Spectroscopy of the Heaviest Elements

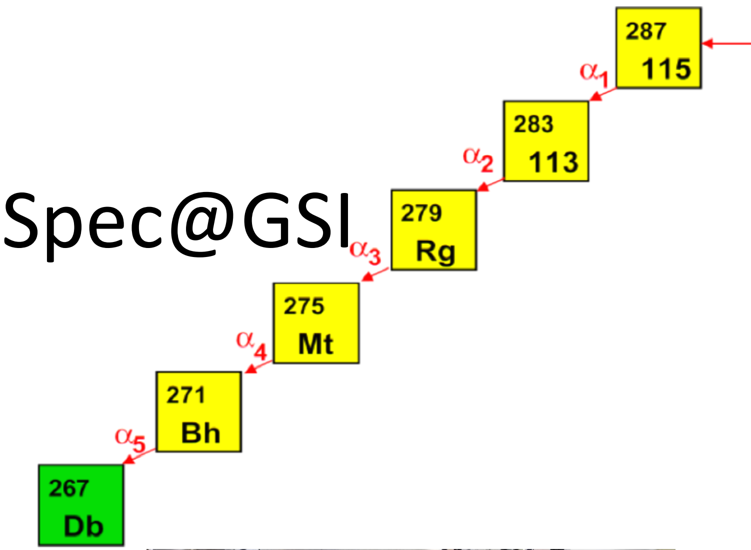
Ulrika Forsberg, Dirk Rudolph, Claes Fahlander et al.

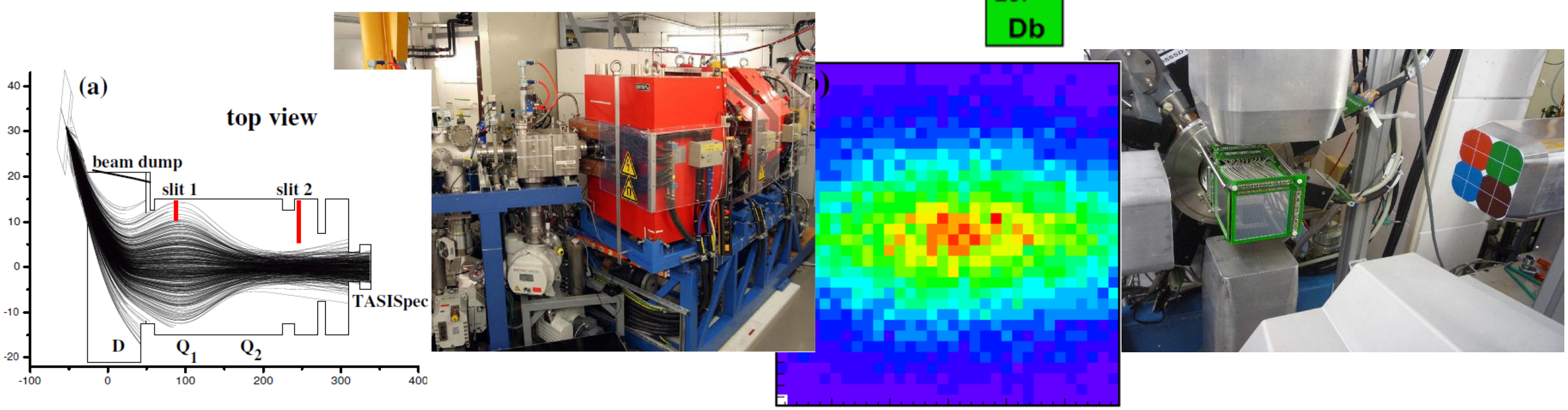
August 27, 2014

CGS15, Dresden

Outline

- The heaviest elements - what do we know about them?
- Spectroscopy setups
- Overview + results TASCA/TASISpec@GSI
- Two interesting physics cases



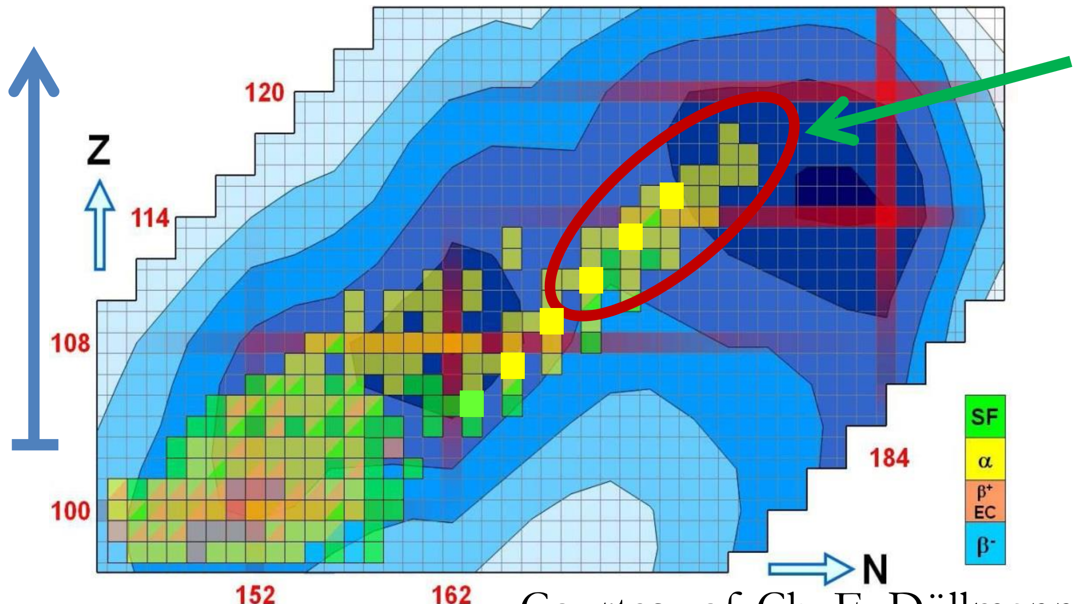


Superheavy Elements

- Definition: Z ≥ 104
- Latest "island": Z = 113-118. Observed or claimed in ^{48}Ca-induced reactions of actinide targets

Yu.Ts.Oganessian, J. Phys.G34, R165 (2007), Radiochim. Acta 99, 429 (2011)

Superheavy elements, Z ≥ 104



Courtesy of Ch. E. Düllmann

Elements Z > 112

- Alpha energies
- Lifetimes
- Production cross sections

but

- No knowledge of excited states!
- …and we have not explicitly measured their atomic numbers…

Flerovium (E114) and **livermorium (E116)**: accepted and named based on this information + observation of ^{283}112 (Cp, copernicium) "anchor".

IUPAC/IUPAP committee wants this to accept the claimed **E113, E115, E117 and E118**

Spectroscopy setups

- TASCA/TASISpec at GSI

Spectroscopy of heavy elements: L.-L. Andersson et al., NIM A622, 164 (2010)
Spectroscopy of superheavy elements: D. Rudolph et al., PRL 111, 112502 (2013)
and more…

- BGS/C^3 at Lawrence Berkeley National Laboratory

Ruthfordium spectroscopy: J. Rissanen et al., PRC 88, 044313 (2013)

TASCA/TASISpec collaboration

… 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)

LUNDS UNIVERSITET

GSI

HIM

JGU

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

OAK RIDGE National Laboratory

JAEA

PAUL SCHERRER INSTITUT PSI

UNIVERSITY OF LIVERPOOL

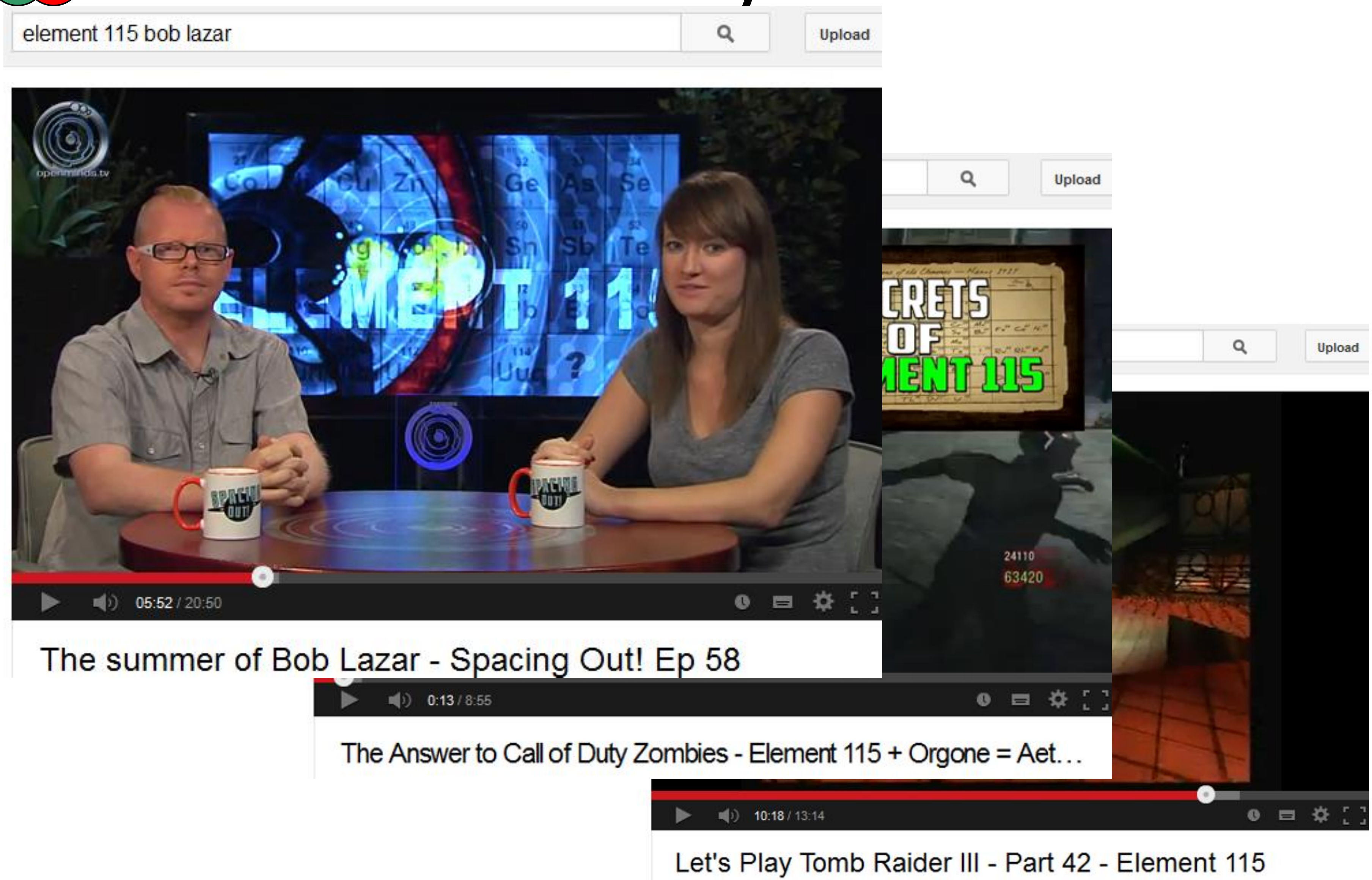
UiO : University of Oslo

Special thanks to …

UNILAC

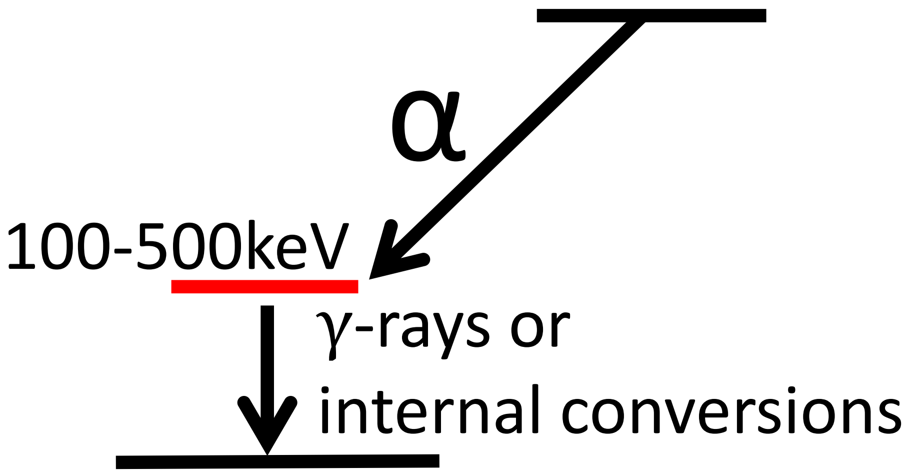
ENSAR

E115 is everywhere…



X-ray Fingerprinting

Look for characteristic X-rays emitted in coincidence with α decays!



→ **X-rays**

Energy depends on proton number!

X-ray Fingerprinting

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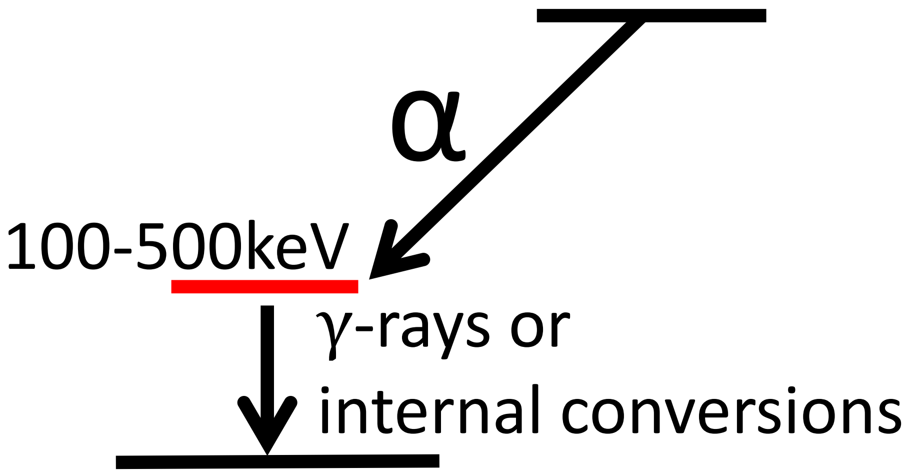
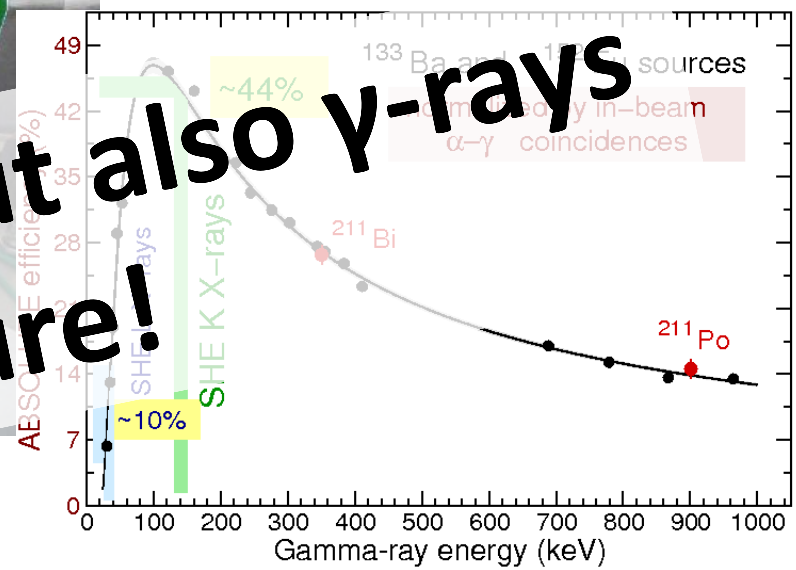


→ **K-X-rays!**

Energy depends on proton number!

TASiSpec



Not only X-rays but also γ-rays → nuclear structure!

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

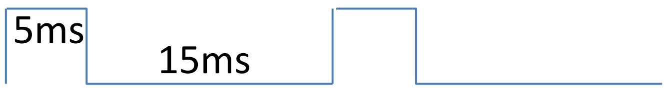
4 Ge Clover (4*4 crystals)
1 Ge Cluster (7 crystals)
=> ~40% γ−detection eff. at 150 keV

L.-L. Andersson *et al.*, NIM A622, 164 (2010)

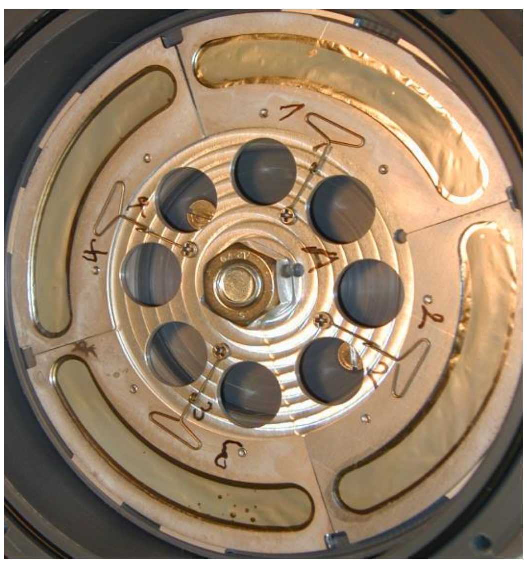
Production of E115 at GSI

Reaction: ${}^{48}_{20}Ca + {}^{243}_{95}Am \rightarrow {}^{288}115 + 3n$

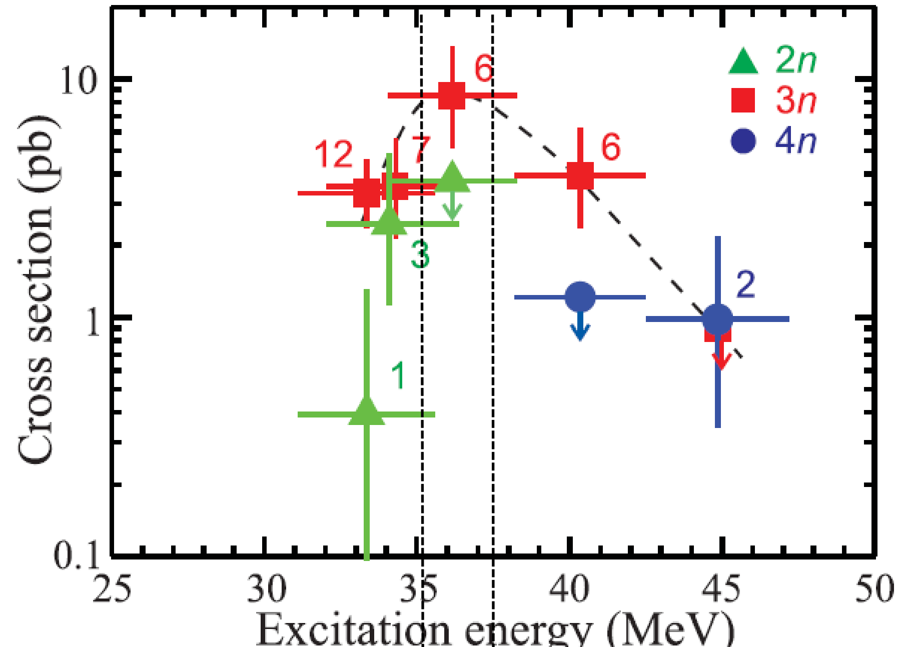
Beam: ${}^{48}Ca$ ions, $6*10^{12}$/s, pulsed (5 ms on, 15 ms off)



Target: 0.83 mg/cm^2 ${}^{243}Am_2O_3$ on 2 µm Ti backing



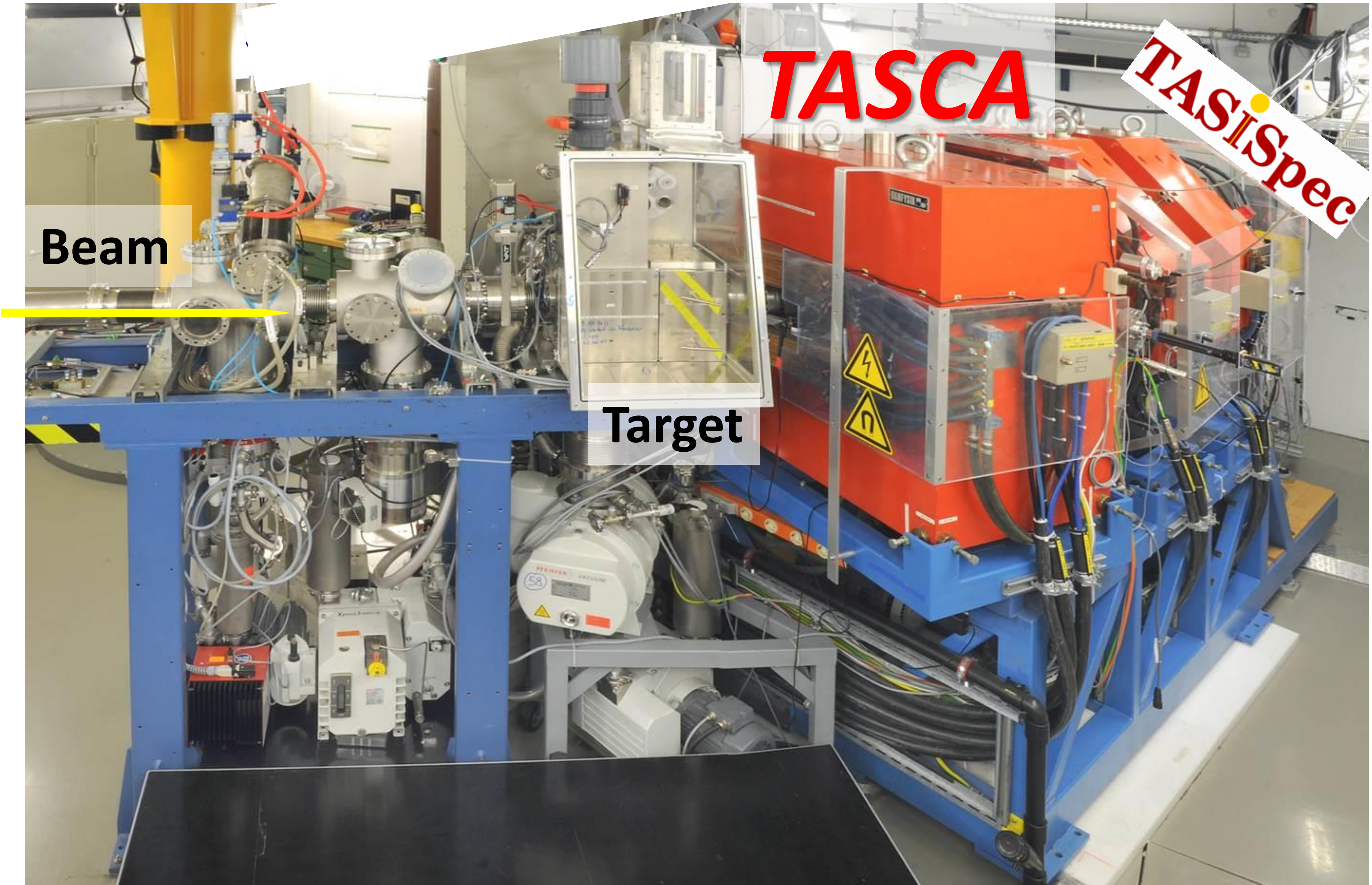
Y. Oganessian et al., PRC **87** 014302 (2013)



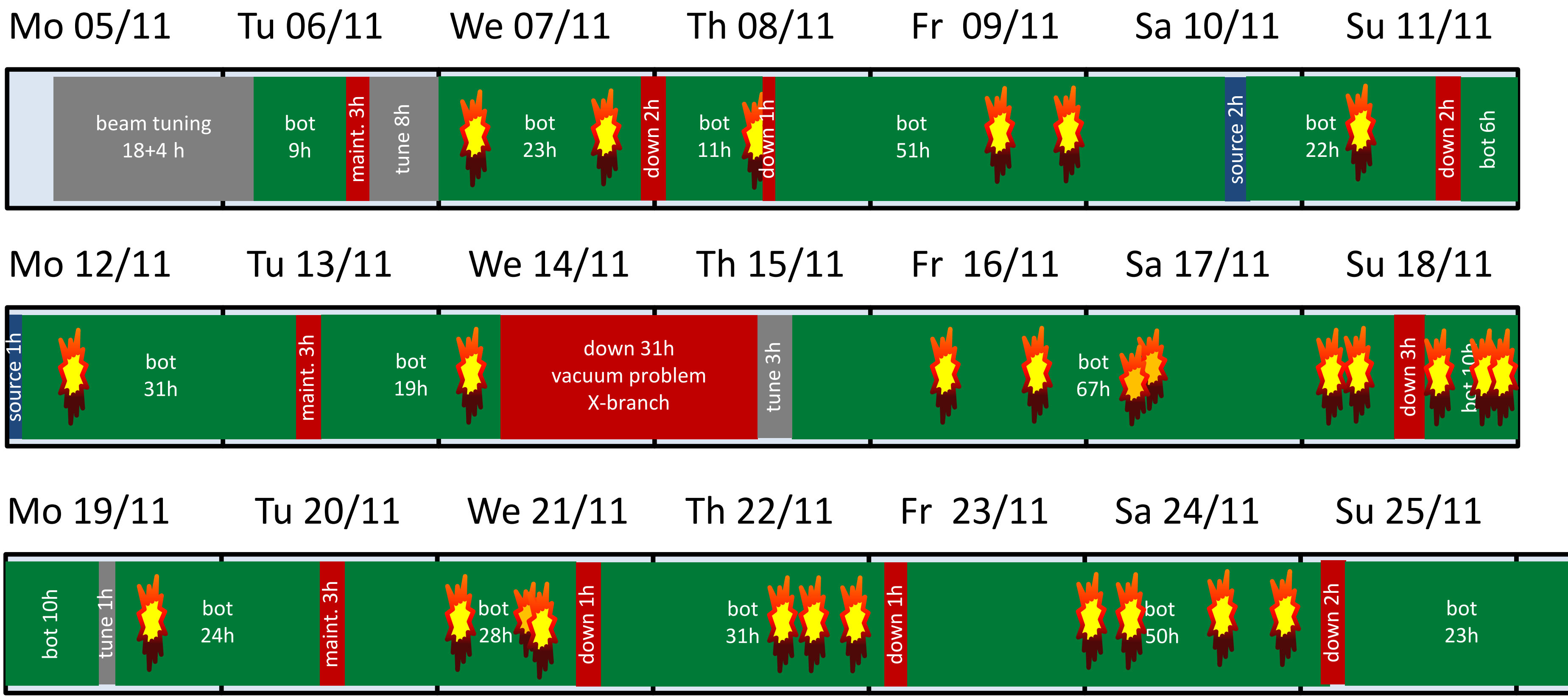
Part 1, 262 MeV
$4*10^{18}$ ${}^{48}Ca$ ions

Part 2, 259 MeV
$2*10^{18}$ ${}^{48}Ca$ ions

Production and Separation of E115

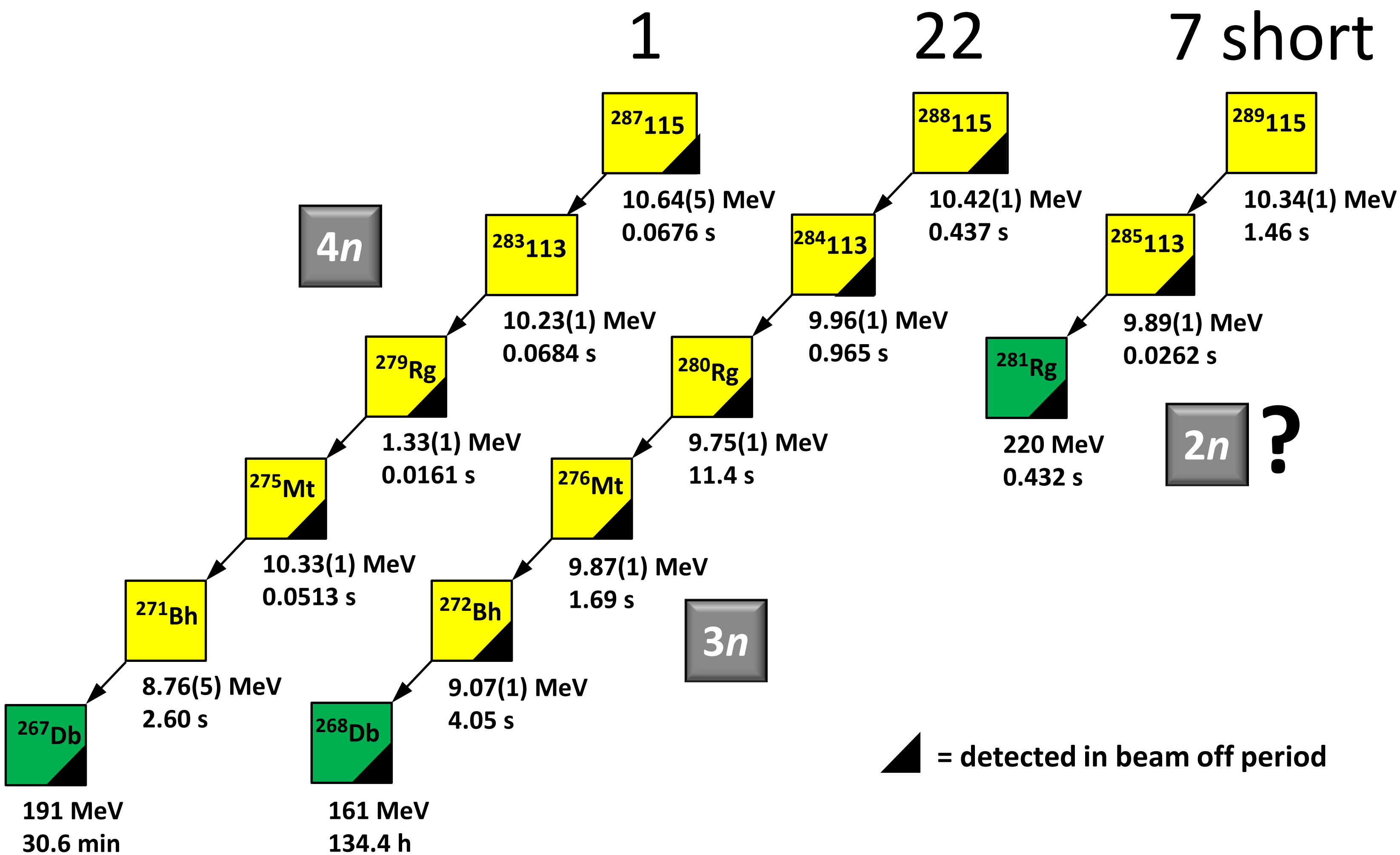


2012 Experiment

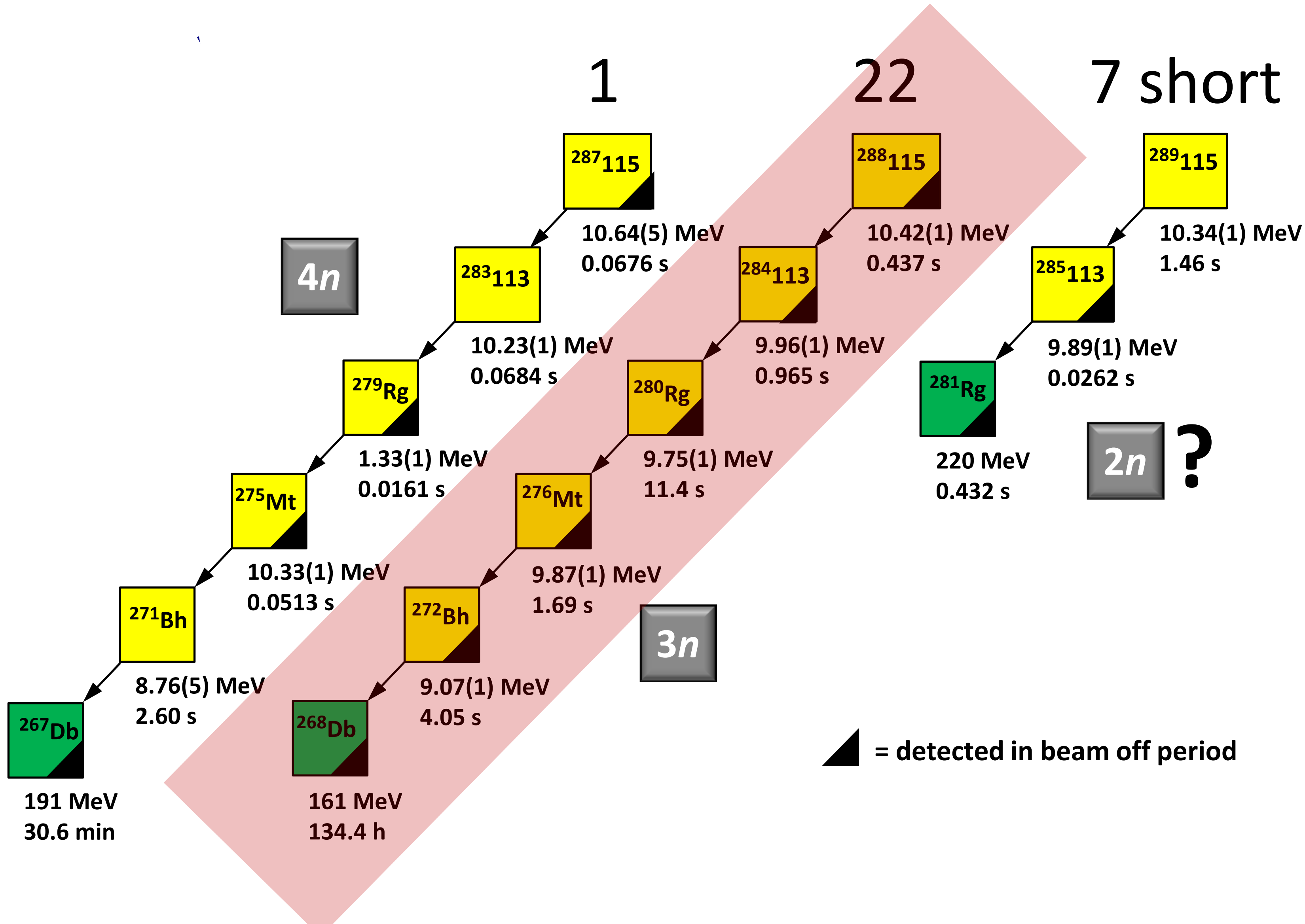


Beam on target: 415h ~6·10^{18} ^{48}Ca 30x

Ξ 30 chains detected in 18 days

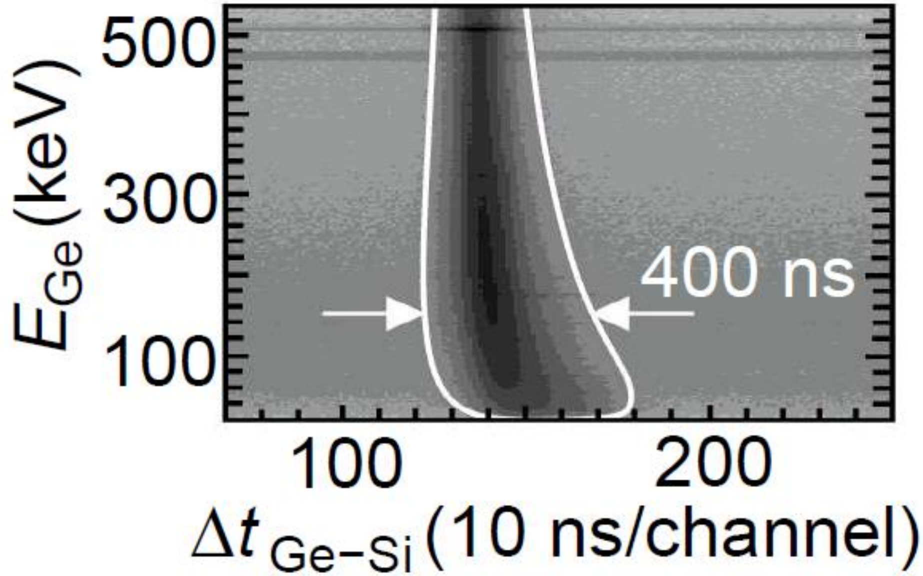


≡ 30 chains detected in 18 days

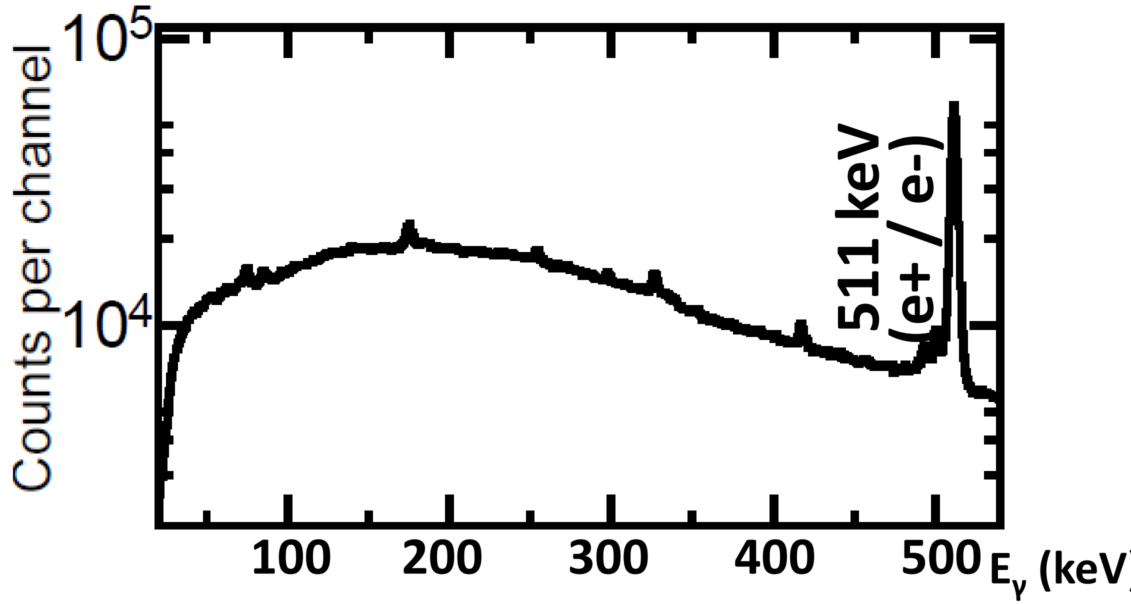


α-photon coincidences

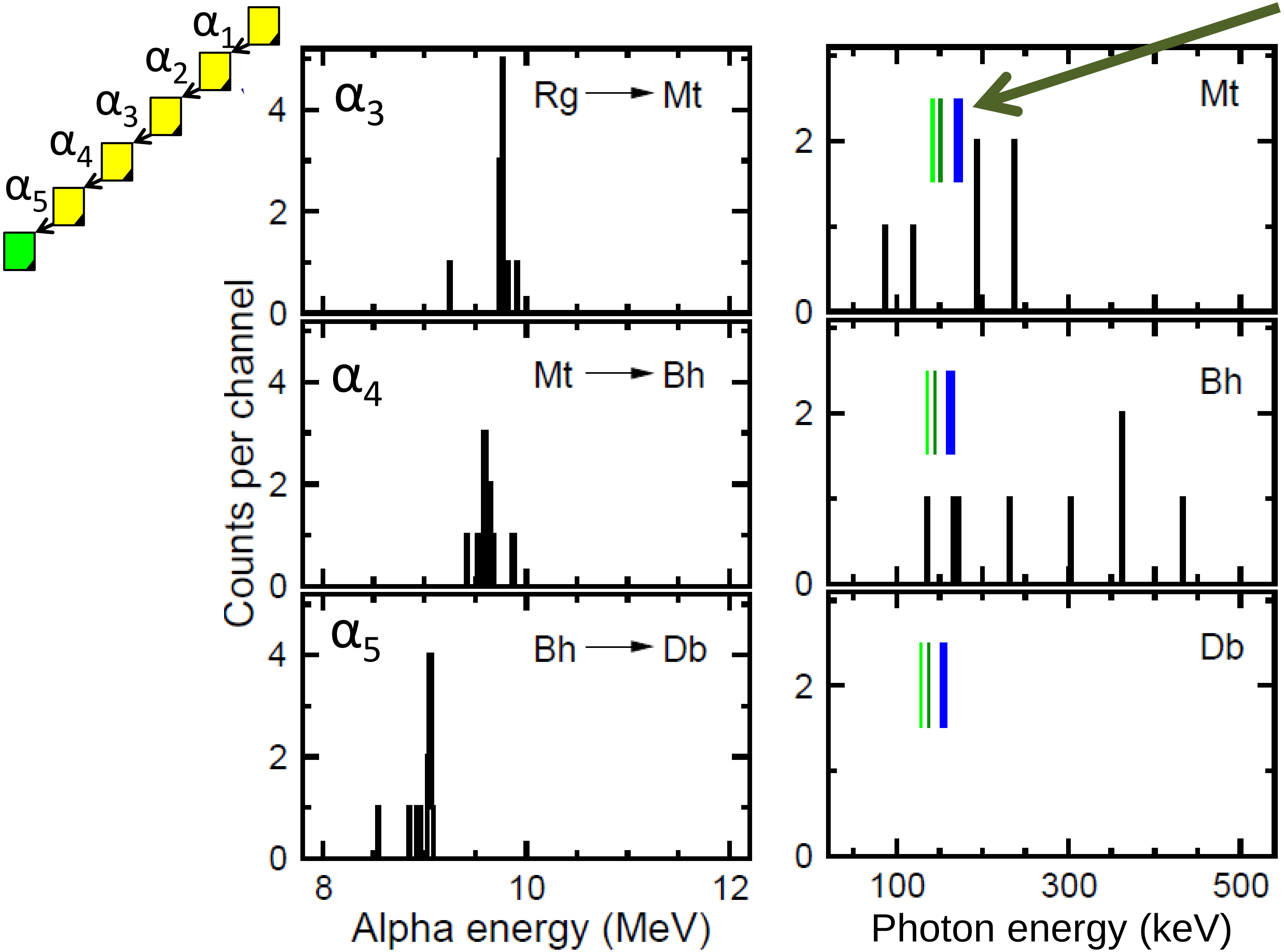
Correlation time between implantation detector and Ge detector. White line marks the gate for prompt coincidences:



Photon spectrum in prompt coincidence with implantation detector, "beam off":



α-photon coincidences



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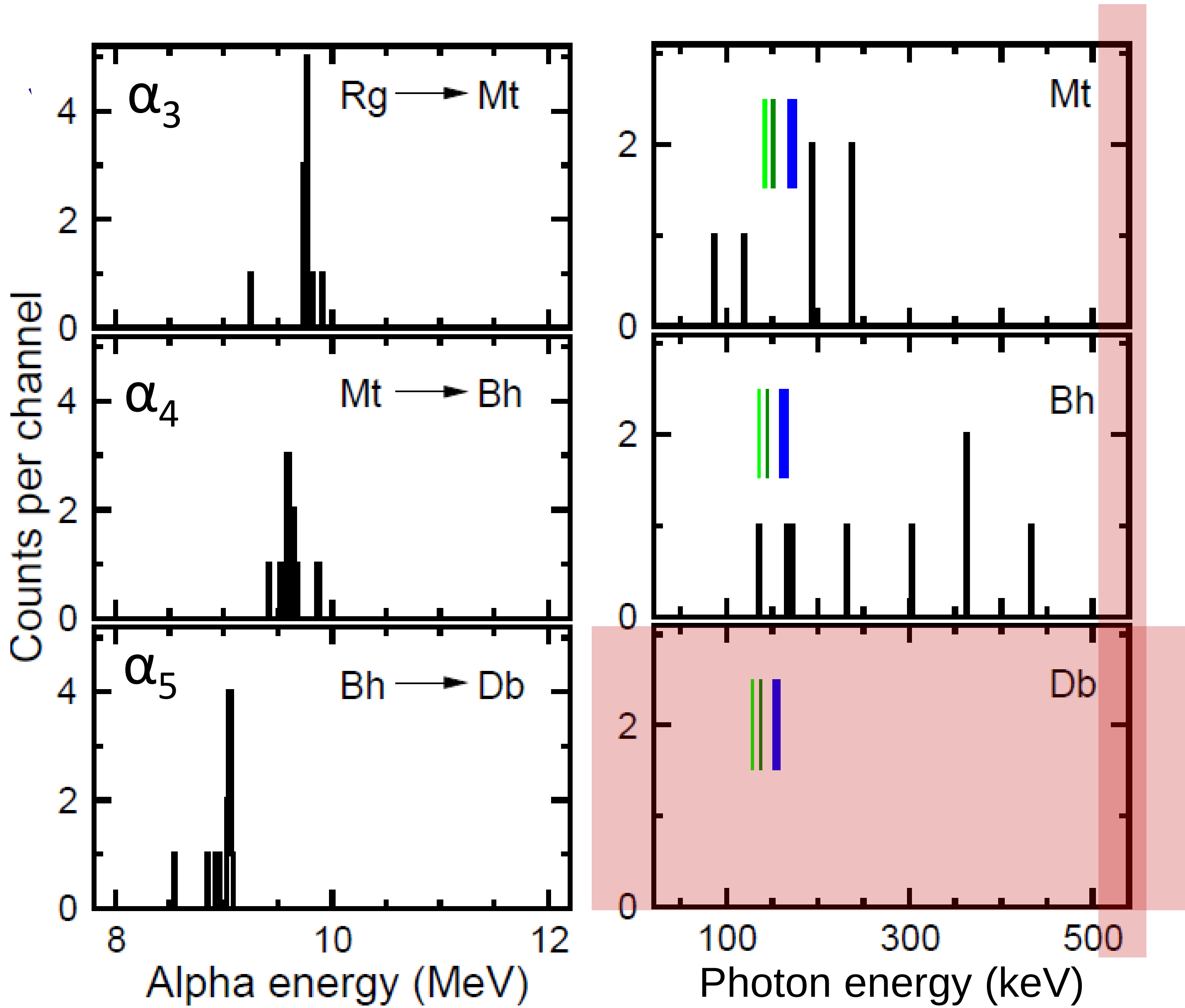
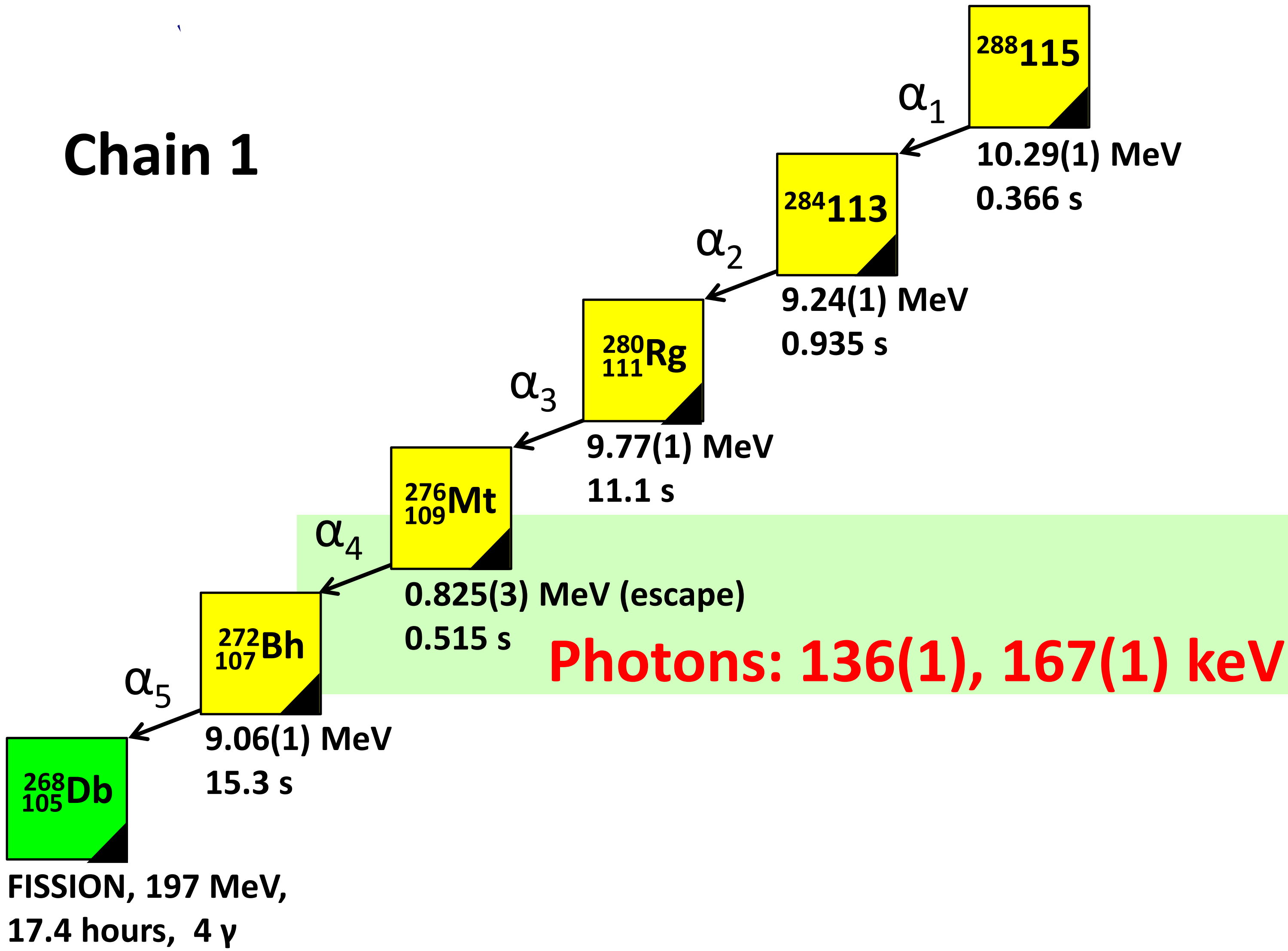


Characteristic X-rays

Chain 1



Characteristic X-rays

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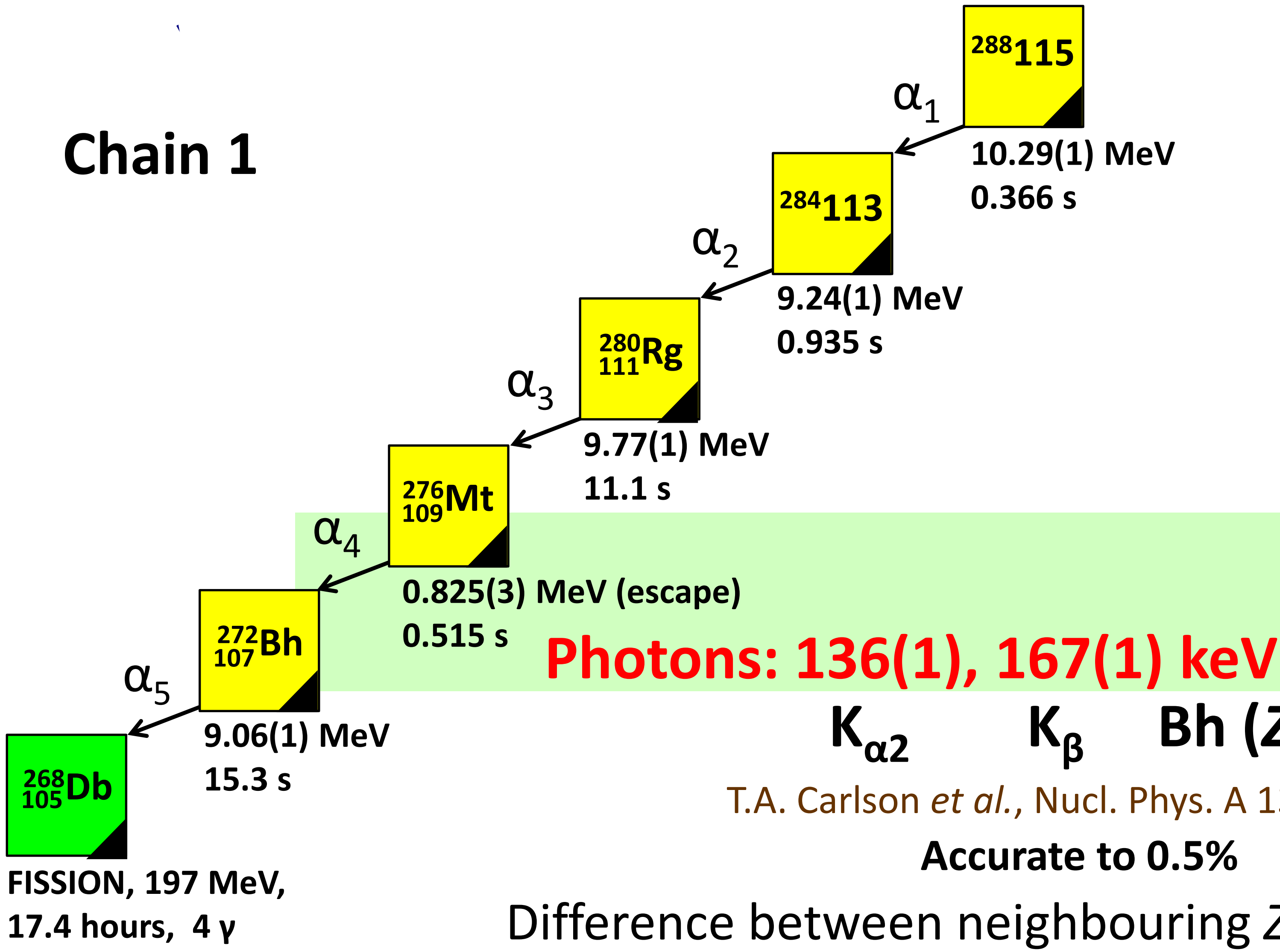


$K_{\alpha 2}$ K_{β} Bh (*Z*=107)

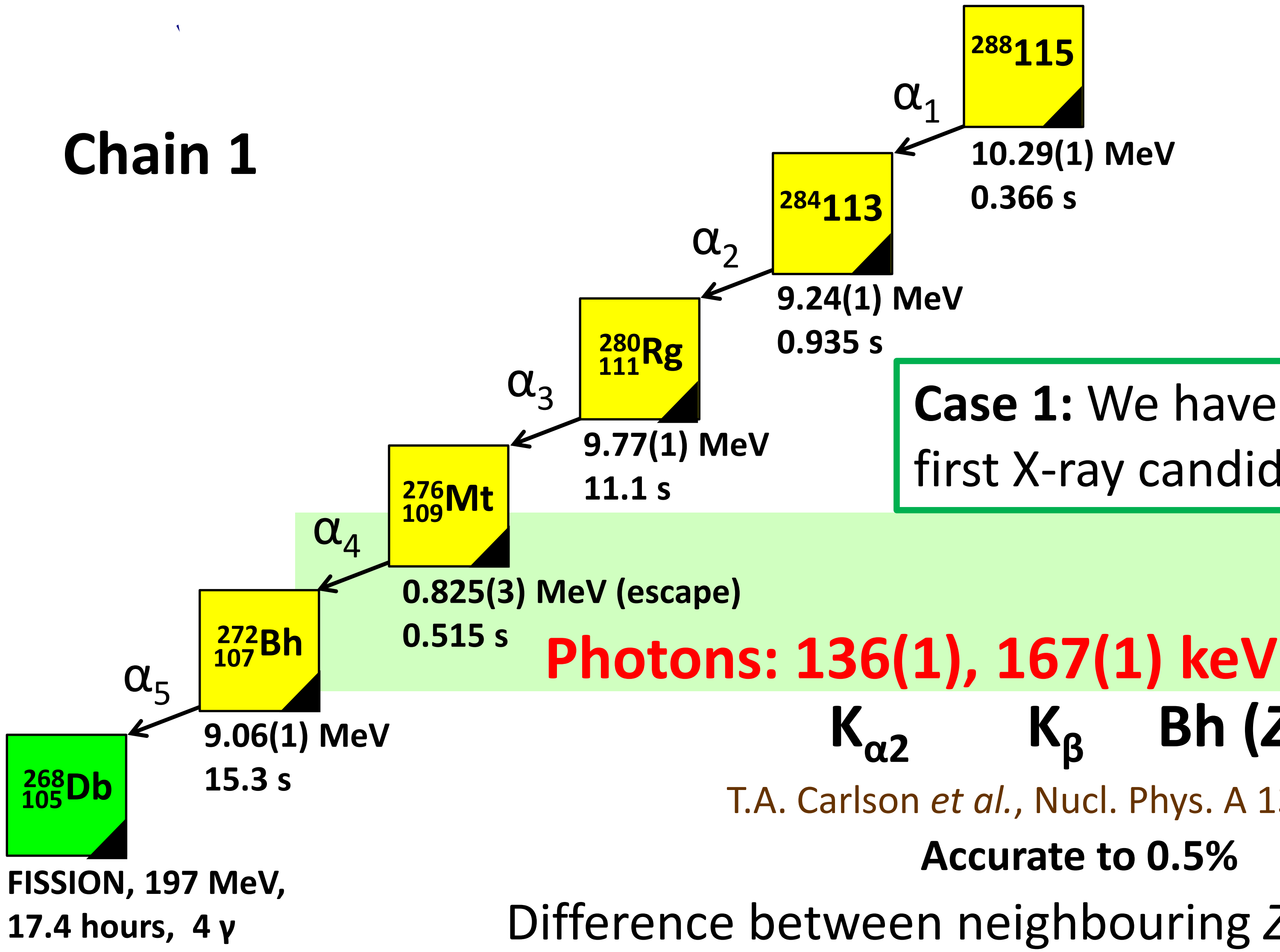
T.A. Carlson *et al.*, Nucl. Phys. A 135, 57 (1969)

Accurate to 0.5%

Difference between neighbouring *Z*: 3-4 keV

Characteristic X-rays

Chain 1



Case 1: We have seen the first X-ray candidates!

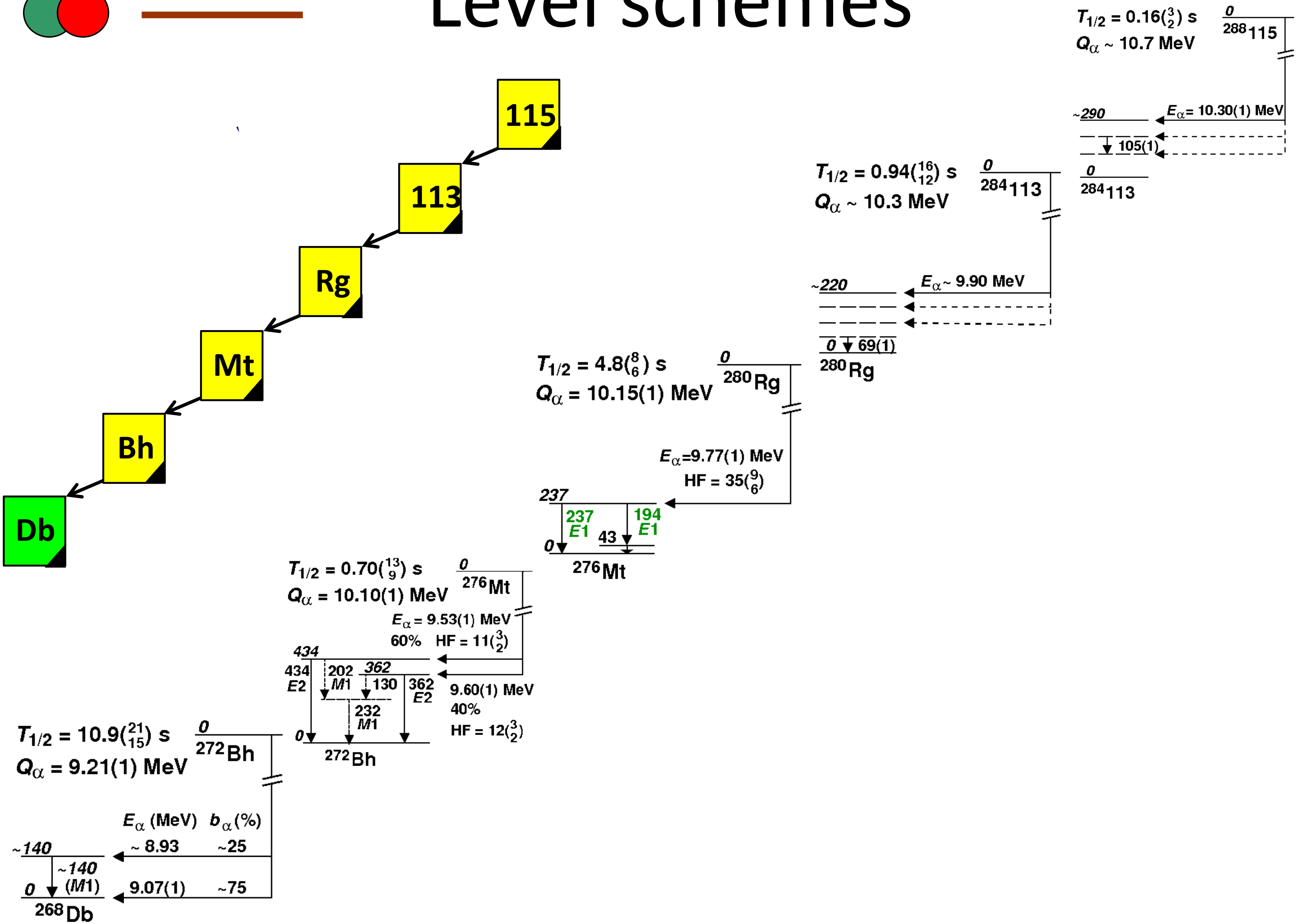
$K_{\alpha 2}$ K_{β} **Bh (Z=107)**

T.A. Carlson *et al.*, Nucl. Phys. A 135, 57 (1969)

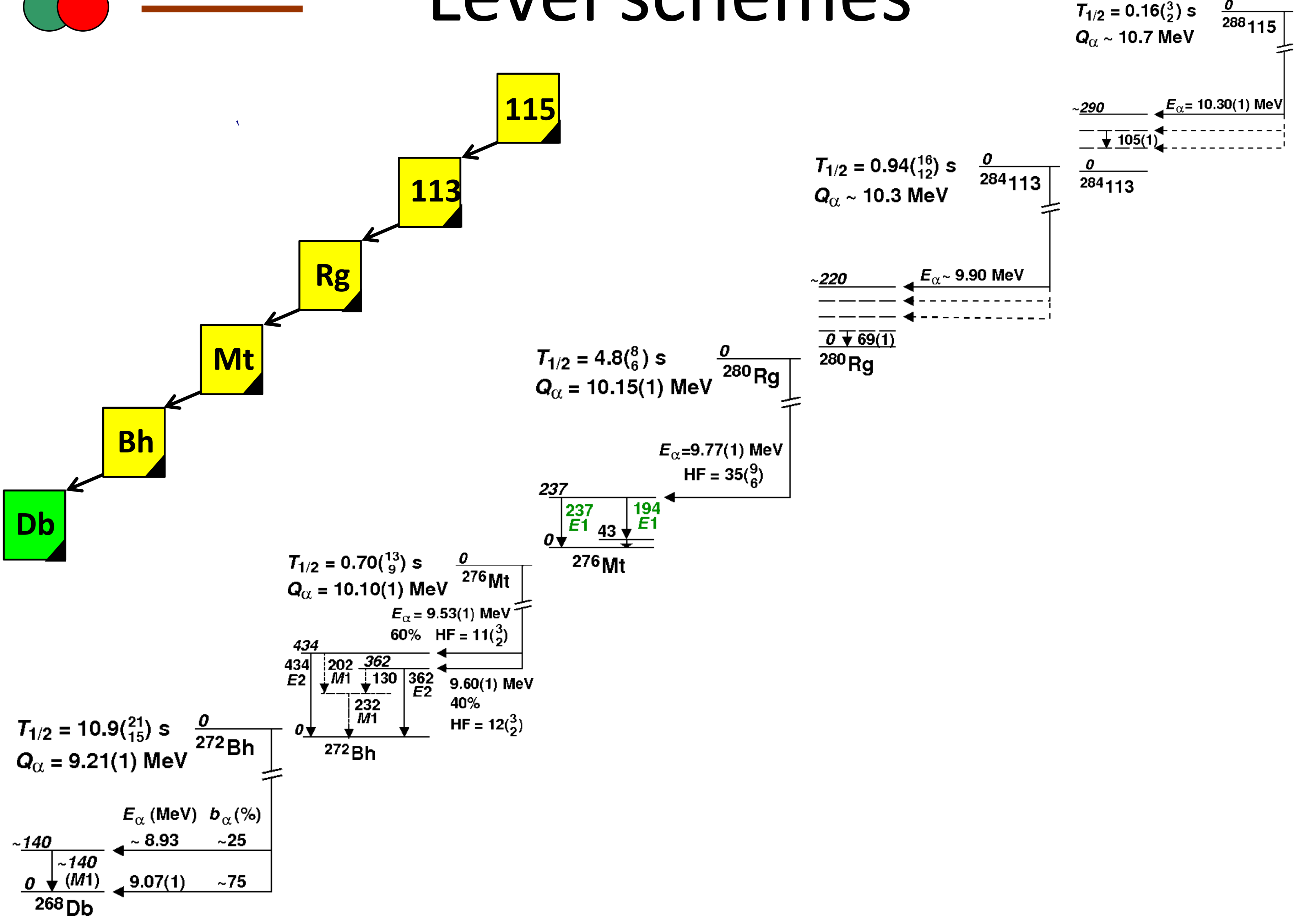
Accurate to 0.5%

Difference between neighbouring Z: 3-4 keV

Level schemes



Level schemes



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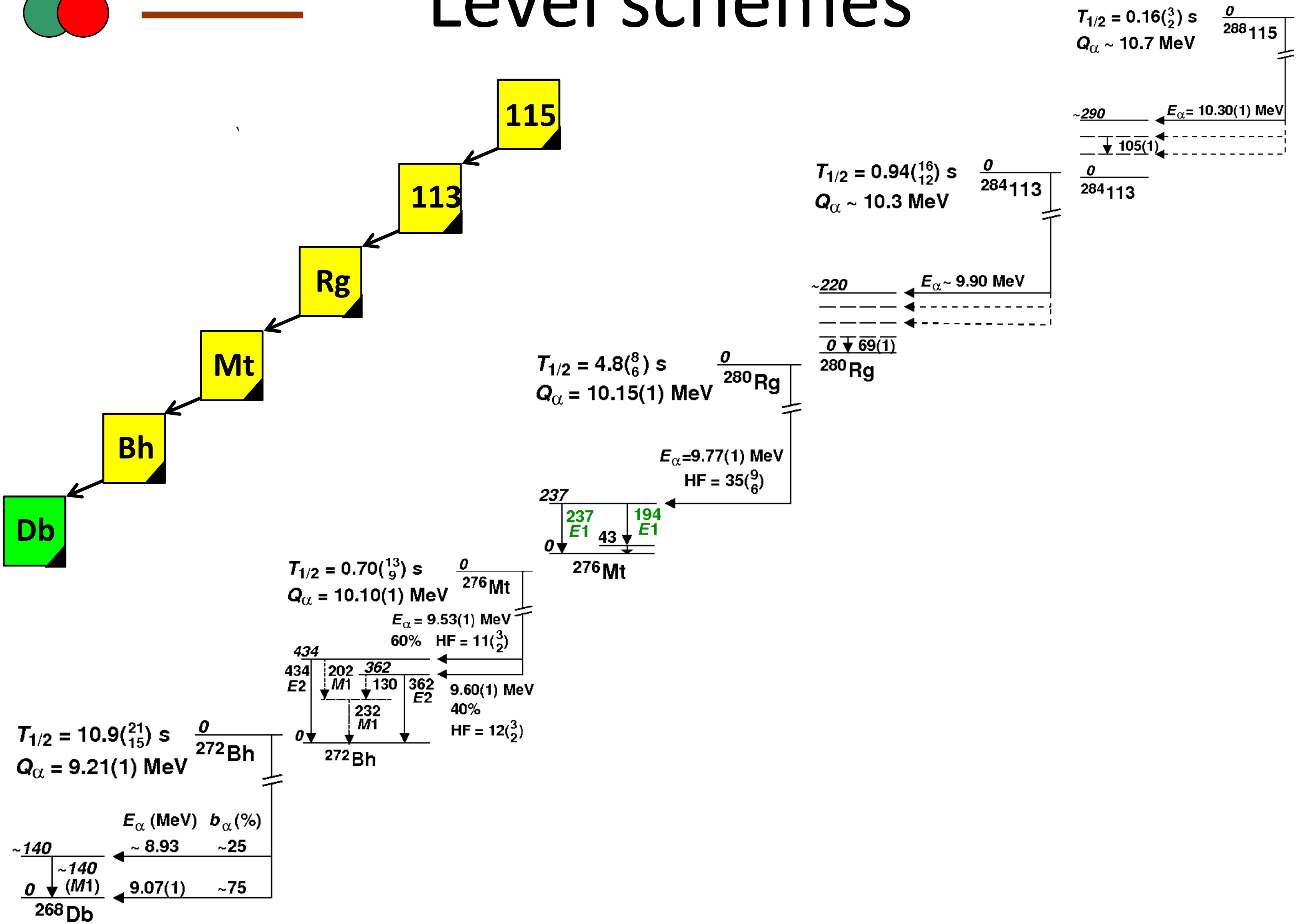
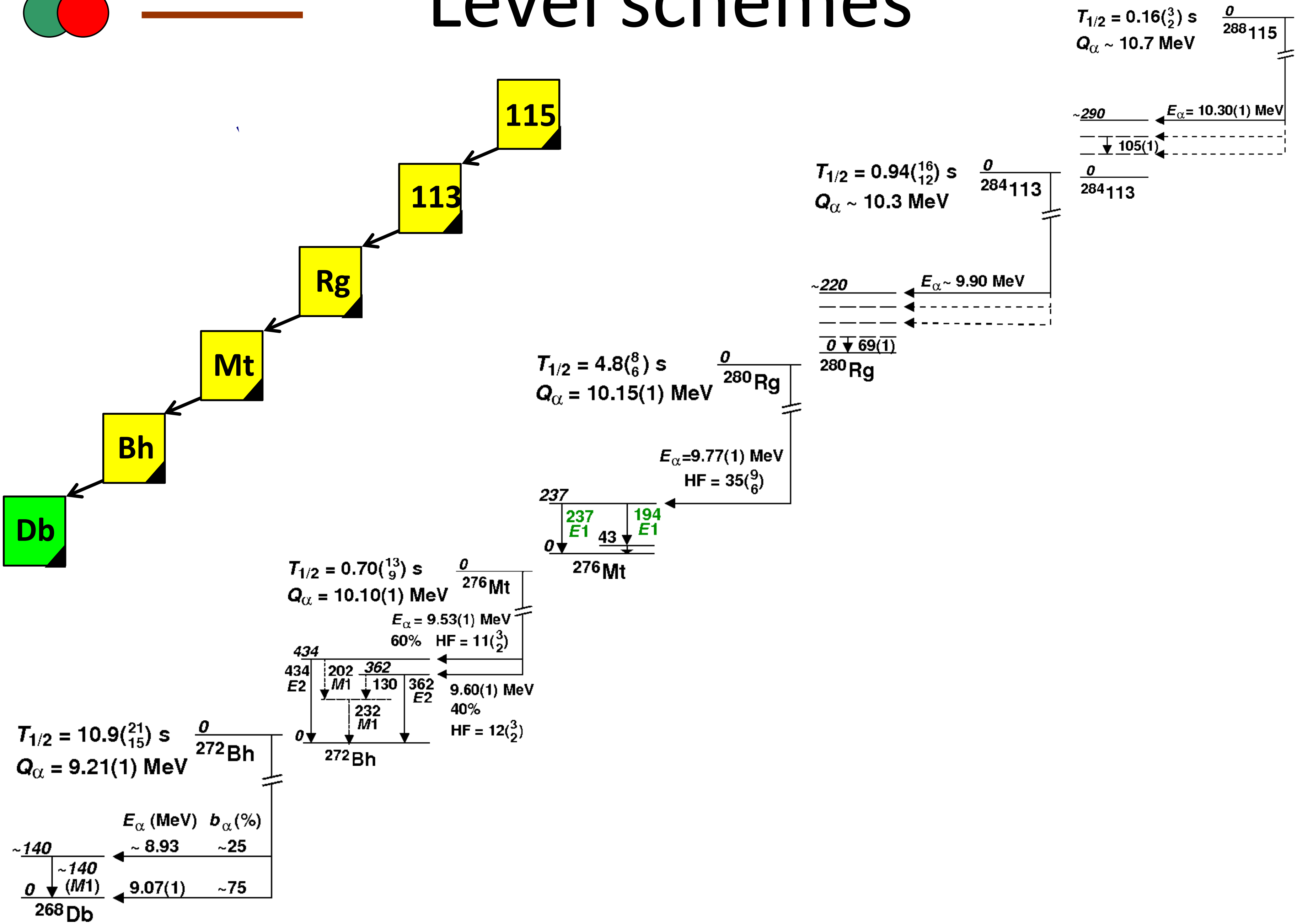


Level schemes



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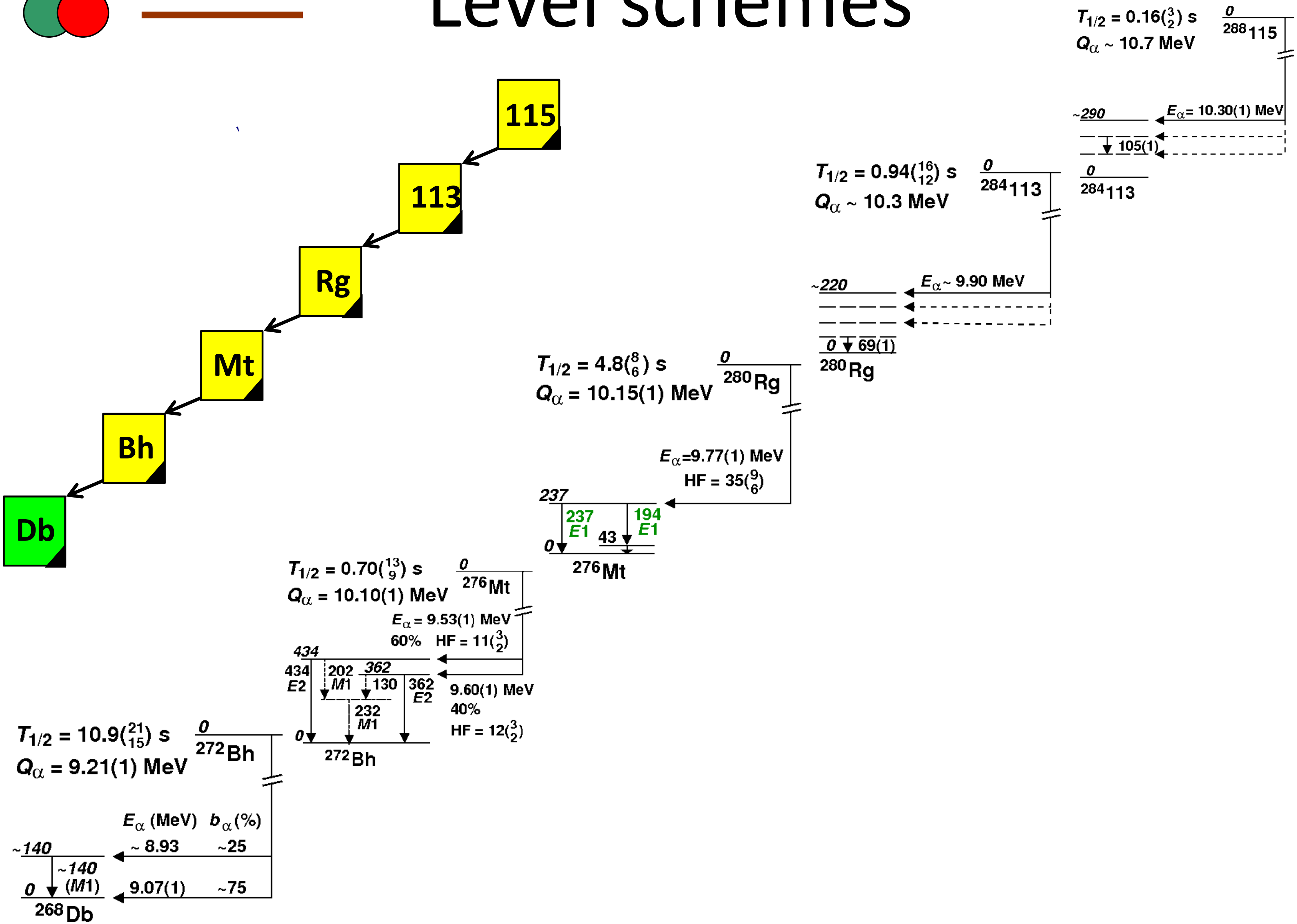
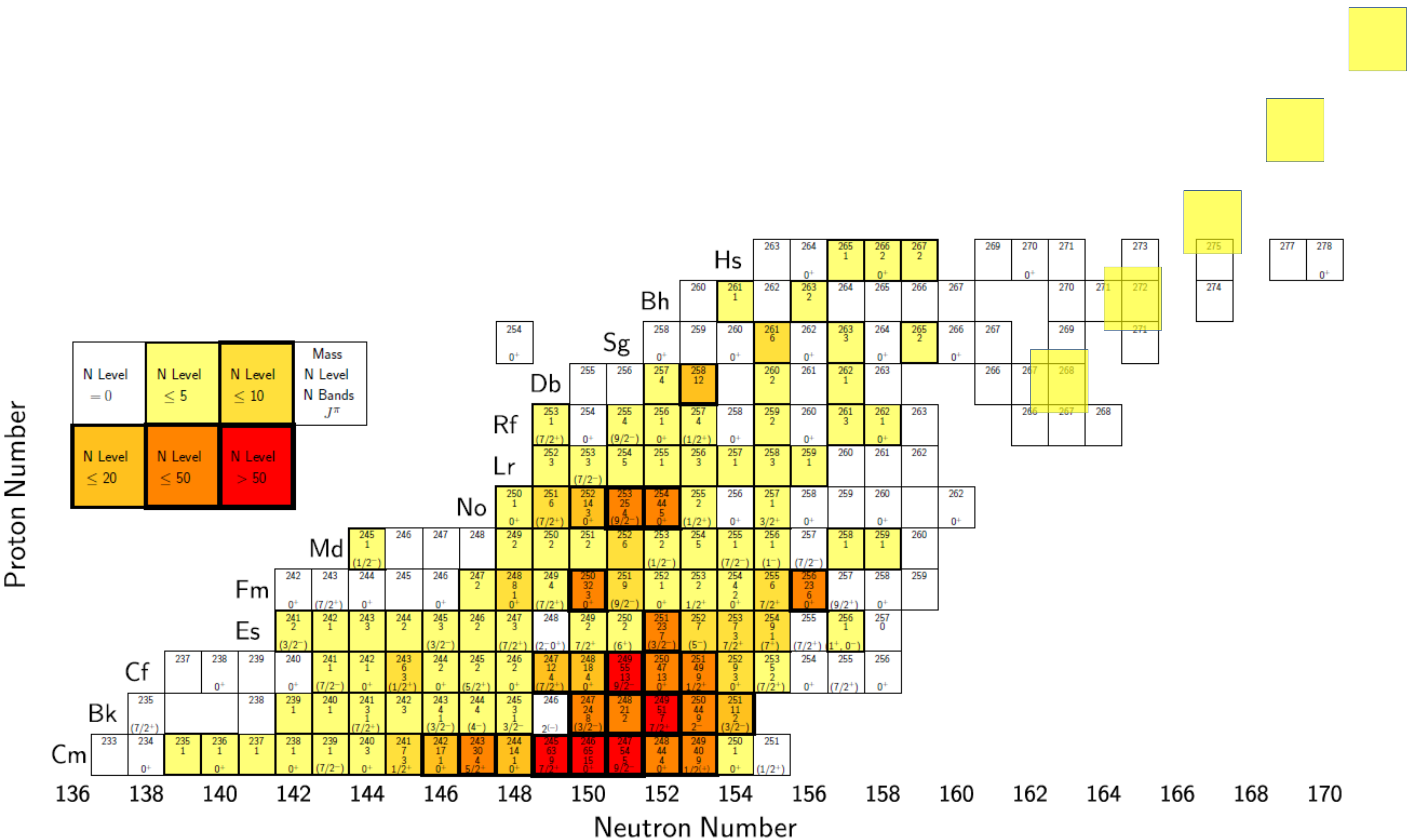
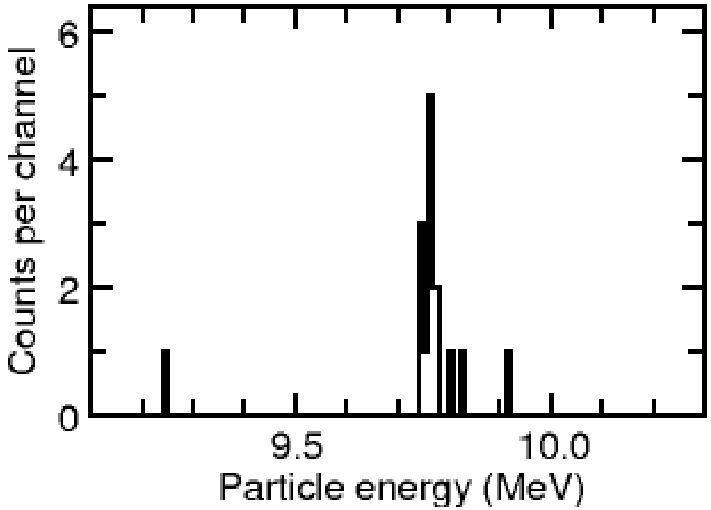
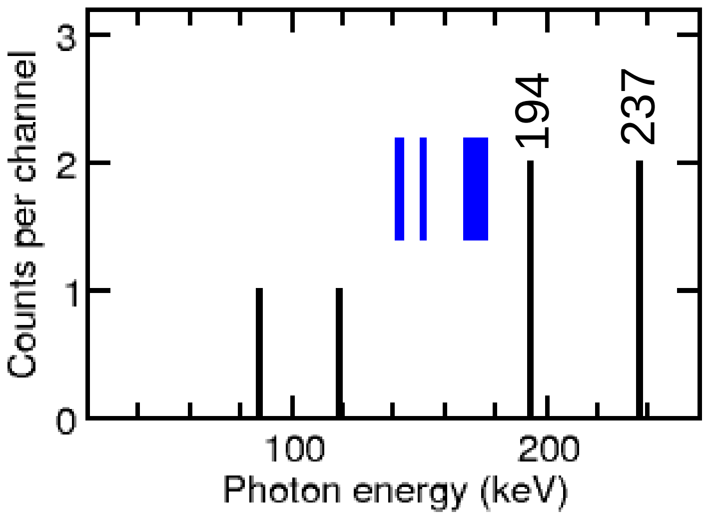


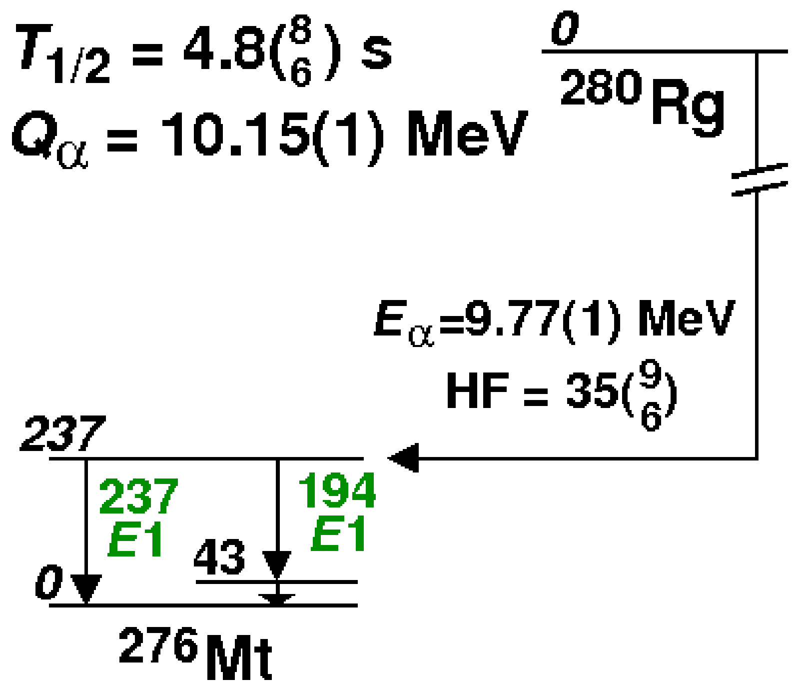
Number of known levels 2007



Rg → Mt level scheme

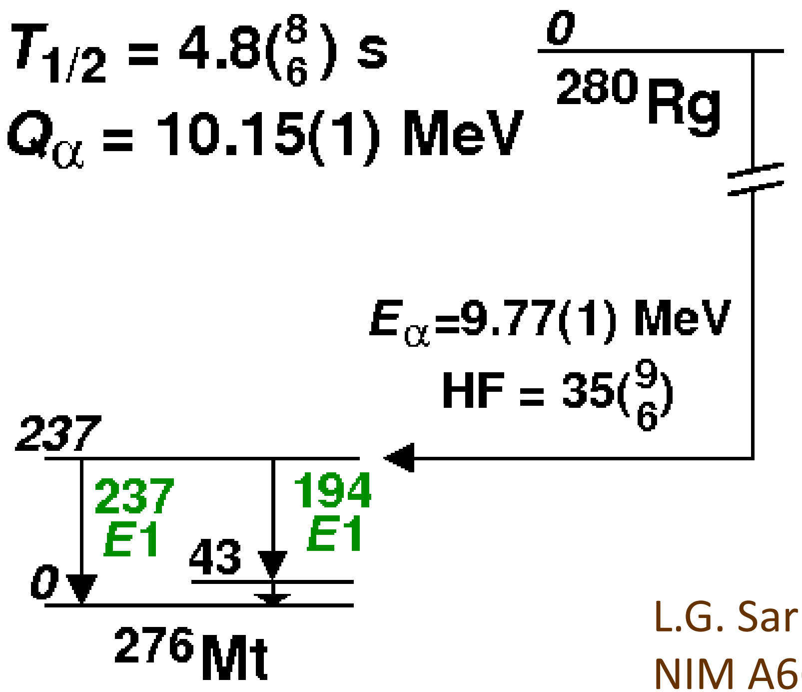


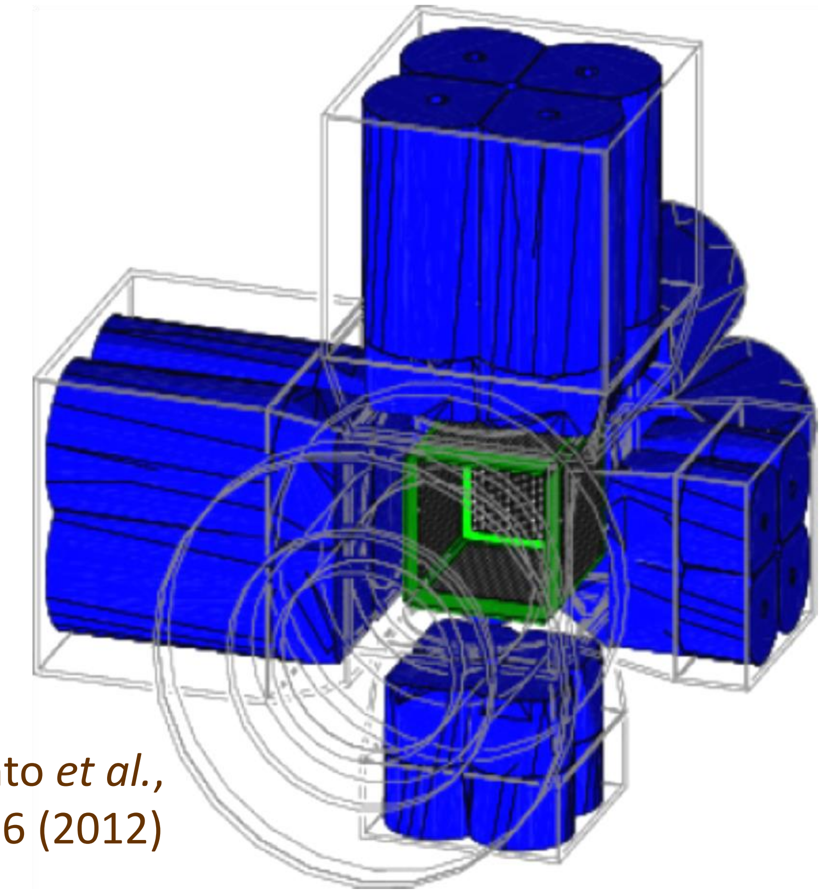




GEANT4 simulations

IF a level scheme looks like this...

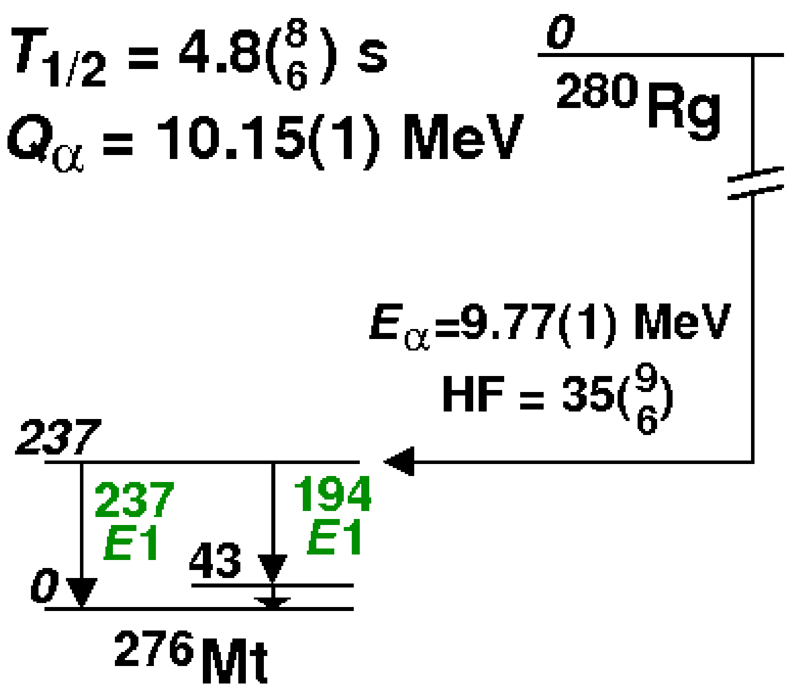


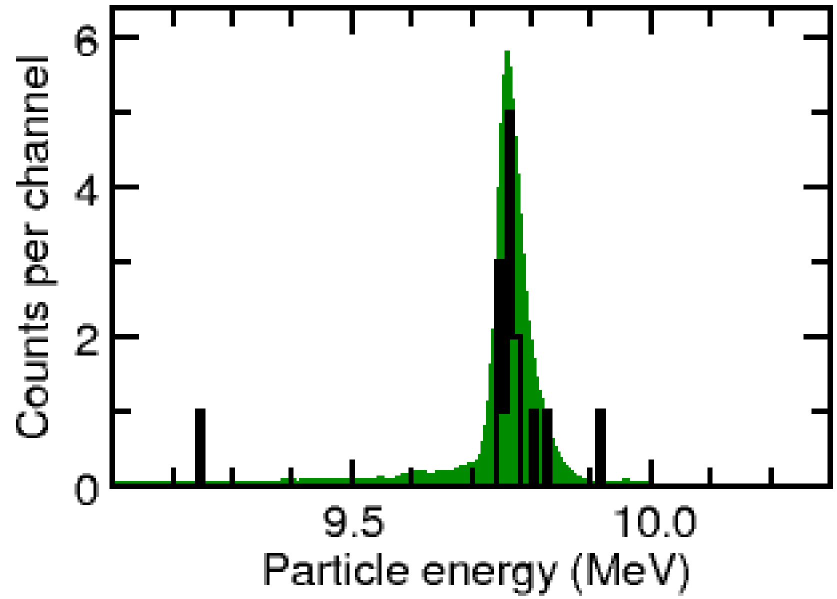


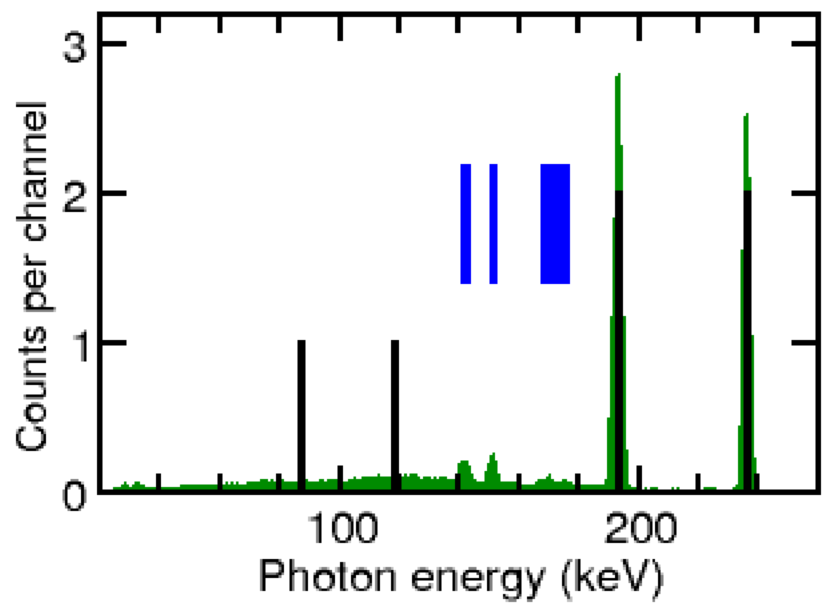
L.G. Sarmiento *et al.*,
NIM A667, 26 (2012)

what is the response of TASISpec?
(α, γ, e$^{\pm}$, X-rays...)

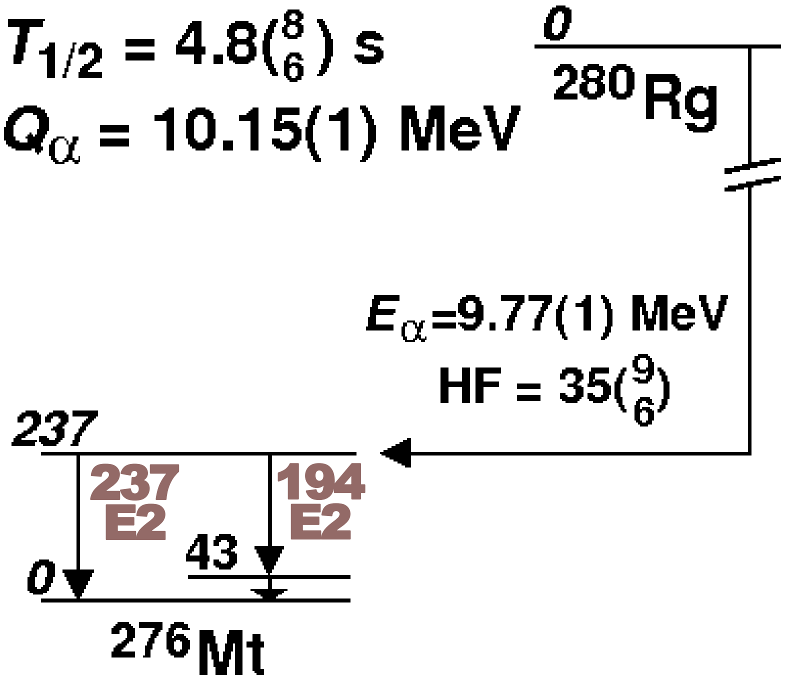
Rg → Mt simulations

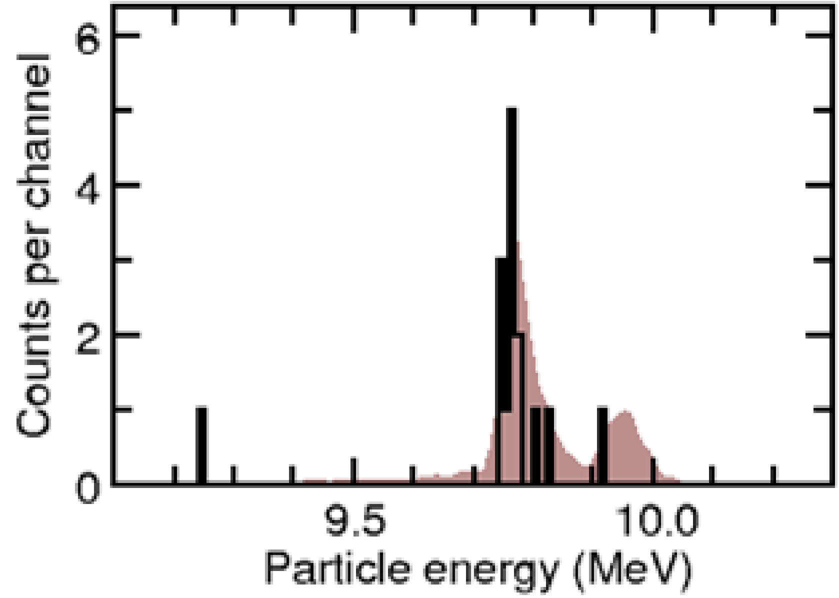


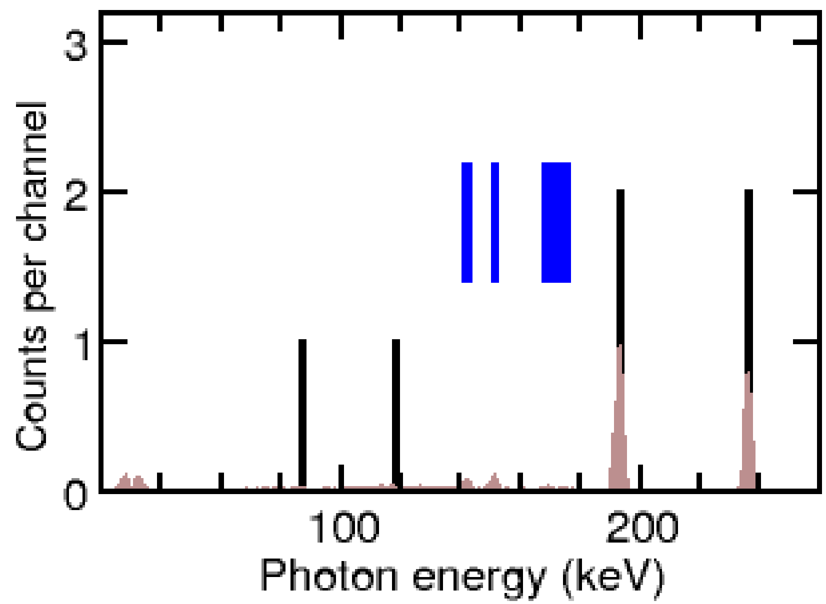




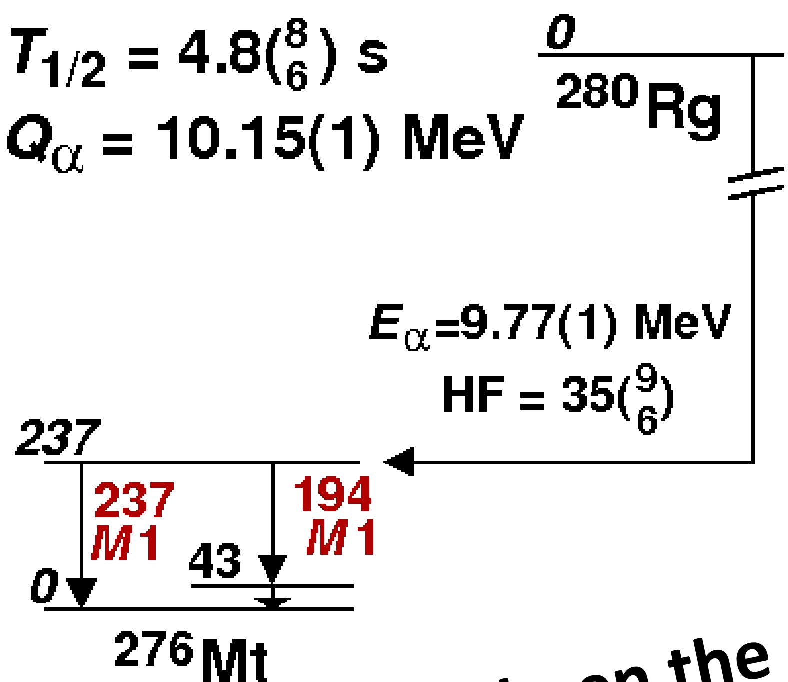
Rg → Mt simulations

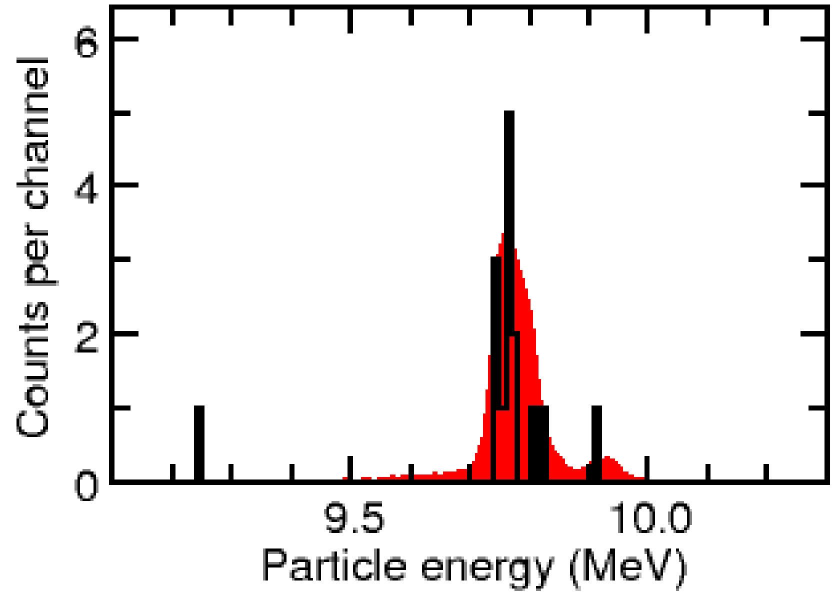


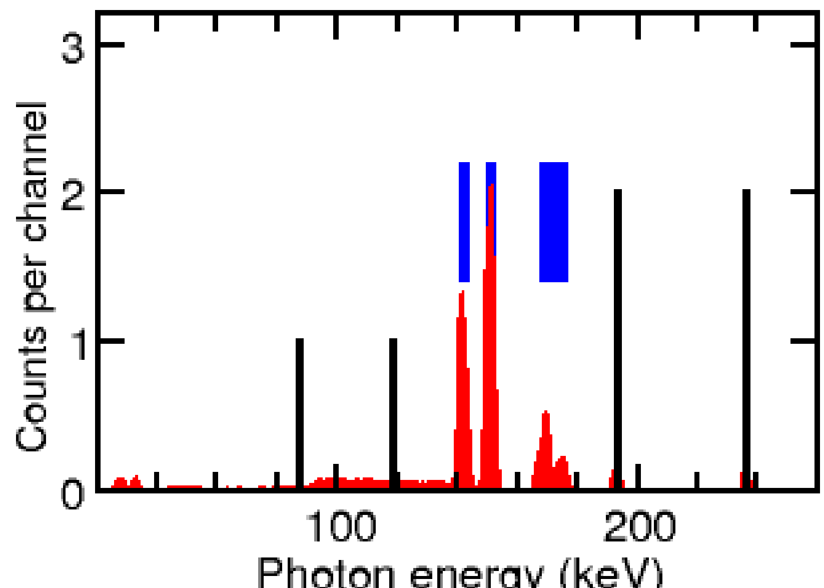




Rg → Mt simulations

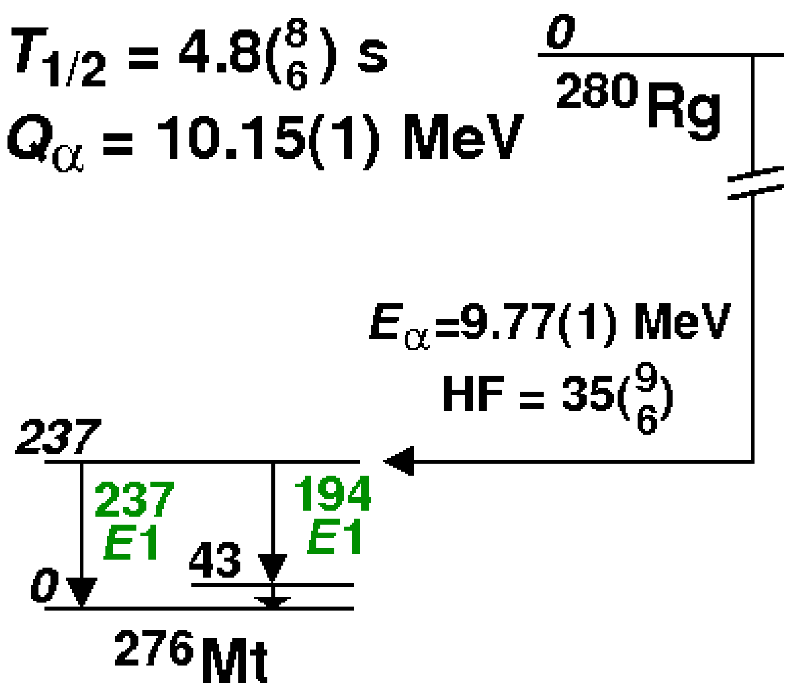


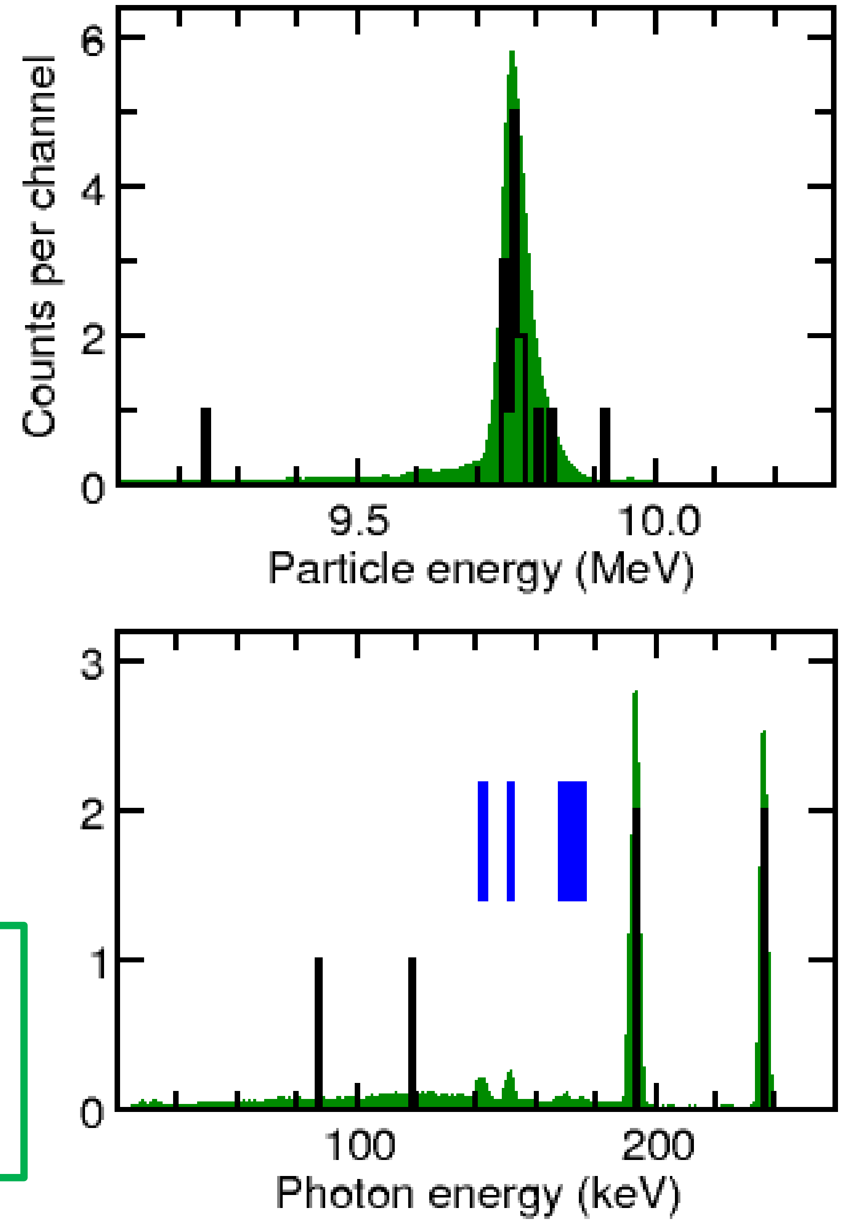




Would have been the perfect fingerprinting case!

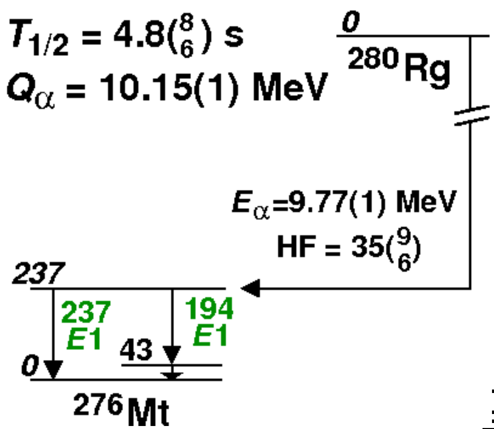
Rg → Mt simulations





Case 2: We have established the **presence of E1 transitions** in this decay step.

Nilsson orbitals, protons

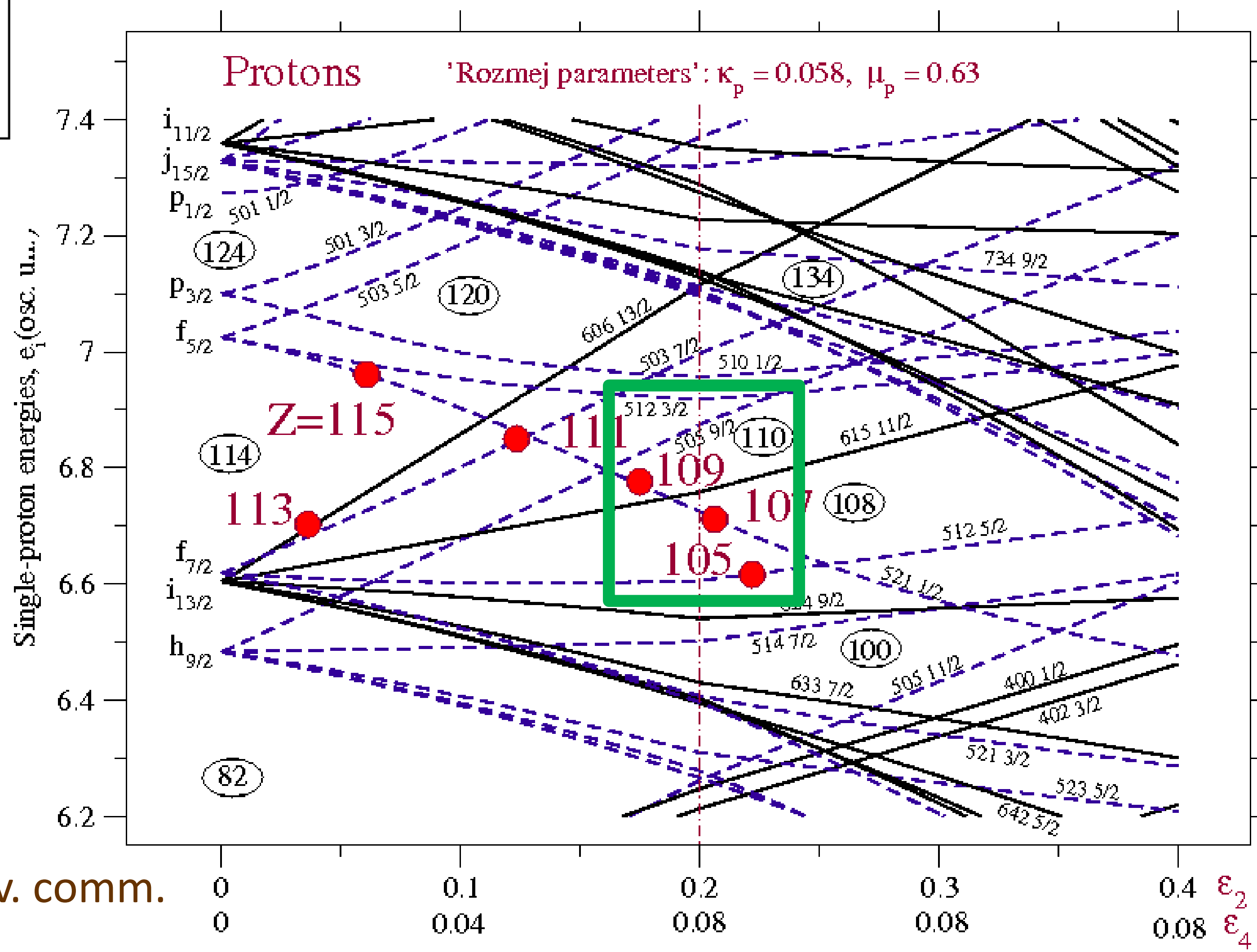


Deformation $\varepsilon_2 \approx 0.2$

(according to various models)

Positive parity

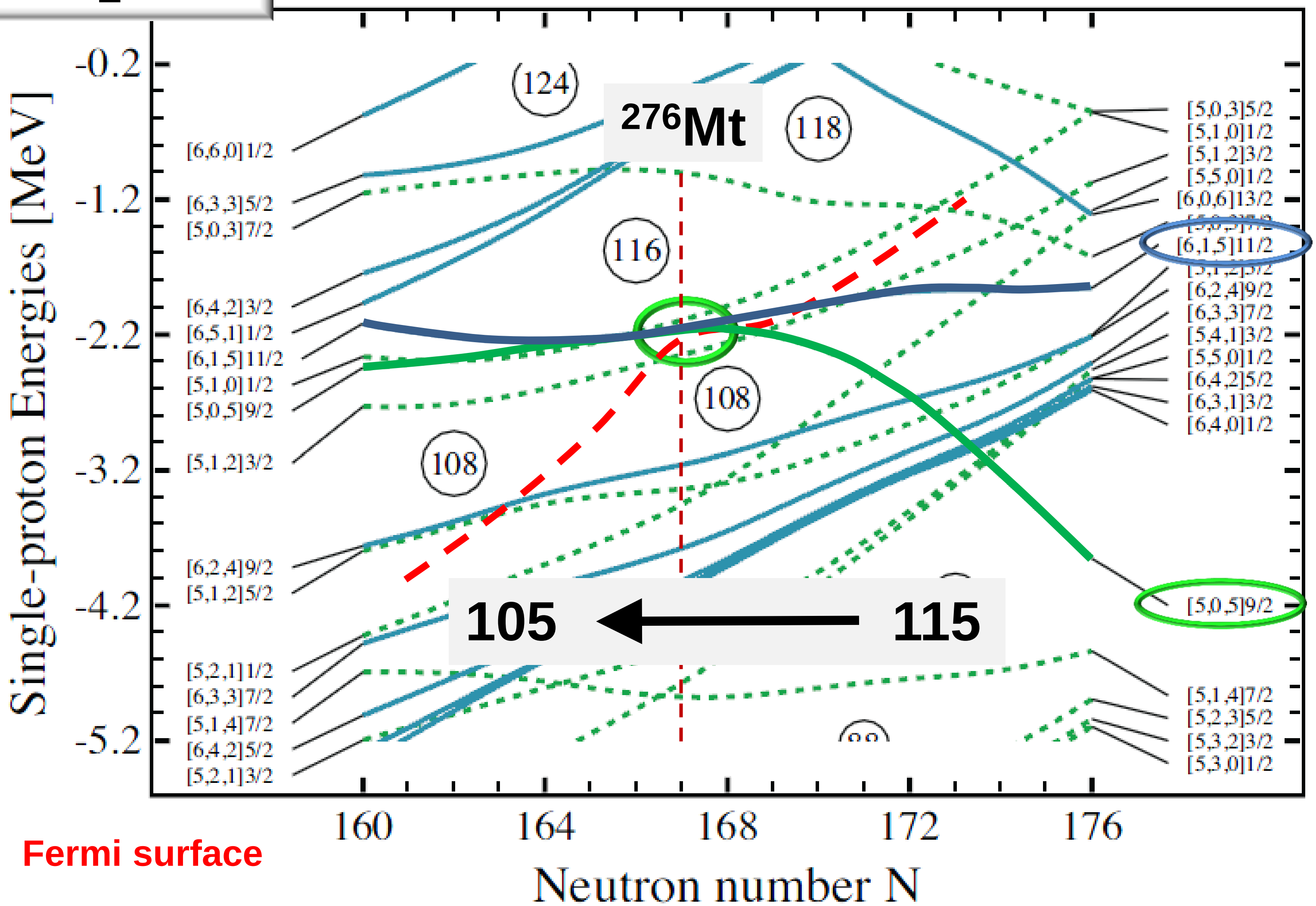
Negative parity



I. Ragnarsson, priv. comm.

Nilsson orbitals, protons

UNEDF1$_L$

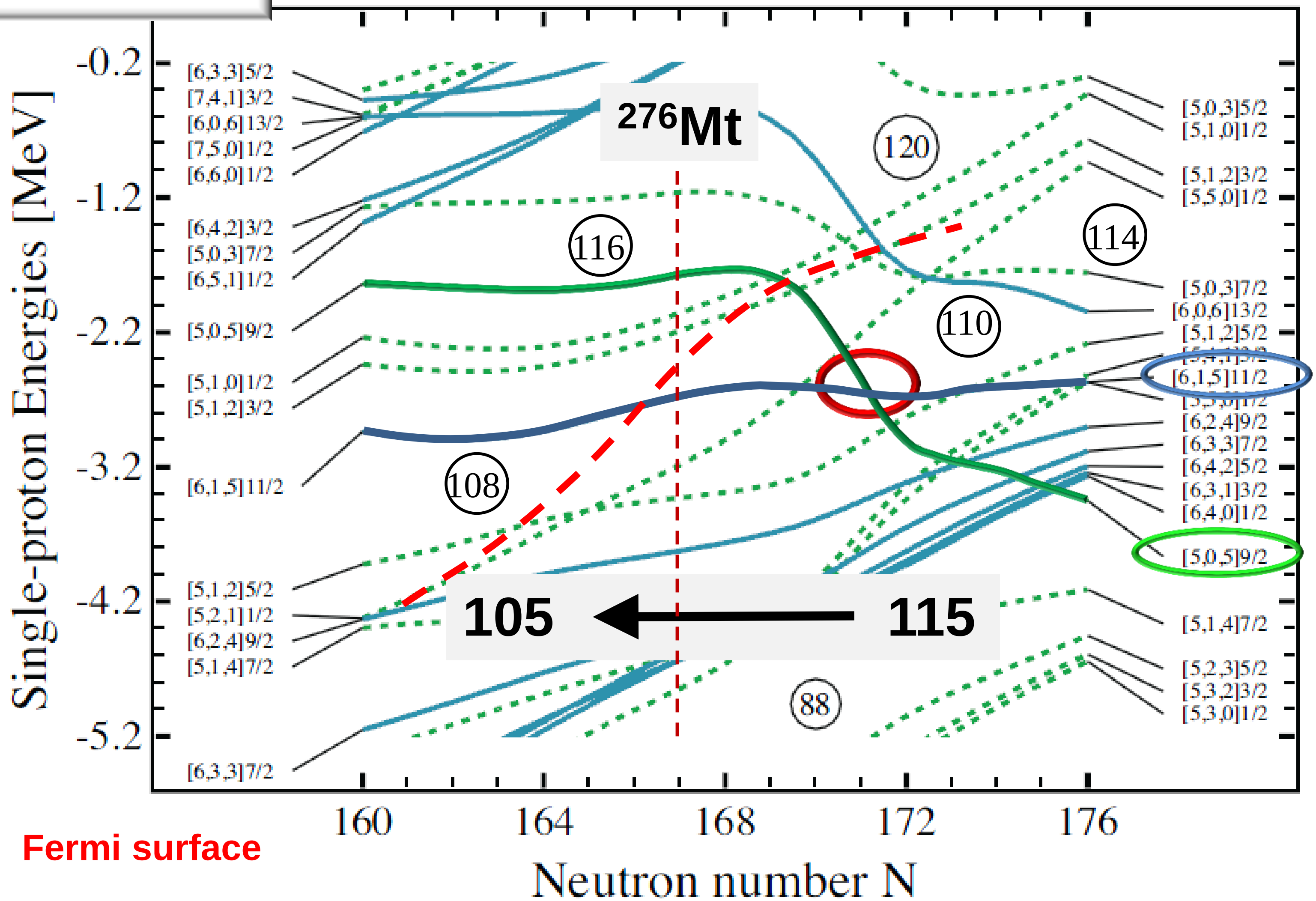


Fermi surface

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

Nilsson orbitals, protons

UNEDF1^{SO}



Fermi surface

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

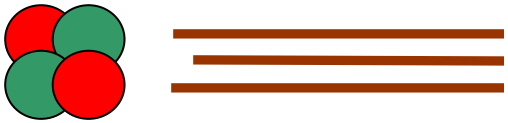
Conclusions

- **30 α-decay chains,** compatible with previous work
- **First candidates for X-rays**, **consistent with E115 assignment**. (Much) more statistics needed!
- **Decay schemes along the E115 chain**

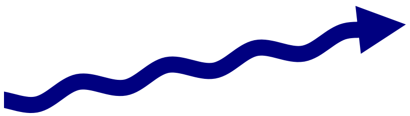
  - establishing the presence of E1 transitions

  - measured precise Q values for the decays

  -> Provide direct constraints on nuclear structure theories near Z = 114!



Thank you for your attention!



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