Measurement of the neutron capture cross section on argon with ACED

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Neutron captures in argon

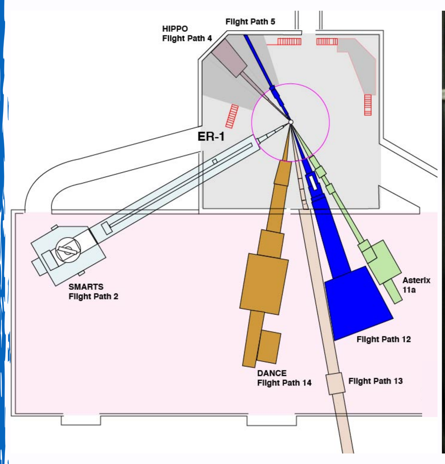
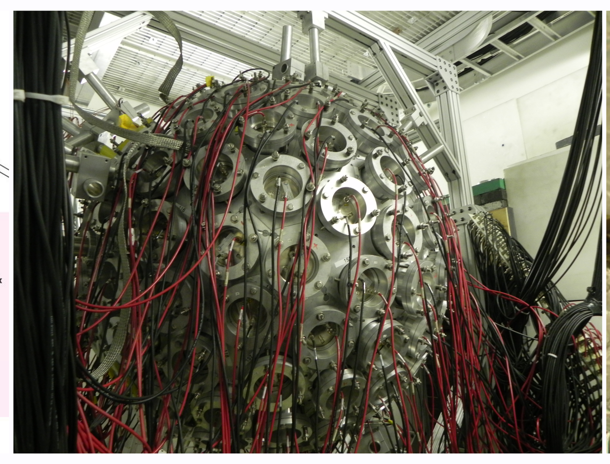
- Argon is widely used for particle detection in
  - low-background dark matter searches (*e.g.* DarkSide)
  - high-energy neutrino experiment (*e.g.* DUNE)

- Neutron captures are both a source of background and a product of signal events (*e.g.* neutrino-induced neutrons)
- It is of paramount importance to better understand the thermal neutron capture cross section since it is poorly understood (existing measurements show significant disagreement)

→ The **A**rgon **C**apture **E**xperiment at **D**ANCE (**ACED**):
- **measure dσ/dE** using a **time-of-flight** (TOF) neutron beam

Where? At Los Alamos

- The DANCE detector is located on Flight Path 14 at Lujan Neutron Scattering Center (20.25m flight path, 800MeV proton beam)
- We performed neutron irradiation on a 30mg **natural argon** target
- Gammas are detected by a 4π calorimeter composed of 160 BaF_2 crystals coupled to PMTs


How to calculate the cross section

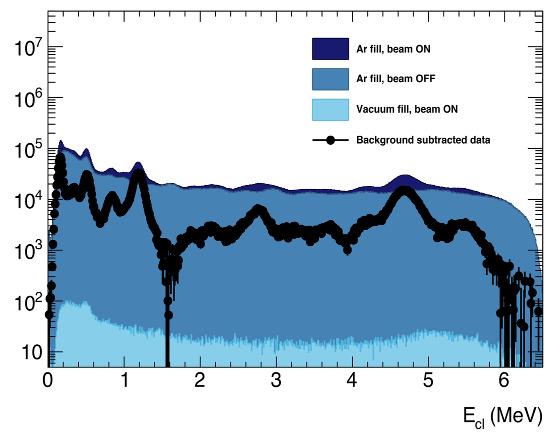
$$\sigma = \alpha\, G / (\varepsilon\, N) - \zeta$$

- α → ^{40}Ar properties (e.g. natural abundance) and target parameters (*e.g.* pressure and temperature)
- **G** → number of neutron captures
- **ε** → efficiency to see the ^{41}Ar gamma cascade after applying the selection cuts
- **N** → number of neutrons seen by the beam monitors
- ζ is a theoretical correction (~1%) to account for the presence of ^{36}Ar (^{38}Ar is negligible) in natural argon

- TOF technique allows to precisely select neutron energy

Background subtraction

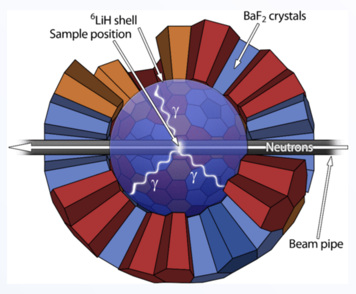
- Quality cuts efficiency is 75%
- Cluster multiplicity cut: $\#_{cl} > 1$ (to see cascade)
- Q-value cut: total energy between [5.2,6.6] MeV
- Different datasets are used:
  1. Beam on argon target (A)
     $\mathbf{D^A} = T_0^A R + \phi^A \sigma_b + \phi^A \sigma_a$
  2. No beam on argon target (S)
     $\mathbf{D^S} = T_0^S R$
  3. Beam on evacuated target (V)
     $\mathbf{D^V} = T_0 V R + \phi^V \sigma_b$
- Argon contribution:
  $\phi^A \sigma_a = \mathbf{D^A} - T_0^A/T_0^S\, \mathbf{D^S} - \phi^A/\phi^V (\mathbf{D^V} - T_0^V/T_0^S\, \mathbf{D^S})$

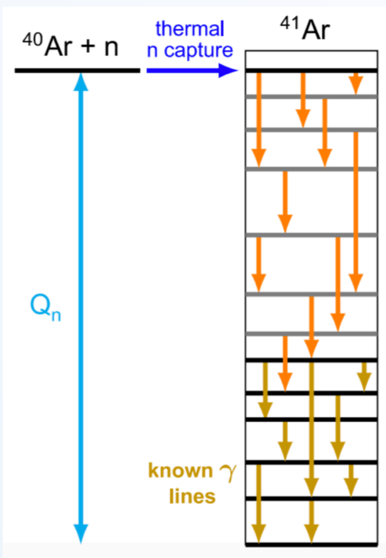


Gamma cascade detection

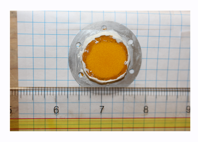
- Detailed Geant4-based simulation of apparatus
- Model crystal response (energy resolution and the minimum detectable energy deposit) on a crystal-by-crystal basis
- ^{41}Ar gamma cascade and uncertainties are assumed from literature PhysScr 1, 85 (1970)
- Include Q-value and cluster multiplicity cuts
- $\varepsilon = 98.9 \pm 0.3_{stat} \pm 0.9_{sys}$ %

- Next steps: assess the validity of the gamma cascade and reduce the uncertainty of relative intensities of ɣ-lines using DICEBOX
  - paper in preparation



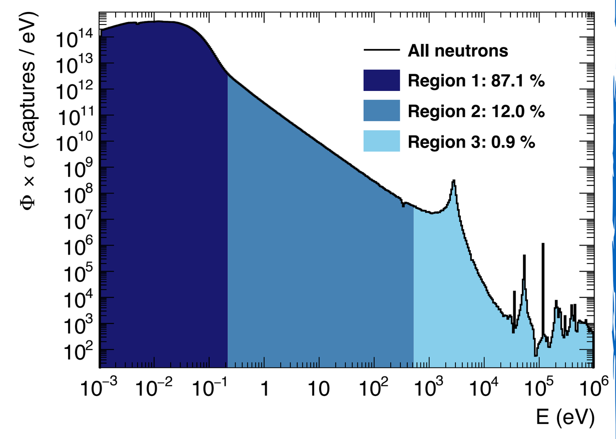


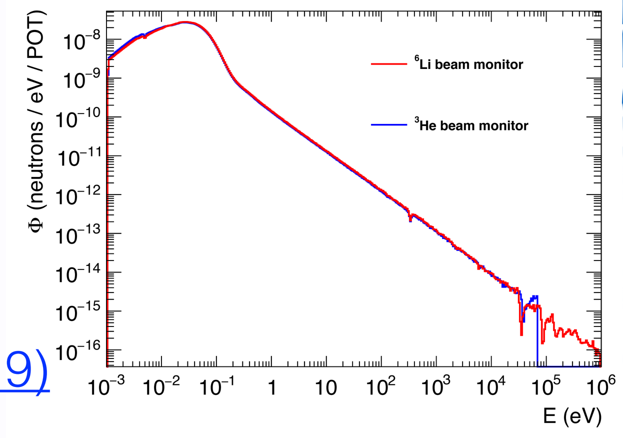
Neutron monitor calibration



- The absolute neutron flux is obtained by a sodium control sample
  - has single stable isotope (^{23}Na)
  - its product, ^{24}Na, has $t_{½}$ = 14.997 h which is convenient for counting
  - has no resonances <500eV
  - cross section is known to within 1%
- Activated sodium is measured by HPGe
- Deduce # of thermal neutrons to a **±5% level**. This is used to normalize the ^{6}Li and ^{3}He monitors

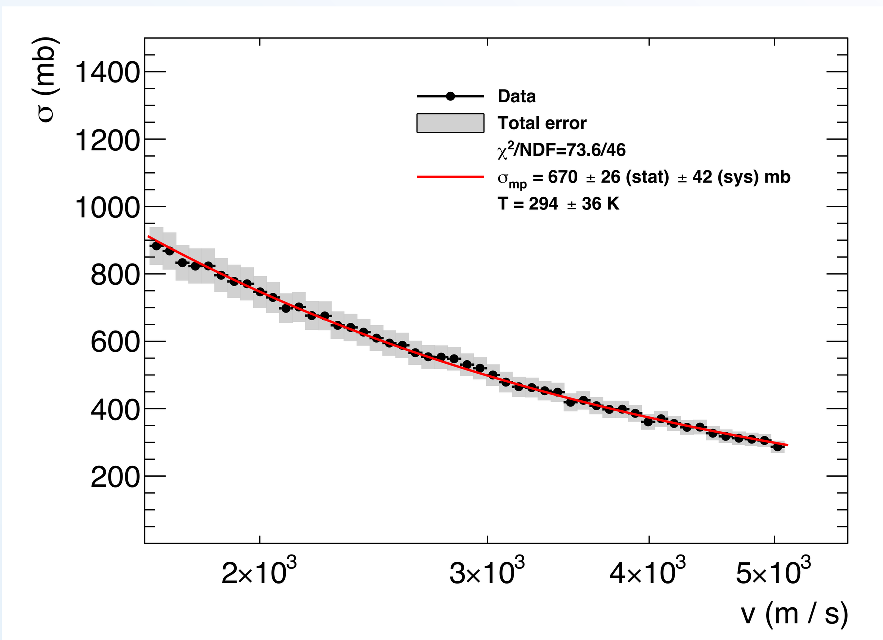
- Method published in NIM A 929, 97 (2019)

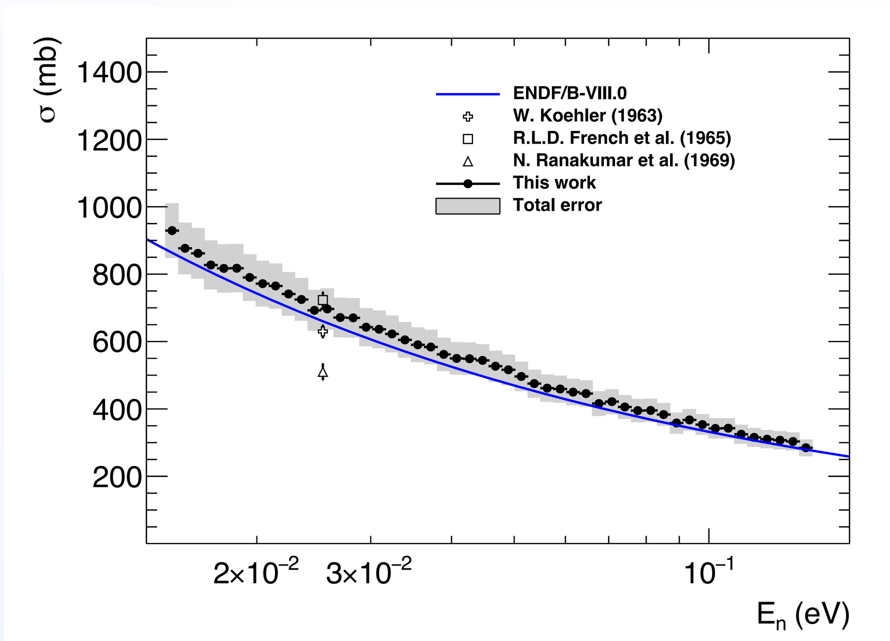




Results

- For a 1/v-absorber: $\sigma(v) = \sigma_{mp}\, v_{mp} / v$, where $v_{mp} = (2kT/m)^{½}$
- Fitting in 0.015-0.15eV neutron energy region yields
  - T = 294±36K and $\sigma_{mp} = 670 \pm 26_{stat} \pm 43_{sys}$ mb
- Total systematic error dominated by uncertainties in # of neutrons (calibration 5%, beam stability 3%, and monitors consistency 2%)
- Correcting for average temperature (of the moderator and target) gives: $\sigma^{2200} = 673 \pm 26_{stat} \pm 59_{sys}$**mb** for thermal neutron cross section
- Results published in PhysRevD 99, 103021 (2019)





Acknowledgements: This material is based upon work supported by the U.S.Department of Energy (DOE) Office of Science under Award. No. DESC0009999, and by DOE National Nuclear Security Administration through the Nuclear Science and Security Consortium under Grant No. DE-NA0003180