Outline: electron spectroscopy

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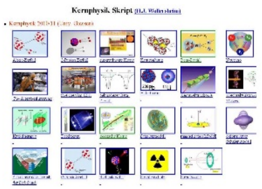
web-page: https://web-docs.gsi.de/~wolle/ and click on



1. Coulomb excitation and fusion reaction
2. surface oscillations in deformed nuclei
3. E0/E2 branching ratio
4. experiments with orange spectrometer

Doppler-corrected e⁻ and γ-ray spectroscopy

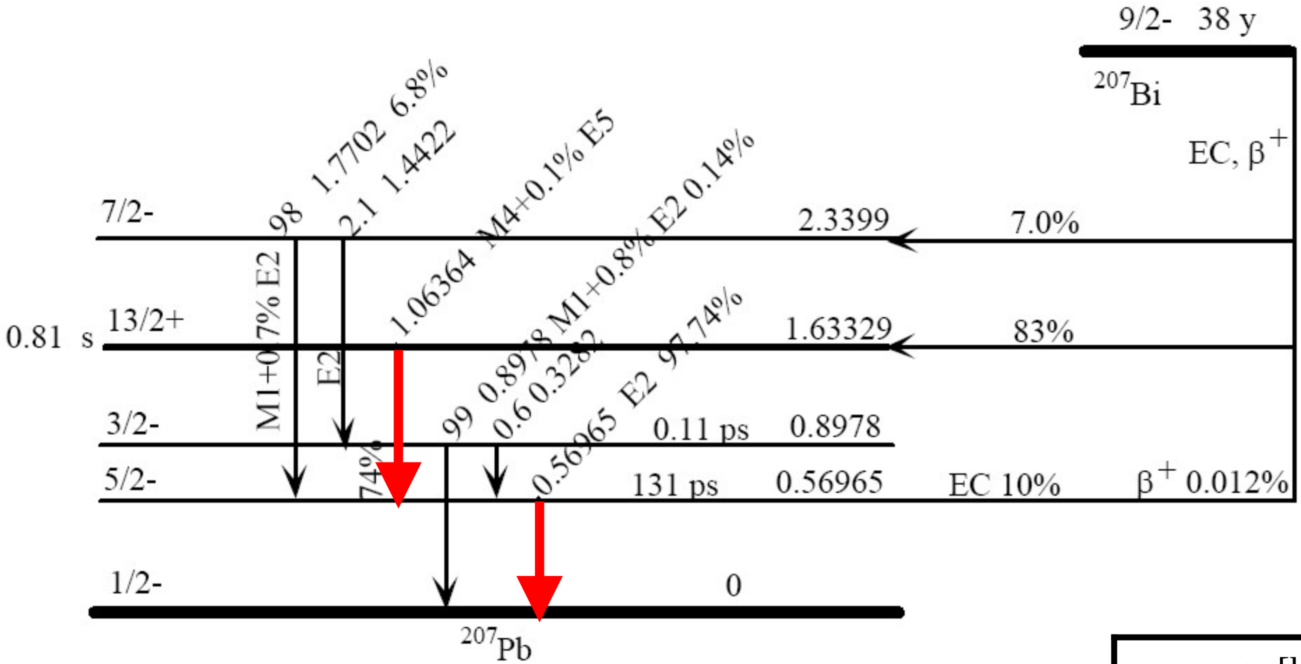
- **Physical Motivation**
  - In-beam conversion electron spectroscopy complements the results obtained from γ-spectroscopy
  - A method for determining the multipolarity of nuclear transitions
  - The only method for detecting E0-transitions

- **Doppler Correction after Inelastic Heavy Ion Scattering**
  - ^{238}U + ^{181}Ta system at the Coulomb barrier
  - Electron spectroscopy with mini-orange devices

- **Doppler Correction after (HI,xn)-Reaction**
  - ^{26}Mg(^{136}Xe,4n)^{158}Dy reaction
  - Electron spectroscopy with high transmission orange-β spectrometer

- **Summary**

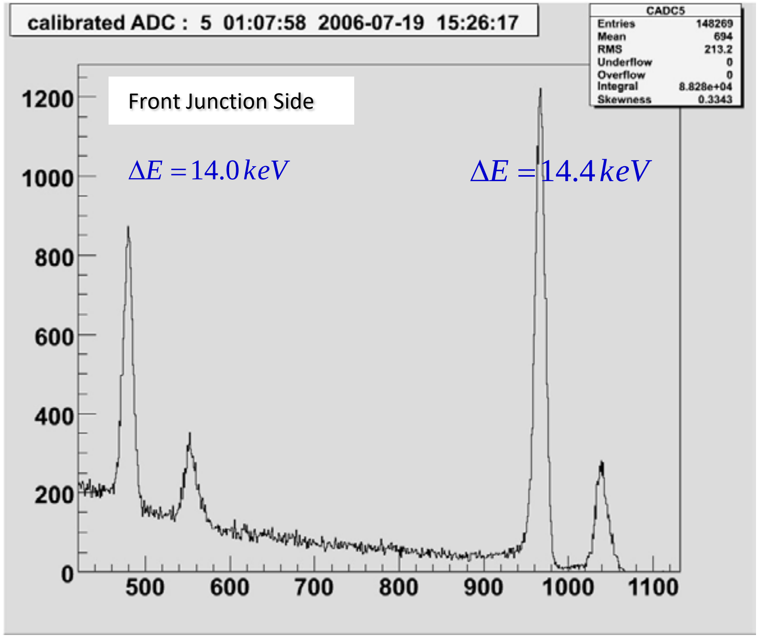
^{207}Bi source

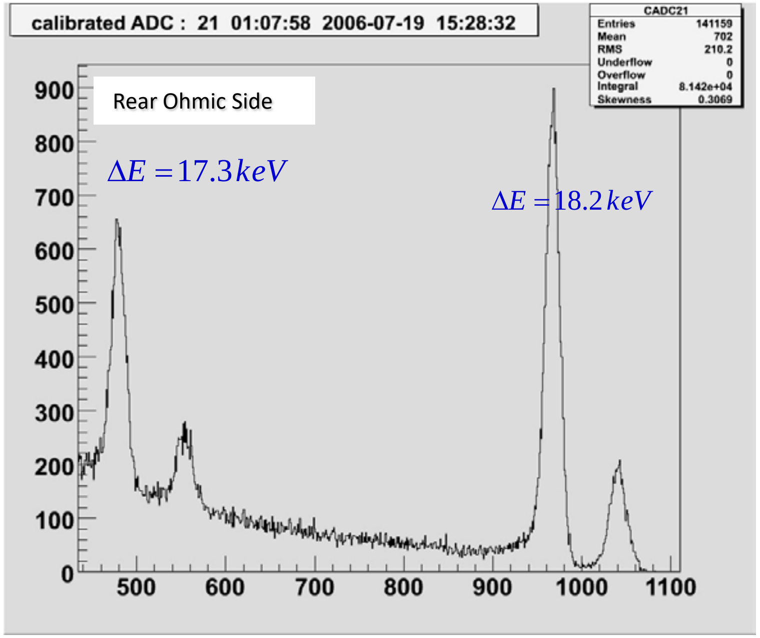


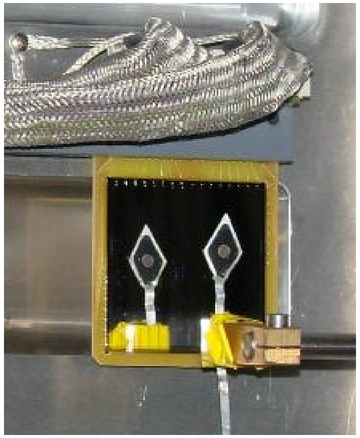
^{207}Bi emits γ-rays and electrons

γ-energy [keV]	e⁻energy [keV]
569.6	481.7 [K]
	553.8-556.7 [L]
	565.8-567.2 [M]
1063.7	975.7 [K]
	1047.8-1050.6 [L]
	1059.8-1061.2 [M]

Energy resolution with ^{207}Bi source in vacuum







experimental set-up

MICRON #2512-17

Voltage: 200V

^{207}Bi E=482, 976 keV

range 0.94, 2.31 mm (e^-e^- interaction) lifetime of a nuclear state:

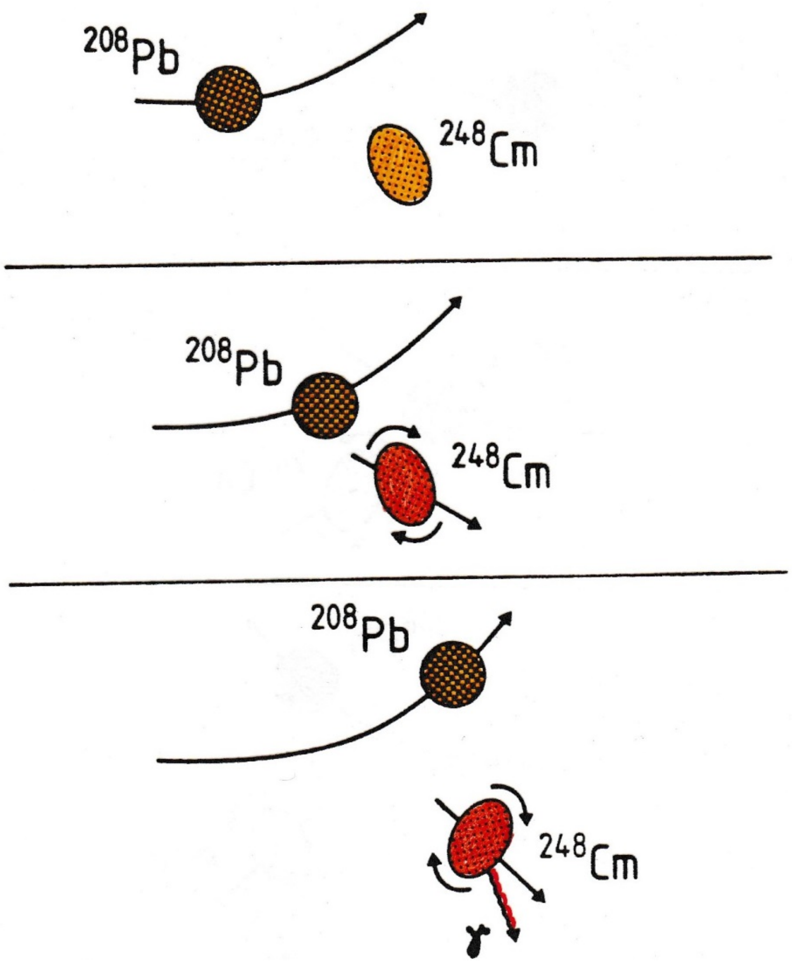
$$\tau = \left\{ \sum_K \sum_L \delta^2_{N\to K}(L) \cdot \left[1 + \alpha_{N\to K}(L)\right] \right\}^{-1}$$

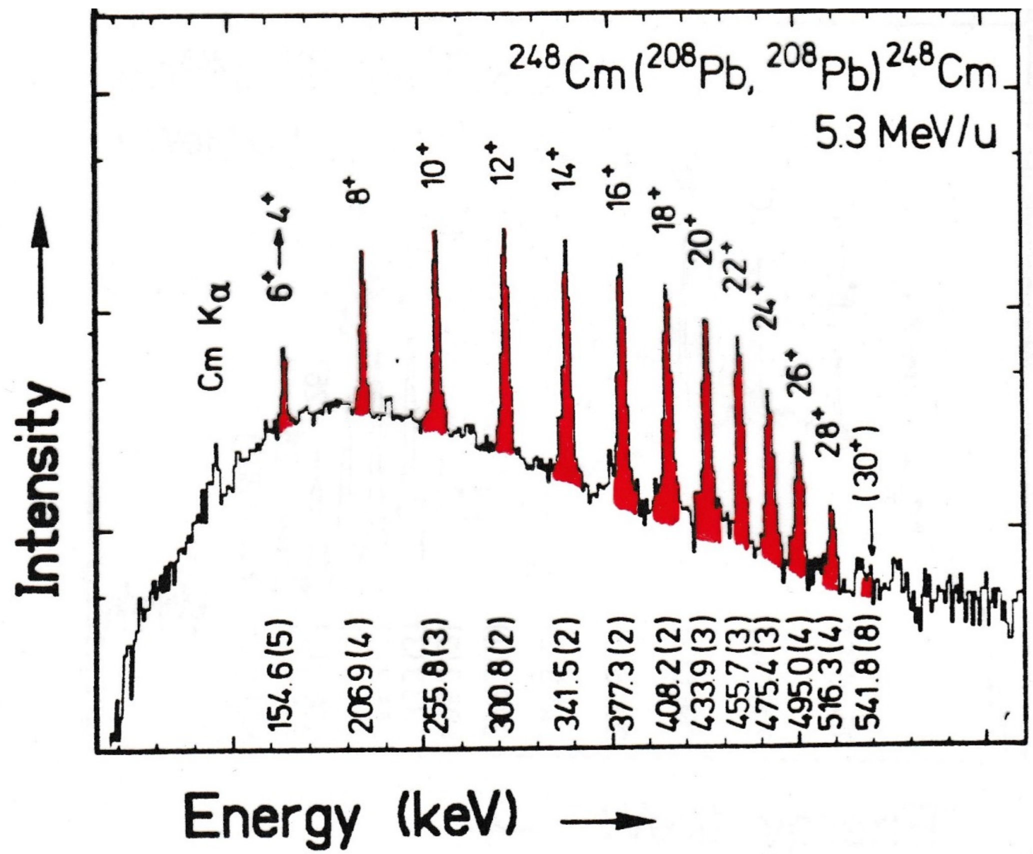
$$\delta^2_{N\to M}(E2) = 1.225 \cdot 10^{13} \cdot E_\gamma^5 \cdot B(E2; N \to M)$$

total conversion coefficient:

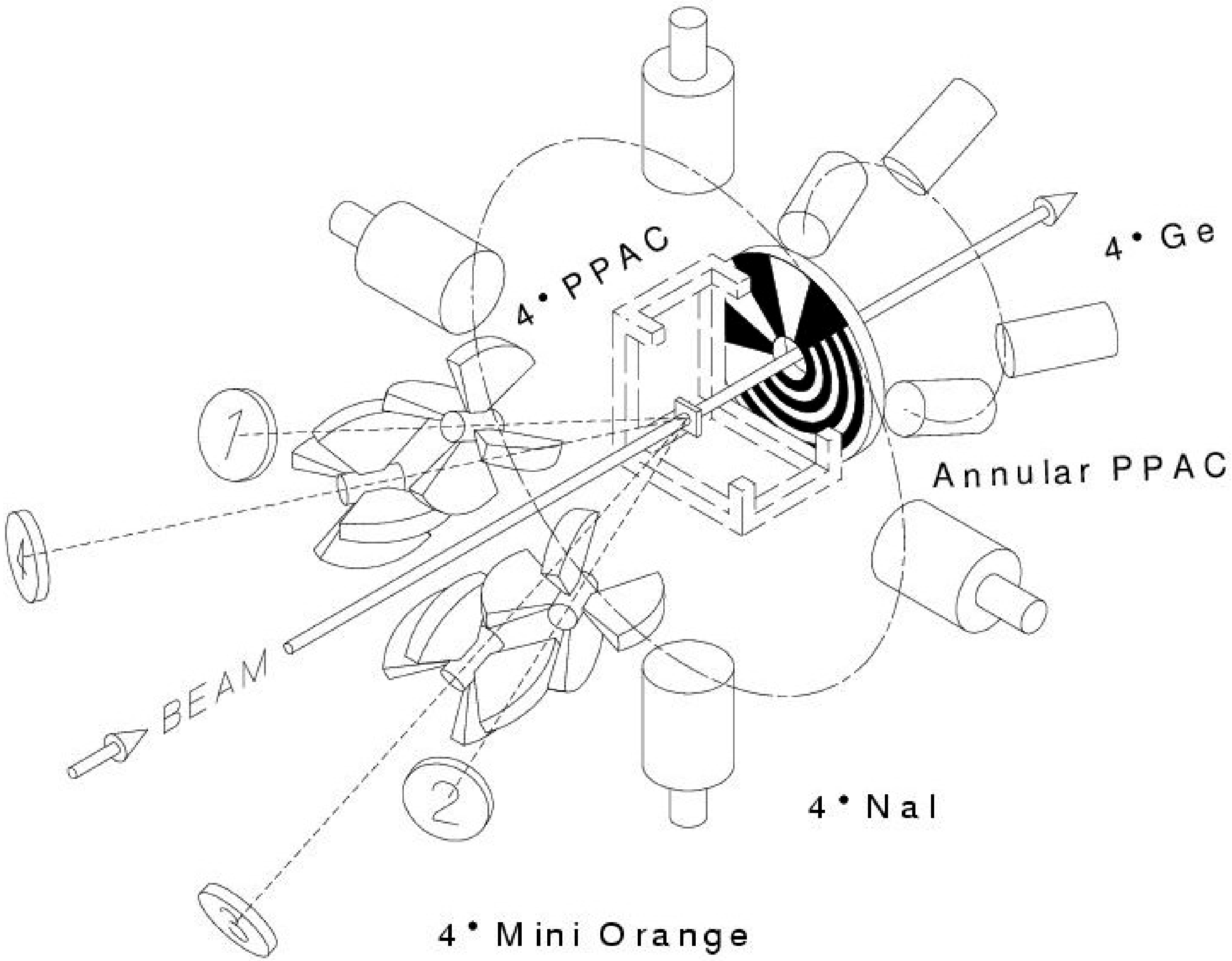
$$\alpha_{N\to K}(L) = \frac{I_e}{I_\gamma}$$

Coulomb excitation

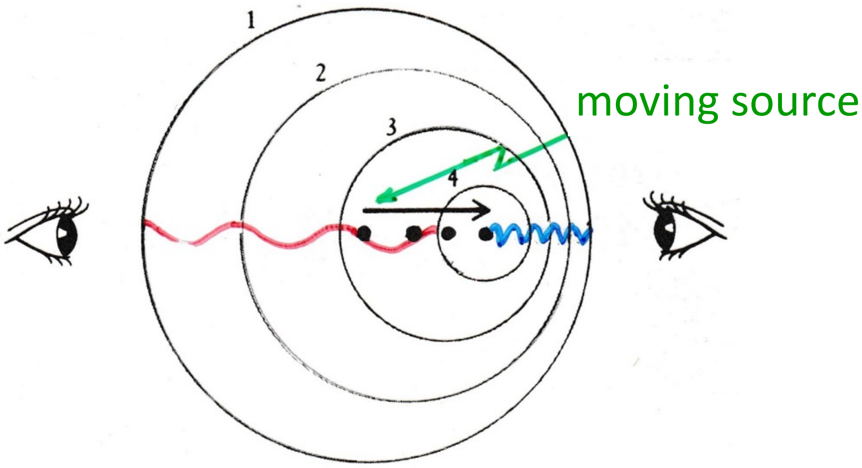


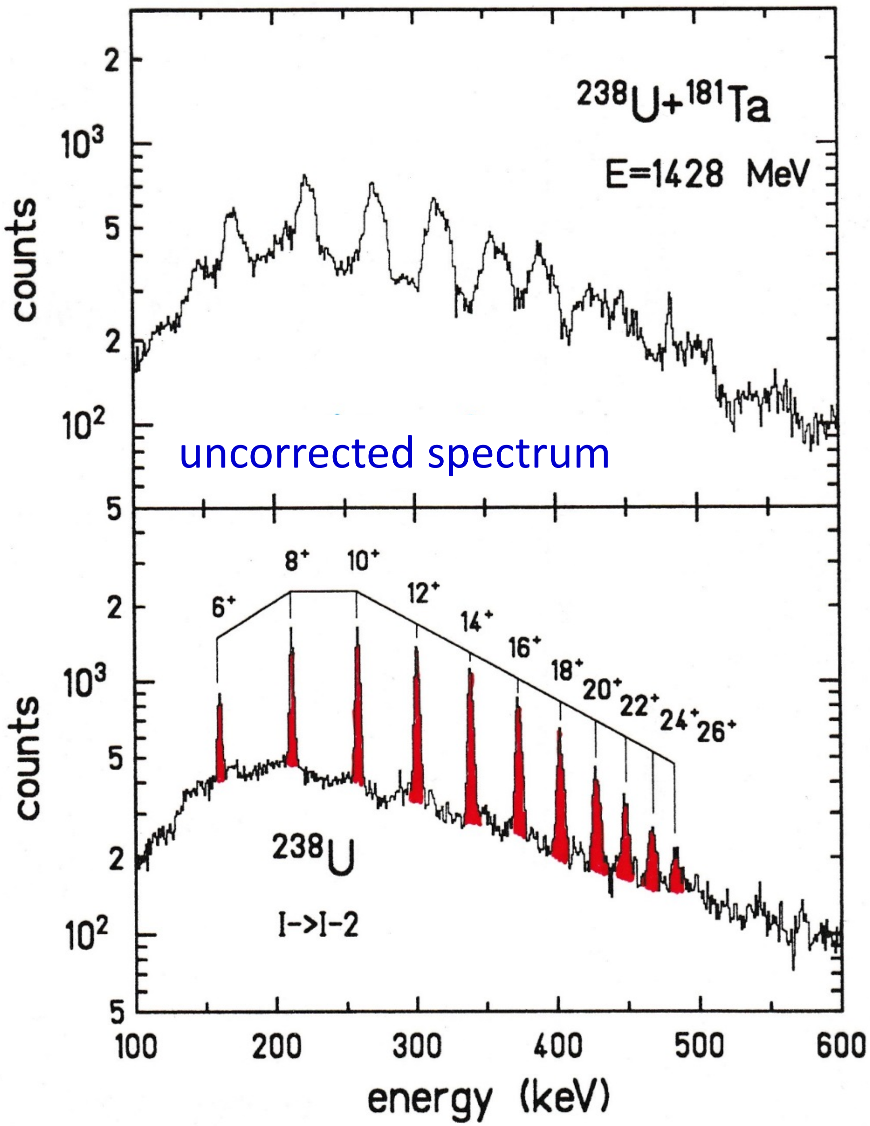


Coulomb excitation experiment



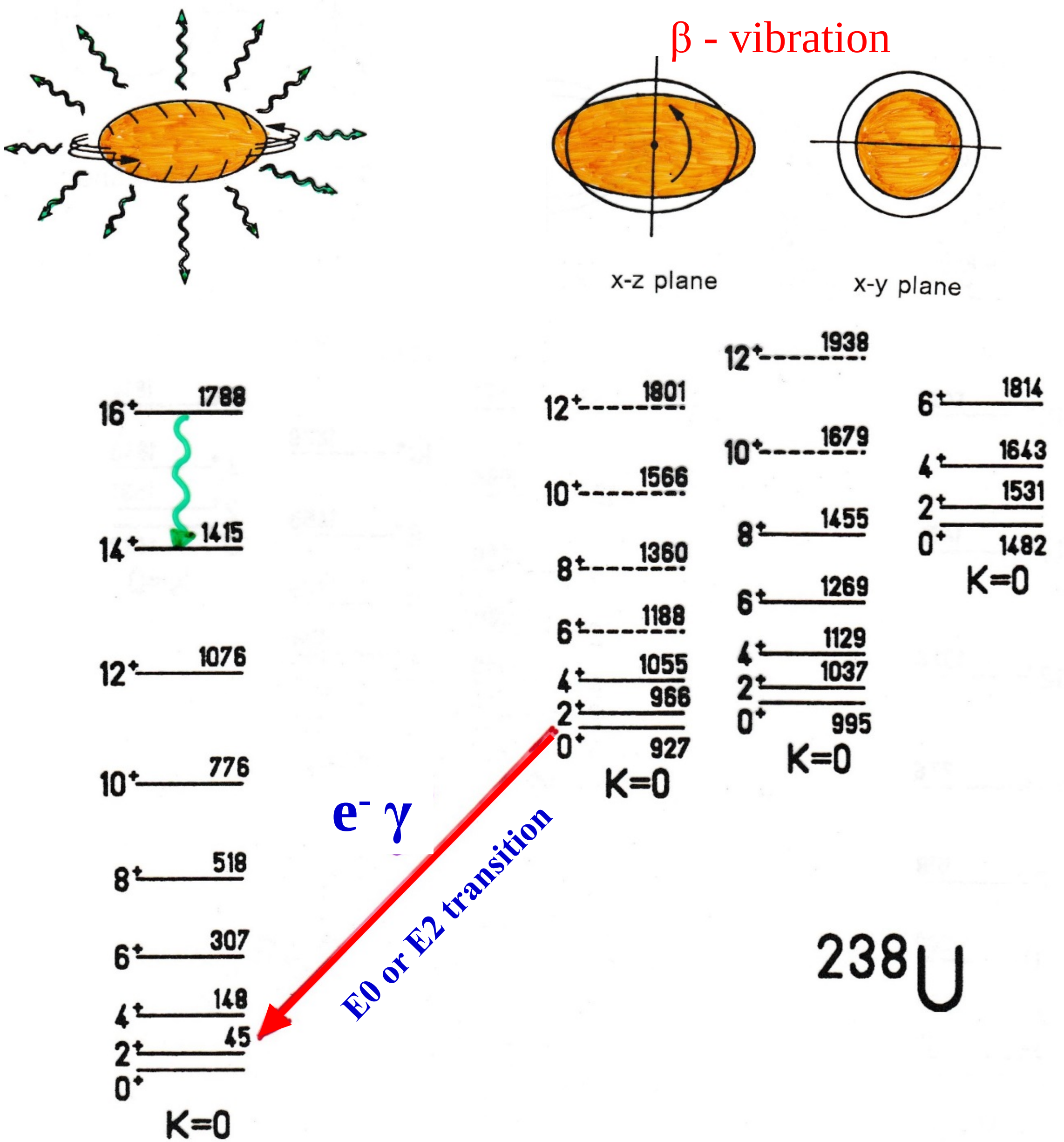
Doppler effect





Christian Doppler

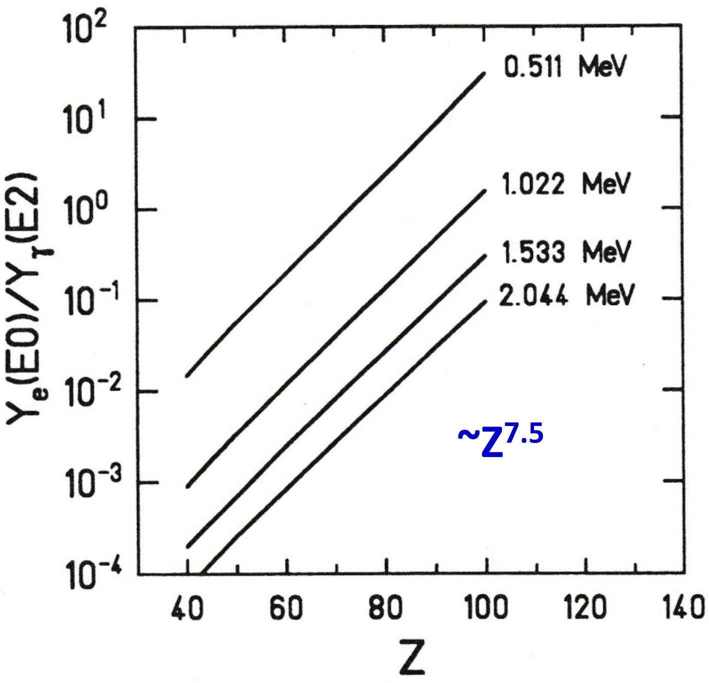
Surface oscillations in deformed nuclei



E0/E2 branching ratio

$$\frac{Y_e(E0)}{Y_\gamma(E2)} = \frac{\Omega_K\ [s^{-1}]}{2.56\cdot 10^9\cdot A^{4/3}\cdot E_\gamma{}^5\ \ [MeV]}\cdot \underbrace{\frac{B(E0;I\to I')}{B(E2;I\to I')}}$$

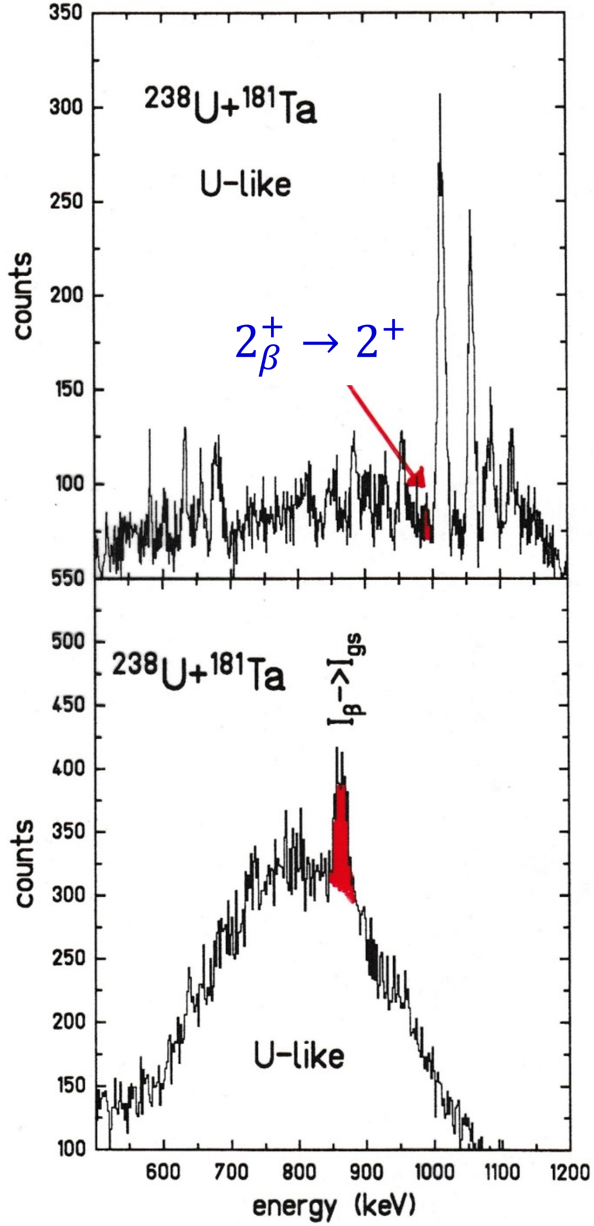
$= 14\ \beta^2$ for $2_\beta \rightarrow 2$



Ω_K: conversion probability electronic factor

D.A. Bell et al.; Can. J. of Phys. 48 (1970),2542

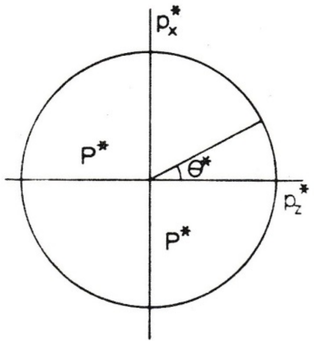
Doppler-corrected e$^-$ and γ-ray spectroscopy



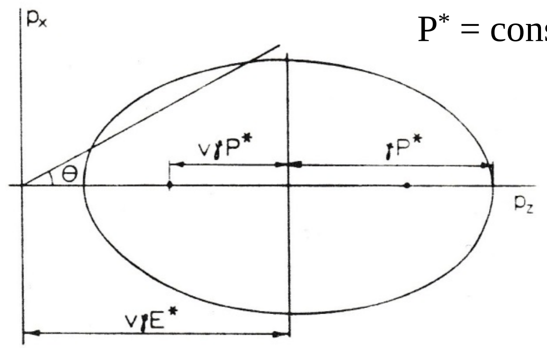
γ-ray spectrum

e$^-$ spectrum

Lorentz transformation



rest system



laboratory system

$P^* = \text{const.}$

total energy:

$$E^* = -\gamma \cdot v \cdot P \cdot cos\theta + \gamma \cdot E$$

with

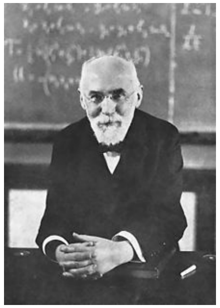
$$E = \sqrt{(mc^2)^2 + (Pc)^2}$$

E^*, P^* total energy and momentum in the rest system
E, P total energy and momentum in the laboratory system

Doppler formula for zero-mass particle (photon): E=Pc

$$E^* = -\gamma \cdot \beta \cdot E \cdot cos\theta + \gamma \cdot E$$

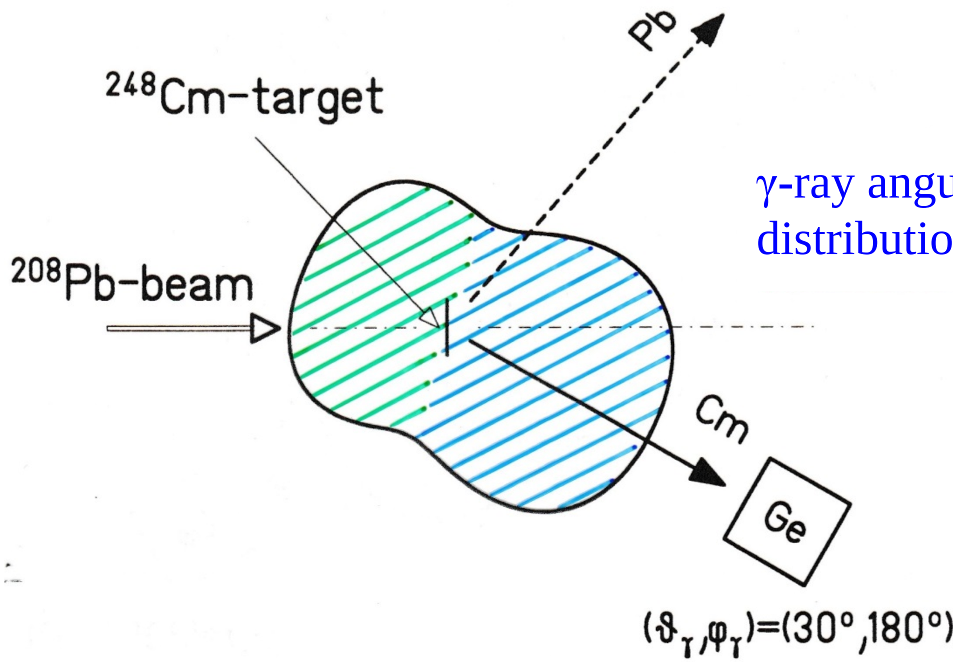
$$\boxed{E^* = \gamma \cdot E(1 - \beta \cdot cos\theta)}$$



Hendrik Lorentz

E. Byckling, K. Kajantie J. Wiley & Sons London

Lorentz transformation



γ-ray angular distribution

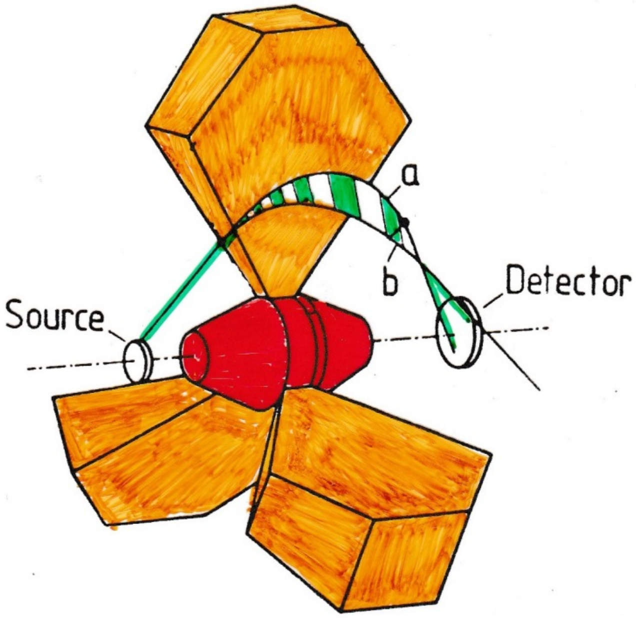
Contraction of the solid angle element in the laboratory system

$$\frac{d\Omega}{d\Omega^*} = \left\{\frac{E^*}{E}\right\}^2$$

with

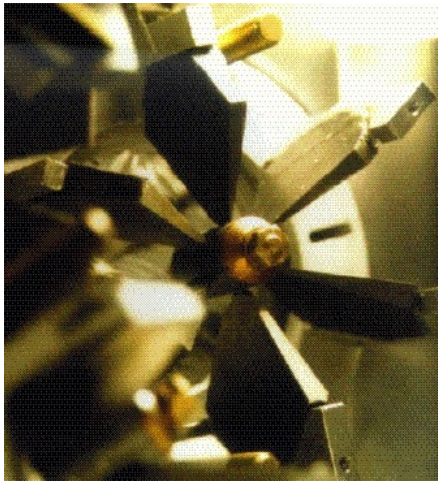
$$E^* = \gamma \cdot E \cdot (1 - \beta \cdot cos\theta)$$ Doppler formula

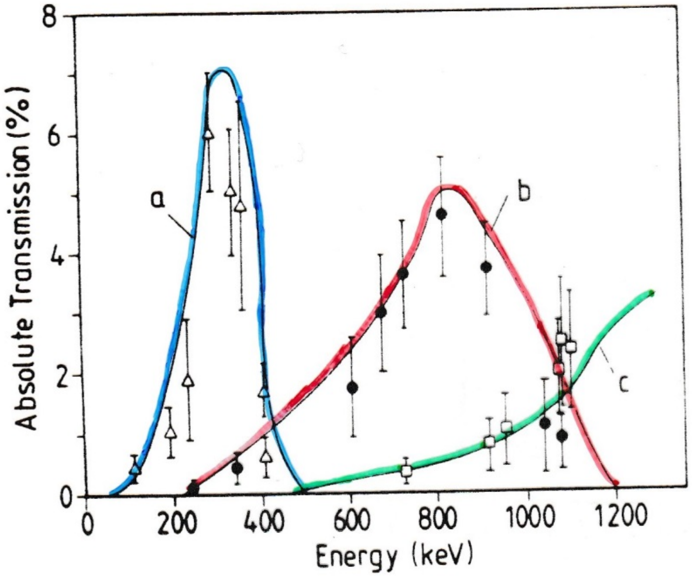
Electron spectroscopy with mini-orange devices



magnetic filters

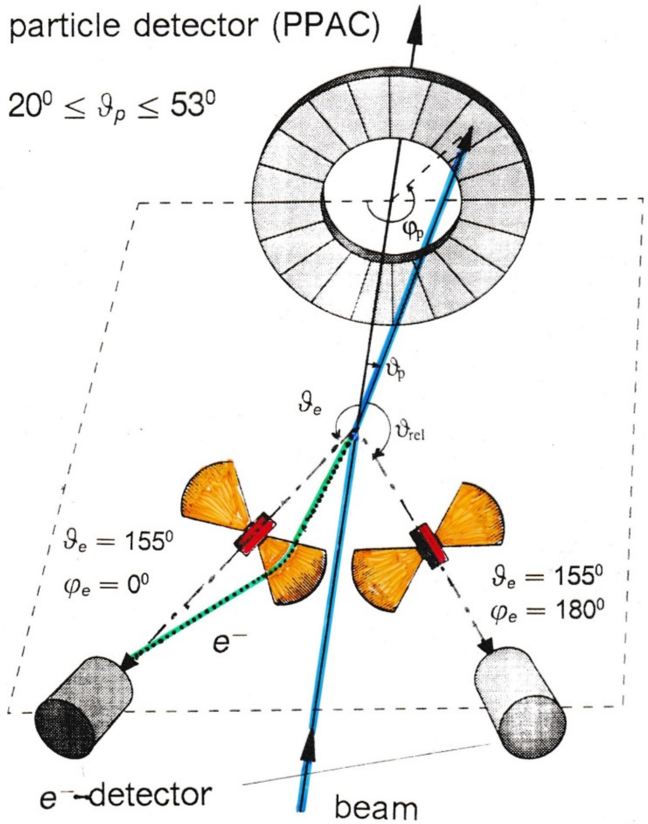
$SmCo_5$ magnets
for symmetric configuration 1 – 5 kG





J. v. Klinken et al.; NIM 151 (1978) 433
T. Dresel et al.; NIM A275 (1989) 301

Experimental arrangement



Doppler broadening

$\Delta\vartheta_e = 20^0$
target – Mini-Orange: 19 cm
Mini-Orange – Si detector: 6 cm

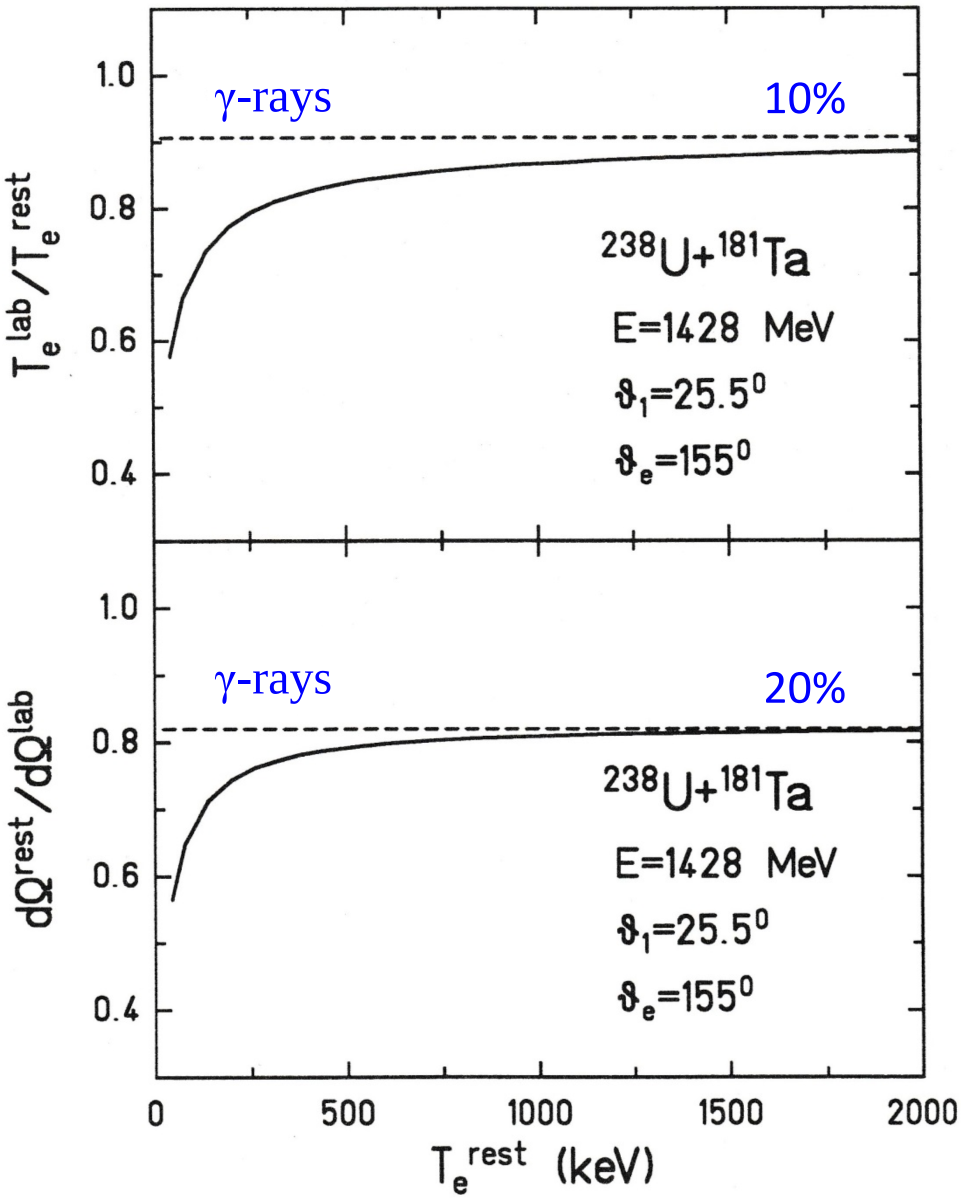
For projectile excitation:

$$T_e^* = \gamma \cdot T_e \cdot \left\{1 - \beta_1 \cdot \sqrt{1 + 2m_e\, c^2/T_e} \cdot cos\theta_{e1}\right\} + m_e c^2 \cdot (\gamma - 1)$$

with

$$cos\theta_{e1} = cos\vartheta_1 cos\vartheta_e + sin\vartheta_1 sin\vartheta_e cos(\varphi_e - \varphi_1)$$

Lorentz transformation



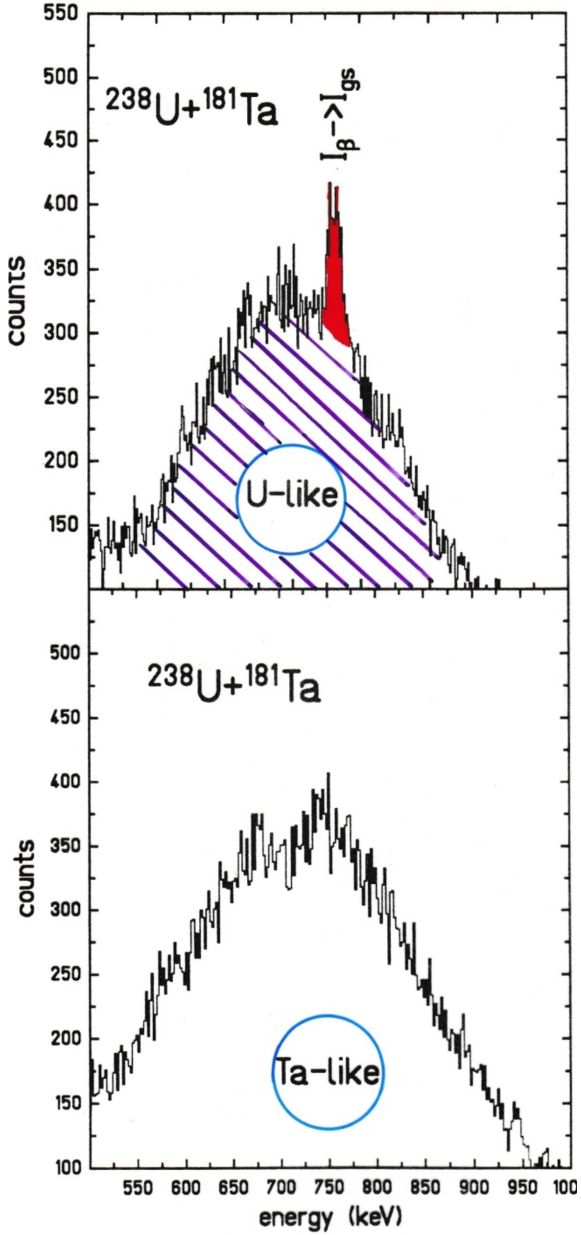
energy shift

The Doppler shift in kinetic energy of electrons is larger than the Doppler shift of massless photons of similar energy.

solid angle contraction

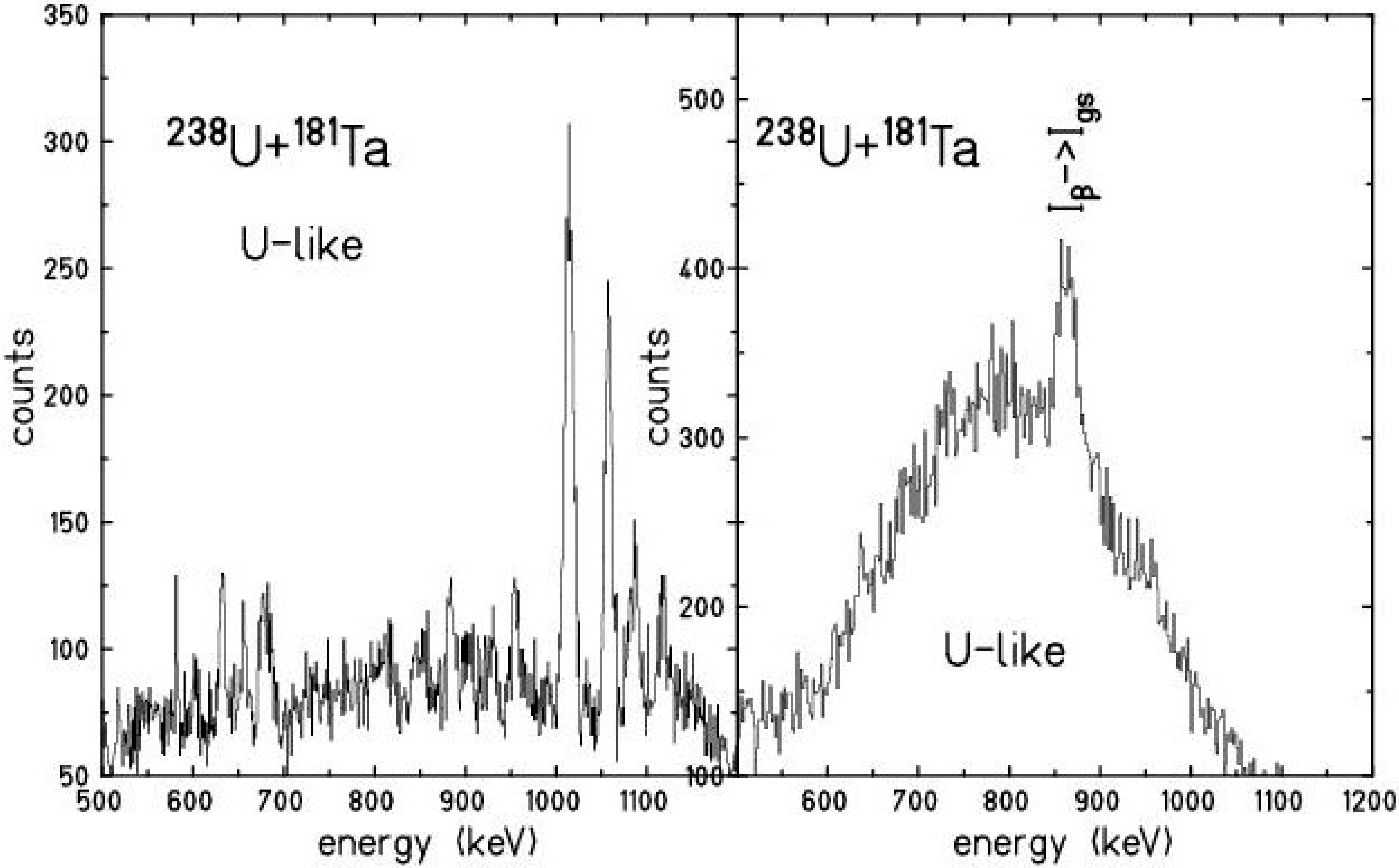
The Lorentz transformation also leads to a contraction of the solid angle in the laboratory system.

Electron spectroscopy with mini-orange devices

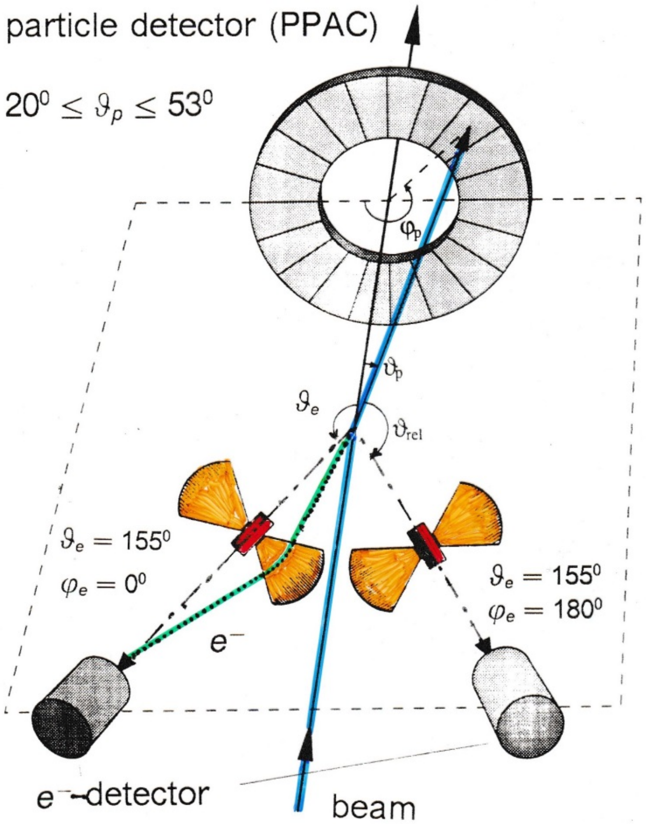


transmission window

Coulomb excitation experiment

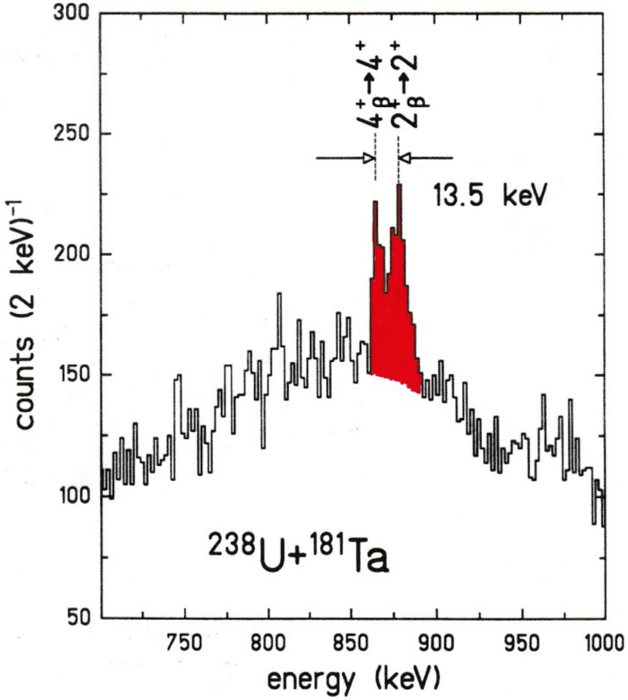


Experimental arrangement

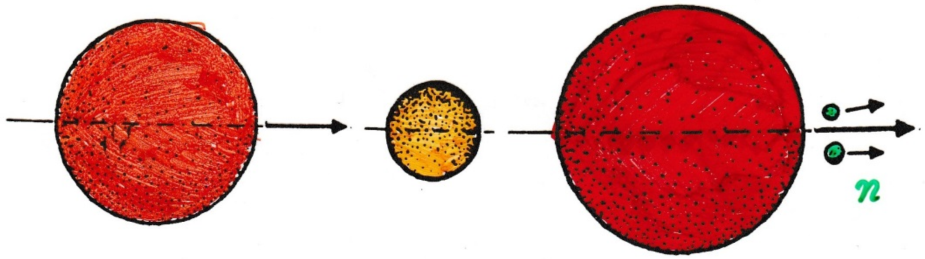


optimal energy resolution:

$\cos \theta_{e1} = \pm 1$



Compound nucleus formation



$$^{136}Xe + {}^{26}Mg \longrightarrow {}^{162}Dy^{*}$$

$E/A_1 = 4.1 \ MeV/u$

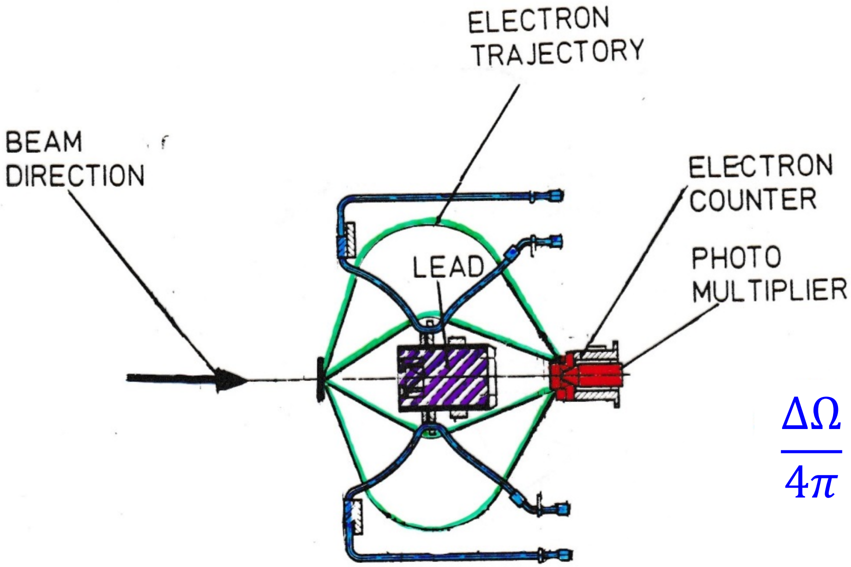
$$\vartheta_C = 0^0$$
$$\beta_C = \beta_{cm} = 0.079$$

Lorentz transformation:

$$T_e^{*} = \gamma T_e \left\{ 1 - \beta_{cm}\sqrt{1 + 2m_ec^2/T_e} \ \cos\vartheta_e \right\} + m_ec^2(\gamma - 1)$$

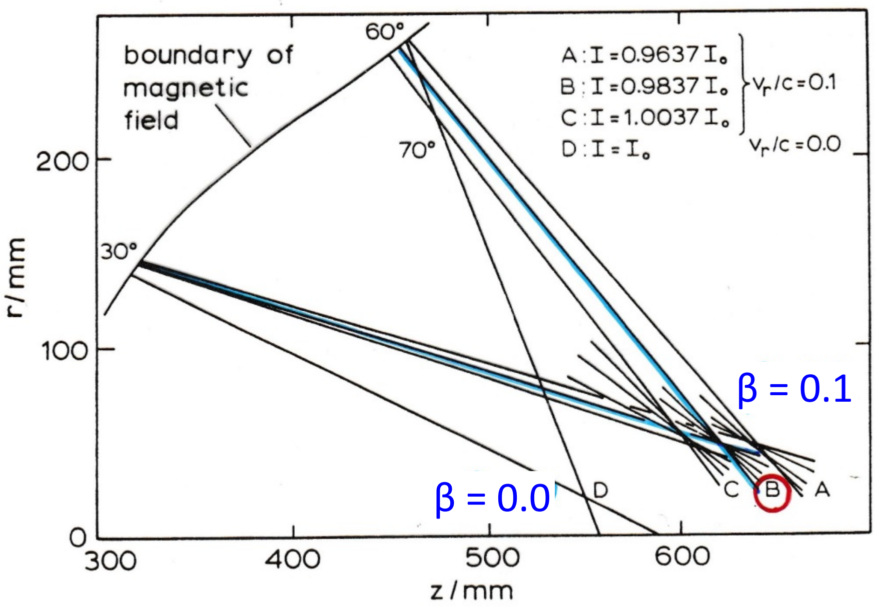
$$\frac{\Delta T_e^{*}}{T_e^{*}} = \frac{\beta_{cm}\sqrt{1 + 2m_ec^2/T_e} \ \sin\vartheta_e \Delta\vartheta_e}{\left\{ 1 - \beta_{cm}\sqrt{1 + 2m_ec^2/T_e} \ \cos\vartheta_e \right\} + m_ec^2(\gamma - 1)}$$

Experimental arrangement with orange spectrometer



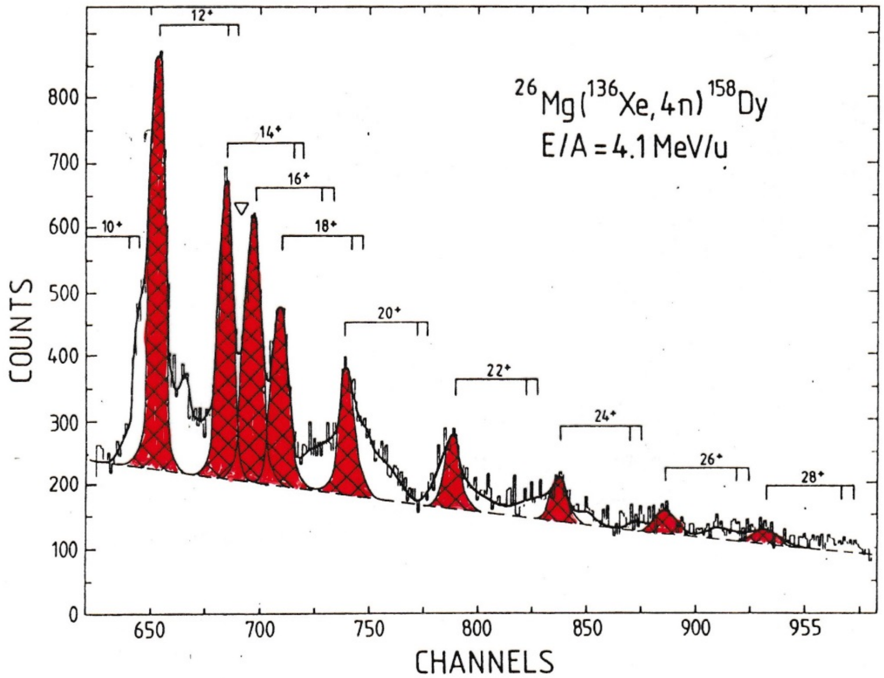
$$\frac{\Delta\Omega}{4\pi} = 26\%$$

optimal focusing: β, T_e^*



L. Handschug et al.; NIM 161 (1979) 117

Conversion electron spectroscopy after (HI,xn)-reactions



		$(\frac{\Delta p}{p})_e$ / %
resolution of the spectrometer including Doppler correction as calculated for a point source		0.4
scattering in the target	(i)	0.004
beam optics	(ii)	0.11
evaporation of neutrons	(iii)	0.09
energy loss in the target	(iv)	0.31
energy straggling of the projectiles	(v)	0.006
quadratic sum		0.53
experimental resolution		0.56

%

A. Balanda et al.; GSI 79-11, p.50

Summary

High resolution in-beam γ-ray and conversion electron spectroscopy can be performed in inelastic HI scattering and in (HI,xn)-reactions.

The strong Doppler broadening can be compensated for by proper positioning of the detection devices.

This is demonstrated for Ge-detectors, mini-orange devices and orange-β-spectrometer.

The observed width of γ-ray lines and conversion lines at an emitter velocity of v/c=10% was $\Delta E_\gamma / E_\gamma = \Delta T_e / T_e \simeq 1\%$.