Fission studies with microscopic level densities
II: Microscopic description of energy partition in fission

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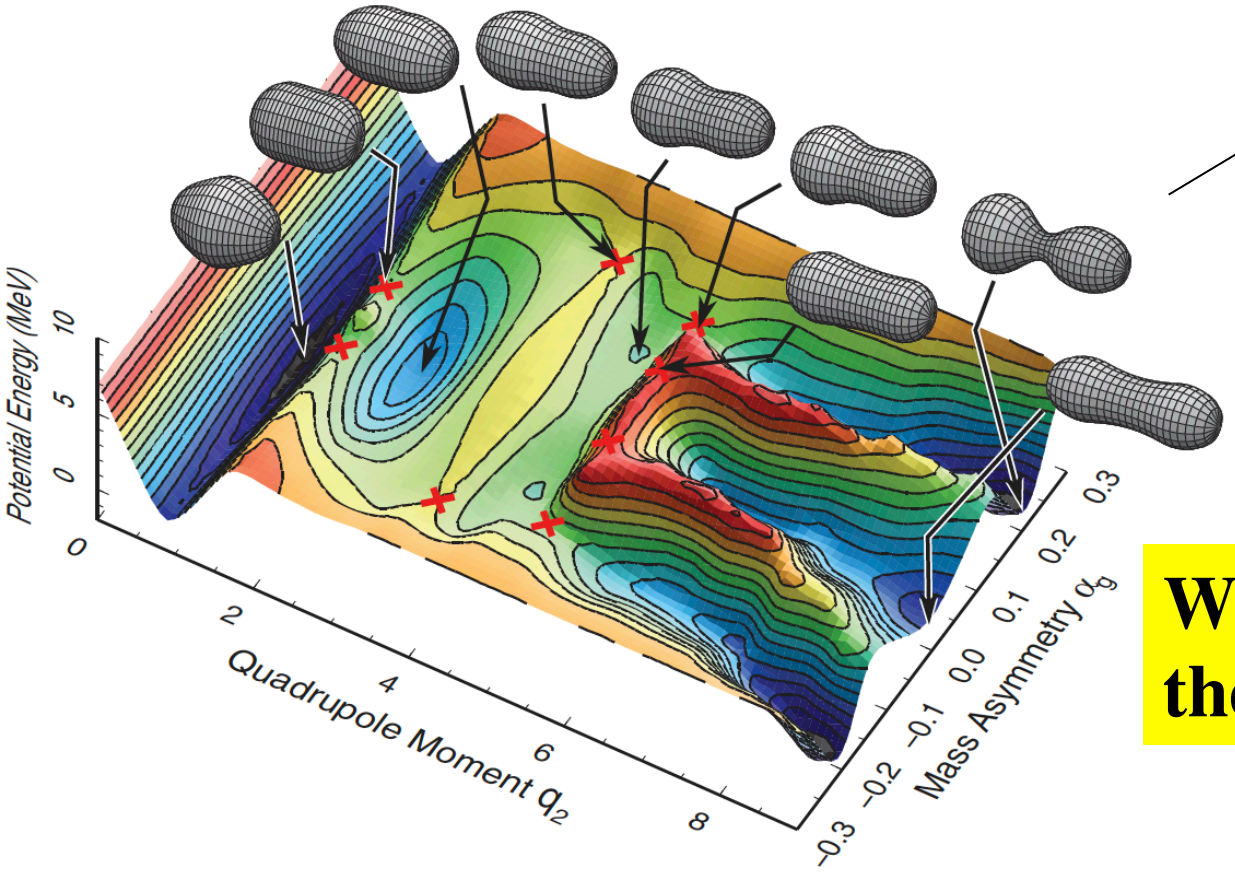
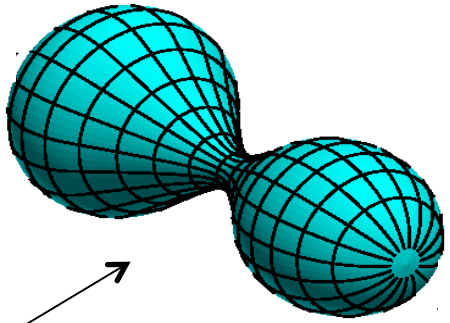
At scission

Register:

Scissioning shape:





Excitation energy: E^*_{tot}

What excitation energy will the two fragments obtain?

Ichikawa et al, PRC86, 024610 (2012)

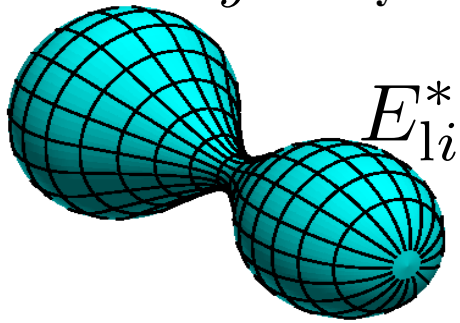
Excitation energy in the two fragments mainly comes from:

1) ***Distortion energy*** **(fragment shape deviates from equilibrium shape)**

2) ***Excitation energy*** **of fissioning nucleus at scission is devided between the fragments**

How is the excitation energy at scission, E^*_{tot}, distributed on the two fragments?

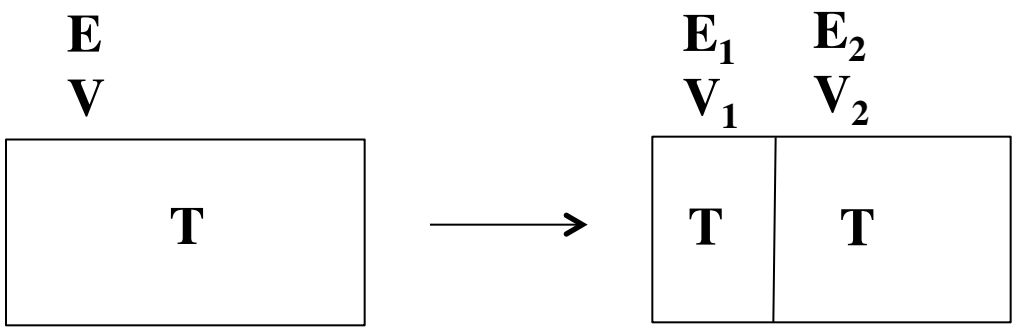
E^*_{heavy} **ε_{heavy}**

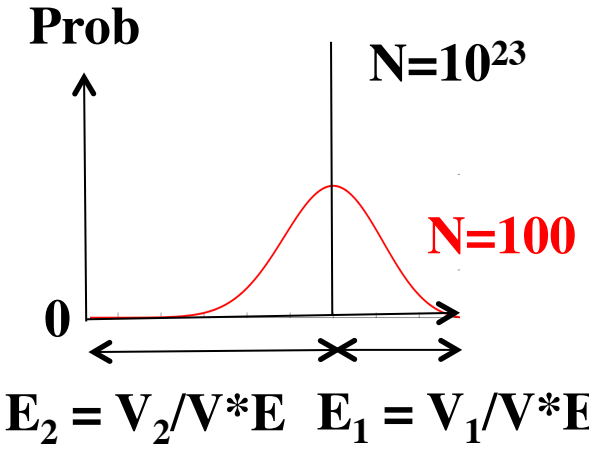


E^*_{light} **ε_{light}**

$$E^*_{tot} = E^*_{heavy} + E^*_{light}$$

Thermodynamics: Division of box containing an ideal gas





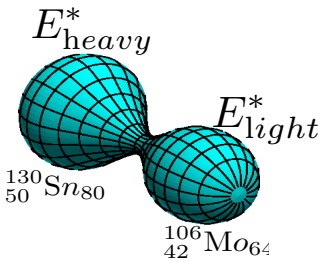
Level densities of the two fragments determine how the energy E_{tot} is distributed:

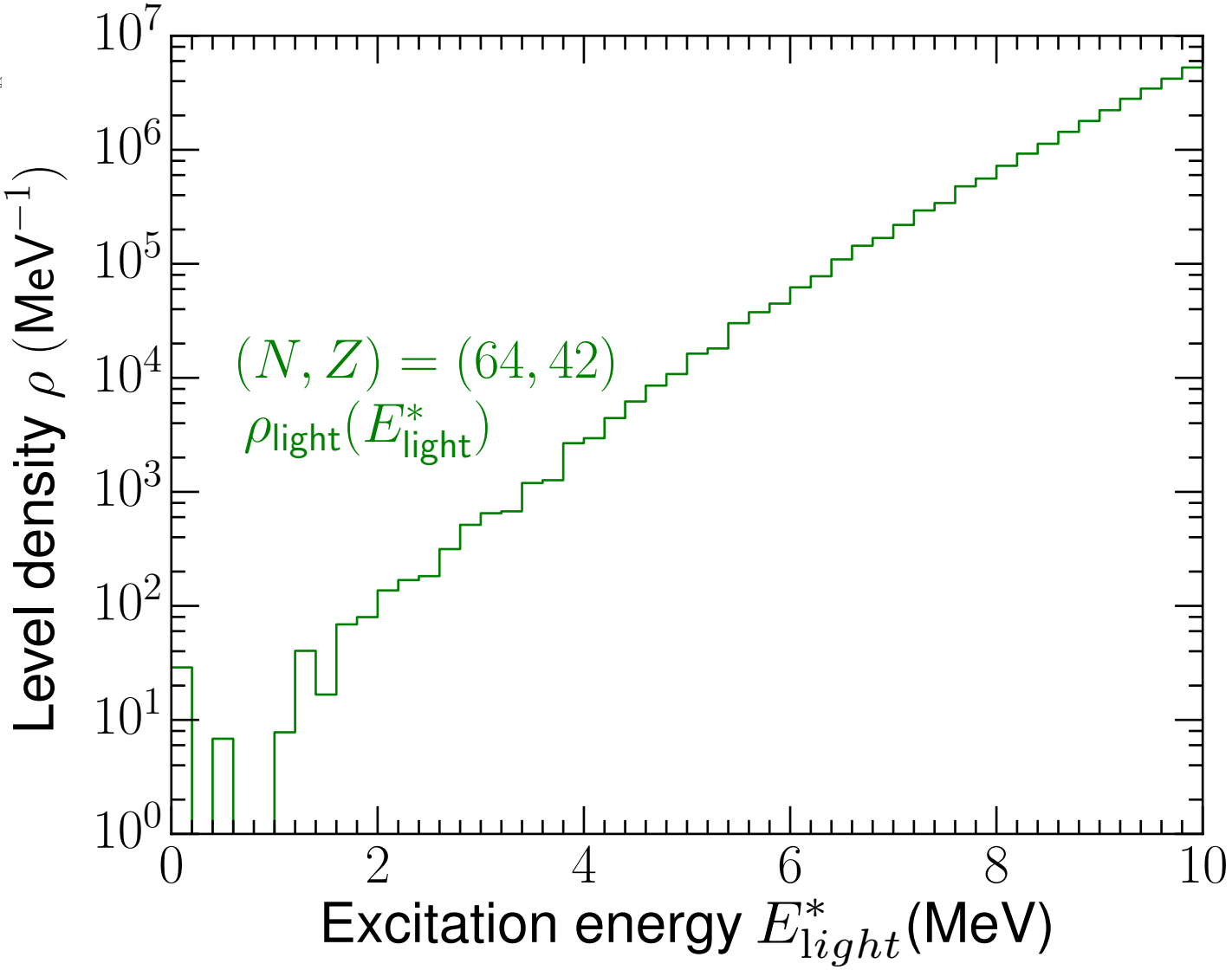
$$P(E^*_{heavy}, E^*_{light}) = \rho_{heavy}(E^*_{heavy}) * \rho_{light}(E^*_{light})$$

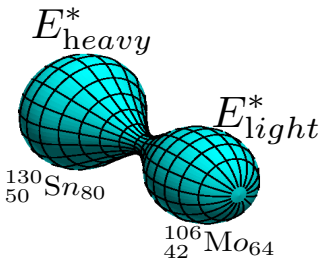
$$E^*_{tot} = E^*_{heavy} + E^*_{light}$$

"energy-partition distribution function"

assuming all states equal probable.


E^*_{heavy}
E^*_{light}
$^{130}_{50}Sn_{80}$
$^{106}_{42}Mo_{64}$


Level density ρ (MeV^{-1})
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
$(N, Z) = (64, 42)$
$\rho_{\text{light}}(E^*_{\text{light}})$
0
2
4
6
8
10
Excitation energy E^*_{light}(MeV)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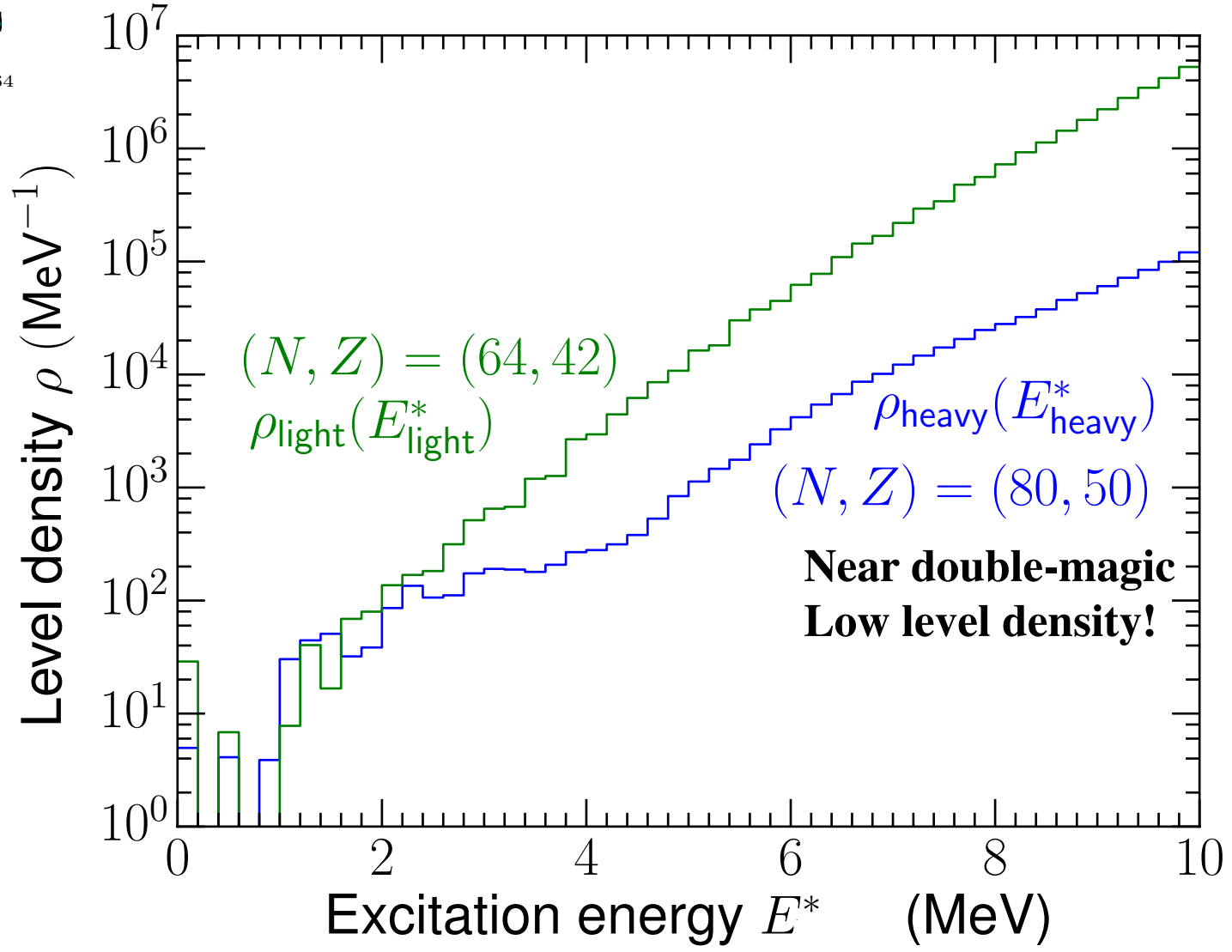
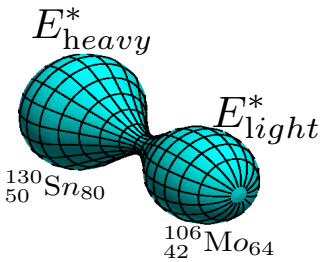
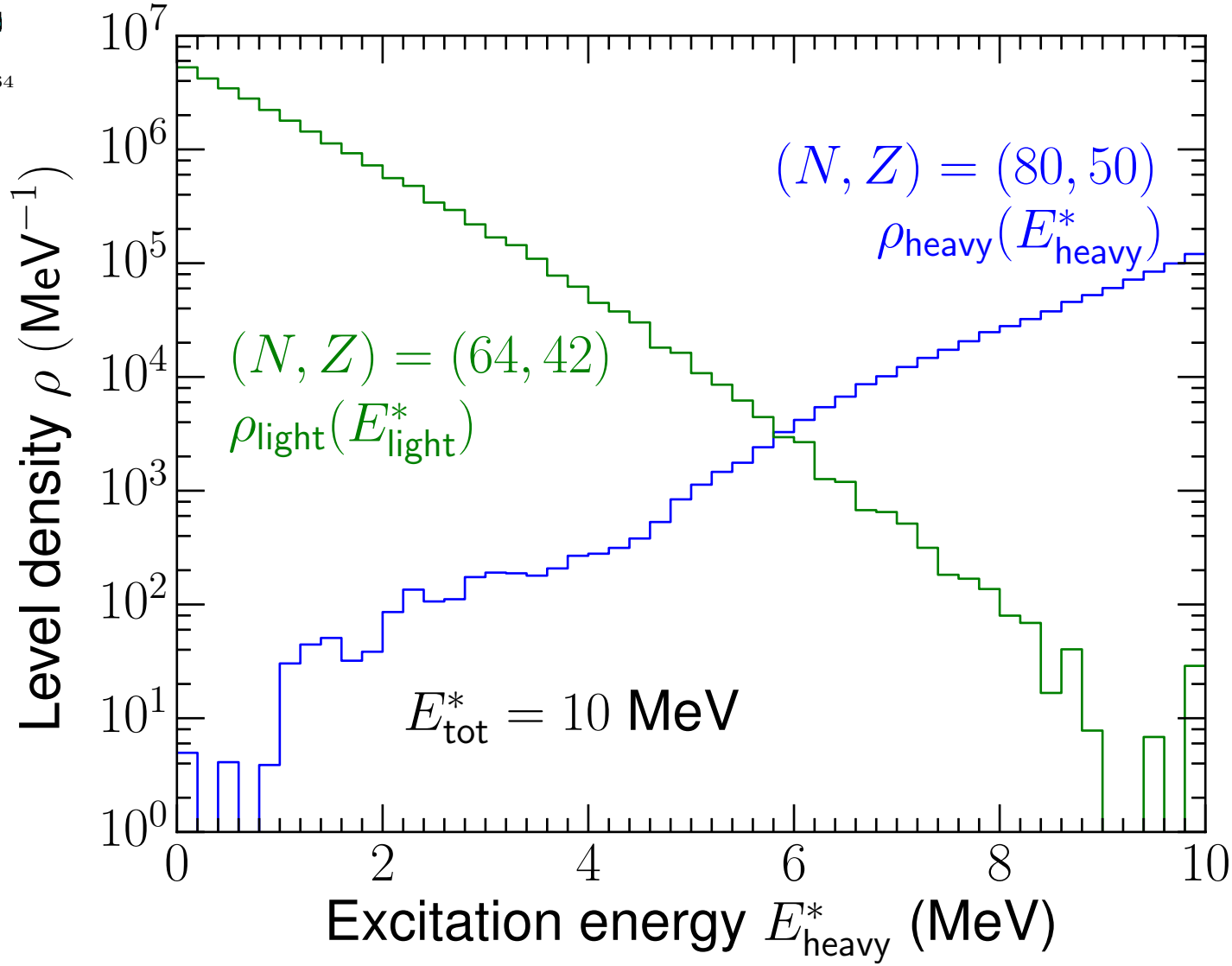
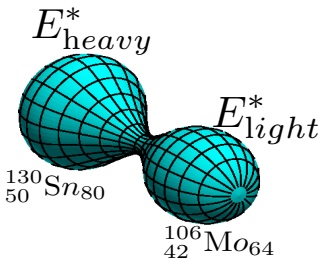

Level density ρ (MeV^{-1})
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
0
2
4
6
8
10
Excitation energy E^* (MeV)
$(N, Z) = (64, 42)$
$\rho_{\text{light}}(E^*_{\text{light}})$
$\rho_{\text{heavy}}(E^*_{\text{heavy}})$
$(N, Z) = (80, 50)$
Near double-magic
Low level density!



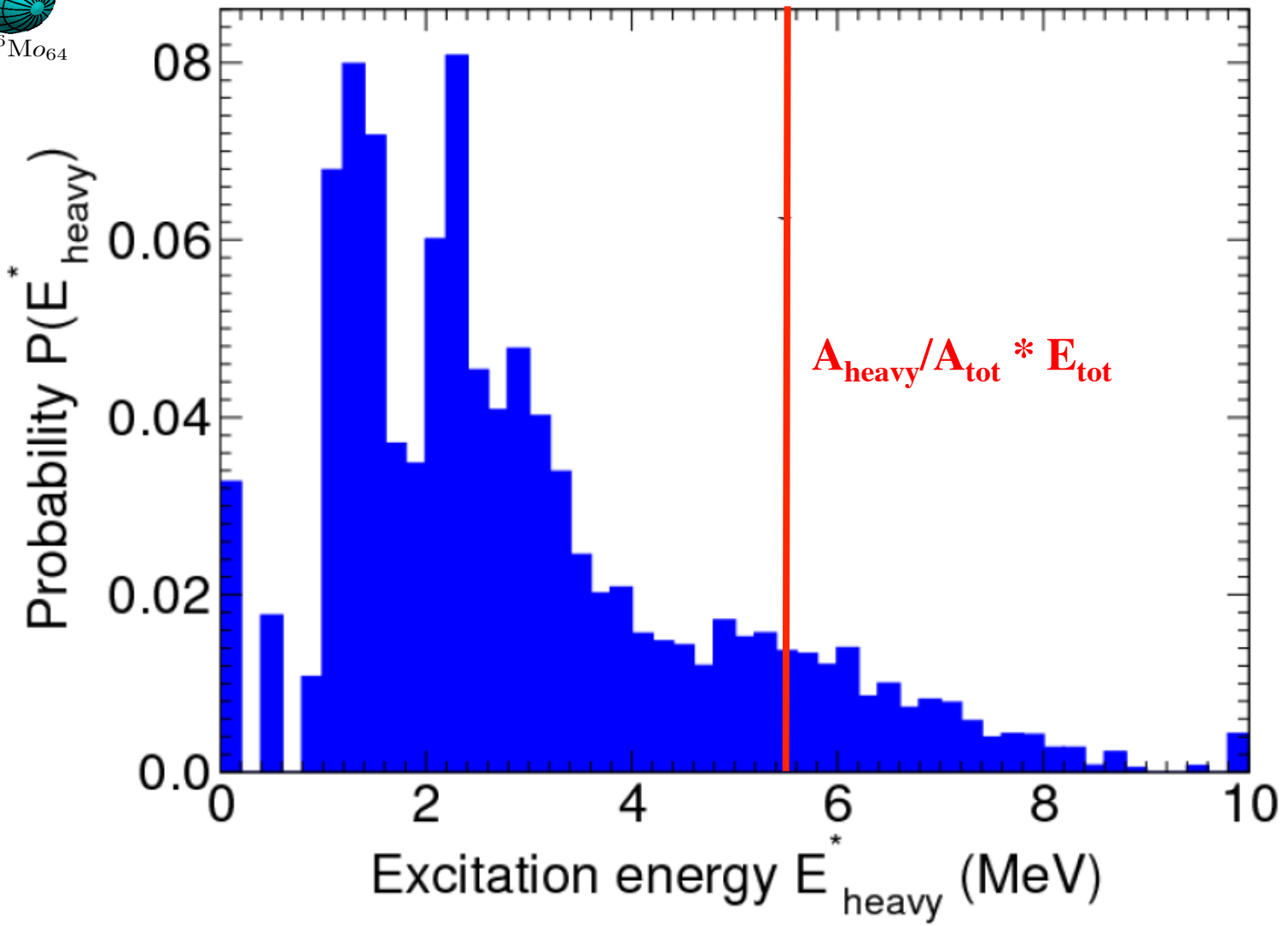


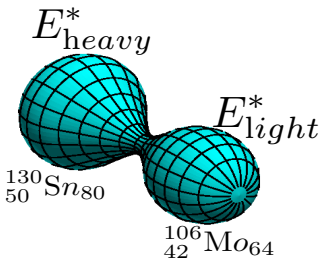
$$E^*_{\text{light}} = E^*_{\text{tot}} - E^*_{\text{heavy}}$$

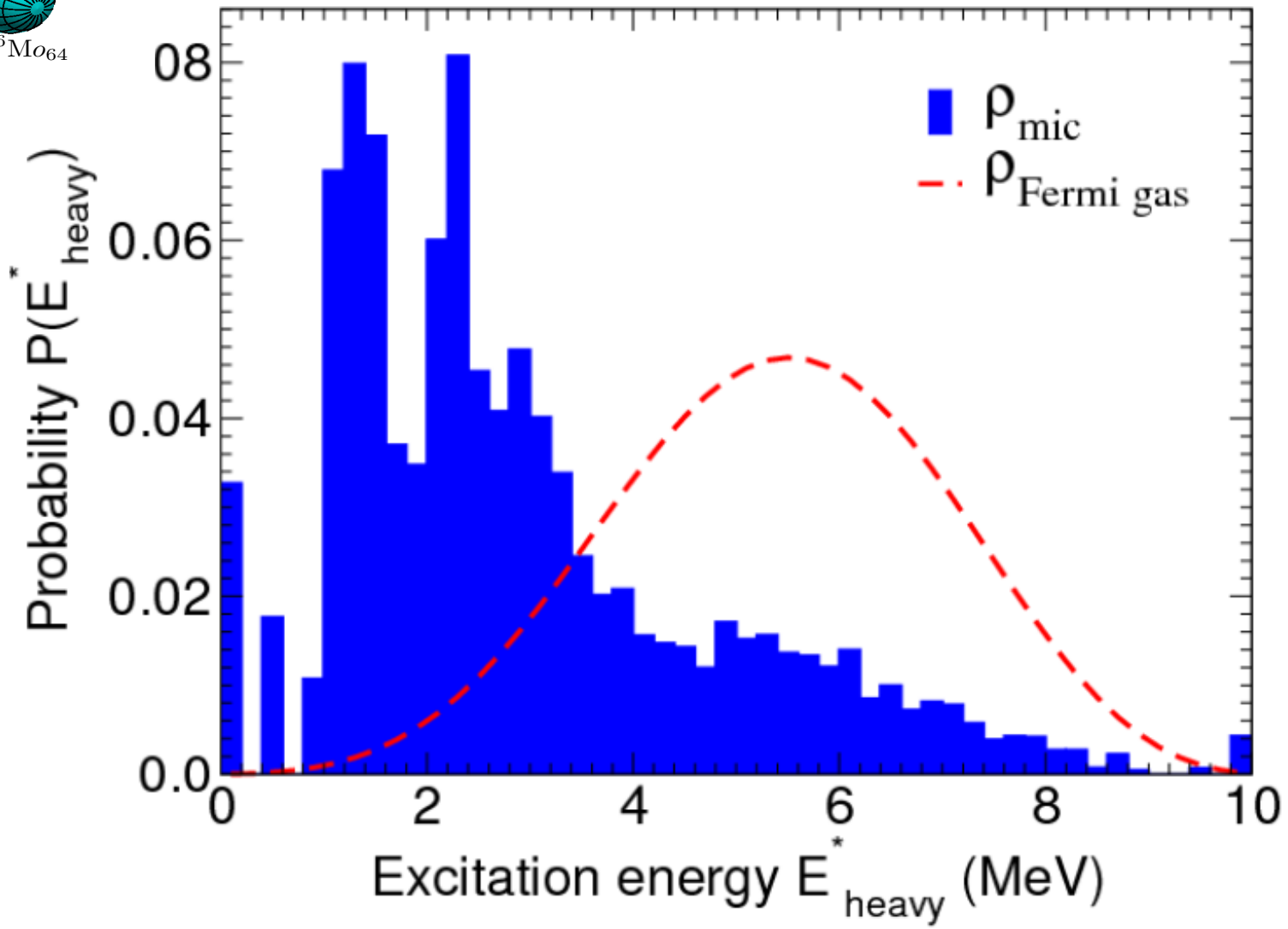


Microscopic energy-partition distribution function

$$P(E^*_{heavy}) = \rho_{heavy}(E^*_{heavy}) * \rho_{light}(E^*_{light})$$



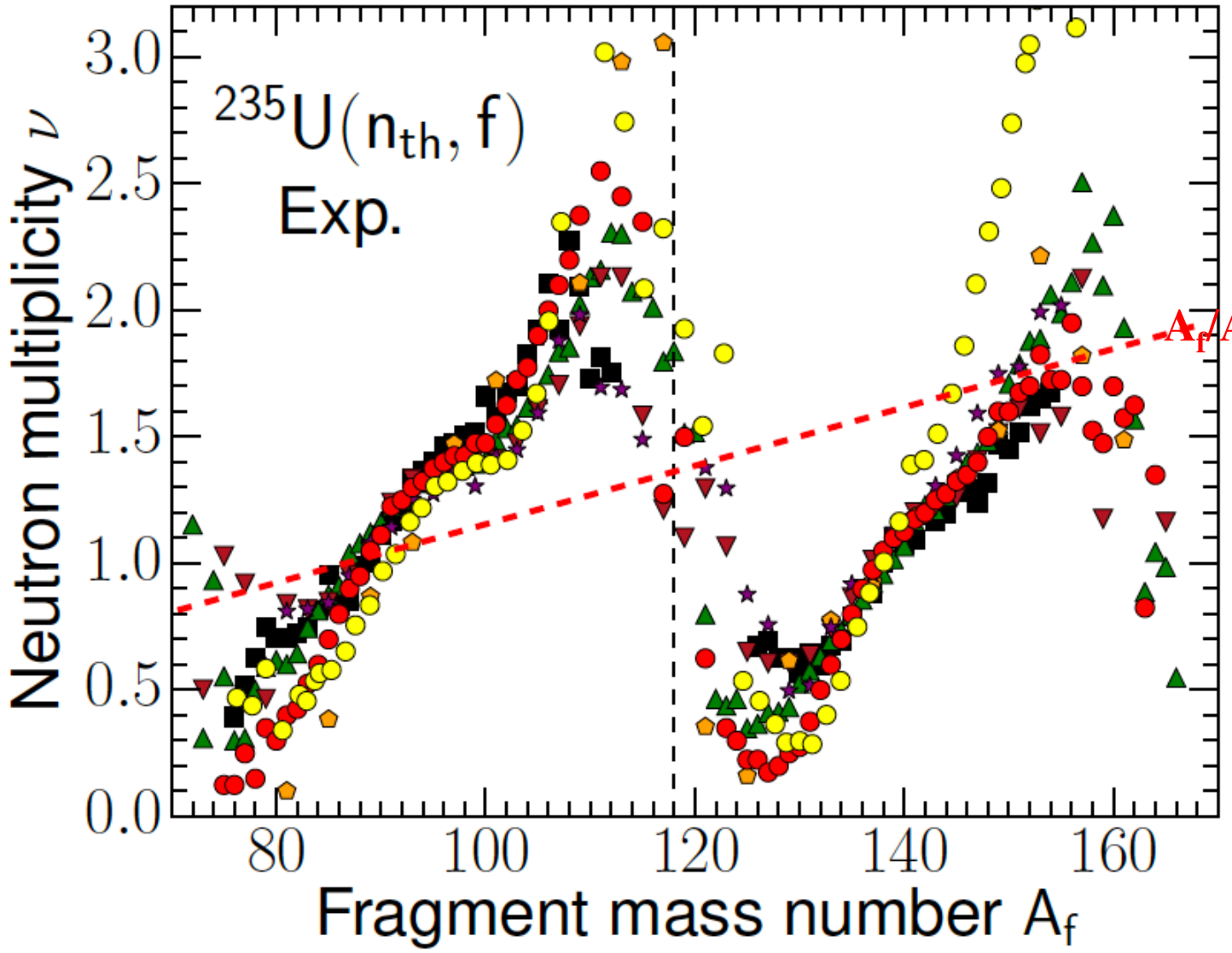




around 2 MeV to heavy fragment
around 8 Mev to light fragment

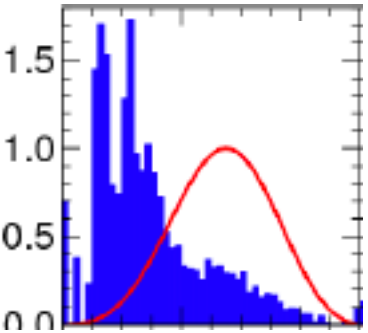
Measured consequences?

Number of emitted neutrons vs fragment mass



Data:

- K. Nishio et al, Nucl Phys A632 (1998)
- V Apalin et al Nucl Phys 553 (1965)
- AS Vorobyev et al EPJ conf 8 (2010)
- OI Batenkov et al AIP conf 769 (2005)
- JW Boldeman et al Aust J Phys 24 (1971)
- EE Maslin et al Phys Rev 164 (1967)
- R Müller et al PRC 29 (1984)



E^*_{heavy}

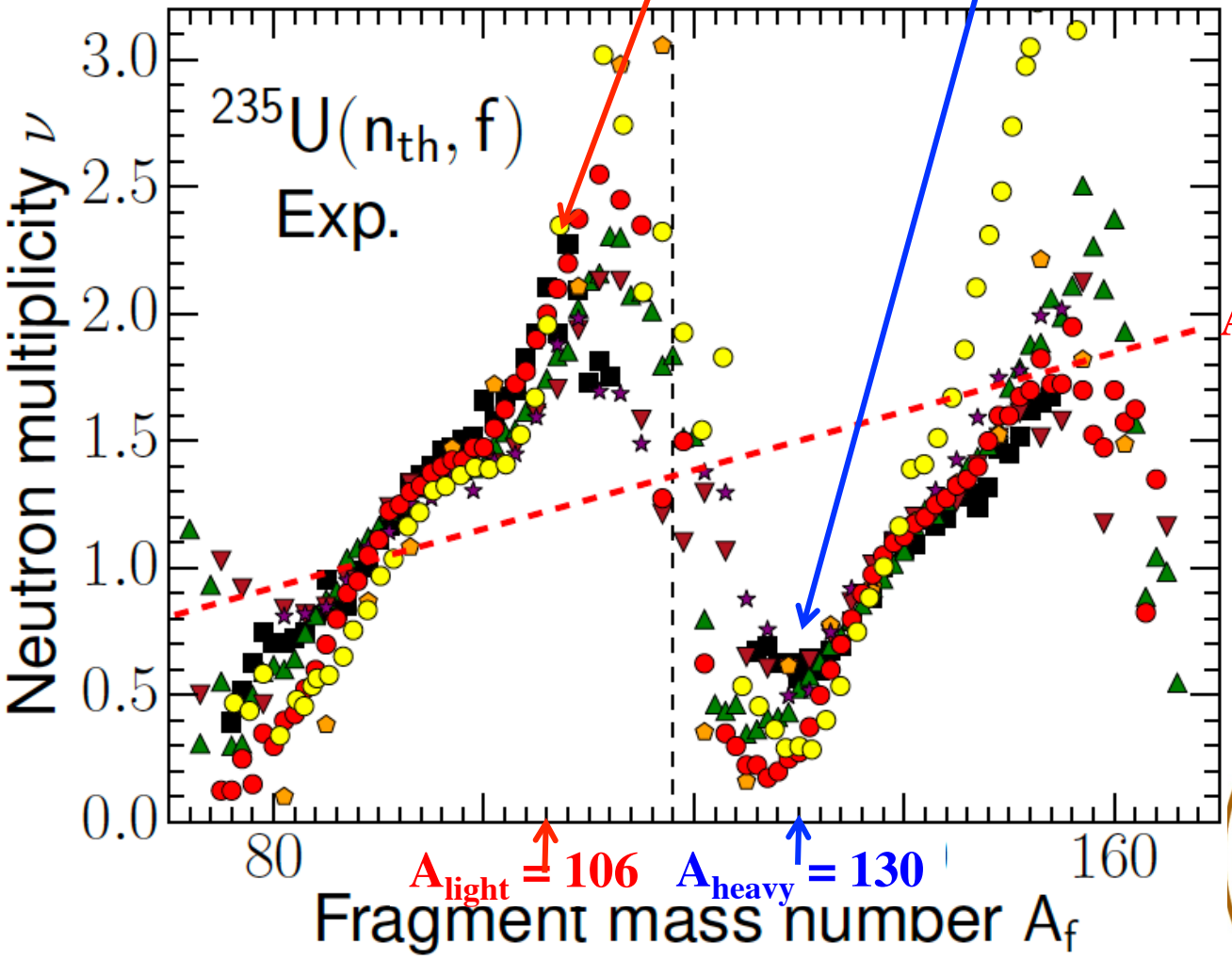
$A_{light} = 106$

$A_{heavy} = 130$

Number of emitted neutrons

High energy to light fragment → *many neutrons* emitted from light

Low energy to heavy fragment → *few neutrons* emitted from heavy



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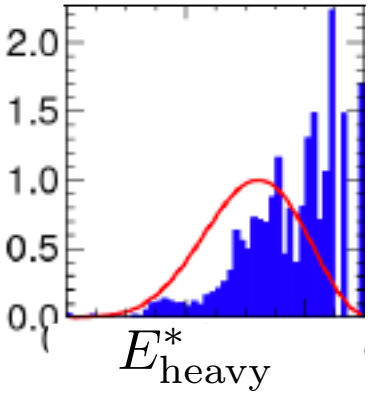
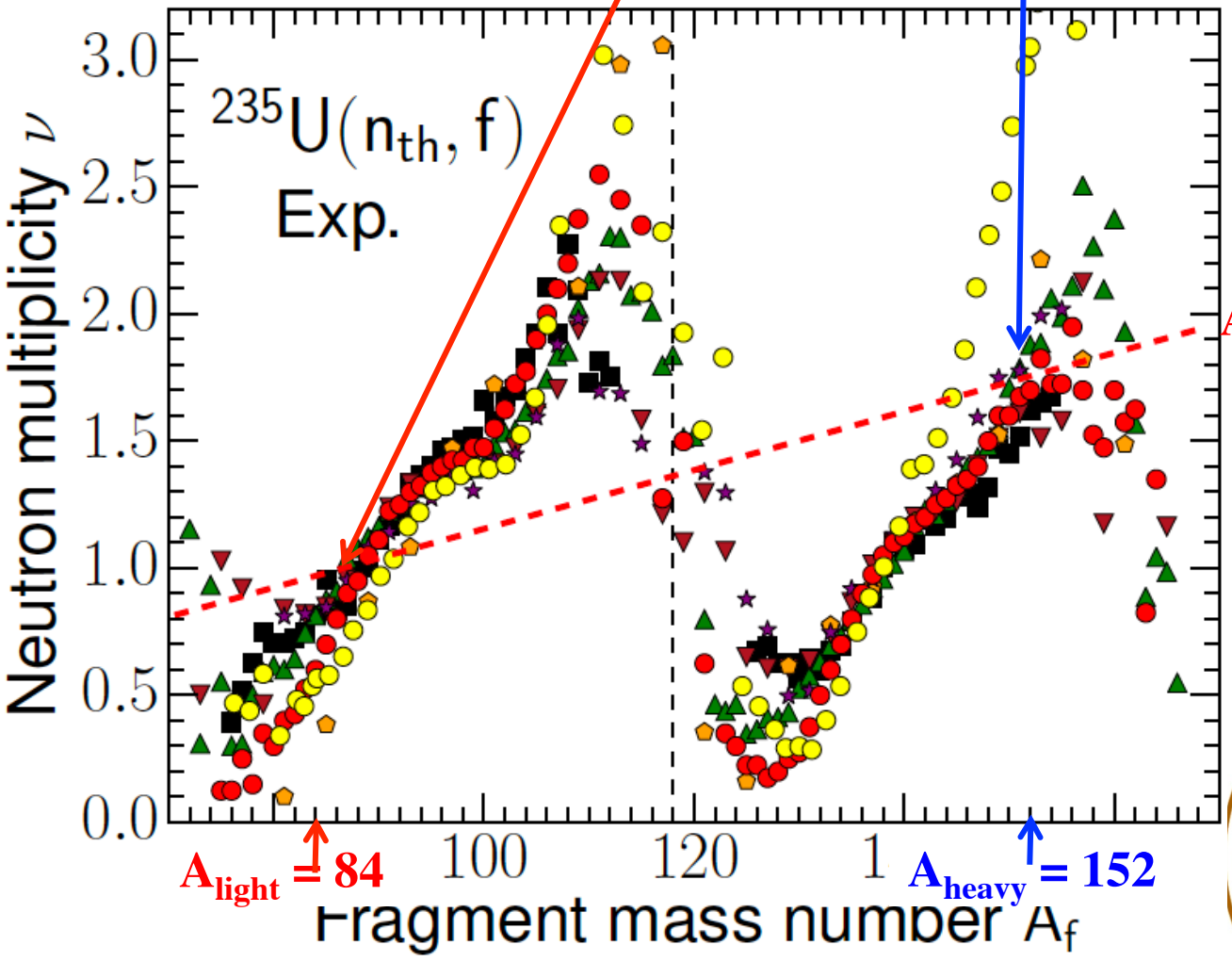


A_{light} = 84

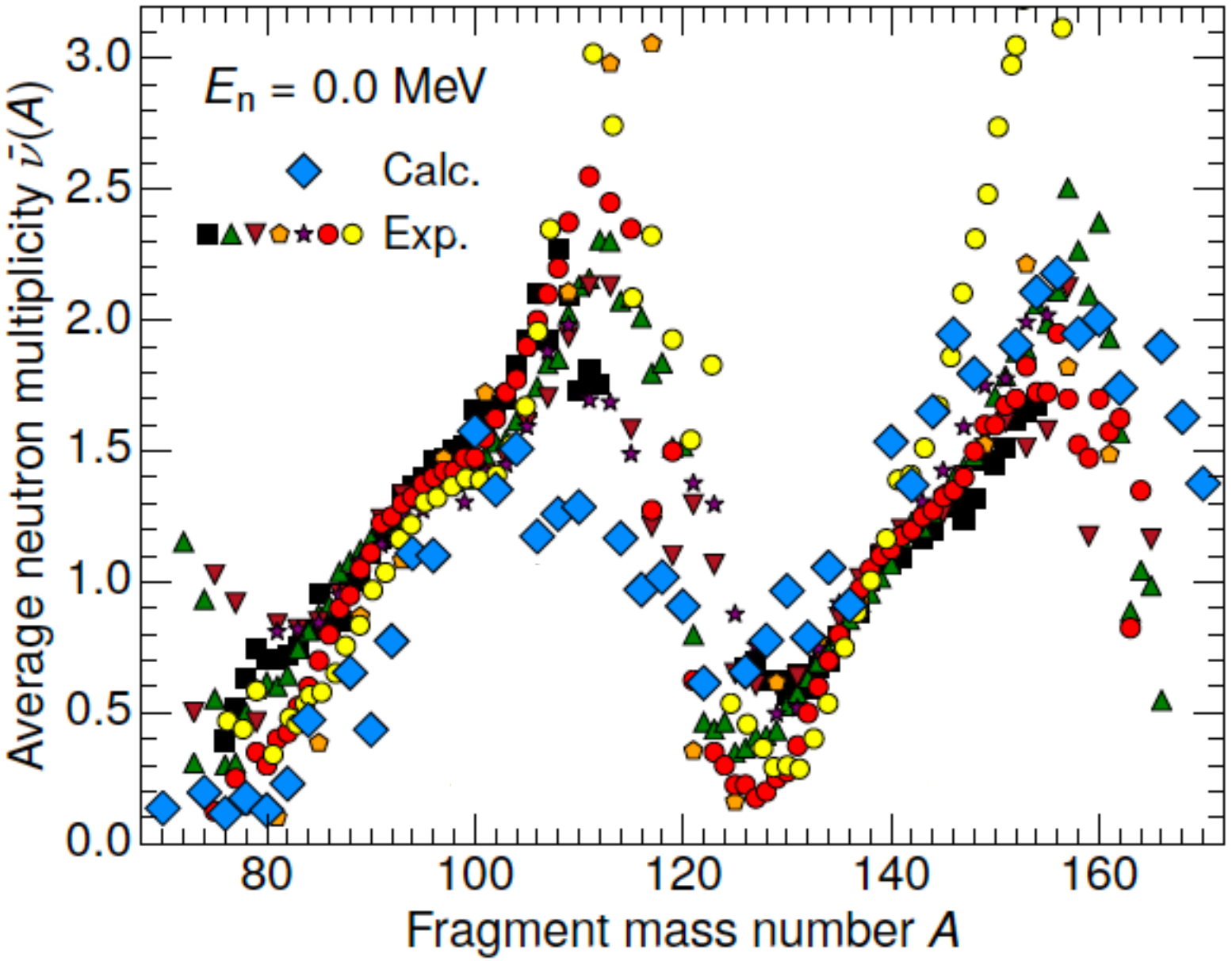
A_{heavy} = 152

Low energy **to light fragment**
High energy **to heavy fragment**

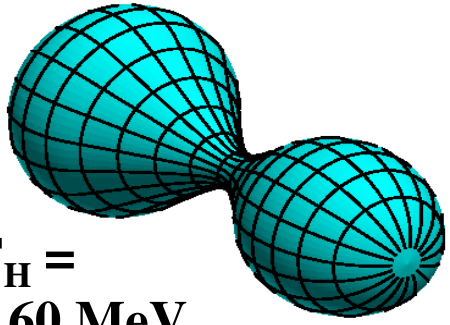
few neutrons **emitted from light**
many neutrons **emitted from heavy**



Calculated and measured neutron multiplicity



Energy partition in constant temperature approximation

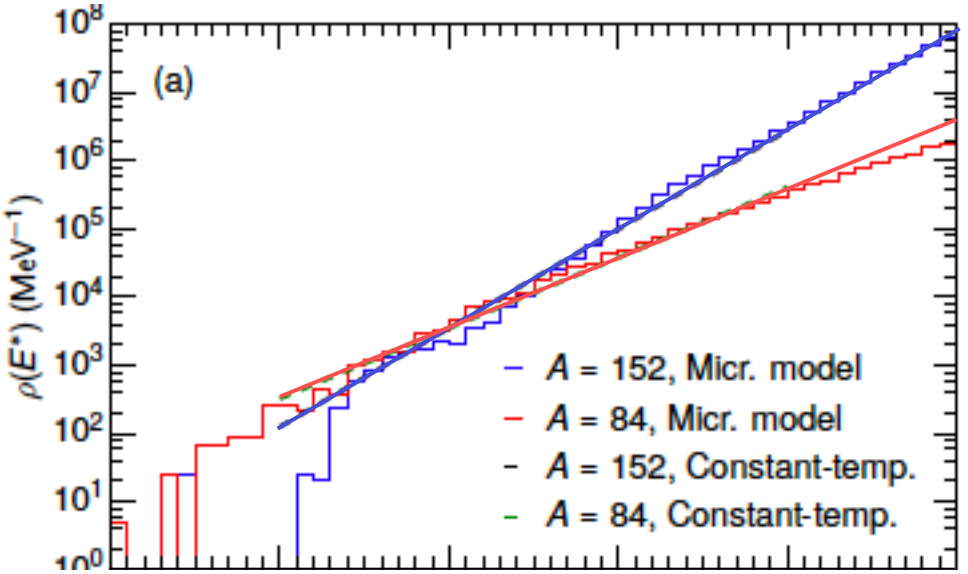


T_H = 0.60 MeV

T_L = 0.84 MeV

Notice:
Non-equilibrium shapes - no data for temperatures!

$$P(E_H; E_{tot}) \sim exp(E_H/T_H - (E_{tot} - E_H)/T_L)$$



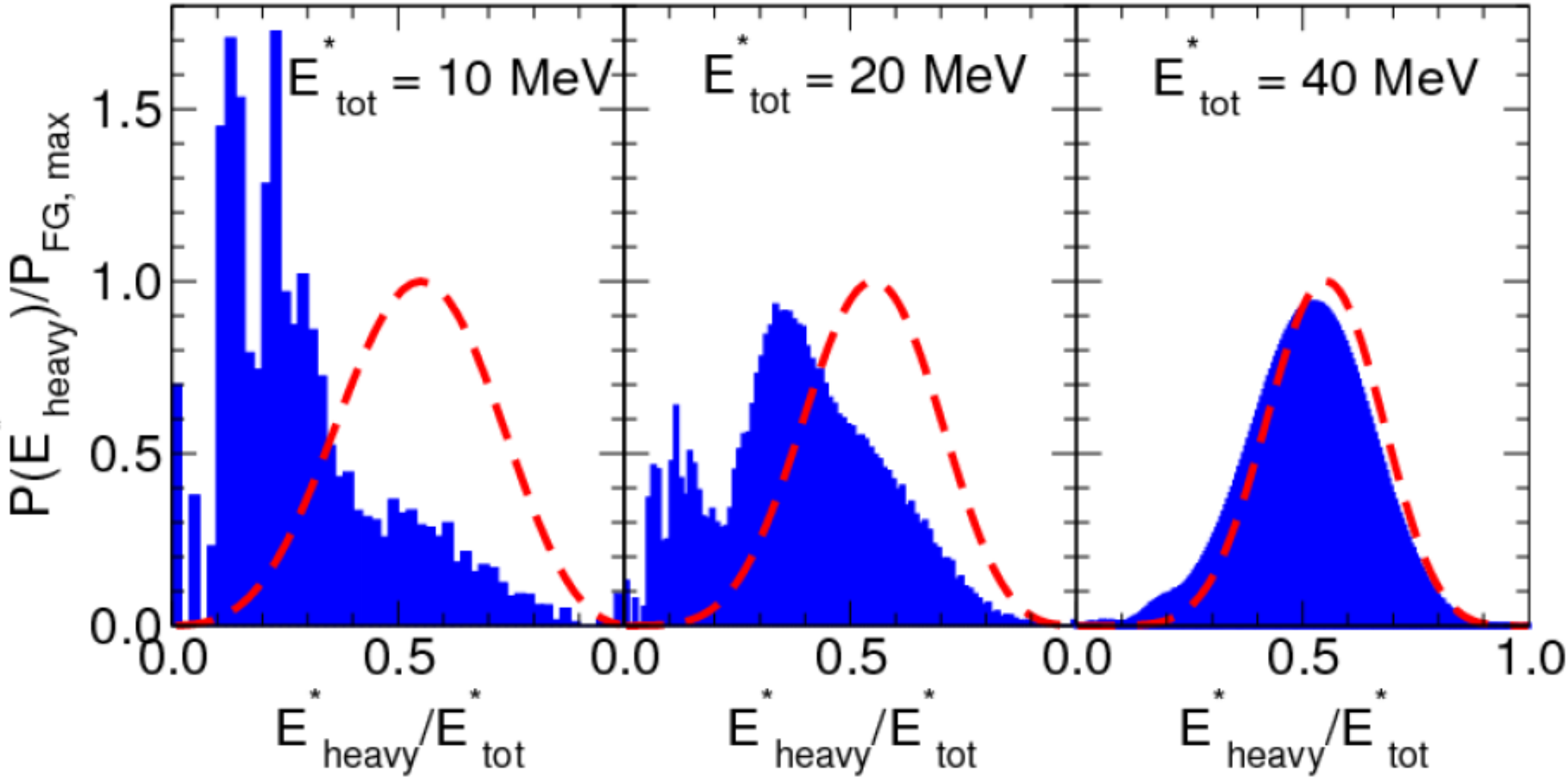
$$\rho(E) \sim exp(E/T)$$

Energy partition distr. approximately described only in limited energy interval!

Excitation energy of heavy fragment, E_H (MeV)

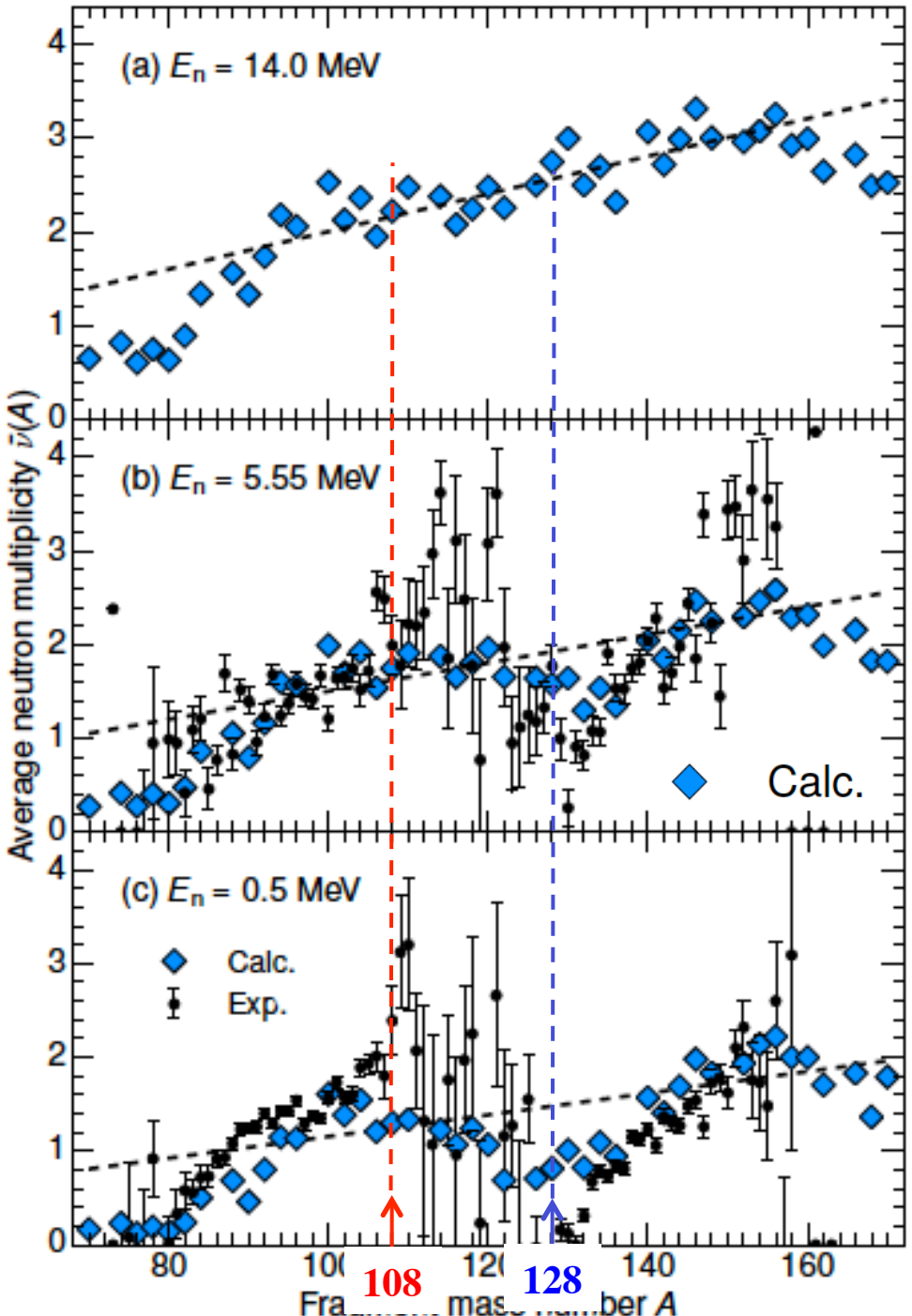
Energy partition distribution at higher energies

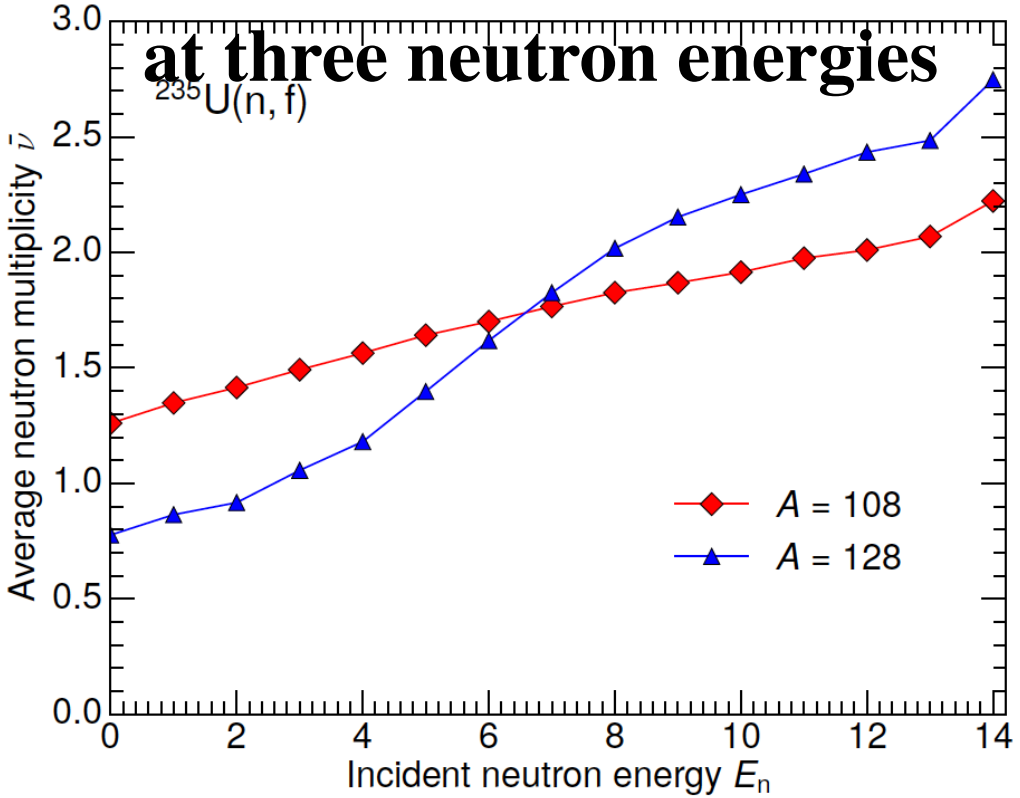
$^{235}U(n, f)$ A_{Heavy}/A_{Light} = 130/106



transition to Fermi-gas behaviour

$^{235}U(n,f)$ at three neutron energies





A≈128 changes much faster with neutron energy than A≈108 due to shell structure

Data:
R. Müller et al PRC 29 (1984) 885
T. Ethvignot et al PRL 94 (2005)

Summary

- **Event-by-event fission dynamics described by Metropolis random walk.**
- **Microscopic level densities and potential energy are based on the same mic-mac model.**
- **Microscopic description of energy partition.**
- **Microscopic level densities appear in:**
  - **1) Metropolis walk**
  - **2) calculation of energy partition**
  - **3) neutron evaporation**

Good description of:
- Structure in fission fragment neutron multiplicity.
- Fragment multiplicity versus excitation energy.
- Total neutron multiplicity versus neutron energy.

All (unknow/known) fission cases can be studied.
All kind of correlations can be calculated.