Beta-decay studies of nuclei near the 1st r-process peak at SPES: challenges and opportunities

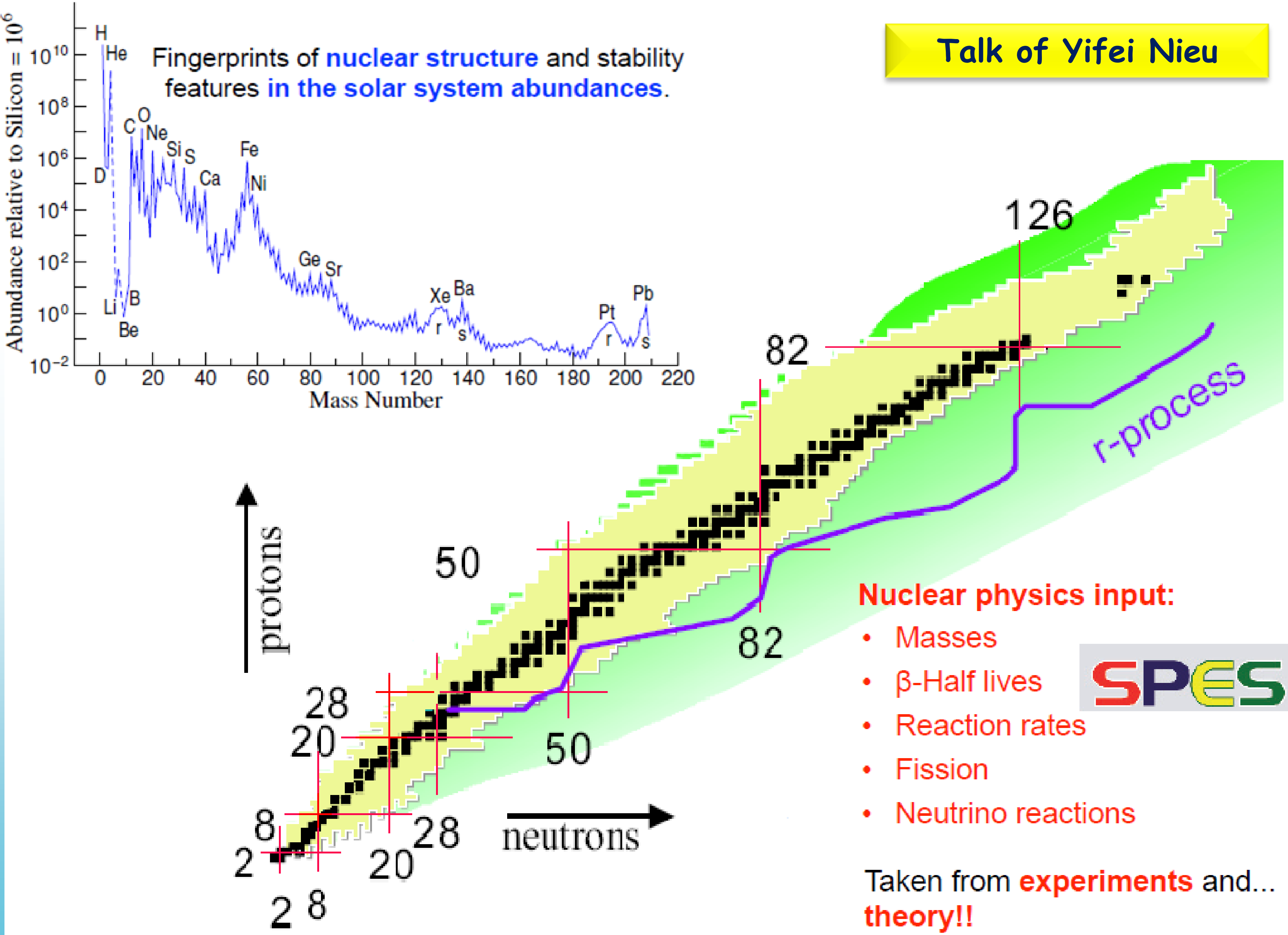
- Teresa Kurtukian-Nieto
- CEN Bordeaux-Gradignan

- SPES one-day Workshop on the Physics at SPES with non reaccelerated beams

- Milan, 20th – 21th April, 2015

Stellar nucleosynthesis r- process

Talk of Yifei Nieu



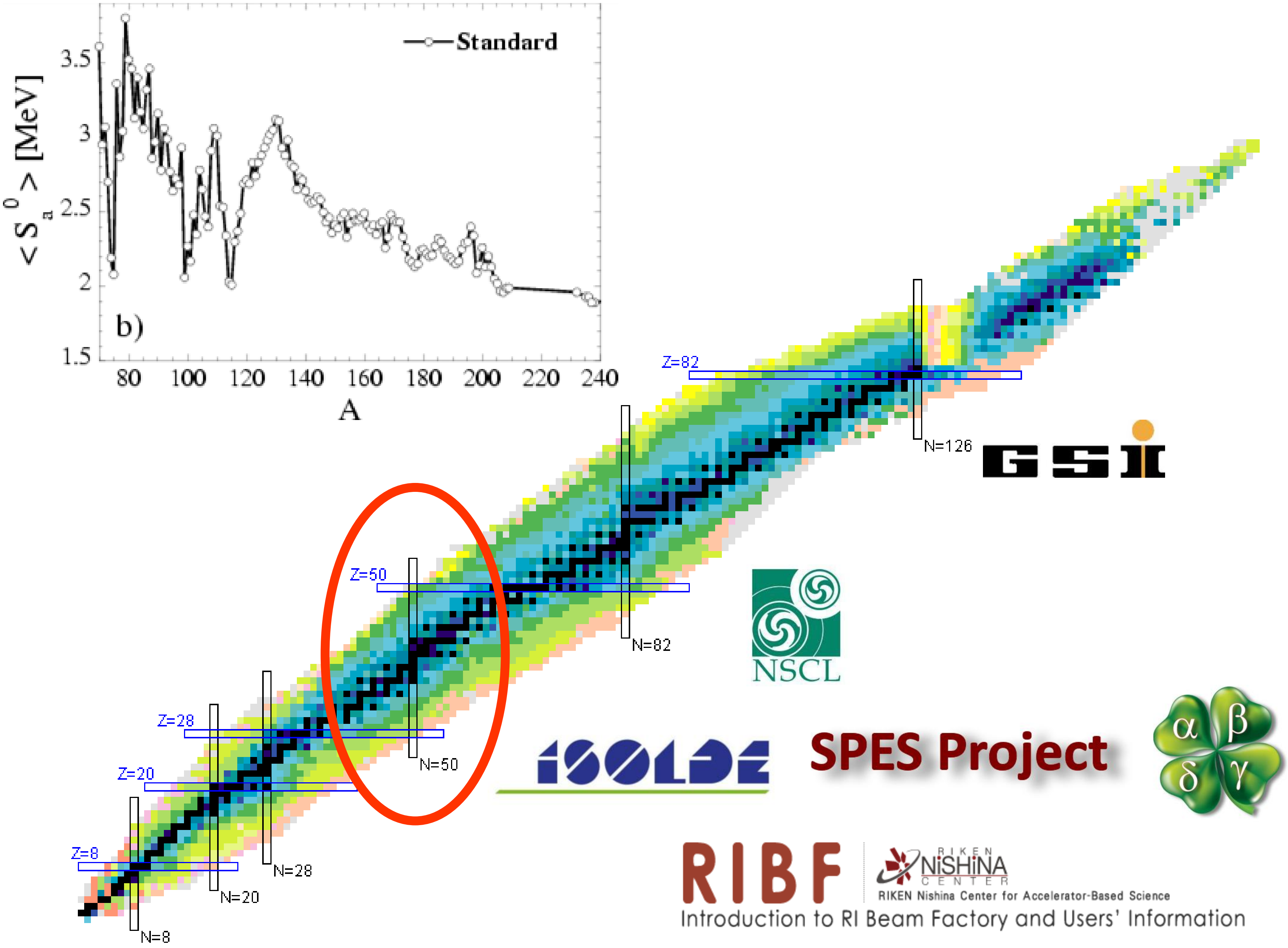
Fingerprints of **nuclear structure** and stability features **in the solar system abundances**.

Nuclear physics input:

- Masses
- β-Half lives
- Reaction rates
- Fission
- Neutrino reactions

Taken from **experiments** and... **theory!!**

Progress on r- process nuclei



GSI

NSCL

ISOLDE

SPES Project

α β δ γ

RIBF

RIKEN NiSHiNA CENTER

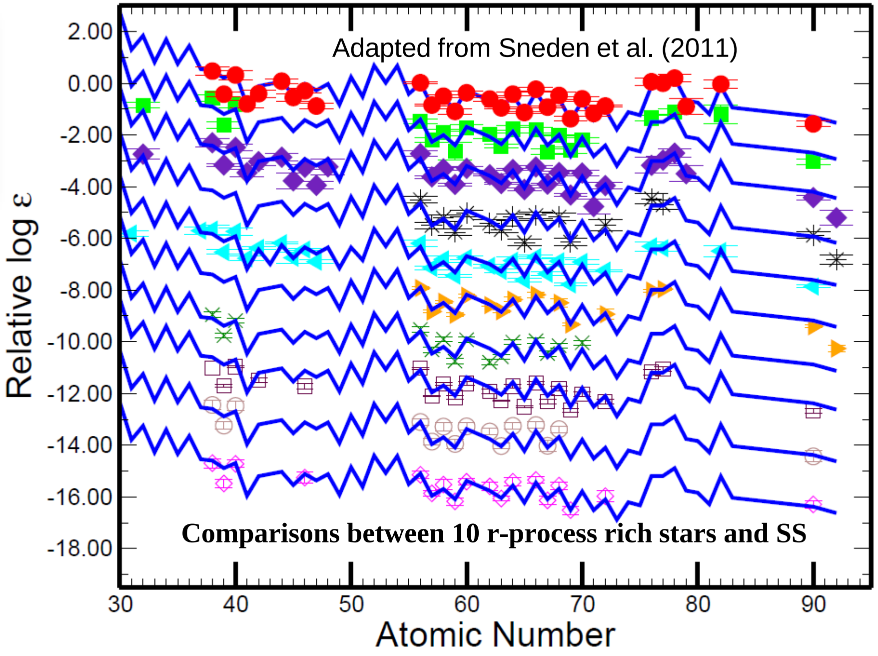
RIKEN Nishina Center for Accelerator-Based Science

Introduction to RI Beam Factory and Users' Information

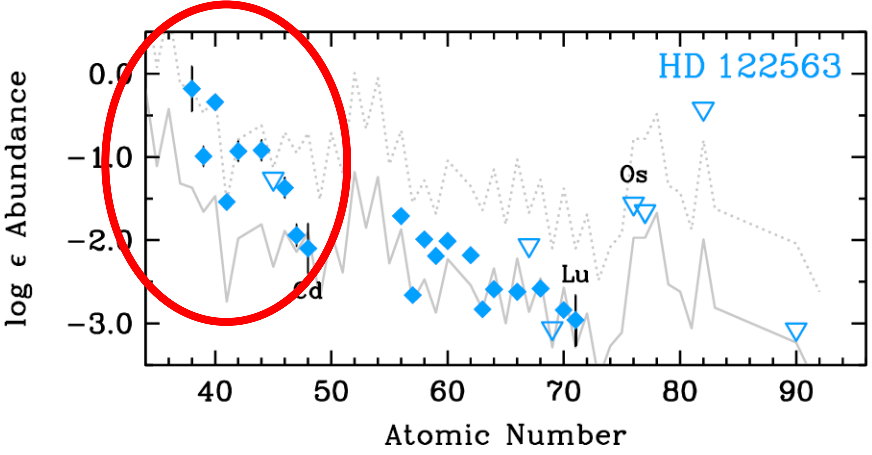
r- process and abundances in ultra metal-poor stars

UMP giants stars provide crucial constraints to the stellar nucleosynthesis.

Its elemental abundances are consistent with the solar r-process elemental distribution.


Adapted from Sneden et al. (2011)

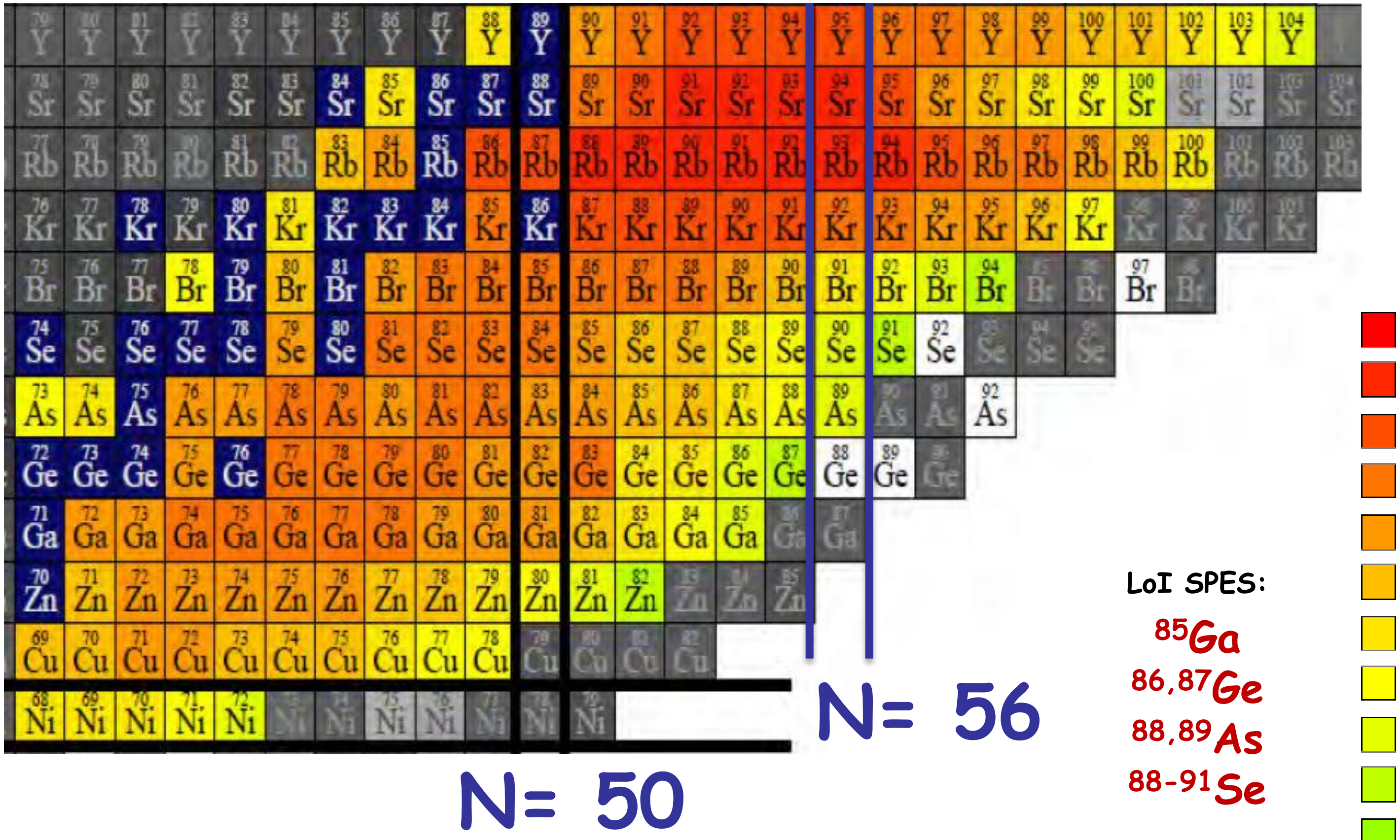
Comparisons between 10 r-process rich stars and SS



Overproduction of stable Sr, Y, and Zr isotopes in some UMP, compared to the SS r-process pattern.

r- process and abundances in ultra metal-poor stars

One explanation suggested would be the possible existence of a new N = 56 subshell.



LoI SPES:

^{85}Ga

^{86,87}Ge

^{88,89}As

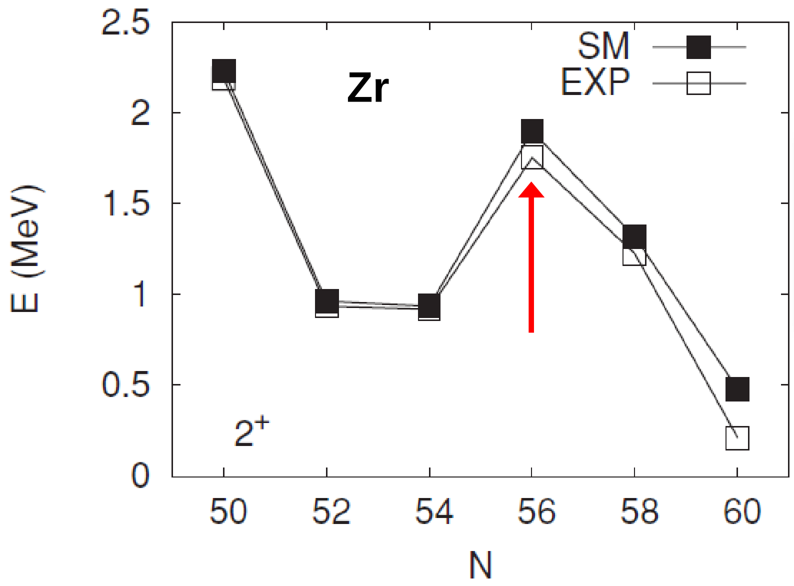
$^{88-91}$Se

- 🟥 > 10^11
- 🟥 10^10 - 10^11
- 🟧 10^9 - 10^10
- 🟧 10^8 - 10^9
- 🟧 10^7 - 10^8
- 🟨 10^6 - 10^7
- 🟨 10^5 - 10^6
- 🟨 10^4 - 10^5
- 🟩 10^3 - 10^4
- 🟩 10^2 - 10^3
- 🟩 10 - 10^2
- 🟩 < 10

SPES beam intensities (*fission on UCx*) after the Ion-Source (1+)

In an hypothetical N = 56 "ladder" the β decay of ^{88}Ge, ^{89}As, and ^{90}Se would immediately translate into an enhanced production of Sr, Y, and Zr.

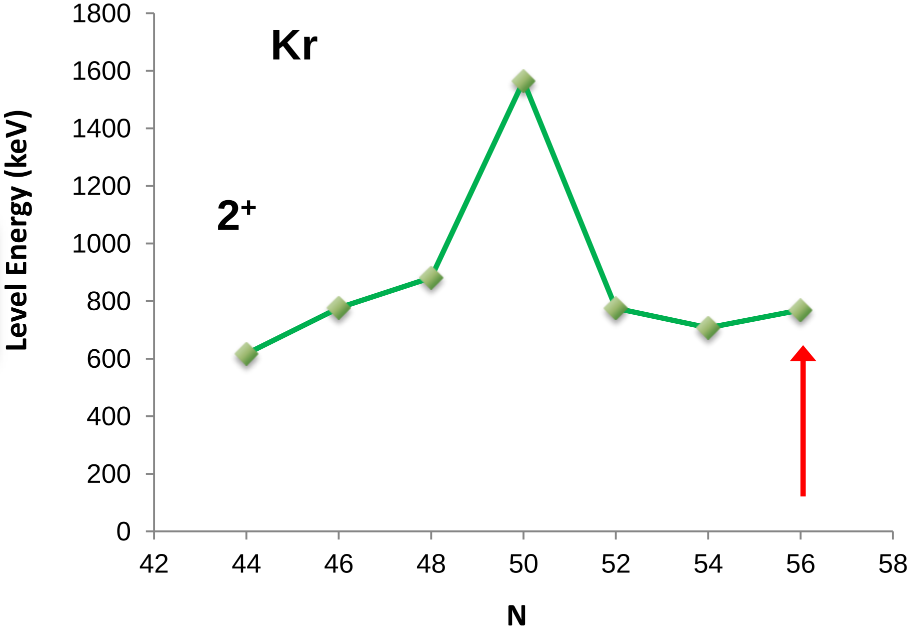
Signatures of a *N = 56 subshell closure ?*



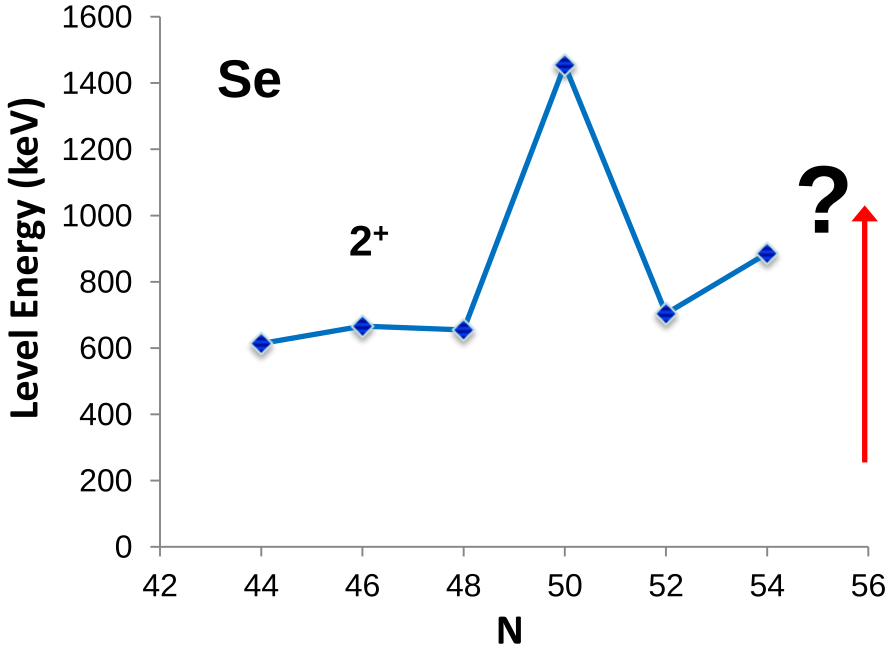
K. Sieja et al. PRC 79, 064310 (2009)

Presence of an *N = 56 subshell gap shown for Z* = 37–42 on the basis of the $E(2_1^+)$ systematic.

Vanishing of this subshell for the Kr isotopes.



Signatures of a *N = 56 subshell closure ?*



✓Unexpectedly high $E(2_1^+)$ measured for $^{88}Se_{54}$

✓*Even* higher in $^{90}Se_{56}$? ⇨ compatible with a spherical shape.

✓$T_{1/2}$ of ^{90}Se recently measured by M. Quinn et al. (PRC 85, 035807, 2012)

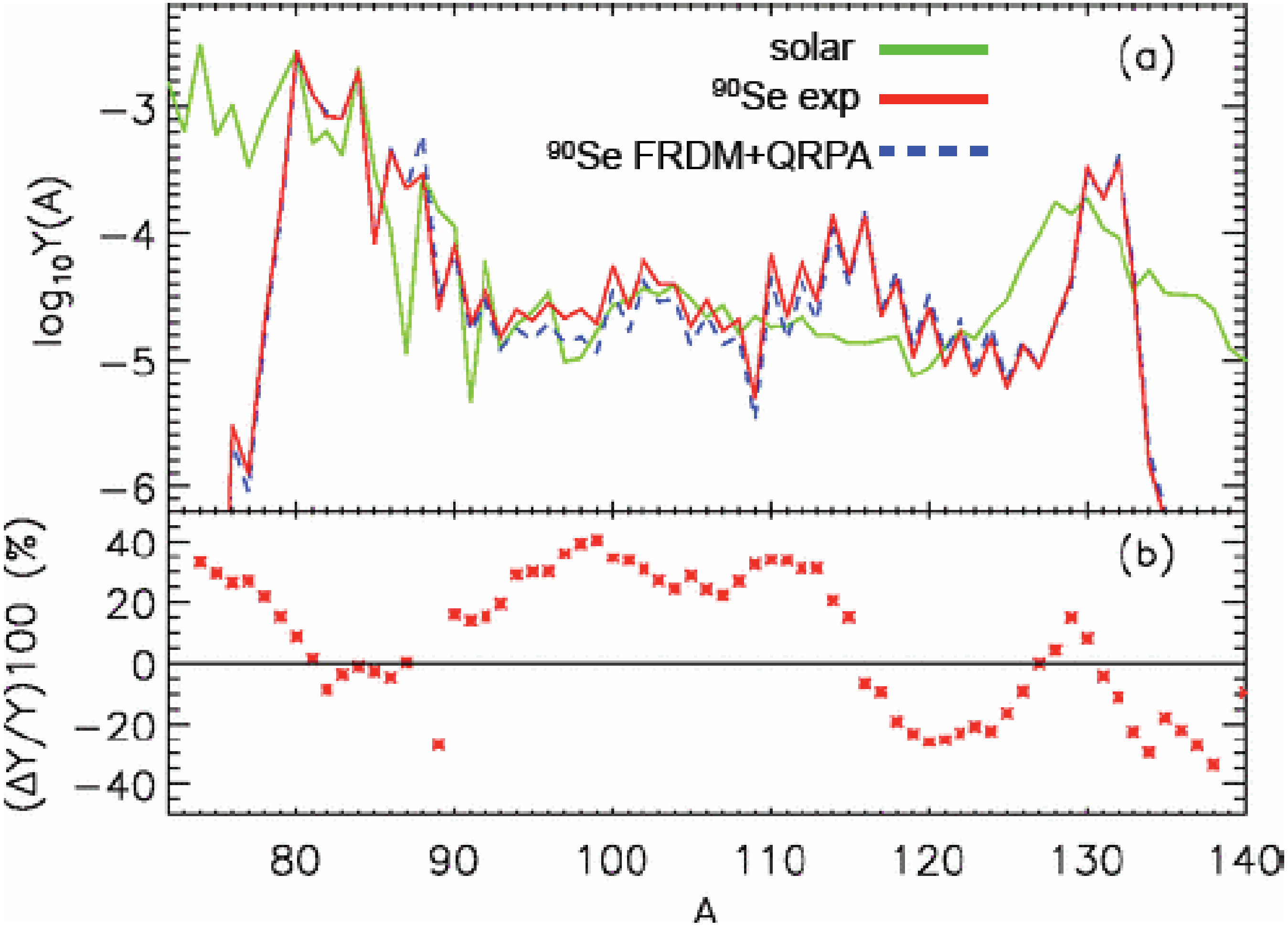
$$T_{1/2} = 195(7)^{+95}_{-65}\,\mathrm{ms}$$

✓The half-life agrees with results obtained from a standard global QRPA model used in r-process calculations, indicating that ^{90}Se has a quadrupole shape incompatible with a closed N=56 subshell in this region.

^{90}Se and the r-process

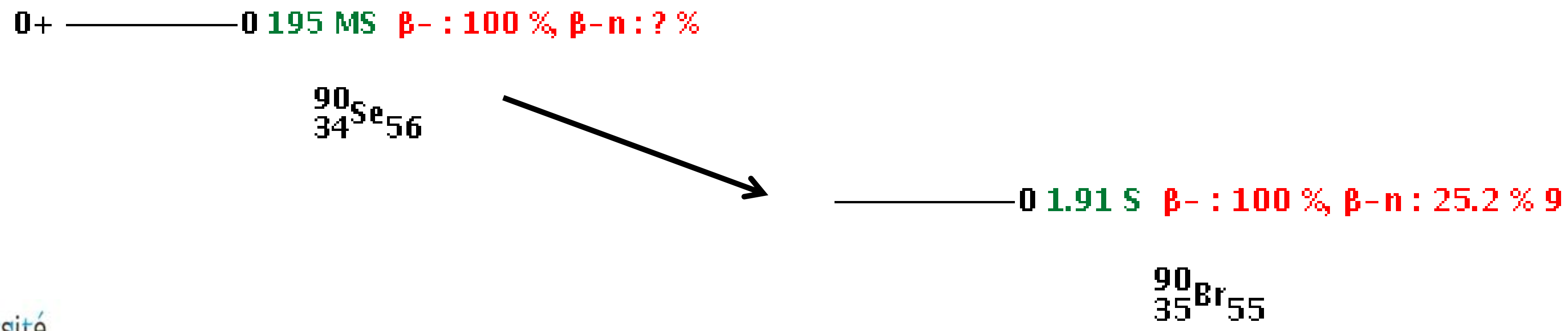
Introduction of measured $T_{1/2}$ in network calculations

More than 40% variations



M. Quinn et al. PRC 85, 035807, 2012

Experimental challenge: background from daughters

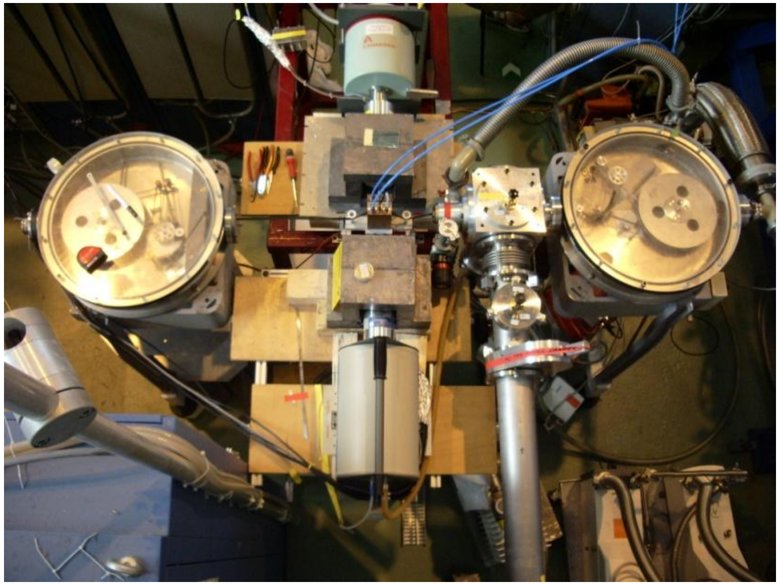


According to SPES Beam Intensity Tables ^{90}Br is produced 50times more than ^{90}Se.

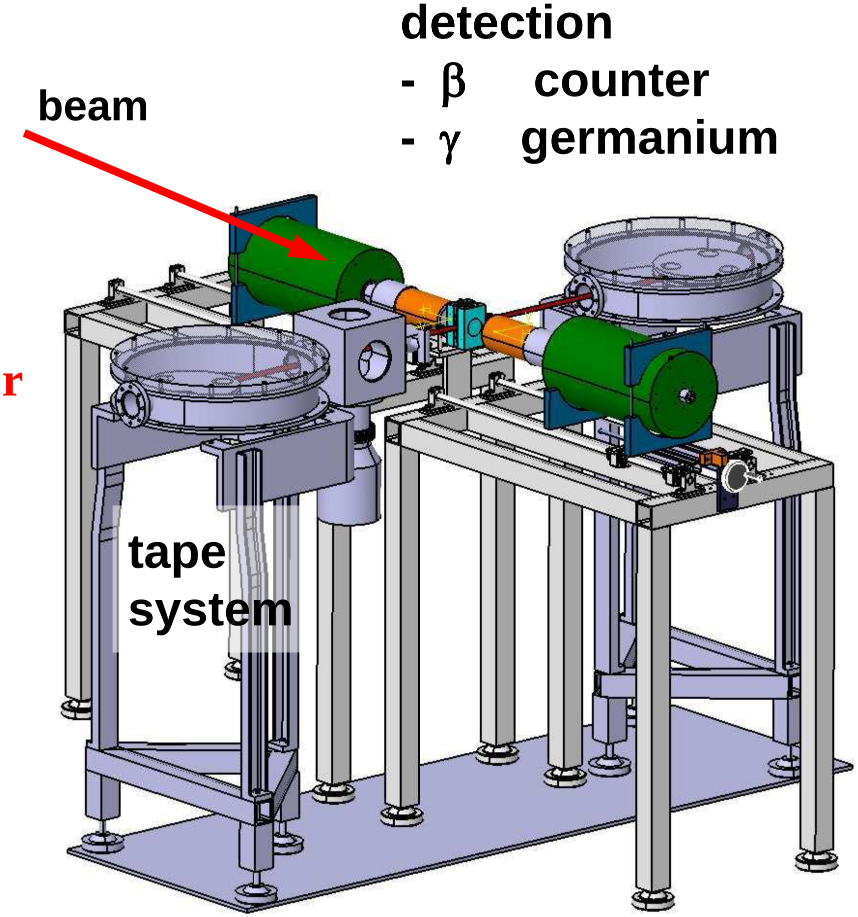
If ^{90}Br directly produced in fission is not removed, even if the half-life of ^{90}Se is 10 times shorter than ^{90}Br one would get, even for very short time-cycles, in every bin 5x more counts from ^{90}Br than from ^{90}Se and for the neutrons it is even worse, since the daughter is an odd-odd nucleus and it has therefore usually a much (about order of magnitude) higher Pn value.

Solution: remove the direct production of ^{90}Br by using beam purification stage → SPES-HRMS

Measurement of the decay characteristics



Tape transport system
Beam-on/off time sequence
β-γ, γ-γ coincidence for β decay studies



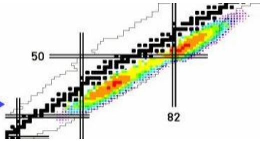
Can be coupled with a neutron-detector

- ✓ Pn of the nuclei of interest.
- ✓ neutron-gated γ-ray spectra

→very sensitive tool to obtain detailed information on the nuclear structure of daughter nuclei and to reveal fine structure in the β-delayed neutron emission process.

Future and present ISOL facilities in Europe

EURISOL $>10^{15}$ fissions/second

Spiral2 

$5\ 10^{13}$ to 10^{14} fissions/second

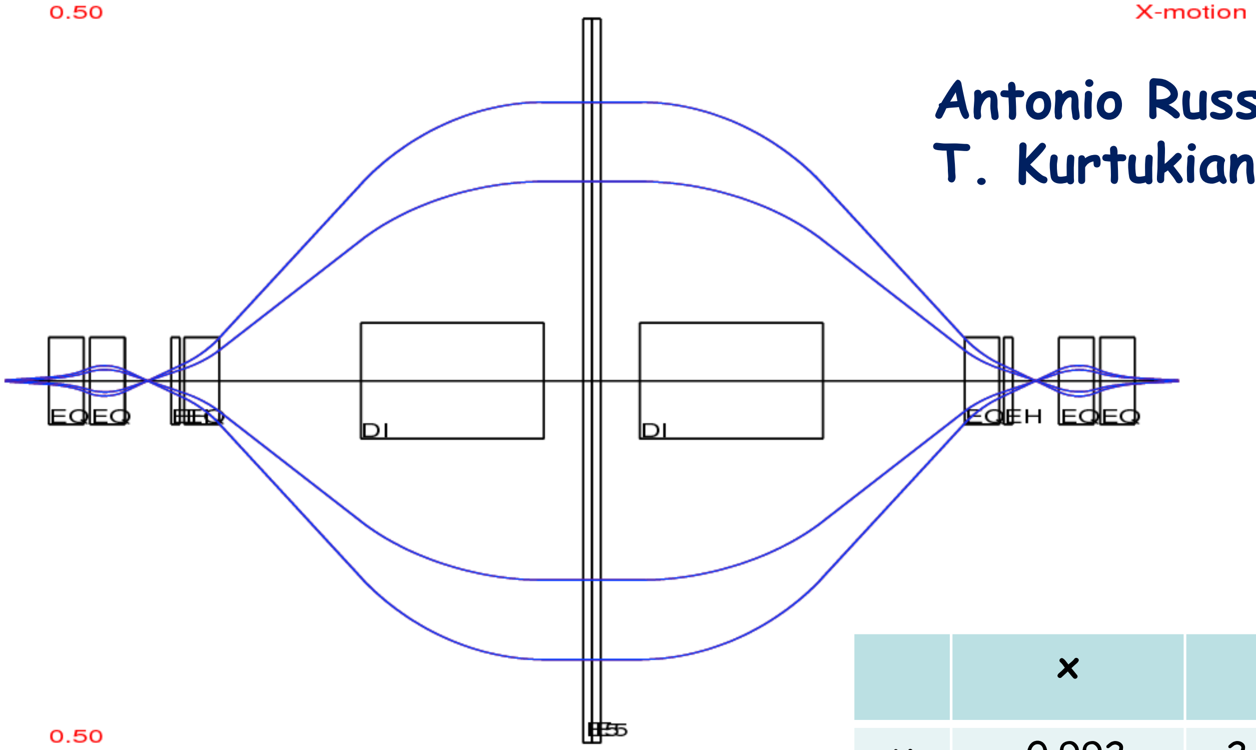
SPES Project 10^{13} fissions/second

ISOLDE 10^{12} (10^{13}) fissions/second

ILL NEUTRONS FOR SCIENCE® LOHENGRIN 10^{12} fissions/second

ALTO IPN 10^{11} fissions/second

SPES HRMS: COSY Infinity calculation

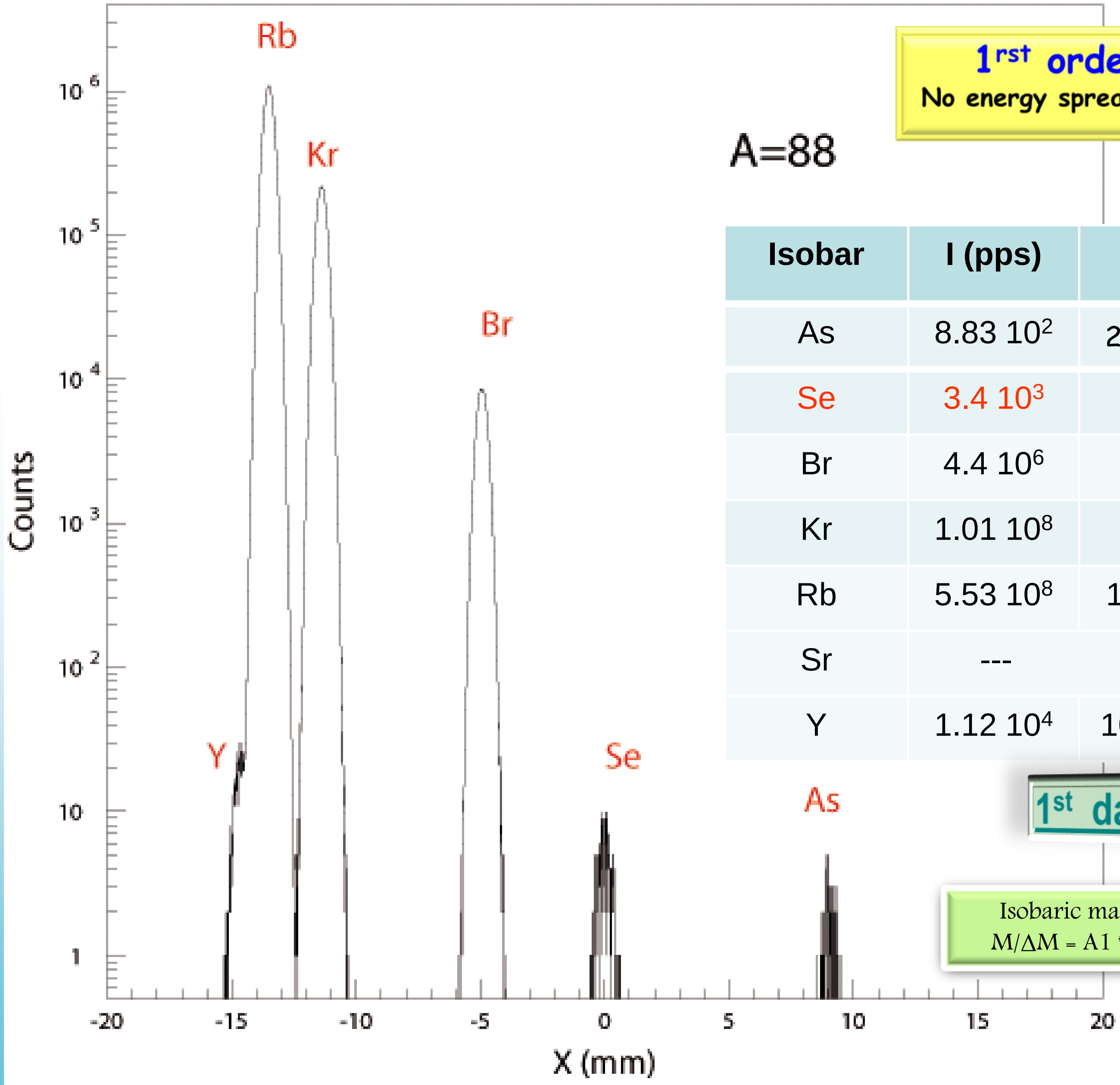


Antonio Russo, LNS Catania
T. Kurtukian-Nieto, CENBG

	x	a	y	b
x	-0.992	-2.647	0	0
a	0.579E-02	-0.992	0	0
y	0	0	1.365	5.429
b	0	0	0.159	1.3652
δm	-58.99	-78.38	0	0

Use of SPES HRMS for isobar purification

1^{rst} order calculation:
No energy spread/misalignment included



A=88

Isobar	I (pps)	$T_{1/2}$	m/Δm
As	$8.83\ 10^2$	$200(5)^{+200}_{-90}$ ms	-6 511
Se	$3.4\ 10^3$	1.53 (6) s	0
Br	$4.4\ 10^6$	16.29(6) s	+11 960
Kr	$1.01\ 10^8$	2.84 (3) h	+5 184
Rb	$5.53\ 10^8$	17.773(11) m	+4 376
Sr	---	stable	+3409
Y	$1.12\ 10^4$	106.626(21) d	+4 014

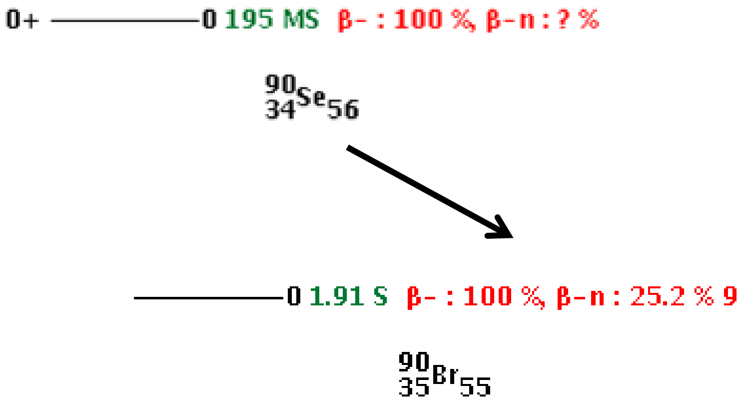
1st day UCx 5µA

Isobaric mass differences are given as
M/ΔM = A1 * 931.494013 / (M1 – M2)

Use of SPES HRMS for isobar purification

A= 90

Isobar	I (pps)	$T_{1/2}$	m/Δm
As	(1)	> 300 ns	- 5 791
Se	$4.60\ 10^{1}$	$195(7)^{+95}_{-65}$ ms	0
Br	$1.08\ 10^{5}$	1.91 (1) s	+ 9 644
Kr	$1.09\ 10^{8}$	32.32 (9) s	+ 4 402
Rb	$2.41\ 10^{9}$	158 (5) s	+ 3 577
Sr	$1.04\ 10^{8}$	28.90 (3) y	+ 2 793
Y	$1.28\ 10^{6}$	64.053(20) h	+ 2 743



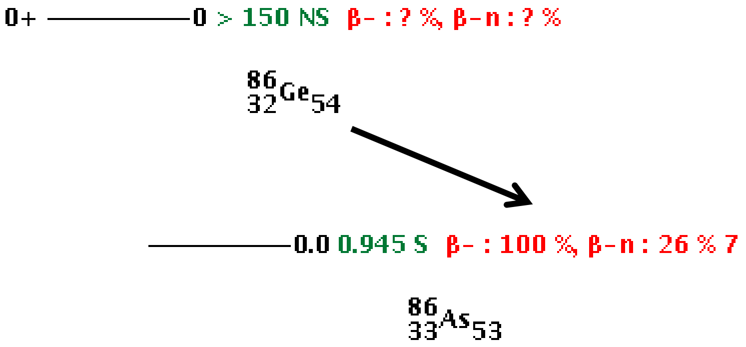
H. Sakai's talk

A= 96

Isobar	I (pps)	$T_{1/2}$	m/Δm
Rb	$2.47\ 10^{7}$	203 (3) ms	- 5 223
Sr	$3.93\ 10^{5}$	1.07 (1) s	-16 536
Y	$1.12\ 10^{7}$	5.34 (5) s	0

Use of SPES HRMS for isobar purification

A= 86



C. Gross's talk ^{86}Br

Isobar	I (pps)	$T_{1/2}$	m/Δm
Ga	(1)	> 150 ns	- 5 171
Ge	1.30 10^2	226(21) ms	0
As	3.85 10^4	0.945(8) s	+ 8 608
Se	1.67 10^5	14.3(3) s	+ 3 871
Br	1.93 10^7	55.1(4) s	+ 3 106
Kr	---	Stable	+ 2 397
Rb	4.75 10^7	18.642(18) d	+ 2 435

A= 72

Isobar	I (pps)	$T_{1/2}$	m/Δm
Ni	9.11 10^3	1.57 (5) s	0
Co	1.39 10^7	6.63 (3)s	11 479
Zn	1.83 10^7	46.5 h 1	4 726
Ga	1.07 10^7	14.10 h 2	4 578

m/Δm < 20 000

Anabel Morales-López 's talk

Use of SPES HRMS for isobar purification

A= 85

Isobar	I (pps)	$T_{1/2}$	m/Δm
Ga	$9.05\ 10^{1}$	92(4) ms	- 6 084
Ge	$2.78\ 10^{3}$	503(18) ms	0
As	$1.46\ 10^{5}$	2.021(12) s	+ 7 720
Se	$5.40\ 10^{5}$	32.9(3) s	+ 4 089
Br	$2.46\ 10^{7}$	2.90(6) m	+ 3 100
Kr	$1.48\ 10^{7}$	10.752(25) y	+ 2 787

A= 87

Isobar	I (pps)	$T_{1/2}$	m/Δm
Ge	$1.75\ 10^{6}$	~0.14 s	- 6 899
As	$5.18\ 10^{3}$	0.56(8) s	0
Se	$2.88\ 10^{4}$	5.50(12) s	+ 7 646
Br	$1.67\ 10^{7}$	55.65(13) s	+ 4 534
Kr	$7.43\ 10^{7}$	73.3(5) m	+ 3 277
Rb	$2.00\ 10^{8}$	$4.81\ 10^{10}$ y	+ 2 832

A= 89

Isobar	I (pps)	$T_{1/2}$	m/Δm
As	$8.18\ 10^{1}$	> 300 ns	- 6 878
Se	$3.78\ 10^{2}$	0.43(5) s	0
Br	$5.58\ 10^{5}$	4.357(22) s	+ 8 842
Kr	$9.98\ 10^{7}$	3.15(4) m	+ 4 729
Rb	$1.19\ 10^{9}$	15.32(10) m	+ 3 682
Sr	$2.11\ 10^{7}$	50.563(25) d	+ 3 069

A= 91

Isobar	I (pps)	$T_{1/2}$	m/Δm
As	(1)	> 150 ns	- 6 289
Se	$1.20\ 10^{1}$	0.27(5) s	0
Br	7.2810^{3}	0.543(4) s	+ 7 589
Kr	$5.30\ 10^{7}$	8.57(4) s	+ 4 042
Rb	$2.41\ 10^{9}$	58.2(3) s	+ 3 093
Sr	$2.53\ 10^{8}$	9.65(6) h	+ 2 545
Y	$6.83\ 10^{6}$	58.51(6) d	+ 2 354

Thank you for your attention