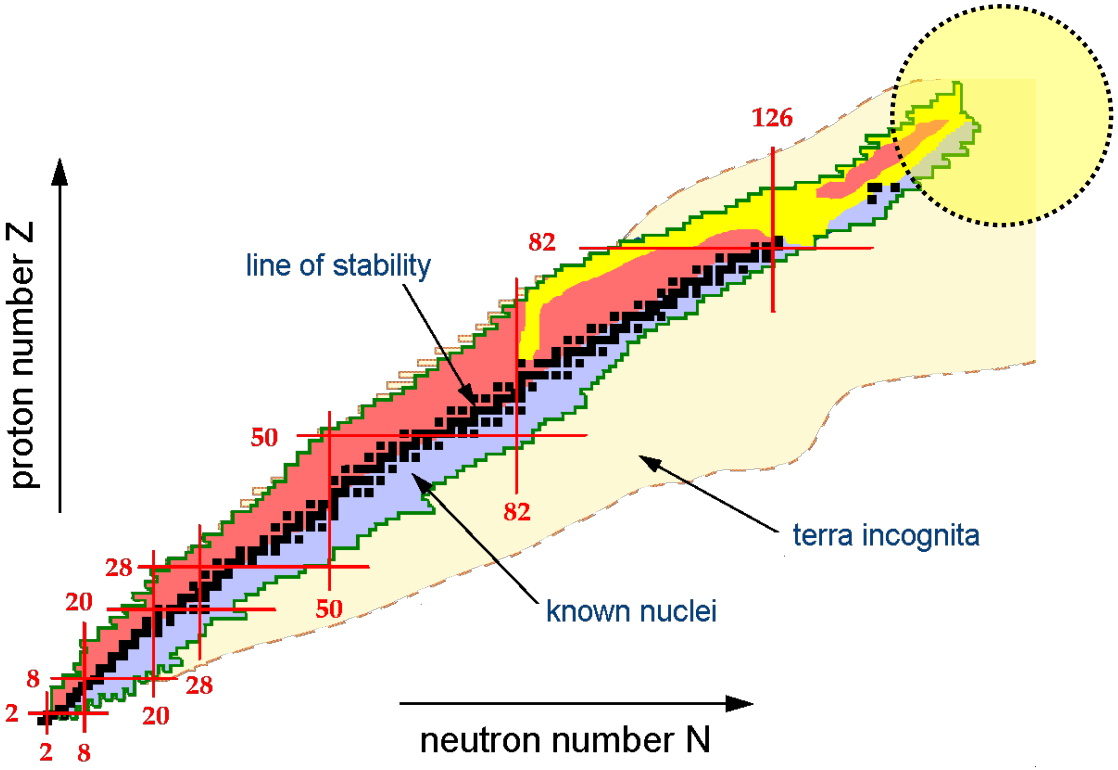
Nuclear spectroscopy with Geant4

L.G. Sarmiento
Lund University

Swedish Nuclear Physics Meeting
Uppsala University
November 2014

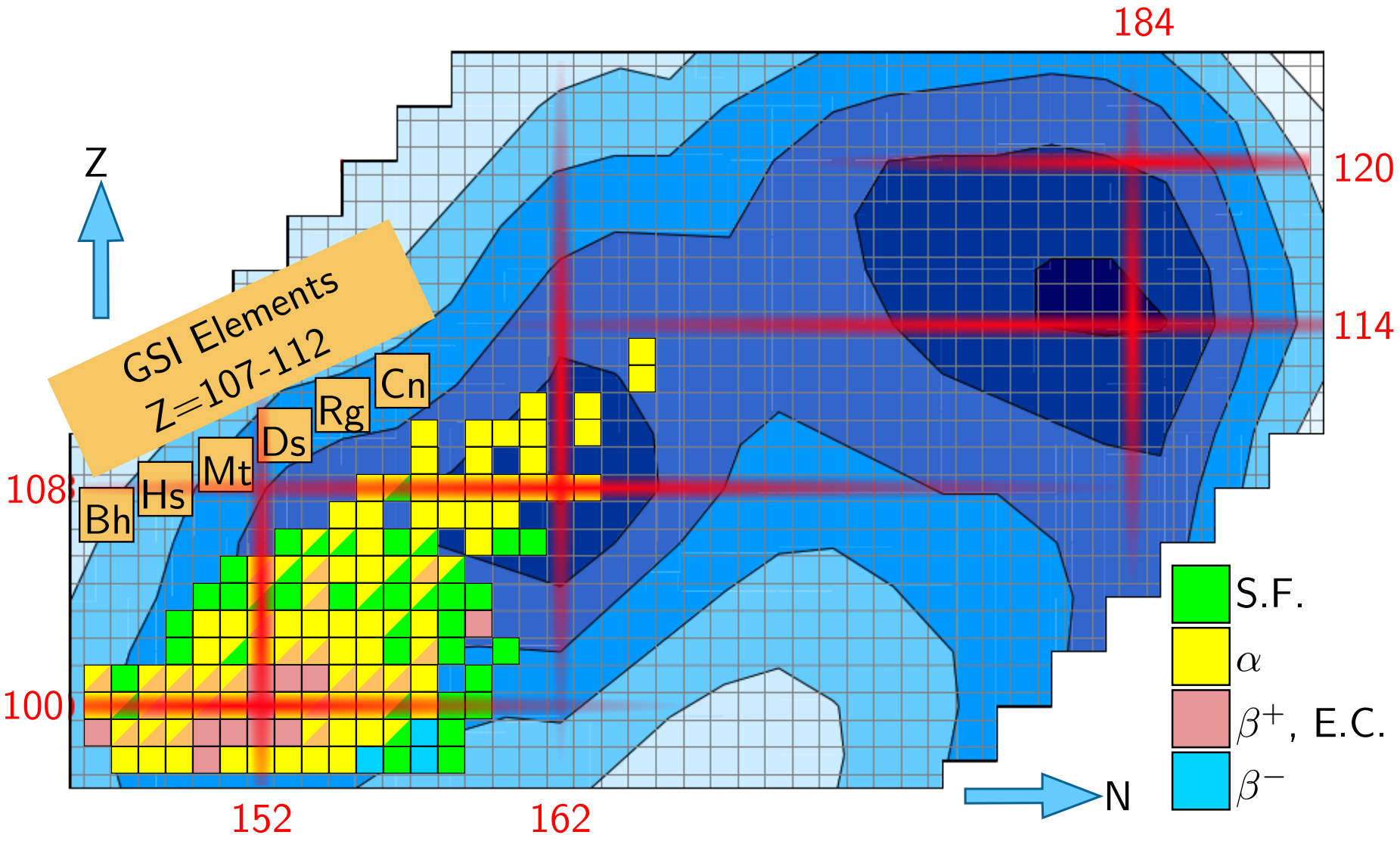
Overview

1. TASISPEC and the E115 experiment
2. TASISPEC in Geant4
3. SHE-Geant4
4. Remarks



@ GSI

Identification Problem $Z > 112$



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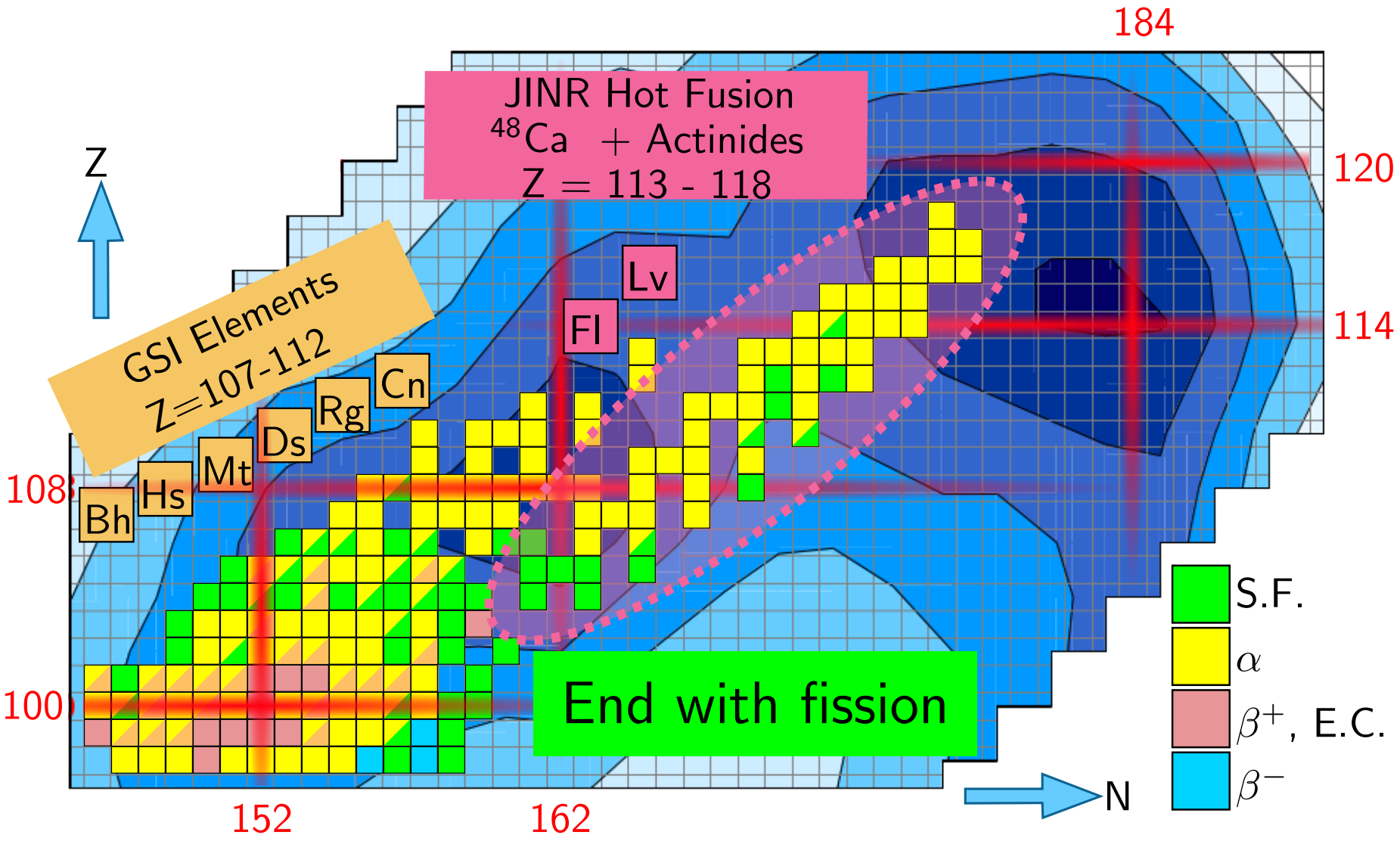

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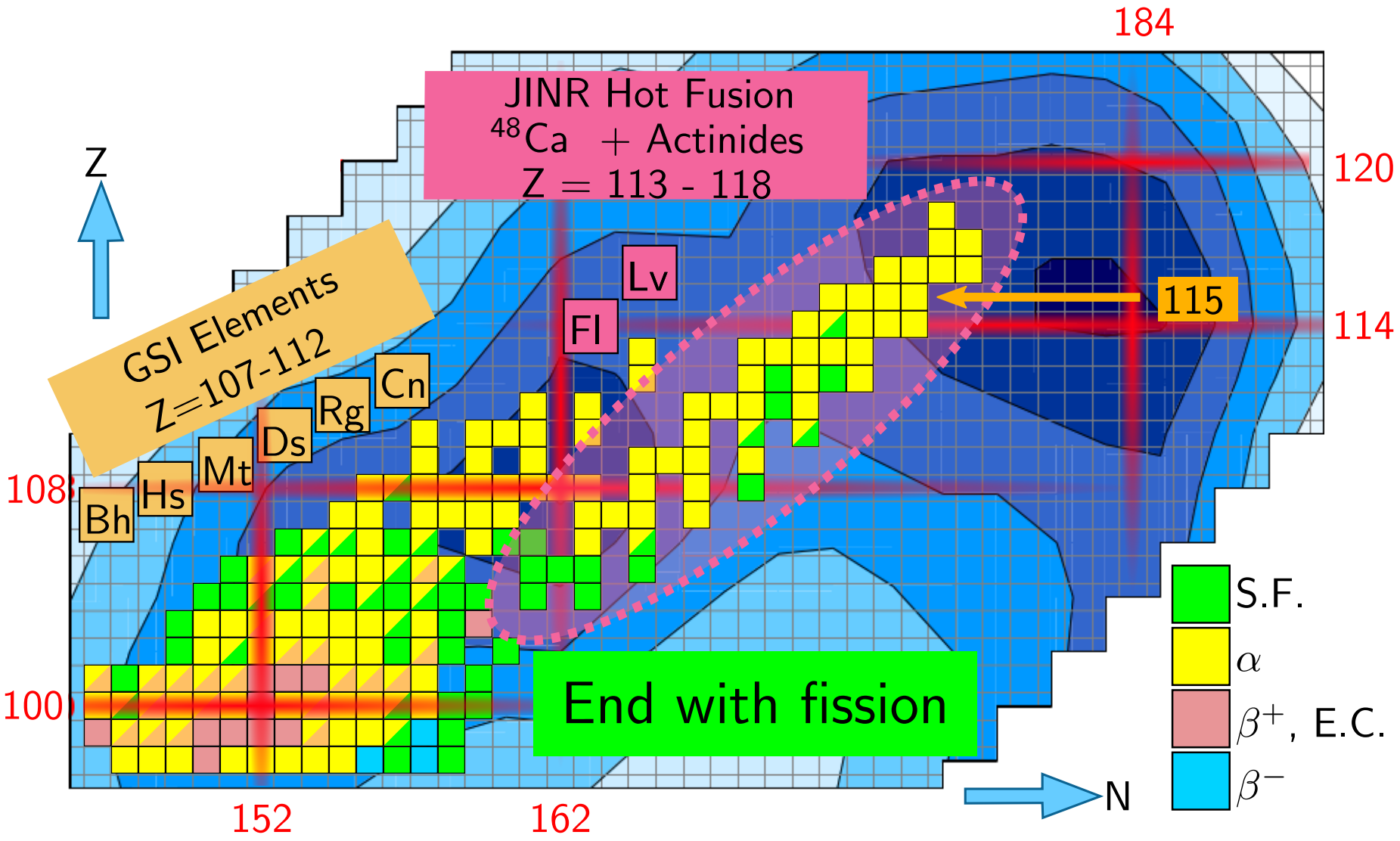

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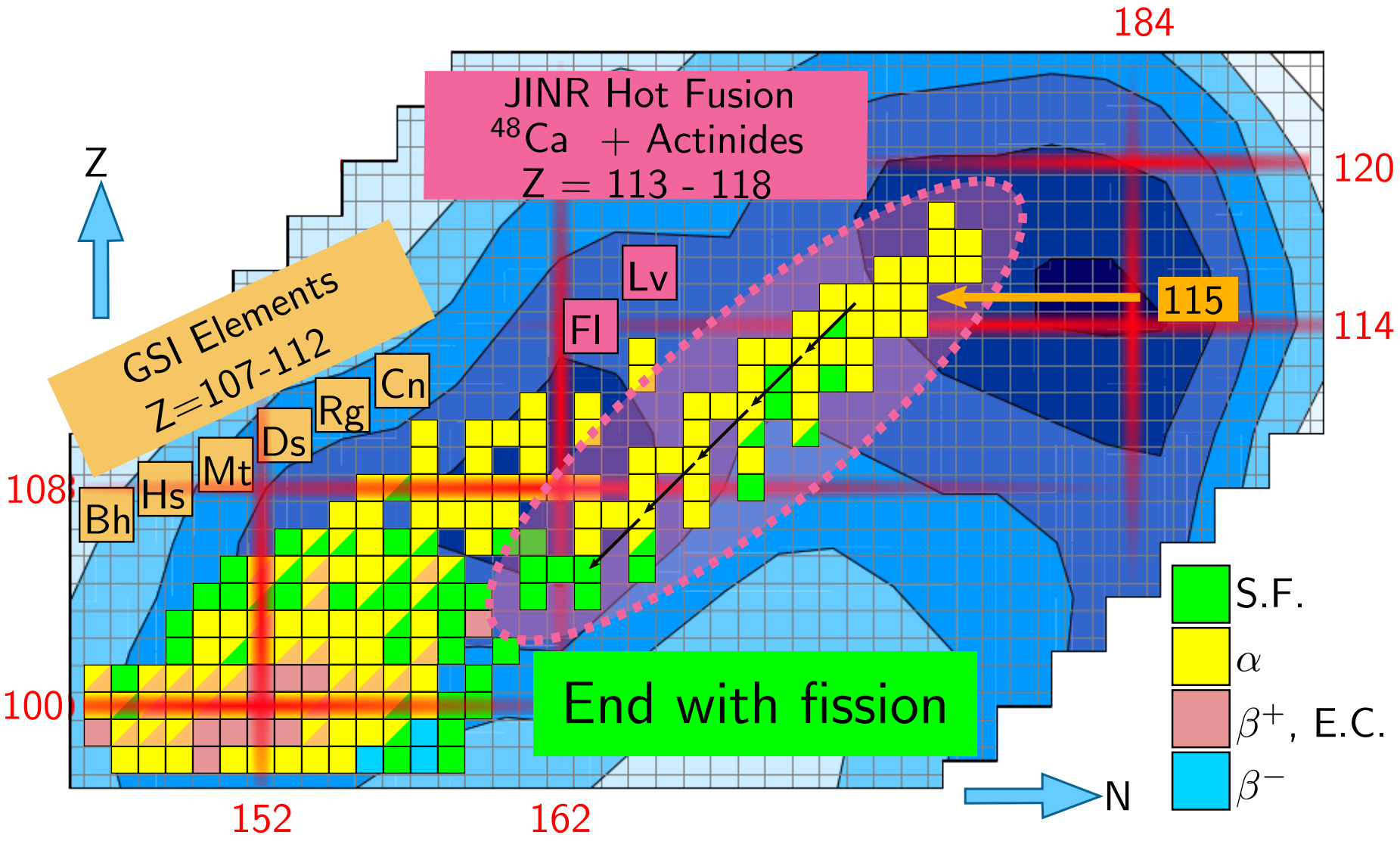
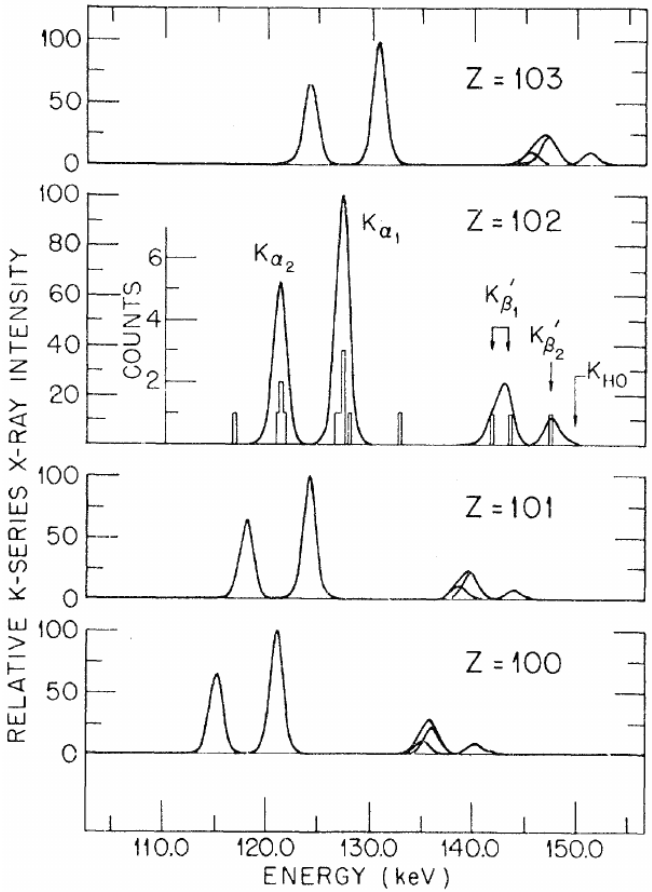
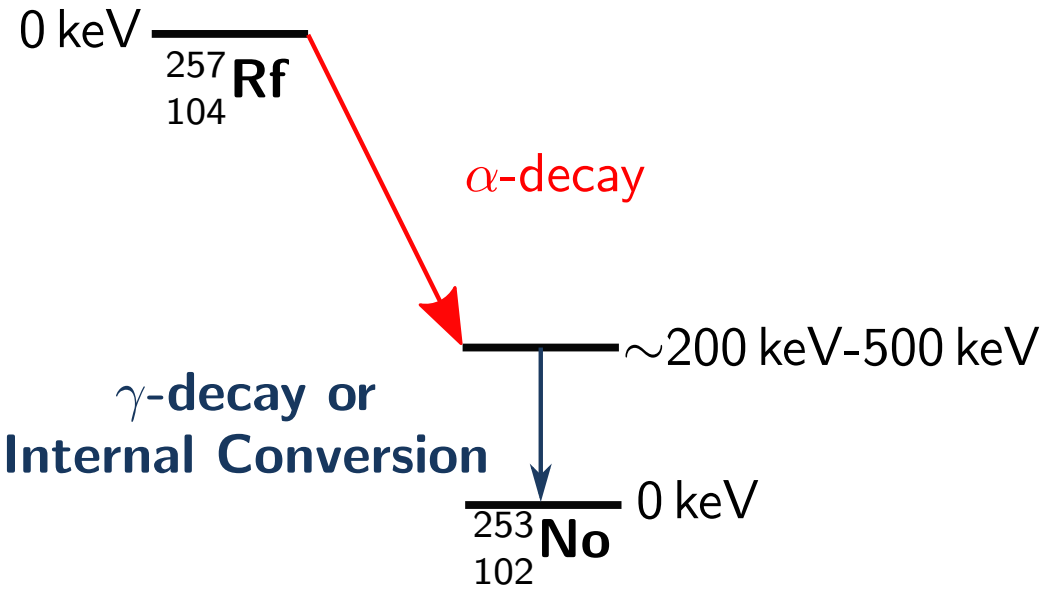


X-ray Fingerprinting of an Element

in the spirit of

R. Bemis et al., PRL 31, 647 (1973)





K X rays

15 α-photon coincidences consistent with No ($Z = 102$) K X rays

Identification of Rf ($Z = 104$)

X-ray Fingerprinting of an Element

in the spirit of

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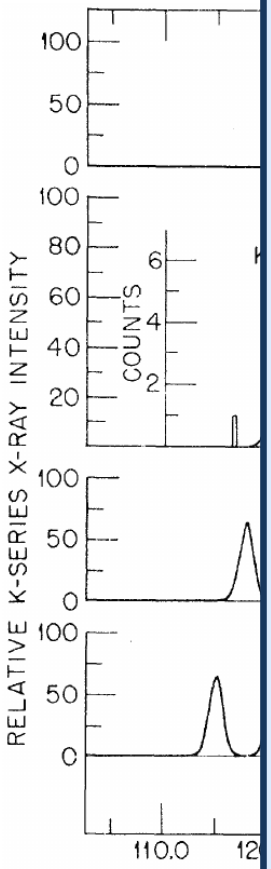
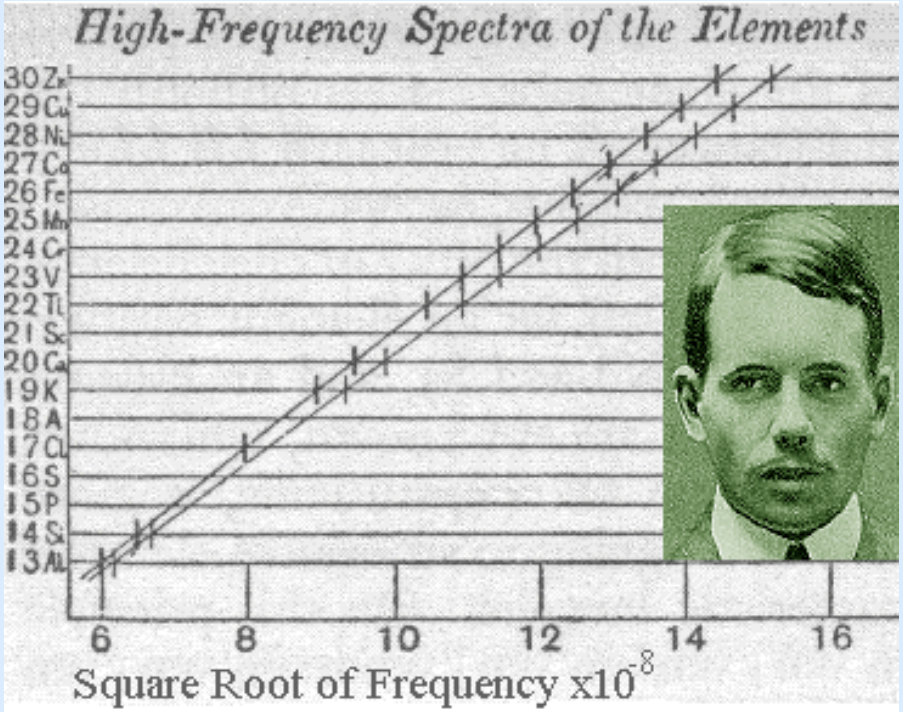


Moseley's Law



$$E_{K_\alpha} \sim f_{K_\alpha} \propto (Z-1)^2$$

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

~200 keV-500 keV

0 keV

K X rays

15 α-phot

consistent with N

Identification of Rf ($Z = 104$)

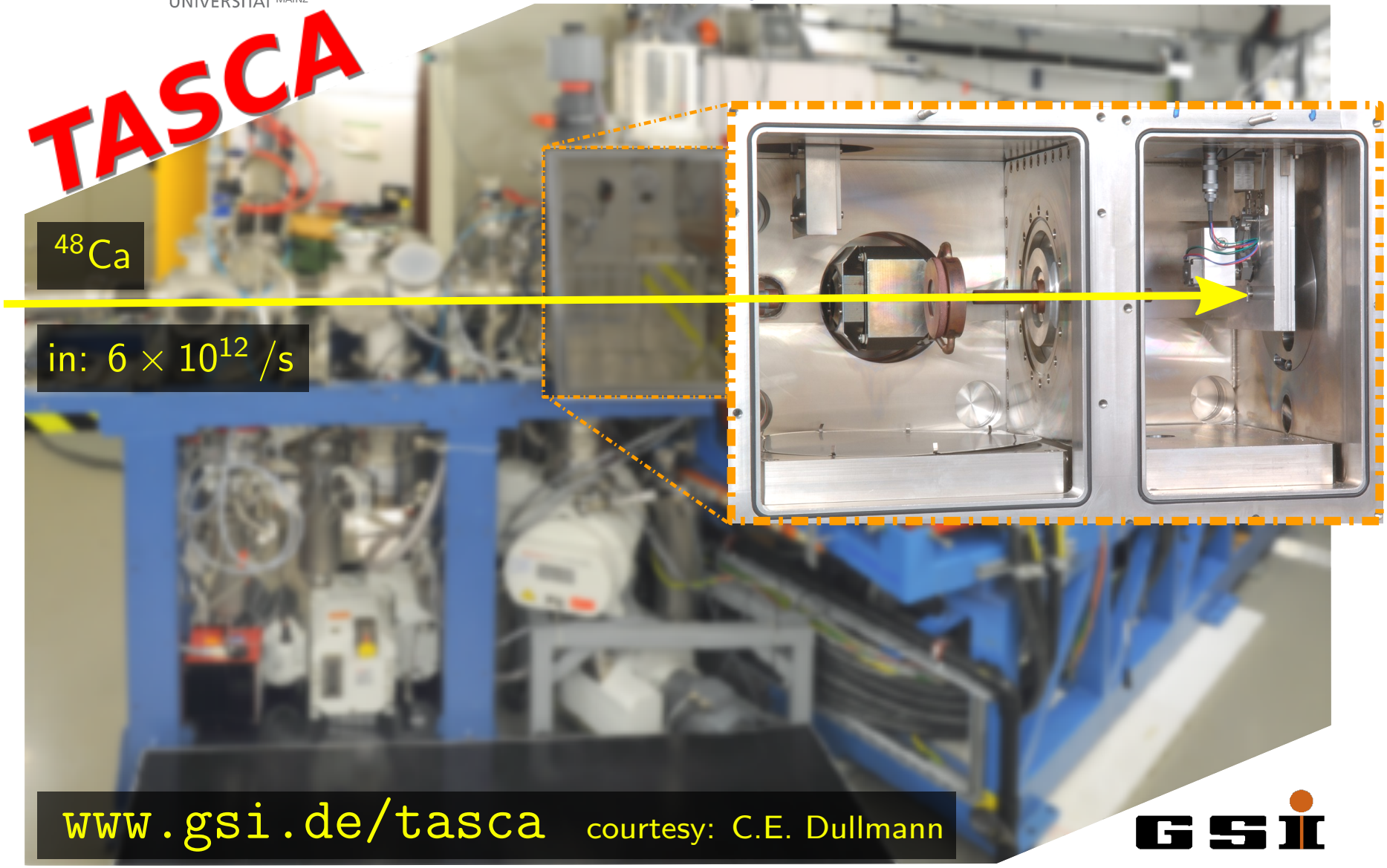
Experiment

www.gsi.de/tasca courtesy: C.E. Dullmann

Experiment

TASCA
^{48}Ca
in: 6×10^{12} /s
www.gsi.de/tasca
courtesy: C.E. Dullmann

Experiment


TASCA
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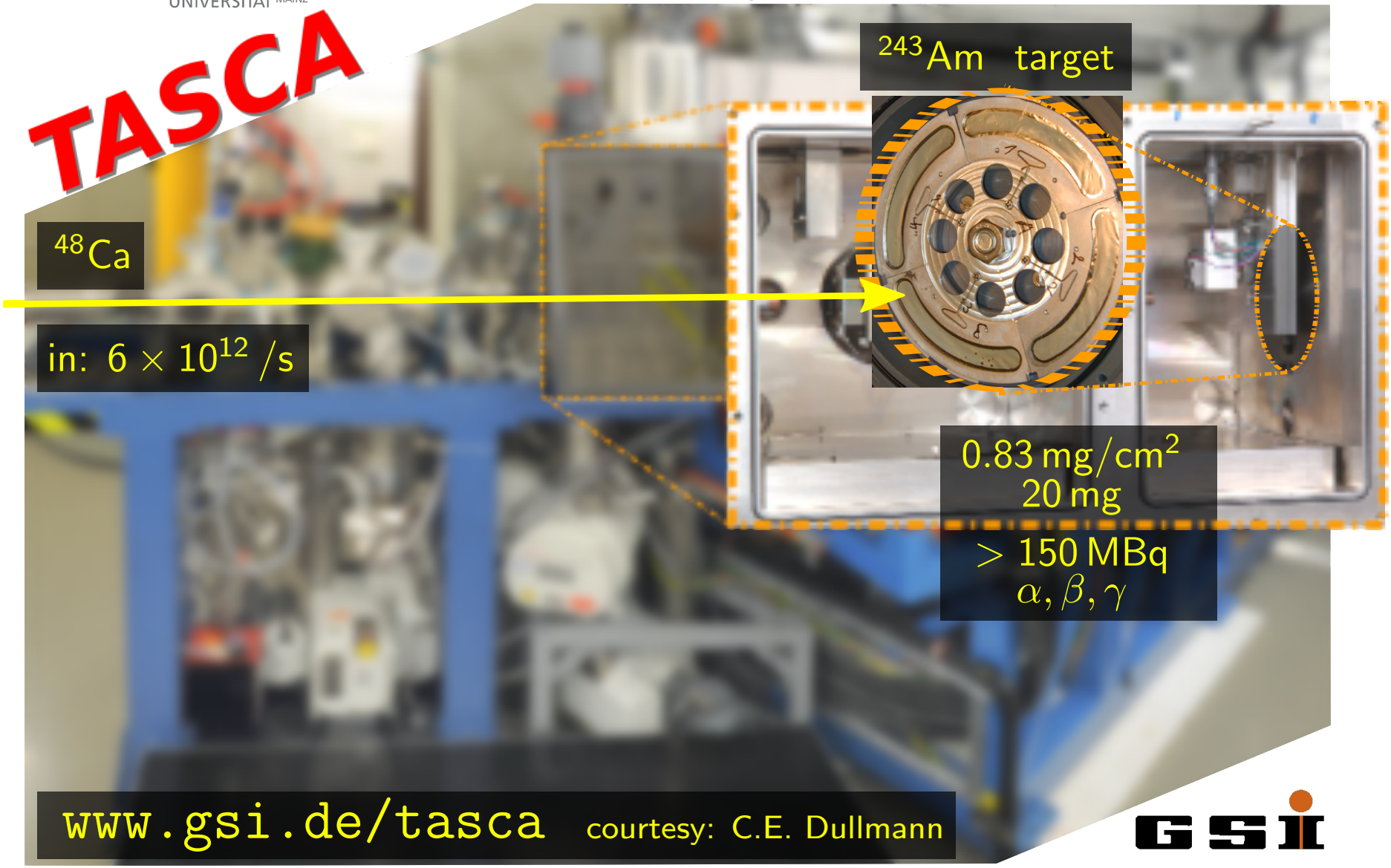

TASCA
^{243}Am target
^{48}Ca
in: 6×10^{12} /s
0.83 mg/cm^2
20 mg
> 150 MBq
α, β, γ
www.gsi.de/tasca
courtesy: C.E. Dullmann

TASiSpec

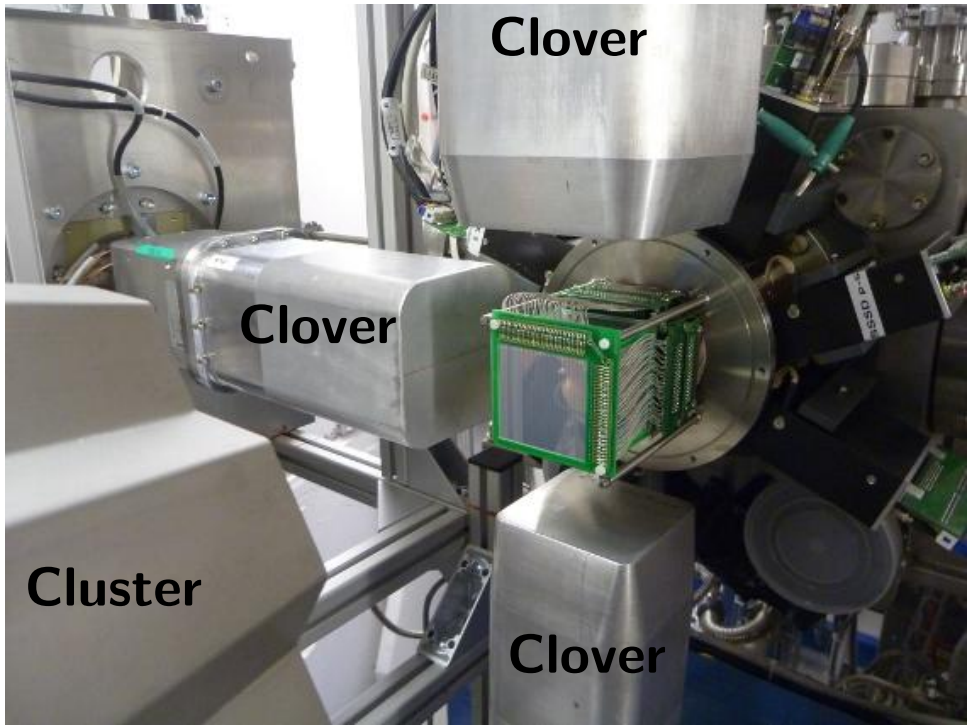
Highly efficient multi-coincidence spectroscopy set-up
for TASCA's very compact focal plane image

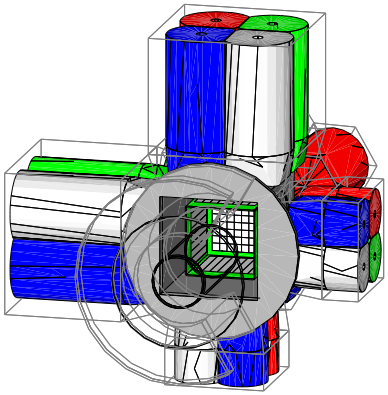
1 Imp. DSSSD (1024 pixels)
\+ 4 Box DSSSDs (1024 pixels)

$\sim$ 80% α-detection efficiency

(3+1) Ge Clover (4 crystals each)
\+ (1+1) Ge Cluster (7 crystals each)

$\sim$ 40% γ-detection effi. @ 150 keV





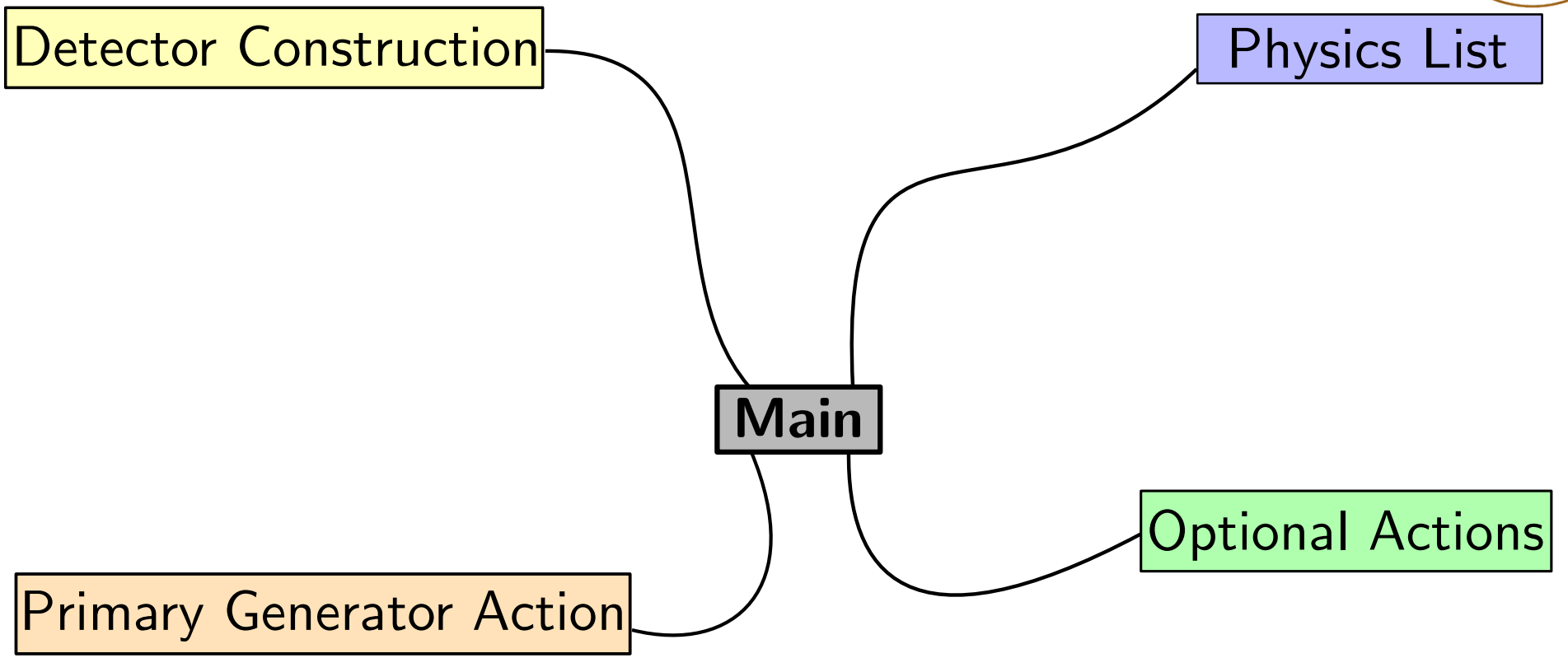
L.-L. Andersson et al., NIM A 622, 164 (2010)

L.G. Sarmiento et al., NIM A 667, 26 (2012).

Fully simulated with Geant4

JOHANNES GUTENBERG UNIVERSITÄT MAINZ · LUND UNIVERSITY · UNIVERSITY OF LIVERPOOL · GSI · HELMHOLTZ GEMEINSCHAFT Helmholtz-Institut Mainz · UNIVERSIDAD NACIONAL DE COLOMBIA

Geant4 Overview



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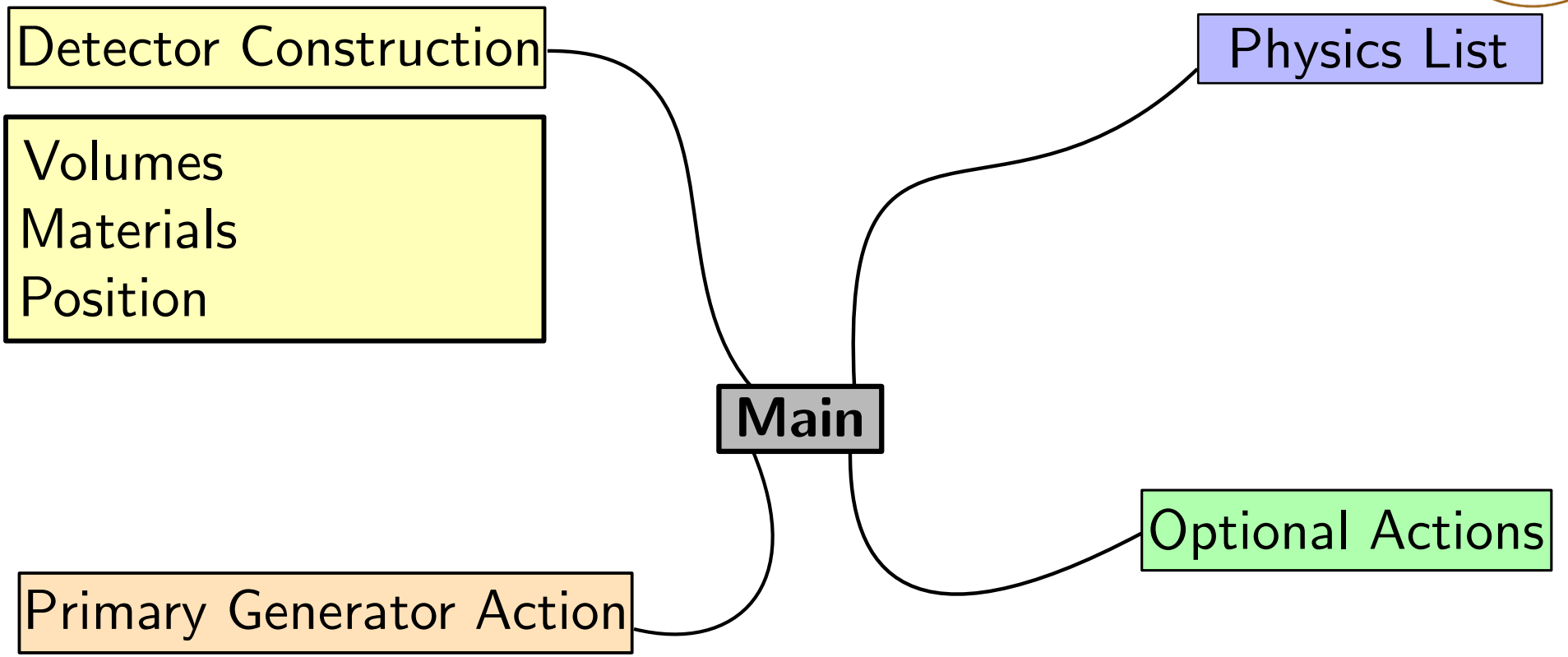

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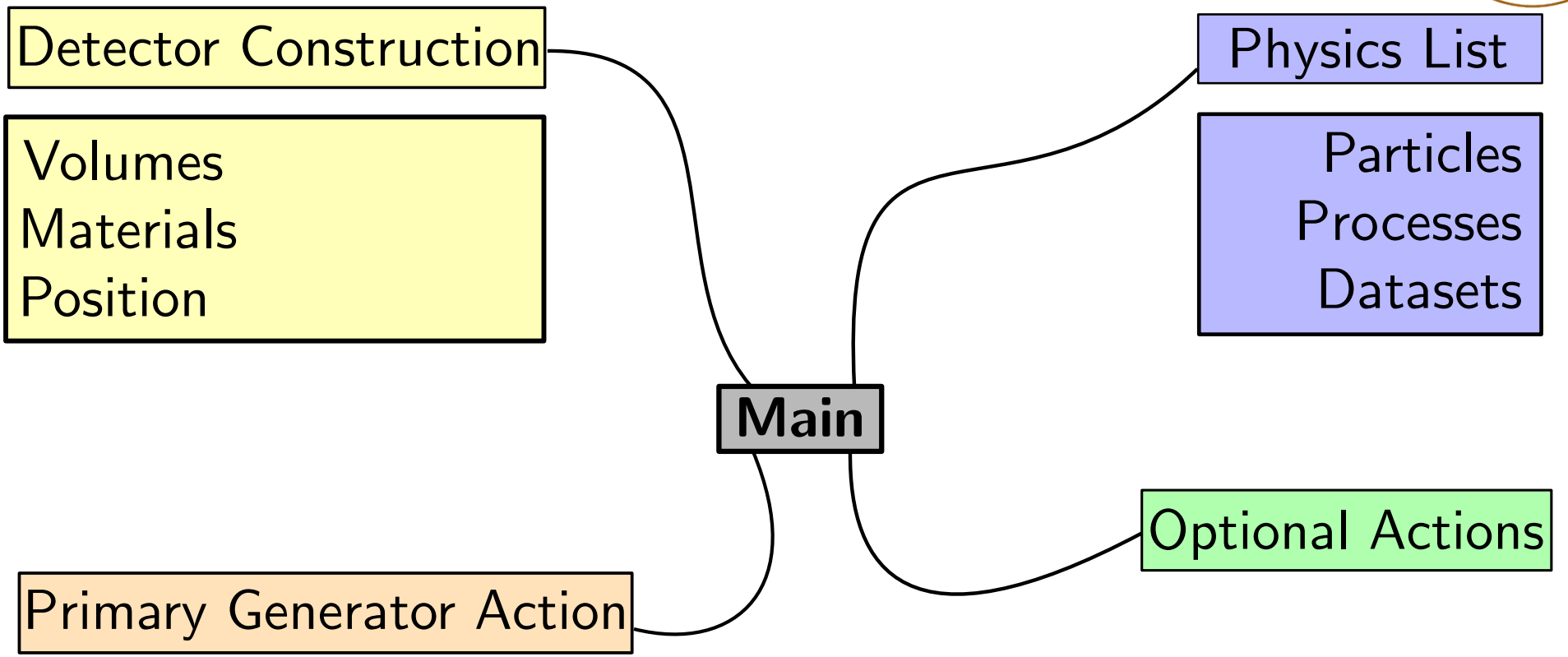

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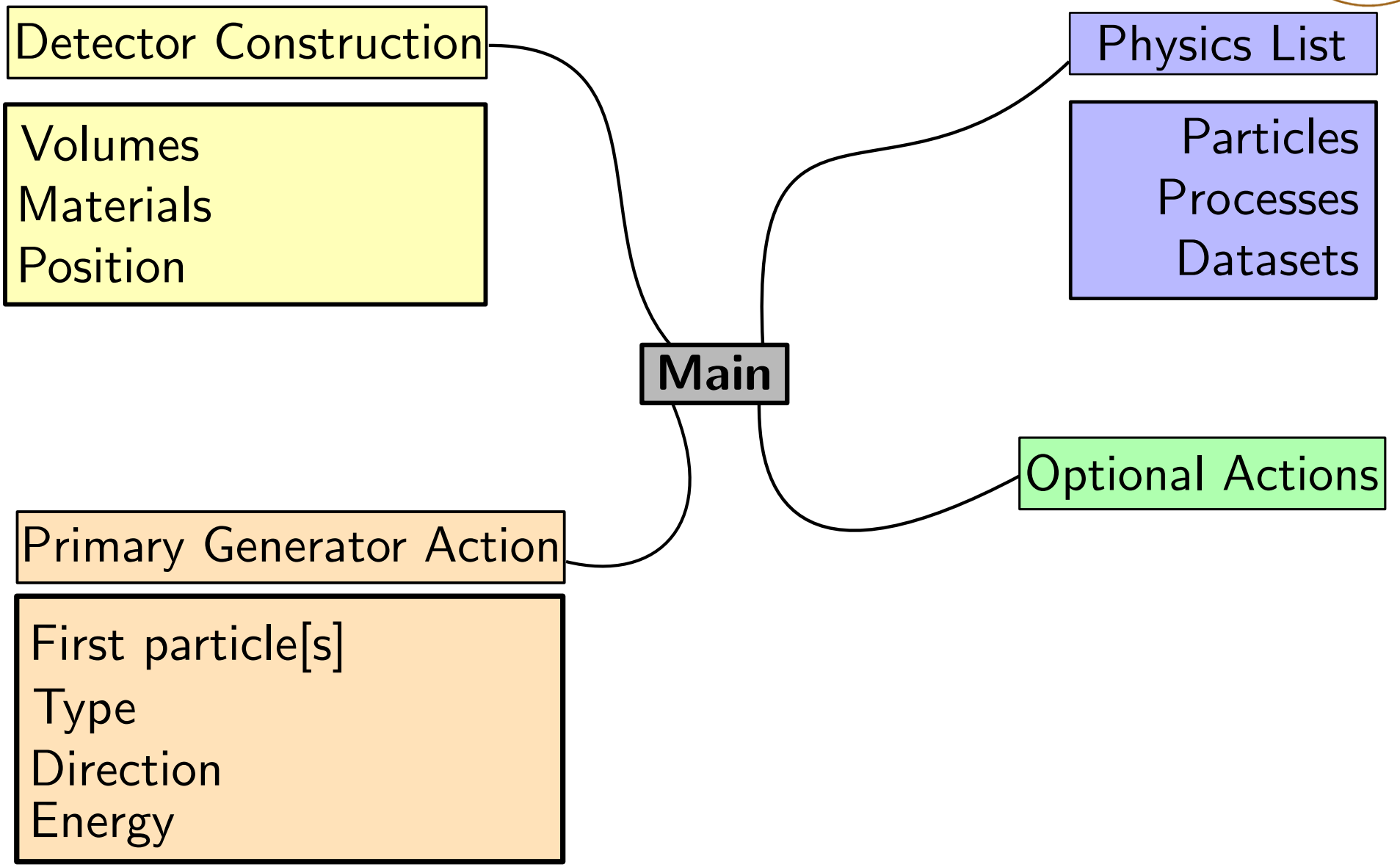

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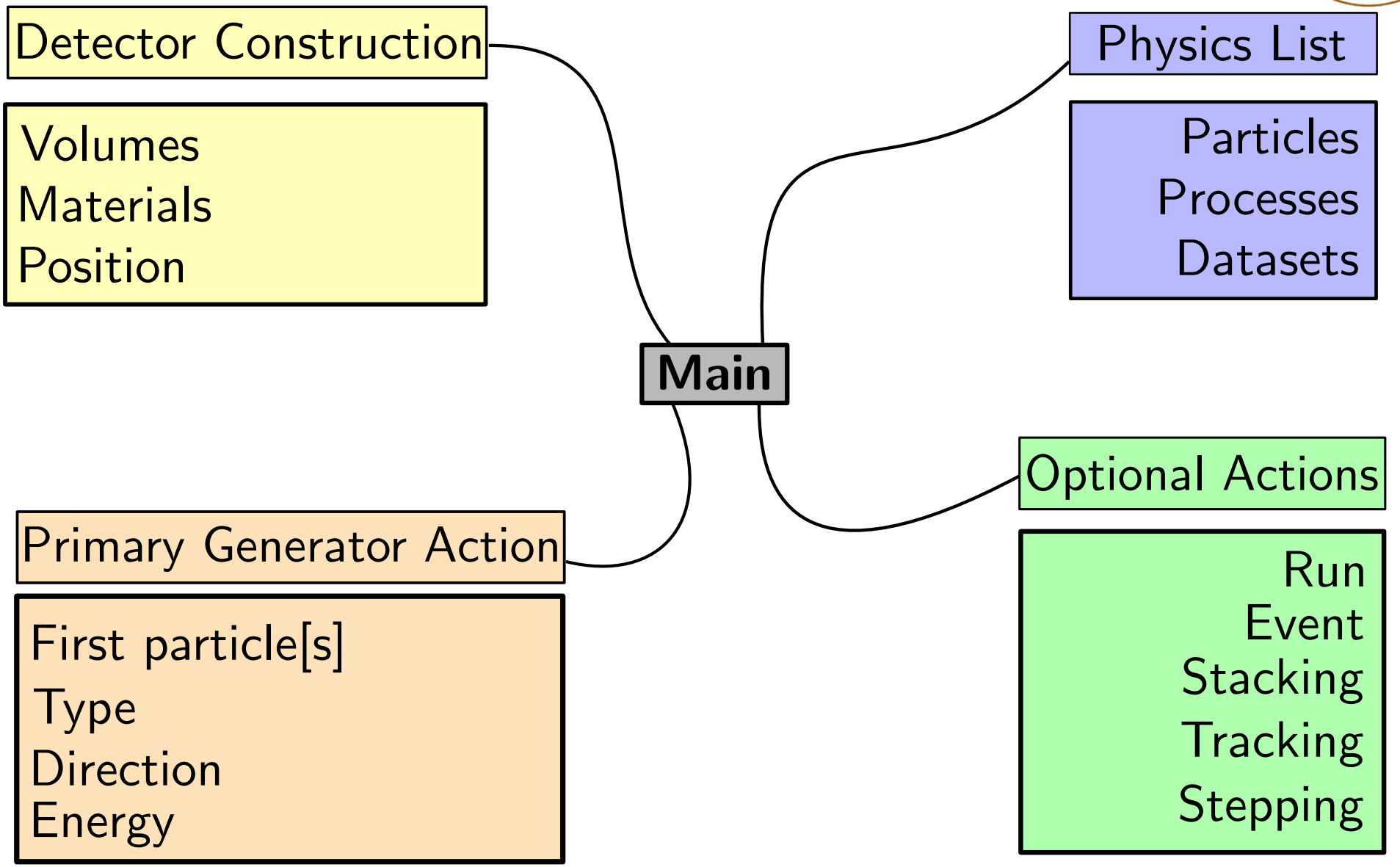

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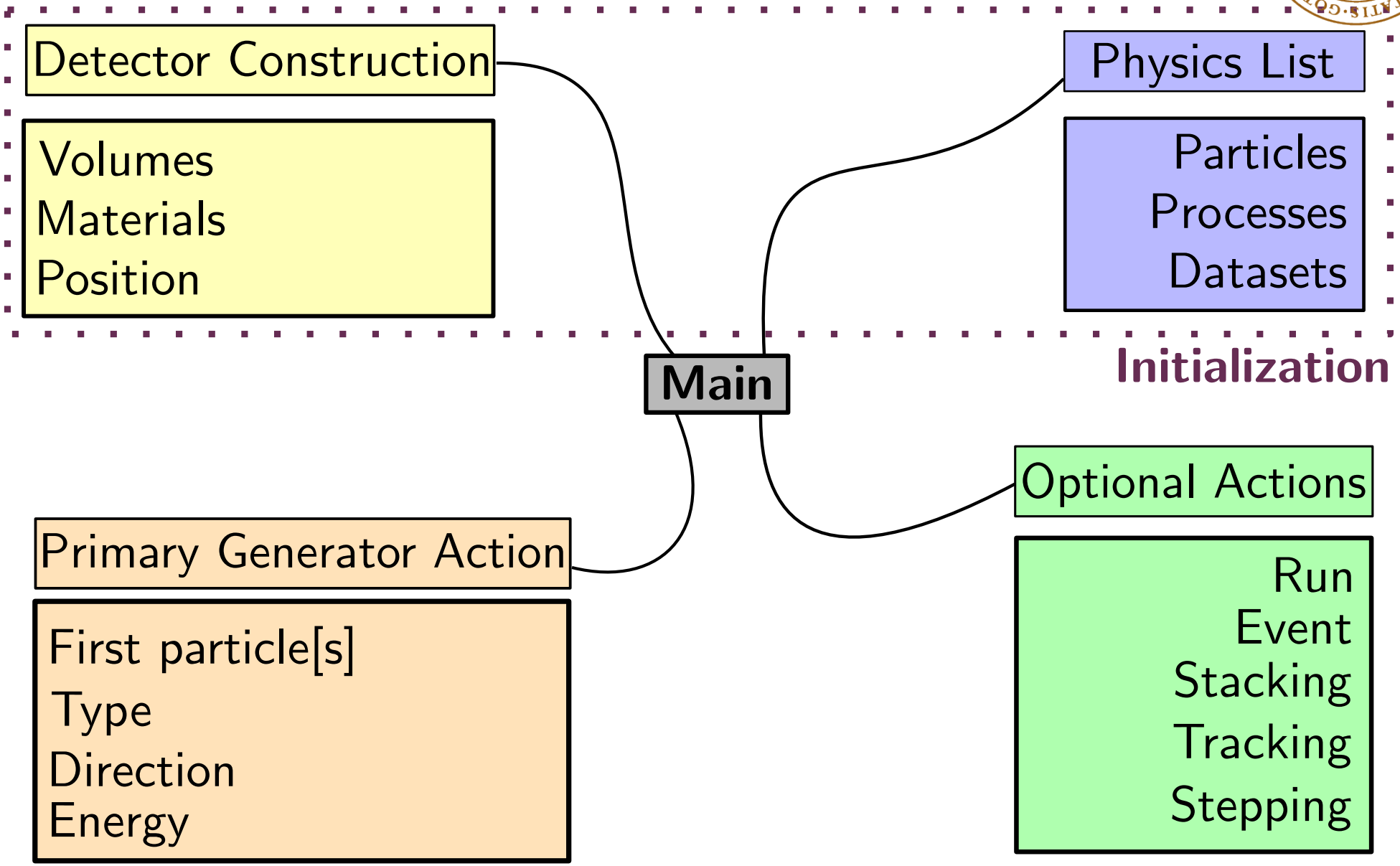
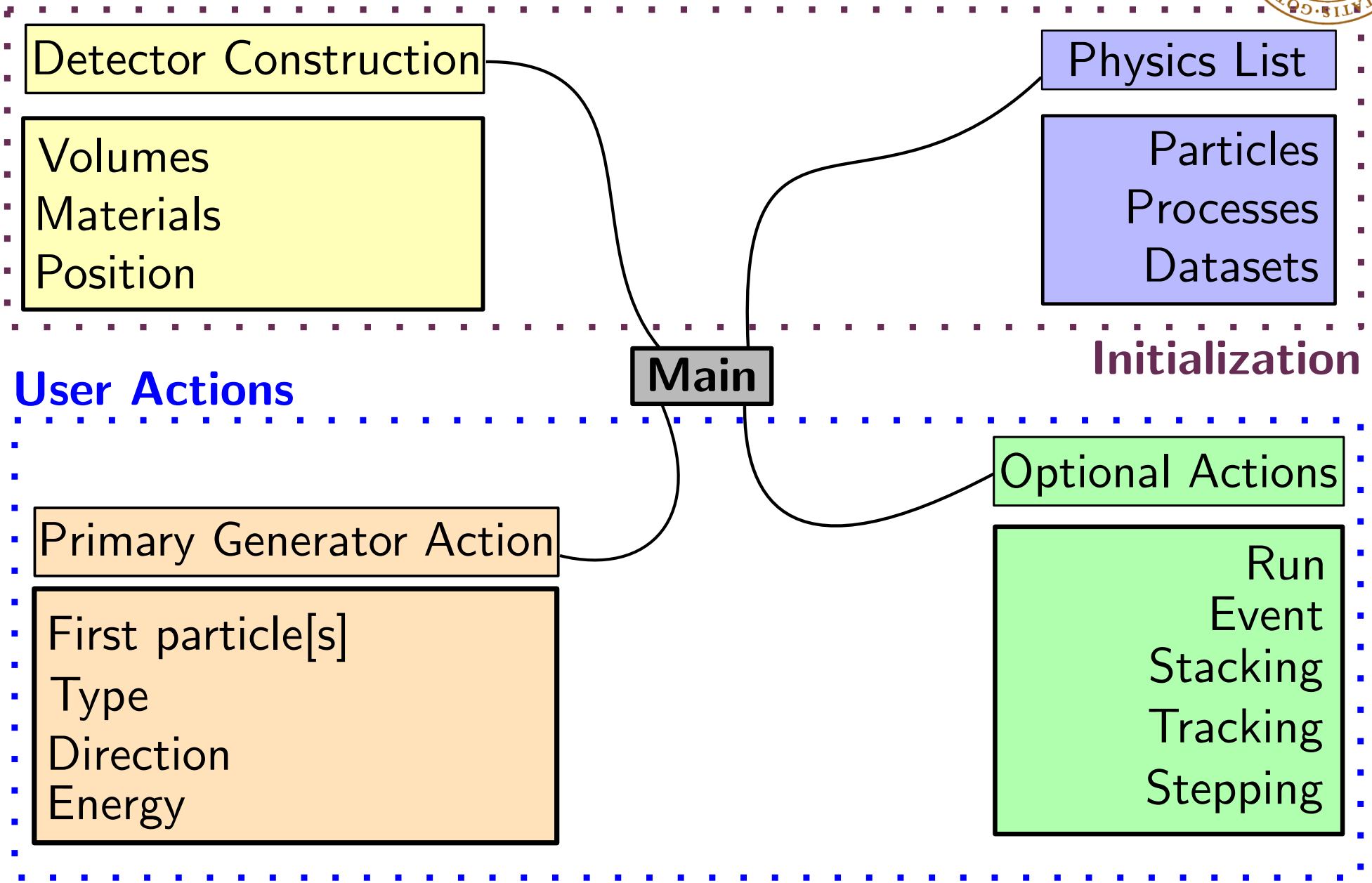


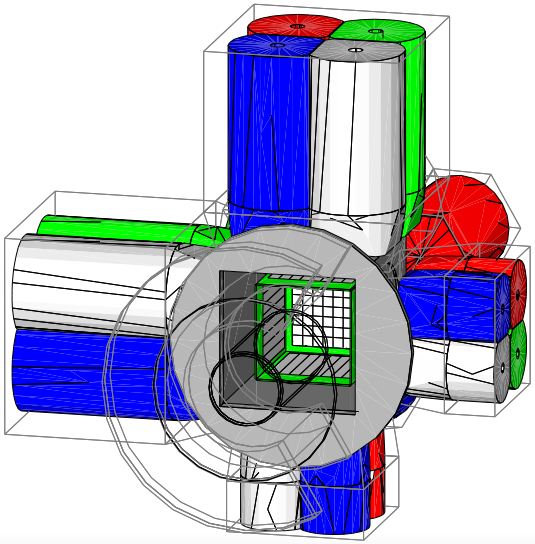
Geant4 Overview



Geant4 Overview

Geant4 Overview

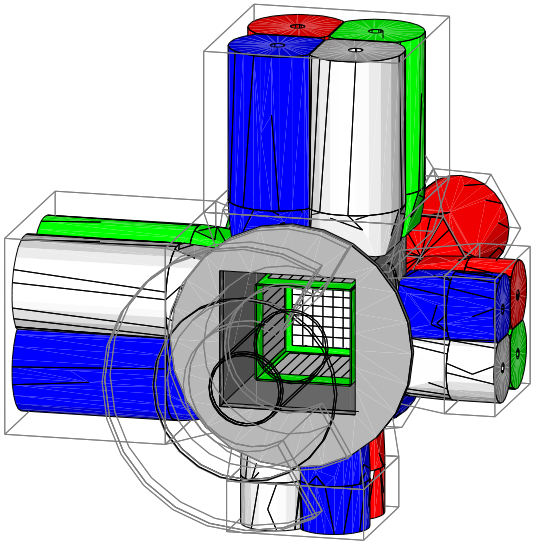
Detector Construction



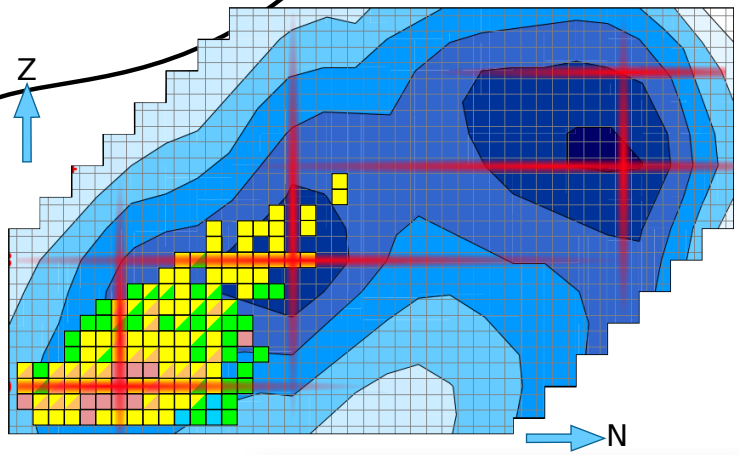
Main

Geant4 Overview

Detector Construction



Physics List



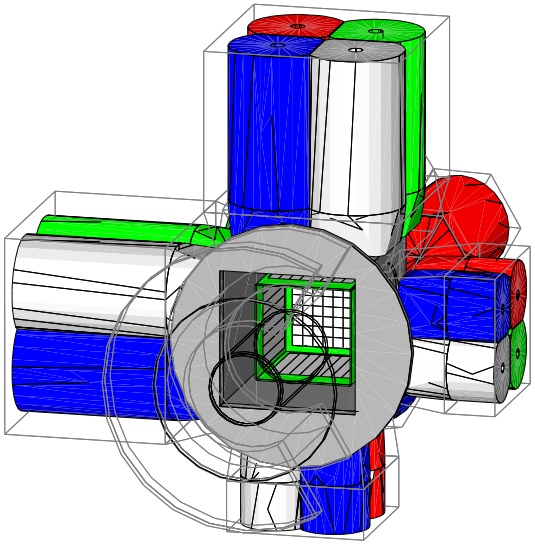
Main

Primary Generator Action

Optional Actions

Geant4 Overview

Detector Construction



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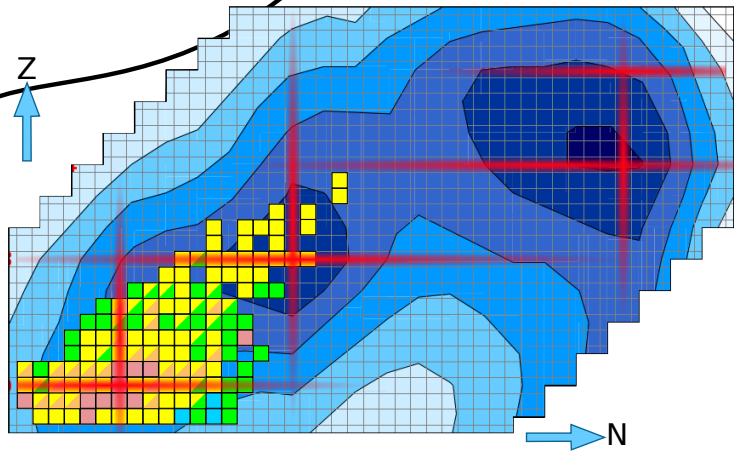

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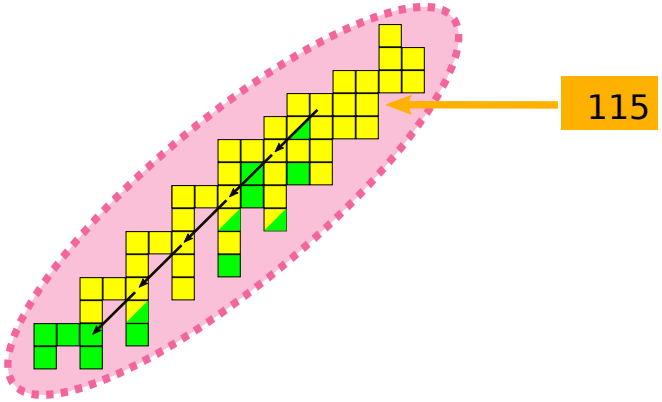

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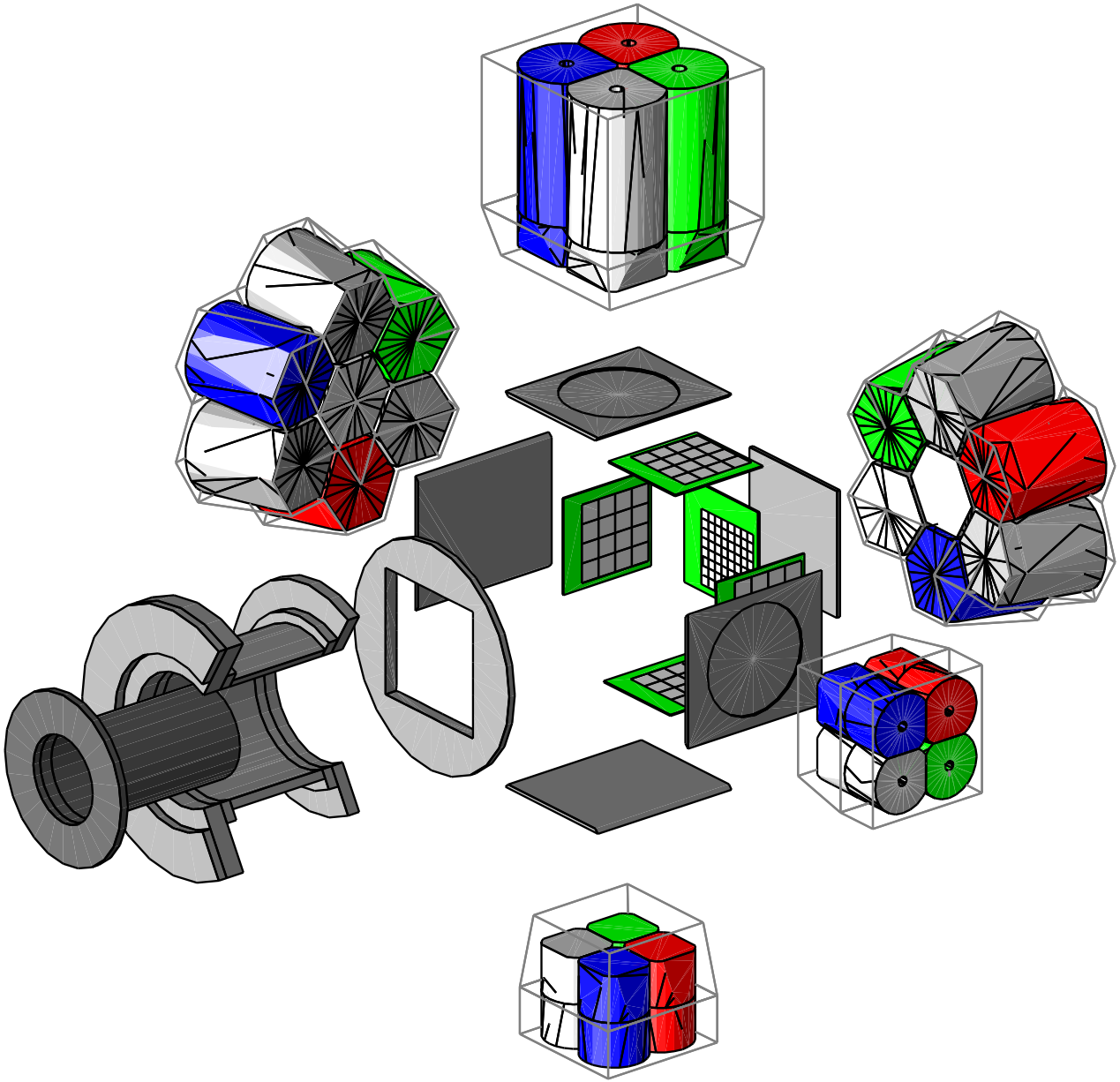
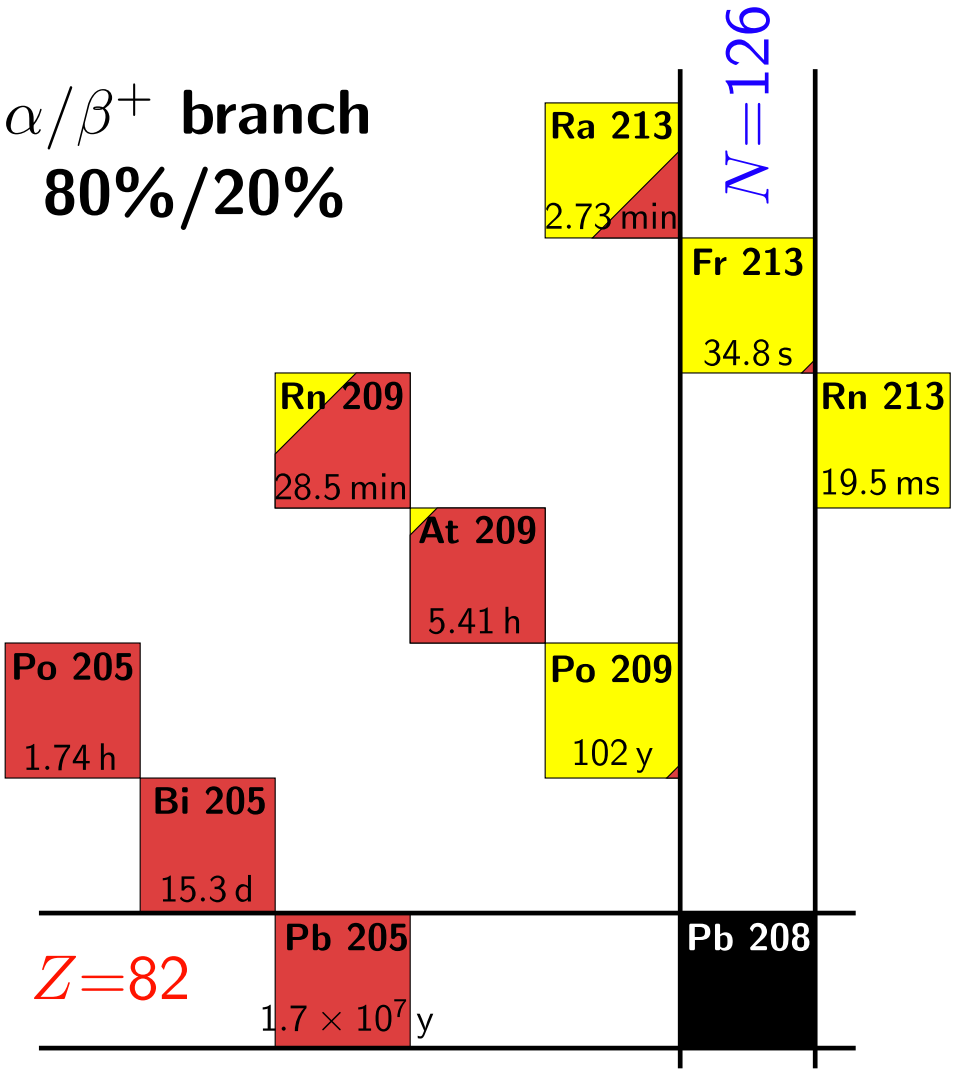
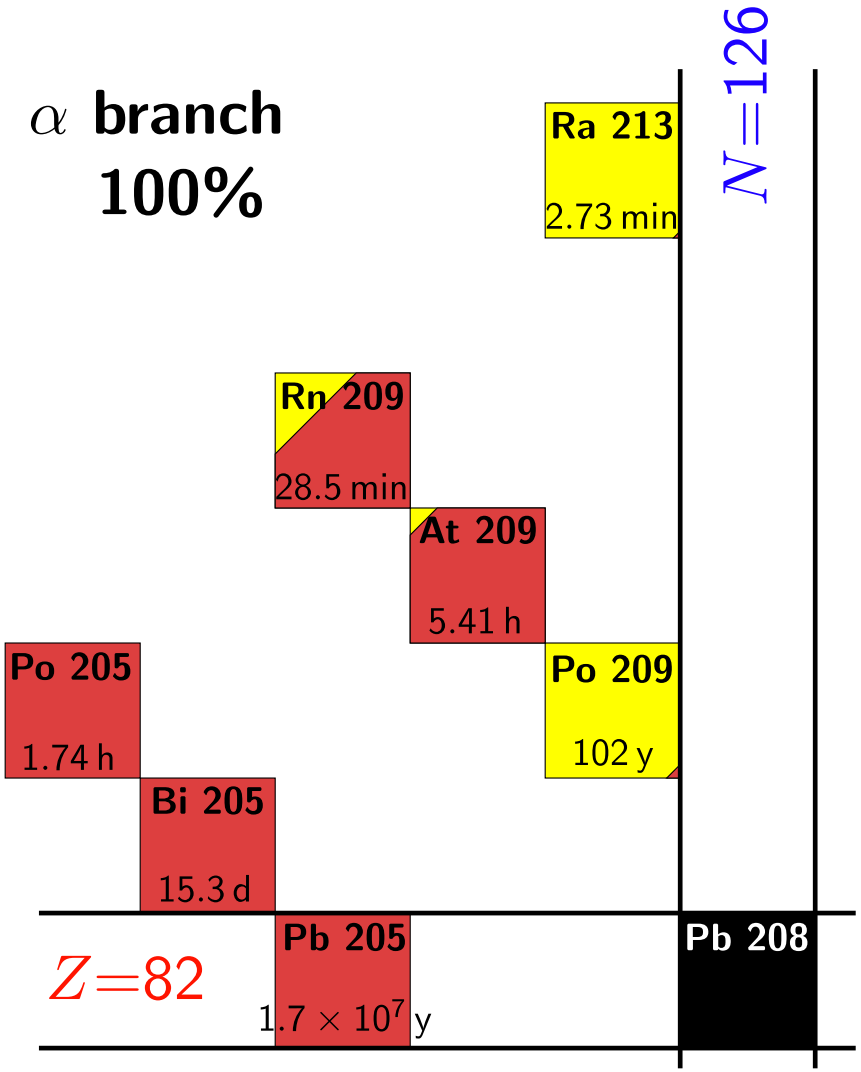


TASISpec

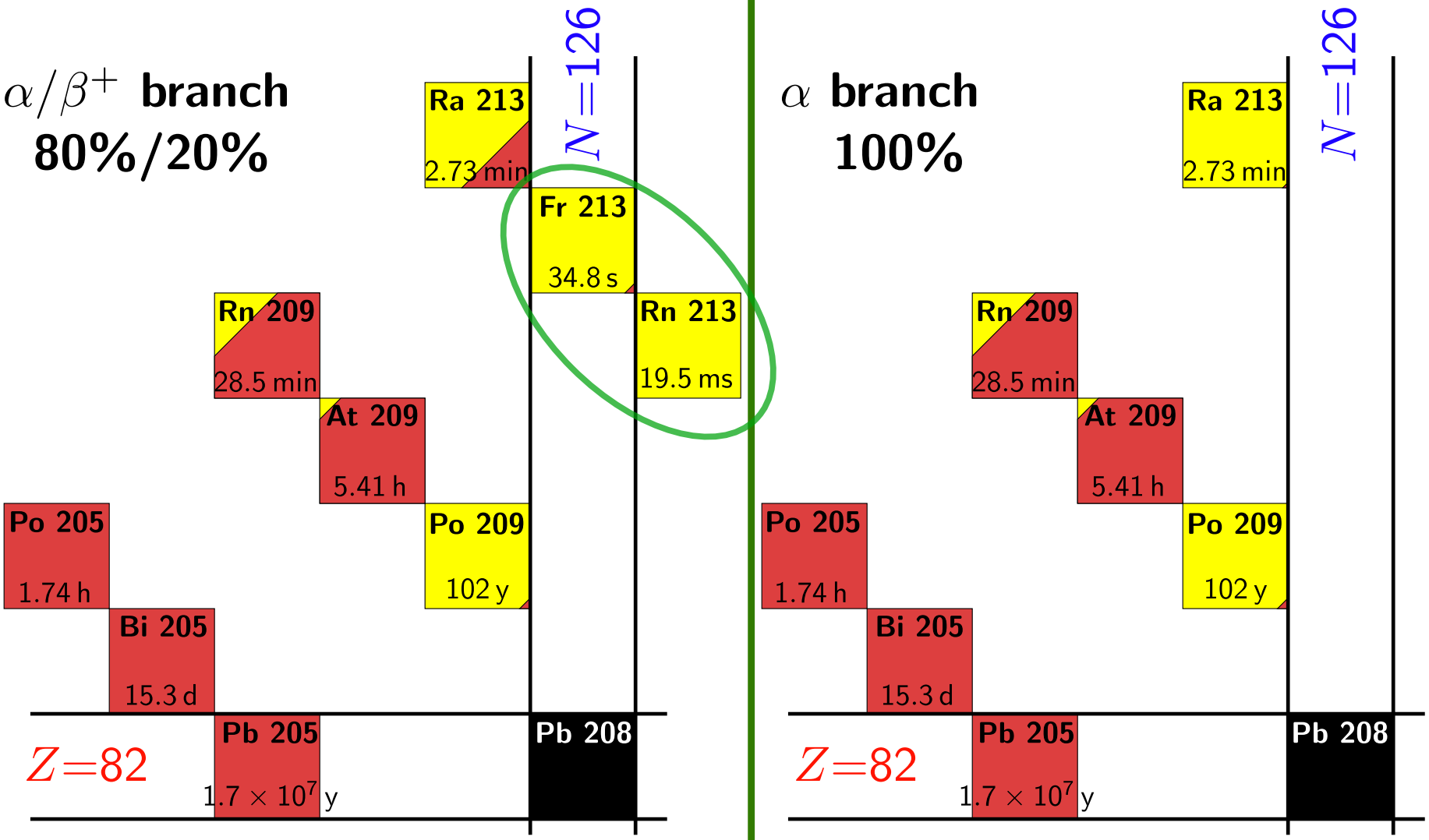
Play/Pause | IN/OUT | OUT/IN

The beginning: ^{213}Ra

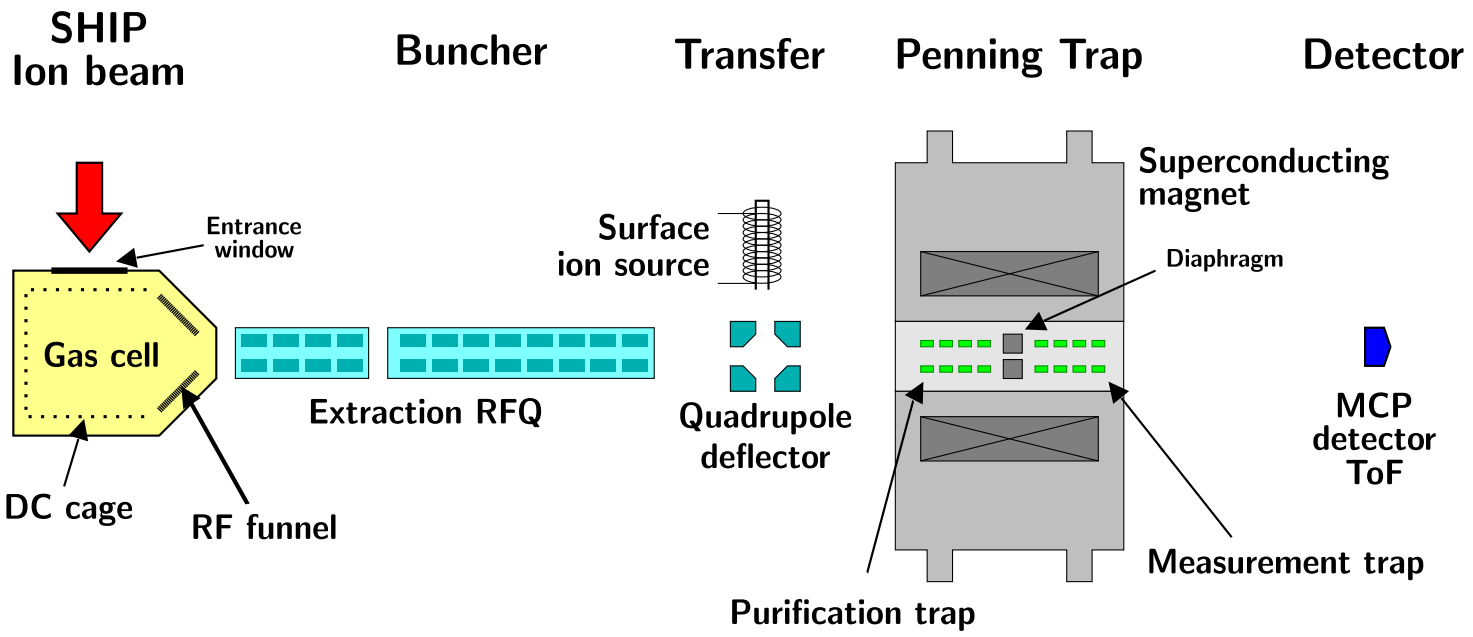




The beginning: ^{213}Ra



Quantum selective spectroscopy



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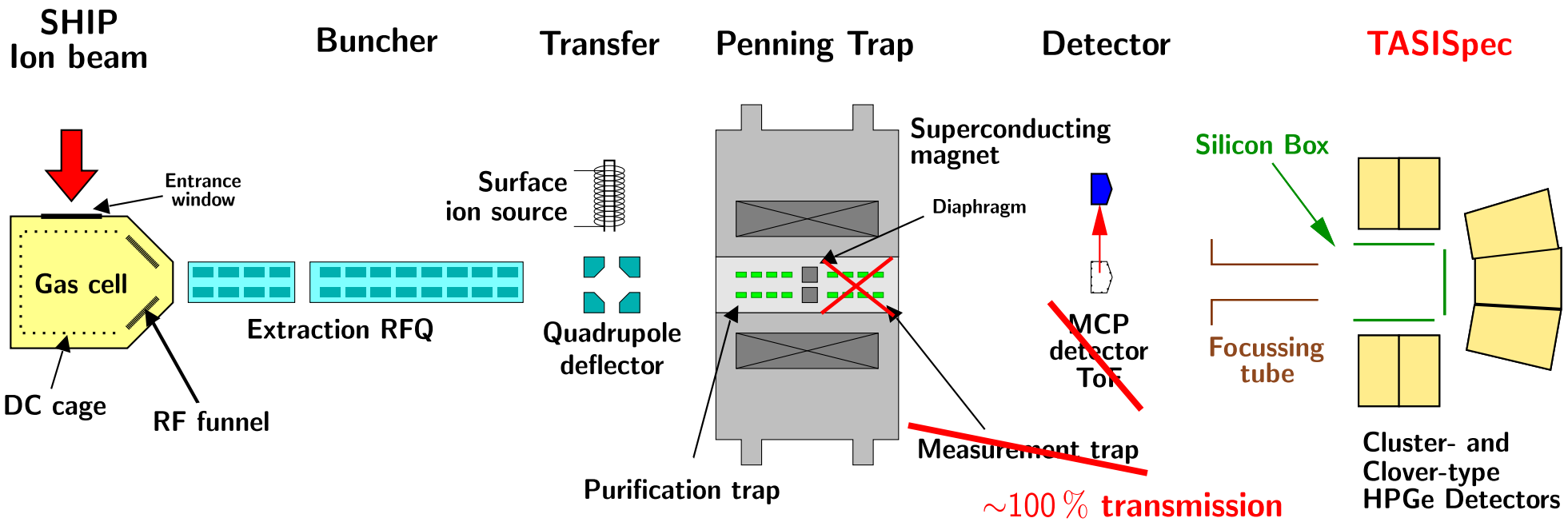
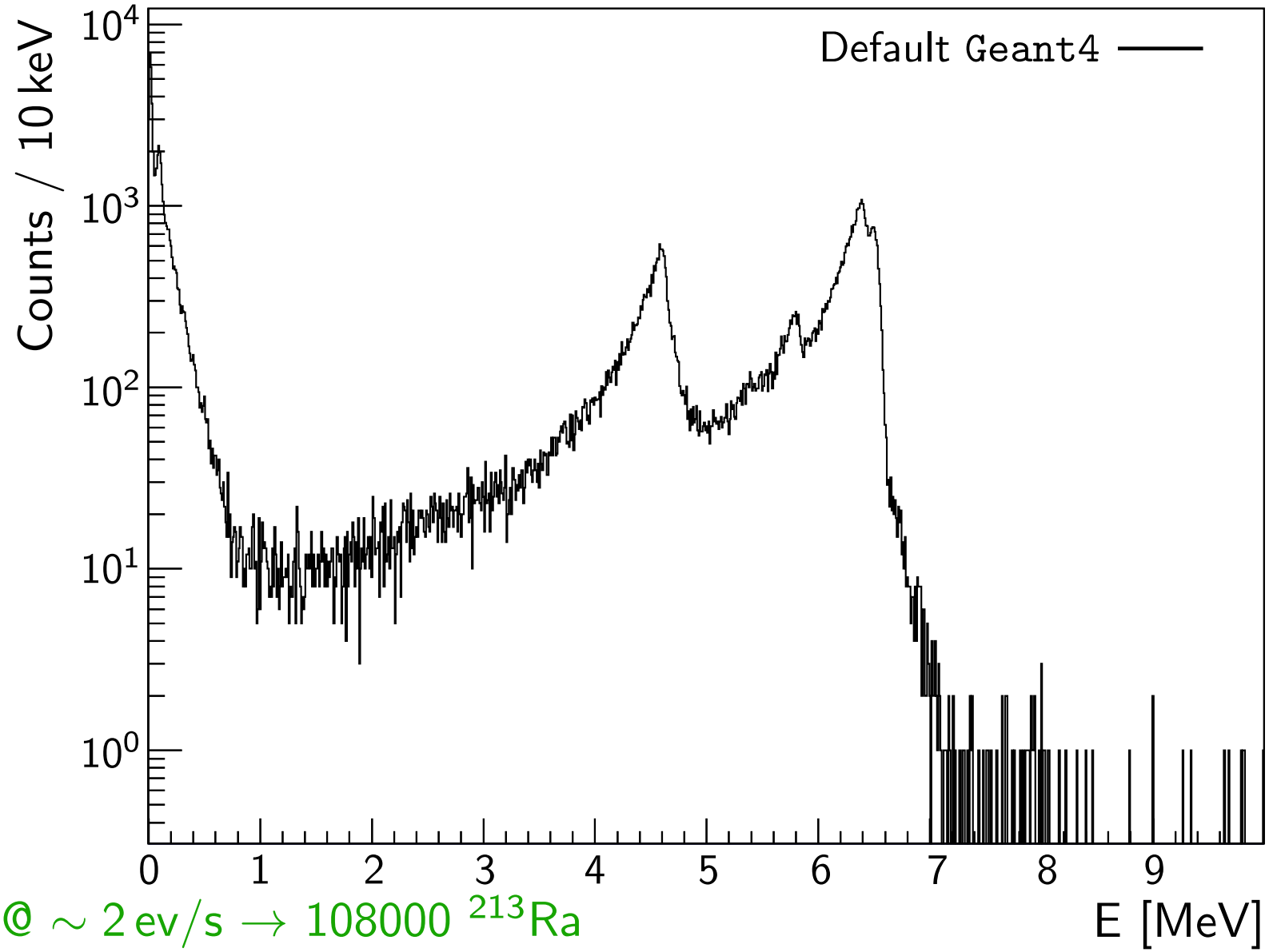
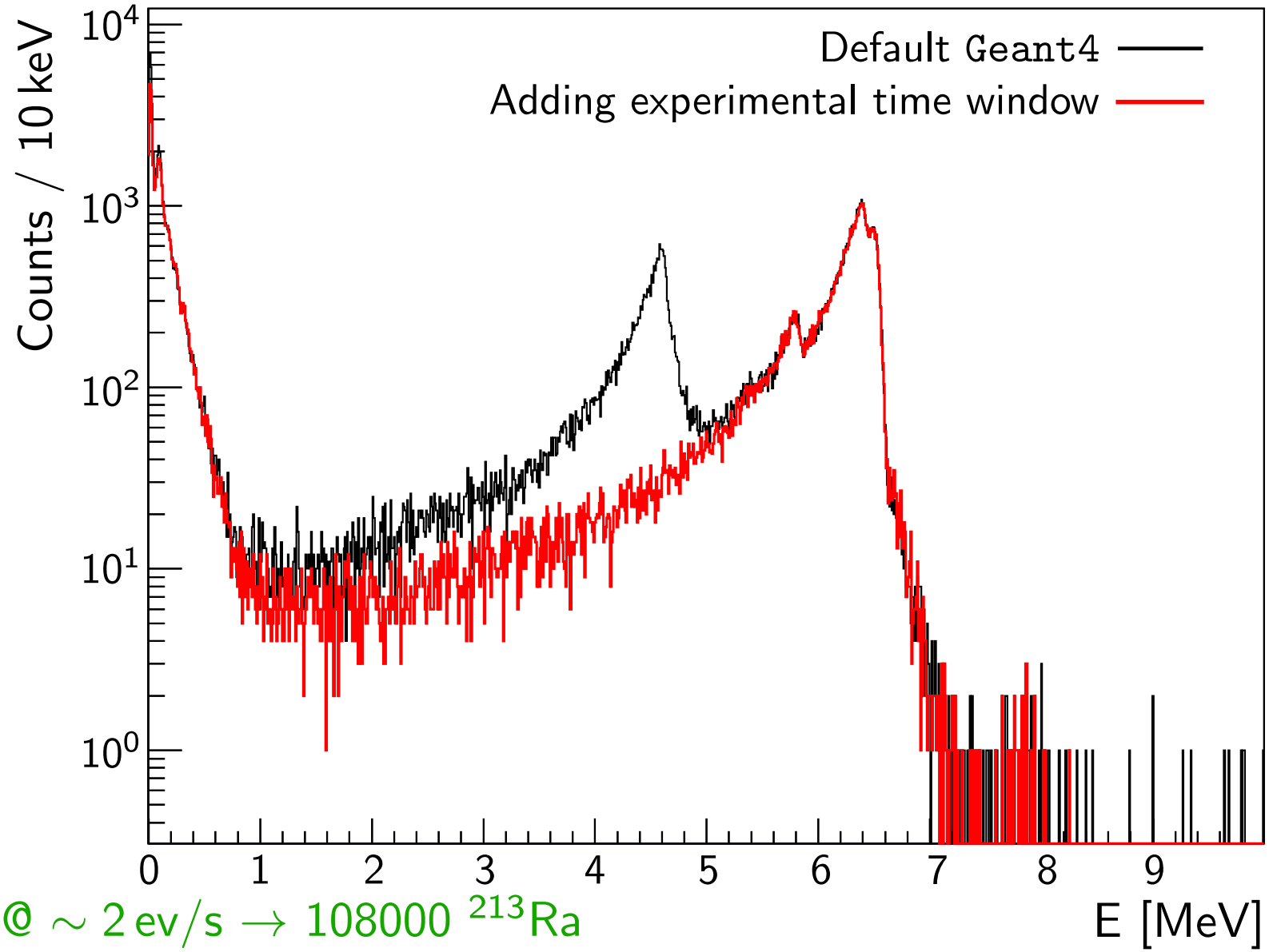


The beginning: ^{213}Ra



11 h @ $\sim$ 2 ev/s $\rightarrow$ 108000 ^{213}Ra

The beginning: ^{213}Ra



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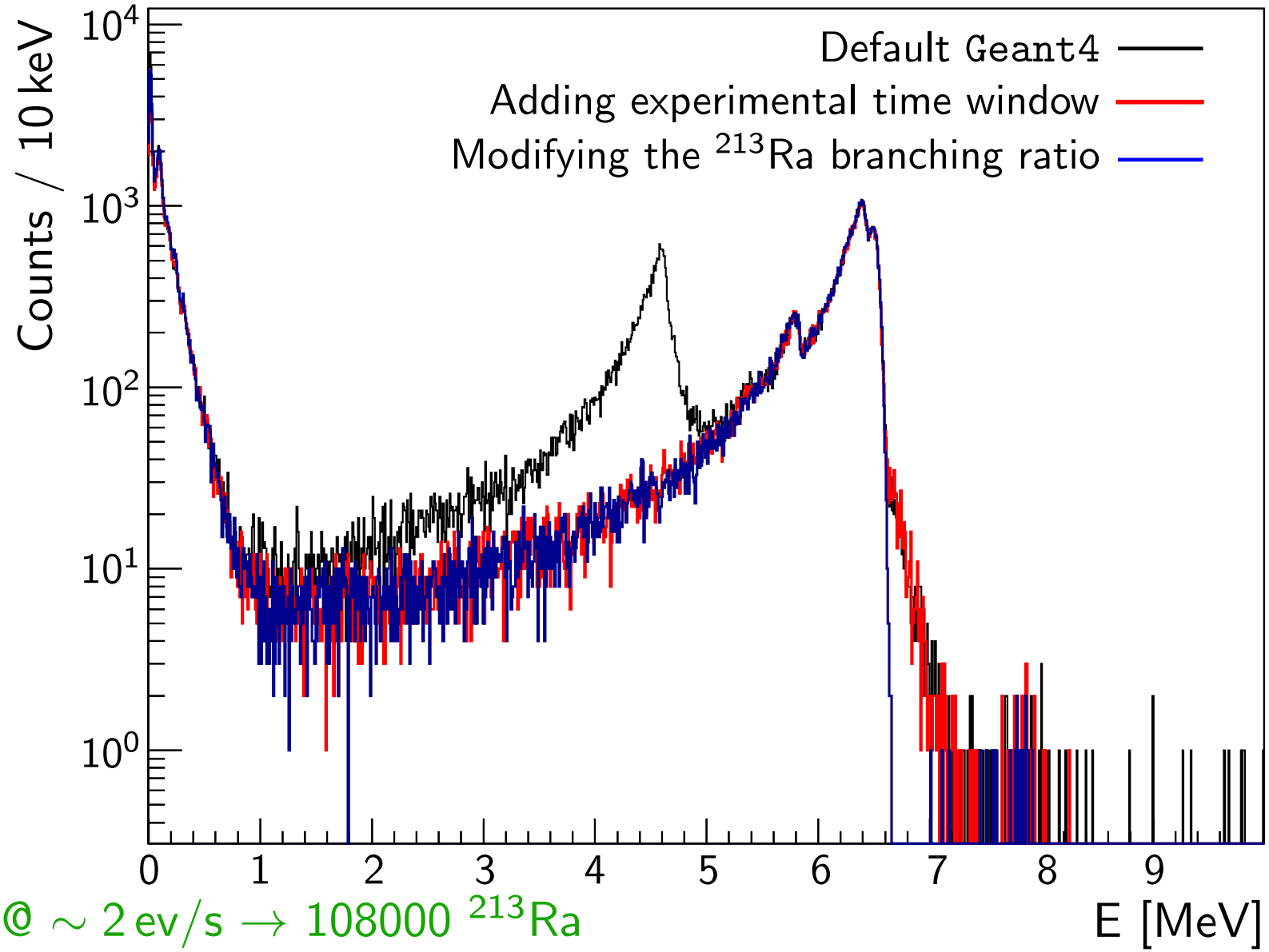

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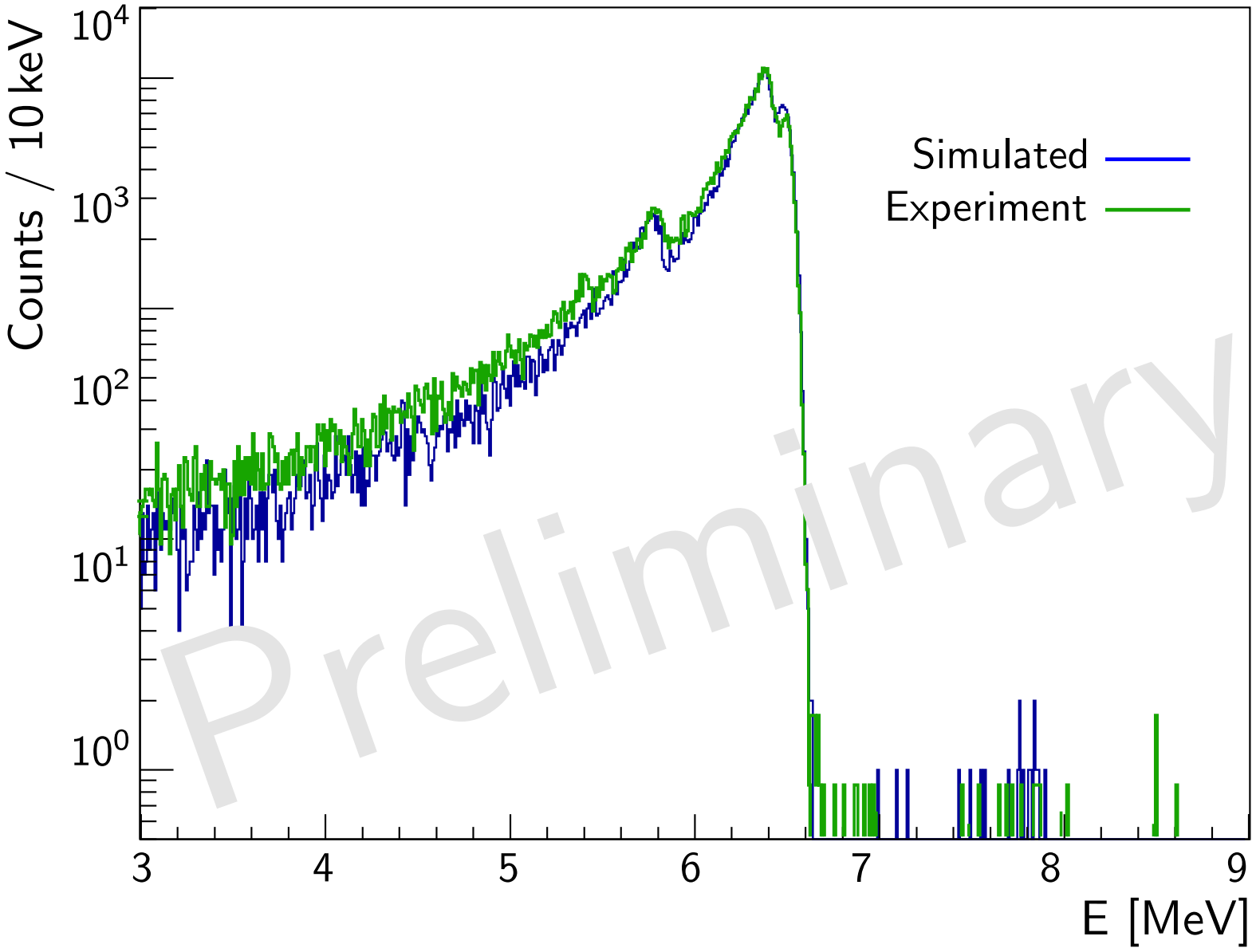
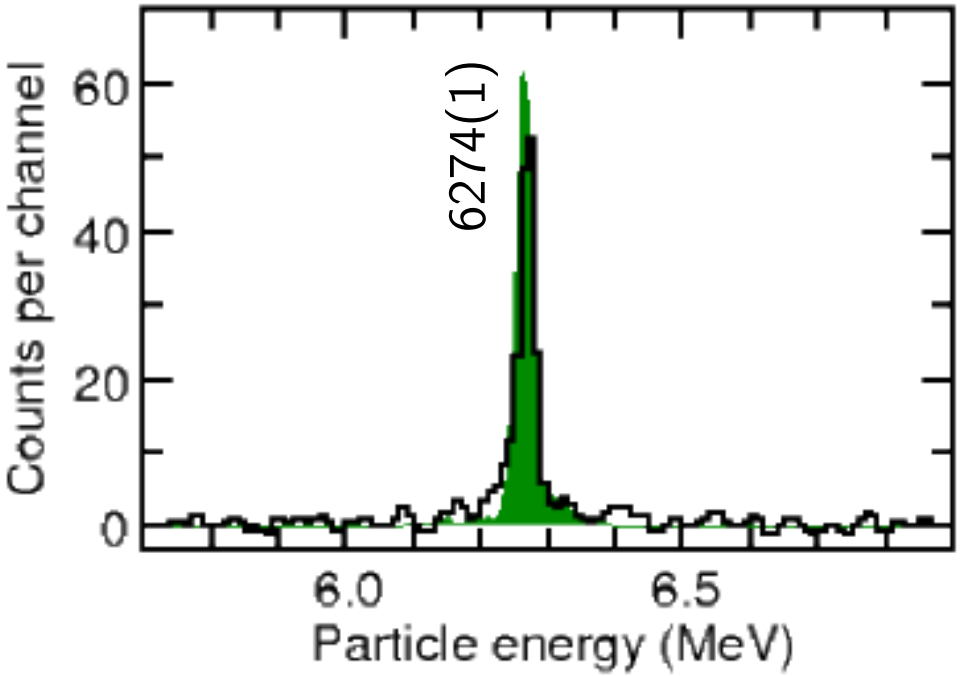
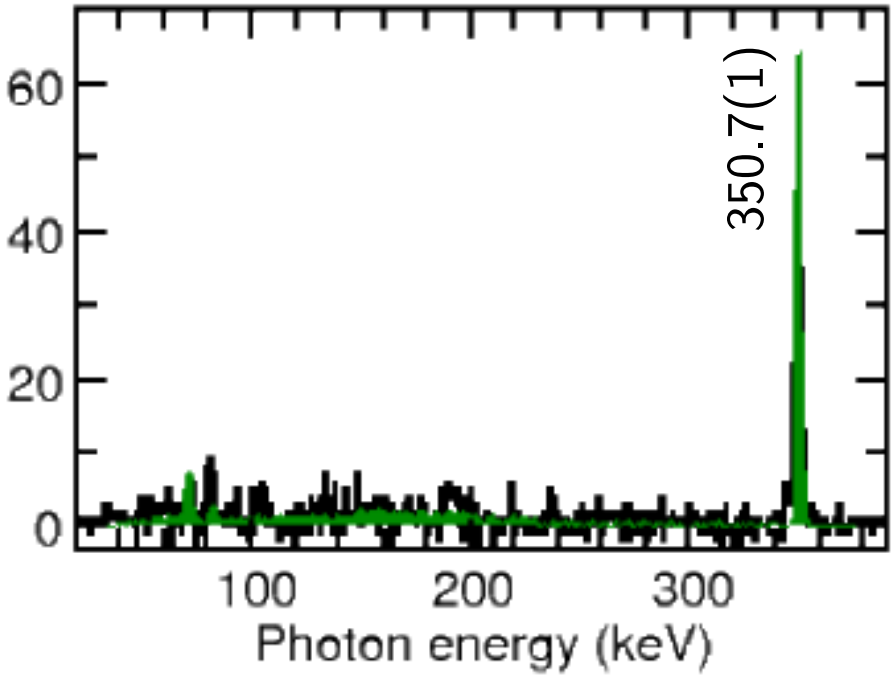


Results: α-γ Coincidences ^{211}Bi $\rightarrow$ ^{207}Tl

... in prompt coincidence with 351 $-$keV γ line



... in prompt coincidence with 6278 $-$keV α line



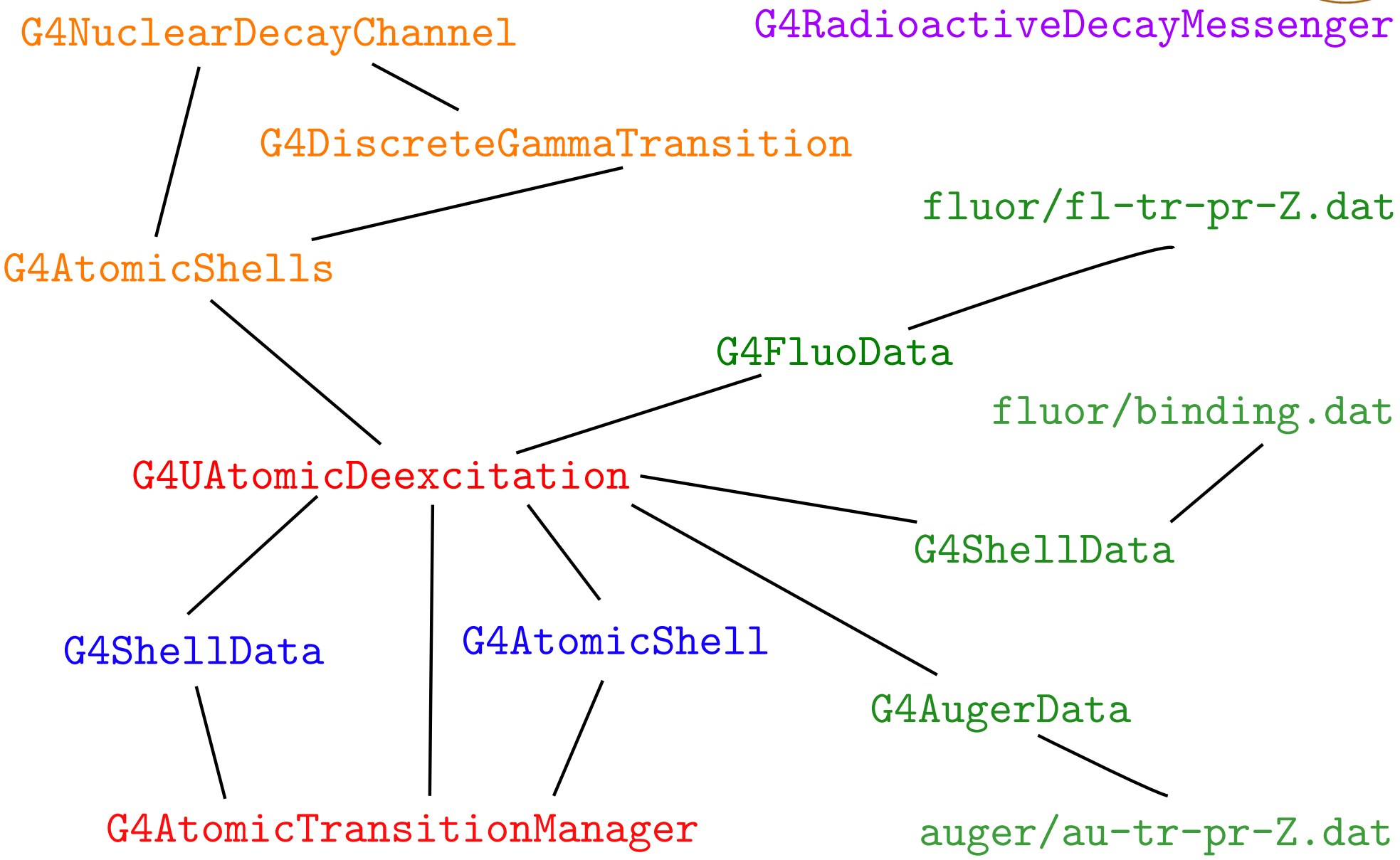
`Geant4` **simulations:** 100000 decays normalized to number of αs

Note: "(1)" only statistical uncertainty of peak fit!

Literature: $E_\alpha = 6278.2(7)$ keV

$E_\gamma = 351.7(5)$ keV

SHE-Geant4

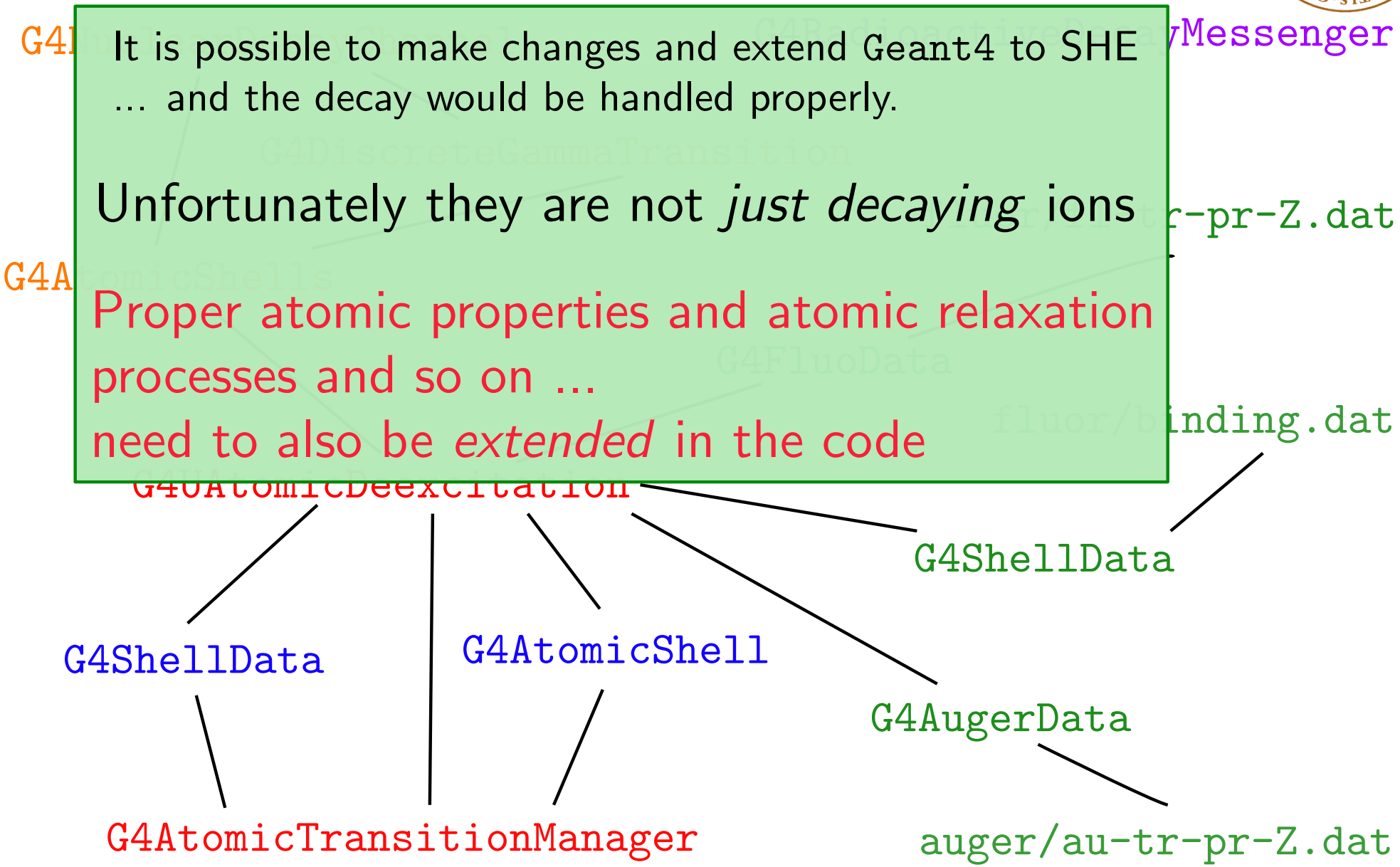

G4NuclearDecayChannel
G4RadioactiveDecayMessenger
G4DiscreteGammaTransition
fluor/fl-tr-pr-Z.dat
G4AtomicShells
G4FluoData
fluor/binding.dat
G4UAtomicDeexcitation
G4ShellData
G4ShellData
G4AtomicShell
G4AugerData
G4AtomicTransitionManager
auger/au-tr-pr-Z.dat

SHE-Geant4

It is possible to make changes and extend Geant4 to SHE
... and the decay would be handled properly.

Unfortunately they are not *just decaying* ions

Proper atomic properties and atomic relaxation processes and so on ...
need to also be *extended* in the code



SHE-Geant4

It is possible to make changes and extend Geant4 to SHE

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Unfortunately they are not *just decaying* ions

Processes and so on

need to also be extended in the code

Solution: **disguise our $Z > 100$ as $Z < 100$ to the eyes of** `Geant4`.
i.e. **E115 → E99**.

The decay results are valid provided:

- proper atomic binding energies
- proper X-ray energies and transition probabilities
- proper Auger energies and transition probabilities

The decay level schemes are defined by:

- Q-values
- Branching ratios
- Electromagnetic properties of the decay

Quantities such as implantation depth and recoil energy will be *slightly* wrong but they **do not compromise** the method.

SHE-Geant4

It is possible to make changes and extend Geant4 to SHE

...

Unfortunately they are not *just decaying* ions

Properties of the decay

processes and so on

need to also be provided

The decay level

- Q-values
- Branching r
- Electromagn

Quantities such as implantation depth and recoil energy will be *slightly* wrong b

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CALCULATION OF K, L, M AND N BINDING ENERGIES AND K X-RAYS FOR ELEMENTS FROM Z = 96-120

THOMAS A. CARLSON, C. W. NESTOR, Jr., F. B. MALIK † and THOMAS C. TUCKER
Oak Ridge National Laboratory, Oak Ridge, Tennessee ††

Received 13 June 1969

T.A. Carlsson et al., NP A 135, 57 (1969)

+ extrapolation of fluorescence and Auger data already available in Geant4 from Z=95-100.

SHE-Geant4

It is possible to make changes and extend Geant4 to SHE

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Solution: **disguise our $Z > 100$ as $Z < 100$ to the eyes of Geant4.**

Actual solution: Modify the Geant4 source code

T.A. Carlsson et al., NP A 135, 57 (1969)

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SHE-Geant4

It is possible to make changes and extend Geant4 to SHE

...

Solution: **disguise our $Z > 100$ as $Z < 100$ to the eyes of Geant4.**

Actual solution: Modify the Geant4 source code

- Nov. 2013: Appointed by the TASCA collaboration
- Apr. 2014: Contact with the Geant4 developers
- Jul. 2014: Accepted as a Geant4 developer
- Aug. 2014: Proton decay included in Geant4
  although not in the RadioactiveDecay database -yet-
- Nov. 2014: Improvements and bugfixes, SHE and not-SHE related.

Quantities such as implantation depth and recoil energy will be *slightly* wrong b

T.A. Carlsson et al., NP A 135, 57 (1969)

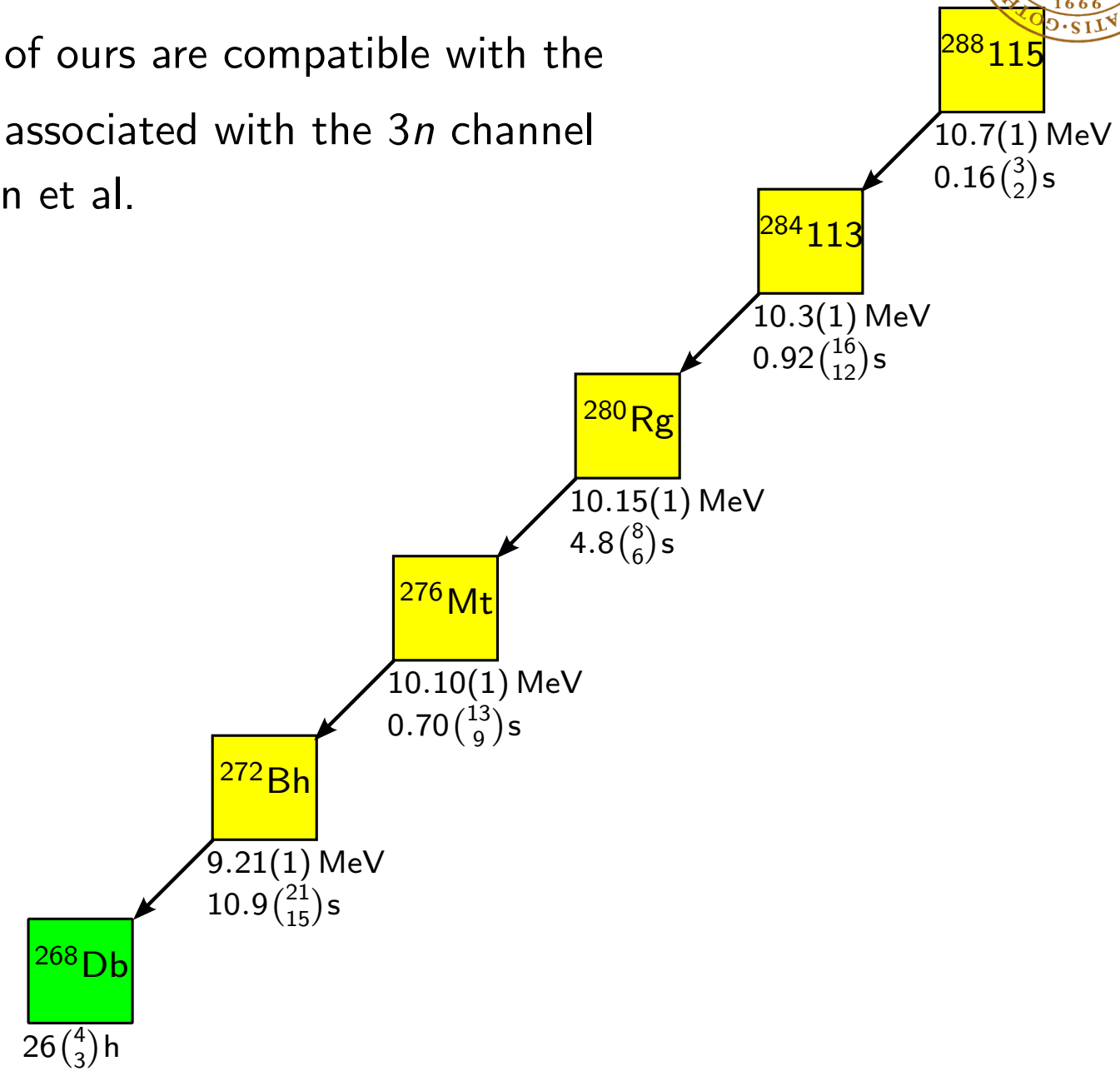
+ extrapolation of fluorescence and Auger data already available in Geant4 from Z=95-100.

Results (3n-chain)

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.



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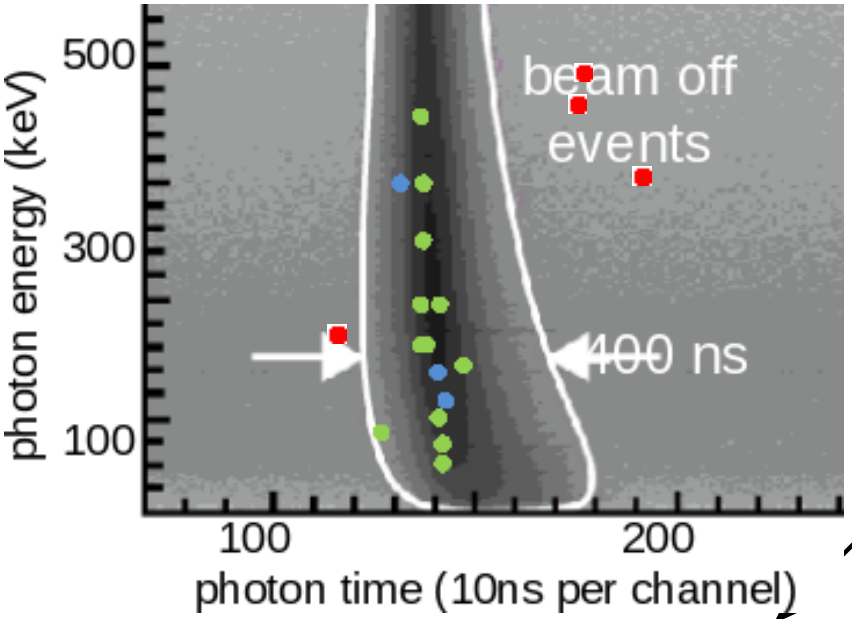
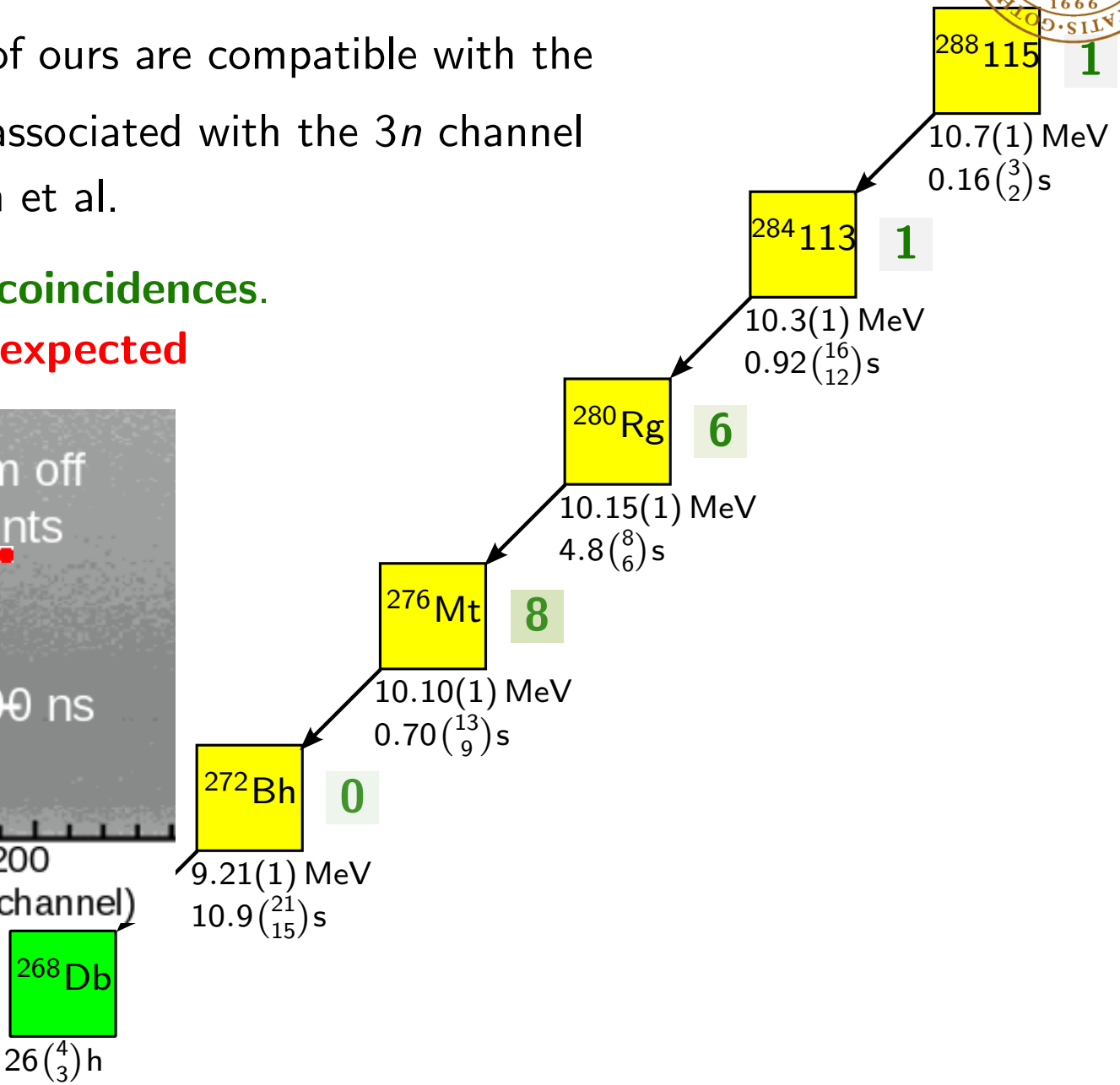
16 prompt α-photon coincidences.

2-3 of random origin expected





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22 chains (out of 30) of ours are compatible with the

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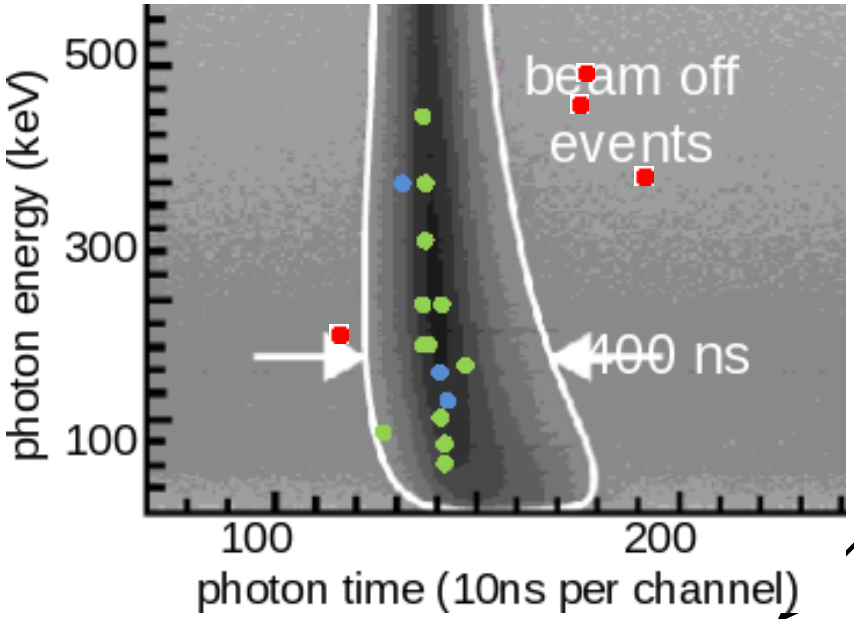

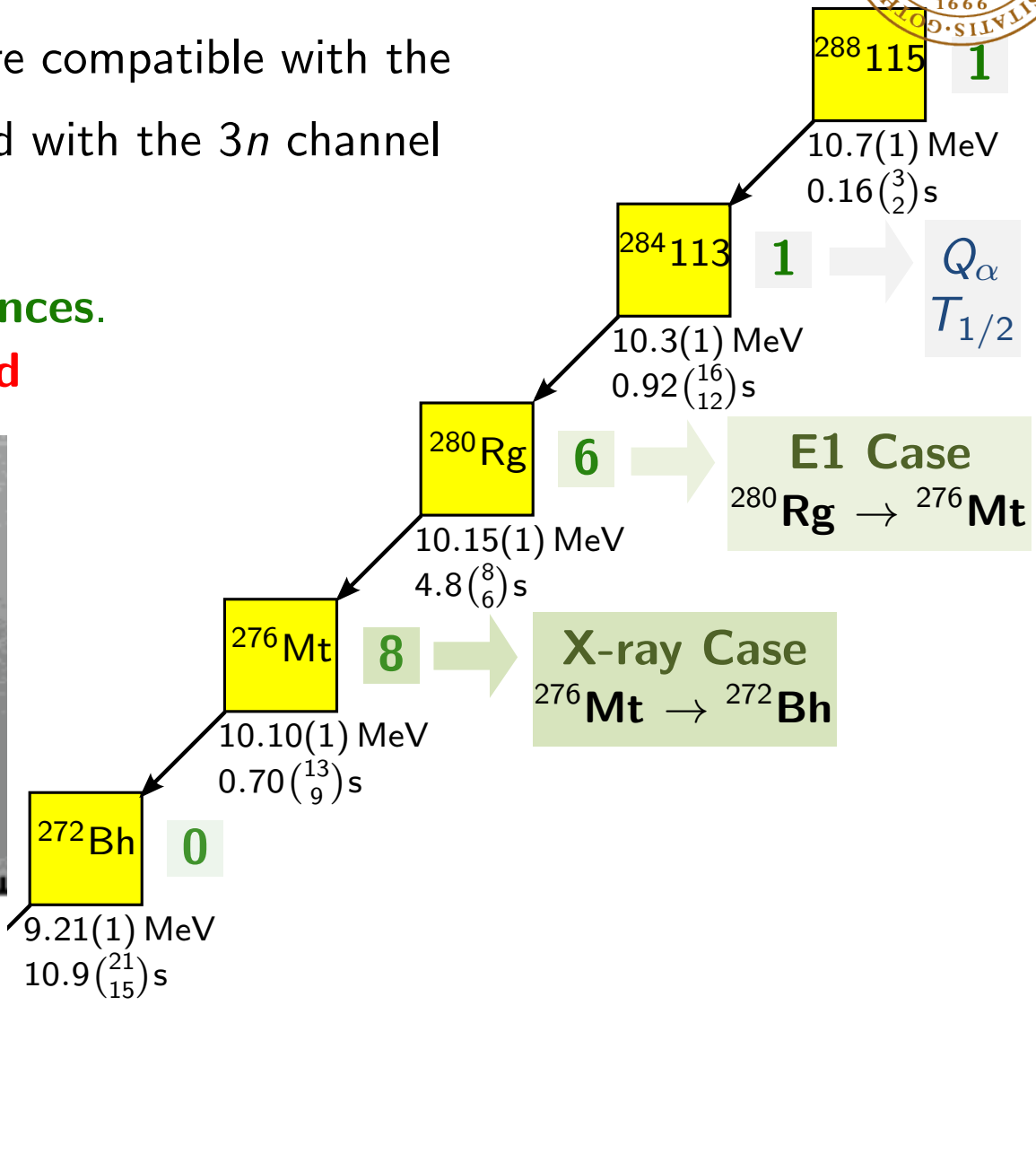

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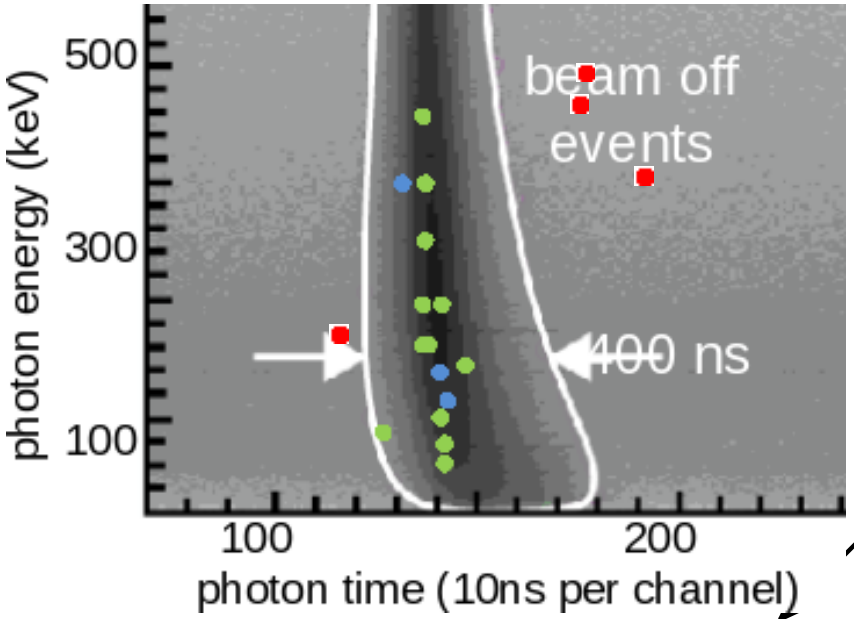
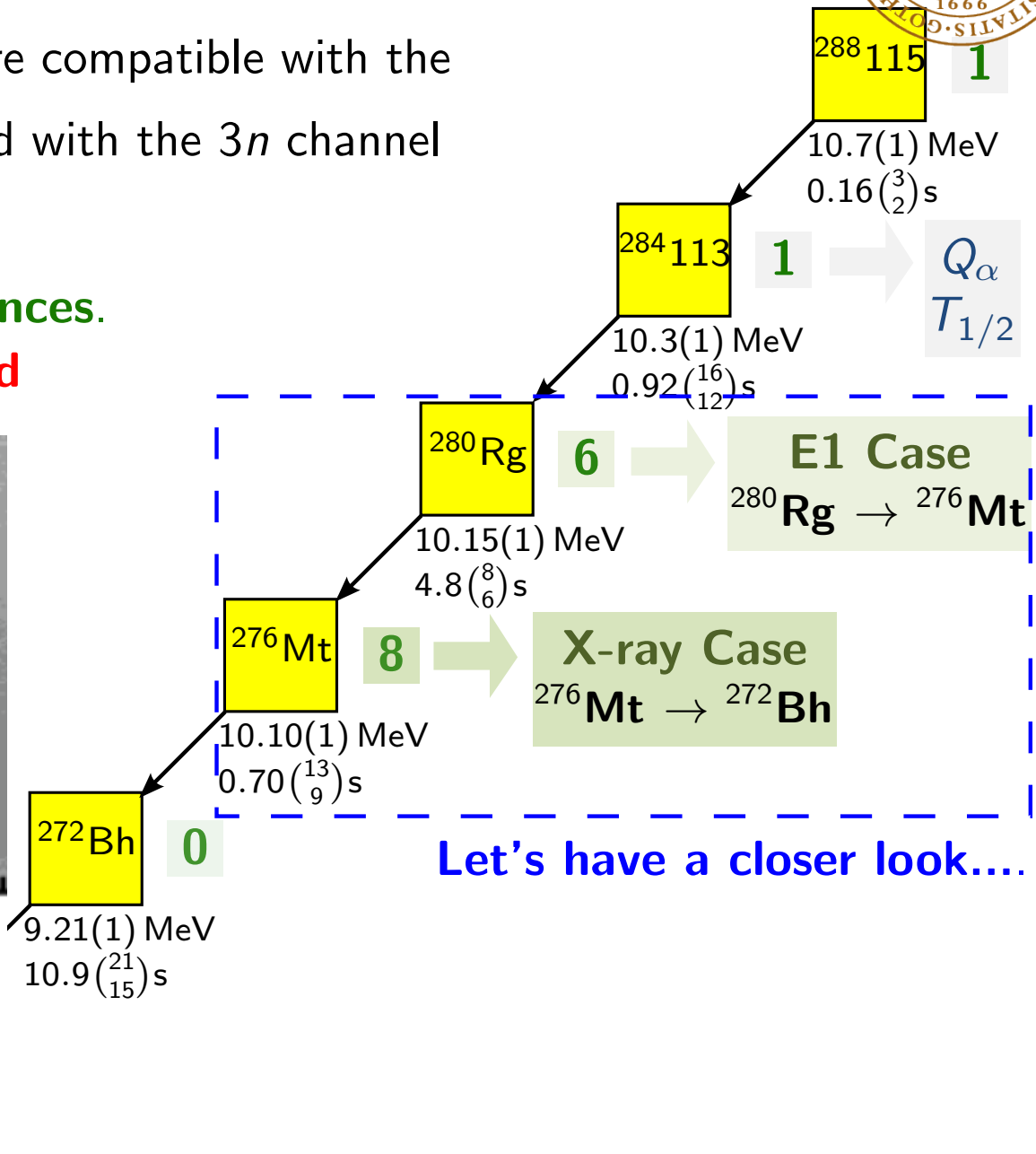


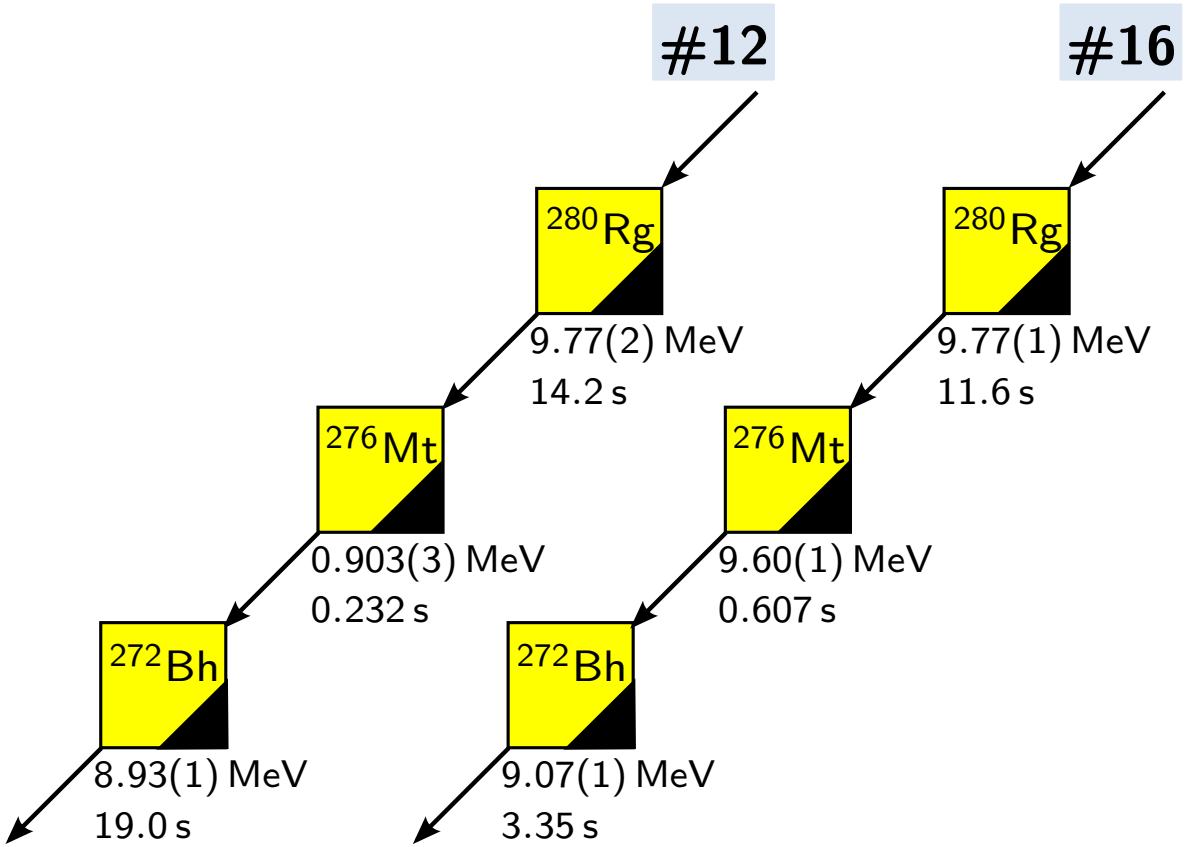


Let's have a closer look....

Results (3n-chain)

X-ray Case
^{276}Mt $\rightarrow$ ^{272}Bh

$8 \times \alpha$-photon coincidences



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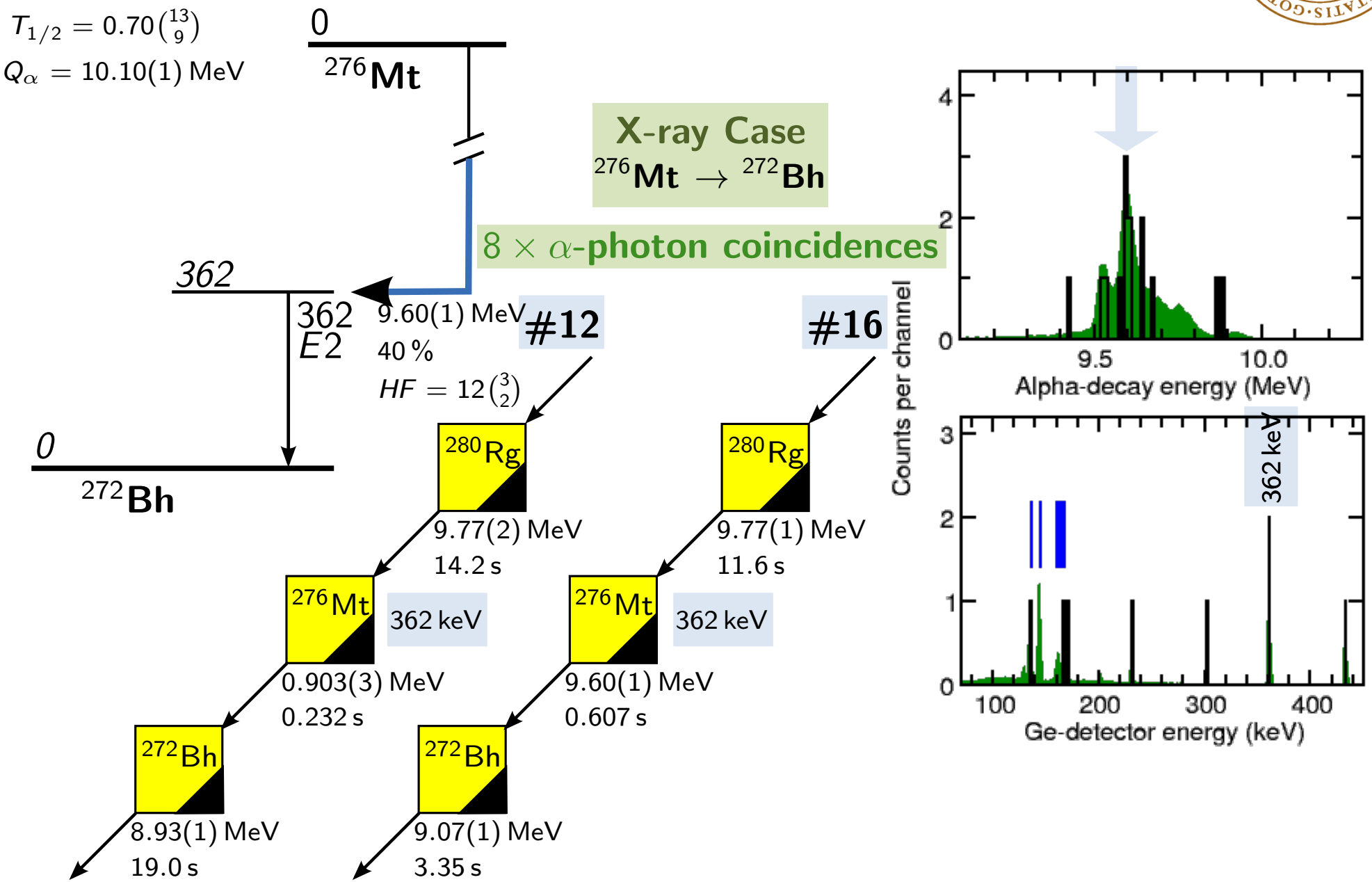

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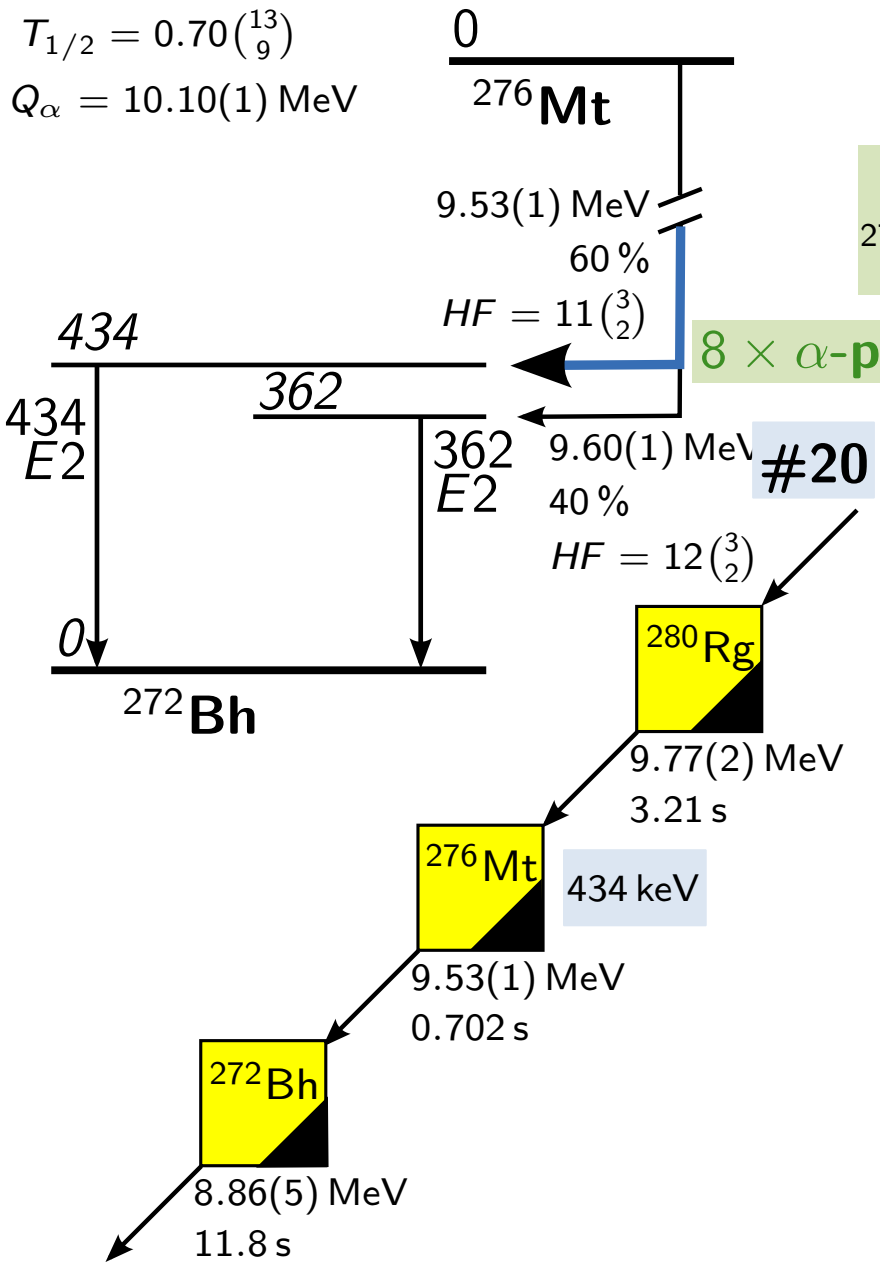

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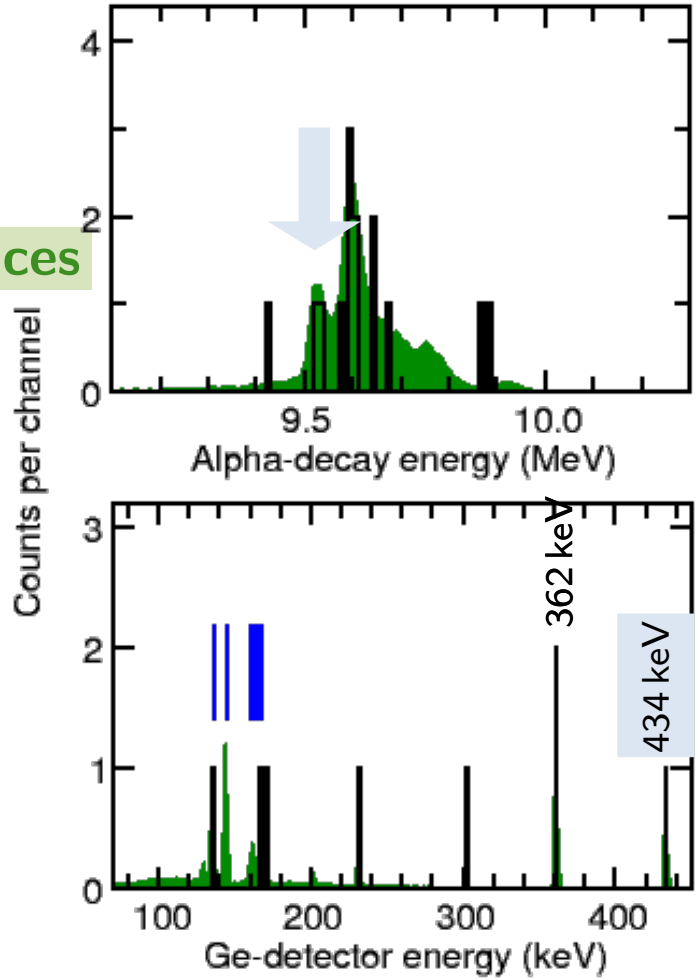

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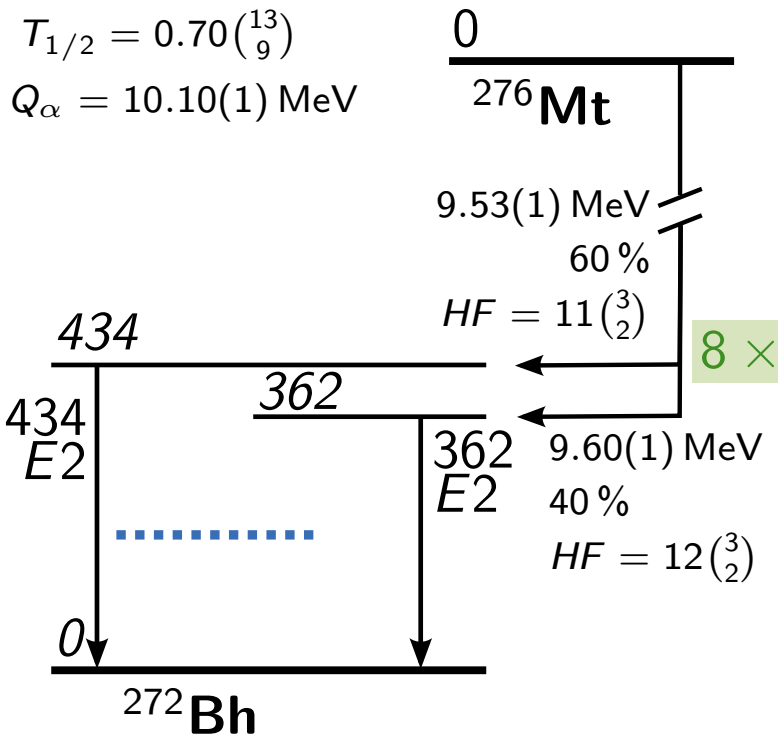

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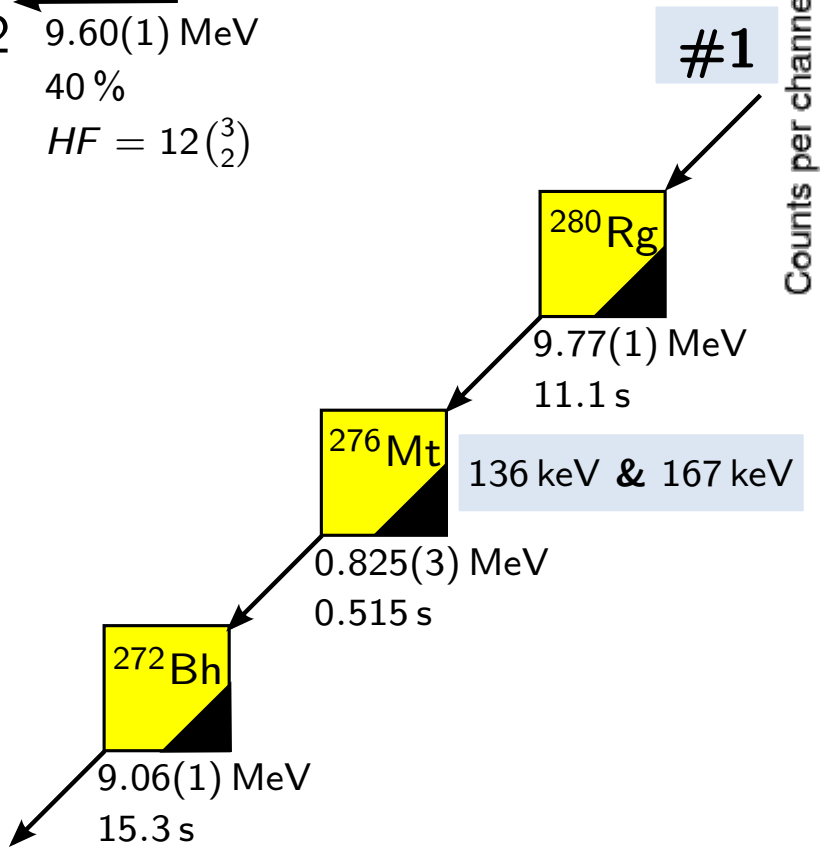

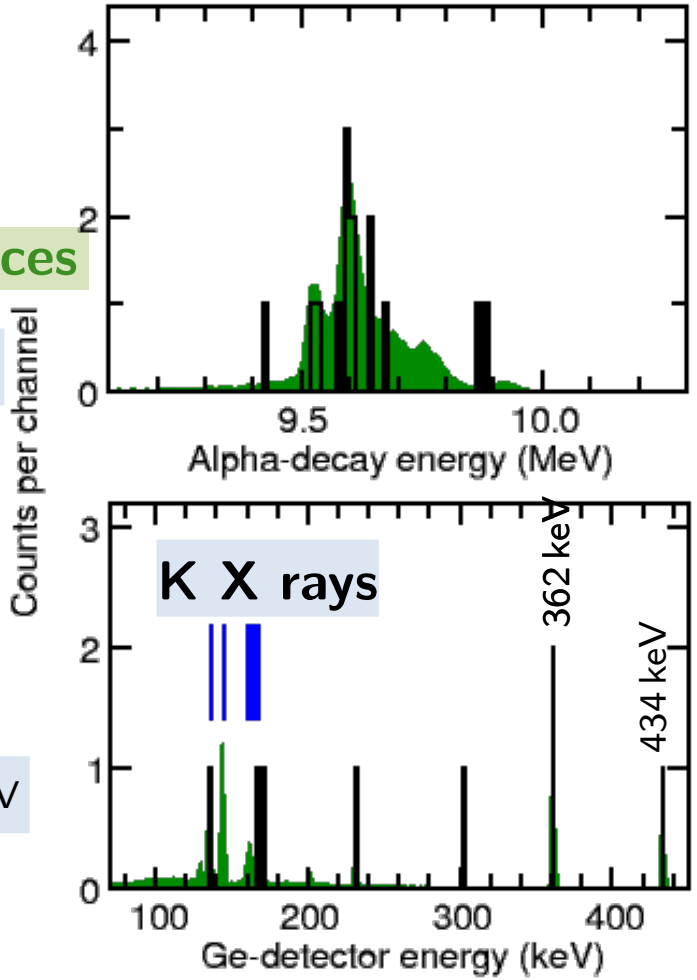

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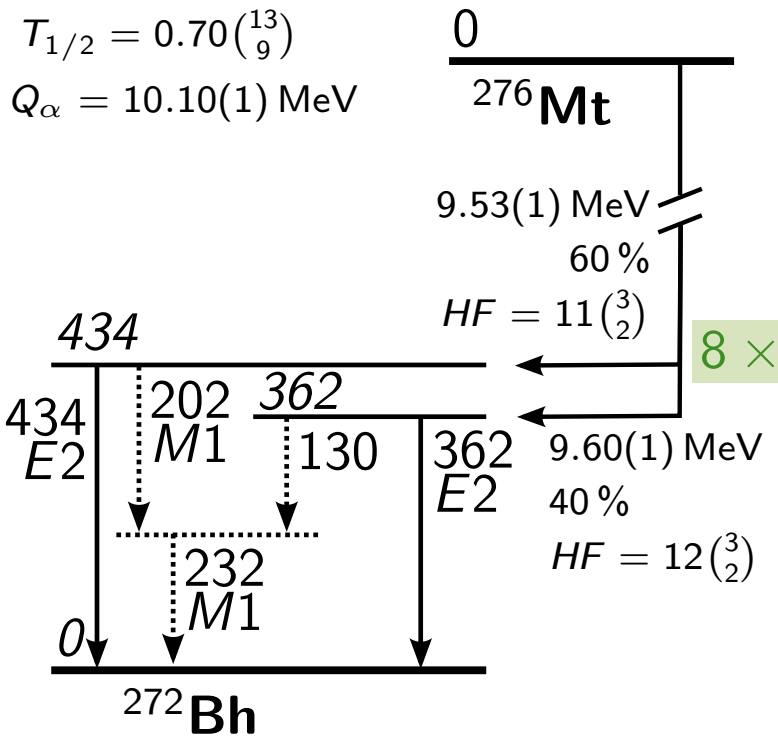

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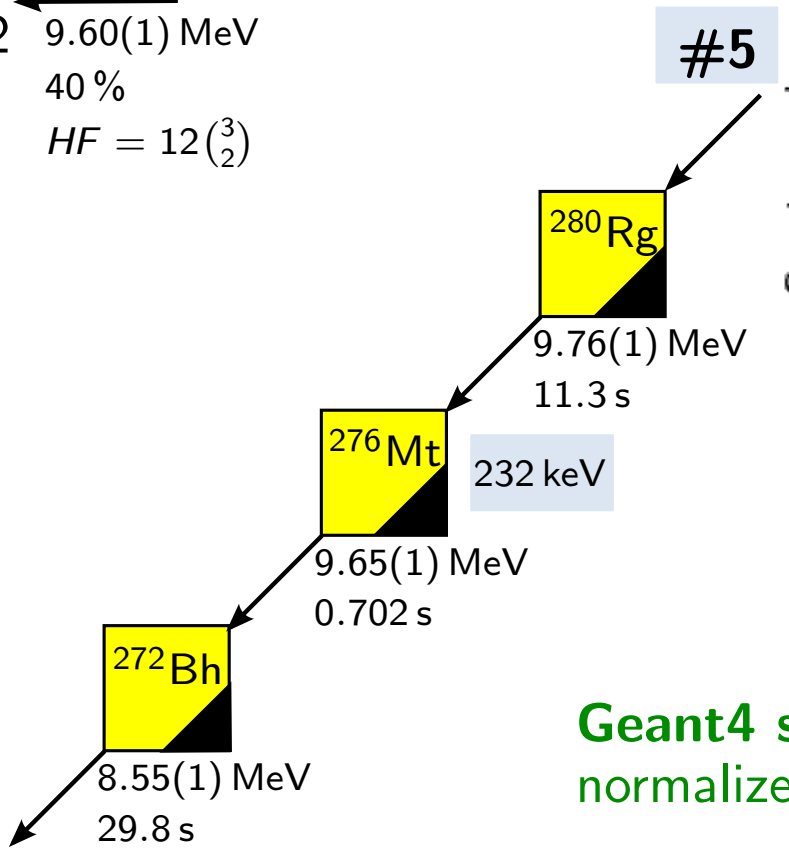

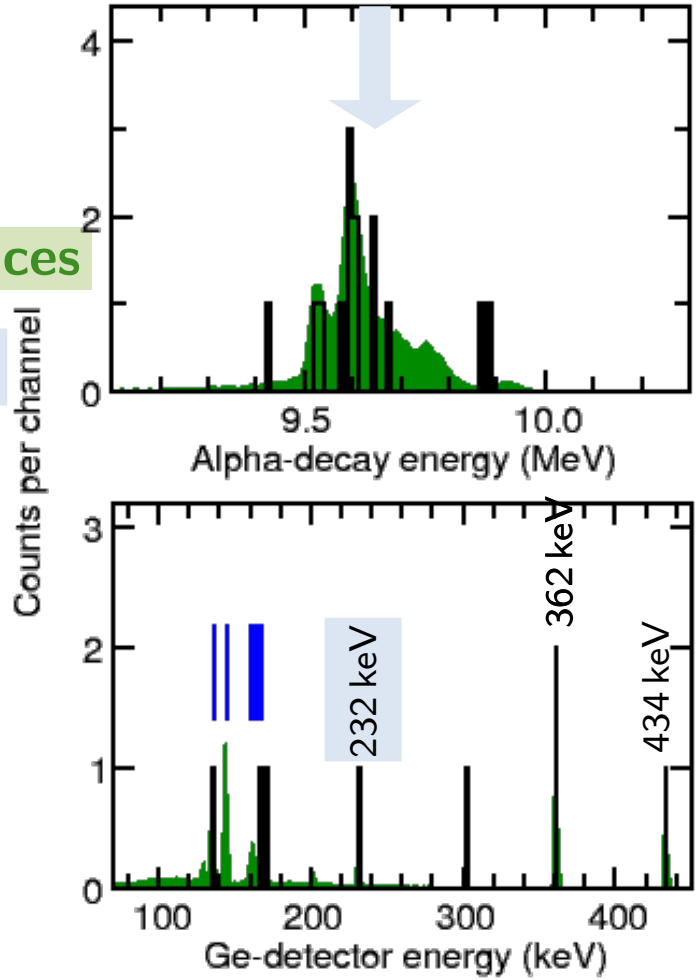

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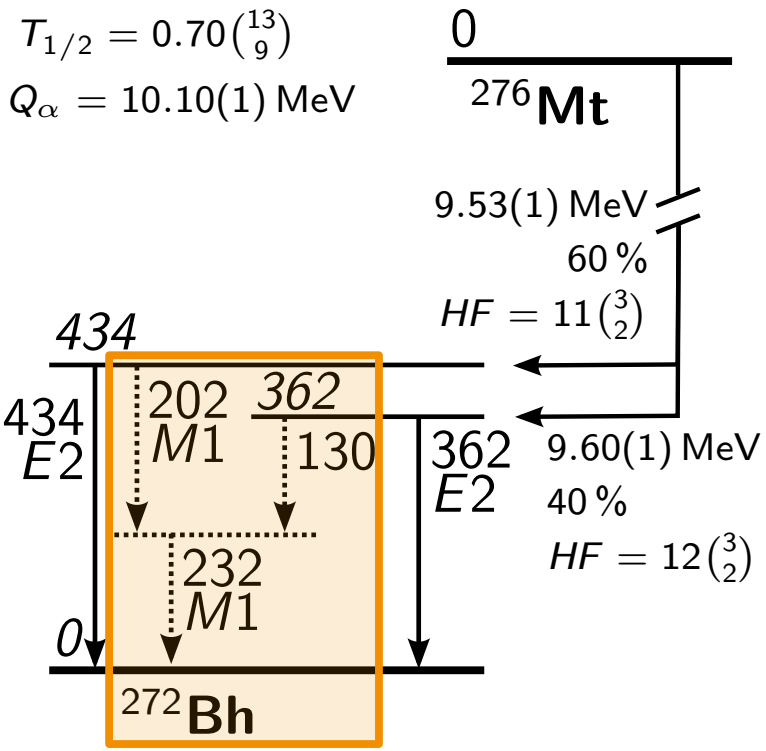
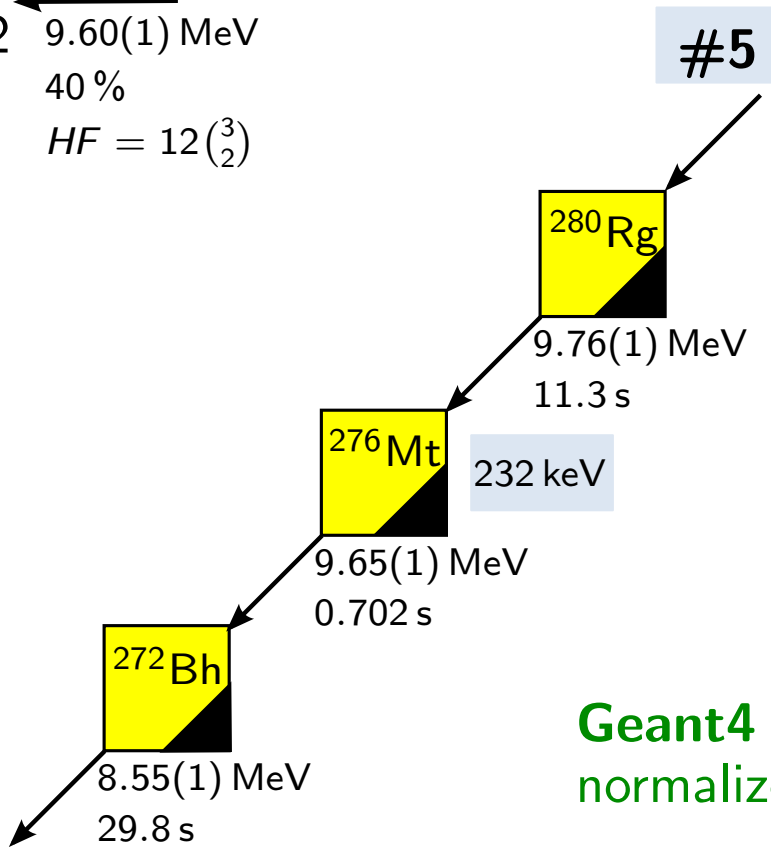
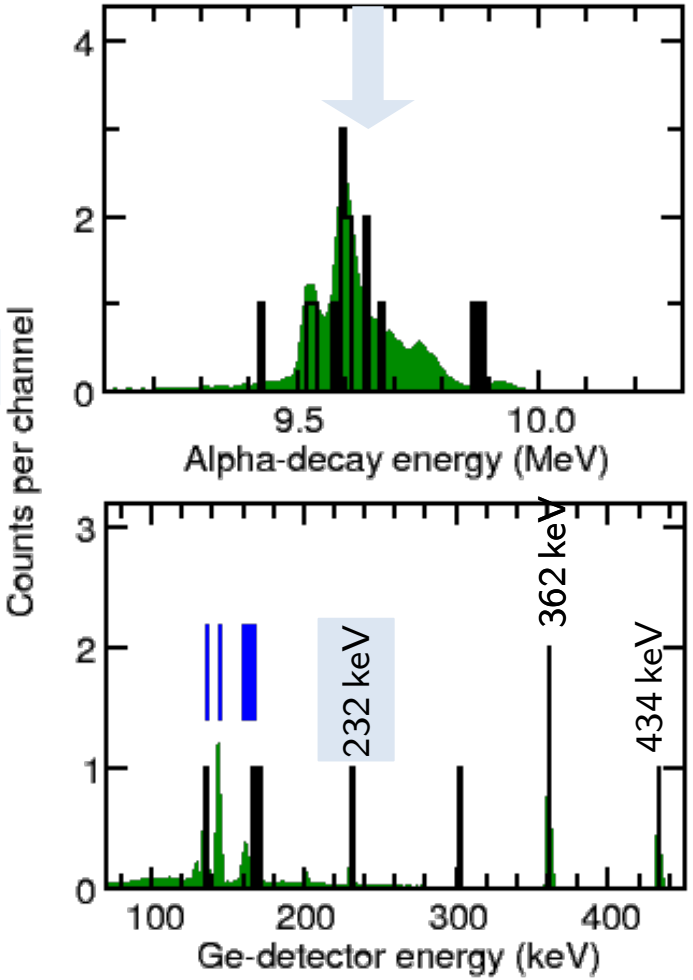


Tentative!





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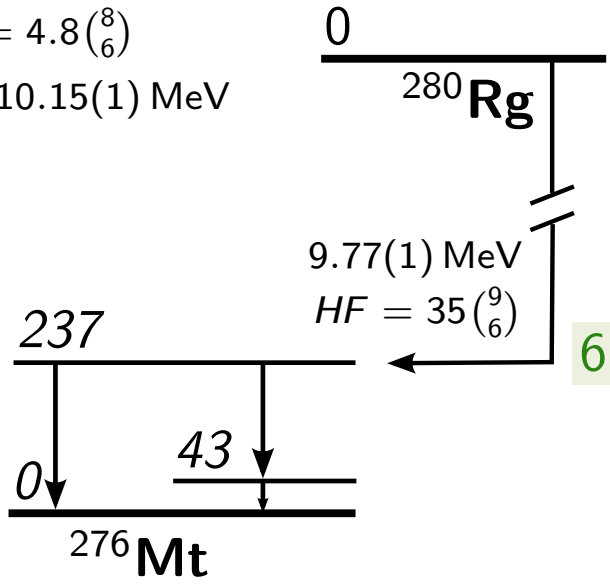

E1 Case

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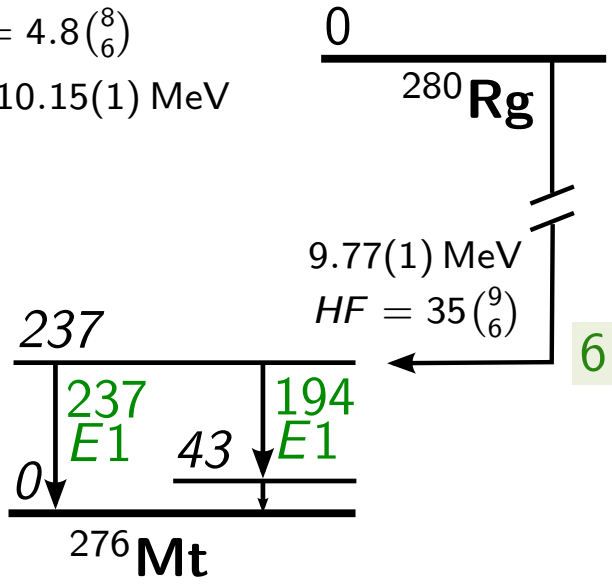

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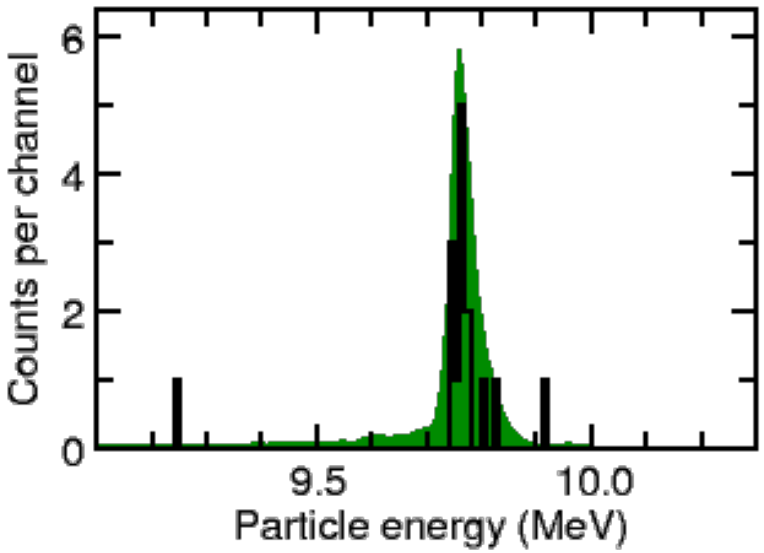

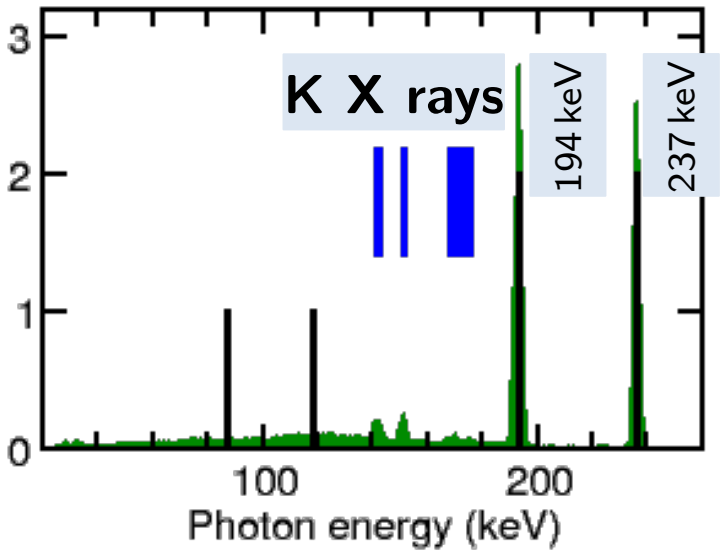

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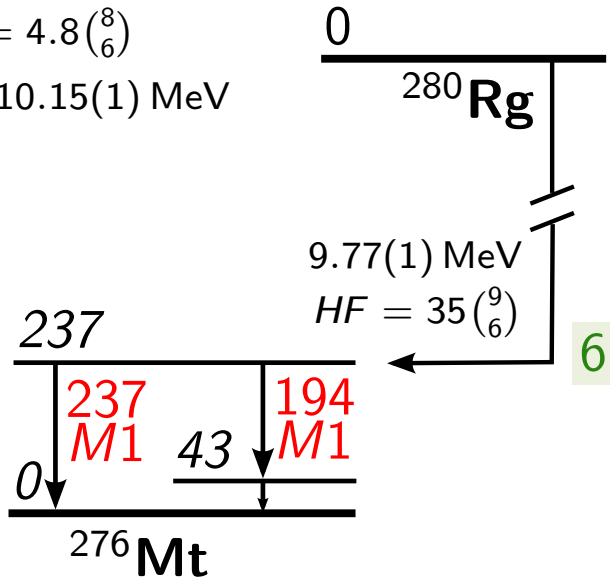

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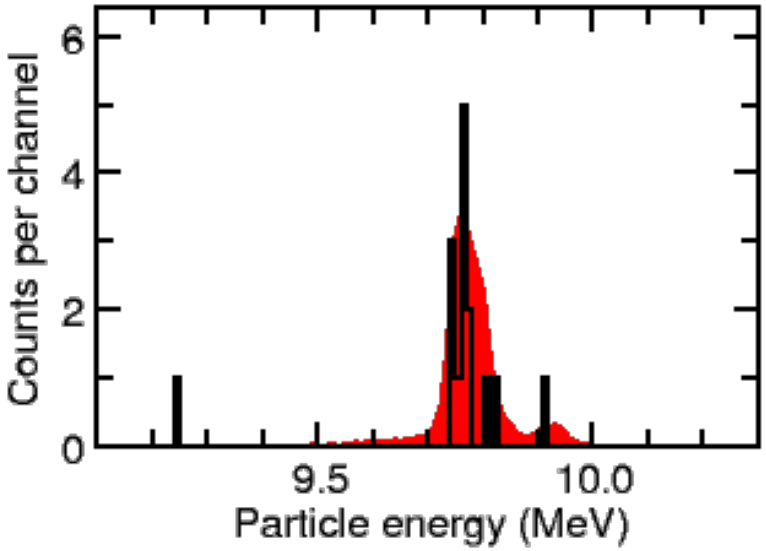

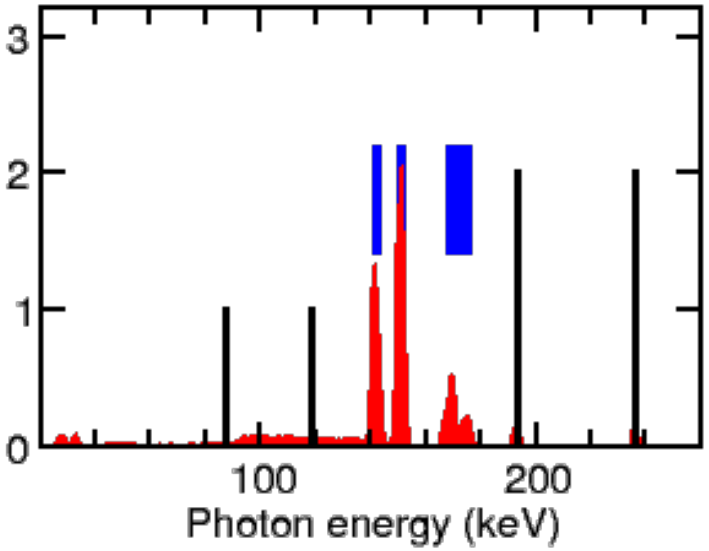

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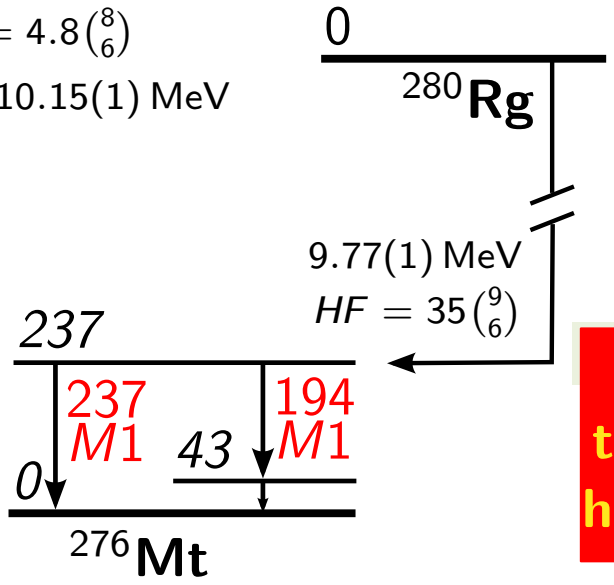

M1 Case

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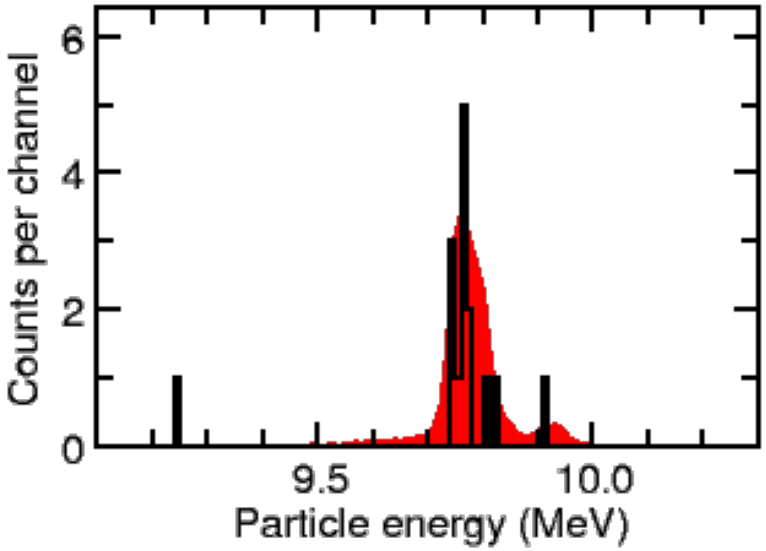
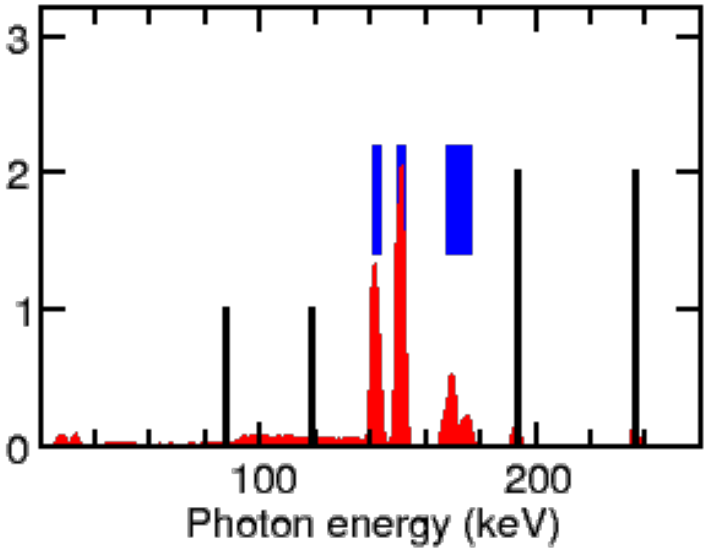
IF Mother Nature had provided these transitions as $M1$ transitions, this would have been THE perfect fingerprinting case!





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Results 30 decay chains compatible with previous reports.
Two X-ray **candidates** compatible with E115.

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Analysis Add a new level of confidence by self-consistent cross checks via **Virtual Geant4 experiments**.
Although Geant4 is not ready for SHE-studies out-of-the-box it is possible to **produce reliable simulations** from it.

The TASCA/TASISPEC Collaboration

PRL **111,** 112502 (2013) PHYSICAL REVIEW LETTERS week ending 13 SEPTEMBER 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]

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[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*

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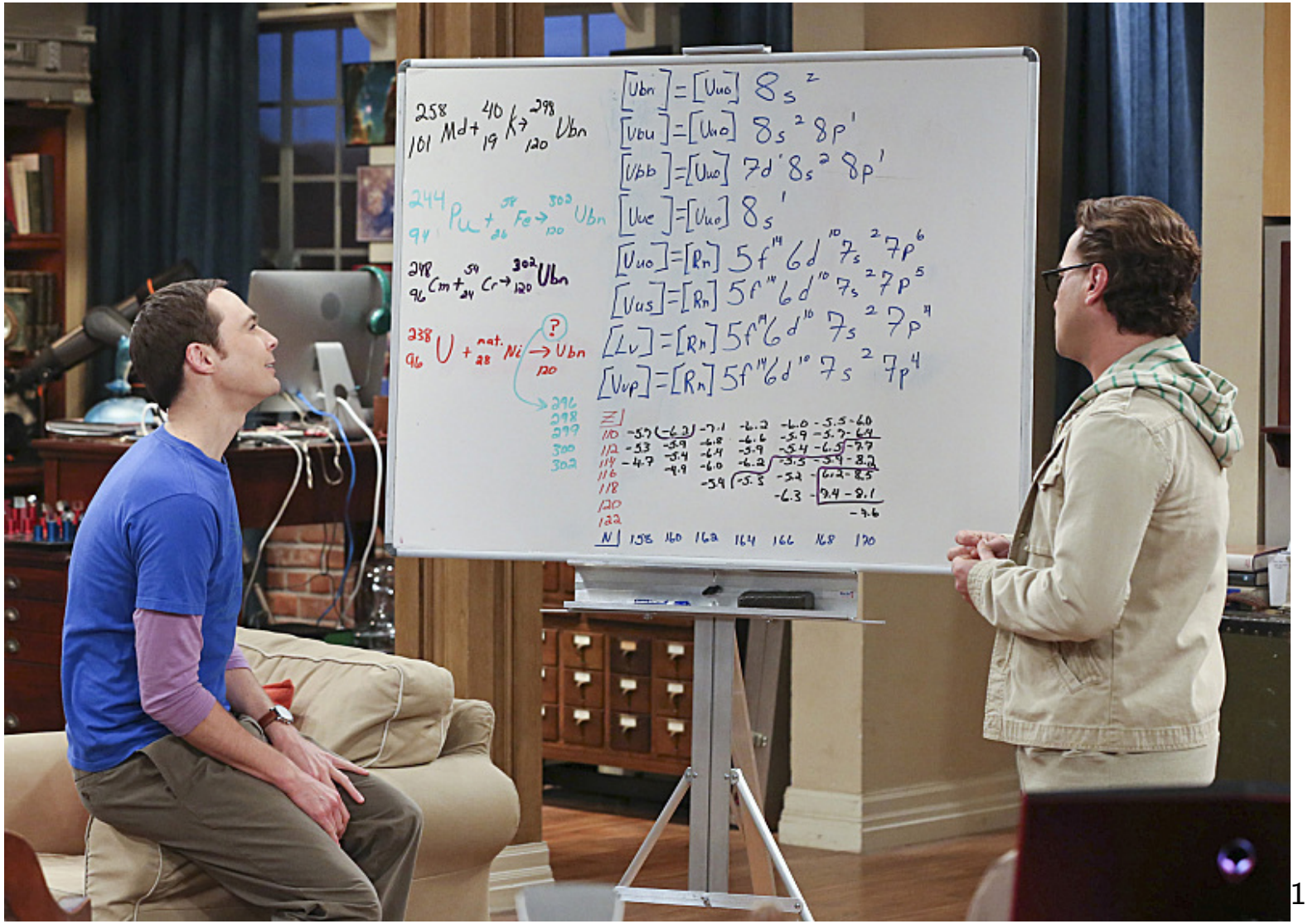
Special thanks to

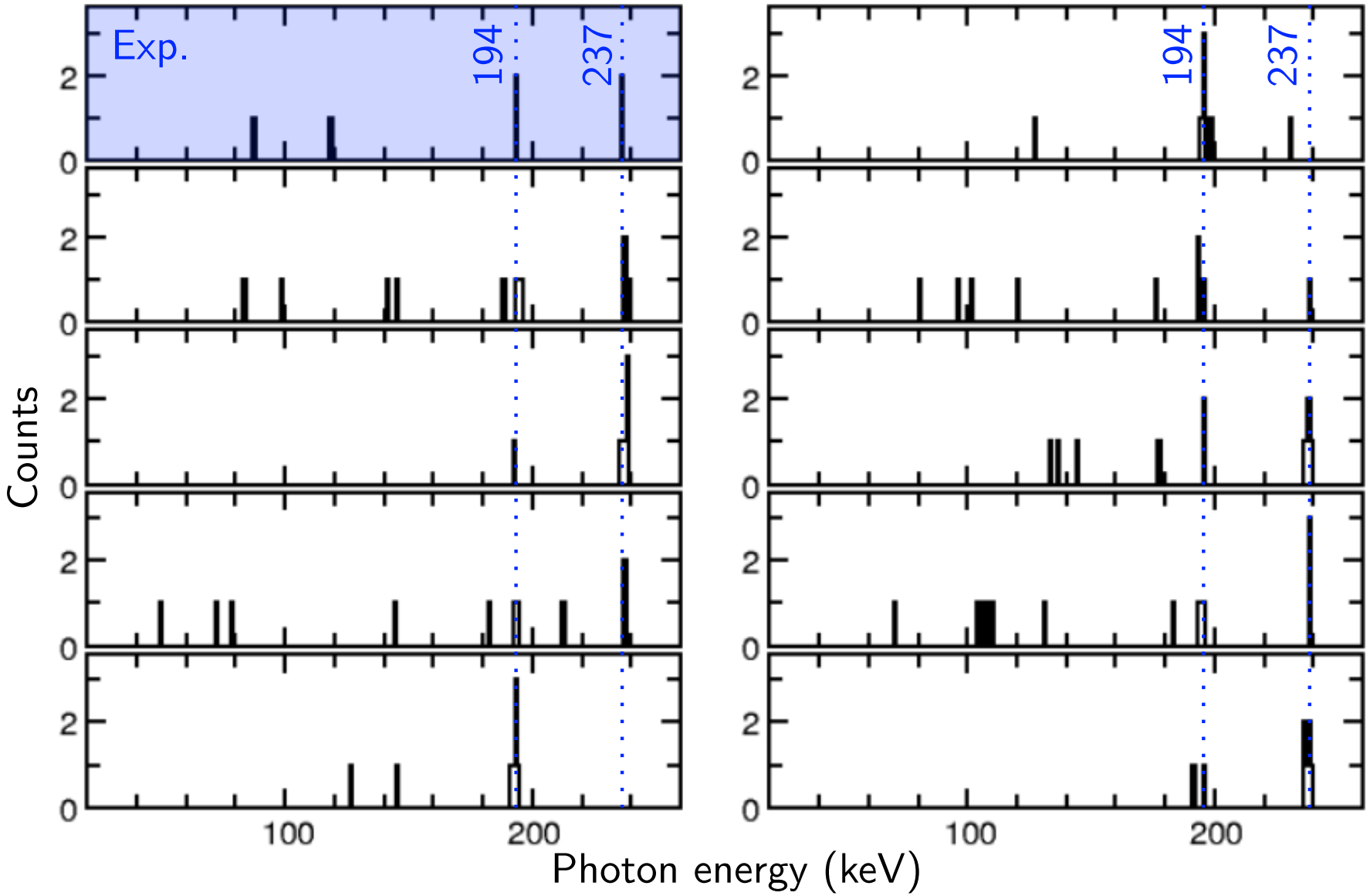
THANK YOU
for your attention



[1]

[1] Photo by Michael Yarish – © 2013 WBEI. All rights reserved.

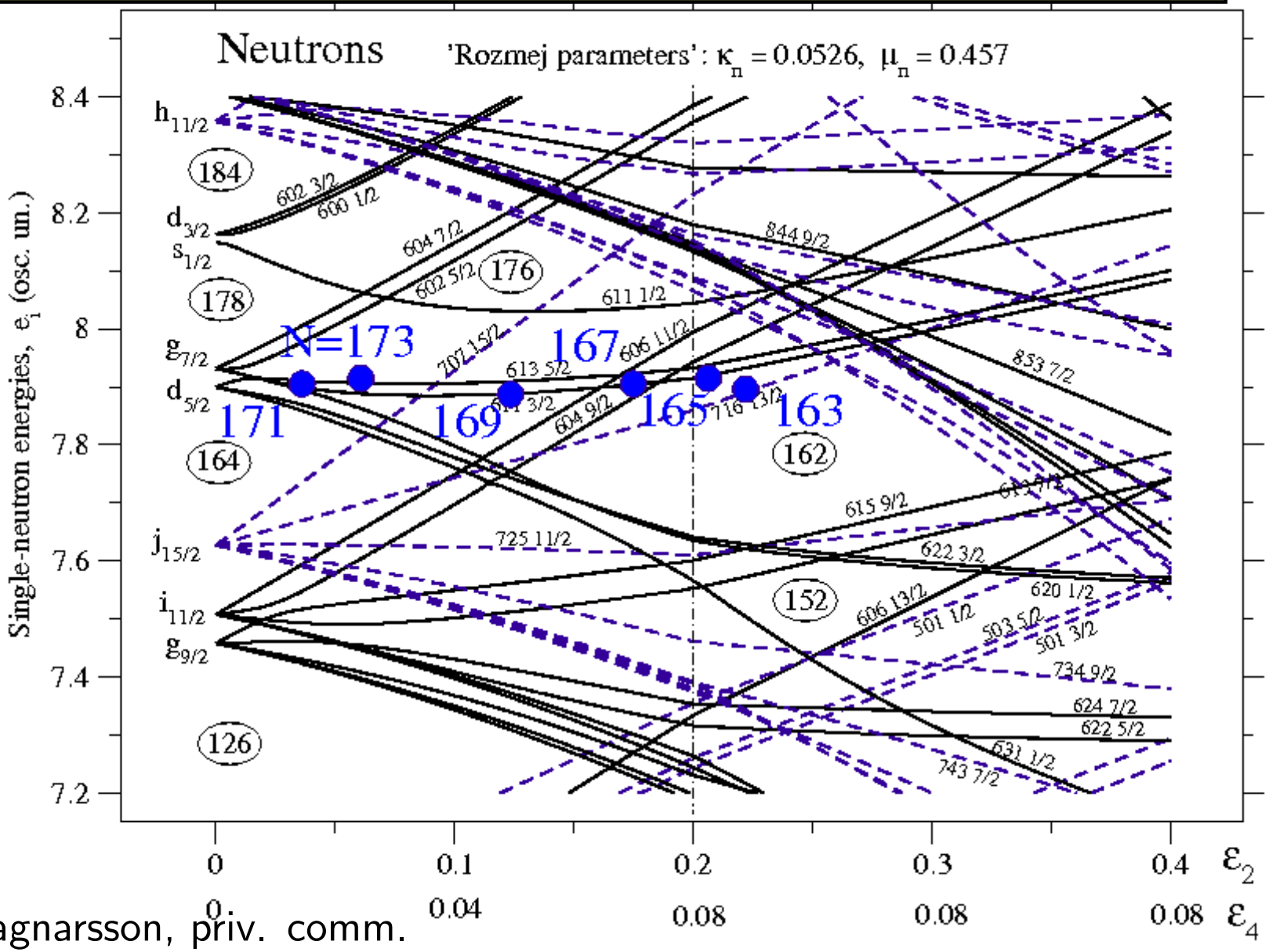
Low-statistics simulations: ^{276}Mt



Geant4 simulations: 9x22 decays

Nilsson single-particle diagrams

parity-changing $\Delta\ell = 1$ single-particle orbitals are required at $\beta_2 = 0.2$



I. Ragnarsson, priv. comm.

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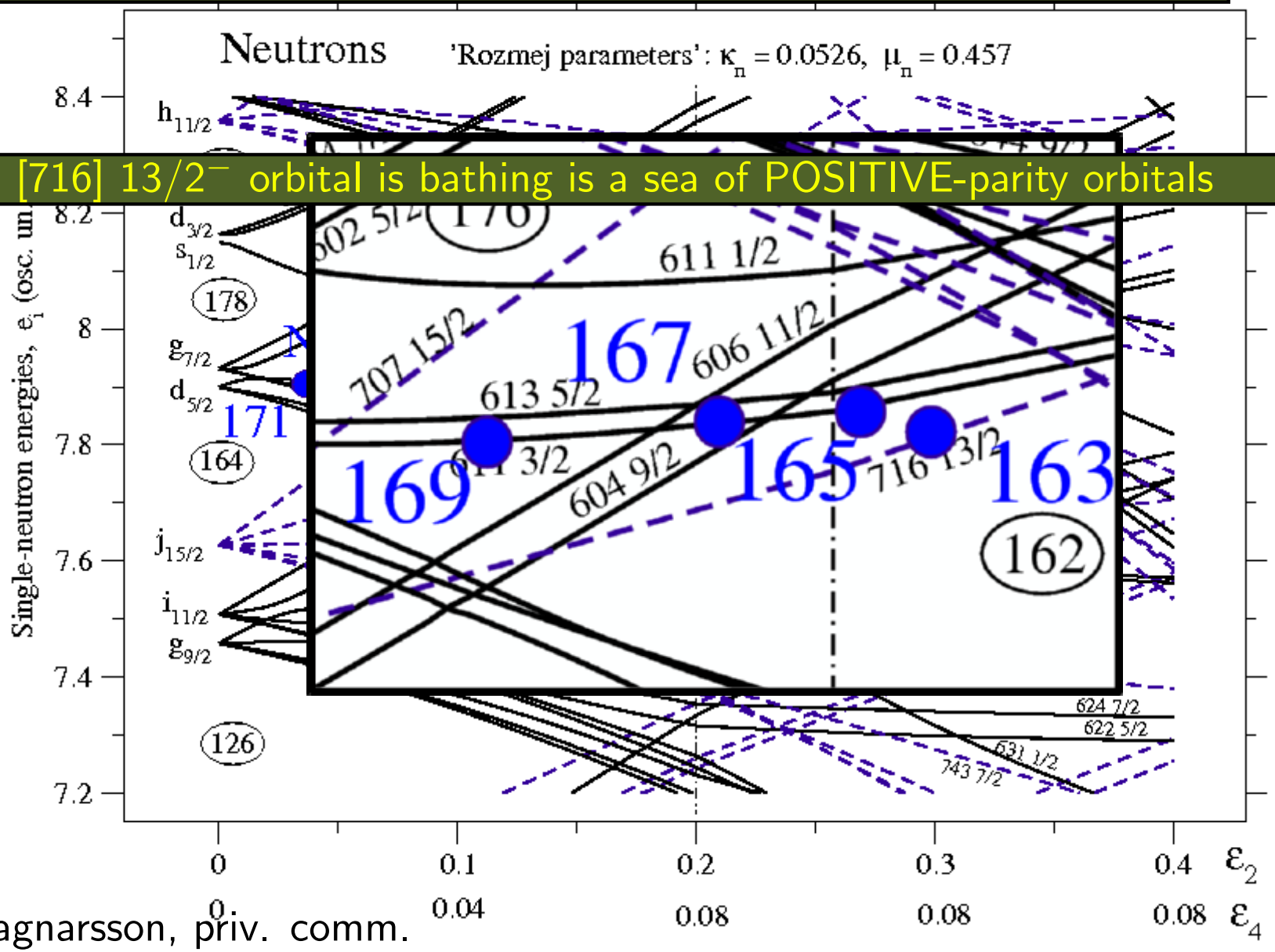
The [716] $13/2^-$ orbital is bathing is a sea of POSITIVE-parity orbitals



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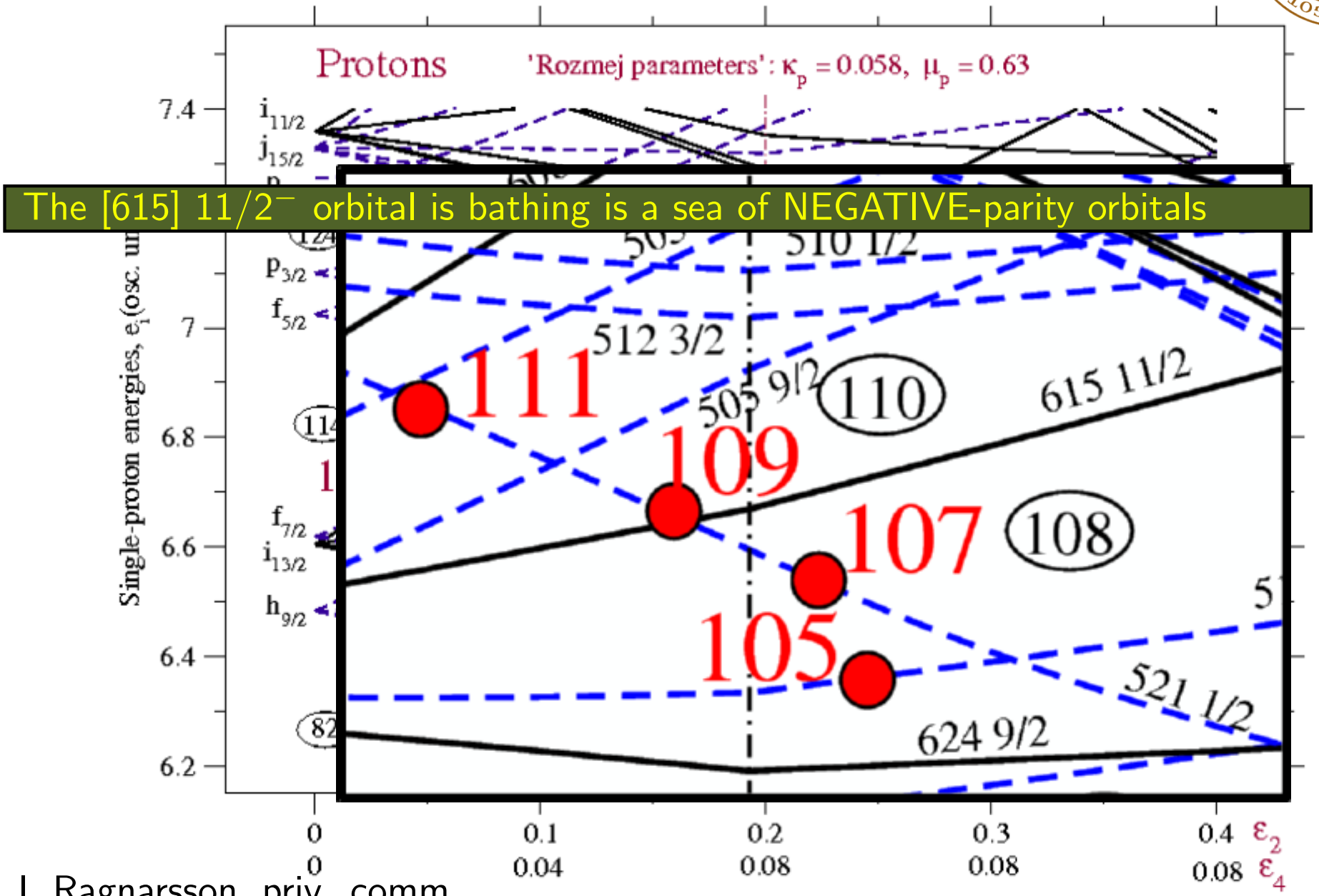

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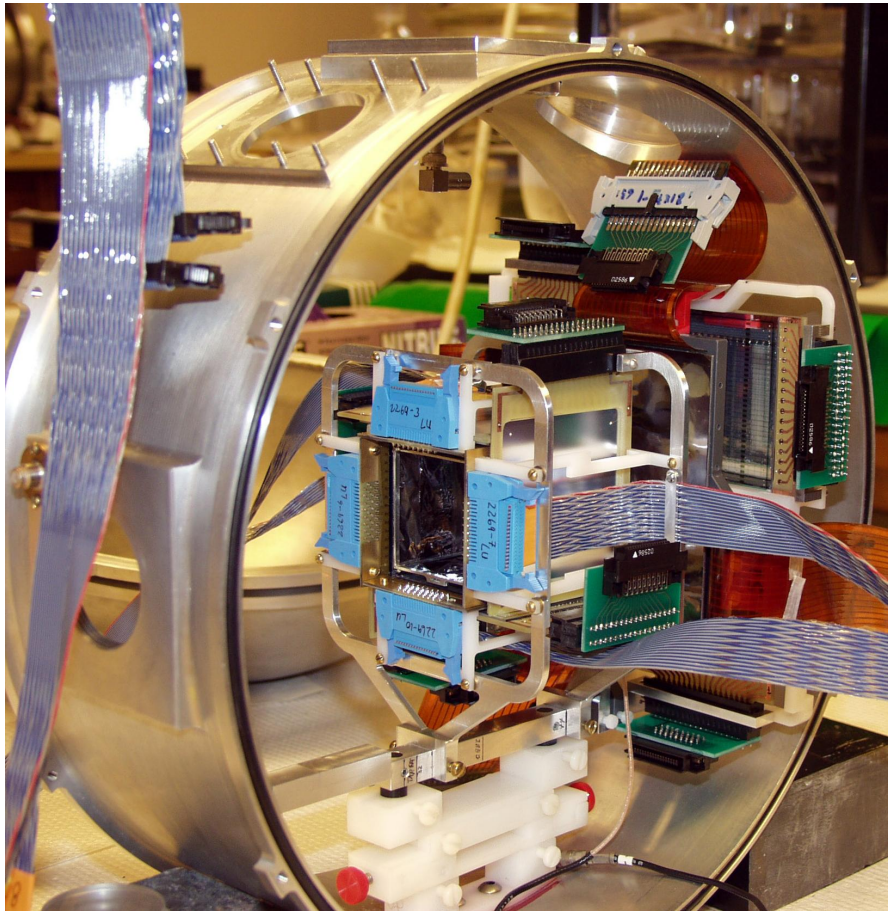
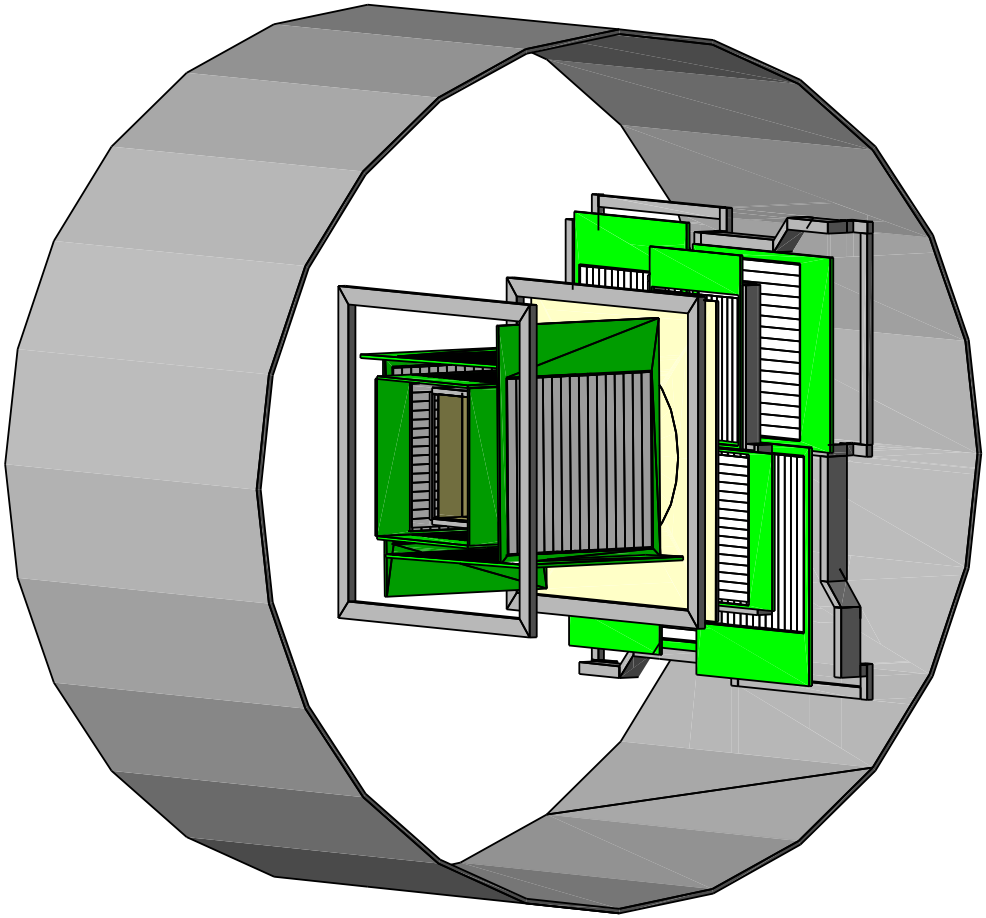
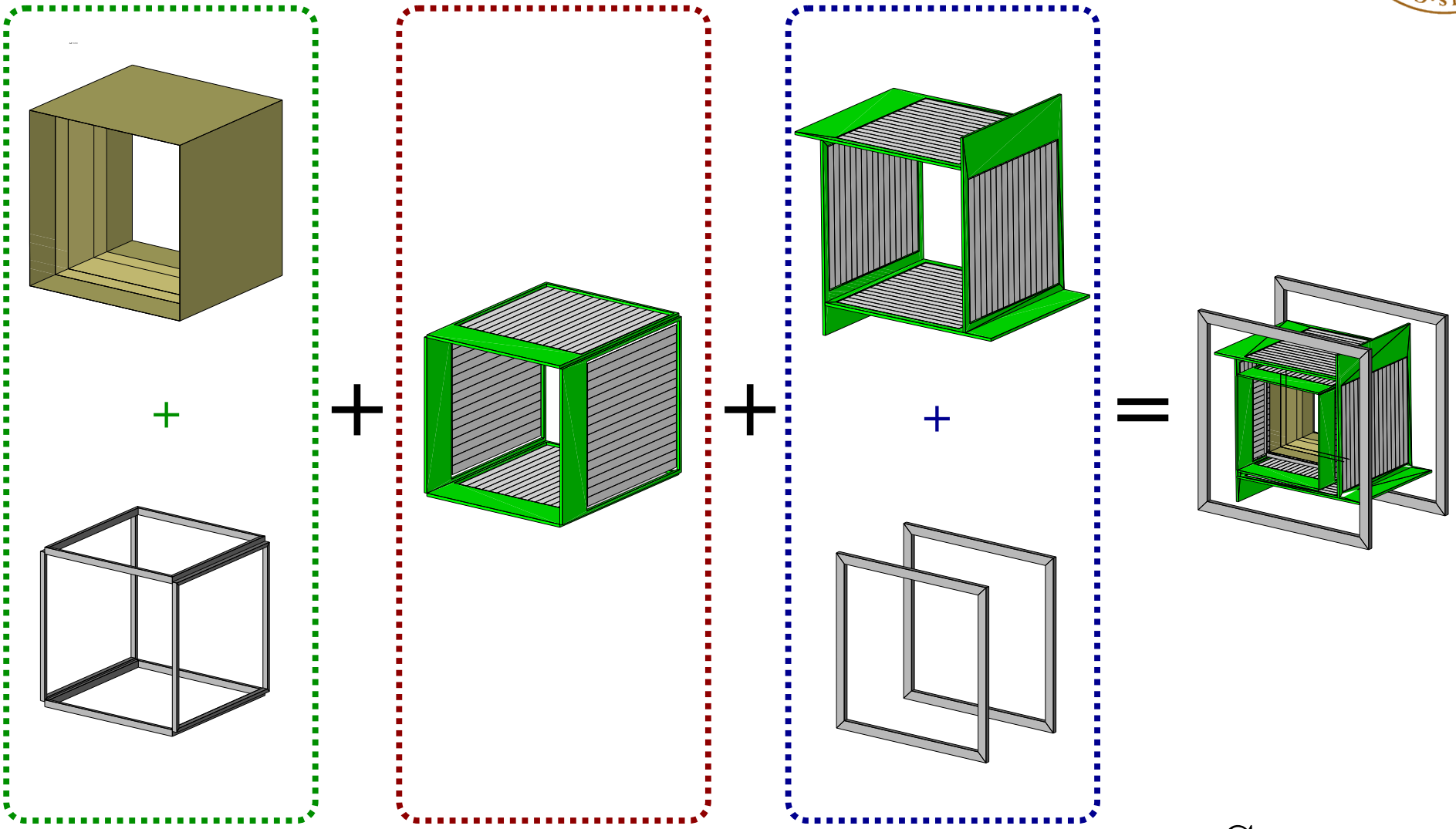
The LuWuSiA setup





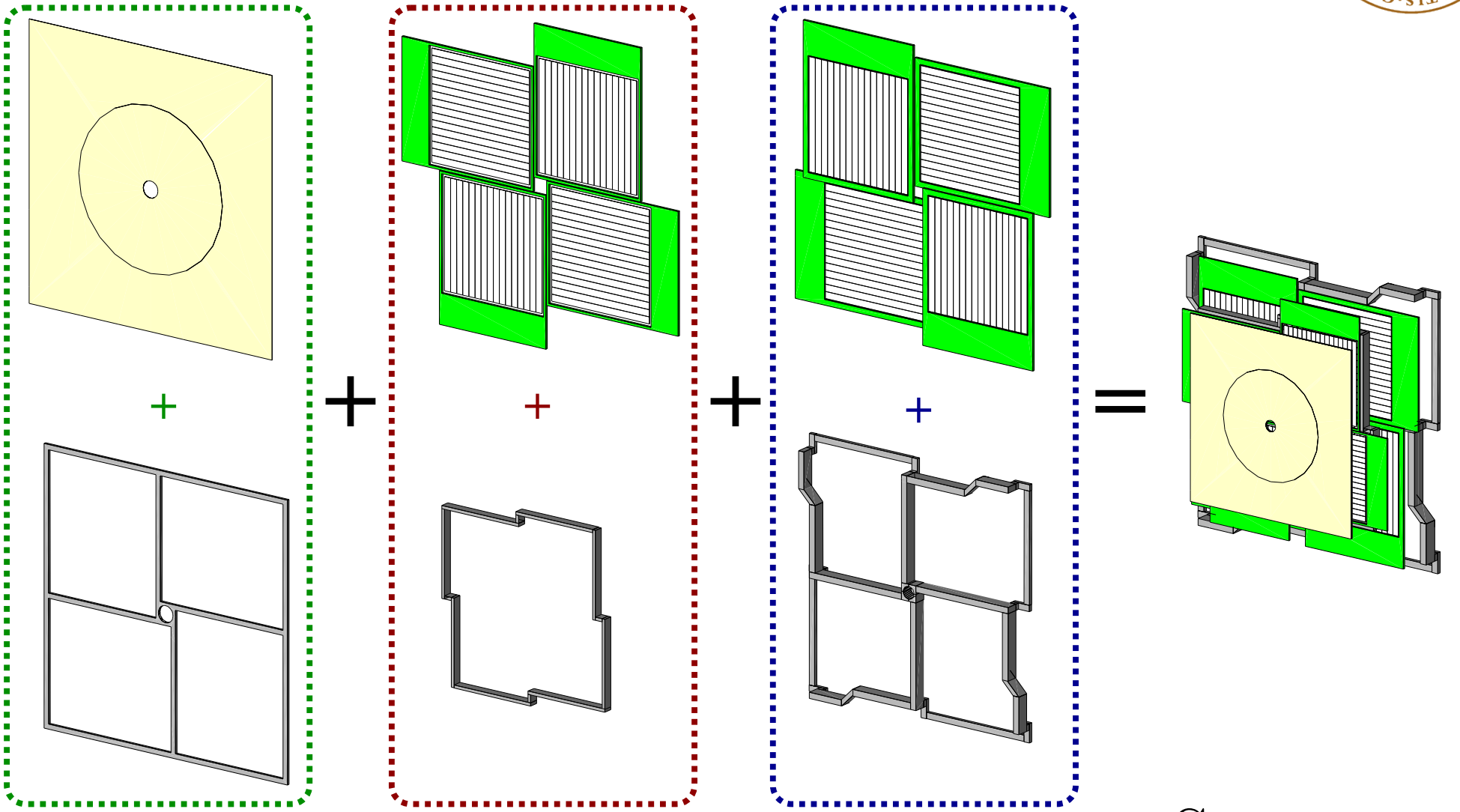
The LuWuSiA detector in real and virtual life

The Silicon Box



Absorbers + ΔE SSSSD + E SSSSD = Silicon Box

The Silicon Wall



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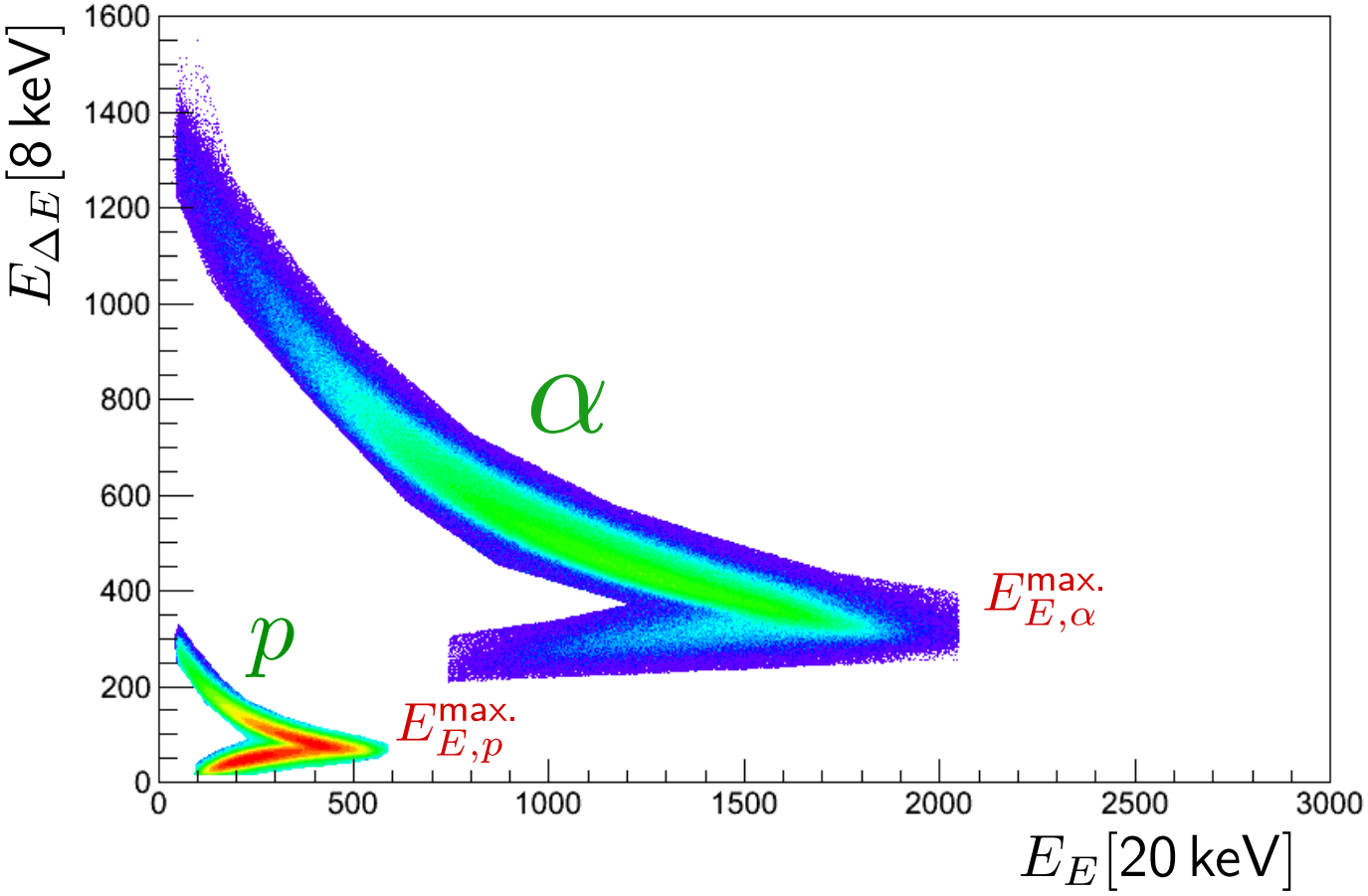
Detector punchthrough



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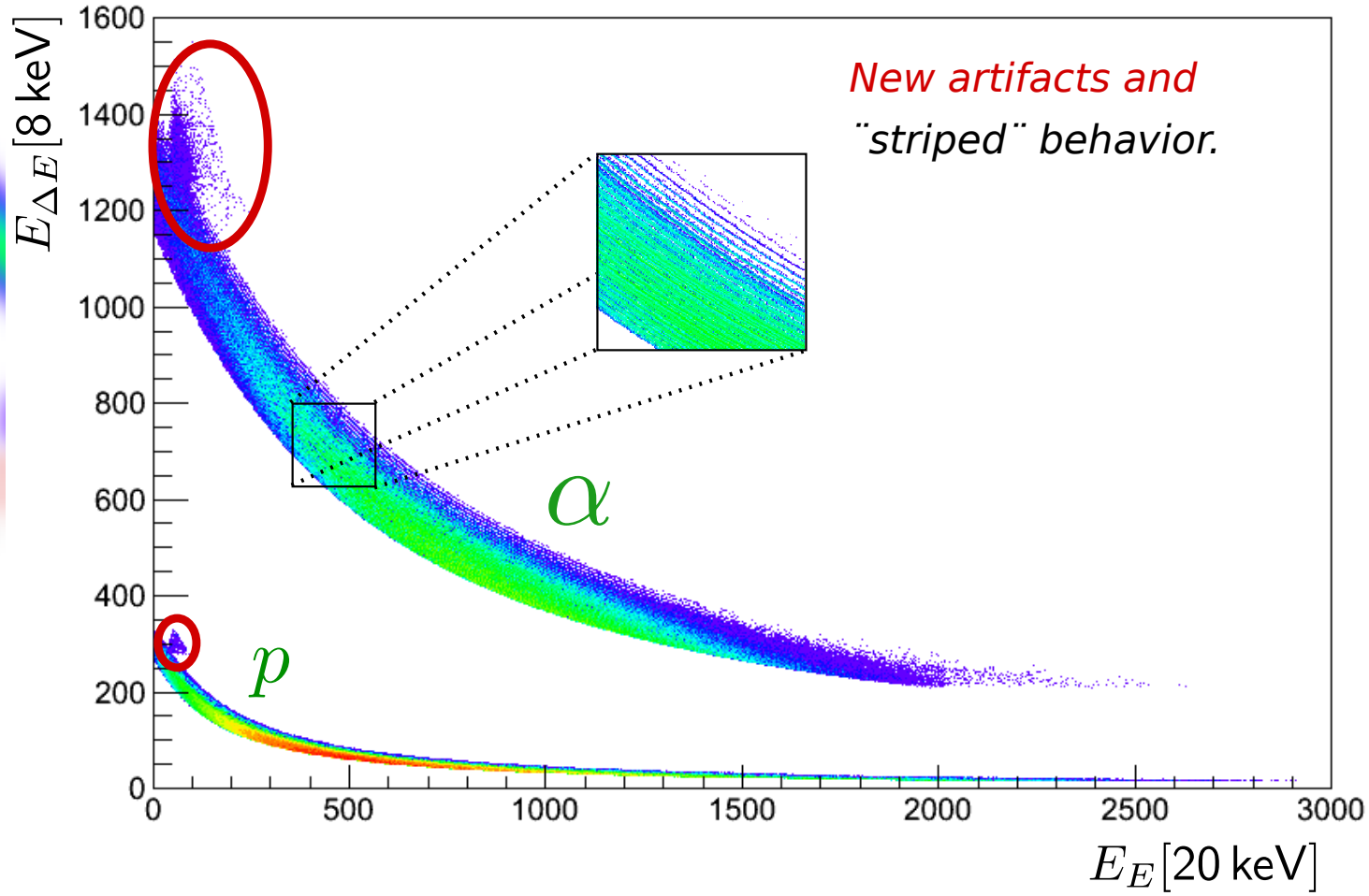
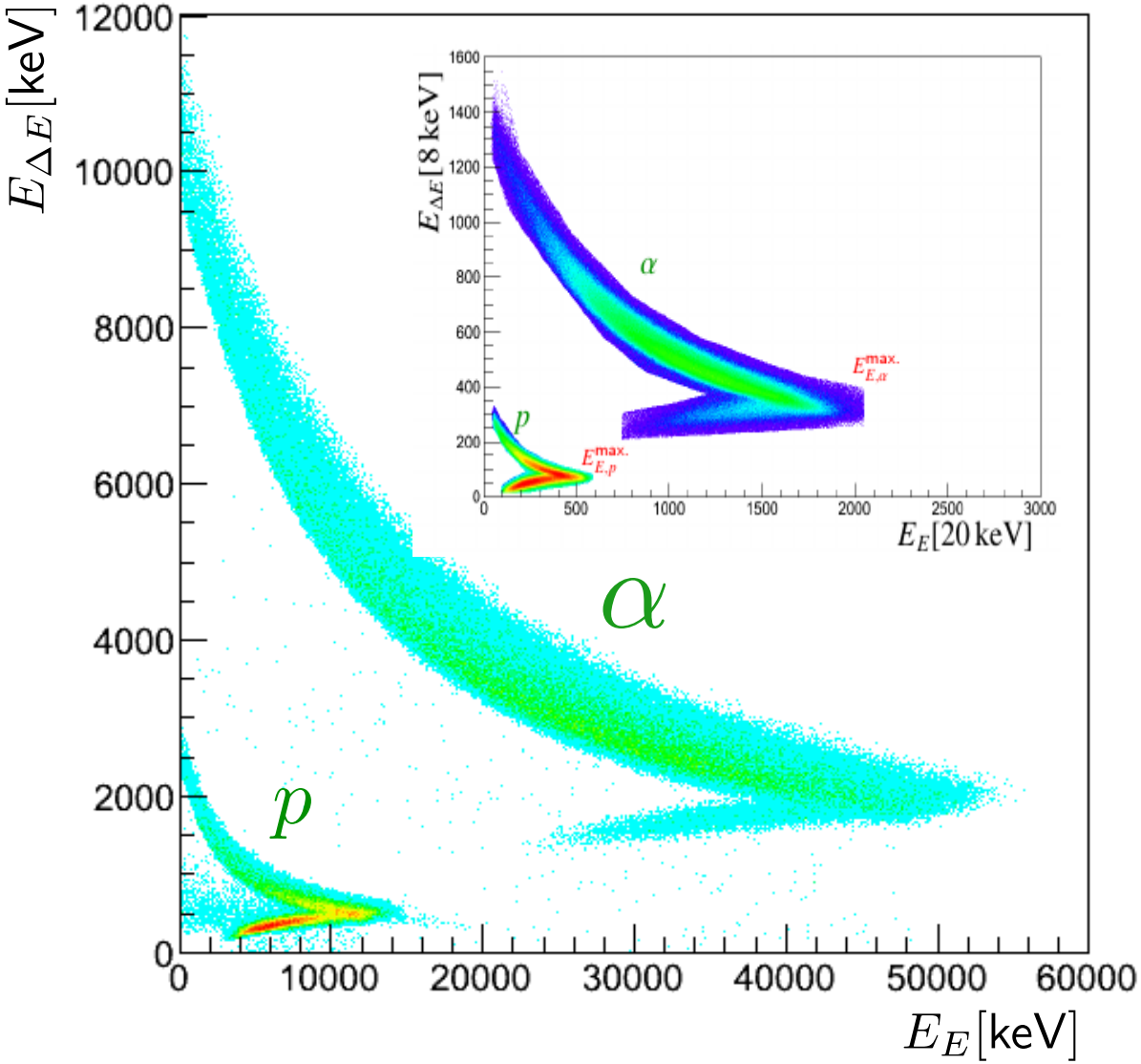


Detector punchthrough in Geant4



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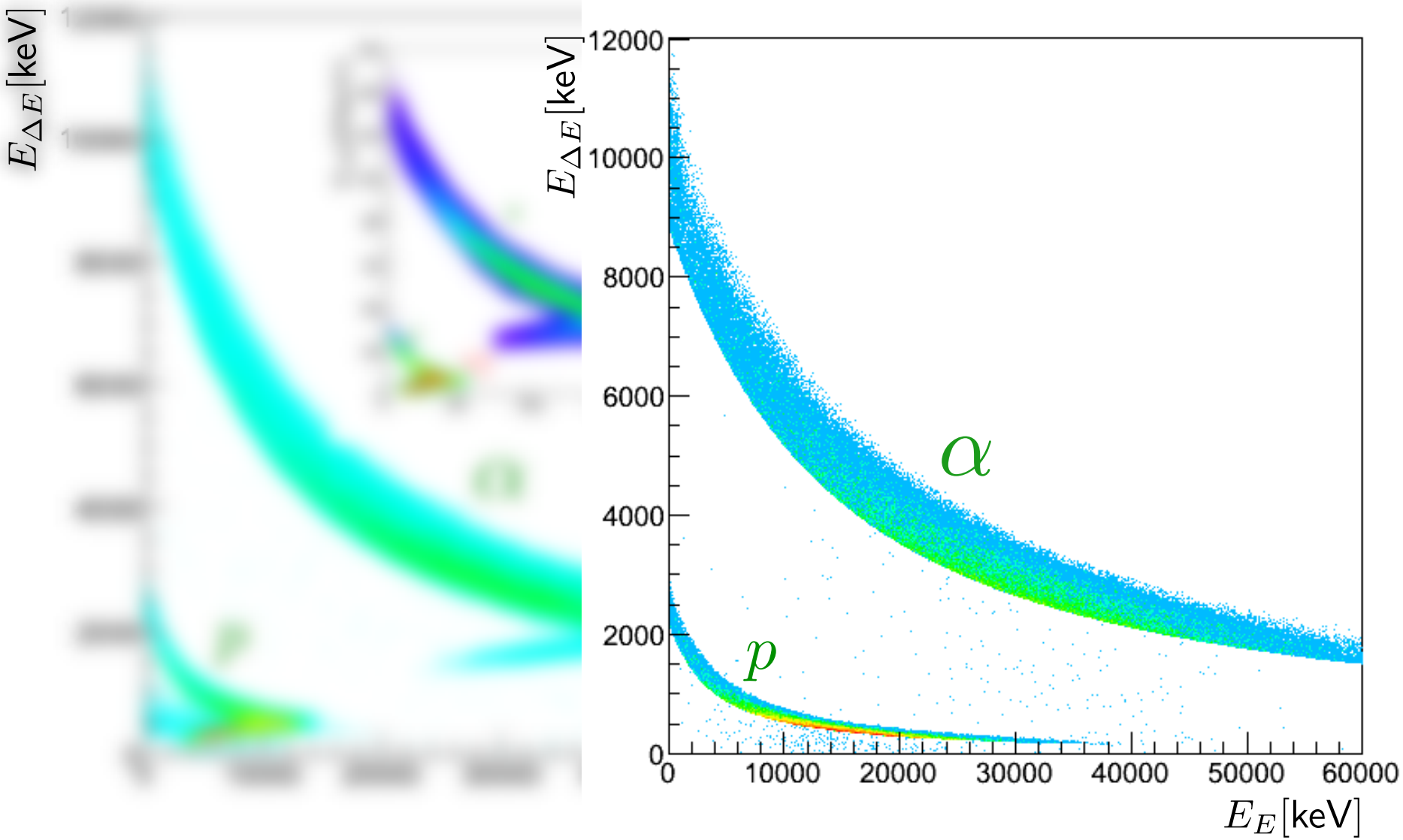
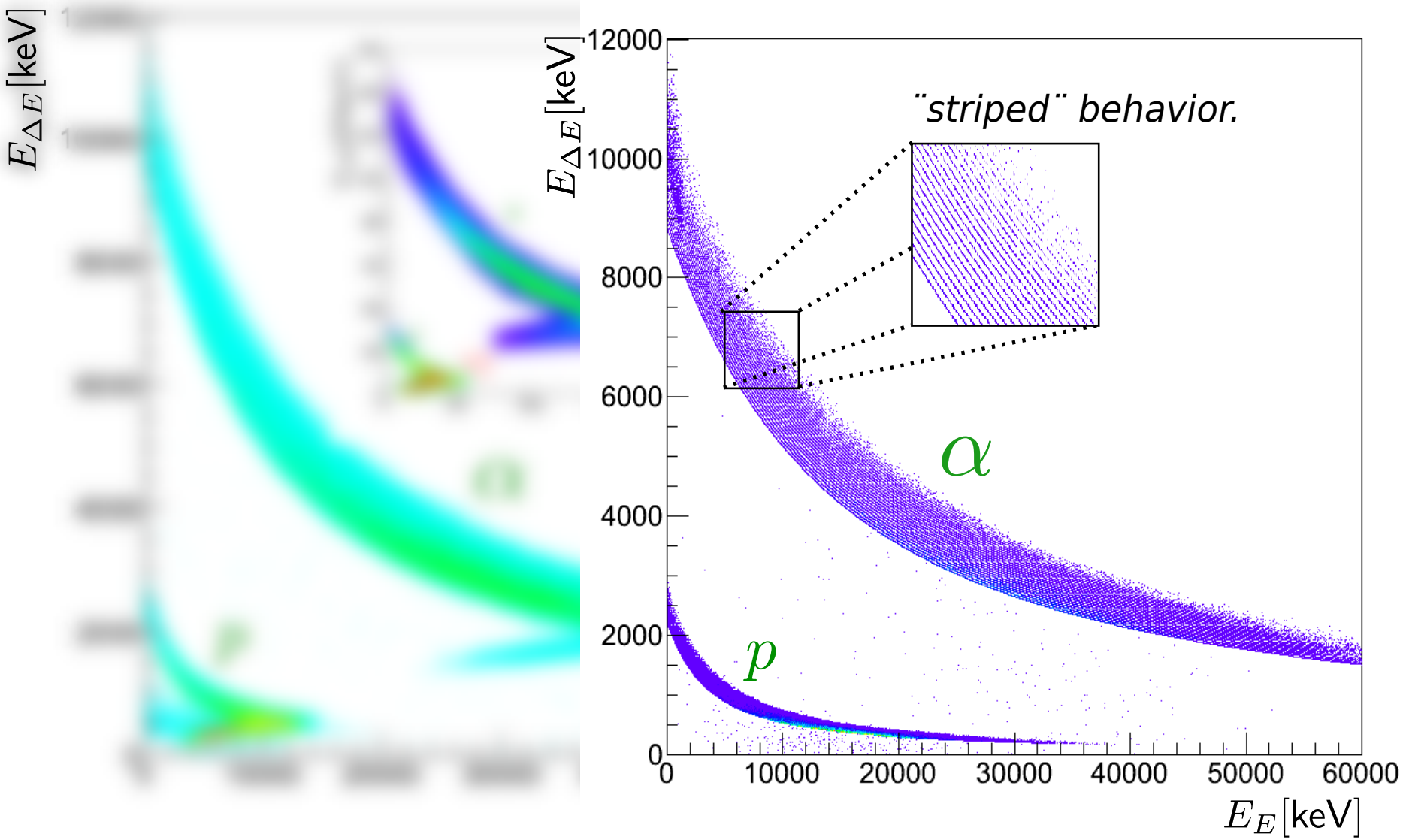
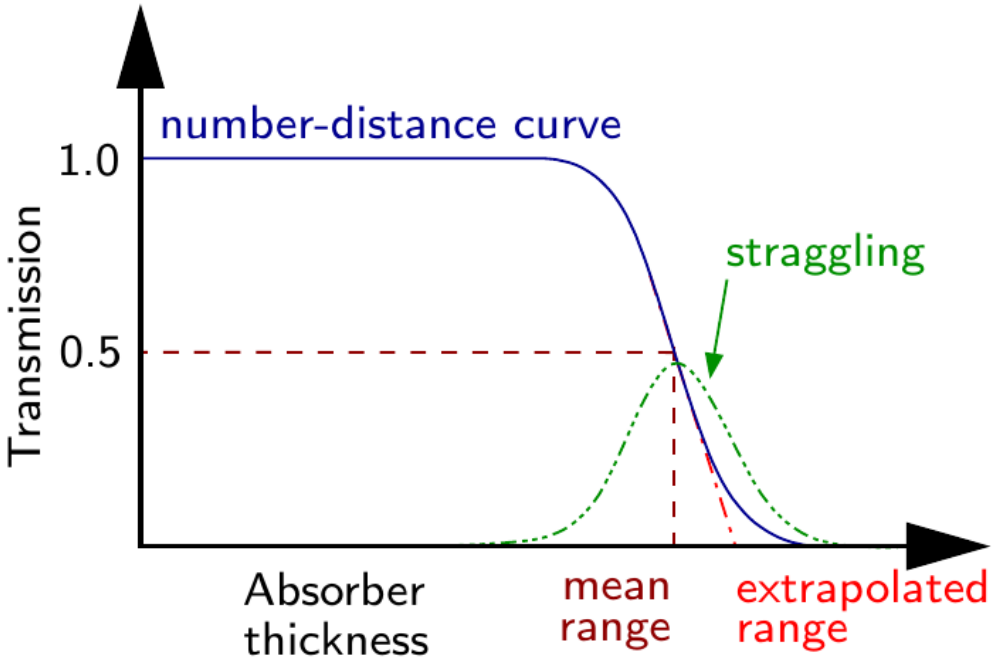
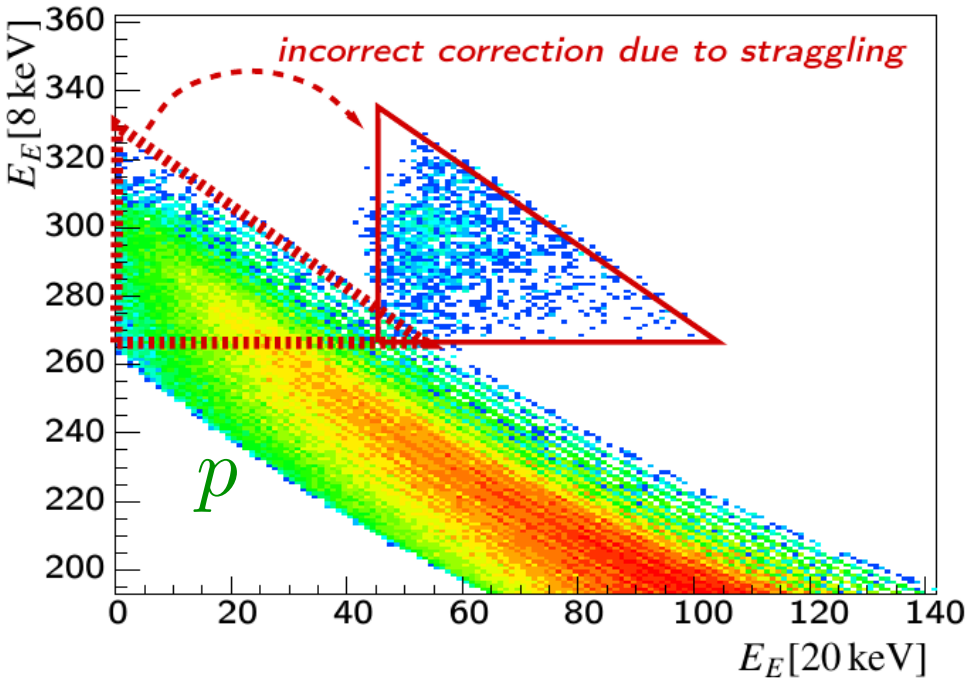


Detector punchthrough in Geant4



Detector punchthrough in Geant4