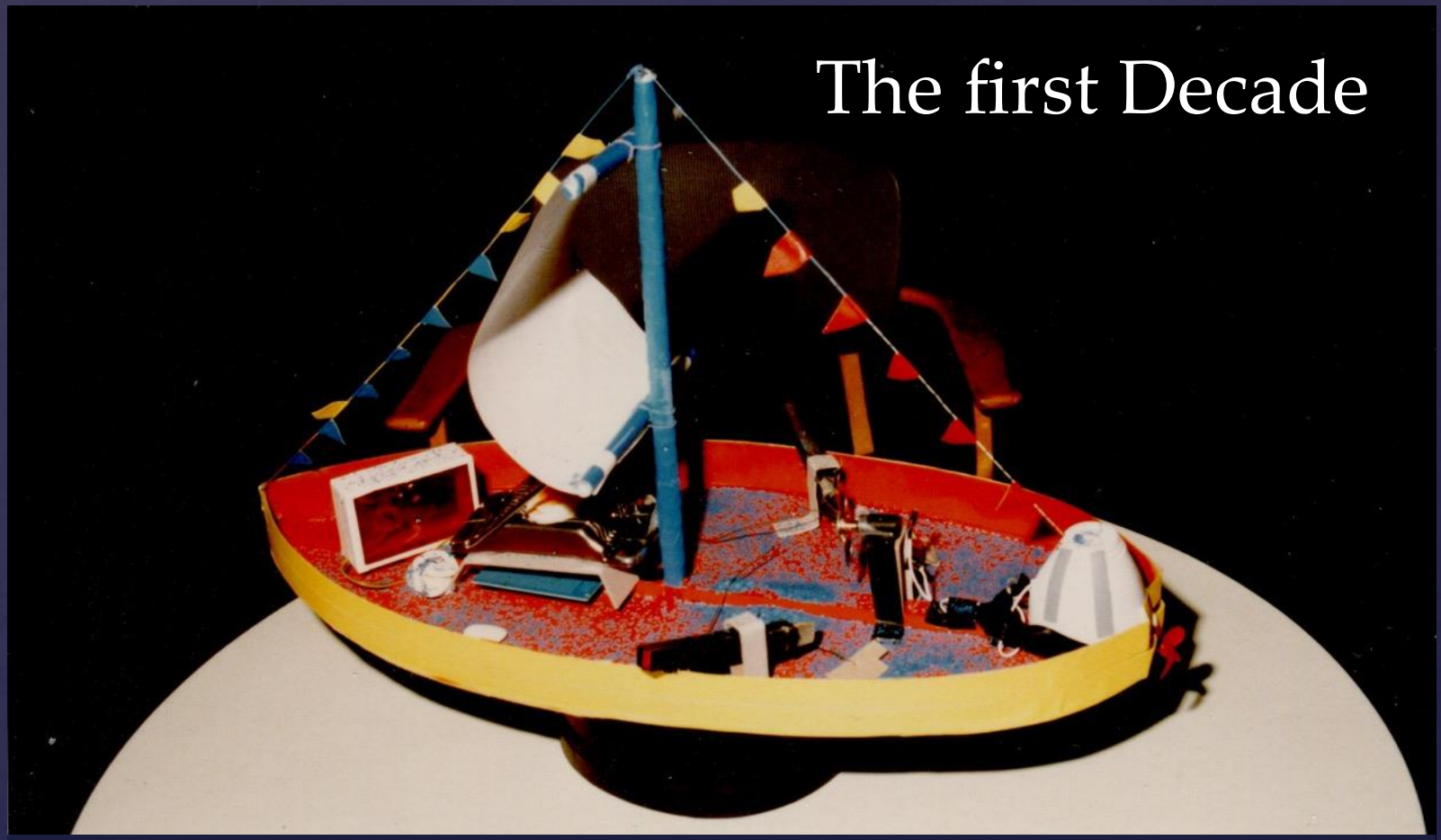
Fifty Years of SHIP



Fritz Peter Heßberger
GSI Darmstadt & Helmholtz Institut Mainz

GSI – the home port of SHIP

Development of a ‚universal' high performance linear accelerator for heavy ions up to uranium by Christoph Schmelzer and his team at the Ruprecht-Karls-Universität Heidelberg.

After some discussions w…vas decided in April 1969 to build the accelerator in Darms…ngly influenced by the Hessian Government and …rbeitsgemeinschaft Hessen', 1966 Universities Frankfurt, G…t …)

Hessen vorn

For realization of the project including experiment facilities a new institute denoted ‚Gesellschaft für Schwerionenforschung' (GSI) was founded on December, 17th, 1969.

The UNILAC went in operation in 1975, first uranium beam above the Coulomb barrier was delivered in spring 1976

Taken from ‚An experimental paradigm opening the world of superheavy elements', P.Armbruster, G.Münzenberg, Eur. Phys. J. H 37, 237 (2012)

Superheavy Elements

Theory: Extrapolation of the nuclear shell model beyond ^{208}Pb (Z=82, N=126), the heaviest known doubly magic nucleus → next spherical closed shells expected at Z = 114, N=184

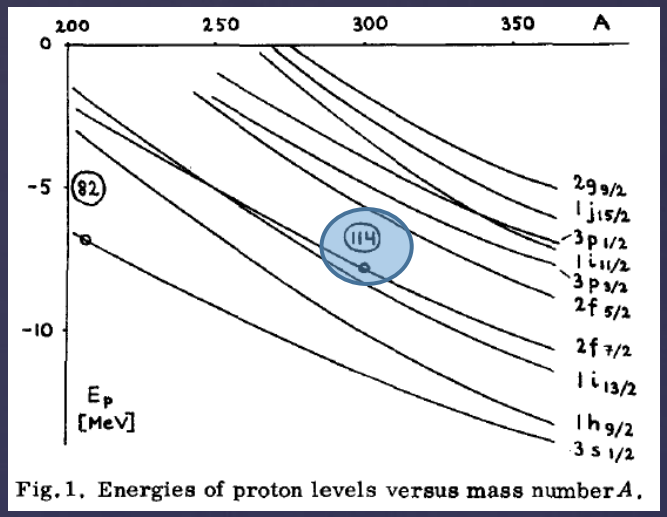


Fig. 1. Energies of proton levels versus mass number A.

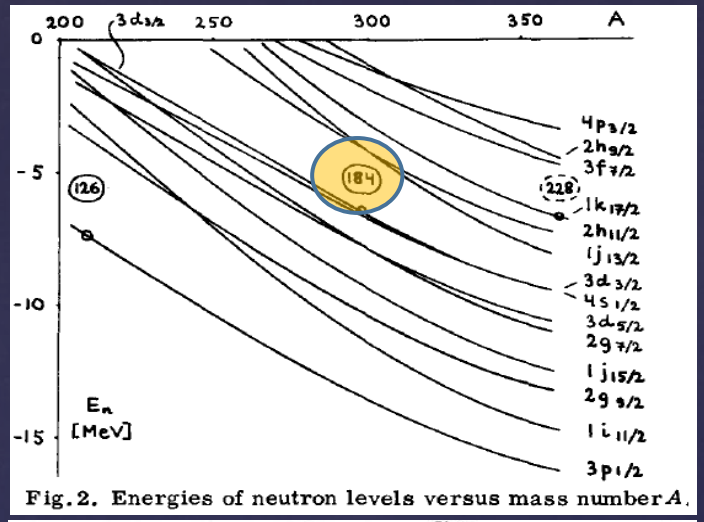
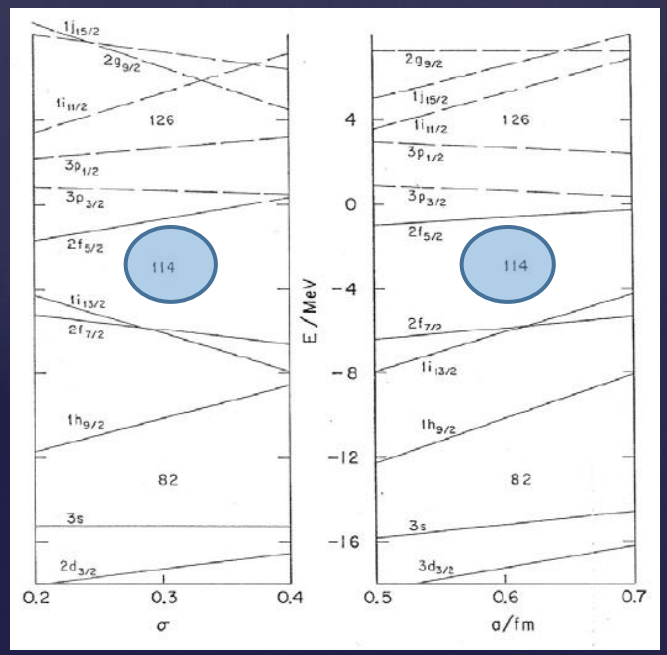
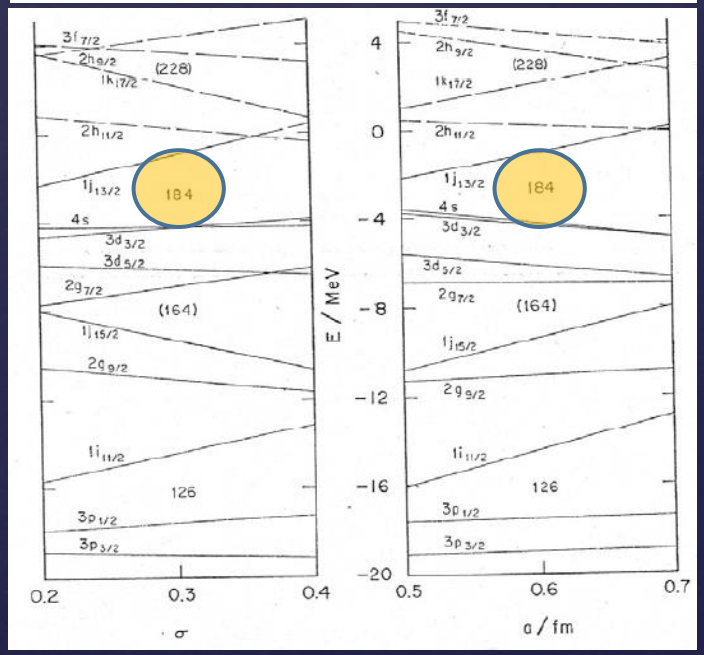


Fig. 2. Energies of neutron levels versus mass number A.

← A. Sobiczewski et al. Phys. Lett. 22,4 500 (1966)

→ high nuclear stability, thus long half-lives expected in the vicinity of the closed shells.





World wide search started, became also a ‚highlight' for research at the UNILAC

← H. Meldner Arkiv För Fysik 36,60 593 /1967)

The way to SHIP

Investigation of SHE requires fast separation from the projectile beam prior to identification by ‚spectroscopic means' if chemical methods are not applicable.

Already 1967 / 1968 a recoil separator was suggested for separation of SHE.

First presentation of possible electro-magnetic isotope separators for the UNILAC at the EMIS conference in Marburg (September 1970)

→ gasfilled separator (P. Armbruster)

→ velocity filter (H. Ewald)

February 1972: Submission of a first Scientific Research Programme for the years 1972-1974 by the GSI Directorate to the Scientific Council. Three items of recoil separators were considered:

a) separators to suppress the primary beam

b) broad-band low-resolution separators

c) high-resolution narrow-band separators

→ no preference for a specific kind suggested

Taken from ‚An experimental paradigm opening the world of superheavy elements', P.Armbruster, G.Münzenberg, Eur. Phys. J. H 37, 237 (2012)

The way to SHIP

January 1973: Meeting on the ‚Large Experimental Facilities at the UNILAC' at GSI.
4 items of a recoil separator were discussed:

1. High-frequency double-chopper (E. Kankeleit, TH Darmstadt).

2. High-resolution separator (Univ. Gießen).

3. Gas-filled separator (P. Arnbruster).

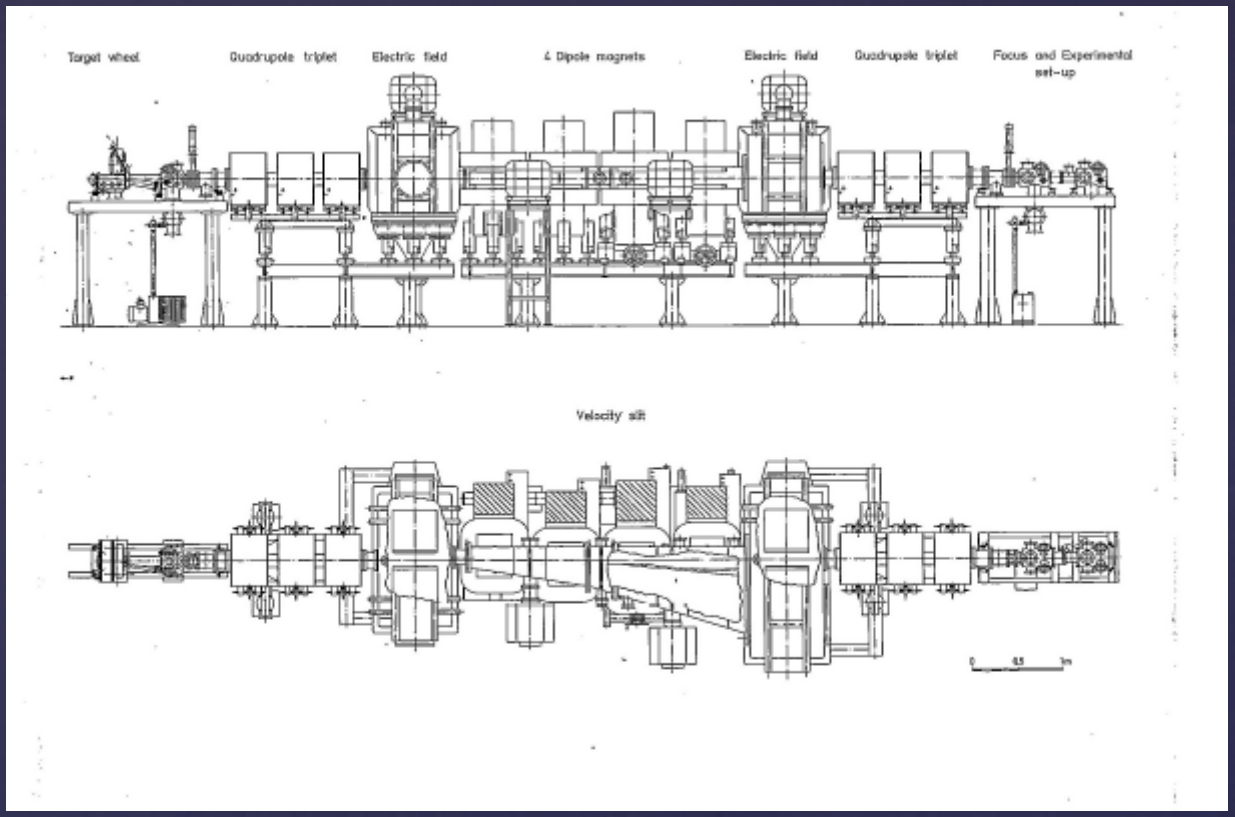
4. The two-stage velocity filter (H. Ewald, G. Münzenberg, Gießen) promised a large suppression of the primary beam (up to 10^{10}); could be combined with a time-of-flight system and further detector systems; could be built within three years.

The two-stage velocity filter was favoured; the proposal was approved in the spring meeting (1973) of the ‚GSI Aufsichtsrat'.
In September 1973 a collaboration contract between the II. Physikalisches Institut, Universität Gießen and GSI to built ‚SHIP' was signed.

Specification of the main components were fixed in 1973
Main components should be delivered until end of 1974

Taken from ‚An experimental paradigm opening the world of superheavy elements', P.Armbruster, G.Münzenberg, Eur. Phys. J. H 37, 237 (2012)

Construction and Commissioning of SHIP



- Dipole magnets delivered in november 1974
- Quadrupoles delivered in january 1975
- First parts of the HV condensors were mounted in april 1975
- Tests with an α- source in the 2nd half of 1975
- First beam at SHIP in december 1975
- **first full operation on march 12, 1976**

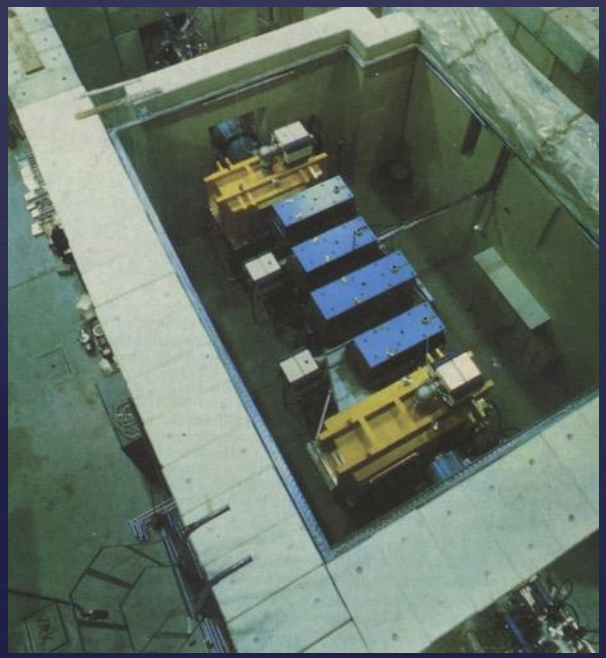
Detector systems:

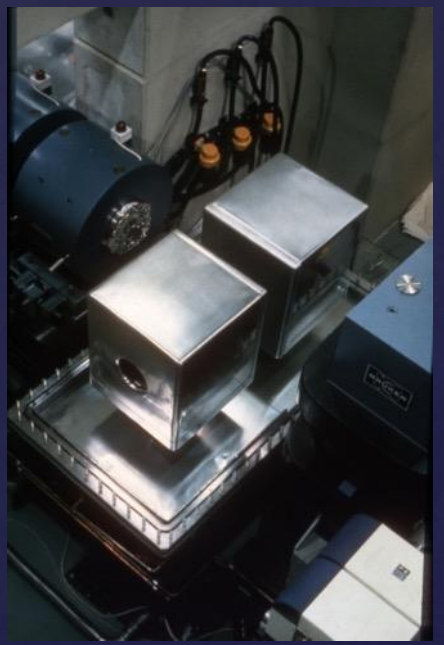
a) He-Jet and also a tape system if beam suppression would be $<10^6$ (S. Hofmann, K. Valli)

b) an energy – time-of-flight detector (W. Schneider), a Si-detector + secondary electron (ΔE - detector, ‚Linse') (K.H. Schmidt) if beam suppression would be $>10^6$

→ **projectile beam suppression was good enough for using Si - detectors**

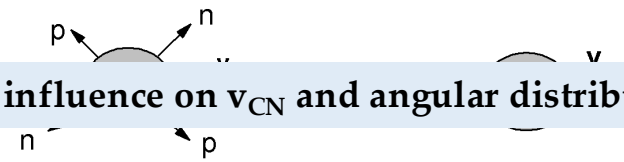
Views of SHIP





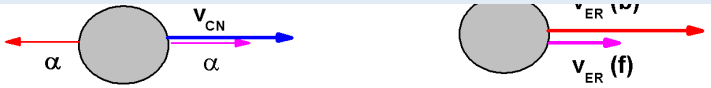
Properties of SHIP – Velocity Distributions

proton, neutron emission



Little influence on v_{CN} and angular distribution

Large influence on v_{CN} and angular distribution, ER only accepted if α-particles are emitted parallel or antiparallel to the flight direction of CN



α – particle emission

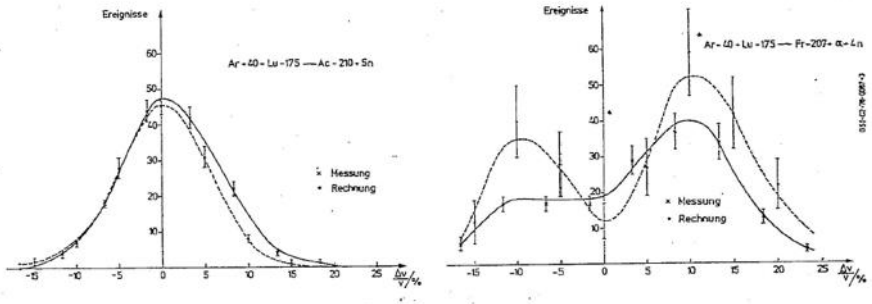
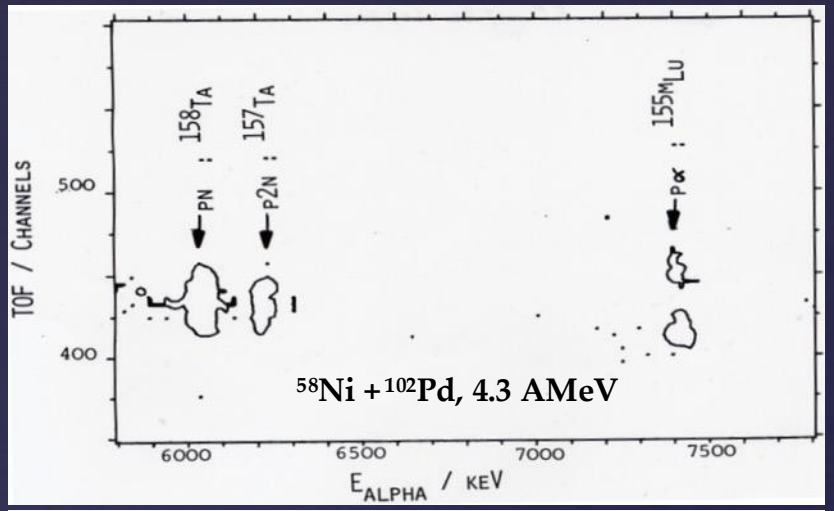
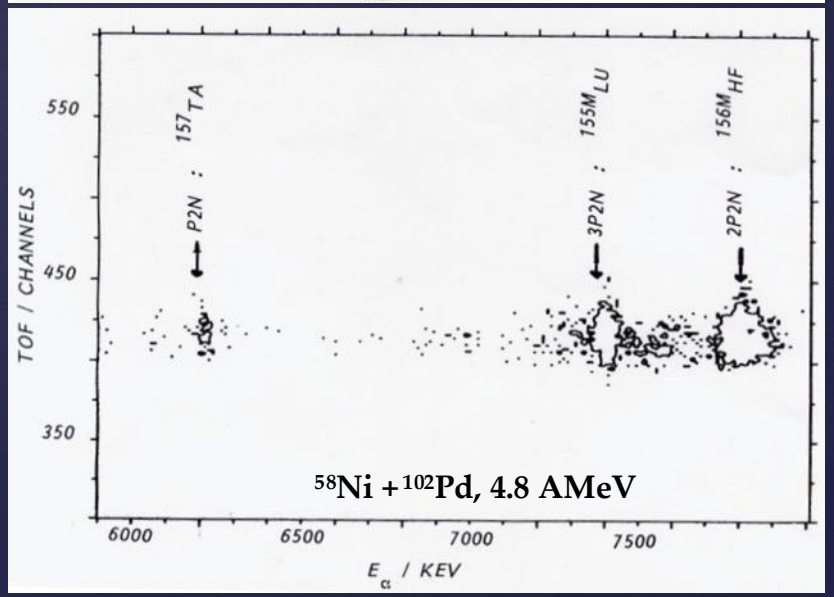


Abb VI.6 : Wirkungsgrad - Messung und Rechnung - für verschiedene Geschwindigkeiten.

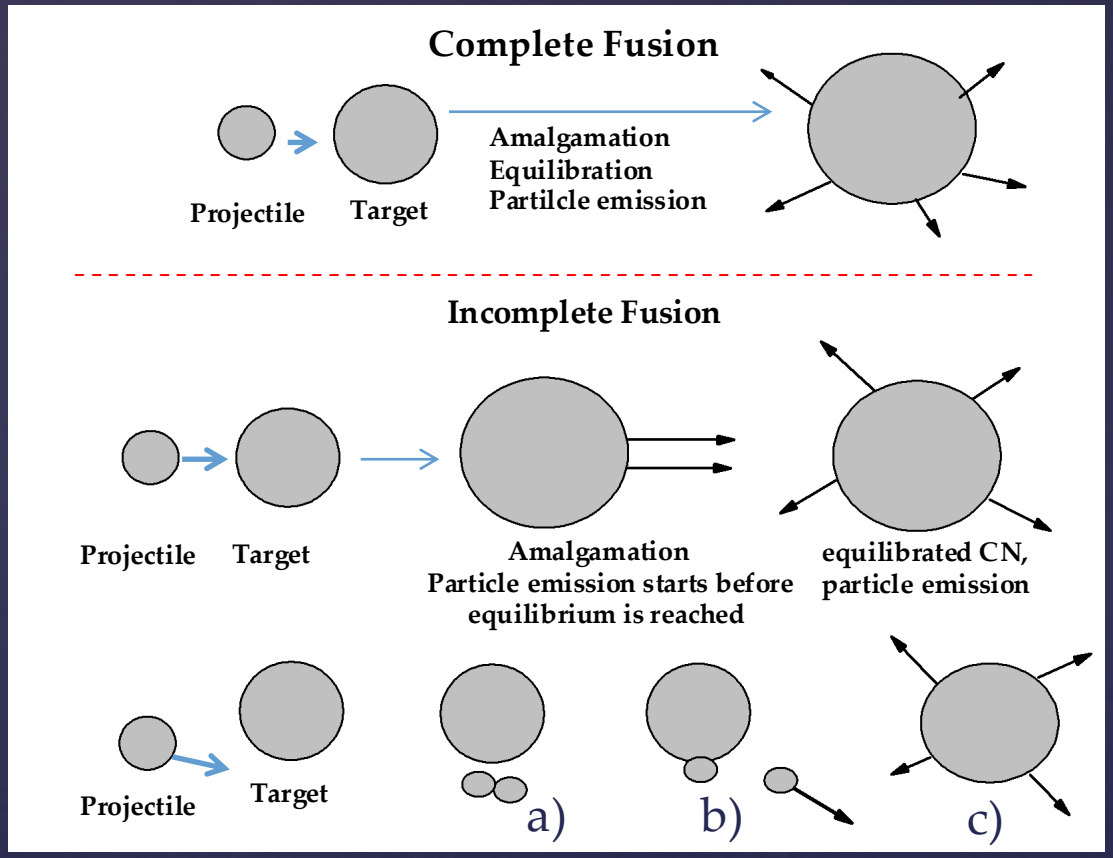


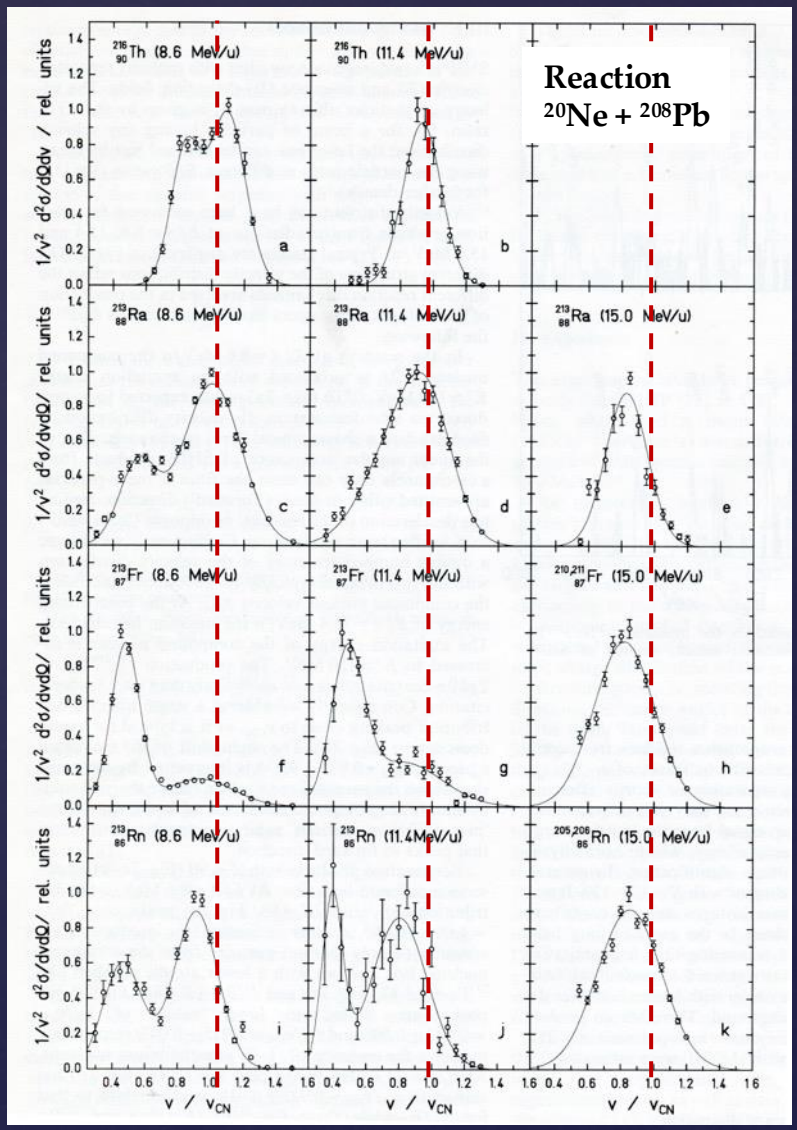


F.P. Heßberger et a. GSI Sci. Rep. 1981, 223 (1982)

W. Faust, Dissertation, Justus-Liebig-Universität Gießen, 1978 GSI-Bericht GSI-P-4-78 (1978)

Nuclear Reaction Studies
Incomplete Fusion, Pre-equilibriun emission



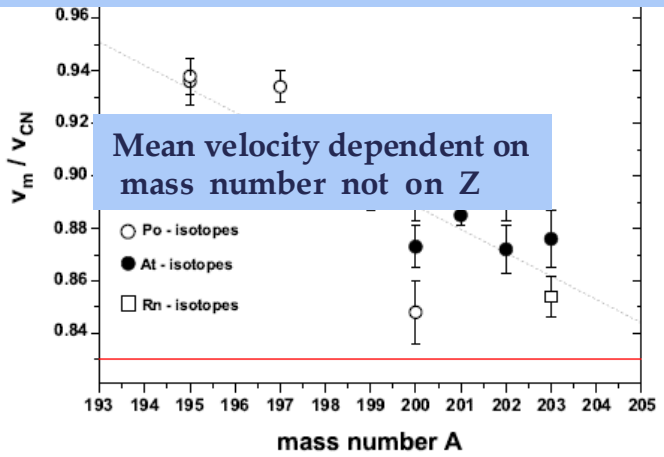


a) Projectile breaks up in the vicinity of the heavy target nucleus
b) One fragment fuses with the target nucleus, the other fragment escapes
c) Particle emission from the equilibrated CN

F.P. Heßberger et al. Z. Phys. A 348, 301 (1994)

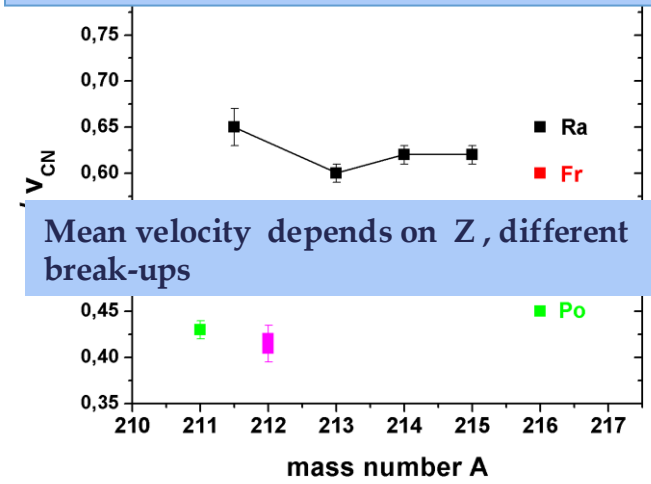
Nuclear Reaction Studies
Incomplete Fusion, Pre-equilibriun emission

Reaction ^{20}Ne + ^{197}Au, E = 14.9 AMeV

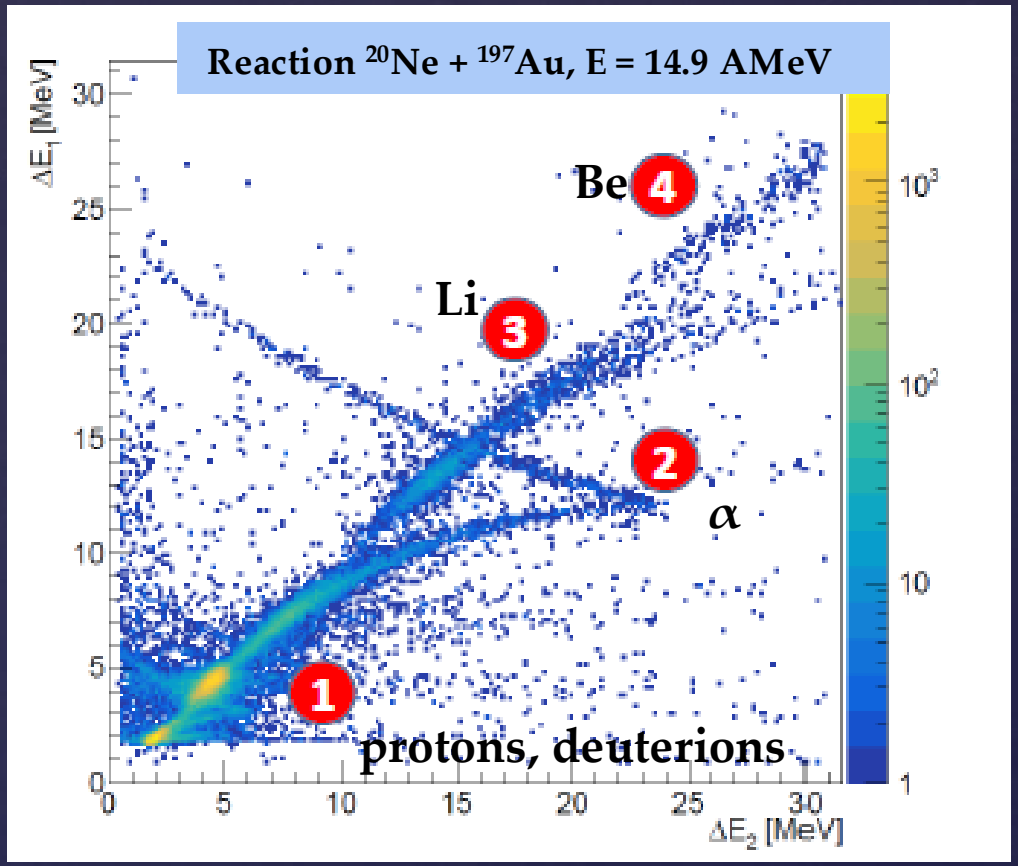


Mean velocity dependent on mass number not on Z

Reaction ^{20}Ne + ^{208}Pb, E = 8.6 AMeV



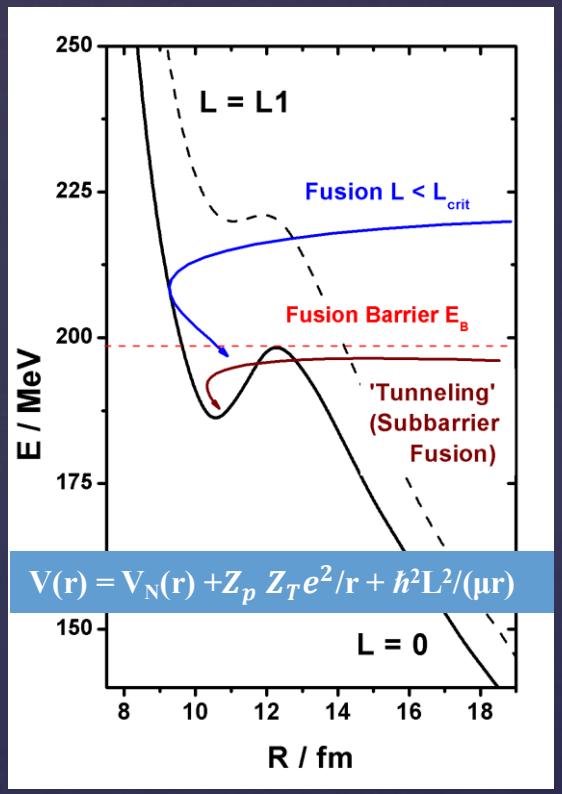
Mean velocity depends on Z , different break-ups



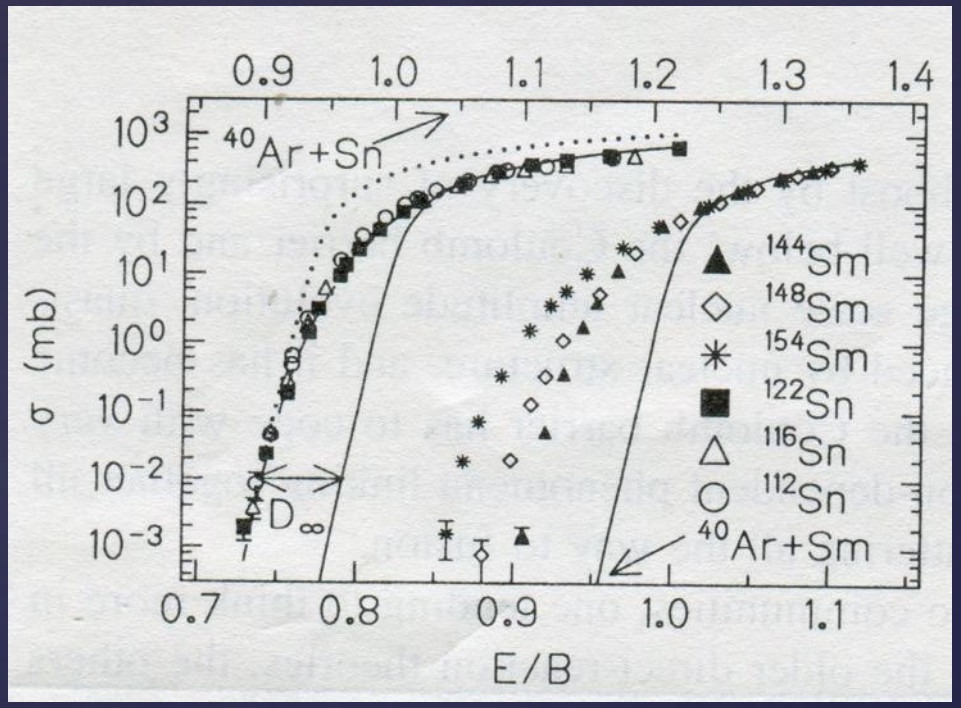
Pre-equilibrium emission: PE particels carry away more excitation energy → less emission of ‚thermal' particles → heavier evaporation residues

Projectile break-up: less momentum transfer for lighter fragments, fully equilibrated CN, emission of thermal particles

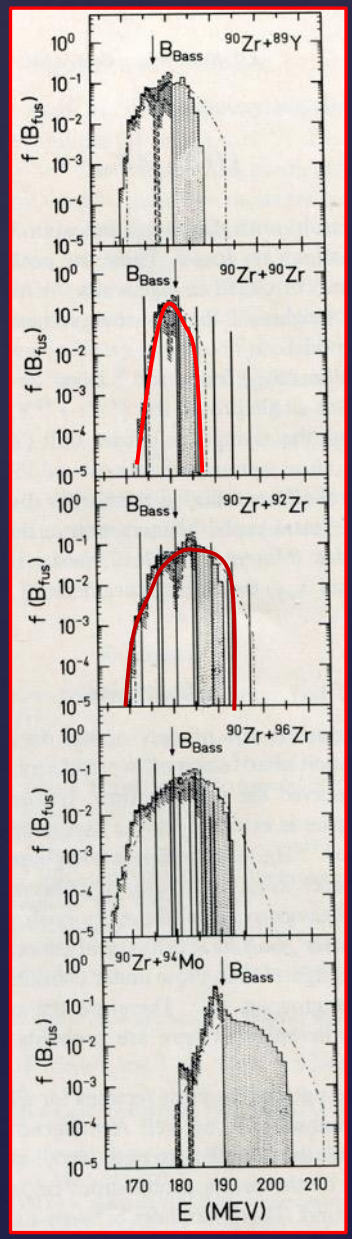
Nuclear Reaction Studies
Fusion below the Barrier



$$V(r) = V_N(r) + Z_p Z_T e^2/r + \hbar^2 L^2/(\mu r)$$



W. Reisdorf et al. Nucl. Phys. A 438, 212 (1985)
W. Reisdorf J.Phys. G: Nucl. Part. Phys. 20, 1297 (1994)

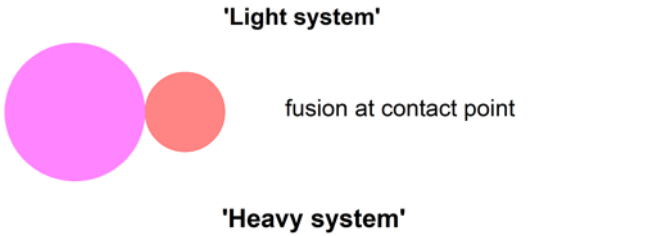


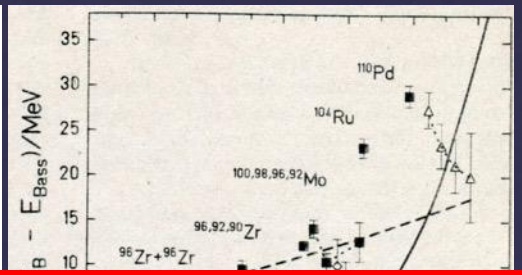
Simple picture: below barrier only ‚tunneling', experiments show significant ‚enhance-ment' below the barrier; example Ar+Sm: strong influence of deformation, but also excitation and transfer; ‚different barriers' for different processes
→ not a single barrier, but a distribution of barriers.

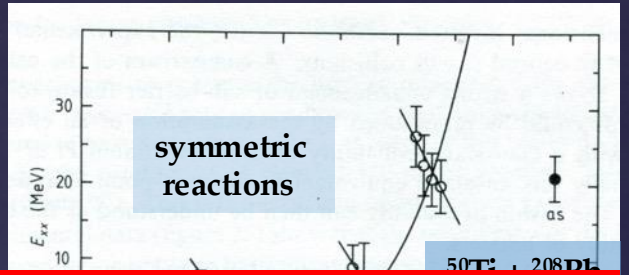
p(E) = ∫f(Bfus)T(E,Bfus) dBfus → deconvolution of the relation, barrier distribution for systems ^{90}Zr + ^{90,92,96}Zr, ^{89}Y, ^{94}Mo; width lowest for semi-magic ^{90}Zr

J.G. Keller et al. Nucl. Phys. A 452, 173 (1986)

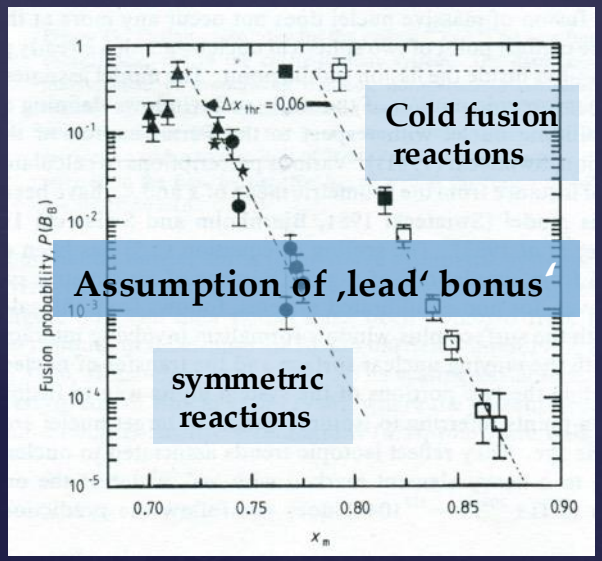
Nuclear Reaction Studies
The ‚extra push'



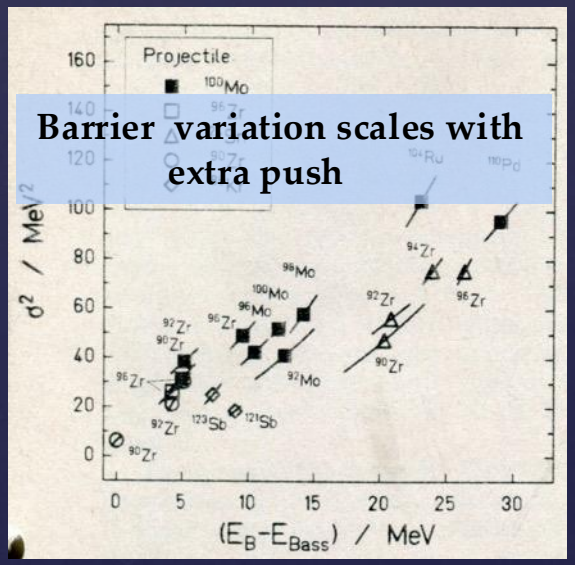




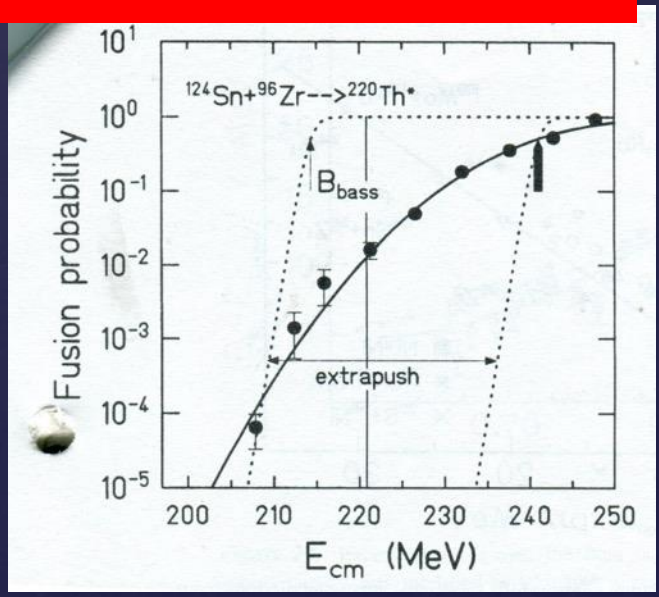
‚Extra push' concept had a large (negtive) influence on the SHE program at SHIP in the 1980ies; finally it was not regarded to be a proper concept and was not regarded in planning the experiments on the synthesis of elements 110 – 112 in the 1990ies.



G. Münzenberg, Rep. Prog. Phys. 51, 57 (1988)



A.B. Quint et al. Z.Phs.A 346, 119 (1993)



W.Reisdorf, J. Phys. G :Nucl. Part. Phys. 20,1297 (1994)
Data: C.-C. Sahm et al. A441, 316 (1995)

Nuclear Reaction Studies

Collaboration GSI (K.-H. Schmidt et al.) and TH Darmstadt (H.G. Clerc + students)

1. Investigation of fusion cross-sections crossing N=126 shell; influence of high gs shell effects on survival probability of CN; relevance for production of SHE around N=184 ?
   → strong damping of shell effects in spherical nuclei, no enhancement at higher excitation energies; enhancement at low E*, 1n-cross sections for ^{124}Sn + ^{90,92,94,96}Zr (K.H. Schmidt, D. Vermeulen, C.-C. Sahm)

2. Investigsation of ‚extra push' (K.H. Schmidt, C.-C. Sahm, B. Quint)

3. Investigation of ‚cold fusion' reaction; identification of ‚gamma – dexcitation channel' in the reaction ^{90}Zr + ^{90}Zr → ^{180}Hg + γ

4. Investigation of γ- and particle emission during deexcitation of nuclei produced in cold fusion reactions (^{90}Zr + ^{90}Zr, ^{89}Y) by ‚recoil – decay – tagging' (K.H. Schmidt, R.S. Simon, U. Gollerthan)

5. ‚Breakdown' of the ‚compound nucleus model' for heavy colliding systems (^{110}Pd + ^{110}Pd); no xn-channels observed → assumed, fusion is only possible for ‚pre-compound emission' of charged particles (not to be mixed up with pre-equilibrium emission) (K.H. Schmidt, W. Morawek)

Proton Radioactivity

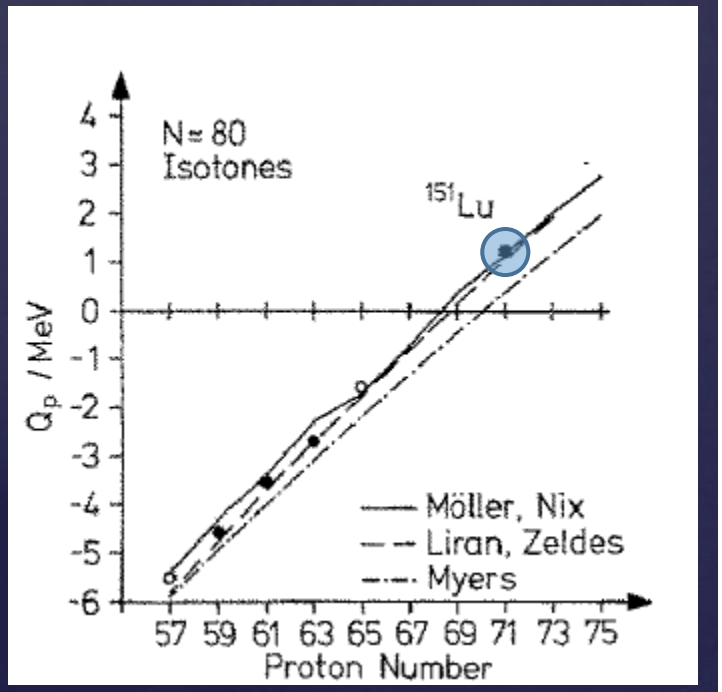
First identification of a proton emitter in 1970 by K.P. Jackson et al., an isomeric state ^{53m}Co, $T_{1/2}$ = 247 ms, $J^{\pi} = 19/2^-$

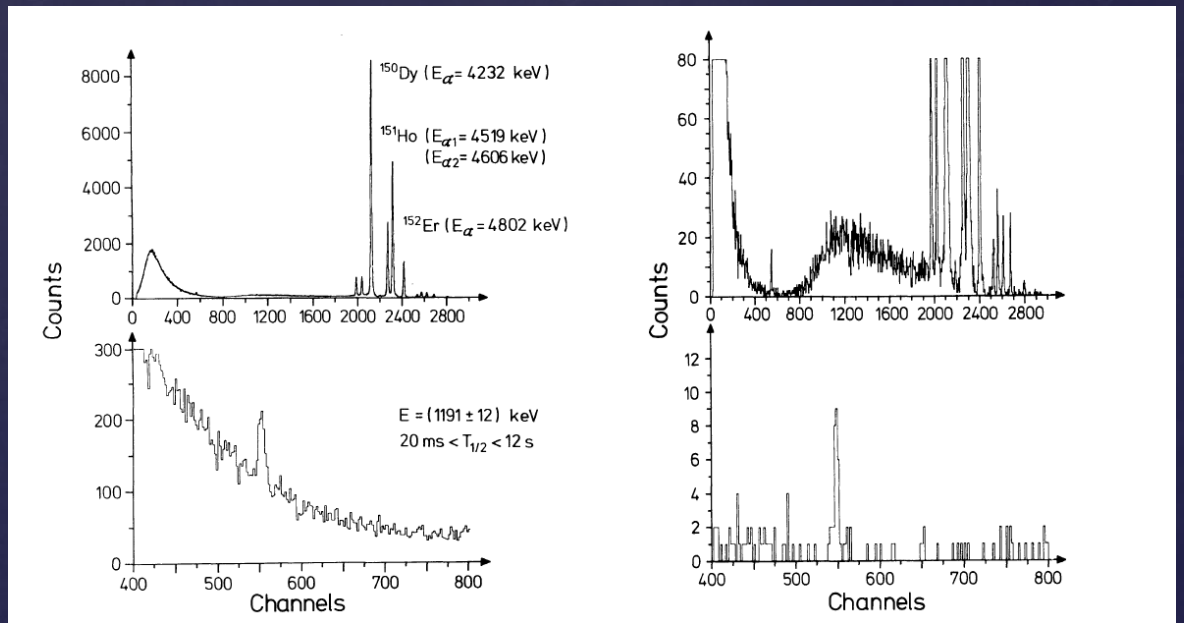
Search for proton emission from the ground state

‚hot candidate' was ^{113}Cs

Another region identified for proton radioactivity below the neutron shell N = 82 around Z = 70; a possible candidate was ^{151}Lu

First successful identification in april 1981



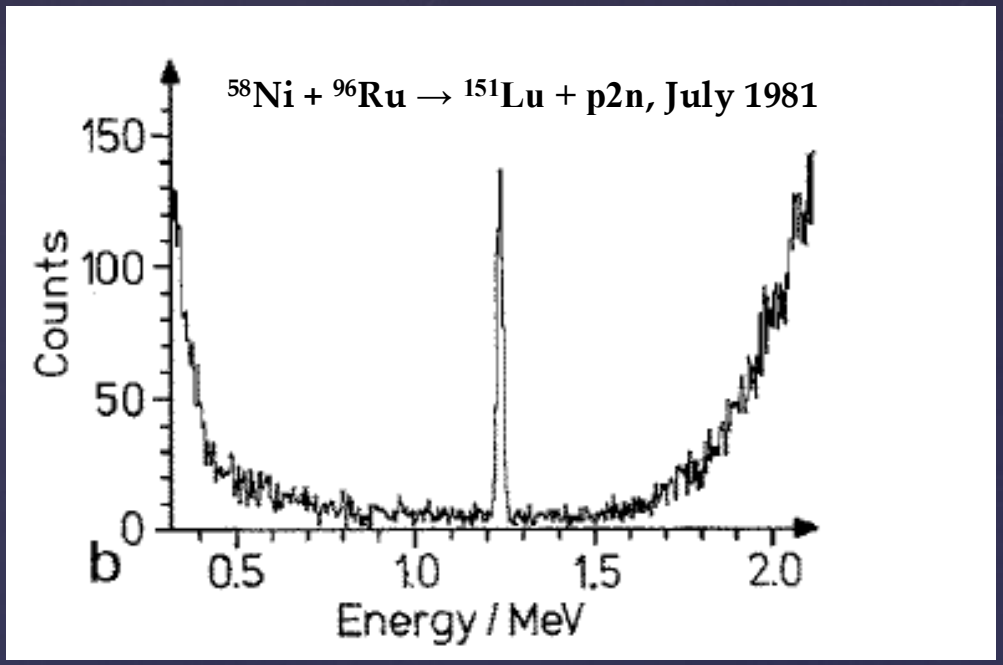


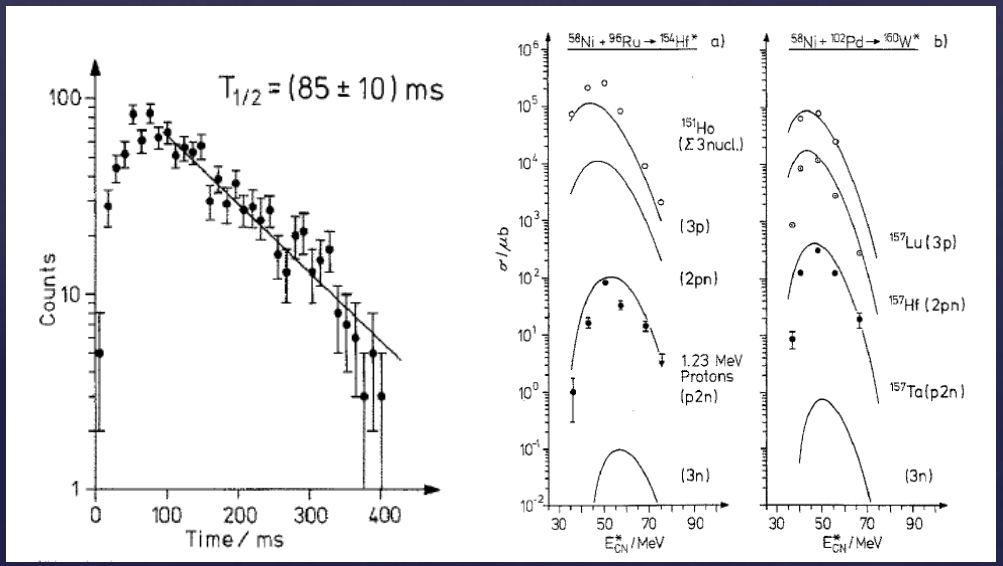
S. Hofmann et al. Contribution to ‚Nuclei far from stability, Helsingör, 1981

Fig. 1o: Energy spectrum taken with a 3oo µm thick Si detector (bin size of channels: 2) Reaction: ^{58}Ni + ^{96}Ru → ^{154}Hf (E^{*}=47 and 54 MeV).

Fig. 11: Energy spectrum taken with a 14o µm thick Si detector (bin size of channels: upper part 4, lower part 2) Reaction: see Fig. 1o

Proton Radioactivity





S. Hofmann et al. Z. Phys. A 305, 111 (1982)

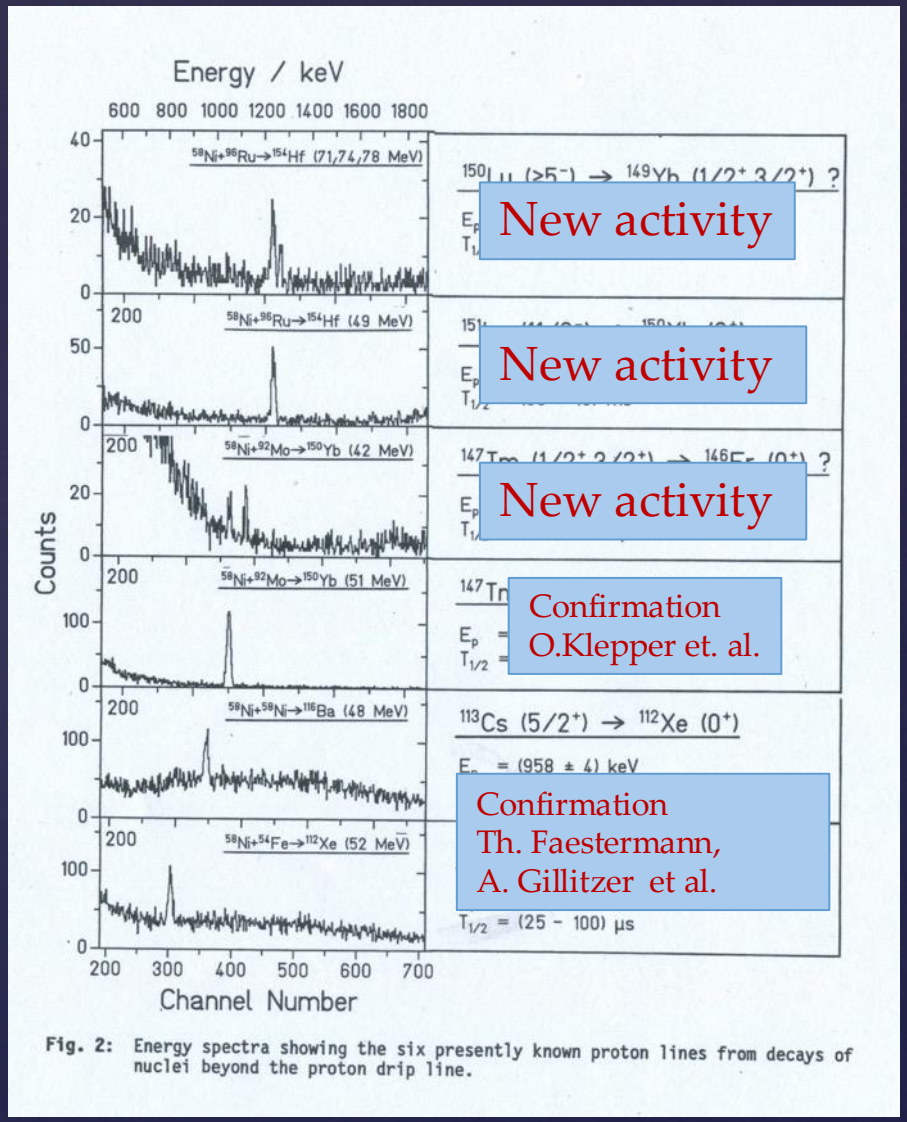


Fig. 2: Energy spectra showing the six presently known proton lines from decays of nuclei beyond the proton drip line.

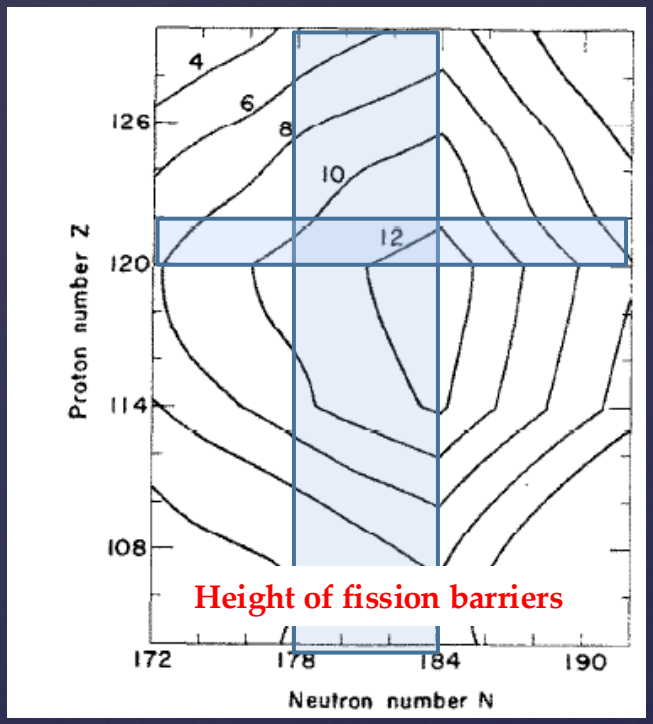
S. Hofmann et al., AMCO 1984

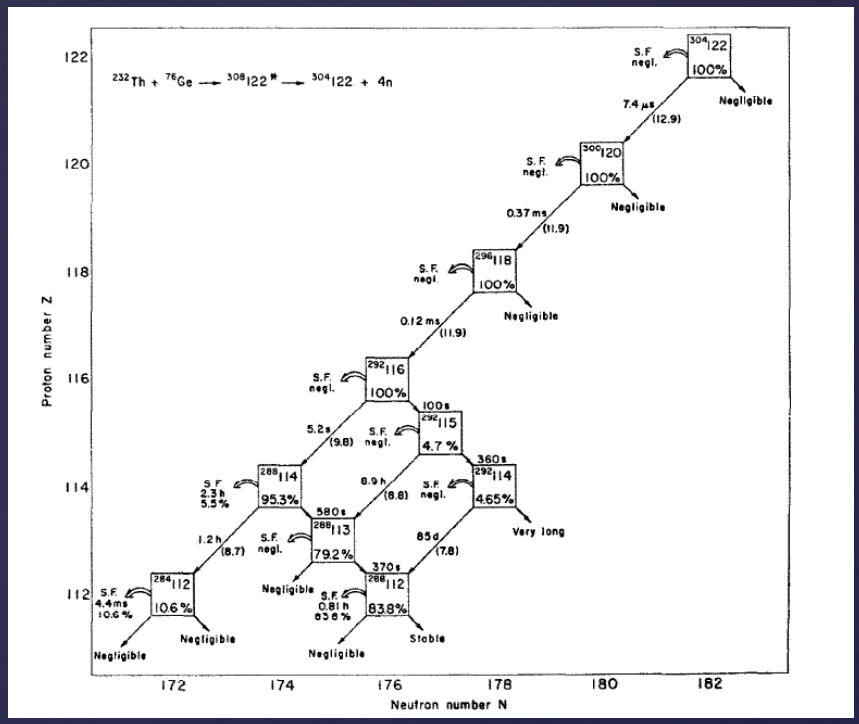
Early SHE research at SHIP

Selected reactions: a) $^{136}Xe + ^{170}Er \rightarrow ^{306}122^*$, b) $^{65}Cu + ^{238}U \rightarrow ^{303}121^*$

→ high fission barriers and long α decay chains expected → high cross sections expected >> 10 mb

E.O. Fiset, J.R. Nix, Nucl. Phys. A193, 647 (1972)





Experiments: (P. Armbruster et al. GSI Annual Reports 1976 / 1977)

Results:

$^{136}Xe + ^{170}Er \rightarrow ^{306}122$, 4.8 – 5.6 AMeV, E*(CN) = 0-60 MeV, 10 pnA, $6x10^{14}$ Projectiles, σ (lim) = 1.5 nb

$^{65}Cu + ^{238}U \rightarrow ^{303}121$, 4.7 – 5.8 AMeV, E*(CN) = 0-60 MeV, 30 pnA, $2x10^{15}$ Projectiles, σ (lim) = 0.4 nb

within 1 μs and 1 week no α – α correlations or SF were recorded

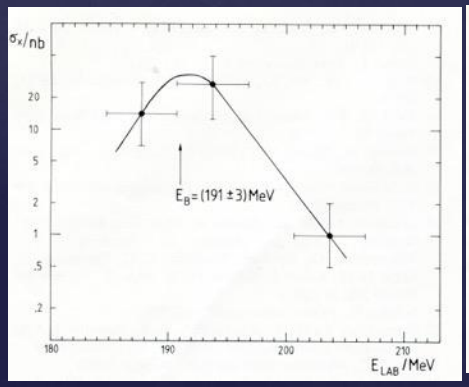
Concept of cold fusion – preparative experiments

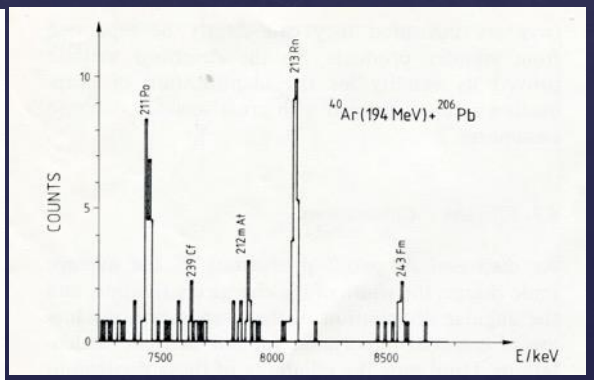
Concept of Cold Fusion suggested by Yu. Ts. Oganessian using targets around double magic ^{208}Pb and medium heavy projectiles (^{50}Ti, ^{54}Cr) allowed to produce low excited CN at the fusion barrier (E* ≈ 20 MeV) and thus high survival probability; no (highly) radioactive targets were needed.

Use of ^{40}Ar induced reactions

^{40}Ar + ^{206,208}Pb → ^{246,248}Fm* for developping and testing the experimental set-ups and conditions

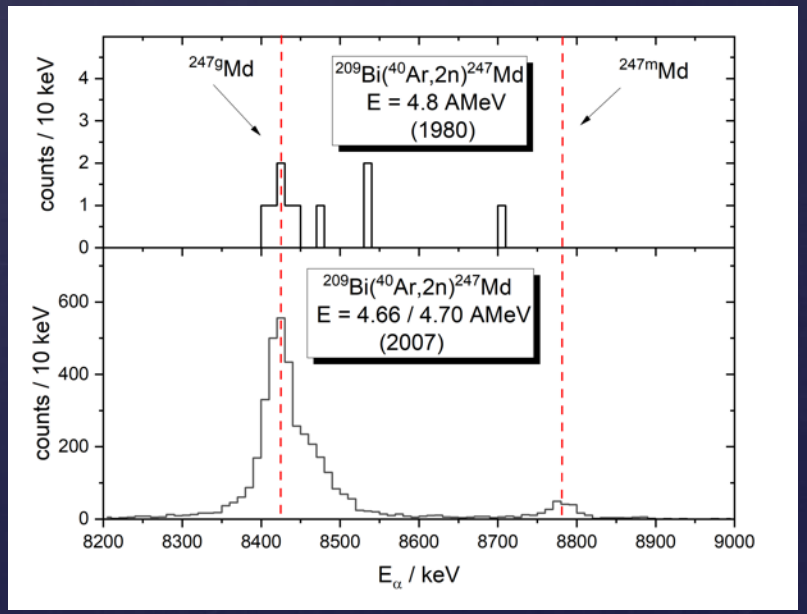
→ application of a target wheel
→ identification of α-decays and SF simultaneously
→ application of the correlation method
→ excitation functions
→ discovery of ^{243}Fm





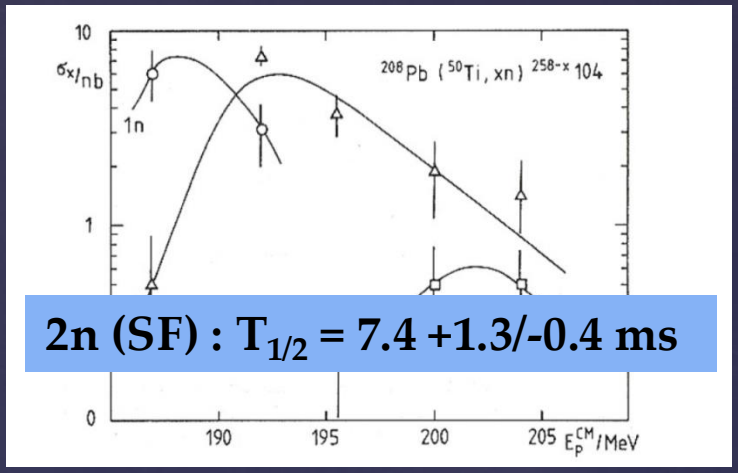
G. Münzenberg et al. Z.Phys. A 302, 7 (1981)

February 1980: completion of the preparative experiments, first irradiation of Bi-targets (with ^{40}Ar – beam); discovery of ^{247}Md, first transfermium isotope discoverd at SHIP



G. Münzenberg et al. Z.Phys. A 302, 7 (1981) (upper figure)
F.P. Heßberger et al. EPJ A 58:11 (2022) (lower figure)

Element 104
first step into the transactinide region



2n (SF) : $T_{1/2}$ = 7.4 +1.3/-0.4 ms

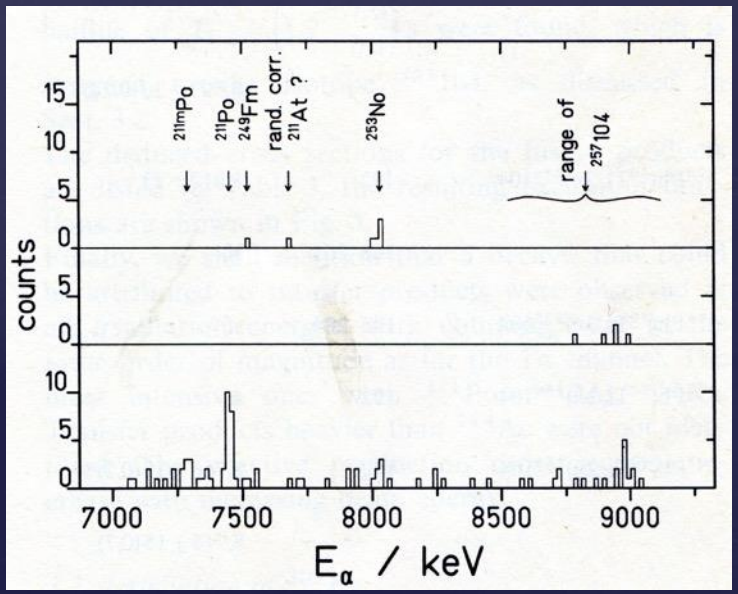
G. Münzenberg et al. Actinides in Perspective, 223 (1981)

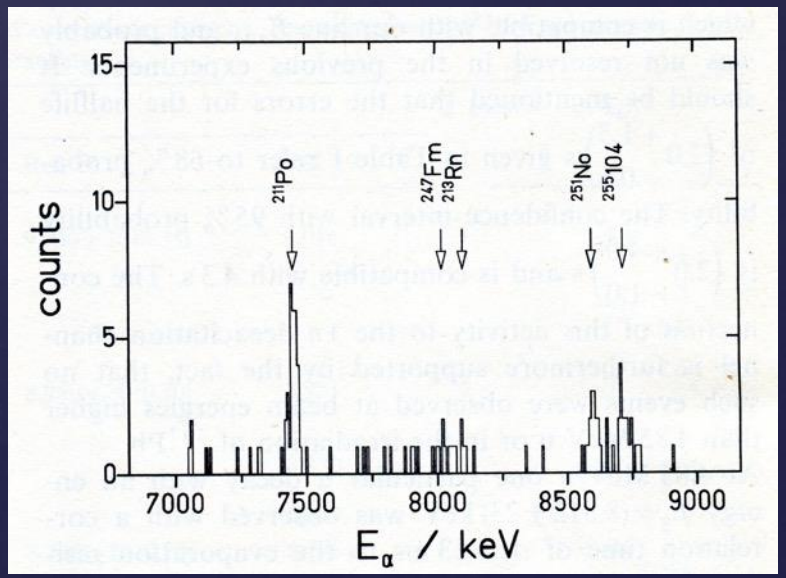
February / March 1980

First step into the transacitinide region, reaction ^{50}Ti + ^{208}Pb. Purpose: confirmation the 5 ms SF activity observed by Yu.Ts. Oganessian et al. attributed to ^{256}Rf (2n channel). Halflife decrease by a factor of ≈6x10^{6} compared to the neighboring N=152 isotone ^{254}No.; result was under discussion.

Surprise: observation of ^{257}Rf, the 1n channel. Proof that nuclei can be produced really cold !

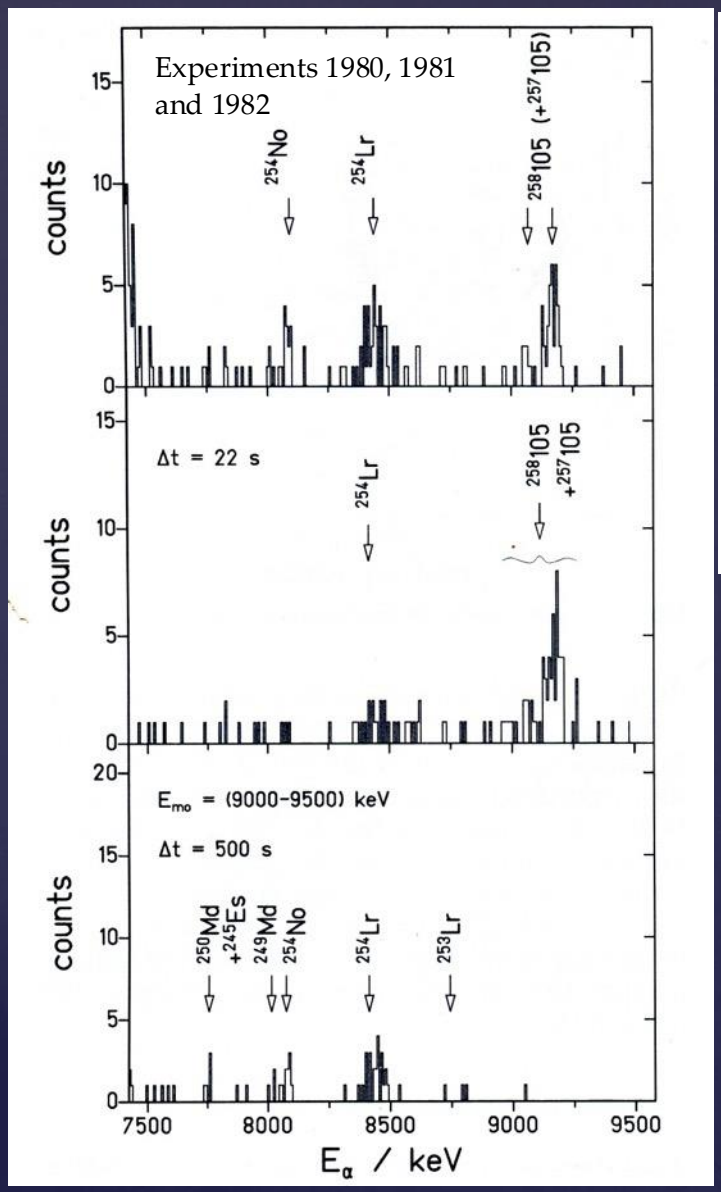
In the reaction ^{50}Ti + ^{207}Pb α-decay of ^{255}Rf was observed first time.



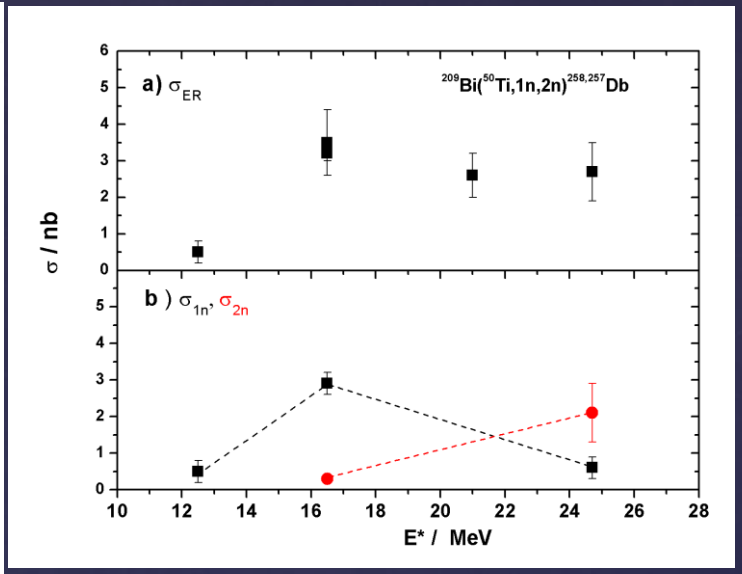


F.P. Heßberger et al. Z.Phys. A 321, 317 (1985)

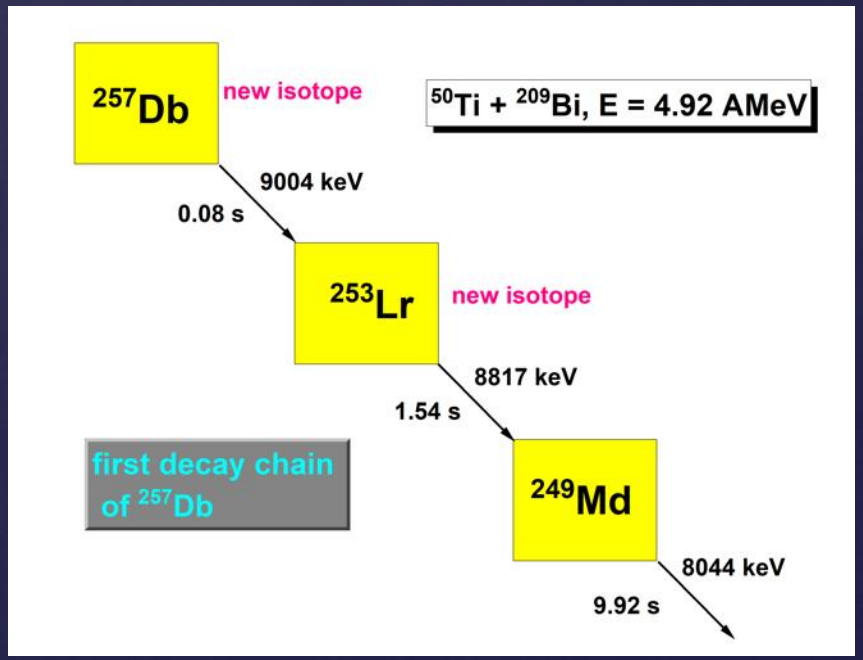
Element 105 – the gate to Element 107



F.P. Heßberger et al. Z.Phys. A 322, 557 (1985)
F.P.Heßberger PHD , TH Darmstadt 1985



Prior to synthesis of Element 107 investigation of Z = 105 daughter nuclei required; synthesis of ^{257,258}105 in the reaction ^{50}Ti + ^{209}Bi ; higher cross section for 1n – channel !



Elements 107 (Bohrium)

‚Dubna Challenge' (Yu.Ts. Oganessian et al. JETP Lett. 23, 277 (1976)):
$^{54}Cr + ^{209}Bi$: 2 SF activities observed:

a) $T_{1/2} \approx 2$ ms (1-2 ms) assigned to $^{261}107$ (2n-channel) (never reproduced; $T_{1/2}$ (^{261}Bh) = 11.8 ms, no SF)
b) $T_{1/2} \approx 5$ s assigned to $^{257}105$ (α-decay product of $^{261}107$) ($^{262}Bh \xrightarrow{\alpha} {}^{258}Db \xrightarrow{EC} {}^{258}Rf \xrightarrow{SF}$)

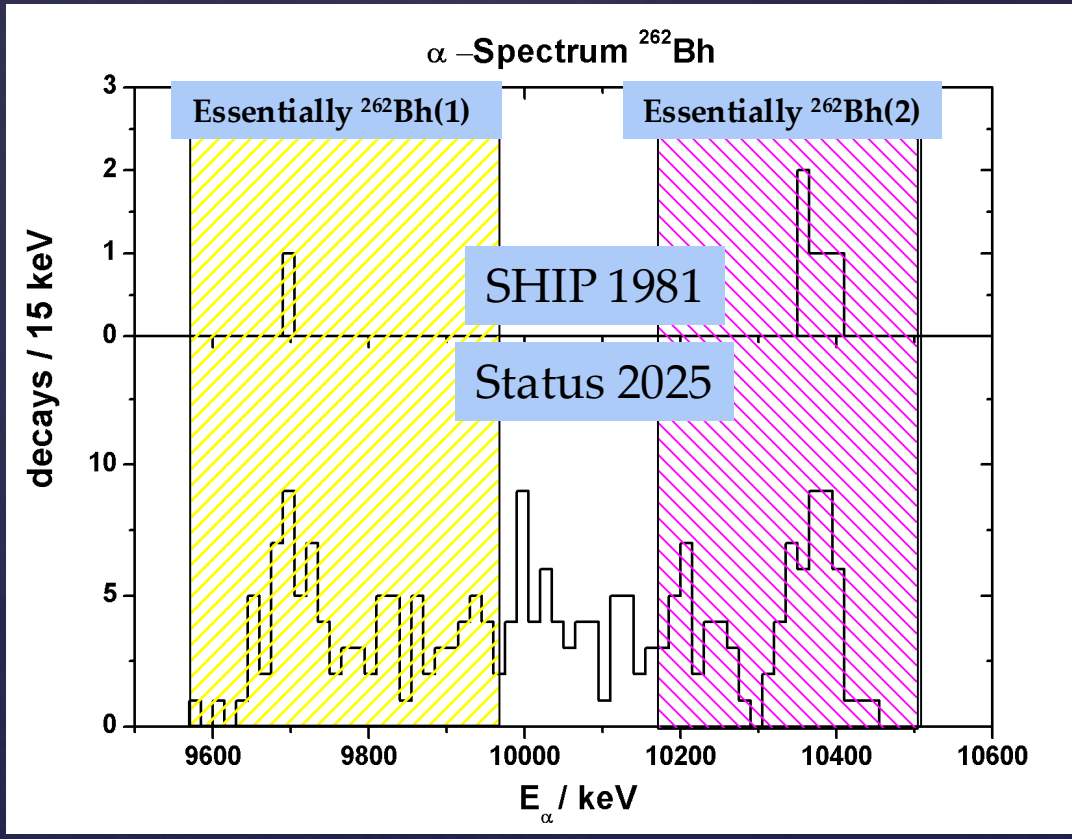
Experiment scheduled February 22 – 26, 1981; due to technical problems started on February, 24, extended until February 28 (thanks to our colleagues from Nuclear Chemistry)

Concentration on 1n – channel ($^{262}107$), higher cross-section expected, also probably produced in the Dubna experiment.

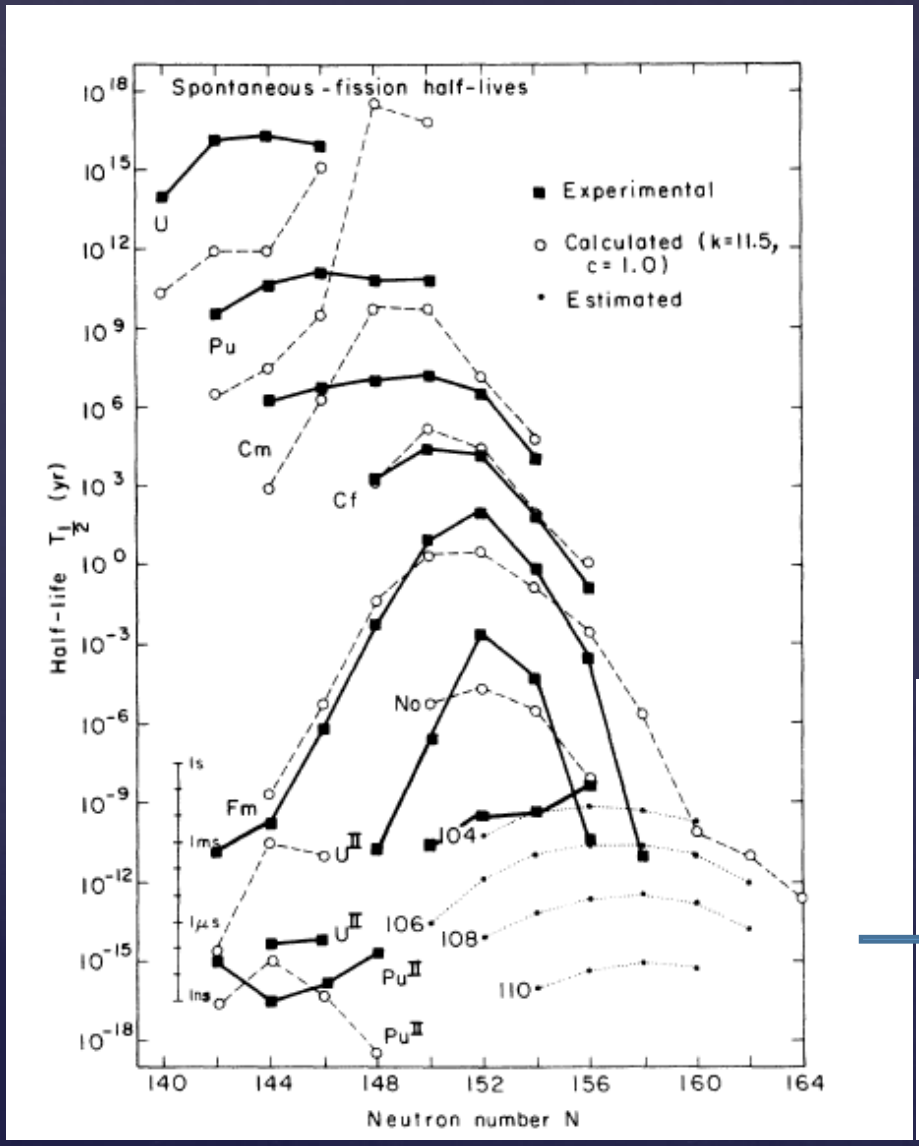
<u>Six decay chains observed:</u>

$^{262}107$ (1) : $E_\alpha = 9.704 \pm 0.050$ MeV, (1 decay)
$T_{1/2} = 115\ +231/-75$ ms
$^{262}107$ (2) : $E_\alpha = 10.376 \pm 0.035$ MeV,
$T_{1/2} = 4.7\ +2.3/-1.6$ ms

(F.P.Heßberger, arXiv:251.05953v1 (2025))

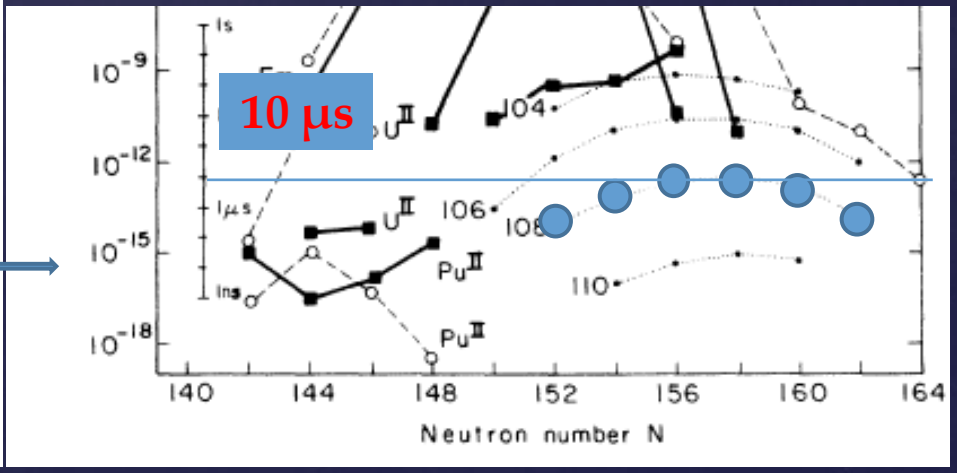


Element 108 or Element 109 ?



Steep drop of fission half-lives at increasing proton number predicted.
For even – even nuclei of element 108 SF - half-lives 1-10 μs expected, for odd-mass isotopes of element 108 SF was expected was dominating decay mode.
How to identify SF safely ?
Due to strong fission hindrance of odd-odd nuclei these isotopes seemed better candidates for α – decay.

→ decision to prefer element 109 - $^{266}109$



J. Randrup et al. Phys. Rev. C 13, 229 (1976)

Element 109

Experiment $^{58}Fe + {}^{209}Bi \rightarrow {}^{267}109^*$ ($E^* \approx 13, 17, 22$ MeV)

August 20, 1982 – September 3, 1982

One decay chain observed at $E^* \approx 22$ MeV

(5.15 AMeV) → highest energy !!

Influence of ‚extra push' assumed !

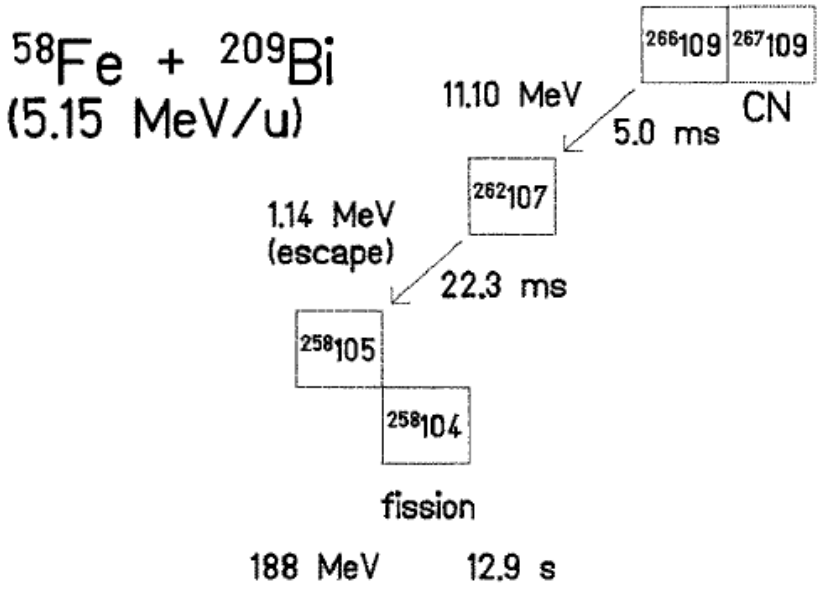
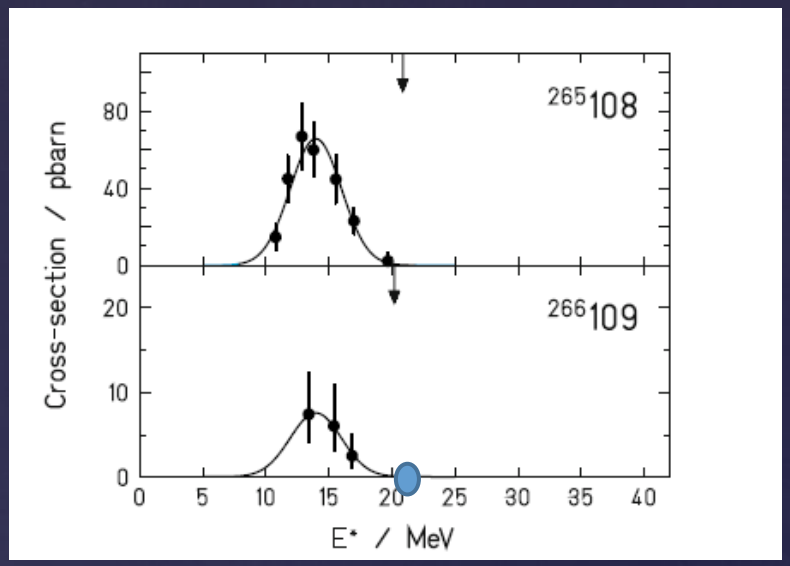


Fig. 1: Interpretation of the observed decay chain.

G. Münzenberg et al. Z. Phys. A 309,89 (1982)

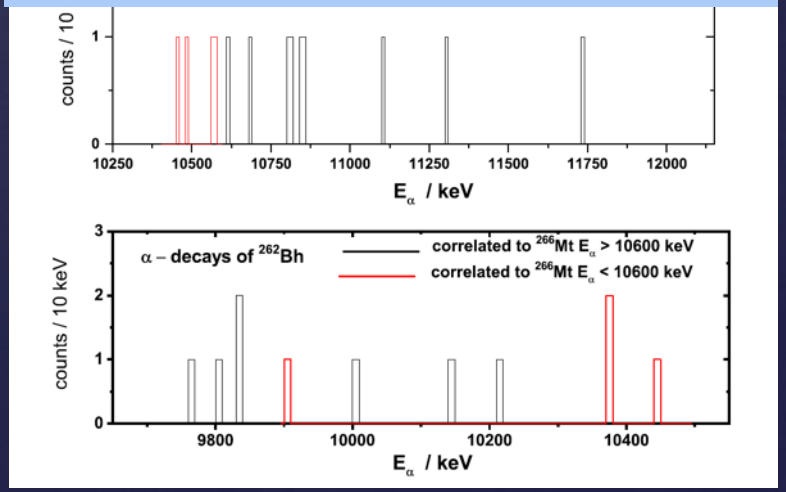


S. Hofmann et al. Z. Phys. A 358, 377 (1997)

$T_{1/2}$ (E< 10.6 MeV) = 1.24 +1.24/-0.41 ms

$T_{1/2}$ = (E> 10.6 MeV) 1.73+0.87/-0.43 ms

Isomeric state ?

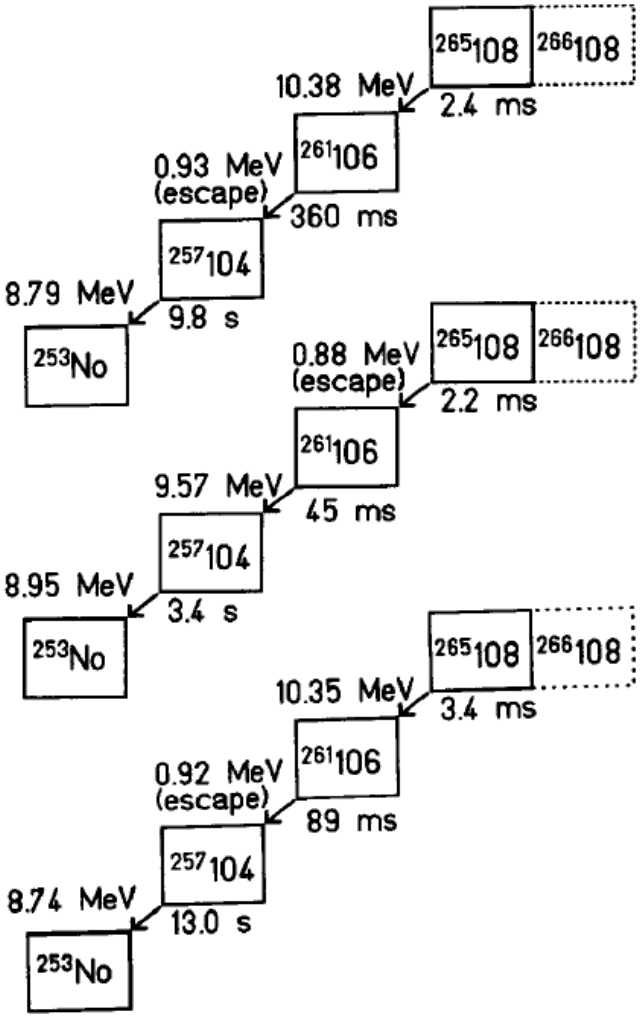


F.P. Heßberger, arXiv: 2510.05953v1 (2025)

Element 108

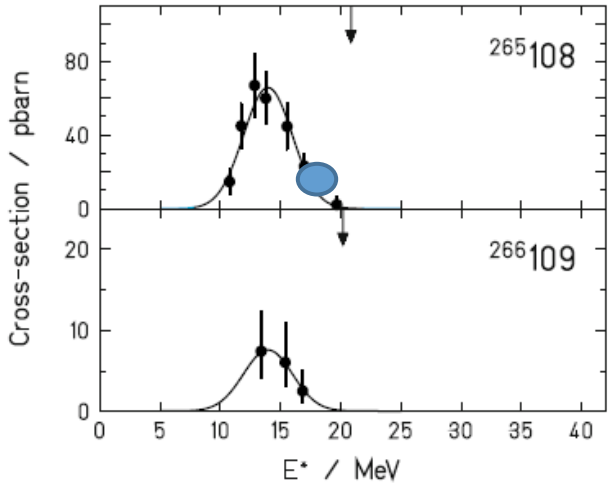
Experiments:

Feb. 27 – March 7, 1984 ; $^{54}Cr + ^{207,208}Pb$, invest. $^{259,260,261}Sg$; March 12 – 24, 1984; $^{58}Fe + ^{208}Pb \rightarrow ^{265}108 + 1n$, $E^* = 18\pm2$ MeV; 3 decay chains observed, $\sigma = 19\ ^{+18}_{-12}$ pb (not uneasonable)

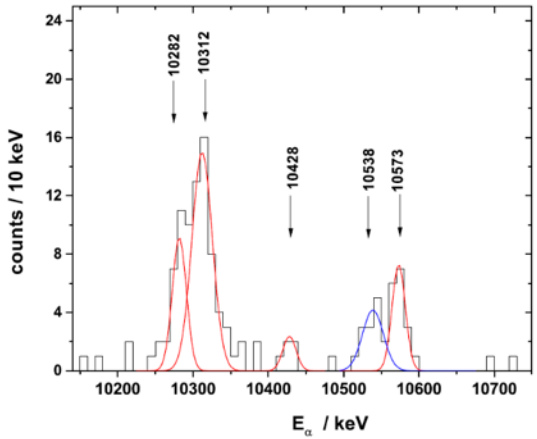


G. Münzenberg et al. Z. Phys. A 317, 235 (1984)

E* above the value for maximun σ (1n)



S. Hofmann et al. Z. Phys. A 317, 235 (1984)



^{265}Hs(1)

$E_\alpha = 10.282$, 10.312, 10.428, 10.573 MeV

$T_{1/2} = 1.9\pm0.2$ ms

^{265}Hs (2)

$E_\alpha = 10.538$MeV

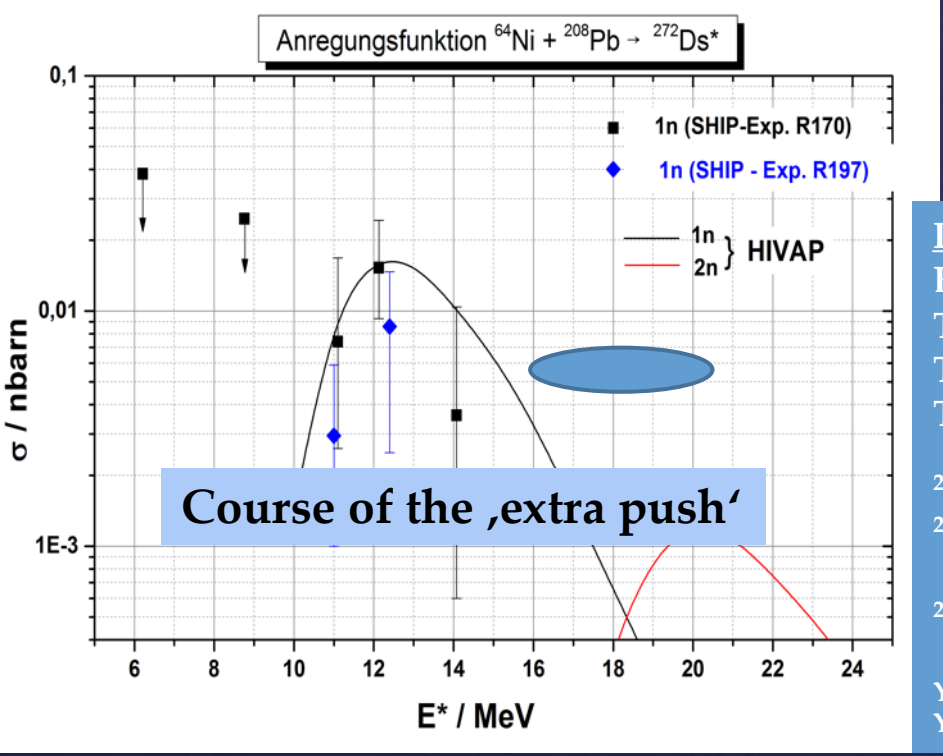
$T_{1/2} = 0.3\ ^{+0.2}_{-0.1}$ ms

F.P. Heßberger et al. Eur. Phys. J. A 41, 145 (2009)

Search for Element 110

Experiment 1:

^{64}Ni + ^{208}Pb, 5.05 AMeV ≡ E* ≈ 18.5 MeV
Date: March 3 – 18, 1985
Projectile Dose: ≈ 1x 10^{18}
No event that could be attributed to the decay of an isotope of element 110 was observed !
Σ σ ≤ 5 pb (one event)
Σ σ ≤ 12 pb (95% confidence level)



1986 – Ten Years of Uranium Beam at the UNILAC
Presentation of Yu. Ts. Oganessian :
Observation of an 8 ms SF activity in reactions
^{44}Ca + ^{232}Th → ^{276}110* and also in ^{40}Ar+ ^{236}U → ^{276}110*
σ ≈ (8-11) pb
Discovery of element 110 ?

Experiment 2:

As ^{236}U was not available, the reaction
^{40}Ar + ^{235}U was chosen
Beam energy: 5.20 AMeV, E* = (33-37) MeV
Date: May 12 – 17, 1986
Projectile Dose: ≈ 1.7 x 10^{18}
No event that could be attributed to the decay of

Present day situation:

Element 110 named ‚Darmstadtium`(Ds)
$T_{1/2}$ (^{273}Ds(a)) = 30 +140/-15 ms (α emitter)
$T_{1/2}$ (^{273}Ds(b)) = 0.17 +0.17/-0.06 ms (α emitter)
$T_{1/2}$ (^{275}Ds) = 0.43 +0.29/-0.12 ms (α emitter)

^{232}Th(^{48}Ca,5n)^{275}Ds : σ_{max} = 0.34 +0.59/-0.15 pb, E*= 56 MeV
^{232}Th(^{48}Ca,4n)^{276}Ds : σ_{max} = 0.11 +0.46/-0.09 pb,
E*= (48.9 – 52.3) MeV
^{238}U(^{40}Ar,5n)^{273}Ds : σ_{max} = 0.18 +0.44/-0.12 pb, E*= 49 MeV

Yu.Ts. Oganessian et al. PRC 108, 024611 (2023)
Yu.Ts. Oganessian et al. PRC 109, 054307 (2024)

Attempts to synthesize element 116

After synthesis of element 107 in ‚cold fusion' a new attempt to synthesize element 116 in the reaction ^{48}Ca + ^{248}Cm was suggested by P. Armbruster and G. Herrmann; collaboration with LBL Berkeley established.
Irradiation at lower energies; previous experiments at LBL were performed at E* ≈ (40-50) MeV.
Collaboration : GSI Darmstadt, LBL Berkeley, Universität Mainz, INCD Los Alamos, Univ. Bern, Univ. Göttingen
Chemistry Experiments at GSI , LBL, Recoil Separator experiments at LBL (SASSY) and GSI (SHIP)

SHIP – Experiment:
March 1 to March 19, 1983
five irradiation energies;
no α – decays or SF that could be attributed to the decay of an element 116 isotope or a decay product were observed during the experiment and a background measurement of 23 days

E / AMeV	E*(ct) / MeV	Projectile Dose/ 10^{16}	σ(lim) /nb
4.69	14.0	4.0	0.66 (SF), 1.21 (α)
4.84	19.6	11	0.24 (SF), 0.44 (α)
4.99	26.1	11	0.24 (SF), 0.44 (α)
5.08	29.8	11	0.24 (SF), 0.44 (α)
5.24	36.1	5.0	0.53 (SF), 1.1 (α)

Yu. Ts. Oganessian,
V.K. Utyonkov Rep. Prog. Phys. 78, 036301 (2015)

Ca-48 + Cm-248
4n (^{292}Lv): σ≈ 1 pb, $T_{1/2}$ ≈ 60 ms
3n (^{293}Lv): σ≈ 4 pb, $T_{1/2}$ ≈ 13 ms

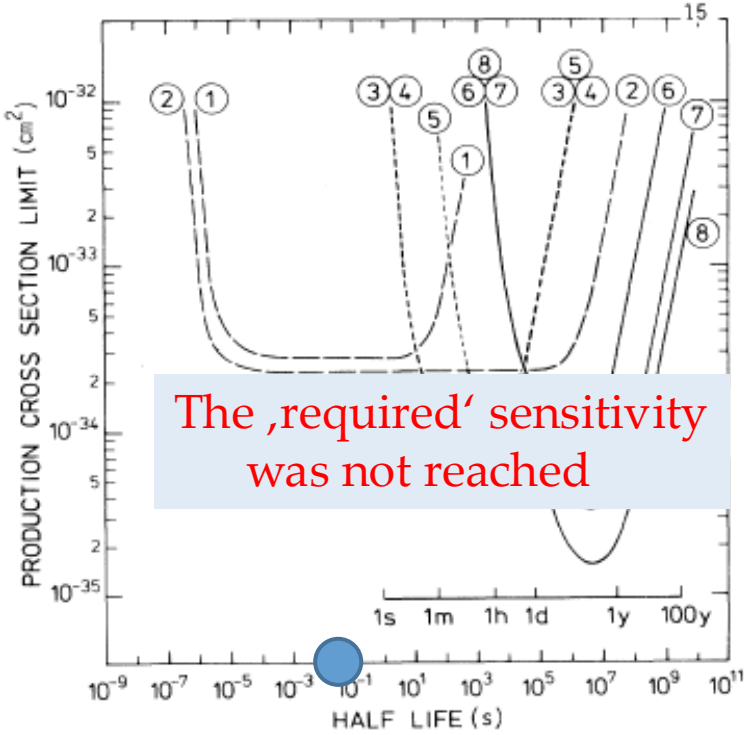


FIG. 1. Upper limits (at 95% confidence level) for the production cross sections of superheavy nuclei in the reaction of ^{48}Ca with ^{248}Cm in the energy range 4.5–5.2 MeV/u as a function of the half-life. The data result from experiments with recoil-fragment separators (curves 1 and 2), with fast on-line chemical separations (3, 4, and 5), and with off-line chemistry (6 and 7), as is pointed out in the text.

P. Armbruster et al. PRL 54, 406 (1985)

Silicon Detectors

Features:

Implantation of the nucleus in a crystal → nucleus remains at the position where it is stopped, specifically important for using position sensitive detectors

Easy performance → no complicated regulation system required, operation in high vacuum

Registration of ‚heavy ions' (ER, fission products), electrons, alpha-particles, protons ….

Measuring alpha-particle energies with high precision; energy resolutions of ΔE(FWHM) ≈ 20 keV can be reached at cooling

Disadvantage of Si – Detector and implantation method:

a) radiation damages (>1.5x10^8 heavy particles/cm^2)

b) Pulse pile-up (>1 kHz or short half-lives)

c) Energy summing of alpha-energy and recoil energy

E_α(measured) = E_α + a x E_{Recoil} (= (m_α/m_d)xQ_α) (a ≈ 0.3)

→ lowering the energy resolution of the detectors (≈ 5 keV)

→ requires careful selection of alpha activities for calibration

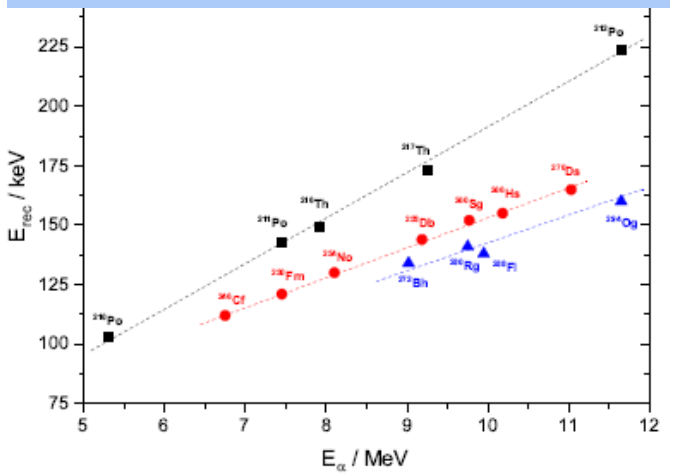
d) Energy summing of α - particles and conversion electrons (CE)

→ shifting peaks, smearing out alpha – energy peaks

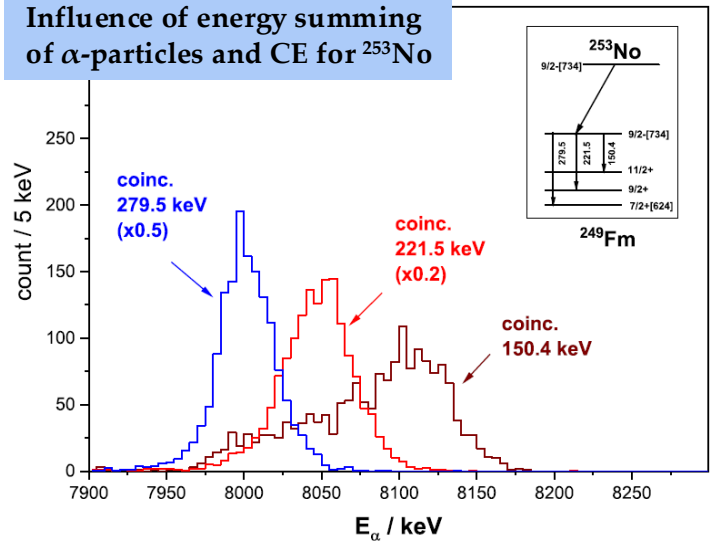
e) Implantation depths of evaporation residues is smaller than range of alpha – particles; about half of the alpha particles escape the dector, delivering only an energy loss signals

Different types of Si-Detectors have been used at SHIP; of specific importance were position sensitive detectors.

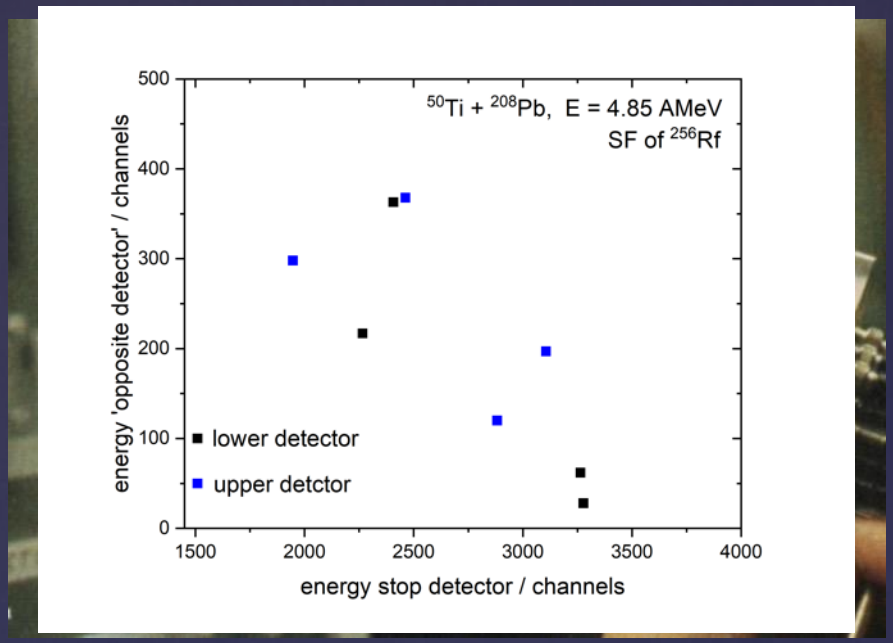
Recoil energies for different sotopes

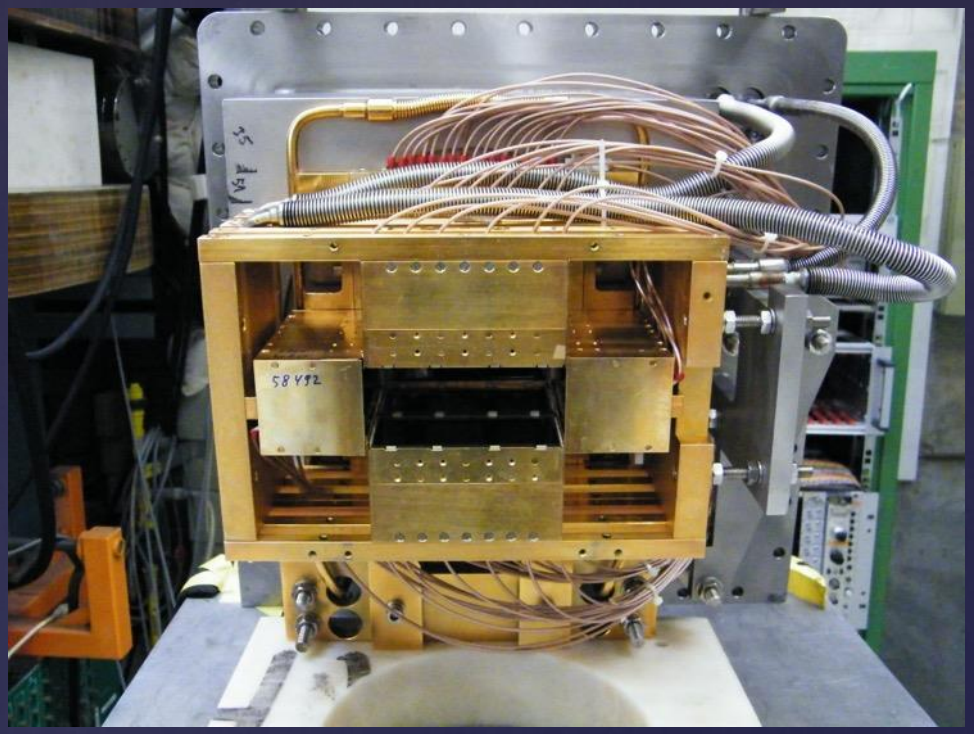


Influence of energy summing of α-particles and CE for ^{253}No



Silicon Detectors





Old ‚Detector – Array' (1978 – 1988)

→ 7 position sensitive (in vertical direction) detectors each 9 x 27 mm², total size 87 x 27 mm² (including frames)

→ position resolution 210 µm (FWHM)

(S. Hofmann et al. NIM 223, 312 (1984))

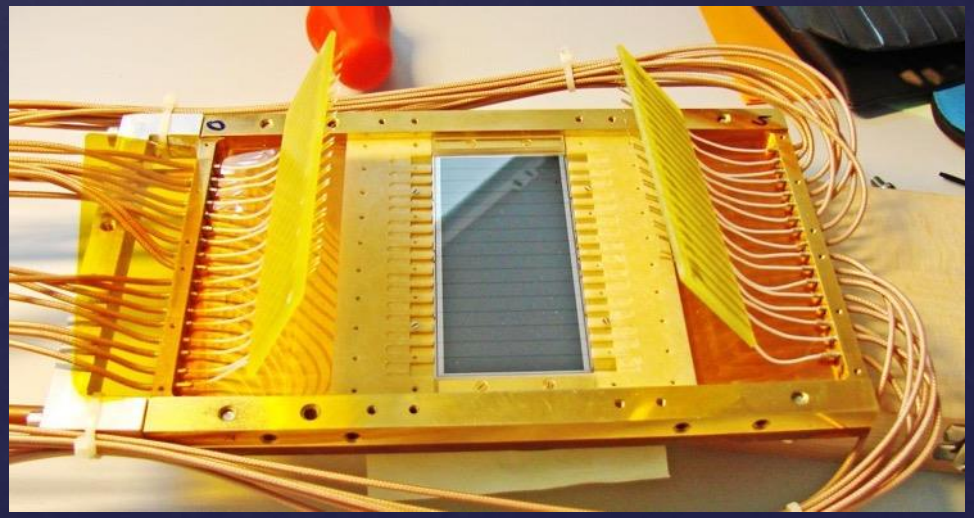
New ‚Detector Array' (1994 – 2015)

→ 16 – Strip – Si-Detector (80x35 mm²), no frames, deadlayers between strips 0.5 mm

→ position resolution 150 µm (FWHM)

→ six Si-detectors of equal shape and size in backward direction for measuring ‚escaping' α's

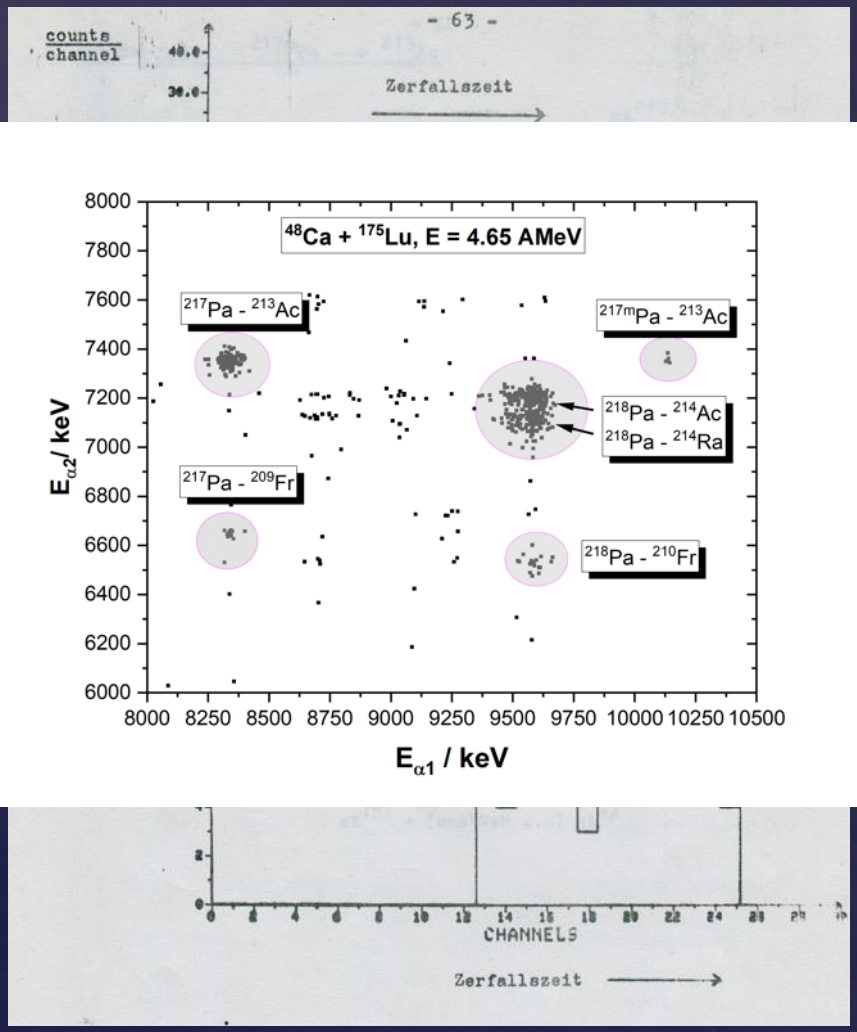
(S. Hofmann et al. Z. Phys. A 350, 277 (1995))



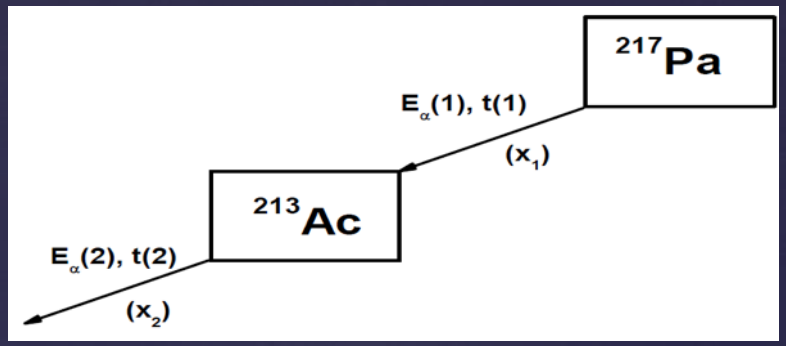
Correlation Method

Purpose: identify an α- emitter by establishing a relation between the mother and daughter decay (K.H. Schmidt et al. Nucl. Phys. A 318, 253 (1979))

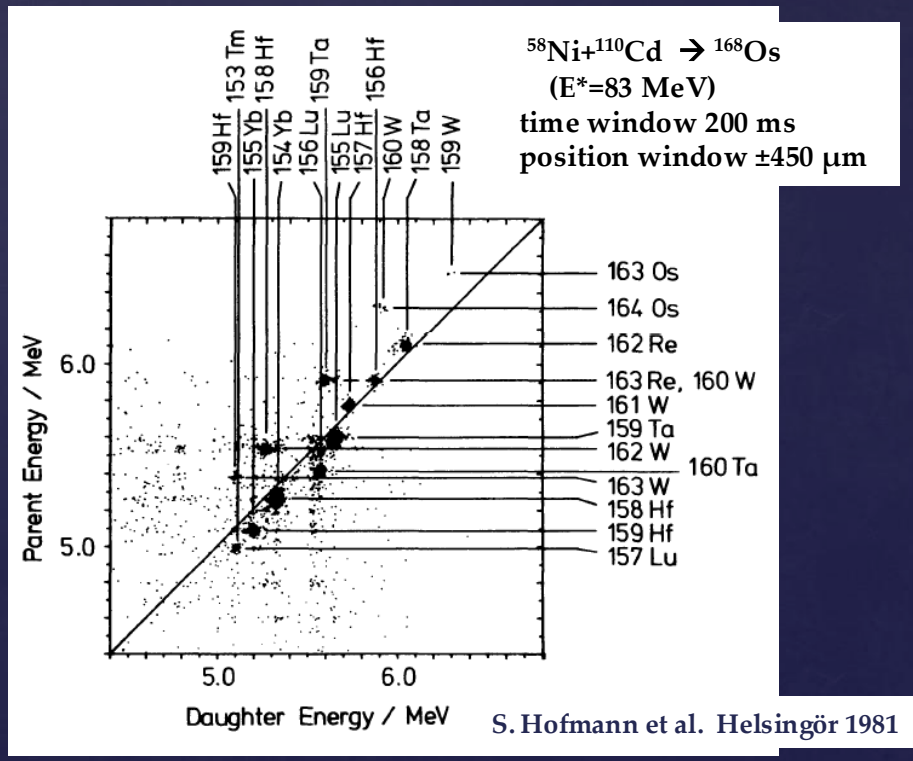
Events following an α-decay activity identified as ^{217}Pa



K. Pielenz, Diplomarbeit, TH Darmstadt 1977



Correlation method was significantly improved by using position sensitive detectors: due to the additional parameter ‚position' background was reduced and correlation times were extented.



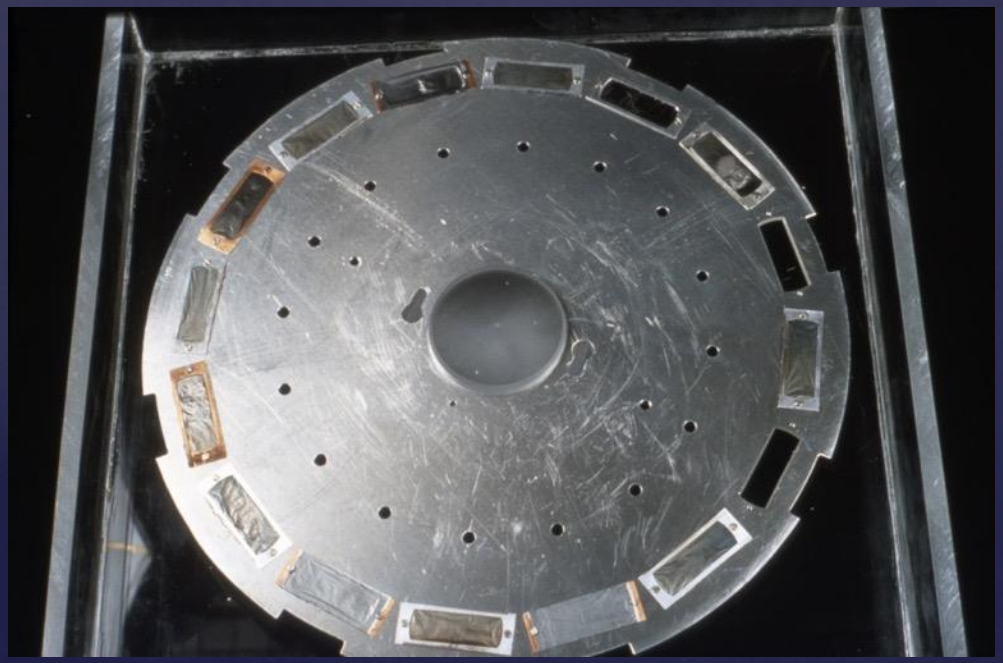
S. Hofmann et al. Helsingör 1981

Target Wheel

Synthesis of new elements requires highest beam intensities.
Drawback for ‚cold fusion‘ reactions: low melting points of lead (600.61 K) and bismuth (544.4 K)
‚Standing‘ targets are thus unsuitable → idea: distribute beam intensity over a large target area.
Solution: mount targets on a wheel rotating synchronuously to the beam pulsing (50 Hz, 5 ms beam, 15 ms ‚pause‘)

Target Wheel 1978 (D. Marx et al. NIM 163, 15 (1979))
Diameter: Ø 30 cm
2 x 8 targets (4.5 x 1.5 cm^2) on a wheel, Pb, Bi (≈ 500 µg/cm^2) evaporated on ≈30 µg/cm^2 C-layer, covered with ≈10 µg/cm^2 C-layer;
Change from one ‚target set‘ to the other one by changing the phase of rotation
→ continouos modification to stand higher beam intensities

Target wheel 2006 (B.Kindler et al. NIM A 561,107 (2006))
Diameter: Ø30 cm, 8 targets (≈10 x 2 cm^2) on a wheel,
Pb, Bi (400 – 500 µg/cm^2 evaporated on ≈30 µg/cm^2 C-layer, covered with ≈10 µg/cm^2 C-layer
Material: PbS (T_{melt} = 1387 K), Bi_2O_3 (T_{melt} =1090 K)
Beam currents: PbS: ≥3 pµA, 1.86 x10^{13} / s (^{40}Ar)
Bi_2O_3: ≈2.2 pµA, 1.36 x10^{13} / s (^{40}Ar)
→ presently for nearly all target materials wheels are used

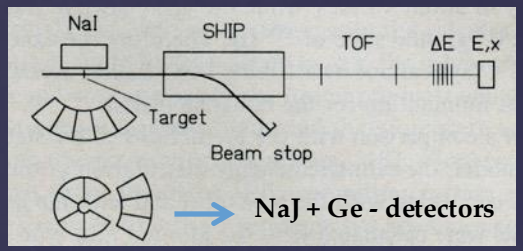


Target wheel 1979

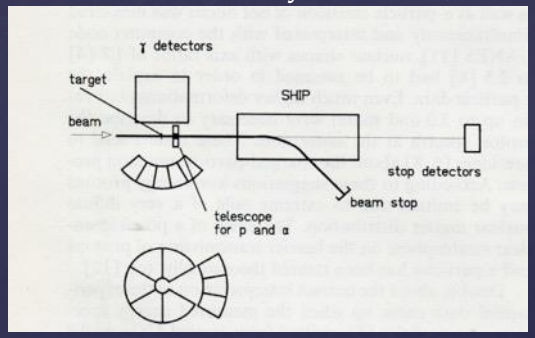
Target wheel 2006

Gamma / Particle - Recoil decay Tagging

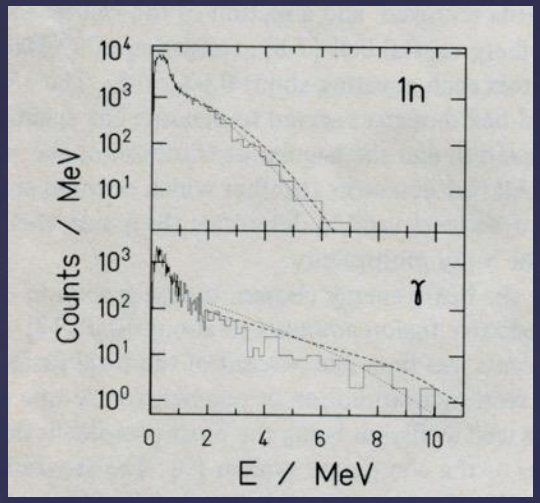
Purpose: investigation of the decay of a compond nucleus by measuring gamma-ray and / or particles emitted during the deexcitation process in delayed coincidence with the evaporation residue; specifically of value in cases of low cros-sections (low production rates) in presence of high background.



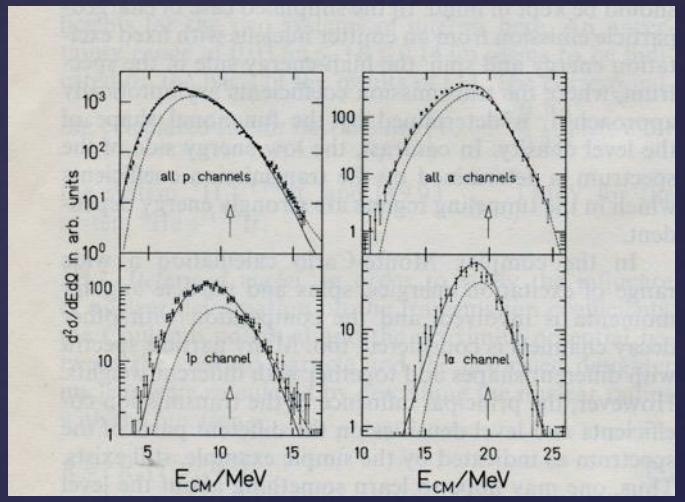
K.H. Schmidt et al. Phys. Lett. 168B, 39 (1986)



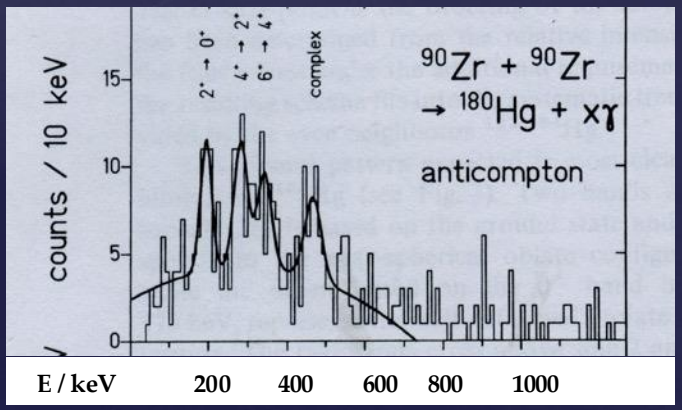
U. Gollerthan et al. Z. Phys. A 338, 51 (1991)

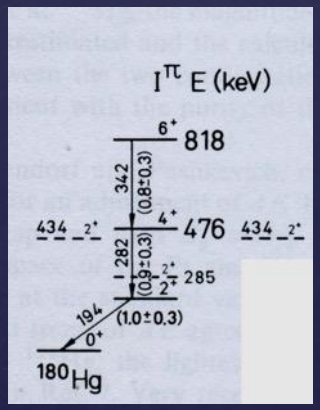


Spectra of individual γ-rays from $^{90}Zr + {}^{90}Zr \rightarrow {}^{179}Hg + n + \gamma$ (upper frame) and $^{90}Zr + {}^{90}Zr \rightarrow {}^{180}Hg + \gamma$ (lower frame)
(K.H. Schmidt et al. Phys. Lett. 168B, 39 (1986))



Spectra of protons (left side) and α-particles measured at target position in delayed coincidence withER from the reaction $^{90}Zr + {}^{89}Y$.
(U. Gollerthan et al. Z. Phys. A 338, 51 (1991))

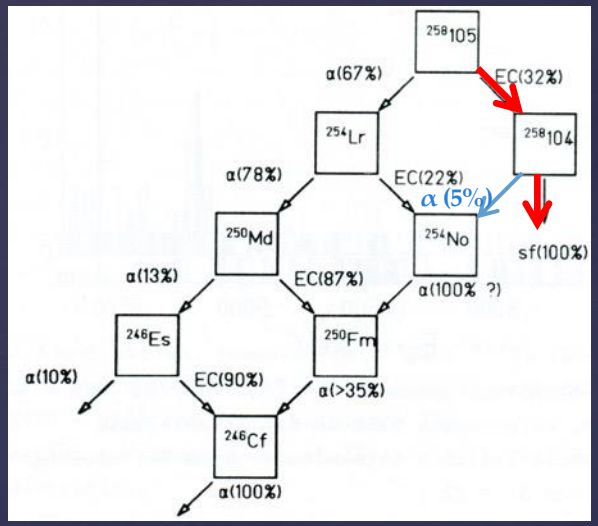




‚In – beam' Spectroscopy of ^{180}Hg; four individual γ – lines observed: 2^+ (prolate) → 0^+ (oblate, gs)
4^+ (prolate) → 2^+ (prolate), 6^+ (prolate) → 4^+ (prolate),
‚complex'→ assignment unclear
→ evidence for shape coexistence (oblate, prolate) in ^{180}Hg
(R.S. Simon et al. Z. Phys. A 325, 197 (1986))

GRDT is presently the standard technique in In-beam spectroscopy of SHE

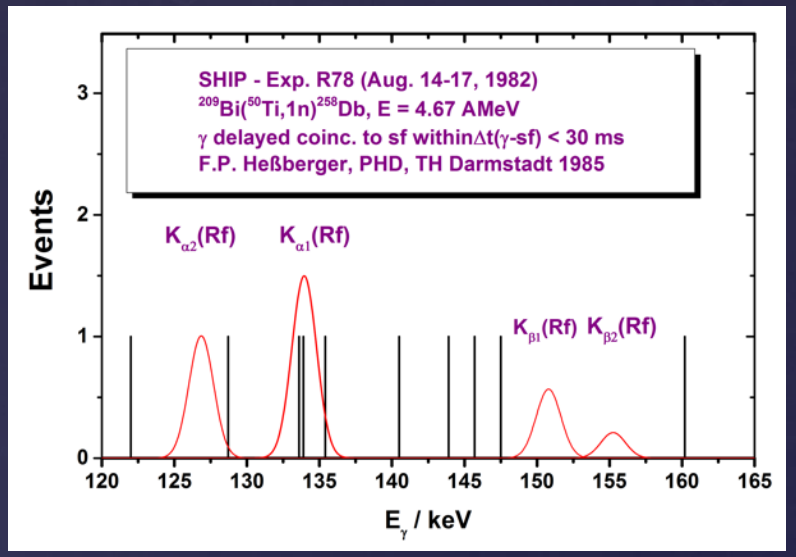
Identification of EC – decay of SHE
Z – Identification of SHE

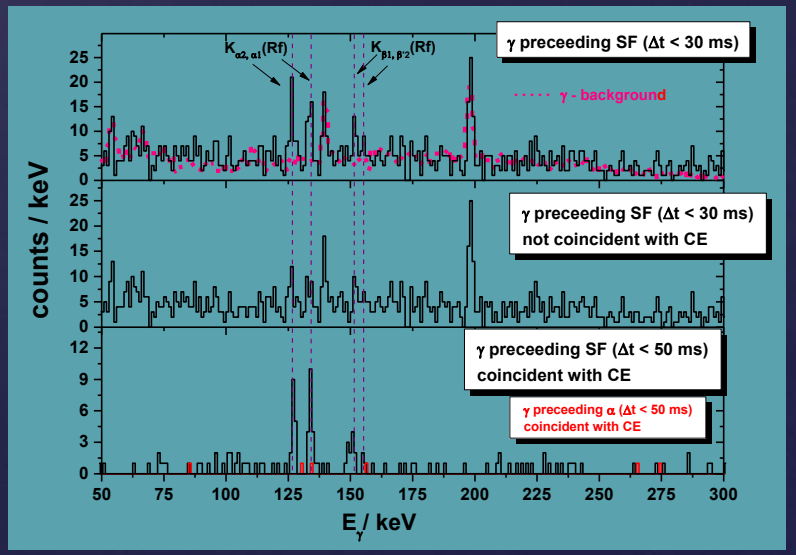


1981: identification of ^{258}Db, α – decay ($T_{1/2}$ = 4.4 +0.9/-0.8 s) and SF ($T_{1/2}$ = 6.1 +1.0/-0.8 s) observed; SF from EC daughter ^{258}Rf ?)

1982: first attempt to identify EC by delayed coincidences between K-X-rays and SF

2014: successful identification





For save identification of new SHE determination the atomic number Z is essential

Unambiguous identification: characteristic X-rays

→ measuring α – X-ray – coincidences

→ GRDT – technique, delayed coincidence between X-rays and ER

→ measuring X-rays from EC –decay, X-rays from EC – process or decay of excited levels populated by internal conversion of levels populated by EC

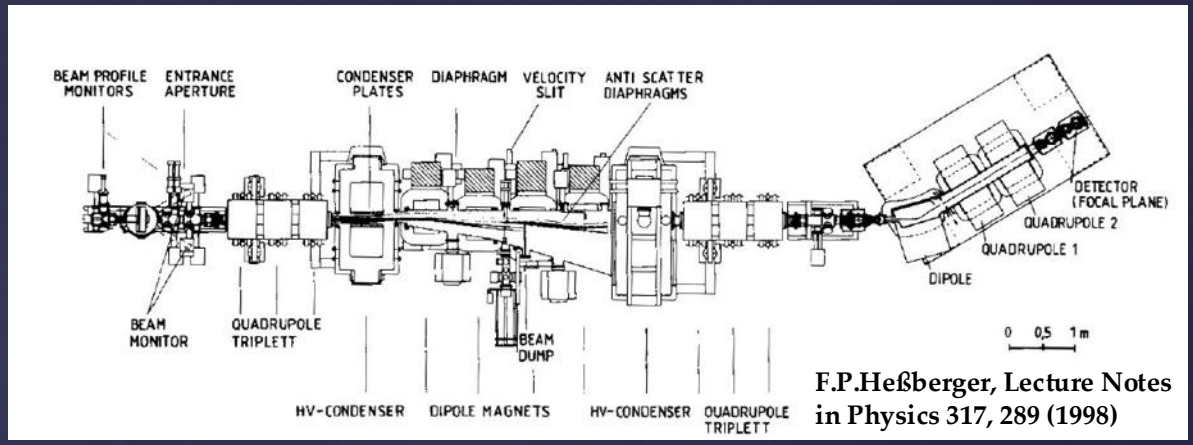
→ specific interest: odd-odd nuclei, direct SF or SF of even-even daughter of CE decay

Postseparator ‚Nase' and gas-filled separator ‚Heck'

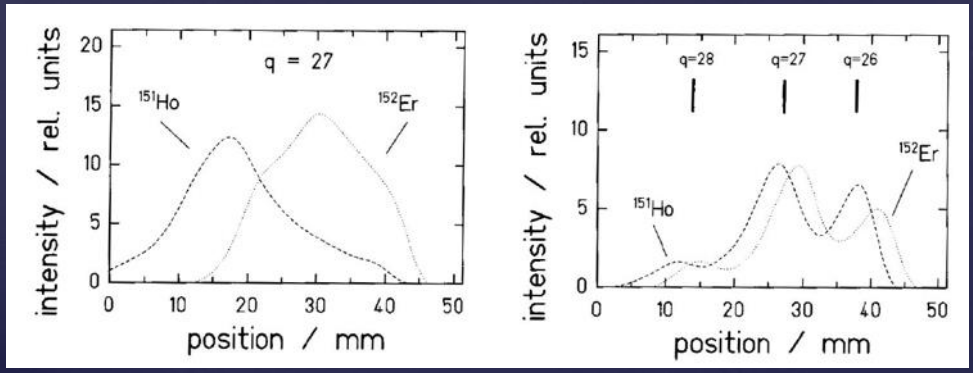
Already in the design phase an extension by an m/q – separator for mass resolution was considered; first calculations were performed by B. Thuma as a 60^0 separator (PHD Uni. Gießen (1982)); construction by G. Berthes (PHD Uni. Mainz (1987)), named NASE; on special request of P. Armbruster it should be laid out also for use as a gas-filled separator, named HECK, realized by V. Ninov (PHD TH Darmstadt (1992), NIM A357,486 (1995))

Table 1
Technical specifications of the magnets of the recoil separator HECK

Dipole	
Deflection angle	30°
Inclination of pole edges	30°
Deflection radius	1.396 m
Gap	90 mm
Max. flux density	1.6 T
Max. current	625 A
Quadrupoles	
–	–
Yoke-length	500 mm
Aperture-radius	110 mm
Max. field gradient	9 T/m
Max. current	625 A

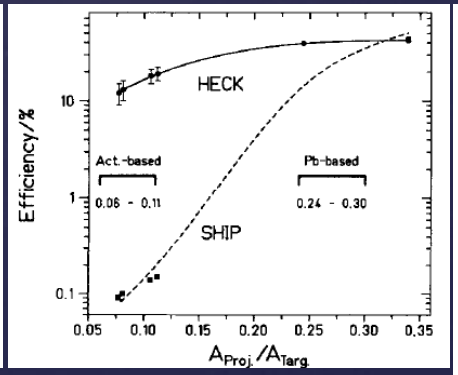


F.P.Heßberger, Lecture Notes in Physics 317, 289 (1998)

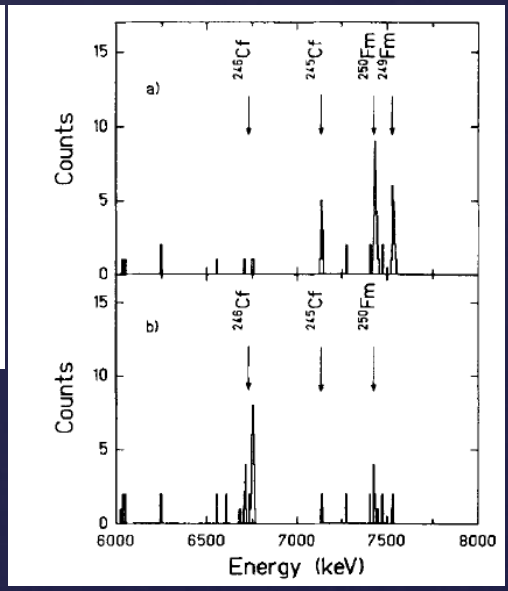


high resolution mode charge focussing mode

(F.P.Heßberger, Lecture Notes in Physics 317, 289 (1998))



Comparison of transmission of SHIP and HECK



α-spectra for $^{238}U(^{16}O,xn)^{254-x}Fm$
a) between beam-bursts
b) 30 h after end of irradiation

No experimental program for NASE (focus on SHE) and HECK (SHIP preferred for cold fusion reactions)
separator was dismounted, later rebuilt as TASCA

Conclusion

Created by KI – Copilot)

50 years of successful operation of SHIP

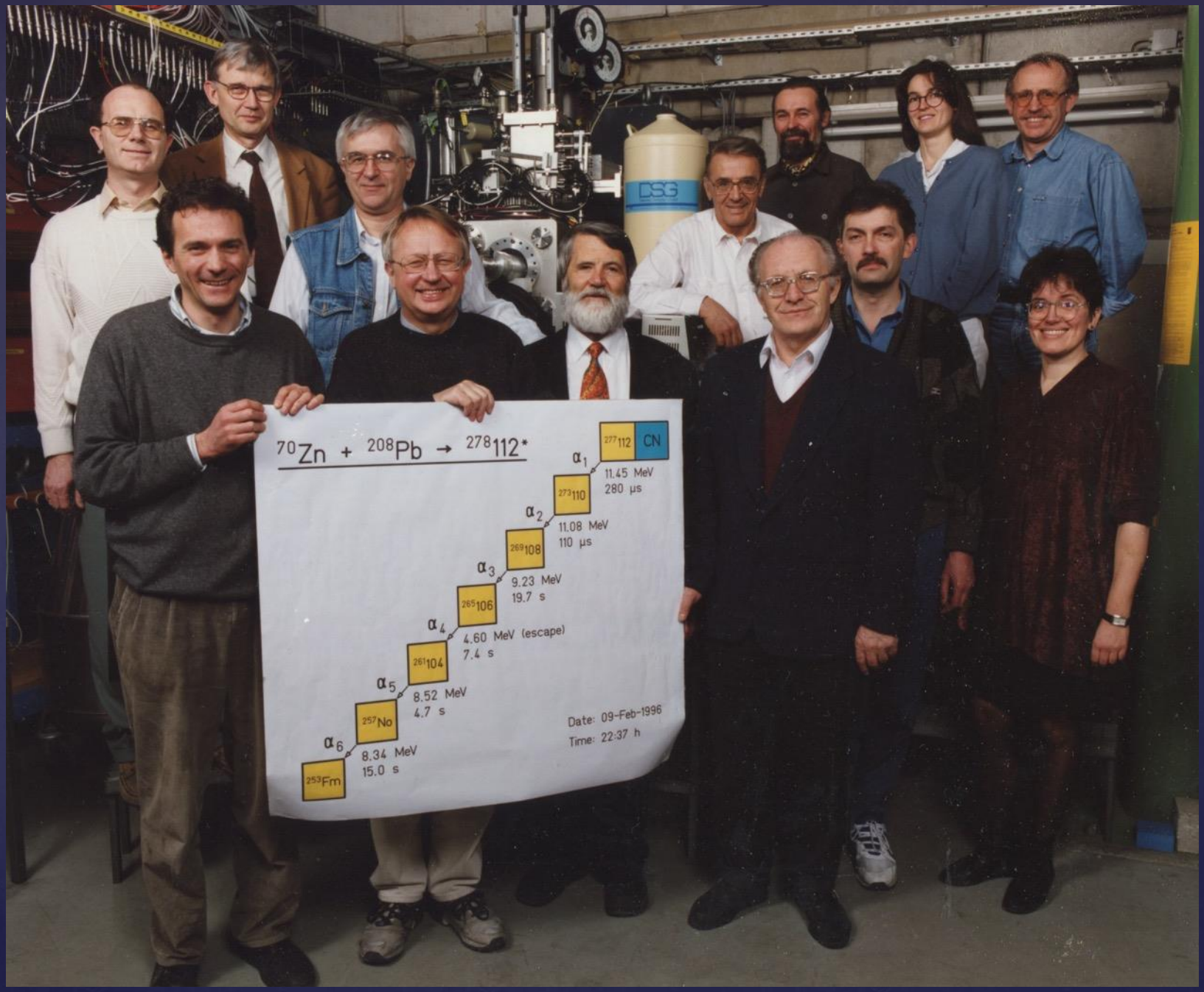
Highlights:

- Discovery of elements Z = 107 – 112
- Discovery of ground state proton radioactivity
- Nuclear spectroscopy of heaviest nuclei
- Identification of new K-isomers in heaviest nuclei
- Direct mass measurements of No, Lr, Rf isotopes
- Laser spectroscopic investigations of No isotopes
- Investigation of subbarrier fusion
- Investigation of fusion of heaviest nuclei
- Investigation of fusion hindrance of heavy nuclei (‚extra push')
- Investigation of decay of hot CN (E*≈ 400 MeV)
- Investigation of incomplete fusion and fusion after projectile break-up
- Technical and Experimental developments

SHIP – Born in 1976

- Still marching strong !

Alternatives Entdeckerphoto Element 110(von links nach rechts) : Sascha Yeremin, Victor Ninov, Peter Armbruster, Andrei Popeko. Hans Specht (GSI Direktor), Sigurd Hofmann, Stefan Saro, Gottfried Münzenberg, Helmut Folger, Fritz Peter Heßberger, Hans-Joachim Schött. Andrei Andreyev, Hans-Georg Burkhard

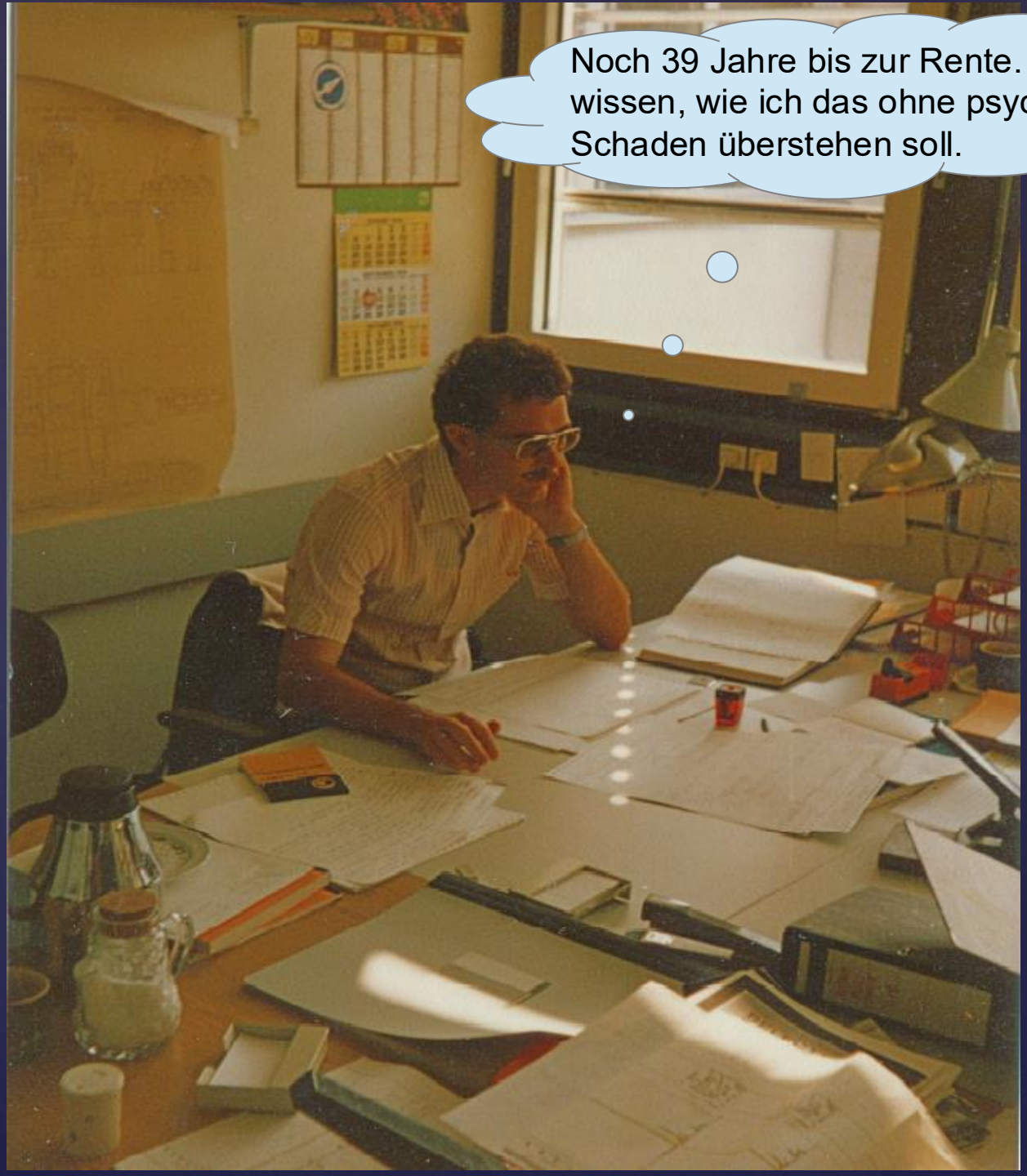


Obere Reihe (links nach rechts): Fritz Peter Heßberger, Gottfried Münzenber, Andrei Popeko, Helmut Folger, Hans-Joachim Schött, Christelle Stodel, Hans-Georg Burkhard; untere Reihe: Victor Ninov, Sigurd Hofmann, Peter Armbruster, Stefan Saro, Sascha Yeremin, Siggo Raiß

10 Jahre SHIP – März 1986

Personen (von links nach rechts) Stehend: Jürgen Zienert, Wolfgang Faust, Klaus Güttner, Peter Armbruster, Fritz Peter Heßberger, Sigurd Hofmann, Paul Kienle, Christoph Schmelzer, Heinz Ewald, Karl-Heinz Schmidt, Hans-Joachim Schött. Gottfried Münzenberg
Sitzend/kniend: Izabella Zychor, Hans Geissel, Steffi Lüttges, Bruno Quint, Gerhard Berthes, Eckhard Hanelt

Der Trost des Forschers



Beginn des Forscherlebens

Die Illusionen junger Forscher

Der Frust langer Strahlzeiten

Was junge Forscher unbedingt lernen müssen

Der Lohn aller Mühen !!