Mapping Low-Energy Fission in the lead region

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On behalf of βDF@ISOLDE and fission@JAEA Collaborations

- Brief (experimental) review on low-energy fission
- Low-energy fission in the "**new" regions** of Nuclear Chart
- Beta Delayed Fission (βDF) at ISOLDE
- Fusion-fission reactions: excitation energy dependence of fission in the lead region
- Multimodal fission of ^{178}Pt at JAEA

Tsukuba, 10th December 2018

Outlook: Why 'new regions of fission'?
(a short answer – to study isospin dependence of fission)

•Most of previous (and current) fission studies are in the classical region of heavy transactinides (N/Z(^{241}Pu)~1.56)

•Many nuclear properties change far from stability line (e.g. disappearance of traditional magic numbers; appearance of new shell gaps; halos, skins…)

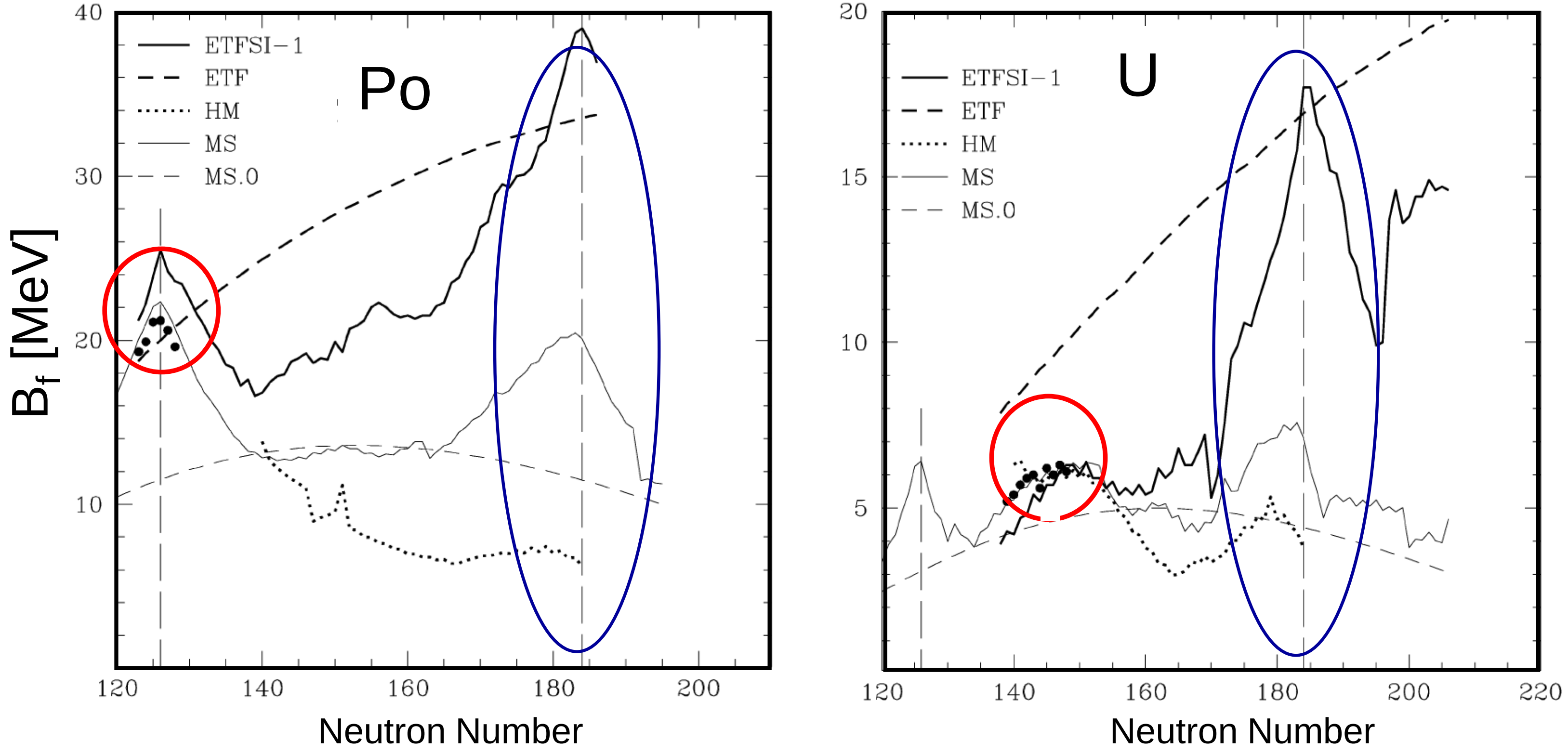
•**What happens to fission far from stability, e.g. on the extremely proton-rich side (as neutron-rich is very difficult to reach at present)**

•Not simple to answer, as to fission these nuclei at **low excitation energy** ($E^*\sim B_f$) is a very challenging task (none fissions from g.s.)

•We run experiments at ISOLDE(CERN) and JAEA tandem **to study fission in proton-rich nuclei in the lead region, with N/Z~1.25-1.3** (yet scarcely studied by fission)

Fission and r-process (or why we need to study isospin dependence of fission)
Fission barrier heights calculations

A. Mamdouh et al. NPA679 (2001), 337



- Good agreement between $B_{f,cal}$ and $B_{f,exp}$ for nuclei close to stability
- Large disagreement far of stability (both on n-def. and n-rich sides)
- Need measured fission data far of stability to 'tune' fission models (see Nishio-san's talk)

Fission and r-process (or why we need to study isospin dependence of fission)

Fission barrier heights calculations

S. Goriely, G. Martínez Pinedo / Nuclear Physics A 944 (2015) 158–176

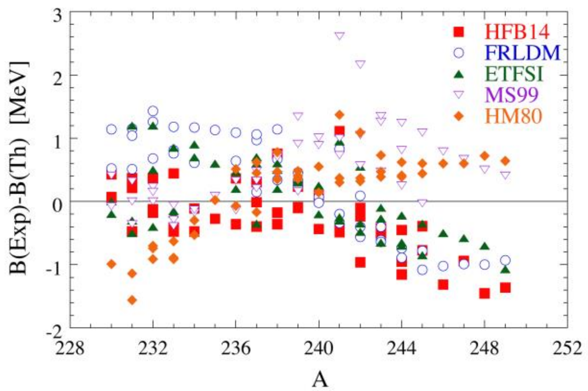


Fig. 1. Deviations between 45 empirical primary fission barriers [71] and those predicted by the HFB-14 [69], FRLDM [68], ETFSI [65], MS99 [66] and HM80 [67] global models for $88 \le Z \le 96$.

Experiment vs Theory

- 45 experimental barriers close to stability
- 5 theory models

Deviation <1 MeV

Theory vs Theory

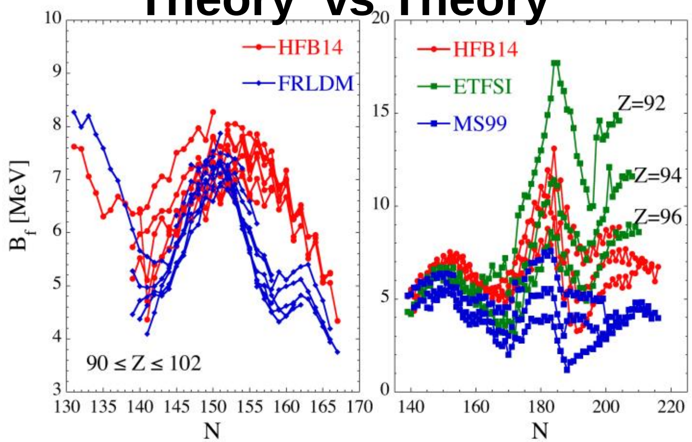
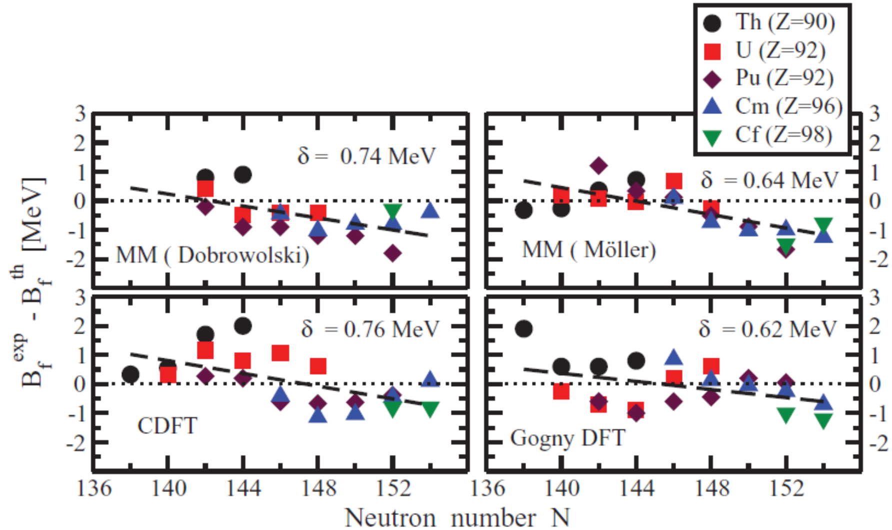


Fig. 2. (Colour online.) *Left*: Comparison between the HFB-14 [69] and FRLDM primary barriers [68] for even Z isotopic chains relatively close to the valley of stability. *Right*: Same for the HFB-14, ETFSI [65] and MS99 model [66] barriers for $Z = 92$, 94 and 96 isotopes up to the neutron drip line.

PHYSICAL REVIEW C **85**, 024314 (2012)

Fission barriers in covariant density functional theory: Extrapolation to superheavy nuclei

H. Abusara,[1,2] A. V. Afanasjev,[1] and P. Ring[3]



Fission and r-process (or why we need to study isospin dependence of fission)

Fission fragments mass distributions models

THE ASTROPHYSICAL JOURNAL, 808:30 (13pp), 2015 July 20 doi:10.1088/0004-637X/808/1/30

THE ROLE OF FISSION IN NEUTRON STAR MERGERS AND ITS IMPACT ON THE *r*-PROCESS PEAKS

M. EICHLER[1], A. ARCONES[2,3], A. KELIC[3], O. KOROBKIN[4], K. LANGANKE[2,3], T. MARKETIN[5], G. MARTINEZ-PINEDO[2,3], I. PANOV[1,6], T. RAUSCHER[1,7], S. ROSSWOG[4], C. WINTELER[8], N. T. ZINNER[9], AND F.-K. THIELEMANN[1]

^{274}Pu(n,f)

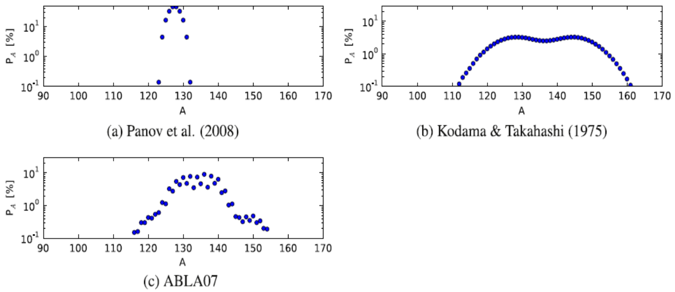


Figure 3. Fission fragment distributions for the models considered in our calculations, here for the case of neutron-induced fission of ^{274}Pu. For this reaction Panov et al. (2008) predict 19 ABLA07-released fission neutrons. Kodama & Takahashi (1975) do not predict any fission neutrons. For Panov et al. (2001) neutrons can be released if the fragments would lie beyond the neutron dripline. The distribution for Panov et al. (2001) consists only of two products with $A_1 = 130$ and $A_2 = 144$.

A=278 (8 isobars)

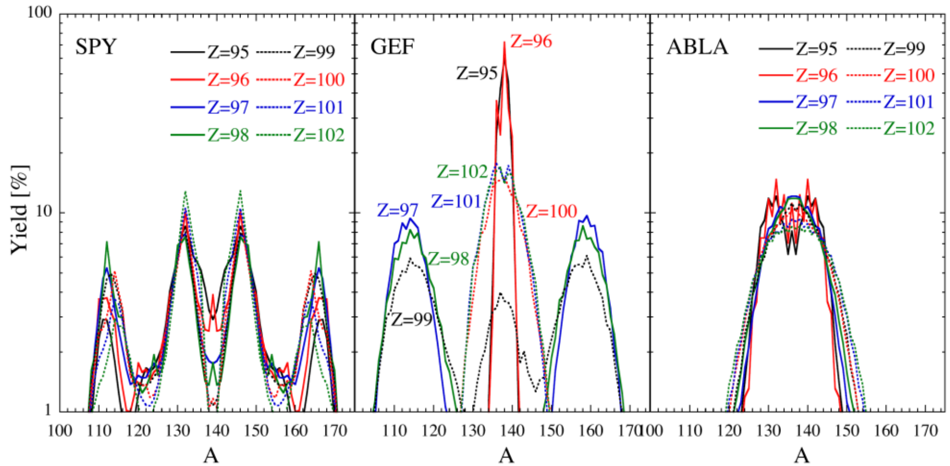
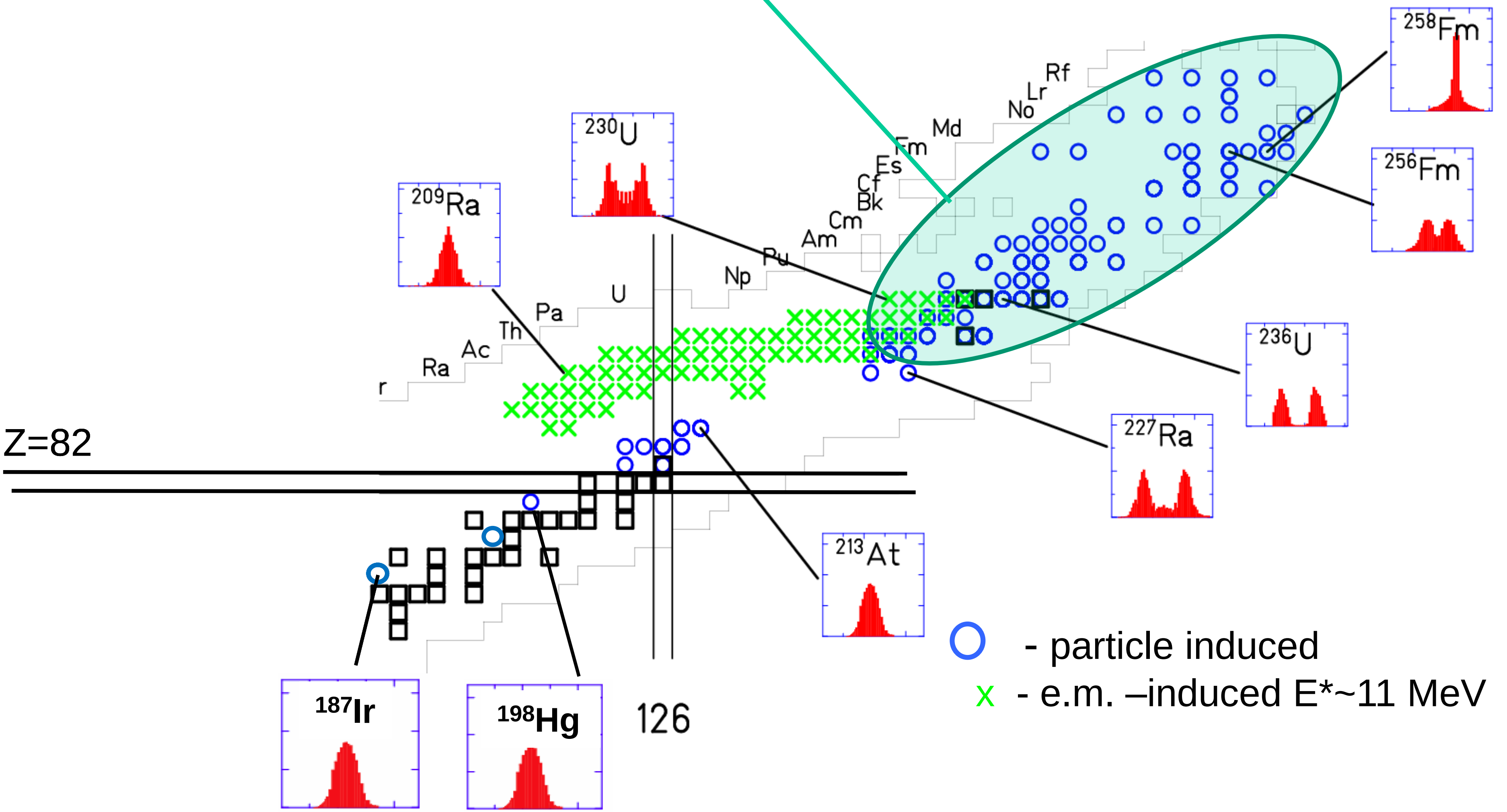


Fig. 5. (Colour online.) FFDs predicted by the SPY (left panel), GEF (middle panel) and ABLA (right panel) models for 8 $A = 278$ isobars. In the SPY case, the 8 FFD have more or less the same 4-humped pattern and in the ABLA case, more or less the same rather symmetrical pattern.

Experimental information on low-energy fission
Nuclei with measured charge/mass split (RIPL-2 + GSI)

Heavy Actinides, N/Z~1.56: predominantly asymmetric; spontaneous fission, fission isomers

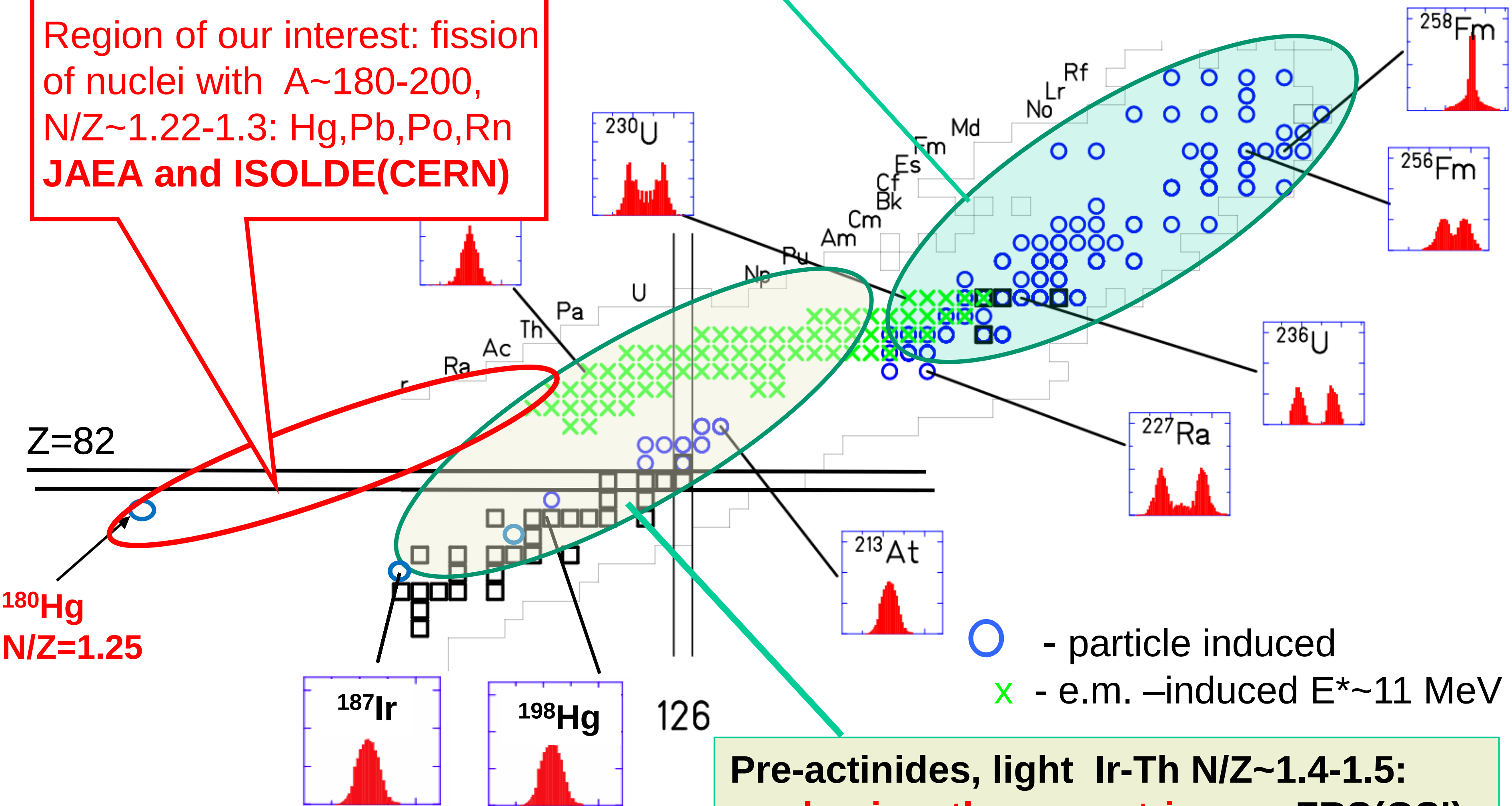


A.N. Andreyev, K. Nishio, K.-H. Schimidt, Reports on Progress in Physics, (2018)

Experimental information on low-energy fission
Nuclei with measured charge/mass split (RIPL-2 + GSI)

Heavy Actinides, N/Z~1.56: predominantly asymmetric; spontaneous fission, fission isomers

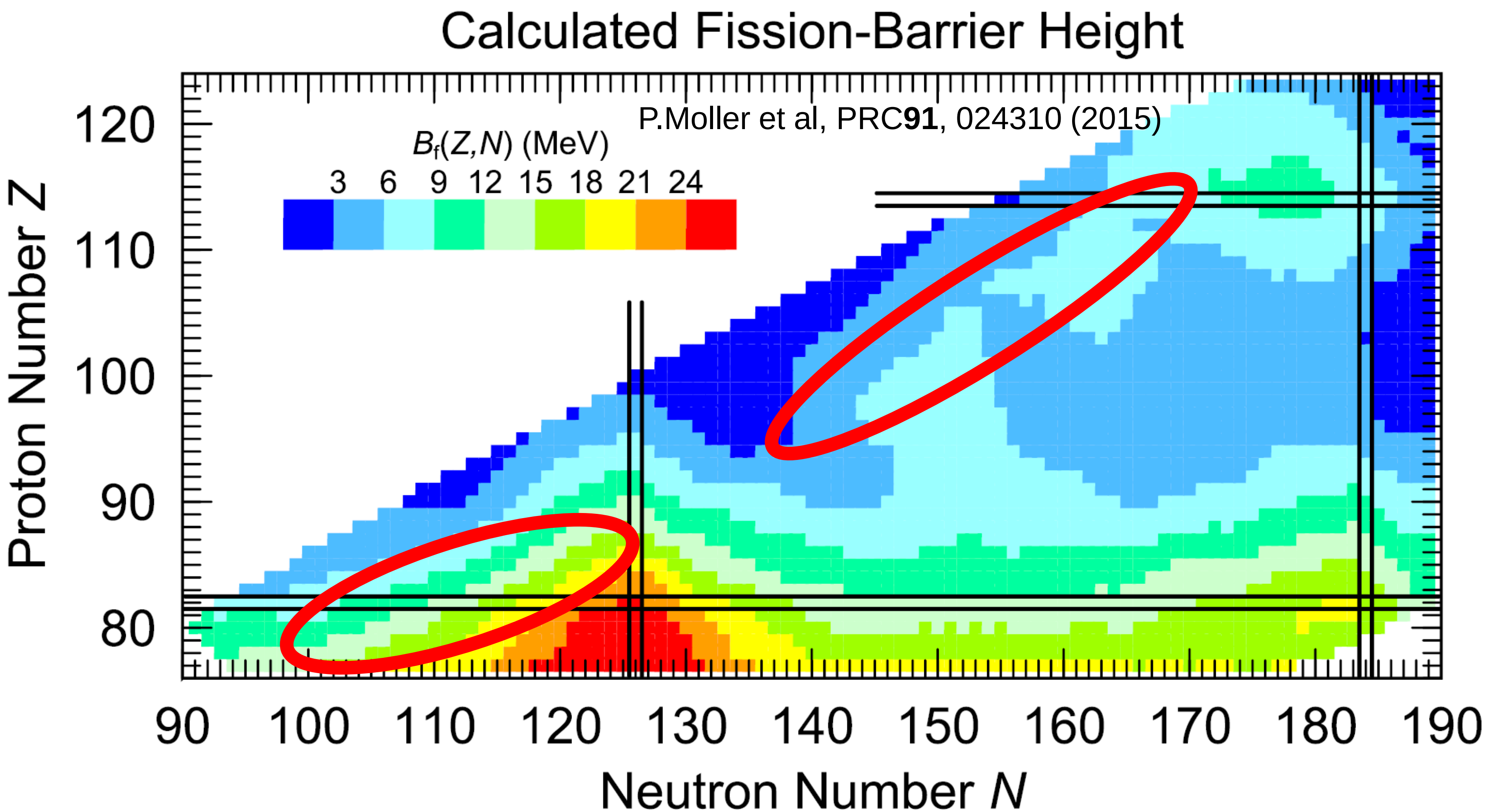
Region of our interest: fission of nuclei with A~180-200, N/Z~1.22-1.3: Hg,Pb,Po,Rn
JAEA and ISOLDE(CERN)



Pre-actinides, light Ir-Th N/Z~1.4-1.5: predominantly symmetric, e.g. FRS(GSI)

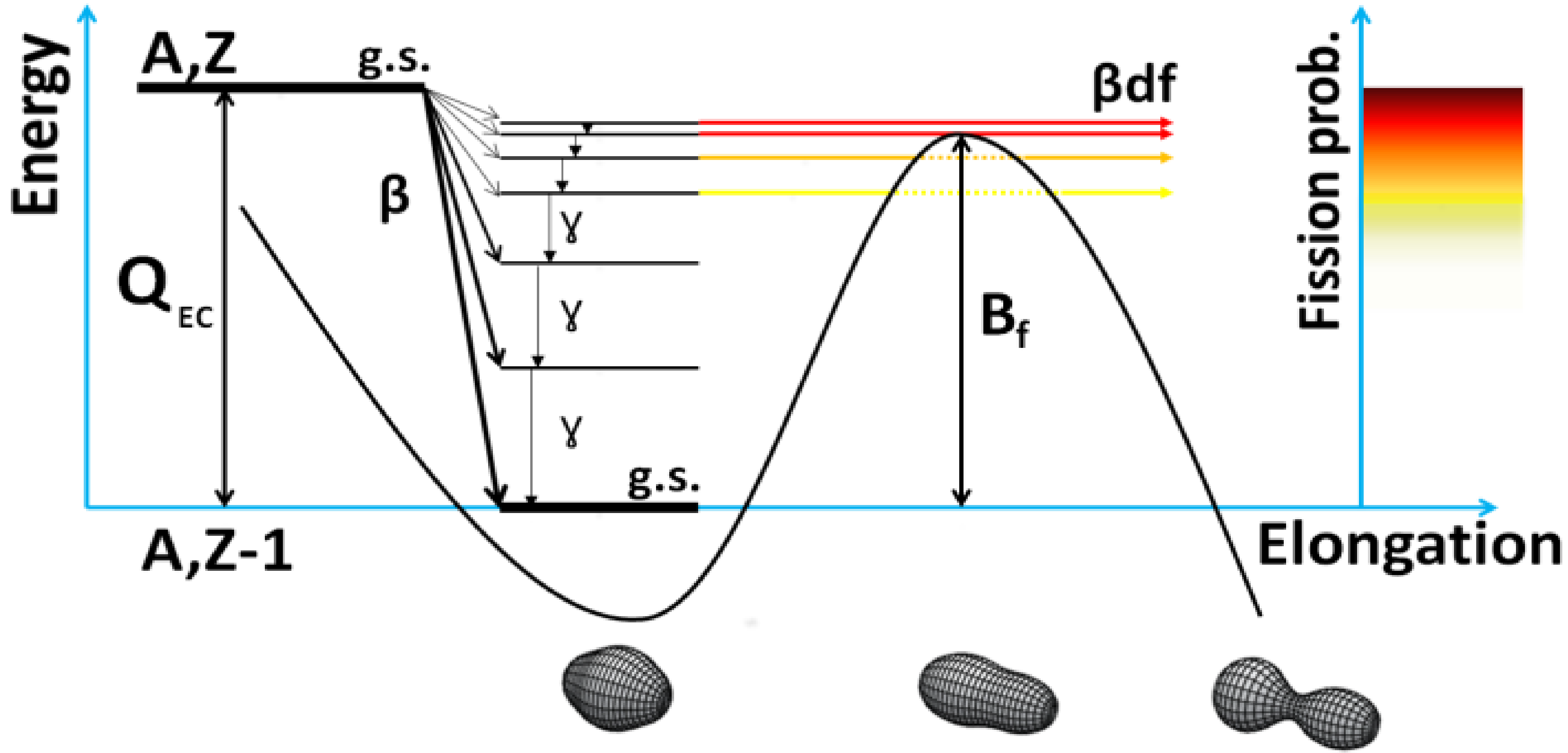
A.N. Andreyev, K. Nishio, K.-H. Schmidt, Reports on Progress in Physics (2

Fission in the light Pb region and in heavy actinides: what differences could be expected?



- Different values of N/Z~1.25-1.3 for the lead region, N/Z~1.55 for transuraniums.
- **Very different fission barriers heights**, >8 MeV for lead region, a few MeV for actinides
- **Shell effects and PES?** No influence of ^{132}Sn in the lead region.
- **Possibly different excitation energy dependence of shell effects/barriers**?

Beta-Delayed Fission
(belived to be of importance for r-process)



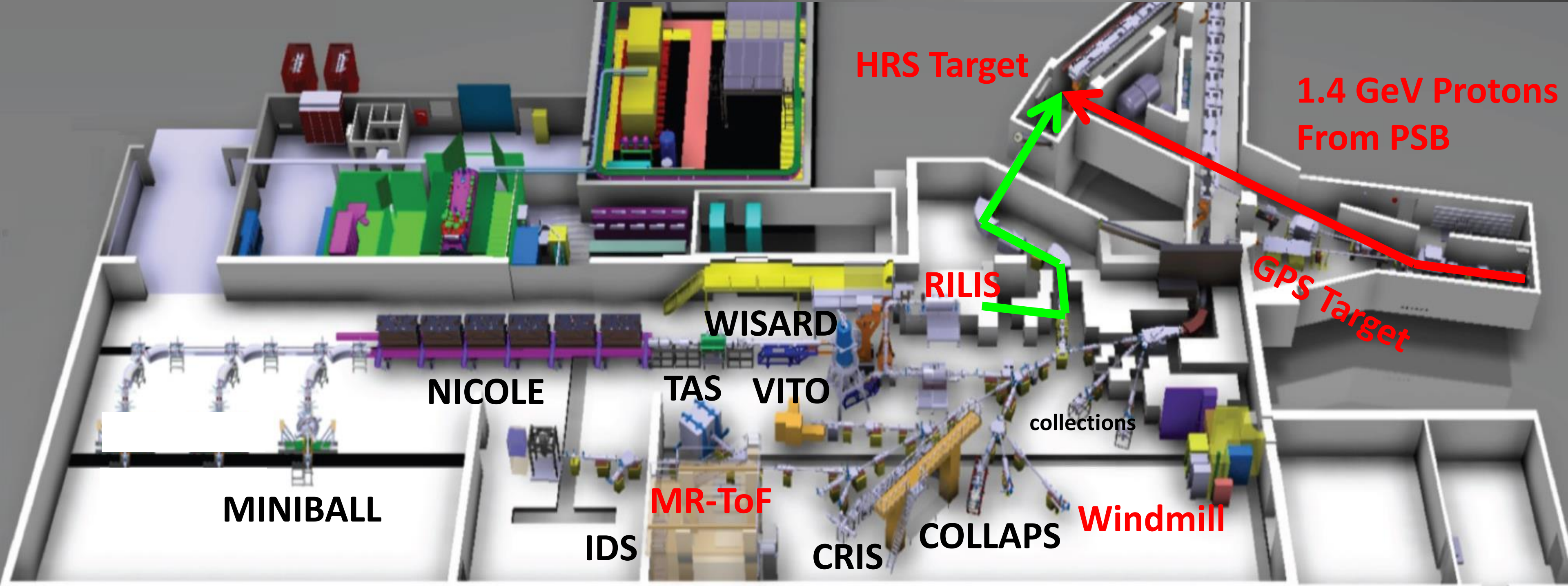
- Two step process: β decay followed by fission
- Low-energy fission (E*~3-12 MeV, limited by Q_{EC})

  e.g. ^{180}Tl: Q_{EC}=10.4 MeV, $B_{f,calc}$=9.8 MeV
- Low angular momentum of the state (easier for theory calculatons

  e.g. ^{180}Tl: I=4 or 5 (some cases: up to 10)

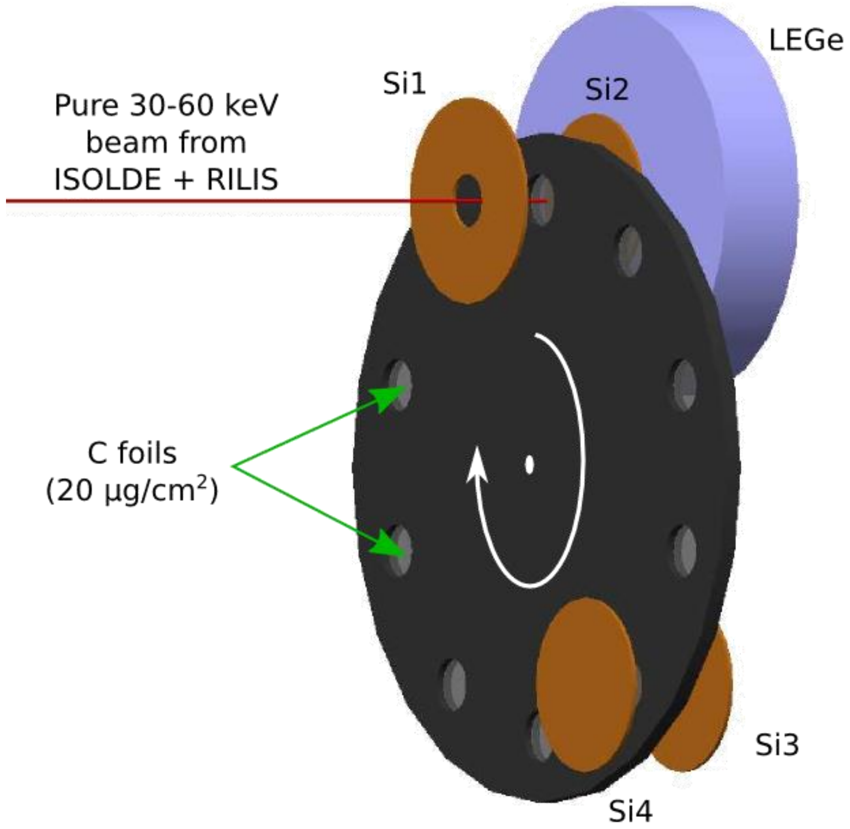
A.N. Andreyev, M. Huyse, P. Van Duppen, Reviews of Modern Physics, 85, 1541 (2013)

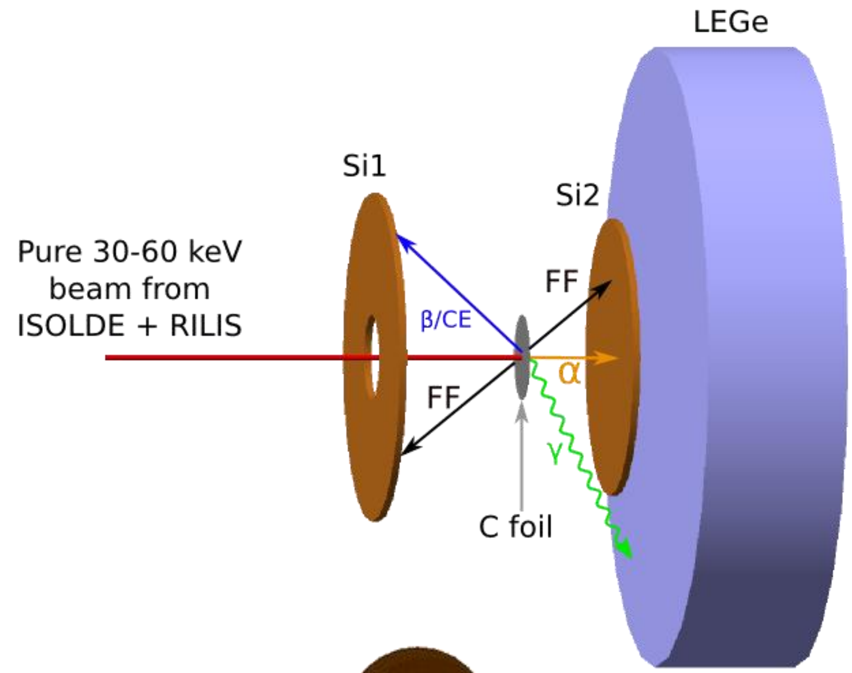
The ISOLDE facility at CERN



Detection system for βDF studies at ISOLDE

A.N. Andreyev et al. PRL 105 (2010)



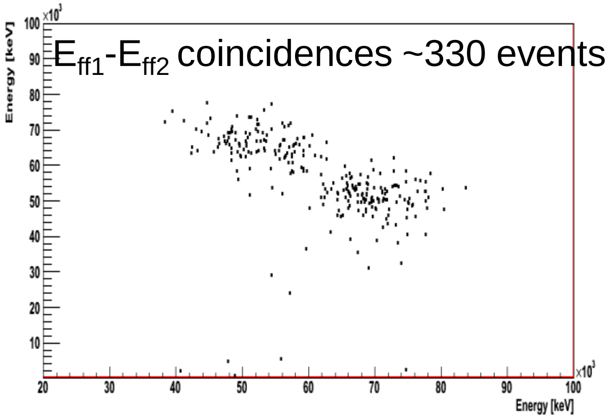


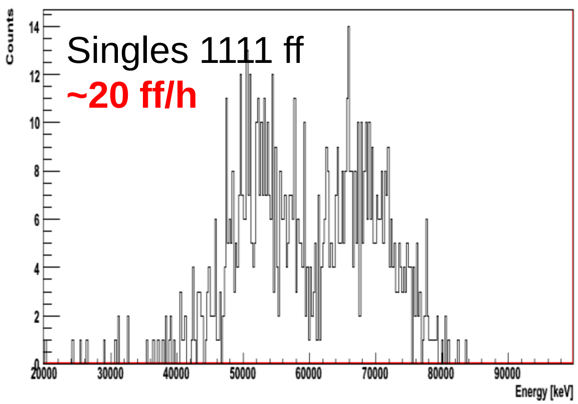
Setup: Si detectors both sides of the C-foil

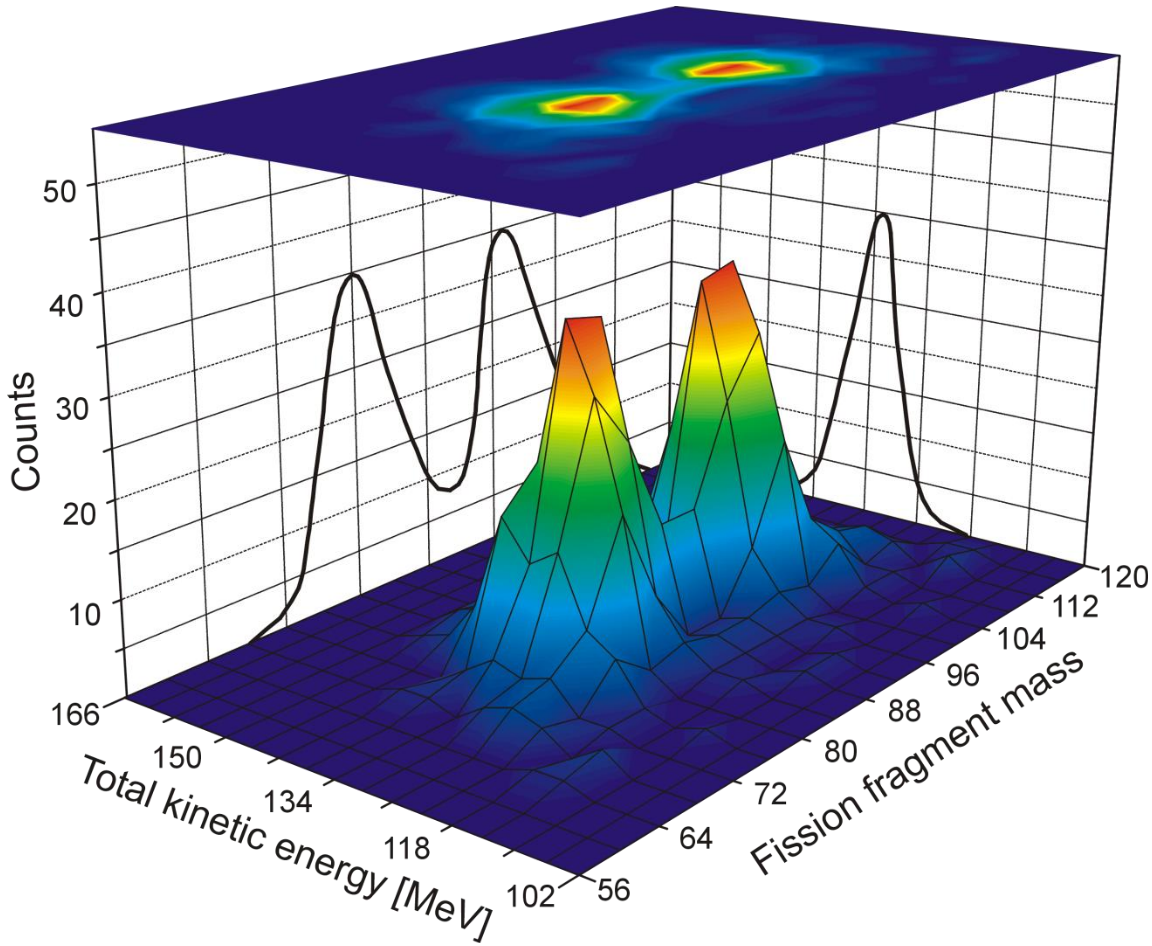
- Simple setup & DAQ: 2 Surface barrier detectors (1 of them – annular) and 2 PIPS detectors.
- 34% geometrical efficiency at implantation site.
- Alpha-gamma coincidences

Mass distribution of fission fragments from ^{180}Hg (βDF of ^{180}Tl) (would one get $2\times{}^{90}Zr$?)

ASYMMETRIC energy split! Thus asymmetric mass split: M_H=100(4) and M_L= 80(4)







A problem: “low-energy” FF’s - 1 AMeV only, A and Z identification difficult
The most probable fission fragments are ^{100}Ru (N=56,Z=44) and ^{80}Kr (N=44,Z=36)

New Type of Asymmetric Fission in Proton-Rich Nuclei

PRL **105,** 252502 (2010) PHYSICAL REVIEW LETTERS week ending 17 DECEMBER 2010

New Type of Asymmetric Fission in Proton-Rich Nuclei

A. N. Andreyev,[1,2] J. Elseviers,[1] M. Huyse,[1] P. Van Duppen,[1] S. Antalic,[3] A. Barzakh,[4] N. Bree,[1] T. E. Cocolios,[1] V. F. Comas,[5] J. Diriken,[1] D. Fedorov,[4] V. Fedosseev,[6] S. Franchoo,[7] J. A. Heredia,[5] O. Ivanov,[1] U. Köster,[8] B. A. Marsh,[6] K. Nishio,[9] R. D. Page,[10] N. Patronis,[1,11] M. Seliverstov,[1,4] I. Tsekhanovich,[12,17] P. Van den Bergh,[1] J. Van De Walle,[6] M. Venhart,[1,3] S. Vermote,[13] M. Veselsky,[14] C. Wagemans,[13] T. Ichikawa,[15] A. Iwamoto,[9] P. Möller,[16] and A. J. Sierk[16]

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[2]*School of Engineering, University of the West of Scotland, Paisley, PA1 2BE, United Kingdom, and the Scottish Universities Physics Alliance (SUPA*

βDF of ^{180}Tl – fissioning nucleus is ^{180}Hg

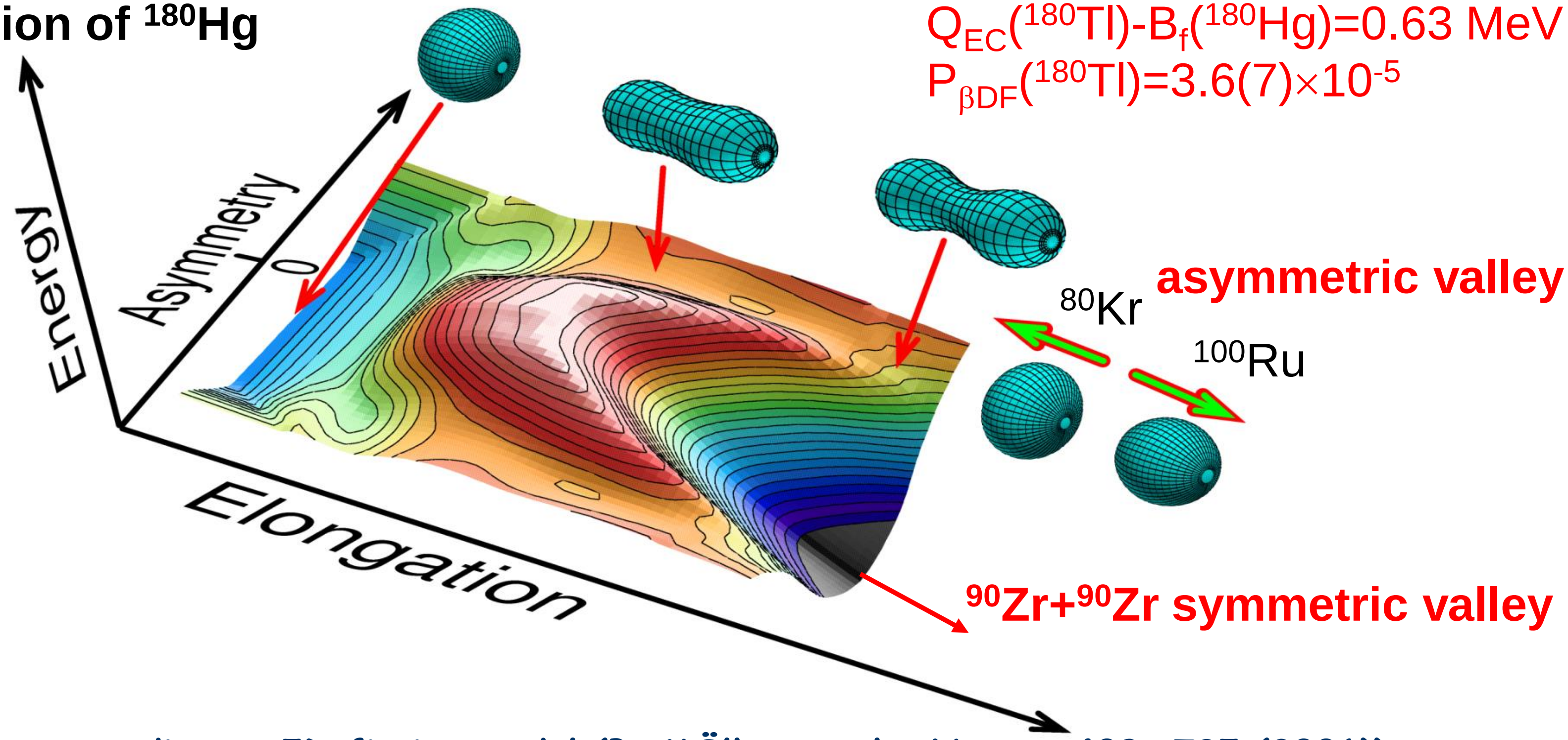
$Q_{EC}(^{180}Tl)=E^*_{max}=10.44$ MeV

$B_f(^{180}Hg)=9.8$ MeV (Moller)

$Q_{EC}(^{180}Tl)-B_f(^{180}Hg)=0.63$ MeV

$P_{\beta DF}(^{180}Tl)=3.6(7)\times10^{-5}$

Fission of ^{180}Hg



Calculations according to 5D fission model (P. MÖller et al., Nature 409, 785 (2001))

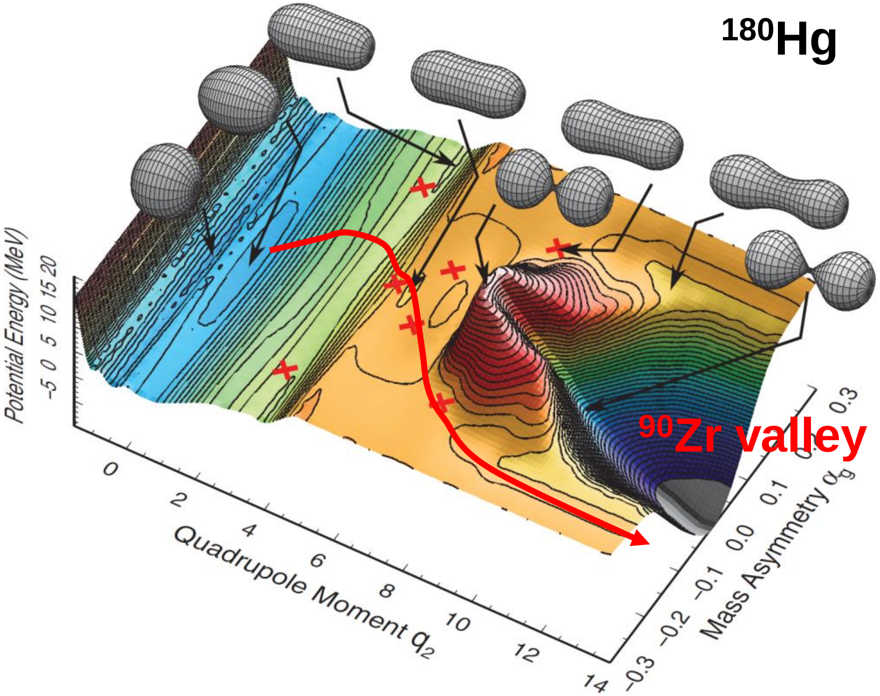
Two types of fission asymmetry: what's the difference?

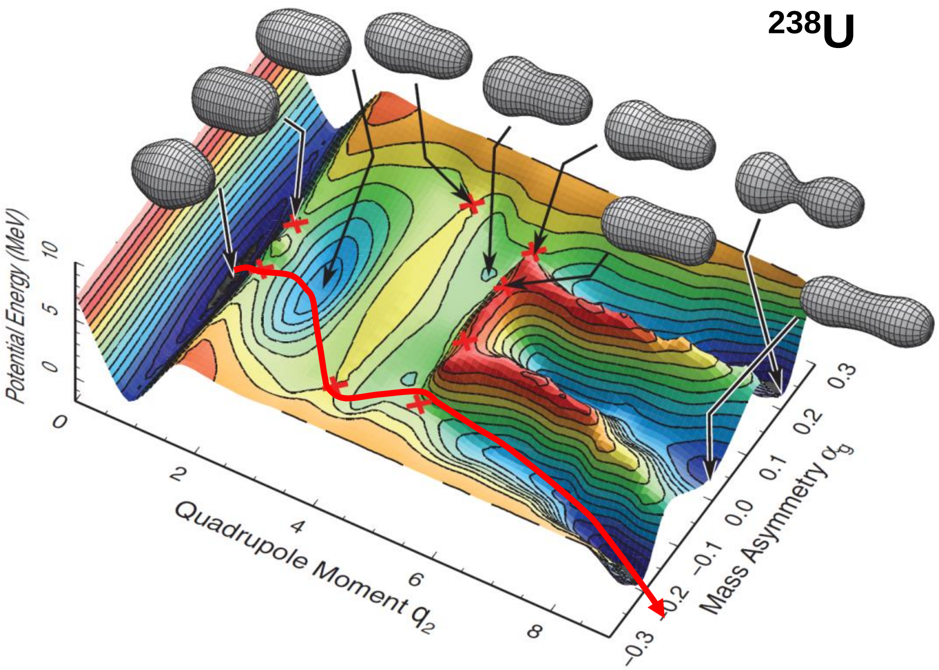
PHYSICAL REVIEW C **86**, 024610 (2012)

Contrasting fission potential-energy structure of actinides and mercury isotopes

Takatoshi Ichikawa,[1] Akira Iwamoto,[2] Peter Möller,[3] and Arnold J. Sierk[3]

Conclusions: The mechanism of asymmetric fission must be very different in the lighter proton-rich mercury isotopes compared to the actinide region and is apparently unrelated to fragment shell structure. Isotopes lighter than ^{192}Hg have the saddle point shielded from a deep symmetric valley by a significant ridge. The ridge vanishes for the heavier Hg isotopes, for which we would expect a qualitatively different asymmetry of the fragments.





Brownian Metropolis Shape Motion

based on J. Randrup and P. Moller, PRL 106, 132503 (2011)

Phys. Rev. C 85, 024306 (2012)

Calculated fission yields of neutron-deficient mercury isotopes

Peter Möller[1],* Jørgen Randrup[2], and Arnold J. Sierk[1]
[1] *Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*
[2] *Nuclear Science Division, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
(Dated: November 21, 2011)

The recent unexpected discovery of asymmetric fission of ^{180}Hg following the electron-capture decay of ^{180}Tl has led to intense interest in experimentally mapping the fission-yield properties over more extended regions of the nuclear chart and compound-system energies. We present here a first calculation of fission-fragment yields for neutron-deficient Hg isotopes, using the recently developed Brownian Metropolis shape motion treatment. The results for ^{180}Hg are in approximate agreement with the experimental data. For ^{174}Hg the symmetric yield increases strongly with decreasing energy, an unusual feature, which would be interesting to verify experimentally.
PACS numbers: 25.85.-w, 24.10.Lx,24.75.+i

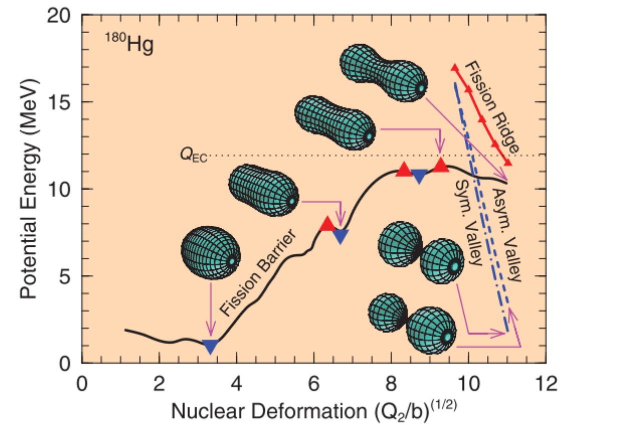
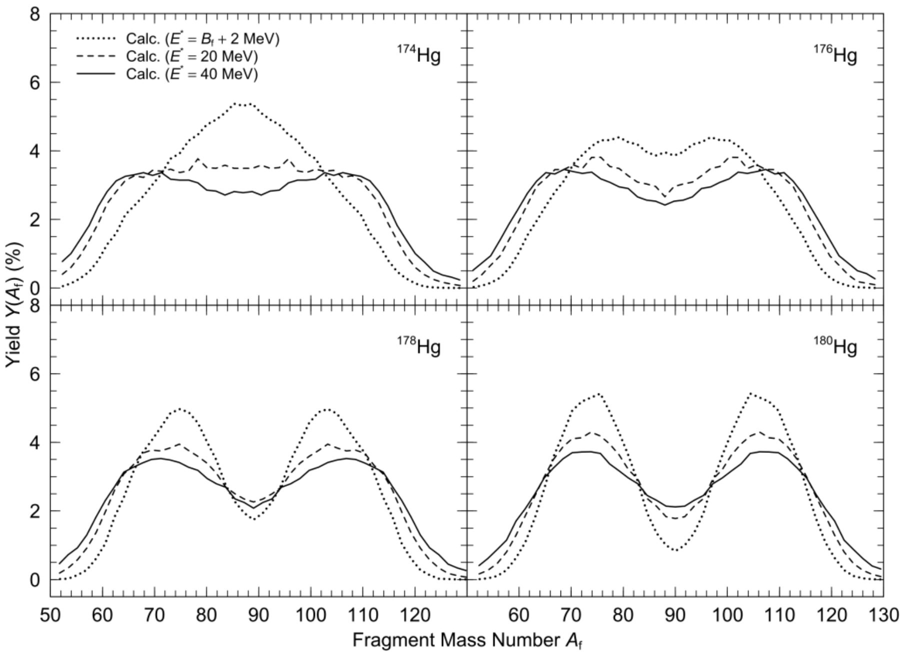
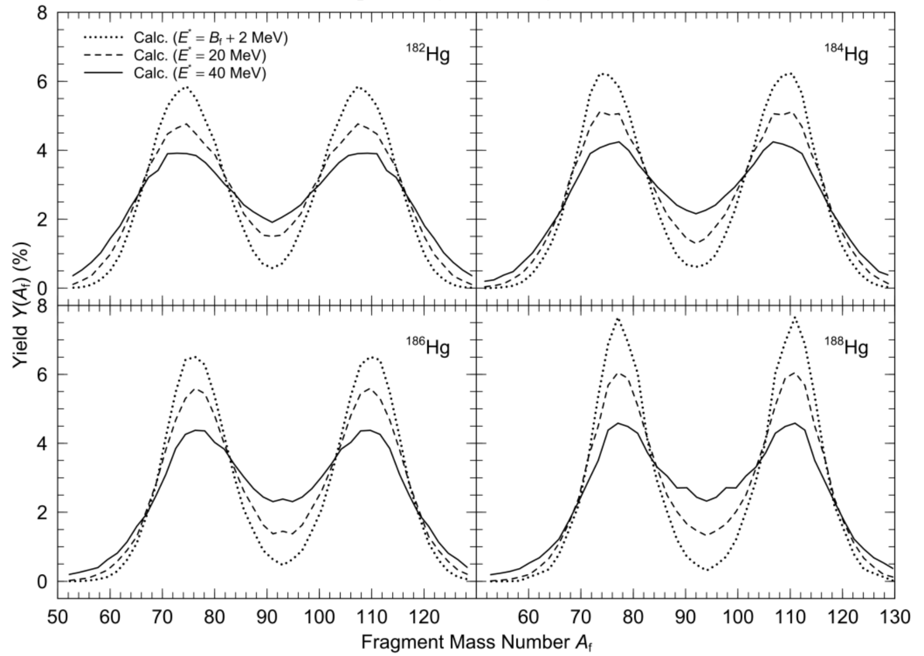


FIG. 4. (Color online) Minima, saddles, major valleys, and ridges in the 5D potential-energy surface of ^{180}Hg (see text). At the last plotted point on the fission barrier, $(Q_2/\mathrm{b})^{(1/2)} \approx 11$, the asymmetry of the shape is $A_\mathrm{H}/A_\mathrm{L} = 108/72$.





'Improved' Scission-Point Model

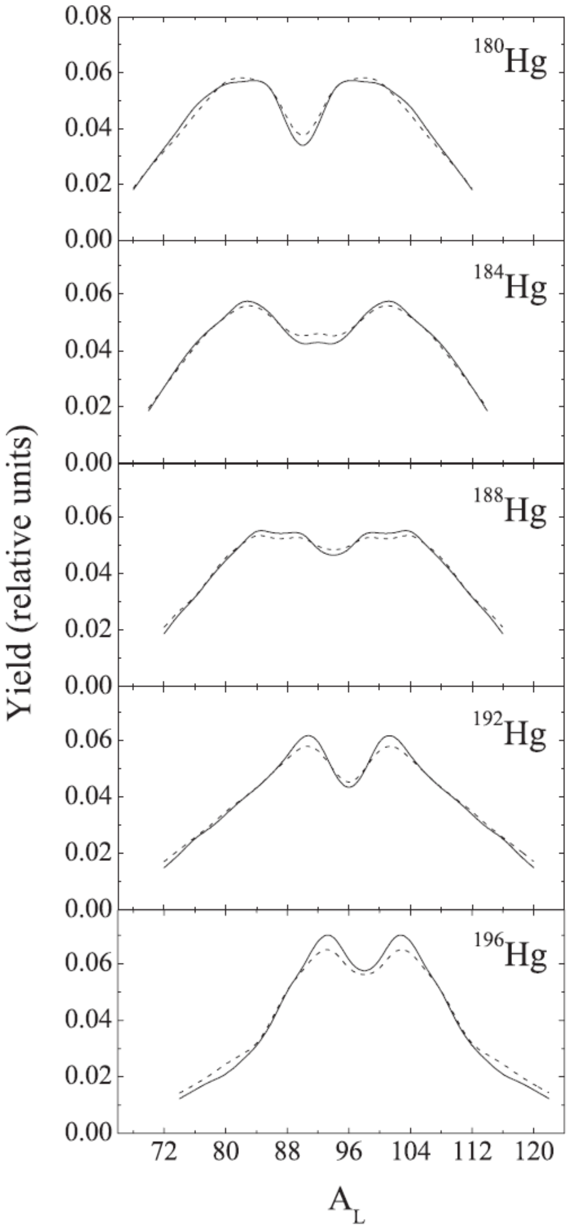
PHYSICAL REVIEW C **86**, 044315 (2012)

Mass distributions for induced fission of different Hg isotopes

A. V. Andreev, G. G. Adamian, and N. V. Antonenko
Joint Institute for Nuclear Research, 141980 Dubna, Russia

(Received 20 June 2012; revised manuscript received 6 September 2012; published 11 October 2012)

With the improved scission-point model mass distributions are calculated for induced fission of different Hg isotopes with even mass numbers $A = 180, 184, 188, 192, 196$, and 198. The calculated mass distribution and mean total kinetic energy of fission fragments are in good agreement with the existing experimental data. The asymmetric mass distribution of fission fragments of ^{180}Hg observed in the recent experiment is explained. The change in the shape of the mass distribution from asymmetric to more symmetric is revealed with increasing A of the fissioning ^{A}Hg nucleus, and reactions are proposed to verify this prediction experimentally.



- Inter-fragment distance is not fixed and calculated.
- values of ~0.5-1 fm result (Wilkins – fixed at 1.4 fm)

- Mass symmetry/asymmetry doesn't change as a function of E* (up to E*~60 MeV) – good for future experiments

'Self-consistent Scission-Point Model'

PHYSICAL REVIEW C **86**, 064601 (2012)

Role of deformed shell effects on the mass asymmetry in nuclear fission of mercury isotopes

Stefano Panebianco, Jean-Luc Sida, Héloïse Goutte, and Jean-François Lemaître
IRFU/Service de Physique Nucléaire, CEA Centre de Saclay, F-91191 Gif-sur-Yvette, France

Noël Dubray and Stéphane Hilaire
CEA, DAM, DIF, F-91297, Arpajon, France
(Received 9 October 2012; published 3 December 2012)

$$E_{\mathrm{av}}(Z_{1,2}, N_{1,2}, \beta_{1,2}, d) \\ = E_{\mathrm{tot}} - E_{\mathrm{HFB}}(Z_1, N_1, \beta_1) - E_{\mathrm{HFB}}(Z_2, N_2, \beta_2) \\ - E_{\mathrm{nucl}}(Z_{1,2}, N_{1,2}, \beta_{1,2}, d) - E_{\mathrm{Coul}}(Z_{1,2}, N_{1,2}, \beta_{1,2}, d).$$

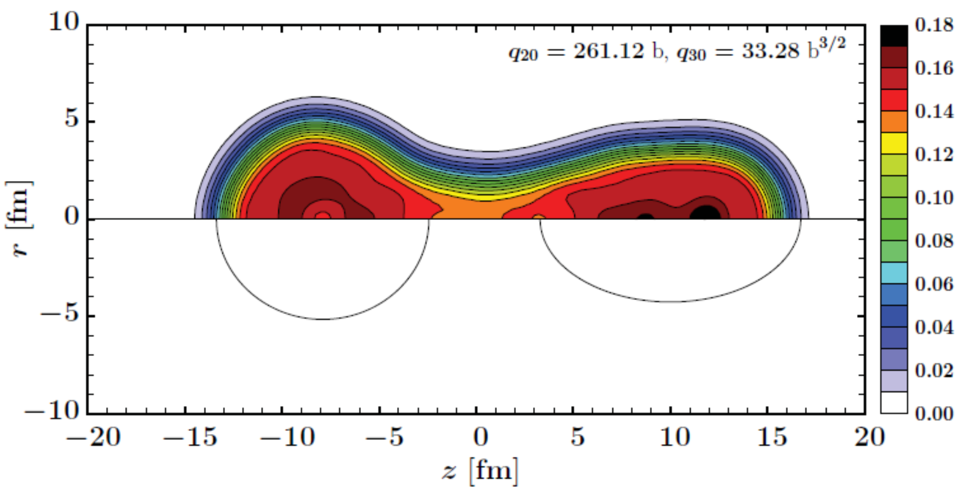


FIG. 4. (Color online) Total nuclear density for the most energetically favorable scission configuration in ^{180}Hg fission, extracted from a self-consistent HFB calculation. In the lower part of the figure, two

^{180}Hg

^{198}Hg

^{235}U(n_{th}.f)

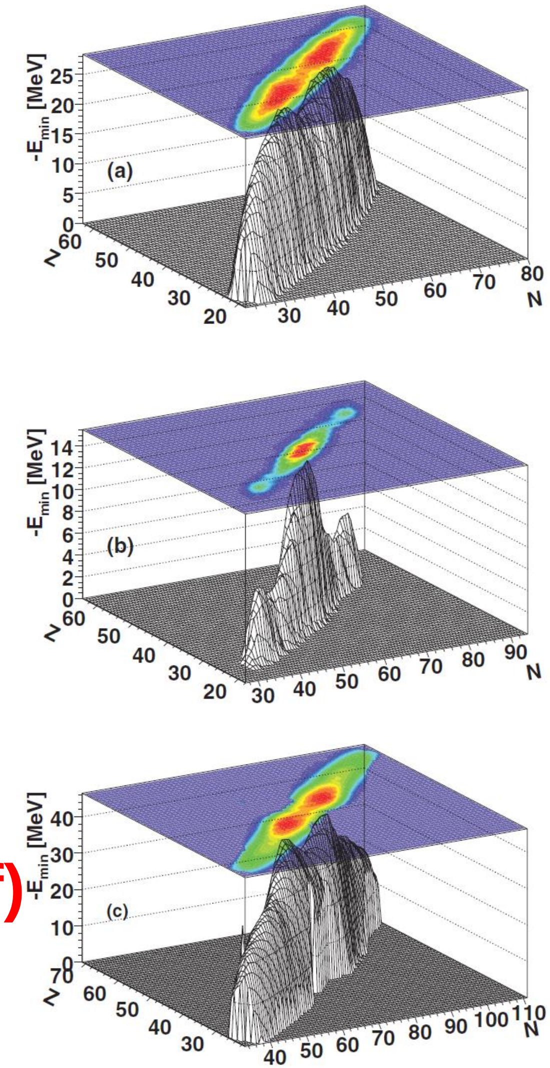


FIG. 2. (Color online) Minimum absolute available energy at scission calculated for all possible fragmentations in (a) ^{180}Hg and (b) ^{198}Hg fission at 10 MeV and in (c) the thermal n-induced fission of ^{235}U.

Mean-field HFB-D1S and HFB-SkM*

PHYSICAL REVIEW C **86**, 024601 (2012)

Fission modes of mercury isotopes

M. Warda,[1] A. Staszczak,[1,2,3] and W. Nazarewicz[2,3,4]

PHYSICAL REVIEW C **90**, 021302(R) (2014)

Excitation-energy dependence of fission in the mercury region

J. D. McDonnell,[1,2] W. Nazarewicz,[2,3,4] J. A. Sheikh,[2,3,5] A. Staszczak,[2,6] and M. Warda[6]

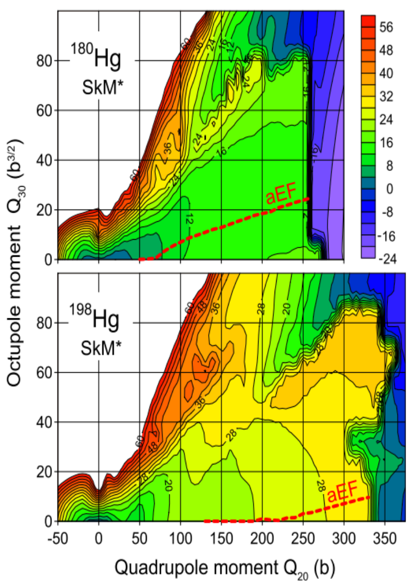


FIG. 2. (Color online) PES for ^{180}Hg (top) and ^{198}Hg (bottom) in the plane of collective coordinates $Q_{20}-Q_{30}$ in HFB-SkM*. The aEF fission pathway corresponding to asymmetric elongated fragments is marked. The difference between contour lines is 4 MeV. The effects due to triaxiality, known to impact inner fission barriers in the actinides, are negligible here.

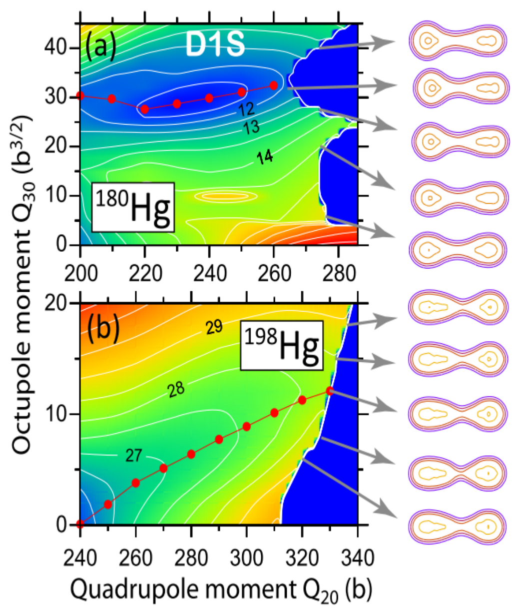
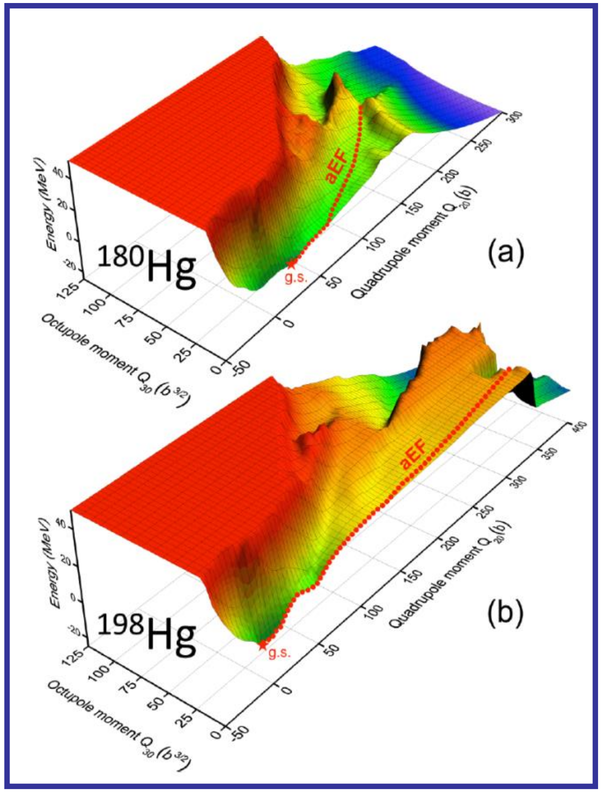


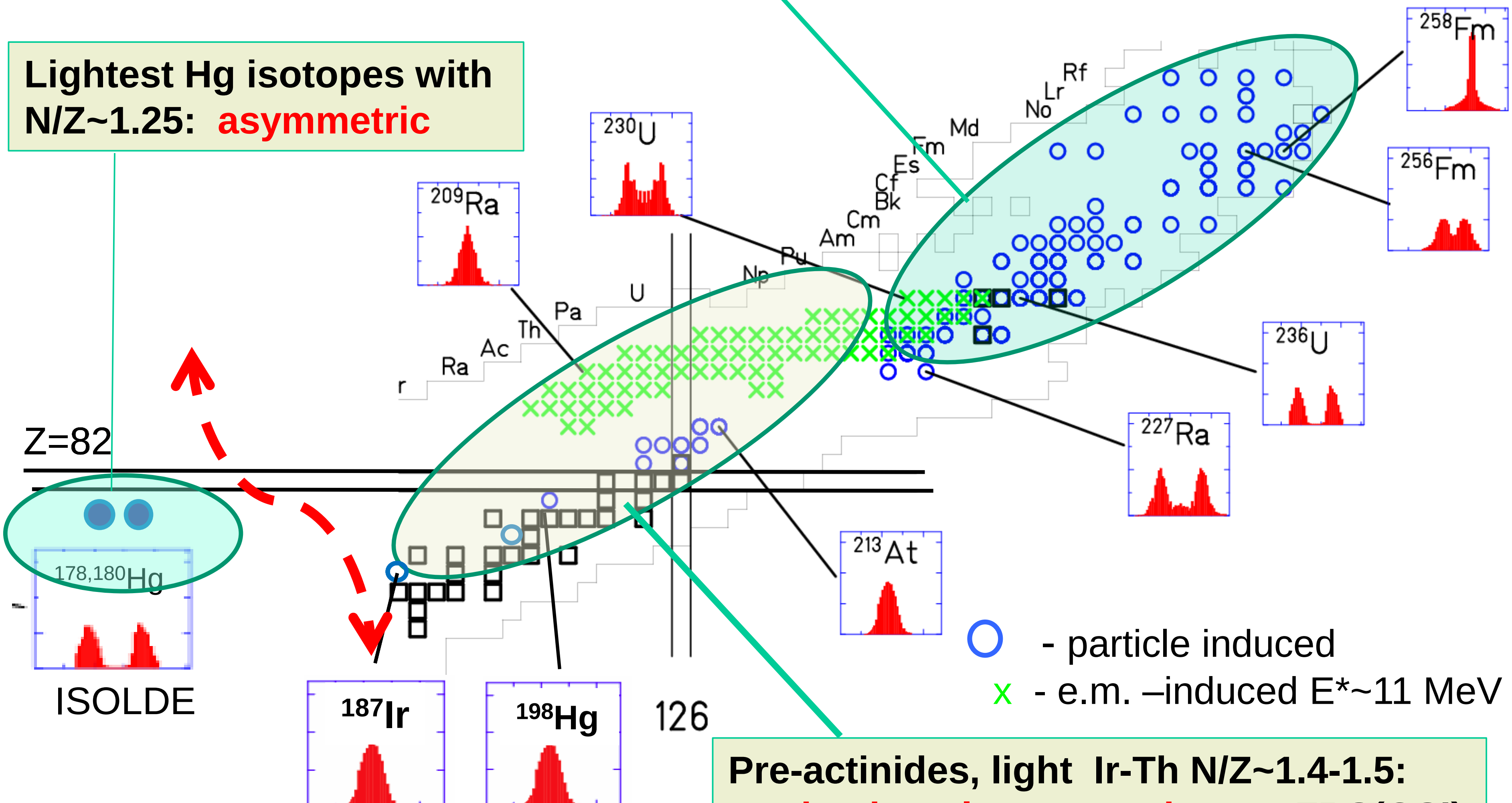
FIG. 3. (Color online) PES in HFB-D1S for ^{180}Hg (top) and ^{198}Hg (bottom) in the (Q_{20}, Q_{30}) plane in the pre-scission region of aEF valley. The symmetric limit corresponds to $Q_{30} = 0$. The aEF valley and density profiles for pre-scission configurations are indicated. The difference between contour lines is 0.5 MeV. Note different Q_{30}-scales in ^{180}Hg and ^{198}Hg plots.



From Asymmetry to Symmetry

Heavy Actinides, N/Z~1.56: predominantly asymmetric; spontaneous fission, fission isomers

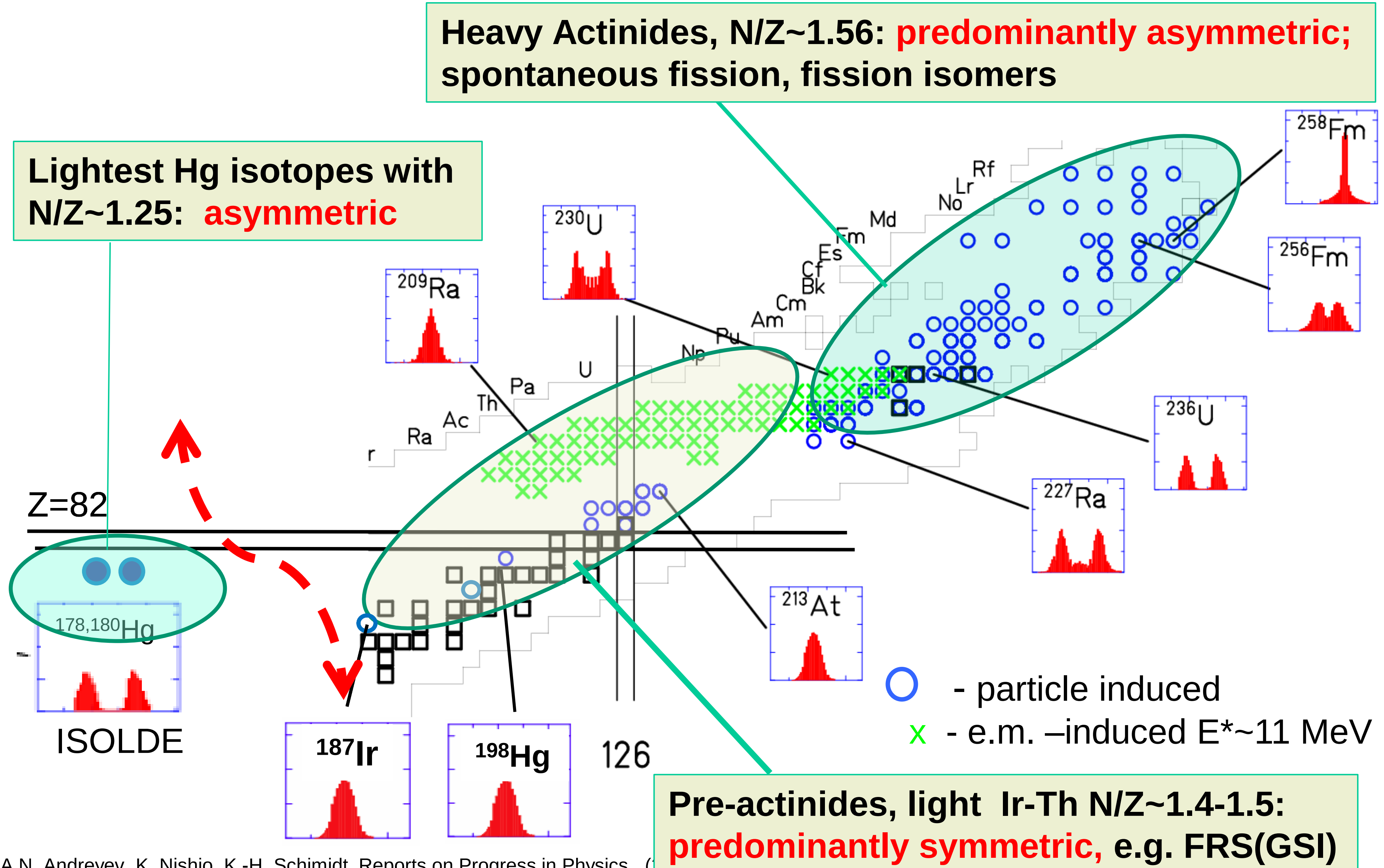
Lightest Hg isotopes with N/Z~1.25: asymmetric



Pre-actinides, light Ir-Th N/Z~1.4-1.5: predominantly symmetric, e.g. FRS(GSI)

A.N. Andreyev, K. Nishio, K.-H. Schmidt, Reports on Progress in Fission, (2

From Asymmetry to Symmetry



A.N. Andreyev, K. Nishio, K.-H. Schimidt, Reports on Progress in Physics, (

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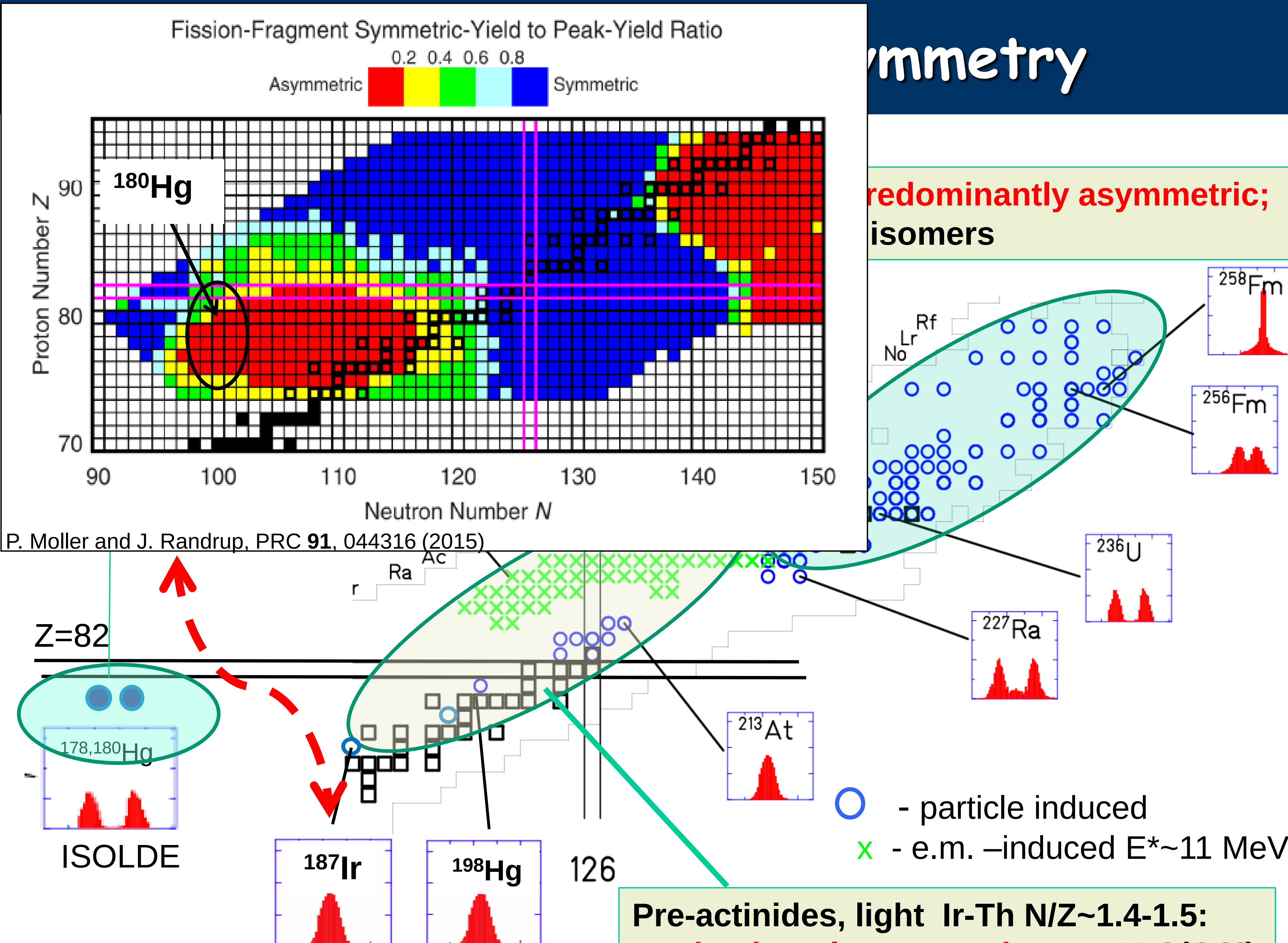


redominantly asymmetric;
isomers

○ - particle induced
x - e.m. –induced E*~11 MeV

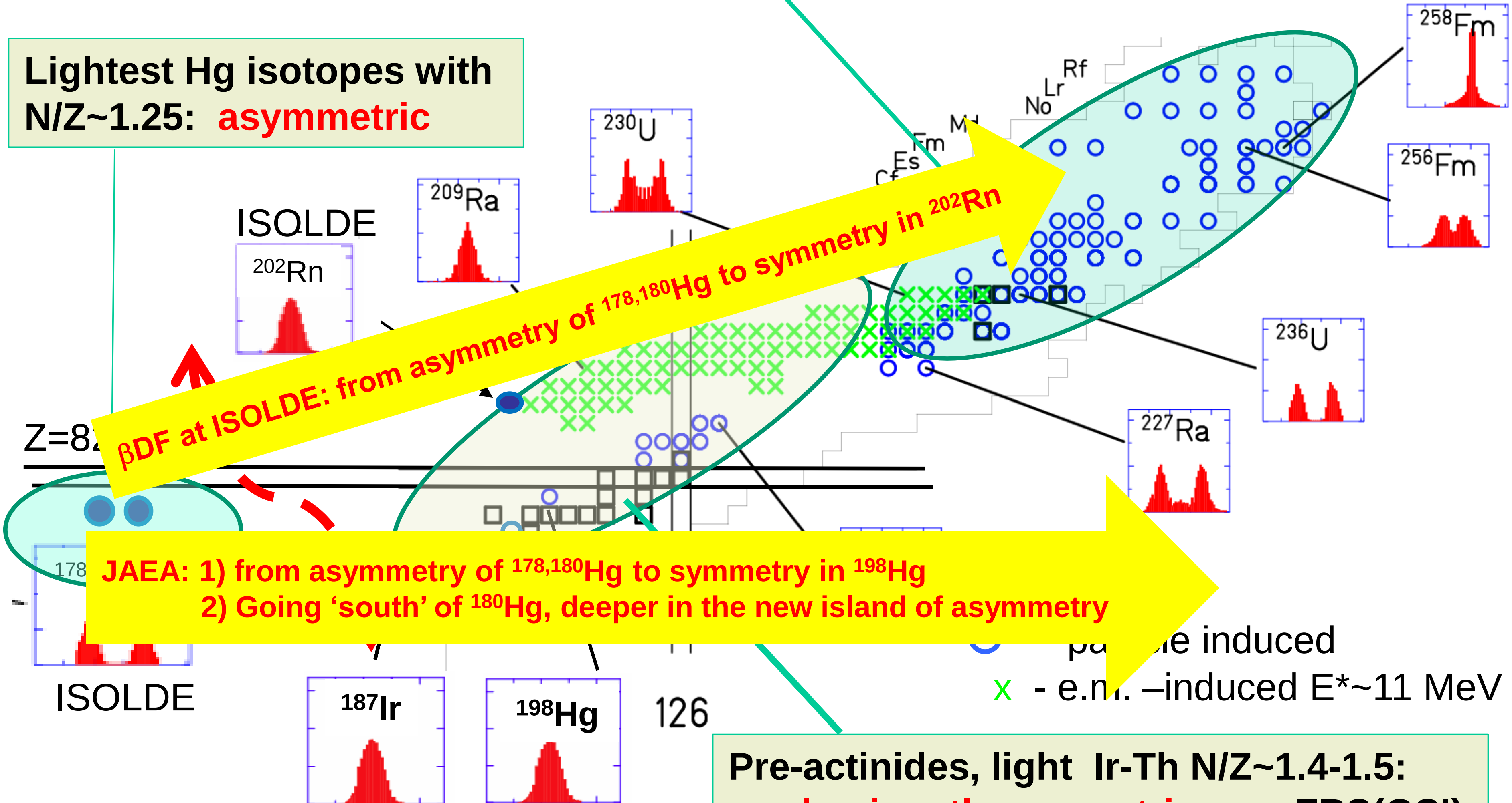
Pre-actinides, light Ir-Th N/Z~1.4-1.5:
predominantly symmetric, e.g. FRS(GSI)

A.N. Andreyev, K. Nishio, K.-H. Schmidt, Reports on Progress in Physics, (

From Asymmetry to Symmetry

Heavy Actinides, N/Z~1.56: predominantly asymmetric; spontaneous fission, fission isomers

Lightest Hg isotopes with N/Z~1.25: asymmetric



βDF at ISOLDE: from asymmetry of 178,180Hg to symmetry in 202Rn

JAEA: 1) from asymmetry of 178,180Hg to symmetry in 198Hg
2) Going 'south' of 180Hg, deeper in the new island of asymmetry

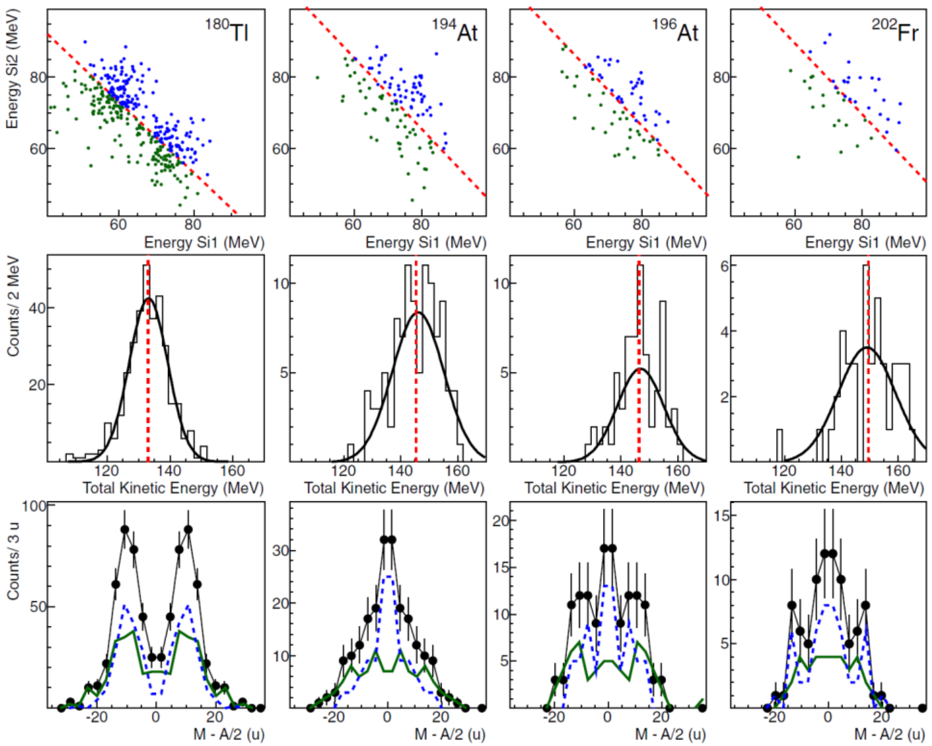
Pre-actinides, light Ir-Th N/Z~1.4-1.5: predominantly symmetric, e.g. FRS(GSI)

Multi-modal fission in the light Pb region

PHYSICAL REVIEW C 90, 041301(R) (2014)

Evolution of fission-fragment mass distributions in the neutron-deficient lead region

L. Ghys,[1,2,*] A. N. Andreyev,[3,4,5] M. Huyse,[1] P. Van Duppen,[1] S. Sels,[1] B. Andel,[6] S. Antalic,[6] A. Barzakh,[7] L. Capponi,[5] T. E. Cocolios,[8,9] X. Derkx,[5,10] H. De Witte,[1] J. Elseviers,[1] D. V. Fedorov,[7] V. N. Fedosseev,[11] F. P. Hessberger,[12,13] Z. Kalaninová,[6] U. Köster,[14] J. F. W. Lane,[5] V. Liberati,[5] K. M. Lynch,[8,9] B. A. Marsh,[11] S. Mitsuoka,[4] P. Möller,[15] Y. Nagame,[4] K. Nishio,[4] S. Ota,[4] D. Pauwels,[2] R. D. Page,[16] L. Popescu,[2] D. Radulov,[1] M. M. Rajabali,[1] J. Randrup,[17] E. Rapisarda,[8] S. Rothe,[11,18] K. Sandhu,[5] M. D. Seliverstov,[1,3,5,7] A. M. Sjödin,[11] V. L. Truesdale,[3] C. Van Beveren,[1] P. Van den Bergh,[1] Y. Wakabayashi,[4,19] and M. Warda[20]



PHYSICAL REVIEW C 90, 021302(R) (2014)

Excitation-energy dependence of fission in the mercury region

J. D. McDonnell,[1,2] W. Nazarewicz,[2,3,4] J. A. Sheikh,[2,3,5] A. Staszczak,[2,6] and M. Warda[6]

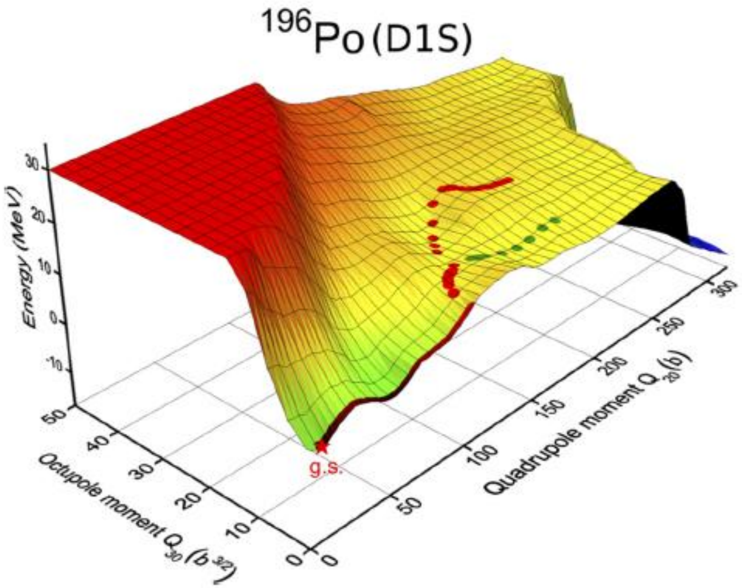


FIG. 2. (Color online) Similar to Fig. 1, but for ^{196}Po in HFB-D1S. Two competing fission pathways corresponding to different mass asymmetry are marked.

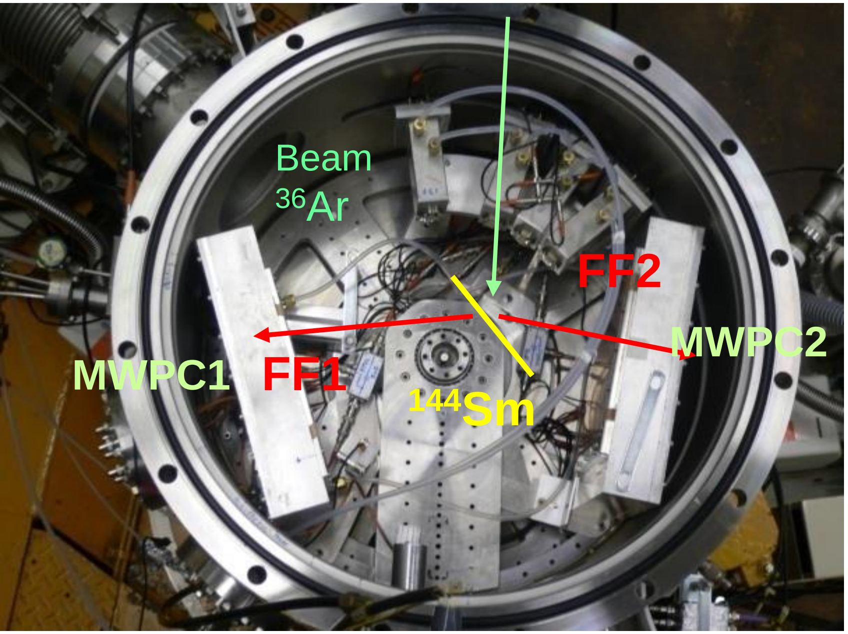
- **Difficulty for theory: flat, structure-less PES's (very different from U's)**
- **Temperature-dependence?**

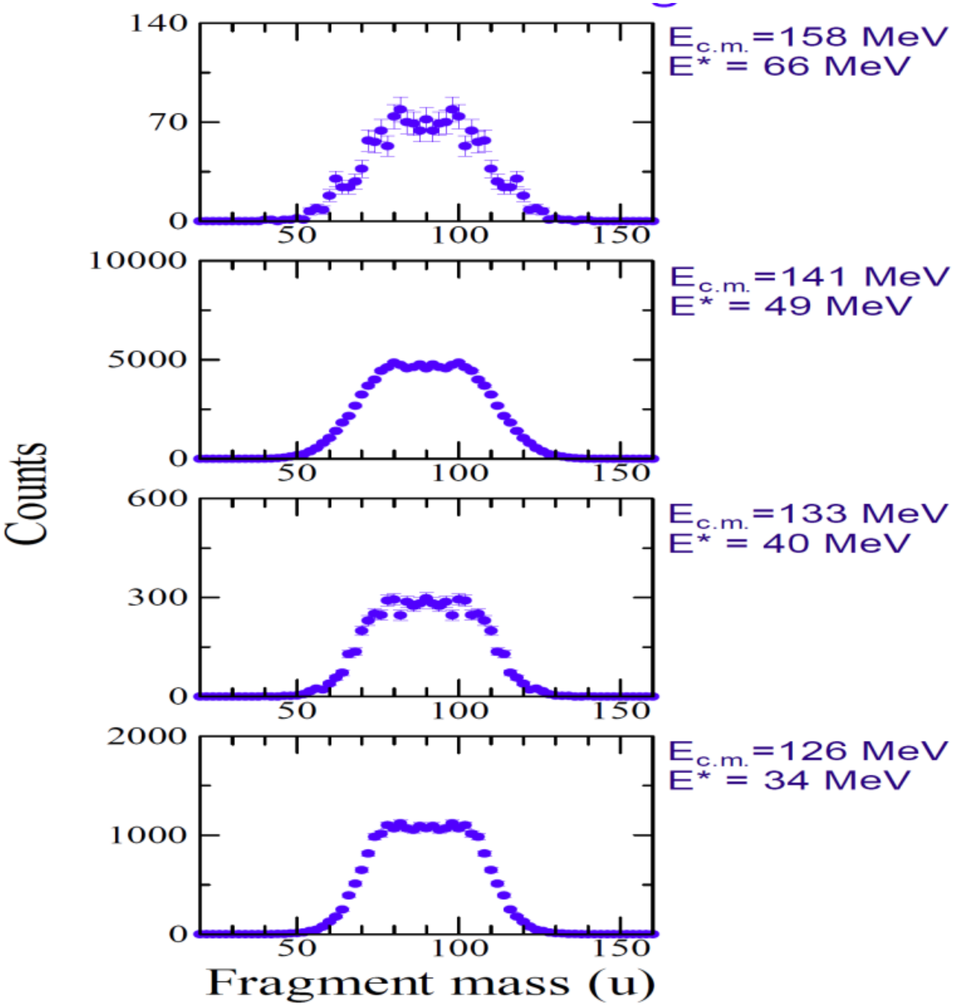
By using the same method, beta-delayed fission was studied at ISOLDE for:

- **^{178,180}Tl,** V.Liberati et al, PRC88 (2013), A.Andreyev et al, PRL105 (2010)
- **^{188m1,m2}Bi**: advanced draft is ready (Andel et al)
- **^{194,196}At, ^{202}Fr:** L.Ghys et al, PRC90 (2014), V.Truesdale, PRC94 (2016)
- **Mix of symmetry and asymmetry (multi-modal) fission is proposed**

^{180}Hg: More surprises?
How does ^{180}Hg fission at <u>higher</u> excitation energies?

- $^{36}Ar + ^{144}Sm \rightarrow ^{180}Hg^*$ E*=34-66 MeV
- 2010-2014: JAEA, Tokai



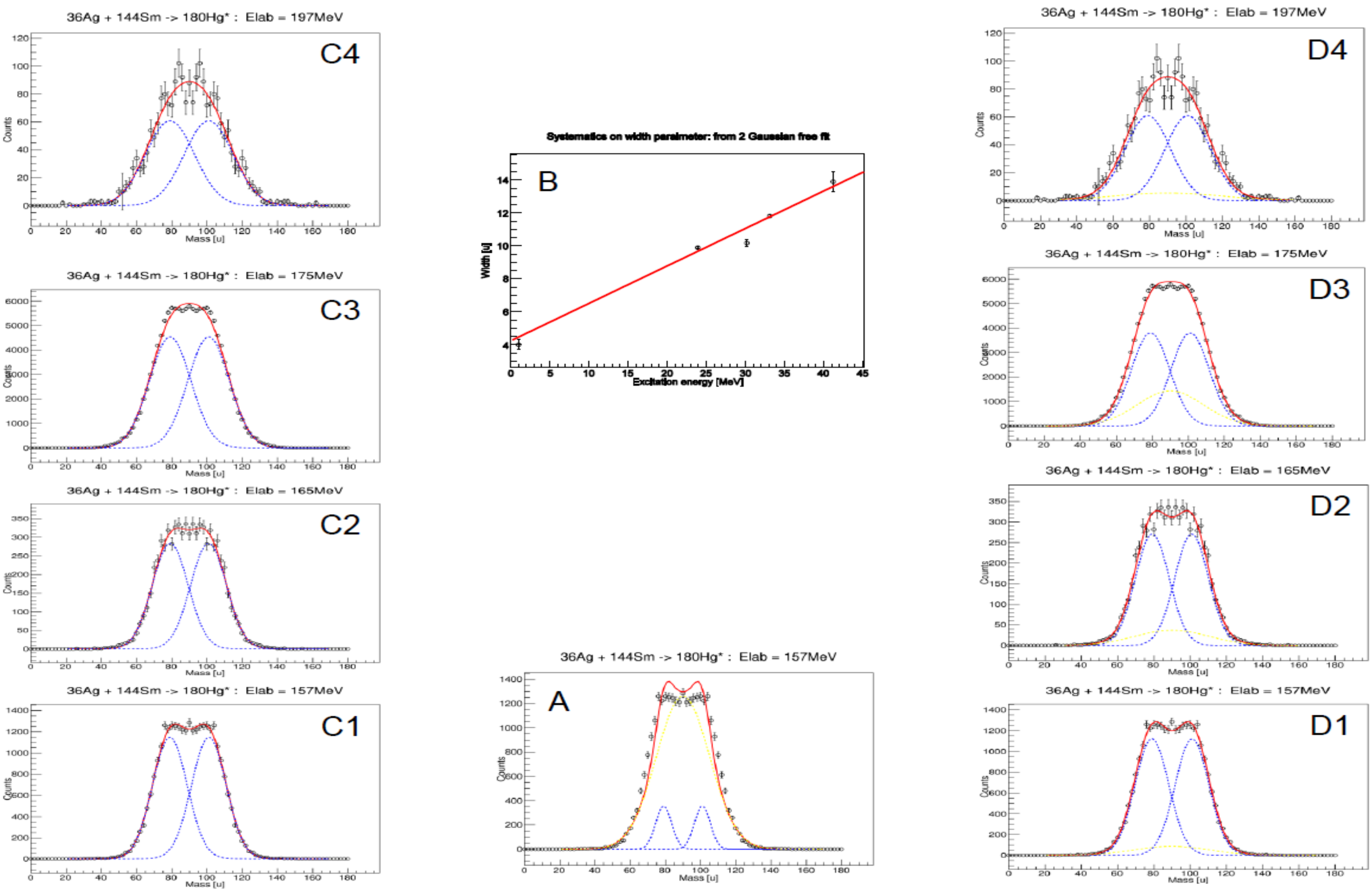


Even at E*=66 MeV: asymmetric mass split with A_1~100, A_2~80

K. Nishio, A.N. Andreyev et al, PLB (2015)

Supported by Reimei Foundation (JAEA)

^{180}Hg: One or two fission modes?

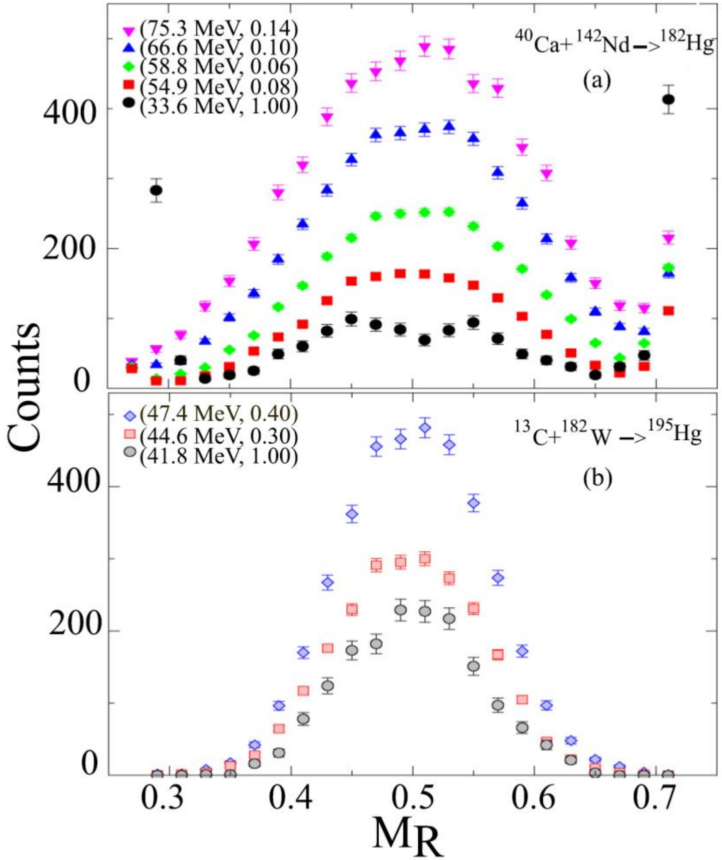


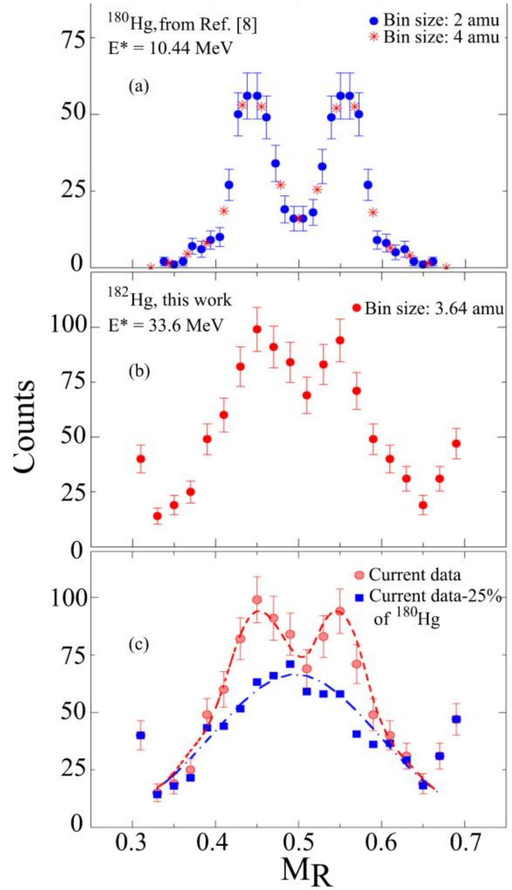
Fusion-Fission of ^{182,195}Hg at ANU

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§
J. Khuyagbaatar Ch. E. Düllmann B. Lommel and B. Kindler



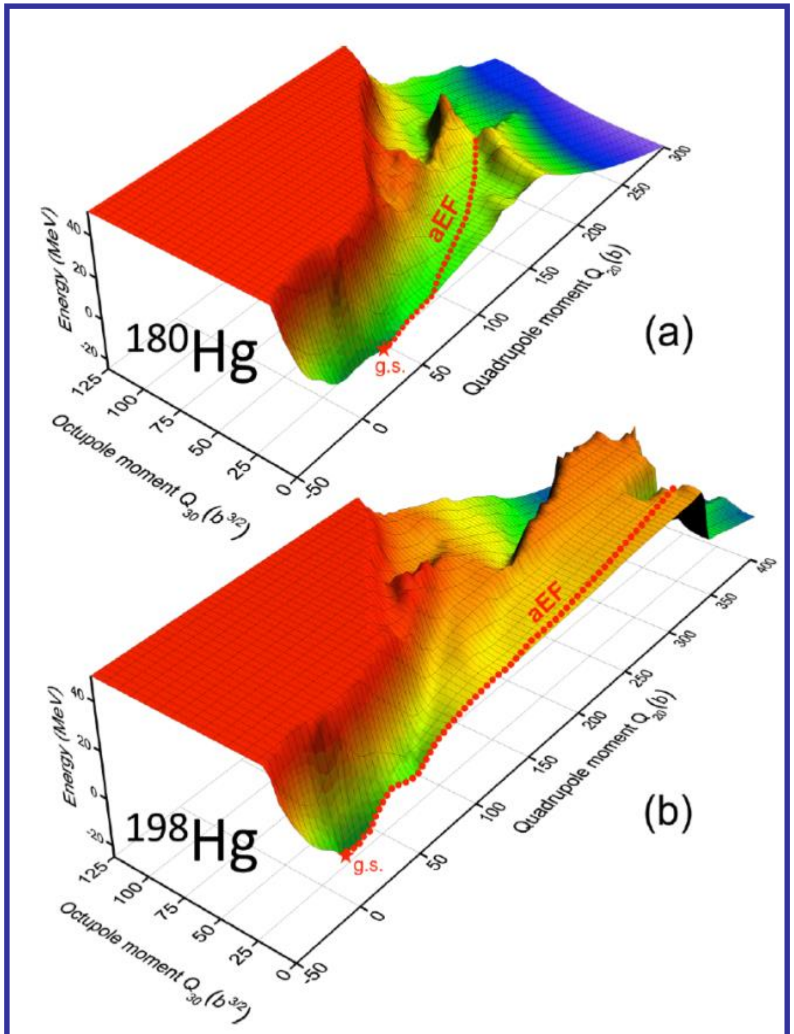


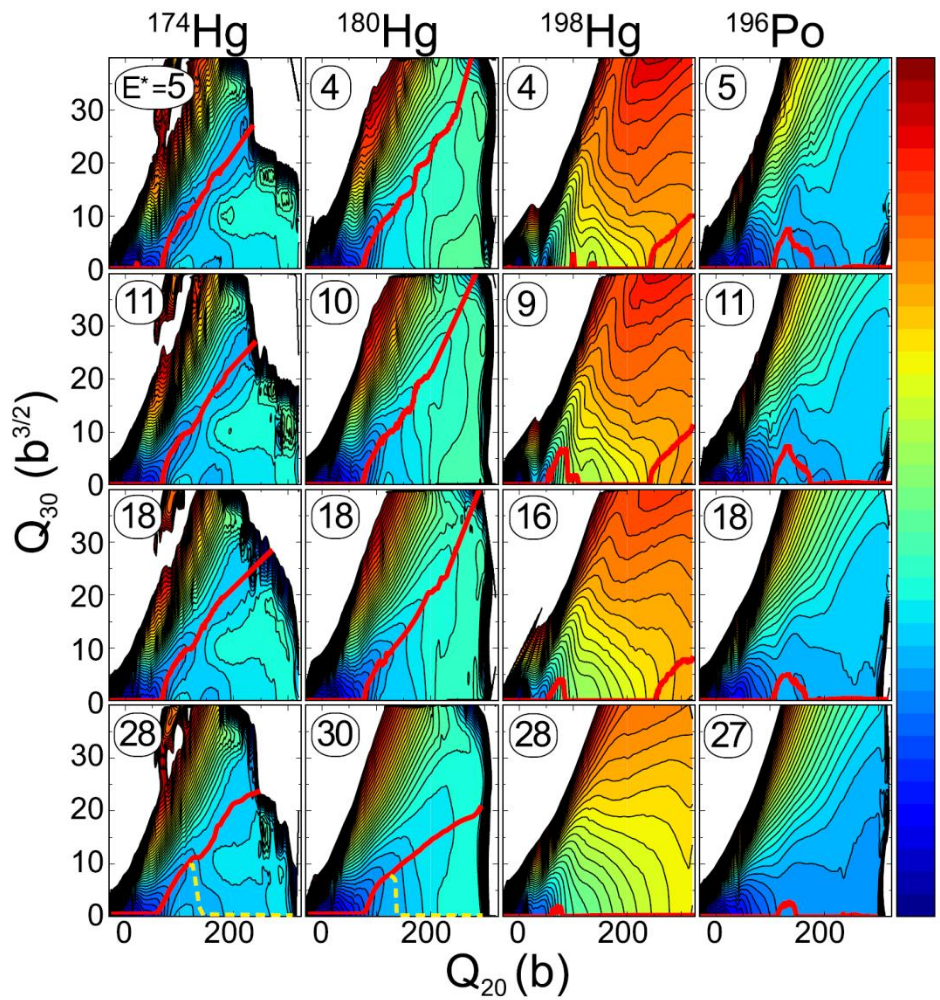
Excitation-energy dependence of shell effects and of the fission barrier in the lead region (SKM*)

PHYSICAL REVIEW C **90**, 021302(R) (2014)

Excitation-energy dependence of fission in the mercury region

J. D. McDonnell,[1,2] W. Nazarewicz,[2,3,4] J. A. Sheikh,[2,3,5] A. Staszczak,[2,6] and M. W





SkM∗ and a density-dependent pairing interaction.

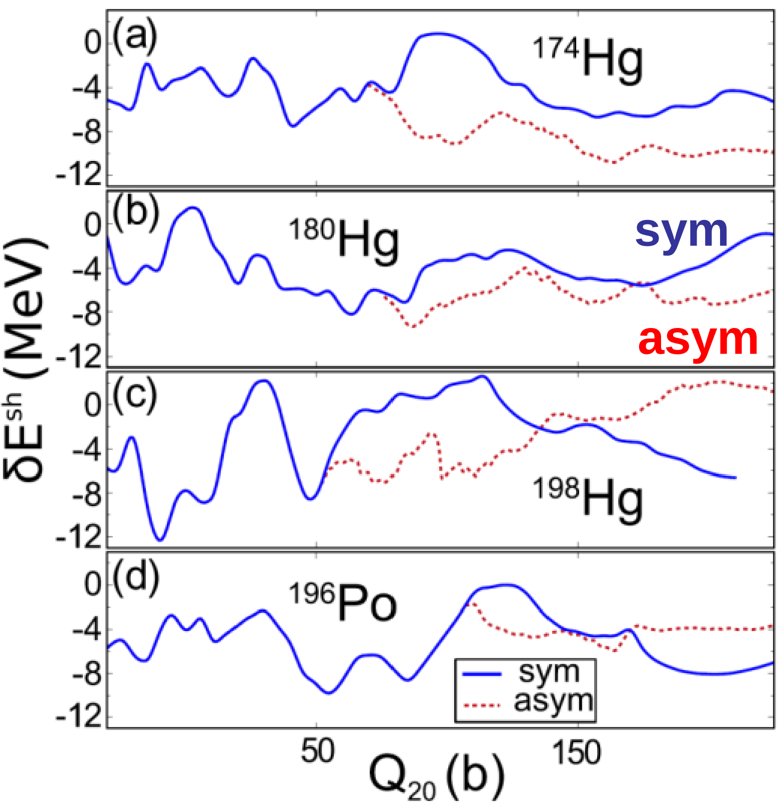
Excitation-energy dependence of shell effects and of the fission barrier in the lead region (SKM*)

PHYSICAL REVIEW C **90**, 021302(R) (2014)

Excitation-energy dependence of fission in the mercury region

J. D. McDonnell,[1,2] W. Nazarewicz,[2,3,4] J. A. Sheikh,[2,3,5] A. Staszczak,[2,6] and M. Warda[6]

Conclusions: Our self-consistent theory suggests that excitation energy weakly affects the fission pattern of the nuclei considered. The transition from the asymmetric fission in the proton-rich nuclei to a more symmetric fission in the heavier isotopes is governed by the shell structure of pre-scission configurations.



EXCITATION-ENERGY DEPENDENCE OF FISSION IN …

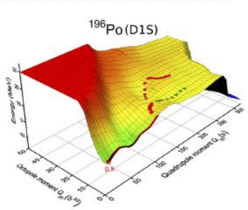
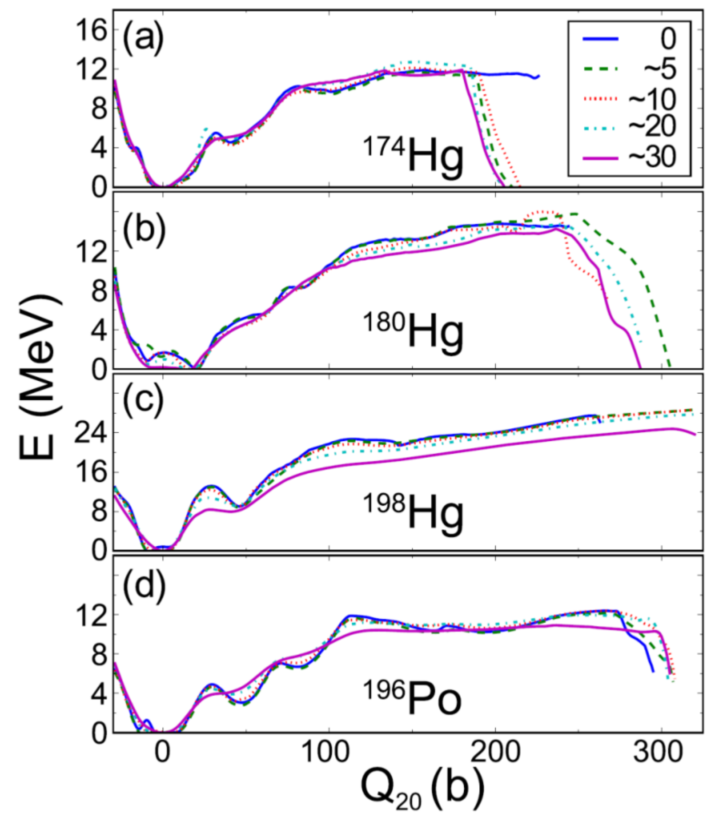
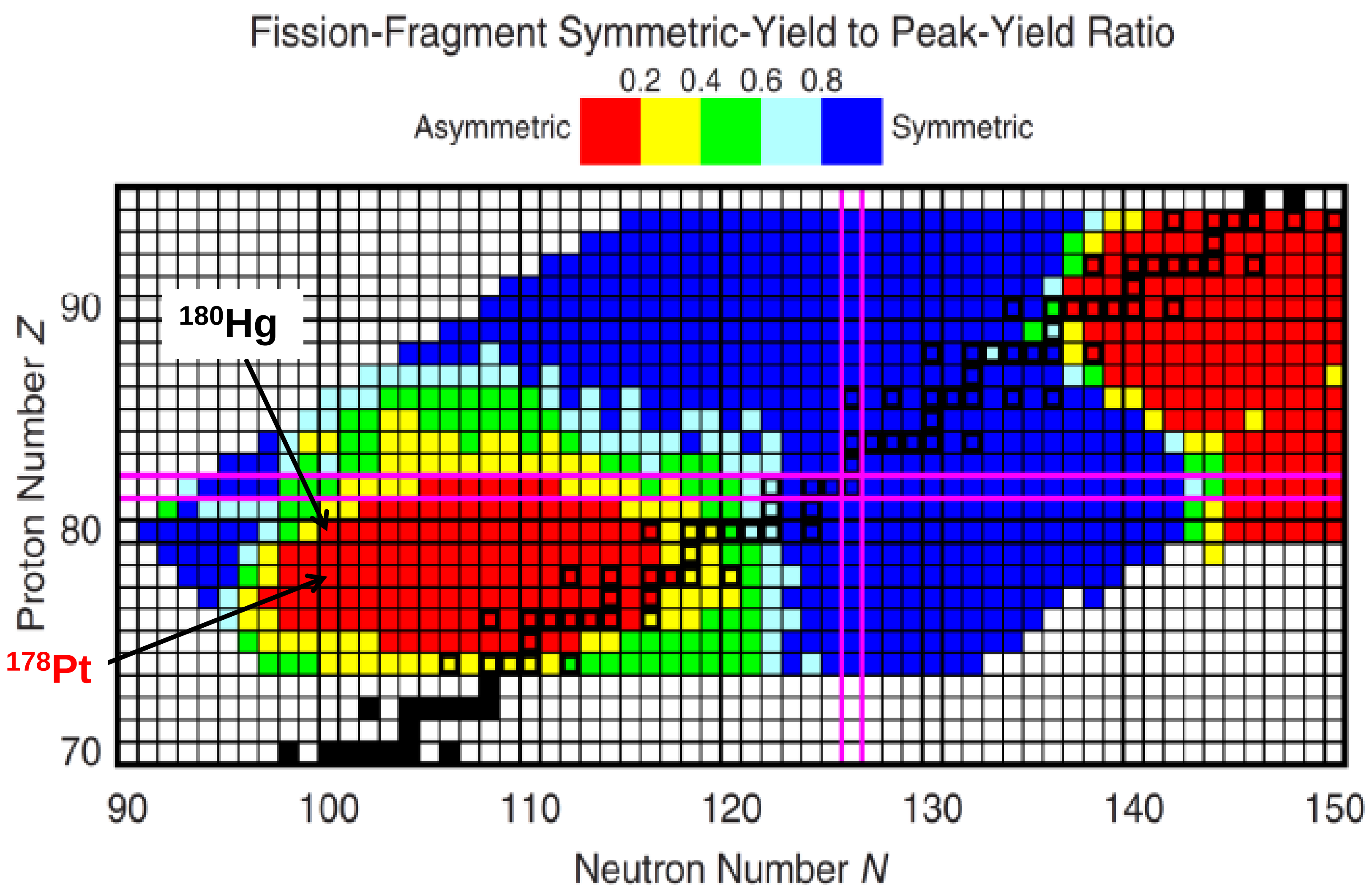


FIG. 2. (Color online) Similar to Fig. 1, but for ^{196}Po in HFB-D1S. Two competing fission pathways corresponding to different mass asymmetry are marked.



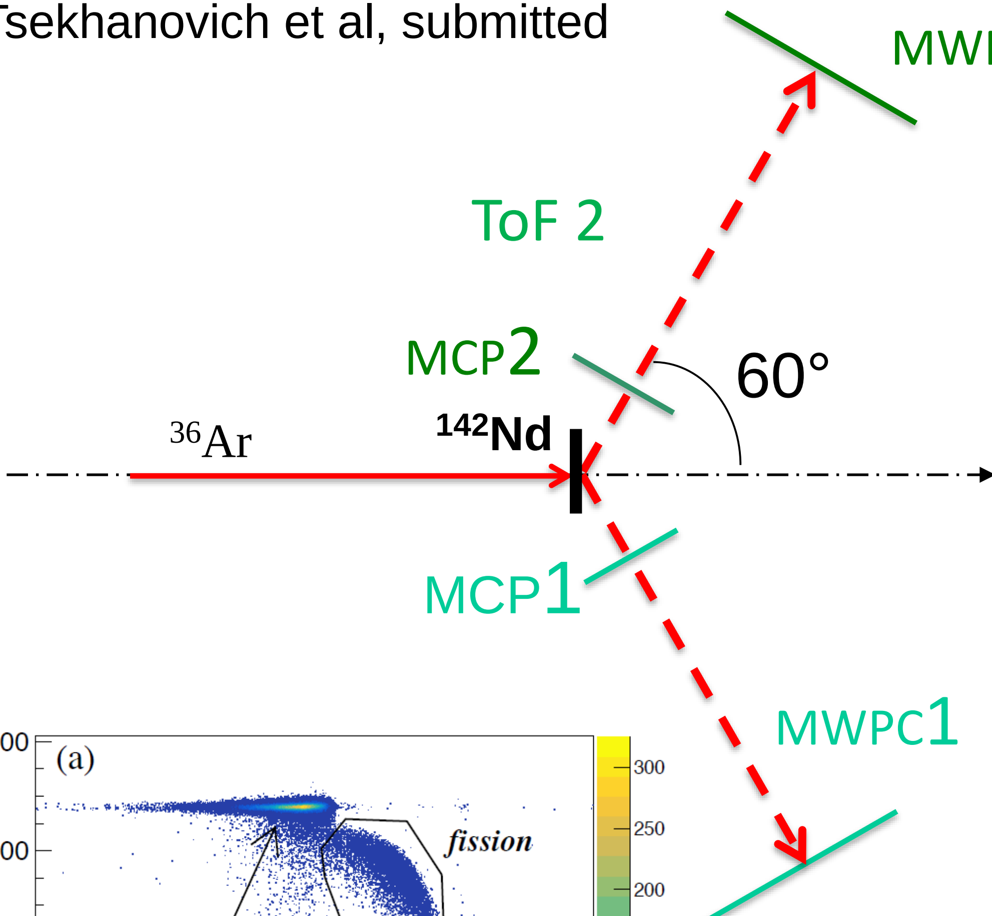
^{178}Pt (Z=78, N=100): will it fission in two doubly-magic ^{100}Sn(Z=N=50)+^{78}Ni(Z=28,N=50)?

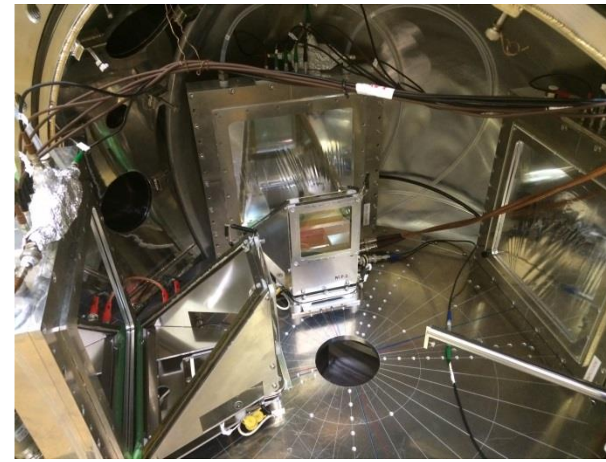


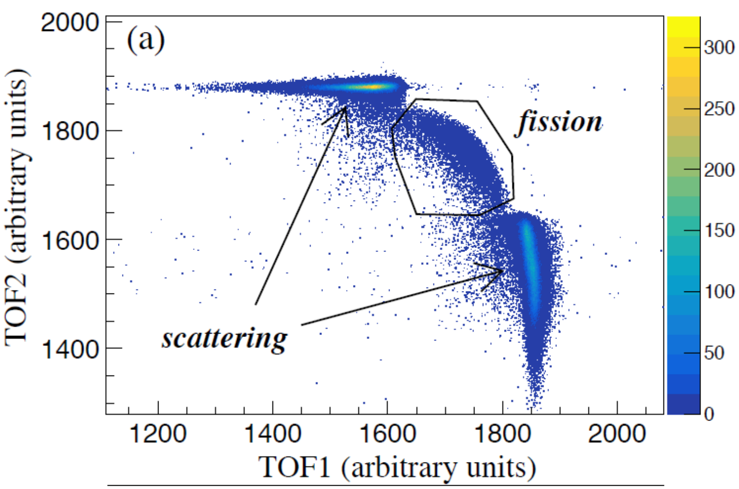
P. Moller and J. Randrup, PRC **91**, 044316 (2015)

^{178}Pt (Z=78, N=100): will it fission in two doubly-magic ^{100}Sn(Z=N=50)+^{78}Ni(Z=28,N=50)?

I.Tsekhanovich et al, submitted







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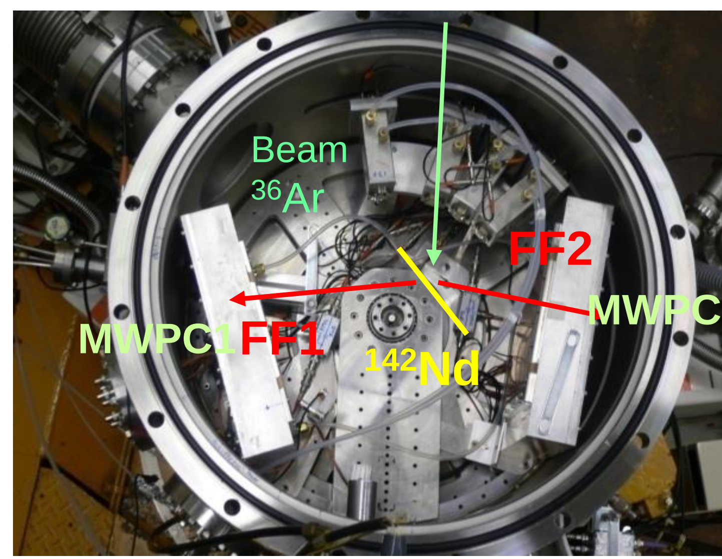
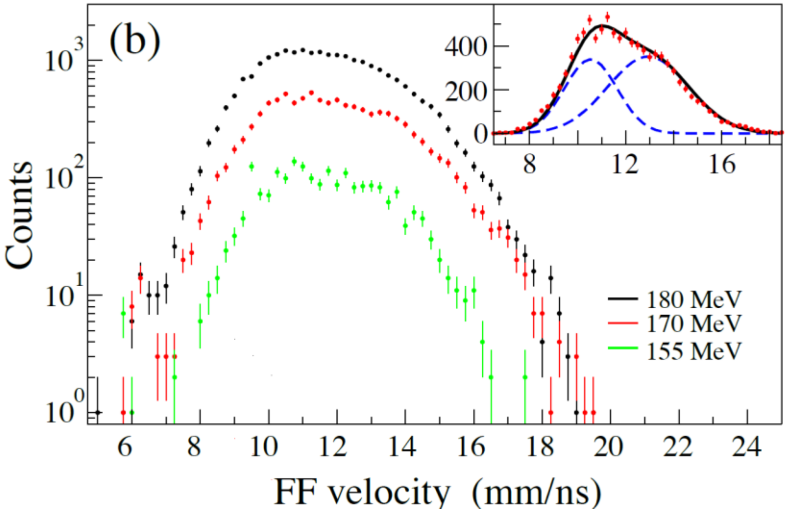
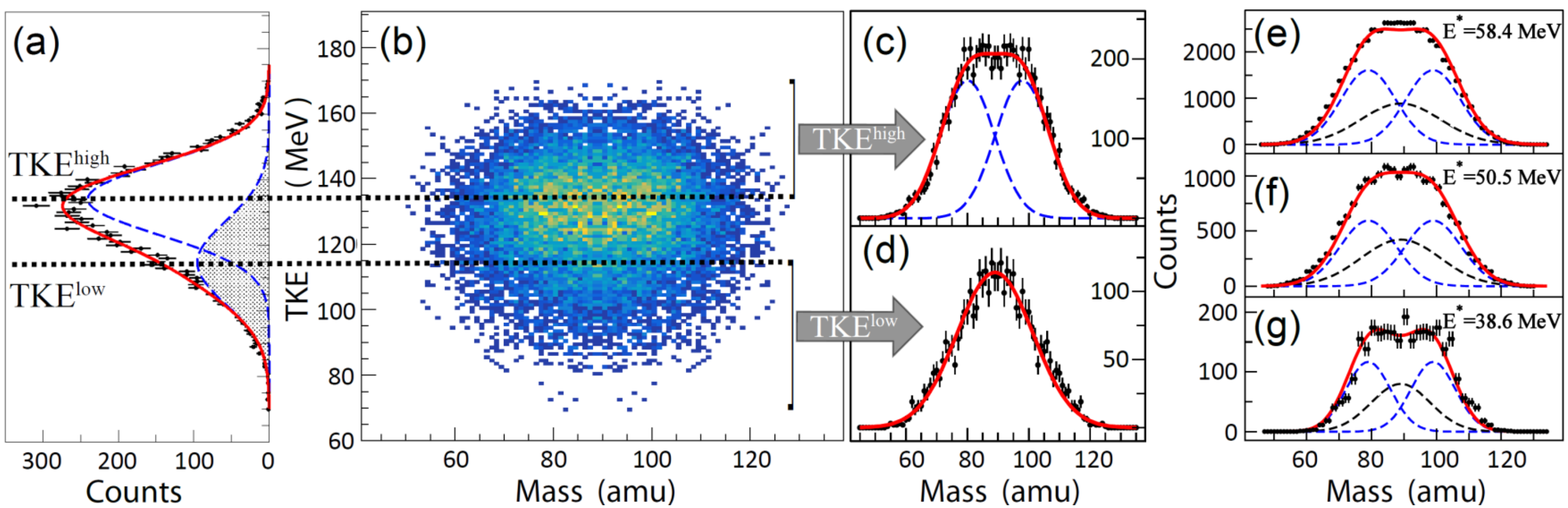


Results – TKE vs Mass; Mass distributions



a) **Left-hand side plot: Fission fragments velocities.**
Asymmetric distribution means that at least **two fission modes contribute**

b) Bottom plot: Total Kinetic Energy vs Mass distributions. Asymmetry in TKE further confirms the presence of two modes



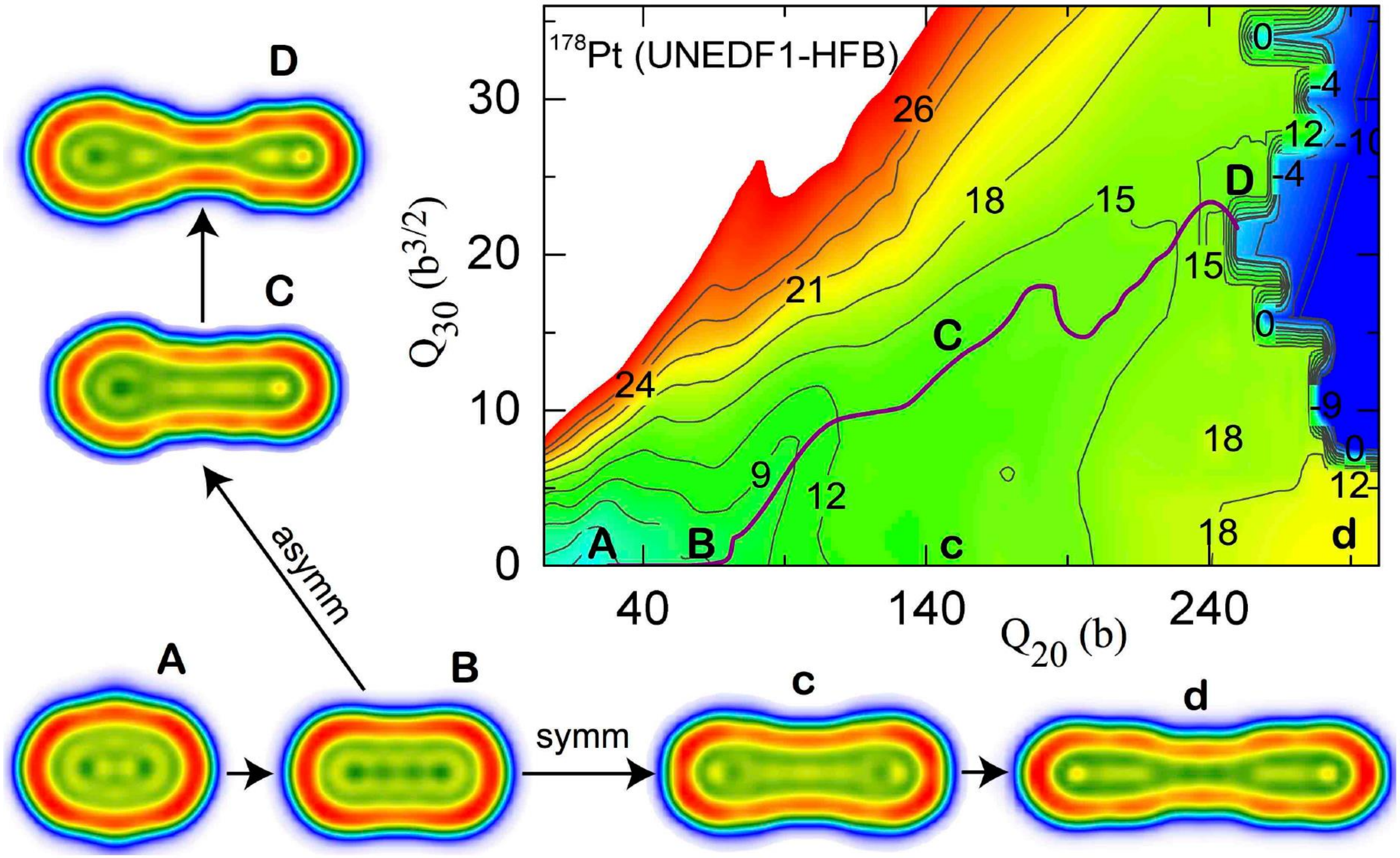
Conclusions: 2 fission modes

symmetric with $A_L=A_H=A_{CN}/2=89$ **Asymmetric mode : $A_L = 79, A_H = 99$**

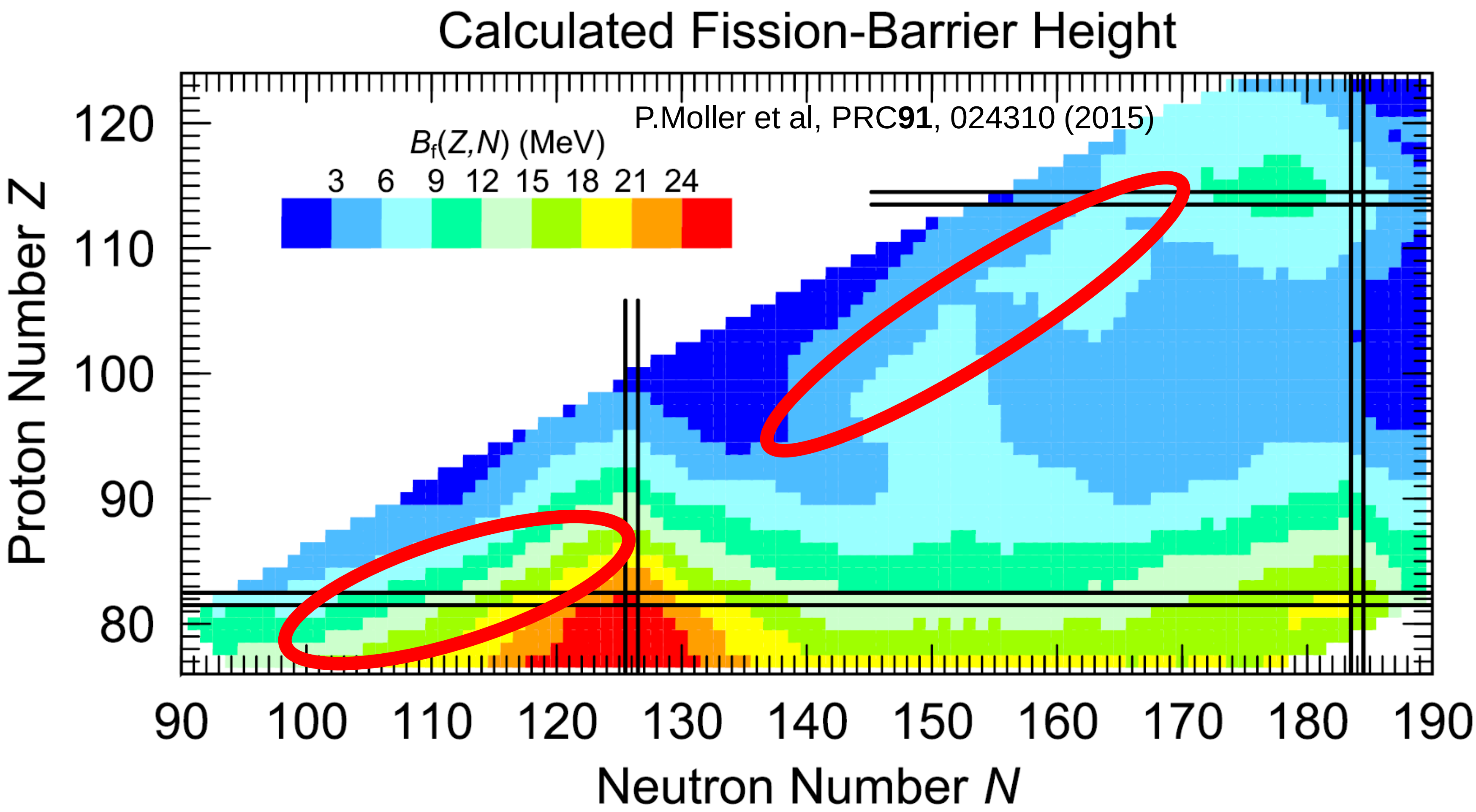
Multimodal fission of ^{178}Pt: Manuscript is on arXiv

First observation of the competing fission modes in the sub-lead region

I. Tsekhanovich,[1] A.N. Andreyev,[2,3] K. Nishio,[3] D. Denis-Petit,[4] K. Hirose,[3] M. Makii,[3] Z. Matheson,[5] K. Morimoto,[6] K. Morita,[6,7] W. Nazarewicz,[5] R. Orlandi,[3] J. Sadhukhan,[8,9] T. Tanaka,[6,7] M. Vermeulen,[3] and M. Warda[10]

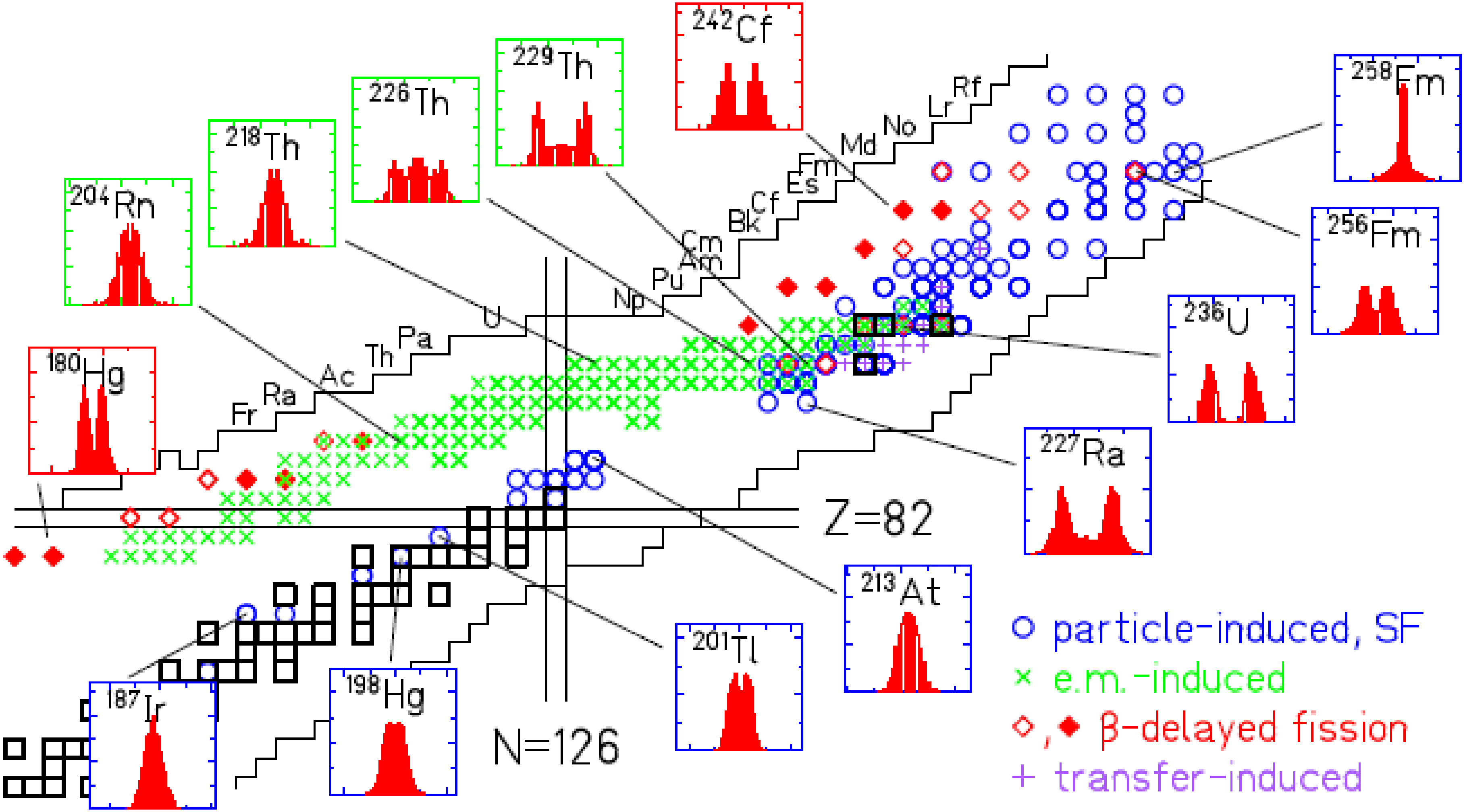


Summary: Fission in the light lead region is different in many respects from the transactinides



- **Very different fission barriers heights**, >8 MeV for lead region, a few MeV for actinides
- **Shell effects and PES are very different** (quite flat and structure-less in the leads)
- **Different excitation energy dependence of shell effects/barriers**!

Thank You for your attention!



A.N. Andreyev, K. Nishio, K.-H. Schmidt, Review on Experimental Progress in Fission, Reports on Progress in Physics, January 2018