Low Energy Physics Program of DUNE

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Seattle Snowmass Summer Meeting 2022
Neutrino Physics Frontier: New Opportunities in Neutrinos

24/JUL/2022
Deep Underground Neutrino Experiment

- Next generation flagship neutrino experiment
  - High intensity neutrino beam
  - Long baseline, with on-axis detector
  - Multiple complementary near detectors
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- Aims at fundamental questions:
  - Neutrino oscillations
  - Nucleon decay
  - Core collapse supernova
DUNE Far Detectors

- Four modules (17 kt each)
  - Module 1, 2 & 3: Liquid Argon TPC
  - Module 4: Opportunity Module!

- DUNE Phase I:
  - Module 1: 3.6 m horizontal drift (wires anode) + light detectors
  - Module 2: 6.5 m vertical drift (PCB anode) + light detectors
Liquid Argon TPCs
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- Excellent 3D imaging
  - few mm scale over large volume detector
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- Excellent energy measurement capability
  - totally active calorimeter
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- Powerful particle ID
  - dE/dx, range, event topology
Low Energy interactions in LAr

- DUNE FDs are sensitive to Solar and core-collapse supernovae (5 < E < 50 MeV)
- Charged-current (CC) interactions on Ar
  - $\nu_e + ^{40}\text{Ar} \rightarrow ^{40}\text{K}^* + e^-$ (dominant)
  - $\bar{\nu}_e + ^{40}\text{Ar} \rightarrow ^{40}\text{Cl}^* + e^+$
- Elastic scattering on electron
  - $\nu_x + e^- \rightarrow \nu_x + e^-$
- Neutral current (NC) interactions on Ar
  - $\nu_x + ^{40}\text{Ar} \rightarrow \nu_x + ^{40}\text{Ar}^*$
- Possible to discriminate interaction by classification of photons from K, Cl or Ar deexcitation (CC and NC) or by the absence of photons (ES)
Low Energy Reconstruction

\( \nu^{-} \) ES event (10.25 MeV \( \nu^{-} \))

\( \nu_{e} \) CC event (20.25 MeV \( \nu_{e} \))

- Cheated space points
- Electrons
- Gammas
- Neutrons
- Protons
- Nuclei
- Positrons

Vertex

30 cm
Core-Collapse Supernova

- Huge source of neutrinos of all flavours
  - ~ 10 sec burst
  - 1~3 per century in our galaxy
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- SN1987A
  - Kamiokande
  - IMB
  - Baksan
Core-Collapse Supernova

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- Measurement provides:
  - Supernova physics
    - Collapse mechanism
    - Time evolution
    - Black hole formation

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- Measurement provides:
  - Supernova physics
    - Collapse mechanism
    - Time evolution
    - Black hole formation
  - Neutrino physics
    - Oscillation
    - Absolute mass

- SN1987A
  - Kamiokande
  - IMB
  - Baksan
Expected signal in DUNE

- 40 kt LAr
- 10 kpc SN

\[ \nu_e + ^{40}\text{Ar} \rightarrow e^- + ^{40}\text{K}^* \]
\[ \bar{\nu}_e + ^{40}\text{Ar} \rightarrow e^+ + ^{40}\text{Cl}^* \]
\[ \nu_X + e^- \rightarrow \nu_X + e^- \]

Total \quad 1047

*EPJC 81 (2021) 423*
Expected signal in DUNE

Galaxy Edge  LMC  Andromeda

Number of interactions

Distance to supernova (kpc)

| 40 kton | 10 kton  
|---------|---------|

\( \sigma(1000) \)

\( \sigma(100) \)

Garching
Supernova ν Burst Triggering

- Online monitoring of raw waveforms

One TPC channel example
Supernova $\nu$ Burst Triggering

- Online monitoring of raw waveforms

![Diagram showing an example of a TPC channel with a peak labeled as 'a Hit'].

One TPC channel example
Supernova ν Burst Triggering

- Online monitoring of raw waveforms
Supernova ν Burst Triggering

- Hits clustering
Supernova $\nu$ Burst Triggering

- Hits clustering $\rightarrow$ Selection efficiency
Radiologicals determine the **fake trigger** rate
Radiologicals

- Radiologicals determine the **fake trigger** rate

**Hit rate (per anode)**

DUNE Work in Progress
Radiologicals

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**Hit rate (per anode)**

DUNE Work in Progress

**Noise**

**Ar/39_Lar**

**Ar42_Lar**

**K42_Lar**

**Kr85_Lar**

**Rn222_Lar**

**K40_CPA**

**K42_CPA**

**U238_CPA**

**Co60_APA**

**U238_APA**

**Rn222_PDS**

**Neutron**

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**4 hits-cluster rate (per 10 kt)**

DUNE Work in Progress

**Ar Volume**

**Cathode**

**Photon Detectors**

**Anode**

**Rock Neutrons**

Drifted from Ar
Radiologicals

- Radiologicals determine the **fake trigger** rate
  - Clusters in a 10 seconds window:

\[
\text{N clusters cut} \quad \begin{array}{c}
\begin{array}{c}
10^{-10} \\
10^{-9} \\
10^{-8} \\
10^{-7} \\
10^{-6} \\
10^{-5} \\
10^{-4} \\
10^{-3} \\
10^{-2} \\
10^{-1} \\
1 \\
10 \\
100 \end{array}
\end{array}
\]

- DUNE Work in Progress
  - (~1 per Month)
  - ~13 Clusters
Triggering Efficiency

- SNB triggering efficiency (for 11.2 M☉ with Hudepohl model and 10 kt)
SNB triggering efficiency (for 11.2 M☉ with Hudepohl model and 10 kt)
• Triggering improvement with shape info
  - Shape -> charge of clusters
Triggering improvements

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Triggering Improvements

- Triggering improvement with shape info
  - Shape -> charge of clusters

- Triggering with photon detectors also feasible
  - Gives $T_0$ of trigger (~ns)
• Induction wires
  – For Region of Interest triggering
    • Reduced data-rates
  – More TPC hits available → better efficiencies
• Online conversion to unipolar pulse:

DUNE Work in Progress

K. Wawrowska (Sussex)
• Sensitivity to neutronization phase
• Possibility to determine the mass ordering
• Neutrino mixing from detected spectrum
• Also sterile-ν; self-interactions, absolute ν mass, etc.
• Stellar evolution
• Explosion mechanisms
• Black hole formation
• DUNE sensitive to $^8$B and hep fluxes
  – $^8$B to measure oscillation parameters
  – hep flux has not been observed yet
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- CC as dominant channel
- Tracks and gamma cascade (TPC) + light
Solar-$\nu$

- DUNE sensitive to $^8$B and hep fluxes
  - $^8$B to measure oscillation parameters
  - hep flux has not been observed yet
- CC as dominant channel
- Tracks and gamma cascade (TPC) + light
- Triggering threshold → large bkg rate at several MeV's
How large backgrounds?

- CNO flux "buried" by ~1000 factor
How large backgrounds?

- CNO flux “buried” by ~1000 factor
  - Possible ideas to overcome this challenge exist (4th module?)
  - A. Avasthi et al., arXiv:2203.08821
Sensitivity to solar oscillations

- Favourable sensitivity for measuring $\Delta m^2_{21}$ from day/night effect
- May push current tension between SK/SNO and KamLAND to $5\sigma$

Capozzi et al., PRL 123 131803
Summary

- Beyond precision measurement of neutrino oscillation, DUNE will provide large datasets of **astrophysical** neutrinos
- Argon detectors uniquely sensitive to $\nu_e$ flux
- **Large** mass and **excellent** tracking
- Huge physics potential in the early running: discovering of hep solar neutrino flux and **100-1000’s events** from any galactic supernova with just **one** FD module (before arrival of the first beam pulse!)
The DUNE Collaboration

Thank you for listening!