mu$ ID	Yes
$\nu_e/\bar{\nu}_e$ ID	Yes
NCπ^0/CCe Rejection	0.1%
NCγ/CCe Rejection	0.2%
CCμ/CCe Rejection	0.01%

*Charge, **p** measurements* ($\mu^{+,-}/e^{+,-}/\pi^+$)

*Vertex, **p** resolution*

Statistics: (1) Abs.Flux, (2) Track-recon, (3) Low occupancy

Know nucl-target, ν-e, e-γ

ν-e, Coh-processes, Q^2, x_{Bj}

FD/ND, match FD-reslolution

δcp, Wrong-sign contamination, Signal Eff.

Oscl-Background, Cross-section, Extrapolation to FD

Near Detector parameter list at
http://lbne2-docdb.fnal.gov:8080/cgi-bin/RetrieveFile?docid=10873&filename=LBNF-DUNE-V1.8-parameters.xlsx&version=26

Absolute and Relative Flux in LBNF using ND

Low ν_0 Method

❧Using $\nu_\mu + N \rightarrow \mu^- + X$

⇒ Expect an FD/ND ratio at ~1--2% precision in $0.5 \leq E_\nu \leq 50$ GeV

❧Using $\bar{\nu}_\mu + N \rightarrow \mu^+ + X$

⇒ Expect an FD/ND ratio at ~1--2% precision in $0.5 \leq E_\nu \leq 50$ GeV

Coherent Pi/Rho Channel

❧Using $\nu_\mu \mathcal{A} \rightarrow \mu\ \pi / \rho\ \mathcal{A}$

⇒ Estimate a high precision (?%) in the $\bar{\nu}_\mu/\nu_\mu$ in $0.5 \leq E_\nu \leq 50$ GeV

❧Discussions of ν_e/ν_μ & $\bar{\nu}_e/\bar{\nu}_\mu$ in $0.5 \leq E_\nu \leq 50$ GeV: Later

ND-Req (Glo-Sci-51 & 23) ⇒ ND shall measure absolute & relative flux

Absolute & Relative Flux in LBNF/DUNE using ND

Leptonic Channel

❧Using $\nu_\mu + e \rightarrowtail \nu_\mu + e$

⇒ Expect a ~2% precision in the absolute flux: $0.5 \leq E_\nu \leq 10$ GeV

❧Using $\nu_\mu + e \rightarrowtail \nu_e + \mu$

⇒ Expect a ~2.5% precision in the absolute flux: $E_\nu \geq 15$ GeV

QE Channel

❧Using $\bar{\nu}_\mu + p \rightarrowtail \mu + n$ (via $[CH_2]_n$ - C subtraction)

⇒ Goal: a ~3% precision in the absolute flux: $0.5 \leq E_\nu \leq 20$ GeV

Coherent Channel

❧Using $\nu_\mu \mathcal{A} \rightarrowtail \mu \rho \mathcal{A}$

⇒ Goal: a ~5% precision in the absolute flux: $2.5 \leq E_\nu \leq 20$ GeV

$\mathscr{B}$ & $\mathscr{C}$: Precision Neutrino Measurements & Searches

✦ **PRECISION MEASUREMENTS**:

- Measurement of $\sin^2\theta_W$ and electroweak physics;
- Measurement of strange sea contribution to the nucleon spin Δs;
- Precision tests of isospin symmetry;
- Precision tests of the structure of the weak current: PCAC, CVC;
- Adler sum rule;
- Studies of QCD and hadron structure of nucleons and nuclei;
- Strange sea and charm production;
- Measurement of Nuclear effects in neutrino interactions;
- Precision measurements of cross-sections and particle production; etc. .....

Deep synergy
with the LBL
oscillation program:
same requirements
and
mutual feedback

✦ **SEARCHES FOR NEW PHYSICS**:

- Search for weakly interacting massive particles (e.g. νMSM sterile neutrinos);
- Search for high Δm^2 neutrino oscillations (e.g. LSND, MiniBooNE)
- Search for light (sub-GeV) Dark Matter; etc. .....

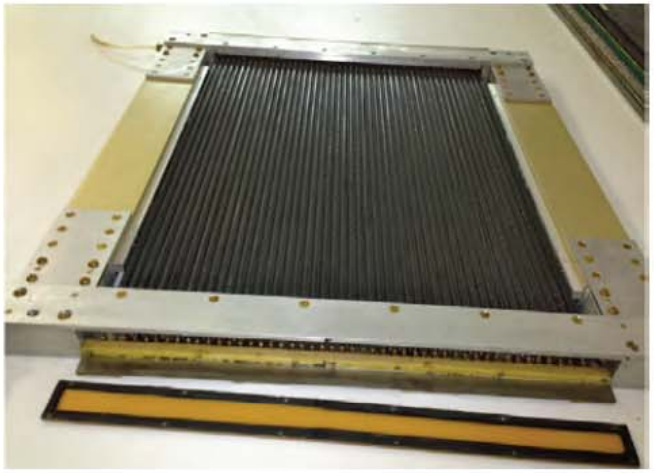
$\Longrightarrow$ The combination of high resolution and unprecedented statistics ($\times 100$) may led to discoveries of new physics in fundamental interactions / structure of matter!

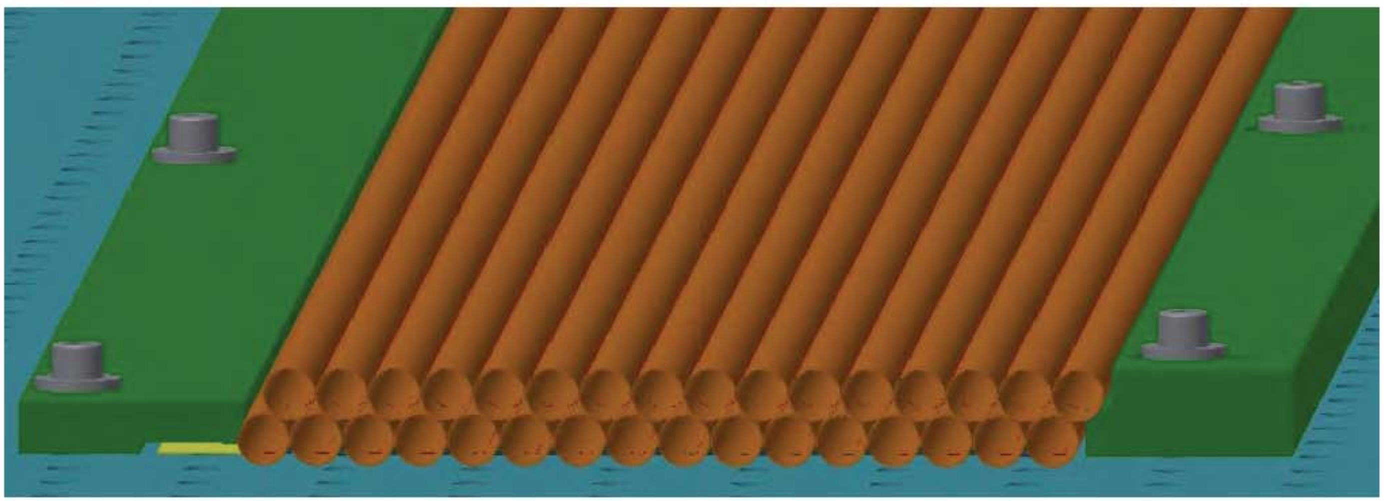
$\Longrightarrow$ More than 200 physics papers and > 100 Ph.D. thesis expected

STT R & D and Prototyping

Build a half scale (in transverse) prototype: 1.8 m x 0.6 m

Test Chambers available at Panjab (operational experience)





Developmental Prototype

Laboratory Infrastructure for the ECAL assembly

At IIT Guwahati, a laboratory space of dimensions **32 m x 12 m** is already identified:

- Laboratory infrastructure needs to be developed for the R & D work as well as for final layer and module assembly.
  - Current focus is on designing a class 10,000 clean room with the necessary hydraulic crane infrastructure in it.

One of the side rooms will be used for detector assembly while the other will be used for material Storage and QA etc.

Dipole Magnet

R & D and Prototyping

Build Single “C” of actual dimensions, One Coil

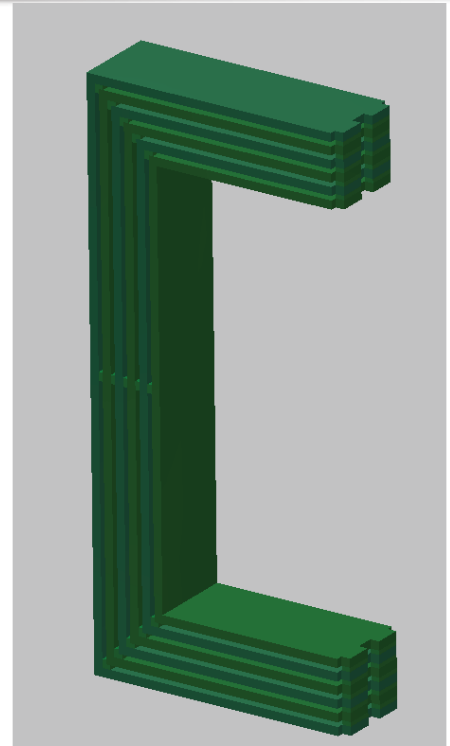
Magnet Work at BARC, Mumbai

- Identified Tasks

  Design of a the Full Magnet (C’s, Coils, Cooling, Power, Base)

  - Establish the Material-Vendor Chain
  - Material **Characterization**
  - **Tooling/Zigs** setup
  - **Infrastructure** setup
  - **Field Mapping/Placement of probes**

1 “C” & 1 coil



- **Total 16 C’s (8 Pairs) and 4 Coils: 0.4 T B field**

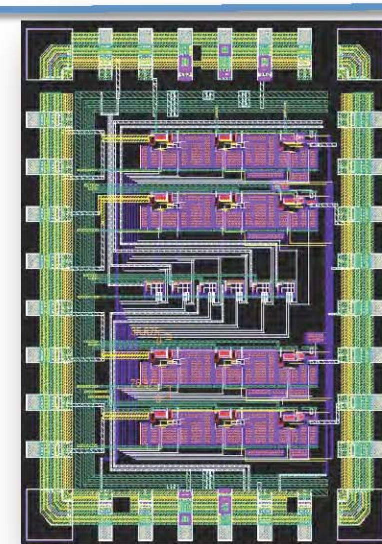
Resistive Plate Chamber (RPC) – Muon Identifier

Fabrication of Large RPCs (2.4m x 1.2m)

Various Fabrication Steps

Readout Electronics and DAQ

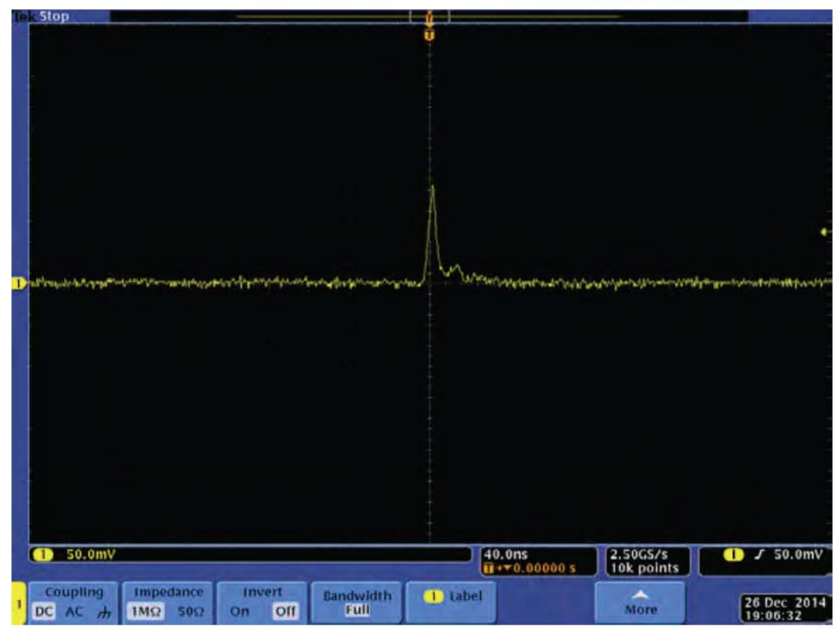
R & D and Prototyping ~450K Channels to be readout



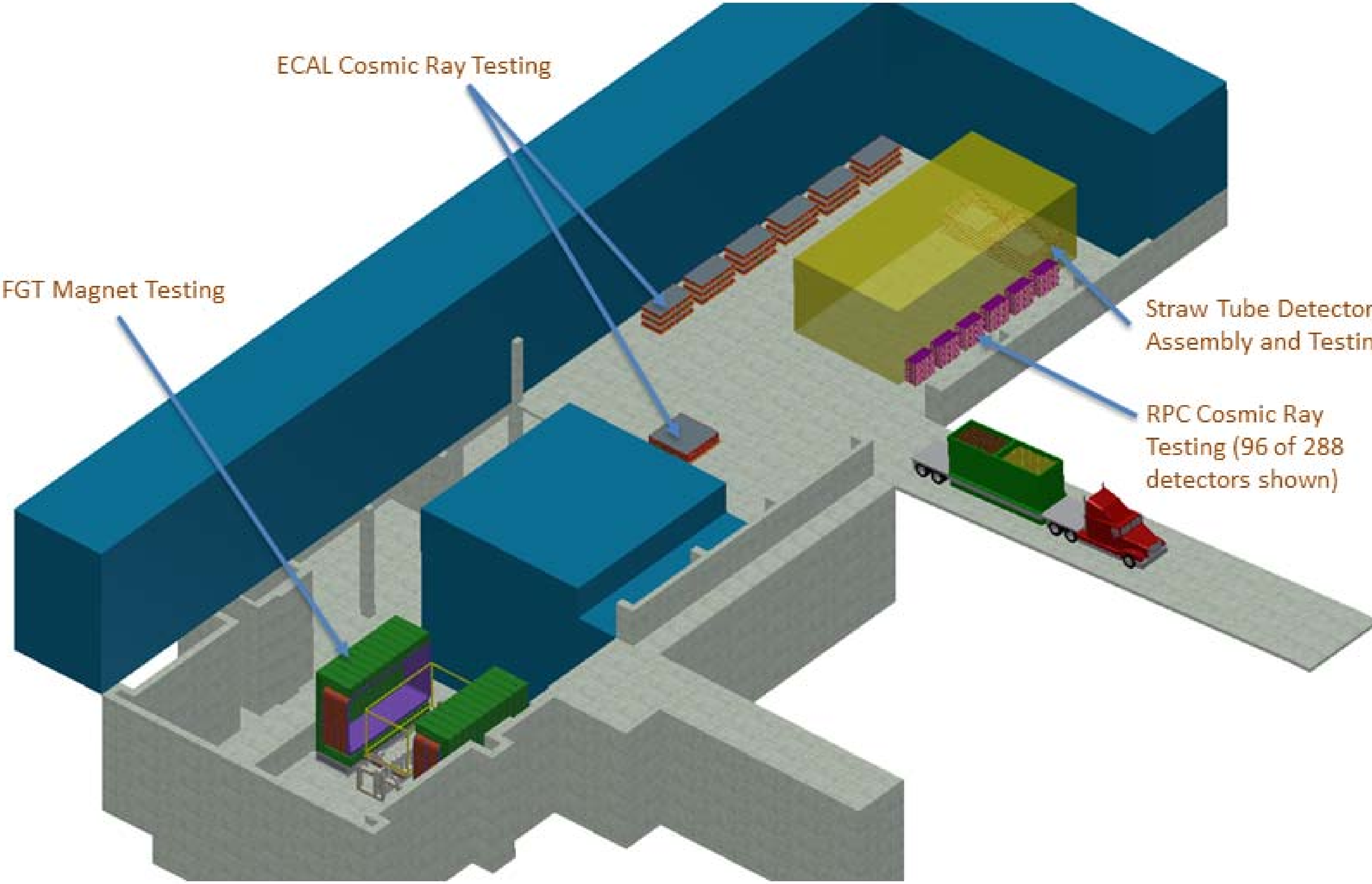
4 Ch Amplifier

Based on the Sub-detector generated output Signals

- Zero down on the
  - **Parameters and Specifications**
  - **Evaluate the existing in-use FEE (ASICs): VMM2, ANUSPARSH**
    - Space
    - Heating
    - Power
    - Cost per channel
  - **Readout of Prototypes as Test-beds**
- **DAQ**
  - **DUNE DAS being explored**

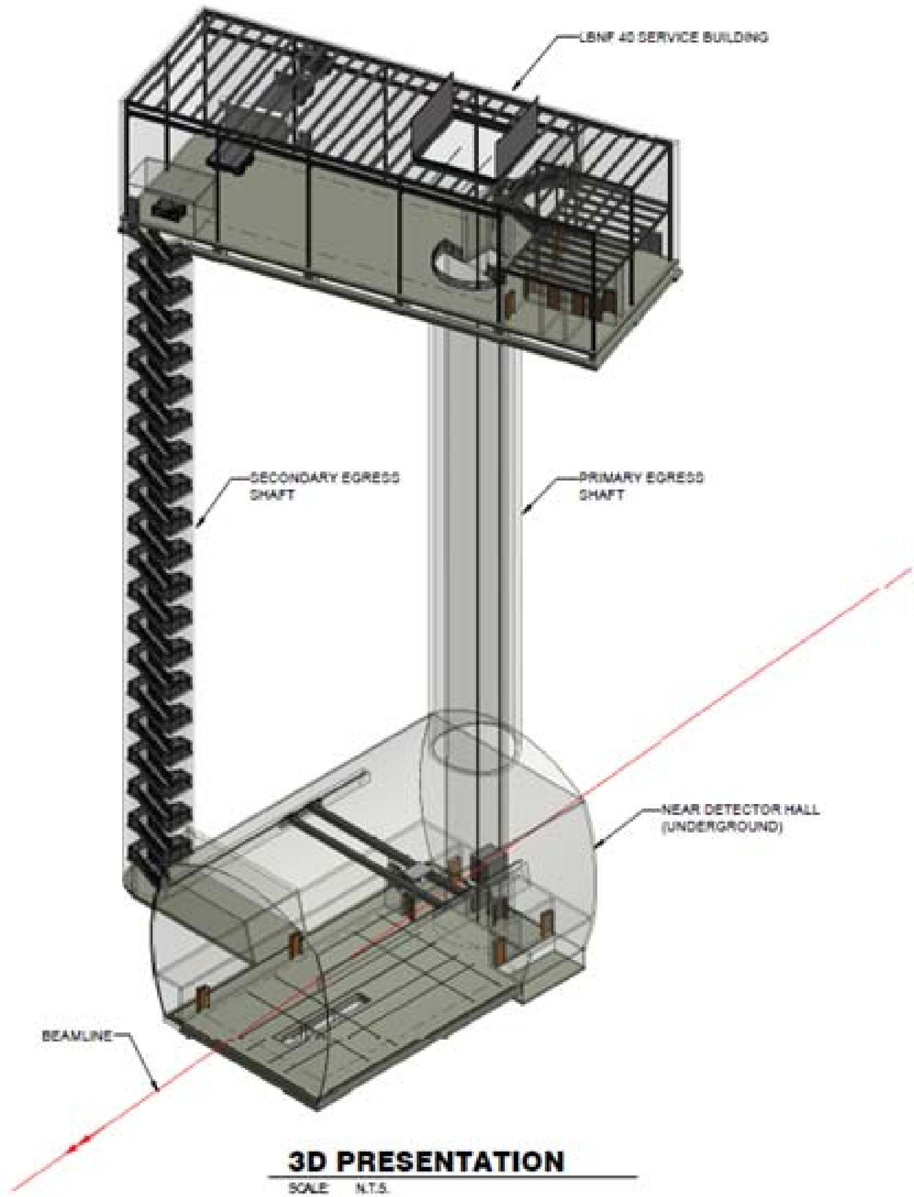


Near Detector Receiving and Testing in D Zero Assembly Hall

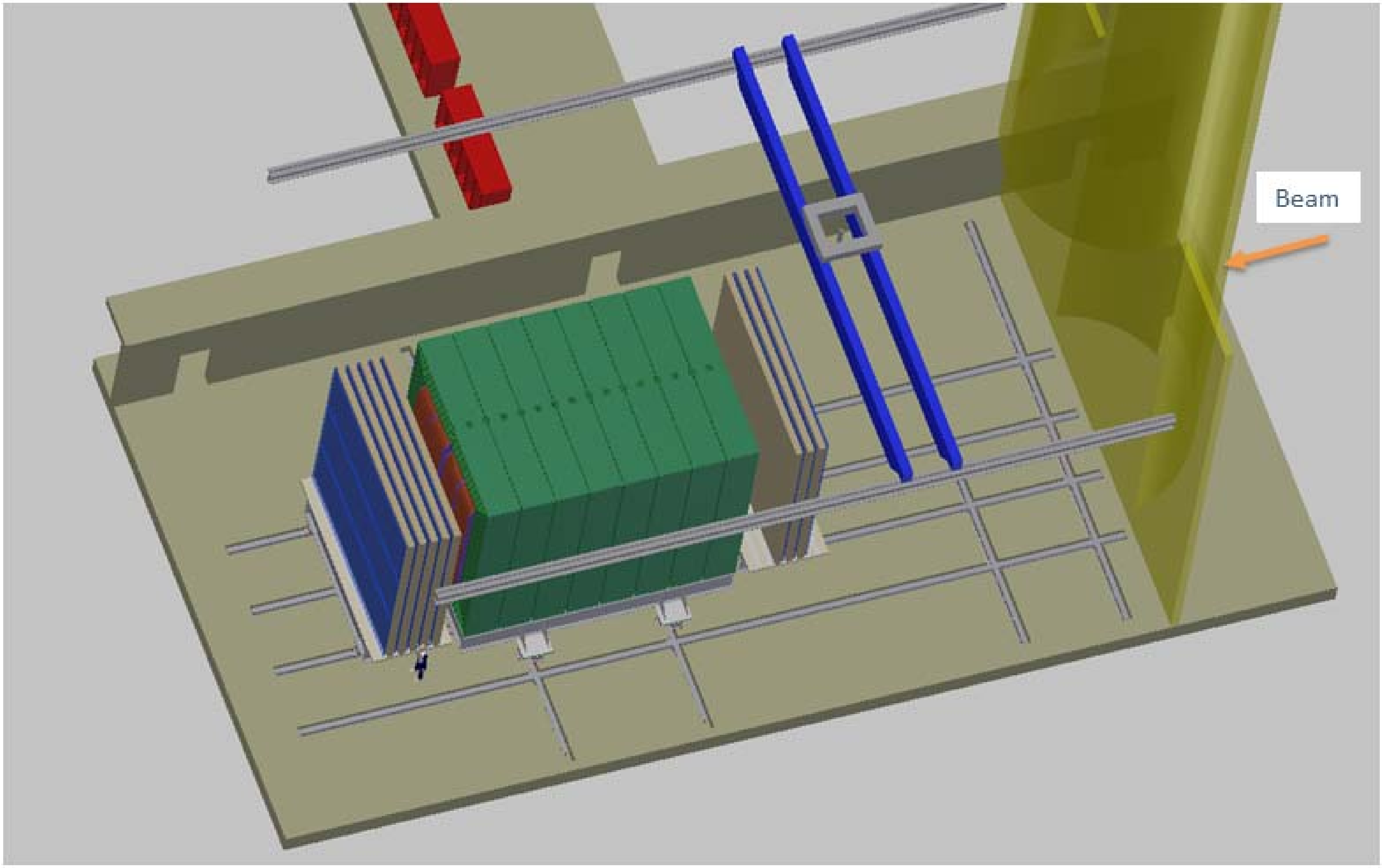


Near Neutrino Detector Hall & Service Building (LBNF-40)

- ~ 14,000 SF
- Approximately 100-foot by 55-foot wide detector cavern
- 45-foot by 136-foot service building with truck bay, bridge crane, and support rooms
- 22-foot diameter primary shaft with septum dividing primary personnel access elevator from equipment/utility access.
- 17-foot diameter secondary shaft for emergency egress.



Near Detector Assembly Complete



LBNF/DUNE Near Site – Critical Path Summary