New experiments on low-energy fission - Methods and results

Karl-Heinz Schmidt

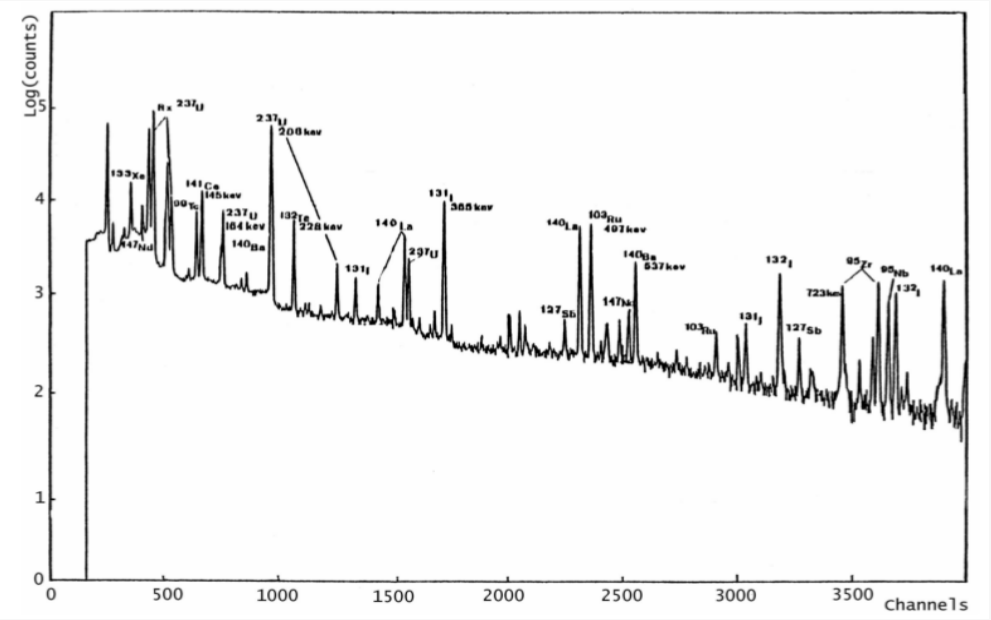
Contribution to the meeting of the WPEG subgroup
“Improved Fission product yield evaluation methodologies”
May 22, 2013
Issy-les-Moulineaux, France

Conventional experimental techniques

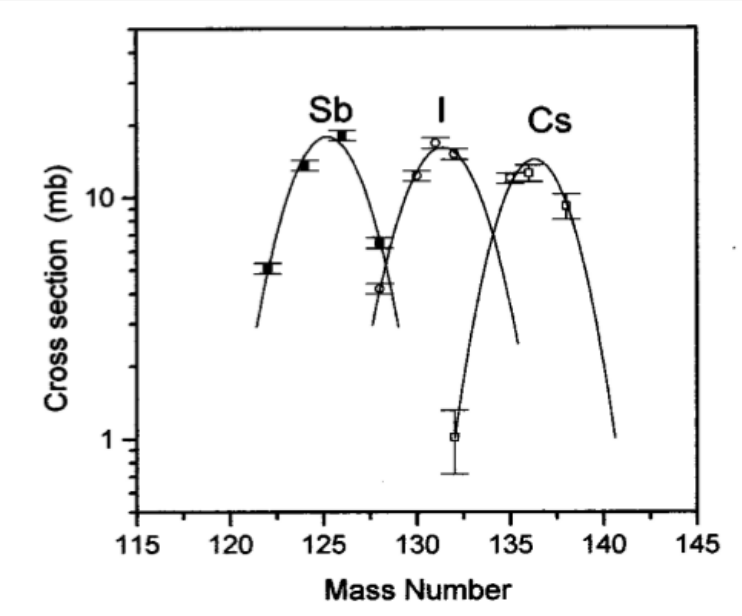
and

some “well established” results

Off-line gamma spectroscopy



Laurec et al., NDS 111 (2010) 2965

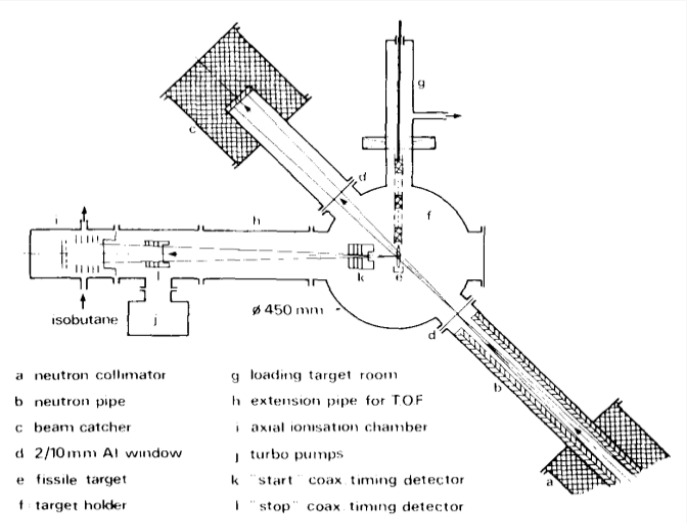


Gubbi et al., PRC 59 (1999) 3224

Independent yields for different initial energies
Too slow for short-lived fission products
Relies on spectroscopic information
(Almost) no information on kinematics

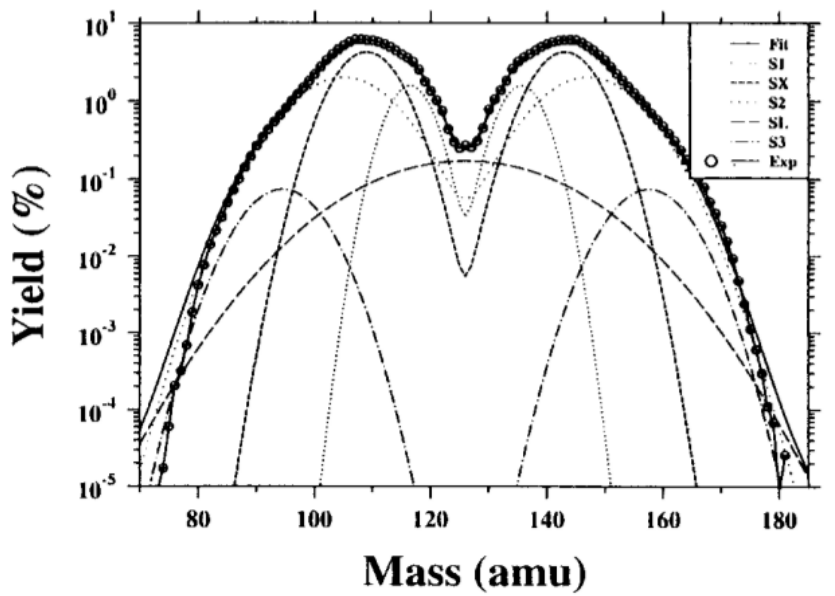
Double energy / double TOF

The Cosi-Fan-Tutte set-up



Bucheneb et al., NPA 502 (1989) 261c

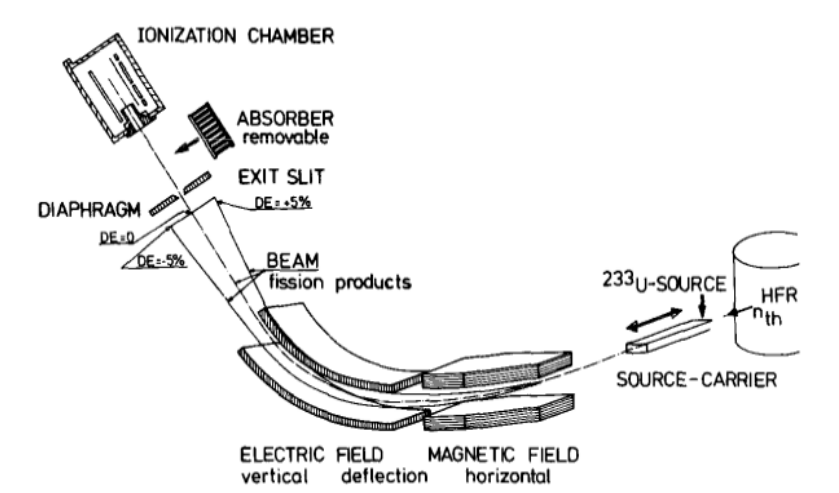
Decomposition in fission channels

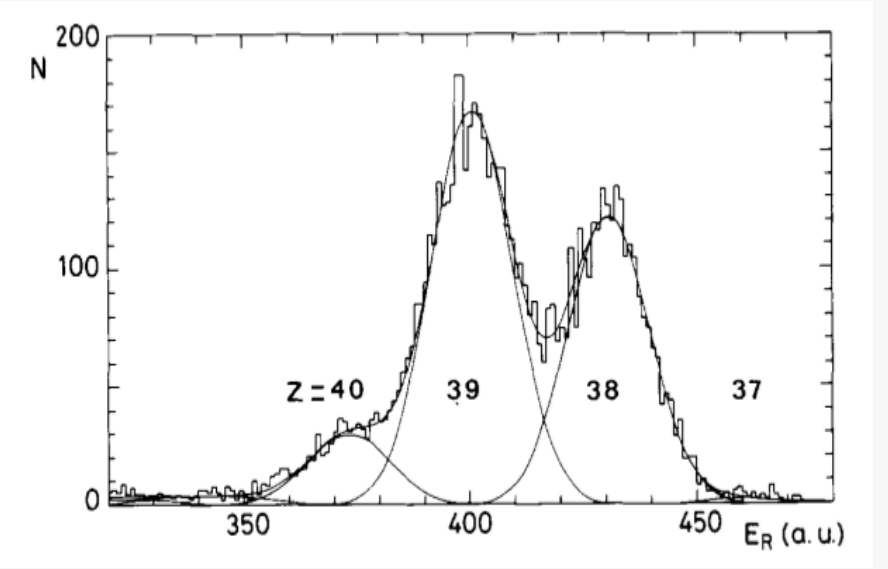


Hambsch in NPA 654 (1999) 855c

Pre-neutron / post-neutron masses ($\Delta A \approx 2$)
Prompt neutron yields can be deduced
Kinematical information (TKE)

Lohengrin





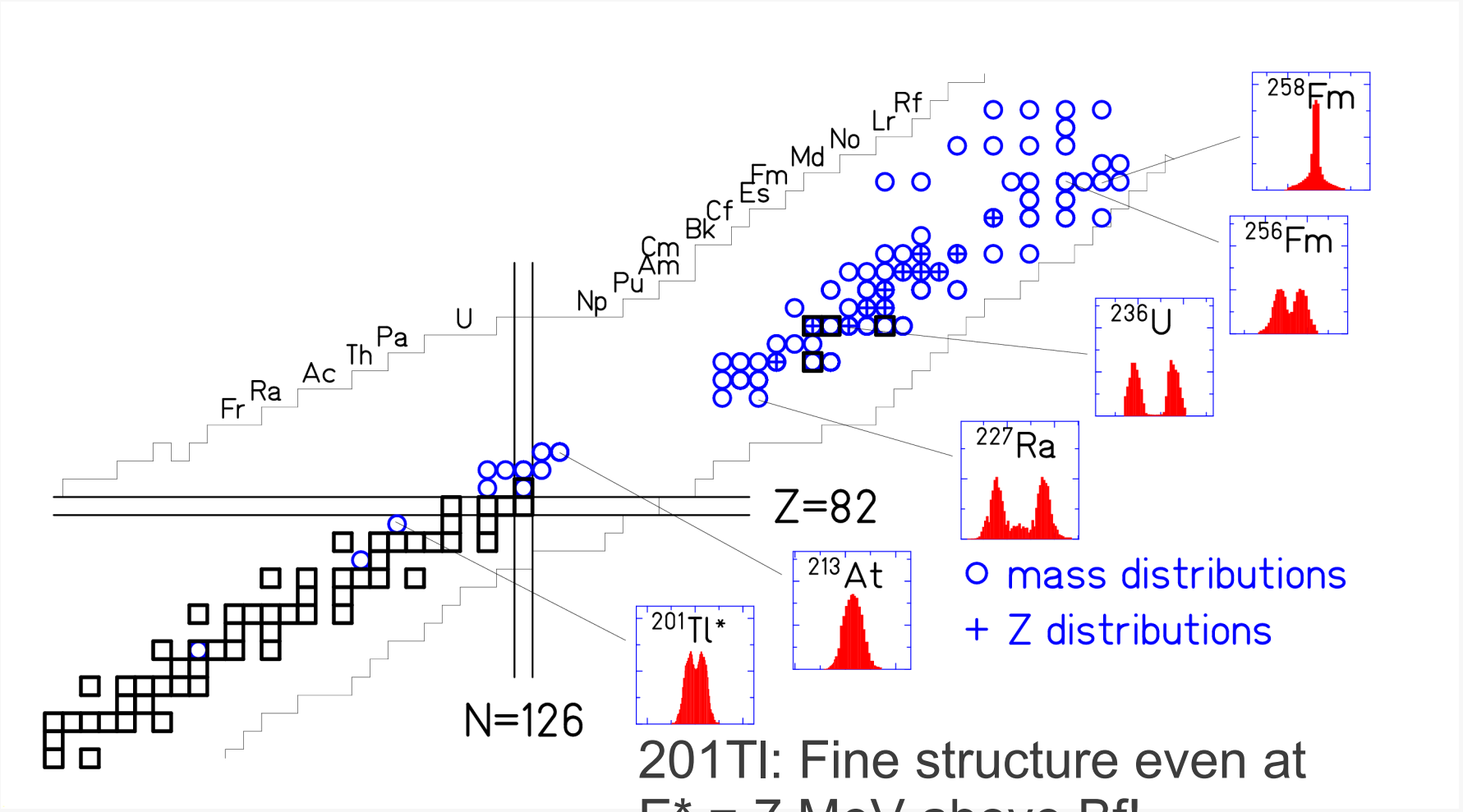
Lohengrin: Spectrograph at
ILL high-flux reactor
U. Quade et al., NPA 487 (1988) 1

ΔE spectrum

Djebara et al., NPA 496 (1989) 346

Good Z resolution in light fragments.
Restricted to (n_{th},f) and long-lived targets.

Systematics of fission-fragment distributions



201Tl: Fine structure even at
E* = 7 MeV above Bf!

Position of heavy fragment

229Th

233U

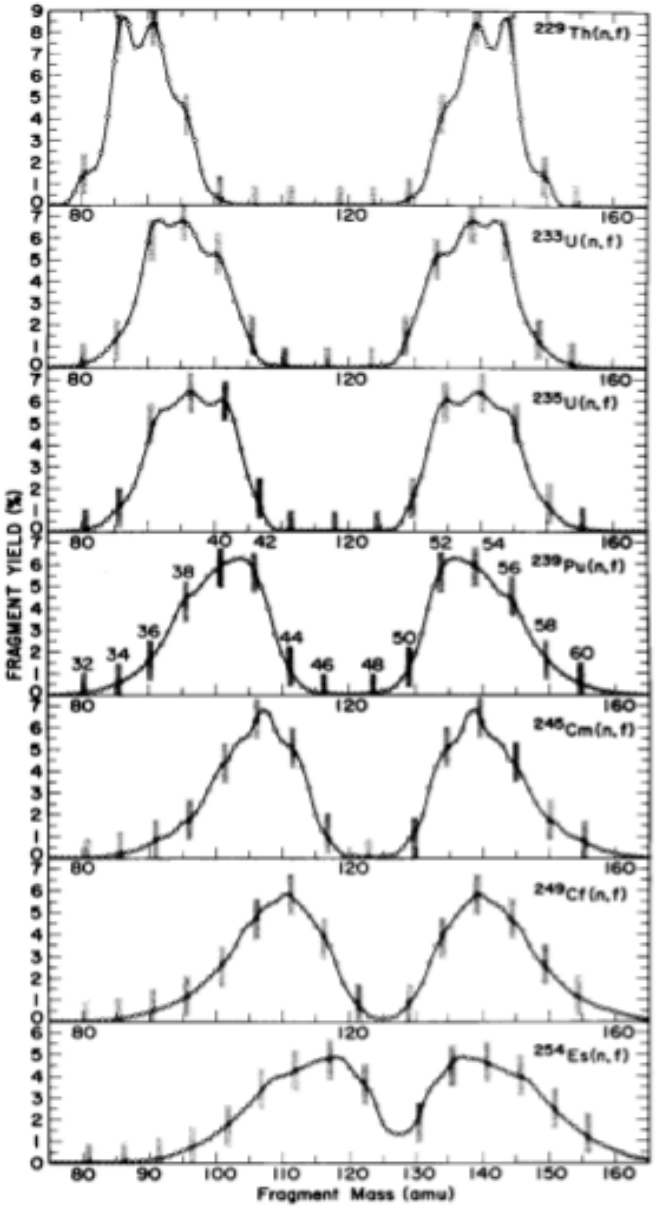
235U

239Pu

245Cm

249Cf

254Es

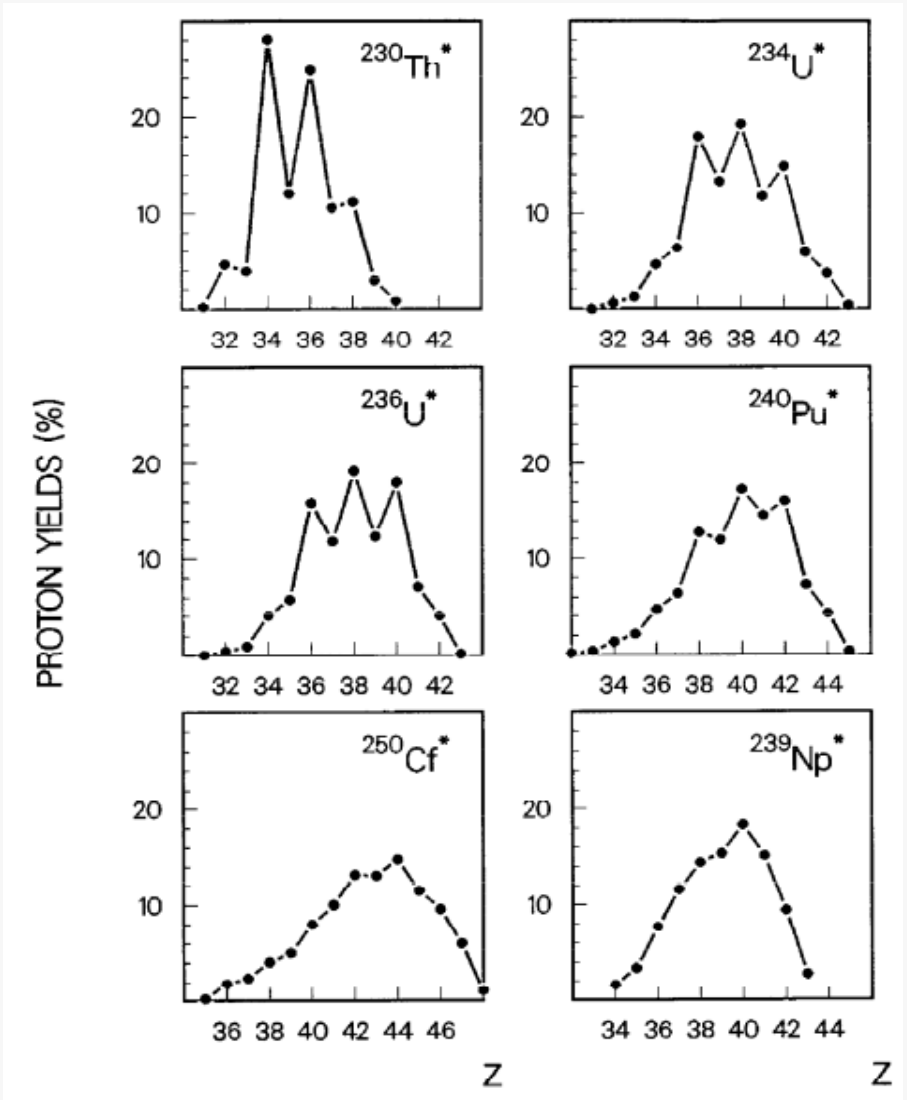


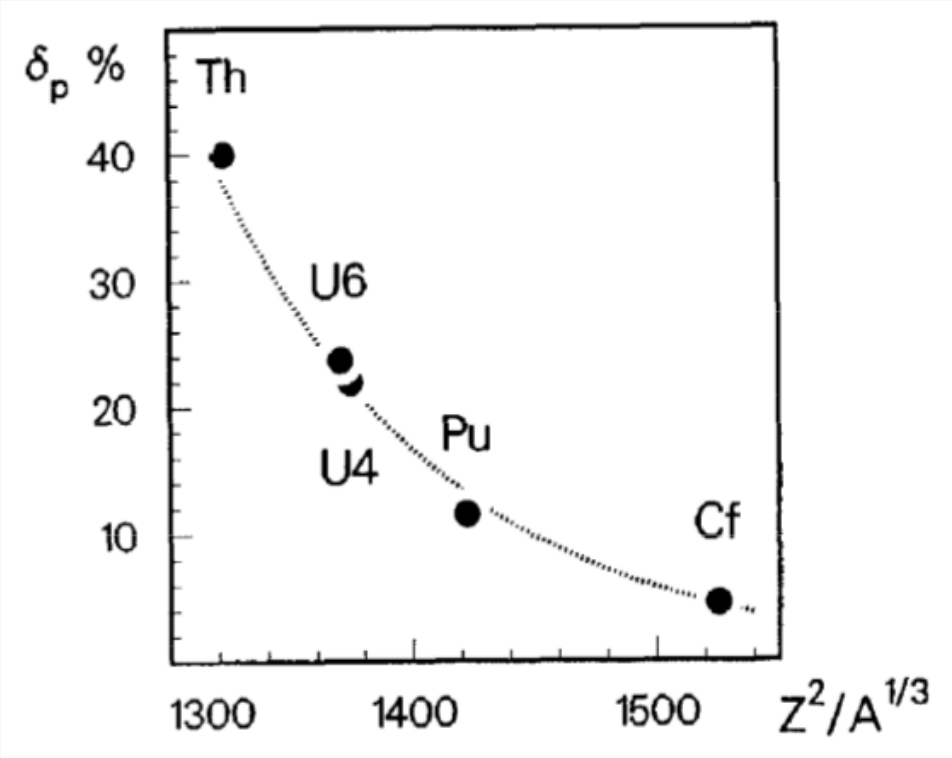
Unik et al., 1973

Fission-fragment mass distribution from Z=90 to Z=99.

The position of the heavy fragment is constant at A = 140.

Global even-odd effect in fission-fragment Z distributions

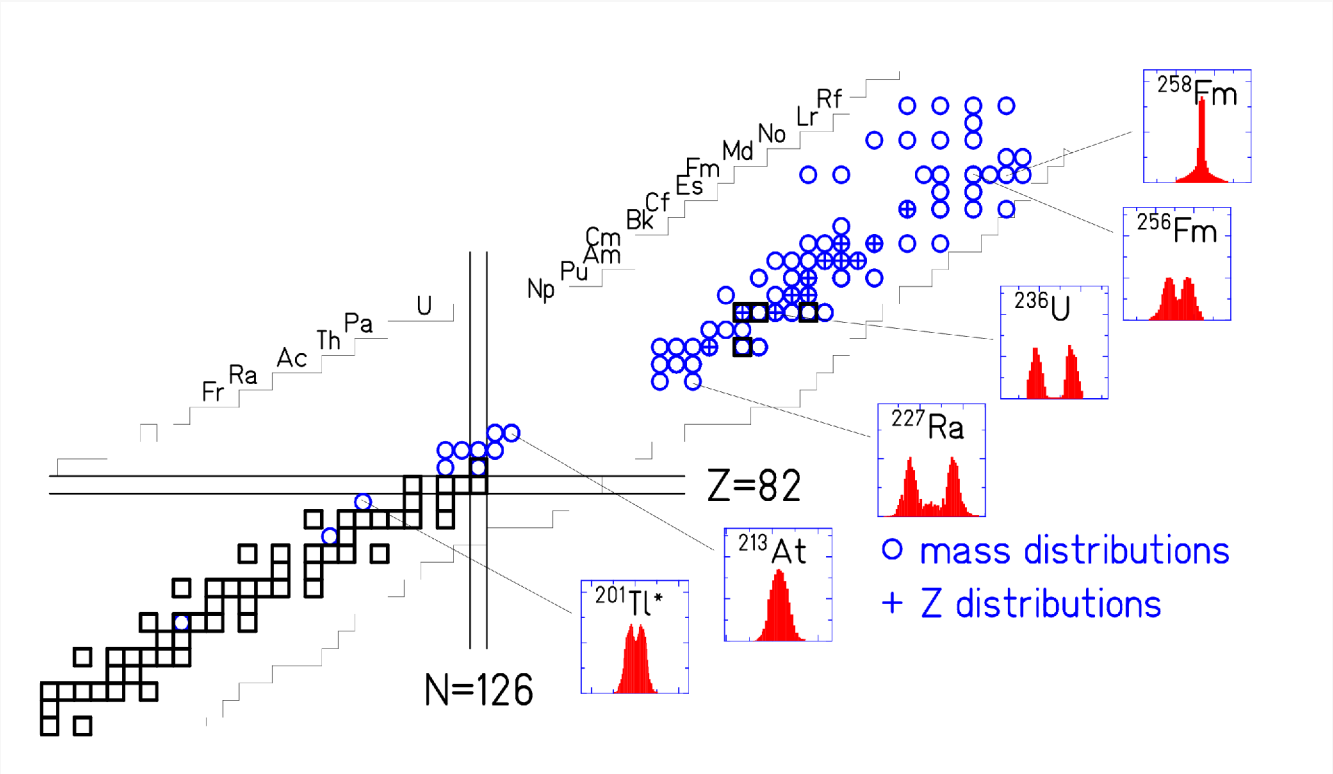




Bocquet, Brissot, 1989

Systematic variation of even-odd effect with Coulomb parameter.

Limitations of conventional experiments



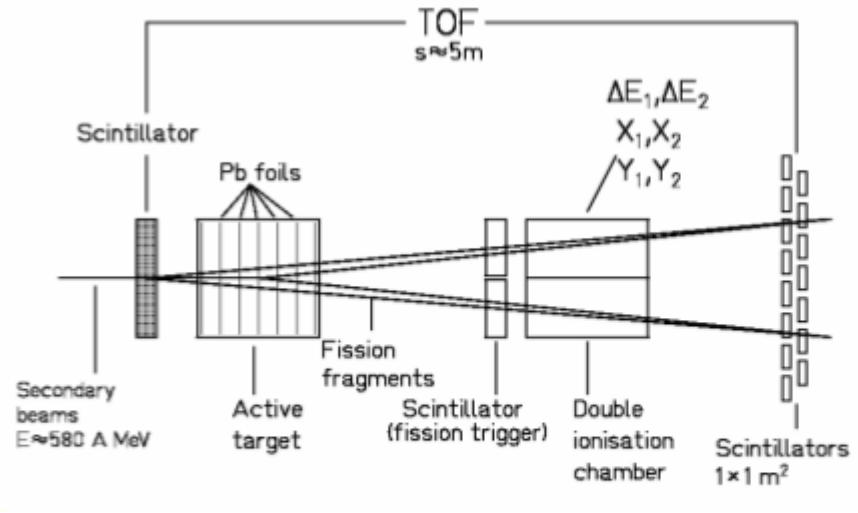
- Choice of fissioning systems severely limited
- Z resolution only in exceptional cases

New experimental approaches

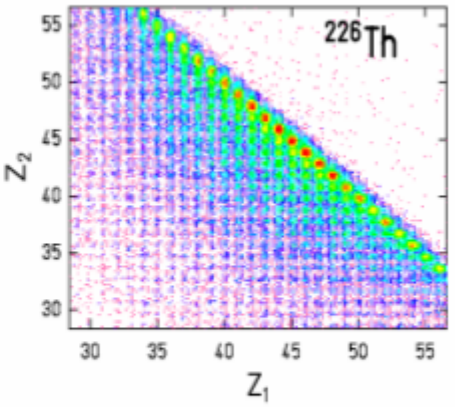
and

new findings

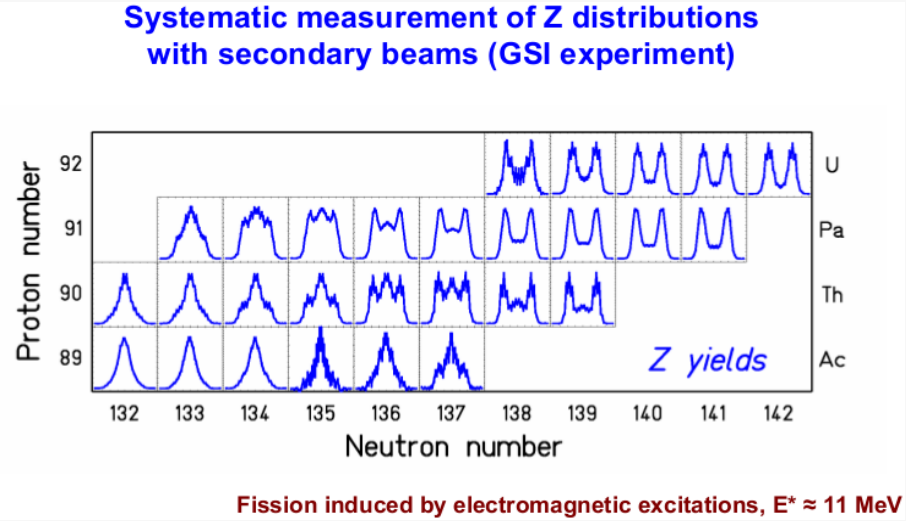
Coulomb fission of relativistic ^{238}U projectile fragments at GSI



The detectors



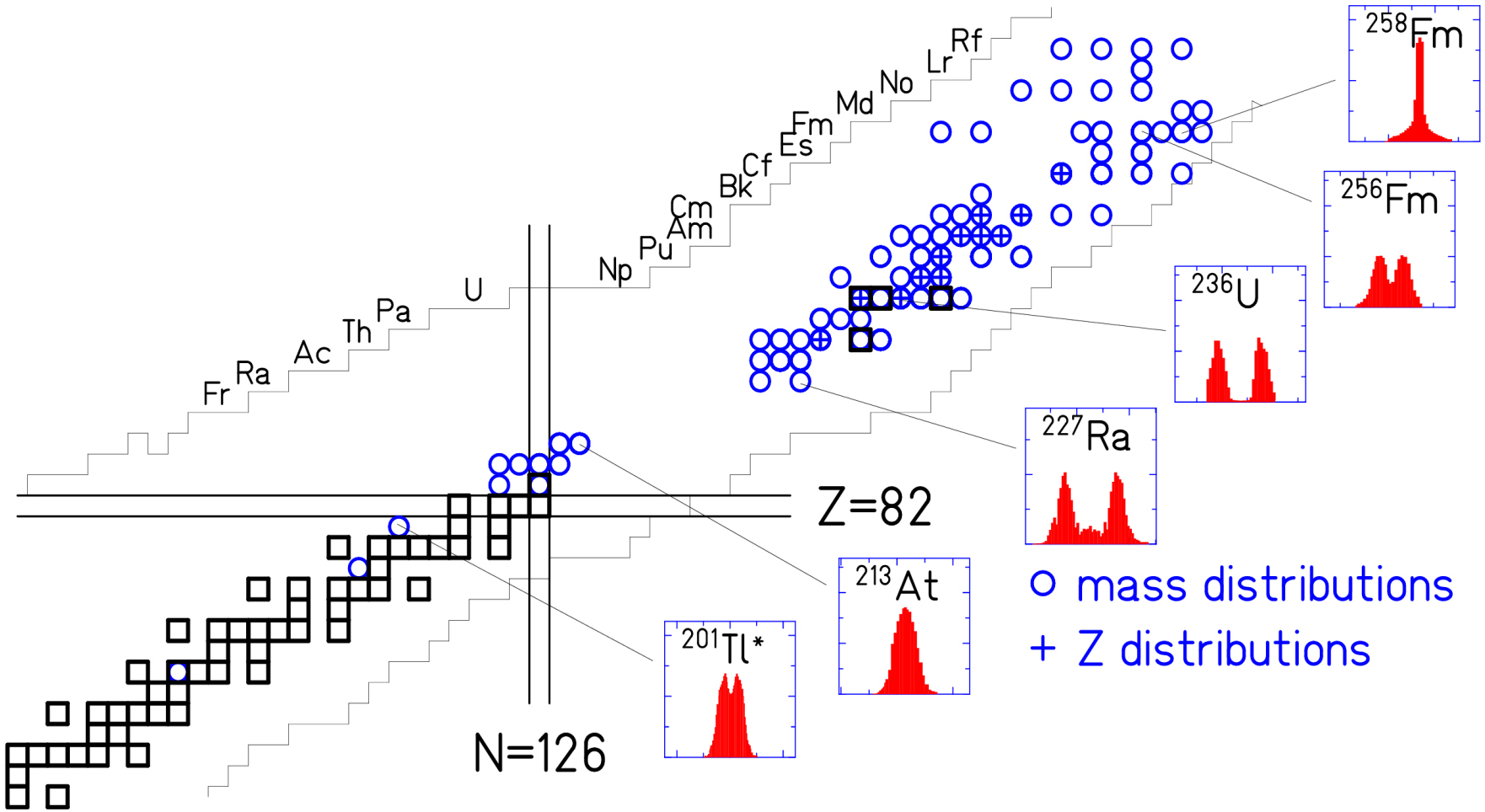
Identification of both fragments in Z



- Access to radioactive nuclei ($A \leq 238$)
- Excellent Z resolution
- Mapping symm. - asymm. fission

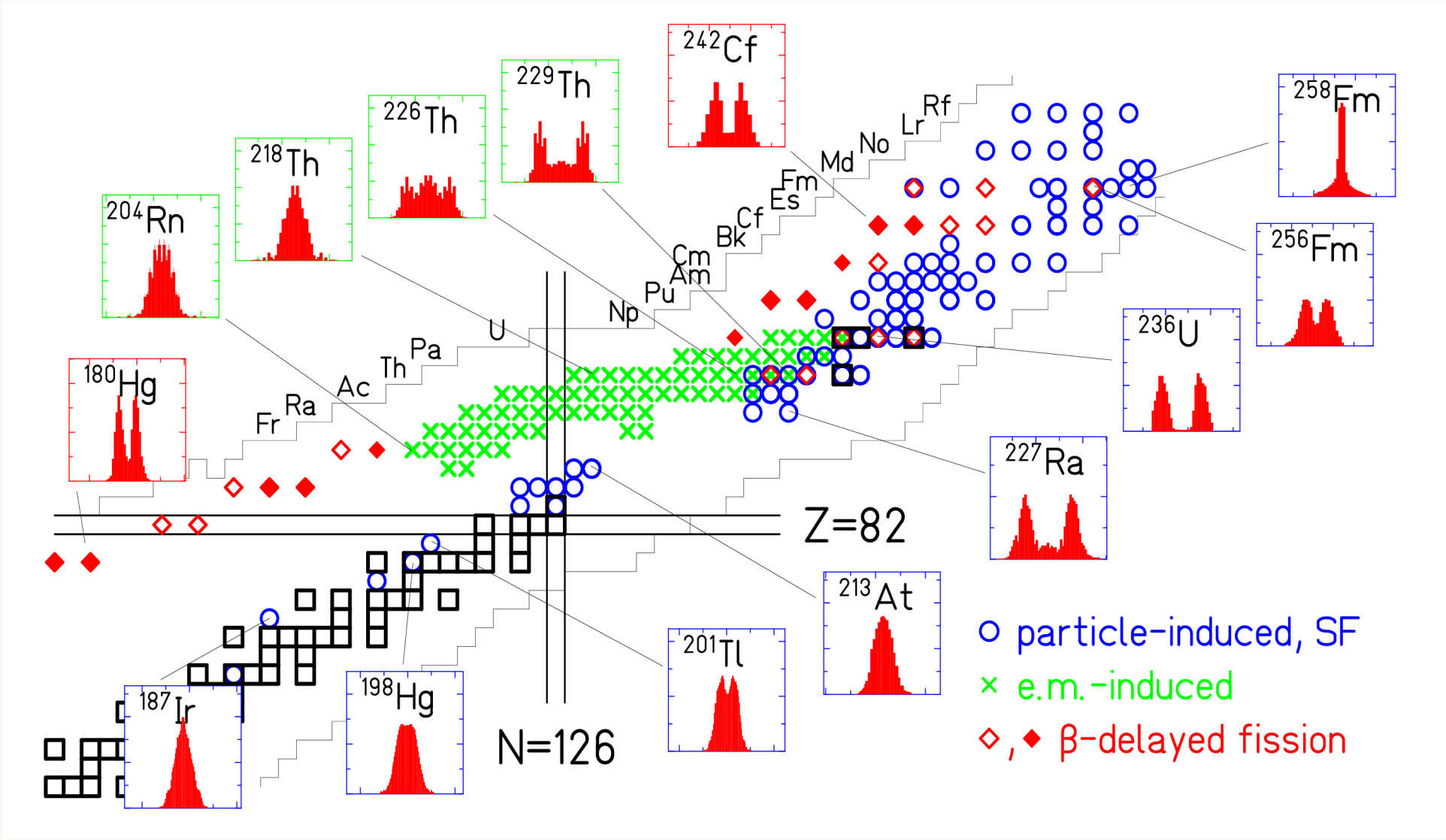
Schmidt et al., NPA 665 (2000) 221

Systematics of fission-fragment distributions

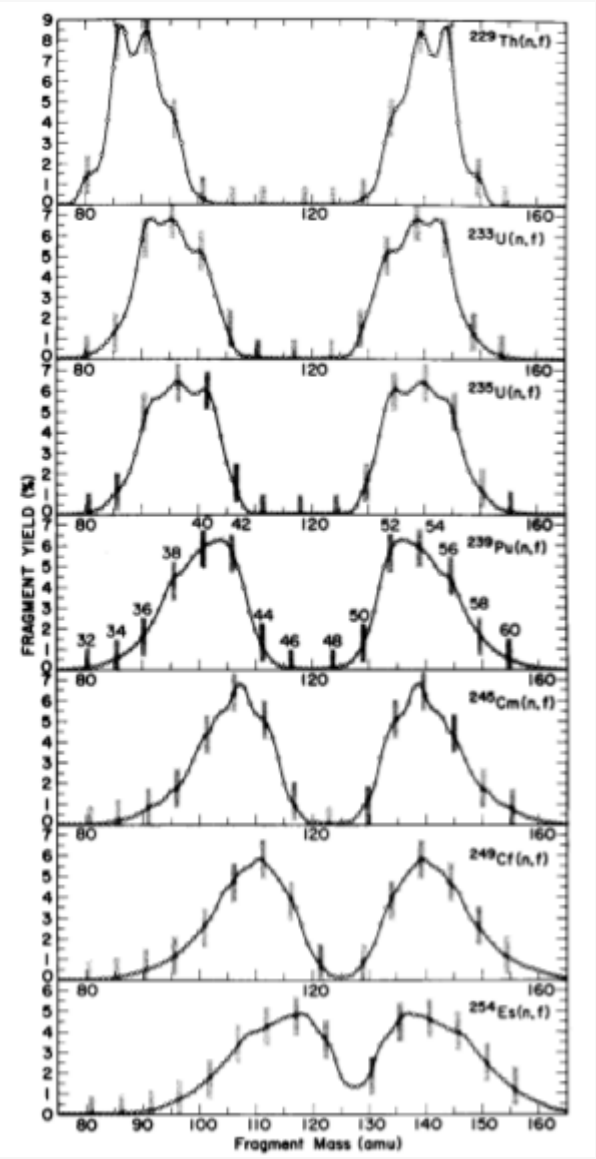


201TI: Fine structure even at
E* = 7 MeV above Bf!

Extended systematics of fission-fragment distributions

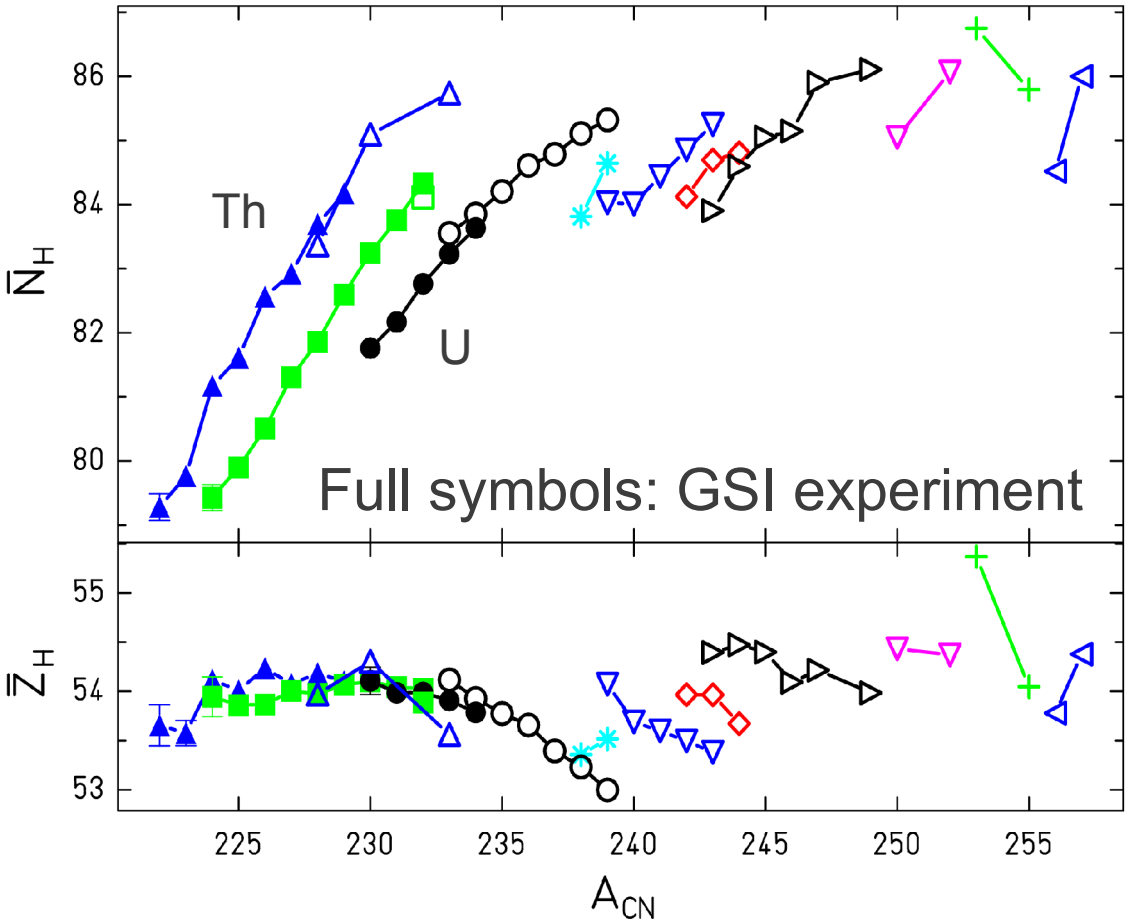


Position of heavy fragment



Unik et al., 1973

<A> ≈ 140

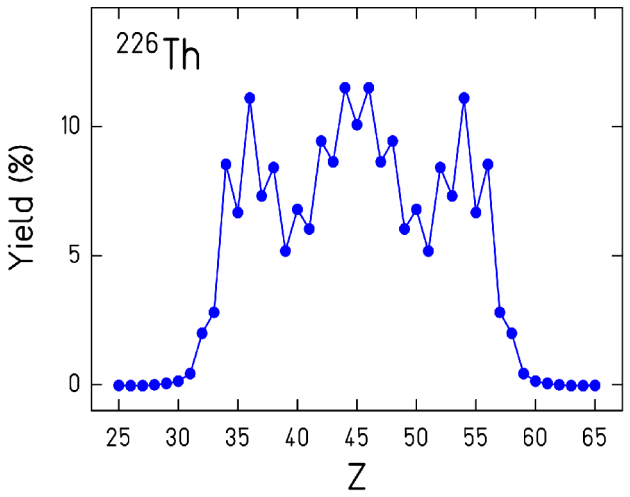


Böckstiegel et al., 2008

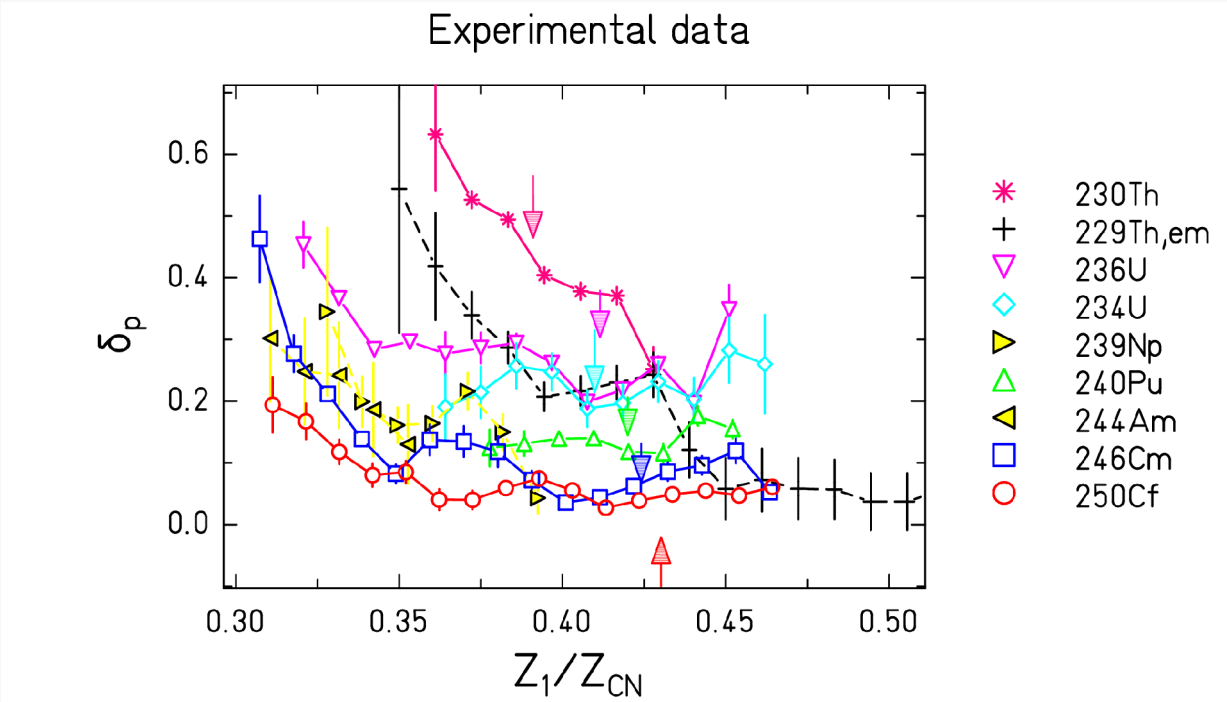
New result:

Position is constant at $Z \approx 54$ and varies strongly in A and N.

Influence of asymmetry on even-odd effect



Schmidt et al., 2000

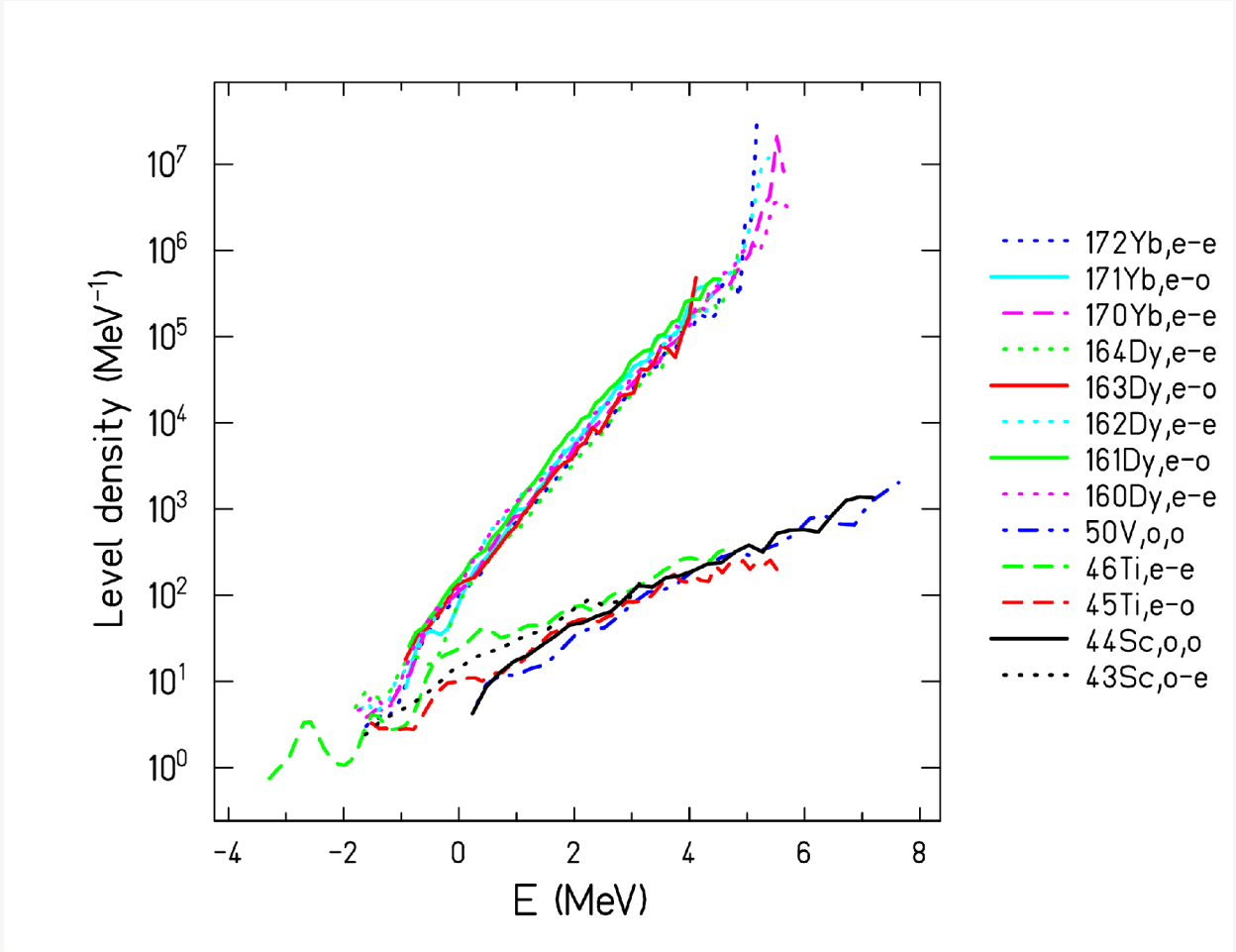


Caamano et al., 2011

GSI-experiment:
Z distribution measured over the whole range

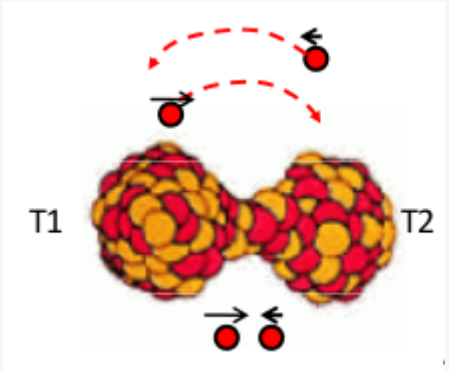
New systematics:
Even-odd effect strongly enhanced in asymmetric splits

New results on level densities suggests energy sorting in fission



Guttormsen et al. 2012

Constant nuclear temperature at low E*.



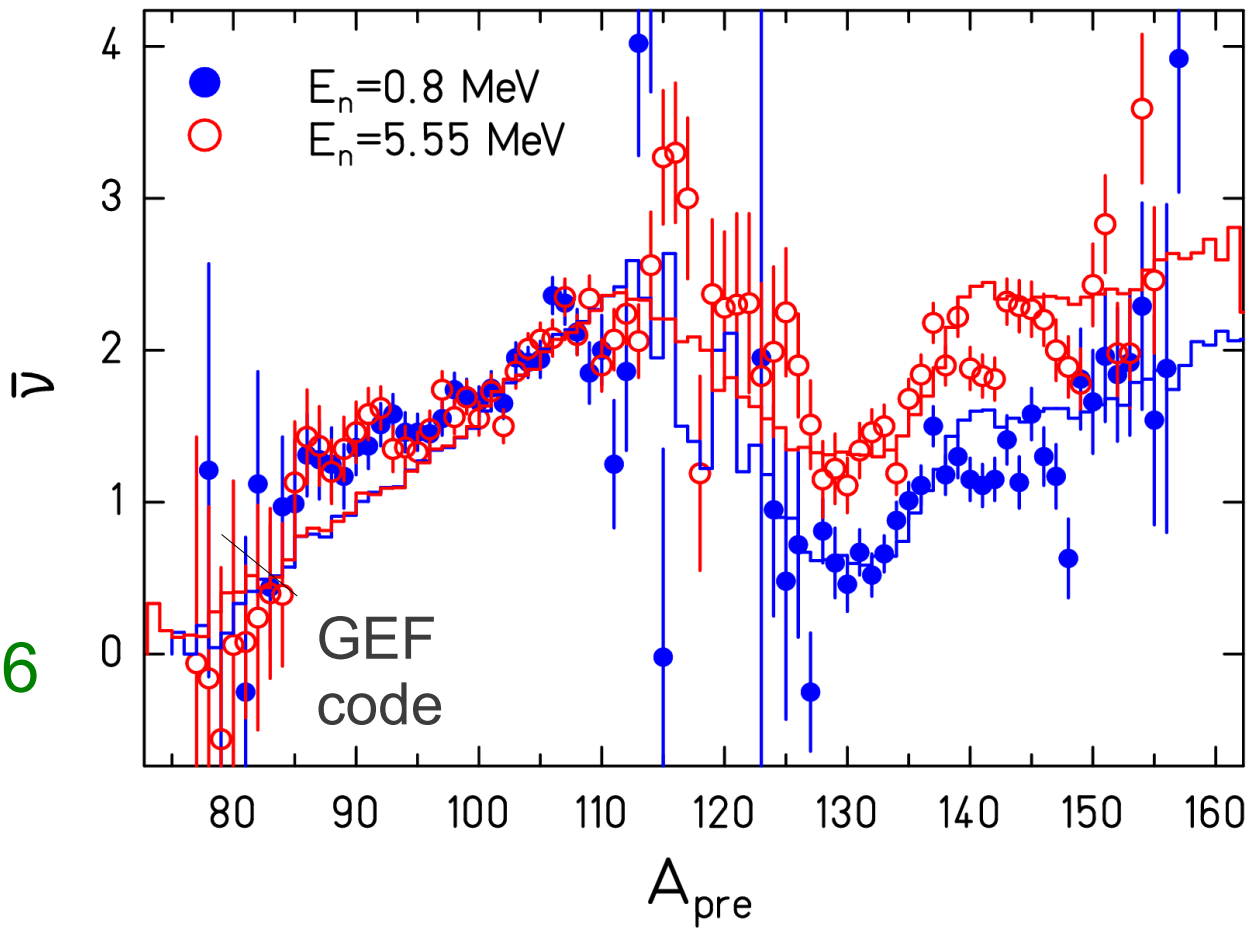
Nascent fragments:

Two thermostats in contact.
→ Energy sorting

Schmidt, Jurado,
PRL 104 (2010) 212501

Prompt-neutron yields

Experiment:
Naqvi et al., 1986



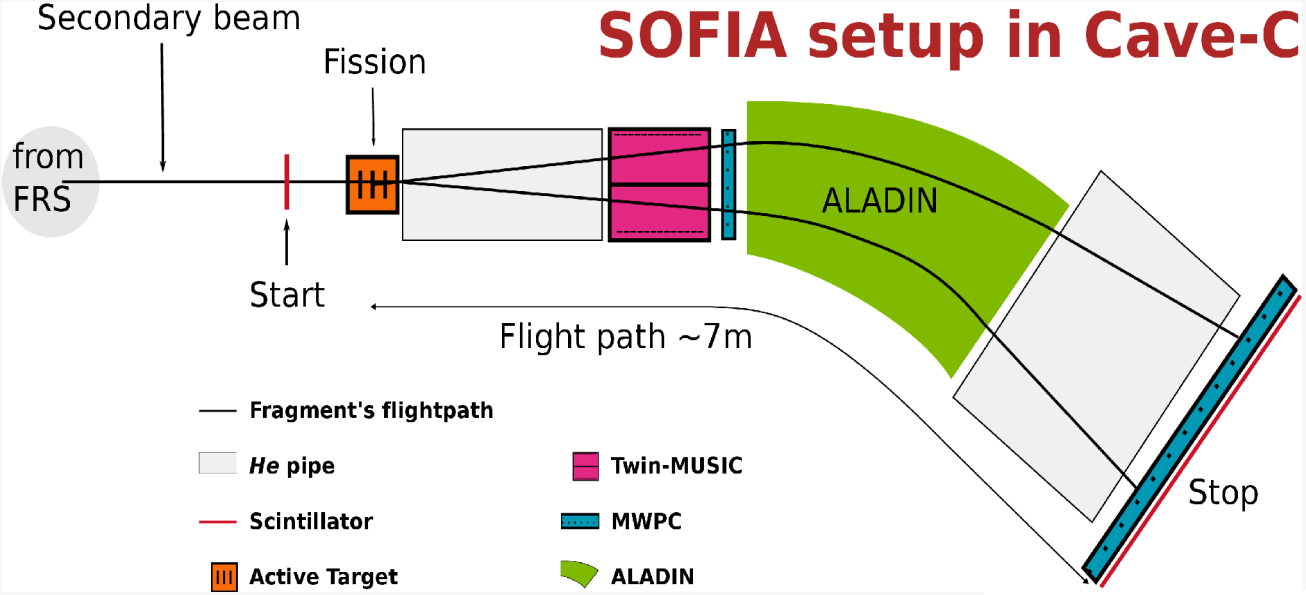
New interpretation:

All additional energy of the neutron ends up in the heavy fragment.
Consequences for masses deduced from kinematical measurements:
(A. Al-Adili et al., Phys. Rev. C 86 (2012) 054601)

Present developments and future prospects from experiments in inverse kinematics

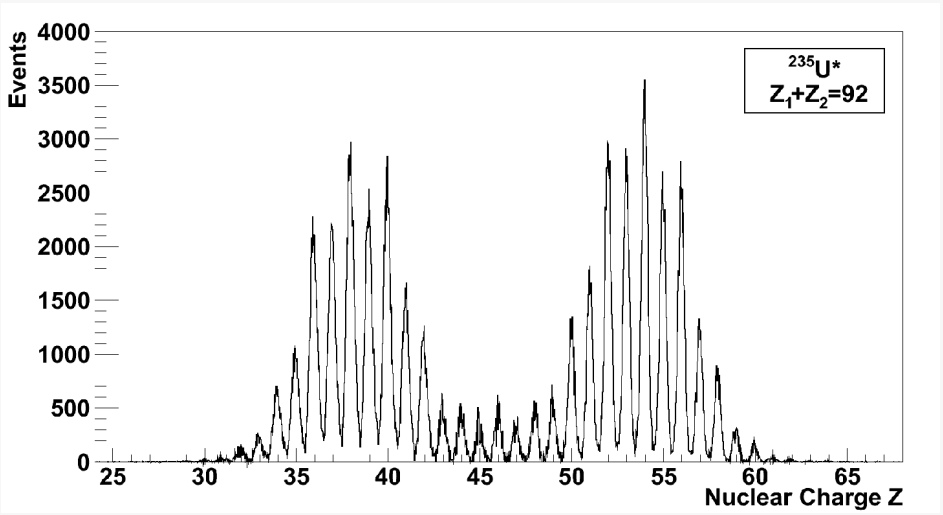
Extension: Sofia experiment at GSI

Julien Taieb et al., 2013

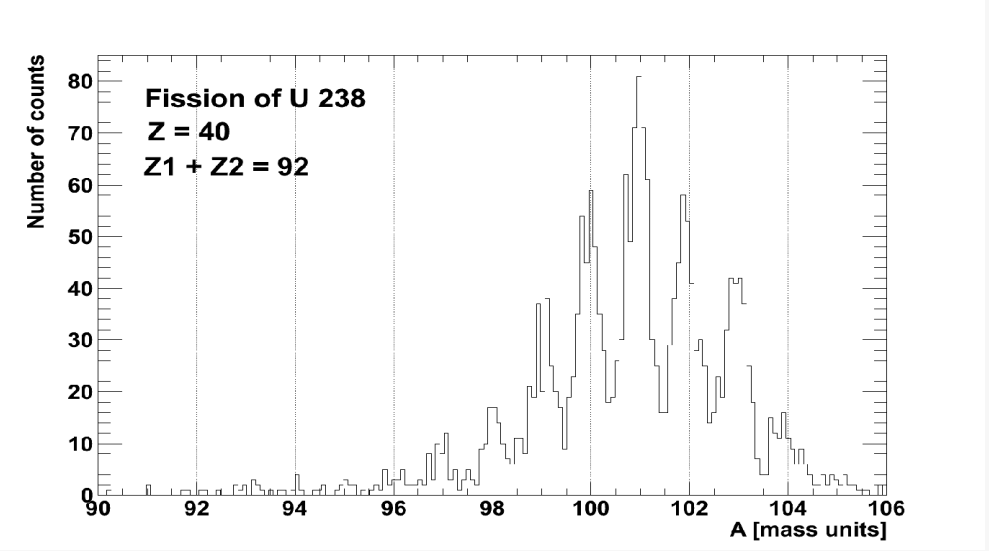


Deflection in a dipole -> additional mass measurement

Analysis in progress.



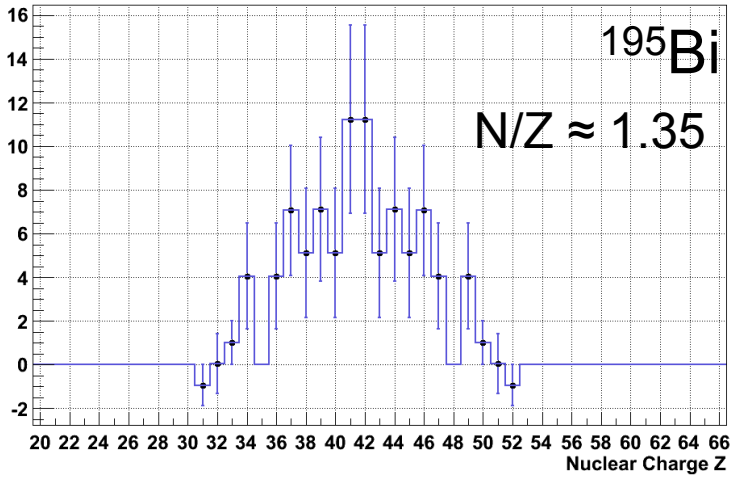
Excellent Z resolution



Mass resolution

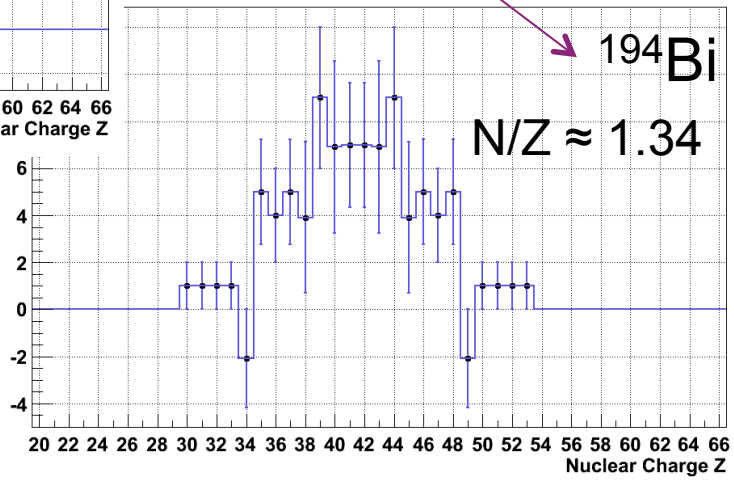
SOFIA: Studies On FIssion with Aladin

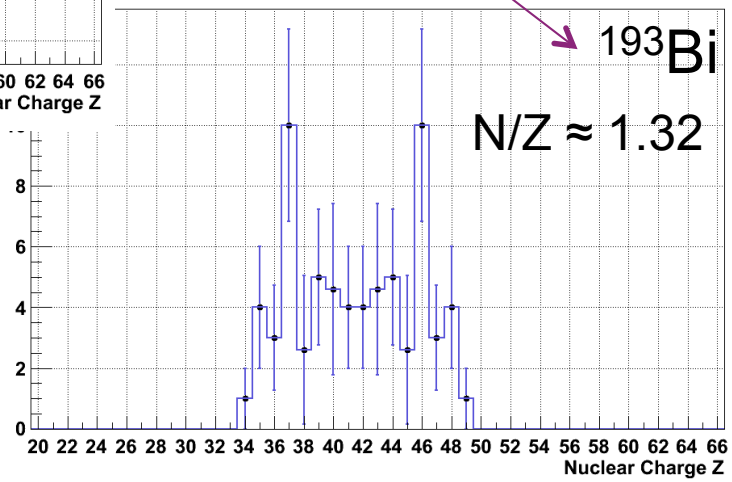
PRELIMINARY



Bismuth isotopes (40 - 60 fissions)

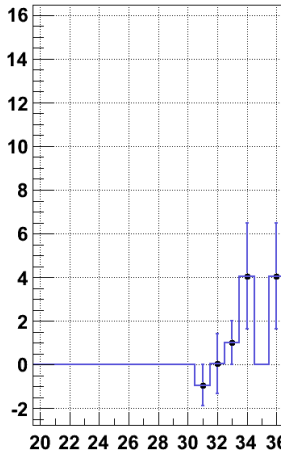
for the <u>first time</u> in this mass region
transition from symmetry to asymmetry
is seen

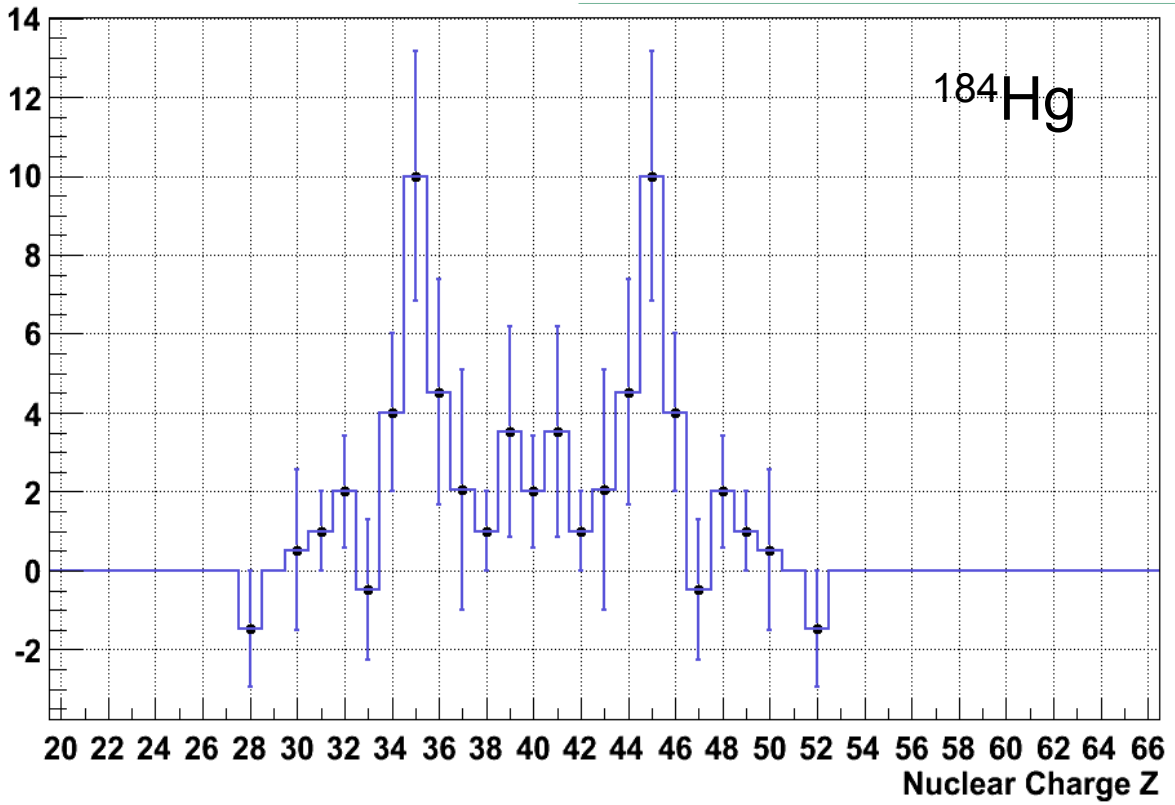




SOFIA: Studies On FIssion with Aladin

PRELIMINARY

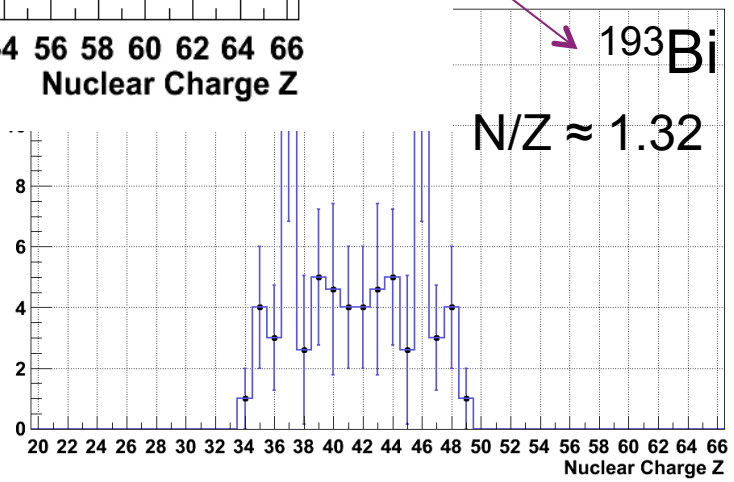




ssions)

region

asymmetry



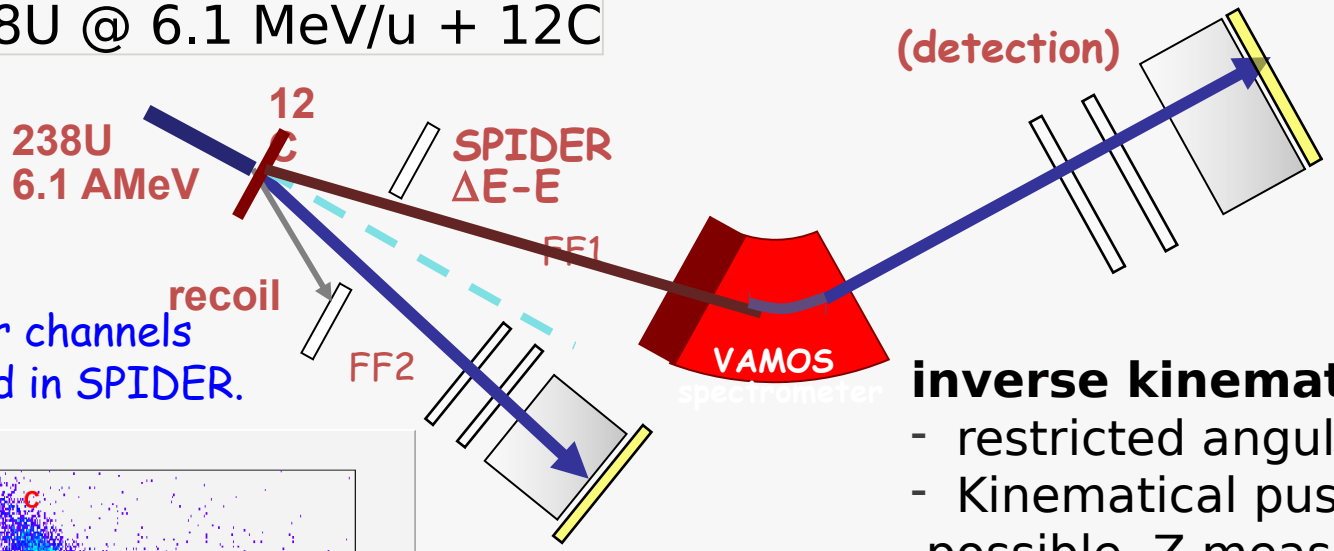
CONFIRMATION

OF ASYMMETRIC BEHAVIOR IN THIS MASS REGION

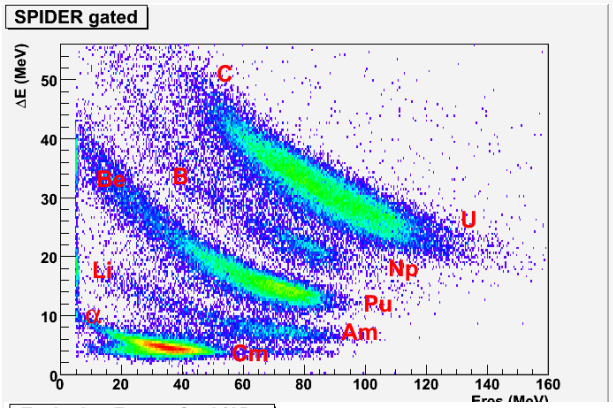
AS FIRST SEEN BY A. ANDREYEV *ET AL.*

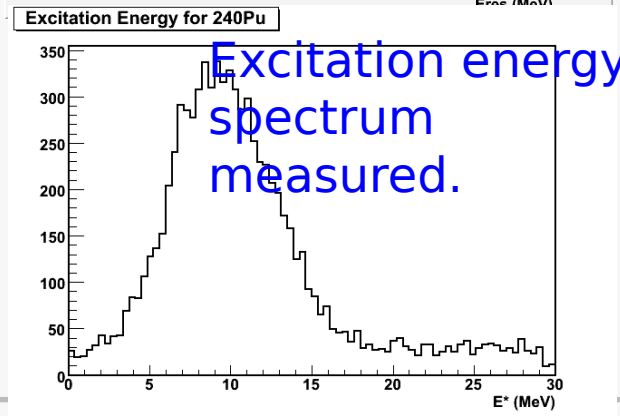
Transfer-induced fission in inverse kinematics @ GANIL

238U @ 6.1 MeV/u + 12C



Transfer channels identified in SPIDER.



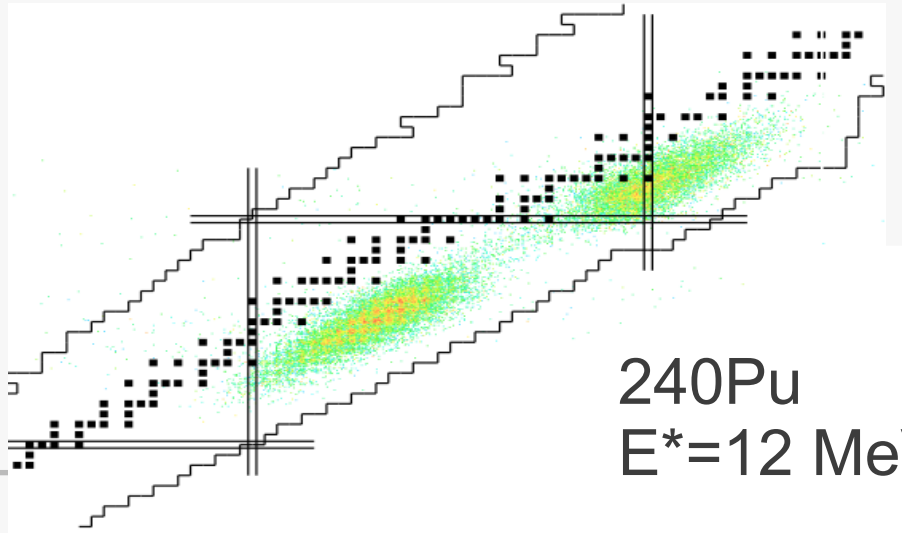


Excitation energy spectrum measured.

inverse kinematics

- restricted angular distribution
- Kinematical push that makes possible Z measurement
- Spectrometer to resolve masses

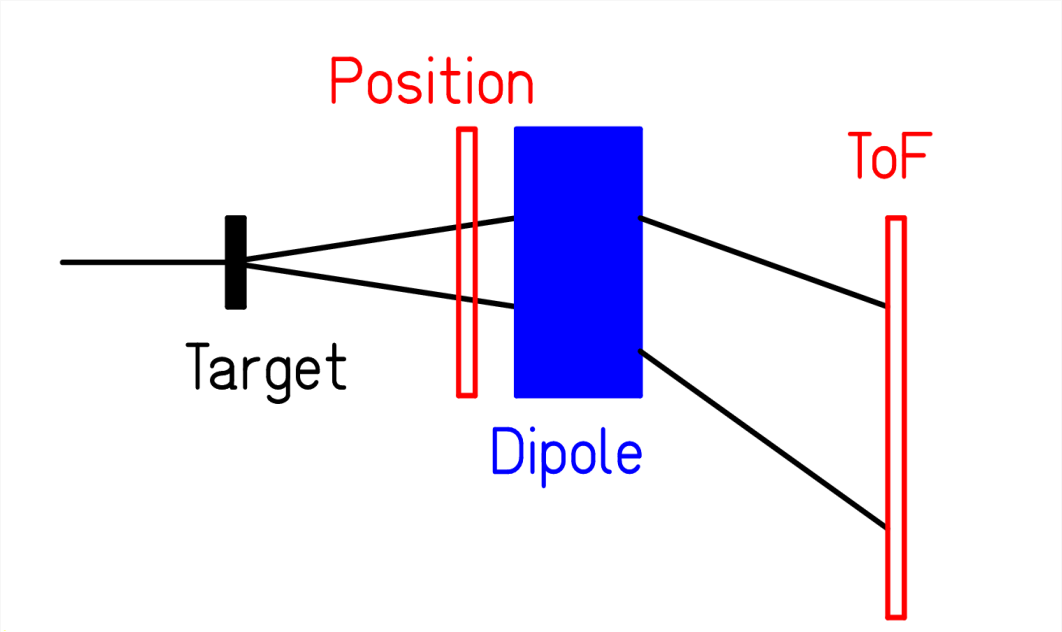
Corresponding isotopic and mass yields



240Pu
E*=12 MeV

Fanny Farget, 2013

Measurement of prompt-neutron yields in inverse kinematics



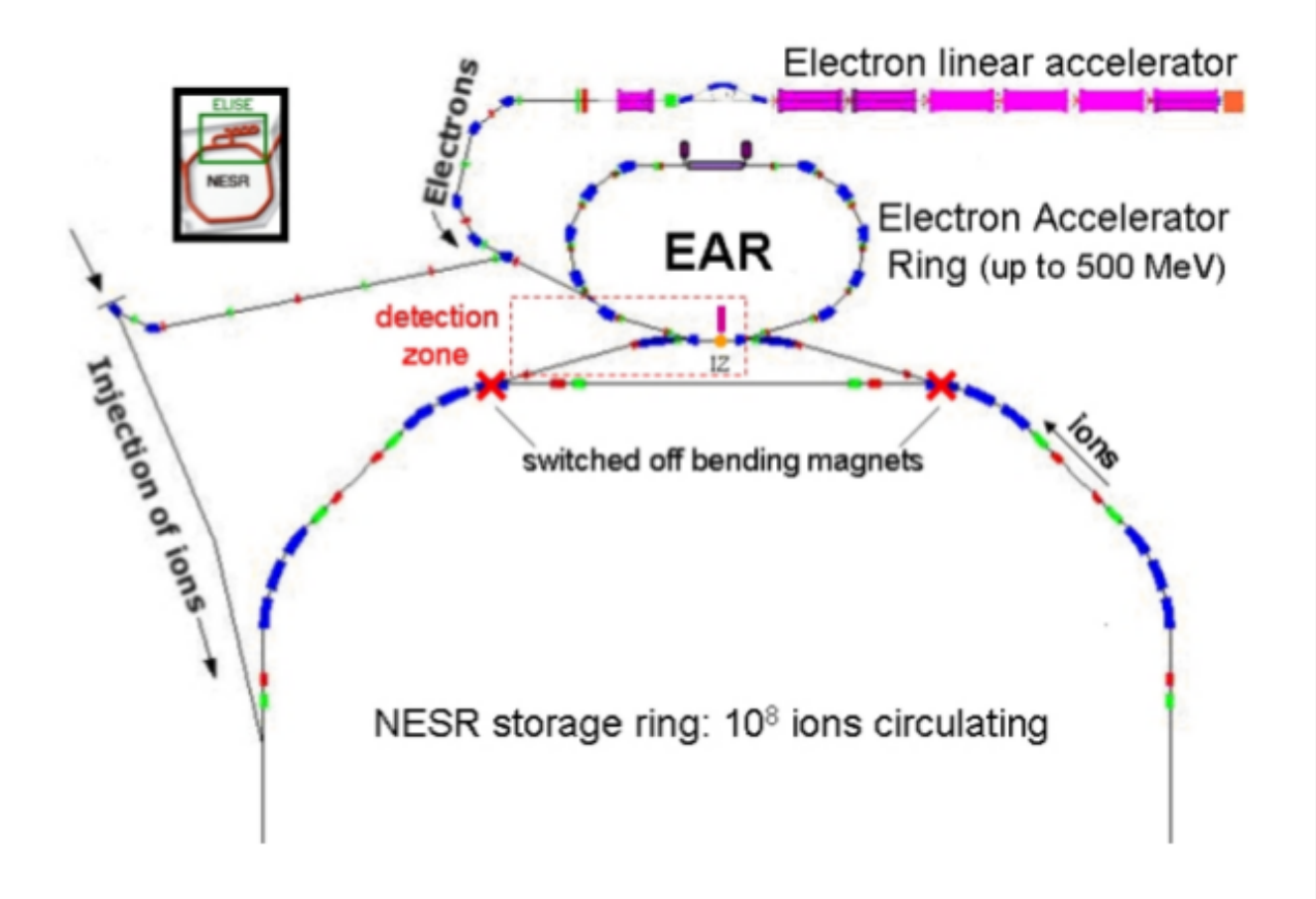
Further extension:

Prompt neutron yields from difference of pre-neutron mass and post-neutorn mass.

Pre-neutron mass from fragment angles (position before dipole) Resolution limited by neutron emission (assumed to be isotropic in fragment frame)

Post-neutron mass from complete kinematical and magnetic analysis (Precise measurement)

FELISE at future FAIR facility



Fission of ^{238}U fragments in inverse kinematics induced by tagged photons

Summary

- Heavy fragment in asymmetric fission is constant at $Z = 54$. The wrong impression on a constant position at $A = 140$ was caused by the limited isotopic range of the data.
- More data on narrow structure in fission of Z=80,81.
- Even-odd effect in Z distributions strongly favoured in asymmetric splits. (Z_{light} = even)
- New data on level densities suggest:
  Nascent fragments act like thermostats with different temperatures. Explains that any thermal energy is transported to the heavy fragment (energy sorting).
- More exciting results to come from new experiments in inverse kinematics.