Multi Nucleon Transfer studies with a kinematic TOF method

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Letter of Intent

Multi-Nucleon Transfer Reactions at GSI

In-depth broadband reaction studies with complementary methods, paving the way towards the production and study of the terra incognita on the nuclear chart

LoI: U325 - Endorsed by GPAC

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[9]*TAU, Tel-Aviv, Israel*
[10]*Soreq NRC, Yavne, Israel*
[11]*RIKEN Nishina Center, Wako, Japan*
[12]*MAHE, Manipal, India*
[13]*University of Surrey, UK*
[14]*University of Edinburgh, UK*

Letter of Intent

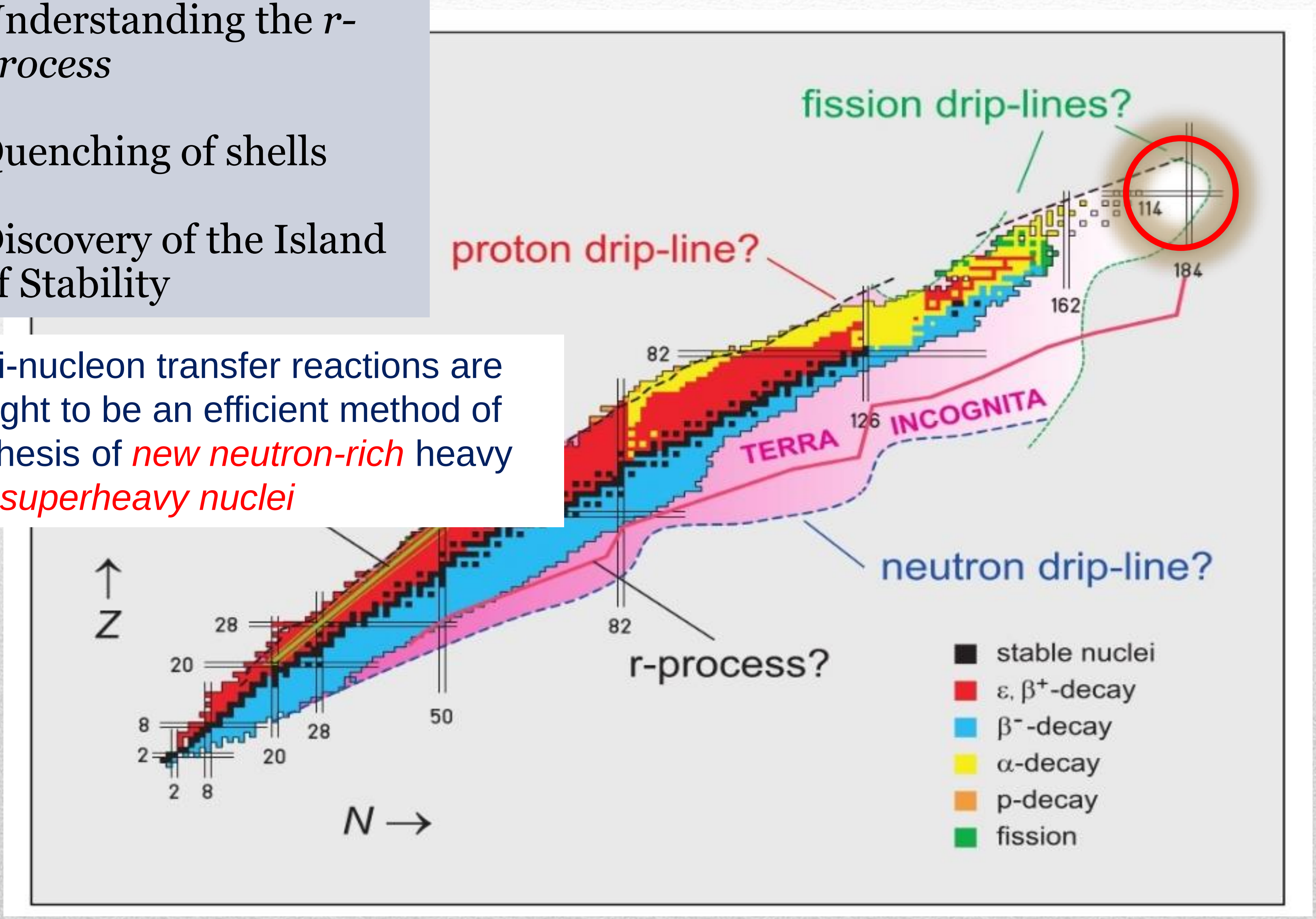
Multi-Nucleon Transfer Reactions at GSI

- Study of the reaction kinematics and energetics
- Use of complementary methods to detect products of multinucleon transfer reactions
- Use of the many beams available (^{136}Xe, ^{208}Pb, ^{238}U)
- Build new dedicated equipment (Target module, TOF spectrometer upgrade, Cryogenic Stopping cells, low energy beam transport, separation and cooling, MR-TOF-MS system)

MNT: A way to explore *Terra Incognita*

- Understanding the *r-process*
- Quenching of shells
- Discovery of the Island of Stability

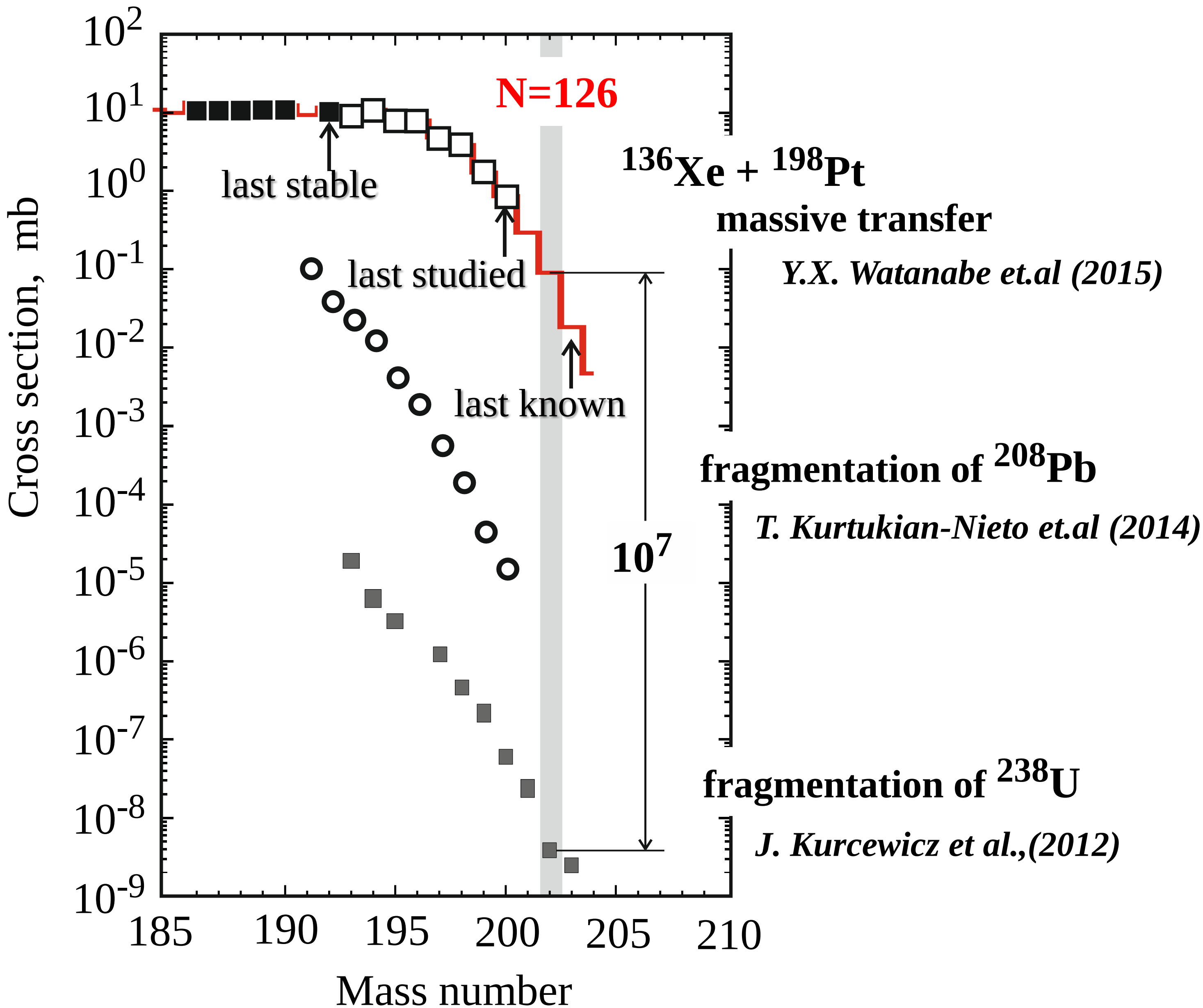
Multi-nucleon transfer reactions are thought to be an efficient method of synthesis of *new neutron-rich* heavy and *superheavy nuclei*



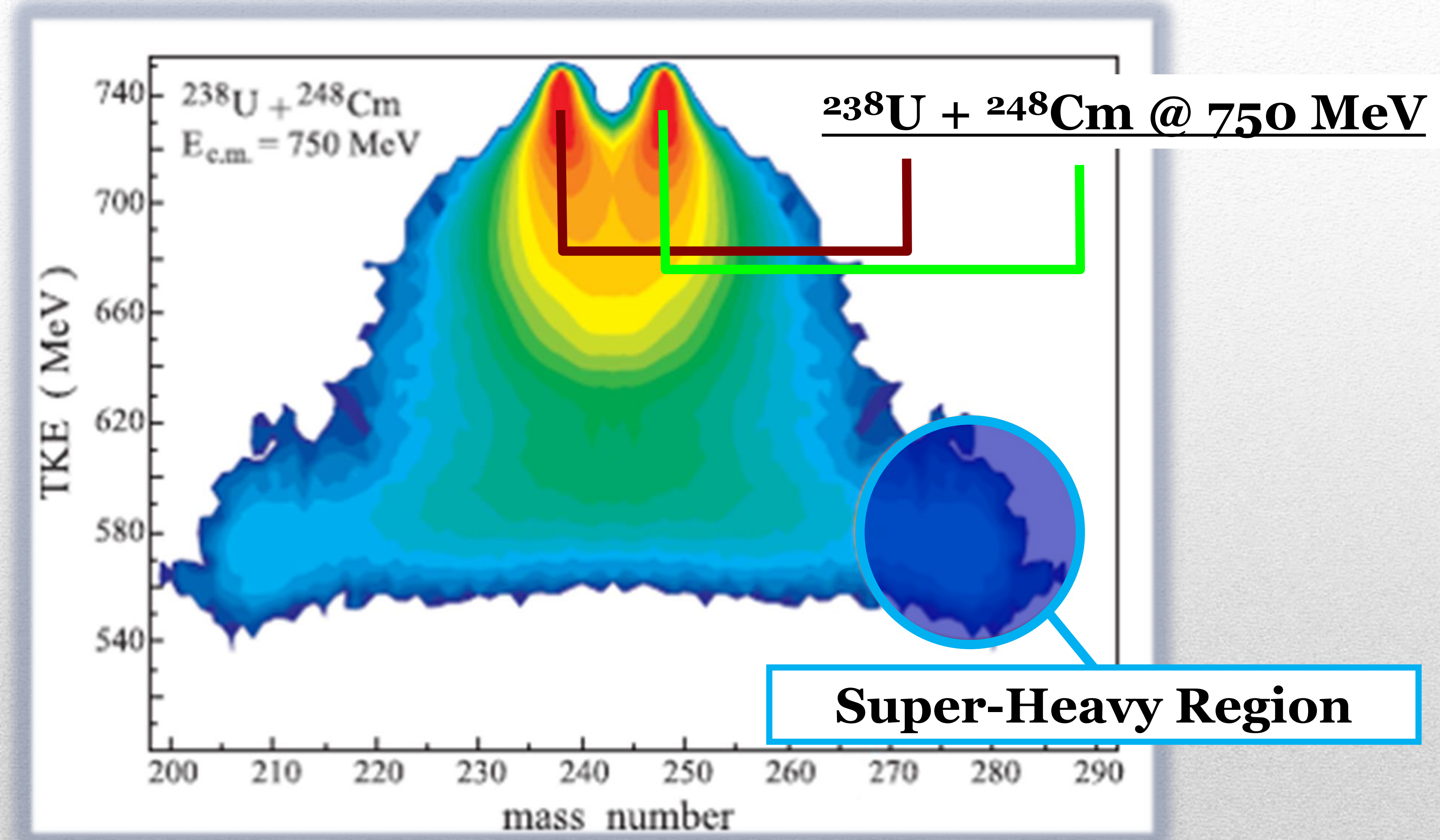
Main issues in MNT research

- Is MNT an efficient reaction mechanism for the *production of neutron-rich heavy nuclei* ?
- Is MNT competitive against cold fragmentation?
- Do *shell effects* play a role ?
- What are the important *degrees of freedom* that drive the dynamical evolution? Single particle or collective? Optimal Q-value?
- What is the impact of *dissipation* and how to find clues about dissipation properties?

Production of neutron-rich Os-isotopes



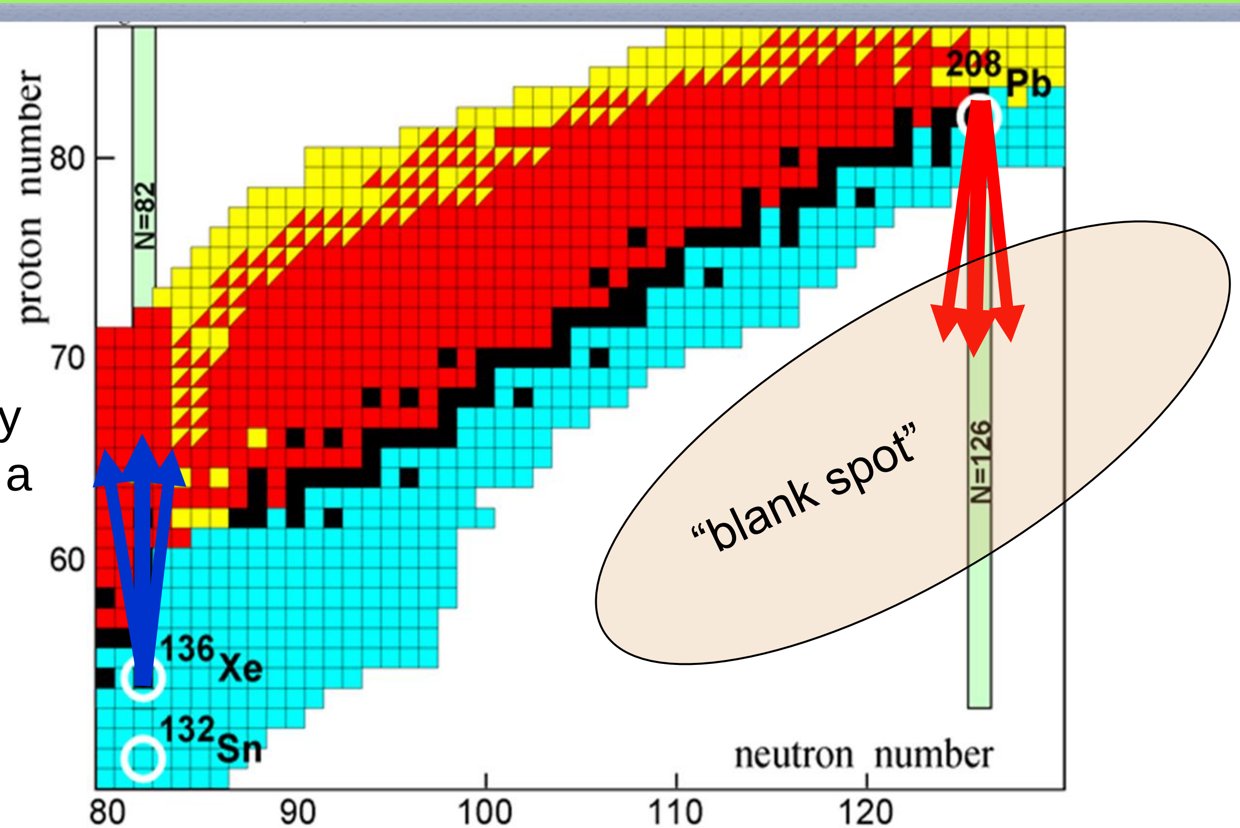
MNT as a channel for production of SHE



V.Zagrebaev and W.Greiner, PRC **83** 044618 (2011)

What are the optimal conditions to produce new nuclei in the Terra Incognita?

protons may experience a higher mobility

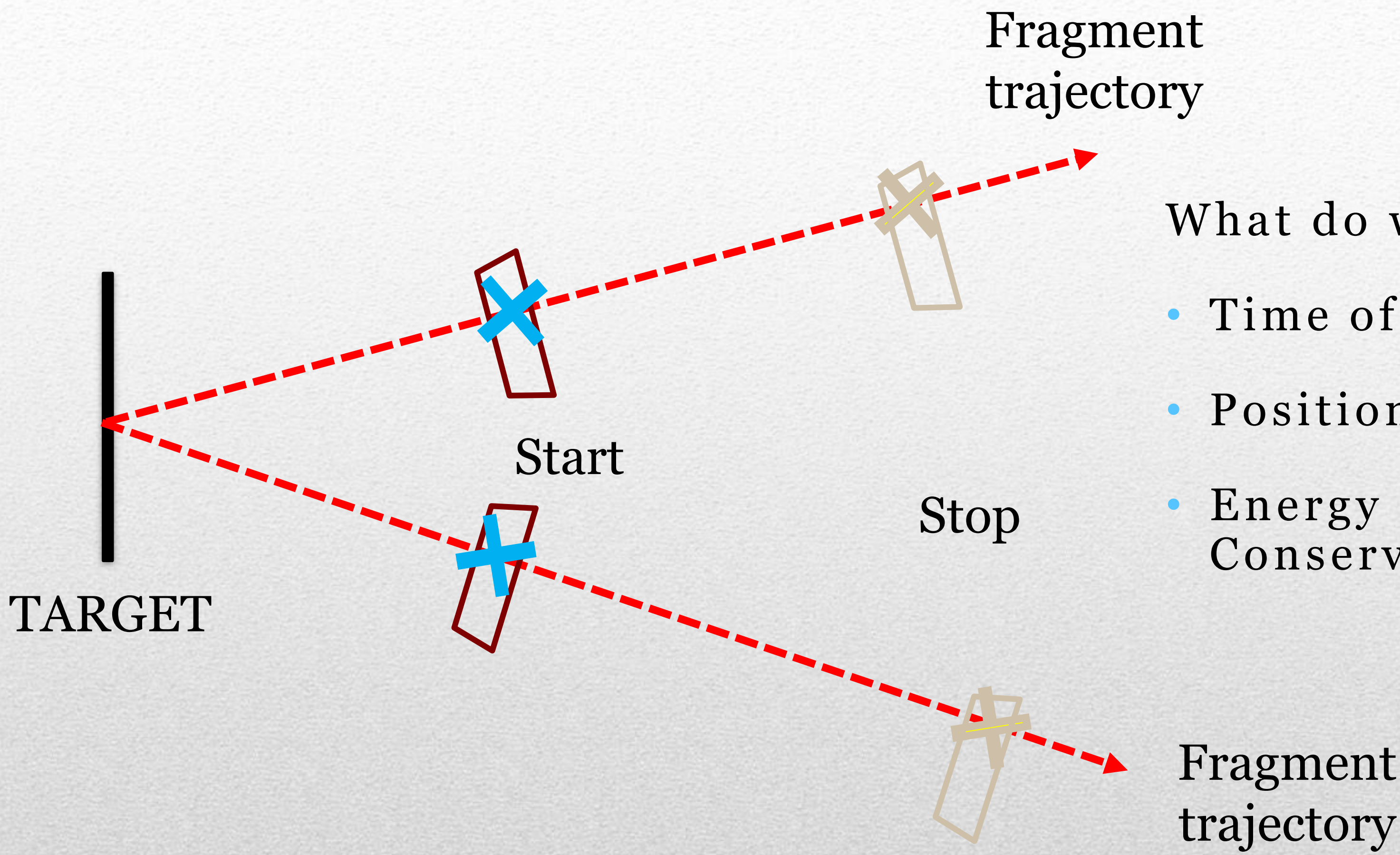


$^{136}Xe_{N=82} + {}^{208}Pb_{N=126} \rightarrow {}^{136+\Delta Z}X_{N=82} + {}^{208-\Delta Z}Y_{N=126}$ Q≈0

$E_x = E_{cm} - TKE + Q_{gg}$ $\rightarrow {}^{140}Ce_{N=82} + {}^{204}Pt_{N=126}$ Q = -1.5 MeV

V.Zagrebaev and W.Greiner
Production of new heavy isotopes in low-energy multinucleon transfer reactions, PRL, **101**, 122701 (2008)

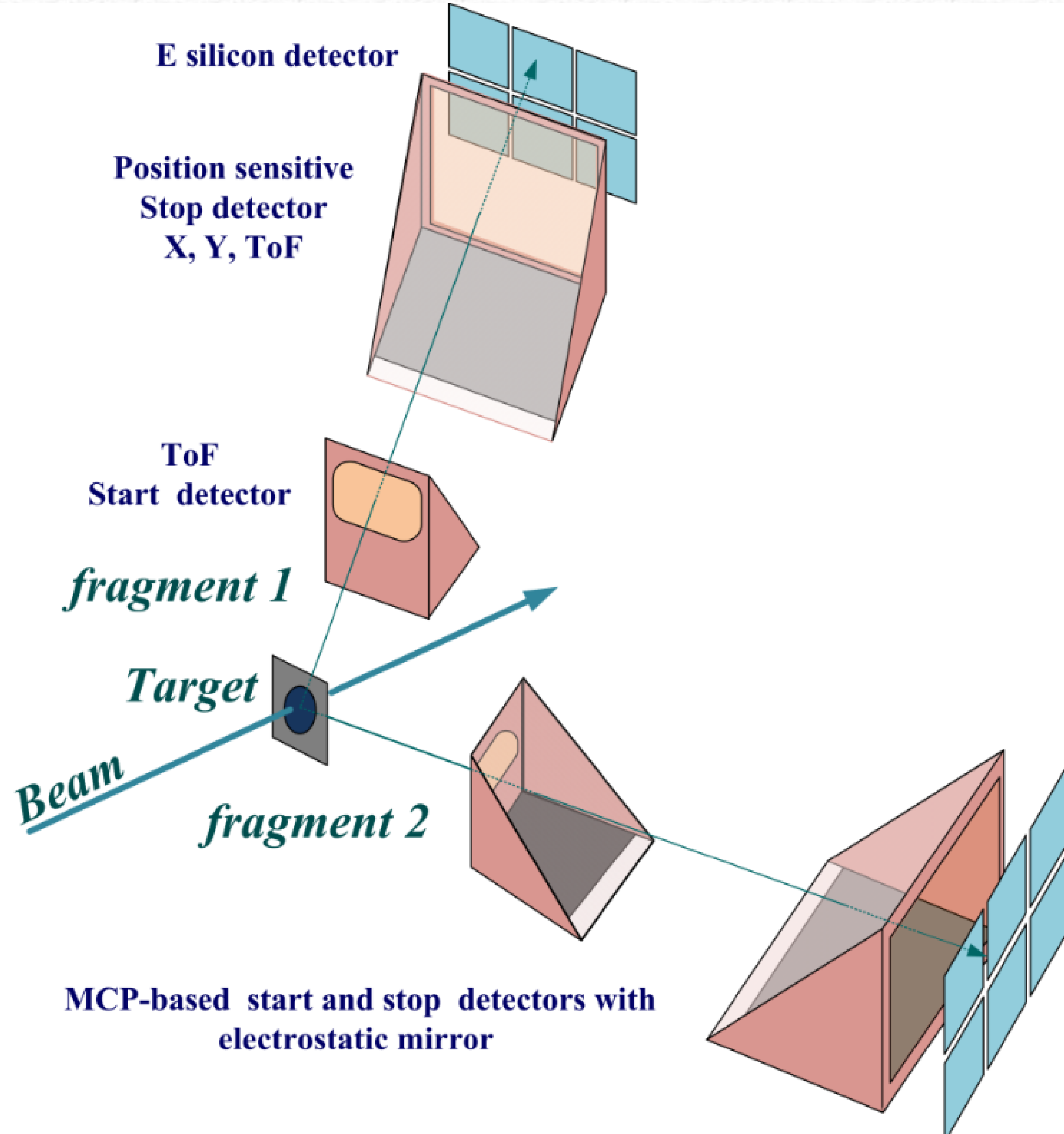
An extraordinary simple Mass Spectrometer



What do we need:

- Time of Flight
- Position
- Energy and Momentum Conservation Law

Double Arm TOF-E CORSET



Time resolution	**150-180 ps**
ToF base	10-30 cm
ToF arm rotation range	15°-165°
Solid angle	100 -200 msr
Angular resolution	**0.3°**
Mass resolution	**2-4 u**
Energy resolution	**1%**

Measured parameters:

- ToF, X, Y, Energy of each fragment

Extracted parameters:

- Velocity, Energy, Angles

Computed parameters :

- Masses and TKE

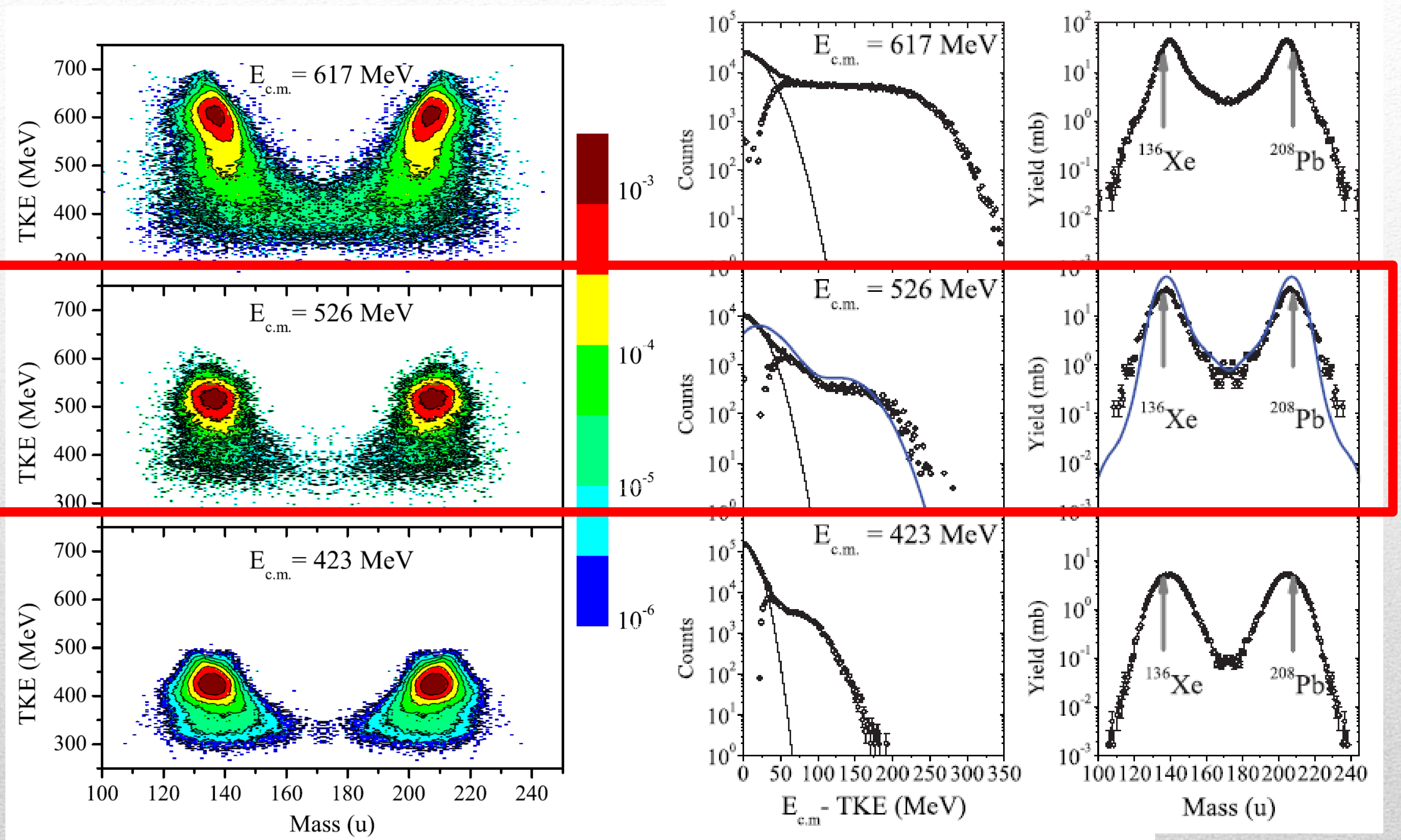
Courtesy of E.M. Kozulin

E. M. Kozulin et al., *Instruments and Experimental Techniques 51, 44* (2008)

Advantages of the kinematics method

- Measurement of the *primary mass* of the TLF and PLF
- Mass distribution vs. different degrees of energy dissipation (TKEL)
- Effect of Q_{gg} values on the secondary mass distribution (after neutron evaporation)

$^{136}Xe + ^{208}Pb$ @ Dubna: Mass-TKE

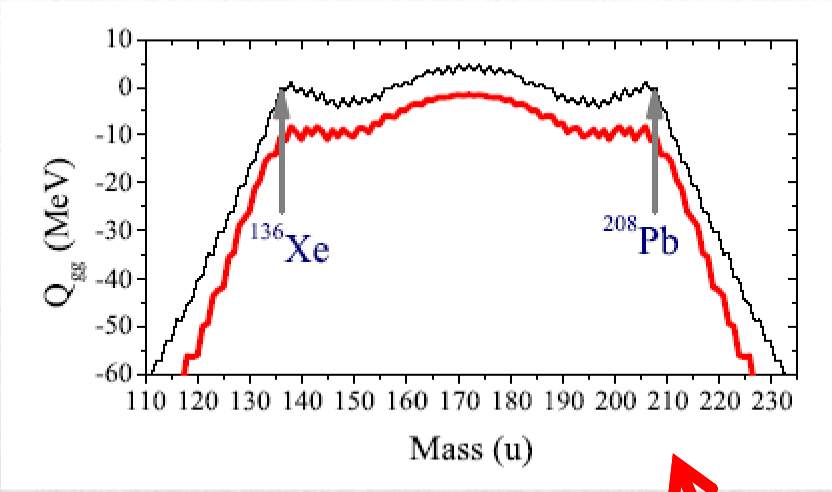


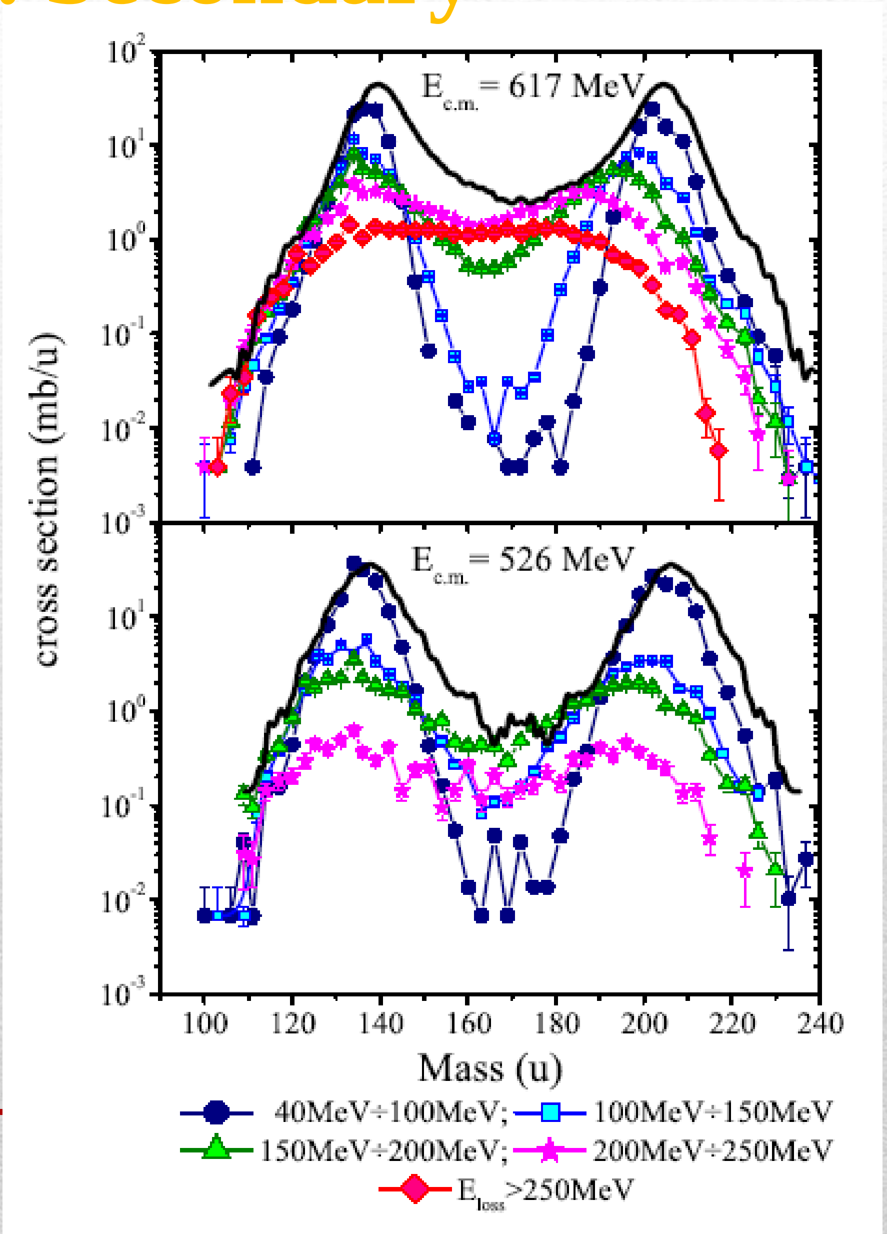
Why Mass-TKE around the barrier ?

E. M. Kozulin, E. Vardaci, G.N. Knyazheva et al. Phys.Rev. C 86 044611 (2012)

TKEL & Qgg : Neutron Evaporation

Primary vs. Secondary

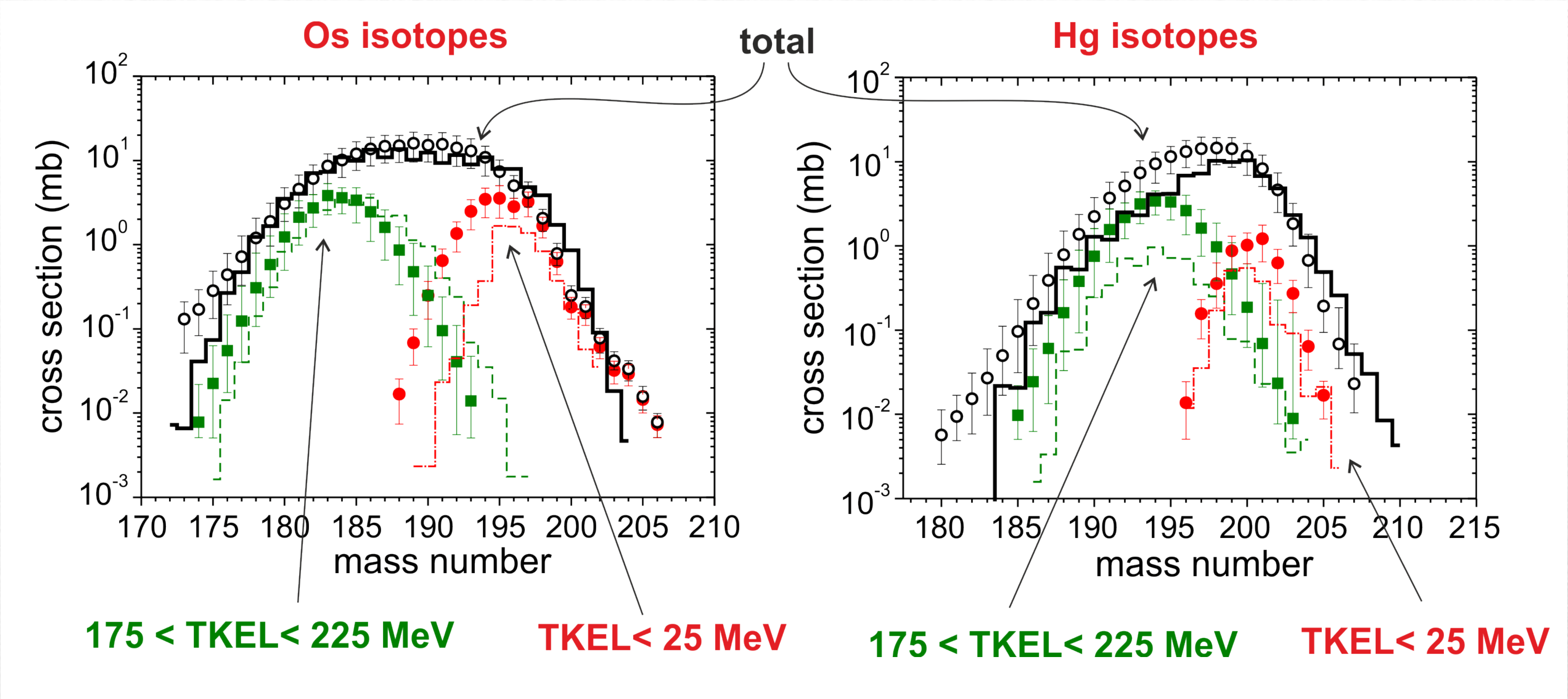




$$E_x = \underbrace{E_{cm} - TKE}_{\text{TKEL}} + Q_{gg}$$

TKEL & Qgg : Energy dissipation

$^{136}Xe+^{198}Pt$ @ 643 MeV Y. X. Watanabe, et al., PRL 115, 172503 (2015)

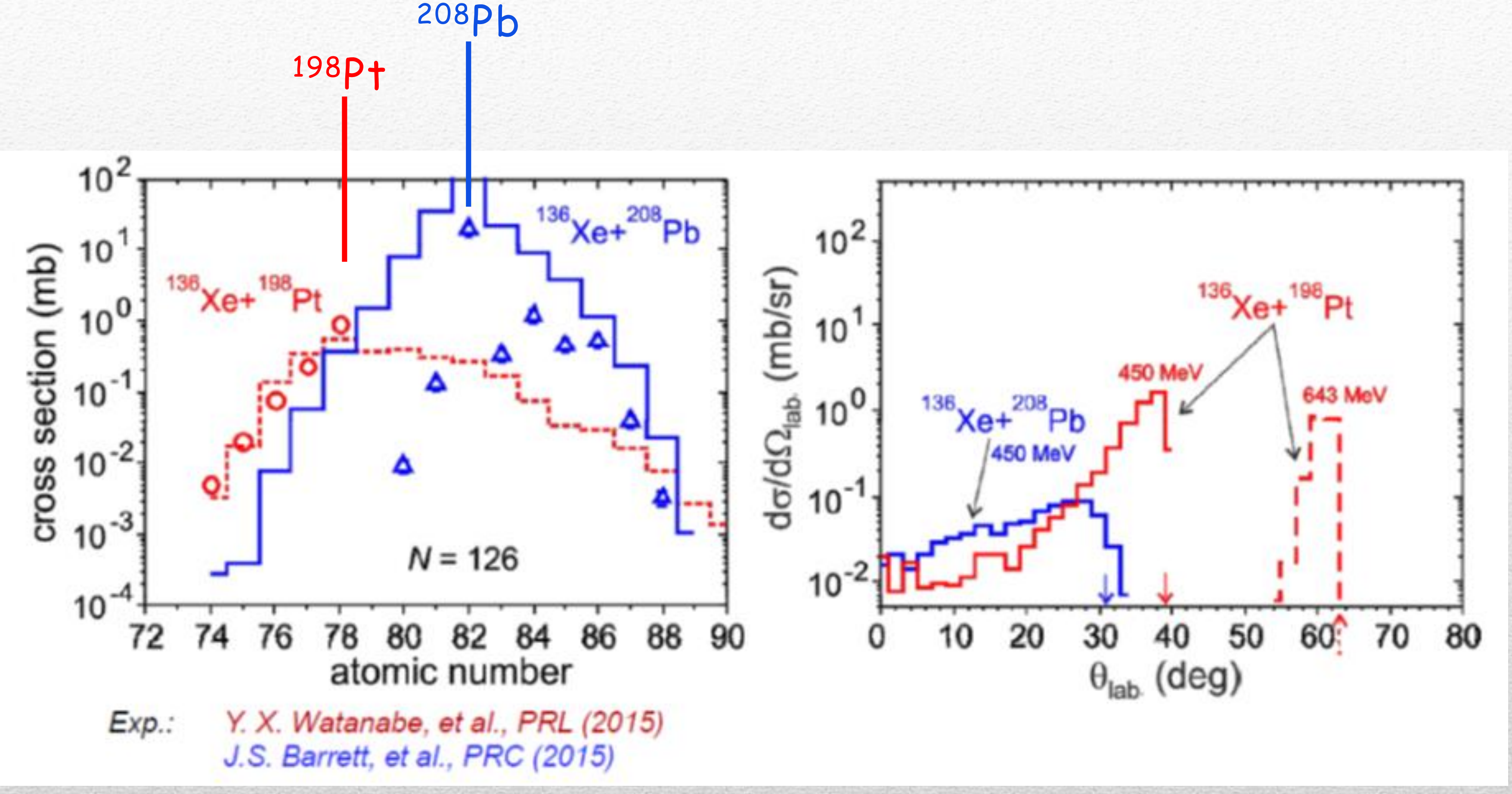


More neutron-rich require less TKEL
(same as in Xe+Pb)

Theory from: A.V. Karpov and V.V. Saiko, Phys. Rev. C 96, 024618 (2017)

($^{136}Xe + ^{208}Pb$) vs. ($^{136}Xe + ^{198}Pt$)

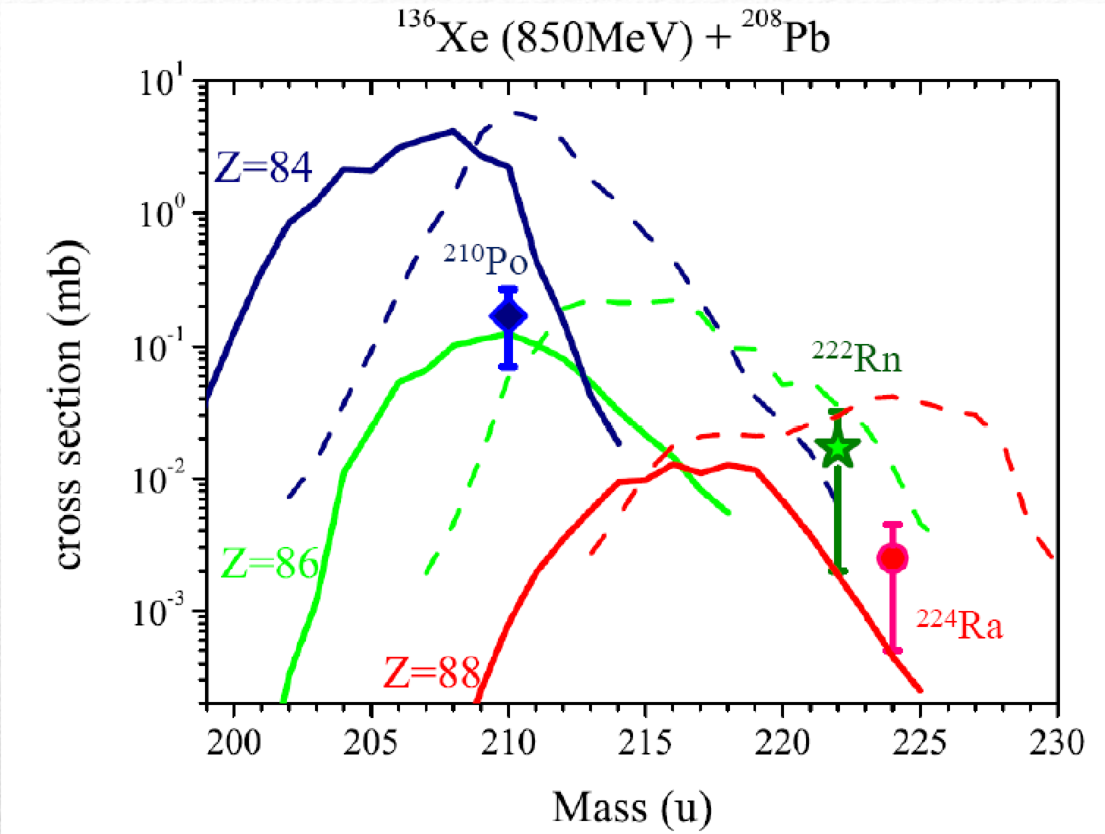
Angular Distributions



A.V. Karpov and V.V. Saiko, Phys. Rev. C 96, 024618 (2017)

Courtesy of A. Karpov

^{136}Xe + ^{208}Pb



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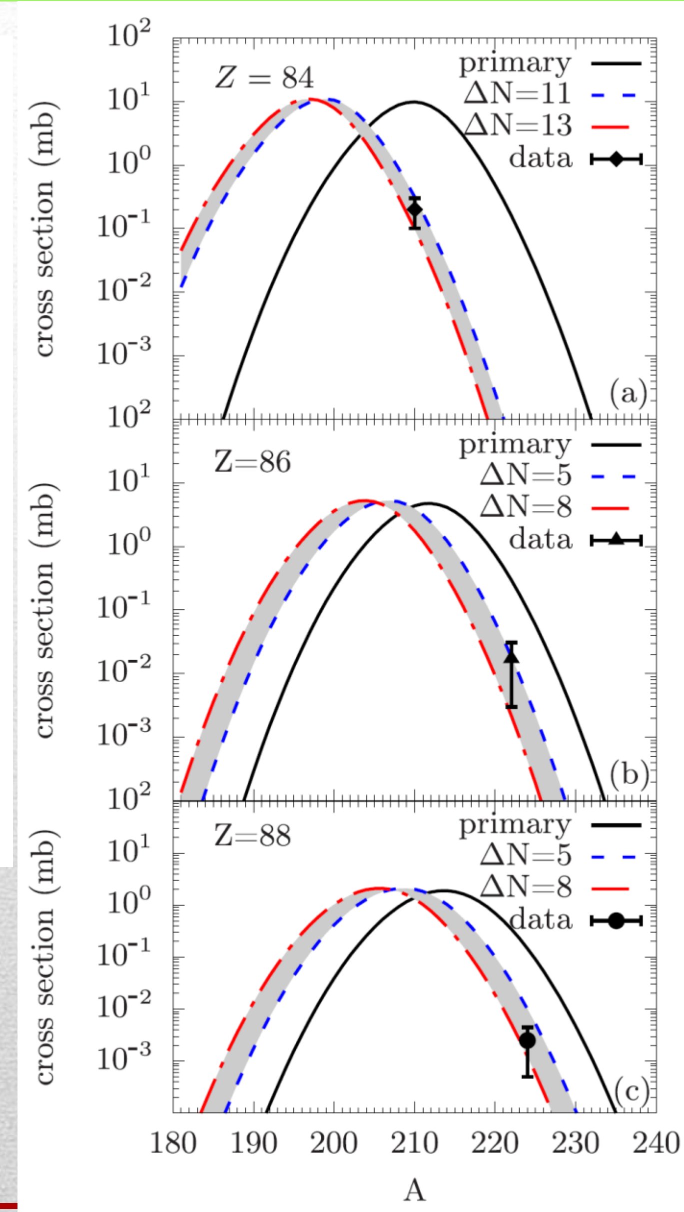

S. Ayik , O. Yilmaz, B. Yilmaz and A. S. Umar, PRC 100, 044614 (2019)

“Heavy-isotope production in ^{136}Xe + ^{208}Pb collisions at Ec.m. = 514 MeV”

Toward the RIBS

- MNT with stable ions combinations can only produce slightly neutron-rich nuclei with measurable cross-sections
- RIBs with larger neutron excess should make nuclei farer from the stability line at reach
- Investigation of MNT induced by RIBs for optimal conditions

Challenges

1. Wide angular distributions
2. Search for conditions that minimize neutron evaporation
3. Isotope separation and identification
4. Upgraded needed for higher beam intensities

Conclusions and Perspectives

1. Role of MNT crucial to access neutron rich nuclei
2. Extensive study needed over the Segre' chart
3. MNT with RIBs accessible and mandatory
4. Gradual step toward RIBs: unique opportunity for stable beams (U and Xe) of high intensity at GSI
5. Detector development mandatory

Thank you for your attention