



22nd ASRC International Workshop

"Nuclear Fission and Exotic Nuclei"

With SHIP through Reefs and Shoals

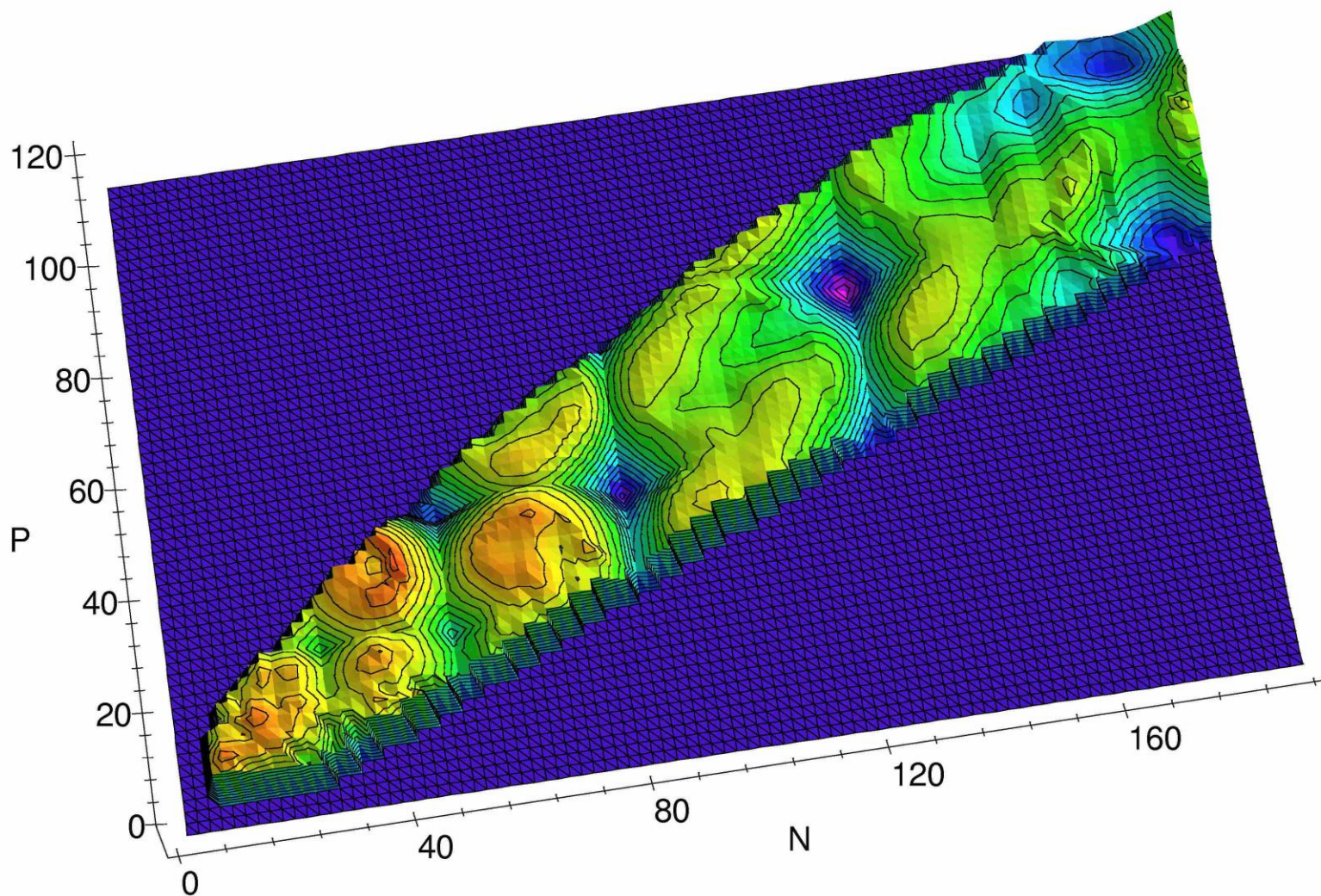
Sigurd Hofmann

GSI Darmstadt and University Frankfurt

Japan Atomic Energy Agency (JAEA), Tokai, Japan

December 3 – 5, 2014

Peter's landscape of shell-correction energies, 1996



SHIP

Design and construction:

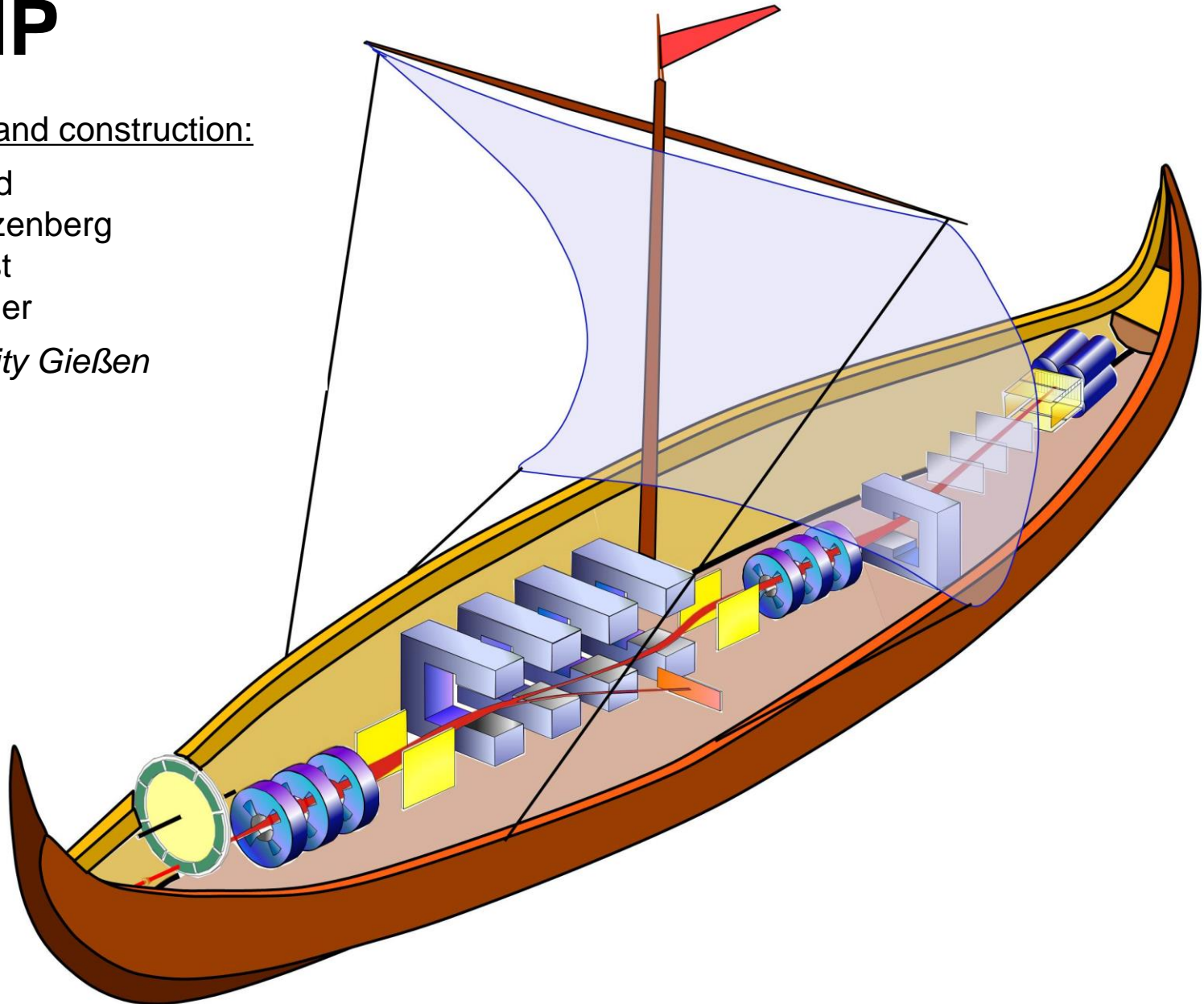
H. Ewald

G. Münzenberg

W. Faust

K. Güttner

University Gießen



People in Gießen have experience in SHIP building

River Lahn



Gießen Marine Club



Great excitement with Sikkeland's prediction

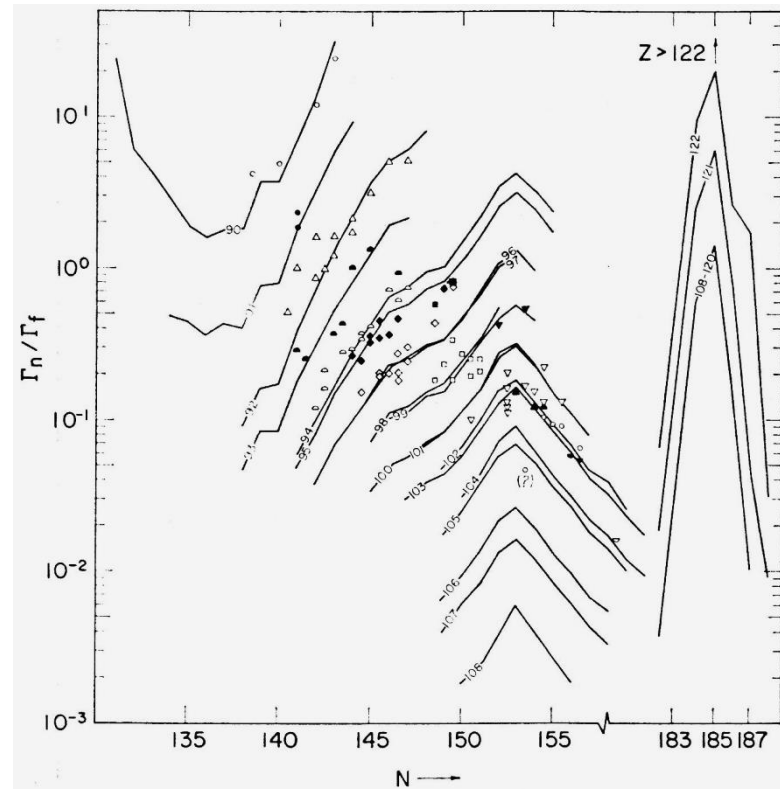
ARKIV FÖR FYSIK Band 36 nr 62

3.66 11 21 Communicated 14 September 1966 by E. RUDBERG and K. SIEGBAHN

Nuclides far off the stability line · Proc. of the Lysekil Symposium, 1966 · Session IX, No. 6

Synthesis of nuclei in the region of $Z=126$ and $N=184$

By TORBJORN SIKKELAND



Sikkeland: tens of mb's cross-sections for element 126

Table 1. Analysis of calculated excitation functions for the production of the nuclides $^{312-x}126$ and $^{200-x}Po$.

System	Spallation product	Peak cross section (mb)		Ion energy (MeV/nucleon)		FWHM (MeV)	
		I ^a	II ^b	I ^a	II ^b	I ^a	II ^b
$^{180}Hf + ^{132}Xe$	$^{312}126$	73	73	5.27	5.27	—	—
	$^{311}126$	92	93	5.39	5.36	19	20
	$^{310}126$	111	115	5.55	5.50	26	20
	$^{309}126$	103	127	5.72	5.63	30	19
	$^{308}126$	77	98	5.89	5.77	35	20
$^{232}Th + ^{80}Kr$	$^{311}126$	.02	.02	5.44	5.44	9	8
	$^{310}126$	12	11	5.49	5.48	10	8
	$^{309}126$	55	48	5.63	5.61	15	14
	$^{308}126$	67	62	5.85	5.76	20	17
$^{252}Cf + ^{60}Ni$	$^{311}126$	.0004	.0004	5.72	5.73	—	—
	$^{310}126$	.5	.4	5.77	5.75	8	8
	$^{309}126$	22	20	5.83	5.82	12	10
	$^{308}126$	59	52	6.05	6.00	18	15

1977-1981: developments, testing field N = 82

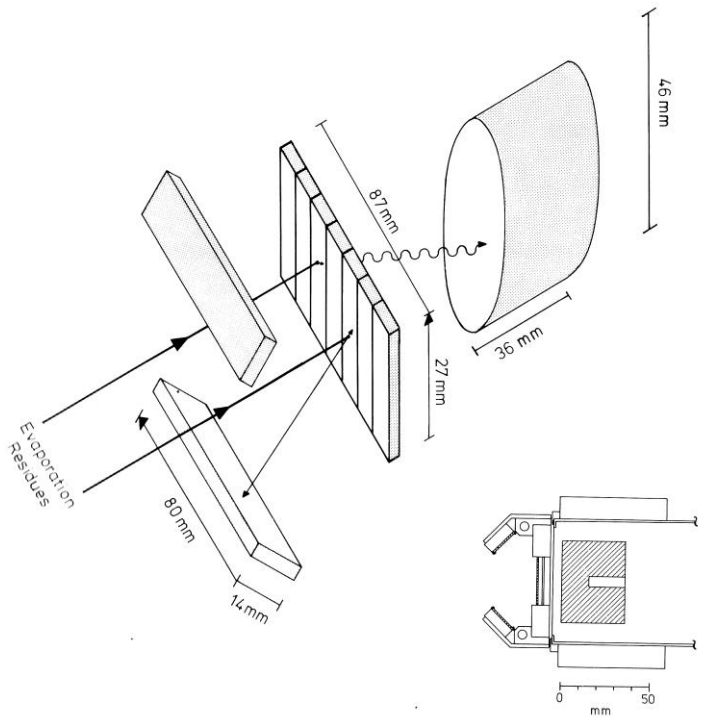
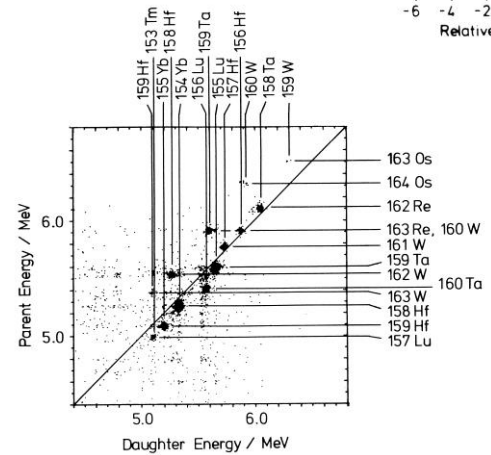
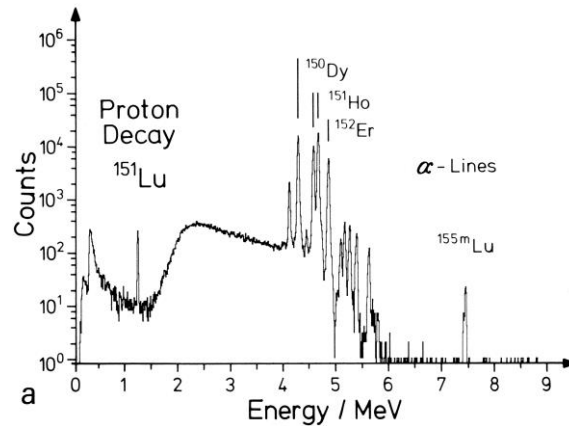
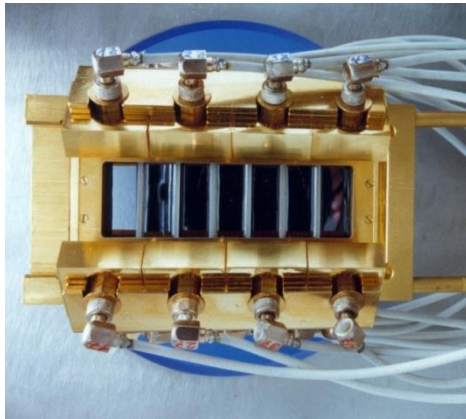
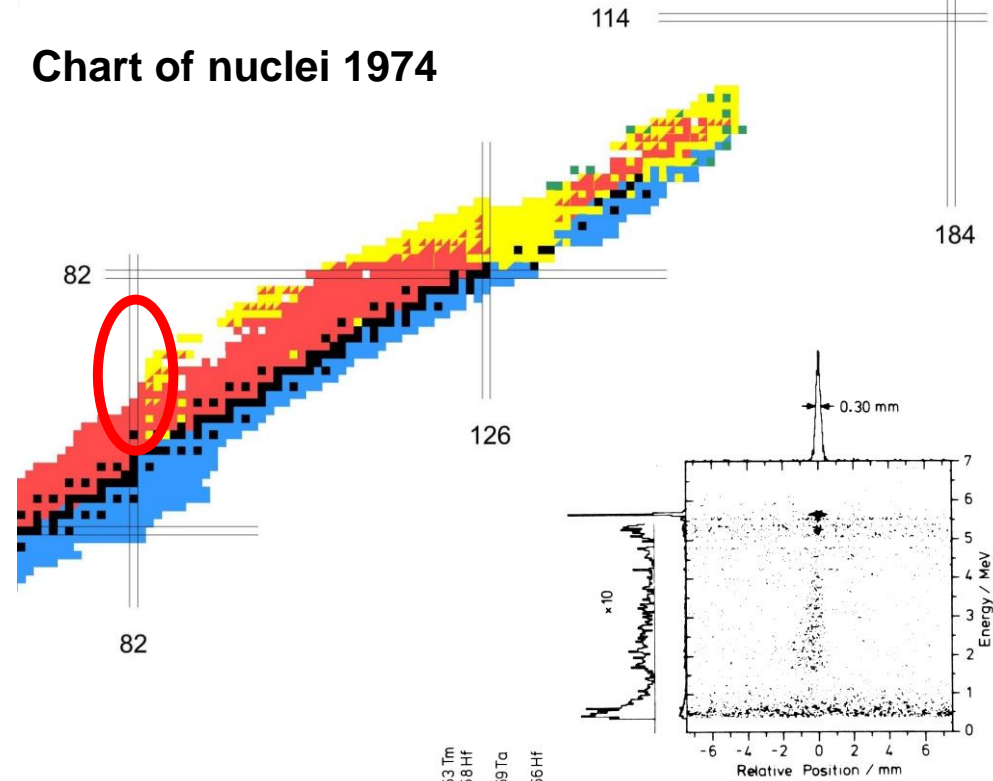
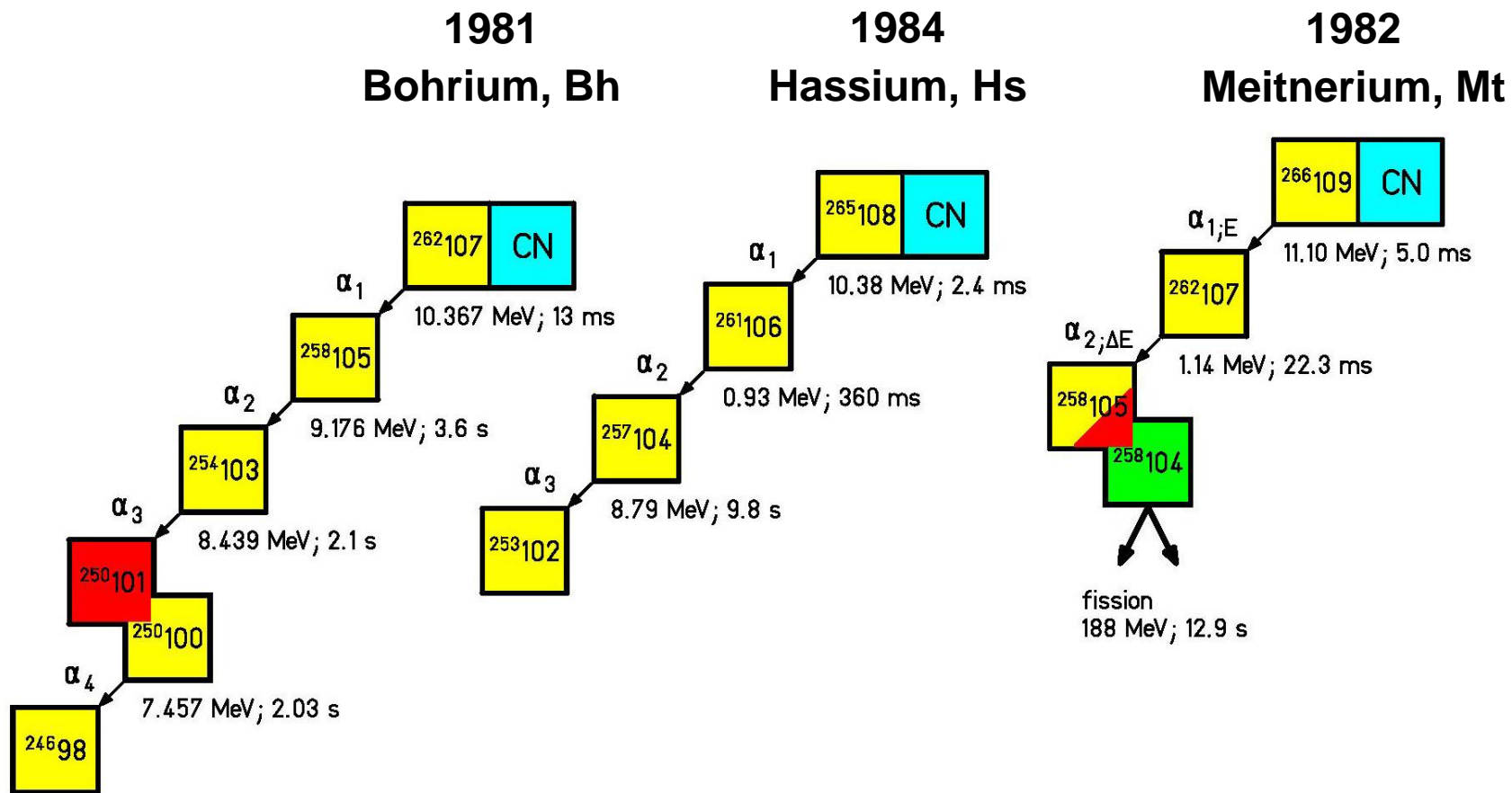


Chart of nuclei 1974



Three new elements



G. Münzenberg et al., 1981–1984

Stability of heavy and superheavy nuclei

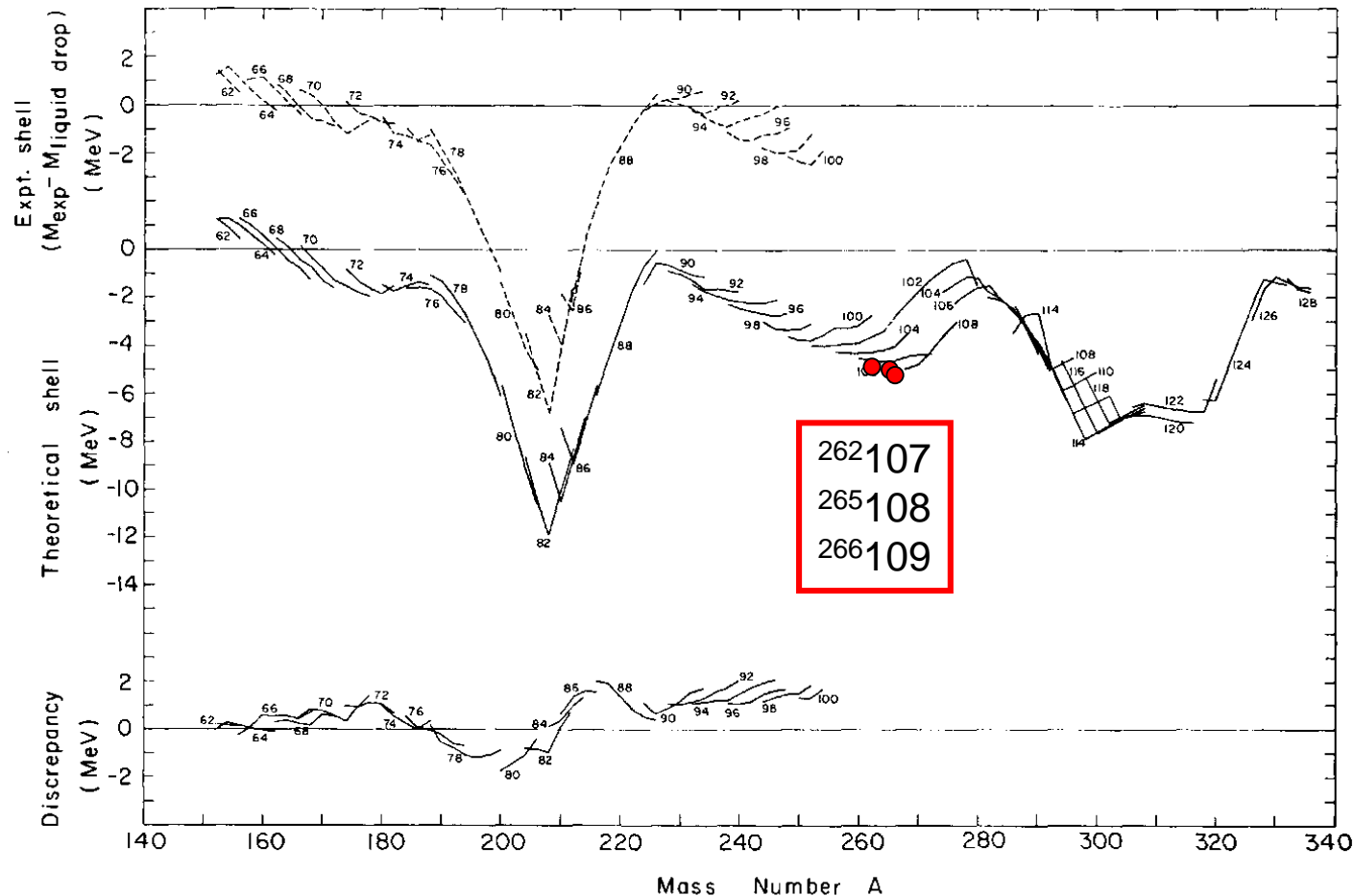


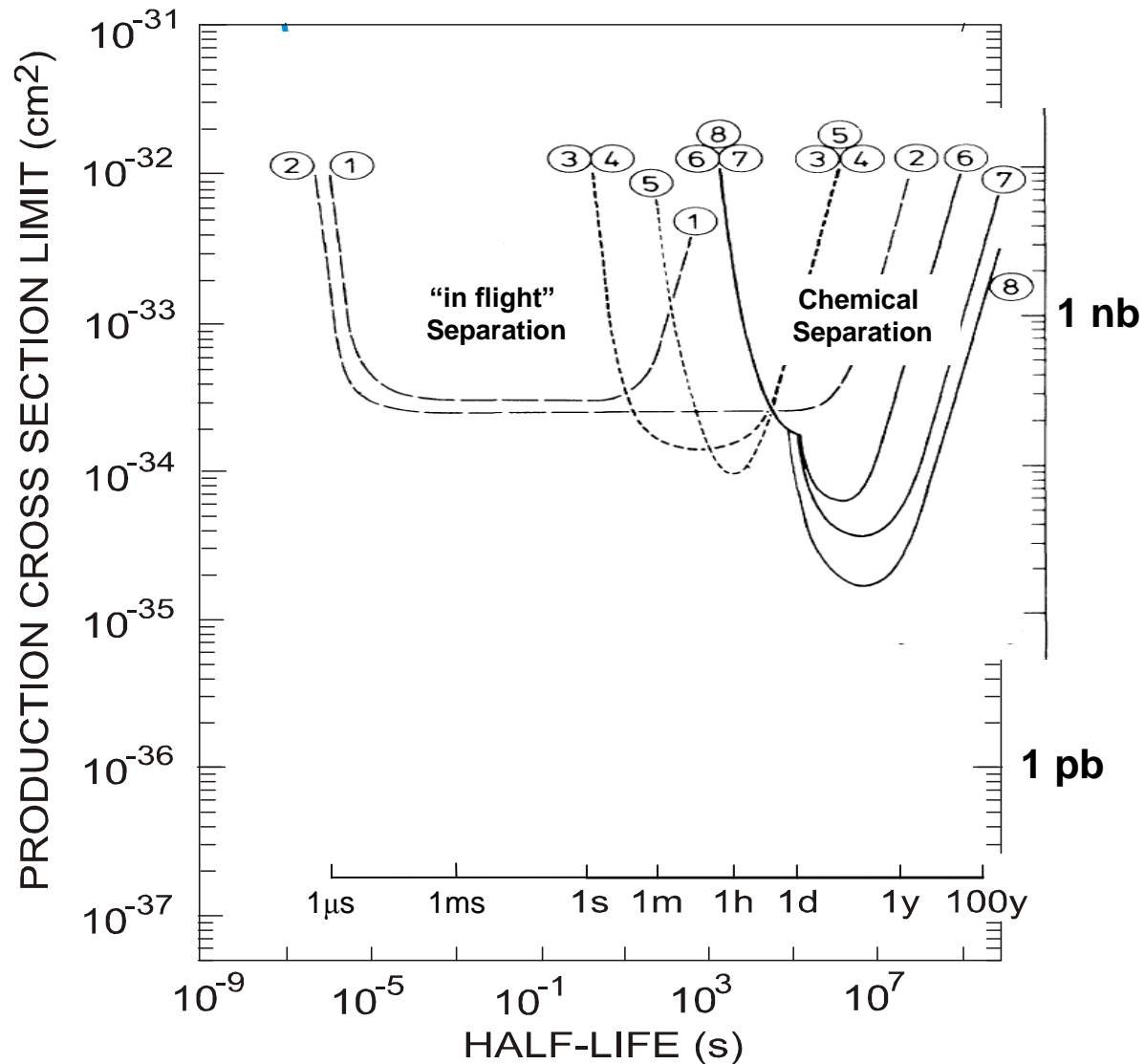
Fig. 16. Experimental and theoretical mass values for $150 < A < 340$ plotted relative to the spherical liquid drop value as of ref. ¹¹).

1982-83: second disillusion, no element 116



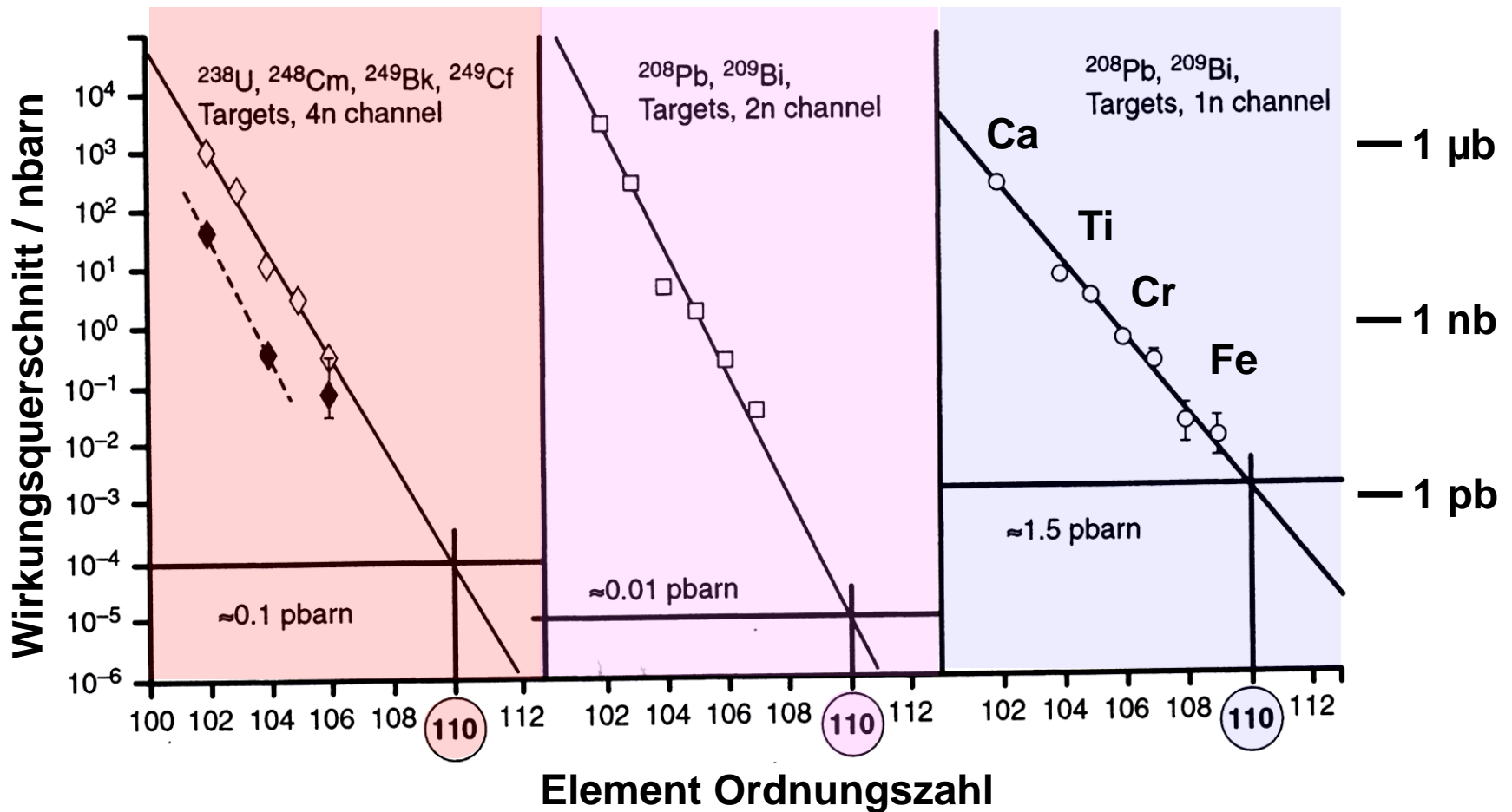
Collaboration

GSI, Darmstadt
LBL, Berkeley
Univ. Mainz
LANL, Los Alamos
EIR, Würenlingen
Univ. Göttingen



ACTINIDES-93, Santa Fe, NM, Sept. 19-24, 1993

Title of talk: Plans to identify heavy elements produced in reactions with cross-sections of 1 pb and below



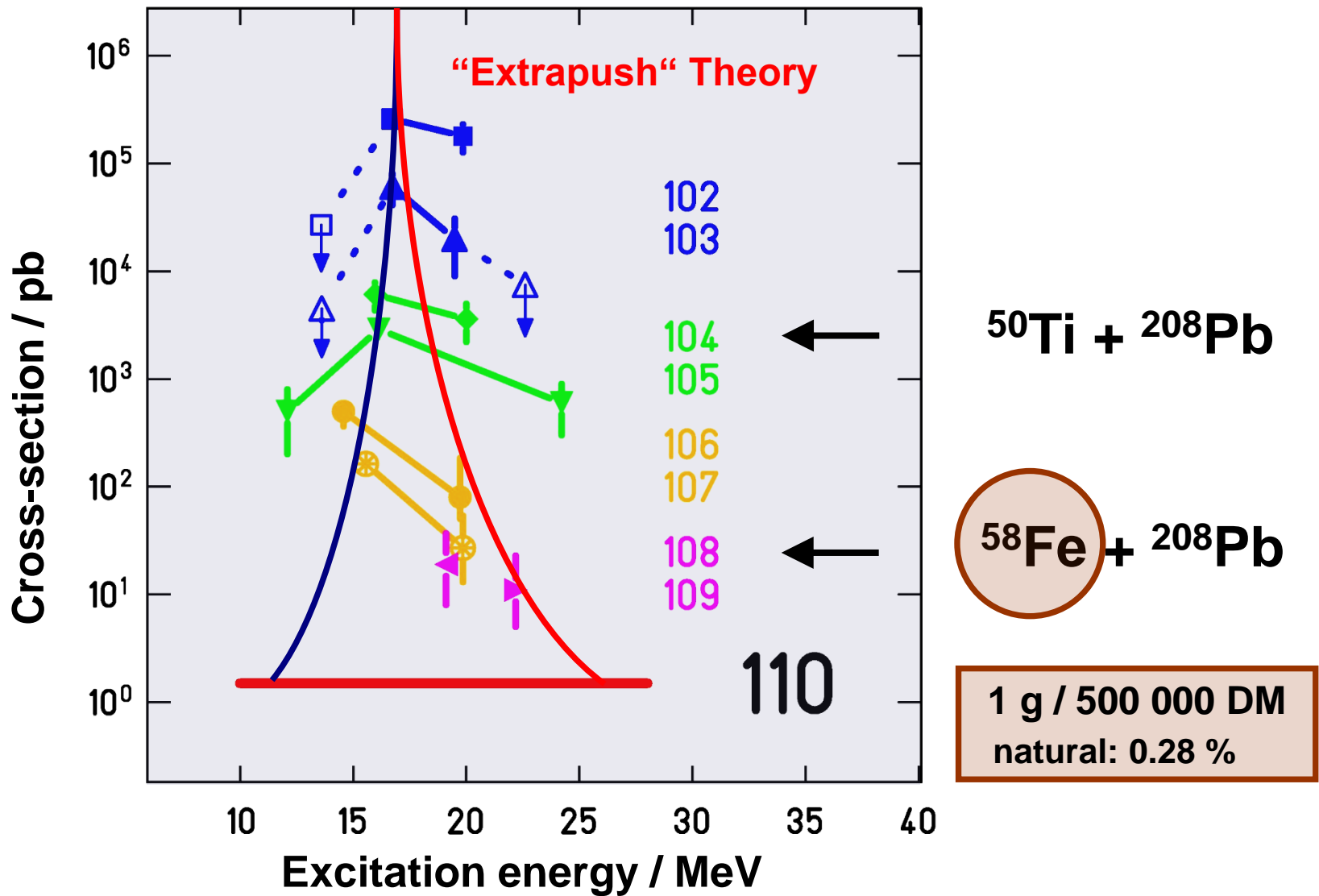
1993: exploring the landscape



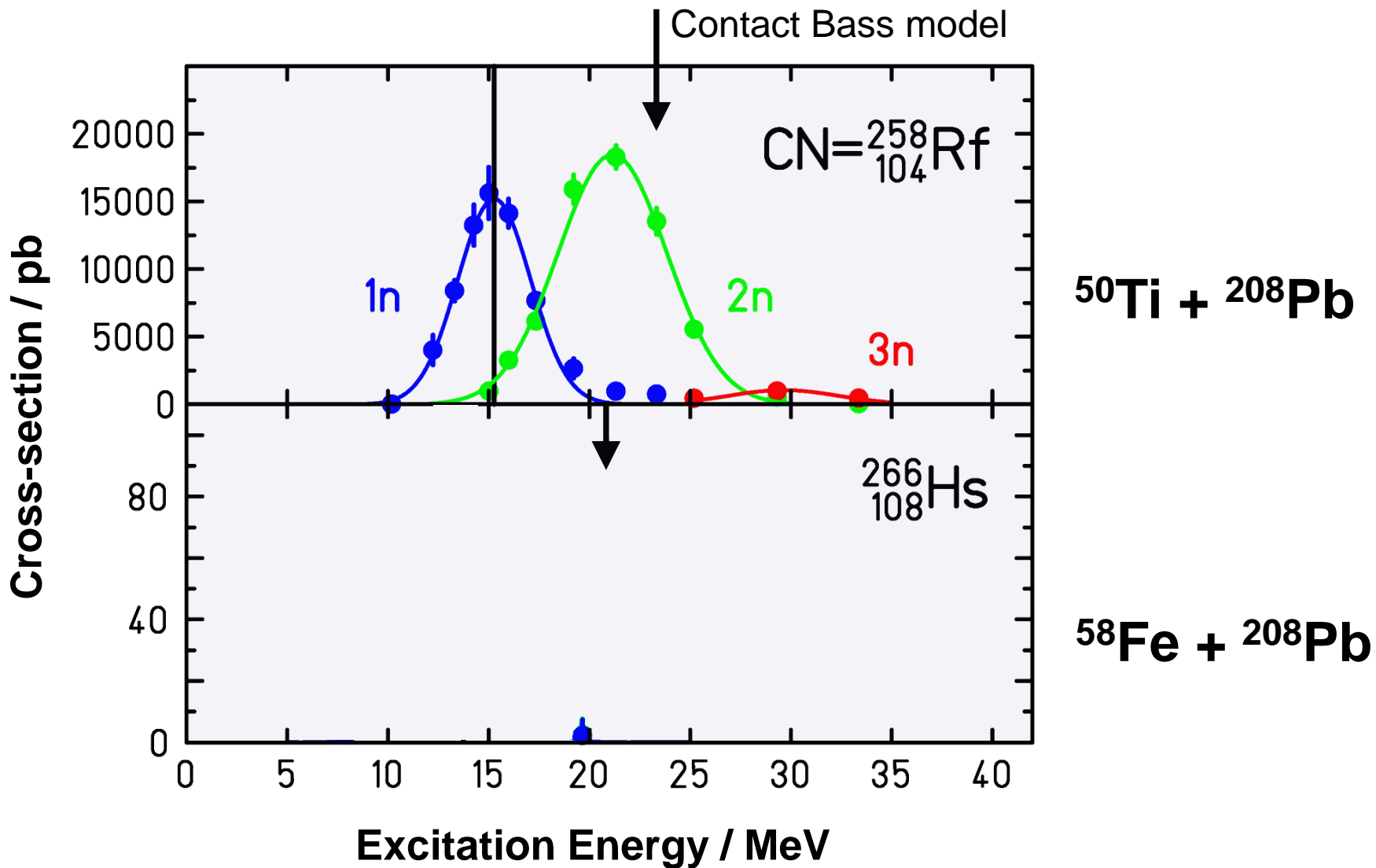
1993: big river, but no SHIP



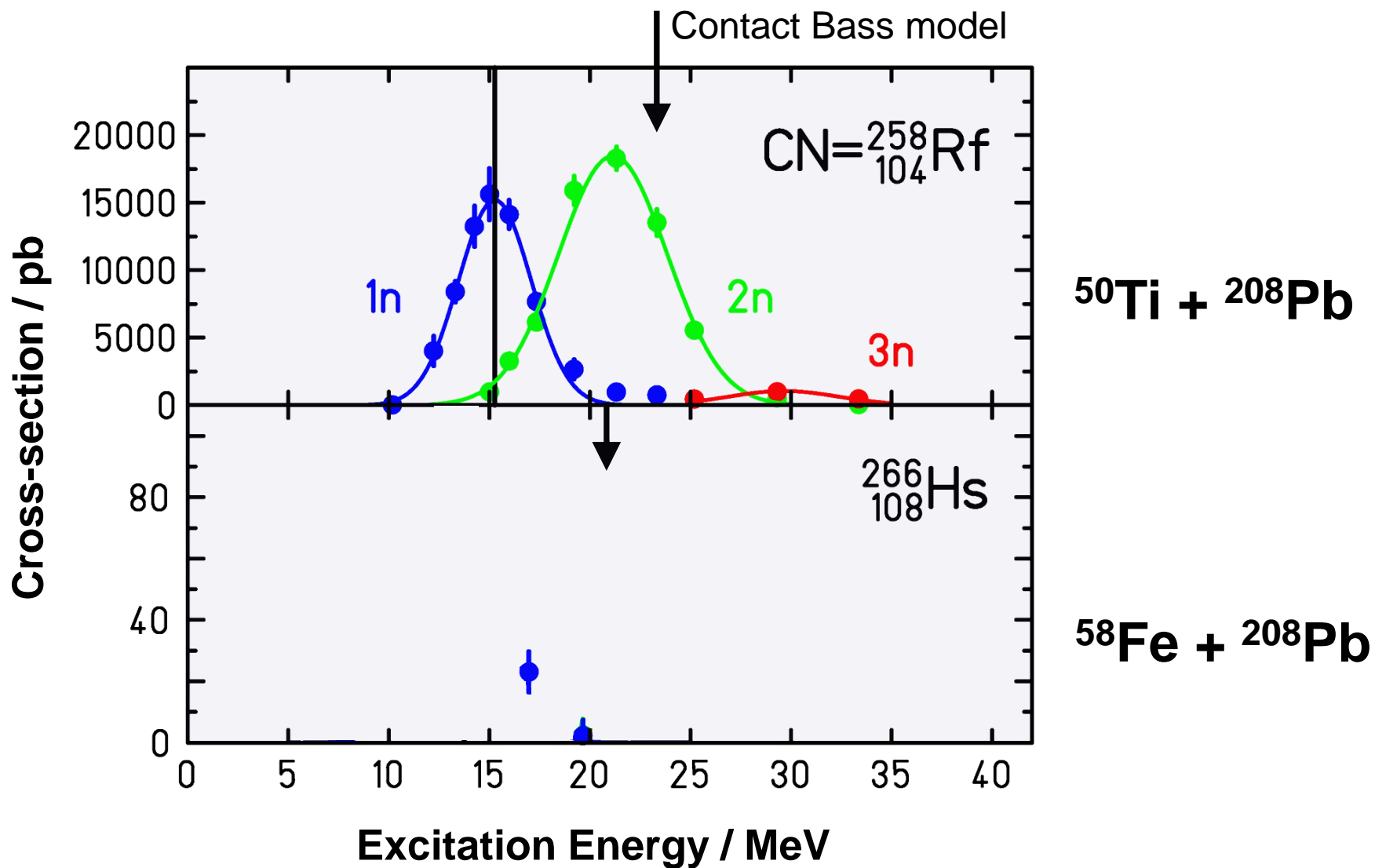
1994: back at home



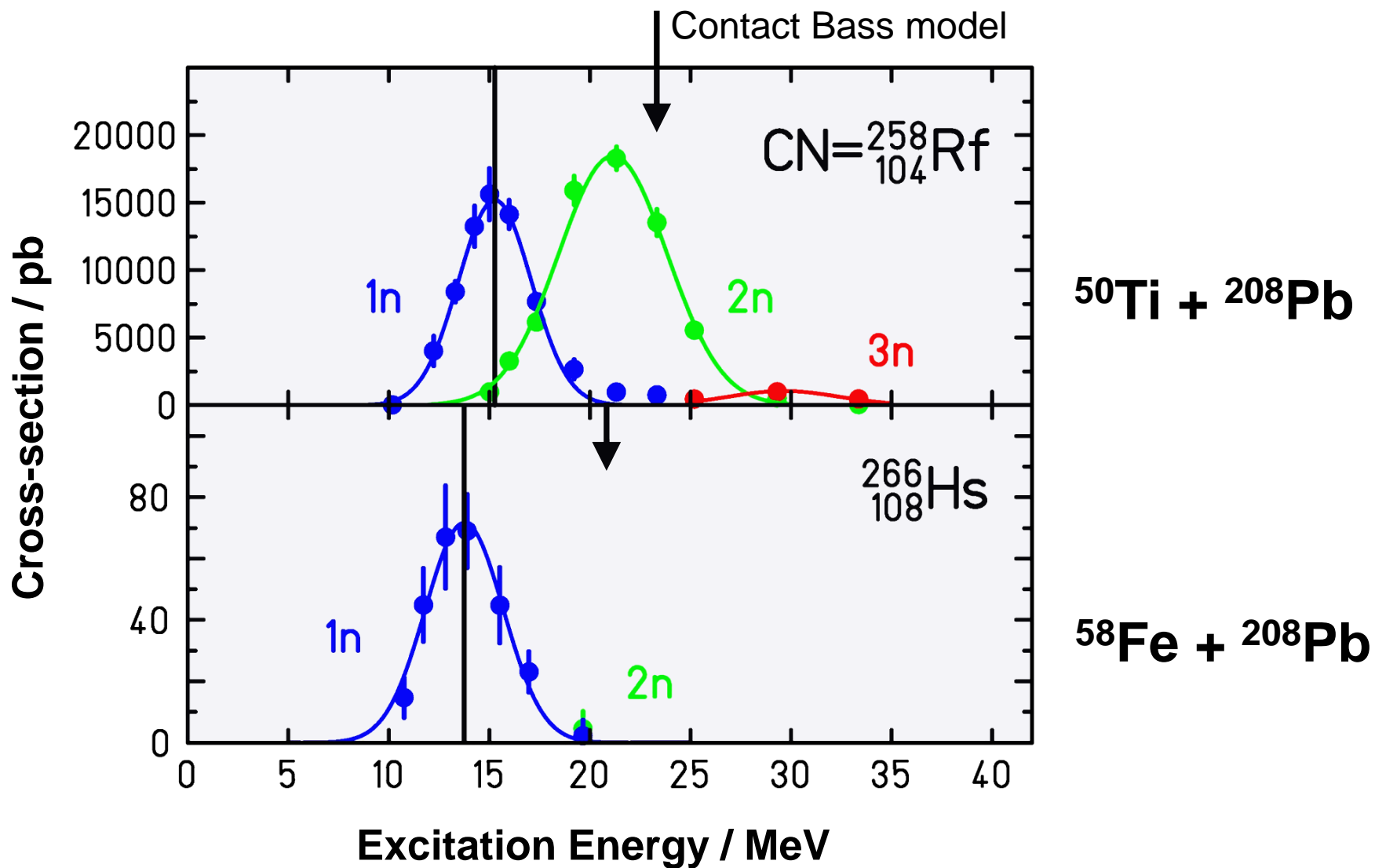
1994: measurement of excitation functions



Increasing cross-section at lower beam energy



Result: no extra-push



1994-1996: GSI-SHIP, 2004-2012: RIKEN-GARIS

1994

1994

1996

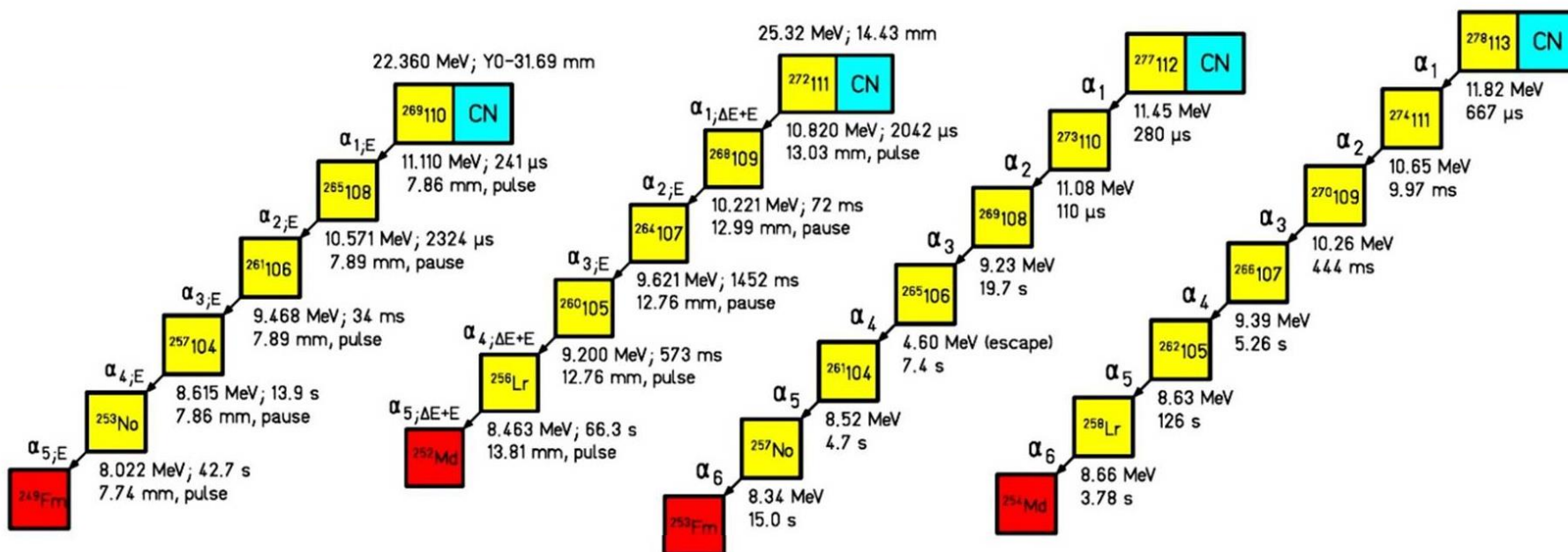
2004

Darmstadtium, Ds

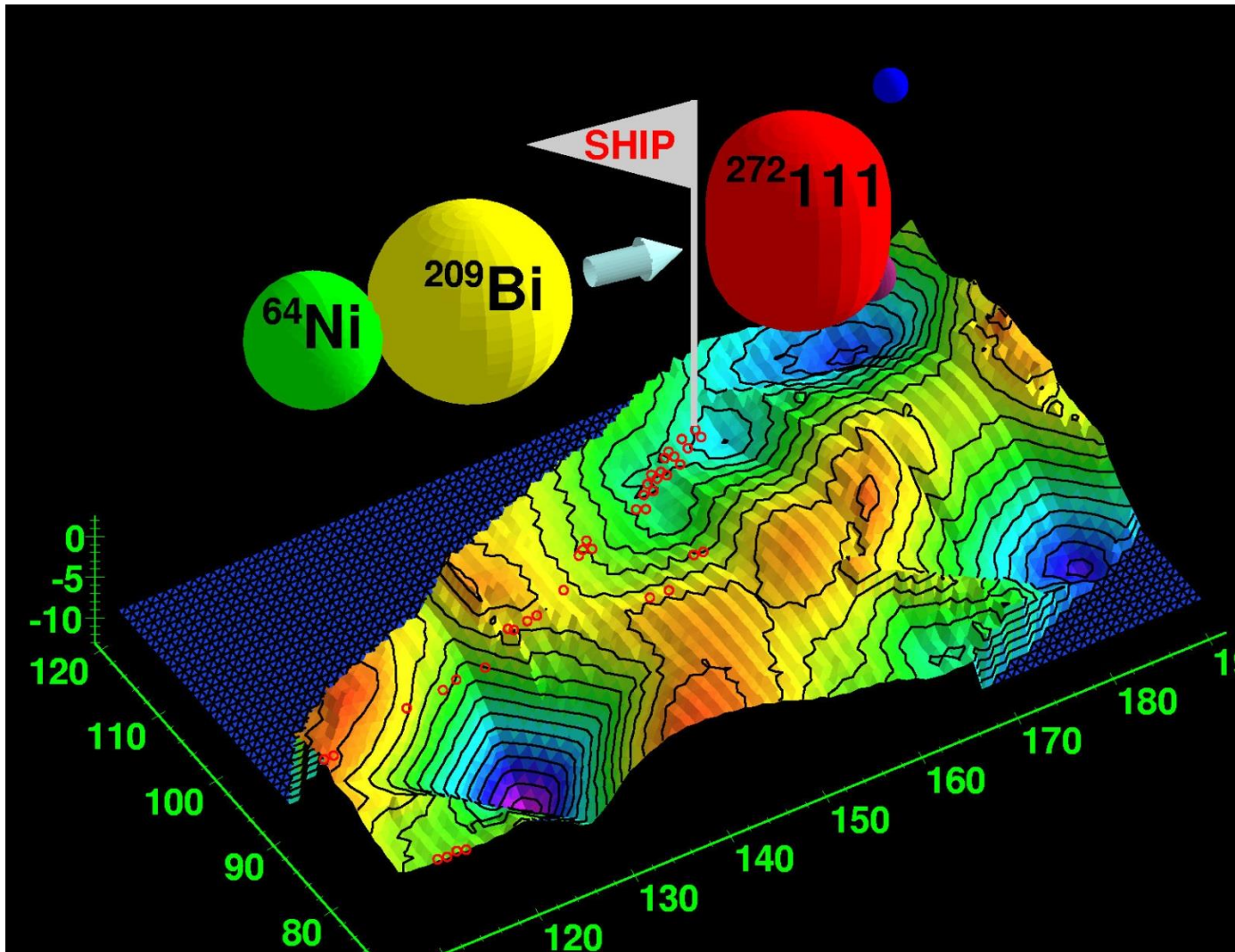
Roentgenium, Rg

Copernicium, Cn

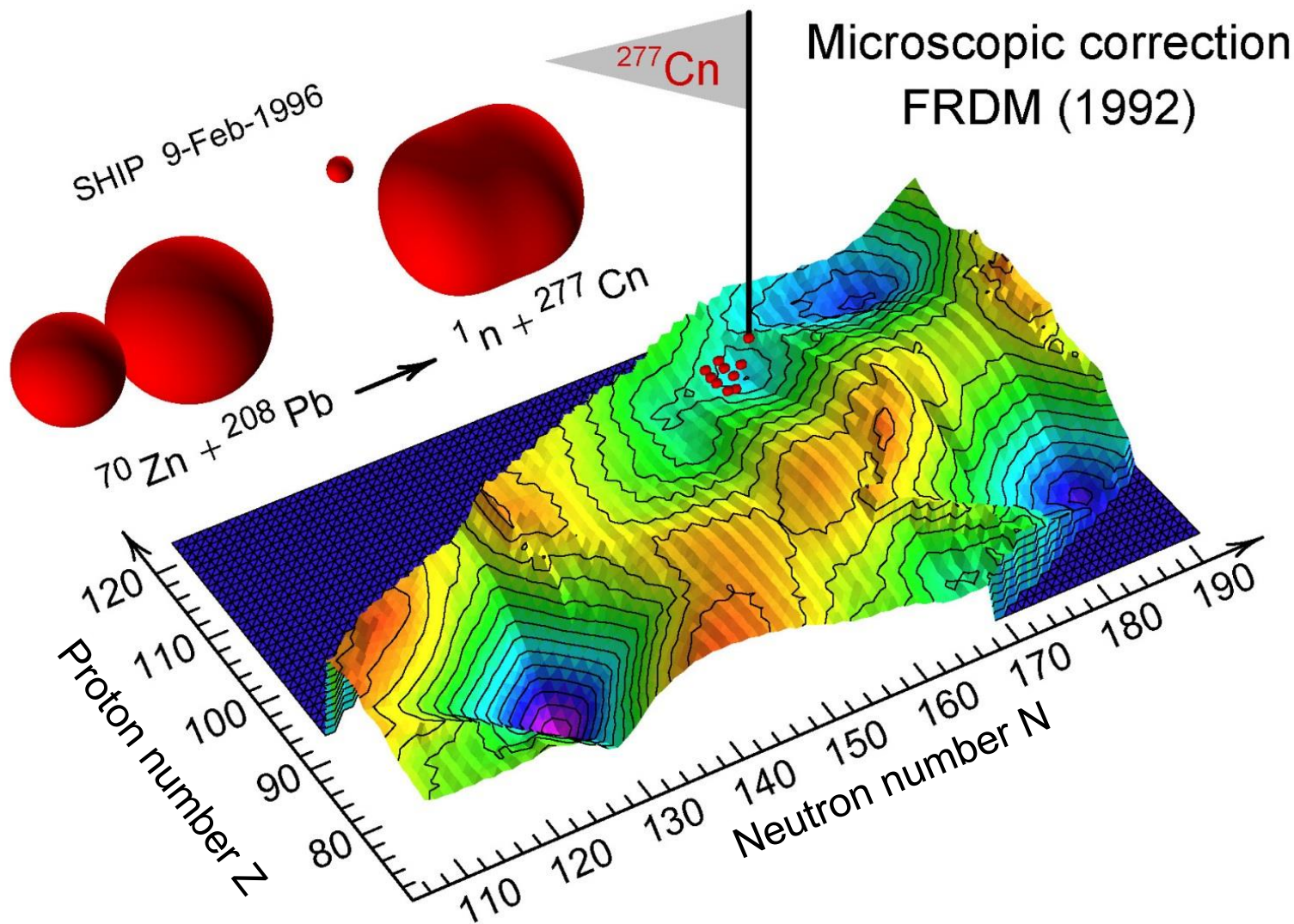
113



1994: Peter's Christmas present

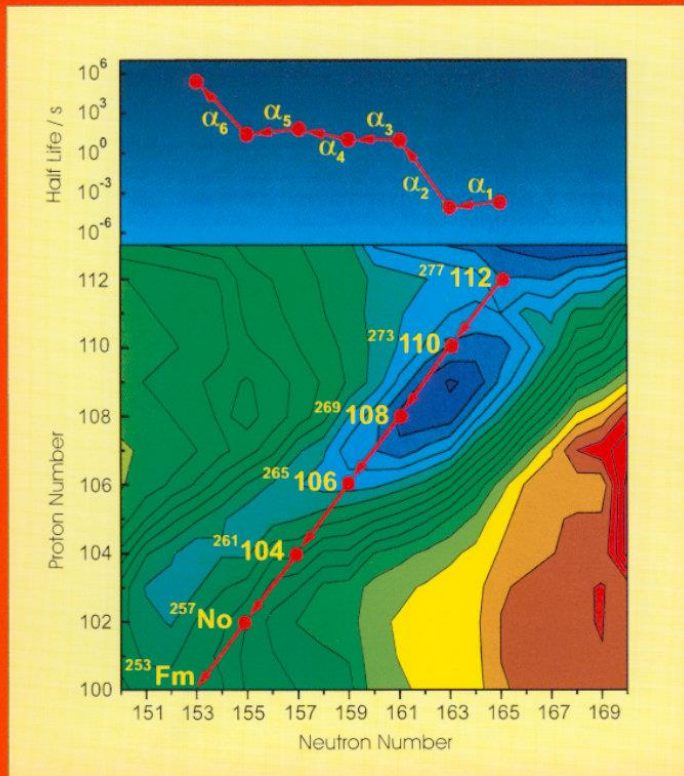


1996: Peter's Easter present



Fruitful collaboration

GSI **ii** GSI 97-1
March 1997
ISSN 0174-0814
SCIENTIFIC REPORT 1996



Gesellschaft für Schwerionenforschung mbH Darmstadt

**Theoretical
shell-correction energies
P. Möller, 1995**

**Experiment SHIP,
February 9th, 1996, 22:36 h**

Peter's contract with GSI: May – July 1996

Tasks of the contract:

1. ...

2. FRDM- and FRLDM-masses for SHE.

Comparison of experimental mass and Q_α -values.

Why is FRDM diverging for $Z > 108$ from experiments?

3. ...

July 12-14, 1996, Brussels



Shortest CW accelerator worldwide

Intensity OK!
Energy too low!



On the occasion of Ray's retirement



**Nuclear Shapes
and Motions**

**A Symposium in
Honor of Ray**

Nix

October 25-27, 1998

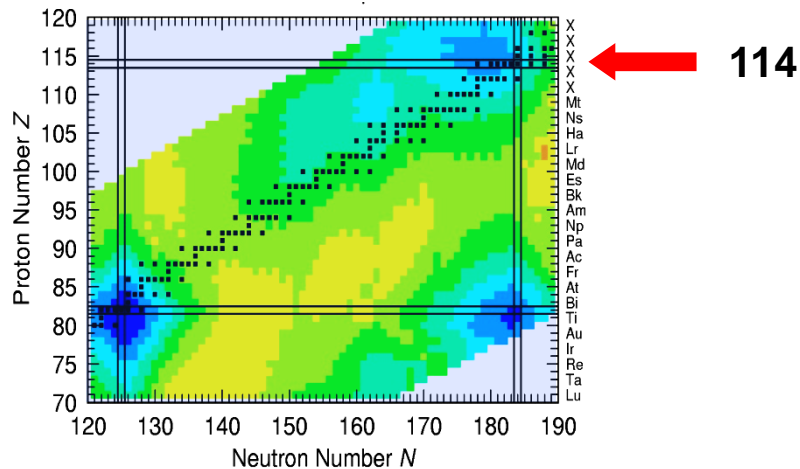
Hotel St. Francis, Santa Fe, NM

October 1998: preparing hot food

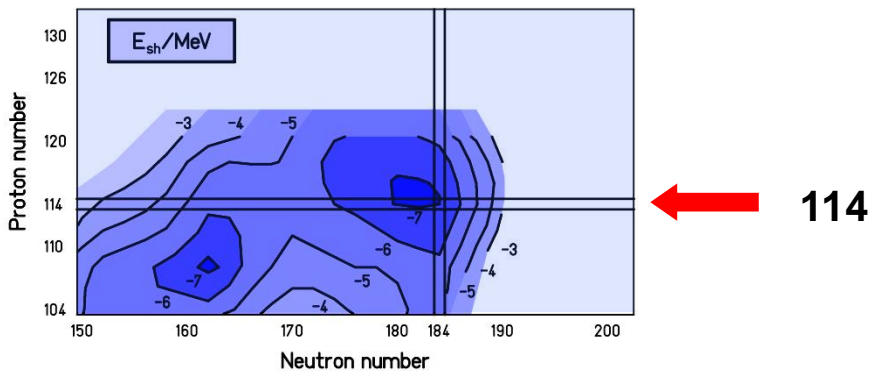


Shell effects in different models

Macroscopic-microscopic

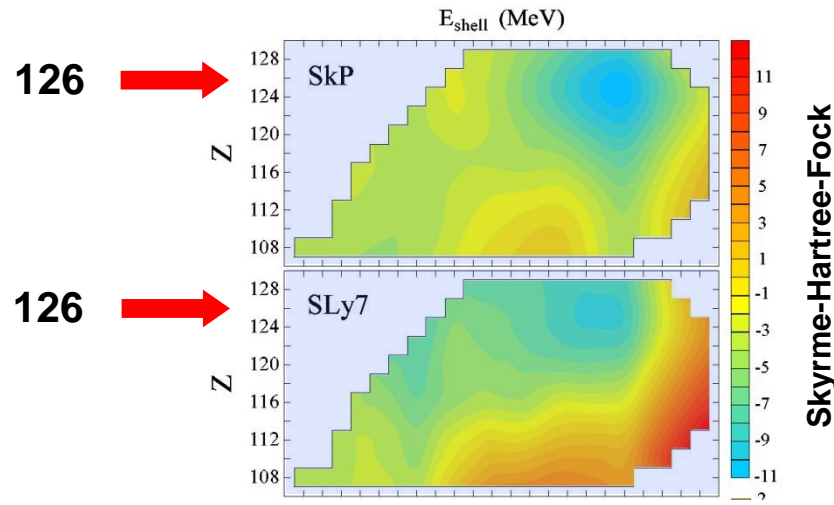
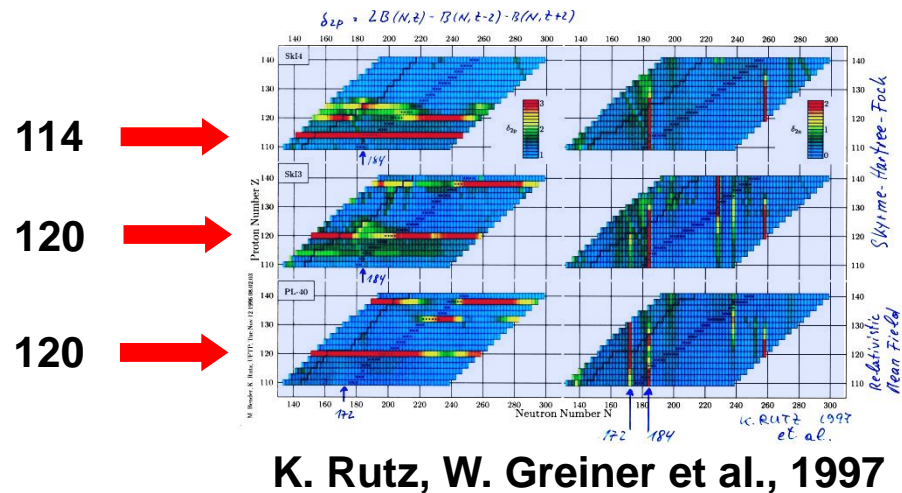


P. Möller, 1995



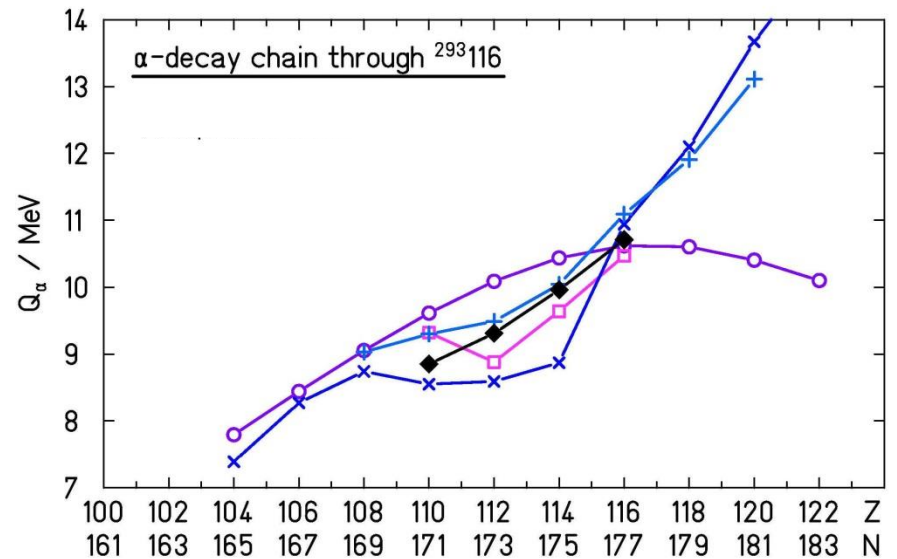
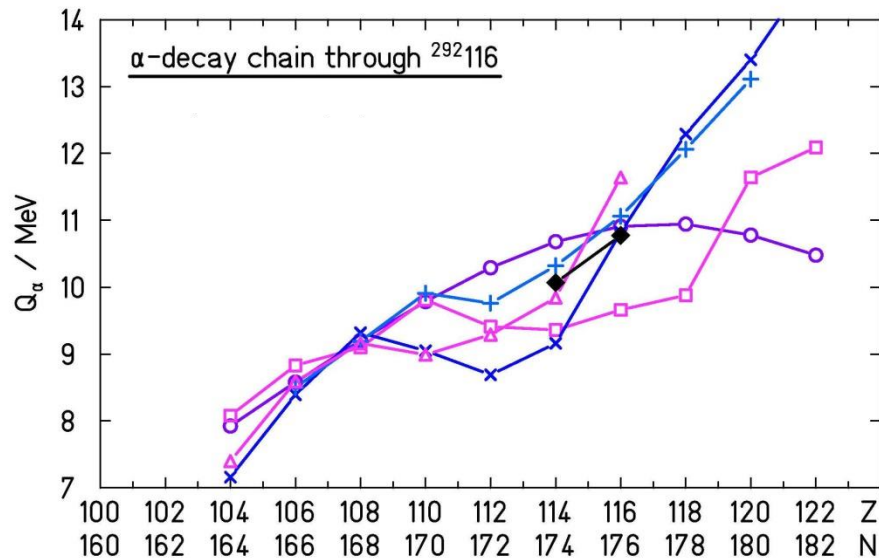
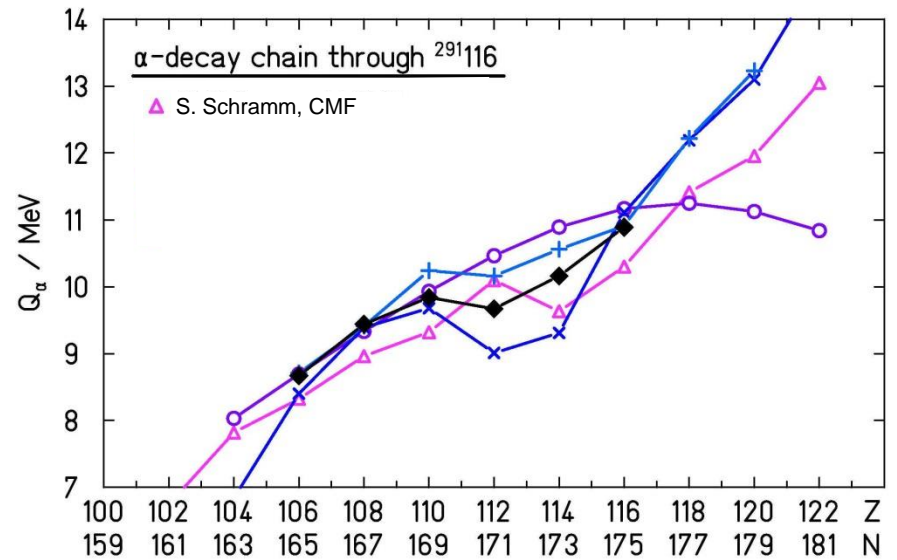
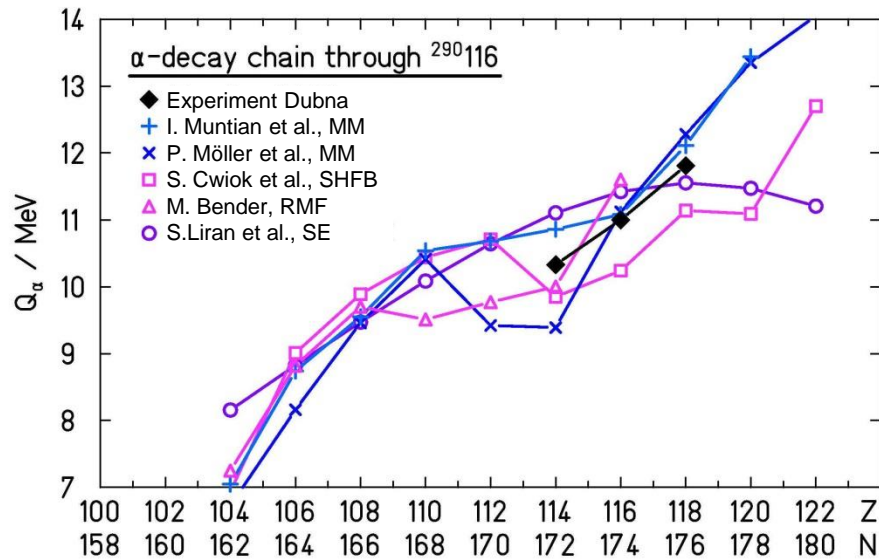
A. Sobiczewski et al., 1995

Mean field

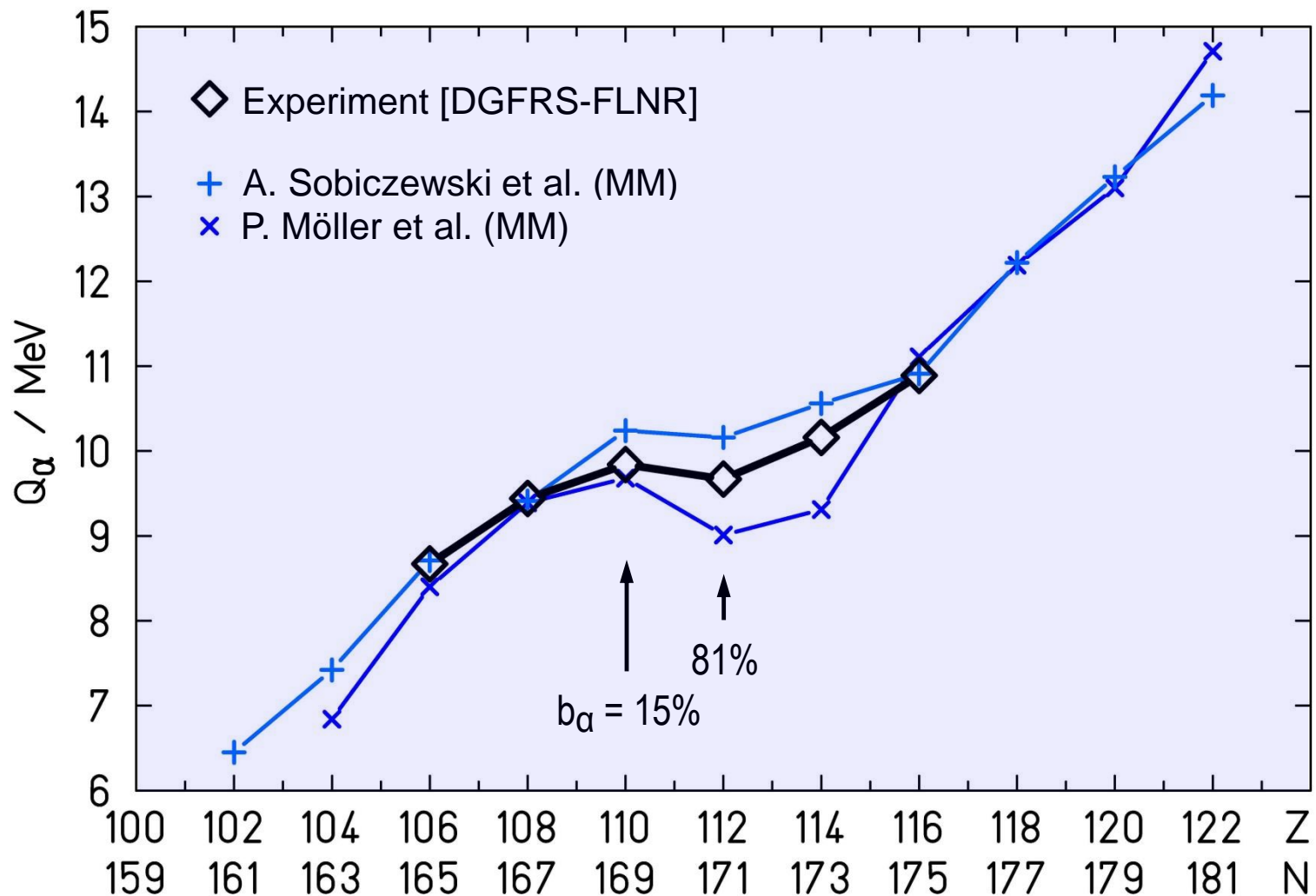


S. Cwiok et al., 1998

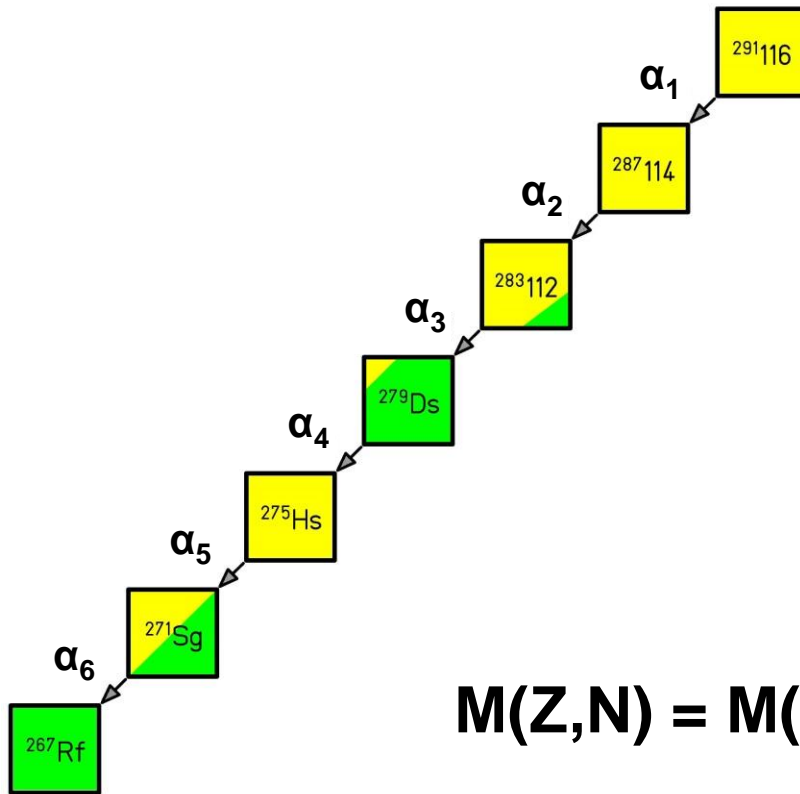
Q_α values: experiment and theory



Alpha-decay chain passing ^{291}Lv



Masses and shell correction energies



$$M(Z,N) = M(Z-2,N-2) + M(2,2) + Q\alpha(Z,N)/c^2$$

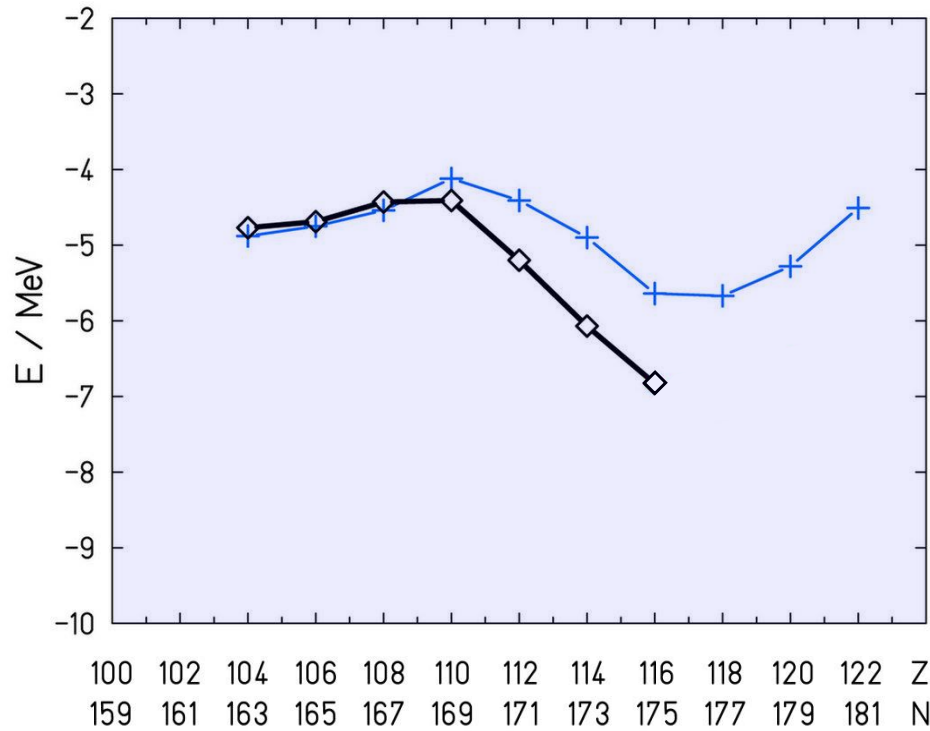
$$E_{\text{mic}}/c^2 = M(Z,N) - M_{\text{LD,theory}}$$

unknown mass of end point
adjusted to theoretical value

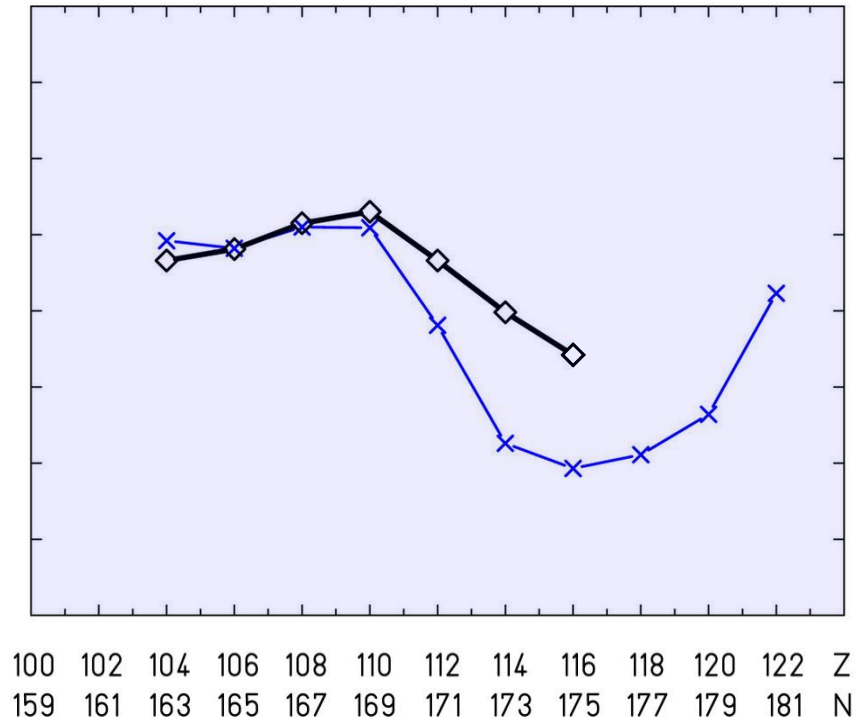
Shell-correction energies

◇ Experiment [DGFRS-FLNR]

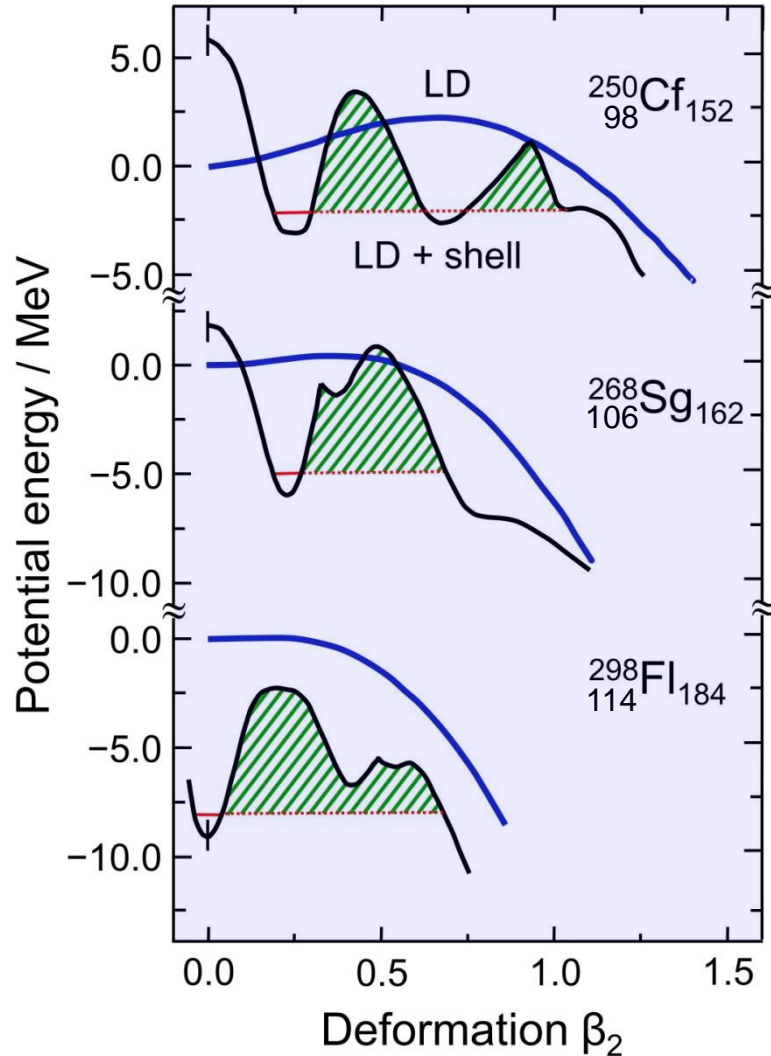
Theory: A. Sobiczewski et al.



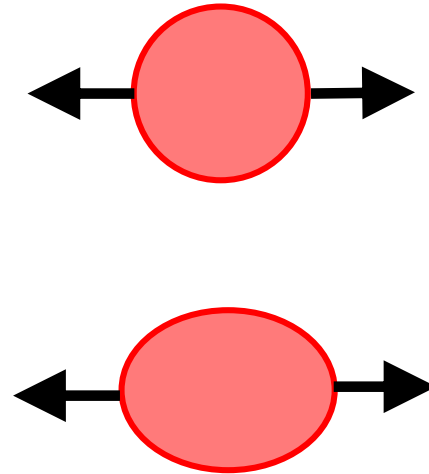
P. Möller et al.



Shell-correction energy and fission barrier



$$T_{1/2} \sim \exp \int B[V(r) - V_0]^{1/2} dr$$

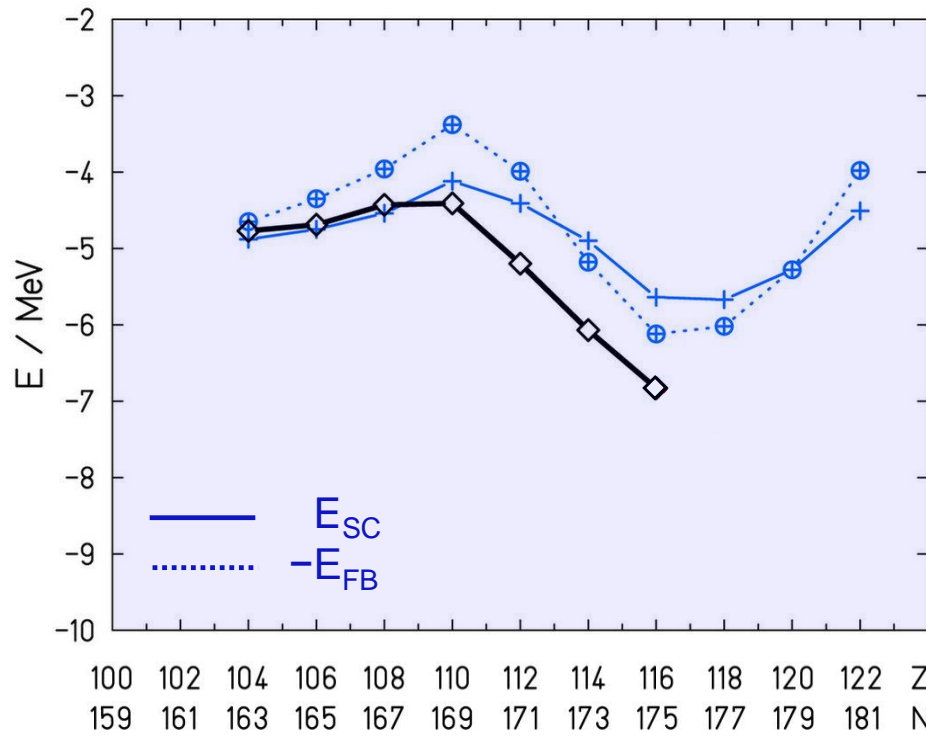


A. Sobiczewski et al.

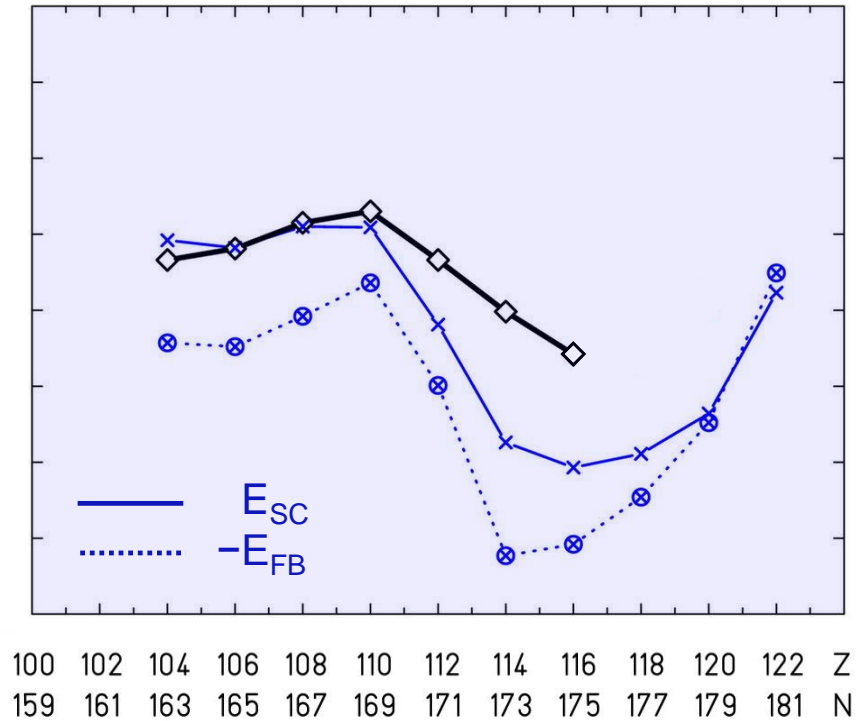
Shell-correction energies and fission barrier

◇ Experiment [DGFRS-FLNR]

Theory: A. Sobiczewski et al.



P. Möller et al.



2014 suggestion for a new contract

The only task:

Why is FRDM diverging for $Z > 110$ from experiments?

White Sands, 2009: longing for water and a SHIP



Sometimes, the situation with SHN research is similar like a walk through the desert: you can easily get lost

Therefore: look for a guide with a map



and a big car



and plans for the future



and an expert in cocktail mixing



and a master in the kitchen



and a friend who helps with the use of chopsticks



Congratulations



**For Peter Möller
on the occasion
of his 70th birthday**

**For the old *SHIP* group,
Sigurd Hofmann**

Tokai, December 4th, 2014