Electron-Positron Emission from Deuterated Zirconium

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Trento, 2025

Astrophysical S-factor

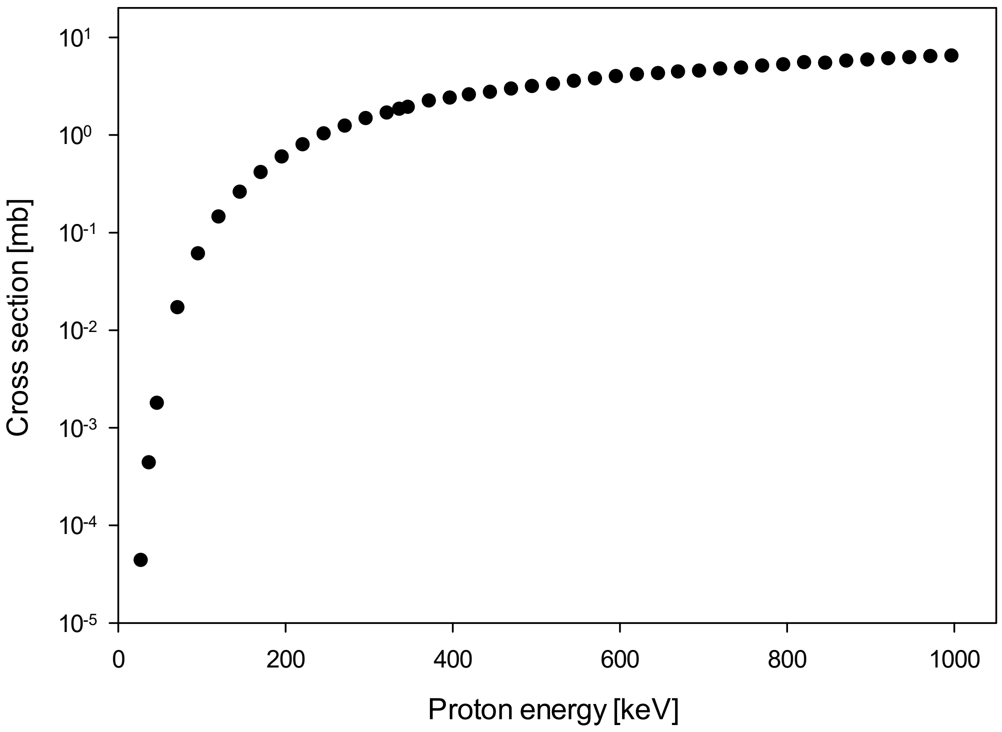
Cross section:

$$\sigma(E) = \frac{S(E)}{E} e^{-2\pi\eta}$$

Sommerfeld parameter:

$$\eta = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 \hbar c}\sqrt{\frac{\mu c^2}{2E}}$$

^{7}Li(p,α)^{4}He Cross section



C. Rolfs and R.W.Kavanagh, Nucl. Phys. **A455** (1986) 179.

Electron Screening

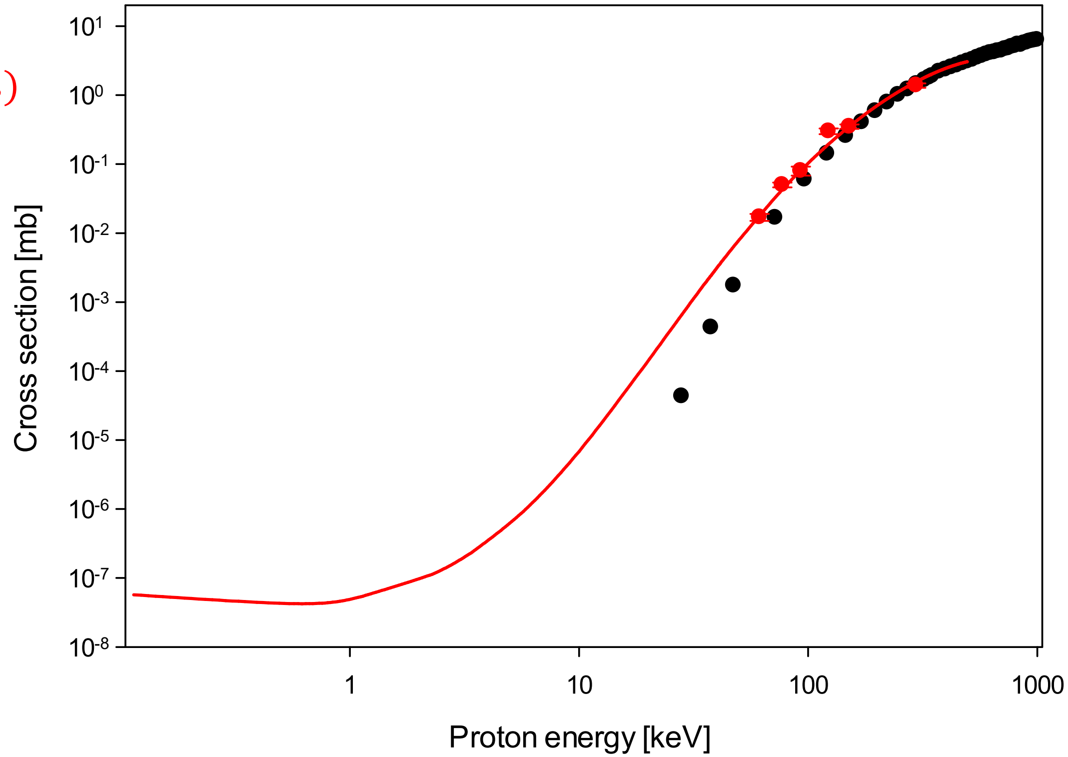
Electron screening potential U_e:

$$\sigma(E) = \frac{S(E)}{\sqrt{E(E+U_e)}} e^{-2\pi\eta(E+U_e)}$$

Screened Sommerfeld parameter:

$$\eta = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 \hbar c}\sqrt{\frac{\mu c^2}{2(E+U_e)}}$$

$^{7}Li(p,\alpha)^{4}He$ Cross Section with screening



A. Cvetinović et al., Phys. Rev. C **92**, (2015) 065801.

Warning

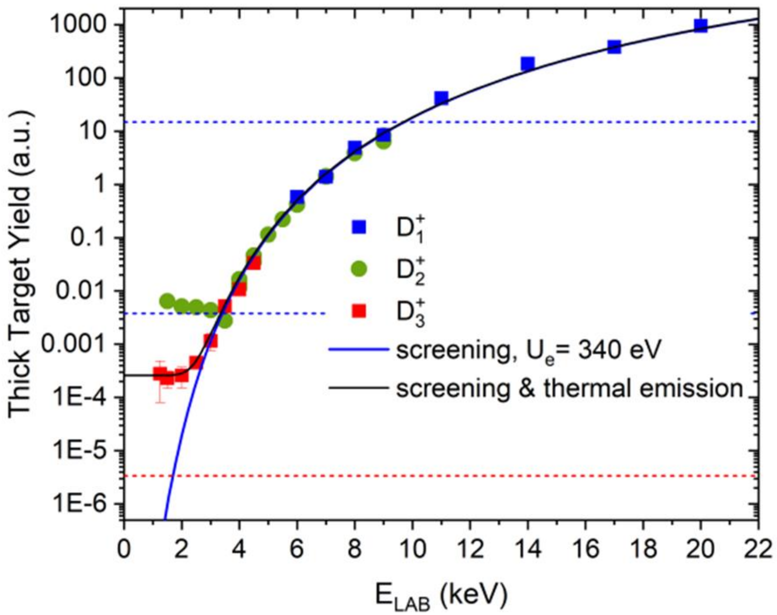
$$\sigma(E) \rightarrow \sigma(E+U_e) = \frac{S(E+U_e)}{E+U_e} e^{-2\pi\eta(E+U_e)}$$

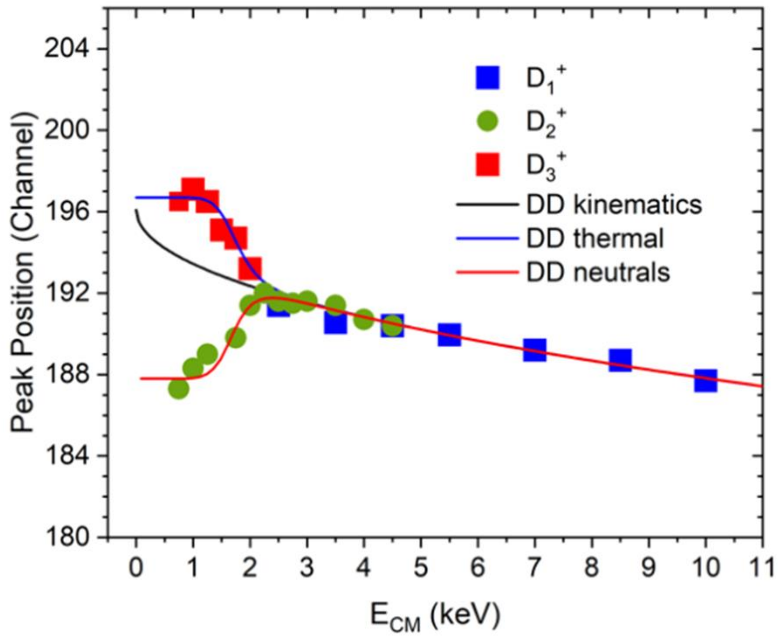
$$\sigma(E) = \frac{S(E)}{E} e^{-2\pi \quad (E+U_e)}$$

$$\sigma(E) = \frac{S(E)}{\sqrt{E(E+U_e)}} e^{-2\pi\eta(E+U_e)}$$

Deuteron fusion reaction

$d + d \rightarrow p + {}^{3}\mathrm{H} \approx 50\%$ branching ratio





K. Czerski et al., submitted to Nature

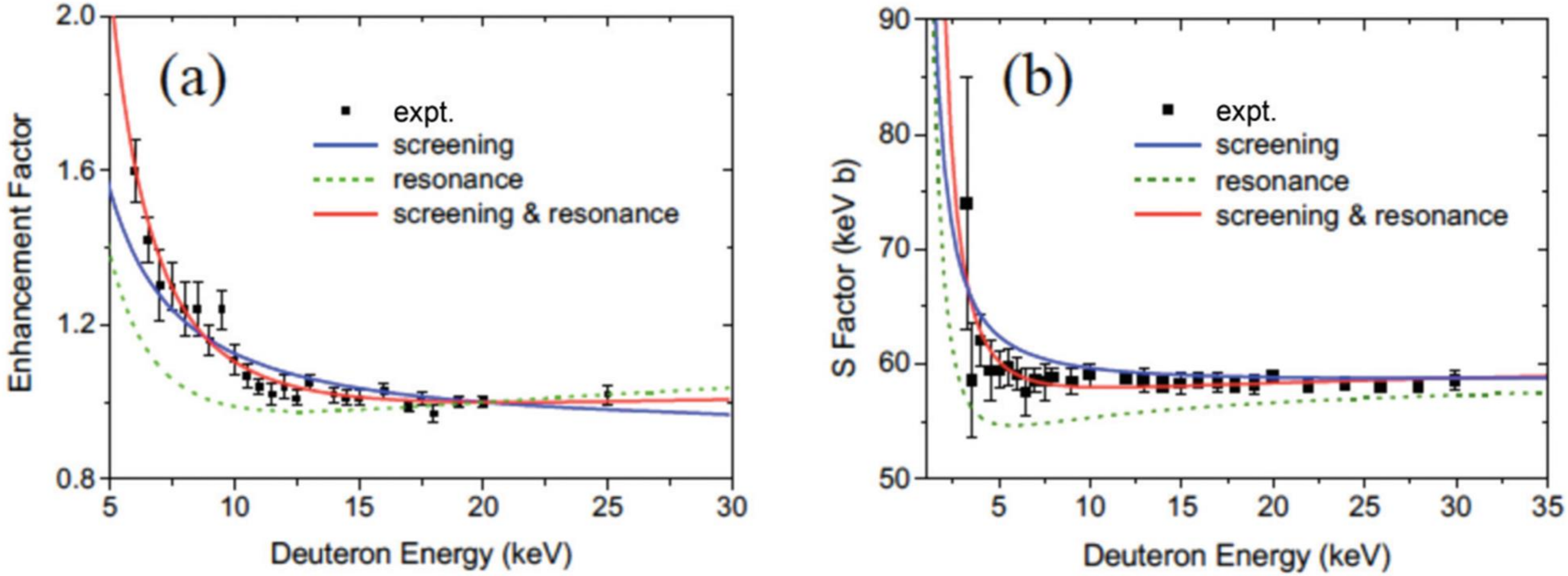
Threshold resonance in ^4He?

PHYSICAL REVIEW C **106**, L011601 (2022)

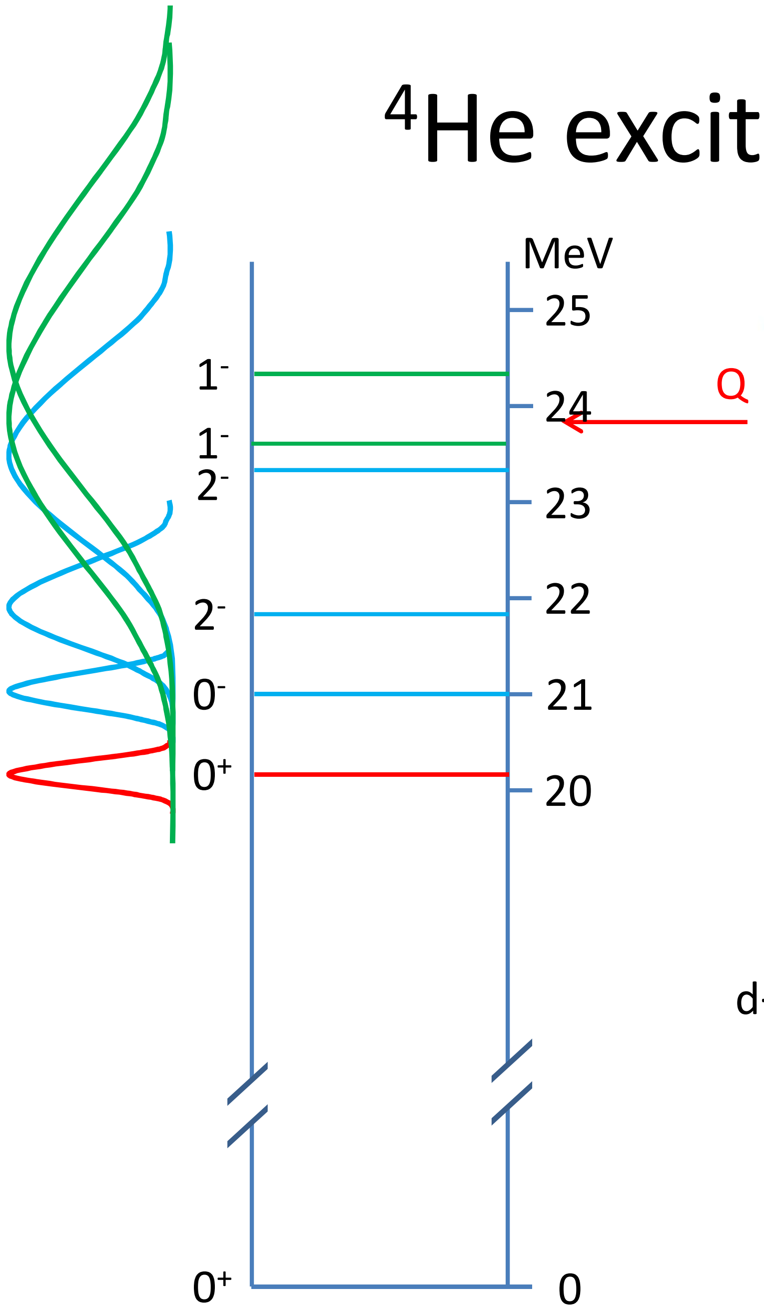
Letter

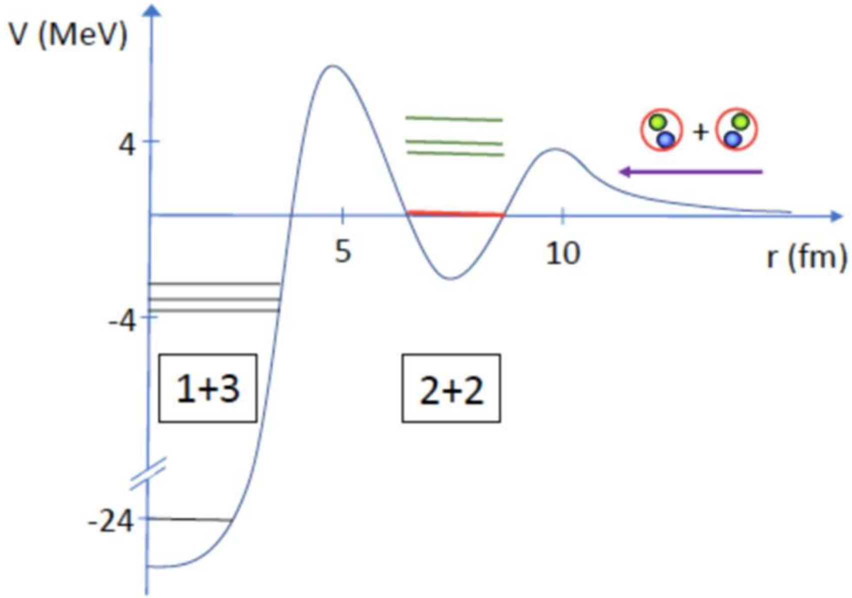
Deuteron-deuteron nuclear reactions at extremely low energies

Konrad Czerski *
Institute of Physics, University of Szczecin, 70-451 Szczecin, Poland



^{4}He excitation





		branching
d+d ⟶	p + ^{3}H	0.5
	n + ^{3}He	0.5
	^{4}He + γ	10^{-7}

Ion gun

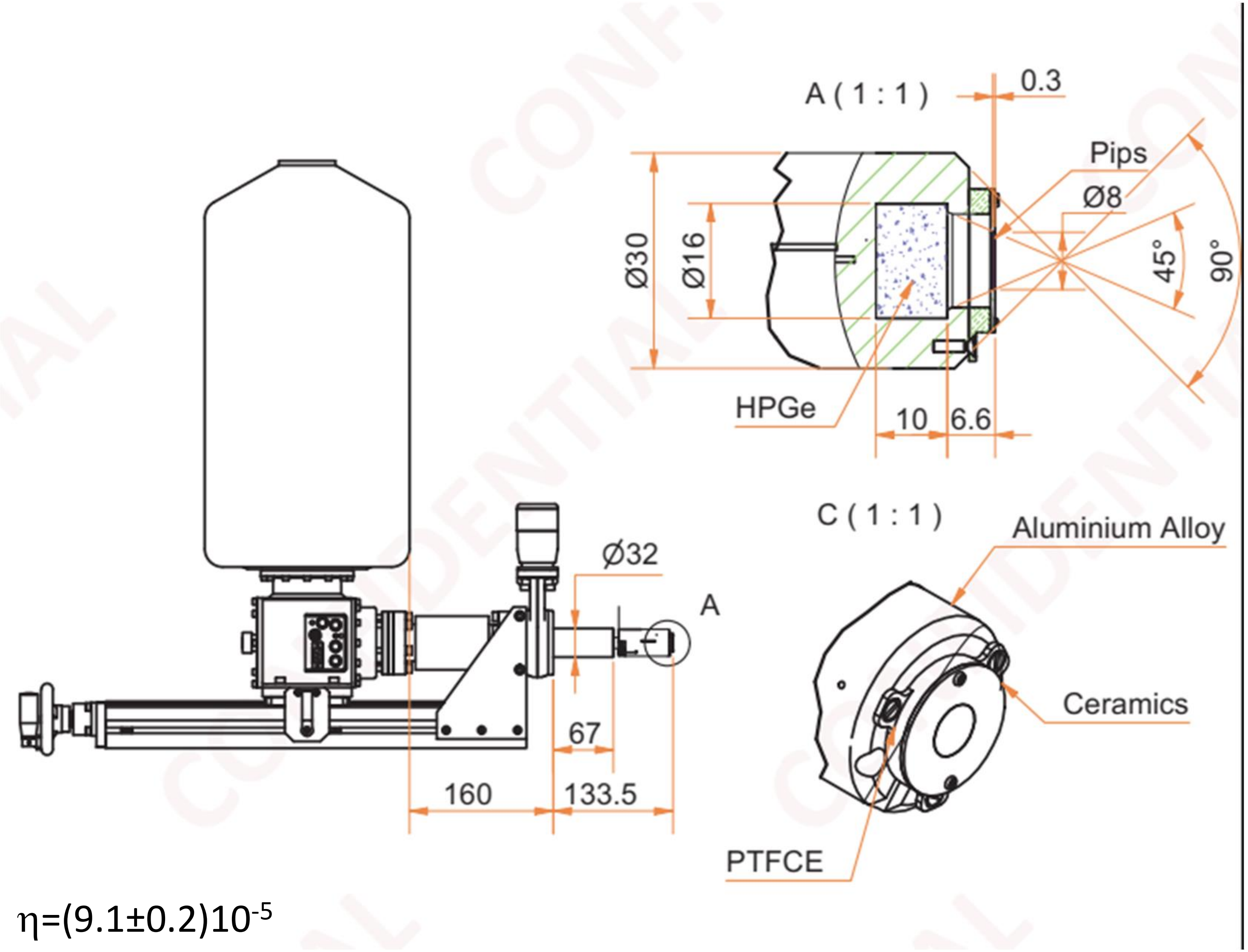
Tectra IonEtch microwave plasma ion gun
Deuterium is implanted into graphite or zirconium at 3.5 kV resulting in up to 200 at. % deuterium concentration.

p=$5 \cdot 10^{-5}$ mbar

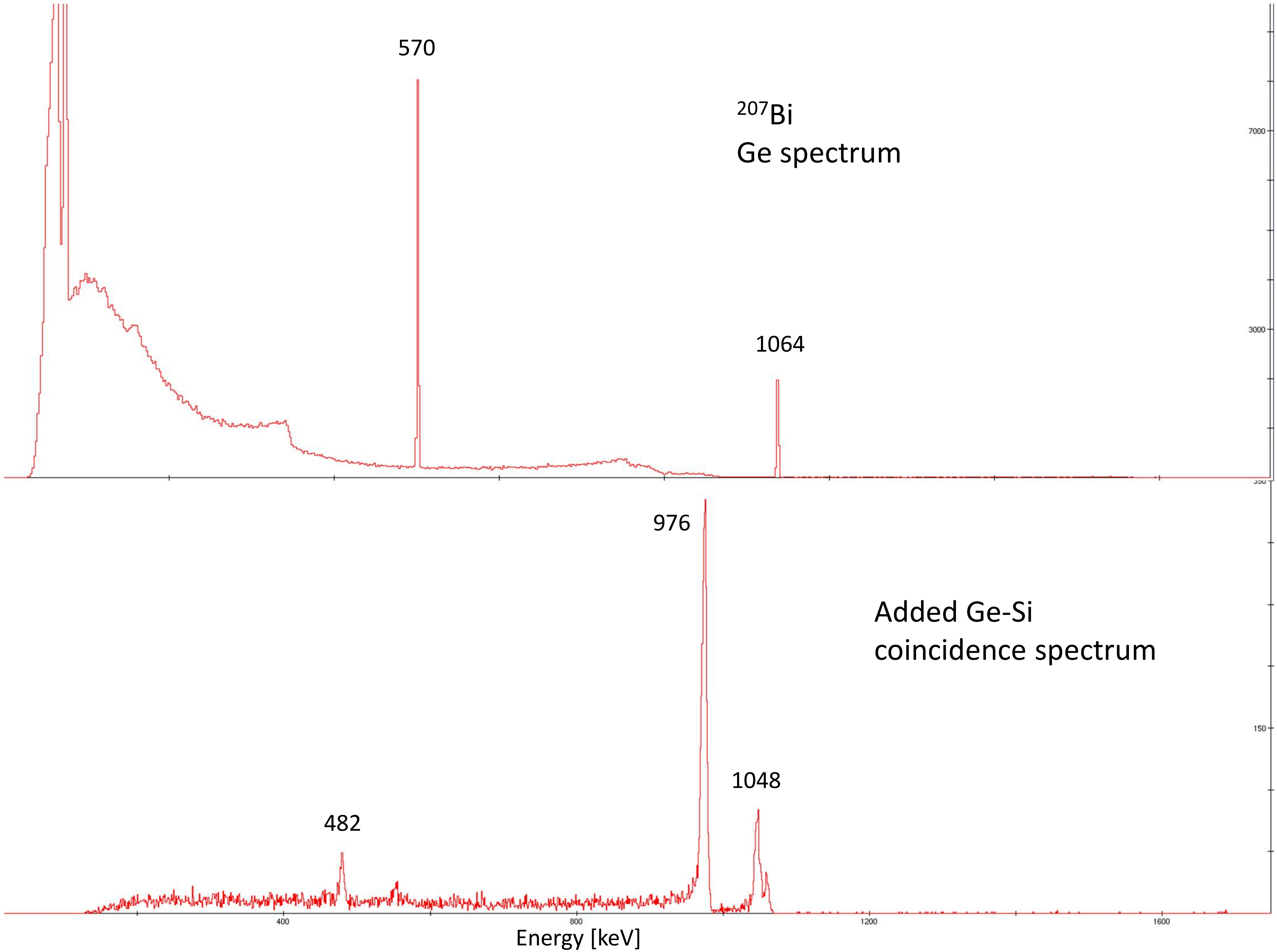
D_3^+ : 86%
D_2^+ : 12%
D^+ : 2%
<E> = 1.3 keV

S. Markelj et al., Nucl. Fusion **59** (2019) 086050.

Electron detector

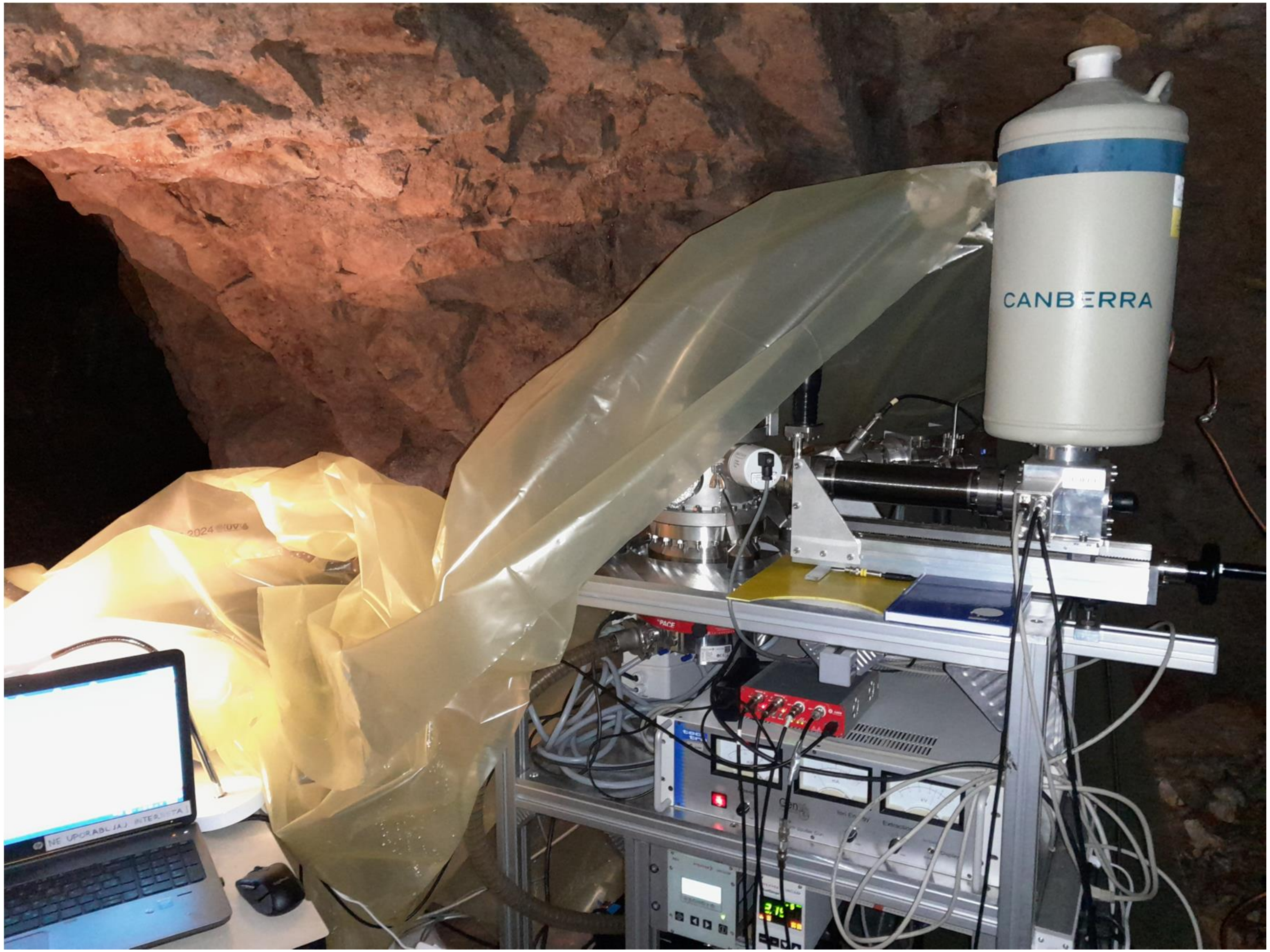


$\eta=(9.1\pm0.2)10^{-5}$


570
207Bi
Ge spectrum
1064
7000
3000
976
Added Ge-Si
coincidence spectrum
150
1048
482
400
800
1200
1600
Energy [keV]

Underground measurements

Underground measurements



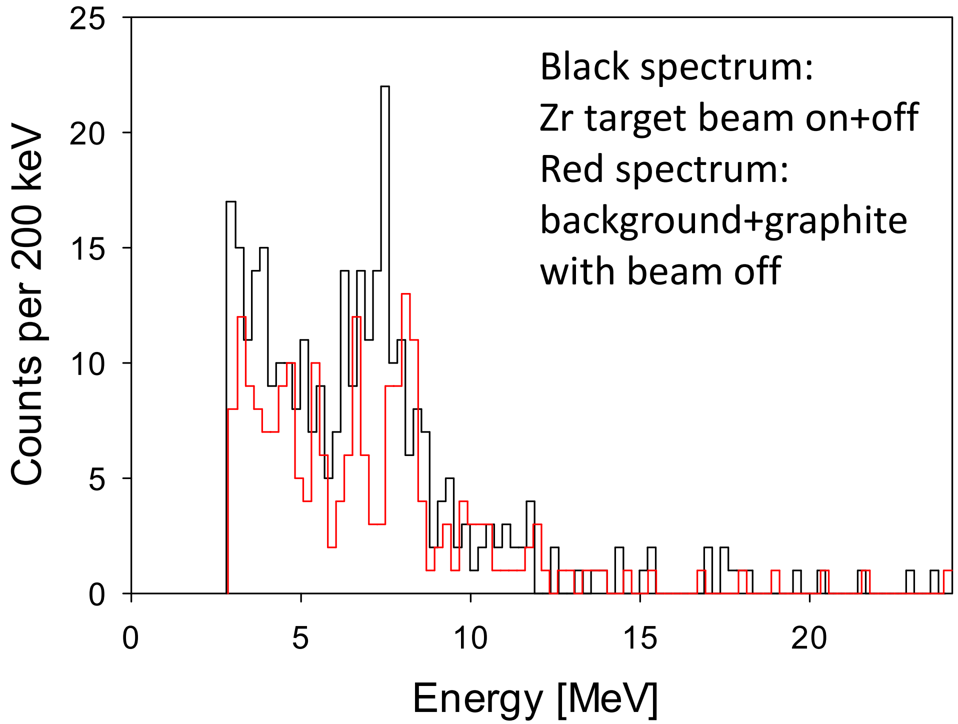
Underground parameters

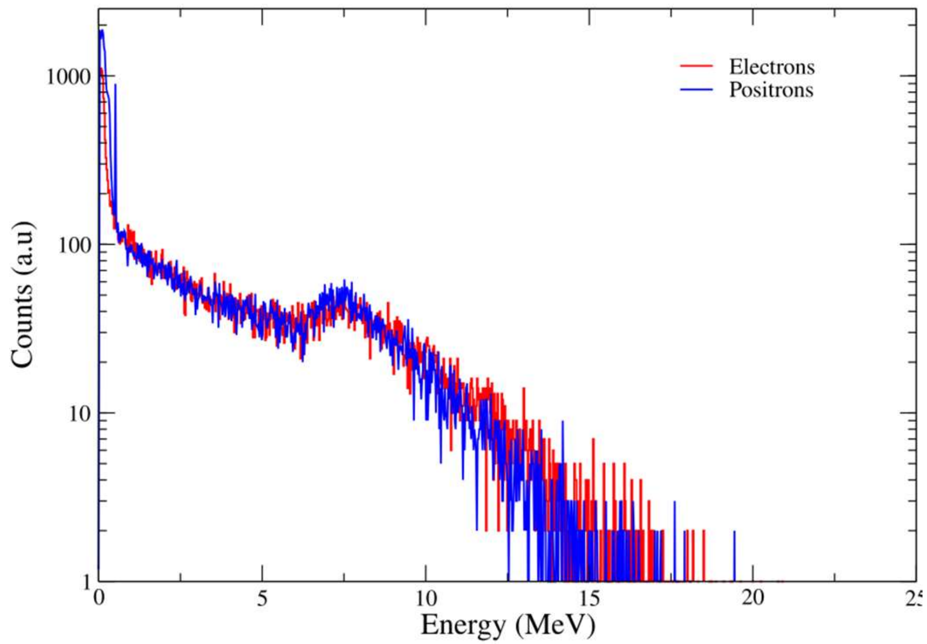
Underground 150 m horizontally, 35 m vertically
Reduction of cosmic ray count rate by a factor of 20 vertically, 12 horizontally compared to the surface

3 months of measurements
Graphite target: 13 days and 14 hours
Zirconium target: 37 days and 4 hours
Background without target: 19 days and 18 hours

Measurement protocol: 4-8 hours with beam on target followed by 2-3 days without beam on target

Underground results





Simulation: Gokul Das Haridas

Underground results

Electron counts above 3 MeV:

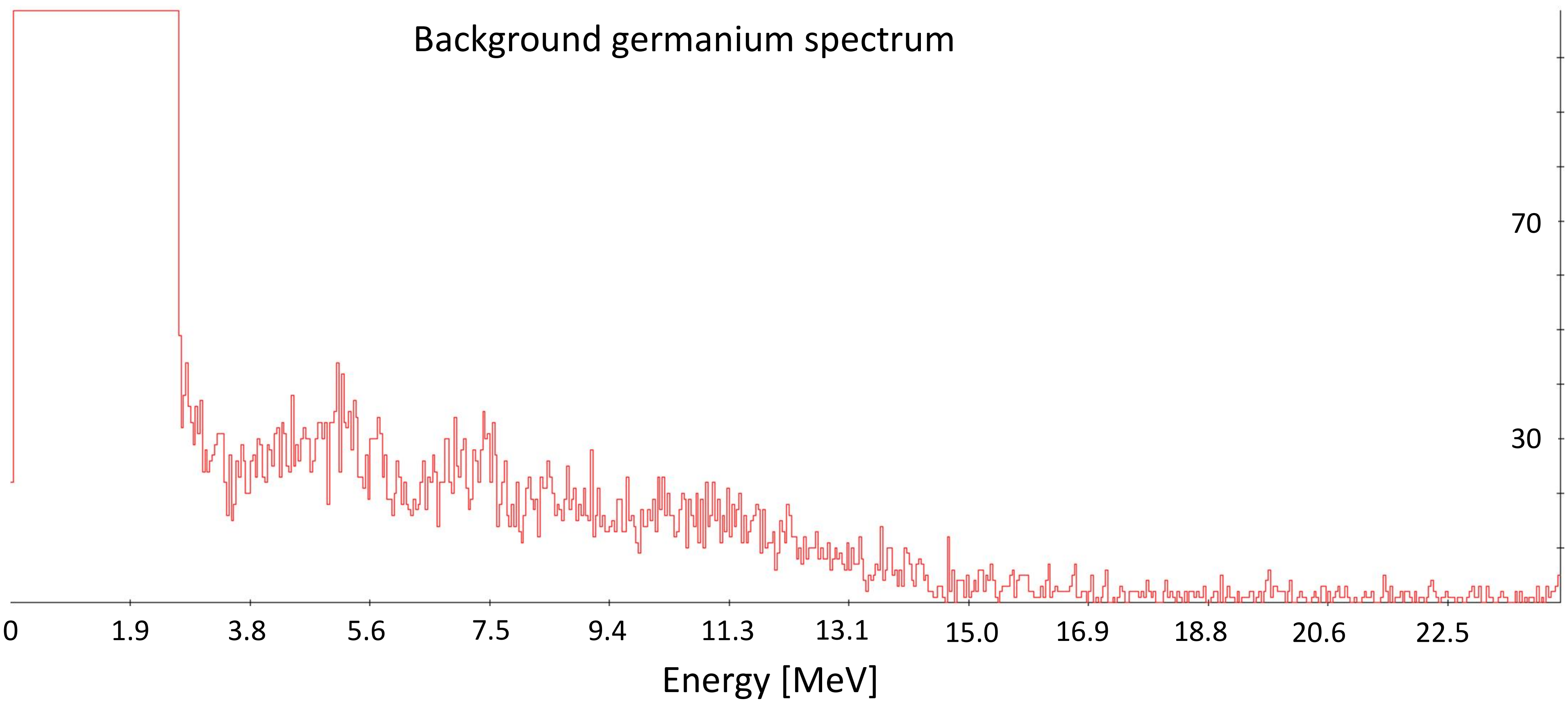
the same rate for: Zr target with beam,
Zr target without beam, — 331 ± 18 counts

the same but lower rate: background without target
graphite target without beam — 220 ± 15 counts

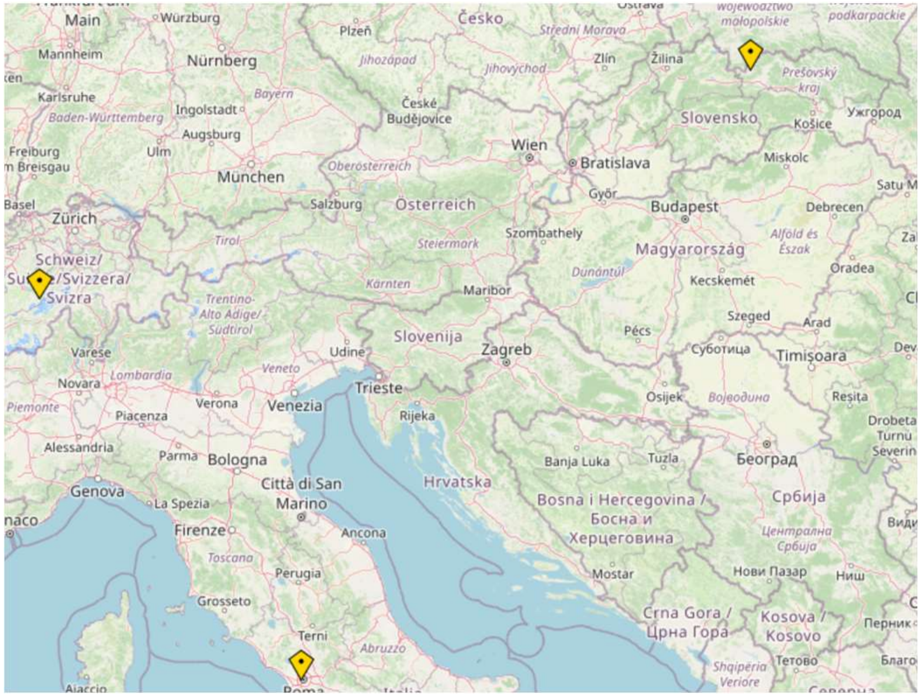
undecided: graphite target with beam due to too low statistics

difference taking into account measuring times: 70 ± 25 counts

Muon spectra

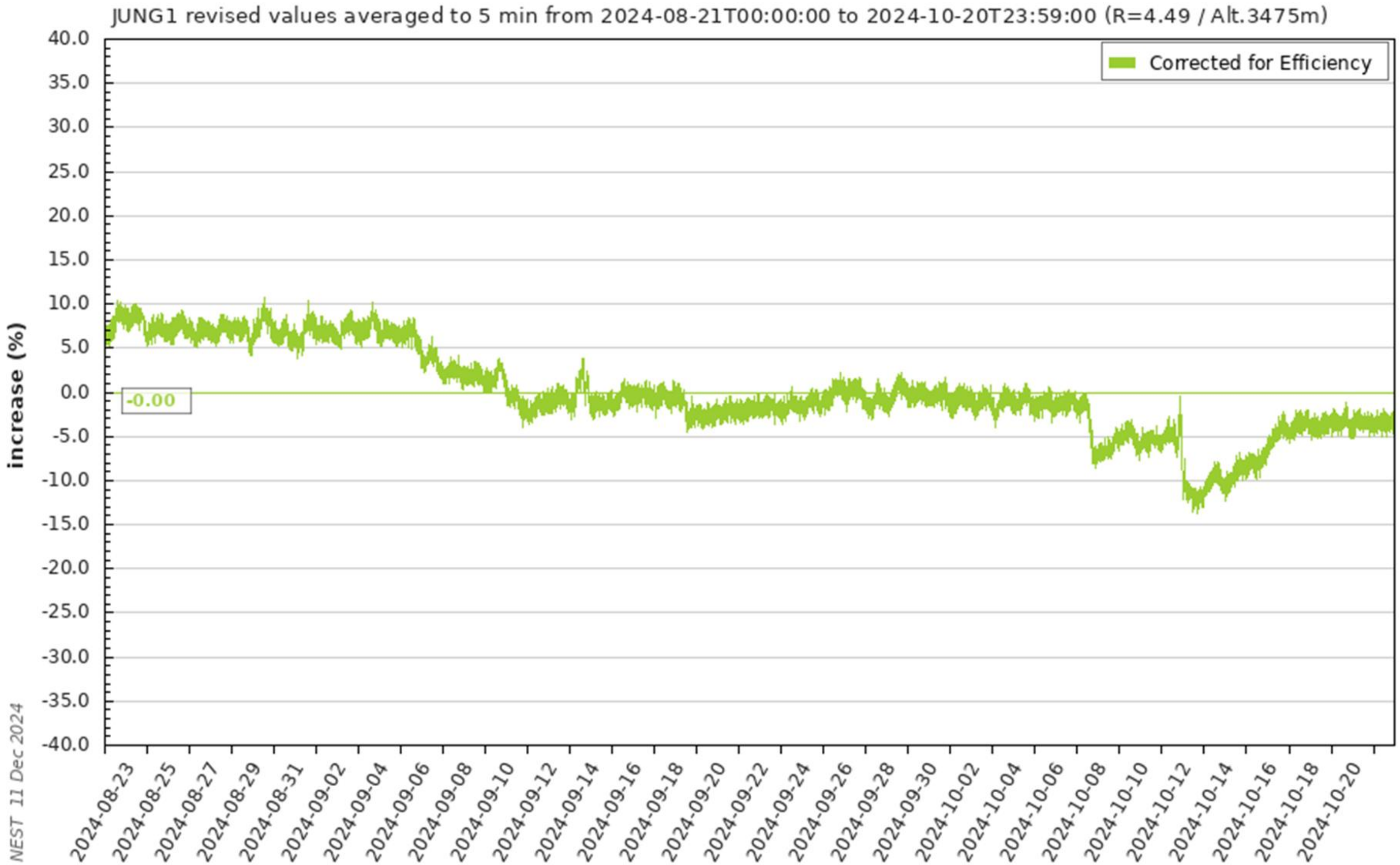


Cosmic neutron monitors



Jungfraujoch, Switzerland

Cosmic neutron counts



Neutron Monitor Database, Paris Observatory-PSL; https://www.nmdb.eu/nest/
Data from Jungfraujoch, Switzerland

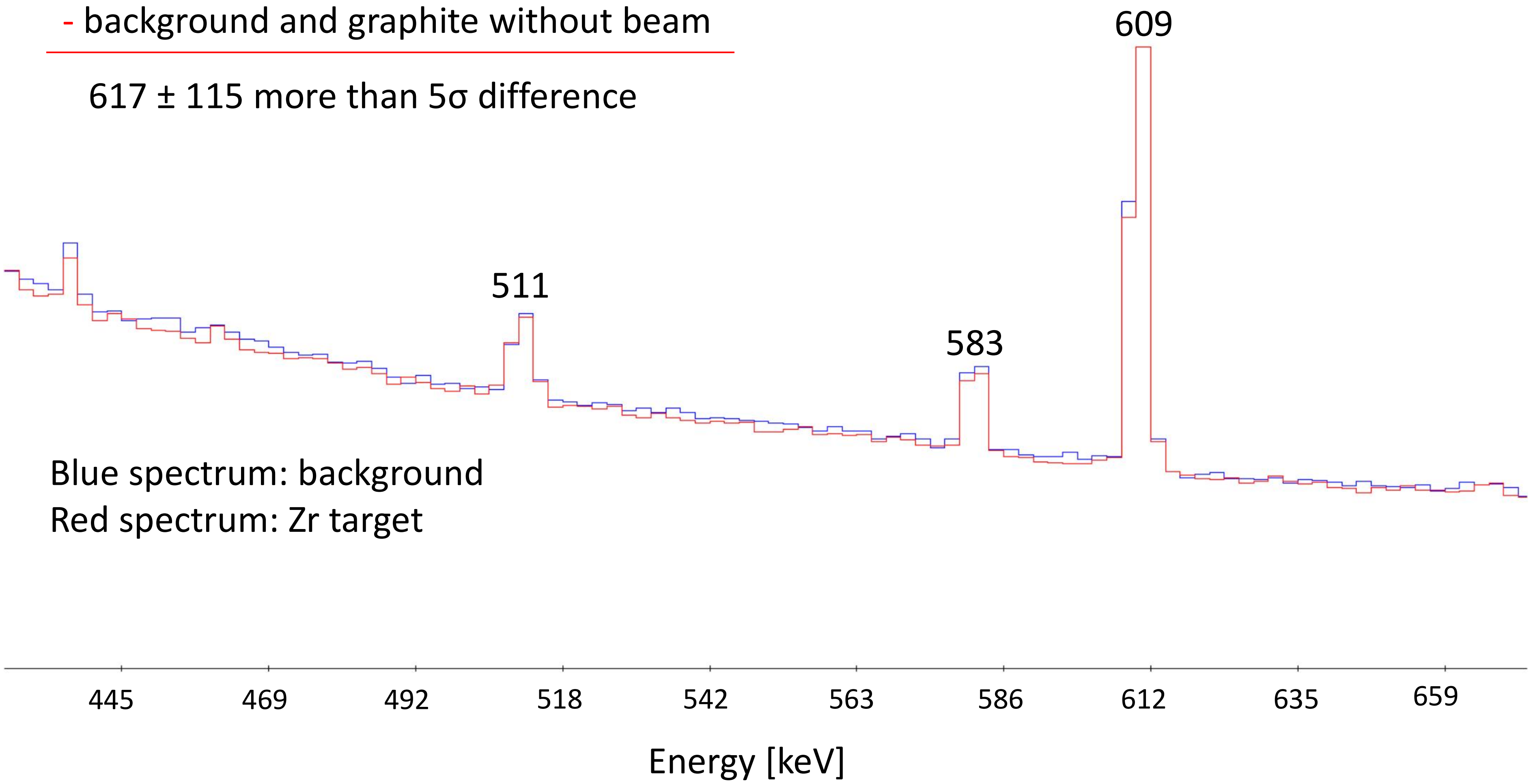
Positron annihilation

Two 511 keV γ rays per positron

Zr target with and without beam

- background and graphite without beam

617 ± 115 more than 5σ difference



Cross section estimate

D to Zr ratio almost 2 uniformly over the whole target, checked by Nuclear Reaction Analysis as a result of long term bombardment with the ion gun

$$N_e = 2\eta N_b \, N_t \sigma / S,$$

Taking into account the diffusion D = $1.1 \cdot 10^{-12}$ cm^2/s

$$\sigma = \frac{N_e}{t 2\eta N_b} \cdot \frac{St}{N_t} = (5.1 \pm 1.8) \cdot 10^{-1} \;\; b$$

Taking into account the S-factor S = 59 keV·b for bare nuclei for the proton channel

$$\sigma = \frac{S(E)}{\sqrt{E(E + U_e)}} e^{-2\pi\alpha\sqrt{\mu c^2 / 2(E+U_e)}}$$

The result is U_e = 400 ± 10 eV

Measurement in a Bunker

Underground 140 m horizontally, 70 m vertically
Reduction of cosmic ray count rate by a factor of 3 vertically compared to the mine

Background: 21 counts in 10 days
Zirconium target: 32 counts in 8 days
Palladium target: 27 counts in 6 days

Conclusions

- We have seen for the first time spontaneous electron and positron emission from a deuterated Zr foil lasting for at least three days.
- Positive result in Zr, negative in graphite due to the difference in diffusion.
- All measured parameters support the existence of the predicted 0^+ threshold resonance in ^{4}He.
- The e^+e^- pair to proton ratio is larger than 10.

Outlook

- Go even deeper underground.