Project «PITRAP» - ion trap at the reactor PIK

Yu.N. Novikov

Laboratory of exotic nuclides of PNPI

General motivation for the project proposal

- From the previous report of Dr. Filianin, we received information that along with a number of advantages, ion traps have an unprecedented sensitivity: at the level of a single nuclide.
- Naturally, if we combine such a device with a high-intensity nuclide producer, one should expect to observe exotic nuclei that are formed with very small cross-sections.
- Therefore with such type of combined installation we can measure directly the mass values (total binding energies) of rare representatives of nuclear community towards the neutron drip-line.
- *Let's remember that mass value is a fundamental property of any physical system.*

High-flux nuclide producer ⟷ Supersensitive (single ion) detector

It is just the case of PIK + Penning trap!

How to combine these unique installations

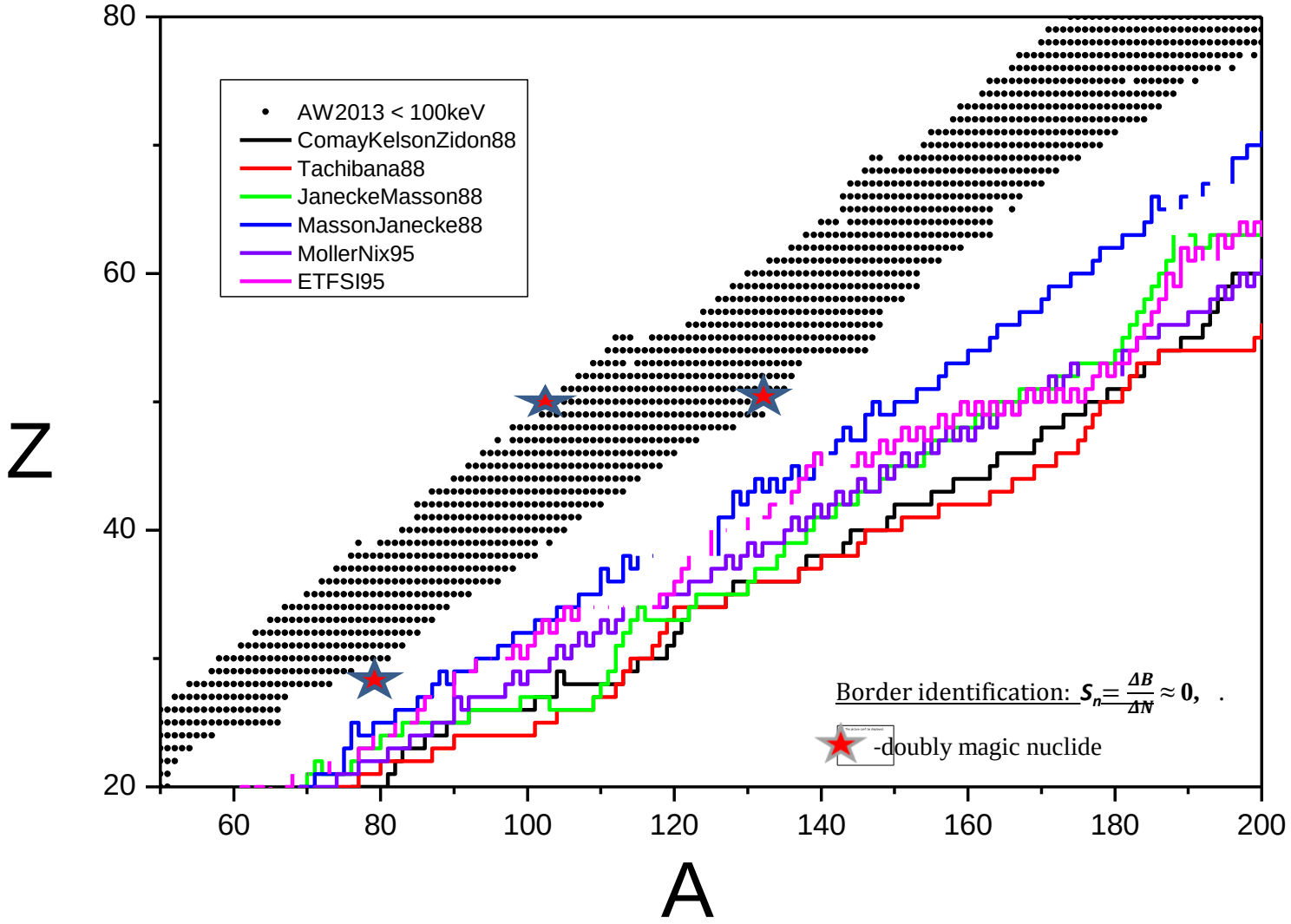
and for what physical goals?

PHYSICS MOTIVATION

Borders of existence of nuclides - the guiding star of nuclear physics and astrophysics

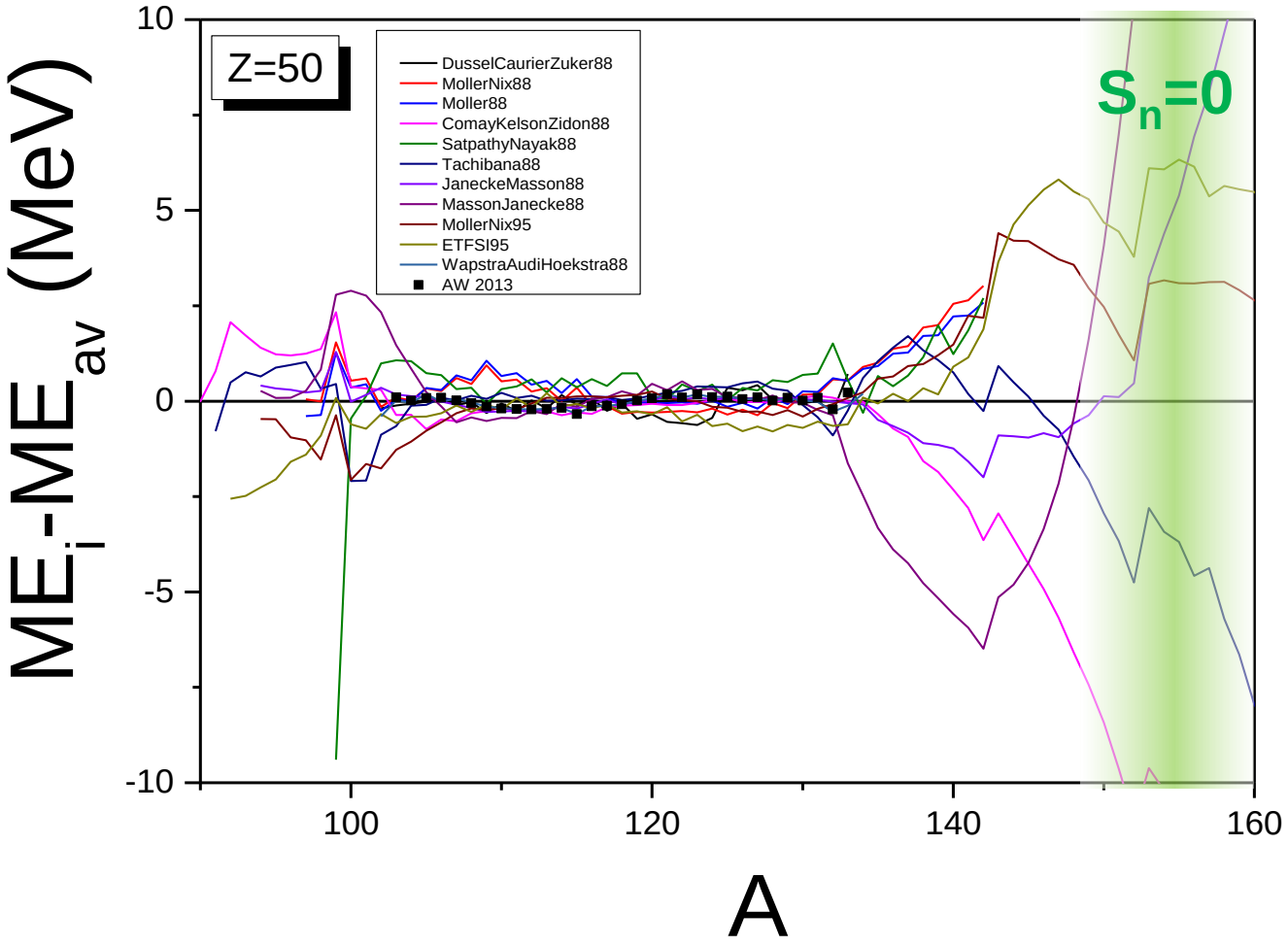
Predictions for neutron drip-line by different mass formulae

$M(Z,N-1) + m_n - M(Z,N) \approx 0$



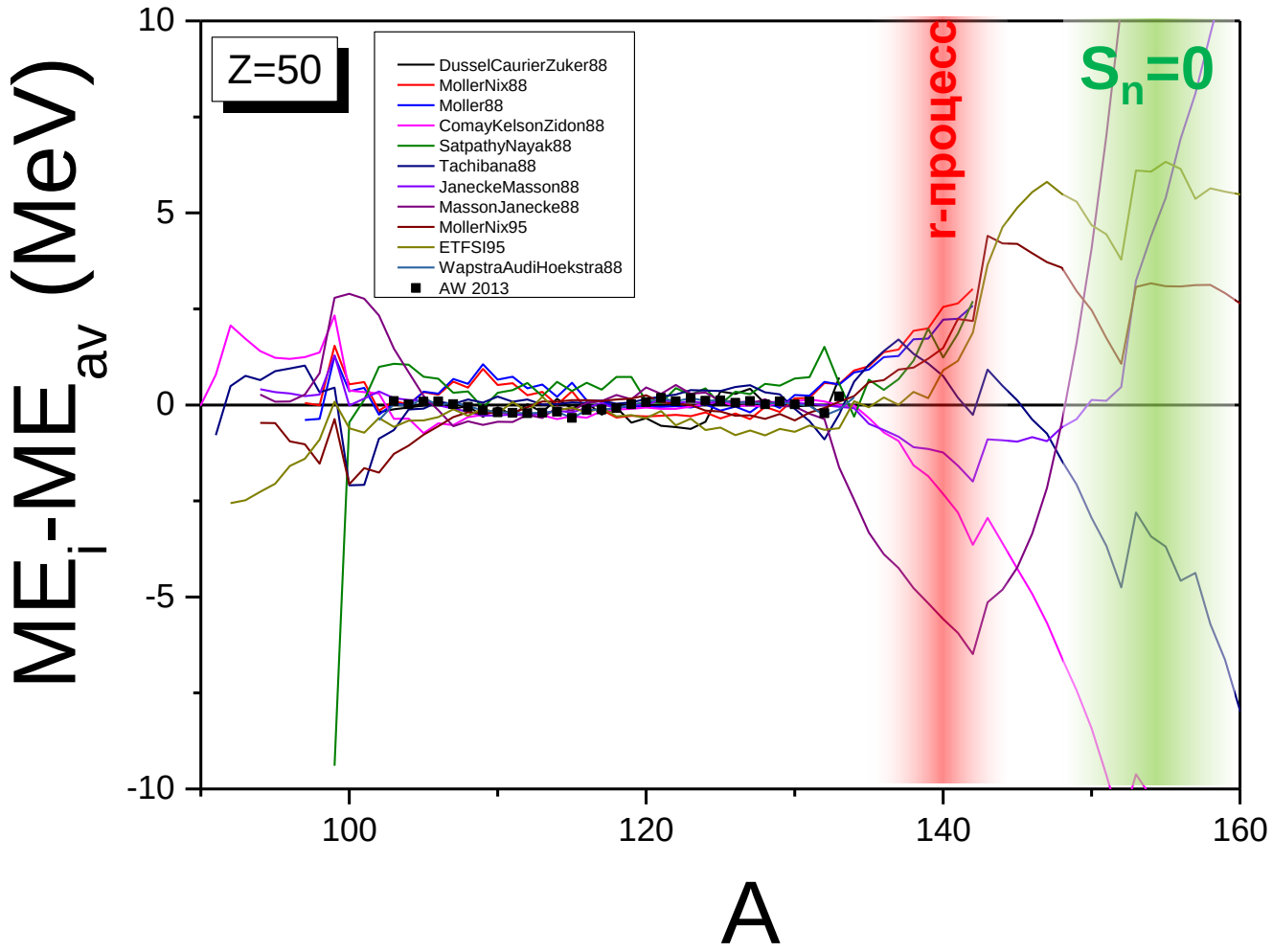
The drip-line positions predicted by various mass formulae are very different. All formulas are based on a relatively small array of well known masses.

Comparison of the predictions for the tin masses given by different mass formulae



By filling in the mass information even by five increased mass units one can get significant refinement in the drip-line position

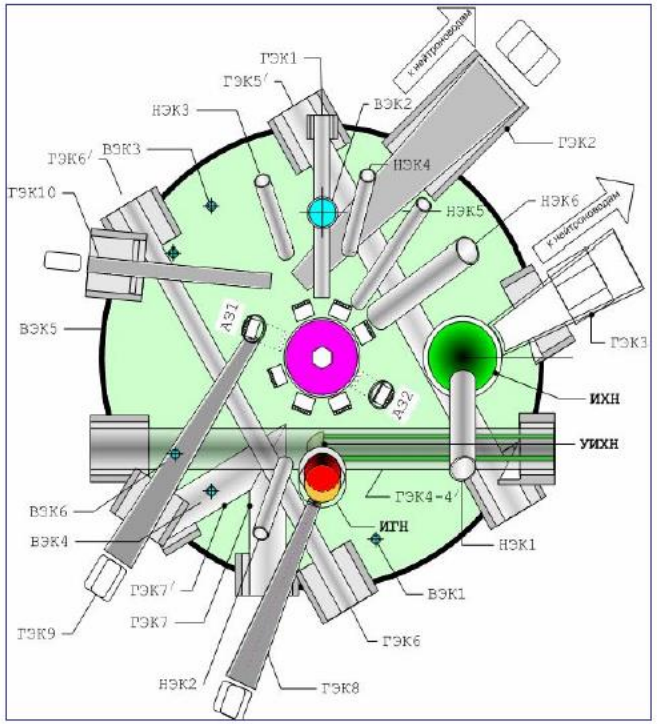
Comparison of the predictions for the tin masses given by different mass formulae (predicted r-process region is indicated by red strip)



The pathway of r-process (rapid neutron capture in hot stellar conditions) depends on the neutron separation energy (i.e. mass differences) which can be experimentally determined with PITRAP .

HOW TO IMPLEMENT TECHNICALLY?

Research Nuclear Reactor PIK



Horizontal, inclined and vertical channels

Basic characteristics:

Power: 100 MW

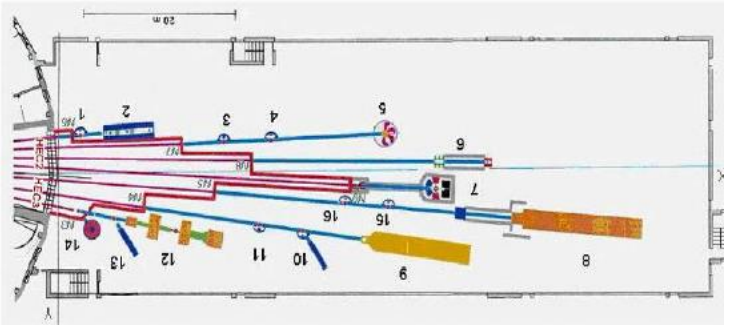
Thermal neutron flux: $5 \cdot 10^{15}$ n/sm^{2}sec

Horizontal channels: 13

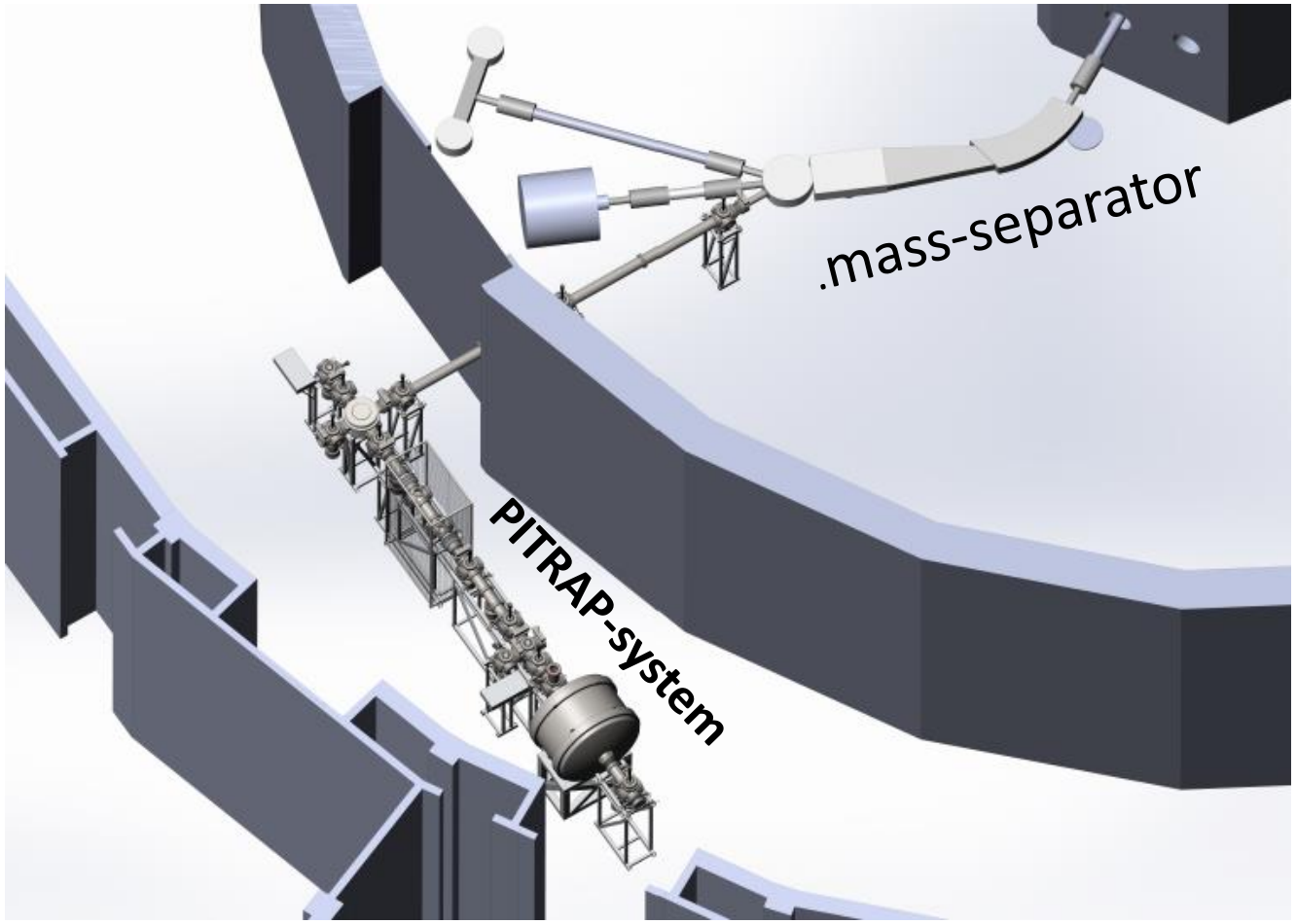
Inclined and vertical channels: 14

Neutron guide channels: 8

50 positions for neutron instruments (about 20 of them are free for today)



Mass-separator IRINA and PITRAP at the channel 5’ of reactor PIK



It is assumed that the mass-separator will deliver three ion beams of separated masses. One of the ion channels can be used to transport an ion beam to a trap located behind a protective wall.

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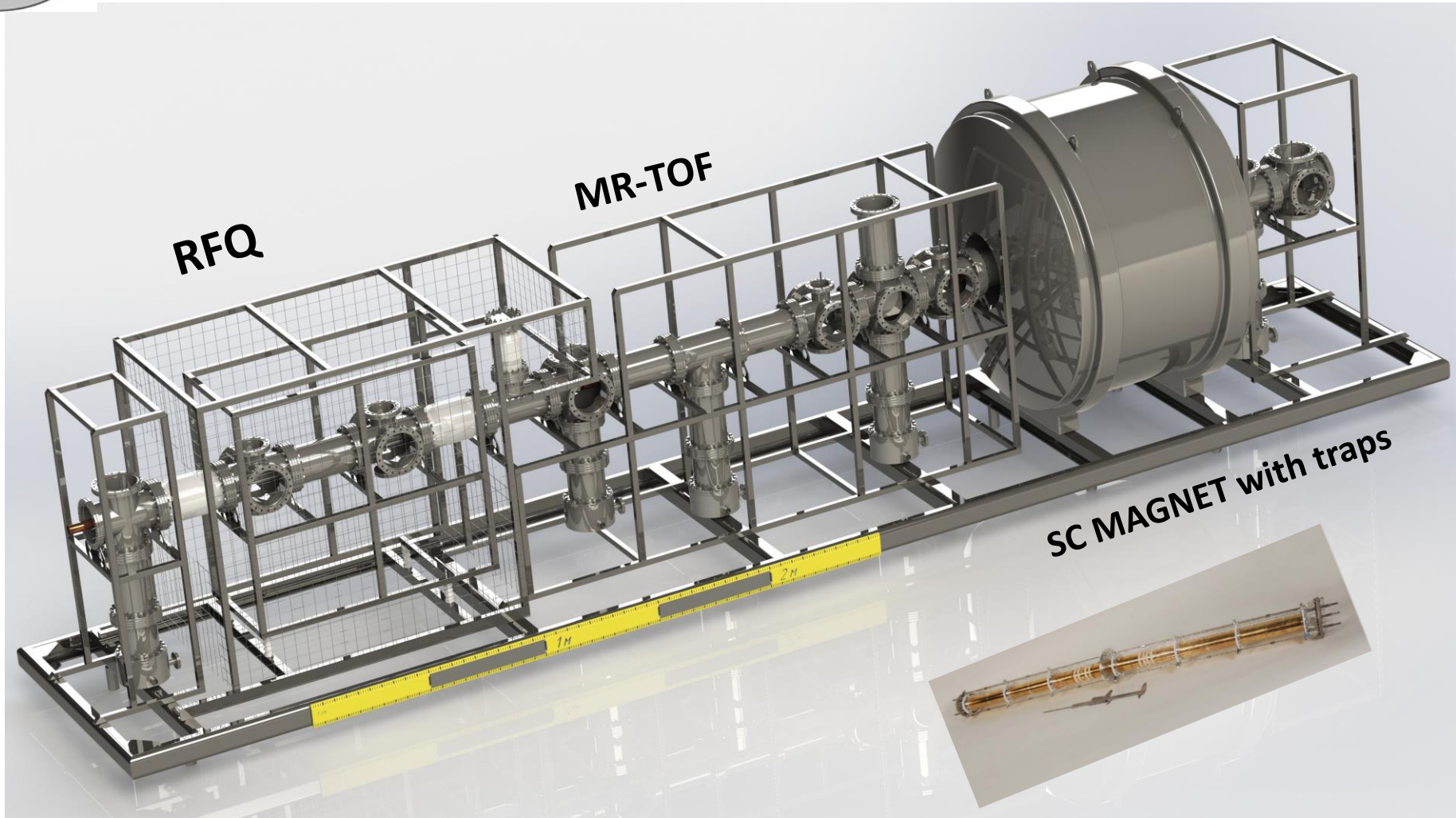
Design of the PITRAP channel



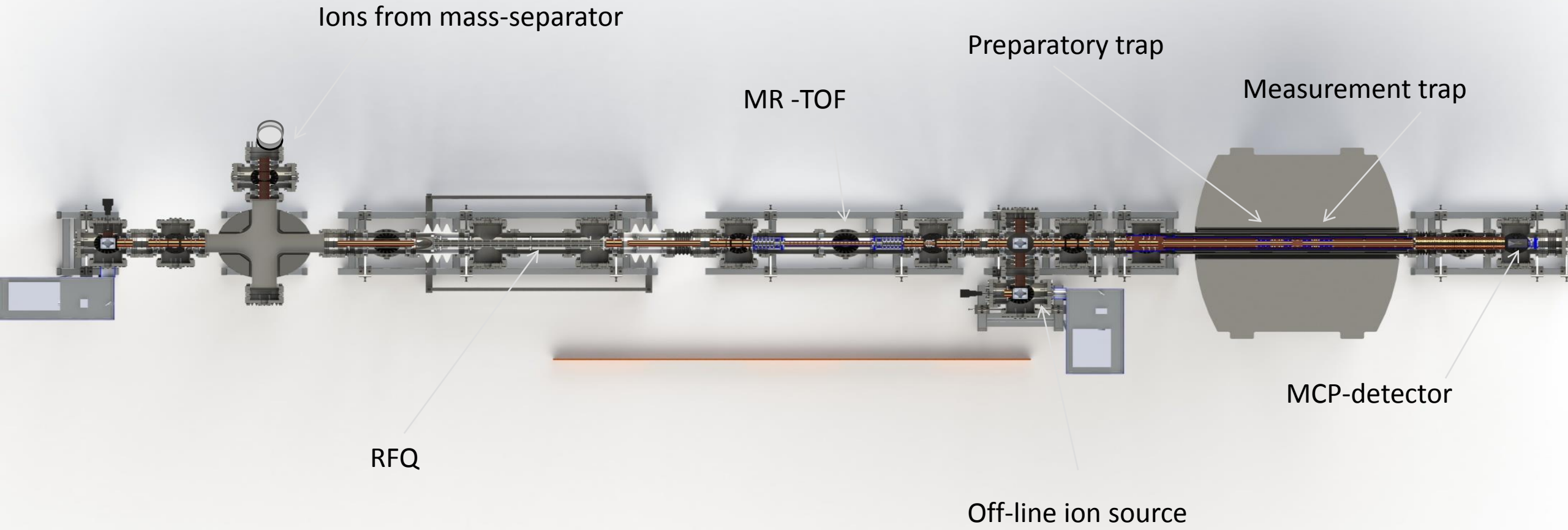
RFQ- cools (30ms) and bunches ions

MR-TOF multireflection

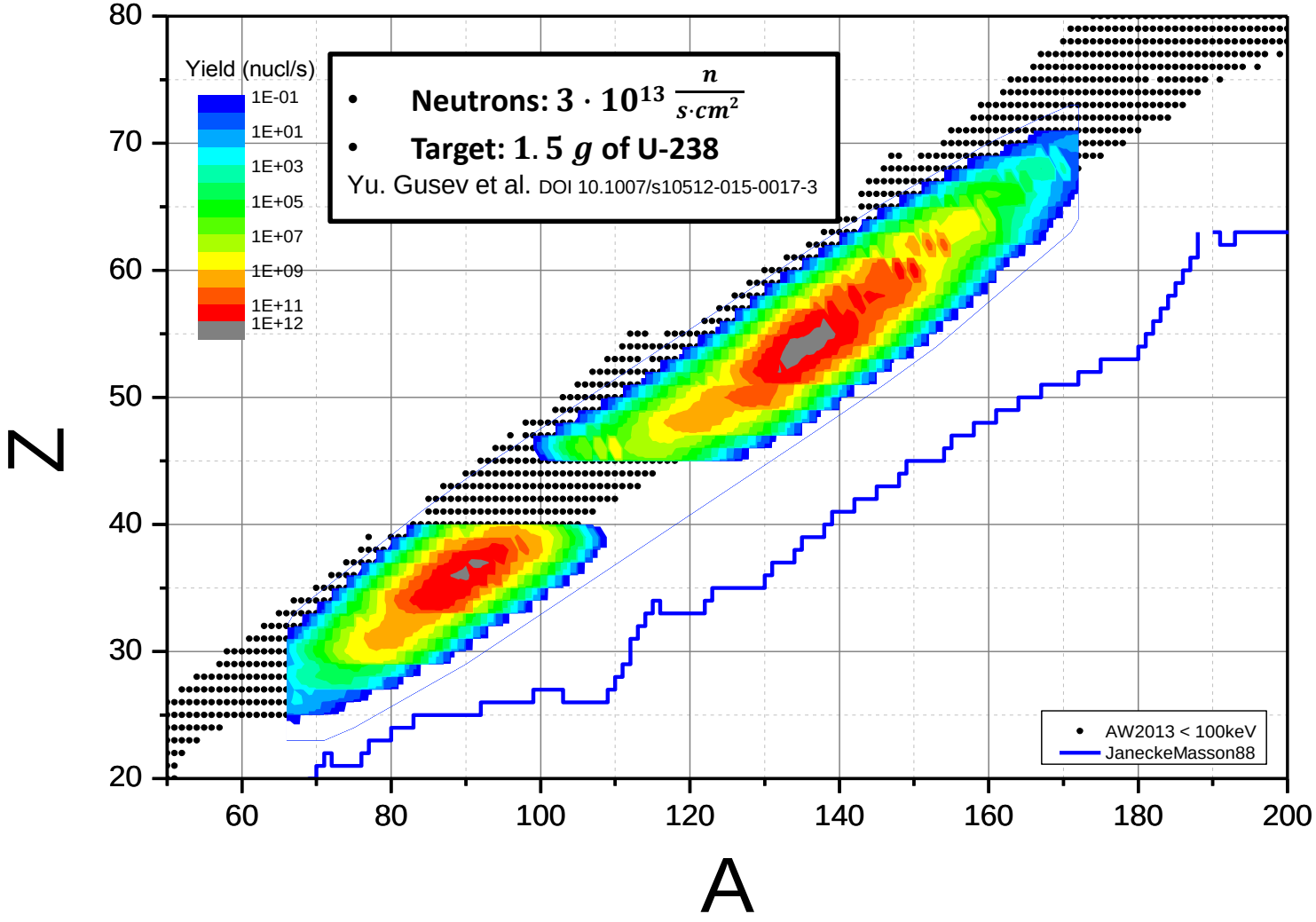
Time-of-flight analyzer

Super Conducting magnet with two regions of homogeneity and two ion traps

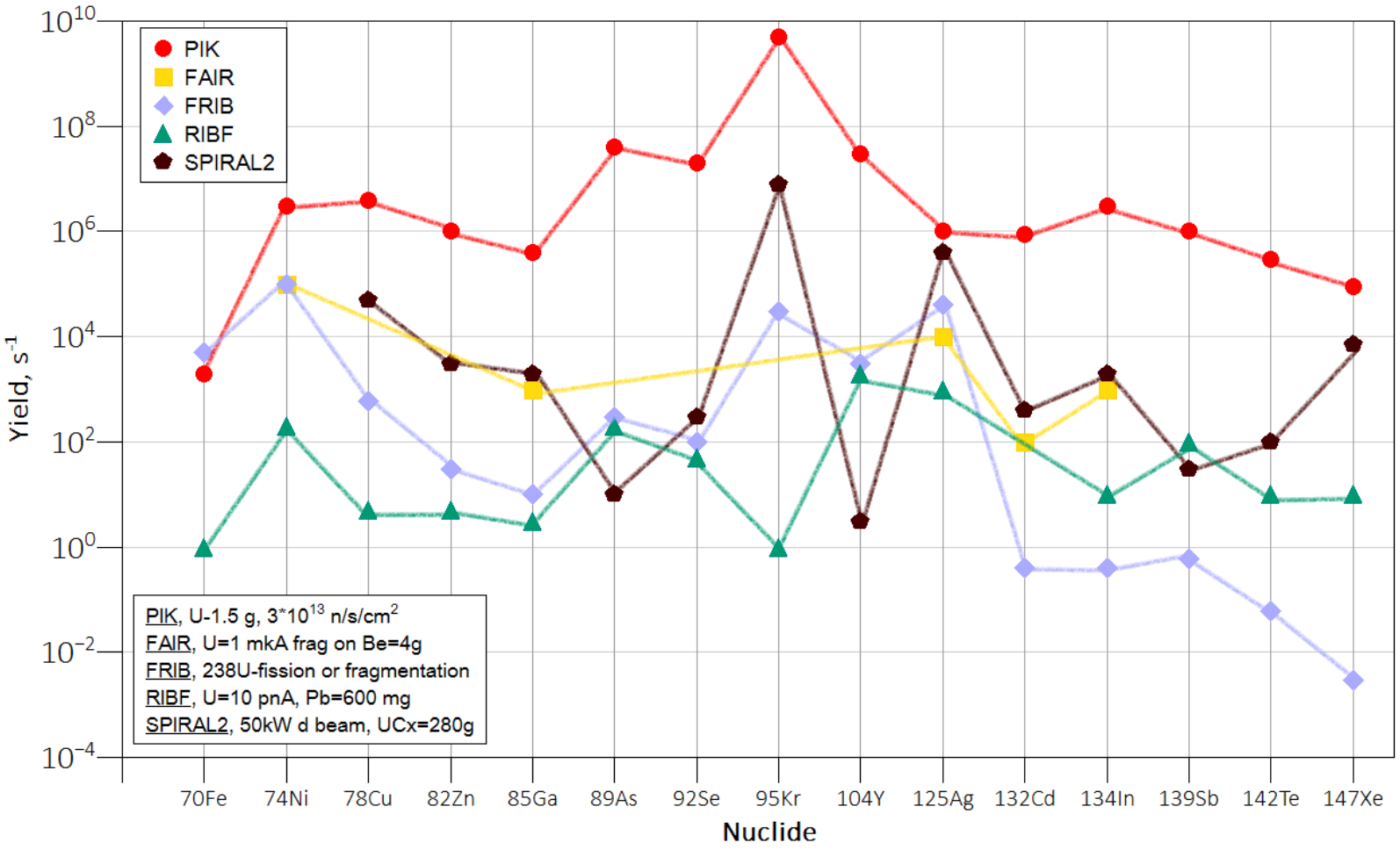
Principle of operation of the system



Estimations of the product yields from the massive target at the reactor PIK

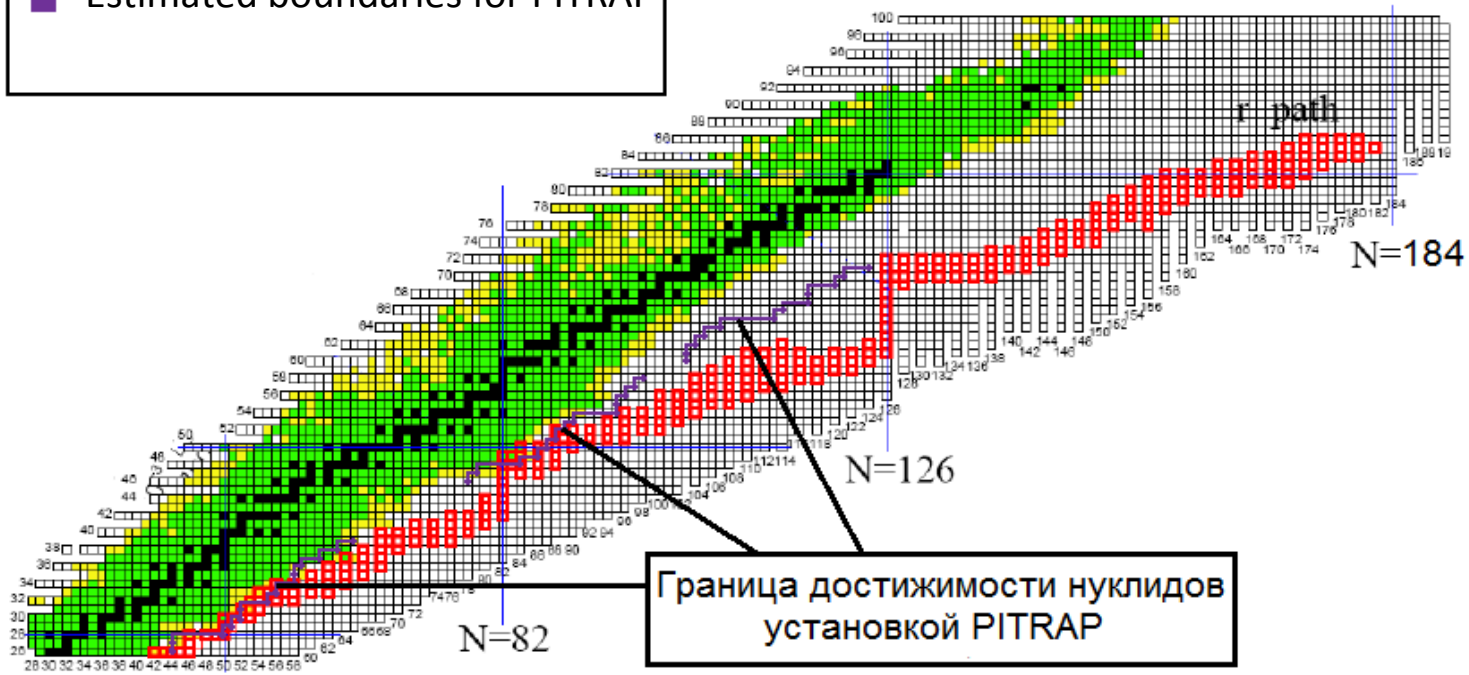


Comparative productivity of different installations



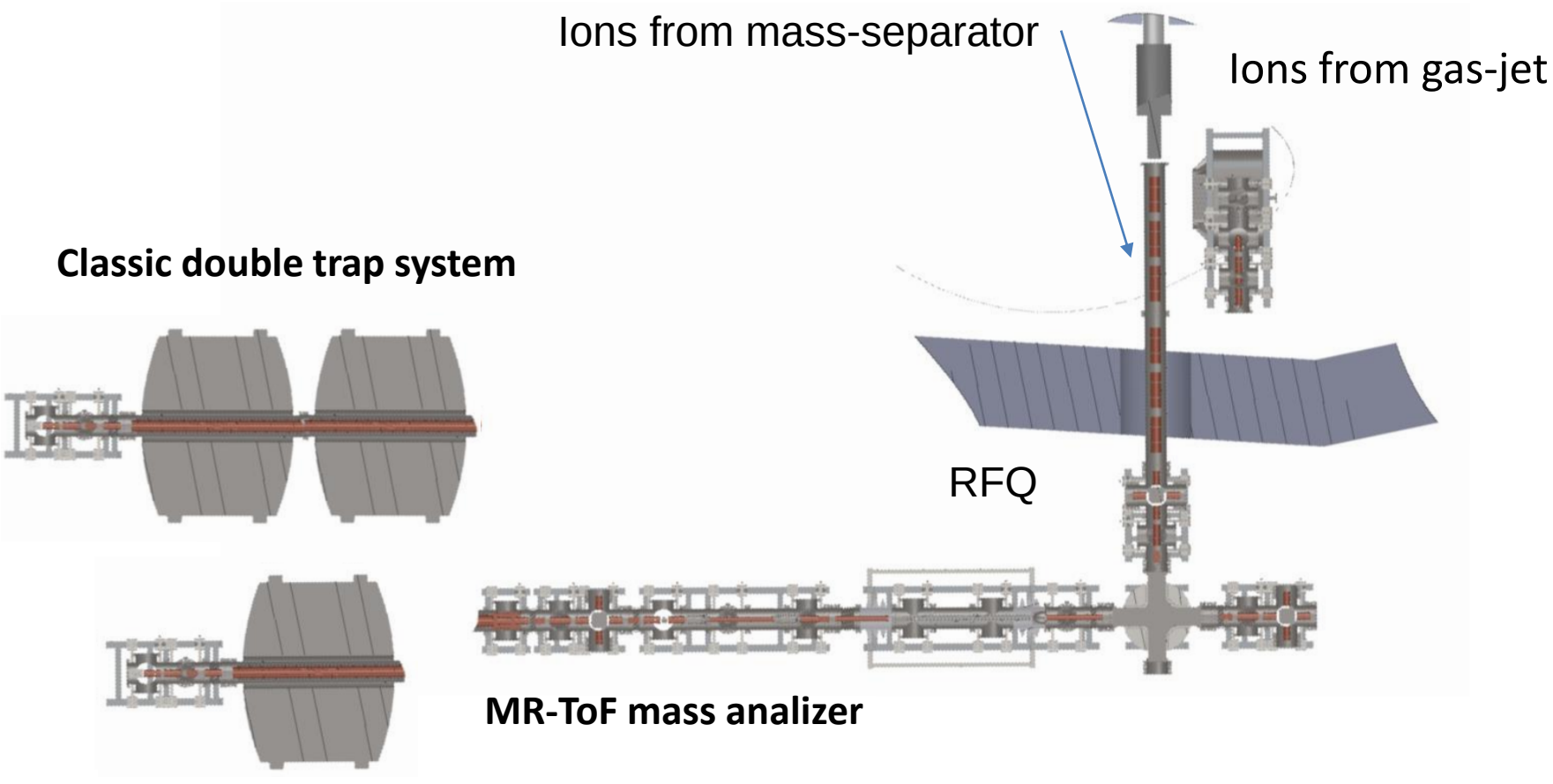
Nuclear Chart with indication of the border of nuclides achievable by the PITRAP(in purple)

- Known masses
- Known half-lives
- Expected r-process
- Estimated boundaries for PITRAP



The boundary of nuclides achievable on PITRAP coincides with the trajectory of the r-process in its initial and middle stages of development

Variants for PITRAP -development



Steps:

- Ended by MR-TOF
- With Combined trap
- Classic trap system

Direct participants :

Laboratory of exotic nuclides of the PNPI
Department of Nuclear Physics of the St.Petersburg State University

Cooperating labs and organizations:

Laboratory of short-lived nuclides of the PNPI
Laboratory of Cryogenic physics of the PNPI
Max-Planck institute for Nuclear Physics (Heidelberg)
GSI/FAIR HC (Darmstadt)
HC (Mainz)

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ОТЧЕТ
О НАУЧНО-ИССЛЕДОВАТЕЛЬСКОЙ КОНСТРУКТОРСКОЙ РАБОТЕ

«Приборная база лабораторного комплекса РК ПИК»

по теме

«Установка ПИТРАП - комплекс ионных ловушек ПИЯФ на горизонтальном экспериментальном канале № 6' РК ПИК для прецизионной масс-спектрометрии нуклидов»
(промежуточный)

СОГЛАСОВАНО
Зам. директора по научной работе В.В. Воронин
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PENNING ION TRAPS FOR HIGH-PRECISION MEASUREMENTS OF THE MASS OF NEUTRON-EXCESS NUCLEI IN THE PIK REACTOR

Yu. I. Gusev, V. S. Gusel'nikov, S. A. Eliseev, T. V. Koneva, D. A. Nesterenko, Yu. N. Novikov, A. V. Popov, M. V. Smirnov, P. E. Filyanin, and S. V. Chenmarev

UDC 621.384.8

A plan for using Penning ion traps to solve fundamental physical problems is presented. Placed in the secondary beam from the high-flux PIK reactor they can be used for direct high-precision measurements of the mass of exotic nuclides participating in different nuclear and astrophysical processes, some of which can be difficult to achieve in other currently existing facilities. Traps used in an autonomous regime outside a beam will make it possible to perform measurements with long-lived and stable nuclei for atomic, nuclei, and neutron physics as well as other areas of science.

Conclusions

1. The advanced nuclear physics project is proposed targeted to astrophysics
2. This project can be considered as a proposal to build the terrestrial lab for investigation of astrophysical processes
3. The combination of a high-flux reactor with a high-sensitive detector will provide the synergy in investigations
4. The PNPI-group has extensive experience in working with the Penning traps and good collaboration with leading laboratories around the Europe

Thanks for your attention!

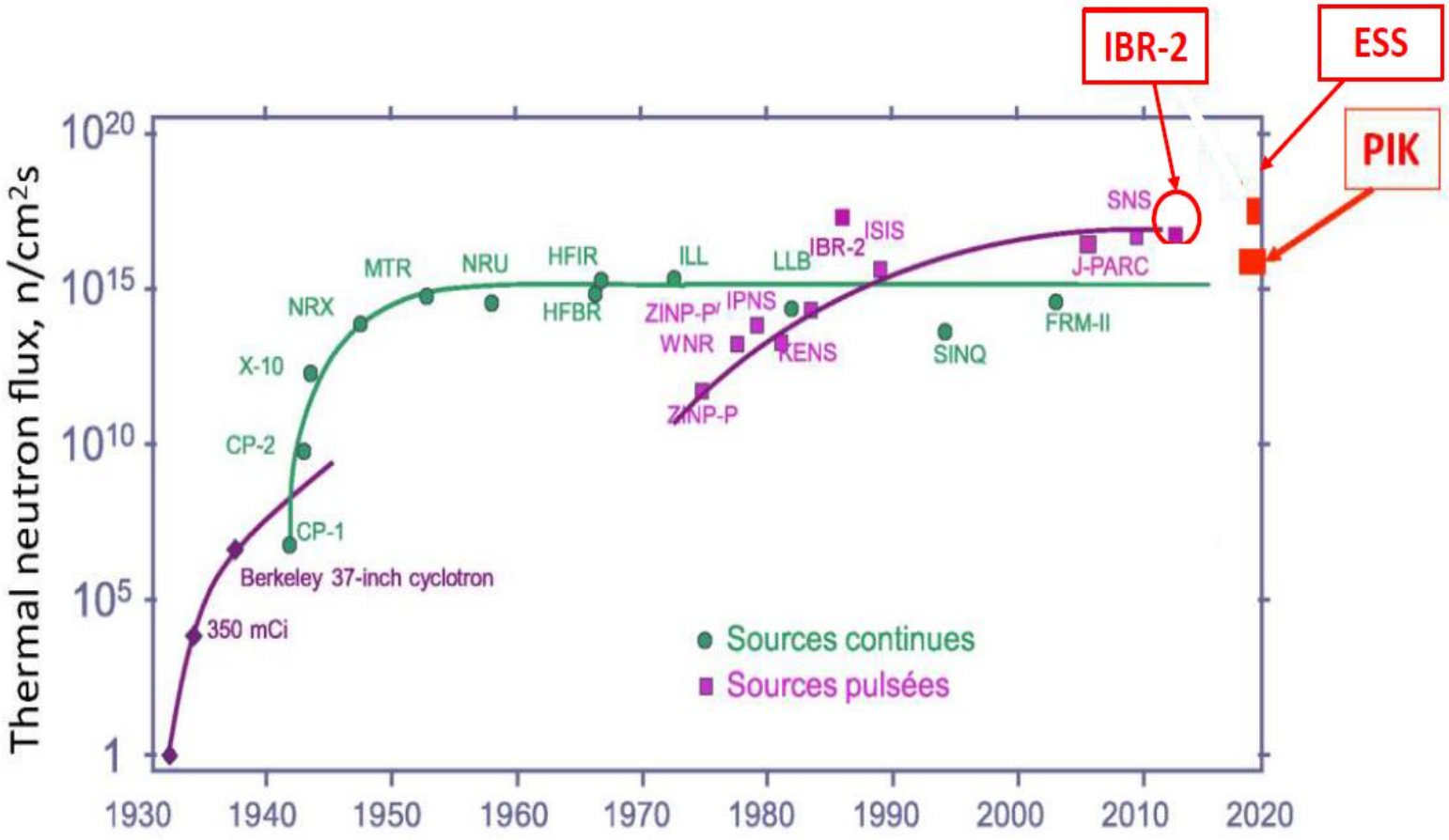
Backups

Advantage of the Penning trap mass spectrometry (PTMS)

1. Unprecedented sensitivity (on the level of individual particle (ion))
2. Reliability (calibration by mass standard - ^{12}C)
3. Very high Precision (frequency measurement) $<10^{-9}$
4. This **superiority** of PTMS allows to claim solving some problems of: QED, QCD, CPT, neutrino physics, Fundamental constants, astrophysics

Advanced neutron sources

courtesy of V. Aksenov



Yield of nuclides at the trap with the He-jet transport system