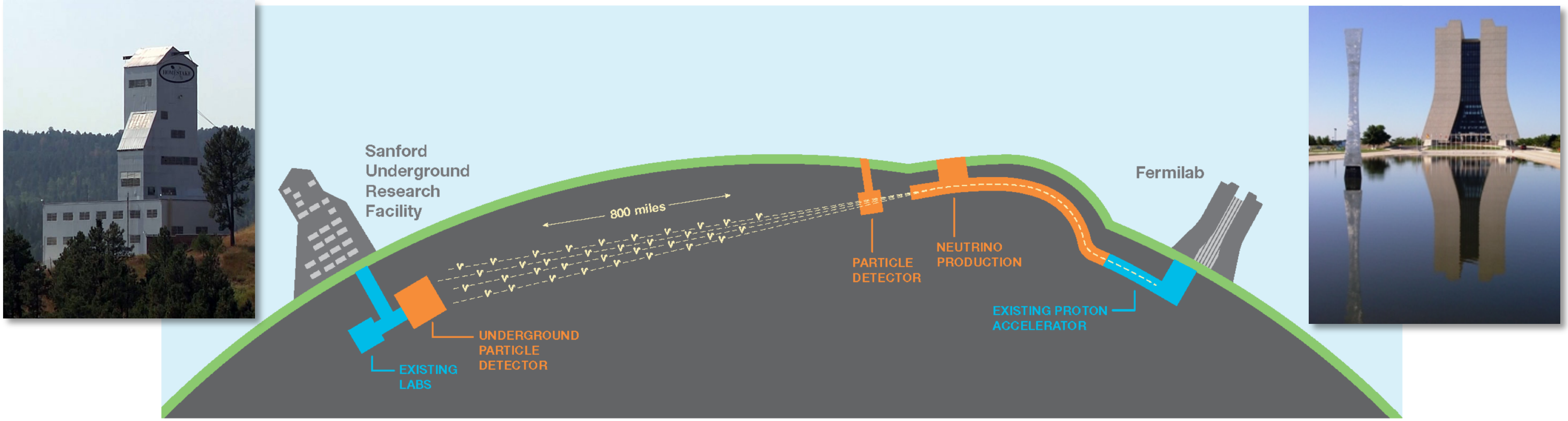
DEEP UNDERGROUND NEUTRINO EXPERIMENT



DUNE Progress and Path to TDR

Ed Blucher
FNAL PAC Meeting
16 July 2018

Topics

- Collaboration news
- Near detector status
- Far detector strategy and ProtoDUNEs
- TDR plans
- Summary

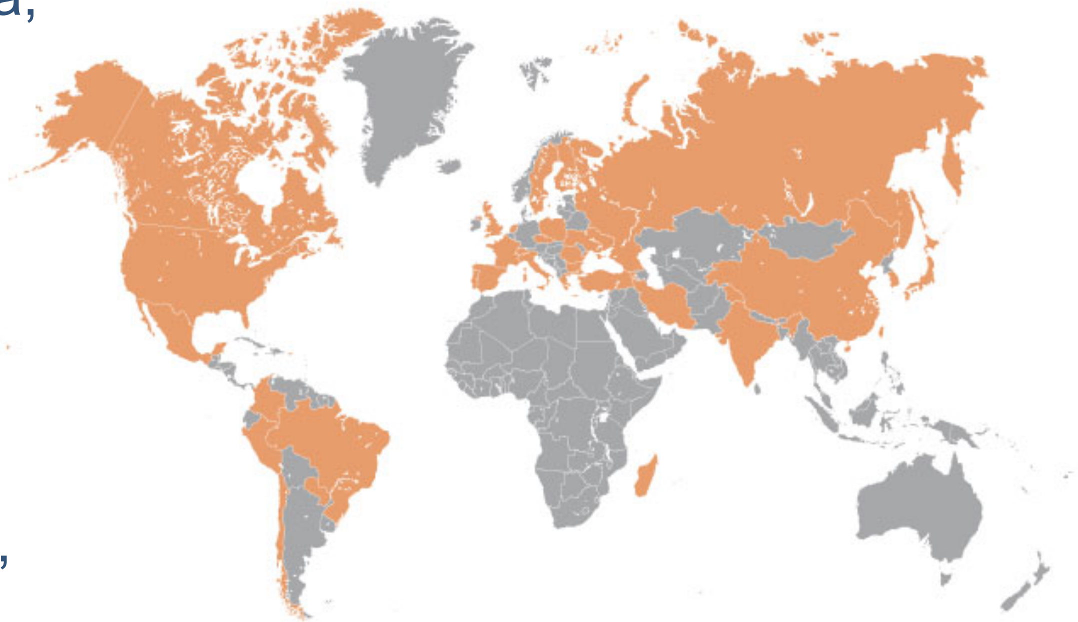
The DUNE Collaboration

As of today:

60 % non-US

1143 collaborators from 178 institutions in 32 nations

Armenia, Brazil, Bulgaria, Canada, CERN, Chile, China, Colombia, Czech Republic, Spain, Finland, France, Greece, India, Iran, Italy, Japan, Madagascar, Mexico, Netherlands, Paraguay, Peru, Poland, Portugal, Romania, Russia, South Korea, Sweden, Switzerland, Turkey, UK, Ukraine, USA



DUNE is still growing: dN/dt > 100 collaborators/year!

Ultimate size: 1500?

DUNE International Progress

- **Europe:**
  - UK: $88M commitment to LBNF/DUNE/PIP-II
  - France: DUNE now on the research infrastructure road map
  - Portugal: joined DUNE at May 2018 meeting
  - Germany: growing interest within community (including DESY)
  - Italy: engaged and interested in near detector, far detector
  - Spain: engaged and funding requests pending
  - Netherlands: discussions ongoing
  - Switzerland: DUNE on Swiss road map
- **Americas:**
  - Latin America: Meetings with FA representatives: Brazil, Colombia, Mexico, Peru
  - Canada: new joint FNAL-York position on DUNE
  - US NSF: discussions ongoing
- **Asia:**
  - India: annex 2 for cooperation on neutrinos was signed
  - Korea: DUNE Satellite Meeting for Korean groups at ICHEP 2018
  - Japan: eager to have broader involvement of Japanese groups

US DOE and CERN

- We continue to receive excellent support from the DOE, Fermilab, and CERN.

Leadership change since last PAC

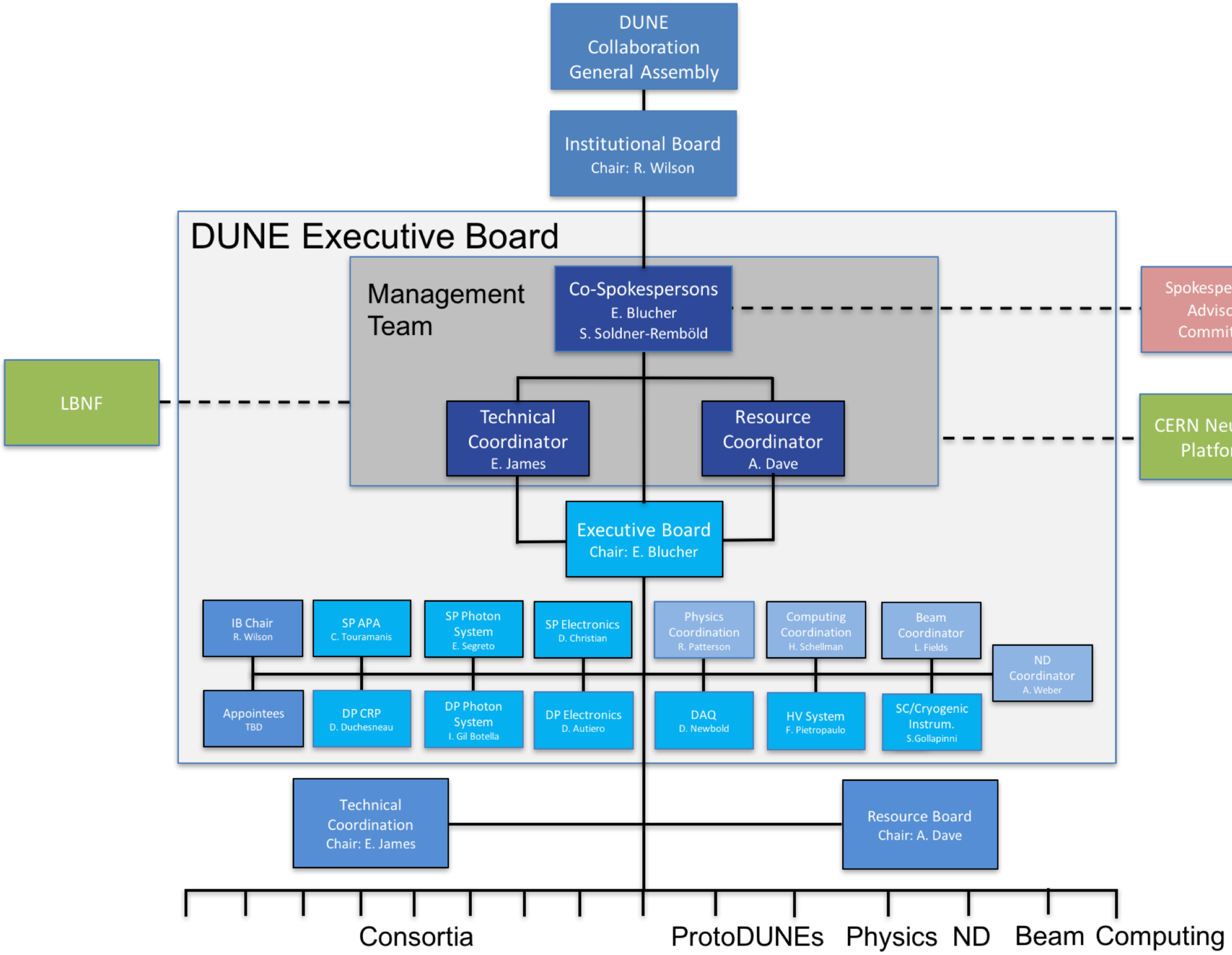
- **Stefan Soldner-Rembold's** term as co-spokesperson began on April 1st.

- **Mark Thomson** is now Executive Chair of STFC.

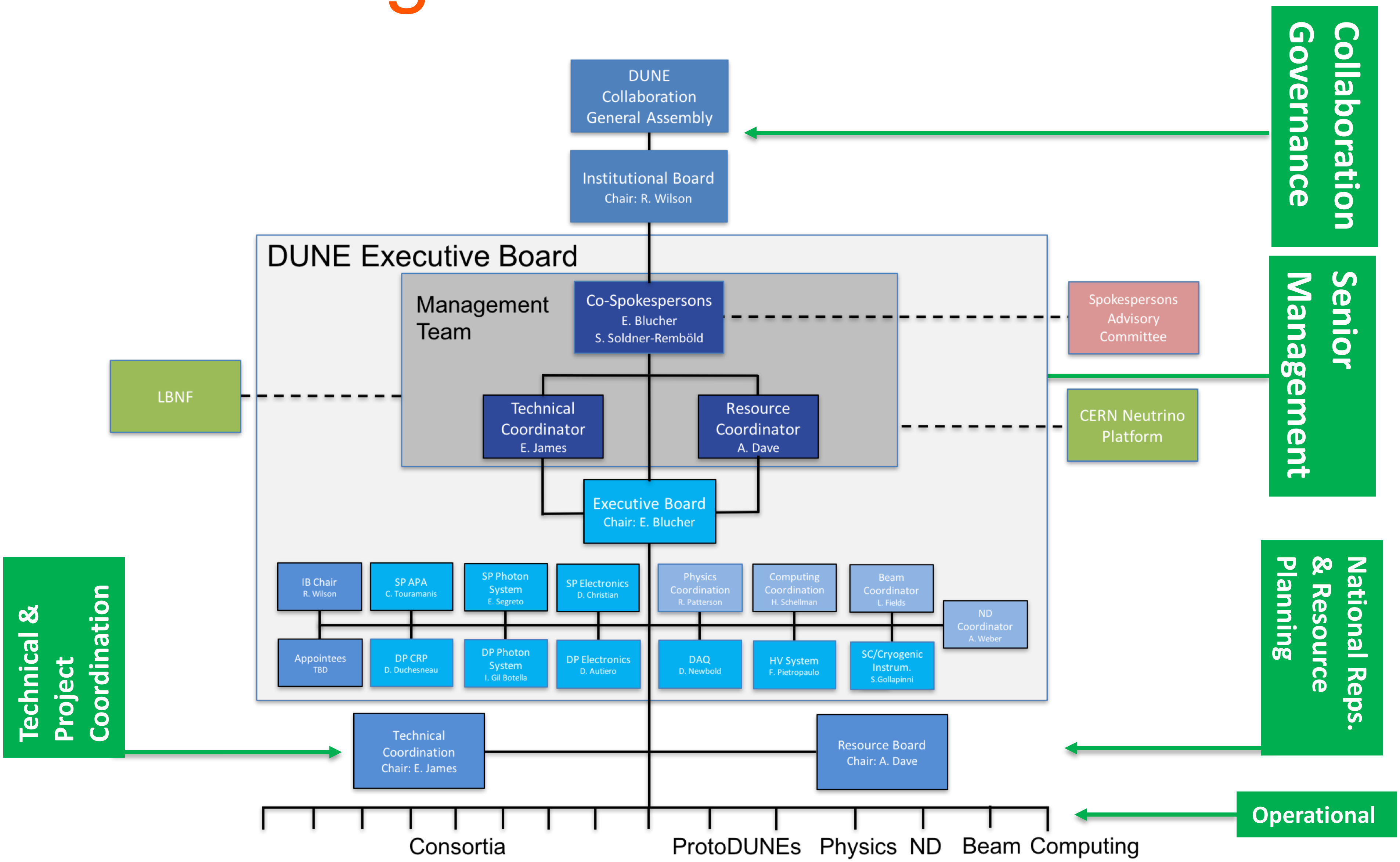
DUNE Collaboration Organization

- **Many simultaneous activities**
  - ProtoDUNEs
  - Far Detector
  - Near Detector
  - Physics studies
  - Funding issues
  - Technical Design Reports
- **Existing management structures are well defined**
  - Collaboration governance document
  - DUNE management plan
- **Collaboration organization has evolved to match coming tasks**
  - Far Detector Consortia formed in August 2017
    - consortia of institutions that have responsibility for detector sub-systems
  - New Executive Board structure adopted in May 2018
    - aiming for greater collaboration representation and buy-in in decision making

New Management Structure



New Management Structure



Collaboration Governance

DUNE Collaboration General Assembly

Institutional Board
Chair: R. Wilson

DUNE Executive Board

Management Team

Co-Spokespersons
E. Blucher
S. Soldner-Remböld

Senior Management

Spokespersons Advisory Committee

LBNF

Technical Coordinator
E. James

Resource Coordinator
A. Dave

CERN Neutrino Platform

Executive Board
Chair: E. Blucher

IB Chair
R. Wilson

SP APA
C. Touramanis

SP Photon System
E. Segreto

SP Electronics
D. Christian

Physics Coordination
R. Patterson

Computing Coordination
H. Schellman

Beam Coordinator
L. Fields

ND Coordinator
A. Weber

Appointees
TBD

DP CRP
D. Duchesneau

DP Photon System
I. Gil Botella

DP Electronics
D. Autiero

DAQ
D. Newbold

HV System
F. Pietropaulo

SC/Cryogenic Instrum.
S.Gollapinni

Technical & Project Coordination

National Reps. & Resource Planning

Technical Coordination
Chair: E. James

Resource Board
Chair: A. Dave

Operational

Consortia

ProtoDUNEs

Physics

ND

Beam

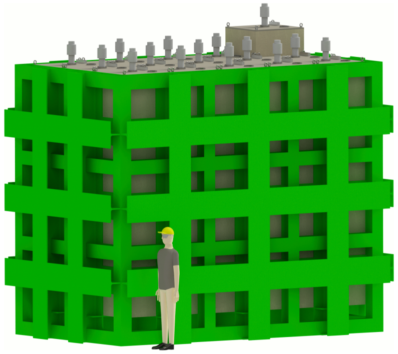
Computing

DUNE Strategic Goals 2017 - 2019

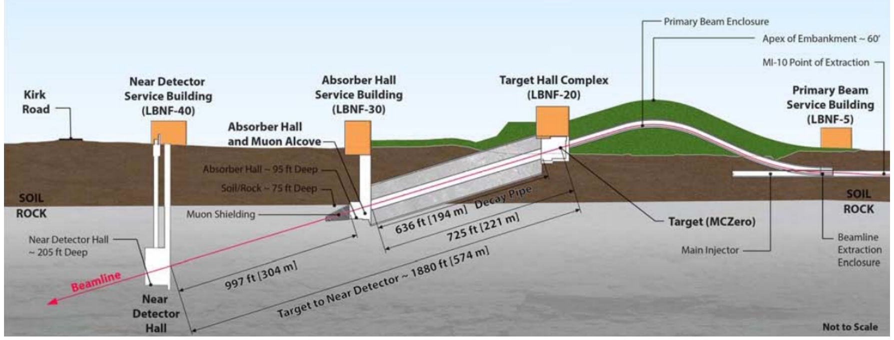
- **Preparation of DUNE TDRs for LBNC review**
  - A major scientific and technical goal for the collaboration
- **Construction and operation of large-scale prototypes at CERN**
  - Critical to demonstrate that the DUNE collaboration can implement a major construction activity
- **Enlarging the Collaboration**
  - Define responsibilities for far and near detectors
- **Resource matrix for construction of DUNE**
  - Funding for TDR scope needs to be understood in 2019

DUNE Near Detector

- Constrain systematic uncertainties for long-baseline oscillation analysis
  - flux, cross-section, and detector



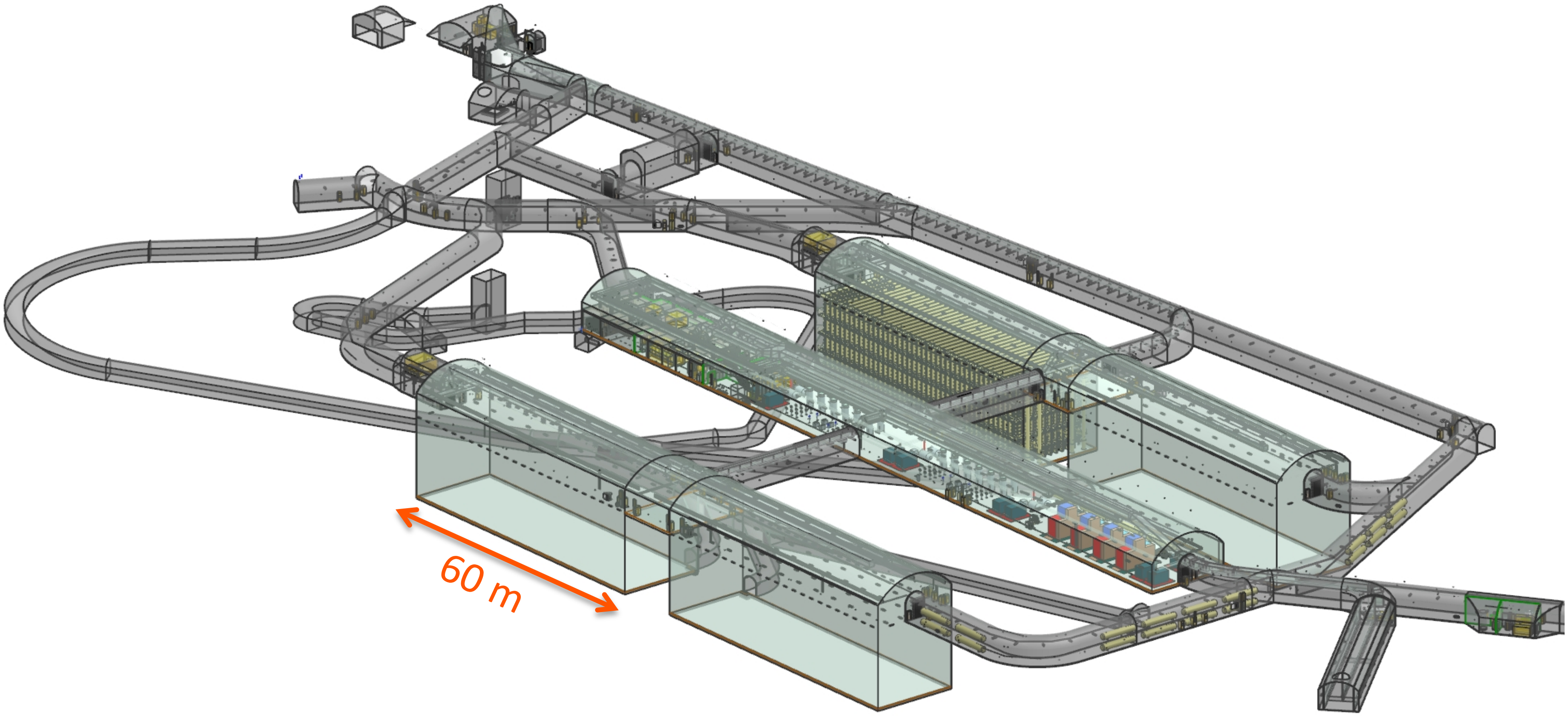
- DUNE ND design concept near final
  - Active ND Design Group
  - ND Conceptual Design Report (CDR) planned for 2019
- DUNE ND design concept is an integrated system composed of multiple detectors:
  - Highly segmented LArTPC
  - Magnetized multi-purpose tracker
  - Electromagnetic calorimeter
  - Muon chambers



- Conceptual design will preserve option to move ND for off-axis measurements

DUNE Far Detector

- **70-kt LAr-TPC = 4 x 17 kt (4 x 10 kt fiducial) detectors**



- **4 chambers, each hosting a 10 kt fiducial module**
- **Interior volume of each cryostat:** 15.1 (W) x 14.0 (H) x 62 (L) m^3
- **Requires excavation of 875,000 tons of rock**

Far Detector Strategy

Four chambers hosting four independent 10-kt FD modules

- Flexibility for staging & evolution of LAr-TPC technology design
  - Assume four "**identical**" cryostats: 15.1 (W) x 14.0 (H) x 62 (L) m^3
  - Do **not** expect that the four 10-kt modules will be identical

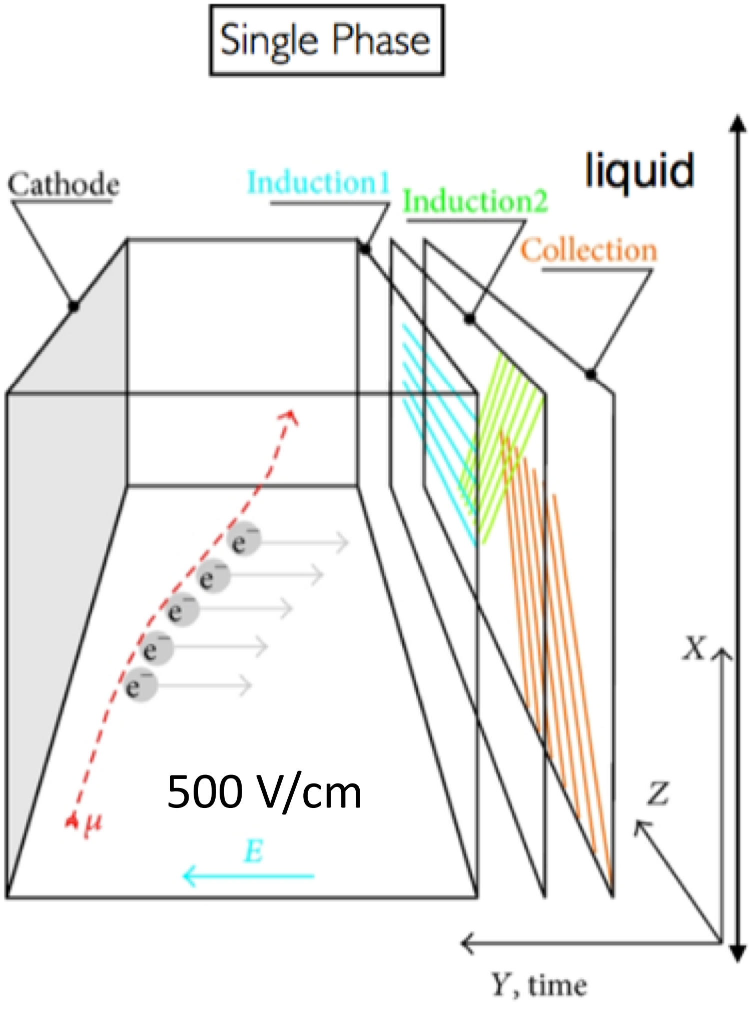
DUNE is pursuing (and prototyping) two LAr-TPC technologies

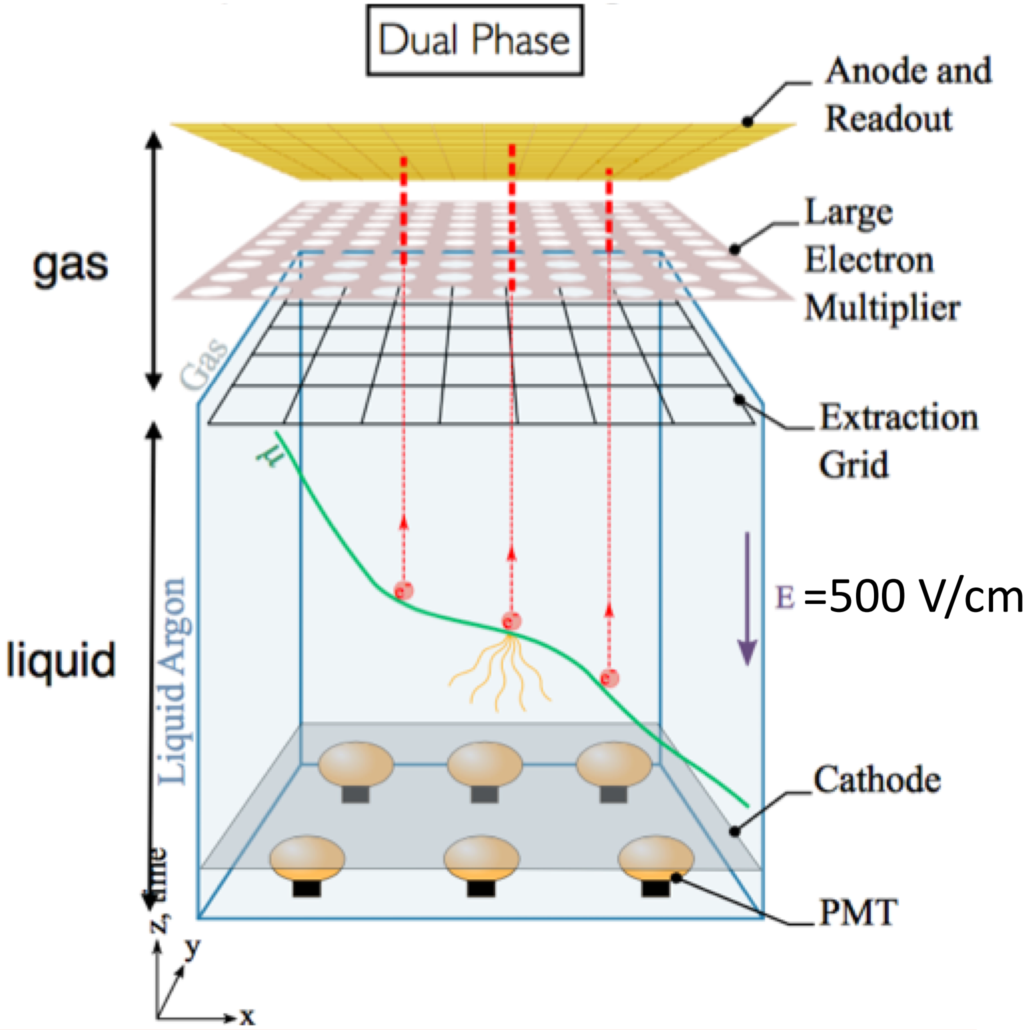
- Single-Phase
  - Technology is mature, e.g., ICARUS, MicroBooNE
- Dual-Phase
  - Lower technical readiness
  - A number of potential advantages & challenges

Liquid argon TPC: Single and dual phase

- Ionization charges drift horizontally and are read out with wires
- No signal amplification in liquid
- 3.6 m maximum drift

- Ionization charges drift vertically and are read out on PCB anode
- Amplification of signal in gas phase by LEM
- 12 m maximum drift





Far Detector Strategy

Four chambers hosting four independent 10-kt FD modules

- Flexibility for staging & evolution of LAr-TPC technology design
  - Assume four "**identical**" cryostats: 15.1 (W) x 14.0 (H) x 62 (L) m^3
  - Do **not** expect that the four 10-kt modules will be identical

DUNE is pursuing (and prototyping) two LAr-TPC technologies

- Single-Phase
  - Technology is mature, e.g., ICARUS, MicroBooNE
- Dual-Phase
  - Lower technical readiness
  - A number of potential advantages & challenges

DUNE is committed to deploying both technologies

- **Decision on staging will depend on**
  - Results from ProtoDUNEs and funding/interests

Role of ProtoDUNEs


EHN1 Extension of CERN North Area

Dual phase cryostat

Single phase clean room and cold box

Single phase cryostat

Role of ProtoDUNEs

- **Large-scale prototyping/calibration**
  - **Production (delivery of the detector components to CERN):**
    - **stress testing of the production and quality assurance processes** of detector components
    - mitigate the associated risks for the far detector.
  - **Installation:**
    - **test of the interfaces** between the detector elements
    - mitigate the associated risks for the far detector.
  - **Operation (cosmic-ray data):**
    - **validation** of the detector designs and performance
  - **Test beam (data analysis):**
    - **essential measurements** of physics response of detector
    - not necessary for the finalization of the FD design

Role of ProtoDUNEs

- **Large-scale prototyping/calibration**
  - **Production (delivery of the detector components to CERN):**
    - **stress testing of the production and quality assurance processes** of detector components
    - mitigate the associated risks for the far detector.
  - **Installation:**
    - **test of the interfaces** between the detector elements
    - mitigate the associated risks for the far detector.
  - **Operation (cosmic-ray data):**
    - **validation** of the detector designs and performance
  - **Test beam (data analysis):**
    - **essential measurements** of physics response of detector
    - not necessary for the finalization of the FD design

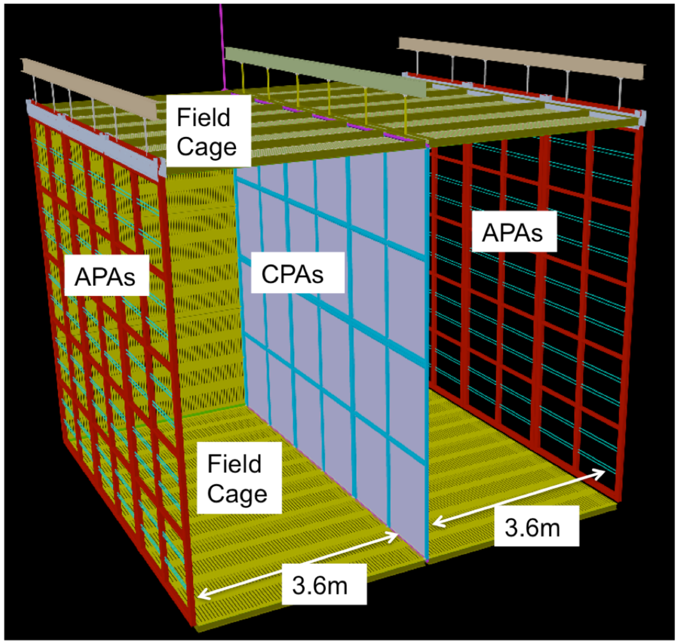
Risk mitigation and understanding of costs for TDR

Detector validation for TDR

Physics calibration for oscillation analyses

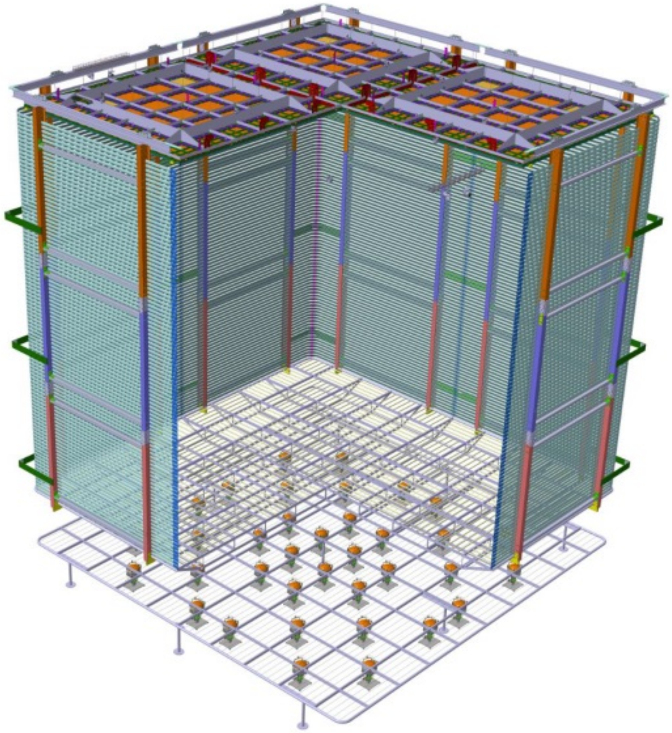
ProtoDUNEs

ProtoDUNE-SP



- 6 full-sized drift cells with 6×2.3m APAs (150 in far detector)
- Same 3.6 m maximum drift length as far detector
- Testing 3 light detection systems embedded in APAs

ProtoDUNE-DP



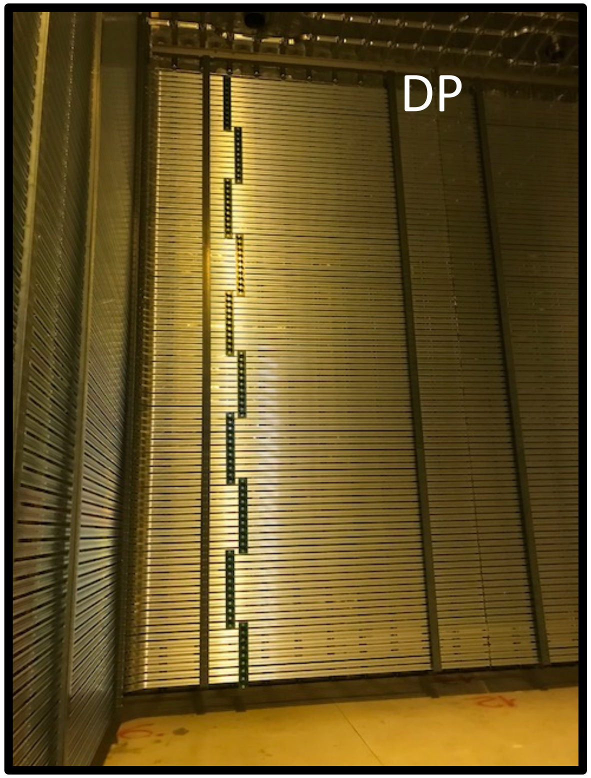
- 4 3×3m CRPs (80 in far detector)
- 6 m vertical drift → 300 kV cathode voltage (half of drift required for DUNE far detector)
- PMT light detection system

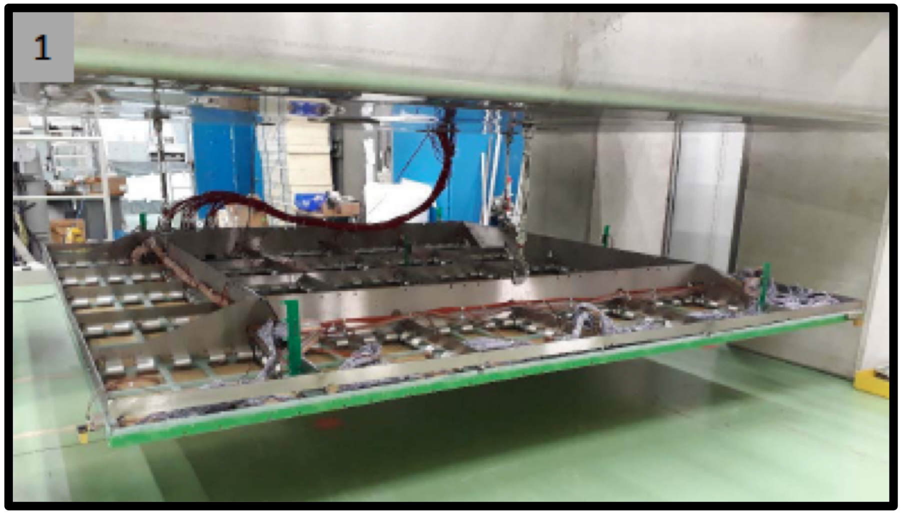
ProtoDUNE Status

- ProtoDUNE-SP
  - Installation complete
  - Cool-down starting this week
  - Data taking with beam and cosmics Aug-Nov 2018
  - Current focus: commissioning, operations, and analysis (see following talk)
- ProtoDUNE-DP
  - Field cage installed
  - Cold-box tests of first CRP underway
  - Plan to close cryostat with 2 of 4 CRPs in Oct 2018
  - Data taking with cosmics starting at end of 2018

Both ProtoDUNEs have made excellent progress, and are on track to collect data needed for the TDR.

ProtoDUNE Status





FD Planning Strategy

- **Agreed by DUNE Executive Committee**
- **Assumes success of both protoDUNE detectors**
  - Success is defined in dune-doc-2765
- **For planning purposes:**
  - "we are assuming that the first far detector module will be single-phase and the second will be dual-phase"
  - "This planning strategy is not intended to prejudice the actual technology decision in late 2018/early 2019, which will be based on the full knowledge at that time and the availability of funding."
  - i.e., plan so that all options can be on the table

Strategy for TDR: 2 + 1 + 1

- **Full detector requires 4 FD modules: "2 + 1 + 1 model"**
  - Reflects current expectations *of what might be reasonable from funding perspective* at time of TDR in 2019
    - 2 Single-phase FD modules, one of which will be the first module
    - 1 Dual-phase FD module
    - 1 [As yet] uncovered "Opportunity" FD module
- **For TDR in 2019**
  - Seeking approval of (at least) two FD modules
  - Requires technical readiness and funding model

Success depends on consortia

Excellent Consortia Leadership

- **Single-Phase**
  - APA: Christos Touramanis (Liverpool)
  - Photon Detection System: Ettore Segreto (Campinas)
  - TPC Electronics: Dave Christian (FNAL)
- **Dual-Phase**
  - **CRP (Interim): Dominique Duchesneau (LAPP)**
  - Photon Detection System: Ines Gil Botella (CIEMAT)
  - TPC Electronics: Dario Autiero (IPNL)
- **Joint**
  - HV System: Francesco Pietropaolo (CERN)
  - DAQ: Dave Newbold (Bristol)
  - Slow Controls/Instrumentation: Sowjanya Gollapinni (Tennessee)

Far Detector Consortia Progress

- Far Detector consortia are working effectively
- An enormous amount of work has been done already
    - Constructed detailed WBS (i.e., scope of activities)
    - Provisional mapping of institute interests to WBS deliverables
    - Interface documentation
    - Defined consortium strategy and decision-making plan to reach TDR
    - Produced sections of Interim Design Report (see below)
- **Next step**
    - TDR in April 2019

Timeline

- **Assumed timeline for DUNE (and LBNF) reviews**
  - May 2018: Interim Design Report for DUNE Far Detectors
  - March 2019: **RRB** for to provide funding status
  - April 2019: LBNF and DUNE internal/external TDR reviews
  - July 2019: **LBNC** review of TDRs
    Review of international DUNE project
  - Sept 2019: **RRB** to review funding status for construction; validation of international funding model
  - October 2019: DOE **CD-2** Review of LBNF/DUNE & "**CD-3**" review for far site and (at least) two far detector modules
  - July 2020: **LBNC** review of TDR for near detector
- **In less than one year**
  - Need technical designs and understanding of inst. responsibilities

GOAL of TDR

Demonstrate to ourselves (and to review committees) that the DUNE design will allow us to accomplish physics goals of the experiment.

TDR Structure

- The TDR will consist of multiple volumes. Each volume is expected to be between 150 – 200 pages
- Detector volumes (single-phase and dual-phase) divided into:
  - Overview volume
  - Sub-system volumes

Volumes

- Volume 1: Executive Summary
- Volume 2: Physics
- Volume 3: Single-Phase Far Detector: Overview
  - + sub-system volumes
- Volume 4: Dual-Phase Far Detector: Overview
  - + sub-system volumes
- CDRs: Computing and Near Detector

~2000 pages

TDR Plans

Editorial team in place and working well

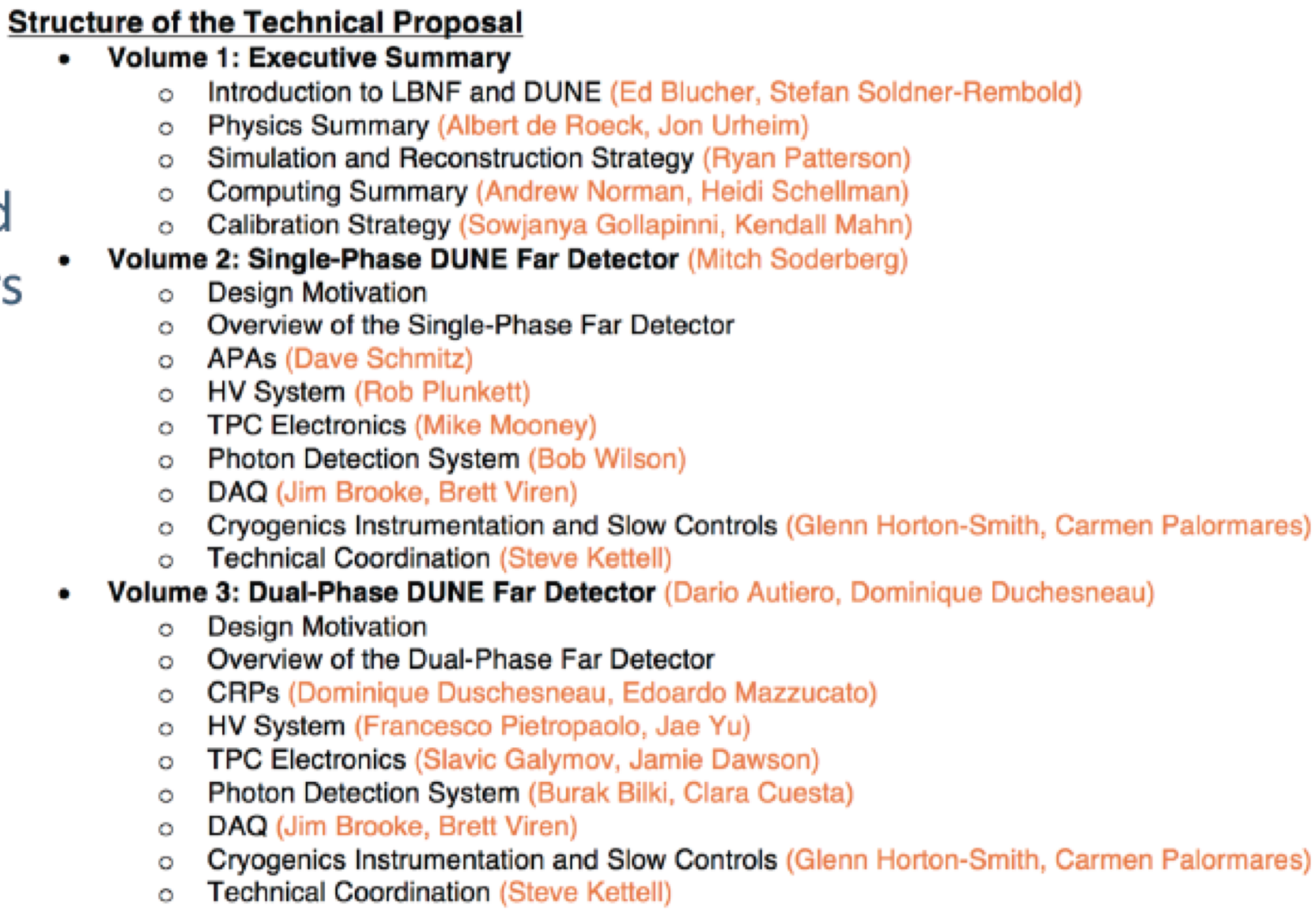
- Overall Editors (Tim Bolton, Sam Zeller)
- Physics Volume Editors (Albert de Roeck, Jon Urheim)
- Detectors – at least one editor from each consortium

Interim Design Report

- As an intermediate step on the path to a TDR, we decided to produce an interim design report
- Same structure as TDR, but
  - ~ ×4 shorter
  - No cost information
  - Physics discussion included in overview volume rather than as separate volume.
- IDR will be reviewed by LBNC, and feedback used as input to TDR
- Led by Tim Bolton and Sam Zeller (editors), working with Anne Heavey
- Enormous effort by a large number of people
- The document (~650 pages) was submitted to LBNC on May 19.

IDR sections with editors

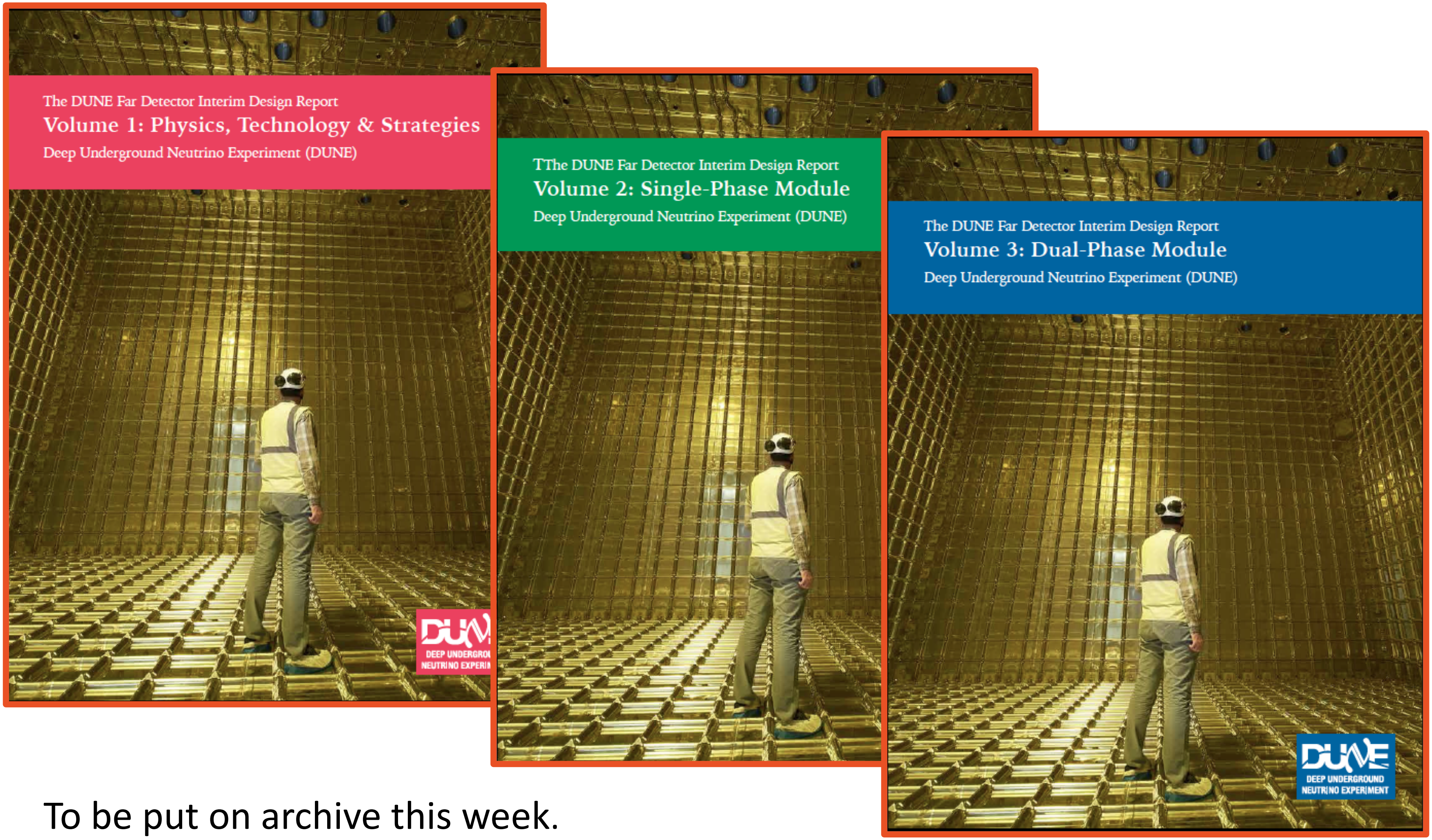
- 28 volume and chapter editors (nominated by the consortia
- Plus, many people who contributed text to the TP



Structure of the Technical Proposal

- **Volume 1: Executive Summary**
    - Introduction to LBNF and DUNE (Ed Blucher, Stefan Soldner-Rembold)
    - Physics Summary (Albert de Roeck, Jon Urheim)
    - Simulation and Reconstruction Strategy (Ryan Patterson)
    - Computing Summary (Andrew Norman, Heidi Schellman)
    - Calibration Strategy (Sowjanya Gollapinni, Kendall Mahn)
- **Volume 2: Single-Phase DUNE Far Detector** (Mitch Soderberg)
    - Design Motivation
    - Overview of the Single-Phase Far Detector
    - APAs (Dave Schmitz)
    - HV System (Rob Plunkett)
    - TPC Electronics (Mike Mooney)
    - Photon Detection System (Bob Wilson)
    - DAQ (Jim Brooke, Brett Viren)
    - Cryogenics Instrumentation and Slow Controls (Glenn Horton-Smith, Carmen Palormares)
    - Technical Coordination (Steve Kettell)
- **Volume 3: Dual-Phase DUNE Far Detector** (Dario Autiero, Dominique Duchesneau)
    - Design Motivation
    - Overview of the Dual-Phase Far Detector
    - CRPs (Dominique Duschesneau, Edoardo Mazzucato)
    - HV System (Francesco Pietropaolo, Jae Yu)
    - TPC Electronics (Slavic Galymov, Jamie Dawson)
    - Photon Detection System (Burak Bilki, Clara Cuesta)
    - DAQ (Jim Brooke, Brett Viren)
    - Cryogenics Instrumentation and Slow Controls (Glenn Horton-Smith, Carmen Palormares)
    - Technical Coordination (Steve Kettell)

DUNE Far Detector Interim Design report



The DUNE Far Detector Interim Design Report
Volume 1: Physics, Technology & Strategies
Deep Underground Neutrino Experiment (DUNE)

TThe DUNE Far Detector Interim Design Report
Volume 2: Single-Phase Module
Deep Underground Neutrino Experiment (DUNE)

The DUNE Far Detector Interim Design Report
Volume 3: Dual-Phase Module
Deep Underground Neutrino Experiment (DUNE)

To be put on archive this week.

IDR -> TDR

- August LBNC meeting will provide detailed feedback on IDR, to be incorporated into TDR
- For Collaboration, IDR was a critical step toward TDR
- Key additions in moving from IDR to TDR include
  - Cost information
  - Performance demonstration from ProtoDUNEs (next talk)
  - Physics sensitivities based on full simulation and automated reconstruction

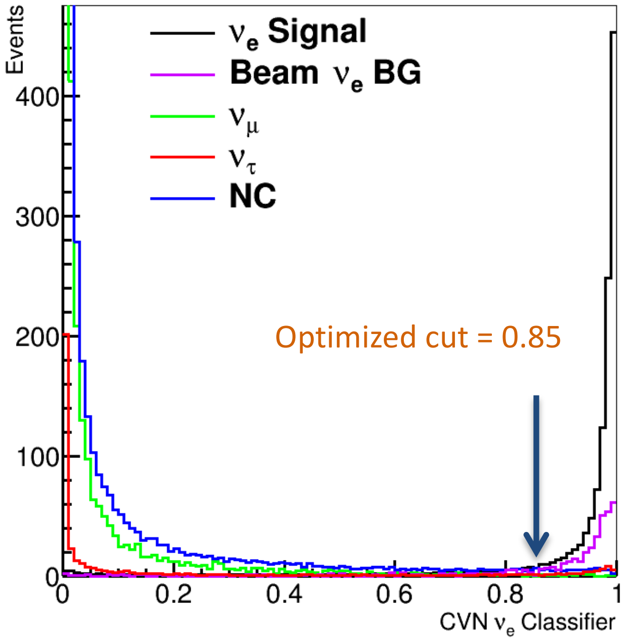
→ All progressing well

Monte Carlo Analysis

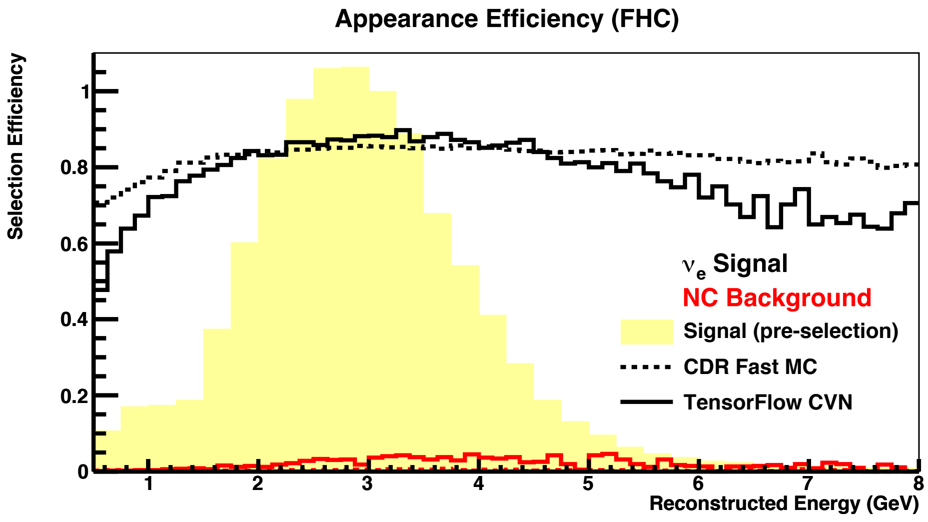
- GEANT4 beam simulation of updated beam design
- Full LArSoft Monte Carlo simulation
  - Shared framework among many LArTPC experiments
  - GENIE event generator and GEANT4 particle propagation
  - Detector readout simulation including realistic waveforms and white noise
- Automated signal processing and hit finding
- Automated energy reconstruction
  - Muon momentum from range (contained) or multiple Coulomb scattering (exiting)
  - Electron and hadron energy from calorimetry
- Event selection using Convolutional Visual Network (CVN)
- Oscillation analysis using CAFAna fitting framework (shared with NOvA)
- CDR-style systematics analysis (update coming in 2019)
- Results are for single phase; dual phase analysis in progress

CVN Event Selection

- ResNet architecture* implemented in TensorFlow
- Training performed on sets of 500 x 500 DUNE MC images
- DUNE MC images classified into categories
  - ν_eCC, ν_μCC, ν_τCC, NC
- Event selection performed by applying cuts on ν_eCC-like and ν_μCC-like CVN classifiers
  - ν_eCC-like cut chosen by optimizing CPV sensitivity

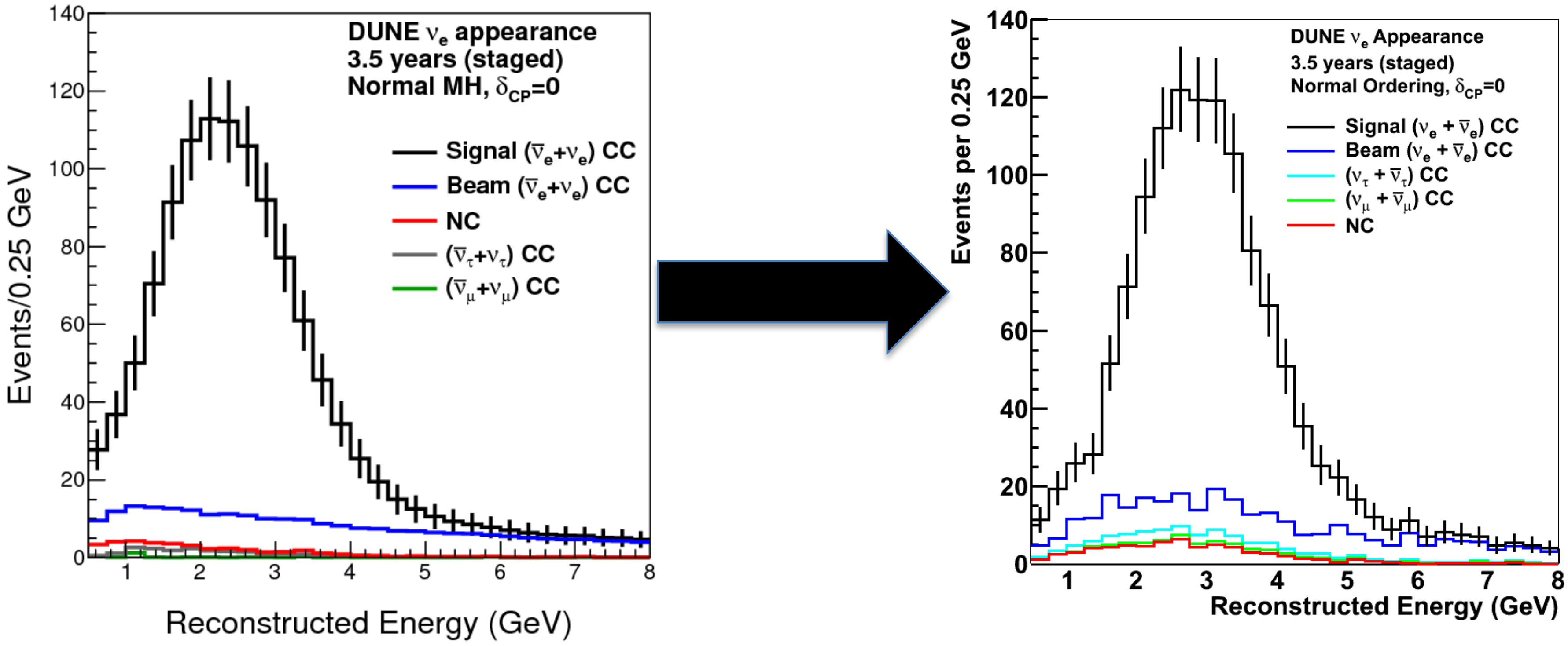


Optimized cut = 0.85



*ImageNet Challenge
arXiv:1605.07678

Results of Monte Carlo analysis



- Sensitivity from MC-based analysis with automated reconstruction and event selection exceeds CDR sensitivity!
- Full sensitivity update to be included in TDR

Summary

- **We have had a very good year**
  - Groundbreaking at SURF
  - Interim Design Report submitted to LBNC
  - Amazing CERN NP & ProtoDUNE progress
  - Consortia driving far detector activities
  - Funding progress (UK, US)
  - Increased interest from other funding agencies
  - Unwavering support from DOE and US Congress
- **Coming year will be critical**
  - Complete, commission, and take data with protoDUNEs
  - Complete far detector TDR
  - Develop near detector design and write CDR
  - Need further progress on funding

The coming months will be challenging and exciting!

Backup

DUNE Timeline

2018: protoDUNEs at CERN

2019: Technical Design Report

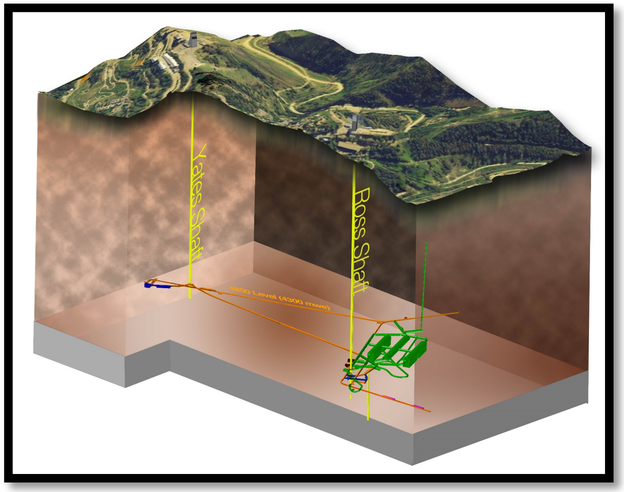
2019: Far Site Primary Excavation Begins

2022: First Module Installation Begins

2026: Neutrino Beam + 2 Far Detectors

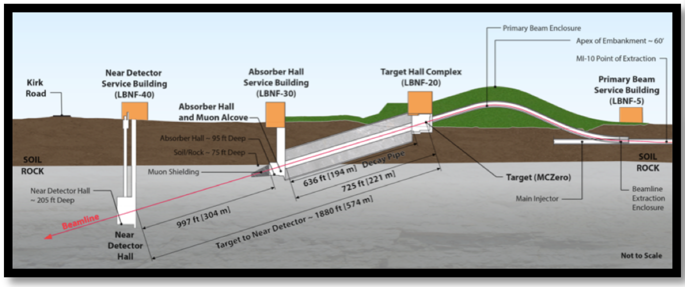
DUNE Far Detector Interim Design Report (2018)

Will be posted on archive this week

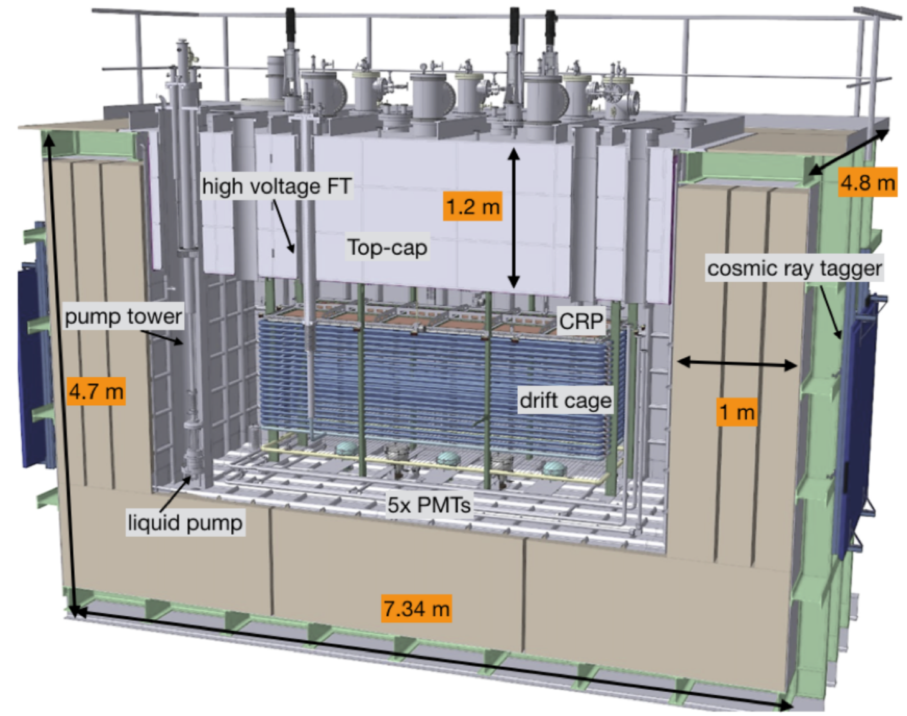


Physics data as soon as 1st module complete

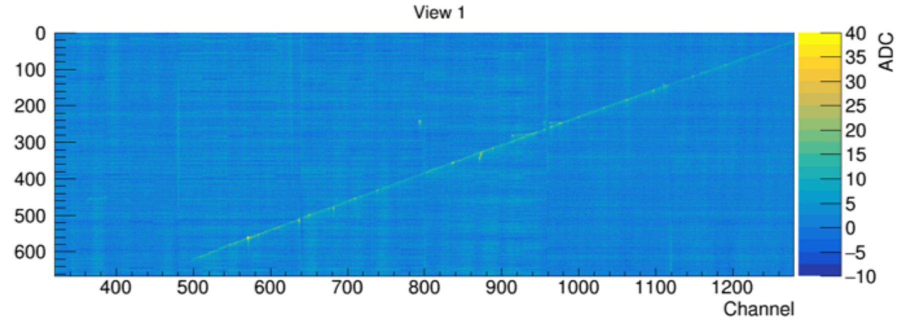
- Atmospheric νs
- SNB and solar νs
- Baryon number violation
- Detector calibration



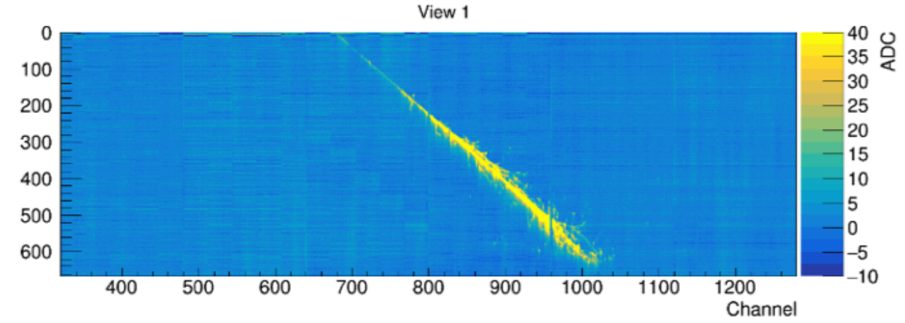
3x1x1 Dual Phase Prototype (WA105)



Muon



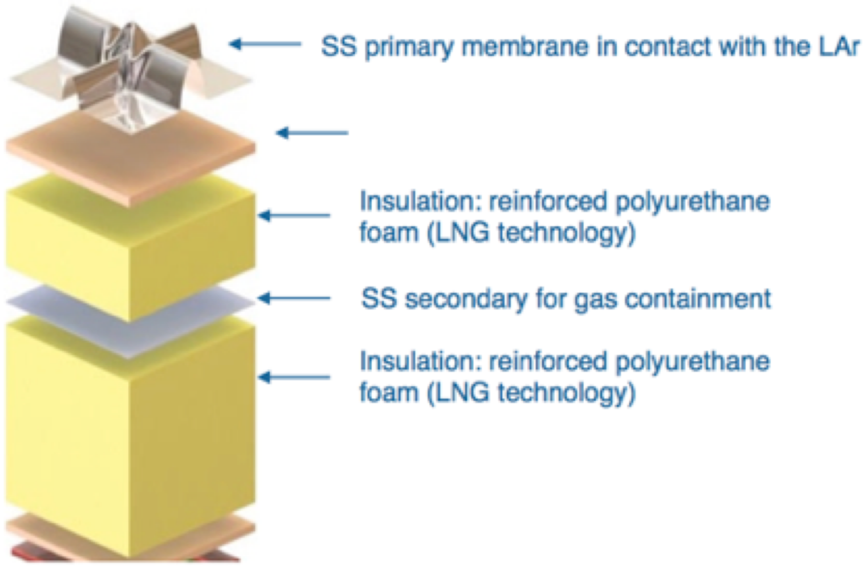
EM Shower



- 3x1x1 prototype ran from June to November 2017
- Successful demonstration of dual phase LArTPC concept
- ENC <1800 e^- (S/N ≈ 100 for a MIP)
- Led to improved designs for protoDUNE dual phase

arXiv:1806.03317

ProtoDUNE cryostats

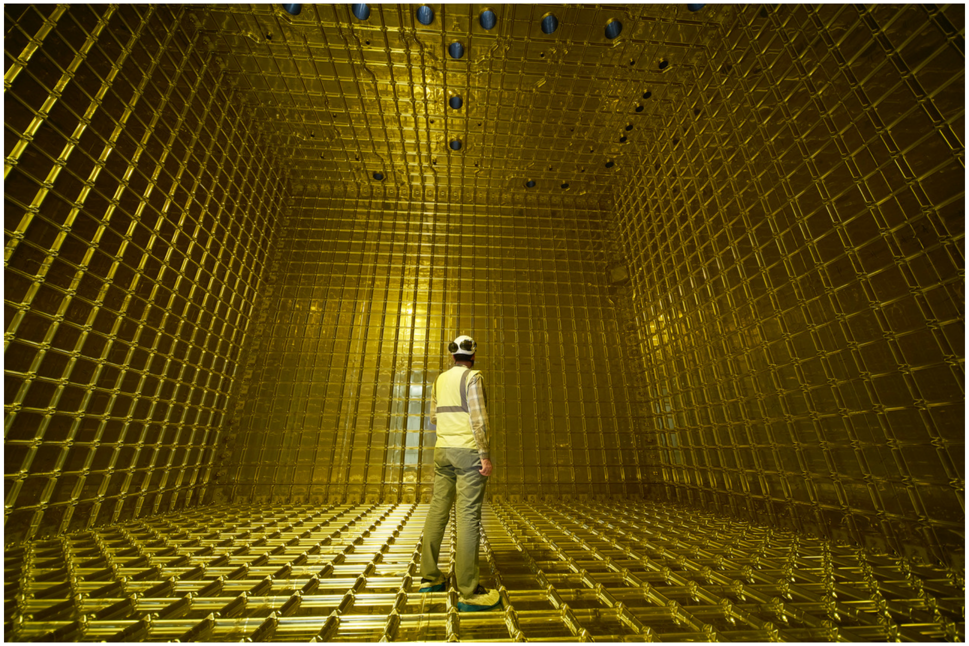


SS primary membrane in contact with the LAr

Insulation: reinforced polyurethane foam (LNG technology)

SS secondary for gas containment

Insulation: reinforced polyurethane foam (LNG technology)



Free-standing steel cryostats

CRP Test in Cold Box

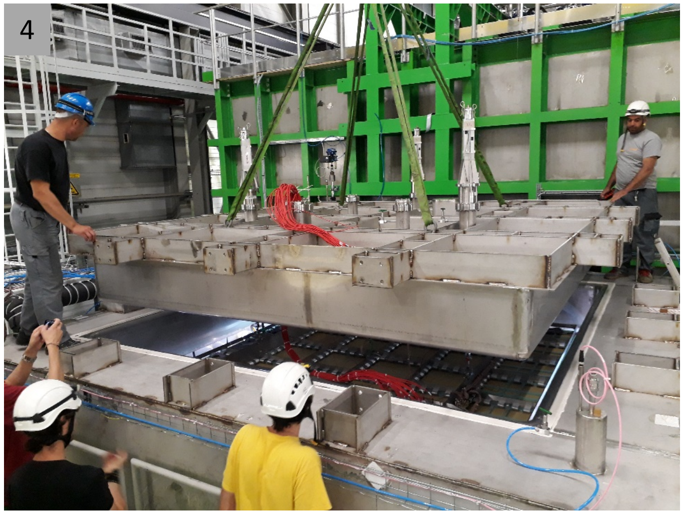
Insertion of the first CRP in the cold box in building 182

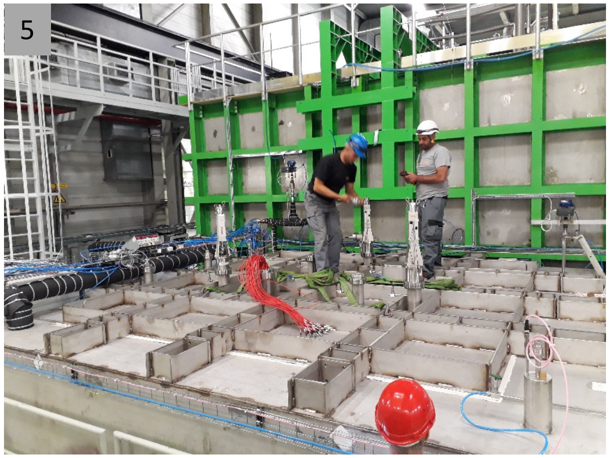
22/06/2018


1


2


3


4


5

D. Duchesneau