Status of DUNE

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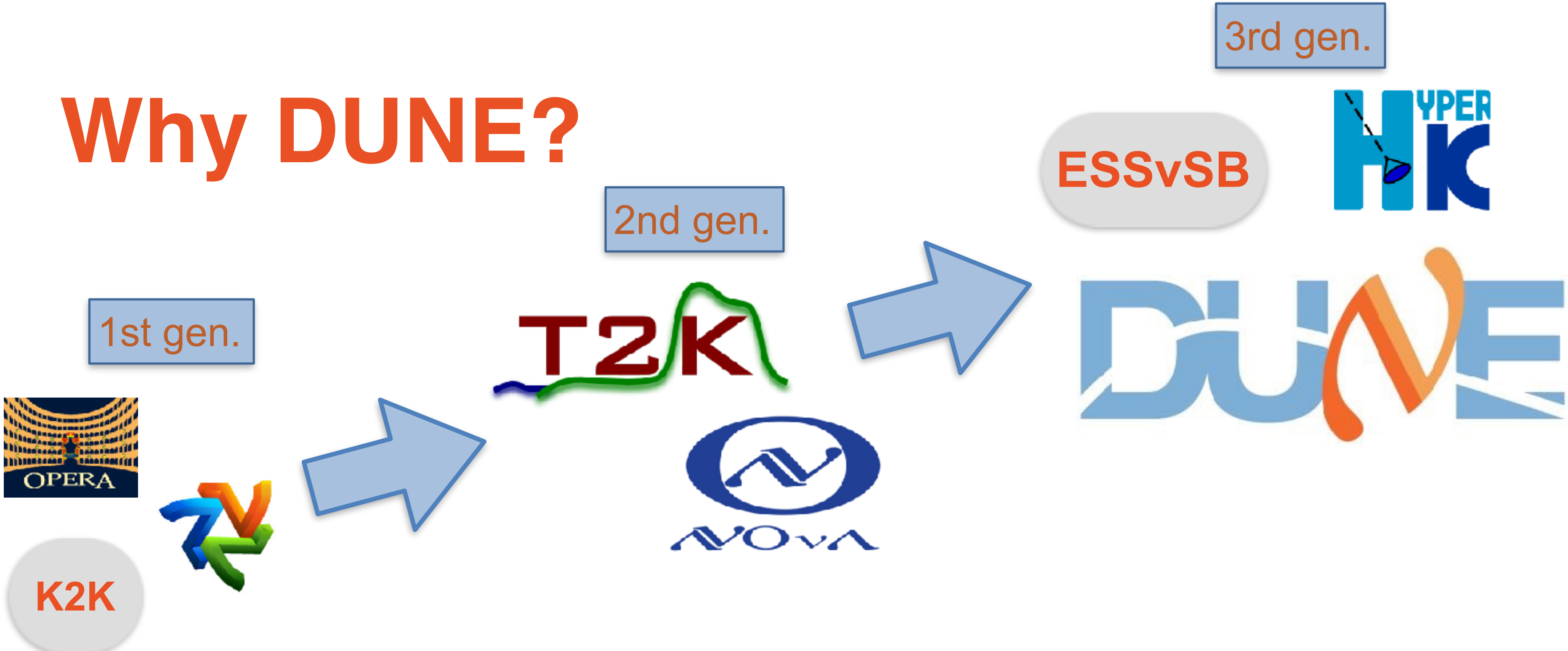
NUFACT 2017, Uppsala (Sweden), September 2017

IFIC INSTITUT DE FÍSICA CORPUSCULAR

DUNE

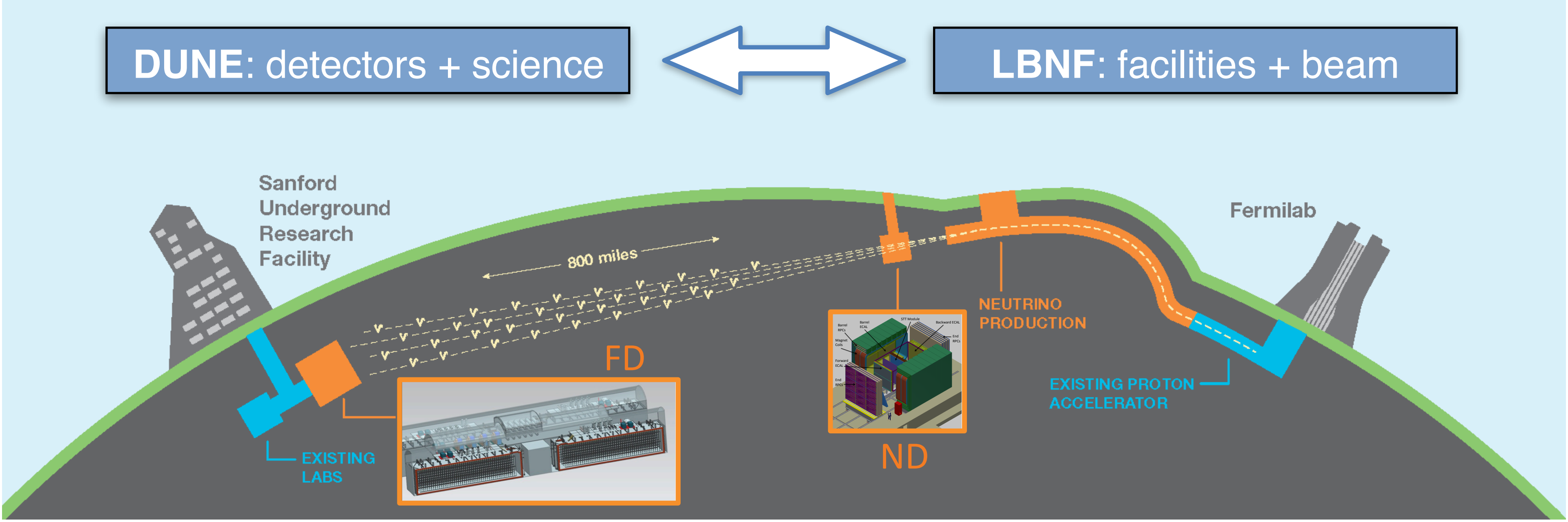
Why DUNE?



- Despite impressive results and projections from current LBL experiments, many questions will **NOT** be **firmly** answered!
- Need new neutrino experiments with larger exposures and better precision
- Future large underground neutrino detectors will also allow us to develop very rich astroparticle physics program

DUNE at LBNF

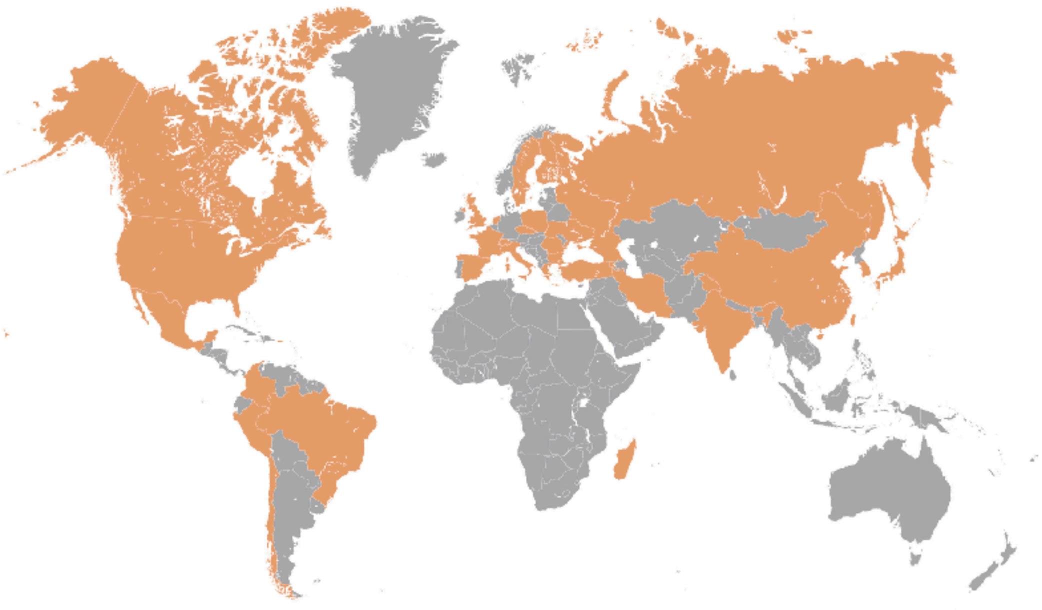
Deep Underground Neutrino Experiment at the Long Baseline Neutrino Facility



- High intensity, wide-band, neutrino beam from Fermilab
- Highly capable neutrino near detector at Fermilab
- 40-kt fiducial mass far detector at SURF based on LAr-TPCs

DUNE Collaboration

- 1000+ collaborators from 176 institutions in 31 countries



- **DUNE**: a fully international science collaboration
- **LBNF**: US-hosted project with international contributions

LBNF/DUNE at NUFACT 2017

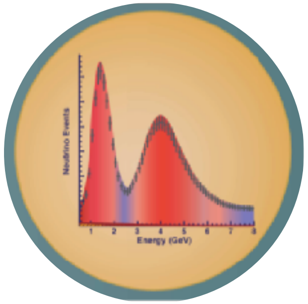
- This talk:
  - Overview of DUNE science
  - Overview of LBNF/DUNE project

- Many more details in three other experimental talks…
  - **Mon 25/09:** Tristan Davenne, *"Status of the LBNF Beamline"* (**WG3**)
  - **Thu 28/09:** Nick Grant, *"DUNE Oscillation Physics"* (**WG1**)
  - **Fri 29/09:** Hongyue Duyang, *"DUNE Near Detector"* (**WG1+WG2**)

- …and in phenomenological talks!

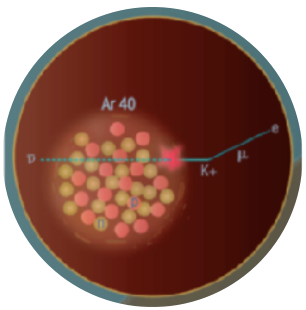
DUNE Science

Primary physics program



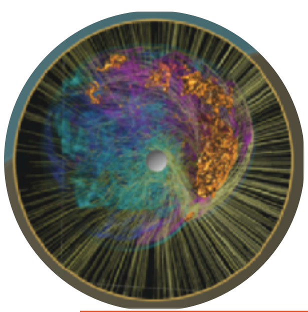
Neutrino oscillations

- CP violation in the ν sector
- Neutrino mass hierarchy
- Precision oscillation measurements
- Testing of 3ν paradigm



Proton decay

- Predicted by BSM theories, but not yet seen
- Unique sensitivity to SUSY-favored modes ($p \rightarrow \bar{\nu} K^+$)



Supernova neutrinos

- Neutrino burst from galactic core-collapse supernova
- Unique sensitivity to supernova ν_e's

Neutrino oscillation measurement strategy

ν_e / $\bar{\nu}_e$ appearance:

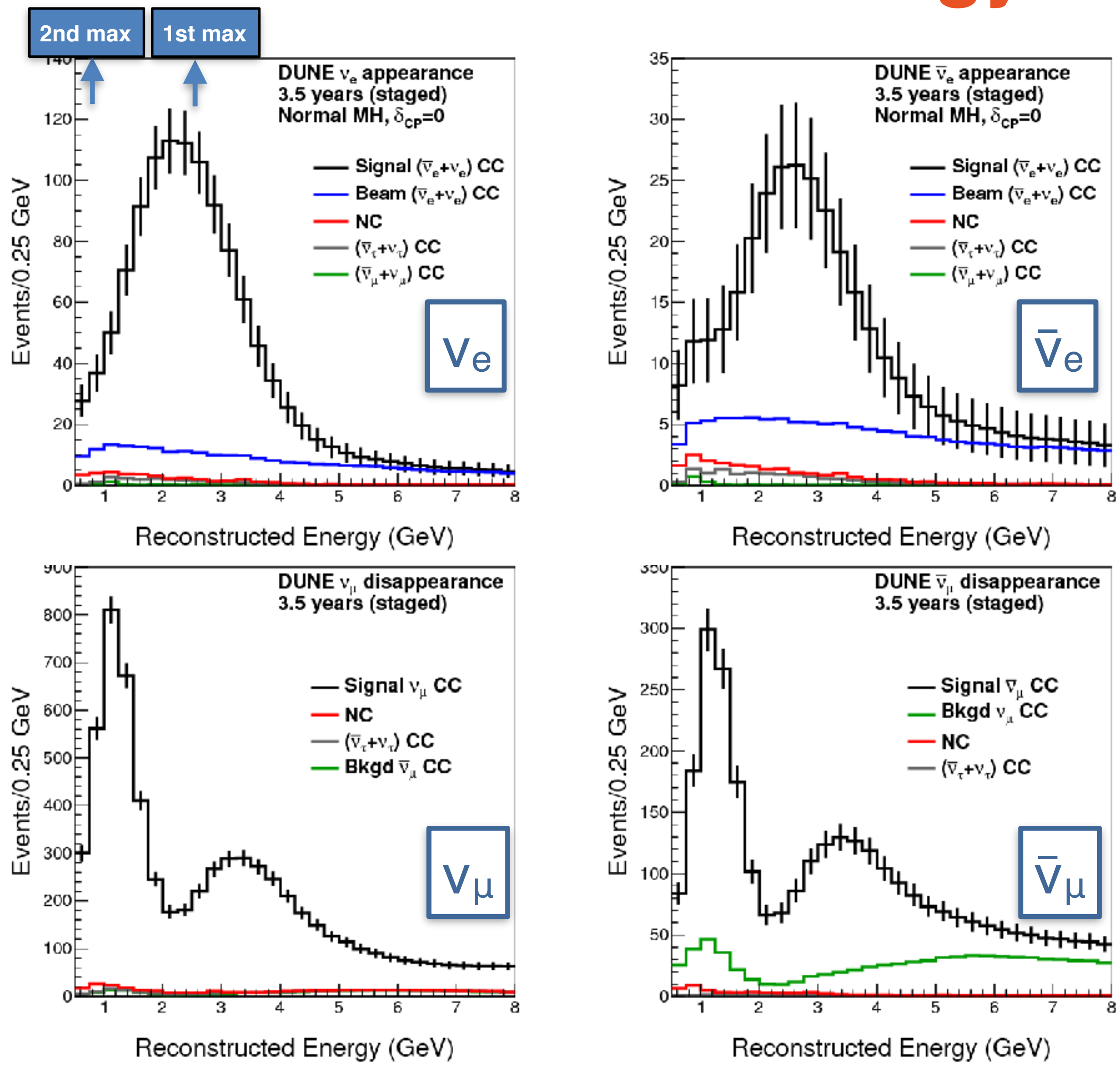
Fit to four samples

↓

oscillation parameters

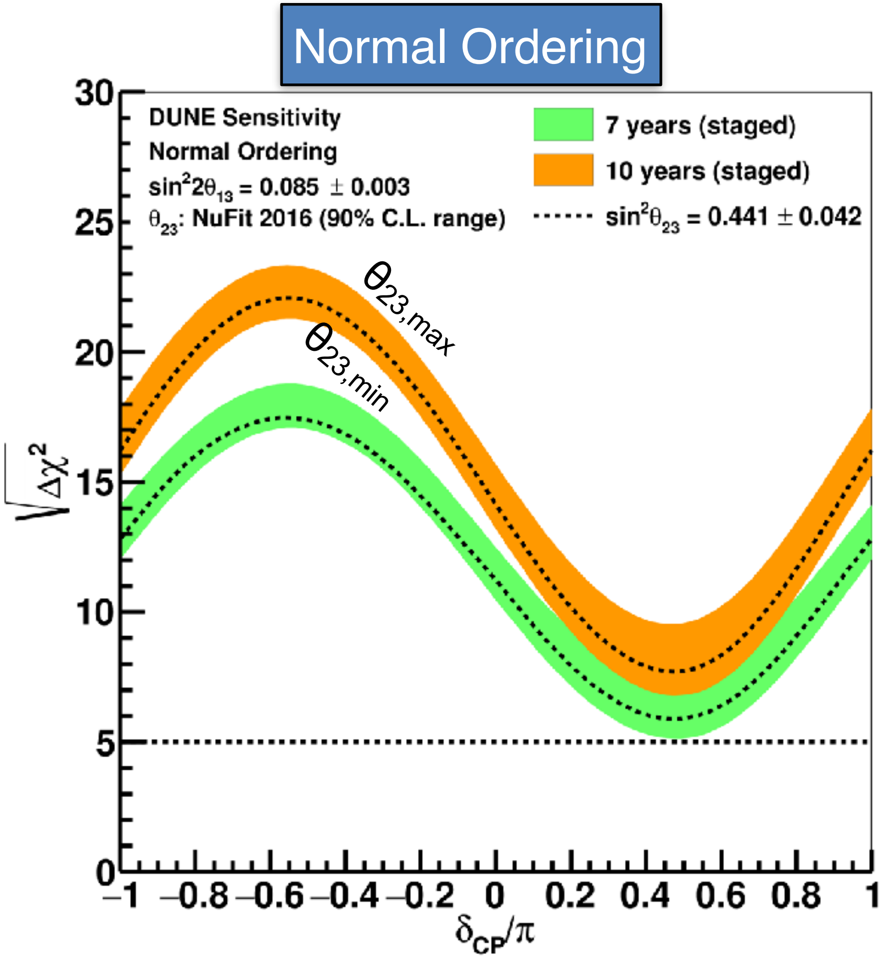
ν_μ / $\bar{\nu}_\mu$ disappearance:

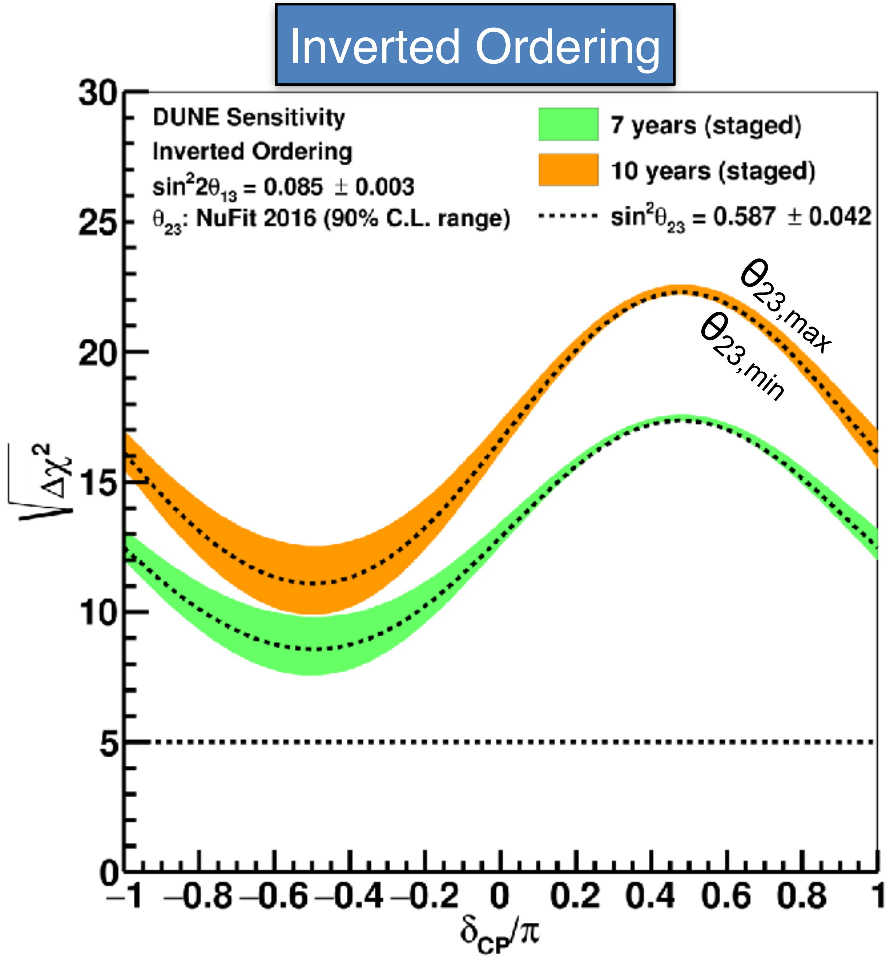
Details about oscillation sensitivity calculations in arXiv:1606.09550



Sensitivity to neutrino mass hierarchy

- 5σ sensitivity after 300 kt·MW·yr exposure (7 yr), for any δ_{CP}

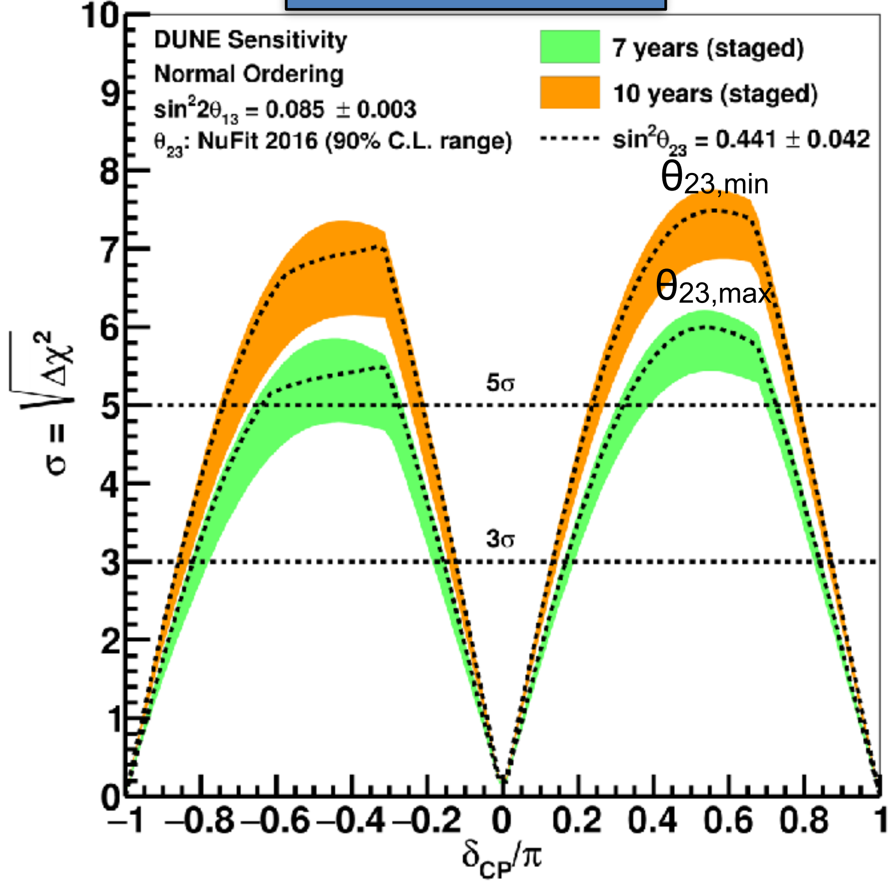




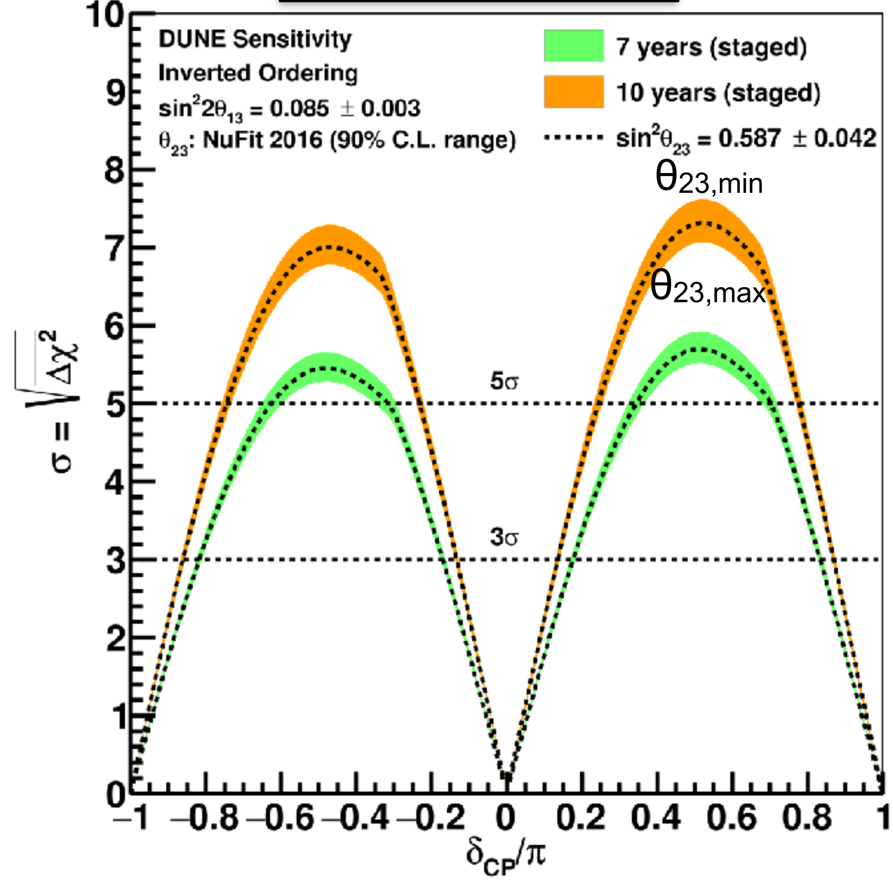
Sensitivity to leptonic CP violation

- 5σ sensitivity after 300 kt·MW·yr exposure (7 yr), for $\delta_{CP} = -\pi/2$

Normal Ordering

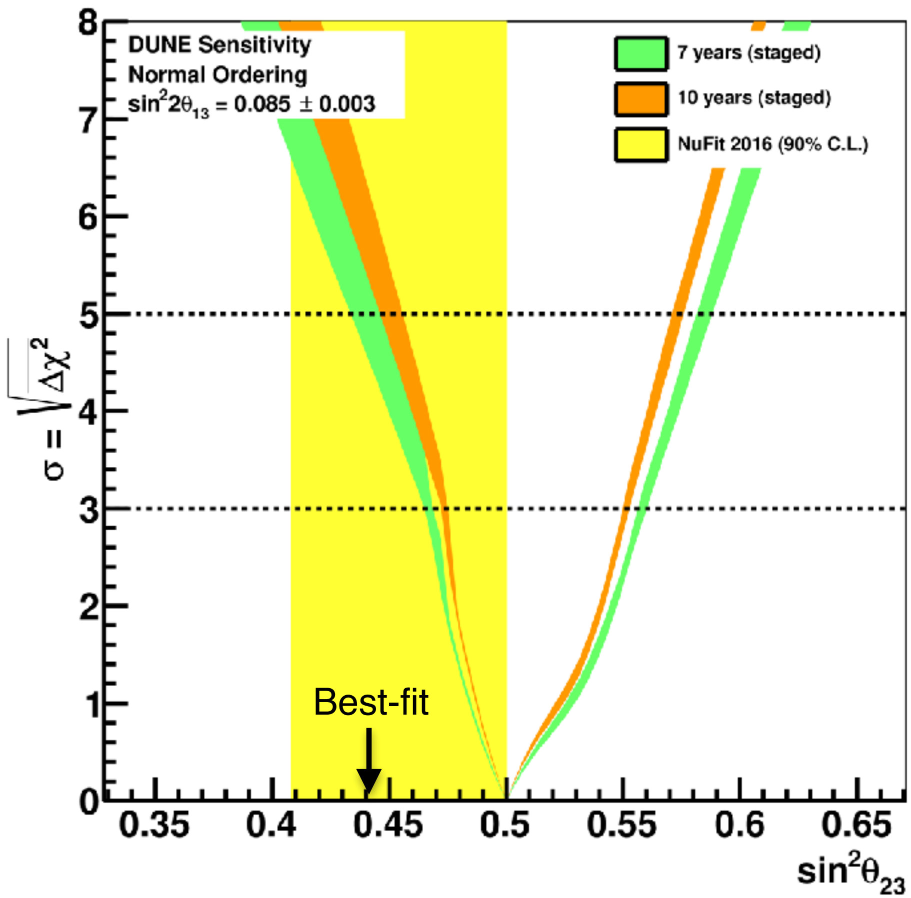


Inverted Ordering



Sensitivity to θ_{23} octant

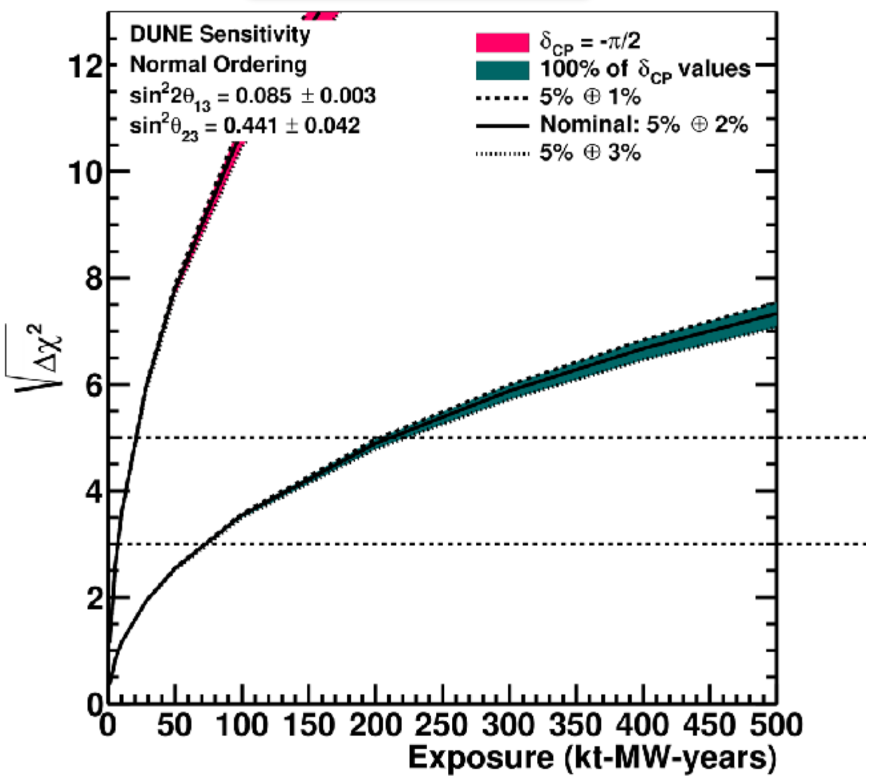
- 5σ sensitivity after 300 kt·MW·yr exposure (7 yr), at NuFit's $\sin^2\theta_{23}$ best-fit value and for 80% fraction of δ_{CP} values



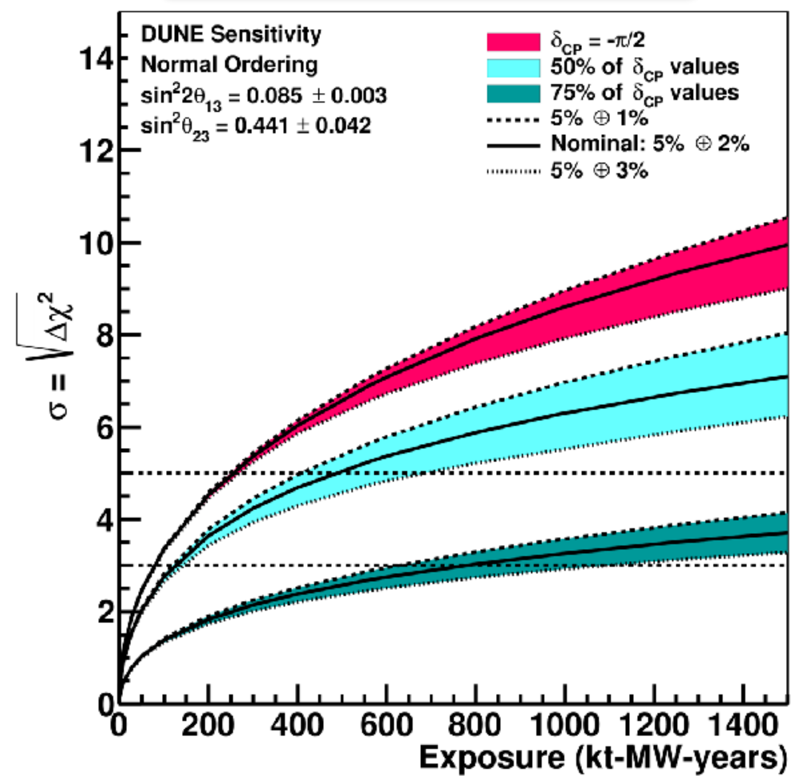
Effect of systematic uncertainties

- Width of sensitivity bands: 1-3% ν_e signal normalisation uncertainty
- Small impact on MH. For CP, important to keep uncertainty at ≲2%

MH Sensitiivity

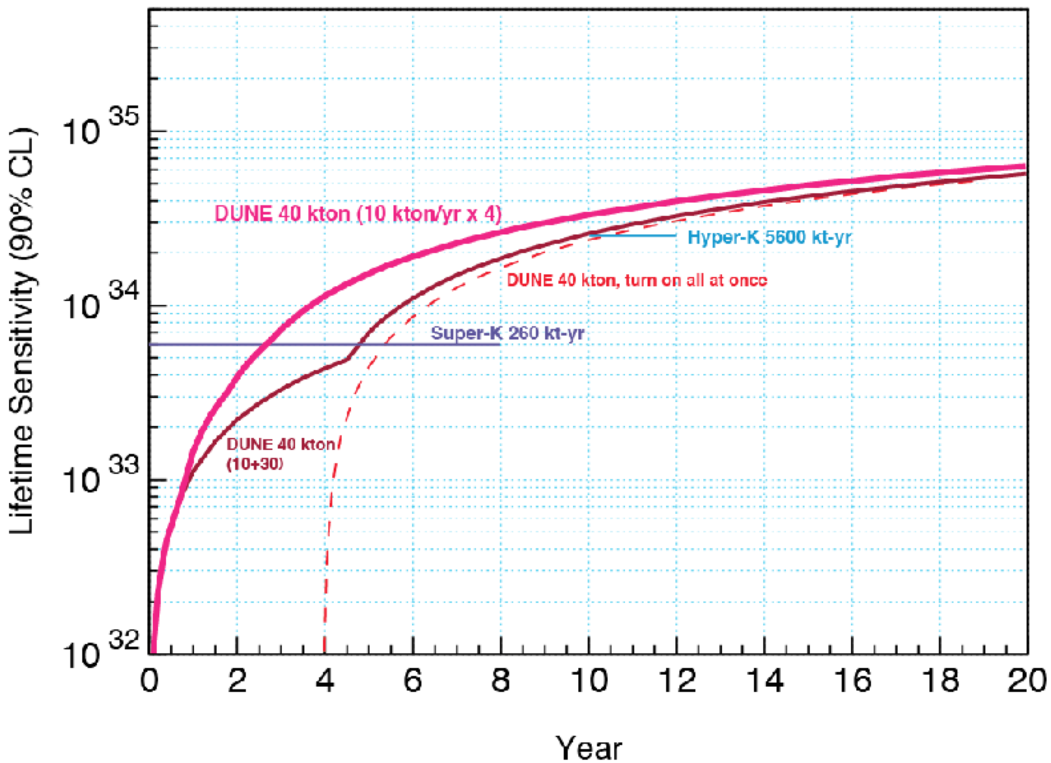


CP Violation Sensitiivity



Nucleon decay searches in DUNE

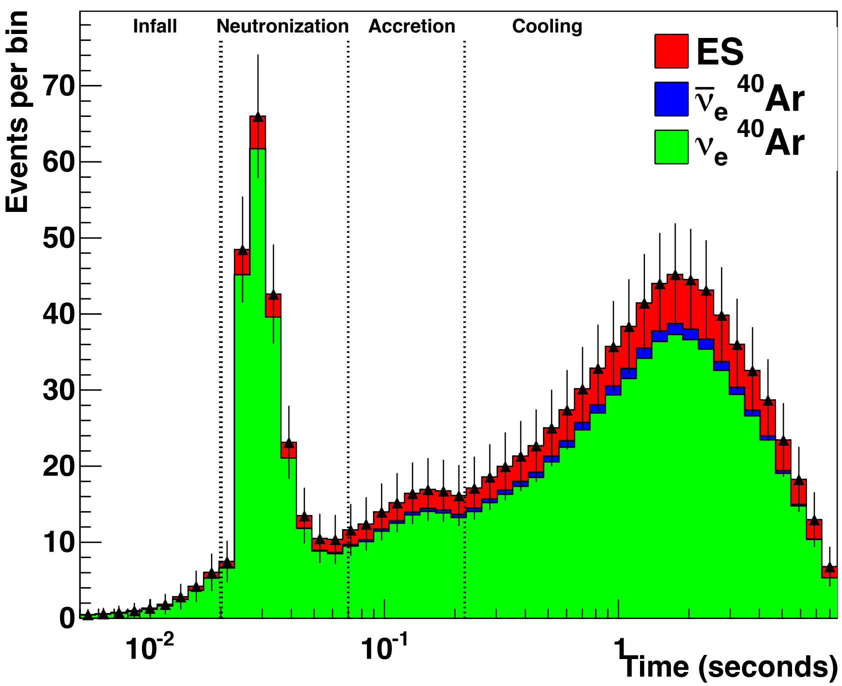
- DUNE's excellent particle identification and tracking capabilities → cast as wide a net as possible for nucleon decay searches
- Unique sensitivity to modes with kaons, e.g. $p \rightarrow \bar{\nu} K^{+}$



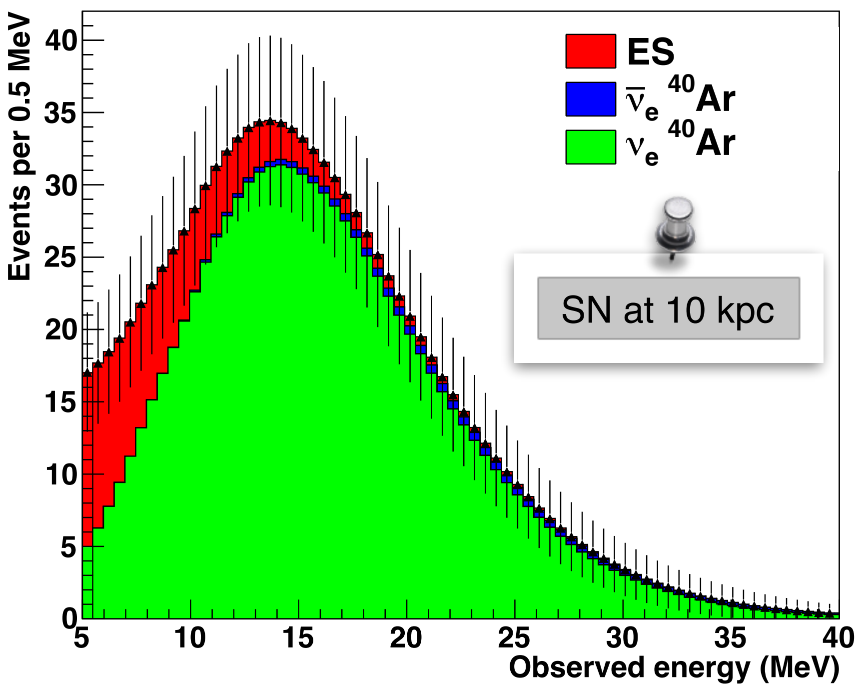
Supernova neutrino bursts

- Vast information from flavour-energy-time profile of events
- Unique sensitivity to ν_e's

Flavour composition versus time



Energy spectra integrated over time



Additional scientific opportunities

Ancillary science program

(Will be pursued)

- Other accelerator-based neutrino flavor transitions
  - *NSIs, sterile neutrinos, ν_τ appearance*
- Physics with atmospheric neutrinos (oscillations, BSM)
- n-nbar oscillation searches
- Neutrino interaction physics program at near detector
- Search for signatures of dark matter

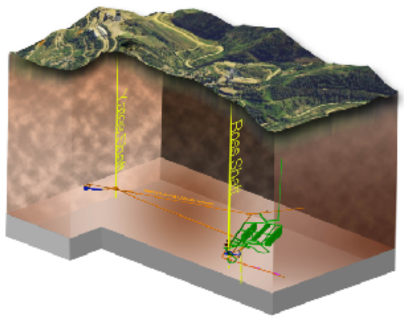
Additional scientific objectives

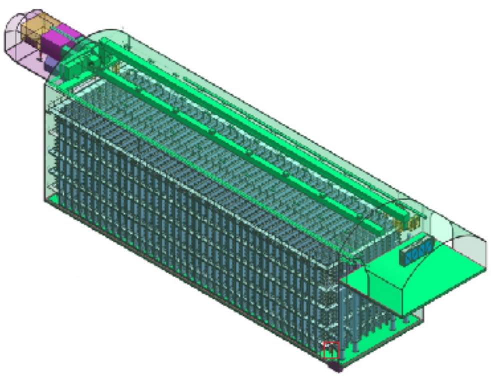
(Might be pursued)

- Oscillations and stellar physics using solar neutrinos
- Detection of the diffuse supernova neutrino flux
- Measurement of HE neutrinos from astrophysical sources

LBNF/DUNE Project

Project timeline





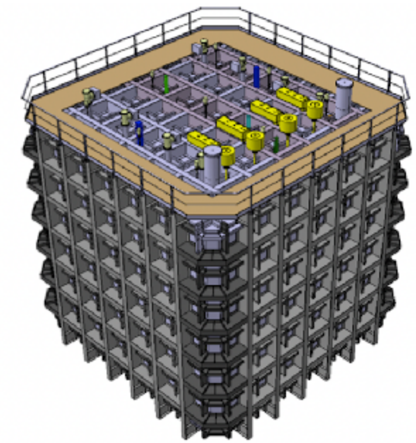
2017
Far Site Construction Begins

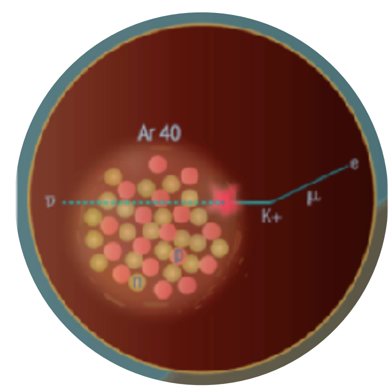
2018
ProtoDUNEs at CERN

2021
Far Detector Installation Begins

2024
Physics Data Begins

2026
Neutrino Beam and Near Detector Available





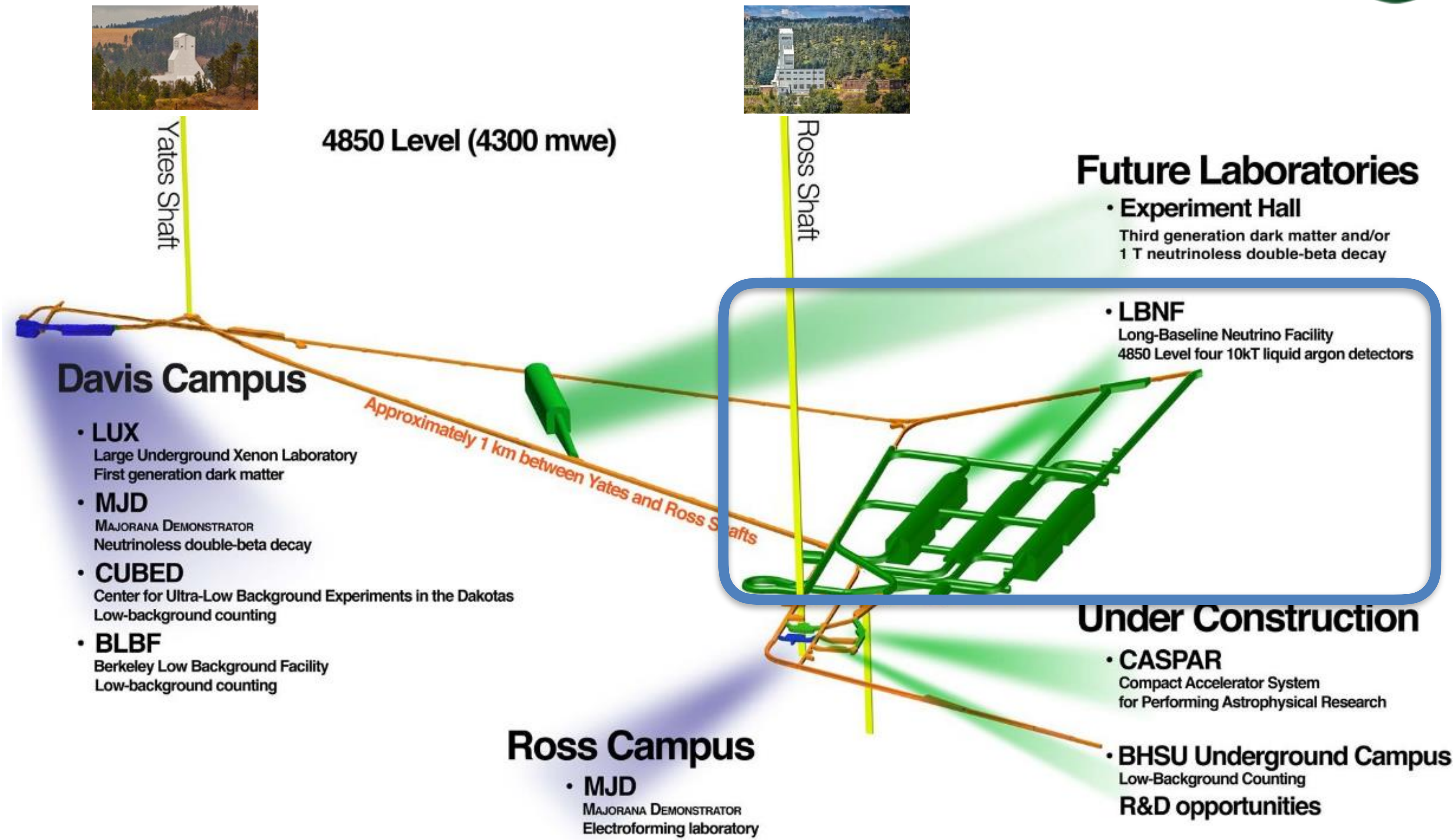
Groundbreaking at SURF

2017
Far Site Construction Begins

- LBNF/DUNE project approved by US DOE in 2016 ("CD-3a")
- $330M for construction work: infrastructures, caverns
- SURF reliability projects underway now, CD-3a starting in 2018

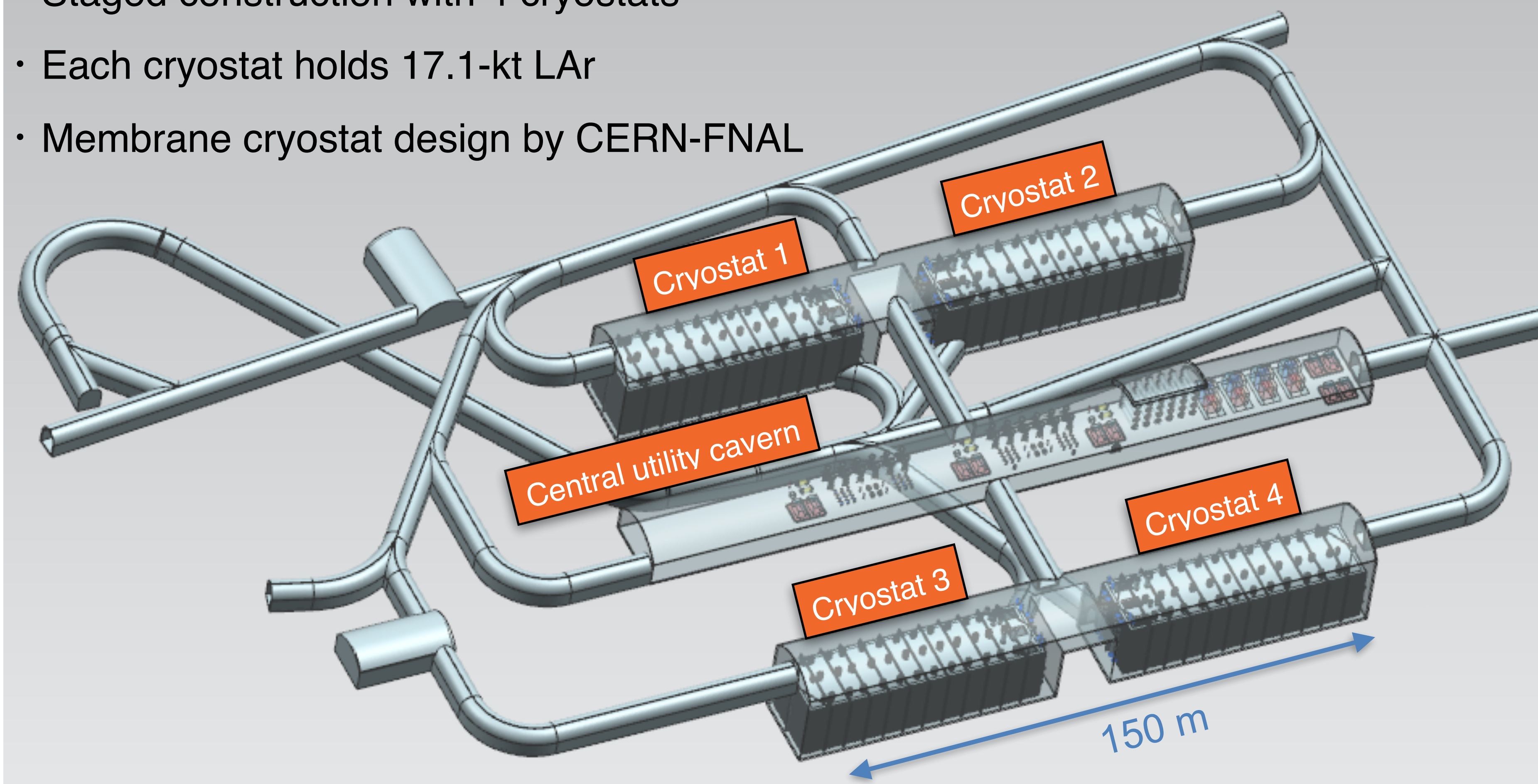
LBNF/DUNE groundbreaking held 21 July at 4850 ft level at SURF

SURF planned caverns



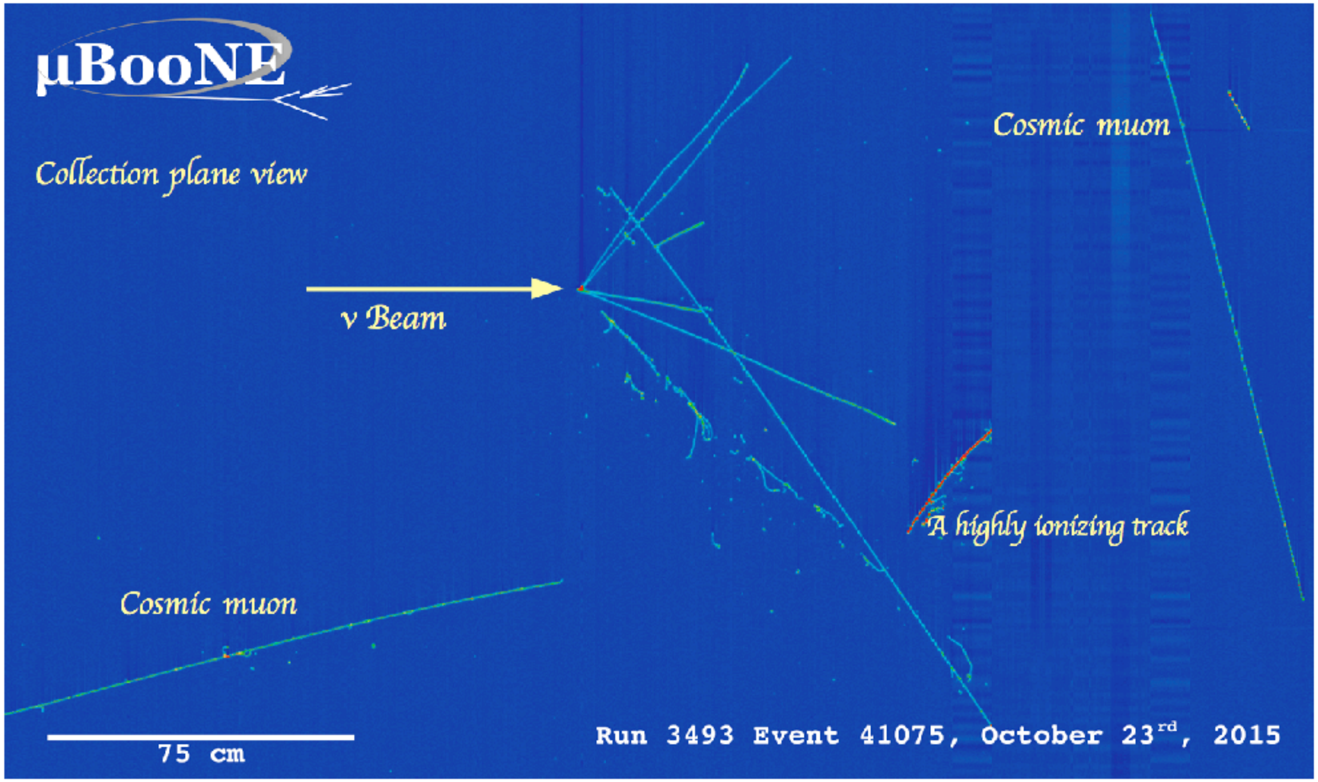
Infrastructures at SURF

- Staged construction with 4 cryostats
- Each cryostat holds 17.1-kt LAr
- Membrane cryostat design by CERN-FNAL



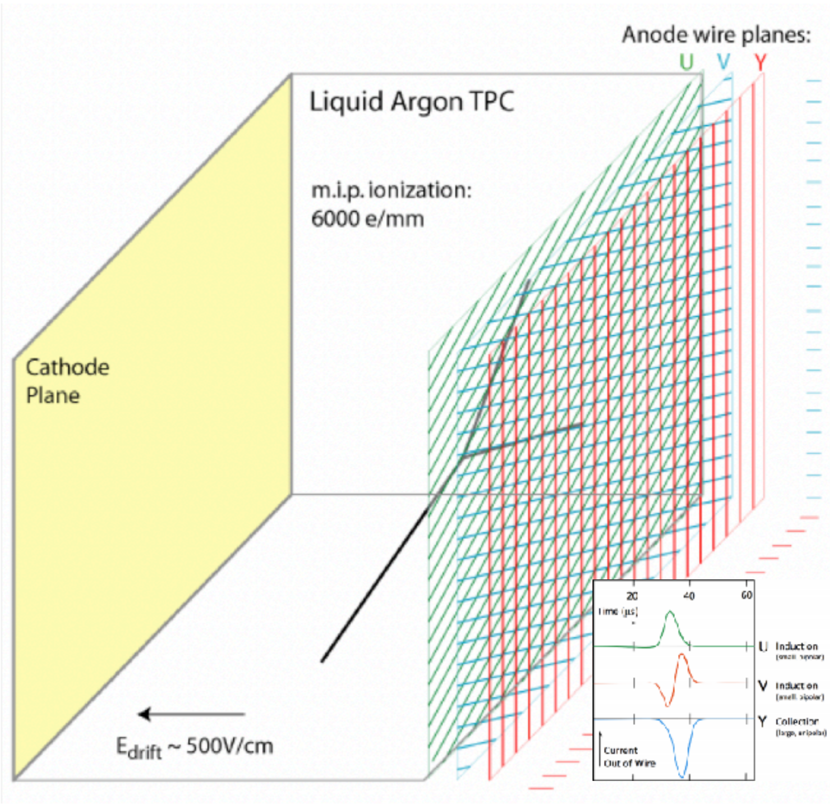
Far detector technology: LAr-TPCs

- Excellent imaging from mm-scale resolution
- Accurate calorimetry from fully active volume and large ionisation signal
- Particle identification from dE/dx, event topology

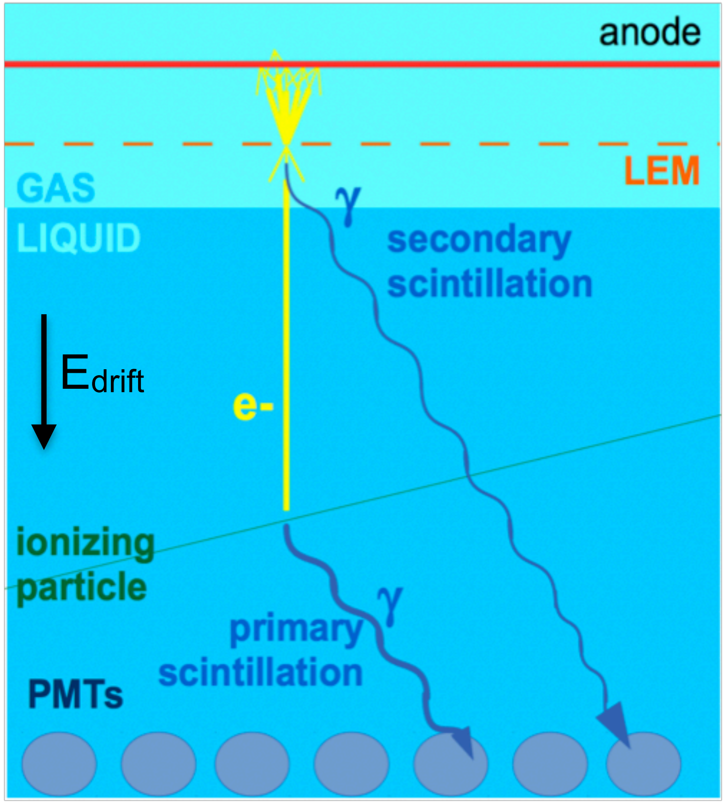


LAr-TPC readouts

Single phase: wire planes readout



Dual phase: amplification + x/y strip readout

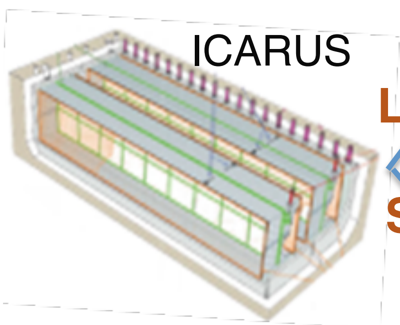


- Also, scintillation light readout for event t_0 and improved reconstruction

Prototyping activities

2018
ProtoDUNEs at CERN

Single-Phase



LBL

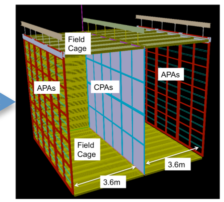
SBL

35-t prototype

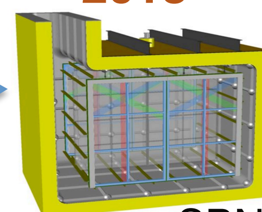
2015

MicroBooNE

ProtoDUNE (NP04)



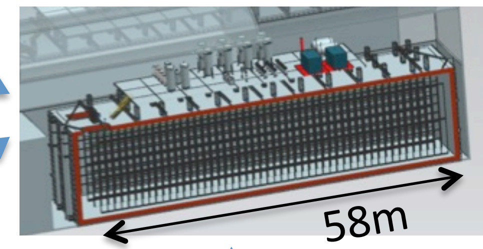
2018



SBND

DUNE SP Design

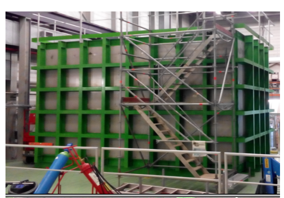
basis for first 10 kt module



46 times larger than ICARUS

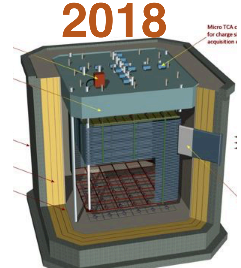
Dual-Phase

2017



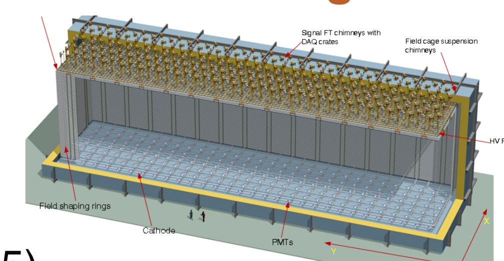
WA105: 50-t 1x1x3 m^3

2018



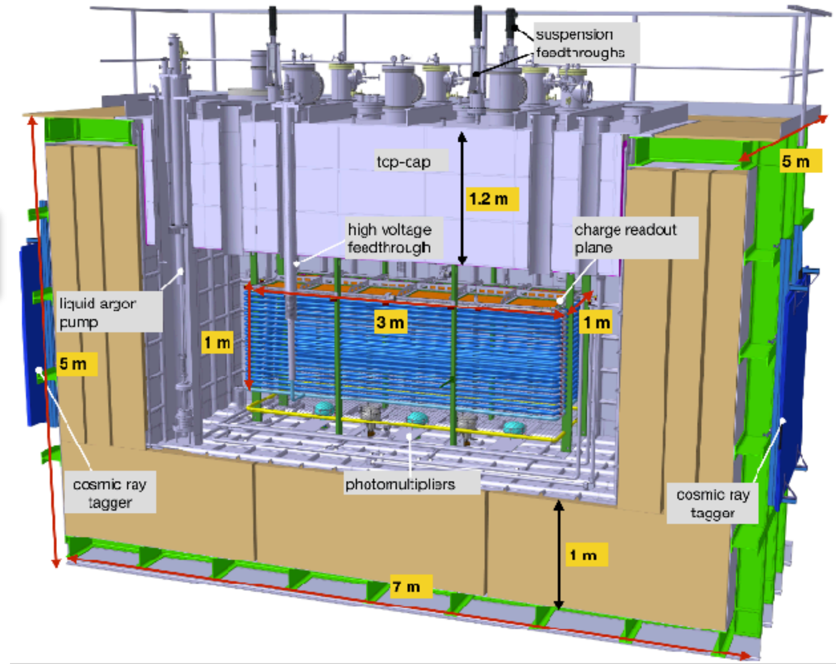
ProtoDUNE (NP02/WA105)

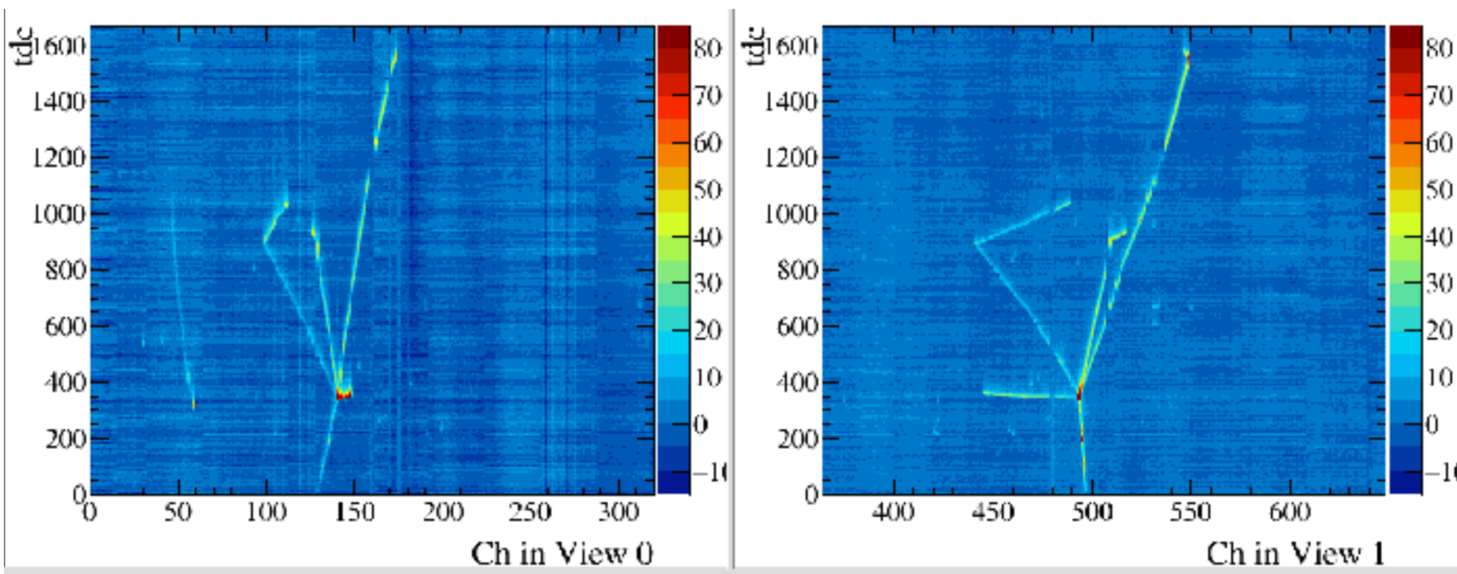
DUNE DP Design



3x1x1 m^3

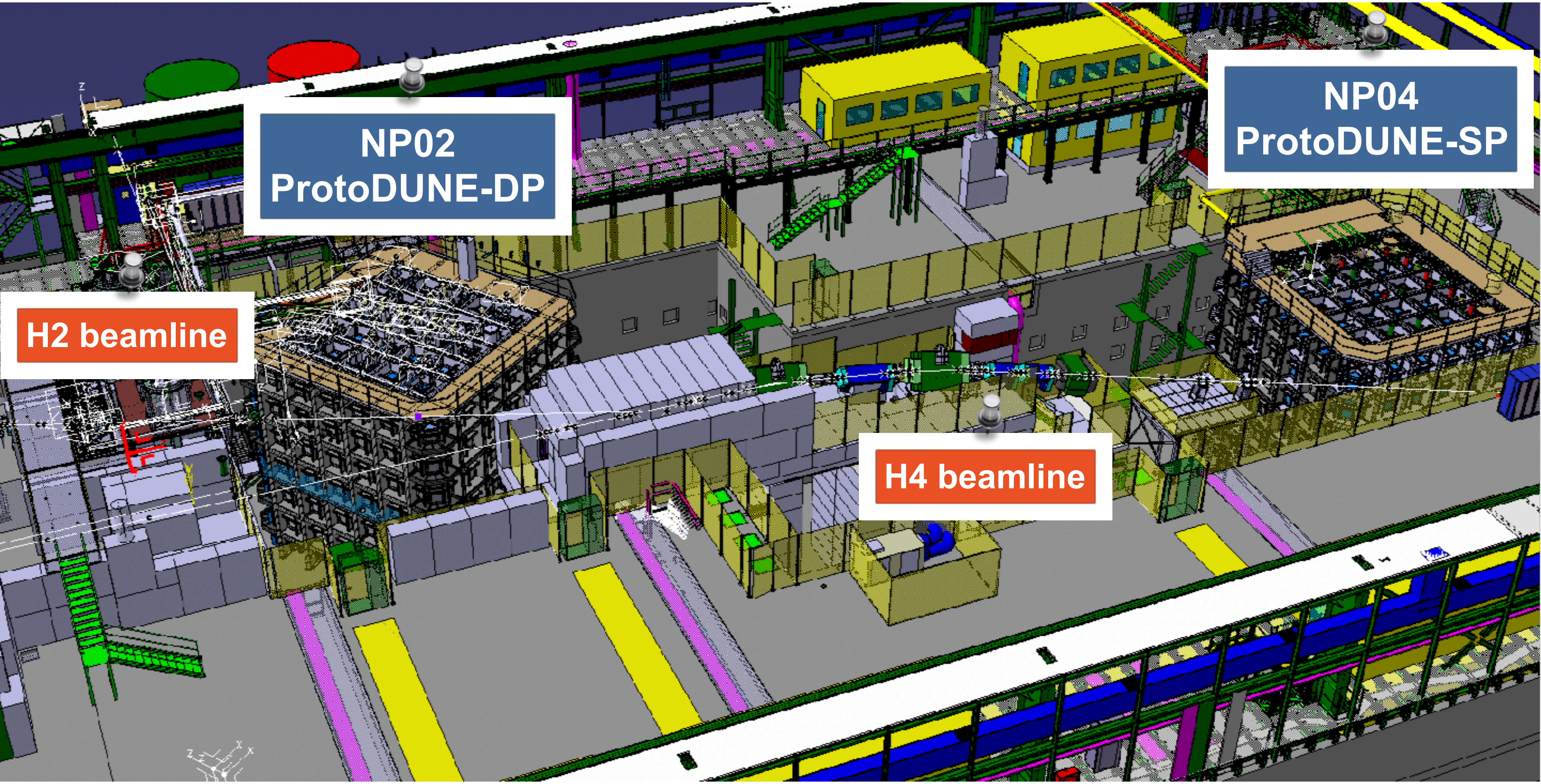
July 2017: first cosmic ray tracks!





CERN Neutrino Platform

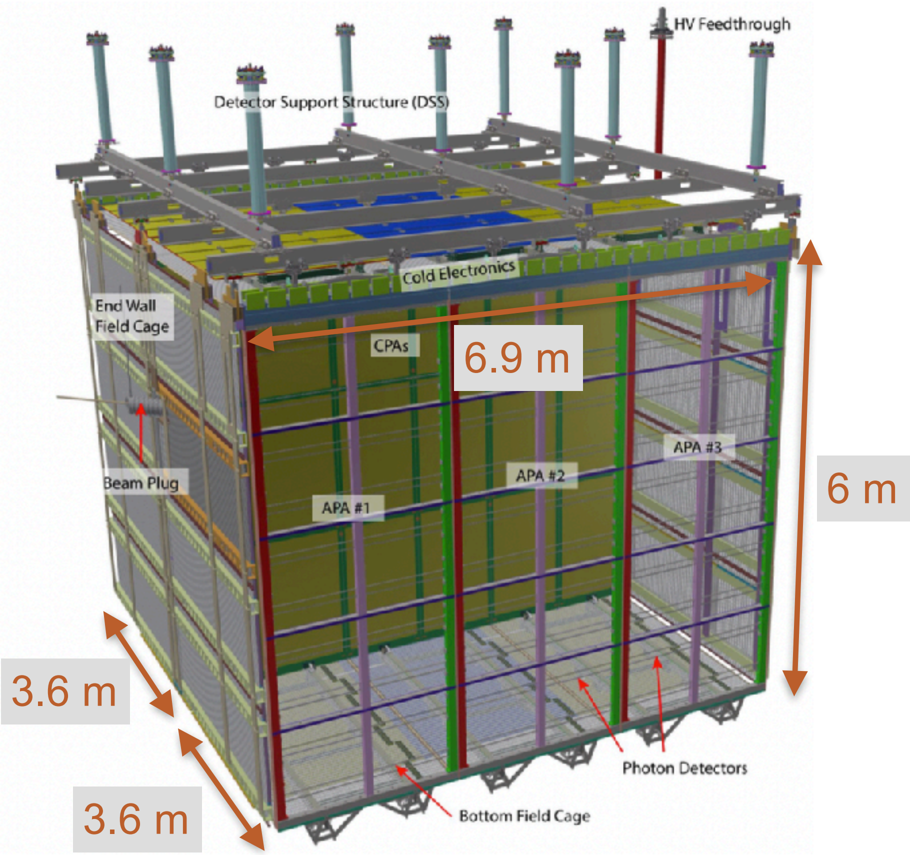
- Large-scale LAr-TPC demonstrators in charged particle test beams



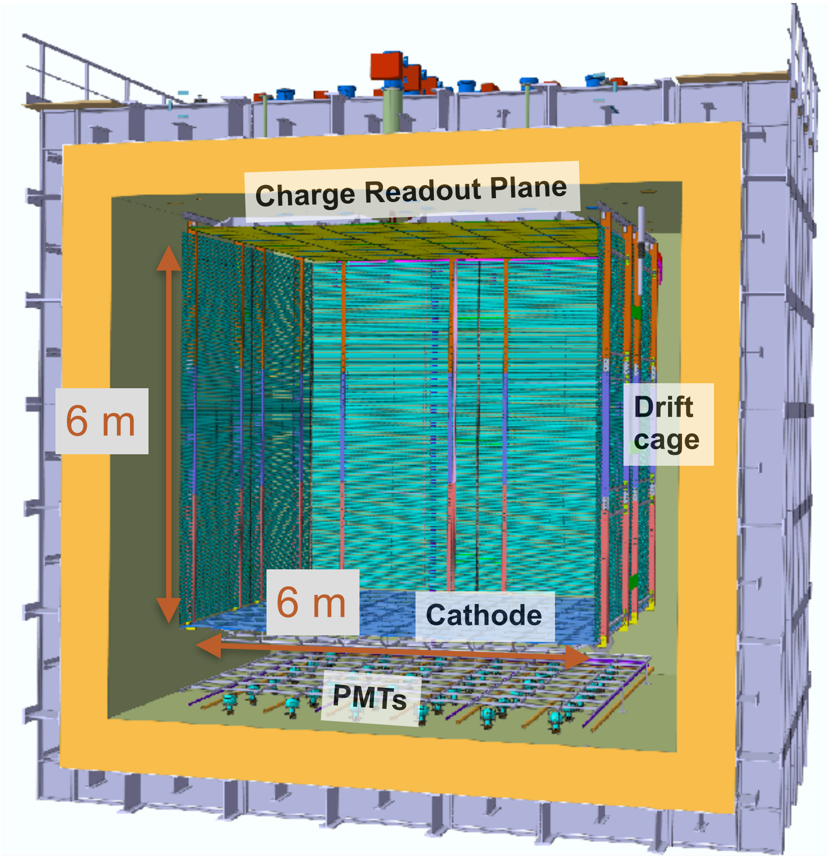
ProtoDUNEs

- 770 t total LAr mass each (ICARUS: 600 t)

ProtoDUNE-SP



ProtoDUNE-DP

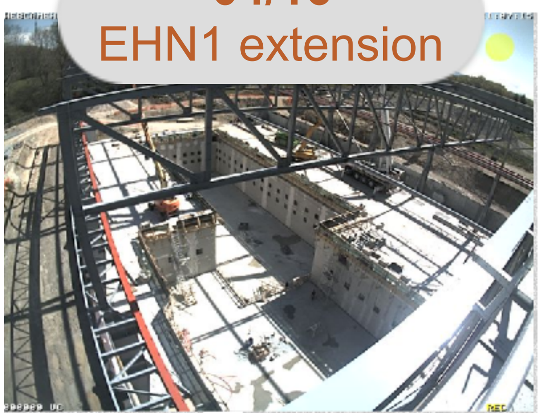


ProtoDUNEs timeline

Time

10/15
ProtoDUNEs approved at CERN

04/16
EHN1 extension



09/16
Beneficial occupancy

11/16
Cryostat steel structures

08/17
First APA at CERN

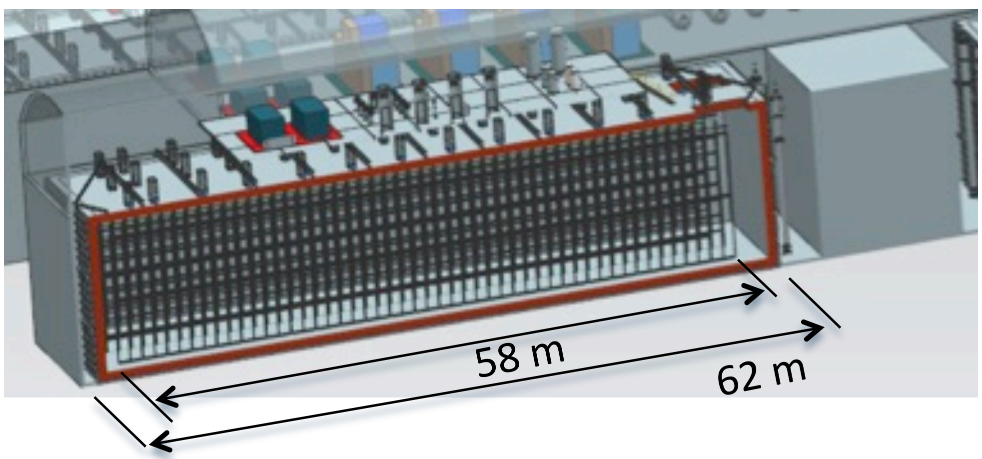
8/18
Expected start of detector operations

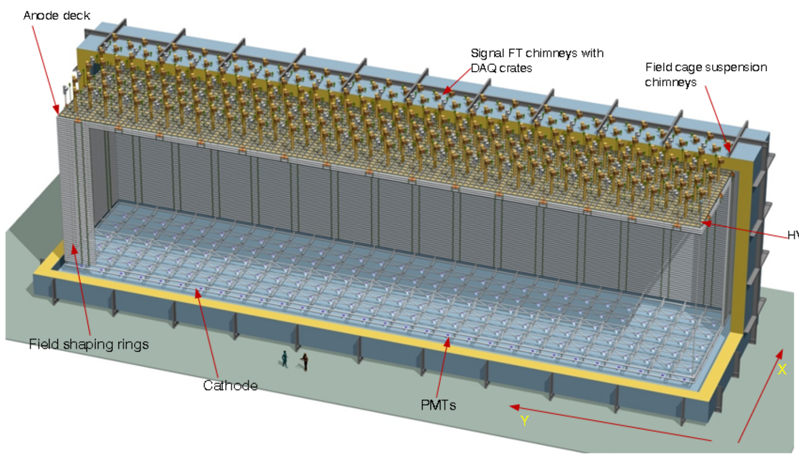
Far detector modules

2021
Far Detector Installation Begins

2024
Physics Data Begins

- Four FD modules, 17.1/13.6/11.6 kton total/active/fiducial LAr mass each, housed in four identical cryostats
- If ProtoDUNEs successful, plan for 1st (2nd) module based on SP (DP) technology
- Far Detector TDRs for first two modules to be delivered in 2019



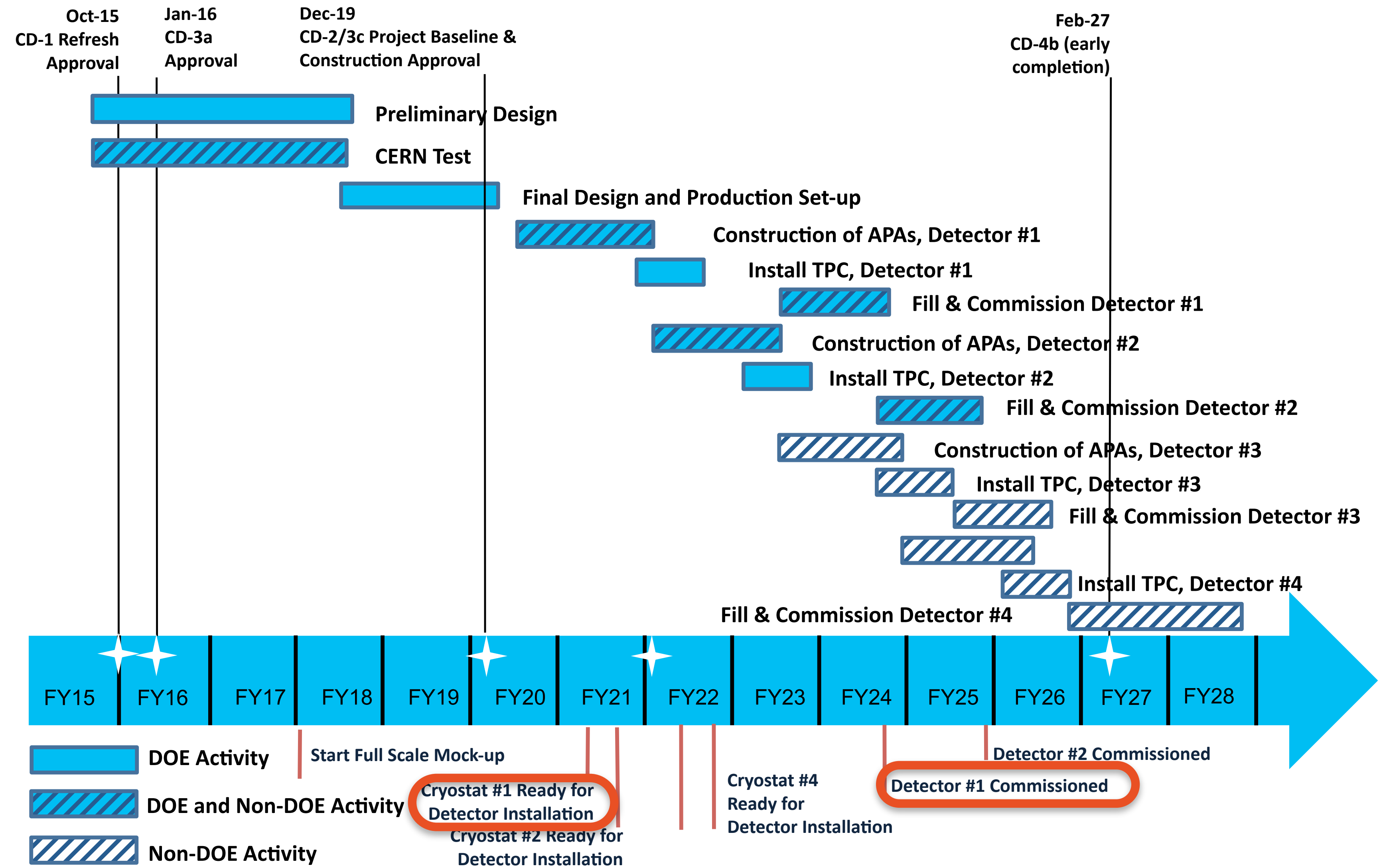


Far detector consortia

- Established in Aug 2017
- **Charge**: plan and execute the construction, installation, and commissioning of the FD subsystems

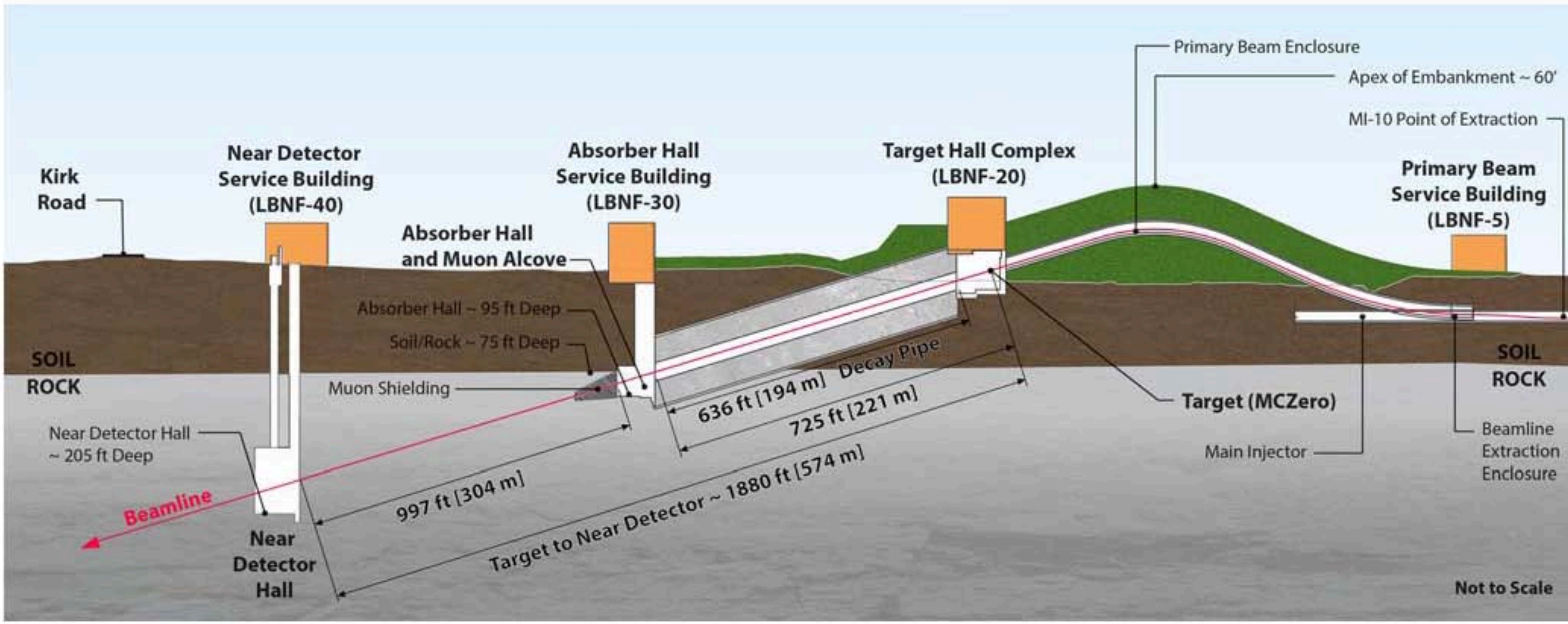
- **Single-phase**
  - Anode Plane Assemblies
  - Photon Detector
  - TPC Cold Electronics
- **Dual-phase**
  - Charge Readout Plane
  - Photon Detector
  - Front-End Electronics
- **Joint SP/DP**
  - HV system
  - DAQ
  - Slow Controls & Cryo Instrum.

Far detector construction timeline



Neutrino beam and near detector

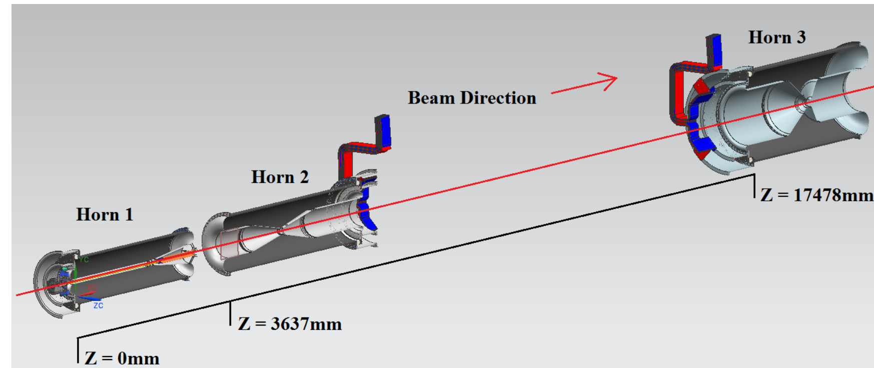
2026
Neutrino Beam and Near
Detector Available

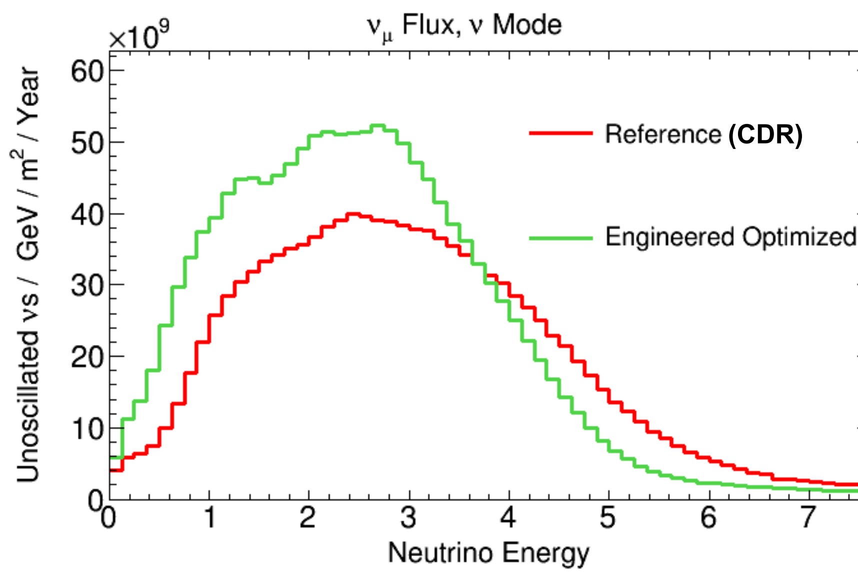


- Primary proton beam @ 60-120 GeV from Main Injector
- Initial 1.2 MW beam power, upgradable to 2.4 MW
- Near detector at 574 m distance from hadron production target

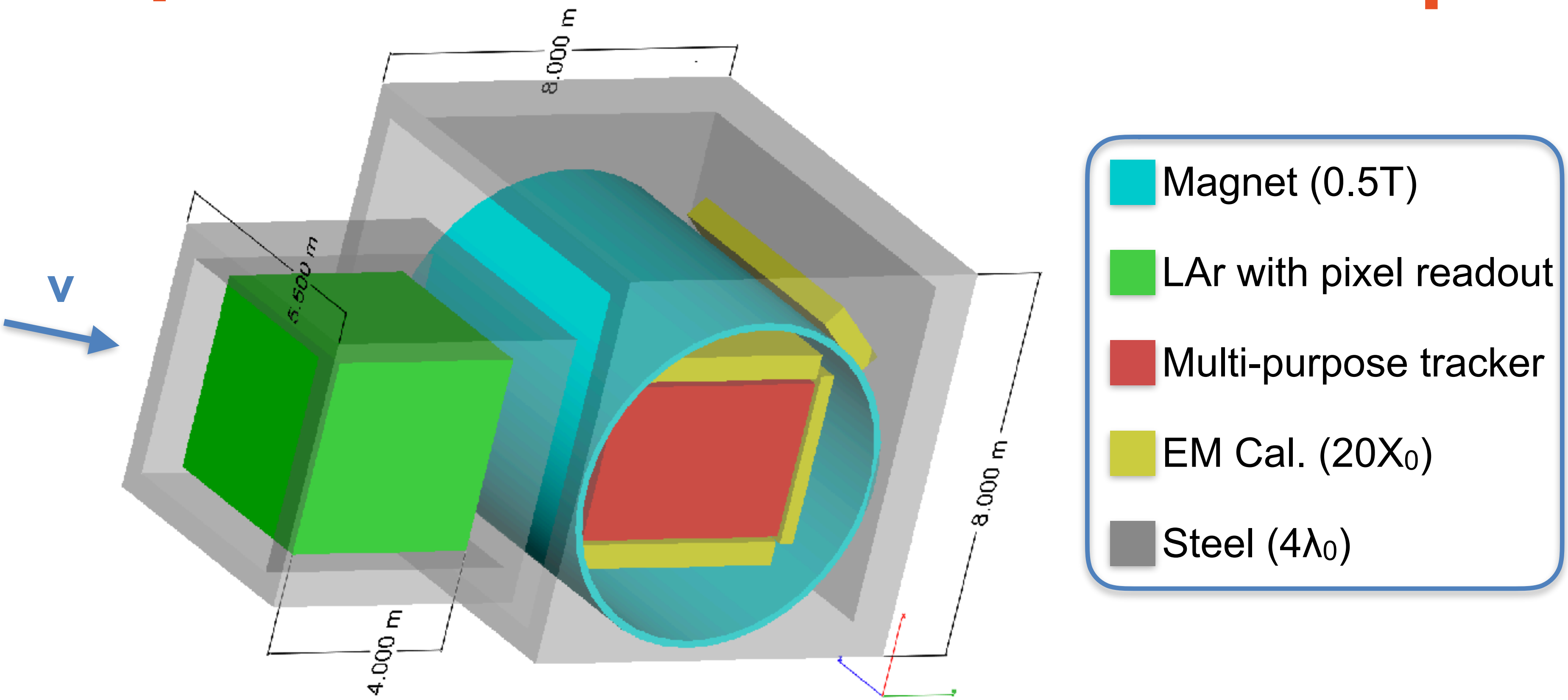
Neutrino beam status

- Target/horns configuration has been optimised to maximise sensitivity to CP violation
  - Includes engineering constraints
  - Larger ν_μ / $\bar{\nu}_\mu$ flux for 0-4 GeV compared to CDR
- Next: LBNF Preliminary Design including cost estimate by 2019





A possible Near Detector concept



- Multi-purpose tracking detector could be a straw tube tracker, a high-pressure argon gas TPC, or something else
- Near Detector concept by 2018, Near Detector TDR in 2020

Conclusions

- DUNE at LBNF is a next-generation experiment for neutrino, nucleon decay and astroparticle physics
- Aims to be the “definitive” experiment based on conventional neutrino beams and the next mega-science project after the LHC
- LBNF/DUNE groundbreaking at SURF in July 2017!
- Physics data-taking starts in 2024, beam from FNAL available in 2026

Backups

Why DUNE?

Should we build [**DUNE**, T2K(K), ESSνSB, …] despite impressive results from currently operating LBL program? **Yes!**

- **Ambiguities** may persist throughout end of T2K/NOνA:

Mass hierarchy	• Parameter degeneracies at 300-800 km baselines
CP violation	• Current CPV hints (2σ) require reactor constraint
Non-maximal mixing	• Some tension between T2K and NOνA results

- Even if no ambiguities, would like to have **>5σ determination** for all 3ν questions, and sensitive searches beyond 3ν paradigm

Long-baseline neutrino oscillations

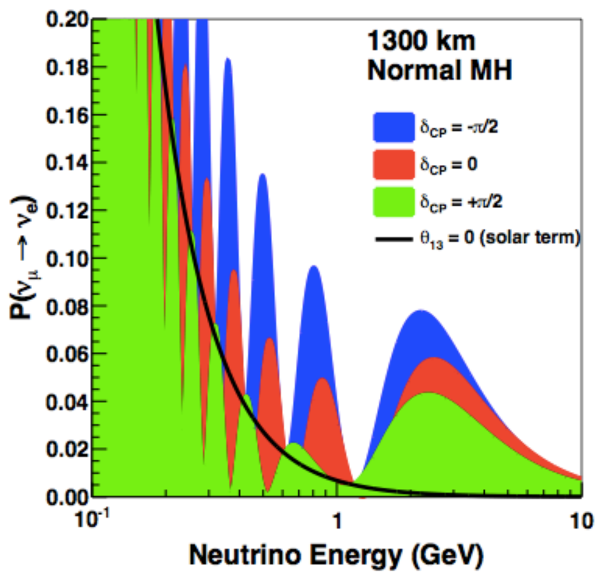
- $\nu_\mu \to \nu_e$ and $\bar{\nu}_\mu \to \bar{\nu}_e$ oscillation probabilities depend, in different ways, on δ_{CP} and sgn(Δ_{31})

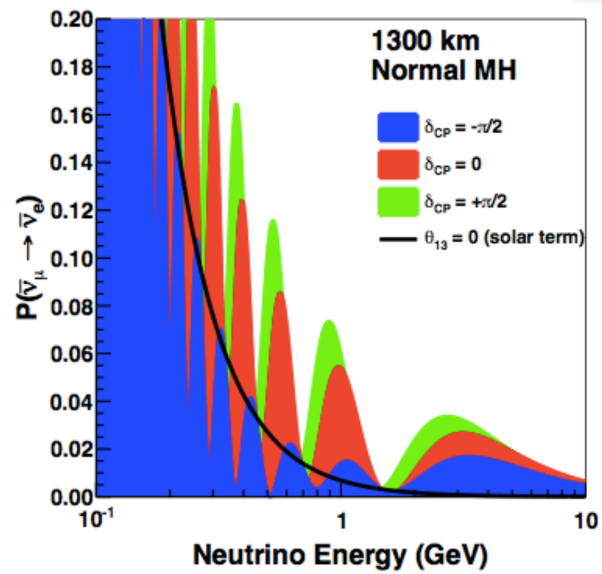
$$
\begin{aligned}
P(\nu_\mu \to \nu_e) \quad \simeq \quad & \sin^2\theta_{23}\sin^2 2\theta_{13}\frac{\sin^2(\Delta_{31}-aL)}{(\Delta_{31}-aL)^2}\Delta_{31}^2 \\
& + \sin 2\theta_{23}\sin 2\theta_{13}\sin 2\theta_{12}\frac{\sin(\Delta_{31}-aL)}{(\Delta_{31}-aL)}\Delta_{31}\frac{\sin(aL)}{(aL)}\Delta_{21}\cos(\Delta_{31}+\delta_{\rm CP}) \\
& + \cos^2\theta_{23}\sin^2 2\theta_{12}\frac{\sin^2(aL)}{(aL)^2}\Delta_{21}^2,
\end{aligned}
$$

atmospheric

interference

solar

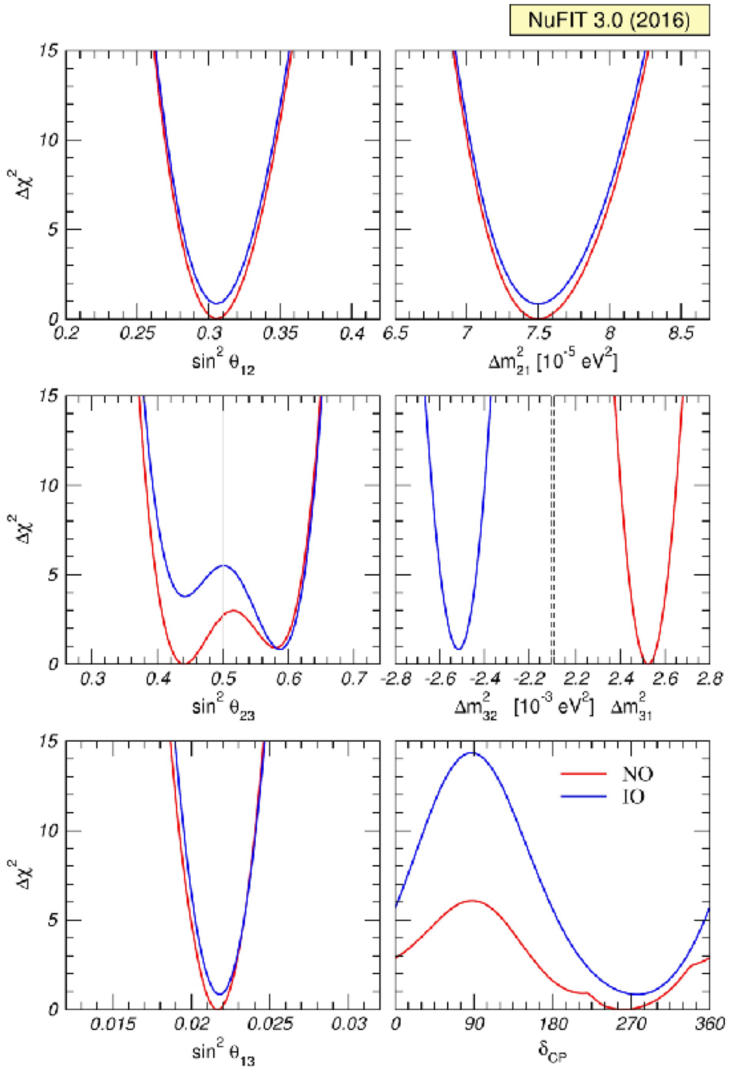




Oscillation sensitivity assumptions

- Oscillation priors from NuFit2016
- GLoBES-based fit to FD samples with parametrised FD response and ND constraints

arXiv:1606.09550

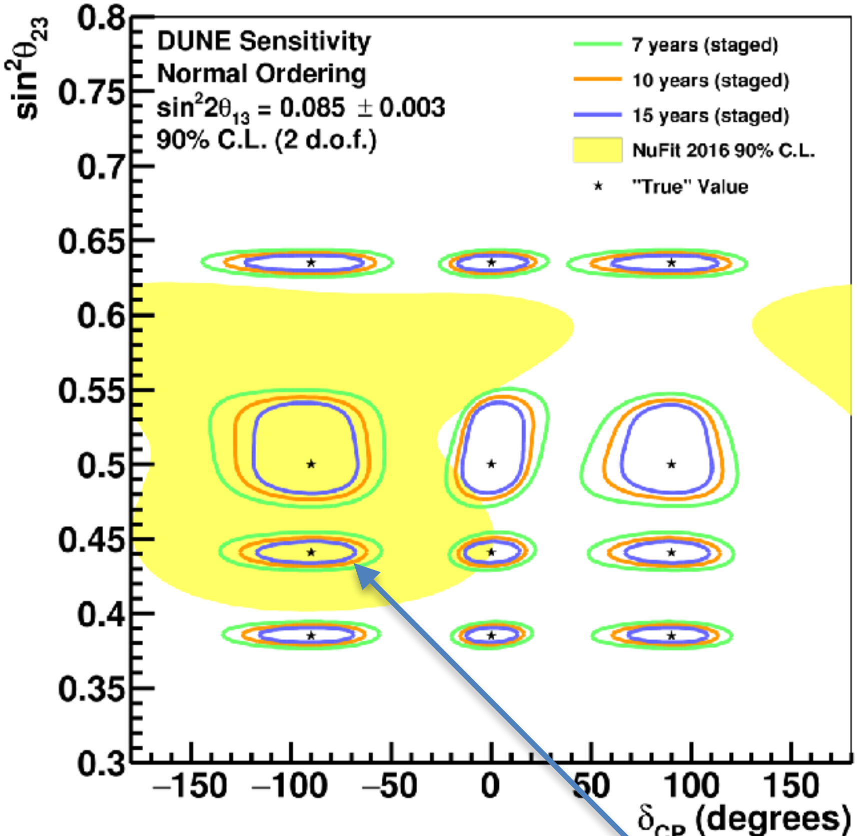


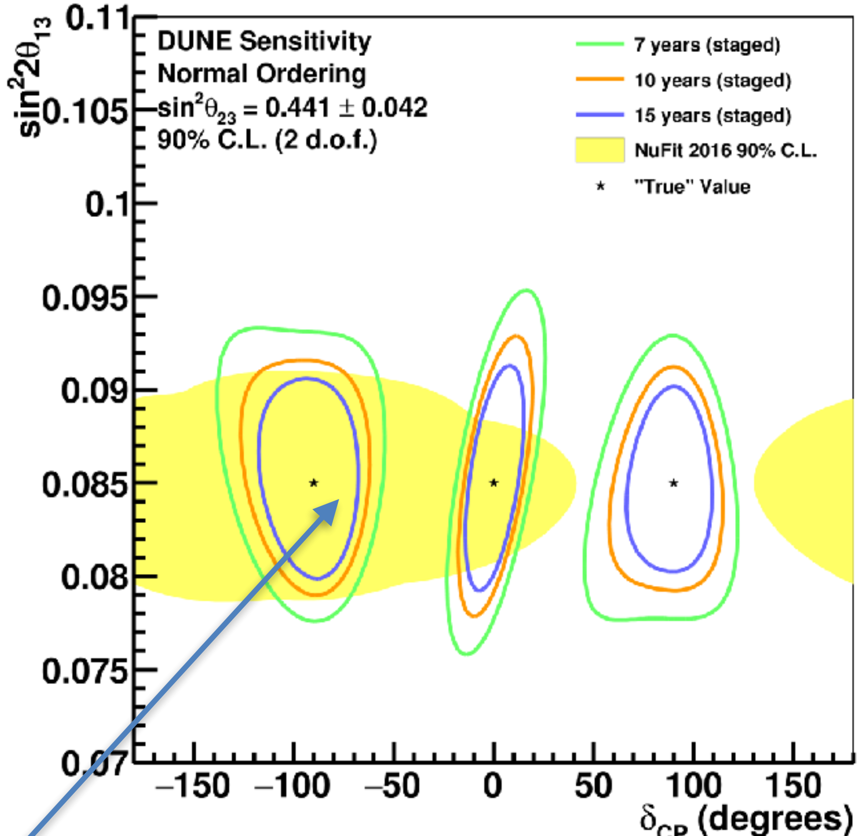
Staging assumptions

- Staging scenario with equal running in neutrino and antineutrino modes:
  - **Year 1** (2026): 20-kt FD, 1.07 MW beam
  - **Year 2** (2027): 30-kt FD
  - **Year 4** (2029): 40-kt FD
  - **Year 7** (2032): 2.14 MW beam

Exposure (kt·MW·yr)	Exposure (yr)
171	5
300	7
556	10
984	15

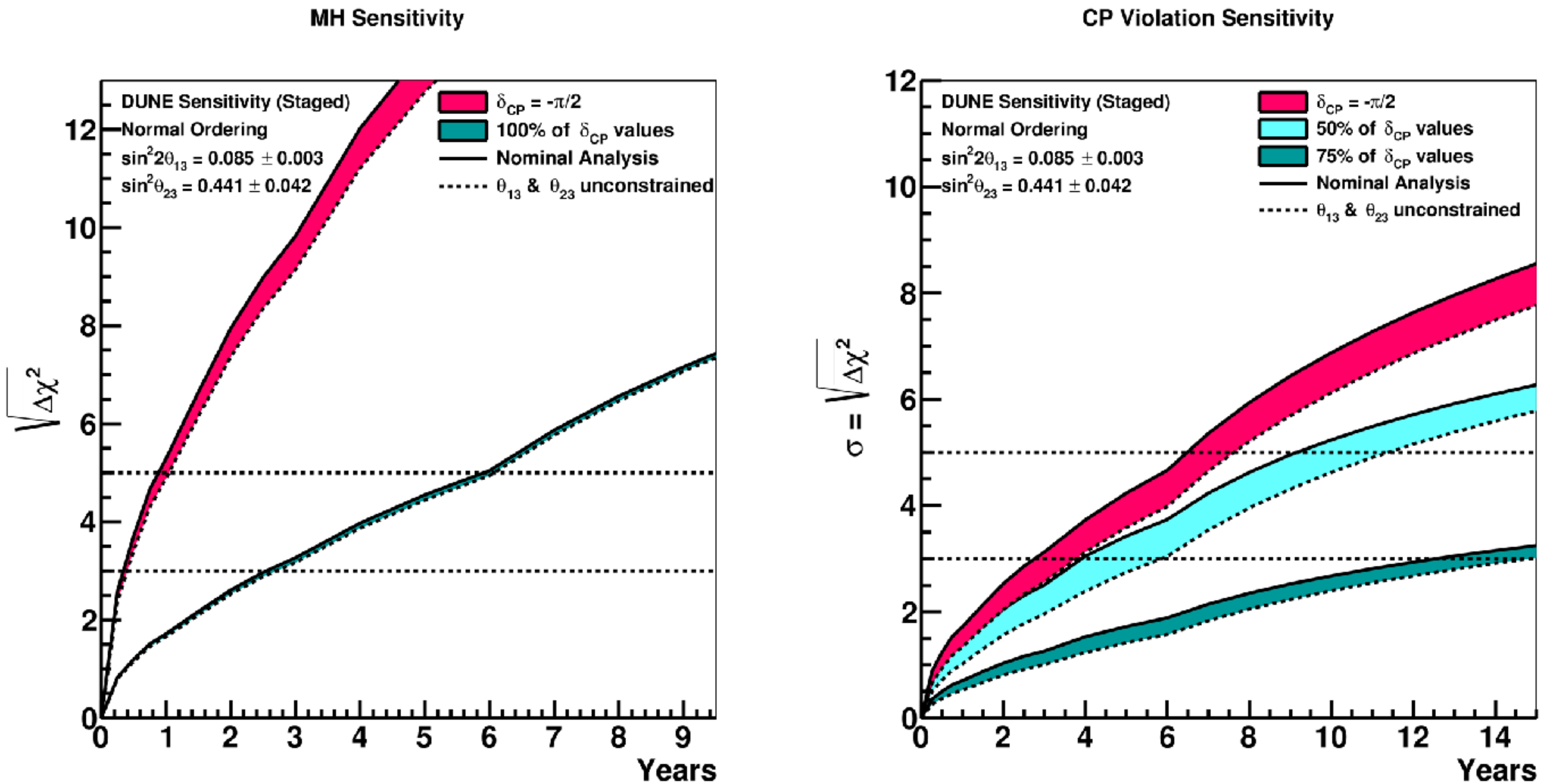
Two-dimensional allowed regions





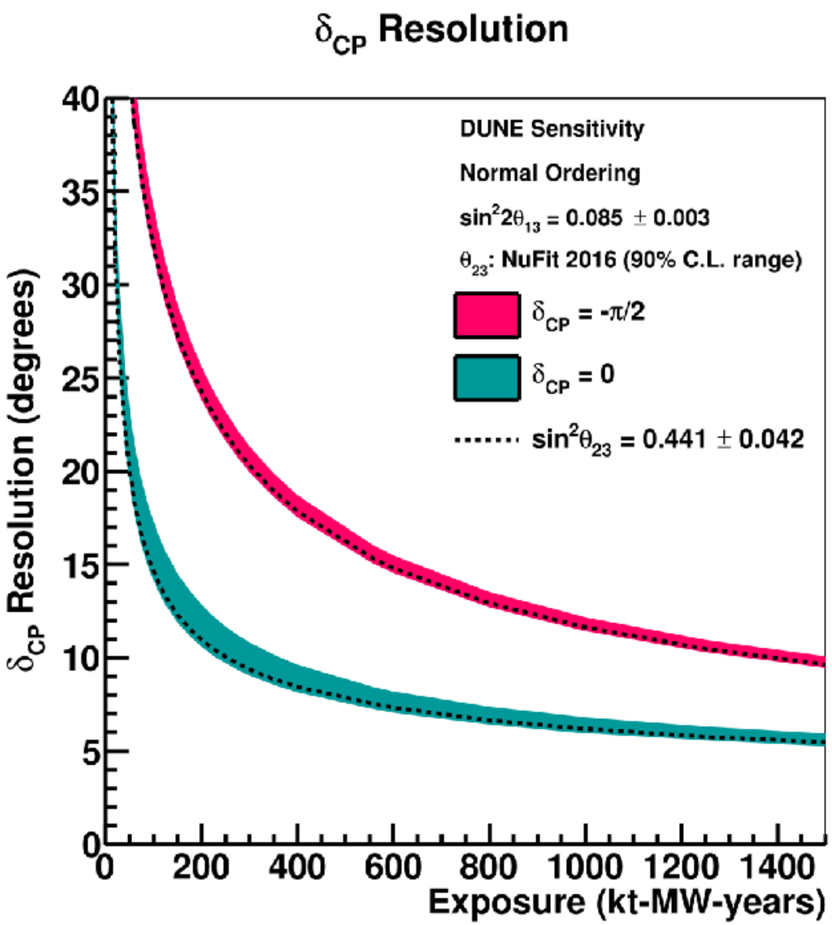
NuFit 2016 best-fit values

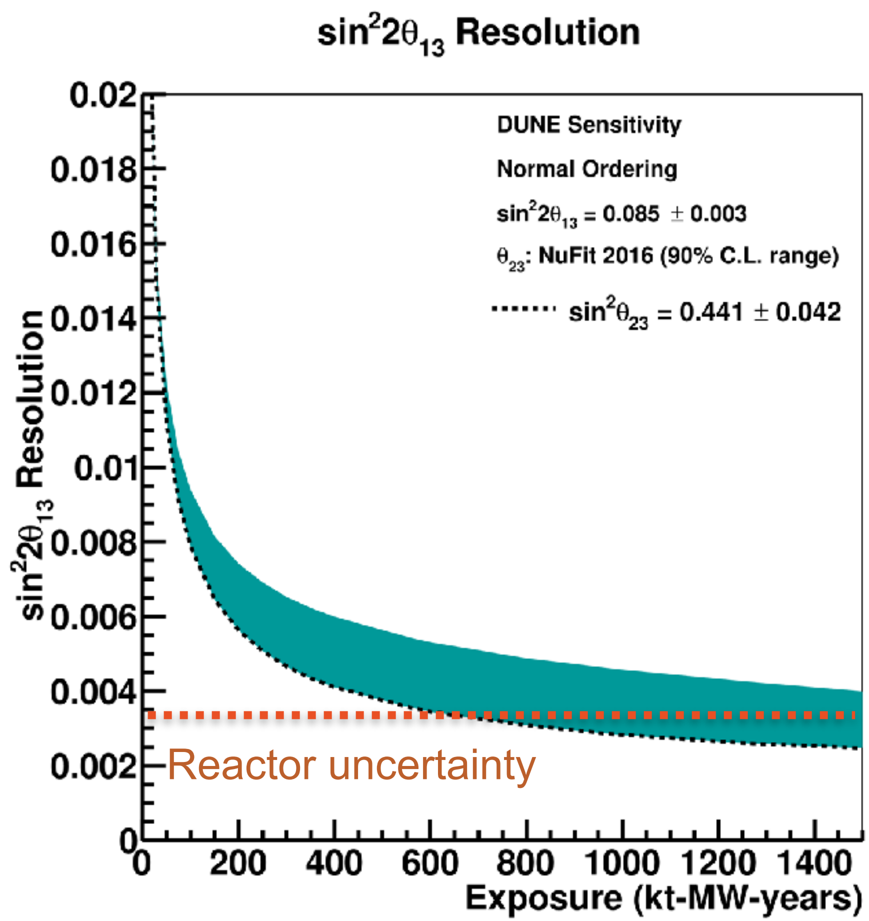
Sensitivity over time



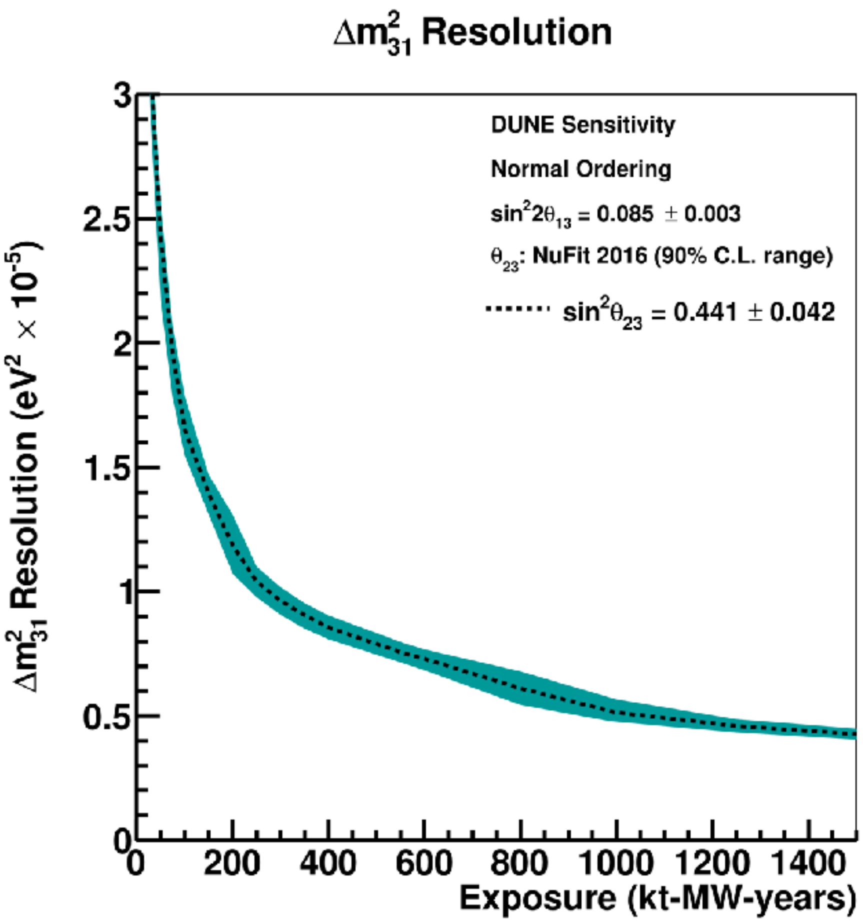
- Interesting measurements will be made throughout the DUNE physics program!

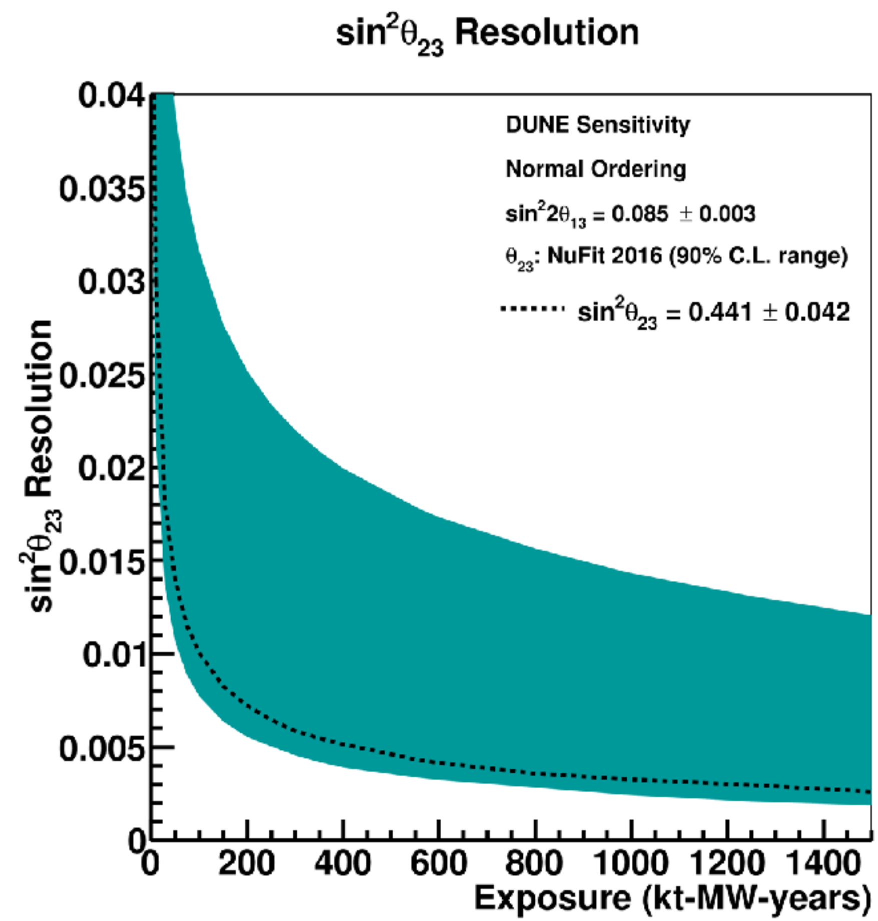
Uncertainties on oscillation parameters





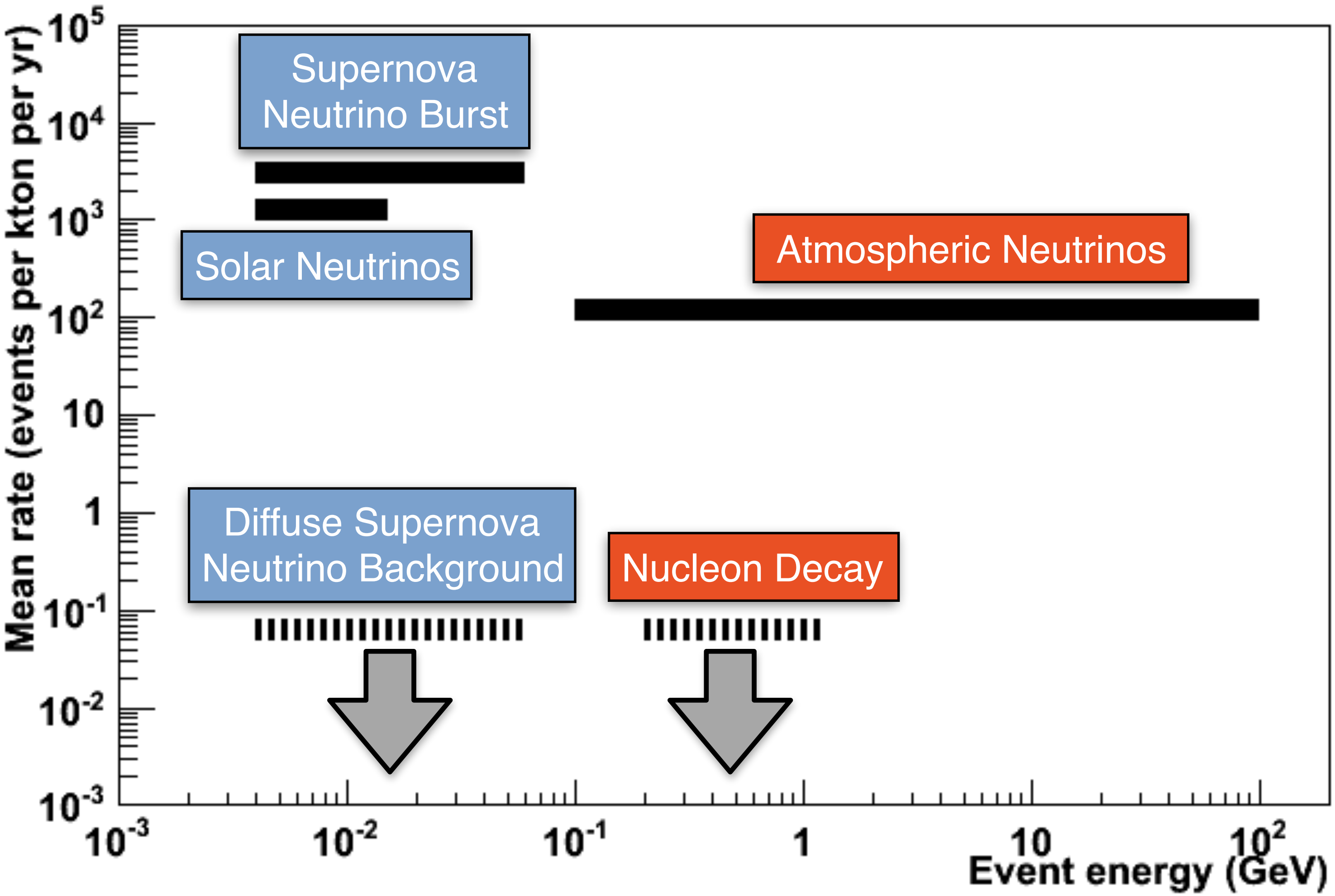
Uncertainties on oscillation parameters





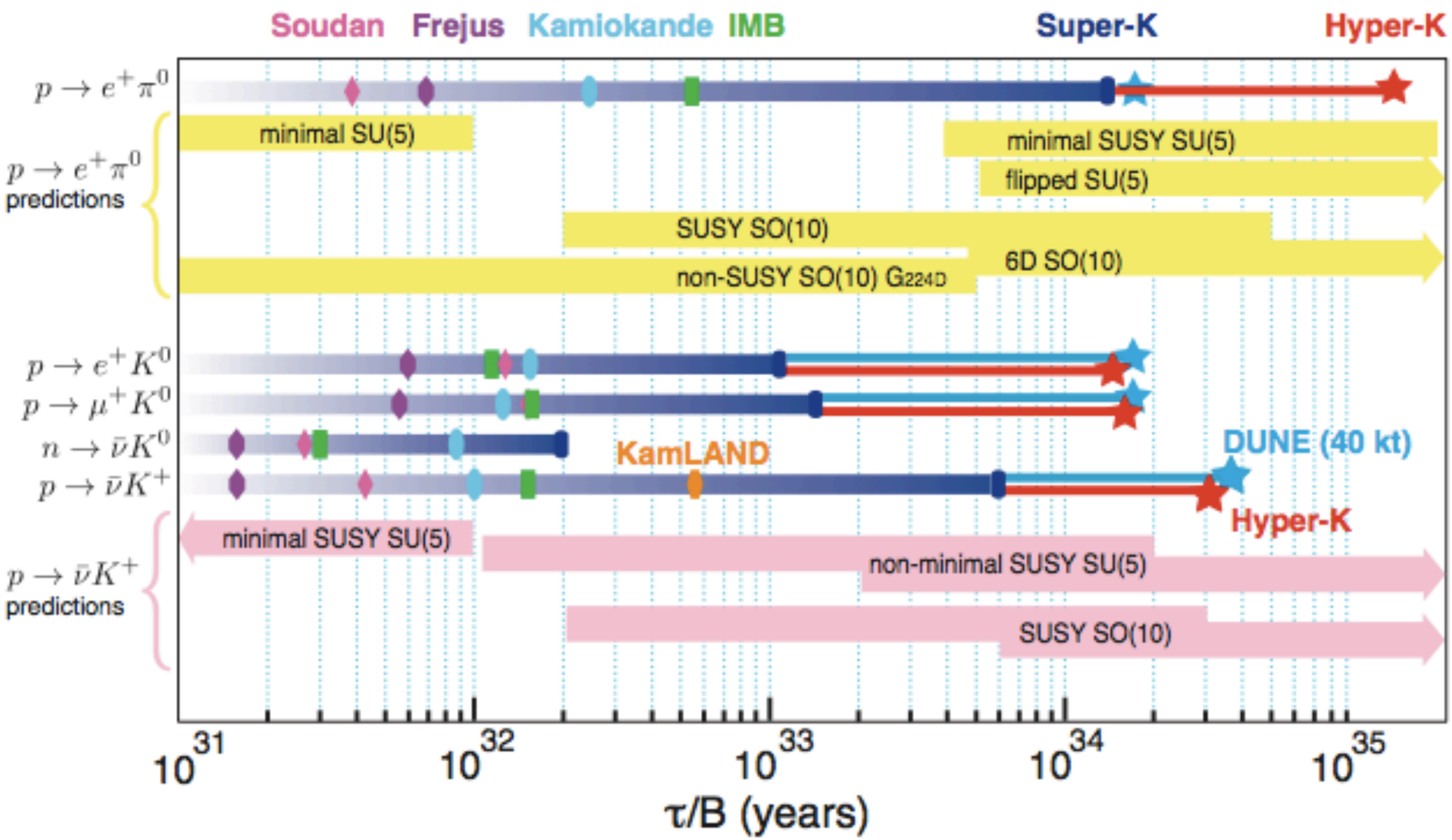
- **Current**: $\delta(\Delta m^2_{31}) = 4\times10^{-5}$ eV^2, $\delta(\sin^2\theta_{23}) = 0.04$

Astroparticle physics in DUNE



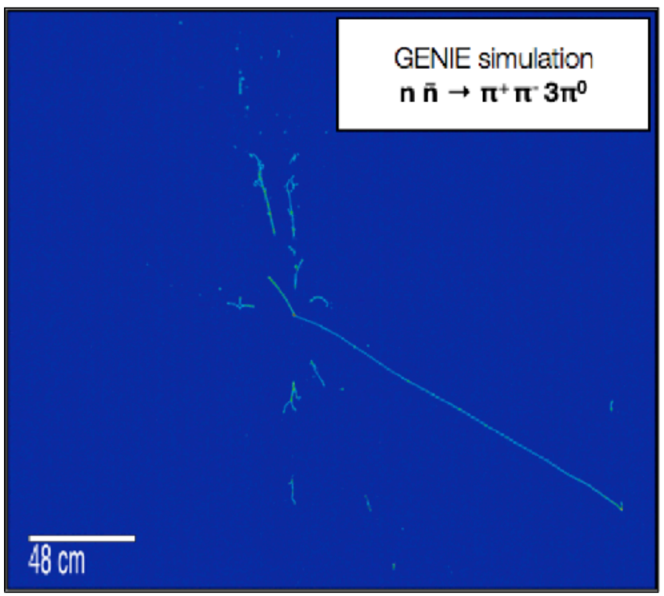
Nucleon decay

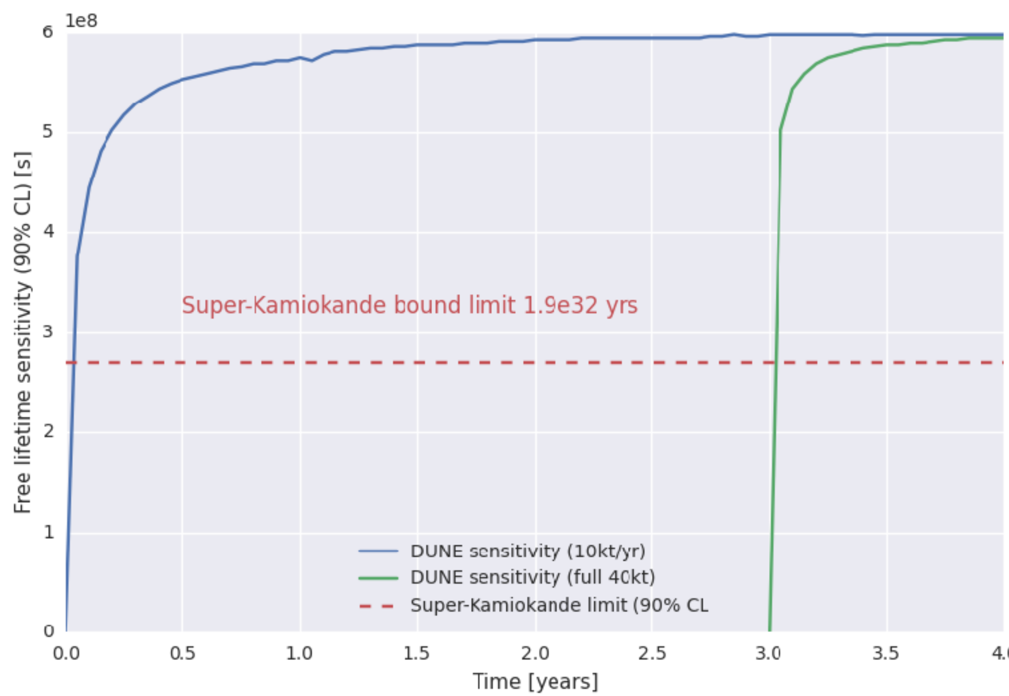
- Limits and sensitivities compared with ranges predicted by Grand Unified Theories, for benchmark decay modes:



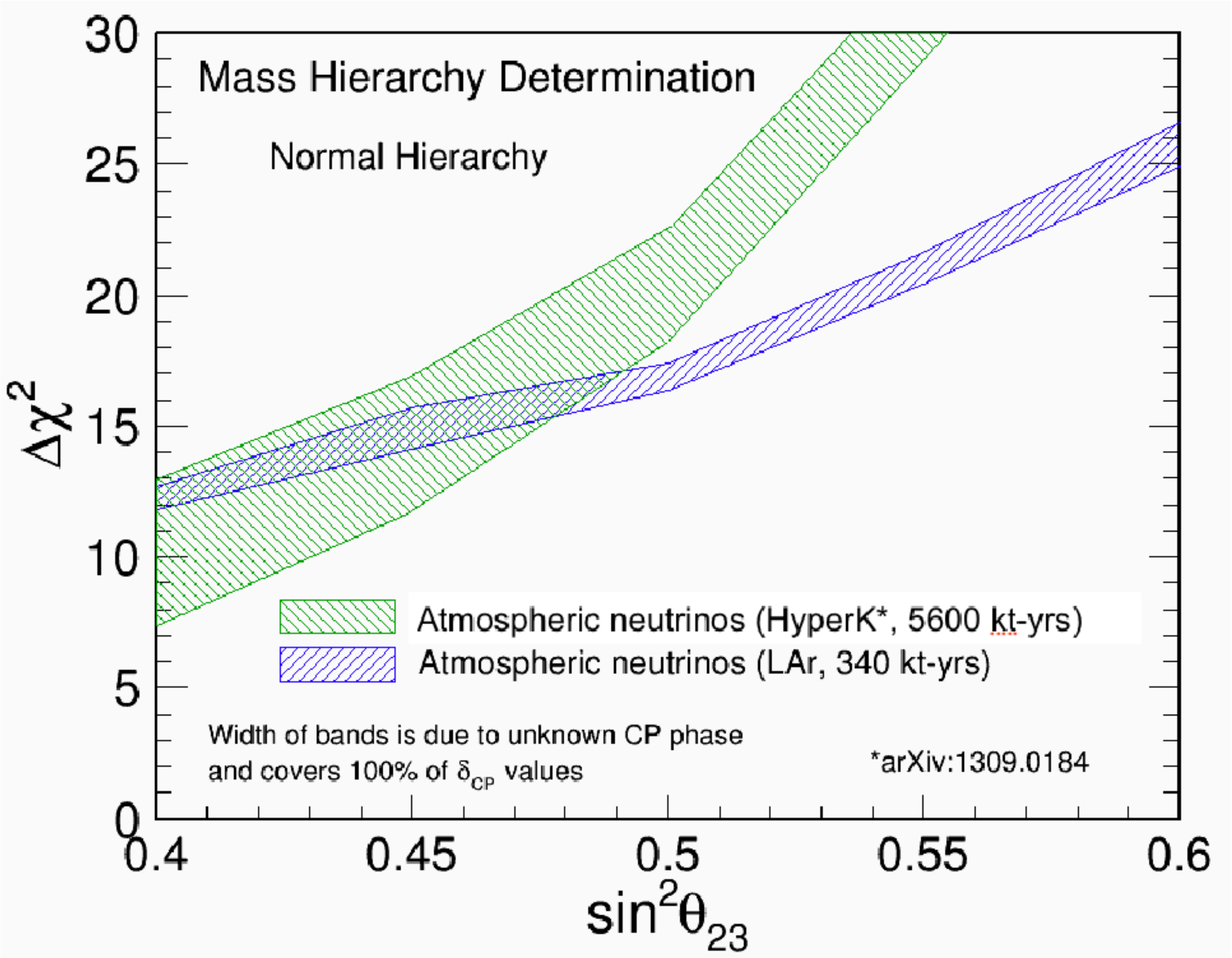
Sensitivity to n-nbar oscillations in DUNE

- ΔB=2 process: neutron spontaneously oscillates into antineutron
- Subsequent annihilation with bound nucleon inside the nucleus
- Preliminary analysis based on convolutional neural network techniques shows promising sensitivity!

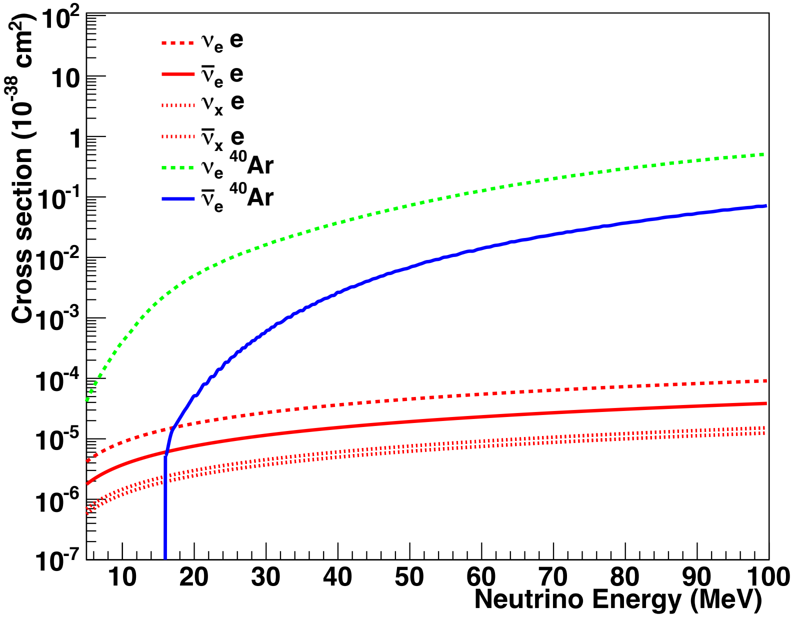


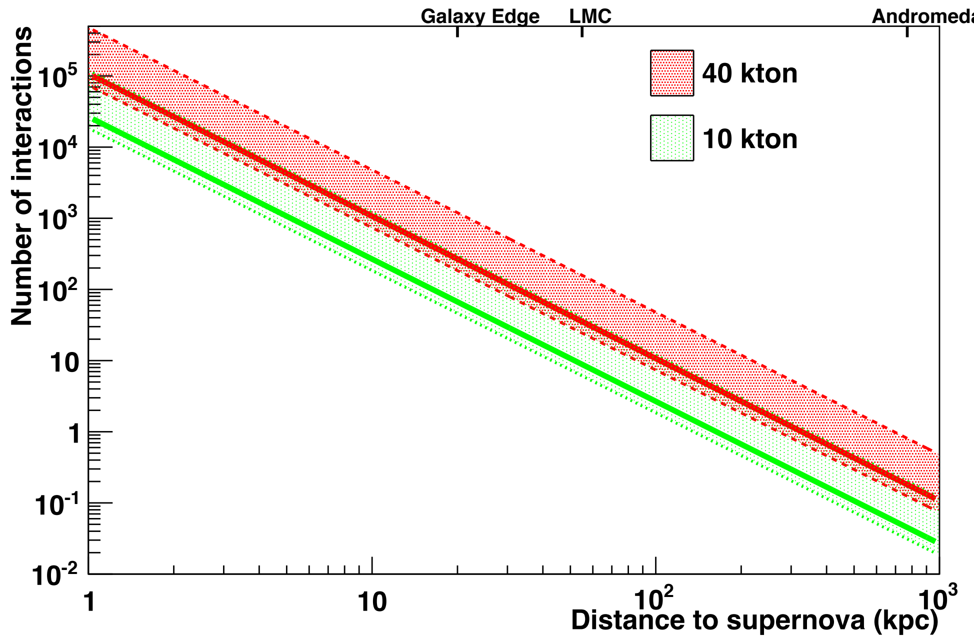


MH sensitivity with atmospheric neutrinos



Supernova neutrino cross sections and rates





ProtoDUNE goals

Detector construction

- Establish production process and quality assurance of full scale detector components

Detector installation

- Test of interfaces between detector elements

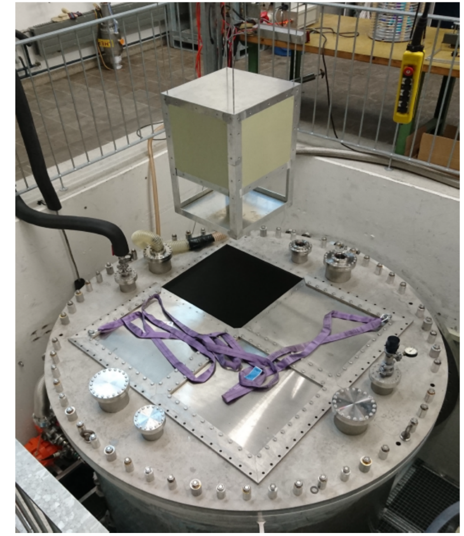
Detector operation

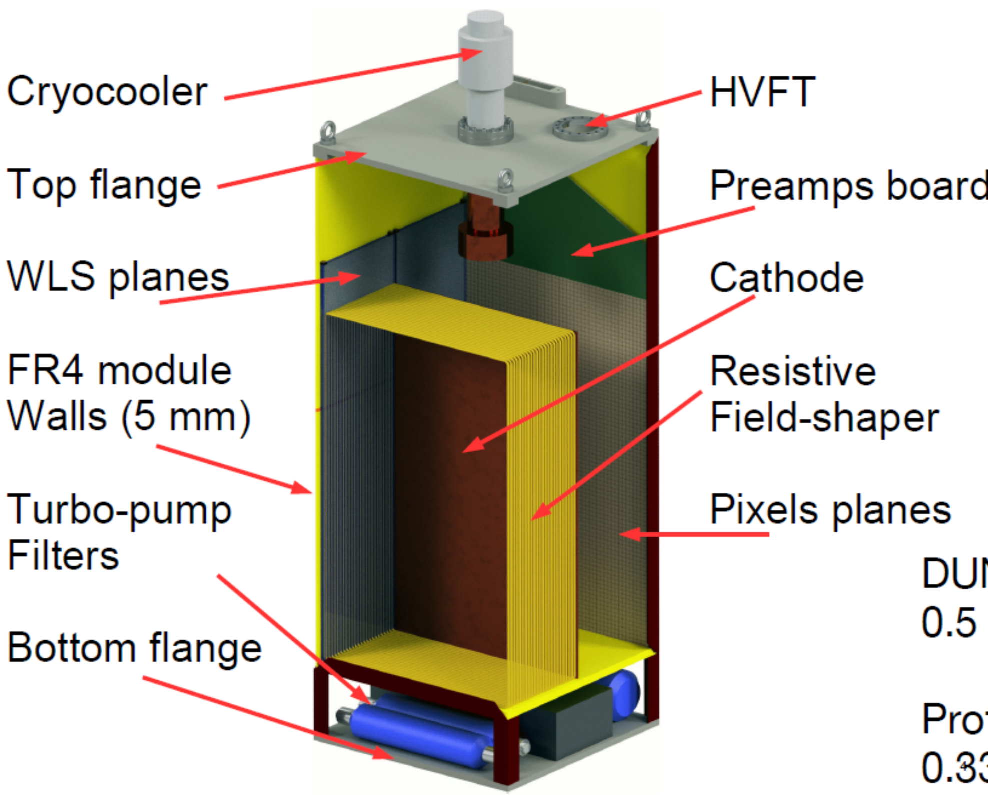
- Validate detector design and long-term detector performance

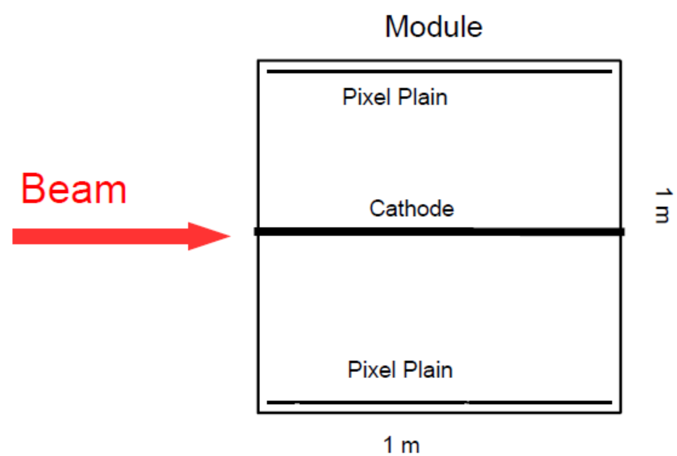
Test beam data

- Assess detector physics response and systematic uncertainties

LAr-TPC with pixel readout (ArgonCube)





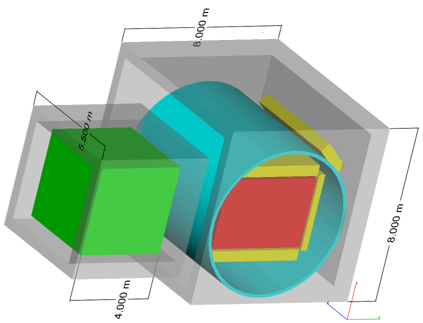


DUNE ND modules: 1.0 x 1.0 x 2.0 m^3.
0.5 m drift length

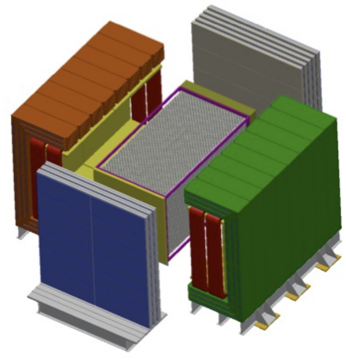
Prototype modules 0.67 x 0.67 x 1.8 m^3.
0.33 m drift

Multi-purpose tracker options

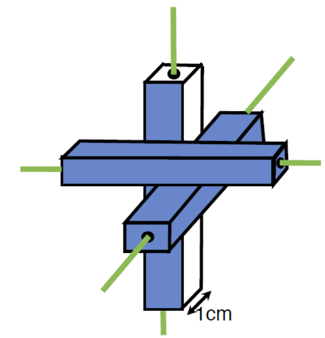
HP Gar TPC



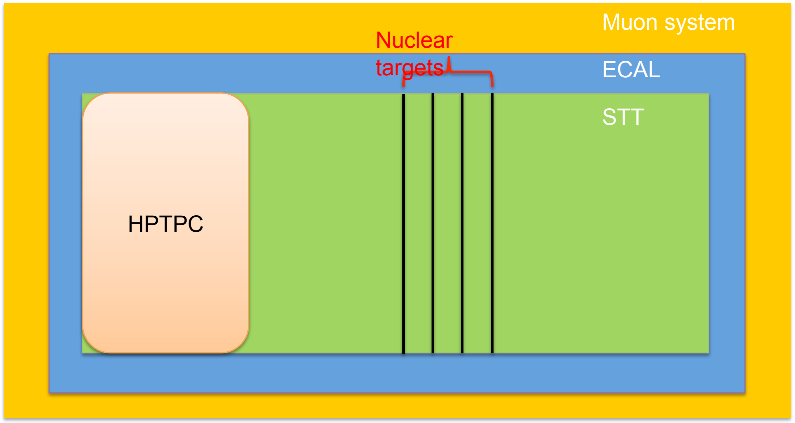
Straw Tube Tracker



3D Scintillator



Other Hybrids (I)



Other Hybrids (II)