LINEAR POLARIZATION MEASUREMENTS OF GAMMA RAYS FOLLOWING ALPHA DECAY

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Historical

Definition of Gamma-Ray Linear Polarization

$$P(\theta) = \frac{W(\theta,\xi=0^\circ) - W(\theta,\xi=90^\circ)}{W(\theta,\xi=0^\circ) + W(\theta,\xi=90^\circ)}$$

$\underline{P(\theta) = +1}$

$$W(\theta,\xi=0^\circ)=100\% \qquad W(\theta,\xi=90^\circ)=0\%$$

$\underline{P(\theta) = -1}$

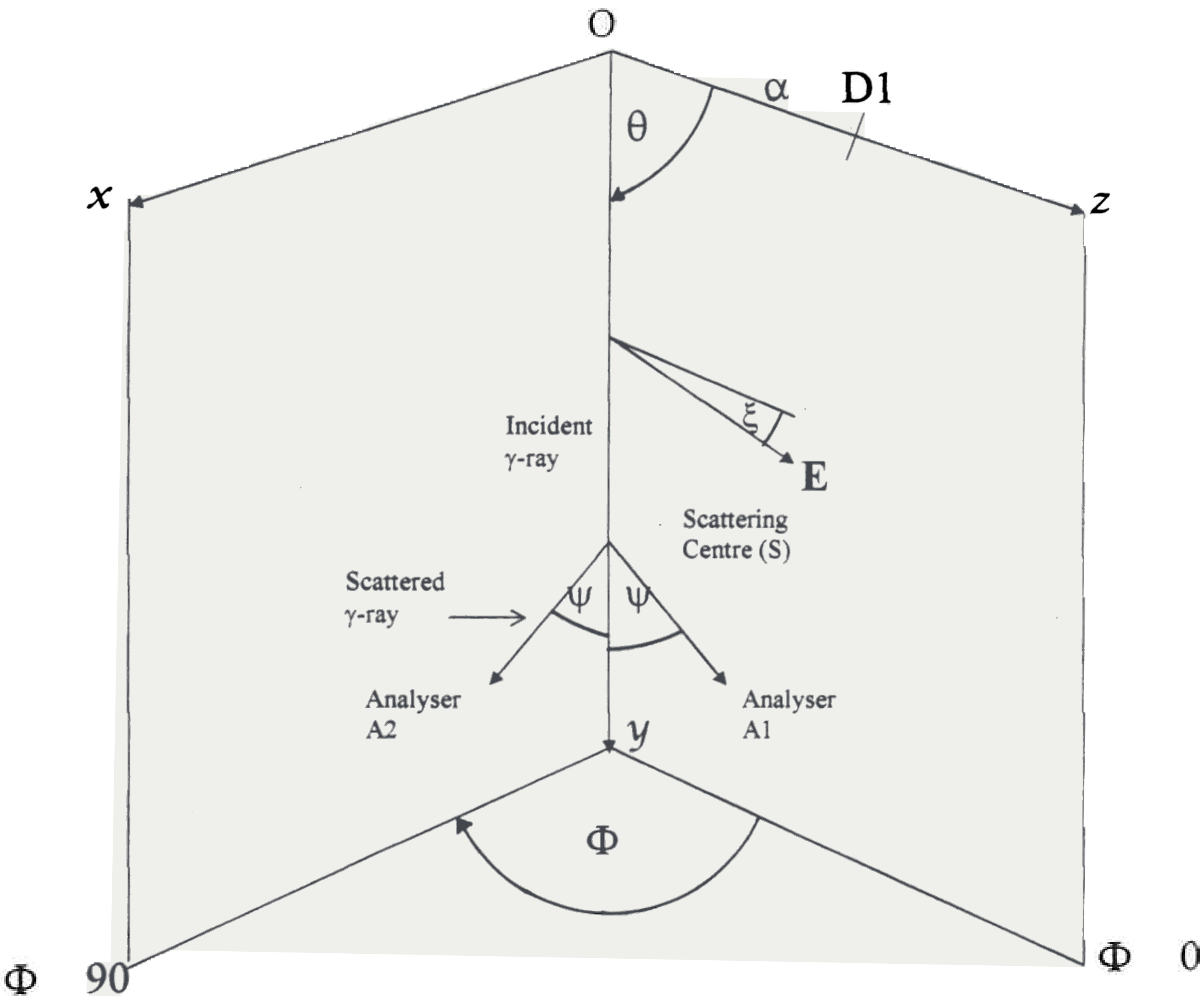
$$W(\theta,\xi=0^\circ)=0\% \qquad W(\theta,\xi=90^\circ)=100\%$$

$\underline{P(\theta) = 0}$

Electric vector at 45° to the reaction plane.

Gamma-rays are preferentially scattered into the plane, normal to the **E** vector of the incident photon.

i.e. $d\sigma_{90} > d\sigma_0$.



$$P(\theta) = \left[\frac{N(\theta,\Phi=90^\circ)-N(\theta,\Phi=0^\circ)}{N(\theta,\Phi=90^\circ)+N(\theta,\Phi=0^\circ)}\right]\left[\frac{d\sigma_{90}+d\sigma_0}{d\sigma_{90}-d\sigma_0}\right]$$

$$= \frac{Asymmetry}{Polarization\ Sensitivity} = \frac{A}{Q(E_\gamma)}$$

Theory (Klein-Nishina) gives

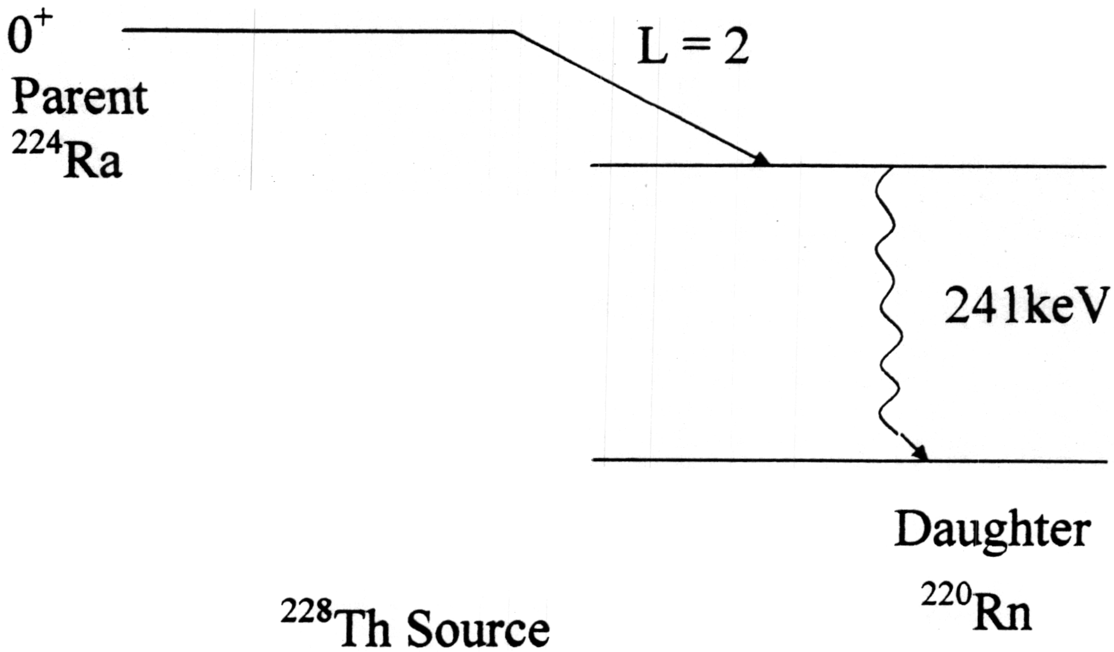
$$Q(E_\gamma) = \frac{\sin^2\psi}{\frac{E_\gamma}{E'}+\frac{E'}{E_\gamma}-\sin^2\psi}$$

where E_γ, E' are incident and scattered gamma-ray energies.

Compton Scattering Formula gives

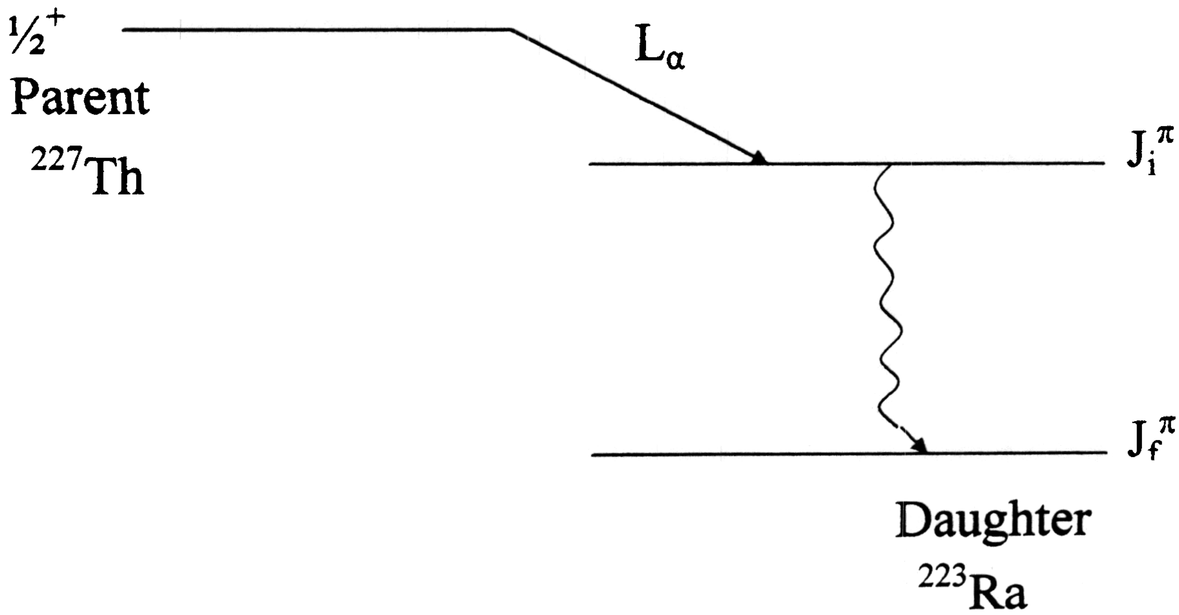
$$\frac{E_\gamma}{E'} = 1+\frac{E_\gamma(1-\cos\psi)}{m_e c^2}$$

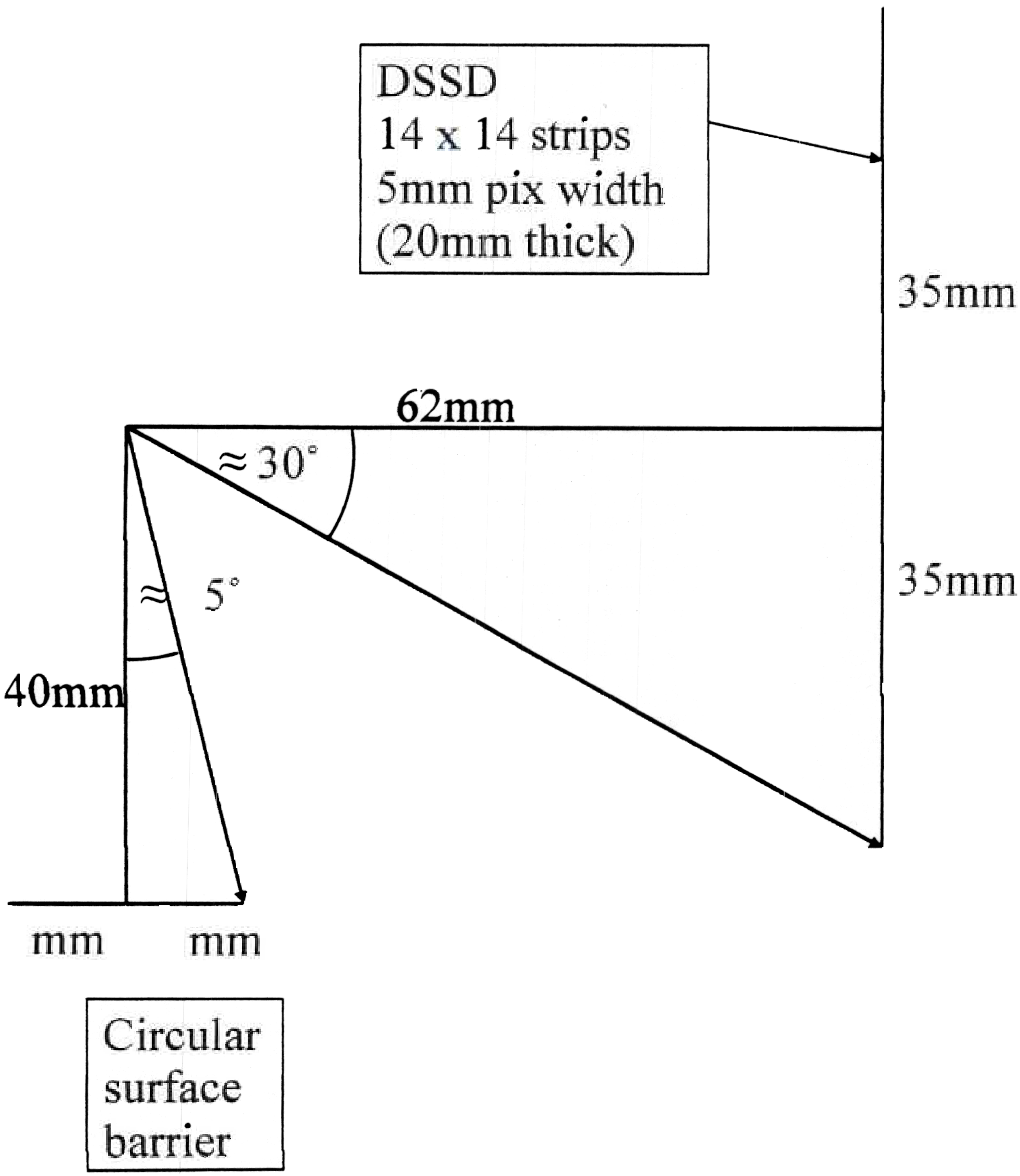
(a) α-decay from even-even nuclei



^{228}Th Source

Also high alignment from ^{227}Th decay




DSSD
14 x 14 strips
5mm pix width
(20mm thick)
35mm
62mm
≈ 30°
35mm
≈ 5°
40mm
mm
mm
Circular
surface
barrier

For pure E2 radiation, the general polarization formula is

$$P(\theta) = \frac{\frac{1}{2}a_2 P_2^{\,2}(\cos\theta) - \frac{1}{12}a_4 P_4^{\,2}(\cos\theta)}{1 + a_2 P_2(\cos\theta) + a_4 P_4(\cos\theta)}$$

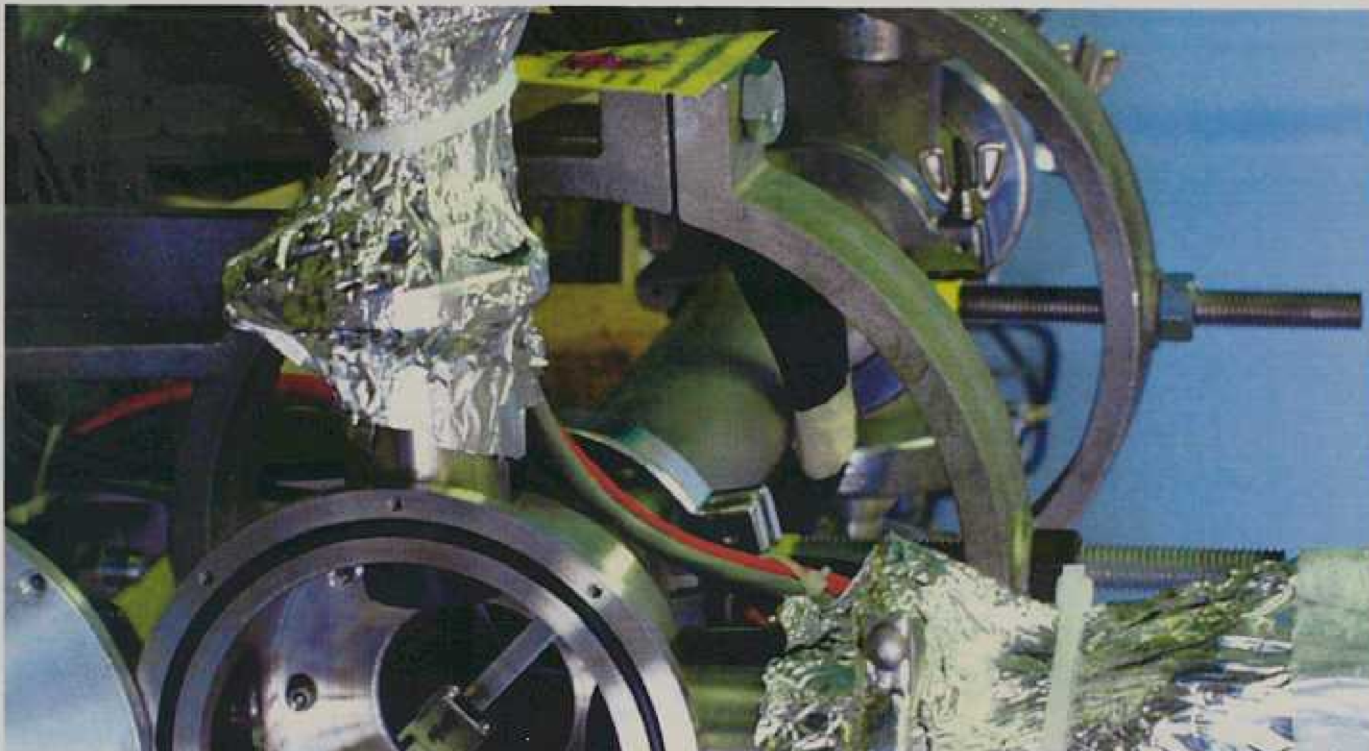
$$\frac{\frac{1}{2}a_2(3-3\cos^2\theta) - \frac{1}{12}a_4\frac{15}{2}(-1+8\cos^2\theta - \cos^4\theta)}{1 + a_2(3\cos^2\theta - 1)/2 + a_4(35\cos^4\theta - 30\cos^2\theta + 3)/8}$$

$$= \frac{3a_2\sin^2\theta + \frac{5}{4}a_4\sin^2\theta - \frac{35}{16}a_4\sin^2 2\theta}{2 + 2a_2 + 2a_4 - 3a_2\sin^2\theta - \frac{5}{4}a_4\sin^2\theta - \frac{35}{16}a_4\sin^2 2\theta}$$

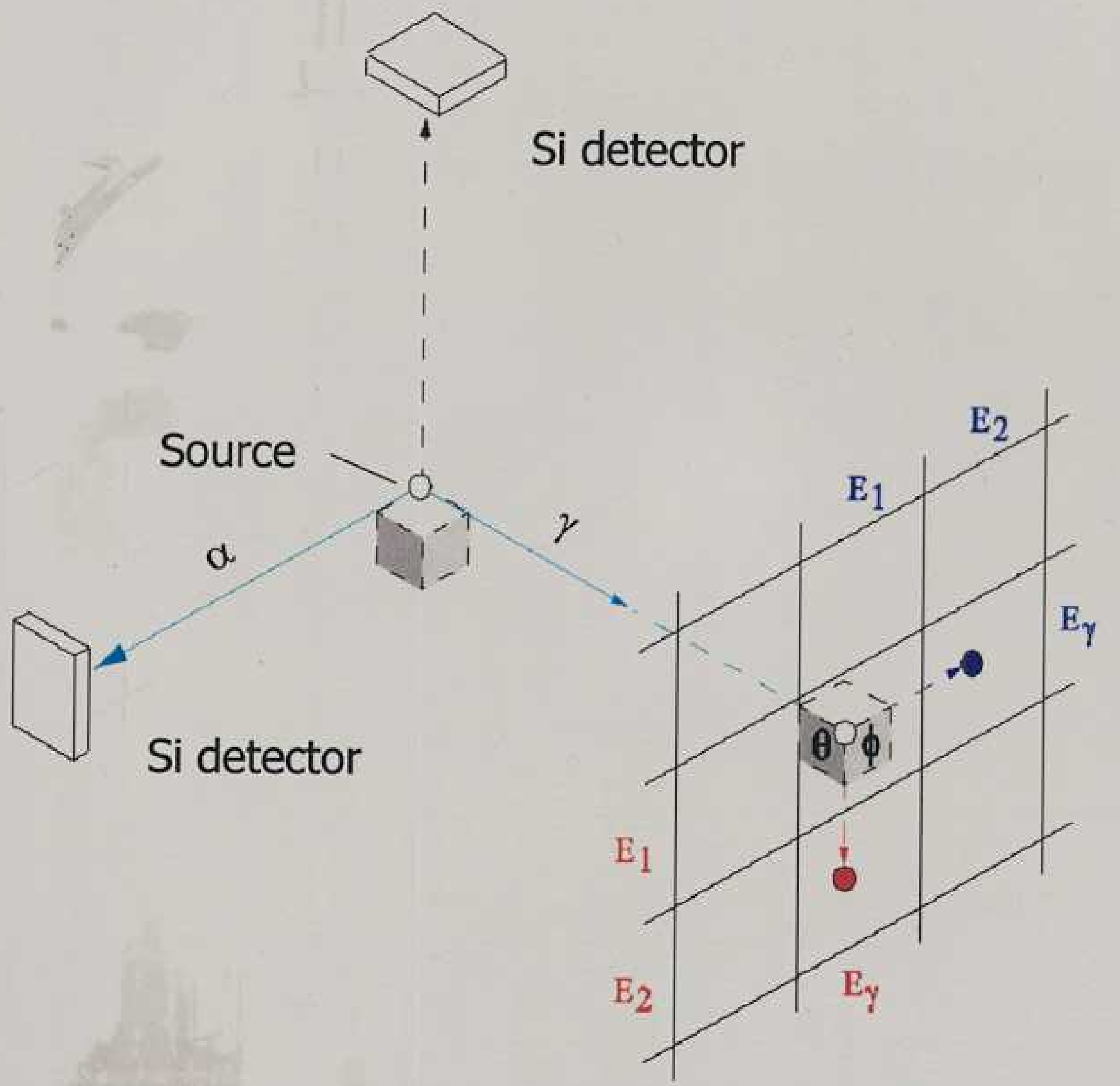
If $2 + 2a_2 + 2a_4 = 0$ and $3a_2 + 5/4\, a_4 = 0$, then $P(\theta) = 1$ for all θ (except $\theta = 0°$ and $\theta = 180°$ again).

Solution is $a_2 = 5/7$ and $a_4 = -12/7$, which occurs for 100% population of m = 0 substate in $J = 2^+$ state followed by pure E2 transition to a $J = 0^+$ state

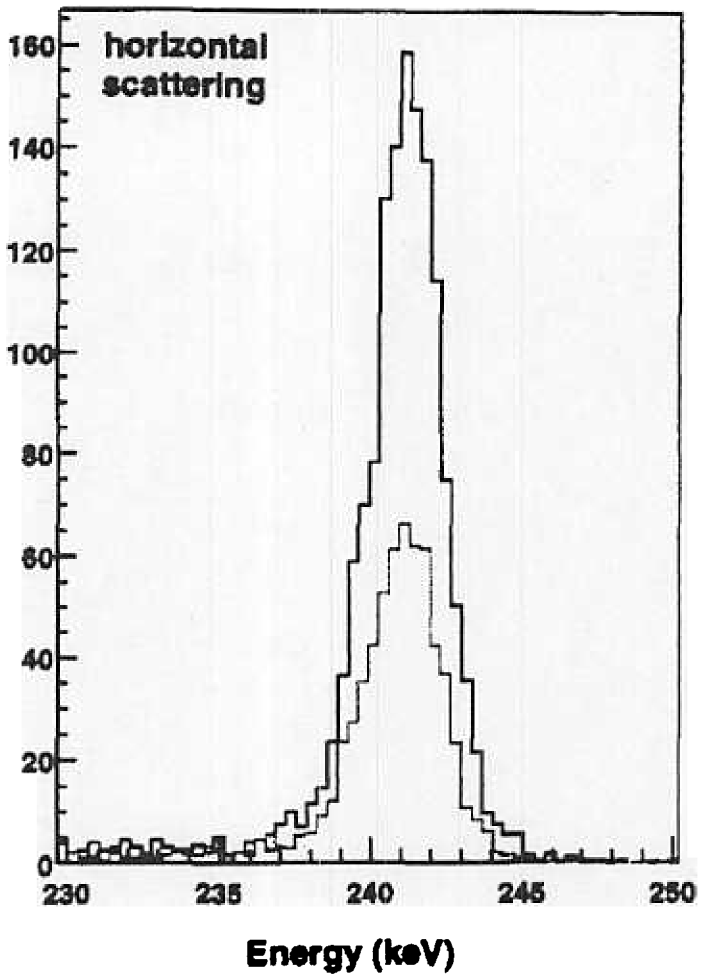
How do we achieve this?

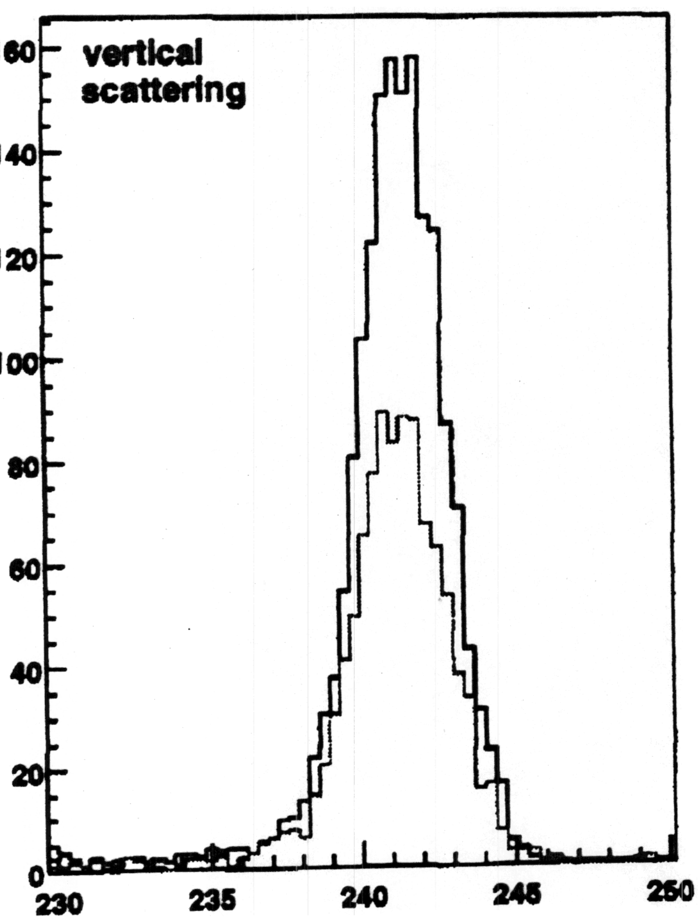

a2


ARGONNE
HpGeDSSD



Si detector
Source
α
γ
Si detector
E2
E1
Eγ
θ
ϕ
E1
E2
Eγ


horizontal
scattering
160
140
120
100
80
60
40
20
0
230
235
240
245
250
Energy (keV)


vertical
scattering
160
140
120
100
80
60
40
20
0
230
235
240
245
250

Polarization sensitivities

Nearest neighbour scatters

$Q_H = 0.36 \pm 0.01$ $\quad$ $Q_V = 0.27 \pm 0.1$

$Q_H = 0.41Q_0$ $\quad$ $Q_V = 0.31Q_0$

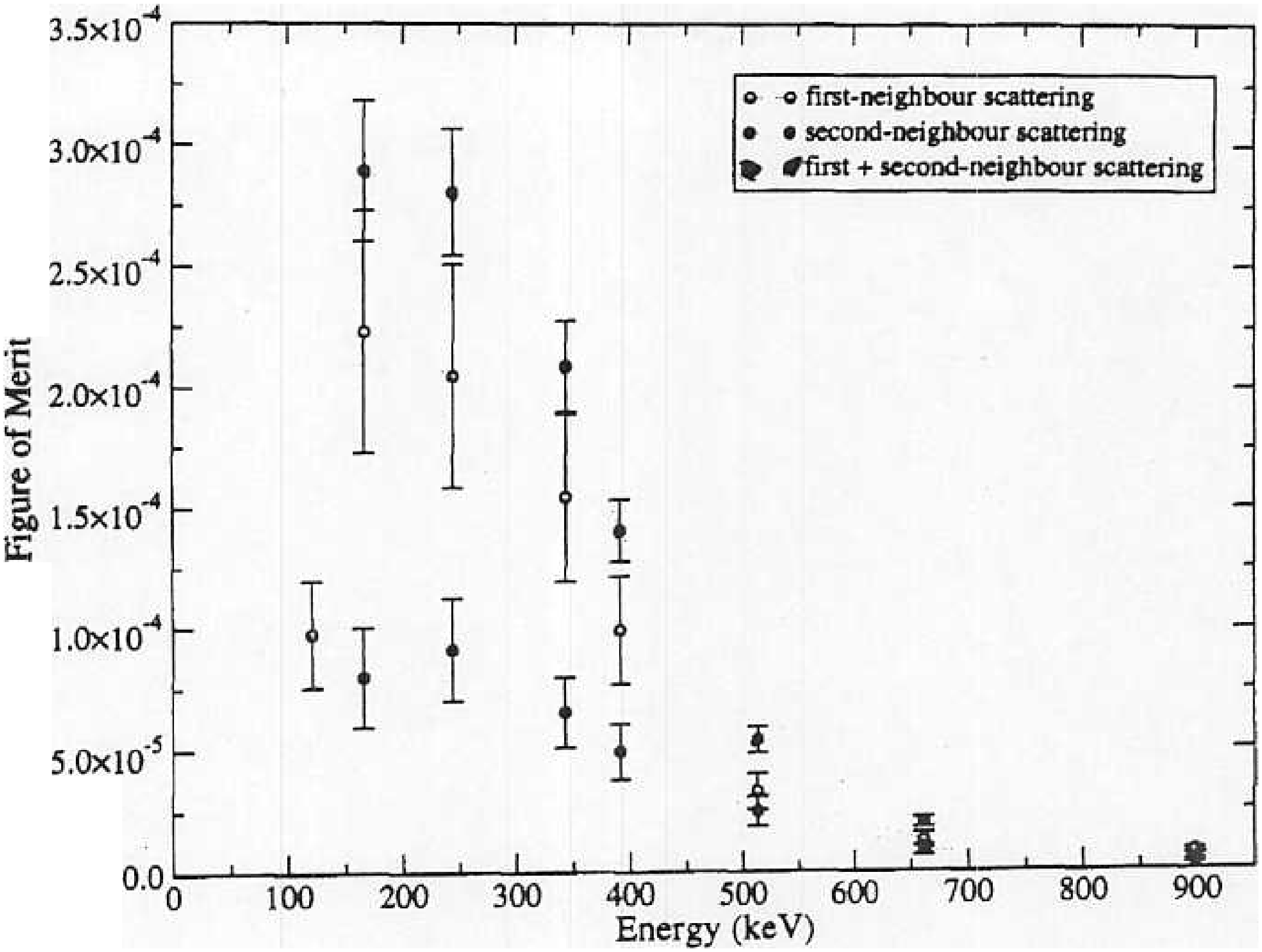
Second neighbour events

$= 0.55 \pm 0.02$ $\quad$ $Q_V = 0.54 \pm 0.02$

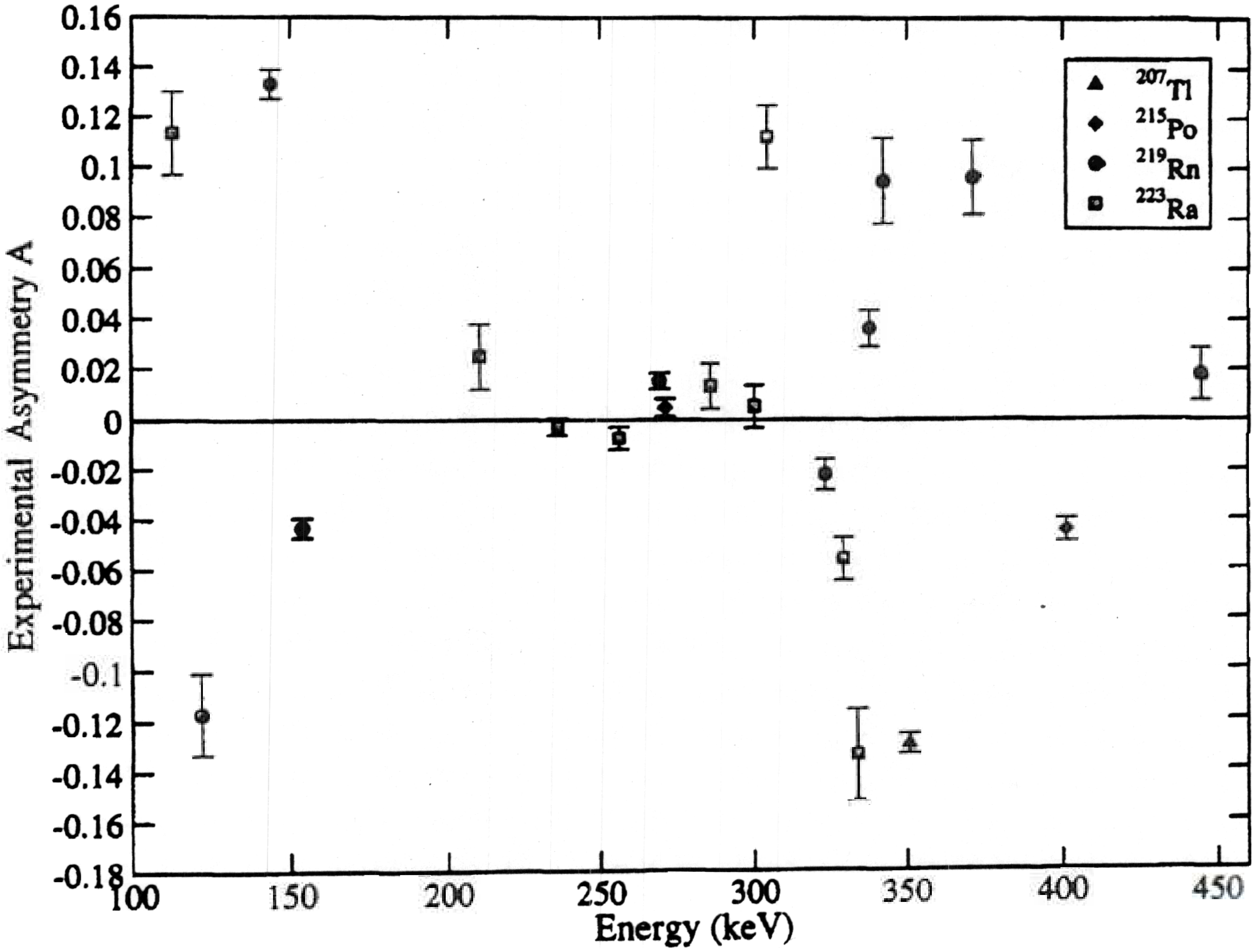
$= 0.63Q_0$ $\quad$ $Q_V = 0.62Q_0$

Third neighbour events

$Q_H = 0.74Q_0$ $\quad$ $Q_V = 0.73Q_0$



first-neighbour scattering
second-neighbour scattering
first + second-neighbour scattering
Figure of Merit
Energy (keV)
3.5×10⁻⁴
3.0×10⁻⁴
2.5×10⁻⁴
2.0×10⁻⁴
1.5×10⁻⁴
1.0×10⁻⁴
5.0×10⁻⁵
0.0
0
100
200
300
400
500
600
700
800
900



0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
100
150
200
250
300
350
400
450
Energy (keV)
Experimental Asymmetry A
207Tl
215Po
219Rn
223Ra