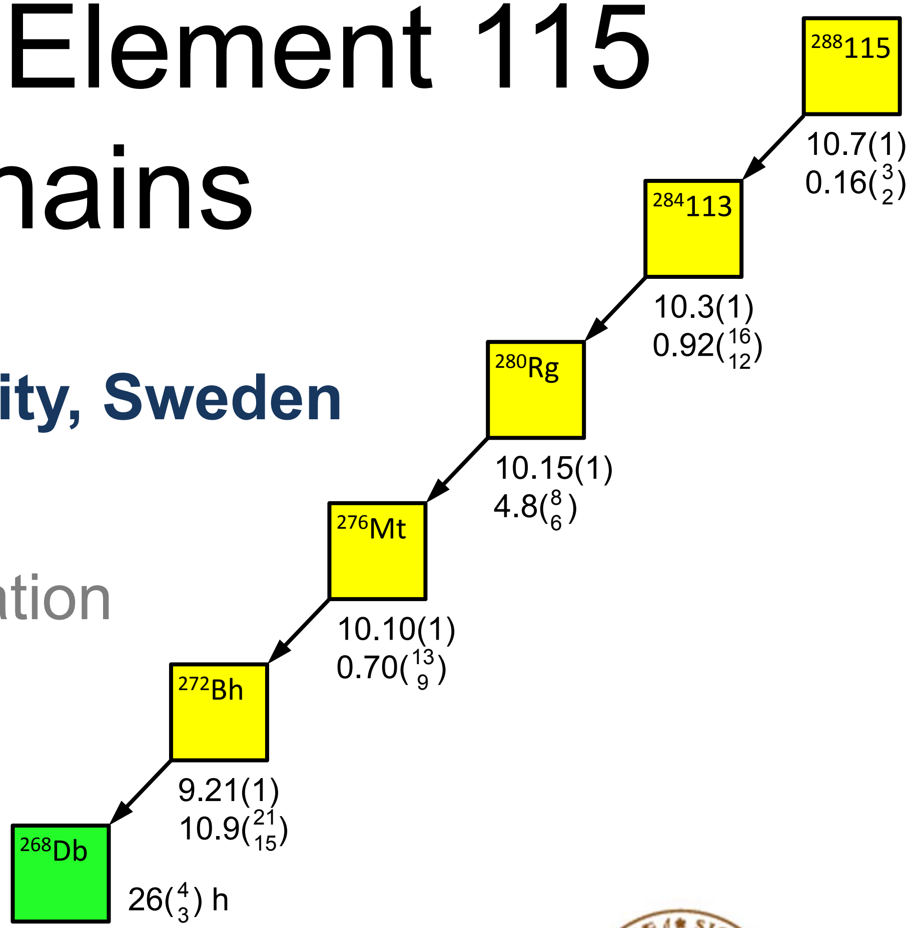
Spectroscopy of Element 115 Decay Chains



D. Rudolph, Lund University, Sweden

on behalf of the

TASCA/TASISpec Collaboration

NUSTAR Week, Helsinki, October 2013

LUNDS UNIVERSITET

The TASISpec / *TASCA* E115 Collaboration

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Spectroscopy of Element 115 Decay Chains

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Special thanks to …

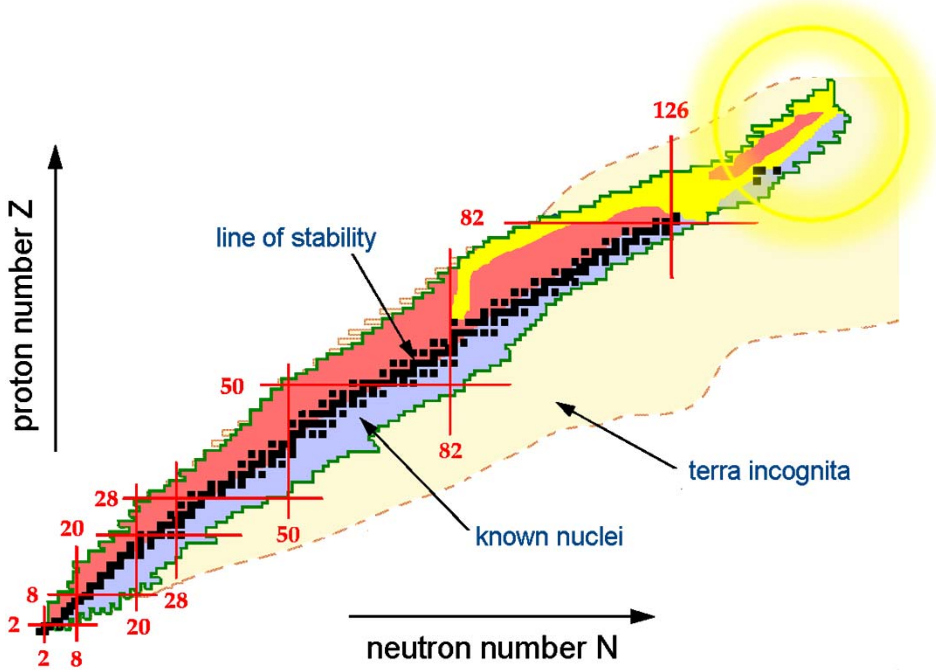
UNILAC

ENSAR

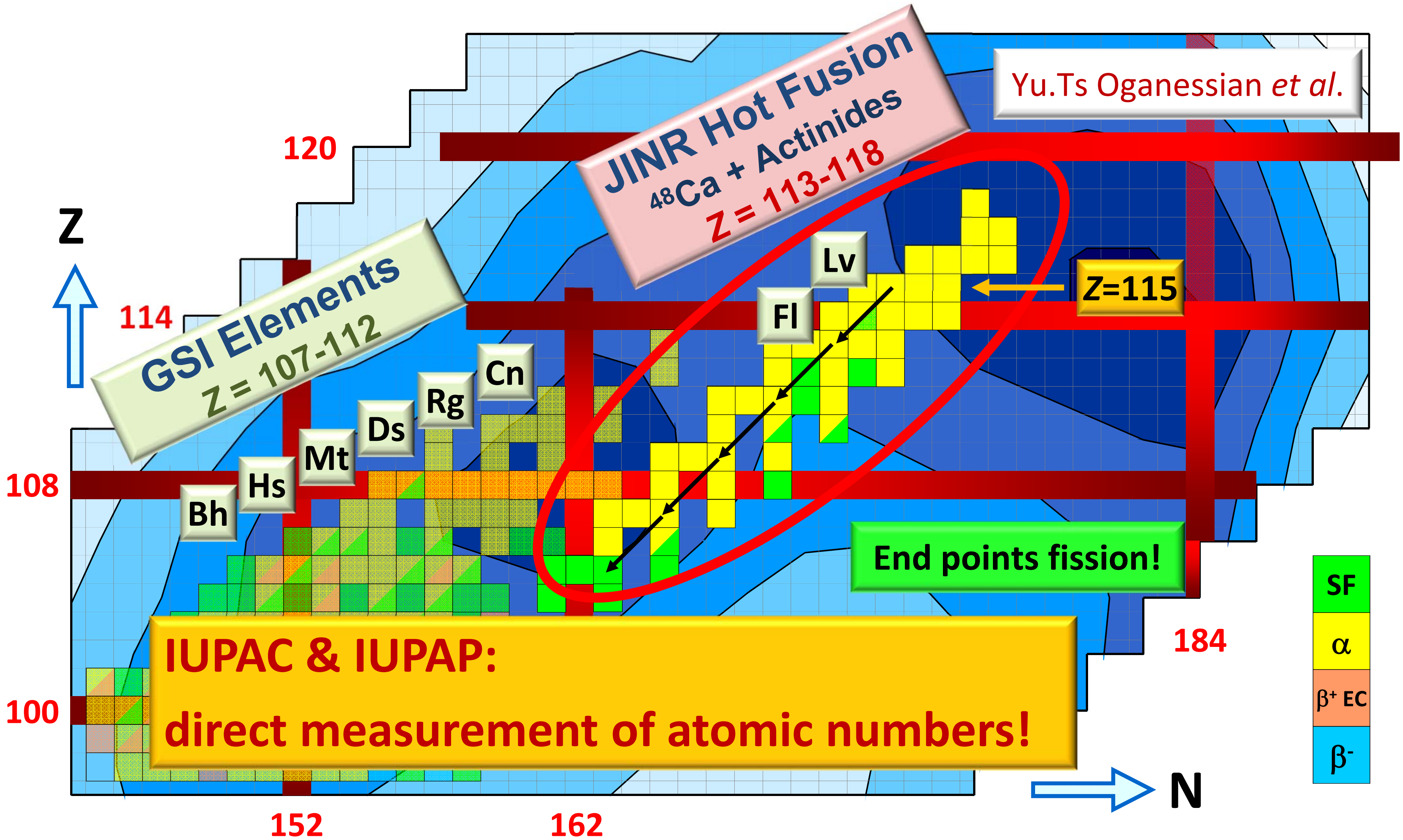
Spectroscopy of Element 115 Decay Chains

- Introduction – the Case
- Experiment at GSI / *TASCA*
- Spectroscopy of ^{288}115 and Daughters
- Summary & Outlook

NUSTAR at GSI



Identification Problem Z > 112

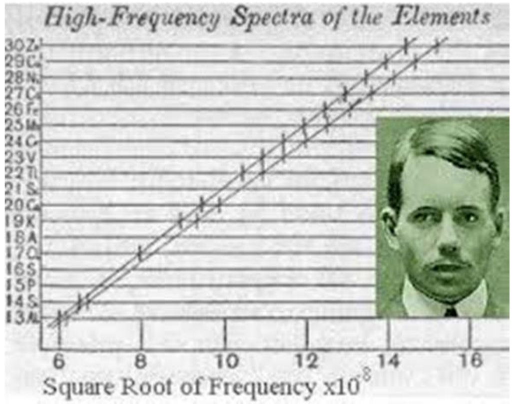


IUPAC & IUPAP:

direct measurement of atomic numbers!

X-ray Fingerprinting of an Element

Moseley's Law, 1913

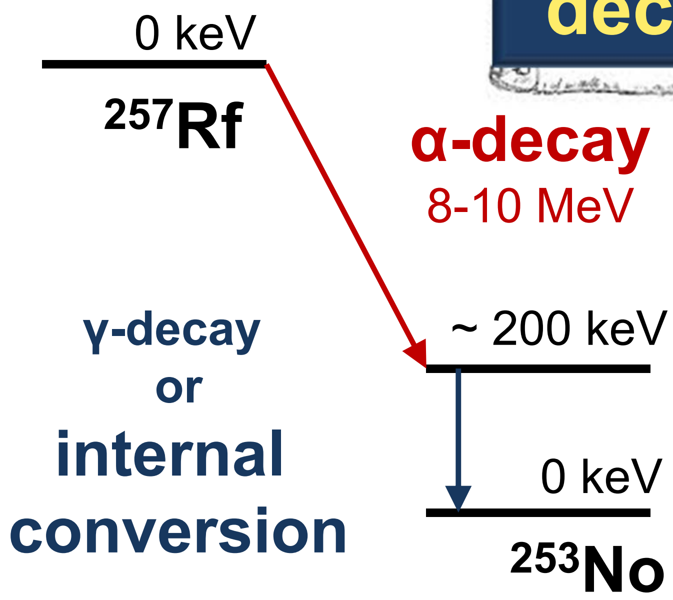


$$E(K_\alpha) \sim f(K_\alpha) \sim (Z\text{-}1)^2$$

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!



R. Bemis *et al*., PRL31, 647 (1973)
(observed 15 α-photon events)

X-ray Fingerprinting of Element 115

- long odd-mass or odd-odd decay chains
- reasonable production cross section

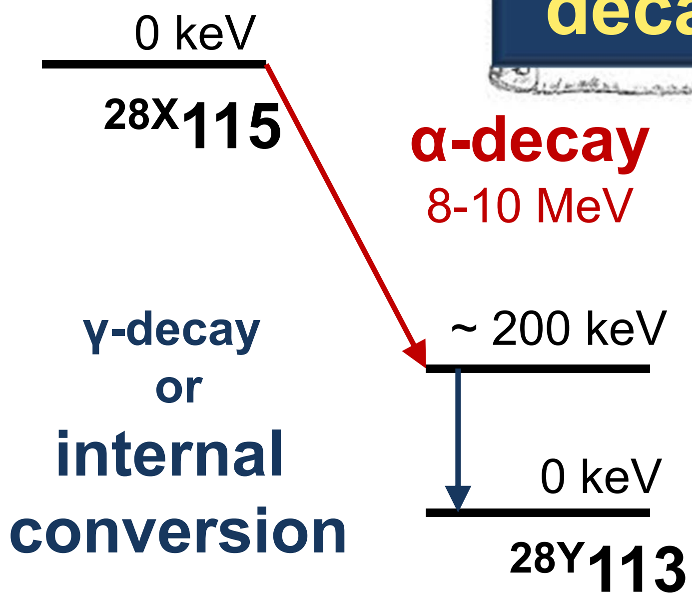
***Z* - identification along E115 chains (sequence of 5 α decays)**

2009: 12 weeks of beamtime requested

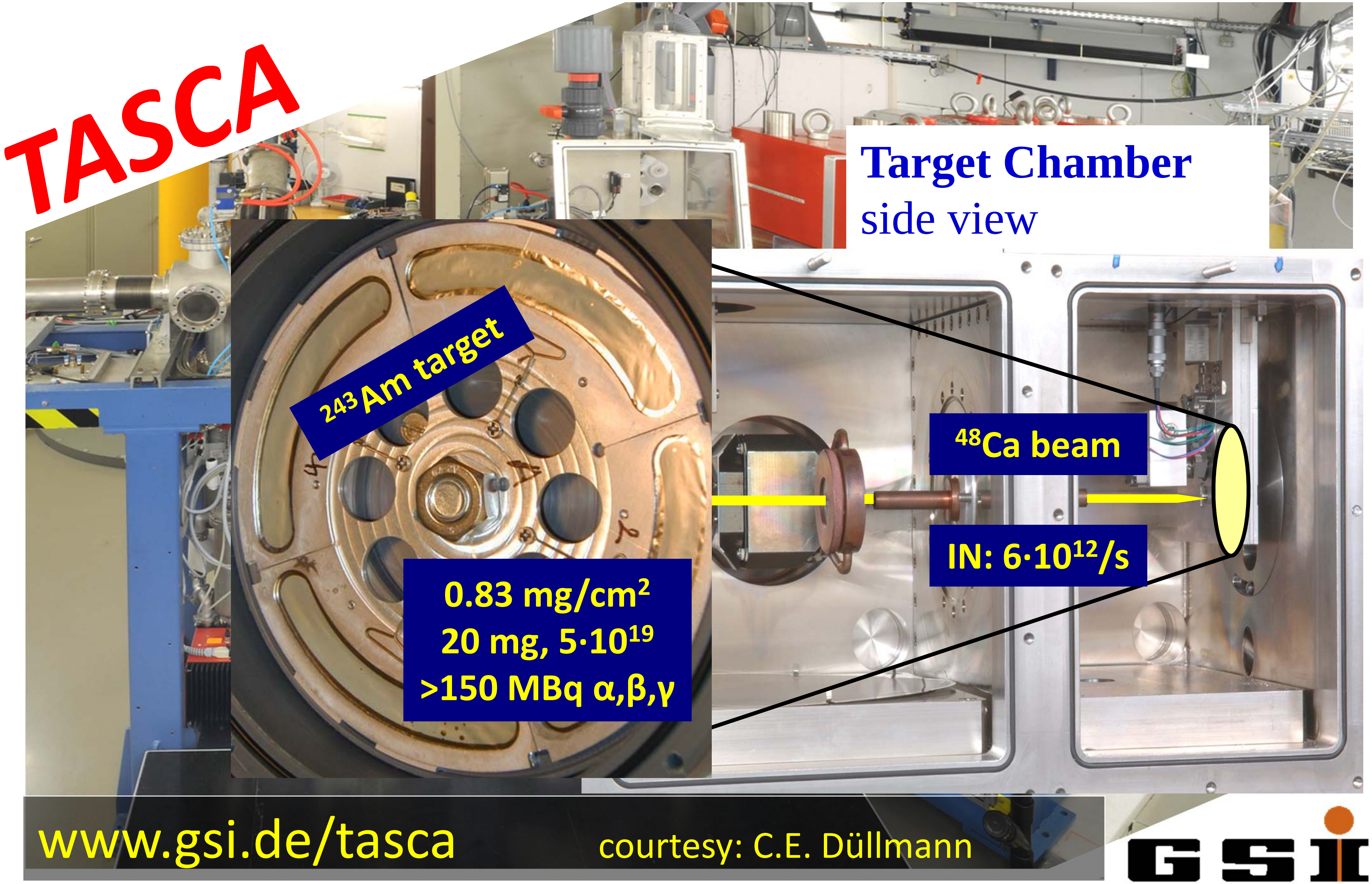
2010: 8 weeks PAC approved and granted

2012: 3 weeks scheduled

Highest *K*-conversion coefficients!



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


TASCA
Target Chamber
side view
^{243}Am target
0.83 mg/cm^2
20 mg, 5·10^{19}
>150 MBq α,β,γ
^{48}Ca beam
IN: 6·10^{12}/s
www.gsi.de/tasca
courtesy: C.E. Düllmann

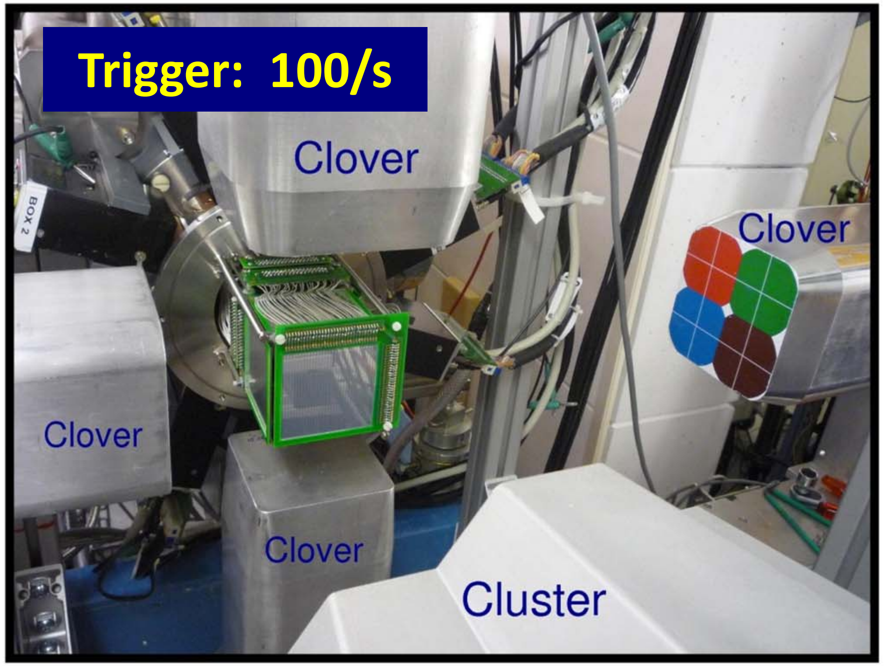
TASISpec

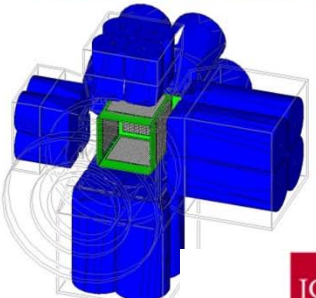
Highly efficient multi–coincidence spectroscopy set–up
for TASCA's very compact focal plane image

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)





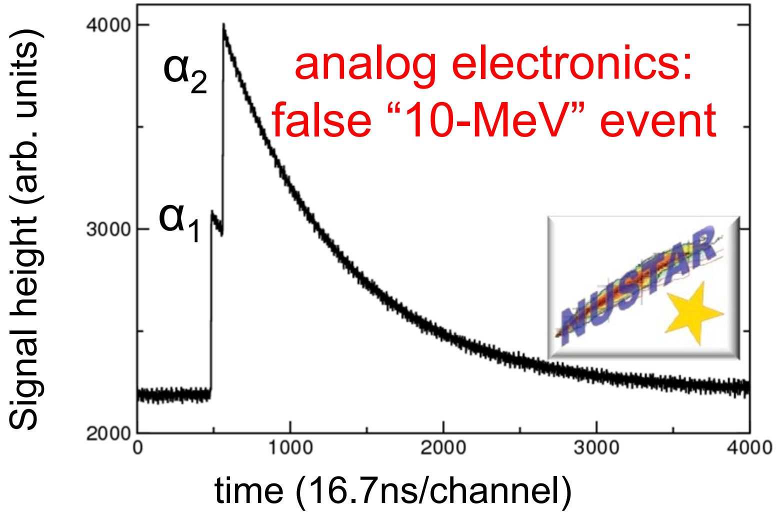
Virtually constructed with GEANT4 simulation package

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

“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)

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.

Some Experimental Numbers

Date & place: November 2012, 3 weeks, ***TASCA***, GSI

Beam: ^{48}**Ca** pulsed (5 ms on, 15 ms off)
time averaged 1 particle μA ($6 \cdot 10^{12}$/s)

Target

ng

Beam 0^{18}

TASCA

Transr

30 correlated decay chains of element 115 in 3 weeks of beamtime!

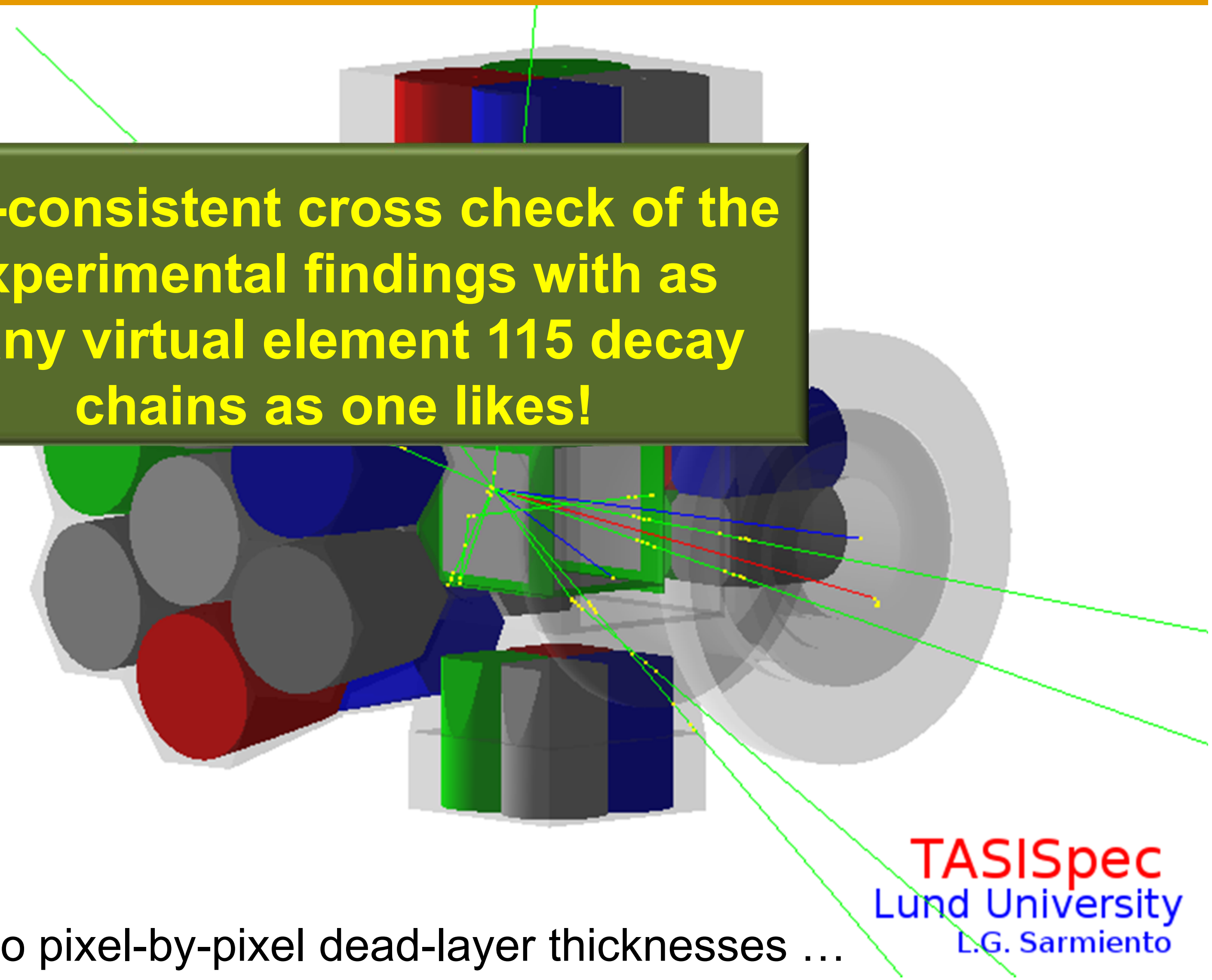
$\sigma_{tot} \sim$ **10 pb**

Only 64 beam-off fission events in 3 weeks spread over 1024 DSSSD pixels.

Trigger rate: 100-120 per second (particles in implantation DSSSD)

Beam shut-off: implemented, two-staged, beam-off α particles

TASISpec – in Virtual GEANT4 Space



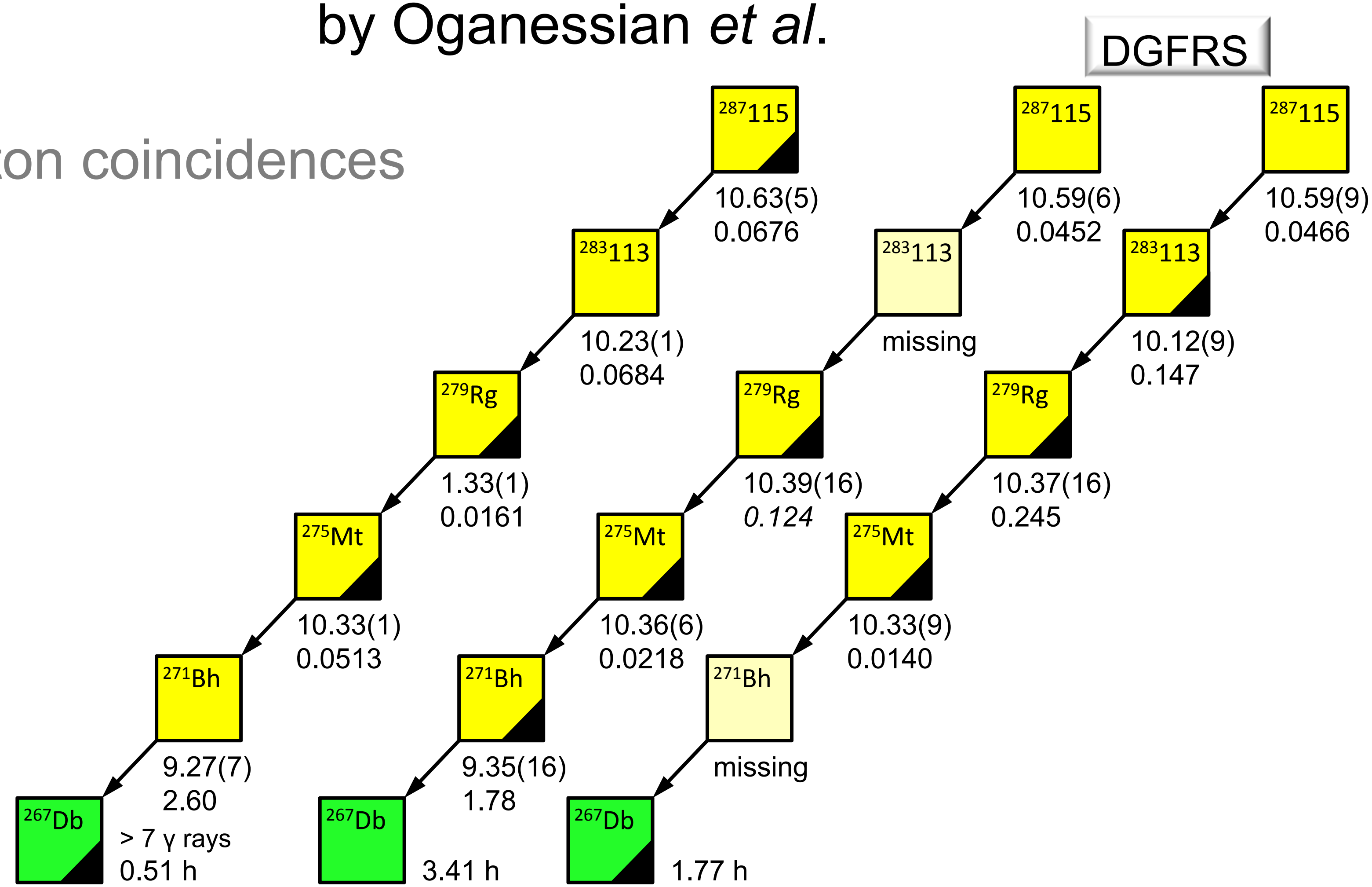
Self-consistent cross check of the experimental findings with as many virtual element 115 decay chains as one likes!

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

Results – $^{287}115$ (4n-channel)

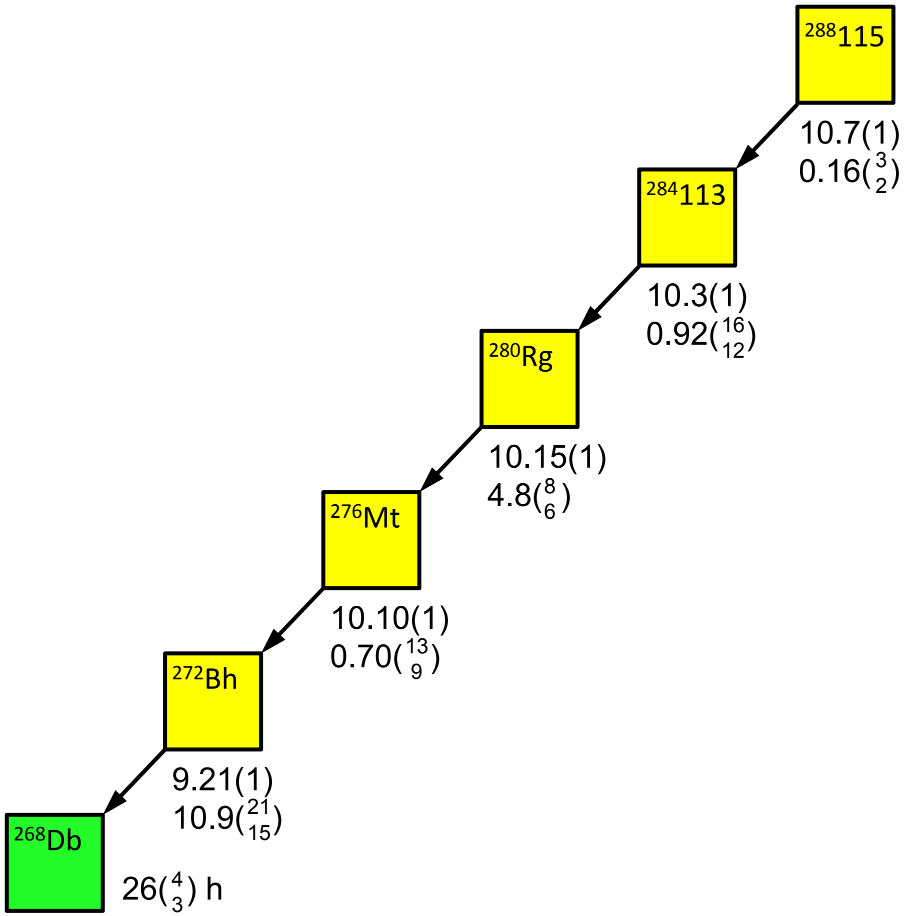
1 chain (out of 30) of ours is compatible with the
2 chains (out of 37) associated with the 4n channel $^{287}115$ by Oganessian *et al.*

no α-photon coincidences



Results – ^{288}115 (3n-channel)

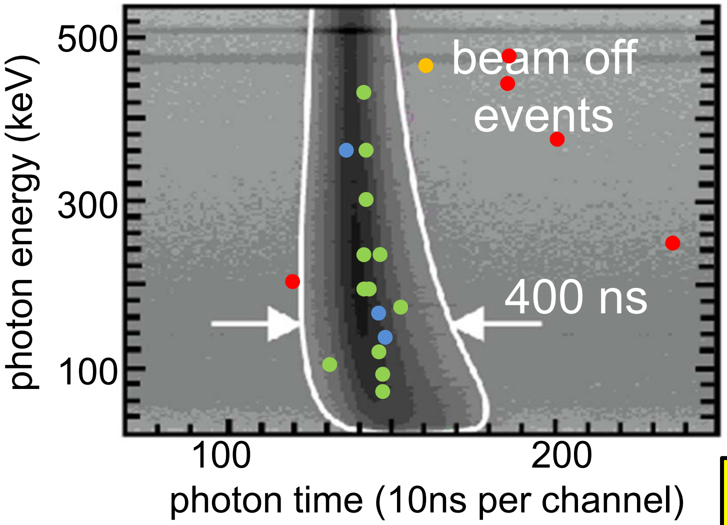
22 chains (out of 30) of ours are compatible with the
31 chains (out of 37) associated with the 3n channel ^{288}115
by Oganessian *et al*.

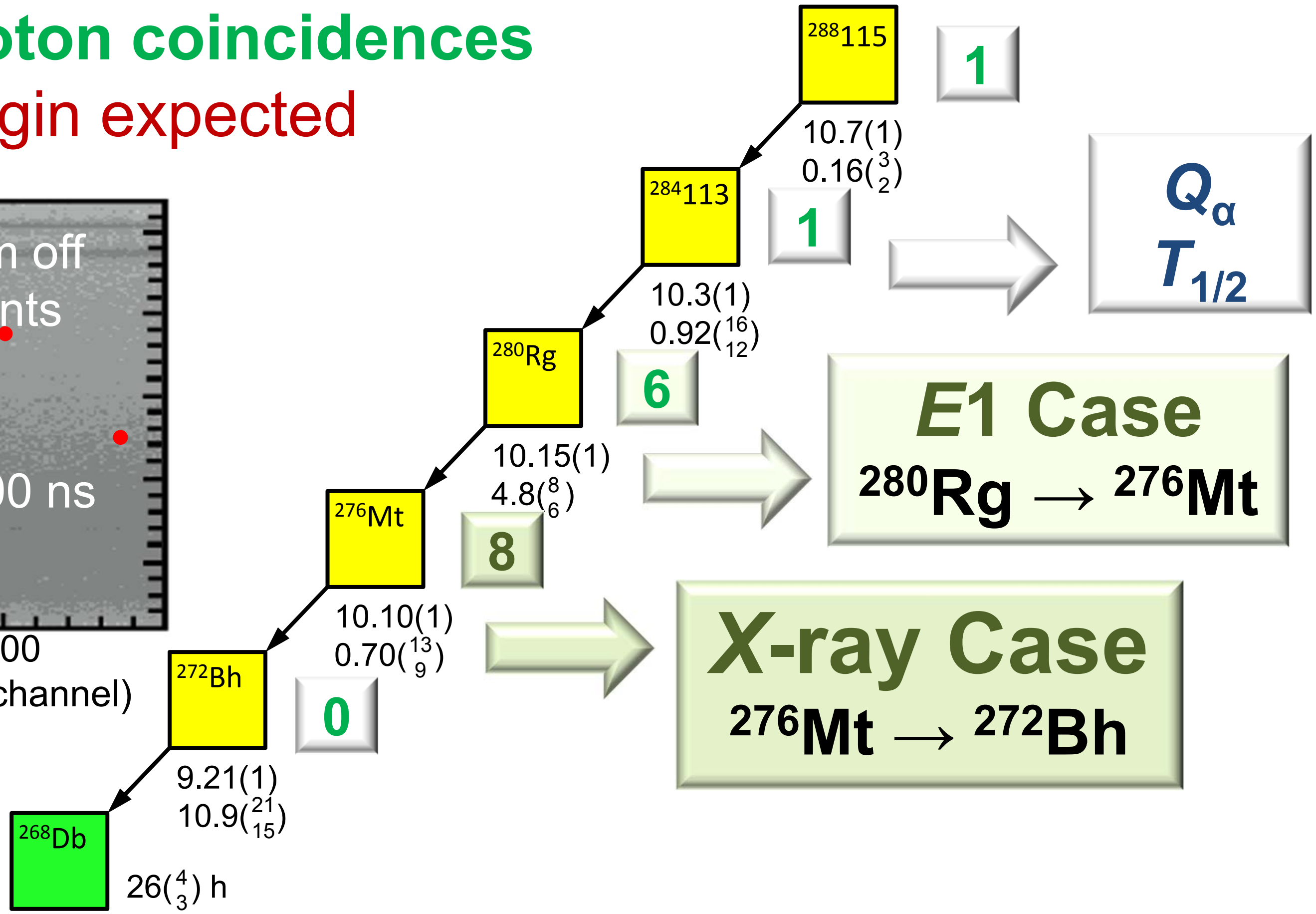


Results – $^{288}115$ (3n-channel)

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*.

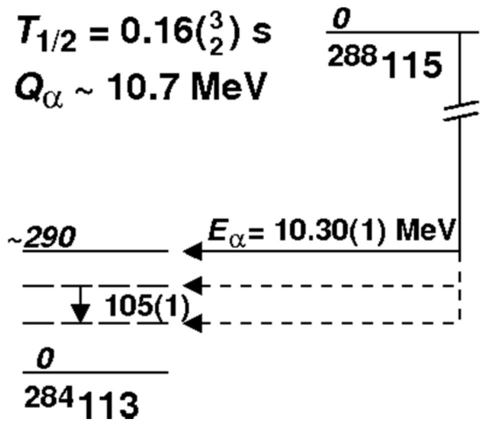
16 prompt α-photon coincidences
2-3 of random origin expected

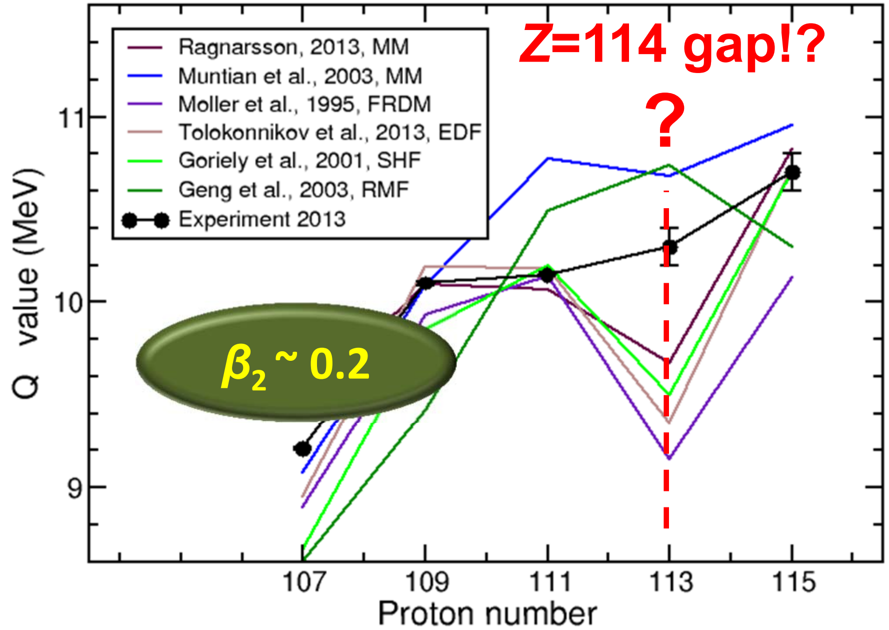




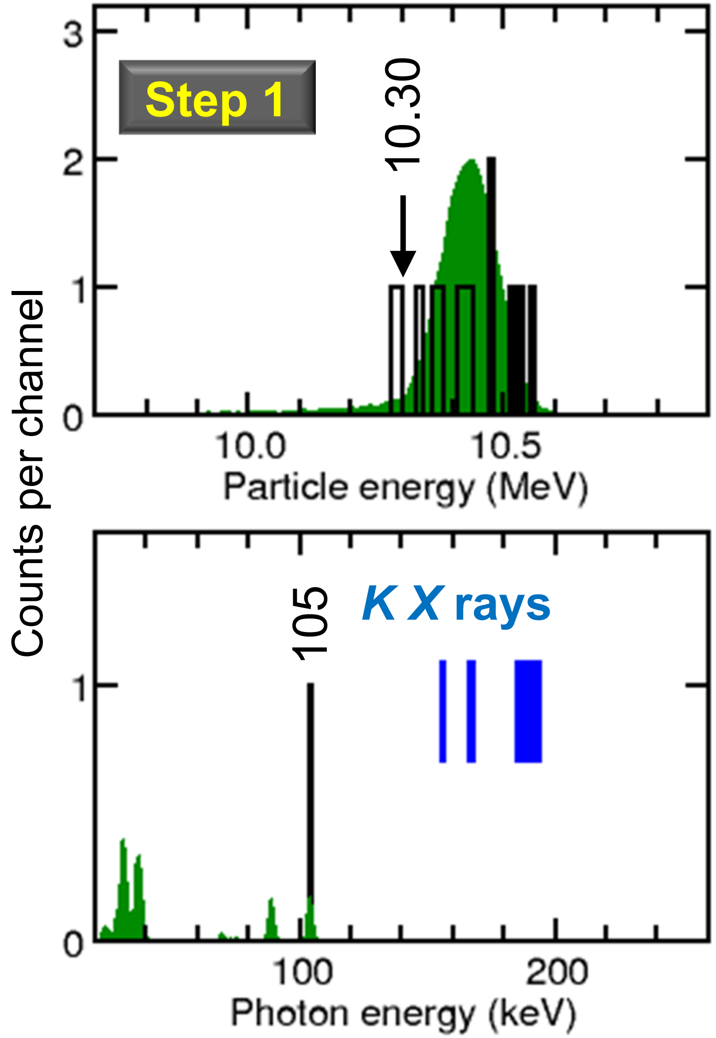
Results – ^{288}115 (3n-chain)

Step 1





Step 1



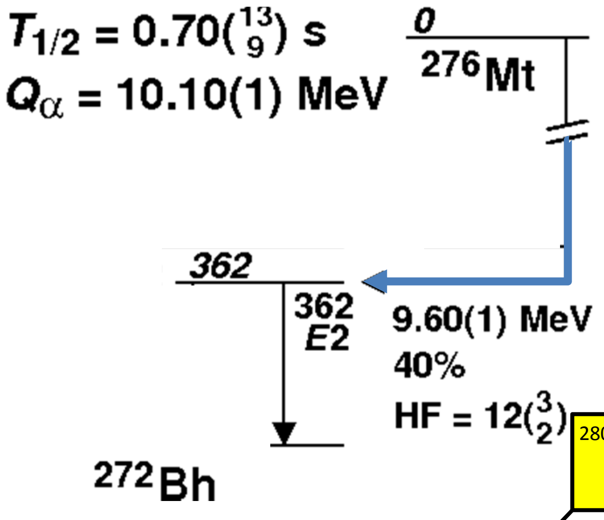
GEANT4 simulations: 100000 decays, normalized to number of α's

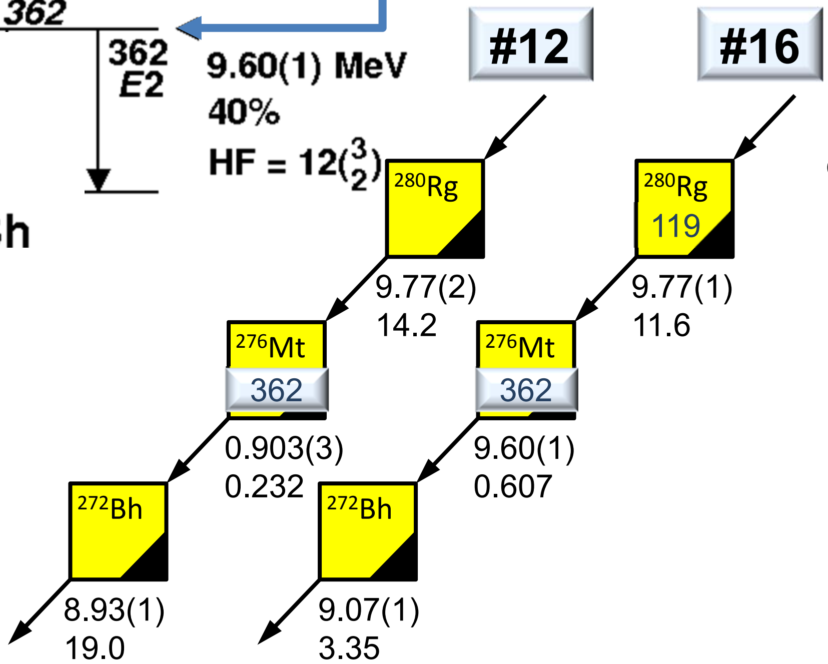
Results – $^{288}115$ (3n-chain)

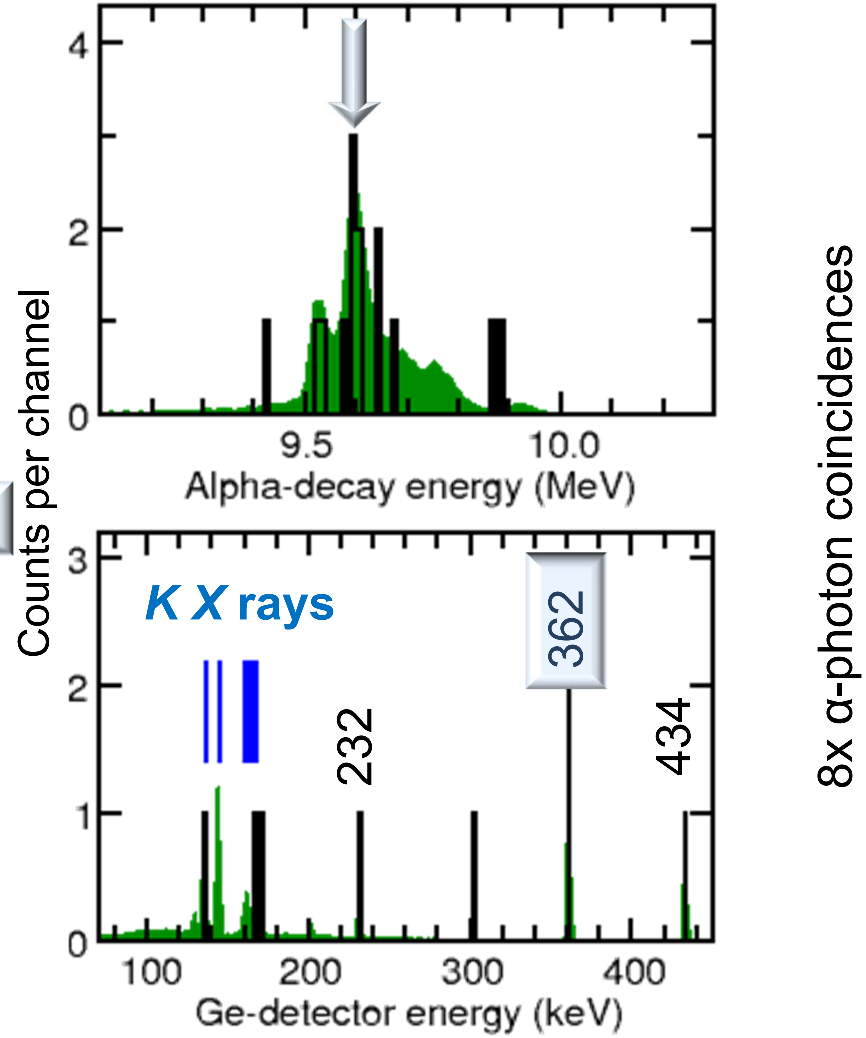
X-ray Case

$^{276}Mt \rightarrow {}^{272}Bh$

Step 4







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

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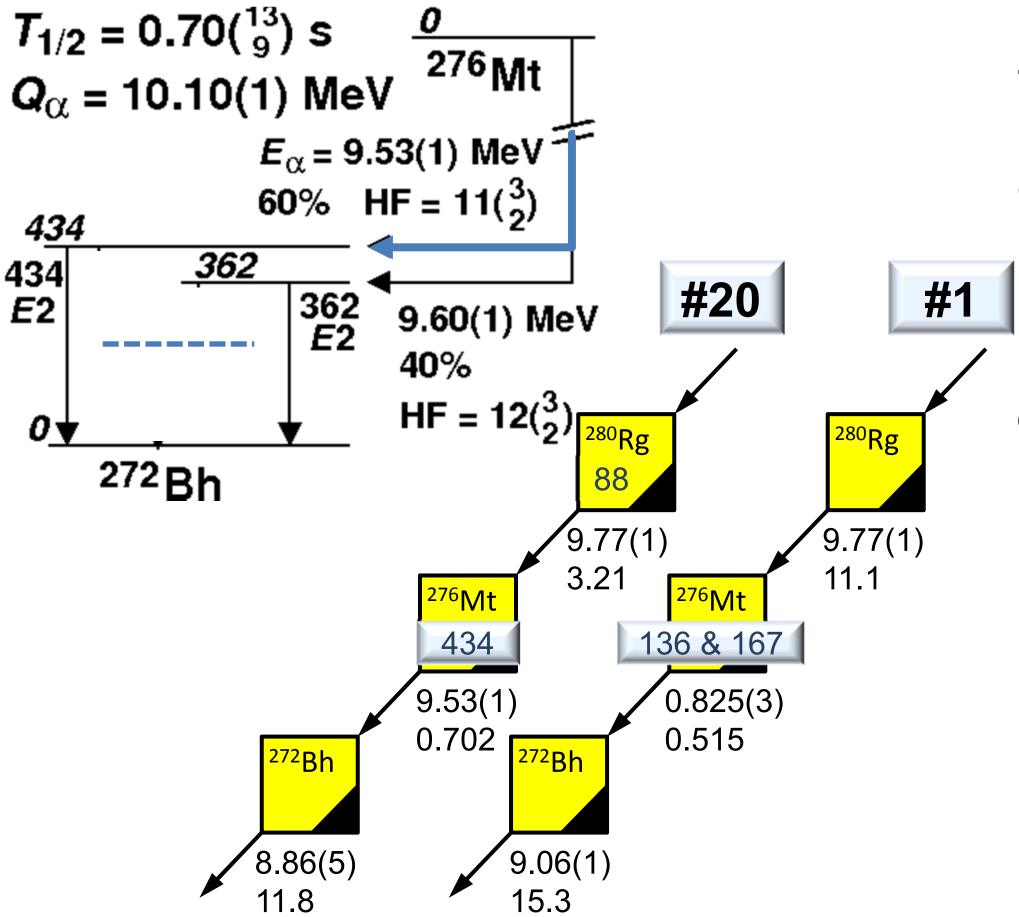
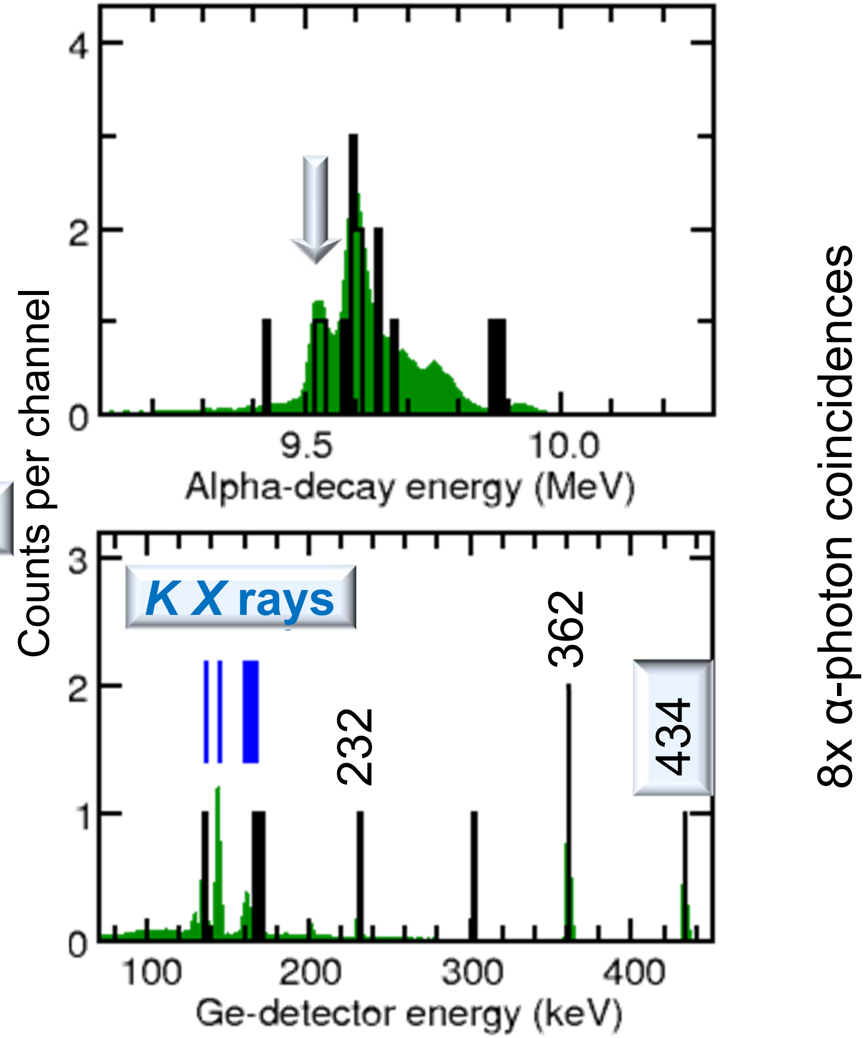
X-ray Case
^{276}Mt → ^{272}Bh

Step 4





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X-ray Case

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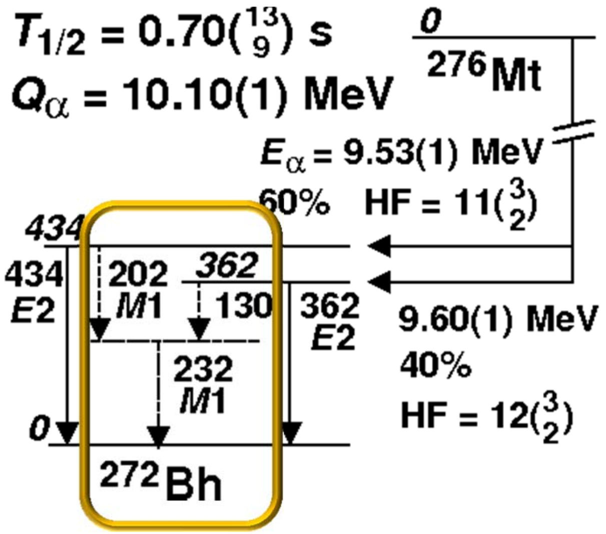
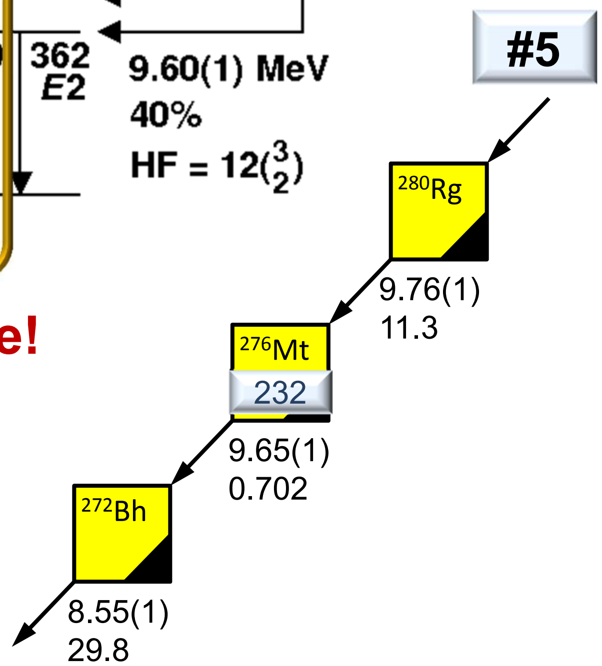
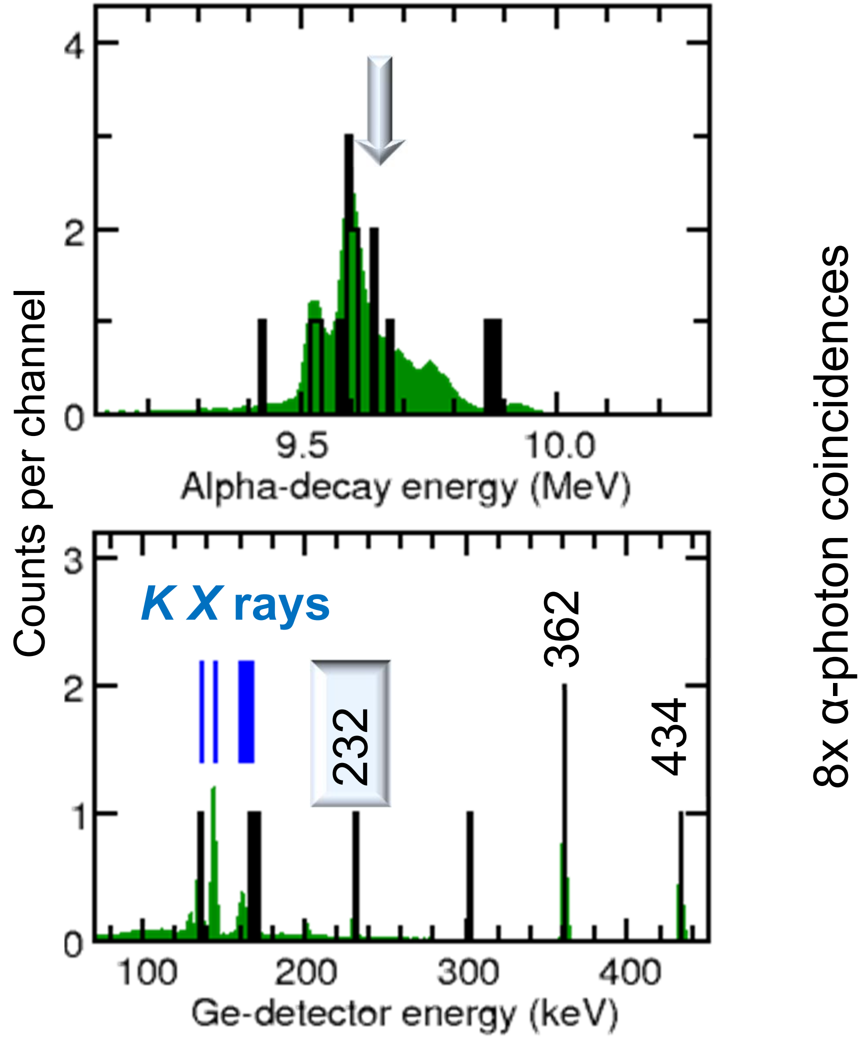


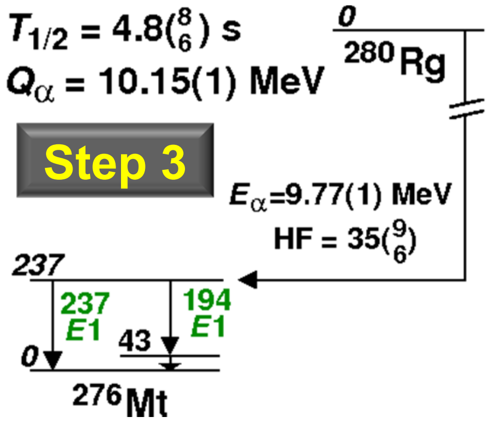
Tentative!





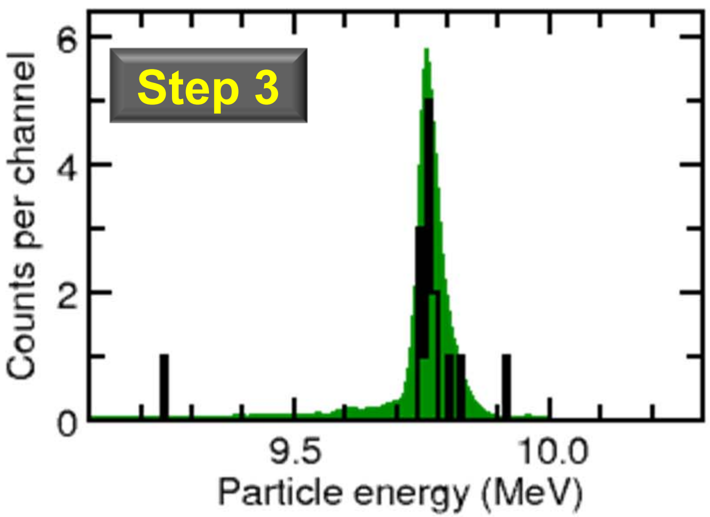
GEANT4 simulations: 100000 decays, normalized to number of α's

Results – ^{288}115 (3n-chain)

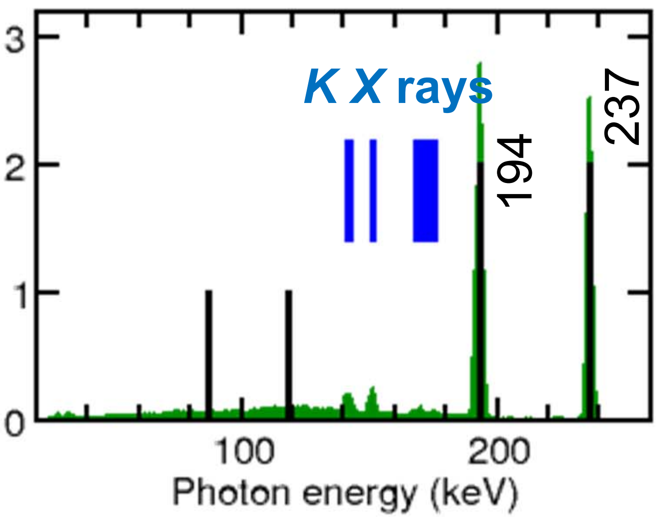


E1 Case

^{280}Rg → ^{276}Mt

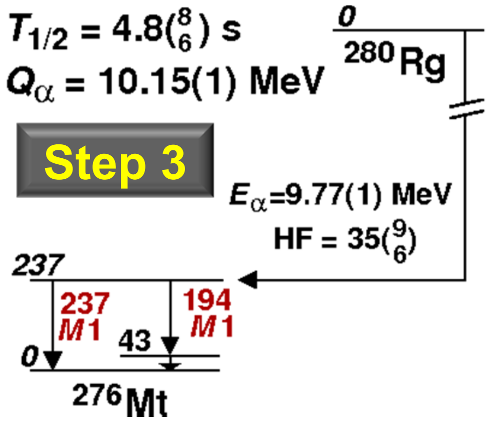


6x α-photon coincidences



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

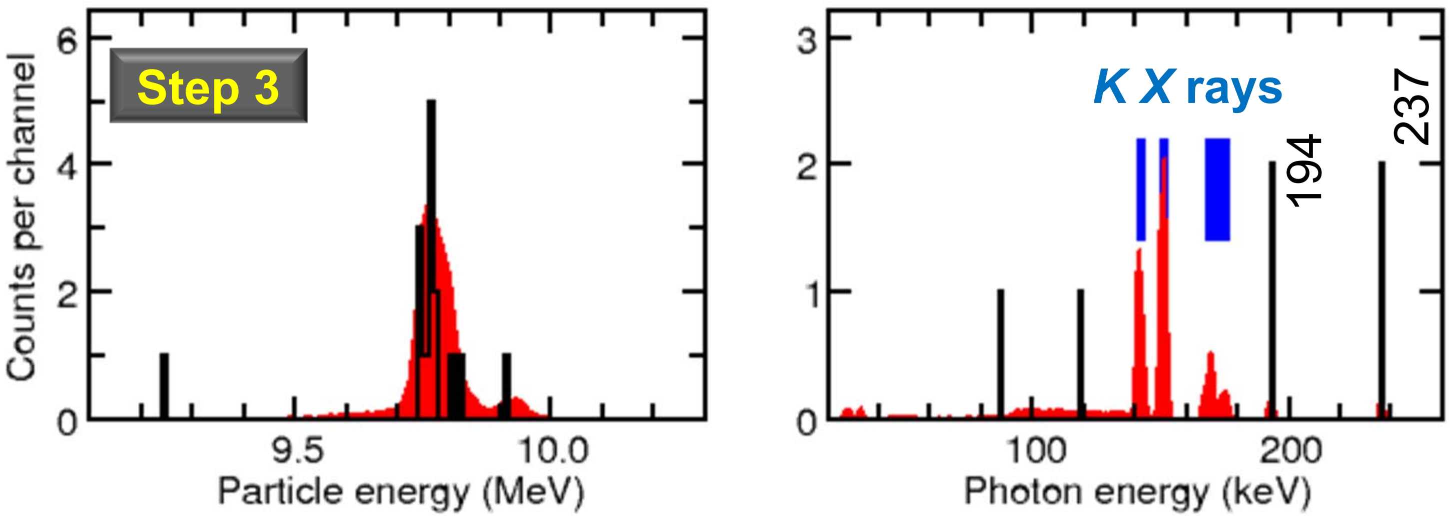
Results – ^{288}115 (3n-chain)



*M*1 Case

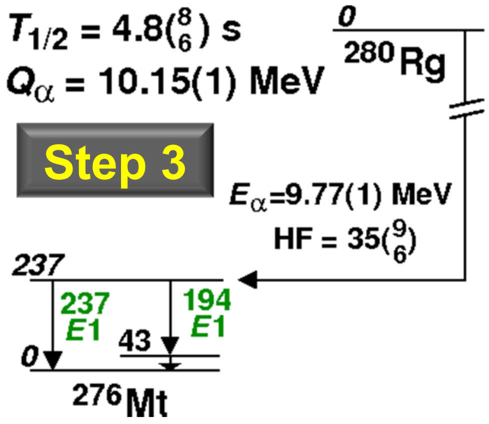
^{280}Rg → ^{276}Mt

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

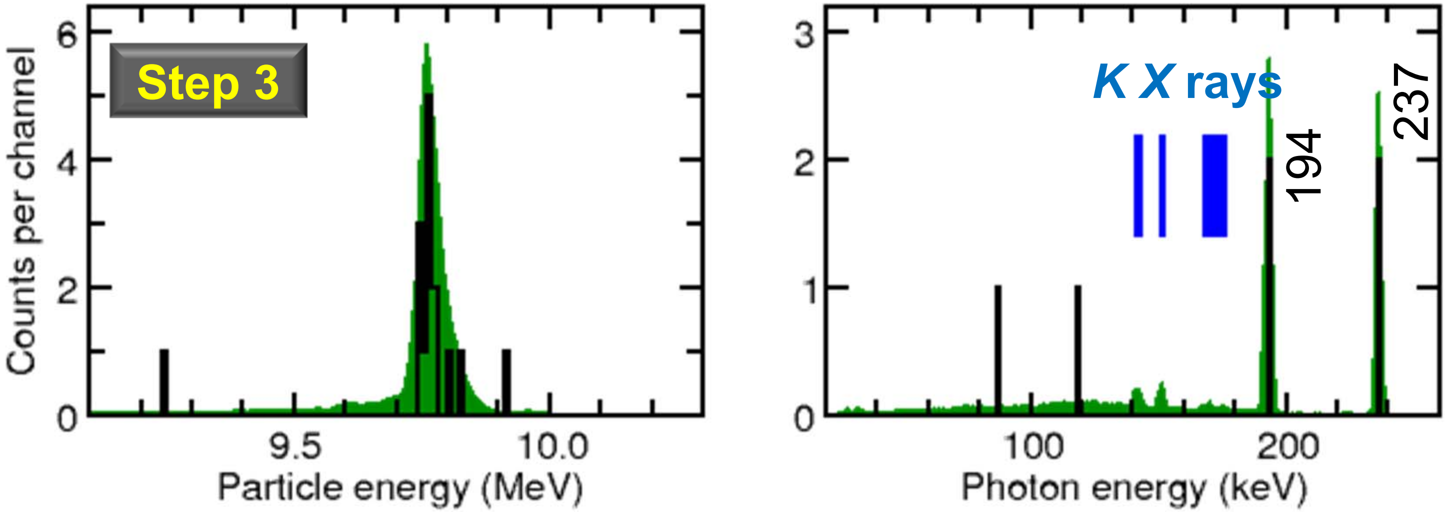
Results – ^{288}115 (3n-chain)



*E*1 Case

^{280}Rg → ^{276}Mt

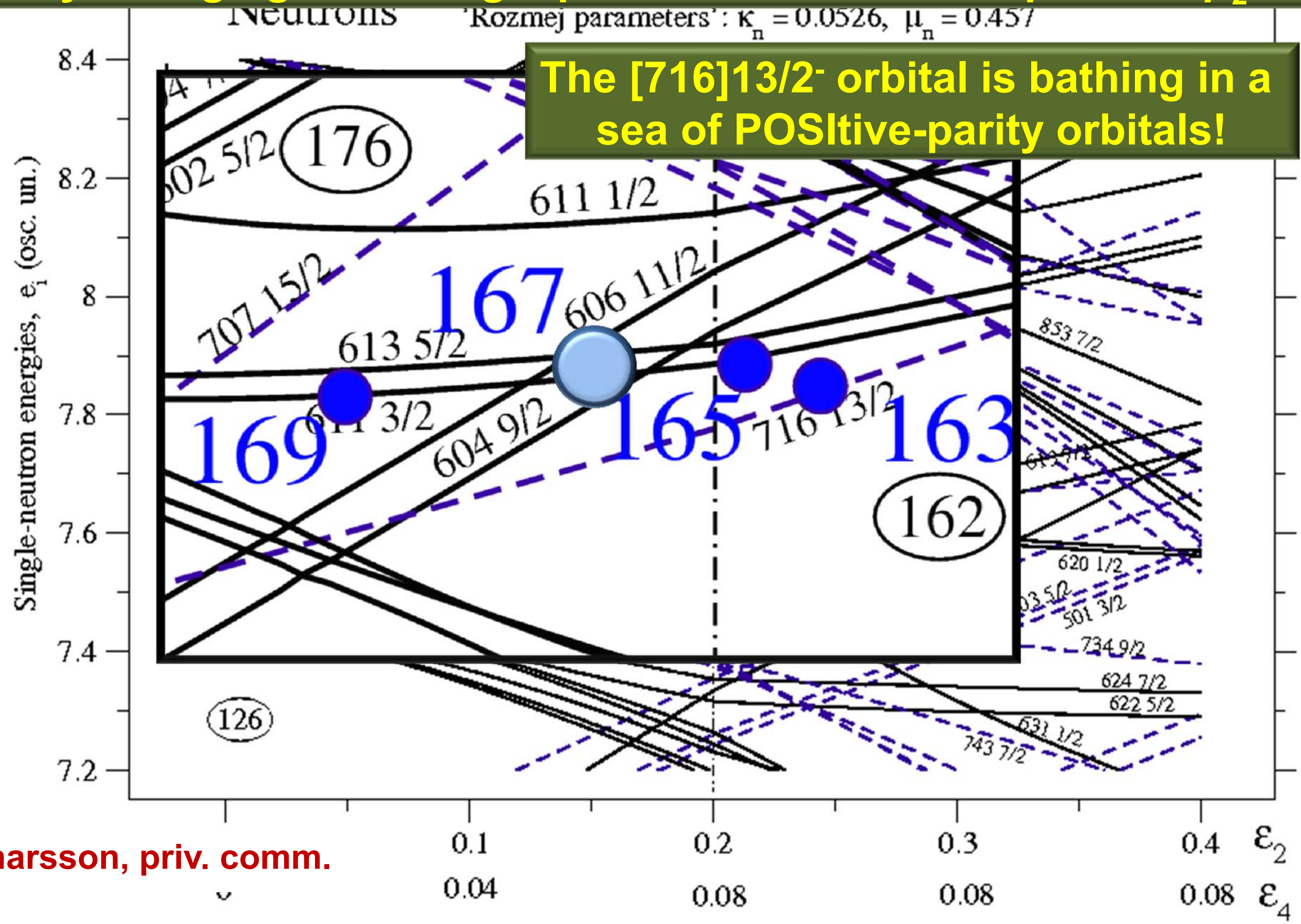
The fact that these transitions are *E*1 transitions puts (seemingly) severe contraints on nuclear structure theory!



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

Nilsson Single-particle Diagrams

Parity-changing $\Delta\ell$ =1 single-particle orbitals are required at β_2~0.2!



I. Ragnarsson, priv. comm.

Summary & Conclusions

Experimental: Pulsed beam is rather useful …
Fully pixelized system for particle **spectroscopy**.
Digital electronics; Si preferential, Ge essential!

Analysis: Add a new level of confidence by self-consistent cross checks via **virtual GEANT experiments**.

Results: 30 decay chains compatible with previous reports.
Two *X*-ray **candidates** compatible with E115.
***X*-ray fingerprinting is feasible!**
Spectroscopic data on E115 descendants may probe Z=114 gap; (**precise Q_α-values and E1 in ^{276}Mt**)
^{293}117/^{289}115 story is far from "trivial" …

Future (@GSI): Check with GSI management …