Lecture notes

Low Energy Nuclear Reactions

Accelerator-driven experiments at University of Szczecin, Poland

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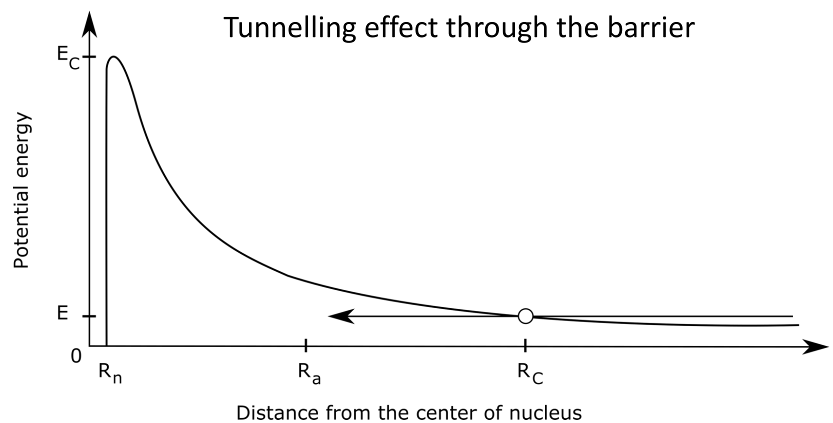
Motivation

- Measurements of the screening effect in proton and deuteron induced reactions on chosen metallic alloys and nanocomposite are performed at the University of Szczecin applying an electrostatic accelerator with ultra-high vacuum placed in *eLBRUS* laboratories.
- The system is equipped with an additional decelerating module to deliver proton and deuteron beam currents of a few mA at the cooled down or heated metallic targets at the lowest possible energies.
- This will allow for measurements of nuclear reaction cross sections at energies down to 1 keV for which reaction enhancement factor due to the screening effect reaches values larger than 1000.
- Influence of crystal lattice defects and nanostructures on the reaction rates are investigated additionally.

Nuclear reactions below Coulomb barrier



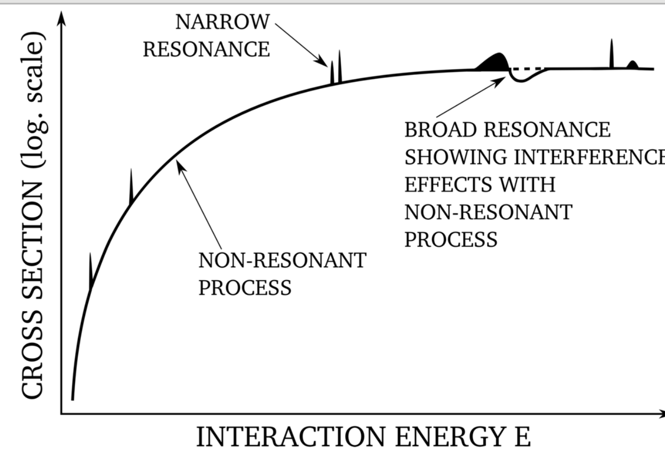
Electrostatic repulsion $$V(R) = \frac{Z_1 Z_2 e^2}{R}$$

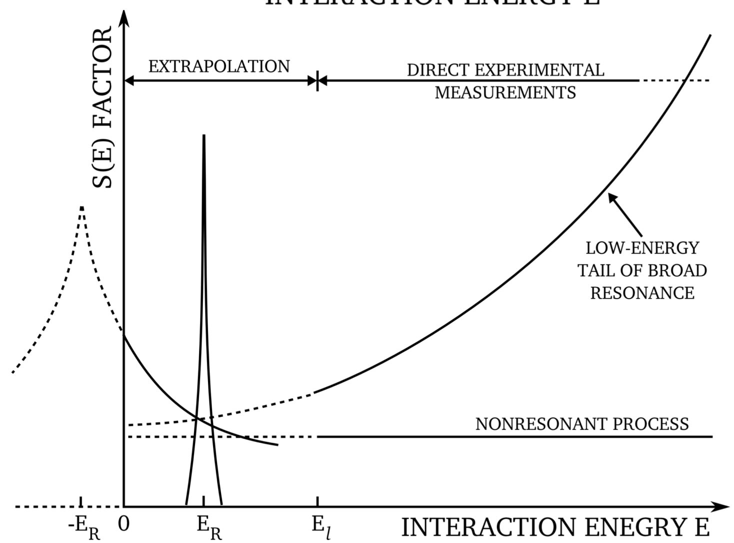
Probability of transition $$P(E) = \sqrt{\frac{E_G}{E}} \exp\left(-\sqrt{\frac{E_G}{E}}\right)$$

Cross section $$\sigma(E) = \frac{1}{E} S(E) \exp\left(-\sqrt{\frac{E_G}{E}}\right)$$

Astrophysical S(E) factor

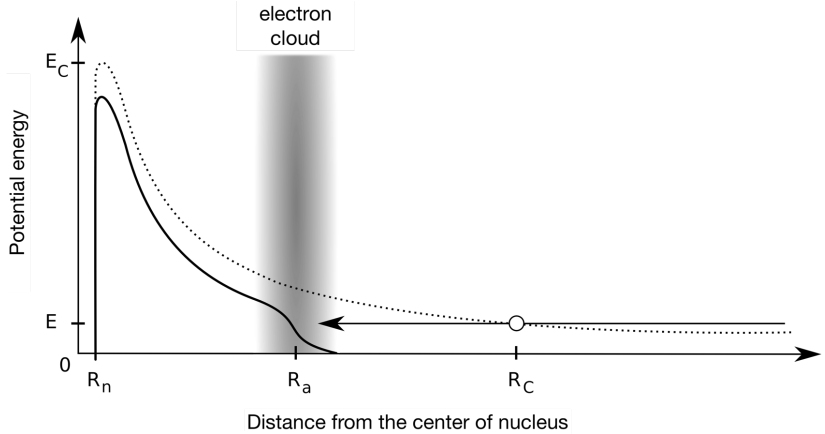
$$S(E) = S_0 + S_1 \cdot E + S_2 \cdot E^2 \overset{E \to 0}{\rightarrow} S(E) = S_0$$





Rolfs C E and Rodney W S, Cauldrons in the Cosmos, Univ. Chicago Press, (1988)

Electron screening effect

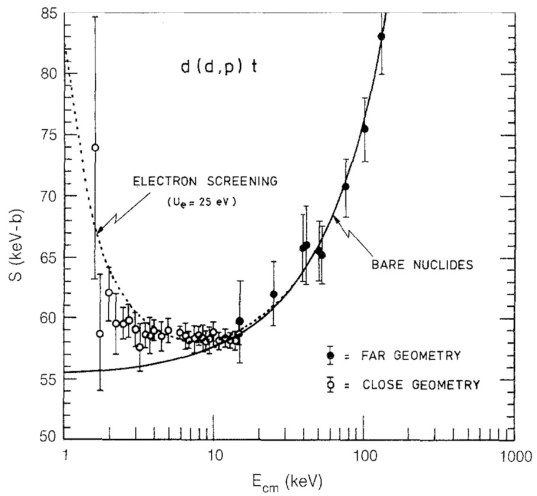


$$V(R) = \frac{Z_1 Z_2 e^2}{R} \exp\left(-\frac{R}{R_a}\right)$$

Electrostatic potential with screening function

$$U_e = \frac{Z_1 Z_2 e^2}{R_a}$$ Screening energy

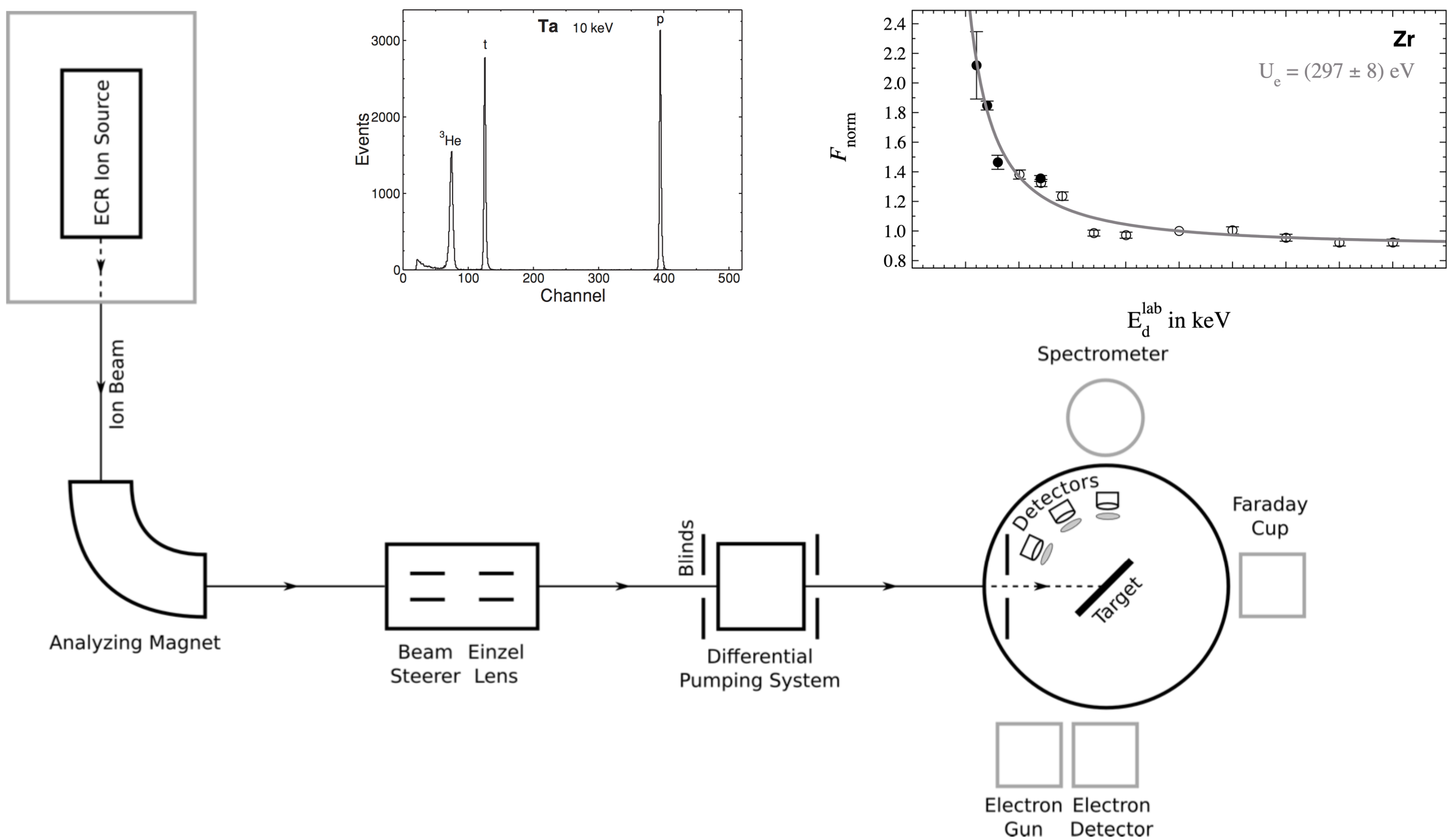
Greife U, Z. Phys. A 315 (1995)



$$P_{scr}(E) = \sqrt{\frac{E_G}{E+U_e}} \exp\left(-\sqrt{\frac{E_G}{E+Ue}}\right)$$

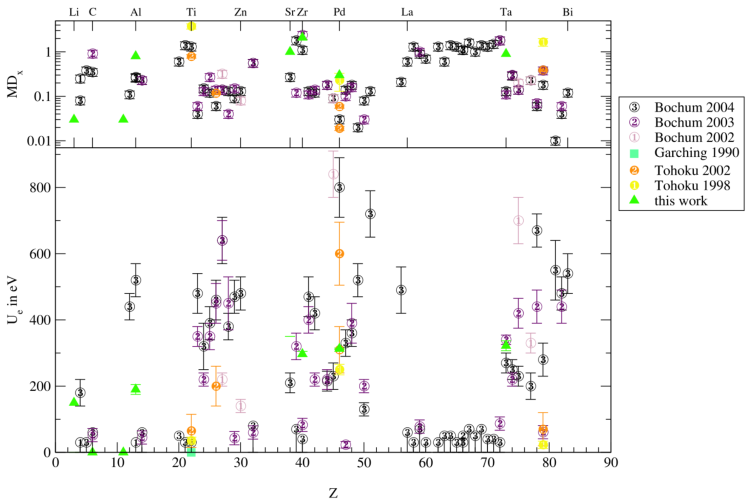
$$\sigma_{scr}(E) = \frac{1}{\sqrt{E(E+U_e)}} S(E) \exp\left(-\sqrt{\frac{E_G}{E+U_e}}\right)$$

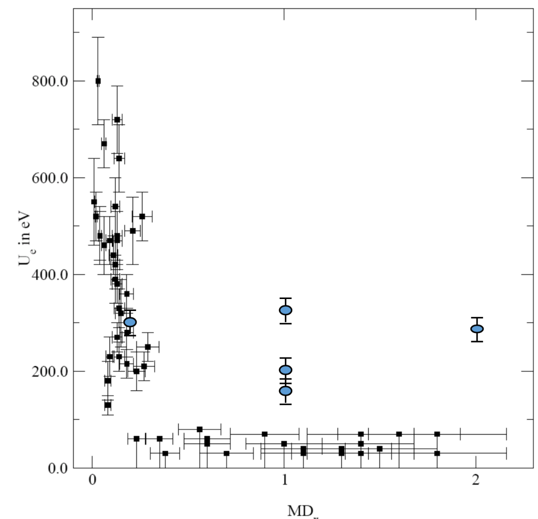
Previous results with HV

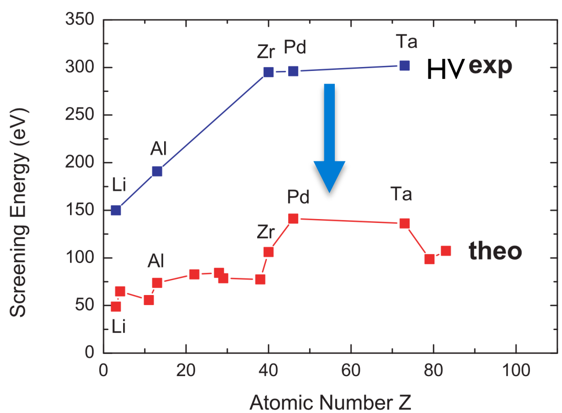


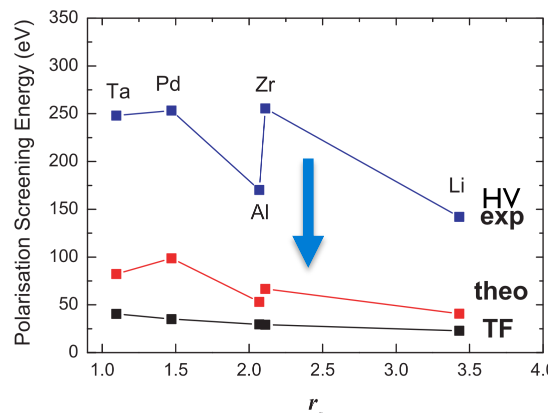
Huke A, Phys. Rev. C 78, 015803 (2008)
Targosz-Ślęczka N, PhD Thesis, University of Szczecin (2012)

Extensive studies worldwide



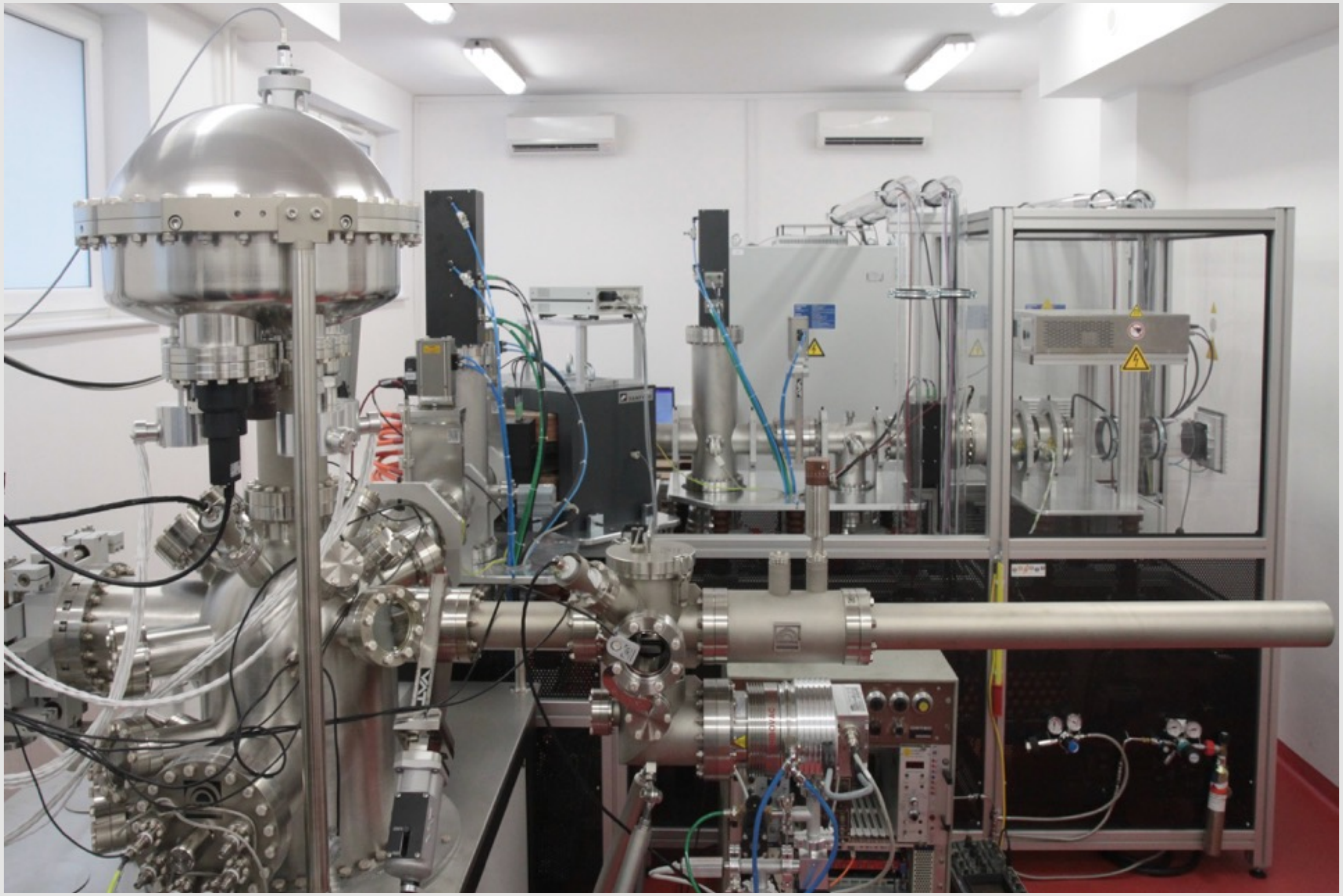




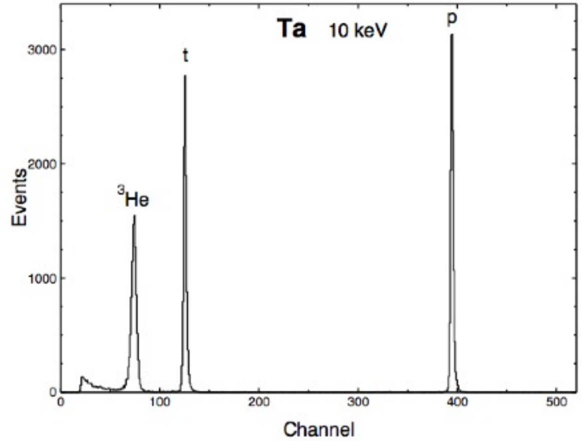


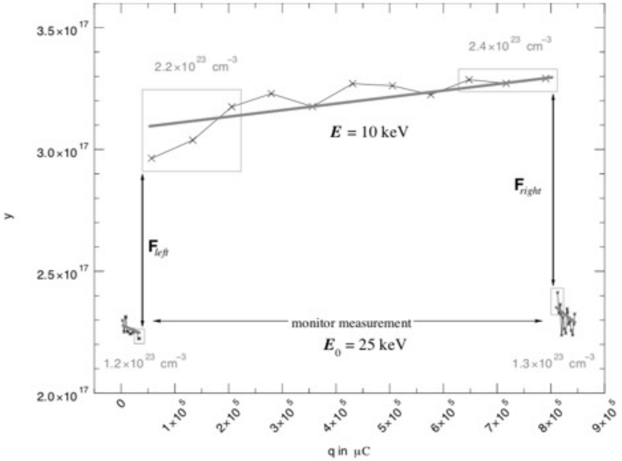
Czerski K, Eur. Phys. J. A 27, 83 (2006)
Huke A, Phys. Rev. C 78, 015803 (2008)

UHV experimental set-up



Full data analysis





Three differential counting numbers were measured and total charge at the target $N(\theta)$ & q

experimental yield

$$Y(E) = \frac{ze}{\varepsilon}\frac{dN}{dq}$$

thick target yield

$$Y_{\text{bare}}(E) = n\int_0^R \sigma_{\text{bare}}(E)dx = n\int_0^E \frac{\sigma_{\text{bare}}(E)}{\frac{dE}{dx}}dE$$

stopping power

$$\frac{dE}{dx} \sim \sqrt{E}$$

reduced yield

$$y(E,q) = \frac{Y_{\text{scr}}(E,q)}{\int_0^E \frac{\sigma_{\text{bare}}(E)}{\sqrt{E}}dE}$$

thick target enhancement factor

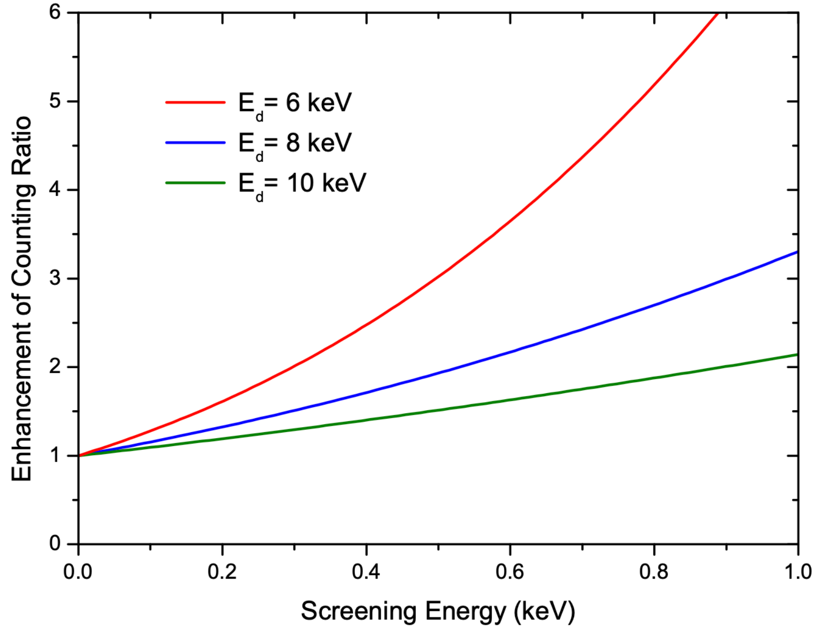
$$F(E) = \frac{\int_0^E \frac{\sigma_{\text{scr}}(E)}{\sqrt{E}}dE}{\int_0^E \frac{\sigma_{\text{bare}}(E)}{\sqrt{E}}dE}$$

Huke A, Phys. Rev. C 78, 015803 (2008)

Estimation of electron screening

- A two-point method for estimation of the screening energy allows to evaluate whether a specific target is worth to be studied in details or not.
- It takes ratio between enhancement in counting rates at two different deuteron energies E_1 (=20 keV) and E_2 (low energy).

$$\frac{\exp\left(-\sqrt{\frac{E_G}{E_2 - U_e}} + \sqrt{\frac{E_G}{E_1 - U_e}}\right)}{\exp\left(-\sqrt{\frac{E_G}{E_2}} + \sqrt{\frac{E_G}{E_1}}\right)}$$



Thank you!

Any questions?

This project has received funding from the European Union's Horizon2020 research and innovation programme under grant agreement no 951974