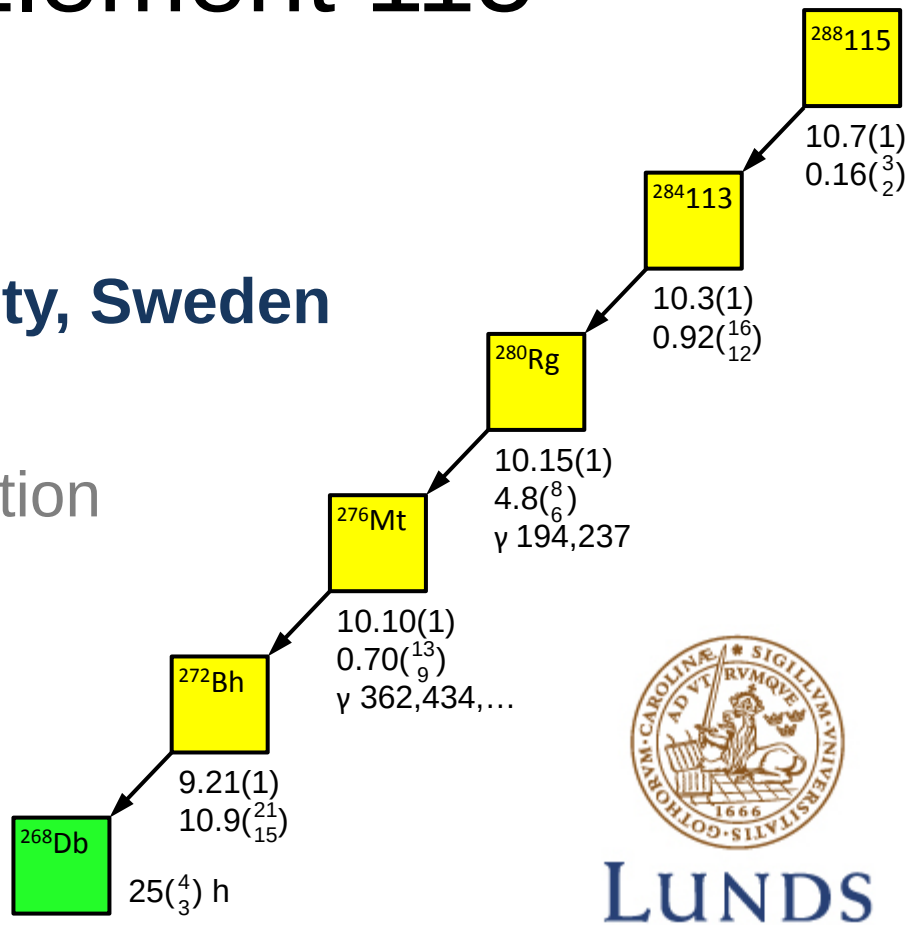
Superheavy Element Studies with *TASCA* at GSI

Spectroscopy of Element 115 Decay Chains

D. Rudolph, Lund University, Sweden

on behalf of the

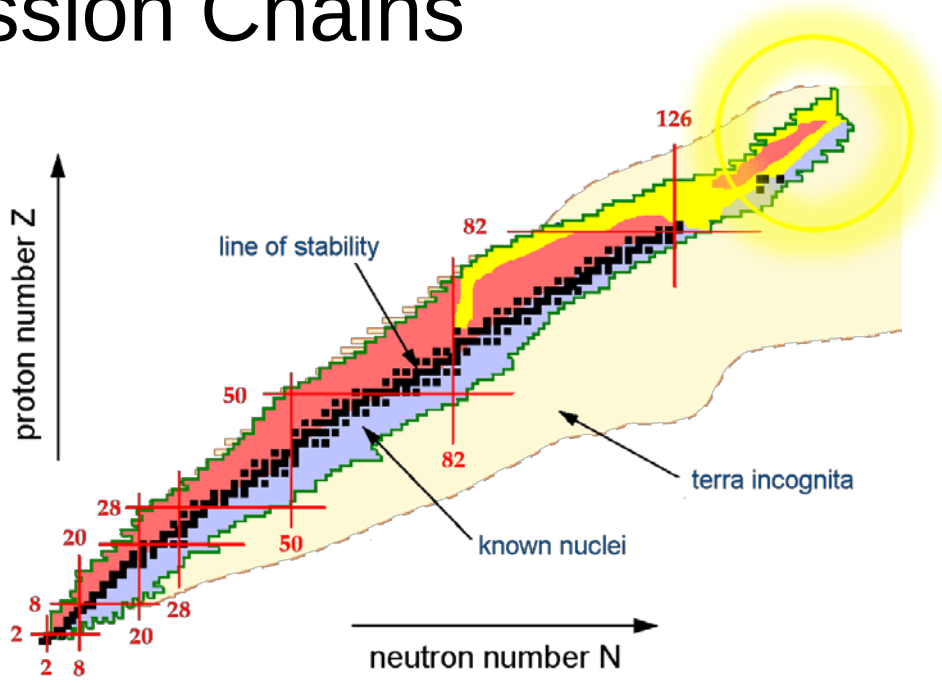
TASCA/TASISpec Collaboration



LUNDS UNIVERSITET

Outline

- Superheavy Element Issues
- Experiments with *TASCA* at GSI
- Spectroscopy of $^{288}115$ and Daughters
- E115 Recoil-α(-α)-Fission Chains
- Conclusions



Main SHE Issues at Present

- **Quest for new elements:**

  E120

  E119

- **Confirmation of anticipated chains from elements**

  E118 & E117

- ***Z* identification of presumed $Z \geq 113$ decay chains**

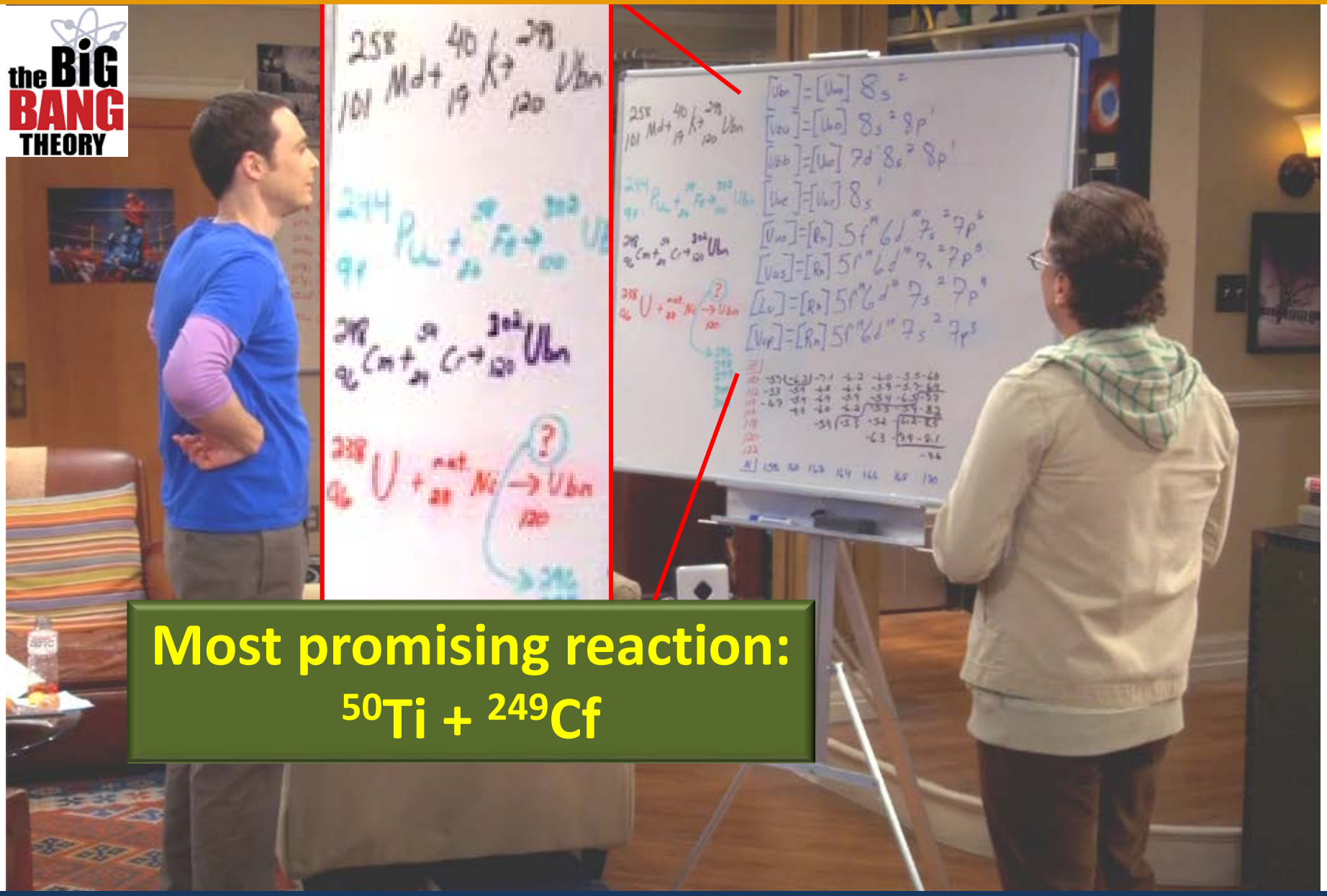
  E115

- **Chemistry $Z \geq 113$ – placement in Mendeleev's table**

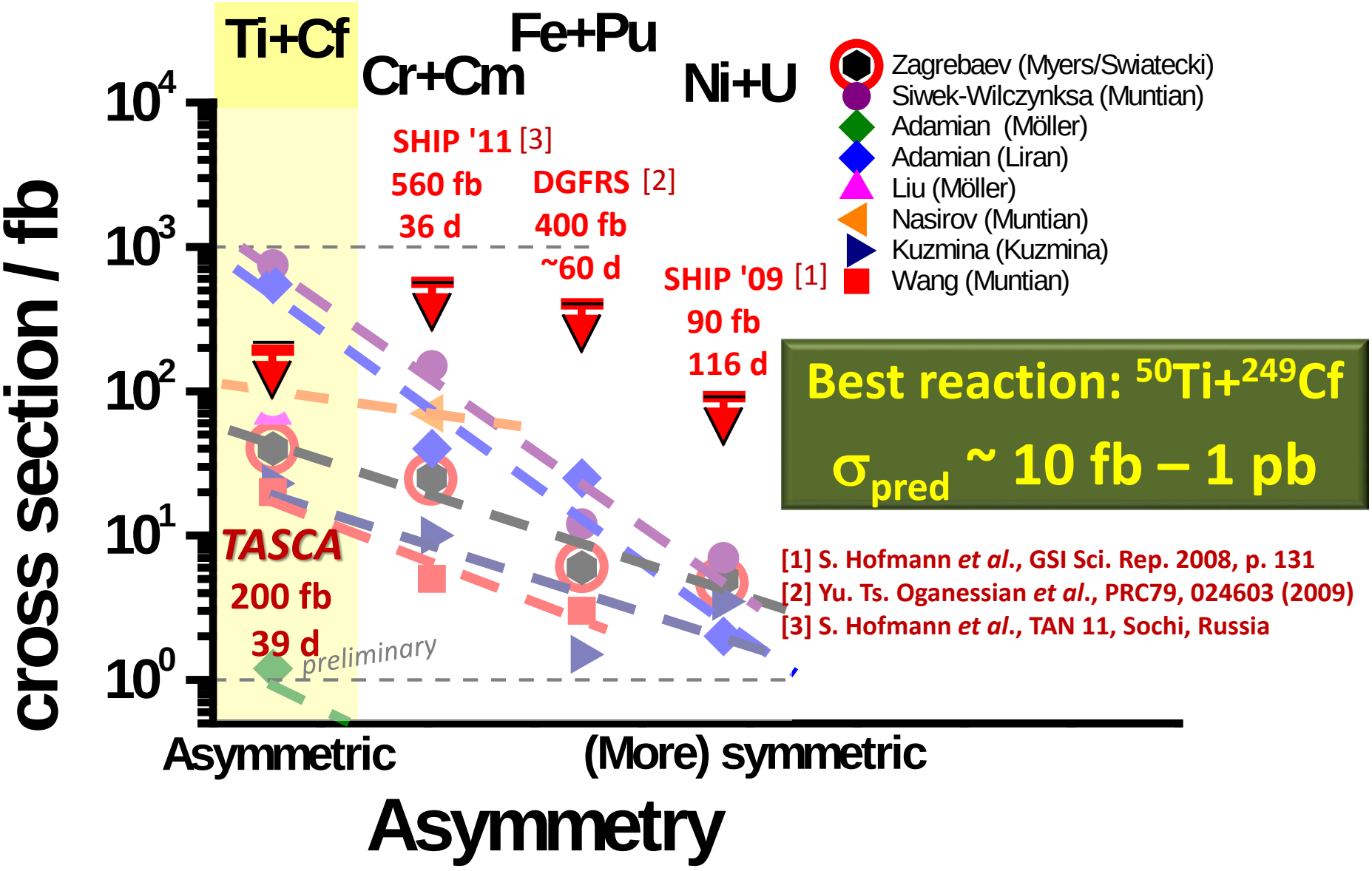
  E114

- **Comprehensive nuclear structure information by studying 'lighter' isotopes (No, Lr, Rf, Db, Sg)**

How to Synthesize Element 120?



TASCA 2011: The Hunt for Element 120



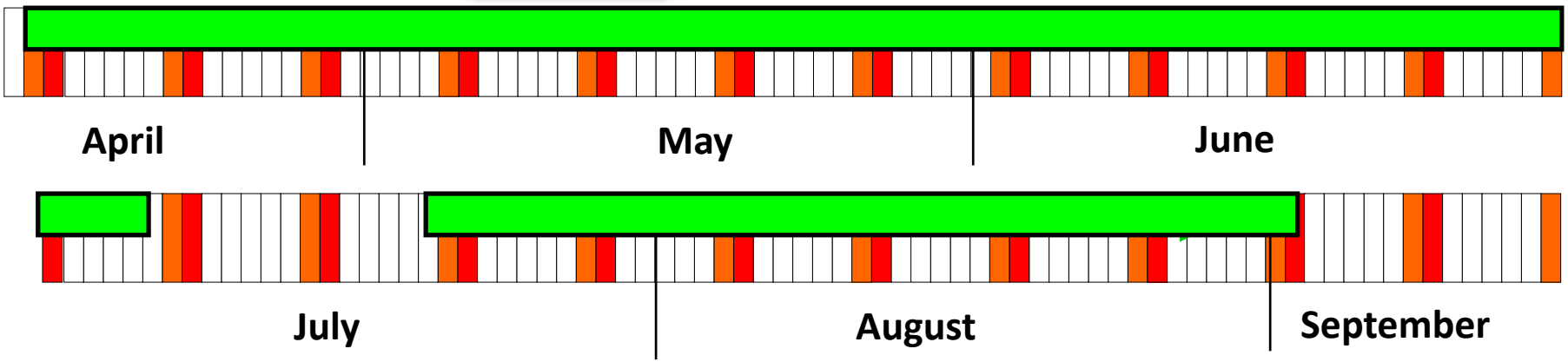
[1] S. Hofmann *et al.*, GSI Sci. Rep. 2008, p. 131
[2] Yu. Ts. Oganessian *et al.*, PRC79, 024603 (2009)
[3] S. Hofmann *et al.*, TAN 11, Sochi, Russia

TASCA 2012: The Hunt for Element 119

$^{50}Ti + {}^{249}Bk \rightarrow$ Element 119

4 months!

^{50}Ti beam 0.75 μA_p and ^{249}Bk targets with initial thickness ≈0.44 mg/cm^2



TransActinide Separator and Chemistry Apparatus

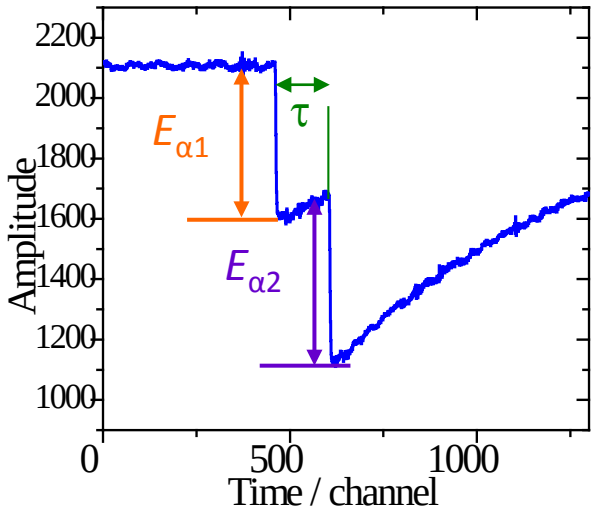
TASC

D Q Q Configuration

Target Wheel

mm

digital DAQ ⇒ access to lifetimes down to 100 ns



Search for Element 119:

$^{50}Ti + ^{249}Bk$, integral $3.6 \cdot 10^{19}$

analysis ongoing (40 TB!)

J. Khujagbaatar *et al.*

www.gsi.de/tasca

GSI

TASCA 2012: The Hunt for Element 119

$^{50}Ti + {}^{249}Bk \rightarrow$ Element 119

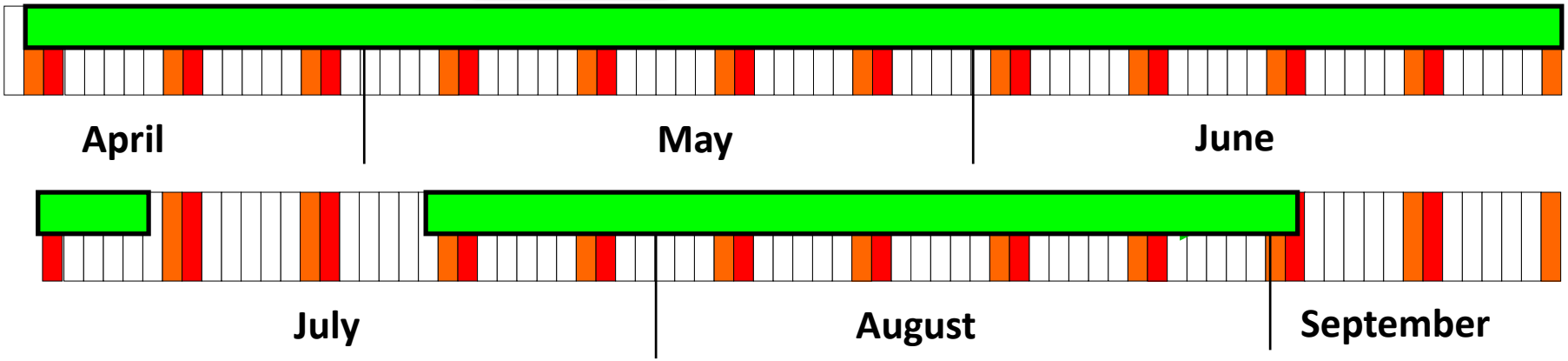
4 months!

^{50}Ti beam 0.75 μA_p and ^{249}Bk targets with initial thickness ≈0.44 mg/cm^2

GSI

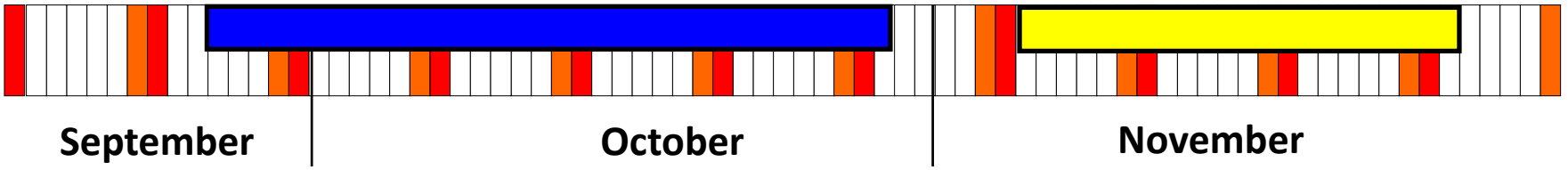
OAK RIDGE National Laboratory

JG|U



$^{48}Ca+{}^{249}Bk \rightarrow$ Element 117

$^{48}Ca+{}^{243}Am \rightarrow$ Element 115



E117: 4 chains from DGFRS 2 *TASCA* chains

^{294}117	10.81 112 ms	^{294}117	10.96 101 ms	^{294}117	10.967 3.99 ms	^{294}117	Missing
^{290}115	9.95 0.023 s	^{290}115	10.28 0.3 s	^{290}115	9.77 0.697 s	^{290}115	10.23 0.389 s
^{286}113	9.63 28.3 s	^{286}113	9.61 5.8 s	^{286}113	9.75 3.7 s	^{286}113	9.65 36.5 s
^{282}Rg	9.00 0.74 s	^{282}Rg	9.18 145 s	^{282}Rg	9.04 29.2 s	^{282}Rg	9.00 167 s
^{278}Mt	9.55 11 s	^{278}Mt	9.396 4.17 s	^{278}Mt	9.38 7.2 s	^{278}Mt	missing
^{274}Bh	8.80 78 s	^{274}Bh	8.79 103 s	^{274}Bh	8.69 55.7 s	^{274}Bh	8.73 39.1 s
a few alpha-like events (7.7-8.2 MeV)							
^{270}Db	219 33.4 h	^{270}Db	142 37.5 h	^{270}Db	196 23.5 h	^{270}Db	221.7 1.1 h
^{266}Lr		^{266}Lr		^{266}Lr			

^{294}117	11.071 55.9 ms	^{294}117	11.047 92.6 ms
^{290}115	10.314 2.98 s	^{290}115	10.17* 0.66 s
^{286}113	0.6+7.7 5.5 s	^{286}113	4.64 2.35 s
^{282}Rg	8.862 172 s	^{282}Rg	9.053 373 s
^{278}Mt	9.421 6.79 s	^{278}Mt	9.471 3.53 s
^{274}Bh	8.837 45.1	^{274}Bh	8.83* 41.3 s
^{270}Db	7.887 1.3 h	^{270}Db	7.904 1.6 h
^{266}Lr	135+7 3.8 h	^{266}Lr	189 29.3 h

J. Khuyagbaatar *et al.*, Phys. Rev. Lett. 112, 172501 (2014)

Main SHE Issues at Present

- **Quest for new elements:** TASCA at GSI

  E120: $^{50}Ti+^{249}Cf$, $9\cdot10^{18}$, 2011, 6 weeks, $\sigma < 200$ fb

  E119: $^{50}Ti+^{249}Bk$, $6\cdot10^{19}$, 2012, 4 months, $\sigma < 70$ fb

- **Confirmation of anticipated chains of elements**

  E117: $^{48}Ca+^{249}Bk$, **J. Khuyagbaatar *et al*., PRL112, 172501 (2014)**

- ***Z* identification of presumed *Z* ≥ 113 decay chains**

E115: TASISpec, $^{48}Ca+^{243}Am$, November 2012

- **Chemistry *Z* ≥ 113 – placement in Mendeleev's table**

  E114: $^{48}Ca+^{244}Pu$, gas-phase, 2010 (2014)
  A. Yakushev *et al*., Inorg.Chem. 53, 1624 (2014)

- **Comprehensive nuclear structure information by studying 'lighter' isotopes (No, Lr, Rf, Db, Sg) t.b.p.**

The TASISpec / *TASCA* E115 Collaboration

PHYSICAL REVIEW LETTERS 111, 112502 (2013)

Spectroscopy of Element 115 Decay Chains

D. Rudolph,[1,*] U. Forsberg,[1] P. Golubev,[1] L. G. Sarmiento,[1] A. Yakushev,[2] L.-L. Andersson,[3] A. Di Nitto,[4] Ch. E. Düllmann,[2,3,4] J. M. Gates,[5] K. E. Gregorich,[5] C. J. Gross,[6] F. P. Heßberger,[2,3] R.-D. Herzberg,[7] J. Khuyagbaatar,[3] J. V. Kratz,[4] K. Rykaczewski,[6] M. Schädel,[2,8] S. Åberg,[1] D. Ackermann,[2] M. Block,[2] H. Brand,[2] B. G. Carlsson,[1] D. Cox,[7] X. Derkx,[3,4] K. Eberhardt,[3,4] J. Even,[3] C. Fahlander,[1] J. Gerl,[2] E. Jäger,[2] B. Kindler,[2] J. Krier,[2] I. Kojouharov,[2] N. Kurz,[2] B. Lommel,[2] A. Mistry,[7] C. Mokry,[3,4] H. Nitsche,[5] J. P. Omtvedt,[9] P. Papadakis,[7] I. Ragnarsson,[1] J. Runke,[2] H. Schaffner,[2] B. Schausten,[2] P. Thörle-Pospiech,[3,4] T. Torres,[2] T. Traut,[4] N. Trautmann,[4] A. Türler,[10] A. Ward,[7] D. E. Ward,[1] and N. Wiehl[3,4]

[1]*Lund University, 22100 Lund, Sweden*
[2]*GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany*
[3]*Helmholtz Institute Mainz, 55099 Mainz, Germany*
[4]*Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany*
[5]*Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[6]*Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831, USA*
[7]*University of Liverpool, Liverpool L69 7ZE, United Kingdom*
[8]*Advanced Science Research Center, Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan*
[9]*University of Oslo, 0315 Oslo, Norway*
[10]*Paul Scherrer Institute and University of Bern, 5232 Villigen, Switzerland*

(Received 11 June 2013)

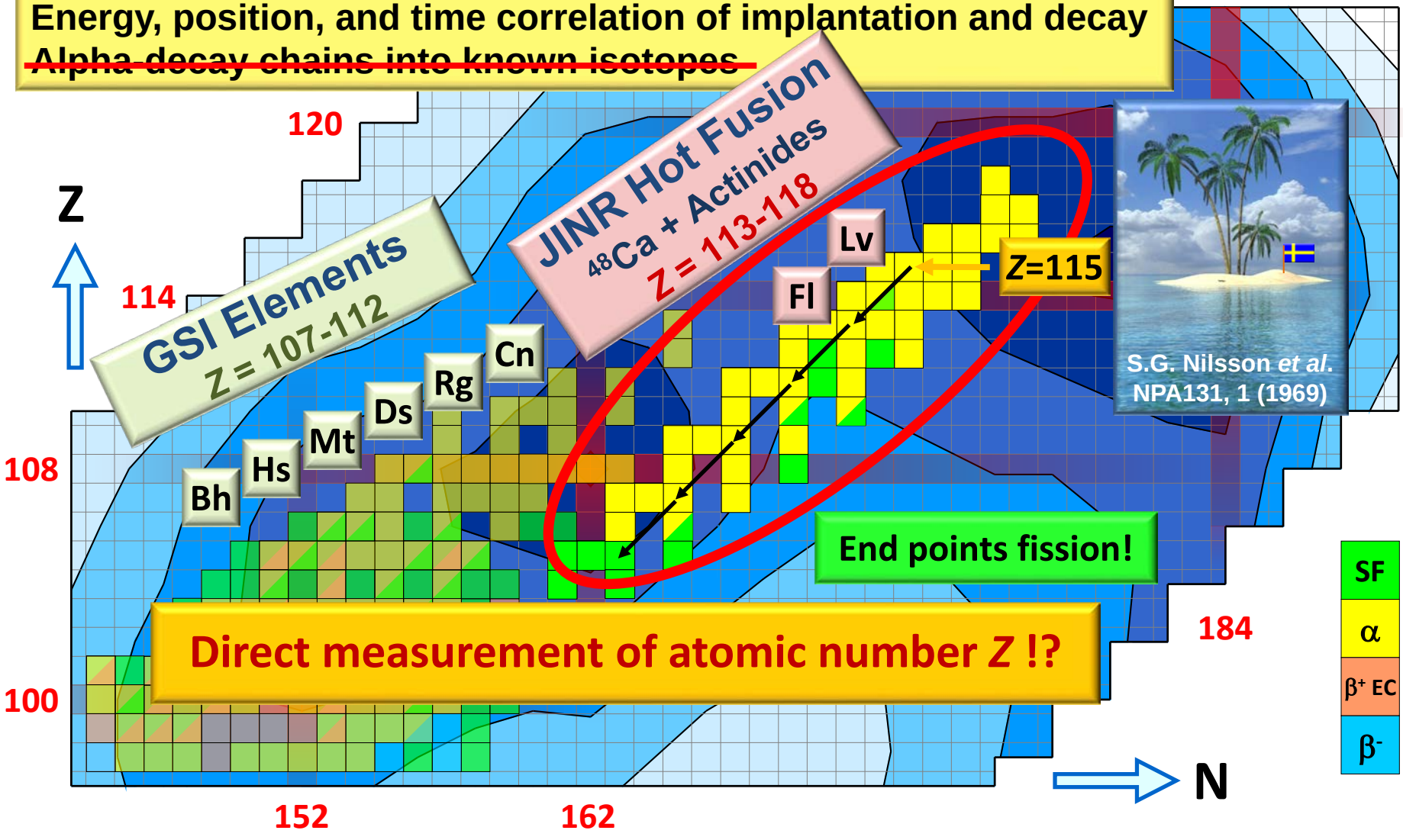
Special thanks to …

UNILAC

ENSAR

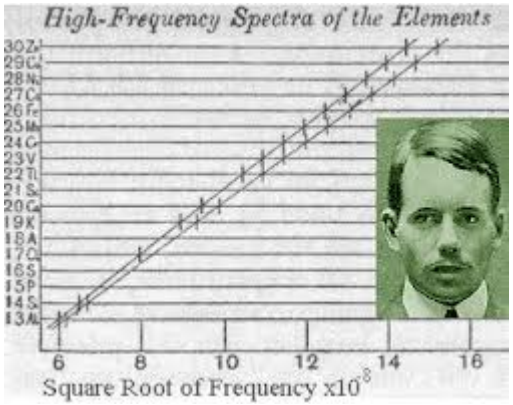
Identification Problem *Z* > 112

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



Highest *K*-conversion coefficients!

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

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

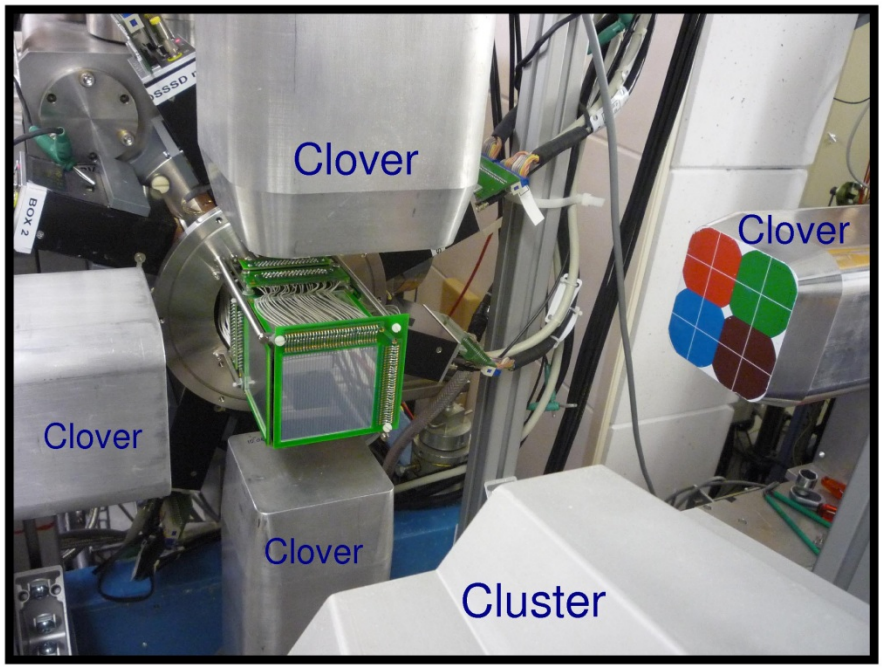
***X*-ray energies predicted down to 0.1 keV precision for superheavy elements (QED!)**

TASISpec

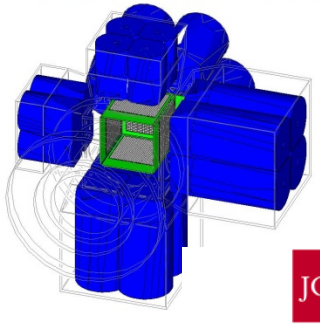
Highly efficient multi–coincidence spectroscopy set–up for TASCA's very compact focal plane image

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)



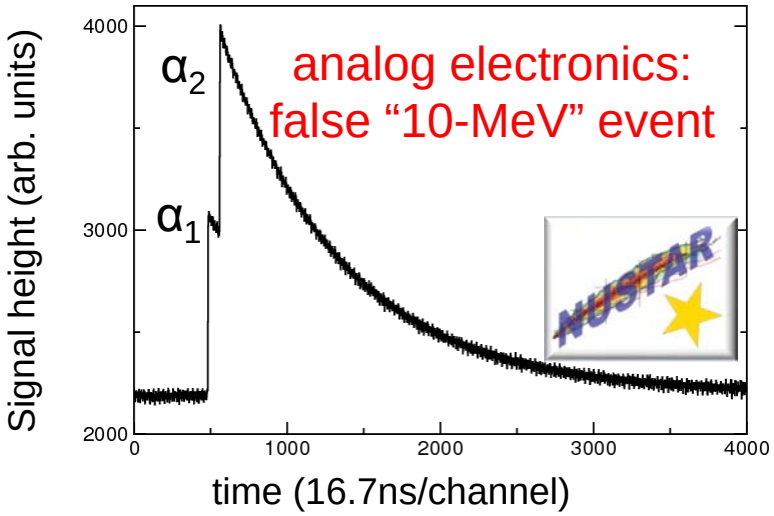
Virtually constructed with GEANT4 simulation package

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

“Digital” (or Sampling) Electonics

96 DSSSD p-sides

60 MHz dead-time free sampling ADC “FEBEX” cards developed at GSI-EE.



- detect summing, reduce background
- software optimization (MWD) towards best possible resolution
- large dynamic range (linear within 0.1-100 MeV, time-over threshold)

Very helpful!

25 Ge crystals

100 MHz commercial sampling ADCs, 4x SIS3302 cards, FPGA processed:

- flat-top energy
- baseline
- pile-up flagging

That allows to …

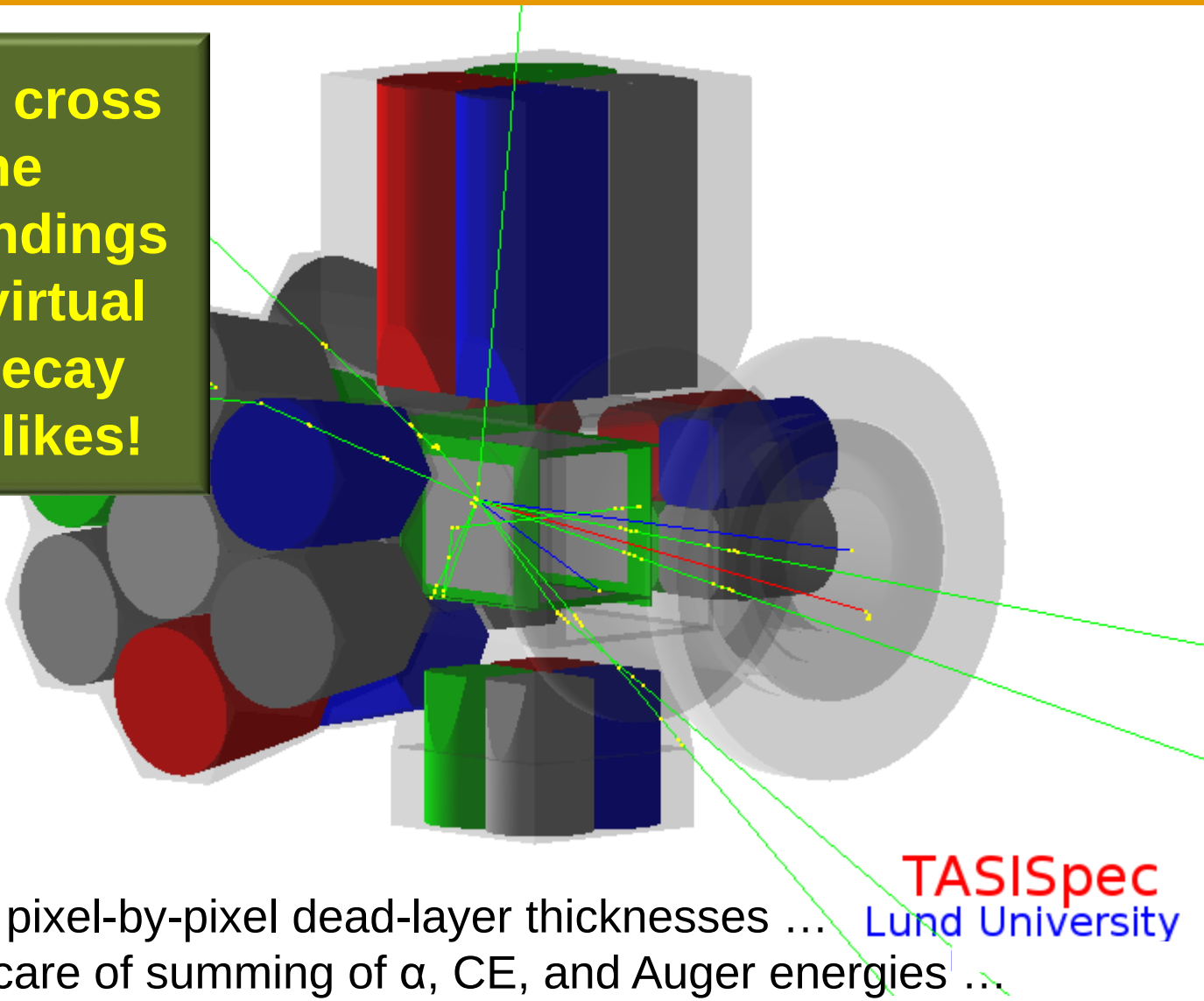
- restore baseline in software
- retain (almost) nominal Ge-detector energy resolution

… at high counting rates.

An absolute MUST!

TASISpec – in Virtual GEANT4 Space

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



TASISpec
Lund University

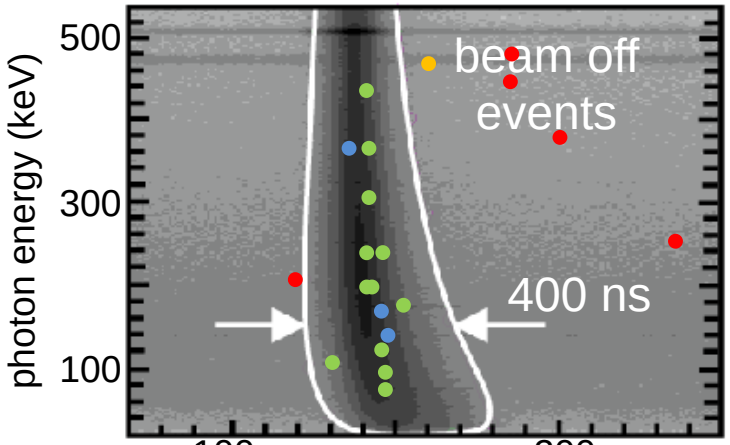
"Input level": down to pixel-by-pixel dead-layer thicknesses …
"Output level": takes care of summing of α, CE, and Auger energies …

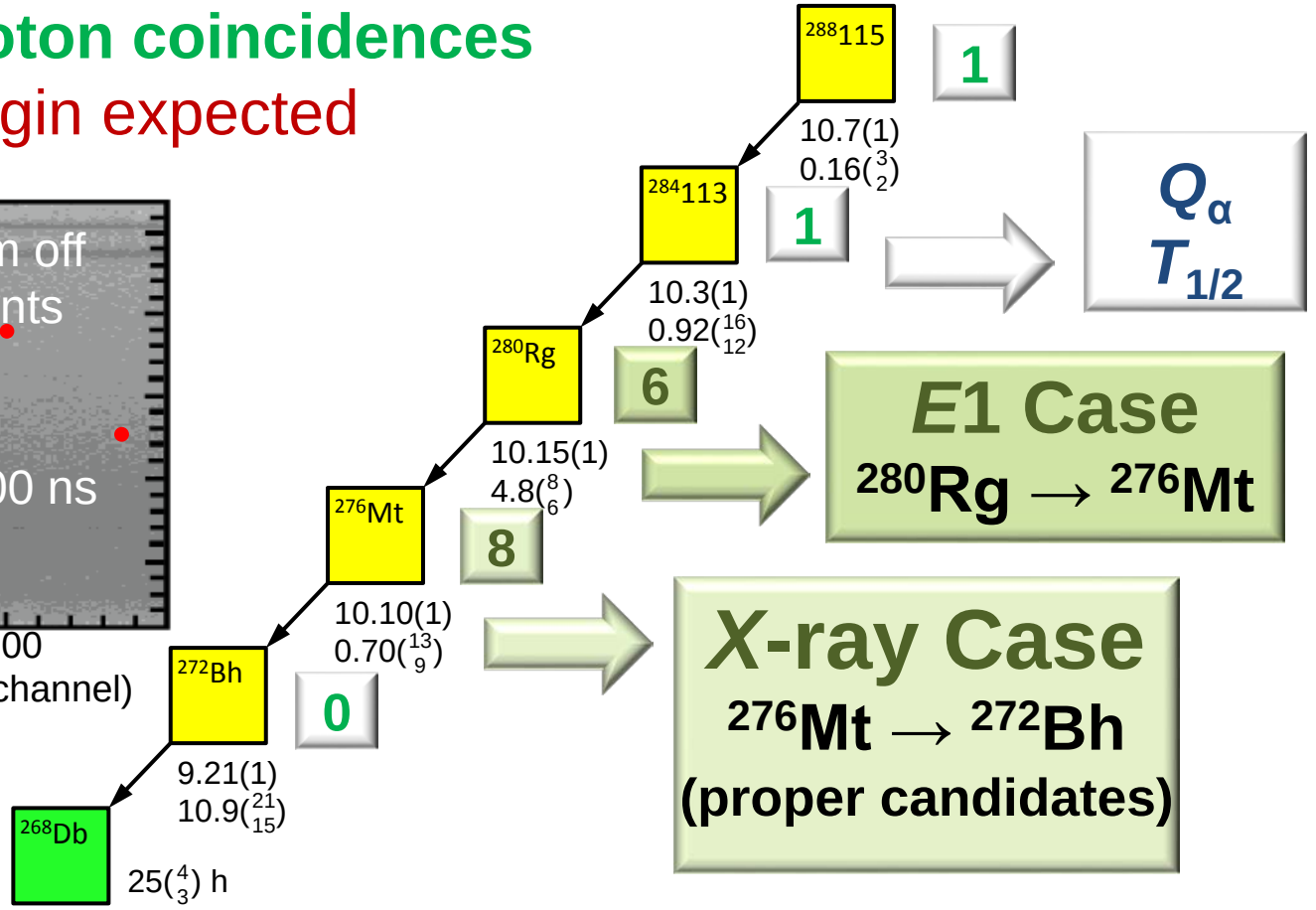
L.G. Sarmiento *et al*., NIM A 667, 26 (2011)

Results – $^{288}115$ (3n-channel)

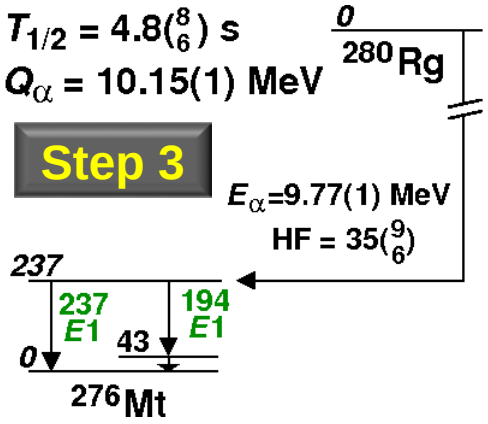
22 chains (out of 30) of ours are compatible with the
31 chains (out of 37) associated with the 3n channel $^{288}115$ by Oganessian *et al*.

16 prompt α-photon coincidences
2-3 of random origin expected





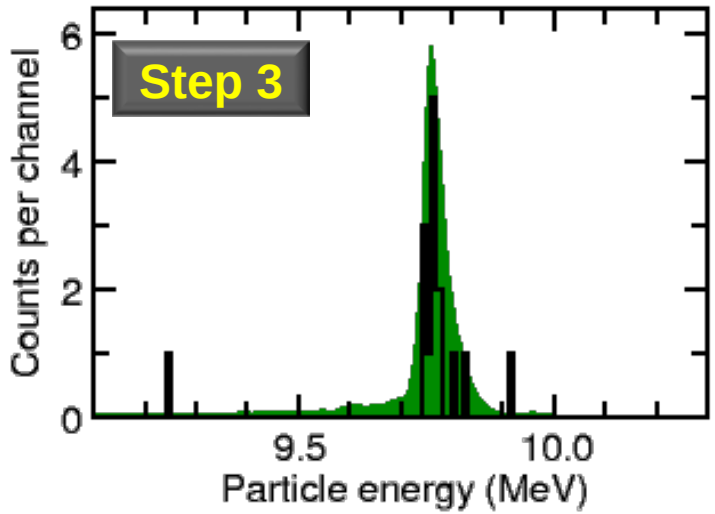
Results – $^{288}115$ (3n-chain)

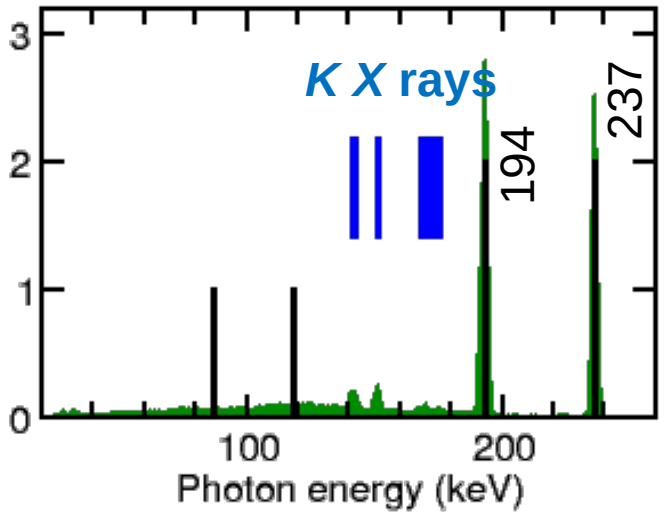


$E1$ Case

^{280}Rg → ^{276}Mt

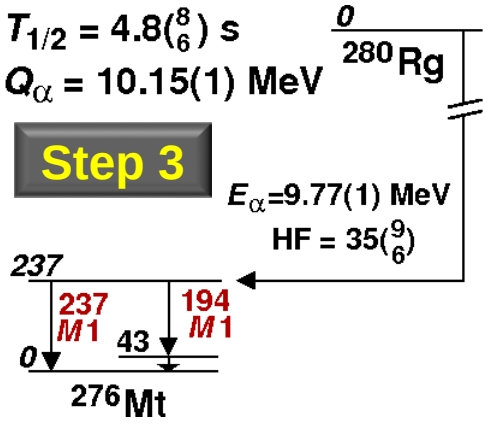
6x α-photon coincidences





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

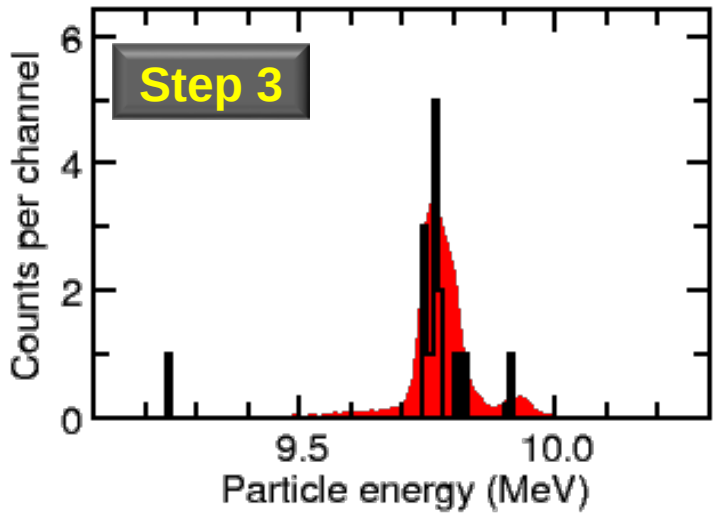
Results – ^{288}115 (3n-chain)

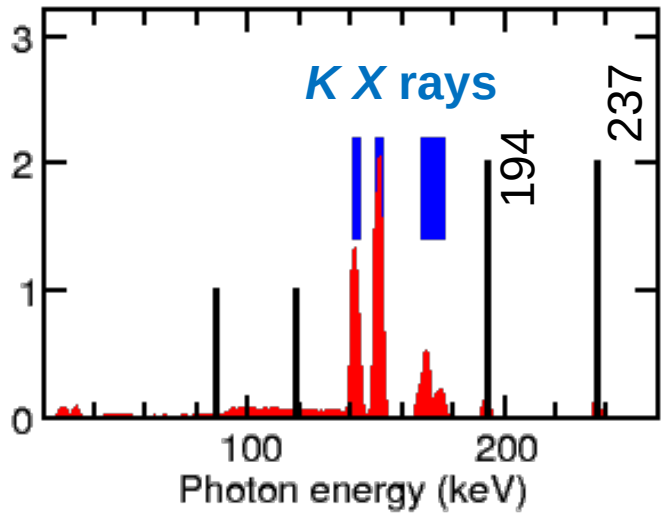


*M*1 Case

^{280}Rg → ^{276}Mt

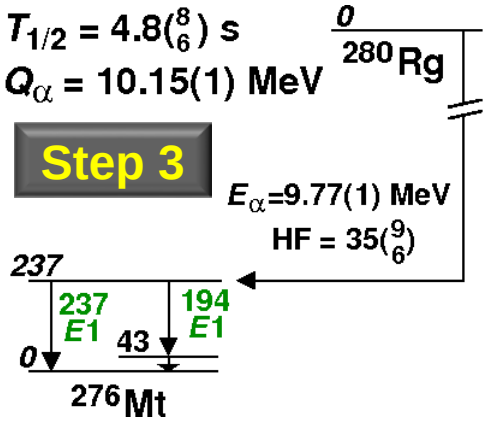
IF Mother Nature had provided these transitions as *M*1 transitions, this would have been THE perfect fingerprinting case!





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

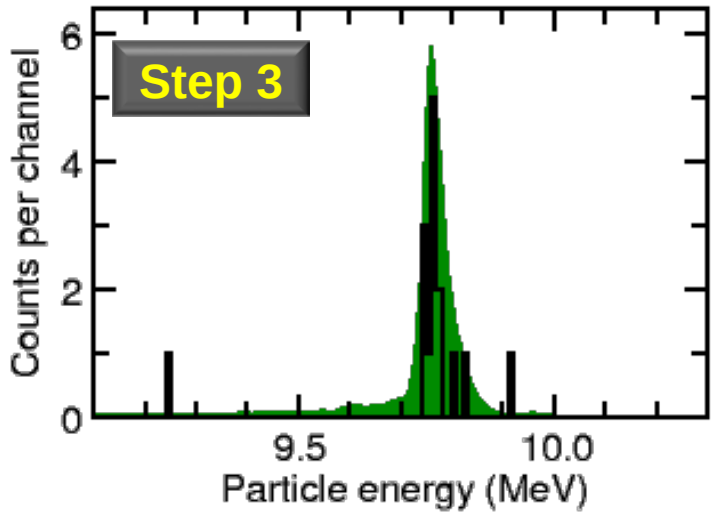
Results – $^{288}115$ (3n-chain)

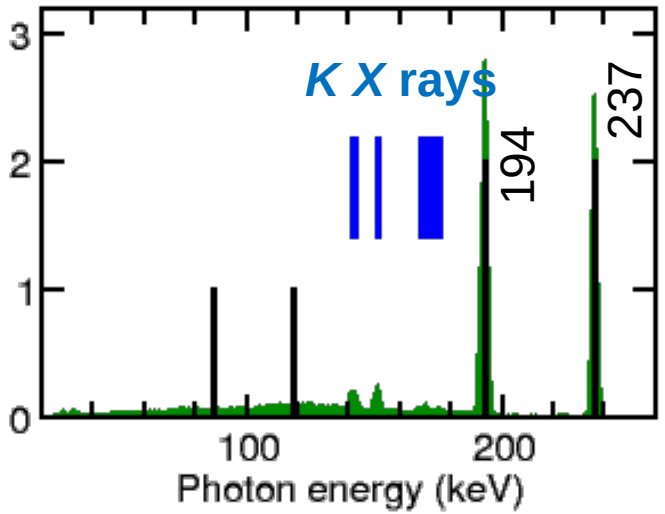


*E*1 Case

^{280}Rg → ^{276}Mt

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

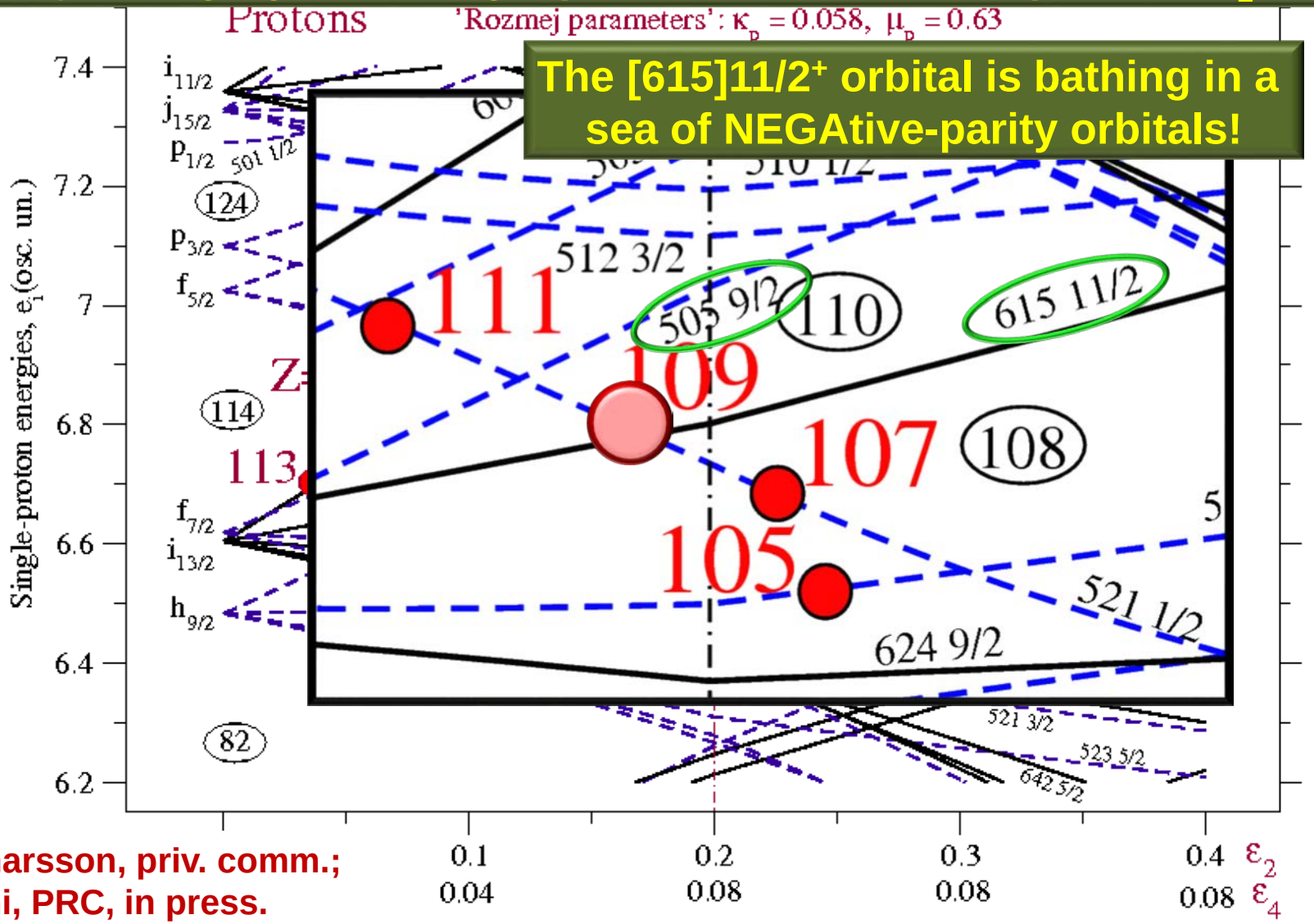




GEANT4 simulations: 100000 decays, normalized to number of α's

Nilsson Single-particle Diagrams

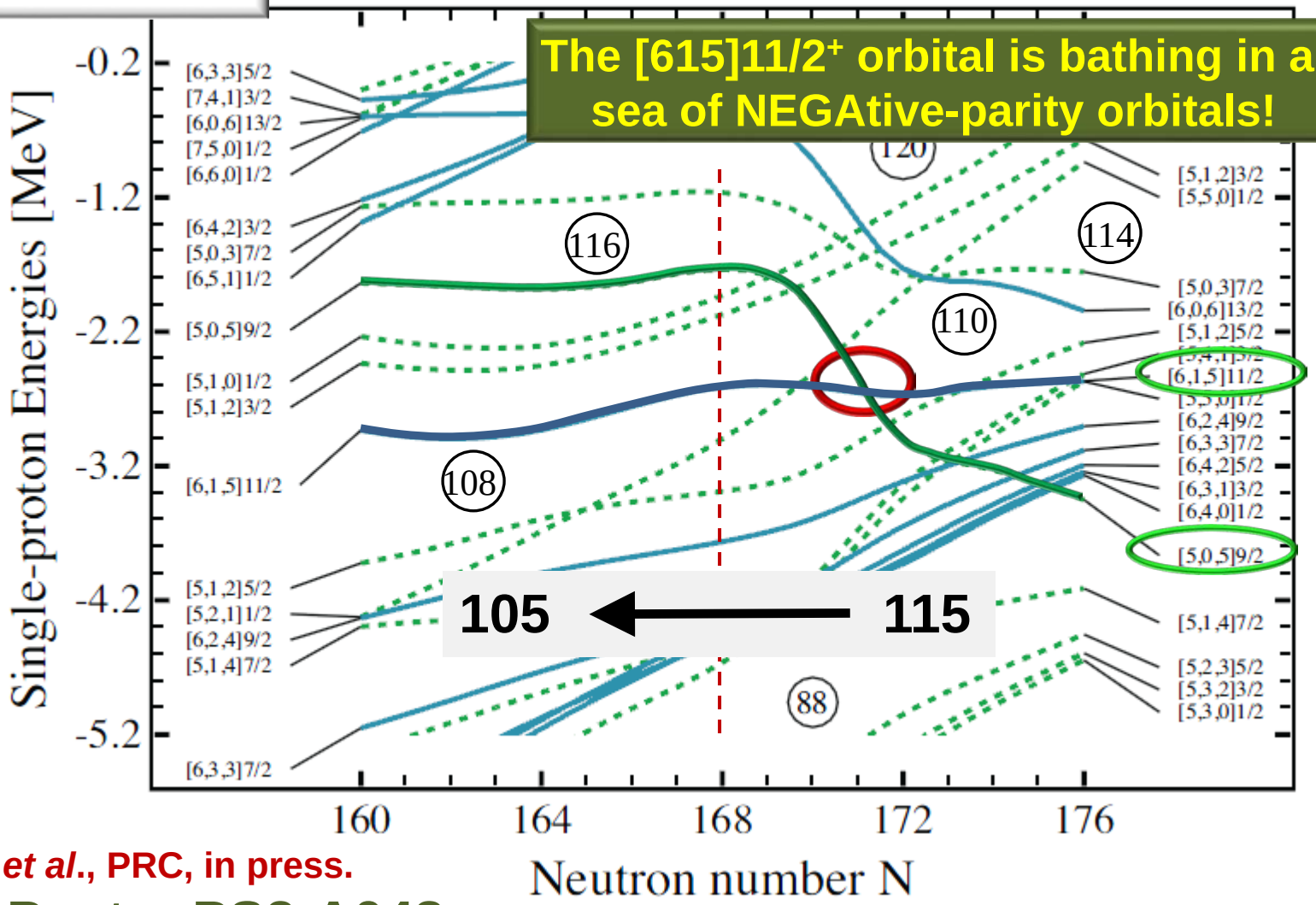
Parity-changing Δl =1 single-particle orbitals are required at β_2~0.2!



I. Ragnarsson, priv. comm.;
Yue Shi, PRC, in press.

EDF Single-particle Diagrams

UNEDF1$^{SO}_{L}$

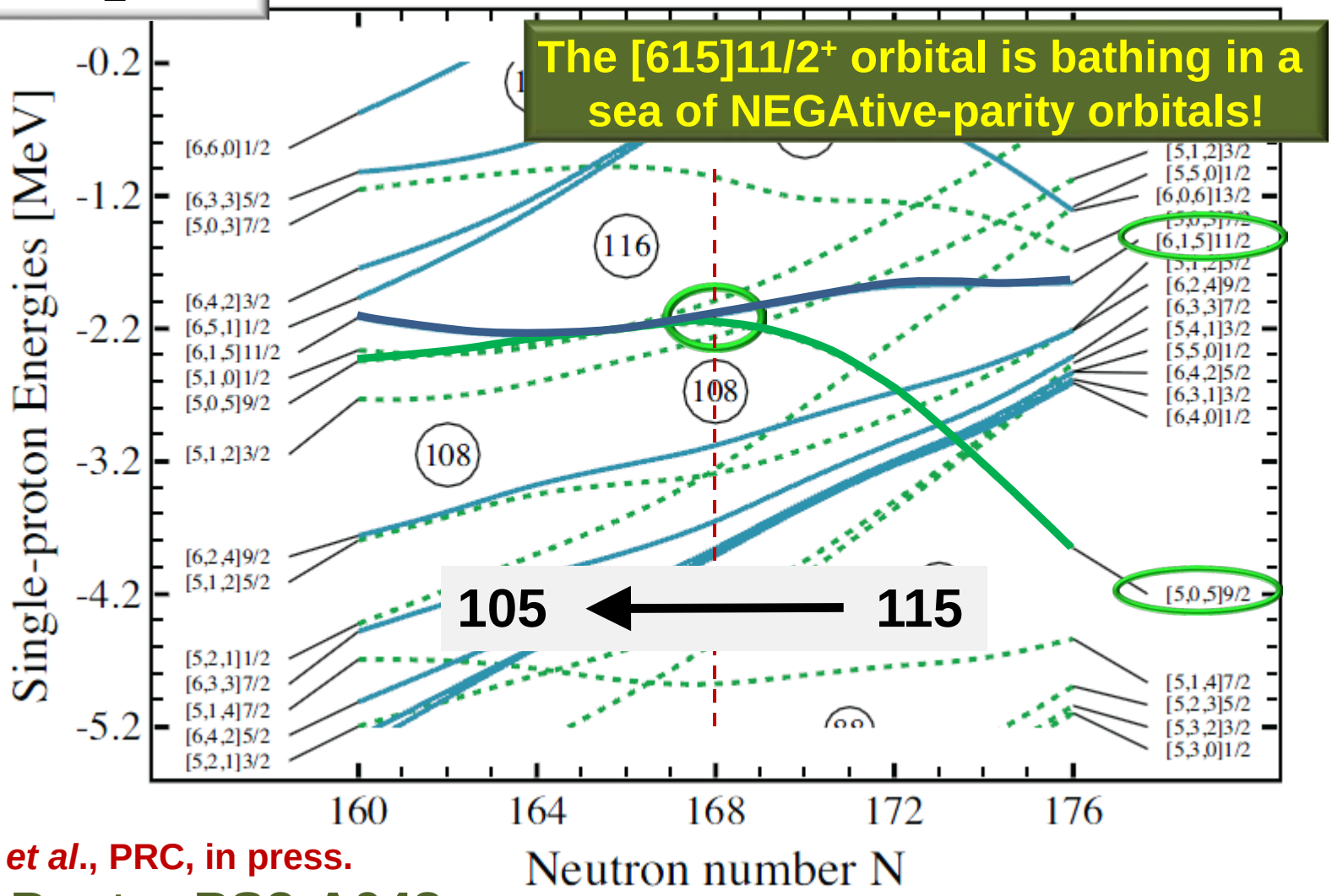


Yue Shi *et al.*, PRC, in press.

ARIS Poster PS2-A048

EDF Single-particle Diagrams

UNEDF1$_L$



Yue Shi *et al.*, PRC, in press.

ARIS Poster PS2-A048

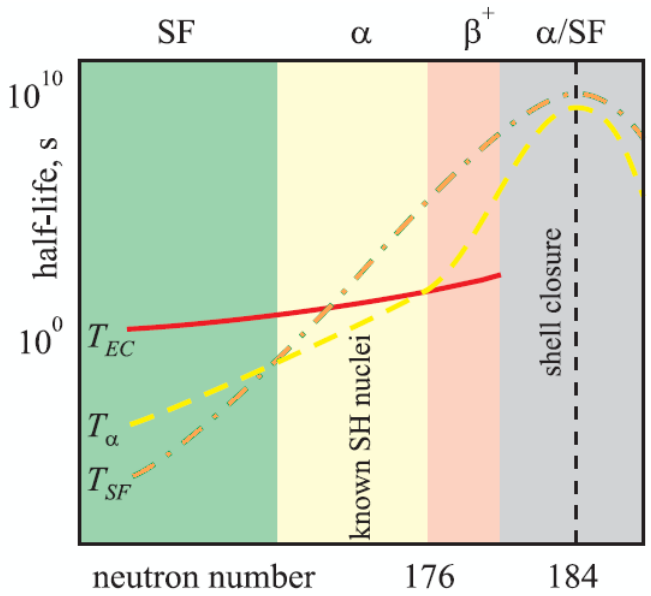
Results – $^{291-x}$115 (xn-channel, x=2?)

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 "brute force" 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!

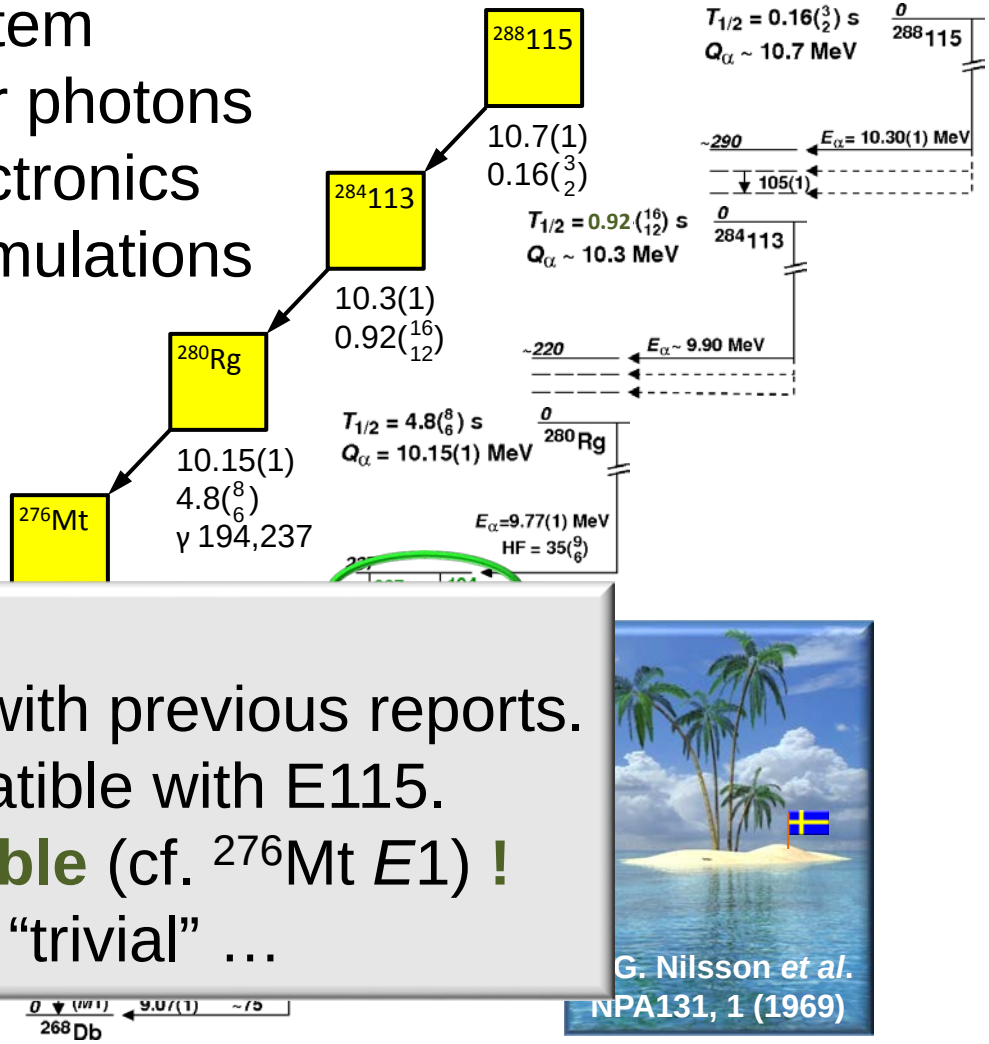


A.V. Karpov *et al.*, Int. J. Mod. Phys. E21, 1250013 (2012)

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” …