THE LBNE NEAR DETECTOR

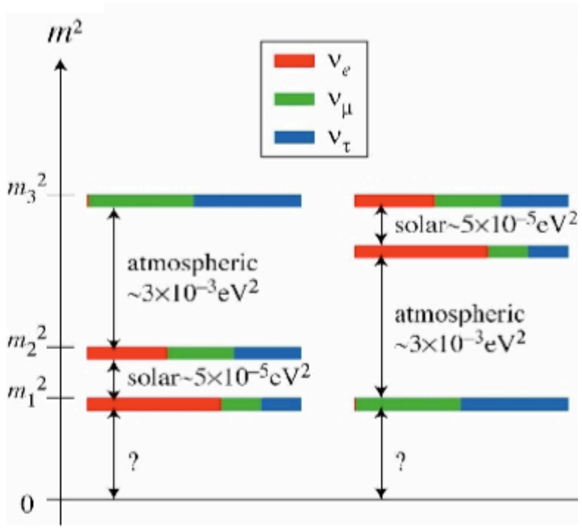
Elena Guardincerri – Los Alamos Laboratory

Status of ν Physics and LBNE

Neutrino oscillation experiments proved that neutrinos are mixed and massive

Open questions

- What is the correct hierarchy pattern?
- Is there ~~CP~~ and what is the value of the CP phases?
- Type of fermion: Dirac or a Majorana?
- What is the absolute mass scale?
- Are there sterile neutrinos?



Normal hierarchy $m_3 > m_2 \sim m_1$ Inverted hierarchy $m_2 \sim m_1 > m_3$

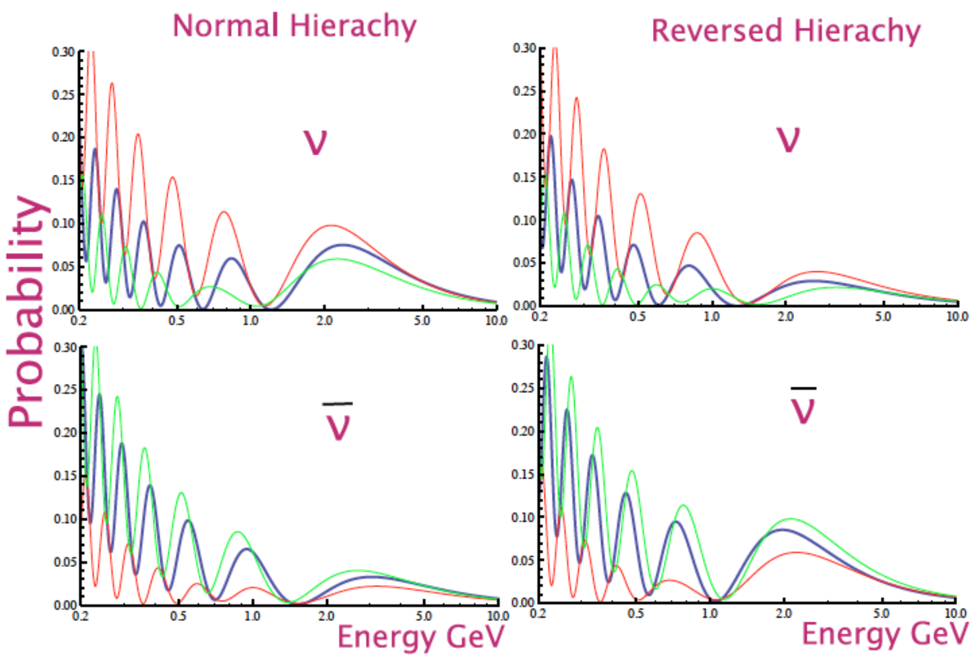
- Principal focus of LBNE: simultaneous measurement of MH & ~~CP~~
- With a baseline of 1300 km and a beam energy peaking between 0.5 GeV and 10 GeV LBNE could study ν_μ disappearance and $\nu_\mu \rightarrow \nu_e$ oscillations with unprecedented sensitivity
- The resolution and redundancies of LBNE will allow unprecedented reach to search for physics beyond PMNS

LBNE

LBNE: the signature

$$A(E_\nu) = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)}$$

- The asymmetry is due to
  - ~~CP~~: if $\delta_{CP} \neq 0,\pi$
  - Matter effect: matter interacts differently with neutrinos and antineutrinos
    - Neutrinos and antineutrinos experience a different index of refraction. $P_{\mu e}$ is different for neutrinos and antineutrinos.
  - The two effects can be searched for (and distinguished) by looking at the spectral features of P($\nu_\mu \to \nu_e$) and P(anti-$\nu_\mu \to$anti-ν_e)



- $\delta CP = 0$
- $\delta CP = \pi/2$
- $\delta CP = -\pi/2$
- $\sin^2 2\theta_{13} = 0.1$

e-Print: **arXiv:1203.4090**

Motivations for a near detector

- LBNE will not measure oscillation probabilities but event rates:

$$R(E)_{FD} = k \times \Phi(E) \times P(\nu_\alpha \rightarrow \nu_\beta) \times \sigma(E) \times \varepsilon(E) + B(E)$$

- At the far detector (FD), the first and the second oscillation maxima occur at about 2.4 GeV and 0.8 GeV, respectively
- In this energy range neutrino cross sections are poorly known (uncertainties ~20 %)

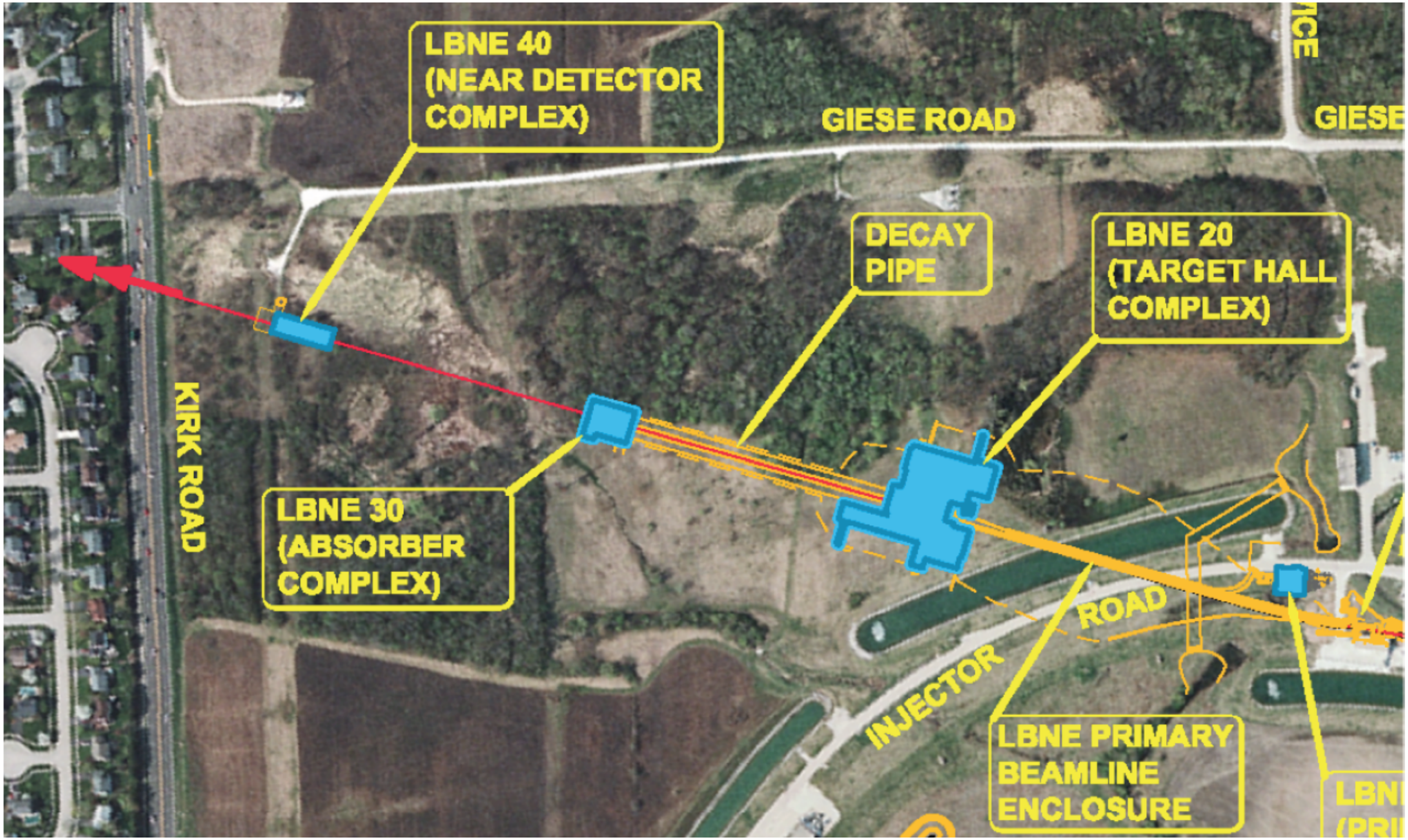
➢ crucial to measure the neutrino fluxes and interaction channels at a near site – before the fluxes have been affected significantly by neutrino oscillations – in order to be able to predict both signal and background at the far site

- It is also critical to identify and measure processes that can mimic oscillation signals at the liquid Argon far detector (FD)
  - Mainly charged and neutral pion production
  - ➢ backgrounds must be measured individually since different backgrounds have different extrapolations to the FD position

Status of the LBNE near detector

- Approved scope:
  - Beamline measurements (more on this next)
- Goal:
  - Beamline measurements
  - Near Neutrino Detector (more on this next)
    - Strong interest from India to build the neutrino detector with US scientists (STT)
    - In addition, explore the possibility of a LAr neutrino detector
      - Non-DOE (NSF or international) partners could provide a LAr TPC that could be placed upstream of the STT
      - We wish to build a hall that can accommodate more than one detector

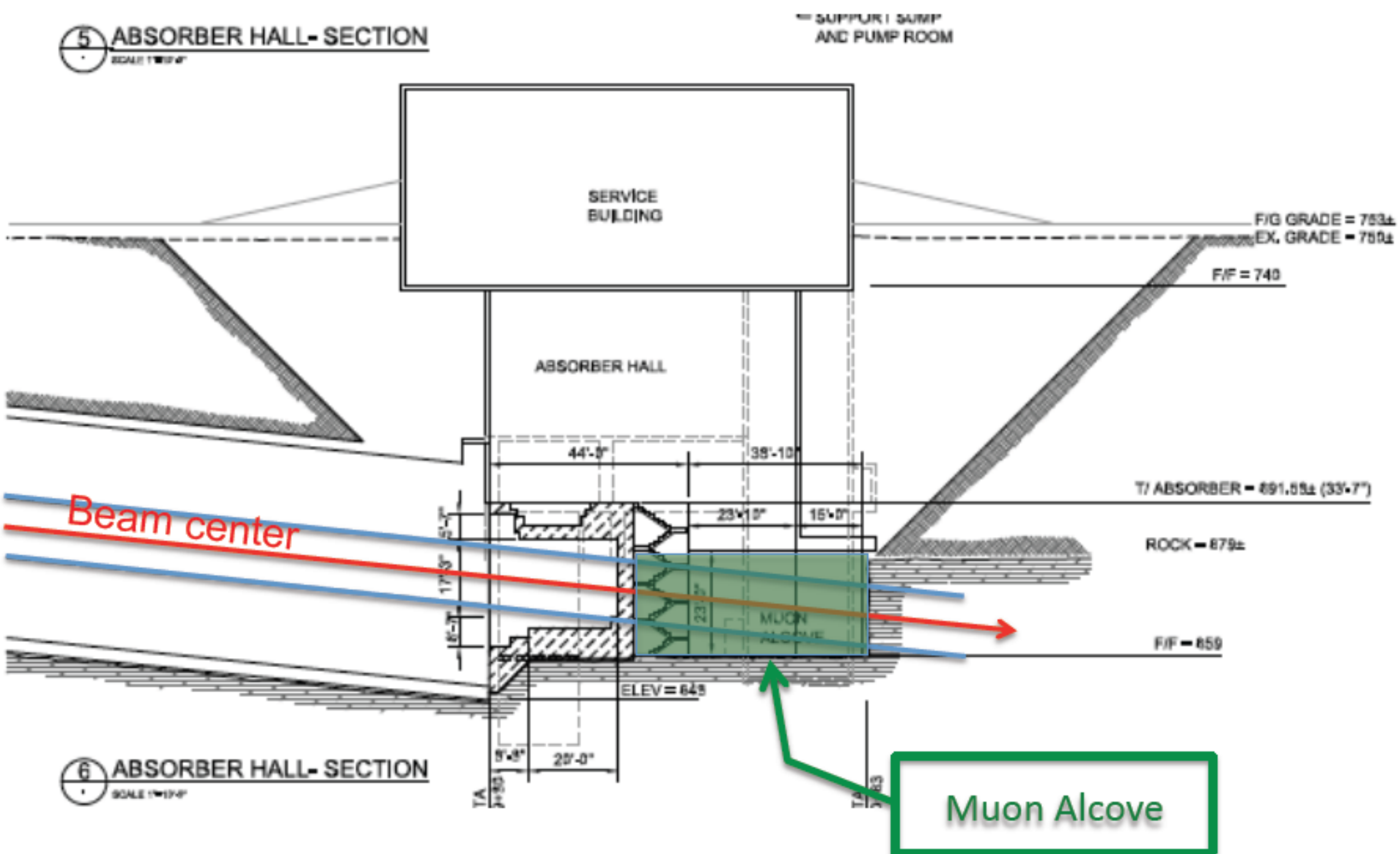
The near detector complex



Proposed near detector complex

- Consists of a beamline measurements system (BLM) and a neutrino-detection system (ND)
- The **ND** will be located at the Near Site (Fermilab), downstream of the beamline
  - Measure the ν_μ, anti-ν_μ, ν_e, anti-ν_e using CC
  - Measure the absolute flux and shape of neutrinos at ND, and predict FD/ND
  - Measure backgrounds to oscillation signal (π^0, π^+, π^-, ..)
  - Measure ν-Ar interactions
- The **BLM** will be located in the region of the Absorber Complex at the downstream end of the decay region to measure the muon flux from hadron decay
  - To determine the neutrino flux and spectrum and to monitor the beam profile on a spill-by-spill basis

Muon measurements facilities



~ 275 m from the target

muon flux at the ND: $10^8/cm^2/s$

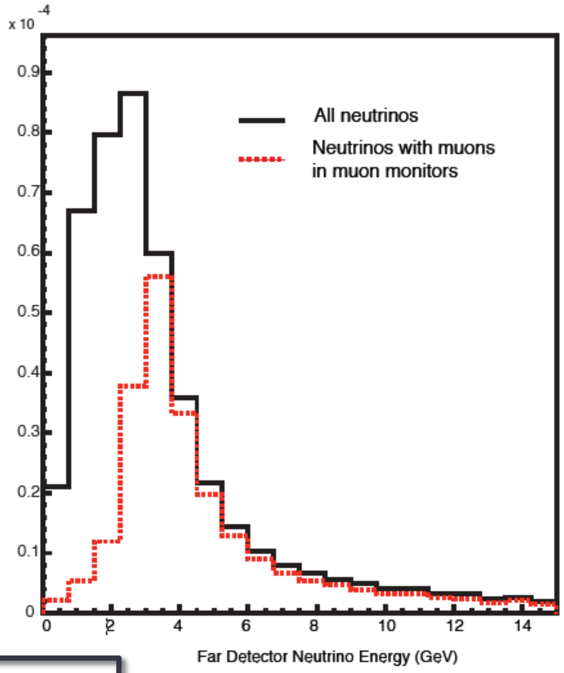
Muon measurements

- Muons and neutrinos come from the same parent pion and kaon decays

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\pi^- \rightarrow \mu^- + \overline{\nu}_\mu$$

dominant channel

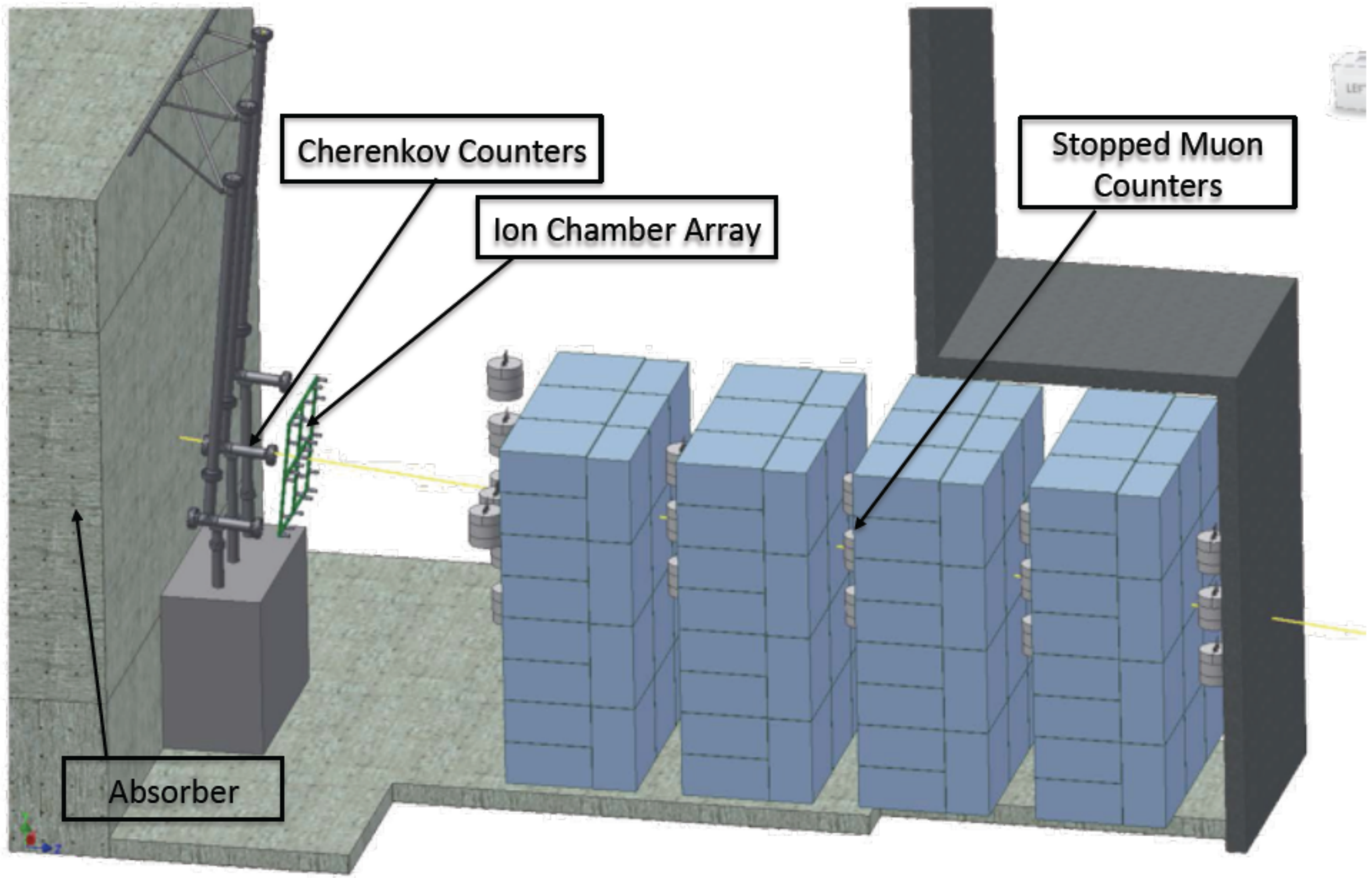
  - a measurement of the absolute muon flux and energy spectrum can confirm the absolute neutrino flux
    - Goal: determine the absolute muon flux to an accuracy of 5% above E_μ ~ 6 GeV (corresponding to E_ν ~ 1.6 GeV)



- Muon ionization detectors
  - Beam direction stability over time
- Stopped-muon (Michel-electron) detectors
  - Measure muon energy spectra in ~ (6, 14) GeV range
- Muon Cherenkov detectors
  - Map the muon momentum distribution

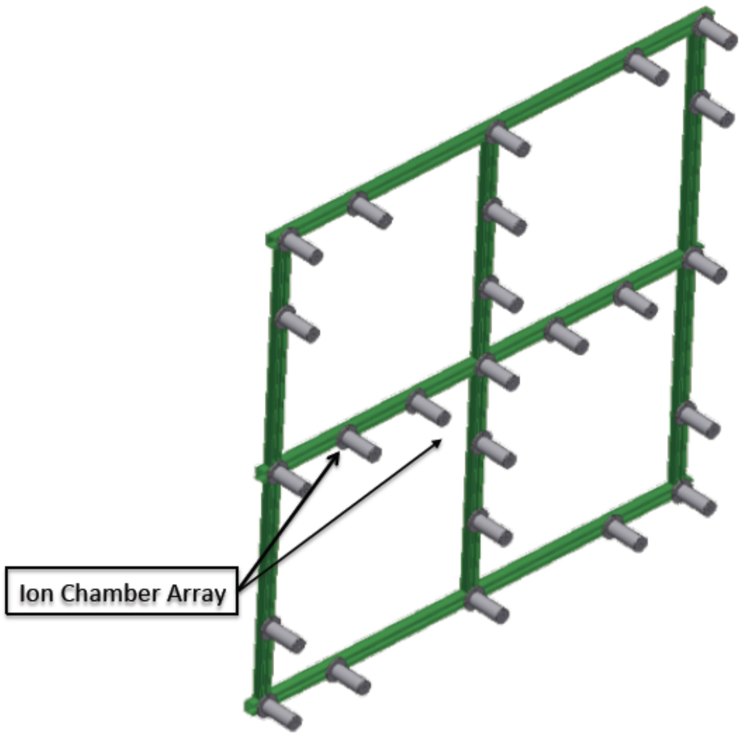
muon flux at the ND: $10^8/cm^2/s$

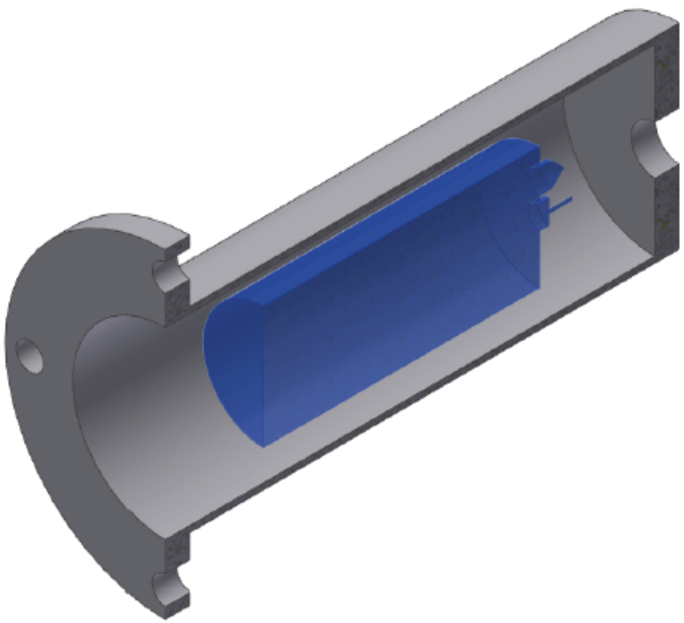
The beamline measurement



Muon ionization detectors

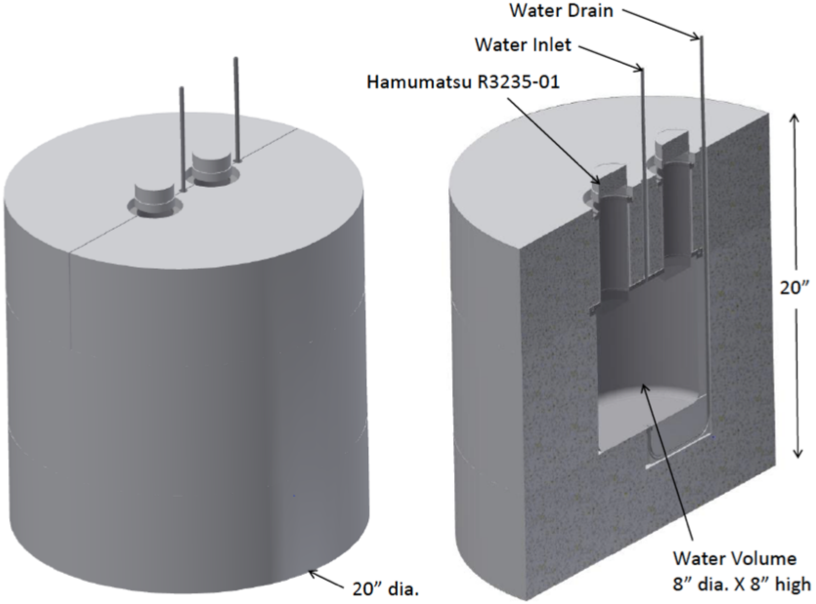
- A misalignment of the beam leads to a change in the ratio $flux_{ND}/flux_{FD}$: to keep the change lesser than 1% in all energy bins the beam direction must be known to ~0.2 mrad ➔ 5 cm
- Sealed ionization counters (rad hard)



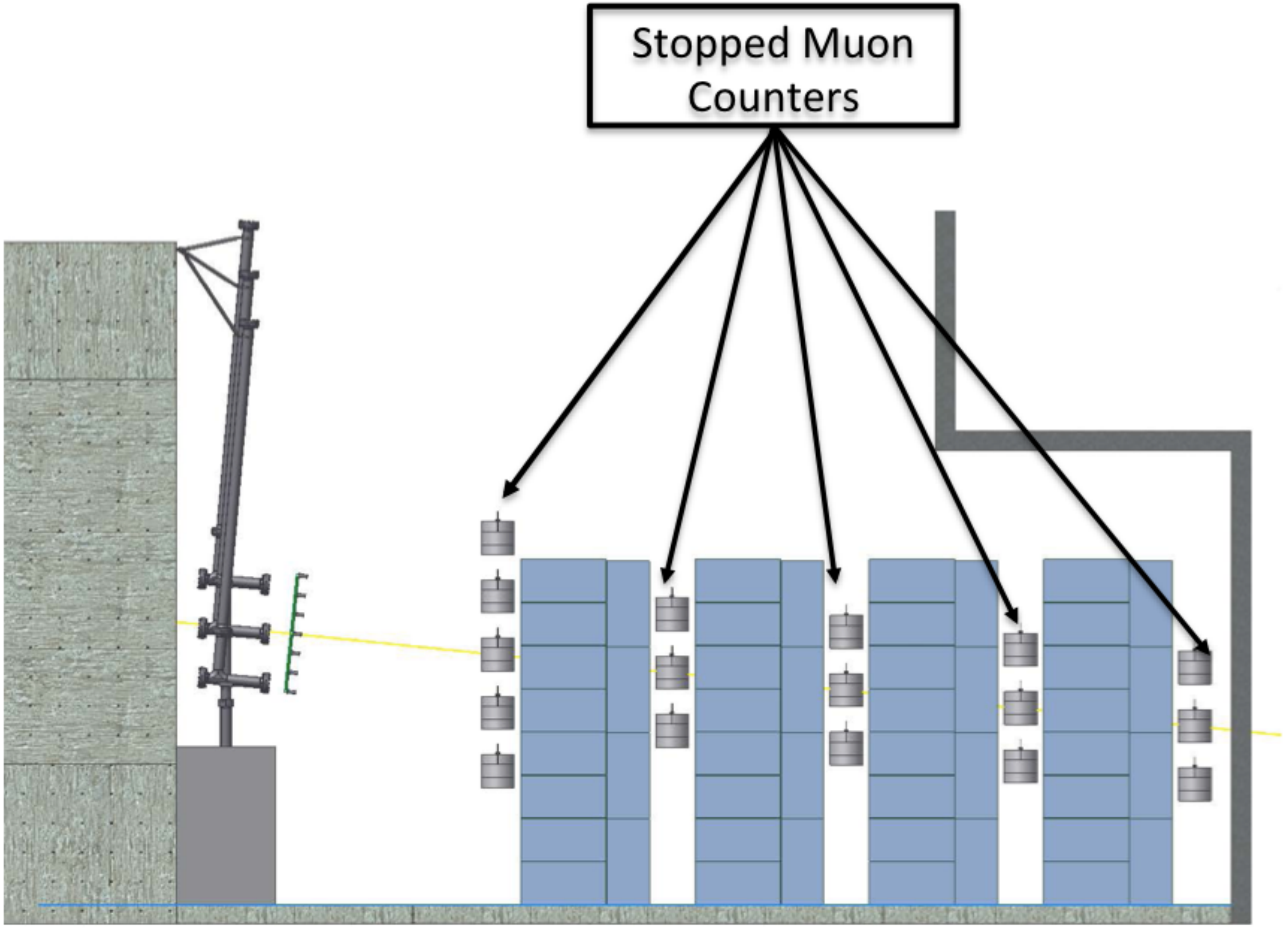


Stopped-muon detectors

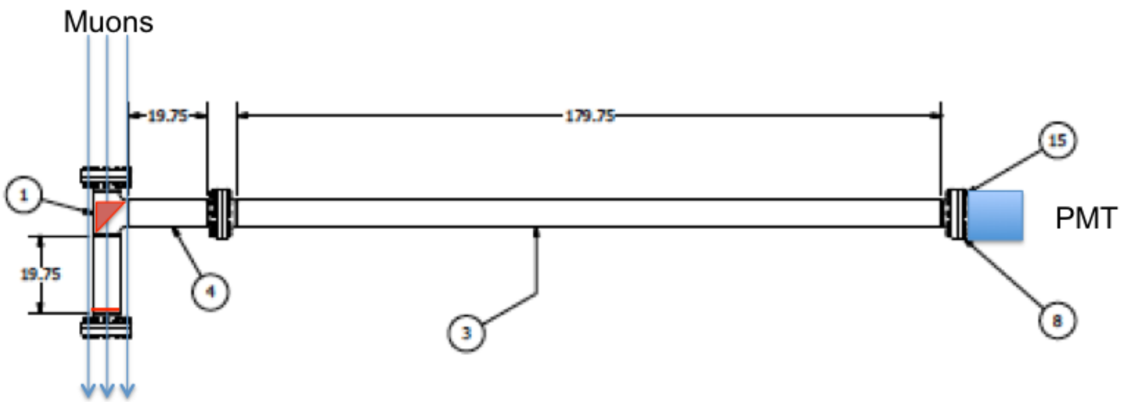
- Detect stopped muons through their decay (μ^+ and μ^-) or capture (μ^-)
  - capable of distinguishing μ^+ and μ^-
  - modules at multiple depths in the shielding/rock behind the absorber to sample the muon flux from different energies

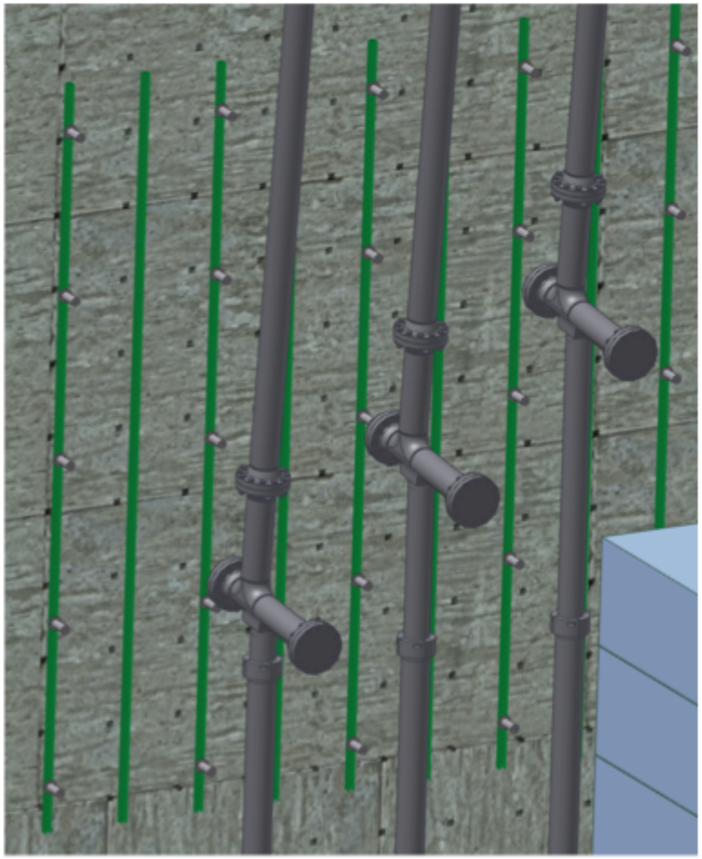


Stopped-muon detectors



Muon Cherenkov detectors



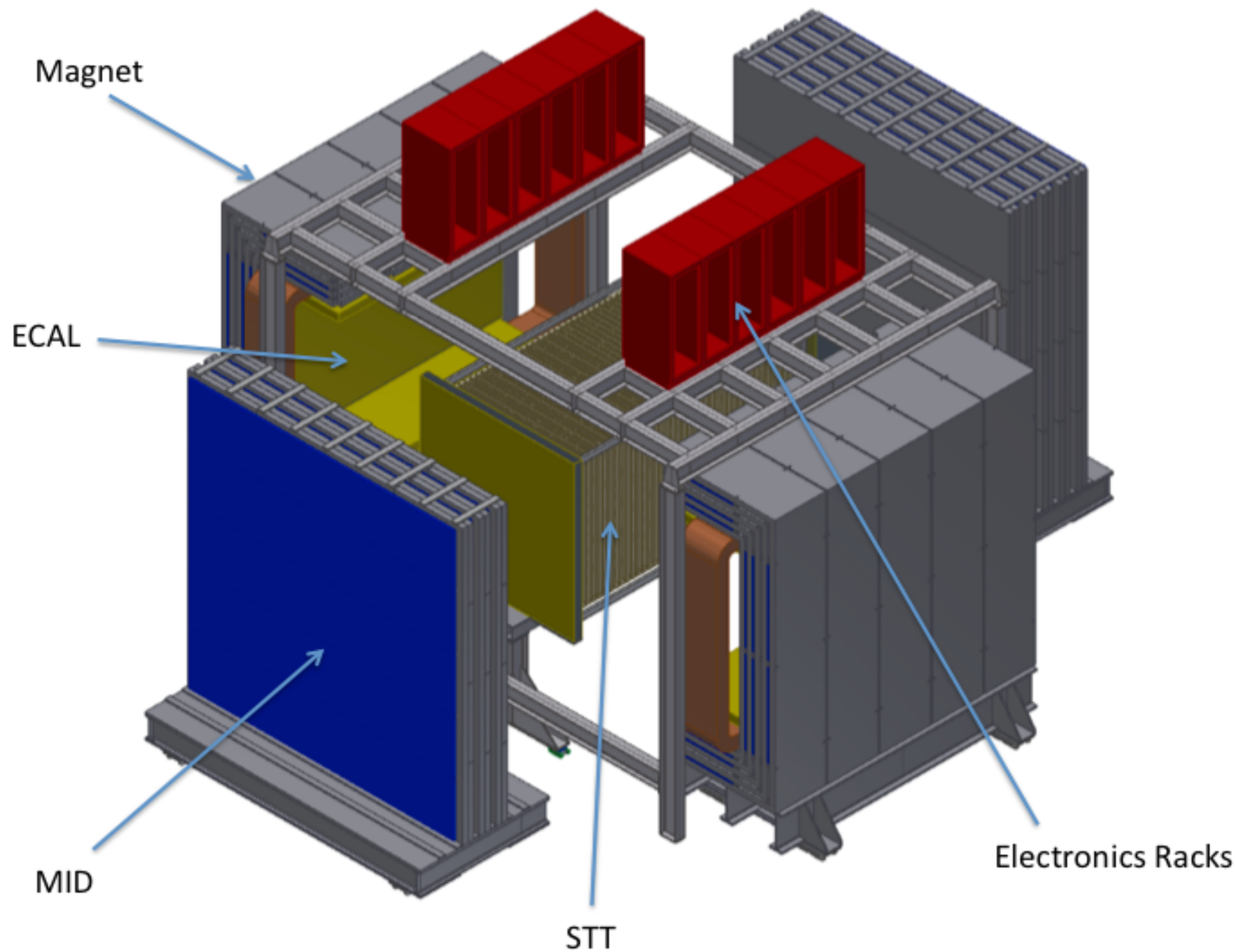


- Counters where a gas (noble gas) radiator is contained in a pressurized tube
- Cherenkov light collected at the end of the tube by a mirror that reflects it 90 degrees towards a PMT
- Gas pressure can be varied from vacuum to several atmospheres
    - this changes the index of refraction, and hence the muon momentum threshold
    - the pressure scan would give the momentum distribution of the muons

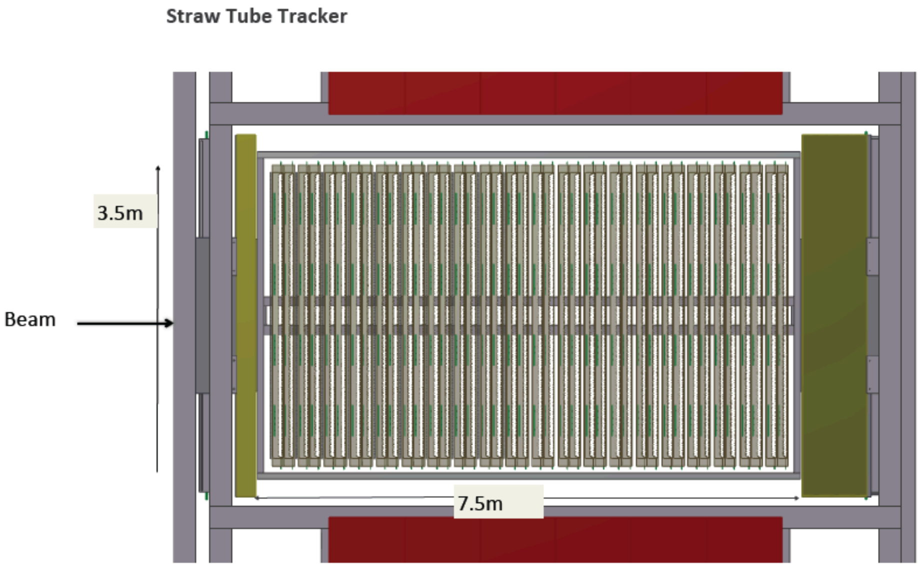
Prototyping effort

- Beam-line detectors being prototyped now
- Assembly of the Cherenkov detector on the surface at Fermilab in progress, transfer underground (alcove 2 of the NuMI beamline) scheduled in August.
  - A stopped-muon counter prototype is being prepared at Drexel also
- Tests scheduled from August 2013 through 2014 using the NuMI beamline parasitically

The neutrino detector



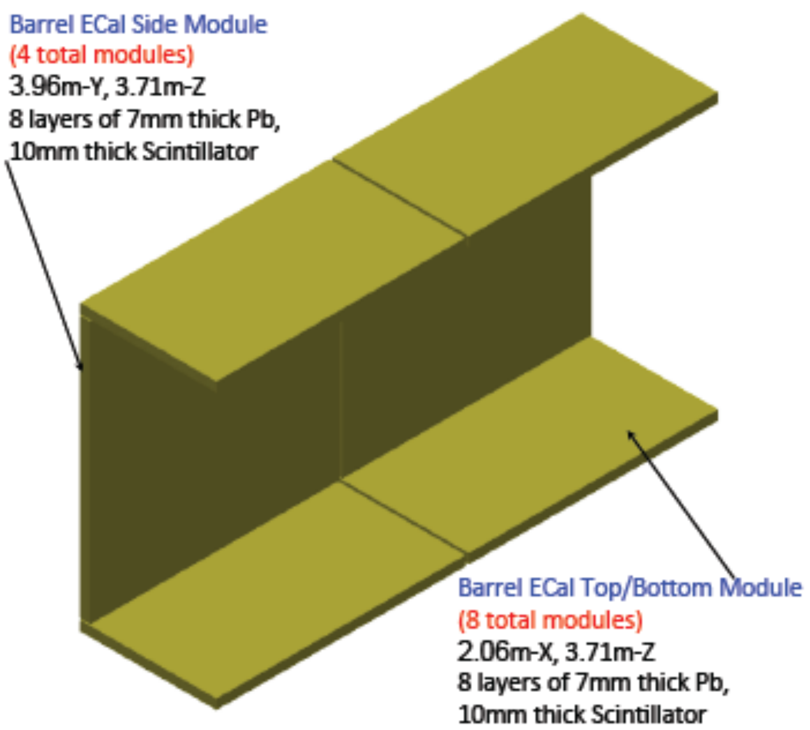
Neutrino detector: the Straw Tube Tracker



- $V = 350 \times 350 \times 750\ cm^3$
  - $\rho \sim 0.1\ g/cm^3$, m =7t
- ~1 cm diameter ST
- Alternated Y and X planes of straws arranged in modules
- TR Radiator foils between the modules
  - Polypropylene $(C_3H_6)n$ films alternating with spacers
  - $X_0 \sim$ 5m in the STT

- Nuclear targets at the upstream end to study ν-nuclear interactions (provide ~ x5 the FD statistics)
- TR ➔ e^-/e^+ ID (γ)
- dE/dx ➔ p, $\pi^{+/-}$, $K^{+/-}$

Neutrino detector: the Electromagnetic CALorimeter



- Tracking volume completely surrounded by an ECAL
- Layers of 10 mm thick scintillator bars with alternating directions separated by 1.75 mm Pb foils
  - DS: 18 X_0
  - Side, US: 10 X_0

- 4π coverage enables detection of neutral particles produced in ν interactions (γ, n, K^0) through their shower (longitudinal/transverse profile)

The magnet and the muon identifier detector

- Magnetic field (0.4 T) required to measure the momentum and charge-sign of the products from ν interactions. Purpose:
  - determine the beam flux at the near site
    - requires μ^+ and μ^- separation
  - measure $e^{+/-}$, necessary for the characterization of ν_e-CC and anti-ν_e-CC interactions and the determination of the neutrino beam content (intrinsic ν_e and anti-ν_e irreducible background for ν_e appearance search at the FD)
- Muon ID: Resistive Plate Chambers (RPC) operated in streamer regime
  - Muon Range Detector (MRD): RPCs in the gaps of the magnet yoke
  - External Muon Identifier (EMI): downstream.
    - Detects forward energetic muons

Expected performances

- 200μm on individual hits, ~100μm on the vertex of a ν_μ-CC event
- $\Delta t \sim 1$ns
- $\sigma_p/p = 0.05/\sqrt{L} \oplus 0.008p/\sqrt{L^5}$ (p in GeV/c², L in m)
- 1/1000 pion rejection from TR

tracker

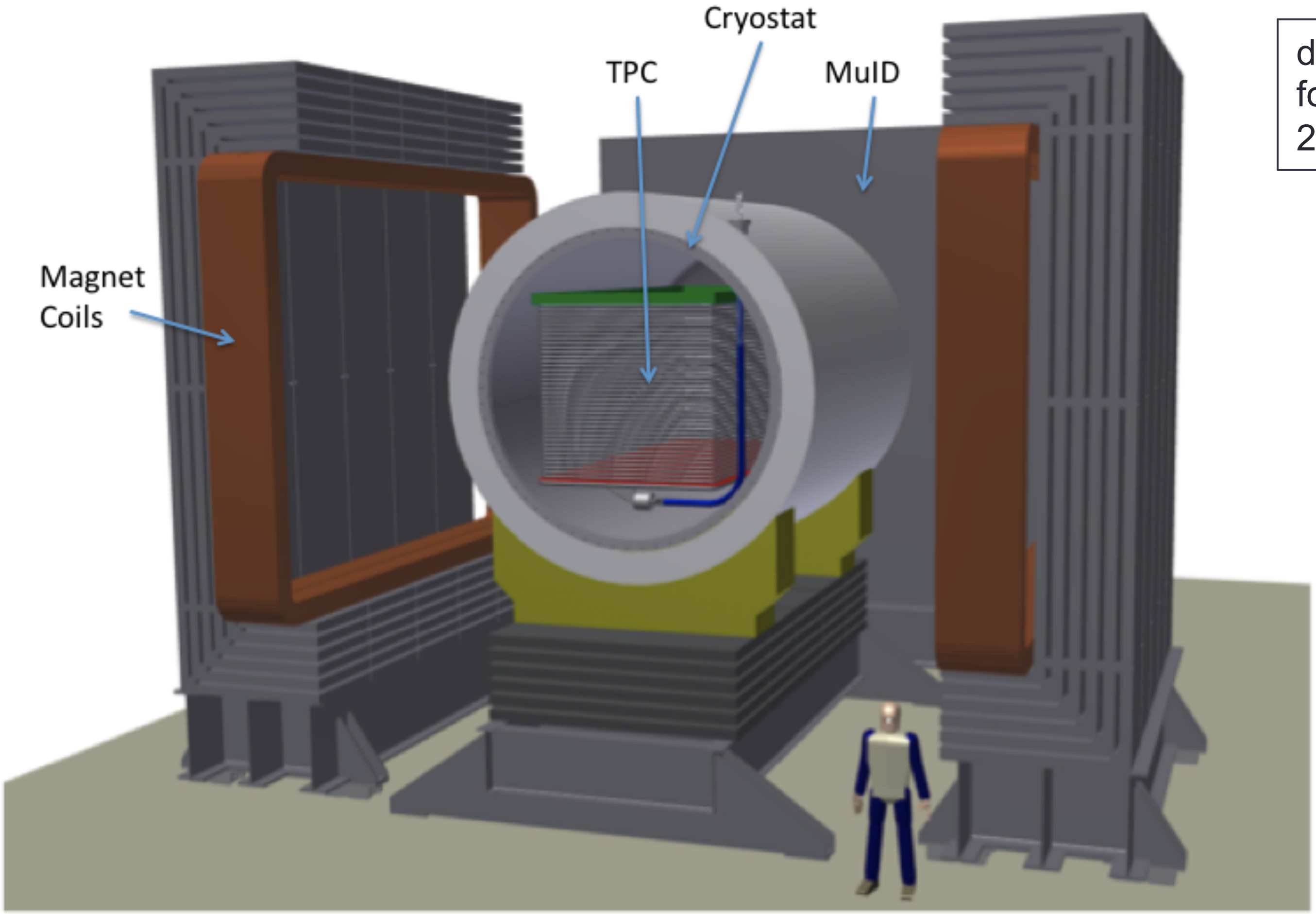
- $\Delta E/E \sim 6\%/\sqrt{E}$
- $\Delta t \sim 1$ns
- Powerful discrimination of EM/hadronic showers

ECAL

- Flux determination:
  - Absolute ν_μ flux ≅2.5% for $E_\nu < 10$ GeV, absolute ν_μ flux ~ 3% at high energy
  - $\nu_\mu(E)$/anti-$\nu_\mu(E)$ < 2% for $1.5 < E_\nu < 30$ GeV, $\nu_\mu(E)$/anti-$\nu_\mu(E)$ ~3 % for $0.5 < E_\nu <$ 1.5 GeV
  - $\nu_e(E)/\nu_\mu(E)$ < 0.1%, anti-$\nu_e(E)$/anti-$\nu_\mu(E)$ < 0.1% → Absolute ν_e(anti-ν_e) ~ 2%
  - Precision on shape of the ν_μ(anti-ν_μ) dominant component ≤ 2% for $1 < E_\nu < 30$ GeV
- Excellent event reconstruction and identification capabilities

arXiv:1307.7335

The neutrino detector: alternative design



design developed for the March 2012 CD-1

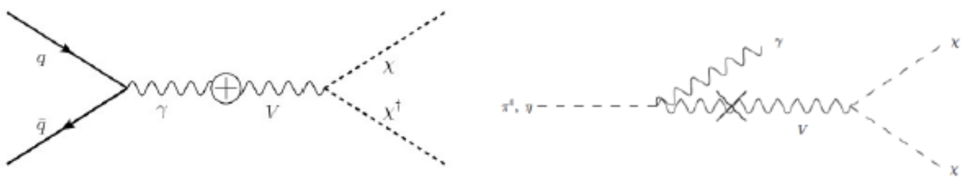
Physics opportunities

- The intense neutrino flux (expected ~10^8 CC interactions for 10^{22} POT) combined with the fine segmentation of the ND offer the opportunity for many physics measurements besides the long-baseline oscillation program
  - Weak mixing angle θ_W
  - Strangeness content of the nucleus
  - Nucleon Structure, Parton Distribution Functions and QCD studies
  - Nuclear effect impact on neutrino-nuclear interactions
  - Search for heavy neutrinos
  - Search for high Δm^2 neutrino oscillations
  - Light Dark Matter searches in the neutrino beam

arXiv:1307.7335

Sub GeV dark matter searches

- Due to the lack of evidence for WIMPS at direct detection experiments and LHC (search for m_W > 10 GeV) new theories with light DM particles formulated
- Light mediator (dark photon V) needed to allow efficient DM annihilation in the early universe
  - In the simplest model an U(1) gauge field mixes with the SM U(1) gauge field
  - Detectable at high flux ν experiments (LBNE)
- V produced by protons striking the target either directly or via π^0 or η production and decay
  - If $m_V > 2m_{DM}$ $V \rightarrow 2\chi$



- χ detectable through NC-like interactions on nucleons/electrons. Same signature as neutrinos but:
  - different timing ($v_\chi << v_\nu$)
  - Electron recoil much more forward
  - A special run with no focusing would reduce the flux of neutrinos

Thank you!