NON-STATISTICAL EFFECTS IN BETA & GAMMA DECAYS AND BETA-DELAYED FISSION ANALYSIS

IGOR IZOSIMOV

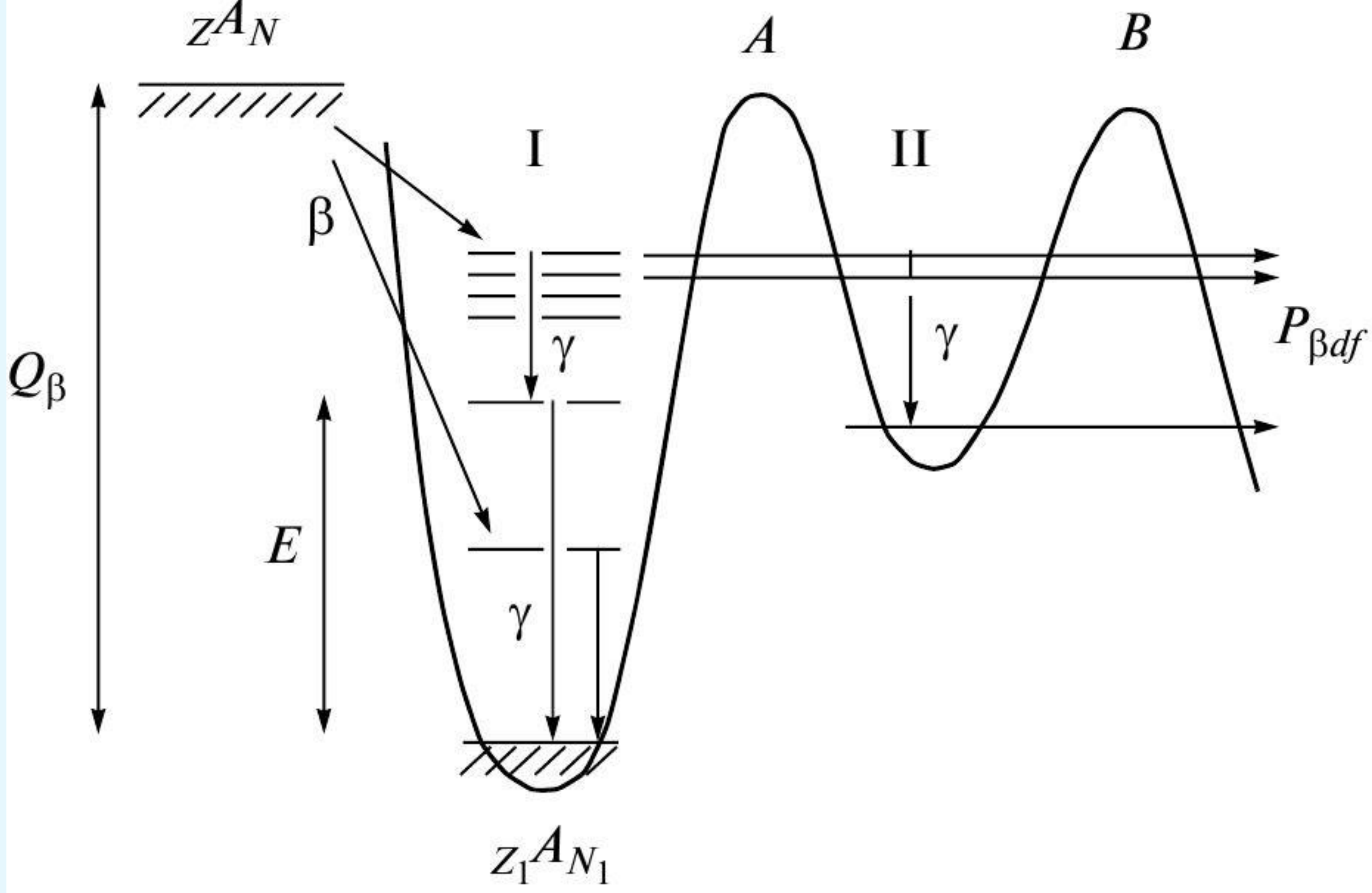


Fig. 8. Scheme of the nuclear β-delayed fission (β*df*). Heights of the internal (*A*) and external (*B*) fission barriers for the daughter nucleus are given.

The probability $P_{\beta d}$ of β-delayed process is :

$$P_{\beta d} = \frac{\int_0^{Q_\beta} S_\beta(E) f(Q_\beta - E)\Gamma_d(E)/\Gamma_{tot}(E)\, dE}{\int_0^{Q_\beta} S_\beta(E) f(Q_\beta - E)\, dE}$$

where $\Gamma_d(E)$ – delayed process width, $\Gamma_{tot}(E)$ – total width.

$$\Gamma_{tot} = \Gamma_d + \Gamma_\gamma$$

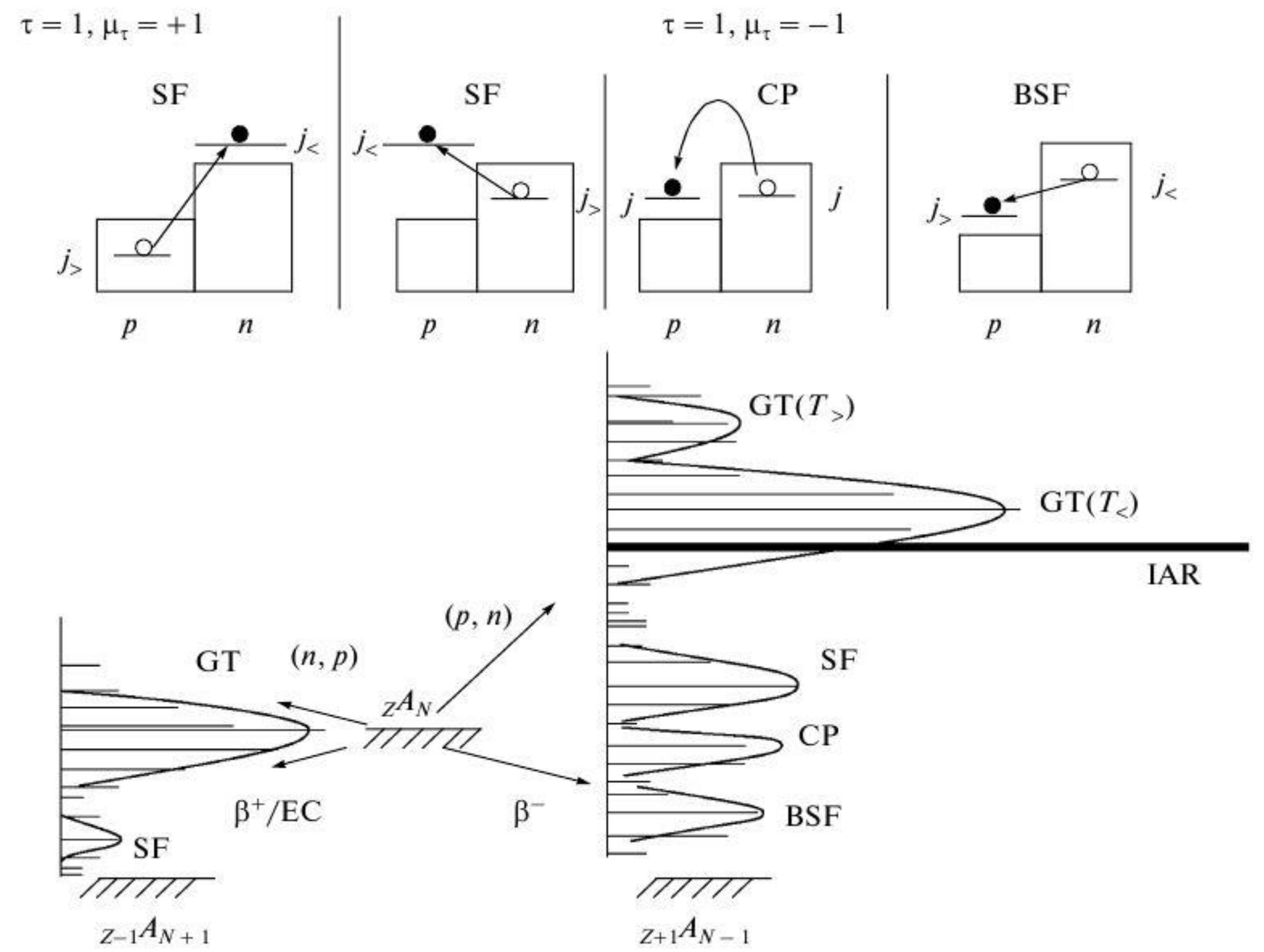
Below Q_β there are local maxima in $S_\beta(E)$ both for *GT* and *FF* β-transitions. The fine structures of these maxima in β^+/EC $S_\beta(E)$ are manifested in the form of resonances in the delayed proton spectrum.

The β–transition probability is proportional to the product of the lepton part described by the Fermi function $f(Q_\beta - E)$ and the nucleon part described by the β-decay strength function $S_\beta(E)$, where E is the excitation energy in daughter nuclei and Q_β is the total energy of β-decay.

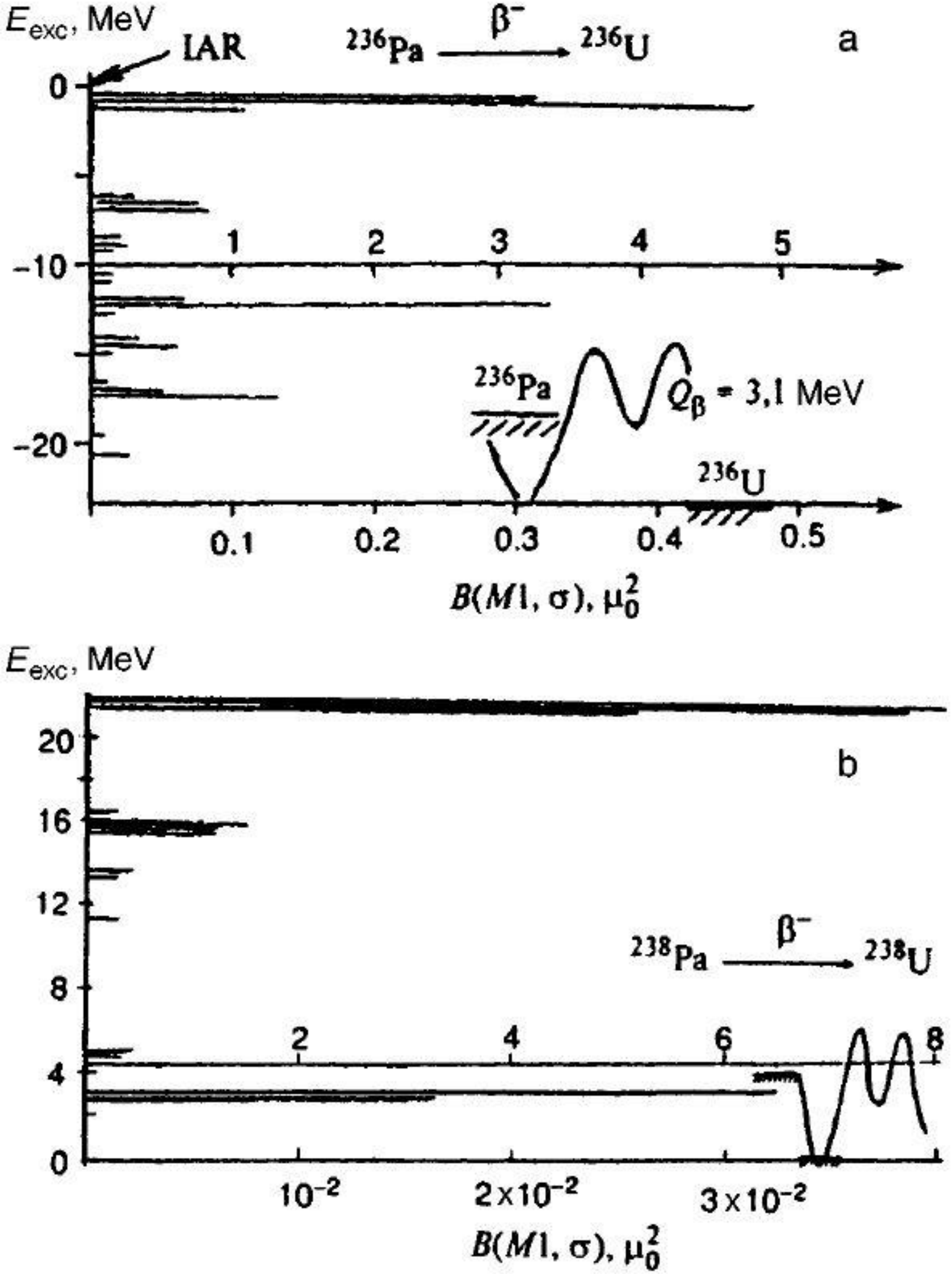
The previously dominant statistical model assumed that there were no resonances in $S_\beta(E)$ in Q_β-window and the relations $S_\beta(E)$ = Const or $S_\beta(E) \sim \rho(E)$, where $\rho(E)$ is the level density of the daughter nucleus, were considered to be a good approximations for medium and heavy nuclei for excitation energies $E > 2–3$ MeV.

Ideas about the non-statistical structure of the strength functions $S_\beta(E)$ have turned out to be important for widely differing areas of nuclear physics including the description of delayed processes by considering the $S_\beta(E)$ structure.

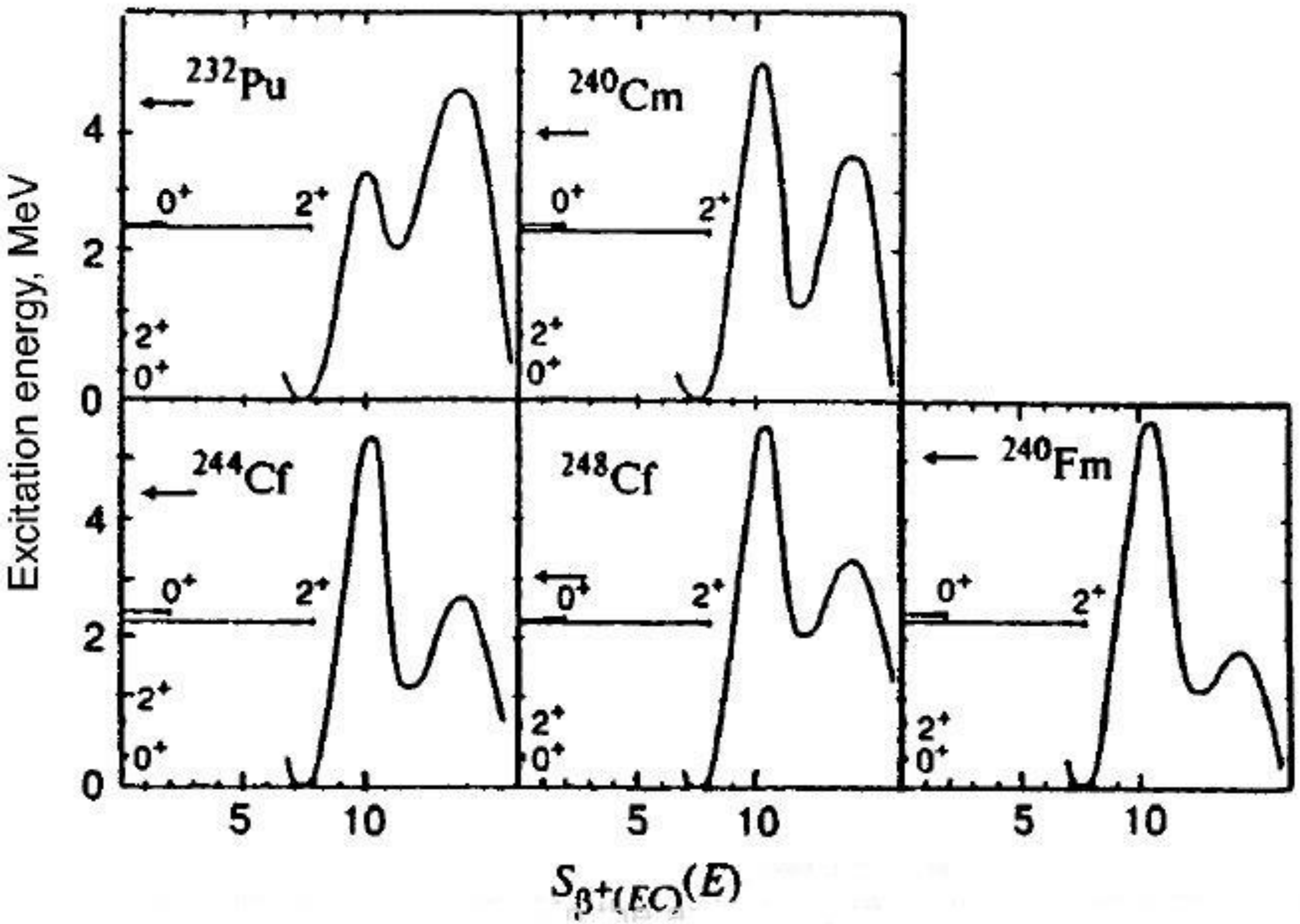
The delayed fission probability substantially depends on the resonance structure of the $S_\beta(E)$ both for β^- and β^+/EC decays. It can therefore be concluded from this analysis of the experimental data on delayed fission that delayed fission can be correctly described only by using the non-statistical β-transition strength function reflecting nuclear-structure effects.



τ = 1, μ_τ = +1
τ = 1, μ_τ = −1
SF
SF
CP
BSF
j<
j>
j
p
n
GT(T>)
GT(T<)
IAR
(p, n)
(n, p)
GT
ZAN
β+/EC
β−
SF
CP
BSF
Z−1AN+1
Z+1AN−1



E_{exc}, MeV
IAR
$^{236}Pa \xrightarrow{\beta^-} {}^{236}U$
a
0
−10
−20
1
2
3
4
5
^{236}Pa
Q_β = 3,1 MeV
^{236}U
0.1
0.2
0.3
0.4
0.5
$B(M1, \sigma)$, μ_0^2
E_{exc}, MeV
b
20
16
12
8
4
0
$^{238}Pa \xrightarrow{\beta^-} {}^{238}U$
2
4
6
8
10^{-2}
2×10^{-2}
3×10^{-2}
$B(M1, \sigma)$, μ_0^2



Excitation energy, MeV
^{232}Pu
^{240}Cm
^{244}Cf
^{248}Cf
^{240}Fm
0$^+$
2$^+$
0
2
4
5
10
$S_{\beta^+(EC)}(E)$

The essential energy window is $\delta = Q_\beta - E_{thr}$, where $E_{thr} = B_n$ for delayed neutrons, $E_{thr}=B_p+ E_{p0}+q$, for delayed protons, $E_{thr} = E_{II}$ for delayed fission, B_n- neutron binding energy, B_p- proton binding energy,
$q \approx$ 1MeV-2MeV, E_{p0} – excitation energy at which the proton emission width is comparable with the gamma emission width, E_{II} – second well energy for delayed fission through two hump fission barrier and :

$$P_{\beta d} \approx \frac{\int_{E_{thr}}^{Q_\beta} S_\beta(E) f(Q_\beta - E)\Gamma_d(E)/\Gamma_{tot}(E)\, dE}{\int_{0}^{Q_\beta} S_\beta(E) f(Q_\beta - E)\, dE}$$

For delayed protons, when the energy dependence of $\Gamma_d(E)/\Gamma_{tot}(E)$ is more stronger than the energy dependence of $f(Q_{EC} - E)$, the $P_{\beta d}$ will be higher when peak in $S_\beta(E)$ is near Q_{EC} (fig. 3a). For delayed neutrons at $E>B_n$ the energy dependence of $f(Q_\beta\text{--}E)$ is more stronger than the $\Gamma_n(E)/\Gamma_{tot}(E)$ energy dependence and $P_{\beta d}$ will be higher when a peak in $S_\beta(E)$ is near B_n (fig.3b).

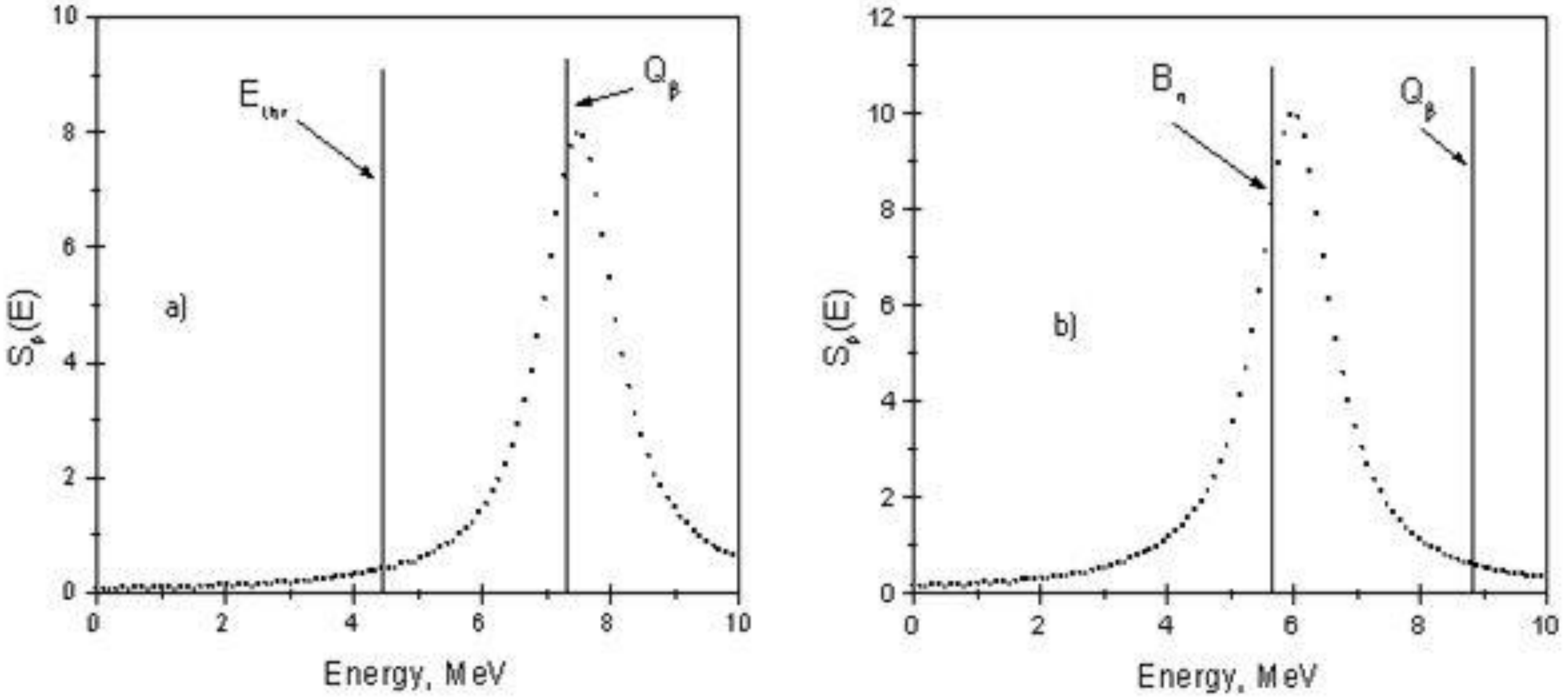


Fig.3. Different $S_\beta(E)$ peak position in the $(Q_\beta - E_{thr})$ energy window.

For beta delayed fission, beta delayed protons and beta delayed alpha particles emission probability analysis the energy dependence of $S_\beta(E)$ is very essential in (Q_β – E_{thr}) window. For beta delayed neutrons as a role only the total part value of beta strength in Q_β – E_{thr} is essential. Of course for delayed particles spectra analysis the energy dependence of $S_\beta(E)$ is essential in all cases.

For correct calculations of the beta-delayed processes probabilities $P_{\beta d}$ it is necessary to have experimental information and systematic on $S_\beta(E)$ peaks width and fine structure.

In β-decay the simple (non-statistical) configurations are populated and as a consequence the non-statistical effects may be observed in γ-decay of such configurations. In delayed fission analysis the γ-decay widths Γ_γ **calculated using the statistical model**, which, in general, can only be an **approximation**.

Because the information about γ-decay is very important for delayed fission analysis, it is necessary to consider the influence of **non-statistical effects on delayed fission** probability not only for β-decay, but also **for γ-decay**.

Non-statistical effects in (p,γ) nuclear reactions in the excitation and decay of the non-analog resonances, for which simple configurations play an important role, were analyzed. The strong non-statistical effects were observed both for $M1$ and $E2$ γ-transitions.

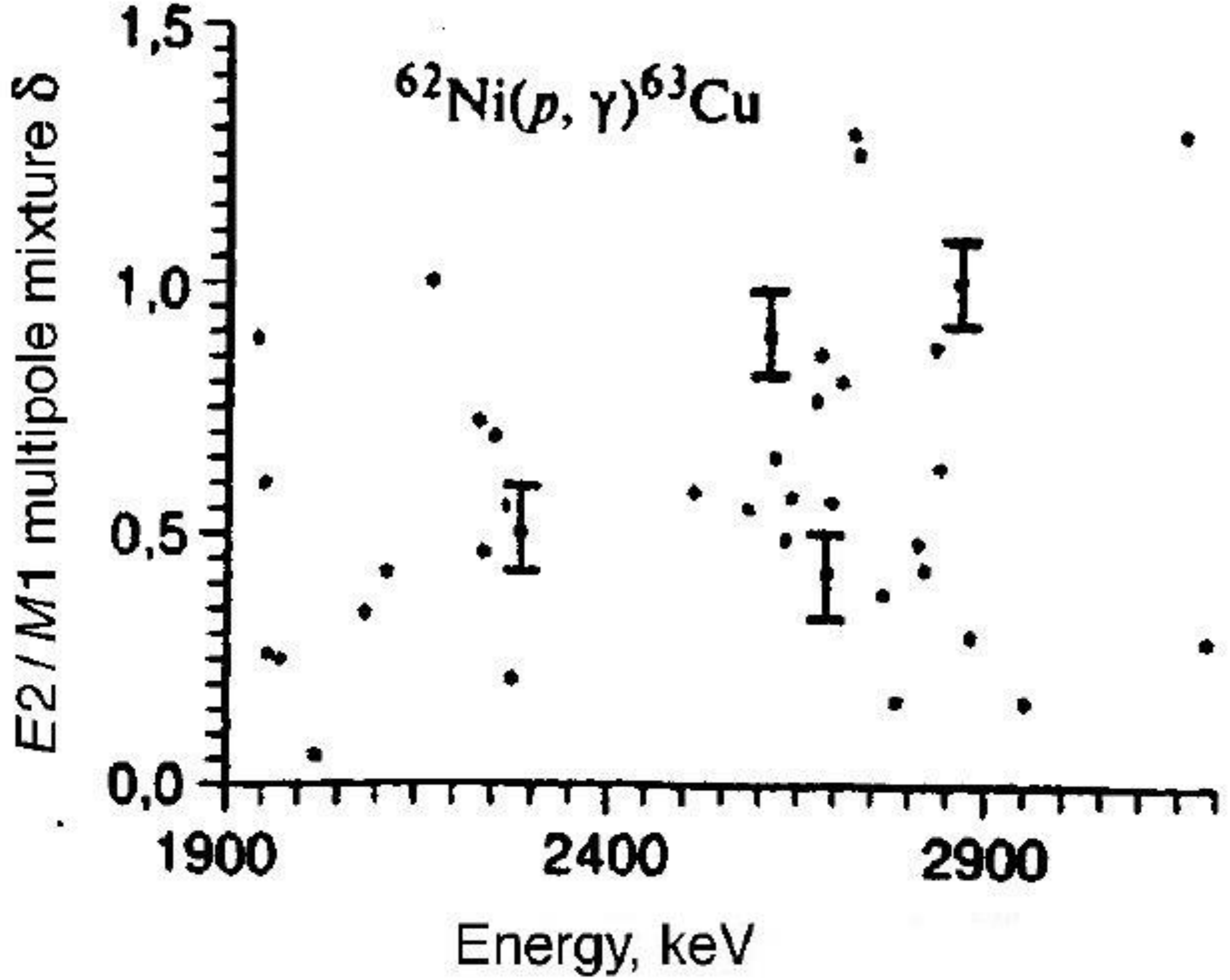


FIG. 21. Dependence of the multipole mixture δ on the incident-proton energy for nonanalog resonances with $I^{\pi} = \frac{3}{2}^{-}$ in ^{63}Cu. The excitation energies of resonances in ^{63}Cu ranged from 8040 to 9250 keV. The average value of δ is $\langle \delta \rangle = (0.6 \pm 0.1)$, while the statistical model gives $\langle \delta \rangle = 0$.

Conclusion

1. GT and FF $S_\beta(E)$ have resonance and fine structure both for spherical, transition, and deformed nuclei.
2. Deformation leads to the splitting of the $S_\beta(E)$ peaks.
3. For correct calculations of the beta-delayed processes probabilities $P_{\beta d}$ it is necessary to have experimental information and systematic both on $S_\beta(E)$ structure and Γ_γ values.
4. Only after proper consideration of non-statistical effects both for β-decay and γ-decay it is possible to make a **quantitative** conclusion about fission barriers.