

supernemo



Quantifying low energy backgrounds in SuperNEMO double-beta experiment

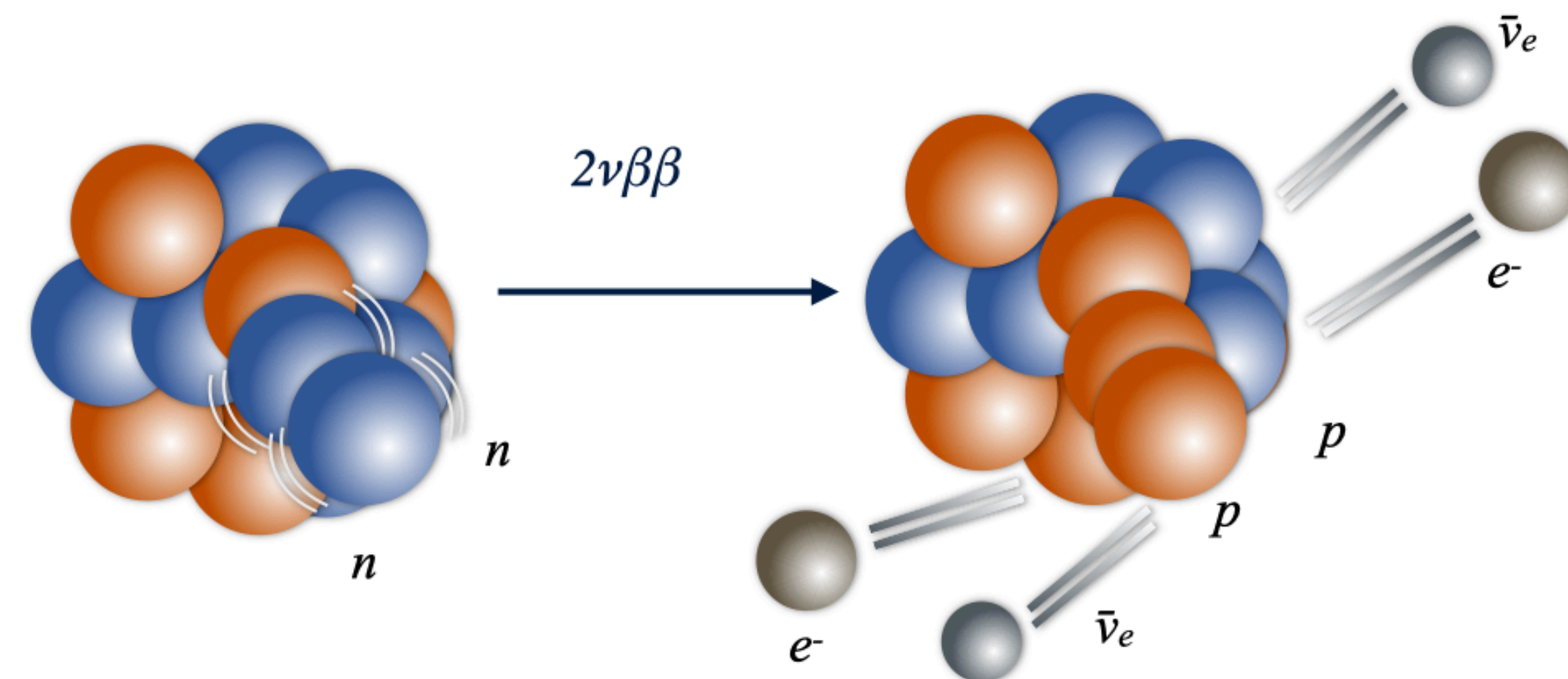


Gil Turnbull - Annual APP and HEPP Conference 2026



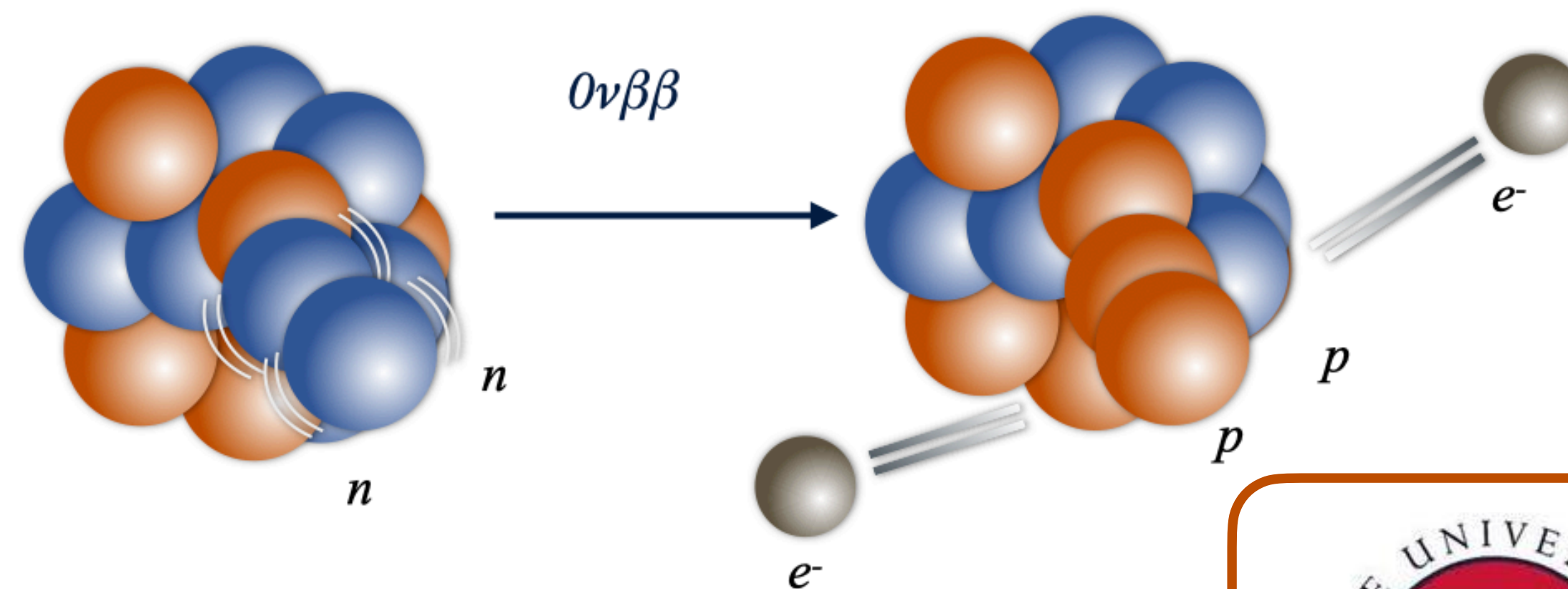
$2\nu\beta\beta$ - Standard model process

- ➔ Observed in 14 isotopes ¹
- ➔ Q-values a few MeV
- ➔ Half-life of around 10^{20} years



$0\nu\beta\beta$ - Beyond standard model process

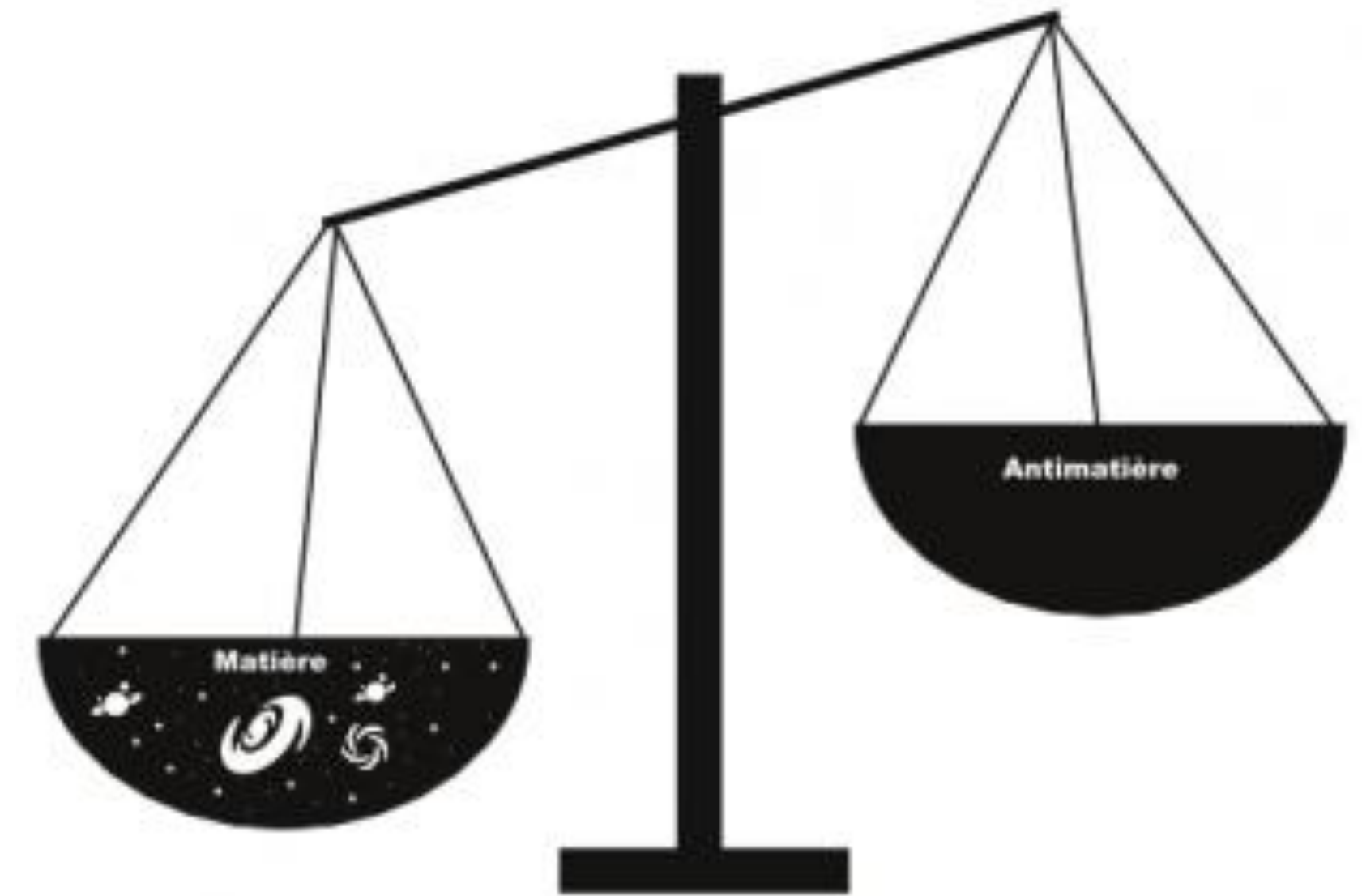
- ➔ Unobserved half-life $> \sim 10^{26}$ years
- ➔ $0\nu\beta\beta$ same Q-Value



1. <https://doi.org/10.1016/j.adt.2024.101694>

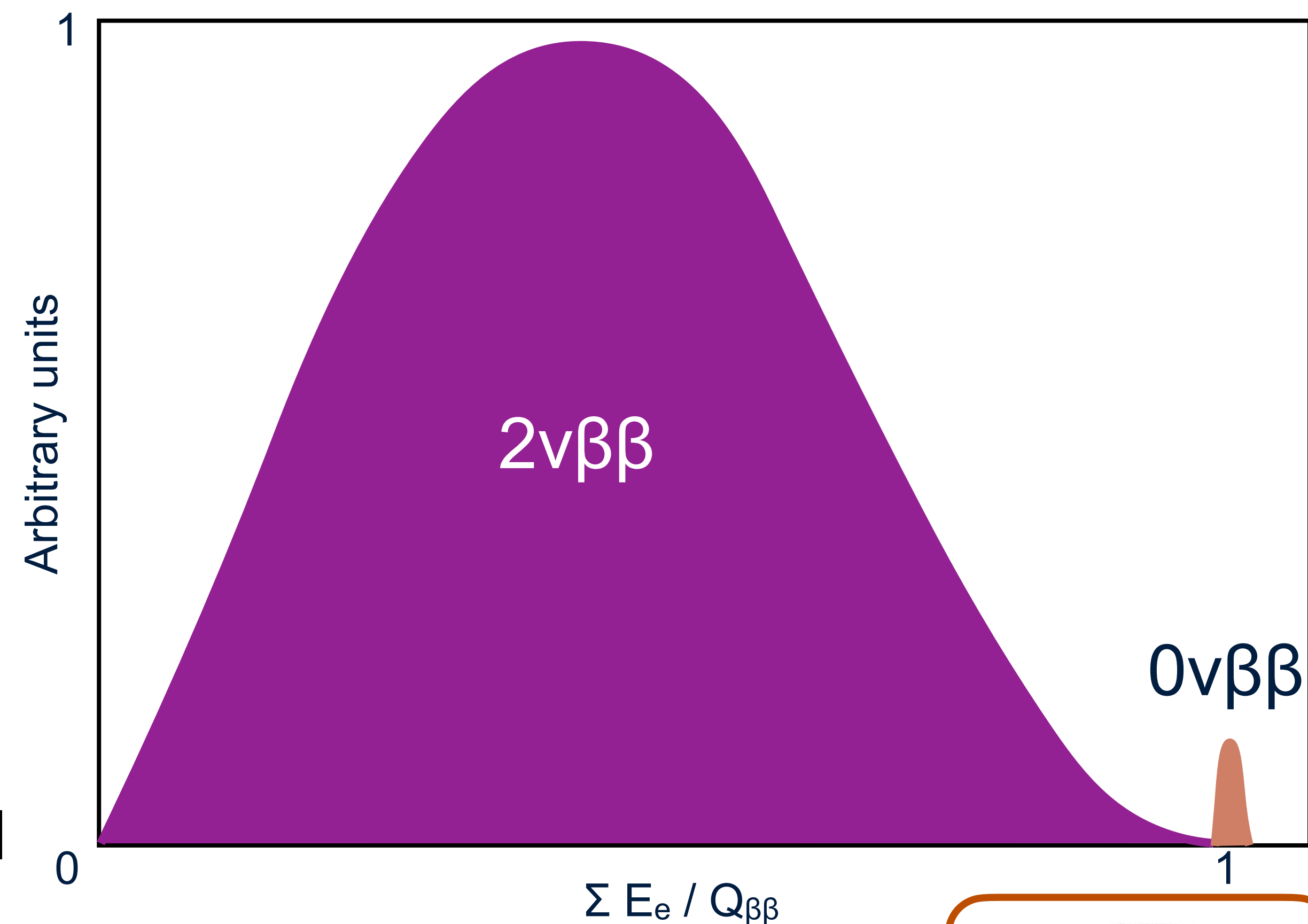
Why search for $0\nu\beta\beta$

- ➔ Proves neutrinos are Majorana
- ➔ Information about neutrino mass
- ➔ Matter/ antimatter asymmetry
- ➔ Violates lepton conservation

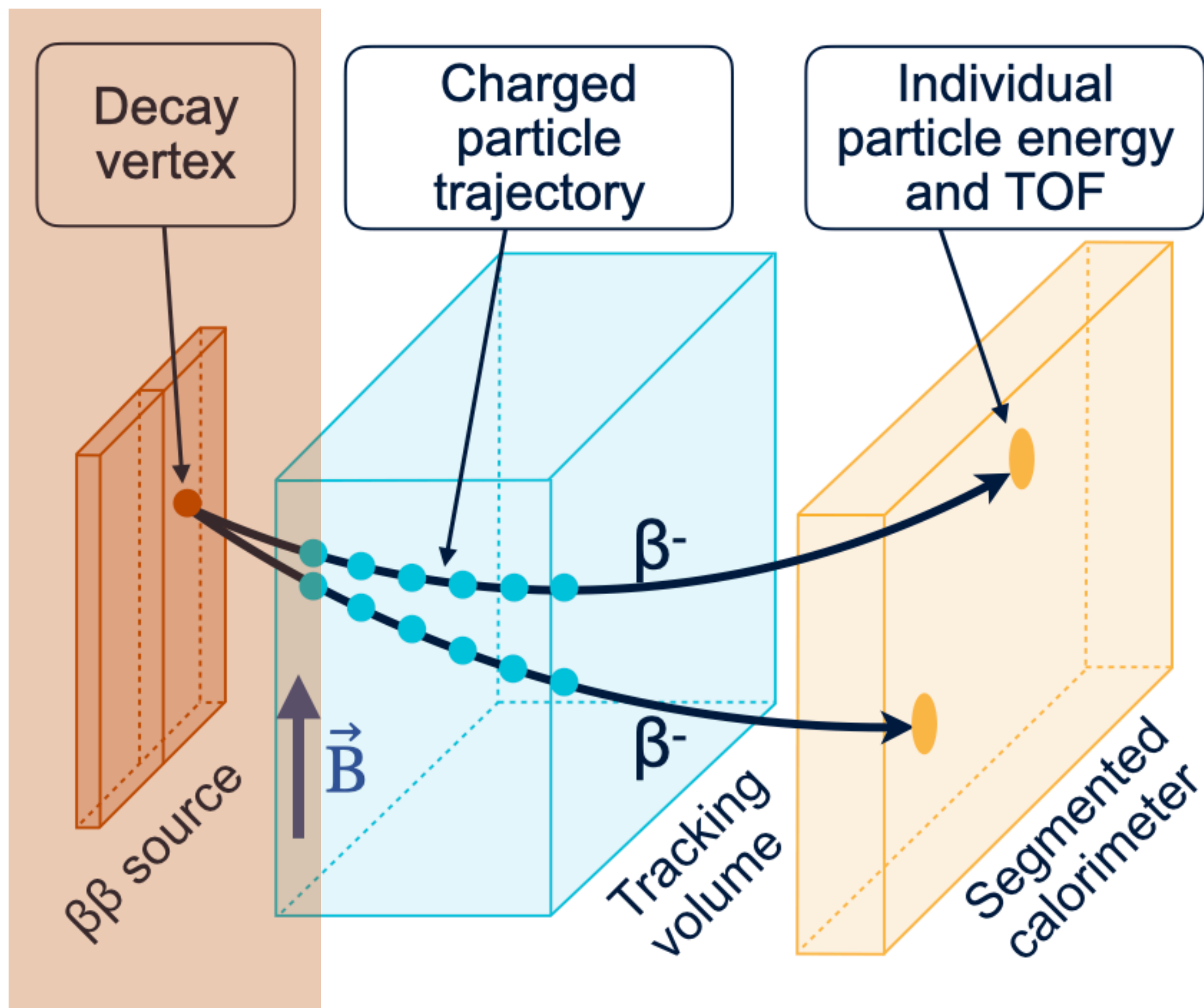


Energy spectrum

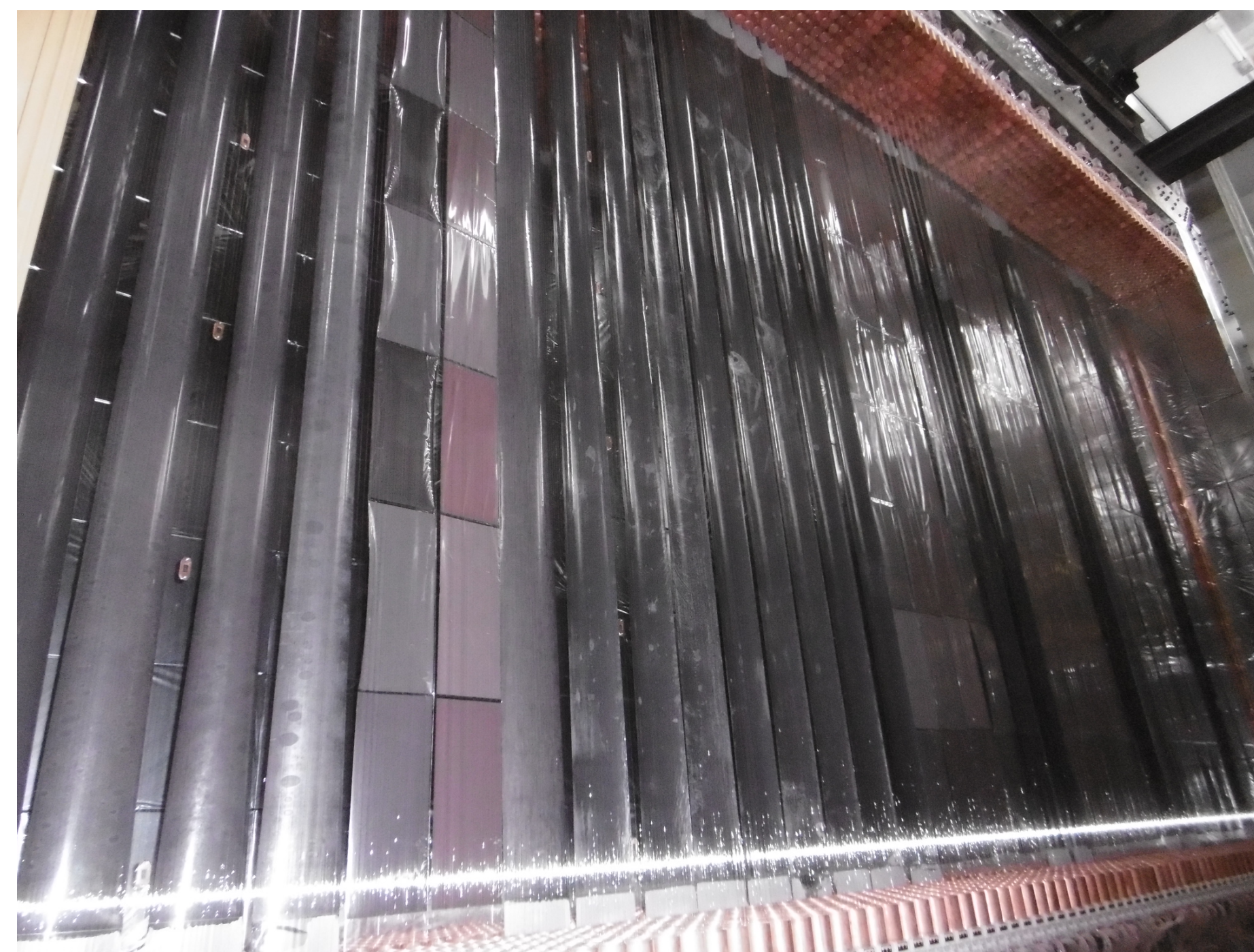
- This is the summed electron energy
- $2\nu\beta\beta$ continuous spectrum
- $0\nu\beta\beta$ peak at the Q-value
- What if we knew more than the summed energy (eg, particle id, topology, individual energies)



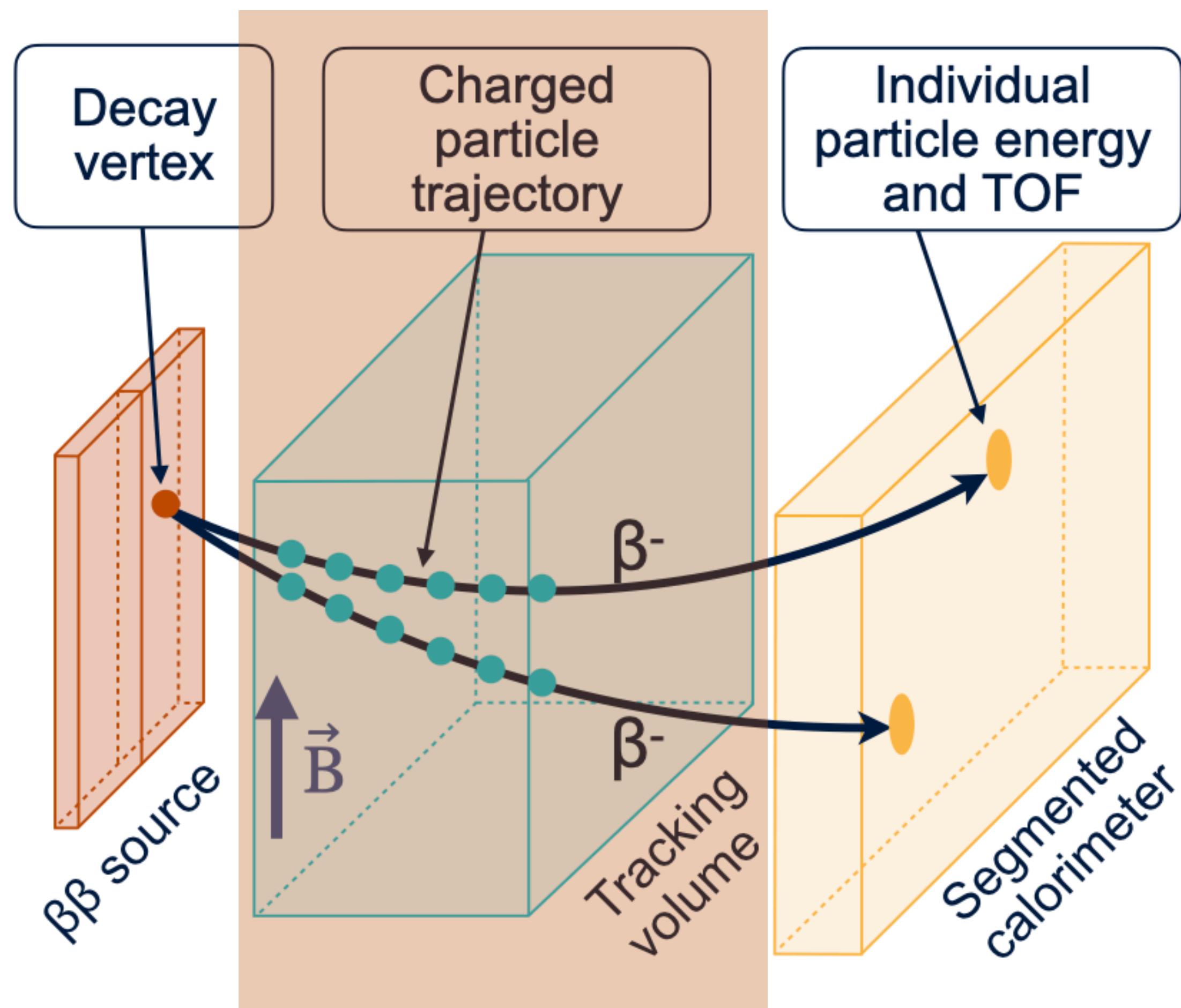
The SuperNEMO detector



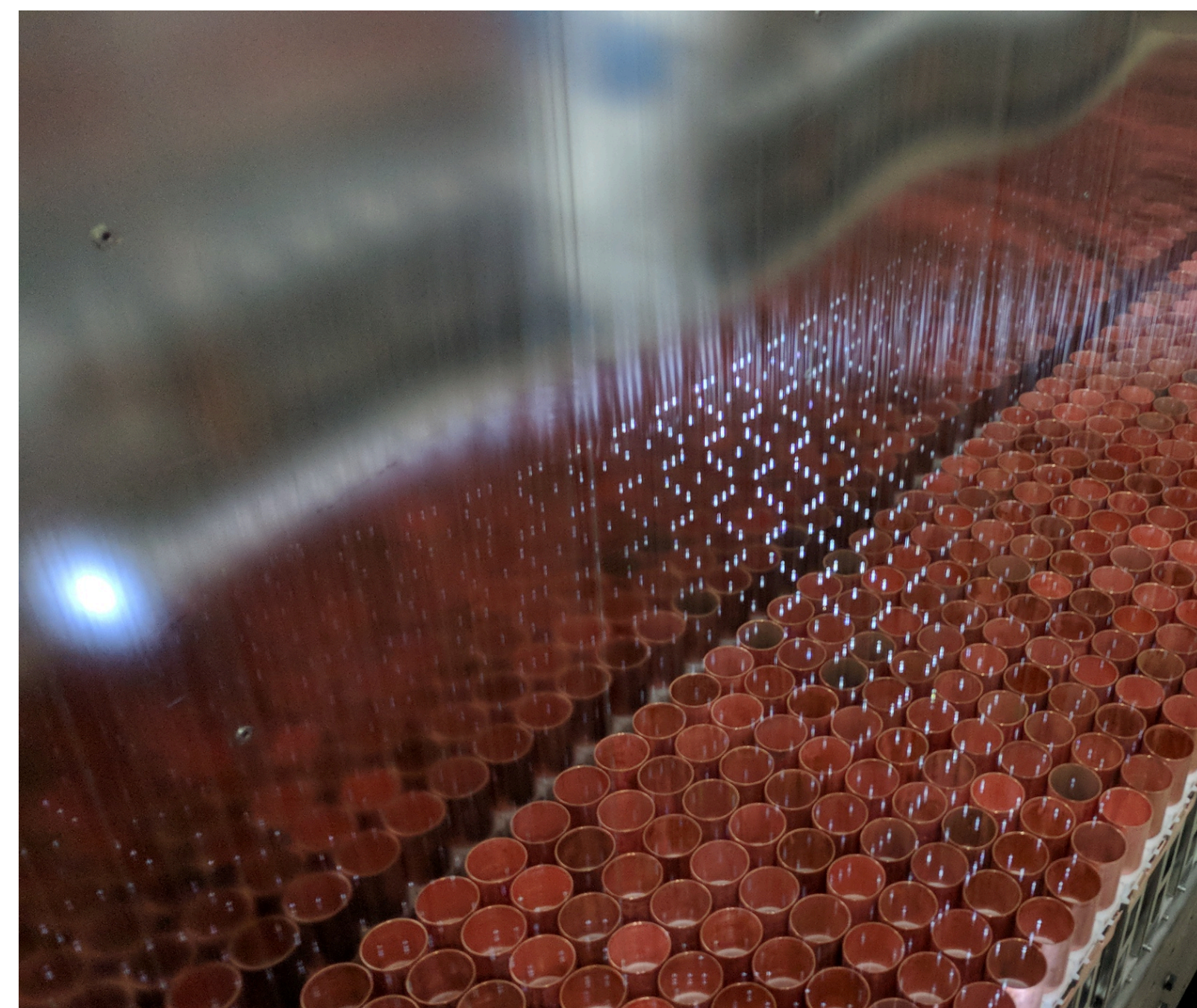
Selenium-82 foil - $\beta\beta$ source Q-Value 3MeV



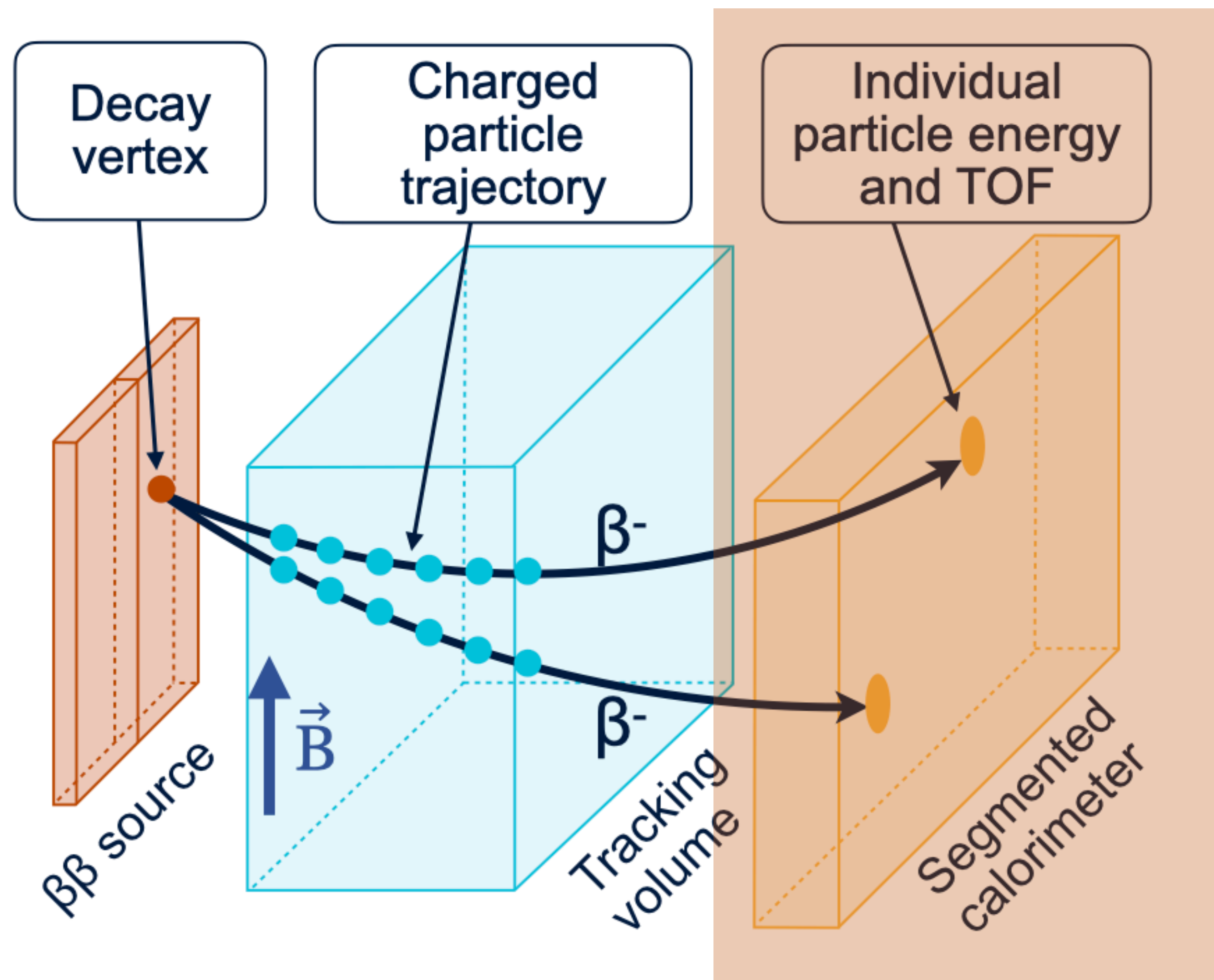
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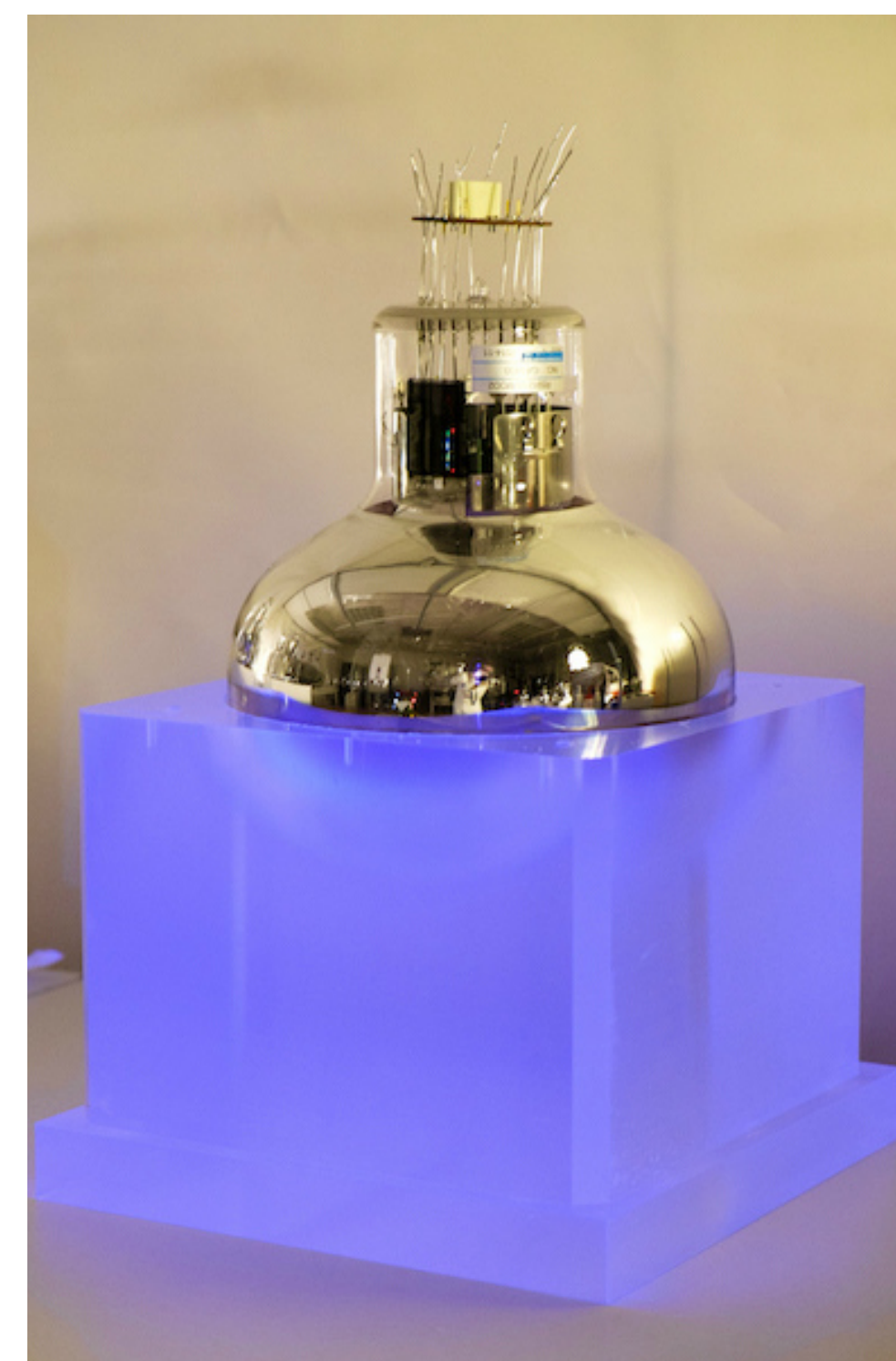
Tracker - Geiger cells allows full 3D picture of charged particles



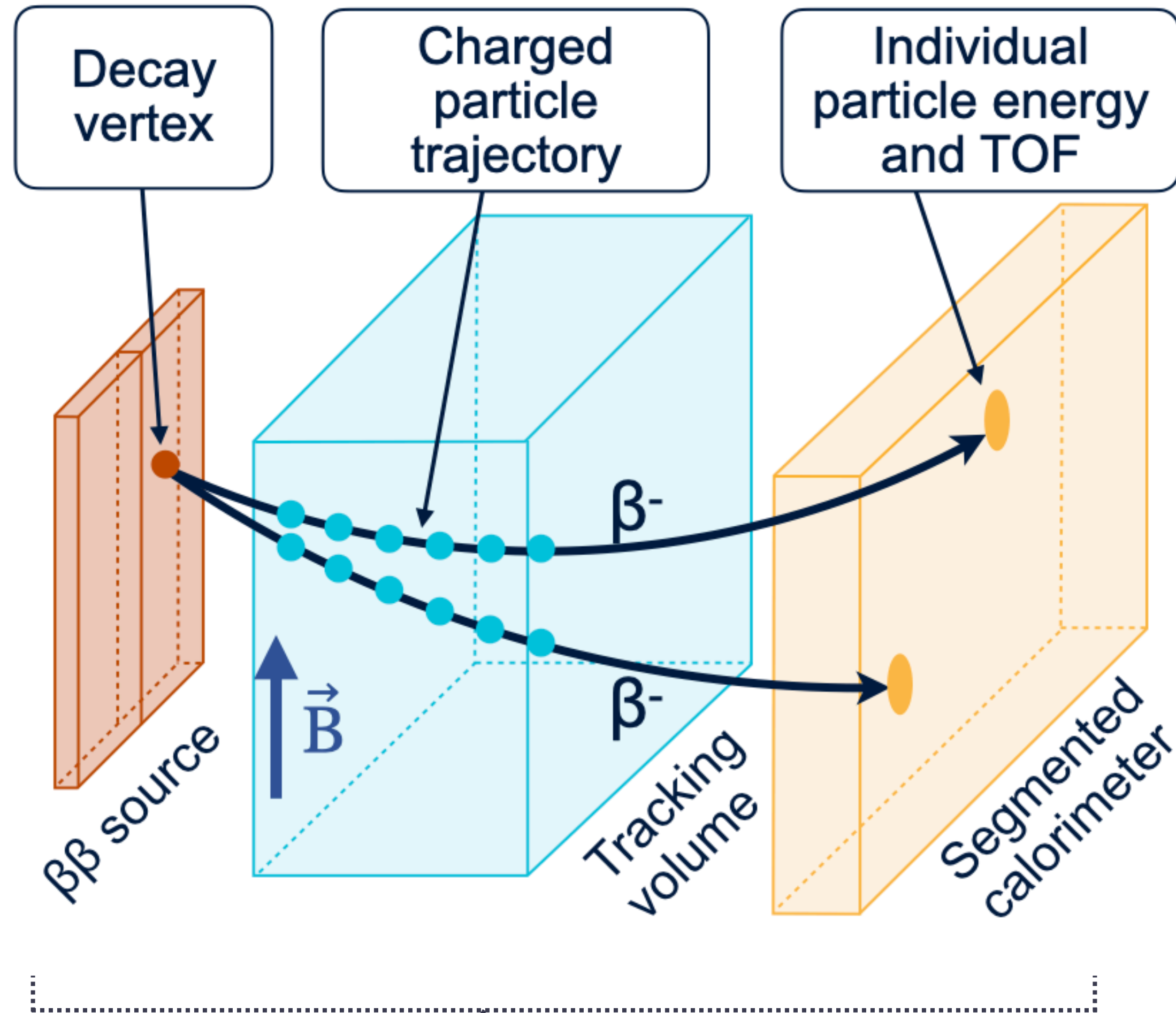
The SuperNEMO detector



Calorimeter - Measure individual energies from electrons



The SuperNEMO detector



Selenium foil - $\beta\beta$ source Q-Value 3MeV

Tracker - Geiger cells allows full 3D picture of charged particles

Calorimeter - Measure individual energies from electrons

Provides full event topology



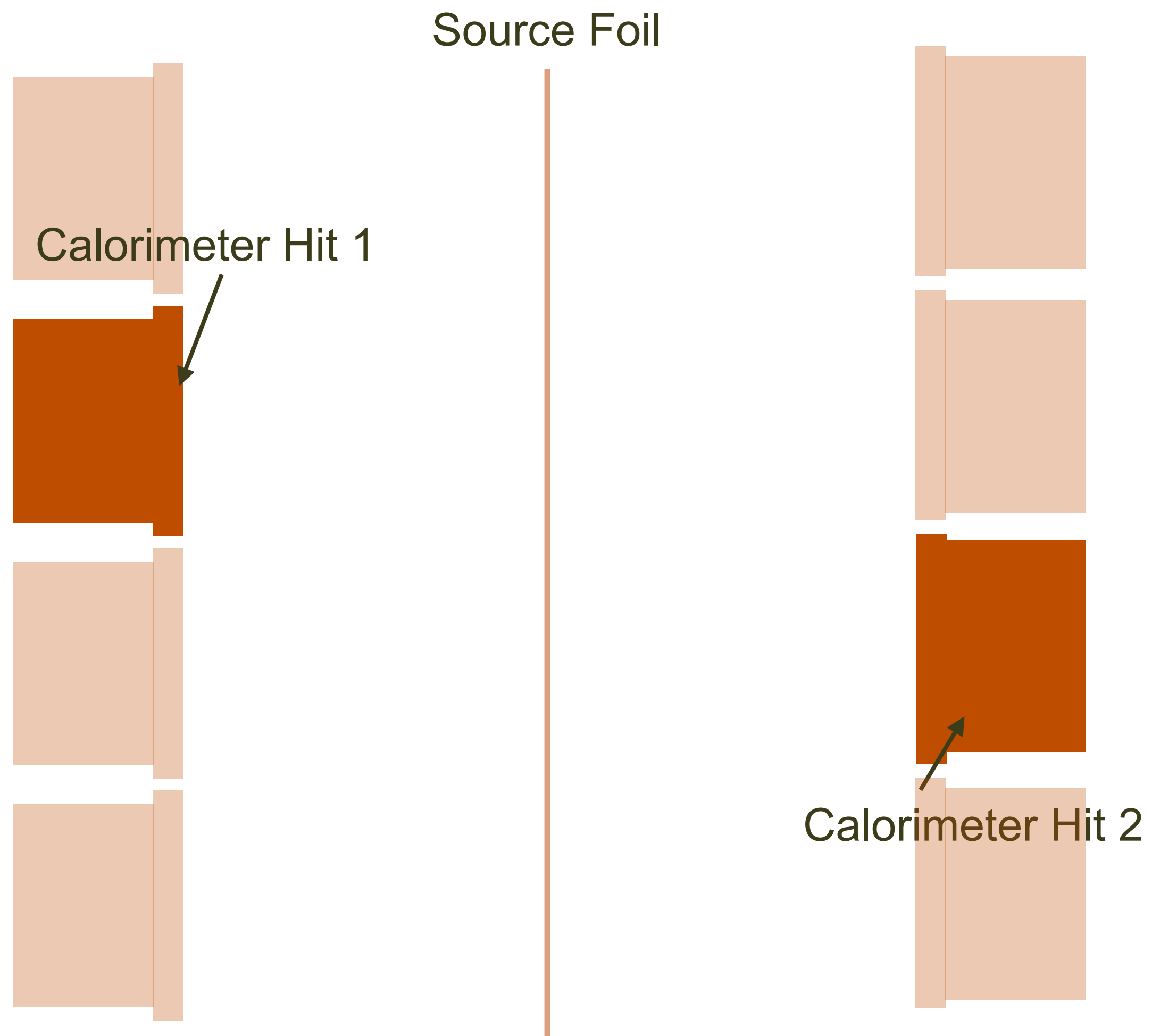
What Topology gives

- Can identify α , γ and electrons
- Vertex and track reconstruction
- Energies and angles
- Can help reduced backgrounds

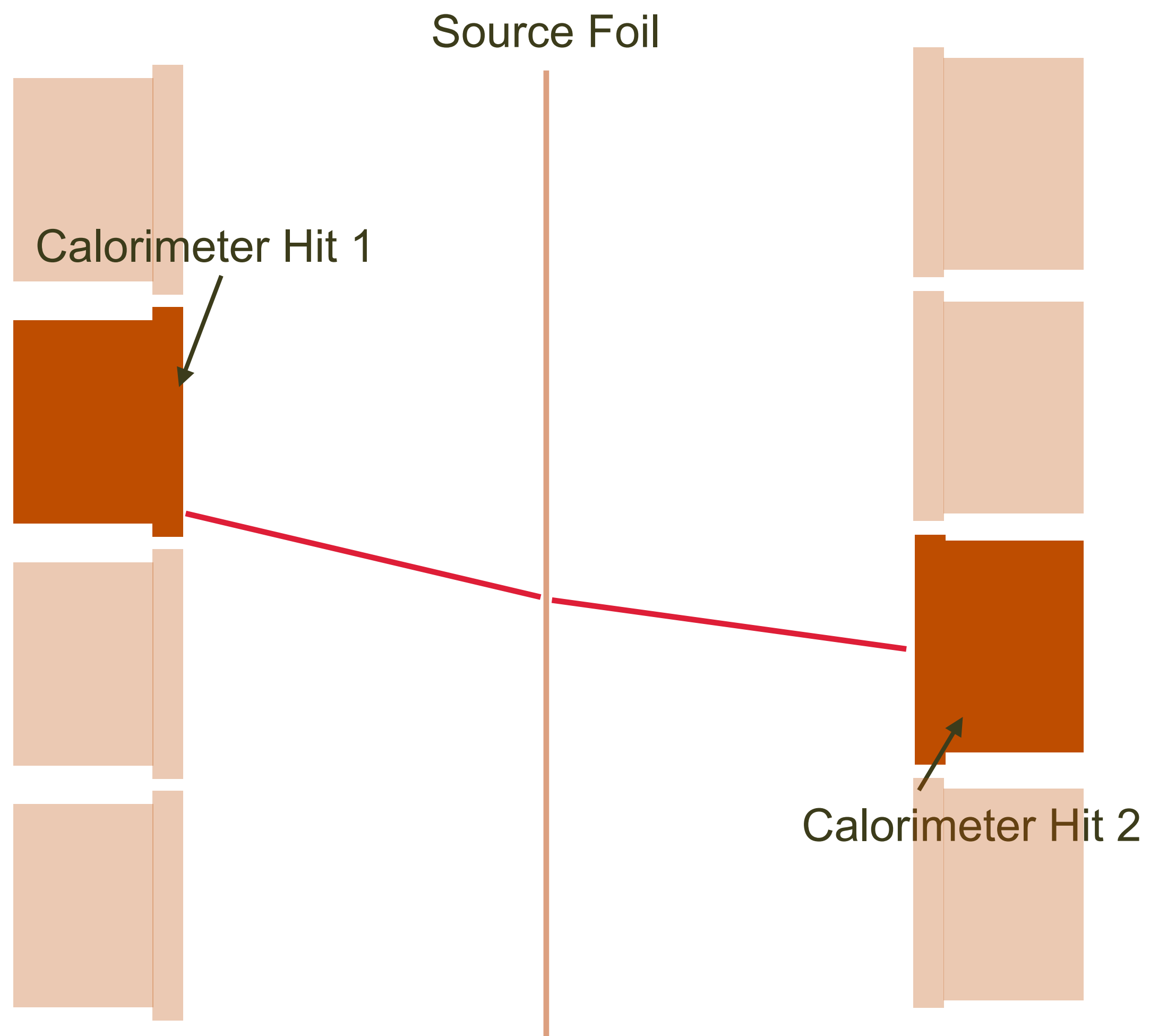
Why Topology helps

- Better understanding of $\beta\beta$ decays (0ν mechanism, 2ν mechanism)
- Better understanding of nuclear processes and exotic decays
- Helps to find the “Golden $0\nu\beta\beta$ ” events

Sketch of a $\beta\beta$ candidate



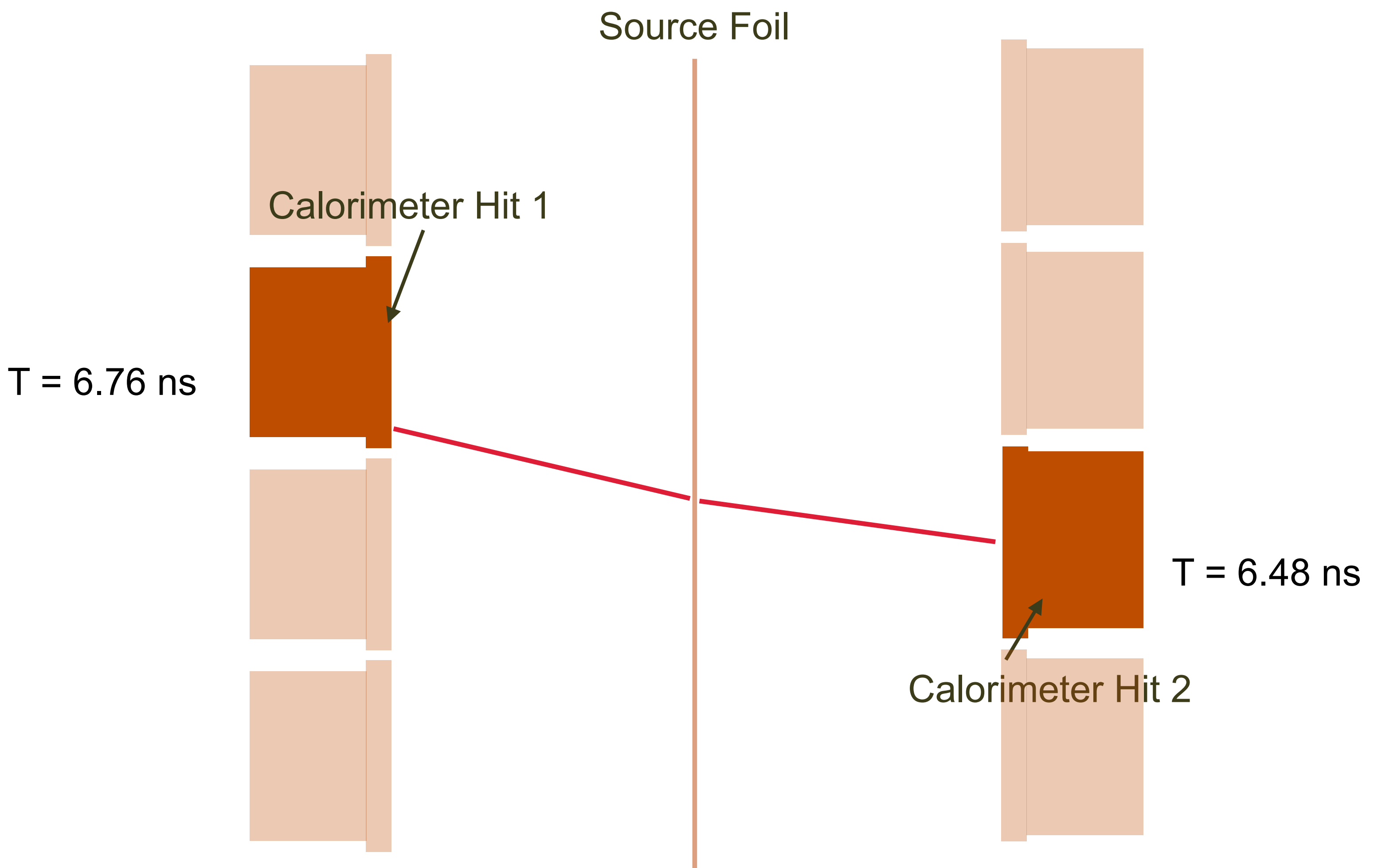
Sketch of a $\beta\beta$ candidate



Shared vertex - possible $\beta\beta$



Sketch of a $\beta\beta$ candidate

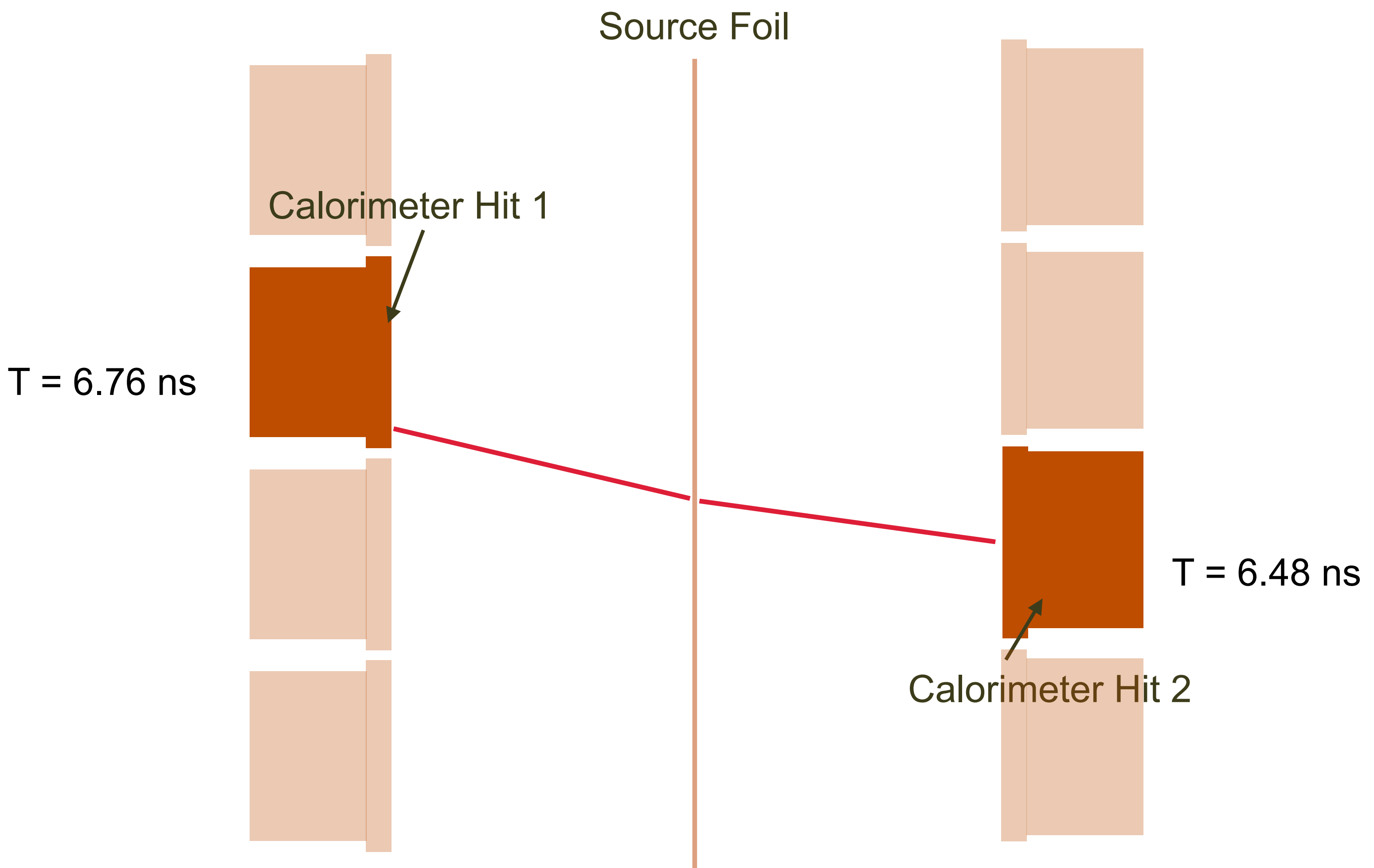


Shared vertex - possible $\beta\beta$

Timing - suggest common source in foil (delta T between 2 hits)



Sketch of a $\beta\beta$ candidate



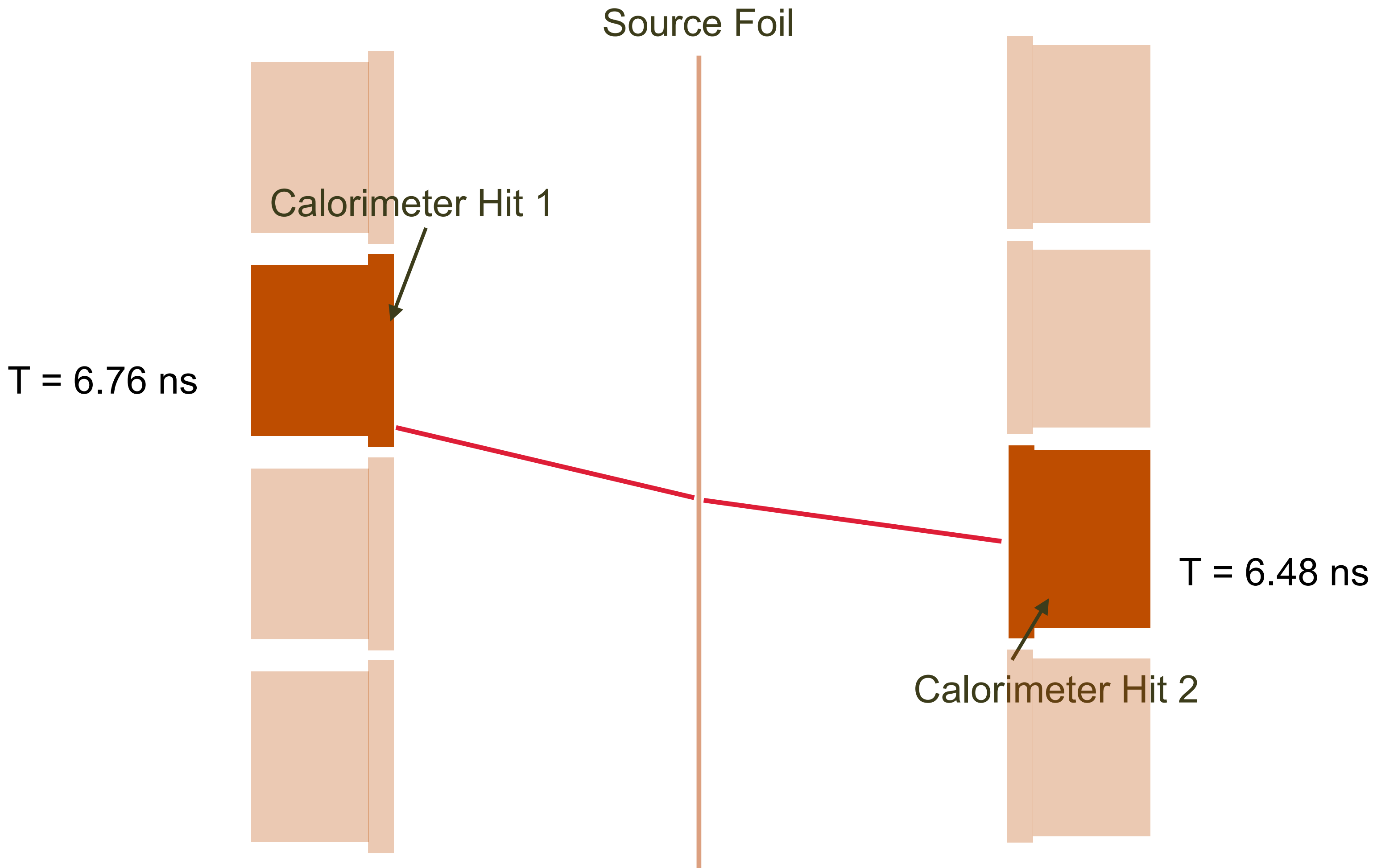
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Other particles - no other particles in event, $\beta\beta$!



Sketch of a $\beta\beta$ candidate



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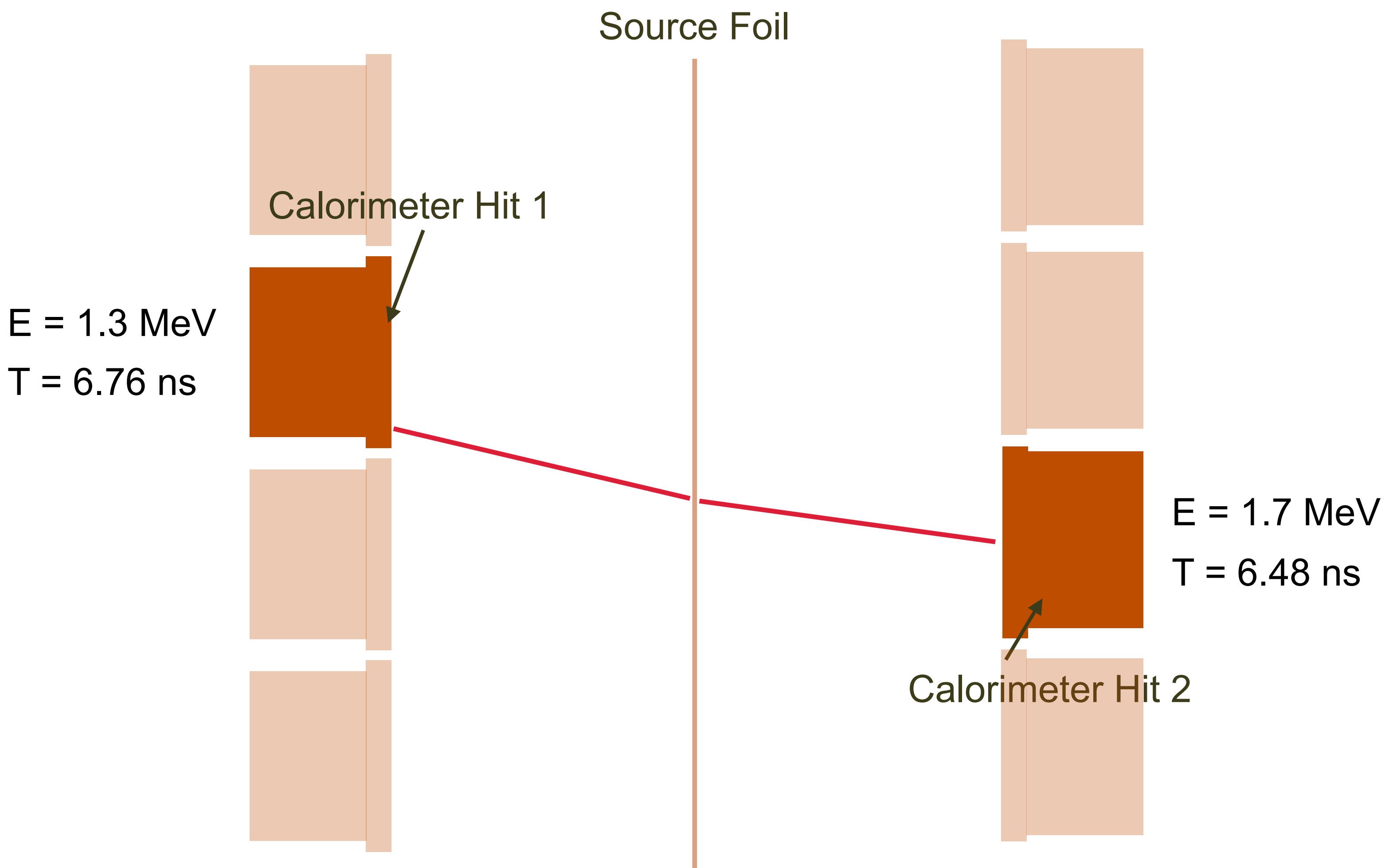
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Angle - can give mechanism



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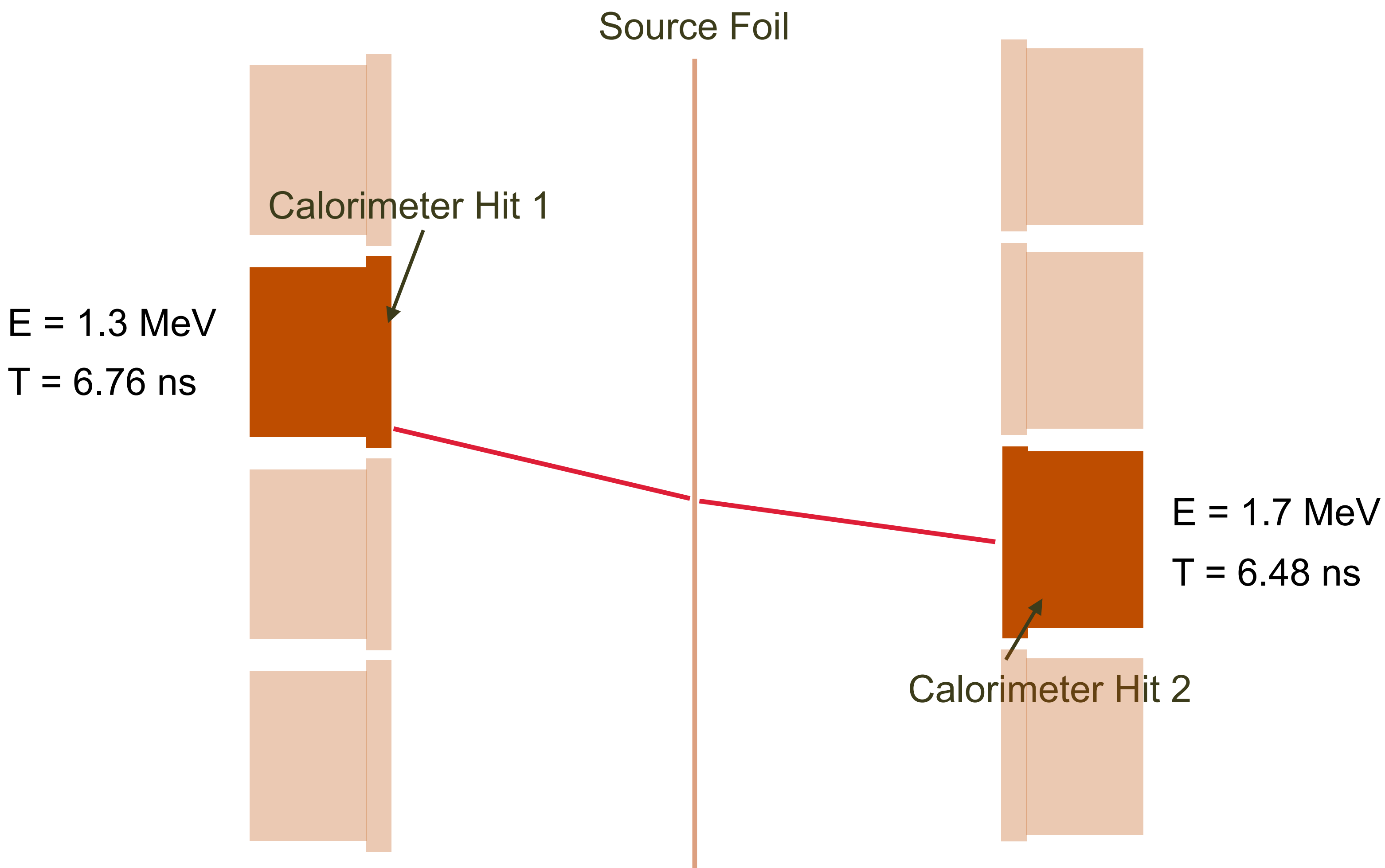
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Energy - Se82 has Q of 3MeV



Sketch of a $\beta\beta$ candidate



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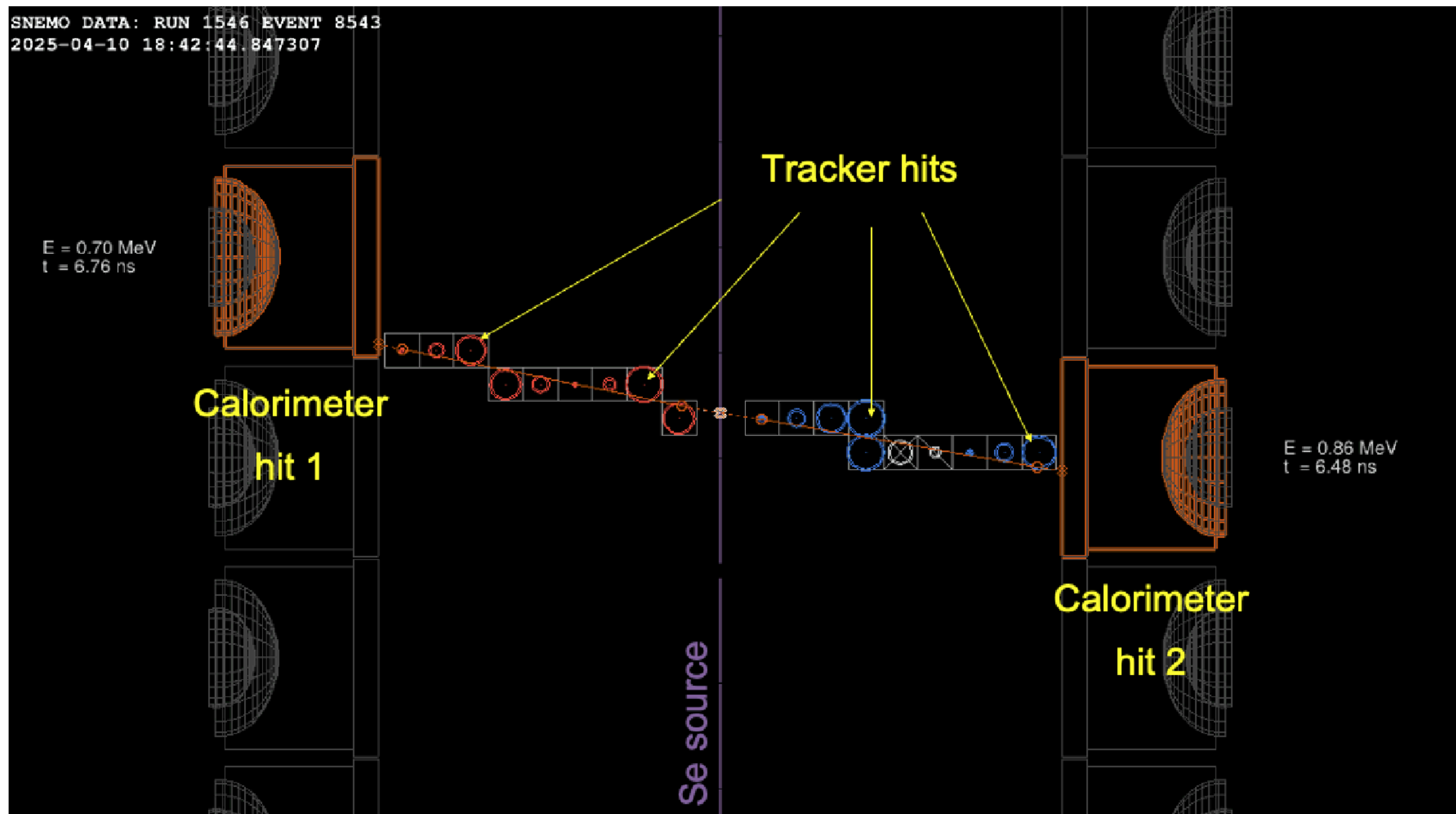
Angle - can give mechanism

Energy - Se82 has Q of 3MeV

Conclusion - "Golden"

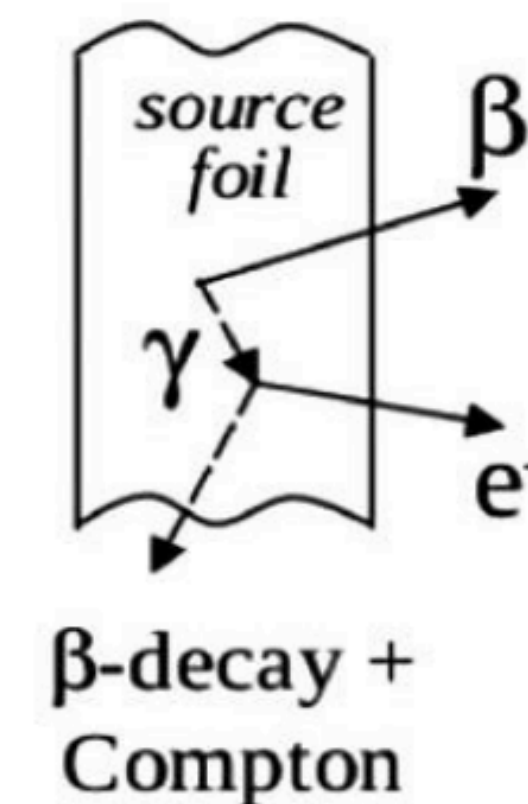
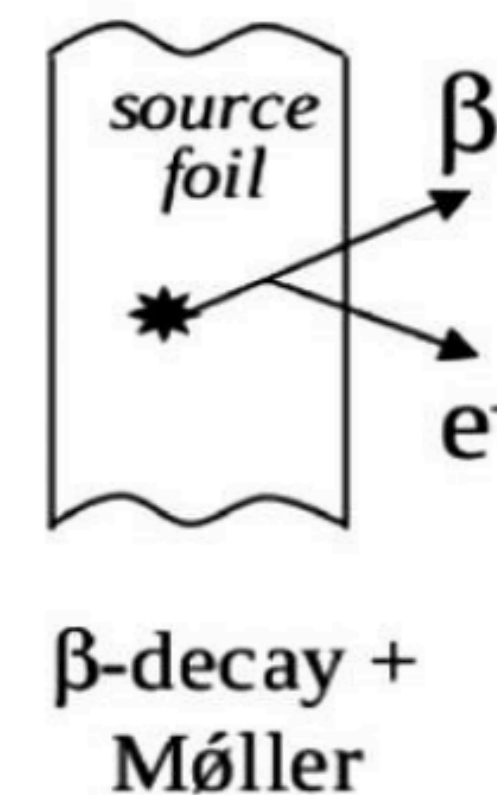
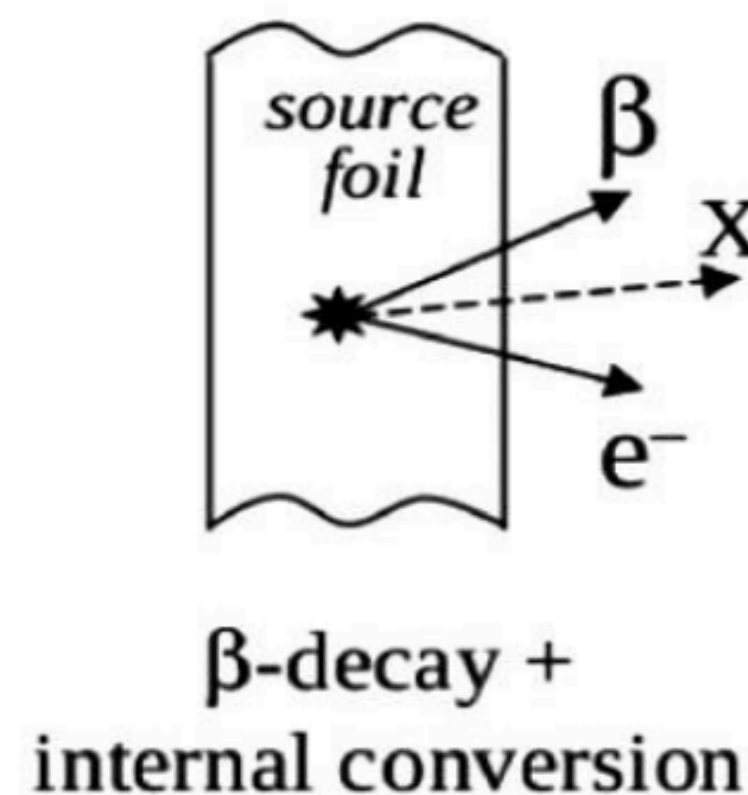


SuperNEMOs first Double-beta candidate!

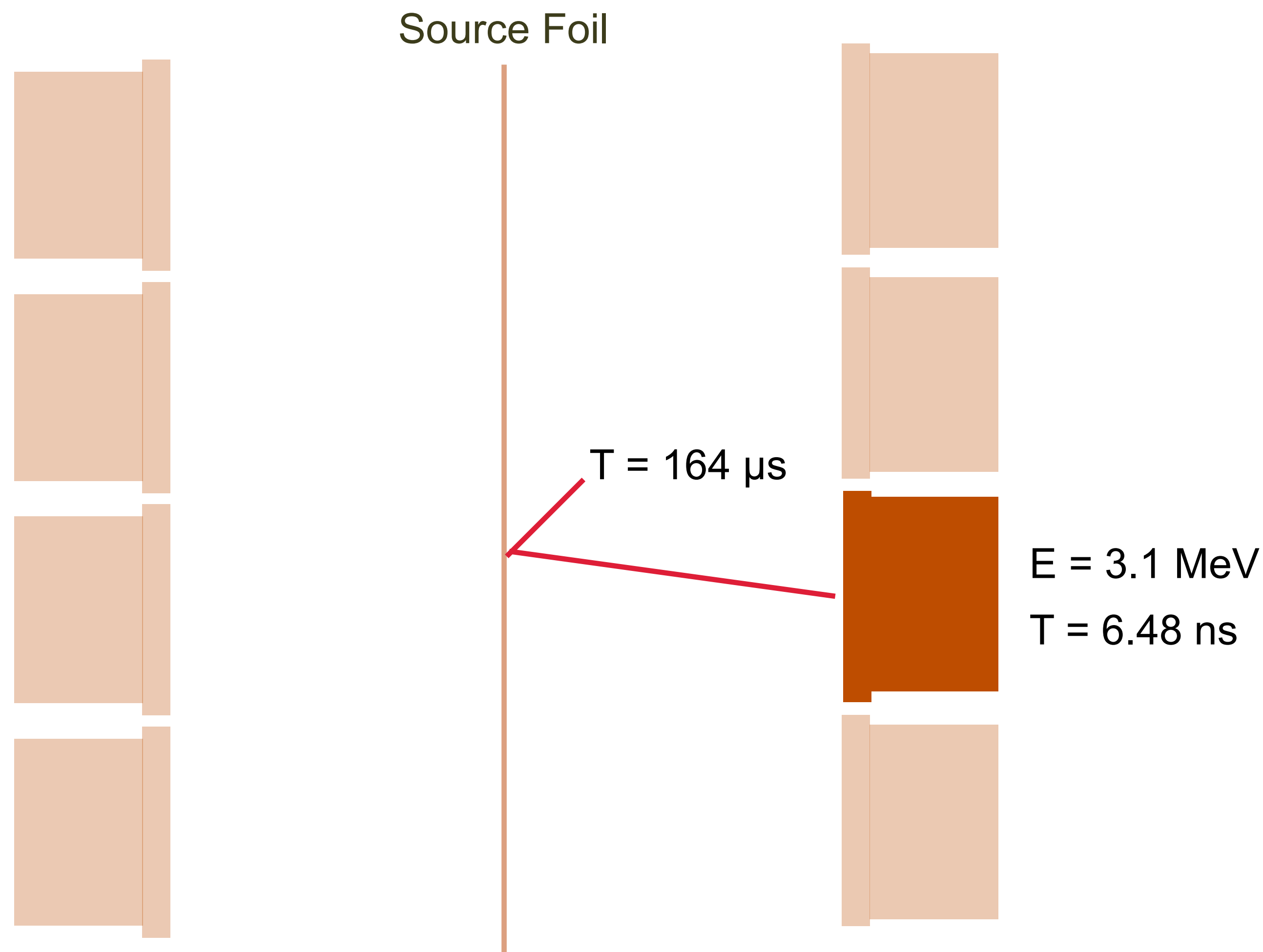


Backgrounds

- ➔ Internal processes can mimic the $\beta\beta$ signal
- ➔ Even after topology cuts, there may be some $\beta\beta$ like events from β decays in the source foil like these
- ➔ measure the activity of isotopes and subtract their expected contribution to isolate the $\beta\beta$ energy spectrum
- ➔ Even tiny background contributions matter, as they can imitate $\beta\beta$ events or hide subtle signals



Sketch of a BiPo event - Bi214



β followed by delayed α - BiPo signature

Clean control channel - high efficiency

Critical background - Bi214
Q-value of 3.27 MeV

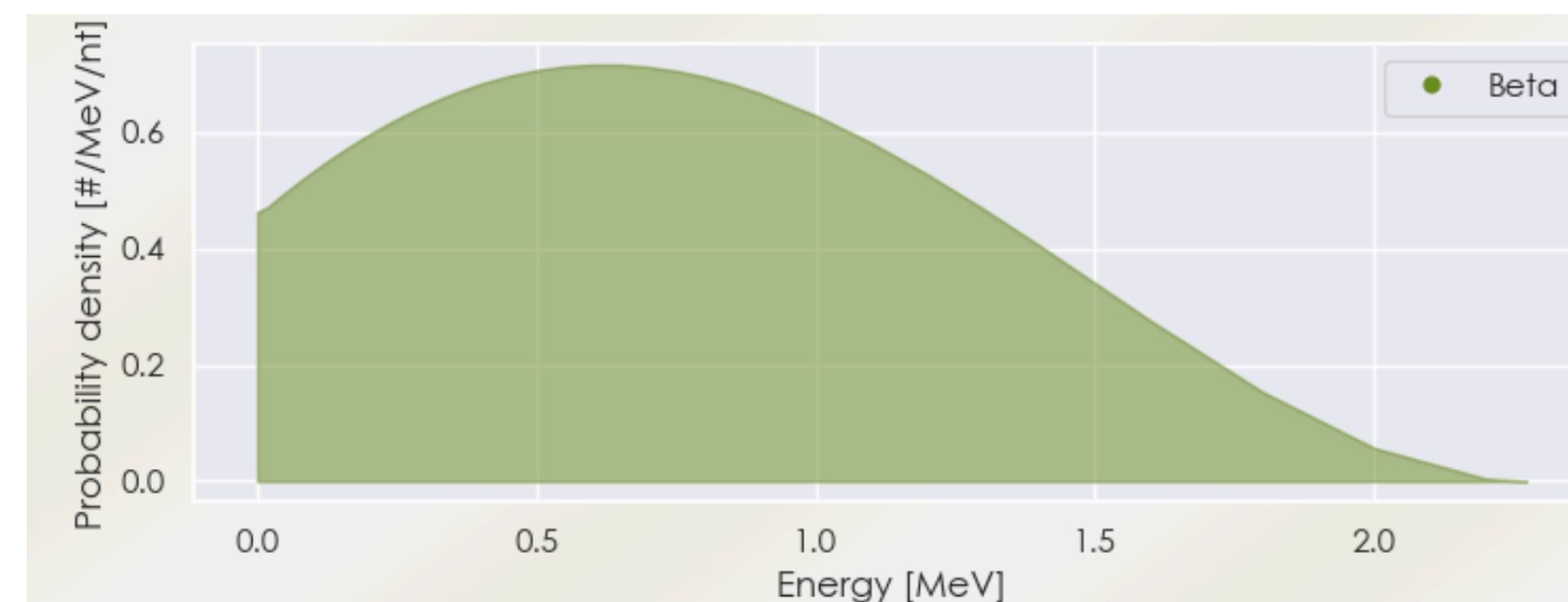


Single electron isotope measurement

- Low energy studies of the $2\nu\beta\beta$ spectrum we need to consider low energy β decayers

Isotopes to study

- Protactinium-234m (Pa234m) - 2.29 MeV

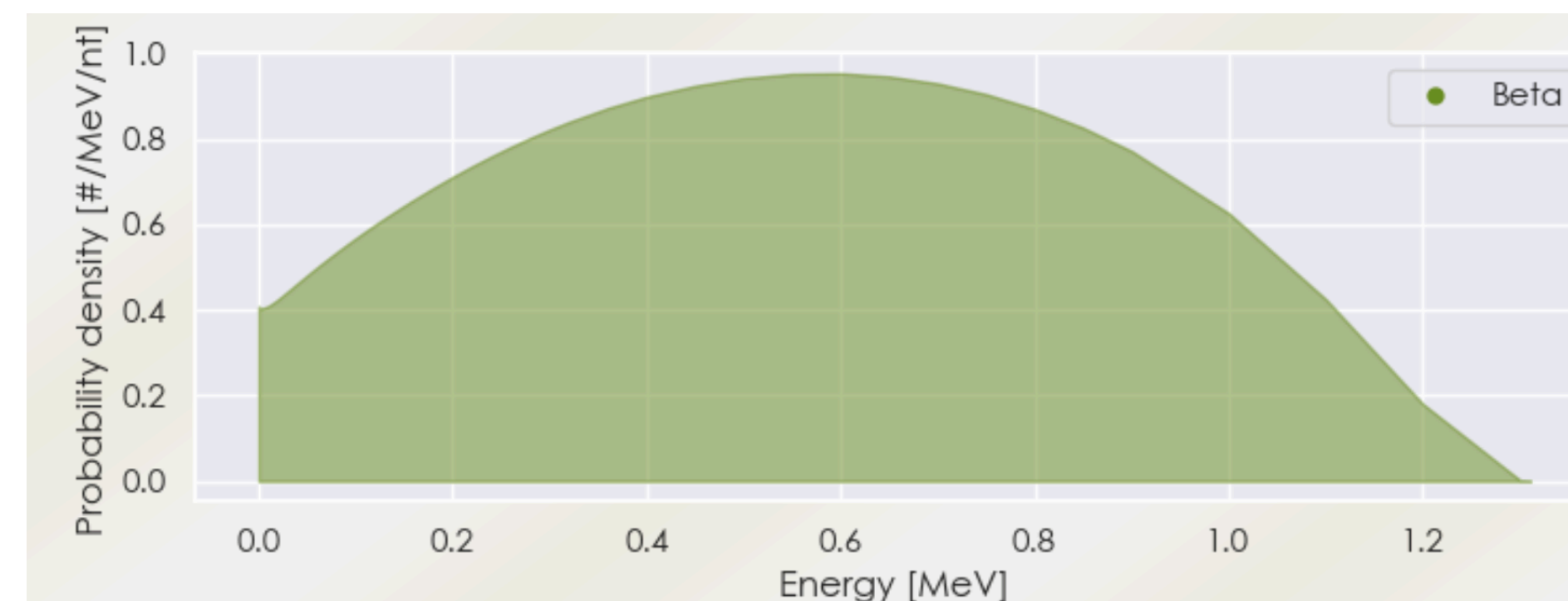
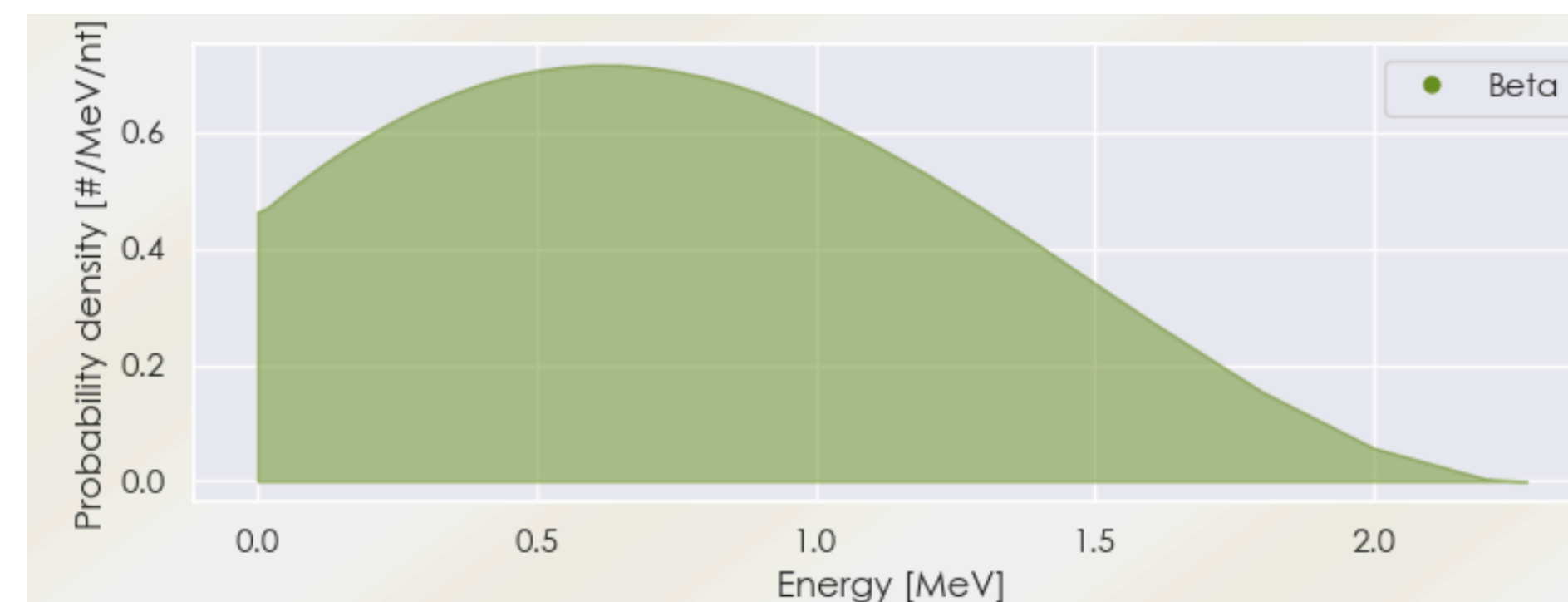


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- Protactinium-234m (Pa234m) - 2.29 MeV
- Potassium-40 (K40) - 1.31 MeV

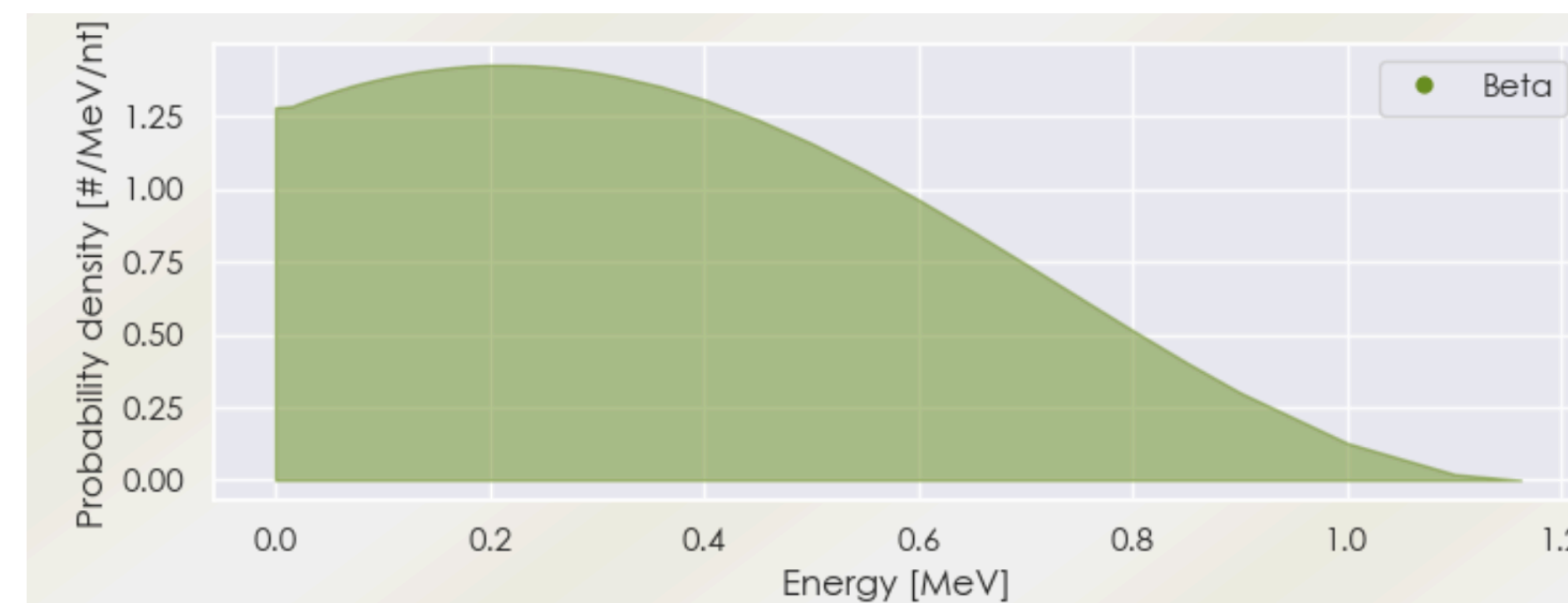
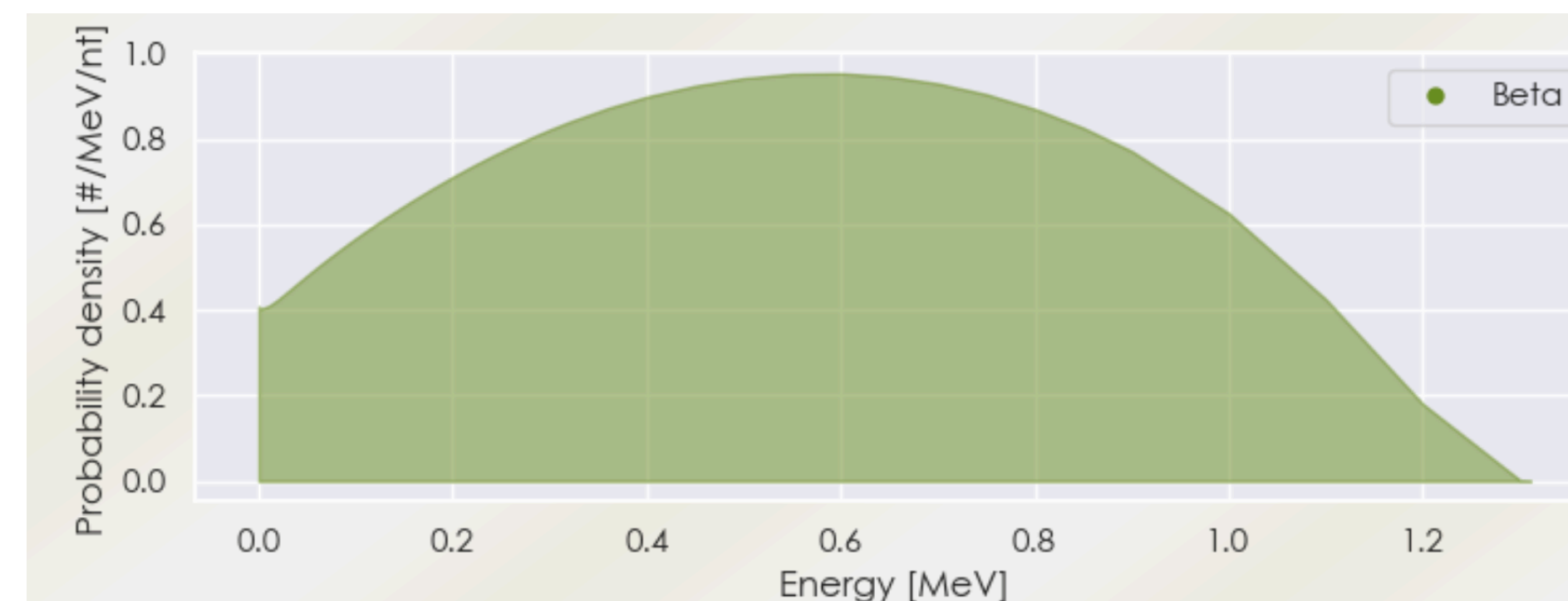
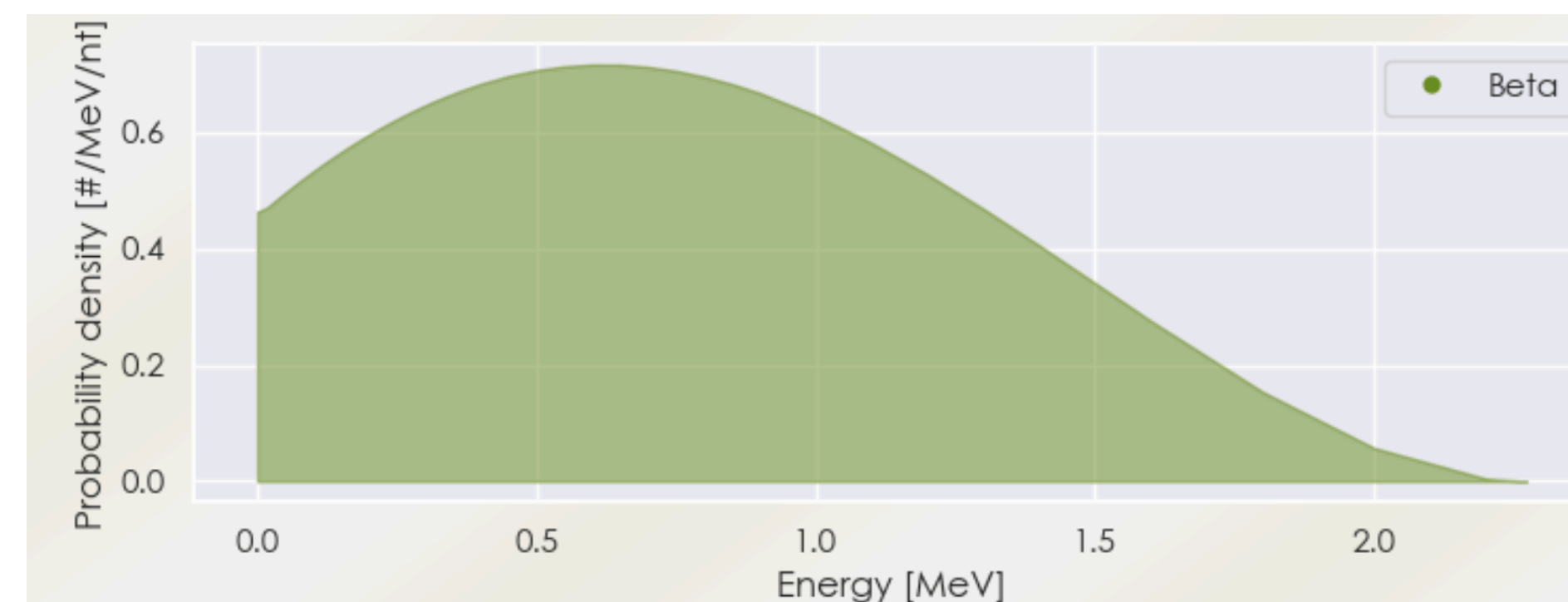


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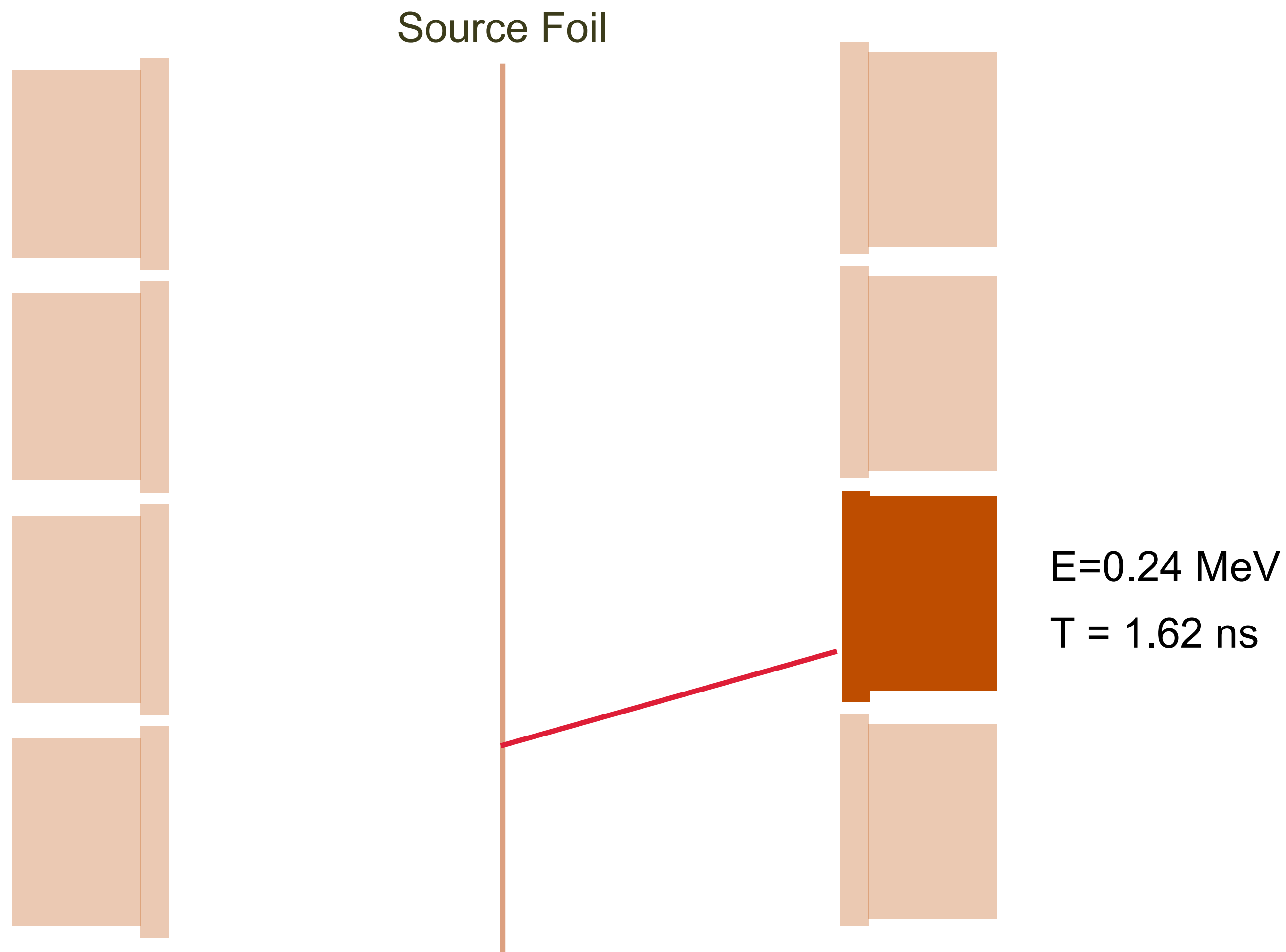
- Low energy studies of the $2\nu\beta\beta$ spectrum we need to consider low energy β decayers

Isotopes to study

- Protactinium-234m (Pa234m) - 2.29 MeV
- Potassium-40 (K40) - 1.31 MeV
- Bismuth-210 (Bi210) - 1.16 MeV



Sketch of a 1e event



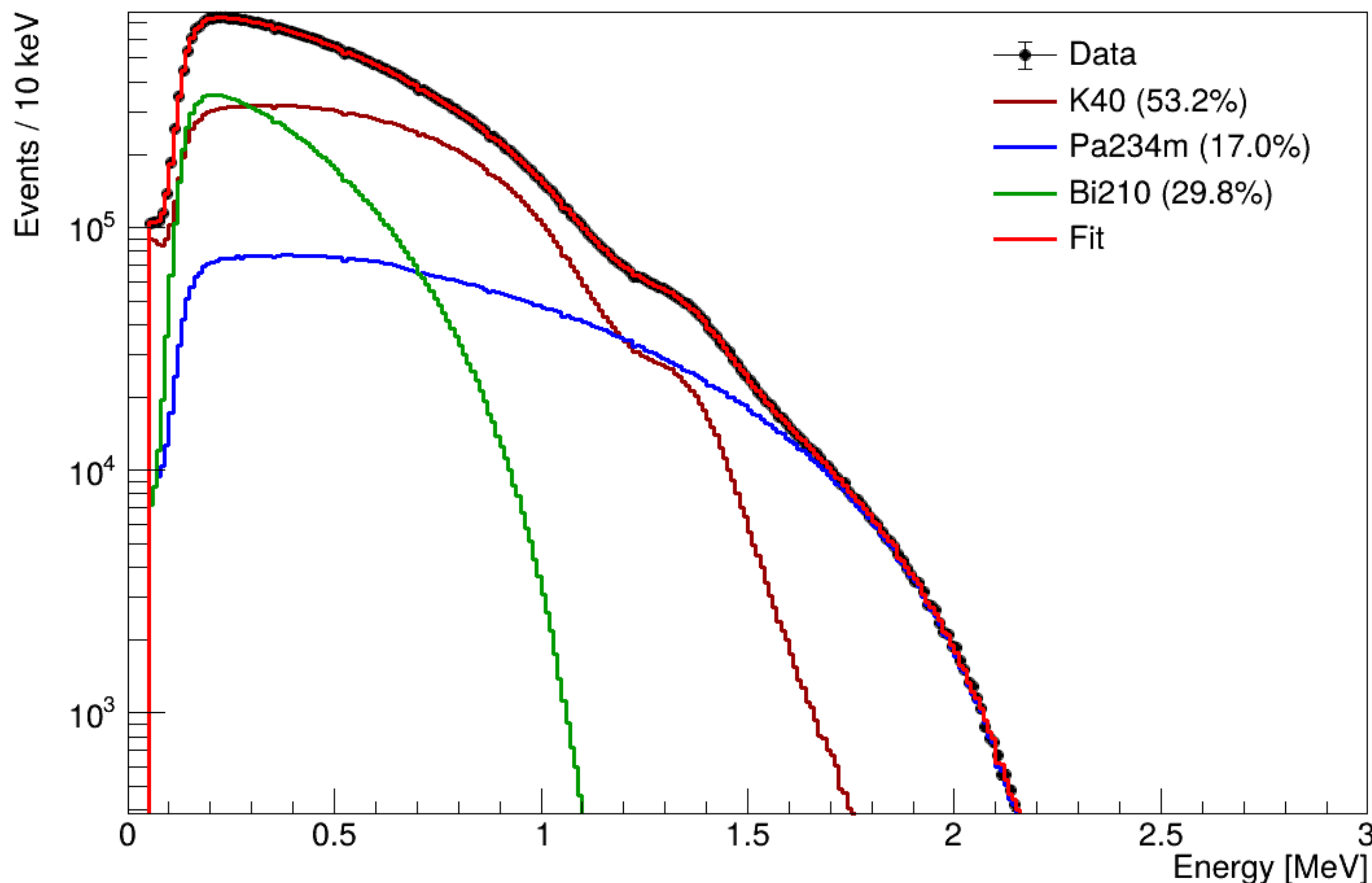
Tracker - 1 electron track from source to calo

Calorimeter - energy deposit on the calorimeter

Gammas - No associated gammas

Measure 1e backgrounds - how it will work

Toy Example



Data - Energy from real runs, cut for the 1e spectrum

Simulation - Same cuts applied to simulation

Use data and simulation - Energy spectra from simulation are fit to data

Measure activity - The best fit of each isotope will provide a measure of how much we see in the region of interest



From 1e Measurement to Expected 2e Events

- ➔ Measure the 1e spectrum for β isotopes
- ➔ Predict the expected 2e events using simulation and scale
- ➔ Quantifies the 2e background contribution from 1e channel



1e study summary

- SuperNEMO reconstructs **full event topology**, enabling powerful $\beta\beta$ signal/background discrimination and allowing $0\nu\beta\beta$ mechanisms and nuclear effects in 2ν .
- Background understanding is essential, especially from internal radioactive contaminants. Especially for nuclear measurements.
- The 1e channel will be used to measure K-40, Pa-234m and Bi-210 activities via MC-to-data spectral fits.
- These results will constrain the 2e background model.

