The phenomenological study of fission yield for U233 induced by neutron in the energy below 20 MeV

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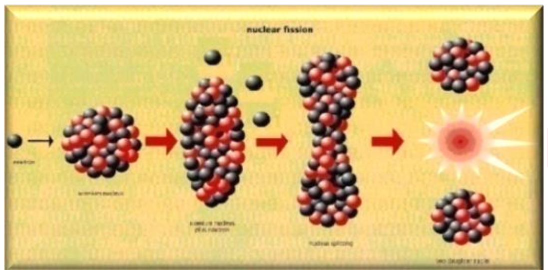
Introduction:

- U233 fission induced by neutron, a key nuclear reaction in the Th/U fuel cycle, is an important link of proliferation and transmutation of nuclear fuel. Its fission yield and the yield-energy dependence are important data bases for reactor calculations.

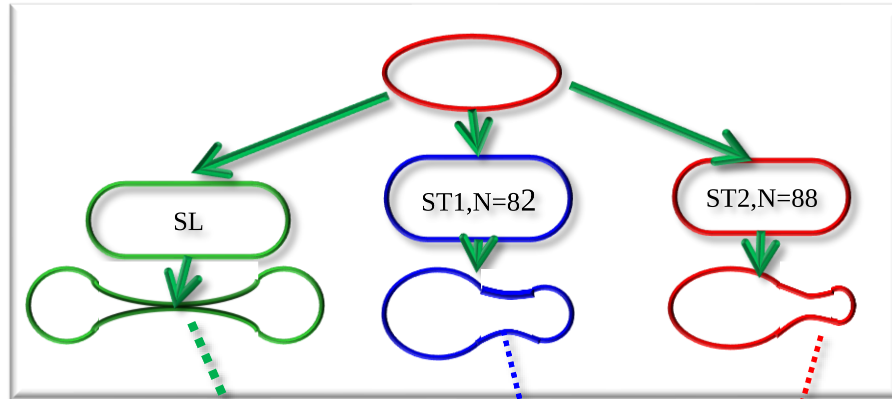
- In this work, a semi-empirical model based on the multiple mode fission was adopted to study the yield mass distribution and the yield-energy dependence for U233 induced by neutron in the energy below 20MeV.

- As a result, the calculated mass distributions are fairly good in agreement with the measured data at most of the incident energies, and the yield-energy dependence could well describe the trend of experimental data for parts of fragment nuclides.

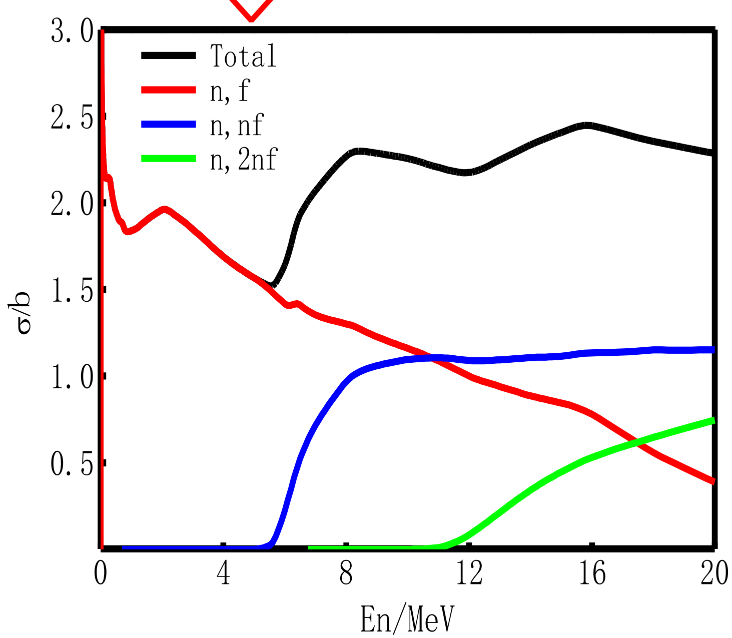
In the model, three fission modes were considered : Super long(SL), standard 1(ST1) and standard 2(ST2) fission, and multi fission chance at higher energy (>~6MeV).

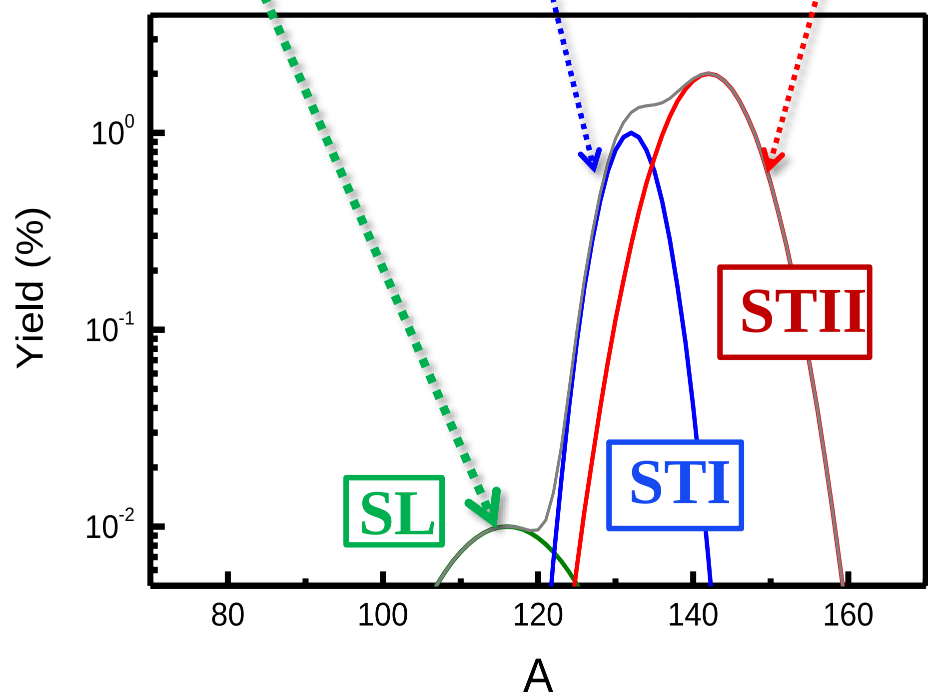


Multi mode



Multi chance





Fission yield for one fission system could be expressed with the following simplified formula including 10 parameters :

$$Y(E_0^*, N) = C_0 \sum_{i=1}^{5} Y_i \times \exp\left[-(N_i - N)^2 / \sigma_i^2\right]$$

Y_i is the maximum probability for each mode: $Y_i = \exp(2\sqrt{aE(E_0^*, N)})$ (a=A_{cn}/8)

The potential at fission barrier: $V_{\text{mac}}(N) = C_{\text{mac}}(N_{\text{cn}}/2 - N)^2$ for $i = 3$

$$V_{\text{sh},i}(N) = \left[\delta U_i + C_i(N_i - N)^2\right]\exp(-\gamma\varepsilon), \qquad i = 4(1), 5(2)$$

The maximum probability and distribution width of fission yield are:

Asymmetry fission: $Y_i = \exp(2\sqrt{a[E_0^* - V_{mac}(N) - V_{sh,i}(N)]})$ $i = 4(2), 5(1)$

$$\sigma_i^2 = \frac{\sigma_{i0}\sqrt{E_0^* - V_{mac}(N) - V_{sh,i}(N)}}{\sqrt{a}C_i \exp(-\gamma\varepsilon)}$$

Symmetry fission: $Y_3 = \exp(2\sqrt{aE_0^*})$

$$\sigma_3^2 = \frac{\sqrt{E_0^*}}{2\sqrt{a}C_{mac}}$$

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When neutron energy is larger, (n,nf) ,(n,2nf) chances are opened:

$$Y(N)=\sum_{i=1}^{n} w_i Y_i(E_{0i}^{\;*}, N) \qquad (w_i=\sigma_i/\sigma_F)$$

The excitation energy of fission system for opened channels:

$$(n,f): E_{0f}^{*}(Z,A+1)=E_n+B_n(Z,A+1)$$

$$(n,nf): E_{0nf}^{*}(Z,A)=E_n-\bar{\varepsilon}(Z,A+1)$$

$$(n,2nf): E_{02nf}^{*}(Z,A-1)=E_n-B_n(Z,A)-\bar{\varepsilon}(Z,A+1)-\bar{\varepsilon}(Z,A)$$

The average energy of emitted neutron:

$$\bar{\varepsilon}(Z,A+1)=\frac{3}{2}T(Z,A+1)$$

$$T(Z,A+1)=\sqrt{E^{*}(Z,A+1)/a(Z,A+1)}$$

The 10 parameters were determined by evaluated experimental data, which included chain yield and cumulative yield of stable nuclide. The experimental data were divided into three groups to adjust to model parameters based on the measuring methods, for there are large systematic error.

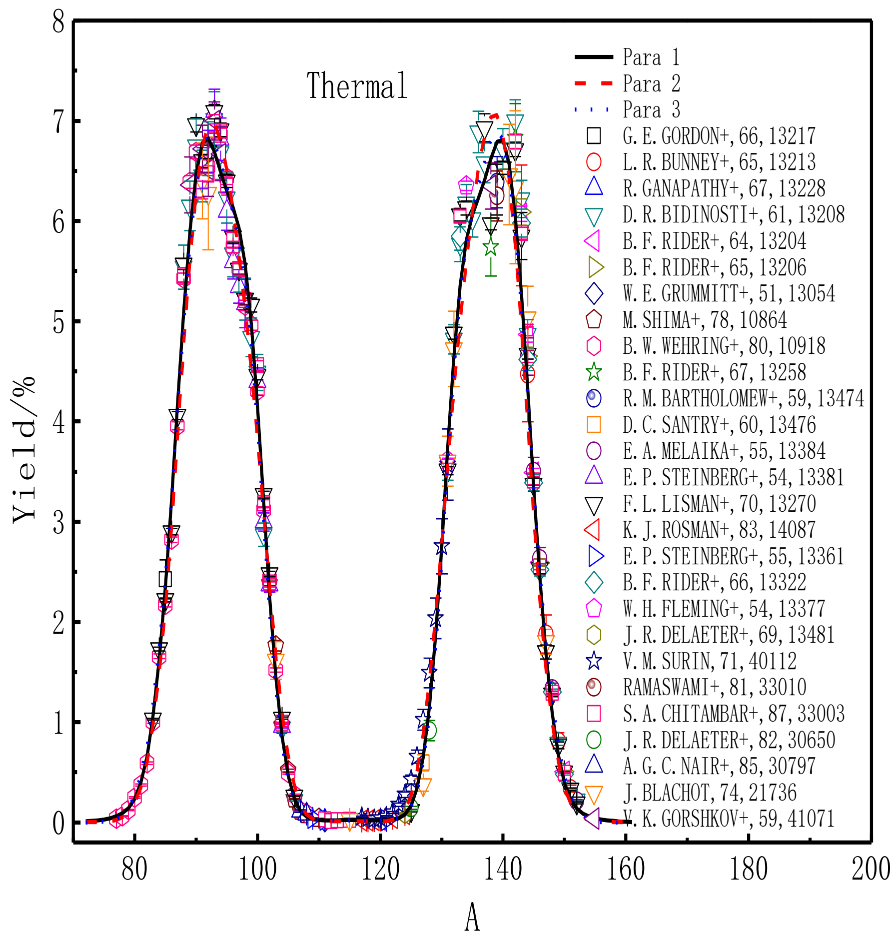
Group 1: experimental data measured by radioactive chemical method;

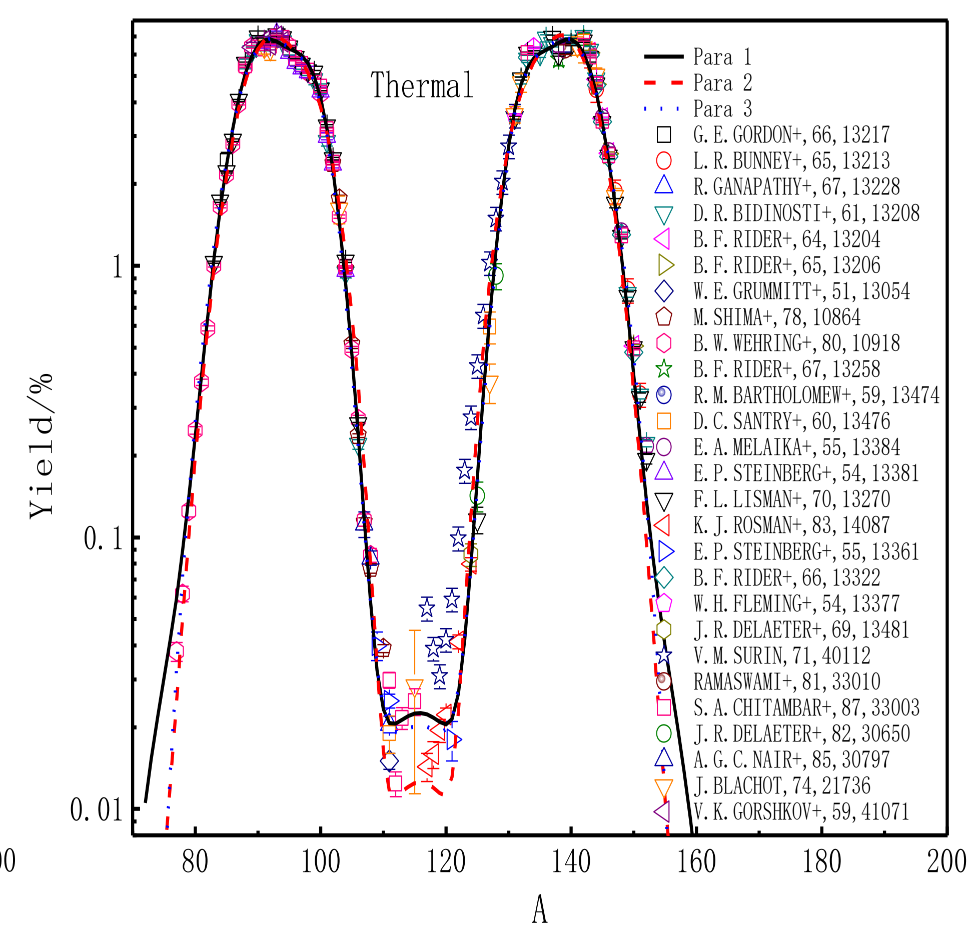
Group 2: experimental data measured by double kinetic energy method;

Group 3: all the experimental data.

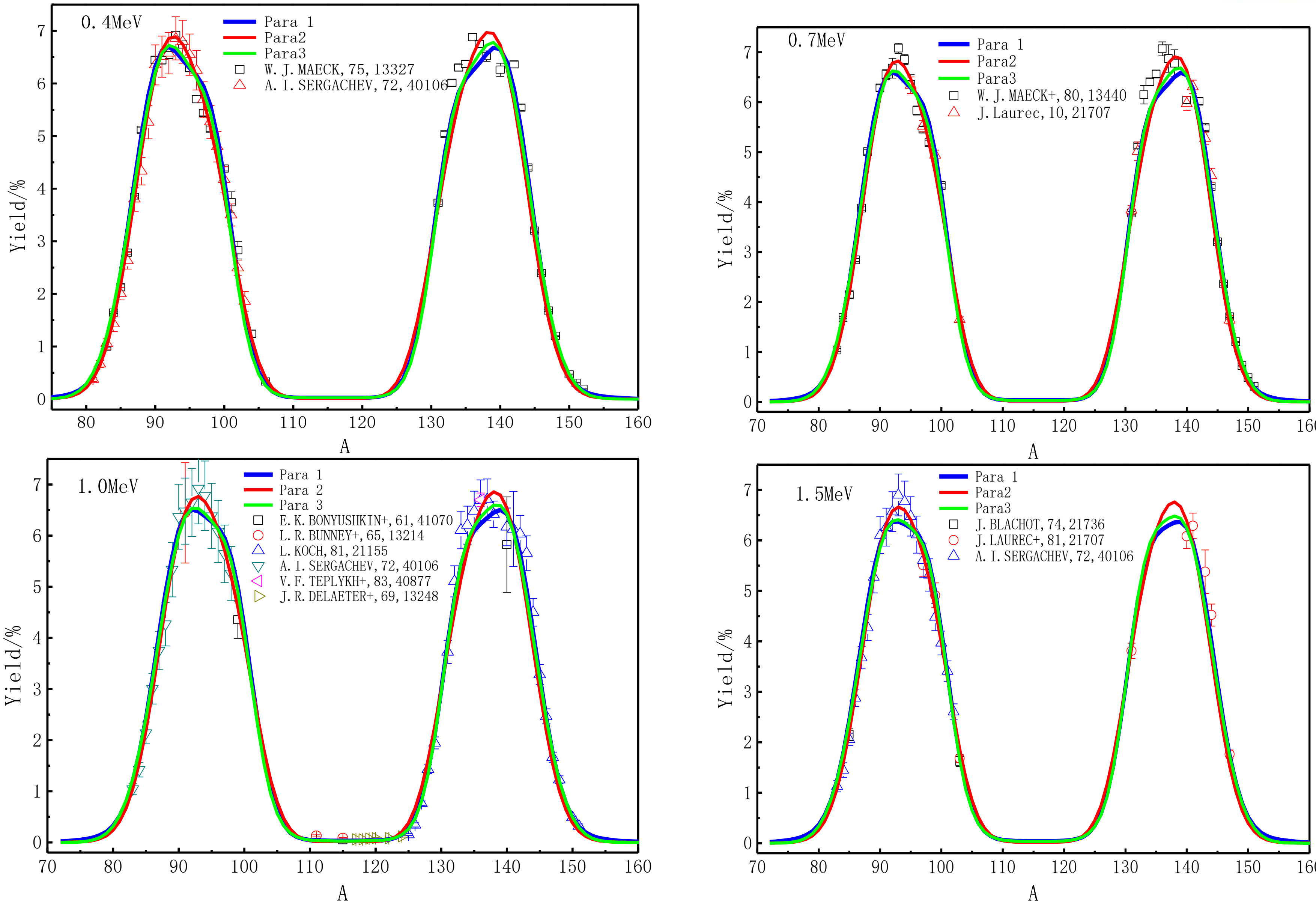
para	δU_5	δU_4	C_5	C_4	σ_{50}	σ_{40}	N_5	N_4	C_{mac}	γ	χ^2
1	-5.385	-3.904	0.053	0.085	1.253	0.849	87.83	81.55	1.24e-3	0.057	2.81
2	-5.696	-4.073	0.038	0.163	1.034	2.419	87.83	81.61	0.011	0.039	1.68
3	-5.466	-3.670	0.039	0.051	1.275	0.424	88.32	81.19	8.83e-3	0.047	9.0

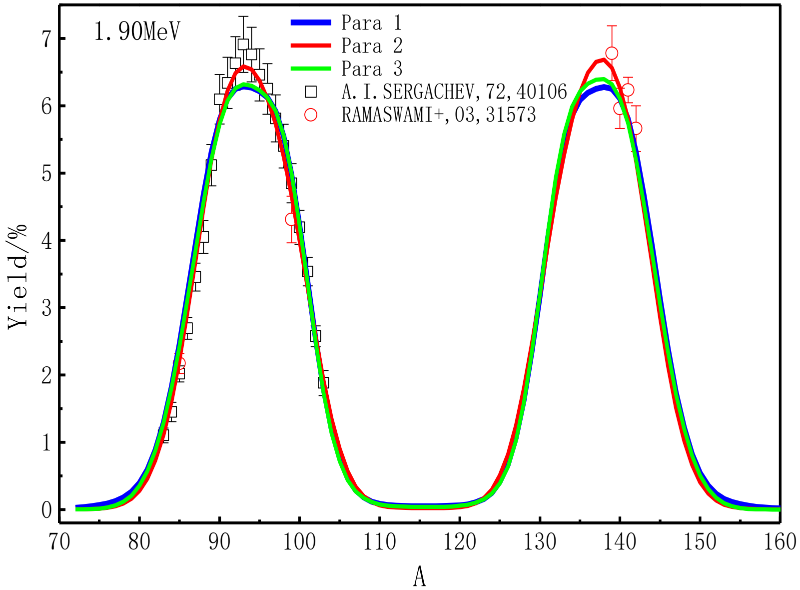
◆ Mass distribution Y(A) of U233(n,f) at thermal energy:

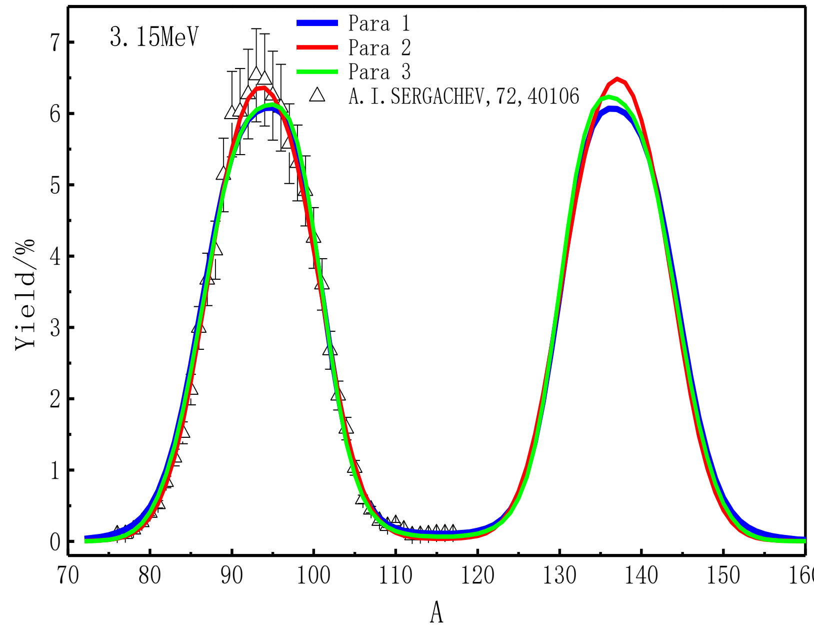


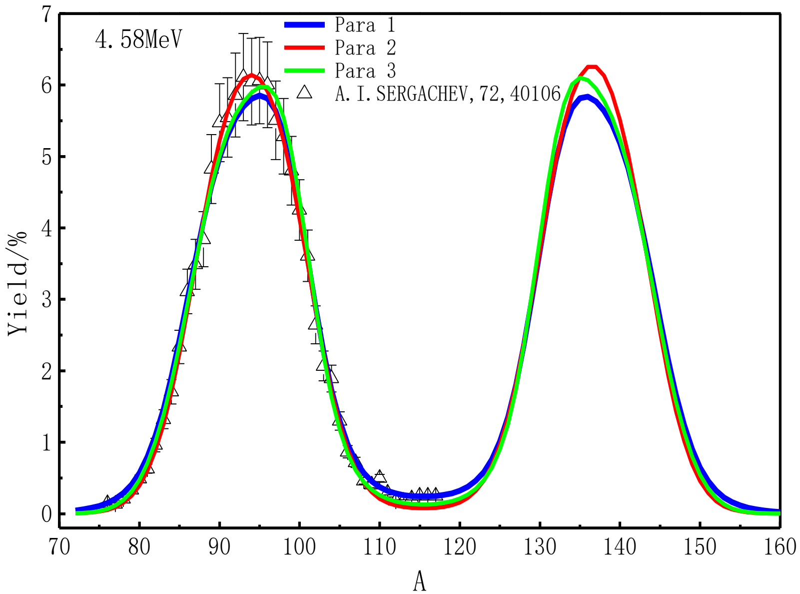


◆Mass distribution Y(A) of U233(n,f) at fission spectrum:



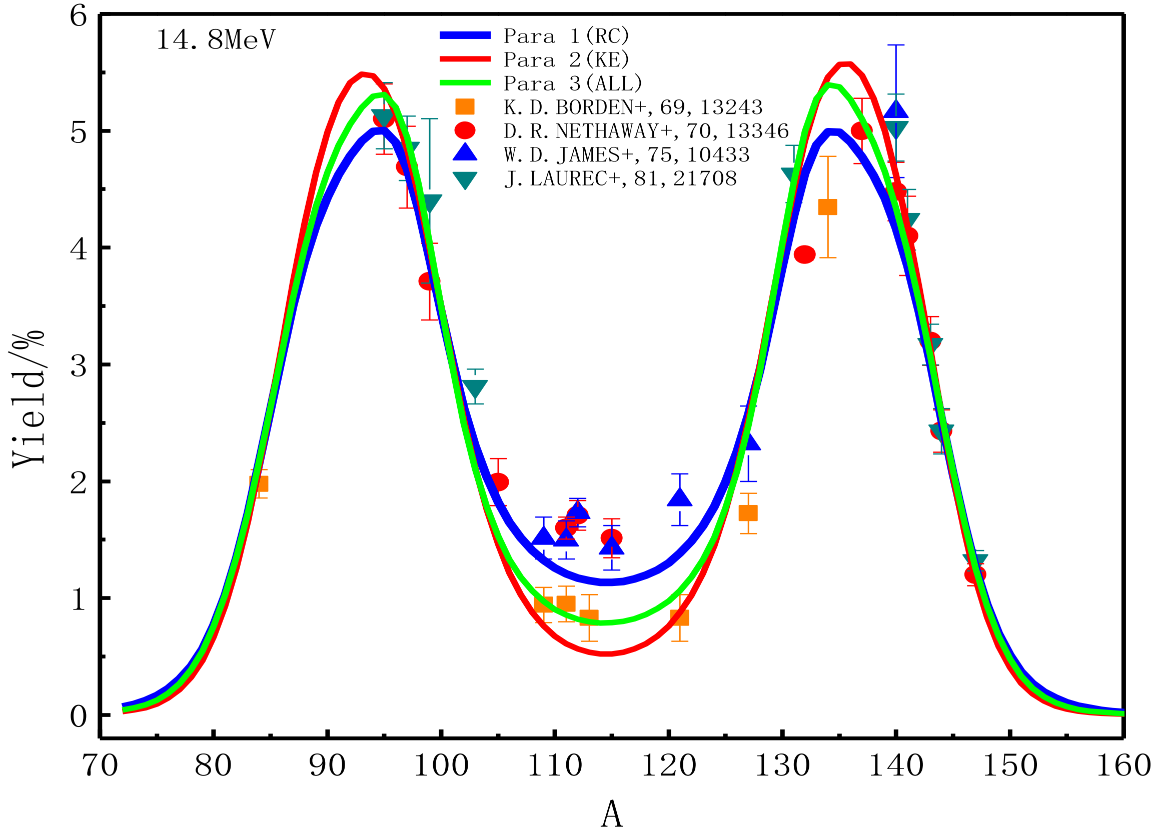






It can be seen that there is a good agreement with experimental data using three groups of parameters at low energy.

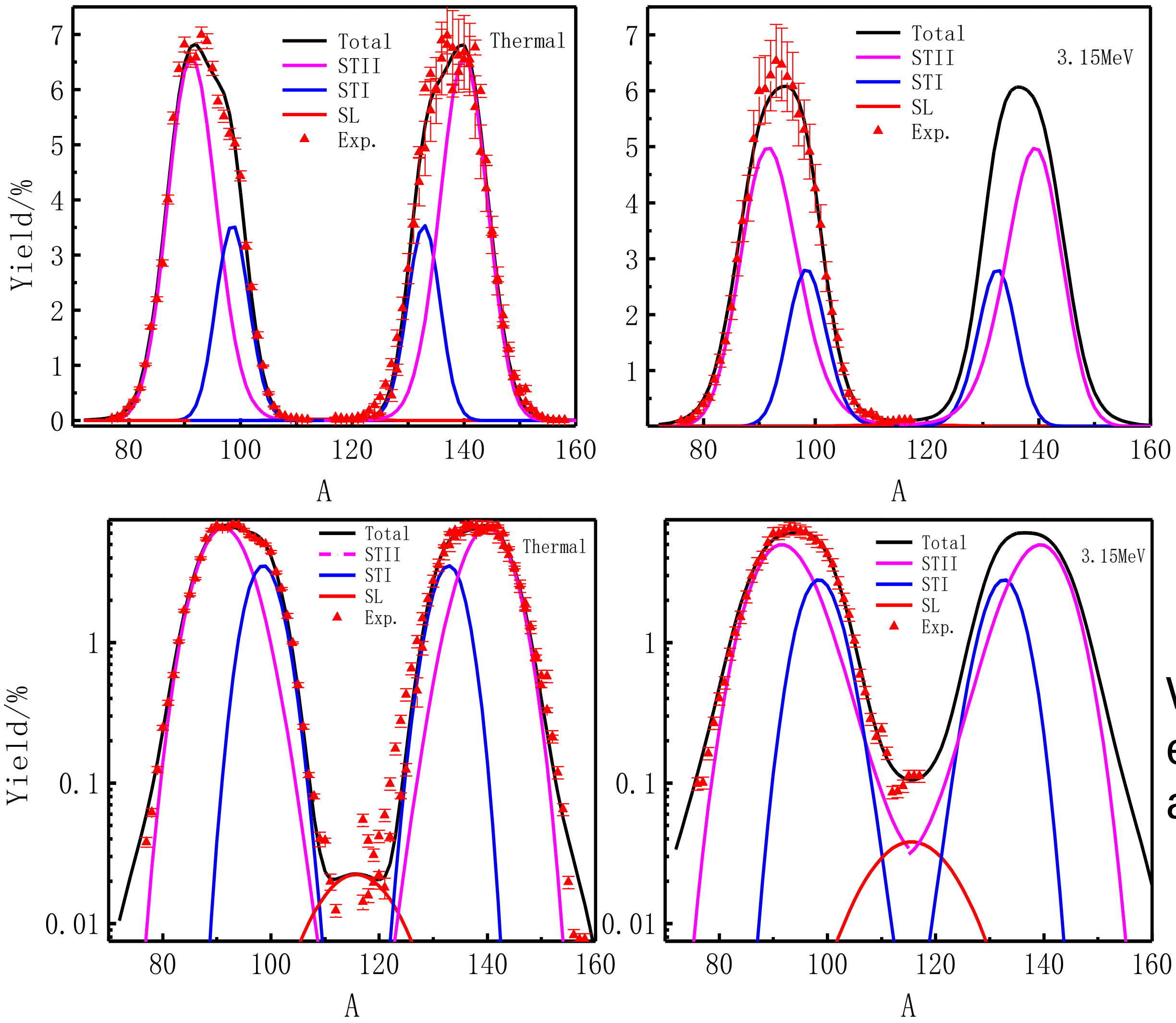
◆ Mass distribution Y(A) of U233(n,f) at 14MeV:



There is a good agreement using the first group parameter, for there are much more experimental data measured by radioactive chemical method.

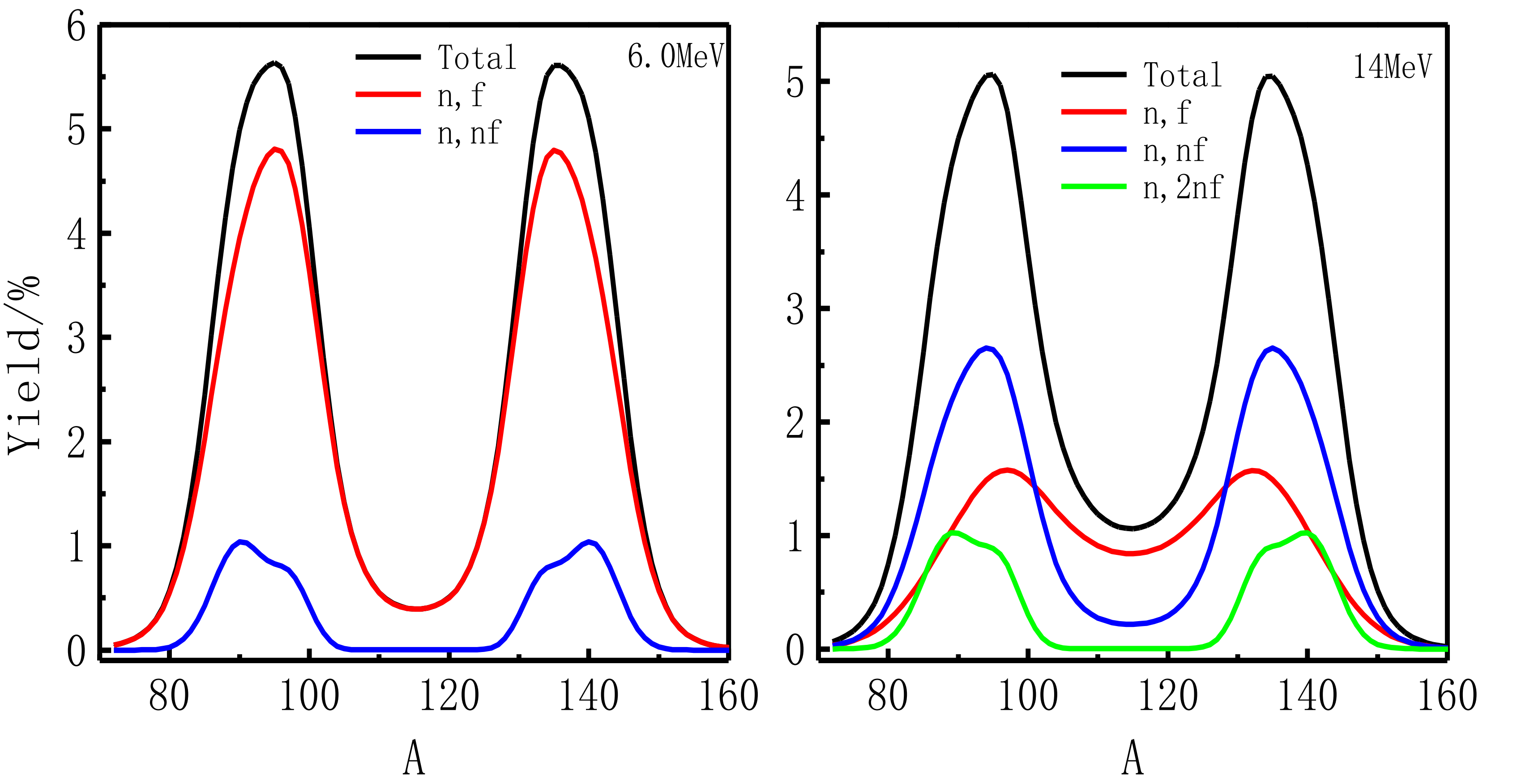
The calculation with phenomenological method largely depends on the experimental data.

◆ The partial mass distribution for each mode:

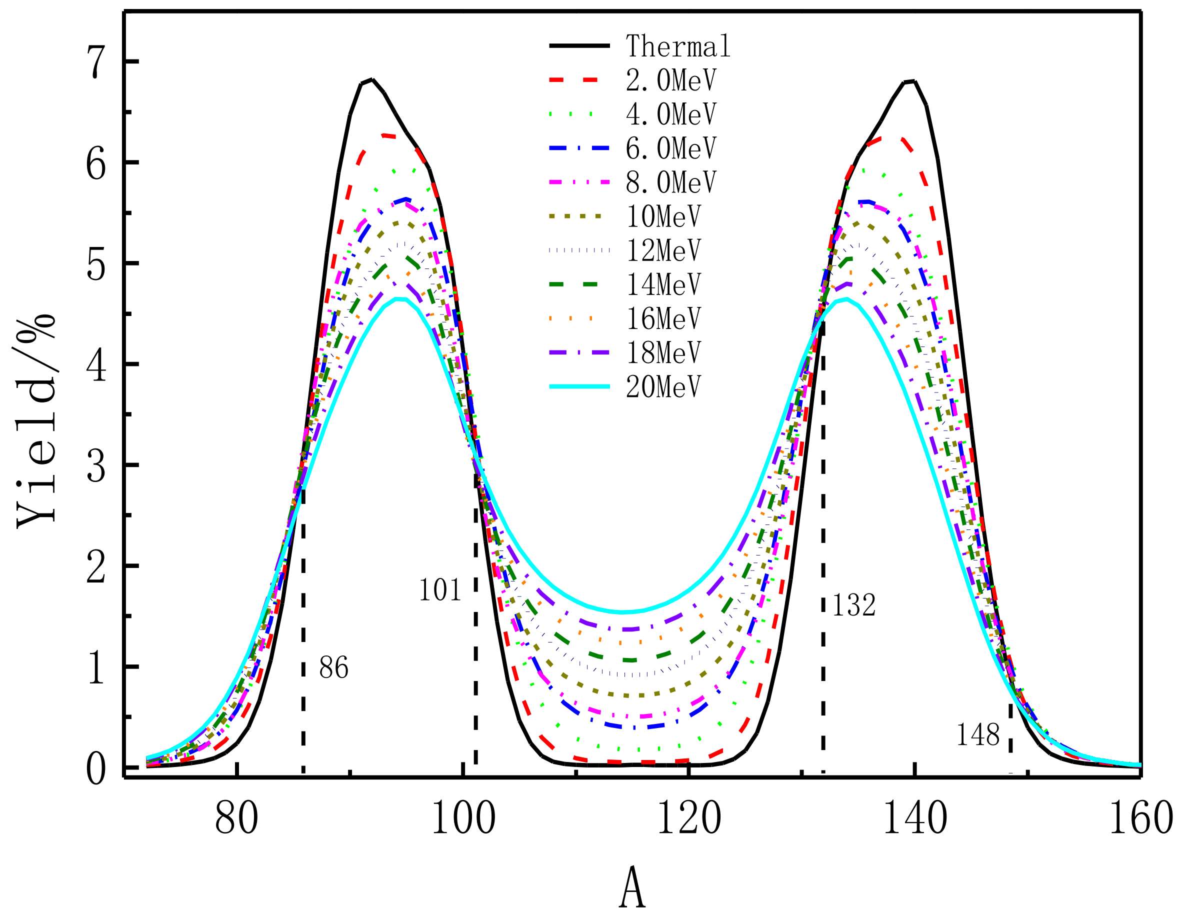


With the increasing neutron energy , the contribution of asymmetric mode decreases.

◆ The partial mass distribution for each fission chance :



It can be seen that with the neutron energy increasing, the yields at valley rise, which mainly originates from the contribution of (n,f) chance.

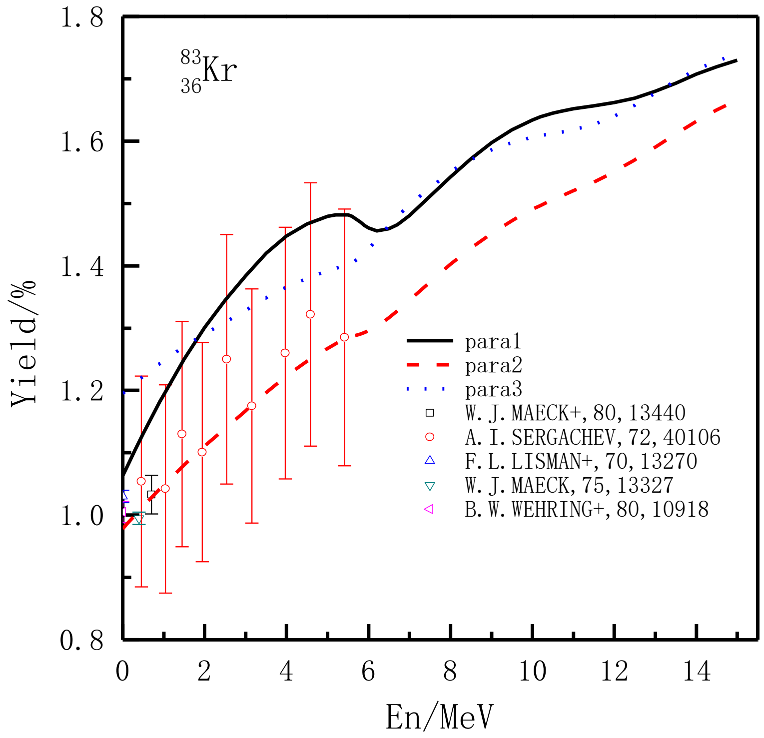


Four cross points appear on the mass distribution with the neutron energy increasing:

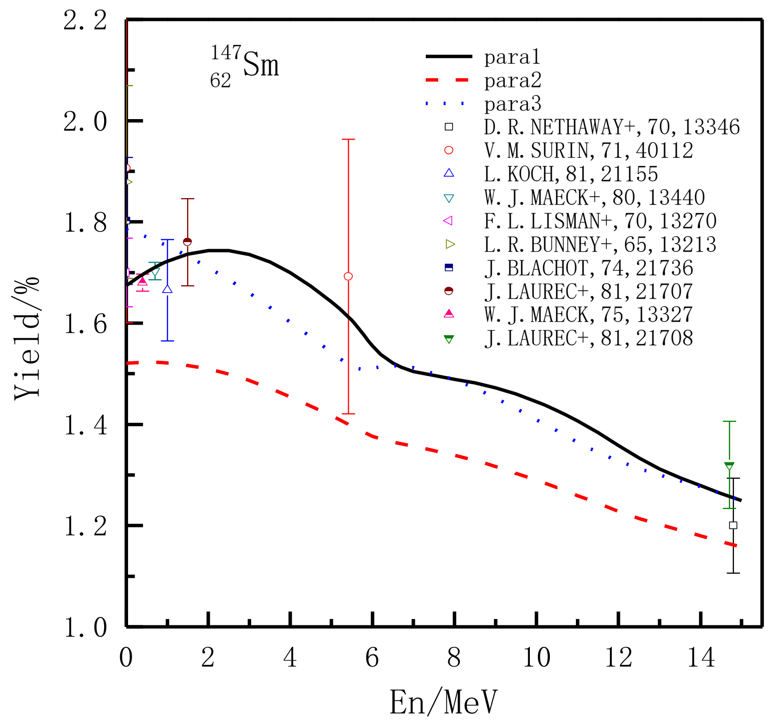
A=86,101,132,148. It could qualitatively show the trend of yield-energy dependence.

◆ Yield-energy dependence for some fission fragments.

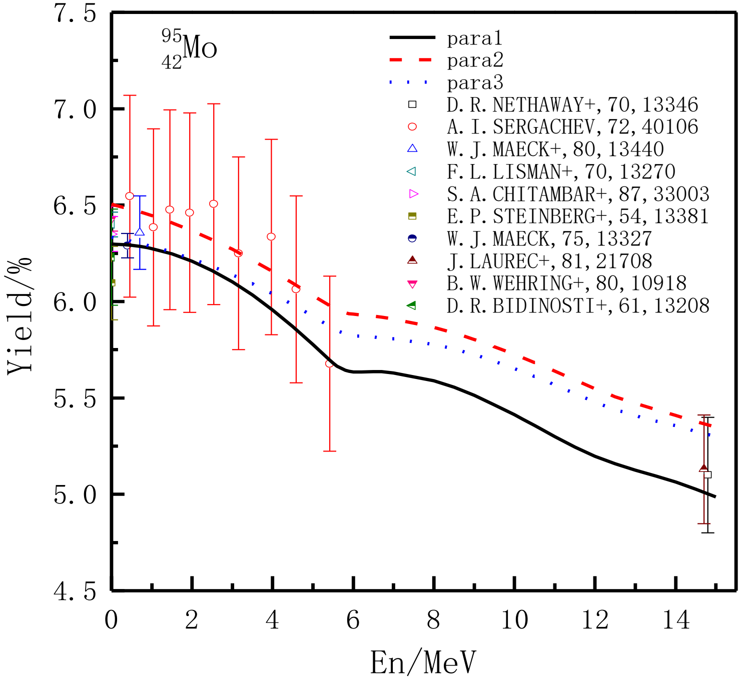
● ^{83}Kr at left tail of light peak



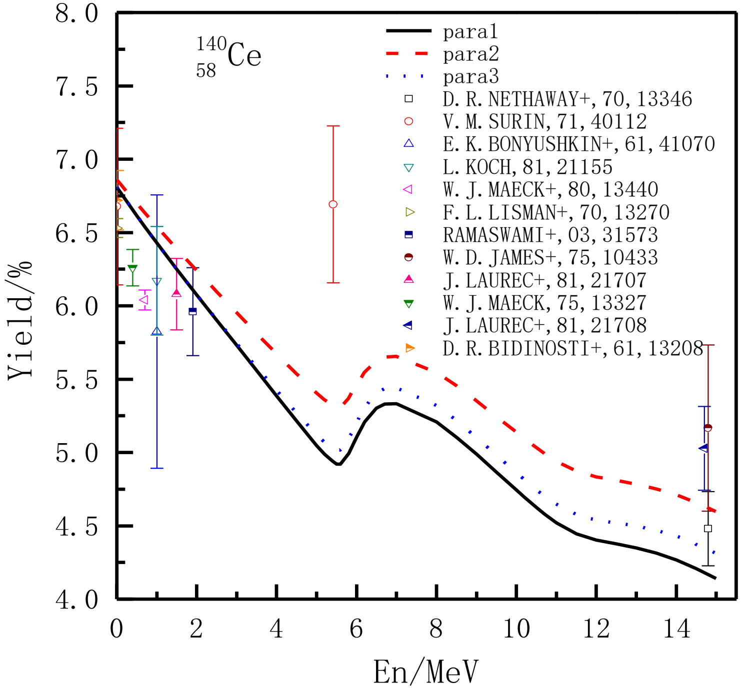
● ^{147}Sm at right wing of heavy peak



● ^{95}Mo around the light peak



● ^{140}Ce around the heavy peak



Summary:

- The mass distributions of fission yield for U233 induced by neutron below 20 MeV were calculated with semi-empirical method, and there is a good agreement with experimental data. In addition, for the yield-energy dependence， there is a qualitative agreement for parts of fission fragments.
- The semi-empirical method significantly depends on the experimental data and has little predictive power.

Outlook:

In order to do further research on the fission, we will study mass distribution and kinetic energy distribution using macroscopic-microscopic model based on the two center shell model and Langevin dynamical model in the future.

Thank you for your attention.