Status of the Deep Underground Neutrino Experiment

Glenn Horton-Smith, Kansas State University, for the DUNE collaboration

International Workshop on “Double Beta Decay and Underground Science”
Hawaii Island, United States – October 21-23, 2018
DUNE science

Primary goals:
- Neutrino oscillations, CP-violation, mass hierarchy
- Proton decay
- Supernova neutrinos

Rich ancillary program.

DUNE collaboration

- 1257 collaborators from 179 institutions in 32 countries
- 628 faculty/scientists, 198 postdocs, 110 engineers, 223 PhD students

May 2018
Locations

Far detector (FD) at SURF’s 4850-foot level. (4300 mwe)  
2×10 kt → 3×10 kt → 4×10 kt

Near detector (ND) and neutrino beamline at Fermilab.  
1.2 MW → → → 2.4 MW
SURF
Sanford Underground Research Facility (Lead, SD)

LBNF Facilities for DUNE Detectors

Future Laboratories
- **Experiment Hall**
  - Proposed third generation dark matter and/or 1 T neutrinoless double-beta decay
- **DUNE at LBNF**
  - Proposed Deep Underground Neutrino Experiment at the Long-Baseline Neutrino Facility
  - 4600 Level — four 16kT liquid argon detectors

Ross Campus
- BHSU Underground Campus
- CASPAR
  - Compact Accelerator System for Performing Astrophysical Research
- MJD
  - Mikromod Demonstrator
  - Electroforming laboratory
SURF
Sanford Underground Research Facility (Lead, SD)

LBNF/DUNE PROJECT GROUNDBREAKING
July 21, 2017

Future Laboratories
• Experiment Hall
  Proposed third generation dark matter and/or
  1 T neutrinoless double-beta decay
• DUNE at LBNF
  Proposed Deep Underground Neutrino Experiment
  at the Long-Baseline Neutrino Facility
  4800 Level—four 10kT liquid argon detectors

Ross Campus
• BHSU Underground Campus
• CASPAR
  Compact Accelerator System for Performing Astrophysical Research
• MJD
  Microjet Demonstrator
  Electroforming laboratory
Liquid argon time projection chambers

**Single Phase**

**Dual Phase**

Animated by Bo Yu (BNL)
https://youtu.be/IH88LSnVvmY
Far detector 10-kt modules

Single Phase

Dual Phase

12 m

58 m

14 m

60 m

12 m

12 m
# Far detector 10-kt modules

<table>
<thead>
<tr>
<th>Single Phase</th>
<th>Dual Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active height</td>
<td>12 m</td>
</tr>
<tr>
<td>Active length</td>
<td>58 m</td>
</tr>
<tr>
<td>Maximum drift</td>
<td>3.5 m</td>
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<tr>
<td>Wire spacing</td>
<td>5 mm</td>
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<tr>
<td>Wire channels</td>
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<tr>
<td>Phot. det. ch.</td>
<td>6000</td>
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</tbody>
</table>

Design drift field: 500 V/cm  
Electron drift speed at 500 V/cm: 1.6 mm/μs
LBNF beamline

- Protons from Main Injector hit target. 101 mrad pitch to aim at FD in South Dakota. ~200 m decay pipe. ND hall at site boundary.
Neutrino beam

- 60-120 GeV proton beam at 1.2 MW (~$10^{14}$ POT/s), upgradeable to 2.4 MW
- Horn-focused, wide-band neutrino beam optimized for CP violation sensitivity using genetic algorithm.
- Engineering design of 3-horn focusing system to optimized parameters in progress
- Neutrino and antineutrino modes

Unoscillated neutrino flux at 1300 km (Conceptual Design Report Optimized Beam)
Near detector

- Constrain systematics for oscillation analysis: flux, cross-section, and detector uncertainties
- DUNE ND design concept near final
  - ND Conceptual Design Report (CDR) planned for 2019
- An integrated system of multiple detectors:
  - Segmented, pixel readout LAr TPC
  - Magnetized multi-purpose tracker
  - Electromagnetic calorimeter
  - Muon chambers
- Conceptual design preserves option to move ND for off-axis measurements
- >100 million interactions will enable a rich non-oscillation physics program
Neutrino oscillation measurements

- Spectra and intensity of $\nu_\mu$, $\bar{\nu}_\mu$, $\nu_e$, $\bar{\nu}_e$, $\nu_\tau$, $\bar{\nu}_\tau$ with neutrino and antineutrino beam data.
- $\nu_\mu$, $\bar{\nu}_\mu$ disappearance.
- $\nu_e$, $\bar{\nu}_e$, $\nu_\tau$, $\bar{\nu}_\tau$ appearance.
- Full set of neutrino oscillation parameters: mass ordering, $\delta_{CP}$, and more.
Oscillation Sensitivity Calculations

- Reconstructed spectra based on GEANT4 beam simulation, GENIE event generator, and Fast MC using detector response parameterized at the single particle level
  - Efficiency tuned based on hand scans
- Order 1000 $\nu_e$ appearance events in ~7 years of equal running in neutrino and antineutrino mode
- Simultaneous fit to four spectra to extract oscillation parameters
- Systematics approximated using normalization uncertainties
- GLoBES configurations arXiv:1606.09550
Mass ordering sensitivity

As function of unknown value of $\delta_{CP}$ for exposures of 7 and 10 years

As function of exposure for any $\delta_{CP}$ and for $\delta_{CP} = -\pi/2$. 
CP violating phase

Significance ($\sqrt{\Delta \chi^2}$) as a function of exposure.

Expected $\delta_{CP}$ resolution (1 sigma) as a function of exposure.
New in 2018: Sensitivity using updated beam, full detector MC, fully automated event analysis

Sensitivity from MC-based analysis with automated reconstruction and event selection exceeds CDR sensitivity!

Supernova

MARLEY event generator: marleygen.org

In LArTPC, SNB signal dominated by electron neutrinos: $\nu_e + ^{40}\text{Ar} \rightarrow e^- + ^{40}\text{K}^*$

Measurement at early times tests mass ordering and SNB model
ProtoDUNE Single Phase

- Field Cage
- APAs
- CPAs

Drift direction: 6 m, 6.9 m, 3.6 m

ProtoDUNE Dual Phase

- 6 m, 6 m, 6 m

Drift direction: 6 m
CERN Neutrino Platform

- Cryostat for ProtoDUNE-DP
- Test-beam line
- ProtoDUNE-SP cleanroom and cryostat
Test beam

- Tertiary beamline provides low energy particles in the momentum range of 0.4 to 12 GeV/c.
- Beamline fully instrumented for momentum selection, tracking, particle ID.
- Use for calibrating and verifying detector response to particles of known type and momentum.
ProtoDUNEs use same basic designs and components as planned for DUNE

- Mechanical design: cryostat type, detector supports
- High voltage systems: drift HV supply, cathode plane(s), field cage, ...
- Anode wire planes (SP) / charge readout plane (DP)
- Photon detectors
- Detector cryogenic instrumentation
- Electronics and DAQ
ProtoDUNE-DP field cage fully assembled, tested to 150 kV in air
ProtoDUNE-DP charge readout plane

CRP #1 under construction

CRP #1 assembled

CRP #1 over LAr in cold box
ProtoDUNE-SP complete TPC: cathode, field cage, anode plane arrays

Looking from “upstream” towards test-beam

“Beam right” side

“Beam left” side
Test beam enters ProtoDUNE-SP here

- Scattering and energy loss reduced by beam “window” through cryostat insulation and “plug” in LAr outside TPC.
ProtoDUNE-SP at full voltage

20 Sep 21 Sep
ProtoDUNE-SP taking data – cosmics

Run 4817
Event 16272
Sept 28, 2018
ProtoDUNE-SP taking data – test beam entering about 3.5 m from anode wires
3.5 m drift
2.2 ms
DUNE general timeline

- 2018: ProtoDUNE at CERN
- 2019: Far site primary excavation begins
- 2022: First module installation begins
- 2026: Neutrino beam available

Physics data as soon as 1st module complete
- Atmospheric ν
- SNB and solar ν
- Proton Decay
- Detector calibration
Acknowledgments

• DUNE would not be possible without the support of agencies and institutions in US, EU, and Worldwide.

• The partnership of the CERN Neutrino Platform and the CERN [TE-CRG, EN-EA, BE-BI, EP-DT-DI and TI] contributions are an integral and fundamental part of the ProtoDUNE effort.

• Fermilab’s role as the host for DUNE near and far detectors, beamline, and LBNF, is of course critical.

• Not to mention the dedication, skills and enthusiasm of the many DUNE Collaborators.
Summary

New Estimates

- LBNF/DUNE: rapid progress to mega neutrino physics facility
- New oscillation sensitivity estimate using full detector MC and reconstruction chain more realistic than CDR
- ProtoDUNE(s): construction→data taking, step up ladder to 40 kt
- Look for DUNE Technical Design Report and protoDUNE SP and DP results in 2019!
- Expect first DUNE FD data in ~2024