SOUTH DAKOTA MINES
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Pulsed Neutron Source for DUNE Far Detector Calibration

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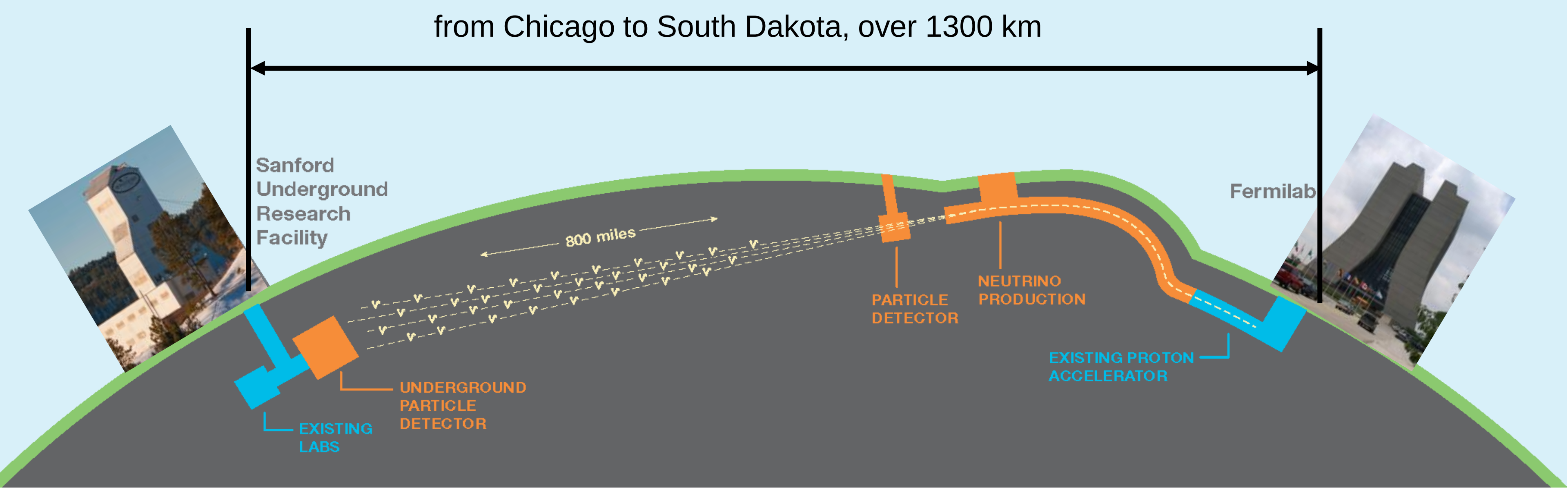
Practice Talk

Outline

- Deep Underground Neutrino Experiment
- DUNE Calibration Challenge
- Pulsed Neutron Source Calibration System
- DD Generator Test
- Summary

DEEP UNDERGROUND NEUTRINO EXPERIMENT

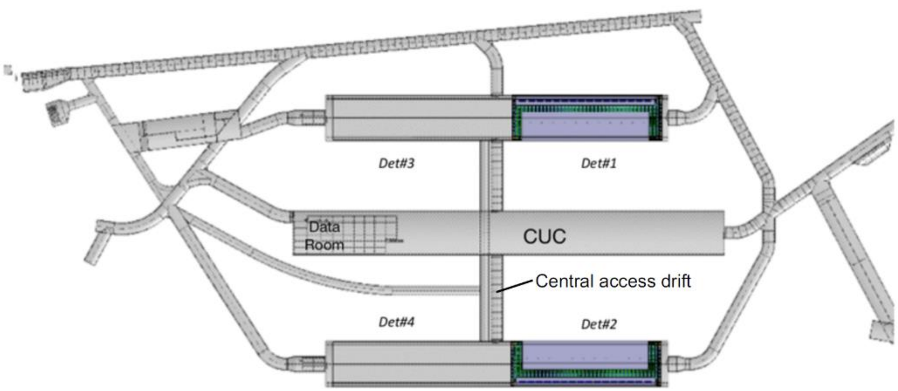


- Long-baseline neutrino experiment
  - Internal collaboration: >30 countires
  - 1300 km baseline
  - Neutrino/antineutrino beams
  - Near Detector complex
  - Large LArTPC far detector: 70 kton mass (40 kton fiducial mass), 1.5 km underground
- Physics program
  - Neutrino oscillation:
    - CP-violating angle δ_{CP}
    - Neutrino mass hierarchy
    - 3-flavor paradigm: θ_{23} octant, …
  - Supernova neutrino
  - Beyond Standard Model physics: nucleon decay, sterile neutrino, non-standard interactono, …

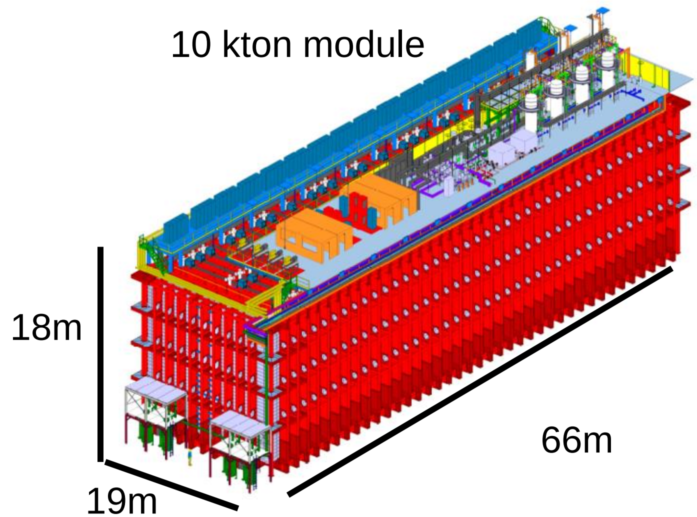
DUNE Calibration is Challenging

- The stringent physics requirements for DUNE are unprecedented
  - Energy scale 2% or better is required for oscillation physics
  - energy scale <5% and energy resolution <10% are required for low-energy physics: supernova, solar physics
- DUNE far detector calibration is challenging
  - **Deep underground** → only 177 stopping muons and 146 Michel electrons /day/10 kt
  - **Large volume** → spatial coverage is limited by the source deployment locations

Far detector top view



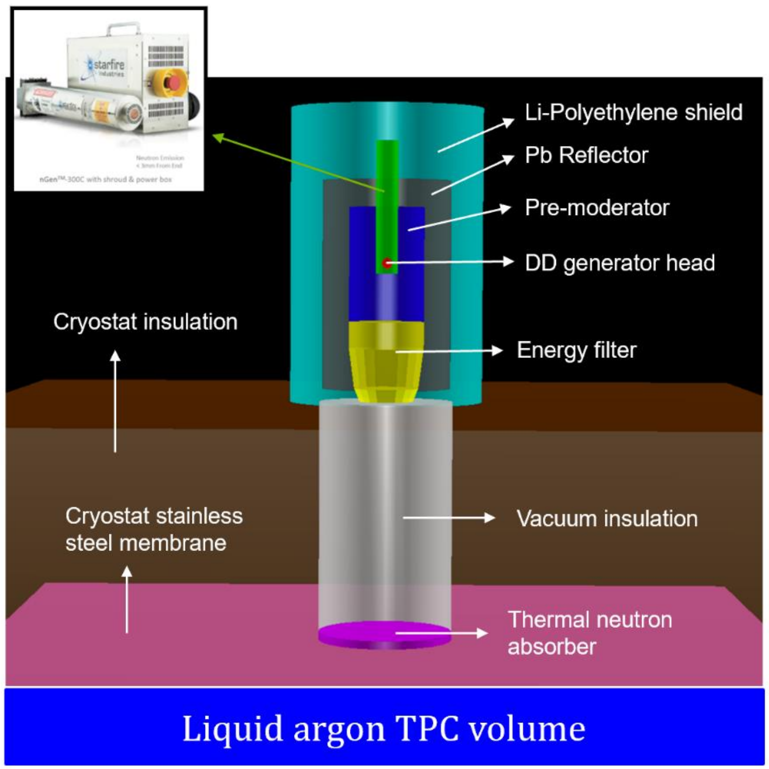
10 kton module



Pulsed Neutron Source

- **Could use an external Pulsed Neutron Source (PNS) system**
  - Neutron-based calibrations were used by SNO and Super-K
  - One of the main strategies in DUNE Technical Design Report

Deuterium-Deuterium (DD) neutron generator $^{2}H + {}^{2}H \rightarrow {}^{3}H + n + Q(2.5\,MeV)$



Neutron Moderator

- **DD generator** → 2.5 MeV neutrons
- **Pre-moderator** → efficiently reduce energy down to below 1 MeV
- **Energy filter** → reduce neutron energy down to <100 keV level
- **Pb reflector** → Increase neutron yield
- **Thermal absorber** → suppress thermal neutrons
- **Li-Polyethylene shield** → radiation protection

How Can Neutrons Help?

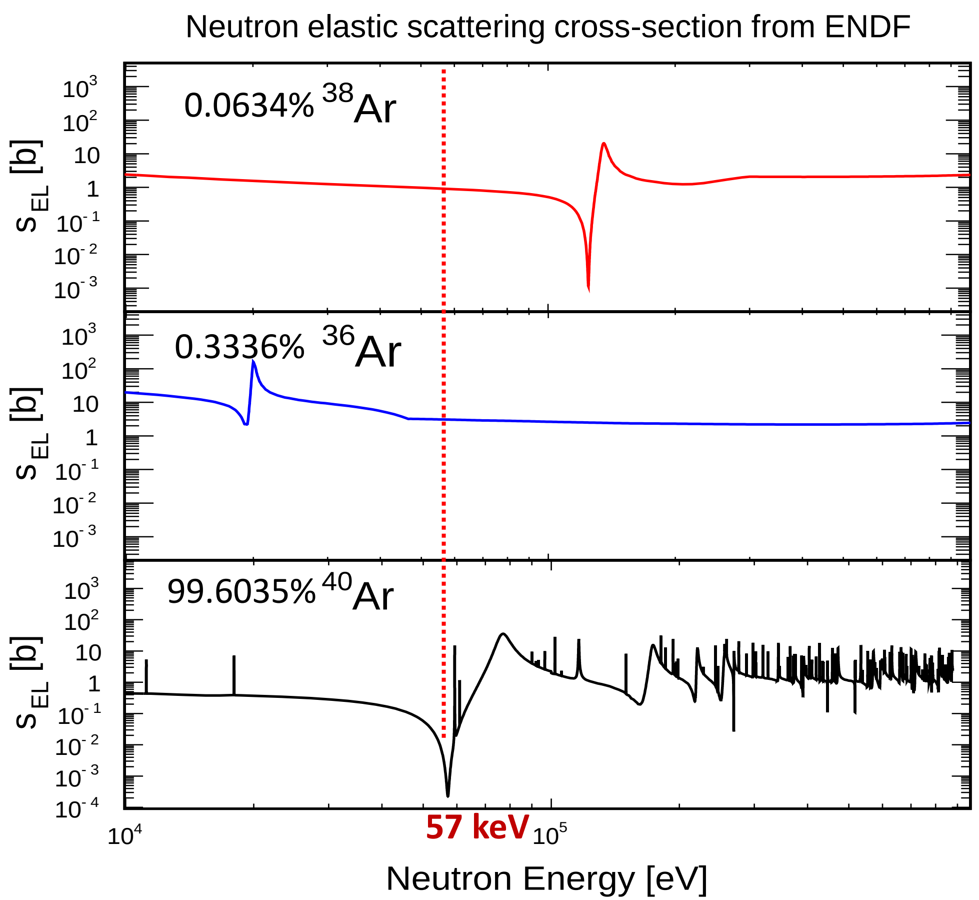
- Neutron's average fractional energy loss per scatter is 4.8% in Ar-40

  Example: for a 70 keV neutron, the energy loss is 3.4 keV on average

- Most neutrons above 57 keV will fall into the anti-resonance where the effective scattering length is about 30 m

- Neutrons need a few scatters to escape the 10-keV-wide anti-resonance at 57 keV.

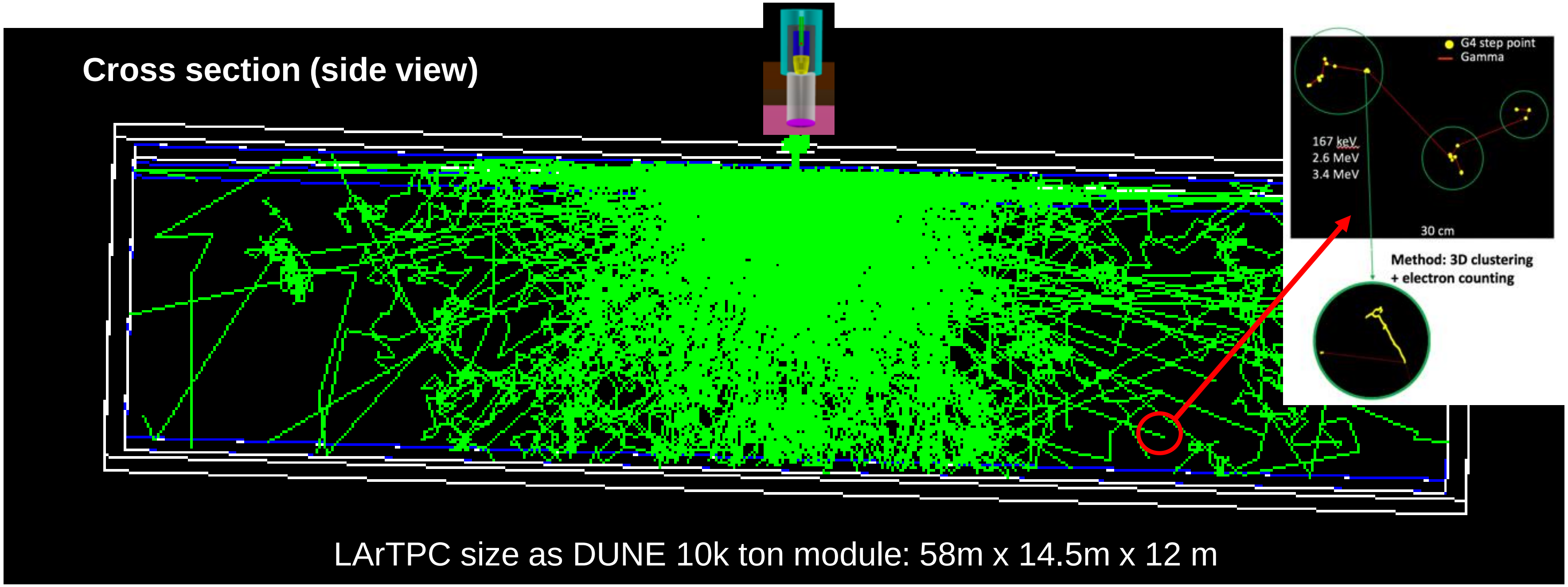
- Neutron capture on Ar-40 emits 6.1 MeV gamma cascade



$n + {}^{40}Ar = {}^{41}Ar + 6.1\ MeV$ ⇨ **"standard candle" calibration signals**

Neutron Transport in DUNE-size TPC

- One source covers about **1/3** the DUNE far detector module. Having several sources is sufficient to cover the entire detector volume
- Measure the energy response at low energy (6.1 MeV)
  - Provide energy scale and resolution as a function of position and time
  - Access various detector response parameters: electron lifetime…
  - Test supernova trigger efficiency

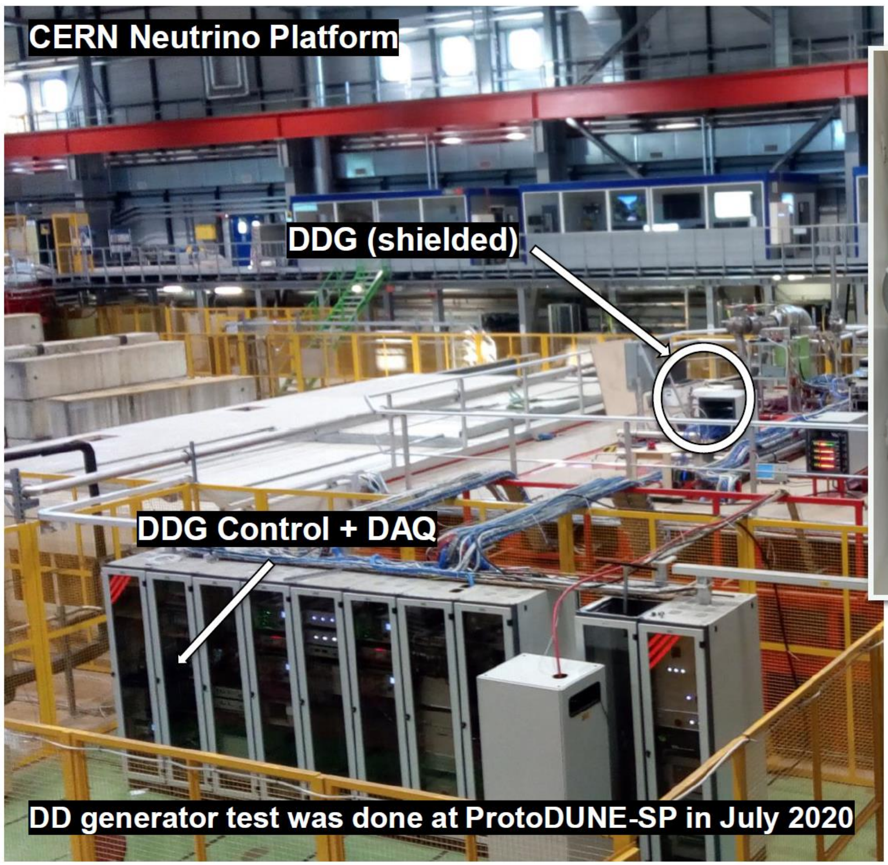


Advantages Using PNS System

- **External deployment: no need to open the cryostat seal**
  - Easy setup. No contamination to argon purity, no field distortion
- **External pulsed trigger: use a pulsed DD generator**
  - Pulsed trigger allows reconstruction of neutron capture location
  - Adjustable pulse width from 0-1000 μs. Adjustable pulse rate from 0-200 kHz.
  - Maximum neutron yield of 10^6-10^8 /s. Expect to complete a calibration run within one day
- **Wide coverage: neutrons can travel long distance**
  - Fractional energy loss per elastic scatter is 4.8%
  - 10-keV wide anti-resonance at 57 keV
  - Can cover an enormous volume of the DUNE far detector
- **Multi-gamma output: neutron capture emits 6.1 MeV gamma cascade**
  - Fixed energy deposition as a “standard candle”

DD Generator Test @CERN

- A DD generator test was performed in 2020 during ProtoDUNE Run-1 at CERN
- Goal: verify the neutron transport model and develop neutron capture analysis algorithms

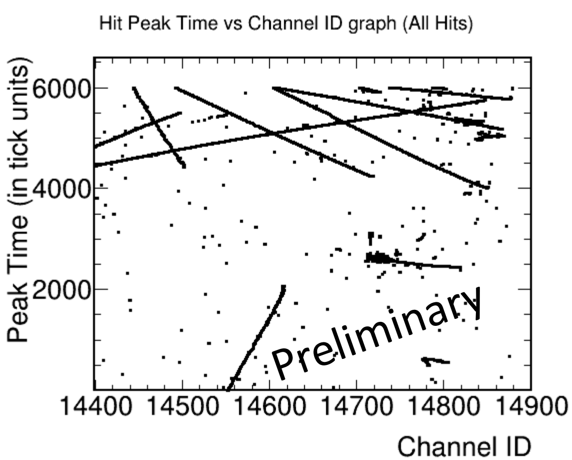


(From left to right) protoDUNE-SP module and the DDG installation location; DDG; DDG inside the shielding; roof feedthrough at which DDG is deployed

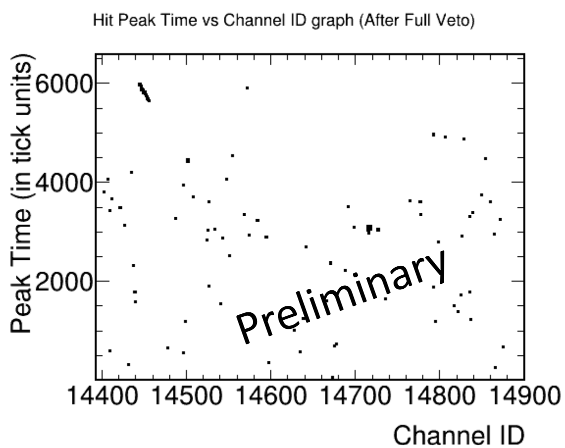
(Images from M. Fanì, DUNE Collab. Meeting, Sep 2020)

DDG Data Analysis

- Data was taken over 10 days with different trigger modes and neutron intensities
- Cosmic ray backgrounds are removed to reveal the neutron activities.
- Stay tuned

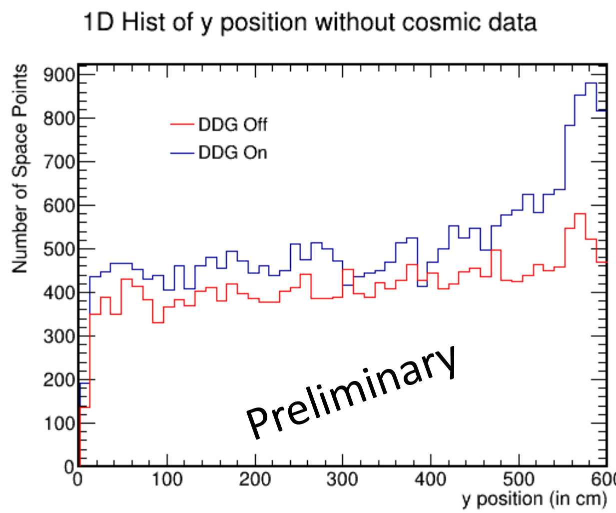


Work done by Y. Bezawada



Peak Time vs Channel ID plot for one event; Before and after cosmic removal respectively

Vertical space point distribution



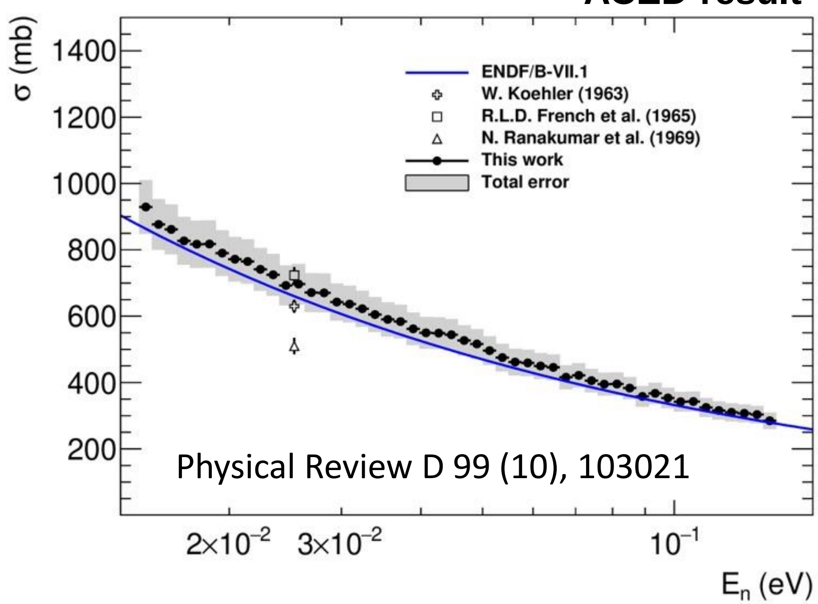
- The complete Pulsed Neutron Source system will be tested in ProtoDUNE Run-2 operation in 2022

Other Supporting Measurements

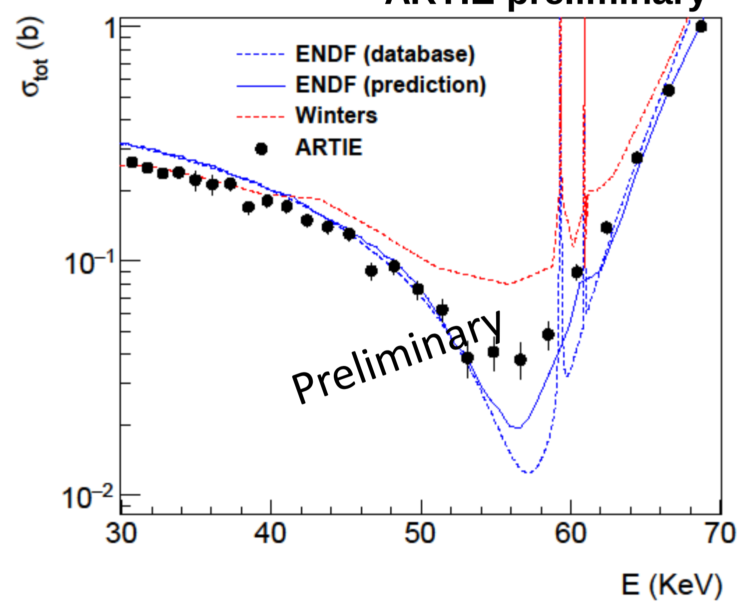
To better understand the neutron transport and capture, we did two experiment at Los Alamos National Laboratory:

- **Argon Capture Experiment at DANCE (ACED)**
  - measured the thermal neutron capture cross-section and the correlated-gamma cascade
- **Argon Resonant Transport Interaction Experiment (ARTIE)**
  - measured the neutron-argon total cross-section around 57 keV

ACED result



ARTIE preliminary



Summary

- DUNE far detector calibration is challenging
- External Pulsed Neutrons Source can be used to calibrate the energy response of liquid argon TPC
- DD generator test was done during ProtoDUNE Run-I at CERN.
- Test of a complete PNS system will be done at ProtoDUNE Run-II