Study of K_x-Ray Multiplicities of Evaporation Residues in Heavy Fusion Systems Using the MINIBALL Spectrometer

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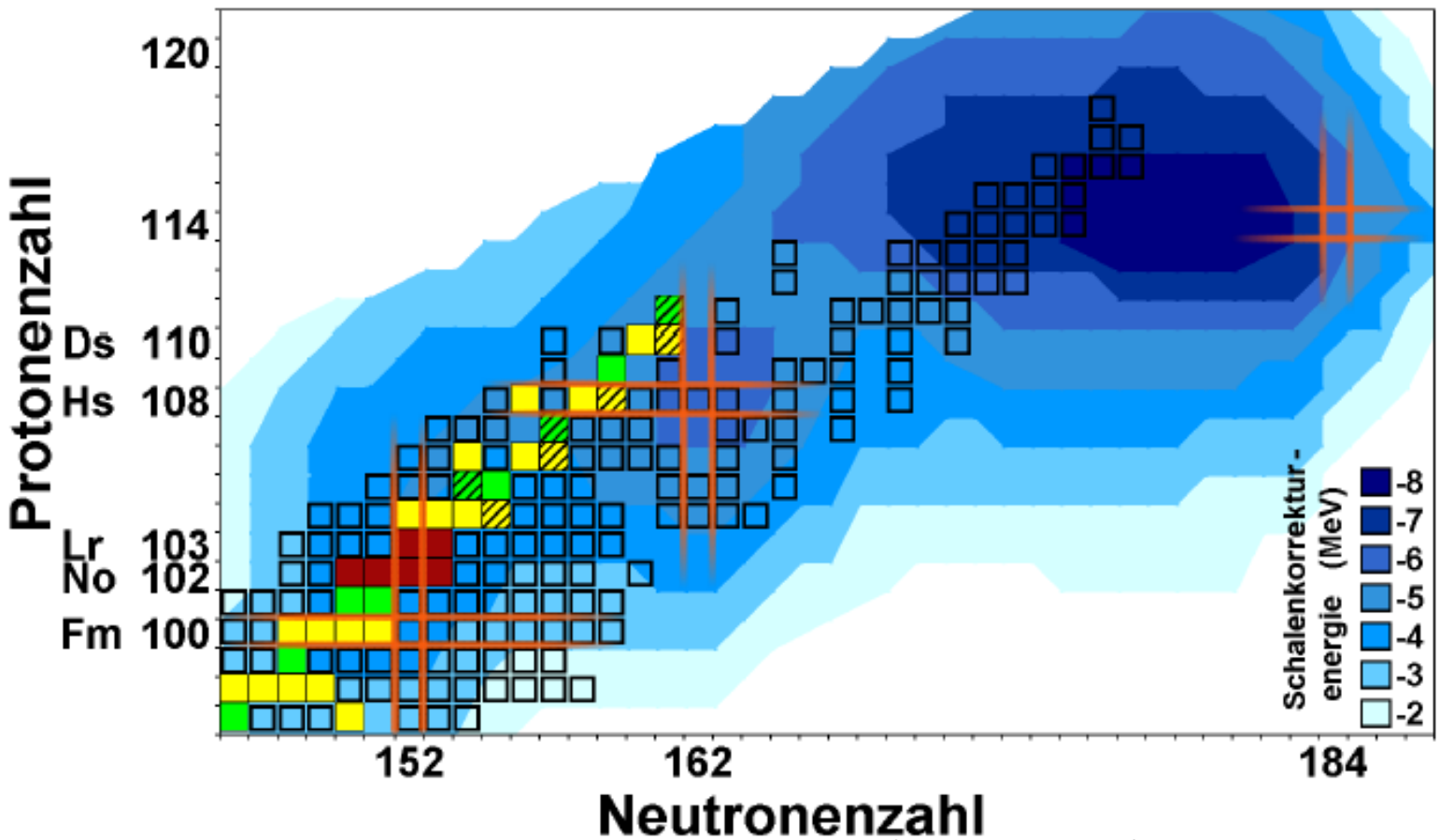
Identification of Super Heavy Elements

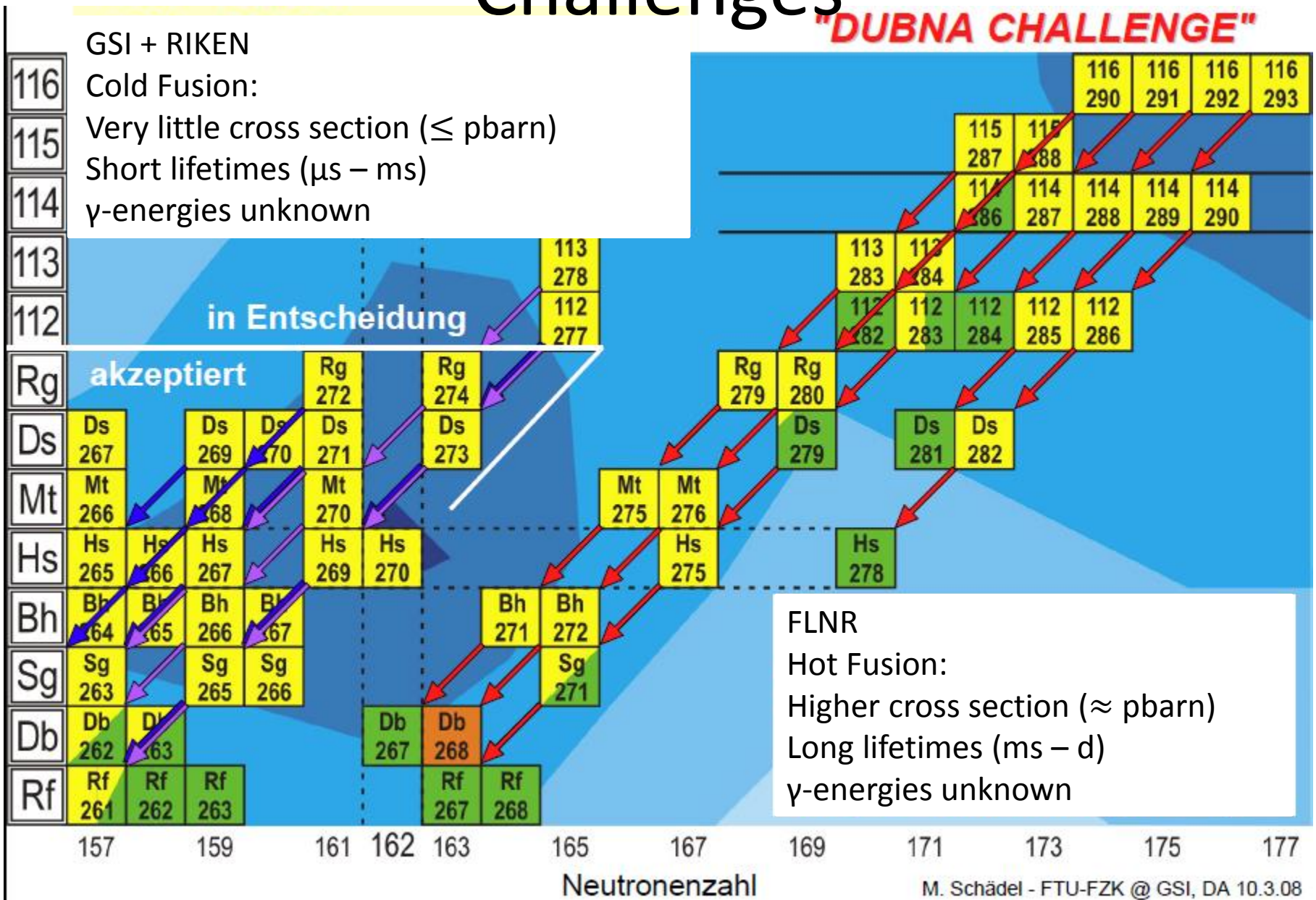


GSI: Research: Super Heavy Elements. http://www.gsi.de/start/forschung/forschungsgebiete_und_experimente/ nu%starenna/ she_physik/research/ super_heavy_elements.htm

- Isle of Stability
- Nuclear structure

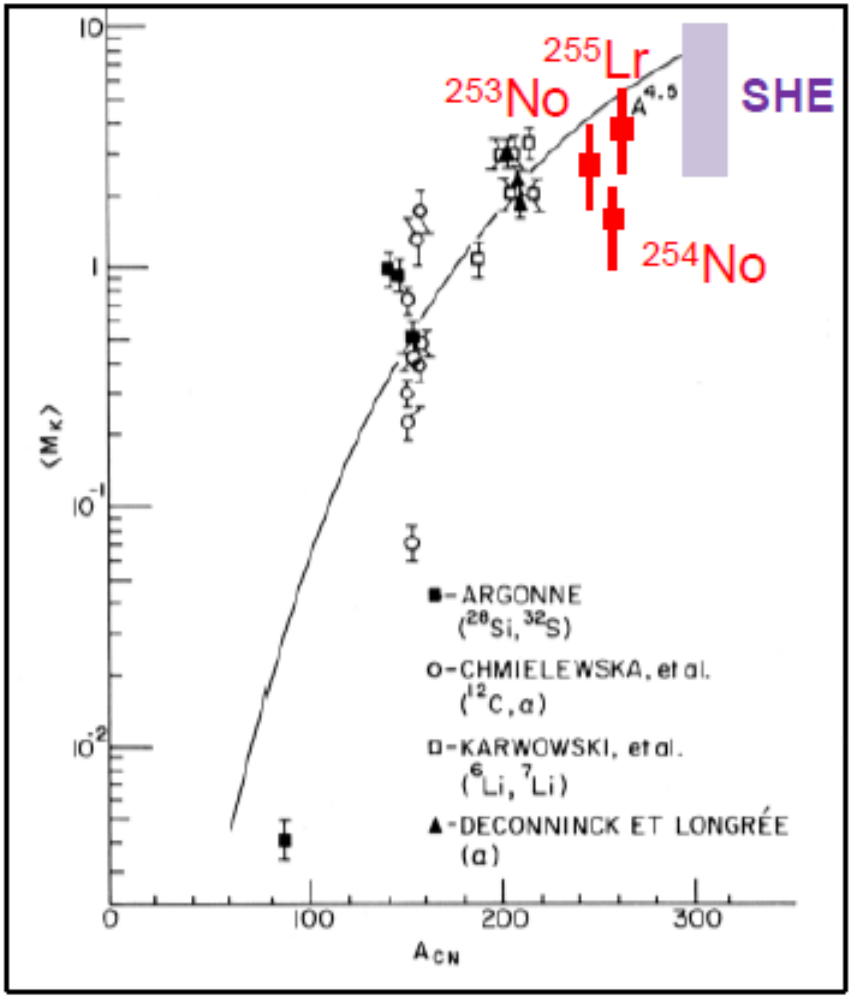
Challenges

GSI + RIKEN
Cold Fusion:
Very little cross section (≤ pbarn)
Short lifetimes (µs – ms)
γ-energies unknown



FLNR
Hot Fusion:
Higher cross section (≈ pbarn)
Long lifetimes (ms – d)
γ-energies unknown

Solution: K_x-ray multiplicity



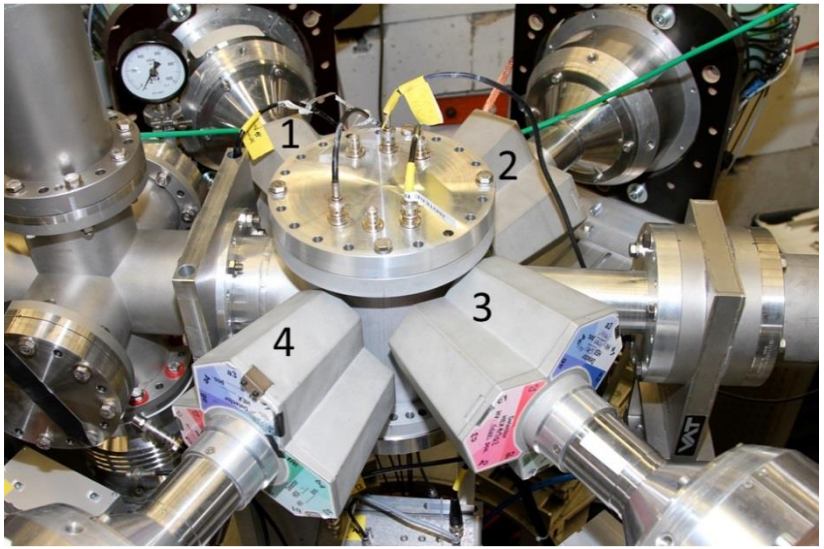
Aims of our work

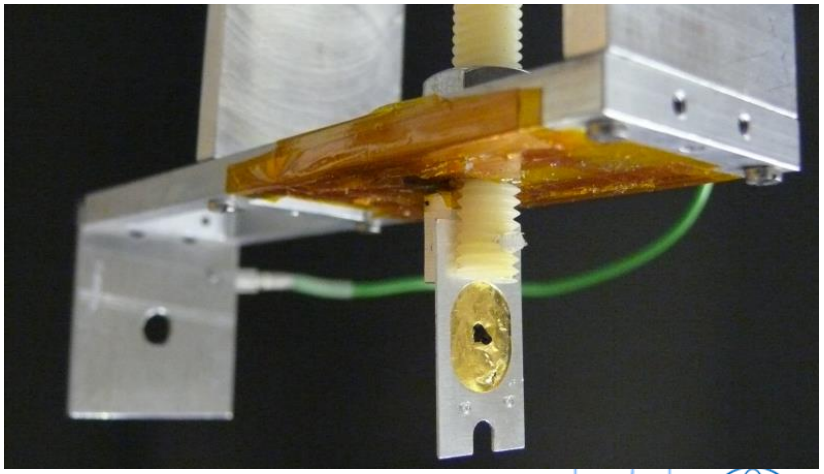
- Semi-empirical mass dependent multiplicity
  - Application: Radon
  - Derivation and further results → Ch. Berner

- Reduction of the background
  - Offline: Searching for coincidenes betweeen K_x-rays and (unknown) γ-energies
  - Online: Appropriate shielding of the fission photons

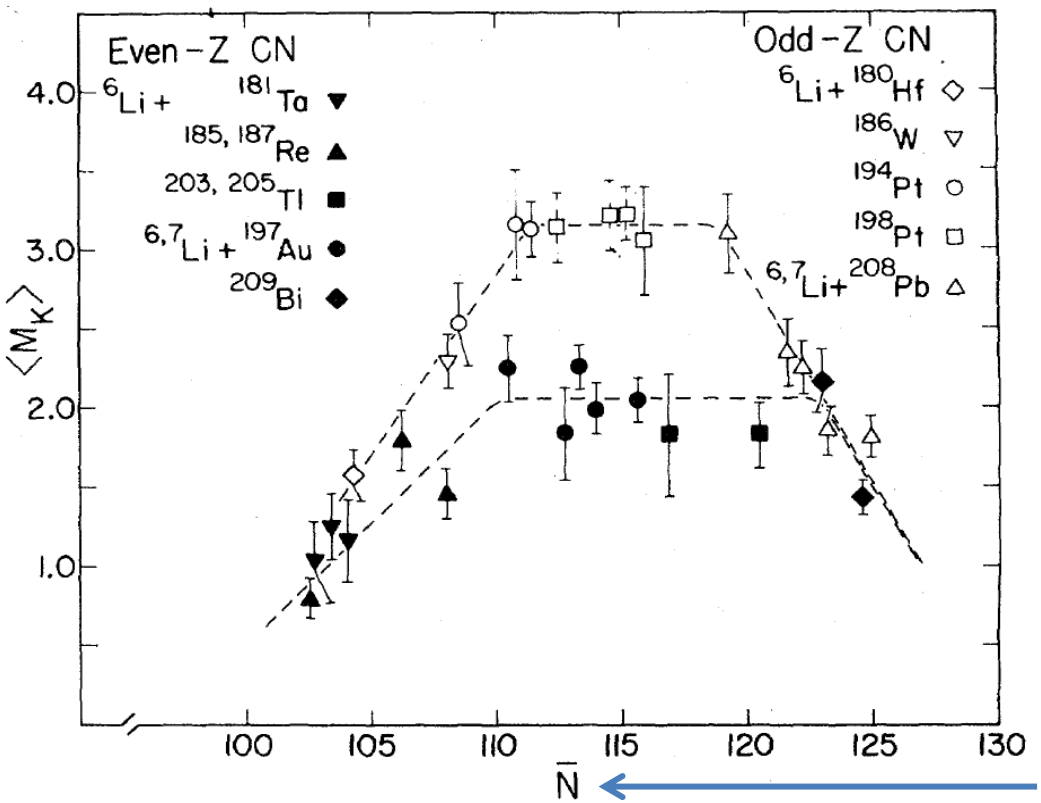
Setup

- MLL in Garching
- Alu-chamber with 2mm wall thickness
- 33% space covering
- Implantation plate





Mass region $A \approx 200$

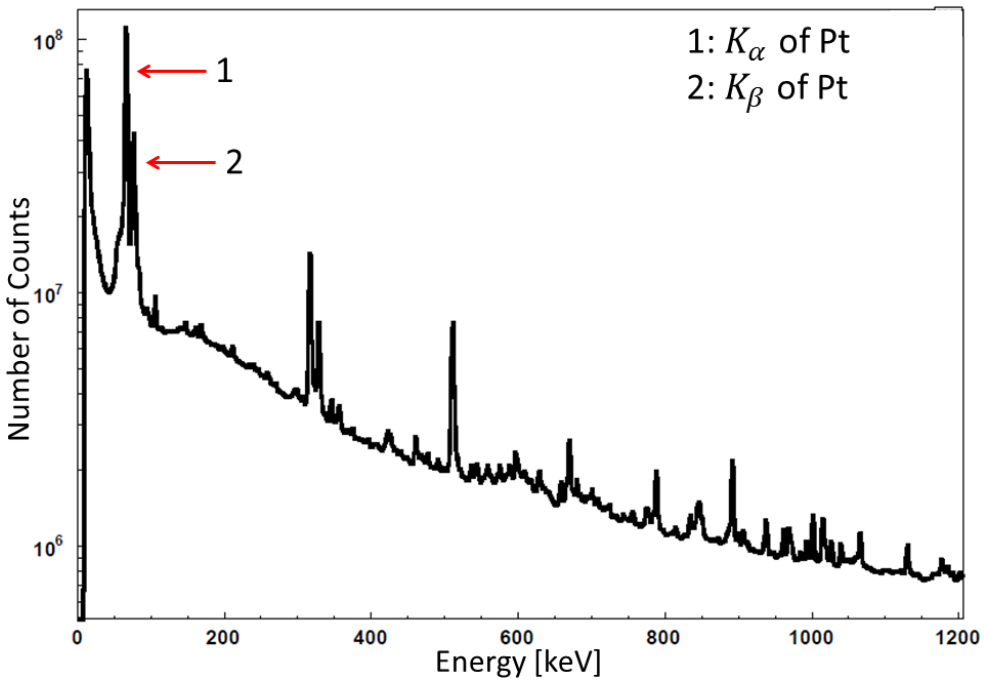


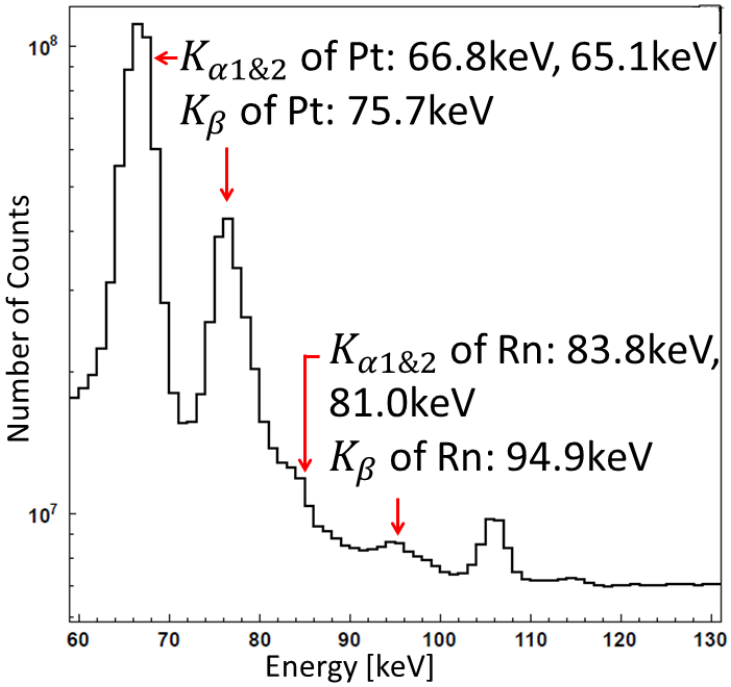
Average neutron number

Karwowski et al. (1982): K_x-ray- K_x-ray coincidence method;

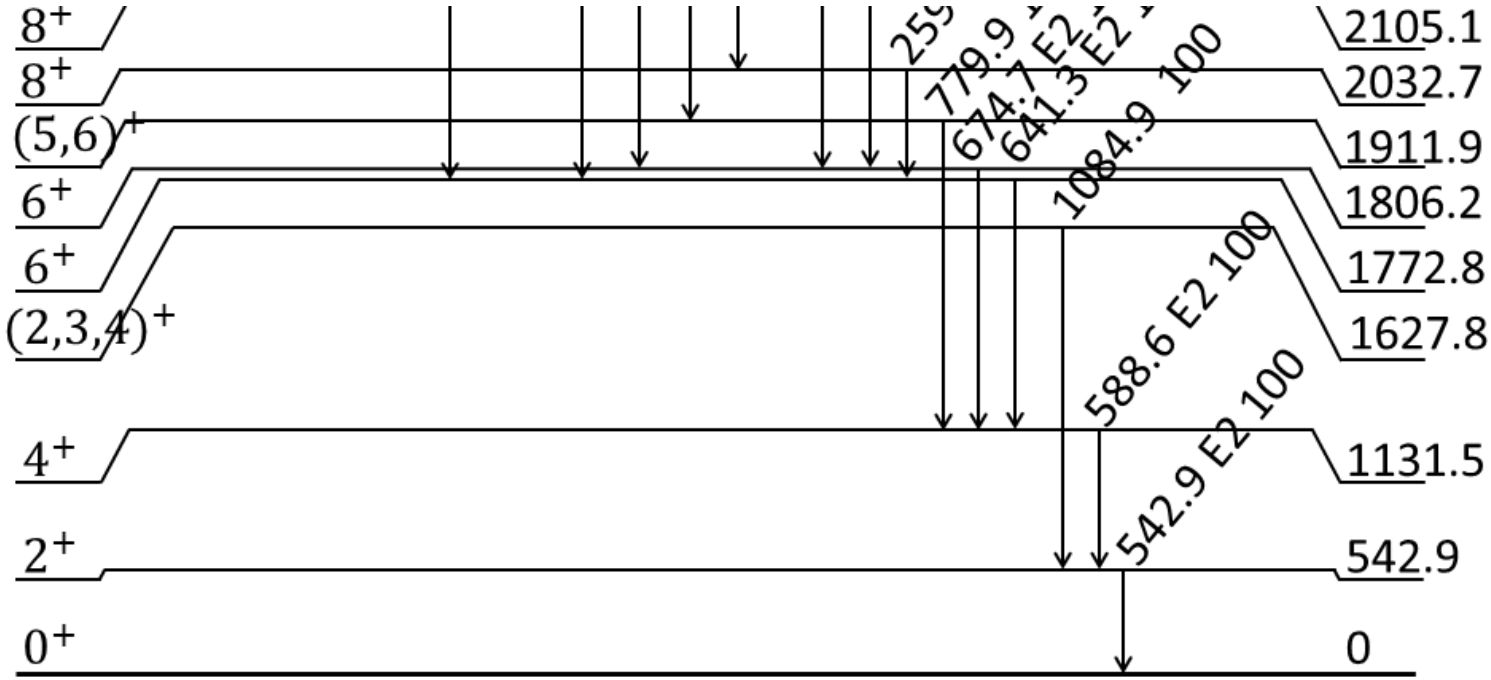
Application: Element Radon

^{192}Pt(^{16}O,4n)^{204}Rn; Beam energy: 87 MeV



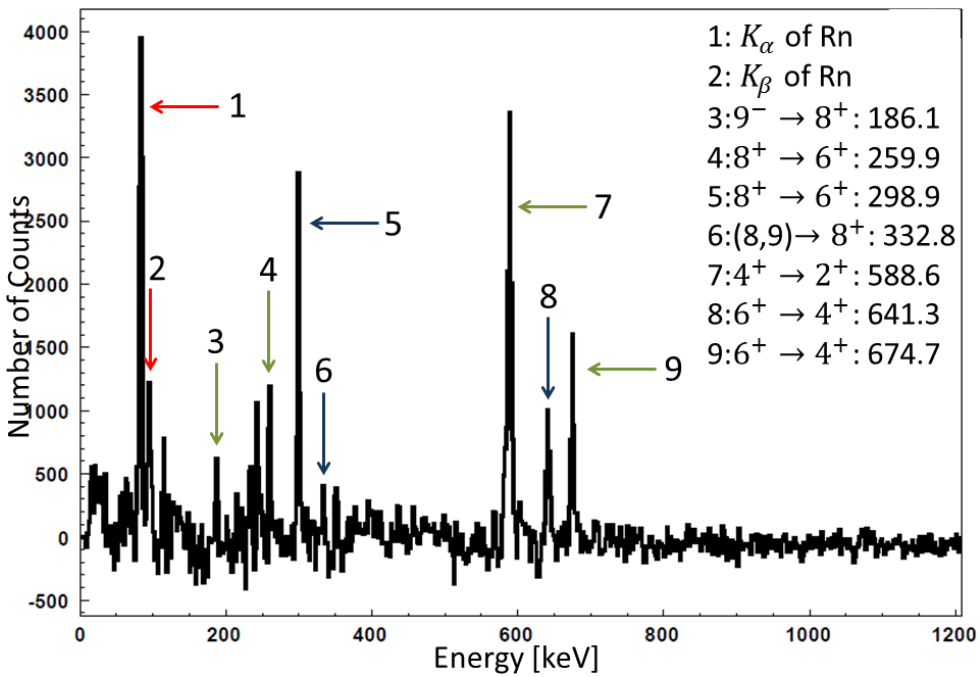


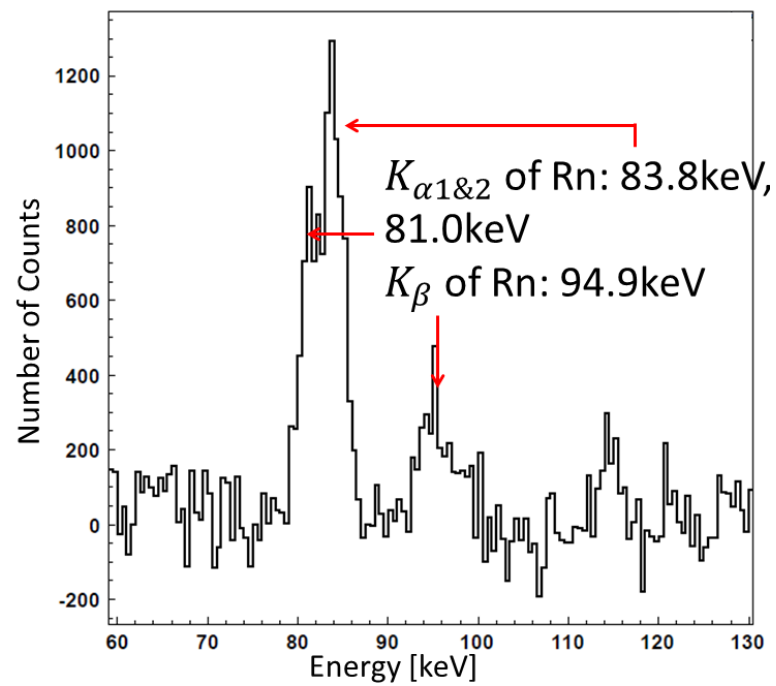
$^{192}Pt(^{16}O,4n)^{204}Rn$



$^{192}Pt(^{16}O,4n)^{204}Rn$

Coincidence-spectrum of the decay of the ground state at $E = 542.9$ keV





^{198}Pt(^{16}O,5n)^{209}Rn
^{198}Pt(^{16}O,4n)^{210}Rn

- $\gamma - K_x$-ray coincidence method

  ^{204}Rn: $M_{\gamma x} = 0.91(22)$

  ^{209}Rn: $M_{\gamma x} = 1.27(42)$

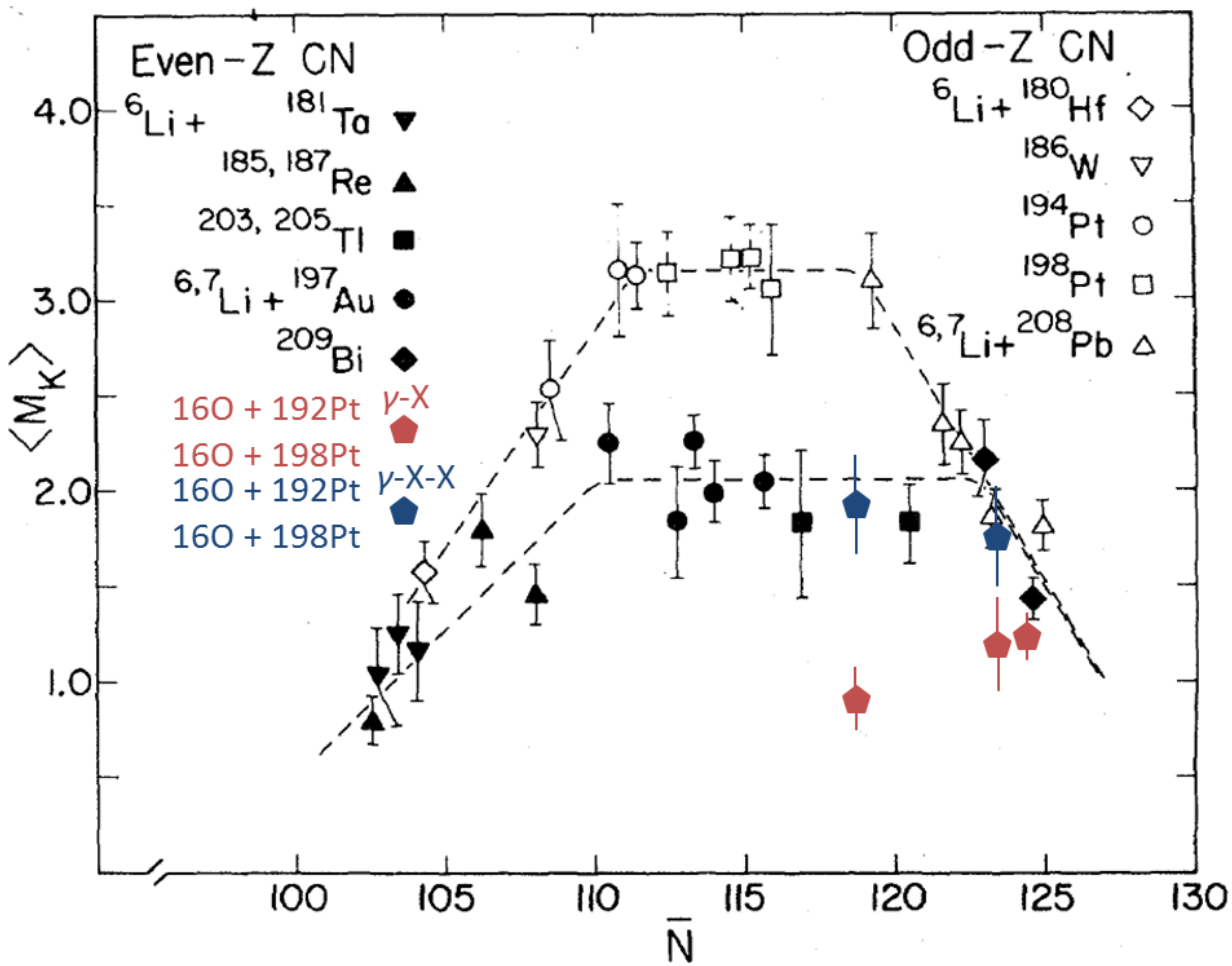
  ^{210}Rn: $M_{\gamma x} = 1.25(11)$

- $\gamma - K_x$-ray$-$ K_x-ray coincidence method

  ^{204}Rn: $M_{\gamma xx} = 1.91(48)$

  ^{209}Rn: $M_{\gamma xx} = 1.81(46)$

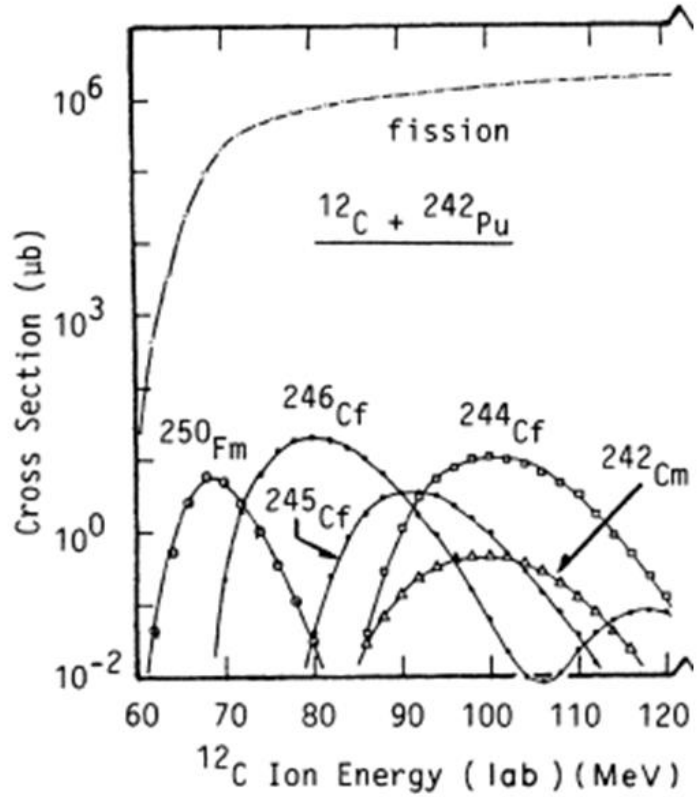
Comparison with further K_x-ray multiplicities



H. J. Karwowski, S. E. Vigdor, W.W. Jacobs, S. Kailas, P. P. Singh, F. Soga, T. G. Throwe, T. E. Ward, D. L. Wark, and J. Wiggins: Phys. Rev. C Vol. 25, No. 3 (1982).

Reduction of the background

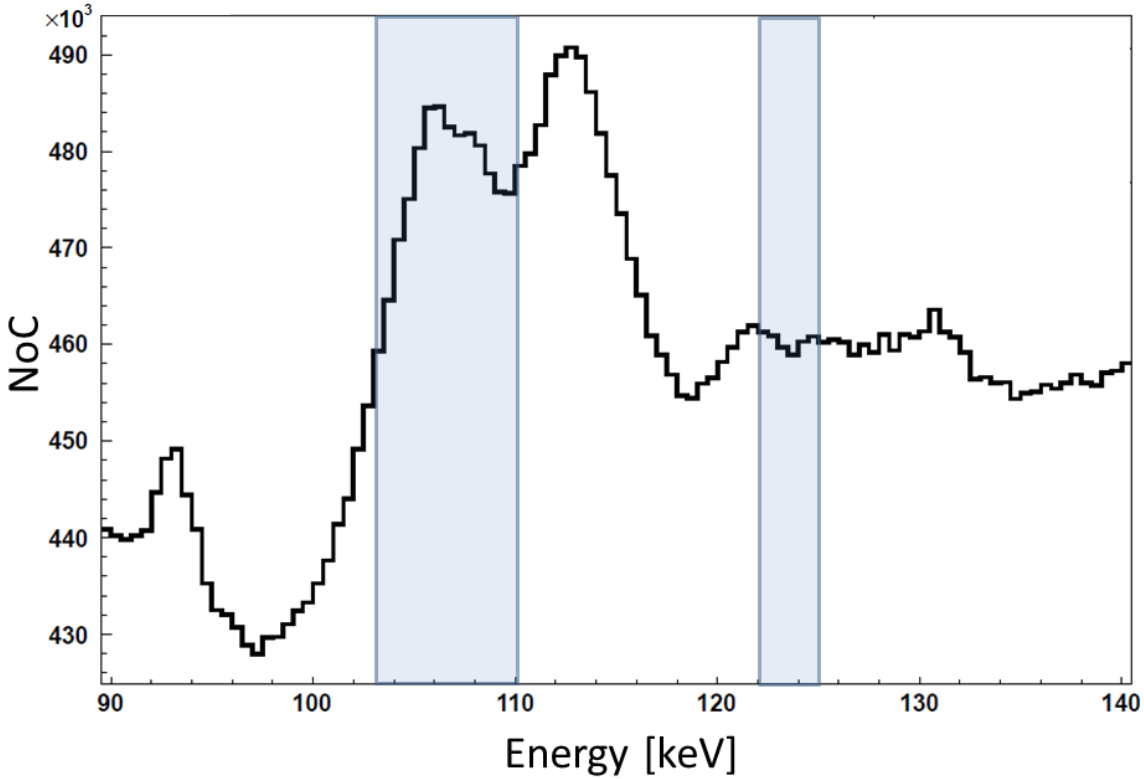
- Heavy fusion elements and high beam energies → Fusion cross sections decrease, fission increases
- 1. Approach: Purifying the spectra
- 2. Approach: Suppression of the fission photons



N. Shinohara, S. Usuda et al.: Phys. Rev. C 34, 909-913 (1986).

Purifying the spectra

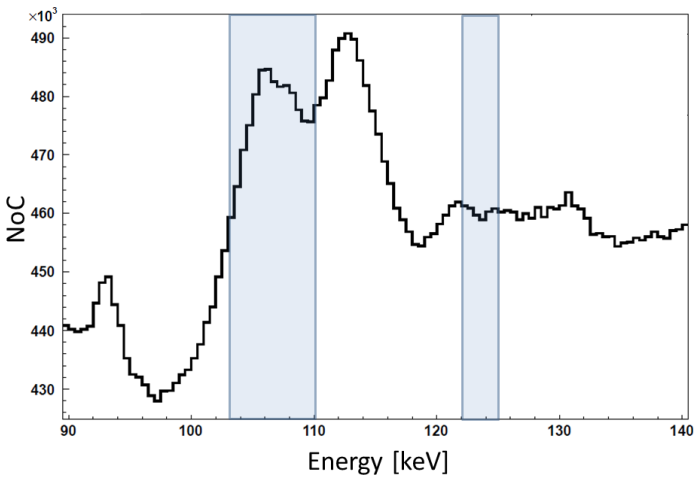
^{232}Th(^{12}C,xn)^{y}Cm at 67 MeV



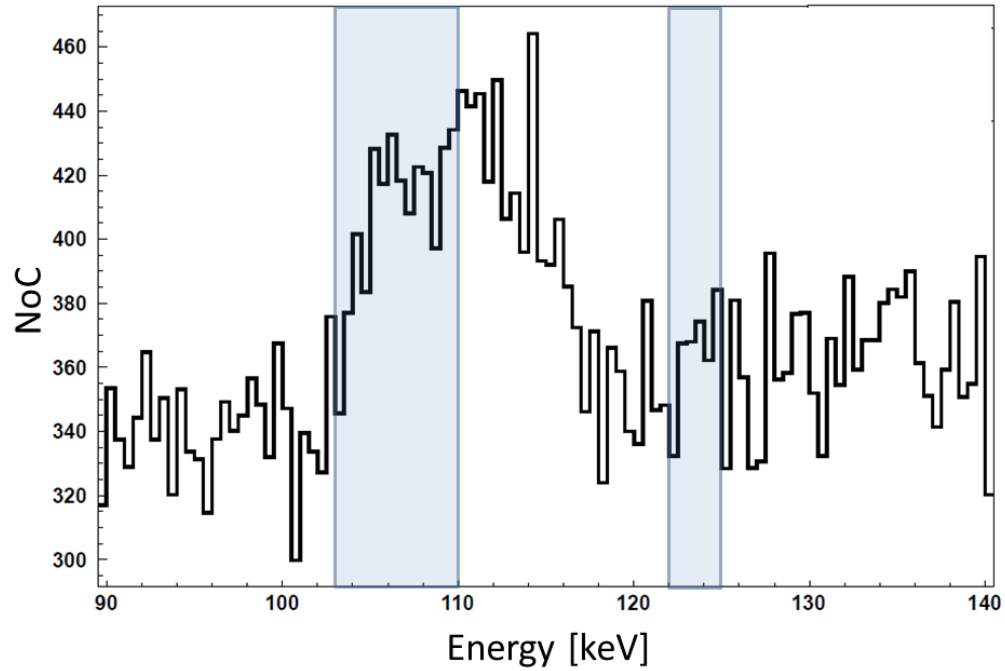
Coincidence-spectrum: No K_x-rays

γ- coincident events

$^{232}\mathrm{Th}(^{12}\mathrm{C},x\mathit{n})^{y}\mathrm{Cm}$

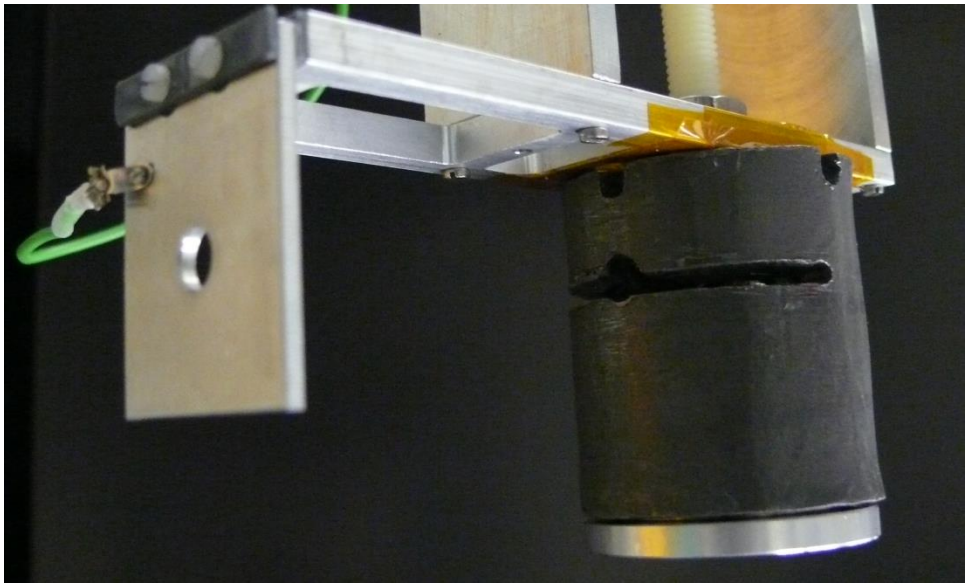


Coincidence-spectrum: No K_x-rays



Gate on 981 keV: Extraction of K_x-rays?

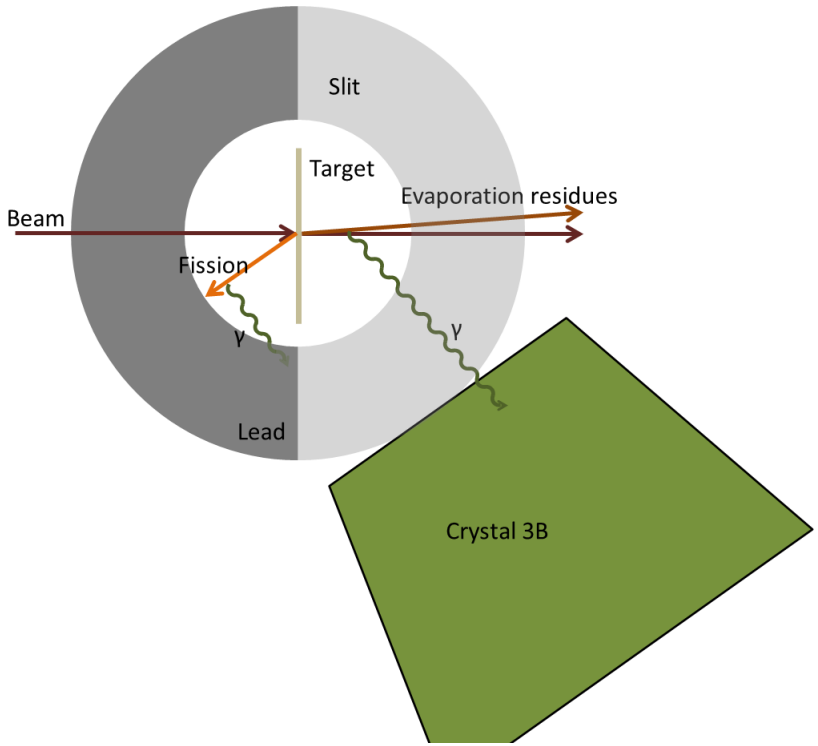
Suppression of the fission photons

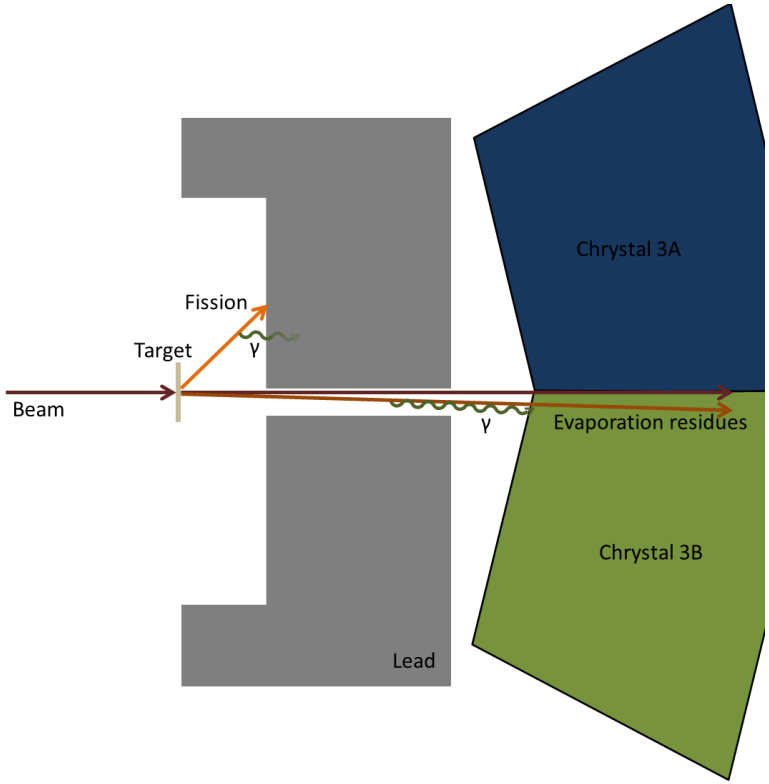


Geometrical consideration

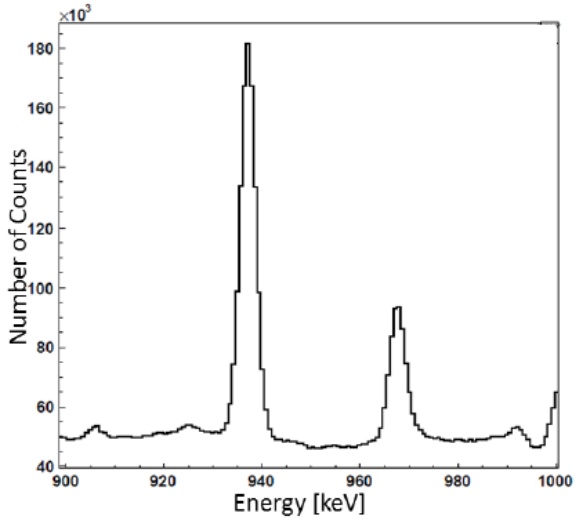
- Evaporation residues towards Beam direction
- Fission products into 4π

Suppression of the fission photons

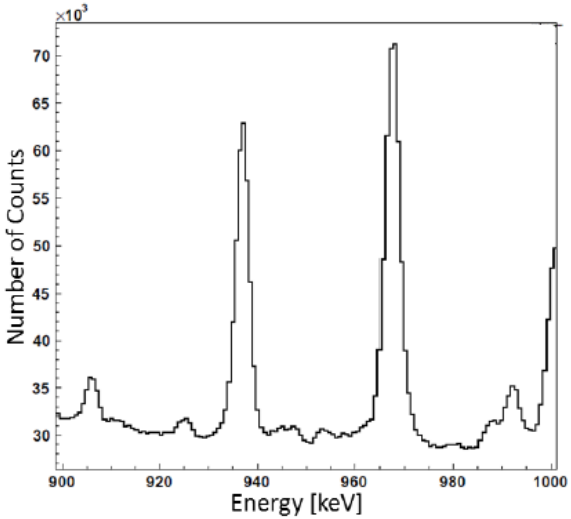




Choice of fusion- and fission-peaks



No shielding



Shielding with slit

Improvement of the ratio: 7.2(13)

Summary

- Application: Radon
  - Different multiplicities for different methods
  - Nuclear structure
- Reduction of the background
  - Offline: Searching for transition energies

  → Result unclear
  - Online: Shielding with lead pot

  → Improvement of the fusion- to fission ratio

Solution: K_x-ray multiplicity

- Internal conversion: Interaction between elect.-magn. fields of the excited nuclei with atomic electrons (mostly of K-shell).
- Vacant shell will be filled from an electron of an higher shell→ Charact. X-ray radiation
- K_x-ray energy calculable via Moseley‘s law

Purifying the spectra

$^{232}\mathrm{Th}(^{12}\mathrm{C},x\mathit{n})^{y}\mathrm{Cm}$

	981 keV		973 keV	
# Mult.	K_x-ray	Ref.	K_x-ray	Ref.
One	5765 (76)	2582 (51)	7950 (89)	3666 (61)
Two	16 (4)	1 (1)	17 (4)	8 (3)
Ratio	0.003 (1)	0.000 (0)	0.002 (1)	0.002 (1)

Result unclear

Processing to determine the multiplicity

$\gamma - K_x$-ray Coincidence method

- Setting gate on decay line
- Out of the originated spectrum:

$$M_{\gamma x} = \frac{N_{K_x}}{N_\gamma}$$

- No absolut effiziency necessary
- Consideration of cascades without internal conversion

K_x-ray– K_x-ray coincidence method

- Unsufficient level scheme and large A→ high multiplicity: $M > 1$
- Several K_x-rays per decay → Gate
- Distribution of coincident signals at fixed multiplicity M_{xx}
- e.g. measurement of exactly one K_x-ray

$$N \cdot \binom{M_{xx}}{1} \cdot \epsilon_{sc}(1 - (\epsilon_{sc} - \epsilon_{det}))^{M_{xx}-1}$$

- Numbers of two simultaneuous measured K_x-rays

$$N \cdot \binom{M_{xx}}{2} \cdot \epsilon_{sc}(\epsilon_{sc} - \epsilon_{det})(1 - (\epsilon_{sc} - 2\epsilon_{det}))^{M_{xx}-2}$$

K_x-ray– K_x-ray coincidence method

- Absolut efficiency ϵ_{det} necessary
- Dirty Spectrum → Cascades with at least twice internal conversion
- If low transition energies known

→ γ – K_x-ray– K_x-ray coincidence method

- Gate on γ-energy purifies spectrum
- Applying the K_x-ray– K_x-ray coincidence method also counts cascades with at least one internal conversion

^{192}Pt(^{16}O,4n)^{204}Rn

- $\gamma - K_x$-ray coincidence method

$M_{\gamma x} = 0.91(22)$

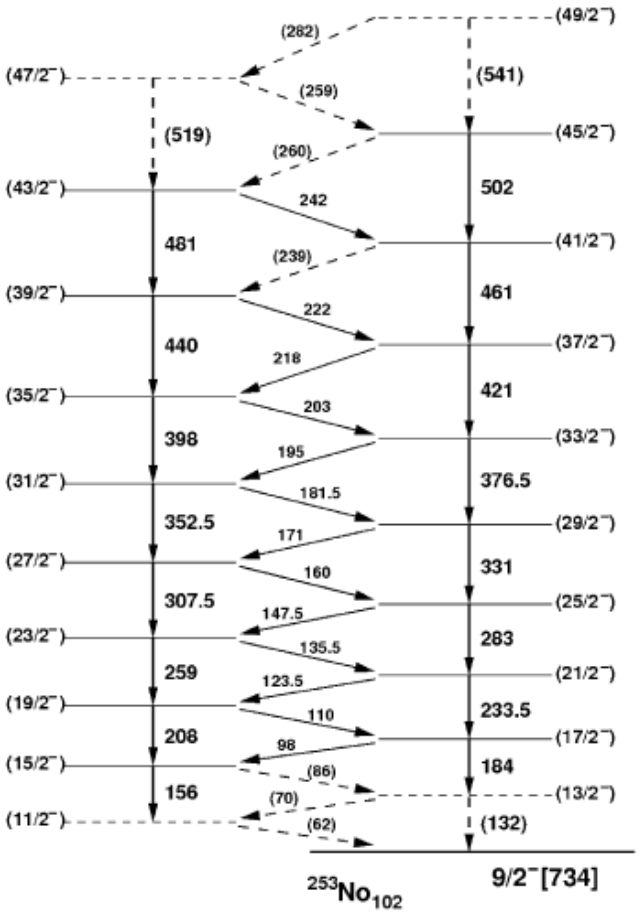
Trans.	Energy [keV]	Area	eff.corr. Area
$K_{\alpha 1}$	81	6616 (123)	7120 (132)
$K_{\alpha 2}$	83	8687 (133)	9282 (142)
K_{β}	95	4557 (117)	4747 (122)
$1131 \rightarrow 542$	588	9070 (156)	23213 (399)
$1627 \rightarrow 542$	1084	0	0
$M_{\gamma x} =$			0.91 (22)

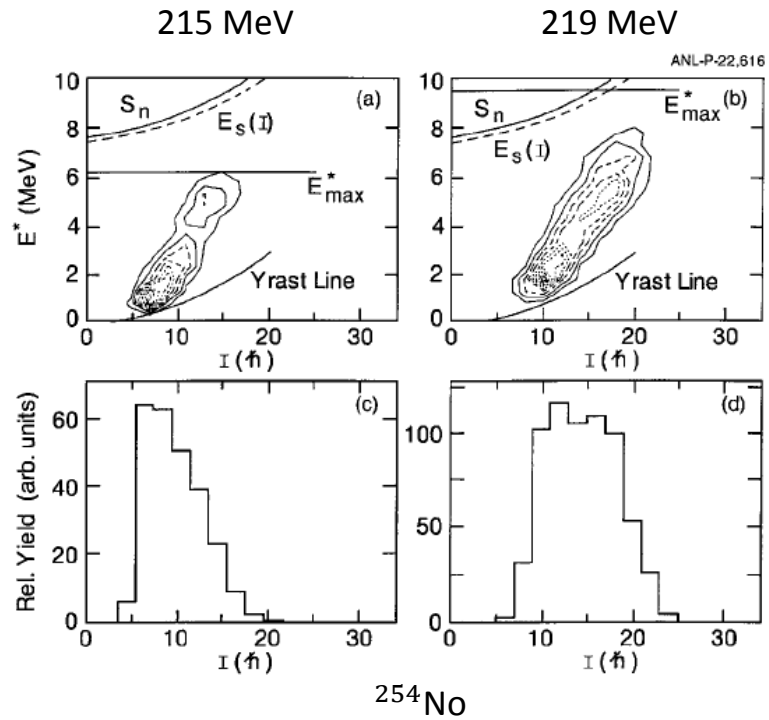
- $\gamma - K_x$-ray$-$ K_x-ray coincidence method

$M_{\gamma xx} = 1.91(48)$

# Mult.	K_x-rays	Ref.	K_x-rays *corr.*
One	38698 (197)	17079 (131)	18203 (135)
Two	299 (17)	27 (5)	272 (16)
Three	2	0	2

Reasons for the different results





$$M_{215} = 2.9^{+1}_{-0.5} \qquad M_{219} = 3.6^{+0.5}_{-0.2}$$

R.-D. Herzberg, S. Moon et al.: Eur. Phys. J. A 42, 333–337 (2009).

P. Reiter, T. L. Khoo, T. Lauritsen, C. J. Lister et al.: Phys. Rev. Letters Vol. 84, No. 16 (2000).

Suppression of the fission photons

	197 keV	360 keV	937 keV
Vol. 3A / Vol. 3B *nLP*	0.910 (2)	0.786 (3)	0.932 (2)
Vol. 3A / Vol. 3B *wLP*	0.910 (7)	0.094 (13)	0.897 (6)
Ratio row 2 / row 1	1.001 (8)	0.120 (17)	0.962 (7)
Vol. 3B *theor. nLP*	1640783 (2669)	729770 (1708)	620456 (2590)
Vol. 3B *theor. wLP wS*	-356 (3331)	91172 (2336)	10659 (1884)
Transmission	-0.000 (2)	0.125 (3)	0.017 (3)

Improvement of the ratio: 7.2(13)