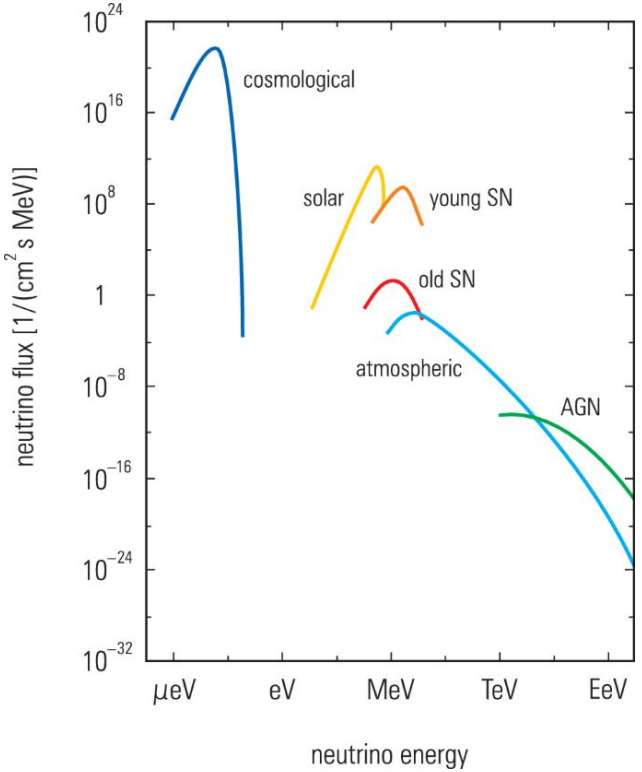
Preparing the DUNE low energy physics program with protoDUNE-II

Luis Manzanillas, Mael Martin
DUNE collaboration meeting
2024.06.05
LAPP

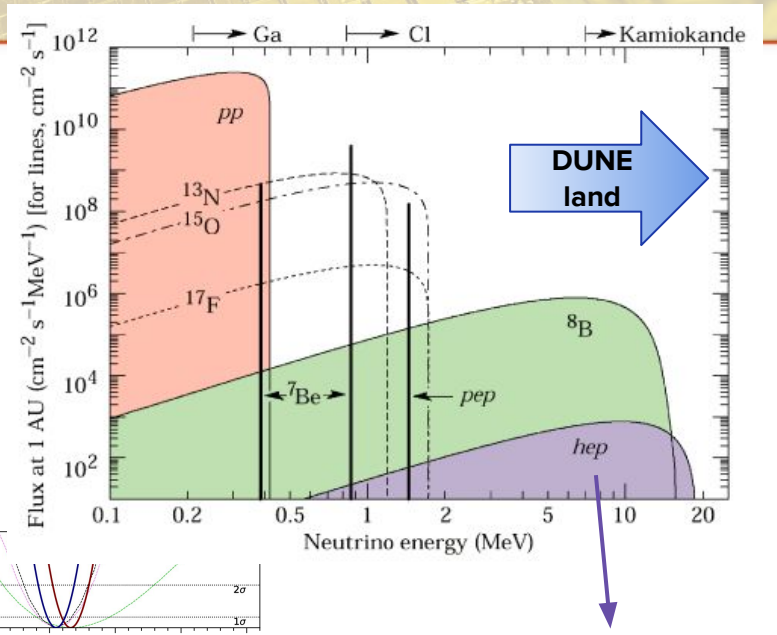
Motivation

- DUNE will be one of the largest underground experiment
  - Potential for astroparticle measurements
    - **SN neutrinos**
    - **Solar neutrinos**
  - Challenge: Phase I conceived for beam at high energy
    - **No shielding** → Backgrounds at low energy expected to be very high
    - *Energy threshold limited by backgrounds*
  - Low energy backgrounds
    - **Neutrons:** natural radioactivity + muon induced
    - Gammas/betas: natural radioactivity + neutron induced
    - **Cosmogenics**
    - **What can we learn from ProtoDUNE-II**

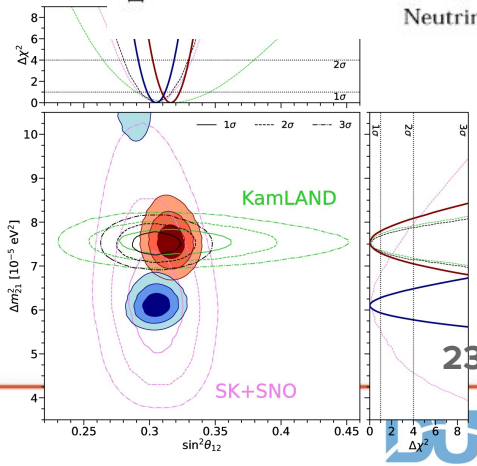


Motivation: Solar neutrinos

- Above 2 MeV **^{8}B** and **hep**
  - **hep not yet observed**
- Two channels: **ES + CC**
  - 10 years of one DUNE module + 5 MeV threshold:
    - ~30 k events in ES channel (**e^- only**)
    - ~100 k events in CC channel (**e^- + K***)
- Solar neutrino oscillations affected by matter effects in the Sun and in the earth (during the night)
  - Tension (~2σ) Δm^2_{21} between reactor and solar experiments
  - Precision measurement needed
    - Reactor: JUNO
    - Solar: DUNE?
  - What are the main backgrounds at this energy range
  - What is the required energy resolution to observe hep neutrinos
    - What can be achieved with ProtoDUNE-II and DUNE?



so far not observed



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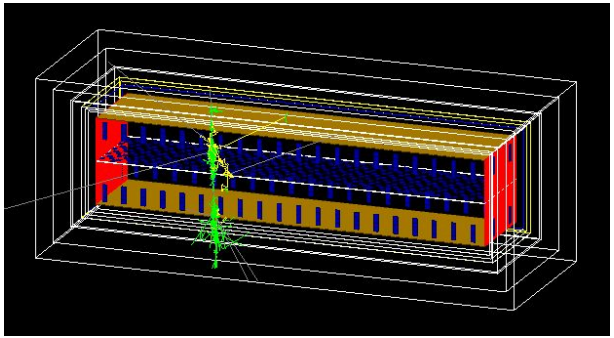
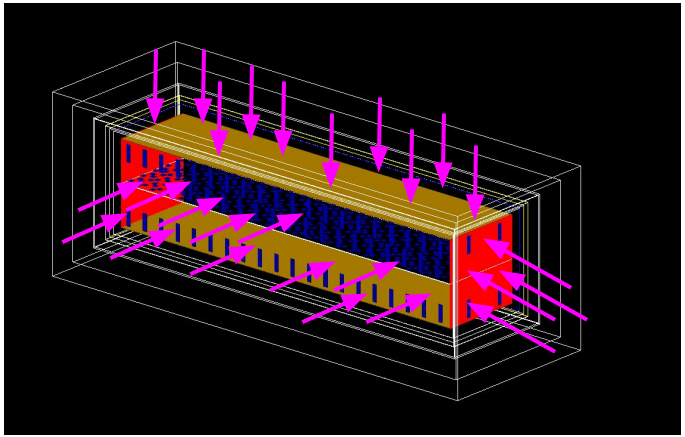
Backgrounds at low energy

- **Cosmogenics:** ~short life isotopes produced by spallation
- DUNE μ rate:
  - 0.05 Hz / module
  - <E> = 238 GeV
- Backgrounds up to 20 MeV



- **Radiogenics:** Natural radioactivity + gammas from **neutron captures**
- ^{39}Ar: 1 Bq/kg, ^{42}Ar/^{42}K: 100 uBq/kg, ^{222}Rn: 1 mBq/Kg
- Neutron rate at SURF: ~1-9 [10^{-6}cm^{-2}s^{-1}]
- DUNE surface: ~40 M cm^2



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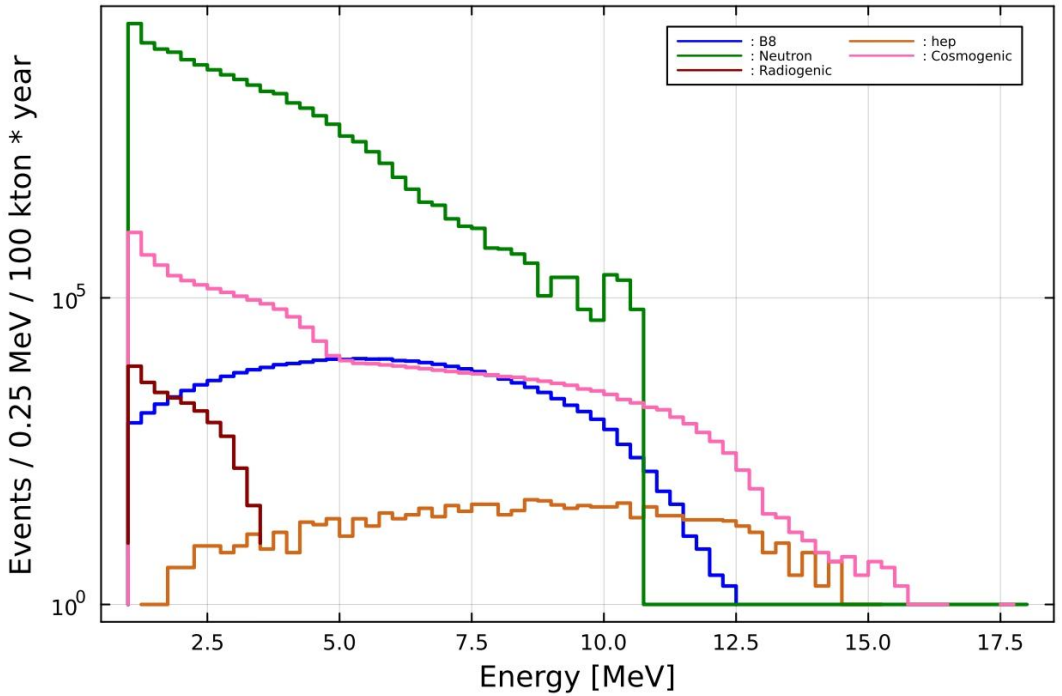
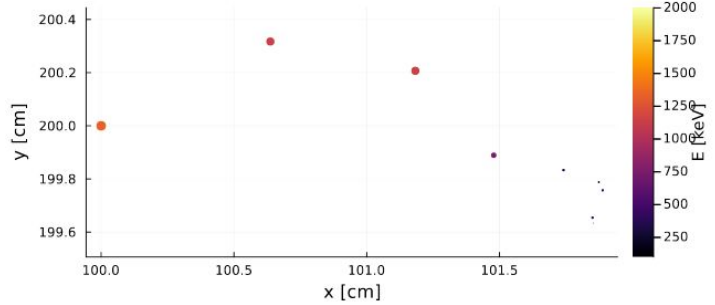
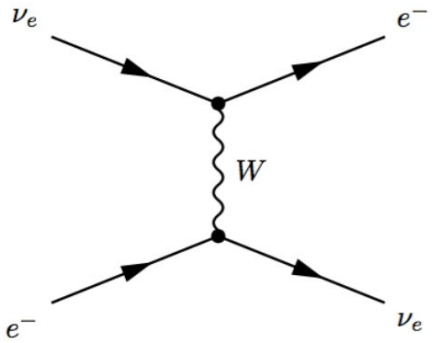


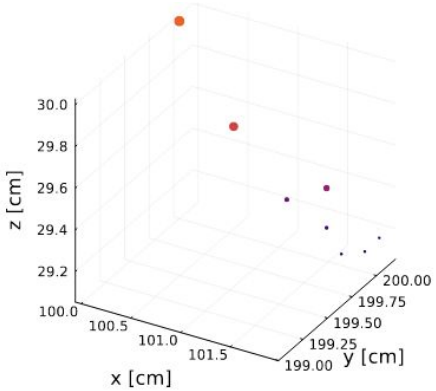
Solar neutrino signal

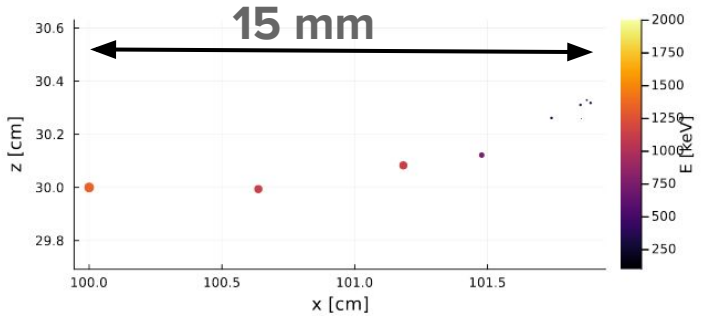
- For **ES channel** a clean signal is expected
  - Electrons absorbed in a couple of cm
  - Well defined gradient of energy deposits
- **CC channel** contains gammas from K* deexcitation

$\nu_e + e^- \rightarrow e^-(6\ \text{MeV}) + \nu_e$



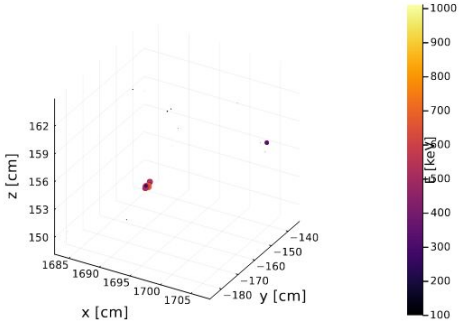


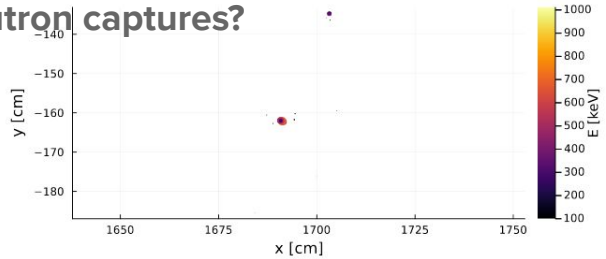


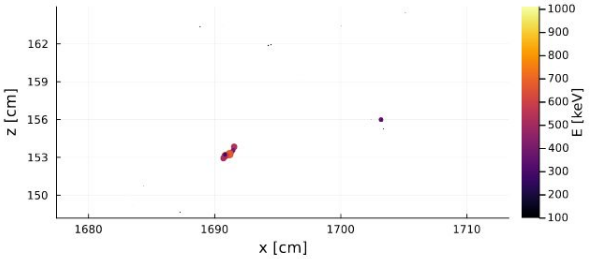


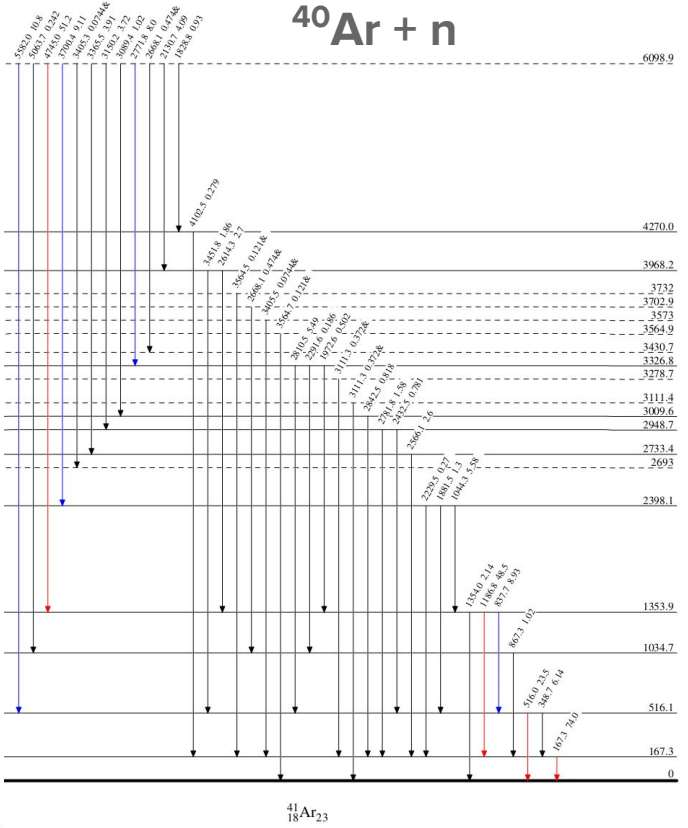
Neutron capture in Argon

- A neutron capture on ^{40}Ar will produce a gamma cascade of ~6 MeV
  - Can mimic low energy neutrinos
  - In general several energy deposits
  - **Can we identify neutron captures?**



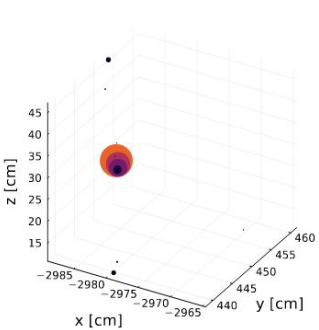




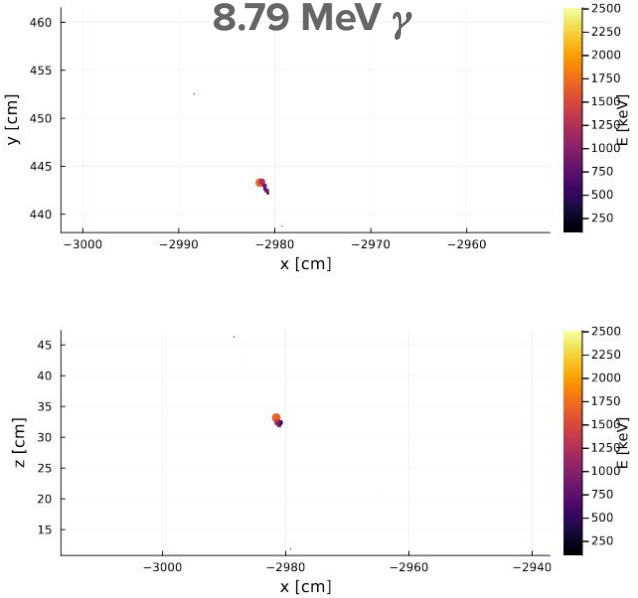


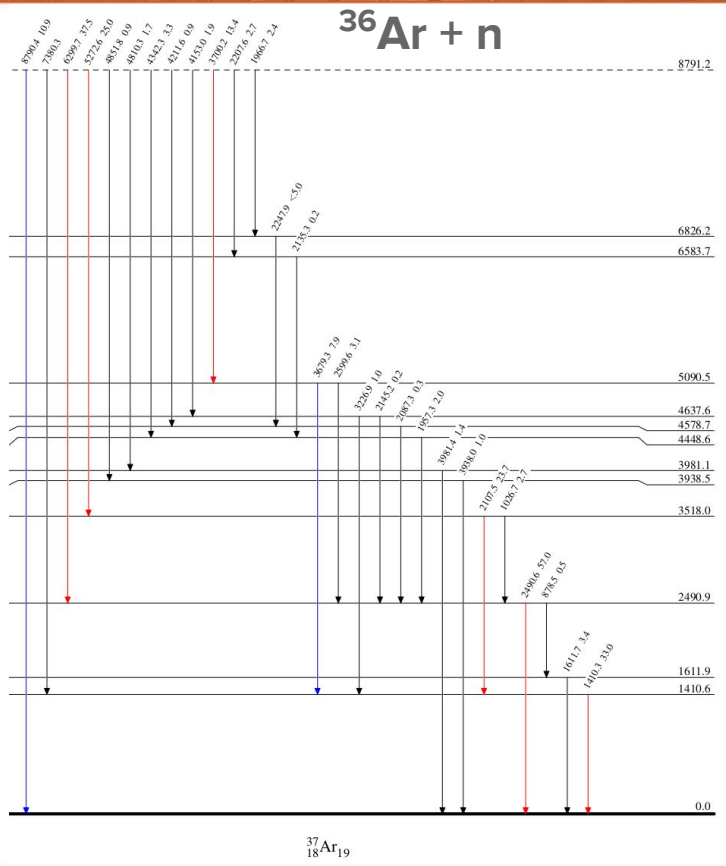
Neutron capture in Argon

- A neutron capture on ^{36}Ar will produce a **gamma cascade of ~8.7 MeV**
  - Can mimic low energy neutrinos
  - A single **8.791 MeV gamma** in some cases
  - **Can we identify neutron captures?**



8.79 MeV γ

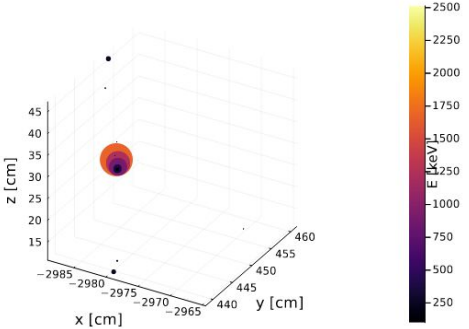


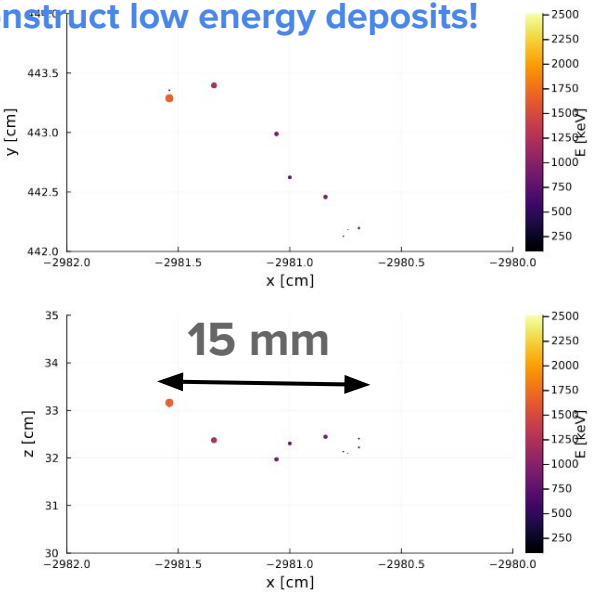


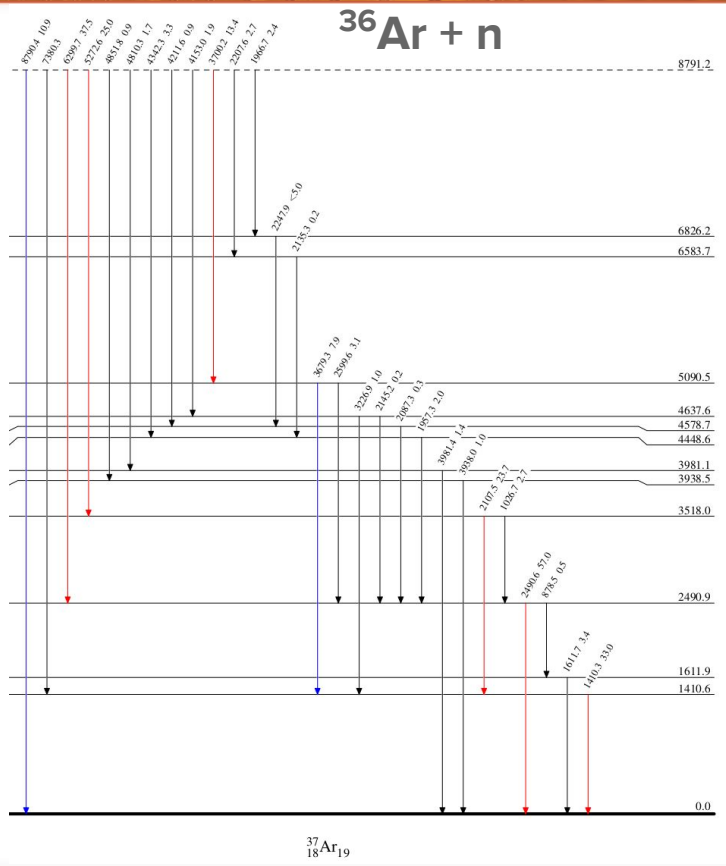
Neutron capture in Argon

- A neutron capture on ^{36}Ar will produce a **gamma cascade of ~8.7 MeV**
  - Can mimic low energy neutrinos
  - A single **8.791 MeV gamma** in some cases
  - **Can we identify neutron captures?**
    - **Need to reconstruct low energy deposits!**

8.79 MeV γ







Neutrons in proto-DUNE II

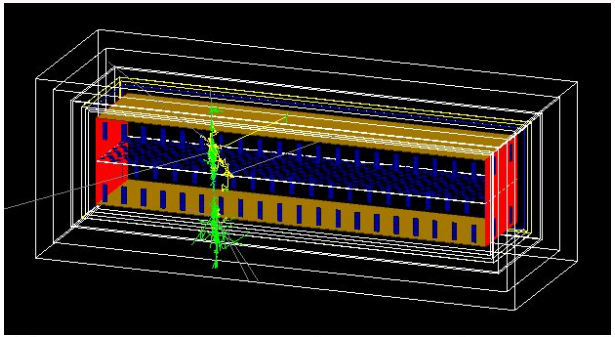
- **Need to understand neutron signals to assess the low energy physics potential of DUNE**
- Neutron sources in Proto-DUNE:
  - Pulsed neutron source:
    - MeV neutrons
    - up to 10^6 n/s
  - Cosmic induced
  - Radioactive source?
- ProtoDUNE-II provides the opportunity to collect a large amount of neutrons under “controlled” conditions
  - Start characterization of neutron response
    - Trigger requirements to detect these signals
    - Energy reconstruction
    - Topology

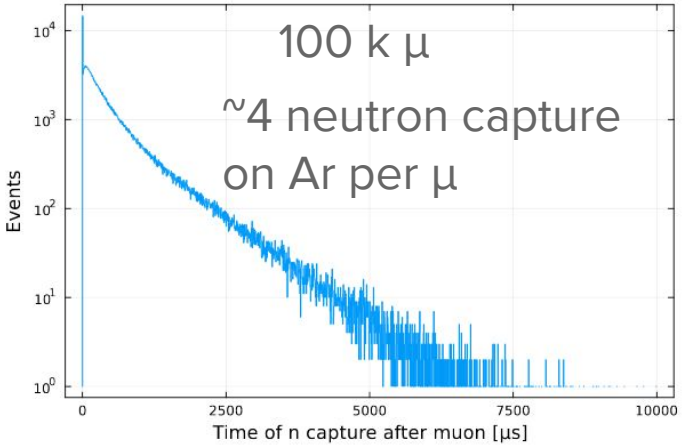
Pulsed neutron source

^{252}Cf source

Neutrons cosmogenic induced

- In the FDs we will have about 4 neutron capture on Ar per muon
  - The capture time will be below ~7 ms
  - A “simple cut” should be enough to remove these neutrons
  - Neutrons induced by non detected muons much more difficult to remove
- Much more muons at NP site
  - Different energy than FDs
  - Need to estimate amount of n’s





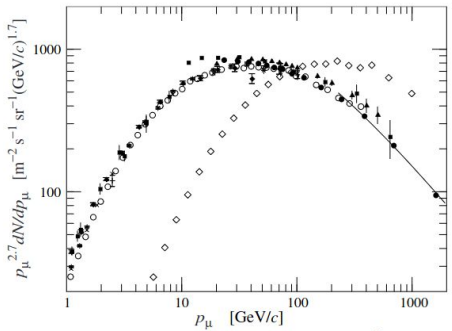
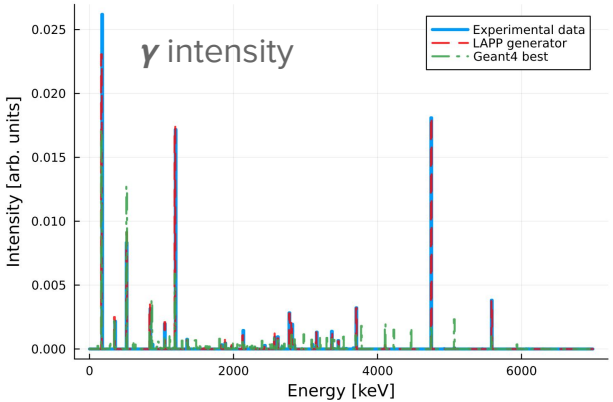
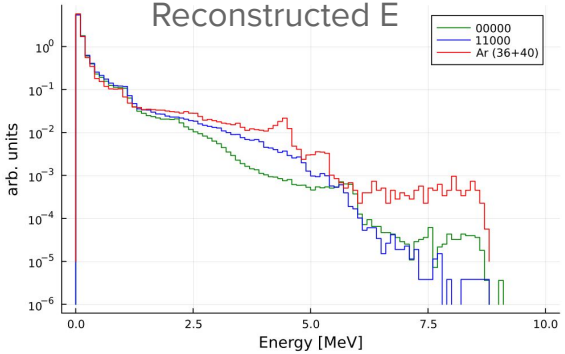


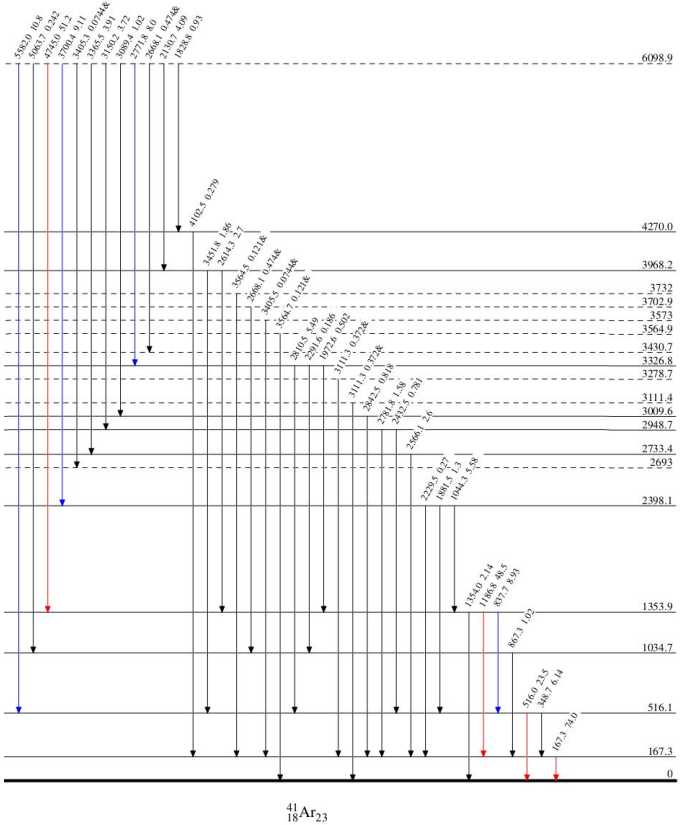
Figure 24.4: Spectrum of muons at $\theta = 0°$ (♦ [41], ■ [46], ▾ [47], ▲ [48], ×, + [43], ○ [44], and ● [45] and $\theta = 75°$ ◊ [49]) . The line plots the result from Eq. (24.4) for vertical showers.

n+Ar Gamma cascade validation

- Default geant4 simulations produce wrong intensities of gammas
  - Underestimation of high energy gammas
  - A lot of gammas that are not expected
- Need to tune simulations to reproduce gamma cascade
  - Use experimental data
  - Validate energy reconstruction

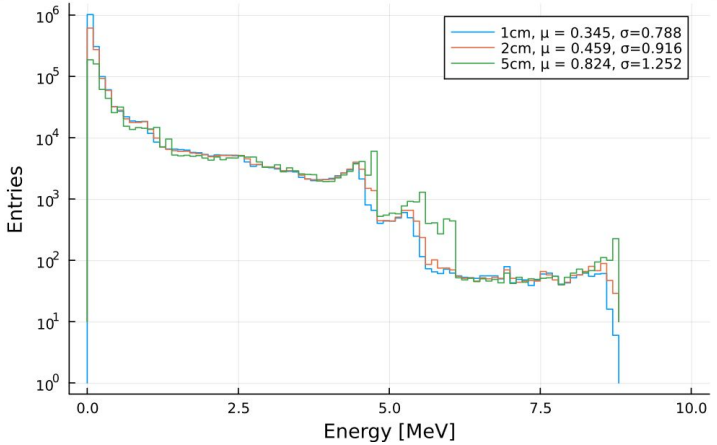




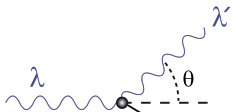


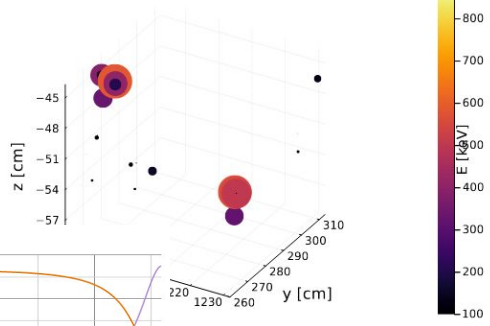
n+Ar energy reconstruction

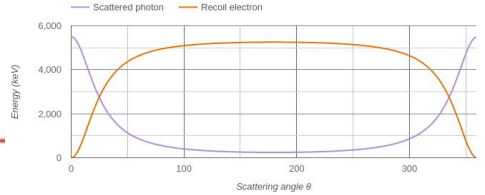
- Energy spectrum of gammas from n capture on Ar depends on cluster reconstruction
  - Limited by strip size (5 mm for VD)
  - Energy deposits correlated in time and position
    - Need $\mathbf{t_0}$ and precise 3D energy reconstruction with **low E threshold** and good **E resolution**
    - Can be combined with **light reconstruction**

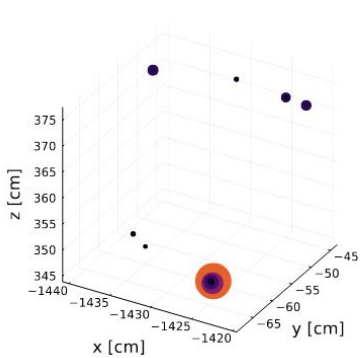


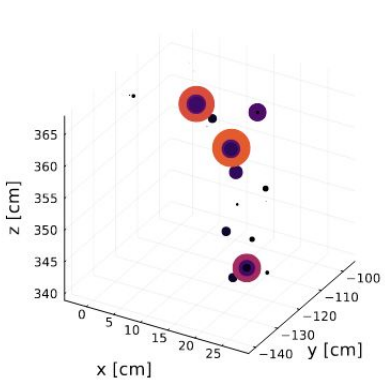
$$E_{\gamma'} = \frac{E_\gamma}{1 + (E_\gamma / m_e c^2)(1 - \cos\theta)}$$





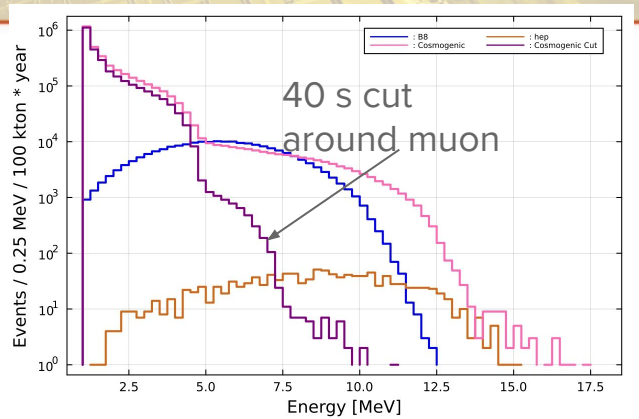


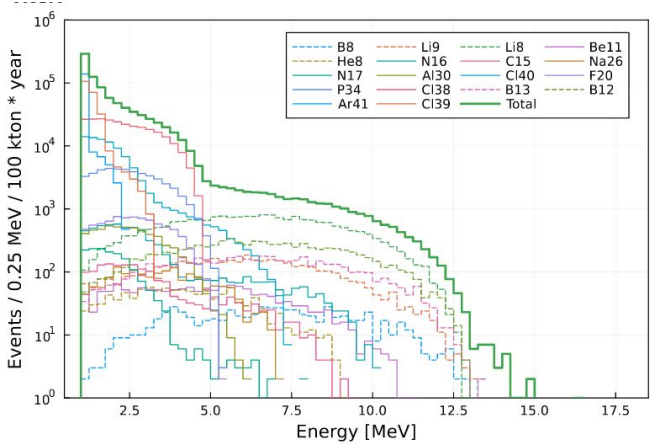




Cosmogenics

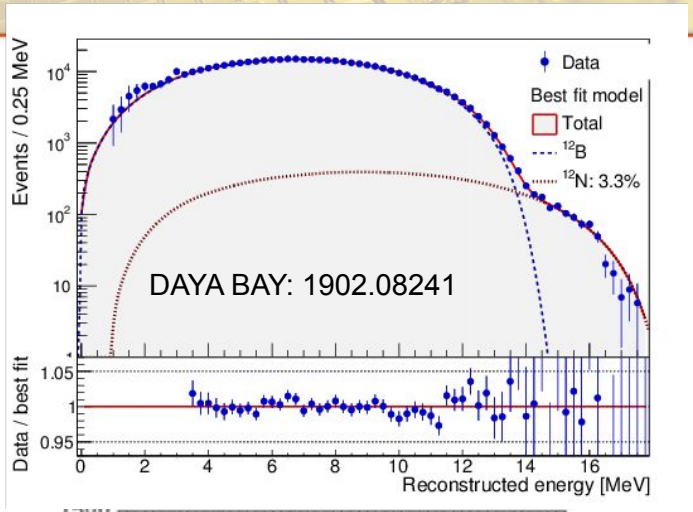
- Cosmogenics: short life isotopes produced by spallation
- Around 1M of events per module in 10 years
- Below 5 MeV
  - Long lived isotopes below 5 MeV
  - Hard to remove
- Above 5 MeV
  - ~40 k above 5 MeV (No E smearing!)
  - Comparable with solar rate
  - Time cut of 40 s around muon shower remove most of them
  - Directionality (if any) can also be exploited
- Possible to reduce most of backgrounds above 10 MeV
  - **hep neutrinos seems accessible**

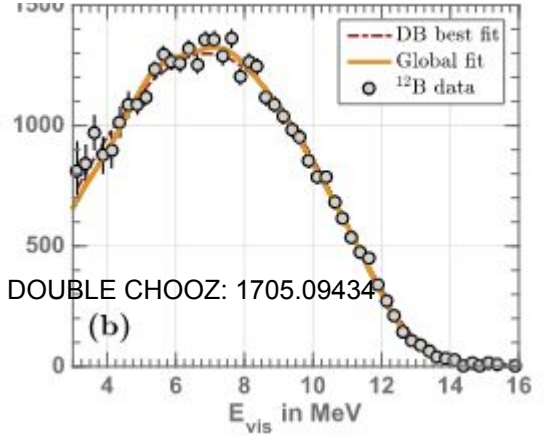




Cosmogenics for calibration

- Cosmogenics used for energy calibration in reactor experiments (scintillator)
- Can we use cosmogenics in DUNE for calibration?
  - High energy part dominated by **^{8}Li and ^{12}B**
  - Need to understand production rate in LAr
  - Simulations needed
  - A lot of data expected in protoDUNE-II
- A similar study could allow a precise estimation of background components
  - Needed to extract signal
  - Calibration of supernova low energy region





Conclusions

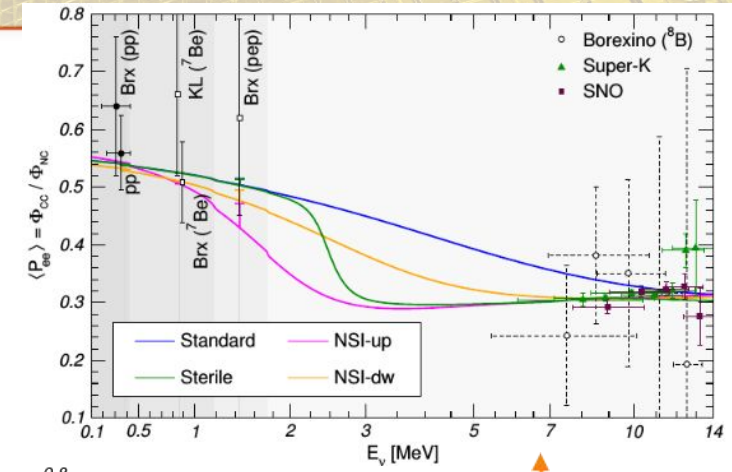
- High potential of DUNE for astrophysical neutrinos
  - Supernova + solar neutrinos
  - **Precision measurement of Δm^2_{21}** to resolve “tension” with KamLAND/JUNO
  - **First observation of hep neutrinos**
  - **First 5σ observation of day/night asymmetry**
- To fully exploit DUNE physics potential at low energy
  - Need to understand backgrounds
    - **neutrons** + **cosmogenics** above 5 MeV
  - Optimize energy reconstruction at low energy
  - Topoly
  - **ProtoDUNE-II will provide data to address some of these questions**

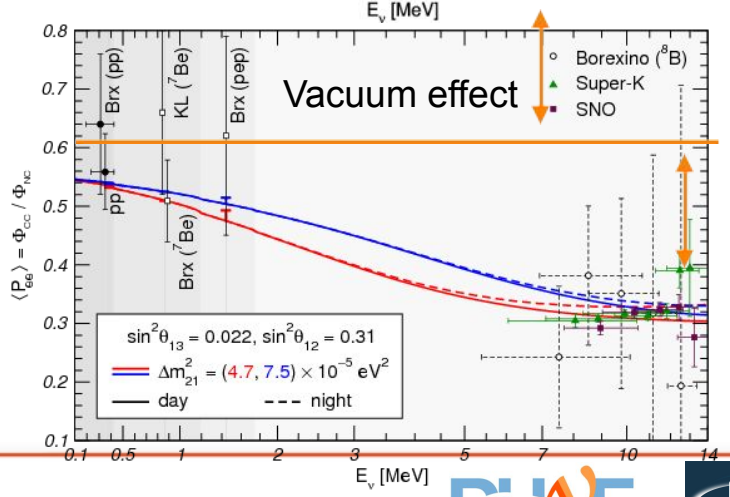
Thanks for your attention

Questions?

Solar neutrino oscillations

- Δm^2_{21} measured by KamLAND higher than SK+SNO
  - ~1.5 σ “tension”
- SK deviates from standard upturn scenario by ~2σ
  - Could be an indication of new physics
  - NSI in the sun?
  - Sterile neutrinos?
  - Just statistical fluctuations?
- Need precise measurement with high statistics





Solar matter effect

Day-Night asymmetry

- So far measured at 3σ with latest SK data
  - SK result compatible with expectations
- Higher asymmetry than what is expected with KamLAND result