GenDecay: Data Driven, General Radioactive Decay Generator and GenTool (DocDB 3700)

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Outline

Current Radioactivity Generators

The GenDecay Package

Comparison with current U/Th generators

Summary

Current state of radioactivity generators

- Implemented as mostly unrelated, stand-alone executables producing HepEVT formatted output.
- Do not integrate well into Gaudi/GenTools.
  - No way to set correct number of events
  - Different random number generators than Geant4/Gaudi
- Some implemented in FORTRAN.
- U/Th generators are cryptic[1], with hard coded and some incorrectness.

[1] My opinion.

Guiding Principles for Developing GenDecay

- Use "official" nuclear decay data.[2]
- Allow data to be updated - no hard coding.
- Data driven: let decay data define the decay chain, do not setup unphysical decay chains or miss branches.
- Keep decay "engine" and GenTool codes separate.
- Allow flexibility, make no assumptions on relative/absolute radioactive parent abundances nor detection mechanism (detector correlation times).

[2] http://www.nndc.bnl.gov/ensdf/

Evaluated Nuclear Structure Data File (ENSDF) Data Sets

ENSDF:

- Maintained by National Nuclear Data Center (NNDC) @ BNL[3].
- **Very** baroque format! Cryptic, FORTRAN oriented.
- α and β decays tabulated differently from γs
- Challenging to algorithmically form decay chain due to slight energy level inconsistencies.
- Geant4 has a digested version in `G4RadioactiveDecay` data files, but wary of provenance, conversion errors and if they are kept up to date.

"`libmore`" (mostly) to the rescue$\longrightarrow$

[3] `http://www.nndc.bnl.gov/`

libmore

- Free Software, C++ library by Petter Urkedal.
- Parses ENSDF files.
- Long time stable, now in bug-fix-only mode.
- Developer very helpful and has given me commit access for a few minor fixes.
- Installed by default after offline upgrade → trunk merge.[4]
- For more info see: `http://more.sf.net/`

In-memory representation still follows ENSDF schema so must do some work to build up chains, particularly careful determination of daughter energy levels.
`GenDecay` library ⟶

[4] See DocDB 3571

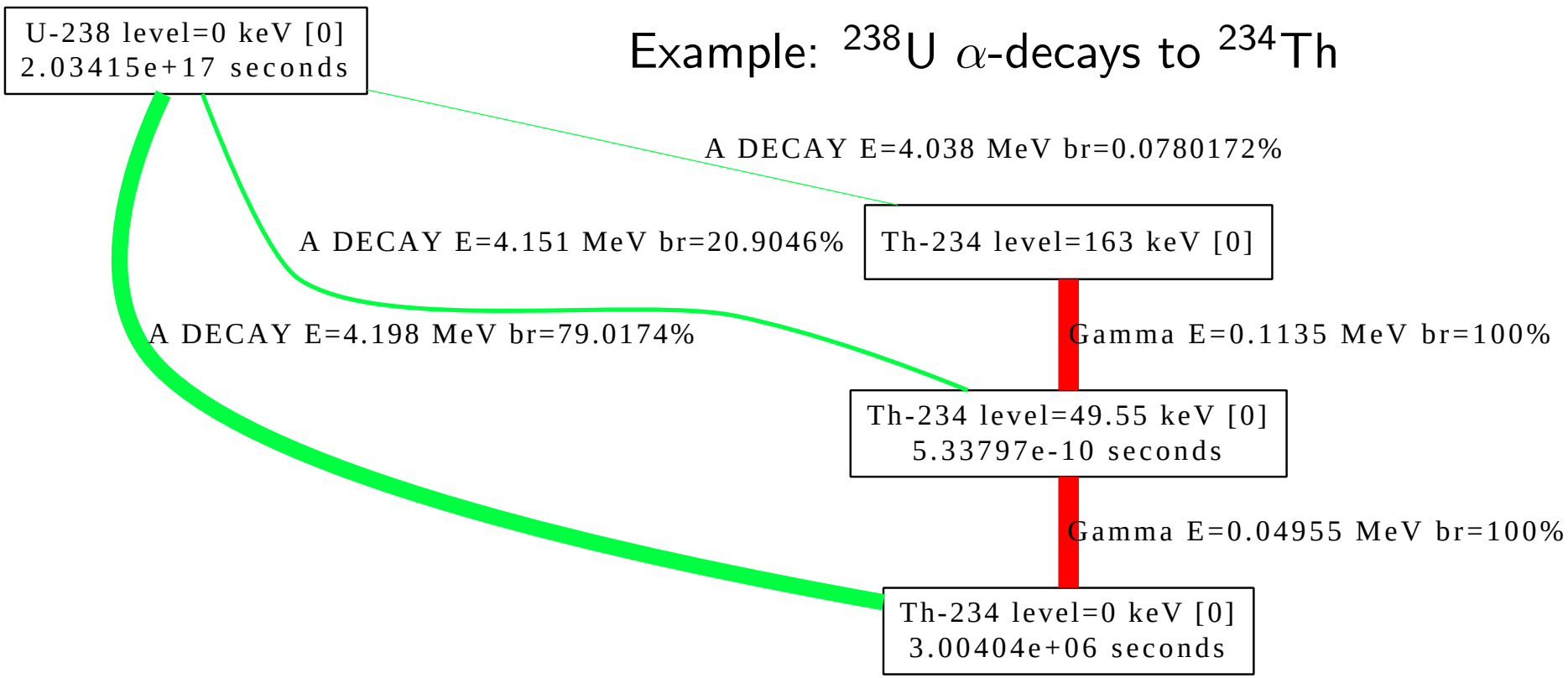
GenDecay library: building a chain

Forms a decay chain in the form of a directed graph of `NucState` objects connected by `NucDecay` objects.

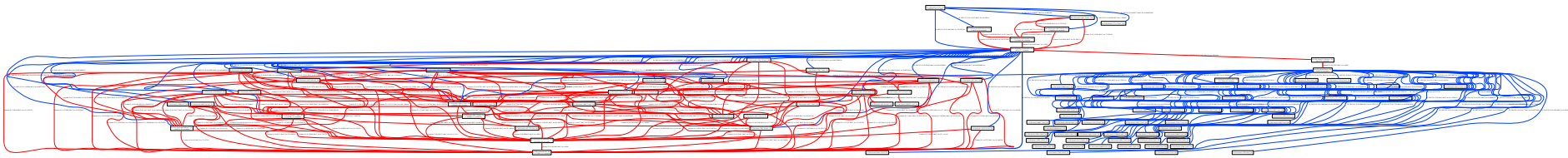
`NucState` Z/A, half life, energy level, collection of `NucDecay`

`NucDecay` pointer to mother and daughter `NucState`'s, decay type, energy of radiation and decay fraction (branching ratio).

Example: ^{238}U α-decays to ^{234}Th

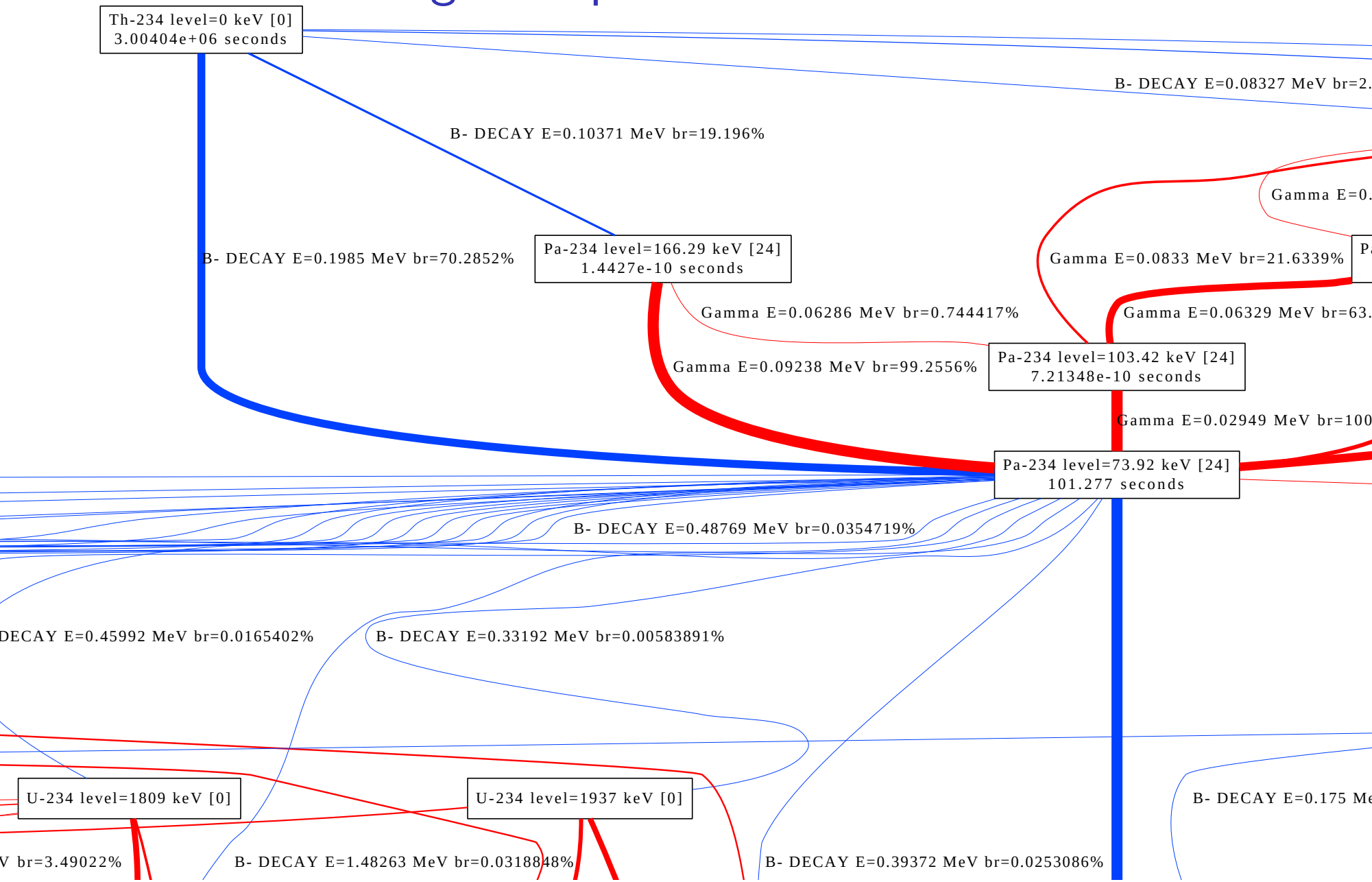


Another interesting example: ^{234}Th $\longrightarrow$ ^{234}Pa $\longrightarrow$ ^{234}U

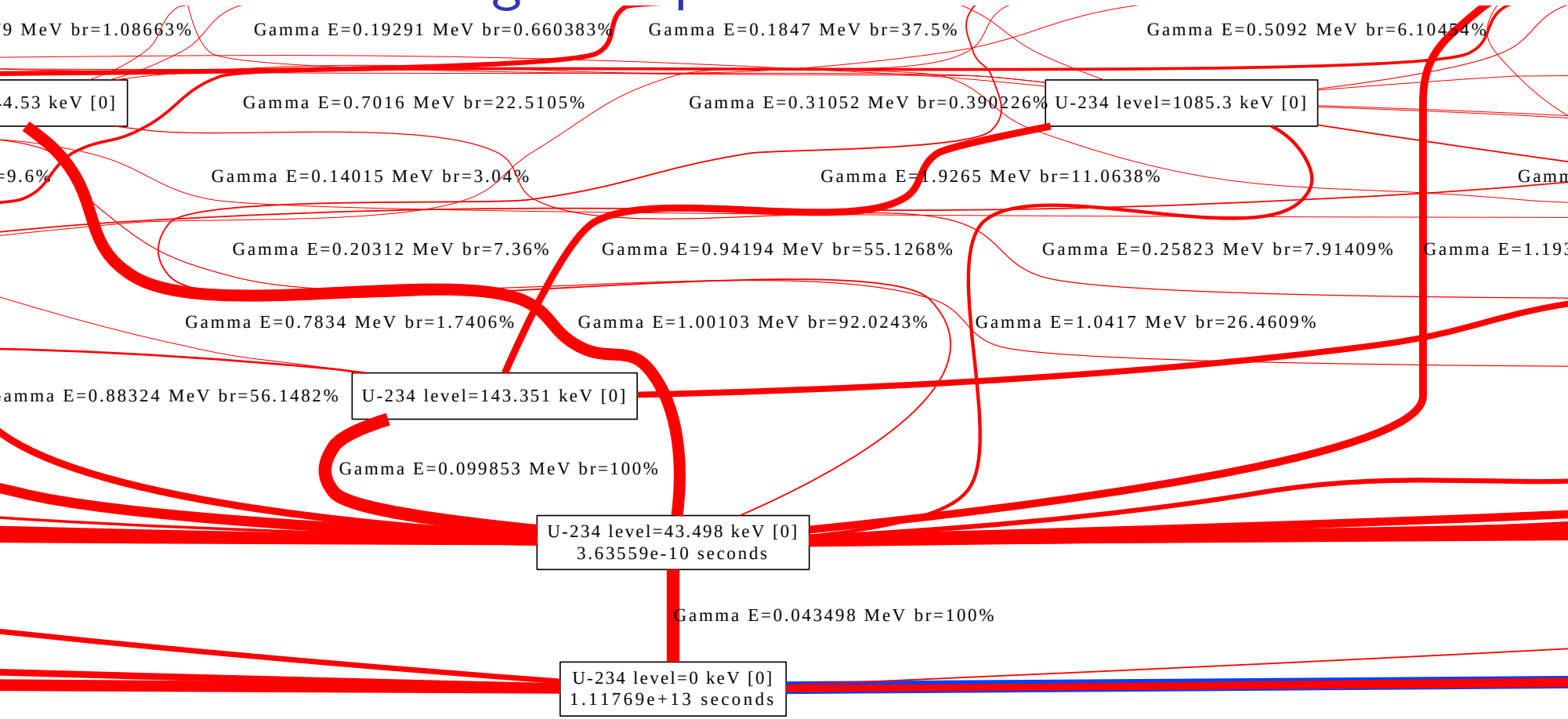


- ^{234}Th can β-decay to ^{234}Pa meta-stable E=74keV* excited state.
  - Unmeasured, small energy splitting between 74keV* and 74keV states (marked as "[24]" and "[0]" in the graph, respectively).
- This **excited** state almost always (br=99.8%) β-decays directly to ^{234}U ground or indirectly and sub-dominantly, but rich, spectra of βs + γs.
- Only rarely (br=0.16%) has isomeric transition (IT) to E=74keV, followed by γ-decay to ^{234}Pa ground and β-decay to ^{234}U states (note: their subsequent β-decays are not shown in graph).

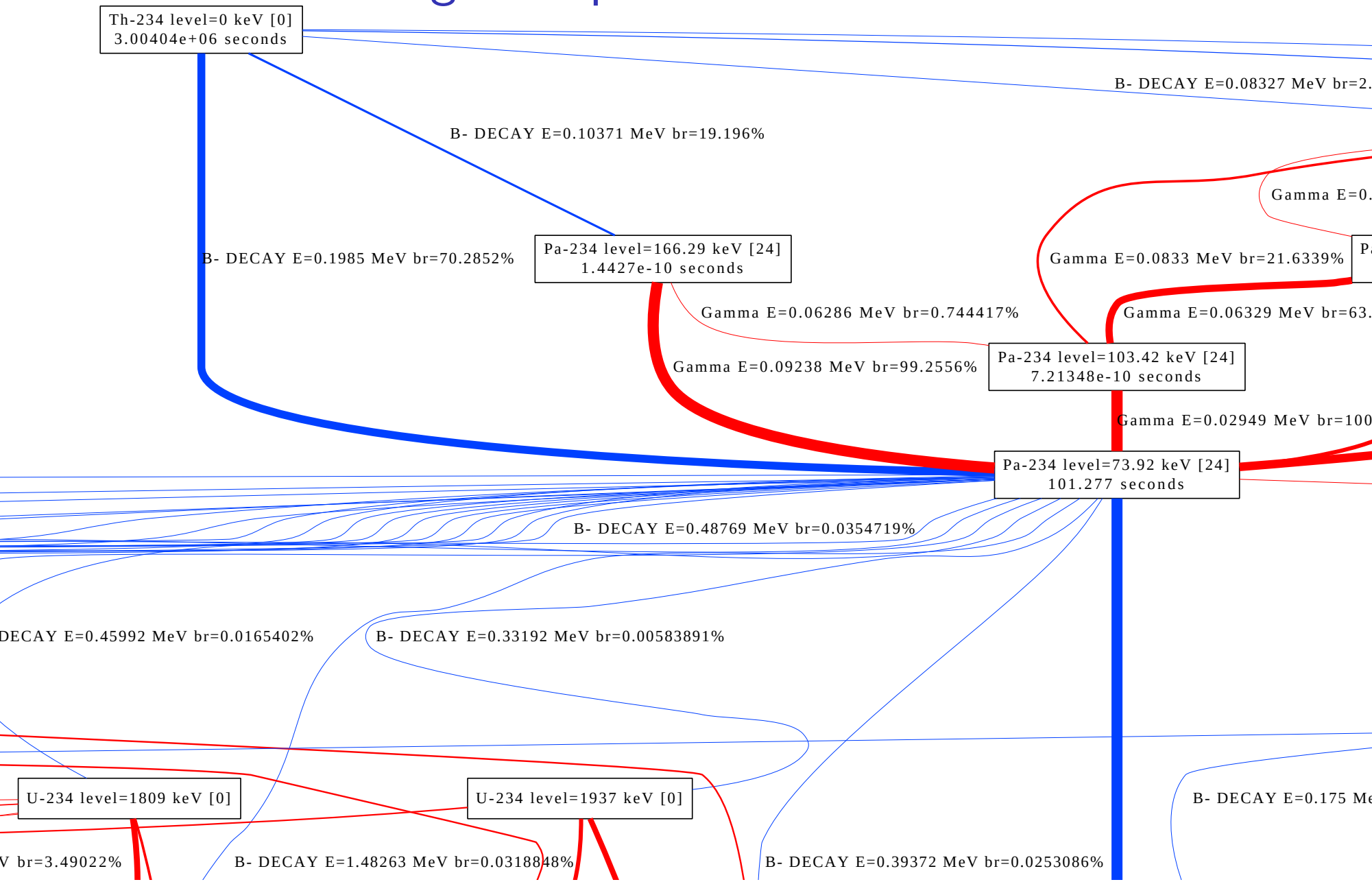
Another interesting example: $^{234}Th \rightarrow {}^{234}Pa \rightarrow {}^{234}U$



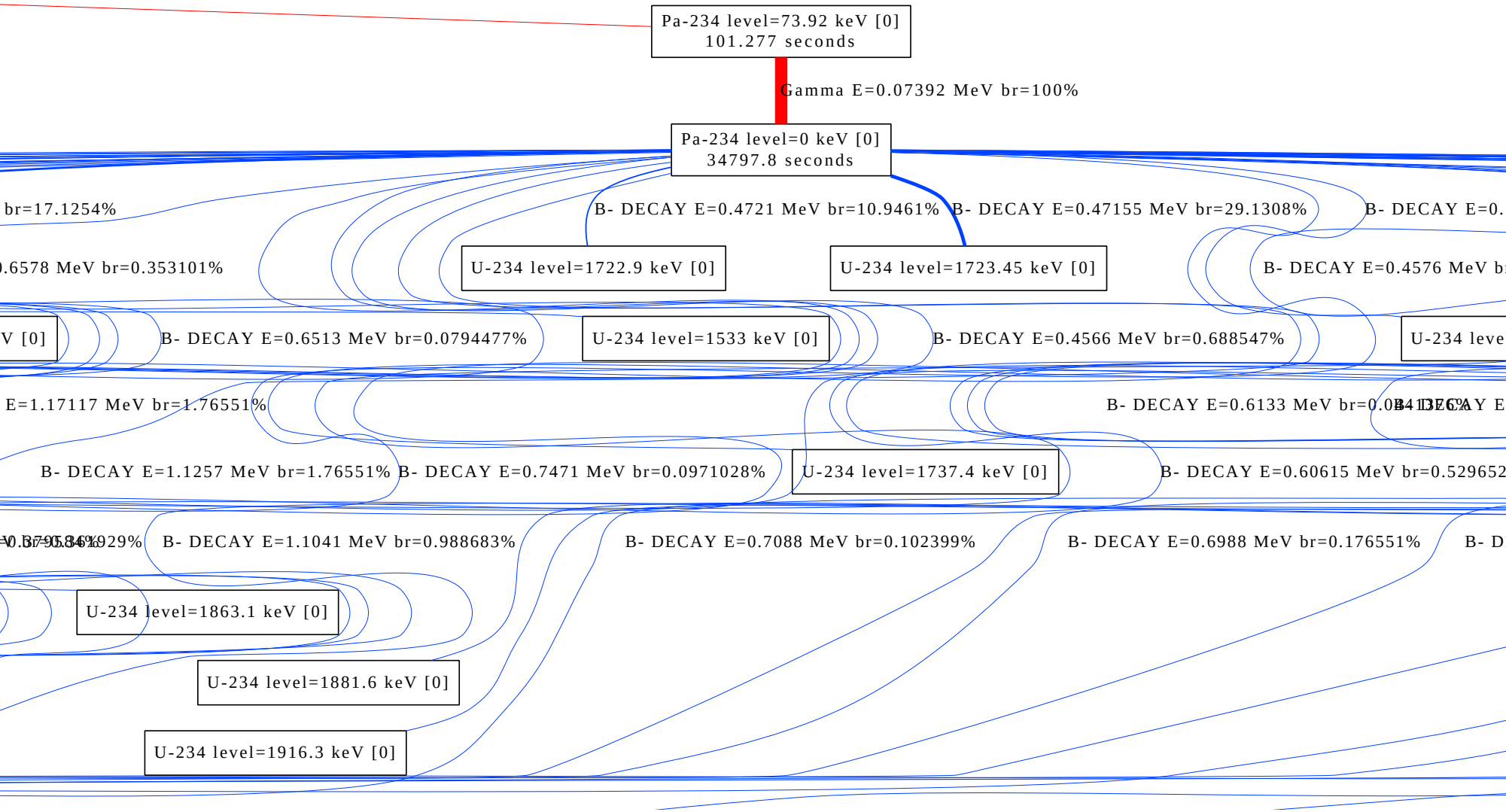
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Current U/Th Generators

Current U/Th generators by A. Peipke (AP)

- DocDB 441, Jianglai Liu & Christopher Mauger,
  - α and $\beta + \gamma$ spectra at kinematics level.
  - below, will compare against this study.
- DocDB 1408, Xiaobo Li, Liangjian Wen & Jun Cao,
  - spectra at Geant4 PMT hit level.
- Secular equilibrium (SE) and correlation time (CT)
  - SE: daughters decay at same rate as mother,
  - CT: unless their half life is less than some cut, then forced to decay along with mother.
  - Correlation time for AP apparently $\sim$4 days.[5]
  - Some decays will never be simulated in practice due to $\ll$ 4 days simulation run.

[5] Based on the chain graphs in these documents.

Simulation Parameters for Comparison

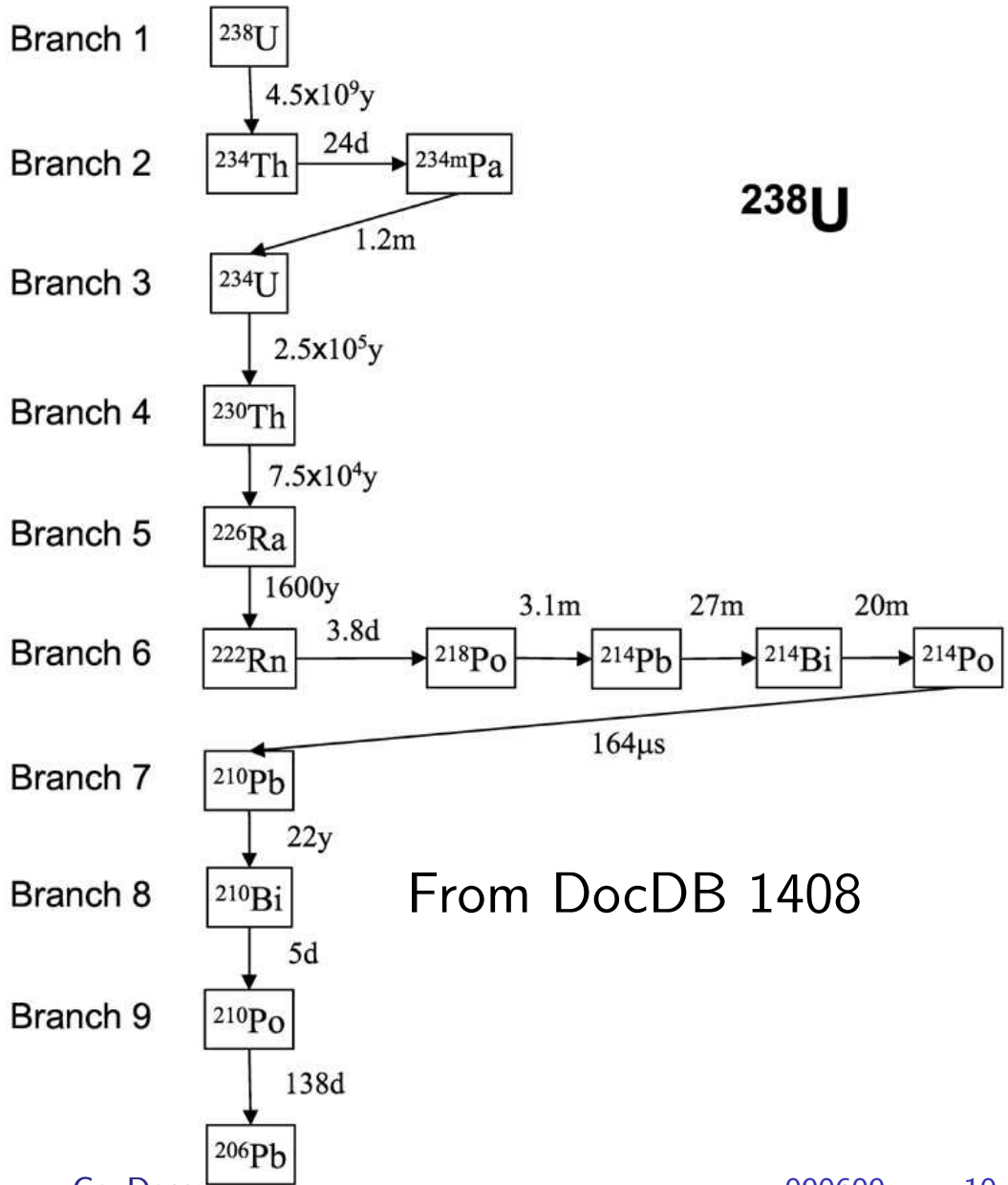
Focus on ^{238}U

- 10^6 decays
- GenDecay: 1 second & 4 day correlation times
- DocDB 441 ROOT files from Jianglai

Plots to follow colored as:

- **GenDecay in black**
- **AP in red**

Look at α, β and γ spectra.

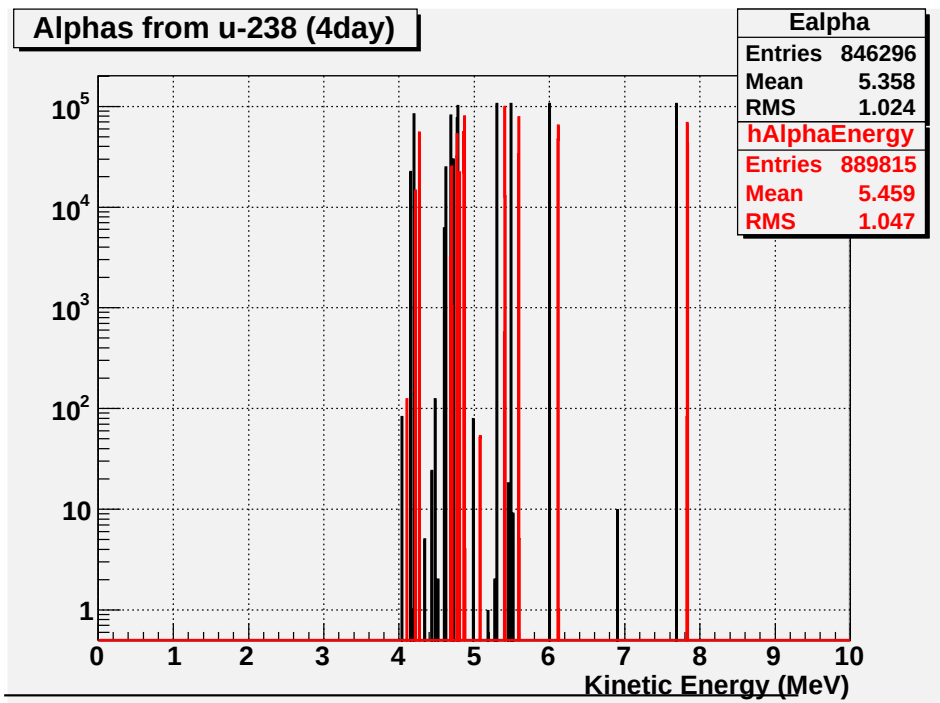


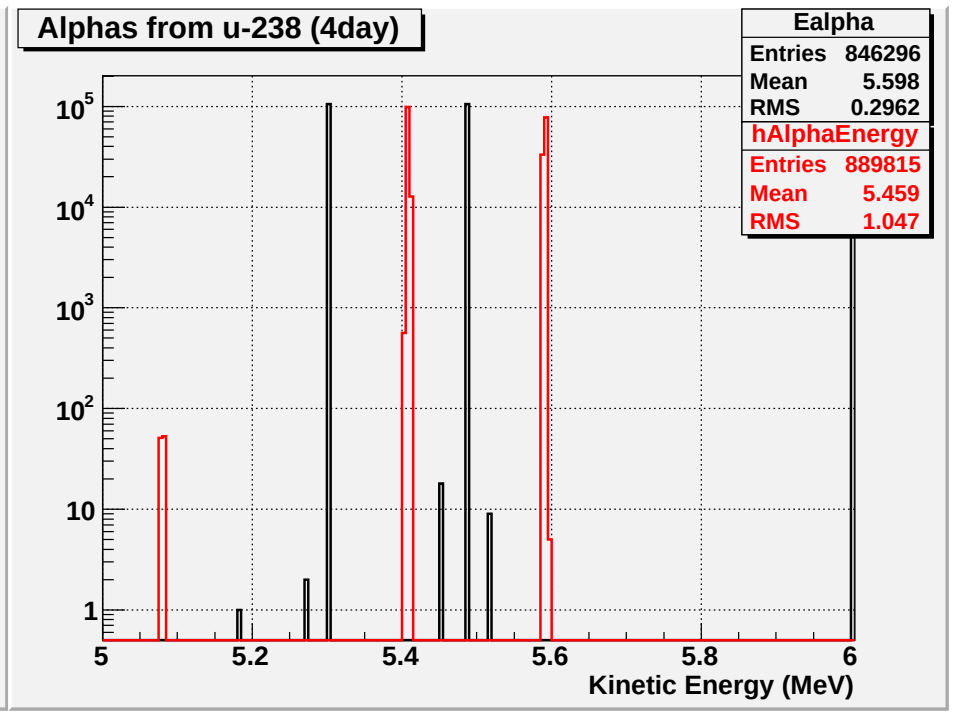
From DocDB 1408

E_α "lines"

Apparent issues with AP generator:

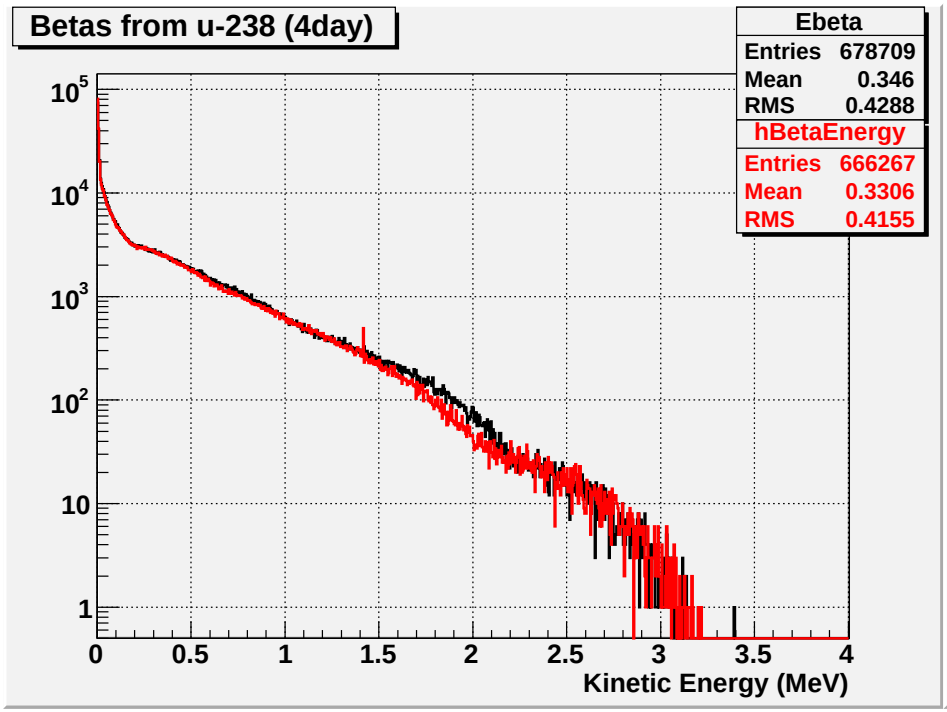
- Mismatch α lines: missing (branch not considered) or over represented (forced to decay with mother due to too-long correlation time).
  - apparently a problem but not yet tracked down specifics
- No daughter nucleus recoil ($\propto \frac{A-4}{A}$) $\Rightarrow E_\alpha \sim 2\%$ too high.
- Artificial broadening due to low precision in HepEVT momentum.[6]

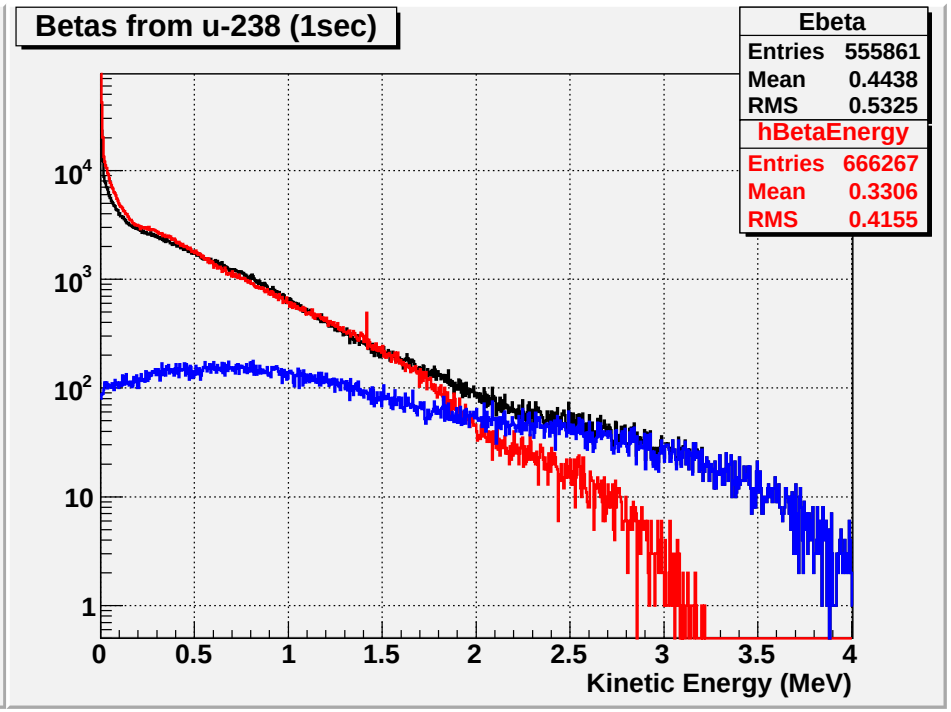




[6] Thanks Jianglai for tracking this down.

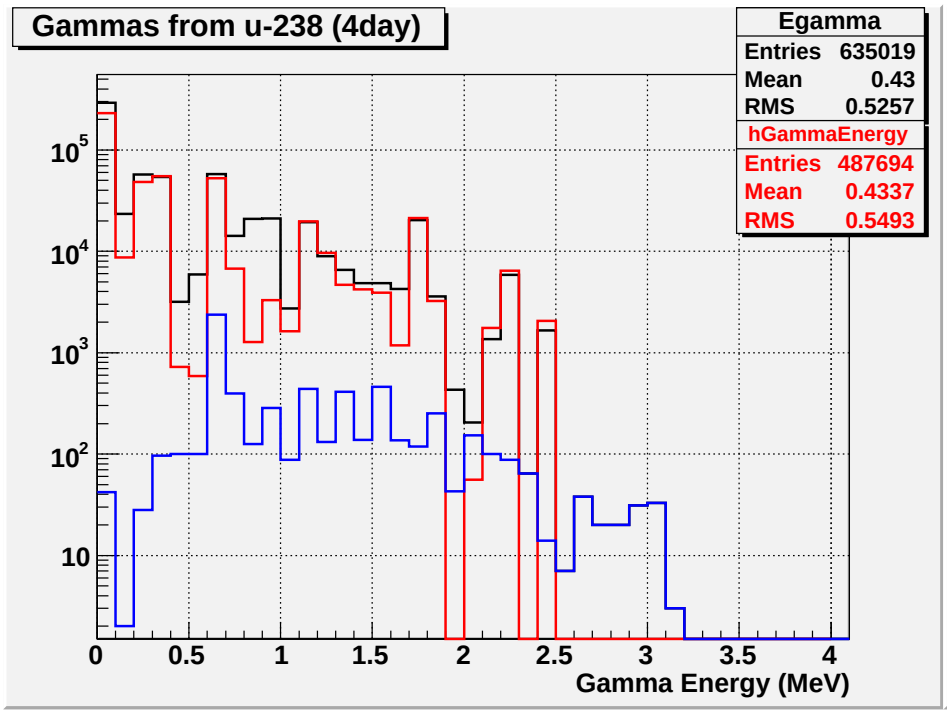
E_β spectra

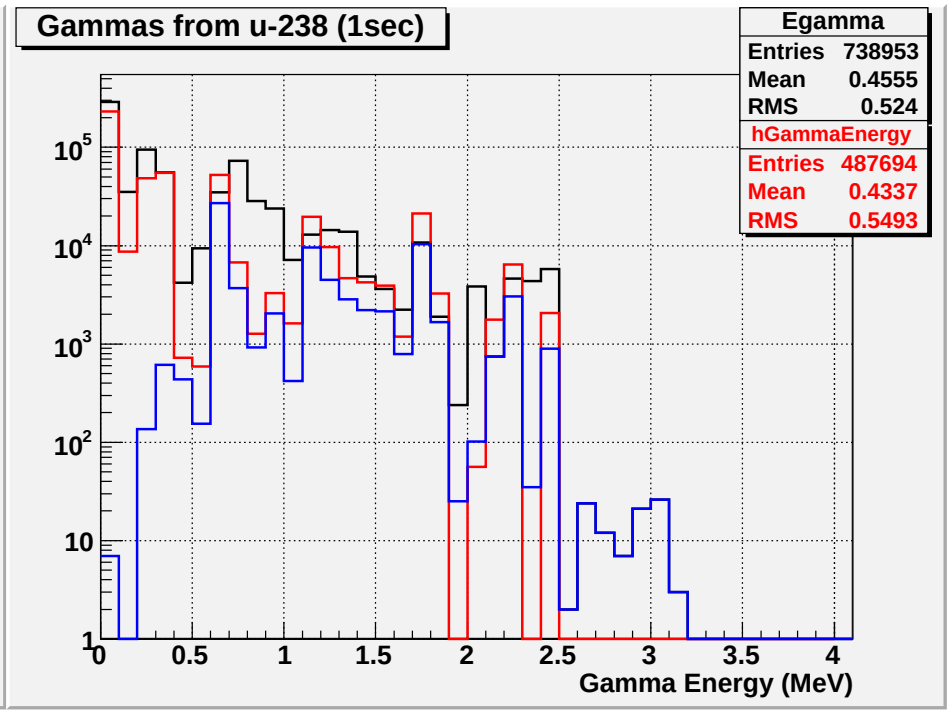




- Mostly reproduce AP shape using 4 day correlation time.
- More realistic correlation time shows some missing beta energy.
- Missing is rare ^{214}Bi α-decay to ^{210}Tl which β-decays with $E_{\beta,max} = 4.4$ MeV
  - **blue curve** shows this contribution to **total** GenDecay spectrum.

E_γ spectra





Apparent AP generator problems:

- Many γs not included.
- No γs above $\sim$2.5MeV
  - In GenDecay, these come from ^{214}Bi excited states.
  - Not checked why AP generator lacks them.

Summary & Future Work

Summary:

- A new data-driven, general-purpose radioactive decay generator engine and GenTool have been developed.
  - Better integration with Gaudi and removes need for FORTRAN.
- Some apparent deficiencies found with current ^{238}U generator.

Future work (open to interested parties!):

- Check ^{232}Th spectra in same manner as ^{238}U.
- Convert other Radioactivity generators.
- Include other decays (eg. "radiated" N & P)
- Survey for any not-yet-considered nuclei?
- Consider expanding scope / applying `libmore` to n-capture.[7]

[7] In talks with David.