Deep Underground Neutrino Experiment

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NuPhys 2019: Prospects in Neutrino Physics

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DUNE Collaboration

Global collaboration

- 34 countries
- 192 institutions
- 1104 collaborators
• 1.2MW neutrino beamline from Fermilab (Illinois, USA) to SURF (South Dakota, USA)
• Far Detector: Liquid argon time projection chamber (1300km downstream)
• Near Detector: composite (574m downstream)
Motivation for DUNE

- Rich neutrino physics programme for DUNE

Long baseline neutrino physics

Beyond Standard Model physics

Astroparticle physics

- ...to name but a few! See DUNE IDR for more! arxiv:1807.10334
Neutrino Oscillation Physics

- Wide band beam, on-axis far detector
  - Sensitivity to first and second oscillation maxima
- Sensitivities from full simulation and reconstruction and event selection with CVN
- Neutrino and antineutrino running modes
- Great statistics at far detector!
  - 10,000 $\nu_\mu$ ($\bar{\nu}_\mu$) disappearance events (7 years)
  - 1,000 $\nu_e$ ($\bar{\nu}_e$) appearance events (7 years)
- 5σ sensitivity to mass ordering after 2 years of beam running (for any value of $\delta_{CP}$)
- 5σ sensitivity to 50% of $\delta_{CP}$ values after 10 years of beam running
Neutrino Oscillation Physics

- Measurement of multiple PMNS parameters in a single experiment

\[ \sin^2 2\theta_{13} \text{ vs. } \delta_{CP} \text{ at 15 years} \]

\[ \text{Octant determination at 10 years} \]
Supernova Neutrinos

• 99% of energy released in a core-collapse supernova is carried away by neutrinos!

• Large mass of far detector gives sensitivity to supernova spectrum
  – 3000 $\nu_e$ over 10 seconds

• Supernova physics:
  – core-collapse mechanism, black hole formation, shock stall/revival, nucleosynthesis, cooling…

• Particle physics:
  – flavor transformations in core, collective effects, mass ordering, nuclear equation of state…

• LAr has unique sensitivity to $\nu_e$ flux

Low energy
10.25 MeV
electron
(simulated + reconstructed)
**Physics Beyond the Standard Model**

- Both near and far detectors have sensitivity to BSM physics!
- **Near detector:**
  - Highly granular detector in high power / high flux beam
  - Sensitivity to heavy neutral leptons
  - Sterile neutrinos
  - Neutrino tridents
  - Millicharged particles
- **Far detector:**
  - Large target mass
  - Proton decay searches
• 1.2MW Neutrino beamline from Fermilab (Illinois, USA) to SURF (South Dakota, USA)

• Liquid argon far detector (1300km downstream)

• Composite near detector (574m downstream)
The LBNF beam

• A new (anti)neutrino beam from Fermilab to SURF
  – 1.2 MW proton beam
  • $10^{21}$ POT/year
• Wide band neutrino beam

Neutrino energy for unoscillated flux at FD (neutrino mode)
DUNE Near Detector

- Composite detector
- Goal: constrain flux and cross-section systematic uncertainties

3D scintillator tracker: On-axis beam monitor

Multi-purpose detector (MPD):
High pressure gaseous argon with magnet

ArgonCube: Liquid argon (LAr)
DUNE Near Detector – DUNE Prism

• ArgonCube and MPD move off axis to sample flux
  – 30m off axis proposed motion
  – Allows to deconvolve flux and cross section
• 3DST-S does not move
  – Beam monitor for stability
DUNE Far Detectors

- Liquid Argon Time Projection Chamber
- Charged particles produce ionisation charge and scintillation light
- Electric field across TPC volume
  - Ionisation electrons drifted towards anode readout plane
  - Charge signal induced on readout plane
  - DUNE SP: 2D projection of ionization read out from 3 planes of wires, time is 3\textsuperscript{rd} dimension

“The digital bubble chamber”
DUNE Far Detector

- Sanford Underground Research Facility
  - South Dakota
  - 1.5km underground
- 4 x 10kt modules
  - Membrane cryostat
  - Cryostat: 62m x 19m x 18m
  - 17kt total LAr per module
  - Staged installation
- Groundbreaking July 2017
  - Work ongoing!
Far Detector – Single Phase

Cathodes

Wire readout anodes
Far Detector – Single Phase Photon Detection system

- X-ARAPUCA “light trap”
  - Increase active area of SiPM
  - Dichroic filter + wavelength shifter
  - Highly reflective interior
  - Acrylic guides shifted light to SiPMs
- 6000 supercells of 48.8 cm x 10 cm x 0.8 cm
- Inserted in APA frames
Dual Phase

- LAr target
- Gas readout
  - Benefit from charge multiplication in gas
ProtoDUNE

• Two ~1kt LArTPCs in a charged particle test beam, at CERN

• Goals:
  - Collect test beam data to measure the response of DUNE readout technology to different particles
  - Test production and installation methods
  - Use data to validate the detector designs

Beamline

Dual phase

Single phase

See also Stefania’s presentation: 12:30pm
ProtoDUNE Detectors

• Single phase TPC

• Dual phase TPC

[Diagram showing single phase TPC and dual phase TPC with labels for Field cage, Read out plane, and Photon detectors under cathode.]
ProtoDUNE - Dual Phase

- LAr filling completed - August 2019
- Currently taking cosmic data!
ProtoDUNE - Single Phase

- Filled with LAr - August 2018
- Beam data taken autumn 2018:
  - Pions, protons, positrons, kaons
  - Energy momentum and resolution
- Currently taking cosmic data!
- First publication coming soon!

Inside one of the TPC drift volumes

7GeV Pion interaction

Cosmic ray muon
ProtoDUNE - Single Phase

- Detector performance publication forthcoming
  - LAr purity
  - Noise level and signal-to-noise ratio
  - Space charge effect and calibration
  - dE/dx for particle species: muons, pions, protons, positrons, kaons
  - Energy and momentum resolution using TPC and photon system

- Huge success for DUNE!
DUNE - Timeline

2024
Start installing first far detector module

2025
Start installing second far detector module

2026
DUNE physics data talking starts: Atmospheric neutrinos
Beam operational at 1.2MW
DUNE physics data with beam starts!
  - Fiducial mass of 20kt

2027
Third far detector module added (30kt fiducial mass)

2029
Add fourth far detector module (40kt fiducial mass)

2032
Upgrade to 2.4MW beam
Summary

• DUNE is an international collaboration with an ambitious and rich physics program
  - Precision oscillation parameter measurements
  - CP violation
  - Supernova physics
  - BSM physics

• International contributions throughout project
  - Detector technology, construction
  - Strong global support for project

• Well on track to make the next generation of neutrino measurements!
  - Recent successes with ProtoDUNE pave the way
Thanks!
Sensitivity

CP Violation Sensitivity

\[ \sigma = \sqrt{\Delta \chi^2} \]

- DUNE Sensitivity
- All Systematics
- Normal Ordering
- \( \sin^2 2\theta_{13} = 0.088 \pm 0.003 \)
- \( 0.4 < \sin^2 \theta_{23} < 0.6 \)

10 years (staged)

7 years (staged)

Median of Throws

1σ: Variations of

statistics, systematics,

and oscillation parameters

15 years (staged)

90% C.L. (2 d.o.f.)

* True Value

NuFIT 4.0 90% C.L.
Supernova: neutronization, accretion, cooling