DUNE Physics

Jim Strait, Fermilab
on behalf of the DUNE Collaboration

NuFact 2015
Rio de Janeiro, Brazil
10 August 2015

The DUNE Collaboration

is a newly formed scientific collaboration, with strong representation from the previous LBNE, LBNO and other collaborations

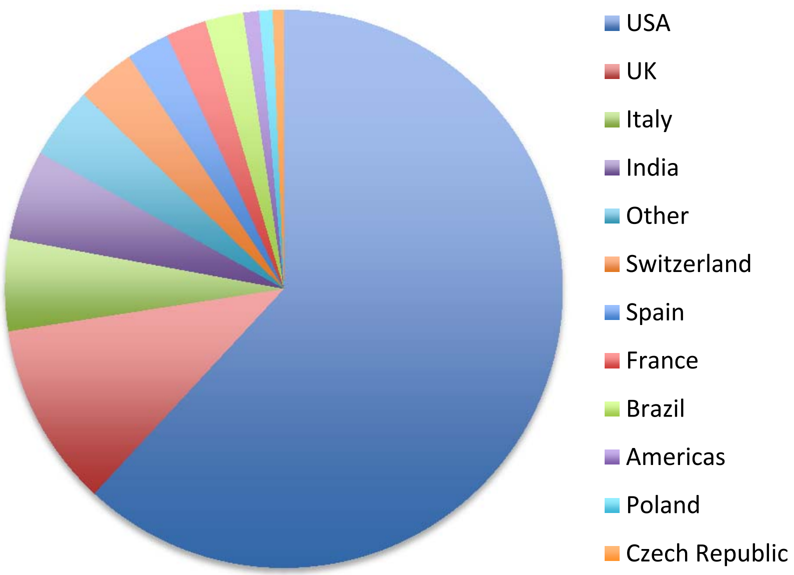
- **Collaboration structure is taking form**
  See http://www.dunescience.org/ for details
- **First formal collaboration meeting 16-18 April 2015**
  Over 200 people attended in person

- **Next collaboration meeting 2-6 September 2015**
  https://indico.fnal.gov/conferenceDisplay.py?confId=10100

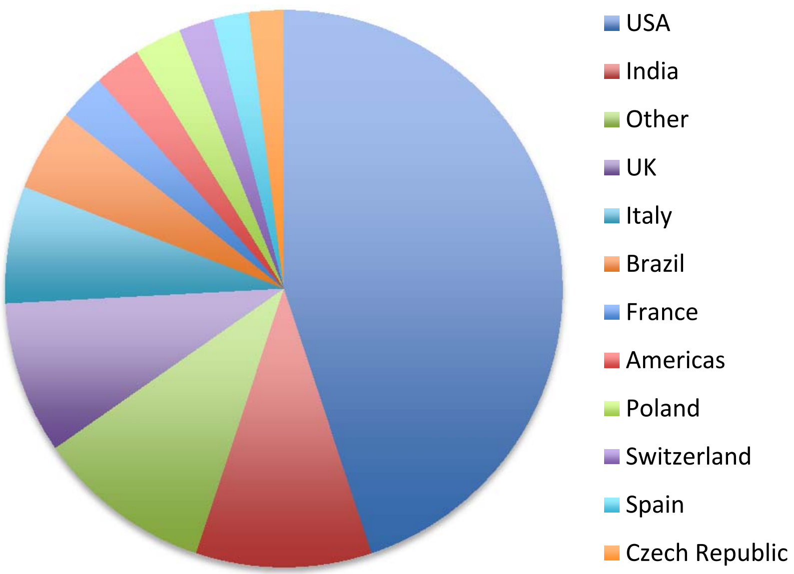
The DUNE Collaboration

Currently: from

776 Collaborators



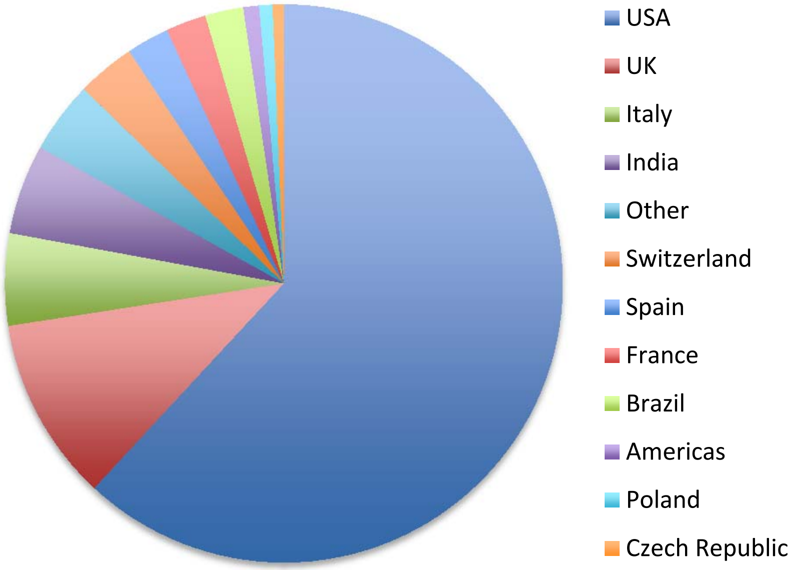
144 Institutes



The DUNE Collaboration

Currently: **from**

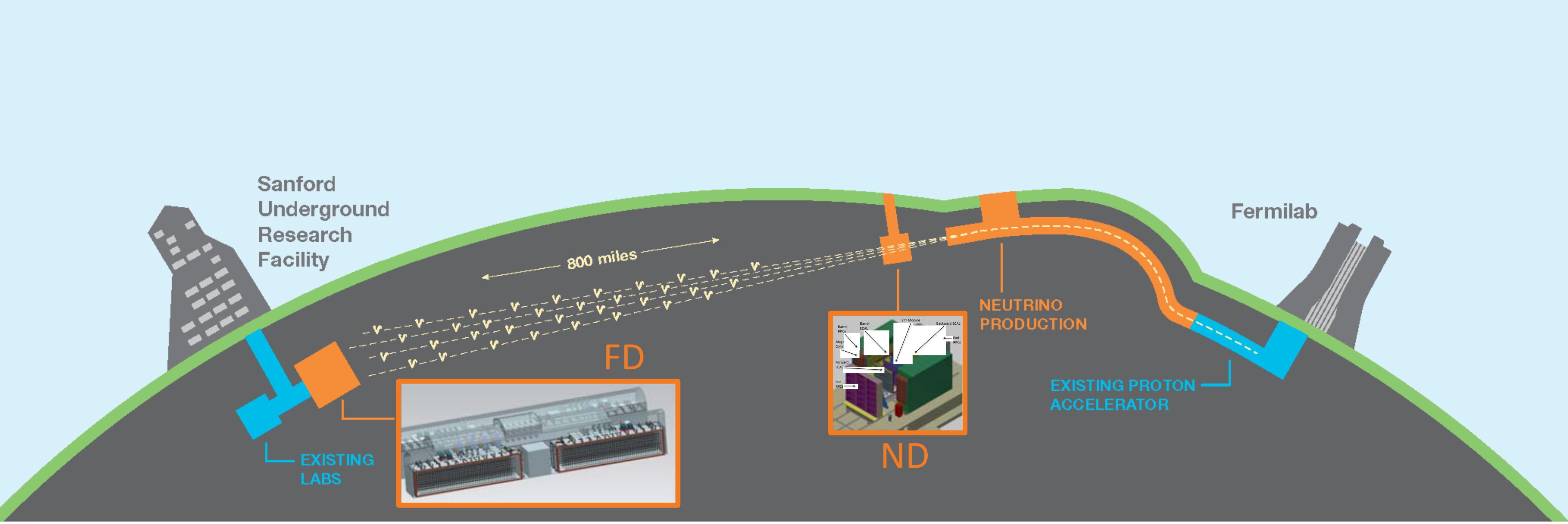
776 Collaborators **26 Nations**



Armenia, Belgium, Brazil, Bulgaria, Canada, Colombia, Czech Republic, France, Germany, India, Iran, Italy, Japan, Madagascar, Mexico, Netherlands, Peru, Poland, Romania, Russia, Spain, Switzerland, Turkey, UK, USA, Ukraine

DUNE already has broad international support

LBNF/DUNE Design

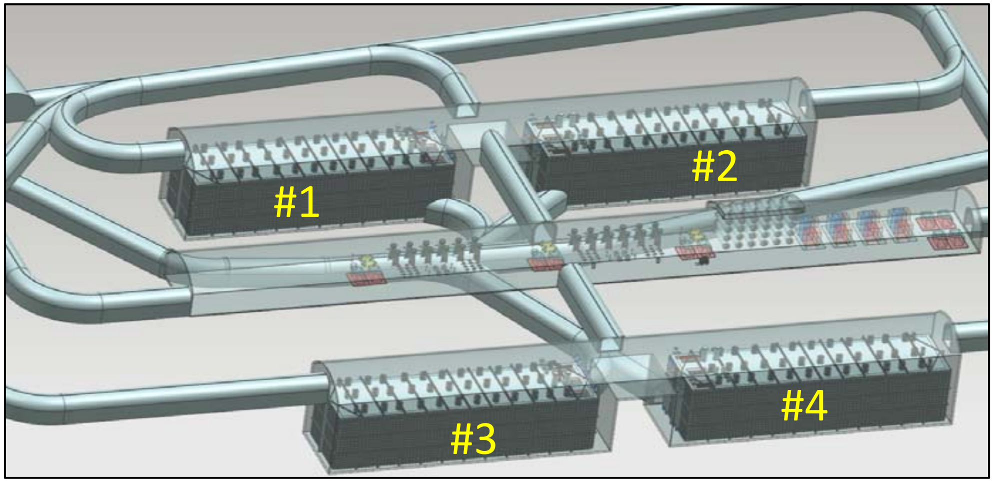


Staged Approach to 40 kt

Four-Cavern Layout at the Sanford Underground Research Facility (SURF) at the 4850 foot Level (4300 m.w.e.)

➡ **four caverns hosting four independent 10-kt (fiducial mass) Far Detector modules**

- Allows for staged construction of the Far Detector
- Gives flexibility for evolution of LArTPC technology design
  - Assume four identical cryostats: 15.1 (W) x 14.0 (H) x 62 (L) m^3
  - Assume the four 10-kt modules will be similar but **not identical**



Reference Design

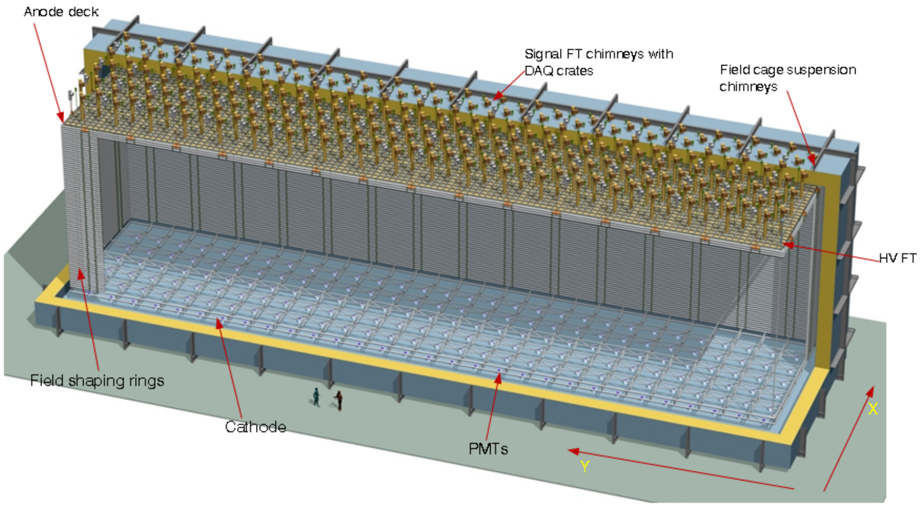
The single-phase LArTPC design is the reference design for the CDR

- **Design is already well advanced for CDR stage**
  - Design follows from the successful ICARUS design
- **Supported by strong development program at Fermilab**
  - 35-t prototype (operational in 2015)
  - MicroBooNE (operational in 2015)
  - SBND & refurbished ICARUS (operational in 2018)
- **"Full-scale prototype" with the DUNE Single-Phase Prototype at the CERN Neutrino Platform**
  - Engineering prototype of DUNE reference design
    - 6 full-sized drift cells
  - Positive (informal) feedback from CERN SPSC (June 2015)
  - Expect approval in September & aiming for operation in 2018

Alternative Design

DUNE collaboration recognizes the potential of the dual-phase technology

- Strongly supports the WA105 development program at the CERN neutrino platform
- A dual-phase implementation of the DUNE far detector is presented as an **alternative design** in the CDR
- If demonstrated, could form basis of second or subsequent 10-kt far detector modules

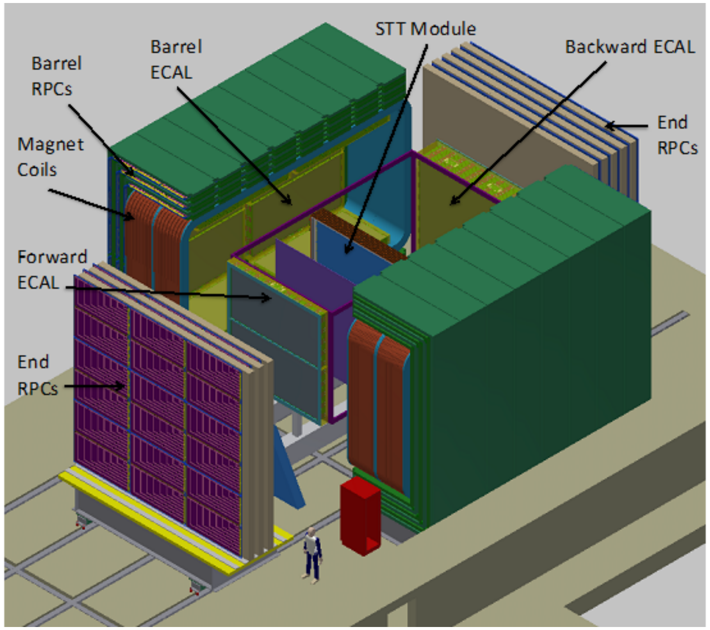


DUNE Near Detector Strategy

- **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

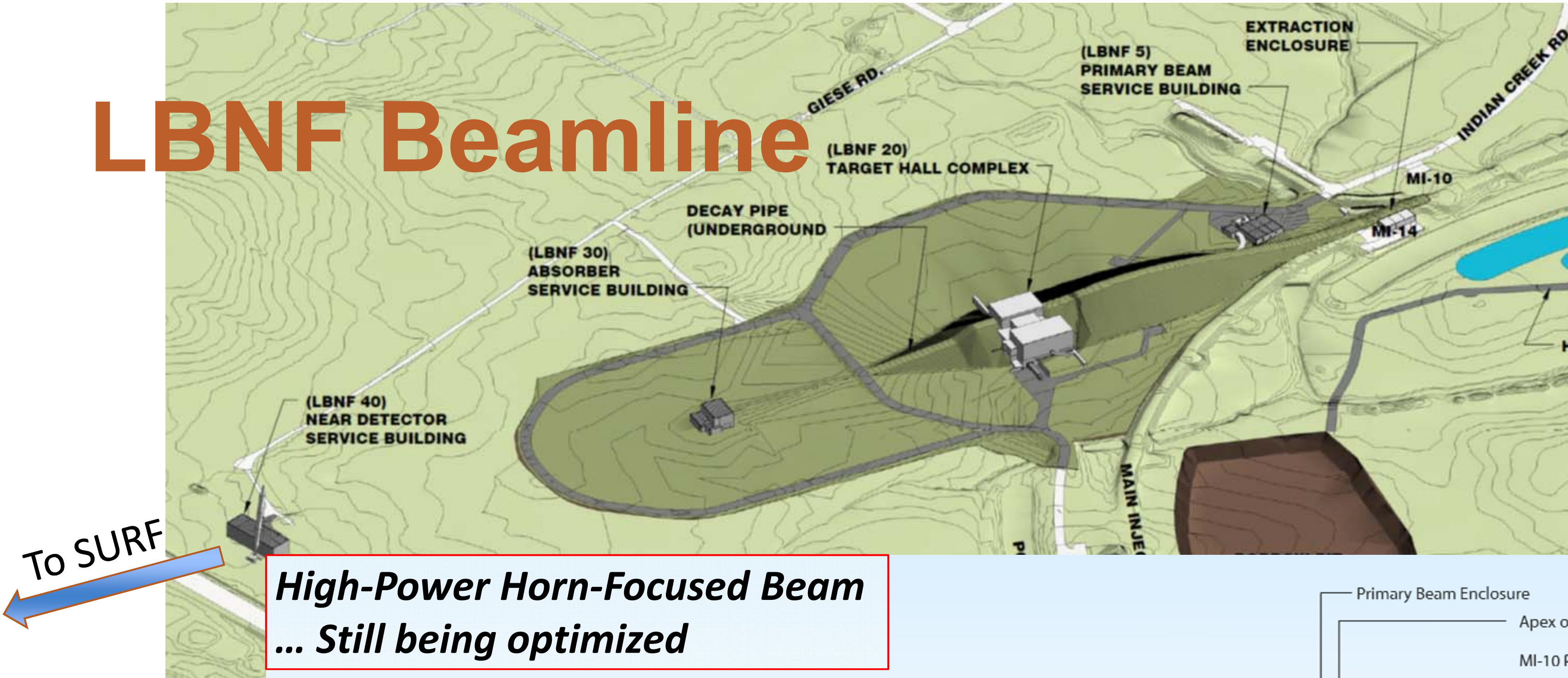
The NOMAD-inspired Fine-Grained Tracker (FGT)



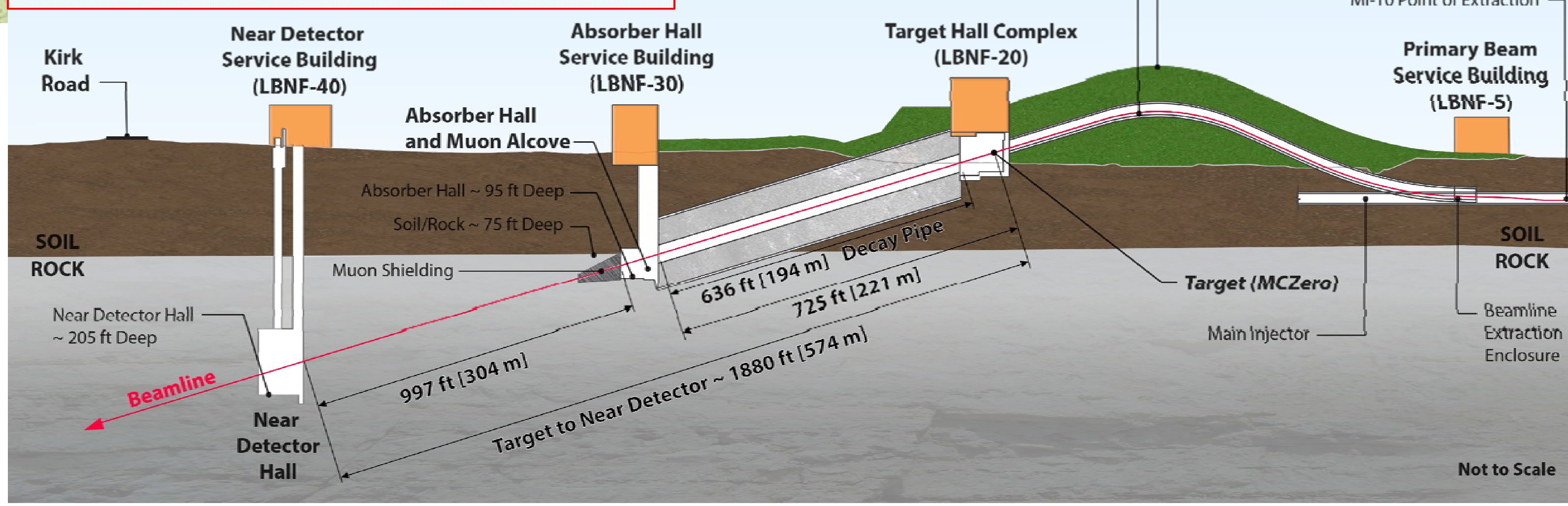
- **It consists of:**
  - Central straw-tube tracking system
  - Lead-scintillator sampling ECAL
  - Large-bore warm dipole magnet
  - RPC-based muon tracking systems
- **It provides:**
  - Constraints on cross sections and the neutrino flux
  - A rich self-contained non-oscillation neutrino physics 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

Details in talk by K.McDonald in WG1+2, Tuesday a.m.

LBNF Beamline

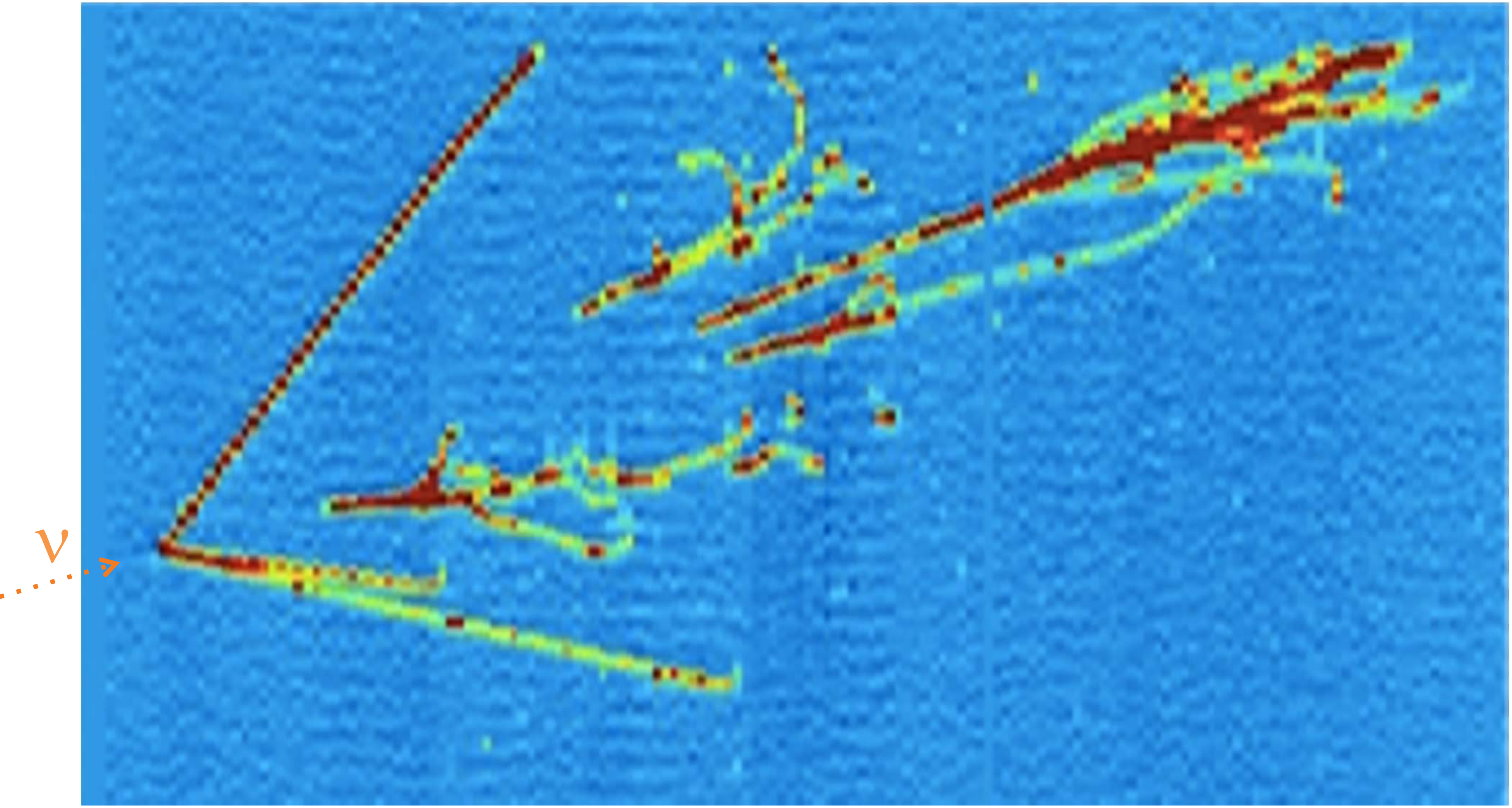


High-Power Horn-Focused Beam
… Still being optimized



Details in talk in WG3, Friday at 15:00

DUNE Science Strategy



A neutrino interaction in the ArgoNEUT detector at Fermilab

Scientific Objectives

The LBNF/DUNE scientific objectives are categorized as

- the *primary science program*, addressing the key science questions highlighted by P5
- The high-priority *ancillary science program* that is enabled by the construction of LBNF and DUNE
- and *additional scientific objectives*

The primary science program drives the high-level requirements for and design of LBNF and DUNE

DUNE Primary Science Program

Focus on fundamental open questions in particle physics and astroparticle physics:

- **1) Neutrino Oscillation Physics**
  - CPV in the leptonic sector
    - "Our best bet for explaining why there is matter in the universe"
  - Mass Hierarchy
  - Precision Oscillation Physics & testing the 3-flavor paradigm
- **2) Nucleon Decay**
  - Predicted in beyond the Standard Model theories [but not yet seen]
    - e.g. the SUSY-favored mode, $p \rightarrow K^+\bar{\nu}$
- **3) Supernova burst physics & astrophysics**
  - Galactic core collapse supernova, sensitivity to ν_e
    - Time information on neutron star or even black-hole formation

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Any would be a major discovery

DUNE Ancillary Science Program

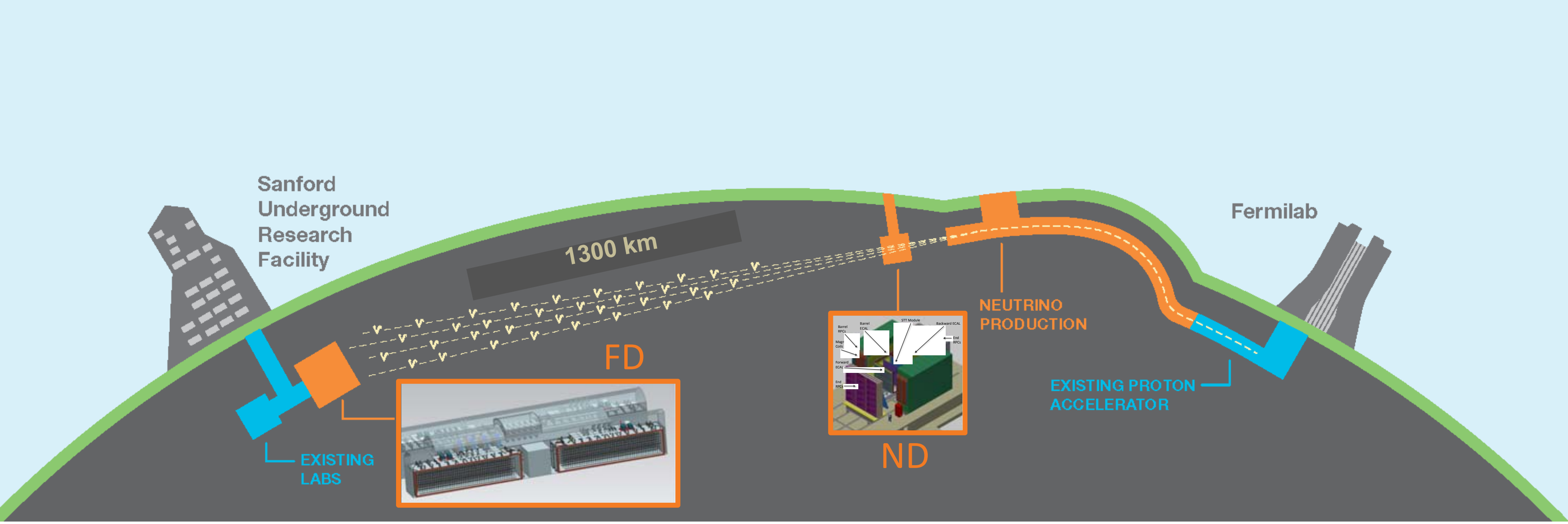
Enabled by the intense LBNF beam and the DUNE near and far detectors

- **Other LBL oscillation physics with BSM sensitivity**
  - Neutrino non-standard interactions (NSIs)
  - Sterile Neutrinos at the near and far sites
  - Measurements of tau neutrino appearance
- **Oscillation physics with atmospheric neutrinos**
- **Neutrino Physics in the near detector**
  - Neutrino cross section measurements
  - Studies of nuclear effects, FSI etc.
  - Measurements of the structure of nucleons
  - Neutrino-based measurements of $\sin^2\theta_W$
- **Search for signatures of Dark Matter**

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 **single experiment**



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

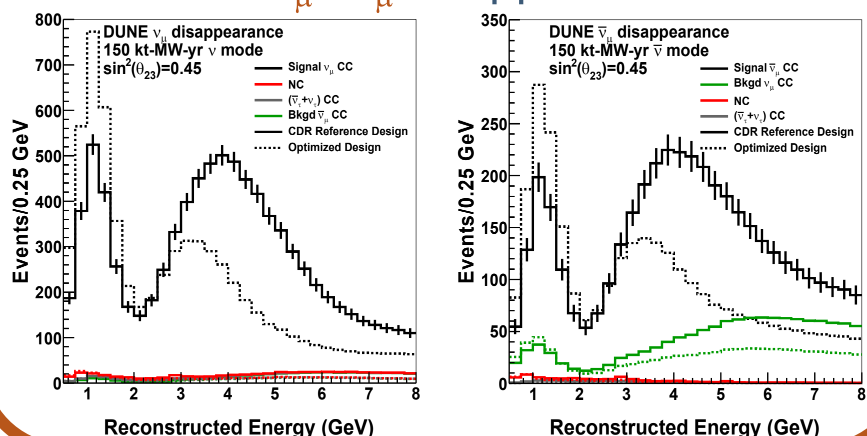
Neutrino Oscillation Strategy

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

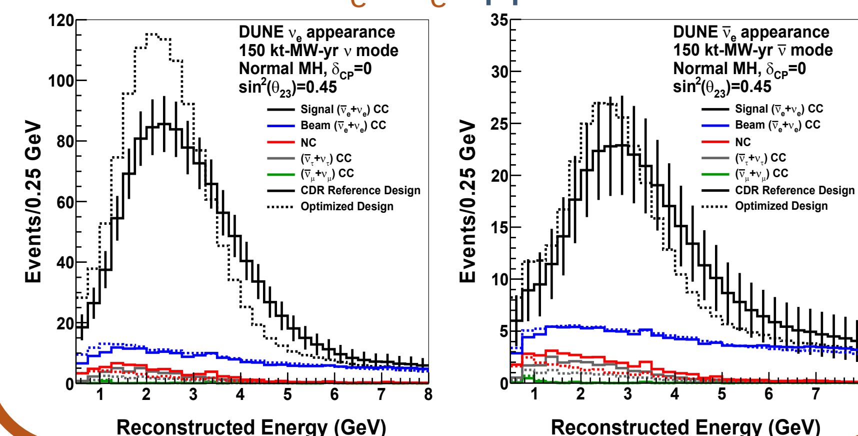
- **Determine MH and θ_{23} octant, probe CPV, test 3-flavor paradigm and search for ν NSI in a single experiment**
  - Long baseline:
    - Matter effects are large ~ 40%
  - Wide-band beam:
    - Measure ν_e appearance and ν_μ disappearance over range of energies
    - MH & CPV effects are separable

E ~ few GeV

ν_μ / $\bar{\nu}_\mu$ disappearance



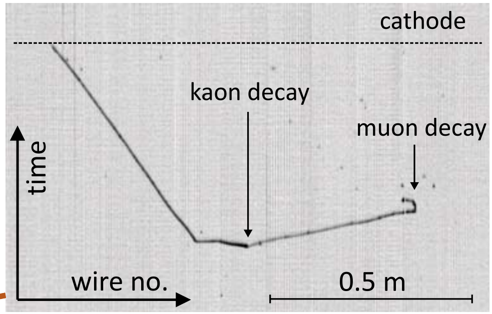
ν_e / $\bar{\nu}_e$ appearance



Nucleon Decay & Supernova νs

Nucleon decay

- **Image particles from nucleon decay**
  - target sensitivity to kaons (from d*E*/d*x*) from SUSY-inspired GUT p-decay modes

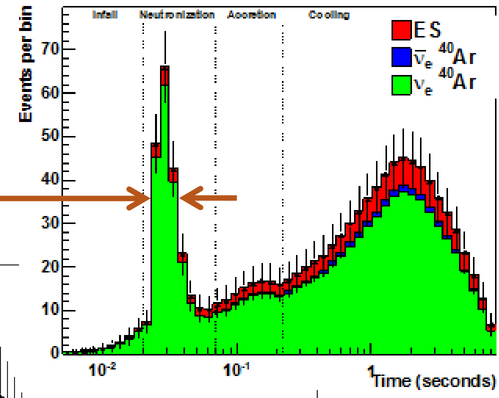


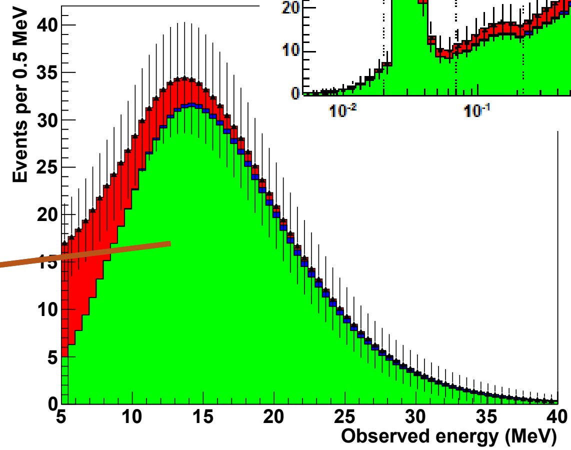
E ~ O(200 MeV)

Supernova burst neutrinos

- **Astrophysics *and* neutrino physics**
  - To date only observed $\bar{\nu}_e$ from single SN
  - In argon, the largest sensitivity is to ν_e
    - CC interaction: $\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$

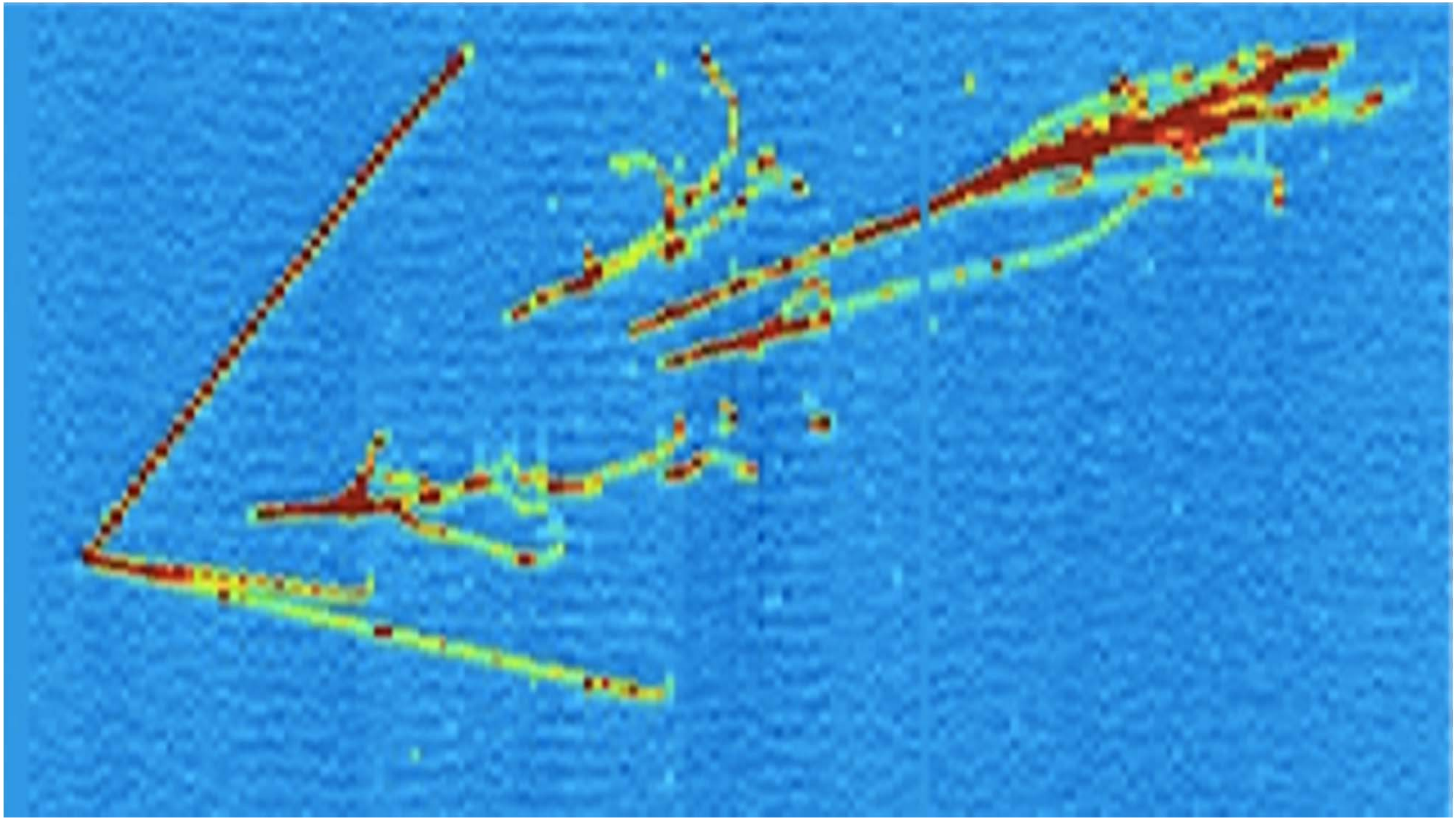
δt ~ O(10 ms)





E ~ O(10 MeV)

DUNE Sensitivities

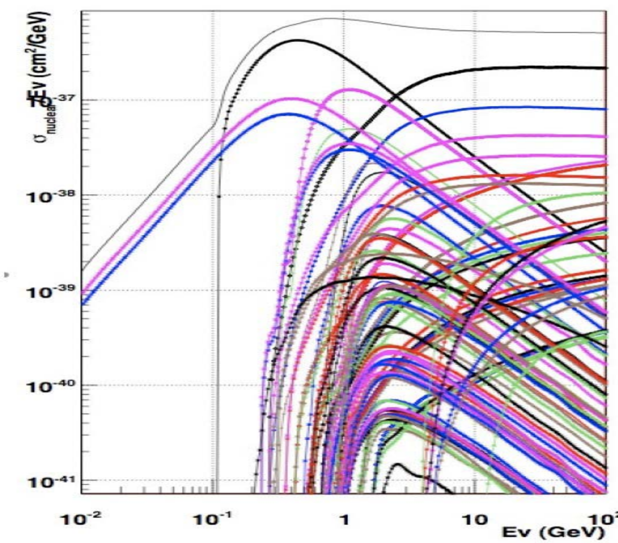


Evaluating DUNE Sensitivities I

Many inputs to calculation (implemented in GLoBeS):

- **Reference Beam Flux**
  - 80 GeV protons
  - 1.07 MW
  - NuMI-style two horn system
- **Cross sections**
  - GENIE 2.8.4
  - CC & NC
  - all (anti)neutrino flavors

Exclusive ν-nucleon cross sections

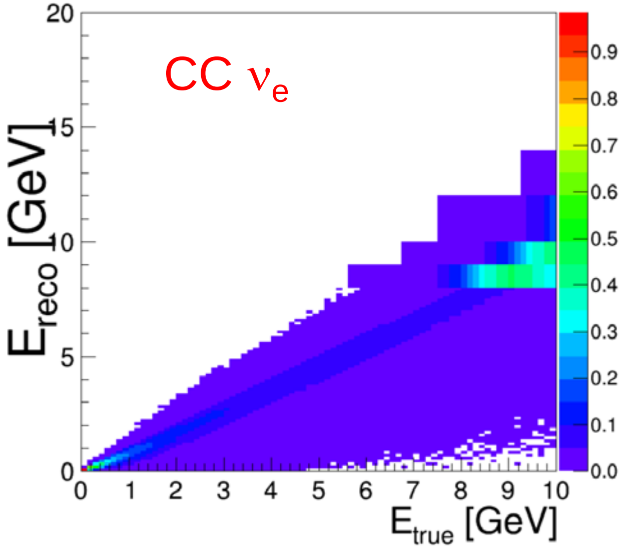


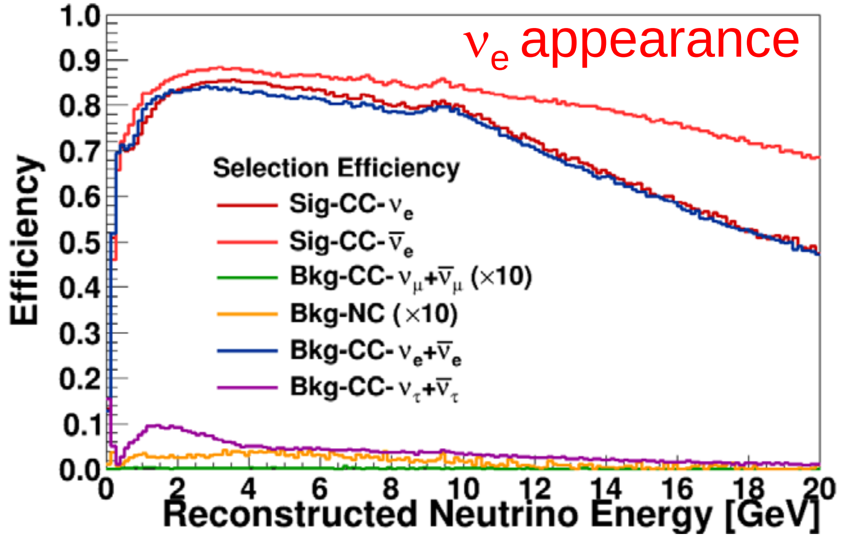
- **Optimized Beam Flux**
  - Horn system optimized for lower energies*
- **Expected Detector Performance**
  - Based on previous experience (ICARUS, ArgoNEUT, …)

****See talk in WG3, Friday at 15:00***

Evaluating DUNE Sensitivities II

- **Efficiencies & Energy Reconstruction from "Fast MC"**
  - Generate neutrino interactions in LAr using GENIE
  - **Fast MC** smears response at generated final-state particle level
    - "Reconstructed" neutrino energy
    - kNN-based MV technique used for ν_e "event selection": parameterized efficiencies
  - Used as inputs to GLoBES

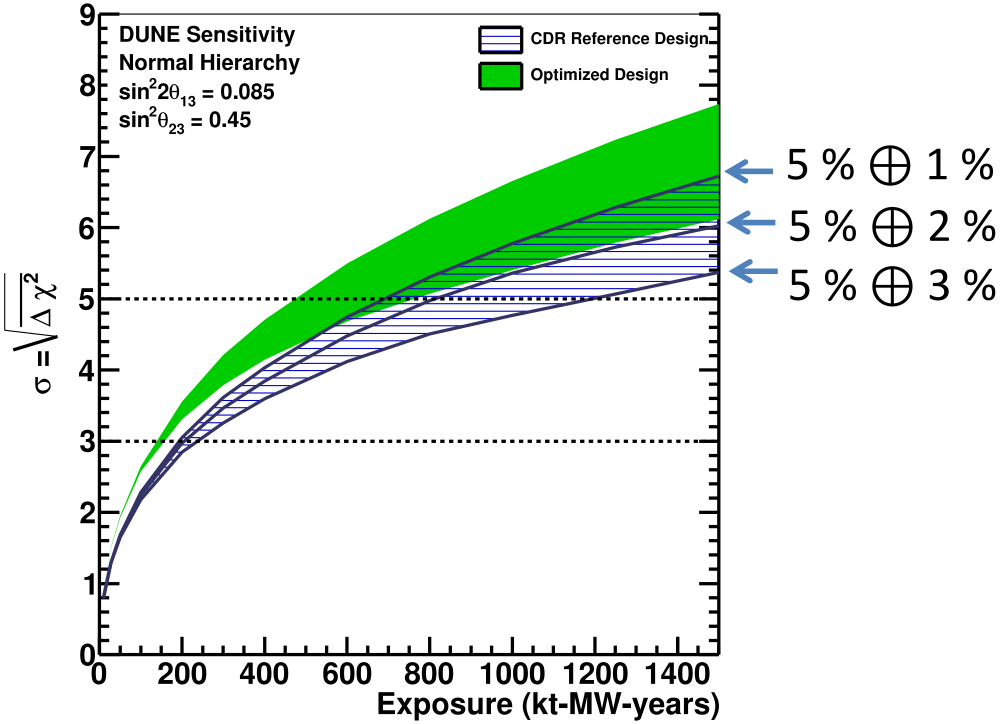




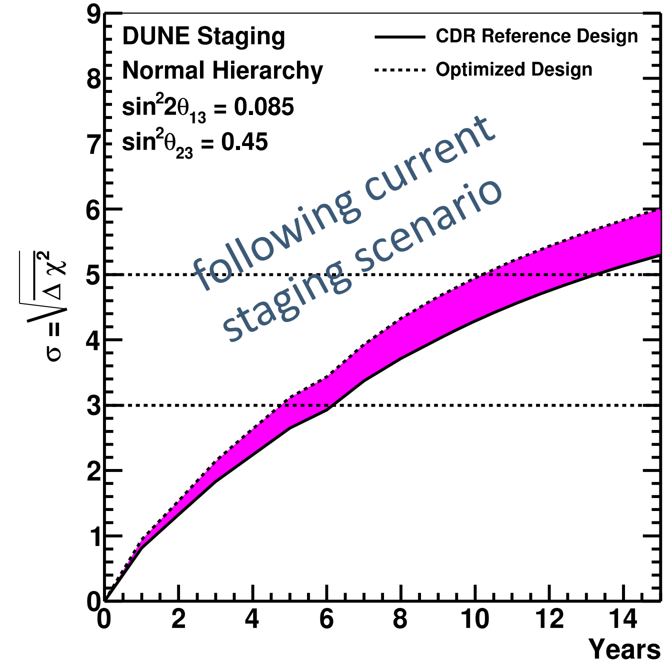
DUNE Sensitivity to CP Violation

Propagate to Oscillation Sensitivities
using assumptions for systematics (from the ND)

50 % CP Violation Sensitivity



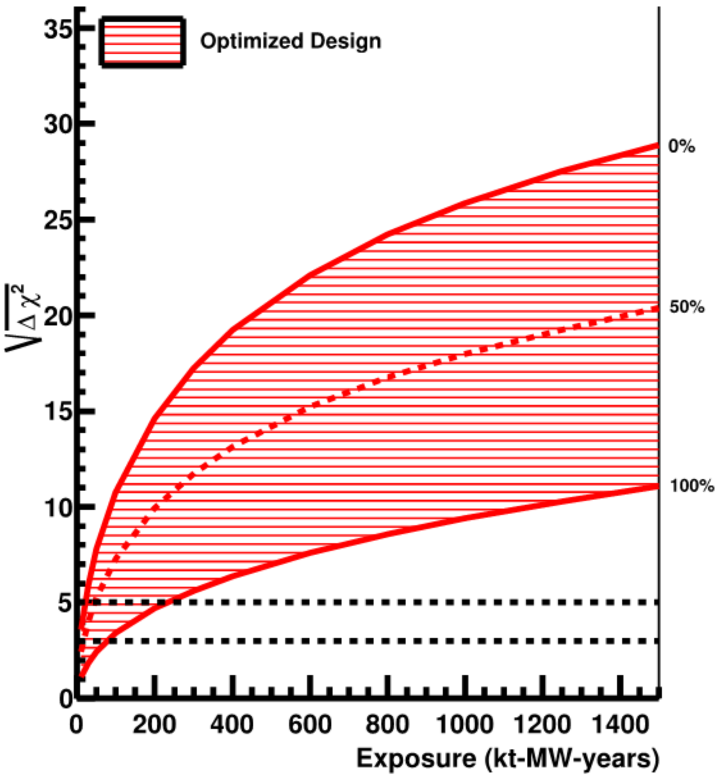
50 % CP Violation Sensitivity

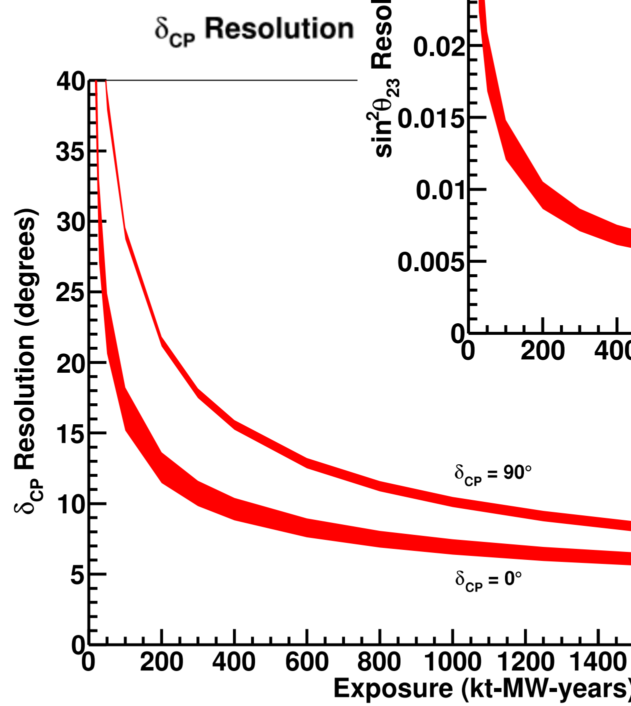


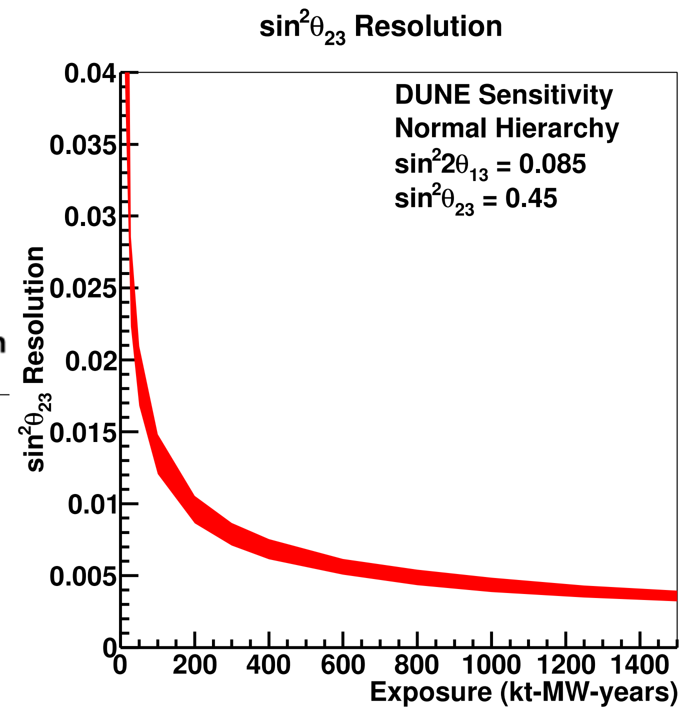
<3 % ν_e systematics important after ~200 kt.MW.yr

=> See talk by Dan Cherdack in WG1+2+3 session Thursday at 11:00

MH, δ_{CP} and $\sin^2\theta_{23}$ Sensitivities



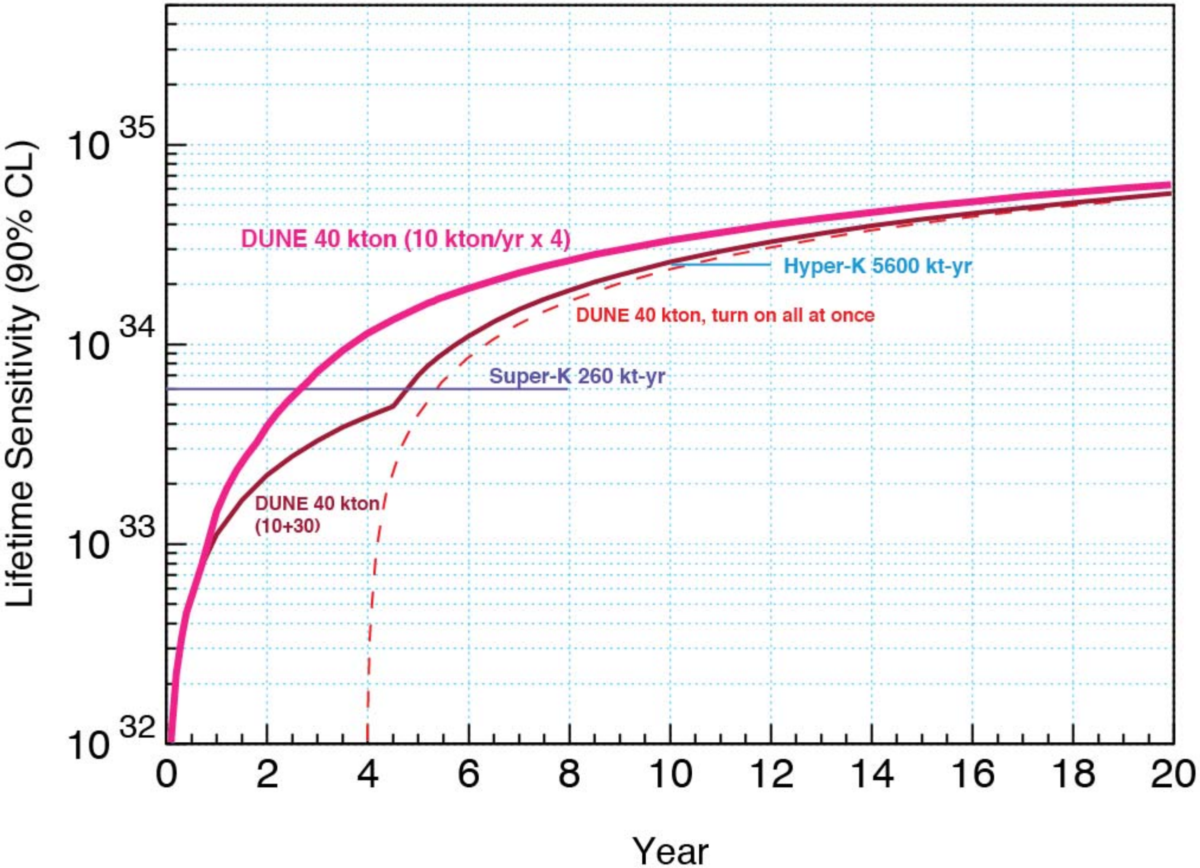




Proton Decay Sensitivity

$p \rightarrow K\nu$

- DUNE for various staging assumptions



Physics Milestones

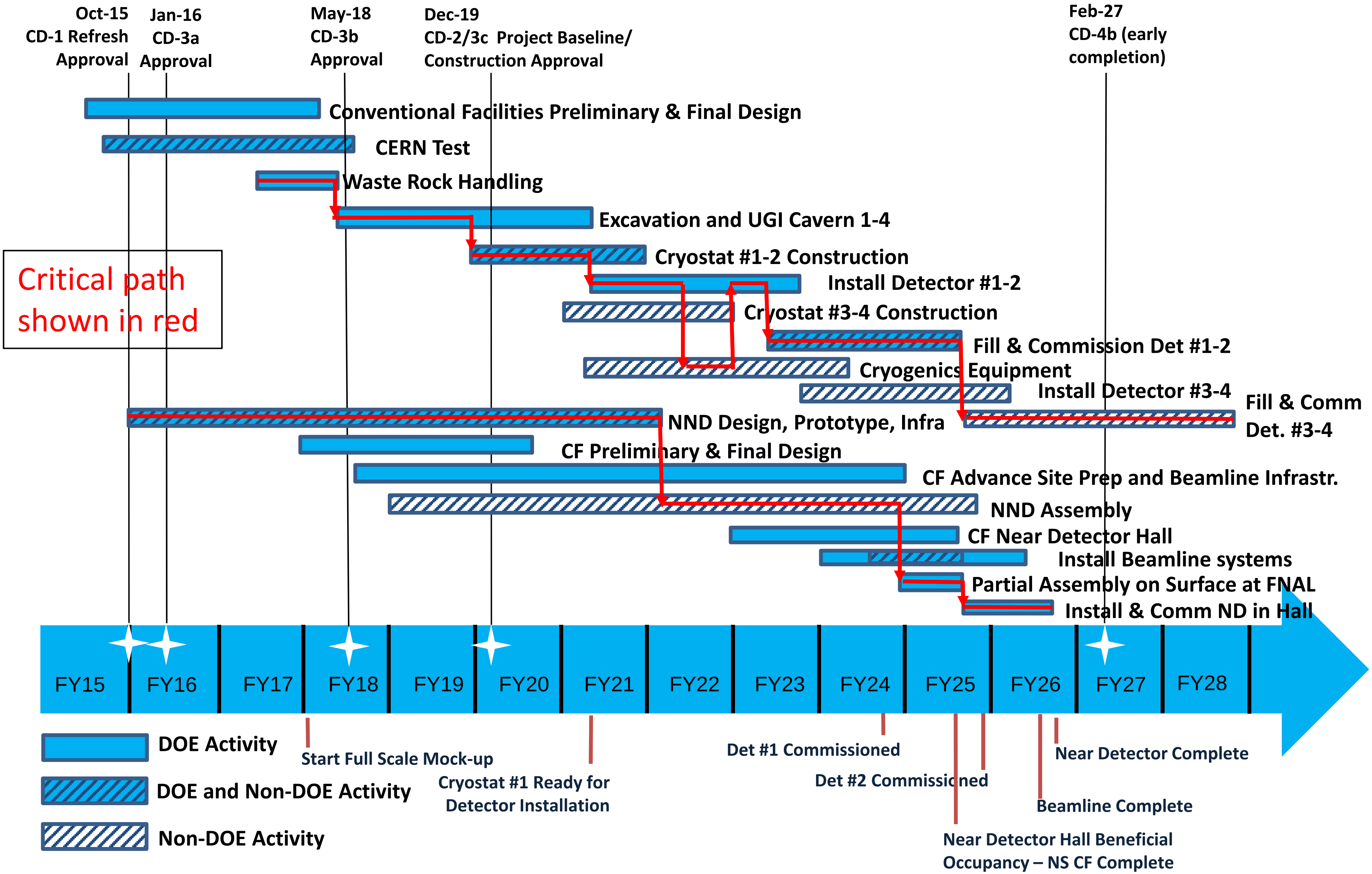
Rapidly reach scientifically interesting sensitivities:

- e.g. in best-case scenario for CPV ($\delta_{CP} = +\pi/2$) :
  - with **60 – 70 kt.MW.year** reach **3σ** CPV sensitivity
- e.g. in best-case scenario for MH :
  - with **20 – 30 kt.MW.year** reach **5σ** MH sensitivity

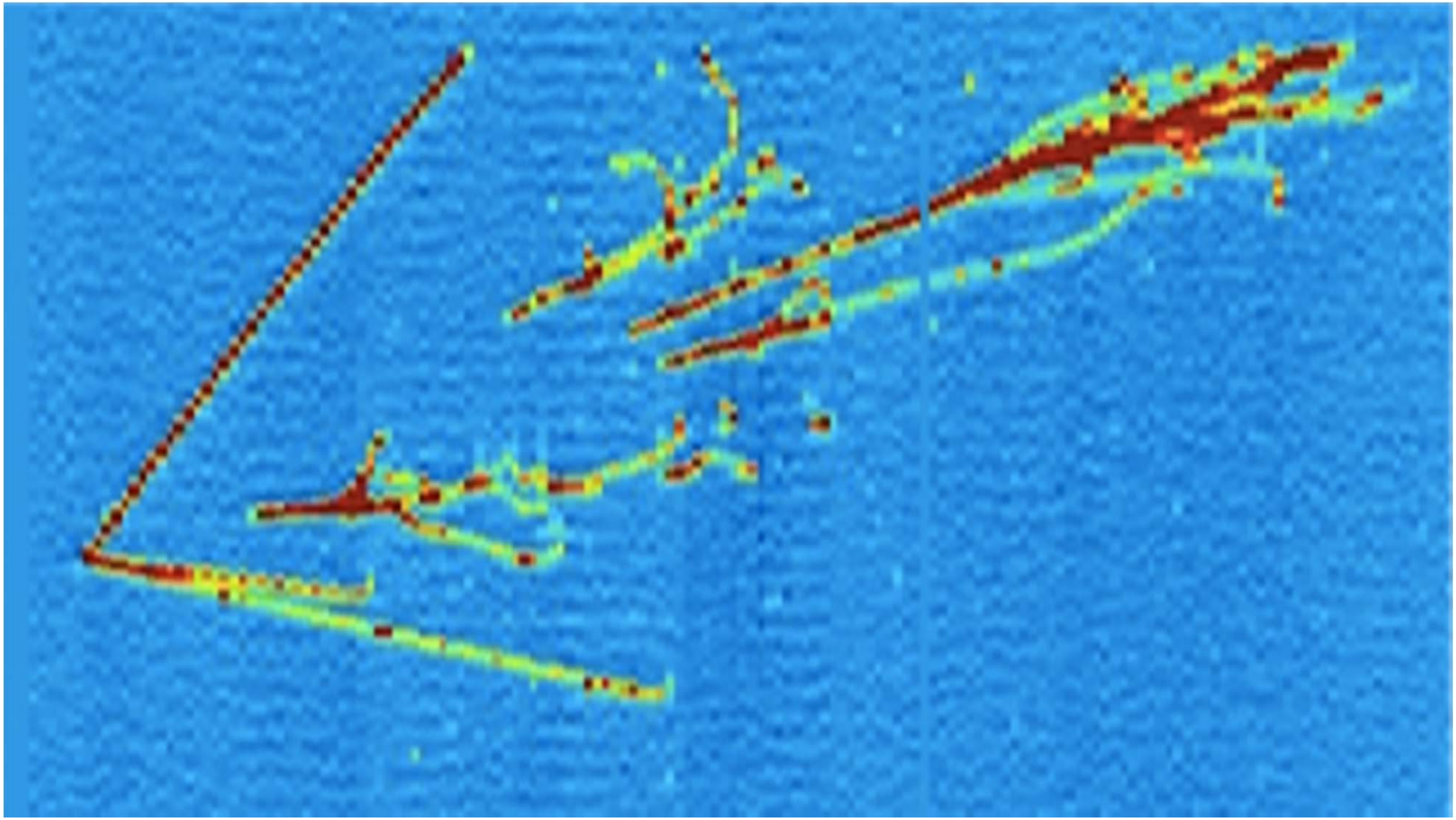
Physics milestone	Exposure kt · MW · year (reference beam)	Exposure kt · MW · year (optimized beam)
1° θ_{23} resolution ($\theta_{23} = 42^\circ$)	70	45
CPV at 3σ ($\delta_{CP} = +\pi/2$)	70	60
CPV at 3σ ($\delta_{CP} = -\pi/2$)	160	100
CPV at 5σ ($\delta_{CP} = +\pi/2$)	280	210
MH at 5σ (worst point)	400	230
10° resolution ($\delta_{CP} = 0$)	450	290
CPV at 5σ ($\delta_{CP} = -\pi/2$)	525	320
CPV at 5σ 50% of δ_{CP}	810	550
Reactor θ_{13} resolution ($\sin^2 2\theta_{13} = 0.084 \pm 0.003$)	1200	850
CPV at 3σ 75% of δ_{CP}	1320	850

★ **Genuine potential for early physics discovery**

LBNF/DUNE Schedule Summary Overview



Summary



Summary

DUNE has

- an advanced design for a world-leading experiment focused on **fundamental open questions in particle physics and astroparticle physics**
- a clear scientific strategy and a project plan to implement it
- the capability of making major discoveries in
  - Long-baseline oscillation physics
  - Nucleon decay
  - Neutrino astrophysics
  - Other areas