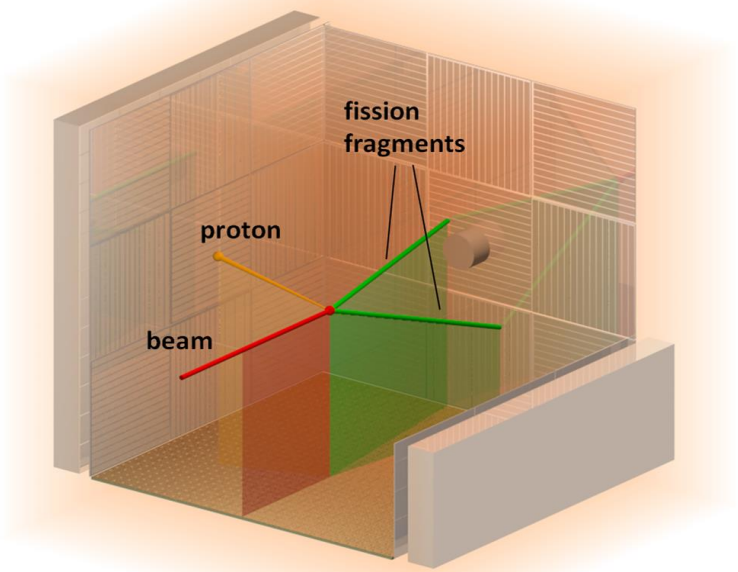
Direct measurement of fission barrier heights of unstable heavy nuclei at ISOL facilities
&
ACTAR TPC

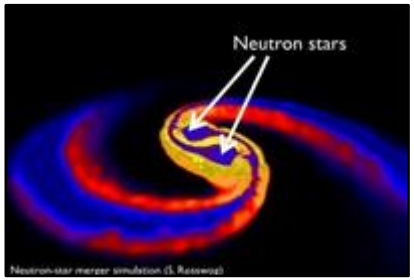
for IS581: Jozef Klimo

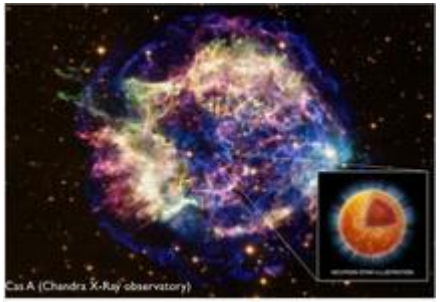
spoken person: Mgr. Martin Veselský, PhD

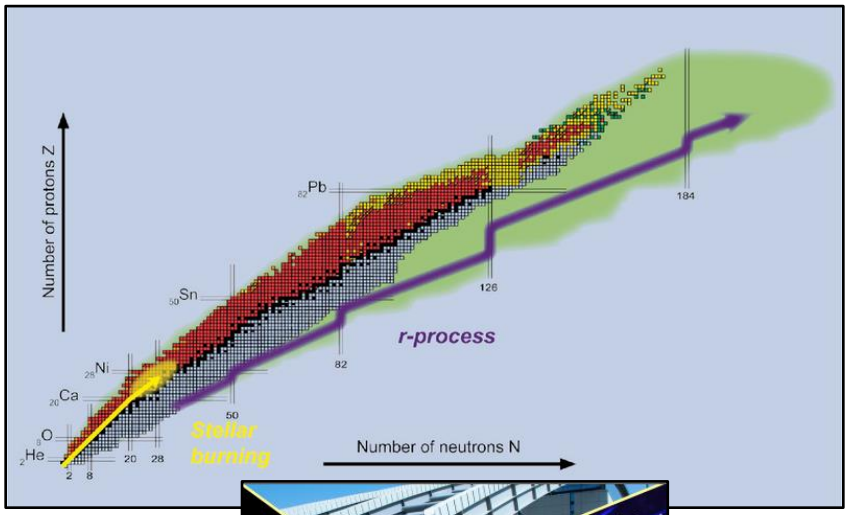


Motivation

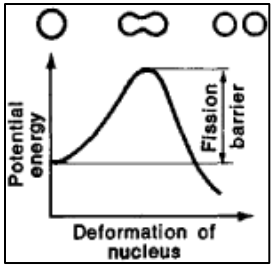
- Fission is expected to play a key role in the description of r-process in nucleosynthesis n-rich nuclei in two neutron star merger







- Fission barrier height is the parameter determining fission rate
- Description of fission rate/fission barrier in induce fission is demanded in **NuPECC Long Range Plan 2017**
- A very little progress was done up to present due to the methodology



The Present Status

- Most of the known, directly measured, fission barriers heights (Bf) were obtained by more than 30 years ago.
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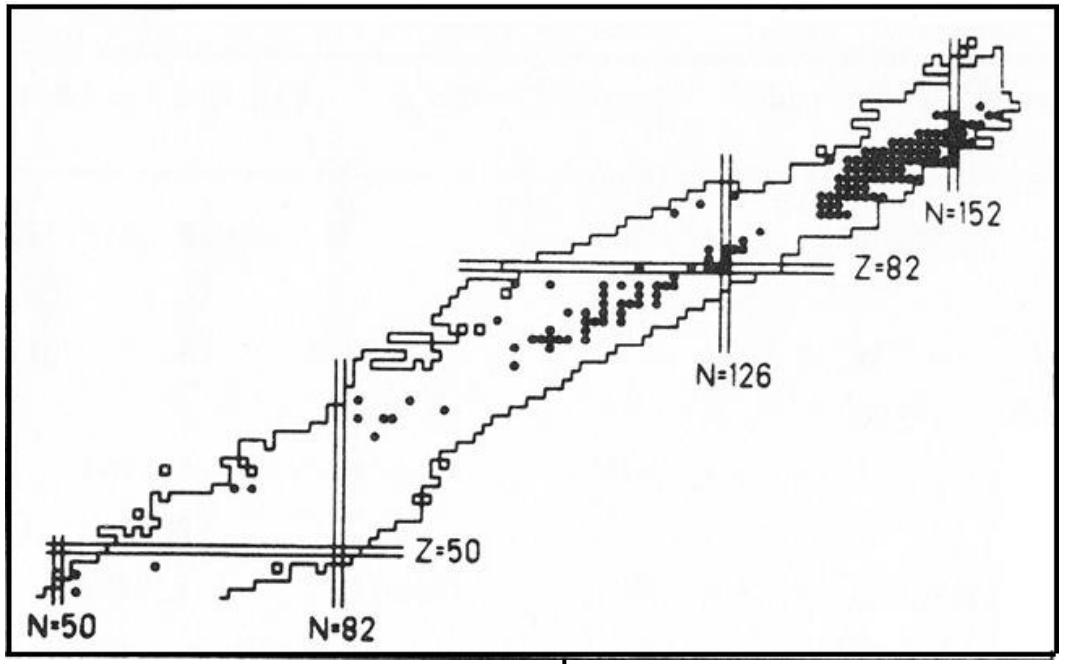

Part of the chart of the nuclides. Nuclei for which the fission barrier was determined experimentally are indicated by an asterisk Dahlinger et. al., 1982

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Region of nuclei Bf ~ Vc

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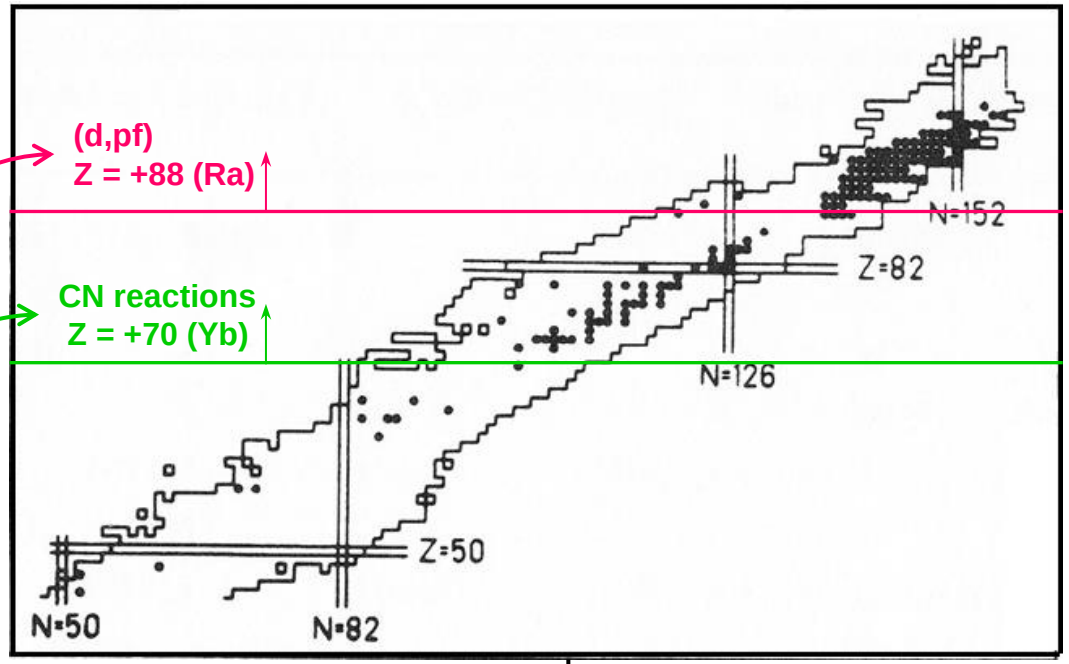
- On the n-deficient side of the NC, Bf parameters determined in induced fission via

⇩

- The most of them from the nearest vicinity of the β stability line



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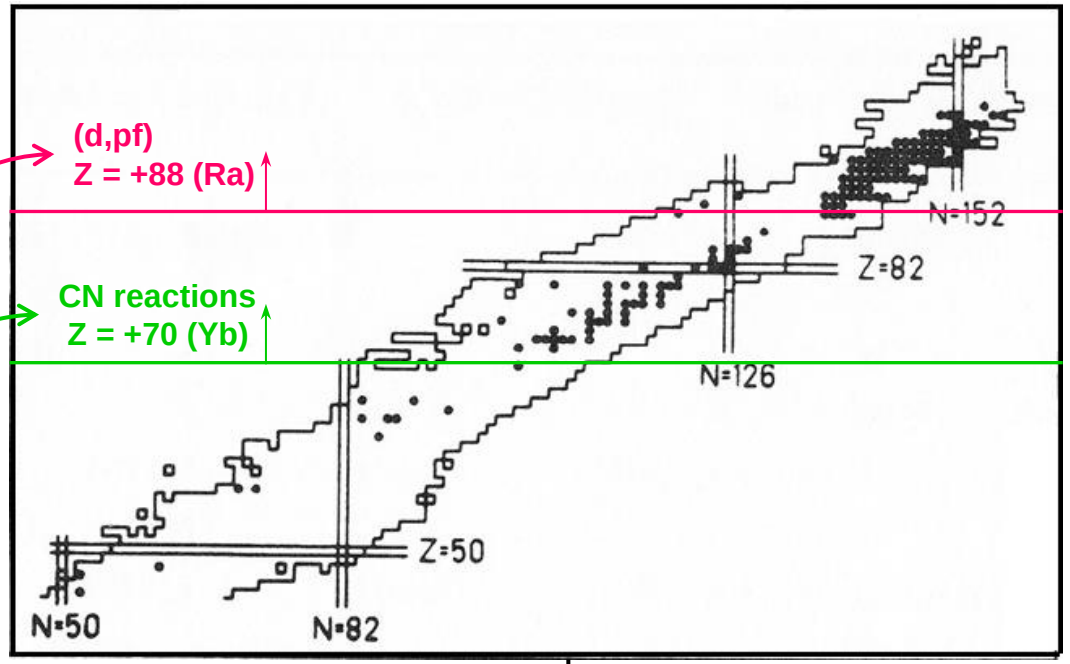

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"The Age of RIB" opens possibilities to measured Bf of exotic n-deficient nuclei in low energy fissions:
-> βDF (even-even nuclei) – significant uncertainty in Bf!
-> (d,pf) - (inverse kinematics) – New method for RIB!

Physical background of fission barriers @ low E*

Probability of low energy fission

$$P_{\mathrm{LEf}} = \frac{\int_0^{E^*_{\mathrm{max}}} W(E^*) \frac{\Gamma_f(E^*)}{\Gamma_f(E^*)+\Gamma_\gamma(E^*)} dE^*}{\int_0^{E^*_{\mathrm{max}}} W(E^*) dE^*}$$

- $W(E^*)$ — Probability to populate a given excited state **–> Exp.**
- $\Gamma_\gamma(E^*)$ — Fission / γ emission decay width, no other channel contributes **-> Exp./Th.**
- $\Gamma_f(E^*)$ — Fission / γ emission decay width, no other channel contributes **-> Exp./Th.**

Fission decay width

$$\Gamma_f(E^*) = \frac{1}{2\pi\rho_c(E^* - \Delta)} \int_0^{E^*-B_f-\Delta_{sp}} \rho_{sp}(E^* - B_f - \Delta_{sp} - E')dE'$$

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Δ_{sp} ??

Because of pairing energy Δ_{sp} at the saddle point configuration of nucleus Bf could not be determined with good precision by present theory -> uncertainty for deduced Bf for others than odd-odd nuclei.

A small difference in Bf can caused a huge difference in P_{LEf} !!

even-even, odd A:	Δ_{sp} **= unnegligible and significant uncertainty - βDF, (d,pf)**
odd-odd:	Δ_{sp} **= zero contribution - (d,pf)**

(d,pf) & HIE-ISOLDE & ACTAR TPC

- ACTAR TPC enables to measure (d,pf) with post-accelerated n-deficient RIB in inverse kinematics

- ACTAR TPC offers **higher fission rate** and enables to obtain **fission cross section for range of the energies → excitation function**

Technique

-> the two fission fragments are detected in the forward-placed silicon array

-> the proton from the transfer is either stopped in the volume or in Si-CsI telescope arrays surrounding the active volume

-> E^*_{RE} from two body kinematics of *proton vs. RE**

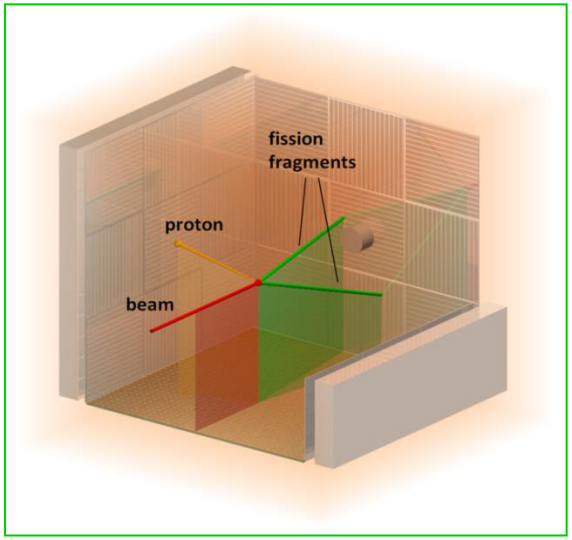
-> ACTAR angle resolution < 1°/proton

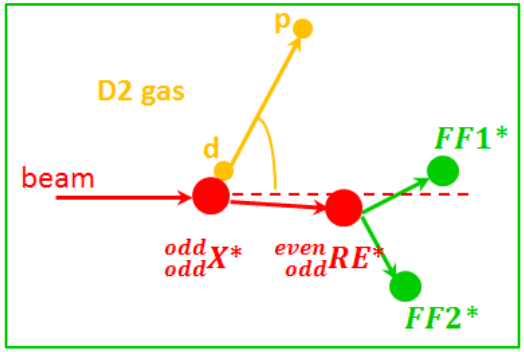
-> uncertainty for E^*_{RE} < 0.5 MeV

-> different position of (d,p) transfer in the ACTAR TPC corresponds to different $E_{(beam)}$ of RIB (5 to 4.1 AMeV)

-> fission excitation function for more than 60 points is possible

-> multiple measured fission probabilities!!





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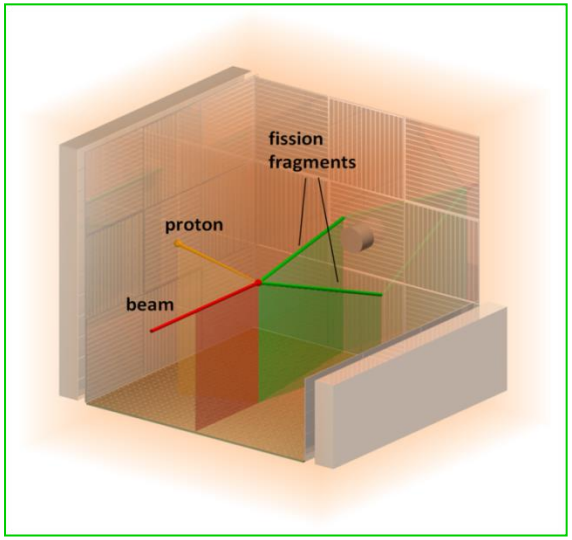

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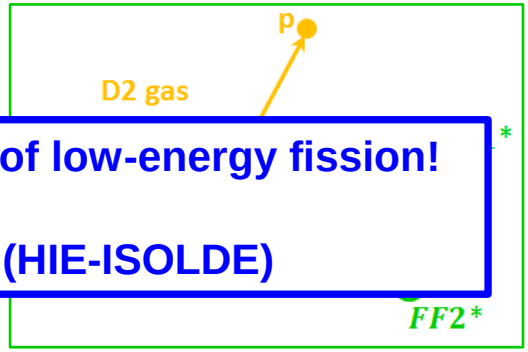
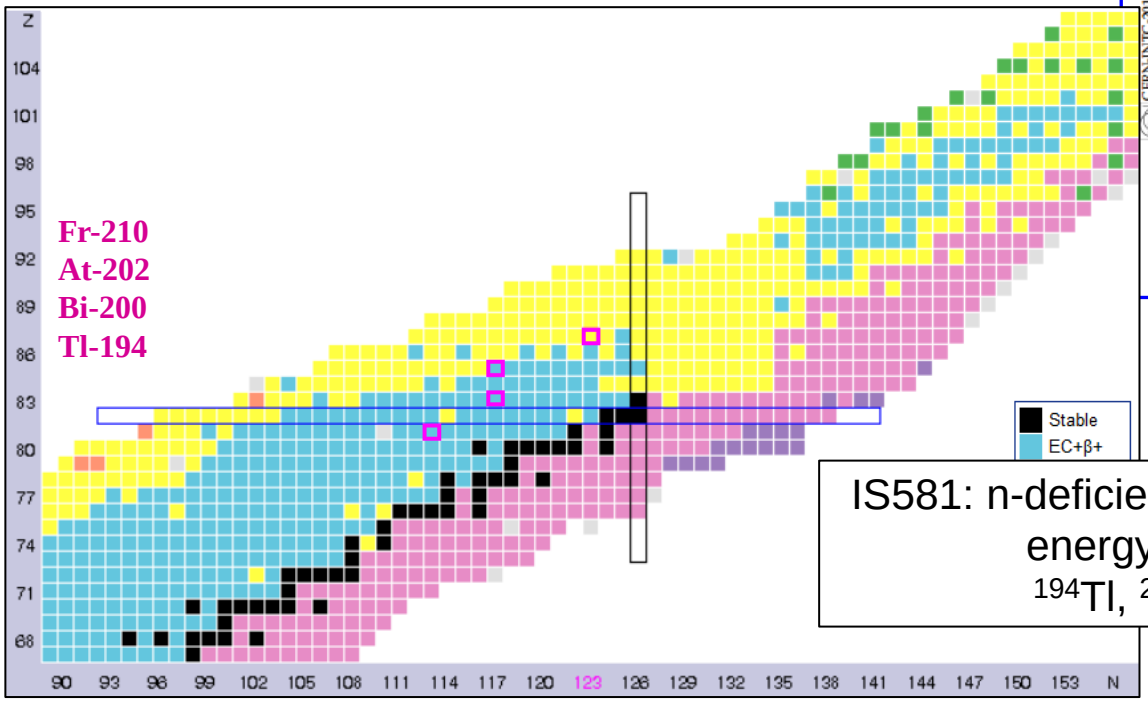


Bf determined with accuracy not achievable in another type of low-energy fission!
&
We proposed such experiment to INTC commission (HIE-ISOLDE)

IS581 experiment

- The experiment for measurement of fission barrier heights of n-deficient odd-odd nuclei in (d,pf) was proposed to INTC in 2012
- IS581 experiment was approved by INTC commission in 2013
- IS581 was put in to the program of planned HIE-ISOLDE experiments



EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Clarification to the ISOLDE and Neutron Time-of-Flight Committee

(Following HIE-ISOLDE proposal CERN-INTC-2012-055/P-356)

Determination of the fission barrier height in fission of heavy radioactive beams induced by the (d,p)-transfer

September 25, 2013

M. Veselsky[1], R. Raabe[2], A.N. Andreyev[3], M. Huyse[2], P. Van Duppen[2], F. Renzi[2], K. Nishio[4], H. Makii[4], I. Nishinaka[4], S. Chiba[4], G. Souliotis[5], P. Fountas[5], N. Vonta[5], T. Grahn[6], P.T. Greenlees[6], J. Pakarinen[6], P. Rahkila[6], M. Venhart[1], J. Kliman[1], S. Hlavac[1], V. Matousek[1], L. Krupa[1], I. Sivacek[1], D. Klc[1], M. Sedlak[1], E. Rapisarda[7], and the ACTAR TPC Collaboration (GANIL, KU Leuven, IPN Orsay, CEA Saclay, CENBG, Univ. Santiago de Compostela)

[1] *Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia*
[2] *Instituut voor Kern- en Stralingsfysica, KU Leuven, Belgium*
[3] *University of York, York, UK*
[4] *Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Japan*
[5] *University of Athens, Athens, Greece*
[6] *University of Jyvskyl and Helsinki Institute of Physics, Finland*
[7] *ISOLDE, CERN*

Spokesperson: M. Veselsky (Martin.Veselsky@savba.sk), R. Raabe (riccardo.raabe@fys.kuleuven.be)
Contact person: E. Rapisarda (Elisa.Rapisarda@cern.ch)

CERN-INTC-2013-032 / INTC-CLI-012
25/09/2013

Abstract: A theoretical framework is described, allowing to determine the fission barrier height using the observed cross sections of fission induced by the (d,p)-transfer with accuracy, which is not achievable in another type of low-energy fission of neutron-deficient nuclei, the β-delayed fission. The
ACTAR TPC, will thus provide t
the moment and which is highly i

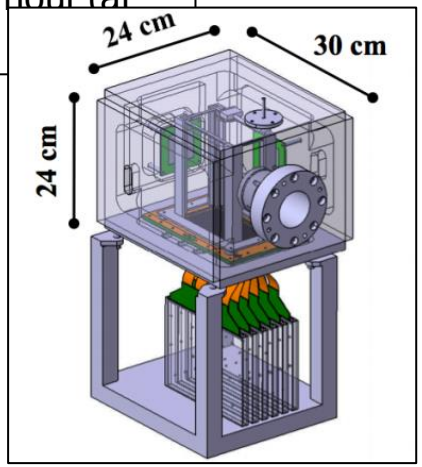
M. Veselsky et. al., HIE-ISOLDE proposal CERN-INTC-2012-055/P-356

IS581: n-deficient nuclei with zero pairing energy @ saddle point
^{194}Tl, ^{200}Bi, ^{202}At, ^{210}Fr

Experimental conditions of IS581 experiment

- the deuterium gas inside the active target (effective target thickness of 1.6 mg/cm^2, target chamber length parrallel to beam of ~ 12.8 cm)
- the beam slows down from the initial energy of 5 AMeV to about 4.1 AMeV
- the reaction vertex can be reconstructed with a resolution better than 3 mm
  –> more than 60 points of the excitation function within the given energy range
- the beam intensity of 10^6 pps
  –> **has to be optimized due to electrostatic mask along the beam of heavy nuclei!**
  –> a rate ranging from about 2 events/minute (at the highest energy) to 1 event/hour (at the lowest energy)

Requested shifts: 28 shifts (split into 2 runs over 2 years)
Beamline: 2nd REX beamline
Experiment approved as IS581 with all 28 shifts !



ACTAR TPC demonstrator

The period 2013 - 2017

- No progress until now – all experiments with ACTAR TPC demonstrator were focused on light ion beams

- There is a need to make the 1-sth measurement of IS581 with ACTAR TPC in 2018 -> longer shutdown of HIE-ISOLDE facilities

- **However, guarantee to get measurement time with ACTAR TPC is necessary!**

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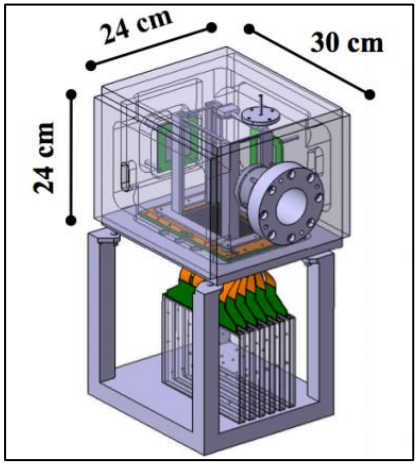

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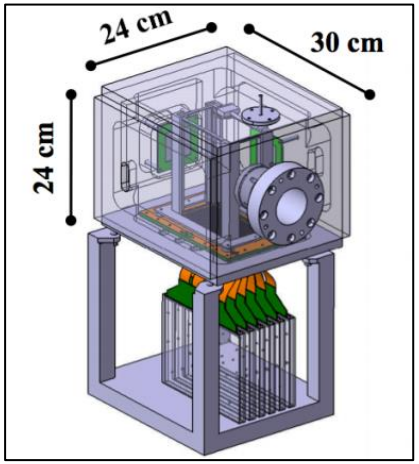

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Thank you for your attention!