Estimation of production rates and secondary beam intensities

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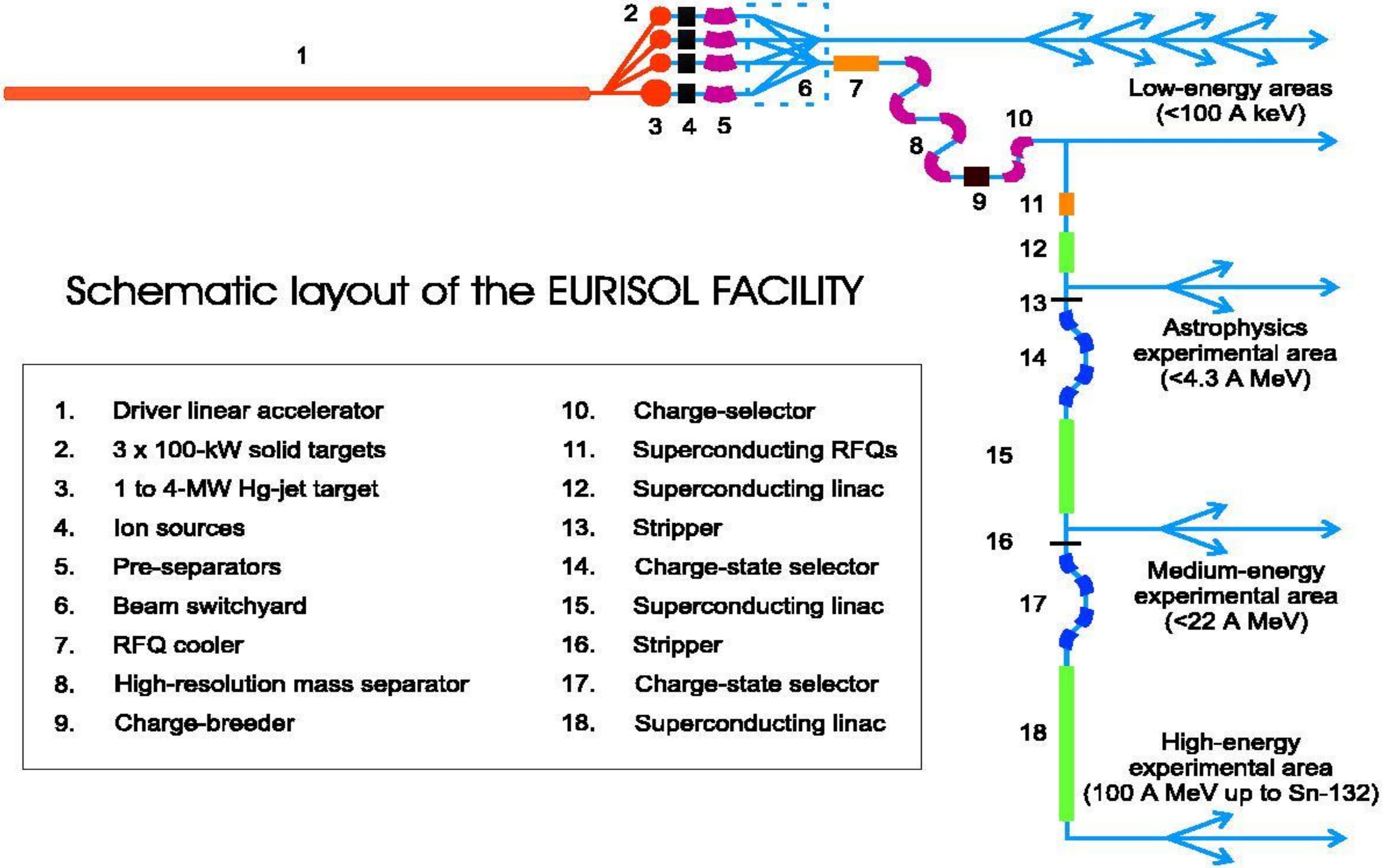


Schematic layout of the EURISOL FACILITY

1. Driver linear accelerator
2. 3 x 100-kW solid targets
3. 1 to 4-MW Hg-jet target
4. Ion sources
5. Pre-separators
6. Beam switchyard
7. RFQ cooler
8. High-resolution mass separator
9. Charge-breeder
10. Charge-selector
11. Superconducting RFQs
12. Superconducting linac
13. Stripper
14. Charge-state selector
15. Superconducting linac
16. Stripper
17. Charge-state selector
18. Superconducting linac

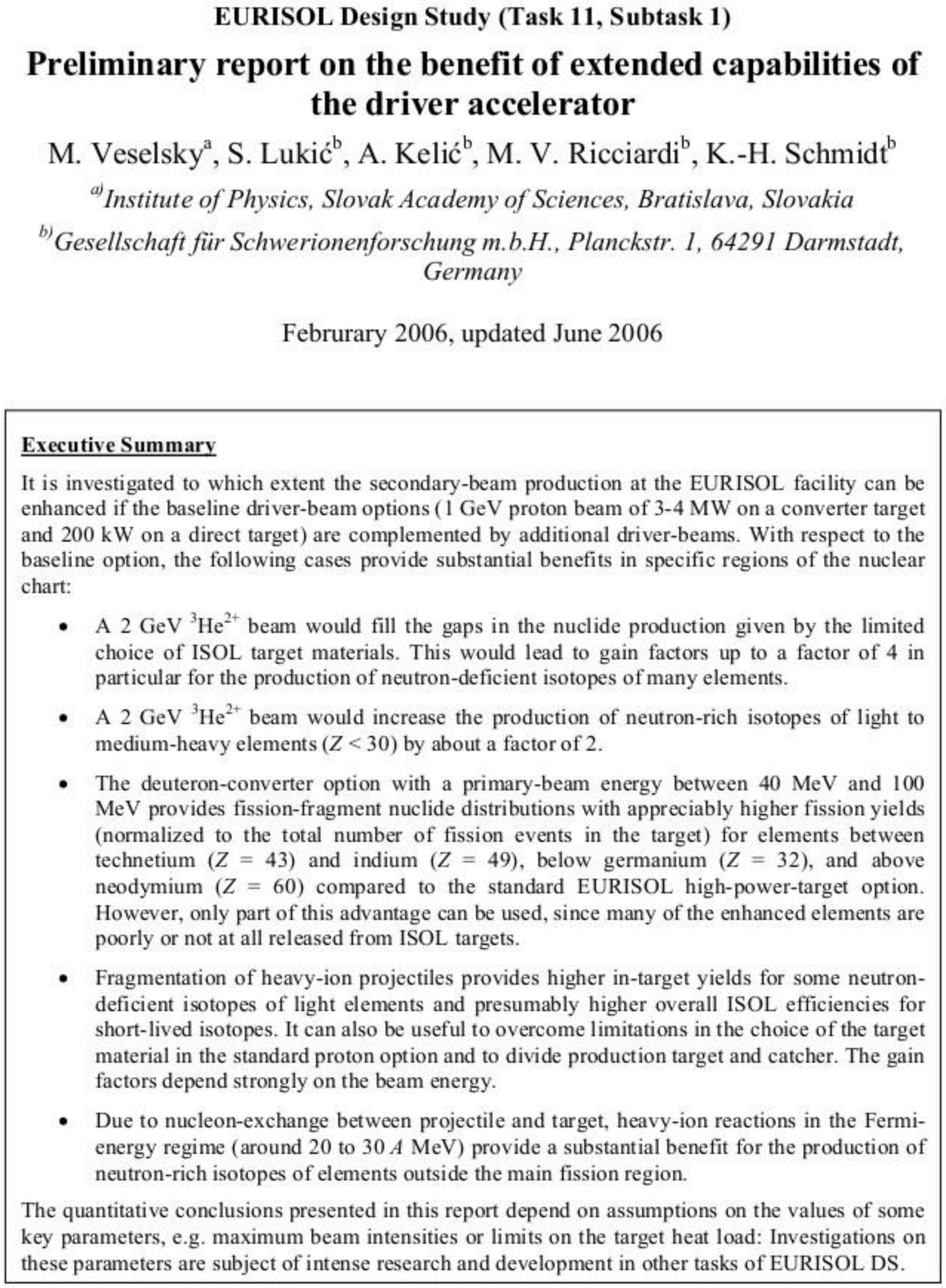
Fig. 4.1: Diagram showing a possible layout of the EURISOL facility. Details of the switchyard and other beamlines are represented very schematically.

EURISOL – possible future of ISOLDE ?

As a part of the EU 6FP project EURISOL Design Study (2005-2009), one task (Task 11, headed by K.H. Schmidt) was devoted to estimates of beam intensities, with one subtask specifically devoted to benefit of extended capabilities of driver accelerator.

Various extensions, ranging from light ion beams to heavy ions accelerated high energy or just to the energy of 28 AMeV, were considered and their eventual benefits were evaluated.

In the recommendations for driver linac, light ion beams were endorsed, while heavy ion option had to be left out due to increased costs and technical difficulties.



EURISOL Design Study (Task 11, Subtask 1)

Preliminary report on the benefit of extended capabilities of the driver accelerator

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Februrary 2006, updated June 2006

Executive Summary

It is investigated to which extent the secondary-beam production at the EURISOL facility can be enhanced if the baseline driver-beam options (1 GeV proton beam of 3-4 MW on a converter target and 200 kW on a direct target) are complemented by additional driver-beams. With respect to the baseline option, the following cases provide substantial benefits in specific regions of the nuclear chart:

- A 2 GeV ^{3}He^{2+} beam would fill the gaps in the nuclide production given by the limited choice of ISOL target materials. This would lead to gain factors up to a factor of 4 in particular for the production of neutron-deficient isotopes of many elements.
- A 2 GeV ^{3}He^{2+} beam would increase the production of neutron-rich isotopes of light to medium-heavy elements ($Z < 30$) by about a factor of 2.
- The deuteron-converter option with a primary-beam energy between 40 MeV and 100 MeV provides fission-fragment nuclide distributions with appreciably higher fission yields (normalized to the total number of fission events in the target) for elements between technetium ($Z = 43$) and indium ($Z = 49$), below germanium ($Z = 32$), and above neodymium ($Z = 60$) compared to the standard EURISOL high-power-target option. However, only part of this advantage can be used, since many of the enhanced elements are poorly or not at all released from ISOL targets.
- Fragmentation of heavy-ion projectiles provides higher in-target yields for some neutron-deficient isotopes of light elements and presumably higher overall ISOL efficiencies for short-lived isotopes. It can also be useful to overcome limitations in the choice of the target material in the standard proton option and to divide production target and catcher. The gain factors depend strongly on the beam energy.
- Due to nucleon-exchange between projectile and target, heavy-ion reactions in the Fermi-energy regime (around 20 to 30 A MeV) provide a substantial benefit for the production of neutron-rich isotopes of elements outside the main fission region.

The quantitative conclusions presented in this report depend on assumptions on the values of some key parameters, e.g. maximum beam intensities or limits on the target heat load: Investigations on these parameters are subject of intense research and development in other tasks of EURISOL DS.

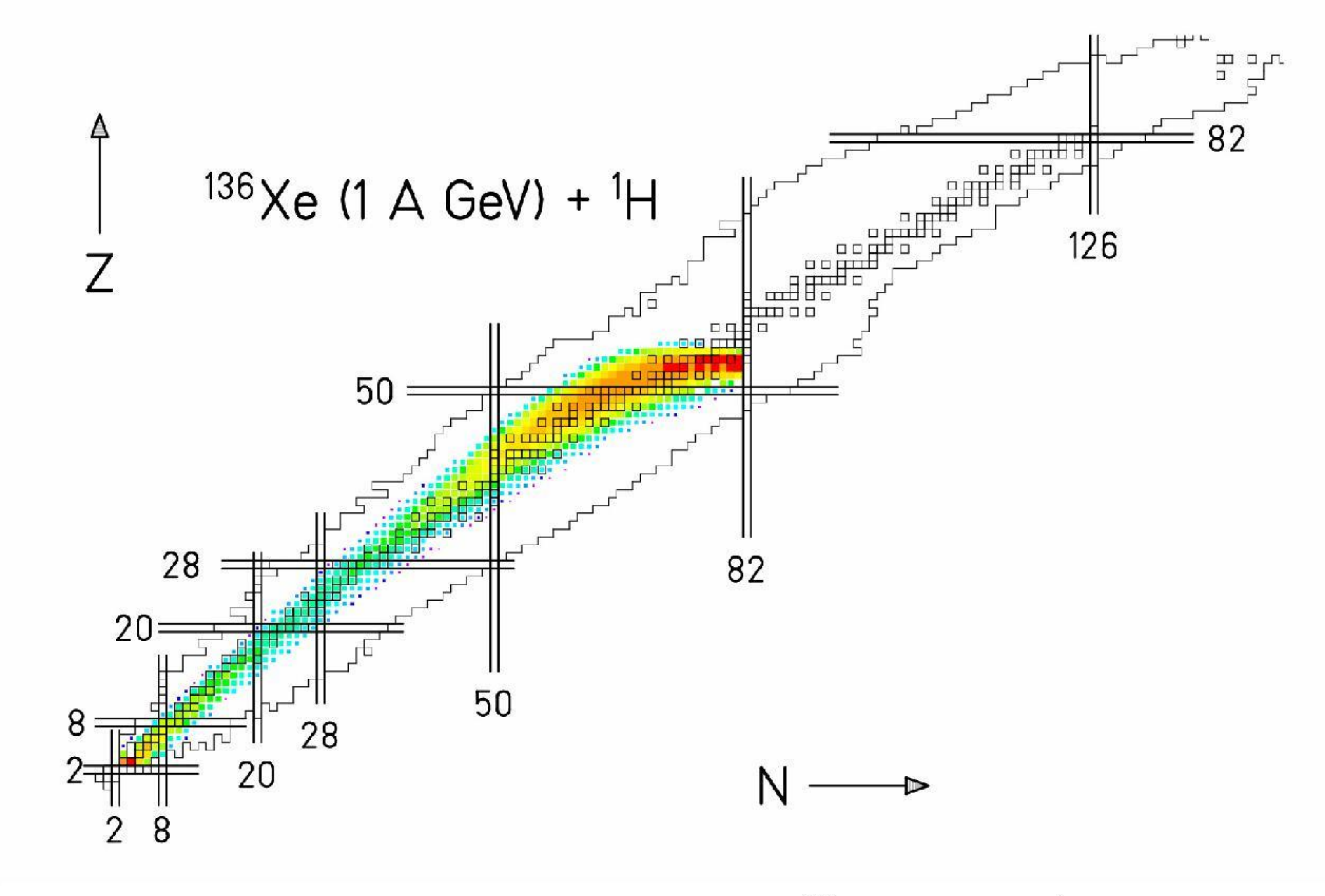


Figure 7: Measured nuclide distribution from the reaction ^{136}Xe (1 *A* GeV) + ^{1}H [10].

136Xe+p – typical spallation data from FRS

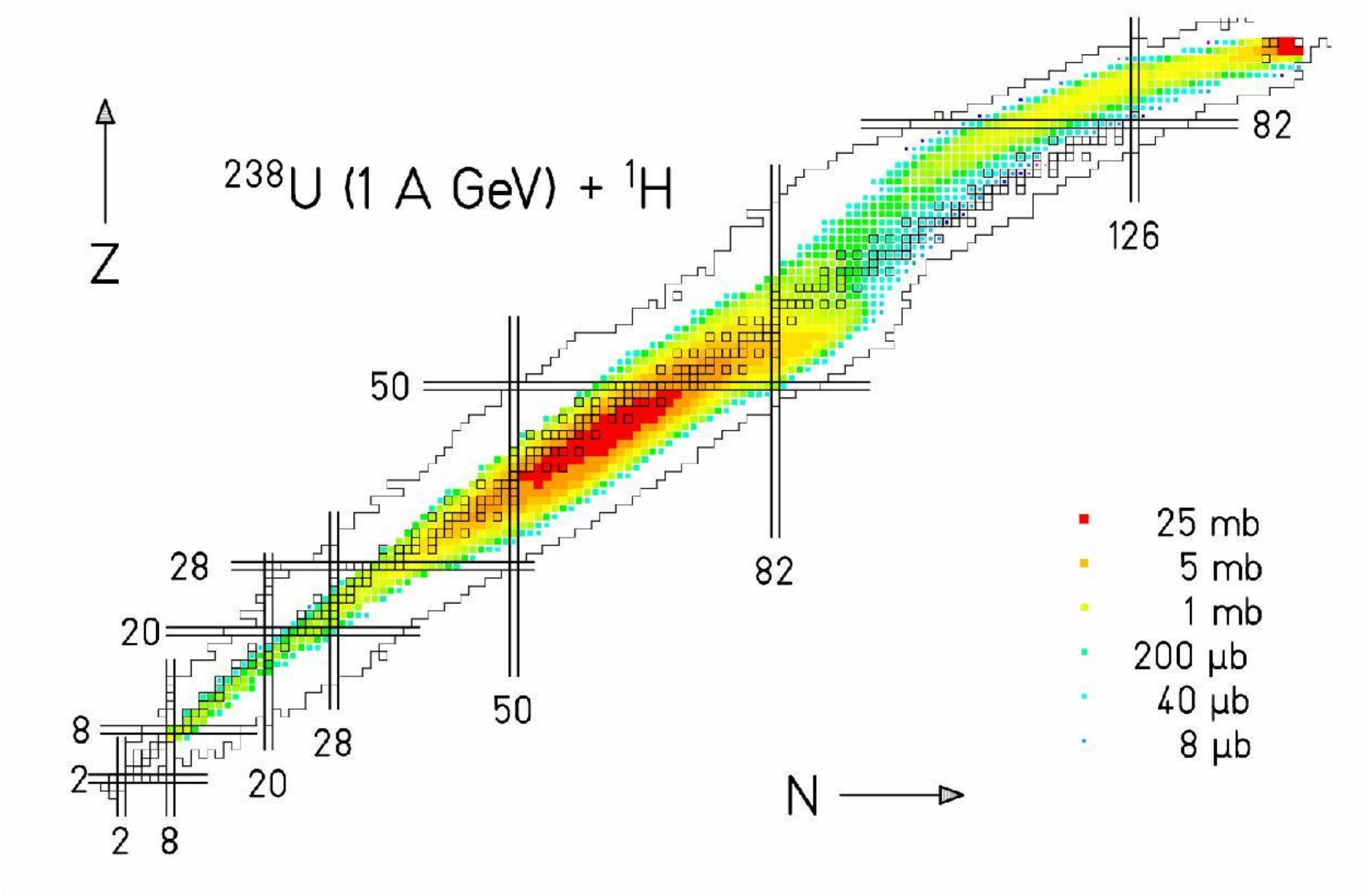
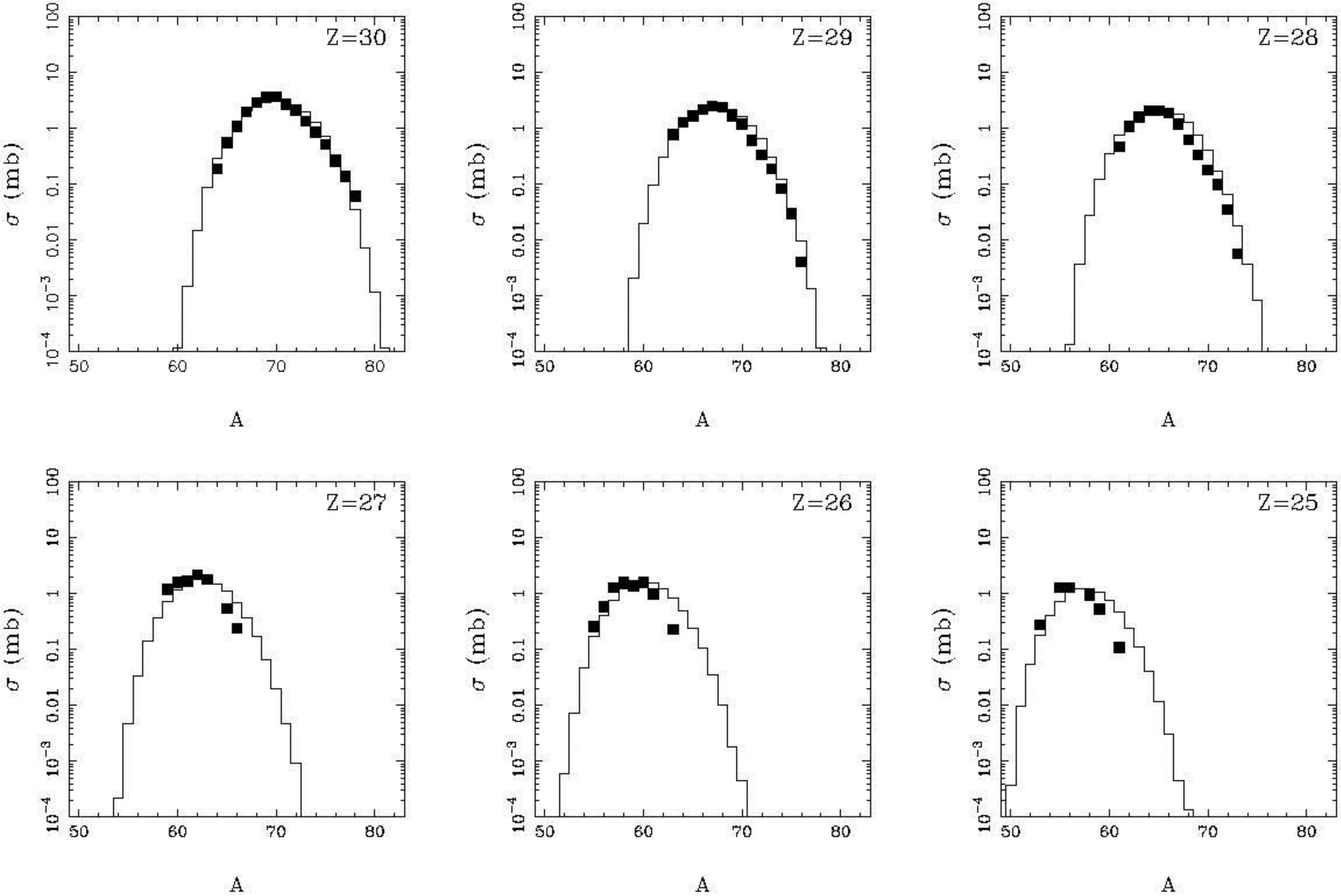
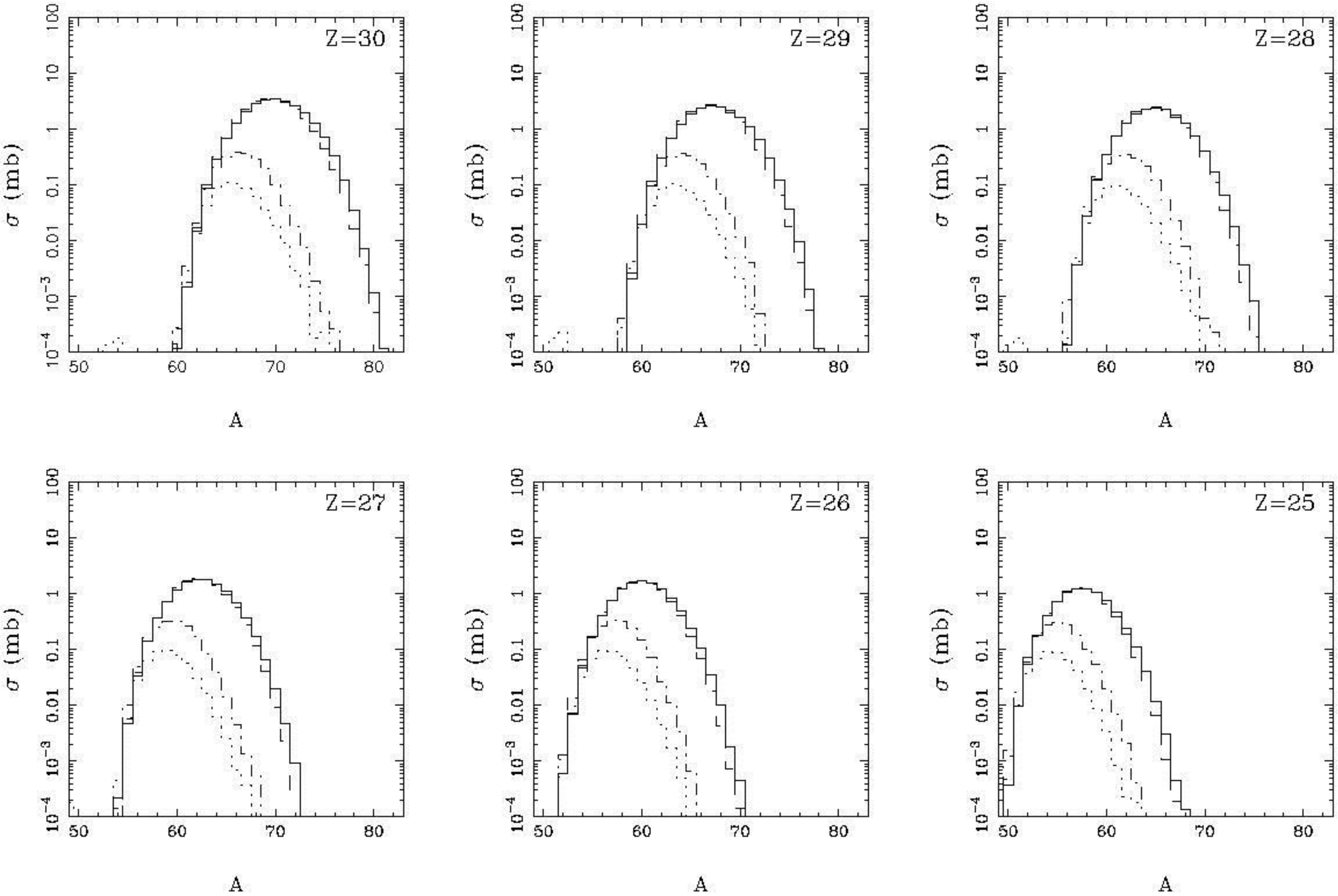


Figure 8: Measured nuclide distribution from the reaction ^{238}U (1 *A* GeV) + ^{1}H [11, 12, 13, 14].

238U+p – spallation and fission data from FRS



Calculated (GSI model ABRABLA) cross sections for 1 GeV proton beam colliding with U (solid line), compared to cross sections measured at GSI (P. Armbruster et al., PRL 93 (2004) 212701).



Effect of the choice of the spallation target. Calculated (GSI model) cross sections for 1 GeV proton beam colliding with U, Th, W and La (solid, dashed, dash-dotted and dotted lines, respectively).

Effect of beam energy and ion mass on distribution of spallation and fission products, experimental data from FRS

Energy or mass increase leads to wider range of produced elements,
light ion beams recommended for EURISOL.

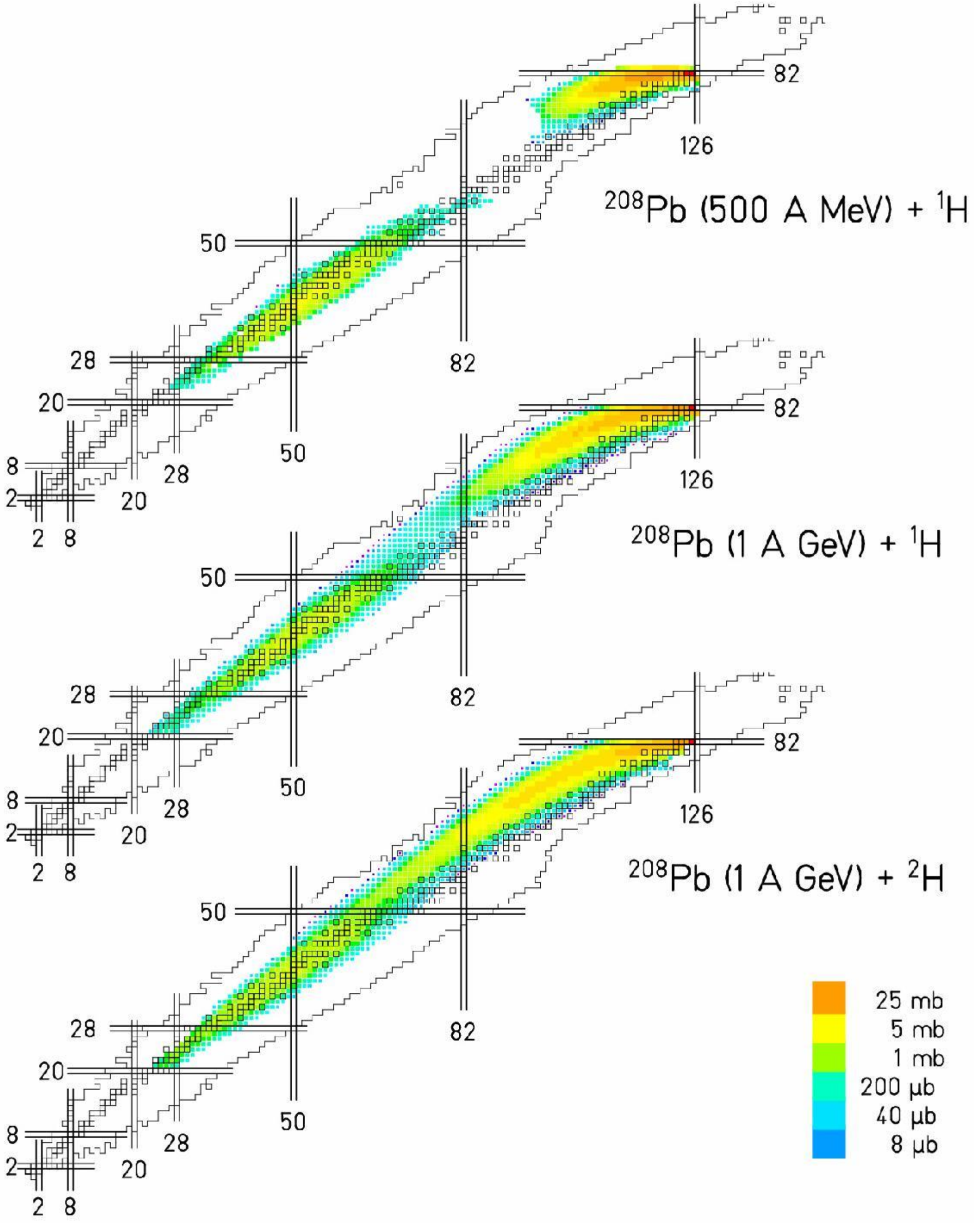


Figure 11: Nuclide distributions of residues produced in the spallation of ^{208}Pb by 500 MeV protons, 1-GeV protons and 2-GeV deuterons, measured at GSI in inverse kinematics [20, 21, 22, 23]. Elements below Z ≈ 20 were not covered in the experiments.

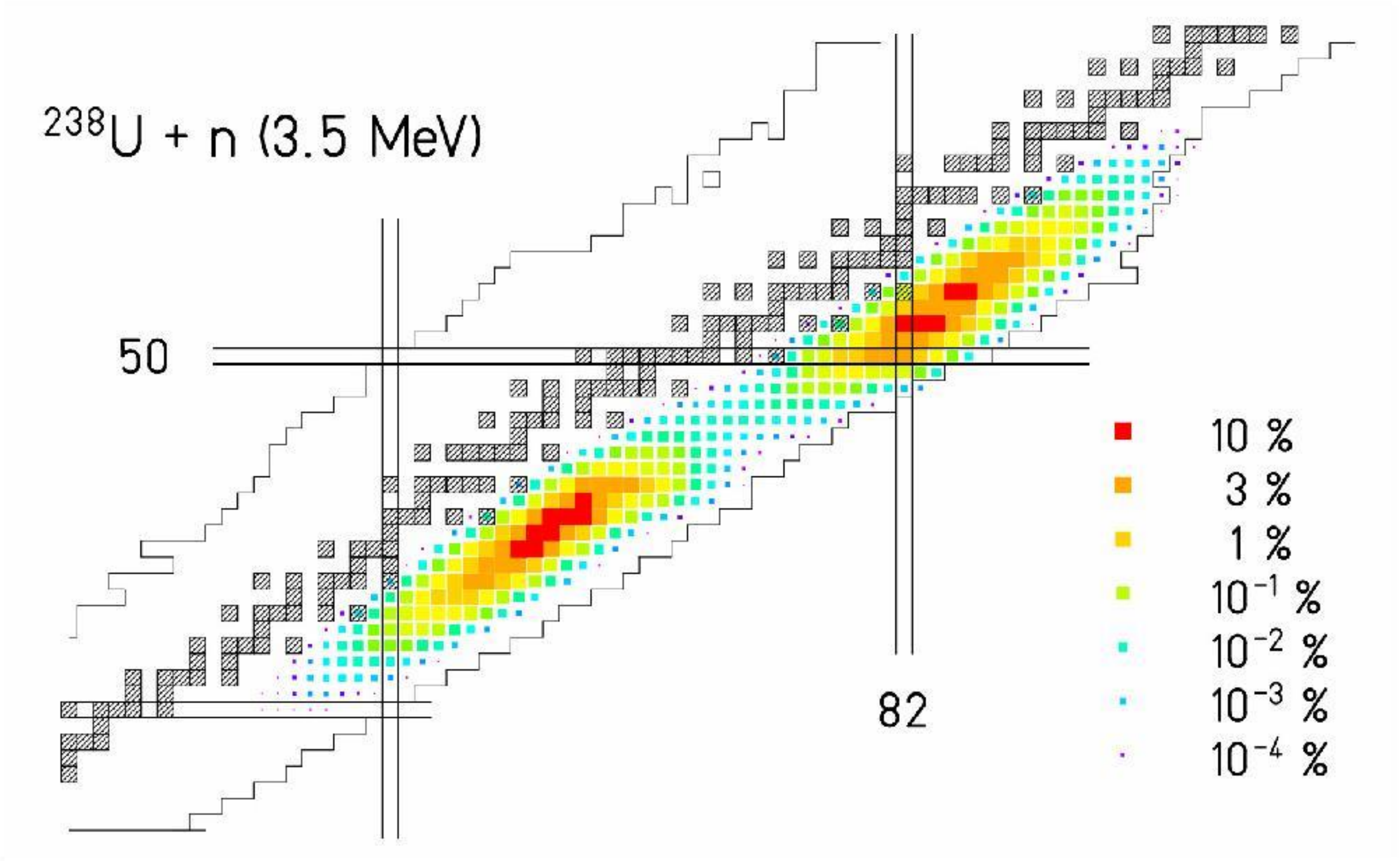


Figure 9: Nuclide distribution of fission products from the neutron-induced fission of ^{238}U for a fixed neutron energy of E_n = 3.5 MeV, calculated with the nuclear-reaction code ABRABLA. The colour code gives the yields in percent.

238U+n – low energy fission data, calculation using ABRABLA

Effect of the choice of fission target at low energy fission, calculation using ABRABLA code.

Low energy fission of thorium a good candidate for production of n-rich nuclei close to N=50, recommended for EURISOL.

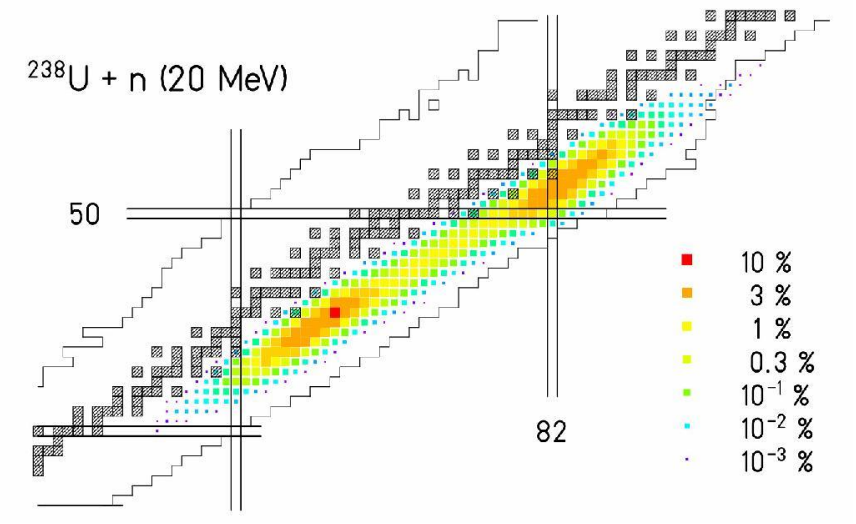


Figure 17: Nuclide distribution of fission products from the neutron-induced fission of ^{238}U for a fixed neutron energy of E_n = 20 MeV, calculated with the nuclear-reaction code ABRABLA. The colour code gives the yields in percent.

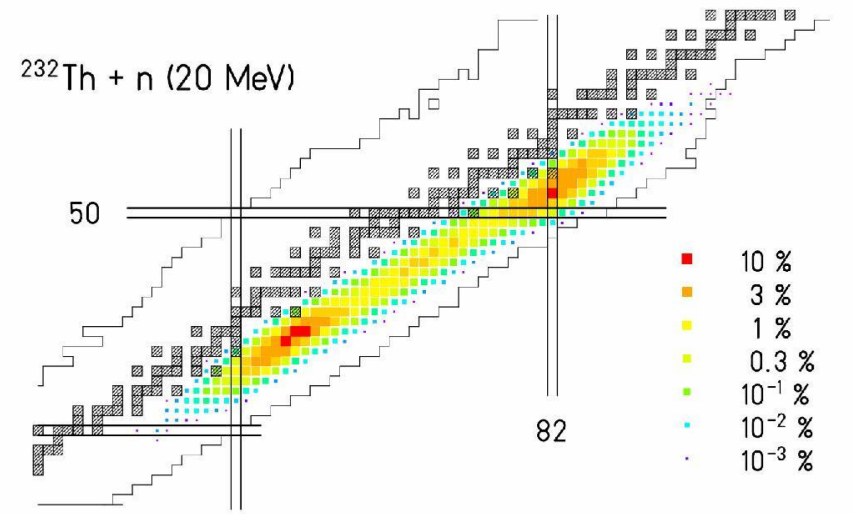


Figure 18: Nuclide distribution of fission products from the neutron-induced fission of ^{232}Th for a fixed neutron energy of E_n = 20 MeV, calculated with the nuclear-reaction code ABRABLA. The colour code gives the yields in percent.

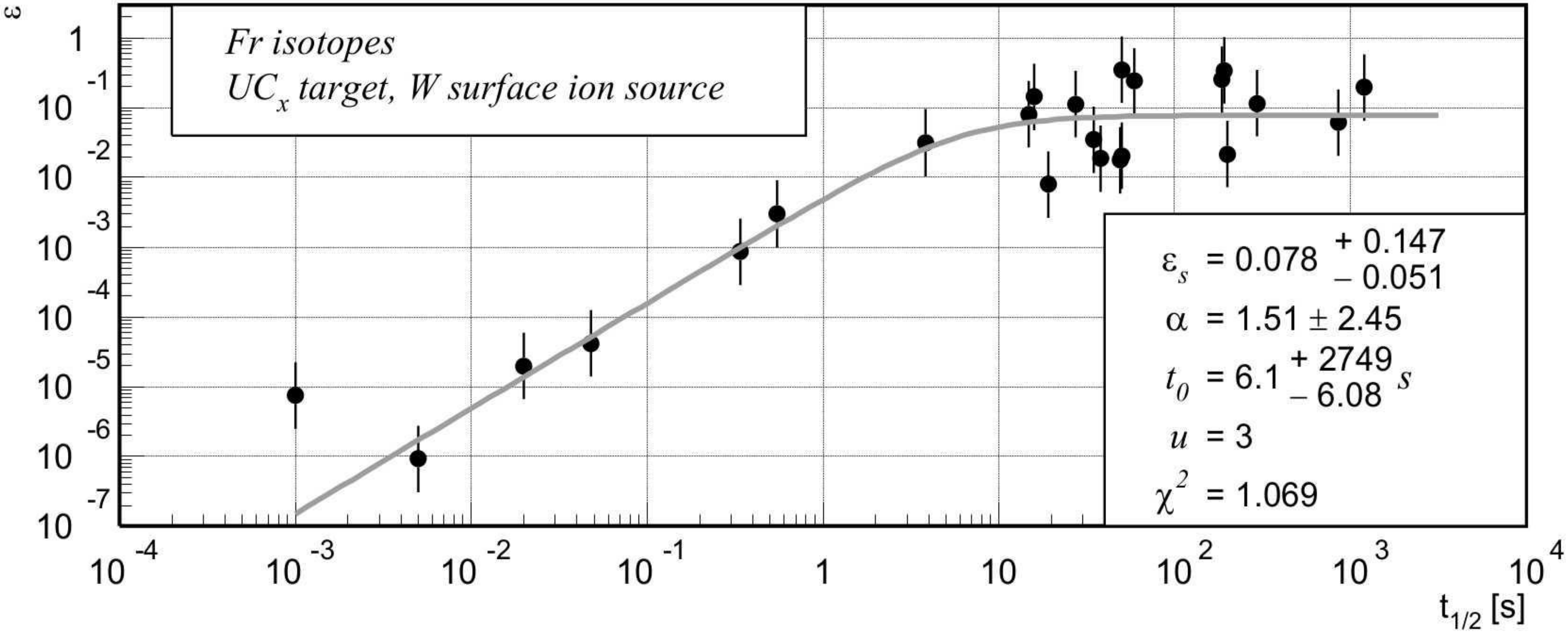


Figure 6: Overall release efficiency in function of the half-life of Fr isotopes from a UC_x target with a W-surface ion source. The values were obtained by comparing ISOLDE SC yields for this system with the in-target yields calculated using ABRABLA. The function described by the equation 14 was fitted to the data. Because of the large variations of the efficiency for the longest-lived isotopes, the data uncertainty factor *u* was assumed to be 3.

ISOLDE yields described using formula
S. Lukic et al, NIM A 565, 784 (2006)

$$\varepsilon\left(t_{1/2}\right) = \frac{\varepsilon_s}{1+\left(\frac{t_{1/2}}{t_0}\right)^{-\alpha}}$$

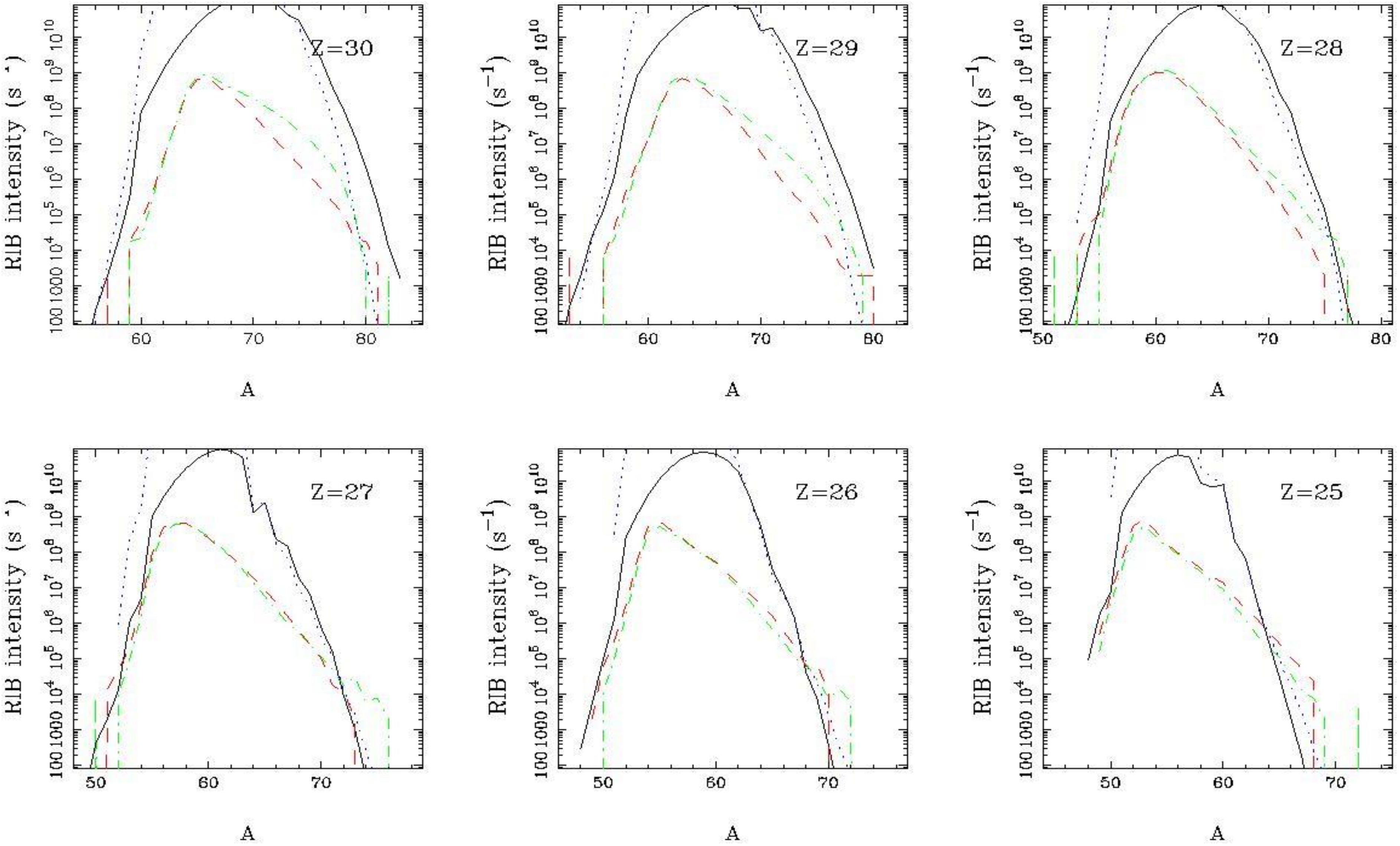
Possible continuation/extension of this work at ISOLDE ?
Detailed simulations of targets ?

As a test case, spallation/fission, fragmentation and peripheral (deep-inelastic) collisions were considered as possible candidates for production of exotic (neutron-rich) nuclei around ^{78}Ni

- spallation - GSI model used (statistical abrasion-ablasion + de-excitation/fission), U-target is optimal for spallation/fission with 1 GeV proton beam

- fragmentation - cross sections calculated using EPAX-2, optimized for each isotope over all stable beams

- Fermi energy: ^{82}Se+^{64}Ni at 25 AMeV, with modified DIT model of Tassan-Got (Veselsky&Souliotis NPA765, 252 (2006)) cross sections of exotic nuclei around ^{78}Ni at 0.1 - 1 ❍b level, cross sections depend weakly on beam energy, with 100pnA beam, 20 mg/cm^2 target (settings assumed in Souliotis et al. PLB543 (2002) 163), the intensities of secondary beams around ^{78}Ni of 10 - 100 /s can be expected

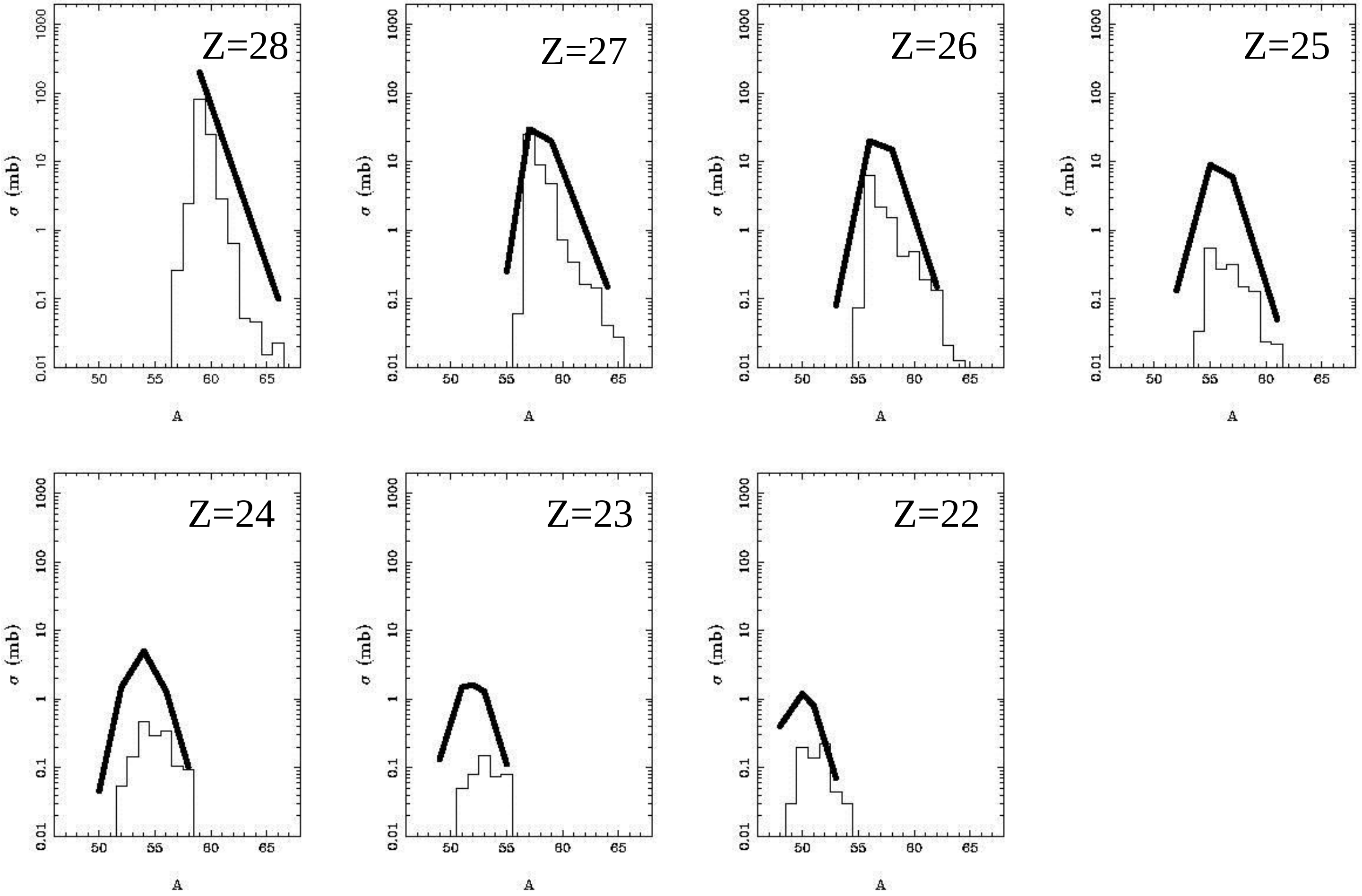


Estimated RIB intensities around ^{78}Ni for 1 GeV proton beam colliding with U (solid line), compared to optimal fragmentation cross sections as given by EPAX-2 (dotted line) and the calculated inclusive cross sections for reactions ^{86}Kr,^{82}Se+^{64}Ni at 25 AMeV (dashed and dash-dotted line, respectively). A global estimate inspired by work of Lukic et al. was used for ISOL extraction efficiency.

Production of very n-rich nuclei using secondary beams at HIE-ISOLDE ?

Test of low energy data (within HIE-ISOLDE energy range)

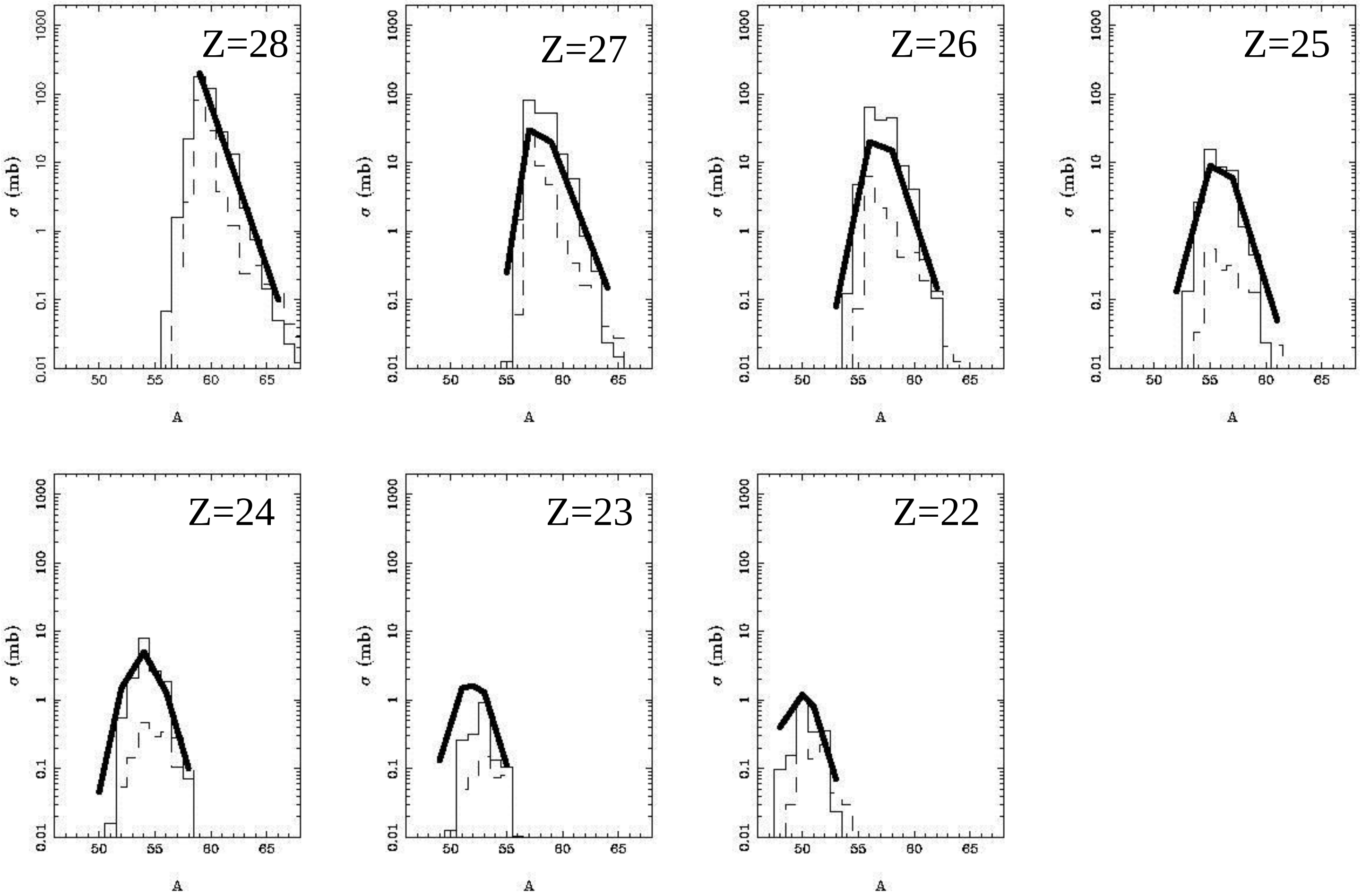
^{58}Ni+^{208}Pb at 5.66 AMeV, angle-integrated data
(L. Corradi et al., Phys. Rev. C 66 (2002) 24606)



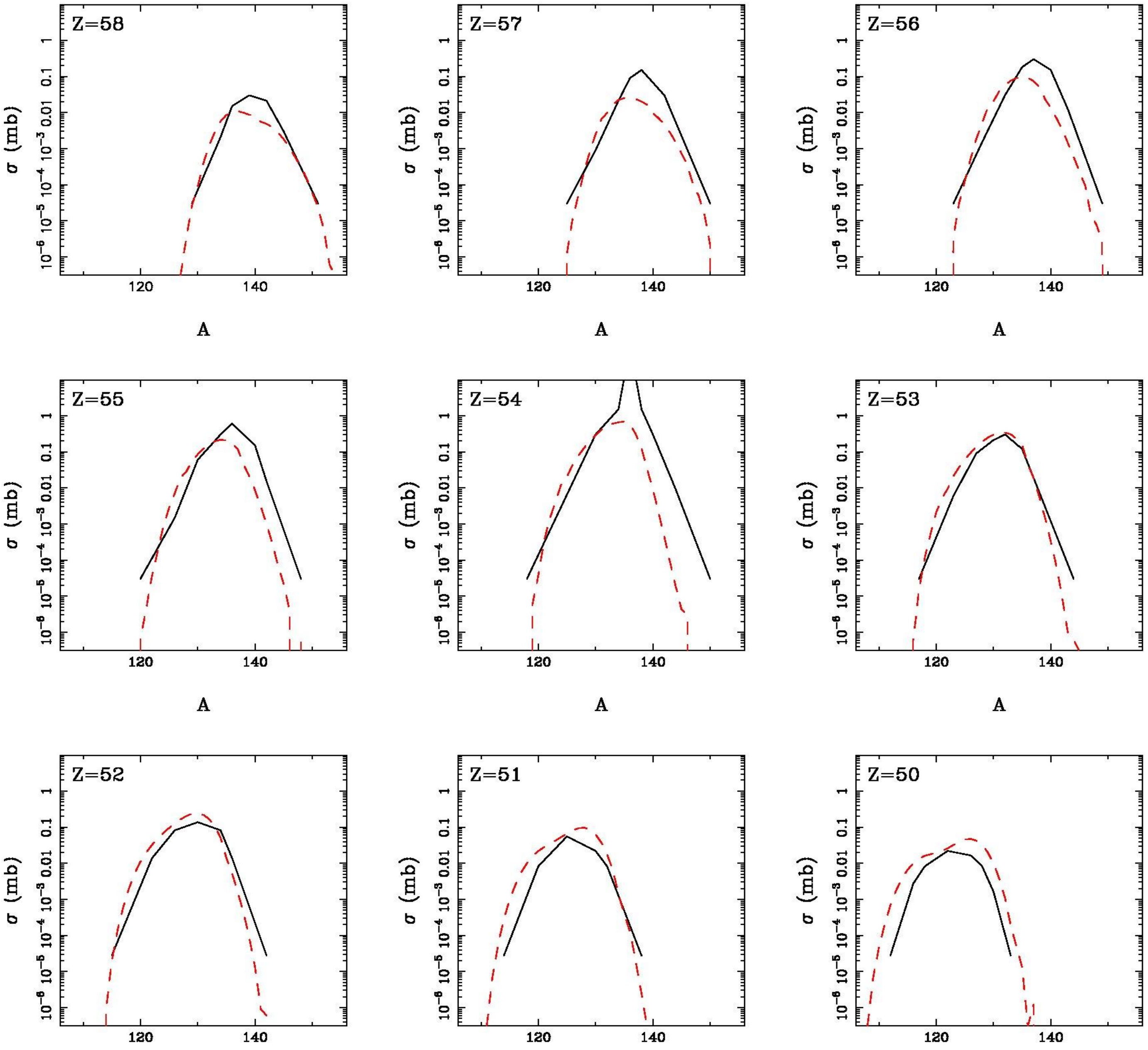
Experimental data vs DIT calculation of Tassan-Got (after de-excitation)

M. Veselsky and G.A. Souliotis, NPA 872 (2011) 1

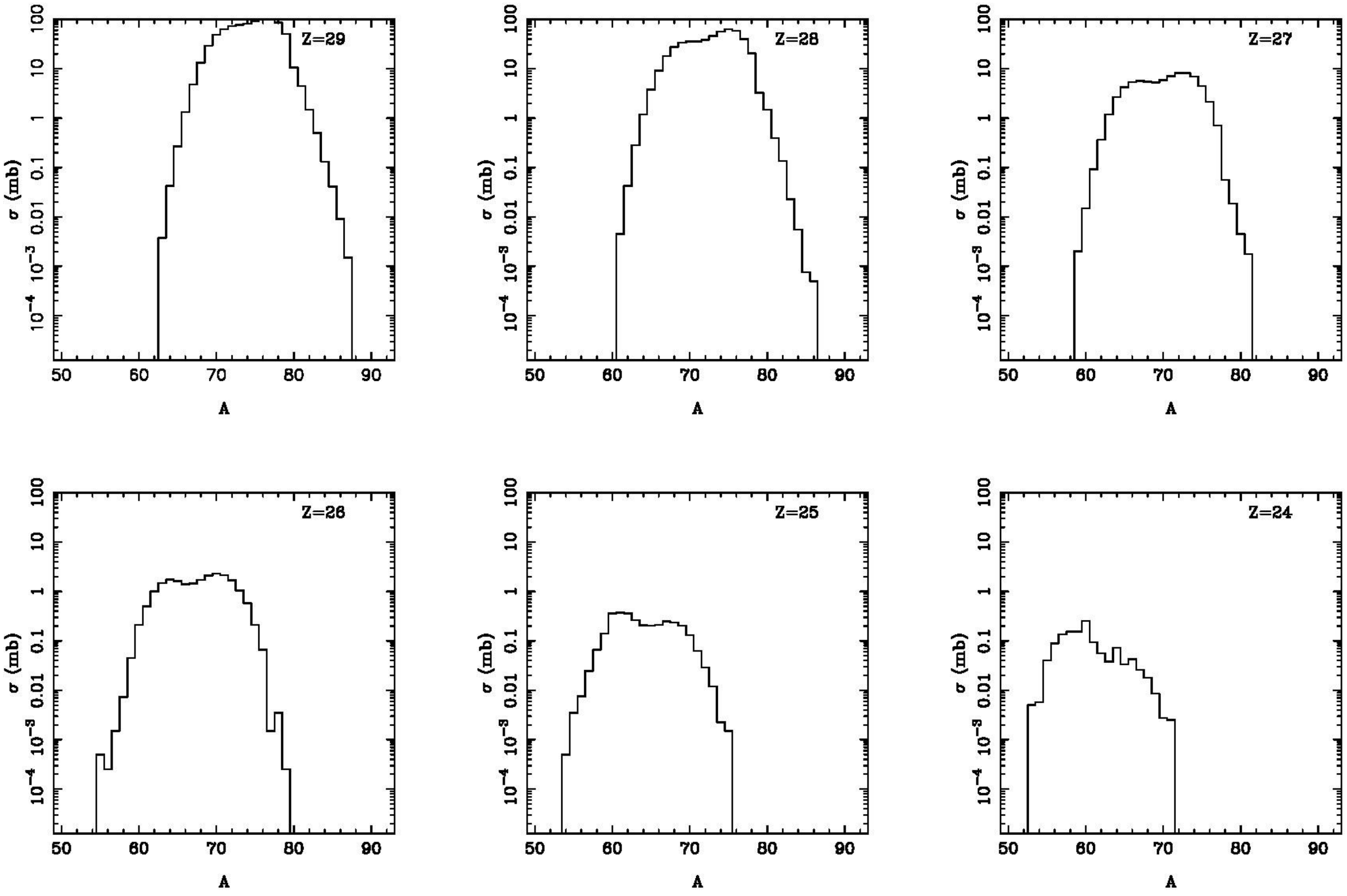
DIT calculation with radius of nuclear potential extended by 0.75 fm.
Possible explanation : deformation, neck structure ?



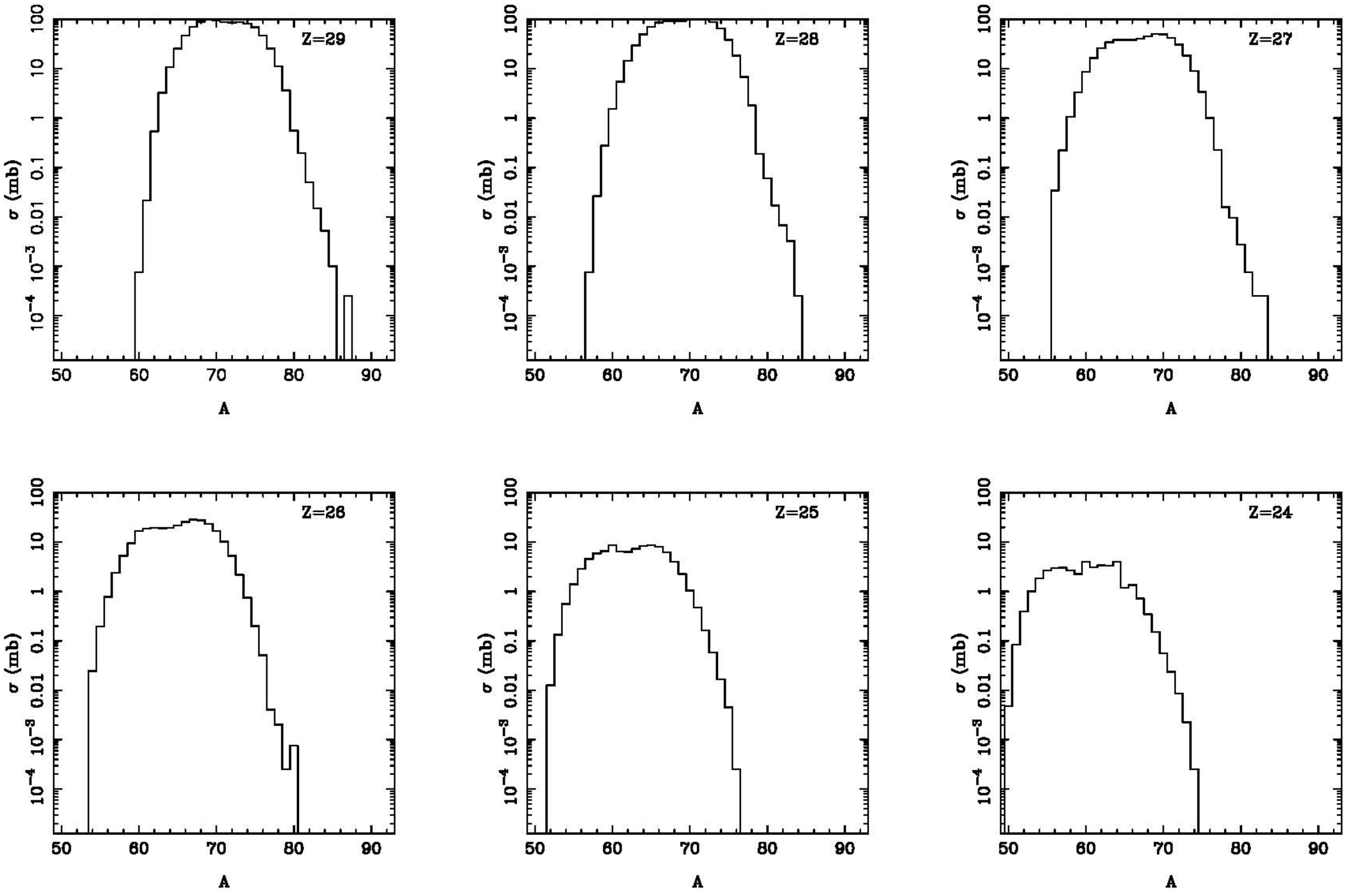
Similar results for other two reactions (^{58,64}Ni+^{238}U) between 5.5 – 6 AMeV, for data at 8 AMeV effect reduced by 25 %, at 15 AMeV no such effect, effect restricted to U,Th targets, M. Veselsky and G.A. Souliotis, NPA 872 (2011) 1



Simulations performed using the hybrid model (in particular model of deep-inelastic transfer, with modifications described in Veselsky and Souliotis, NPA 872 (2011) 1, dashed line) and compared to recent data in reaction of 136Xe+198Pt at 8 AMeV (Watanabe et al, NIMB 371 (2013) 752, solid line, test for KISS/GALS)



Test for HIE-ISOLDE at low energy data
^{78}Zn+^{238}U at 6 AMeV, angle-integrated data
(using extended nuclear profile setting for 5.5-6 AMeV)



Test for HIE-ISOLDE at low energy data

^{74}Zn+^{238}U at 8 AMeV, angle-integrated data

(using extended nuclear profile setting for 8 AMeV)

Using yields of RIBs from ISOLDE database and moderately thick target the calculated cross sections for 78Ni between 1 and 10 mb lead to in-target production rate of 1 nucleus in few seconds.

Angular distribution is wide, products can be easily separated from the direct beam, also scattered beam can be possibly suppressed.

Experimental solution for HIE-ISOLDE ?

Conference in Slovakia:

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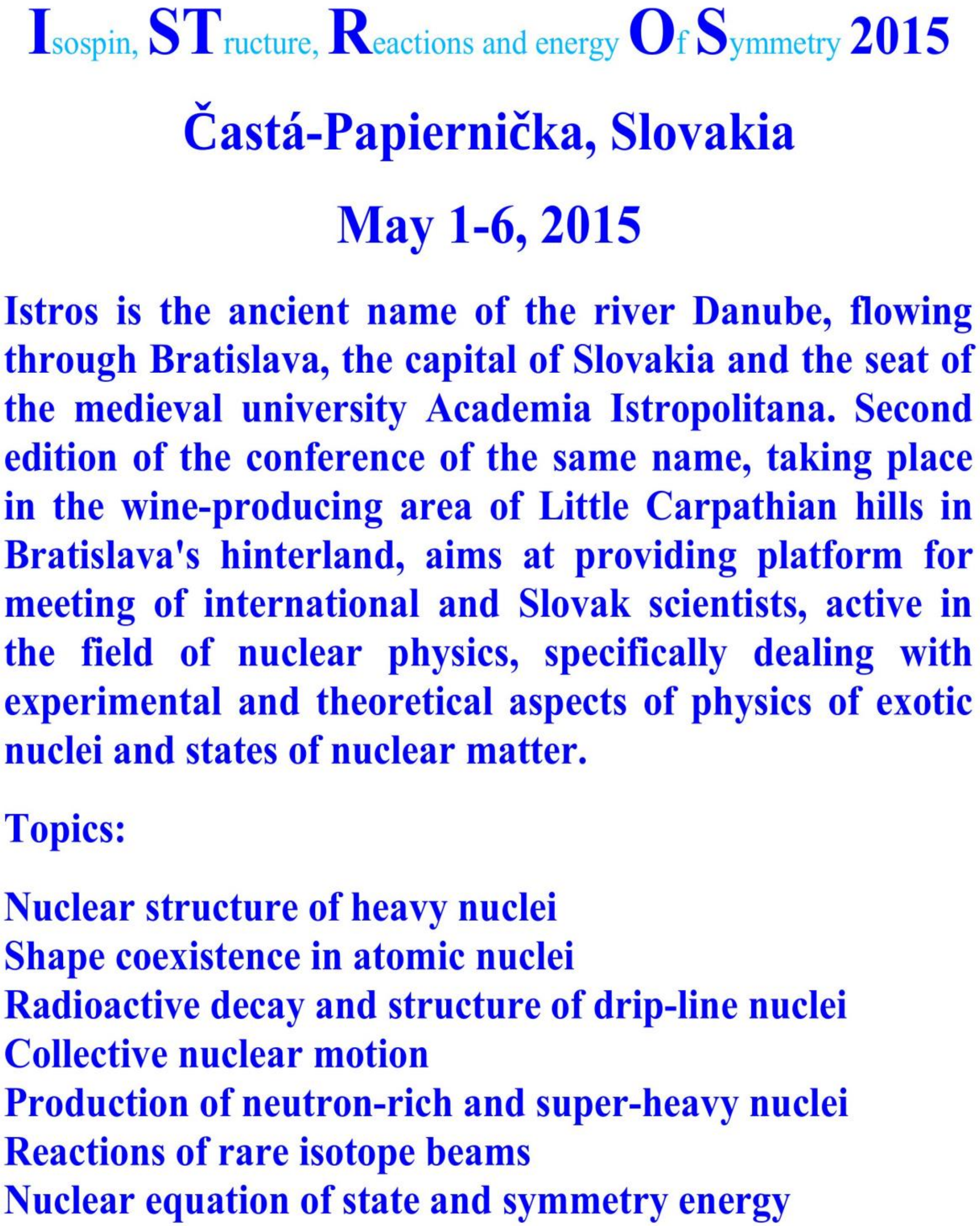

Isospin, STructure, Reactions and energy Of Symmetry 2015

Častá-Papiernička, Slovakia

May 1-6, 2015

Istros is the ancient name of the river Danube, flowing through Bratislava, the capital of Slovakia and the seat of the medieval university Academia Istropolitana. Second edition of the conference of the same name, taking place in the wine-producing area of Little Carpathian hills in Bratislava's hinterland, aims at providing platform for meeting of international and Slovak scientists, active in the field of nuclear physics, specifically dealing with experimental and theoretical aspects of physics of exotic nuclei and states of nuclear matter.

Topics:

Nuclear structure of heavy nuclei
Shape coexistence in atomic nuclei
Radioactive decay and structure of drip-line nuclei
Collective nuclear motion
Production of neutron-rich and super-heavy nuclei
Reactions of rare isotope beams
Nuclear equation of state and symmetry energy