MANCHESTER 1824
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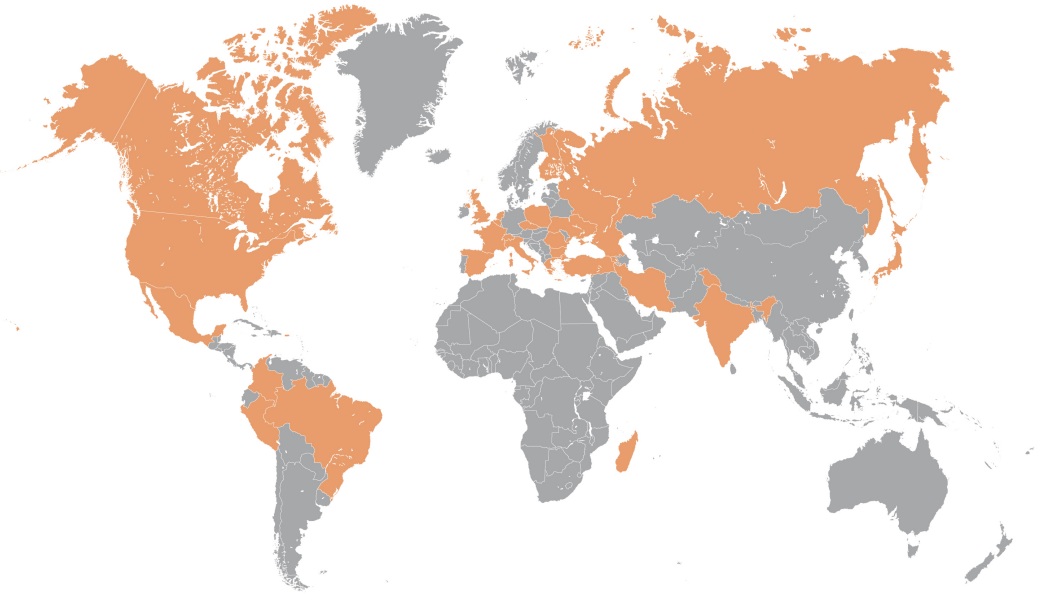
DEEP UNDERGROUND NEUTRINO EXPERIMENT

Status of LBNF and DUNE

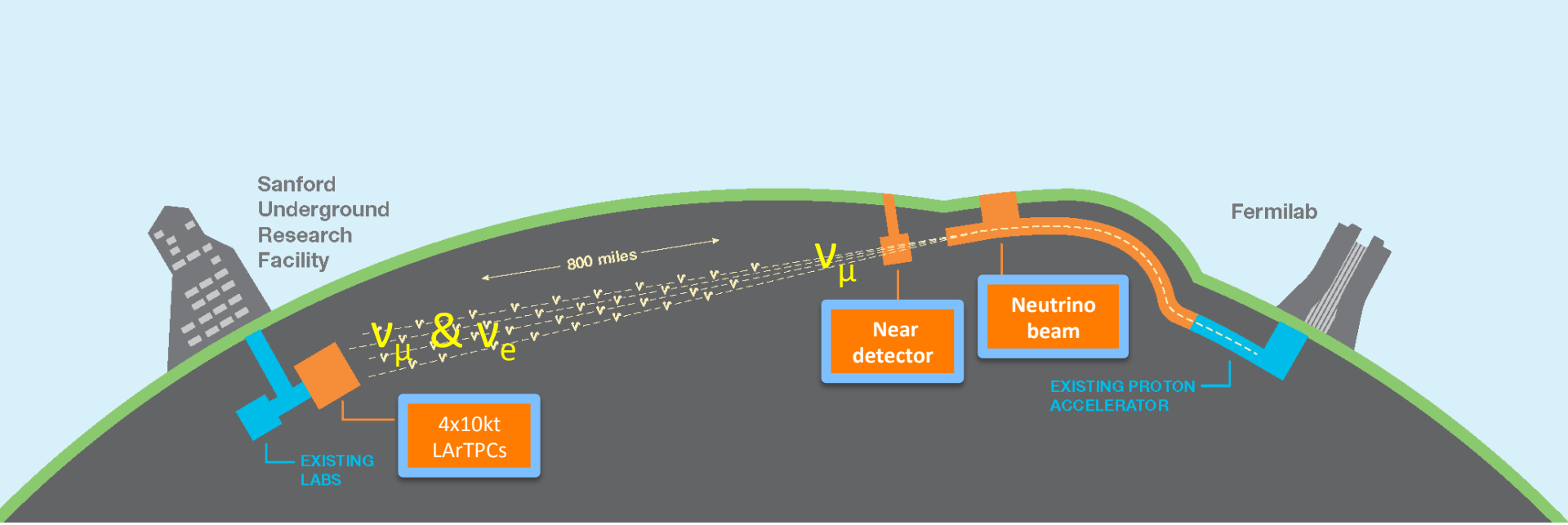
Diego Garcia-Gamez
For the DUNE Collaboration

DUNE Collaboration

International collaboration of about 890 physicists, nearby 160 institutions and 29 countries



Long Baseline Neutrino Facility

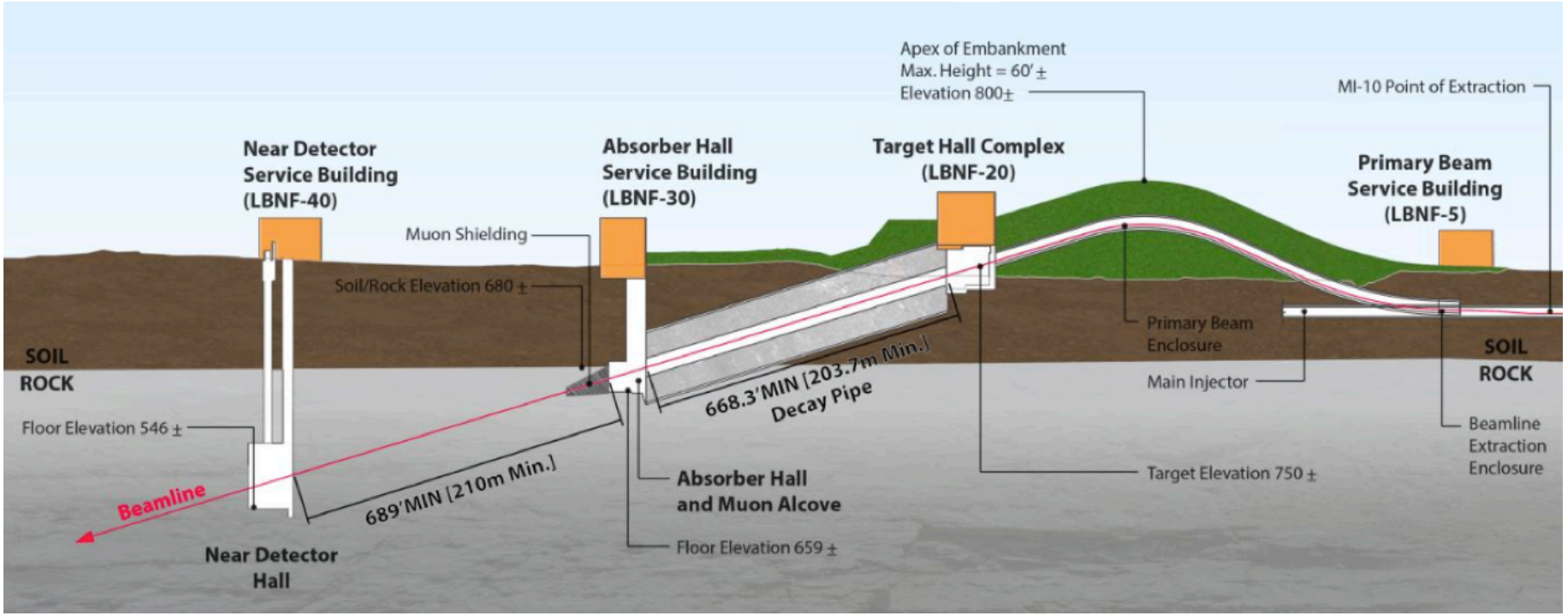


- Facilities for a powerful 1.2 MW beam, upgradable to 2.4 MW
- Fine-grained near detector complex, enabling unprecedented studies of neutrino interactions
- Underground caverns at Sanford Underground Research Facility (SURF)

→1.5 km underground, > 4000 m.w.e

1300 km baseline, 1st (2nd) oscillation maximum at about 2.4 (0.8) GeV

LBNF Beamline



Conventional horn-focused ν-beam:

- Proton beam extracted from Main Injector and transported to the target
- Secondary particles focused toward the FD → neutrino beam from decays of the secondary particles

Key options for the optimization:

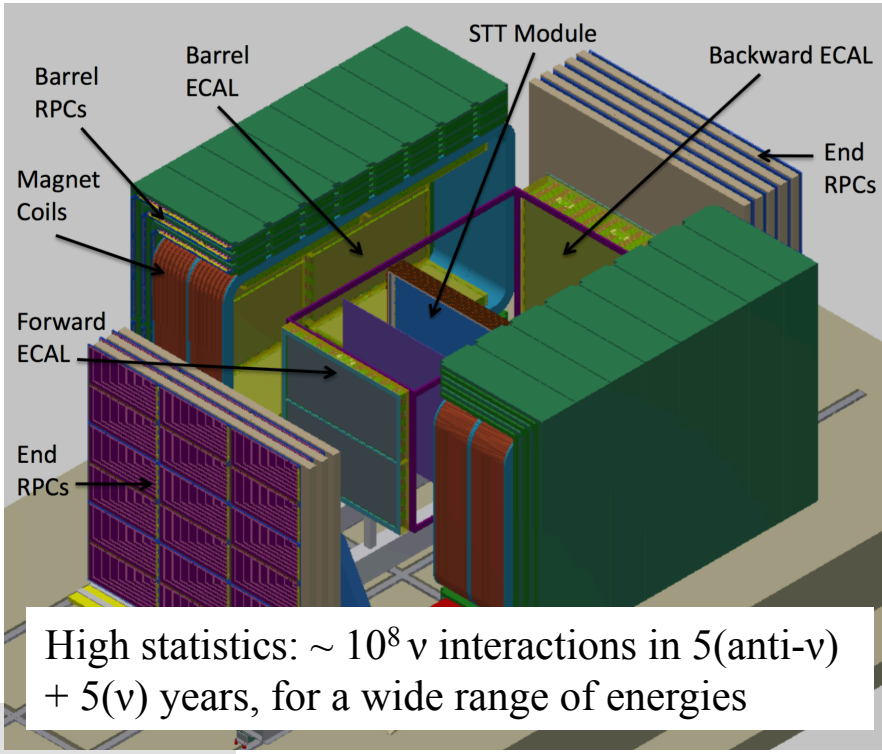
- More advanced focusing system: bigger horn spaced farther apart
- Material, geometry and structure of the target assembly
- Length and diameter of the decay pipe

The DUNE Near Detector Reference Design

Primary role of the near detector :

- characterize the energy spectrum and the composition of the neutrino beam at the source ($\nu_{e/\mu}$ and anti-$\nu_{e/\mu}$)
- measurements of neutrino interaction cross sections

→ necessary to control systematic uncertainties



High statistics: ~ 10^8 ν interactions in 5(anti-ν) + 5(ν) years, for a wide range of energies

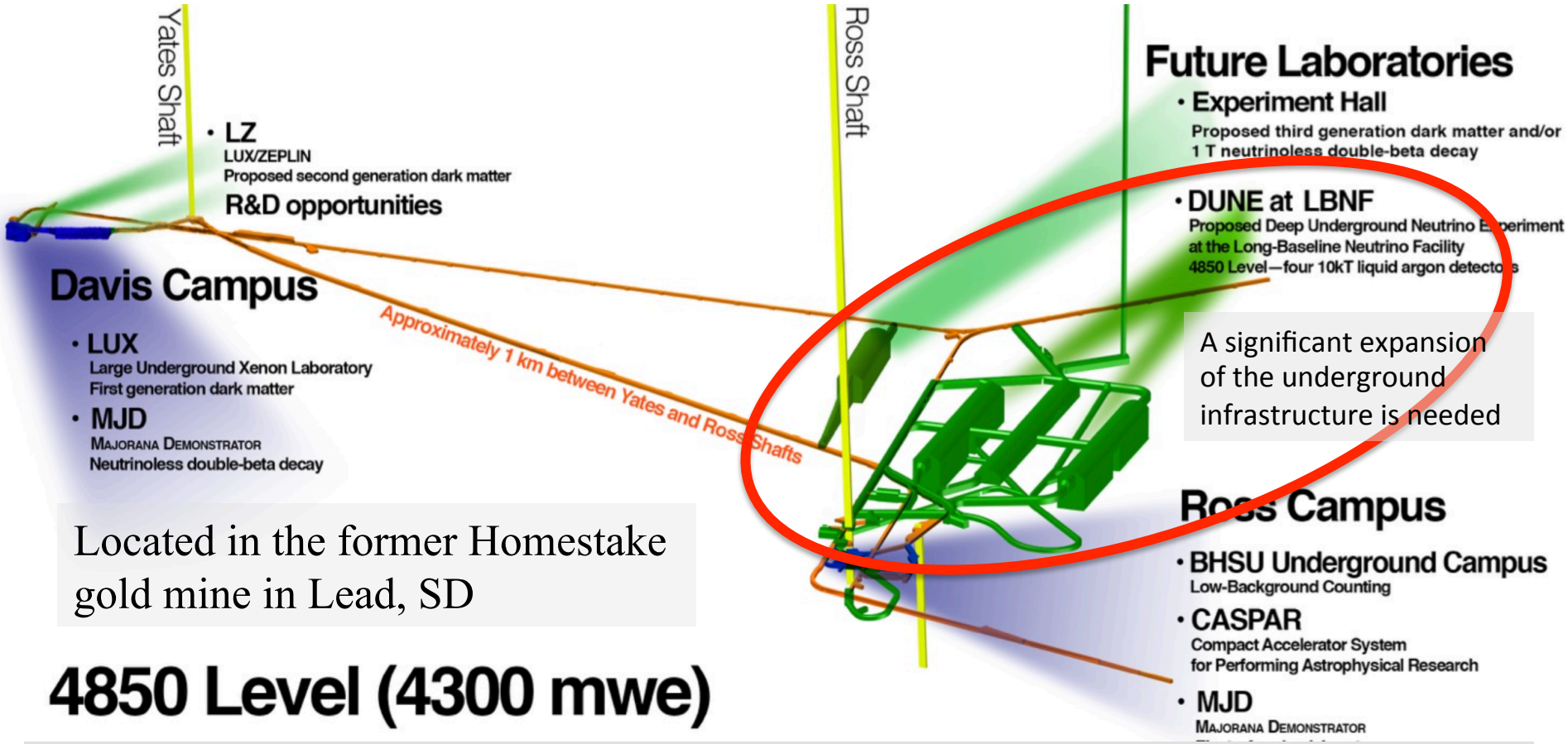
Reference design (NOMAD inspired):

- Active straw tube tracker (STT) system with embedded nuclear targets (CH, C, Ar, ...)
- 4π lead-plastic scintillator ECAL
- dipole 0.4 T magnet surrounding STT and ECAL
- 4π RPC based muon detector

Alternative systems:

- High-pressure Ar Gas TPC
- Magnetized LAr TPC

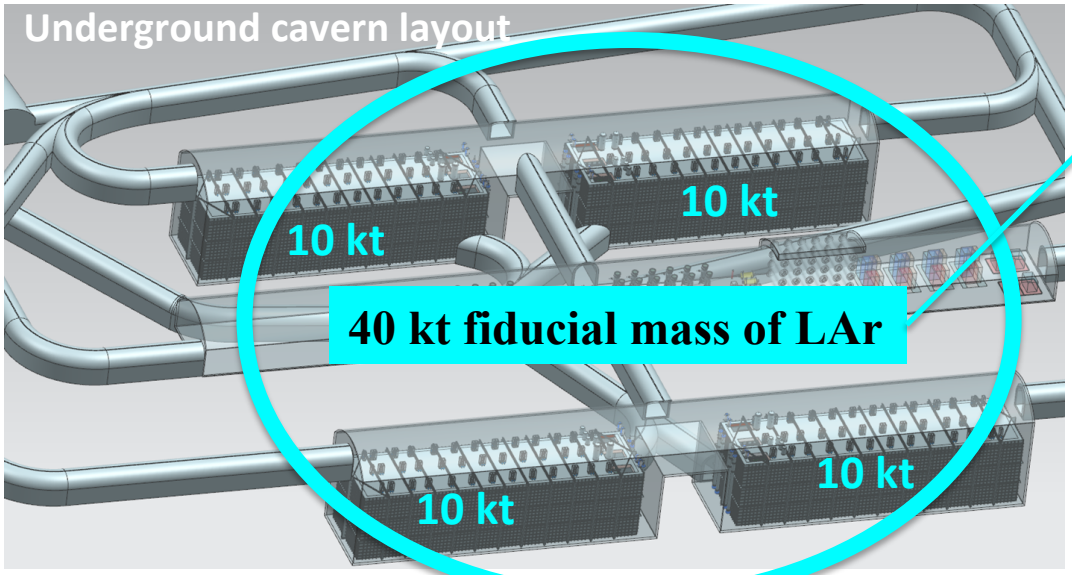
Sanford Underground Research Facility



Located in the former Homestake gold mine in Lead, SD

- The scope of the Far Site includes: the excavation of four underground caverns, each housing a cryostat for a minimum 10 kt fiducial mass LArTPC; and connecting drifts
- Excavations will start in 2017: test blasts have already been conducted (March 2016) to measure vibrations

The DUNE Far Detector



LArTPC provides:

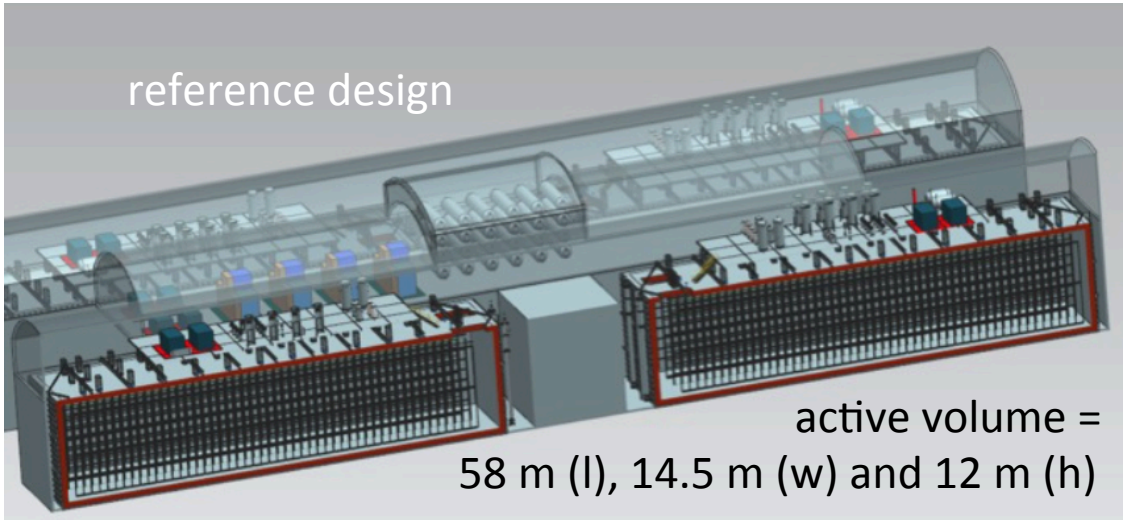
excellent tracking and calorimetry performance

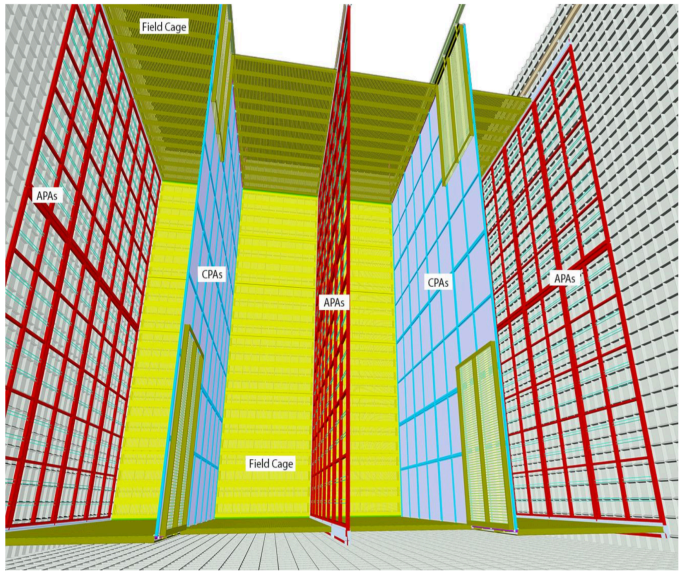
→ high signal efficiency and background discrimination

→ excellent kinematical reconstruction

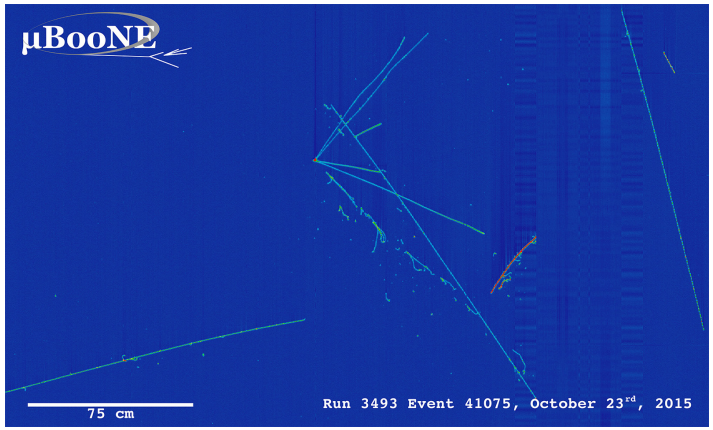
- 4 identical cryostats 62m (length) x 14m (width) x 15m (height)
- Each DUNE 10-kt LArTPC module is O(50x) scale-up w.r.t. largest LArTPC to date (ICARUS)
- To address this challenge, DUNE is developing two far detector options (next slides)
  - a global prototyping strategy for both designs is taking place
  - full-scale engineering prototypes (protoDUNE SP & DP) will be assembled and commissioned at CERN by 2018

The DUNE Far Detector: Single Phase

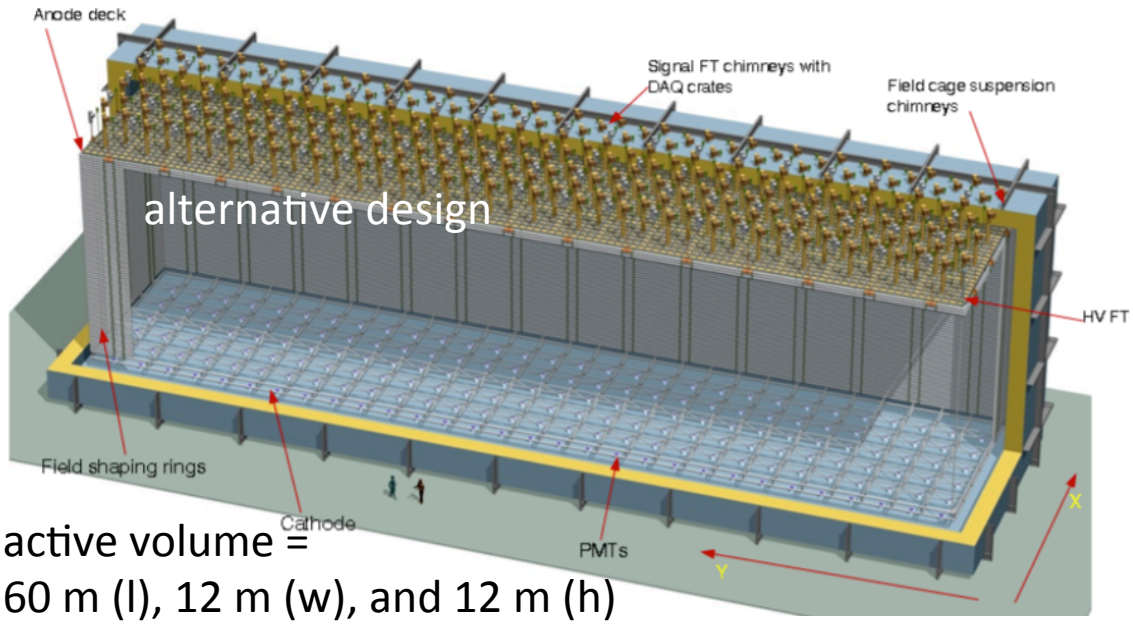




- Based on modular drift cells (ionization read out in liquid Ar)
- Suspended Anode/Cathode assemblies (with 3.6 m maximum drift distance)
- Induction planes at angle of 37.7^{o} wrapped around the frame
- Scintillation detection based on light guide bars embedded in the APAs

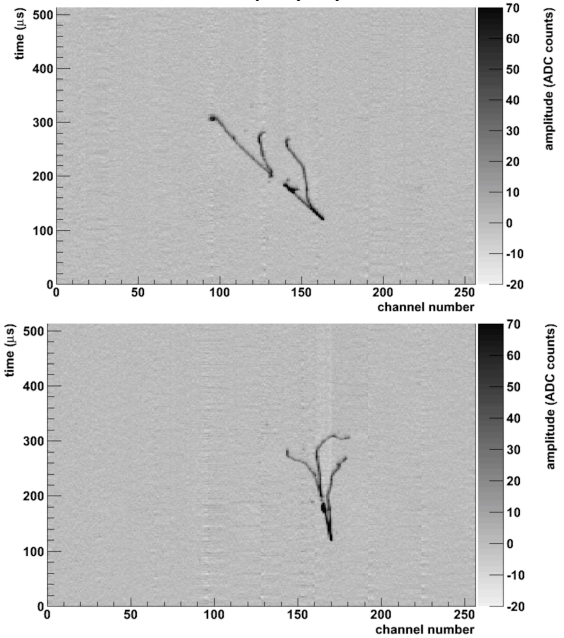


The DUNE Far Detector: Dual Phase



active volume =
60 m (l), 12 m (w), and 12 m (h)

Cosmic event display by LAr LEM-TPC



arXiv:1204.3530

- Dual-phase TPC inspired by LBNO design (ionization amplified & read out in the gaseous Ar)
- 12 m vertical drift, LEM amplification in the gas phase
- Excellent signal/noise ratio (> 100:1)
- Scintillation detection based on PMTs below the cathode

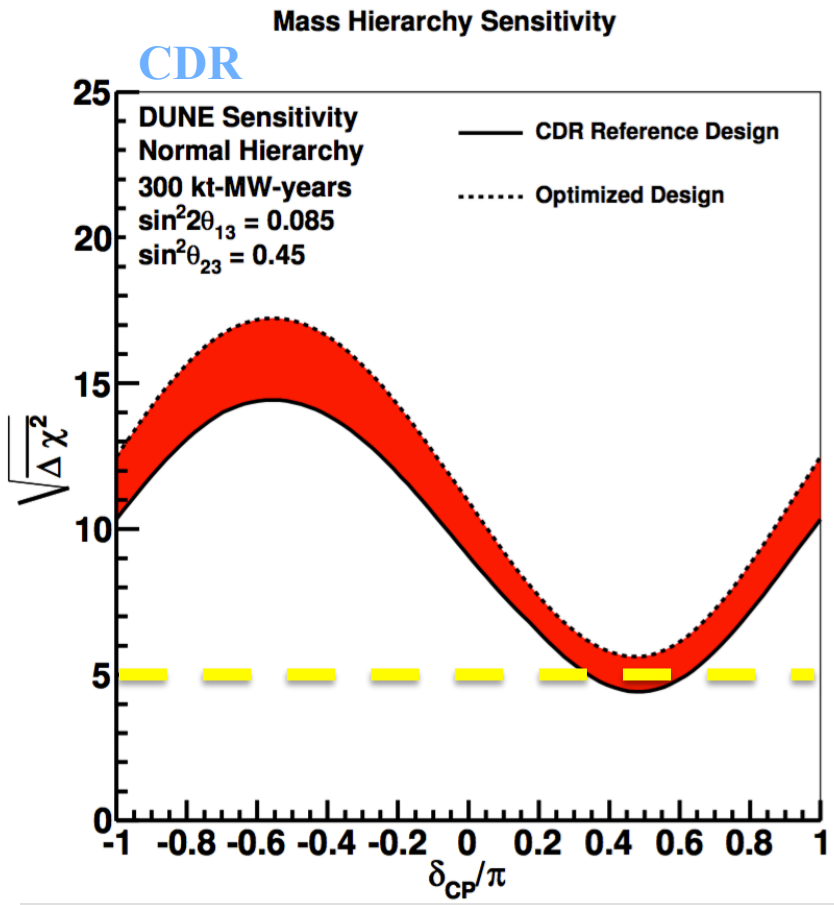
The DUNE Neutrino Oscillation Program

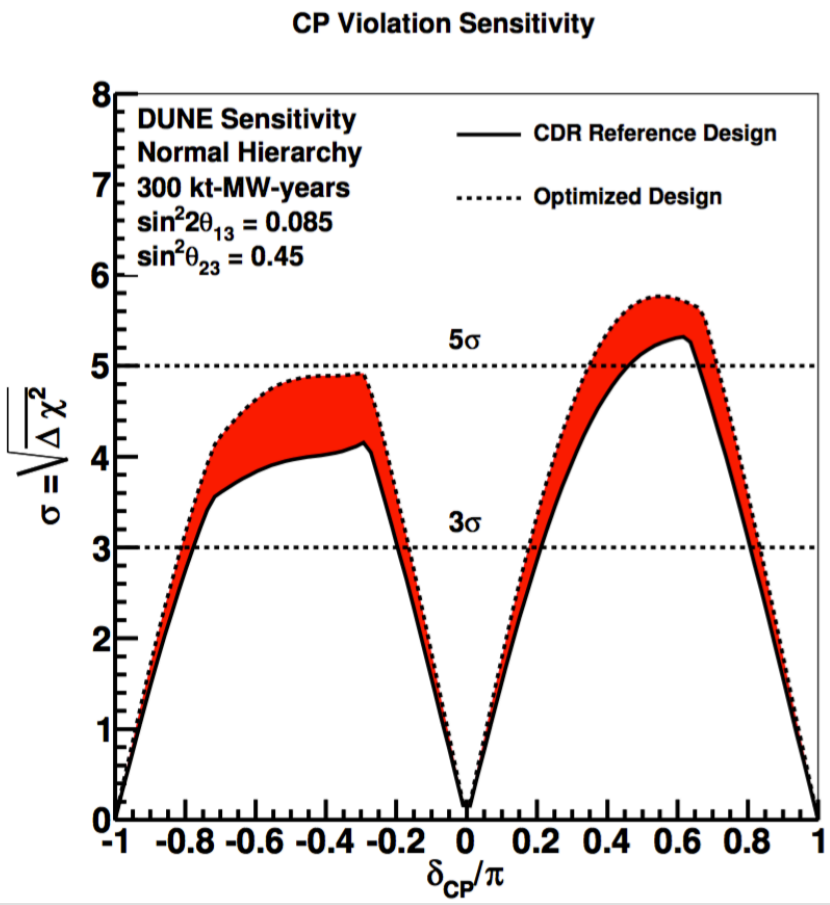
Integrated [0.5 - 8.0 GeV] rate of selected $\nu_{\mu/e}$ CC-like events assuming:
150 kt · MW · year exposure, CDR optimized design, $\theta_{23} = 45^{o}$ and $\delta = 0$

ν mode | Anti-ν mode	ν_e appearance		ν_μ disappearance	
Signal events NH (IH)	**945 (521)**	**168 (438)**	**7929**	**2639**
Wrong-sign signal NH (IH)	13 (26)	47 (28)	511	1525
Beam ν_e background	204	105	---	---
NC background	17	9	76	41
Other background	22	13	29	18

Precise measurement of electron (anti)neutrino appearance and muon (anti)neutrino disappearance → to extract **θ_{23}, θ_{13}, δ and matter effects (MH)**

Mass Hierarchy and CPV sensitivity

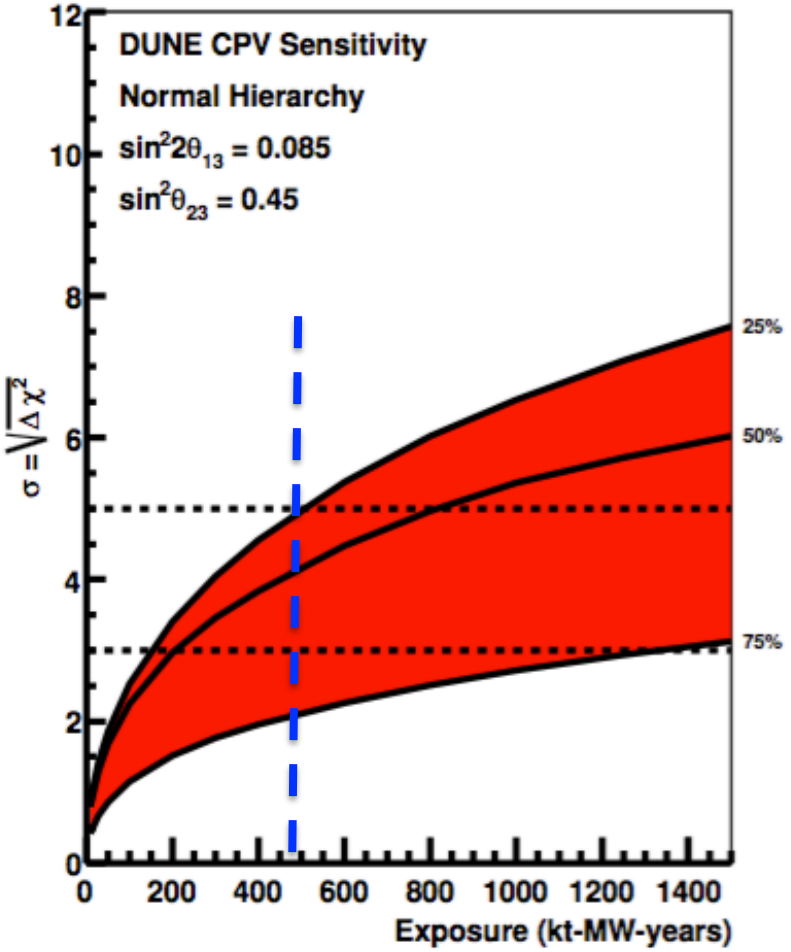


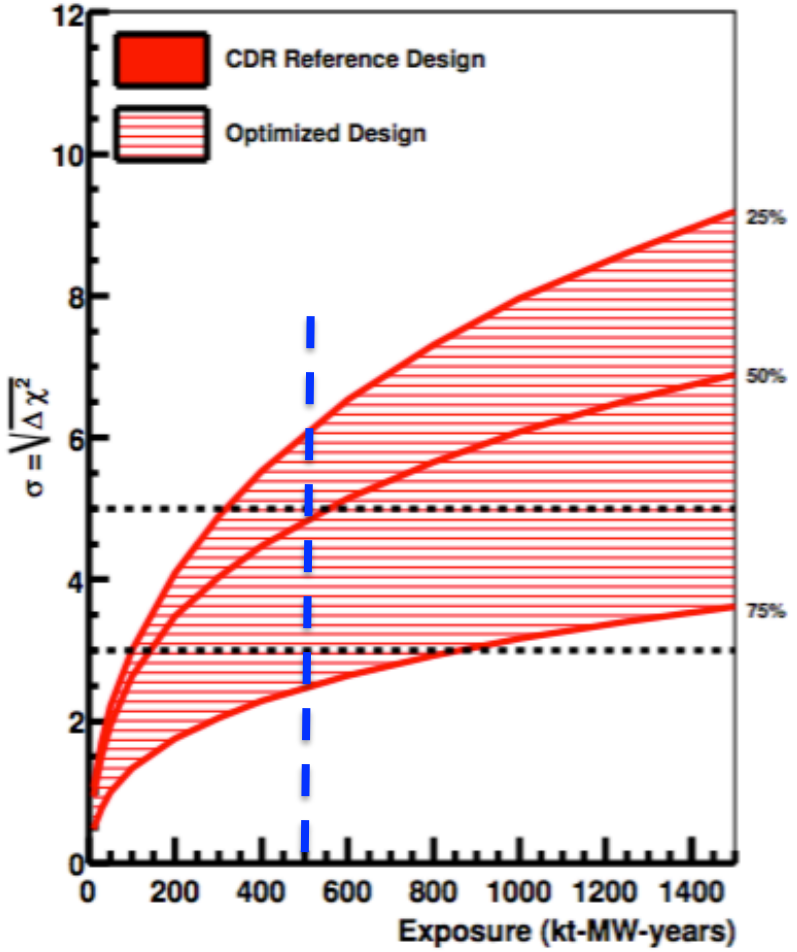


- Significance with which the mass ordering (left) and the CP violation (right) can be determined as a function of δ_{CP} (the inverted hierarchy case is very similar)
- Width of band indicates variation among differing neutrino beam designs
- Includes simple normalization systematics and oscillation parameter variations

Sensitivity over time

CDR





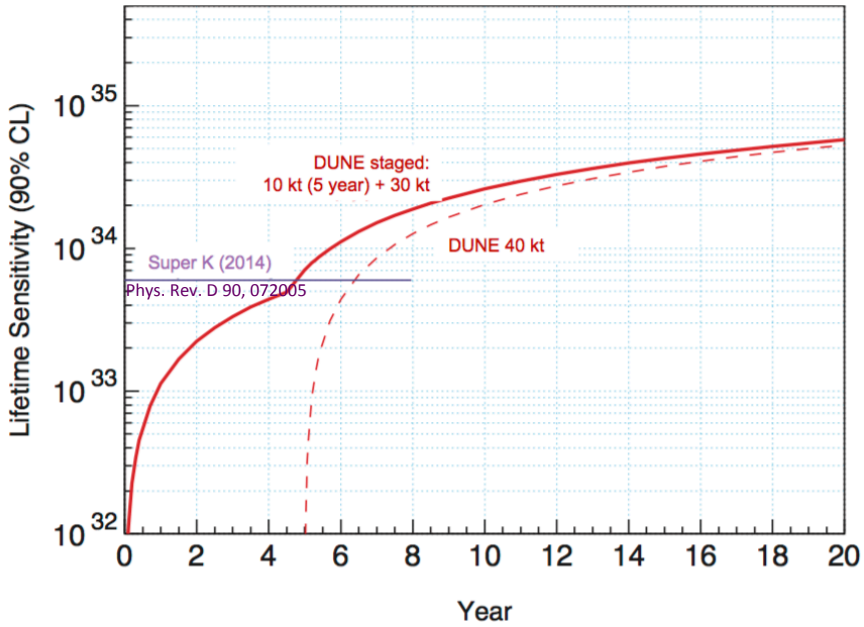
Proton decay search in DUNE

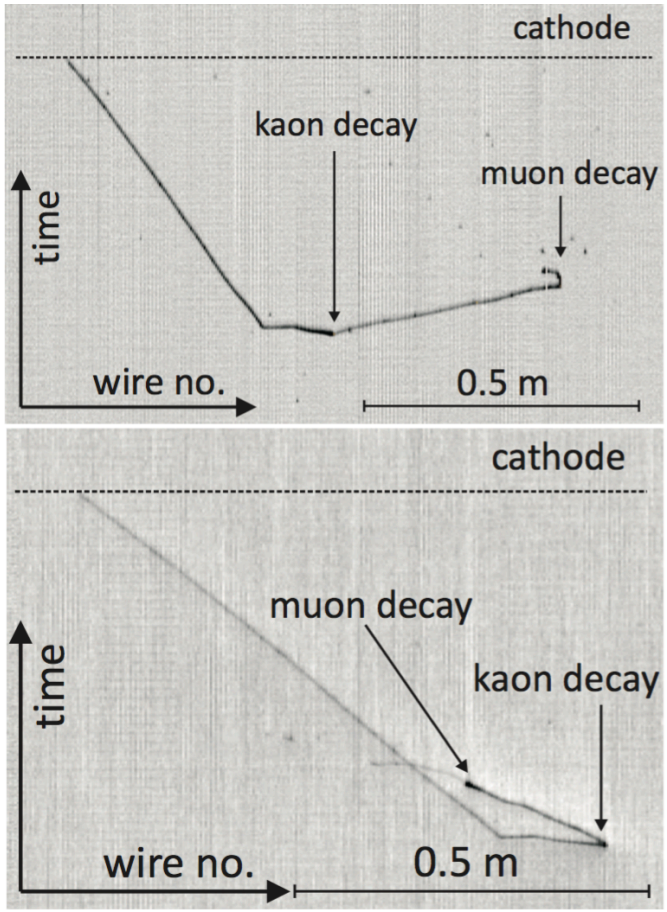
CDR

events per Mt · year

Decay Mode	Water Cherenkov		Liquid Argon TPC	
	Efficiency	Background	Efficiency	Background
$p \to K^+\bar{\nu}$	19%	4	97%	1
$p \to K^0\mu^+$	10%	8	47%	< 2
$p \to K^+\mu^-\pi^+$			97%	1
$n \to K^+e^-$	10%	3	96%	< 2
$n \to e^+\pi^-$	19%	2	44%	0.8

Imaging, particle identification, calorimetric capabilities of LArTPC enable sensitive, **background-free** searches

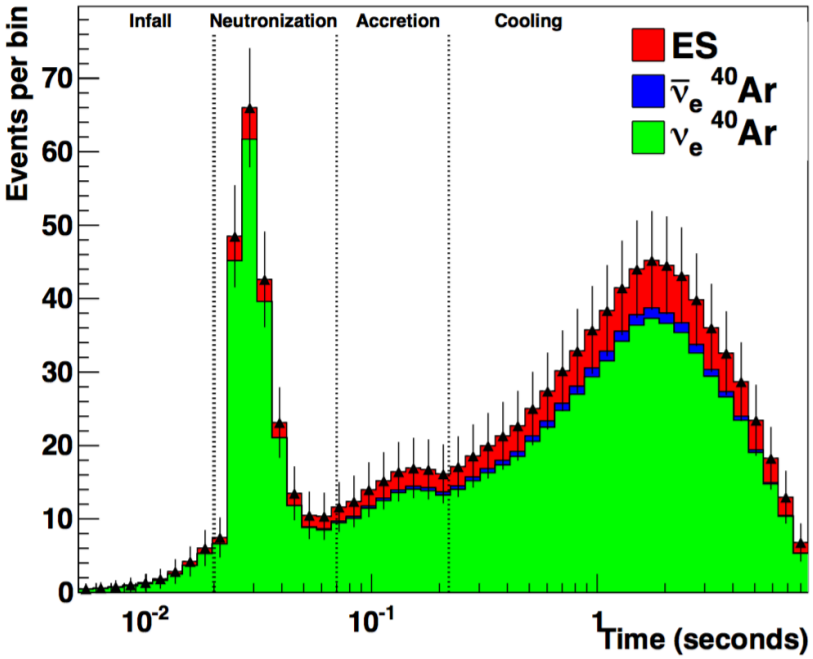




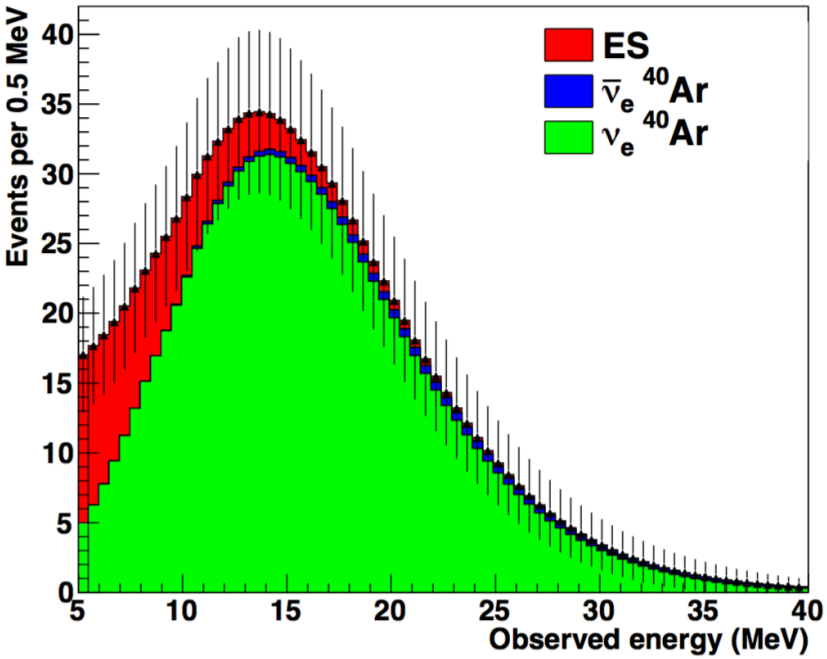
Event display for a decaying kaon candidate in the ICARUS T600 detector observed in the CNGS data

Supernova Signal in DUNE

Flavor composition as function of time



Energy spectra integrated over time



Expected signal in 40 kt of liquid argon for the electron-capture supernova at 10 kpc, calculated using SNoWGLoBES

Dominant process in LAr → in contrast with water or scintillator detectors (anti-ν_e)

Channel	Events "Livermore" model	Events "GKVM" model
$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$	2720	3350
$\bar{\nu}_e + {}^{40}\mathrm{Ar} \rightarrow e^+ + {}^{40}\mathrm{Cl}^*$	230	160
$\nu_x + e^- \rightarrow \nu_x + e^-$	350	260
Total	3300	3770

DUNE Timeline

2017	Cavern excavation
2018	ProtoDUNEs (SP & DP) operational at CERN
2020	Cryostat Construction
2022	Far detector installation (1st module)
2023	Far detector installation (2st module)
2024	**20 kt operational and first data taking**
2026	**First beam operations at 1.2 MW**

Summary

- LBNF/DUNE will be a world-leading facility for pursuing a cutting-edge program of neutrino and astroparticle physics:
  - mass ordering
  - CP violating phase δ_{CP}
  - neutrino mixing angles
  - nucleon decay
  - supernova burst neutrinos
- On the path to building a 40 kt of liquid argon detector and a 1.2 MW neutrino beam:

  Construction phase starting→ beginning excavation of far site next year and in 2018 ProtoDUNEs will start taking data

Back-Up

Beamline specifications

CDR vol.3

combined uptime and efficiency of the FNAL accelerator complex and the LBNF beamline of 56%

Table 3.1: Expected POT per year at various primary proton beam momenta.

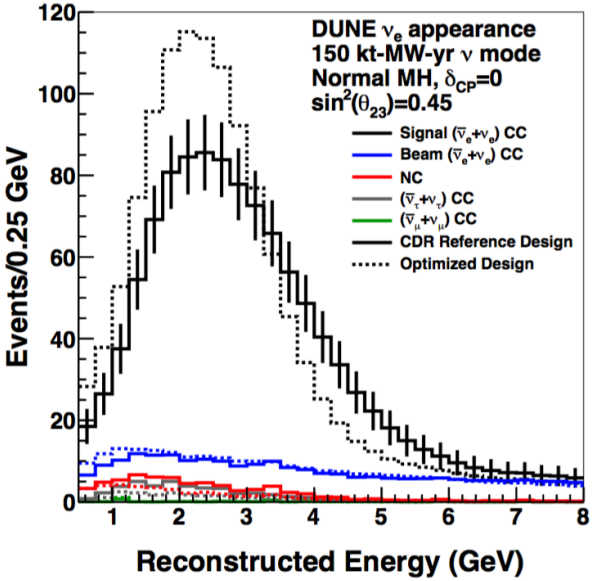
Proton Momentum (GeV/c)	Expected Beam Power (MW)	Expected POT/year
120	1.2	1.1×10^{21}
80	1.07	1.47×10^{21}
60	1.03	1.89×10^{21}

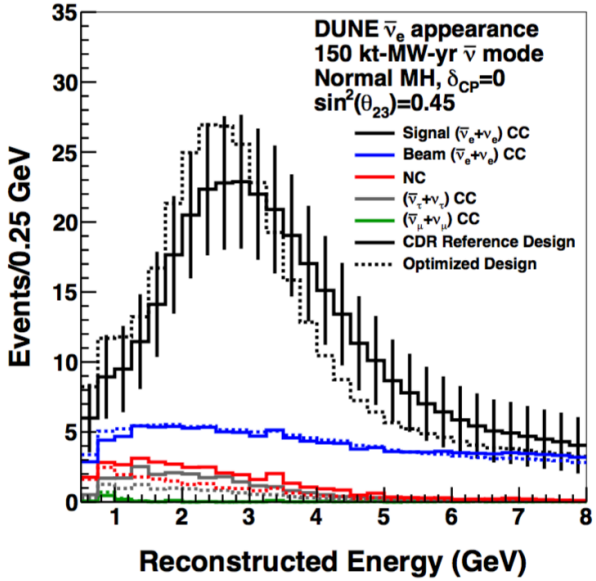
Table 3.2: A comparison of the beamline parameters assumed for the CDR Reference Design flux and the Optimized Design flux used in the sensitivity calculations presented in this chapter. Section 3.9.1 provides the details.

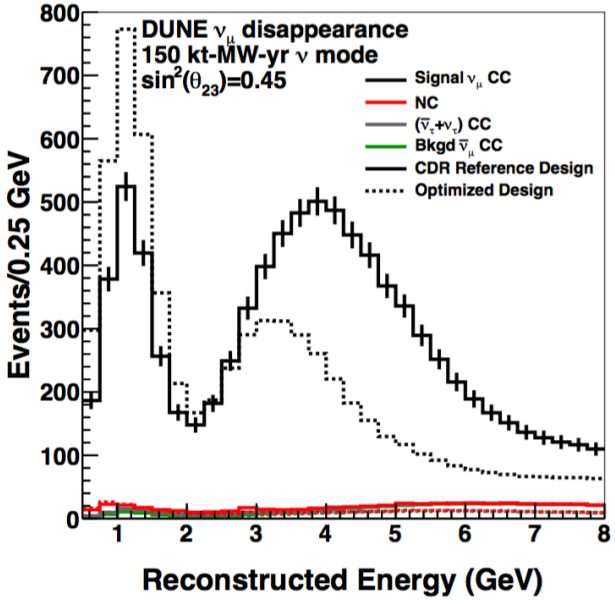
Parameter	CDR Reference Design	Optimized Design
Proton Beam Energy	80 GeV	80 GeV
Proton Beam Power	1.07 MW	1.07 MW
Target	Graphite	Graphite
Horn Current	230 kA	297 kA
Horn Design	NuMI-style	Genetic Optimization
Decay Pipe Length	204 m	241 m
Decay Pipe Diameter	4 m	4 m

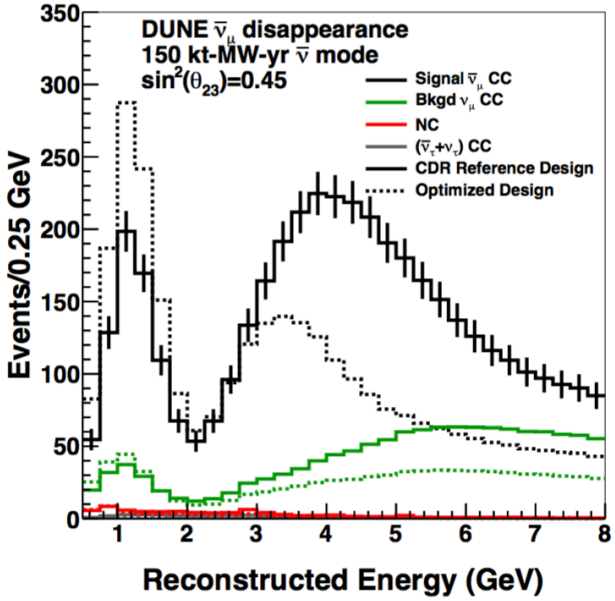
Expected Event Rate

CDR vol.3

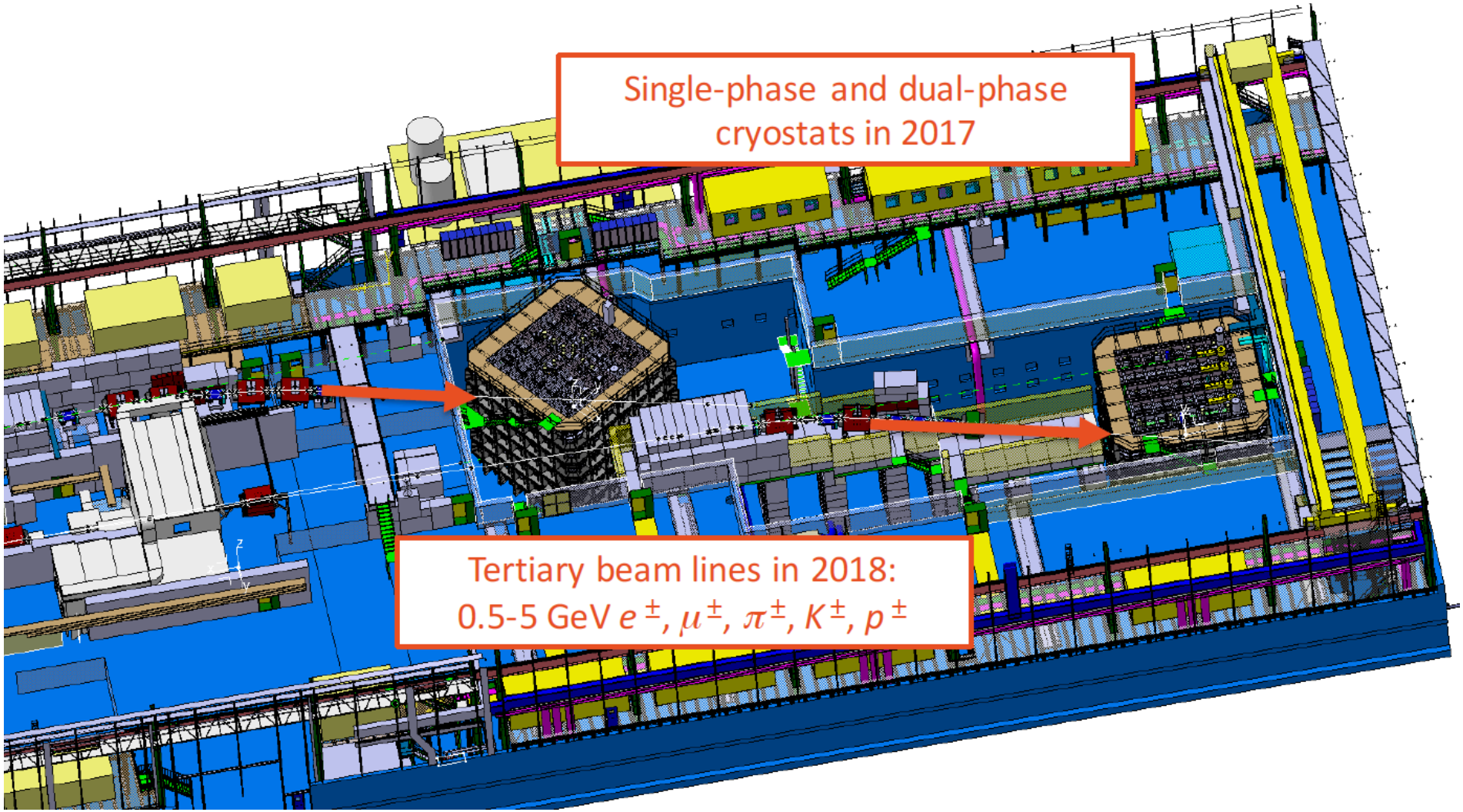








The CERN Neutrino Platform



Some details about the readoutin both, reference and alternative designs

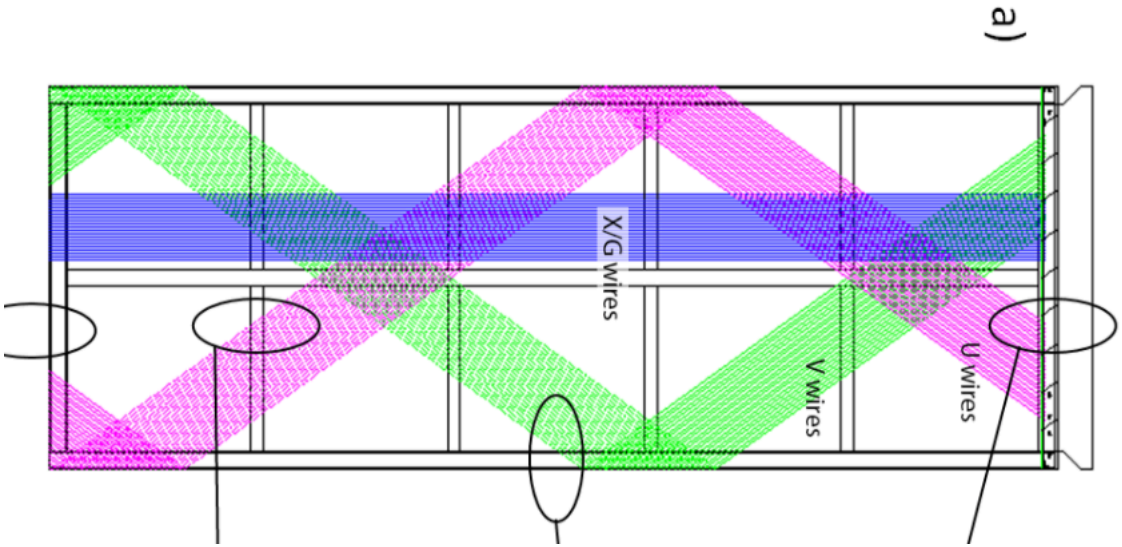
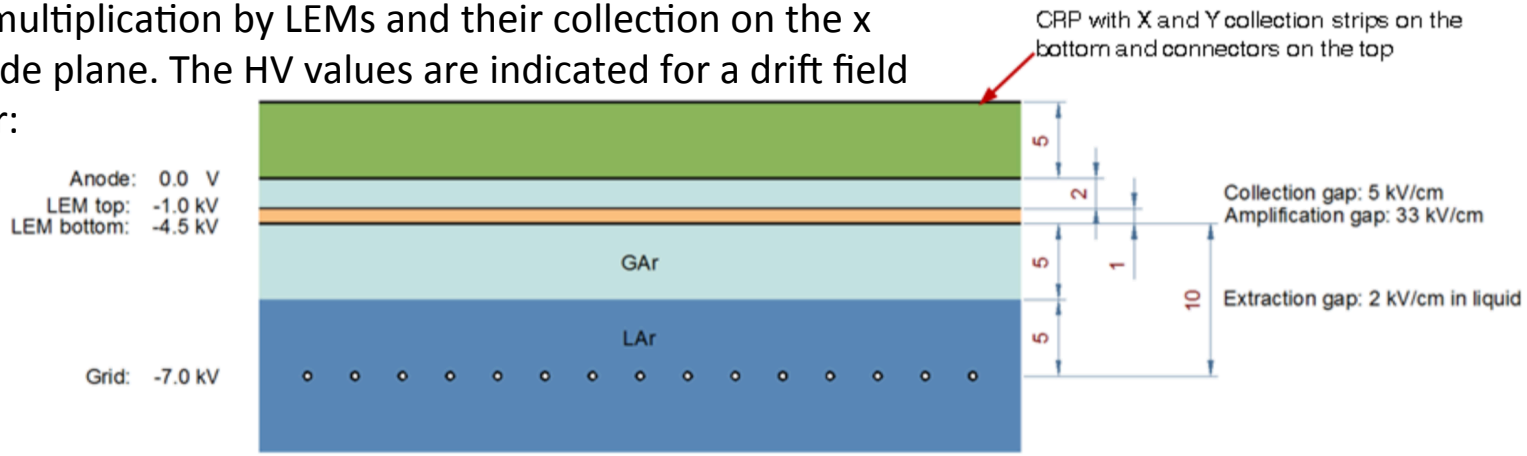


Illustration of the APA wire wrapping scheme color: magenta (U), green (V), blue (X). The fourth wire plane (G) above these three, parallel with X, is present to improve the pulse shape on the U plane signals.

Thicknesses and HV values for electron extraction from liquid to gaseous Ar, their multiplication by LEMs and their collection on the x and y readout anode plane. The HV values are indicated for a drift field of 0.5 kV/cm in Lar: