# Analysis on fission of W, Au and U by LEPF/SCF model

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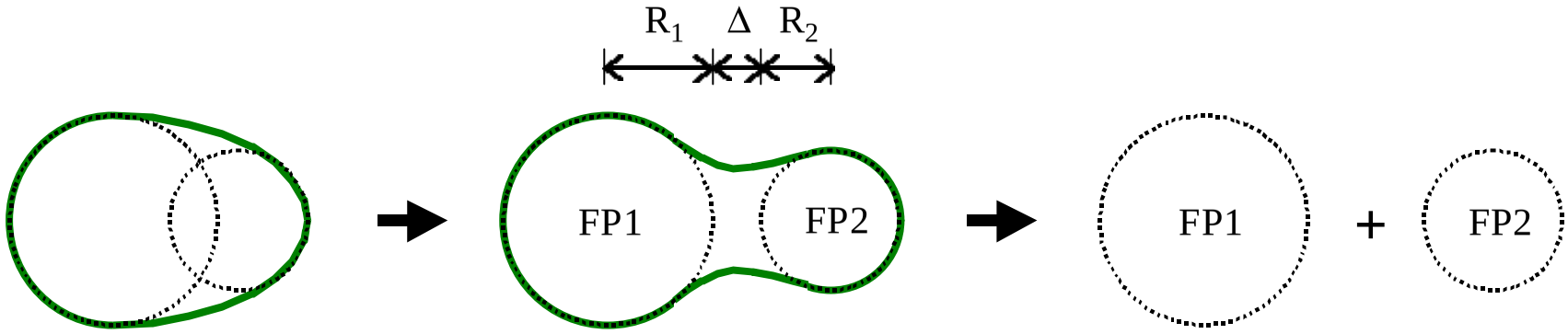
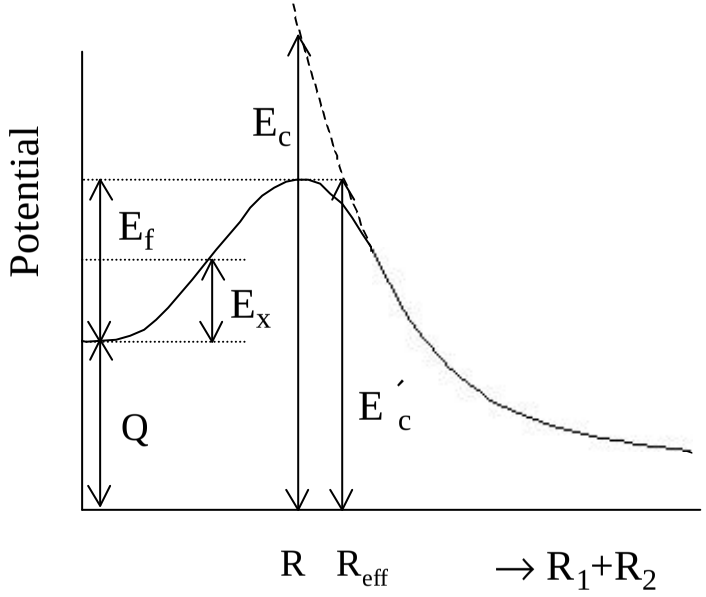



Elliptic-Deformation Dumbbell-Oscillation Scission




$E_c \propto Z_1 Z_2/(R_1+R_2)$
:Coulomb repulsion

$R \propto A^{1/3}$

$E'_c$: Effective Coulomb Energy

$E_x$: Excitation Energy

$E_f$: Fission Barrier

$R_{eff} = R_1+R_2+\Delta = (1+ \alpha(A)\varepsilon(A))\ (R_1+R_2)$

$\Delta$: Scission Distance

$(\Delta(A) = \alpha(A)\varepsilon(A)R_{eff})$

## For n+$^{235}$U fission

- LB = 6.53 MeV (excitaion energy)
- with 2～3 neutron emission ⇒ Fig.1

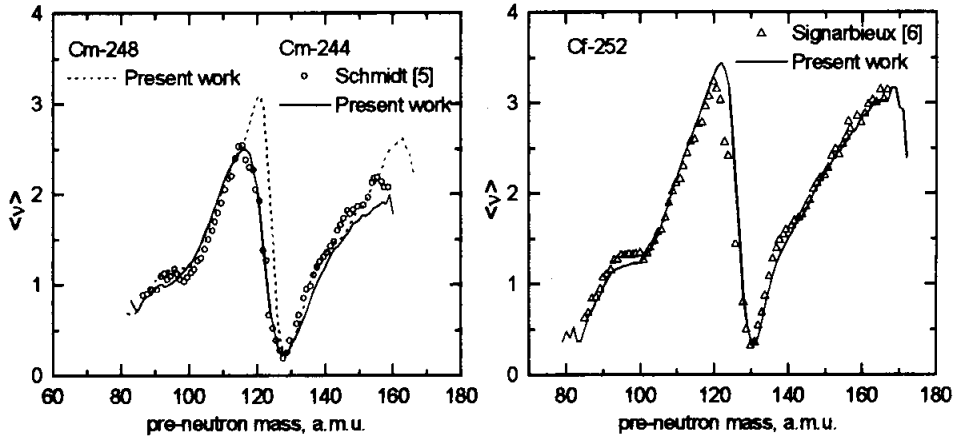
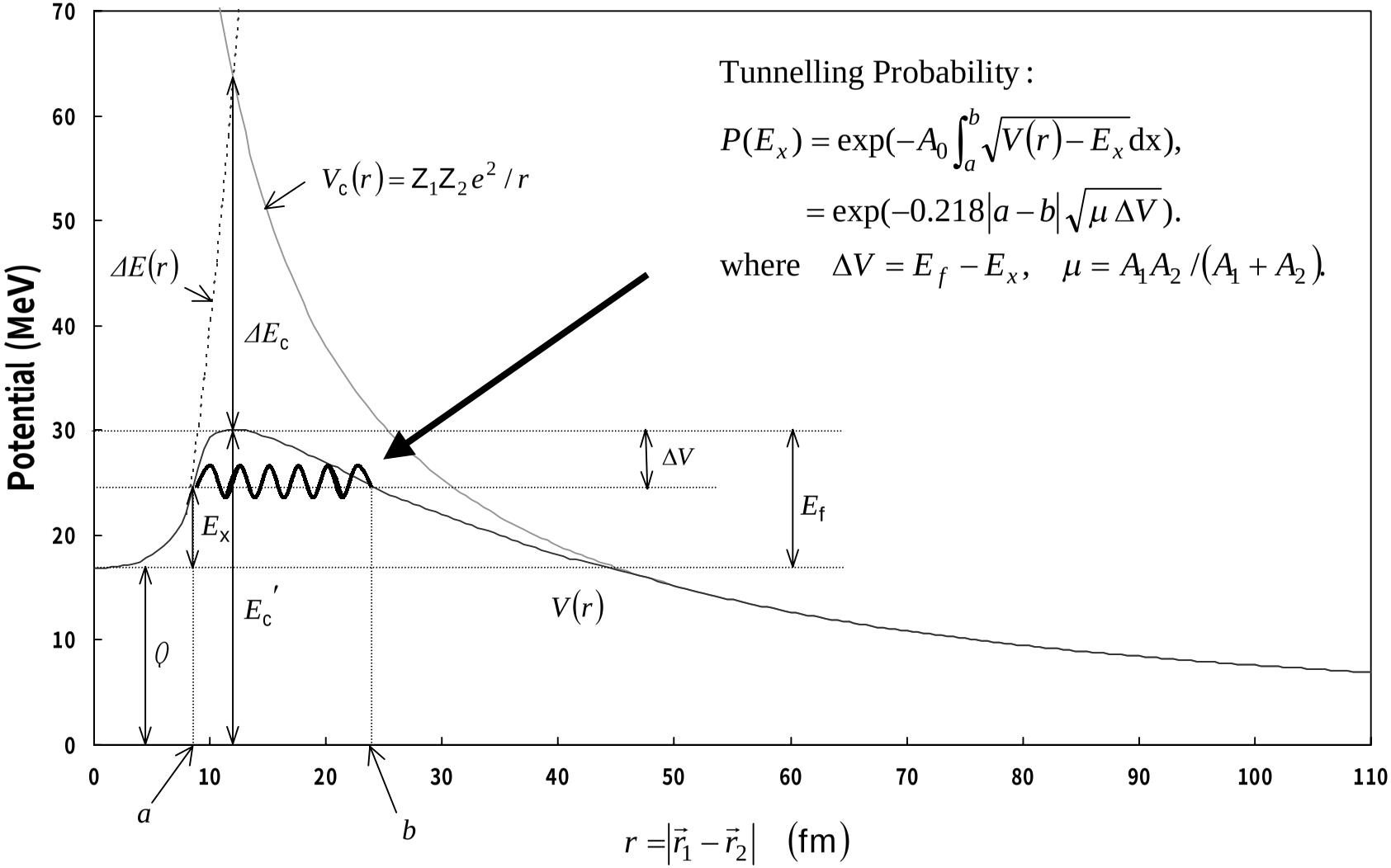



**Figure 7.** Mean neutron multiplicity as a function of fragment mass.

Fig.1 Mean neutron multiplicity as a function of fragment mass
(Ed. C.Wagemans et al., SEMINAR ON FISSION, World Scientfic )

# Tunnelling Probability




Tunnelling Probability :

$$P(E_x) = \exp(-A_0 \int_a^b \sqrt{V(r) - E_x}\,\mathrm{dx}),$$

$$= \exp(-0.218 |a - b| \sqrt{\mu\,\Delta V}).$$

where $\Delta V = E_f - E_x$, $\mu = A_1 A_2 / (A_1 + A_2)$.

## List of top ten channels

$^{236}\mathrm{U} \rightarrow {}^{104}\mathrm{Mo} + {}^{132}\mathrm{Sn} + 199.39$ MeV. ($\mathrm{E_f} = -11.59$ MeV)

$^{236}\mathrm{U} \rightarrow {}^{106}\mathrm{Mo} + {}^{130}\mathrm{Sn} + 198.94$ MeV. ($\mathrm{E_f} = -11.21$ MeV)

$^{236}\mathrm{U} \rightarrow {}^{102}\mathrm{Zr} + {}^{134}\mathrm{Te} + 196.57$ MeV. ($\mathrm{E_f} = -10.46$ MeV)

$^{236}\mathrm{U} \rightarrow {}^{103}\mathrm{Nb} + {}^{133}\mathrm{Sb} + 196.72$ MeV. ($\mathrm{E_f} = -9.68$ MeV)

$^{236}\mathrm{U} \rightarrow {}^{108}\mathrm{Mo} + {}^{128}\mathrm{Sn} + 197.08$ MeV. ($\mathrm{E_f} = -9.42$ MeV)

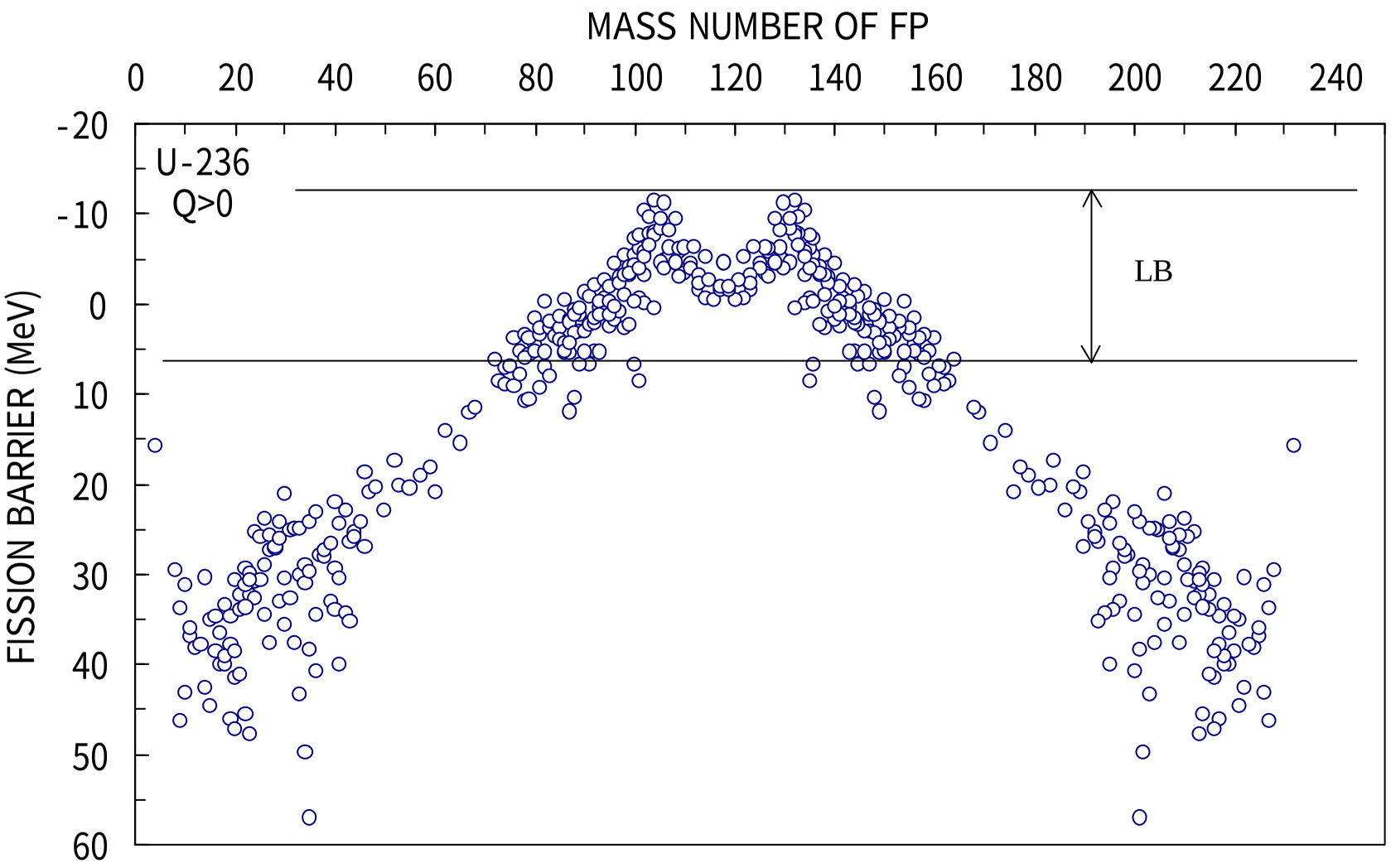
$^{236}\mathrm{U} \rightarrow {}^{105}\mathrm{Mo} + {}^{131}\mathrm{Sn} + 197.16$ MeV. ($\mathrm{E_f} = -9.40$ MeV)

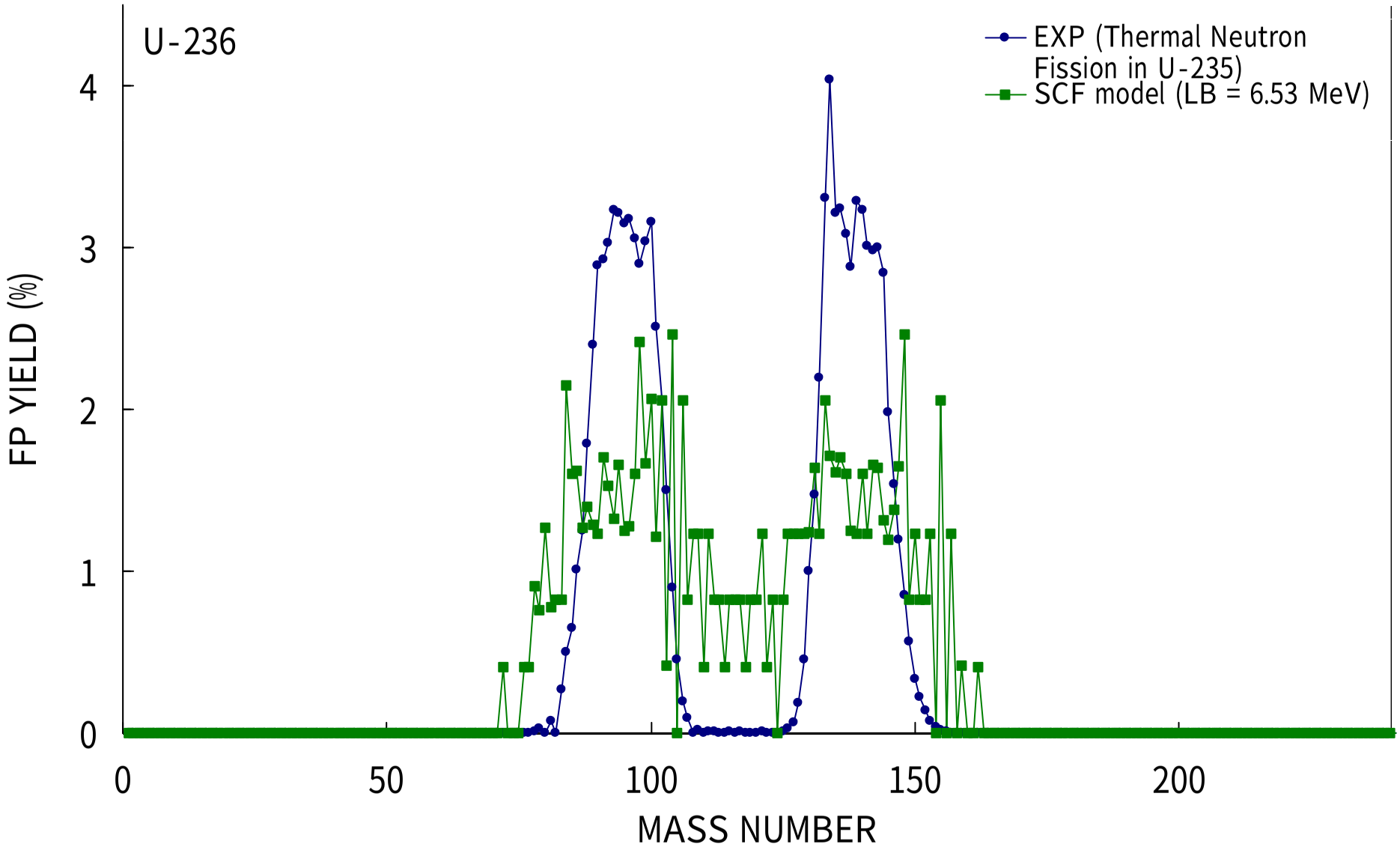
$^{236}\mathrm{U} \rightarrow {}^{105}\mathrm{Nb} + {}^{131}\mathrm{Sb} + 195.32$ MeV. ($\mathrm{E_f} = -8.36$ MeV)

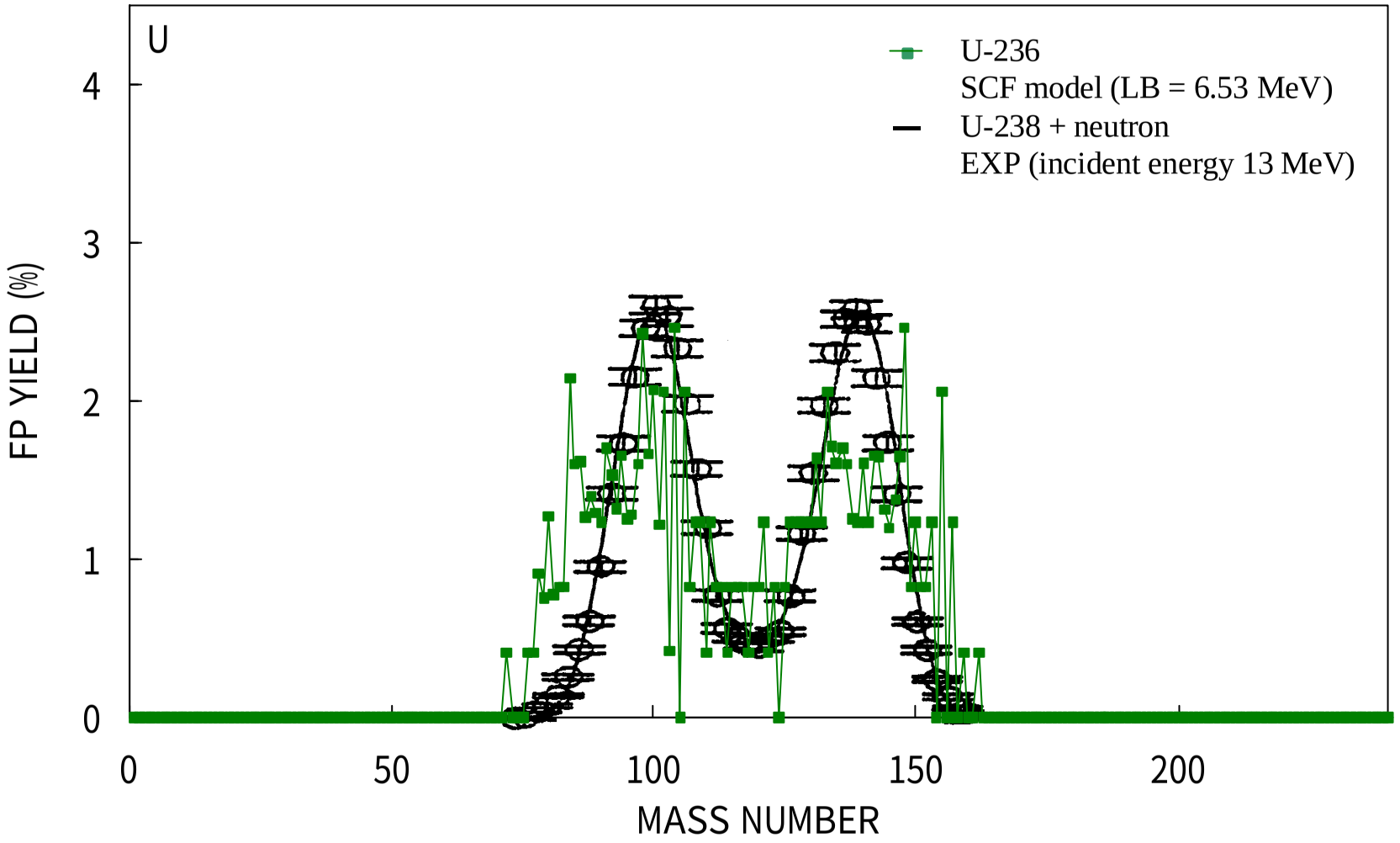
$^{236}\mathrm{U} \rightarrow {}^{107}\mathrm{Mo} + {}^{129}\mathrm{Sn} + 196.01$ MeV. ($\mathrm{E_f} = -8.32$ MeV)

$^{236}\mathrm{U} \rightarrow {}^{104}\mathrm{Zr} + {}^{132}\mathrm{Te} + 193.95$ MeV. ($\mathrm{E_f} = -7.93$ MeV)

$^{236}\mathrm{U} \rightarrow {}^{103}\mathrm{Zr} + {}^{133}\mathrm{Te} + 193.77$ MeV. ($\mathrm{E_f} = -7.71$ MeV)


MASS NUMBER OF FP
0
20
40
60
80
100
120
140
160
180
200
220
240
FISSION BARRIER (MeV)
-20
-10
0
10
20
30
40
50
60
U-236
Q>0
LB


U-236
EXP (Thermal Neutron Fission in U-235)
SCF model (LB = 6.53 MeV)
FP YIELD (%)
0
1
2
3
4
0
50
100
150
200
MASS NUMBER


U
U-236
SCF model (LB = 6.53 MeV)
U-238 + neutron
EXP (incident energy 13 MeV)
FP YIELD (%)
0
1
2
3
4
0
50
100
150
200
MASS NUMBER

## List of top ten channels

$^{180}\mathrm{W} \rightarrow {}^{88}\mathrm{Kr}(\cdots)^{88}\mathrm{Sr} + {}^{92}\mathrm{Sr}(\cdots)^{92}\mathrm{Zr} + 112.97$ MeV.
($\mathrm{E_f} = 5.21$ MeV)

$^{180}\mathrm{W} \rightarrow {}^{86}\mathrm{Kr} + {}^{94}\mathrm{Sr}(\cdots)^{94}\mathrm{Zr} + 112.46$ MeV.
($\mathrm{E_f} = 5.74$ MeV)

$^{180}\mathrm{W} \rightarrow {}^{84}\mathrm{Se}(\cdots)^{84}\mathrm{Kr} + {}^{96}\mathrm{Zr} + 111.75$ MeV.
($\mathrm{E_f} = 5.78$ MeV)

$^{180}\mathrm{W} \rightarrow {}^{90}\mathrm{Kr}(\cdots)^{90}\mathrm{Sr}(28.78\ \mathrm{y})^{*} + {}^{90}\mathrm{Sr}(28.78\ \mathrm{y})^{*} + 111.26$ MeV.
($\mathrm{E_f} = 6.91$ MeV)

$^{180}\mathrm{W} \rightarrow {}^{87}\mathrm{Kr}(1.27\ \mathrm{h})^{87}\mathrm{Rb} + {}^{93}\mathrm{Sr}(\cdots)^{93}\mathrm{Zr}(1.53 \times 10^{6}\ \mathrm{y})^{*} + 111.22$ MeV.
($\mathrm{E_f} = 6.96$ MeV)

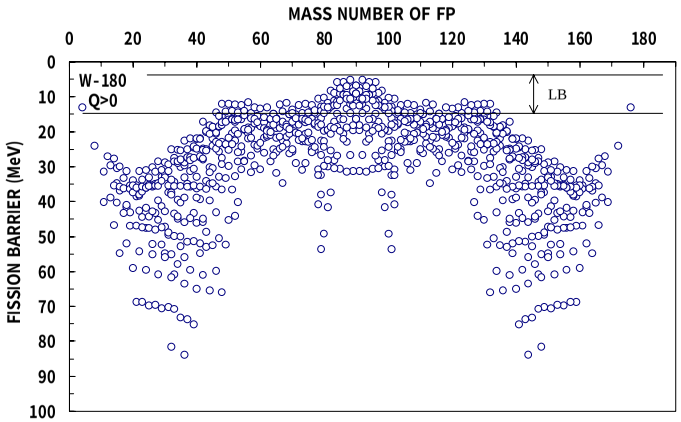
$^{180}\mathrm{W} \rightarrow {}^{89}\mathrm{Kr}(\cdots)^{89}\mathrm{Sr}(50.53\ \mathrm{d})^{*} + {}^{91}\mathrm{Sr}(9.63\ \mathrm{h})^{91}\mathrm{Y}(58.51\ \mathrm{d})^{*} + 110.73$ MeV.
($\mathrm{E_f} = 7.44$ MeV)

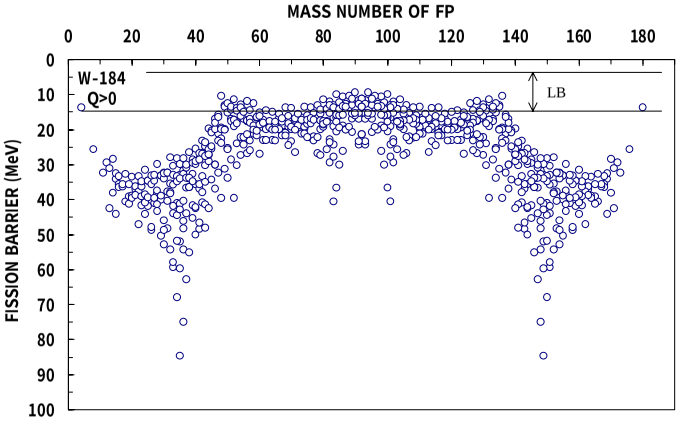
$^{182}\mathrm{W} \rightarrow {}^{88}\mathrm{Kr}(\cdots)^{88}\mathrm{Sr} + {}^{94}\mathrm{Sr}(\cdots)^{94}\mathrm{Zr} + 110.28$ MeV.
($\mathrm{E_f} = 7.47$ MeV)

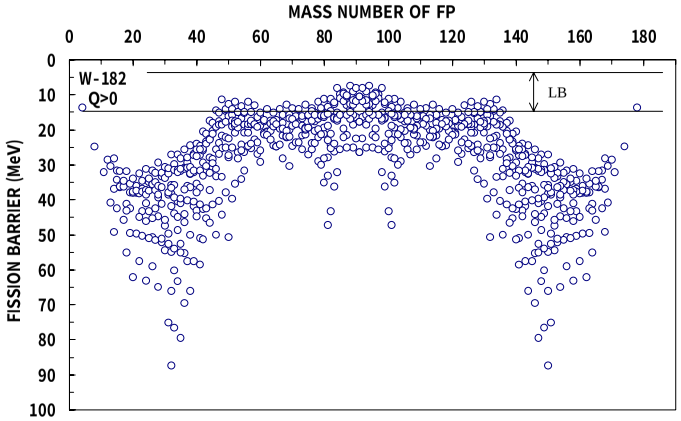
$^{180}\mathrm{W} \rightarrow {}^{85}\mathrm{Br}(2.90\ \mathrm{m})^{85}\mathrm{Kr}(10.77\ \mathrm{y})^{*} + {}^{95}\mathrm{Y}(10.3\ \mathrm{m})^{95}\mathrm{Zr}(64.02\ \mathrm{d})^{*} + 110.20$ MeV.
($\mathrm{E_f} = 7.74$ MeV)

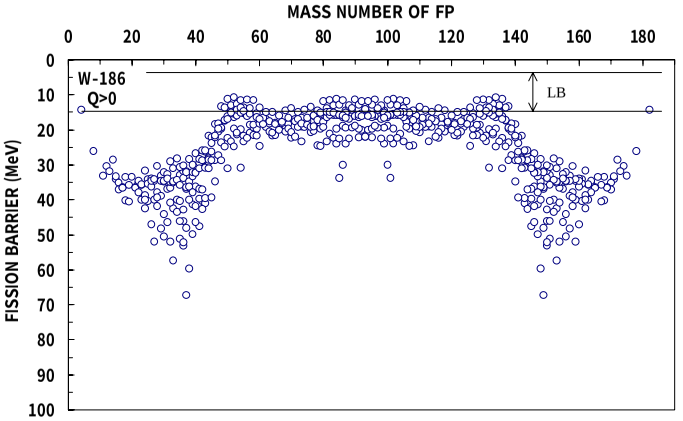
$^{182}\mathrm{W} \rightarrow {}^{90}\mathrm{Kr}(\cdots)^{90}\mathrm{Sr}(28.78\ \mathrm{y})^{*} + {}^{92}\mathrm{Sr}(\cdots)^{92}\mathrm{Zr} + 109.63$ MeV.
($\mathrm{E_f} = 8.10$ MeV)

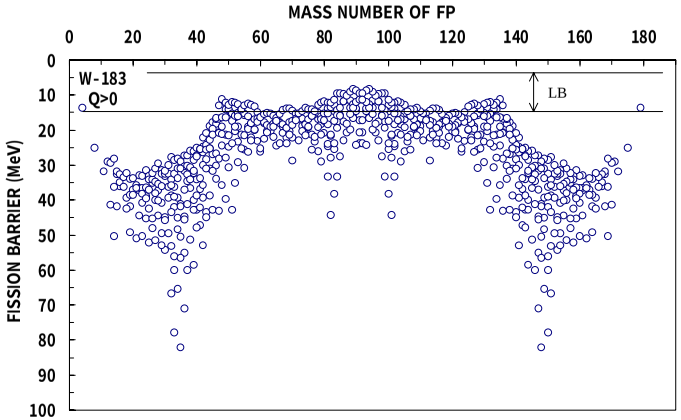
$^{182}\mathrm{W} \rightarrow {}^{84}\mathrm{Se}(\cdots)^{84}\mathrm{Kr} + {}^{98}\mathrm{Zr}(\cdots)^{98}\mathrm{Mo} + 108.97$ MeV.
($\mathrm{E_f} = 8.15$ MeV)



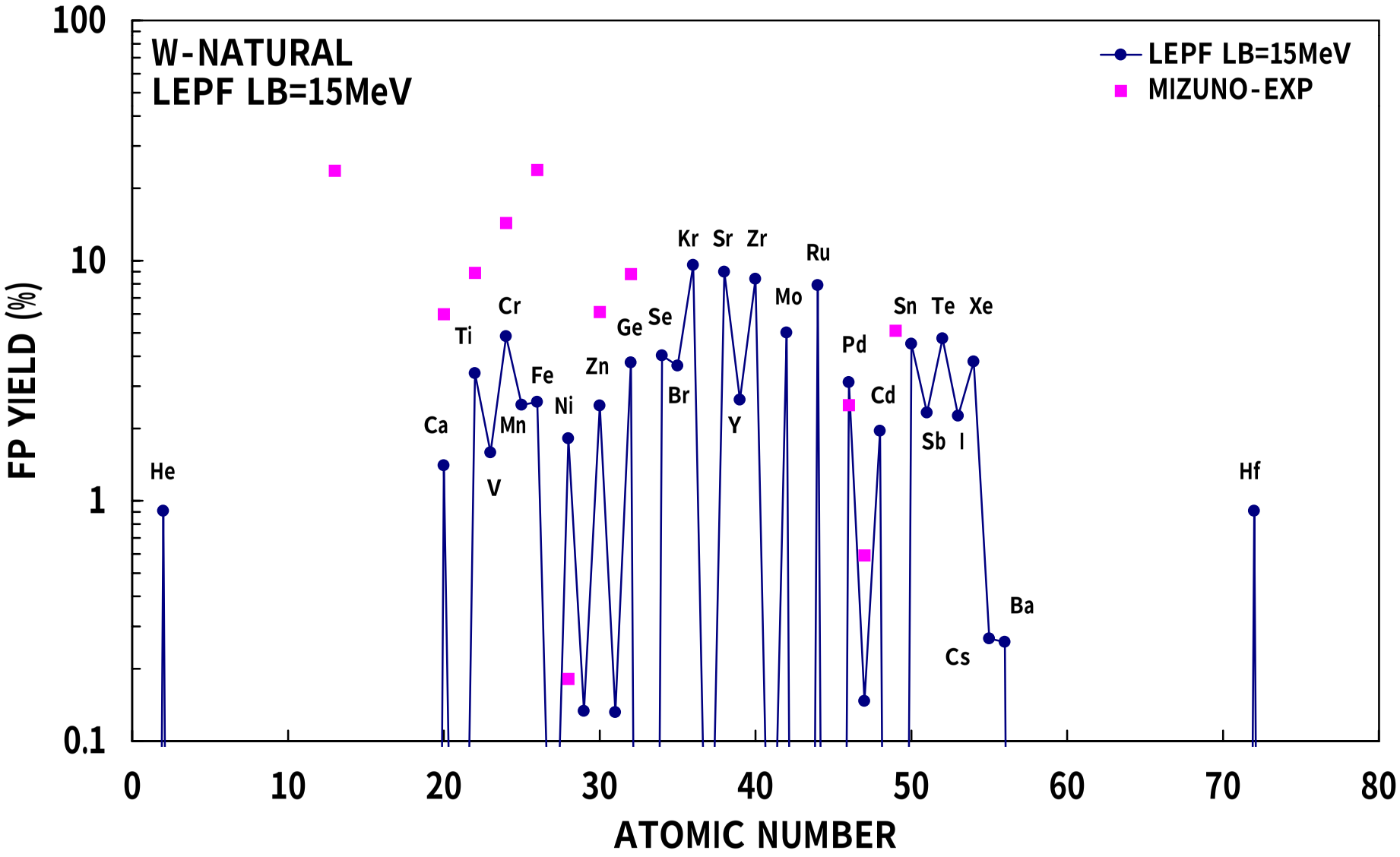



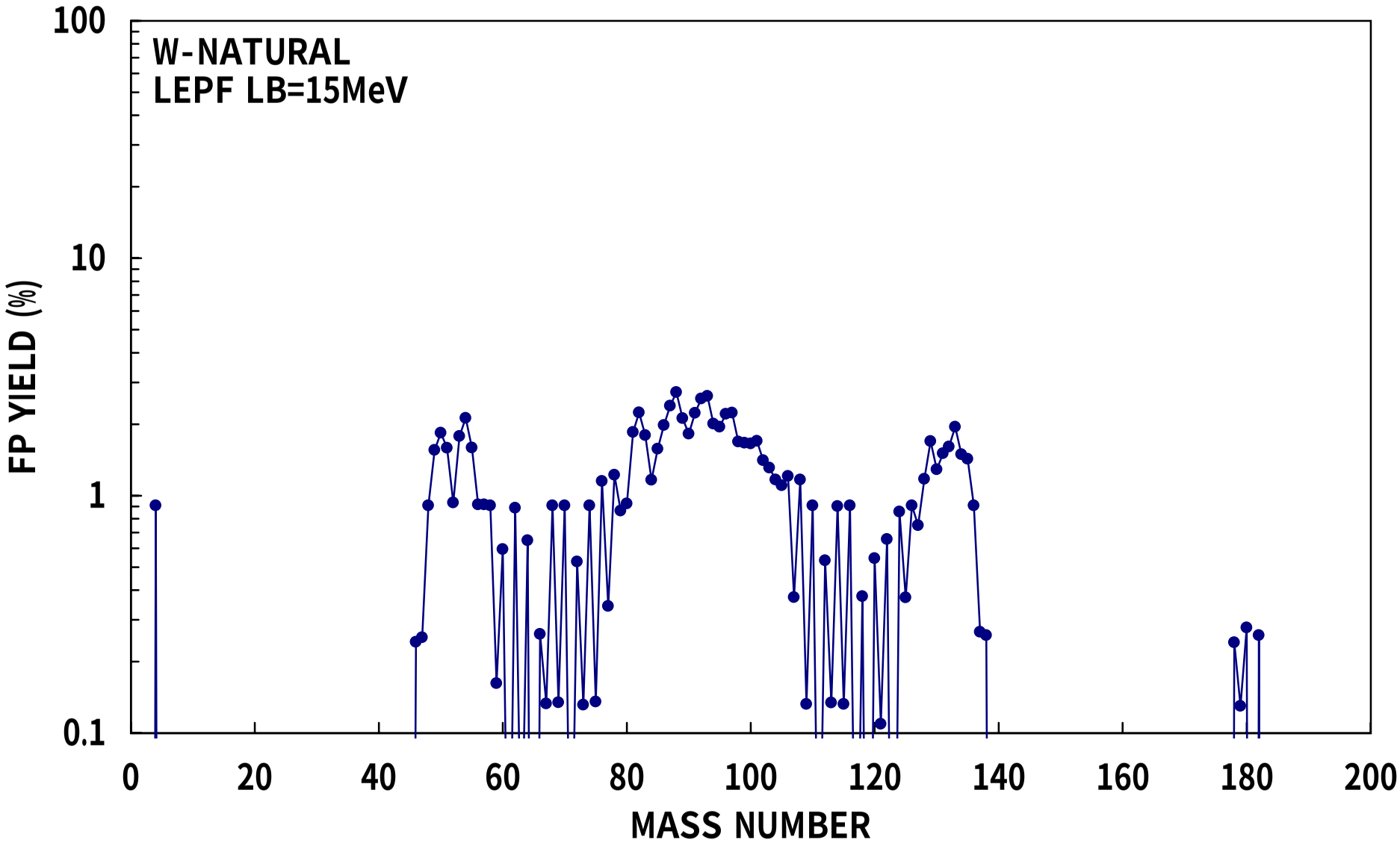




| $^{74}$W | abundance（%） |
|---|---|
| 180 | 0.120 |
| 182 | 26.498 |
| 183 | 14.314 |
| 184 | 30.642 |
| 186 | 28.426 |


W-NATURAL
LEPF LB=15MeV
LEPF LB=15MeV
MIZUNO-EXP
FP YIELD (%)
ATOMIC NUMBER
100
10
1
0.1
0
10
20
30
40
50
60
70
80
He
Ca
Ti
V
Cr
Mn
Fe
Ni
Zn
Ge
Se
Br
Kr
Sr
Y
Zr
Mo
Ru
Pd
Cd
Sn
Sb
Te
I
Xe
Cs
Ba
Hf


W-NATURAL
LEPF LB=15MeV
FP YIELD (%)
100
10
1
0.1
0
20
40
60
80
100
120
140
160
180
200
MASS NUMBER

## List of top ten channels

$$^{197}\mathrm{Au} \rightarrow {}^{68}\mathrm{Ni}(\cdots)^{68}\mathrm{Zn} + {}^{129}\mathrm{Sb}(4.40\ \mathrm{h})^{129}\mathrm{Te}(33.6\ \mathrm{d})^{*} + 116.95\ \mathrm{MeV}. \quad (\mathrm{E_f} = 6.89\ \mathrm{MeV})$$

$$^{197}\mathrm{Au} \rightarrow {}^{66}\mathrm{Ni}(\cdots)^{66}\mathrm{Zn} + {}^{131}\mathrm{Sb}(\cdots)^{131}\mathrm{Xe} + 116.89\ \mathrm{MeV}. \quad (\mathrm{E_f} = 7.15\ \mathrm{MeV})$$

$$^{197}\mathrm{Au} \rightarrow {}^{69}\mathrm{Cu}(\cdots)^{69}\mathrm{Ga} + {}^{128}\mathrm{Sn}(\cdots)^{128}\mathrm{Te} + 117.92\ \mathrm{MeV}. \quad (\mathrm{E_f} = 7.74\ \mathrm{MeV})$$

$$^{197}\mathrm{Au} \rightarrow {}^{71}\mathrm{Cu}(\cdots)^{71}\mathrm{Ga} + {}^{126}\mathrm{Sn}(10^{5}\ \mathrm{y})^{*} + 117.62\ \mathrm{MeV}. \quad (\mathrm{E_f} = 7.86\ \mathrm{MeV})$$

$$^{197}\mathrm{Au} \rightarrow {}^{84}\mathrm{Se}(\cdots)^{84}\mathrm{Kr} + {}^{113}\mathrm{Rh}(\cdots)^{113}\mathrm{Cd} + 123.59\ \mathrm{MeV}. \quad (\mathrm{E_f} = 7.95\ \mathrm{MeV})$$

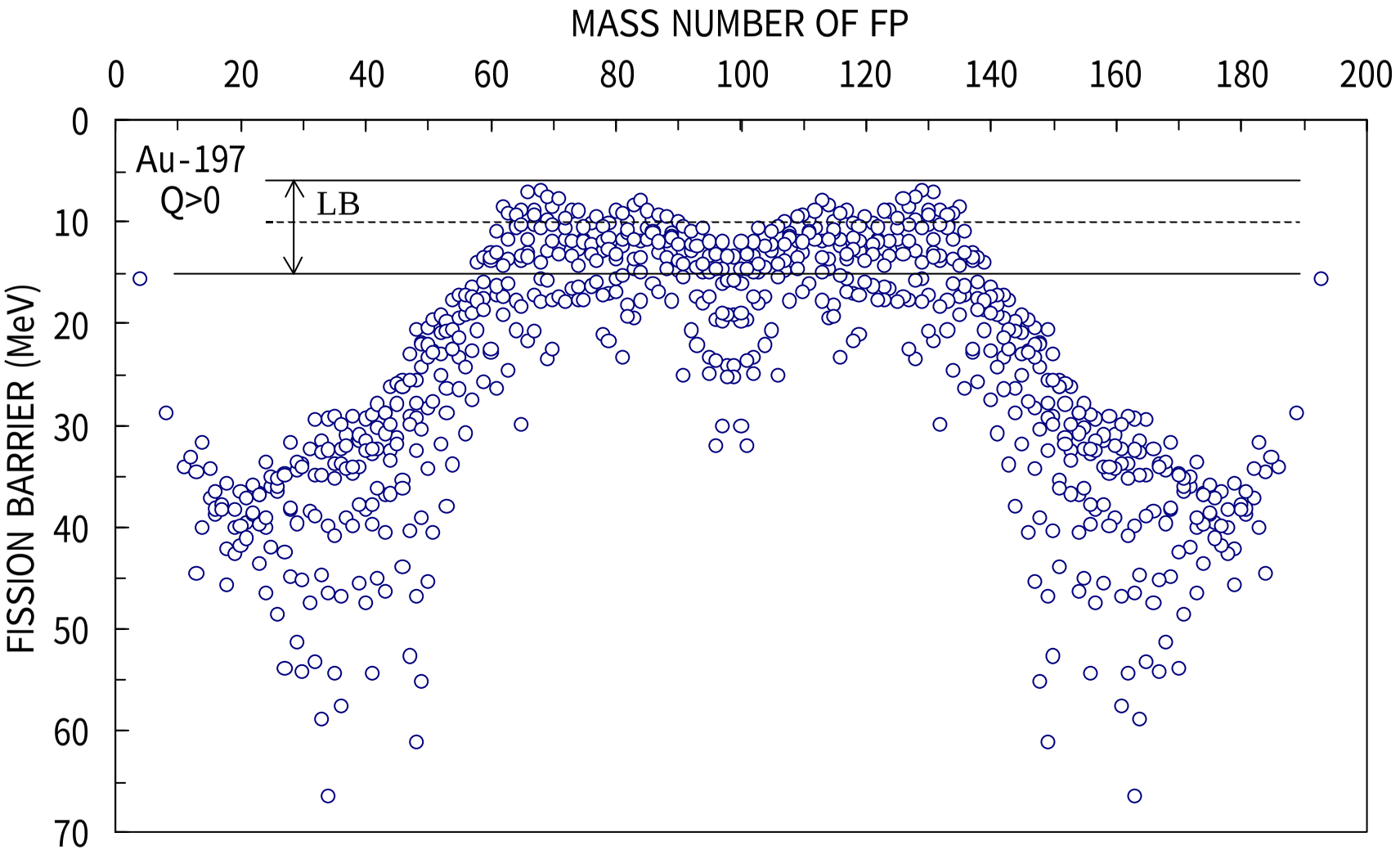
$$^{197}\mathrm{Au} \rightarrow {}^{83}\mathrm{As}(\cdots)^{83}\mathrm{Kr} + {}^{114}\mathrm{Pd}(\cdots)^{114}\mathrm{Cd} + 122.22\ \mathrm{MeV}. \quad (\mathrm{E_f} = 8.34\ \mathrm{MeV})$$

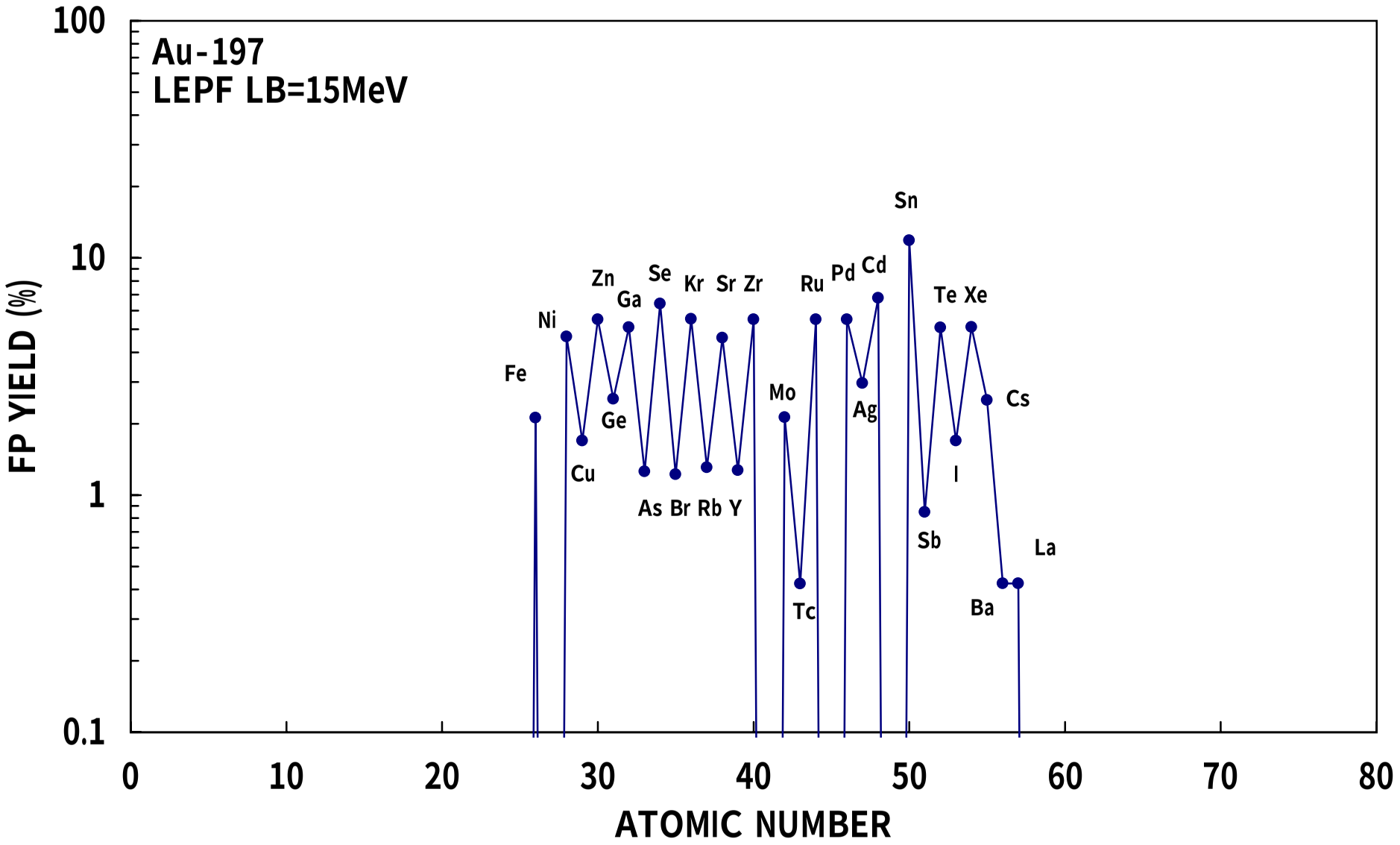
$$^{197}\mathrm{Au} \rightarrow {}^{62}\mathrm{Fe}(\cdots)^{62}\mathrm{Ni} + {}^{135}\mathrm{I}(\cdots)^{135}\mathrm{Cs}(2.3 \times 10^{6}\ \mathrm{y})^{*} + 111.53\ \mathrm{MeV}. \quad (\mathrm{E_f} = 8.59\ \mathrm{MeV})$$

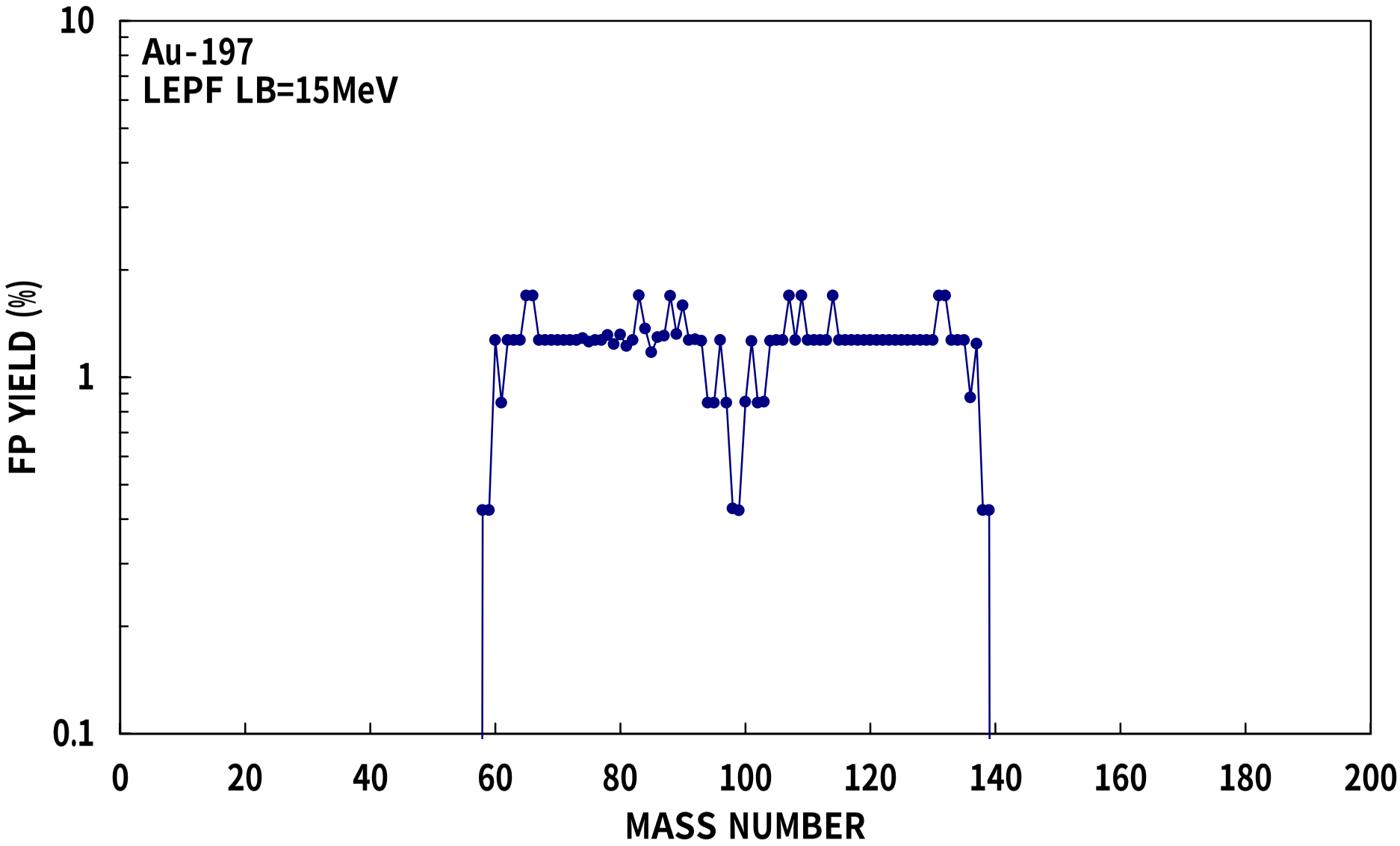
$$^{197}\mathrm{Au} \rightarrow {}^{70}\mathrm{Ni}(\cdots)^{70}\mathrm{Zn} + {}^{127}\mathrm{Sb}(3.85\ \mathrm{d})^{127}\mathrm{Te}(109\ \mathrm{d})^{*} + 115.05\ \mathrm{MeV}. \quad (\mathrm{E_f} = 8.61\ \mathrm{MeV})$$

$$^{197}\mathrm{Au} \rightarrow {}^{65}\mathrm{Co}(\cdots)^{65}\mathrm{Cu} + {}^{132}\mathrm{Te}(\cdots)^{132}\mathrm{Xe} + 113.22\ \mathrm{MeV}. \quad (\mathrm{E_f} = 8.84\ \mathrm{MeV})$$

$$^{197}\mathrm{Au} \rightarrow {}^{67}\mathrm{Ni}(\cdots)^{67}\mathrm{Zn} + {}^{130}\mathrm{Sb}(39.5\ \mathrm{m})^{130}\mathrm{Te} + 114.98\ \mathrm{MeV}. \quad (\mathrm{E_f} = 8.96\ \mathrm{MeV})$$


MASS NUMBER OF FP
0
20
40
60
80
100
120
140
160
180
200
FISSION BARRIER (MeV)
0
10
20
30
40
50
60
70
Au-197
Q>0
LB


Au-197
LEPF LB=15MeV
FP YIELD (%)
100
10
1
0.1
0
10
20
30
40
50
60
70
80
ATOMIC NUMBER
Fe
Ni
Cu
Zn
Ga
Ge
Se
As
Kr
Br
Rb
Sr
Y
Zr
Mo
Tc
Ru
Pd
Ag
Cd
Sn
Sb
Te
I
Xe
Cs
Ba
La


Au-197
LEPF LB=15MeV
FP YIELD (%)
10
1
0.1
0
20
40
60
80
100
120
140
160
180
200
MASS NUMBER

# Summary

- U

⇒
- Potential (namely the definition of $\alpha(A)$ and $\varepsilon(A)$) must be changed.
- Analysis on the case of U-fission by thermal neutron ～ high energy neutron.

- W
- Au

⇒
- Re-analyze. (And Pd)

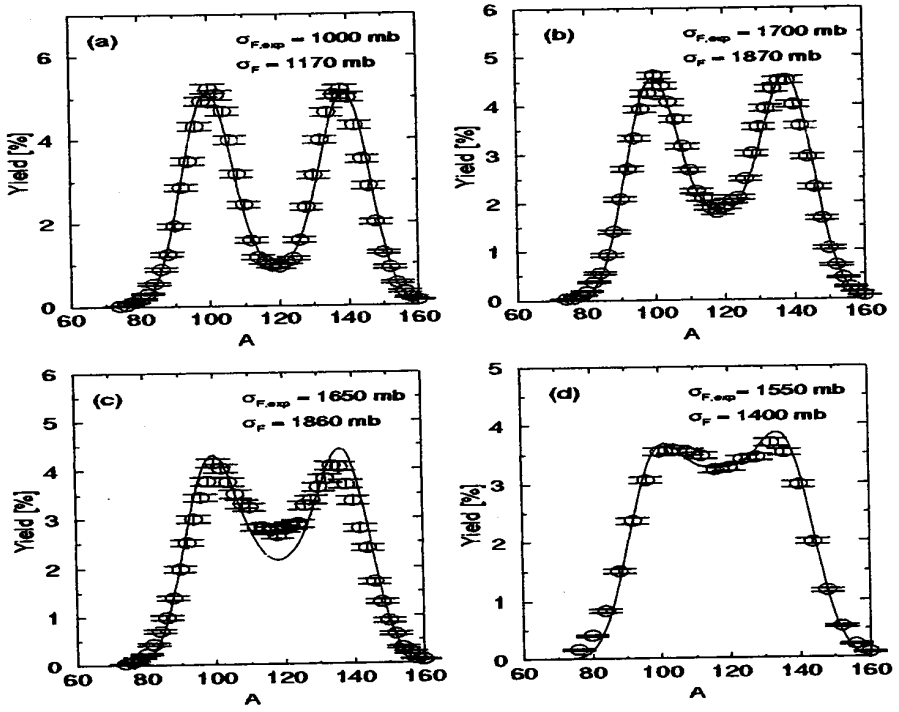



**Figure 5. Fission fragment pre-neutron emission mass yields from neutron-induced reactions on $^{238}$U with an incident energy of 13 MeV (a), 28 MeV (b), 50 MeV (c), and 100 MeV (d), taken from Zöller [3]. The calculation are done using the RLDM and an $a_f/a_n$-ratio resulting in the best description of the shape of the mass yield curve: $a_f/a_n$=1.10 (a), $a_f/a_n$=1.08 (b), $a_f/a_n$=1.07 (c), and $a_f/a_n$=1.05 (d).**

(Ref.: Ed. C.Wagemans et al., SEMINAR ON FISSION, World Scientfic )