# Study of the $^{176}$Hf(n,2n) Cross Section At 18.9MeV.

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# Motivation

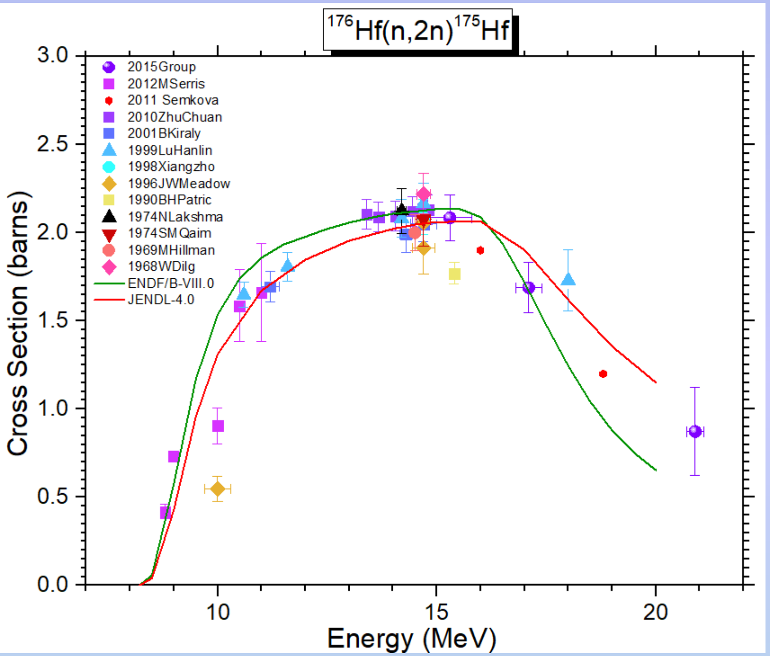
Neutron nuclear reactions can provide significant information in the field of nuclear physics and applications

**Hf**

is important for many reasons:

- Excellent mechanical & chemical properties
- Widely used in industry
- Large absorption cross section for thermal neutrons
- Used for reactor control rods
- Production of long live isomeric states

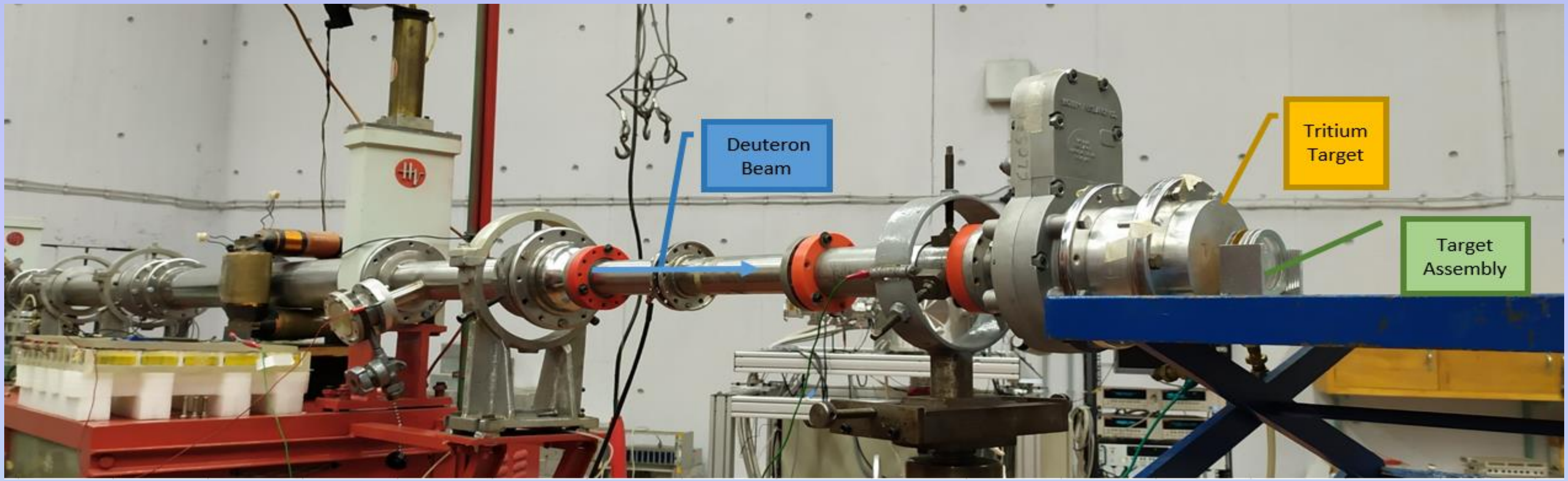
Thus, the knowledge of neutron cross-sections on Hf isotopes is of great importance for basic research in Nuclear Physics as well as for nuclear applications, while the existing experimental data are scarce and discrepant




Existing experimental data

# Experimental Method

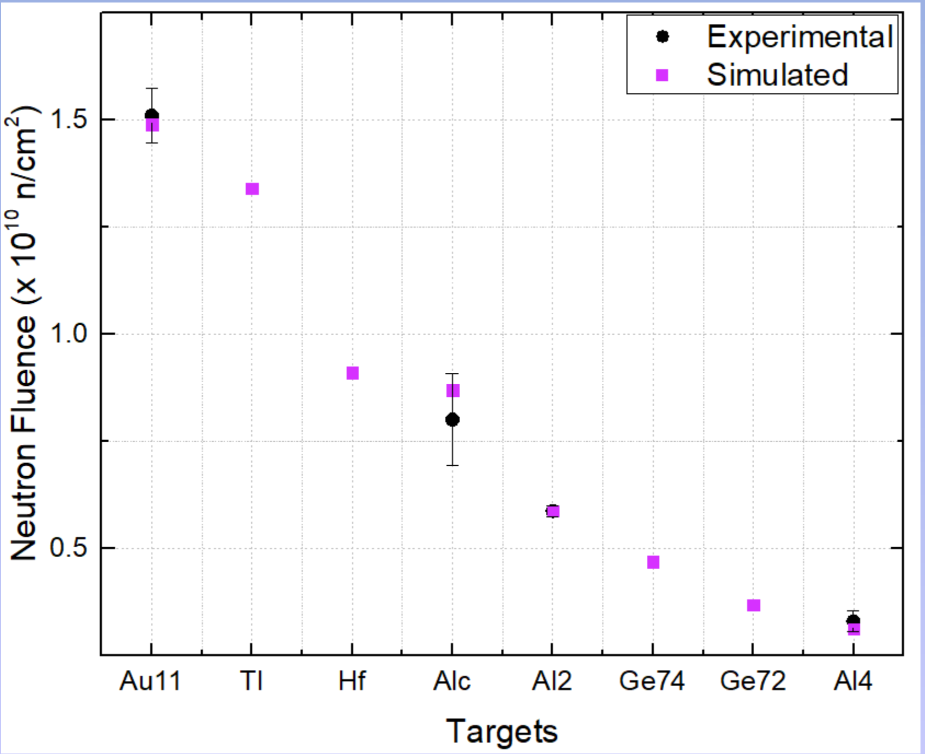
In this study measurements of experimental cross section for the **$^{176}$Hf(n,2n)$^{175}$Hf** reaction were carried out, **using the activation technique.** The experiment was performed at the 5.5 MV Tandem accelerator of N.C.S.R. “Demokritos”. The neutron beam energy at 18.9 MeV was produced via the $^{3}$H(d,n)$^{4}$He reaction, using a Ti-T target and a deuteron beam at 3.45 MeV.



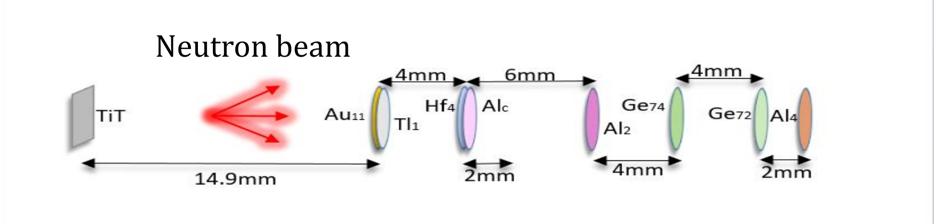

The setup of the experiment

# Determination of neutron flux

A thin metallic foil of natural Hf was used along with reference foils of Al and Au for the determination of the neutron flux at the target position through the $^{27}Al(n,\alpha)^{24}Na$ and $^{197}Au(n,2n)^{196}Au$ reactions. Extensive Monte Carlo simulations with MCNP code were also used for the neutron flux determination. The value of the total neutron fluence at the Hf target was ~$10^{10}$ n/cm$^2$. In order for the neutron flux to be monitored, a $BF_3$ detector had been used.




Experimental fluences in the reference foils along with the simulated ones




Schematic representation of the target assembly

# Measurement

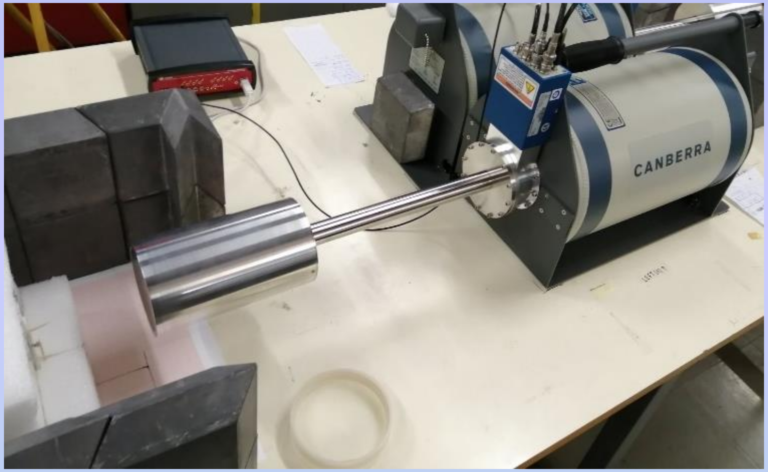
After the end of irradiation (~28 hours) the activities of the Hf target and the reference foils were measured off-line by three HPGe detectors (80%) characterized with $^{152}Eu$ sources. The samples were placed at a 10 cm distance from the detector window. Of all five isotopes of natural Hf ($^{180,179,178,176,174}Hf$) only the $^{176}Hf(n,2n)^{175}Hf$ reaction could be measured in this experiment. The characteristic γ-ray from the residual nucleus $^{175}Hf$, with a half-life of 70 d, is the 343.4keV one (Iγ 84%).

Determination of the cross section σ:

$$\boxed{\sigma = \frac{N_p}{N_T} \cdot \frac{1}{\Phi}}$$

Where:

- $N_p$ : The produced nuclei ($N_p = \frac{N_\gamma}{\varepsilon \cdot I_\gamma \cdot D \cdot F \cdot f_c}$)
- $N_T$ : The number of target nuclei
- Φ : Neutron flux resulted from the reference foils and MCNP simulations

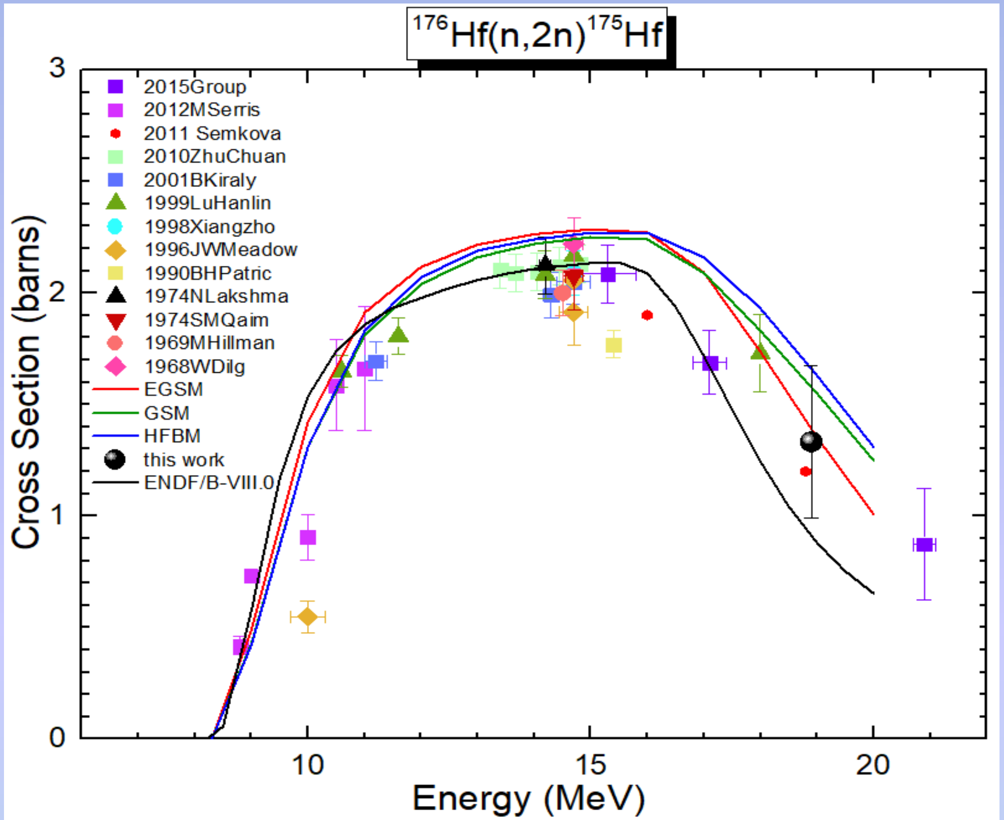



One of the HPGe detectors

# Results and Theoretical Calculations

The cross section σ for the $^{176}Hf(n,2n)^{175}Hf$ reaction, after the correction for the contamination from the $^{177}Hf(n,3n)^{175}Hf$ reaction, was defined : **σ=(1.33±0.34) b**

Theoretical calculations were carried out with **Empire 3.2.3 code**




The basic input includes:

- ➢ **Optical model parameters by** F.D.Becchetti, Jr. and G.W.Greenlees
- ➢ **Empire level density models**
- Enhanced Generalized Superfluid Model(EGSM)
- Generalized Superfluid Model(GSM)
- Hartee-Fock-Bogoliubov Microscopic (HFBM)

The level density model that better describes the data is **EGSM**

Further measurements are planned to be performed in the energy region of 15-21MeV