Width Fluctuation Correction Factor for Beta-delayed Neutron Emission

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Beta-delayed neutron emission important for neutron-rich reaction networks

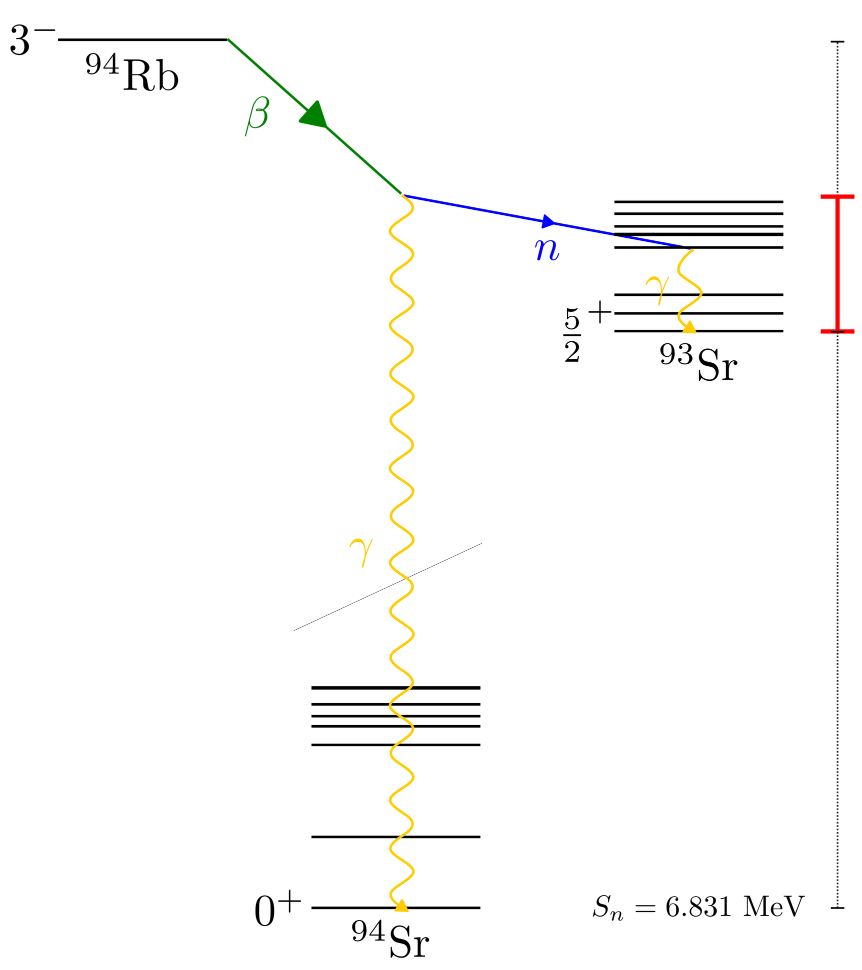

Fig. 1. **Beta-delayed neutron emission is important for the r-process and decay of fission fragments**. In the r-process, neutron capture and beta-decay compete for dominance and shape the observed isotopic abundances.

Beta-delayed neutron emission interrupts the balance between capture and beta-decay by producing additional "delayed" neutrons, altering the decay pathways and final abundance patterns.

Without correction Hauser-Feshbach has too many neutrons; not enough gammas

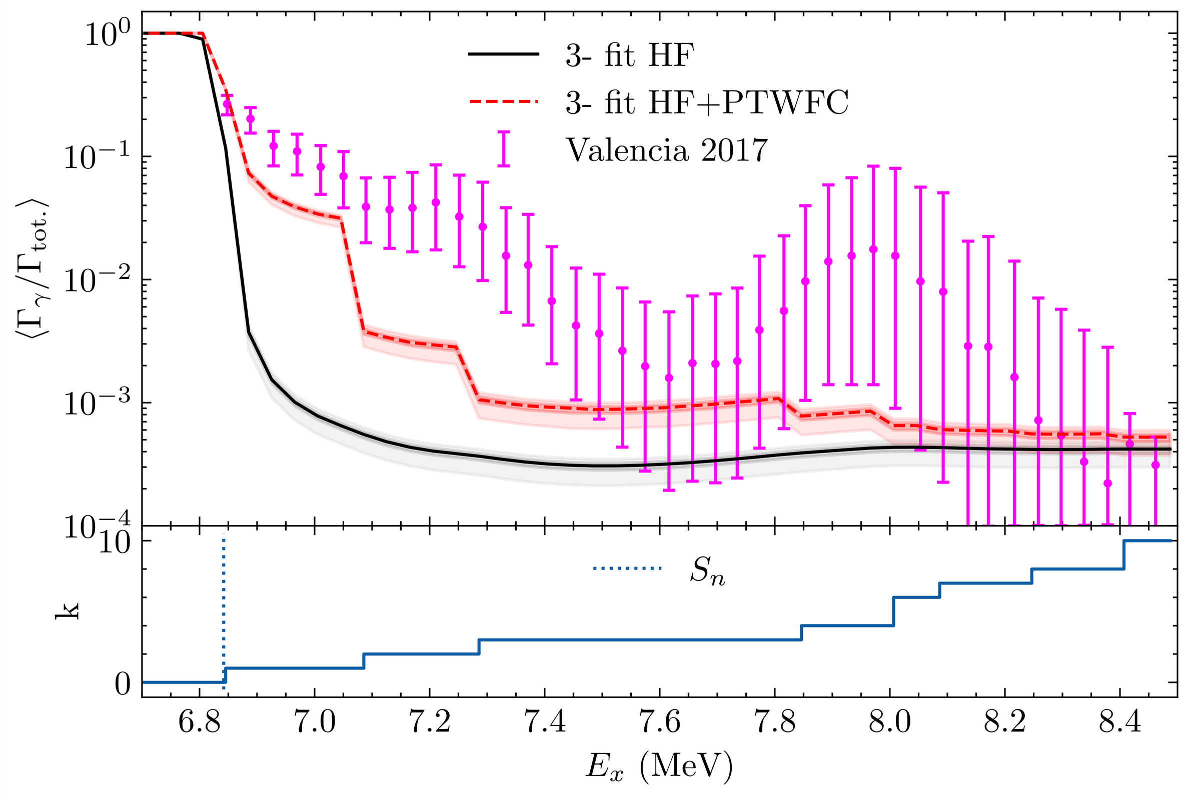

Fig. 2. Measured[1] probability of gamma emission vs. energy of the nucleus after beta decay. Valencia et al. pointed out a significant discrepancy with Hauser-Feshbach value; one must account for Porter-Thomas fluctuations of the neutron partial widths.

[1]PRC95,024320(2017)

Valencia et al. used a Monte Carlo simulation akin to DICEBOX to add the effect of width fluctuations. **I propose a Moldauer correction factor to replace this costly MC simulation.**

What is fluctuating? Individual decay widths are "random" and so are total decay widths

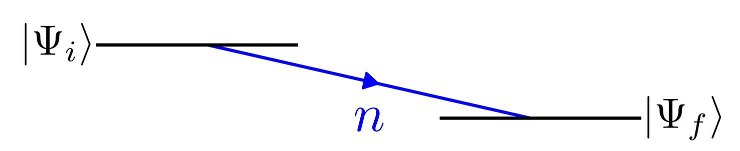

Fig. 3.a. The partial decay width is proportional to the square of a transition matrix element:

$$\Gamma_{if} \propto |\langle\Psi_f|\hat{O}|\Psi_i\rangle|^2$$

These follow a Porter-Thomas distribution.

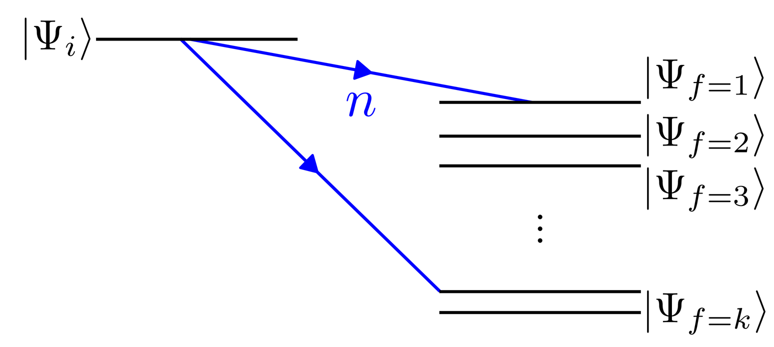

Fig. 3.b. The total decay width is the sum over all partial decay widths for all allowed final states:

$$\Gamma_i = \sum_{f=1}^{k} \Gamma_{if}$$ k = number of final states

These follow a chi-squared distribution.

Porter-Thomas distribution and family: A sum of k gaussians is a chi-squared

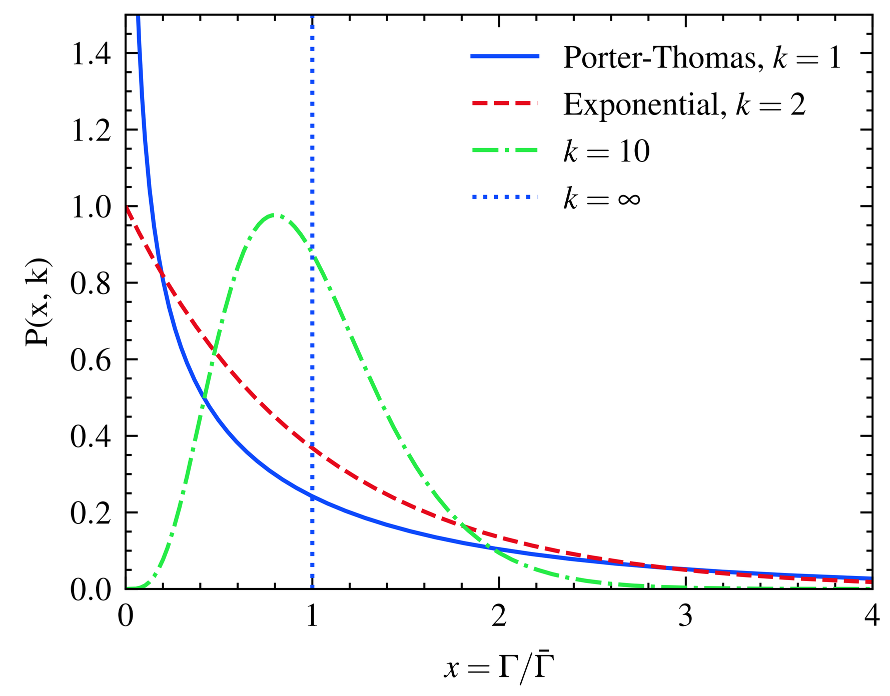

Fig. 4. The Porter-Thomas distribution is a special case of the chi-squared distribution with k = 1 (degrees of freedom). Adding k such samples together yields a chi-squared distribution with k degrees of freedom:

$$P(x, k=2r) = \Gamma(r)^{-1} r (rx)^{r-1} e^{-rx}$$

As k becomes large, the distribution becomes "Gaussian" and eventually a delta function (constant). Hauser-Feshbach theory works in this limit.

Numerical experiment: with few neutron final states, Hauser-Feshbach underpredicts gammas

Simulation:

1. Randomly generate widths:
   $$\Gamma_n \to \Gamma_n/\langle\Gamma_n\rangle \equiv x \sim P(x,k)$$
   $$\Gamma_\gamma \to \Gamma_\gamma/\langle\Gamma_\gamma\rangle = 1 \sim P(x, k\to\infty)$$
2. Compute ratios and averages
   Experiment measures:
   $$\left\langle \frac{\Gamma_\gamma}{\Gamma_\gamma+\Gamma_n} \right\rangle = \left\langle \frac{1}{1+x} \right\rangle$$
   Hauser-Feshbach computes:
   $$\frac{\langle\Gamma_\gamma\rangle}{\langle\Gamma_\gamma\rangle+\langle\Gamma_n\rangle} = \frac{1}{1+1}$$

This could be improved with finite k_γ.

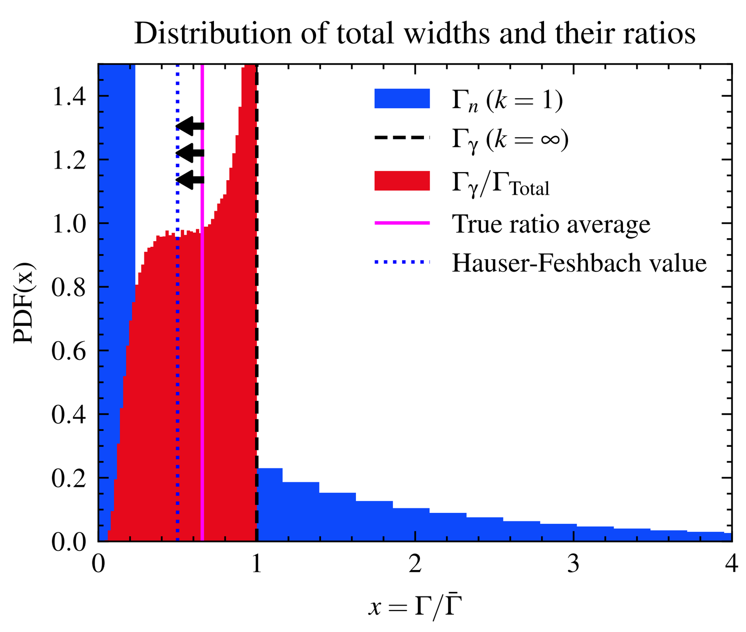

Fig. 5.a. For small k, long-tailed distribution causes HF neutron width to be over-valued, reducing predicted gamma channel.

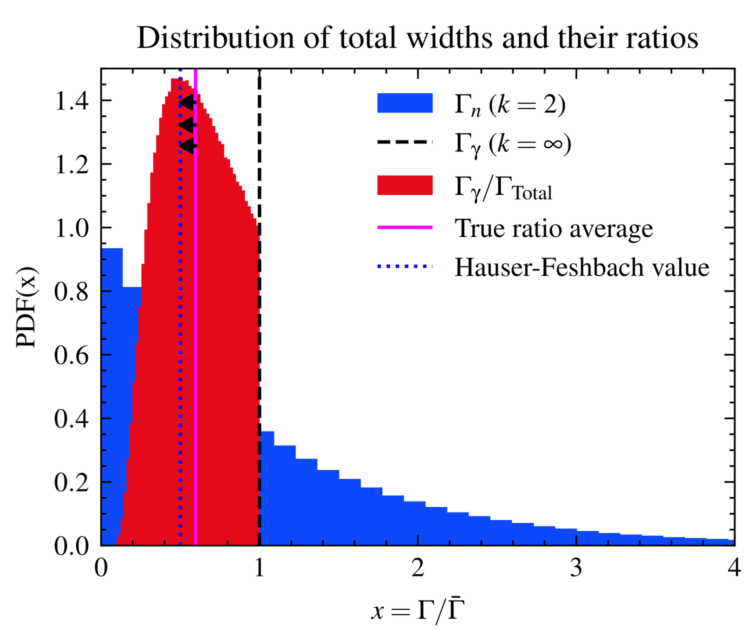

Fig. 5.b. The ratio of the averages is not equal to the average of the ratios even with k > 1.

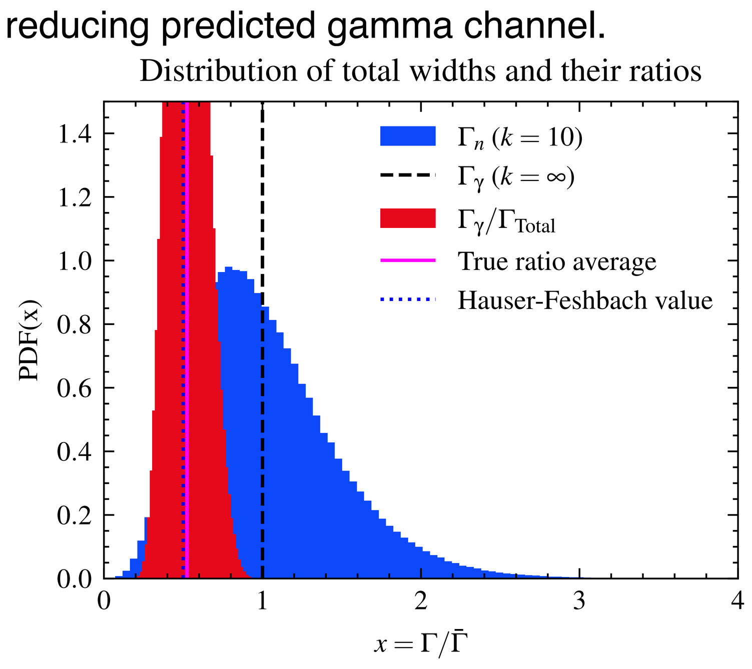

Fig. 5.c. As k grows, the true ratio approaches Hauser-Feshbach predictiont

A Moldauer correction factor for near-threshold decay

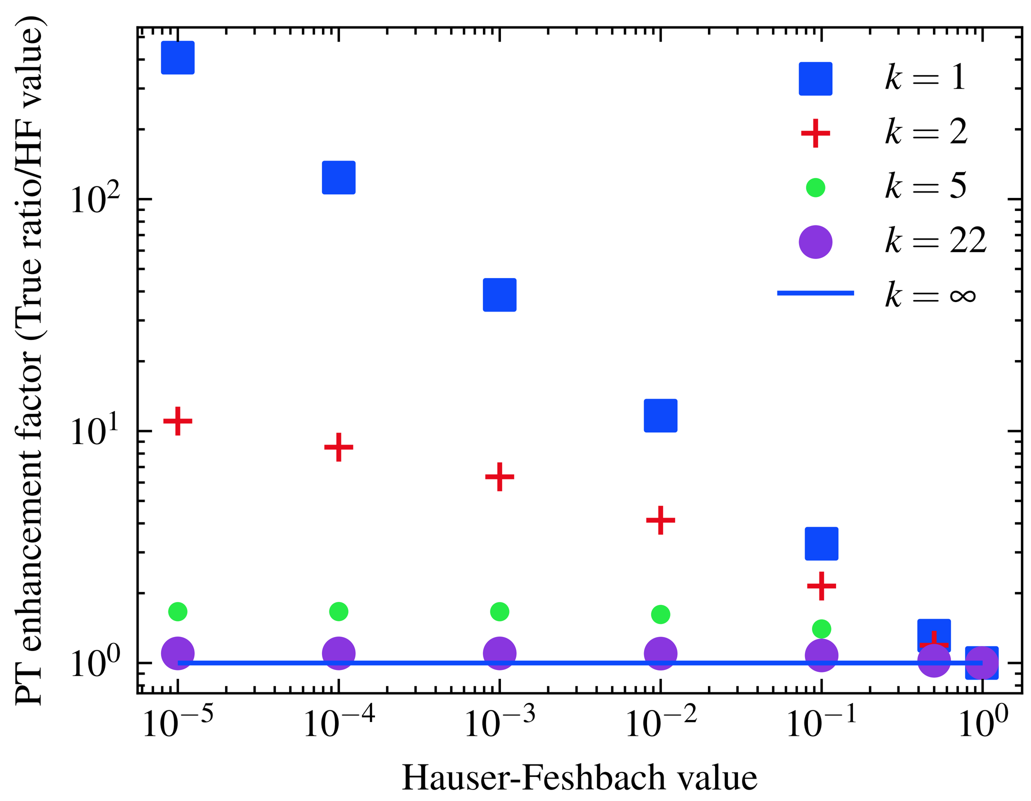

Fig. 6. Enhancement of the predicted gamma emission (true value versus Hauser-Feshbach approximation) as a function of the Hauser-Feshbach value and the number of neutron final states k.

I define a "new"[2] width fluctuation correction factor computed using the numerical integration; it depends only on the number of neutron final states k, and the relative strength of gamma width y:

$$W(k,y) \equiv \left\langle \frac{\Gamma_\gamma}{\Gamma_\gamma+\Gamma_n} \right\rangle \frac{\langle\Gamma_\gamma\rangle+\langle\Gamma_n\rangle}{\langle\Gamma_\gamma\rangle} = \frac{\text{True ratio}}{\text{Hauser-Feshbach value } y}$$

[2]Moldauer PRC 14, 2 (1976)

Hauser-Feshbach theory under-predicts gamma emission in BDNE unless width fluctuations are taken into account. To avoid costly Monte Carlo simulations, I propose a "new", Moldauer-inspired correction factor to correct the Hauser-Feshbach approximation.

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