Study of quaternary spontaneous fission of ^{252}Cf

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Motivation

The goal of the experiment was:

- a comprehensive study of the ternary and quaternary spontaneous fission of ^{252}Cf using position-sensitive pixel detectors;
- determine the yields and energy distributions of LCP from the ternary and quaternary spontaneous fission;
- estimate the probabilities of true and pseudo quaternary fission;
- reconstruction of the energy spectrum of unstable short-lived ^{8}Be emitted during pseudo quaternary fission.

Introduction / Ternary fission

Binary Fission | **Ternary Fission**

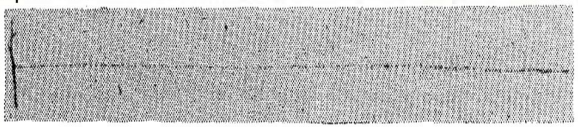
The two heavy fragments are sometimes accompanied by a Light Charged Particle (LCP): Ternary fission

The possibility of fission into three charged nuclei has been pointed out by theoretical physicists, predicting a liberation of maximum energy of 210-220 MeV, even 10-20 MeV higher than that of binary fission.

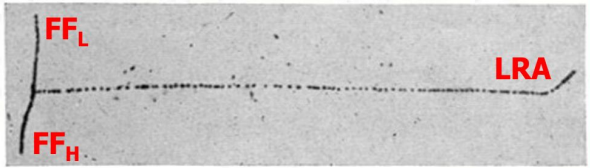
- N.Bohr and J.A.Wheeler, Phys.Rev.50, 426 (1939)
- R.D.,Present, Phys.Rev.59, 466 (1941)

Experimentally observed for the first time in 1946

Ternary fission: third fragment—mass-6, range=44 cm air equivalent.



Ternary fission: third fragment—mass-9, range=17 cm air equivalent.



- Tsien San-Tsiang, Phys. Rev. 71 (1947), 382
- L. W. Alvarez, as reported by G. Farewell, E. Segre and C. Wiegand, Phys.Rev.71, 327 (1947)

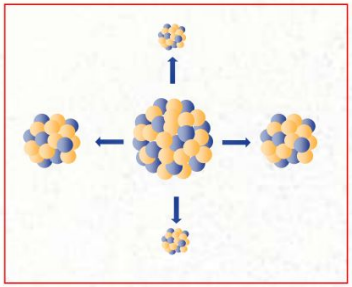
LCP - p, d, t, α (with an average energy of 16 MeV), Li, Be.

Mainly (> 90%) the isotopes H and He are emitted.

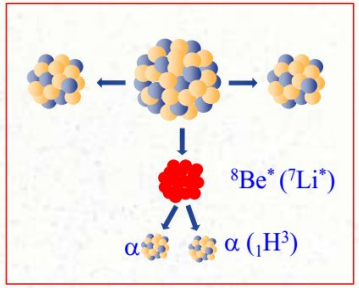
The probability of the creation of LCP in the spontaneous fission of ^{252}Cf is approximately $4 \cdot 10^{-3}$ from ordinary binary fission.

Introduction / Quaternary fission

"True" Quaternary Fission



"Pseudo" Quaternary Fission

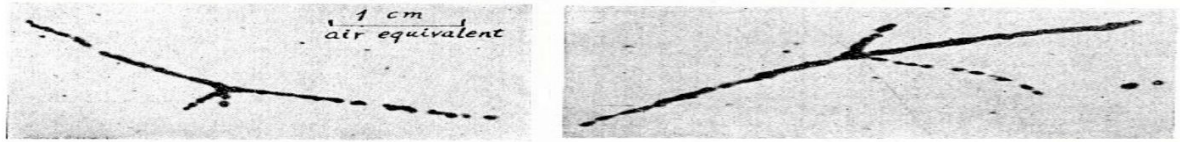


The two heavy fragments are sometimes accompanied by two Light Charged Particle (LCP)

- N.Bohr and J.A.Wheeler, Phys.Rev.50, 426 (1939)
- R.D.,Present, Phys.Rev.59, 466 (1941)

Experimentally observed for the first time in 1946

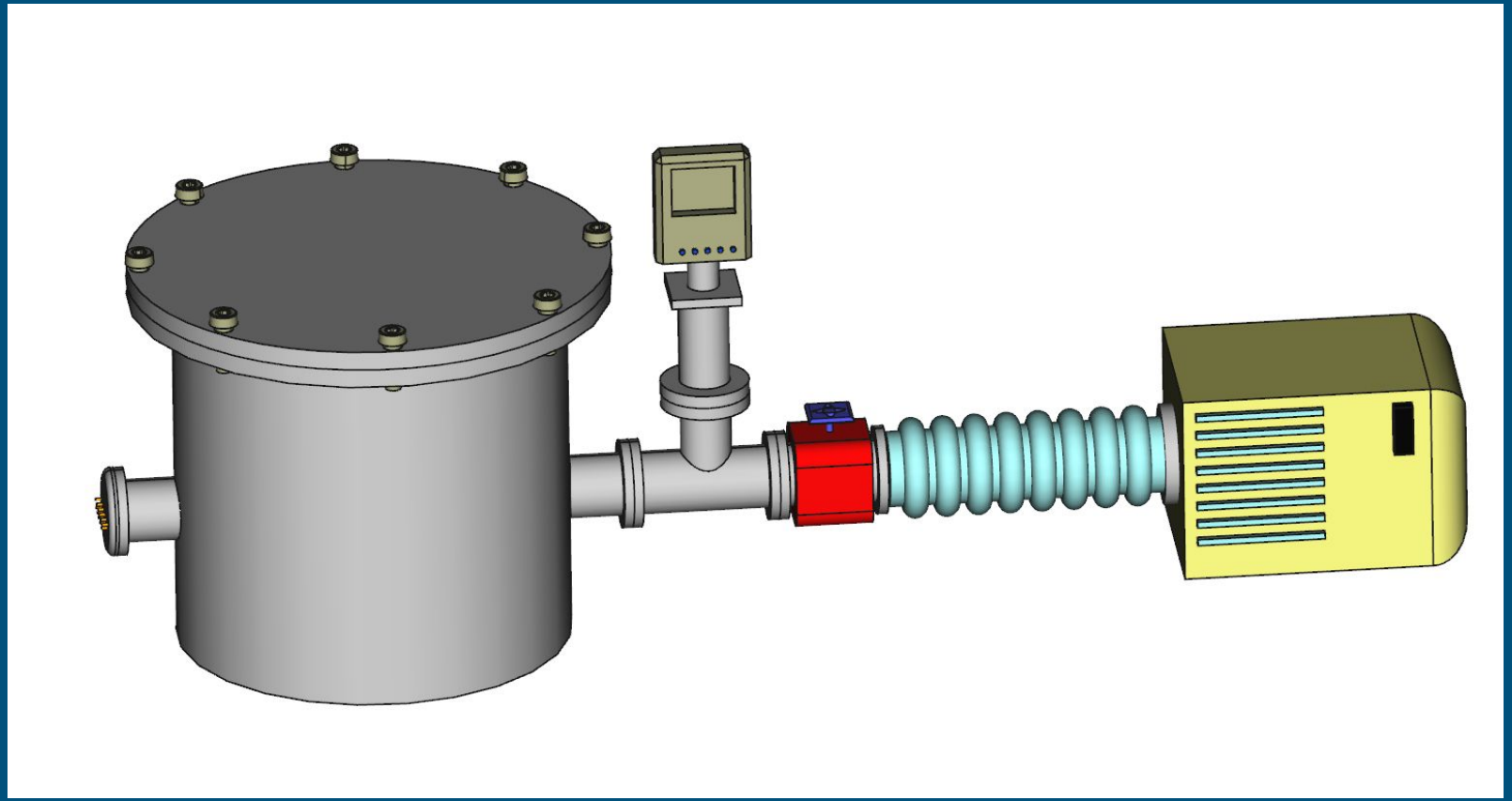
Tsien San-Tsiang, Phys. Rev. 71 (1947), 382



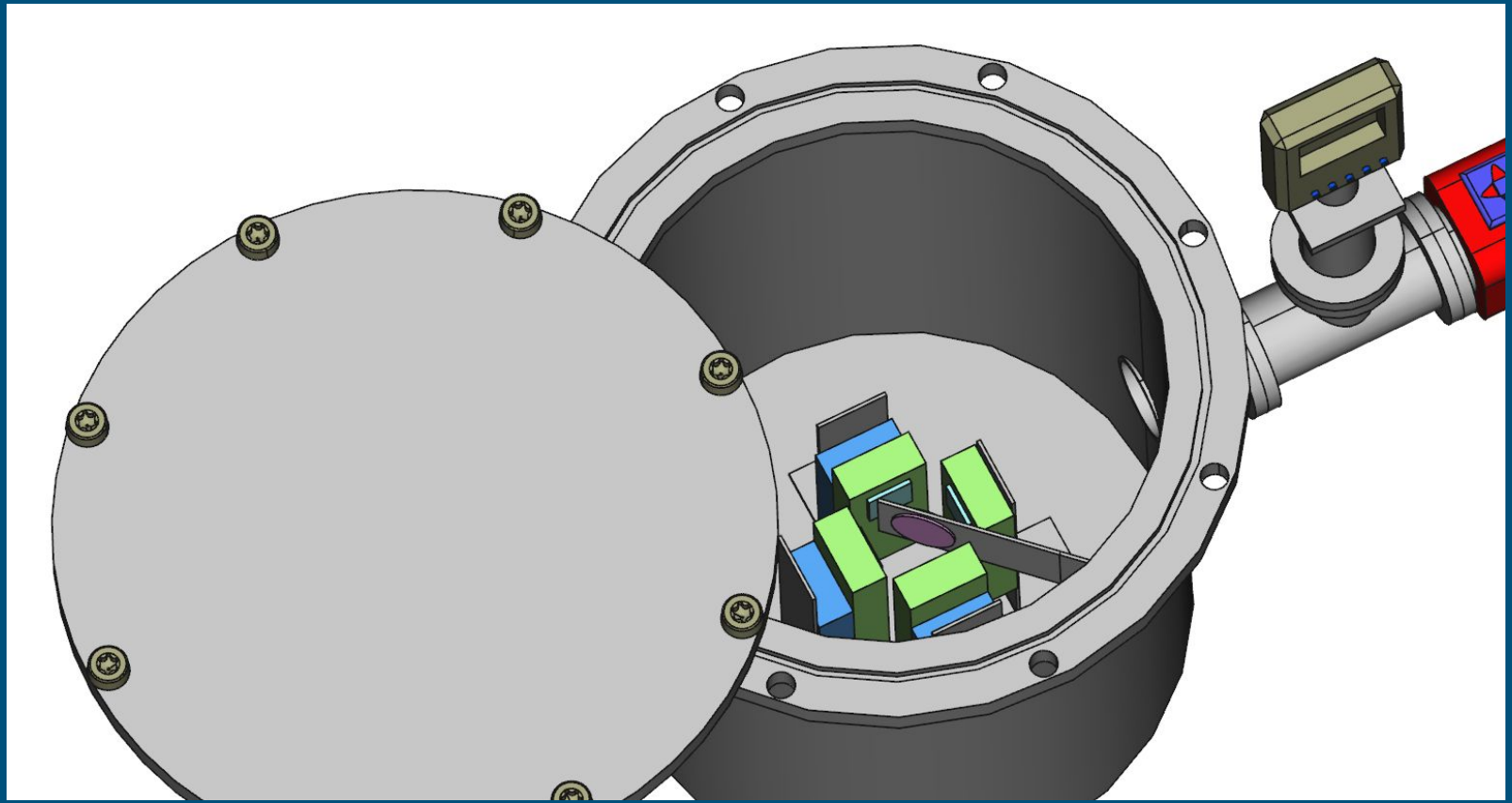
two heavy fragments and two LCP are emitted from the fissile nucleus with a probability in the range from 10^{-7} to 10^{-6}.

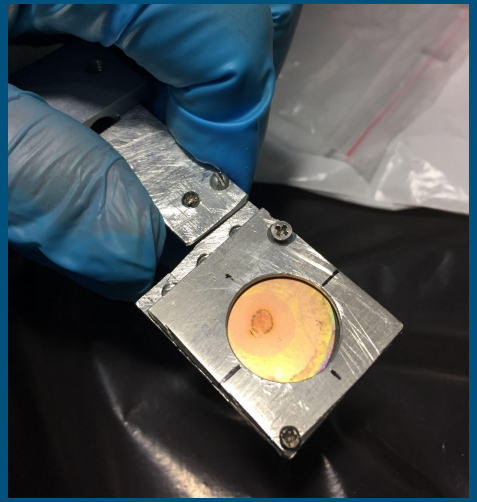
α-α coincidences - about 80%
α-t coincidences - about 16%

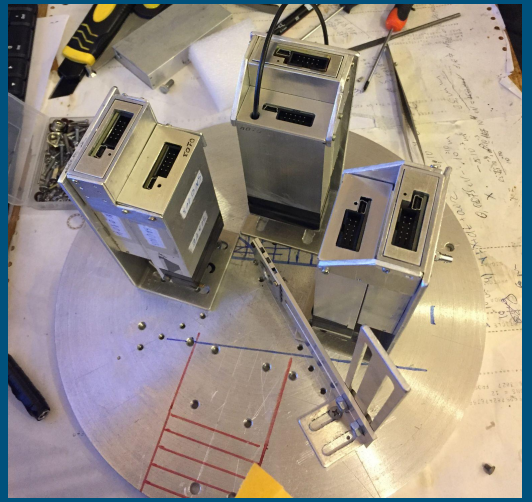
Experimental setup

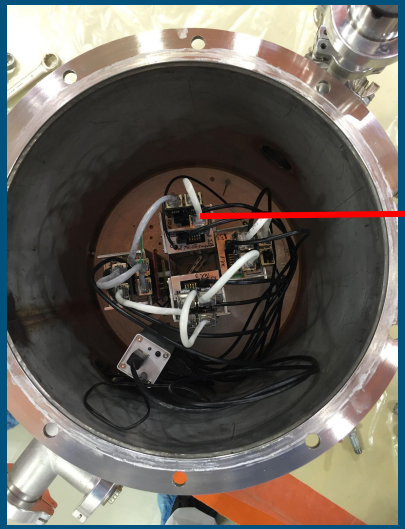


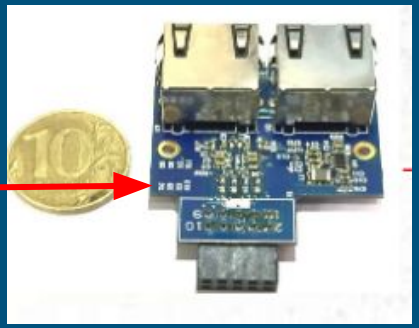
Experimental setup





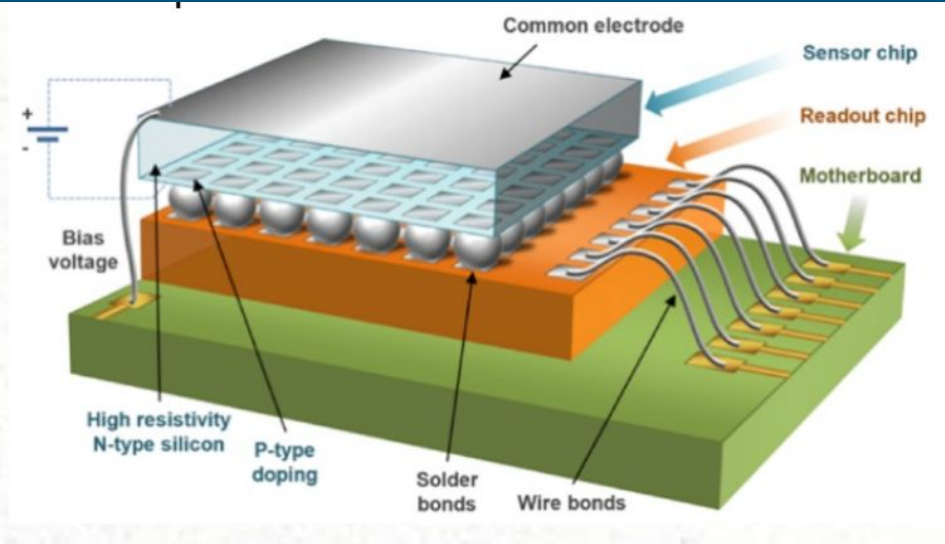




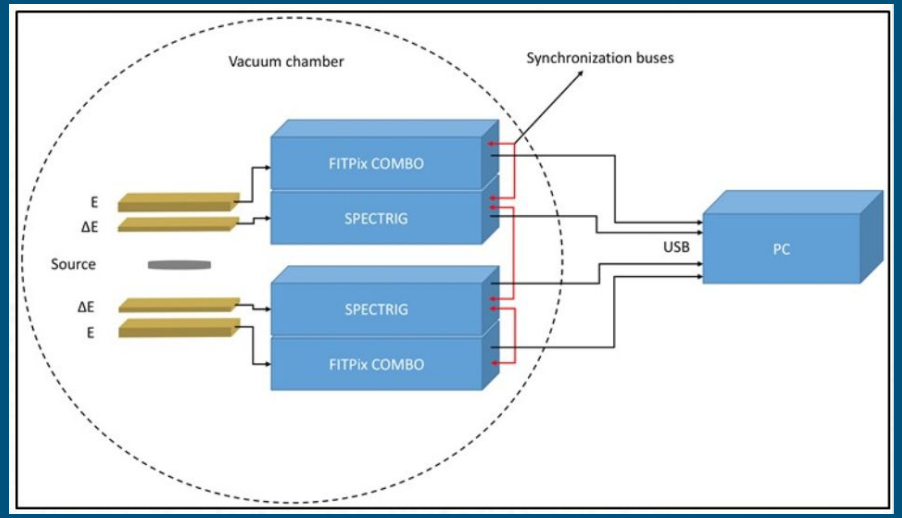


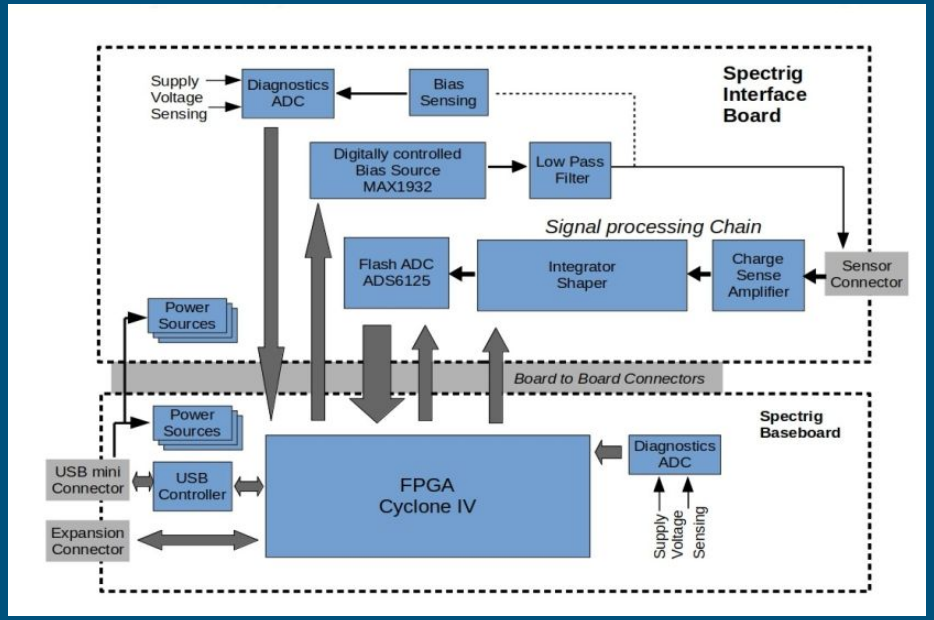
Synchronization module

Timepix detector



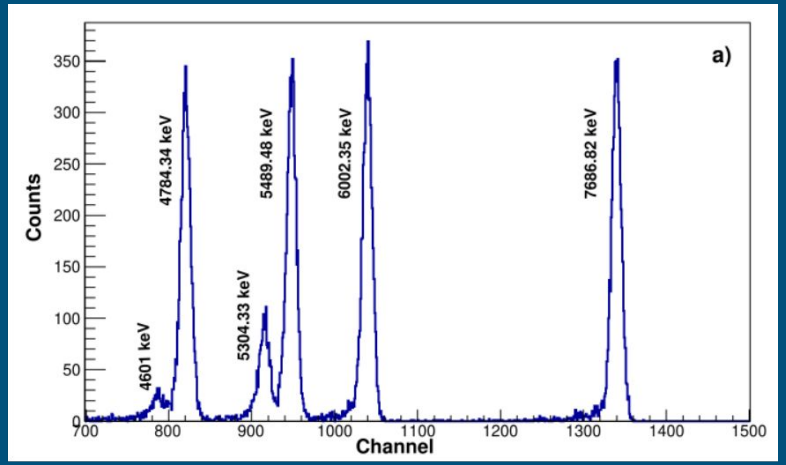
Spectrig device



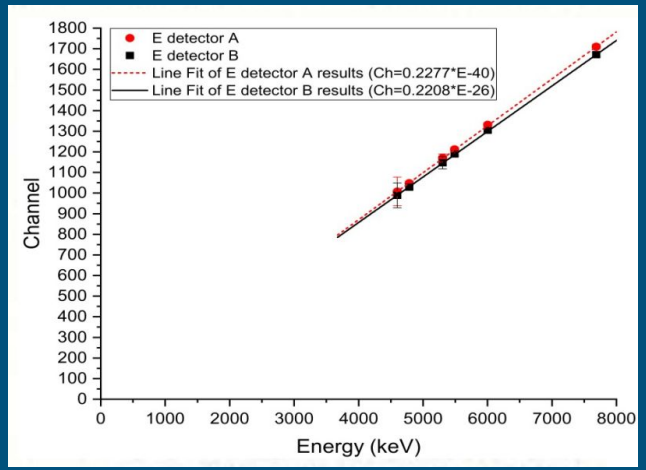


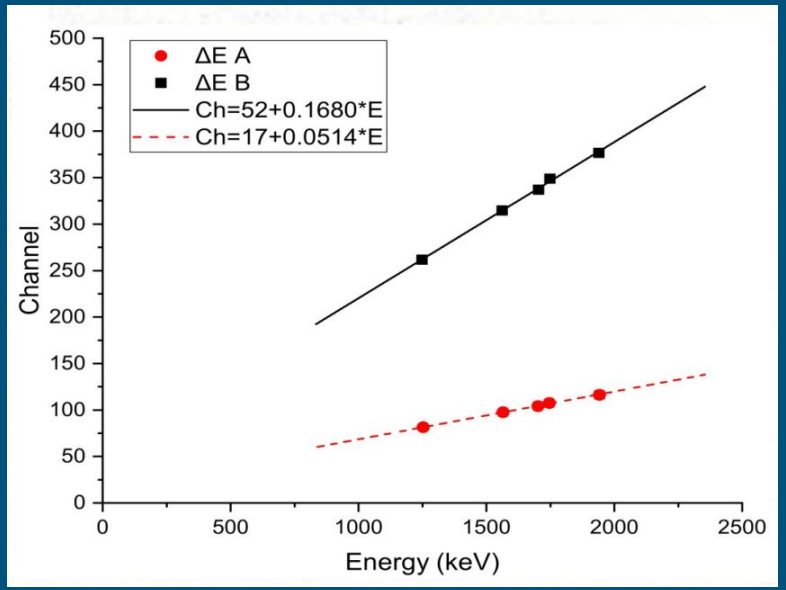
M. Holik, G. Ahmadov, D. Berikov et al. Journal of Instrumentation. -2018. -Vol. 13, Iss. 11. -P. C11019

Energy calibration of detectors



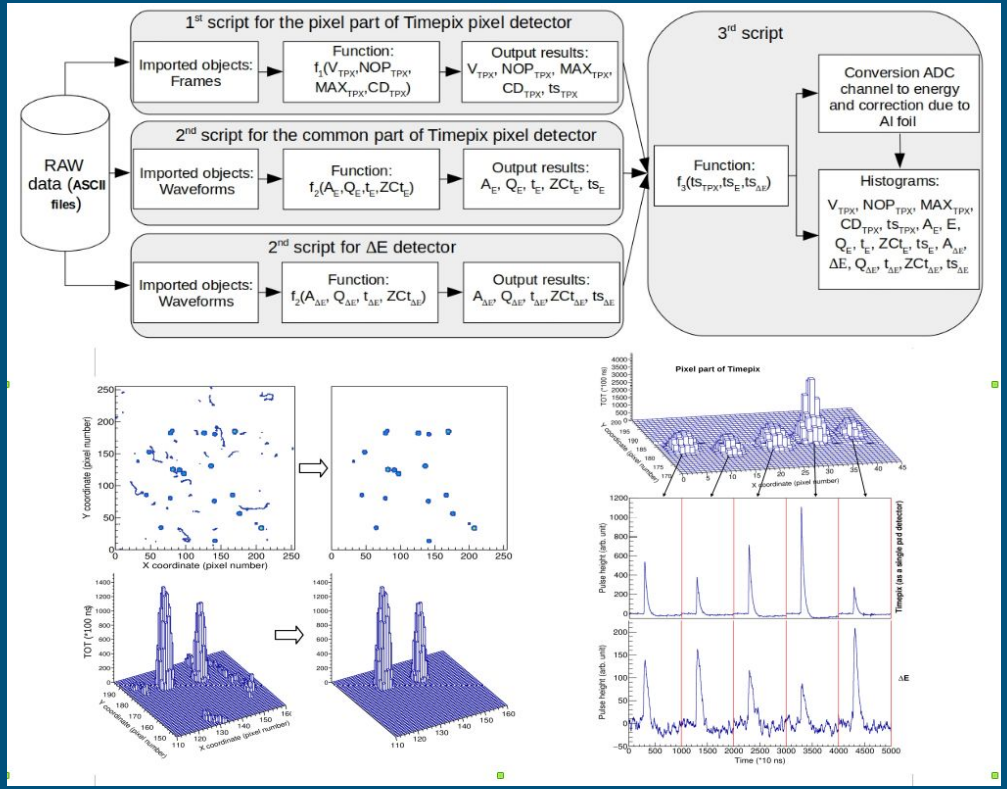
M. Holik, G. Ahmadov, J. Broulim, J. Zich, D. Berikov et al.
Journal of Instrumentation. -2019. -Vol. 14, Iss. 6. -P. C06022





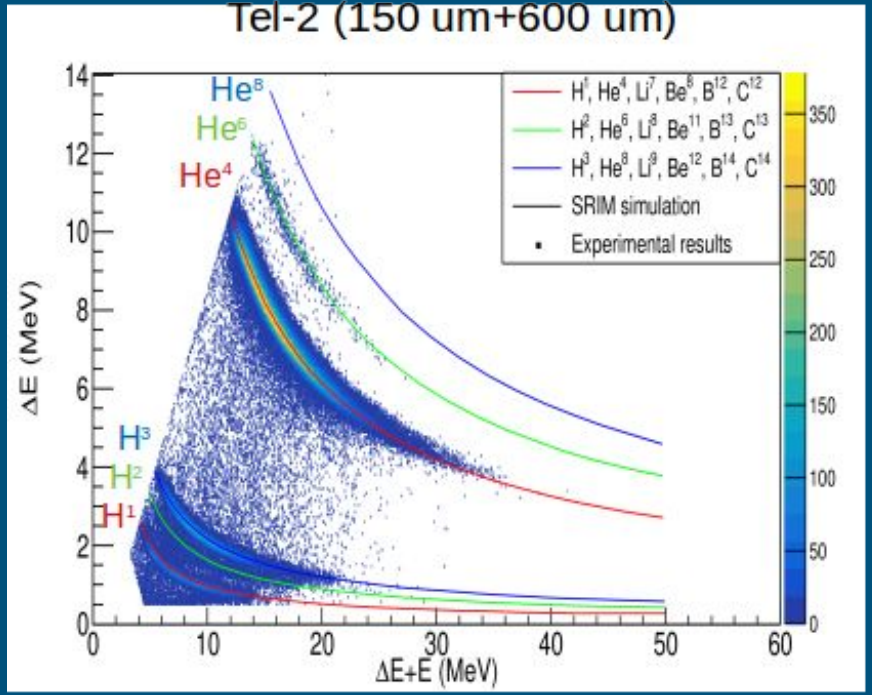
Data processing

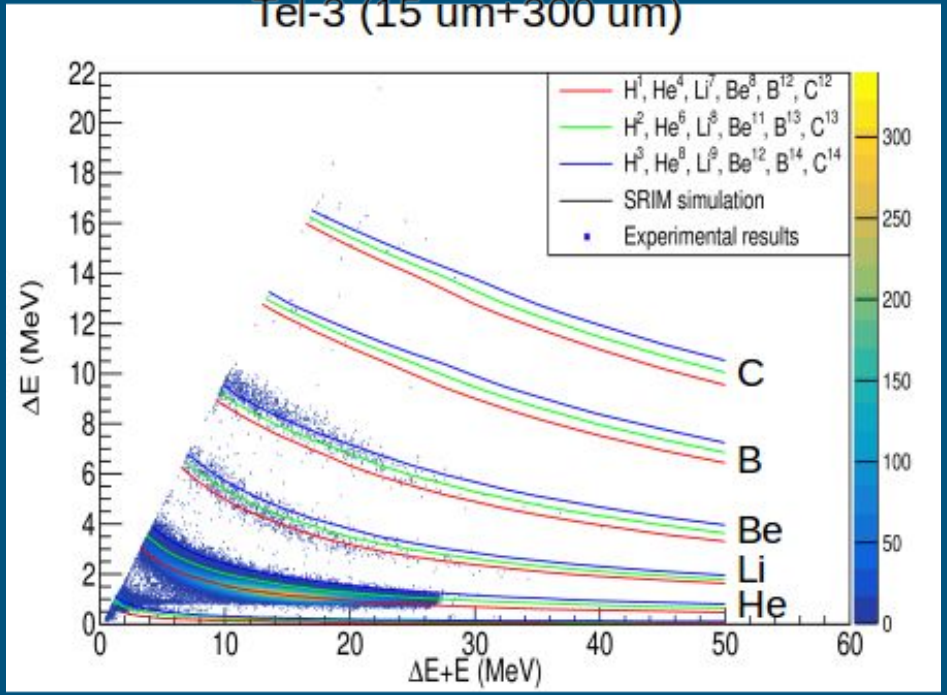
A ROOT based program, consisting of many scripts for analyzing and/or filtering ternary and quaternary fission particles among various fission events. The program can process long collected files in ASCII and binary formats, compare the results from all detectors, give results in terms of particle interaction time, coordinates, particle energy and their types.



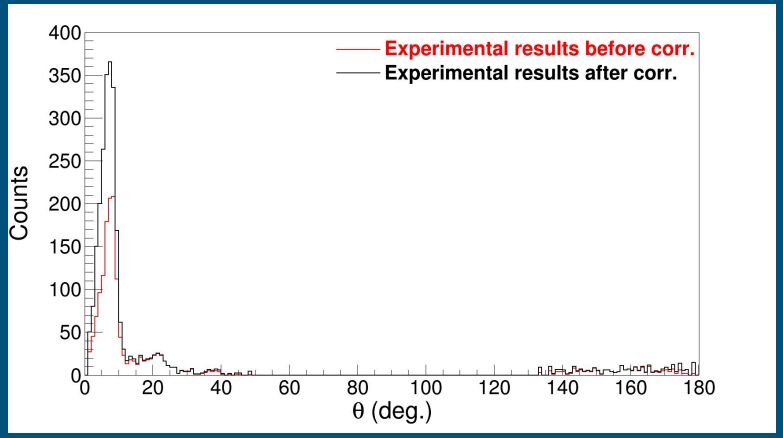
M. Holik, G. Ahmadov, D. Berikov et al., Advanced Physical Research. -2020. Vol. 2. -P. 71-78.

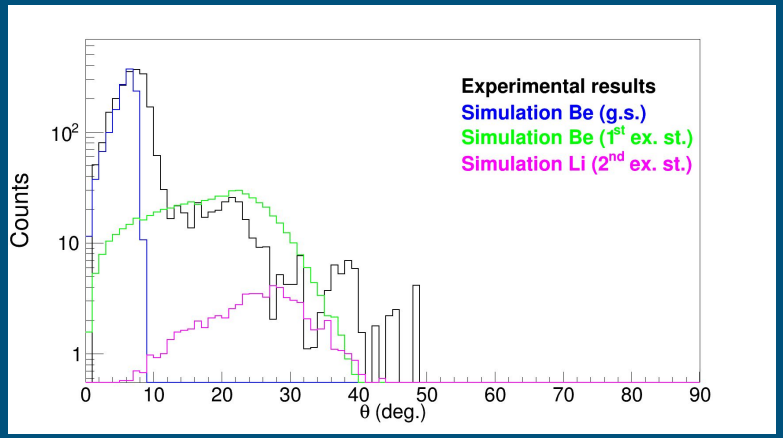
2D spectra from ΔE-E telescopes



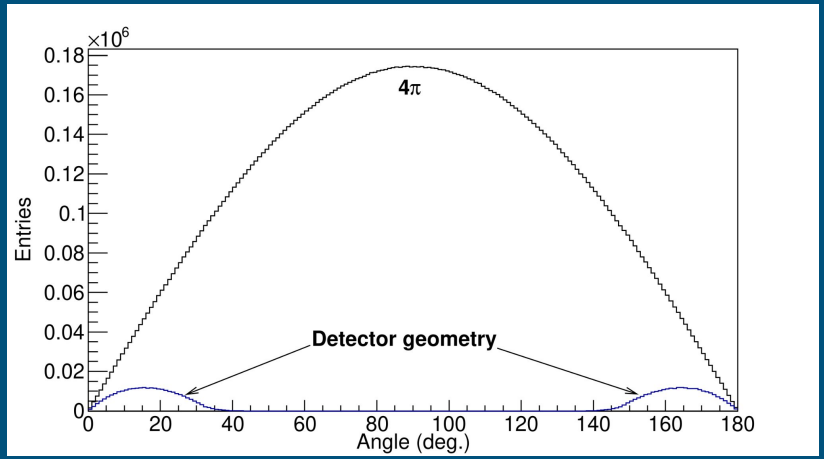


^{252}Cf - quaternary fission



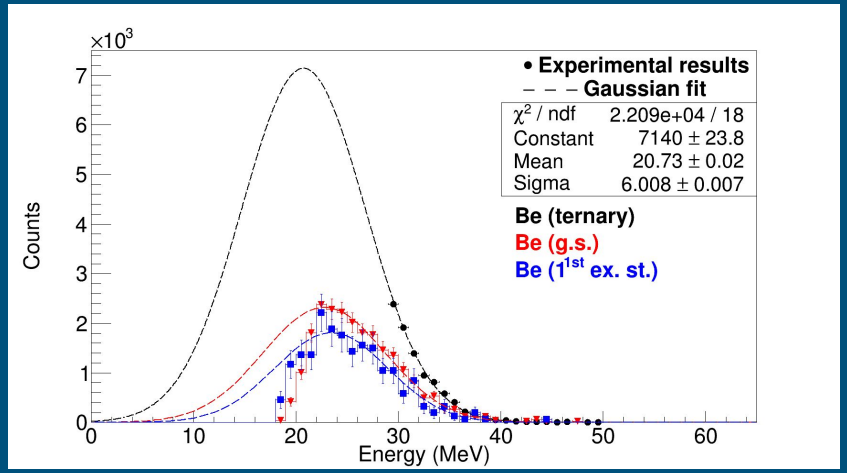


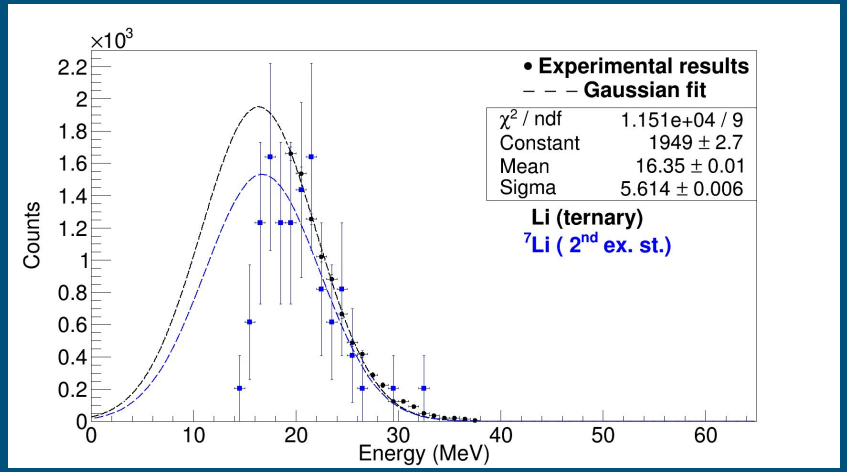
Thanks to the per pixel sensitivity of Timepix, we could measure angle (α, α) and (α, t) pairs by analyzing their corresponding clusters. Uncorrected and corrected angular distributions measured for (α, α) coincidences in one detector are displayed. The angular distribution from the trajectory calculation is also shown in figure for ^{8}Be ground and excited states. As shown in the figure there is good agreement with the experimental data.



Simulation of the angle between two particles which can be detected in our detection system consisting of two telescopes

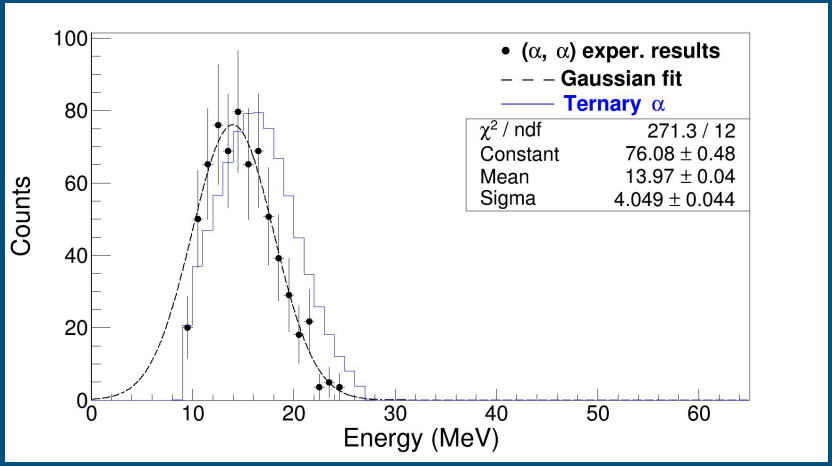
^{252}Cf - quaternary fission (“Pseudo”)

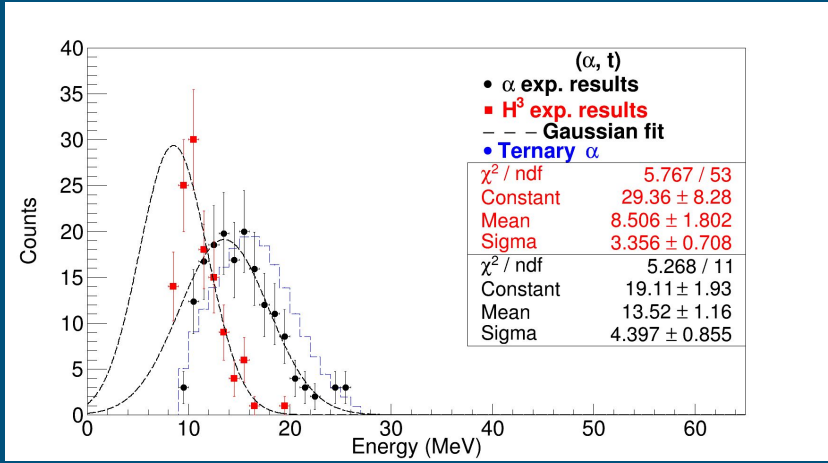




The results from (α, α) and (α, t) pairs registered in single detector (telescope). Energy spectra of Be and Li particles (corrected for energy losses) from pseudo (α, α) and (α, t) quaternary fission of ^{252}Cf

^{252}Cf - quaternary fission (“True”)





The results from (α, α) and (α, t) pairs registered in opposite detectors (telescopes). Energy spectra of α-particles (corrected for energy losses) from true (α, α) and (α, t) quaternary fission of ^{252}Cf

^{252}Cf - quaternary fission

The information obtained on the total yields of each of the particle types is presented in Table. All yields are normalized to 10^4 α-particles from the respective reaction. *indicates the results after geometry correction

Particle	Energy (MeV)	σ (MeV)	Yield (per 10^4 α)	Energy (MeV) (Ref.)	Yield (per 10^4 α) (Ref.)
Be (α, α) (g.s.*)	22.76(90)	5.942(433)	5.34(32)	10 (per α)[1]	10(6)[1]
Be (α, α) (1^{st} ex. s.*)	23.46(25)	5.326(214)	0.62(1)	11.2(8) (per α)[1]	2(1)[1]
Li (α, t) (2^{nd} ex. s.*)	19.25(34)	4.279(430)	0.13(1)	-	0.3(1)[1]
(α, α)	14.32(96)	4.919(370)	1.12(8)	13.7(8)[1]	3(1)[1]
(α, t)	13.77(25) 8.51(1.8)	4.397(855) 3.356(708)	0.31(5)	-	0.4(1)[1]

[1]P. Jesinger, Yu.N. Kopatch, M. Mutterer et al., Eur. Phys. J. A 24, 379–388 (2005)

Thank You for Your attention!