DUNE as the next-generation solar neutrino experiment

Guanying Zhu

Collaborators: Francesco Capozzi, Shirley Li, John Beacom (Ph.D. advisor)

The Ohio State University
MeV Solar neutrinos (8B + hep)

Above few MeV

- **8B**
  \[ ^8 \text{B} \rightarrow ^8 \text{Be} + e^+ + \nu_e \]

- **hep**
  \[ ^3 \text{He} + p \rightarrow ^4 \text{He} + e^+ + \nu_e \]
Deep Underground Neutrino Experiment

Detection channel in LAr

- **Charge Current (CC)**
  \[ \nu_e + ^{40}Ar \rightarrow e^- + ^{40}K^* \]

- **Elastic Scattering (ES)**
  \[ \nu_e + e^- \rightarrow \nu_e + e^- \]
  \[ \nu_{\mu,\tau} + e^- \rightarrow \nu_{\mu,\tau} + e^- \]
  \[ \sigma(\nu_{\mu,\tau}) \sim \frac{1}{6} \sigma(\nu_e) \]

Isolate angle and flux with TWO channels

\[ P(\nu_e \to \nu_e) \propto \sin^2 \theta_{12} \]
\[ R_{\text{CC}} \propto \Phi(\theta) \times \sin^2 \theta \]
\[ R_{\text{ES}} \propto \Phi(\theta) \times \sin^2 \theta + \frac{1}{6} \Phi(\theta) \times \cos^2 \theta \]

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Pheno, 2018

Capozzi et al, in prep

\[ P(\nu_e \rightarrow \nu_\mu) \text{ at NIGHT, Earth matter effect} \]

\[ \Delta m^2_{21} \left[ 10^{-5} \text{ eV}^2 \right] \]

Isolate $\Delta m^2$ with day-night

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Background for solar detection I — spallation

- delayed beta from radioactive decay

\[
\mu \rightarrow \mu + \text{secondary} \\
\text{secondary} + X \rightarrow X' \\
X' \rightarrow (\overline{e} + \text{others})
\]
Background for solar detection I — spallation

![Graph showing energy distribution and time delay](image)

- **Energy Distribution:**
  - $T_e < 5\text{MeV}$
  - $T_e > 5\text{MeV}$
  - $41\text{Ar}$, $38\text{Cl}$, $8\text{Li}$, $12\text{B}$
  - Energy resolution: 7%

- **Time Delay Distribution:**
  - $< 250\text{ms}$
  - Peaks at $41\text{Ar}$, $35\text{S}$, $39\text{Ar}$, $36\text{Cl}$

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Background for solar detection I — spallation

- After a (R~2.5 m) & (t ~ 2 min) cylinder cut

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Where are neutrons from?
- $^{238}$U/$^{232}$Th alpha decay, (alpha, n) in the rock
- $^{238}$U Spontaneous Fission $\rightarrow$ n

What do neutrons do in the detector?
- Elastic scatter (ES) to lose energy
- Eventually get captured and emit gamma
Solar neutrinos @ DUNE — Signal vs. Background

- **Signal**
  - 8B flux, ~2.5%
  - First detection of hep, ~11%

- **Background**
  - Spallation after cut is harmless
  - Neutron needs ~ 40 cm water shielding
DUNE is required
Summary

- Solar neutrinos @ DUNE: best $\sin^2, \text{dm}^2, \Phi(8\text{B})$; first detection of hep
- Background for MeV detection is manageable
  - Spallation — Low atomic number isotopes (Li, B, Be, ...) matter most
  - Neutron — Prefer water shielding, if not, a longer exposure works fine
- We would learn more if MeV, GeV, TeV... are simultaneously making discoveries!
Back up
Background for MeV detection II — neutron

\[ n + ^{40}Ar \rightarrow ^{41}Ar + \gamma \]

\[ \gamma + e^- \rightarrow \gamma + e^- \]

Graph 1: Relative intensity vs. energy (MeV)

Graph 2: d\(N/dE\) (MeV\(^{-1}\) per neutron capture) vs. electron kinetic energy (MeV)
Cross Section