Neutrons for Characterizing Dark Matter Detectors

WNPPC 2021

Thursday February 11th

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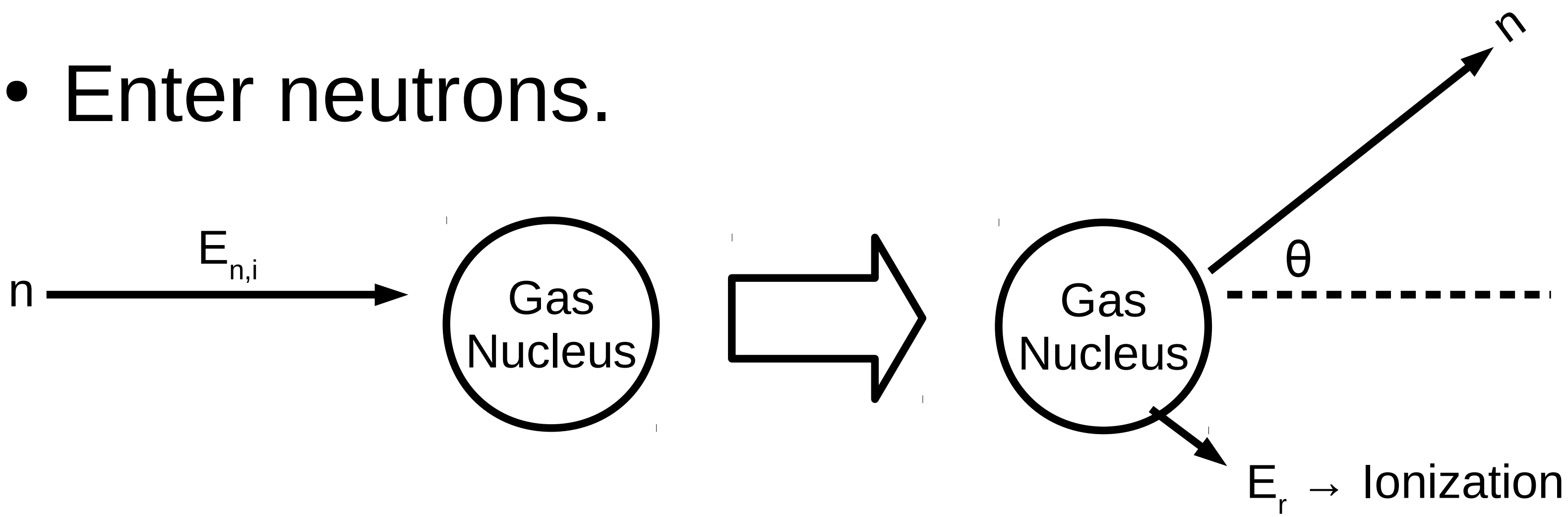
Calibrating

- We need a mapping between detector amplitude and energy deposited by a dark matter particle.
- Convenient sources interact with the electrons around atoms (laser, X-rays, α, β, cosmic μ).
- Dark matter sought by NEWS-G will interact with the nucleus!
  - The nucleus ionizes the gas, releasing electrons.
  - We only “see” the effect on the electrons.
- The fraction of energy given by a nucleus to its electrons is called the ***quenching factor*** (QF).
- Note: radioactive neutron sources are ~MeV and thus unsuitable for the ~keV recoils relevant to NEWS-G

Measuring Quenching Factors

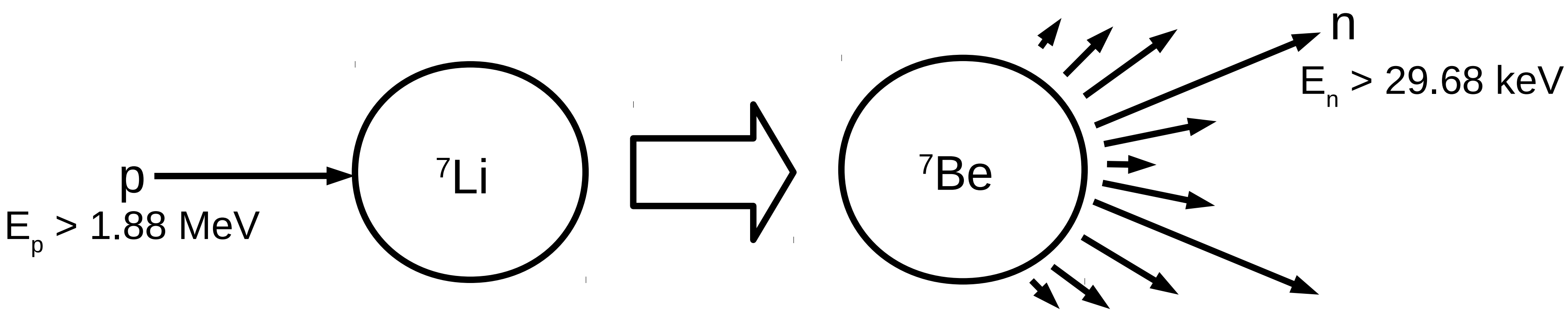
- If we can hit a nucleus with a few known energies, we can determine the quenching factor/function and use our convenient calibration sources.
- Enter neutrons.



- E_r is a function of $E_{n,i}$ and θ only!
- What remains is to make a beam of quasi-monoenergetic neutrons with a suitable energy.

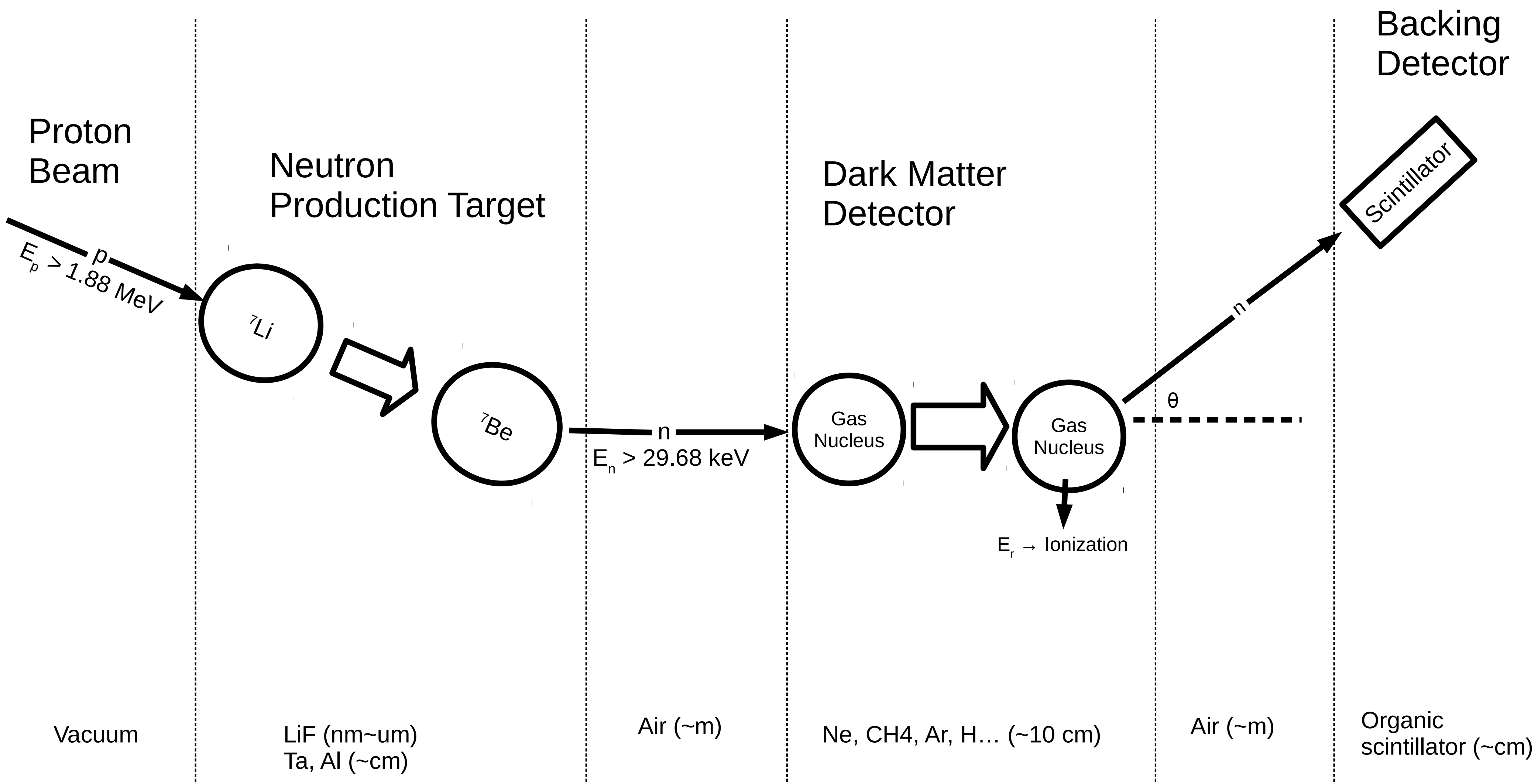
Quenching factors are actually energy-dependent functions, and different for each material.

How to Make Neutrons



- In nuclear lingo this is ${}^{7}Li(p,n){}^{7}Be$.
- Li metal is very reactive, so LiF is used for stability.
- LiF is hygroscopic (and toxic), but manageable.
- At a specific neutron production angle, the neutrons are monoenergetic → detector angle selects for energy.

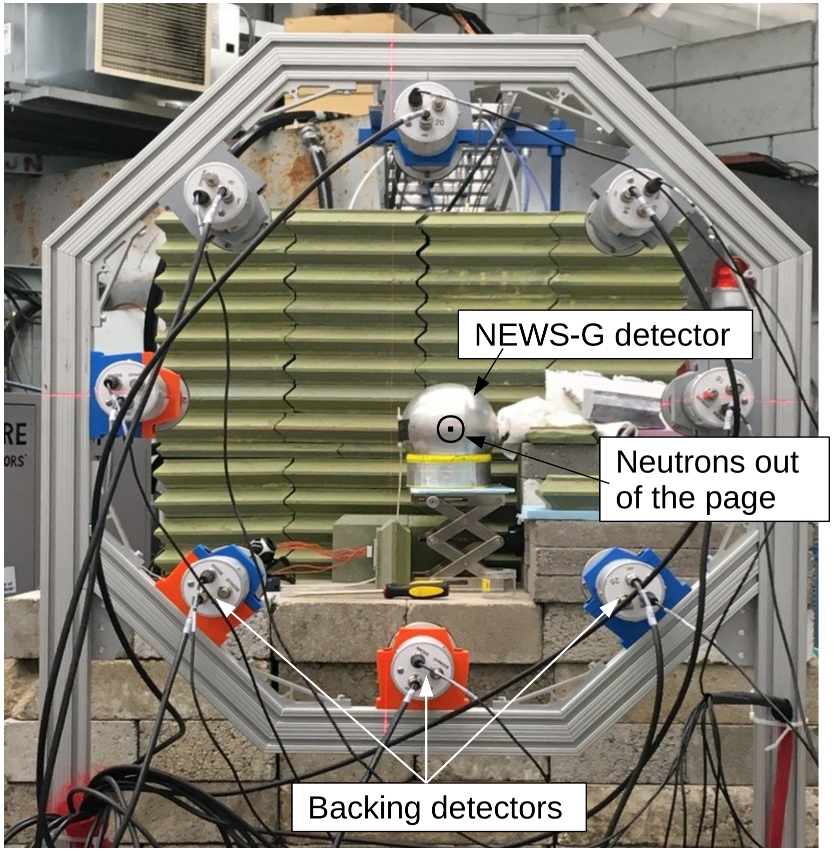
Measuring Quenching Factors 2



Crappy art credit: me

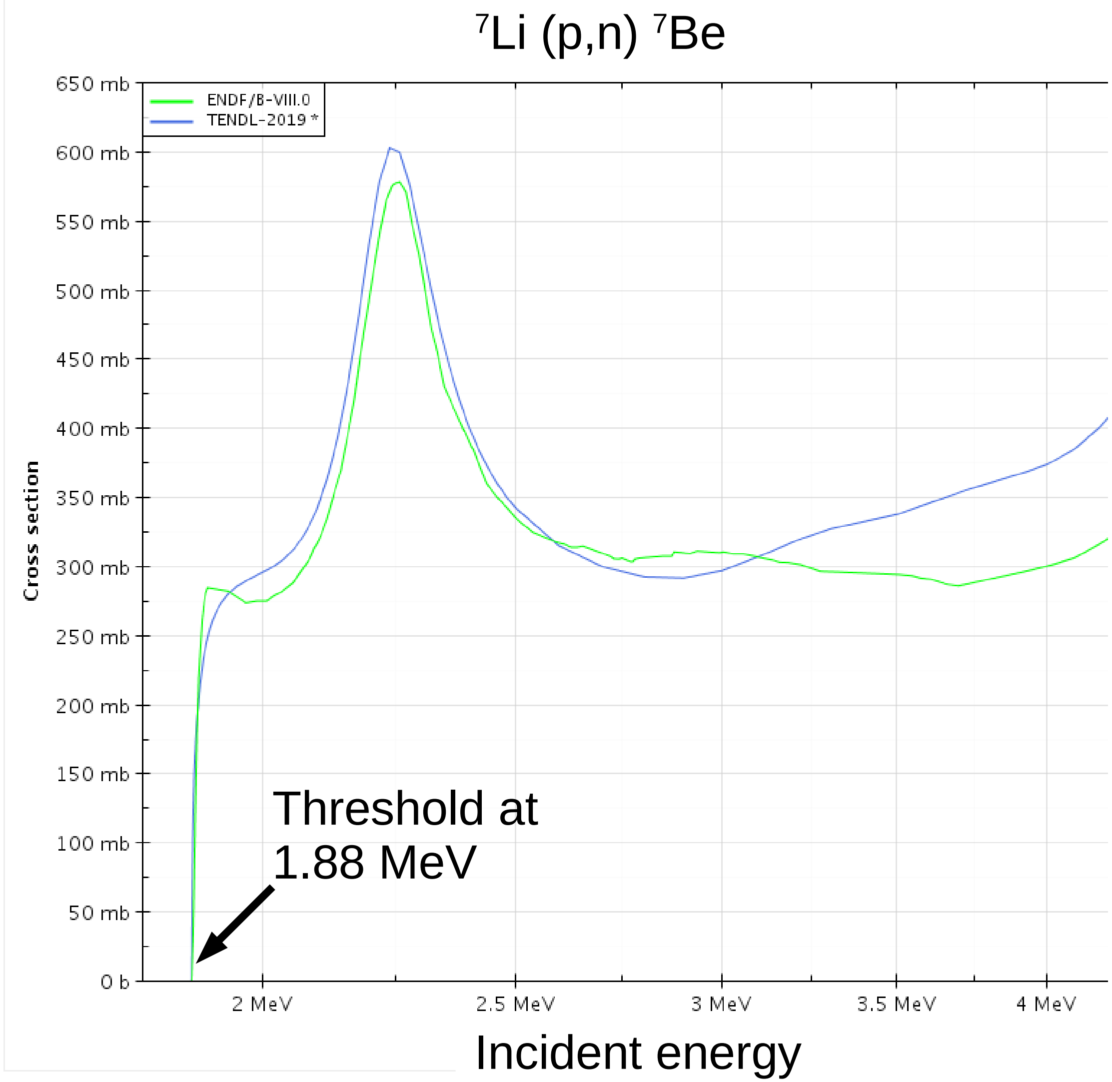
Prior/Ongoing Work

- QF experiments were done at the Triangle Universities Nuclear Laboratory (TUNL) in North Carolina.
- QF were measured in neon with a 545 keV neutron beam.
- Nuclear recoil energies selected by moving the backing detector to select neutron recoil angle θ.
- Paper by Marie Vidal *et al* in preparation.



Lower Recoil Energies

- Lower energy neutrons (~30 keV) are desired to reach even-lower nuclear recoil energies.
- LiF neutron production drops dramatically as you approach the threshold.
- High beam current can compensate, but TUNL maxes out at 400 nA.



From JANIS (https://www.oecd-nea.org/janisweb/) reaction MT4 on Li7.

Moving to Kingston, ON

- In Kingston we have the Reactor Materials Testing Laboratory (RMTL) in the Queen’s University Mechanical and Materials Engineering Department.
- RMTL’s maximum proton current is 45 µA (112.5x higher than TUNL), allowing us to push closer to the threshold while maintaining a usable neutron flux.
- Being internal users in the same city, we have much easier access to the beam.
- Caveat: as a nuclear irradiation facility, RMTL lacks some instrumentation taken for-granted at a particle physics lab - notably the proton beam spectrum.

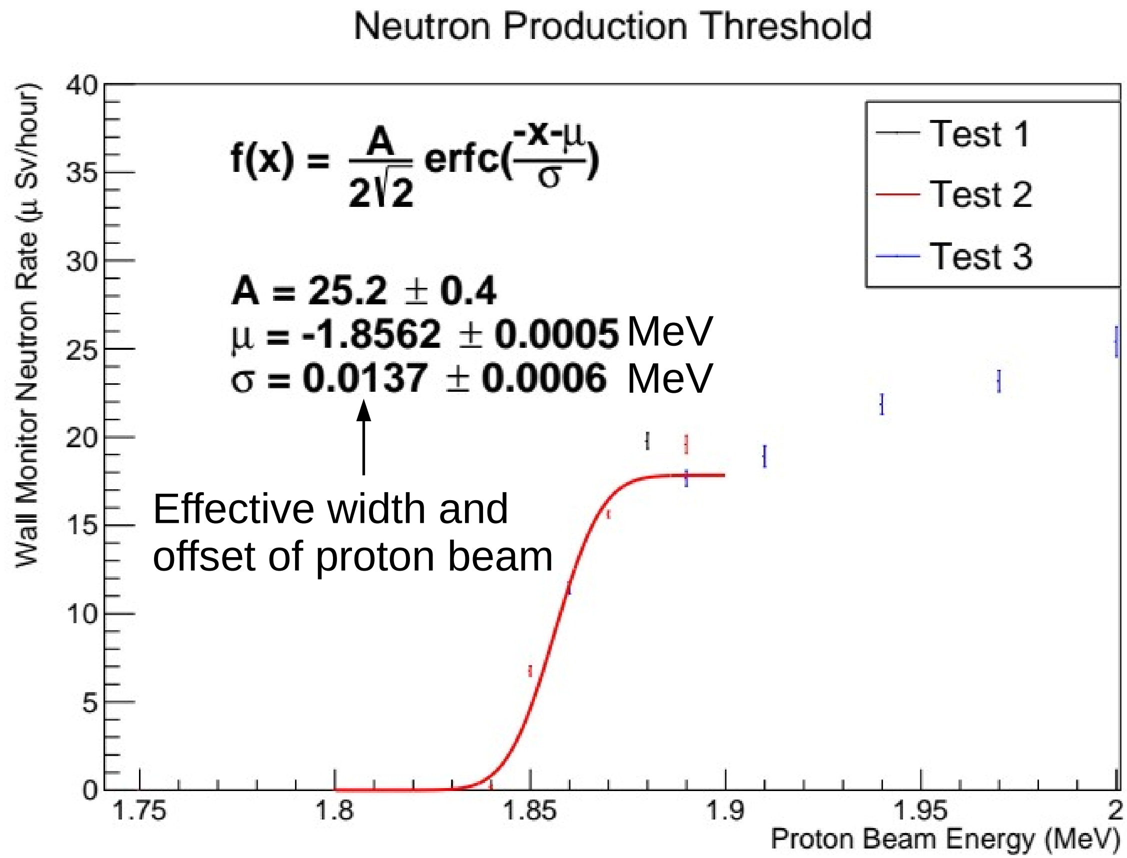
2019 Results

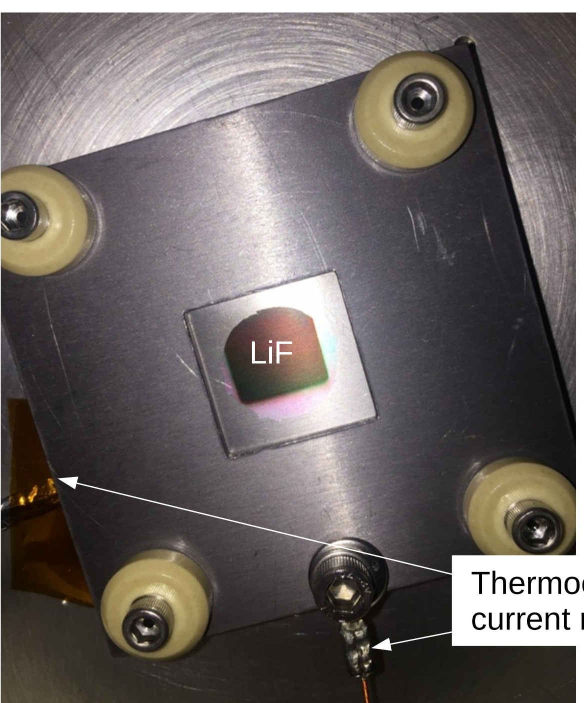
Lessons: need to reduce smearing from:

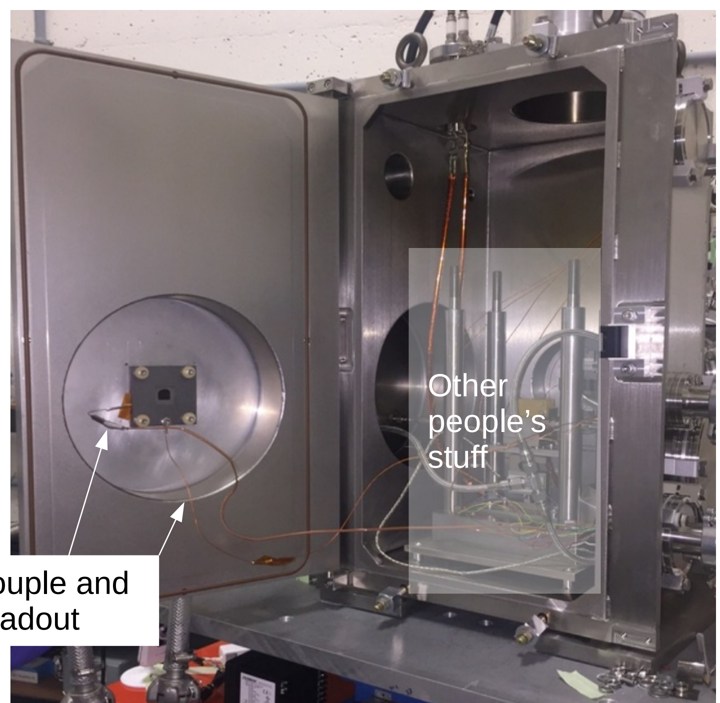
- LiF target itself (~1 um)
- cooling system (~cm H_2O, Al)
- detection of reflected neutrons

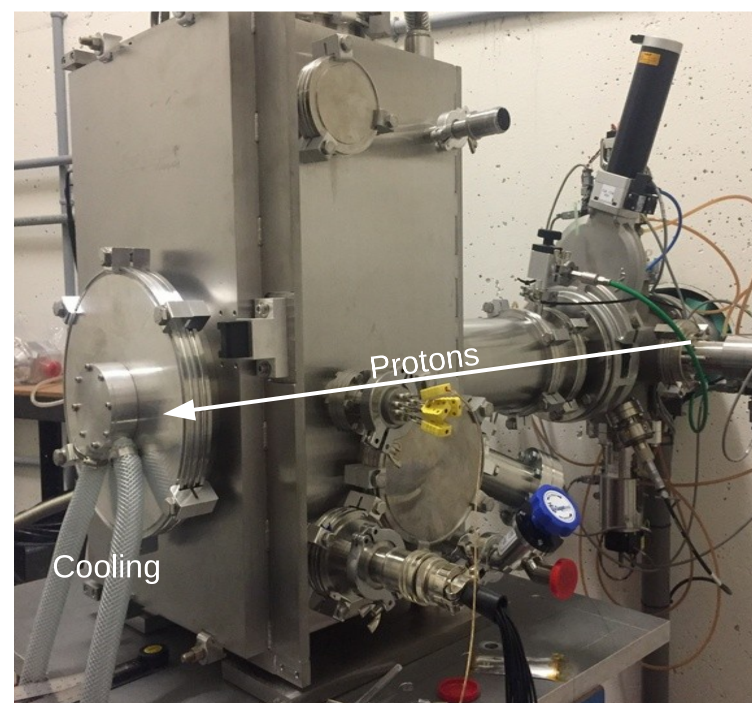
Inconclusive results with:

- angular distribution of neutrons
- neutron spectrum

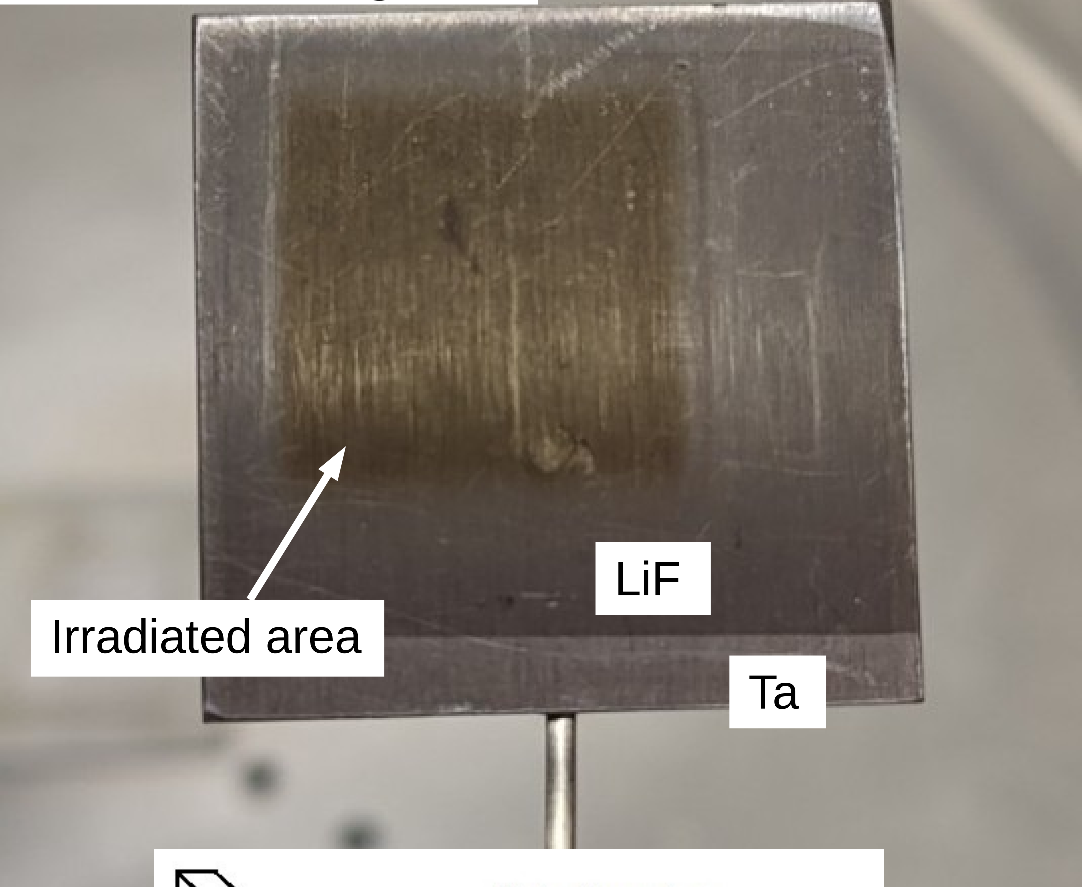


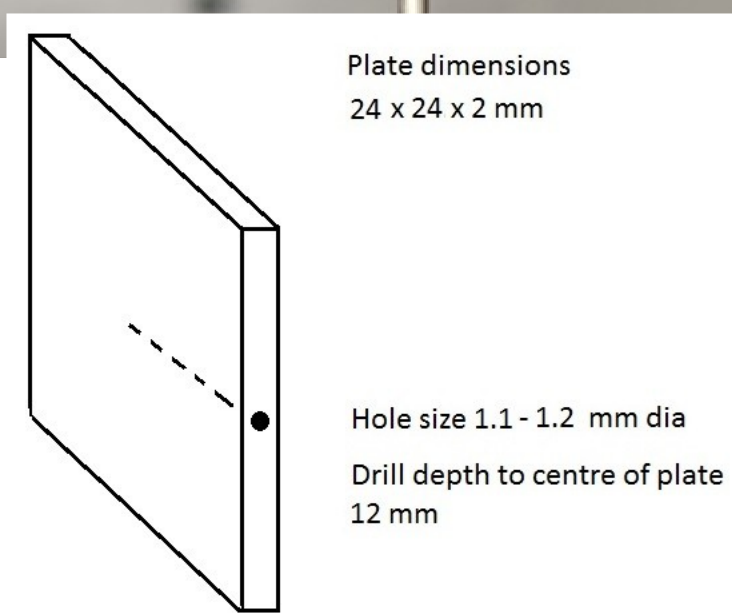






New Targets





Three new targets were made by Université de Montréal.

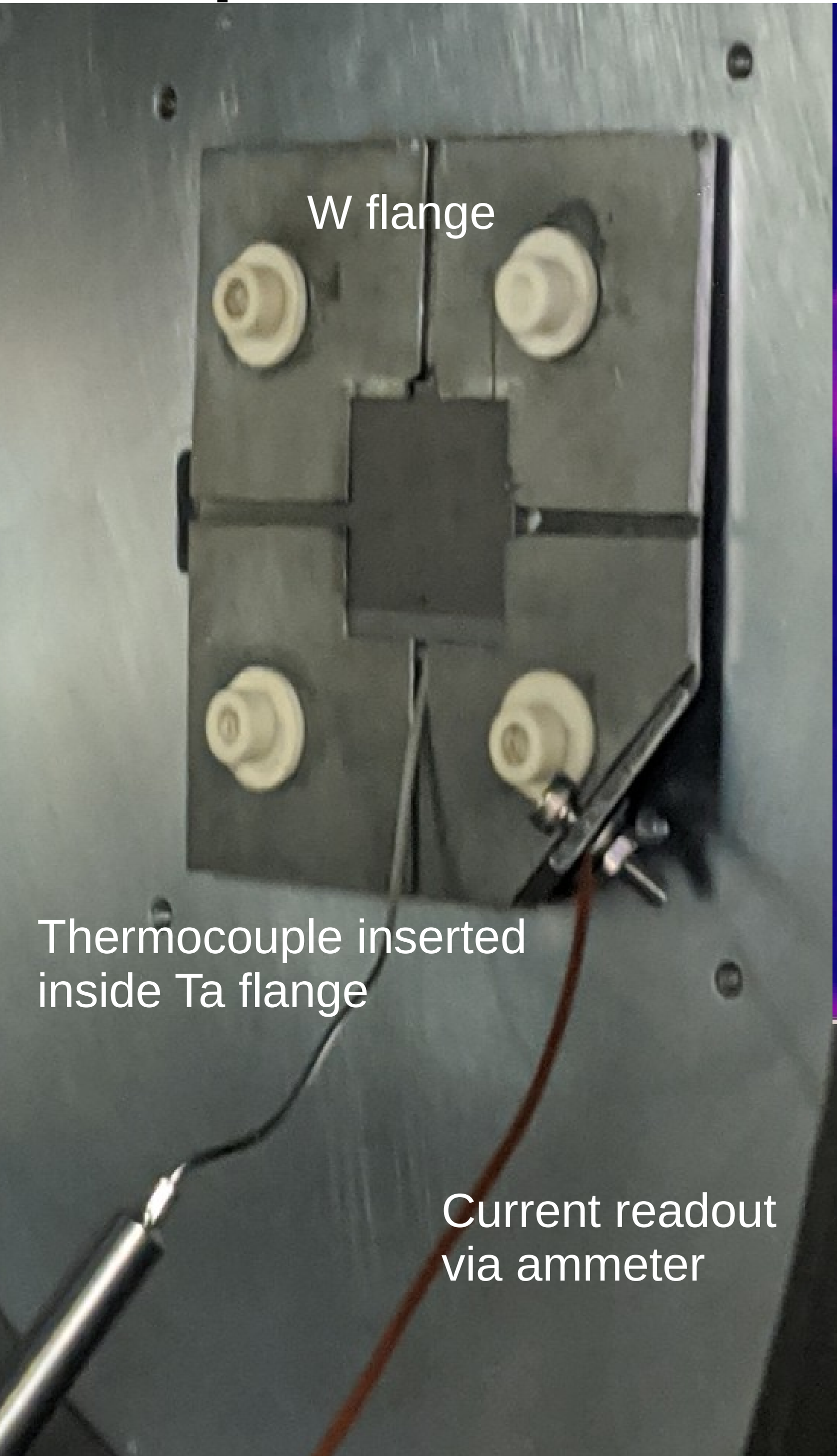
The new targets have a hole for **direct thermocouple measurement**.

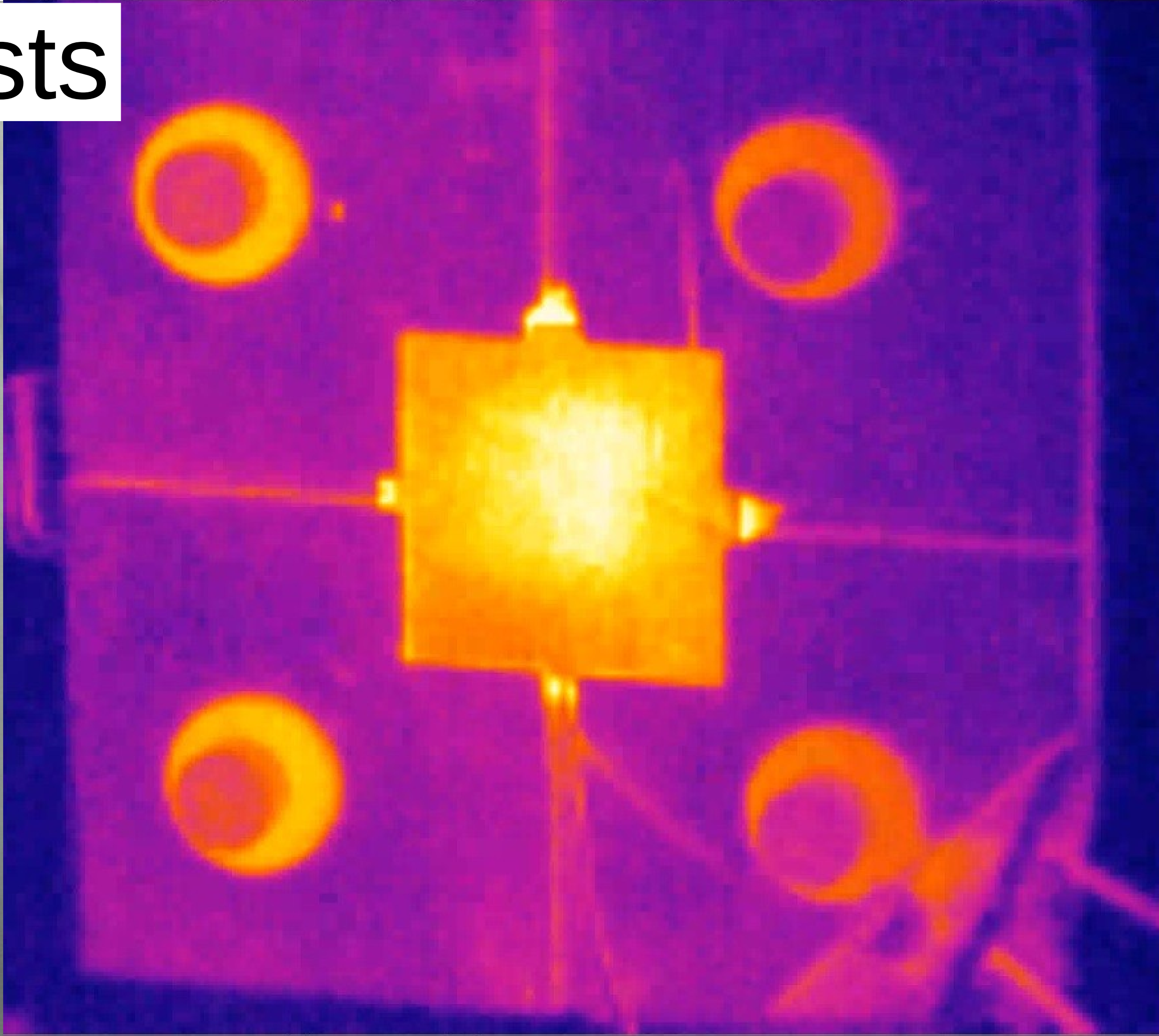
Thinner LiF means less proton energy smearing.

- LiF-A: 250 nm 10 keV
- LiF-B: 120 nm 5 keV
- LiF-C: 38 nm 1.5 keV
- Old target: ~1um 30 keV

Note: no independent verification of thickness & smoothness.

Temperature Tests





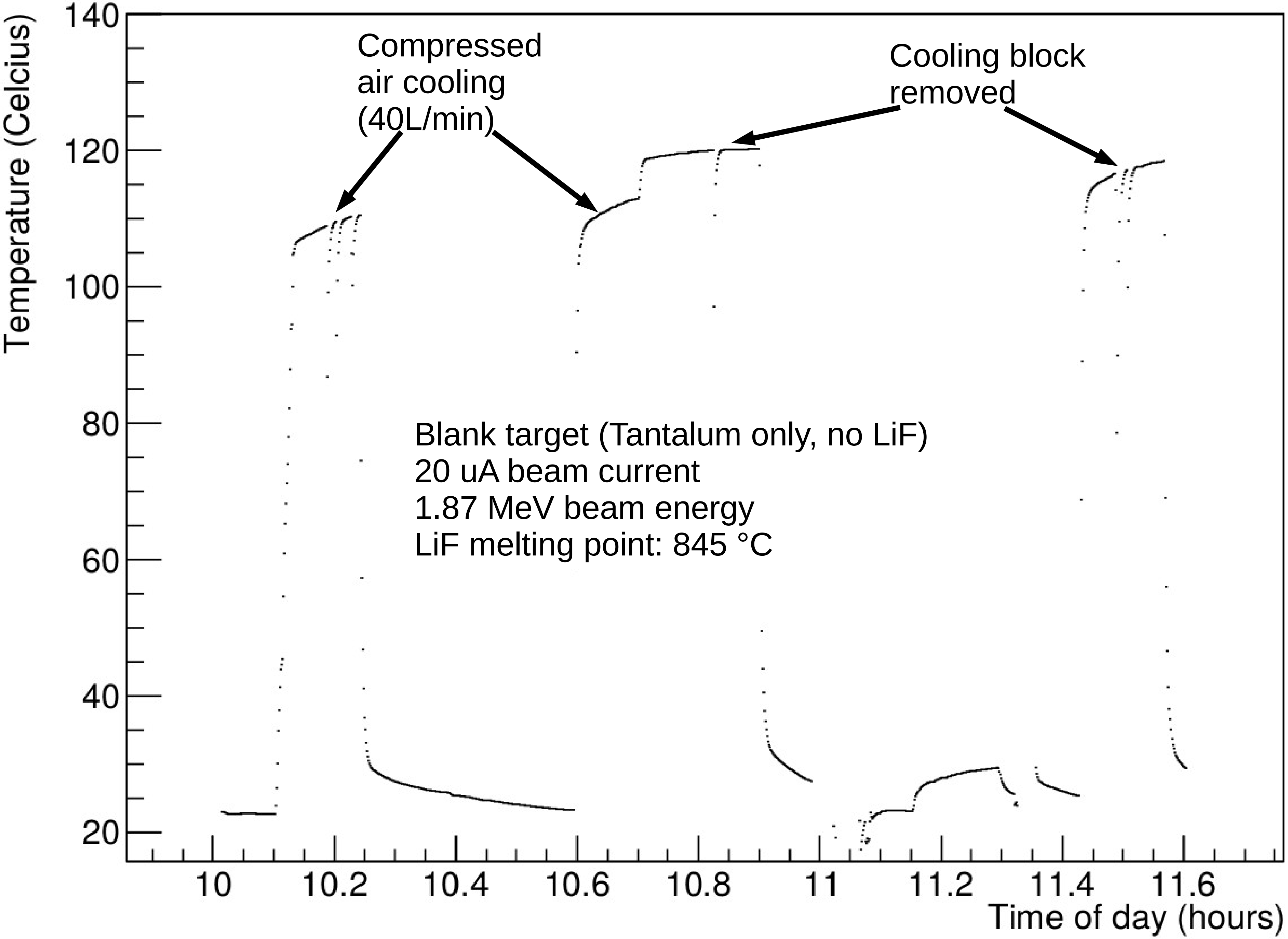
LiF is deposited on a Ta backing plate.

Ta backing plate is held down by W flange.

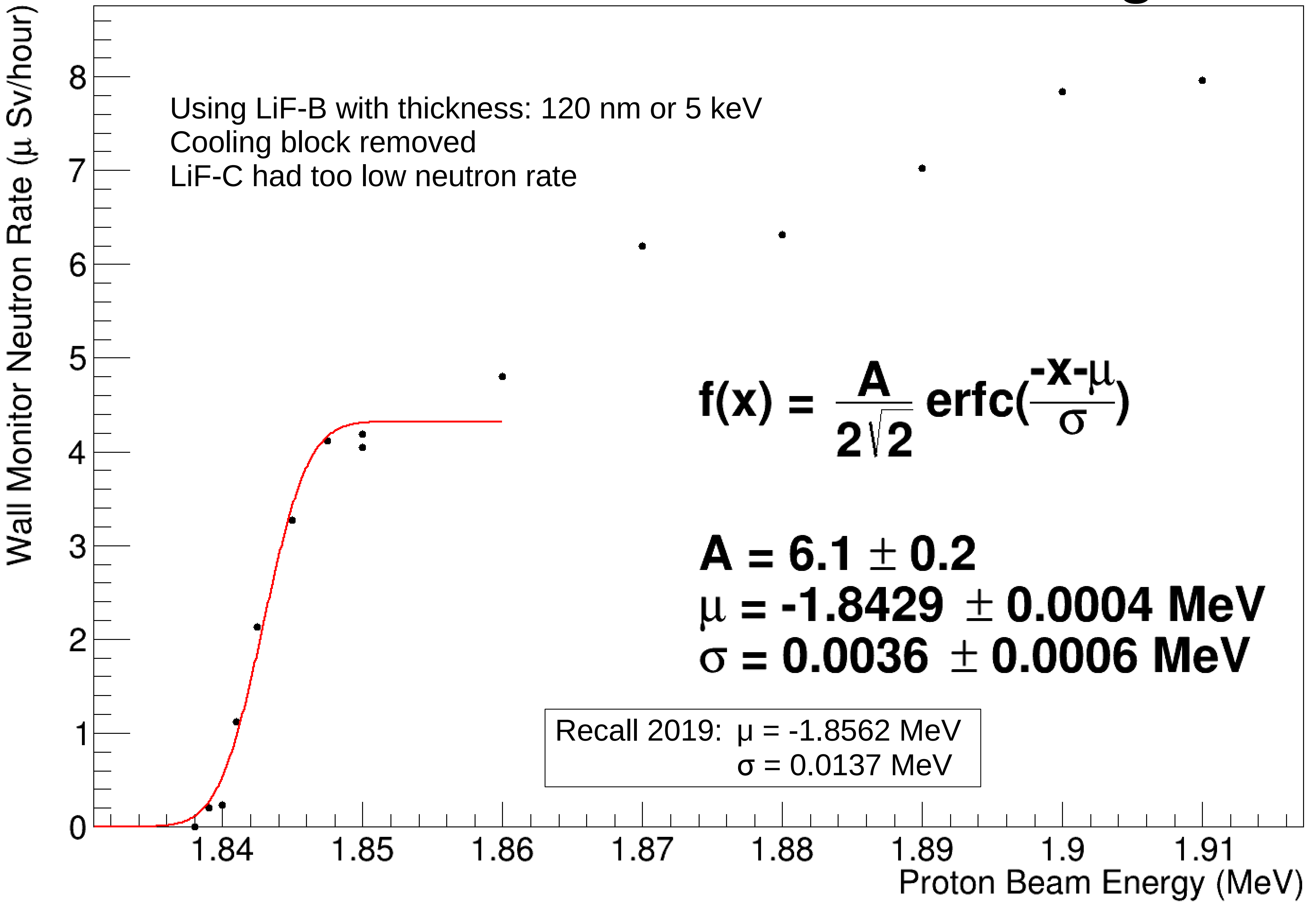
Ta and flange are electrically isolated from vacuum chamber by ceramic spacer and by using ceramic bolts.

Thermal compound is applied on both sides of ceramic spacer.

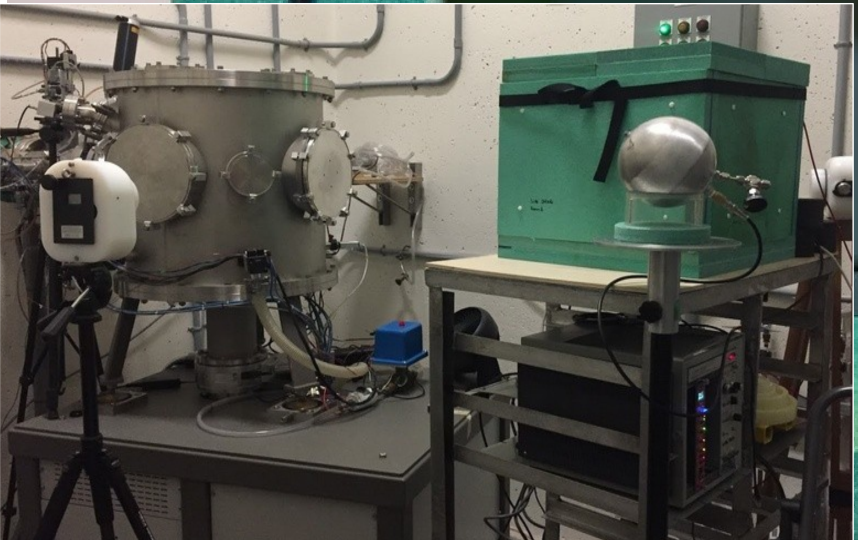
Target Temperature



Neutron Production with New Targets



New Shielding

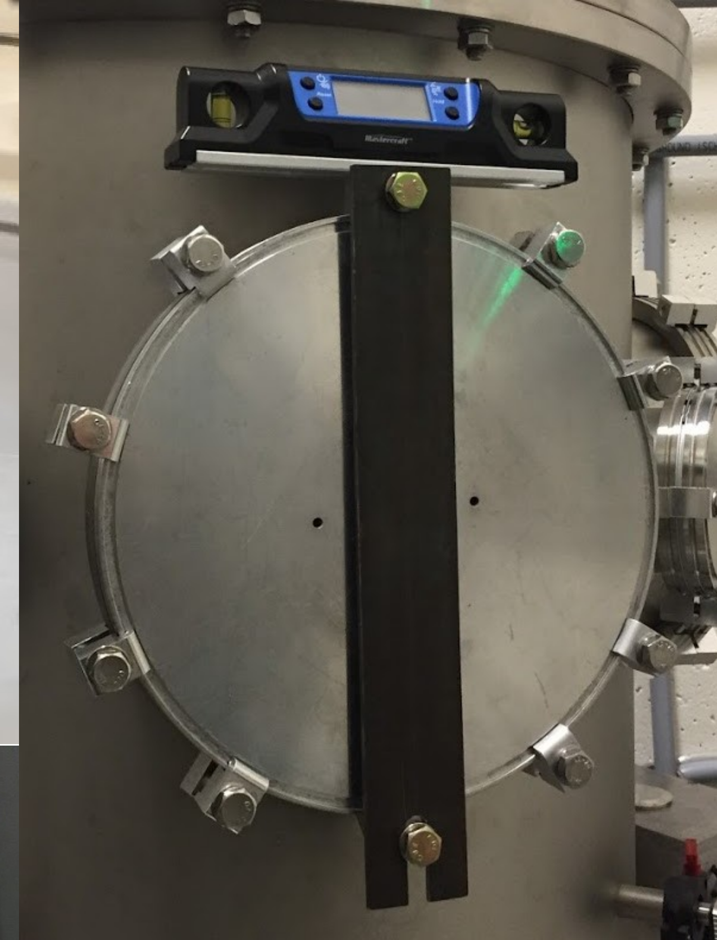


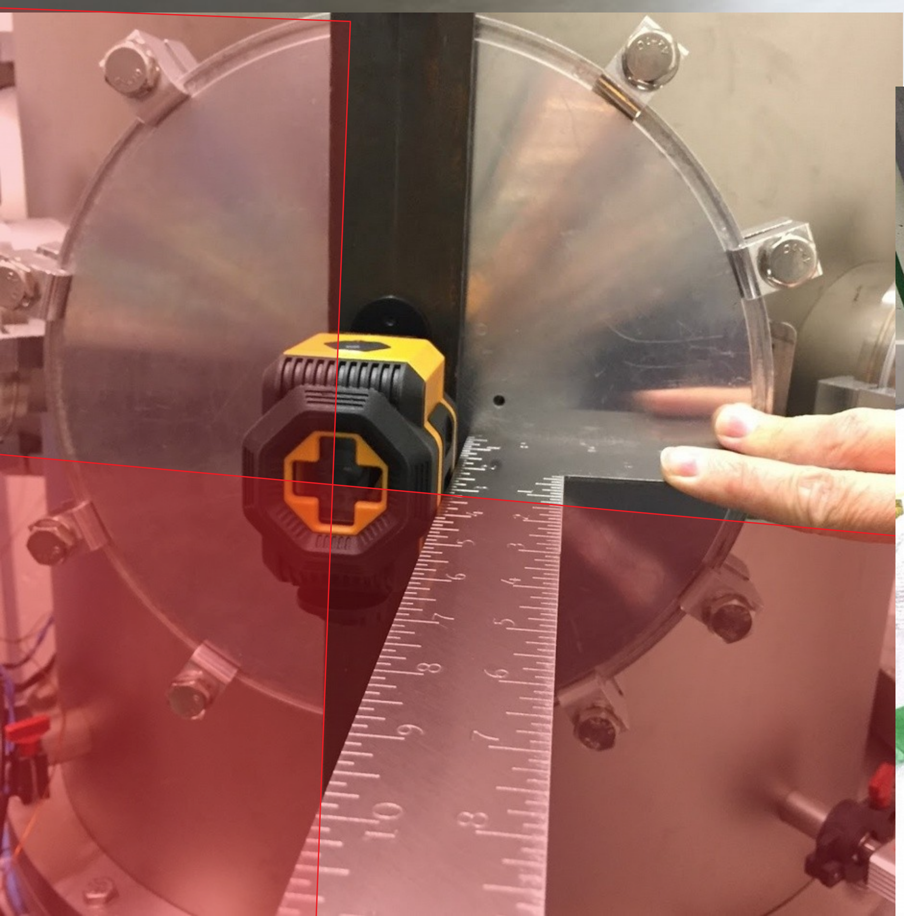
Pb:
- 1/2” thick cylinder
- 12” tall, 12” outer diameter
- 61 kg
- made by Alchemy Extrusions

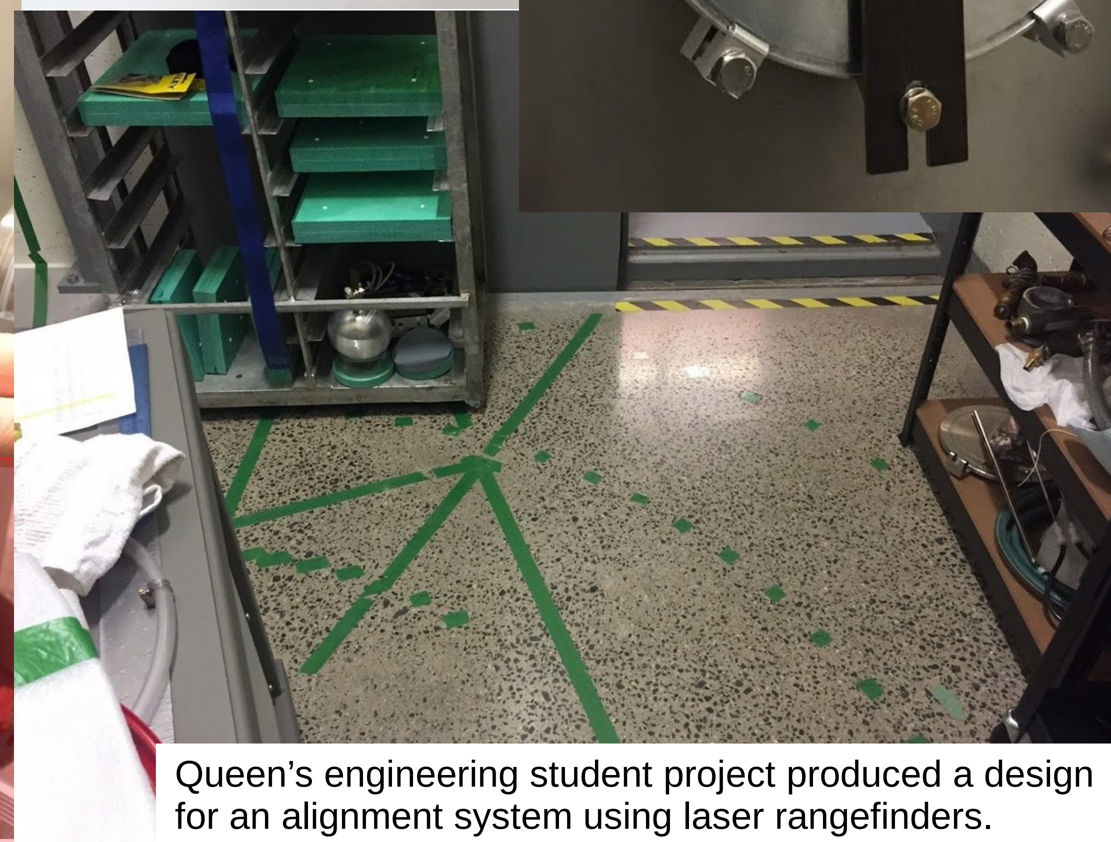
Borated polyethylene:
- 2” thick box
- 89 kg
- made from leftover scraps
- made by myself in the machine shop

- sized for neutron spectrometer or 15cm NEWS-G sphere
- 1 hole for SHV cable
- changeable windows
- customized cart from cafeteria

New Alignment



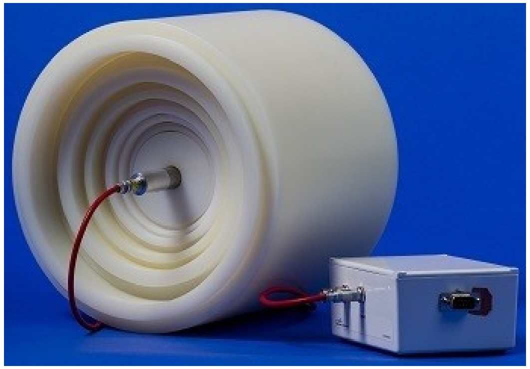




Queen’s engineering student project produced a design for an alignment system using laser rangefinders.

Things that didn't work

- Neutron spectrometer at ~30 keV
  - Output spectrum is parametrized by energy regions, and 30 keV is right at a boundary.
  - The effect of the shielding was inconclusive.



- Angular distribution measurements
  - Portable detectors found to be faulty, sent back for refurbishment.

- NEWS-G sphere data in beam
  - "Home-made" detector has poor gain homogeneity.
  - No calibration source at RMTL.
  - Gas inside was likely contaminated.

Conclusions Summary

- We can run with only passive cooling!
- LiF-B (120nm) produces a decent neutron rate.
- Much improved detector positioning & alignment.
- Narrower threshold “turn-on” curve than 2019, but also different offset.

Next Steps

- Produce 545 keV neutrons like at TUNL.
  - Neutron spectrometer should work better.
  - Angular measurement with portable detectors.
  - Get clean signals in NEWS-G sphere.
- Commission backing detector with faster DAQ.
- Neutron scattering experiments!
- Reduce neutron energy towards 30 keV goal.

End

Kinematics

Knowing the incident neutron energy and the scattering angle, the nuclear recoil energy deposited in the gas can be determined:

$$E_{nr}(\theta_s, E_n) = 2E_n \frac{M_n^2}{(M_n + M_T)^2} \times \left(\frac{M_T}{M_n} + \sin^2\theta_s - \cos\theta_s \sqrt{\left(\frac{M_T}{M_n}\right)^2 - \sin^2\theta_s} \right), \quad (2)$$

where θ_s is the scattering angle of the neutron with respect to its initial trajectory, E_n is the incident neutron energy, M_n is the neutron mass and M_T is the target mass of the nucleus (in our case neon nucleus).