Determination of Lifetimes of Hypernuclei with the Fission Fragment Detector

Version 20

About this note

This note describes ways to extract the lifetime of the hypernuclei by using the fission fragment chamber with or without knowing the delay times in the readout channels.

In the text, indexes have the following meanings. Index "*m*" denotes the measured quantities. Index "*a*" denotes actual quantities. Index "*f*" denotes flight. Index "*i*" denotes module # i. Index "*p*" denotes prompt fission. Index "*d*" denotes delayed fission of the hypernucleus. "*u*" and "*v*" are event counters. Index "*4*" denotes quantities for the upper half, and index "*1*" denotes quantities for the lower half of the detector.

Geometry of the detector and tracks

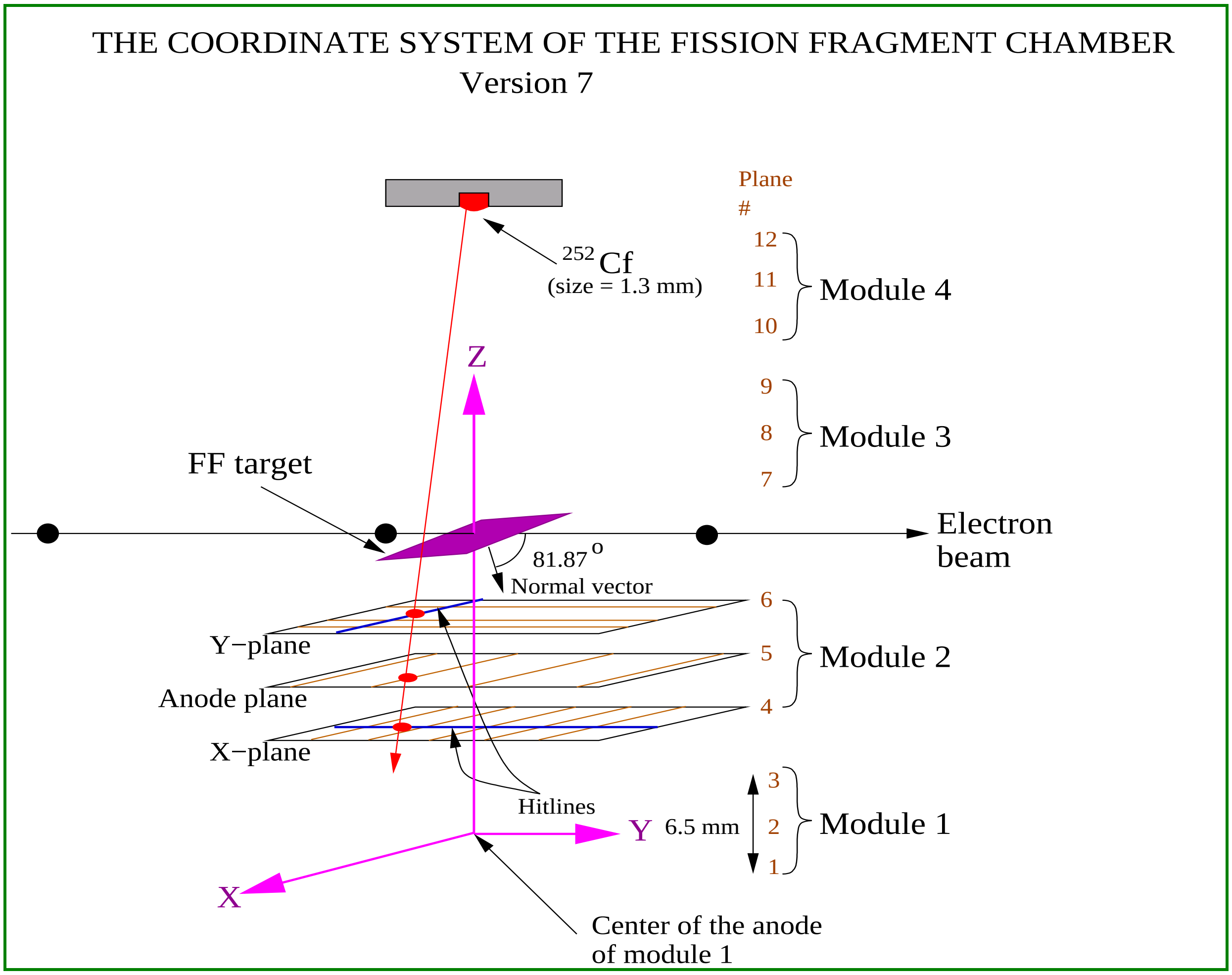

Fig. 1. General view and numbering of modules.

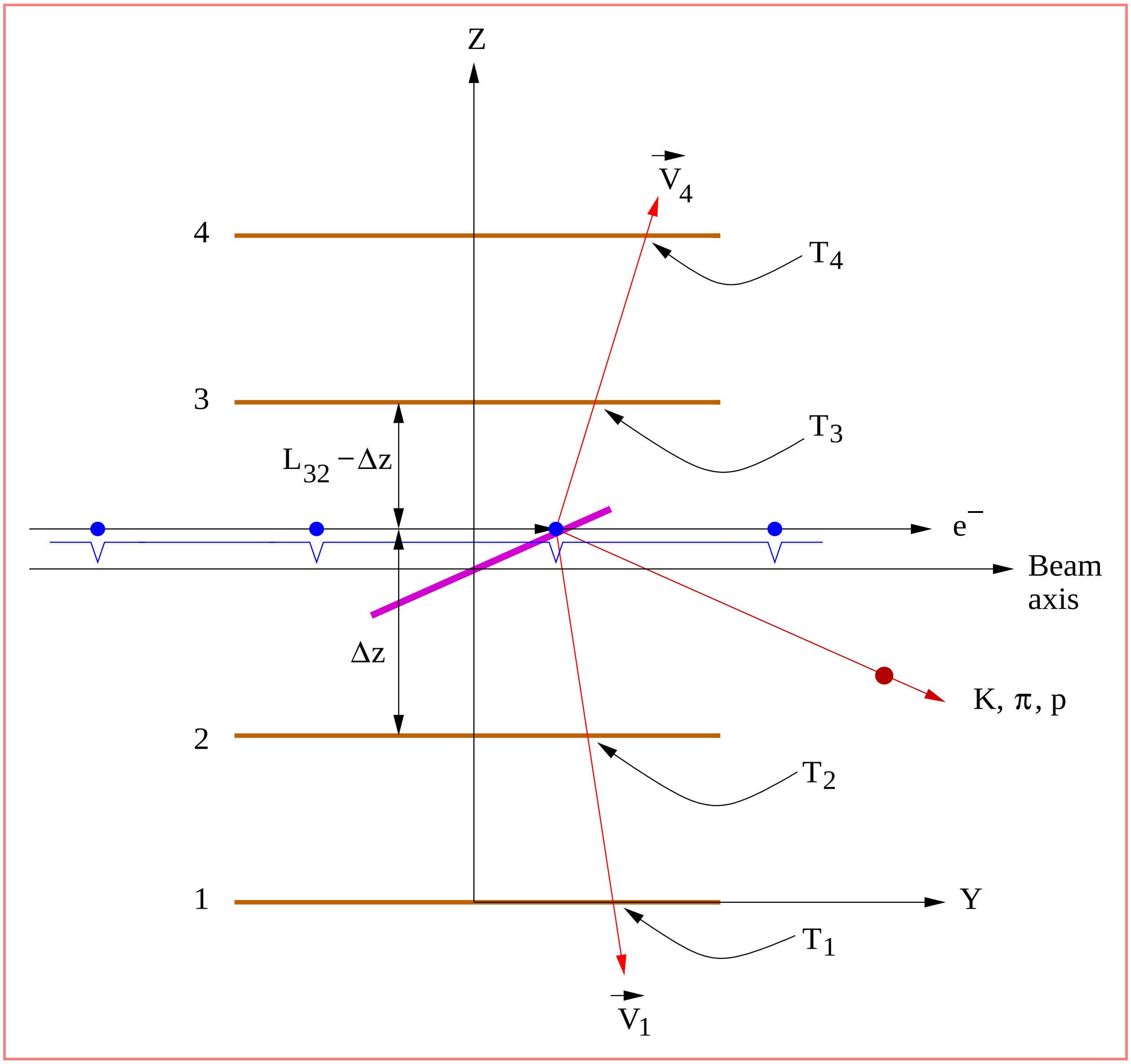

Fig. 2. Paths of fragments and times.

Determination of times

We measure times relative to the trigger (or RF, or the bunch crossing) time plus a constant shift T_{shift}. For any time, there is a delay between measured time and actual time (actual times are also relative to the trigger time plus T_{shift}) in any readout channel i :

$$T_i^m = T_i^a + D_i; \quad D_i > 0 \quad .$$

Assuming constant velocity of a nuclear fragment $\vec{v}_4$, the z component of it is $v_{4z}^a = \dfrac{L_{43}}{T_4^a - T_3^a}$.

Denote the actual flight time of the fragment from its birth to the module 4 (last place in the detector where it can leave a trace) with $T_{4\mathrm{f}}^a$ .Then, evidently,

$$T_{4\mathrm{f}}^a = T_4^a - T_3^a + \frac{T_4^a - T_3^a}{L_{43}}(L_{32} - \Delta z)$$

Relating actual times to measured times, we get:

$$T_{4\mathrm{f}}^a = (T_4^m - D_4) - (T_3^m - D_3) + \frac{T_4^m - D_4 - T_3^m + D_3}{L_{43}}(L_{32} - \Delta z) \tag{1}$$

Denoting with M a combination of quantities which are measured:

$$M \equiv T_4^m - T_3^m + \frac{T_4^m - T_3^m}{L_{43}}(L_{32} - \Delta z) = T_4^m - T_3^m + (T_4^m - T_3^m) G_4$$, where G_4 is a geometrical factor $G_4 = \dfrac{L_{32} - \Delta z}{L_{43}}$, for the actual flight time we get

$$T_{4\mathrm{f}}^a = M + F_4(D, \Delta z) \ . \tag{2}$$

Here the expression $F_4(D, \Delta z)$ **depends** on delays and interaction point and **does not depend** on measured times:

$$F_4(D, \Delta z) = (D_3 - D_4) + (D_3 - D_4) G_4$$

We have the following expression for the experimentally measured flight time:

$T_{4f}^{m} = T_4^m - T_3^m + \frac{L_{32} - \Delta z}{v_{4z}^m}$. Substituting $v_{4z}^m = \frac{L_{43}}{T_4^m - T_3^m}$, we get for the measured flight time:

$$T_{4f}^{m} = T_4^m - T_3^m + (T_4^m - T_3^m)\frac{L_{32} - \Delta z}{L_{43}} = T_4^m - T_3^m + (T_4^m - T_3^m) G_4 = M$$

Comparing the last expression with (2), we see the following relationship between actual and measured times of flight:

$$T_{4f}^{a} = T_{4f}^{m} + F_4(D, \Delta z)$$

Measurement of the lifetime

There are several methods to extract the lifetime τ .

First method: The main, probably the most accurate method, is the fitting of the decay histogram.

Let us look at the expressions $T_{40}^{m} \equiv T_{4}^{m} - T_{4f}^{m}$ and $T_{40}^{a} \equiv T_{4}^{a} - T_{4f}^{a}$. For a perfect detector without delays, $T_{40}^{m} = T_{40}^{a}$. In addition, for perfect detector and prompt events, $T_{40}^{m} = T_{40}^{a} = T_{shift}$.

T_{40}^{a} is equal to the lifetime of the nucleus (which is 0 in case of prompt fission) plus T_{shift} . That is, $T_{40}^{a} = t_{decay} + T_{shift}$. We will use this equation below.

For a **prompt fission** event, T_{40}^{mp} will show the amount of delays in the detector:

$$T_{40}^{mp} = T_{4}^{mp} - T_{4f}^{mp} = T_{4}^{ap} + D_4 - T_{4f}^{ap} + F_4(D, \Delta z) = T_{shift} + D_4 + F_4(D, \Delta z) \quad . \tag{3}$$

For a **delayed fission** event, T_{40}^{md} will contain the lifetime and the delays:

$$T_{40}^{md} = T_{4}^{md} - T_{4f}^{md} = T_{4}^{ad} + D_4 - T_{4f}^{ad} + F_4(D, \Delta z) = t_{decay} + T_{shift} + D_4 + F_4(D, \Delta z) \quad . \tag{4}$$

The histograms of T_{40}^{mp} and T_{40}^{md} will look like this:

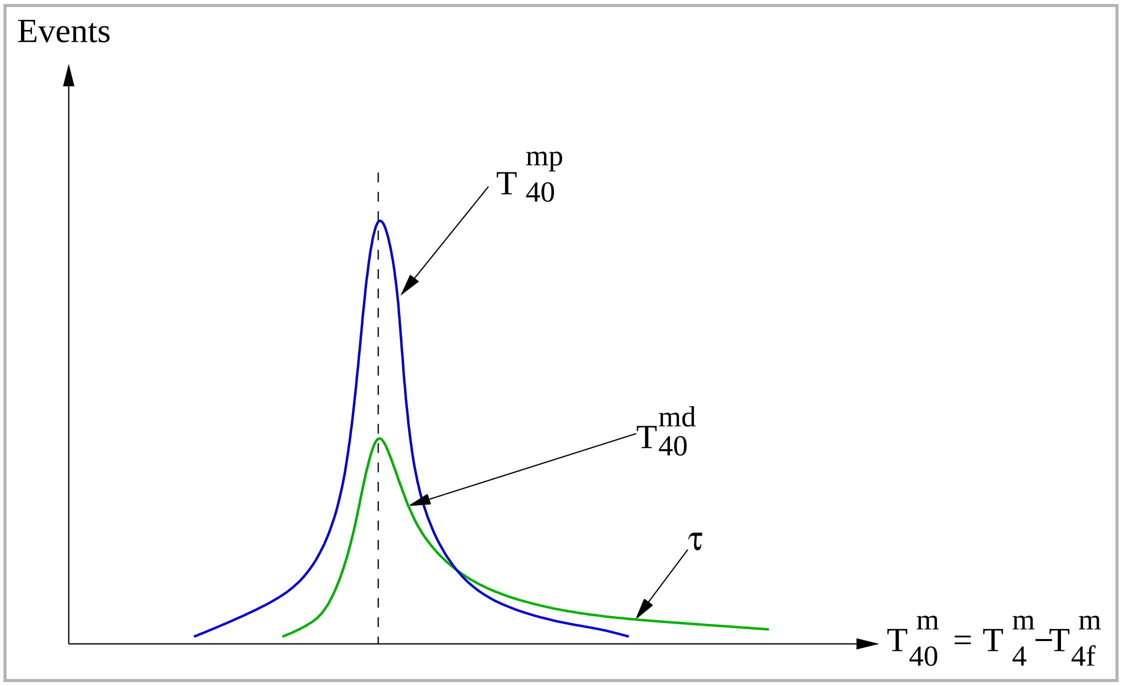

Fig. 3. Prompt time spectrum (blue) and decay time spectrum (green).

From plot of (3), through fitting it with a Gaussian, we obtain its average (central value) $<T_{40}^{mp}>$ and width σ . Here σ is the response time of the detector.

There are many prompt fission events, and we do the determination of the average value and width, say, once per minute. **For each decay event**, we subtract from T_{40}^{md} the nearest $<T_{40}^{mp}>$, which will give us the measured decay time, plus $F_4(D,\Delta z)$. To determine the quantity $F_4(D,\Delta z)$, one needs the geometry of the detector, reconstructed tracks and delays. The geometry is known. The tracks will be reconstructed in a way that does not involve time measurements. Delays will be determined by using ^{252}Cf source, already positioned in the detector. (For details of delay measurements, see the note at http://www.jlab.org/~misp/ffc/notes/delays.pdf) As a result, we will have the decay time for each decay event. We plot the histogram of these decay times, and fit it with an exponential function convoluted with the time response function with the already known σ . From the fit, we obtain lifetime of the hypernuclei τ .

Second method: A coarser method based on cancellation of averages.

We average (3) and (4) over the events. The last terms in (3) and (4) have different values in every event, but their averages are equal, since the set of delays does not change and Δz is determined by the incident beam rather than by the prompt or delayed outcome of the event. Thus, the averaged over the events terms $<F_4(D, \Delta z)>$ will cancel out in the difference of <(3)> and <(4)>. The terms $<T_{shift}>$ and $<D_4>$ will also cancel out, and the difference will yield:

$$<T_{40}^{md}>-<T_{40}^{mp}> \;=\; <t_{decay}>=\tau$$

To avoid errors caused by drifts of delay times and slow changes of other parameters, the averagings and subtraction must be performed over time intervals which are not very far from each other, say, every minute.

Third method: Canceling the unknown delays by selecting similar pairs.

There is one more way to deal with unknown quantities $F_4(D, \Delta z)$ (assuming the delays have not been determined). **After performing track reconstruction** and getting Δz for every event, we can select pairs of events with same Δz with one event in the pair (labeled u) being prompt type and the other (labeled v) being delayed type. We also require that events *u* and *v* are not very far from each other. The quantities $F_4(D, \Delta z)$, though being unknown, will be equal:

$$T_{40}^{mpu} \;=\; T_4^{mpu}-T_{4f}^{mpu} \;=\; T_4^{apu}+D_4-T_{4f}^{apu}+F_4(D,\Delta z^u) \;=\; T_{shift}+D_4+F_4(D,\Delta z^u) \quad . \qquad (5)$$

$$T_{40}^{mdv} \;=\; T_4^{mdv}-T_{4f}^{mdv} \;=\; T_4^{adv}+D_4-T_{4f}^{adv}+F_4(D,\Delta z^v) \;=\; t_{decay}+T_{shift}+D_4+F_4(D,\Delta z^v) \quad . \qquad (6)$$

We can now subtract (5) and (6) to get
$T_{40}^{mdv}-T_{40}^{mpu} \;=\; t_{decay}$. Averaging over such pairs, we will get the lifetime:

$$<T_{40}^{mdv}> \;-\; <T_{40}^{mpu}> \;=\; <t_{decay}> \;=\; \tau$$

To be more accurate, we may select not just one event u , but a set of events $\{u\}$ with same Δz from the set of prompt events. In all cases, events with pairs shall be chosen in a way that they do not span a large time interval, but still are sufficiently large in number. A fine analysis with fitting and determination of lifetime can be performed; thus, lifetime would be determined not through averaging, but through fitting, which is possibly less background-sensitive.

Naturally, each method has its advantages and disadvantages.

Appendix: Dimensions of chamber's elements in mm

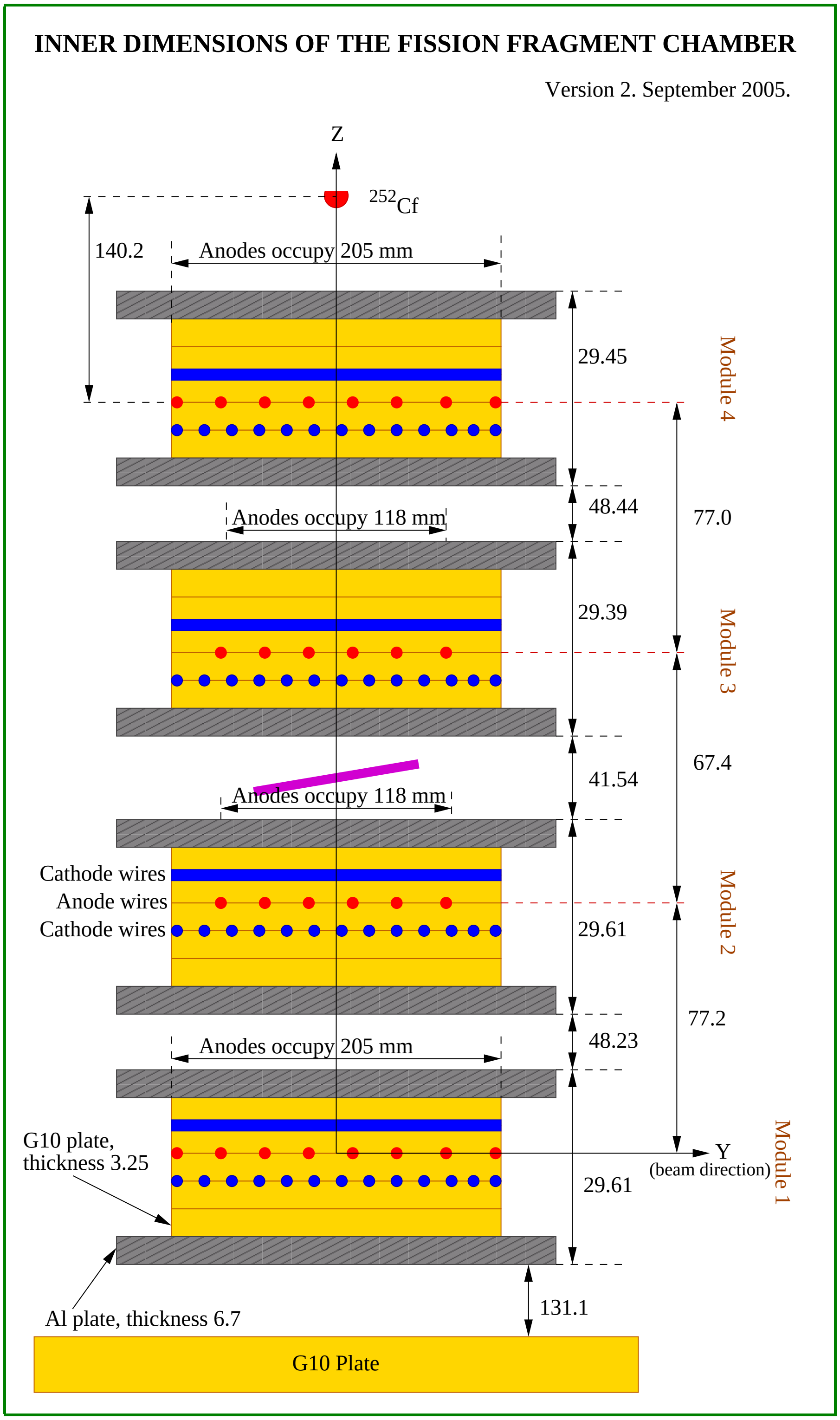

Fig. 4. Measured and/or nominal dimensions and distances.