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北京航空航天大學
BEIHANG UNIVERSITY

Study of fission dynamics and program in CSNS

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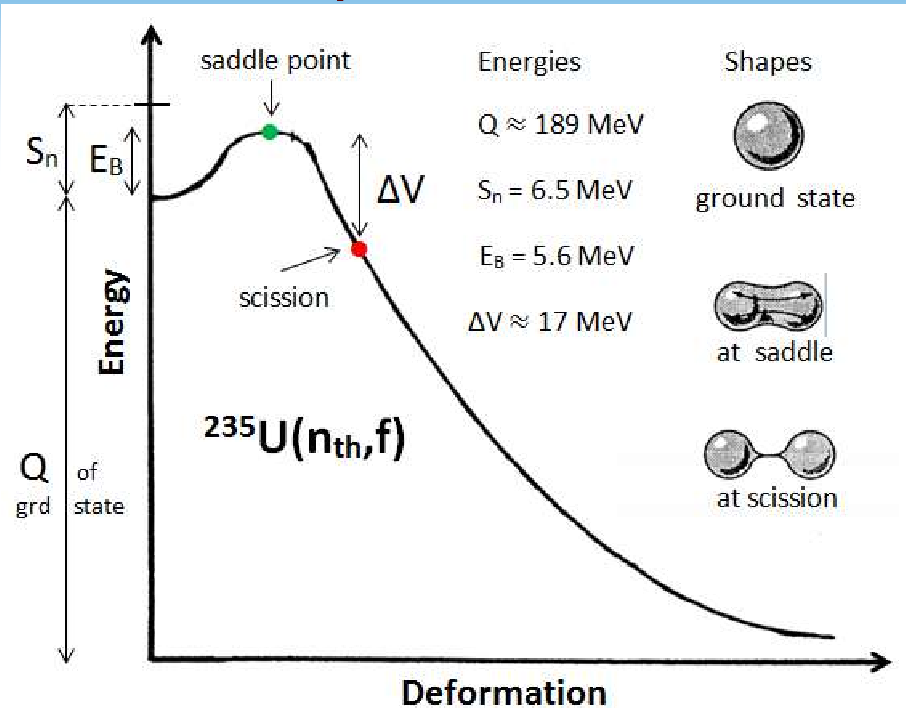
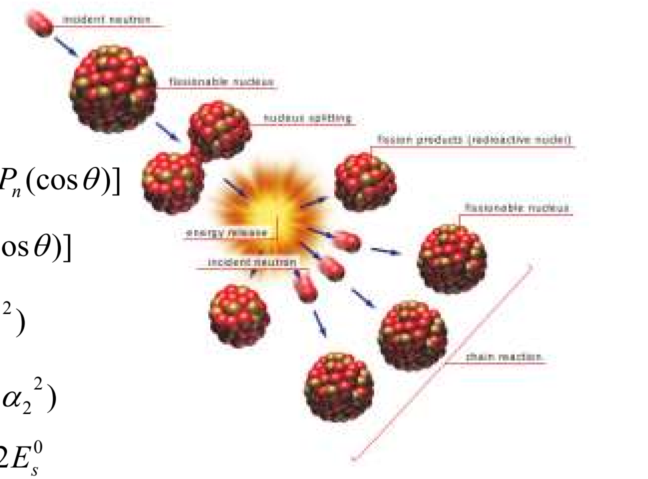
   University of California at Davis, Davis, USA
3. Jørgen Randrup *Lawrence Berkeley National Laboratory, USA*

Dynamics from sadle to scission in fission reaction





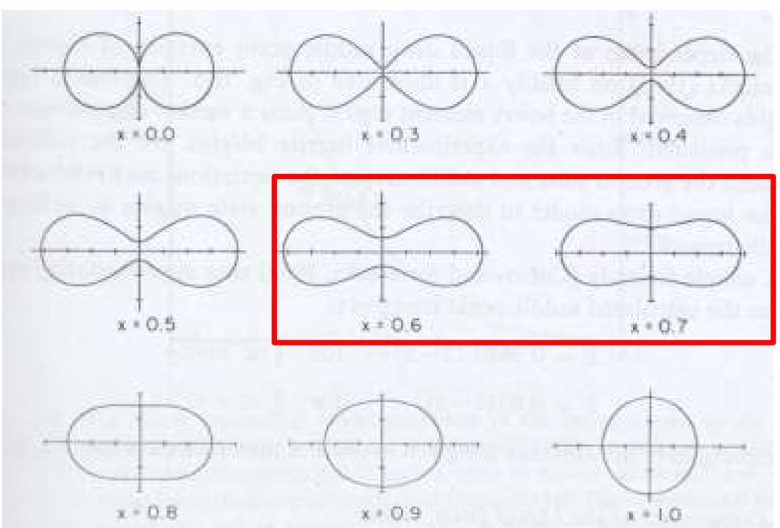
$$R(\theta) = (R_0/\lambda)[1 + \sum_{n=1} \alpha_n P_n(\cos\theta)]$$

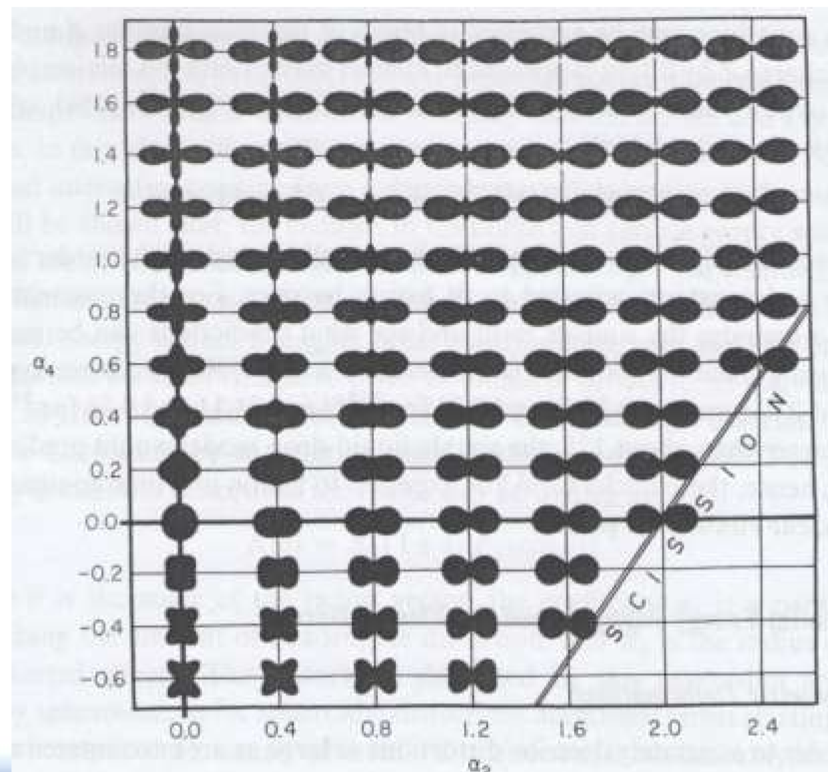
$$R(\theta) = R_0[1 + \alpha_2 P_2(\cos\theta)]$$

$$E_s = E_s^0(1 + \frac{2}{5}\alpha_2{}^2)$$

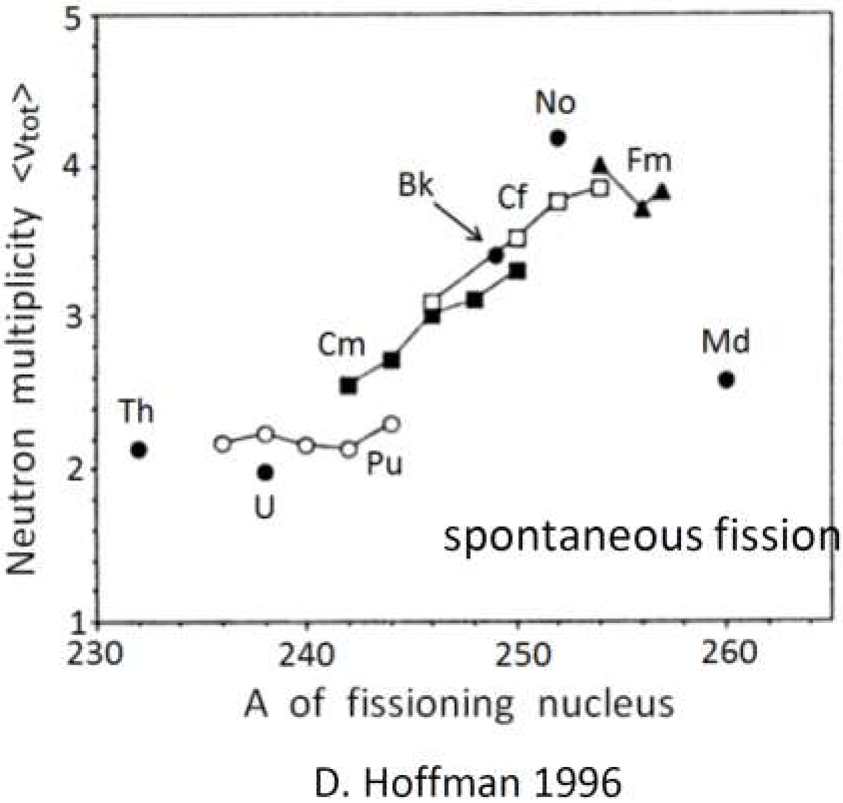
$$E_c = E_c^0(1 - \frac{1}{5}\alpha_2{}^2)$$

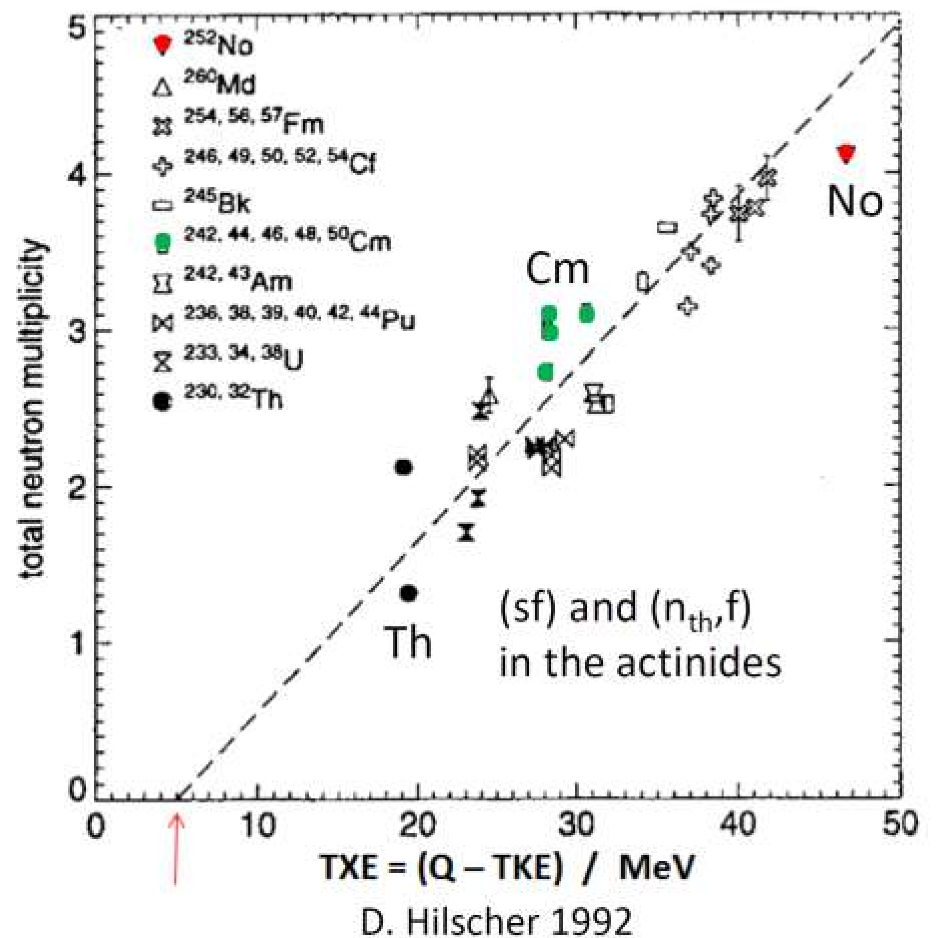
$$x = E_c^0 / 2E_s^0$$

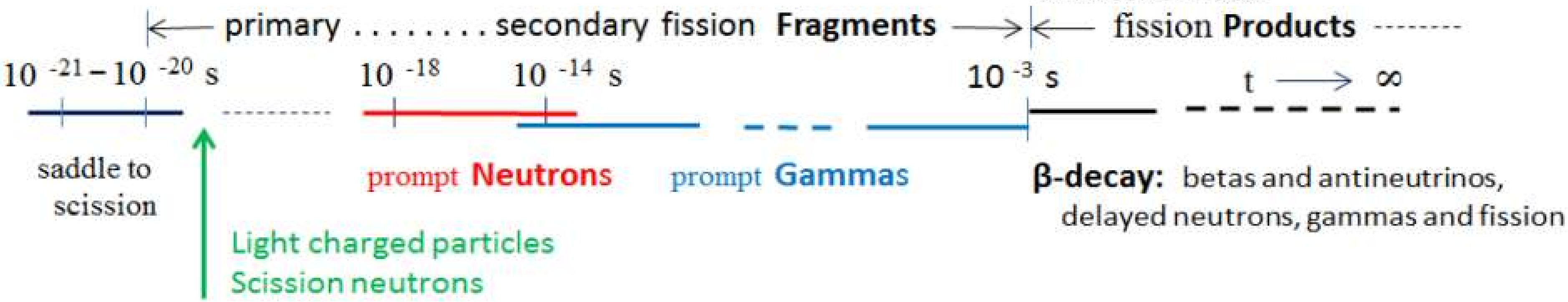




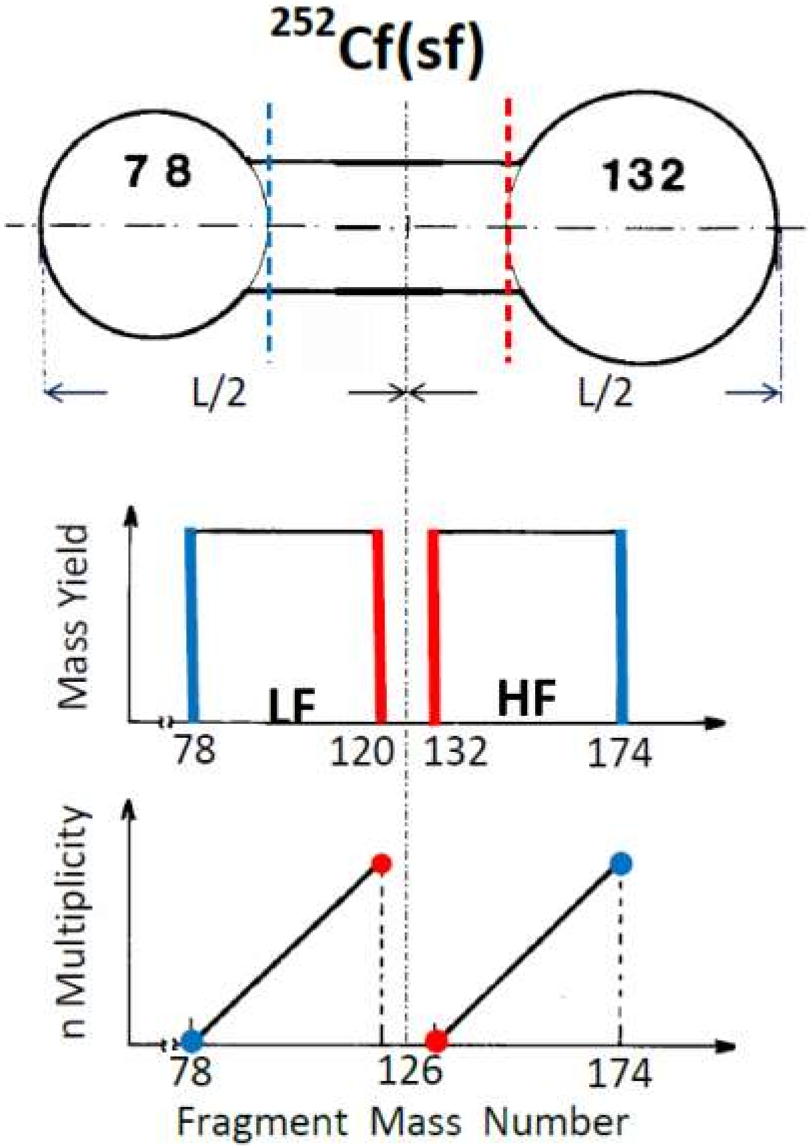
Neutron and Gamma Multiplicity



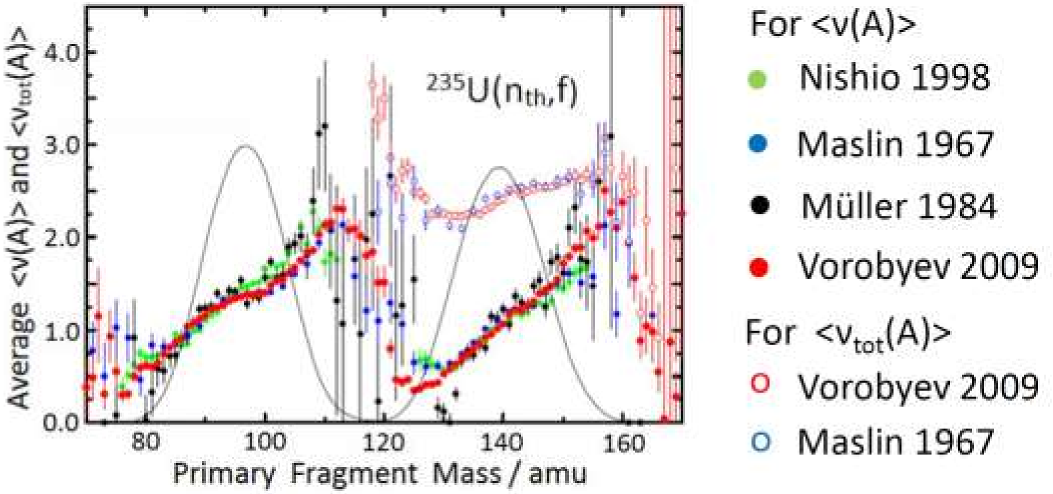




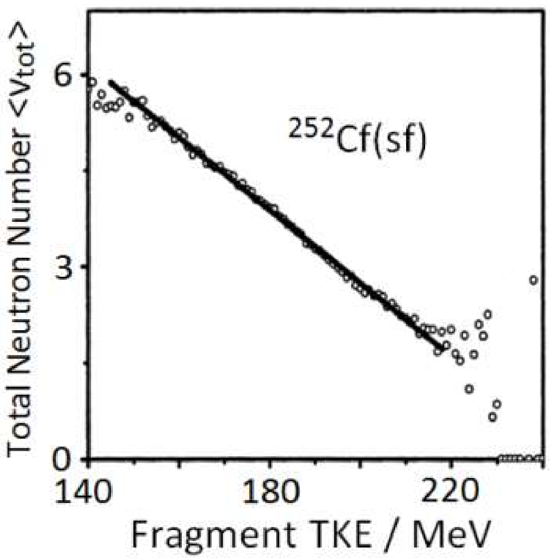
Neutron and Gamma Multiplicity



Brosa 1991



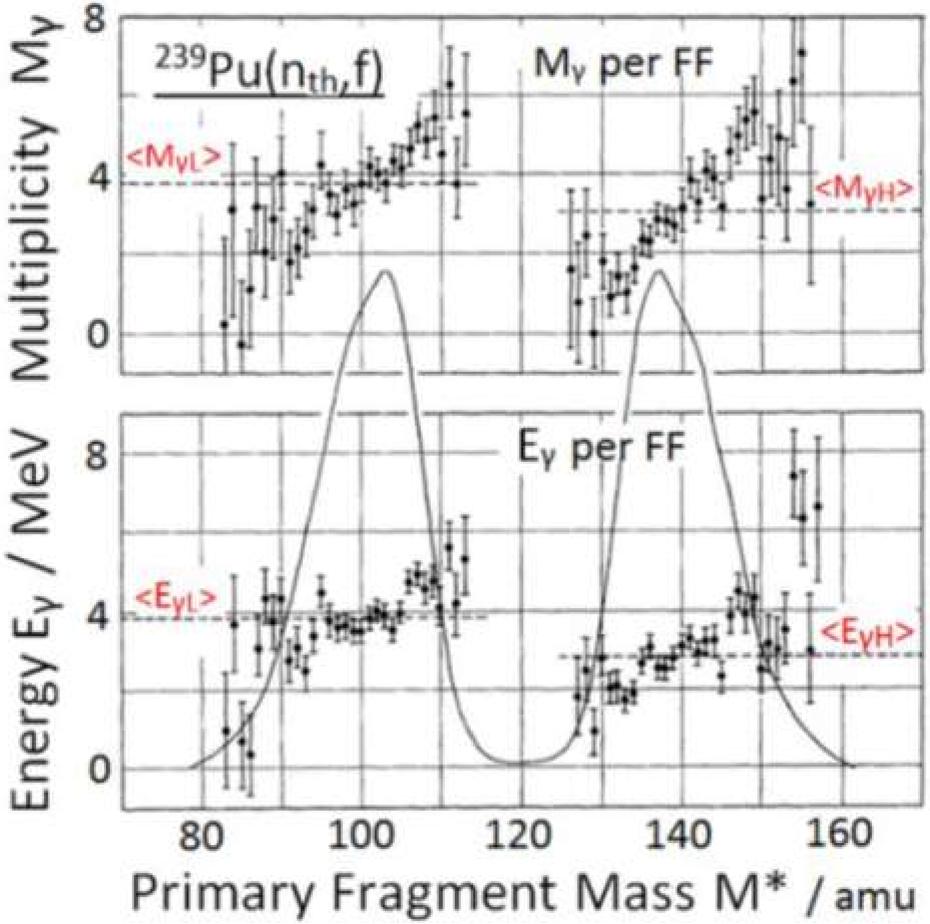
A.S. Vorobyev 2009

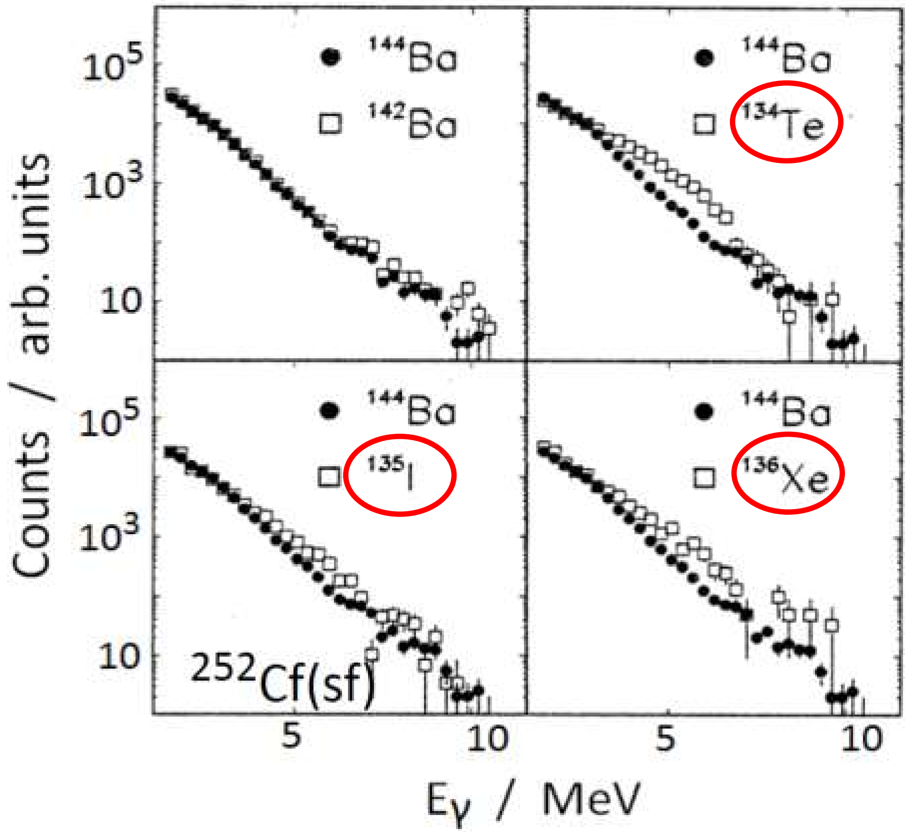


Zeynalov 2009

How about gamma multiplicity?

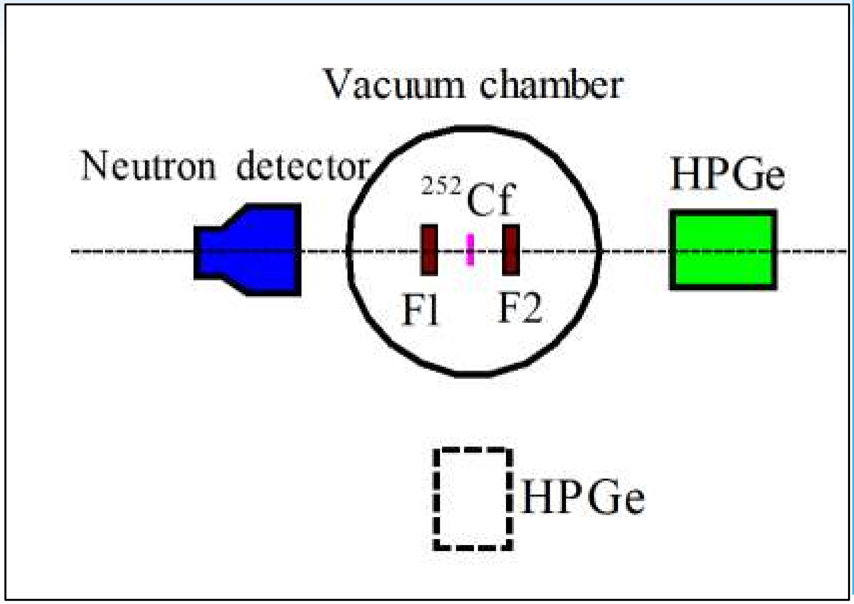
Gamma spectra and Multiplicity



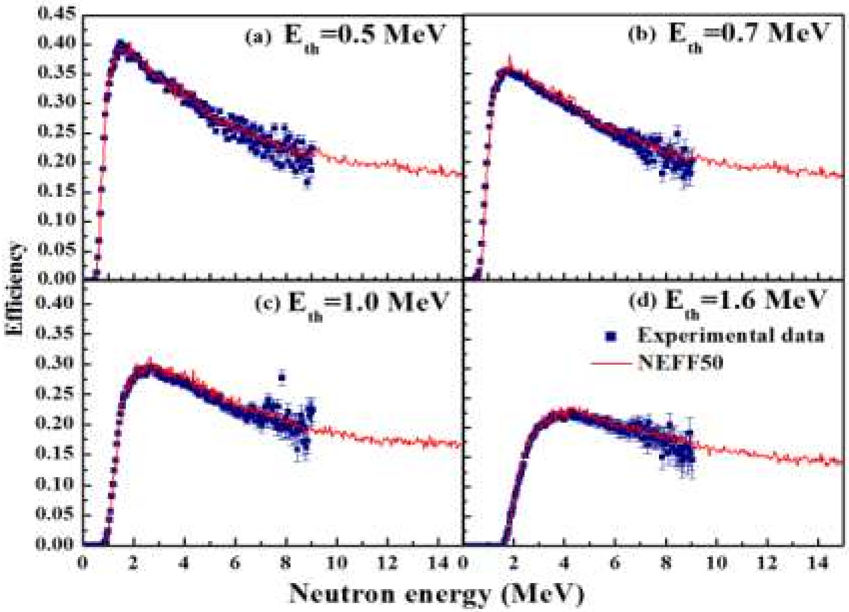


Biswas 1999

Correlation of neutron multiplicity and γ multiplicity

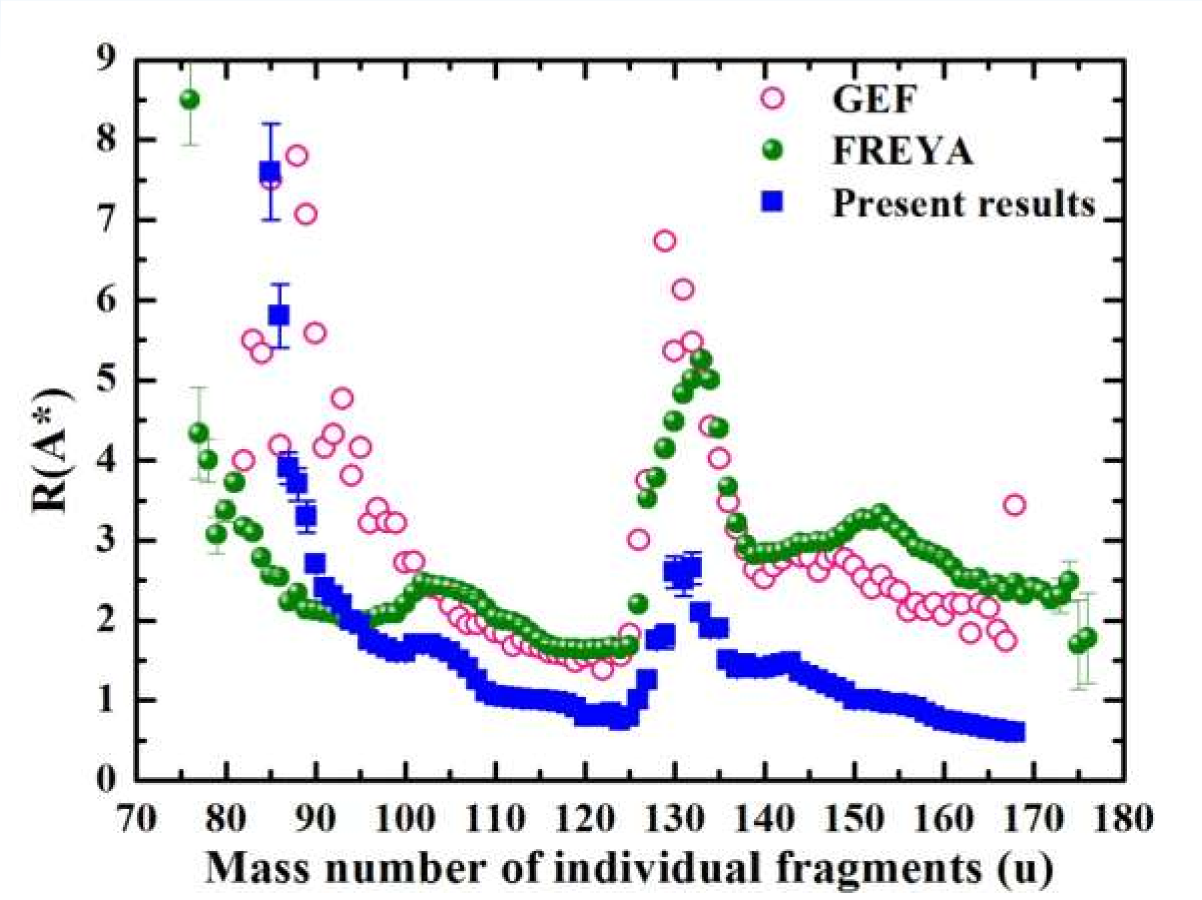


- ^{252}Cf spontaneous fission source on C foil
- with ~3*10^3 fissions/s rate
- 2E method was used to determine F mass
- Si detectors measure the fission fragments
- 0° Neurton detector: liquid scintillator
- 0° HPGe involve γ-rays with Doppler effect
- 90° HPGe without Doppler effect



- Neutron detction efficiency was measured by mini ^{252}Cf ion chamber
- Compared with M-C calculation
- HPGe was calibrated by standard sources
- HPGe was shieled by Pb house
- Correct the pulse heigth defects of Si
- Gamma spectra were unfolded

Ratio of γ-ray multiplicity to neutron multiplicity with mass A*

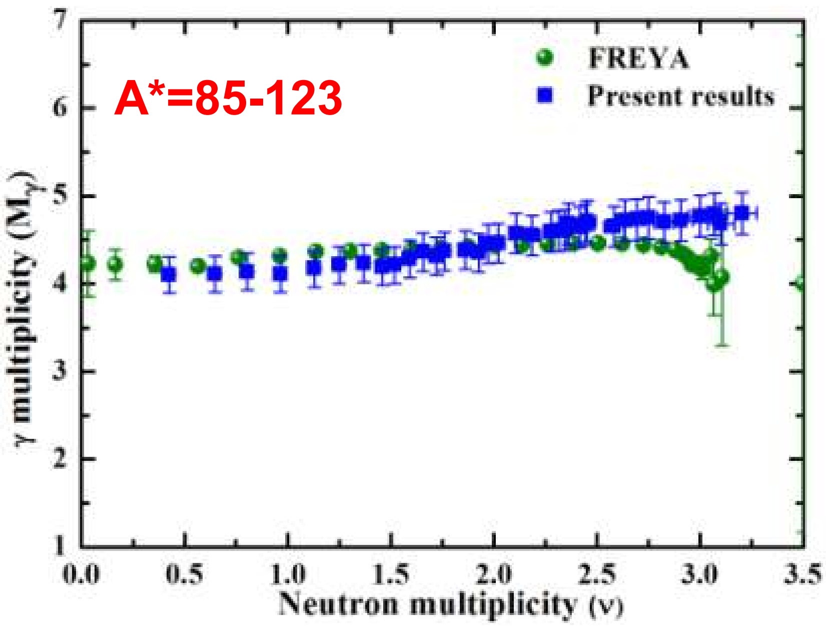


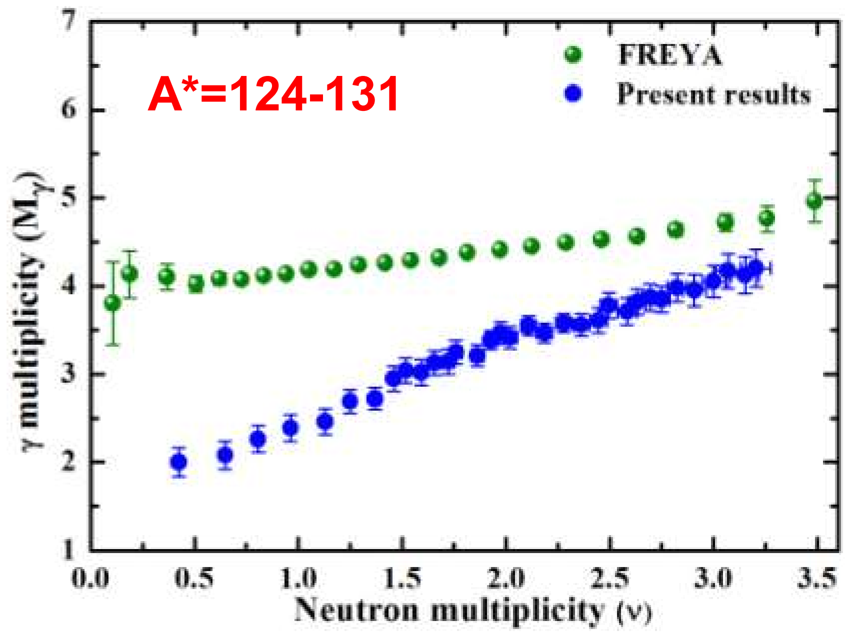
- Pronounced peak occurs in the mass region ~132, near double magic number (Z=50, N=82)
- High enhancement exist near 85, where the effects of N=50 and Z=28 shell are evident

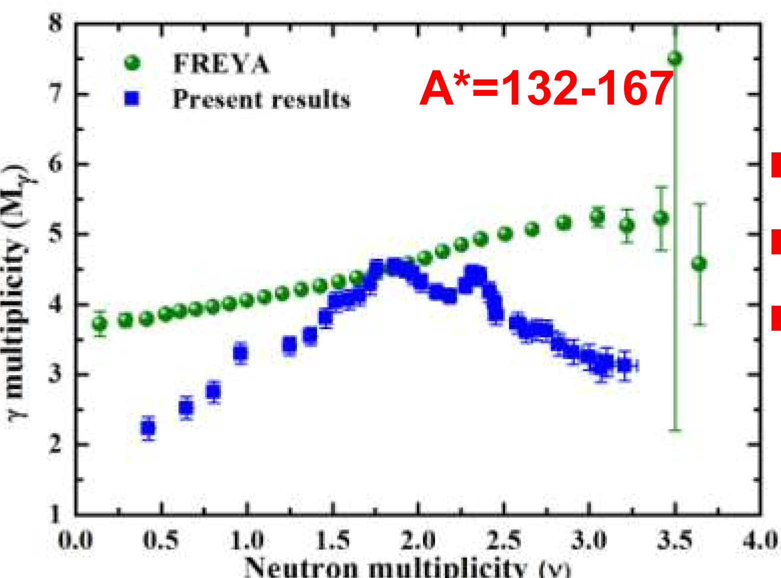
R(*A**): ratio of γ-ray multiplicity to neutron multiplicity for individual fragments

Taofeng Wang, et al., Phys. Rev. C, 93, 014606 (2016)

Correlation of neutron multiplicity and γ-ray multiplicity

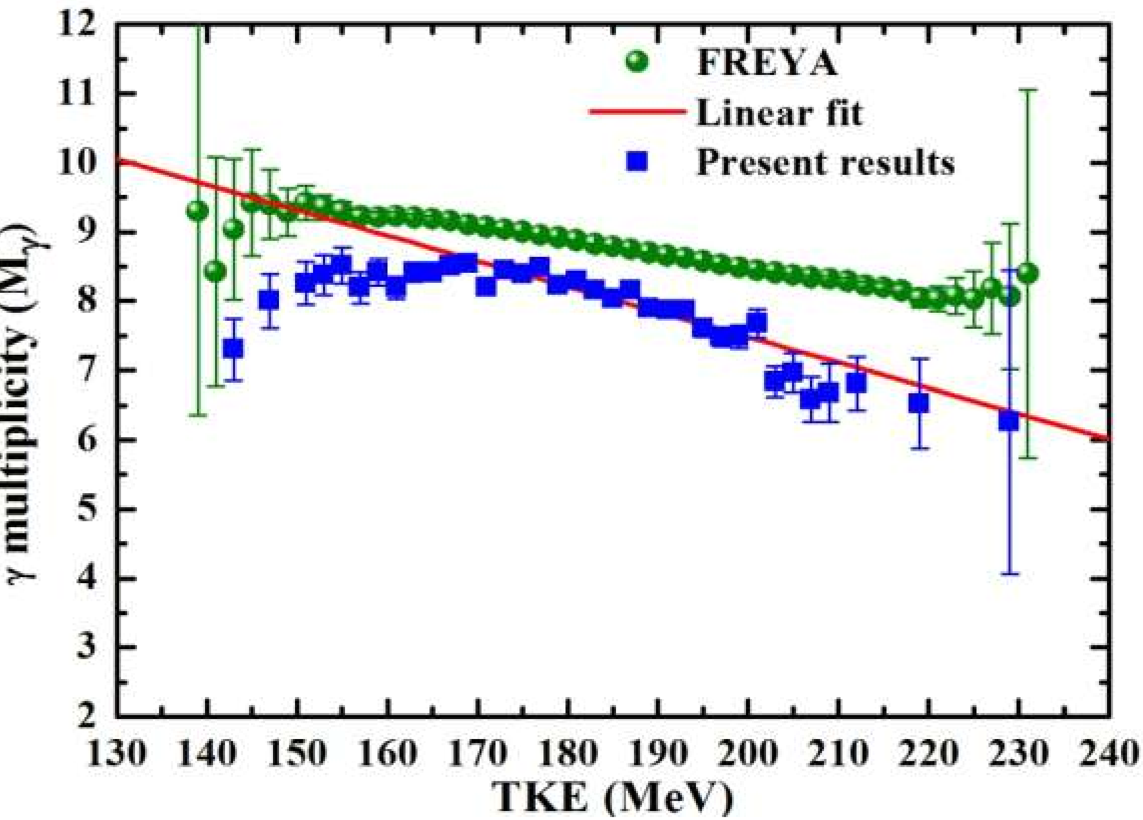


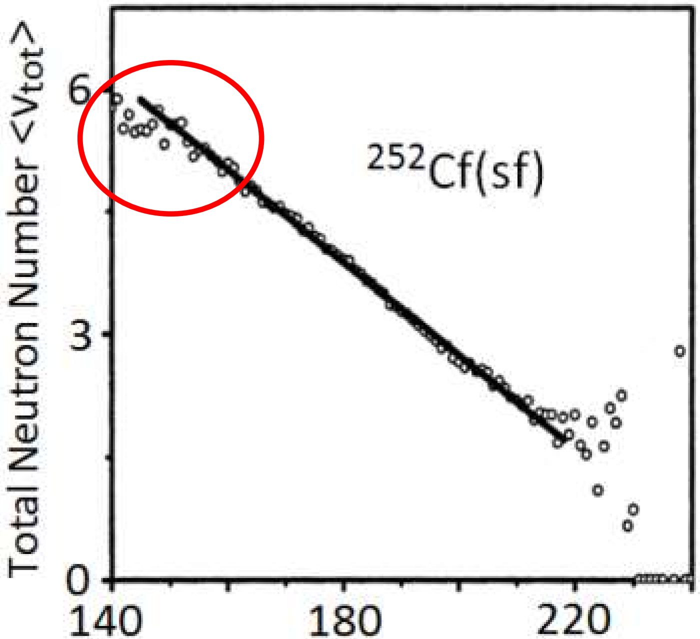




- For A*=85-123, $M_\gamma(v)$ has a approximately linear trend
- For A*=124-131, $M_\gamma(v)$ is monotonic increasing
- For A*=132-167, a strong and complex correlation, exist strong neutron and gamma competition.

Gamma multiplicity with the total kinetic energy



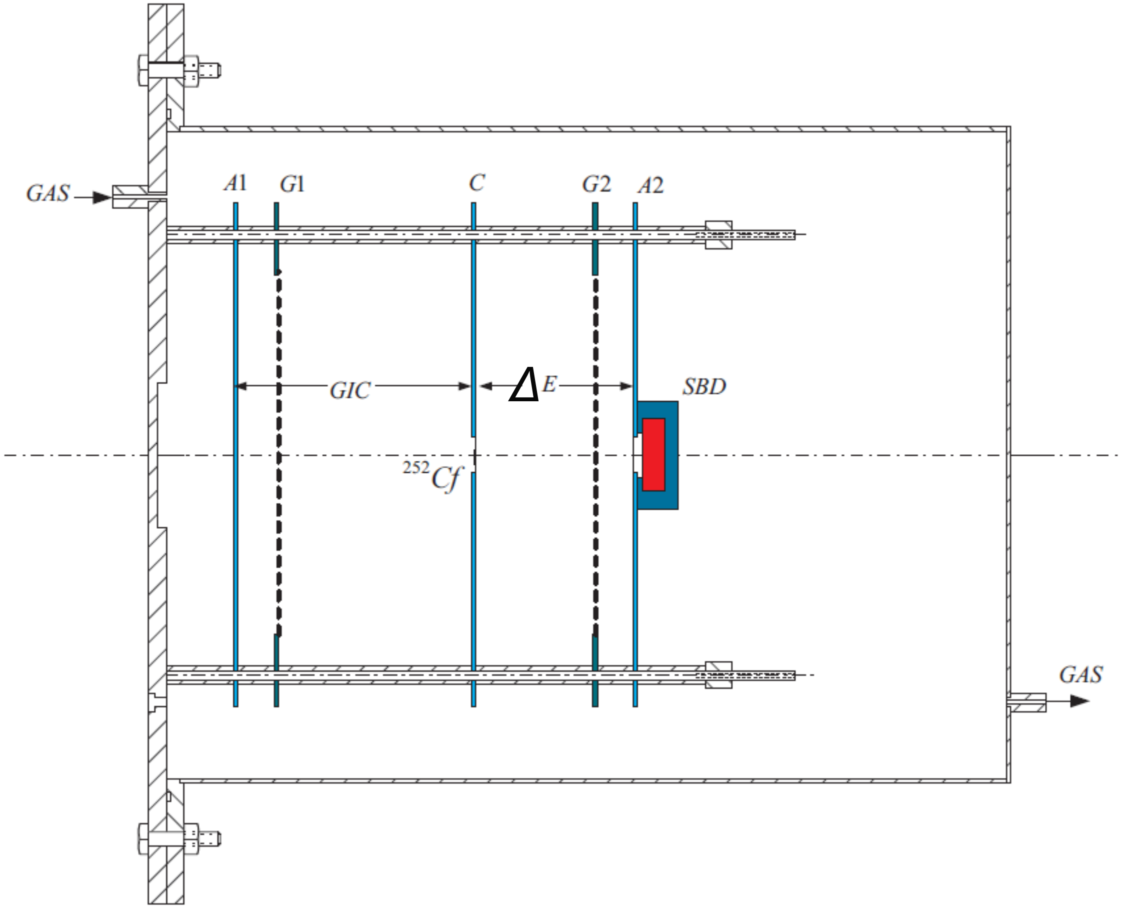


Zeynalov 2009

- M_γ has a maximum value for TKE=165-170 MeV
- Fitting with linear function for TKE>170 MeV
- TKE< 170 MeV, M_γ sharply deviate from the linear fit.

Charge distribution measurement

For a fragment with a given mass number and kinetic energy, the nuclear charge can be determined by the deposited energy of the fragment passing through an absorber.



Gas: 90% Ar+10% CH_4

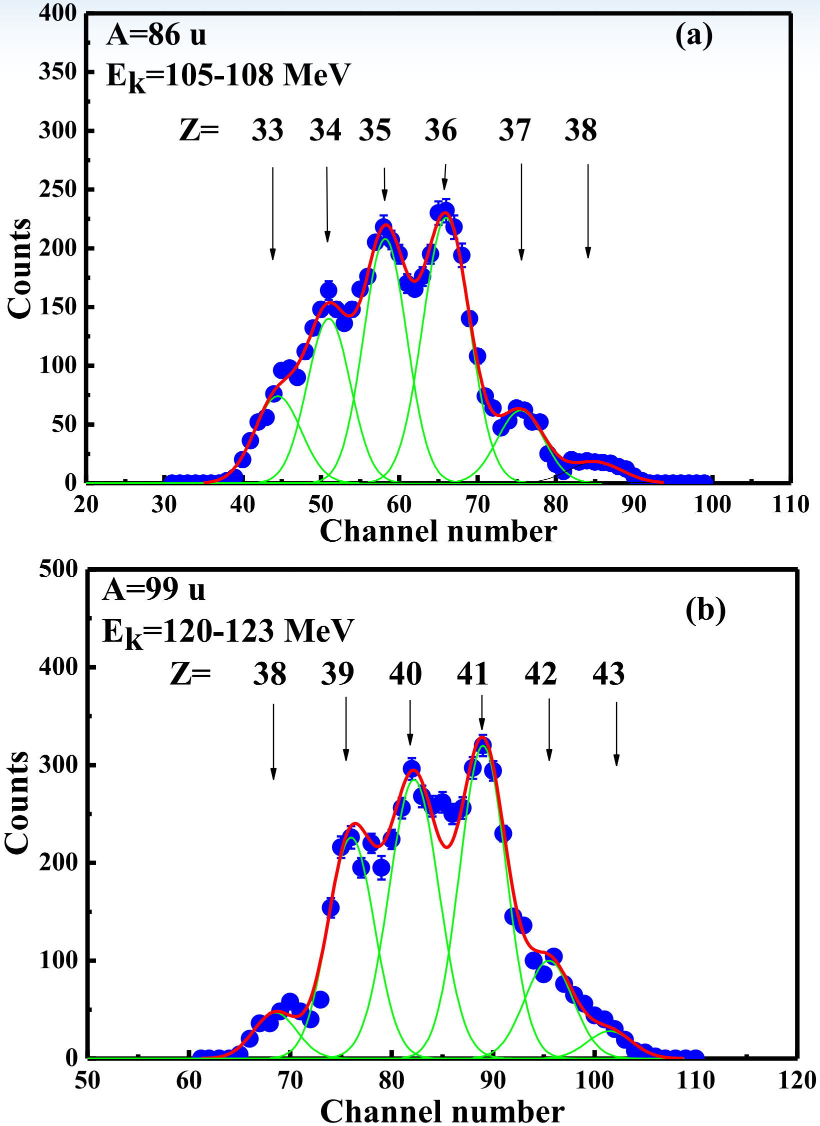
Pressure: 2.6×10^4 Pa

Solid angle: ~2% of 4π

^{252}Cf source: transferred on a thin Au-evaporated polyimide foil

Taofeng Wang, et al., NIM A, 697, 7 (2013)

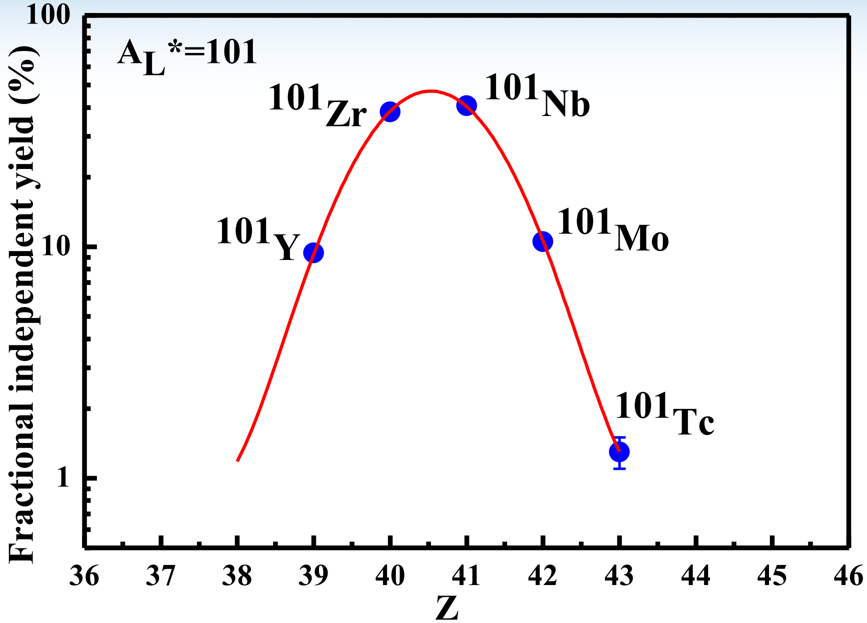
Fits for ΔE_f using multi-Gaussian function



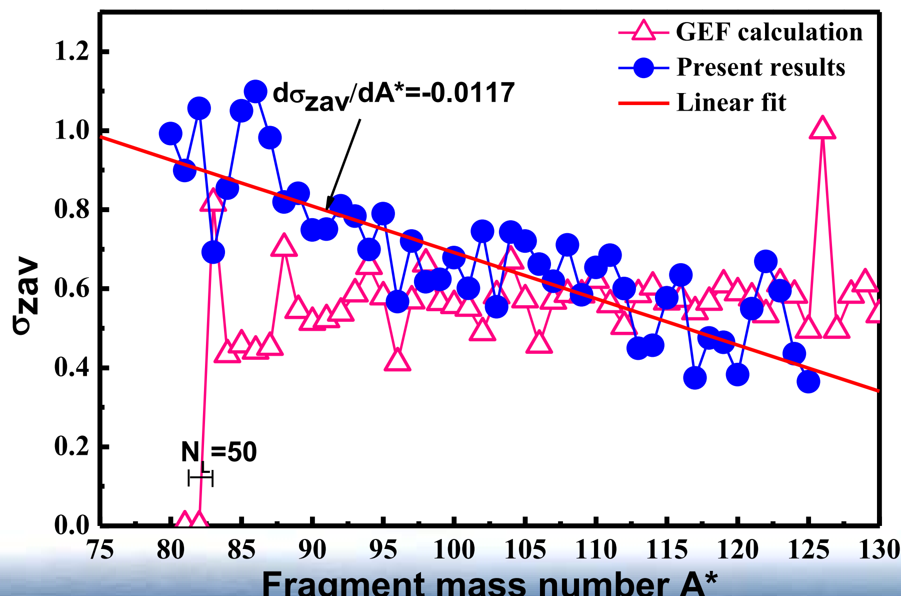
FWHM of each Gaussian is around 0.8, it implies that the charge resolution of Z:ΔZ > 40:1 has been obtained.

The charge resolution is expected to improve with increasing fragment kinetic energy.

Taofeng Wang, et al., NIM A, 697, 7 (2013)



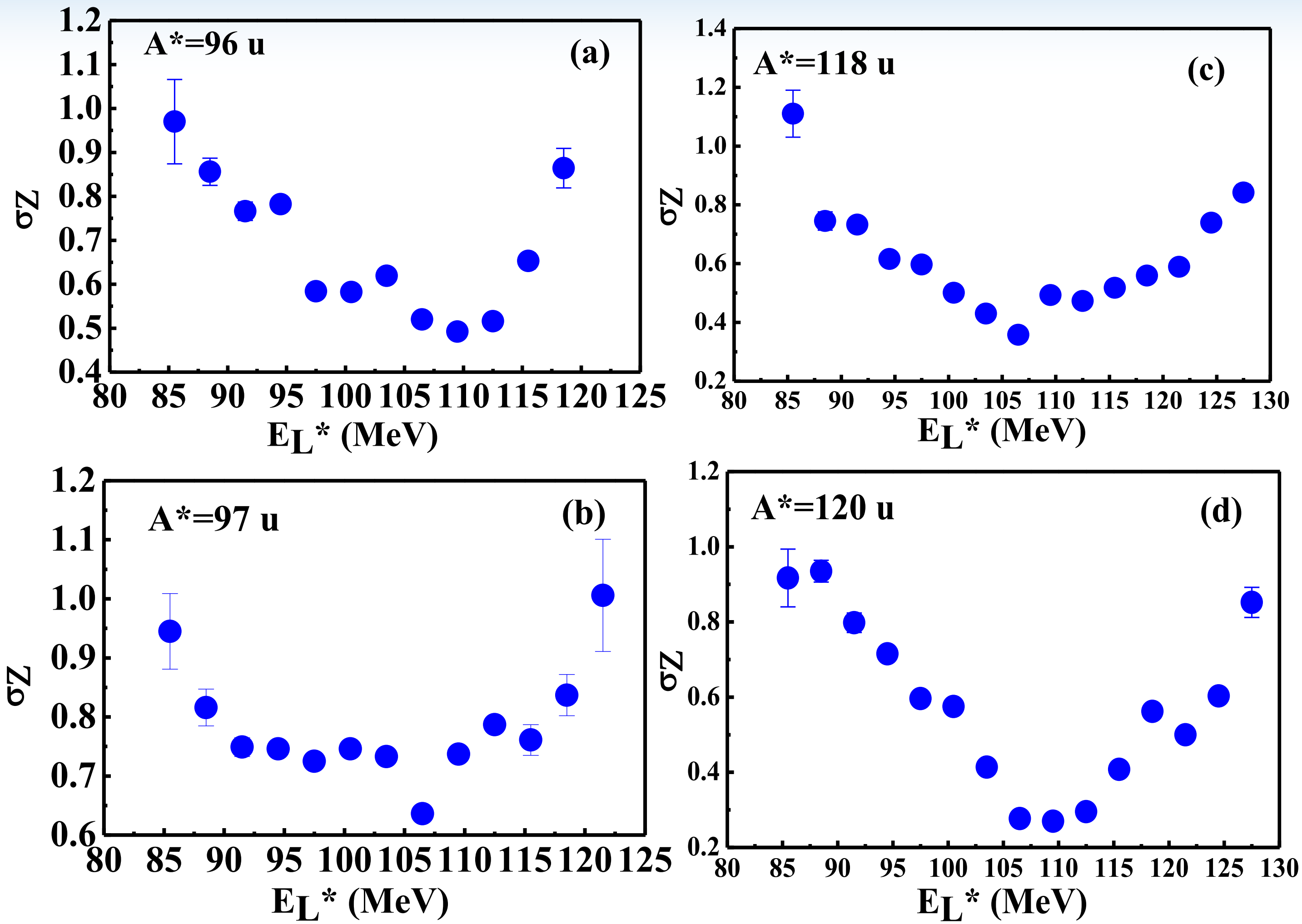
Fractional independent yields for the fragments with A*=101 u and E=118.5 MeV



- **Systematically, average width of charge distributions decrease with the fragment mass number.**
- **Largest deviation occur near N=50 neutron shell.**
- **Oscillating nature of σ_{zav} indicates the presence of odd-even effect.**

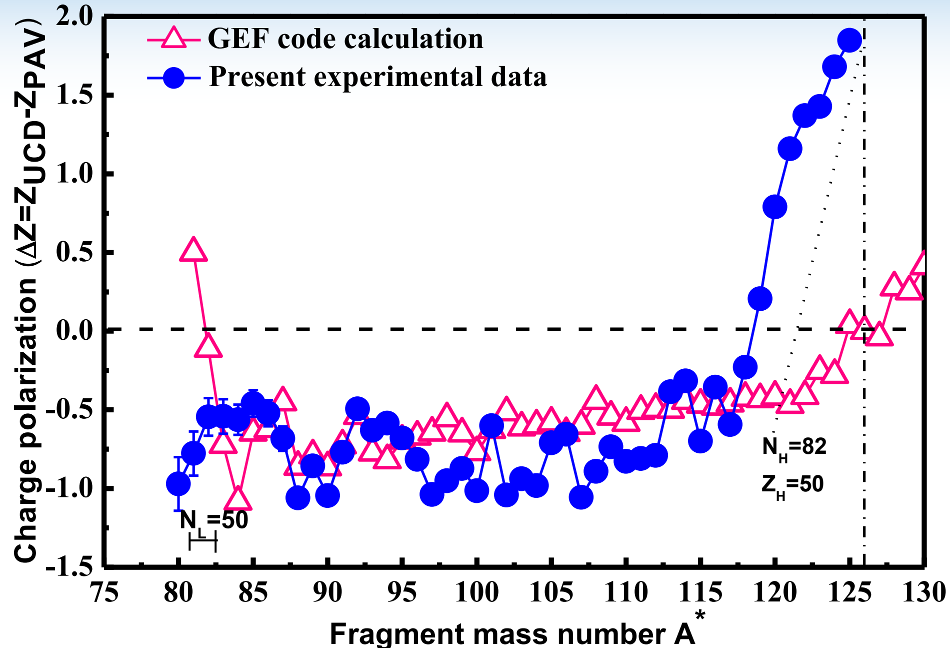
Taofeng Wang, et al., Physical Review C 96 (2017) 034611

Width σ_z dependent on the kinetic energy



- The smaller kinetic energy corresponds to higher excitation energy, large number of evaporated neutrons, large variance $\sigma^2(v)$. The intrinsic charge distribution will be spread.
- Cold fission (highest kinetic energy) has low yield making σ_z large.

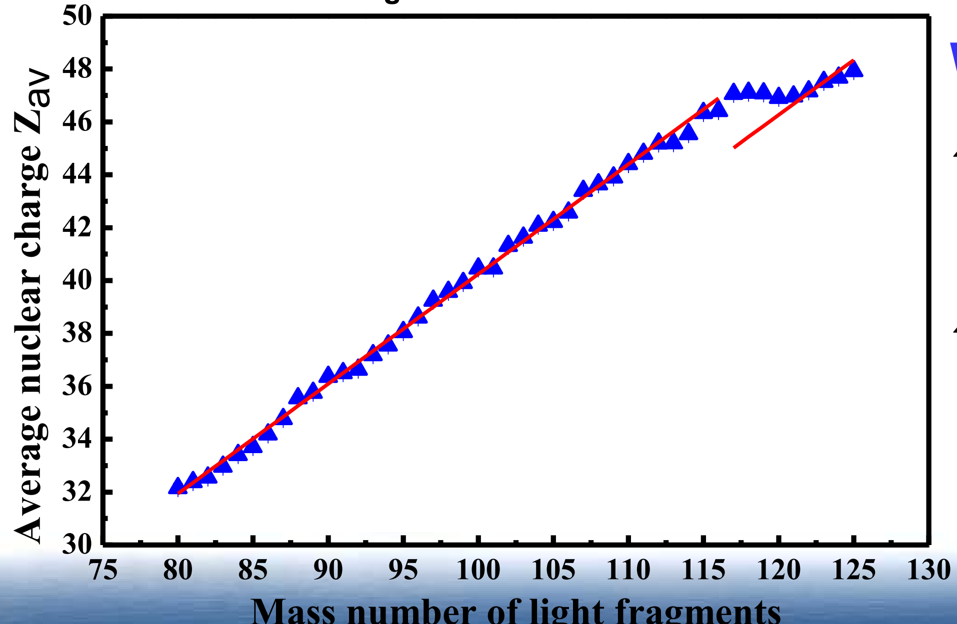
Charge Polarization of light fragments



$$\Delta Z=(\bar{Z}_p-Z_{UCD})_H=(Z_{UCD}-\bar{Z}_p)_L,$$

$$Z_{UCD}=(Z_F/A_F)\times(A+\nu_A),$$

- Closed proton shell Z=50, neutron shell N=82 effects
- Odd-even effects



Wsldo's formula

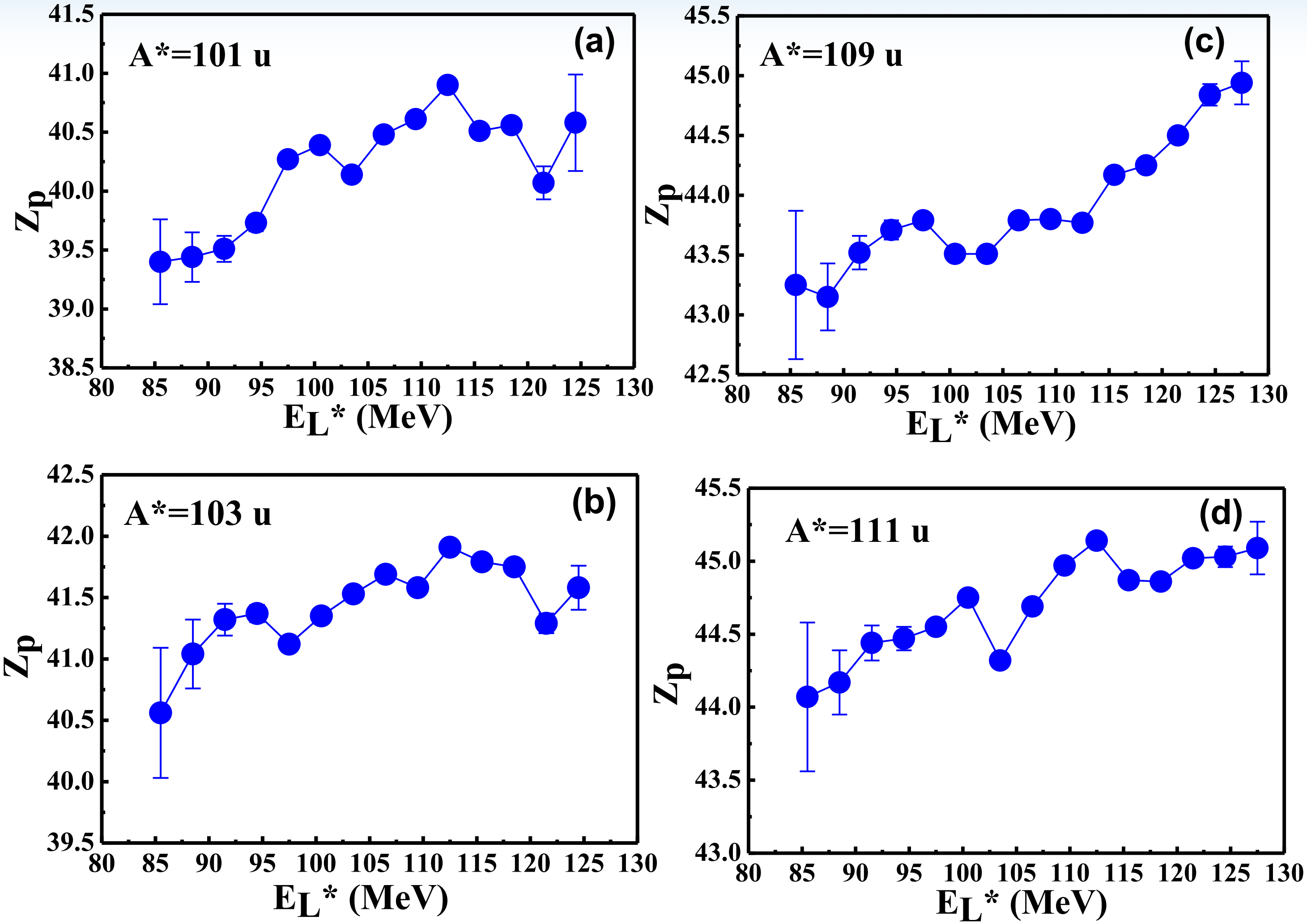
$$Z_p(A)=0.4153\cdot A-1.19+0.167\cdot(236-92\cdot A_F/C_F),$$

A<116

$$Z_p(A)=0.4153\cdot A-3.43+0.243\cdot(236-92\cdot A_F/C_F),$$

A>116

Energy dependence of the most probable charge

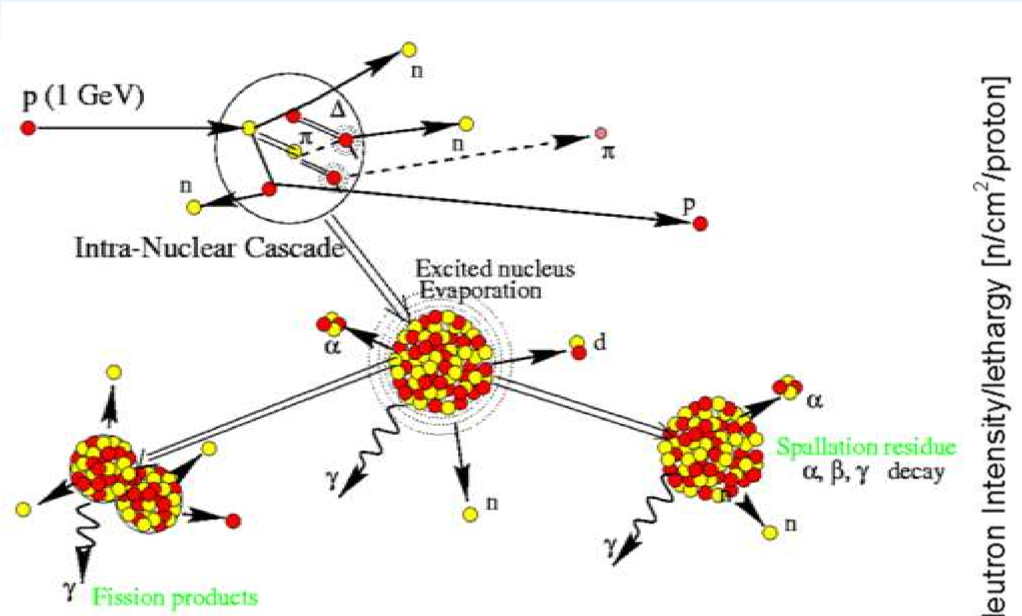


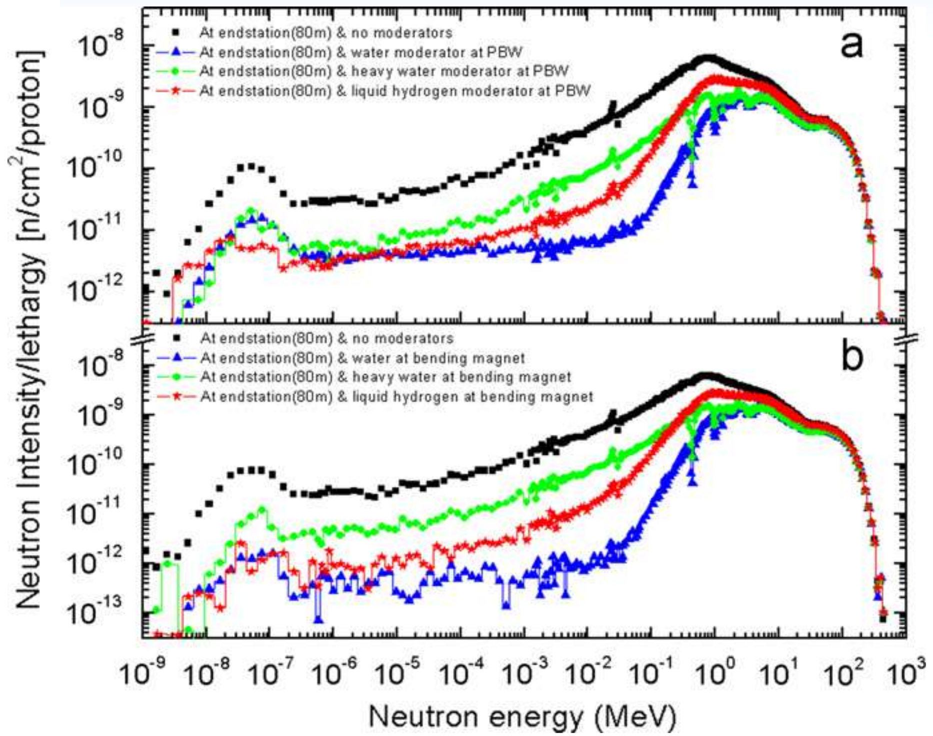
Increasing tendencies for Z_p with the kinetic energies

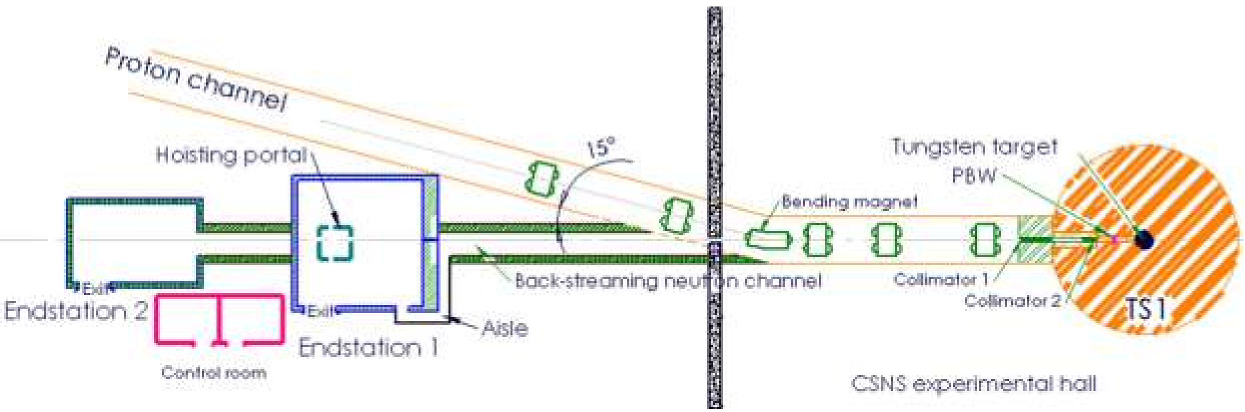
(1) Connected only with prompt neutron emission

(2) Related with a decrease of the charge polarization in primary fission fragments, which lead to a increase of charge density of light fragment

CSNS back-n white neutron

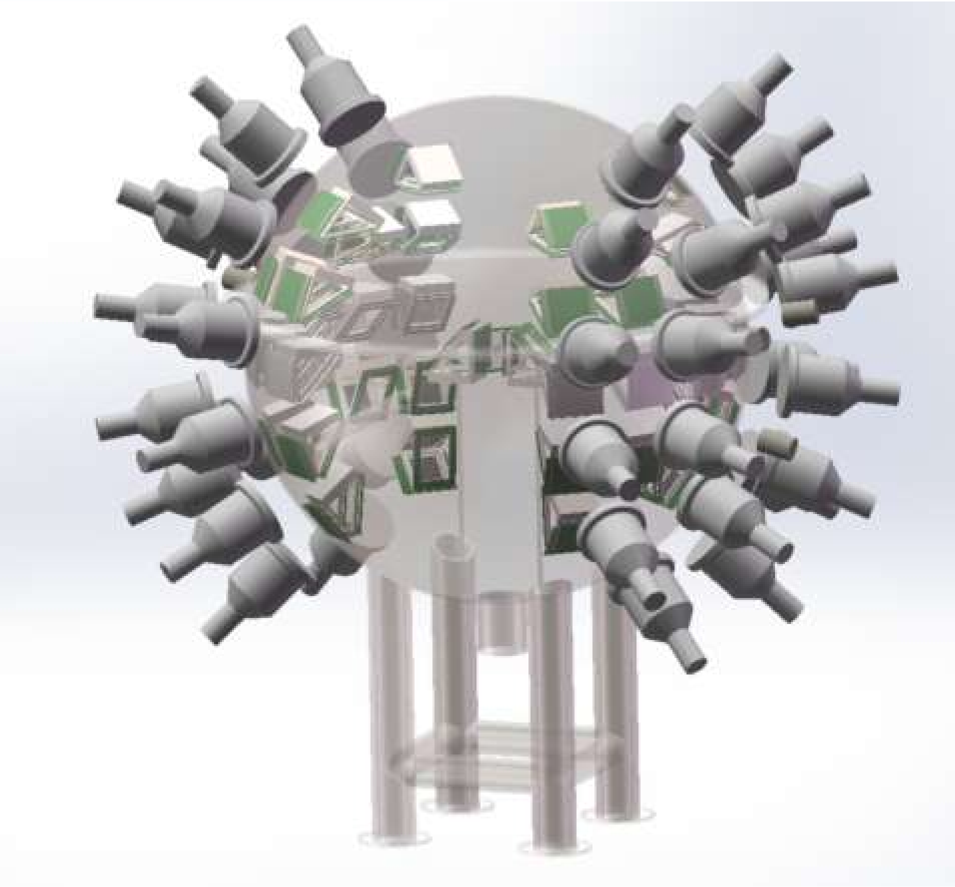






H. T. Jing, J. Y. Tang…
NIM A 621(2010) 91

Neutron capture of unstable nuclei



Los Alamos model:

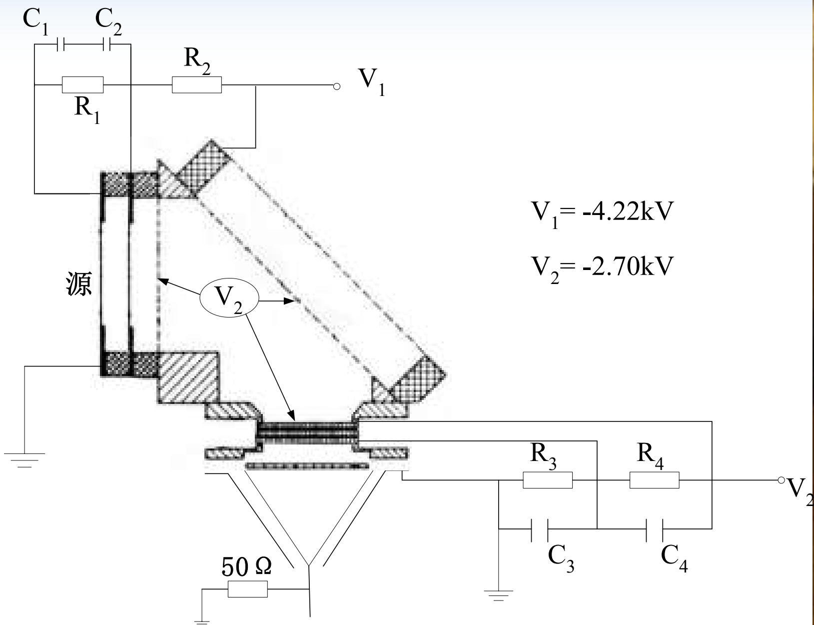
neutron spectrum can be expressed by

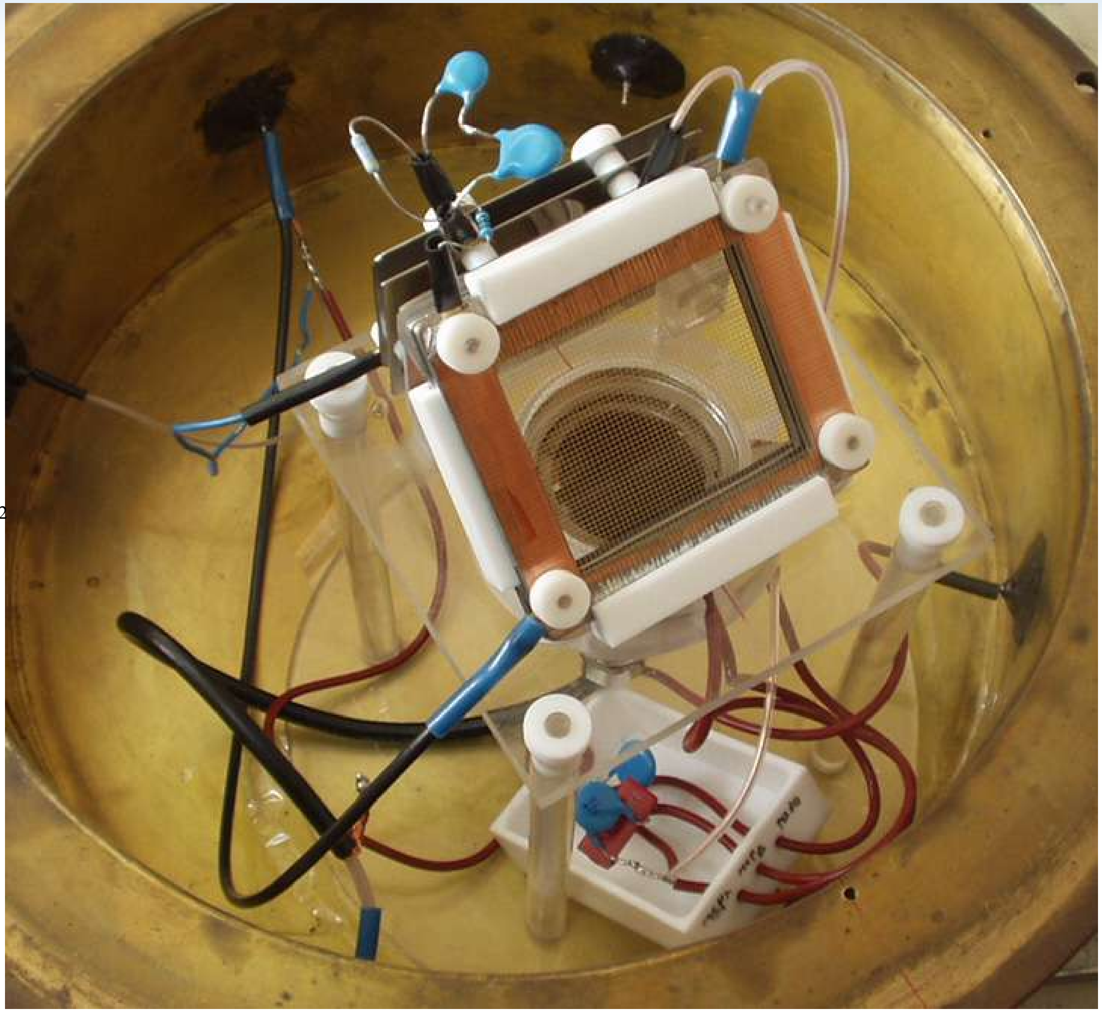
$$\phi(\varepsilon) = k(T)\sigma_c(\varepsilon)e^{-\varepsilon/T}$$

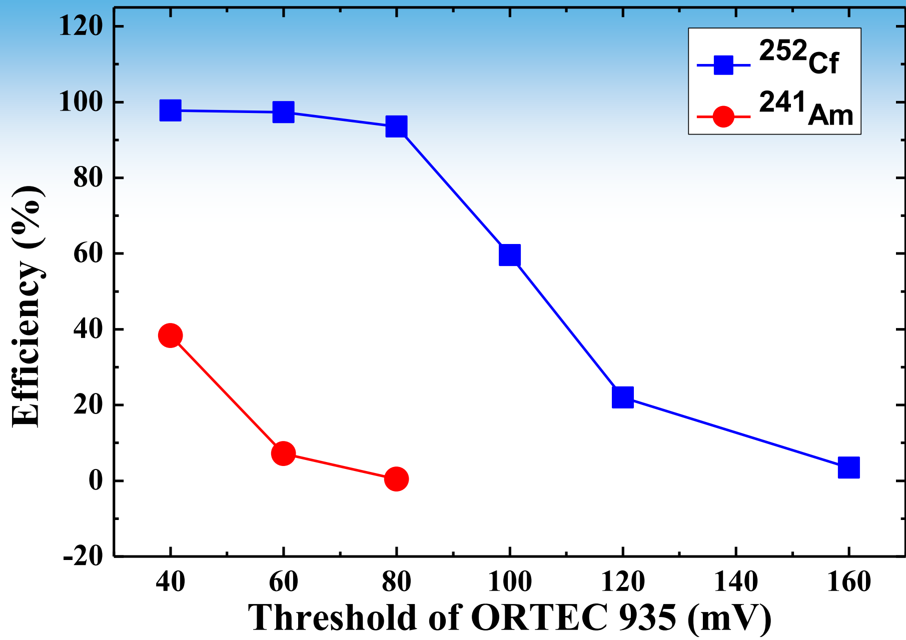
$\sigma_c(\varepsilon)$ is inverse reaction cross section namely, neutron capture cross section

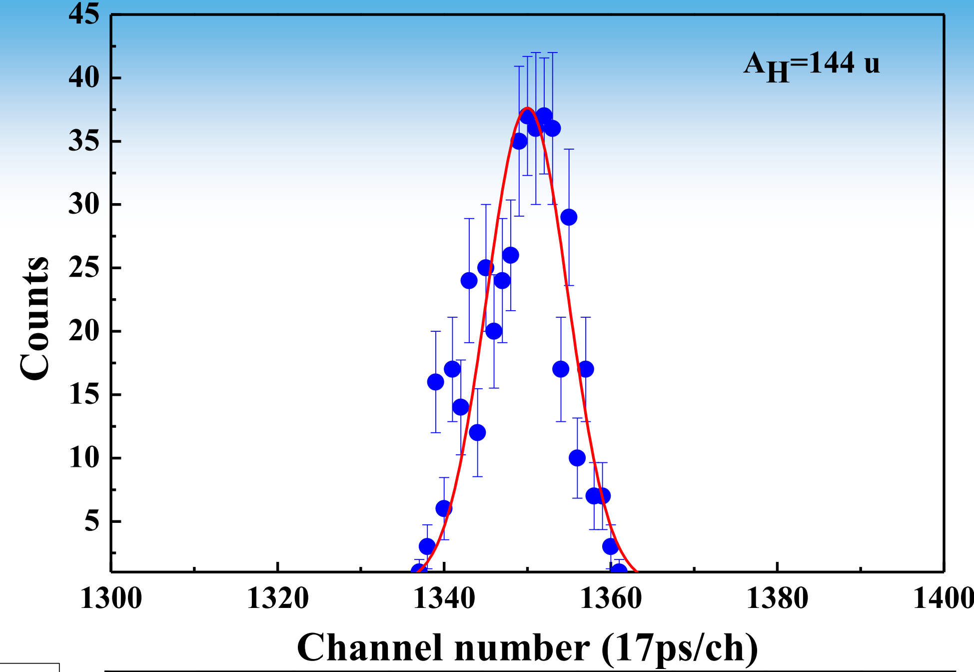
- 2E-2V method to determine F mass
- MCP+MCP+ double layers chamber
- Thin chamber serves as ΔE
- Thick chamber servers as E
- ΔE-E used to determine F charge
- Flight path length is ~50cm
- Time resolution < 150 ps
- Mass resolution < 1 amu

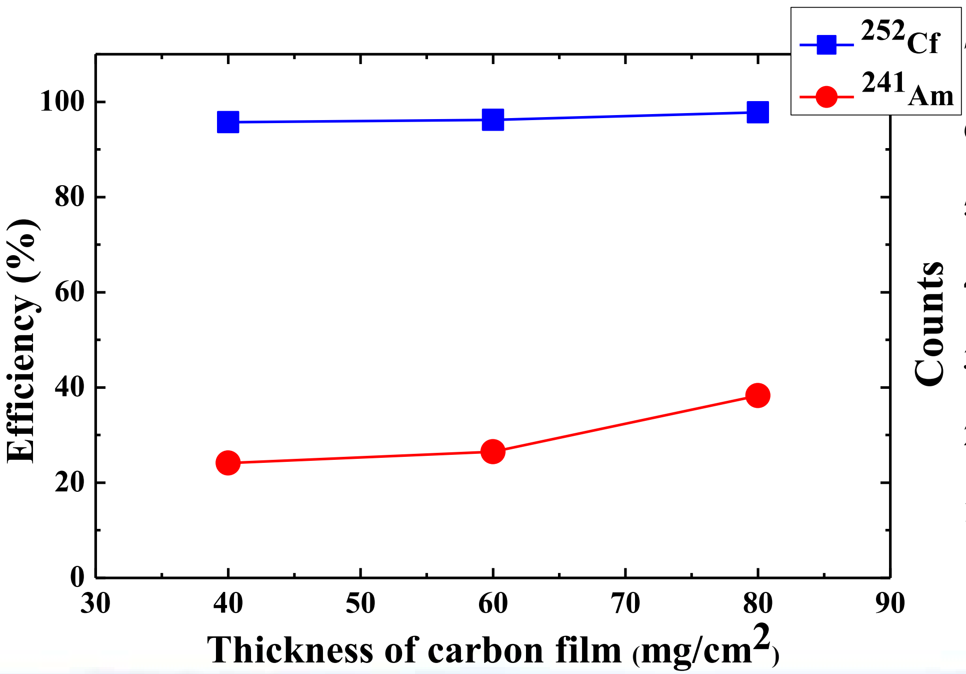
Testing of MCP

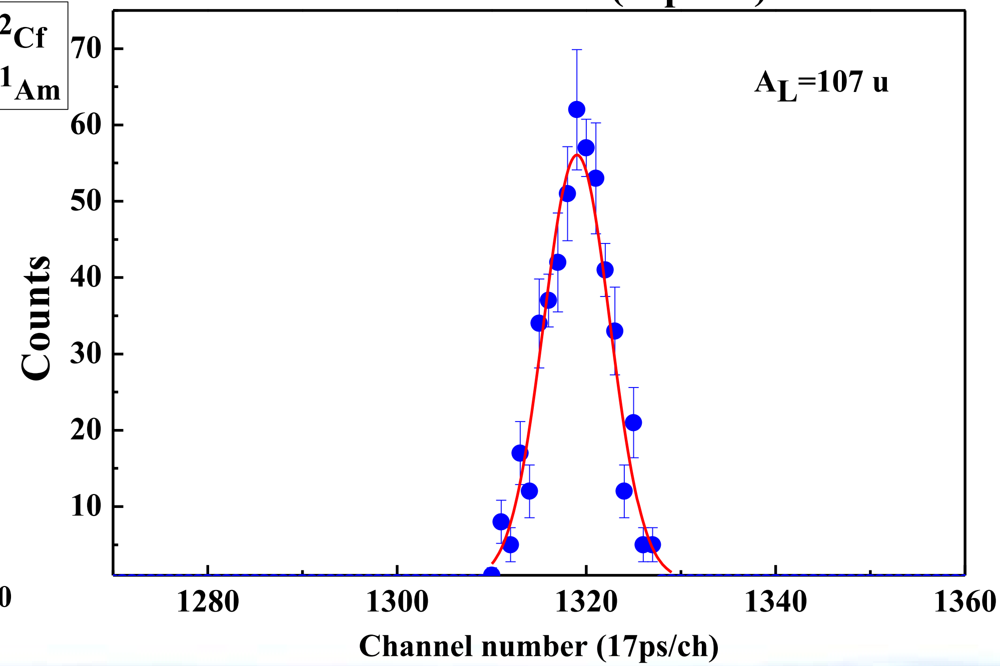





252Cf
241Am
Efficiency (%)
Threshold of ORTEC 935 (mV)


AH=144 u
Counts
Channel number (17ps/ch)


252Cf
241Am
Efficiency (%)
Thickness of carbon film (mg/cm2)


AL=107 u
Counts
Channel number (17ps/ch)

Summary

- **Correlation of neutron multiplicity and gamma multiplicity**
  - **Pronounced peaks of ratio of gamma to neutron multiplicity around A*=78, 132 were observed**
  - **Competition between neutron and gamma emission was observed for heavy fragments region**
- **Charge distribition measuremnt**
  - **Average widths of distribution decrease with fragment mass**
  - **Positive charge polarization in the A*=132 region**
  - **Most probable charge increase with fragment kinetic energy**
- **Proposal for the study of neutron capture of unstable nuclei**

Thank You !