Radioactive nuclei stopped in nuclear track emulsion

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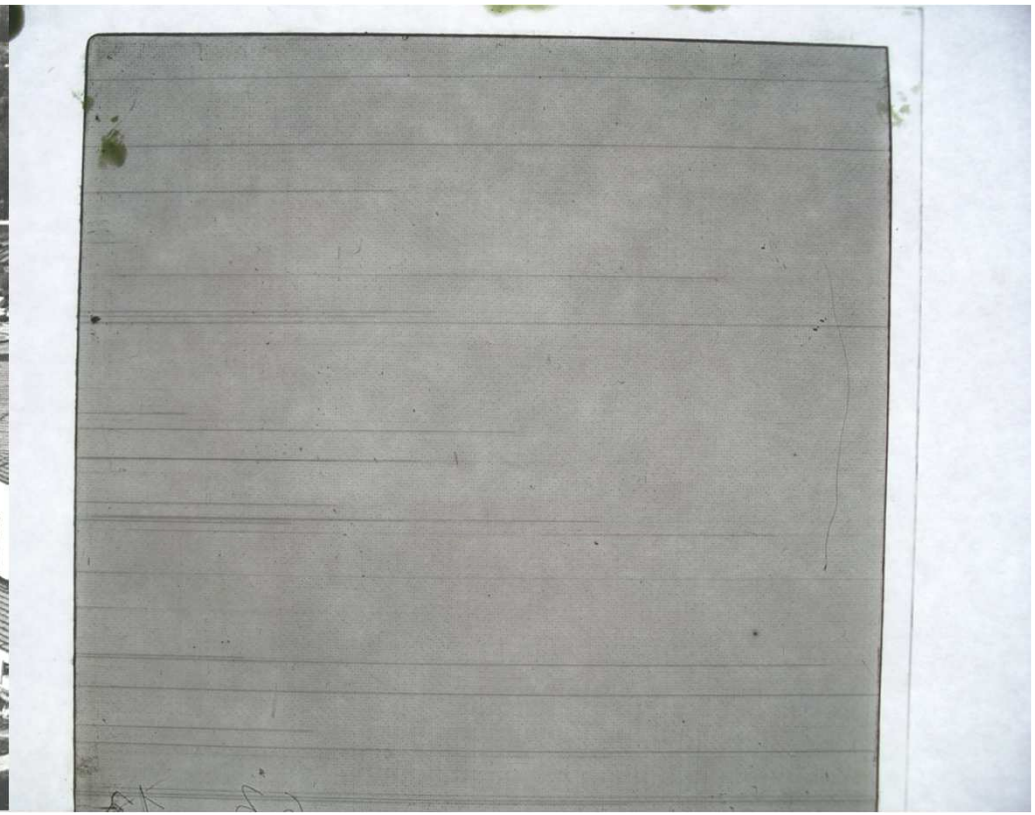
VBLHEP, JINR (for the BECQUEREL collaboration)

BECQUEREL at the JINR Nuclotron is devoted systematic exploration of clustering features of light stable and radioactive nuclei.



The fragmentation of a large variety of light nuclei was investigated using the emulsions exposed to few A GeV nuclear beams at JINR Nuclotron. A nuclear track emulsion is used to explore the fragmentation of the relativistic nuclei.

In the energy range of nuclei several MeV per nucleon, there is a possibility of implantation of radioactive nuclei into detector material. Of course, in this approach daughter nuclei are investigated rather than the nuclei themselves. In this respect it is worth mentioning the known, although somewhat forgotten, possibilities of NTE (Nuclear Track Emulsion) for the detection of slow radioactive nuclei. More than half a century ago, alpha tracks from the decay of ^{8}Be nuclei through the first excited state 2^{+} of about 2.0 MeV were observed. They occurred in the alpha decays of stopped ^{8}Li.

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Alpha Spectrum in the Decay of Li^{8}†

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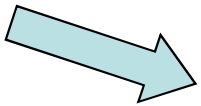
(Received February 28, 1955)

The alpha-particle spectrum in the successive beta-alpha decay of Li^{8} was observed with magnetic analysis from 1 to 6.5 Mev, corresponding to excitation energies in Be^{8} from 2 to 13 Mev. The only definite structure in the spectrum corresponds to the well-known broad state at 2.9 Mev.

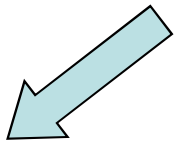
^{8}He

Atomic Mass: 8.0339218 ± 0.0000076 amu
Excess Mass: 31597.983 ± 7.077 keV
Binding Energy: 31407.892 ± 7.077 keV
Half life: 119.0 ms
Mode of decay: β^- to ^{8}Li
Decay energy: 10.65 MeV



^{8}Li

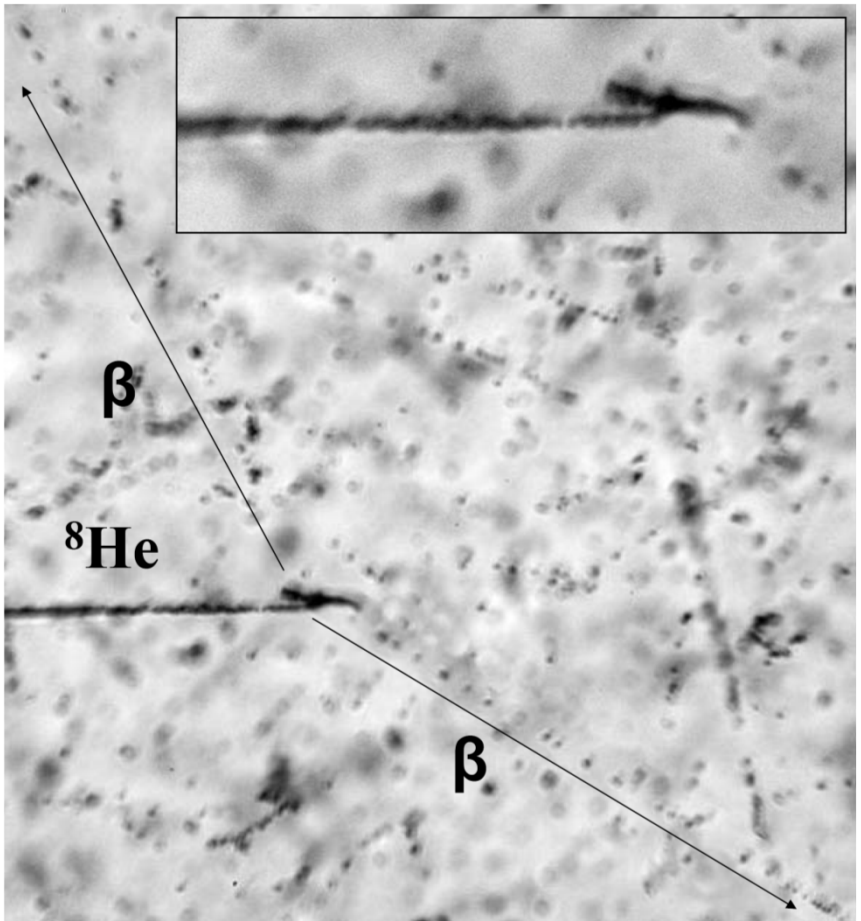
Atomic Mass: 8.0224867 ± 0.0000005 amu
Excess Mass: 20946.195 ± 0.488 keV
Binding Energy: 41277.328 ± 0.488 keV
Half life: 838 ms
Mode of decay: β^- to ^{8}Be
Decay energy: 16.004 MeV
Possible parent nuclides: β^- from ^{8}He



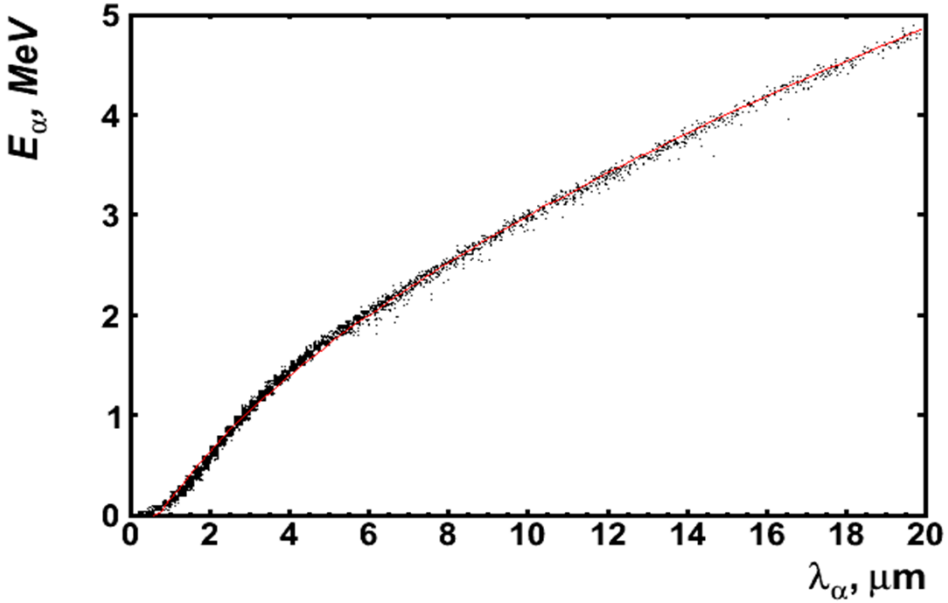
^{8}Be

Atomic Mass: 8.0053051 ± 0.0000000 amu
Excess Mass: 4941.662 ± 0.035 keV
Binding Energy: 56499.506 ± 0.037 keV
Half life: 6.8 eV ($\approx 9.7 \cdot 10^{-17}$ c)
Mode of decay: 2 Alpha
Decay energy: 0.092 MeV

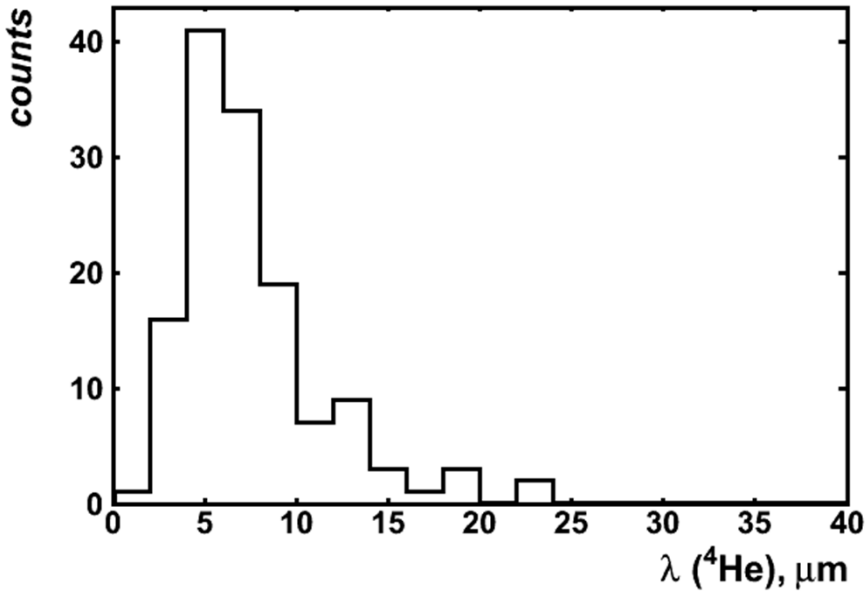
In March 2012 NTE was exposed at the Flerov Laboratory of Nuclear Reactions (JINR) at the ACCULINNA spectrometer (http://aculina.jinr.ru/). The beam in use was enriched by ≈7 A MeV ^{8}He nuclei. A 107 μm thick NTE pellicle was oriented at a 10° angle during irradiation, which provided approximately a five-fold effective thickness increase. For 10 minutes of irradiation, statistics of about 2 thousand of such decays was obtained. It is pleasant to note that the used NTE have been recently reproduced by the enterprises «Slavich» (Pereslavl-Zalessky, Russia).



Track length and kinetic energy of alpha particles

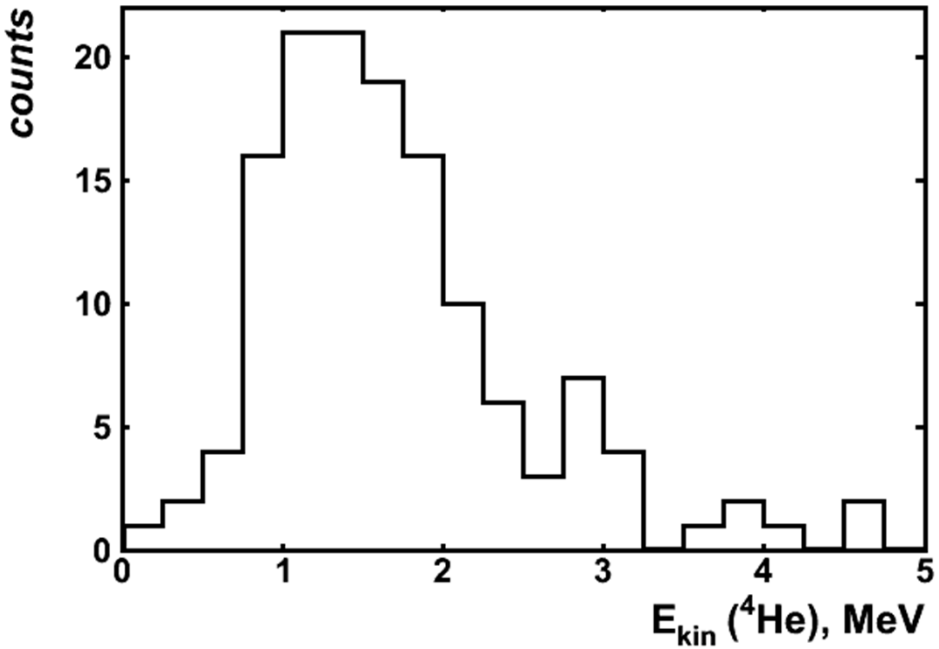


Track length / kinetic energy curve for alpha fragments (Geant4)



Track length of produced alpha particles

All data analysis based on free path and angular measurements for produced alpha fragments



Alpha spectrum from

(our experiment)

$$^{8}He \xrightarrow{\beta} {}^{8}Li \xrightarrow{\beta} {}^{8}Be \rightarrow 2\alpha$$

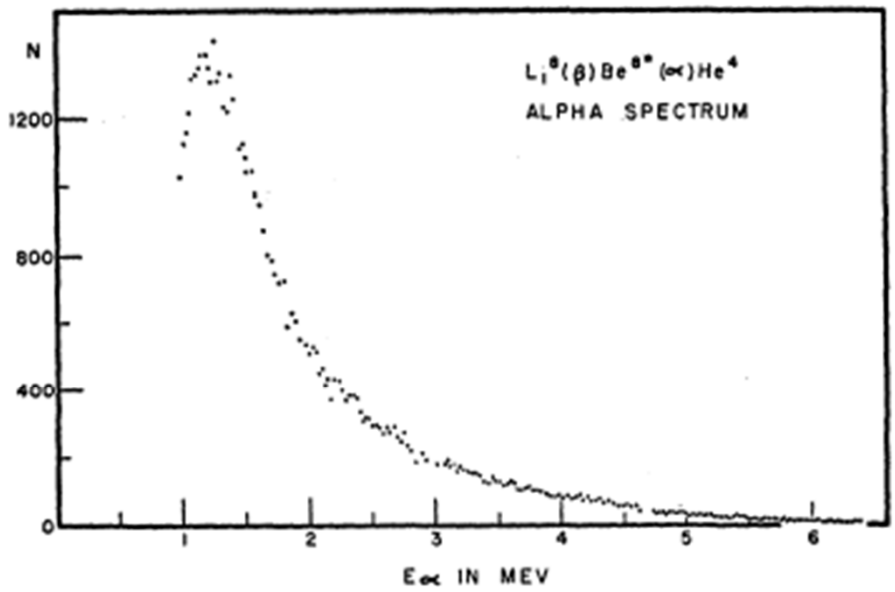


FIG. 1. Alpha spectrum from $Li^8(\beta)Be^{8*}(\alpha)He^4$. The vertical intensity scale is arbitrary. The numbers given indicate approximately the actual number of particles counted for the points below 3 Mev. Above 3 Mev the actual count is about twice that indicated by the numbers.

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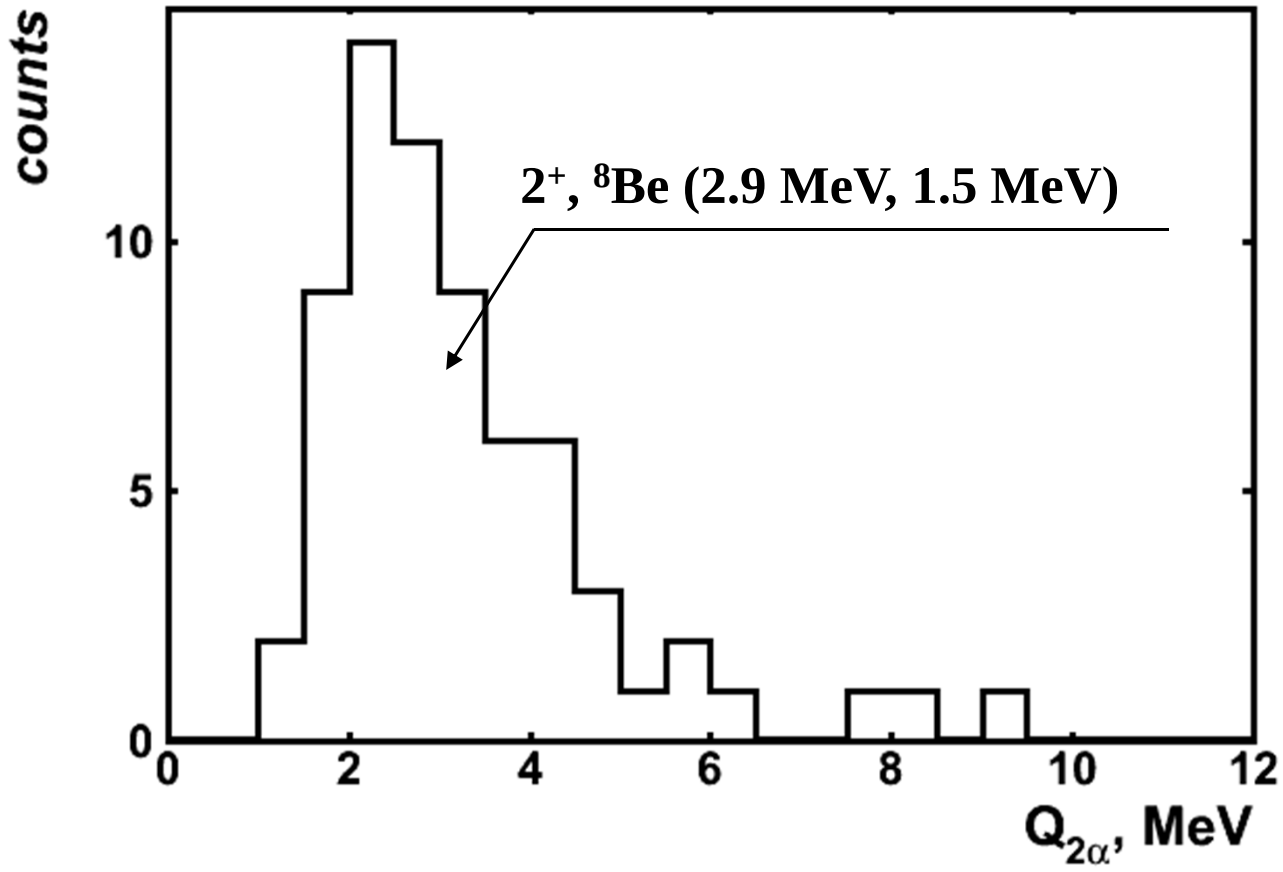
$$^{8}He \xrightarrow{\beta} {}^{8}Li \xrightarrow{\beta} {}^{8}Be \rightarrow 2\alpha$$ **at ~7 A MeV**

$$M_{2\alpha} = \left[2\left(m_{\alpha}^{2} + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}$$

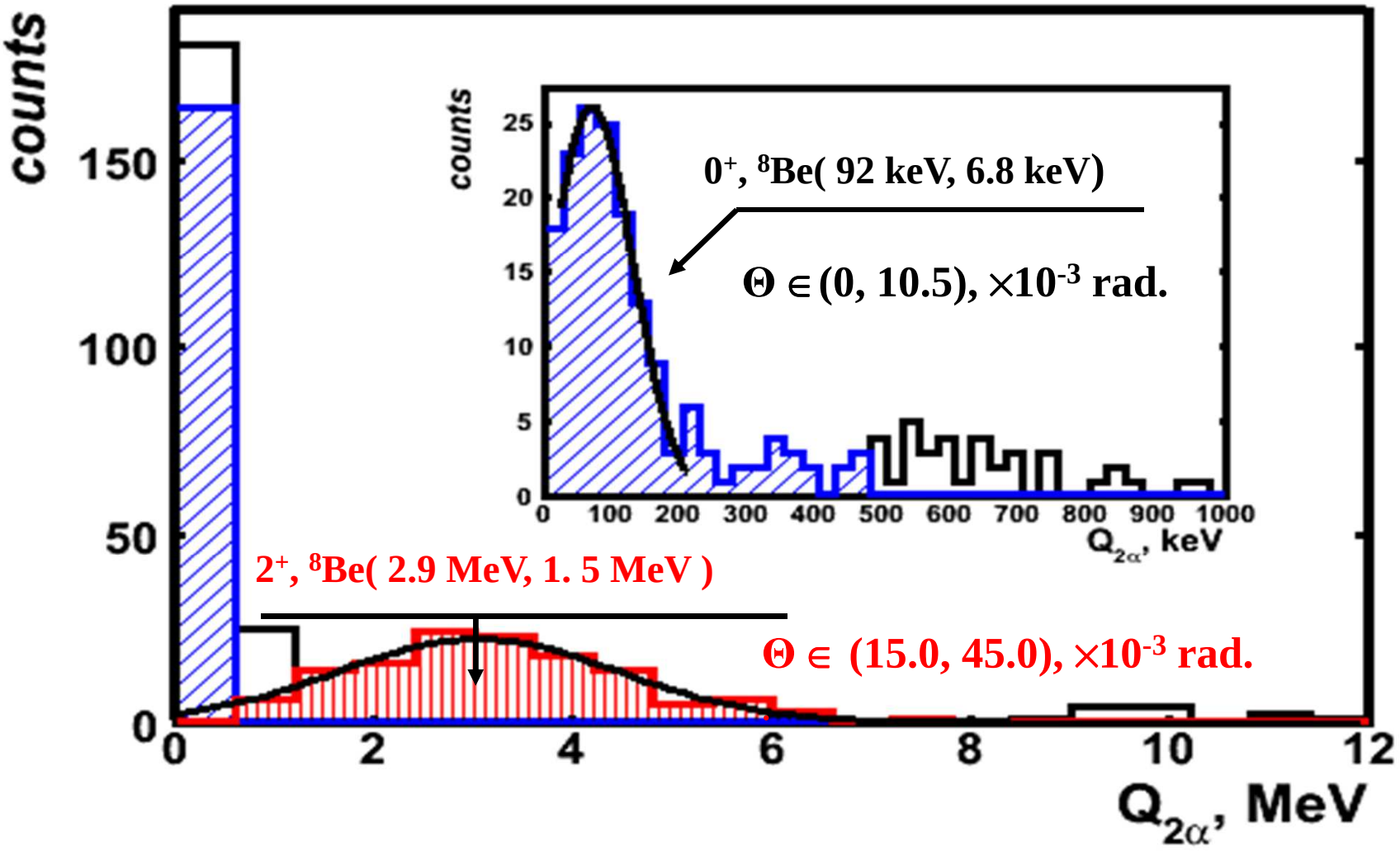
$$Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_{\alpha}$$



^{9}Be→2α at 1.2 AGeV

$$M_{2\alpha} = \left[2\left(m_{\alpha}^{2} + E_{\alpha 1}E_{\alpha 2} - p_{\alpha 1}p_{\alpha 2}\cos(\Theta_{12})\right)\right]^{\frac{1}{2}}$$

$$Q_{2\alpha} = M_{2\alpha} - 2 \cdot m_{\alpha}$$

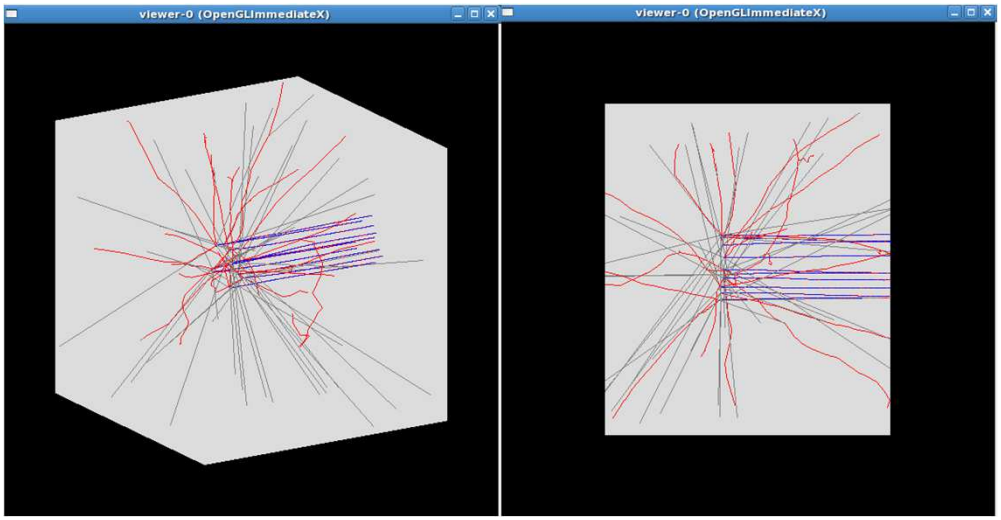


Ion Physics
Radioactive Decay

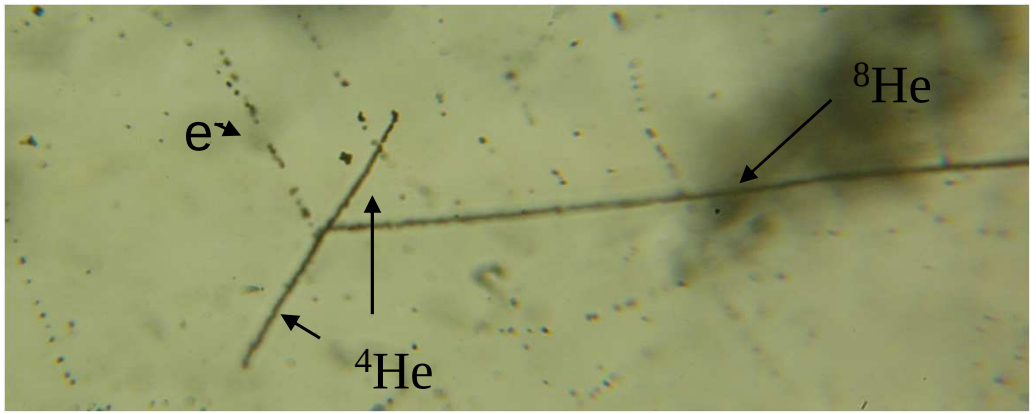
- To simulate the decay of radioactive nuclei
- Empirical and data-driven model
- α, β^+, β^- decay electron capture (EC) are implemented
- Data (RadioactiveDecay) derived from Evaluated Nuclear Structure Data File (ENSDF)
  - nuclear half-lives
  - nuclear level structure for the parent or daughter nuclide
  - decay branching ratios
  - the energy of the decay process.
- If the daughter of a nuclear decay is an excited isomer, its prompt nuclear de-excitation is treated using the G4PhotonEvapolation

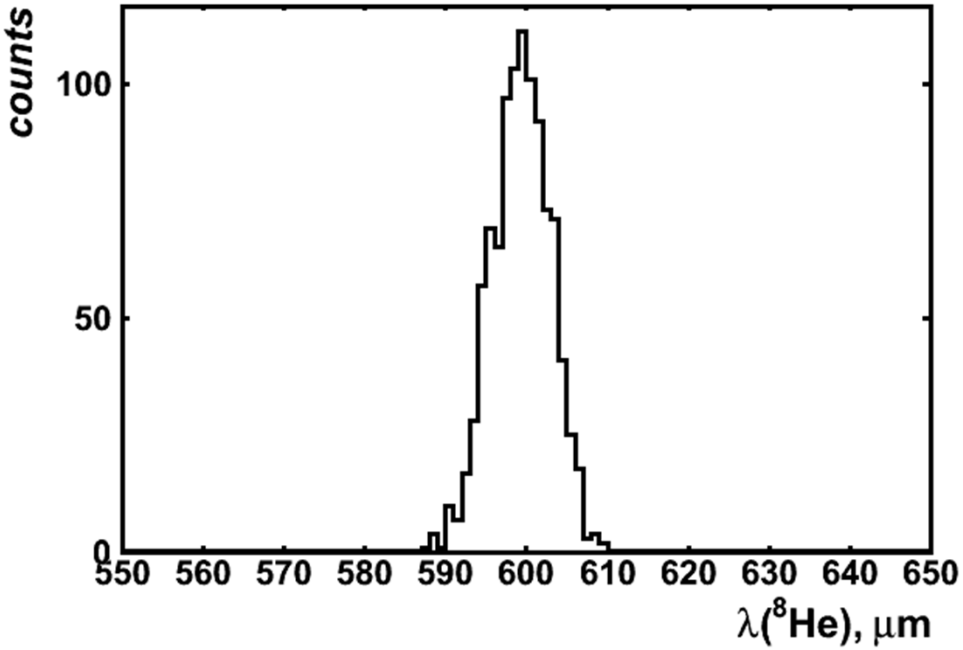
Data modeling and experiment (^{8}He at ≈7 A MeV)

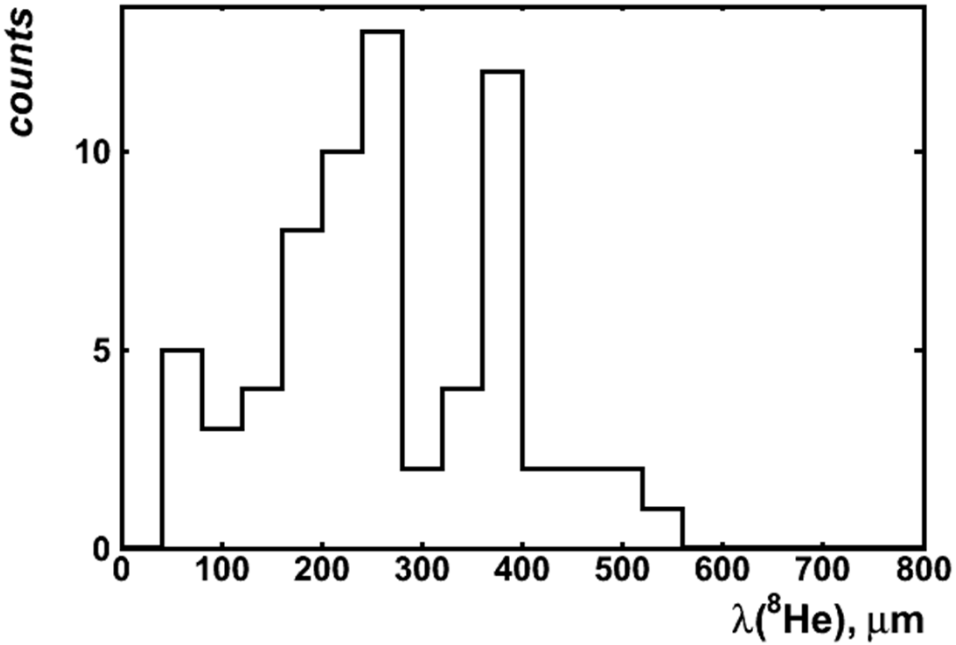
Radioactive Decay (Geant4)



Experiment

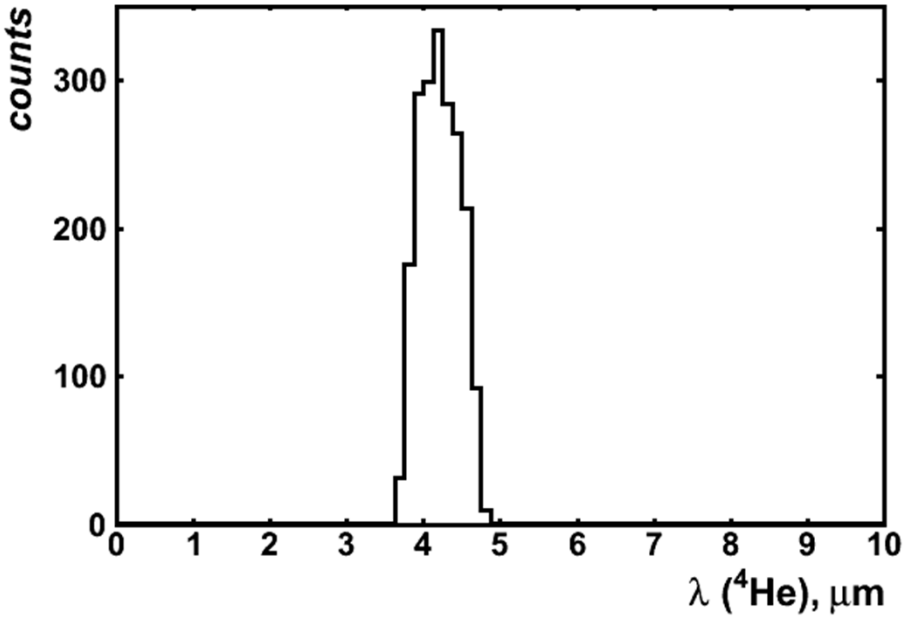


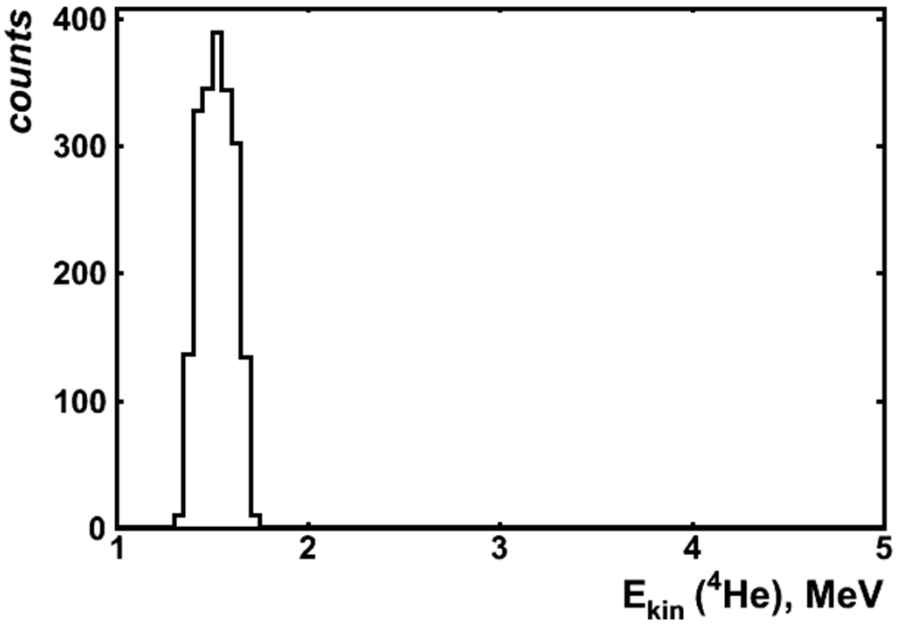




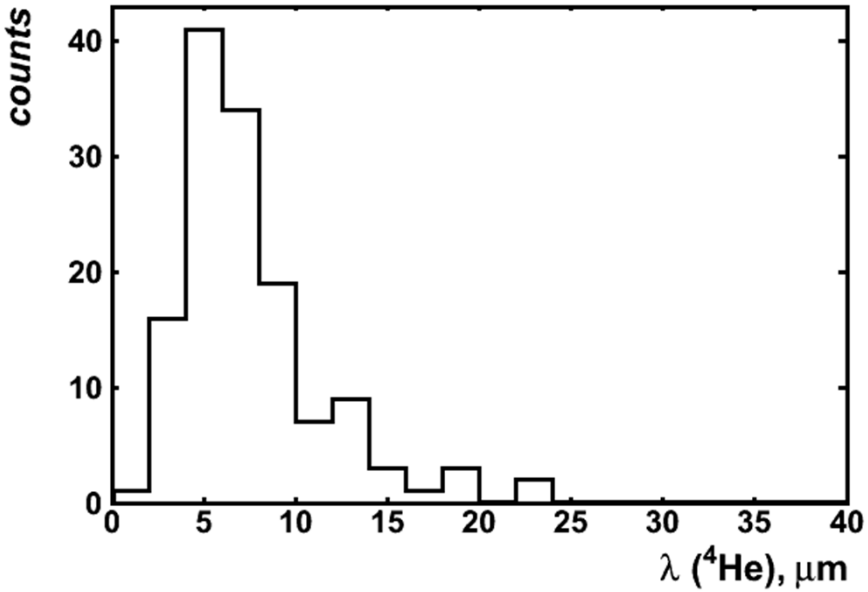
Track length and kinetic energy

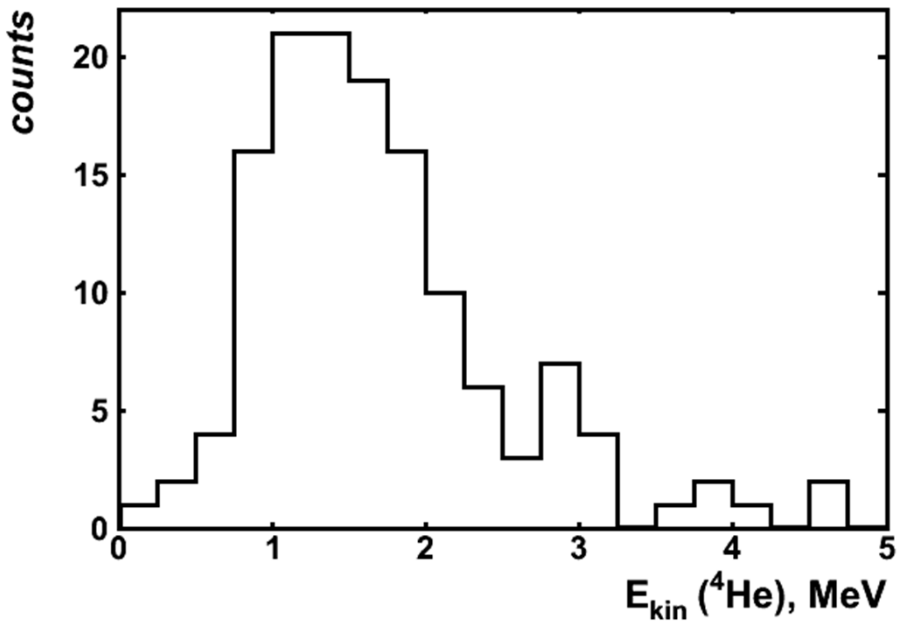
Radioactive Decay (Geant4)

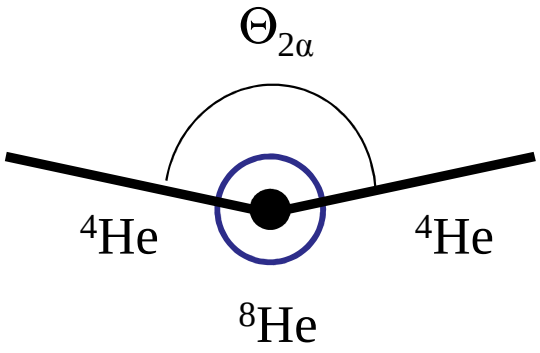




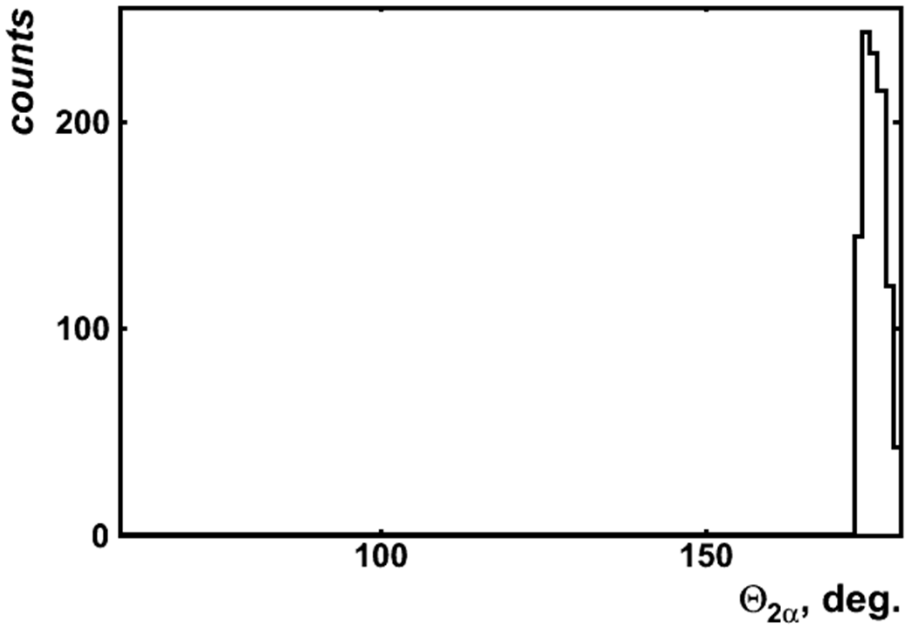
Experiment



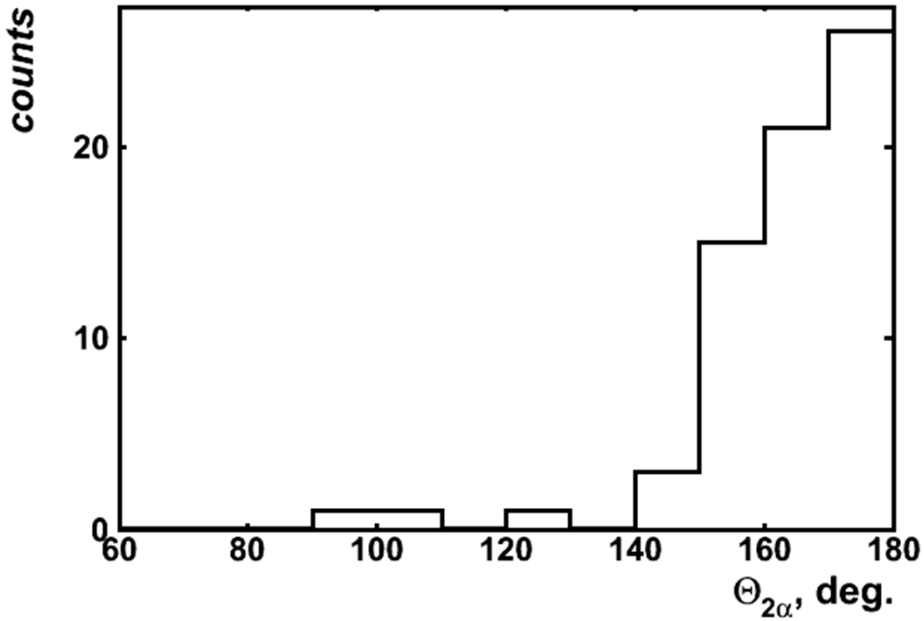




Radioactive Decay (Geant4)



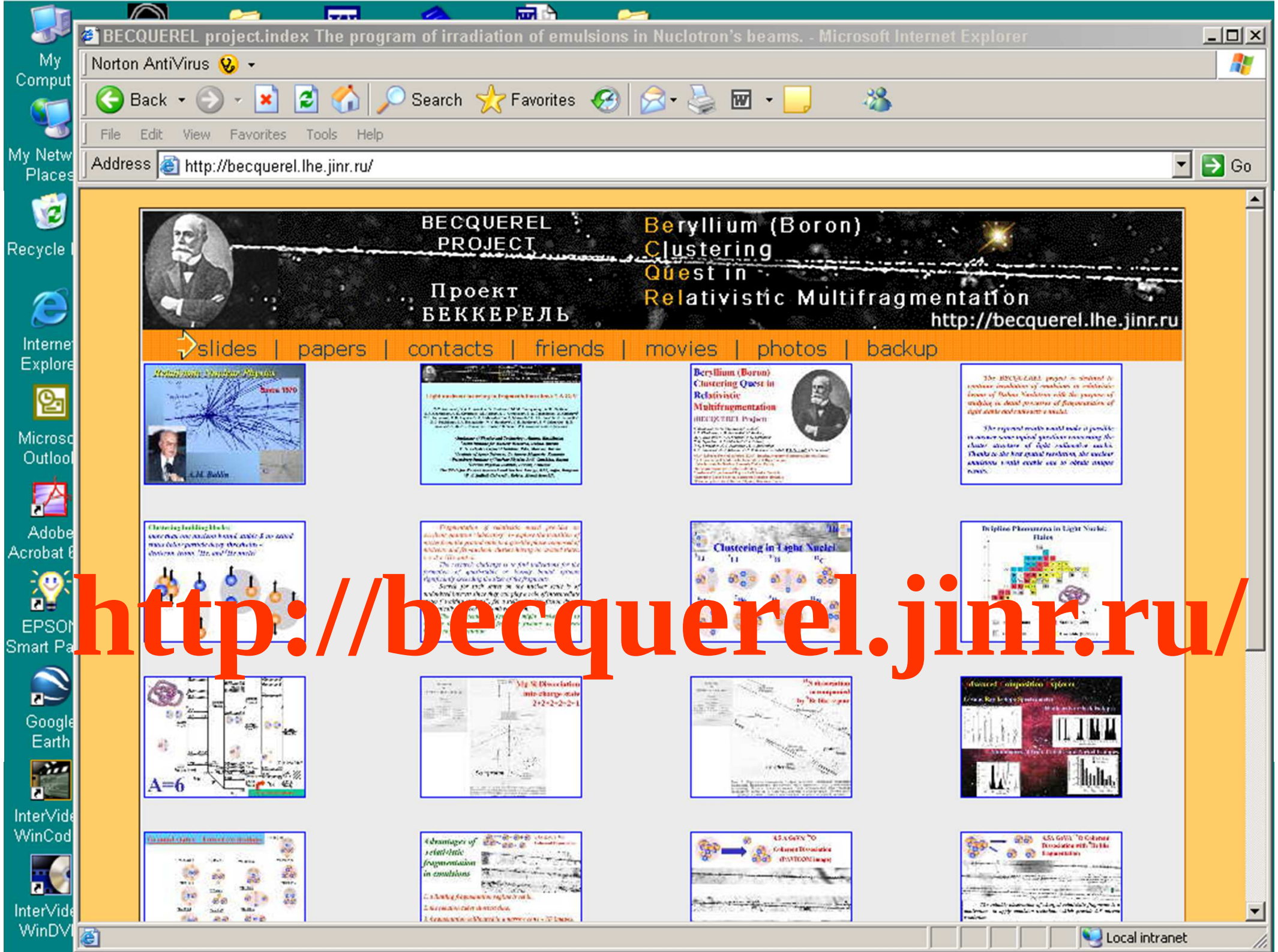
Experiment



Summary

- **In the energy range of nuclei several MeV per nucleon, there is a possibility of implantation of radioactive nuclei into detector material.**
- **In the present talk the NTE usage for this kind of investigations is shown.**

Thank you for your attention!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