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SOFIA

STUDIES ON FISSION WITH ALADIN

A fission programme for FAIR/R3B

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For the R3B/SOFIA Collaboration

Worms Conf., October, 16th, 2014

GSI AND THE FISSION STUDIES

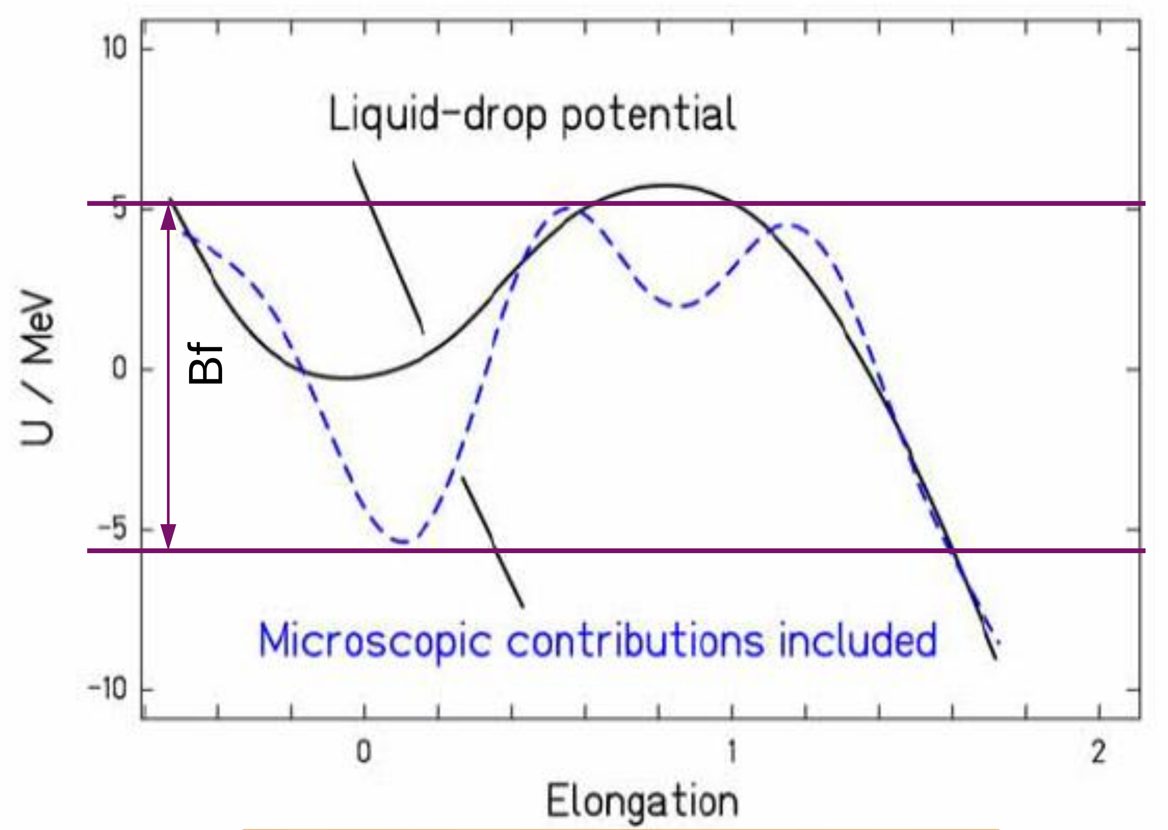
Long-lasting relationship between fission and GSI

- Strongly pushed by P. Armbruster
  - Use of the first uranium beams at GSI in the early 90's
- Full programme on incineration of nuclear wastes in 90's, early 2000's
- Major breakthrough in low energy fission studies from K.-H. Schmidt et al. in 2000 : first study of the fission of secondary beams

- Both fundamental and applied science motivations for those studies
  - Improve the basic understanding of the process
  - Contribute to the qualification of fission theoretical codes
  - Improve the modelling of the r-process cycling
  - Better estimate of the superheavy nuclides survival probability

- We learnt from the Fukushima accident that an accurate estimate fission fragment production is of major importance
- The residual power of a nuclear core in an accidental configuration depends mostly on the fission fragment population

THE FISSION STUDIES



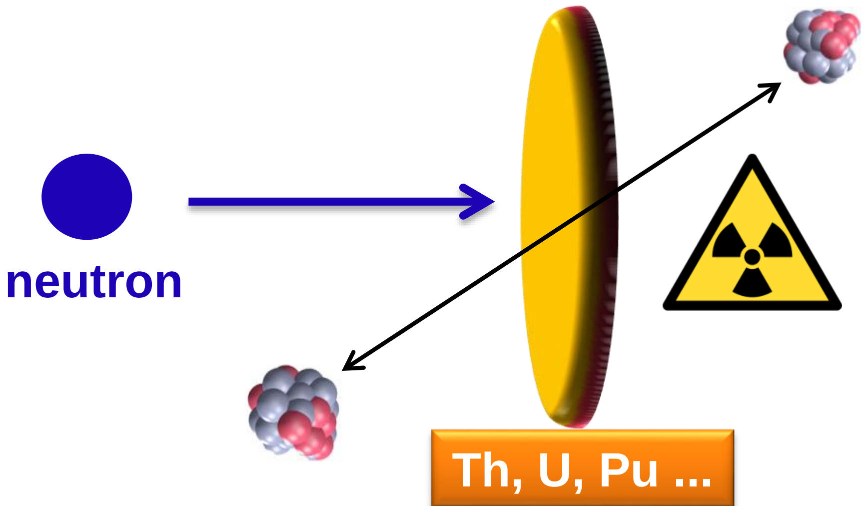
Basically , two types of studies

- Fission probability ≅ early stage of the barrier, Bf
- Fission fragment yields ≅ late stage of the barrier, descent from saddle to scission configurations

THE MODELLING OF THE FISSION PROCESS

- A proper modelling of the process is currently not reached
  - Accurate description of the barrier topology
  - Nuclear structure challenges : potential of heavily deformed heavy nucleus with strange shapes
  - Include the dynamics of the descent fro saddle to scission
- Many statistical attempts based on the macroscopic/microscopic approaches
- In the last 10 years, full HFB simulation appears
- None are able to described the fission observable accurately

THE FF YIELDS MEASUREMENT TECHNIQUES



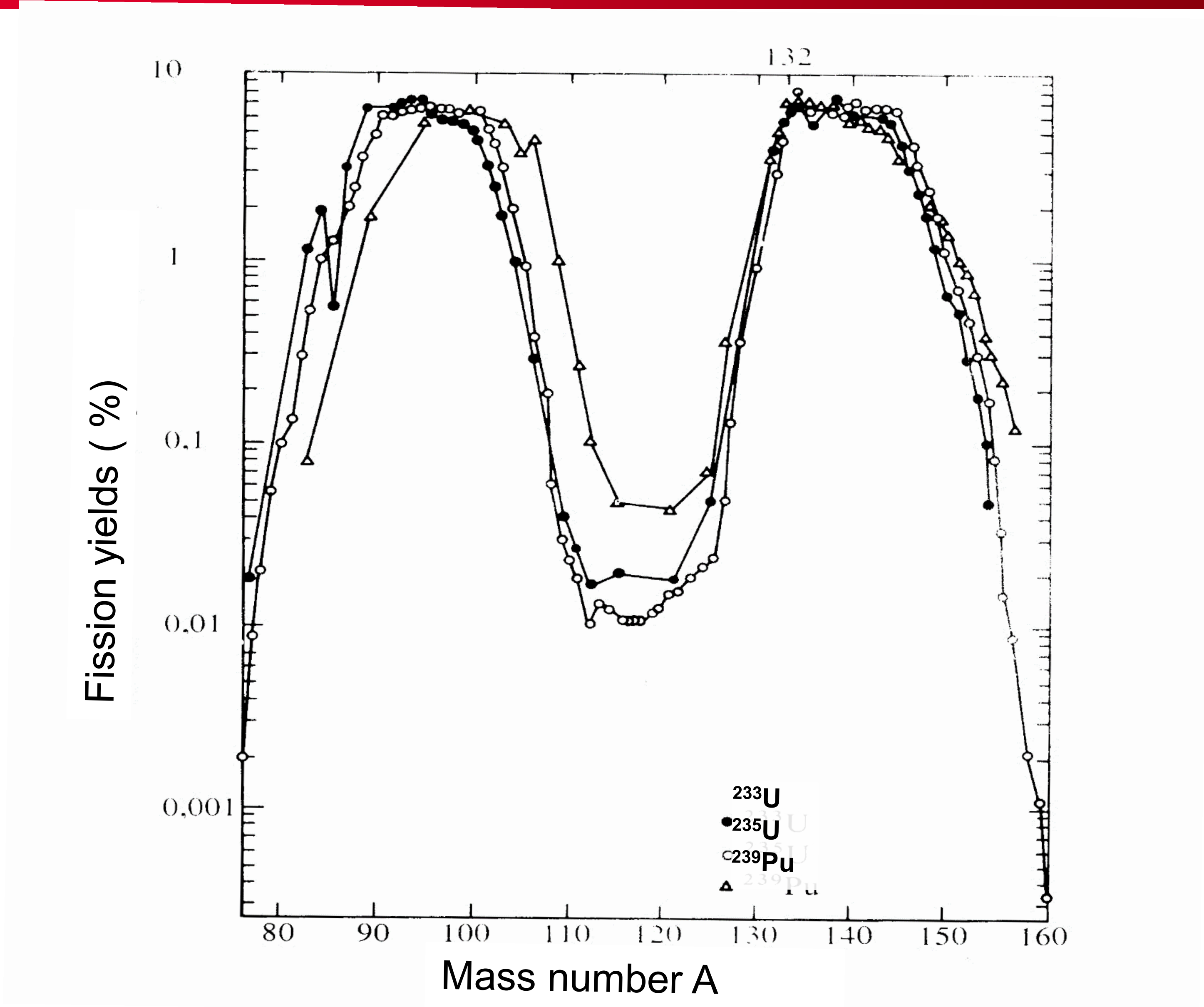
- 1 or 2 FF detected
- Identified in A or Z

Major difficulties

- (Thin) target usually radioactive
- Low detection efficiency
- Mass number only measured in most experiments
- Atomic number almost impossible to get

Despite 75 years of effort, there is no way to identify all FF

THE FF MASS YIELDS MAJOR ACTINIDES

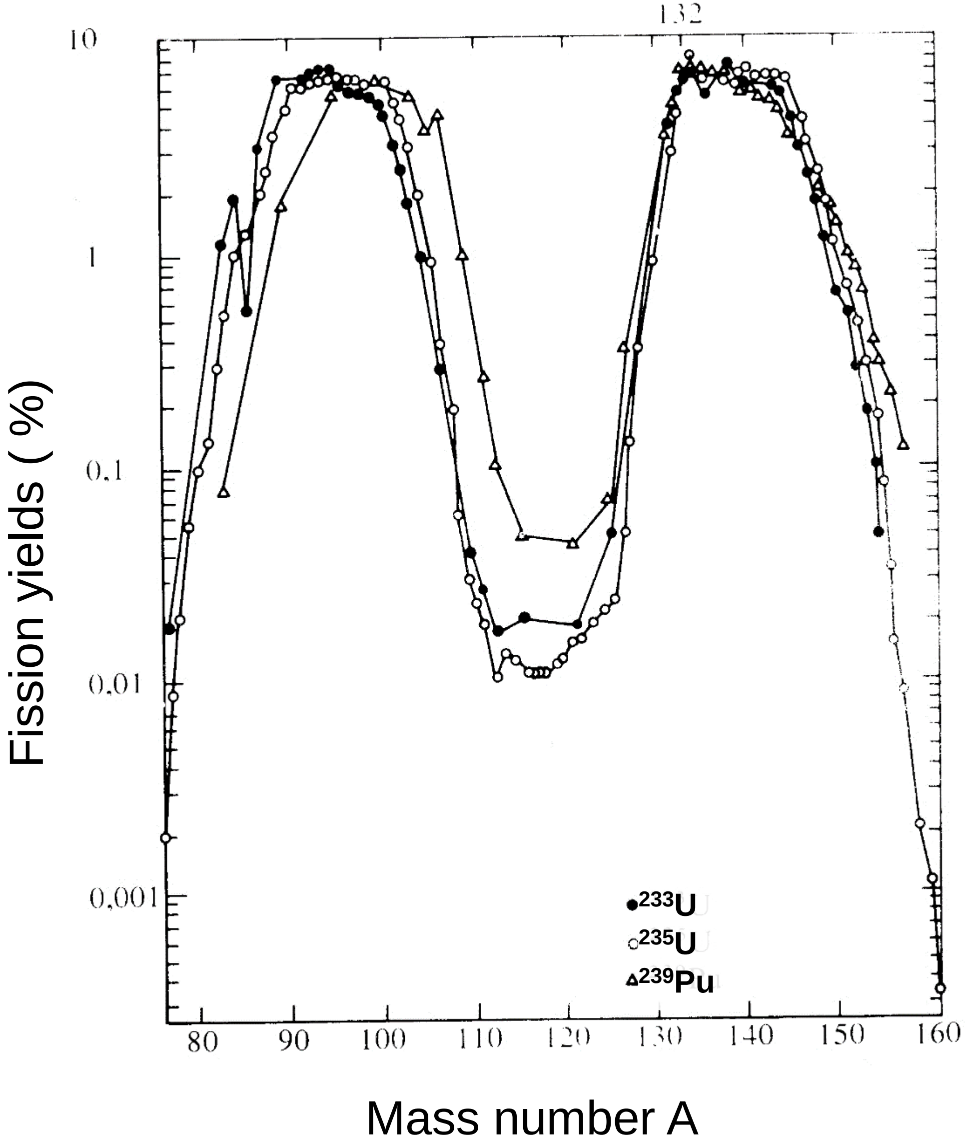


THE NUCLEAR CHARGE MEASUREMENT ISSUE

Measurement of the nuclear charge of FF

- Full ID needed for applications and for understanding of the process
  - Mass number does not mean much
- How to measure the Z ?
  - Specific methods
    - Chemical separation + Gamma spectroscopy
    - X-ray identification
  - General method : energy loss (ΔE)
    - $\Delta E \propto Z^2$
    - Does work for the light FF
    - No separation for the heavy FF
    - Very low recoil velocity
  - **Only light fission fragments can be identified in Z and A**

THE FF MASS YIELDS MAJOR ACTINIDES



Heavy peak seems to be stable

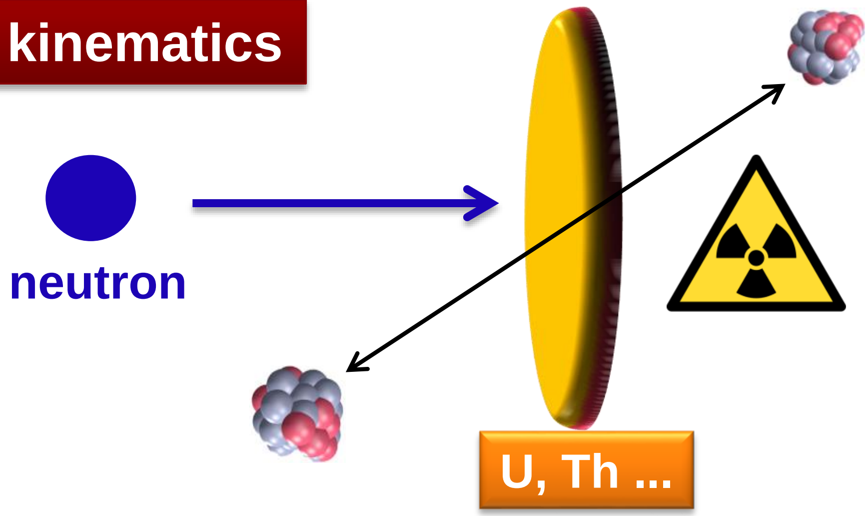
Light peak adjusts

The physics of the fission of actinides lies in the heavy peak

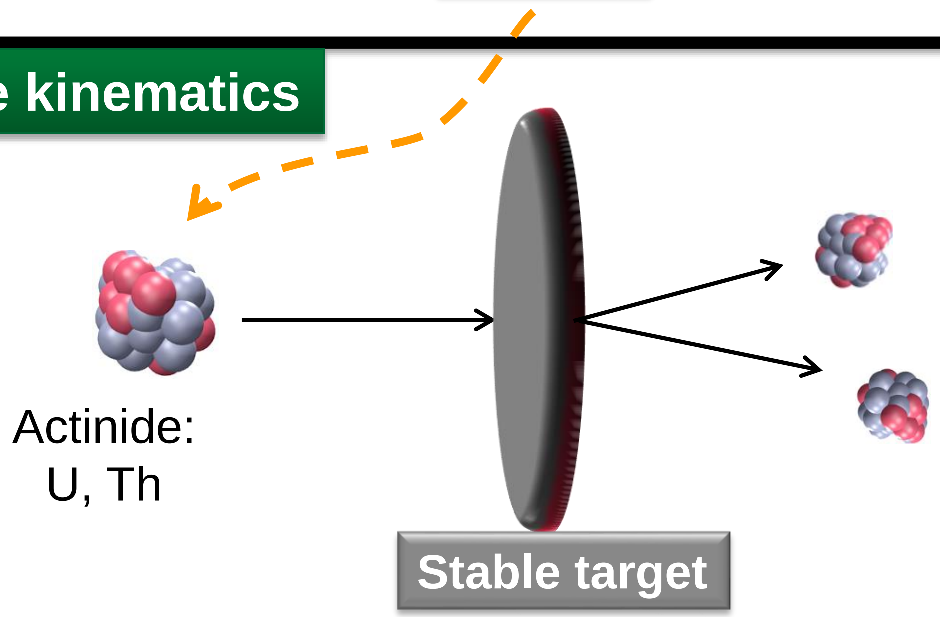
Only possible at GSI

NEW EXPERIMENTAL APPROACH (K.H. SCHMIDT 96)

direct kinematics

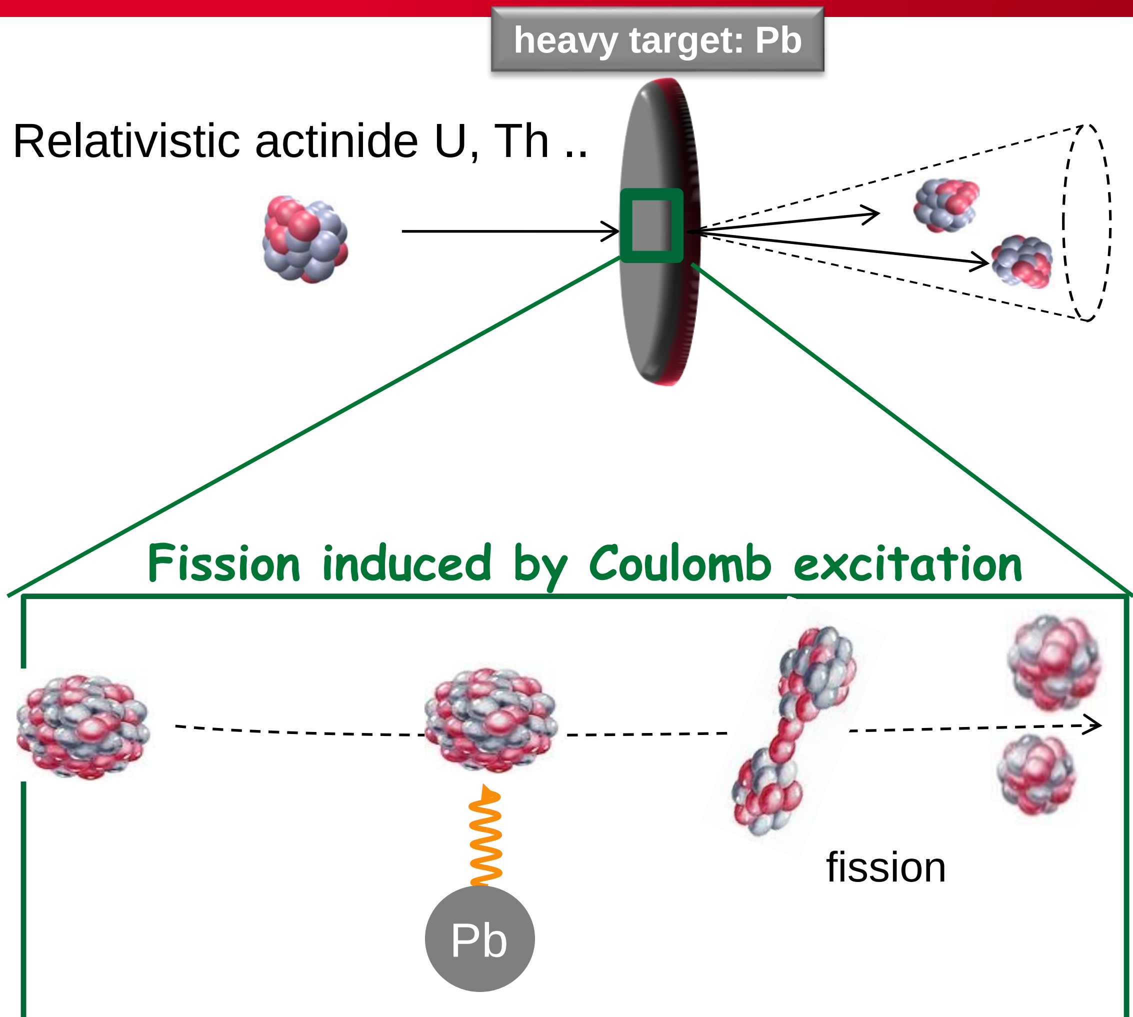


Reverse kinematics



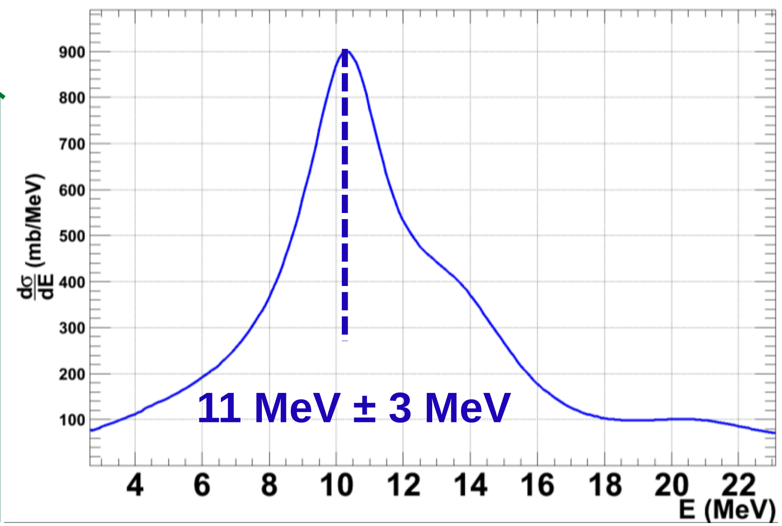
- Study the fission of radioactive nuclides
- Two FF emitted in forward direction : ϵ_{geom}
- Centre of mass boost: easier identification of FF
- Nuclear charge measured

COULEX FISSION IN REVERSE KINEMATICS AT GSI



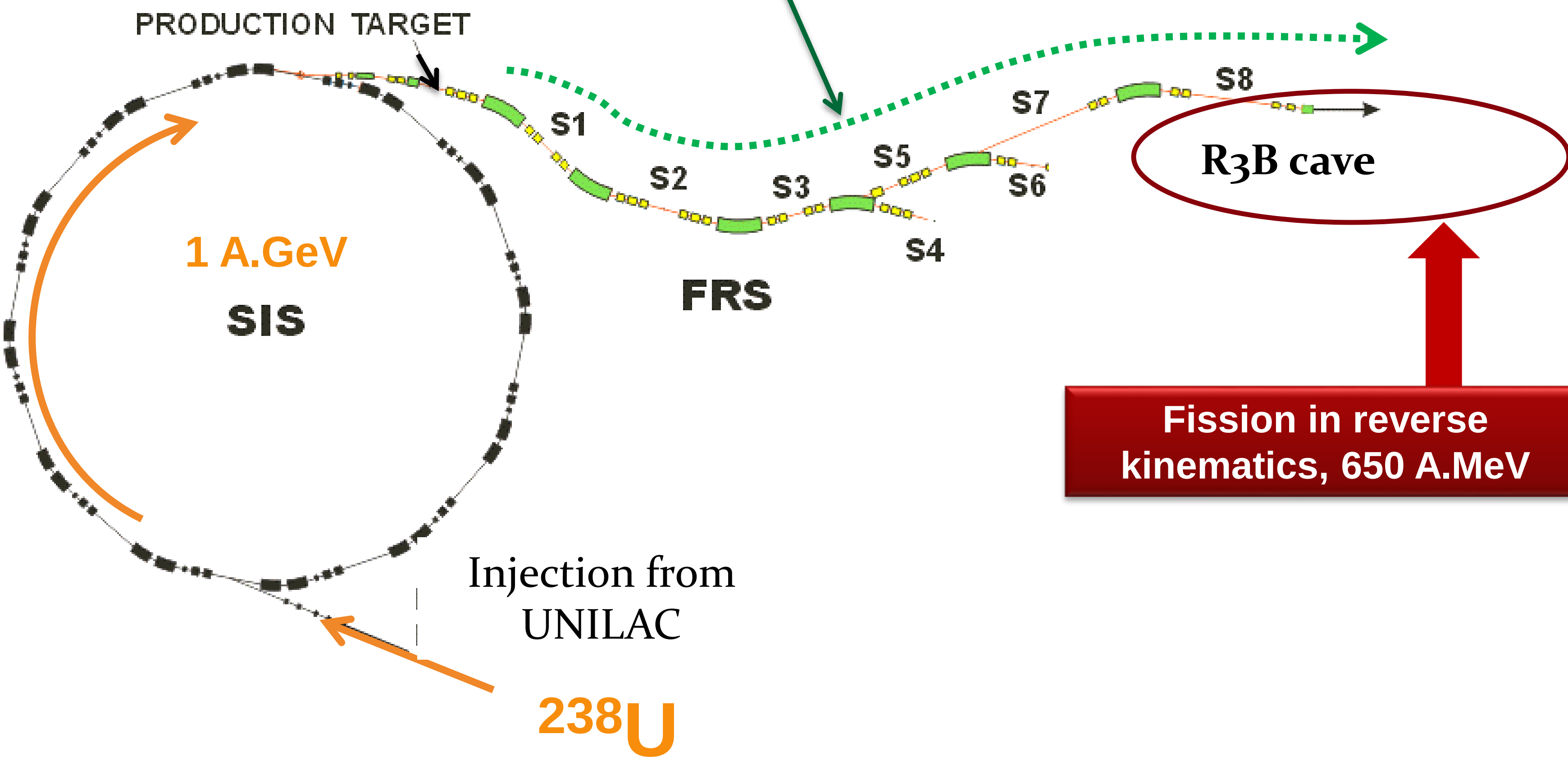
The Giant Dipole Resonances (GDR) are populated

E* distribution



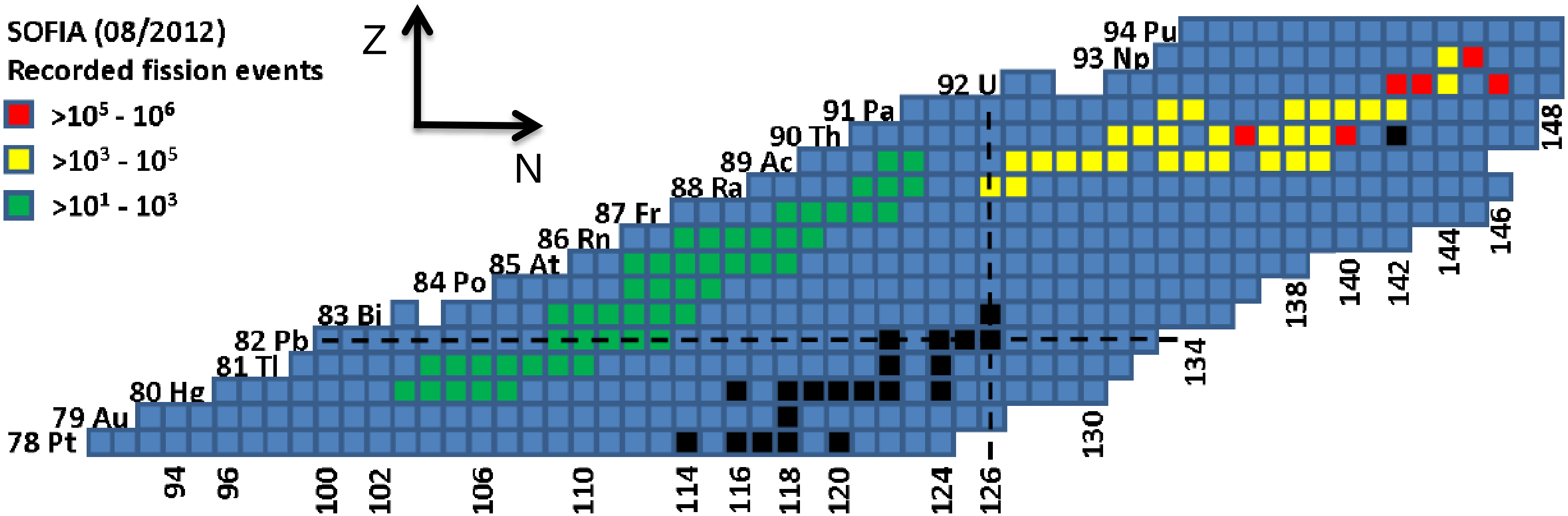
→ <E*> =12.5, similar to
7 MeV neutron induced fission

Actinide secondary beams from fragmentation reactions of ^{238}U



Fission in reverse kinematics, 650 A.MeV

1ST SOFIA EXPERIMENT, 08/2012



For both fragments, we measure

Z and A

Target : resolution < 1 (FWHM) over the full FF range

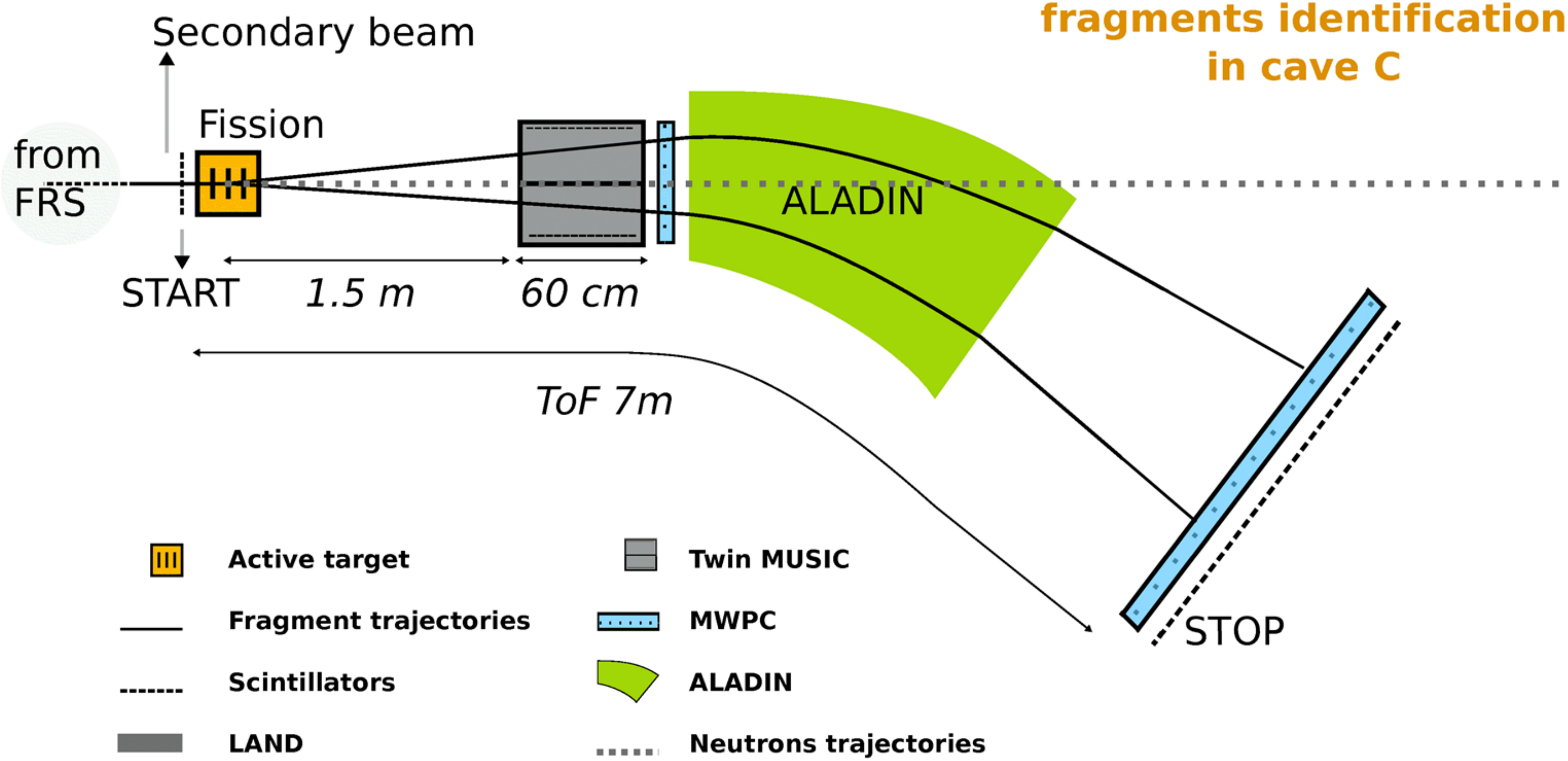
<u>In addition</u>:

- **Number of emitted neutrons $\overline{\upsilon}$ = A_{fiss} – (A1 +A2)**
- **TKE**

The R3B/SOFIA set up

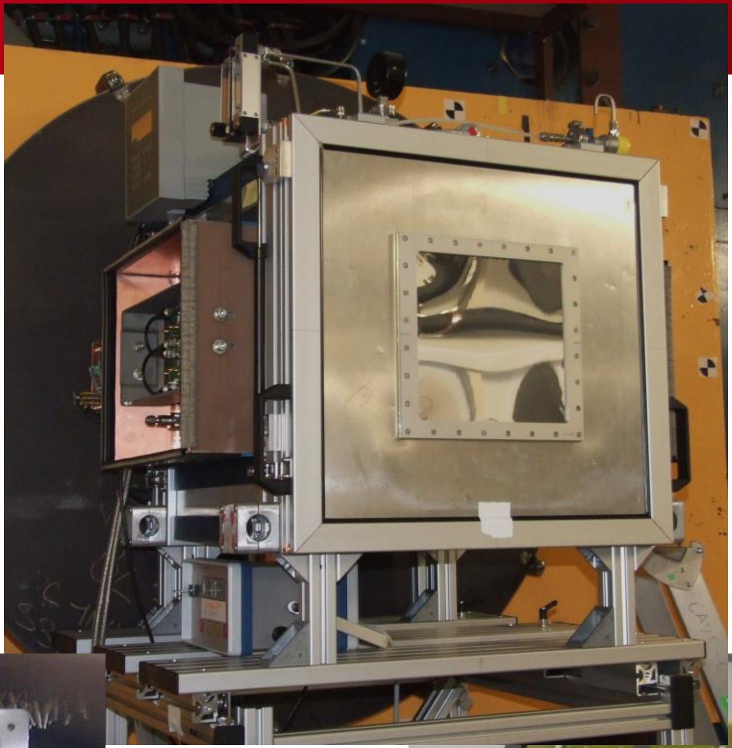
THE R3B/SOFIA SET UP

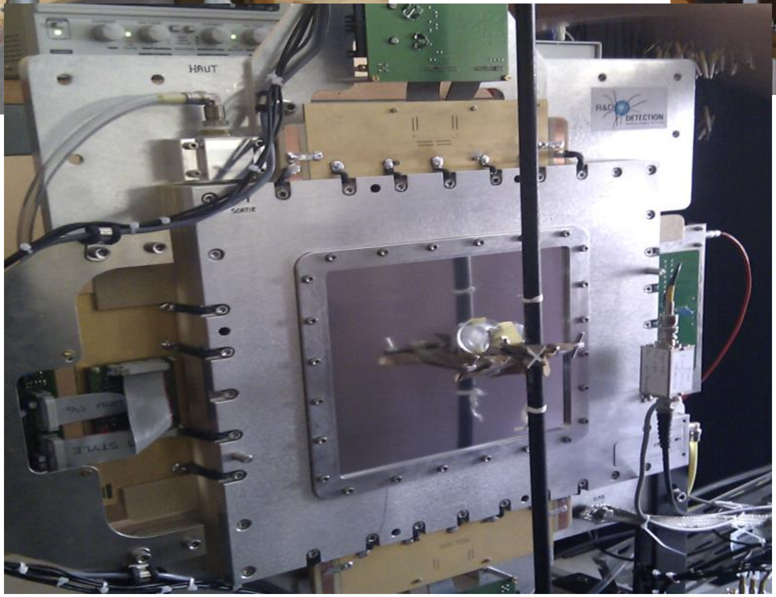
Fission and fragments identification in cave C

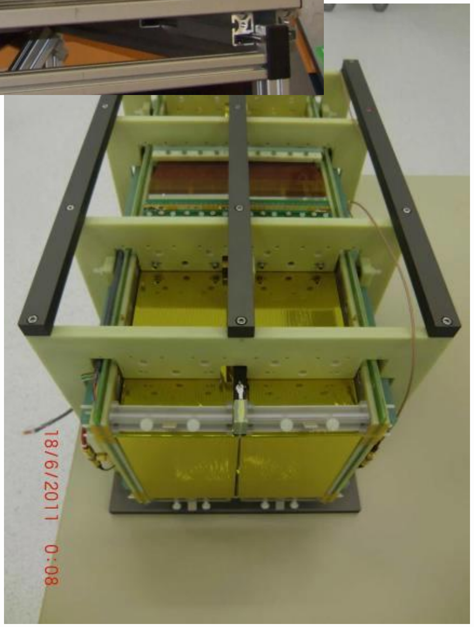


Challenge : mass identification in the FF region


← BEAM ←




HAUT
R&D DETECTION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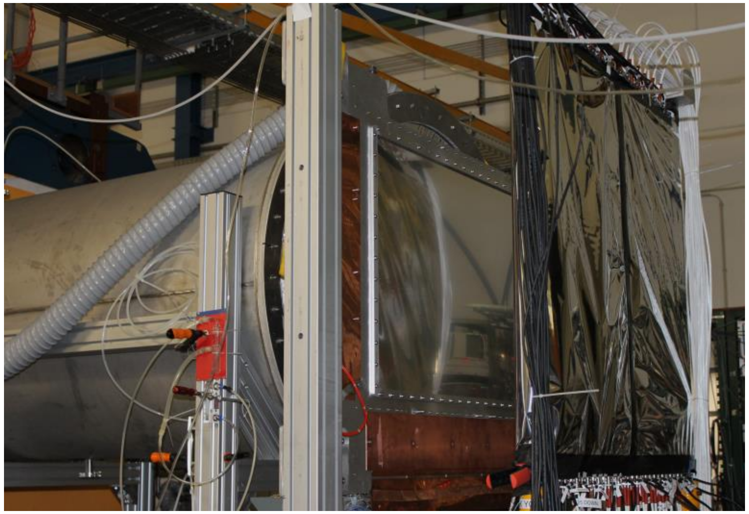
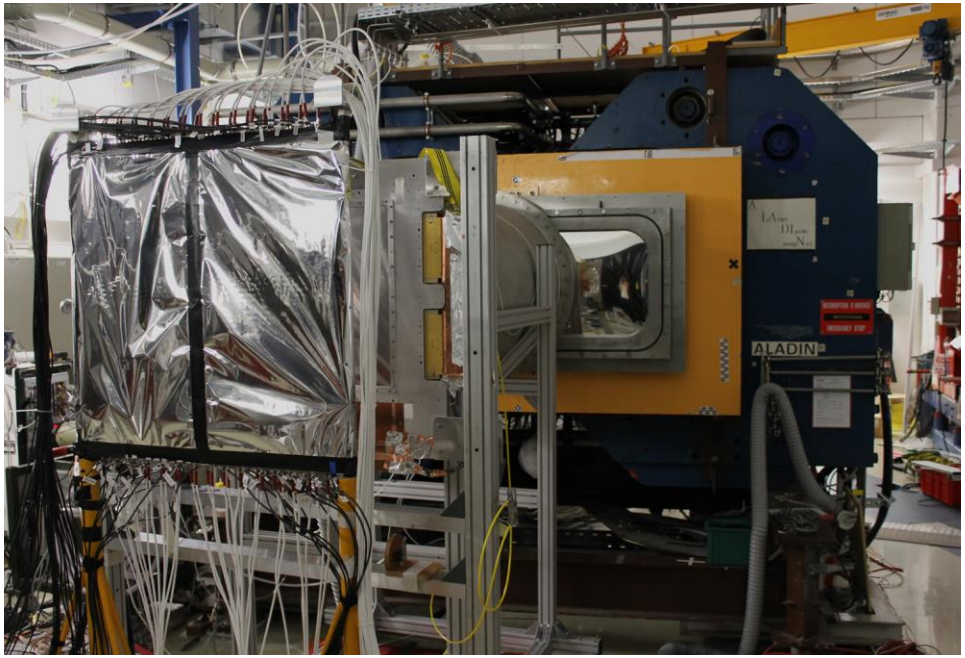
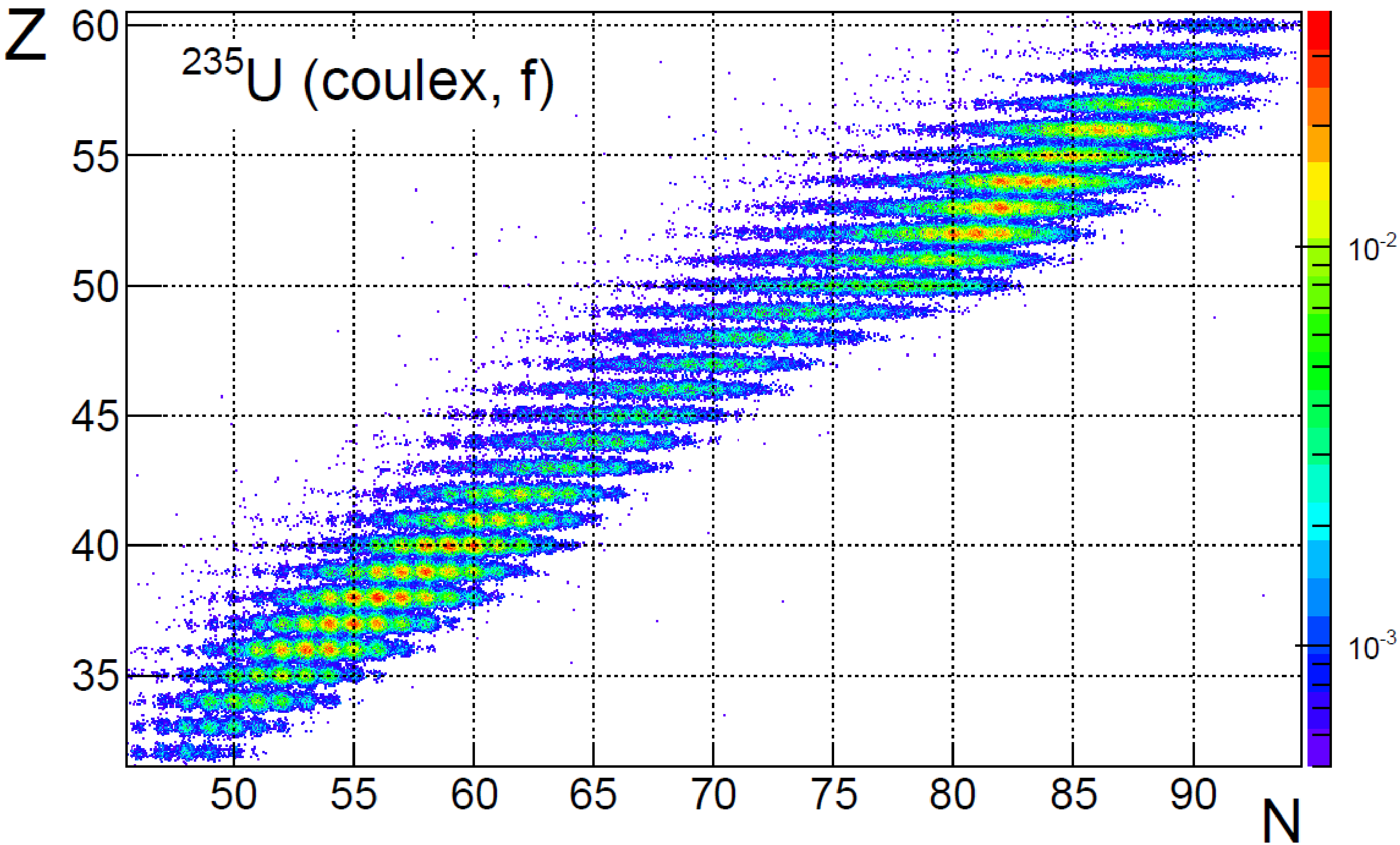



ALADIN

Spectra

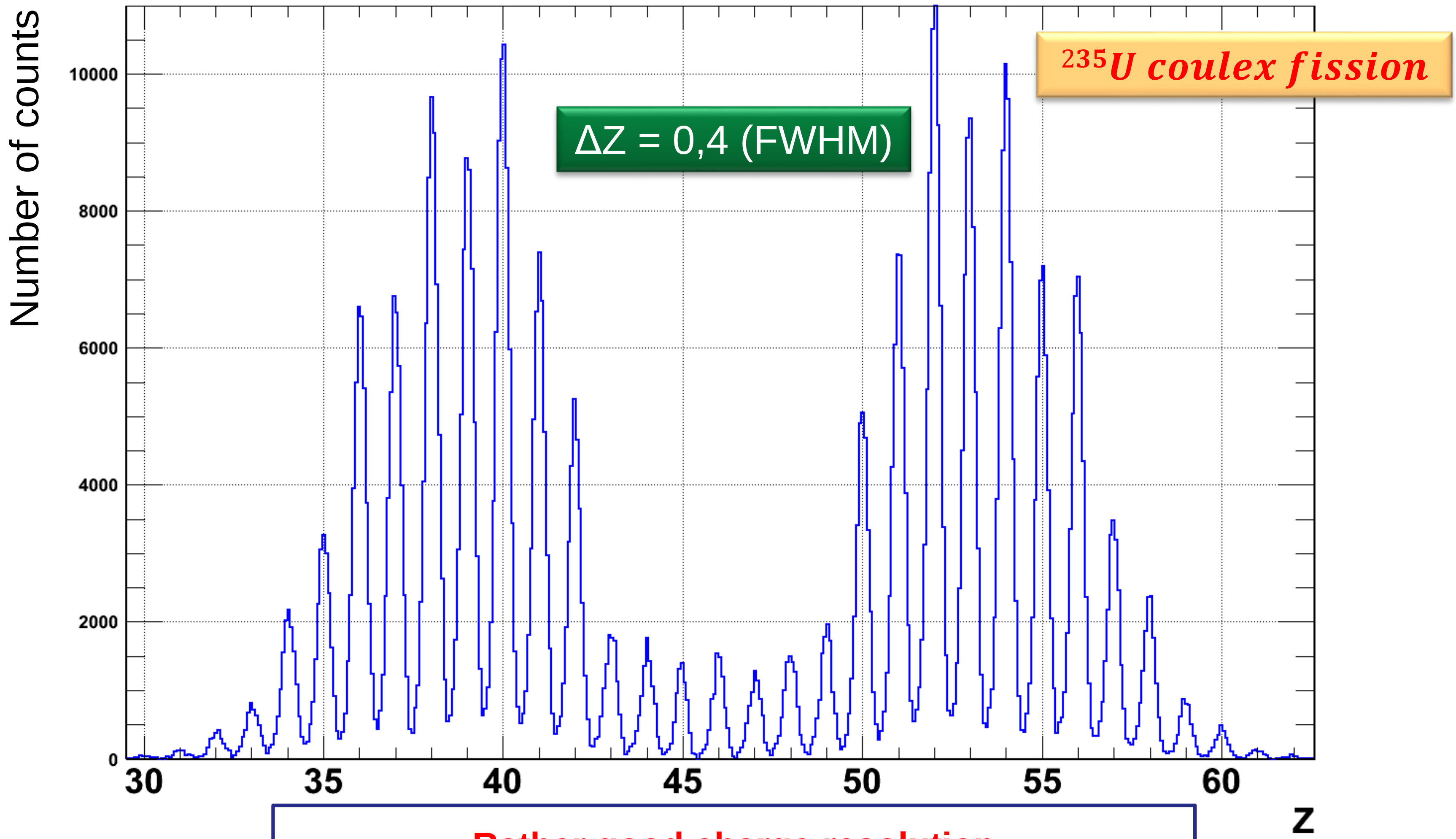
1) Chart of nuclide
2) Nuclear Charges
3) Masses

CHART OF MEASURED FF



PhD thesis : Julie Martin

NUCLEAR CHARGE SPECTRUM.

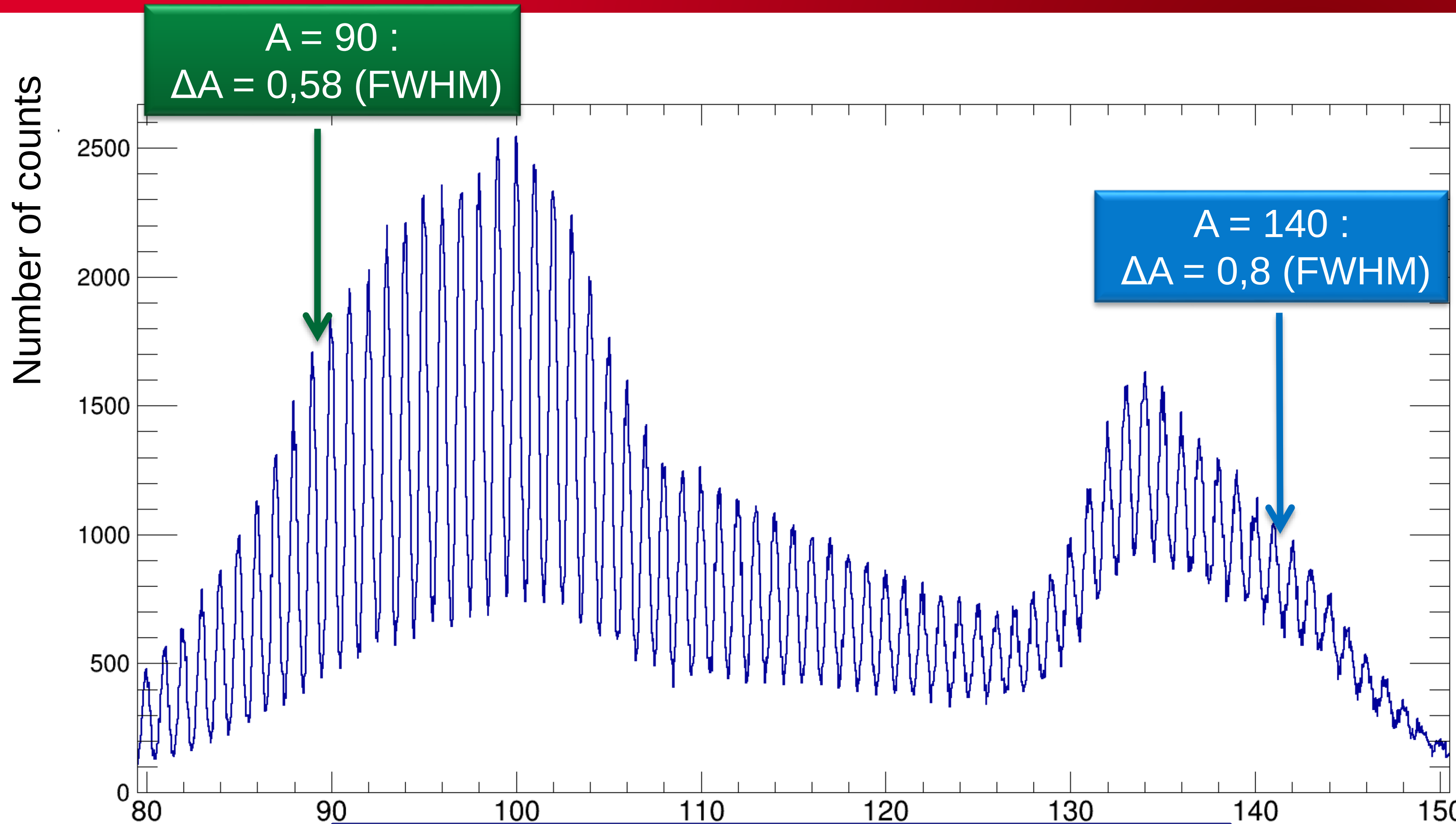


Rather good charge resolution

Visible odd-even staggering

PhD thesis : Julie Martin

MASS NUMBER SPECTRUM

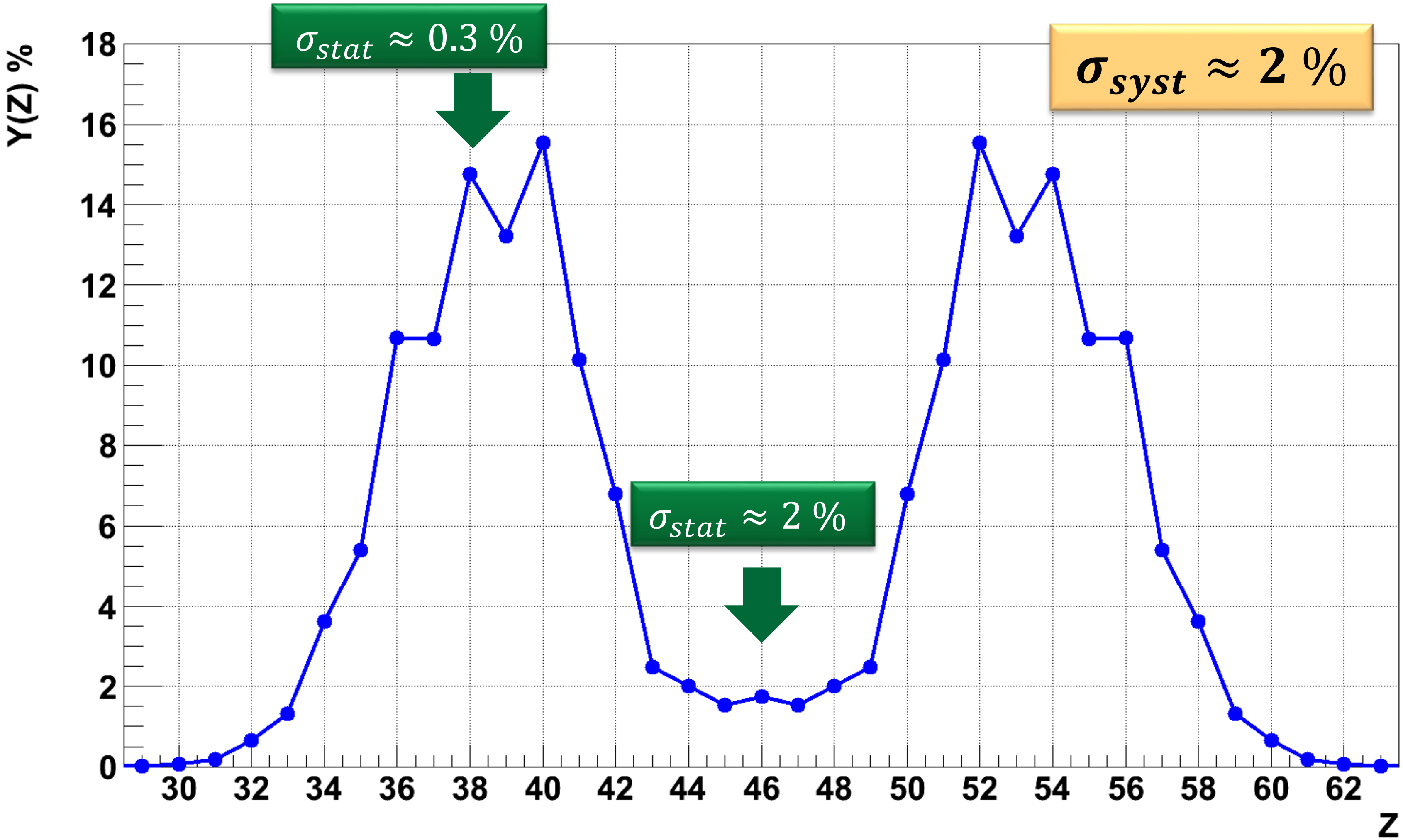


Very good mass resolution for the light FF
Degrades for the heavy FF, still neighbouring isotopes disantangled

Fission yields

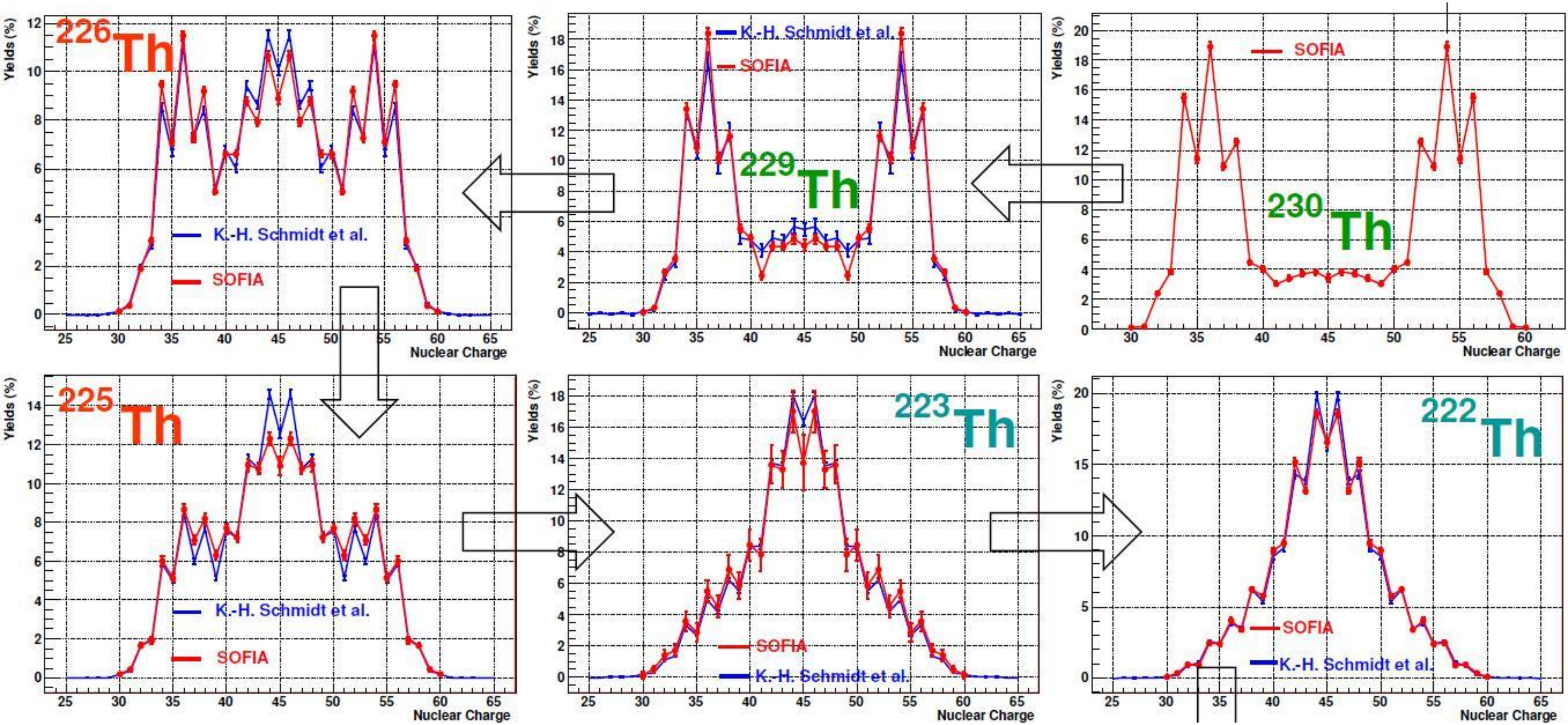
1) Element
2) Isotonic
3) Isotopic
4) Mass
5) Prompt Neutrons $\overline{\nu}$

^{238}U, CHARGE YIELDS



PhD thesis : Eric Pellereau

THE THORIUM CHAIN, K.-H. SCHMIDT VS R3B/SOFIA

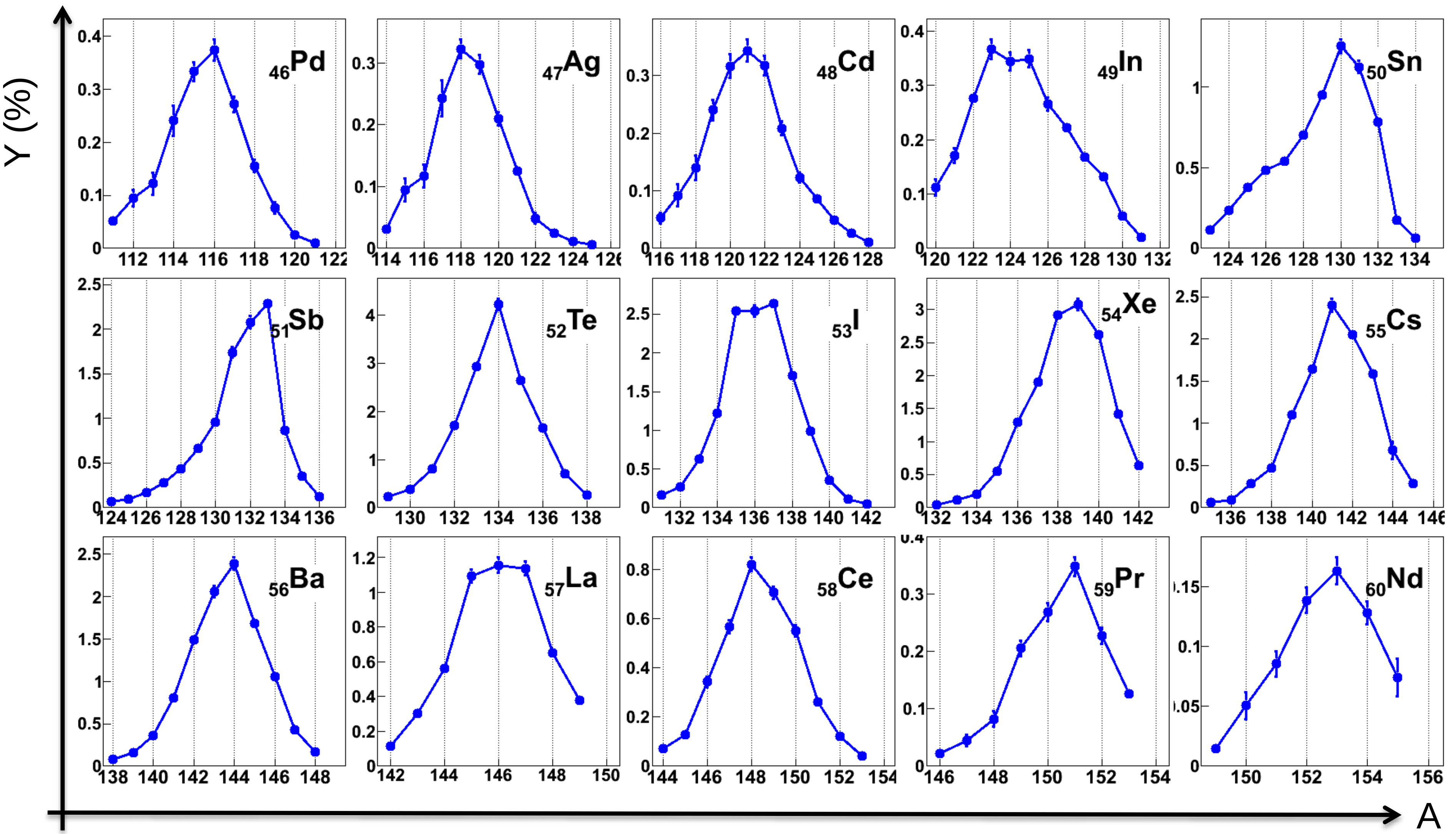


Courtesy : Audrey Chatillon

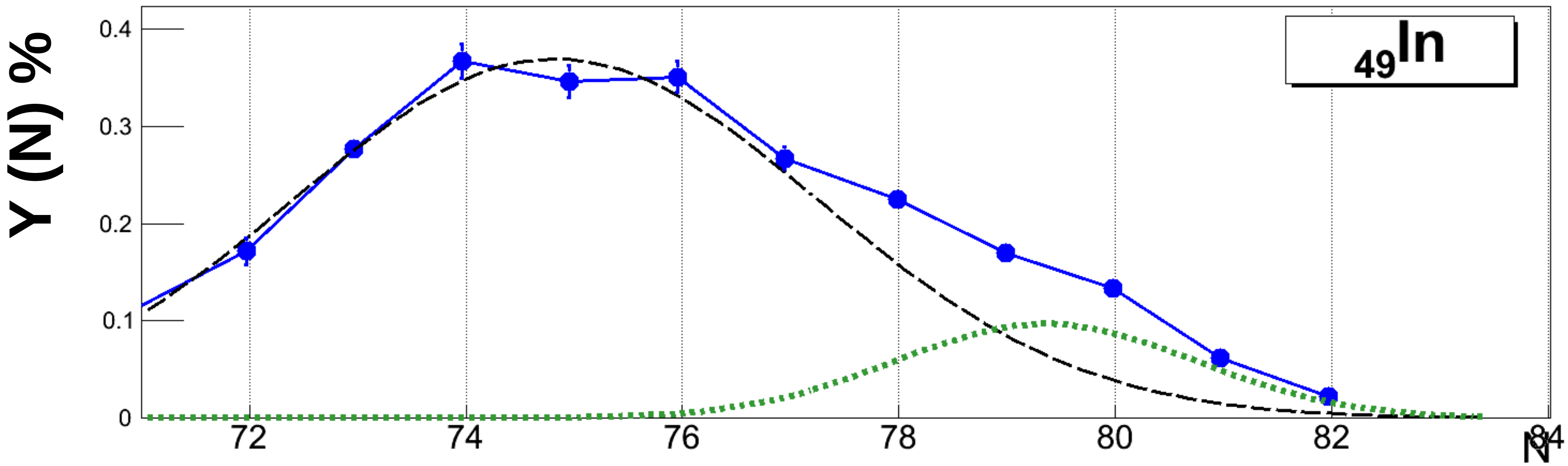
Fission yields

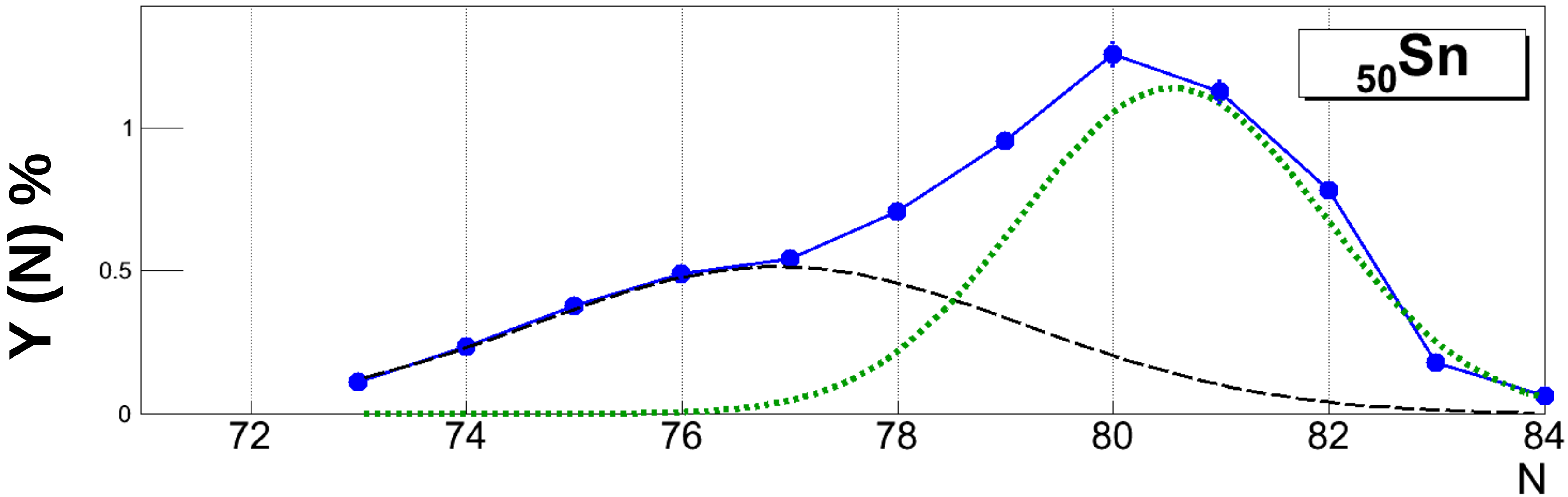
1) Element
2) Isotonic
3) Isotopic
4) Mass
5) Prompt Neutrons $\overline{\nu}$

ISOTOPIC YIELDS (HEAVY FF)



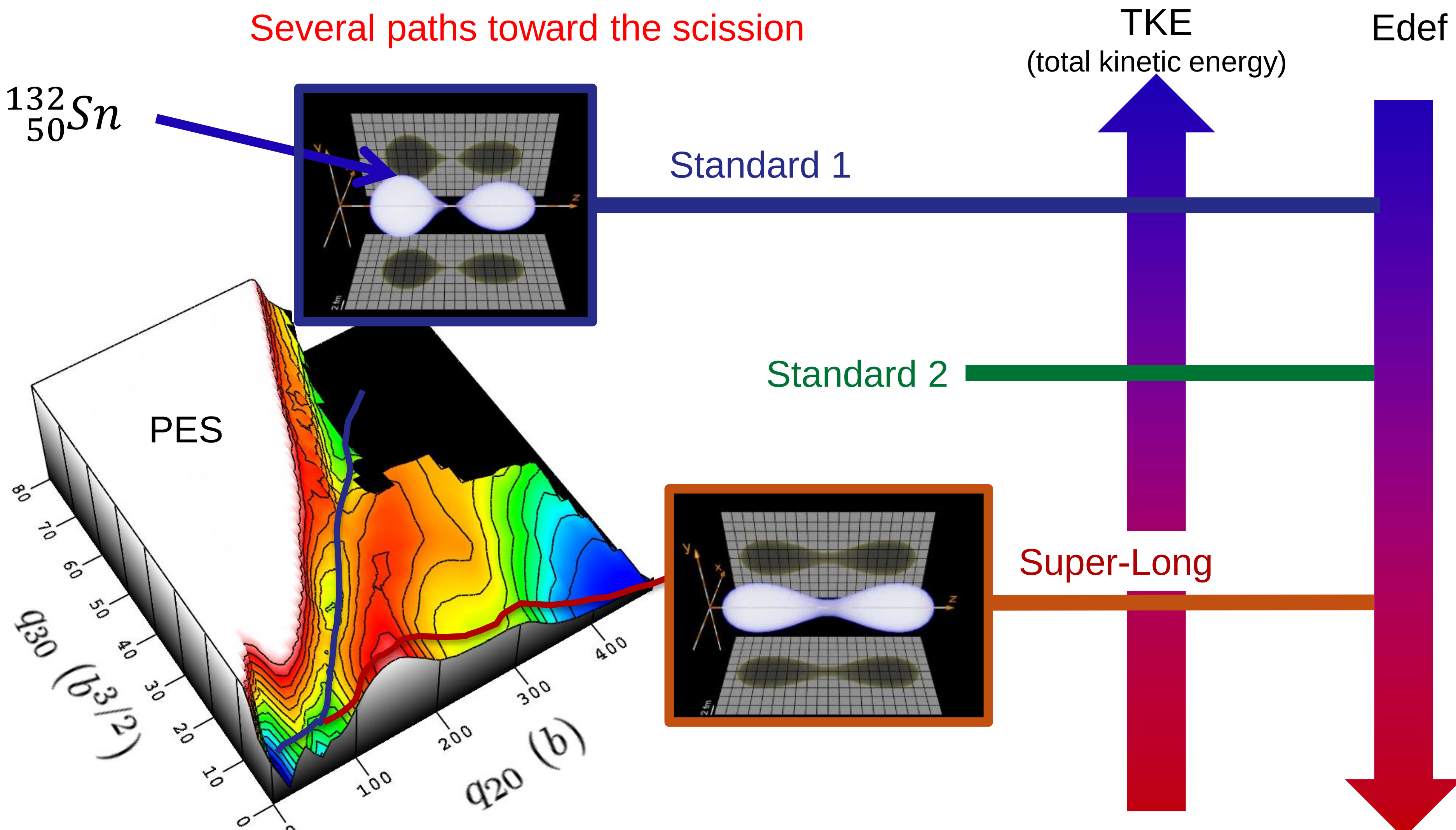
ISOTOPIC YIELDS ; ZOOM Z = 49-50





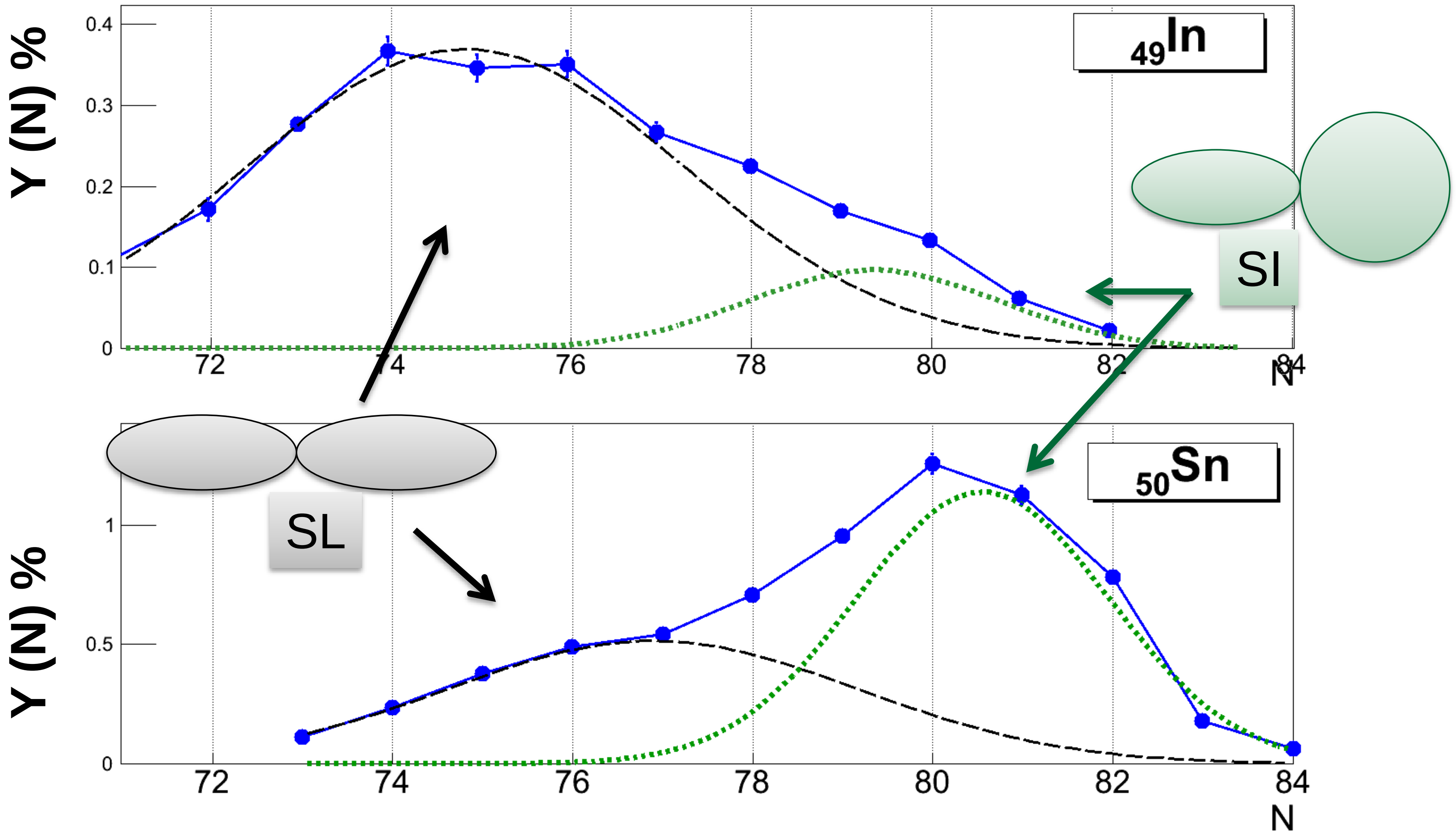
FISSION MODES

Several paths toward the scission

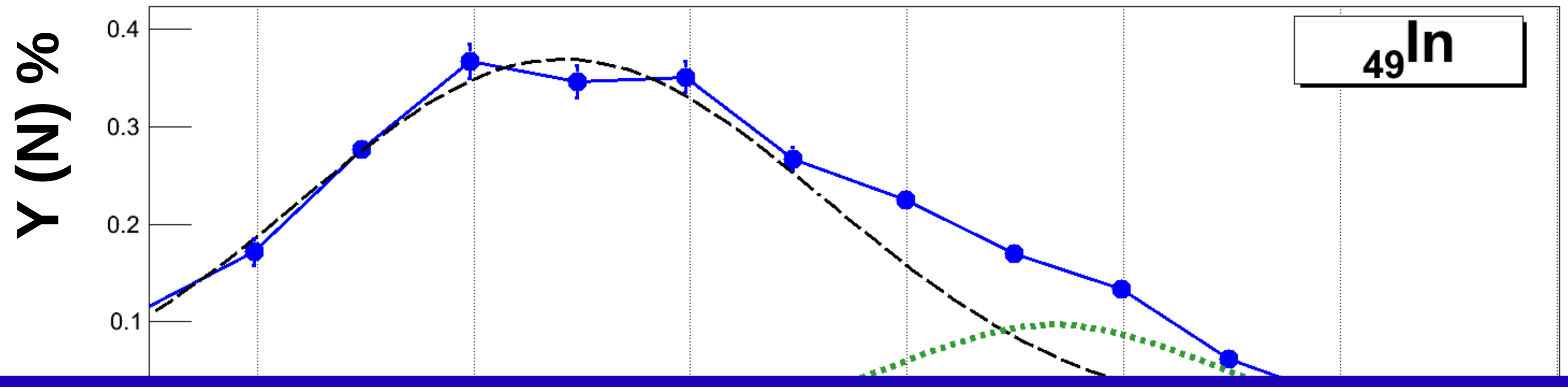


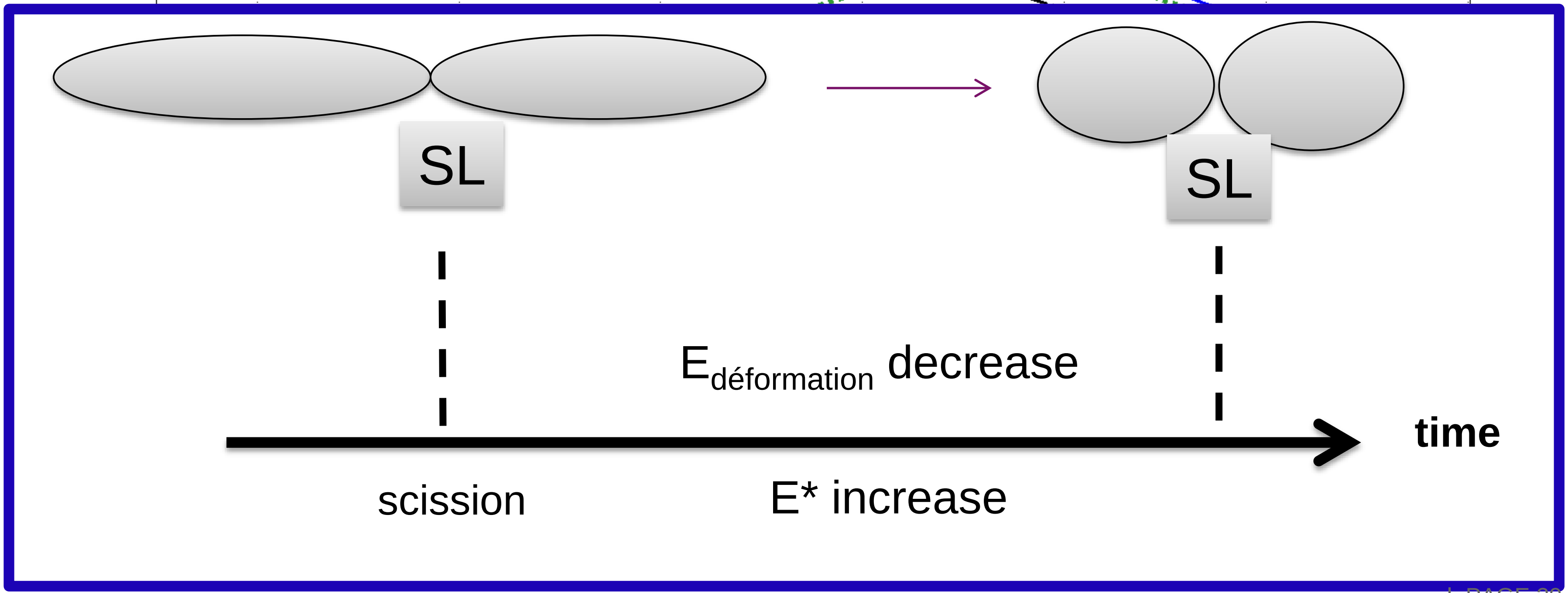
Courtesy: Noel Dubray

ISOTOPIC YIELDS; Z = 49-50



ISOTOPIC YIELDS; Z = 49-50



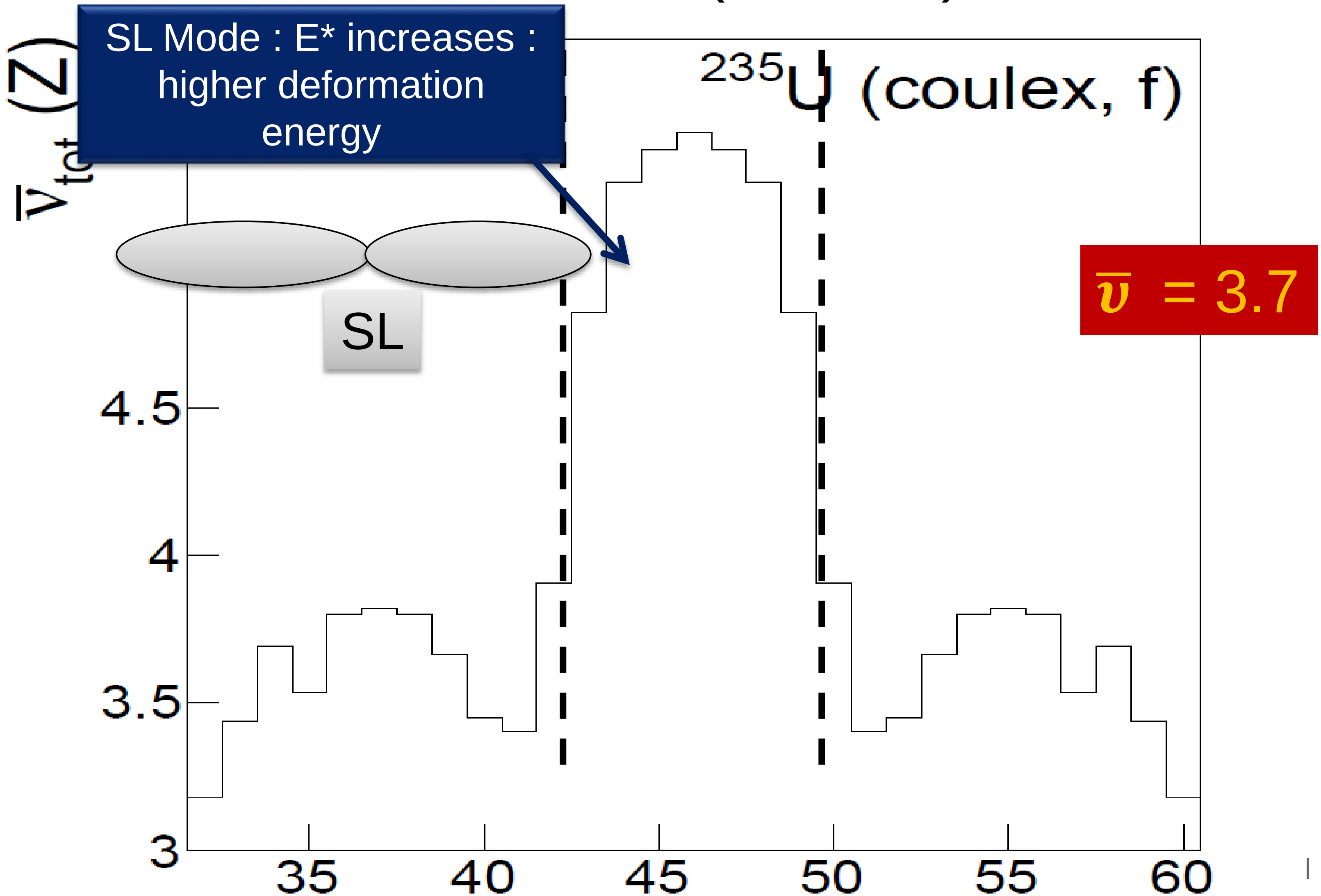


Fission yields

1) Element
2) Isotonic
3) Isotopic
4) Prompt Neutrons $\overline{\nu}$
5) Mass

$\bar{\upsilon}$ VS Z , FISSION OF ^{235}U

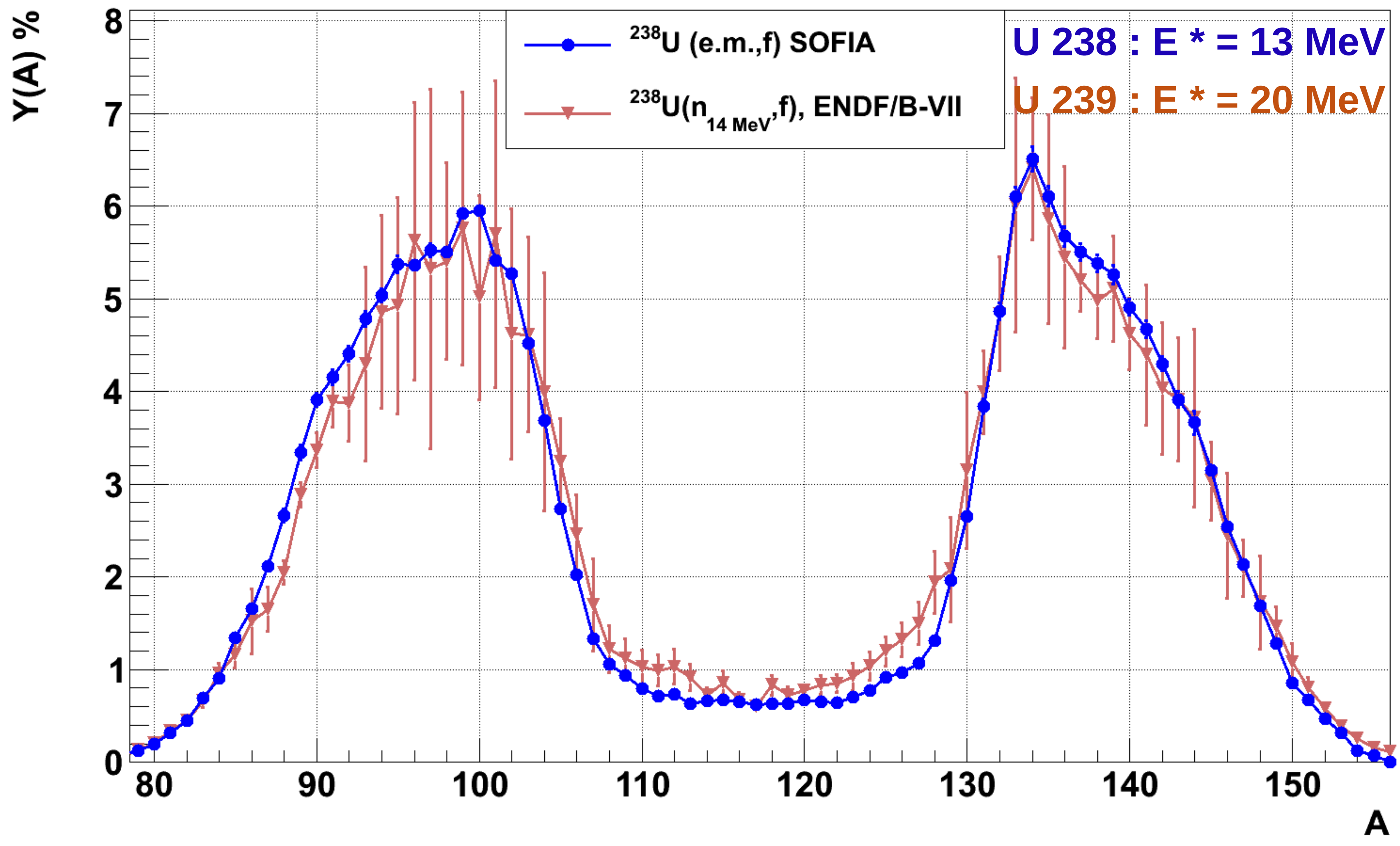
$\bar{\upsilon}$ = 235 – (A1 + A2)



Fission yields

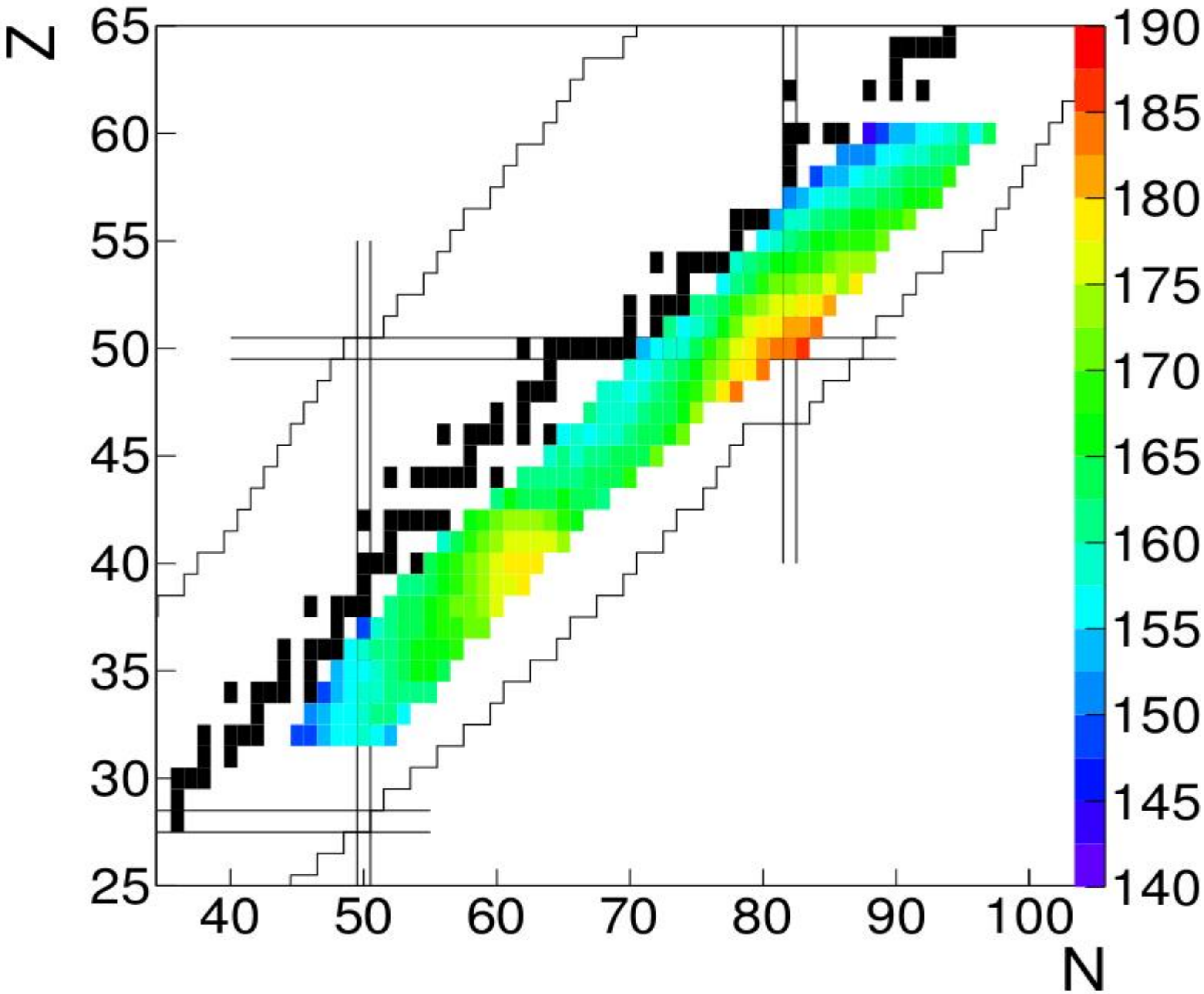
1) Element
2) Isotonic
3) Isotopic
4) Prompt Neutrons $\overline{\nu}$
5) Mass

MASS YIELDS, COMPARISON TO THE EVALUATION



Fission yields

1) Element
2) Isotonic
3) Isotopic
4) Mass
5) Prompt Neutrons $\overline{\nu}$
6) TKE


Z
65
60
55
50
45
40
35
30
25
40
50
60
70
80
90
100
N
190
185
180
175
170
165
160
155
150
145
140

THE (RECENT) PAST : R3B/SOFIA

R3B/SOFIA1 opened a new era in the fission studies:

- Fission of tens of nuclide studied in one experiment
- All fission fragments identified unambiguously for the 1st time in low energy fission

- Nuclear charge resolution = 0,4 u FWHM
- Mass resolution = 0,8 u FWHM for A = 140
- Big step forward w/ respect to previous knowledge

- Detailed information on fission modes
- several correlated observables of fission : Y(Z,A), nu, TKE
- New data on the scission configurations
  - Total kinetic energy
  - Number of emitted neutrons

THE FUTURE

The future looks nice

- FAIR/R3B could continue to provide more major data on fission
  - GSI is the only option for those studies

- A new large acceptance magnet at R3B : GLAD
  - Better mass resolution expected
  - More accurate data on the heavy peak
  - Better estimate of the neutron multiplicity

- New high efficiency neutron detector : NeuLAND
  - We will correlate the neutron to a given fragment
    - New studies : how the energy is shared between both fragments

- New CALIFA gamma / light charge particle calorimeter installation
  - Data on the total gamma energy

THE FUTURE

The future looks nice (2)

- A standard beam intensity permits the investigation of neutron deficient exotic preactinides : seek for new fission modes and deformed shells

- The new fission yield data on actinides (Uranium, Neptunium) will contribute to the improvement of the safety of all nuclear reactors
- New request from OECD/NEA to provide fission yields for heavier actinides, ^{240}Am, ^{241}Am, ^{242}Am, ^{239}Pu, ^{240}Pu, ^{241}Pu
- Could be possible with a ^{242}Pu primary beam at FAIR (1/3 Million year)

- Not discussed here : studies on fission probability at R3B
  - Could be done on exotic nuclides with (p,2p) reactions
  - Nice test of the fission barrier height estimate of usual models used

The R3B/SOFIA collaboration

CEA – De la recherche à l'industrie

GSI

IPN – Institut de Physique Nucléaire Orsay

CENBG

GANIL Spiral2 – laboratoire commun CEA/DSM CNRS/IN2P3

USC – Universidade de Santiago de Compostela

Universidade de Vigo

Chalmers University of Technology