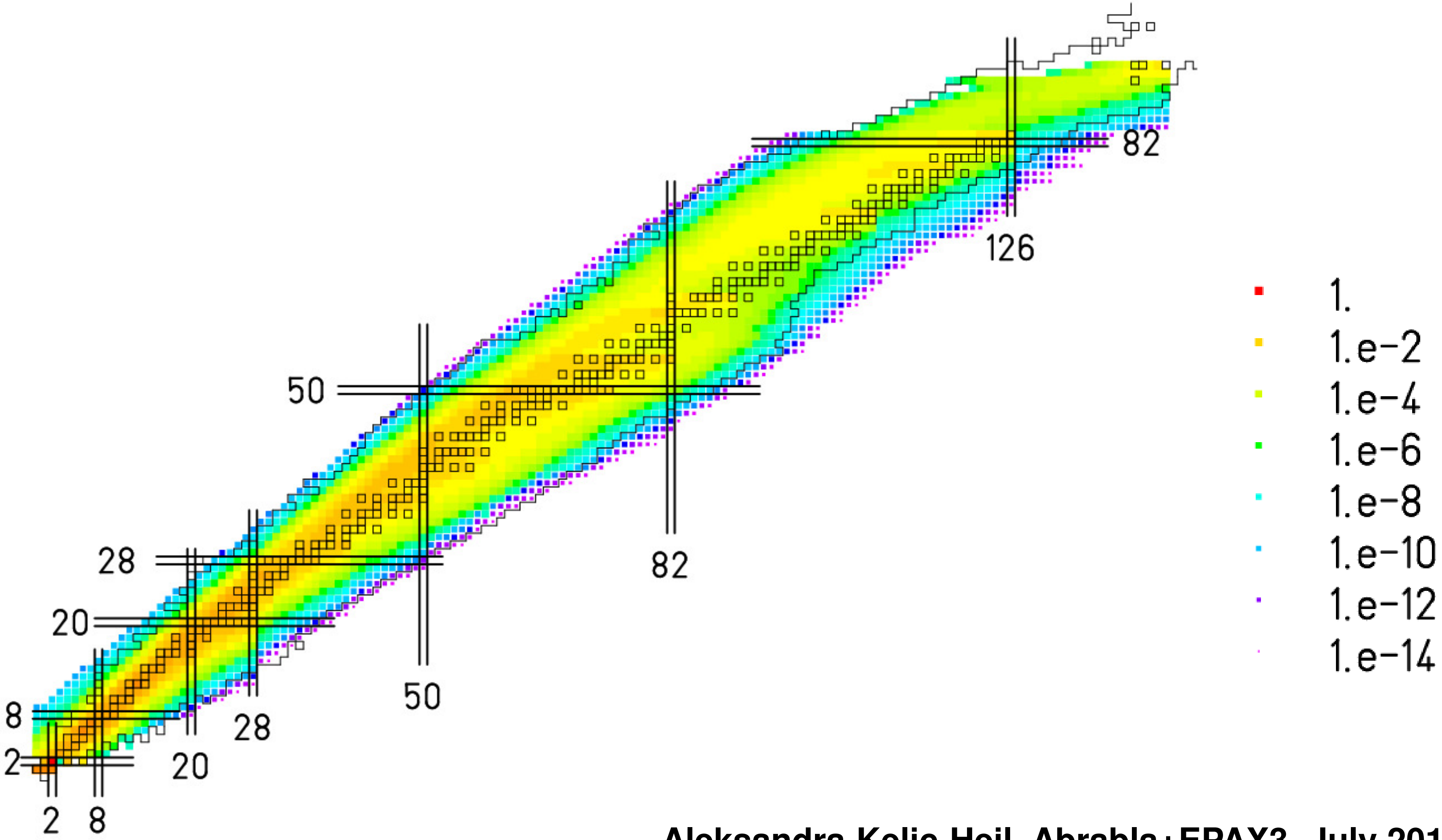
Super-FRS Performance: Production, Separation, Detection

Helmut Weick, GSI
HIC4FAIR workshop,
Hamburg, 30.07.2015

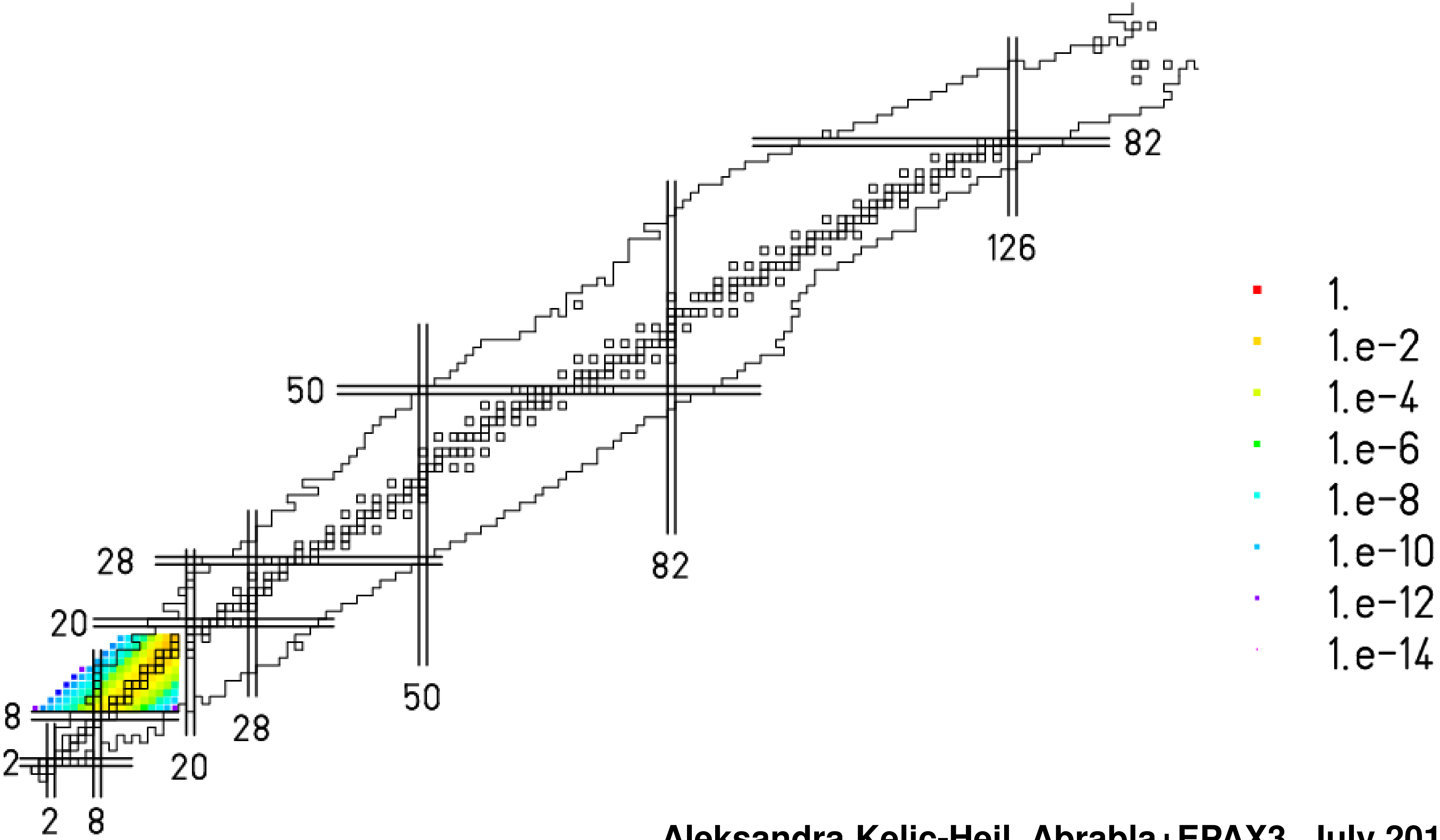
- Production Cross Sections
- Separation
- Identification Detectors

Production of nuclides from 52 considered primary beams



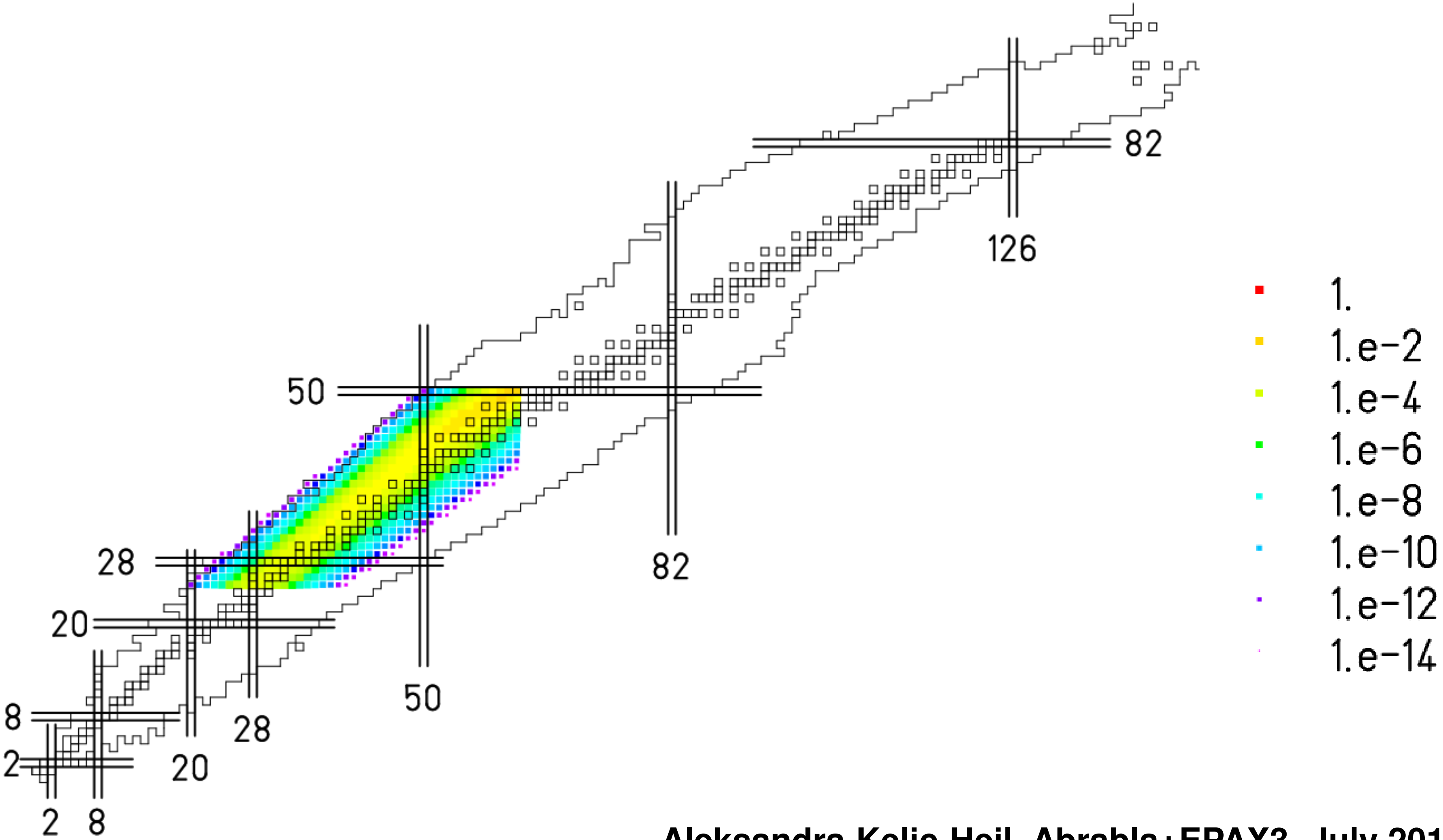
Aleksandra Kelic-Heil, Abrabla+EPAX3, July 2015

^{36}Ar --> ^{12}C target



Aleksandra Kelic-Heil, Abrabla+EPAX3, July 2015

^{112}Sn --> ^{12}C target



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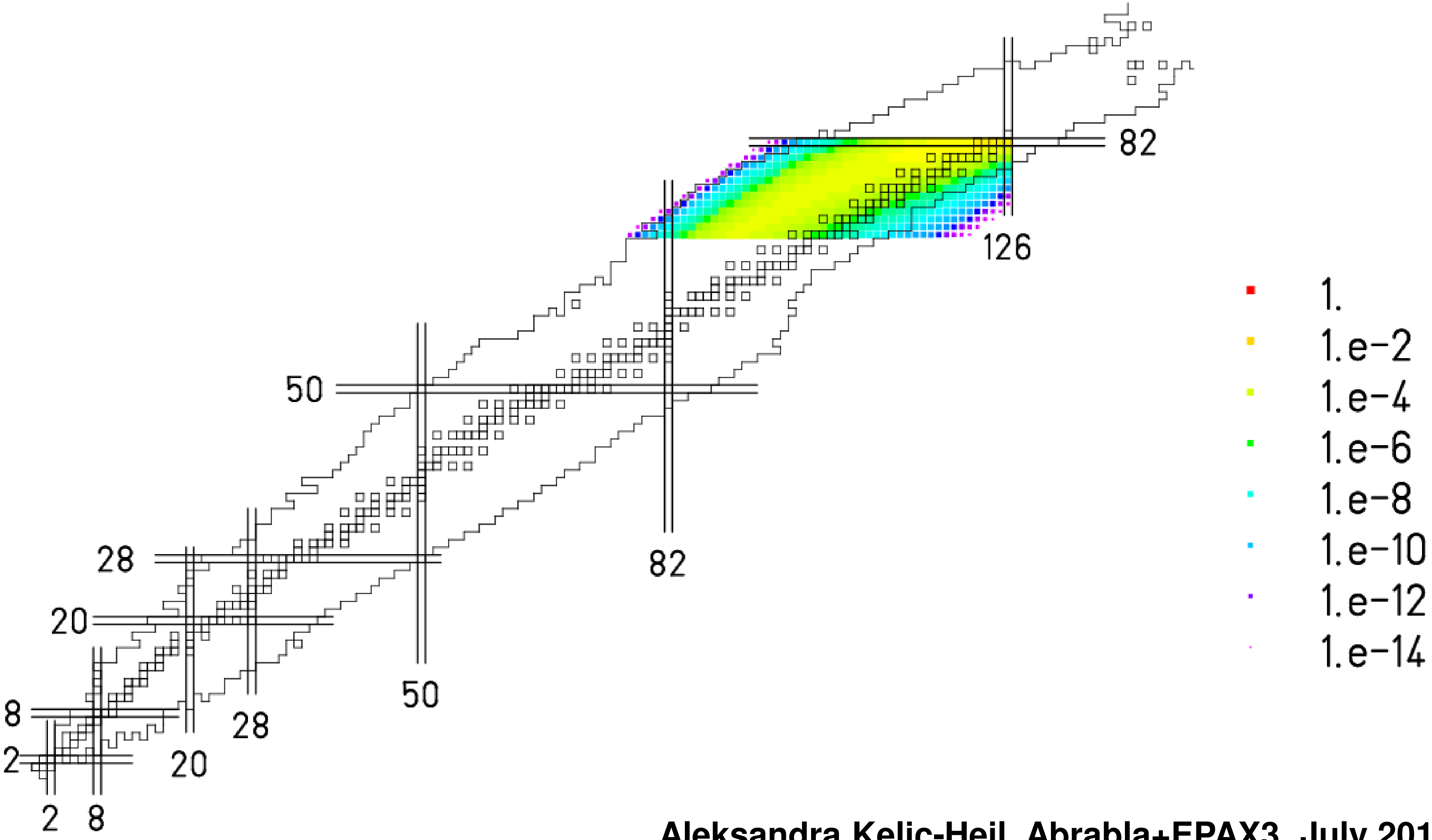
^{208}Pb --> ^{12}C target



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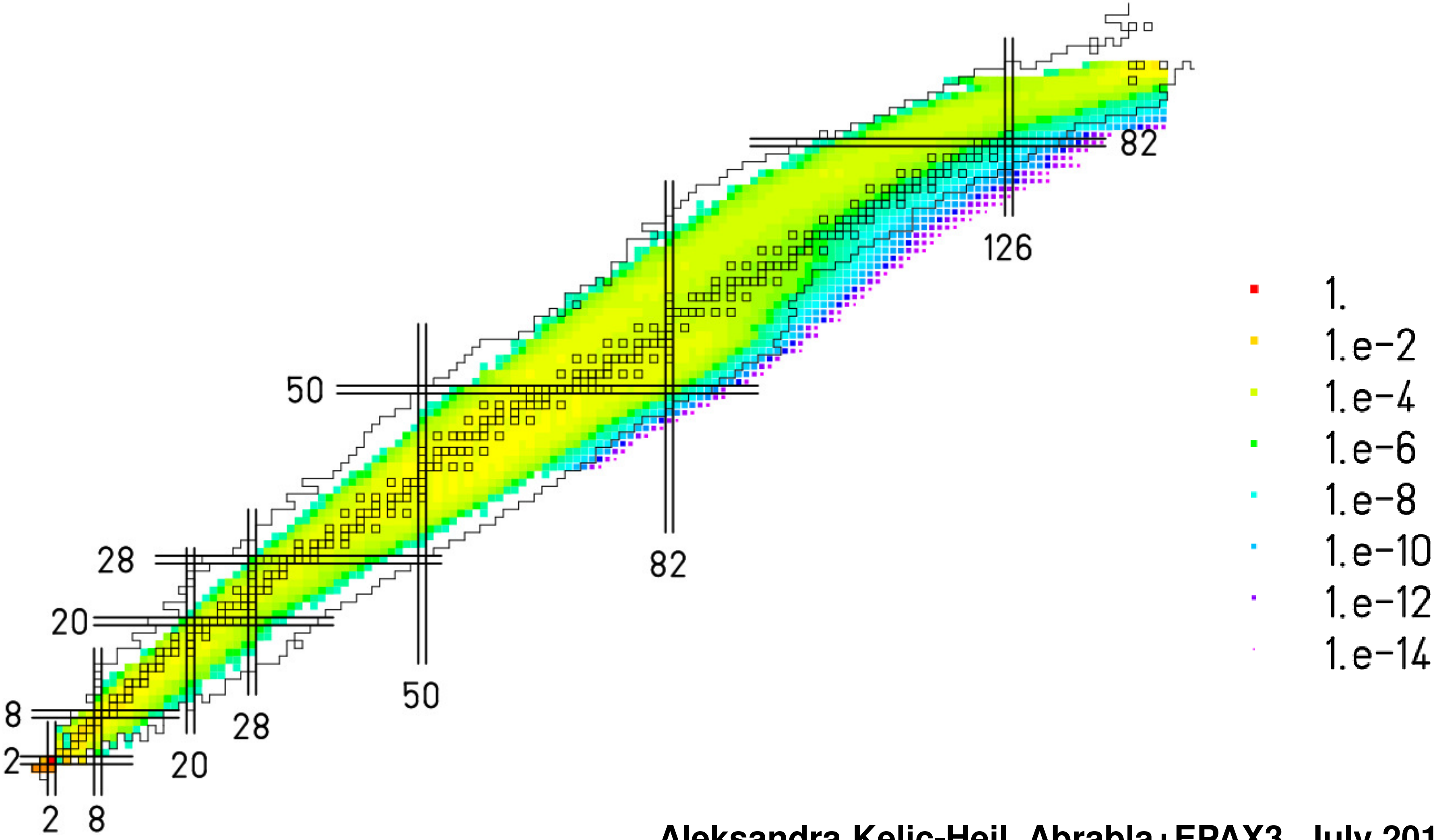
^{238}U --> ^{12}C target

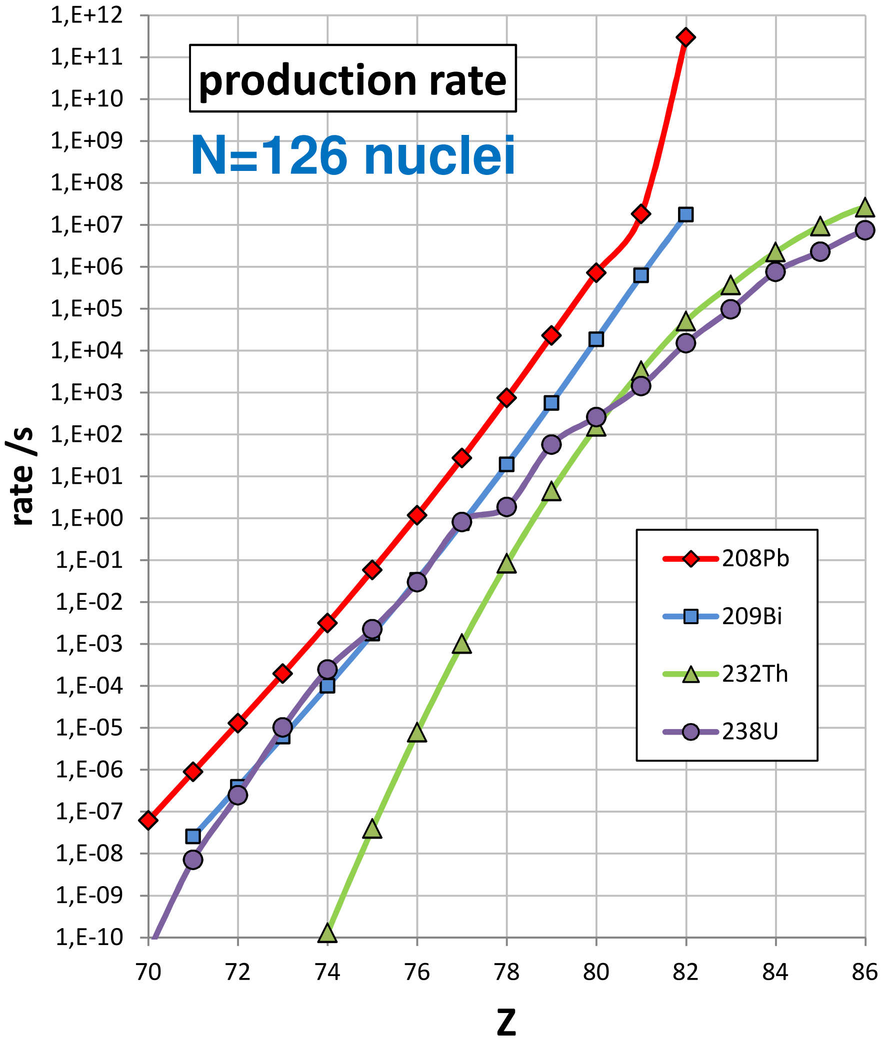


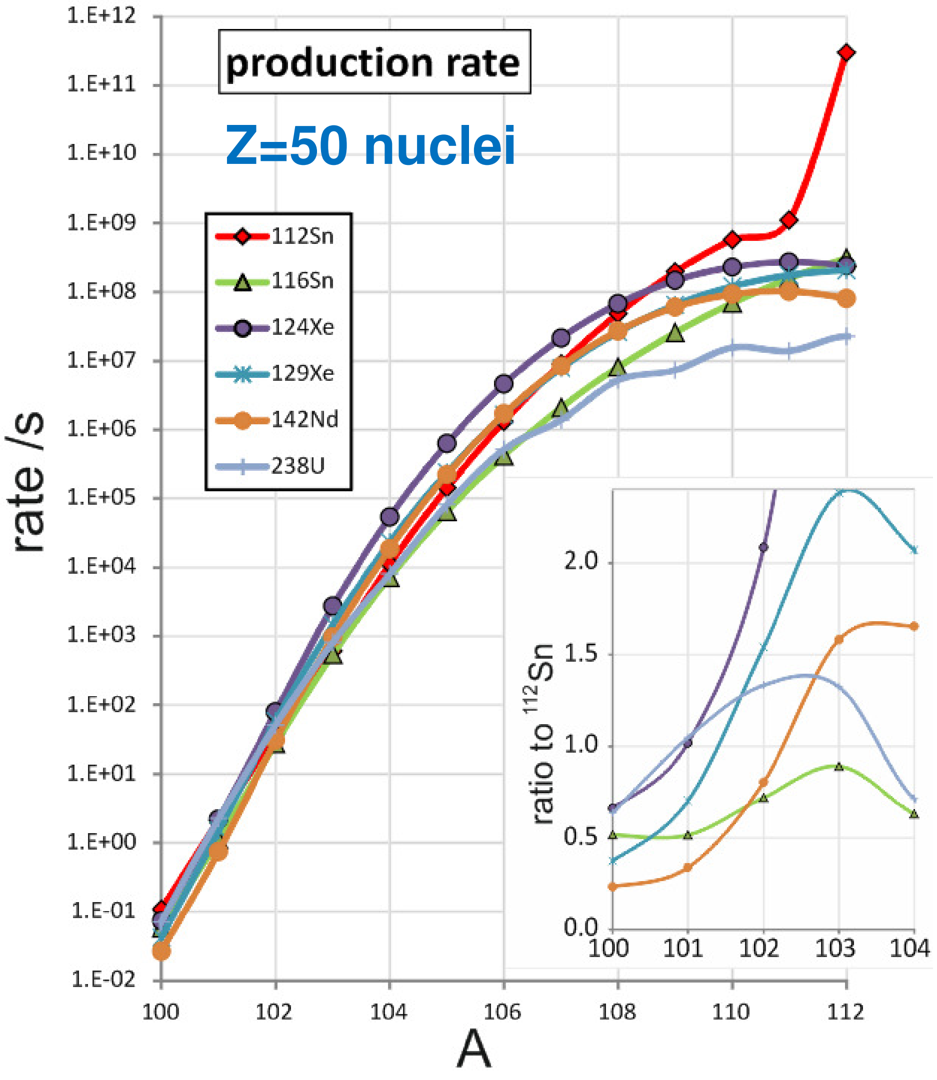
Aleksandra Kelic-Heil, Abrabla+EPAX3, July 2015

Best Beams for Production

Optimum cross section and transmission

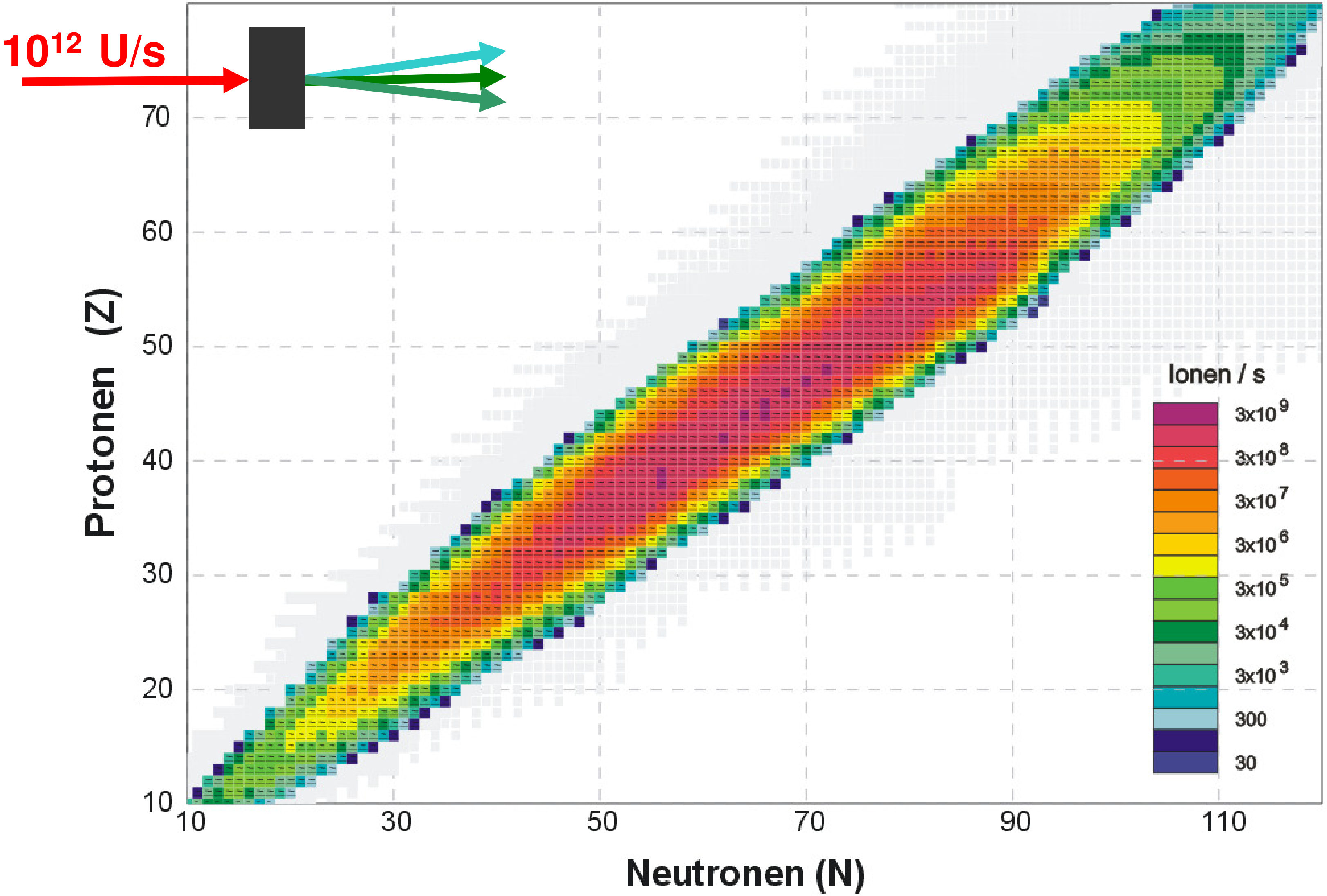
3x10^{11}/s for all beams, including acceptance, ABRABLA from A. Kelic





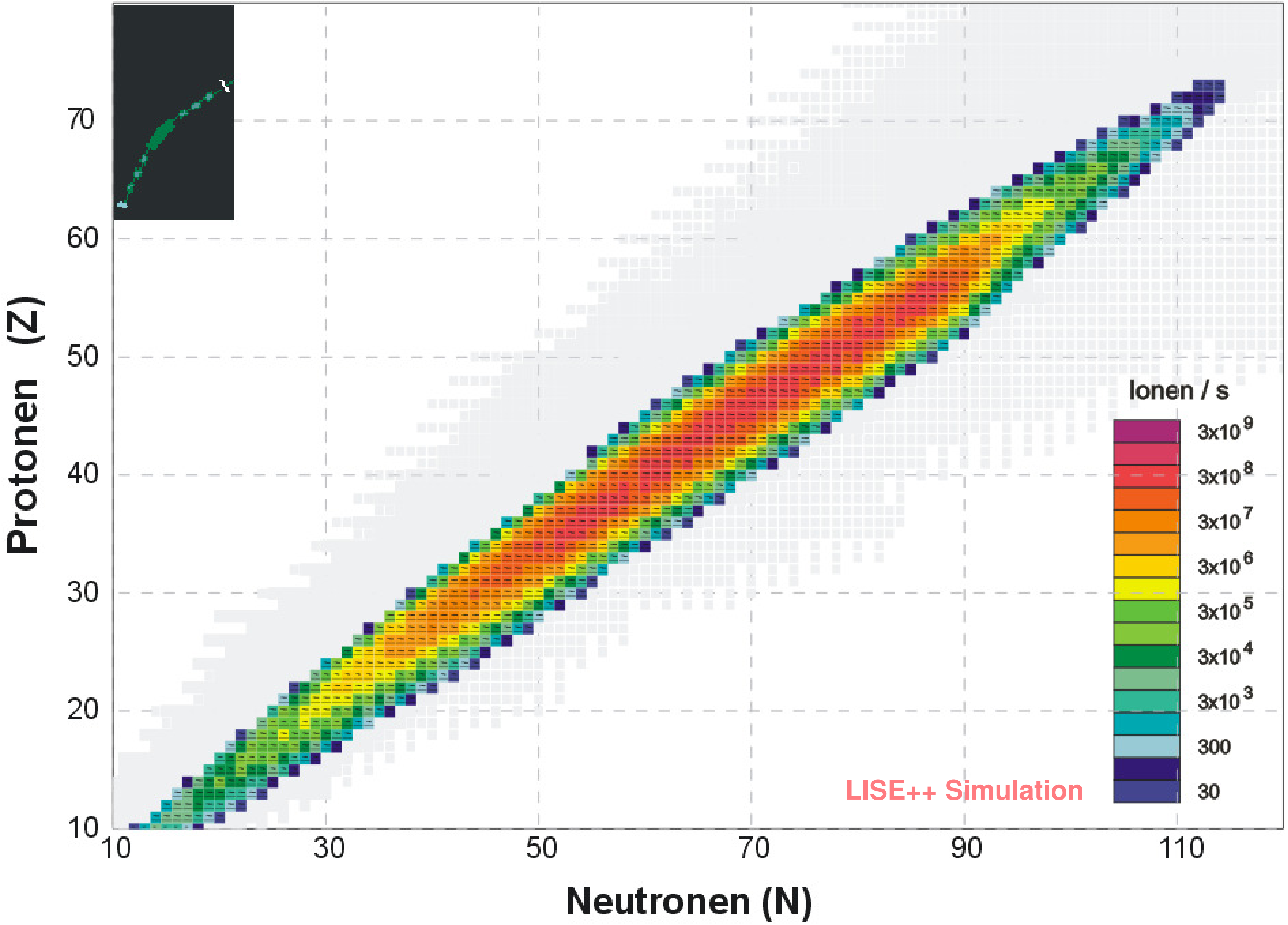
Separation

All Fission fragments after target, 1.5 GeV/u ^{238}U --> 4 g/cm^2 ^{12}C



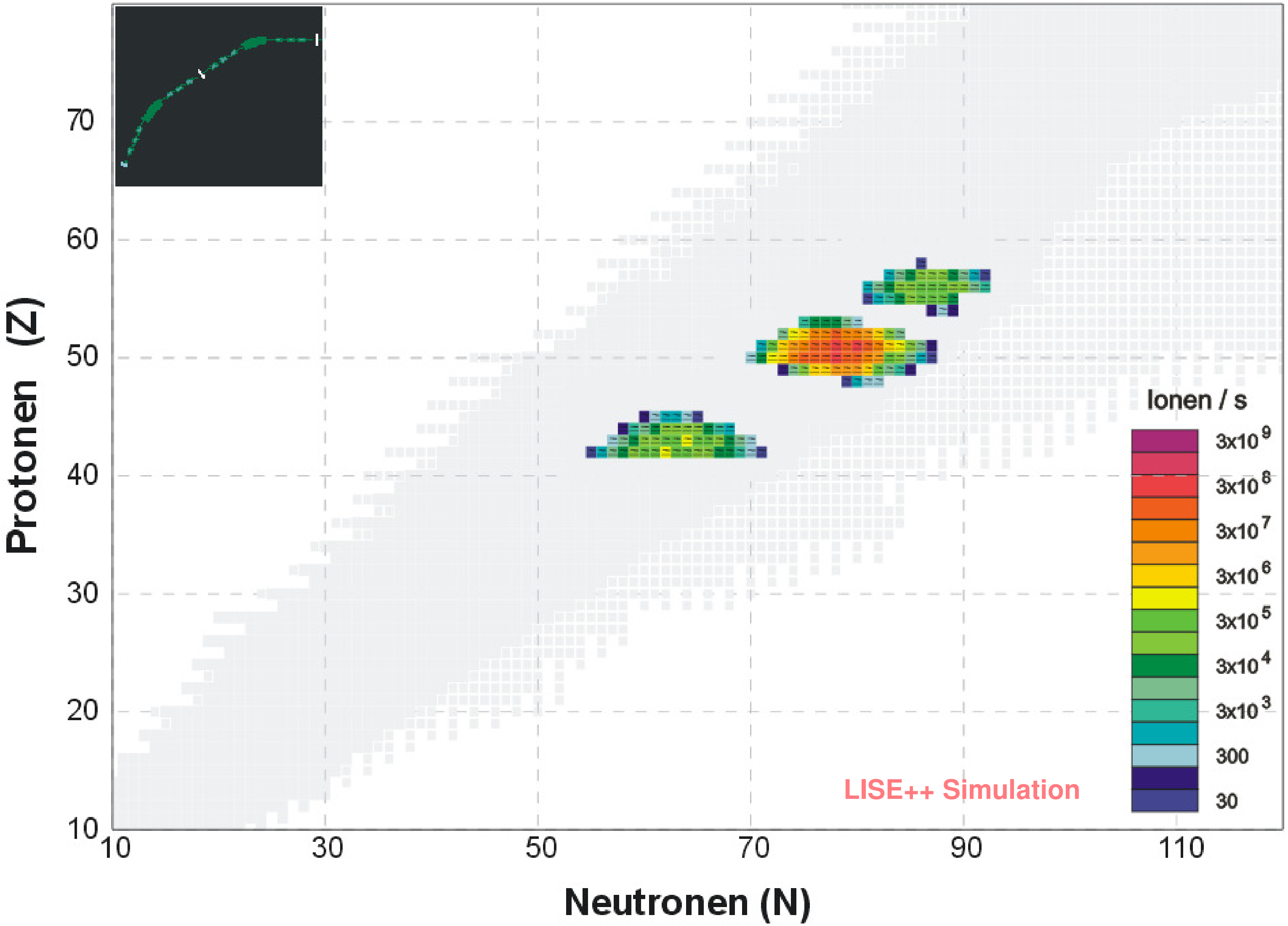
Separation

Separation only by Bρ



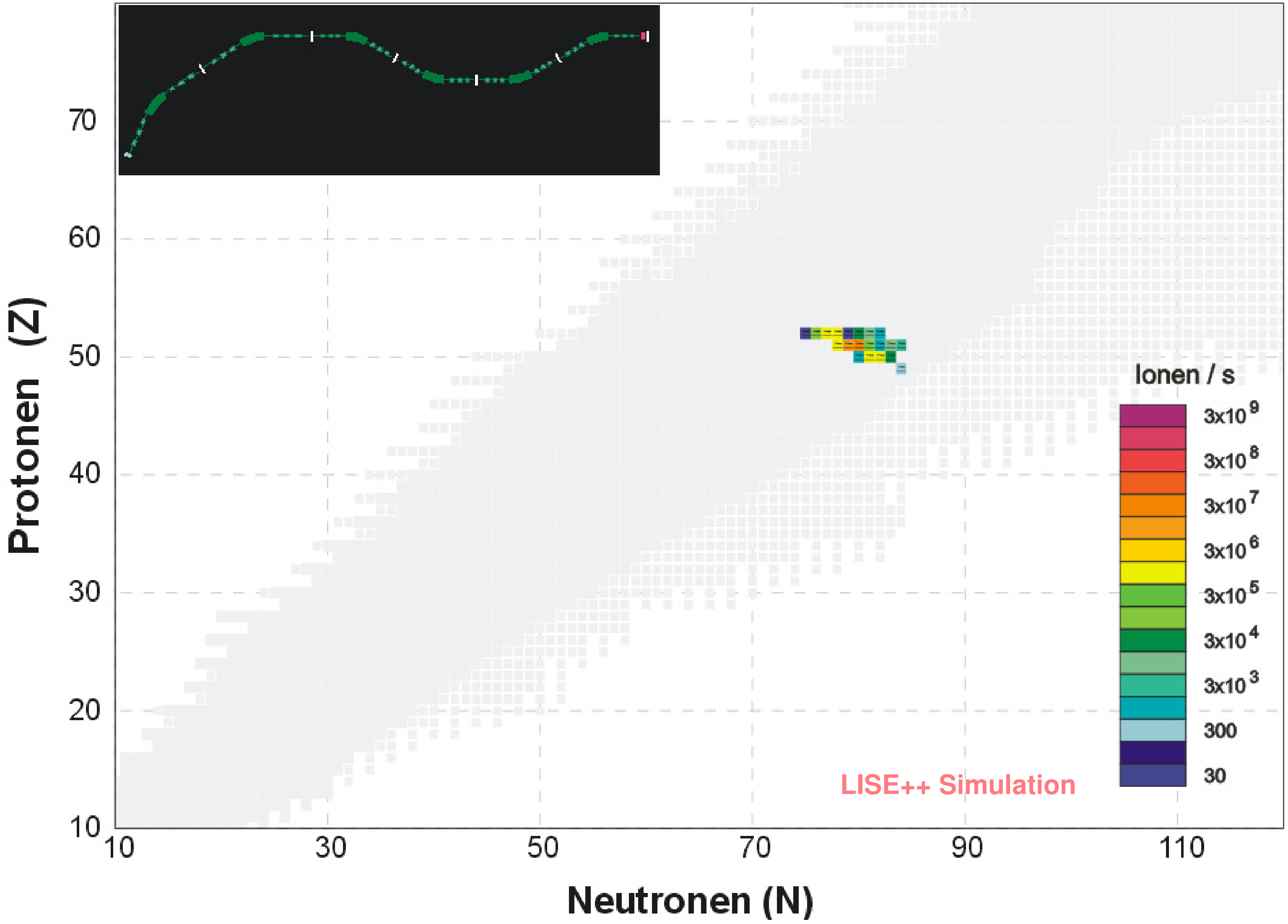
Separation

Separation after pre-separator (Bρ-ΔE-Bρ)



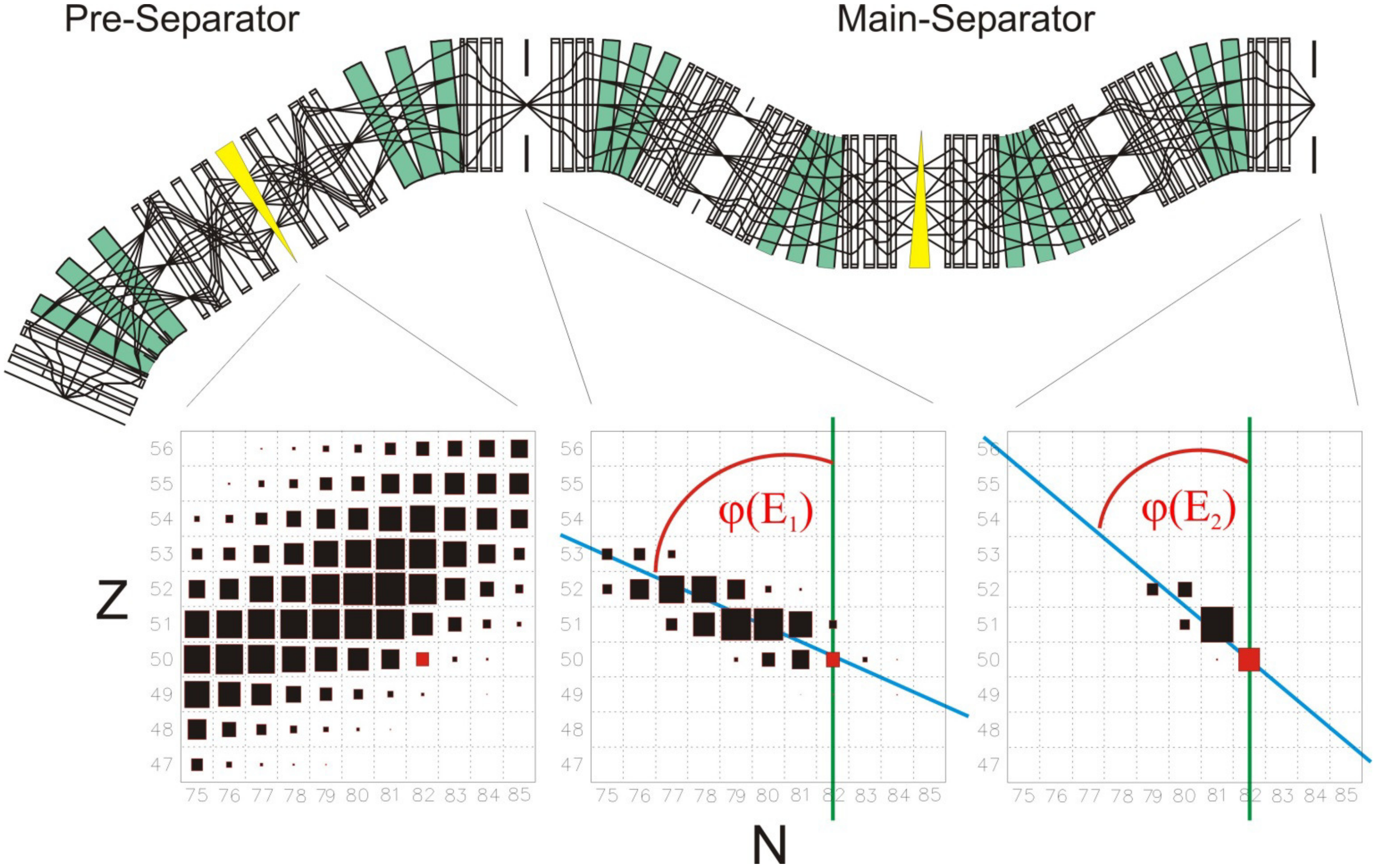
Separation

Separation after main separator (Bρ-ΔE-Bρ) x (Bρ-ΔE-Bρ)



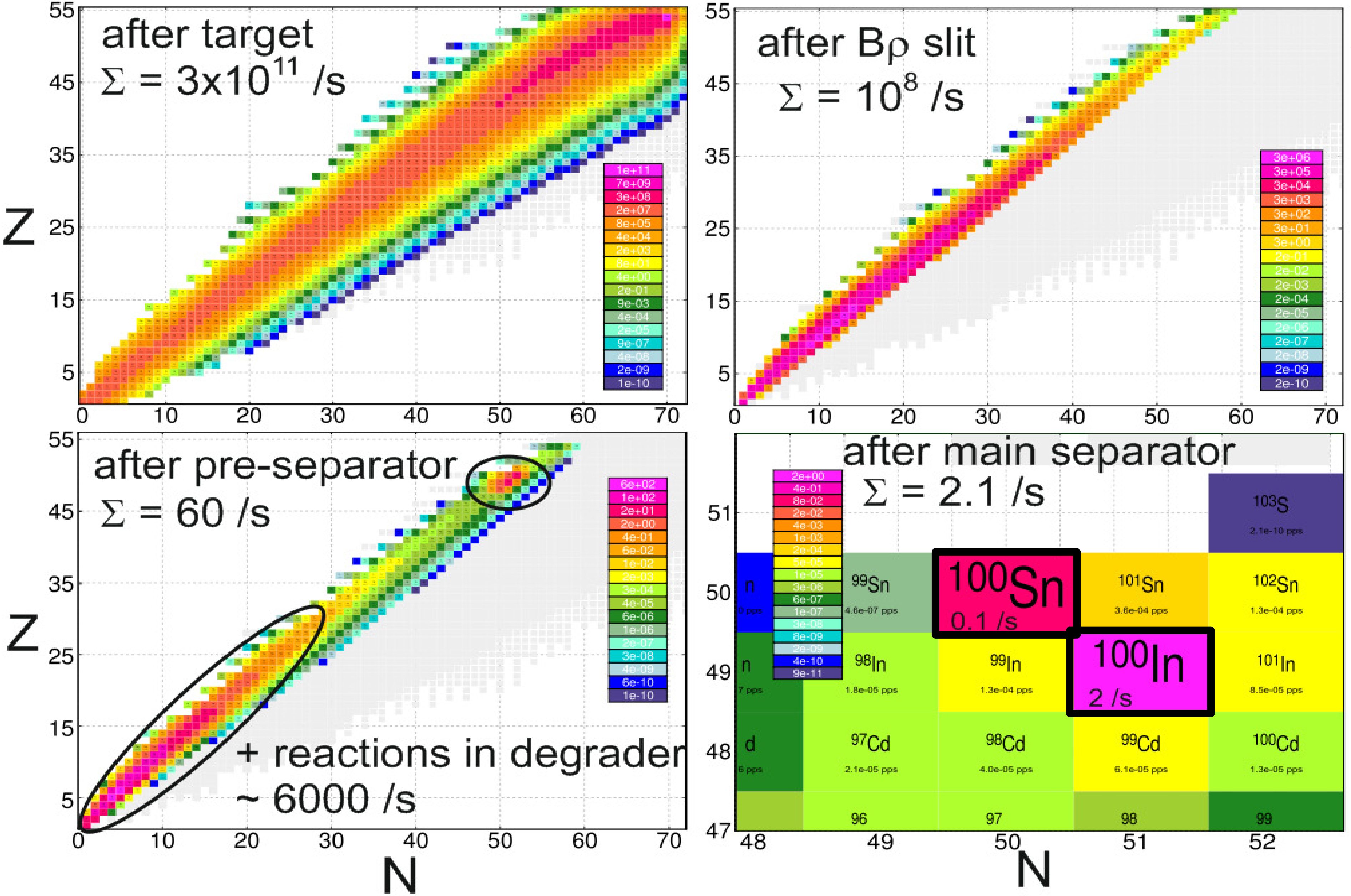
Separation Performance

1.1 A GeV ^{238}U on 4 g/cm^2 C target, two Al degraders d/R=0.3, d/R=0.7



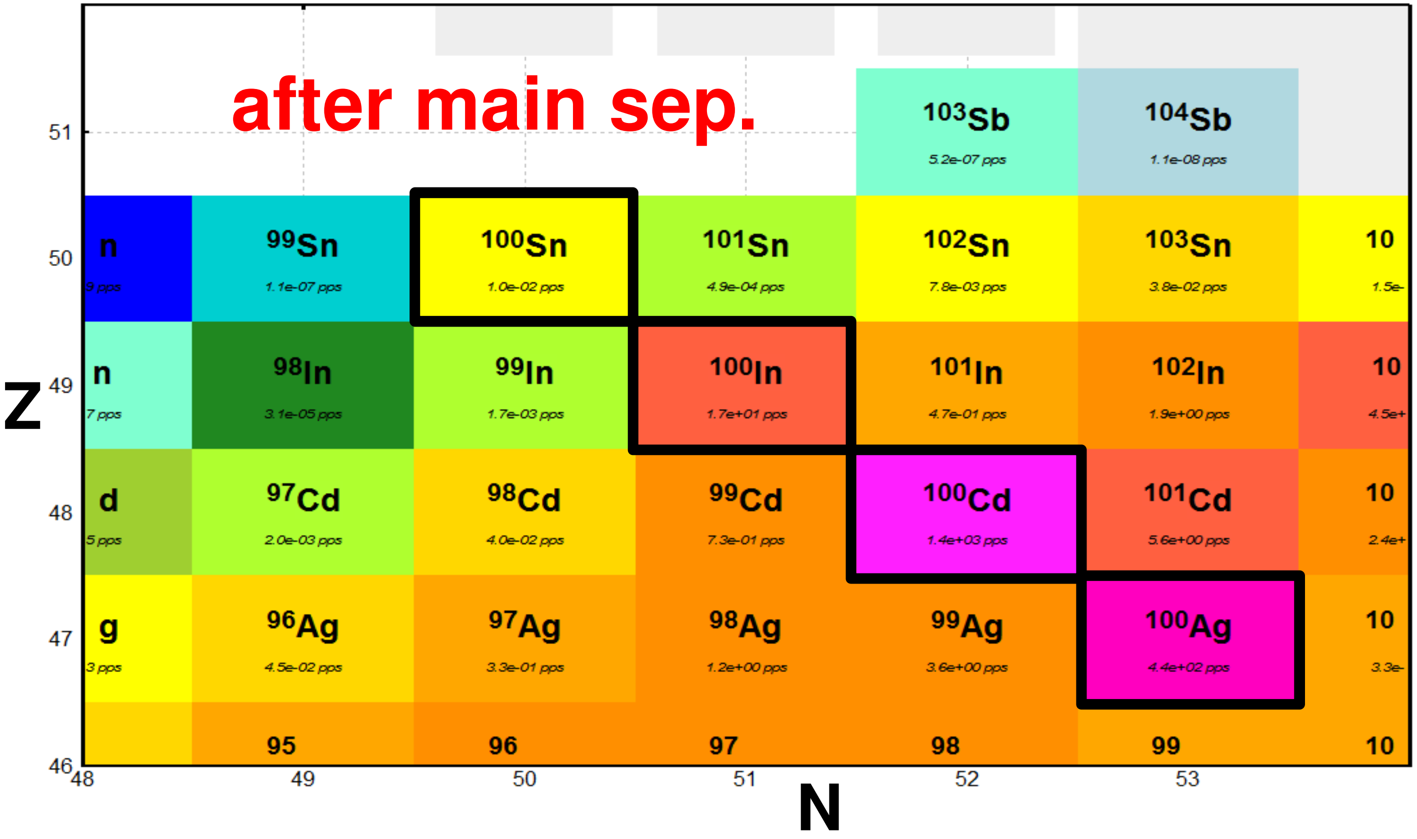
For fission fragments separation is difficult, other beams more pure

Separation Performance, ^{100}Sn



Separation of ^{100}Sn produced from ^{238}U

	from ^{124}Xe	from ^{238}U	(both at $3\text{x}10^{11}$/s)
^{100}Sn	0.09	0.03 /s	
$\Sigma_{\text{pre-sep.}}$	6400	$3.3\text{x}10^{6}$ /s	
$\Sigma_{\text{main sep.}}$	2.1	5700 /s	



after main sep.

Z \ N	48	49	50	51	52	53	
51					^{103}Sb 5.2e-07 pps	^{104}Sb 1.1e-08 pps	
50	n 9 pps	^{99}Sn 1.1e-07 pps	^{100}Sn 1.0e-02 pps	^{101}Sn 4.9e-04 pps	^{102}Sn 7.8e-03 pps	^{103}Sn 3.8e-02 pps	10 1.5e-
49	n 7 pps	^{98}In 3.1e-05 pps	^{99}In 1.7e-03 pps	^{100}In 1.7e+01 pps	^{101}In 4.7e-01 pps	^{102}In 1.9e+00 pps	10 4.5e+
48	d 5 pps	^{97}Cd 2.0e-03 pps	^{98}Cd 4.0e-02 pps	^{99}Cd 7.3e-01 pps	^{100}Cd 1.4e+03 pps	^{101}Cd 5.6e+00 pps	10 2.4e+
47	g 3 pps	^{96}Ag 4.5e-02 pps	^{97}Ag 3.3e-01 pps	^{98}Ag 1.2e+00 pps	^{99}Ag 3.6e+00 pps	^{100}Ag 4.4e+02 pps	10 3.3e-
46		95	96	97	98	99	10

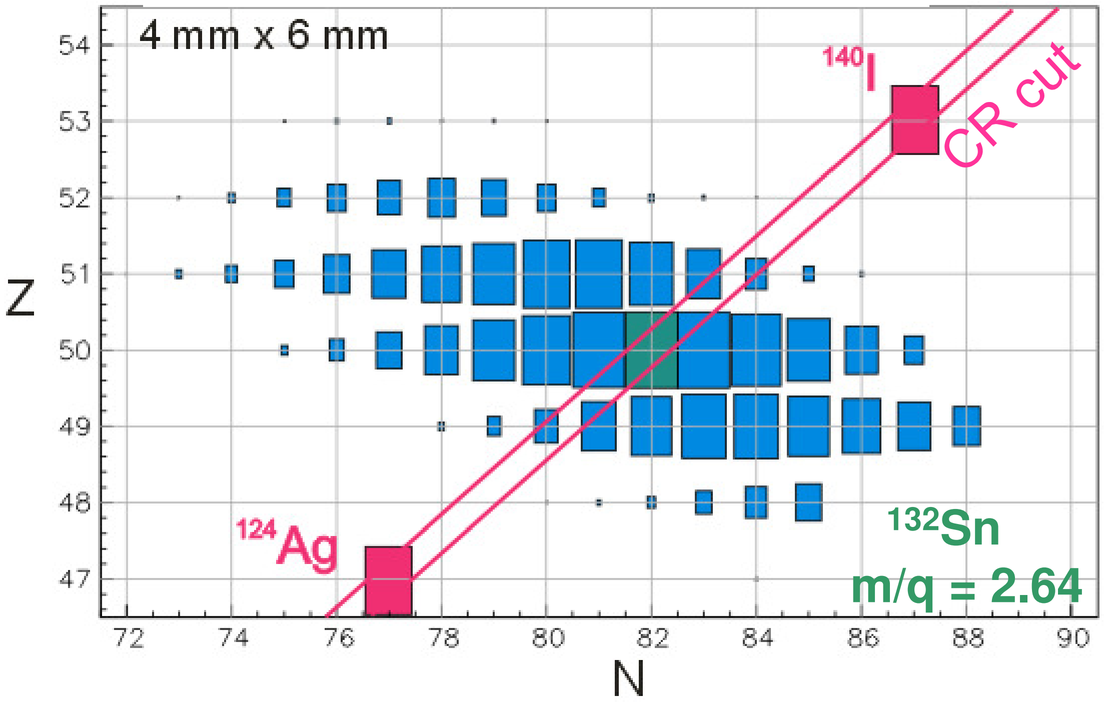
Separation with enlarged beam spot

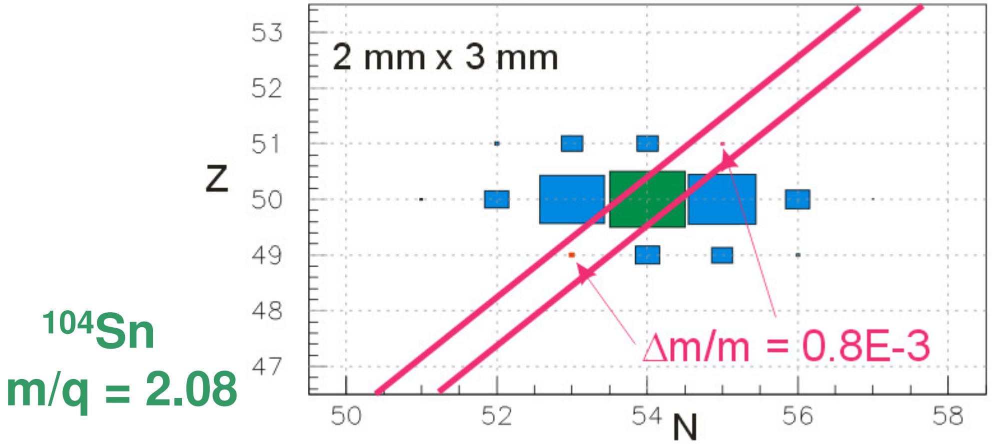
Fast extraction with intense U beam requires larger beam spot on target.

Stochastic cooling is a mass selective RF filter.
$\Delta(m/q)/(m/q) \sim 10^{-3}$
cooled down to $\Delta p/p \sim 10^{-4}$
→ scrapers in rings can be used.

Still Super-FRS must separate nuclides with $\Delta(m/q)/(m/q) < 10^{-3}$. For ^{132}Sn next critical ones ^{124}Ag and ^{140}I ($<10^{-3}$) are separated. Problems only with m/q = 2.0 or 2.5

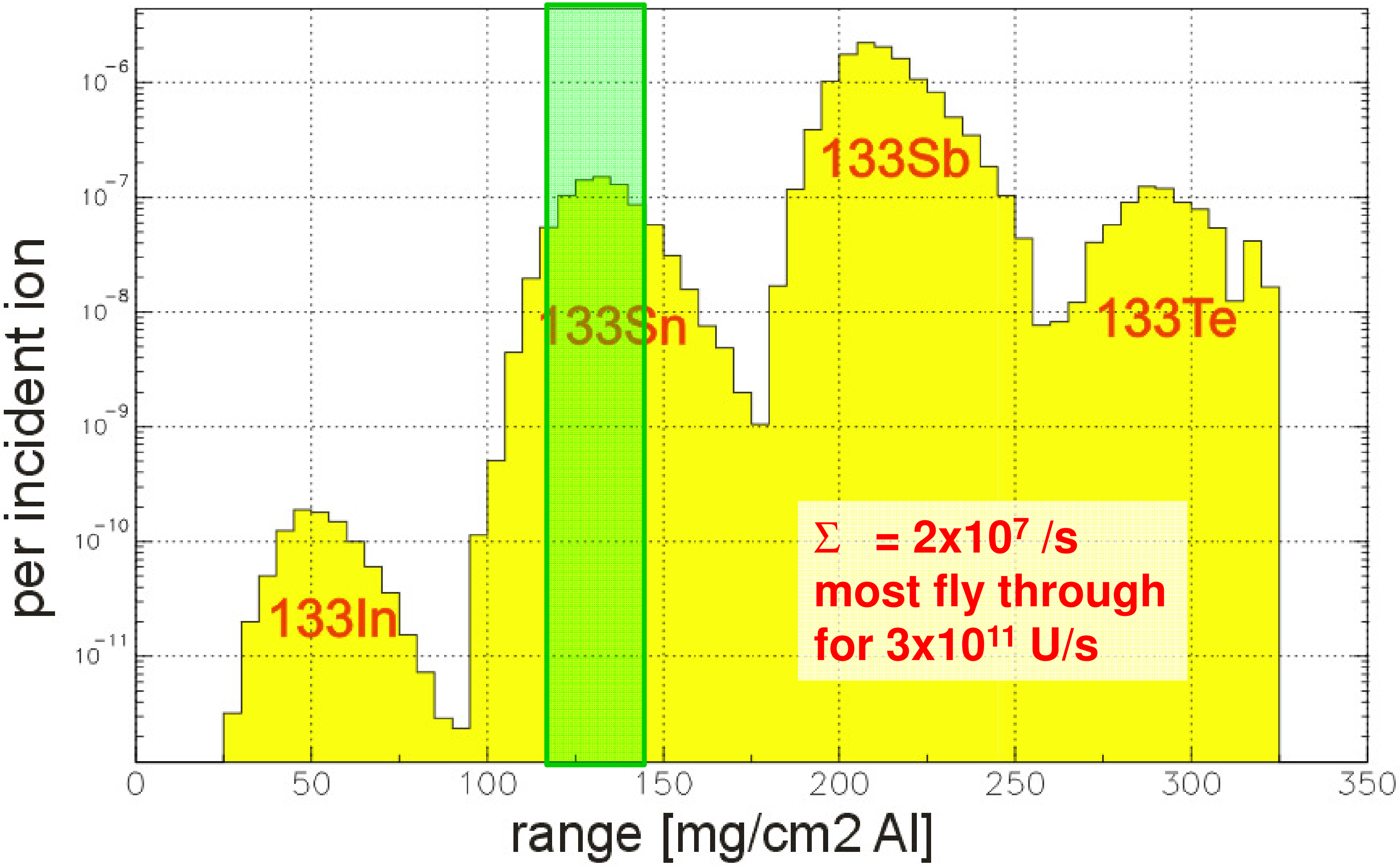
transmitted through Super-FRS





Separation of Isobars in Range
- LEB with Energy Buncher -

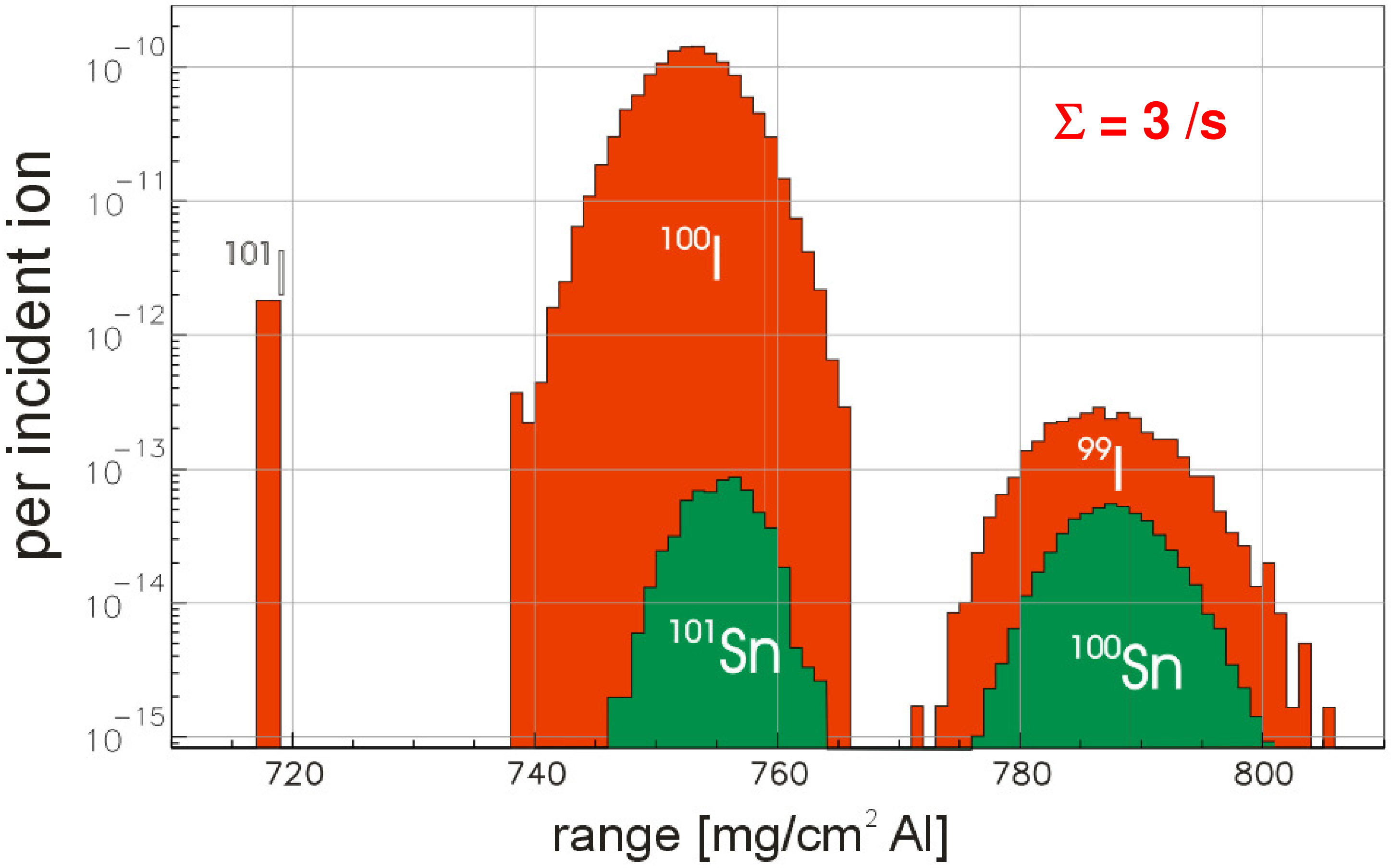
^{133}Sn from fission, after two thick degraders (d/R=0.5),
energy bunched at 340 MeV/u with monoenergetic degrader



Σ = 2x10^7 /s
most fly through
for 3x10^{11} U/s

Separation of ^{100}Sn in Range

1000 MeV/u ^{124}Xe -> 6g/cm^2 C-target, twice d/R=0.5 Al degrader
Ranges of all fragments arriving at last degrader

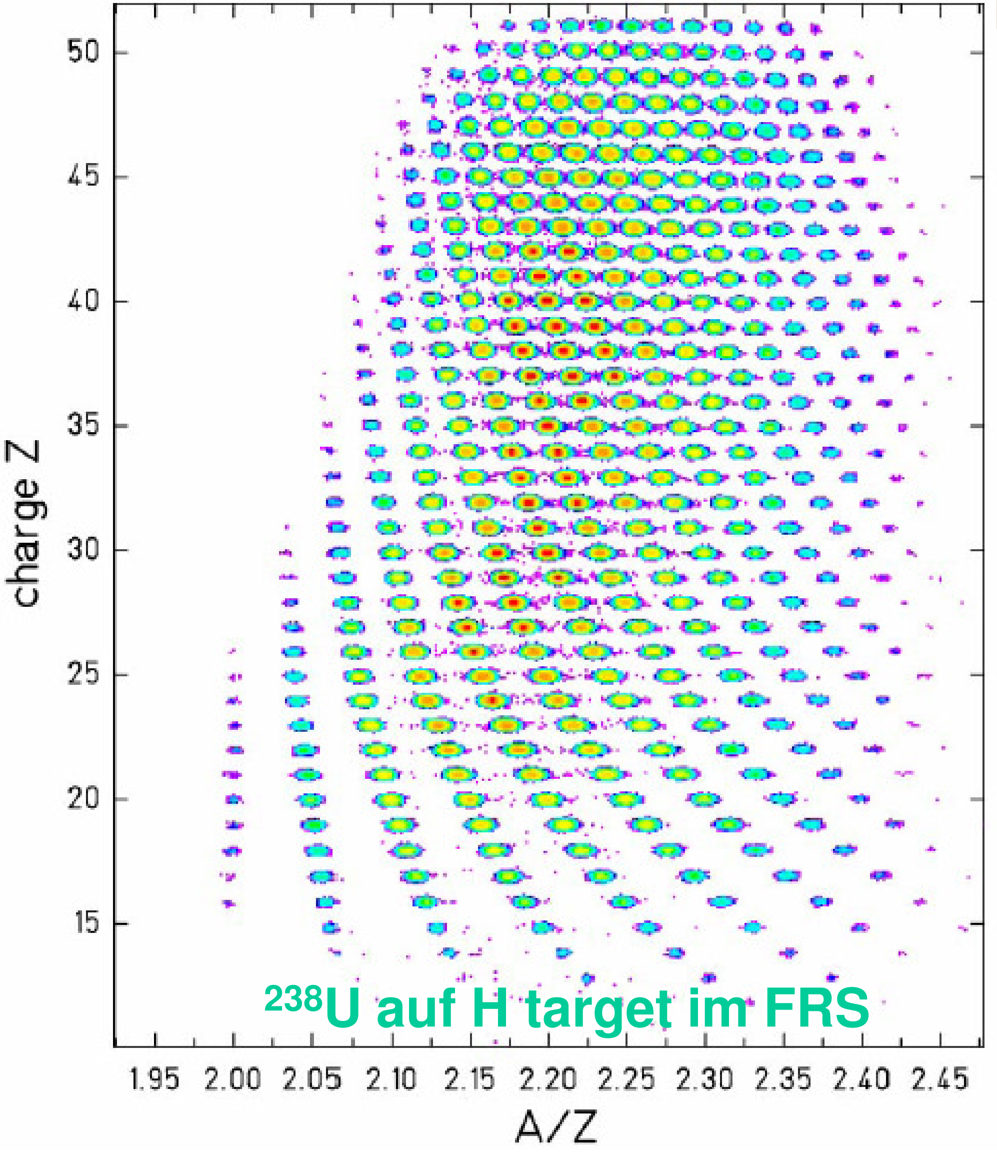


Identification in flight

$B\rho = m/q\ \beta\gamma\ c_0$

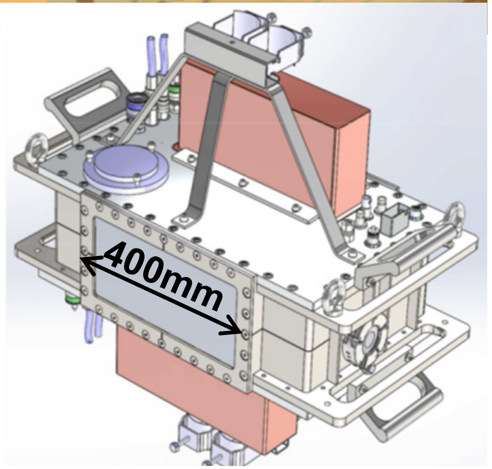
Identification of single ions
with particle detectors.
- Ionization chamber (MUSIC) -> Z
- Si and scintillators, ToF -> $\beta\gamma$
- x-position, B-field -> $B\rho$

Requires rates < 10^5-10^6 ions/s,
some experiments < 100 /s



Dissertation Vladimir Henzl, CTU Prag 2005.

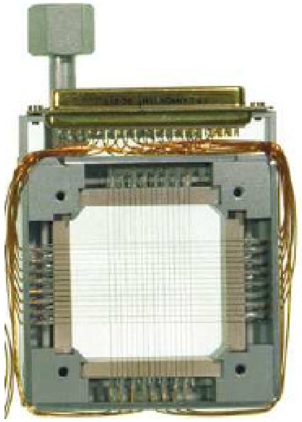
Detectors

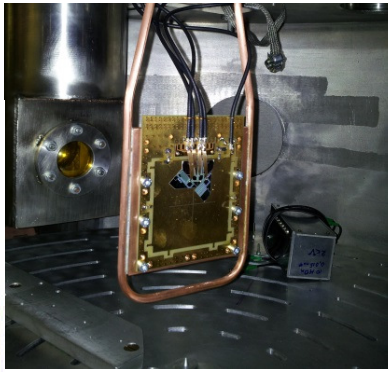


Position: X, Y by twin GEM-TPC for
double hit reconstruction
700-800 kHz reached for Au ions at 90% eff.,
up to 2 MHz possible, single TPC ~100 kHz,
also for angle measurement and focus tuning.

MUSICs: 0.1 – 1 MHz, sample double hits
higher energy needed for high Z ions (>500 MeV/u for U)

ToF: plastic scintillators,
radiation hard Si for position and ToF





Profiles: SEM grids,
IR camera on target

Intensity: Seetram, diamond, IC, trafo

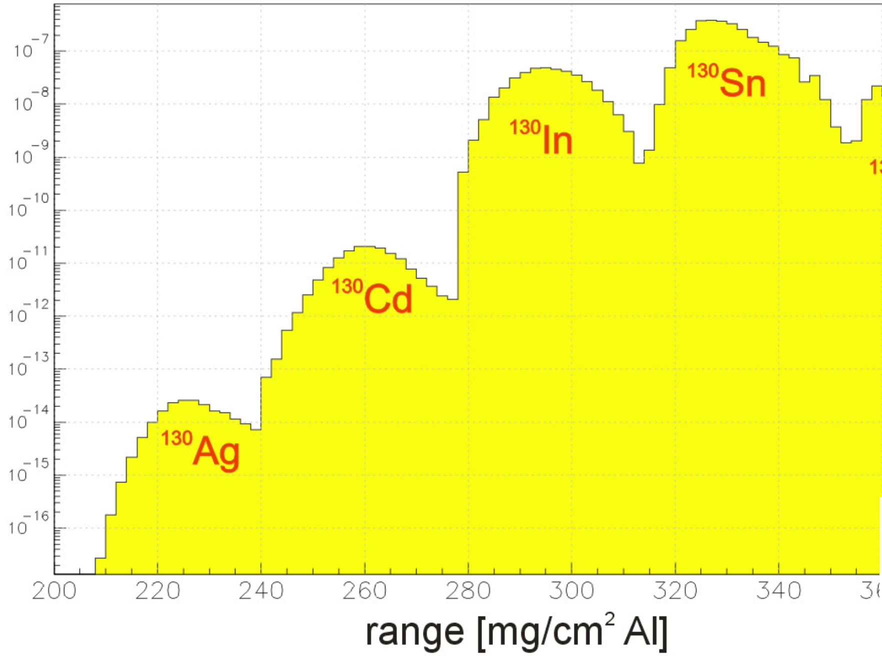
Summary

Production rates with cross sections calculated.
Good basis for new nuclides still larger uncertainty.
Requires many different primary beams.

Separation:
Most pure RIBs of all fragment separators in the world.
Still some cases come with high background (fission).
Separation in range is even better.

Identification needs fast detectors, under development.
Together selectivity 1:10^{20} of what was produced.

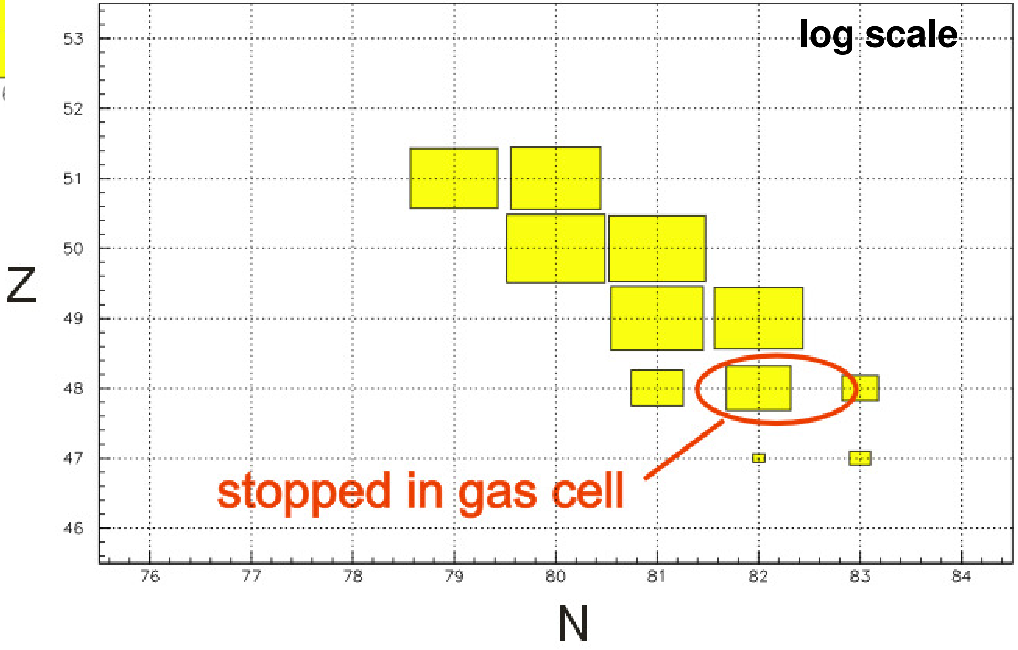
^{130}Cd Separation



Separation of isobars in range.

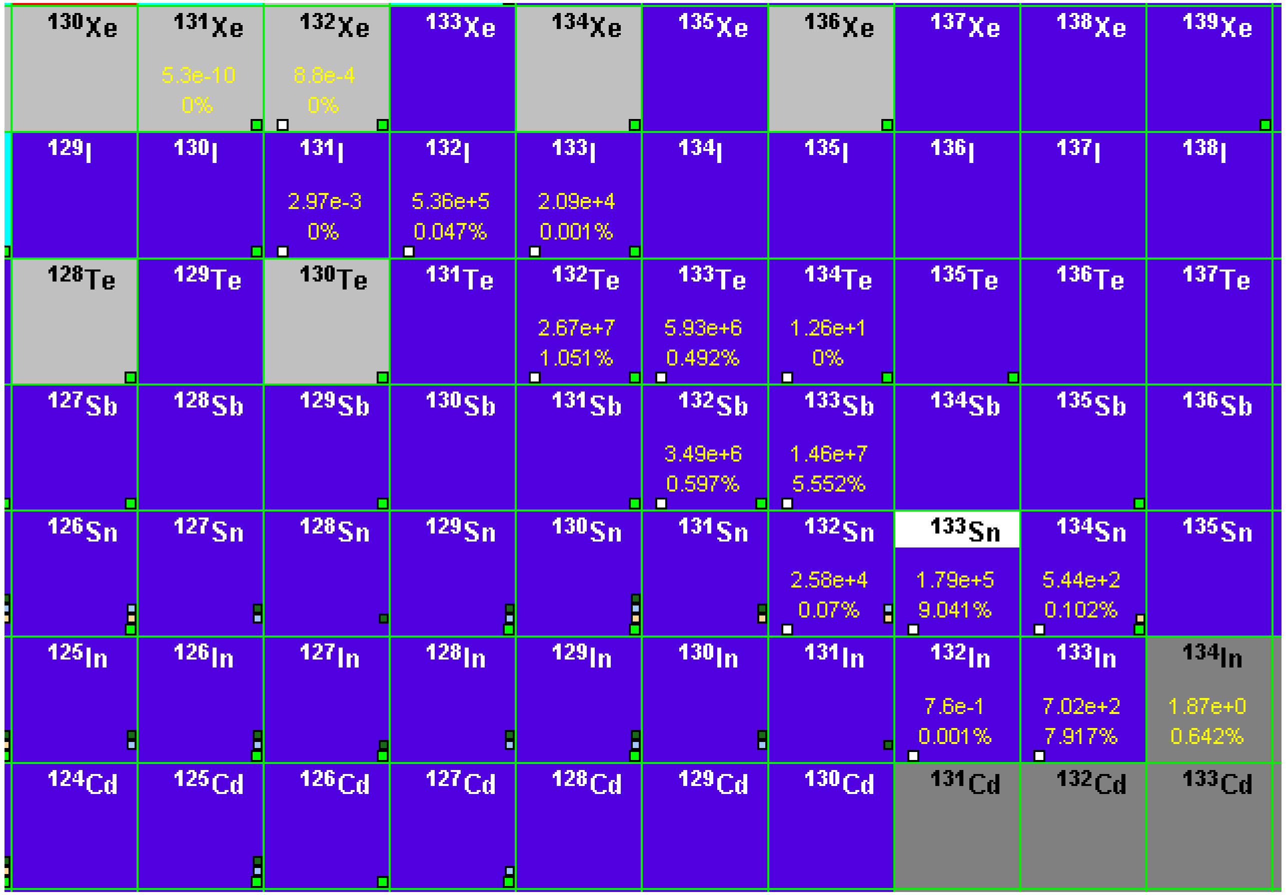
σ_R (^{130}Cd) = 7.5 mg/cm^2

Nuclides transmitted to and stopped in gas cell



Separation of Fission Fragments

^{133}Sn from uranium fission E = 1217 MeV/u, 3 g/cm^2 C-target after two thick achromatic degraders (d/R=0.5).
Wide energy spread of fission fragments makes separation hard.



^{130}Xe	^{131}Xe 5.3e-10 0%	^{132}Xe 8.8e-4 0%	^{133}Xe	^{134}Xe	^{135}Xe	^{136}Xe	^{137}Xe	^{138}Xe	^{139}Xe
^{129}I	^{130}I	^{131}I 2.97e-3 0%	^{132}I 5.36e+5 0.047%	^{133}I 2.09e+4 0.001%	^{134}I	^{135}I	^{136}I	^{137}I	^{138}I
^{128}Te	^{129}Te	^{130}Te	^{131}Te	^{132}Te 2.67e+7 1.051%	^{133}Te 5.93e+6 0.492%	^{134}Te 1.26e+1 0%	^{135}Te	^{136}Te	^{137}Te
^{127}Sb	^{128}Sb	^{129}Sb	^{130}Sb	^{131}Sb	^{132}Sb 3.49e+6 0.597%	^{133}Sb 1.46e+7 5.552%	^{134}Sb	^{135}Sb	^{136}Sb
^{126}Sn	^{127}Sn	^{128}Sn	^{129}Sn	^{130}Sn	^{131}Sn	^{132}Sn 2.58e+4 0.07%	^{133}Sn 1.79e+5 9.041%	^{134}Sn 5.44e+2 0.102%	^{135}Sn
^{125}In	^{126}In	^{127}In	^{128}In	^{129}In	^{130}In	^{131}In	^{132}In 7.6e-1 0.001%	^{133}In 7.02e+2 7.917%	^{134}In 1.87e+0 0.642%
^{124}Cd	^{125}Cd	^{126}Cd	^{127}Cd	^{128}Cd	^{129}Cd	^{130}Cd	^{131}Cd	^{132}Cd	^{133}Cd

LISE++ simulation

Best Energy for Range Bunching

	ac+ac+me	ac+me	
E_(238U) =	438.81	438.81	MeV/u
at exit of Super-FRS			
rate 132Sn =	5.0E-06	4.1E-06	ions / primary
total rate =	9.5E-05	6.4E-05	ions / primary
ratio =	19.1	15.5	
after slowing-down			
σ_R =	3.68	6.71	mg/cm^2 Al

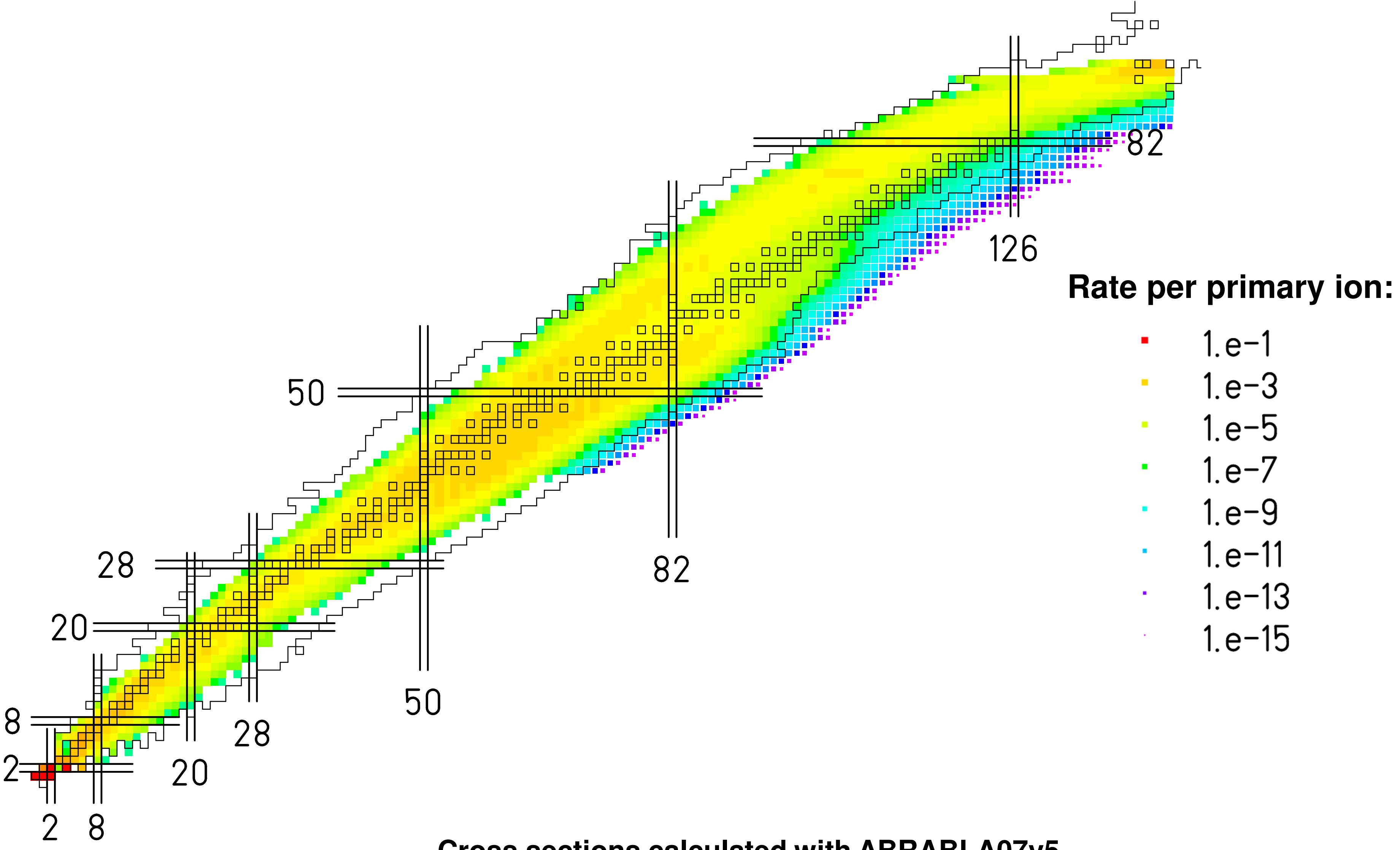
	ac+ac+me	ac+me	
E_(238U) =	530.0	530.0	MeV/u
at exit of Super-FRS			
rate 78Ni =	1.3E-10	1.8E-10	ions / primary
total rate =	2.7E-05	4.2E-04	ions / primary
ratio =	2.1E+05	2.4E+06	
after slowing-down			
σ_R =	8.57	16.25	mg/cm^2 Al

	ac+ac+me	ac+me	
E_(40Ar) =	200.0	200.0	MeV/u
at exit of Super-FRS			
rate 19C =	1.1E-10	8.2E-11	ions / primary
total rate =	1.1E-10	8.6E-11	ions / primary
ratio =	1.0	1.0	
after slowing-down			
σ_R =	20.09	30.03	mg/cm^2 Al

	ac+ac+me	ac+me	
E_(238U) =	1000.0	1000.0	MeV/u
at exit of Super-FRS			
rate 232Fr =	3.8E-10	7.8E-10	ions / primary
total rate =	4.4E-07	9.4E-06	ions / primary
ratio =	1154.9	12065.0	
after slowing-down			
σ_R =	2.89	6.74	mg/cm^2 Al

Higher initial energies increase σ_R and decrease overall efficiency but help in particle identification and setup (MUSIC for high Z). Low Z could be FRIB or RIKEN.

^{238}U+^{12}C at 1AGeV

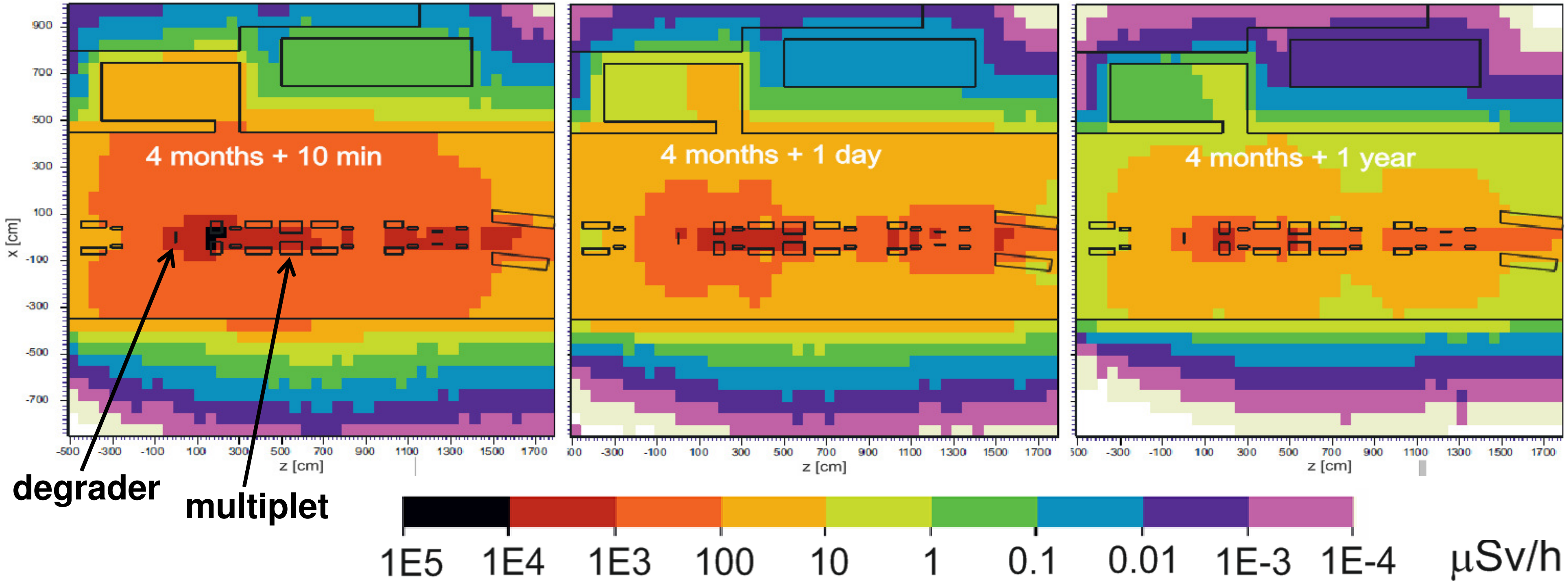


Cross sections calculated with ABRABLA07v5.

Residual Dose Rates
- FPF2 -

Dose rate by activation around FPF2, calculated with FLUKA
Al degrader and magnets as components
Beam up to: 3x10^{10}/s fission fragments for 1x10^{12} ^{238}U/s on target.
Downscaled to more real average beam intensity (x 1/5).

beam on target + cooling time

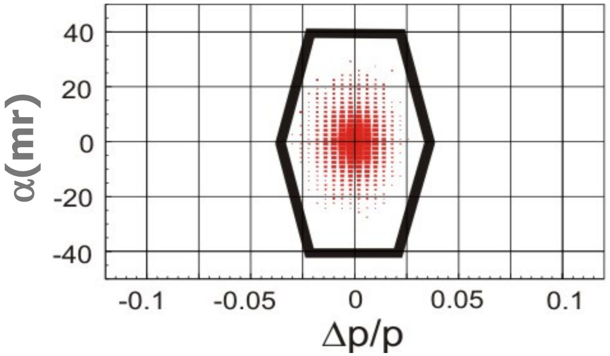


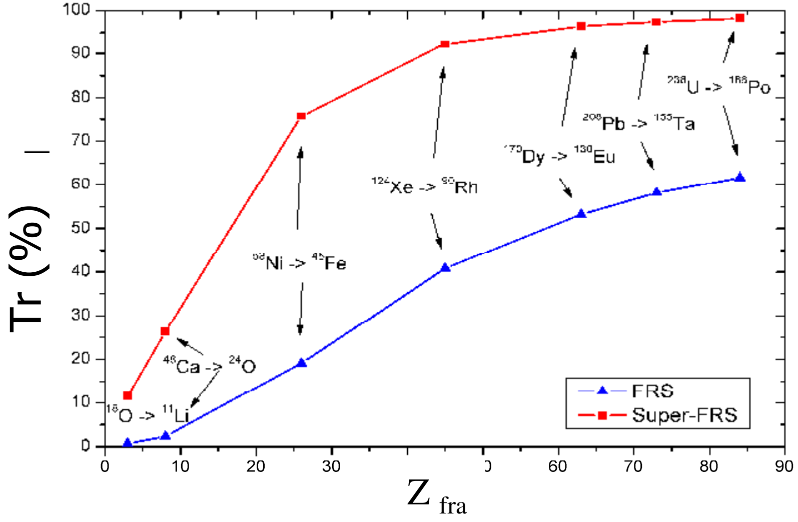
Comparison FRS – Super-FRS

Transmission gain

- Fragmentation

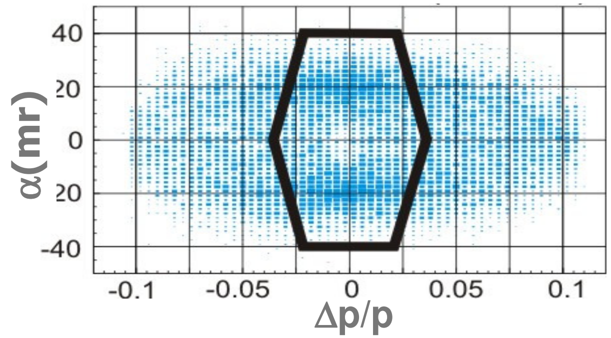
$^{124}\mathrm{Xe} + \mathrm{C} \rightarrow {}^{100}\mathrm{Sn}$

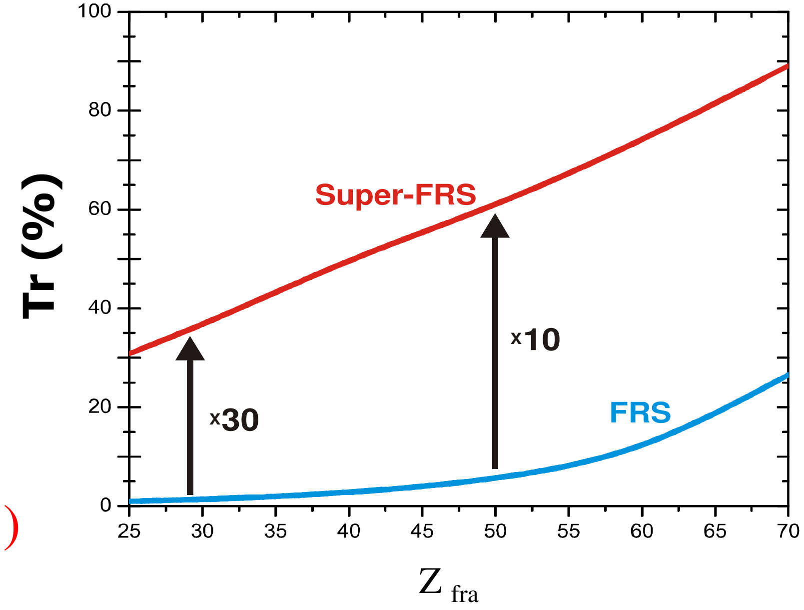




- Fission

$^{238}\mathrm{U} + \mathrm{C} \rightarrow {}^{78}\mathrm{Ni}$

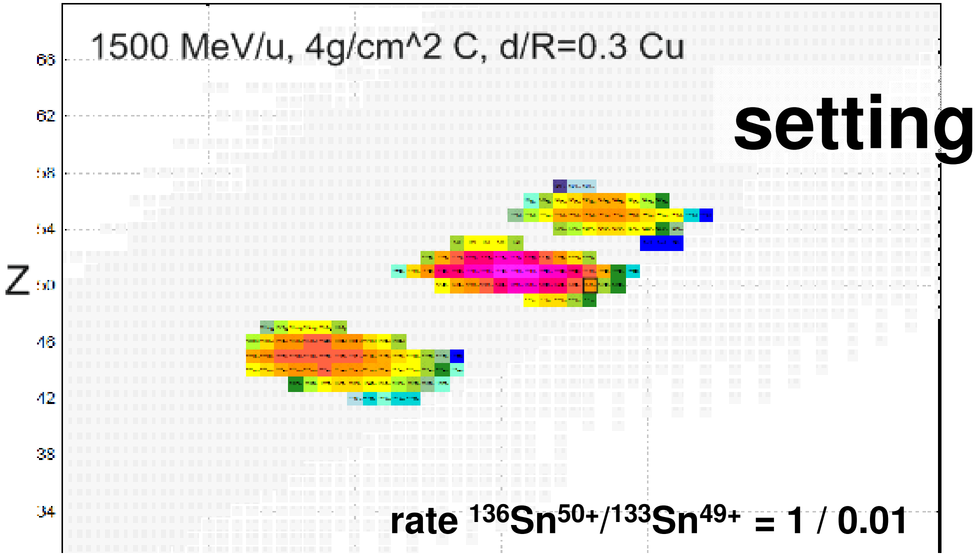




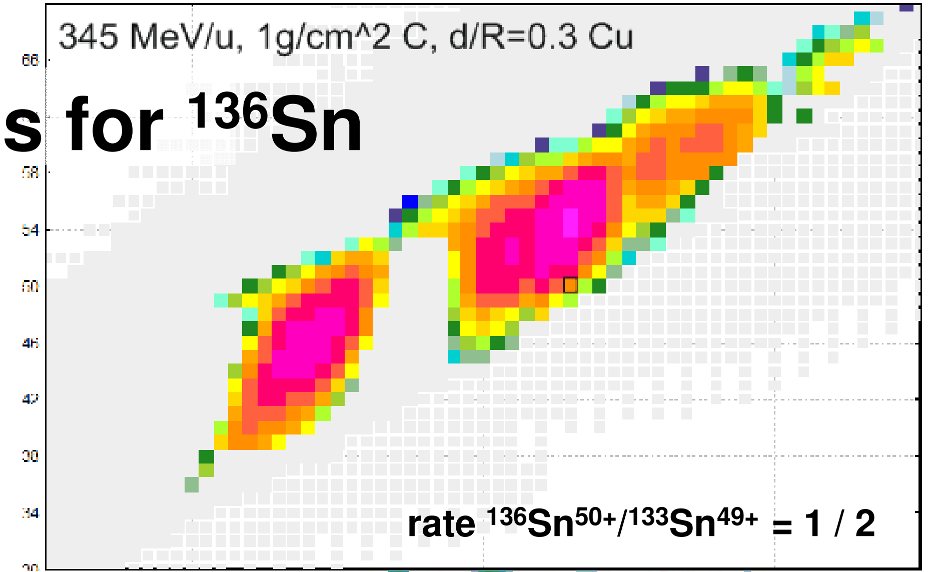
Apertures (Super-FRS) ≈ 2 x Apertures (FRS)

Charge-separation capability for different Energies

settings for ^{136}Sn



rate $^{136}\text{Sn}^{50+}/^{133}\text{Sn}^{49+}$ = 1 / 0.01



rate $^{136}\text{Sn}^{50+}/^{133}\text{Sn}^{49+}$ = 1 / 2