Quasi-fission as a Source for New Exotic Nuclei?

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Workshop on Nuclear Fission and Structure of Exotic Nuclei
JAEA, Tokai, Japan, March 25 - 27, 2019

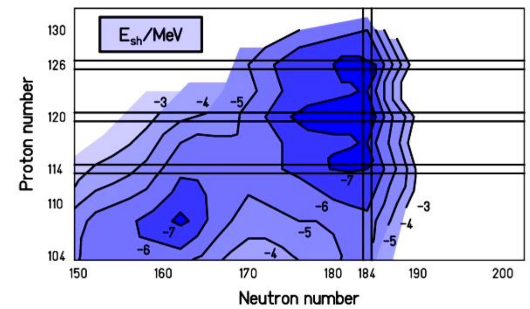
The present Chart of Nuclides

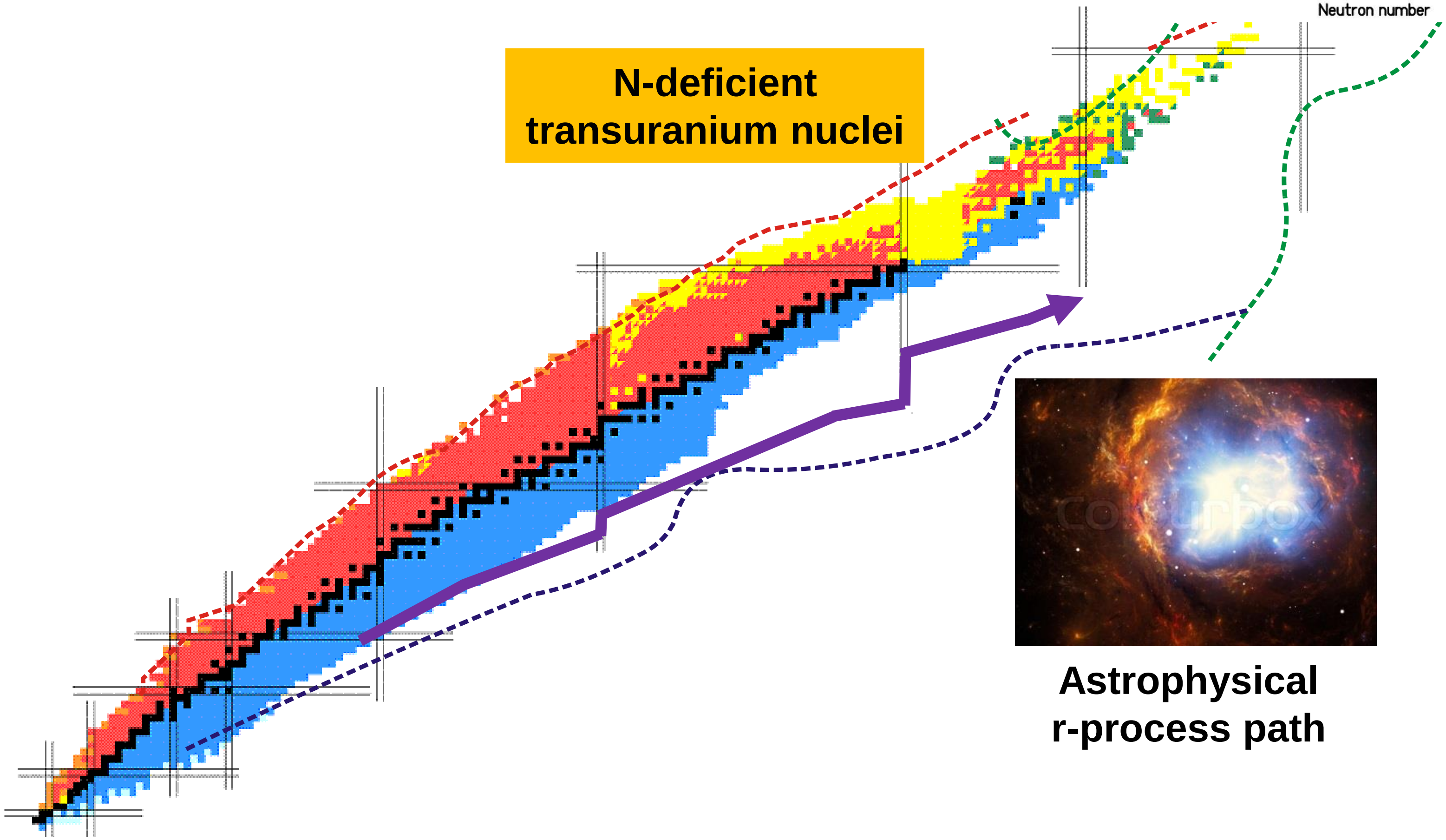
118 known elements

~4000 known isotopes

~4000 further isotopes expected

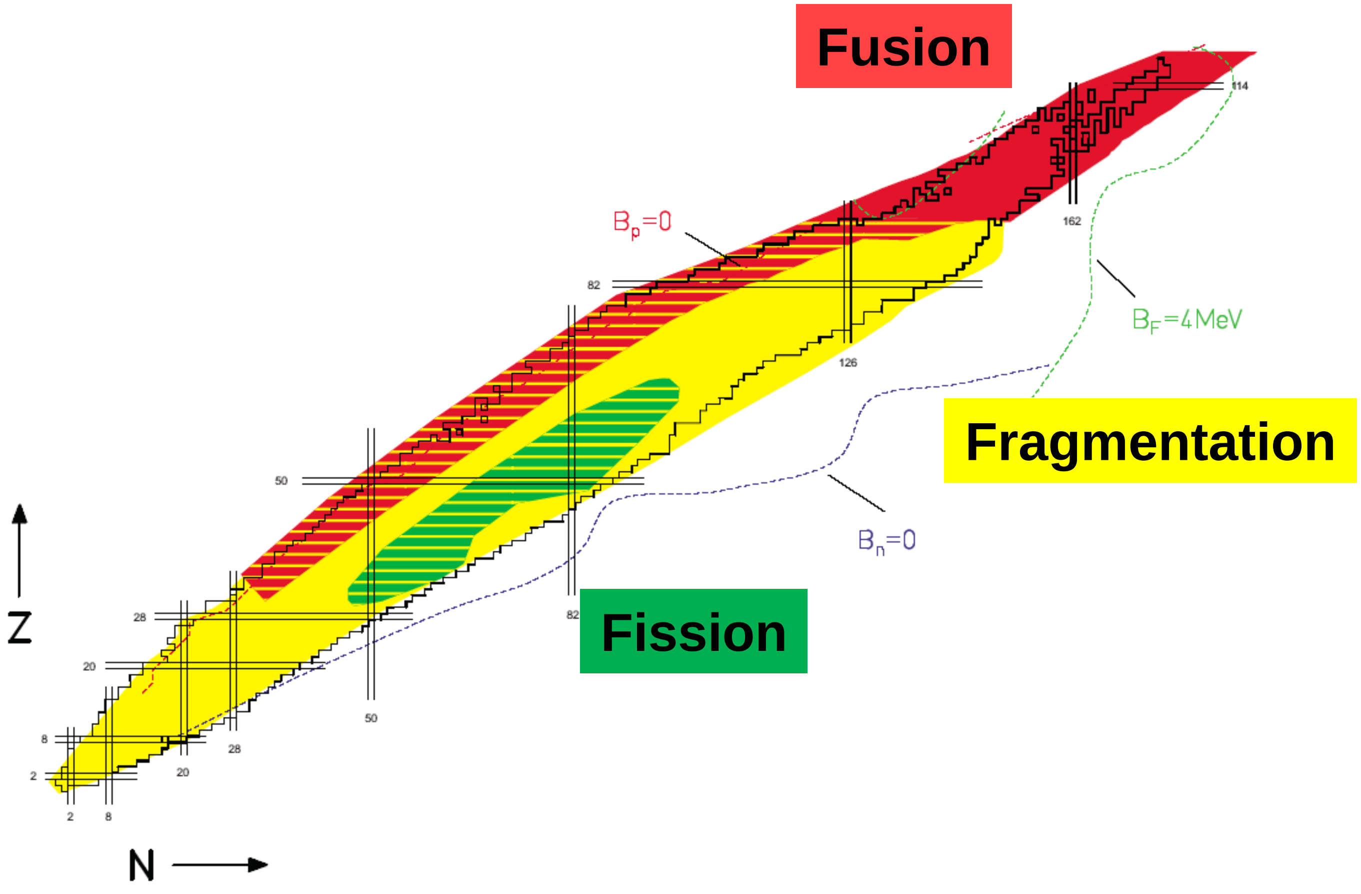
Superheavy nuclei





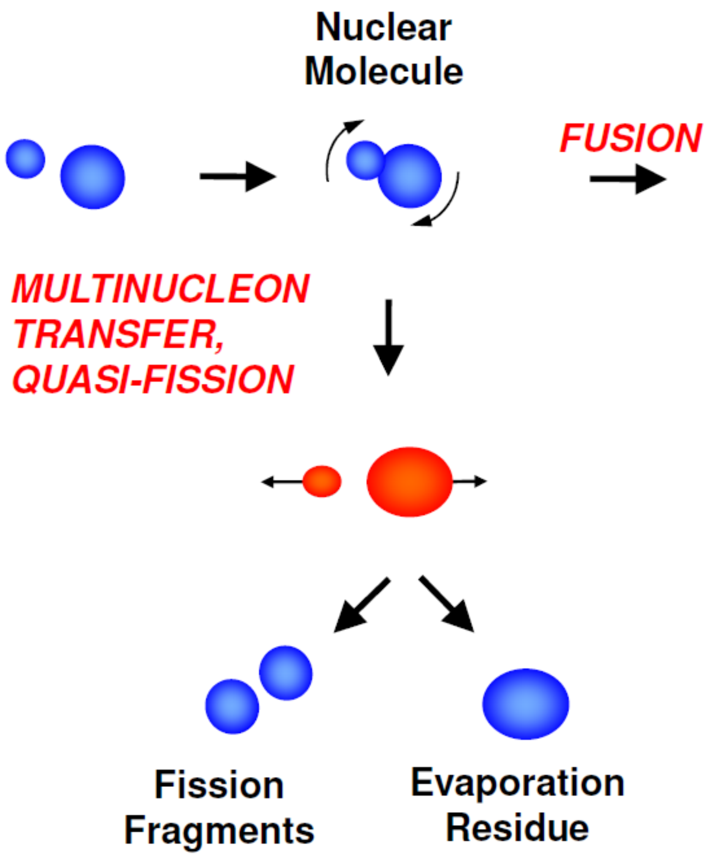
Astrophysical r-process path

Nucleosynthesis in the Lab

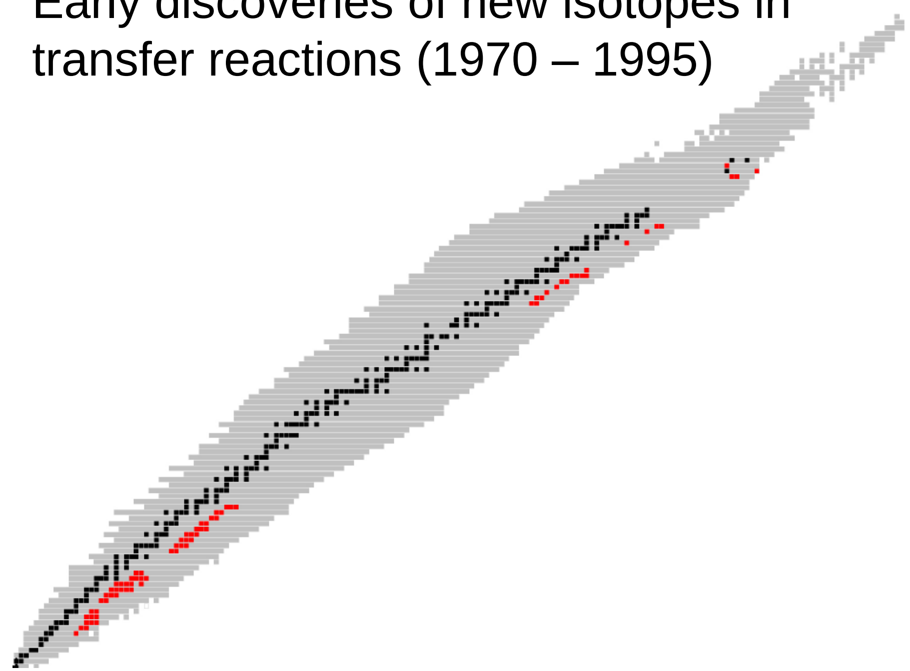


How can we fill the empty areas?

Proceeding of Low-energy Heavy Ion Reactions



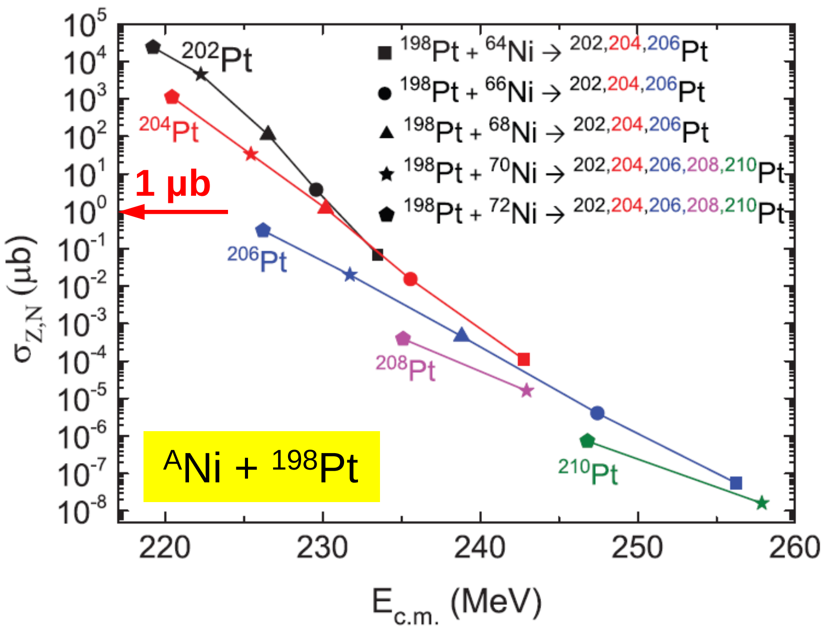
Early discoveries of new isotopes in transfer reactions (1970 – 1995)



Neutron-rich N = 126 Nuclei

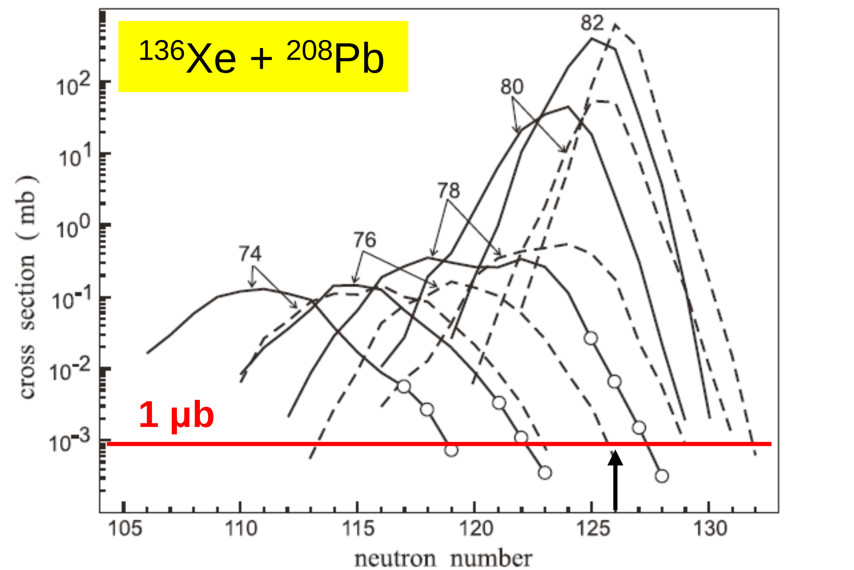
Fragmentation or transfer – what is better?

Theoretical predictions for transfer products along N = 126, Z < 82



dinuclear system (DNS) model, diabatic internuclear potentials

Myeong-Hwan Mun, G.G. Adamian, N.V. Antonenko et al., PRC 89, 034622 (2014).



Langevin type equations of motion, adiabatic internuclear potentials

V. Zagrebaev, W. Greiner, PRL 101, 122701 (2008).

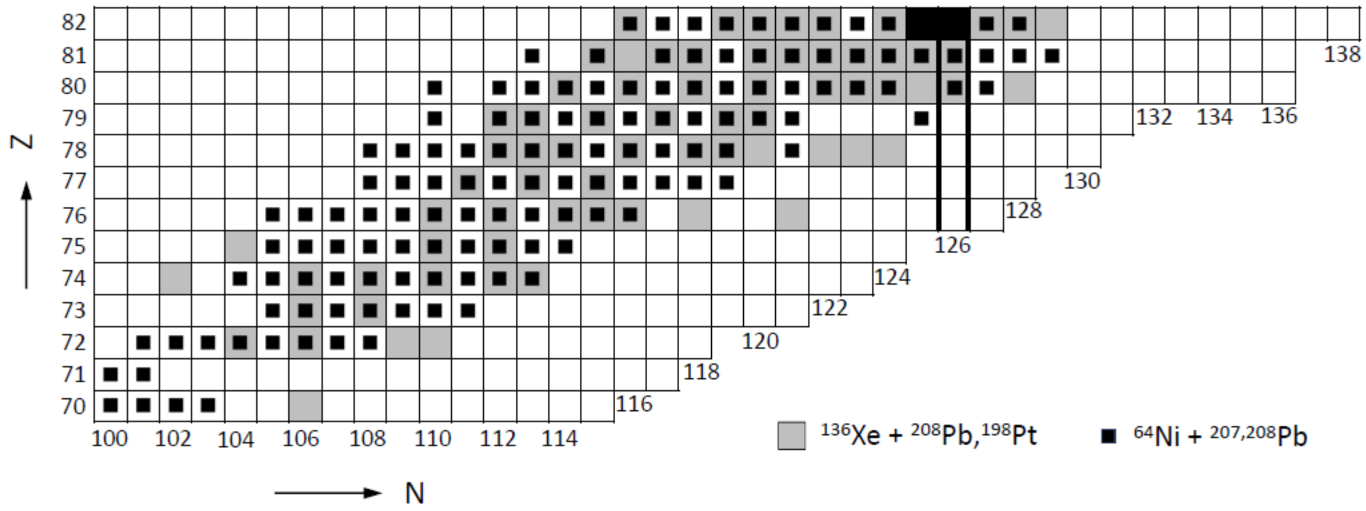
Neutron-rich N = 126 Nuclei

Experimental results: state-of-the-art

$^{64}Ni + ^{208}Pb$: Legnaro; W. Krolas et al., NPA A 724, 289 (2003)

$^{64}Ni + ^{207}Pb$: velocity filter SHIP, GSI; O. Beliuskina et al., EPJ A 50, 161 (2014)

$^{136}Xe + ^{208}Pb$, ^{196}Pt: J.S. Barrett et al., PRC 91, 064615 (2015)



→ isotope ID via gamma decays

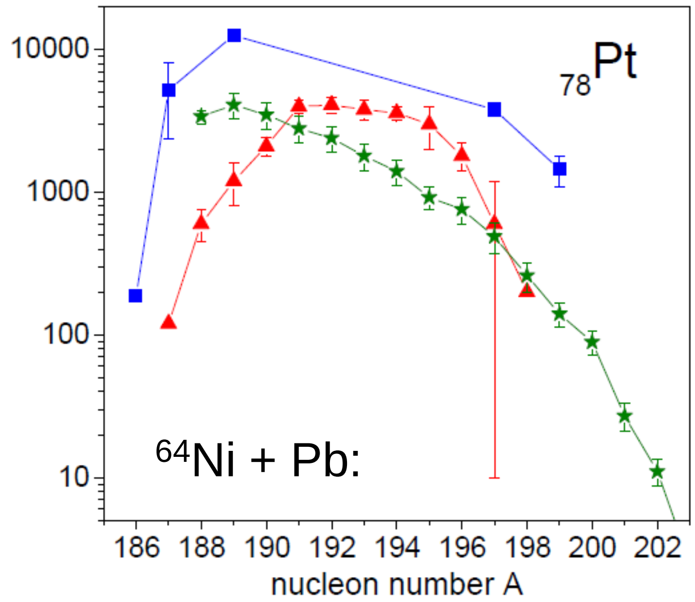
→ cross-section limits: μb

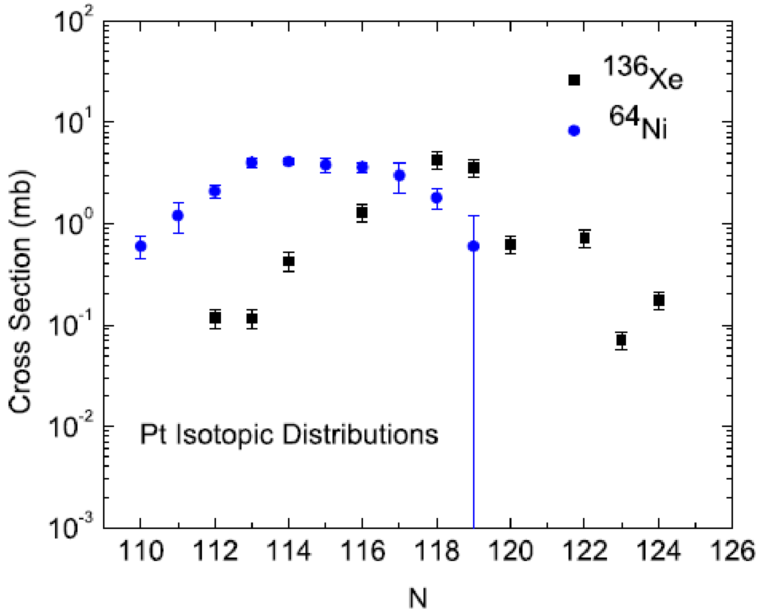
→ no new isotopes discovered in those experiments

Neutron-rich N = 126 Nuclei

Measured transfer and fragmentation cross-sections

Pt isotopes (representative example);





W. Krolas et al., Legnaro;
O. Beliuskina et al., SHIP

W. Krolas et al., Legnaro;
J.S. Barrett et al., Argonne

for n-rich nuclei: $\sigma_{Transfer} \geq \sigma_{Fragmentation}$

Neutron-rich N = 126 Nuclei

And what‘s about yields?

Experimental conditions in transfer and fragmentation

	Transfer	Fragmentation
N_{beam}	$\sim 5 \cdot 10^{12}$ / s	$\sim 10^{10}$ / s
d_{Target}	500 μg / cm^2	5 g / cm^2
efficiency	<< 100 %	(50 – 100) %
Emission angle	~50º (Coulomb barrier)	few degree (relativistic energies)
Isotope ID	α, β decays	E, ΔE, TOF, Bρ

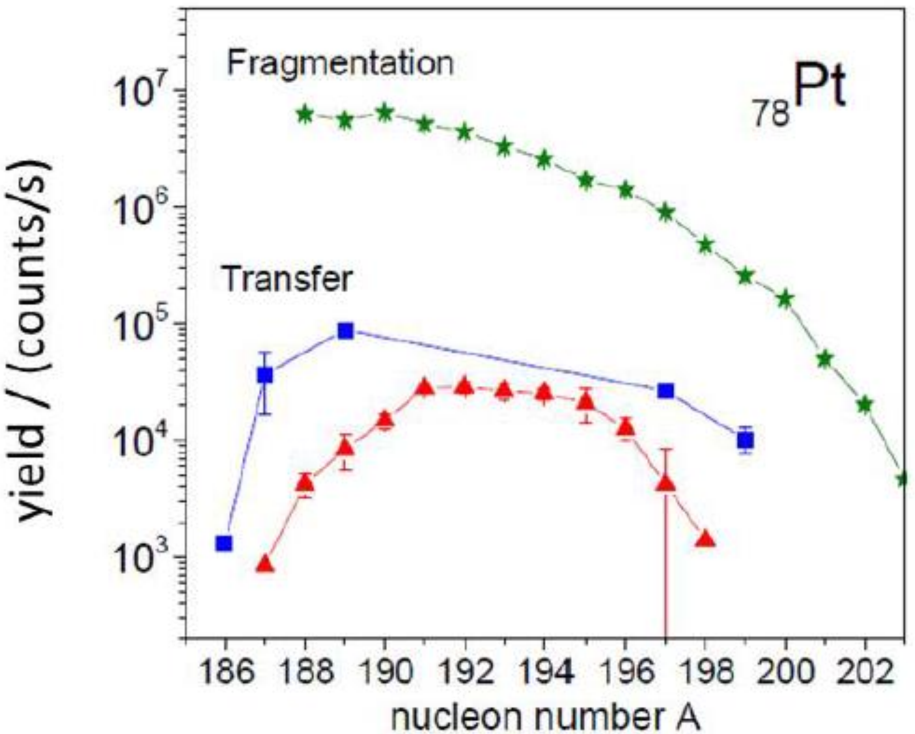
only applicable for nuclei with appropriate decay properties

applicable for all nuclei

→ more favourable in fragmentation reactions

Neutron-rich N = 126 Nuclei

Transfer and fragmentation yields

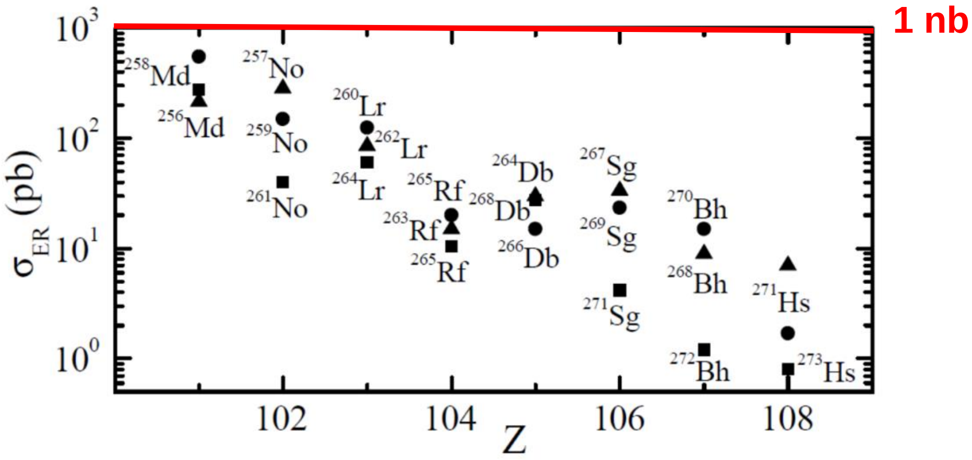


$\text{yield}_{\text{Fragmentation}} \gg \text{yield}_{\text{Transfer}}$

Transuranium and Superheavy Nuclei

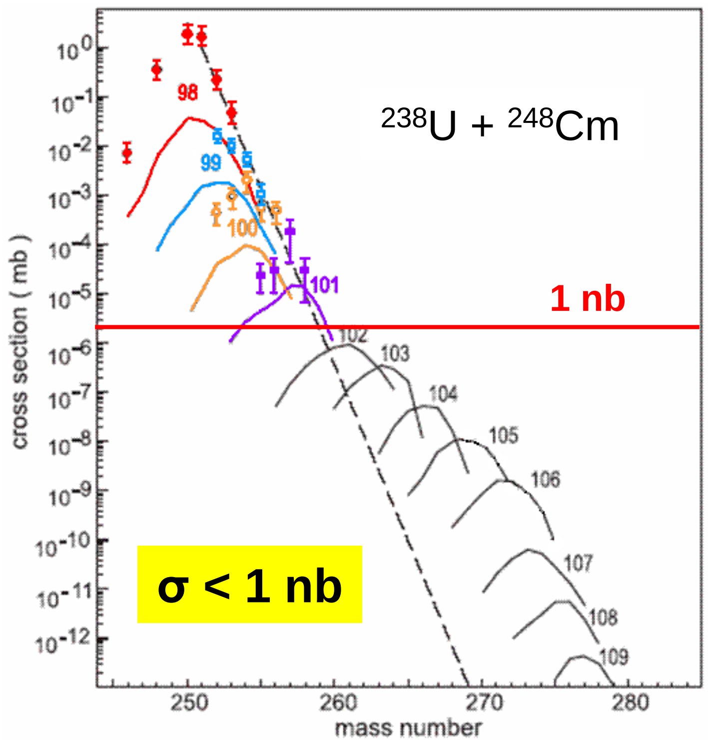
Model predictions

Ca + Cm



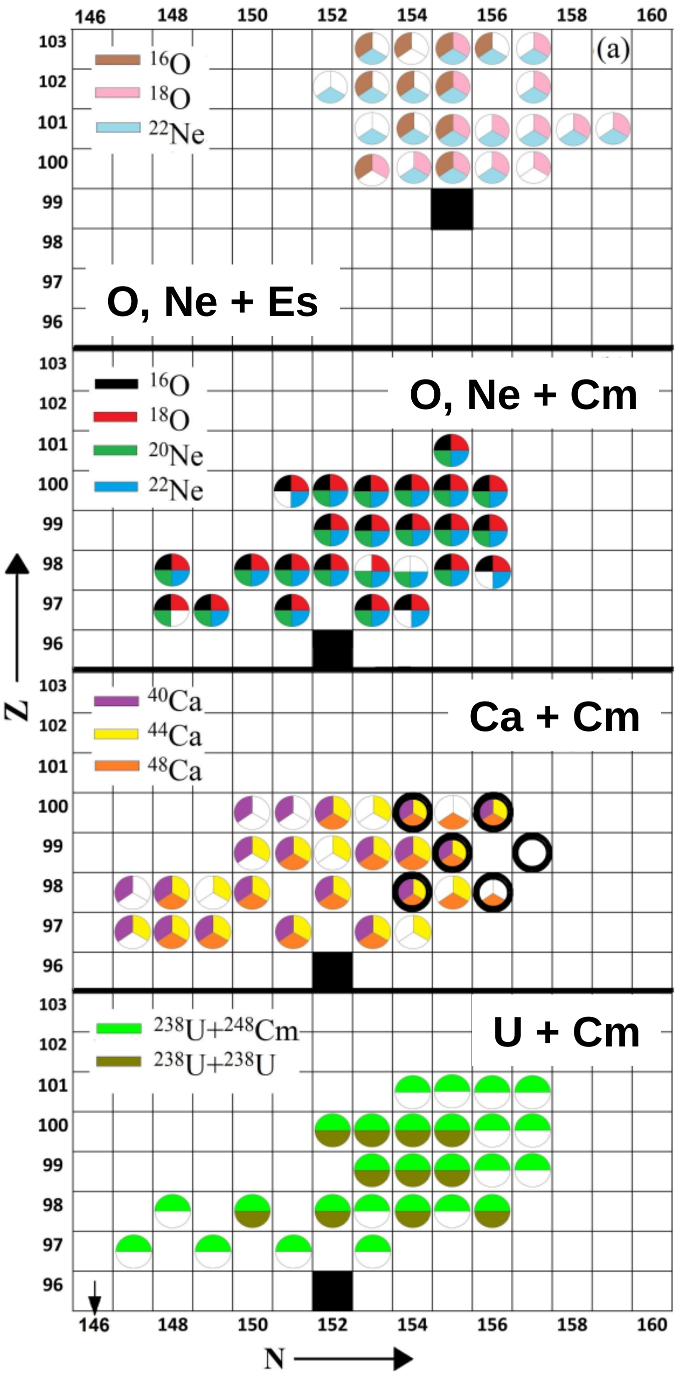
- Dinuclear system model
(G. Adamian, N. Antonenko et al.)
- diabatic internuclear potentials

U + Cm



- adiabatic internuclear potentials
(V. Zagrebaev, W. Greiner et al.)

- **New n-rich superheavy isotopes up to Z ~ 105 are experimentally feasible**
- **the expected „island of stability“ at Z=114, 120 or 126, N=184, is too far above this range**

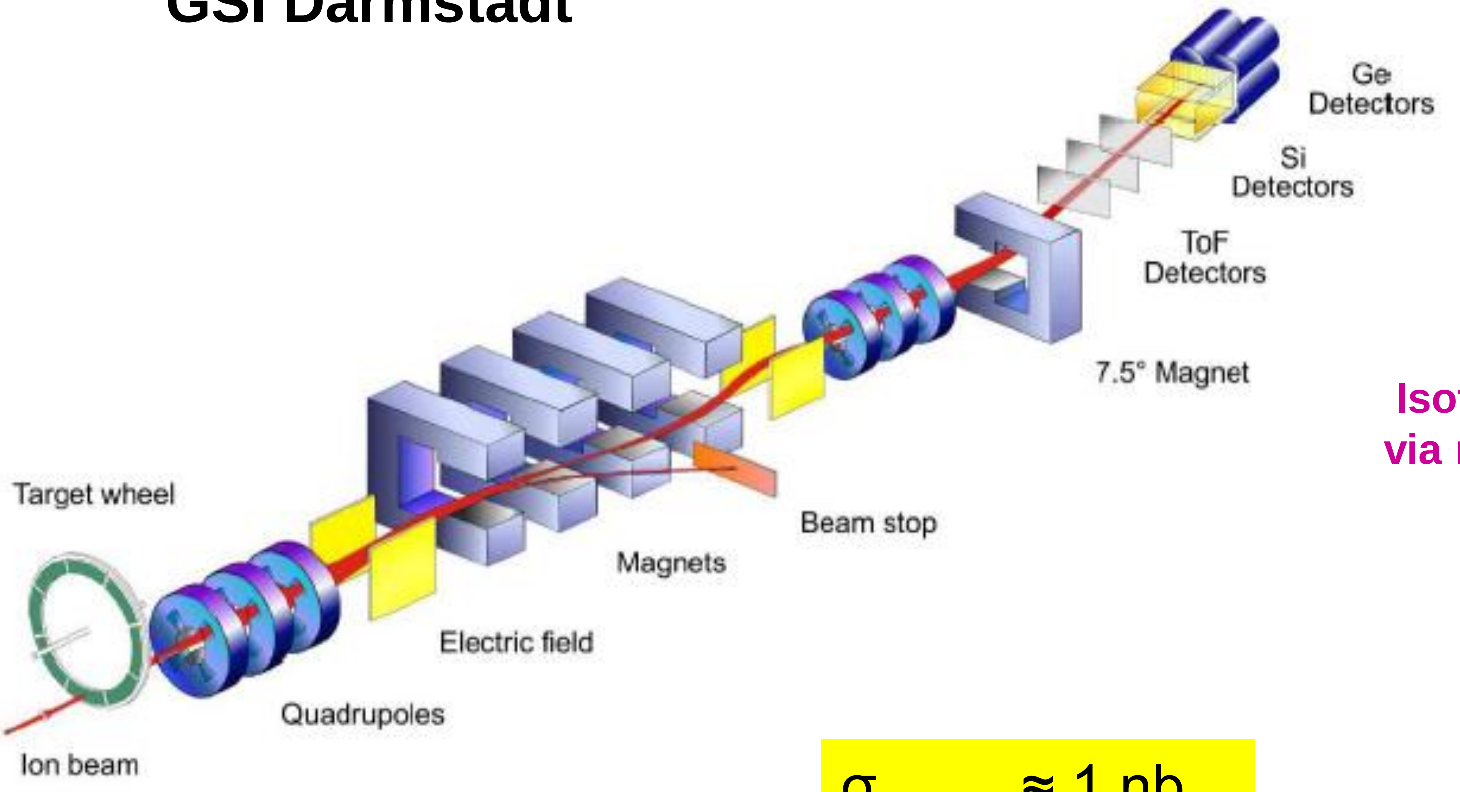


Early studies of transuranium nuclei in MNT reactions

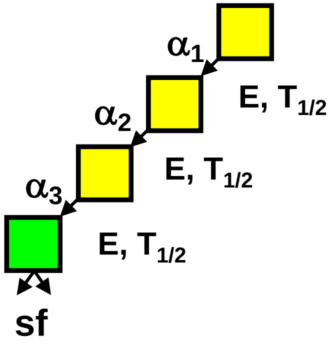
- years 1975 – 1995, LBL and GSI
- **radiochemical methods** for isotope separation and ID
- **limit values:**
  $\sigma \sim 20$ nb; $T_{1/2} > 30$ min.
- **observation:**
  - MNT products with **Z ≤ 101**
  - no *new* nuclides observed

Our New Approach: a Velocity Filter for Separation

Velocity filter SHIP,
GSI Darmstadt



Isotope identification via radioactive decays

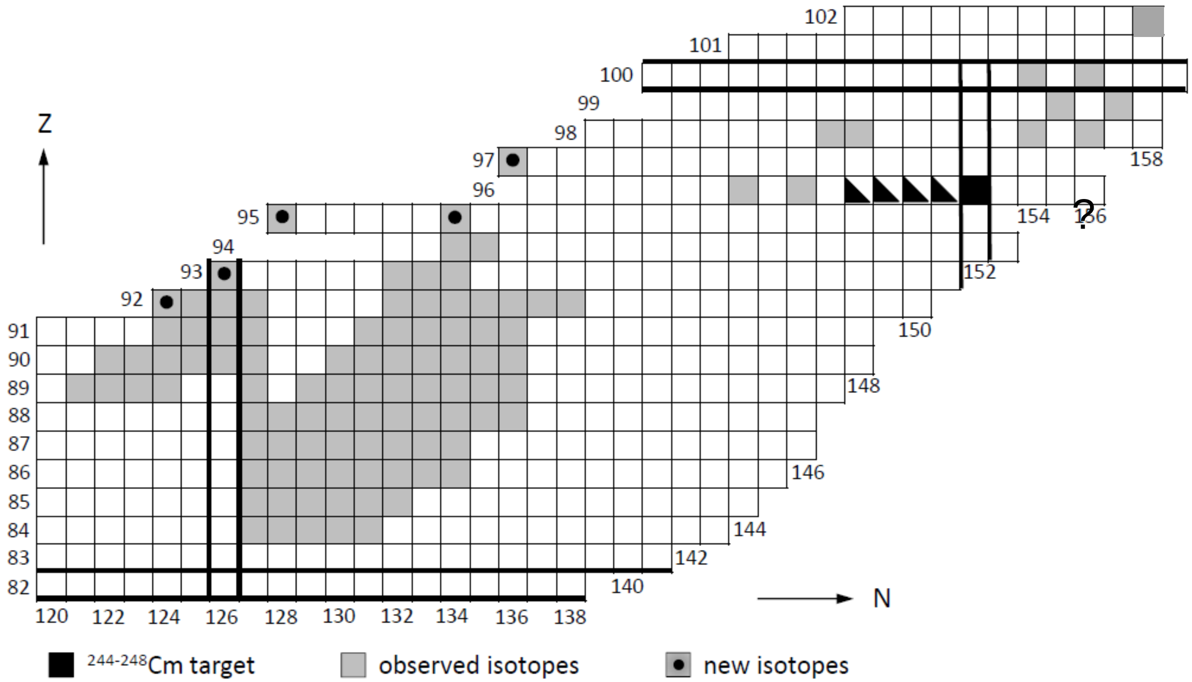


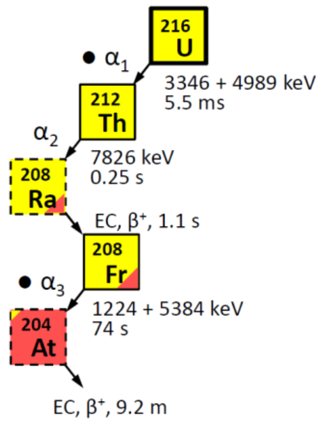
$\Delta\theta = (0 \pm 2)°$

$\sigma_{1\ event} \approx 1$ nb

$T_{1/2} > 10\ \mu s$

Transfer Reactions in $^{48}Ca + ^{248}Cm$ at SHIP



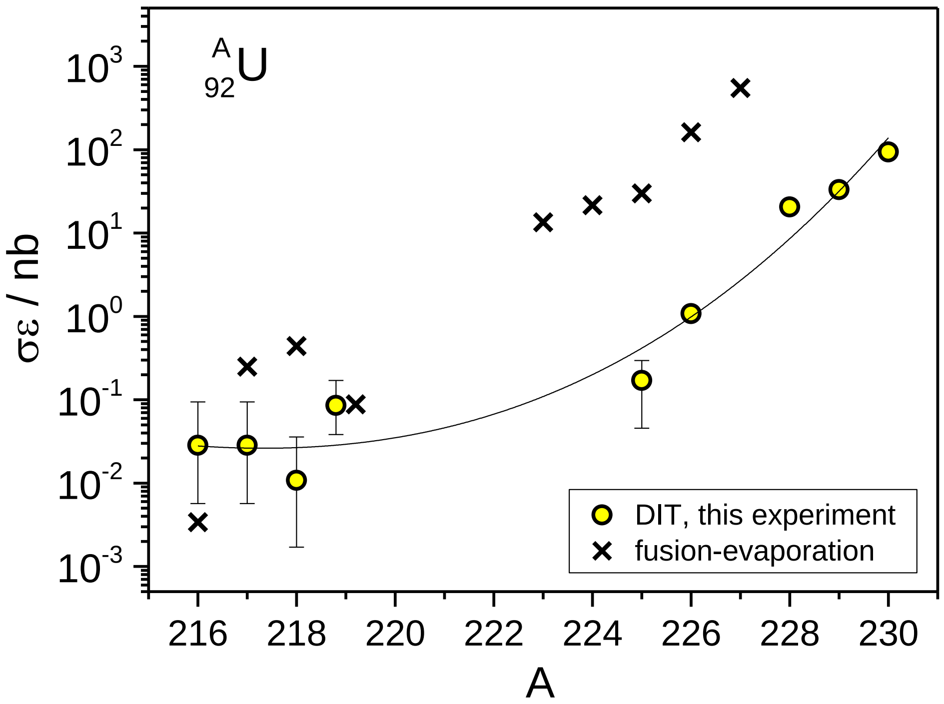


- Identification of ~100 transfer products up to Z = 102
- Observation of 5 new neutron-deficient isotopes with Z ≥ 92

H.M. Devaraja et al., PLB 748, 199 (2015).
H.M. Devaraja et al., EPJ A 55, 25 (2019).

N-deficient Transuranium Nuclei: Transfer vs. Fusion

Yield of uranium isotopes from transfer and fusion reactions



- for very n-deficient isotopes with Z ≈ 92 and above: $\boldsymbol{\sigma\varepsilon_{\mathrm{fusion}} \approx \sigma\varepsilon_{\mathrm{transfer}}}$
- but MNT reactions enable wide-band population of isotopes

→ **MNT reactions might become preferable to populate this region**

Summary and Outlook

► MNT reactions are intensively discussed as a means to produce new isotopes in the region of neutron-rich superheavy nuclei and in the region $Z < 82$, $N \approx 126$ (r-process nuclei)

► In MNT reactions at the velocity filter SHIP we reached the so far lowest limit cross-sections for MNT products: $\sigma_{1\ \text{event}} \sim 1$ nb and observed several new n-deficient transuranium isotopes

► Are MNT reactions suitable / favourable for the production of heavy nuclei?

- $Z > 92$, $N \approx 126$ → MNT appears favourable for n-deficient transuraniums
- $Z < 82$, $N \approx 126$ → Fragmentation appears favourable
- n-rich SHN → new isotopes up to $Z \sim 105$ seem feasible