中性子過剰核のベータ崩壊と遅発中性子

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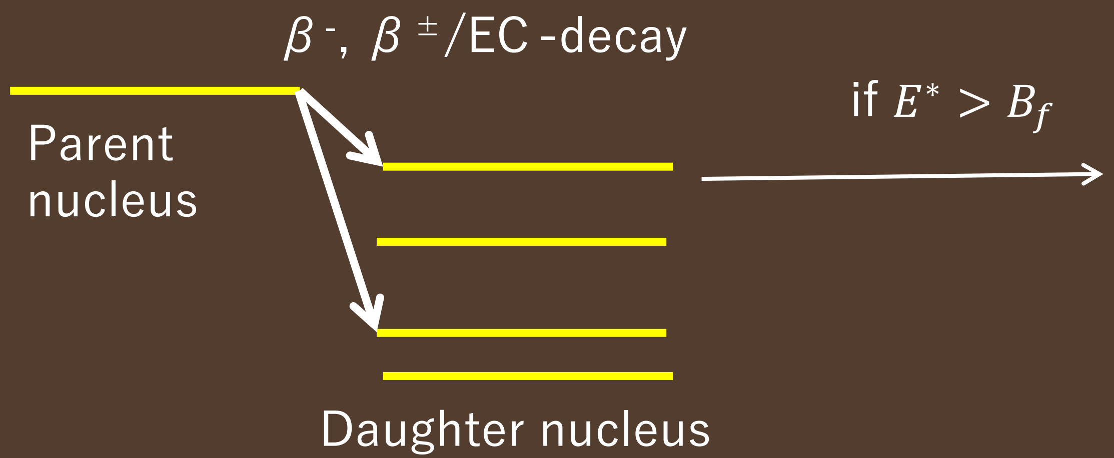
1)Background
2)Fission Fragment Yield
3)β-delayed neutron & fission
4)Summary

理論と実験で拓く中性子過剰核の核分裂@理研, 2023 2/16

BACKGOUND

Nucleus can be excited by $\beta^{\pm}$ decays

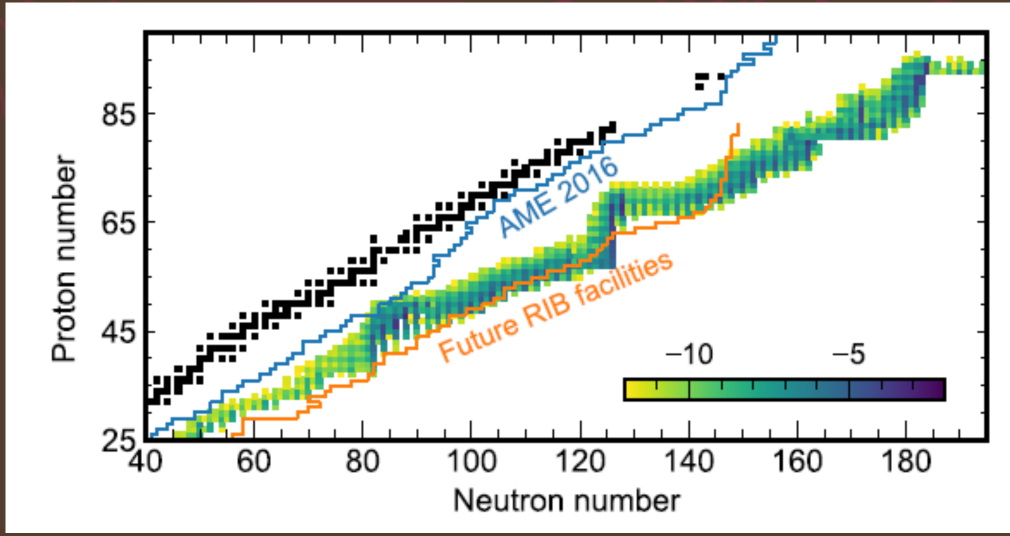


Beta-Delayed Fission

BACKGOUND

Role of Beta-Delayed Fission in r-process

1. Competing β-delayed Neutron Emission
2. Termination of heavy element synthesis after freeze-out



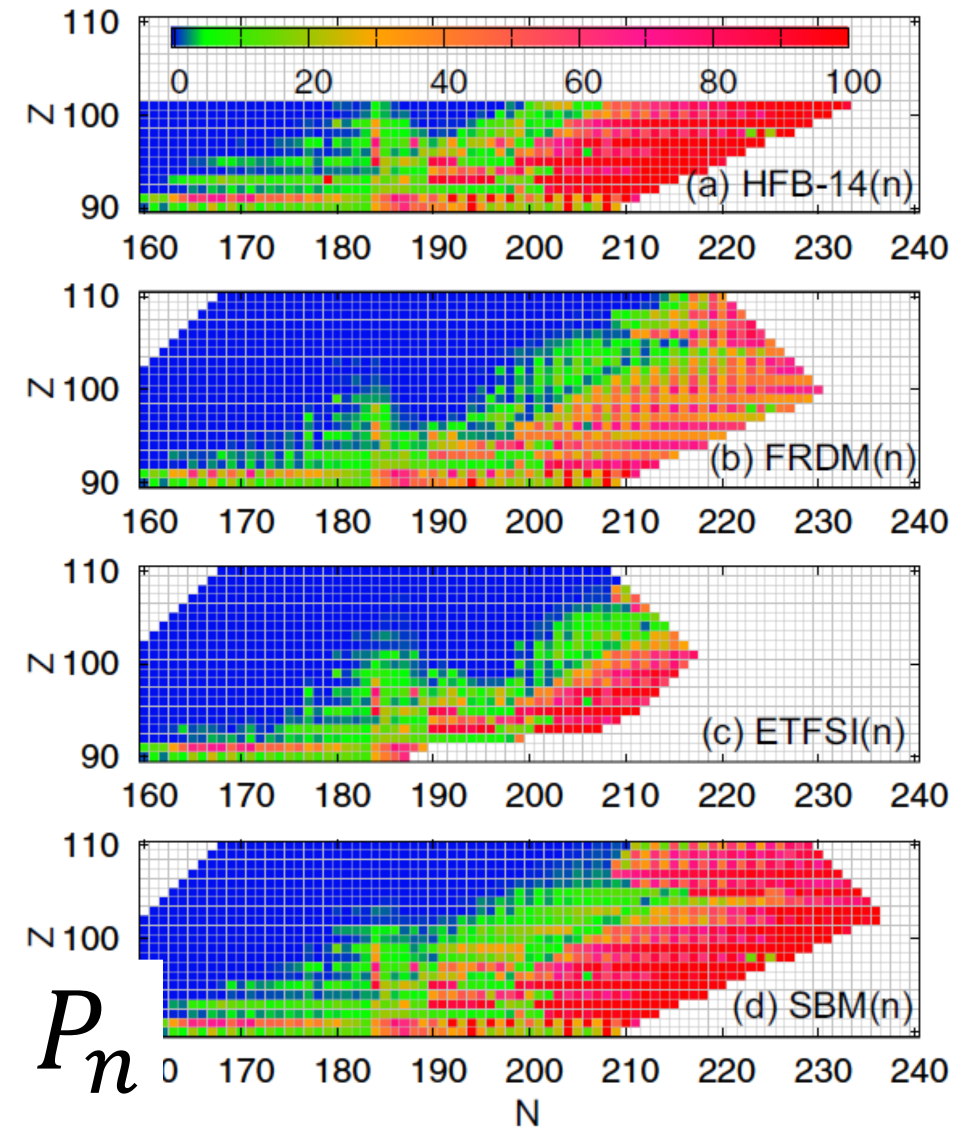
Substantial Effect of β-Delayed Fission on r-process

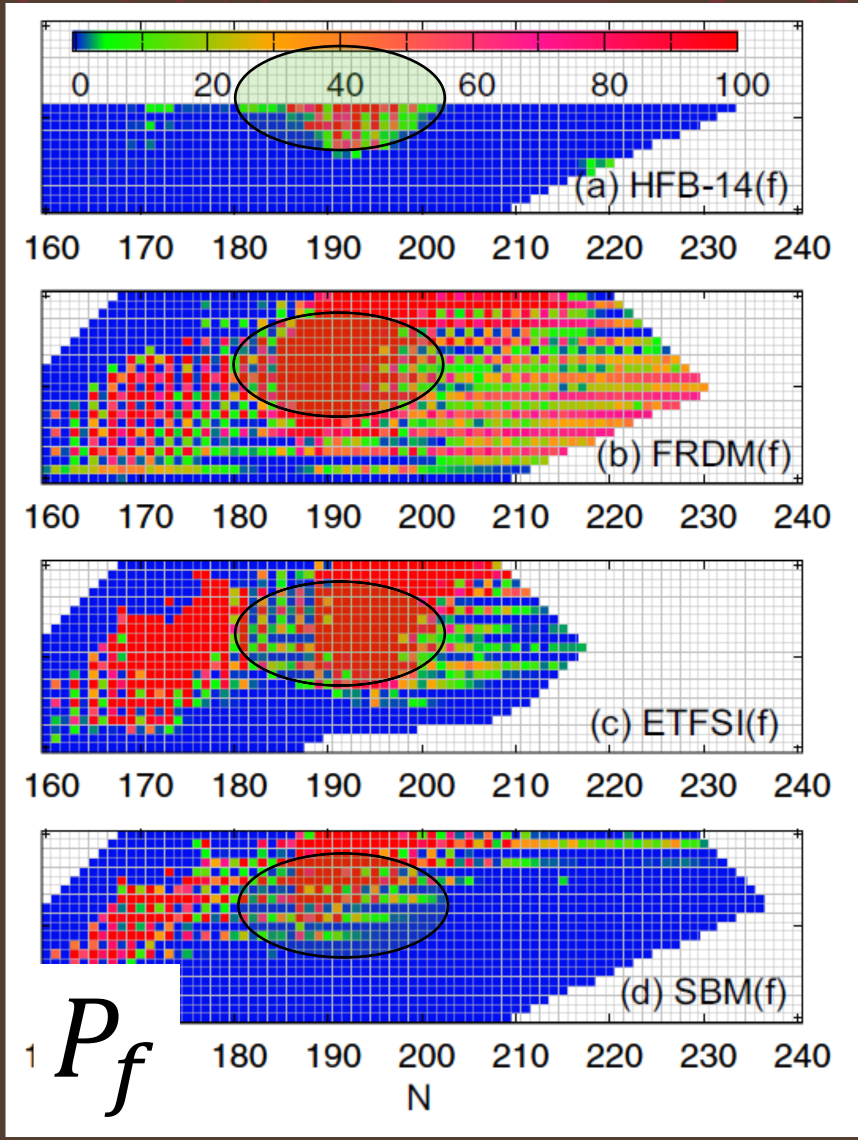
1. Source of neutron (prompt fission neutron)
2. Reaccumulating abundance of middle heavy nuclei

Need fission fragment distribution (FFD)

BACKGOUND

FM, T. Marketin, N. Paar, PRC **104**, 044321 (2021)





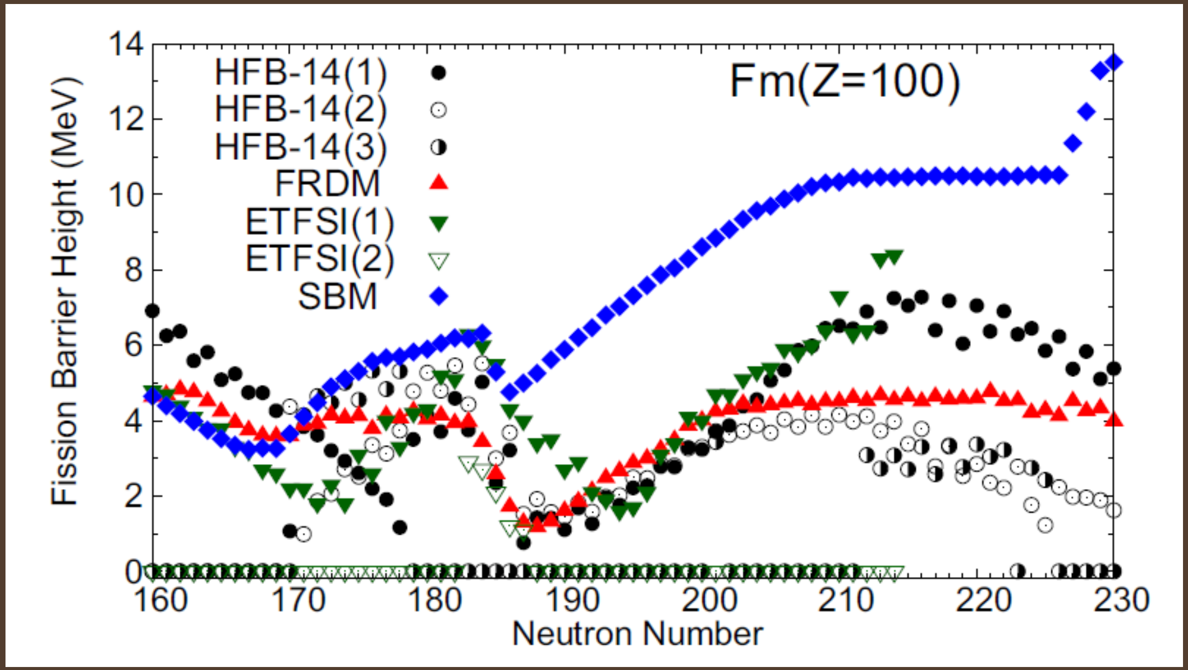
$$Z \sim 100, N \sim 190$$

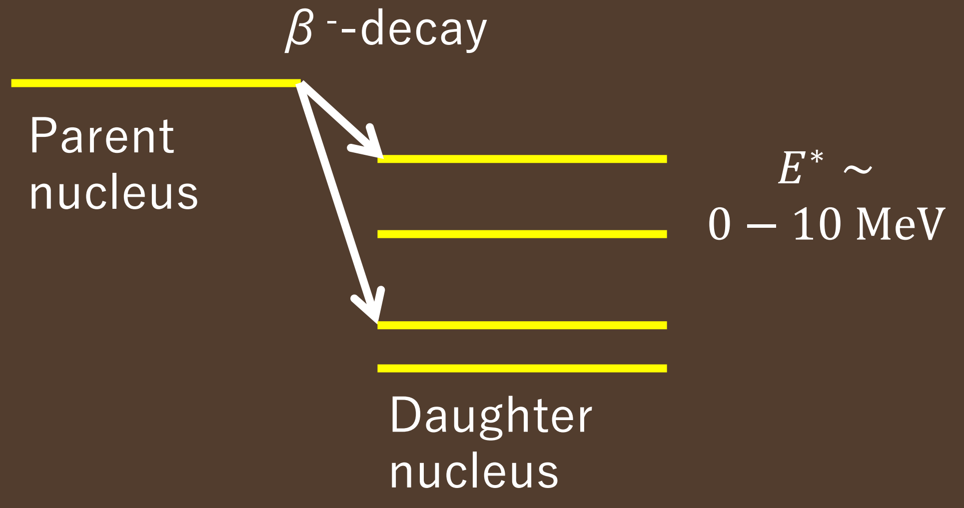
BACKGOUND

$$Z \sim 100, N \sim 190 \rightarrow Q_\beta = 8 - 10\ \mathrm{MeV}$$

$$B_f = 1 - 6\ \mathrm{MeV}$$

$$S_n = 5\ \mathrm{MeV}$$





Estimating FFD for n-rich nuclei

Katakura Model JAERI-Research 2003-004

$$\begin{aligned}\psi(A,E^*) &= N_s\psi_s(A,E^*) + N_a\psi_a(A,E^*)\\ &= N_s\psi_s(A,E^*) + N_a\left[\psi_{h1}(A,E^*) + \psi_{l1}(A,E^*) + F\left\{\psi_{h2}(A,E^*) + \psi_{l2}(A,E^*)\right\}\right]\end{aligned}$$

$$\begin{aligned}\psi_s(A,E^*) &= \frac{1}{\sqrt{2\pi}\sigma_s}\exp\left\{-(A-A_s)^2/2\sigma_s^2\right\},\\ \psi_{h1}(A,E^*) &= \frac{1}{\sqrt{2\pi}\sigma_{h1}}\exp\left\{-(A-A_{h1})^2/2\sigma_{h1}^2\right\},\\ \psi_{h2}(A,E^*) &= \frac{1}{\sqrt{2\pi}\sigma_{h2}}\exp\left\{-(A-A_{h2})^2/2\sigma_{h2}^2\right\},\end{aligned}$$

$$\begin{aligned}N_s &= 200/(1+2R),\\ N_a &= 200R/\left\{(1+F)(1+2R)\right\},\end{aligned}$$

$$R = [112.0 + 41.24\sin(3.675S)]\cdot\frac{1.0}{BN^{0.331}+0.2067}\cdot\frac{1.0}{E^{0.993}+0.0951}, \tag{3.2}$$

$$F = 10.4 - 1.44S, \tag{3.3}$$

$$\sigma_s = 12.6, \tag{3.4}$$

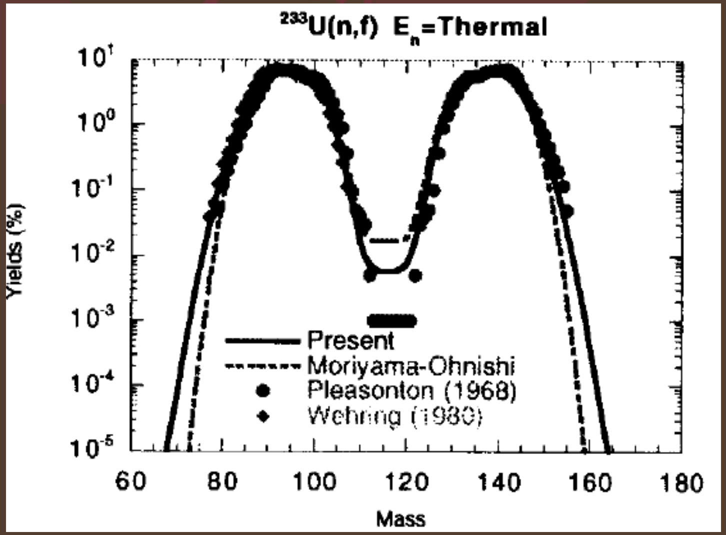
$$\sigma_{h1} = (-25.27 + 0.0345A_f + 0.216Z_f)(0.438 + E + 0.333BN^{0.333})^{0.0864}, \tag{3.5}$$

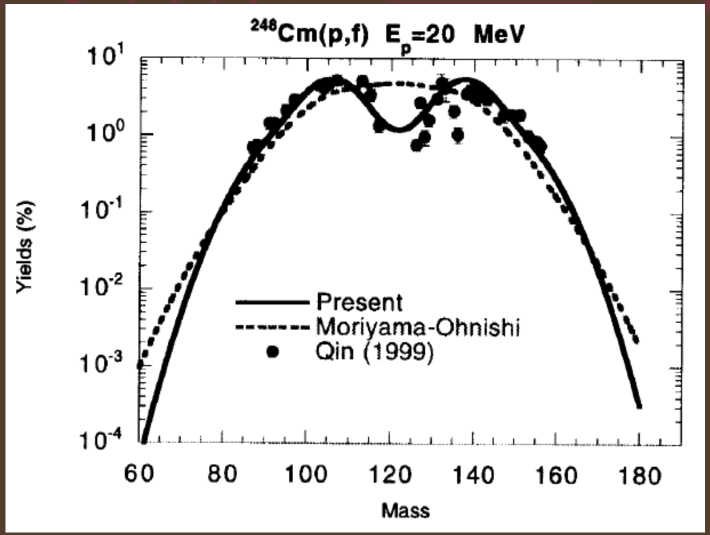
$$\sigma_{h2} = (-30.73 + 0.0394A_f + 0.285Z_f)(0.438 + E + 0.333BN^{0.333})^{0.0864}, \tag{3.6}$$

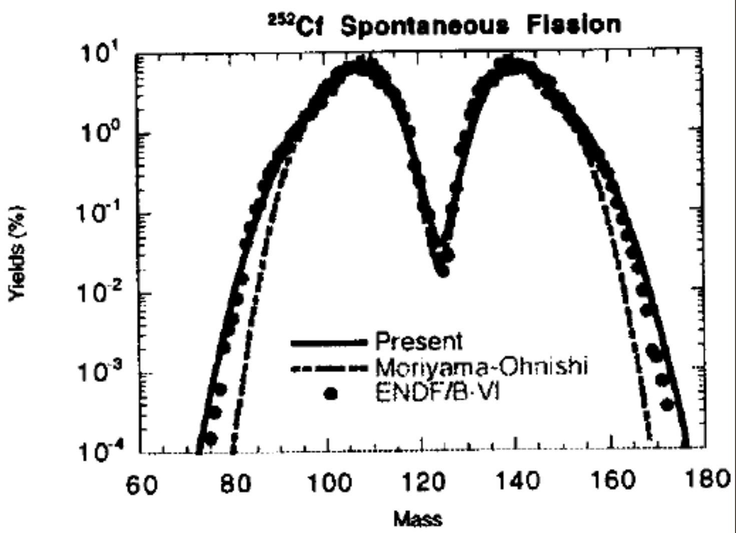
$$A_{h1} = 0.5393(A_f - \bar{\nu}) + 0.01542A_f(40.2 - Z_f^2/A_f)^{1/2}, \tag{3.7}$$

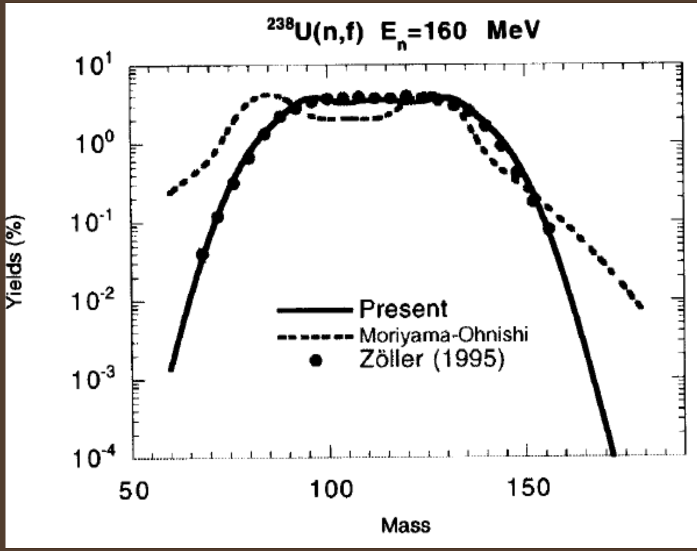
$$A_{h2} = 0.5612(A_f - \bar{\nu}) + 0.01910A_f(40.2 - Z_f^2/A_f)^{1/2}. \tag{3.8}$$

Estimating FFD for n-rich nuclei





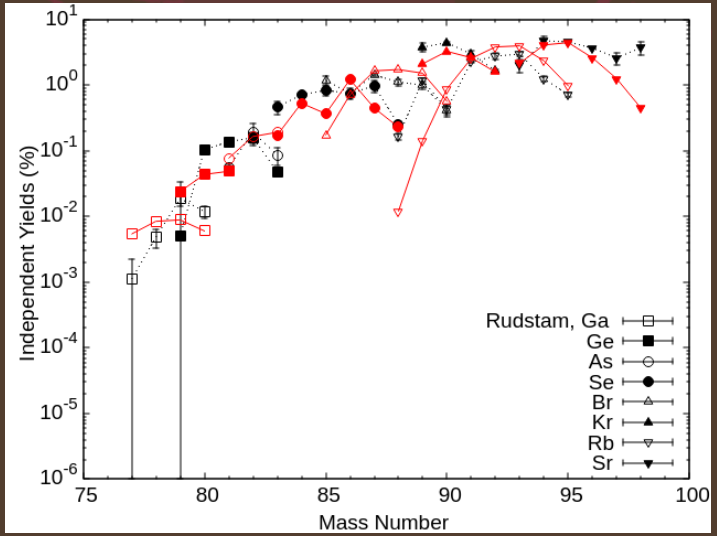




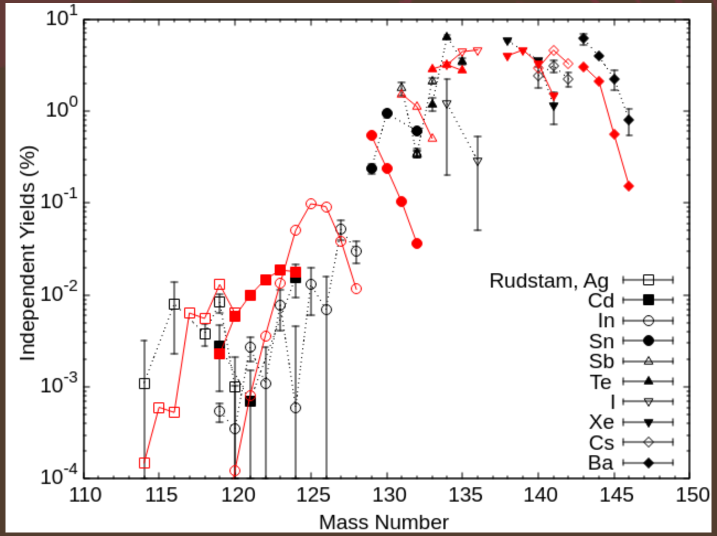
Katakura model is reasonable for nuclei near β-stability line

Results of Recent Phenomenological Model [CCONE]

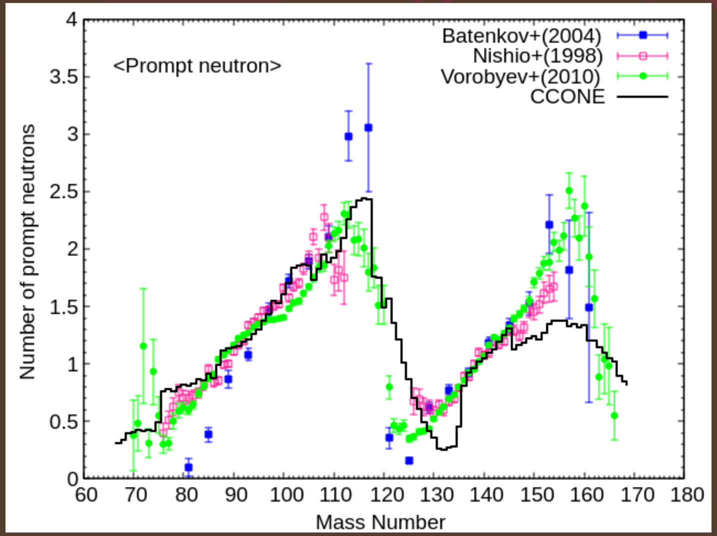
Light fragment yield



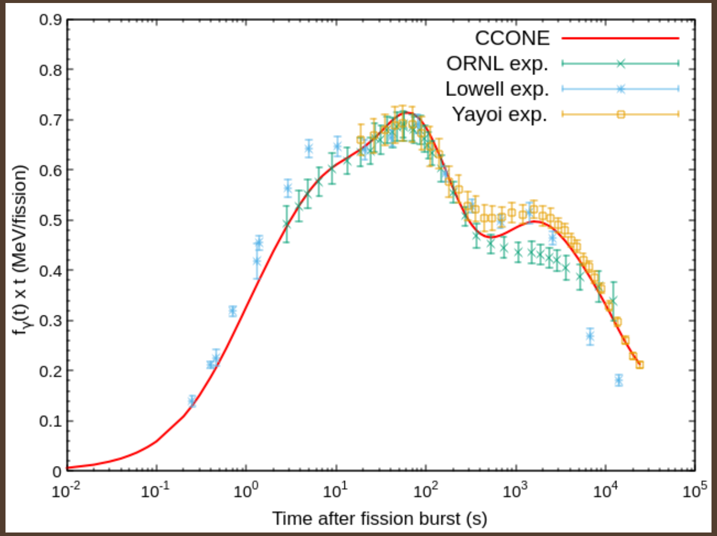
Heavy fragment yield



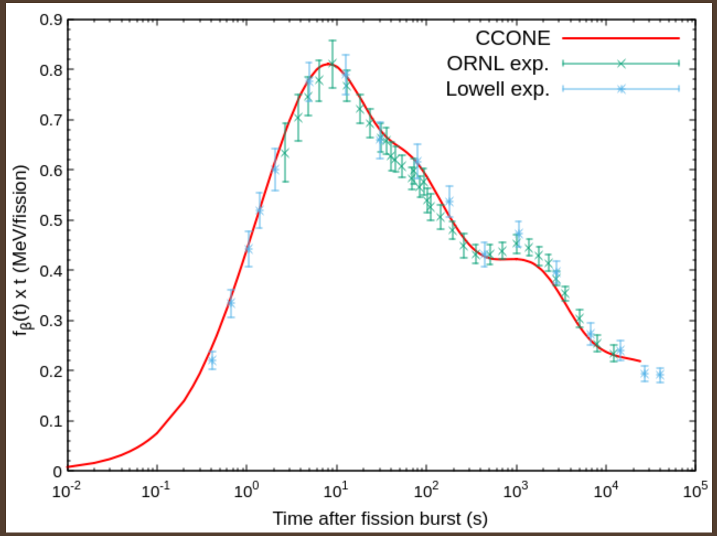
Neutron multiplicity



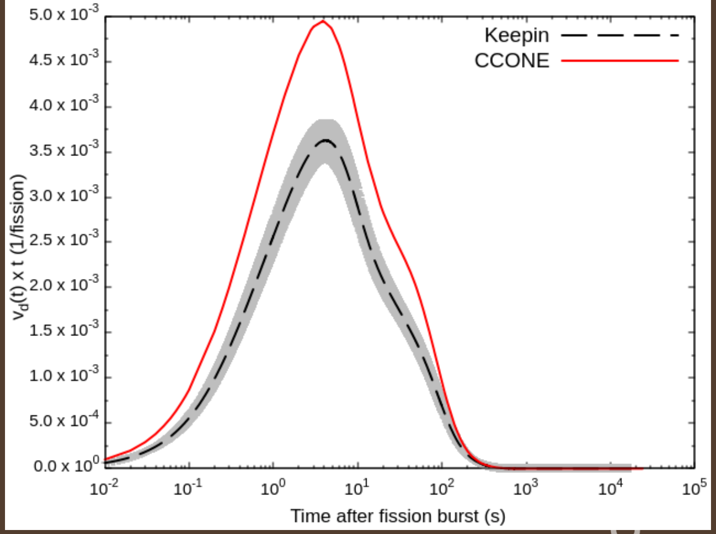
Gamma-ray Decay Heat



Beta-ray Decay Heat



Delayed Neutron Yield



Estimating FFD for n-rich nuclei

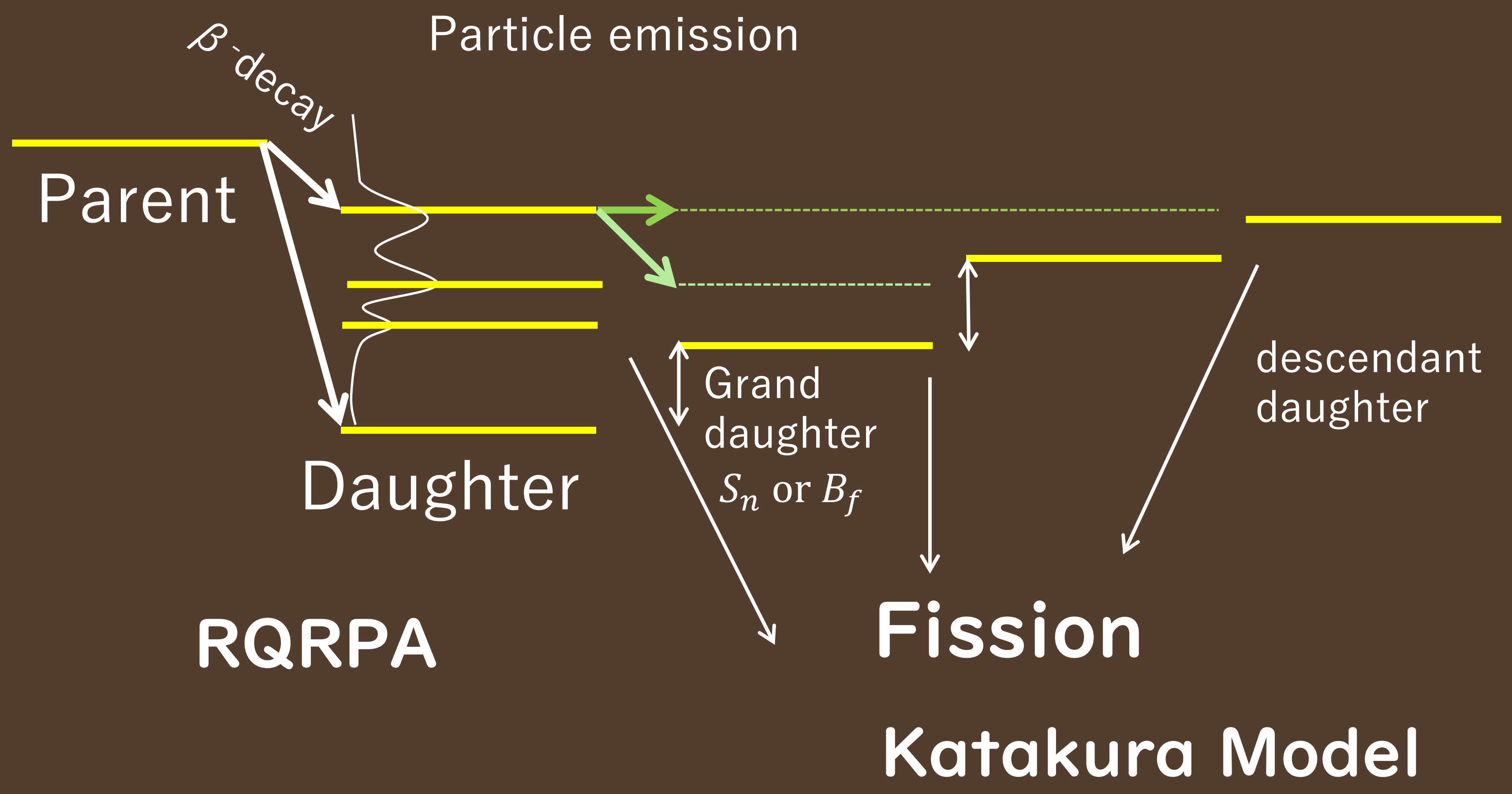
	Target Nucleus	Energy Range
Katakura-Moriyama Model (Phenomenological)	Experimentally Reachable Region	0-200 MeV
Langevin Model (Dynamical model on PES of two-center shell model)	Wide Range of Nuclei	> 10 MeV

Optimizing parameters in KM model using Langevin Model at high E*

→Future Work

PURPOSE

Fission Yield Distribution of β-delayed fission



Theoretical Framework

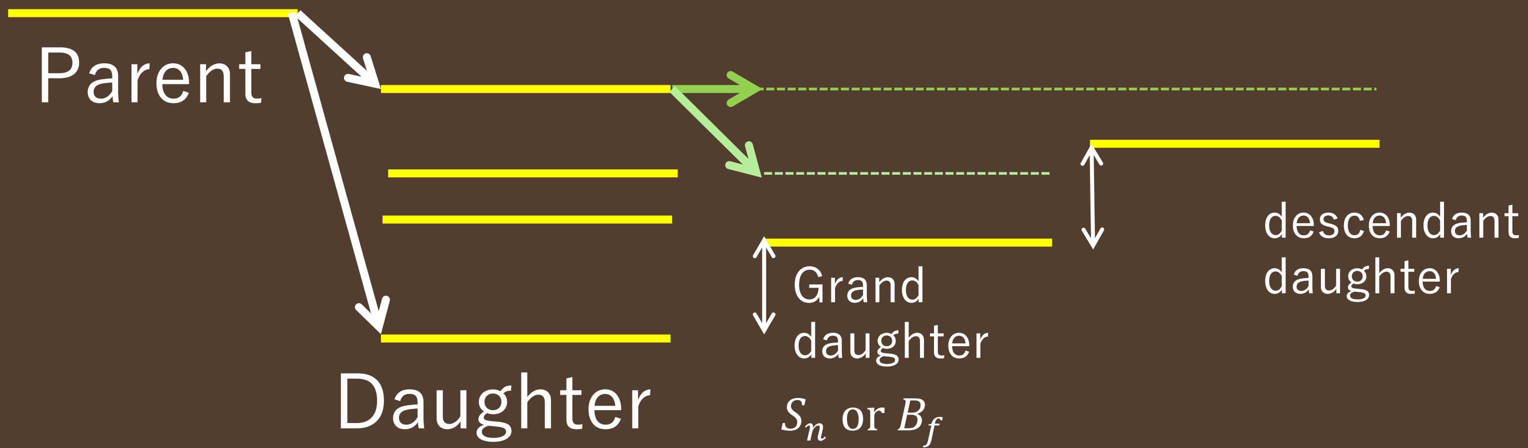
FFD
of β-Delayed
Fission

$$Y(Z,A,M) = \sum_x Y_x(Z,A,M)$$

$$= \int_0^{Q_\beta} \Bigg[r_{0nf,i}(E^*) Y_{0nf}(Z,A,M,E^*)$$

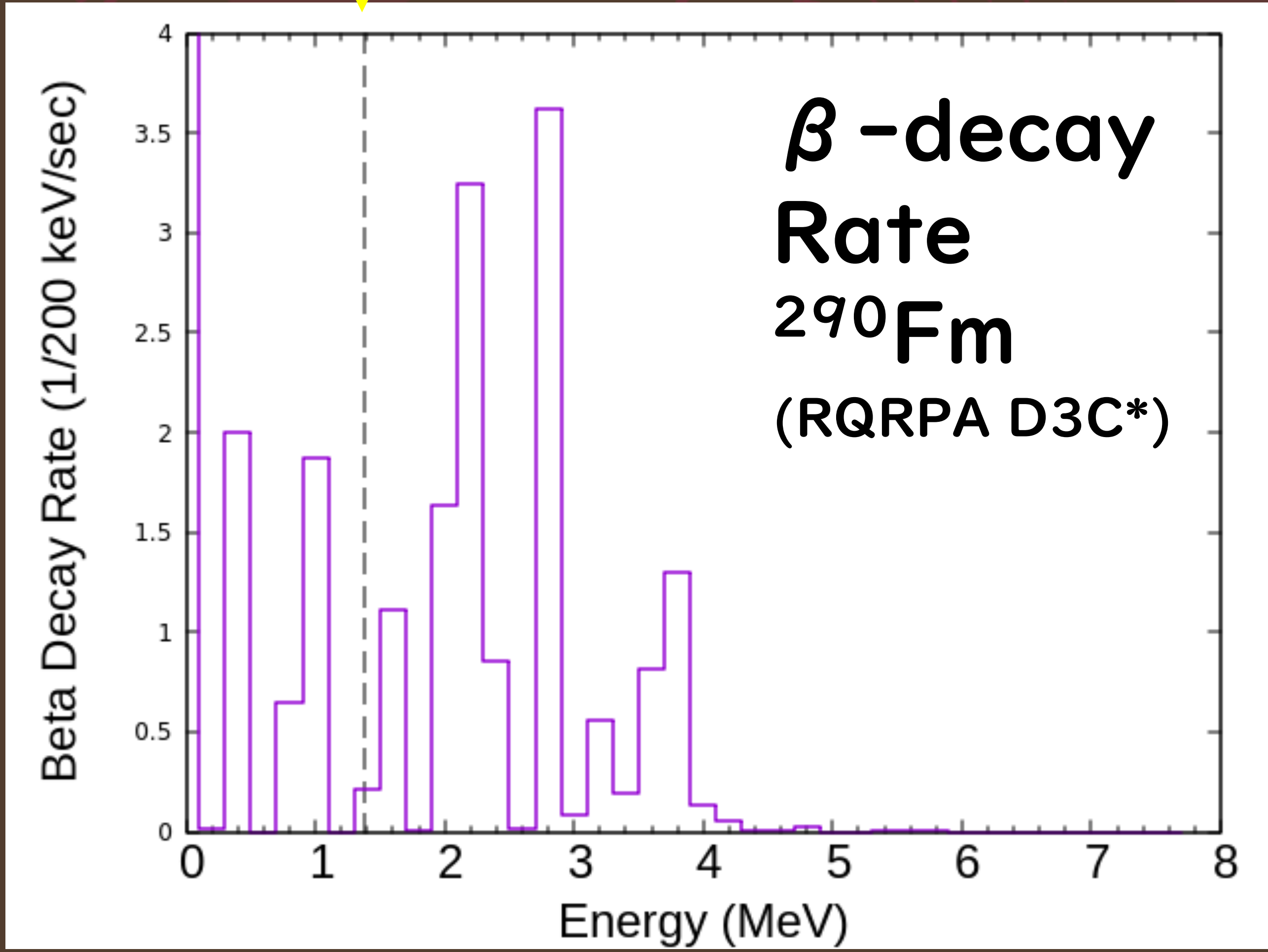
$$+ \int_0^{E^* - \epsilon_n(E^*)} r_{1nf,i}(E_1^*) Y_{1nf}(Z,A,M,E_1^*) dE_1^* + \cdots \Bigg] dE^*$$

Only 1st chance fission is considered



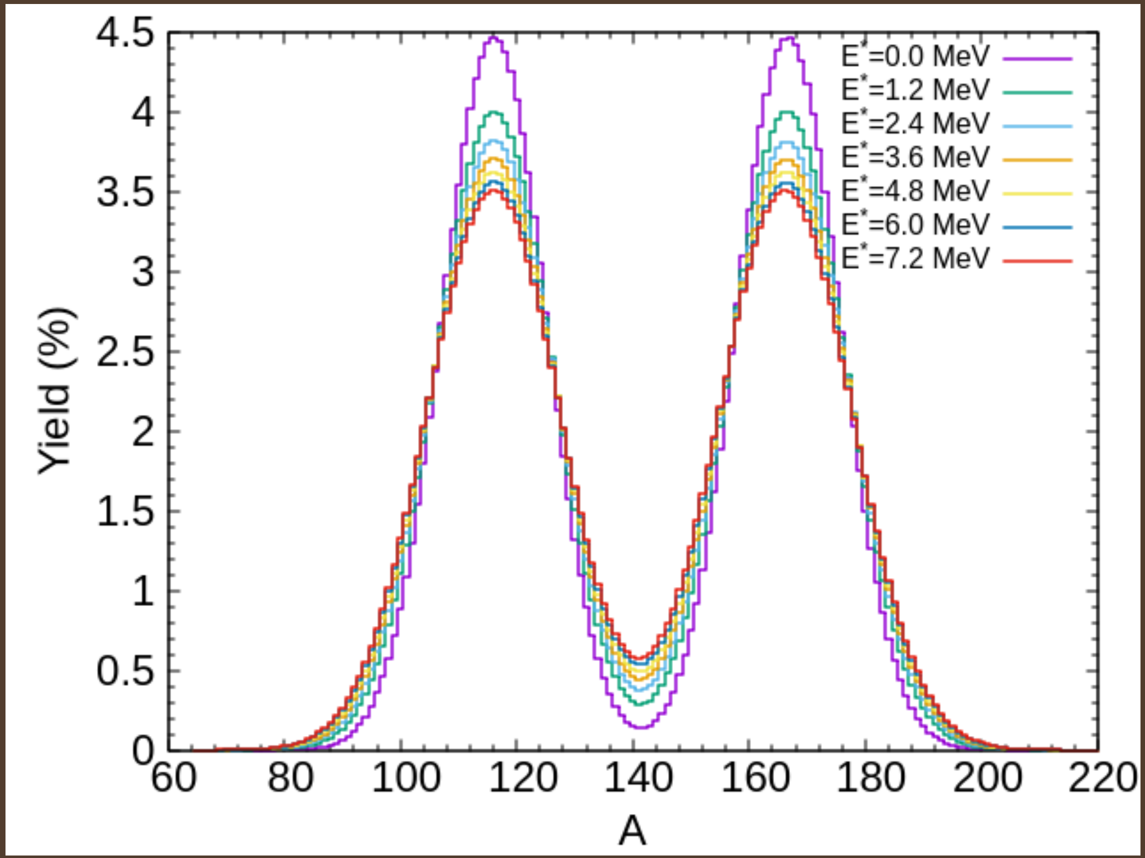
RESULT

FRDM fission barrier (Bf=1.38 MeV)

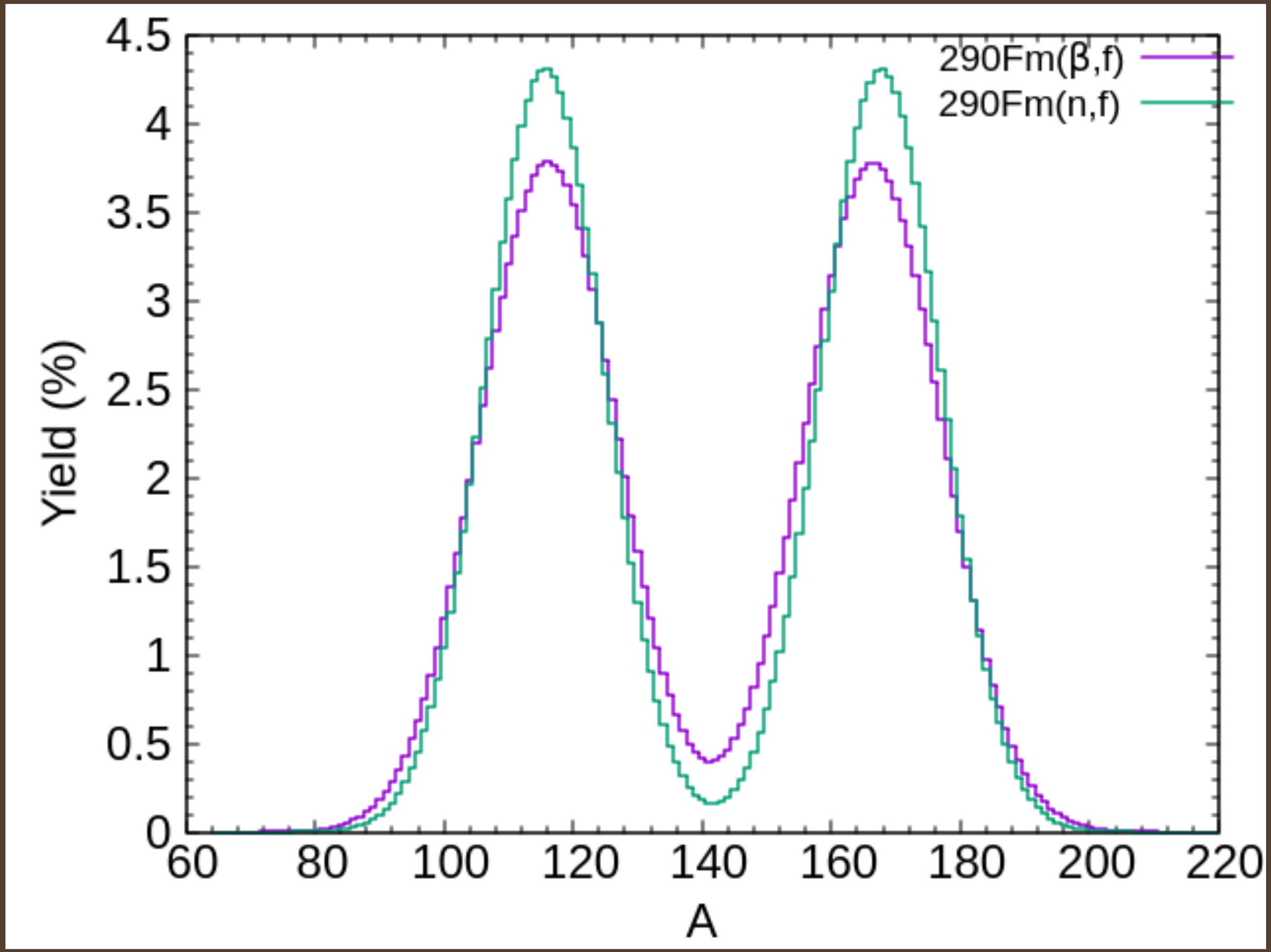


	P0f	P1f	Pf	Pn
^{290}Fm	99.854	0.144	99.999	0.001

FFD of ^{290}Md at different E* (Katakura model)



$^{290}Fm(n_{th},f)$ vs $^{290}Fm(\beta,f)$



Summary

✓ Calculate delayed-neutron emission and fission probabilities with beta-strength function of relativistic Skyrme EDF+QRPA

✓ Estimate FFD of beta-delayed fission of ^{290}Fm, where FFD is estimated by K-M model, and Compare with thermal-induced fission

I am sure that further study will make us excited!

Next stage:
Phenomenological approach disciplined by Langevin model