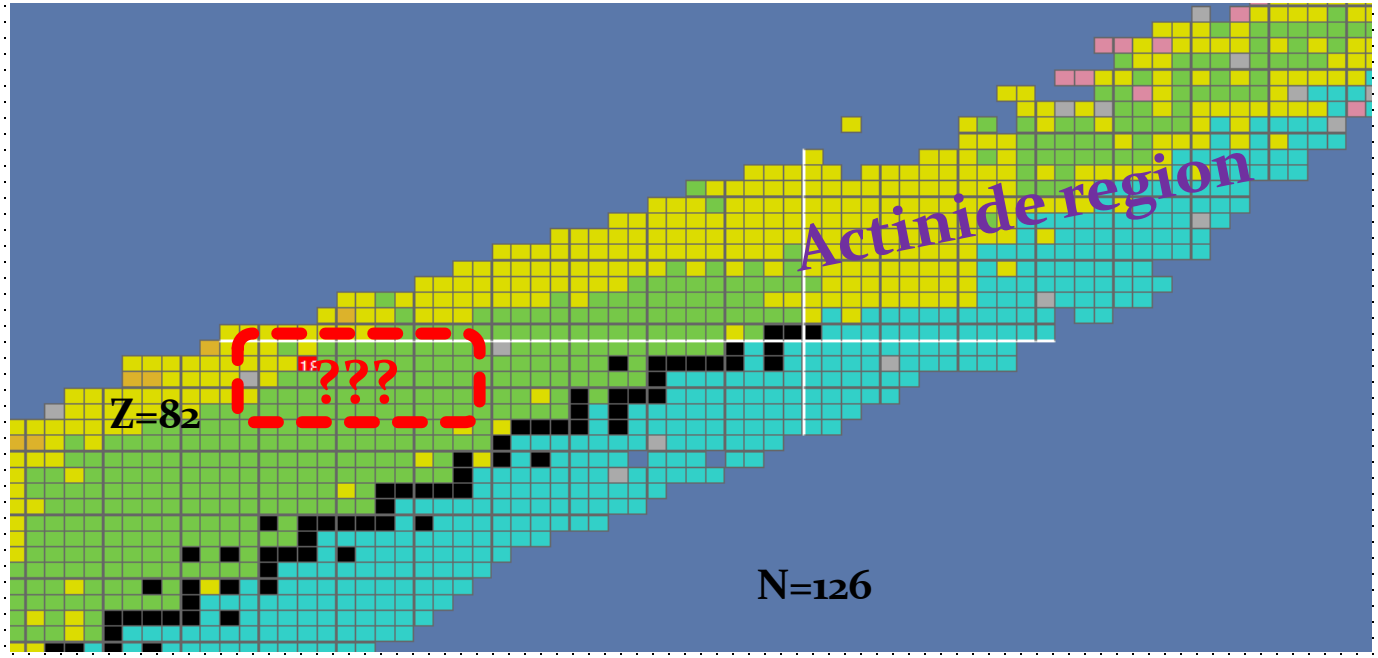
Igor Tsekhanovich

FISSION MODES IN ^{178}PT



ASRC International Workshop on
Nuclear Fission and Structure of Exotic Nuclei
JAEA, Tokai, March 25-27, 2019

OUTLOOK

- Introduction:
  1) Interest to the ^{180}Hg region and
  2) Some selected previous experimental results

- JAEA experiment : fusion-fission of ^{178}Pt

  1) Experiment
  2) Results (velocities, MED, fission modes)

- Hot questions and Future work

Fission modes in actinides : MD – TKE correlation

PHYSICAL REVIEW C 93, 034603 (2016)

Fragment-mass, kinetic energy, and angular distributions for ^{234}U(n, f) at incident neutron energies from $E_n = 0.2$ MeV to 5.0 MeV

A. Al-Adili,[1,2] F.-J. Hambsch,[1,*] S. Pomp,[2] S. Oberstedt,[1] and M. Vidali[1]
[1]*European Commission, Joint Research Centre, Institute for Reference Materials and Measurement (IRMM), B-2440 Geel, Belgium*
[2]*Department of Physics and Astronomy,*
(Received 19 Augus

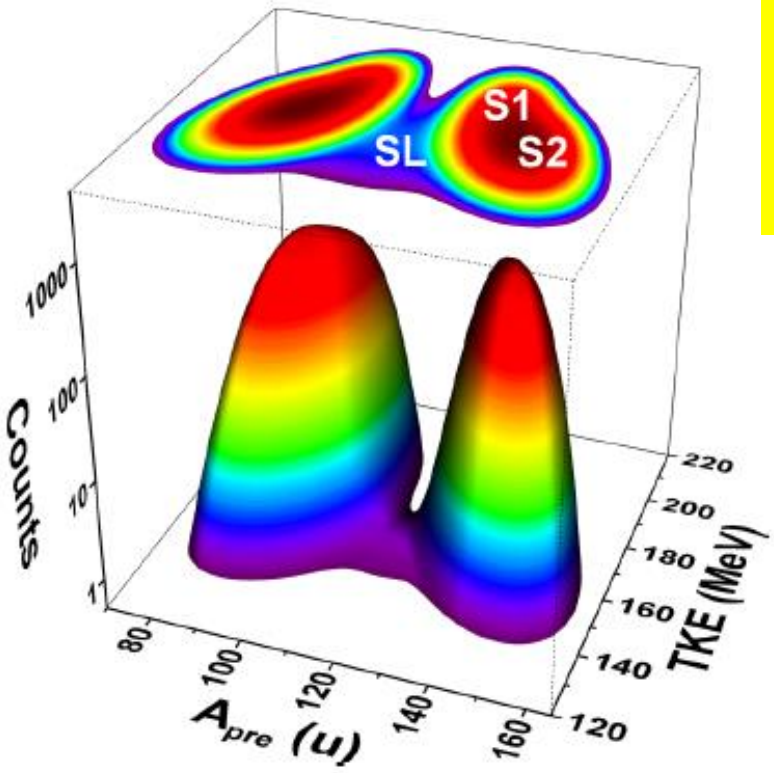


FIG. 9. The experimental two-dimensional TKE vs mass data is fitted with three modes. Equation (12) was used to parametrize the data. In total, three fission modes (S1, S2, and SL) were taken into account.

Definition :

(A)Symmetric mode :

(a)symmetric mass division

$$\overline{TKE}_{symm} < \overline{TKE}_{asymm}$$

$$\sigma^{A}_{symm} > \sigma^{A}_{asymm}$$

Region of interest : nuclei with low isospin

Fission properties as a function of isospin ??

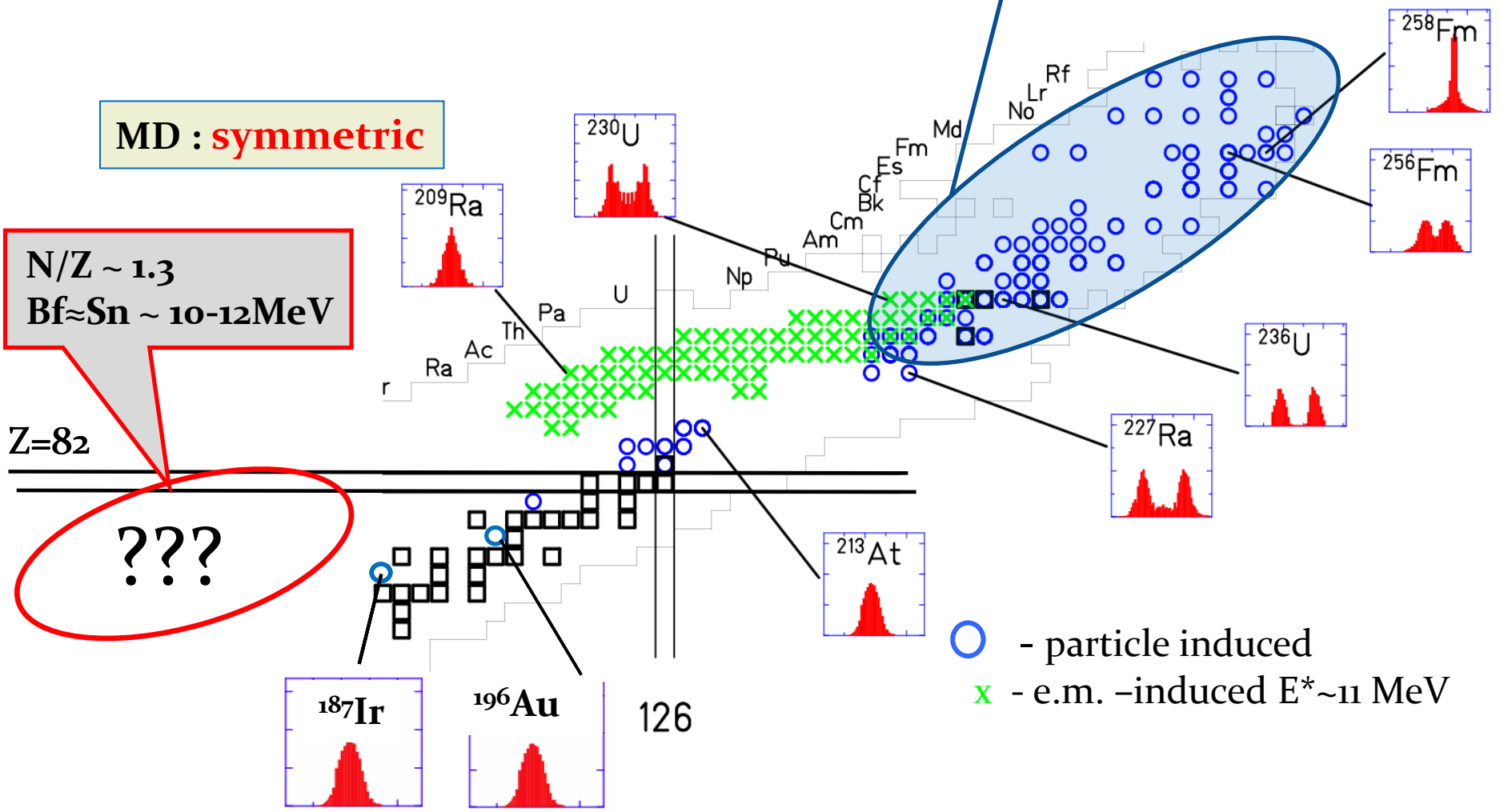
Actinides N/Z ~1.57 : MD : asymmetric

MD : symmetric

N/Z ~ 1.3
Bf≈Sn ~ 10-12MeV

Z=82

???



○ - particle induced

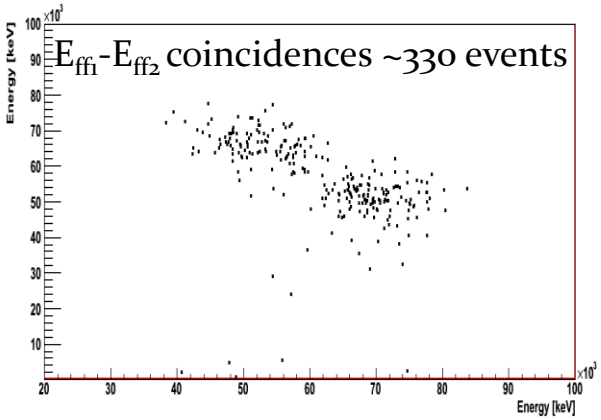
x - e.m. –induced E*~11 MeV

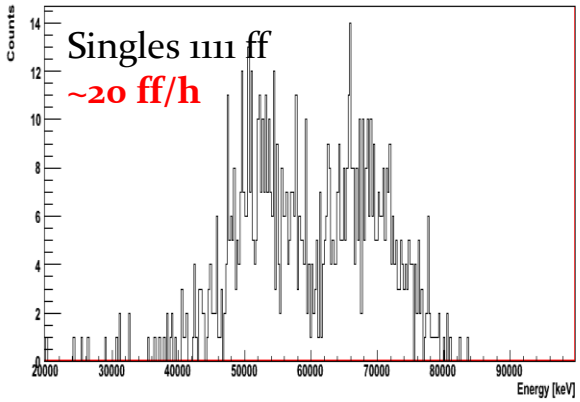
K.-H. Schmidt et al.

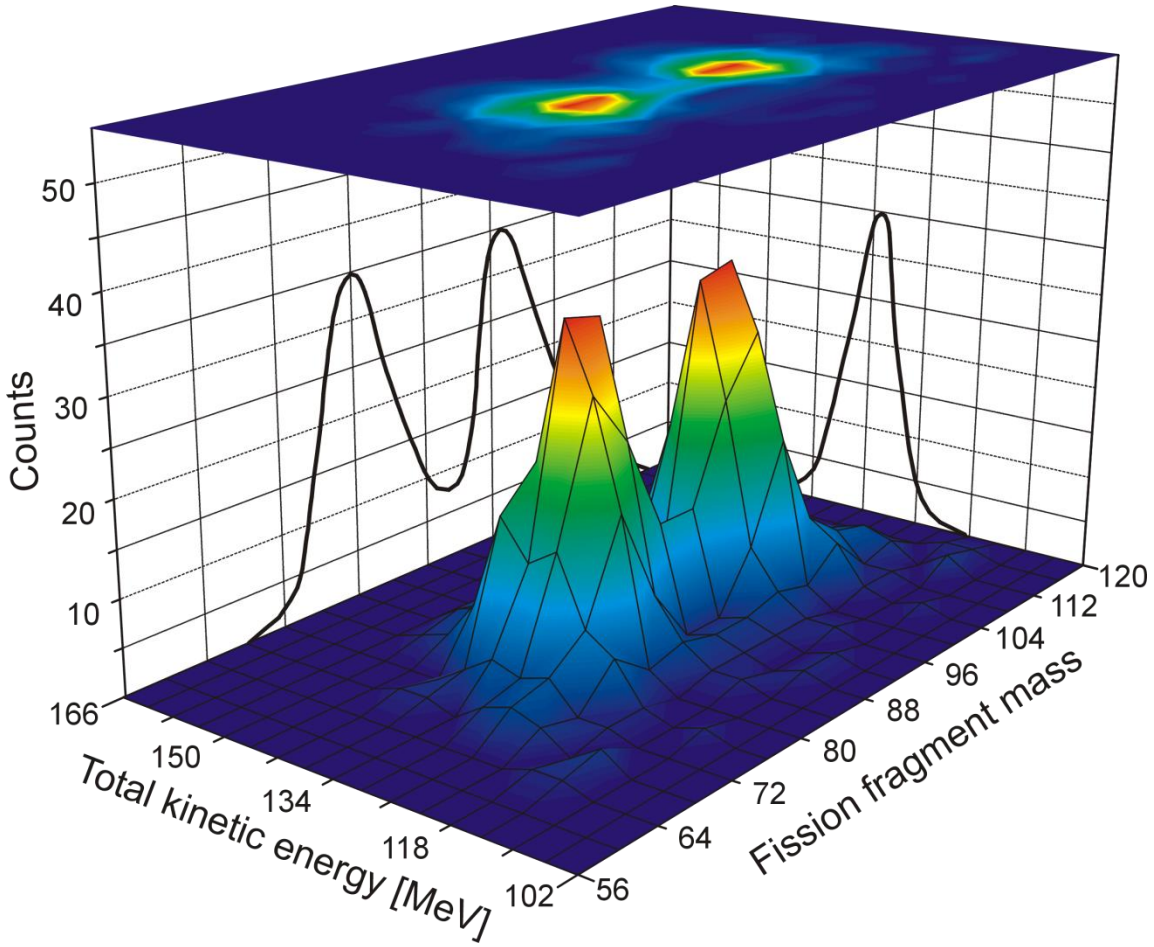
Trigger : Mass Distribution from fission of ^{180}Hg

Andreyev *et al.* (PRL 105 (2010) 252502):

ASYMMETRIC mass split : M_H=100(4) & M_L= 80(4)

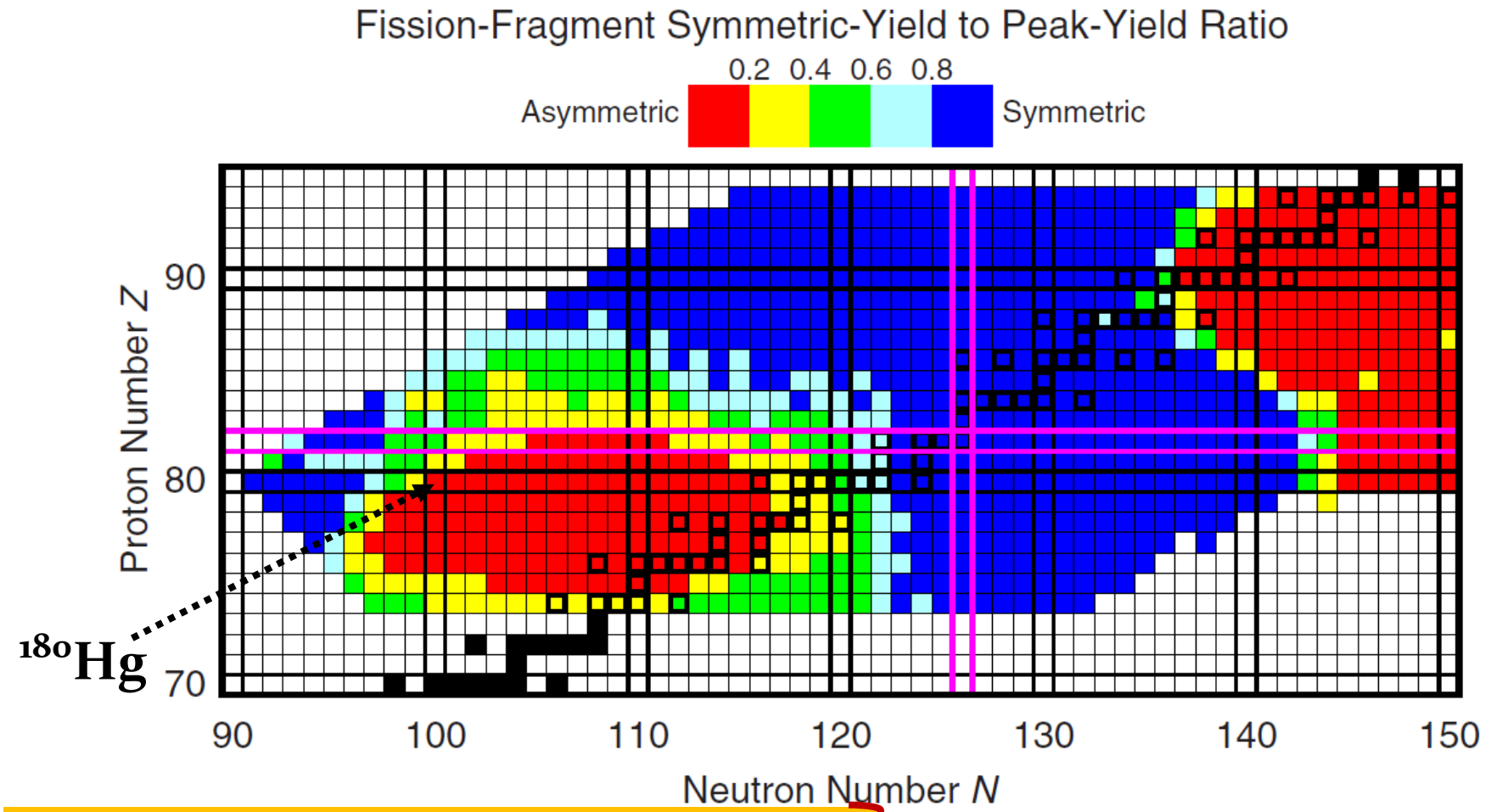






Z identification : UCD rule ➔ ^{100}Ru (N=56,Z=44) and ^{80}Kr (N=44,Z=36)

New Region of Asymmetric Fission : p-rich sub-lead region



^{178,180,190}Hg & ^{178}Pt : ISOLDE/JAEA data

^{179,189}Au & ^{182,184,195}Hg : BARC (India) + ANU (Australia) data

$E^* > 30\ MeV$

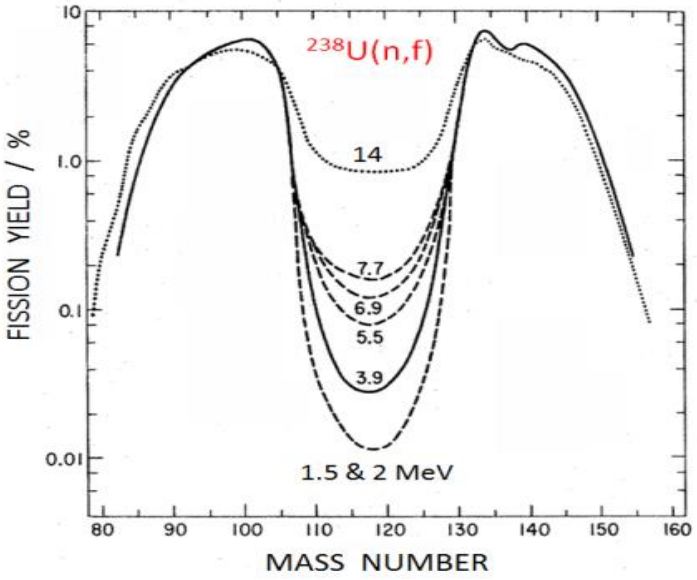
P. Moller & J. Randrup: PRC 91, 044316 (2015)

JAEA : Mass Distributions from fission of ^{180,190}Hg

- E* = 34-71 MeV
- 2010-2014: JAEA,Tokai

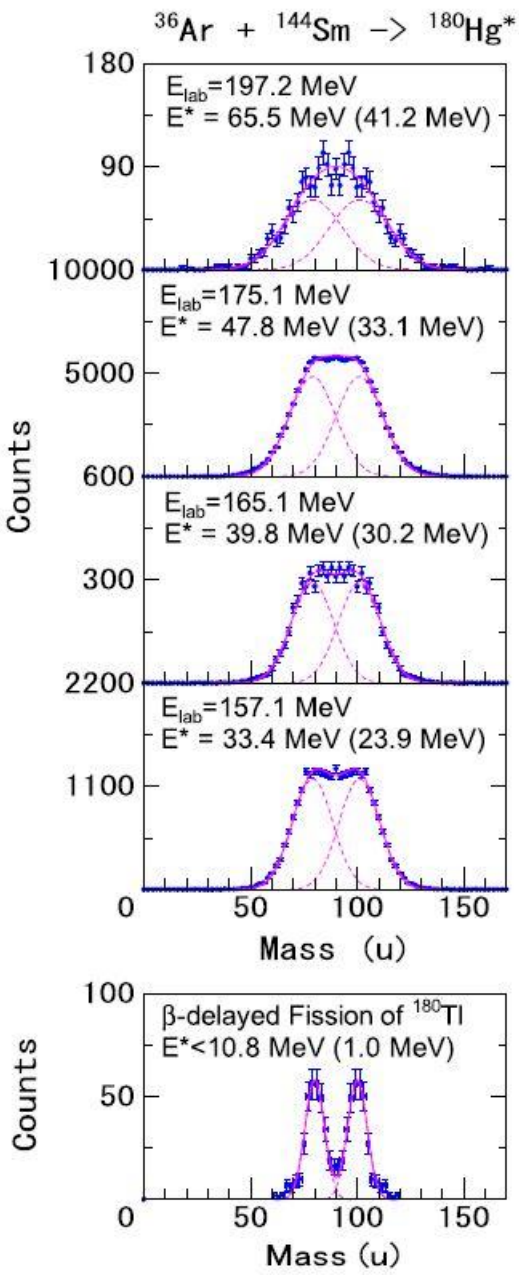
✓ **Robustness with Eexc :**

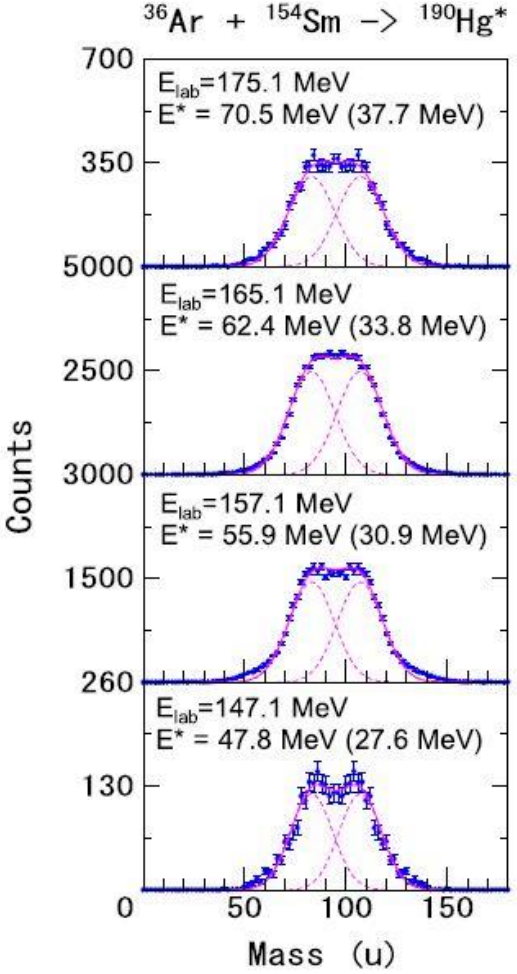
Asymmetric MD up to E*= 70 MeV



"The mass distributions for both Hg isotopes could be well reproduced with a single asymmetric fission mode"

➢ **No symmetric mode ?**





K. Nishio et al, PLB (2015)

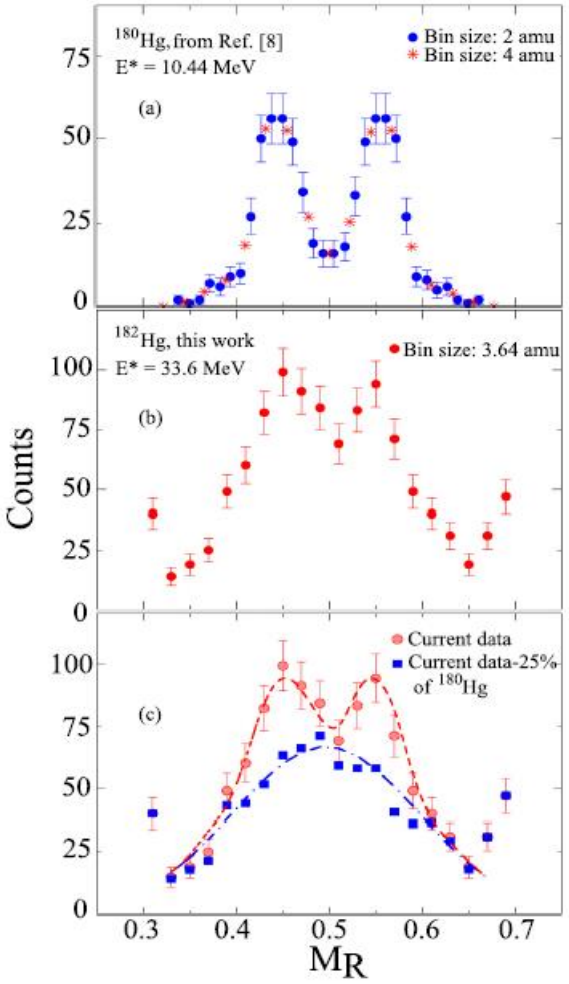
ANU : Mass Distributions from fission of ^{182,195}Hg

PHYSICAL REVIEW C **91**, 064605 (2015)

Observation of mass-asymmetric fission of mercury nuclei in heavy ion fusion

E. Prasad,* D. J. Hinde,† K. Ramachandran,‡ E. Williams, M. Dasgupta, I. P. Carter, K. J. Cook, D. Y. Jeung, D. H. Luong, S. McNeil, C. S. Palshetkar, D. C. Rafferty, C. Simenel, and A. Wakhle§

Department of Nuclear Physics, Research School of Physical Sciences and Engineering, The Australian National University, Canberra, ACT 2601, Australia



fission is shown by the dashed line. These results show that a contribution of a 25% from fission of ^{180}Hg, that would occur after evaporation of two neutrons from the CN, could explain the mass-asymmetric fission observed in this work.

NEED:

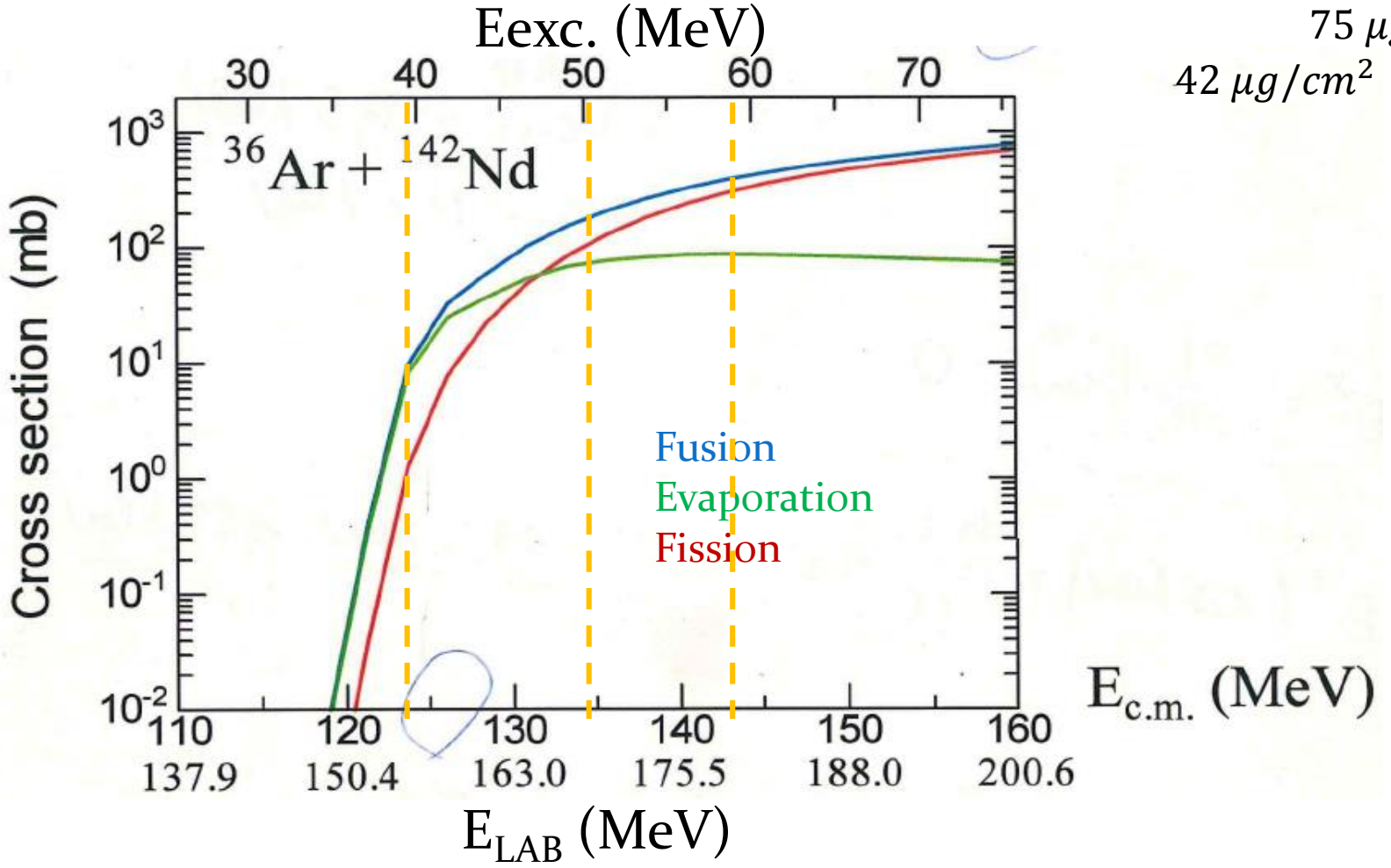
- Pin down the modes
- Determine their properties

^{178}Pt Experiment : - July 2016, JAEA : $^{36}Ar + {}^{142}Nd \rightarrow {}^{178}Pt$

Target: C + **Nd**F_3

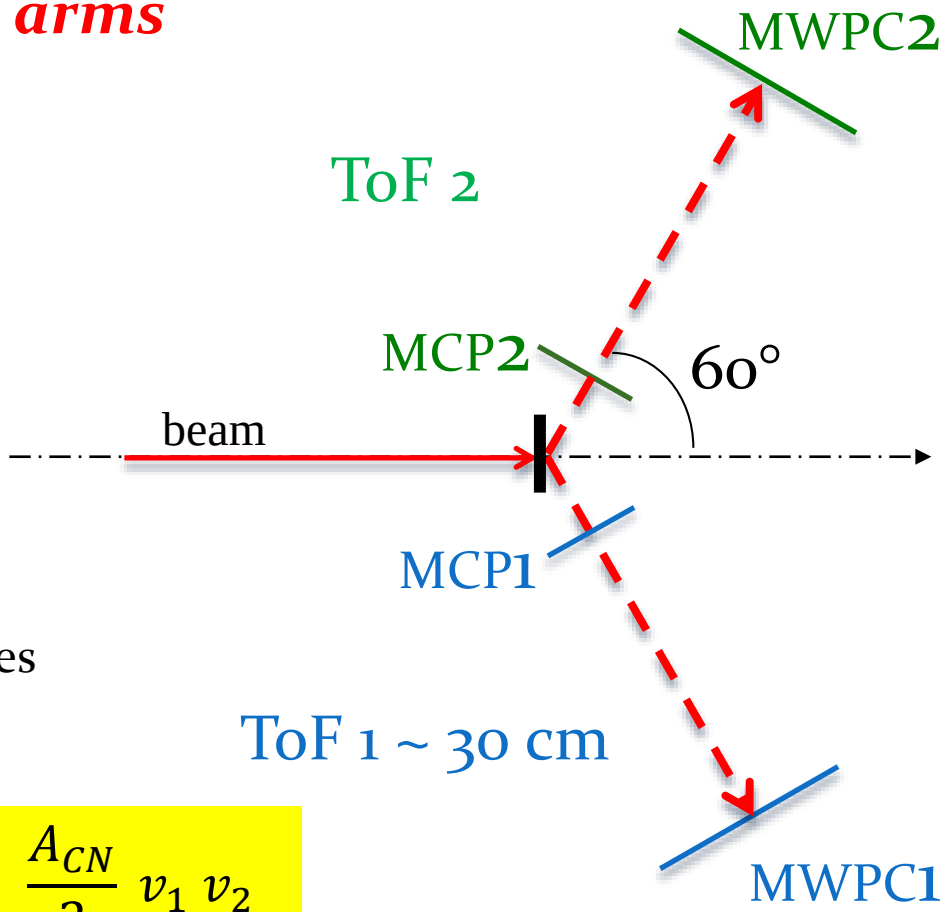
$75\ \mu g/cm^2$

$42\ \mu g/cm^2$



JAEA: Experimental Setup and Geometry

✓ ***2 independent TOF arms***



Observables:

- TOF (MCP -- MWPC)
- X, Y coordinates (MWPC)
- ΔE (MWPC cathode)

Calculated quantities:

- Relative angles
- Velocities → true fission velocities
- FF masses & kinetic energies

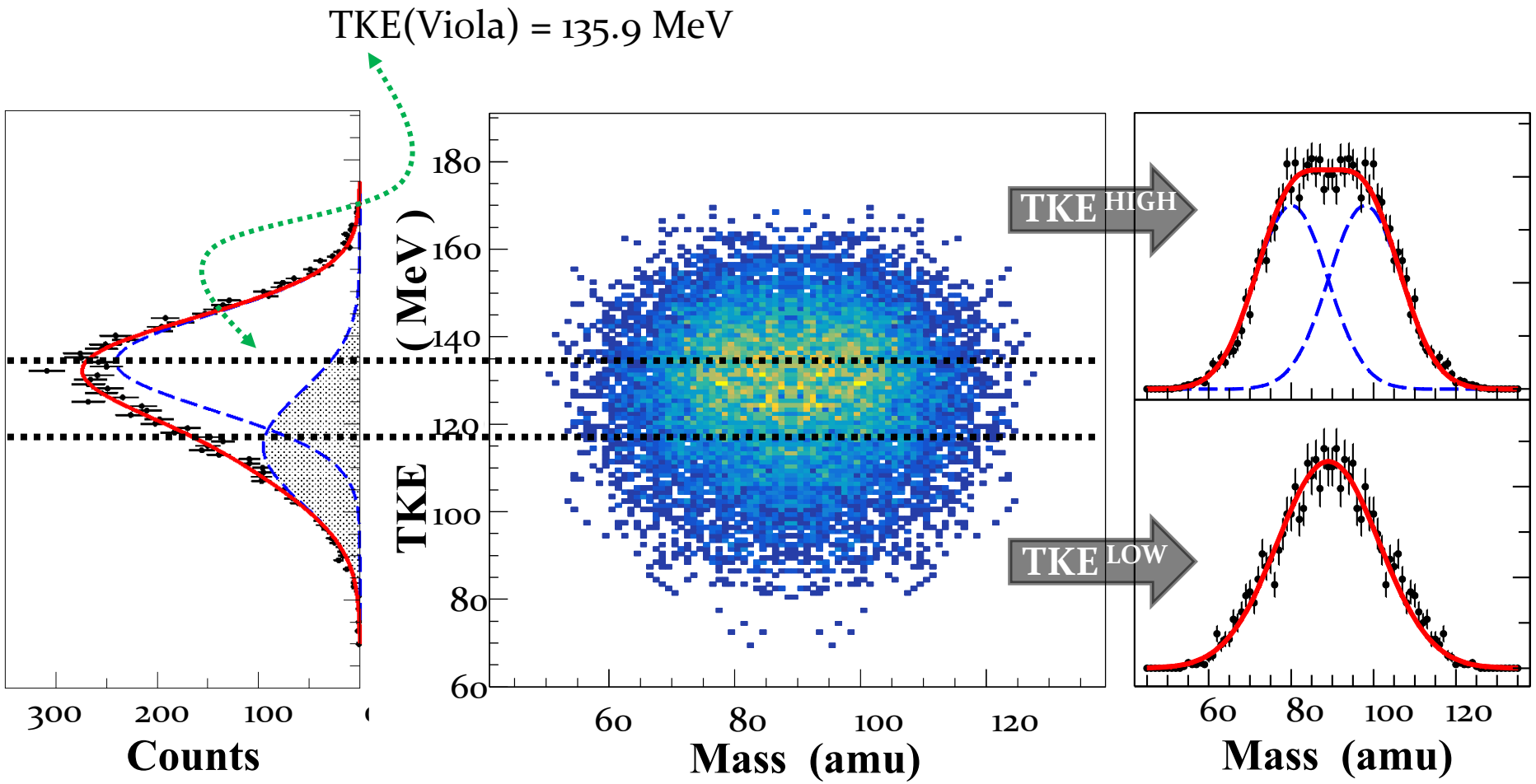
$$A_1 + A_2 = A_{CN} = 178$$

$$\overrightarrow{p_1} = \overrightarrow{p_2}$$

$$\begin{cases} TKE = \dfrac{A_{CN}}{2}\, v_1\, v_2 \\ A_1 v_1 = A_2 v_2 \end{cases}$$

Data acquisition : - digital triggerless --> events to construct

Mode position : Partial Mass Distributions



Asymmetric mode in 178Pt :

in agreement with Viola

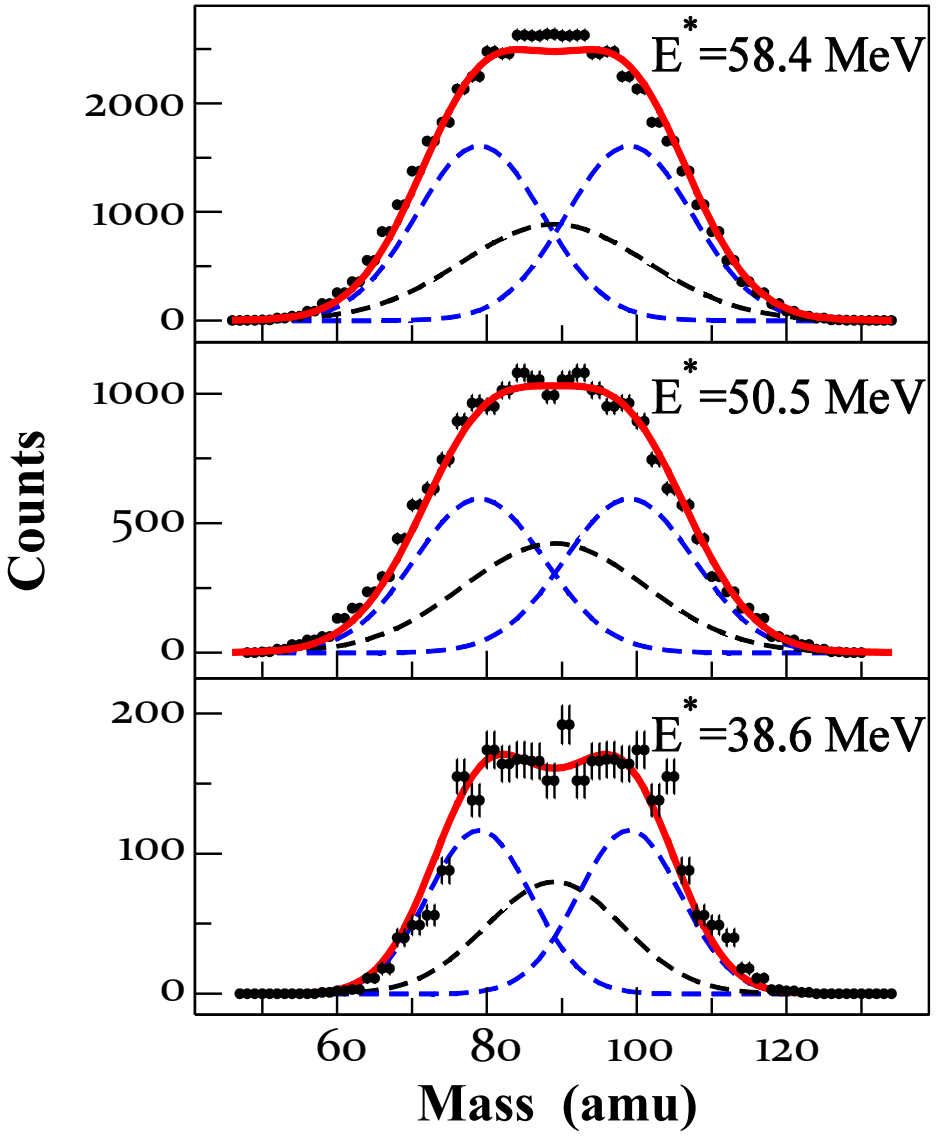
(= **similar to actinides**)

Symmetric mode : $\frac{A_{CN}}{2}$

Asymmetric mode : $A_L = 79$

$A_H = 99$

Results : Fission-Fragment Mass Distributions



(fit with fixed peak positions)

- MD shapes well reproduced
- Symmetric mode is wider

- Symmetric mode yield ~ 30 %

Mode competition:
Challenge for theory !

Fission of ^{178}Pt : PES

Nuclear Density Functional Theory results :

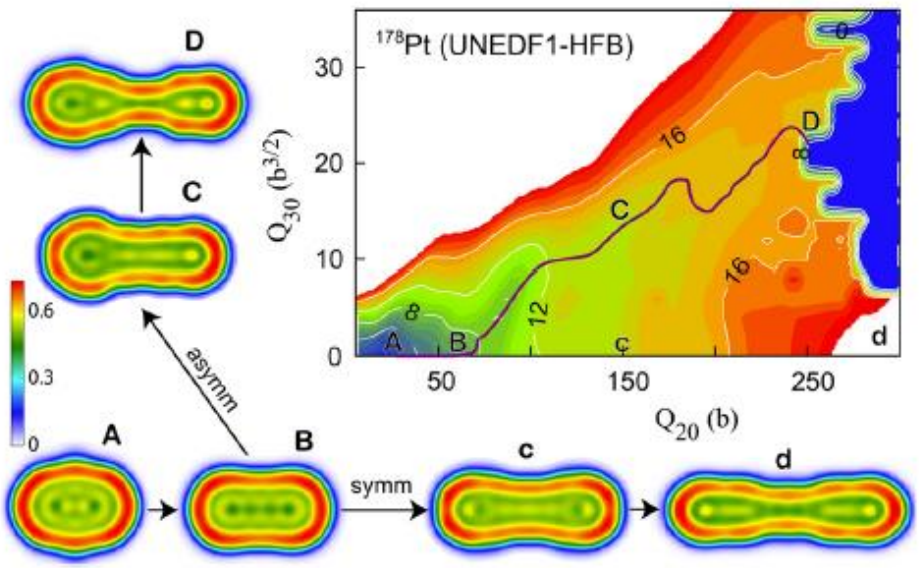


Fig. 3. PES of ^{178}Pt in the (Q_{20}, Q_{30}) plane calculated in UNEDF-HFB. The solid thick line indicates the static fission path obtained by the local minimization of PES. To illustrate the shapes on the way to fission, and the emergent pre-fragments, the neutron localization functions [43,44] corresponding to various intrinsic configurations along the asymmetric (ABCD) and symmetric (ABcd) paths are plotted.

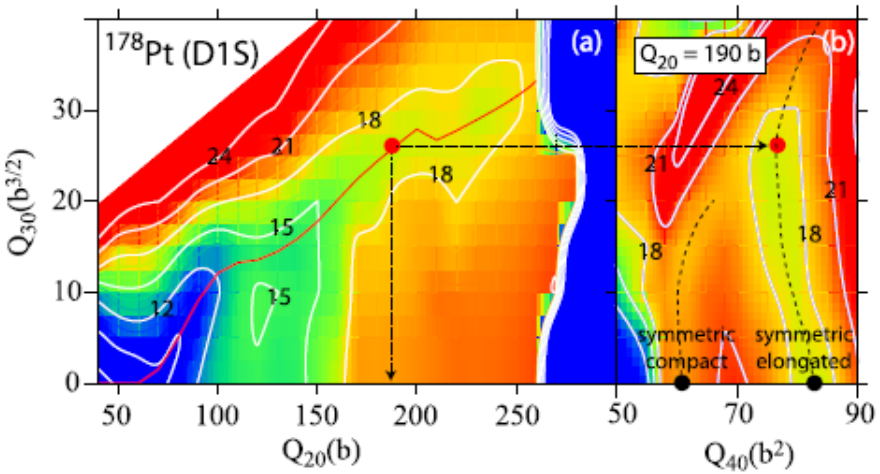


Fig. 4. PES of ^{178}Pt in the (Q_{20}, Q_{30}) plane (a) and in the (Q_{30}, Q_{40}) plane at Q_{20} = 190 b (b) obtained in D1S. The solid thick line in (a) indicates the static fission path obtained by the local minimization of PES. Dashed lines in (b) indicate the symmetric PESs corresponding to compact (smaller Q_{40}) and elongated (larger Q_{40}) fragments. The minimum corresponding to the static fission path in (a) is marked by the red dot.

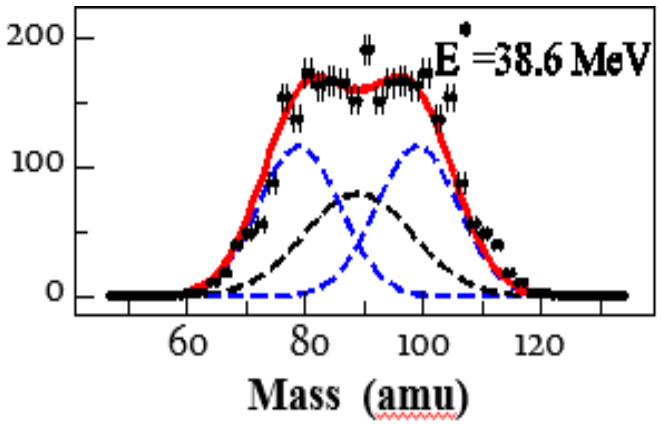
☑ *Most probable division :* **^{80}Br + ^{98}Tc**

☑ *Symmetric division :* **in competition**

By : W. Nazarewich & Team
From: I. Tsekhanovich et al., PLB 2019

Asymmetric fission : systematics on A_L & A_H

(SF & low-energy fission)



- no ^{132}Sn in MDs !

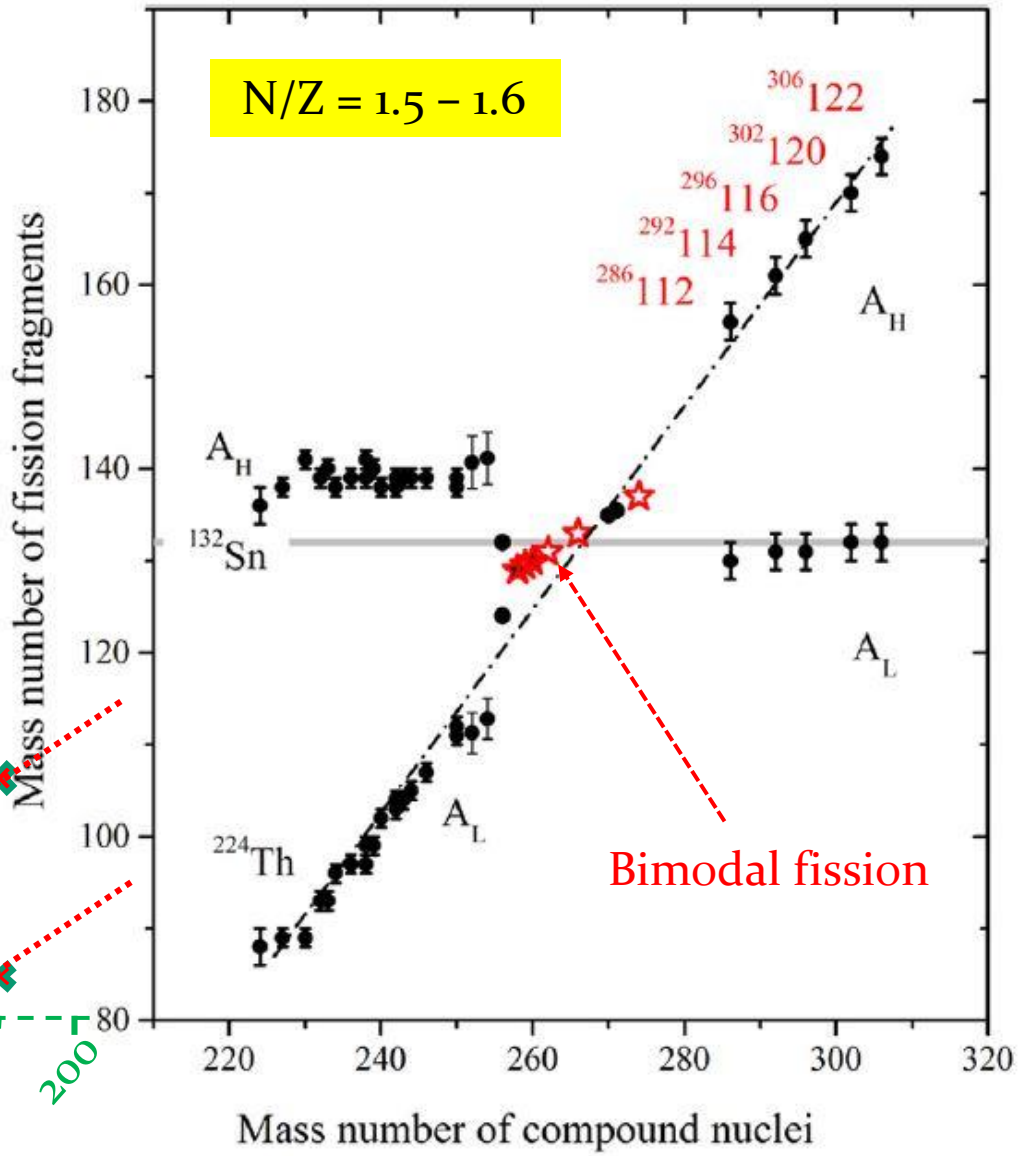
??

Non-stabilized LFF, HFF =
no link to any particular ***N, Z***

N/Z ~ 1.3

M.G. Itkis et al. / Nuclear Physics A 944 (2015) 204–237

N/Z = 1.5 – 1.6



Summary from ^{178}Pt :

- New MED data : Predominantly asymmetric mass distribution
- Co-existing fission modes
- Fission mode properties as in actinides: apparent insensitivity to isospin

Work to do :

- Need for more experimental data in the new island of asymmetric fission :
  i. To establish systematics on yields (LF & HF peak positions)
  ii. Fission mode competition, as function of *N*, *Z* and *Eexc* of CN

New Challenge :

fission studies at ***Eexc ~ Sn***

symmetric fusion reactions :

^{90}Zr + ^{90}Zr → ^{180}Hg*
^{90}Zr + ^{89}Y → ^{179}Au*
^{90}Zr + ^{88}Sr → ^{178}Pt*
^{90}Zr + ^{87}Rb → ^{177}Ir*

JAEA tandem :
Zr beams available !!

Who is involved (^{178}Pt work):

CENBG :

- **S. Czajkowski**
- **B. Jurado**
- **I. Tsekhanovich**

JAEA :

- **K. Nishio**
- **K. Hirose**
- **H. Makii**
- **R. Orlandi**
- **M. Vermeulen**

York University :

- **A. Andreyev**

RIKEN :

- **K. Morimoto**
- **T. Tanaka (& Kyushu University)**
- **K. Morita (& Kyushu University)**

Theory :

- W. Nazarewich (MSU/FRIB, USA)
- Z. Matheson (MSU/FRIB, USA)
- M. Warda (Lublin, Poland)
- J. Sadhukhan (Kolcata, India)

Thank you for your attention !