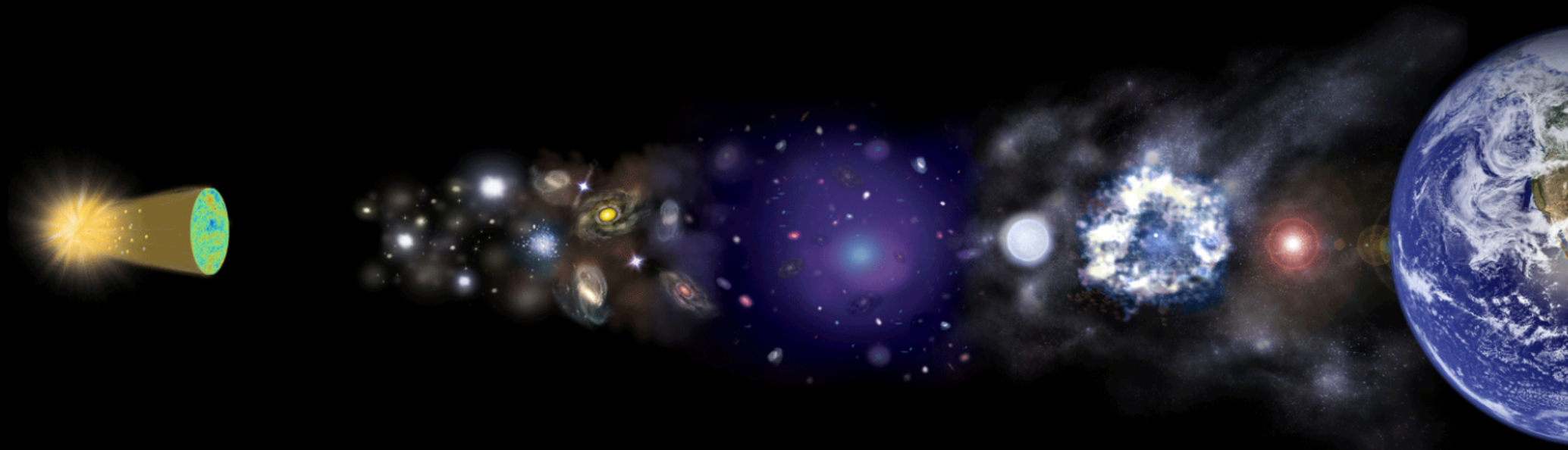
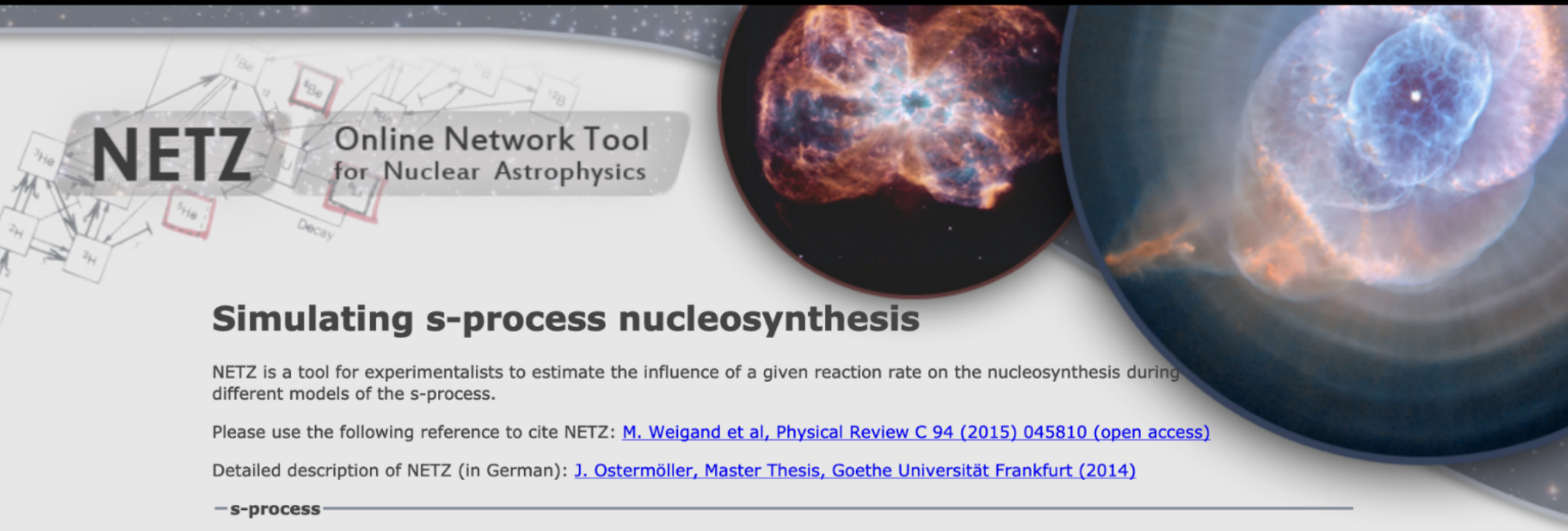
Experimental Astrophysics

Kathrin Göbel & René Reifarth



Chandra, NASA

www.exp-astro.de



Simulating s-process nucleosynthesis

NETZ is a tool for experimentalists to estimate the influence of a given reaction rate on the nucleosynthesis during different models of the s-process.

Please use the following reference to cite NETZ: M. Weigand et al, Physical Review C 94 (2015) 045810 (open access)

Detailed description of NETZ (in German): J. Ostermöller, Master Thesis, Goethe Universität Frankfurt (2014)

s-process

Model: Main component- T-AGB

Reaction

Element: Fe

Mass: 56

Reaction: (n,g)

Factor: 0.5

exp-astro.de/netz/

Start simulation

main: $90 < A < 210$

TP-AGB stars 1-3 M_{sun}

shell H-burning	He flash
kT = 8 keV	kT = 25 keV
10^7 - 10^8 cm^{-3}	10^{10} - 10^{11} cm^{-3}
^{13}C(a,n)	^{22}Ne(a,n)

weak: $A < 90$

massive stars > 8 M_{sun}

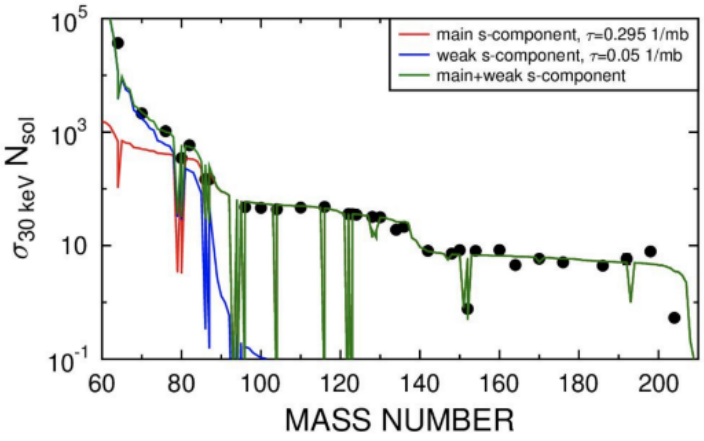
core He burning	shell C burning
kT = 25 keV	kT = 90 keV
10^6 cm^{-3}	10^{11} - 10^{12} cm^{-3}
^{22}Ne(a,n)	^{22}Ne(a,n)

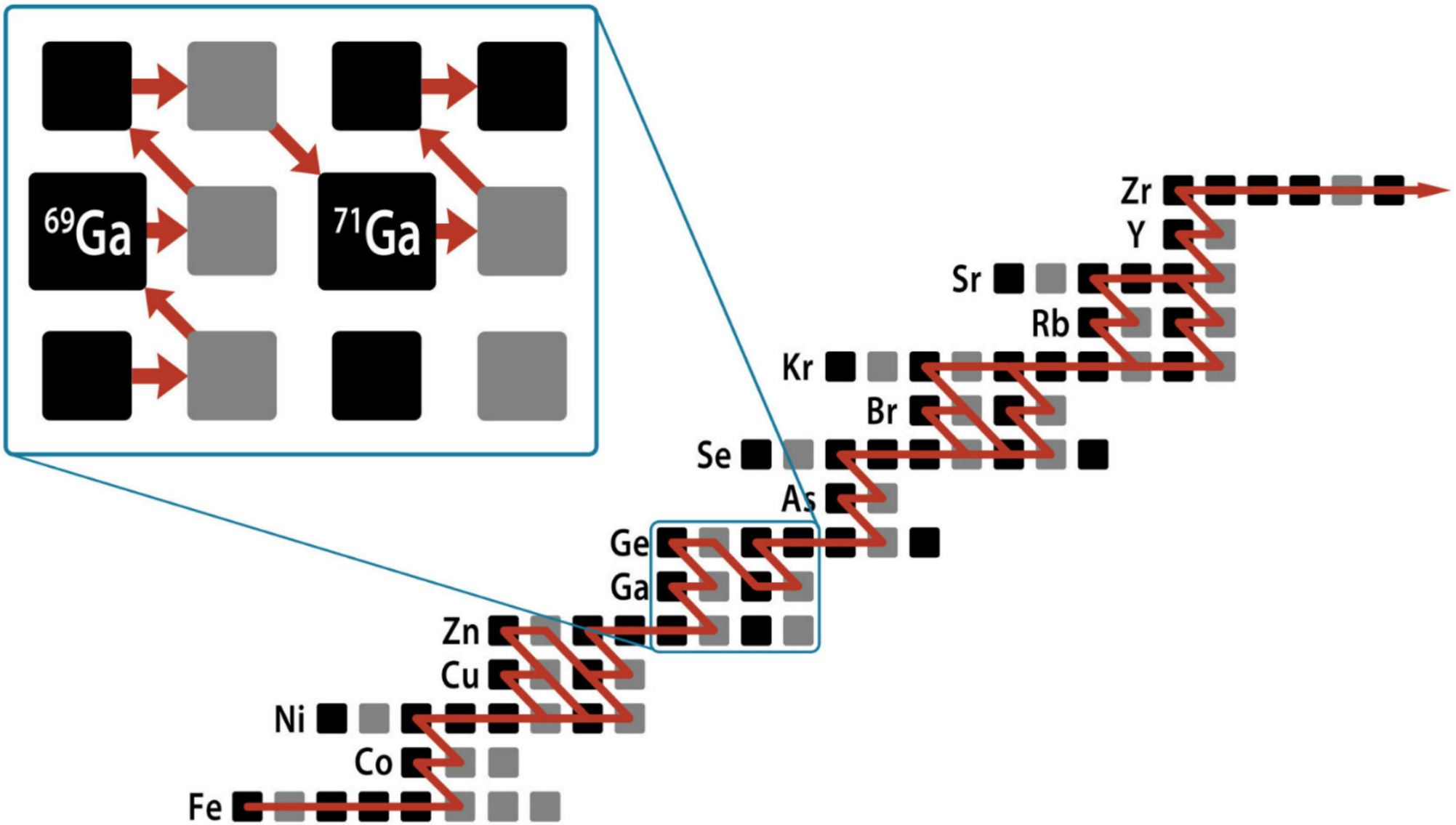
Estimate the influence of different reaction rates.

What are the differences between the main and weak s process?

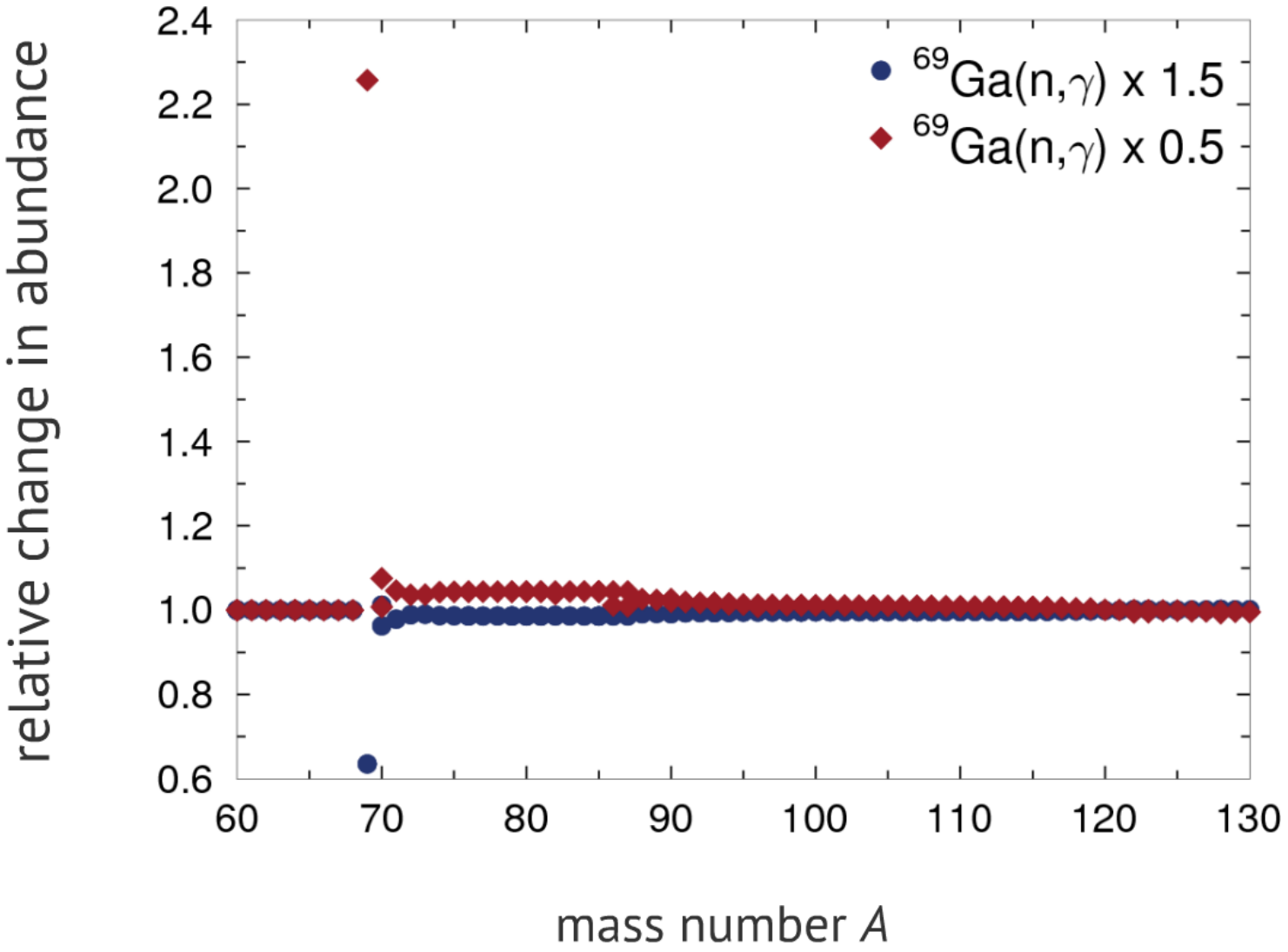
exp-astro.de/netz/

$$N(A) = \text{const.} \cdot \frac{1}{\sigma(A)} \cdot \prod_{i=56}^{A} \left(1 + \frac{1}{\sigma_i \cdot \tau_0}\right)^{-1}$$

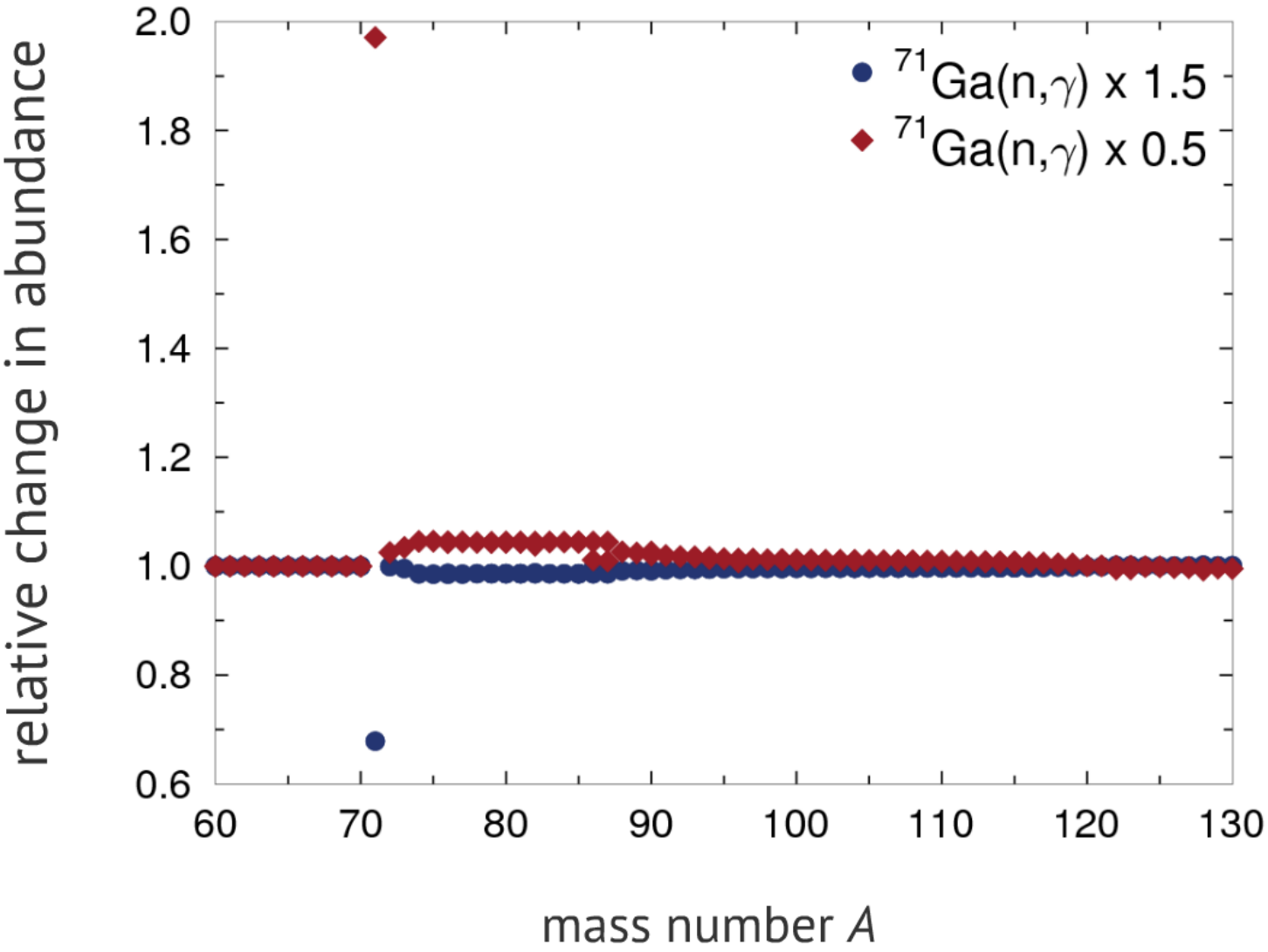



^{69}Ga
^{71}Ga
Zr
Y
Sr
Rb
Kr
Br
Se
As
Ge
Ga
Zn
Cu
Ni
Co
Fe

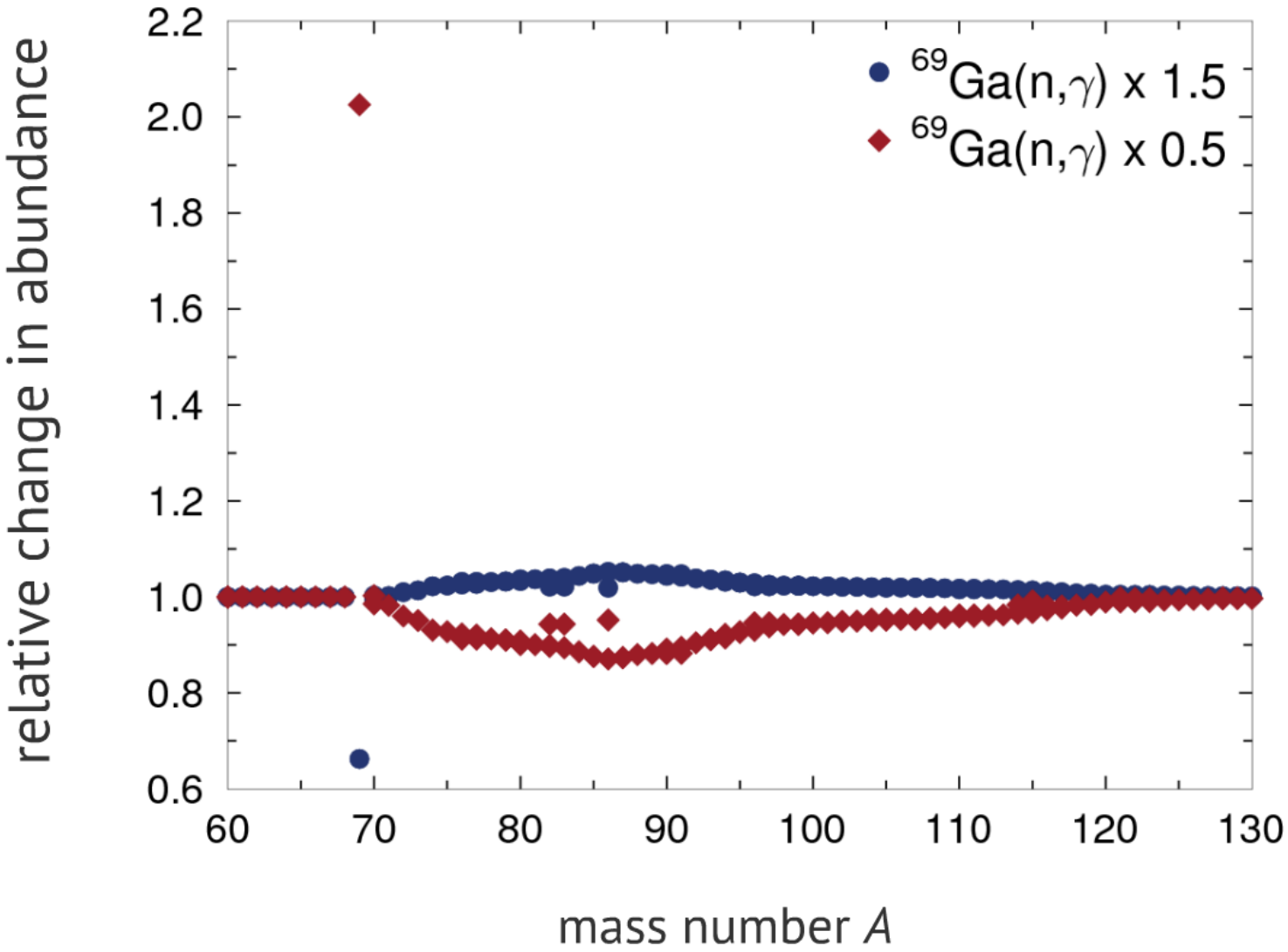
main s process



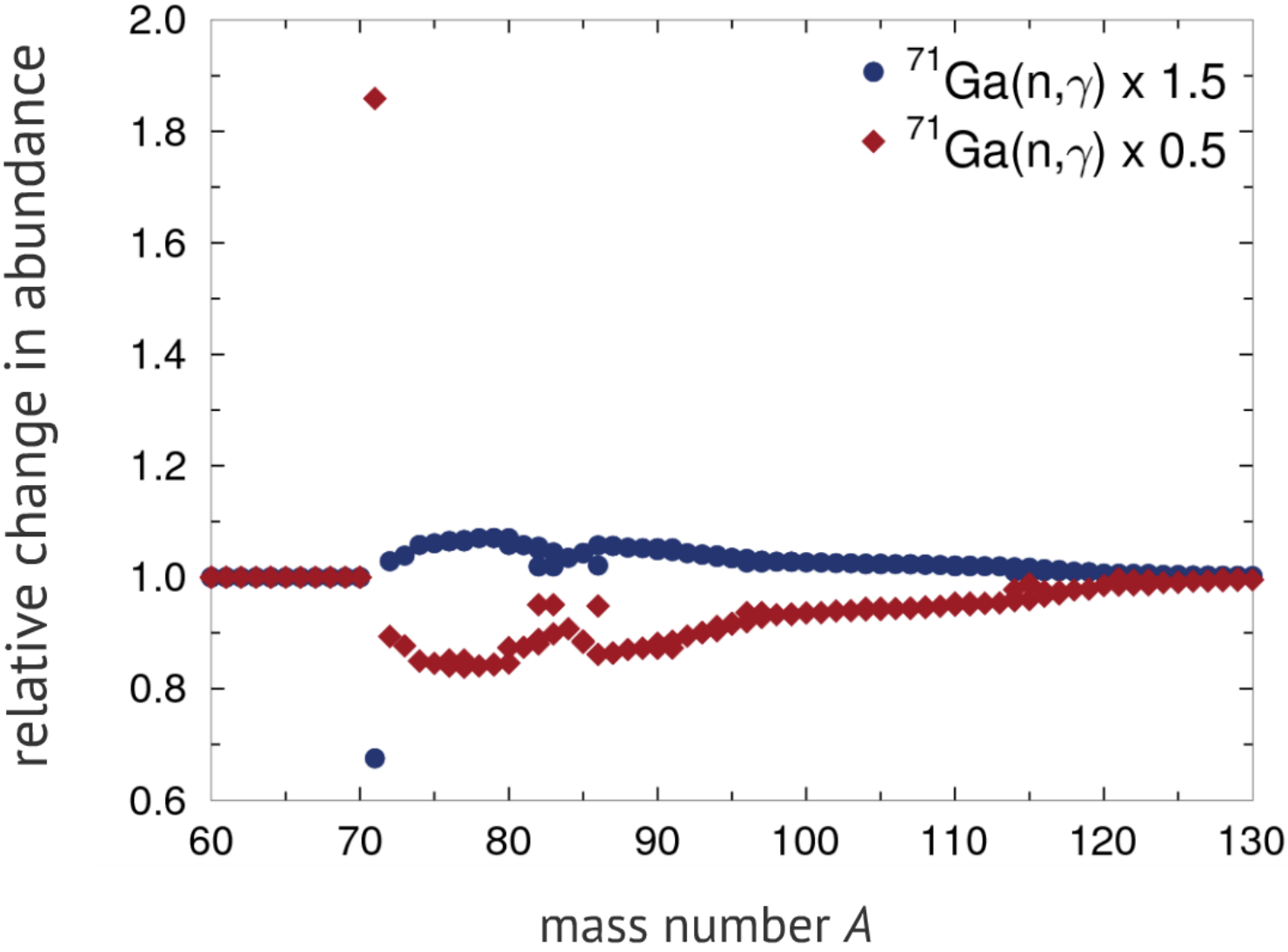
main s process



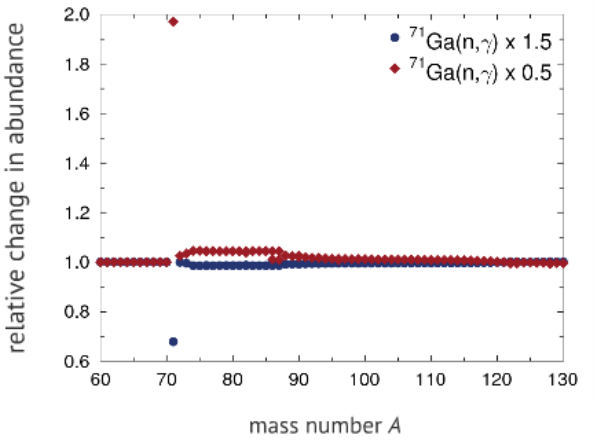
weak s process



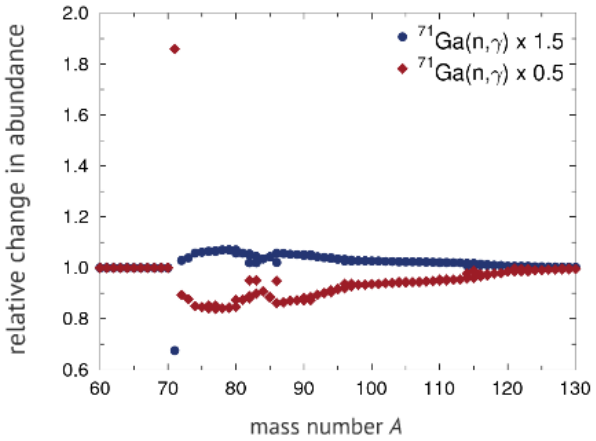
weak s process



main s process



weak s process



We need the

(n,γ) cross sections of

^{69}Ga and ^{71}Ga

for 25 keV and 90 keV

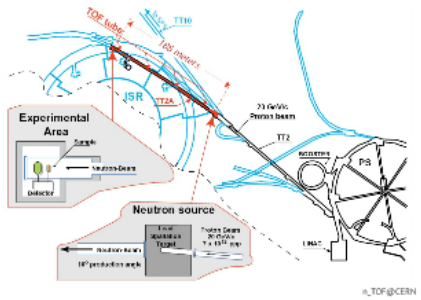
(n, γ) cross section measurements

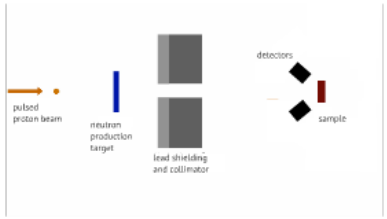
time-of-flight

activation

In the lab @ n_TOF/CERN

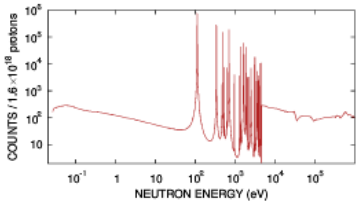
neutron time-of-flight

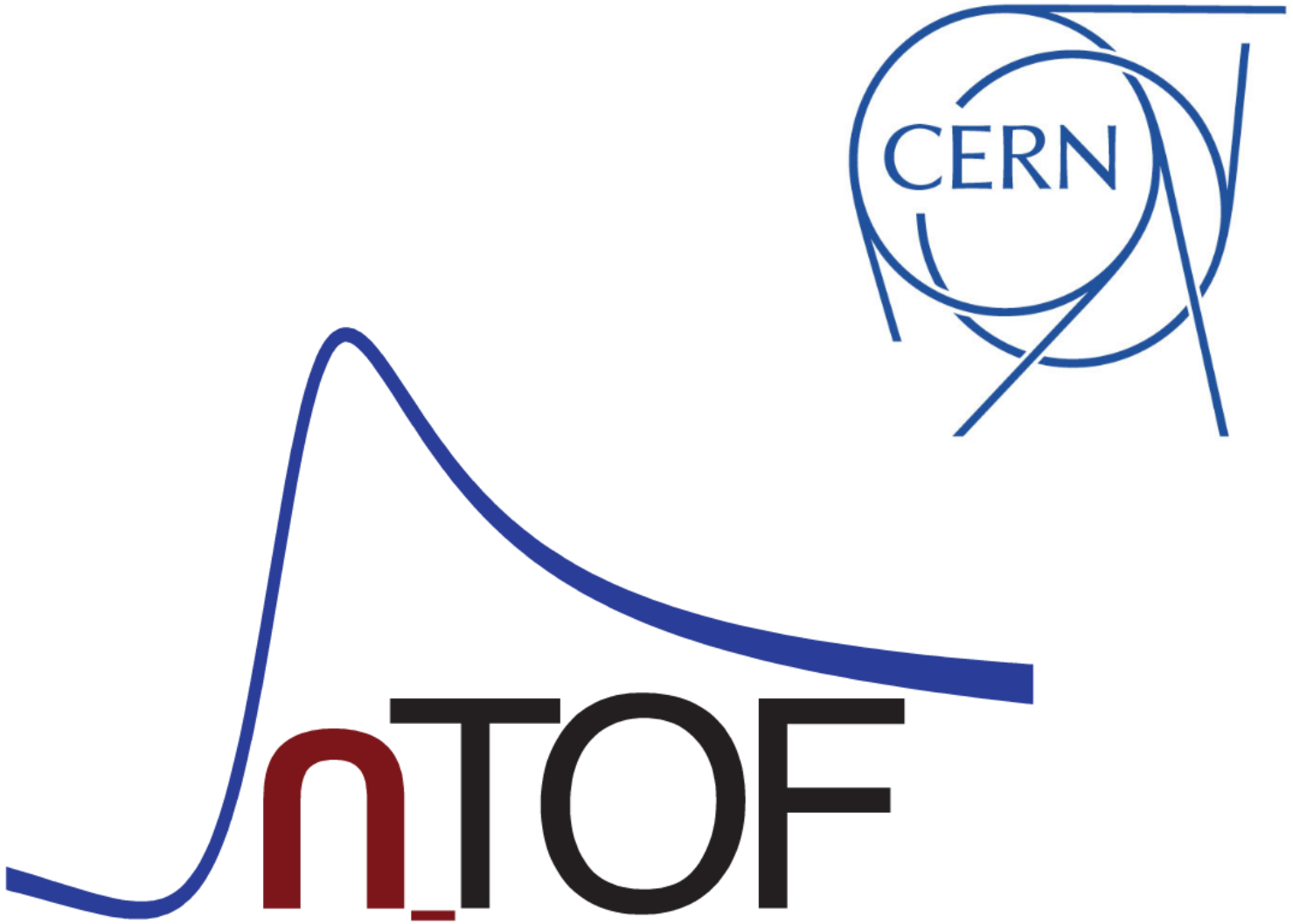




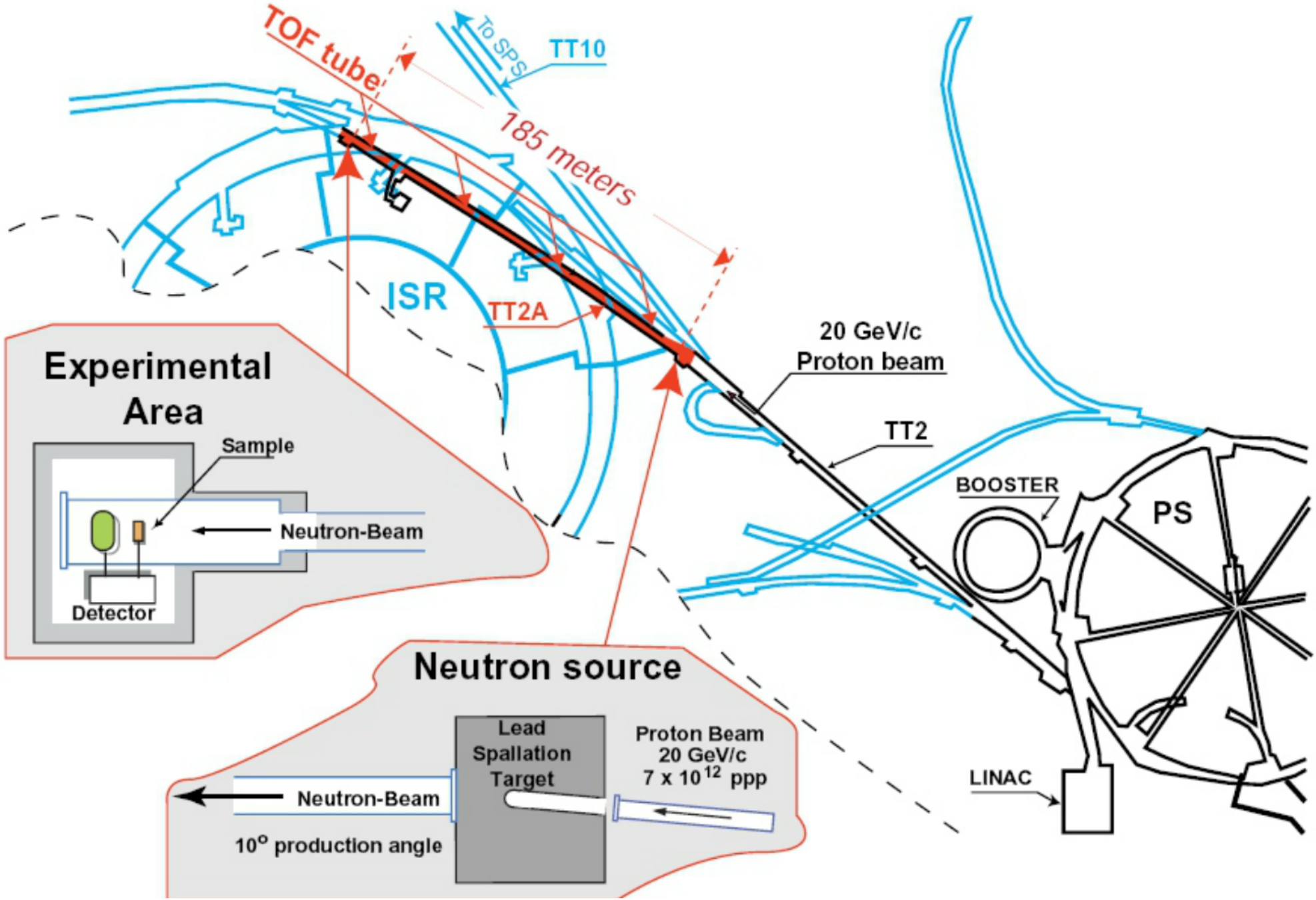

Gallium samples and detectors

expectation for ^{69}Ga

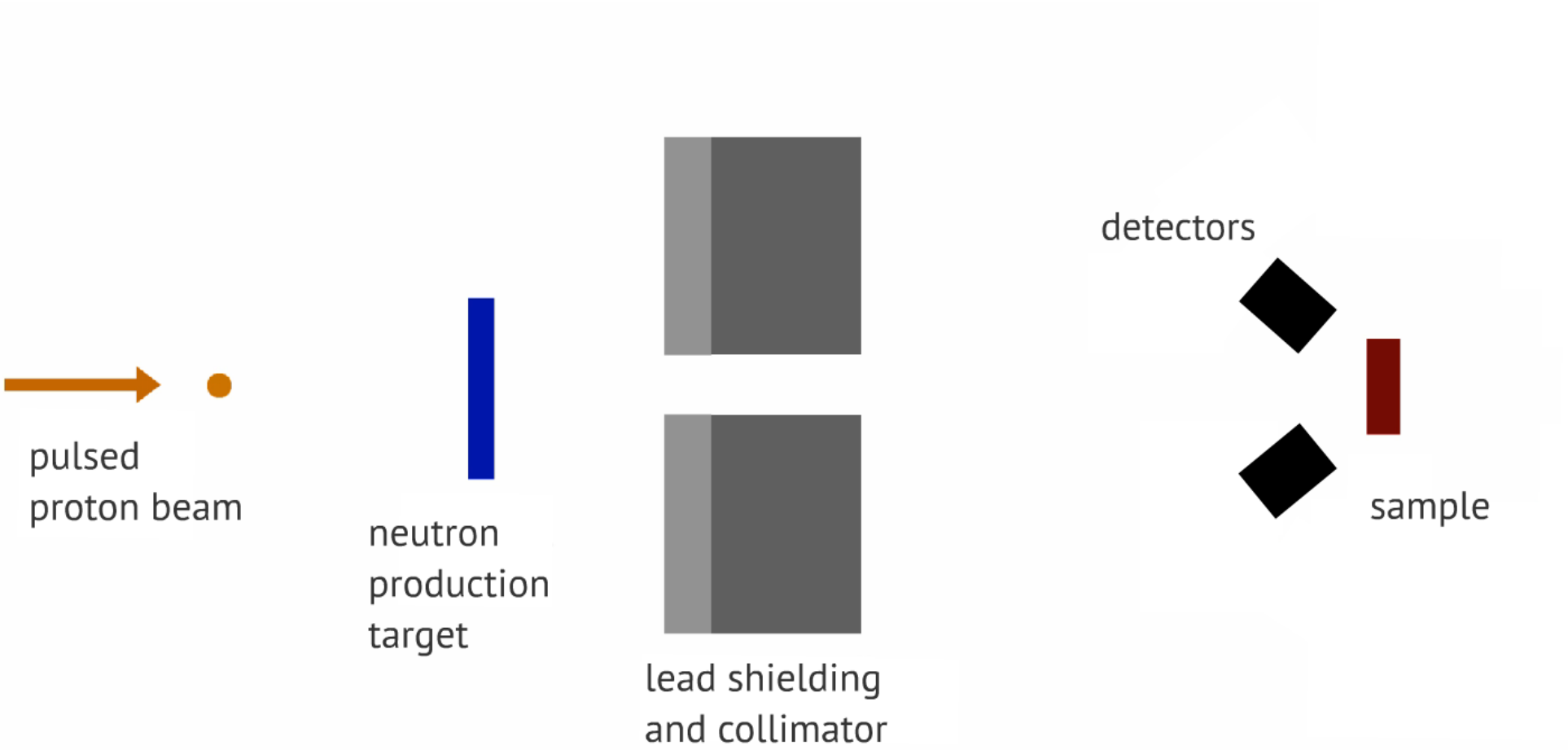




neutron time-of-flight


TOF tube
To SPS
TT10
185 meters
ISR
TT2A
20 GeV/c
Proton beam
TT2
BOOSTER
PS
LINAC
Experimental
Area
Sample
Neutron-Beam
Detector
Neutron source
Lead
Spallation
Target
Proton Beam
20 GeV/c
7 x 10 12 ppp
Neutron-Beam
10° production angle

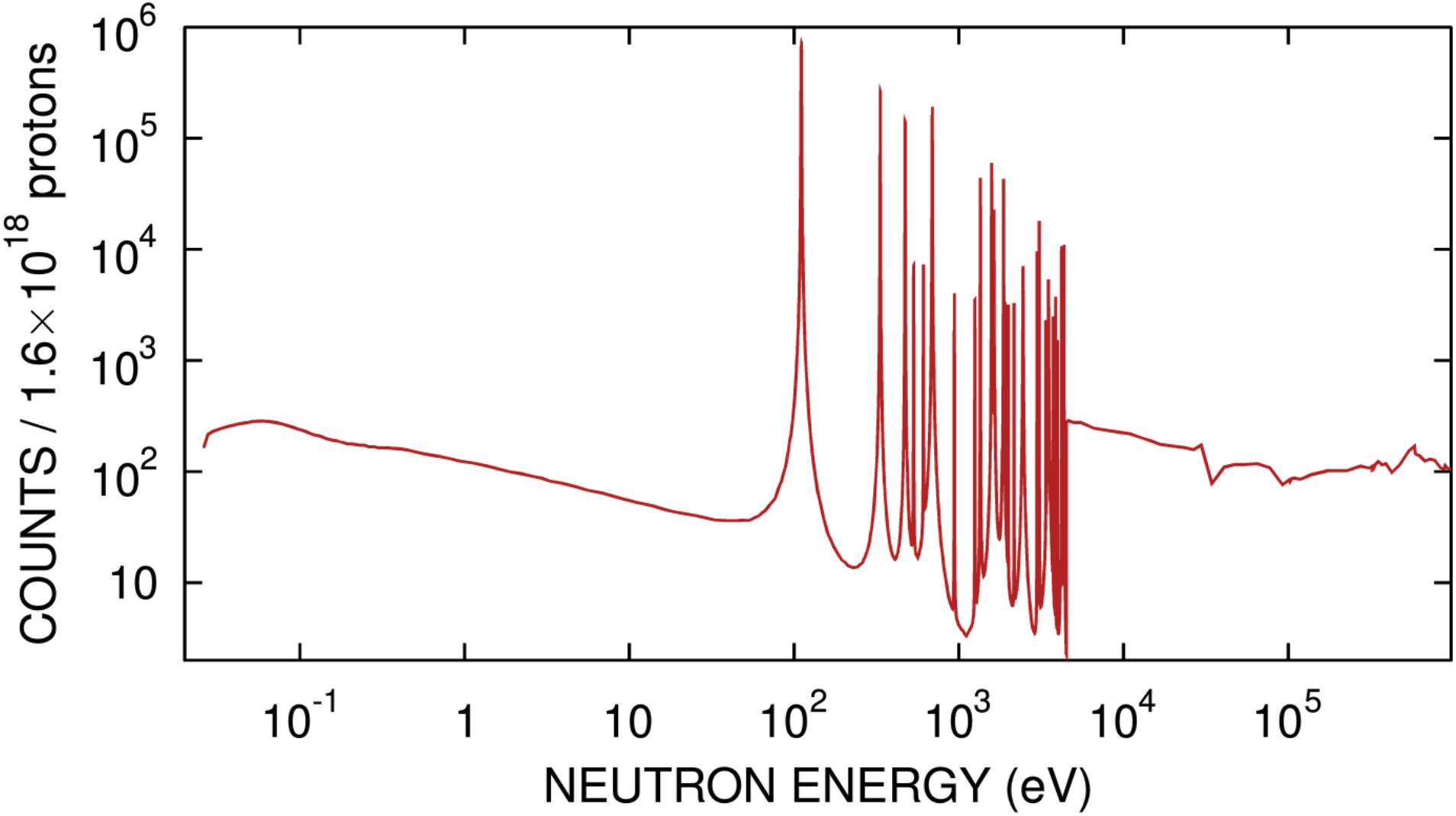
n_TOF@CERN


pulsed
proton beam
neutron
production
target
lead shielding
and collimator
detectors
sample

Gallium samples and detectors

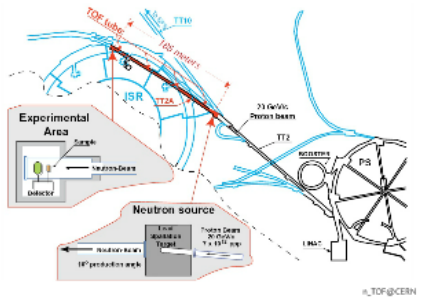
Photo: Deniz Kurtulgil

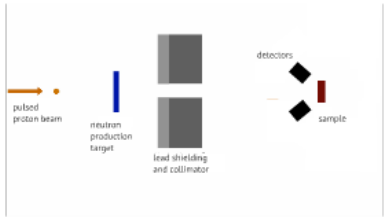
expectation for ^{69}Ga



In the lab @ n_TOF/CERN

neutron time-of-flight






Gallium samples and detectors

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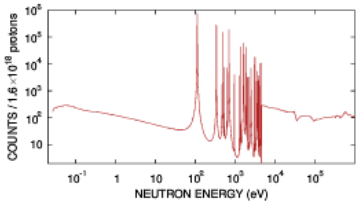
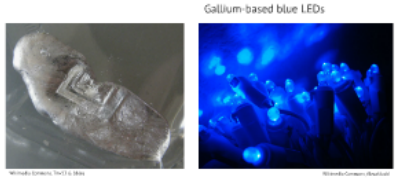


In the lab @ GUF

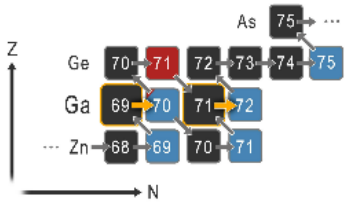
Gallium



Gallium

two stable isotopes

^{69}Ga	^{71}Ga
60%	40%



Neutron capture cross section

$$\sigma = \frac{N_{\text{produced}}}{\Phi_n \cdot N_{\text{sample}}}$$

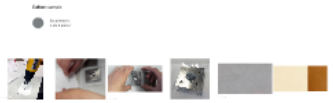
Number of produced nuclei

$$N_{\text{produced}} = \frac{C}{I_\gamma \cdot \epsilon \cdot \kappa \cdot f_{\text{dt}} \cdot f_{\text{b}} \cdot f_{\text{dw}} \cdot f_{\text{casc}}}$$

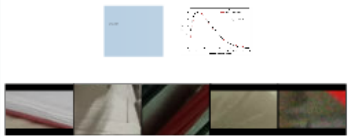
correct counts in detector for...

- gamma intensity
- efficiency
- gamma absorption
- dead time
- decays during activation
- waiting time
- gamma cascades

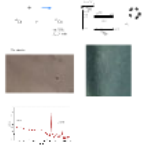
1. Gallium sample

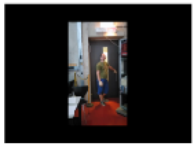


2. Neutrons



3. Count products





Gallium

Wikimedia Commons, Tmv23 & Dblay

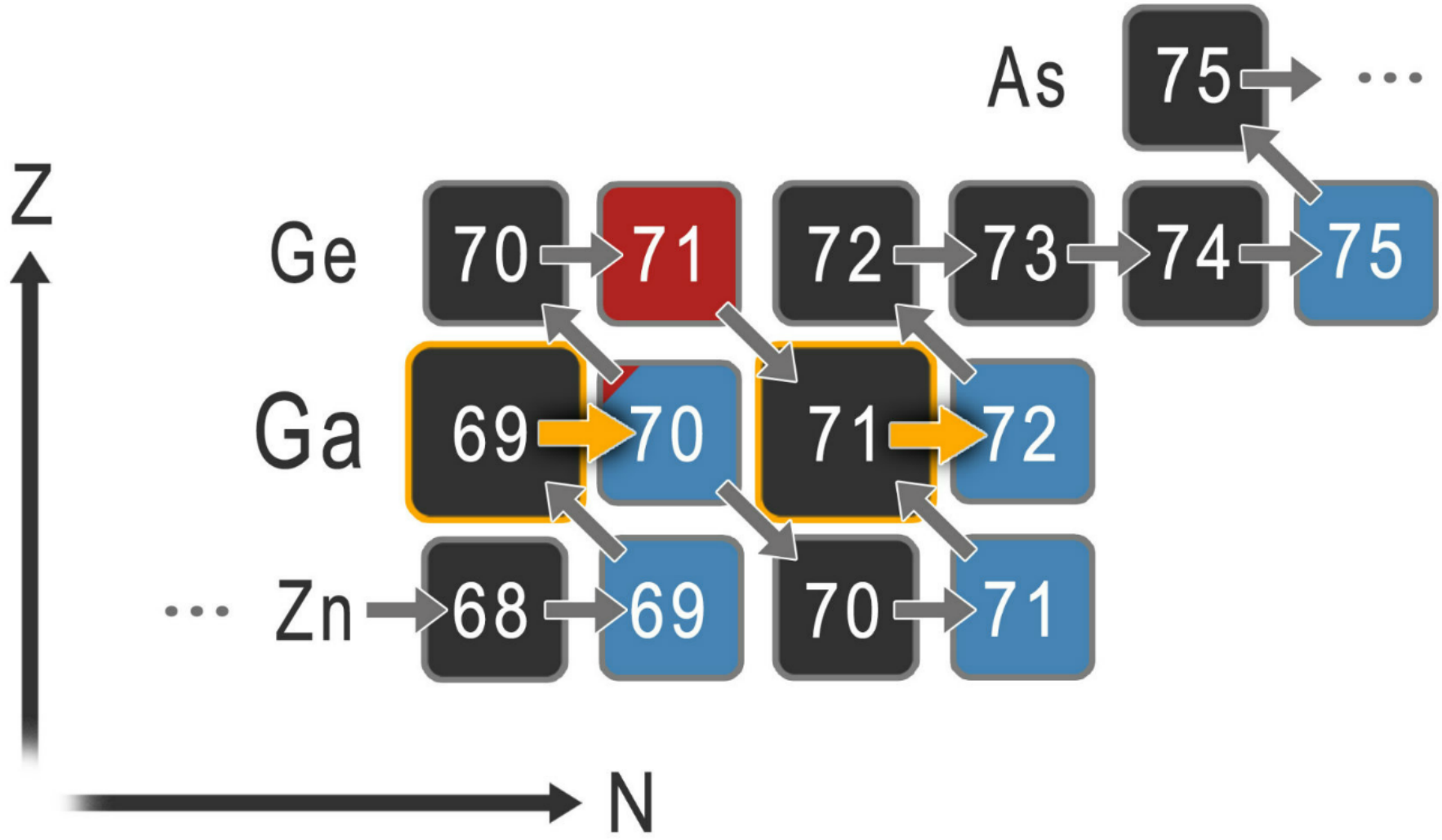
Gallium-based blue LEDs

Wikimedia Commons, Alexofdodd

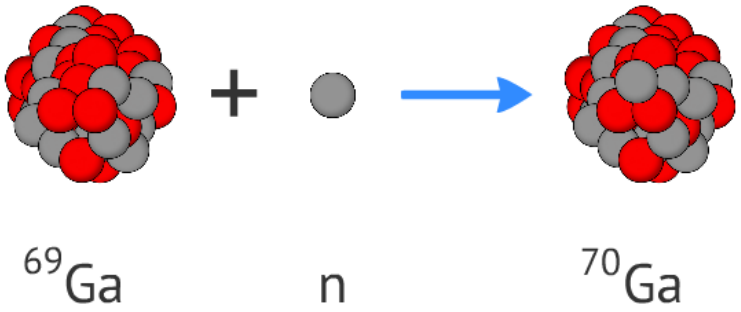
Gallium

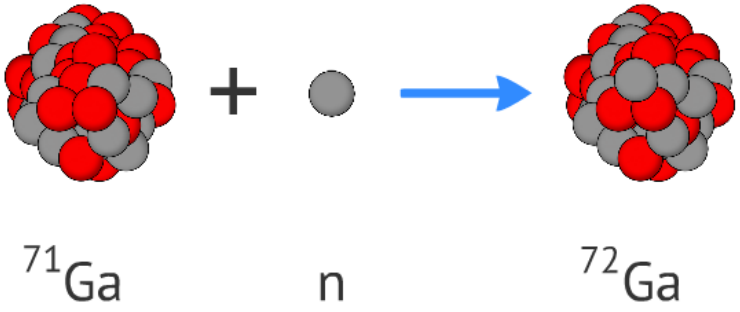
two stable isotopes

^{69}Ga	^{71}Ga
60%	40%


As
75
...
Z
Ge
70
71
72
73
74
75
Ga
69
70
71
72
... Zn
68
69
70
71
N

Neutron capture cross section





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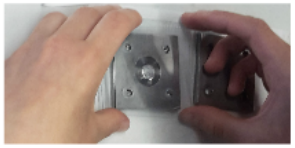
correct counts in detector for...

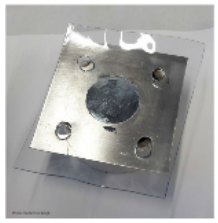
- gamma intensity
- efficiency
- gamma absorption
- dead time
- decays during activation
- waiting time
- gamma cascades

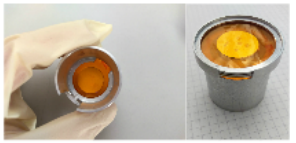
1. Gallium sample

Gallium sample

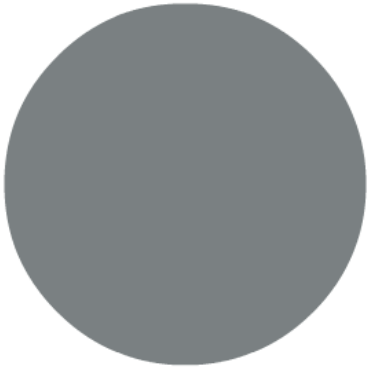
Requirement:
2 cm diameter







Gallium sample



Requirement:
2 cm diameter

Photo: Deniz Kurtulgil

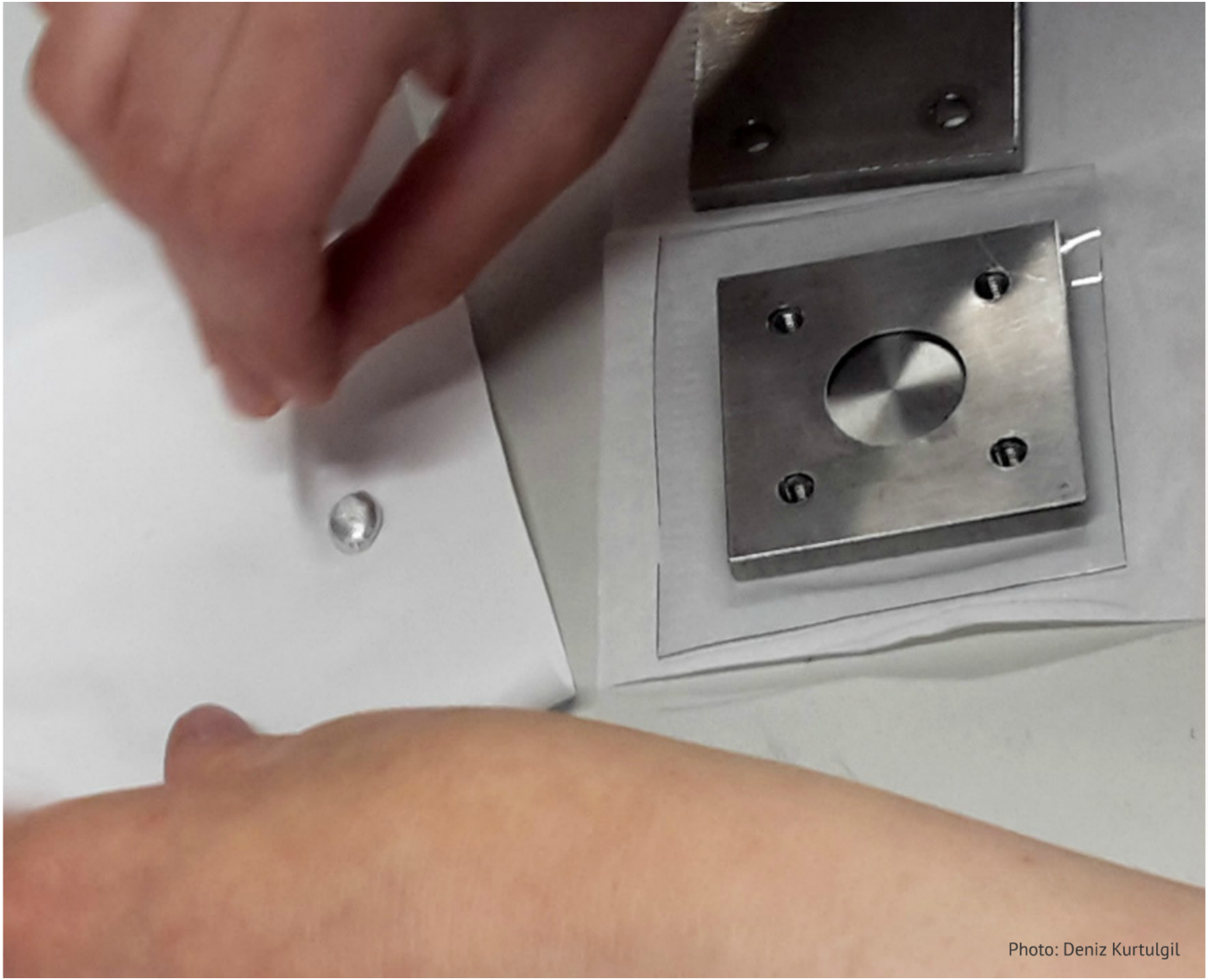


Photo: Deniz Kurtulgil

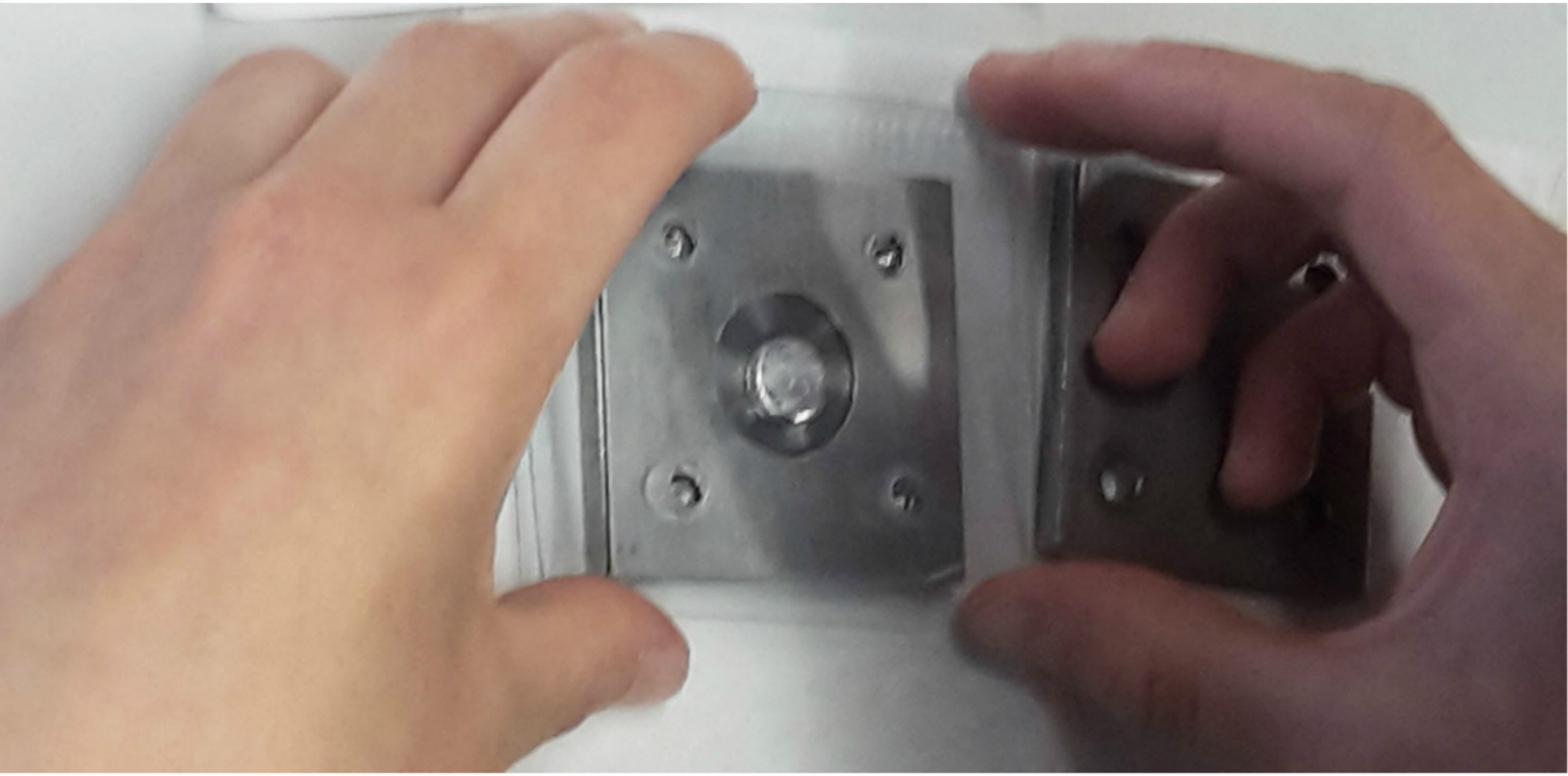


Photo: Deniz Kurtulgil

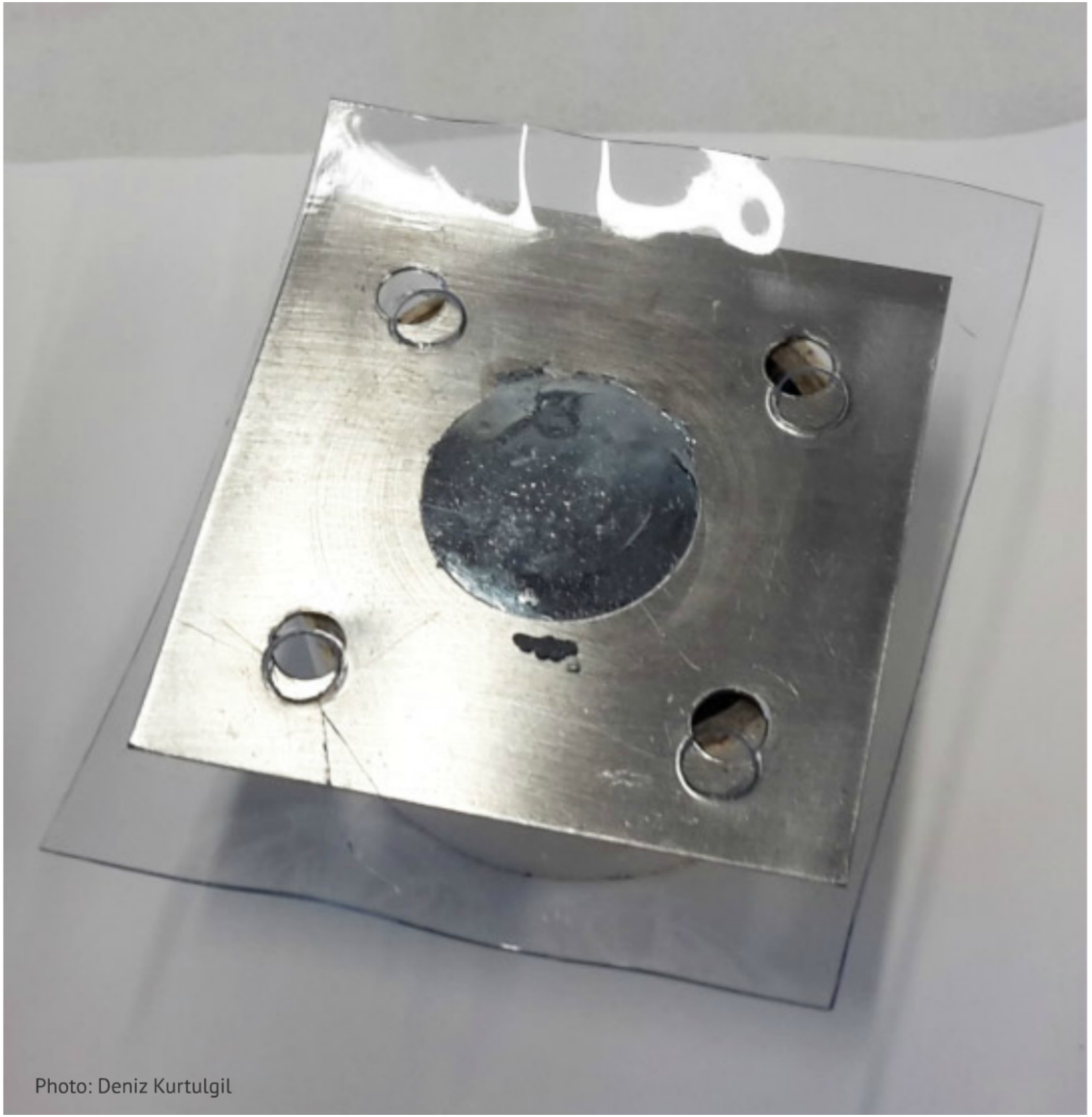


Photo: Deniz Kurtulgil

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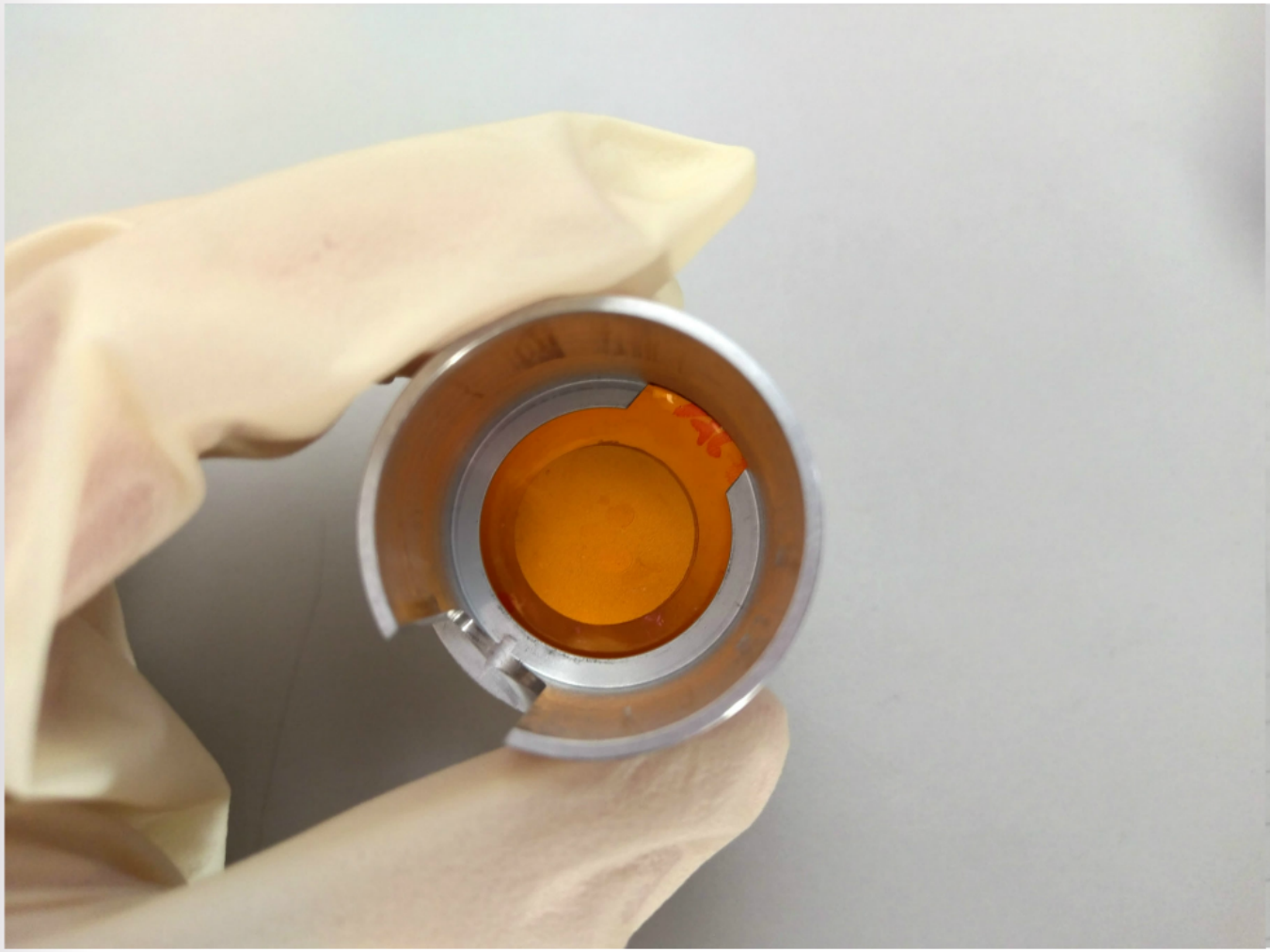
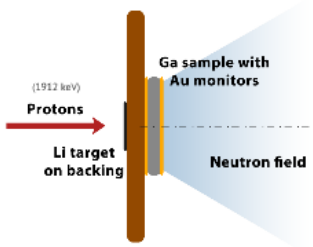
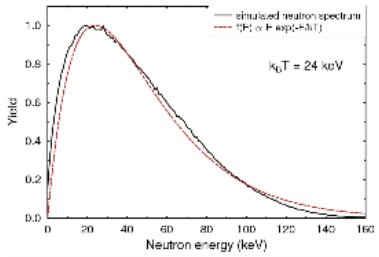
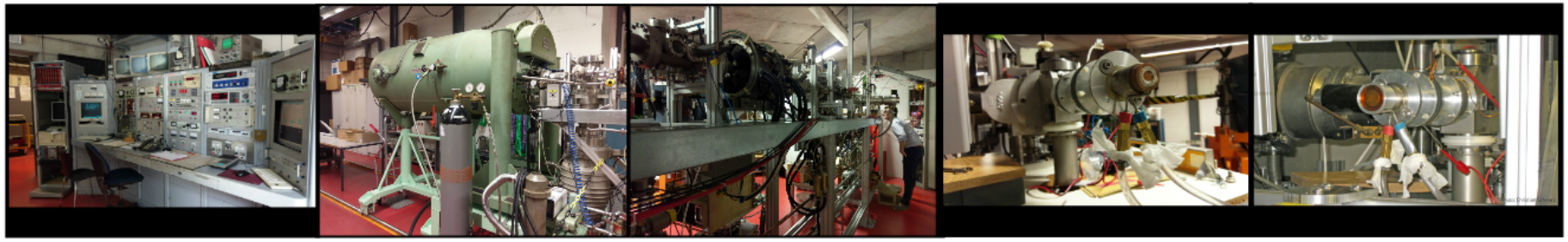
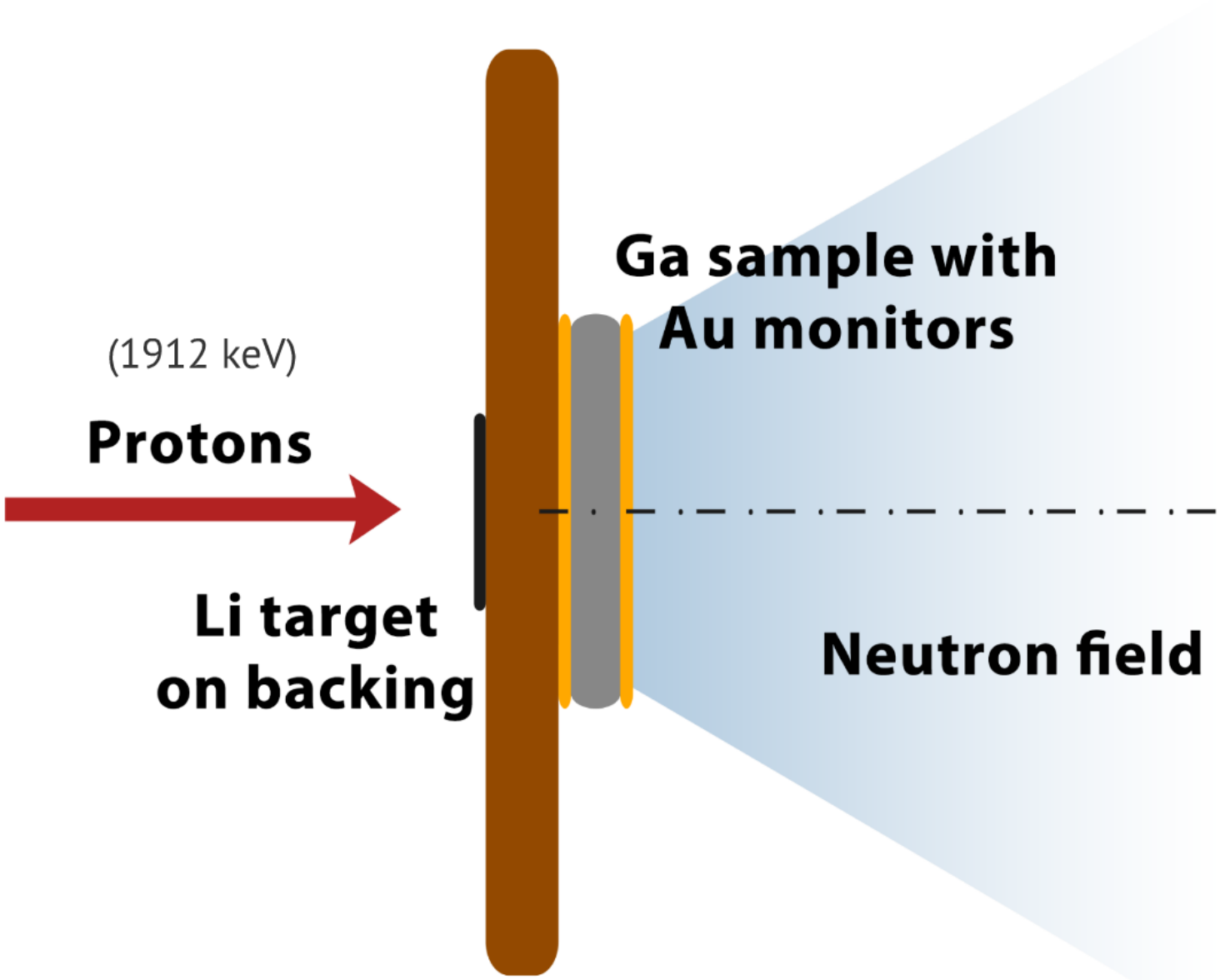


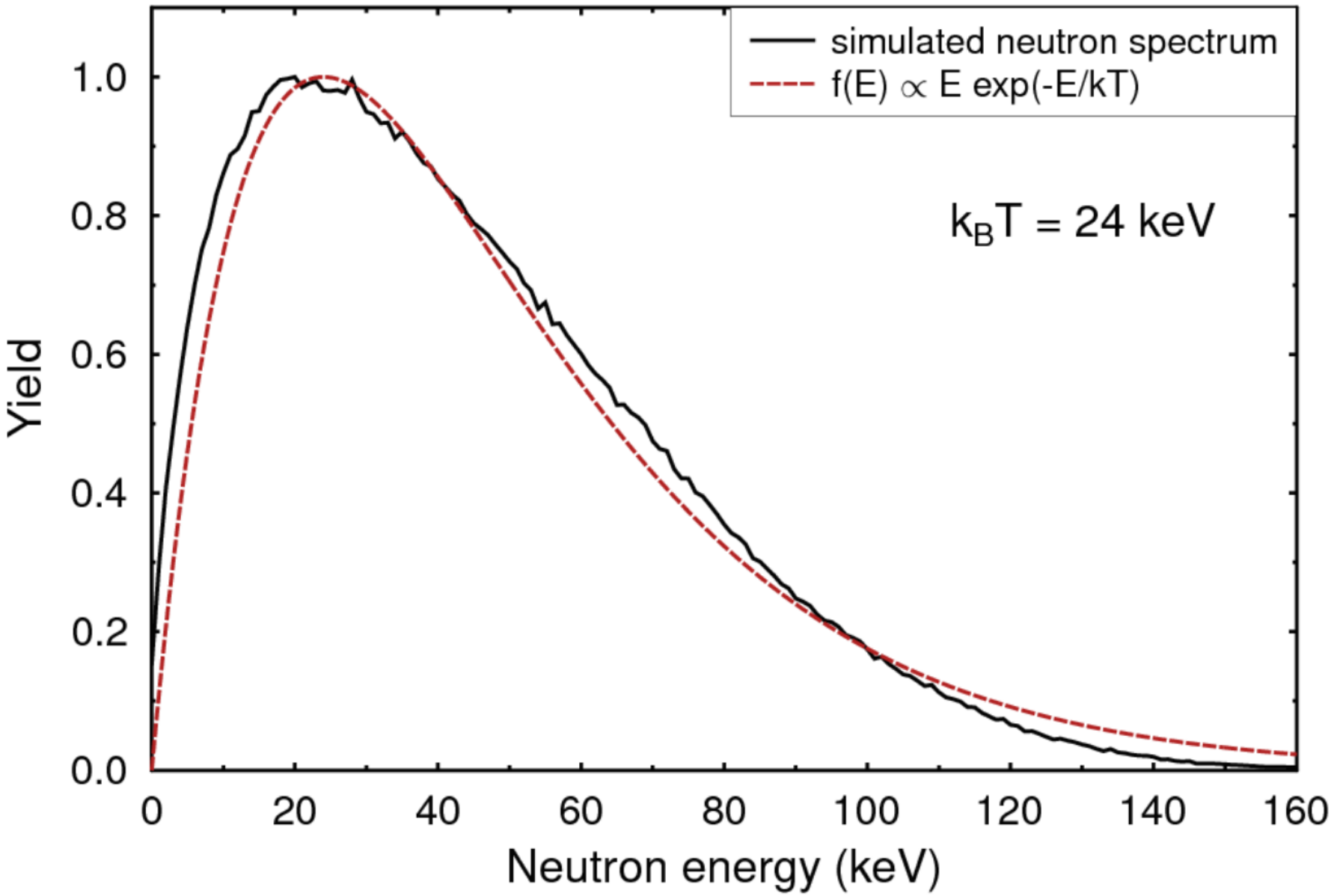
2. Neutrons


(1912 keV)
Protons
Li target
on backing
Ga sample with
Au monitors
Neutron field

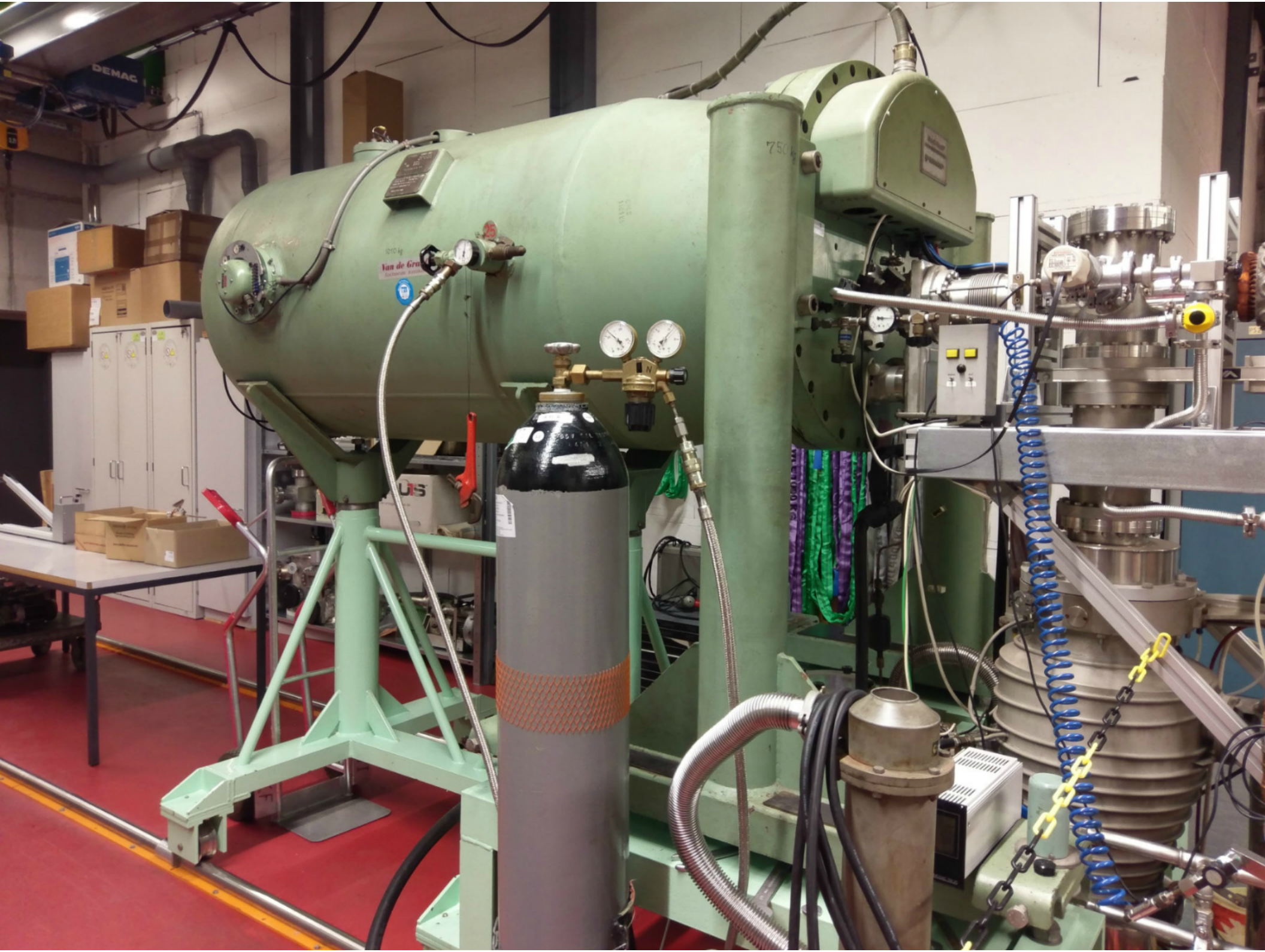

simulated neutron spectrum
$k_B T$ = 24 keV
Yield
Neutron energy (keV)

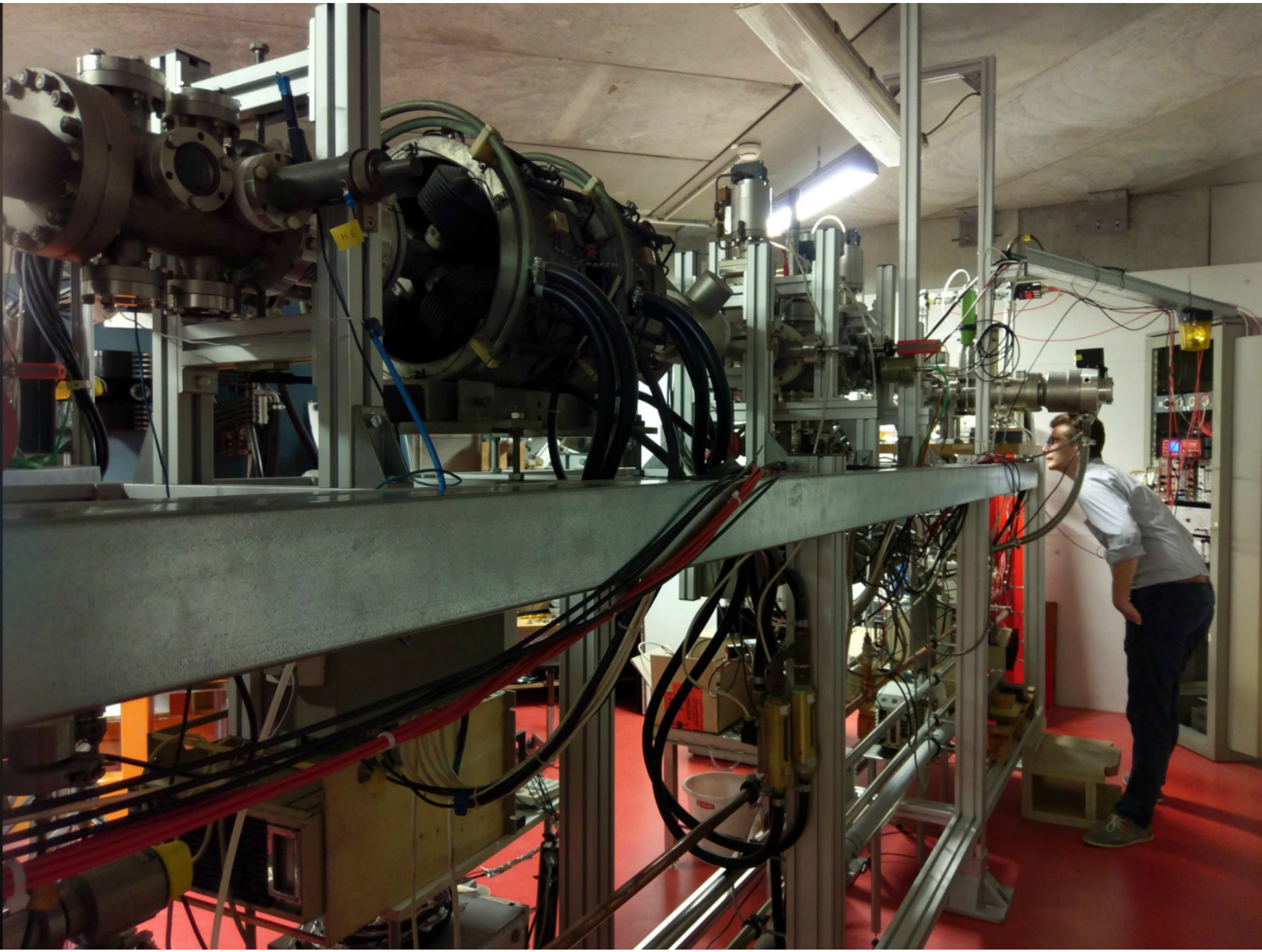


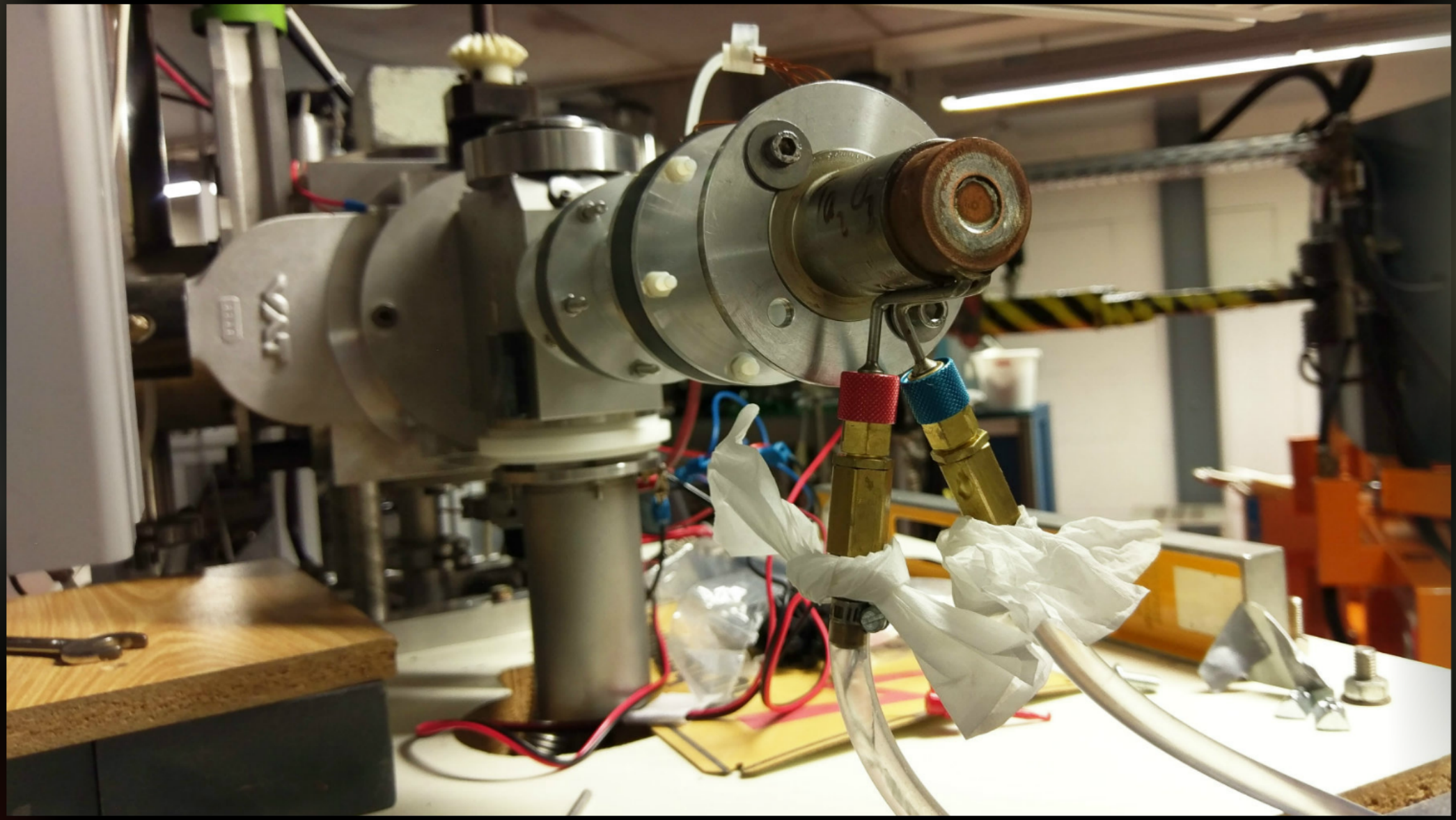

Ga sample with
Au monitors
(1912 keV)
Protons
Li target
on backing
Neutron field


simulated neutron spectrum
f(E) ∝ E exp(-E/kT)
k_BT = 24 keV
Yield
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
160
Neutron energy (keV)


High Voltage Engineering Corp.
Burlington Massachusetts, U.S.A.
Feld E
Feld F


DEMAC





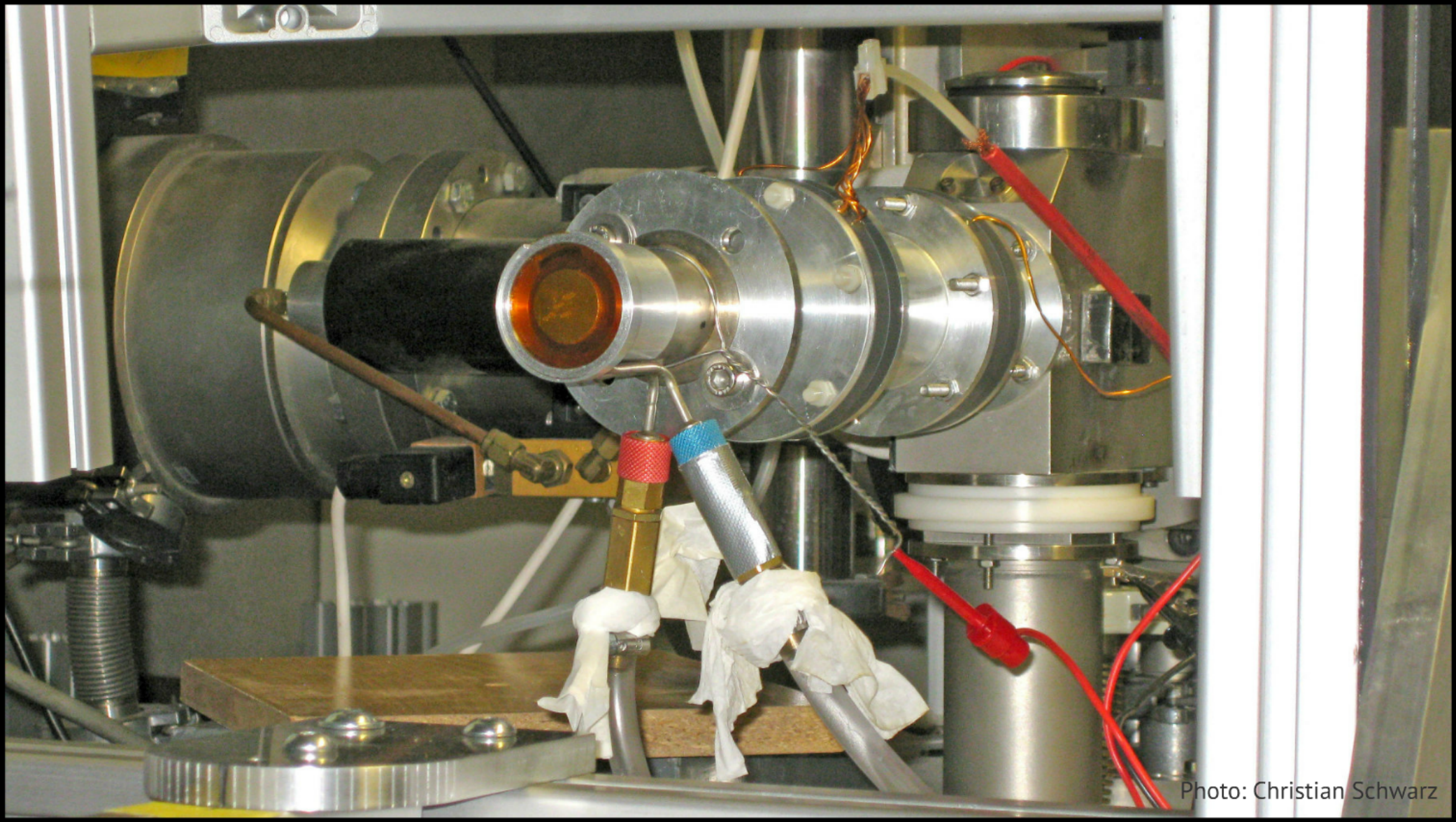
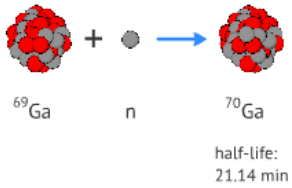
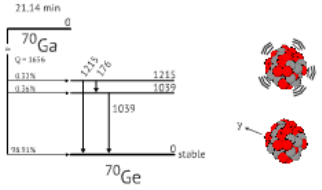


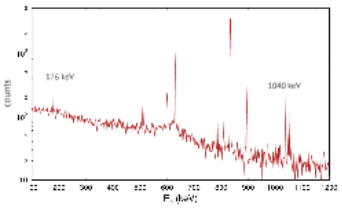
Photo: Christian Schwarz

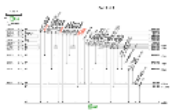
3. Count products

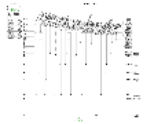


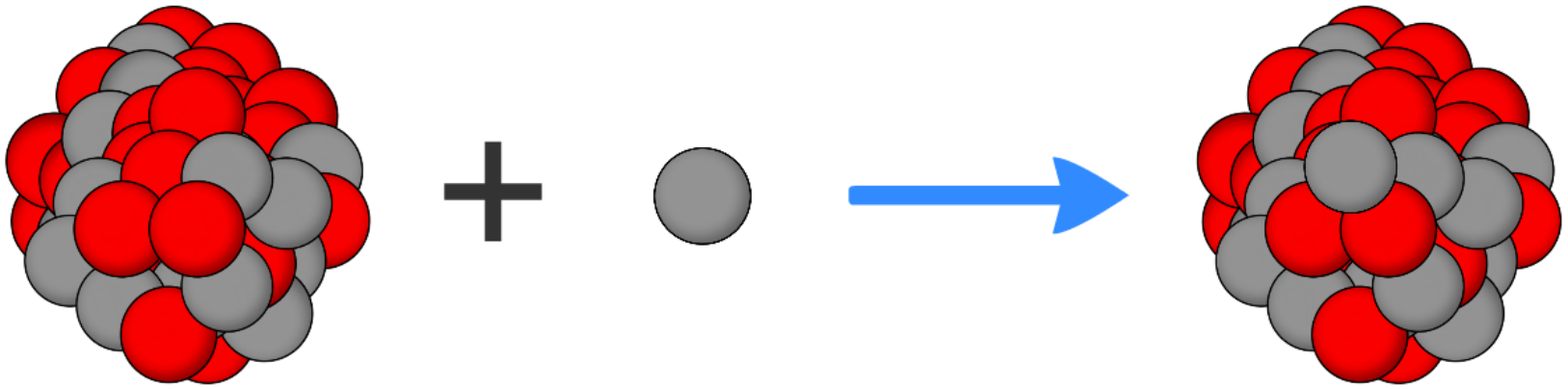


HPGe detector





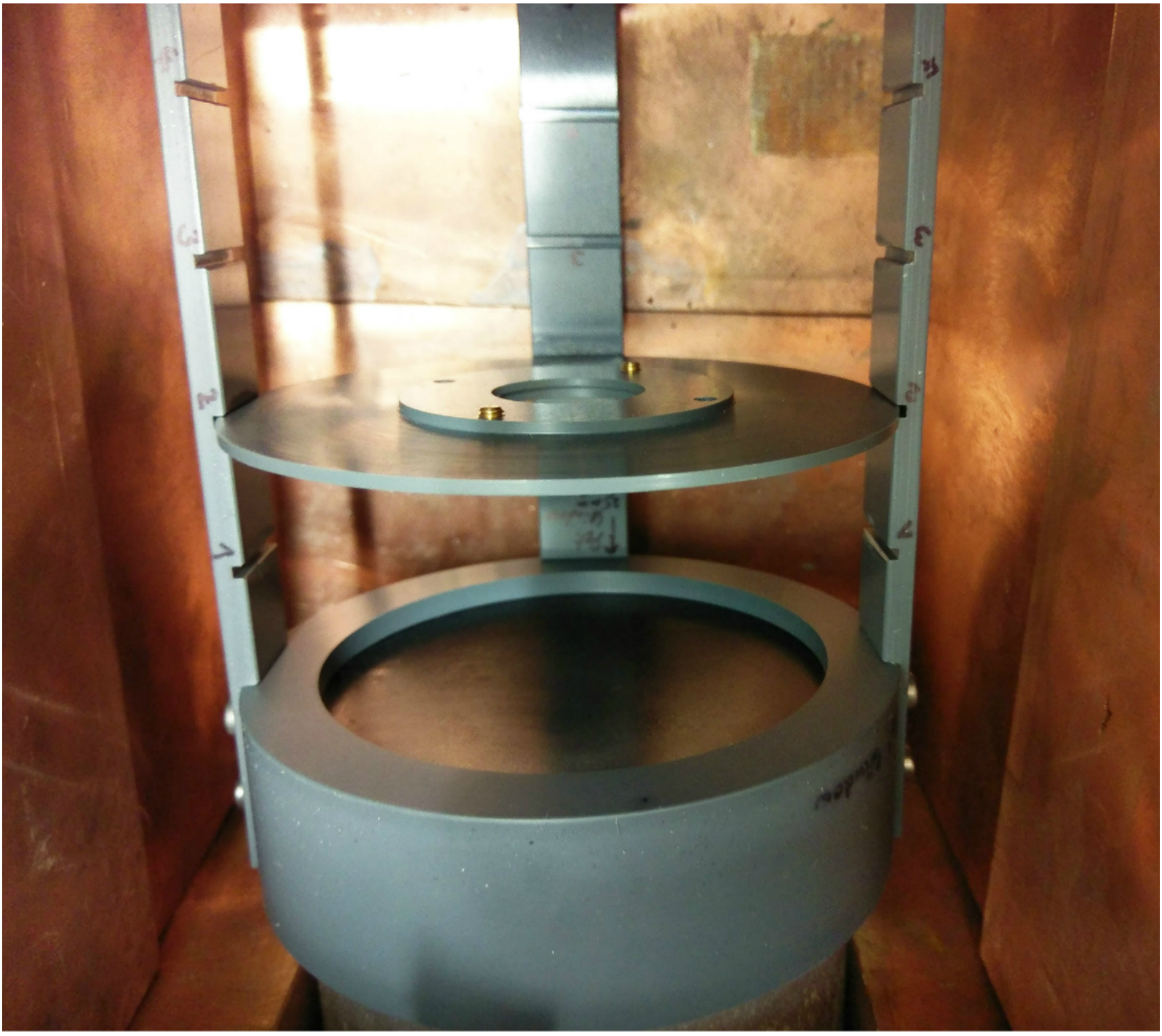


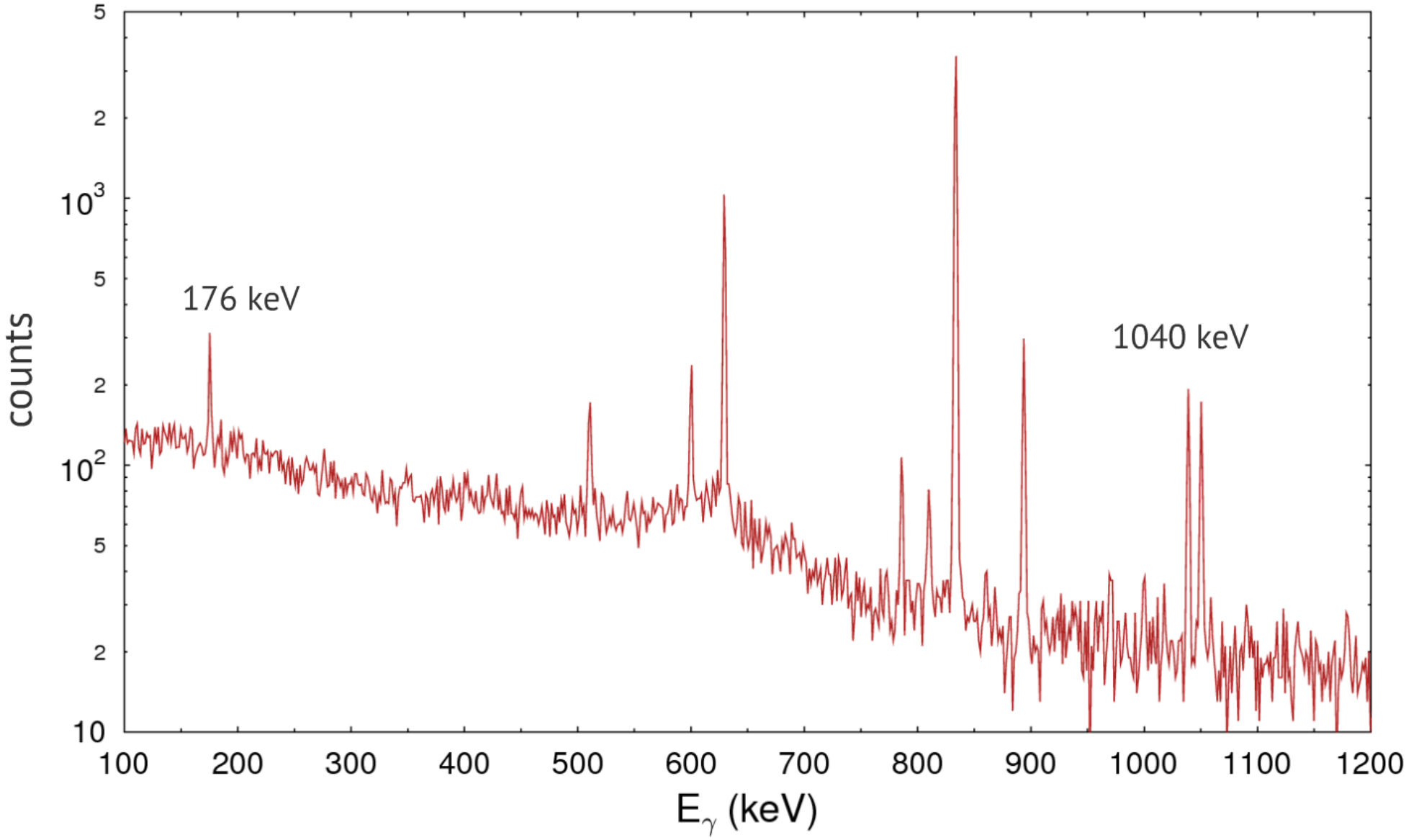


^{69}Ga n ^{70}Ga

half-life:
21.14 min

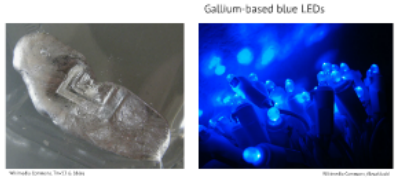
HPGe detector




counts
5
2
10^3
5
2
10^2
5
2
10
176 keV
1040 keV
100
200
300
400
500
600
700
800
900
1000
1100
1200
E_γ (keV)

In the lab @ GUF

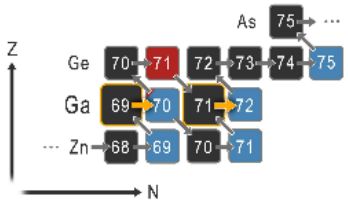
Gallium



Gallium

two stable isotopes

^{69}Ga	^{71}Ga
60%	40%



Neutron capture cross section

$$\sigma = \frac{N_{\text{produced}}}{\Phi_n \cdot N_{\text{sample}}}$$

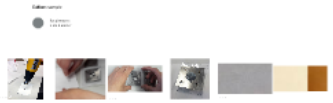
Number of produced nuclei

$$N_{\text{produced}} = \frac{C}{I_\gamma \cdot \epsilon \cdot \kappa \cdot f_{\text{dt}} \cdot f_{\text{b}} \cdot f_{\text{dw}} \cdot f_{\text{casc}}}$$

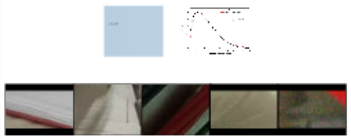
correct counts in detector for...

- gamma intensity
- efficiency
- gamma absorption
- dead time
- decays during activation
- waiting time
- gamma cascades

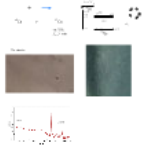
1. Gallium sample

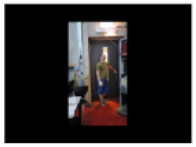


2. Neutrons



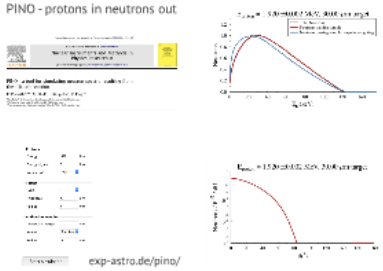
3. Count products





Let's plan the activation...

PINO - protons in neutrons out



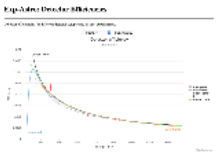
exp-astro.de/pino/

exp-astro.de/activations/

some reasonable assumptions...

- ^{nat}Ga sample
- use ^{197}Au monitors (25 µm)
- accelerator shift: 8 h / day
- proton current: 10 µA
- use HPGe detector
- statistical error < 3%

calibration sources



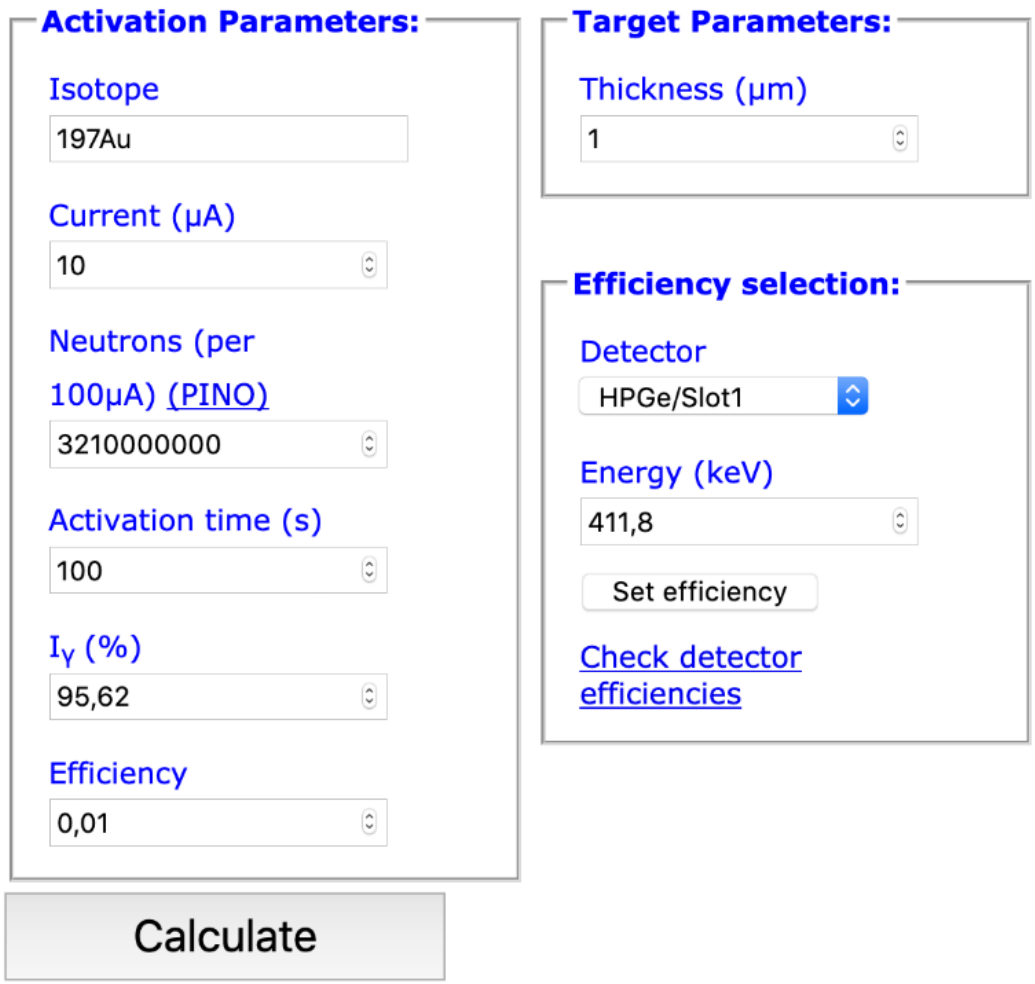
133Ba: 276 keV, 303 keV, 356 keV, 384 keV
137Cs: 662 keV
54Mn: 835 keV
22Na: 1275 keV
60Co: 1173 keV, 1332 keV
88Y: 898 keV, 1836 keV

```
Cross section (mb):                  582.0
Product nucleus:                     198Au
Half life:                           2.6941 d
Half life (s):                       2.328e+05
Number of Neutrons (1/s):            3.210e+08
Area density (at/cm**2):             5.907e+18

Target atom production (1/s):                    1.103528e+03
Produced atoms at the end of activation:         1.103364e+05
Activity (total) (1/s):                          3.285616e-01
Activity (Ig) (1/s):                             3.141766e-01
Detector count rate (1/s):                       3.141766e-03
Total detector counts in 3*T_1/2:                9.231572e+02
```

Task:
plan 25 keV activation and counting
of sample and monitors at the detector

exp-astro.de/activations/



PINO - protons in neutrons out

Nuclear Instruments and Methods in Physics Research A 608 (2009) 139–143

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Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

PINO—a tool for simulating neutron spectra resulting from the ^{7}Li(p,n) reaction

R. Reifarth [a,b,*], M. Heil [a], F. Käppeler [c], R. Plag [a,b]

[a] *Gesellschaft für Schwerionenforschung mbH, Darmstadt D-64291, Germany*
[b] *J.W. Goethe Universität, Frankfurt a.M D-60438, Germany*
[c] *Forschungszentrum Karlsruhe, Postfach 3640, D-76021 Karlsruhe, Germany*

Protons

Energy	1920	keV
Energy sigma	2	keV
Number of	100k	

Target

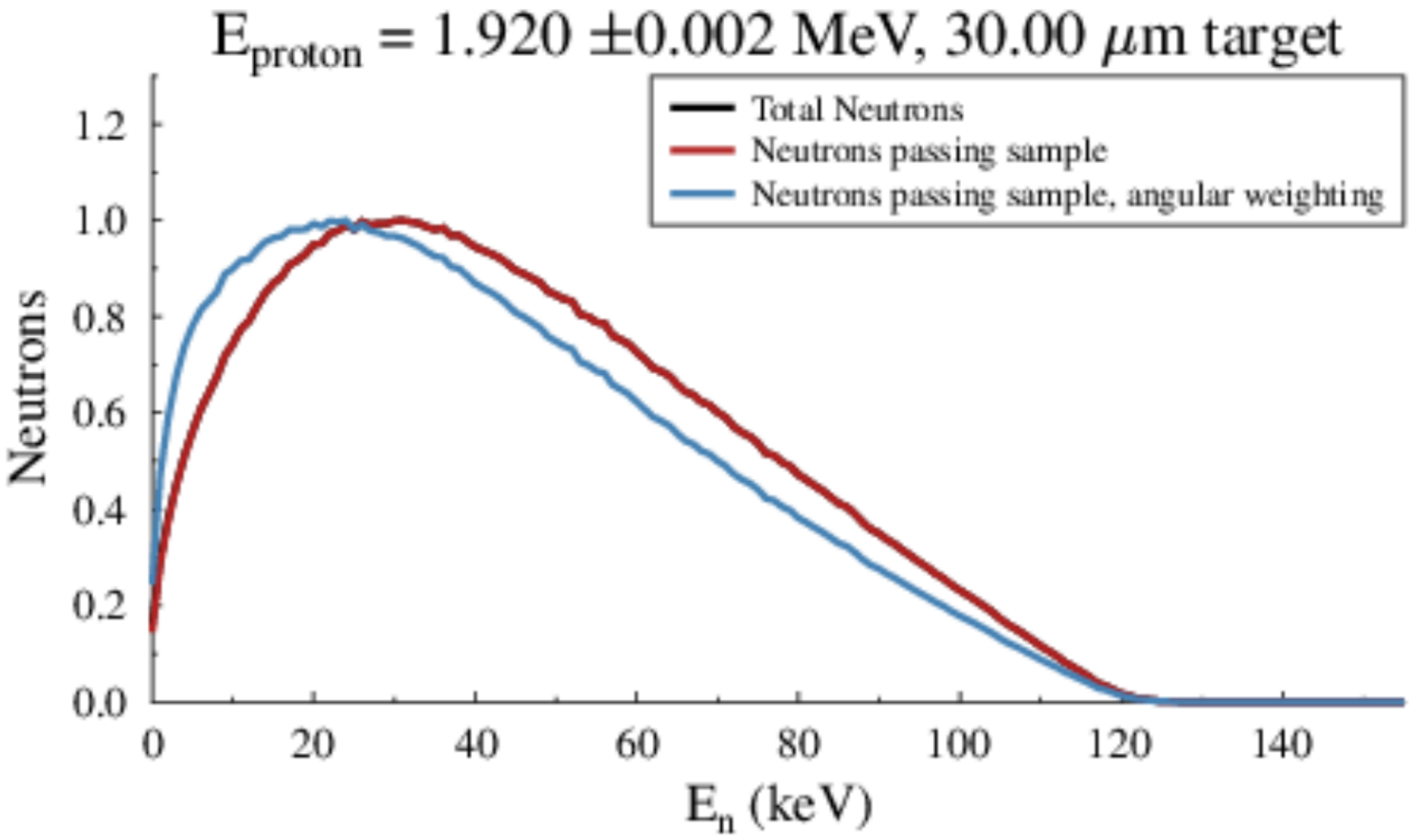
Type	Li	
Thickness	30	µm
Radius	3	mm

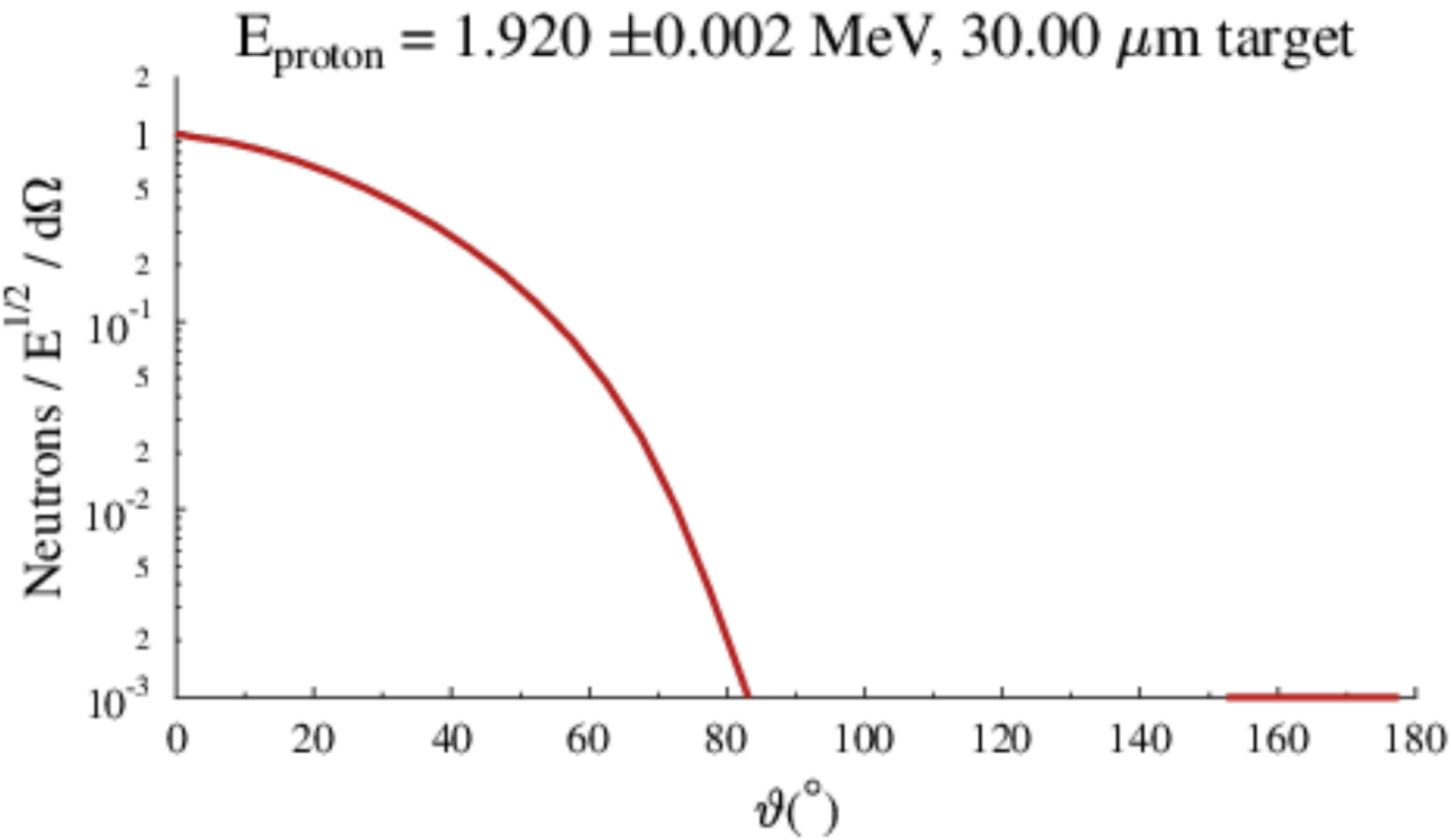
Activation sample

Distance to target	1	mm
Shape	Circ. disc	
Radius	10	mm

Start simulation

exp-astro.de/pino/


E_{proton} = 1.920 ±0.002 MeV, 30.00 μm target
Total Neutrons
Neutrons passing sample
Neutrons passing sample, angular weighting
Neutrons
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
20
40
60
80
100
120
140
E_n (keV)


E_proton = 1.920 ±0.002 MeV, 30.00 μm target
Neutrons / E^1/2 / dΩ
2
1
5
2
10^-1
5
2
10^-2
5
2
10^-3
0
20
40
60
80
100
120
140
160
180
ϑ(°)

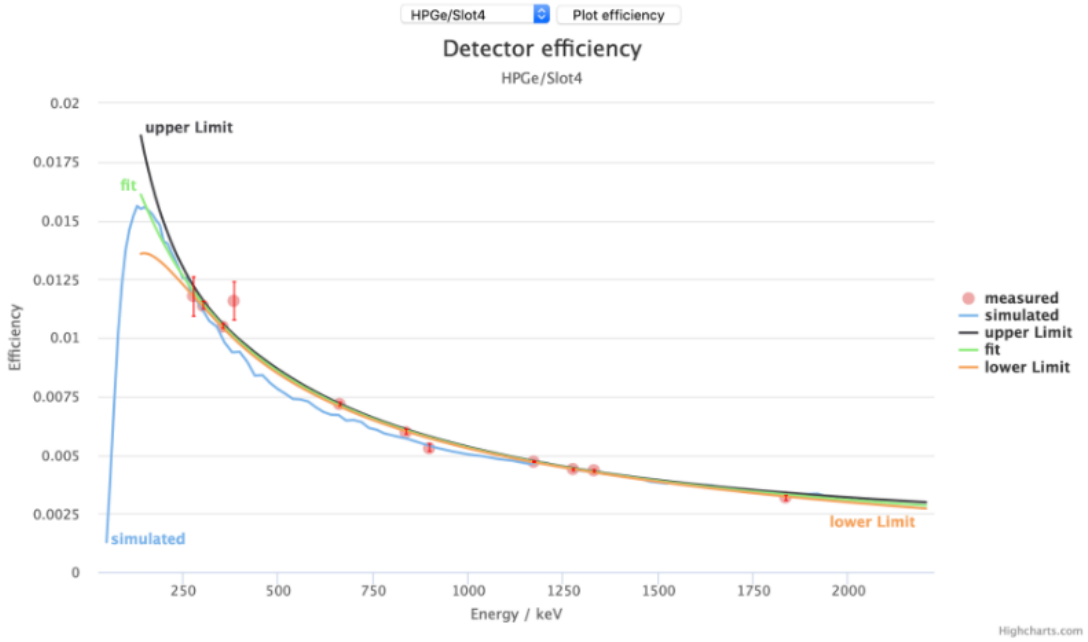
Exp-Astro: Detector Efficiencies

Detector efficiencies for different detector setups used in past experiments.

calibration sources

Exp-Astro: Detector Efficiencies

Detector efficiencies for different detector setups used in past experiments.



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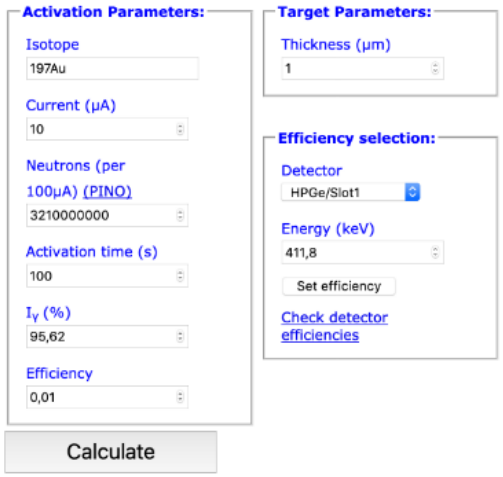
exp-astro.de/activations/



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THE EUROPEAN PHYSICAL JOURNAL PLUS

Review

Neutron-induced cross sections*

From raw data to astrophysical rates

René Reifarth[1,a], Philipp Erbacher[1], Stefan Fiebiger[1], Kathrin Göbel[1], Tanja Heftrich[1], Michael Heil[2], Franz Käppeler[3], Nadine Klapper[1], Deniz Kurtulgil[1], Christoph Langer[1], Claudia Lederer-Woods[4], Alberto Mengoni[5,6], Benedikt Thomas[1], Stefan Schmidt[7], Mario Weigand[1], and Michael Wiescher[8]

[1] Goethe University Frankfurt am Main, Frankfurt, Germany
[2] GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany
[3] Karlsruhe Institute of Technology, Karlsruhe, Germany
[4] School of Physics and Astronomy, University of Edinburgh, Edinburgh, UK
[5] ENEA, Bologna, Italy
[6] INFN, Sezione di Bologna, Bologna, Italy
[7] Frankfurt Institute for Advanced Studies, Frankfurt, Germany
[8] University of Notre Dame, Notre Dame, IN, USA

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