ARTIE-II

Argon Resonant Tranport Interaction Experiment

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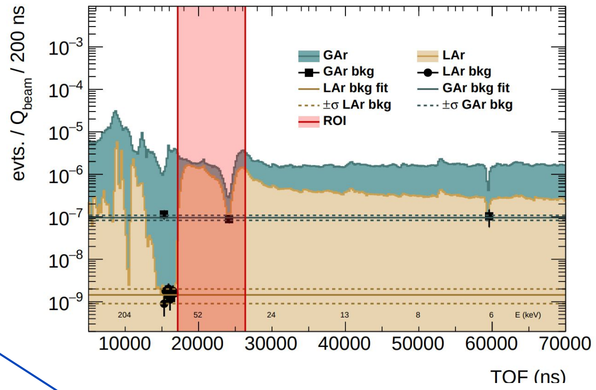
Neutron Calibration

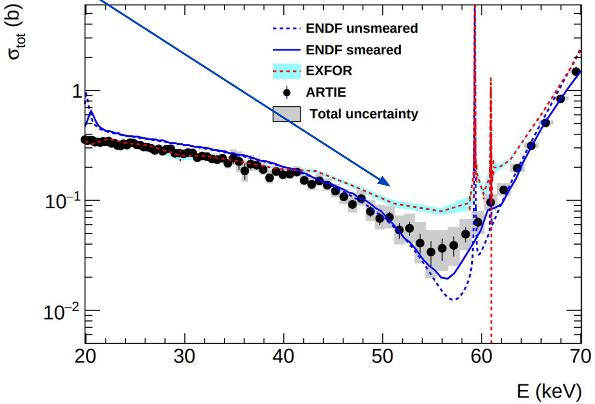
Benefits of low-energy neutrons for calibration:

- ***Scattering Length*** - Some percentage of neutrons above 57 keV will fall into the resonance well.
  - Average *fractional energy loss* is ~4.8%.
  - The *effective scattering length* is ~30 m.
  - The resonance well has been measured by the ARTIE[1] experiment at LANL, with a ***higher precision follow-up*** planned for this year.
- ***Standard Candle*** - Neutron captures on Ar-40 emit a 6.1 MeV gamma cascade.

$$\mathrm{n} + {}^{40}\mathrm{Ar} = {}^{41}\mathrm{Ar} + \{\gamma_j\}$$

$$\sum_j E(\gamma_j) \approx 6.1\mathrm{MeV}$$





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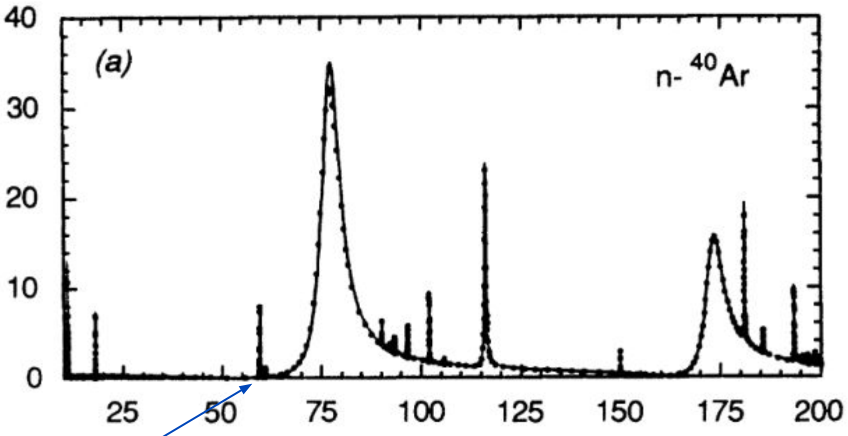
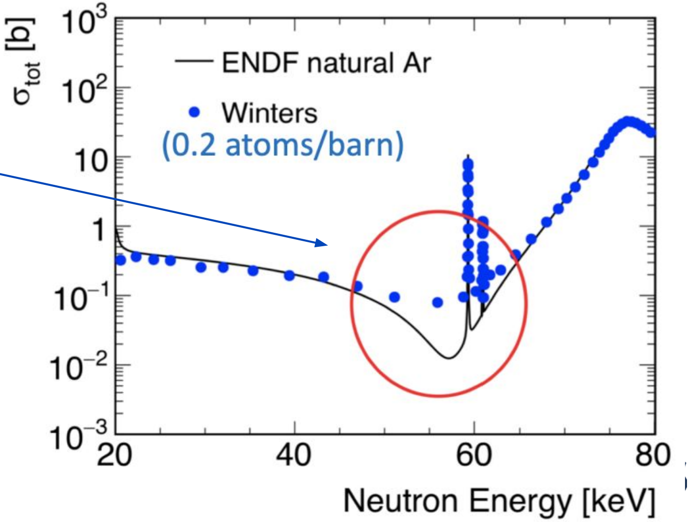
[1] *Measurement of the total neutron cross section on argon in the 20 to 70 keV energy range,* The ARTIE Collaboration, In review at PRL, 2023, (https://arxiv.org/abs/2212.05448).

Why ARTIE?

Previous measurements of the neutron cross section on Argon were done by Winters et. al.[2]

- The Winters experiment used a long target (221.6 cm) filled with Ar gas.
- This amounted to an ***areal density*** of approximately 0.211 atom/b.
- This density is not sensitive enough to measure the resonance well predicted at 57 keV.





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[2] *Total cross section and neutron resonance spectroscopy for n + ^{40}Ar,* R. R. Winters et. al., Physical Review C, 43 (2), 1991.

Cross Section

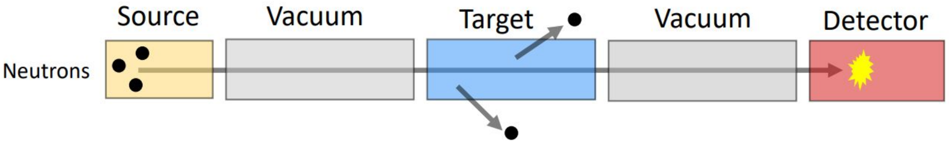
The cross section is experimentally determined from:

$$\sigma(E) = -\frac{1}{n}\log T(E)$$

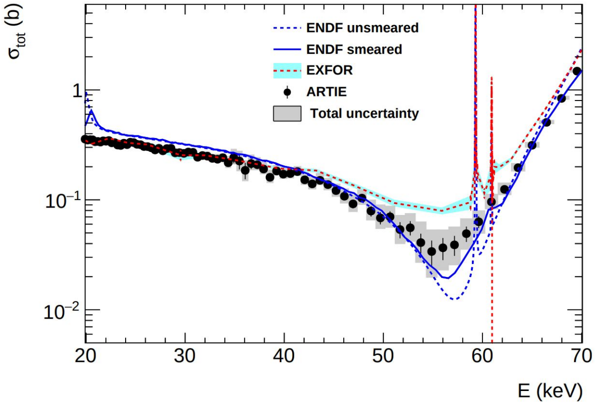
where T(E) is the ***transmission*** as a function of energy, and *n* is the ***areal density***:

$$n = \frac{\rho d}{m_{\mathrm{Ar}}}\ [\mathrm{atoms/b}]$$

where ρ is the density of the target, *d* is the length, and m_{Ar} is the mass of an Argon atom.



The areal density for ARTIE-I was approximately **3.3 atoms/b**, compared to the Winters experiment (**0.211 atoms/b**), which allowed the measurement to be sensitive in the ***40-70 keV ROI.***



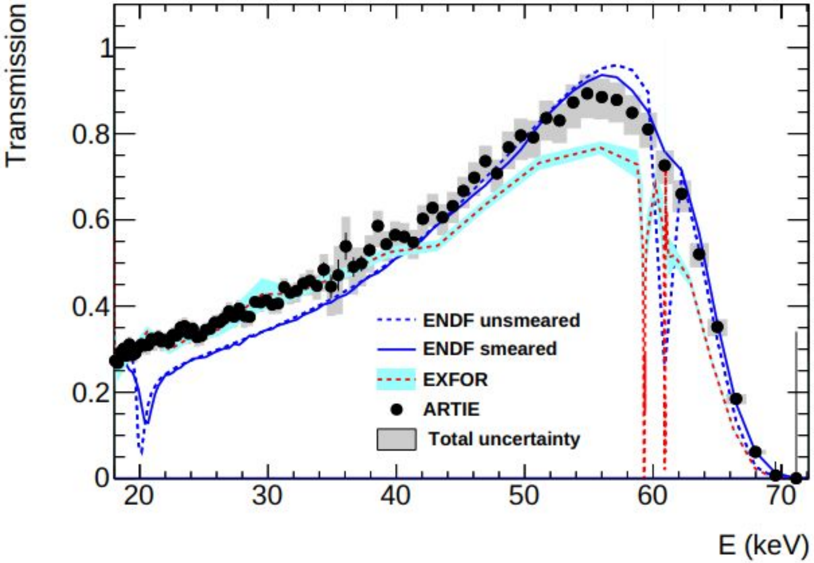
Transmission

The beauty of the experiment lies in its simplicity. The transmission is calculated with the following quantities:

- N_a - Number of neutrons reaching the detector with material “ɑ” in the active volume.
- B_a - Expected background counts with “ɑ”.
- Q_a - Time integrated beam current from the beam monitor with “ɑ”.

The transmission is then computed as:

$$T(E)=\frac{N_{\mathrm{LAr}}-B_{\mathrm{LAr}}}{N_{\mathrm{vac}}-B_{\mathrm{vac}}}\frac{Q_{\mathrm{vac}}}{Q_{\mathrm{LAr}}}$$



Backgrounds

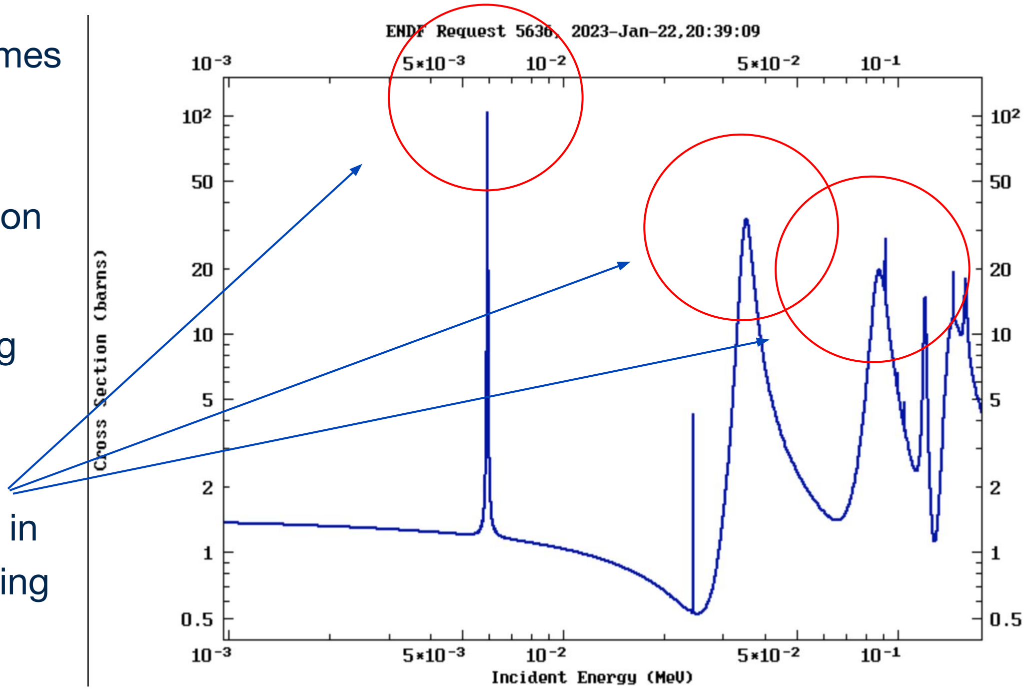
There were two major backgrounds in ARTIE-I:

- Scattered neutrons from earlier times than the ROI which arrived at the detector later.
- Gammas produced from capture on water in the moderator.

These backgrounds are measured using the ***black notch*** or ***black resonance*** method[3].

By placing filters with large resonances in the ROI, we can block almost all incoming neutrons.

Aluminum neutron cross section in the ROI, with black resonances at **5.9**, **35** and **88** keV



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[3] *Neutron transmission measurements and resonance analysis of molybdenum-96*, J.M. Brown et. al., AccApp, 2017..

Black Resonance

For a given active volume material “α”, we perform a measurement with and without a filter present.

$$T^f(E) = \frac{N_\alpha^f - B_\alpha^f}{N_\alpha - B_\alpha}$$

The *effective transmission* and hence the *background rate* at the black resonance energies can be determined via:

$$B_\alpha = \frac{N_\alpha^f - N_\alpha T^f}{1 - T^f}$$

The background rate can then be interpolated for all energies in the ROI from the black resonance values.

3 *Neutron transmission measurements and resonance analysis of molybdenum-96,*
J.M. Brown et. al., AccApp, 2017..

ARTIE-I (tof)

The ARTIE-I experiment was conducted at the **LANSCE** (*Los Alamos Neutron Science Center*) facility at Los Alamos National Lab[3] in flight path 13 (FP13).

- We know the flight path length, so then time-of-flight (TOF) determines the energy.

$$\Delta t = t_n - t_0$$

Detection time

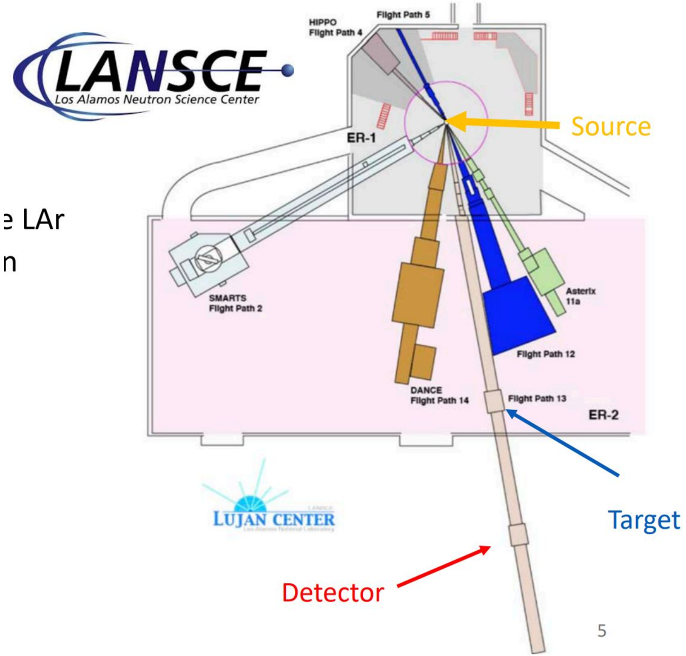
Time from beam trigger

$$t_{\mathrm{tof}} = \Delta t + f_{\mathrm{mod}}(\Delta t) + f_{\mathrm{fit}}$$

Fluctuations from the water moderator

$$E = mc^2 \left[\frac{1}{\sqrt{1 - \frac{L_{\mathrm{fit}}^2}{t_{\mathrm{tof}}^2 c^2}}} - 1 \right]$$

Flight path length fit from data



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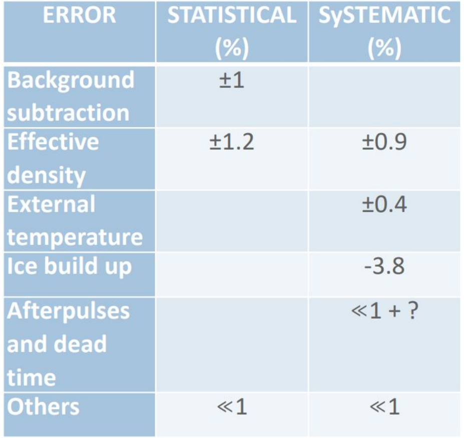
Pitfalls for ARTIE-I

- **Thermal insulation** - since there only existed a foam insulation layer around the target, the boil off rate was quite large (~ 1L / hr).
    - This required **constant refilling**, which sometimes led to spilling and ice formation on the target.
    - This also caused air bubbles to form in the target, disrupting its uniformity in density.

- **External temperature effects** - another systematic came from fluctuations in the beam monitor, which seemed to be correlated with changes in temperature.



ERROR	STATISTICAL (%)	SySTEMATIC (%)
Background subtraction	±1	
Effective density	±1.2	±0.9
External temperature		±0.4
Ice build up		-3.8
Afterpulses and dead time		≪1 + ?
Others	≪1	≪1

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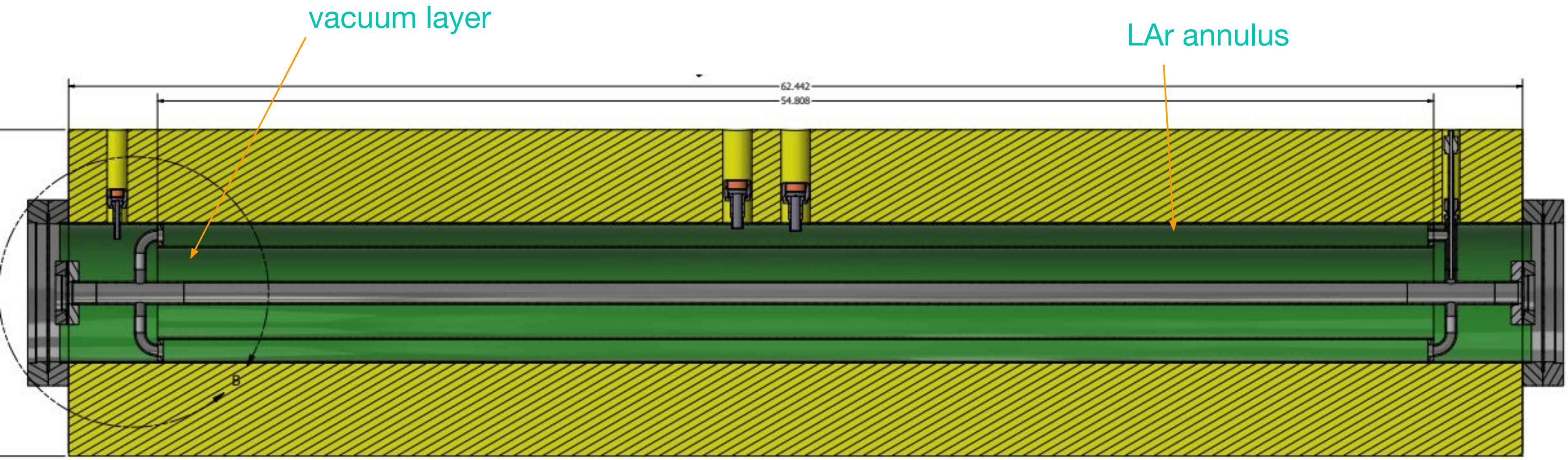
ARTIE-II Improvements

- **Thermal insulation** - a new target design will incorporate a vacuum insulation layer, as well as an outer LAr annulus to reduce the heat load to the central target.

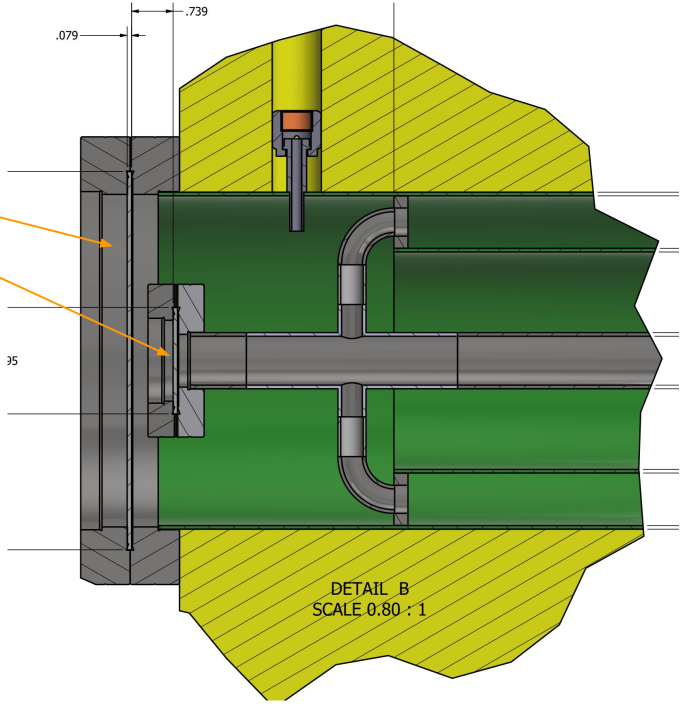


ARTIE-II Improvements

- **Aluminum windows** - replacing the mylar windows from ARTIE-I with an inner and outer window (with a vacuum in-between) will help to reduce ice buildup.

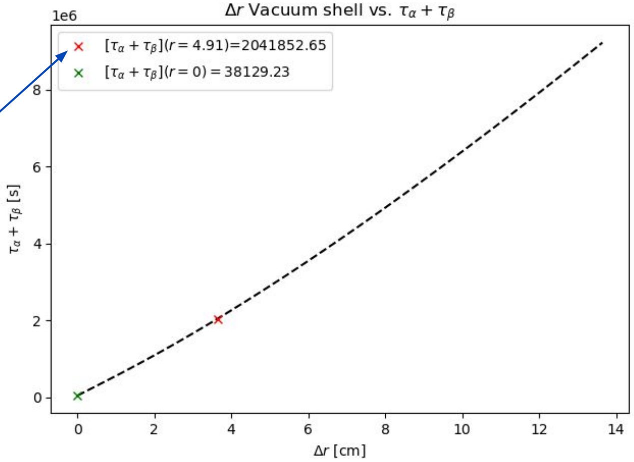
aluminum windows

- Simulations and back-of-the-envelope calculations of thermal loads for this design show an order of magnitude improvement in reducing the boil-off-rate.



Boil off rate (τ_{α}) as a function of the vacuum thickness (Δr).

At the design value (r=4.91cm), the rate is ~27mL/hr.



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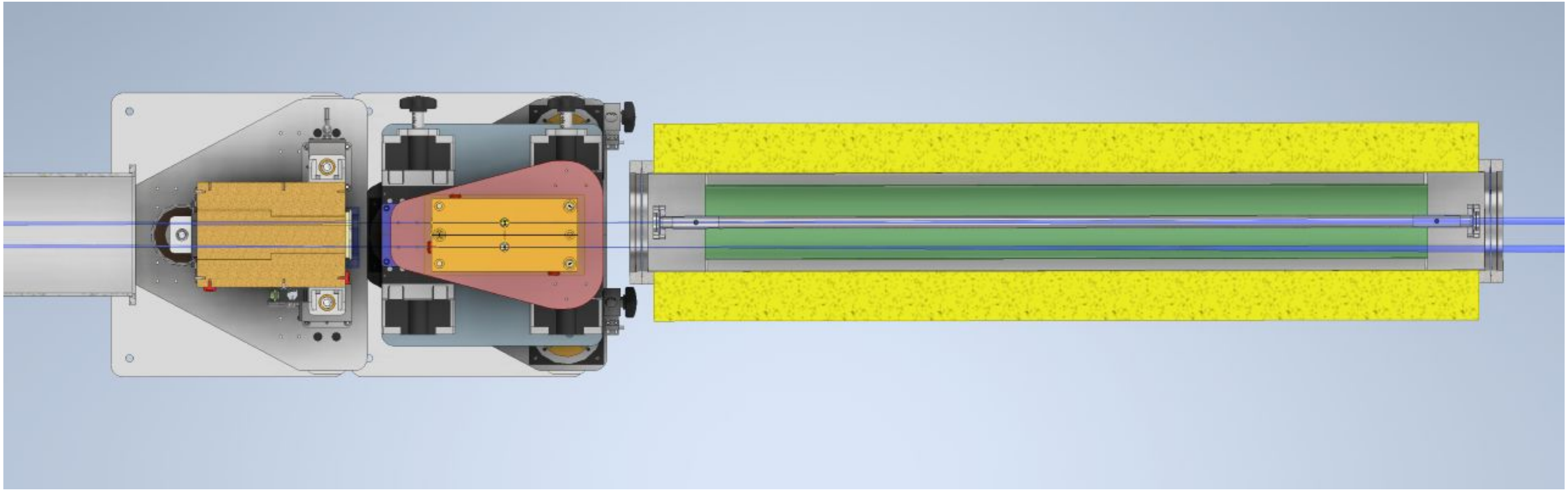
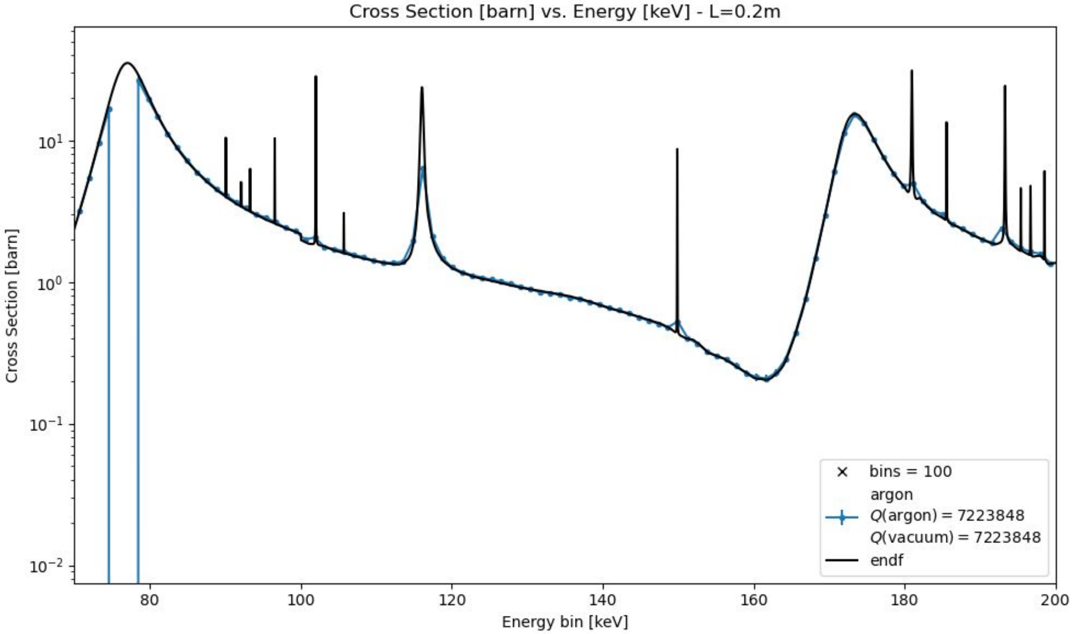
ARTIE-II Improvements

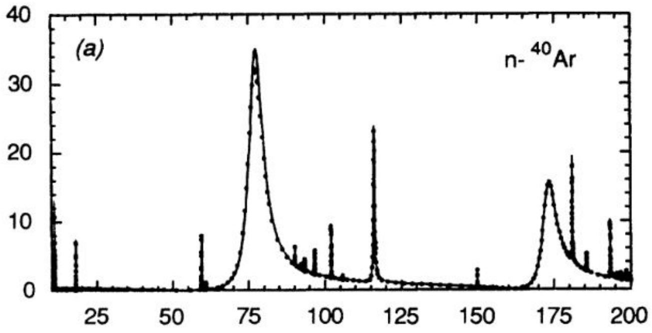
- **DICER binocular setup -** The binocular setup at DICER allows simultaneous target-in/target-out, which reduces the needed beam time and helps with various systematics.



ARTIE-II Improvements

- **Additional short target** - we will also modify the target to decrease the active volume to ~ 20cm, allowing us to be sensitive to higher energies and directly compare with Winters result in the 70-200 keV range.





Simulations of the 20cm target using the ***ArtieSim*** code (https://github.com/ARTIE-II/ArtieSim)