

# Development of a cryogenic neutron monitor and Dark Matter search with a Lithium-based target



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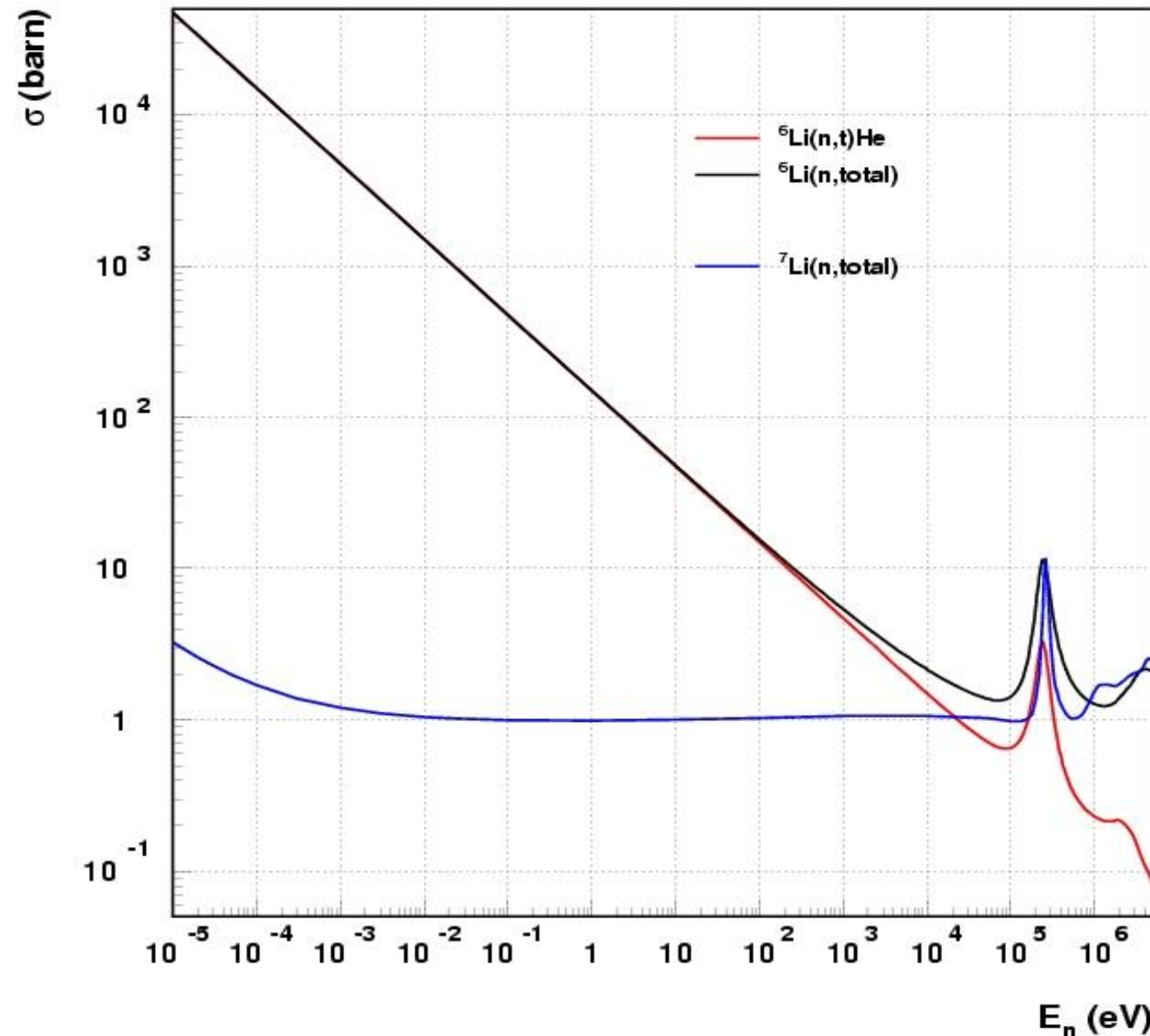


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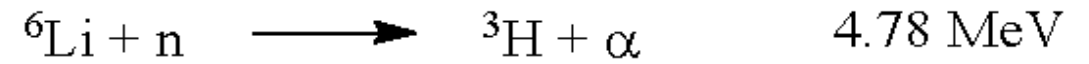
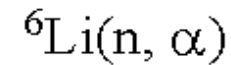
# Why detecting neutrons?

- **Dangerous background** for direct dark matter search experiments (like **CRESST**). Neutrons cause **Nuclear Recoils**, as expected from dark matter particles
- Measuring the **neutron spectrum** inside the experimental setup would give us useful information for the **development of a Background Model** (input for Monte Carlo simulations)

# How to detect neutrons?



- Crystals containing Lithium as a target, to take advantage of neutron capture:



$$E_{3H} = 2.73 \text{ MeV}, E_{\alpha} = 2.05 \text{ MeV}$$

- Detect phonons (heat) and photons (light) to achieve particle discrimination, operating the detector at cryogenic temperatures

# Which crystal as a target?

One big advantage of CRESST is that we can easily change target inside our experimental setup.

There are multiple crystals containing Lithium to choose from:

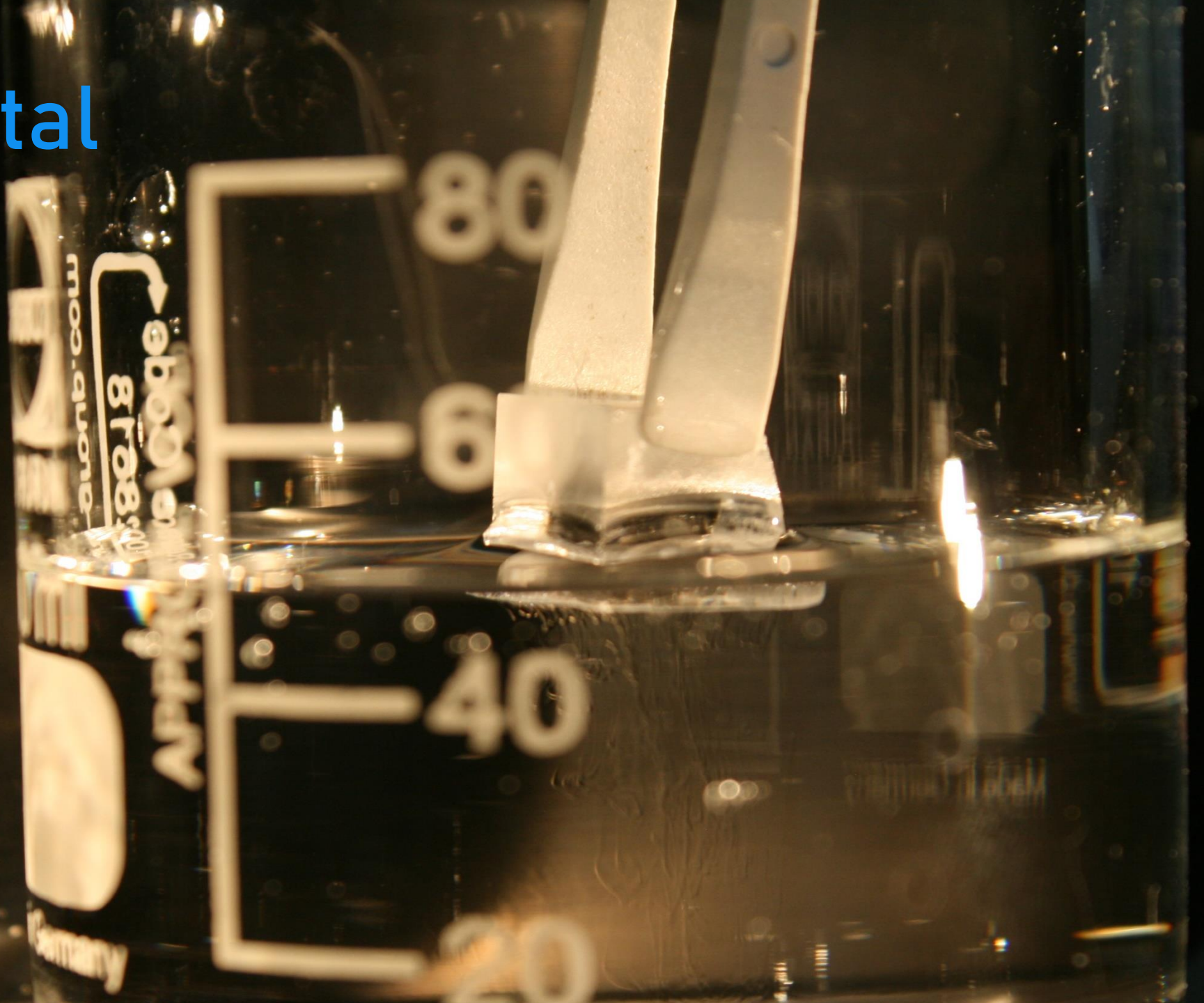
- Lithium Molybdate –  $\text{Li}_2\text{MoO}_4$  (8.0% – 0.25 g/cm<sup>3</sup> Lithium)
  - Lithium Fluoride –  $\text{LiF}$  (26.8% – 0.64 g/cm<sup>3</sup> Lithium)
- Lithium Aluminate –  $\text{LiAlO}_2$  (10.5% – 0.27 g/cm<sup>3</sup> Lithium)
- Lithium Tantalate –  $\text{LiTaO}_3$  (2.9% – 0.22 g/cm<sup>3</sup> Lithium)
- Lithium Niobate –  $\text{LiNbO}_3$  (4.7% – 0.22 g/cm<sup>3</sup> Lithium)

...



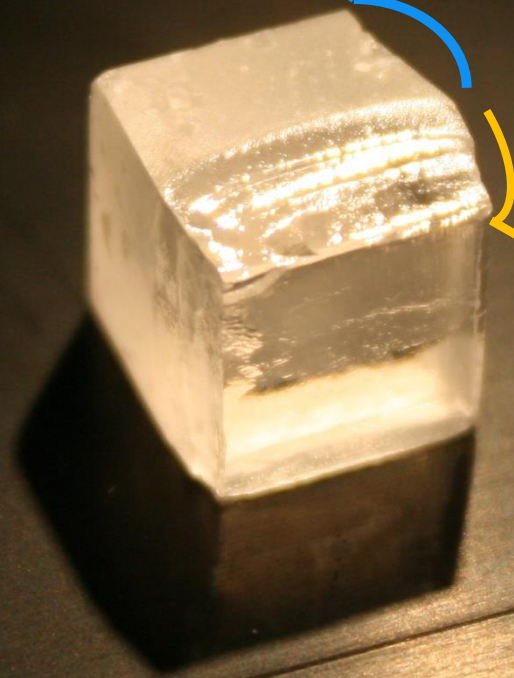
# $\text{Li}_2\text{MoO}_4$ crystal

- High purity
- Soluble
- Scintillating
- Easy polishing

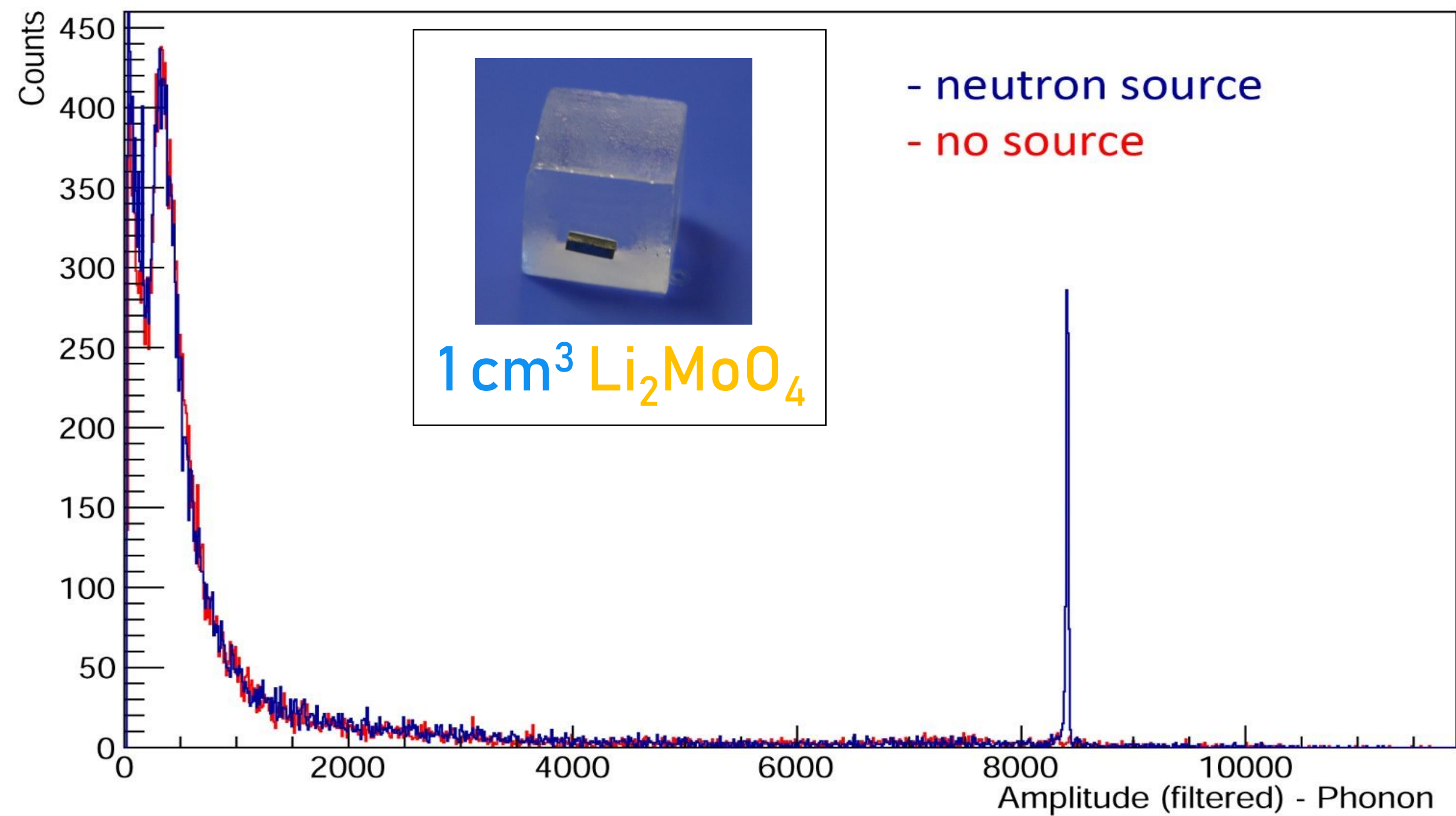


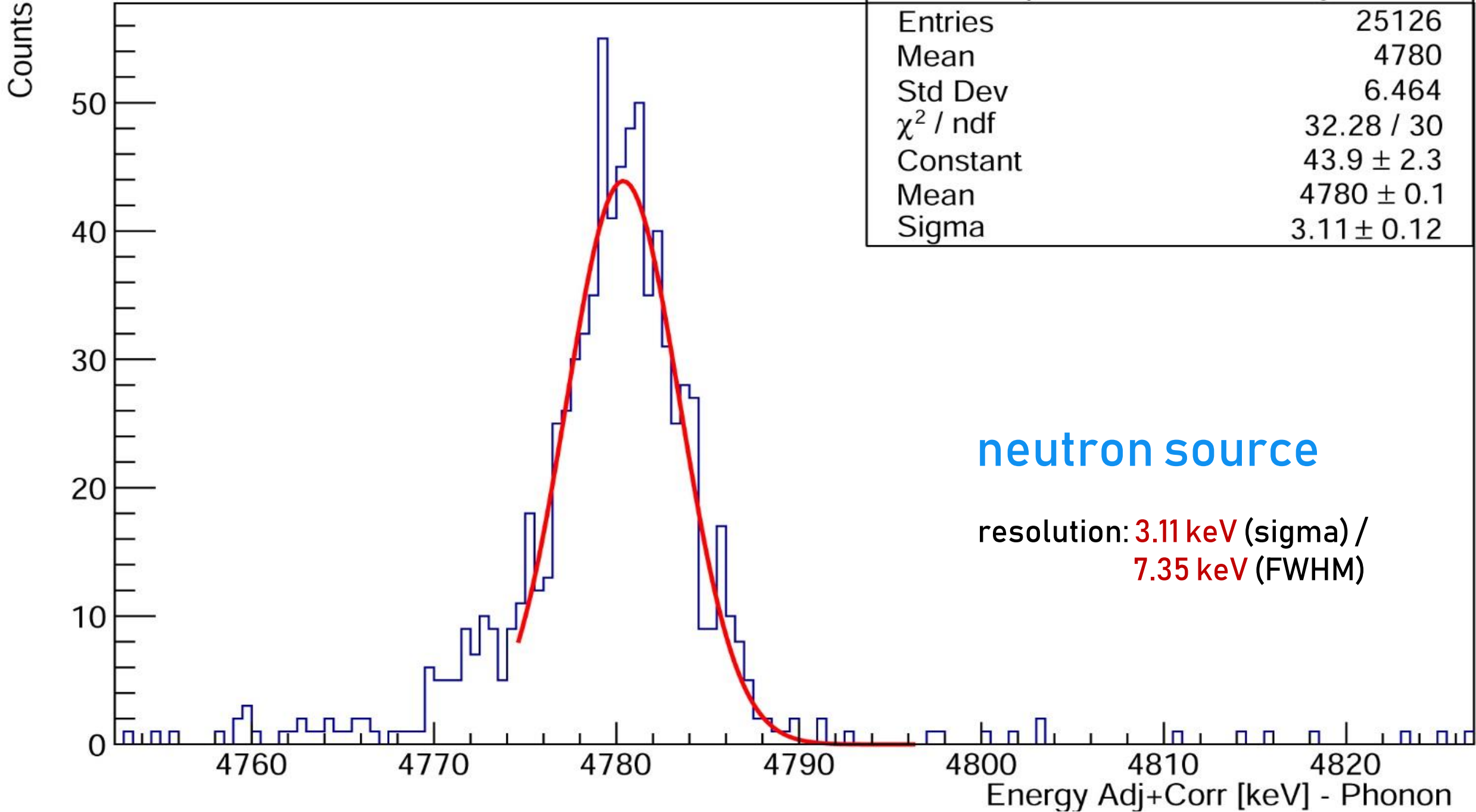


no polishing



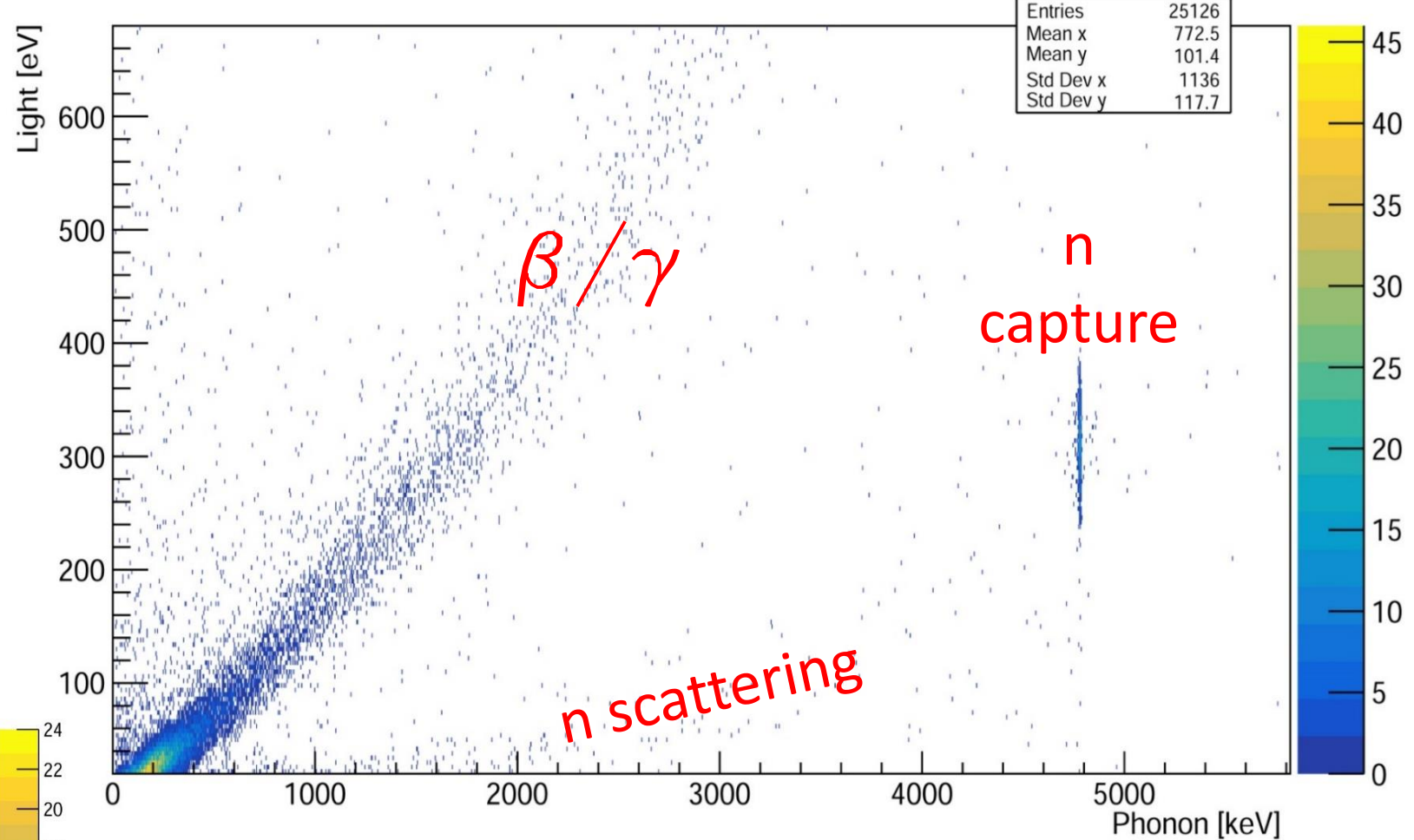
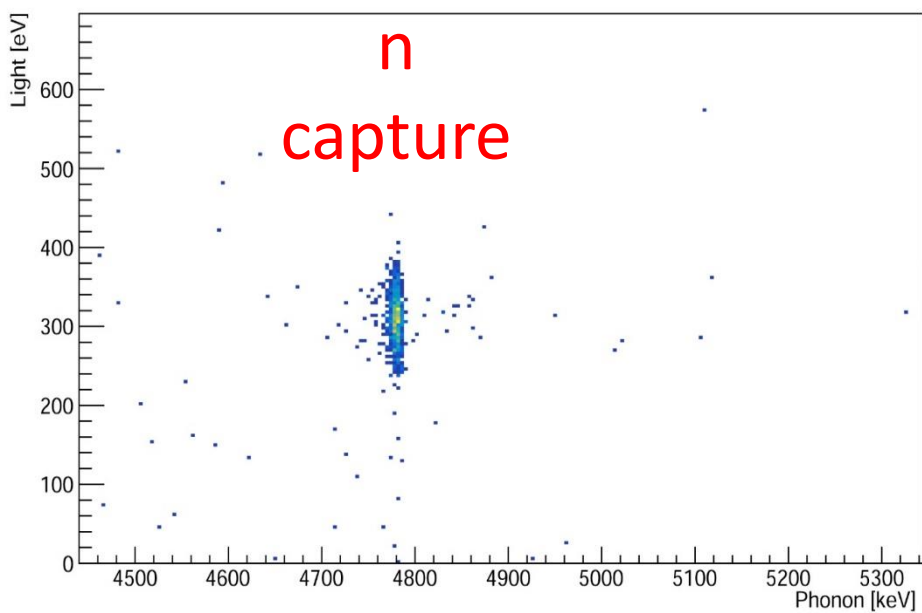
water polishing  
(30-60-90 s)







# neutron source

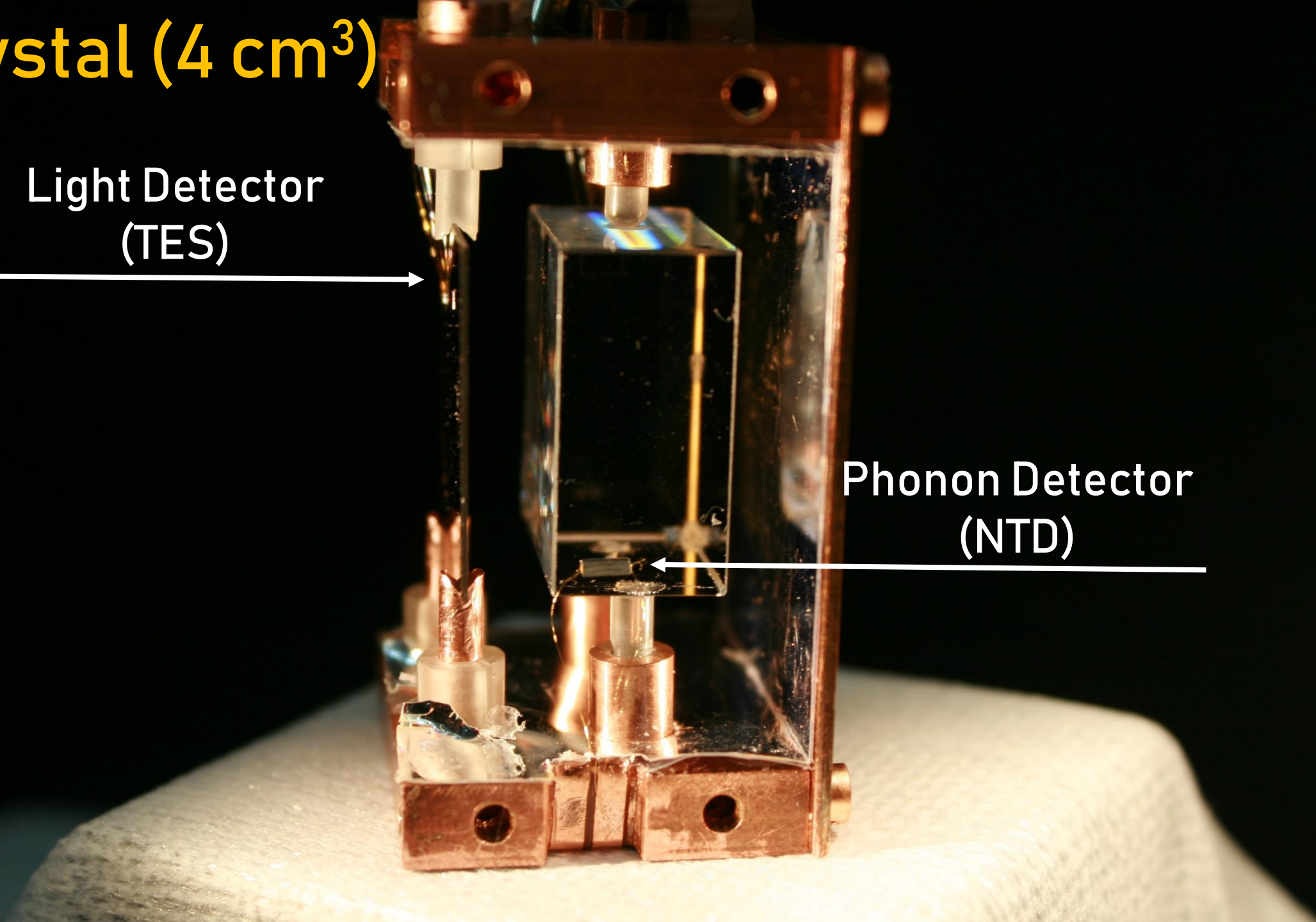
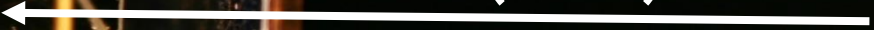


LiF crystal ( $4\text{ cm}^3$ )

Light Detector  
(TES)



Phonon Detector  
(NTD)

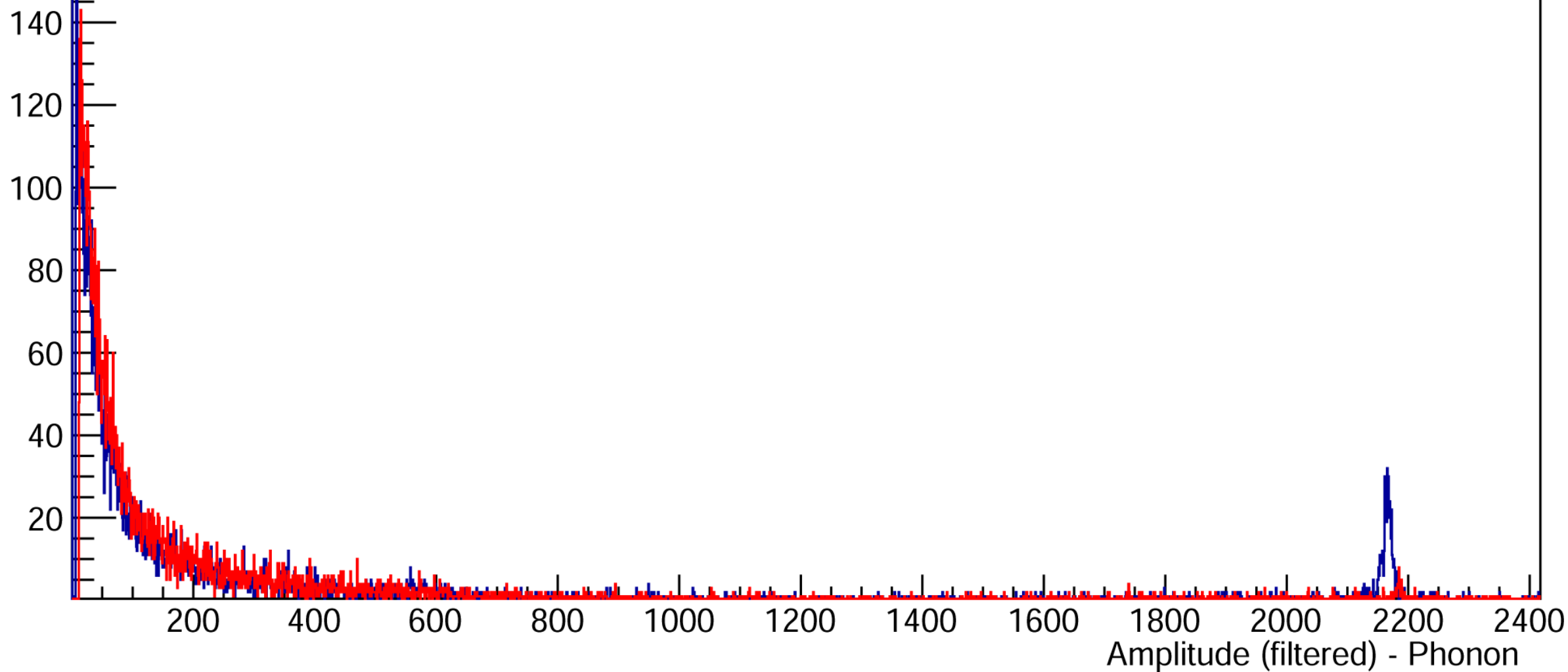


Counts

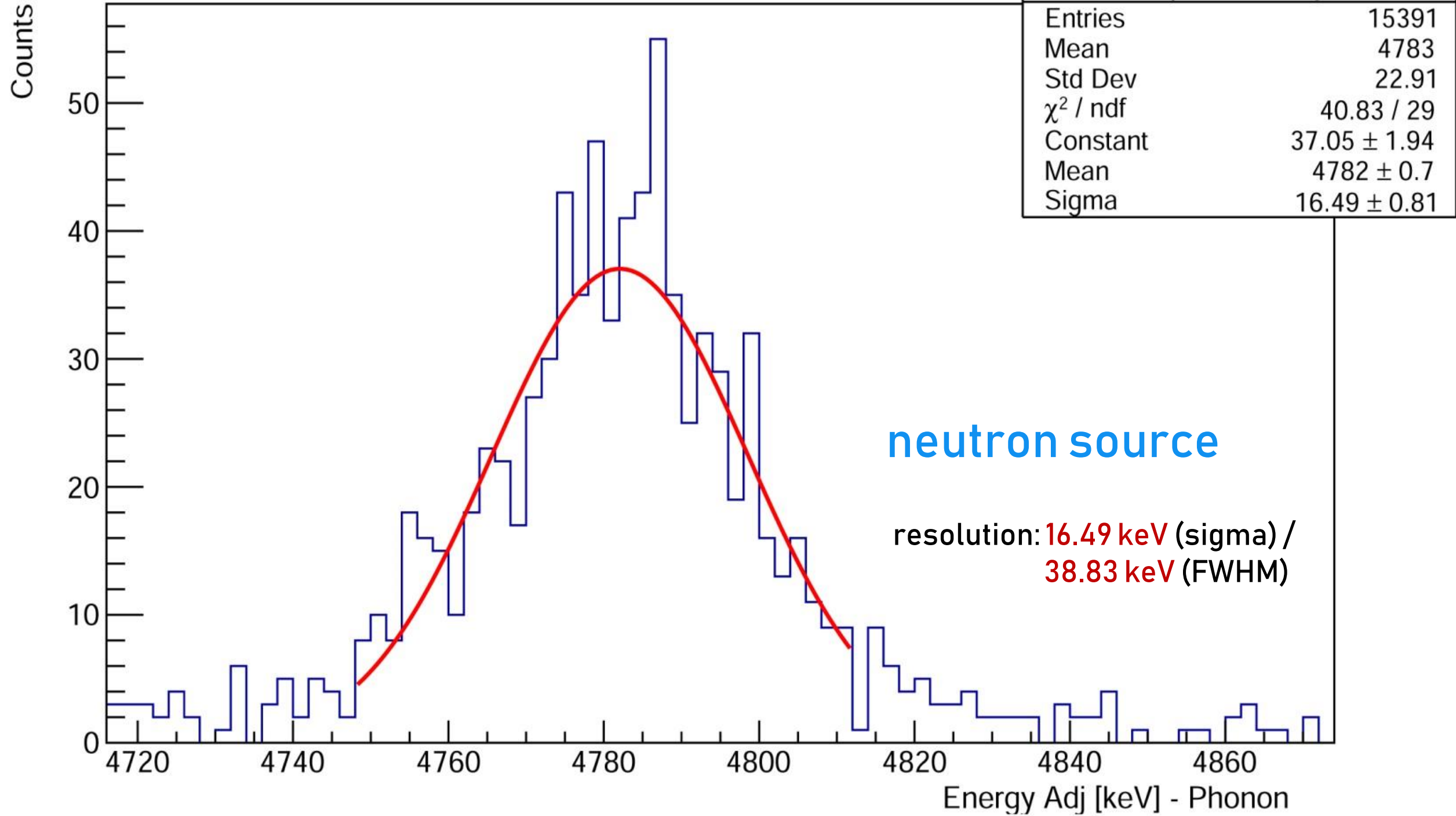
4 cm<sup>3</sup> LiF

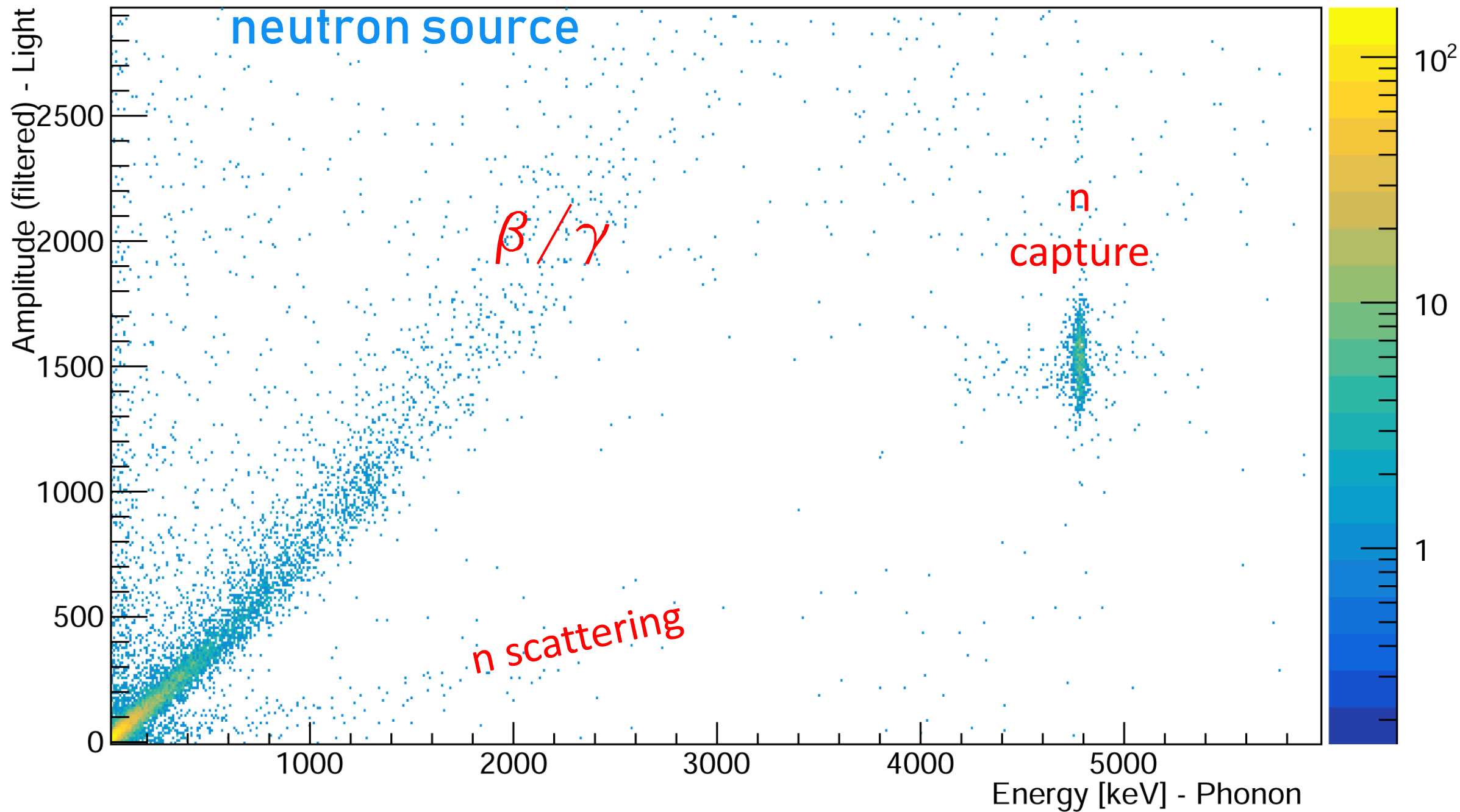
- neutron source at ~ 5m (600 minutes)

- neutron source at ~ 1m (600 minutes)









# Direct Dark Matter Search with Lithium

1 IA																	18 VIII A
1 H Hydrogen 1.00794	2 He Helium 4.002602																
3 Li Lithium 6.941	4 Be Beryllium 9.012182																
11 Na Sodium 22.98976928	12 Mg Magnesium 24.305	13 Al Aluminium 26.9815386	14 Si Silicon 28.0855	15 P Phosphorus 30.973762	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948										
19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.9559	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938045	26 Fe Iron 55.845	27 Co Cobalt 58.933195	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.38	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.9216	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.796
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.9063	42 Mo Molybdenum 95.96	43 Tc Technetium [98]	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.9055	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.90447	54 Xe Xenon 131.293
55 Cs Caesium 132.9054519	56 Ba Barium 137.327	57-71 Lanthanoids	72 Hf Hafnium 178.49	73 Ta Tantalum 180.94788	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.084	79 Au Gold 196.966569	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.9804	84 Po Polonium [209]	85 At Astatine [210]	86 Rn Radon [222]
87 Fr Francium [223]	88 Ra Radium [226]	89-103 Actinoids	104 Rf Rutherfordium [267]	105 Db Dubnium [268]	106 Sg Seaborgium [271]	107 Bh Bohrium [272]	108 Hs Hassium [270]	109 Mt Meitnerium [276]	110 Ds Darmstadtium [281]	111 Rg Roentgenium [280]	112 Cn Copernicium [285]	113 Nh Nihonium [286]	114 Fl Flerovium [289]	115 Mc Moscovium [288]	116 Lv Livermorium [293]	117 Ts Tennessine [294]	118 Og Oganesson [294]
57 La Lanthanum 138.90547	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.242	61 Pm Promethium [145]	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.9253	66 Dy Dysprosium 162.5	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.9668			
89 Ac Actinium [227]	90 Th Thorium 232.03806	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium [237]	94 Pu Plutonium [244]	95 Am Americium [243]	96 Cm Curium [247]	97 Bk Berkelium [247]	98 Cf Californium [251]	99 Es Einsteinium [252]	100 Fm Fermium [257]	101 Md Mendelevium [258]	102 No Nobelium [262]	103 Lr Lawrencium [262]			



## Expected Rate – Spin Independent

$$\frac{dR}{dE} \left[ \frac{1}{\text{keV} \cdot \text{kg} \cdot \text{day}} \right] = \varphi' \cdot \frac{m_T}{A m_\chi \mu_p^2} \cdot A^2 \cdot F^2(E_r) \cdot I_{halo} \cdot \sigma^{SI}$$

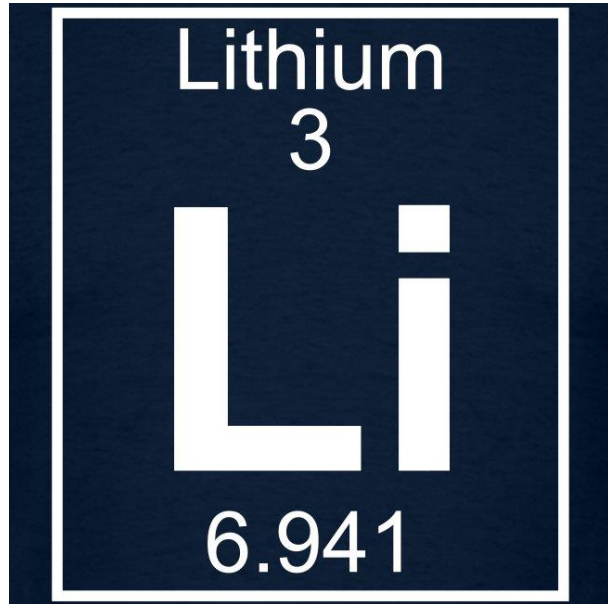
## Expected Rate – Spin Dependent

$$\frac{dR}{dE} \left[ \frac{1}{\text{keV} \cdot \text{kg} \cdot \text{day}} \right] = \varphi \cdot \frac{m_T}{A m_\chi \mu_{p/n}^2} \frac{J}{(J+1)} \cdot \langle S_{p/n} \rangle^2 \cdot F^2(E_r) \cdot I_{halo} \cdot \sigma_{p/n}^{SD}$$

$$I_{halo} = \frac{\rho_0}{k} \int_{v_{min}}^{v_{max}} \frac{f(\mathbf{v}, \mathbf{v}_E)}{v} d^3\mathbf{v}$$

$$v_{min} = \sqrt{\frac{m_T E_{th}}{2\mu_T^2}}$$

Spin Dependent interaction  
requires targets with  
odd-numbered nuclei

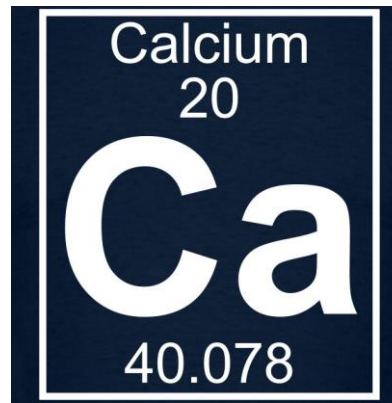


${}^6\text{Li}$  – 7.59%  
 ${}^7\text{Li}$  – 92.41%

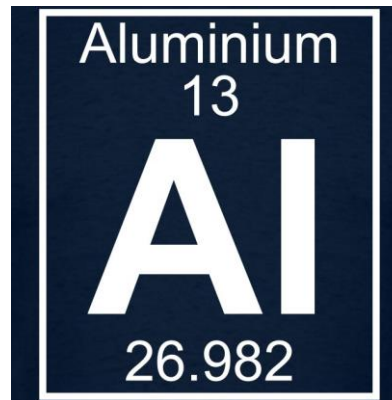
Calcium  
Tungstate

CRESST  
TARGETS

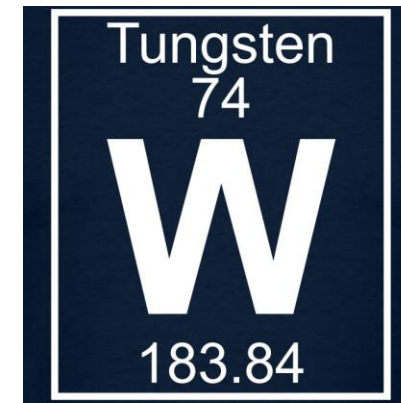
Sapphire



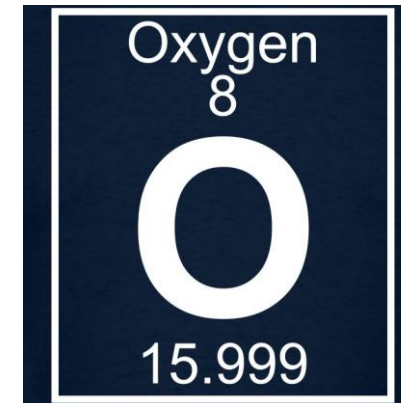
${}^{40}\text{Ca}$  – 96.941%  
 ${}^{42}\text{Ca}$  – 0.647%  
 ${}^{43}\text{Ca}$  – 0.135%  
 ${}^{44}\text{Ca}$  – 2.086%  
 ${}^{46}\text{Ca}$  – 0.004%  
 ${}^{48}\text{Ca}$  – 0.187%



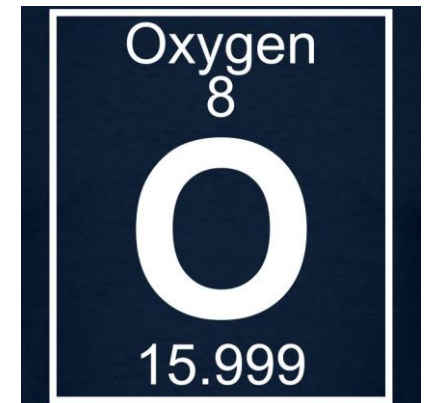
${}^{27}\text{Al}$  – 100.00%



${}^{180}\text{W}$  – 0.12%  
 ${}^{182}\text{W}$  – 26.50%  
 ${}^{183}\text{W}$  – 14.31%  
 ${}^{184}\text{W}$  – 30.64%  
 ${}^{186}\text{W}$  – 28.43%

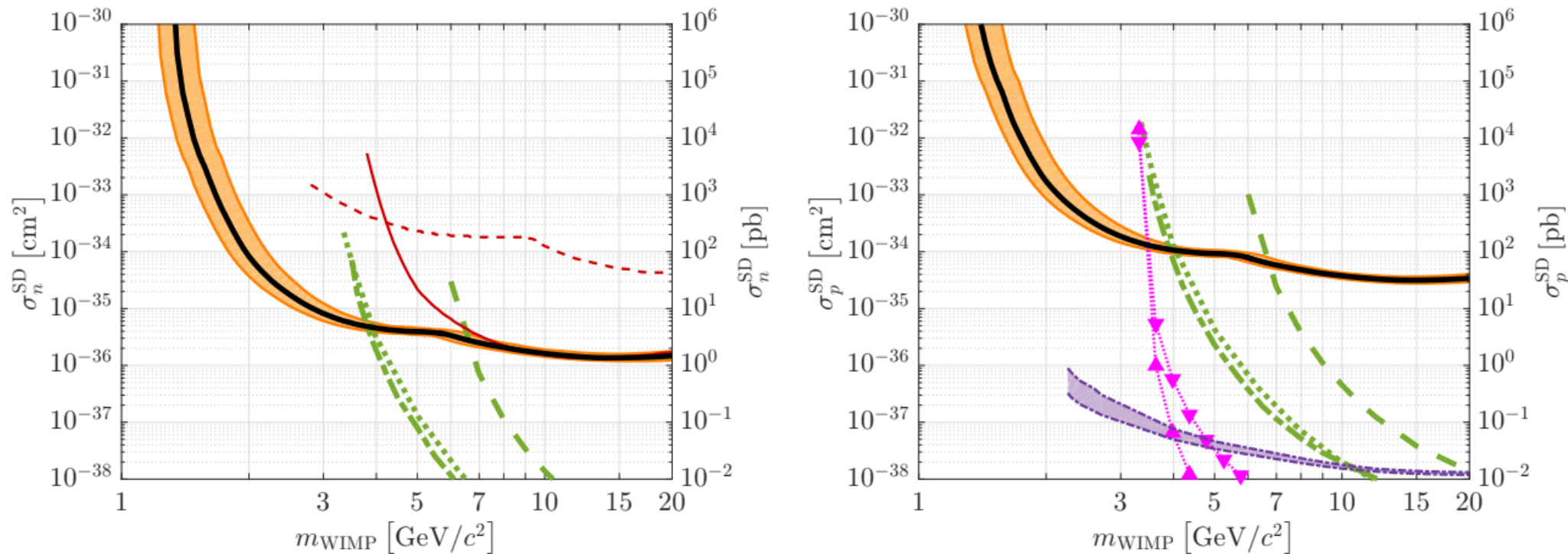


${}^{16}\text{O}$  – 99.76%  
 ${}^{17}\text{O}$  – 0.04%  
 ${}^{18}\text{O}$  – 0.20%



${}^{16}\text{O}$  – 99.76%  
 ${}^{17}\text{O}$  – 0.04%  
 ${}^{18}\text{O}$  – 0.20%

# Spin Dependent Search – State of the Art



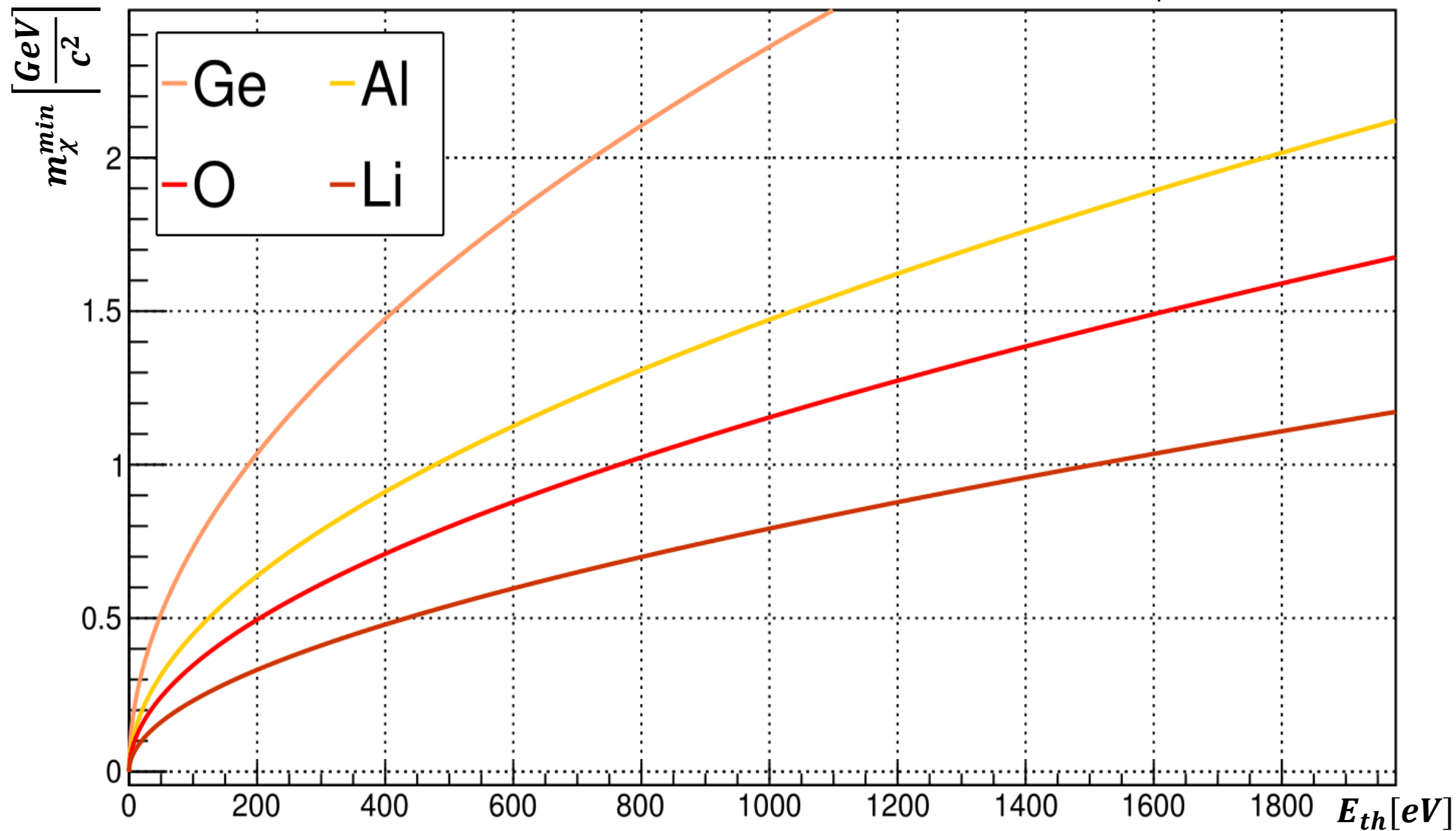
\* Figure 32. Upper limits on the spin-dependent free neutron  $\sigma_n^{\text{SD}}$  (left) and free proton  $\sigma_p^{\text{SD}}$  (right) WIMP scattering cross sections in the proton- and neutron-only models, respectively. For both, the median (90% C.L.) (thick black solid curve) upper limit from CDMSlite Run 2 is compared to other selected direct-detection limits from PANDAX-II (thick-green dotted curve) [61], LUX (thick-green dot-dashed curve) [62], XENON100 (thick-green dashed curve) [63], PICO-60 (magenta upward triangles) [64], PICO-2L (magenta downward triangles) [65], PICASSO (purple dot-dashed band) [66], CDEX-0 (thin-red dashed curve) [67, 68], and CDEX-1 (thin-red solid curve) [68]. The orange band surrounding the Run 2 result is the 95% uncertainty interval on the upper limit. The Run 2 limits are the most sensitive for  $m_{\text{WIMP}} \lesssim 4$  and  $\lesssim 2 \text{ GeV}/c^2$  for the neutron- and proton-only models, respectively.

(\* *Low-mass dark matter search with CDMSlite*, SuperCDMS Collaboration, 2017)



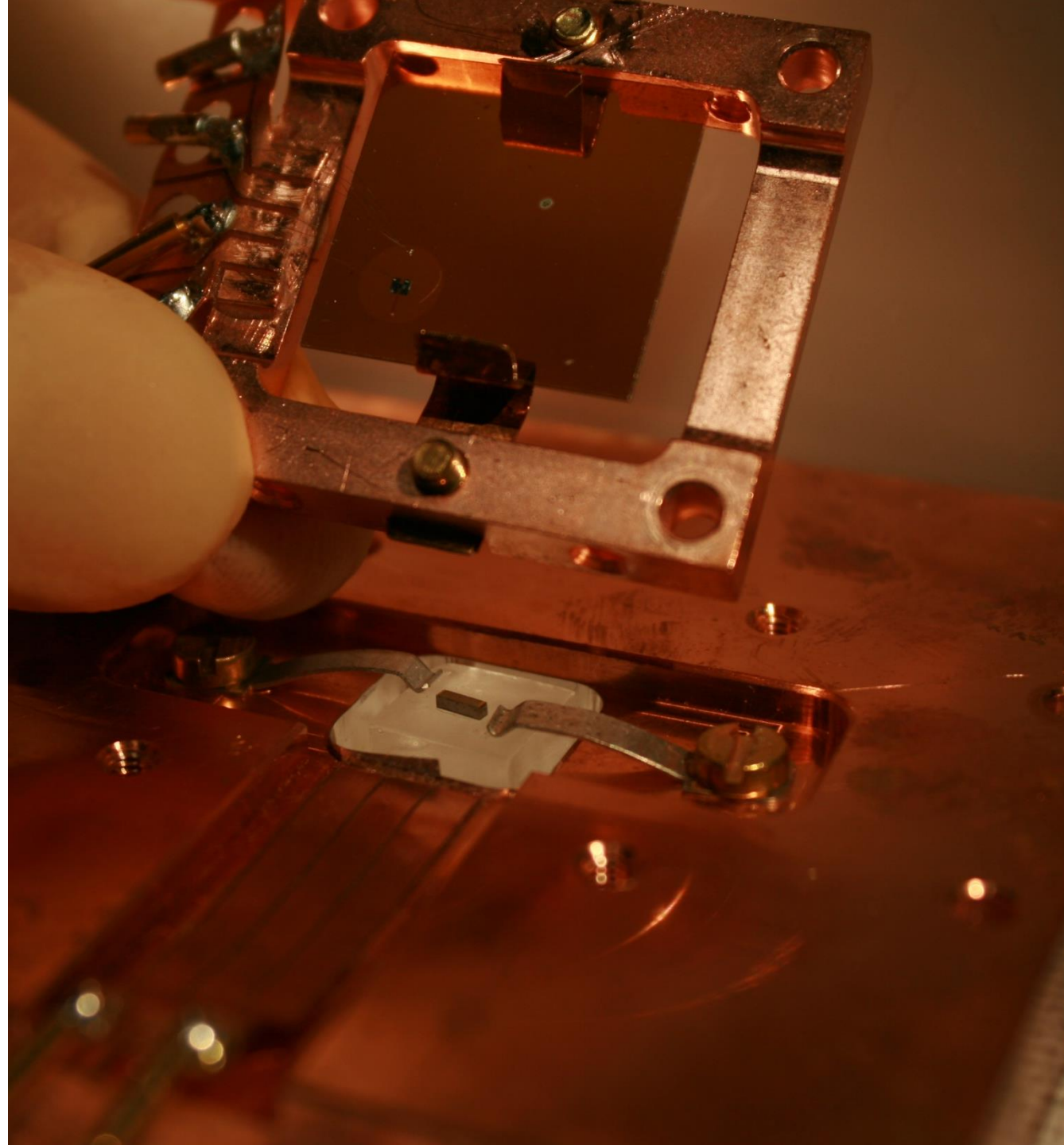
# Probing Power:

$$v_{min} = \sqrt{\frac{m_T E_{th}}{2\mu_T^2}} \longrightarrow m_\chi^{min} = \frac{m_T}{\sqrt{\frac{2m_T v_{max}^2}{E_{th}} - 1}}$$



# SUMMARY

- **R&D** to find a suitable crystal ( $\text{Li}_2\text{MoO}_4$ ) to build a cryogenic neutron monitor for CRESST experiment
- **Motivation** to use Lithium-based crystals for Dark Matter search
- **First results** for Spin-Dependent DM search with Lithium are coming soon
- **R&D** on crystals containing Lithium ( $\text{LiAlO}_2$ ,  $\text{LiTaO}_3$ , and  $\text{LiNbO}_3$ ) to be done

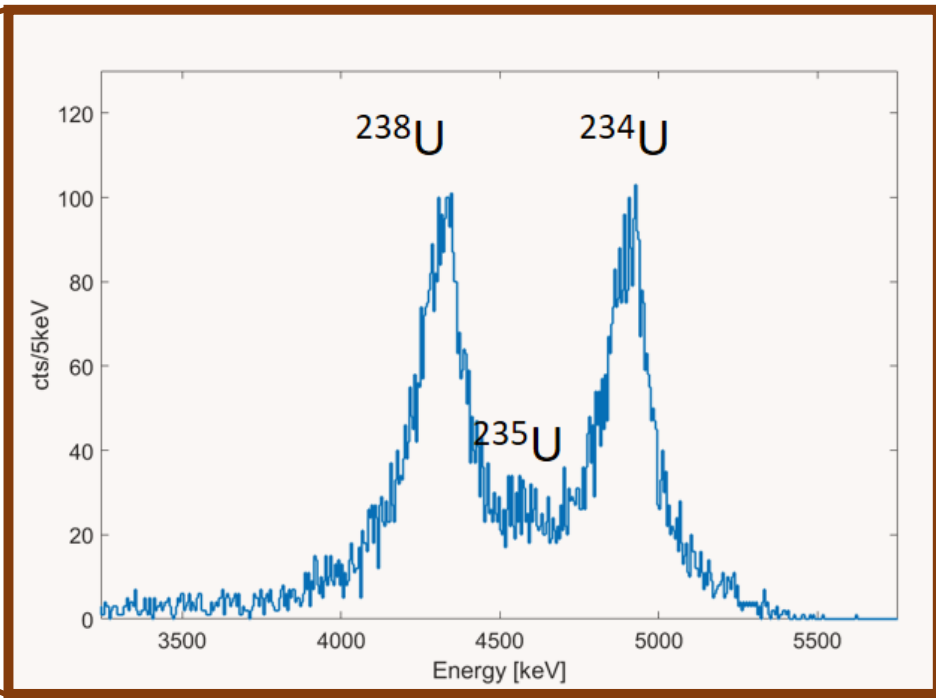
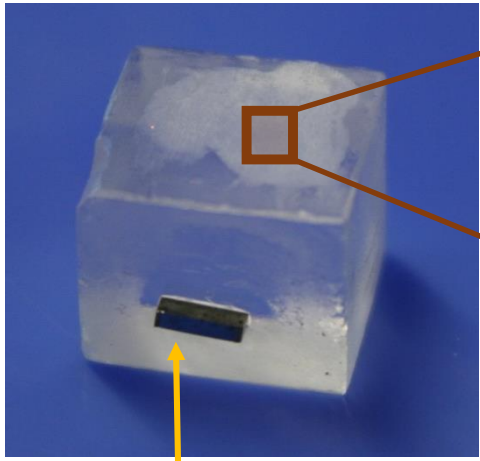




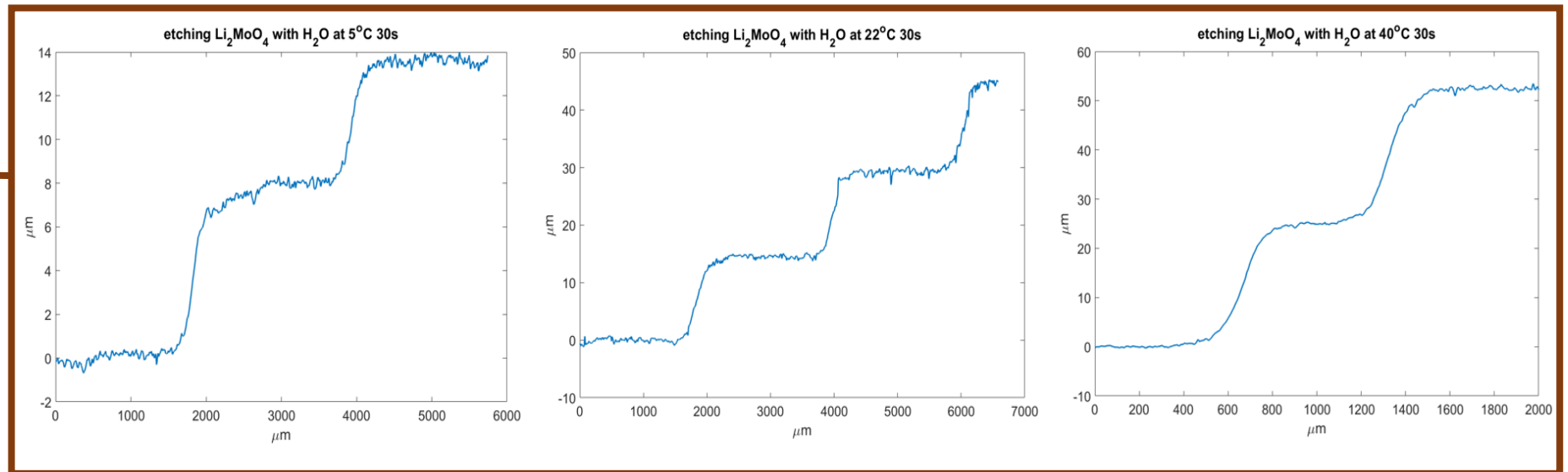
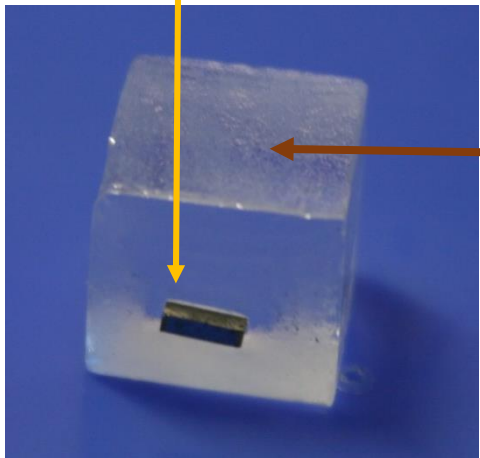
"I can't tell you what's in the dark matter sandwich. No one knows what's in the dark matter sandwich."

# THANK YOU





NTD - Neutron Transmutation Doped Ge  
(Phonon Detector)



water polishing

