SHE-related research with RIBs

Sophie Heinz

GSI Helmholtzzentrum and Justus-Liebig-Universität Gießen

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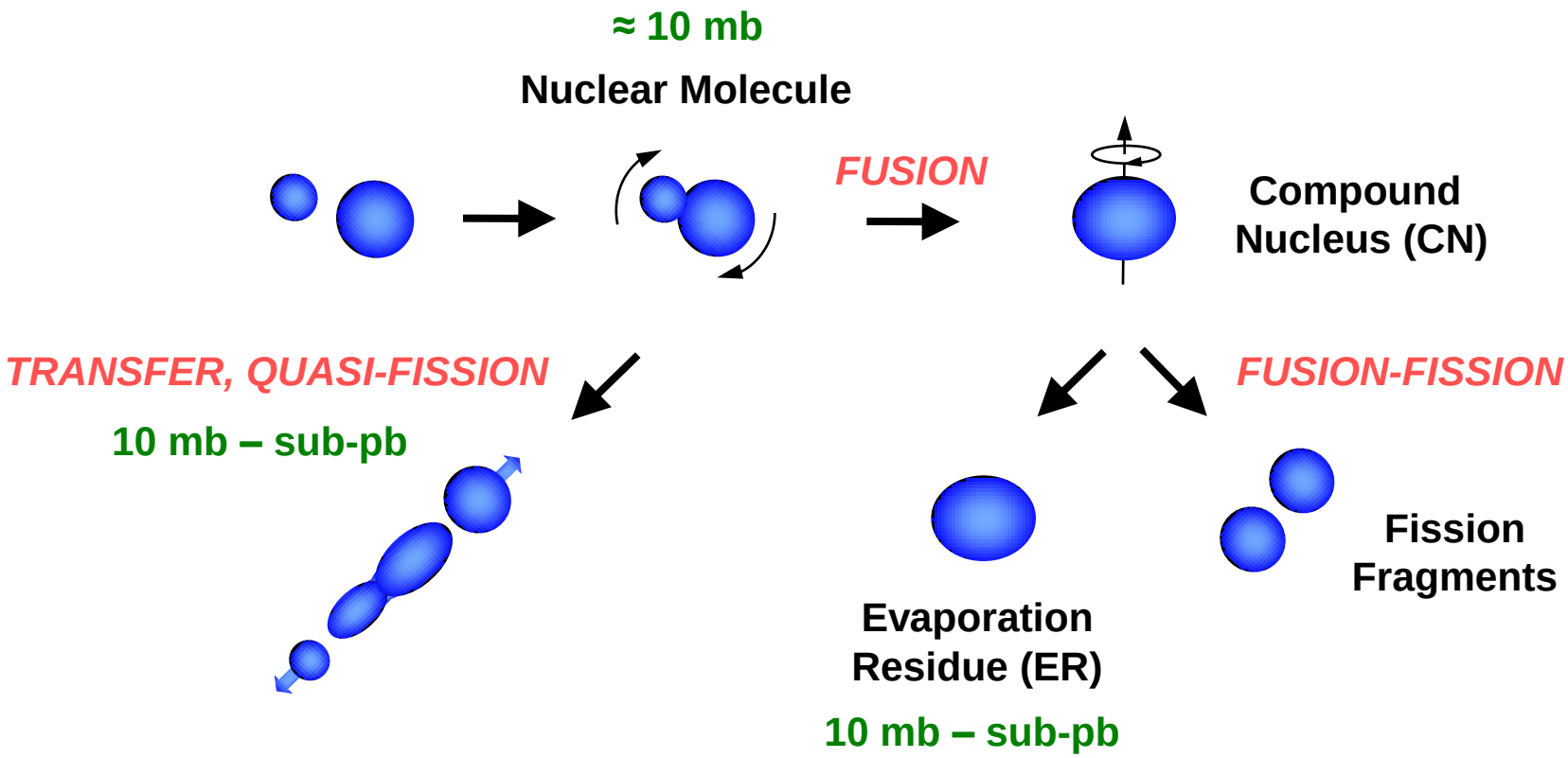
Deep Inelastic Reactions in Heavy Systems



Applications:

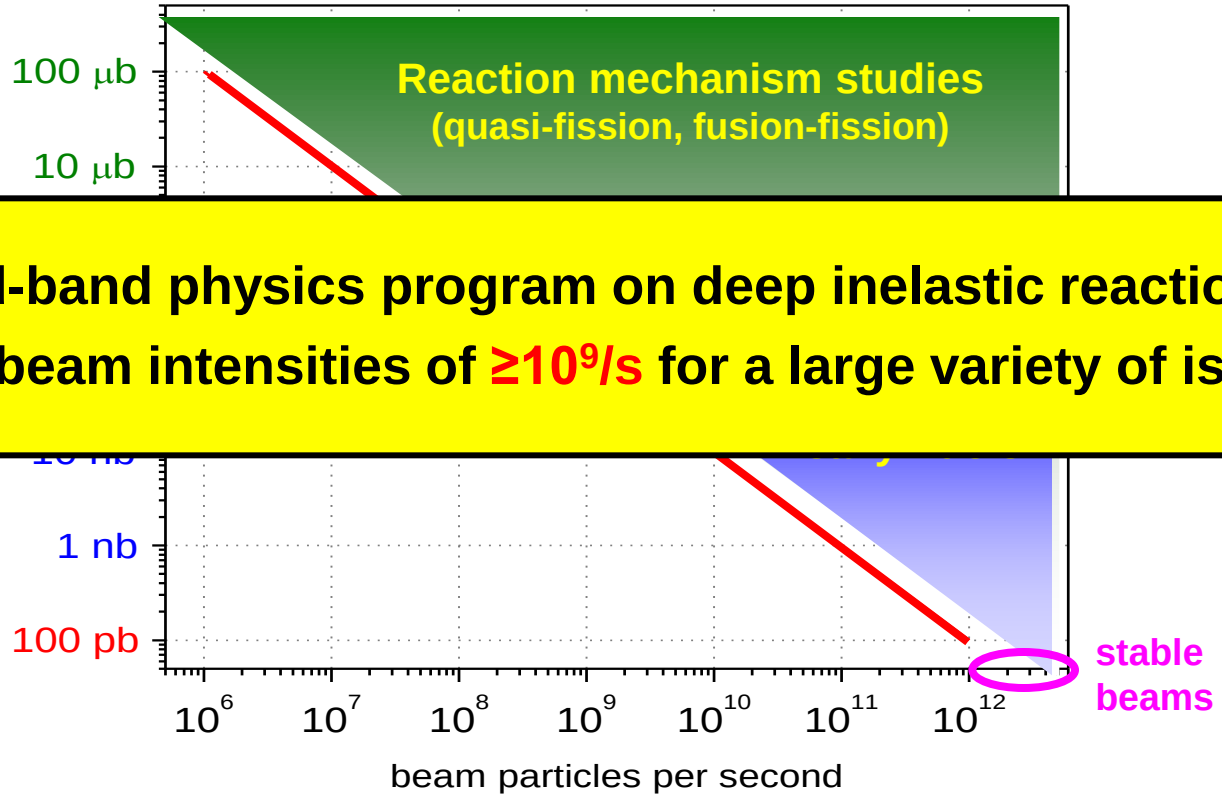
- Reaction mechanism studies
- Synthesis of new isotopes

$$\sigma_{ER} = \sigma_{capture} \times P_{CN} \times P_{survival}$$

Required Beam Intensities

Required beam intensities to obtain 10 events per day at the given cross-section

500 µg / cm^2 targets



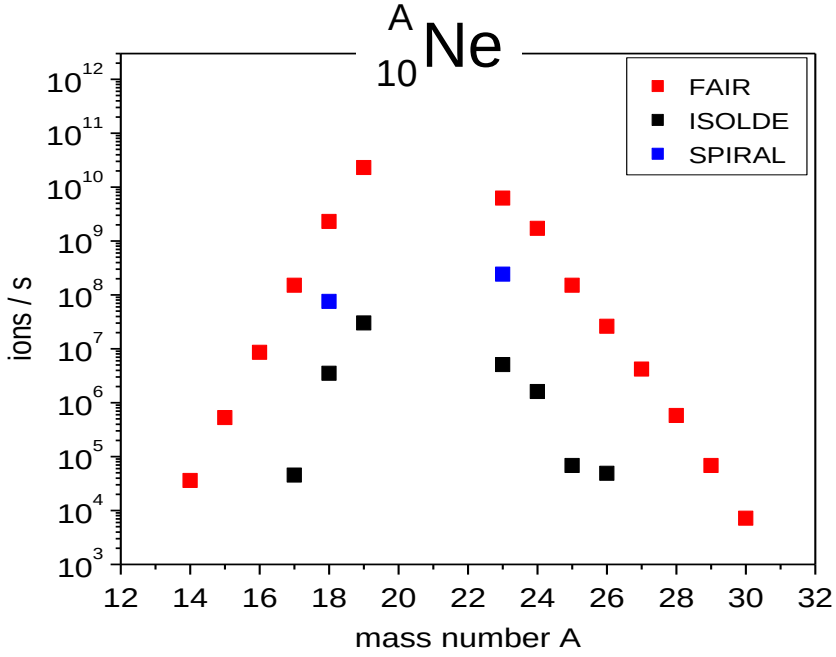
broad-band physics program on deep inelastic reactions requires beam intensities of ≥10^9/s for a large variety of isotopes

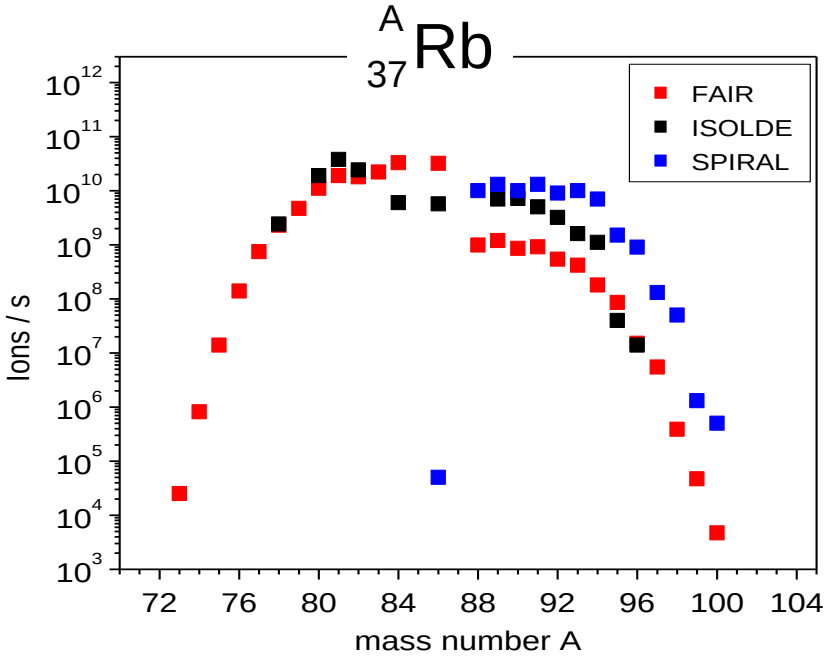
RIBs at FAIR, ISOLDE and SPIRAL

FAIR:
In-flight technique

ISOLDE, SPIRAL:
ISOL technique

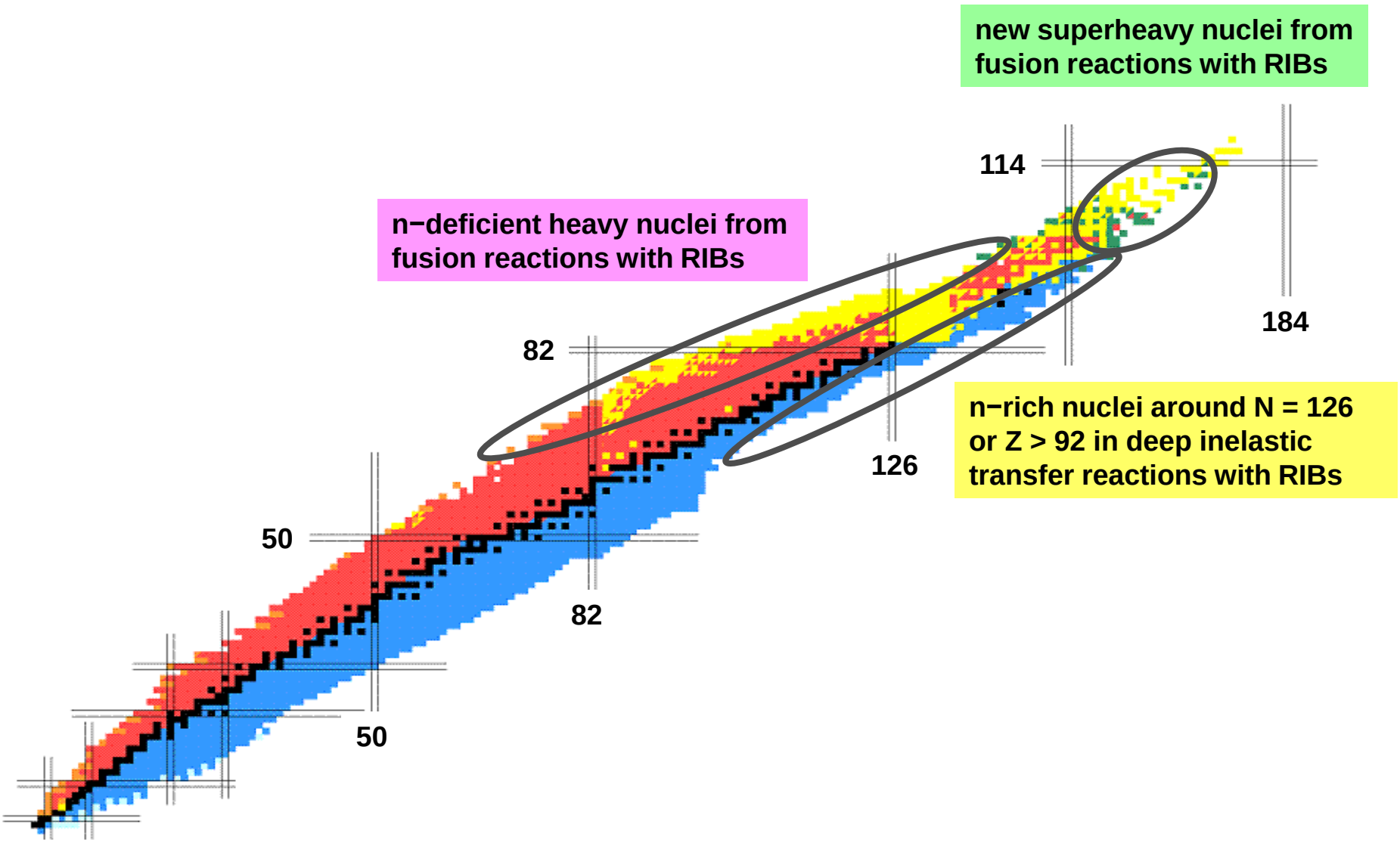
RIB intensities – representative examples



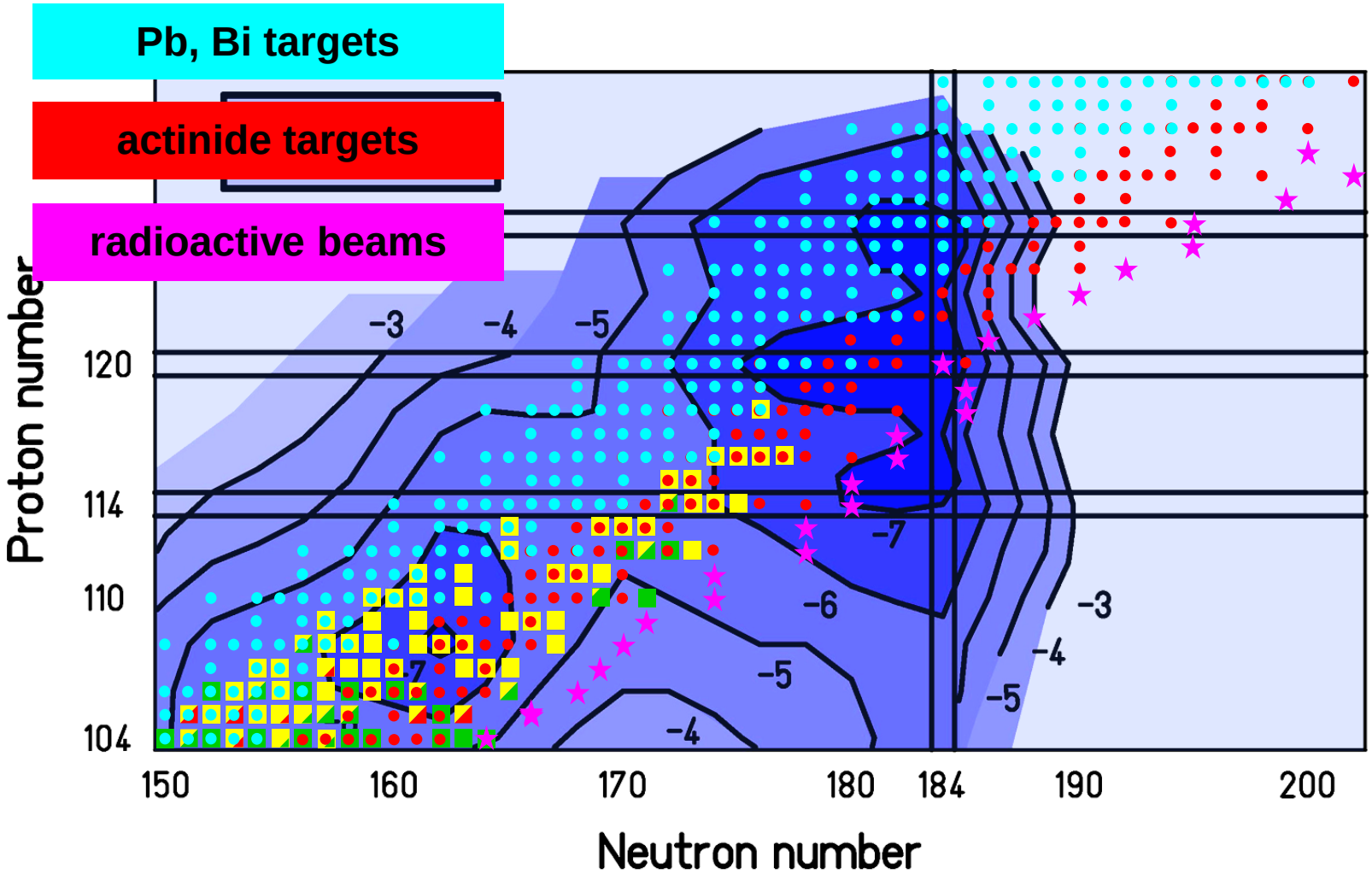


FAIR → particularly high yields for RIBs with A < 30

Synthesis of New Isotopes with RIBs



Synthesis of Superheavy Nuclei with RIBs



Synthesis of „heavy“ SHN

Influence of projectile neutron number on σ_{ER}

Predictions from macroscopic-microscopic models (e.g. ^{A}Ni + ^{208}Pb → ^{A}110*)

	E^*_{CN} (MeV)	P_{CN}	σ_c (mb)	W_{sur}	σ^{th}_{ER}	σ^{exp}_{ER}
$^{62}Ni + ^{208}Pb \rightarrow ^{269}110 + 1n$	12.3	4.5×10^{-6}	3.5	5×10^{-4}	7 pb	$3.5^{+2.7}_{-1.8}$ pb
$^{64}Ni + ^{208}Pb \rightarrow ^{271}110 + 1n$	10.7	1×10^{-5}	3.4	5×10^{-4}	17 pb	15^{+9}_{-6} pb
$^{70}Ni + ^{208}Pb \rightarrow ^{277}110 + 1n$	13.5	7×10^{-8}	3.1	5×10^{-3}	1.1 pb	
$^{74}Ni + ^{208}Pb \rightarrow ^{281}110 + 1n$	15.0	6×10^{-8}	3.0	2×10^{-2}	3.6 pb	
$^{78}Ni + ^{208}Pb \rightarrow ^{284}110 + 2n$	17.5	2×10^{-7}	3.0	6×10^{-2}	36 pb	

G.G. Adamian, N.V. Antonenko, W. Scheid et al.

$$\sigma_{ER} = \sigma_{cap} \cdot P_{CN} \cdot W_{sur}$$

projectile neutron number has no strong influence on the ER cross-sections

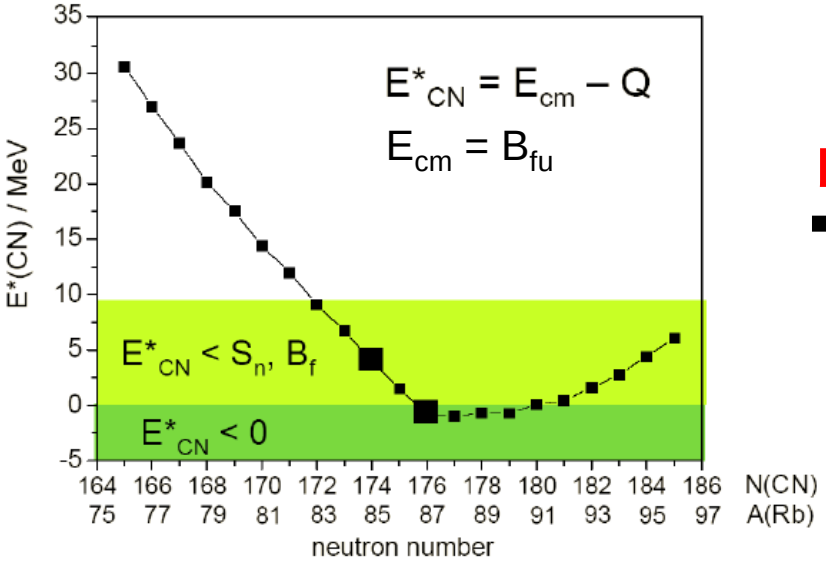
- σ_{cap} increases with increasing β_2 deformation but only for $E_{cm} << B_{fu}$
- P_{CN} can fluctuate due to deformation effects or binding energies
- W_{sur} increases with increasing neutron number

expected yields for σ = 10 pb and 10^9 p/s → 10^{-3} / day

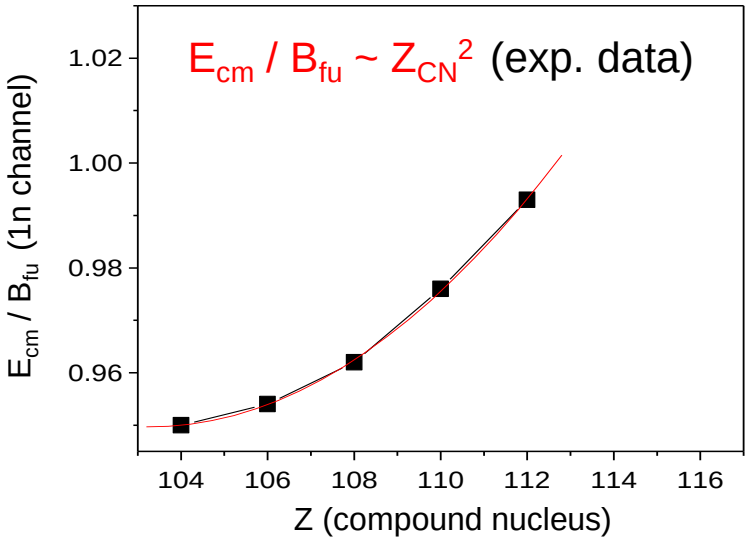
Synthesis of „heavy“ SHN

Cold fusion reactions of $^{A}Rb + {}^{209}Bi \rightarrow {}^{A}120^*$

→ allows for reaching the predicted shell closures at N = 184, Z = 120



but:

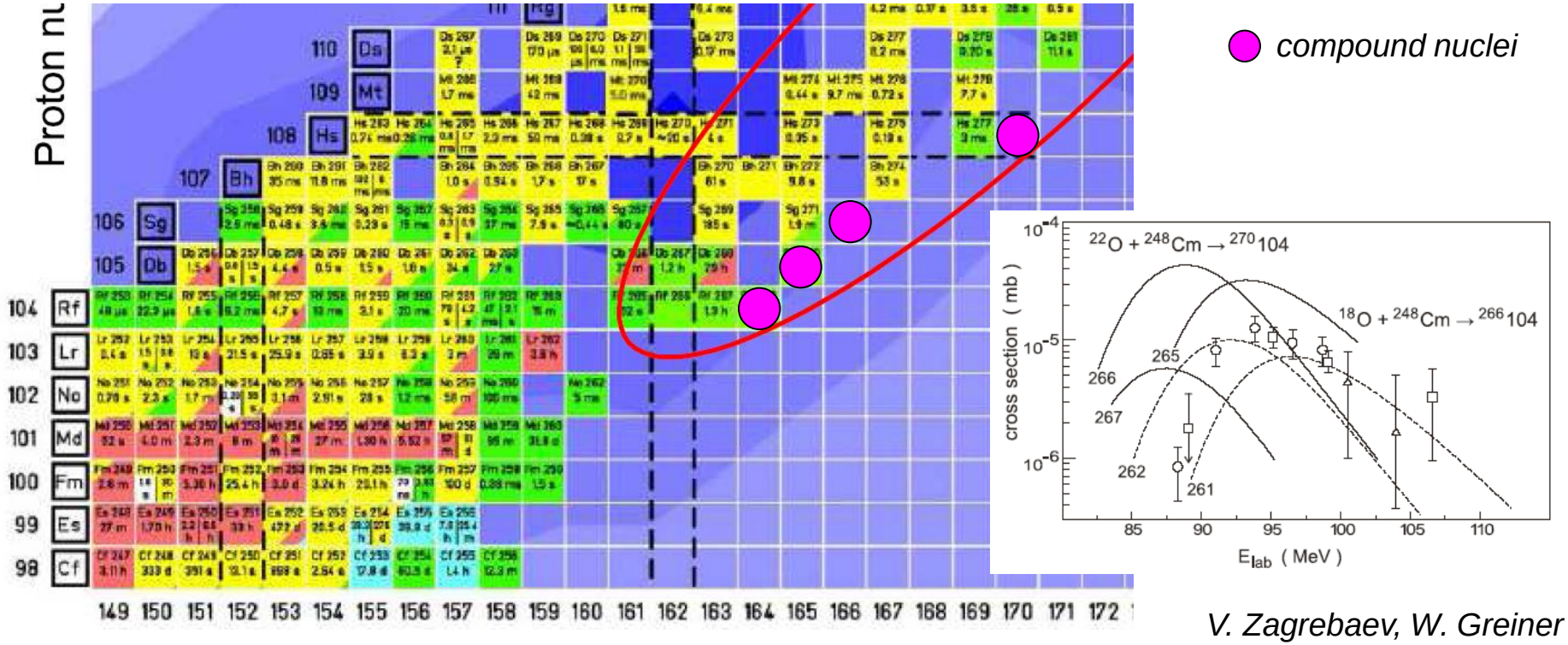


$E^*_{CN} < S_n \approx 10$ MeV → no neutron evaporation
$E^*_{CN} < B_f \approx 5$ MeV → no CN fission
$E^*_{CN} < 0$ → no CN formation

hindrance to fusion increases with Z
→ requires increasing beam energy

Synthesis of „light“ SHN

Fusion reactions with light n-rich RIBs (O, Ne, …) + actinide targets



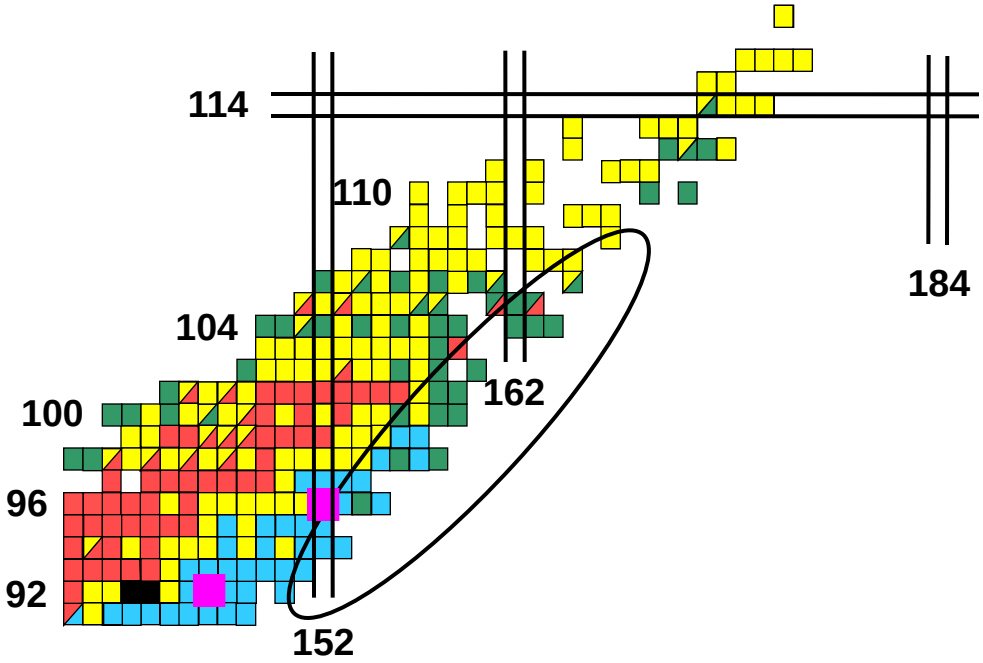
V. Zagrebaev, W. Greiner

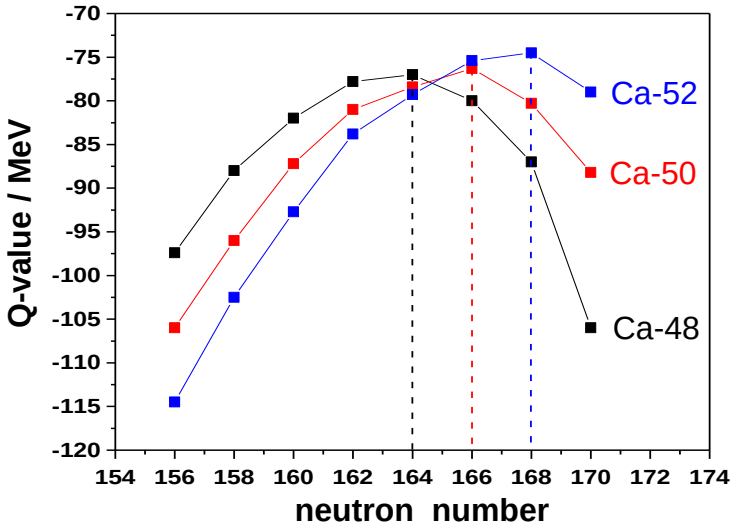
predicted cross-sections: (1 – 10) nb → yields at 10^9 p/s: (0.1 – 1) / day

→ feasibility depends on final RIB intensities at Coulomb barrier energies

Synthesis of SHN in Transfer Reactions

Example: Transfer reactions of $^{A}Ca + ^{248}Cm \rightarrow ^{A}Rf$ (Z = 104)





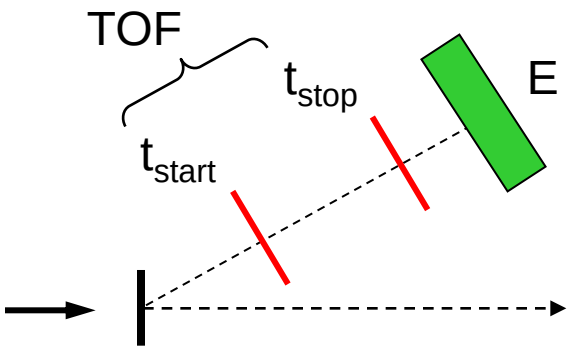
yield of transfer products is influenced by the Q-value: $Q = [m_1 + m_2 - (m_3 + m_4)]c^2$

cross-sections increase by up to factor 10^3 with neutron-rich projectiles
but: effect is cancelled by the much lower intensities of RIBs

SHE-related Reaction Studies

$\sigma_{ER} = \sigma_{cap} \cdot P_{CN} \cdot P_{sur}$ → **Study of quasi-fission and fusion-fission**

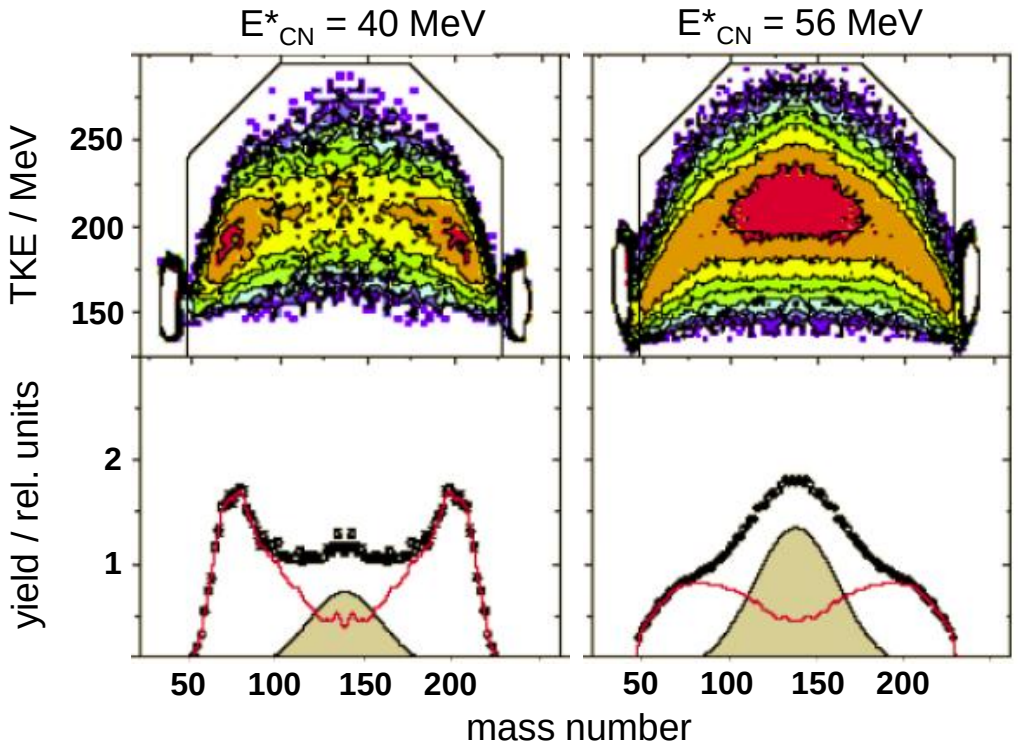
- large cross-sections
- simple setups



E, TOF → A

plus θ and TKE

$^{36}S + ^{238}U \rightarrow ^{274}Hs$ (Z = 108)



courtesy: Y. Itkis et al.

Summary

- **Deep inelastic reactions with RIBs at Coulomb barrier energies (quasi-fission, fusion-fission, fusion):**
  - **Reaction mechanism studies → $N_{beam} \geq 10^6$ / s**
  - **Synthesis of new isotopes → $N_{beam} \geq 10^9$ / s**

- **Synthesis of „heavy“ SHN ($Z \gtrsim 108$) requires $N_{beam} \geq 10^{12}$ / s**
  Synthesis of „light“ SHN ($Z \lesssim 108$) requires $N_{beam} \geq 10^9$ / s

- **special feature at FAIR → high intensities for light RIBs with $Z < 30$ ($\leq 10^{10}$ / s)**

- **critical point: beam losses during preparation for Coulomb barrier energies**