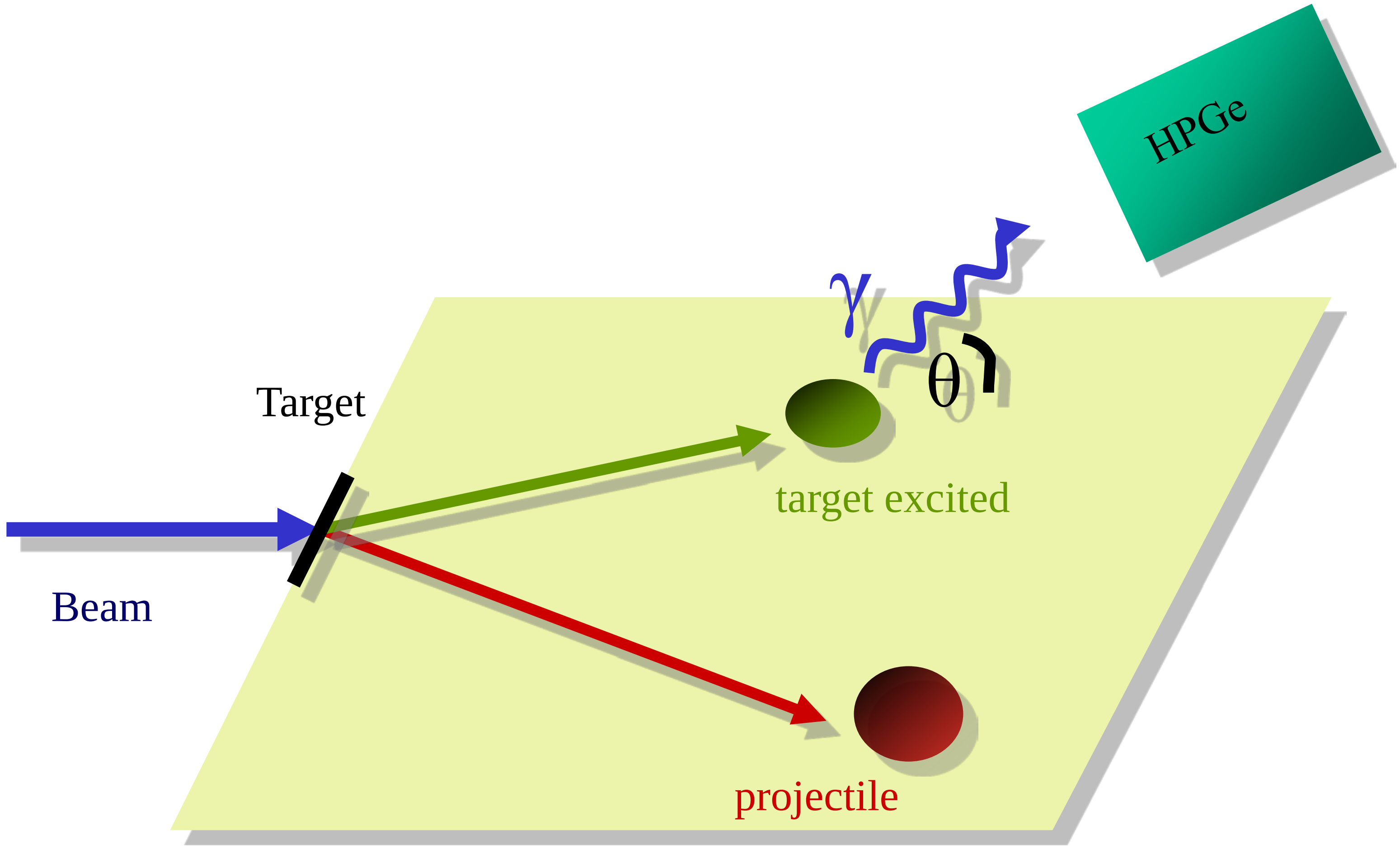
Coulomb excitation

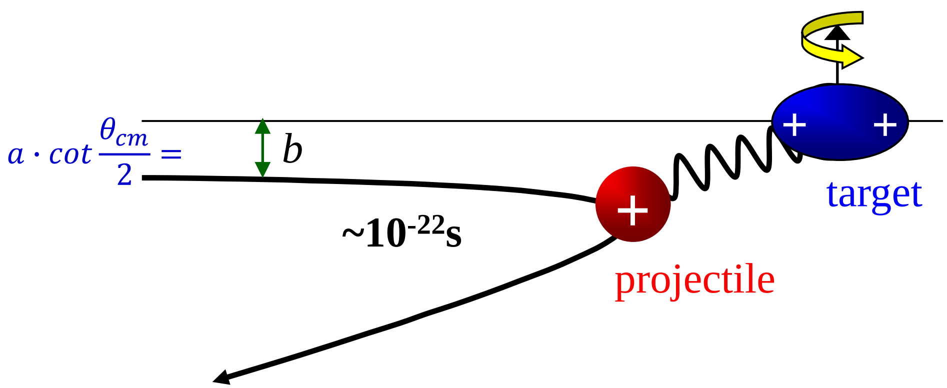
Hans-Jürgen Wollersheim



Coulomb excitation

particle detection

Nuclear excitation by electromagnetic field acting between nuclei.

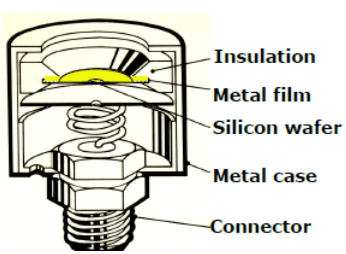


observables:

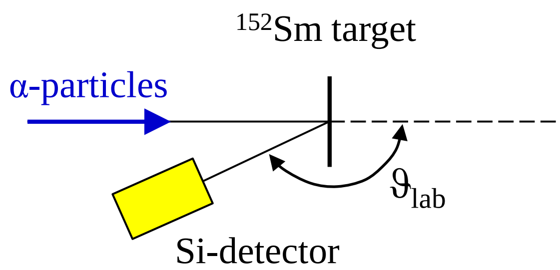
1. scattering angle $\vartheta_{lab} \Longrightarrow \theta_{cm}$

2. intensity $\frac{d\sigma_{Ruth}}{d\Omega_{cm}} = \frac{a^2}{4} \cdot sin^{-4}\frac{\theta_{cm}}{2}$

$$\frac{d\sigma_{inel}}{d\Omega_{cm}} = |a_{i \to f}|^2 \cdot \frac{d\sigma_{Ruth}}{d\Omega_{cm}}$$

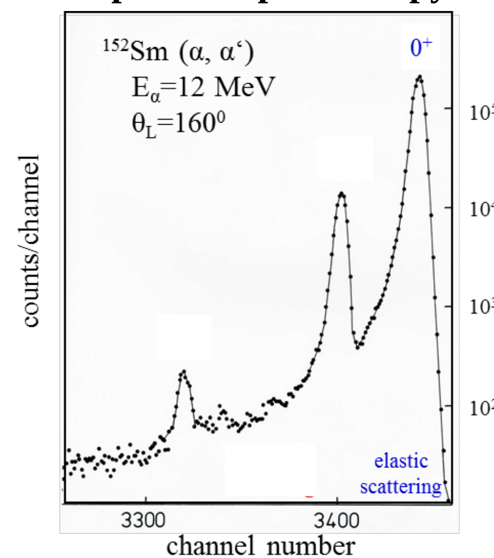


Possible:
depletion depth ~ 300μm
dead layer $d_d \leq 1\mu$
V ~ 0.5 V/μ
Over-bias reduces d_d



inelastic scattering: *kinetic energy is transferred into nuclear excitation energy*

α-particle spectroscopy



H.J. Wollersheim et al., Phys. Lett 48B (1974) 323

Coulomb excitation

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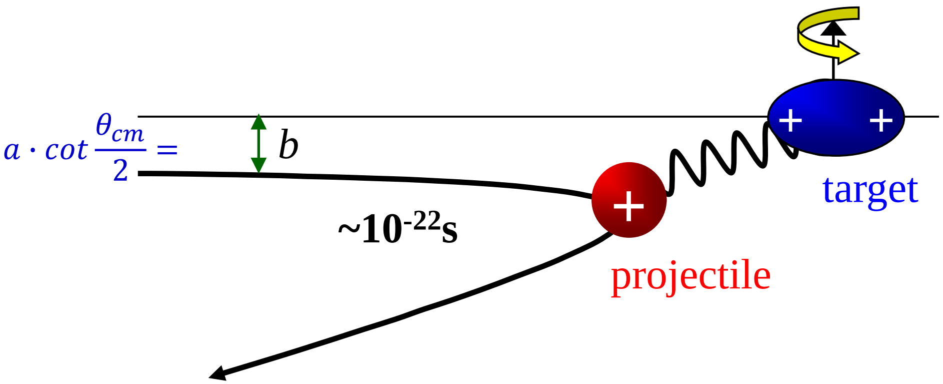
Nuclear excitation by electromagnetic field acting between nuclei.



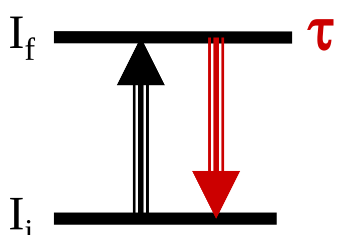
observables:

1. scattering angle $\vartheta_{lab} \Rightarrow \theta_{cm}$

2. intensity $\frac{d\sigma_{Ruth}}{d\Omega_{cm}} = \frac{a^2}{4} \cdot sin^{-4}\frac{\theta_{cm}}{2}$

$$\frac{d\sigma_{inel}}{d\Omega_{cm}} = \left|a_{i\to f}\right|^2 \cdot \frac{d\sigma_{Ruth}}{d\Omega_{cm}}$$

lifetime



~10^{-12}-10^{-9}s

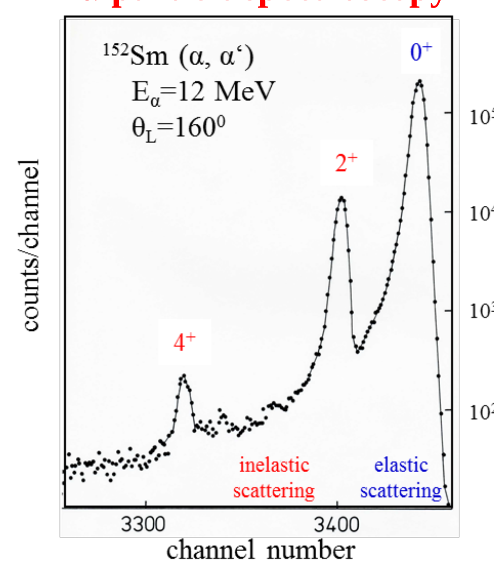
$$\frac{1}{\tau} \cong 1.23 \cdot 10^{13} \cdot B(E2; I_f \to I_i) \cdot E_\gamma^5 \quad [s^{-1}]$$

1st order:

$$a^{(1)}_{i\to f} \propto \langle I_f \| \mathbf{M}(E2) \| I_i \rangle$$

$$B(E2; I_i \to I_f) = \frac{1}{2I_i + 1} \langle I_f \| M(E2) \| I_i \rangle^2$$

α-particle spectroscopy

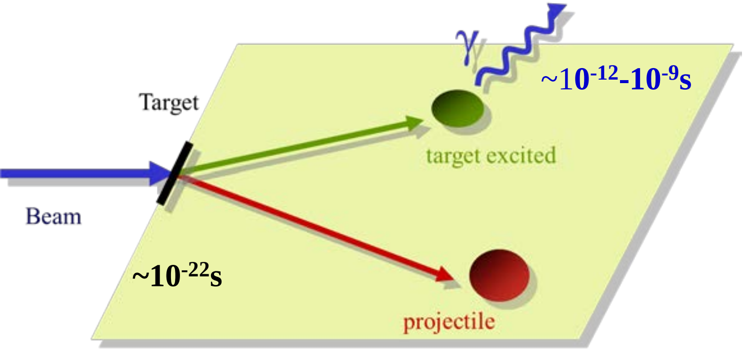


The inelastic cross section $d\sigma_{inel}/d\Omega_{cm}$
is a direct measure of the E2 matrix elements

H.J. Wollersheim et al., Phys. Lett 48B (1974) 323

Coulomb excitation

particle – γ-ray coincidence measurement



$$\frac{d^2\sigma}{d\Omega_p^{lab}\, d\Omega_\gamma^{lab}} = \underbrace{\left|a_{i\to f}\right|^2}_{\equiv P_I \text{ (excitation probability)}} \frac{d\sigma_{Ruth}}{d\Omega_p^{cm}} \frac{d\Omega_p^{cm}}{d\Omega_p^{lab}} \cdot \frac{dW\left(\gamma_{f\to i}\right)}{d\Omega_\gamma^{Rest}} \frac{d\Omega_\gamma^{Rest}}{d\Omega_\gamma^{lab}}$$

$$\frac{d\sigma_{Ruth}}{d\Omega_p^{cm}} = \frac{a^2}{4} \cdot sin^{-4}\frac{\theta_{cm}}{2}$$

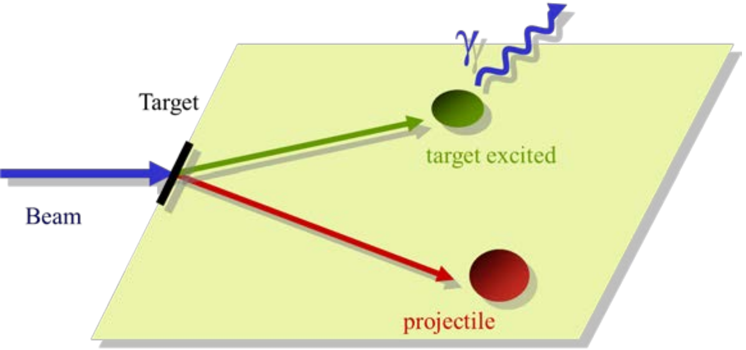
$$\frac{d\Omega_p^{cm}}{d\Omega_p^{lab}} = 4 \cdot cos\vartheta_2$$

$$\frac{dW\left(\gamma_{f\to i}\right)}{d\Omega_\gamma^{Rest}} = (4\pi)^{-1/2} \sum_{k=0,2,4} \sum_{-k\le\kappa\le k} A_{k\kappa} Q_k G_k F_k(I_M, I_N) Y_{k\kappa}\left(\theta_\gamma, \phi_\gamma\right)$$

$$\frac{d\Omega_\gamma^{Rest}}{d\Omega_\gamma^{lab}} = \left[\frac{E_\gamma}{E_{\gamma 0}}\right]^2 = \frac{\left[1-(v_i/c)^2\right]}{\left[1 - v_i/c \cdot cos\vartheta_{\gamma i}\right]^2}$$

Coulomb excitation

particle – γ-ray coincidence measurement



$$\frac{d^2\sigma}{d\Omega_p^{lab}\, d\Omega_\gamma^{lab}} = \left|a_{i\to f}\right|^2 \frac{d\sigma_{Ruth}}{d\Omega_p^{cm}} \frac{d\Omega_p^{cm}}{d\Omega_p^{lab}} \cdot \frac{dW\left(\gamma_{f\to i}\right)}{d\Omega_\gamma^{Rest}} \frac{d\Omega_\gamma^{Rest}}{d\Omega_\gamma^{lab}}$$

$$\frac{d\sigma_{Ruth}}{d\Omega_p^{cm}} = \frac{a^2}{4} \cdot sin^{-4} \frac{\theta_{cm}}{2}$$

$$\frac{d\Omega_p^{cm}}{d\Omega_p^{lab}} = 4 \cdot cos\vartheta_2$$

$$\frac{dW\left(\gamma_{f\to i}\right)}{d\Omega_\gamma^{Rest}} \cong a_0 \cdot \left[1 + \frac{a_2}{a_0} P_2\left(cos\vartheta_{\gamma 2}\right) + \frac{a_4}{a_0} P_4\left(cos\vartheta_{\gamma 2}\right)\right]$$

$$\frac{d\Omega_\gamma^{Rest}}{d\Omega_\gamma^{lab}} = \left[\frac{E_\gamma}{E_{\gamma 0}}\right]^2$$

$$a_0 = \frac{1}{1 + \alpha_T(I \to I-2)} \frac{1}{4\pi}$$

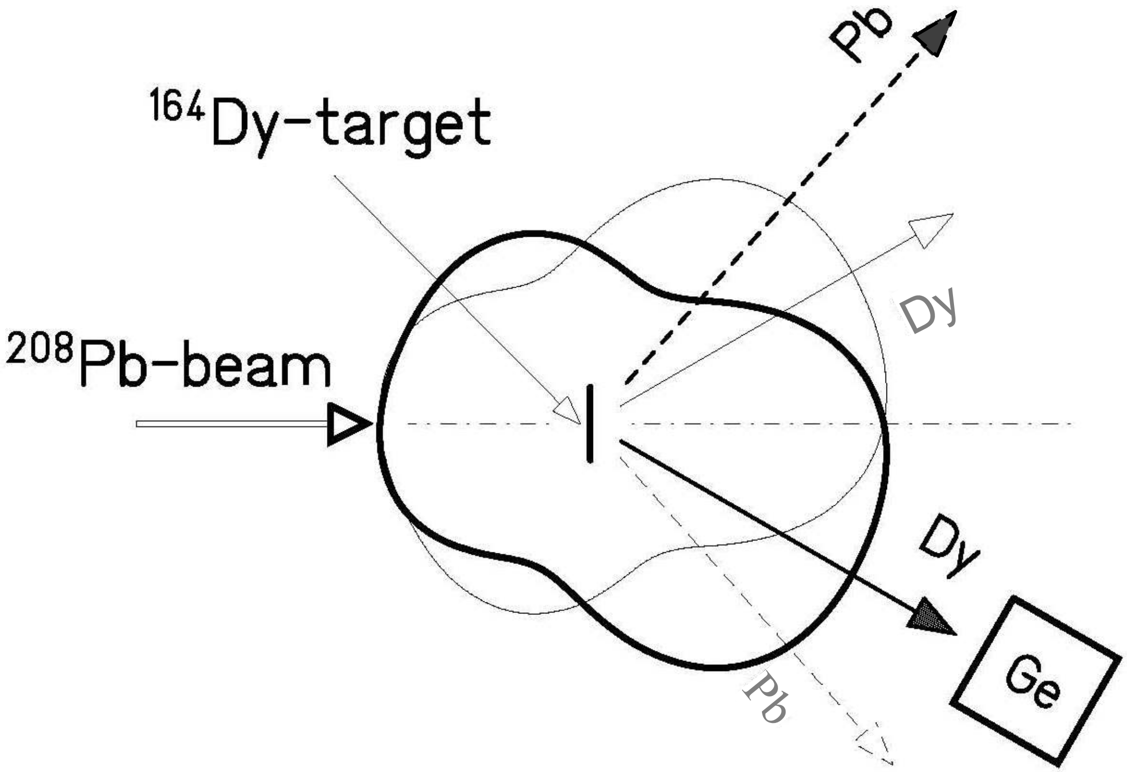
$$\frac{a_2}{a_0} = \frac{5}{7} \frac{I+1}{2I-1}$$

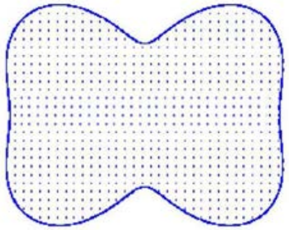
$$\frac{a_4}{a_0} = -\frac{3}{7} \frac{(I+1)\cdot(I+2)}{(2I-3)\cdot(2I-1)}$$

$$cos\vartheta_{\gamma 2} = cos\vartheta_\gamma \cdot cos\vartheta_2 + sin\vartheta_\gamma \cdot sin\vartheta_2 \cdot cos\left(\varphi_\gamma - \varphi_2\right)$$

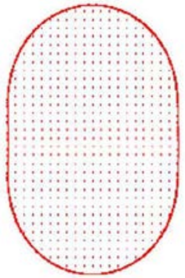
Coulomb excitation

particle – γ-ray coincidence measurement



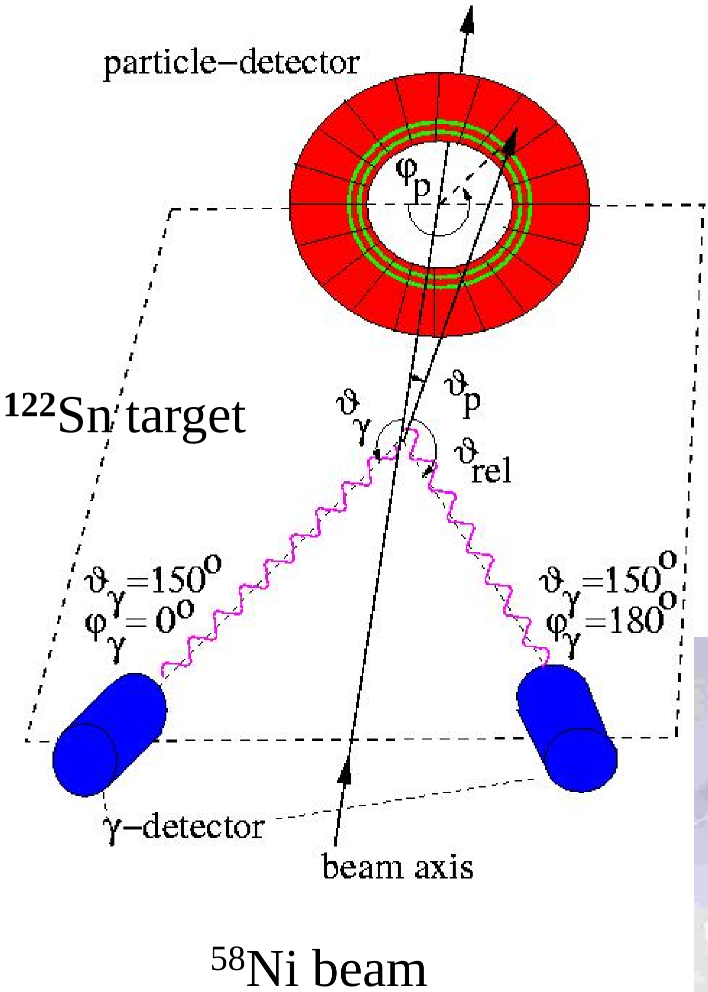


$4^+ \rightarrow 2^+$

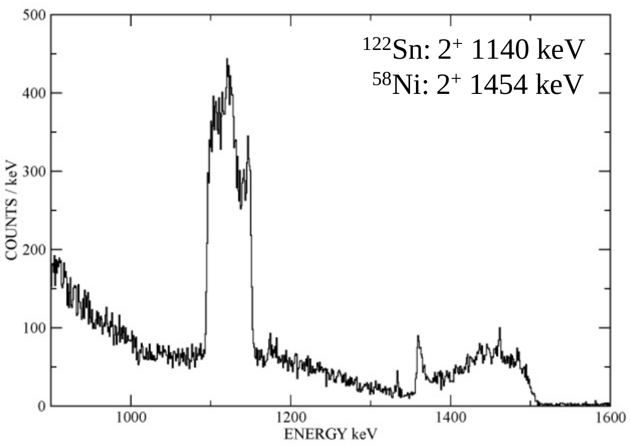


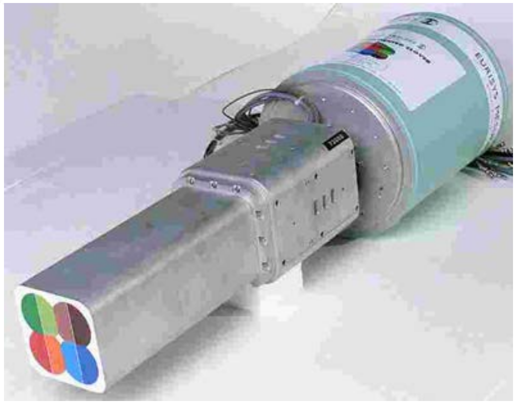
$12^+ \rightarrow 11^-$

Coulomb excitation at IUAC



$^{58}Ni \rightarrow {}^{122}Sn$ at 175 MeV



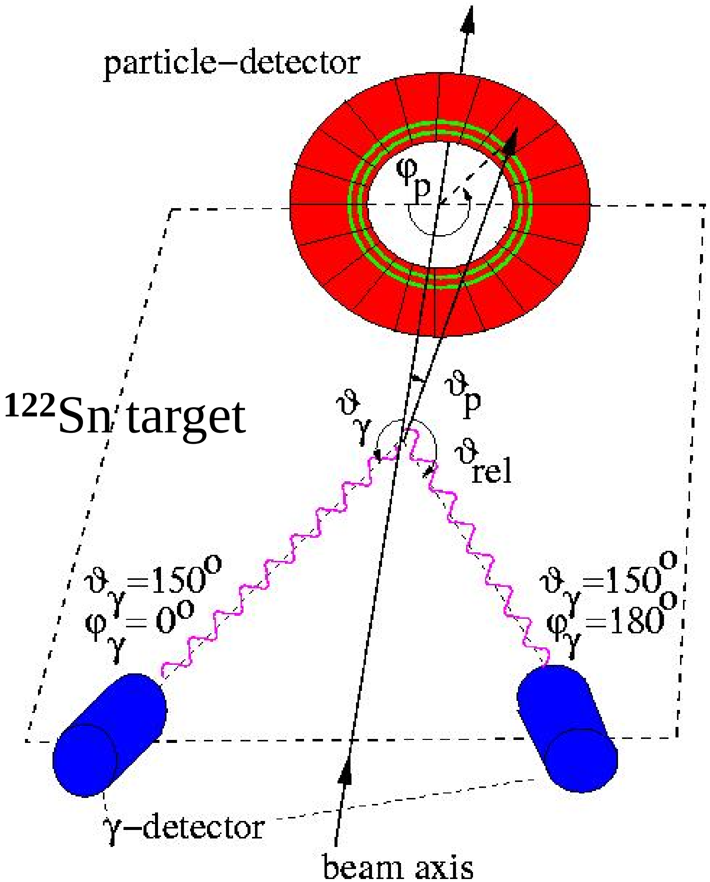


Clover Ge detector

R. Kumar et al., Phys. Rev. C81, 024306 (2010)   M. Saxena et al., Phys. Rev. C90, 024316 (2014)

Doppler shift correction

^{58}Ni + ^{122}Sn at 175 MeV



^{58}Ni beam

delay line: inner – outer contact ≈ tanϑ

$$tan\vartheta = \frac{tan45^0 - tan15^0}{ch_2 - ch_1} \cdot (ch - ch_1) + tan15^0$$

φ-segmentation : 36^0, 72^0, 108^0, etc

^{58}Ni projectile measured with PPAC (^{122}Sn target excitation)

index 1 ≡ projectile (^{58}Ni) index 2 ≡ target nucleus (^{122}Sn)

$$v_{cm} = 0.04634 \cdot (1 + A_2/A_1)^{-1}\sqrt{E_{lab}/A_1} \quad (= 0.02594)$$

$$\theta_{cm} = \vartheta_1 + arcsin\left(\frac{A_1}{A_2} sin\vartheta_1\right)$$

$$\vartheta_2 = 0.5 \cdot (180^0 - \theta_{cm})$$

$$v_2 = 2 \cdot v_{cm} \cdot cos\vartheta_2$$

$$cos\vartheta_{\gamma 2} = cos\vartheta_\gamma \cdot cos\vartheta_2 - sin\vartheta_\gamma \cdot sin\vartheta_2 \cdot cos(\varphi_\gamma - \varphi_1)$$

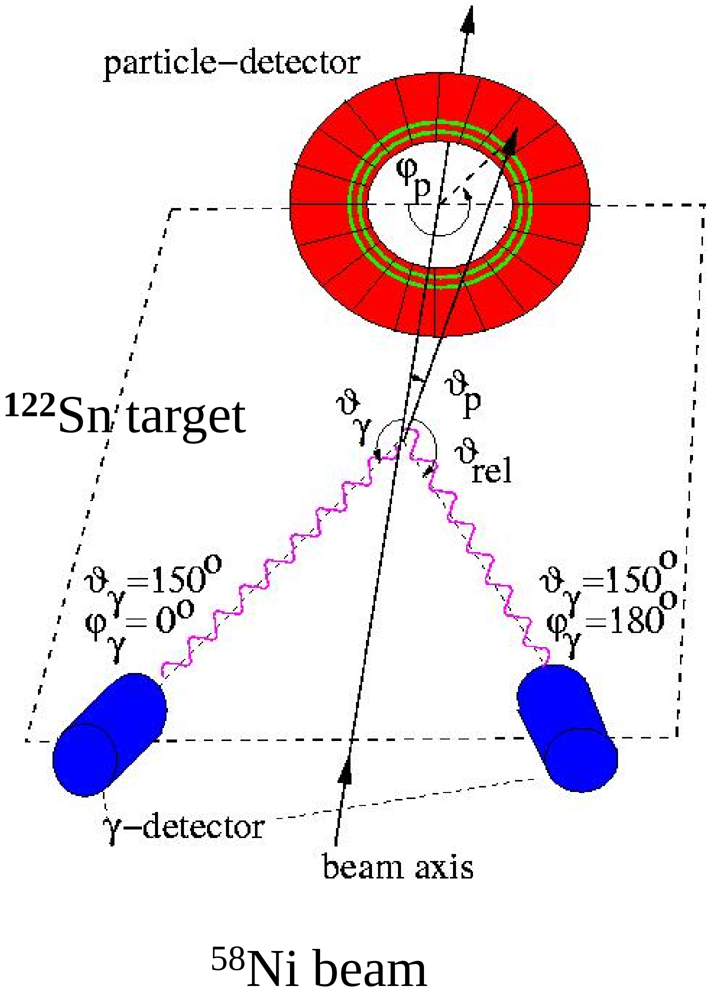
$$cos(\varphi_\gamma - \varphi_1) = cos\varphi_\gamma \cdot cos\varphi_1 + sin\varphi_\gamma \cdot sin\varphi_1$$

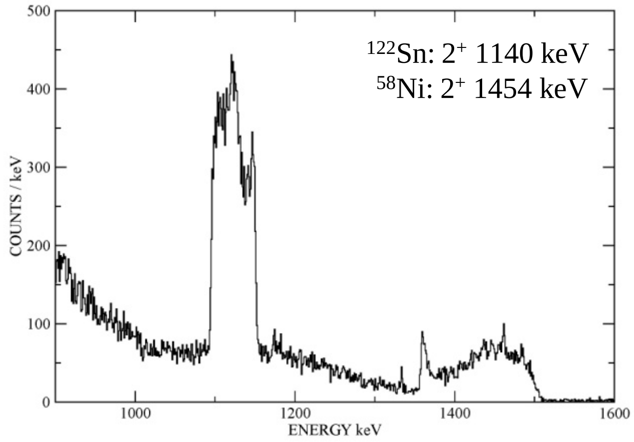
$$\frac{E_{\gamma 0}}{E_\gamma} = \frac{1 - v_2 \cdot cos\vartheta_{\gamma 2}}{\sqrt{1 - v_2^2}}$$

D. Schwalm et al. Nucl.Phys. A192 (1972), 449

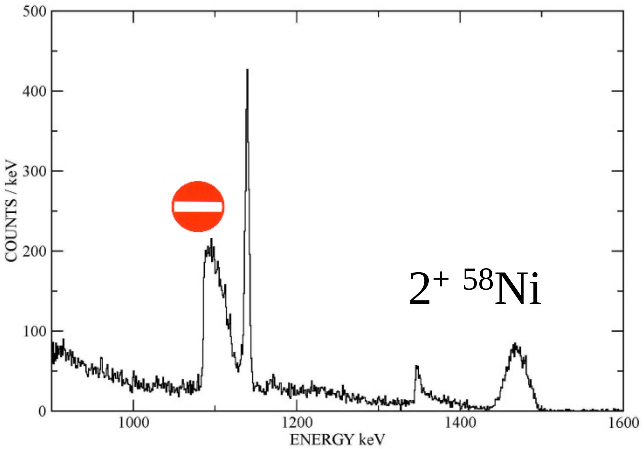
Doppler shift correction

^{58}Ni + ^{122}Sn at 175 MeV



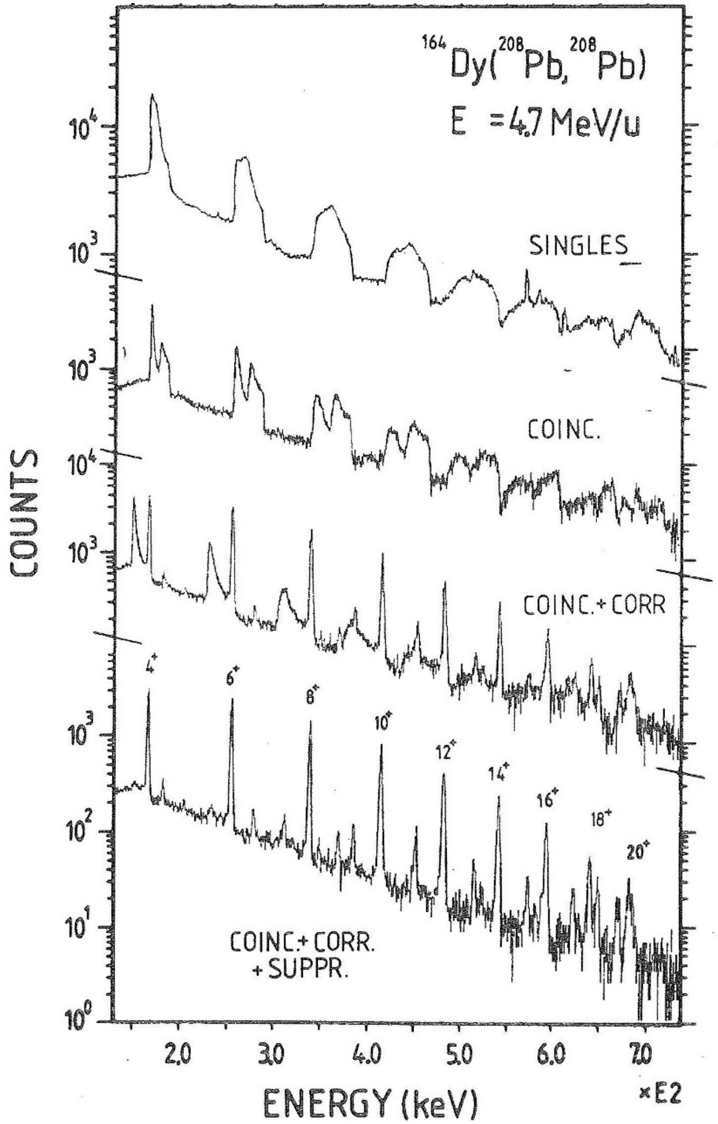


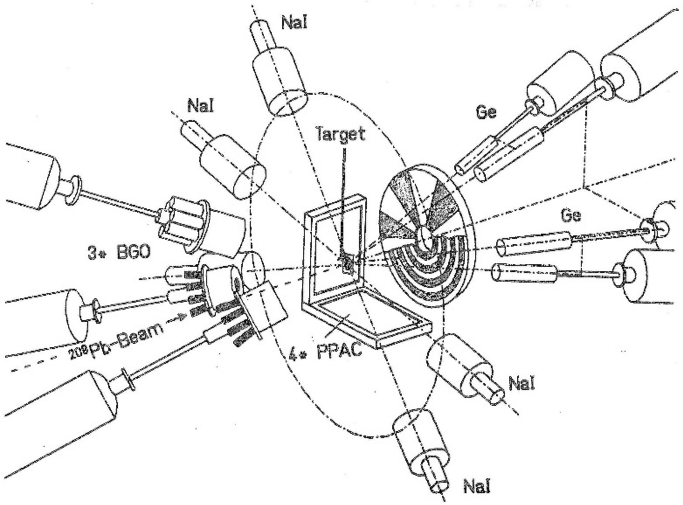
2^+ ^{122}Sn

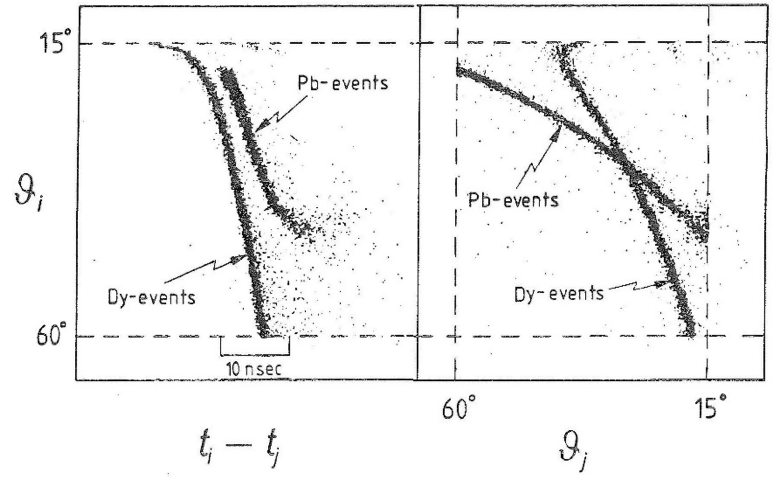


Doppler shift correction

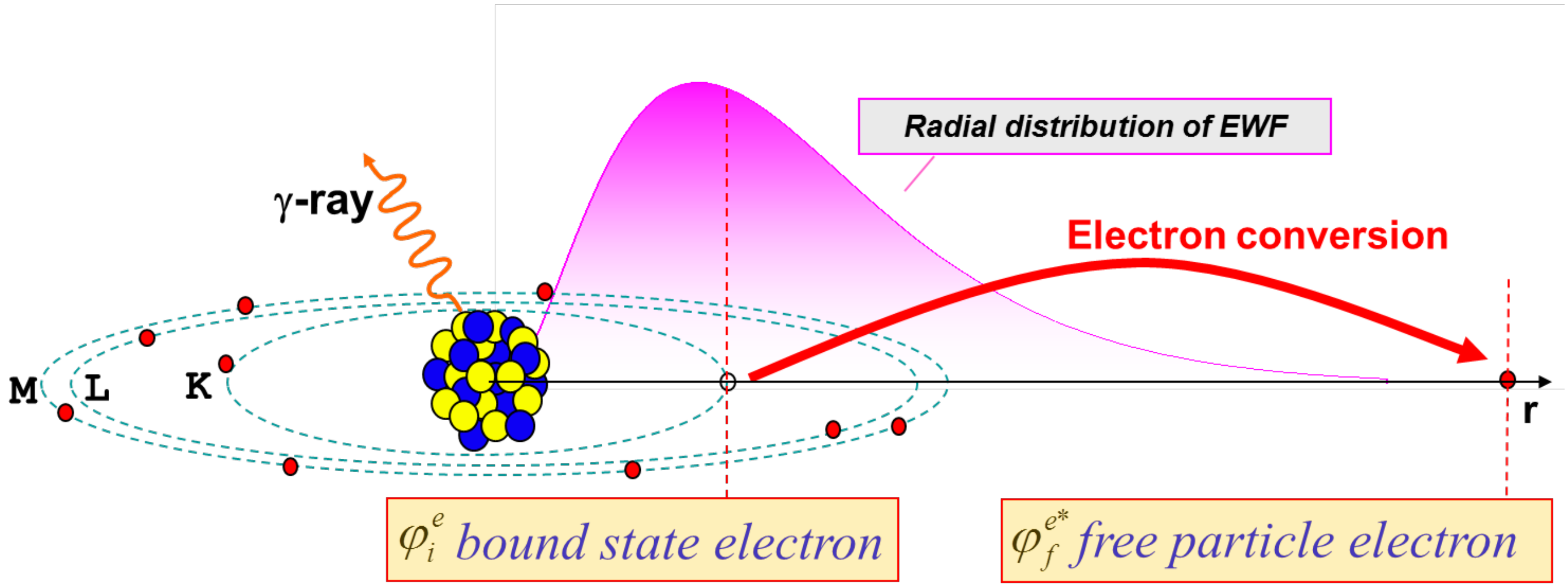
$^{208}Pb + ^{164}Dy$ at 978 MeV







Conversion electrons



Energetics of CE-decay (i=K, L, M,….)

$E_i = E_f + E_{ce,i} + E_{BE,i}$

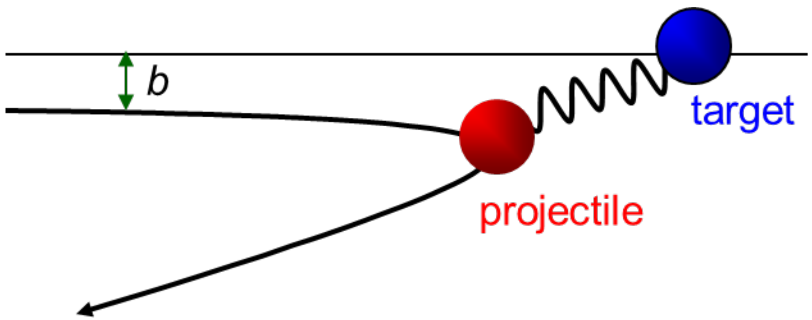
γ- and CE-decays are independent; transition probability (λ ~ Intensity)

$$\lambda_T = \lambda_\gamma + \lambda_{CE} = \lambda_\gamma + \lambda_K + \lambda_L + \lambda_M \ldots\ldots$$

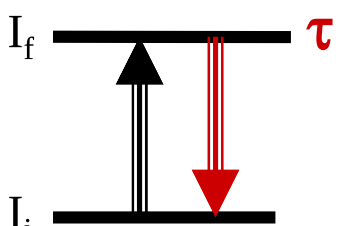
Conversion coefficient

$$a_i = \lambda_{CE,i} / \lambda_\gamma$$

The reorientation effect

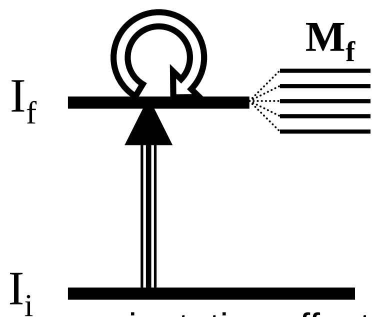


The excitation cross section is a direct measure of the $E\lambda$ matrix elements.



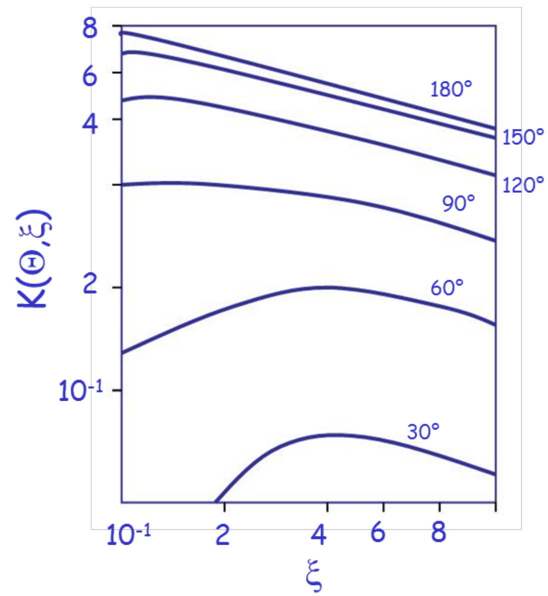
1st order:

$$a^{(1)}_{i\to f} \propto \langle I_f \| \mathbf{M}(E2) \| I_i \rangle$$



reorientation effect:

$$a^{(2)}_{i\to f} \propto \langle I_f \| \mathbf{M}(E2) \| I_f \rangle \langle I_f \| \mathbf{M}(E2) \| I_i \rangle$$



$$P^{(2)}_{0\to2}(\theta,\xi) = P^{(1)}_{0\to2}(\theta,\xi) \cdot \left[1 + \sqrt{\frac{7}{2\pi}\frac{5}{4}} \cdot \frac{A_p}{Z_p} \cdot \frac{\Delta E}{1 + {A_p}/{A_t}} \cdot Q_2 \cdot K(\theta,\xi) \right]$$

$$Q(2^+) = -\sqrt{\frac{2\pi}{7}\frac{4}{5}} \cdot \langle 2 \| M(E2) \| 2 \rangle$$

Shape coexistence in ^{74}Kr