Quaternary Fission of ^{252}Cf ^{B,G}

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The rare ternary fission process ($\simeq 1/260$ relative to binary fission, for ^{252}Cf) is of particular interest not only for the understanding of the fission process itself, but also as a source of various neutron-rich light nuclei [1]. The study of "exotic" light nuclei is a major topic in modern nuclear structure physics with radioactive beams. The even rarer quaternary fission (QF) mode [2], when two light charged particles (LCP) are emitted simultaneously in addition to the main fission fragments, can originate either from a break-up of unstable species among the LCPs, e.g. ^{7}Li*, ^{8}Be, ^{9}Be* ("pseudo" quaternary fission), or from the independent emission of two LCPs ("true" quaternary fission).

The QF processes were studied at GSI using a spontaneous ^{252}Cf fission source (~ 5000 fissions/sec). The LCPs were identified by a set of eight ΔE-E telescopes (12 μm + 380 μm Si detectors of 1 cm^2 each) subtending a total solid angle of $\sim 20\%$. Fission fragments and the 6.1 MeV α-particles from the ^{252}Cf radioactivity were stopped in suitable absorbers placed between source and detectors. The telescopes allowed for a clean separation of the LCP nuclear charges. A total of 255 α-α coincidences were detected, within a time window of 10 nsec. Simultaneously, single LCP events with the emission of ternary α, Li and Be particles were registered and could be used as a reference.

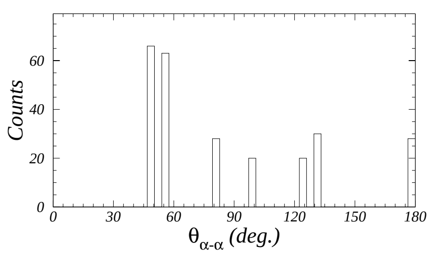

Figure 1: Measured relative angles for α-α coincidences.

Figure 1 shows the number of α-α coincidences as a function of the relative angle between the centers of the telescope surfaces. There is a clear enhancement of the quaternary fission yield at the smaller angles which is attributed to the break-up of ^{8}Be LCPs, while the homogeneous distribution at the larger angles signals the true QF events. Simple estimates based on the kinematics of the ternary ^{8}Be decay in flight show that the largest possible angle between the two α-particles from the ^{8}Be ground-state decay ($T_{1/2} = 0.07$ fs, $Q = 0.092$ MeV) equals 8^{o}, while the smallest distance between neighbouring telescopes corresponds to an opening angle of 16^{o}. Thus, the observed enhancement in the angular distribution is presumably due to the decay from the first excited level in ^{8}Be ($T_{1/2} = 3 \times 10^{-22}$ s, $Q = 3.13$ MeV). In that case the distribution of the relative angles is expected to be significantly broader [2].

The energy spectra of the true and pseudo QF components are presented in Fig. 2. The yield for the true

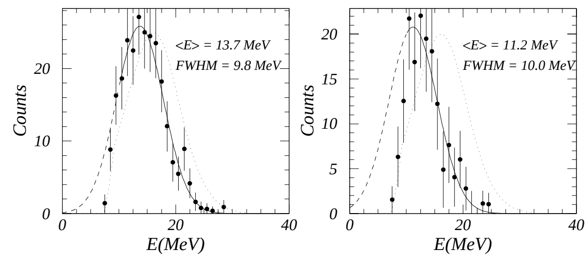

Figure 2: Energy spectra (corrected for the energy loss in the absorbers) of the true quaternary α-particles (left) and α-particles mediated by ^{8}Be* LCPs (right). The solid lines are Gaussian fits, the dotted line is the measured ternary α-particle spectrum ($< E >= 15.9$ MeV).

α-α QF, assuming isotropic distribution of the relative angles, is estimated as $(3 \pm 1) \times 10^{-4}$ relative to the yield of ternary ^{4}He. The two quaternary α-particles mediated by the ground-state decay of ^{8}Be are registered in our set-up as an admixture to the Li spectrum, as they fall into the same range in the ΔE-E patterns. An attempt was made to disentangle these two contributions by fitting the known Li energy spectrum [3] and the sum spectrum of the two α-particles from the ^{8}Be decay, considering the energy loss in the absorbers and ΔE detectors, to the measured E_{rest} spectrum (Fig. 3).

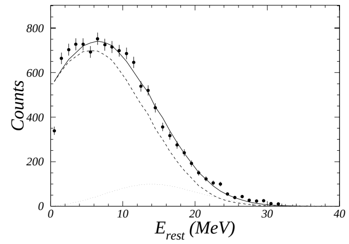

Figure 3: Decomposition of the E_{rest} spectrum gated on the ΔE-E patterns for Li (points): Dashed line - ternary Li spectrum, dotted line - sum spectrum of two α's hitting a telescope, solid line - sum of both components.

The result (still preliminary) for the ^{8}Be ground-state yield is $\simeq 1 \times 10^{-3}$ relative to the yield of ternary ^{4}He. The systematic error in this procedure is fairly large ($\geq 50\%$), because of the uncertainty in the energy loss corrections and the not precisely known ternary Li spectrum. In a forthcoming experiment it is thus planned to separate the Li ternary particles unambiguously from the double α-particle hits in each telescope by applying pulse-shape discrimination in suitable E_{rest} detectors.

References

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