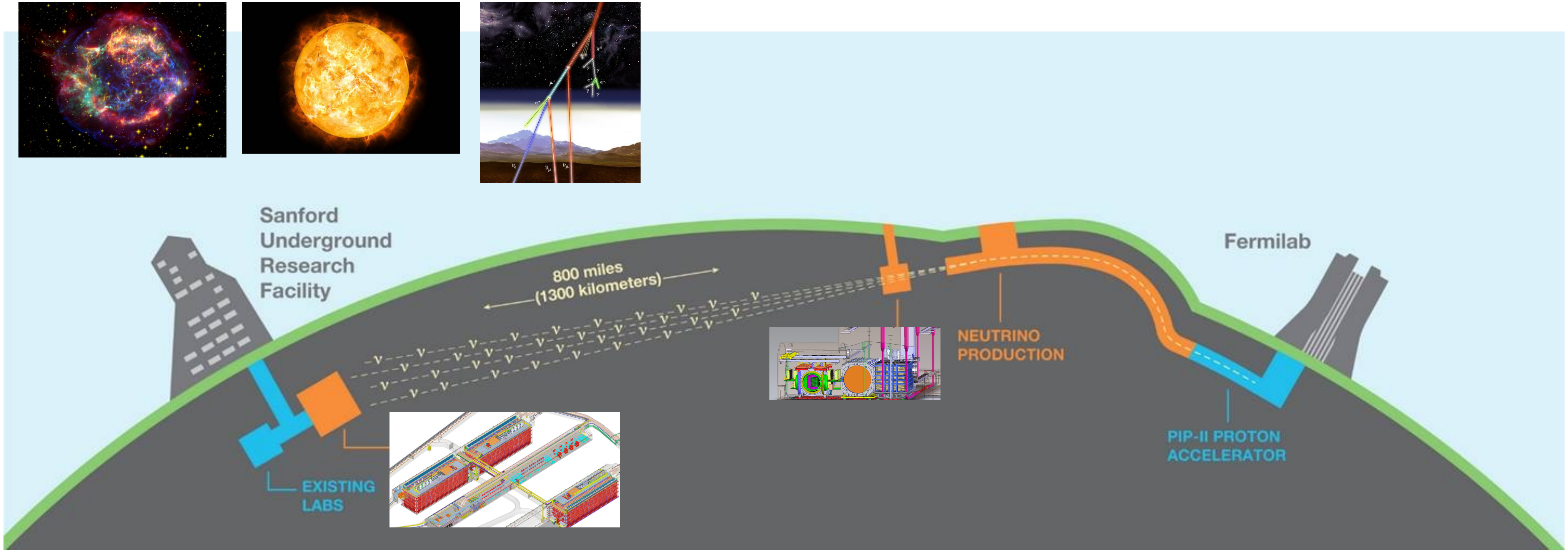
DUNE Status

Stefan Söldner-Rembold
Regina Rameika

DUNE UK Meeting

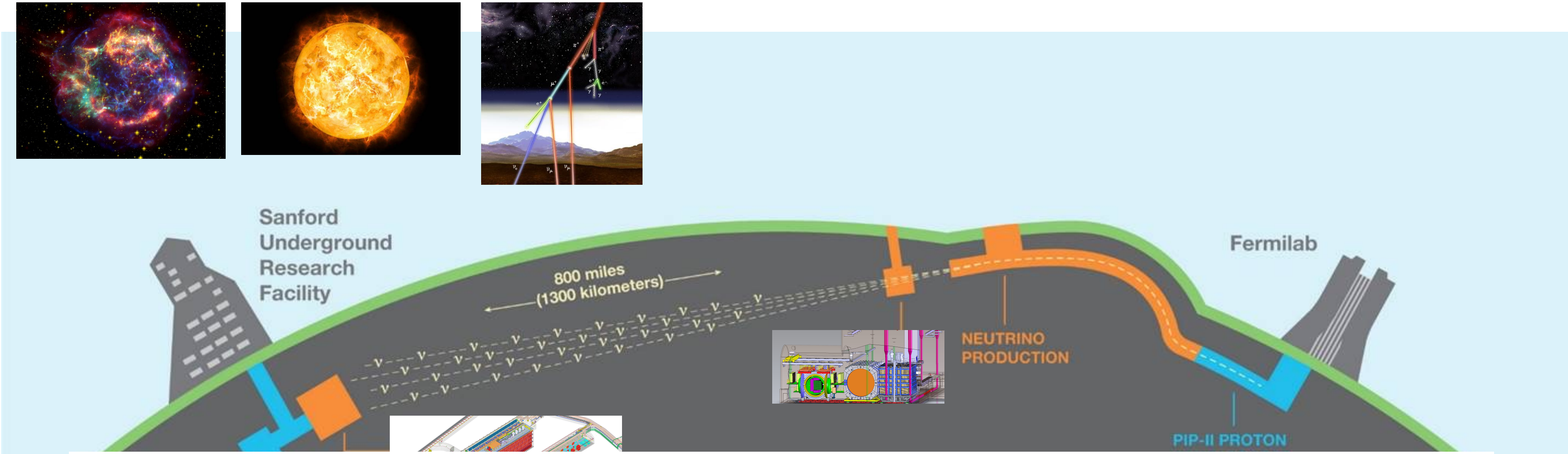
17 January 2022

DUNE Vision and Goal



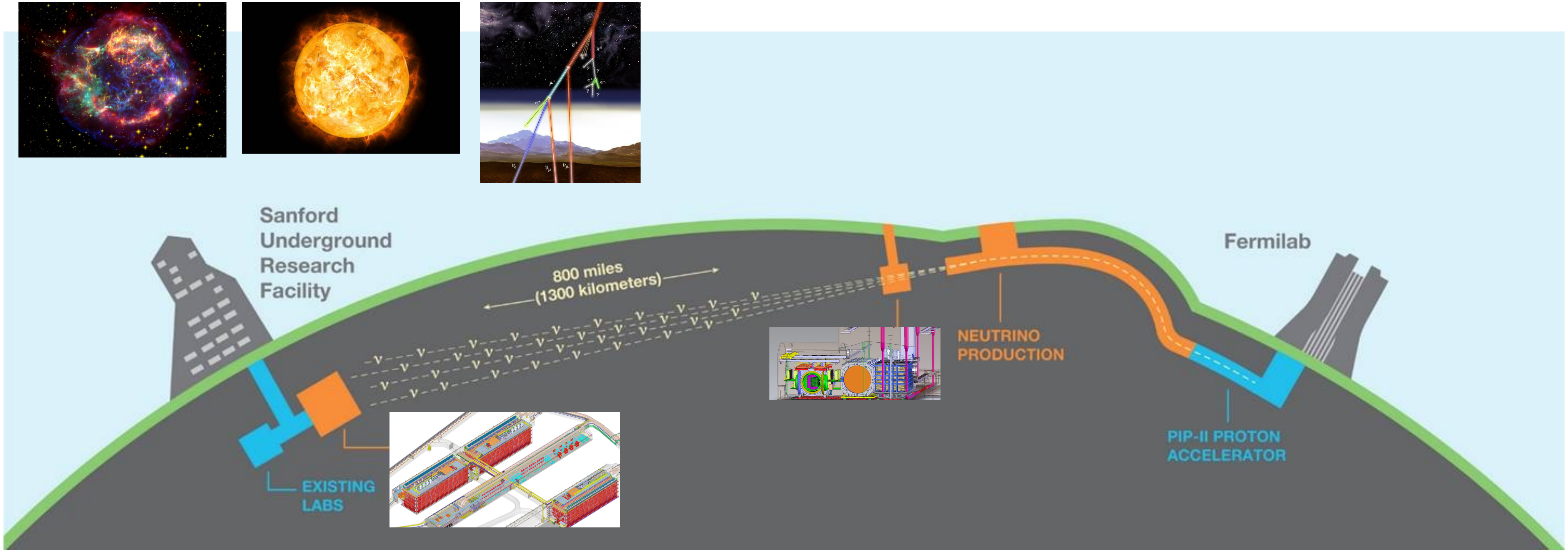
- The primary science goal of DUNE is to measure neutrino oscillation parameters, in particular the CP-phase δ and the neutrino mass ordering in a single experiment.
- DUNE will also detect supernova neutrinos, measure solar and atmospheric neutrinos and search for physics beyond the SM.

DUNE Vision and Goal

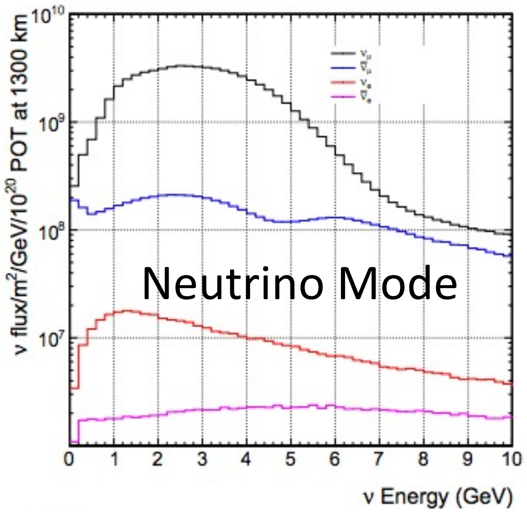


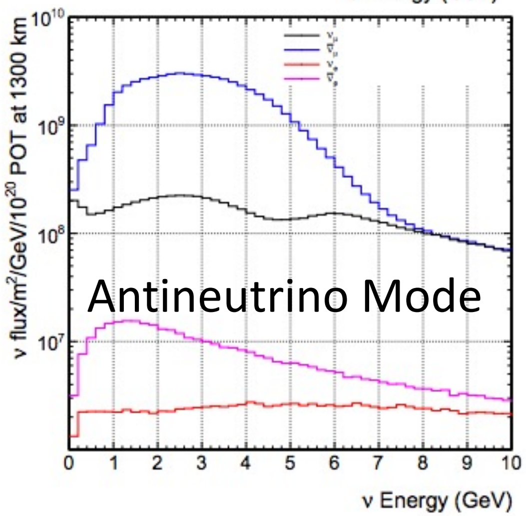
- The DUNE neutrino oscillation program is **exceptional** due to several key features of the experiment and facility design :
  - The **1300 km baseline** between Fermilab and SURF location for the far detectors enables an unambiguous measurement of the neutrino mass ordering (mass hierarchy)
  - The detector’s on-axis location provides for a **wide-band energy spectrum of neutrinos** to be seen in the near and far locations enabling detailed fitting of the oscillation parameters
  - The **liquid argon detector technology** enables precise reconstruction of the neutrino interactions
  - The Near Detector complex at Fermilab will support near detectors that will provide **unprecedented control of systematic uncertainties** in the prediction of the un-oscillated neutrino flux

DUNE Vision and Goal

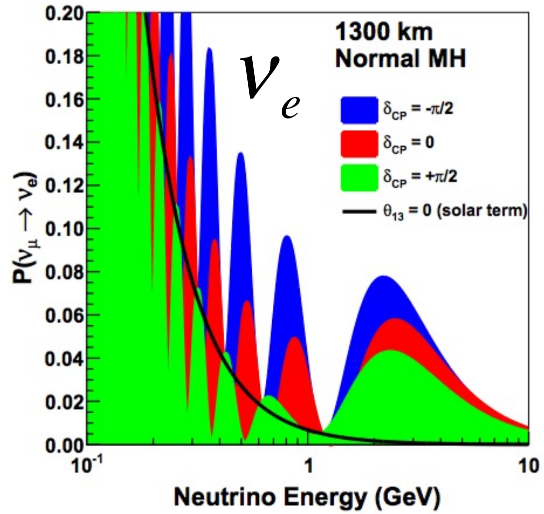


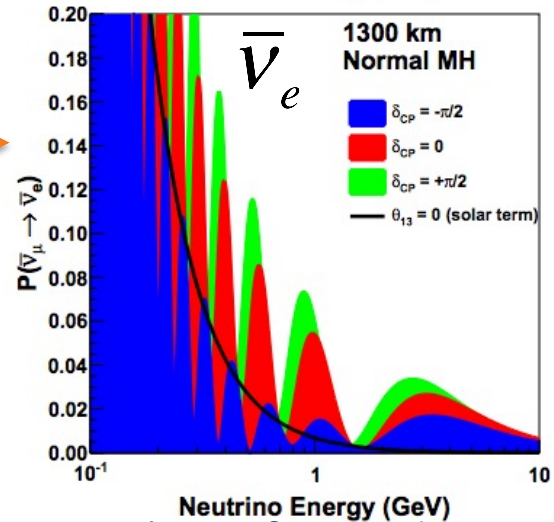
- The ultimate DUNE detector will therefore comprise
  - Four far detector modules
  - The Near Detector Reference Design described in CDR
  - A 1.2 MW beam upgradeable to 2.4 MW





Initial neutrino energy spectra (left) will be modified by neutrino oscillation probabilities (right)

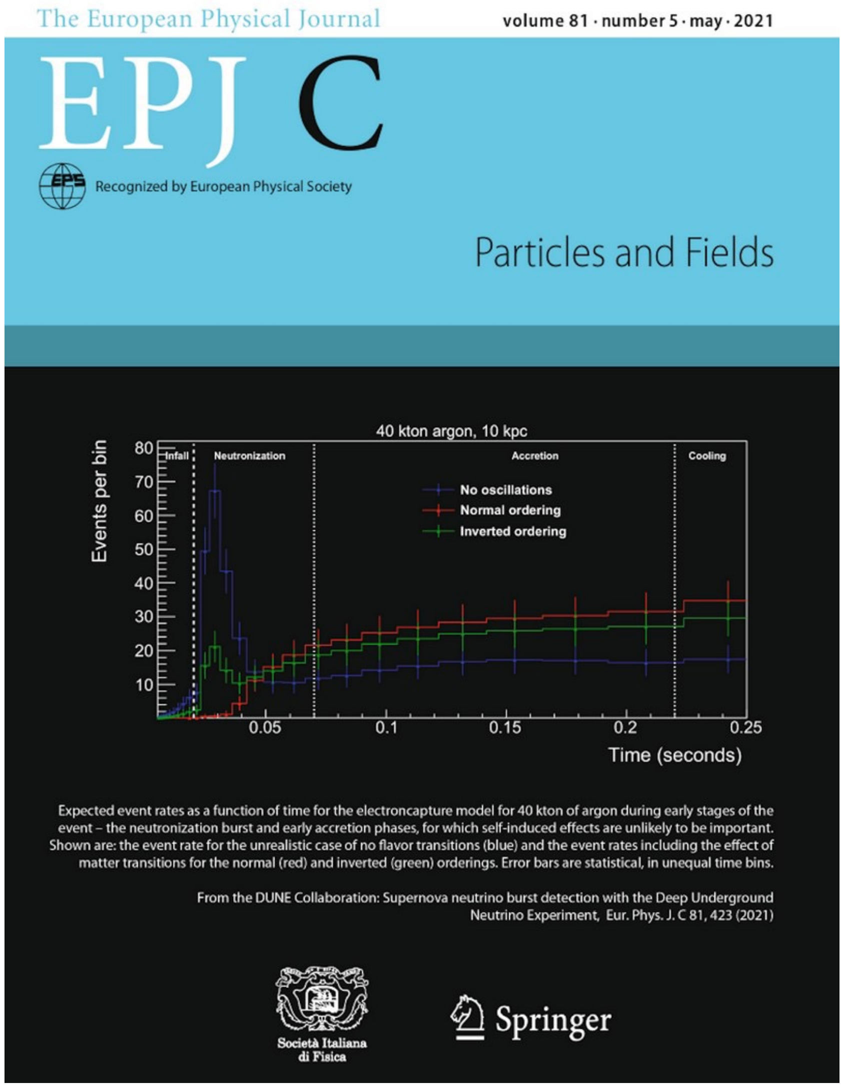




- ν_e appearance probability depends on mixing angles, CPV phase δ_{CP}, and matter effects. All four can be measured in a single experiment.
- Wide-band beam and long baseline break the degeneracy between CP violation and effect of neutrino mass ordering.

Supernova Neutrinos

- About 3000 events would be expected in the full DUNE Far Detector for a supernova at a distance of 10 kpc.
- Measurement at early times tests mass ordering and SNB model (spectral parameters)
- Three physics sensitivity papers (Long-baseline, Supernova, Beyond the Standard Searches) published in Eur. Phys. J C.

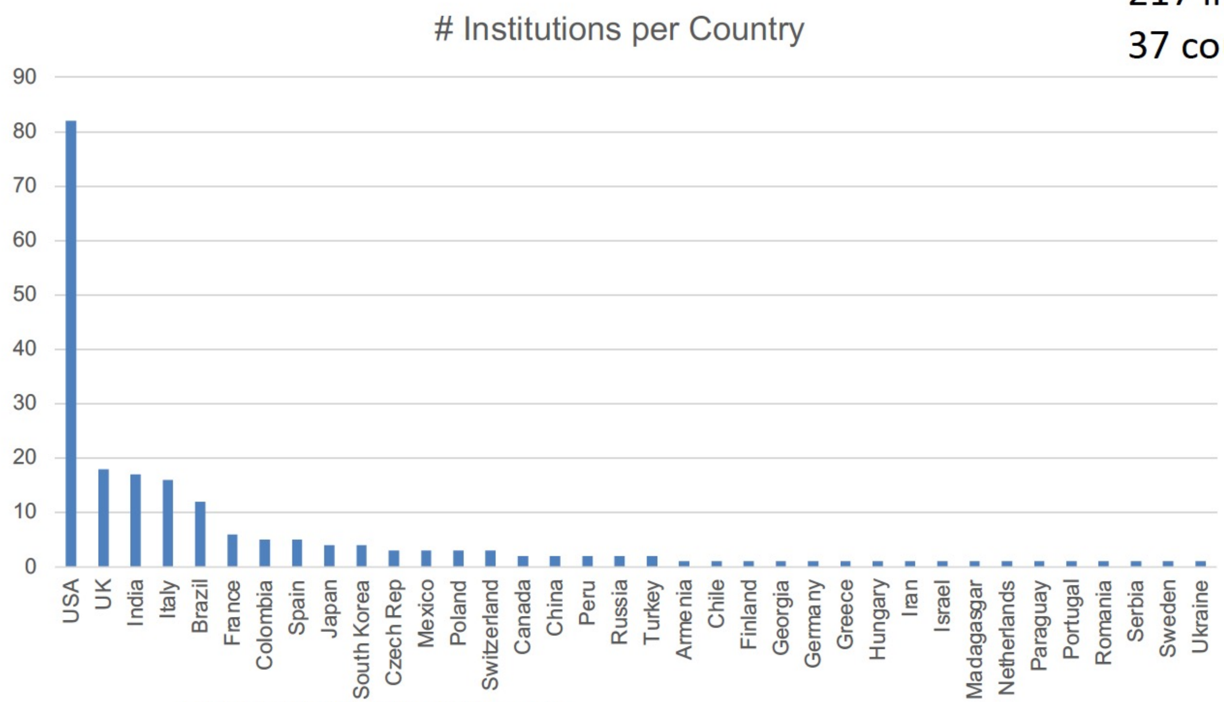


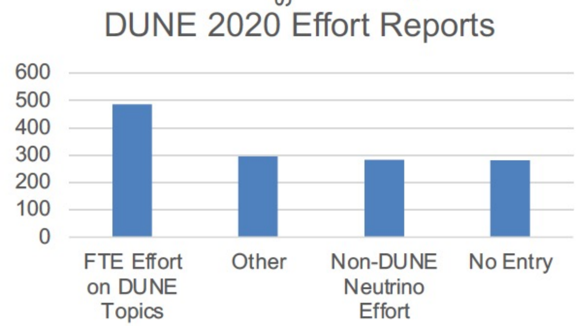

Collaboration Meeting
September 2021
DUNE
DEEP UNDERGROUND
NEUTRINO EXPERIMENT

Collaboration Statistics

October 2021

1432 Collaborators
217 institutions
37 countries (incl. CERN)





Effort reporting done annually;
Results as expected for an experiment many years out from 1st science

Collaboration Demographics

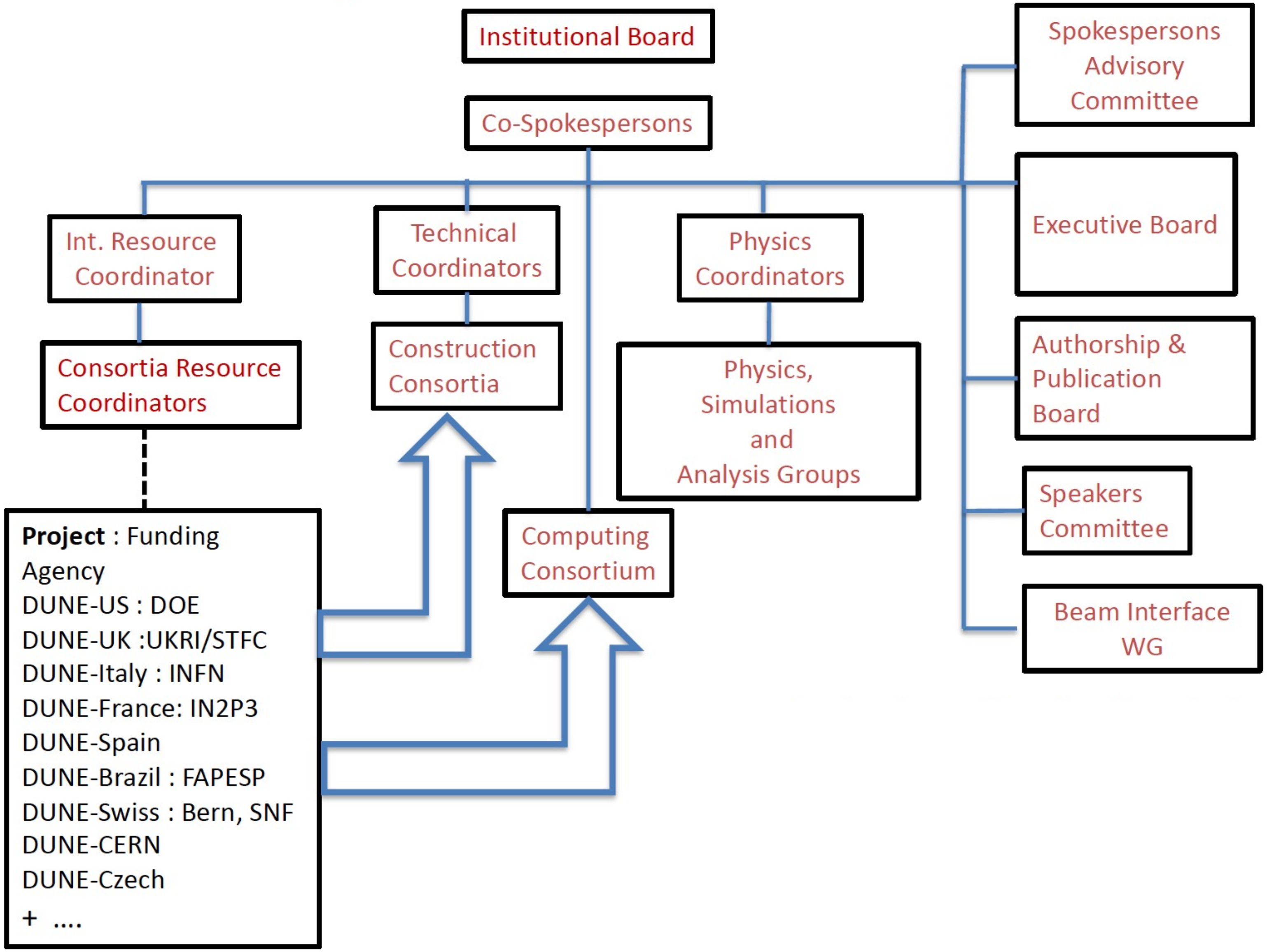
From 2020 effort reports

International Collaboration

Position	In Collaboration	Effort on DUNE
Faculty	676	200
Post Docs	240	77
Graduate Students	319	104
Engineers, CP	158	67

Reporting for 2021 starting this month.

DUNE Collaboration Organization



Physics Working Groups

Physics Coordination Inés Gil-Botella Chris Marshall	**Long-baseline** Callum Wilkinson Luke Pickering	**High energy** Lisa Koerner Yun-Tse Tsai	**FD sim/reco** Chris Backhouse Dom Brailsford
DUNE Physics Working Groups	**Neutrino Interactions** Cheryl Patrick Mateus Carneiro	**BSM** Justo Martin-Albo Alex Sousa	**ND sim/reco** Linda Cremonesi Mat Muether
Liaisons Dan Cherdack (ND) Tom Junk (computing)	**Low Energy** Clara Cuesta Dan Pershey	**Calibration** David Caratelli Mike Mooney	**protoDUNE analysis** Leigh Whitehead Tingjun Yang

Low-energy = 1-10s MeV-scale physics: supernovae, solar, etc.
This group also works with the backgrounds task force,
as natural radioactivity is an important background for LE physics

High-energy = GeV-scale non-accelerator physics: atmospheric neutrinos,
nucleon decay & other signals for which atmospheric neutrinos are a background.
Formerly known as the nucleon decay WG.

BSM = other BSM physics, historically more phenomenologically-oriented.
Steriles, NSI, dark matter, BSM searches at the ND.

Detector Consortia

DUNE Detector Construction Consortia

Near Detectors

ND-LAr

SAND

Data Acquisition
FD1, FD2, ND

Far Detectors

Anode Plane
Assemblies - FD1

TPC Electronics
FD1, FD2-B

Charge Readout
Planes - FD2

TPC Electronics
FD2-T

High Voltage
FD1, FD2

CALCI
FD1, FD2

Photon Detection
FD1, FD2

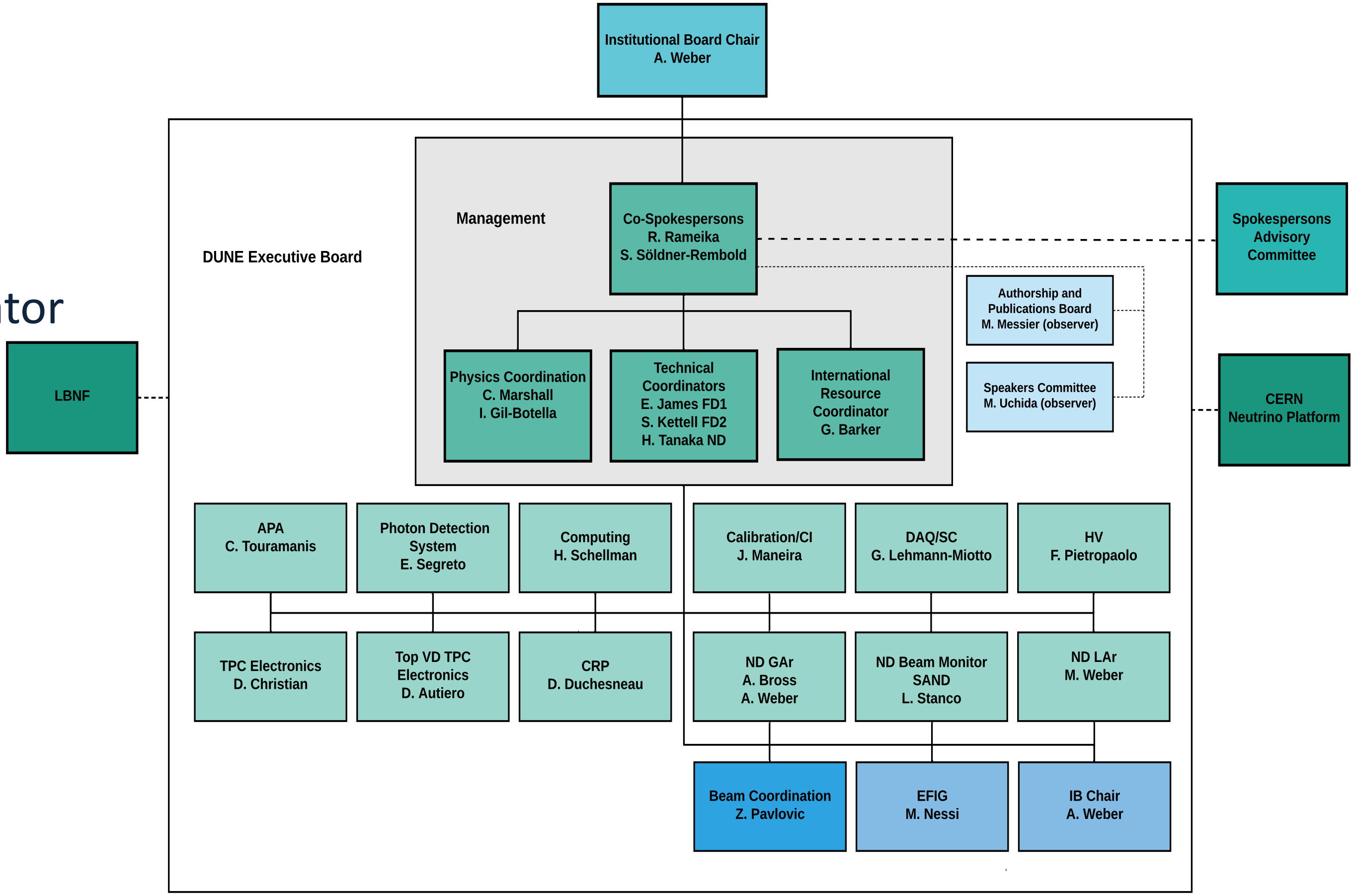
DUNE Executive Board

<u>DUNE Management:</u>

Spokespersons
Technical Coordinators
Int. Resources Coordinator
Physics Coordinators

<u>plus:</u>

Consortia Leaders
Beam Coordinator
IB Chair
EFIG Co-chair



Neutrino Cost Group

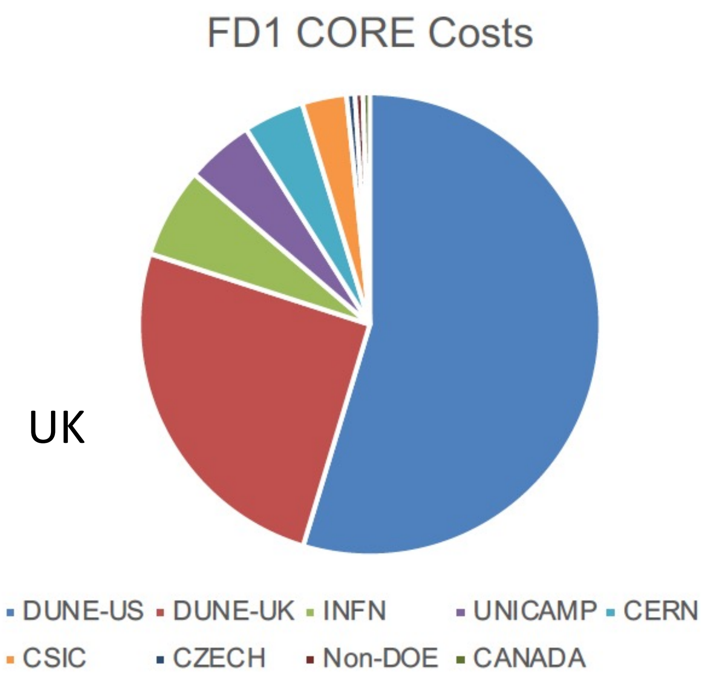
From the original charge

The purpose of the NCG is to review the cost, schedule, and associated risks for the DUNE experiment, and to provide reports and recommendations to the Fermilab Director and the RRB. This includes:

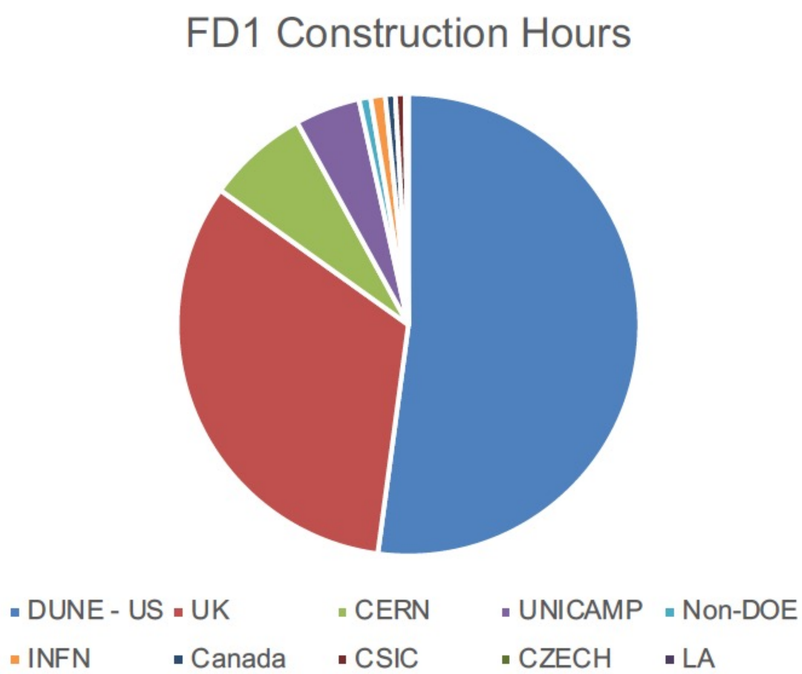
- *Evaluating the reliability, completeness and appropriateness of the cost estimate for the DUNE experiment including computing.*
- *Assessing the feasibility of the schedule for DUNE and the availability of the manpower necessary to execute the project.*
- *Evaluating the project management structure and the risk analysis for DUNE, along with the LBNC, including proposed levels of cost realism and schedule contingency to address identified risk mitigation strategies.*
- *Monitoring progress of DUNE against the cost and schedule associated with the Technical Design Reports.*

The NCG will establish a common methodology which can be used to value international contributions to DUNE.

International DUNE partner contributions to FD1 (from Cost Book data)

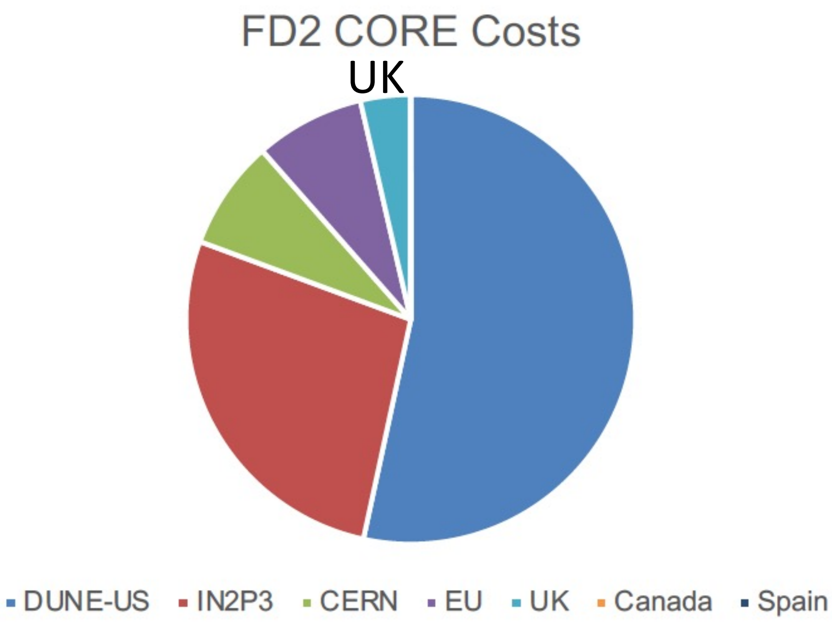


Total CORE ~$55M

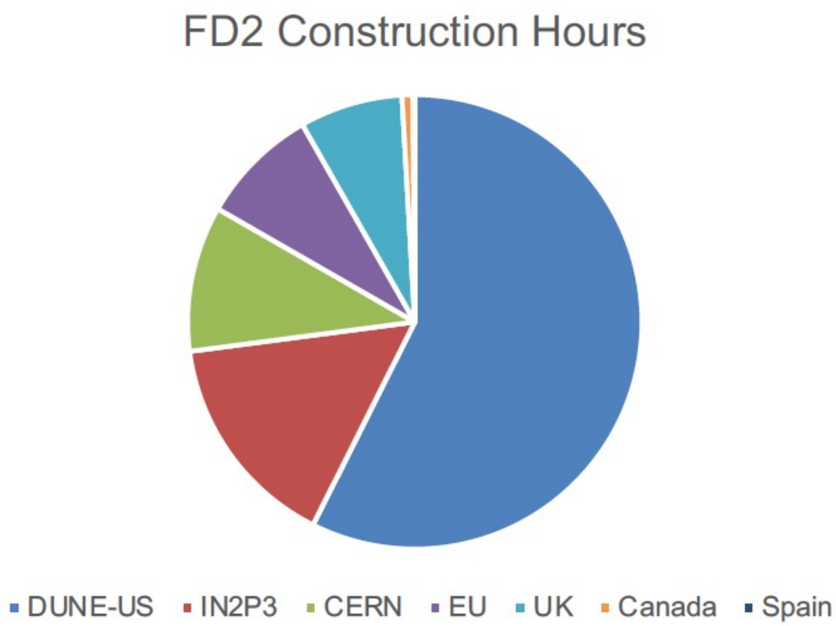


>900,000 hours
~500 person-years

International DUNE partner contributions to FD2 (preliminary)

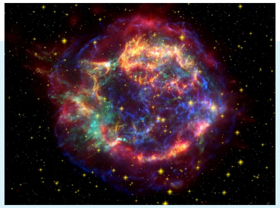


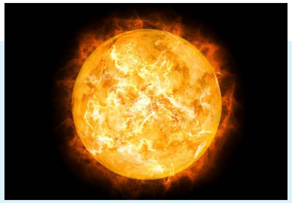
Total CORE ~$45M

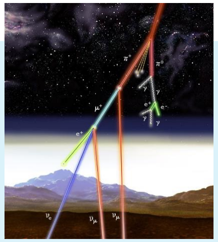


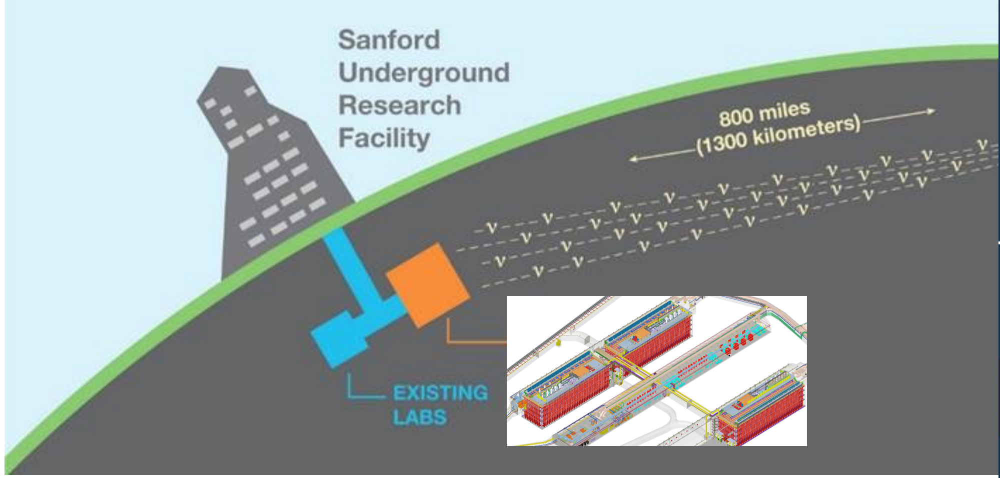
>300,000 hours
~180 person-years

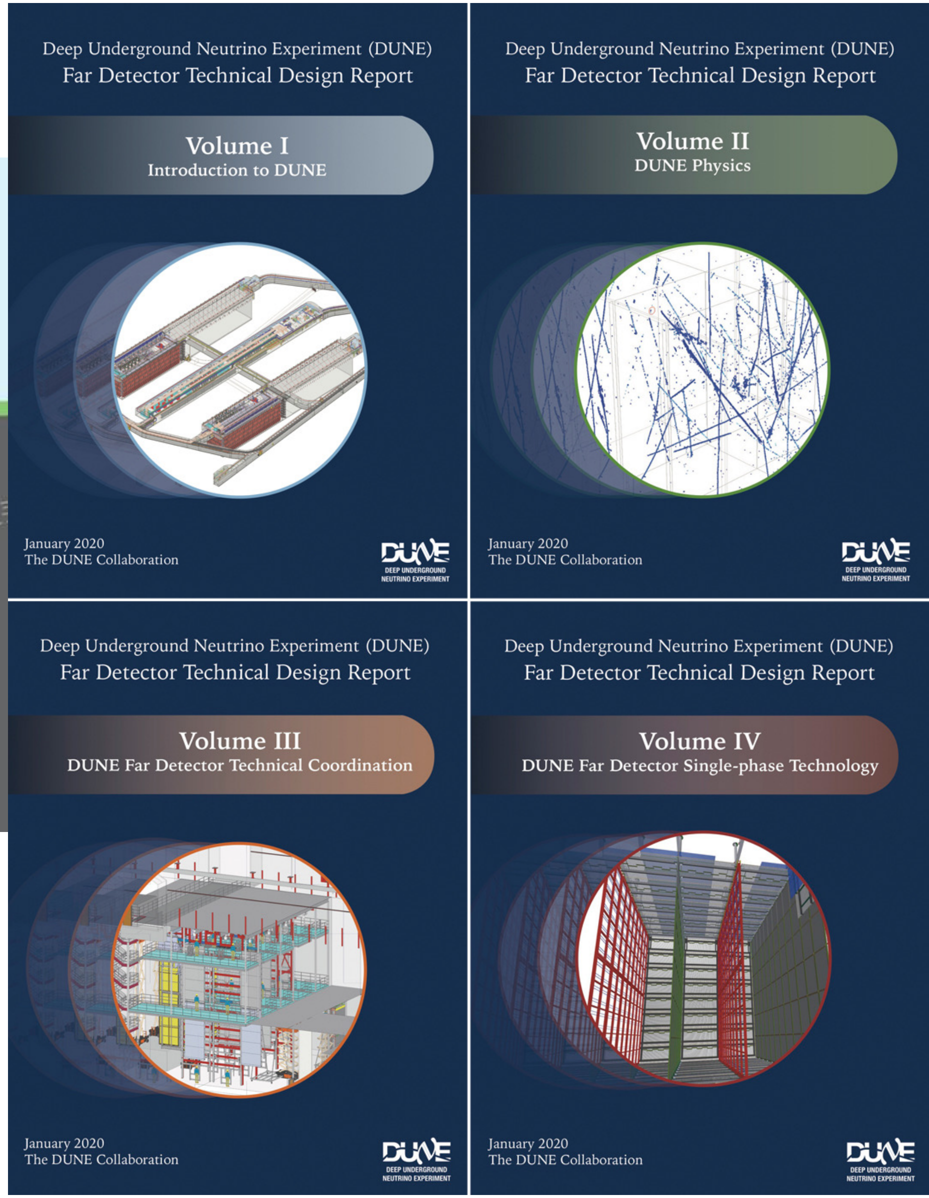
DUNE TDR











OPEN ACCESS

Volume I. Introduction to DUNE

B. Abi[1], R. Acciarri[2], M.A. Acero[3], G. Adamov[4], D. Adams[5], M. Adinolfi[6], Z. Ahmad[7], J. Ahmed[8], T. Alion[9], S. Alonso Monsalve[10] + Show full author list

Published 27 August 2020 • © 2020 CERN

Journal of Instrumentation, Volume 15, August 2020

DUNE Far Detector Technical Design Report, Volumes I, III, and IV

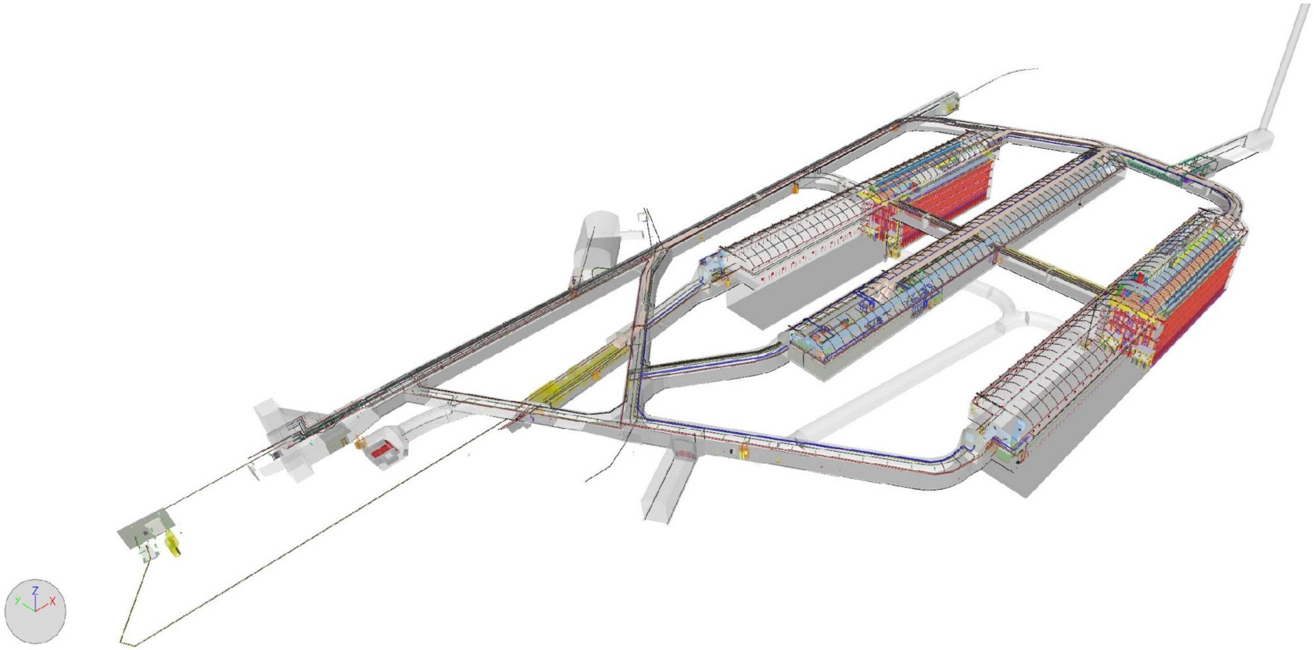
Citation B. Abi *et al* 2020 *JINST* **15** T08008

TDR published in 2020

TDR Far Detector Strategy

TDR described 4 identically sized cryostats:

2 single phase (SP) + 1 dual phase (DP) + 1 “module of opportunity”, each about 17 kt



We have moved on from this – first two modules will be horizontal drift (FD1-HD) and vertical drift (FD2-VD), respectively.

Fermilab MANCHESTER 1824 DUNE

US funding profile

Implementation of "Reference Profile" - Assumptions and Parameters

- HEP provided updated annual funding guidance, the "reference profile," on 13 August as described in previous presentation.
- Project implemented the reference profile, guided by the following sequencing, closely coordinated with DUNE collaboration leadership:

Impacts Compared to Technically Limited Plan

1. Construct Far Detector 1 and Far Detector 2
   - Dependent on: FSCF construction and cryogenics infrastructure
   - Enables: start of science

   No impact
   Start science in 2nd FD in early 2029

2. Construct Primary and Neutrino Beamline
   - Dependent on: NSCF Beamline Complex construction
   - Enables: start of oscillation physics

   ~2.5-year impact
   Start operation in 2031

3. Construct Near Detector
   - Dependent on NSCF ND Complex construction
   - Enables: understanding of detector systematics for ultimate science objectives

   ~3 year-impact
   Start operation in 2032

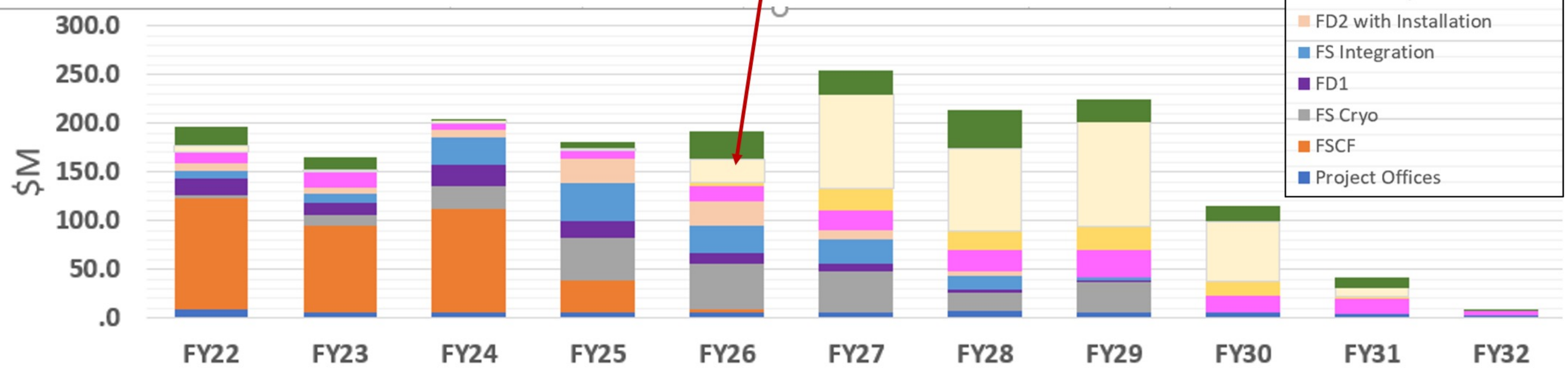
If reconciliation bill passes and provides resources for science infrastructure, anticipate technically limited schedule

Implementation of Reference Profile – Obligations (August status, prior to subprojects)

	Prior Years	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	Total
Reference Profile	772	180	180	200	225	250	250	250	250	250	250	95	-	3,152
Obs Plan	661	196	166	203	181	191	254	214	225	115	42	9	-	2,458
Obs Plan + 15% (except FD1/FD2 at 25%)	661	228	192	237	213	223	294	247	259	132	48	10	-	2,744
Scenario Carry Over	111	63	51	14	26	53	9	12	4	122	323	408	408	

Project obligations + 15% contingency plan except for FD1/FD2 with 25% contingency

NSCF effort delayed 2 ¾ years. Funding available to begin earlier (see green line in table above) but cannot finish sooner



Fermilab MANCHESTER 1824 DUNE

Construction Sequencing

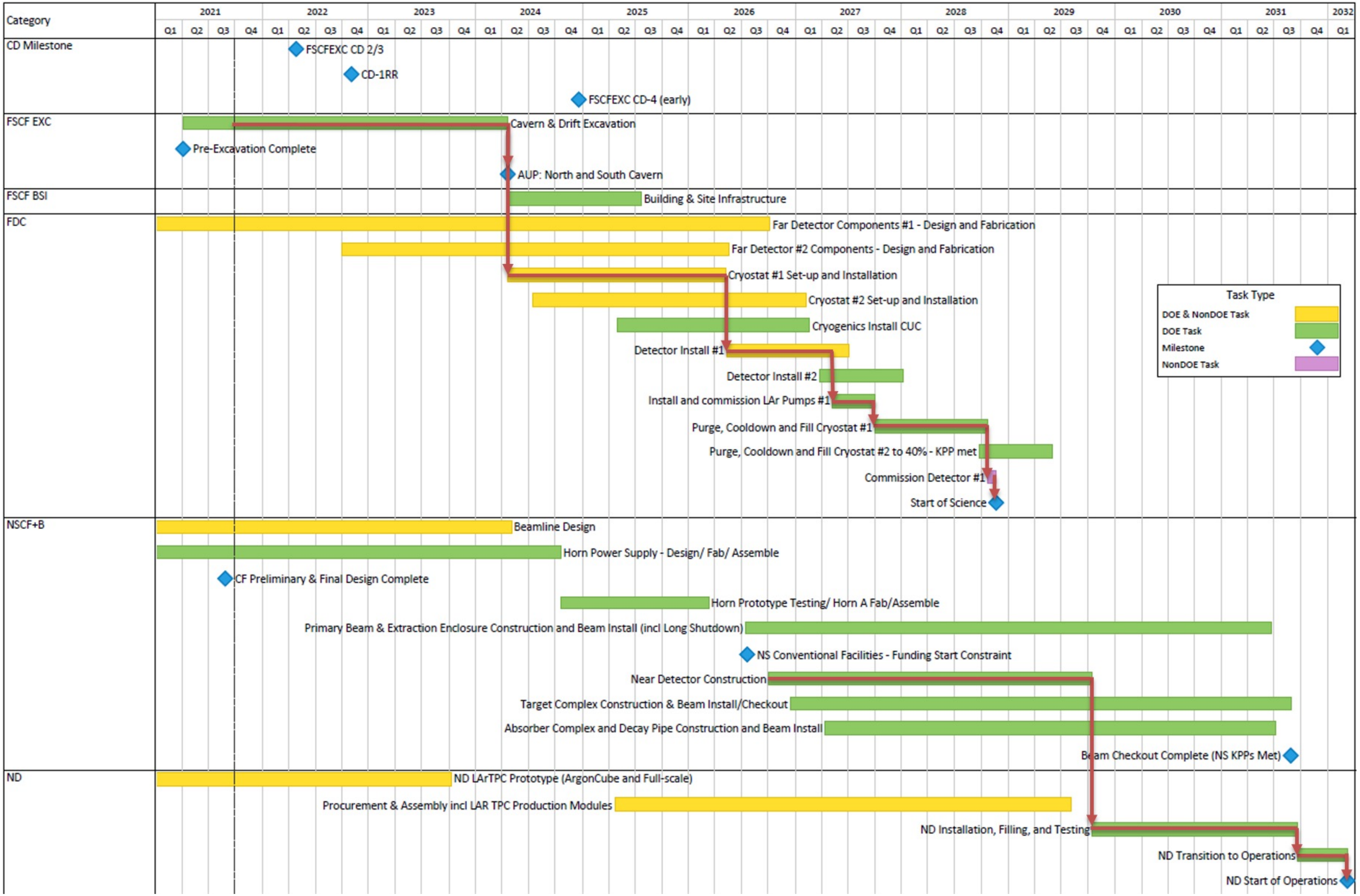
Given the funding constraints for the facility and DOE contributions to the detectors that we are faced with, we believe that the following principles should apply :

- The Far Detectors should be completed ASAP
- Followed by the Beam, ASAP
- Followed by the Near Detector - Phase 1

Sequencing is not Prioritization!

LOGIC :

Without a Far Detector, we don't need a beam; without a beam we don't need a Near Detector



Category
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
Q1 Q2 Q3 Q4
CD Milestone
FSCFEXC CD 2/3
CD-1RR
FSCFEXC CD-4 (early)
FSCF EXC
Cavern & Drift Excavation
Pre-Excavation Complete
AUP: North and South Cavern
FSCF BSI
Building & Site Infrastructure
FDC
Far Detector Components #1 - Design and Fabrication
Far Detector #2 Components - Design and Fabrication
Cryostat #1 Set-up and Installation
Cryostat #2 Set-up and Installation
Cryogenics Install CUC
Detector Install #1
Detector Install #2
Install and commission LAr Pumps #1
Purge, Cooldown and Fill Cryostat #1
Purge, Cooldown and Fill Cryostat #2 to 40% - KPP met
Commission Detector #1
Start of Science
NSCF+B
Beamline Design
Horn Power Supply - Design/ Fab/ Assemble
CF Preliminary & Final Design Complete
Horn Prototype Testing/ Horn A Fab/Assemble
Primary Beam & Extraction Enclosure Construction and Beam Install (incl Long Shutdown)
NS Conventional Facilities - Funding Start Constraint
Near Detector Construction
Target Complex Construction & Beam Install/Checkout
Absorber Complex and Decay Pipe Construction and Beam Install
Beam Checkout Complete (NS KPPs Met)
ND
ND LArTPC Prototype (ArgonCube and Full-scale)
Procurement & Assembly incl LAR TPC Production Modules
ND Installation, Filling, and Testing
ND Transition to Operations
ND Start of Operations
Task Type
DOE & NonDOE Task
DOE Task
Milestone
NonDOE Task

Phasing

- The International DUNE Experiment
  - Proposed post-P5 (2015)
    - 40 kT fiducial mass of LAr in 4 detector modules
    - "capable" Near Detector
    - 1.2 MW proton beam power
- DUNE Phase I (accomplished with LBNF/DUNE-US and PIP-II projects and international partners)
  - Two far detectors : 1 HD + 1 VD
  - Near detector = NDLAr + TMS + SAND + PRISM movement
  - 1.2 MW beam power
- DUNE Phase II (or upgrade paths)
  - Additional mass at Far Detector
  - MCND (i.e. ND-GAr) replaces TMS
  - Increased beam power (up to 2.4 MW) provided by Booster replacement

Day 1 DUNE is when FD1 is filled and turned on

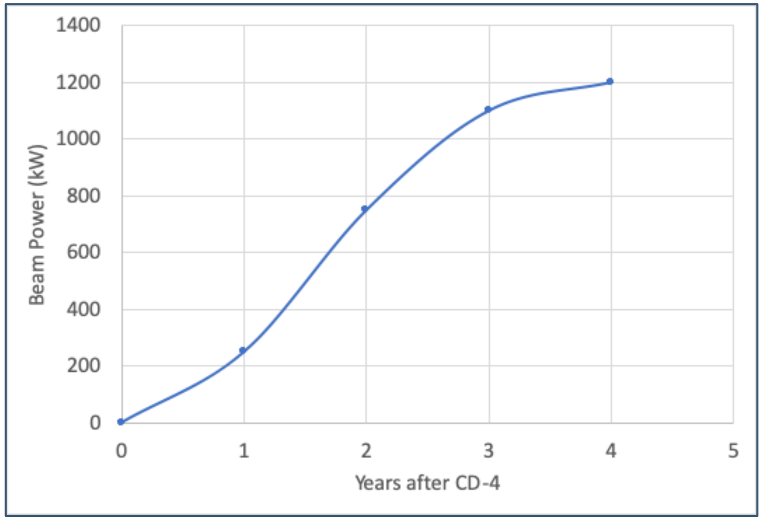
Science begins

LBNC comment at December meeting

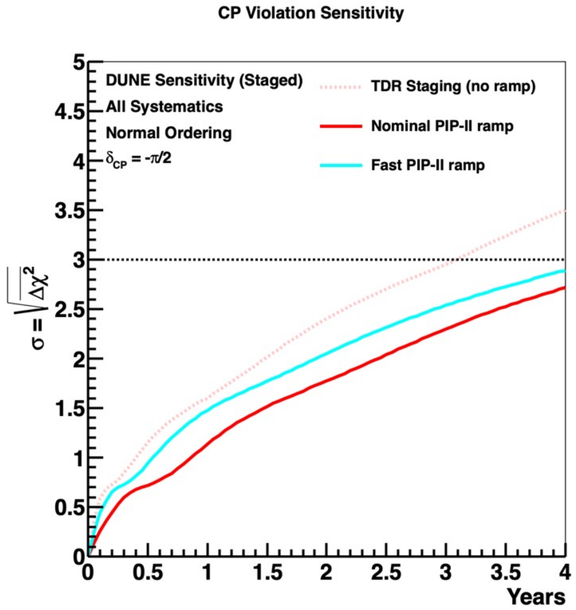
In our September meeting we heard about the funding profile advanced by DOE. In this meeting we have seen, in several areas, the difficulties that this leads to in the management of the project and the experiment, and the resulting impact on physics. DUNE has been designed with the P5 vision in mind and it was understood that with competing programs and projects and finite resources, the time to physics would be quite long. However, the LBNC sees that LBNF is developing the facilities, and DUNE is developing the experiment. Together they provide enormous breadth and depth and match the P5 vision. They will set the scene for several decades of neutrino physics. However, it cannot be ignored that the delays incurred in the schedule will have an impact especially on the initial physics; we urge the stakeholders to seek a remedy.

DUNE Sensitivity vs time

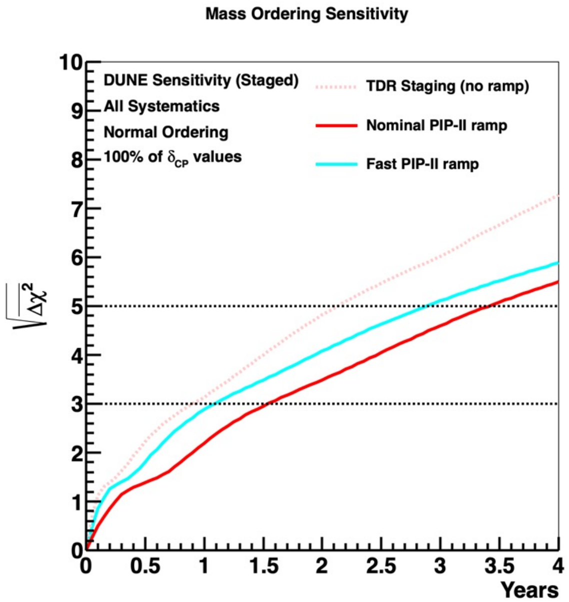
- PIP-II expected power ramp
- This profile assumes LBNF is ready for PIP-II upgrade



Q1FY29



Mass Ordering
100% δ_{CP} values

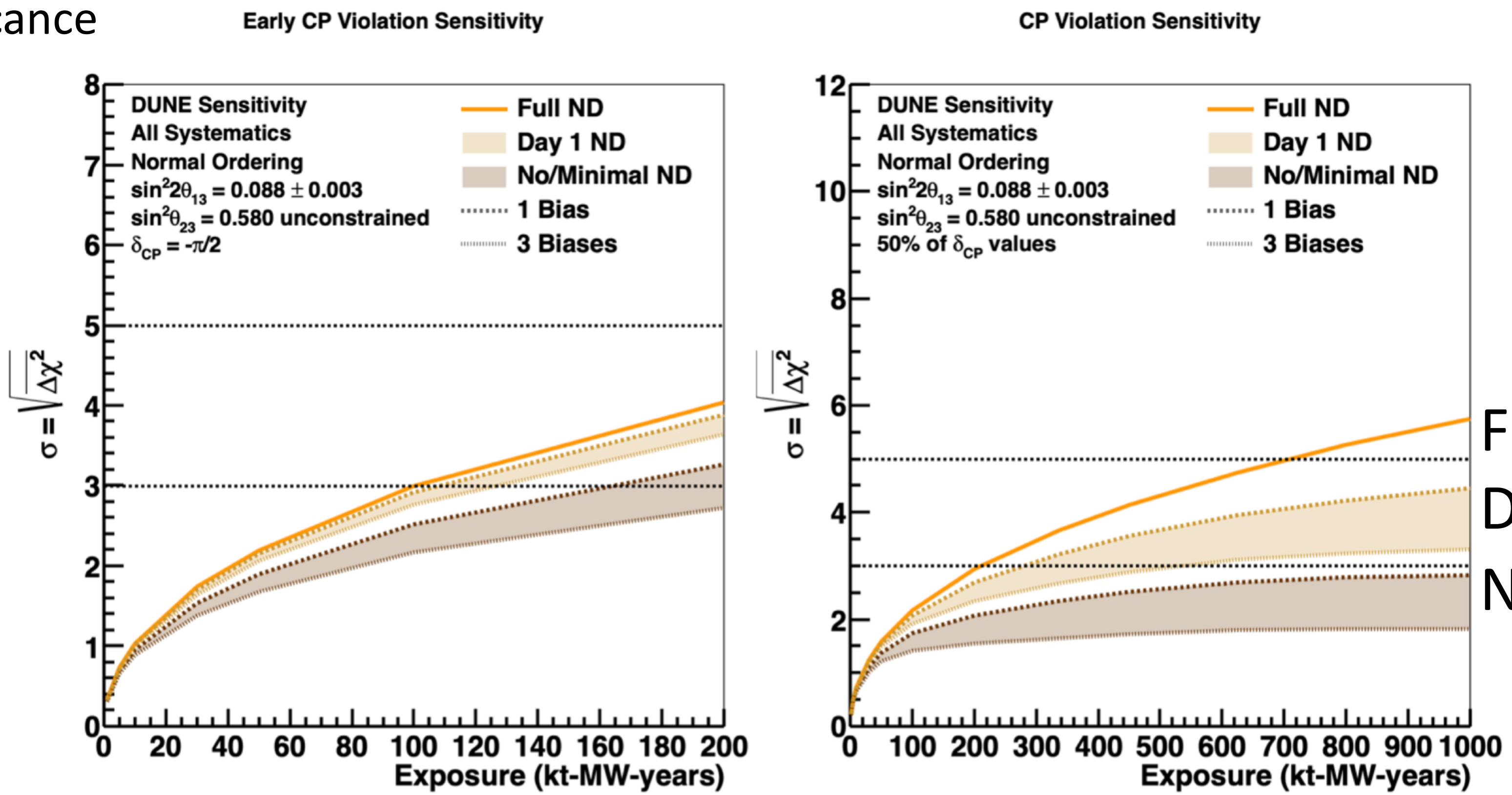


CP Violation
$\delta_{CP} = -\pi/2$

- Staging scenario with two far detectors and beam power ramp.
- Initial physics goals for physics with the neutrino beam are mass ordering and 3σ sensitivity for maximal CPV.

Impact of Near Detector

Significance



Full ND

Day 1 –ND

No ND

Exposure

Near Detector crucial to achieve science goals

Lots of successes

- Excavation and Site preparation at SURF progressing well
- APA construction started
- ProtoDUNEs (both HD and VD) cold box tests at CERN
- VD-CDR signed off and being published
- NDLAr prototypes providing excellent data
- Computing CDR in preparation
- DUNE publications

Collaboration Publications

- 5 full DUNE authorship publications in 2021 so far, and 9 journal publications in 2020 (22 in total)
- Focusing on detector studies, physics sensitivities and ProtoDUNE results.
- Recent Highlights:
  - Low exposure long-baseline neutrino oscillation sensitivity of the DUNE experiment, 2109.01304, submitted to PRD
  - Searching for Solar KDAR with DUNE, 2109.01304, submitted to PRD
  - Deep Underground Neutrino Experiment (DUNE) Near Detector Conceptual Design Report, Instruments 5 (2021) 4, 31.
  - Design, construction and operation of the ProtoDUNE-SP Liquid Argon TPC, *JINST* 15 (2022) 01, P01005.
  - Prospects for beyond the Standard Model physics searches at the Deep Underground Neutrino Experiment, *Eur. Phys. J. C* 81 (2021)
- We are aiming for more ProtoDUNE physics publications in near future.

Summary

- DUNE is committed to be the ‘best in class’ experiment to deliver world-leading science.
- Initial physics goals for physics with the neutrino beam are mass ordering and 3σ sensitivity for maximal CPV – only DUNE can measure both in a single experiment.
- Schedule remains a major challenge.
- Consortia are making excellent progress in terms of delivering two far-detector modules and the near detector components.
- ”Strategic decisions need to involve all stakeholders.” UK should play a core role as the first committed international partner in these discussions.