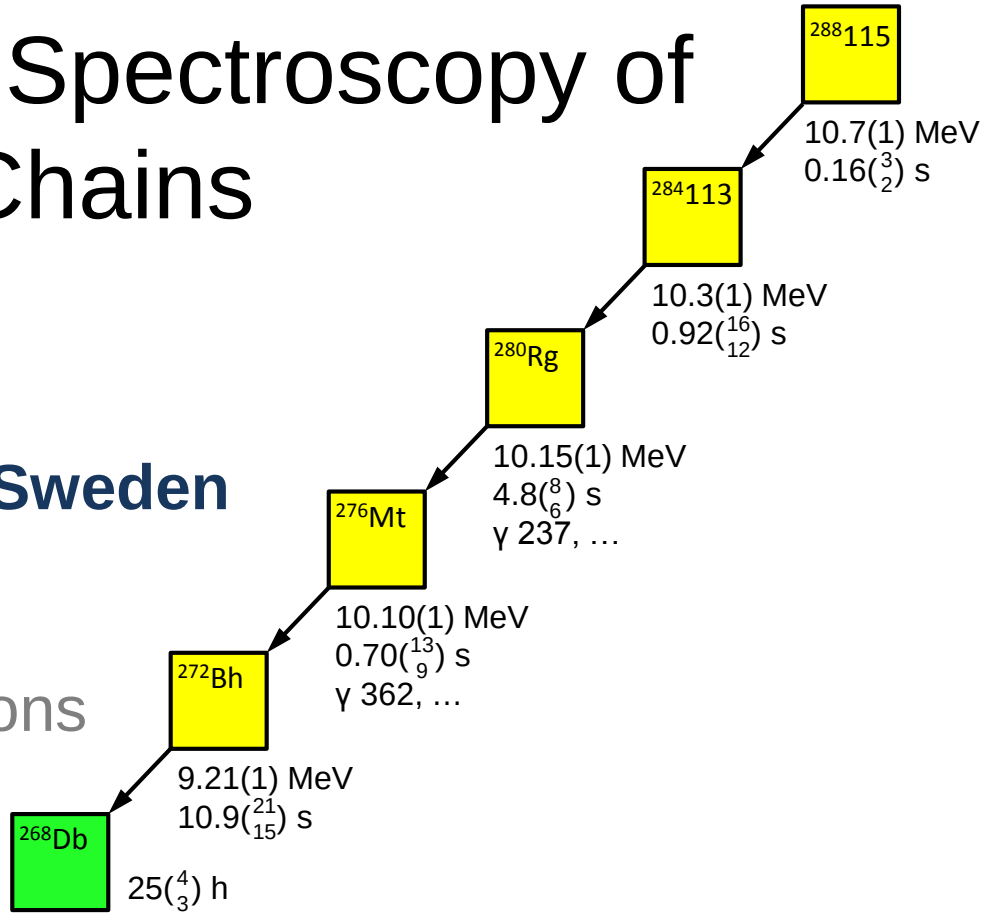
Alpha-Photon Decay Spectroscopy of Element 115 Decay Chains

D. Rudolph, Lund University, Sweden

on behalf of the

TASCA & TASISpec Collaborations



Nucleus-Nucleus Collisions

June 2015, Catania, Italy

The TASISpec / *TASCA* E115 Collaboration

… and among the top ten **APS Physics Newsmakers of 2013**

PHYSICAL REVIEW LETTERS **111, 112502 (2013)**

Spectroscopy of Element 115 Decay Chains

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(Received 11 June 2013)

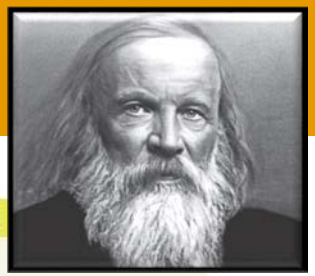
Special thanks to …

UNILAC ENSAR

Outline

- Introduction
- Experiment at GSI / *TASCA*
- Spectroscopy of $^{288}115$ and Daughters
- Nuclear Structure Results
- Links between $^{293}117$ and $^{289}115$?
- Conclusions

The Chemistry Perspective



Group #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Period 1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	(117) (Uus)	118

2011: JWG IUPAC/IUPAP approves elements 114 and 116

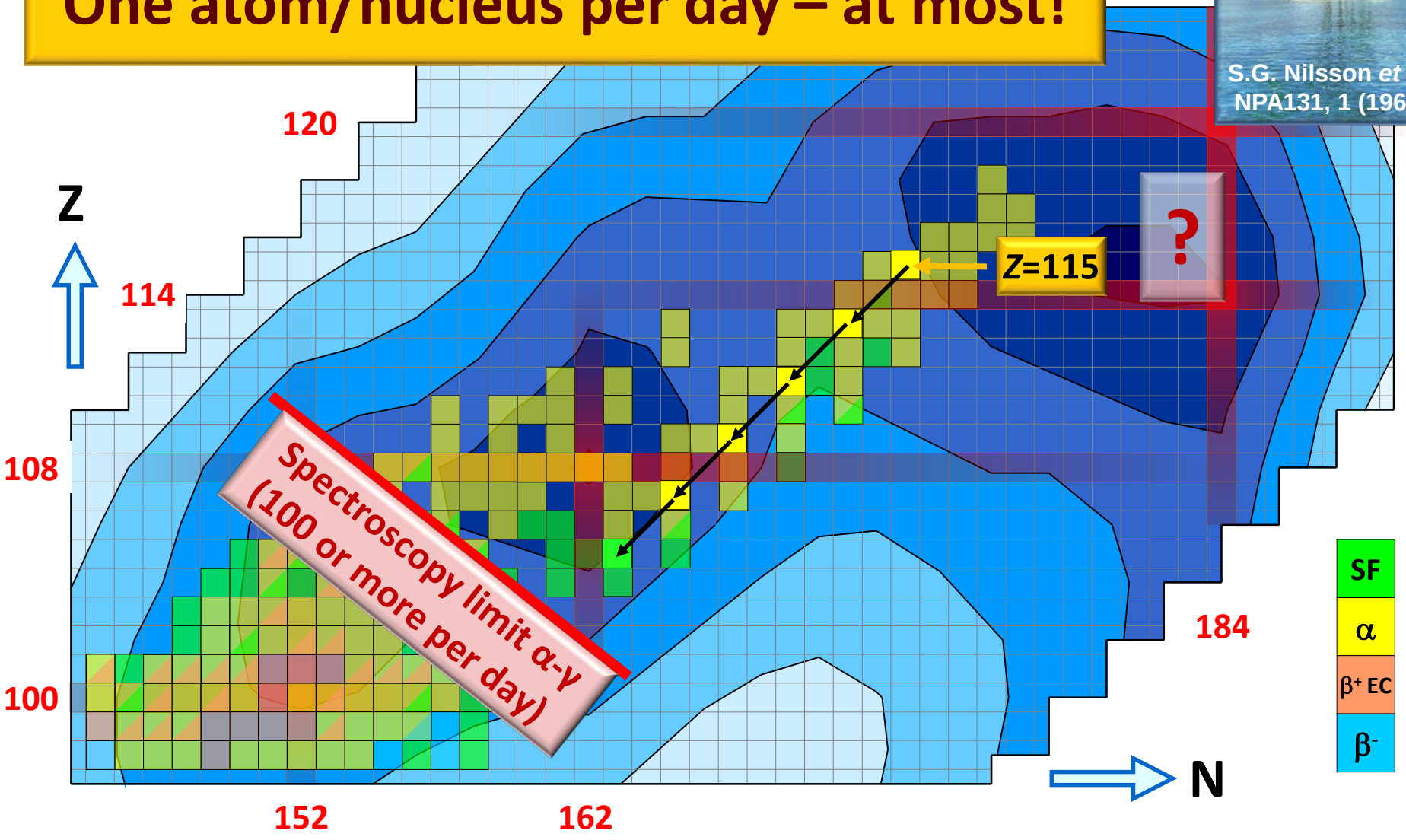
119 120

anoids	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
** Actinoids	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

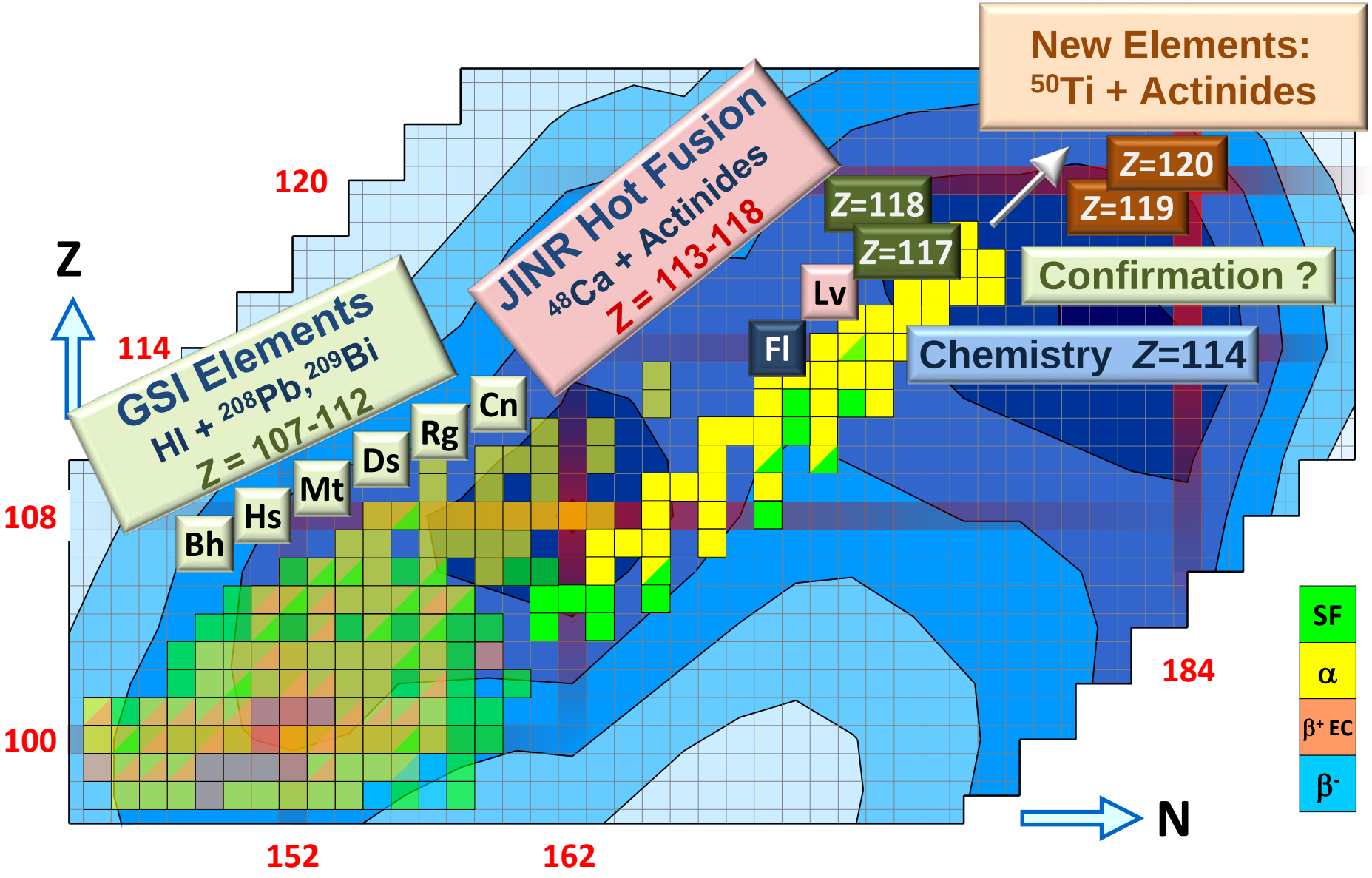
The superheavy elements are the Transactinides, $Z \geq 104$!

The Physics Perspective

One atom/nucleus per day – at most!

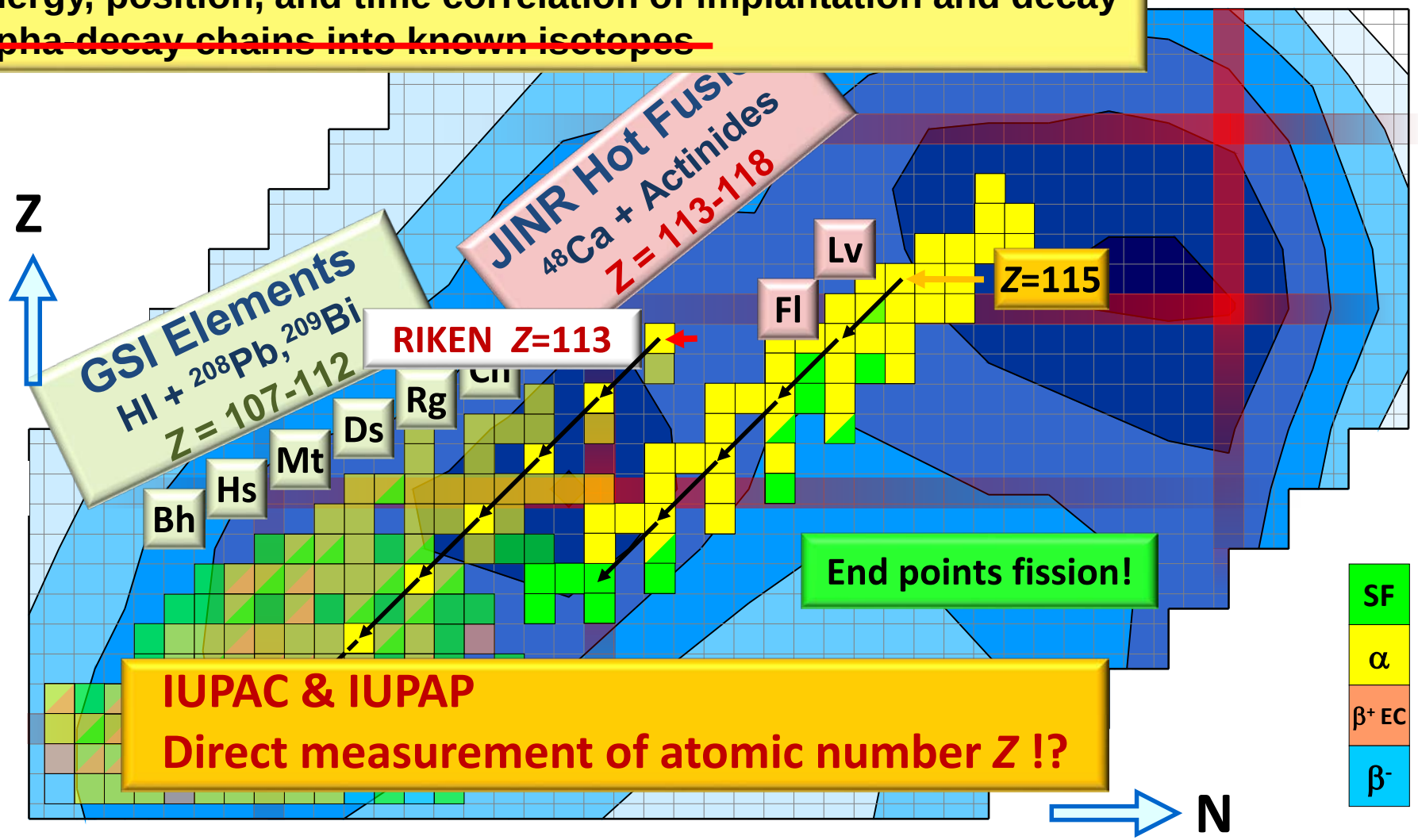


The Discovery Perspective



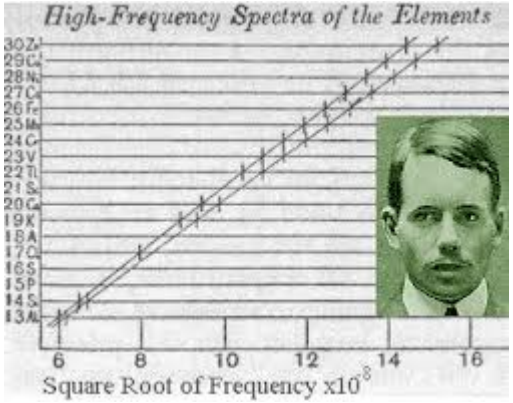
Identification Problem: $Z > 112$

Separation and implantation of fusion-evaporation products
Energy, position, and time correlation of implantation and decay
~~**Alpha-decay chains into known isotopes**~~



X-ray Fingerprinting of an Element

Moseley's Law, 1913

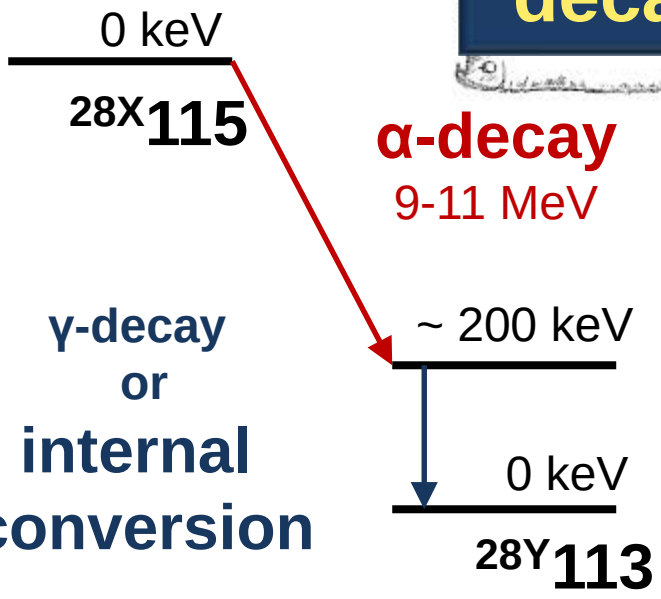


$$E(K_\alpha) \sim f(K_\alpha) \sim (Z\text{-}1)^2$$

H.G.J. Moseley, Phil. Mag. 26, 1024 (1913)

***X*-ray energies predicted down to 0.1 keV precision for superheavy elements (QED!)**

Highest *K*-conversion coefficients!



in the Rutherfordium spirit of
R. Bemis *et al*., PRL31, 647 (1973)
(observed 15 α-photon events)

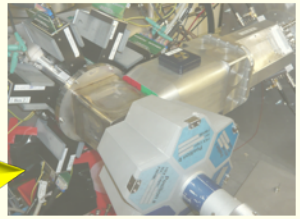
The Basic Ingredients (at GSI Darmstadt)

$^{48}Ca + {}^{243}Am \rightarrow {}^{288}115 + 3n$ αγ

$6 \cdot 10^{12}$/s 20 mg,~0.5 GBq 1-2/day

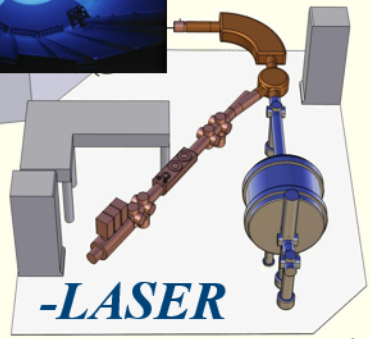
Actinide targets

TASCA



TASISpec

TRIGA-



-LASER

-TRAP

Radiochem. labs

30 E115 chains in 3 weeks!

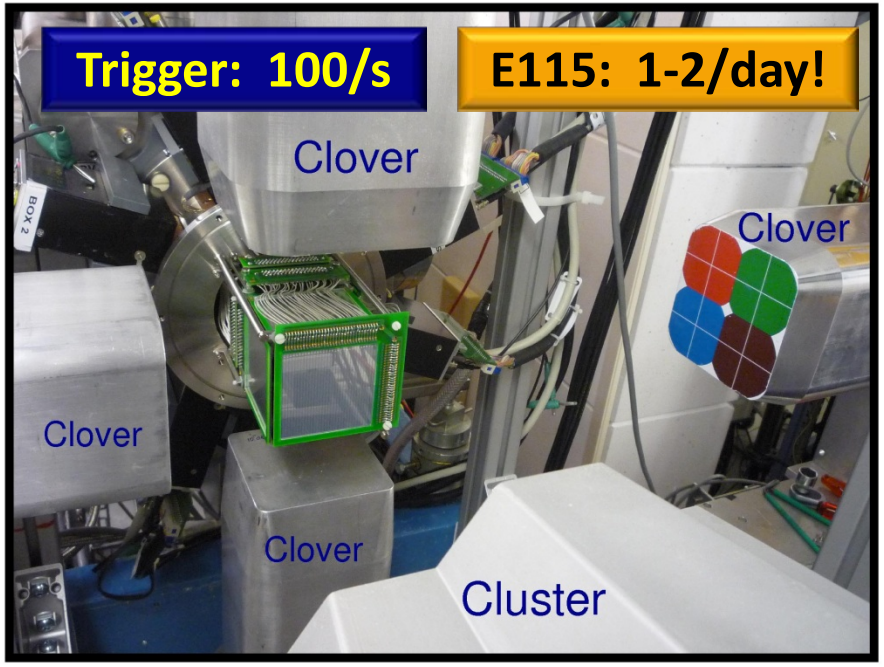
(November 2012)

TASISpec

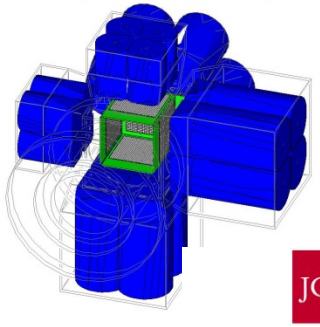
Highly efficient multi–coincidence spectroscopy set–up for TASCA's very compact focal plane image

1 Implantation DSSSD (1024 pixels)
4 box–DSSSDs (1024 pixels)
=> ~80% α–detection efficiency

4 Ge Clover (4*4 crystals)
1 Ge Cluster (7 crystals)
=> ~40% γ–detection eff. at 150 keV



L–L Andersson et al., NIM A 622, 164 (2010)
L.G. Sarmiento et al., NIM A 667, 26 (2011)



Virtually constructed with GEANT4 simulation package

JOHANNES GUTENBERG UNIVERSITÄT MAINZ
LUND UNIVERSITY
UNIVERSITY OF LIVERPOOL
HELMHOLTZ ASSOCIATION
Helmholtz Institute Mainz
GSI
UNIVERSIDAD NACIONAL DE COLOMBIA

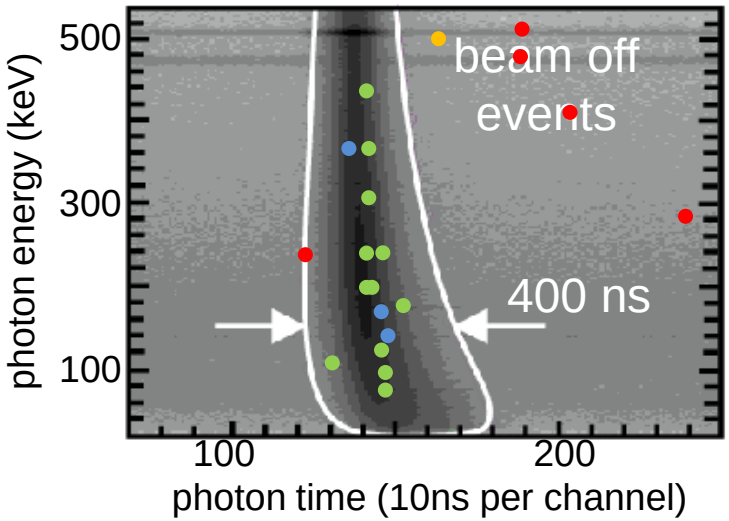
Results – $^{288}115$ (3n-channel)

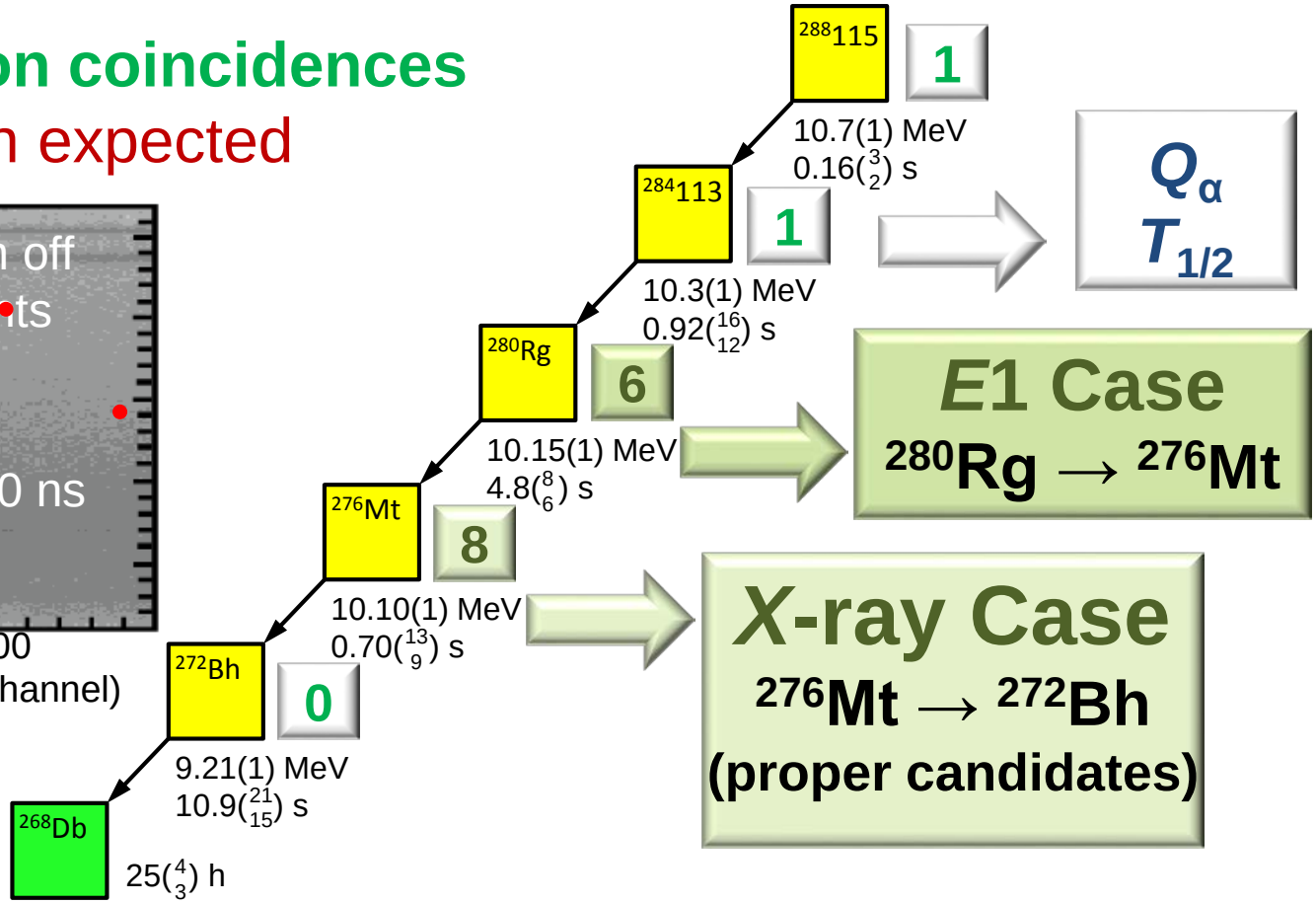
22 chains (out of 30 *TASISpec*) are compatible with the
31 chains (out of 37 DGFRS) associated with $^{288}115$

Yu. Ts. Oganessian *et al.*, Phys. Rev. C87, 014302 (2013)

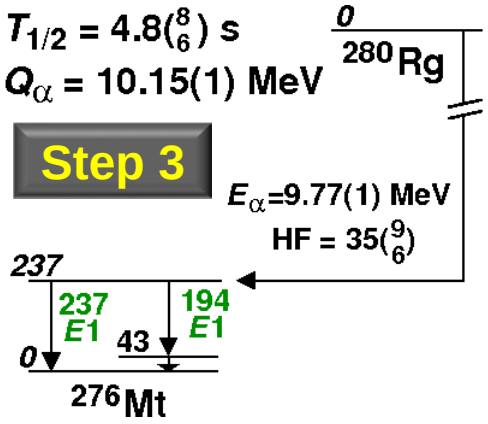
16 prompt α-photon coincidences

2-3 of random origin expected



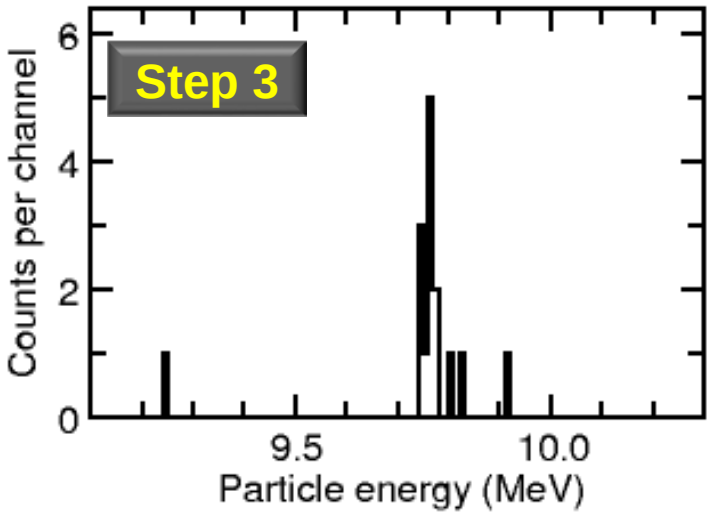


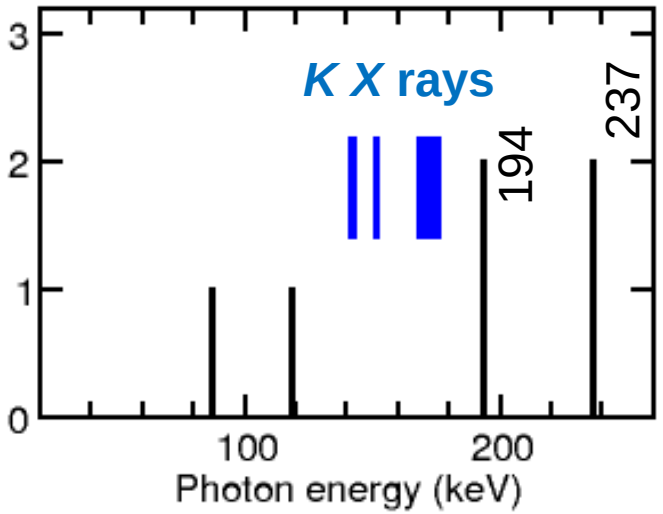
Results – $^{288}115$ (3n-chain)



$^{280}Rg \rightarrow {}^{276}Mt$

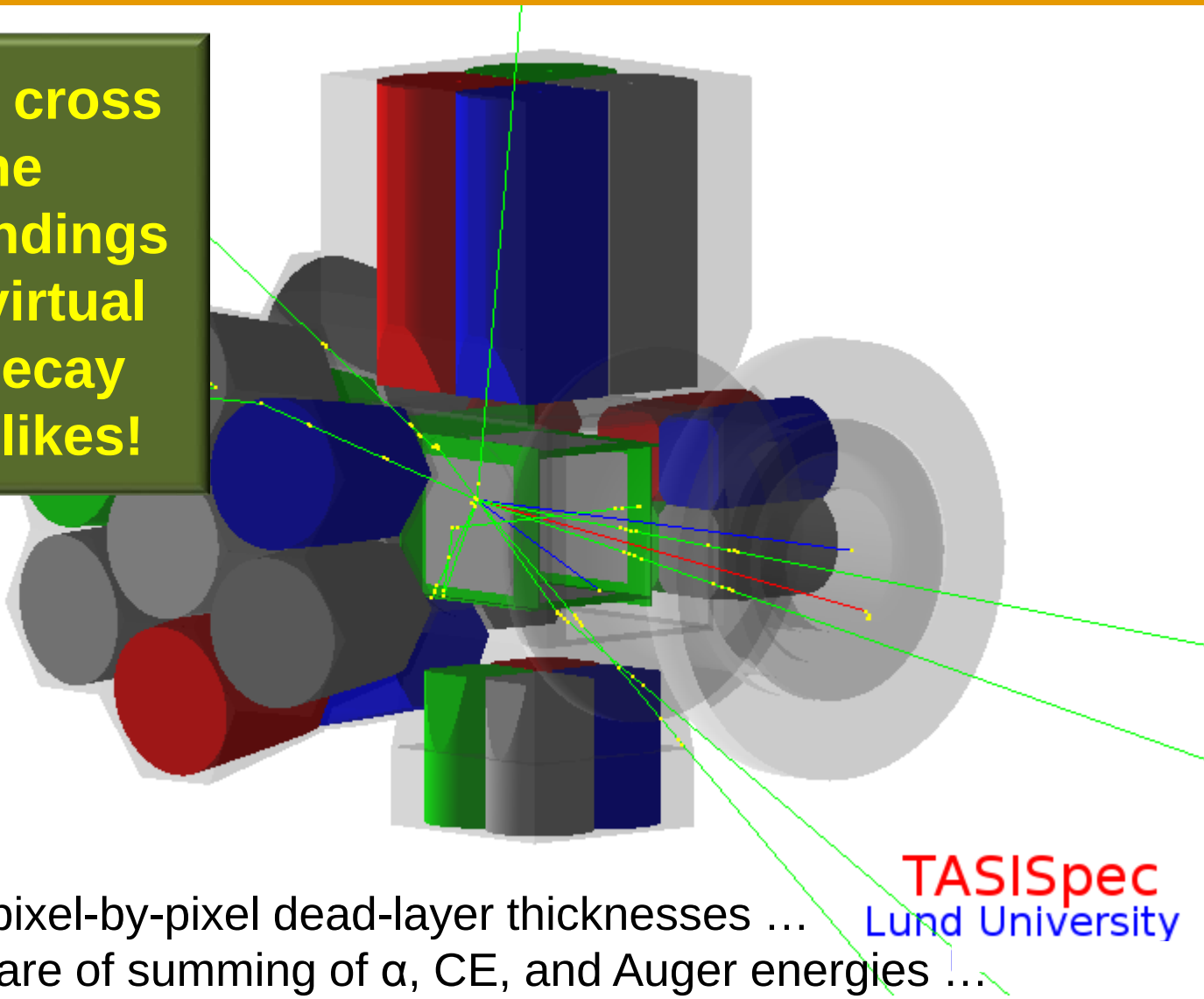
6x α-photon coincidences





TASISpec – in Virtual Geant4 Space

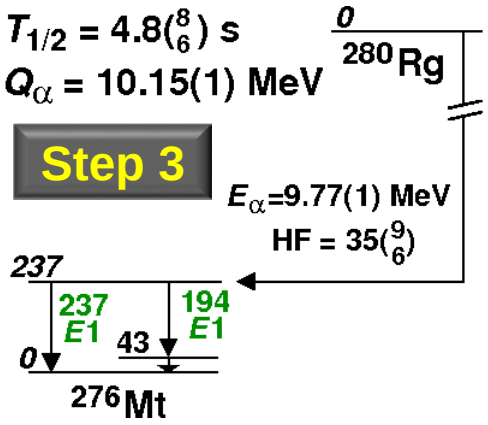
Self-consistent cross check of the experimental findings with as many virtual element 115 decay chains as one likes!



"Input level": down to pixel-by-pixel dead-layer thicknesses …
"Output level": takes care of summing of α, CE, and Auger energies …

L.G. Sarmiento *et al*., NIM A 667, 26 (2011); Proc. Science PoS(X LASNPA)057 (2014).

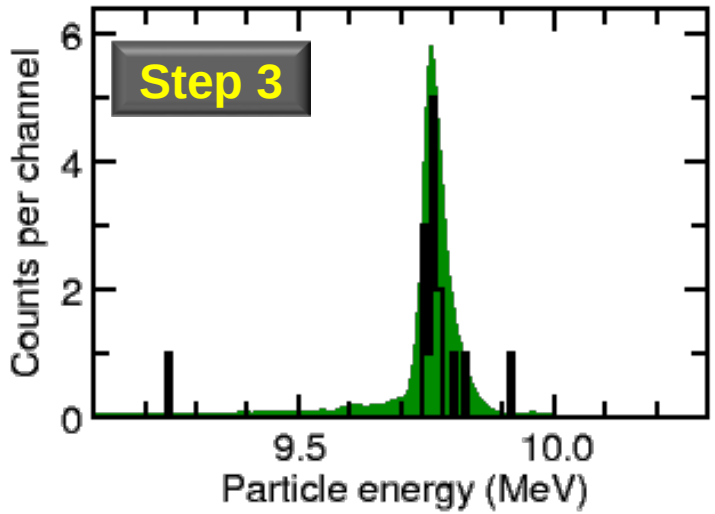
Results – $^{288}115$ (3n-chain)

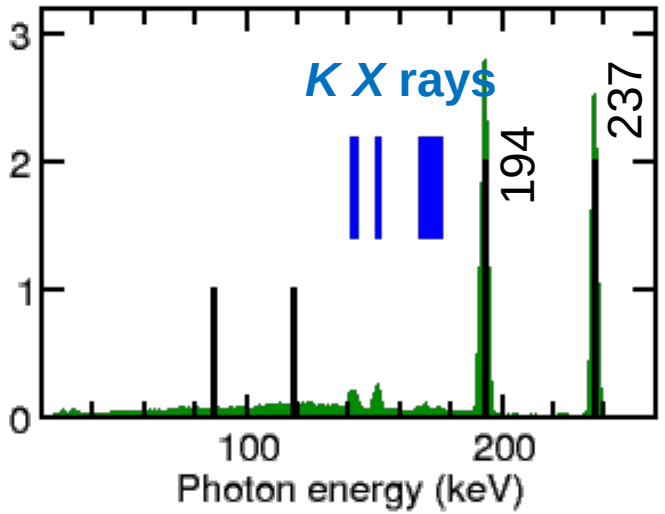


$E1$ Case

^{280}Rg → ^{276}Mt

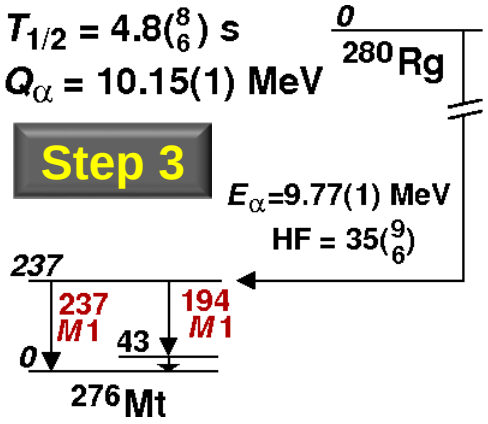
6x α-photon coincidences





GEANT4 simulations: 100000 decays, normalized to number of α's

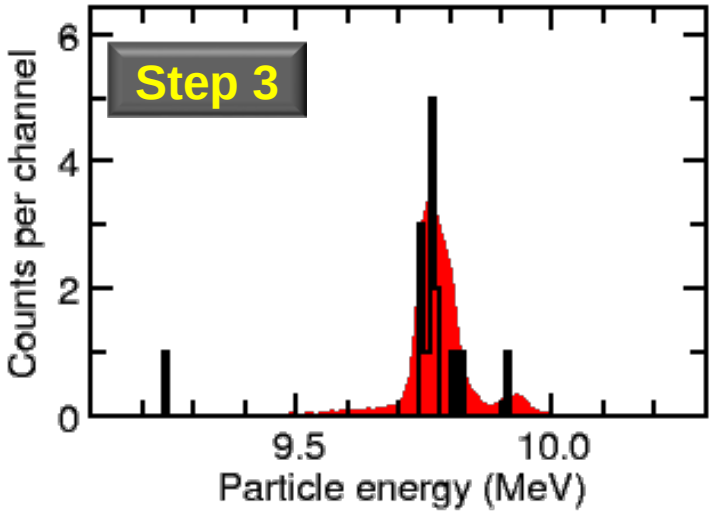
Results – $^{288}115$ (3n-chain)

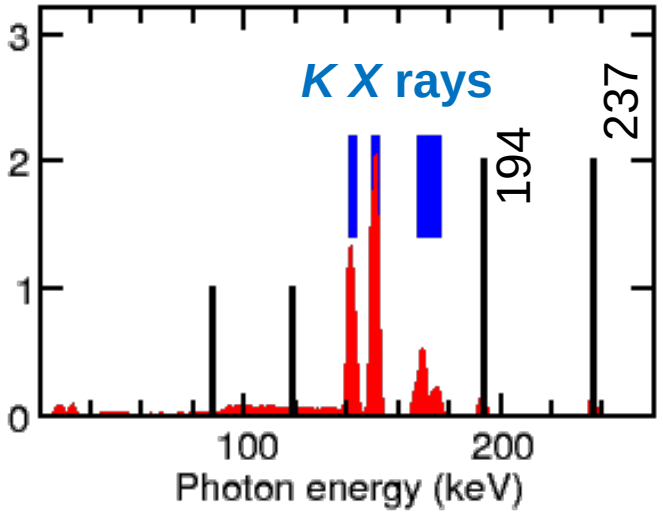


*M*1 Case

^{280}Rg → ^{276}Mt

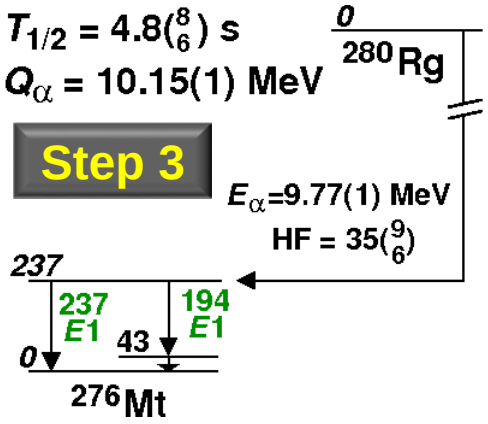
IF Mother Nature had provided these transitions as *M*1 transitions, this would have been THE perfect fingerprinting case!





GEANT4 simulations: 100000 decays, normalized to number of α's

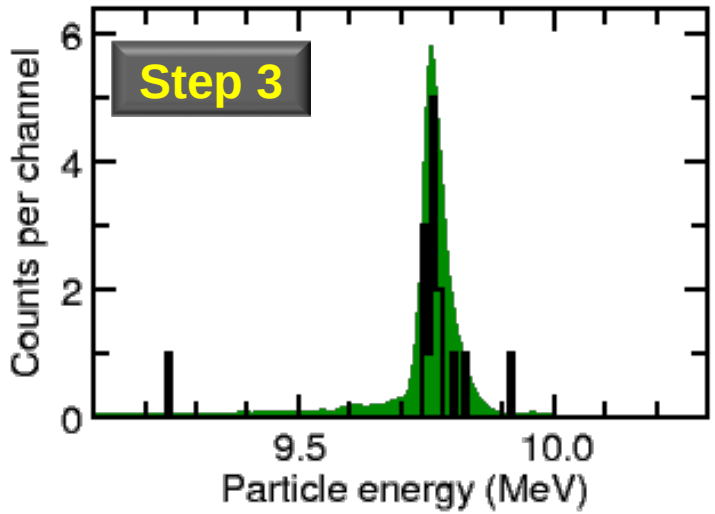
Results – $^{288}115$ (3n-chain)

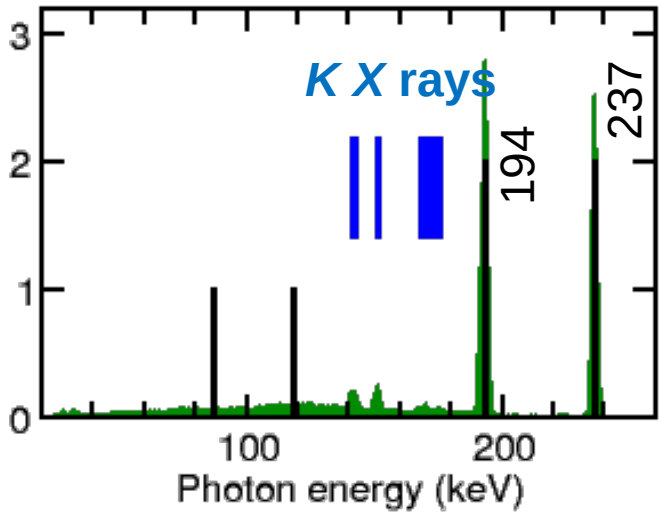


*E*1 Case

^{280}Rg → ^{276}Mt

The fact that these transitions are *E*1 transitions puts exciting contraints on nuclear structure theory!

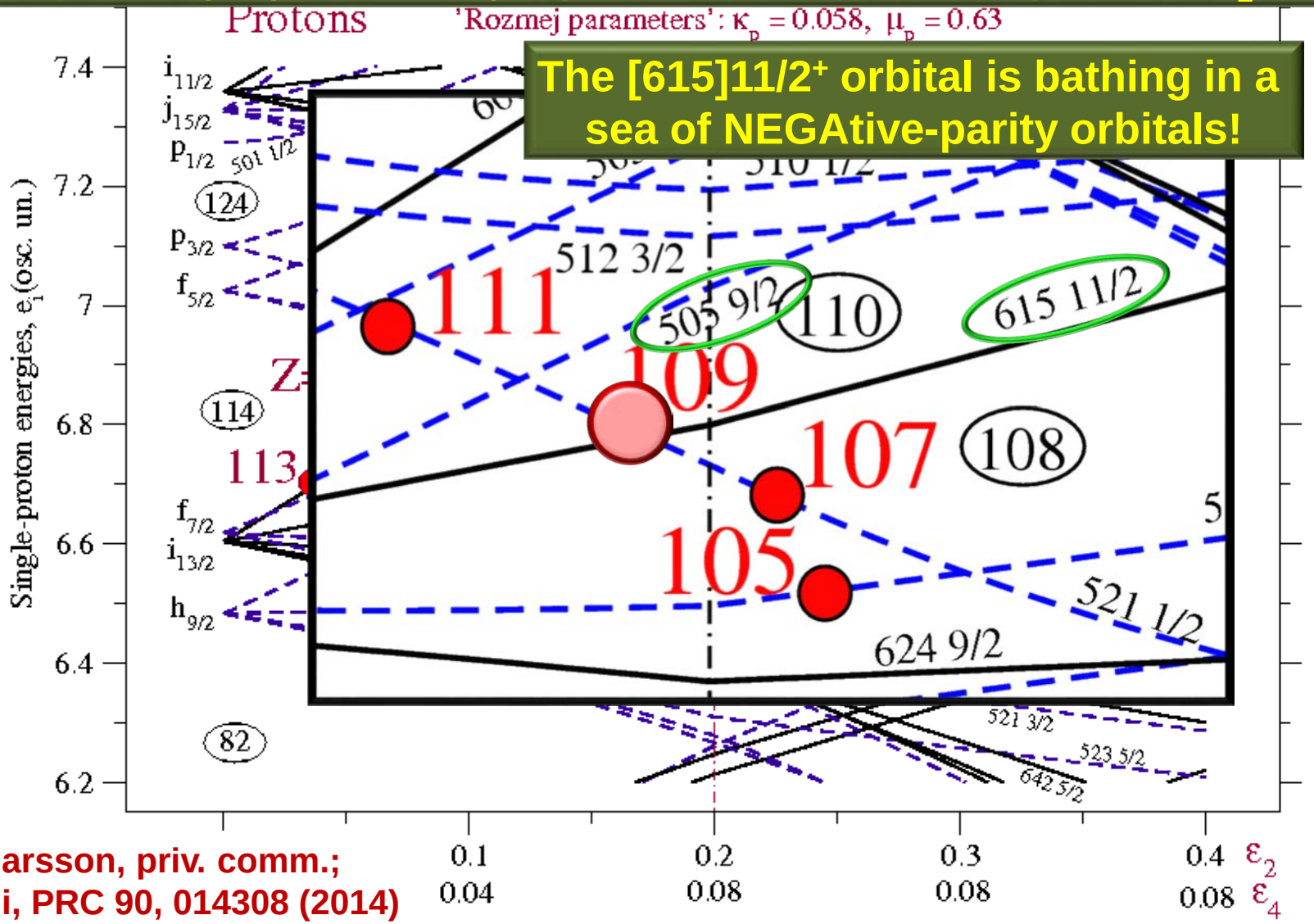




GEANT4 simulations: 100000 decays, normalized to number of α's

Nilsson Single-particle Diagrams

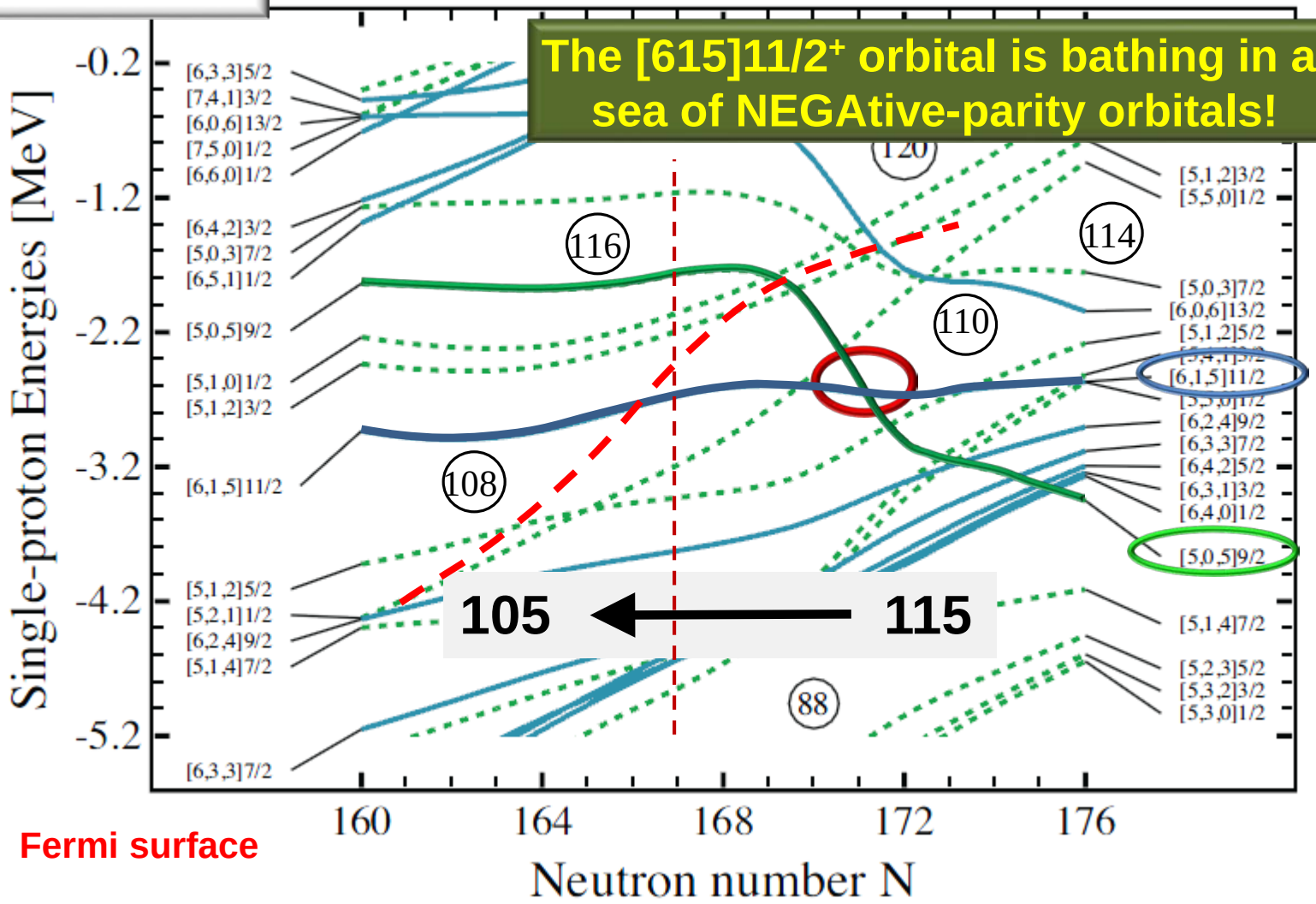
Parity-changing Δl =1 single-particle orbitals are required at β_2~0.2!



I. Ragnarsson, priv. comm.;
Yue Shi, PRC 90, 014308 (2014)

EDF Single-particle Diagrams

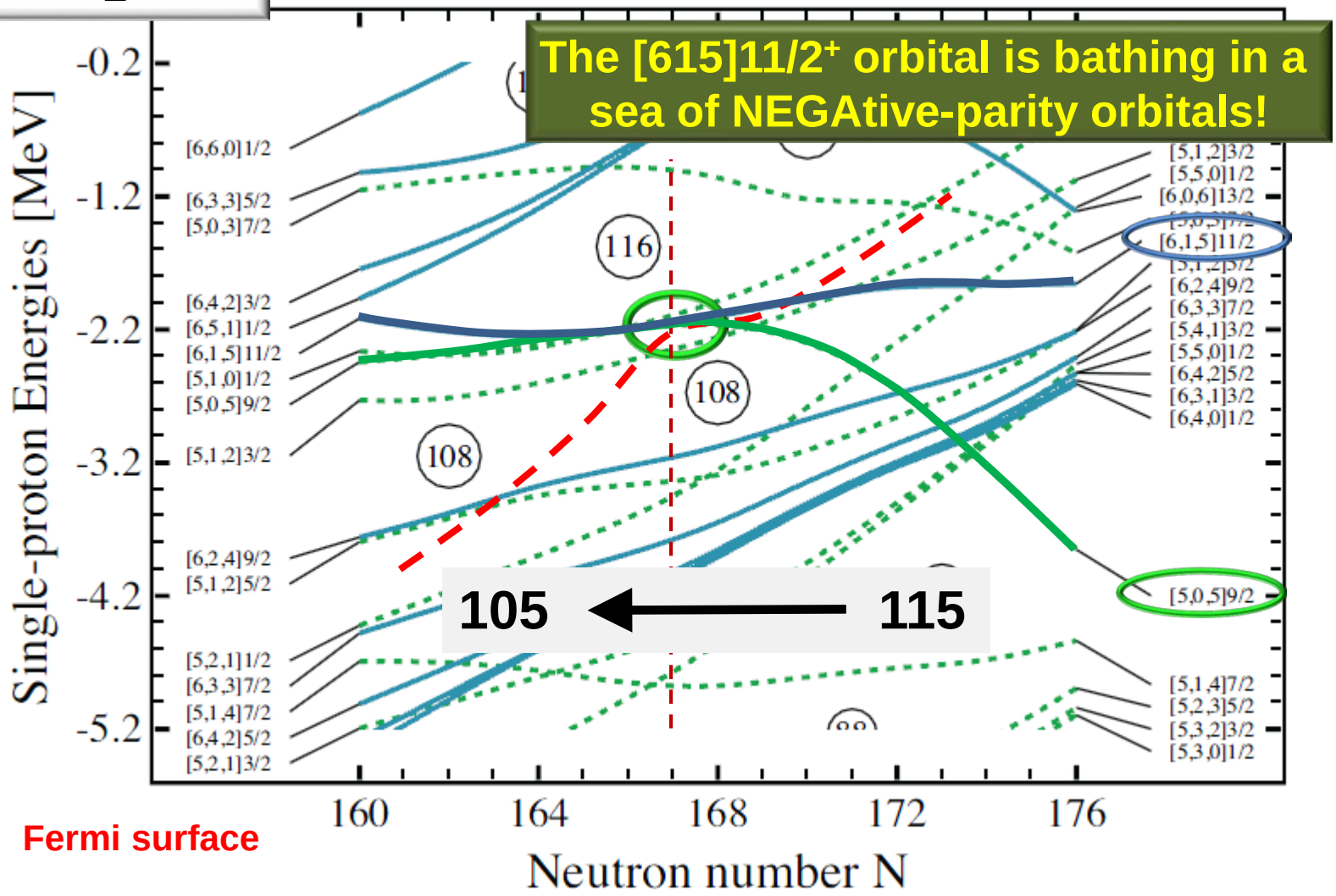
UNEDF1$^{SO}_{L}$



Yue Shi *et al.*, PRC 90, 014308 (2014)

EDF Single-particle Diagrams

UNEDF1$_L$



Yue Shi *et al.*, PRC 90, 014308 (2014)

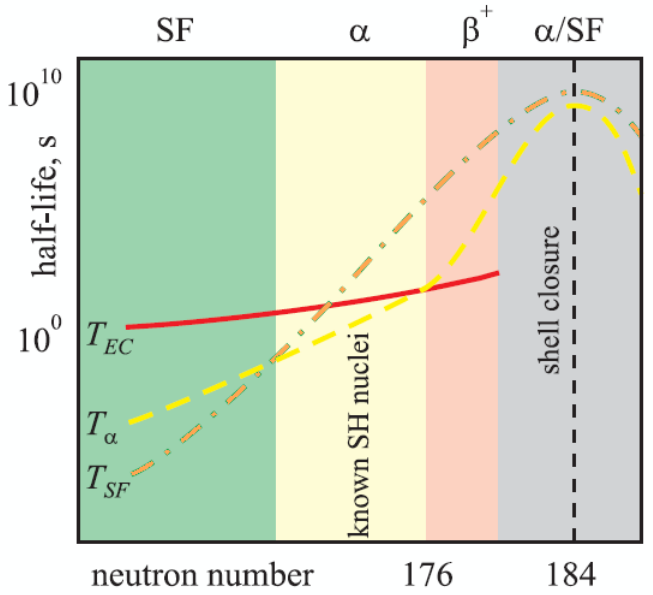
Results – $^{291-x}$115 (xn-channel, x=2?)

7 chains (out of 30 *TASISpec*) are of recoil-α(-α)-SF type.

4 chains (out of 37 DGFRS) are of recoil-α-α-SF type.
All 4 are interpreted as the 2n channel ^{289}115.

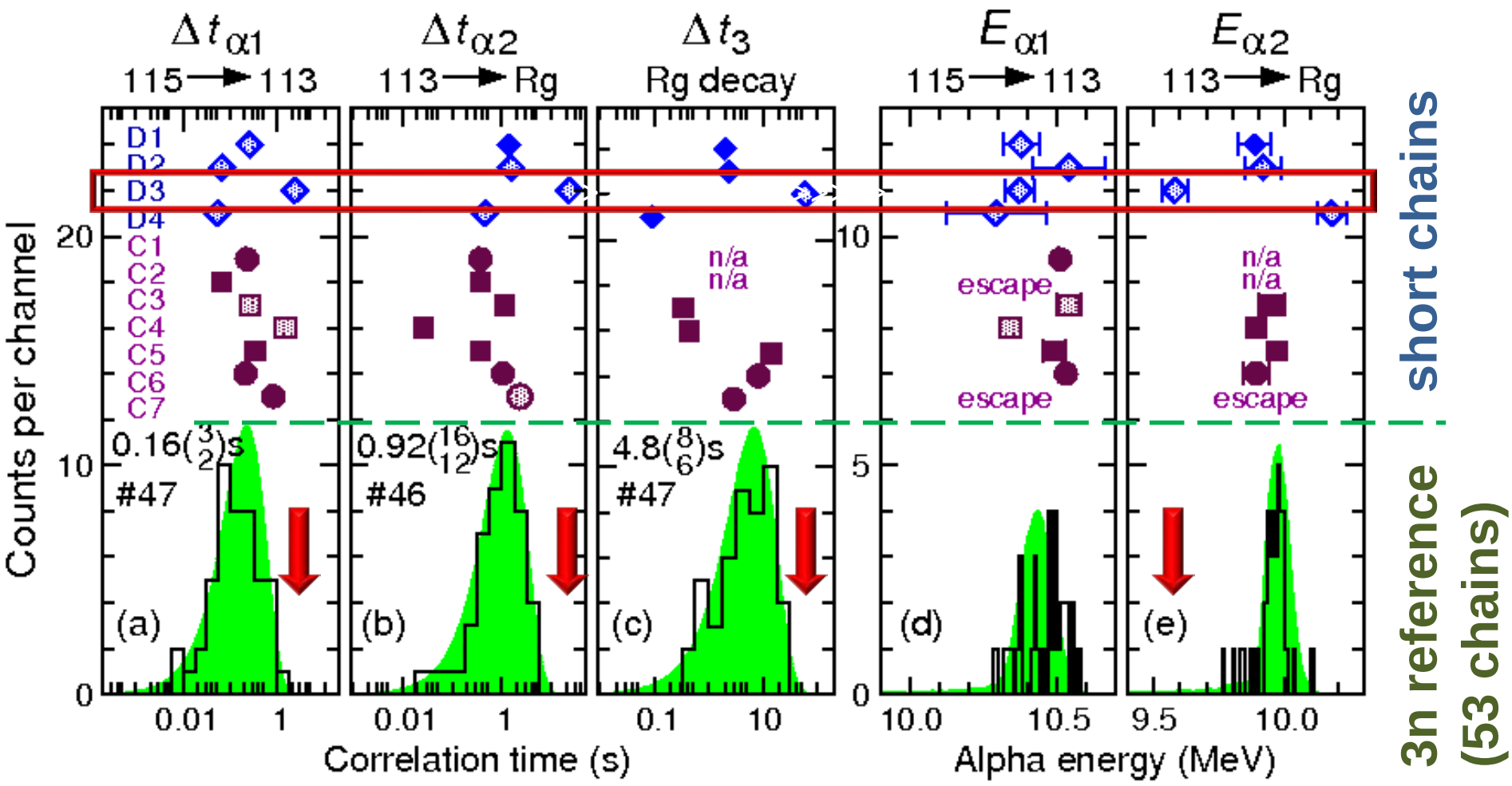
A simple mapping of **all** those **11** short chains and the chains presumably starting from ^{293}117 is no longer possible!

Proper statistical assessments, nuclear structure, and the possibility of electron-capture decays have to be considered!



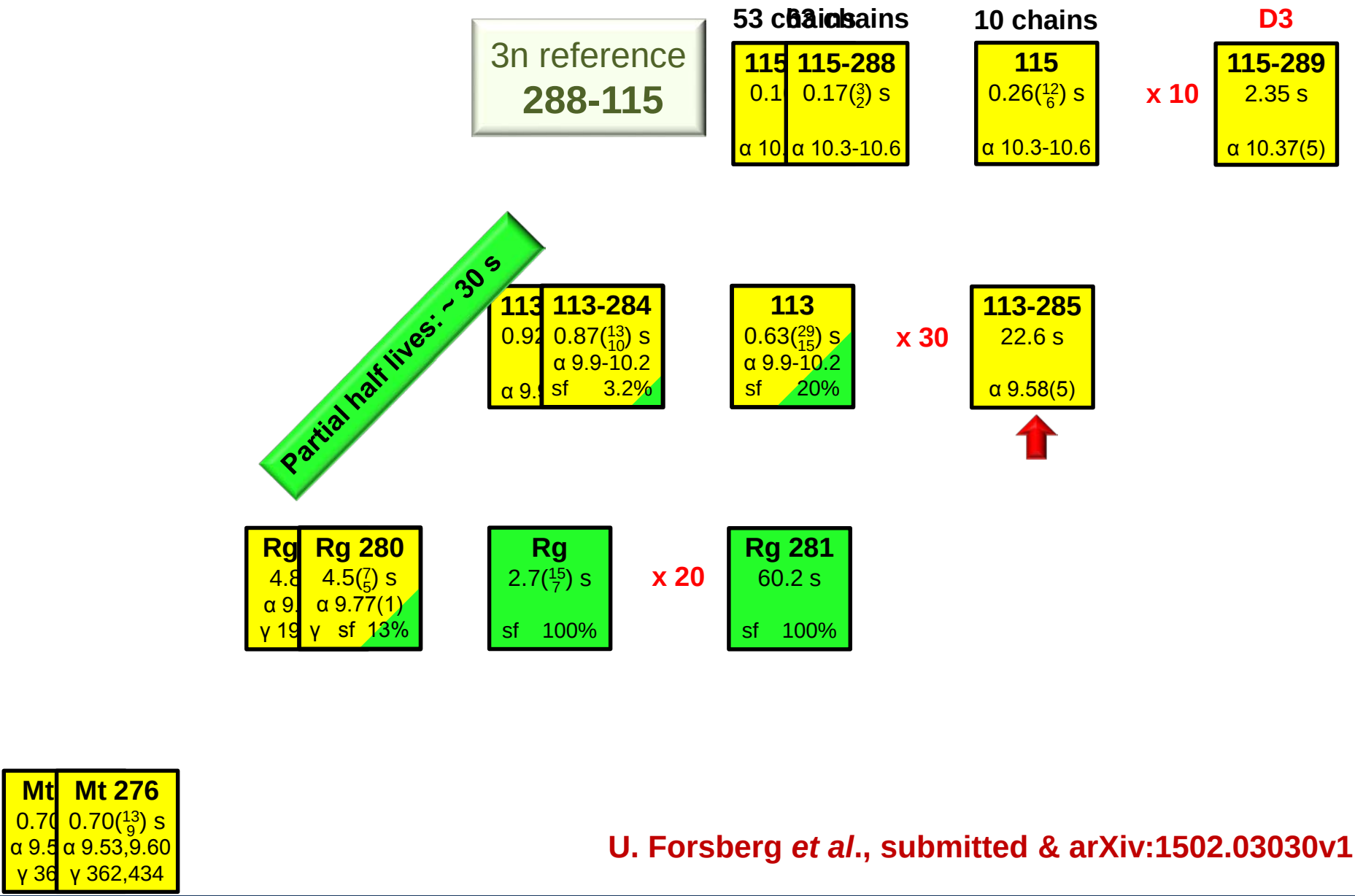
A.V. Karpov *et al*., Int. J. Mod. Phys. E21, 1250013 (2012)

Results – $^{291-x}$115 (xn-channel, x=2?)



U. Forsberg *et al.*, submitted & arXiv:1502.03030v1

Results – $^{291-x}$115 (xn-channel, x=2?)



U. Forsberg *et al.*, submitted & arXiv:1502.03030v1

Results – $^{291-x}$115 (xn-channel, x=2?)

3n reference
288-115

53 chains

115-288
0.16($^{3}_{2}$) s
α 10.3-10.6

10 chains D3

115-289
0.26($^{12}_{6}$) s
α 10.3-10.6

115-289
2.35 s
α 10.37(5)

113-284
0.92($^{16}_{12}$) s
α 9.9-10.1

113-285
0.63($^{29}_{15}$) s
α 9.9-10.2
sf 20%

113-285
22.6 s
α 9.58(5)

Rg 280
4.8($^{8}_{6}$) s
α 9.77(1)
γ 194,237

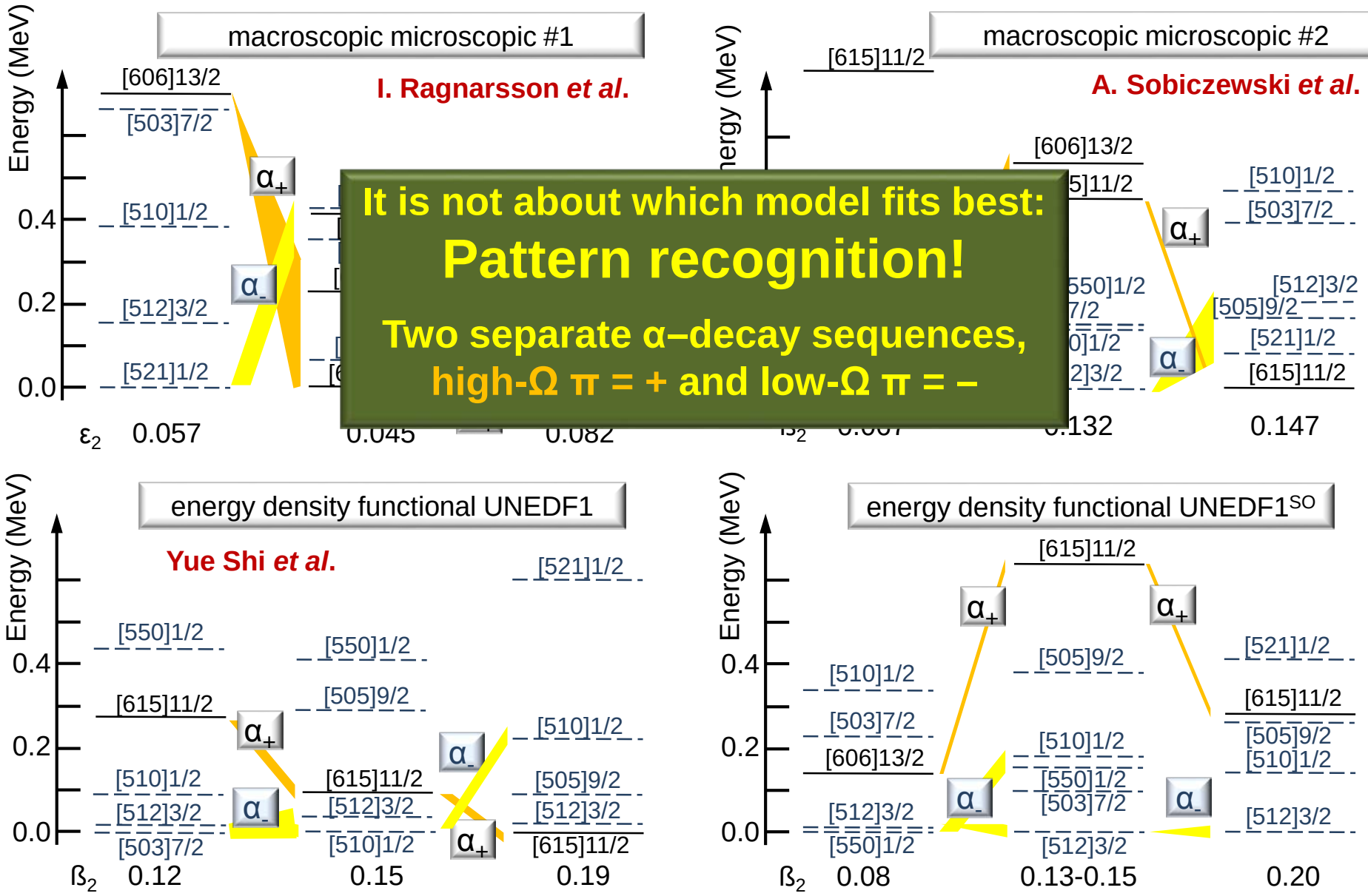
Rg-281
2.7($^{15}_{7}$) s
sf 100%

Rg 281
60.2 s
sf 100%

Mt 276
0.70($^{13}_{9}$) s
α 9.53,9.60
γ 362,434

U. Forsberg *et al*., submitted & arXiv:1502.03030v1

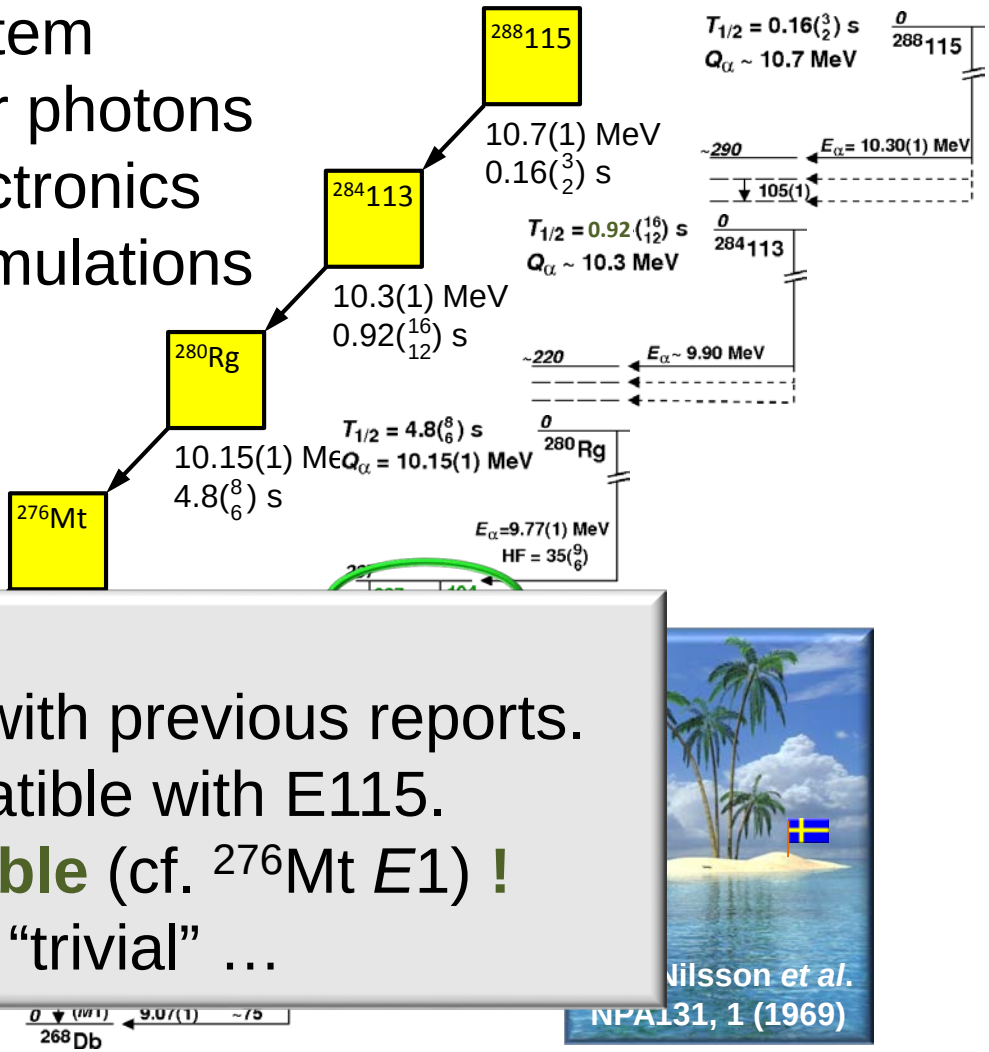
Nuclear Structure Theory $^{289}115$-$^{285}113$-^{281}Rg



Summary & Conclusions

Open the modern **spectroscopy** toolbox …

- fully pixelized Si detector system
- complement with Ge array for photons
- employ “digital” sampling electronics
- cross-check with GEANT4 simulations
- **nuclear structure theory**



E115 Results:

30 decay chains compatible with previous reports.

Two *X*-ray **candidates** compatible with E115.

***X*-ray fingerprinting is feasible** (cf. ^{276}Mt *E*1) **!**

^{293}117/^{289}115 story is far from “trivial” …