Suggestion for examination of a role of multi-chance fission

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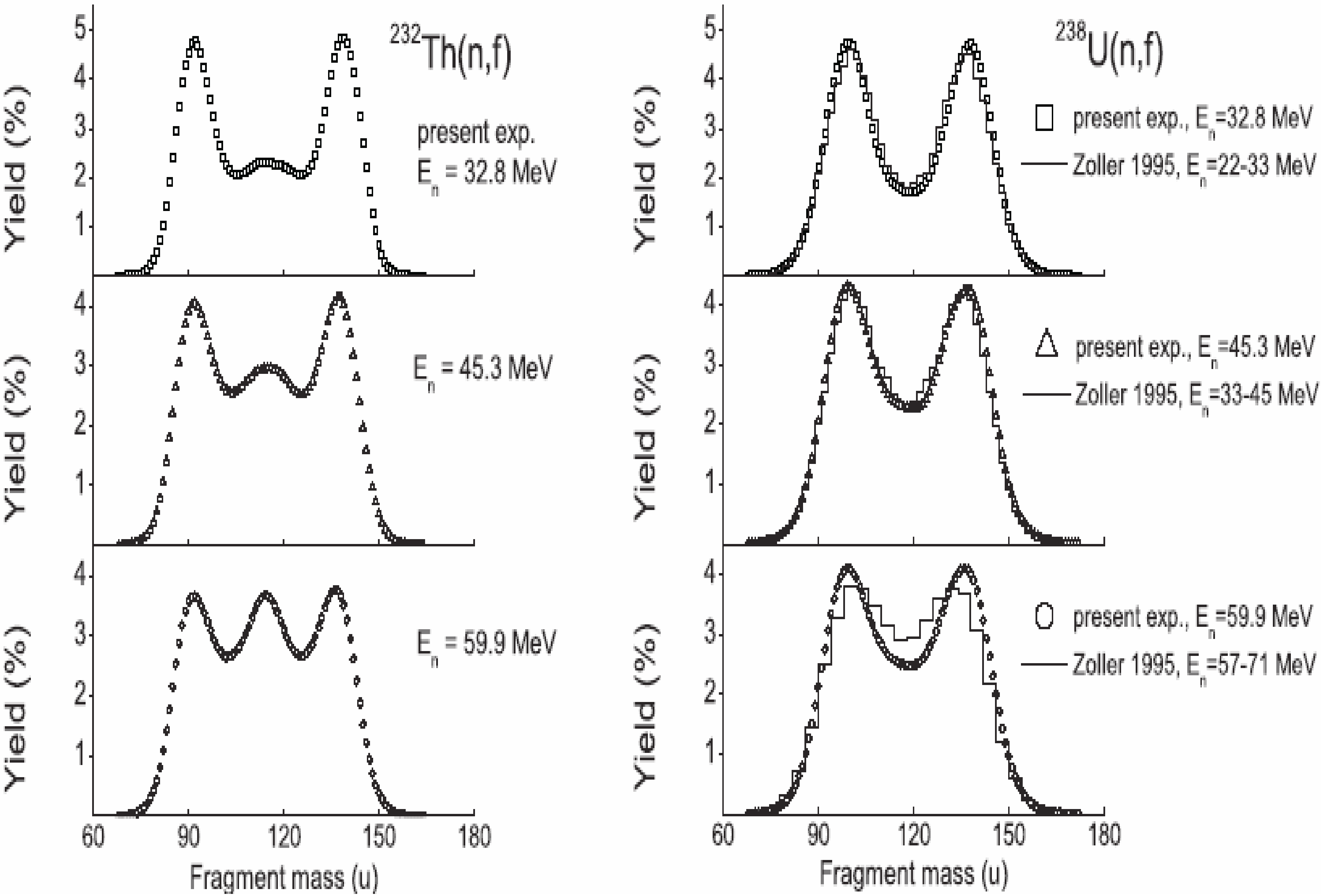
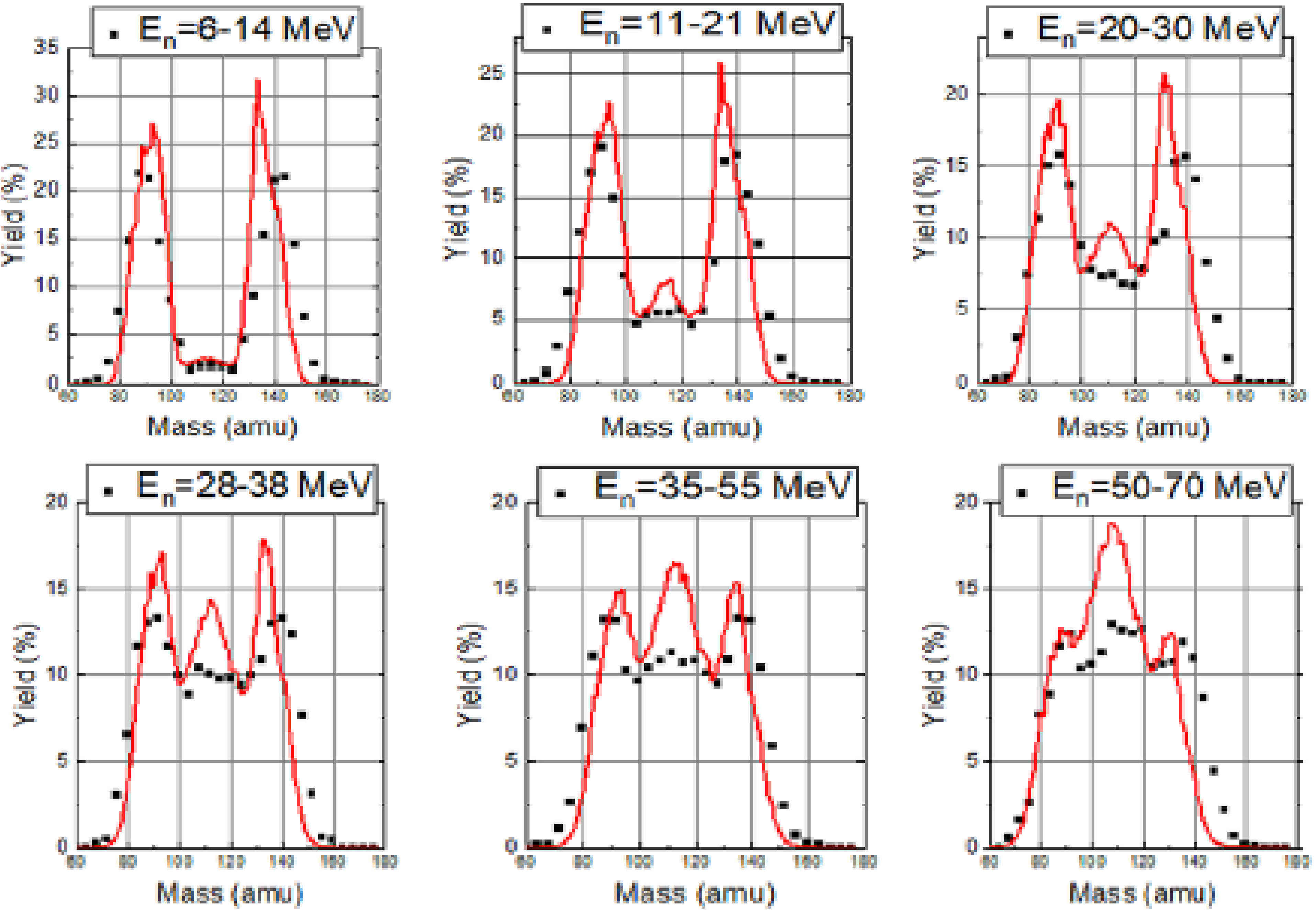
Exper. data for high-energy (60 – 70 MeV) fission of actinides shows conservation of asymmetric mass distribution, even though shell effects are supposed to be damped !

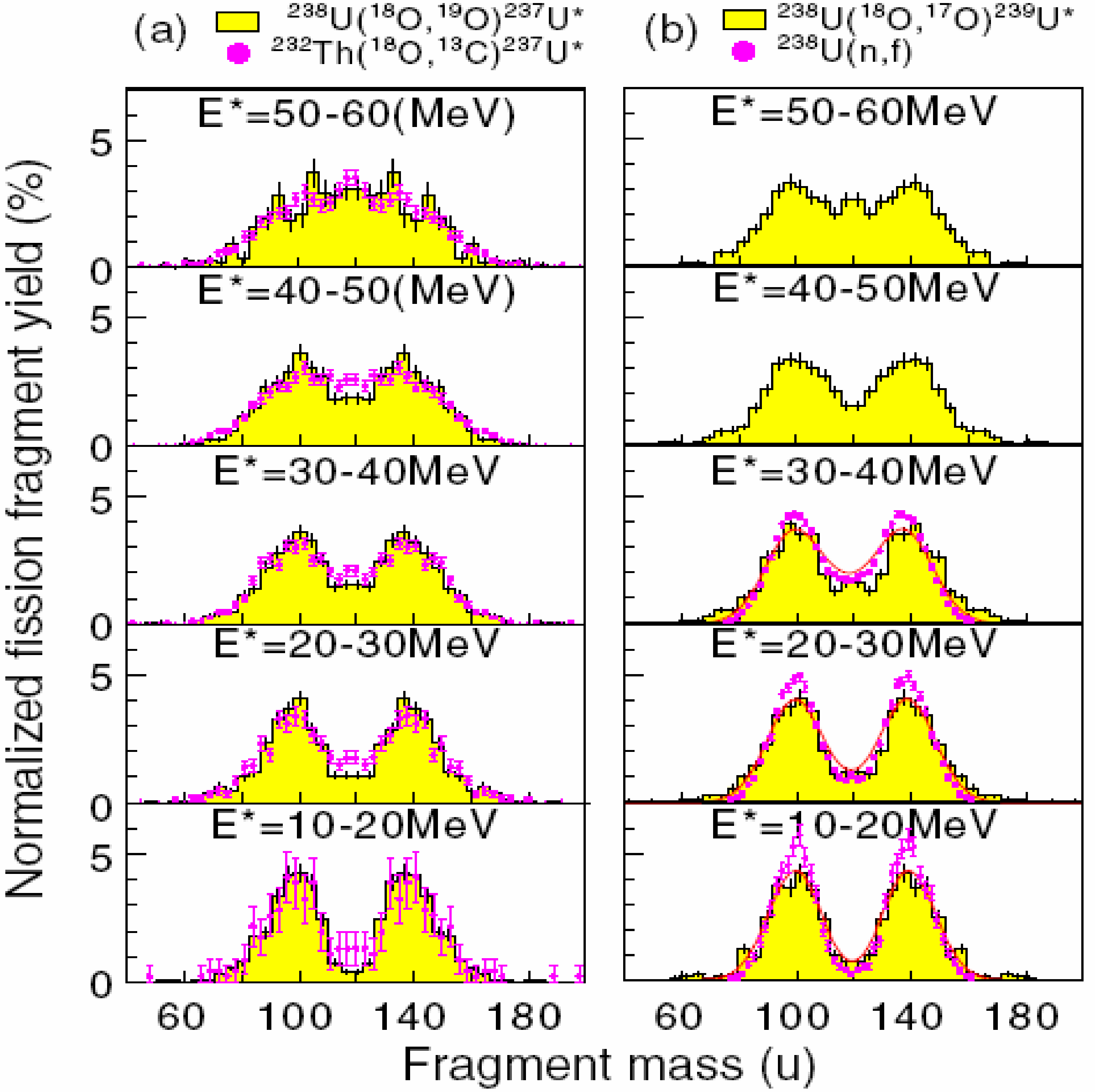
I.Ryzhov et al. PRC83(2011)054603



J.King et al. EPJA 53(2017)238

232Th



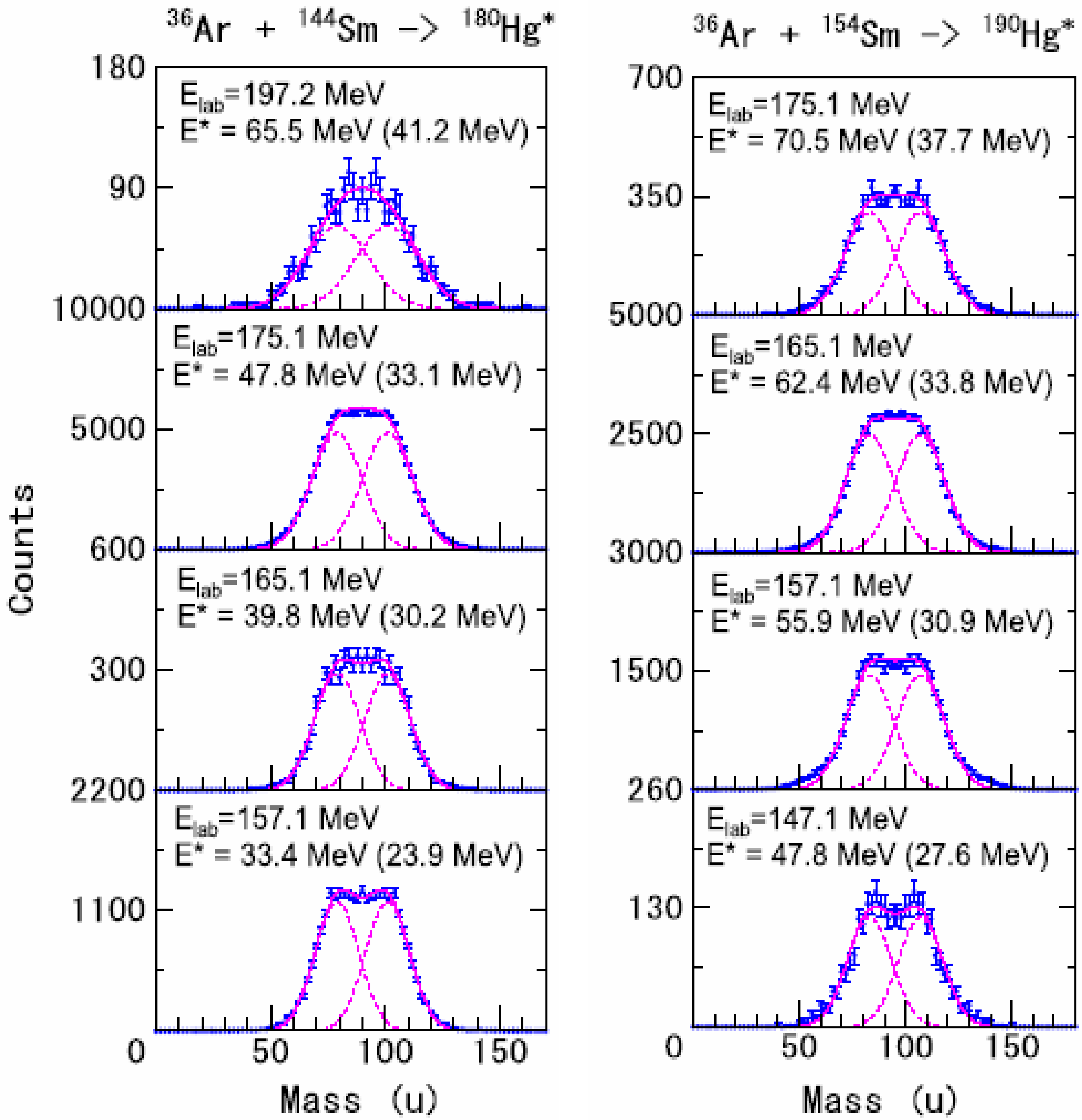


K.Hirose et al.,
PRL119(2017)222501

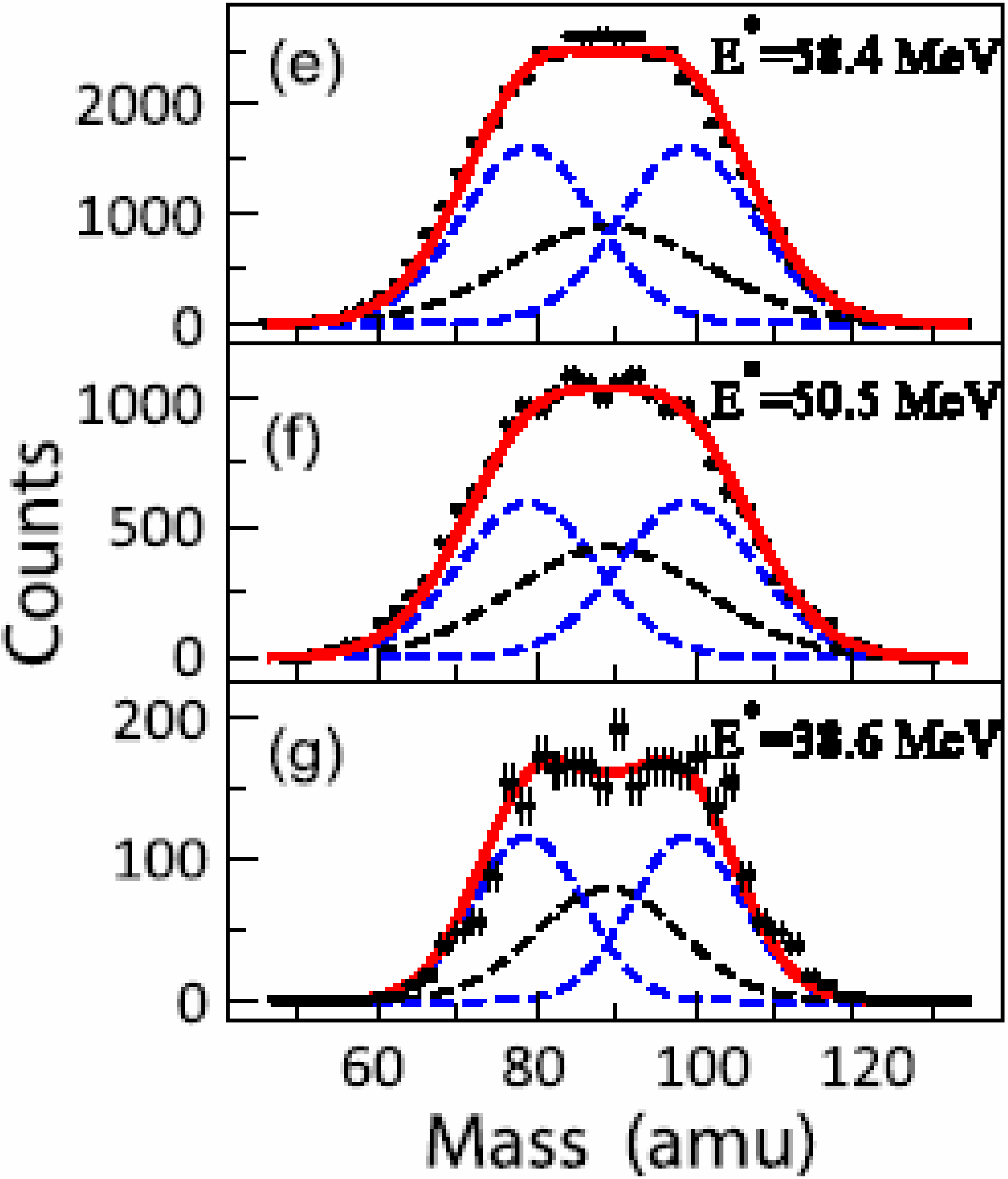
Exper. asymmetric mass yields result in fission of highly excited (~60-70 MeV) nuclei 232Th, 237-240U, 239-242Np, 241-244Pu, 240-244Am, 242-246Cm, 244-248Bk produced in transfer reactions 18O+232Th,238U,237Np !

K.Hirose et al. PRL119(17)22250

R.Leguillon et al.PLB761(16)125



K.Nishio et al.
PLB 748(2015)89



I.Tsekhanovich et al.
PLB 790(2019)583

Conservation of asymmetric mass distribution, even though shell effects are supposed to be damped !

Revolution in fission ?!

There is explanation based on

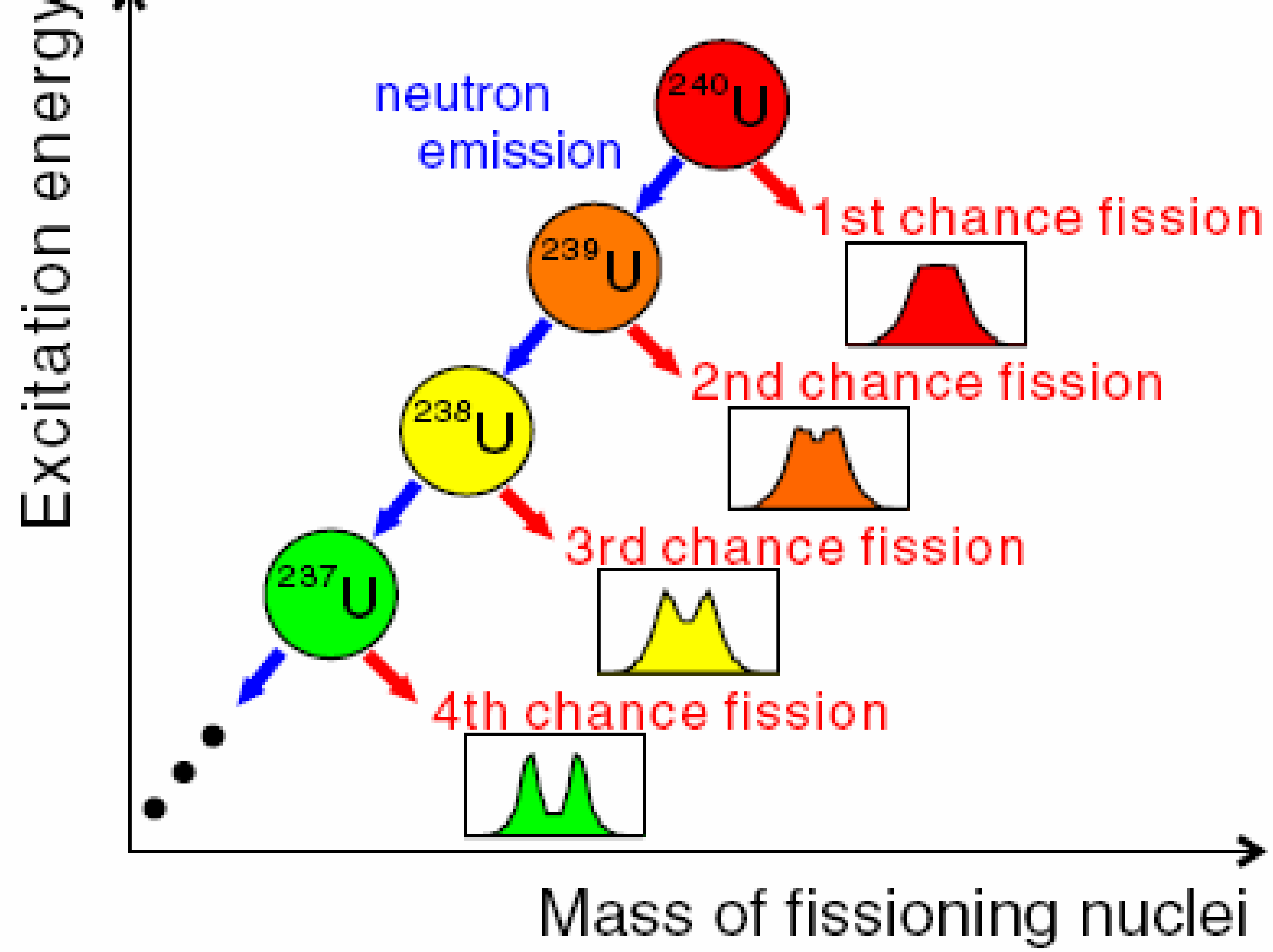
Multi-Chance Fission Assumption !

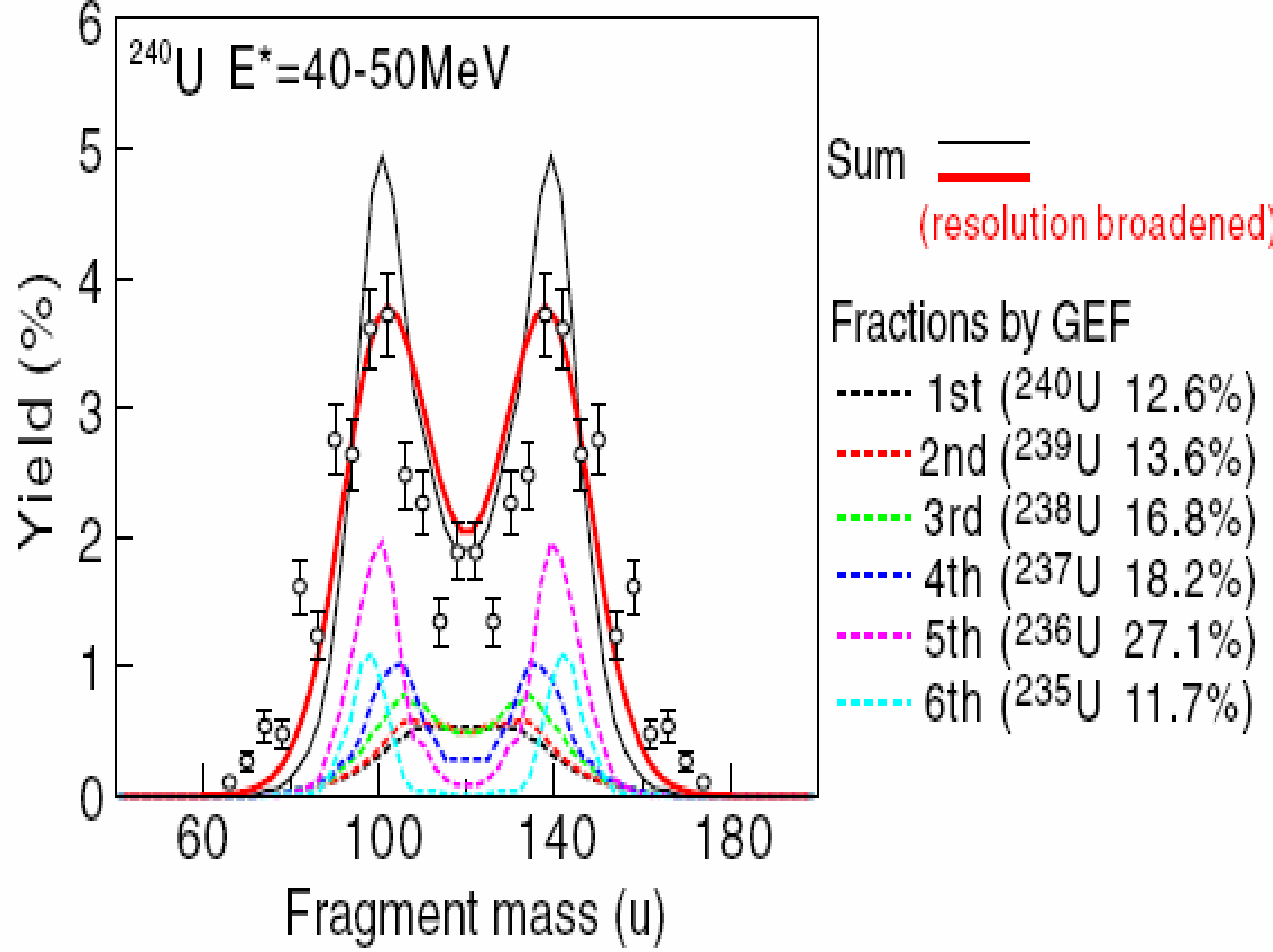
Multi-chance fission:

1) Distribution originates from 1st-, 2nd-, 3rd-…, last-chance fission

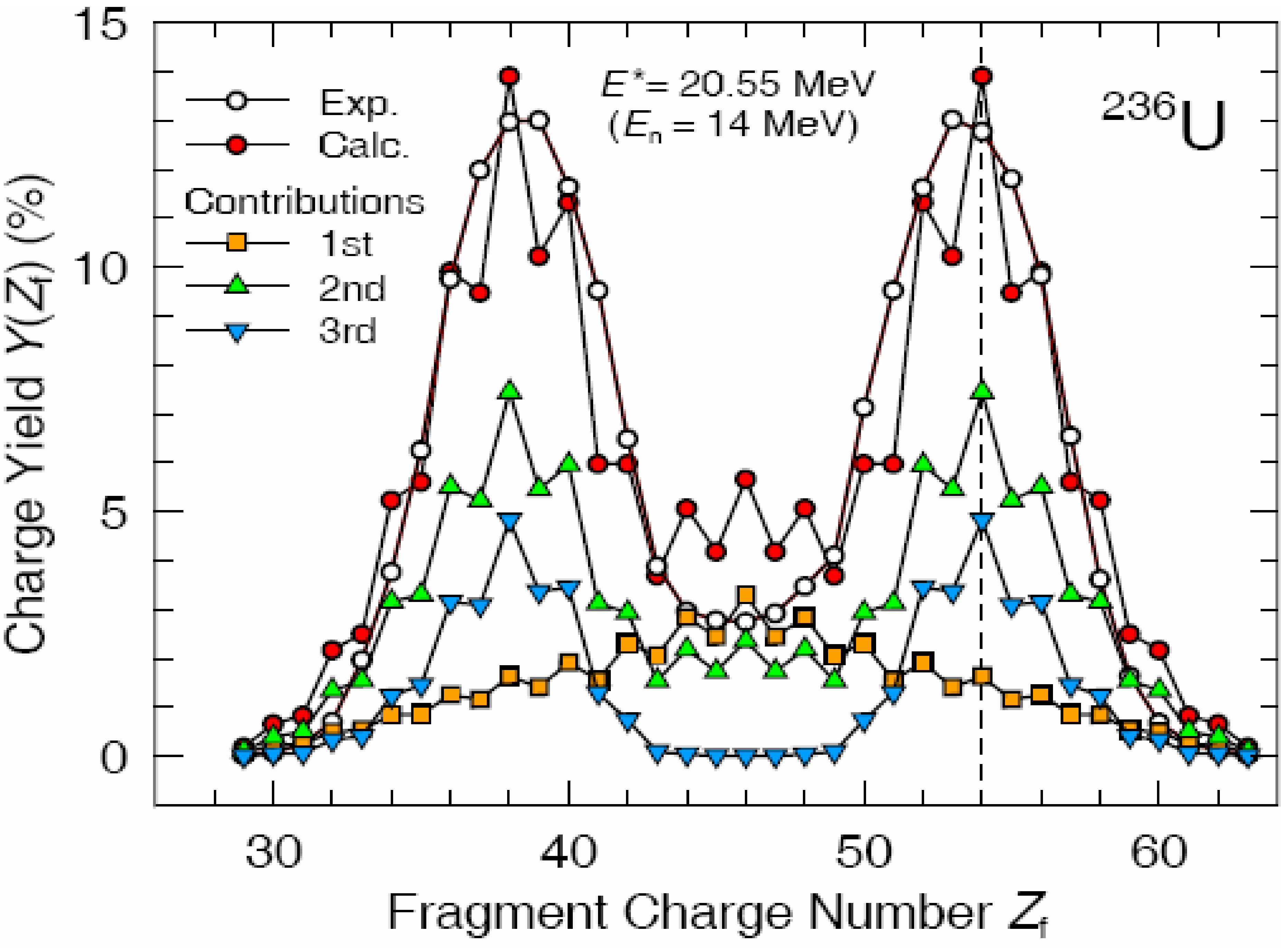
2) 1st-chance fission leads to symmetric component of distribution

3) After n-evaporations excitation energy is reduced & late-chance fission leads to asymmetric component of distribution


Excitation energy
neutron emission
240U
239U
238U
237U
1st chance fission
2nd chance fission
3rd chance fission
4th chance fission
Mass of fissioning nuclei



^{240}U E*=40-50MeV
Yield (%)
Fragment mass (u)
0
1
2
3
4
5
6
60
100
140
180
Sum
(resolution broadened)
Fractions by GEF
1st (^{240}U 12.6%)
2nd (^{239}U 13.6%)
3rd (^{238}U 16.8%)
4th (^{237}U 18.2%)
5th (^{236}U 27.1%)
6th (^{235}U 11.7%)



Charge Yield Y(Z_f) (%)
15
10
5
0
30
40
50
60
Fragment Charge Number Z_f
Exp.
Calc.
Contributions
1st
2nd
3rd
E* = 20.55 MeV
(E_n = 14 MeV)
236U

Disadvantage of multi-chance fission:

With small changes of weights in multi-chance fission ratio between symmetric and asymmetric yields can strongly change !

Absence of reliable information about competitions between particle-, gamma-emission and fission as function of E* and L leads to large uncertanties & to strong dependence of results on parameters !

Fission of ^{240}U at E*=50 MeV :

	GEF	Our
1st-chance	13%	34%
2nd-chance	14%	25%
3rd-chance	17%	16%

GEF: NDS131(16)107

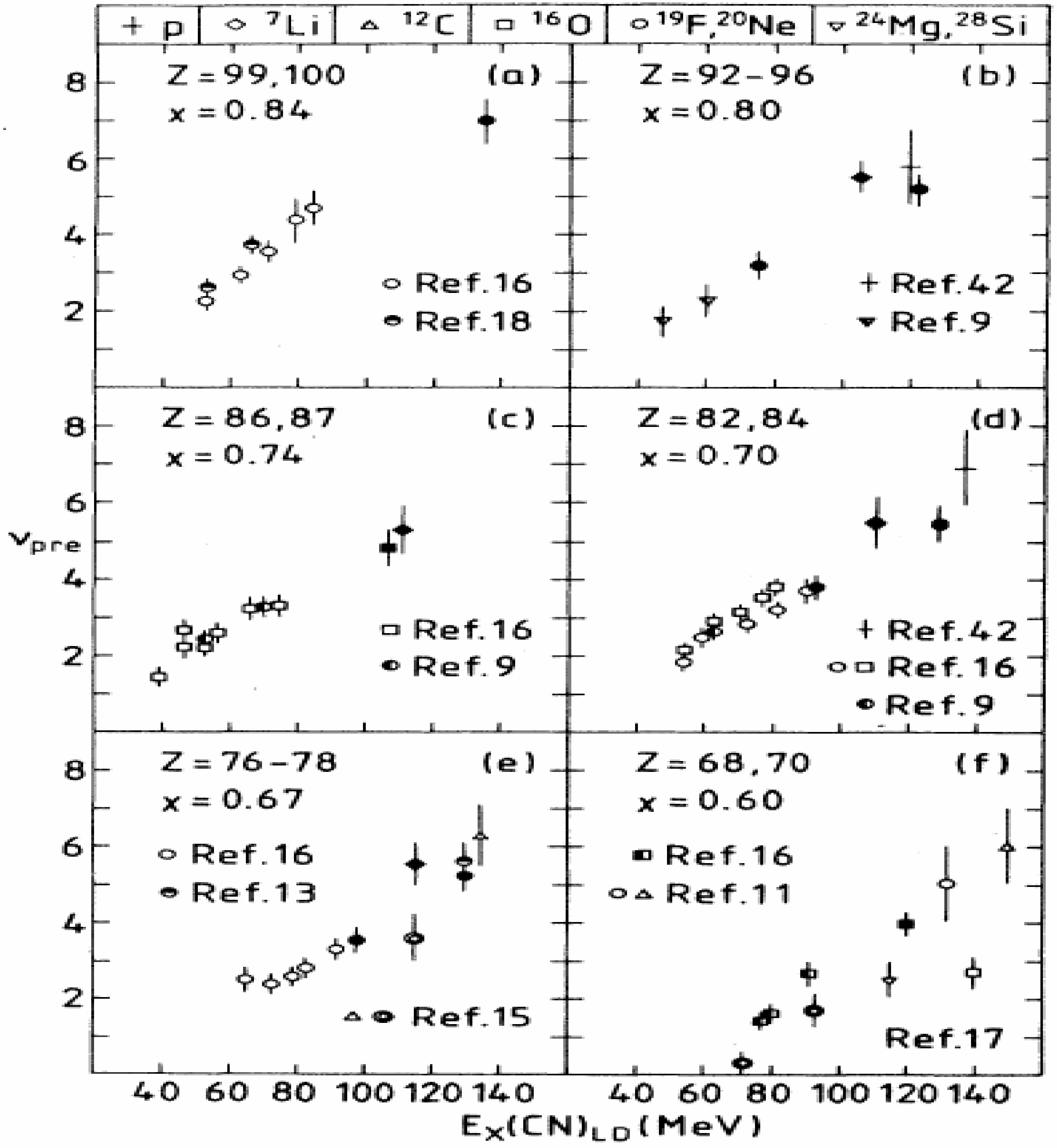
Our: EPJA54(18)104

With small changes of weights ratio between symmetric and asymmetric yields strongly can change !

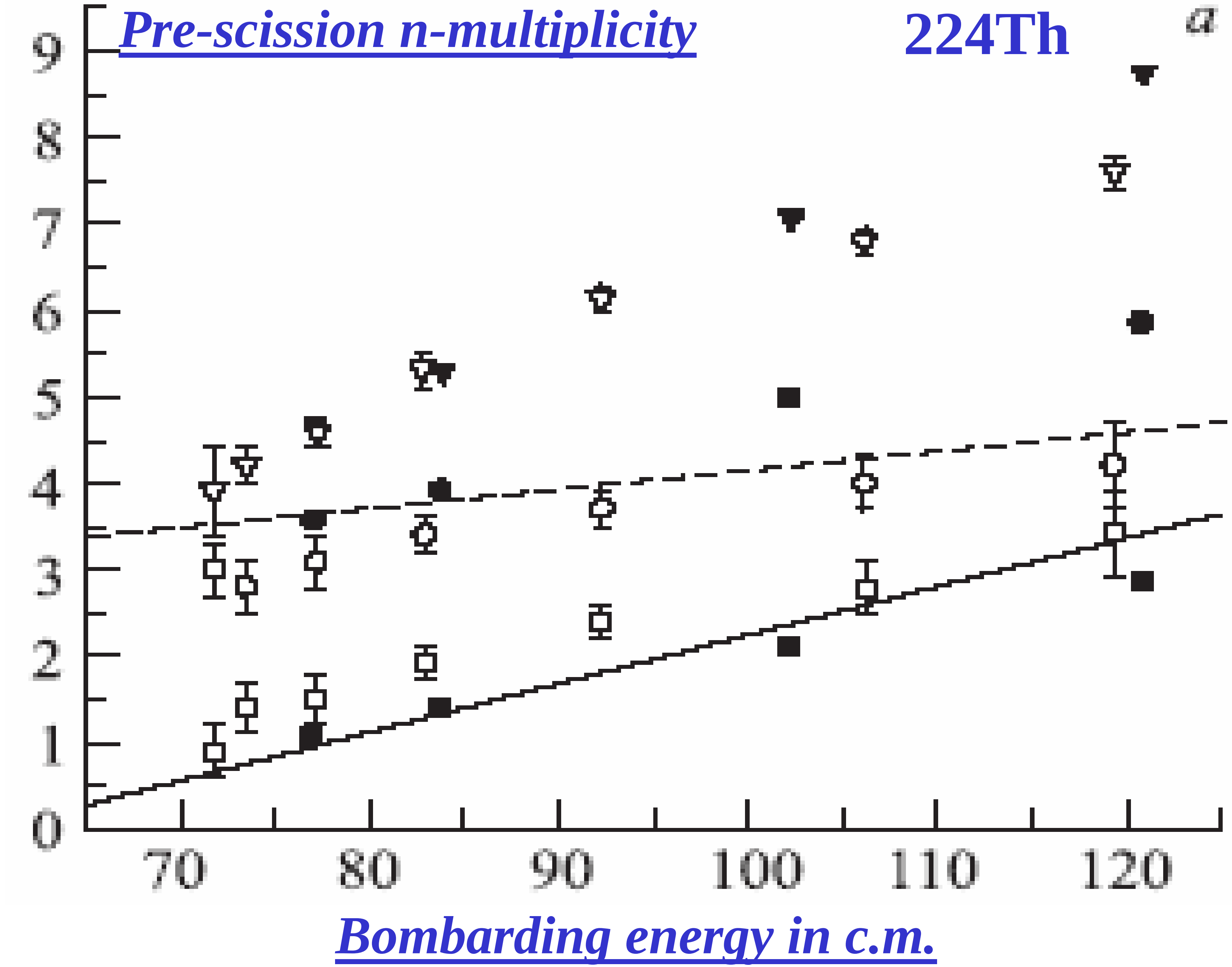
TABLE X. Calculated most probable fission energies and probabilities of the different fission chances for fission of ^{250}Cf at $E^* = 45$ MeV and $J_{rms} = 20\hbar$.

GEF

Chance	E^*_{peak} (MeV)	Probability
1.	45.0	39.0 %
2.	37.3	31.8 %
3.	29.5	22.2 %
4.	20.9	6.4 %
5.	14.2	0.5 %



D.Hinde et al.
PRC 39(1989)2268

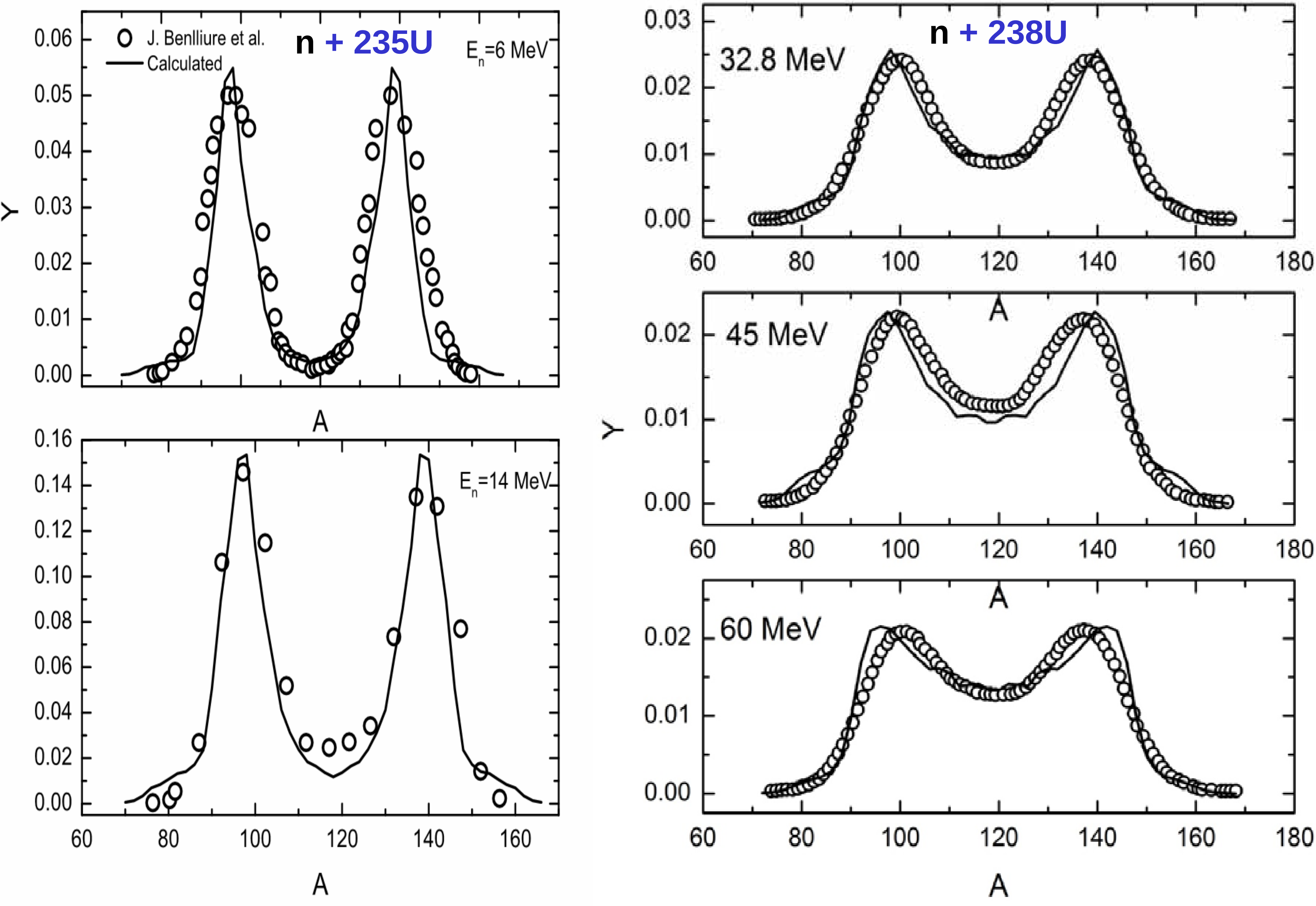

Pre-scission n-multiplicity
224Th
a
0
1
2
3
4
5
6
7
8
9
70
80
90
100
110
120
Bombarding energy in c.m.

Statistical Scission-point Model
or
Cluster model of fission

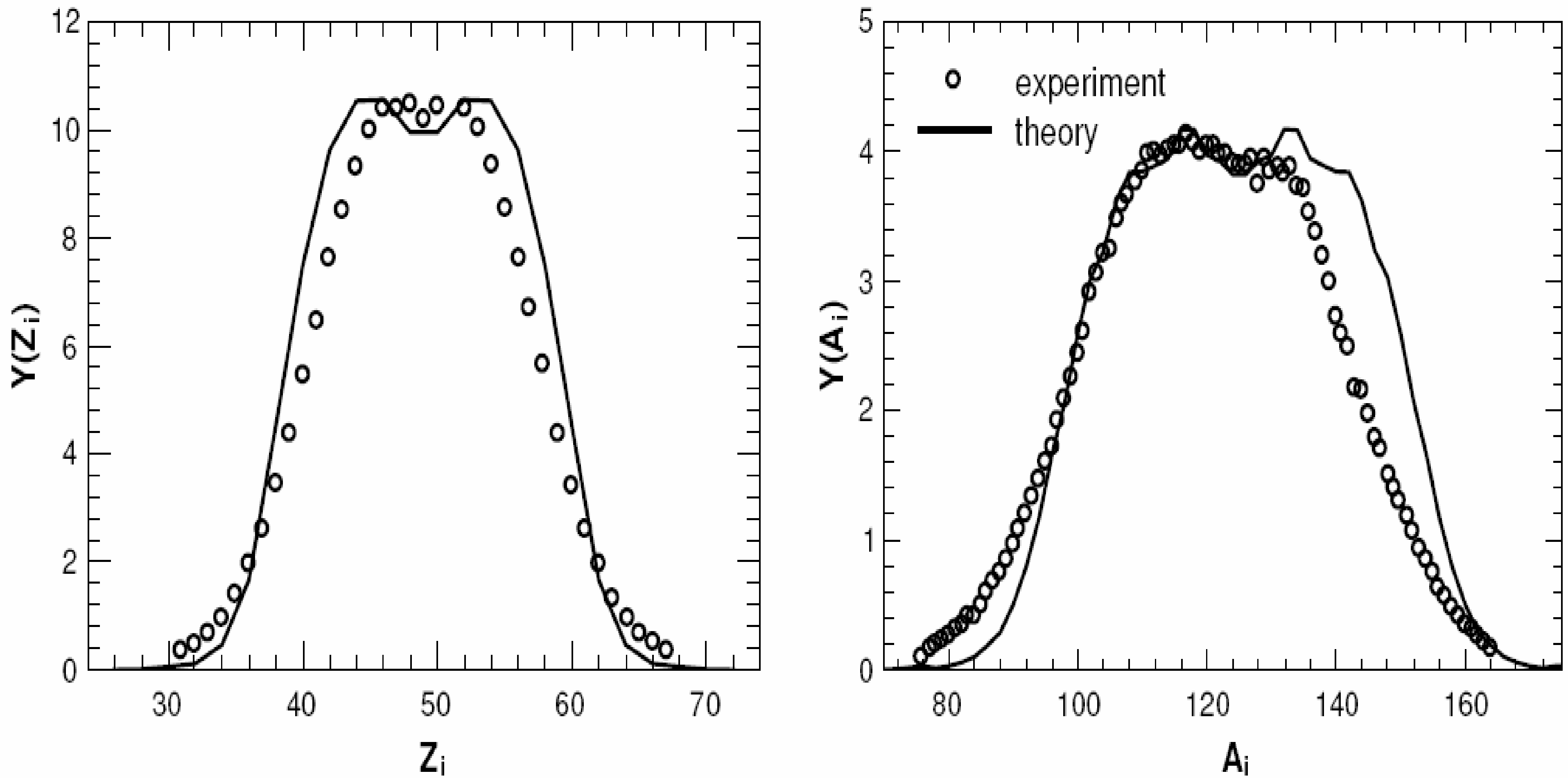
- Scission-point model relies on assumption that statistical equilibrium is established at scission where observable characteristics of fission are formed

- 1^{st}-chance fission is most important ! Contribution of multi-chance fission does not change distribution

High excitation energy of fissioning nucleus

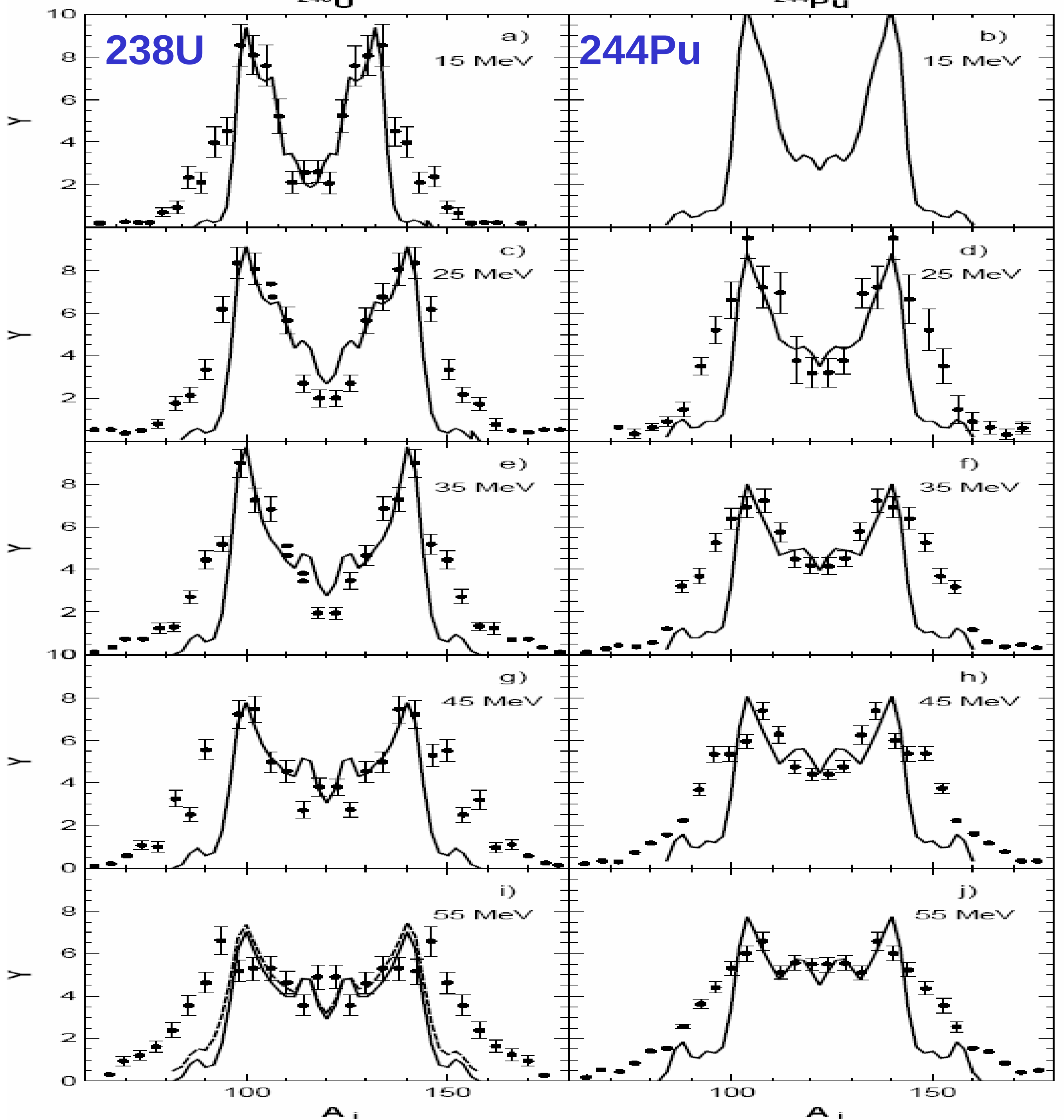


250Cf (46 MeV)



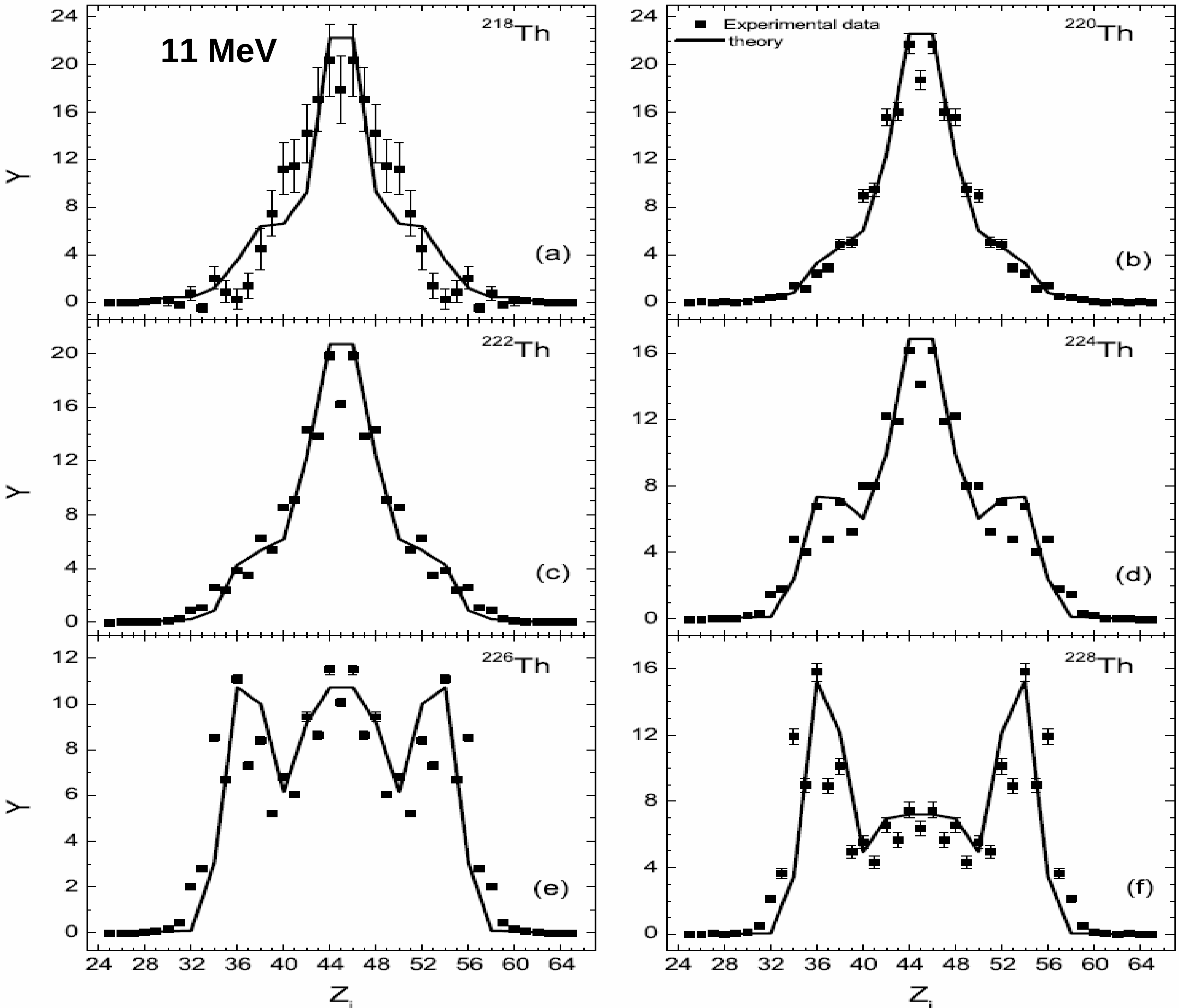
Exp.:D.Ramos et al.
PRC 97(2018)054612

Exper.:K.Hirose et al. PRL119(2017)222501



About 75% of fission events occur during emission of 2 pre-scission neutrons leading to almost unchanged distribution !

Experimental (model independent) verification of multi-chance fission



11 MeV
^{218}Th
^{220}Th
^{222}Th
^{224}Th
^{226}Th
^{228}Th
Experimental data
theory
(a)
(b)
(c)
(d)
(e)
(f)
Y
Z_i

Fission of 228Th at excitation energies E*=0-60MeV

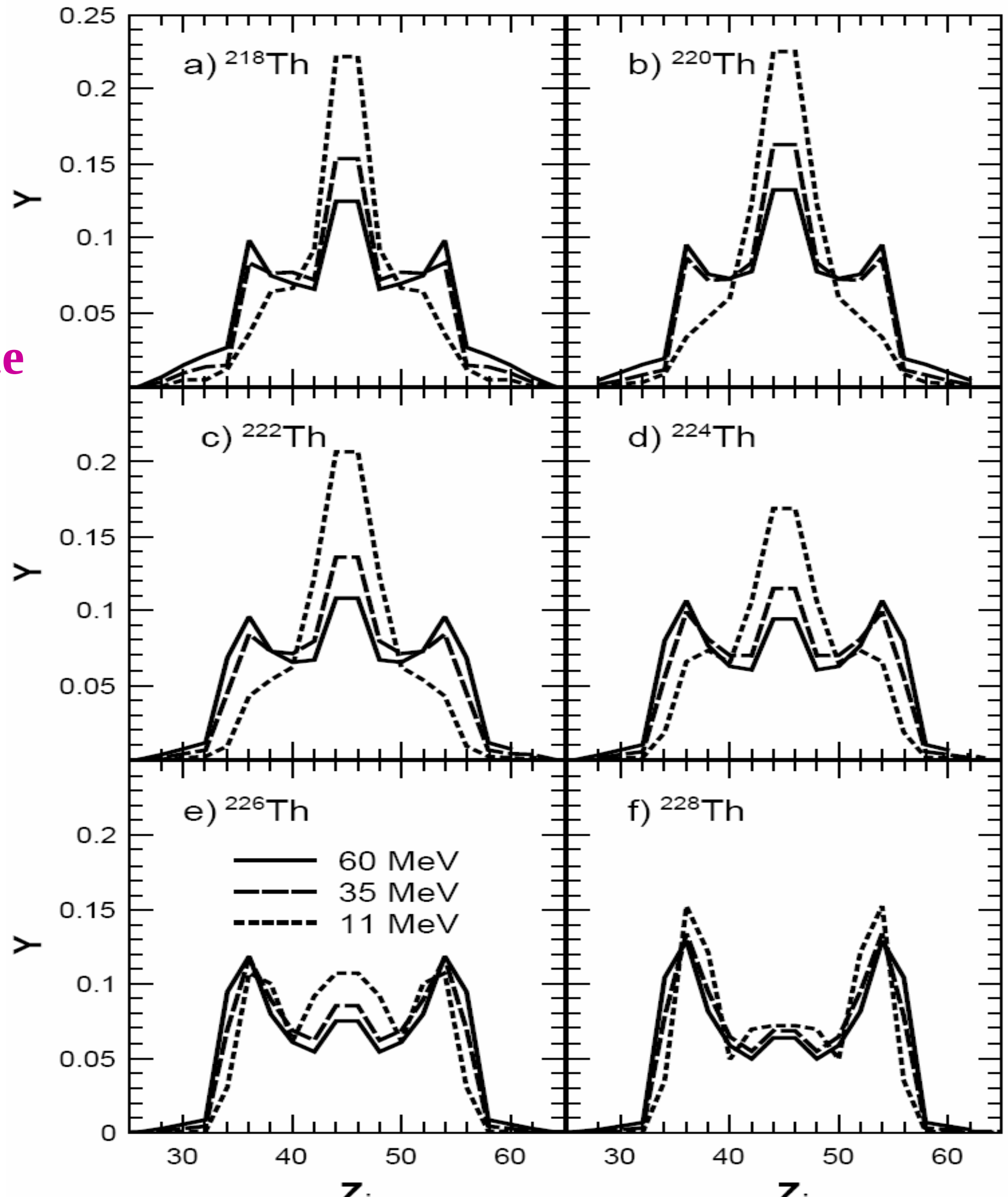
If multi-chance fission is important:

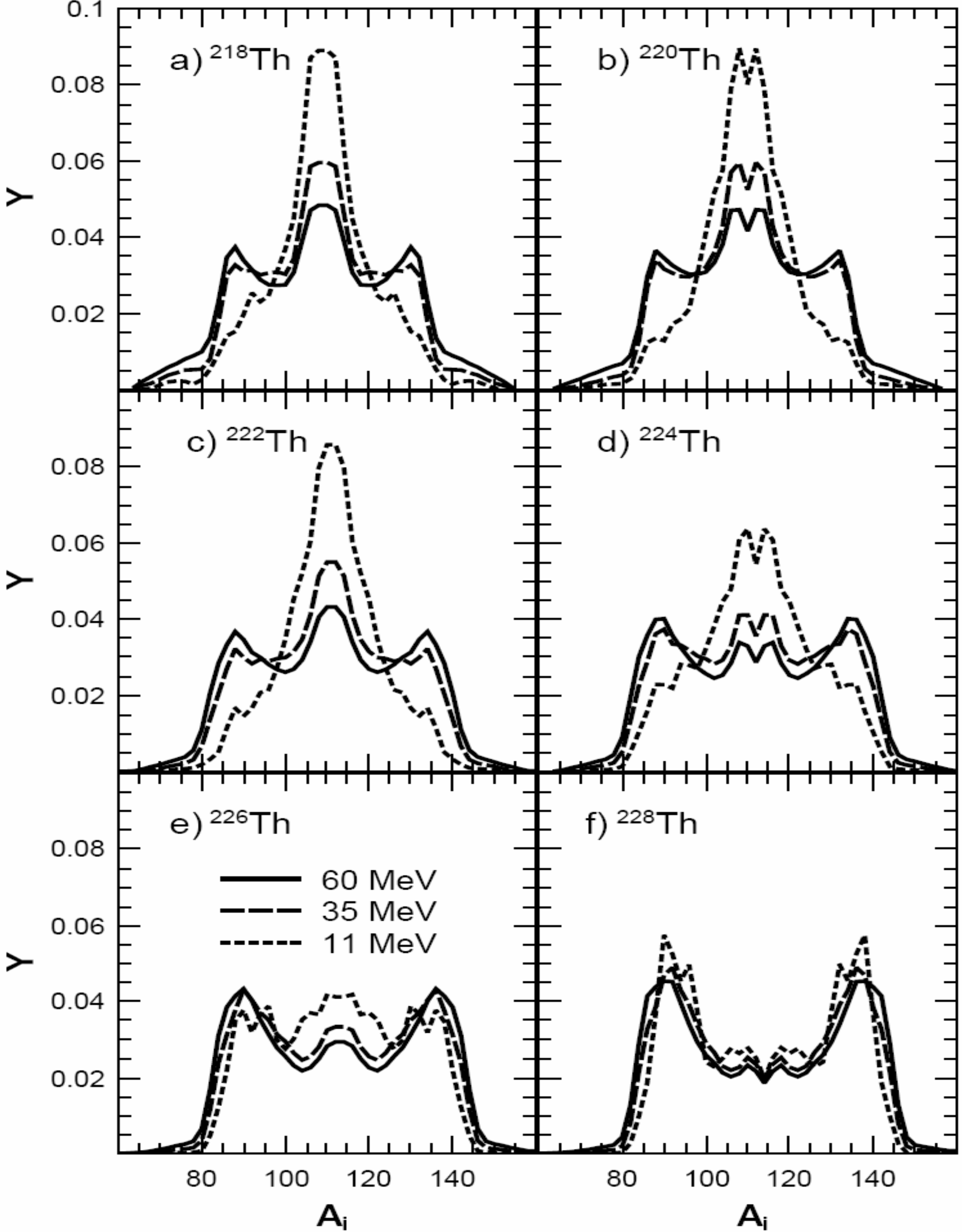
1) Contributions to fission yields from neutron-deficient Th formed after several neutron emission should increase with E*

2) Distribution of 228Th will be asymmetric at low E*, with gradual increase and final domination of symmetric mode towards to higher E*

F.e., in fission of 228Th at E*=50 MeV, distribution should be symmetric based on multi-chance assumption

Opposite behavior will be obtained based on first-chance assumption in scission-point model !





a) 218Th
b) 220Th
c) 222Th
d) 224Th
e) 226Th
f) 228Th
60 MeV
35 MeV
11 MeV
Y
Ai
0.1
0.08
0.06
0.04
0.02
80
100
120
140

Conclusions

Experimental verification of multi-chance fission (MCF) assumption is desirable !

One can study fission of 228Th produced in transfer reaction 16O+226Ra or 40Ca+226Ra or 32S+226Ra as function of excitation energy

If MCF assumption is correct, distribution at high E* should be symmetric !

These experimental data will allow us to distinguish between fission models

Thank You For Your Attention !