Neutron measurement in the IS581 experiment

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for IS581 experiment (Prague-Bratislava-Leuven-York-Lowell-Athens-GANIL-Orsay-Saclay-CENBG-Santiago de Compostela)

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EMPIRICAL SADDLE-POINT AND GROUND-STATE MASSES AS A PROBE OF THE DROPLET MODEL

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Experimentally measured fission barriers

Most of the known fission barriers were obtained more than 30 years ago (summarized by Dahlinger et al.) . Since then very little progress was made, due to problems with methodology.

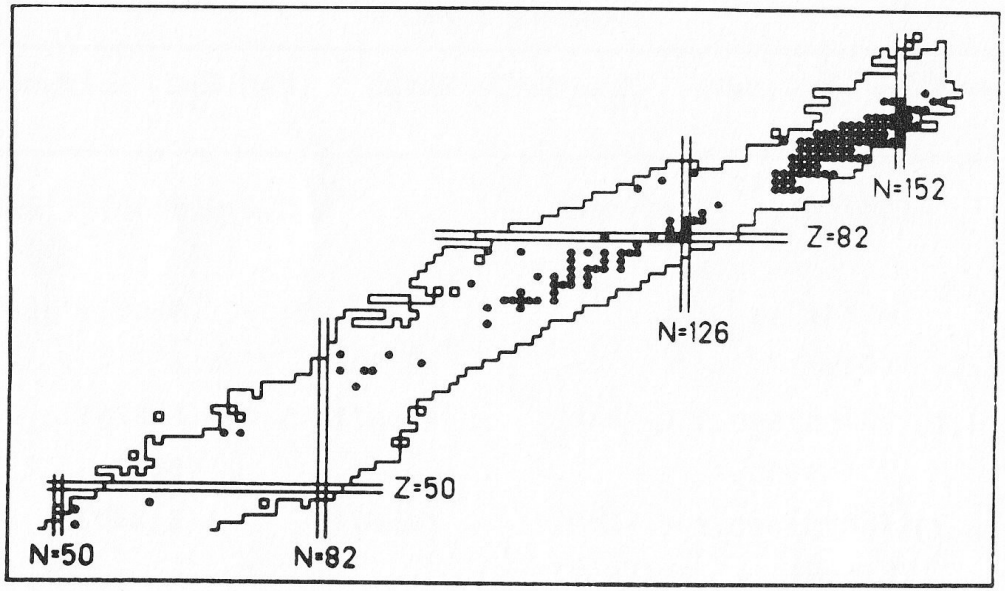


Fig. 2. Part of the chart of the nuclides. Nuclei for which the fission barrier was determined experimentally are indicated by an asterisk.

Direct measurement of fission barriers

Best and unambiguous method of measurement, possible when Coulomb barrier is lower than fission barrier, which can be observed as a fission threshold. Possible with light beams, preformed using restricted set of stable target nuclei.
Among others, the **(d,pf) reaction was used for nuclei heavier than radium**, where fission barriers are low and comparable to Coulomb barrier.
In normal kinematics, this method can not be used for exotic nuclei.

Unsolved problem: Fission barriers of neutron-deficient nuclei

- extracted from evaporation residue cross sections (in channels with emission of several nucleons) using statistical model
- lower than predictions of model calculations by 15-25 % (Sierk), 30-40 % (Cohen-Plasil-Swiatecki).
- are the macroscopic barriers wrong or is it a problem with description of fission decay width ?

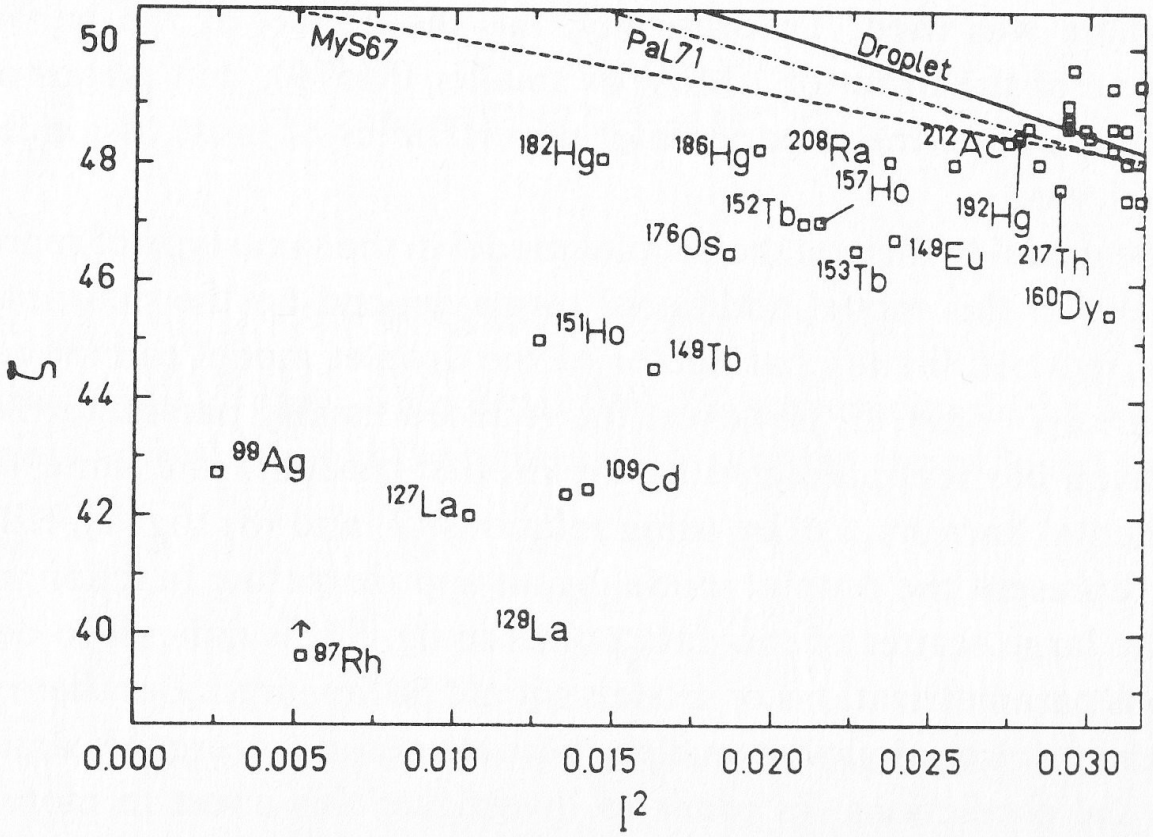


Fig. 7. Neutron-deficient part of fig. 5. The data points are marked with the element symbol and the mass number.

M. Dahlinger, D. Vermeulen and K.H. Schmidt, Nucl. Phys. A 376 (1982) 94

Statistical model

Survival probability is calculated as a product of emission probabilities over the whole cascade

cascade). The probability of a given decay channel i is

$$P_i(l) = \Gamma_i(l)/\Gamma_{tot}(l) \tag{7}$$

where $\Gamma_i(l), \Gamma_{tot}(l)$ represent the width of a decay channel i and the total decay width at a given de-excitation stage. The partial emission widths for particle emission are determined as

$$\Gamma_i(E,l) \propto (2l+1)(2s_i+1)\int_0^{E-E_B(l)-E_{rot}(l)} \rho(E-E_B(l)-E_{rot}(l)-\epsilon)\epsilon\sigma_i d\epsilon \tag{8}$$

and the fission width as

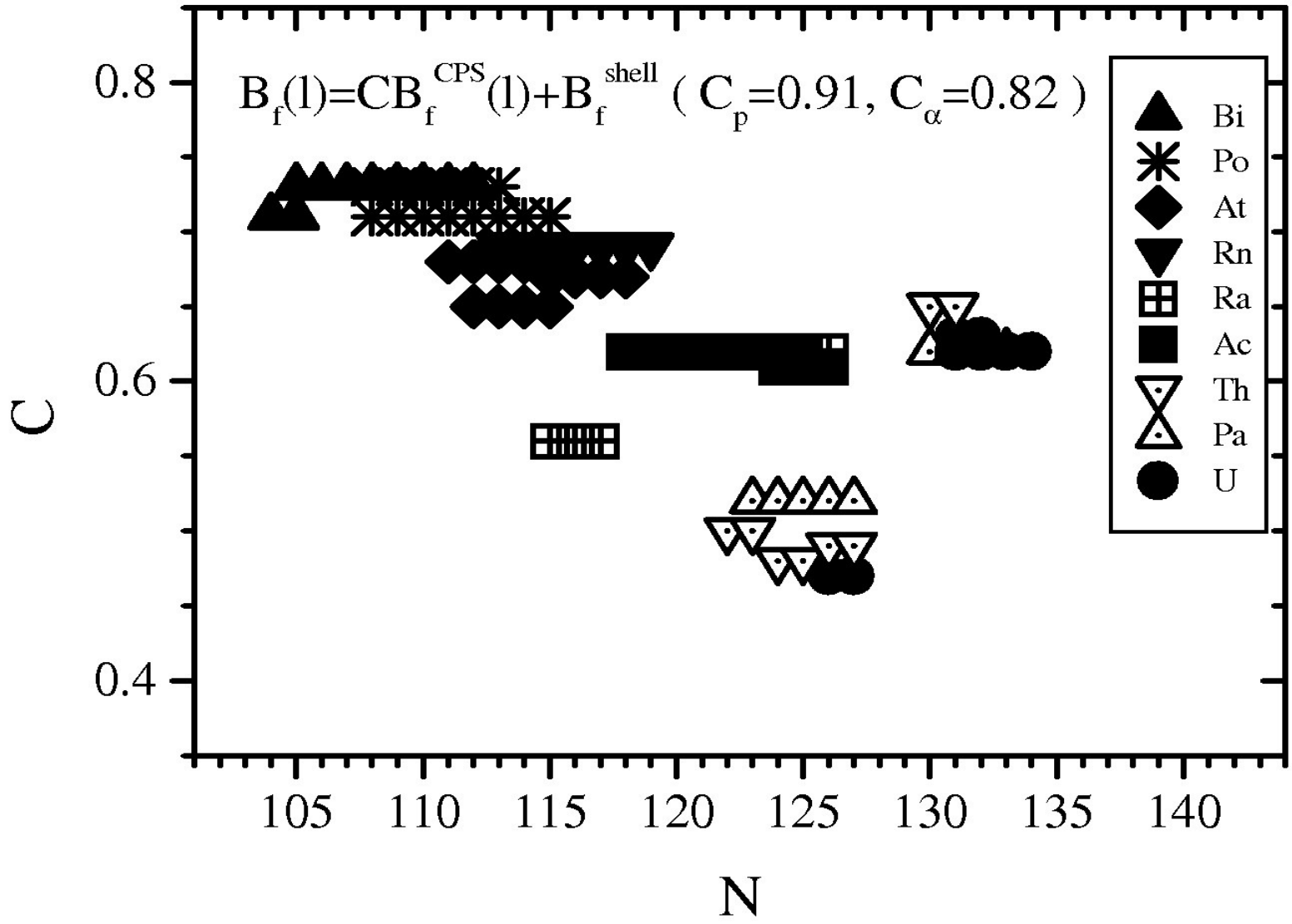
$$\Gamma_f(E,l) \propto (2l+1)\int_0^{E-B_f(l)-E_{rot}(l)} \rho(E-B_f(l)-E_{rot}(l)-\epsilon)d\epsilon \tag{9}$$

where ρ is the level density calculated using the Fermi gas formula [23] and σ_i the inverse cross section for particle emission, l again denotes the angular momentum, s_i the spin of the particle, E_B the binding energy of the particle, E_{rot} the rotational energy

$$E_{rot}(l) = \frac{\hbar^2 l(l+1)}{2\mathcal{J}} \tag{10}$$

Fission barrier is used as a cutoff parameter in the formula for fission width !
However, interplay with the level density parameter in fission channel (a_f/a_n) !

Systematics of extracted fission barriers – scaling factor C applied to macroscopic part (rotating liquid-drop barriers of Cohen-Plasil-Swiatecki)

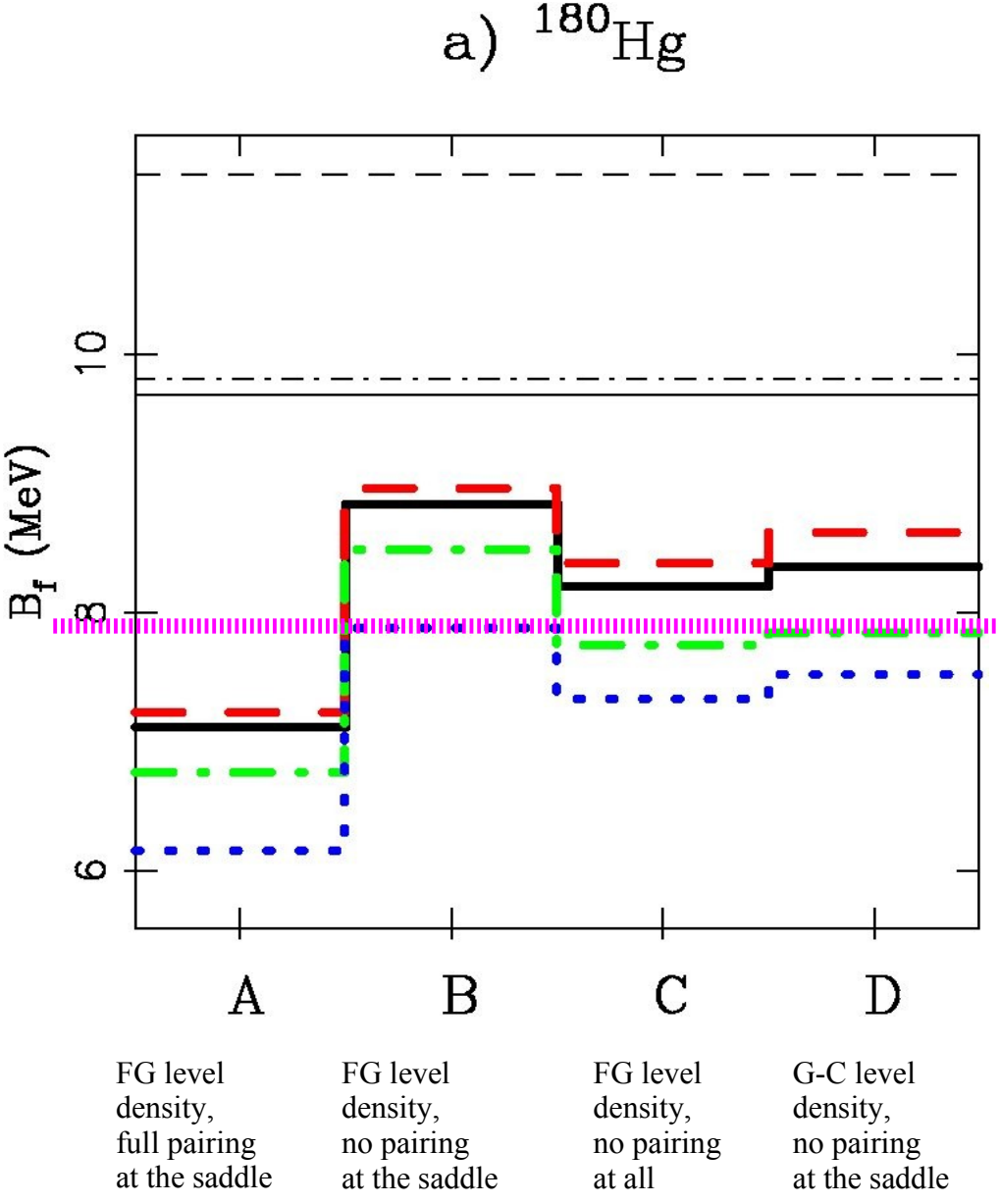


Different values on and off the N=126 neutron shell !
Why macroscopic barrier would be influenced by shell structure ?

Previous effort at ISOLDE:
EC-delayed fission of ^{180}Tl (new mass-asymmetric fission mode !)

$P_{bdf} = 3.2(2) \cdot 10^{-5}$
(obtained by the experiment IS466 at ISOLDE)

- used to deduce fission barrier height of the daughter isotope ^{180}Hg.
- four alternative strength functions (thick lines) and four variants of statistical calculations (A-D) are used to determine the fission barrier. A-C – Fermi-gas level density formula, D – Gilbert-Cameron formula, pairing see explanation below figure.
- deduced fission barriers appear to be 10-40 % smaller than theoretical estimates (thin lines), thus apparently confirming the results from compound nucleus reactions.
- uncertainty in determined fission barrier heights results dominantly from uncertainty concerning the magnitude of the pairing gap in the saddle configuration. Possible solution: study fission of odd-odd nuclei at low excitation energies
- analogous results for ^{178}Tl, ^{188}Bi, ^{196}At



Accepted as HIE-ISOLDE experiment IS581

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

(d,p)-transfer induced fission of heavy radioactive beams (based on LoI INTC-I-095 and INTC-I-119)

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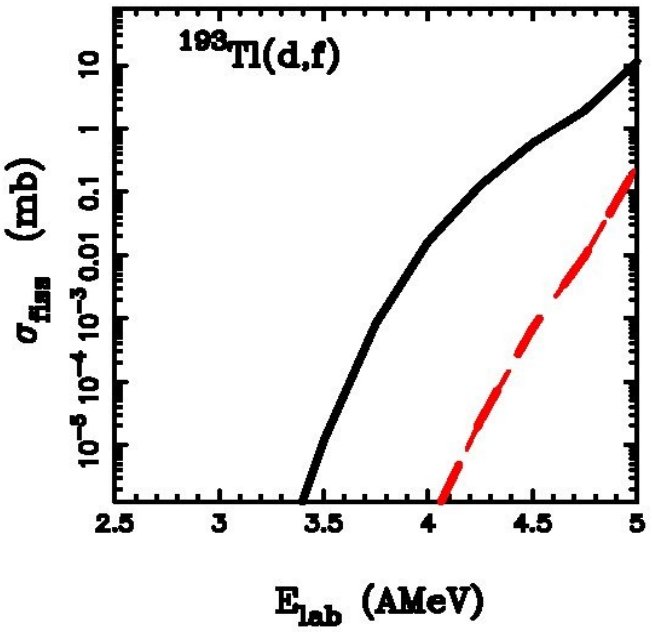
Abstract

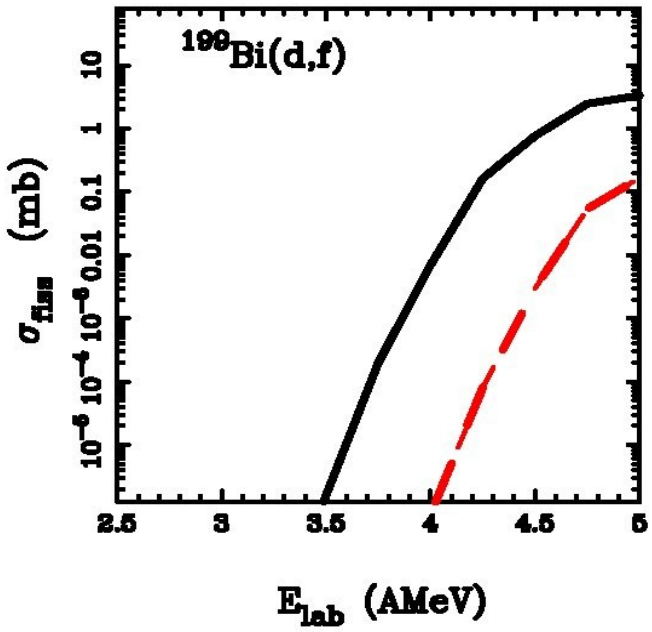
(d,p)-transfer induced fission is proposed as a tool to study low energy fission of exotic heavy nuclei. Primary goal is to directly determine the fission barrier height of proton-rich fissile nuclei, preferably using the radio-active beams of isotopes of odd elements, and thus confirm or exclude the low values of fission barrier heights, typically extracted using statistical calculations in the compound nucleus reactions at higher excitation energies. Calculated fission cross sections in transfer reactions of the radioactive beams show sufficient sensitivity to fission barrier height. In the probable case that fission rates will be high enough, mass asymmetry of fission fragments can be determined. Results will be relevant for nuclear astrophysics and for production of super-heavy nuclei. Transfer induced fission offers a possibility for systematic study the low energy fission of heavy exotic nuclei at the ISOLDE.

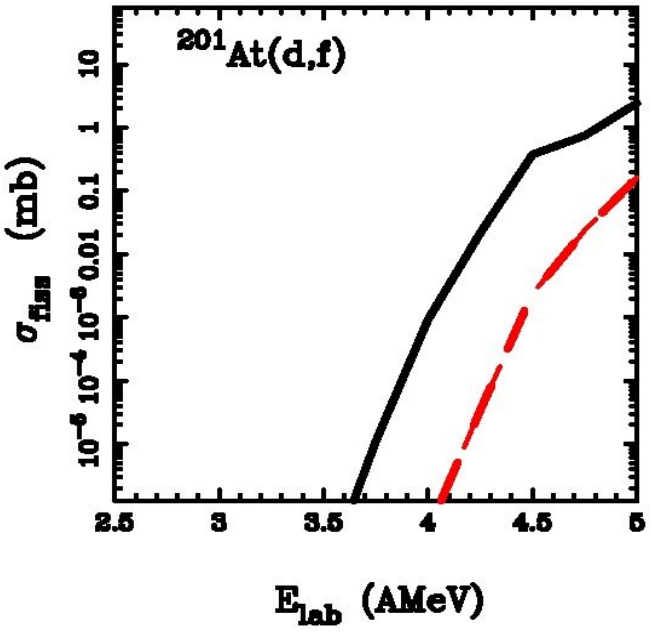
New method: (d,p)-transfer induced fission of heavy radioactive beams in inverse kinematics (at HIE-ISOLDE)

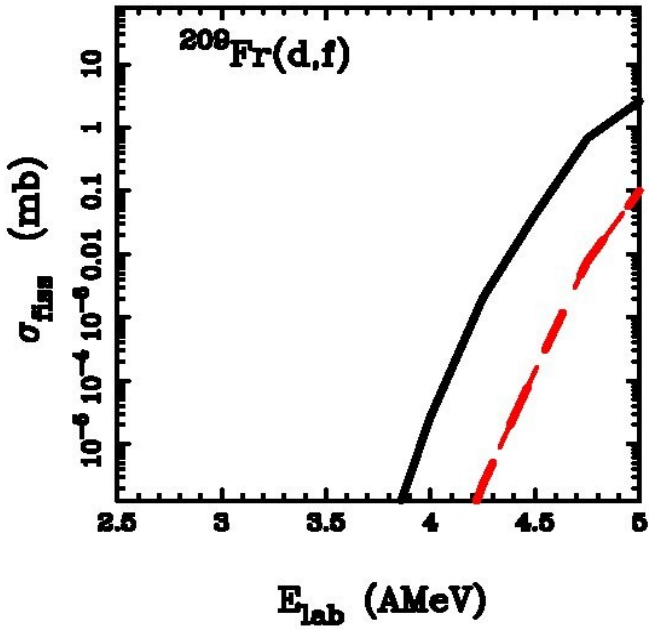
It is of primary interest to observe **transfer-induced fission of odd elements such as Tl, Bi, At or Fr**, since in this case the estimated fission barriers will not be influenced by uncertainty in estimation of the pairing gap in the saddle configuration.

Observed fission rates of these beams can be used to **directly determine values of the fission barrier heights.**



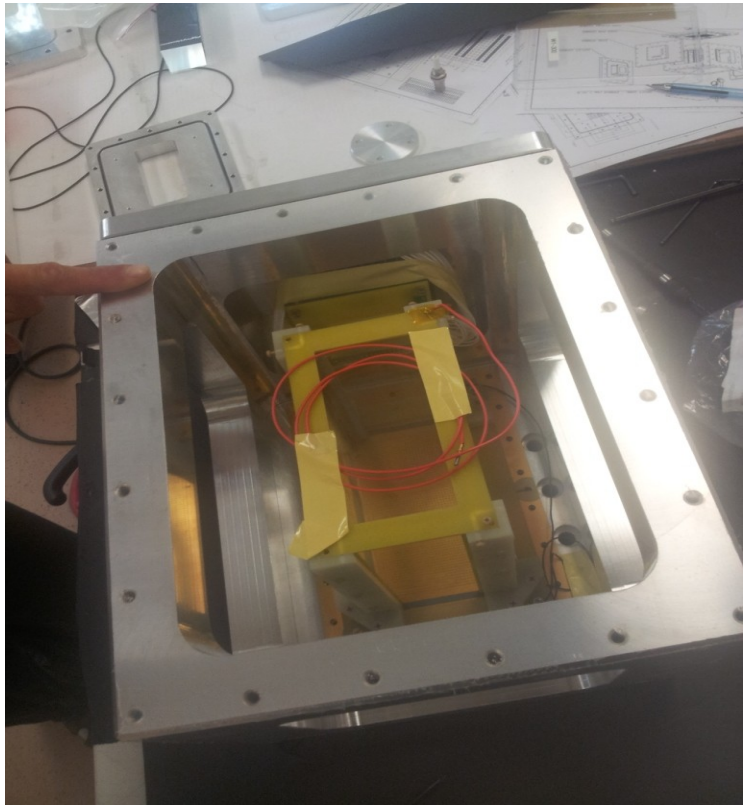


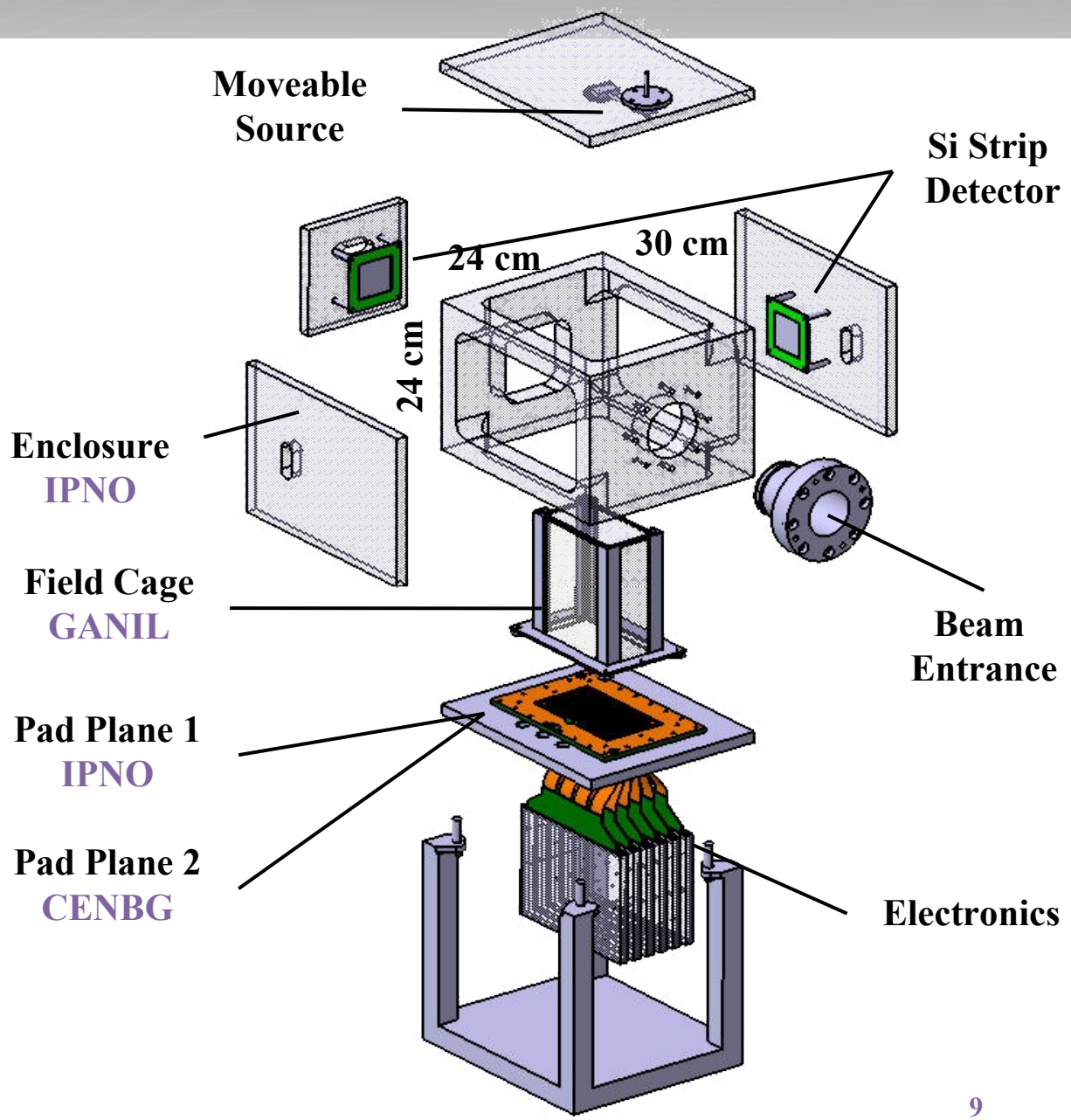


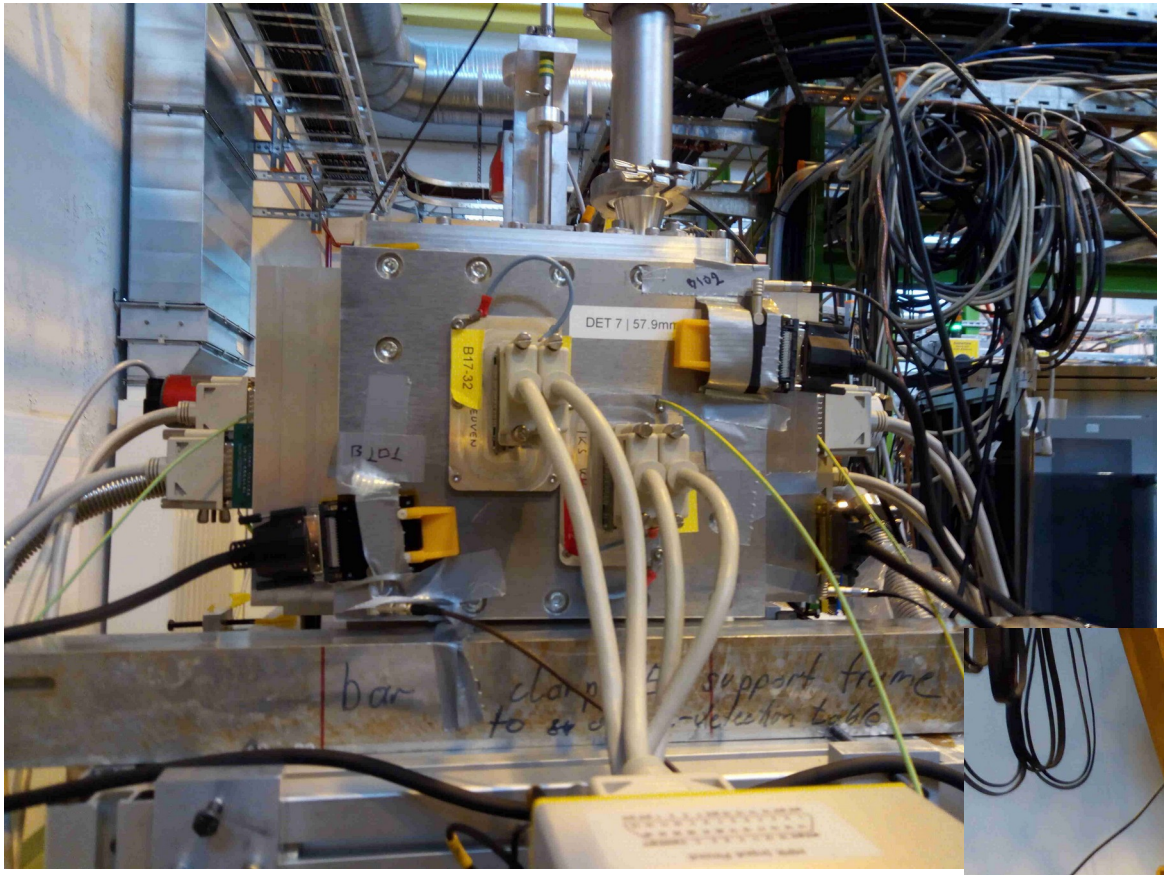


ACTAR TPC Demonstrator

- 12 × 6 cm2; 2 × 2 mm2 × 2,048 pads
- Test high-density connection
  - High-density connector (IPNO)
  - Direct insertion to Micromegas
- Test GET electronics

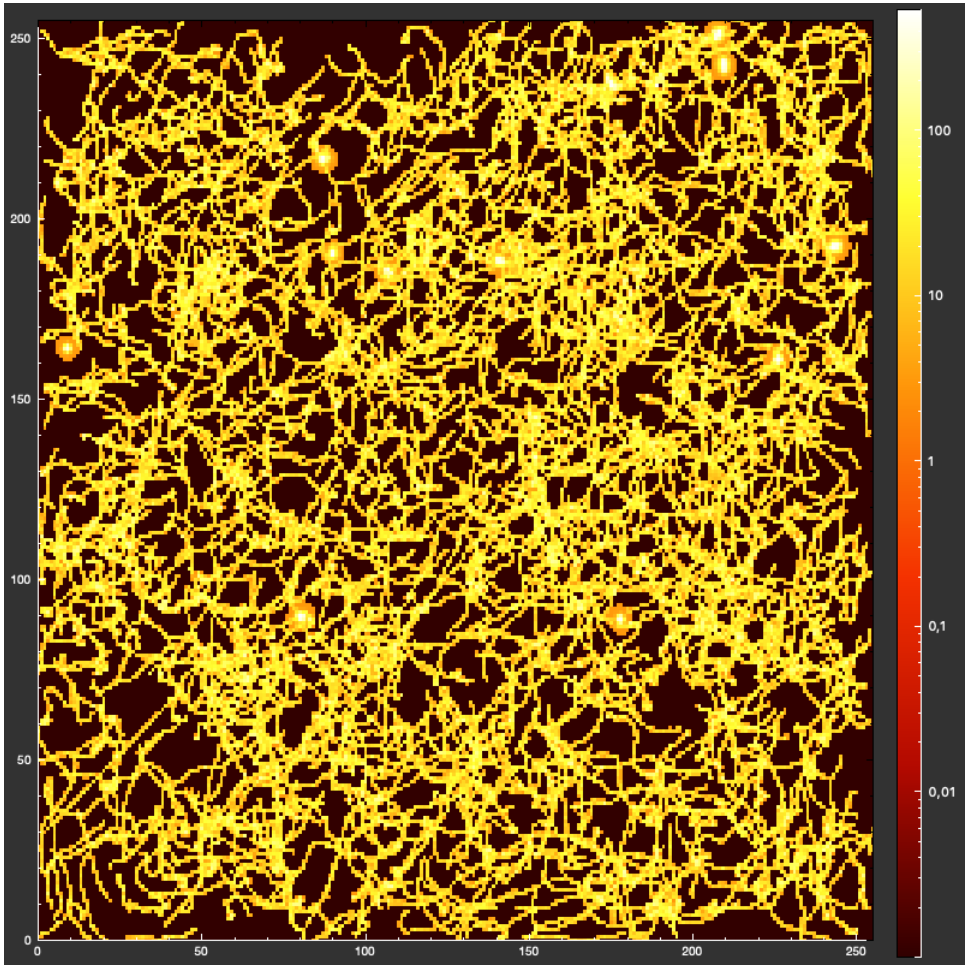






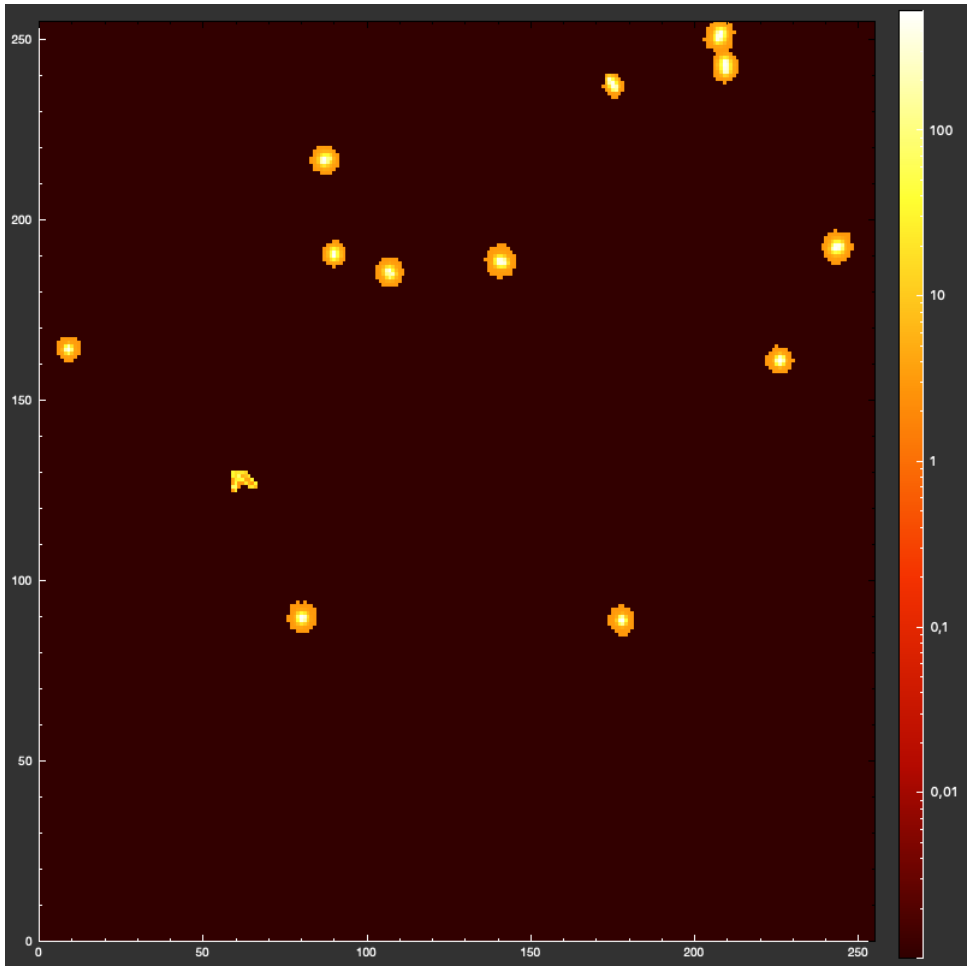
4 TPX3 pixel detectors placed on the body of ACTAR TPC chamber.

Polyethylene converter used for detection of fast neutrons, this method used successfully to detect fusion neutrons in high-power laser experiment.



Analysis of hits in TPX3 pixel detectors

- selection by cluster size, energy, "roundness"
- software by L. Meduna, analysis performed by P. Rubovic



Fast neutrons detected almost exclusively with beam on, practically no fast neutron background.

Simulations:

Beam energy losses from Srim (500 and 800 mbar)

(d,p) and (d,n) cross sections from Talys ((d,np) at 1 %)

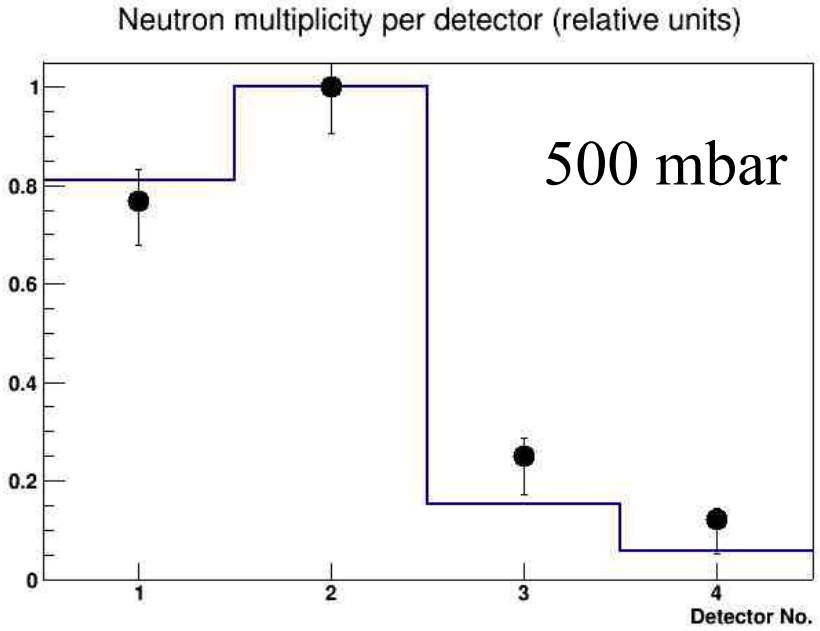
2-body kinematics, emission of neutrons

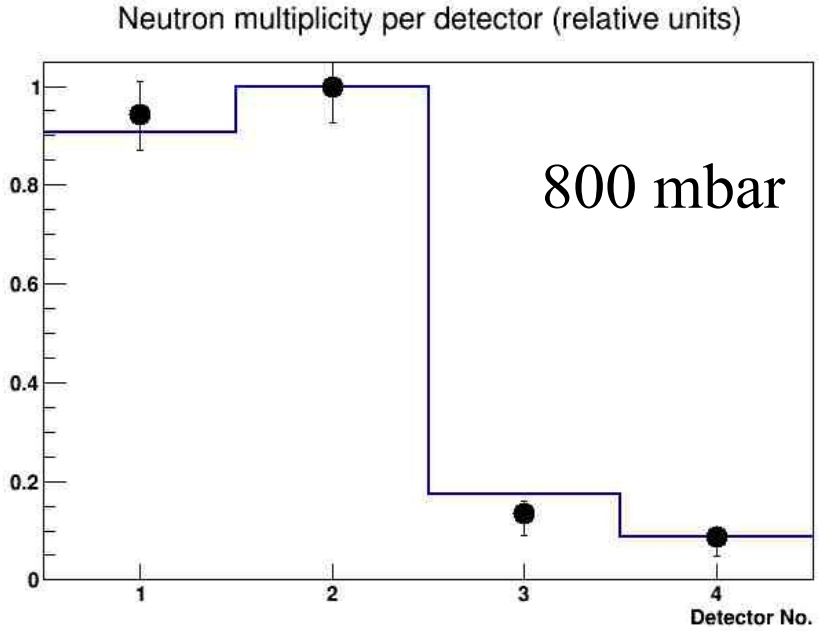
Excitation energy vs fission barrier (Sierk scaled down by 0 – 25 %)

Fragment mass distributions and TKE from PhD thesis of Bockstiegel (GSI)

Emission of neutrons from fragments (neutron multiplicity up to 2)

Geometric acceptance of Timepix3 detectors

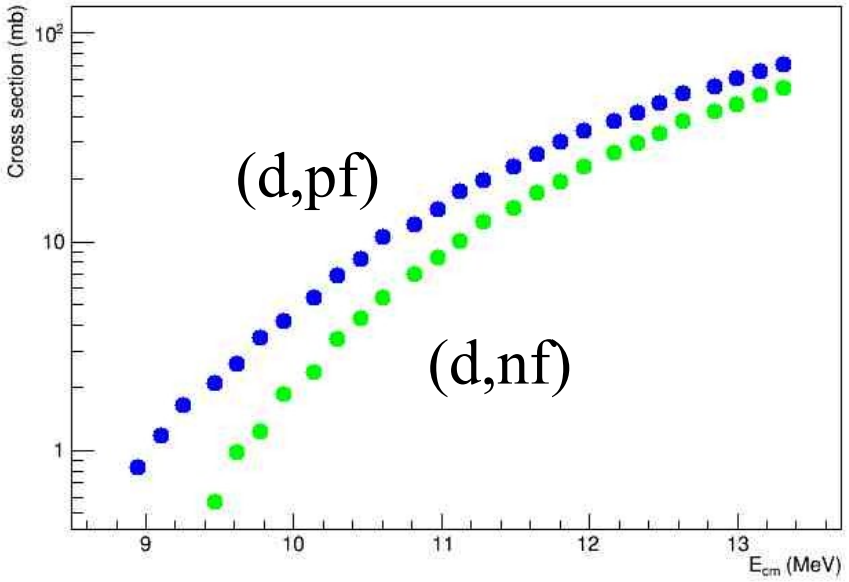




Normalized neutron multiplicities for successful simulations:

B_f = 85% of B_f(Sierk)

n-multiplicity = 2



Conclusions

Fission barrier height determined using neutron angular distribution obtained by TPX3 pixel detectors with PE converter - new “light-weight” method

Reduction of fission barriers at very proton-rich nuclei confirmed

Second part of measurement on the neutron-rich side
– relevant for study of nucleosynthesis of heaviest elements

More TPX3 pixel detectors available

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