An Intermediate-Energy Neutron Beam for Calibrating Dark Matter Detectors

RMTL

CAP Virtual Congress 2020
Tuesday June 9th
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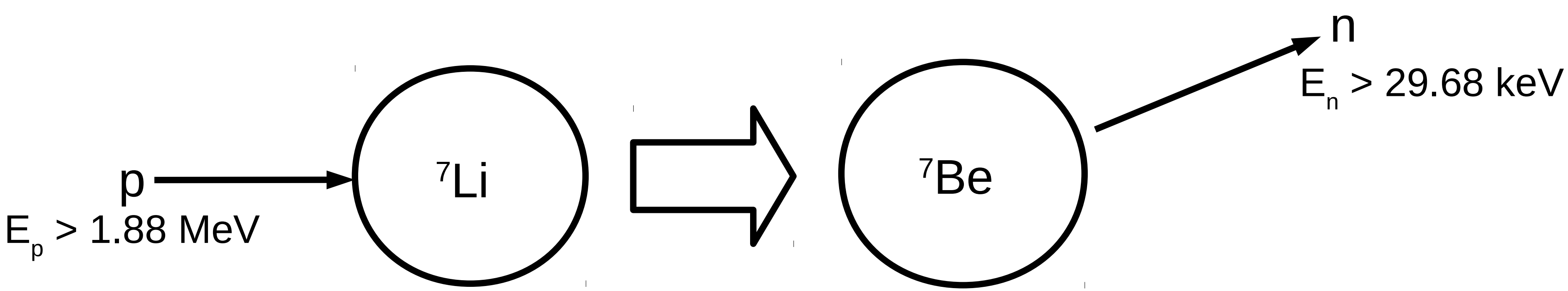
Background/Purpose

- NEWS-G is a dark matter experiment that detects ionization caused by dark matter particles colliding with atomic nuclei in gas.
- Dark matter particles are expected to be neutral.
- Neutrons are a good tool for calibrating the detector response (see Marie Vidal's talk from Monday).
- NEWS-G looks for lightweight dark matter, so intermediate-energy (~30 keV) neutrons are desired.

How to Make Neutrons



- In nuclear lingo this is $^7Li(p,n)^7Be$.
- Li metal is very reactive, so LiF is used for stability.
- LiF is still hygroscopic (and toxic).
- There are other useful reactions we could use.
- ^{7}Be is radioactive with an inconvenient 53-day half-life, but only 10% of decays actually radiate, and the quantity produced is small.

Why RMTL at Queen’s?

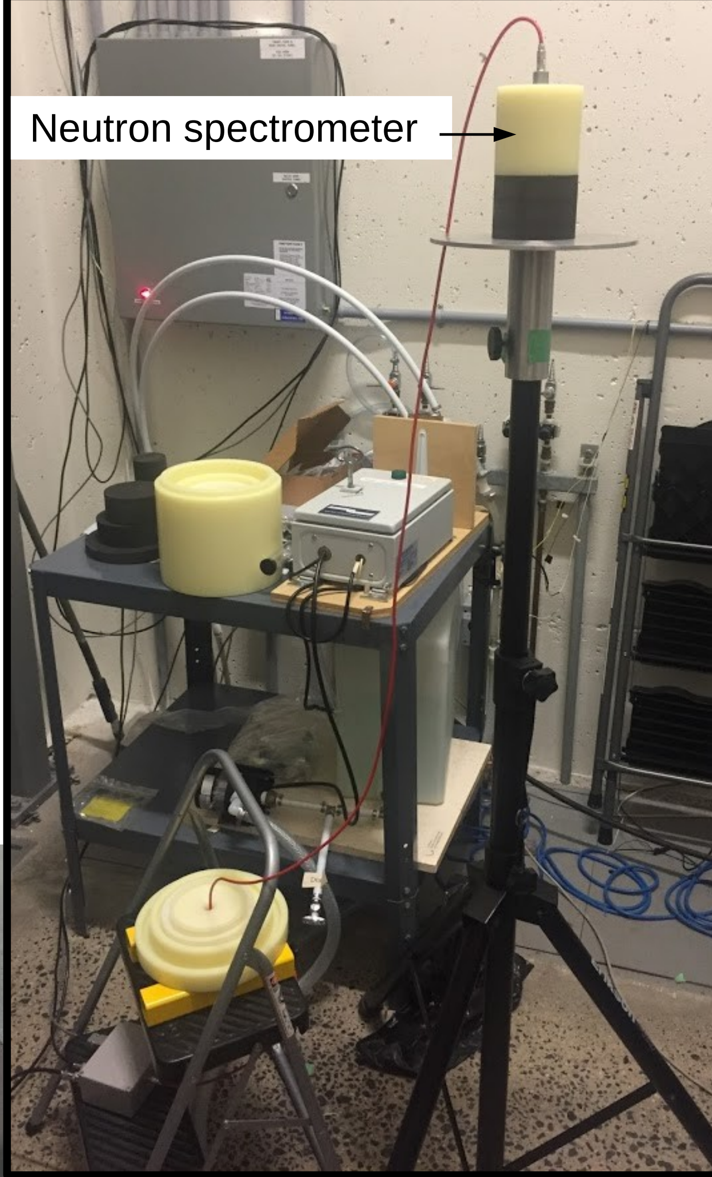
- The LiF technique is very inefficient as E_n approaches the minimum of 29.64 keV.
- Previously-used neutron beams at particle physics facilities do not have enough beam current to overcome the low efficiency.
- The Reactor Materials Testing Laboratory is an 8 MeV tandem accelerator in Kingston Ontario.
- As a nuclear irradiation facility, RMTL has enough current (45μA) to produce a usable neutron rate.
- Our goal is to produce a beam of quasi-monoenergetic neutrons at ~30 keV.

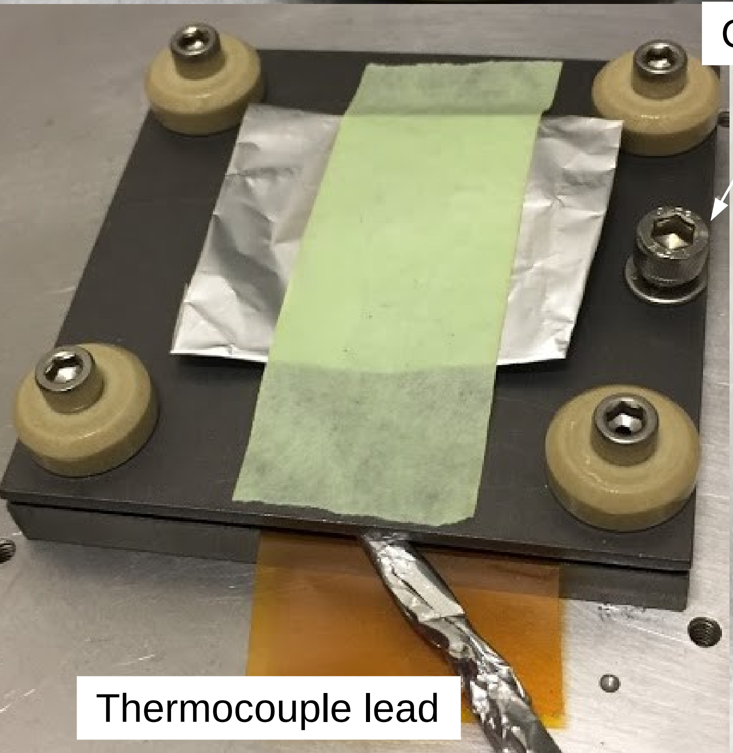
What have we accomplished?

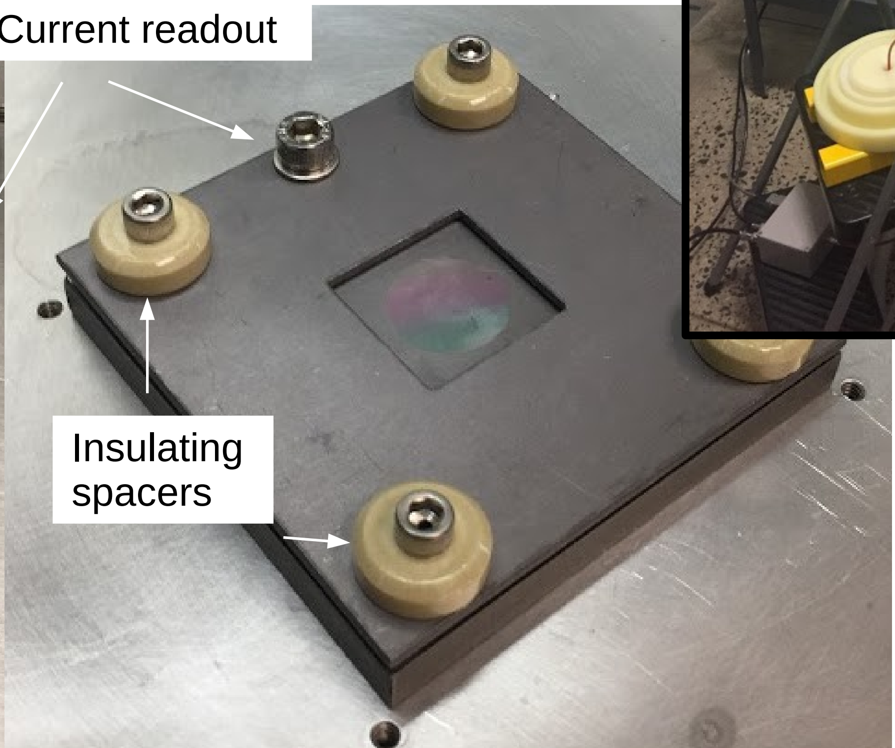
- We did 3 beam tests with a LiF target in 2019.
  - We measured the neutron production rate across the production threshold.
  - We obtained neutron spectra at two different beam energies.
- New LiF targets were made at Université de Montréal.
- We have a design for a multi-target holder.
- We have improved simulations of spectrum broadening by materials.

RMTL Irradiation Tests

Test 1

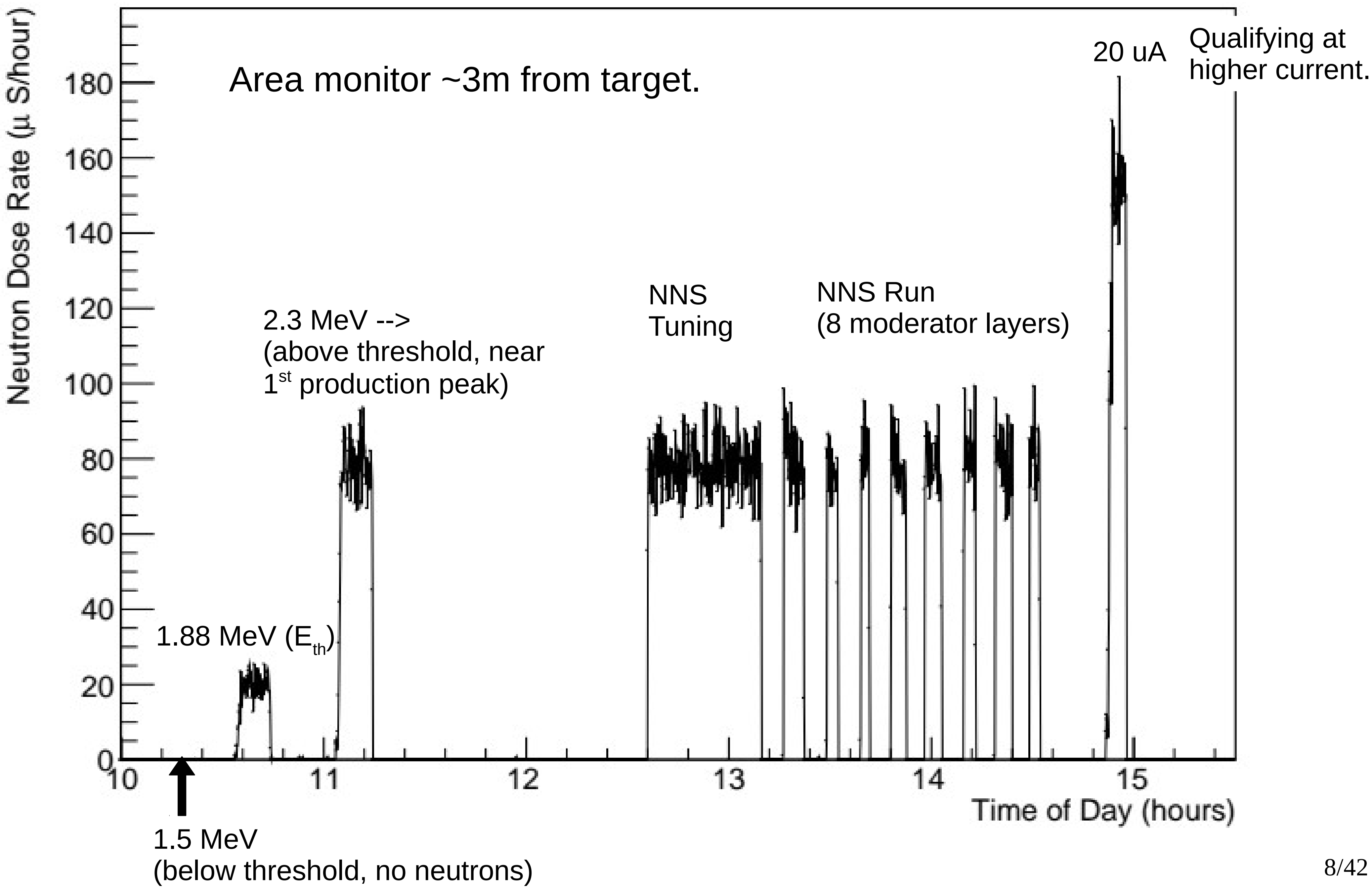






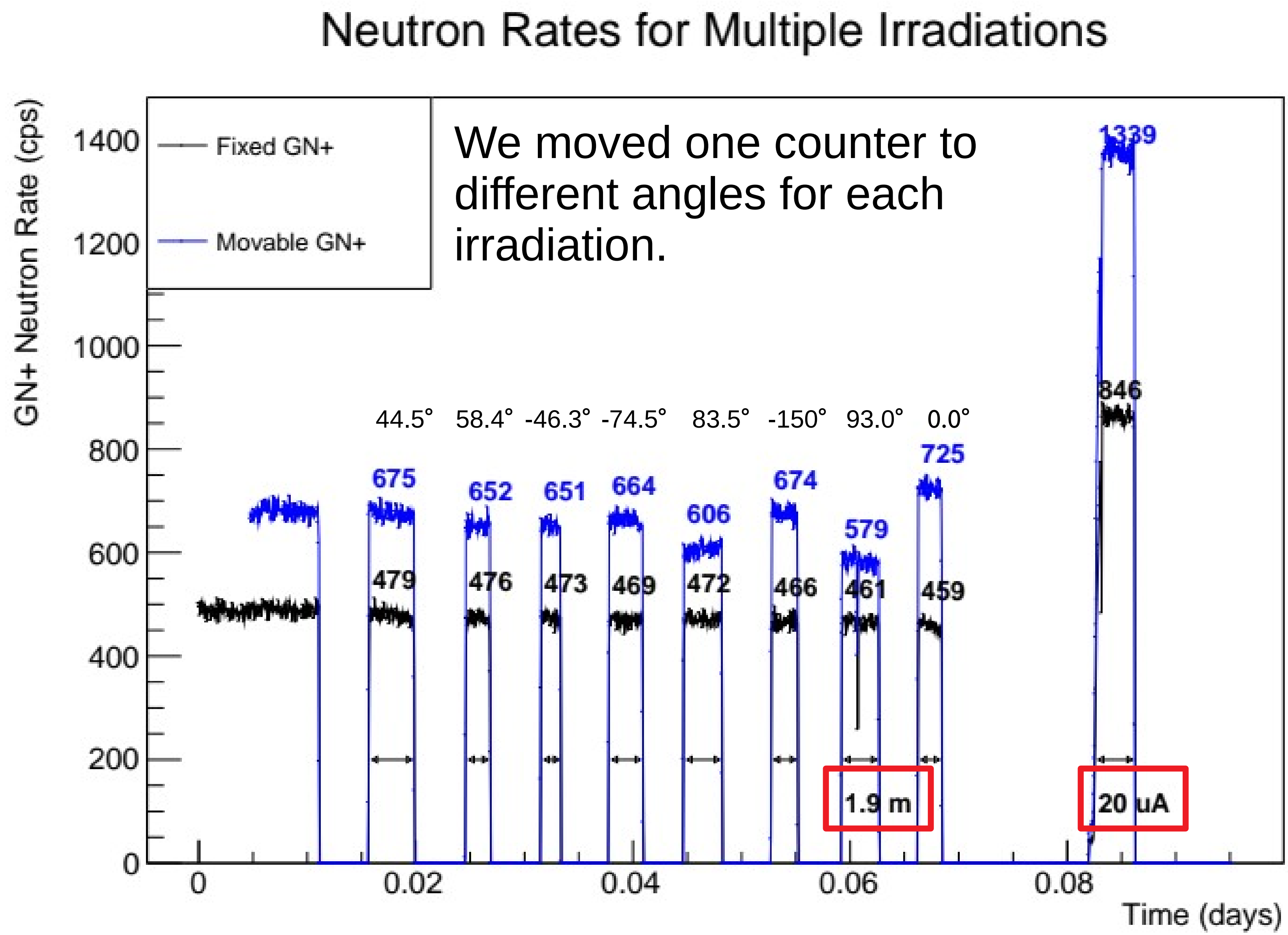
Photos from Test 1
Sept 12, 2019

Overview of First Test



GN+ CLYC[1] Count Rates

1: Handheld gamma and neutron detectors with pulse-shape discrimination.



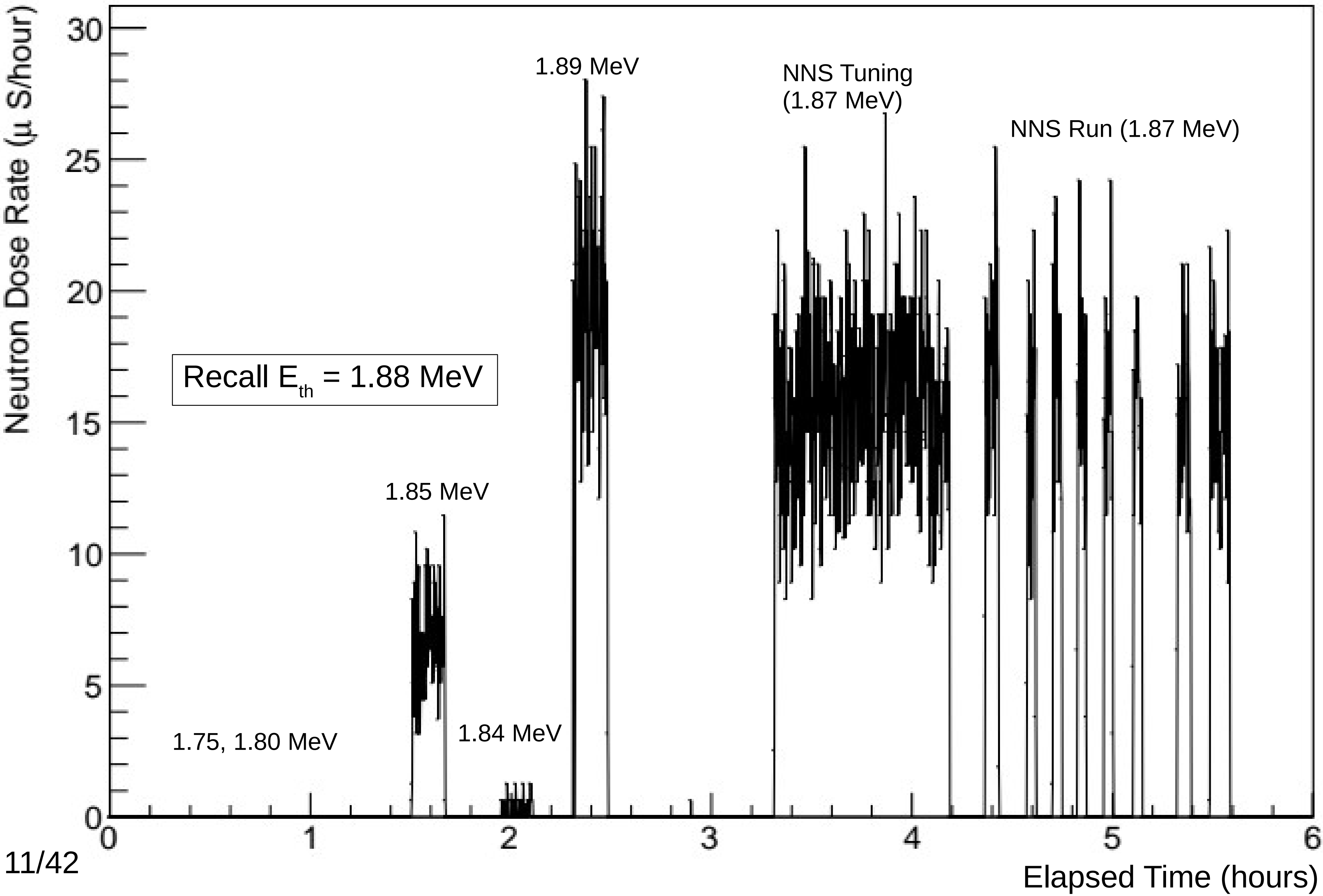
Lessons from Test 1

- LiF target is qualified for up to 20uA at 2.3 MeV.
- Target barely gets warm with the existing water cooling system (~46W power, 32°C max).
- More neutrons than expected near threshold.
- Angular distribution measurement inconclusive.

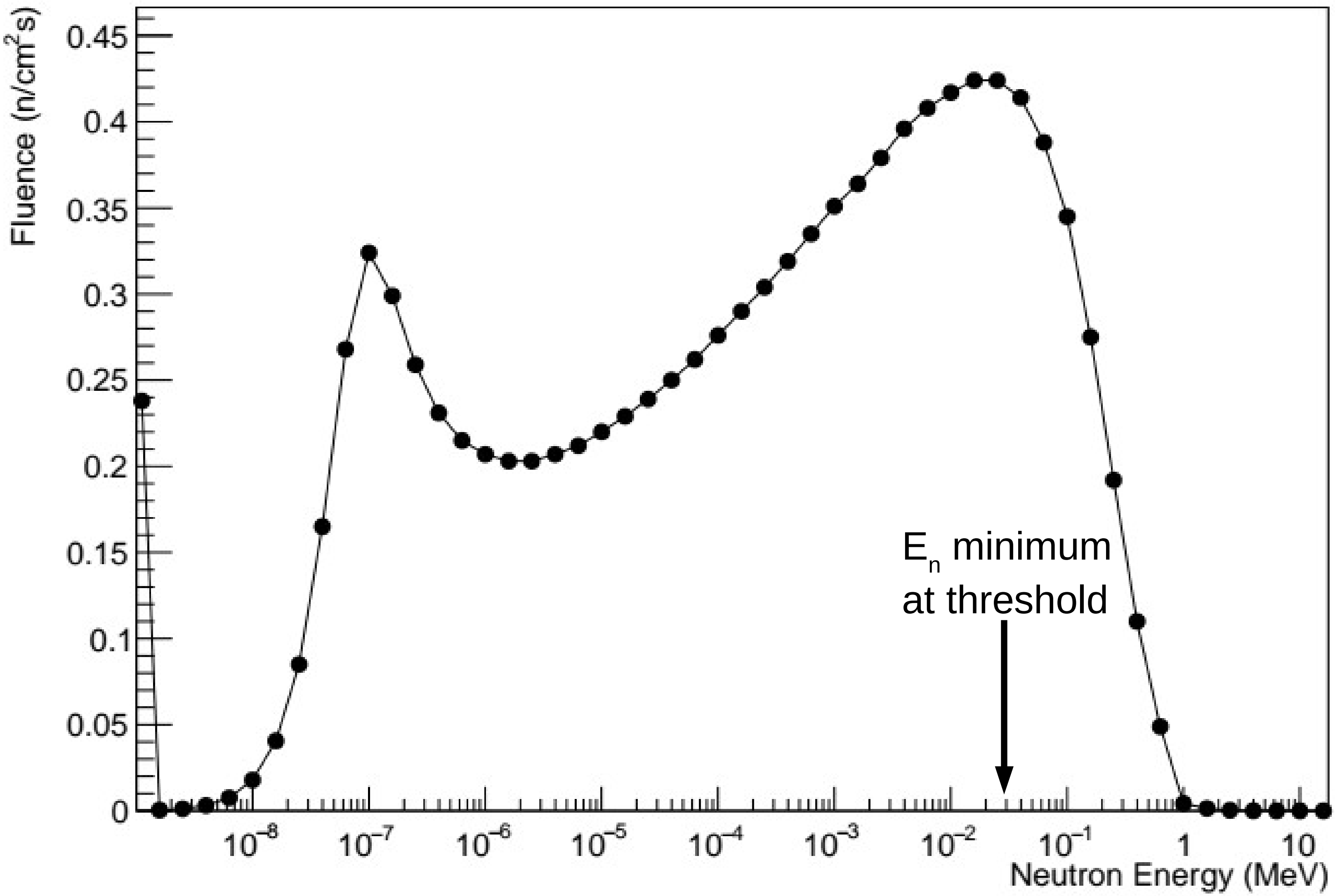
Test 2 goals:

- Take more data at proton energies near threshold.
- Measure neutron spectrum near threshold.

Overview of Second Test



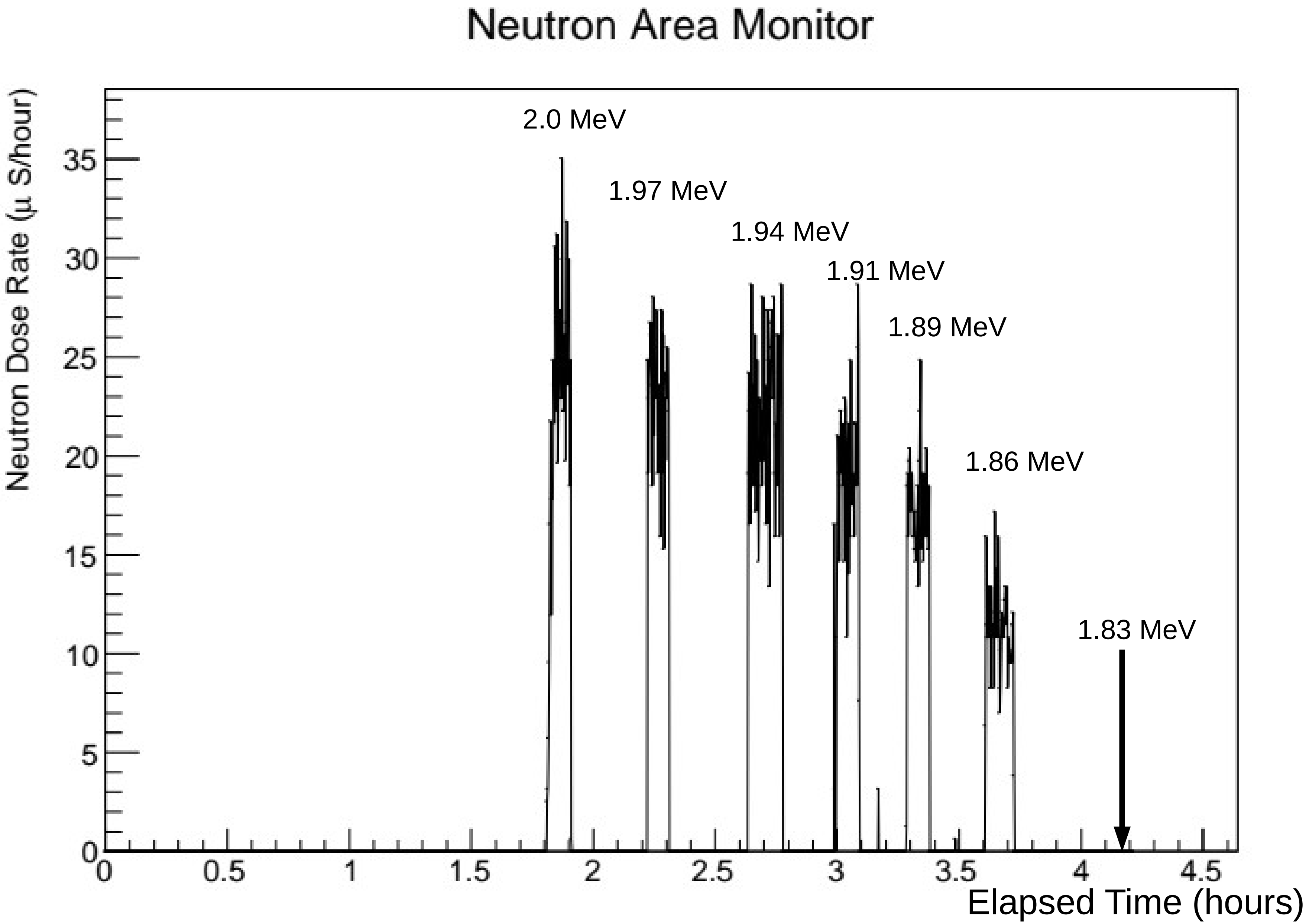
Neutron Spectrum at 1.87 MeV



Lessons from Test 2

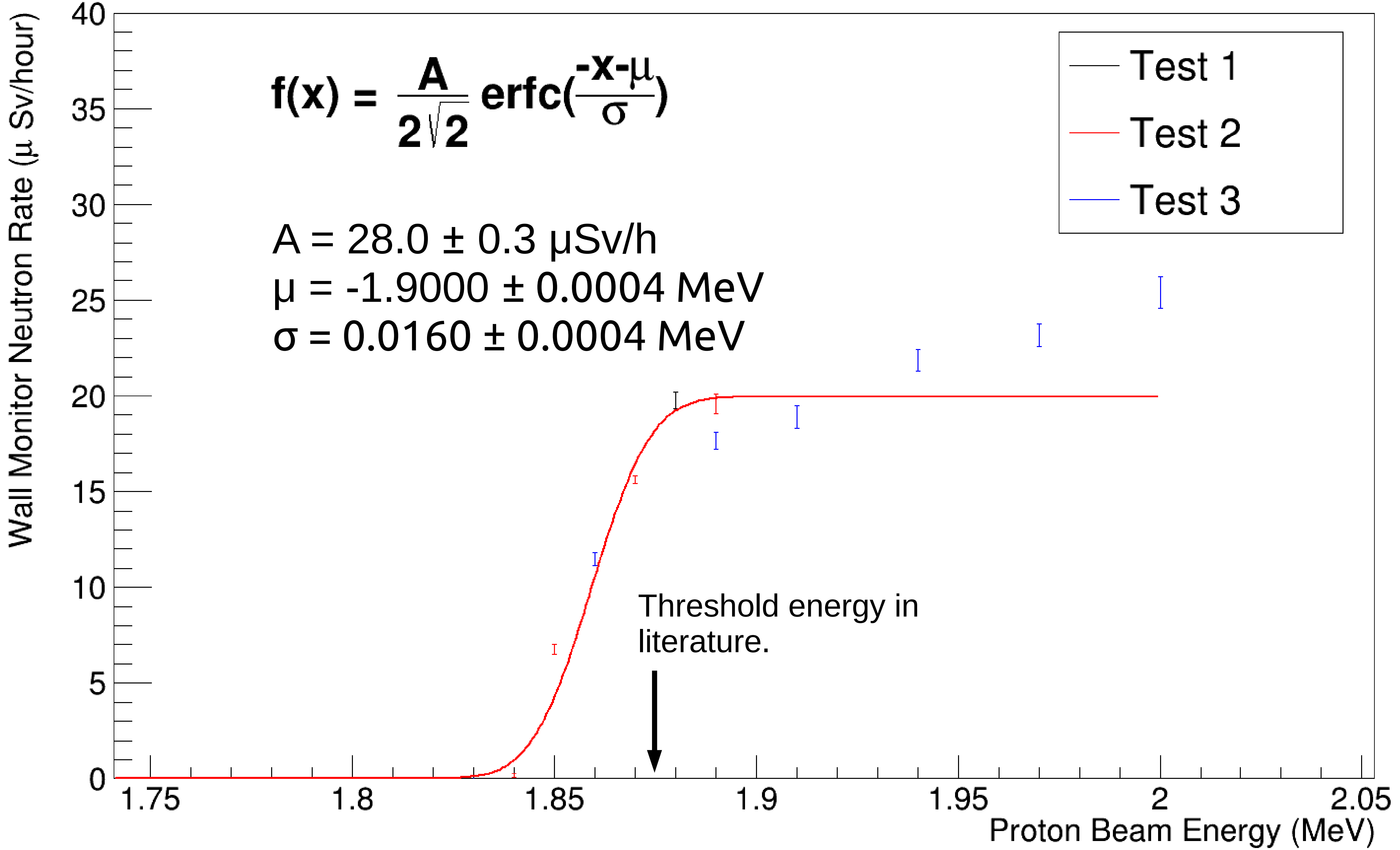
- Neutron spectrum is very broad:
  - The cooling system uses water.
  - The room is small enough that neutrons can bounce around several times.
- Neutron production started at ~1.84 MeV
  - We need more neutron rate vs proton energy points.

Test 3



Neutron Area Monitor
Neutron Dose Rate (μ S/hour)
Elapsed Time (hours)
2.0 MeV
1.97 MeV
1.94 MeV
1.91 MeV
1.89 MeV
1.86 MeV
1.83 MeV
0
5
10
15
20
25
30
35
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5

Neutron Production Threshold



Lessons from Test 3

- Proton beam energy is either offset or broadened by ~30 keV.
- Next steps:
  - Take neutron spectrum with water cooling off and cooling block removed.
    - This requires more-direct thermal monitoring.
  - Add shielding for reflected neutrons.
  - Repeat tests with new (thinner) targets.

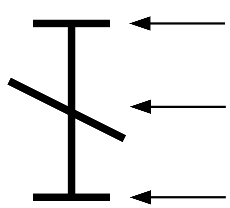
Simulations

Neutron Transport

- Alexis Brossard, (new post-doc) provided a GEANT4 simulation program to allow multiple layers of material.
- It simulates N neutrons with energy E going through 5 layers of material.
- The output is the spectrum of neutrons, gammas, etc that have escaped all the layers of material.
- This will help us design shielding to reduce scattered neutron, and plan experiments.

Attenuation Through Materials (Single Layer)

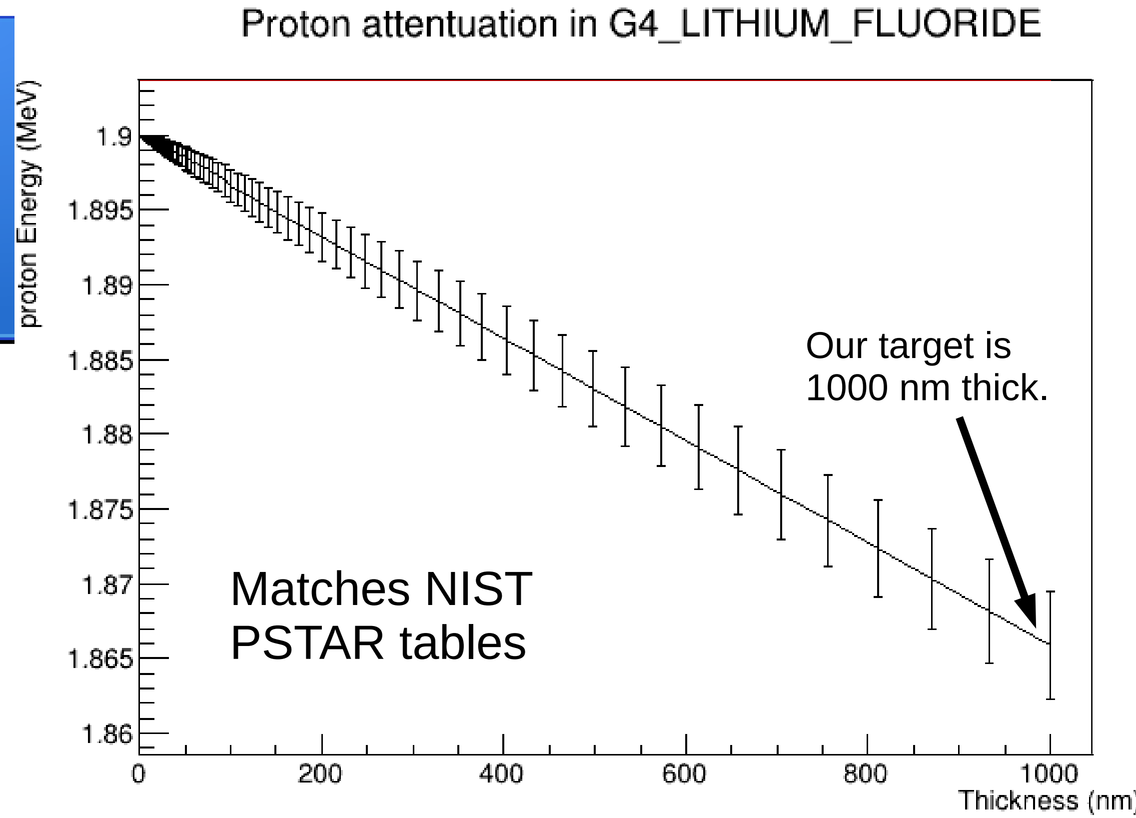
Data points are median energies, upper and lower bars are quartiles.

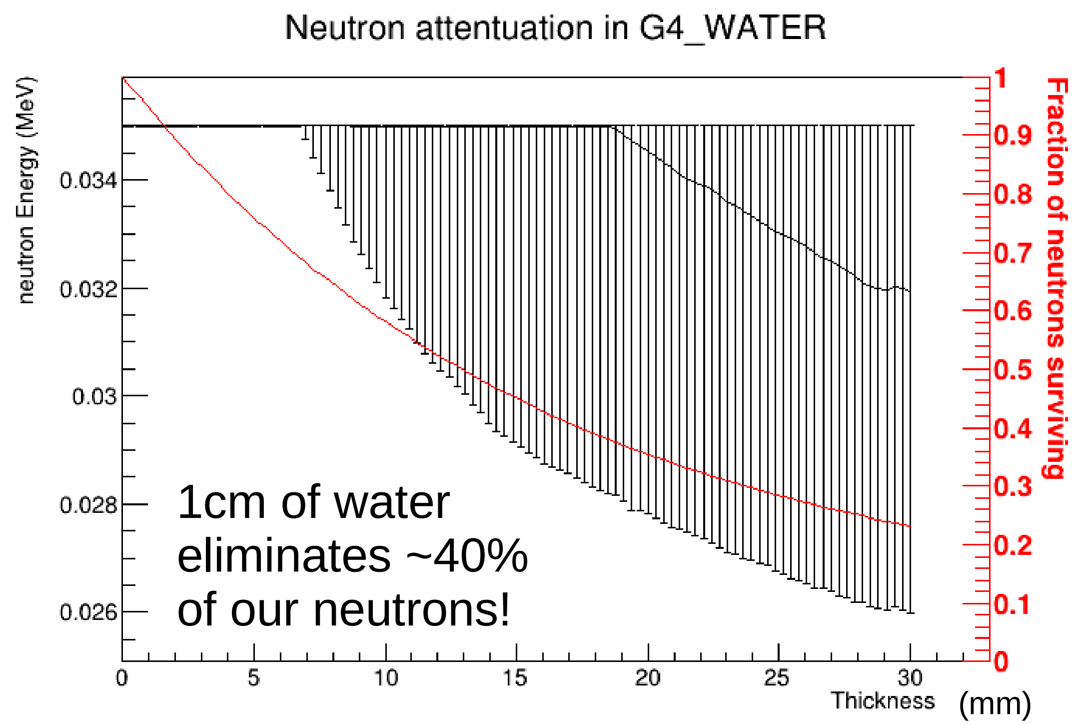


25% have *more* energy than this

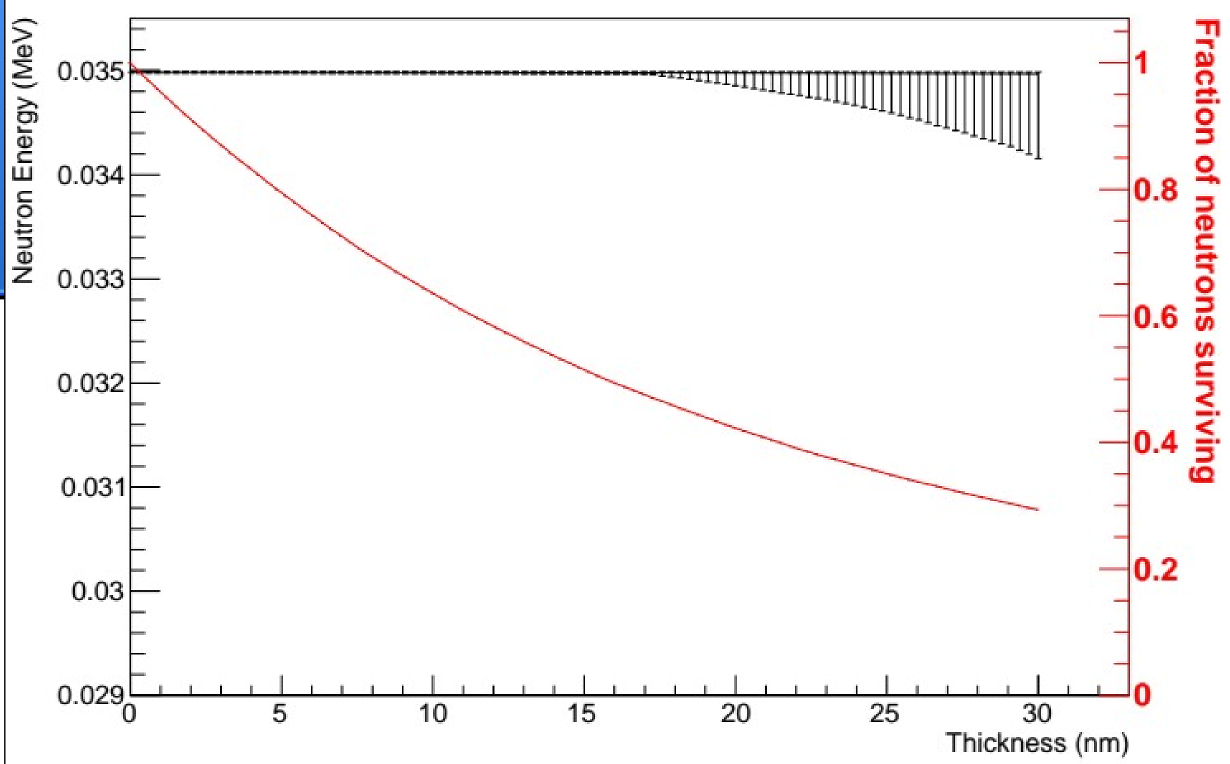
Middle value of energy (median)

25% have *less* energy than this

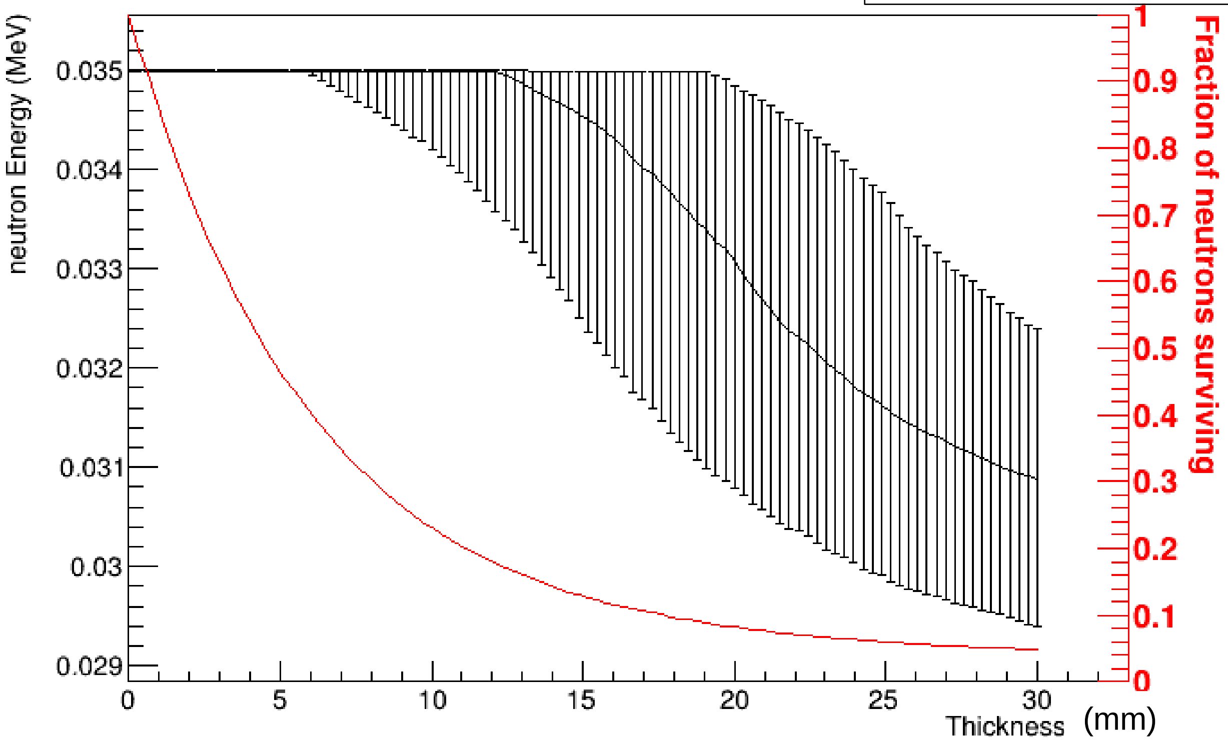




Comparing Materials

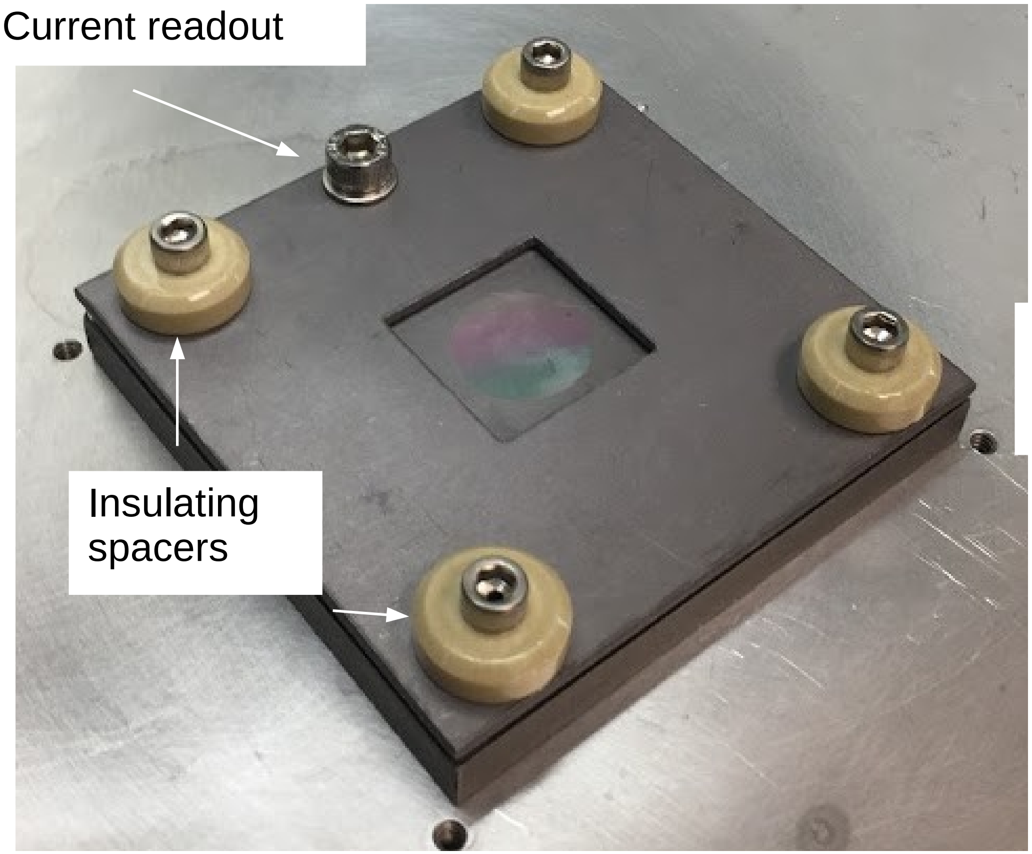


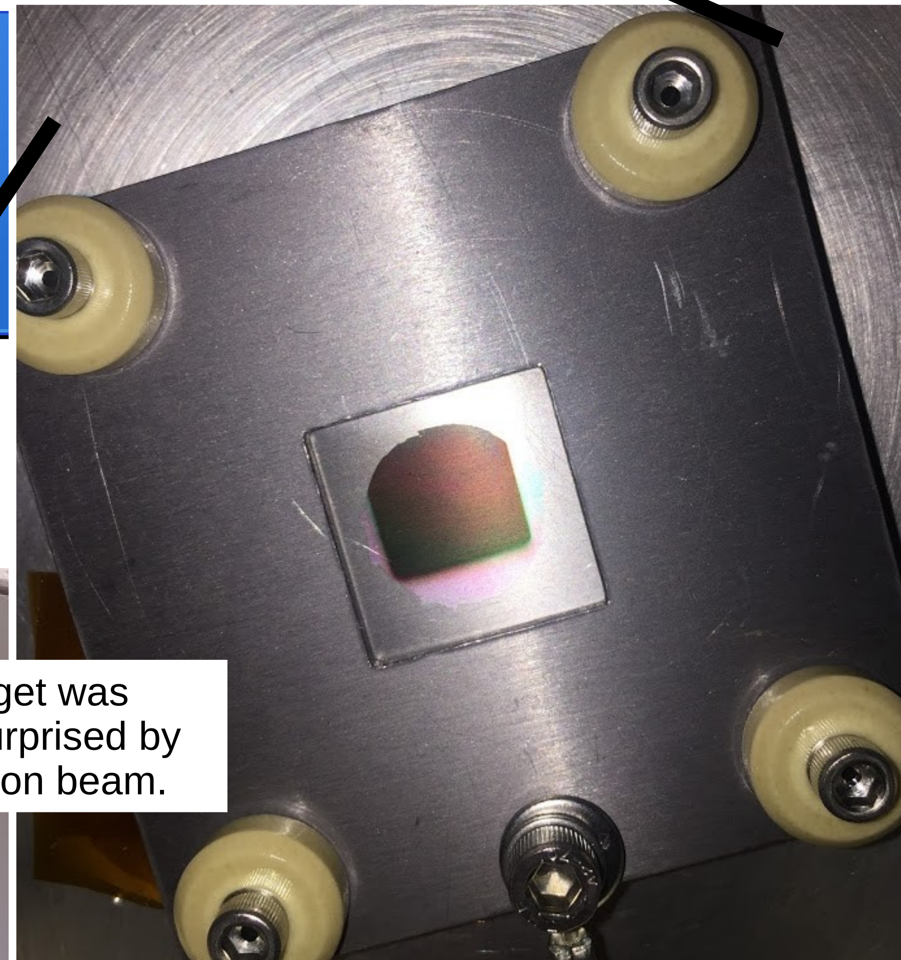
Neutron attenuation in Aluminium

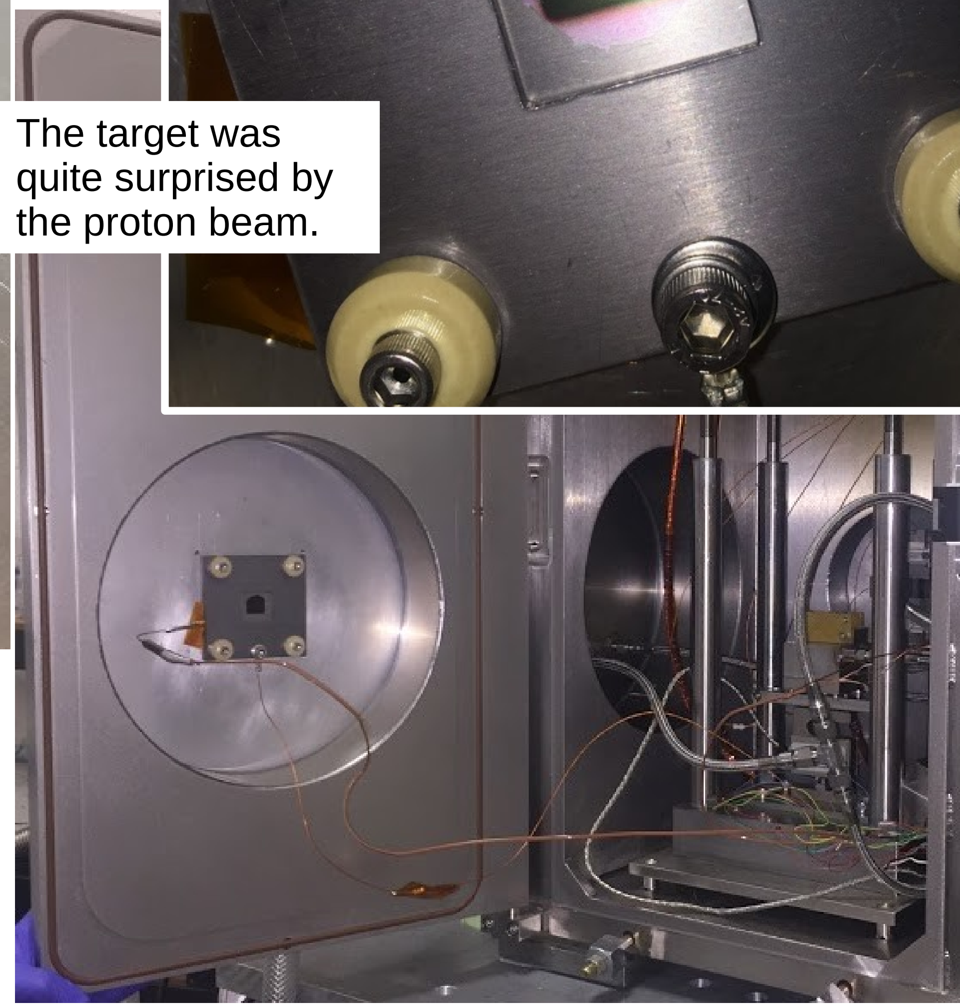


Targets

Old Target





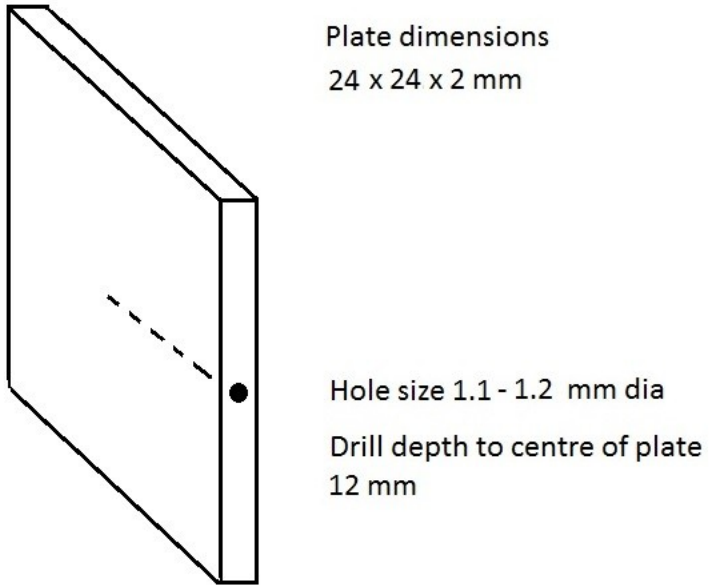


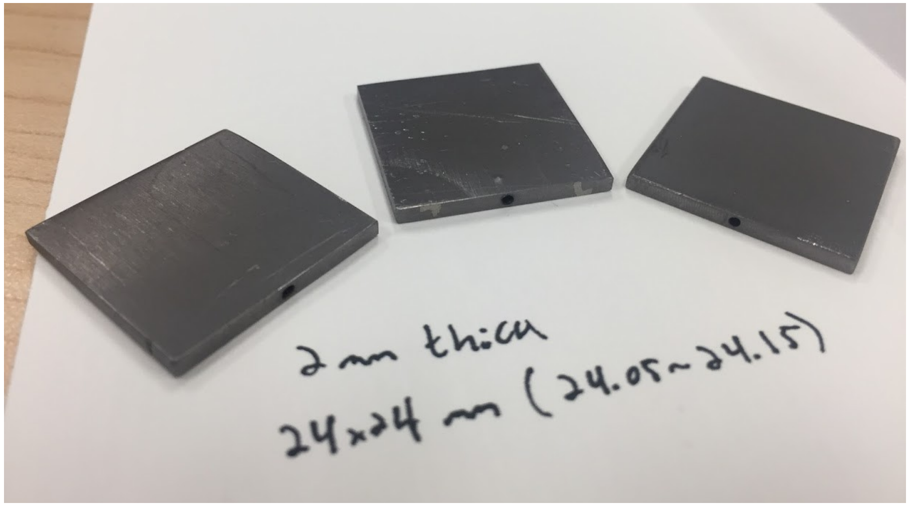
The target was quite surprised by the proton beam.

New Targets

- 3 new targets
  - Tantalum machining at Queen's
  - Chemical vapor deposition at Université de Montréal
- Different LiF thicknesses:

  250nm, 120 nm, and 38 nm
- Corresponding energy loss for 1.88 MeV protons is
  10 keV, 5 keV, and 1.5 keV, respectively.
- Hole for direct thermocouple measurement.



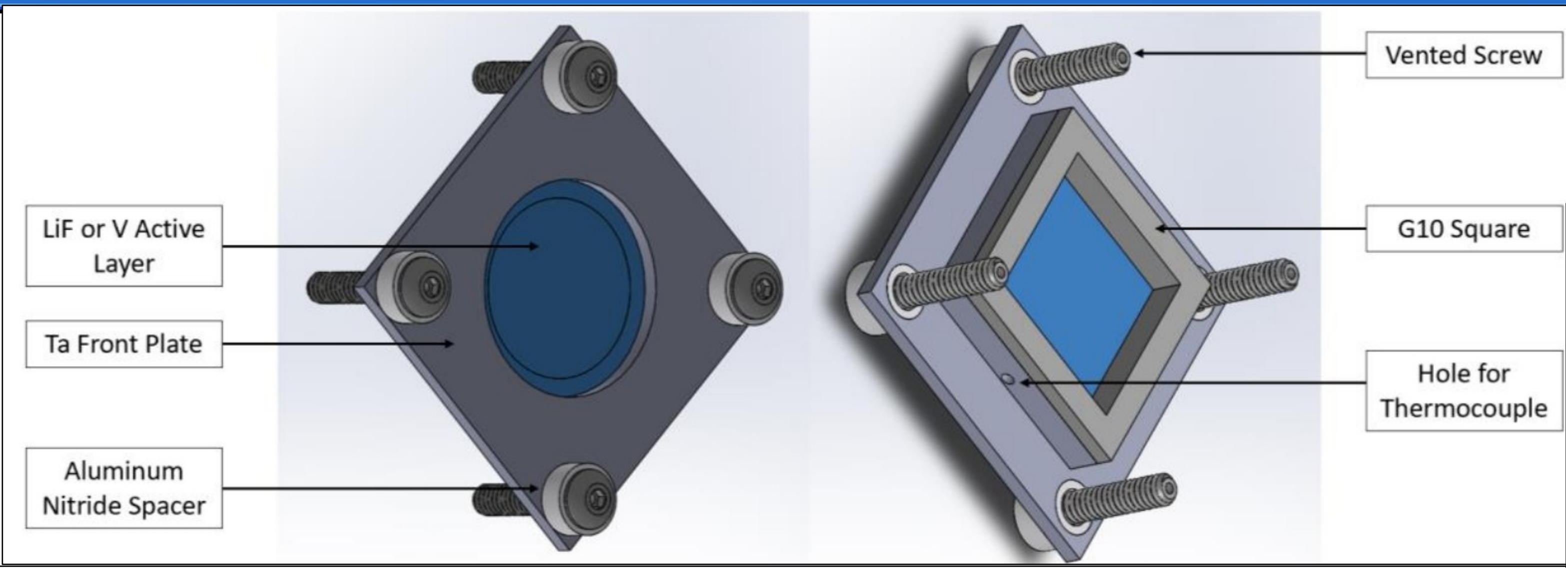


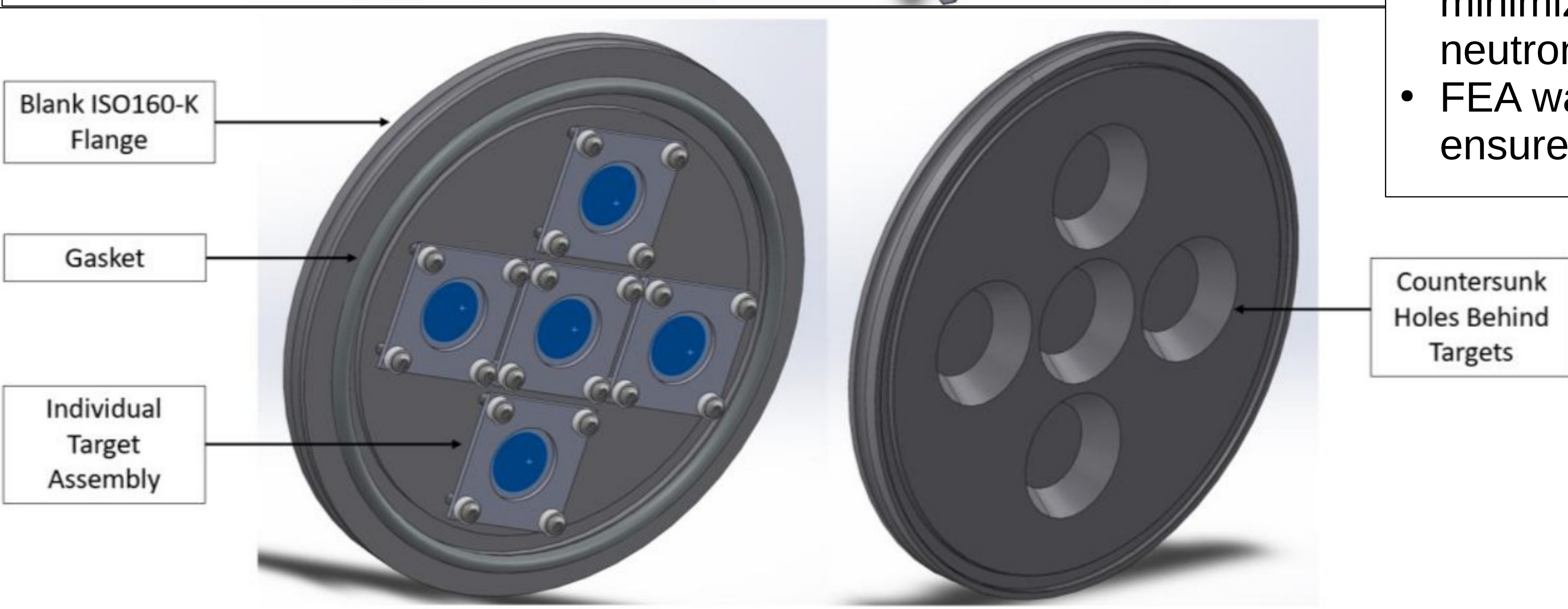
Multi-Target Holder

Multi-Target Holder

- Matthew Mawby (undergraduate) did a senior engineering thesis project to design a holder for multiple targets.
- The targets can be selected without breaking vacuum.
- Allowed budget was 5000$, not including stands.
- Very thorough - with final touches we could actually make this.

Multi-Target Holder 2

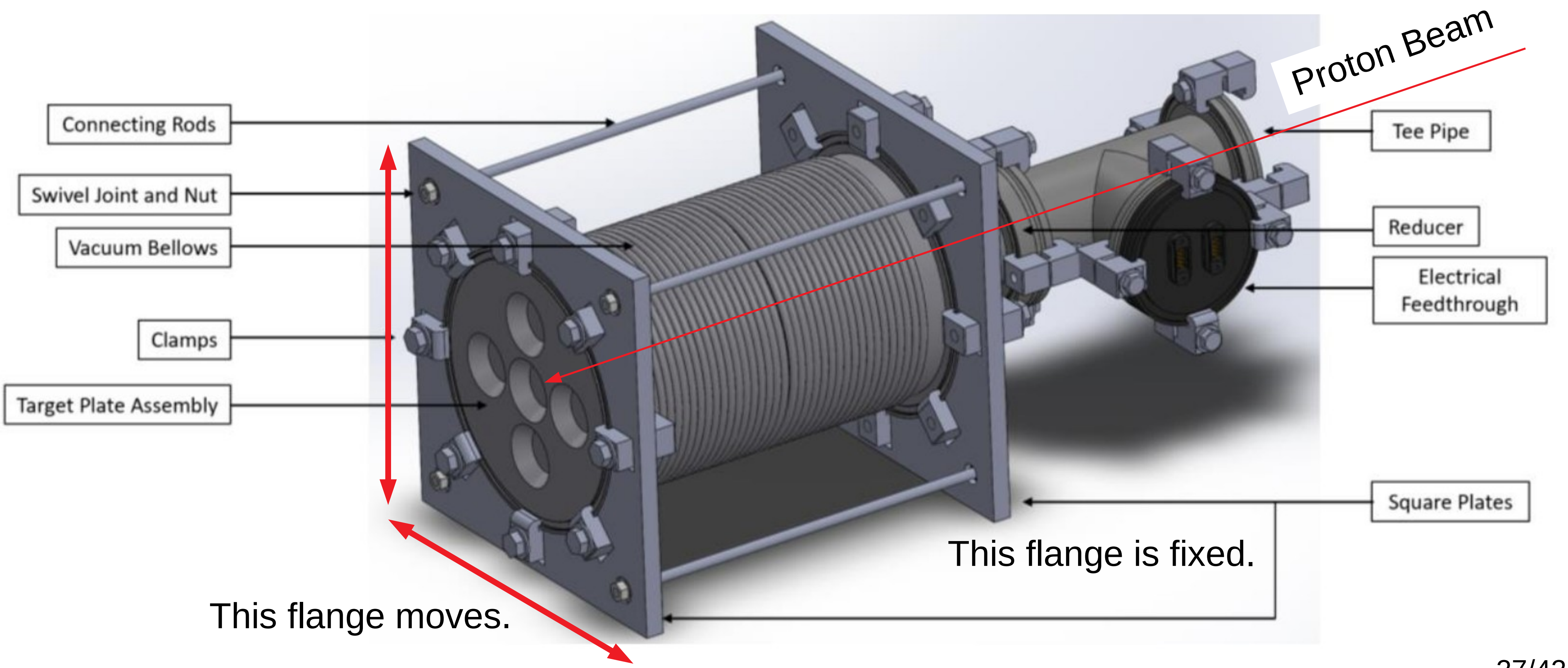




- New single-target holder with smaller footprint.
- Multi-holder takes 5 single holders.
- Countersunk holes minimize outgoing neutron scattering.
- FEA was done to ensure safety factors.

Multi-Target Holder 3

- ISO160-K bellows minimum bending radius is 317.5mm.
- A 254mm-long bellows gives maximum displacement of of 50.12mm.
- Necessary displacements <= 44.02mm.



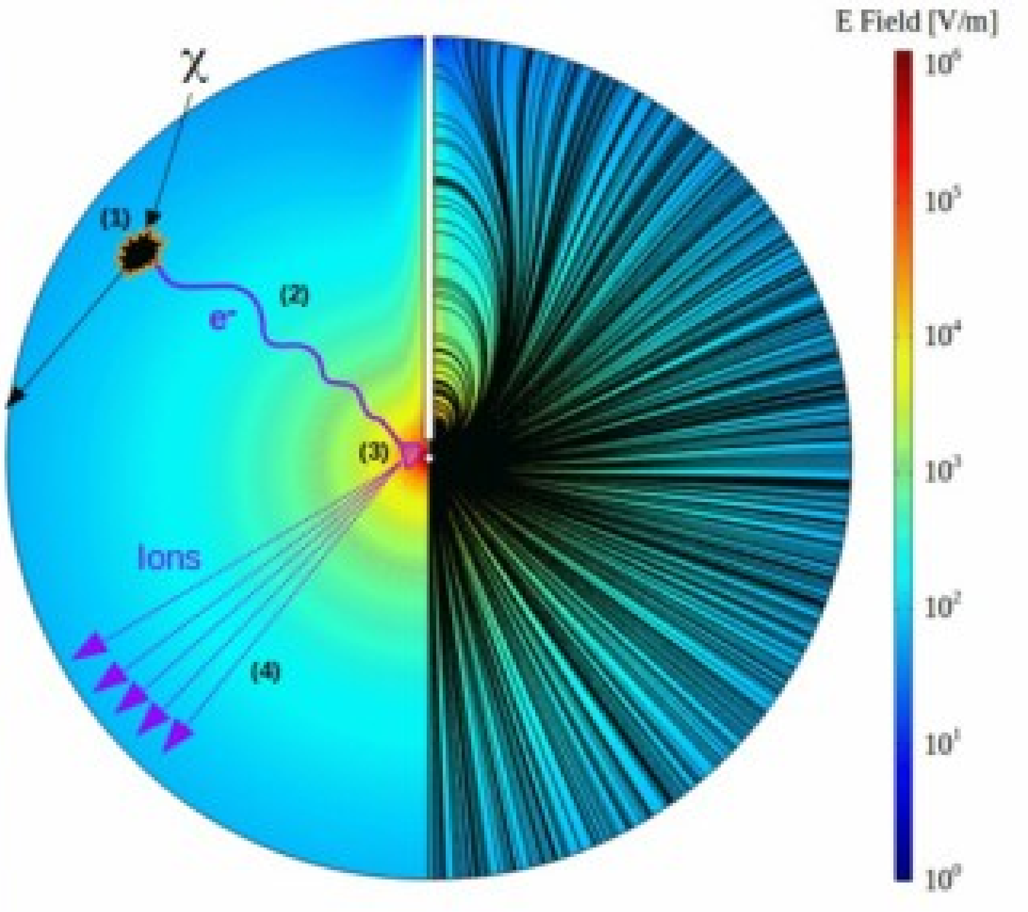
What’s Next?

- Do beam tests with new targets to confirm we can eschew water cooling.
- Do beam tests with passive cooling only.
- Finish compact shield design to block reflected neutrons (using the simulations).
- Build shielding and do tests.
- Do tests with a NEWS-G detector.

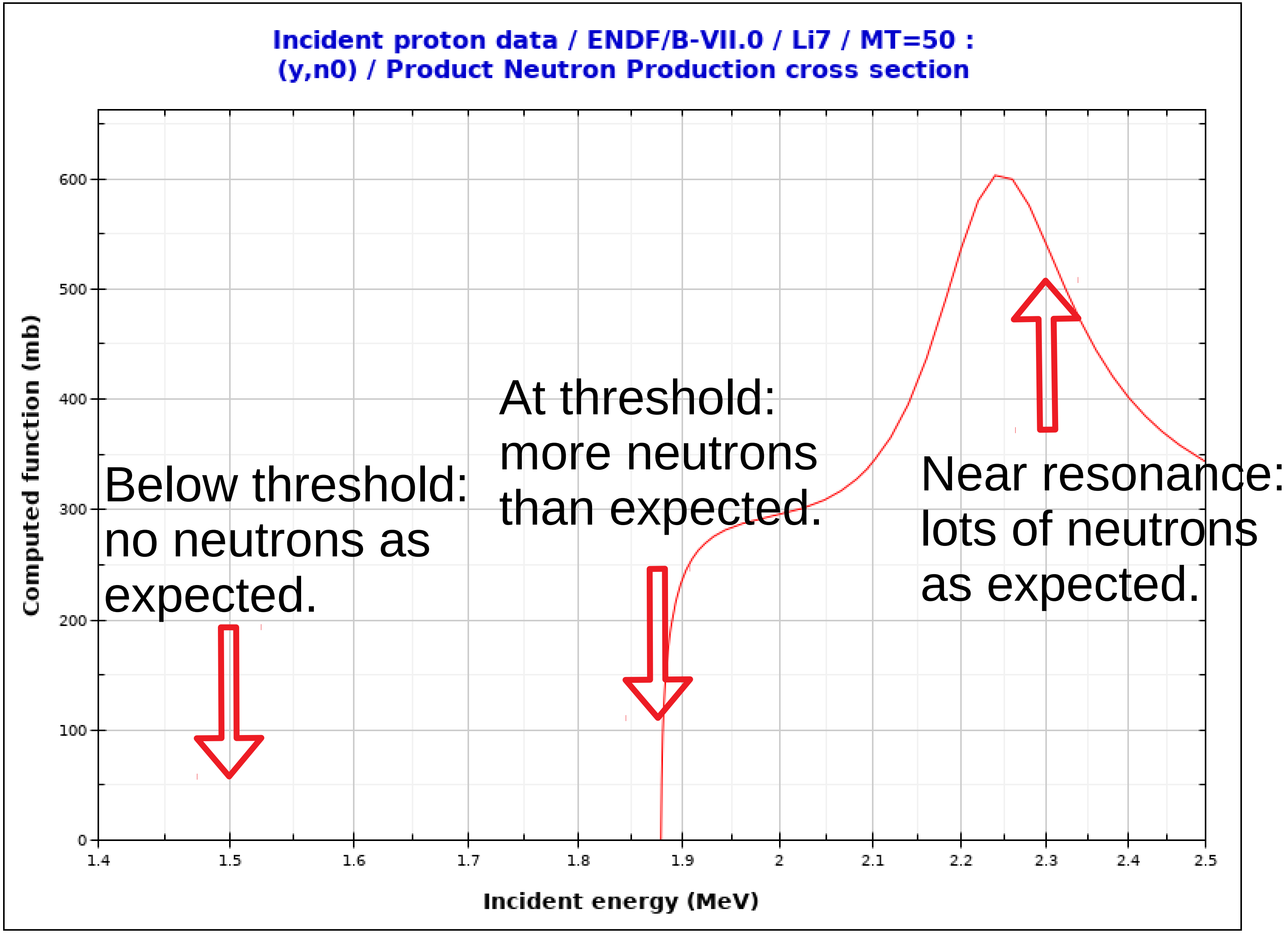
The End

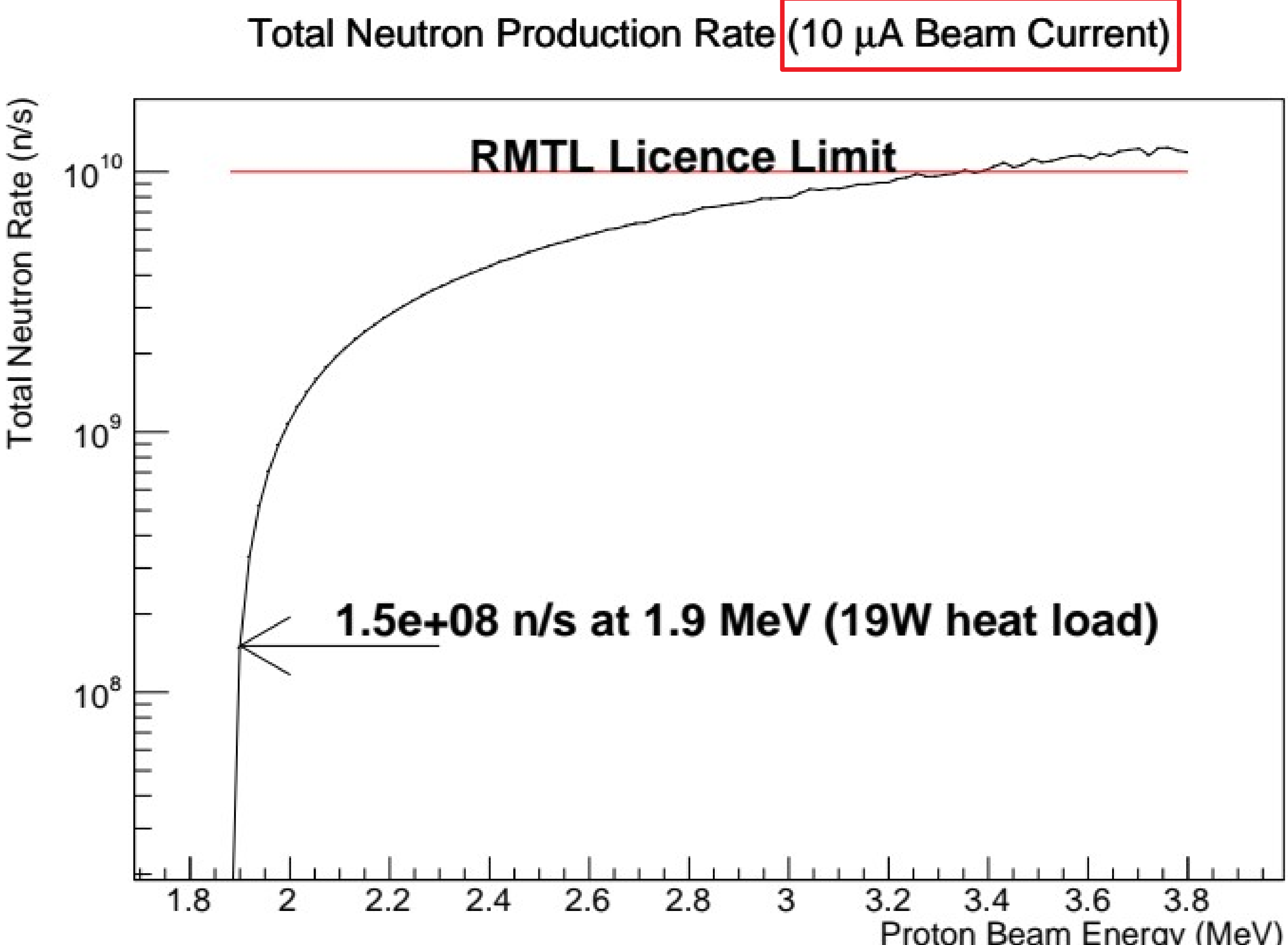
Backup/Photo Slides

Spherical Proportional Counter



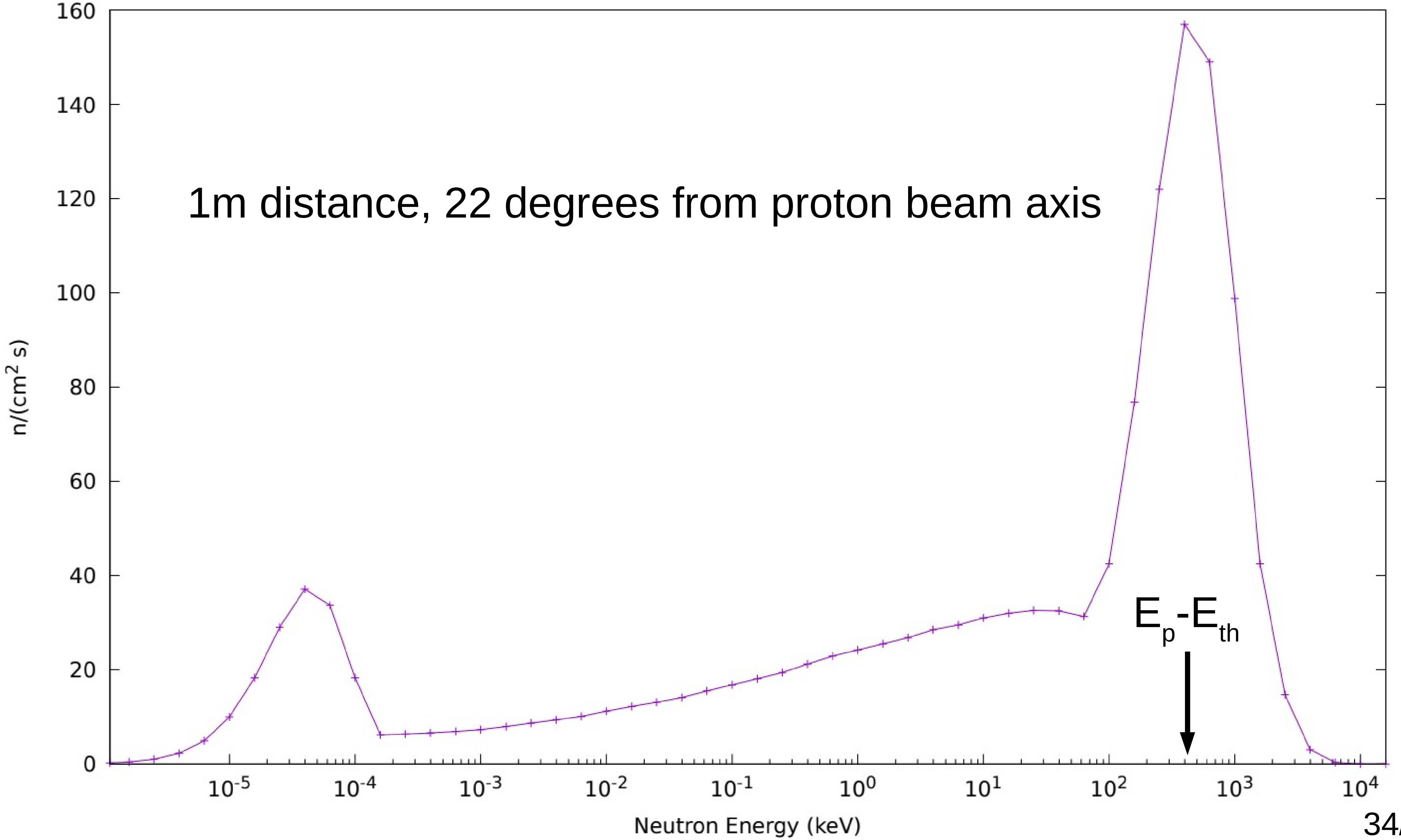
Li(p,n)Be cross-section



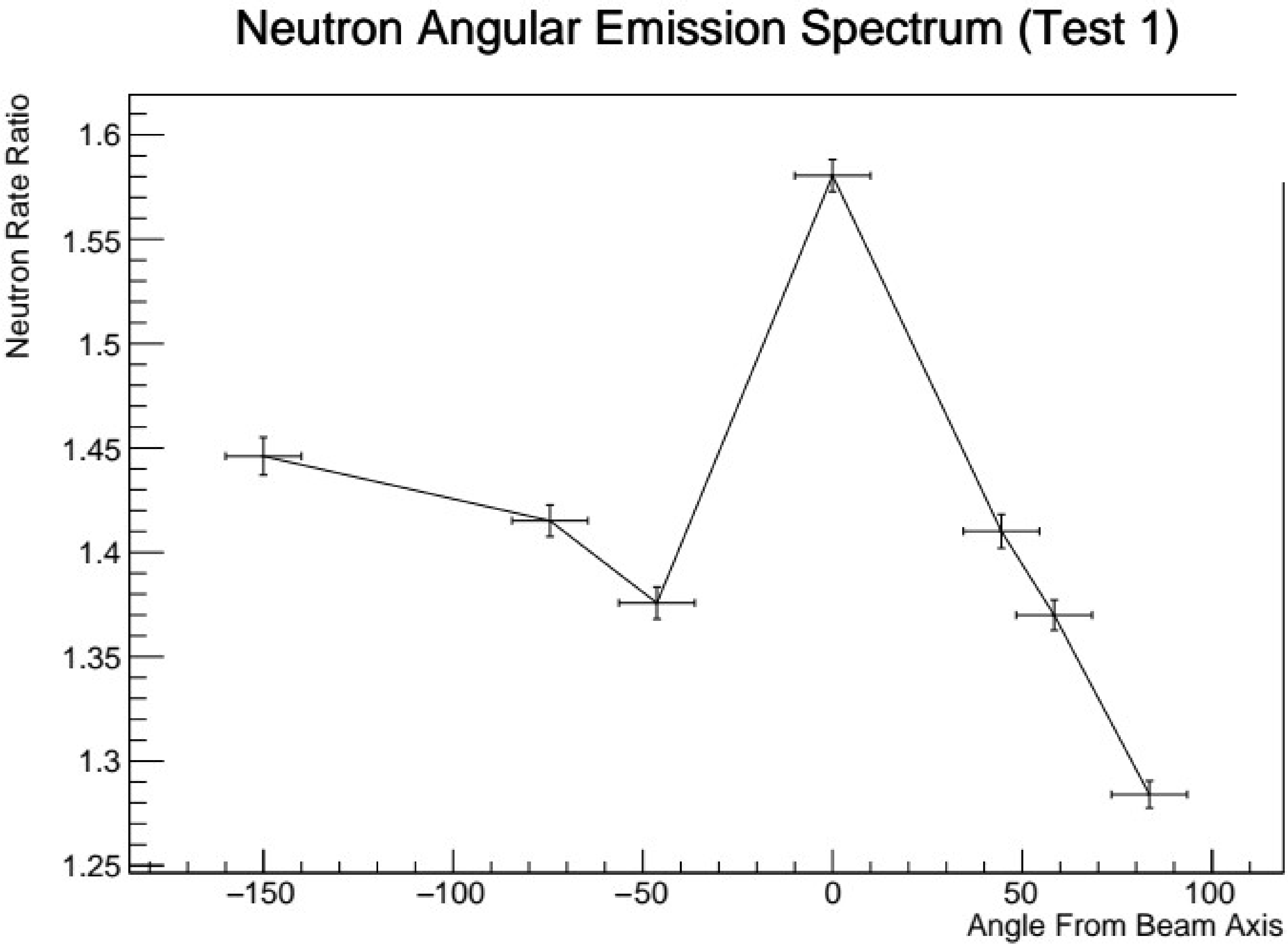


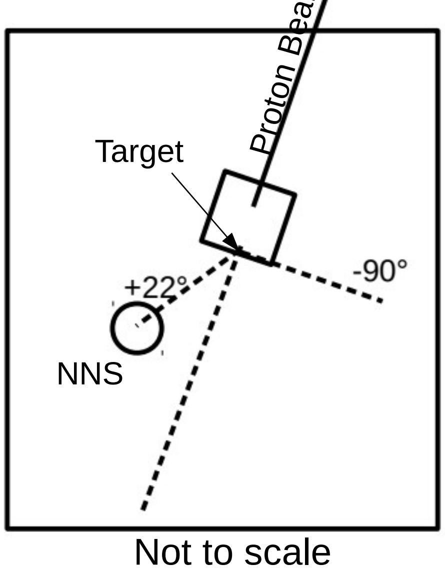
This is integrated over the full 4π emission angle and all neutron energies, for a **monochromatic beam**, with a **thick target**.
A larger beam current helps us get closer to threshold while maintaining a usable neutron rate. The heat load on the target is a limiting factor.

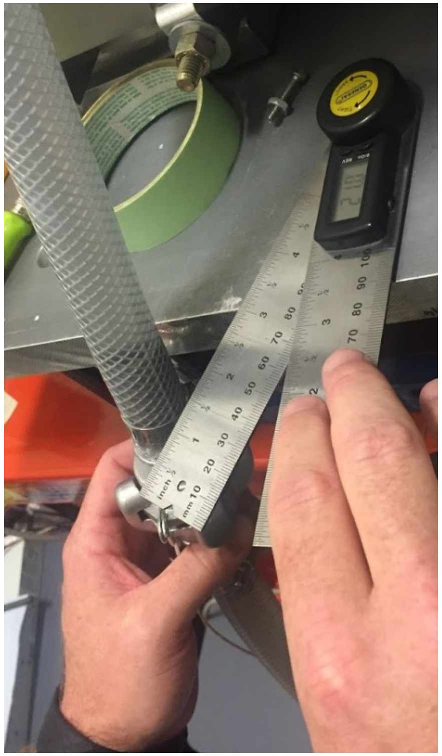
Neutron Spectrum at E_p = **2.3 MeV**



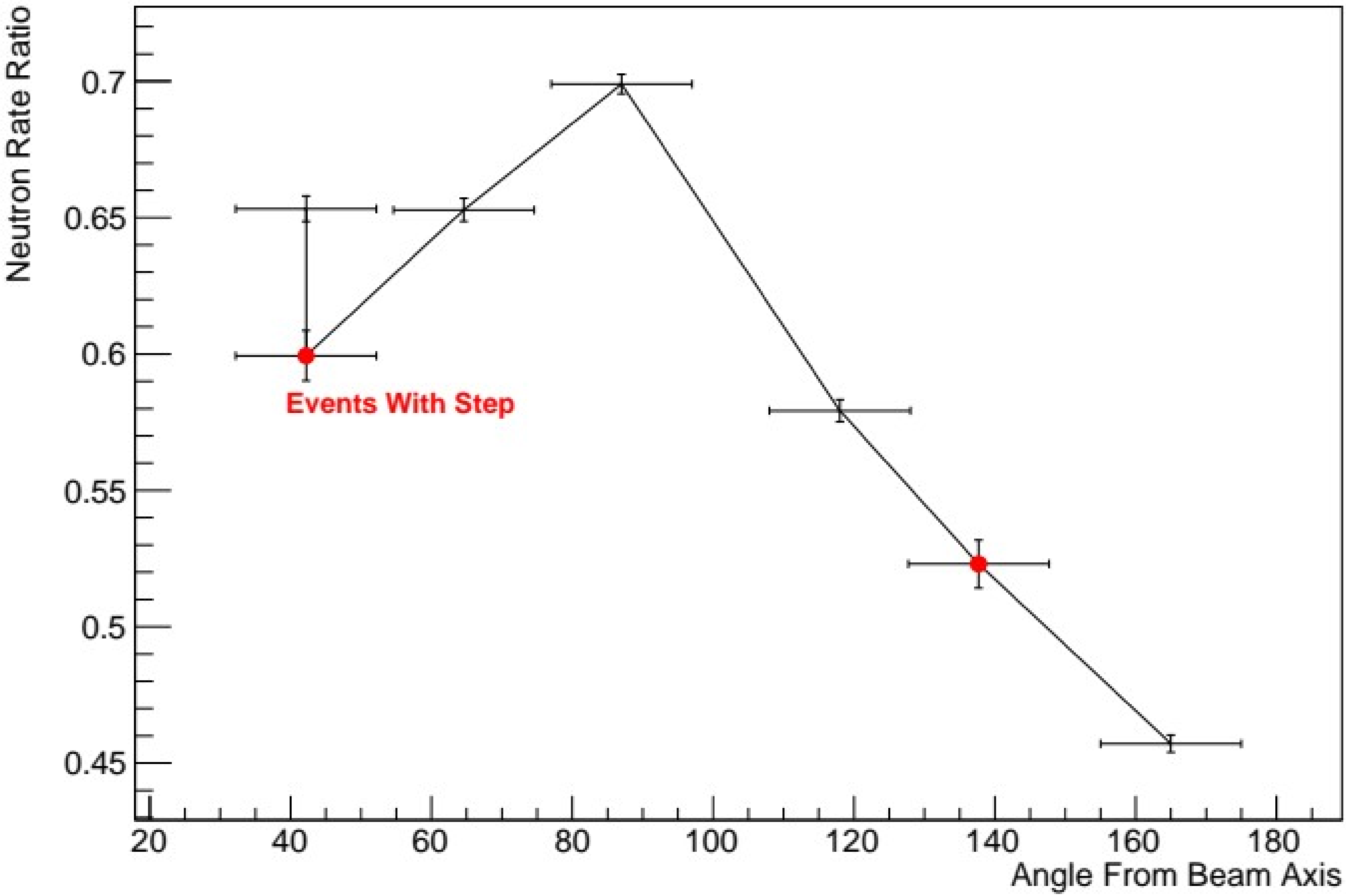
Neutron Angular Spectrum



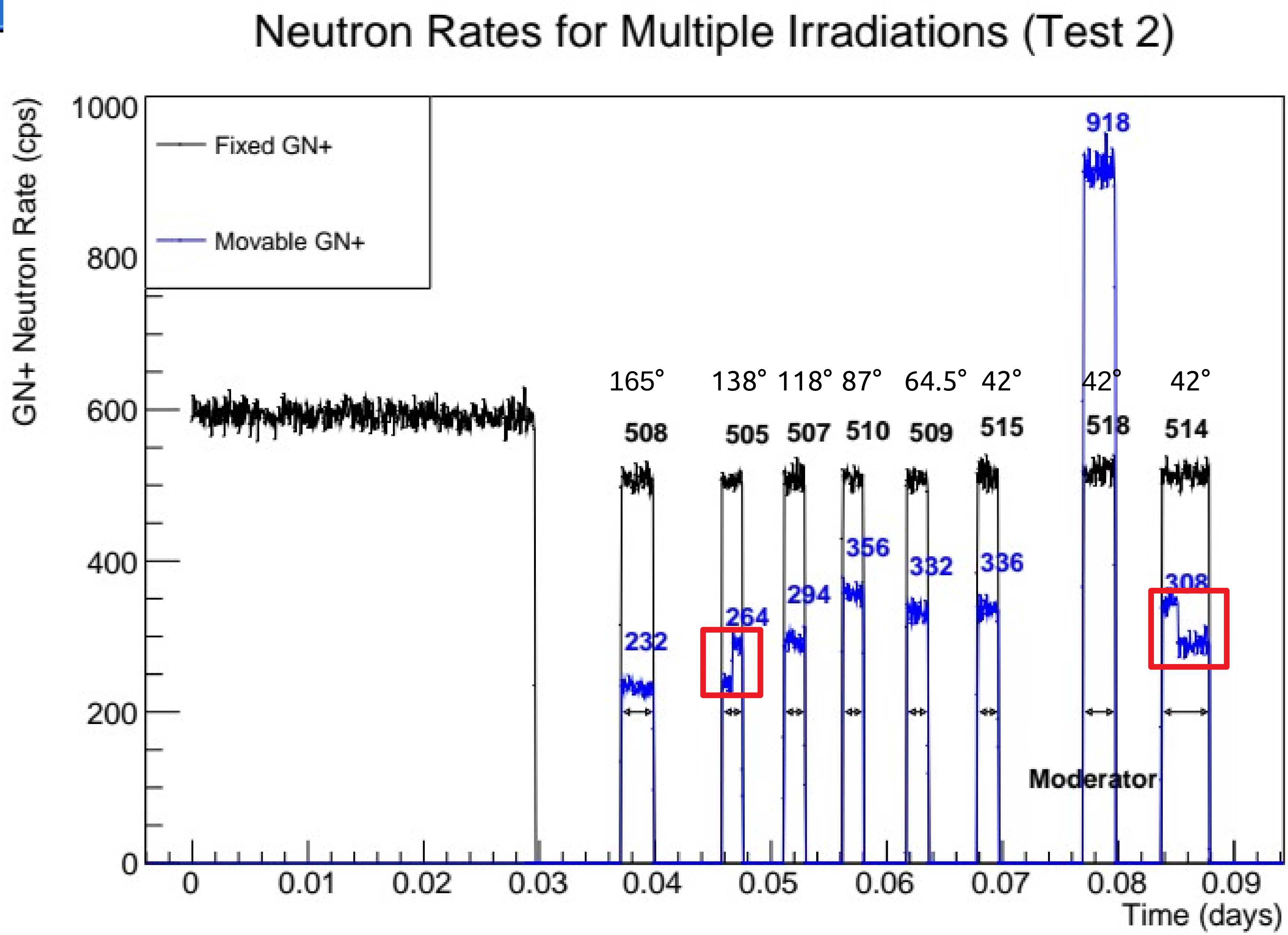




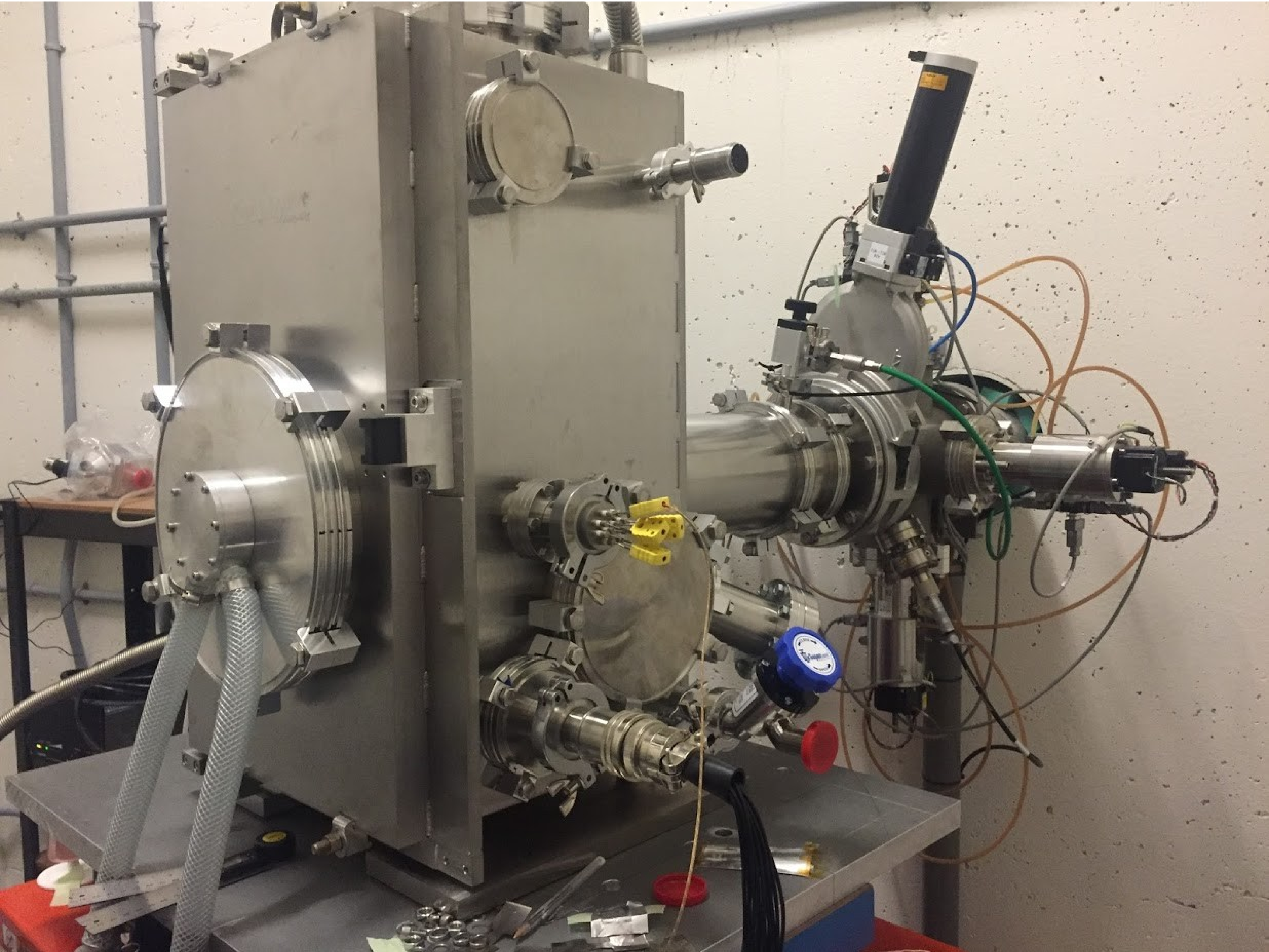
Neutron Angular Emission Spectrum (Test 2)



GN+ CLYC Count Rates (2)




For dose rate estim tions. Please point
bottom of the modera towards the source
In cps mode the following ule of thumb
factors for neutrons 2-4 Me may be used:
RadEye NL: 1 cps = 5 Sv/h
RadEye GN: 1 cps = 1 µSv/h
RadEye GN PLUS



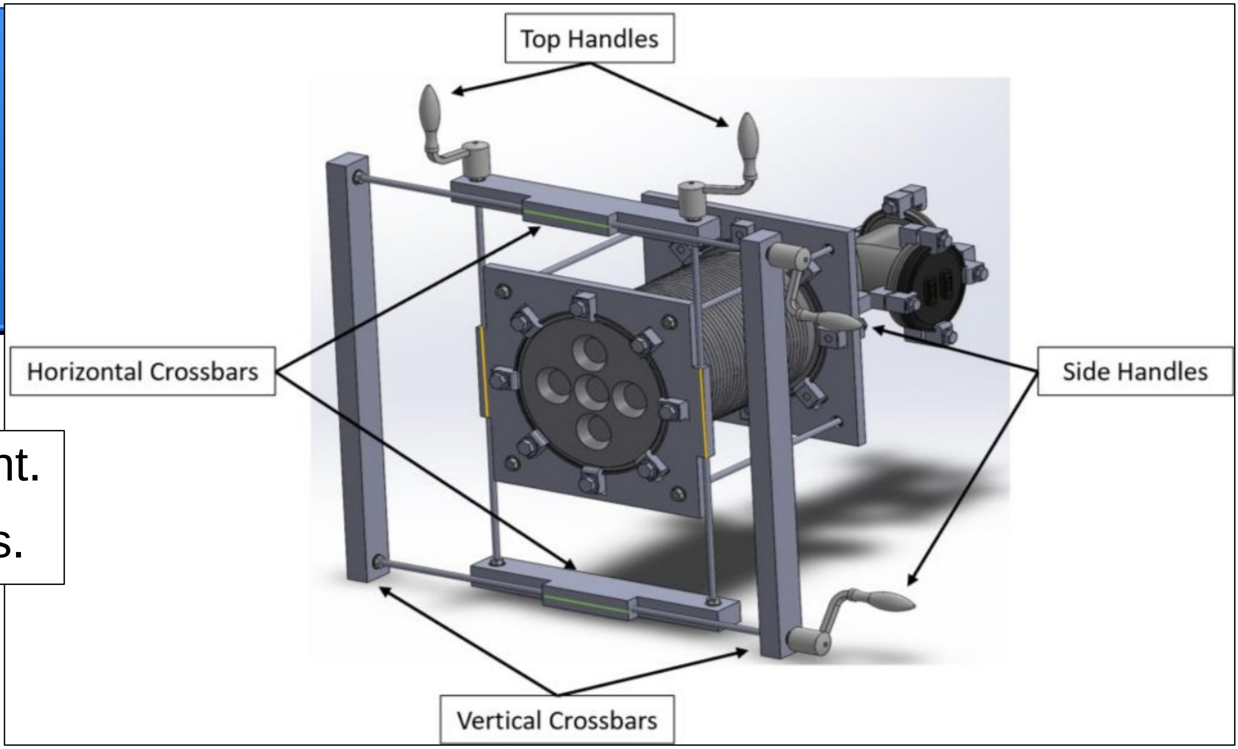
Proton Beam

- RMTL has a 1-8 MeV proton beam.
- The precision of accelerator voltage is 0.1%
  - (=> 4 keV steps in principle)
- The beam profile is *not* monitored or even known. We can close slits to narrow the profile of the pre-accelerator H^- ions.
- The beam current is 0.05~45 μA.

Old Nuclear Target

- We have on-hand a 1μm LiF target on tantalum backing.
- The neutron production threshold is 1880.57 keV.
- Our target is “semi-thick”: protons do lose non-negligible energy in the target, but won’t always dip below threshold.
- Neutrons produced at threshold have 29.68 keV.
- Above threshold, neutrons of different energies have different emission angles.
- The neutron production rate drops precipitously near threshold.

Multi-Target Holder 4



- Initial design is for manual movement.
- Easily upgradable to linear actuators.