Production cross section measurement and identification of new isotopes in the vicinity of ^{100}Sn

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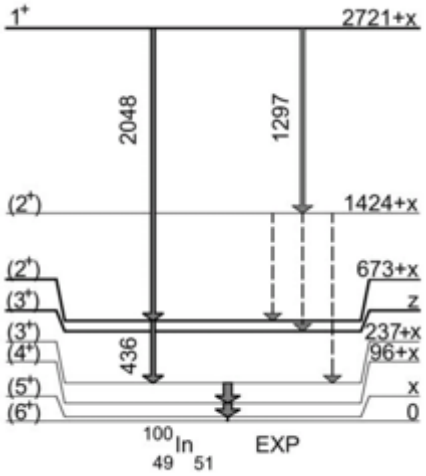
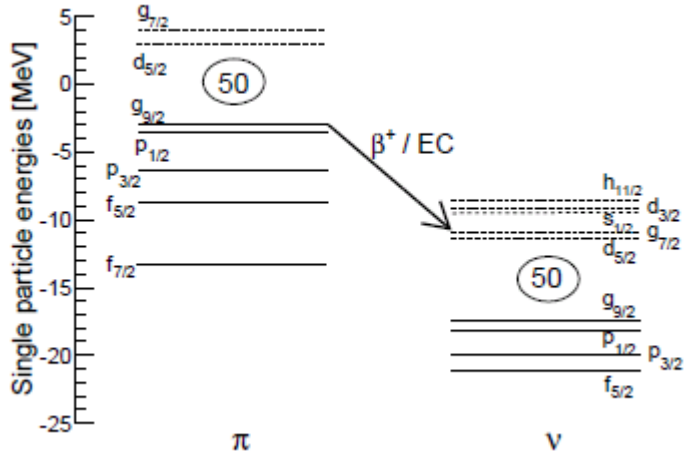
RIBF009 Experiment Collaboration

General motivation: The N=Z ^{100}Sn region

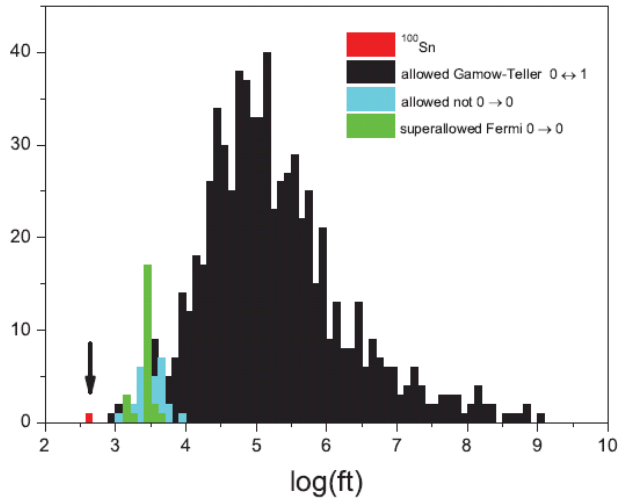
The main objectives of this study:

- Shell structure and single particle energies
- pn interaction in isospin symmetric matter
- Gamow-Teller β+/*EC decay*
- Proton and alpha decay from ground and excited states
- Astrophysical rp-process





H Grawe et al., *Phys. Scripta, T56 (1995) 71–78*.

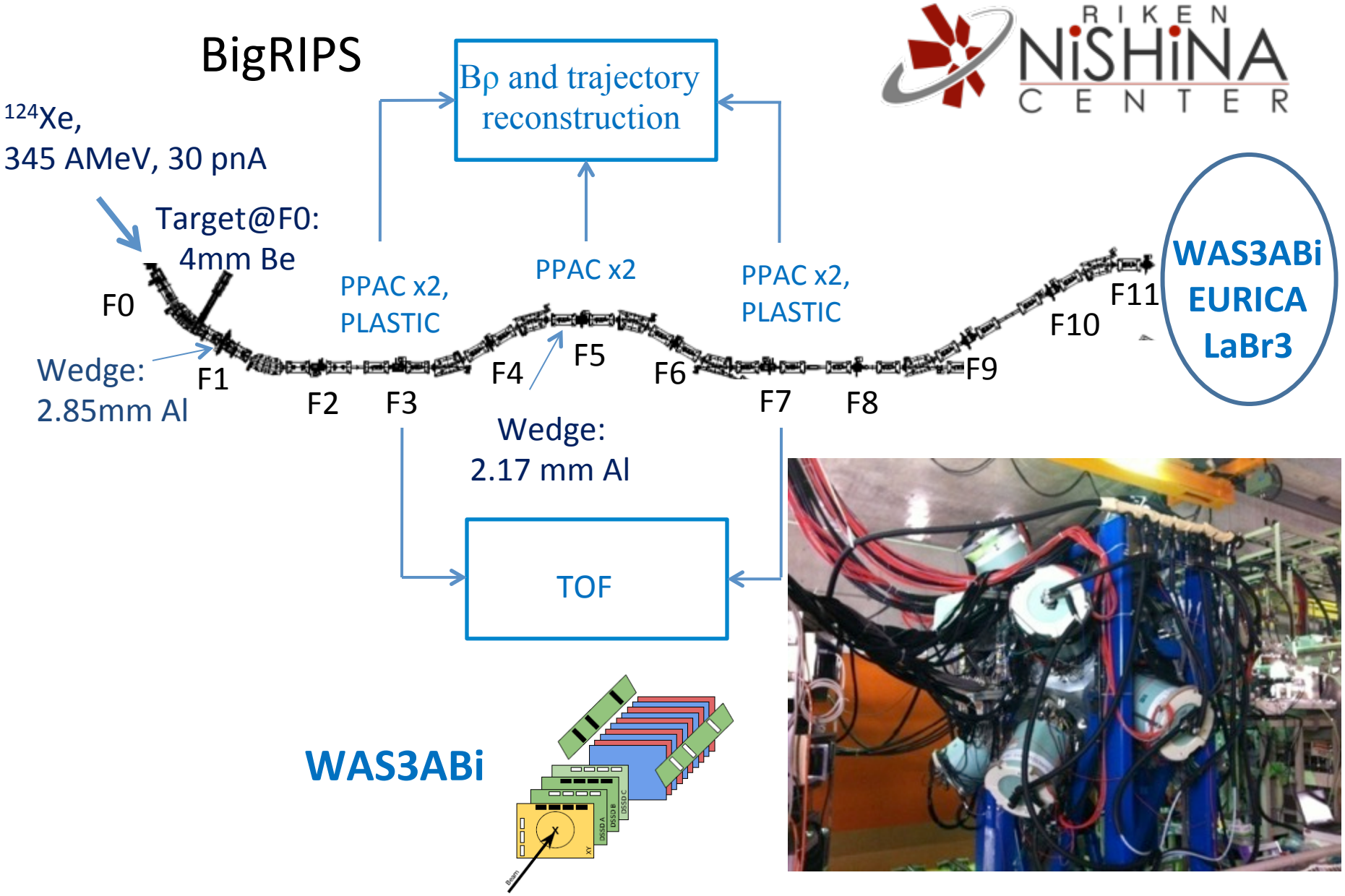


C .Hinke et al., *Nature 428 (2012) 341.*

This work: The N=Z ^{100}Sn region

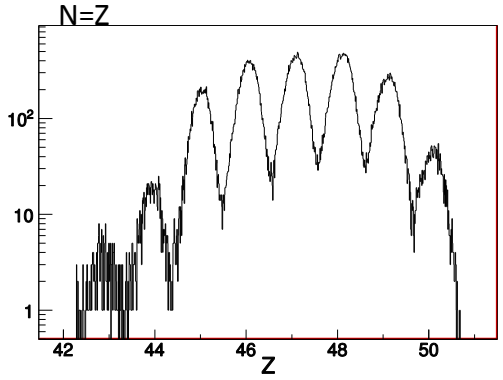
- Production cross section
  - Energy dependence of ^{100}Sn production cross-section?
  - Effects of secondary reactions
  - Checking models used for CS predictions
- Identification of new isotopes and proton emitters
  - Mapping the proton drip-line
  - Testing different mass models

Experimental setup:

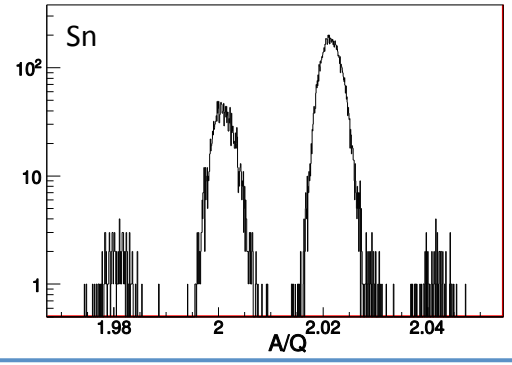


Particle identification and new isotopes

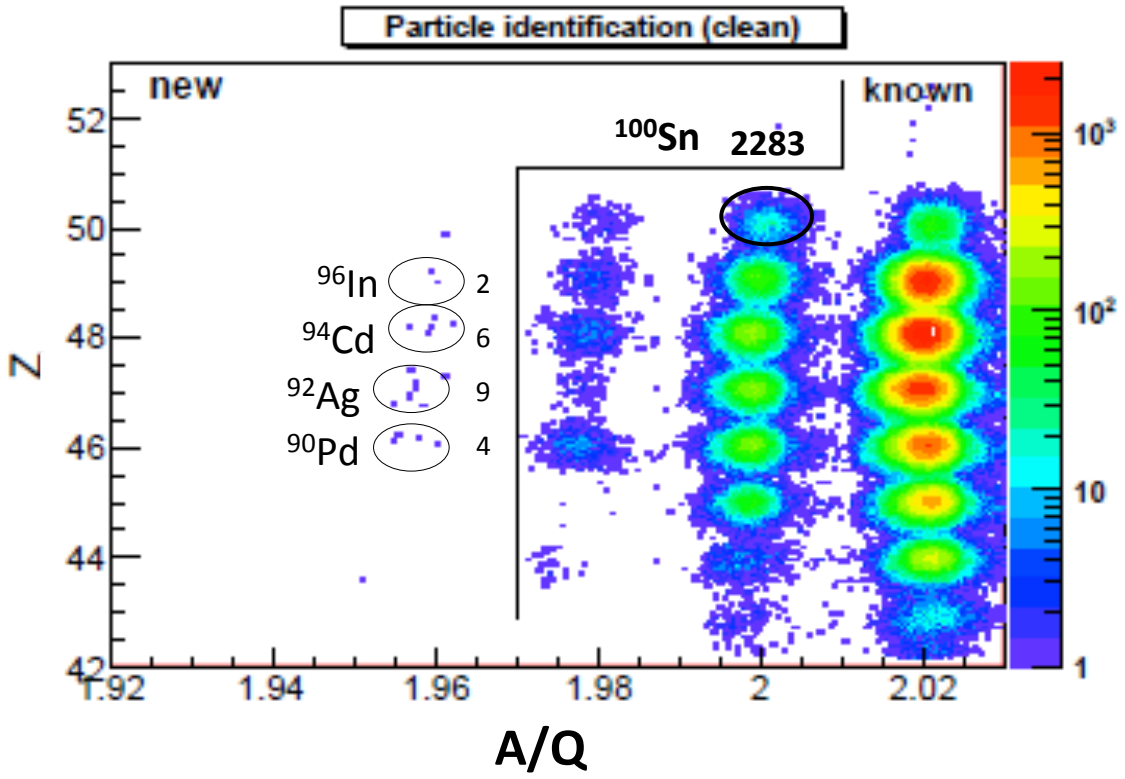
- ΔE – Bρ – TOF method:
  - from ΔE and TOF → Z
  - from Bρ and TOF → A/Q
- A/Q and Z confirmation by characteristic γ-lines from ^{98m}Cd and ^{96m}Pd
- PID around ^{100}Sn: full statistics (irradiation with 30 pnA during 203 h)



$$\frac{\Delta Z}{Z} = 0.41\%$$



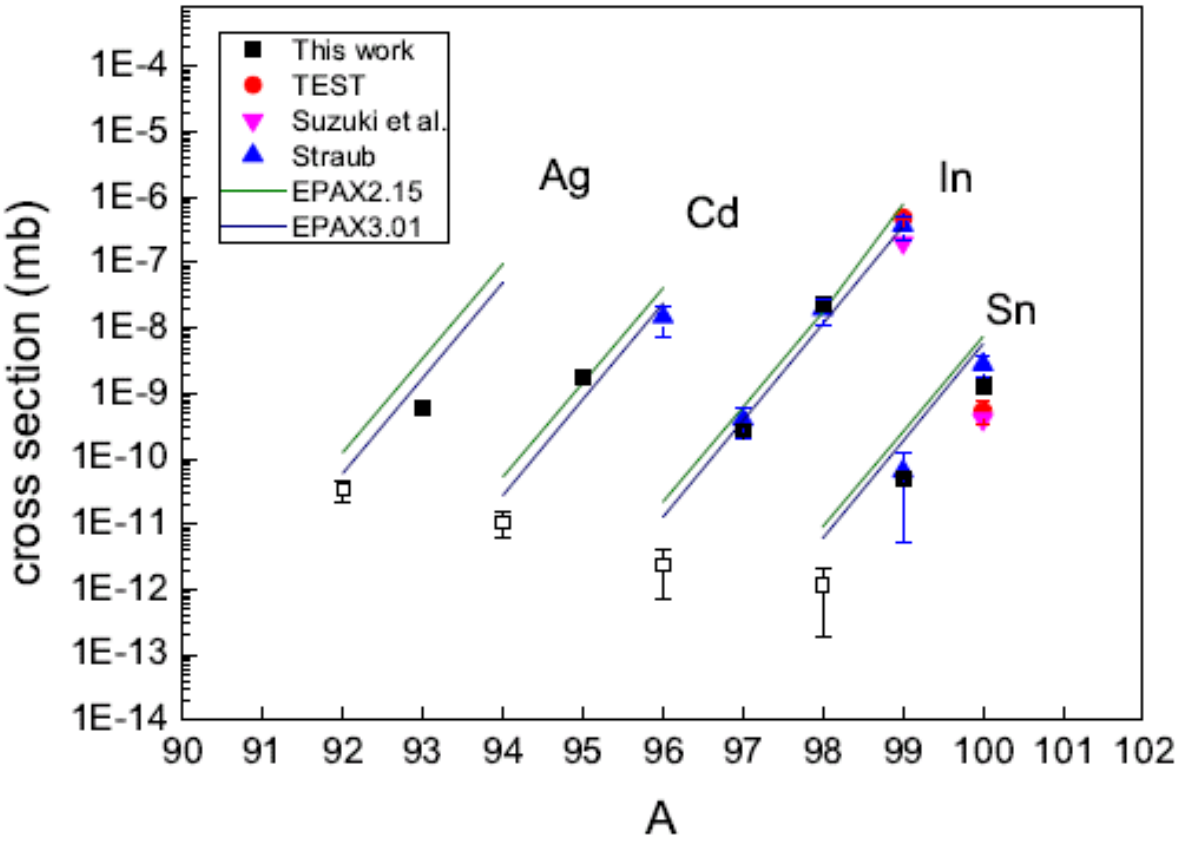
$$\frac{\Delta A/Q}{A/Q} = 0.09\%$$



- New isotopes identified: ^{96}In, ^{94}Cd, ^{92}Ag, ^{90}Pd

Production cross section:

- Transmission: average of Monte Carlo and Distribution Method from LISE++
- CS deduced for transmission > 5%
- Correction on effect of secondary reactions in target



^{100}Sn cross section: discrepancy between RIKEN, GSI and EPAX

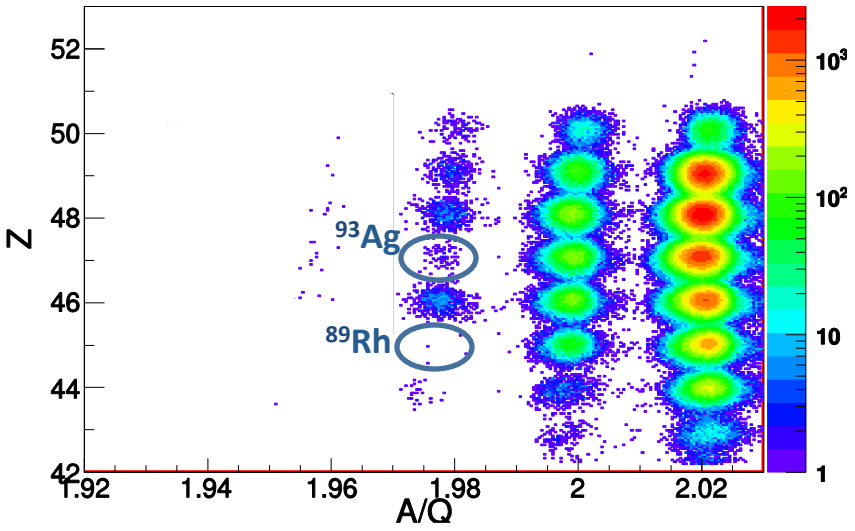
- discrepancy between GSI and RIKEN ^{100}Sn production cross sections
- possible and/or target thickness dependence

Experiment	Be target (mm)	Energy (MeV/u)	**Cross section (pb)**	
			Uncorrected	Corrected on Sec. Reactions (EPAX3.01)
This work	4	345	1.54±0.24±0.46	1.33 ±0.21±0.40
H. Suzuki et al.,	4	345	0.86±0.2±0.43	0.74 ±0.17±0.37
TEST exp.	8 + 0.2 W	345	1.5±0.6±0.45	1.1 ±0.44±0.33
C. Hinke et al,	21.6	1000	5.8 ± 2.1	2.8 ± 1.0
EPAX 3.01			5.76	
EPAX 2.15			7.43	

H.Suzuki, et al, NIMB 317 (2013) 756, C.B.Hinke, et al, Nature 486 (2012) 341, TEST exp.: I. Celikovic, PhD Thesis, GANIL 2013, EPAX 2.15: K. Sümmer, B. Blank, Phys. Rev. C 61, 034607 (2000). EPAX 3.01 K. Sümmer, Phys. Rev. C 86, 014601 (2012).

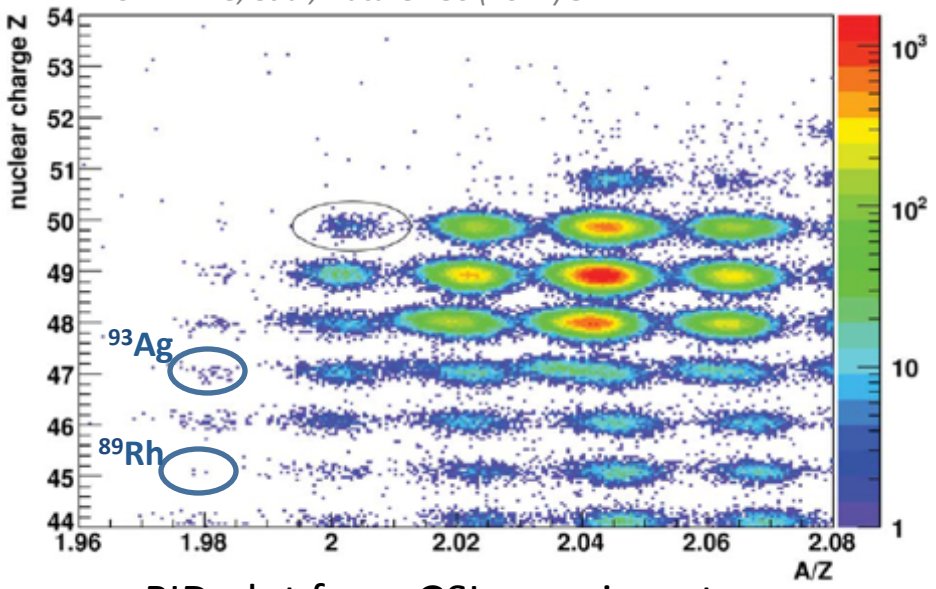
- reduced discrepancy when correction on sec. reactions in target applied
- growing discrepancies in neutron deficient region call for new EPAX parameterization

New proton emitters:

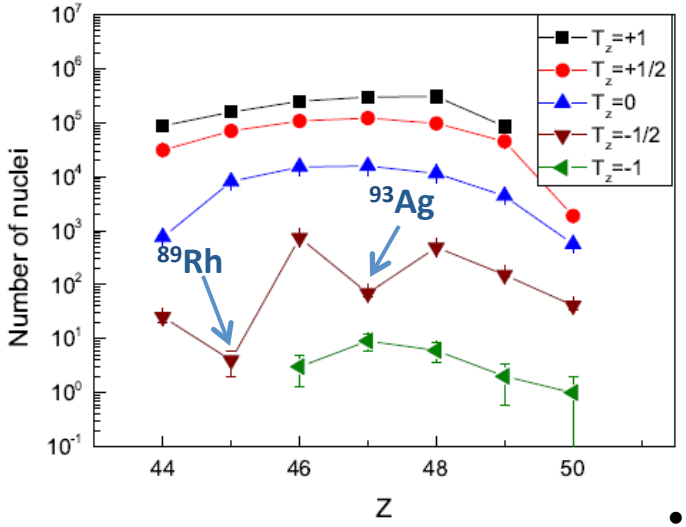


PID plot from RIBF experiment

C.B.Hinke, et al, Nature 486 (2012) 341



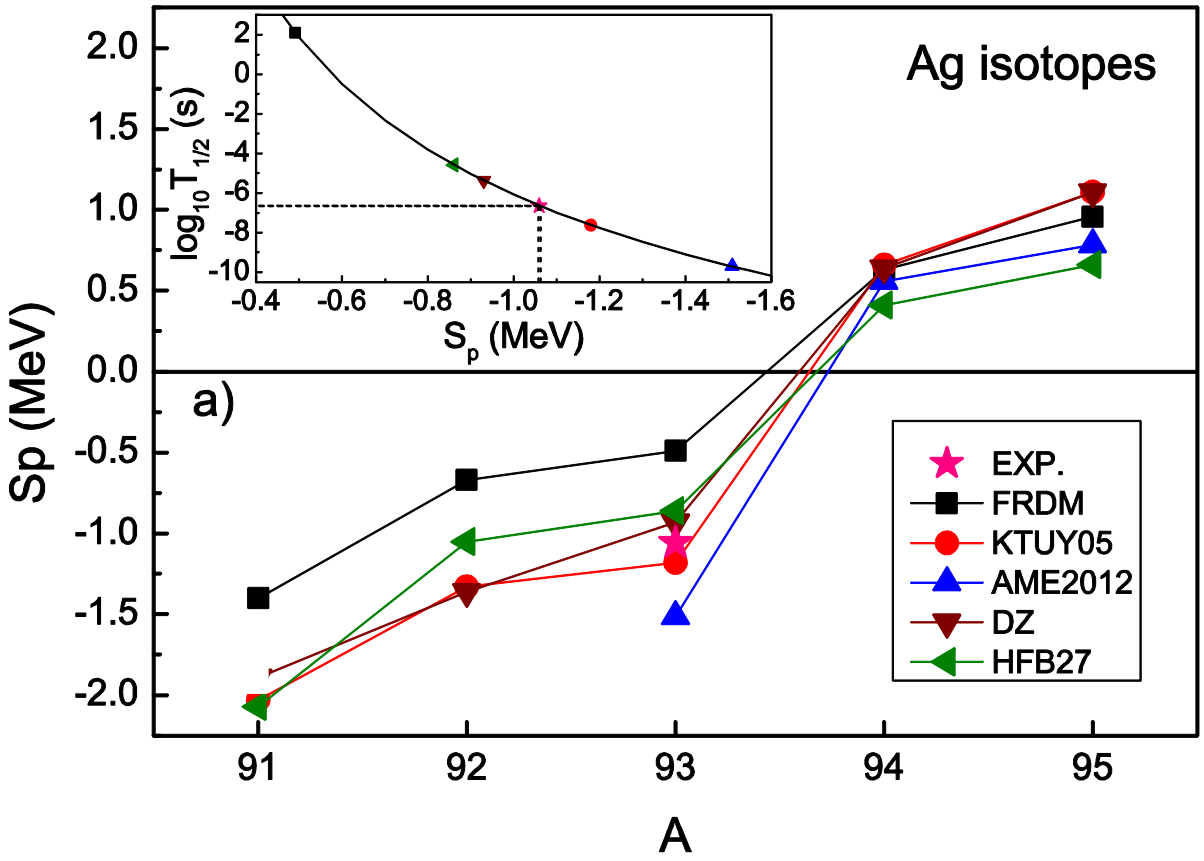
PID plot from GSI experiment



- drop in number of detected ^{93}Ag and ^{89}Rh nuclei (from GSI and RIKEN experiments)
- ^{93}Ag and ^{89}Rh: proton emitters
  - $T_{1/2}$ ~ TOF
  - > 10σ confidence interval
- all identified nuclei are stable against 2p and α emission

New proton emitters: ^{93}Ag

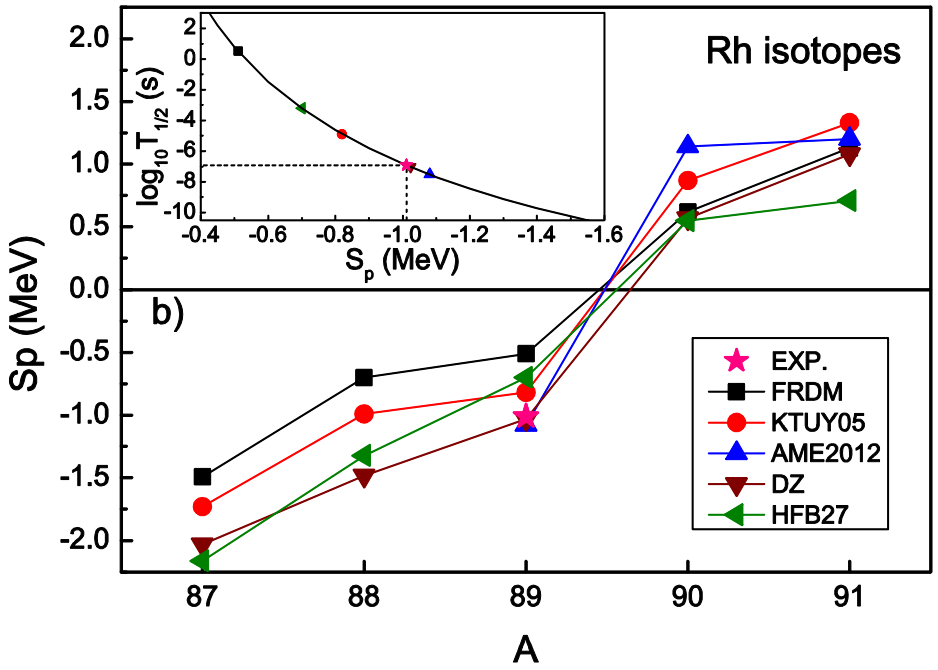
- Proton separation energies S_p deduced:
  - from measured half-lives,
  - using simple model of proton emission (S. Delion et al., PRL96 (2013) 072501)
  - assuming proton is emitted from $\pi g_{9/2}$ orbital



$$T_{1/2}(^{93}\mathrm{Ag}) = 225^{+10}_{-8}\ \mathrm{ns}$$

$$S_p(^{93}\mathrm{Ag}) = -1061 \pm 2\ \mathrm{keV}$$

New proton emitters: ^{89}Rh and lower limit for ^{97}In



$$T_{1/2}(^{89}\mathrm{Rh}) = 119^{+17}_{-7}\ \mathrm{ns}$$

$$S_p(^{89}\mathrm{Rh}) = -1012^{+7}_{-3}\ \mathrm{keV}$$

Lower limit of the half-life of ^{97}In

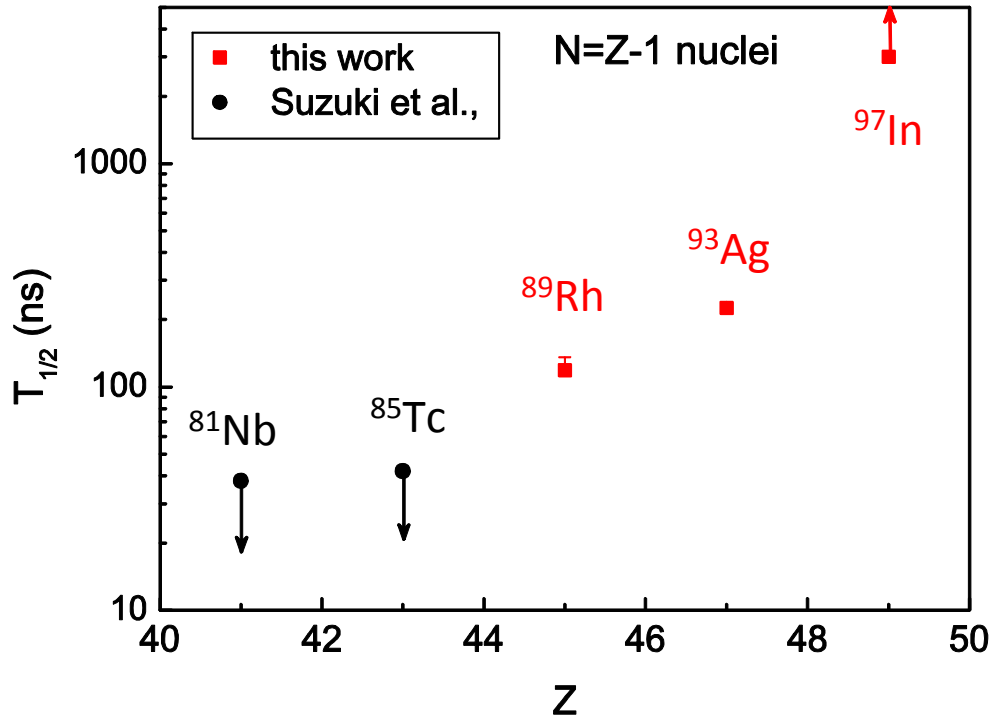
- A drop in number of detected numbers of ^{97}In not observed
- Assumption: drop will be observed if detected number of ^{97}In would be at least 2σ of the number of events

$$T_{1/2}(^{97}\mathrm{In}) > 3\ \mu\mathrm{s}$$

β-$T_{1/2}$ (^{97}In) = 31ms - preliminary

Systematics of N=Z-1 proton emitters from $\pi g_{9/2}$

$T_{1/2}$ (^{97}In) = 31ms - preliminary



- Half-lives of N=Z-1 nuclei are increasing towards Z=50
- Systematics shows stabilising effect of the Z=50 shell closure

Conclusions:

- Influence of secondary reactions in target on cross section measurements
- Cross sections in good agreement between diff. experiments
- Discovery of new isotopes: ^{96}In, ^{94}Cd, ^{92}Ag, ^{90}Pd
- The p drip-line crossed for odd-Z nuclei below ^{100}Sn
- Discovery of new proton emitters: ^{93}Ag, ^{89}Rh
  - deduced half-lives
  - S_p estimated using simple model of proton emission
- Estimated lower limit of the half-life of ^{97}In
- Demonstrated stabilizing effect of the N=50 shell closure

  (from the systematics of the half-lives of N=Z-1 nuclei)

I. Čeliković[1,2], M. Lewitowicz[1], G. de France[1], R. Gernhäuser[3], R. Krücken[4], S. Nishimura[5], H. Sakurai[6], H. Baba[5], B. Blank[7], A. Blazhev[8], P. Boutachkov[9], F. Browne[10], P. Doornenbal[5], T. Faestermann[3], Y. Fang[11], J. Giovinazzo[7], N. Goel[9], M. Gorska[9], S. Ilieva[12], T. Isobe[5], A. Jungclaus[13], G. D. Kim[14], Y.-K. Kim[14], I. Kojouharov[9], N. Kurz[9], G. Lorusso[5], D. Lubos[3], K. Moschner[8], I. Nishizuka[15], J. Park[4], Z. Patel[16], M. Rajabali[4], S. Rice[16], H. Schaffner[9], L. Sinclair[17], P. A. Söderström[5], K. Steiger[3], T. Sumikama[15], Z. Wang[4], H. Watanabe[18], J. Wu[19], and Z. Xu[6]

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Thank you for your attention