Nuclear Spectroscopy with GEANT4: The Superheavy Challenge

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Lund University, Sweden

TASCA 16
GSI
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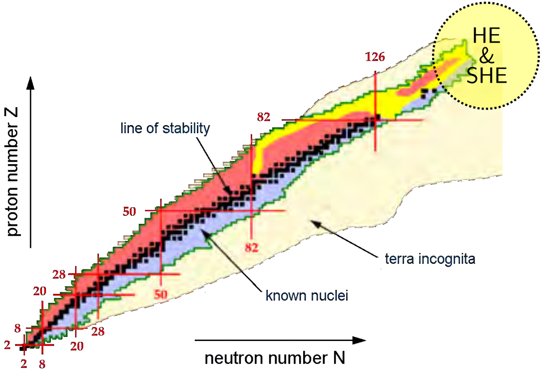
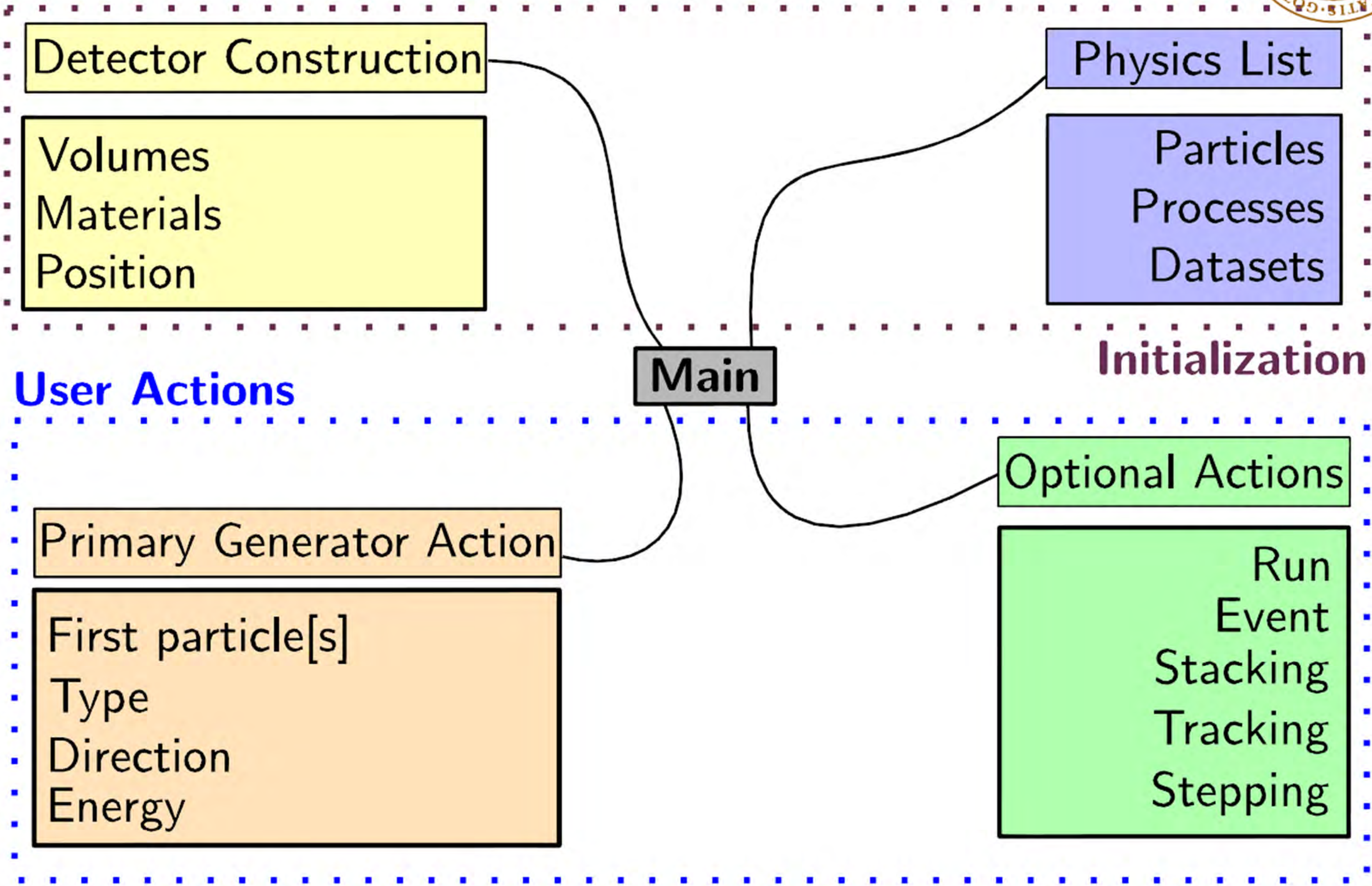
Overview

1. Geant4
2. TASISpec in Geant4
3. SHE-Geant4
4. What's next?

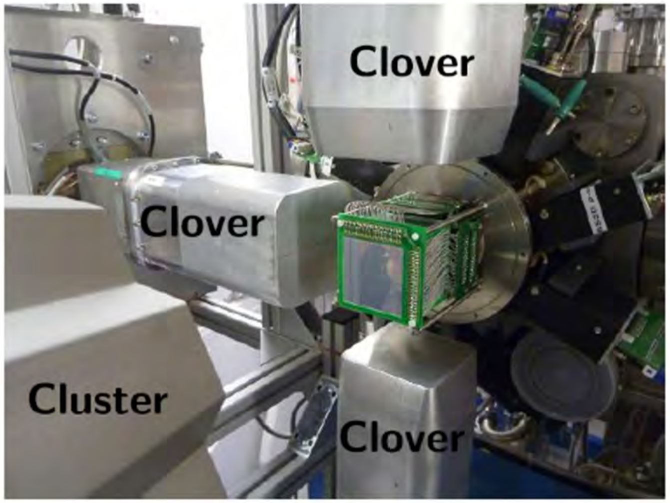


Geant4 Overview

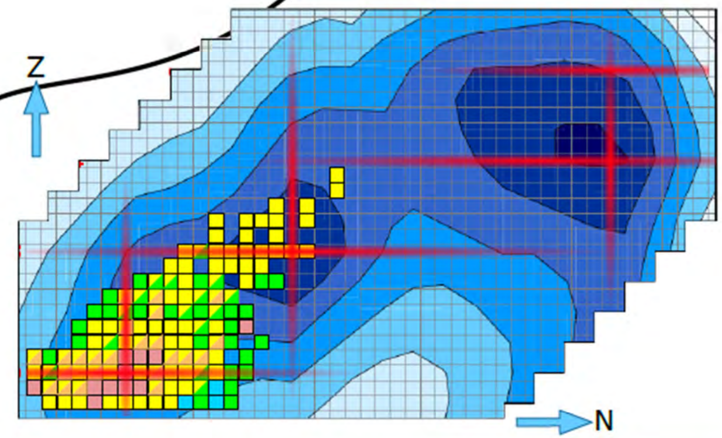


Geant4 Overview

Detector Construction



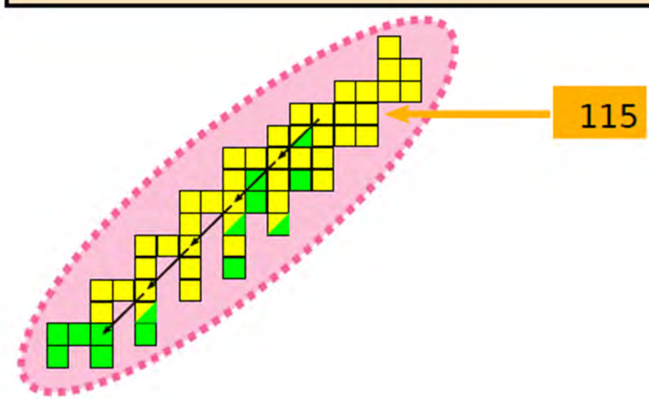
Physics List



Main

Optional Actions

Primary Generator Action



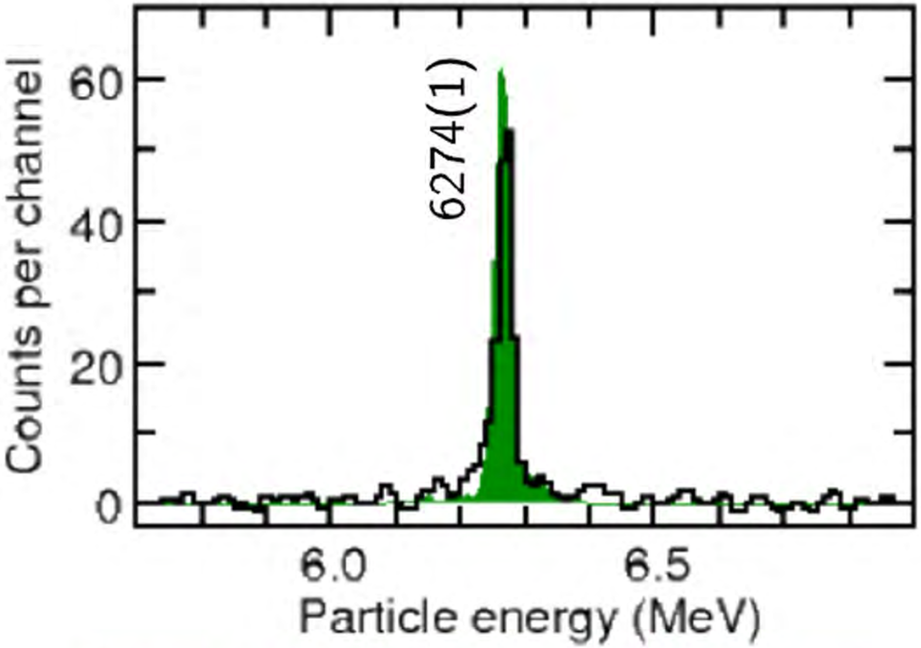
Detector Construction

Self-consistent cross check of the experimental findings with as many virtual decays as one likes!

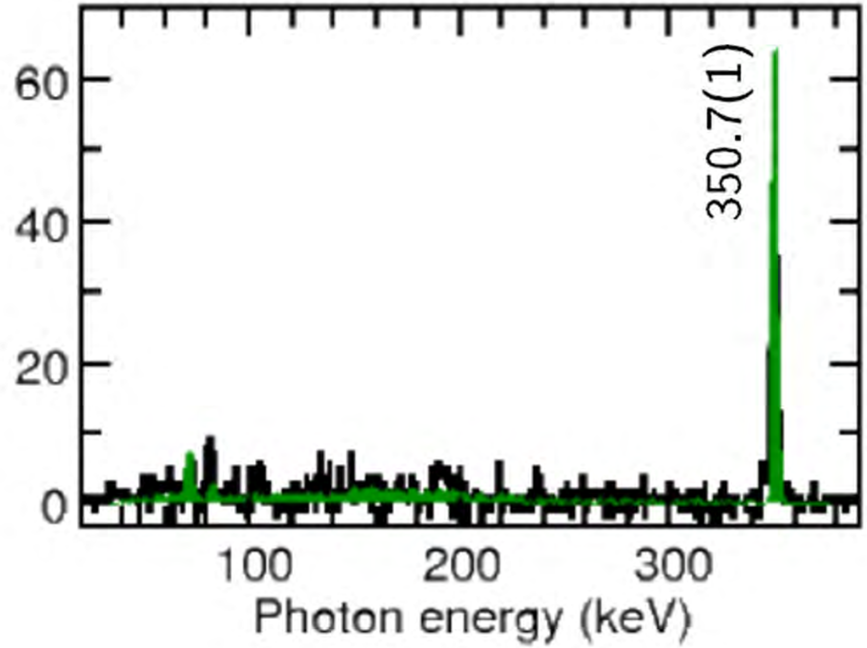
"Input level": down to pixel-by-pixel dead-layer thicknesses ...
"Output level": takes care of summing of α, CE, and Auger energies ...

In-beam benchmark: 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!

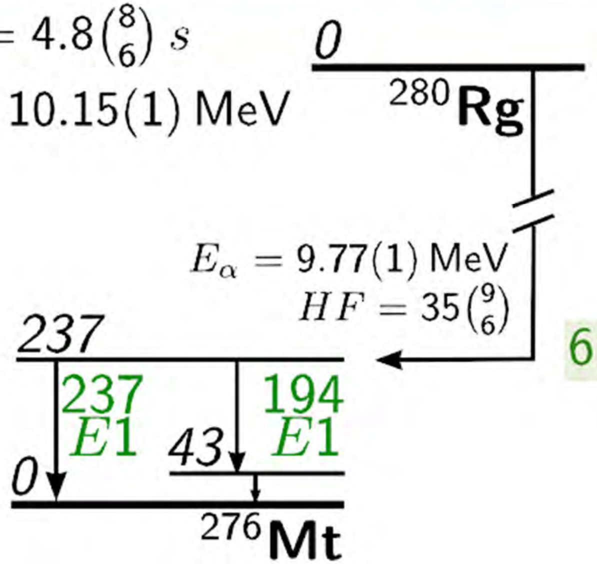
Literature: $E_\alpha = 6278.2(7)$ keV

$E_\gamma = 351.7(5)$ keV

Geant4 spectroscopy of SHE

$T_{1/2} = 4.8\binom{8}{6}\ s$

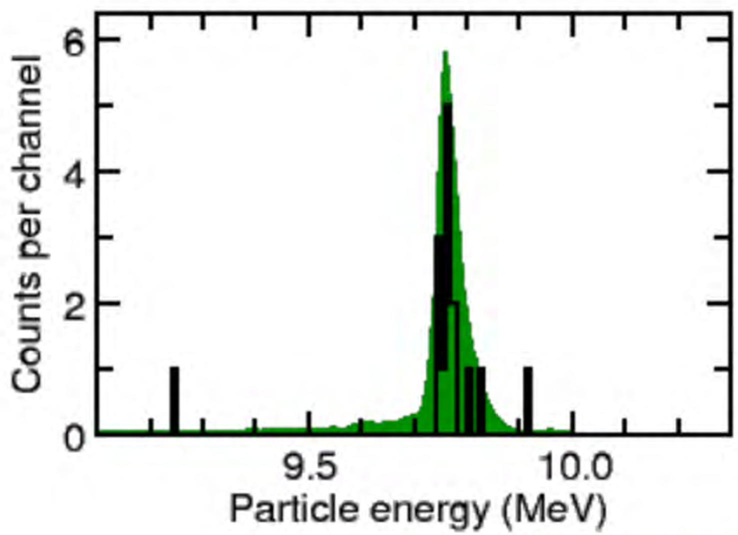
$Q_\alpha = 10.15(1)$ MeV

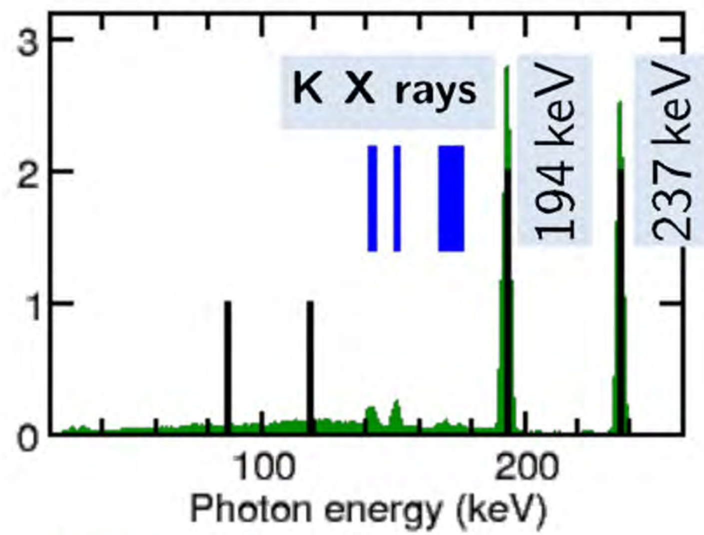


$E1$ Case

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

$6 \times \alpha$-photon coincidences





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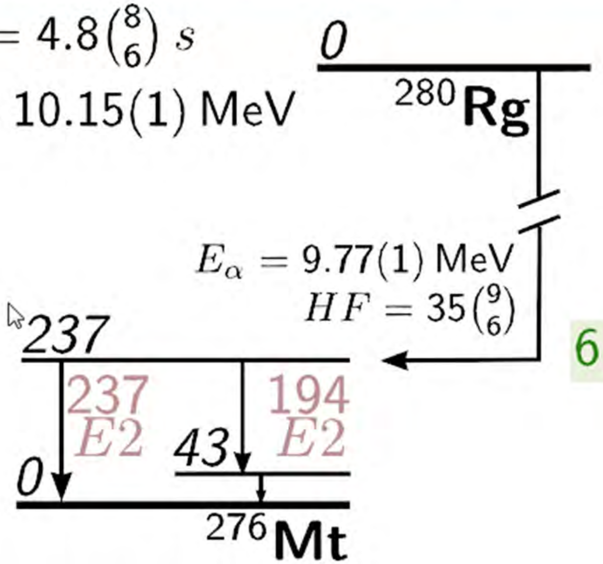
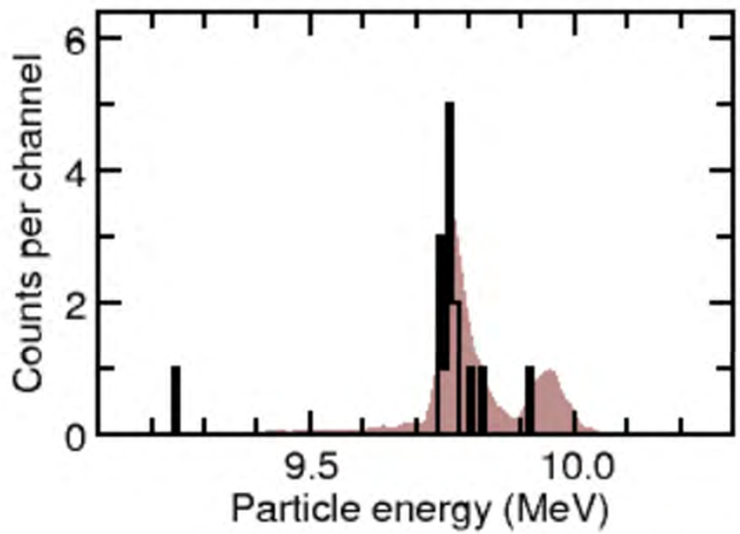
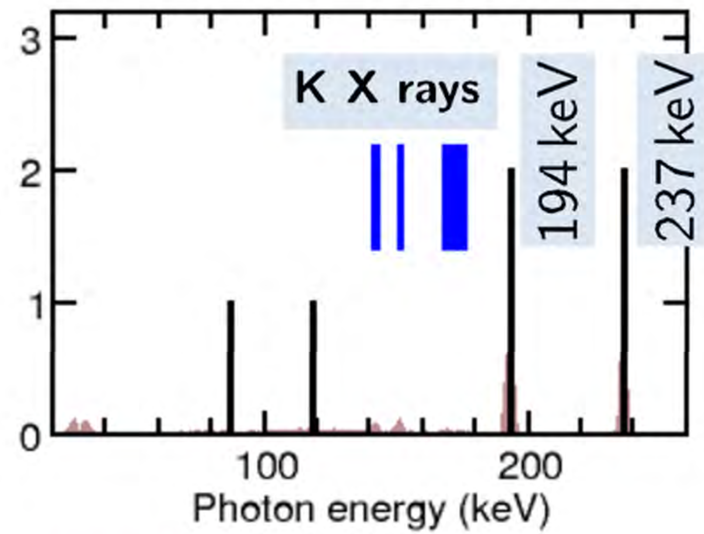


$E2$ Case

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

6 × α-photon coincidences





Geant4 simulations: 100000 decays
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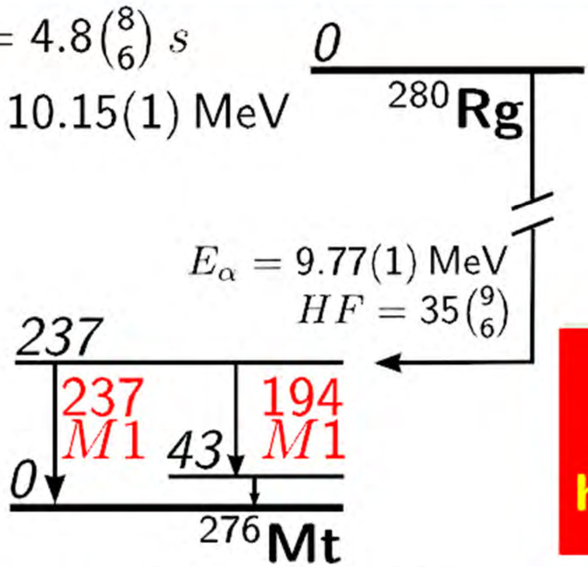
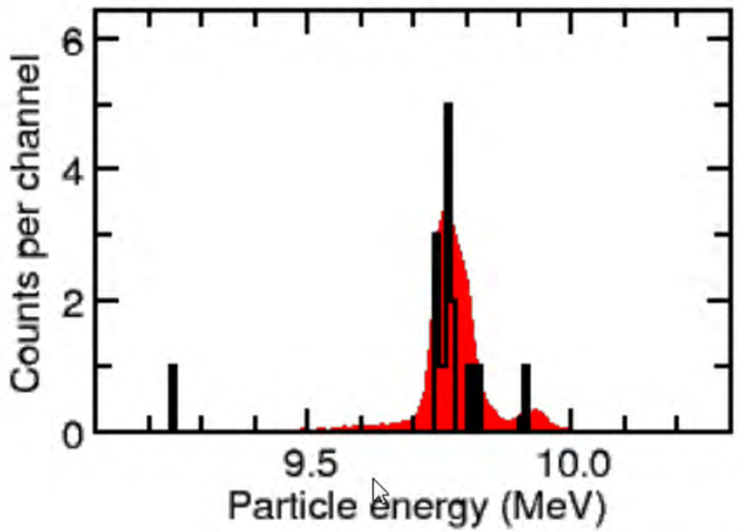
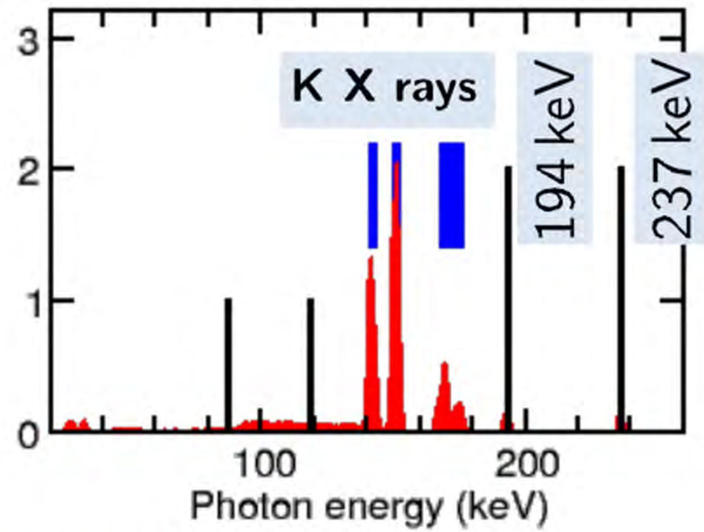


$M1$ Case

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

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





Geant4 simulations: 100000 decays normalized to number of αs

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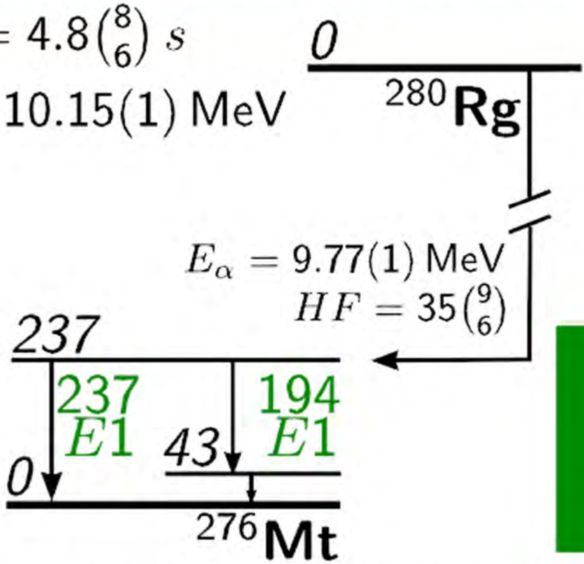
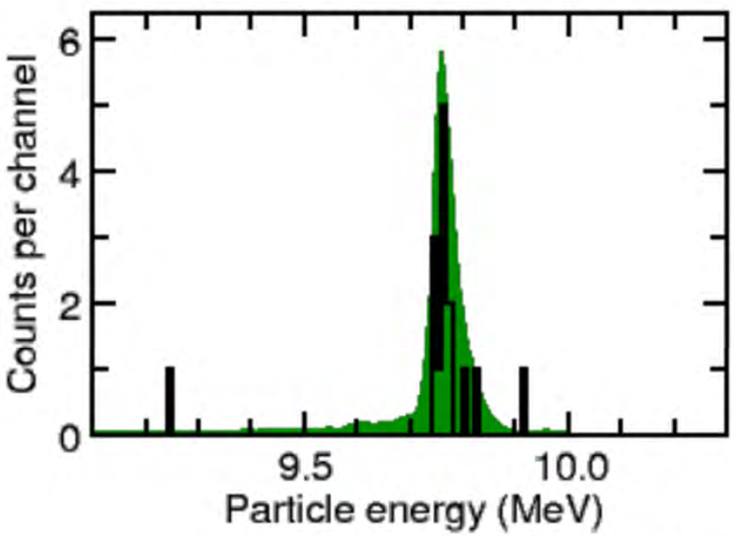
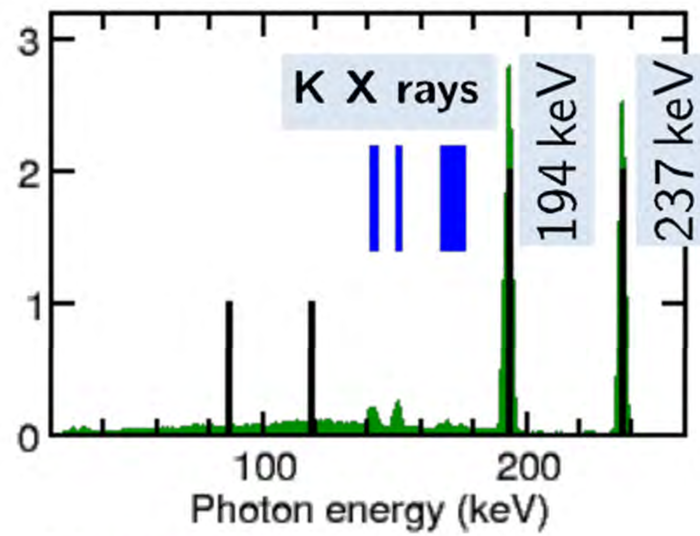


$E1$ Case

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

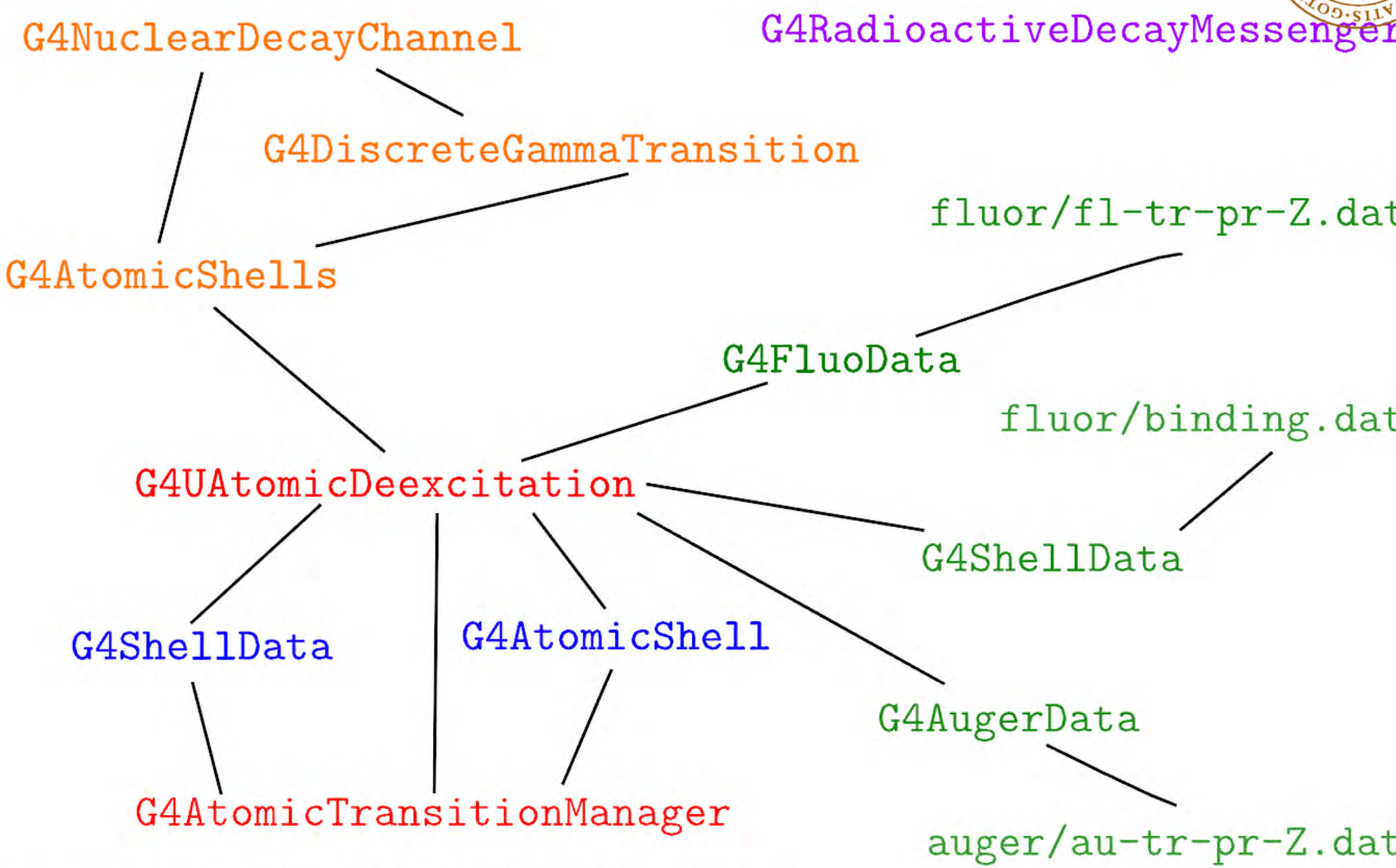
The fact that these transitions are $E1$ transitions puts exciting constrains on nuclear structure theory!





Geant4 simulations: 100000 decays normalized to number of αs

SHE-Geant4



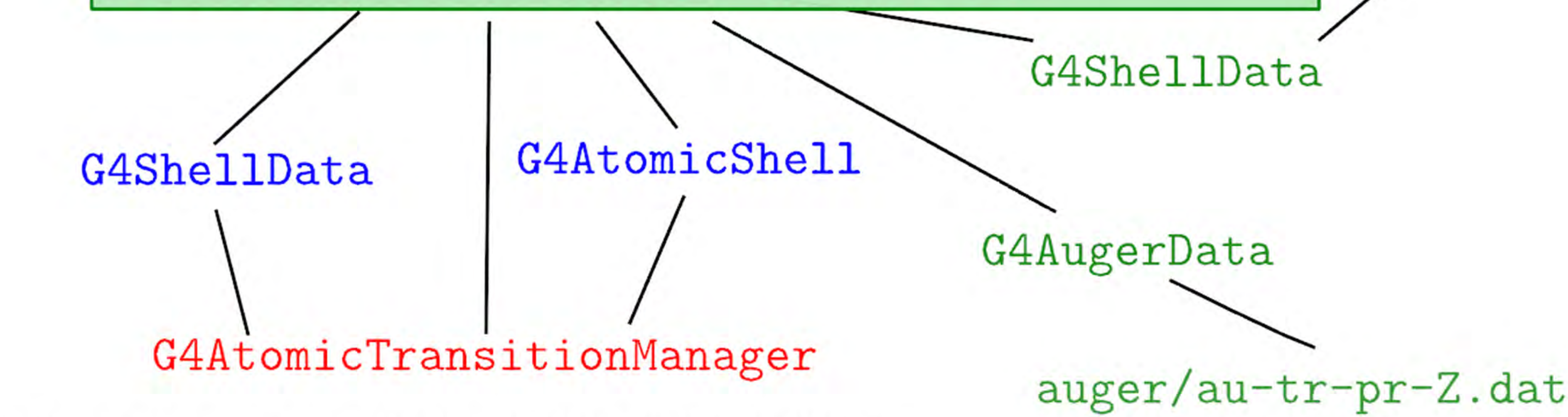
L.G. Sarmiento, PoS(X LASNPA)057, (2014)

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



L.G. Sarmiento, PoS(X LASNPA)057, (2014)

SHE-Geant4

G4I … Messenger

It is possible to make changes and extend Geant4 to SHE

…

Ur

G4A

Pr

pro

ne

-Z.dat

ng.dat

G4Sh

G

-Z.dat

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.

L.G. Sarmiento, PoS(X LASNPA)057, (2014)

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The decay lev

- Q-values
- Branching r
- Electromagn

Quantities such
slightly wrong l

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.

L.G. Sarmiento, PoS(X L

SHE-Geant4

Messenger

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: p and n *decay* now in Geant4 in the G4RADIOACTIVEDATA for V10.2 (Dec. 4 2015)

Mar./Sep. 2015: I have led this discussion at collaborations meetings

Feb. 2016: New Atomic De-excitation Database approved, **WIP**

→ Auger and fluorecense transition probabilites

→ non-disruptive with existing database/physics

G4AtomicShells, Icc, and EADL

ATOMIC DATA AND NUCLEAR DATA TABLES **12,** 311–406 (1973)

RELATIVISTIC DIRAC-FOCK EXPECTATION VALUES
FOR ATOMS WITH $Z = 1$ TO $Z = 120$

J. P. DESCLAUX
Centre d'Études de Limeil, B.P. 27
9419C euve St-Georges, France

As suggested by **Prof. Peter Schwerdtfeger**.
[New Zealand Institute for Advanced Study]

G4AtomicShells, Icc, and EADL

However... there are many compilations to choose from...

- by Carlson [Geant4 -partly-],
- by Sevier,
- Table of Isotopes,
- by Williams (use X-Ray Booklet and CRC Handbook)
- **E**valuated **A**tomic **D**ata **L**ibrary [Geant4 -mainly-]

I try to stay as consistent as possible, so...

Evaluation of atomic electron binding energies for Monte Carlo particle transport

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Maria Grazia Pia[a*], Hee Seo[b], Matej Batič[ac], Marcia Begalli[d], Chan Hyeong Kim[b], Lina Quintieri[e] and Paolo Saracco[a]

arXiv:1109.6079 [physics.comp-ph]

G4AtomicShells, Icc, and EADL

Available online at www.sciencedirect.com

ScienceDirect

Nuclear Instruments and Methods in Physics Research A 589 (2008) 202–229

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

www.elsevier.com/locate/nima

up to $Z = 110$

Evaluation of theoretical conversion coefficients using *BrIcc*

T. Kibédi[a,*], T.W. Burrows[b], M.B. Trzhaskovskaya[c], P.M. Davidson[a], C.W. Nestor Jr.[d]

Atomic Data and Nuclear Data Tables 98 (2012) 313–355

Contents lists available at SciVerse ScienceDirect

Atomic Data and Nuclear Data Tables

journal homepage: www.elsevier.com/locate/adt

for $110 < Z \leq 126$

Conversion coefficients for superheavy elements

T. Kibédi [a,*], M.B. Trzhaskovskaya [b], M. Gupta [c], A.E. Stuchbery [a]

[a] Department of Nuclear Physics, Research School of Physics and Engineering, The Australian National University, Canberra, ACT 0200, Australia
[b] Petersburg Nuclear Physics Institute, Gatchina 188300, Russia
[c] Manipal University, Manipal 576104, Karnataka, India

BrIccFO (web) only up to $Z \leq 110$

G4AtomicShells, Icc, and EADL

Now all that is needed is a consistent database of:

- electron binding energies (✓)
- electron occupancies (✓)
- radiative (fluo) transition probabilities
- non-radiative (Auger*) transition probabilities

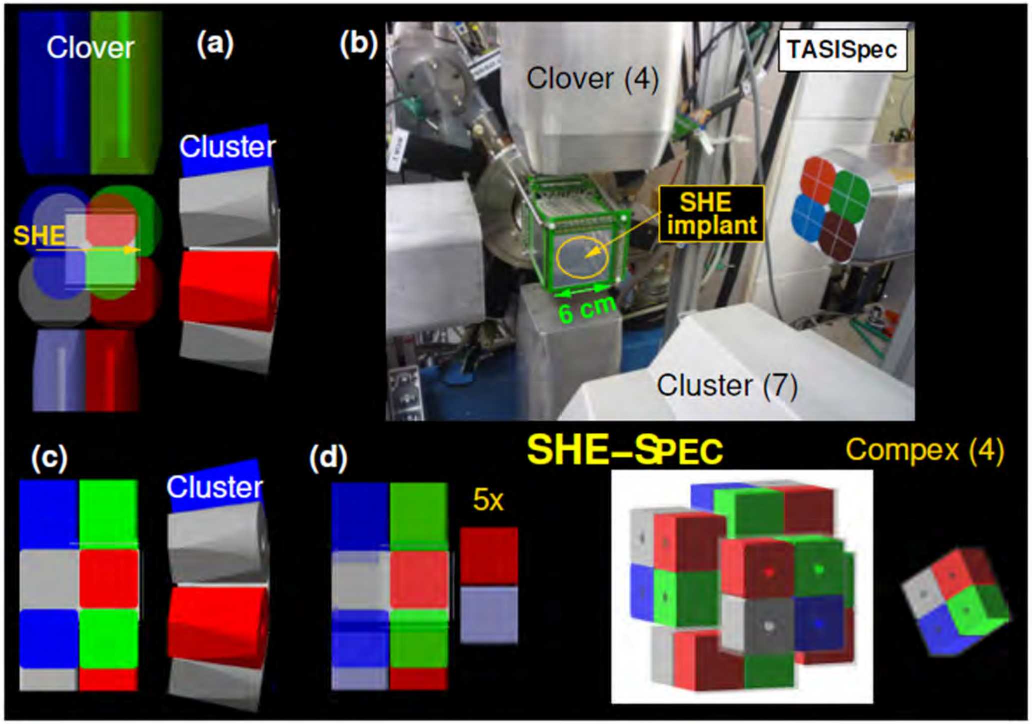
For $5 \leq Z \leq 120^{(?)}$

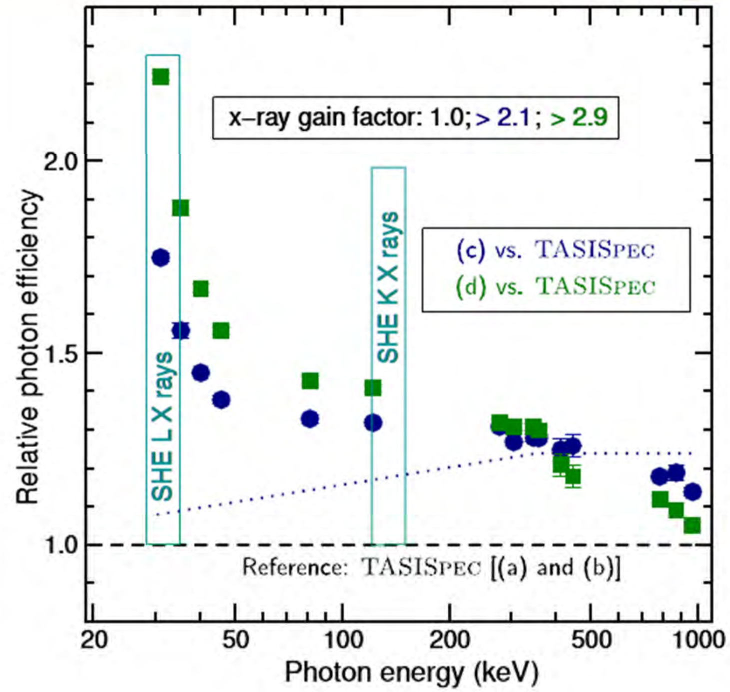
G4AtomicShells, Icc, and EADL

OK, the simulation are to be improved, but ...

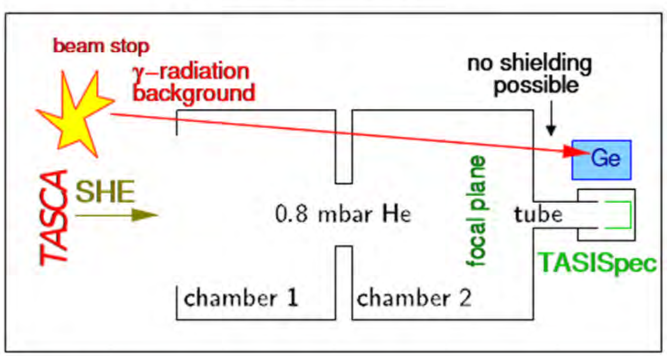
where is the improvement in the **measurements** ?

Upgrades to TASISPEC

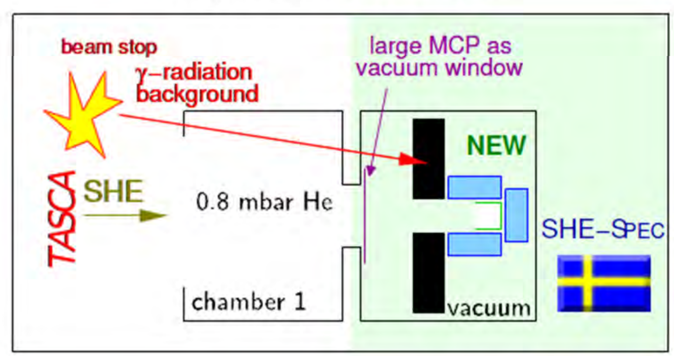




present chamber



improved chamber



Summary & Conclusions

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

Simulations `Geant4` is not *just* an useful tool. Over the years it has continue to grow as the established as the **FREE**[1] **Swiss knife** of nuclear physics

- before the experiment,
- during the data analysis, and even
- proposing new physics or re-interpreting physical cases

Future ... "*X*-**rays are coming**"

[1] as in freedom