Compound-Nuclear Reactions and Related Topics (CNR*24)

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Semi-classical treatment of photon cascades in nuclei

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- based on work done with Thomas Døssing (Niels Bohr Institute, Copenhagen):

J. Randrup and Thomas Døssing, Physical Review C **109**, 054613 (2024)

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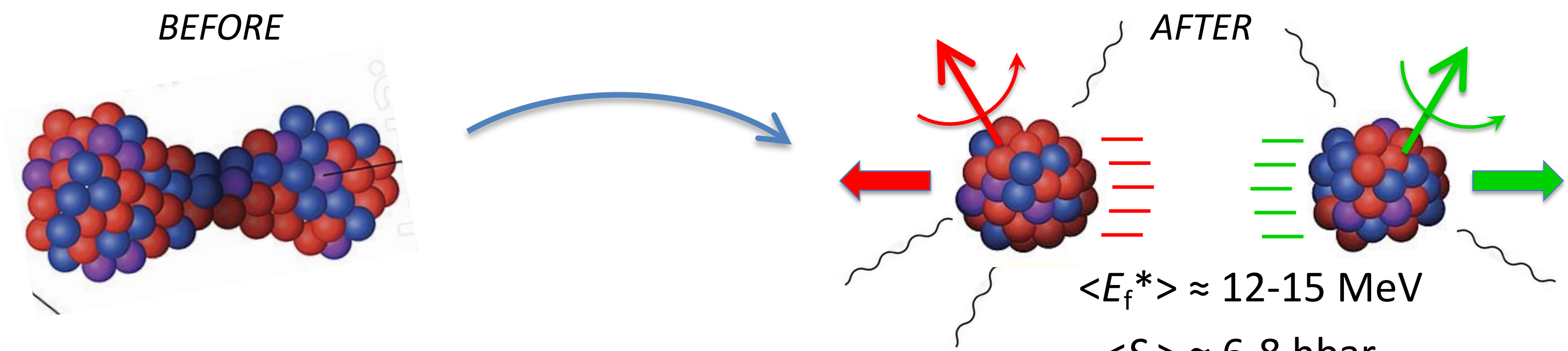
MOTIVATION



The (correlated) fragment spin distribution
$P(\boldsymbol{S}_L,\boldsymbol{S}_H)$ is sensitive to the fission mechanism

The fragment spin *magnitudes* and *directions*
can be probed by suitable *photon* measurements

Example: The fragment spin direction is ≈ perpendicular to the fission direction [Wilhelmy *et al.*] => *wriggling* & *bending* modes dominate — PRC **5**, 2041 (1972)

Example: A modern Wilhelmy-type experiment can reveal the relative importance of *twisting* — PRC **106**, 014609 (2022)

Example: The relative role of *wriggling* & *bending* can be determined by *helicity*-tagged photons — PRC **106**,014609 (2022)

Such studies need *accurate calculations of photon cascades*

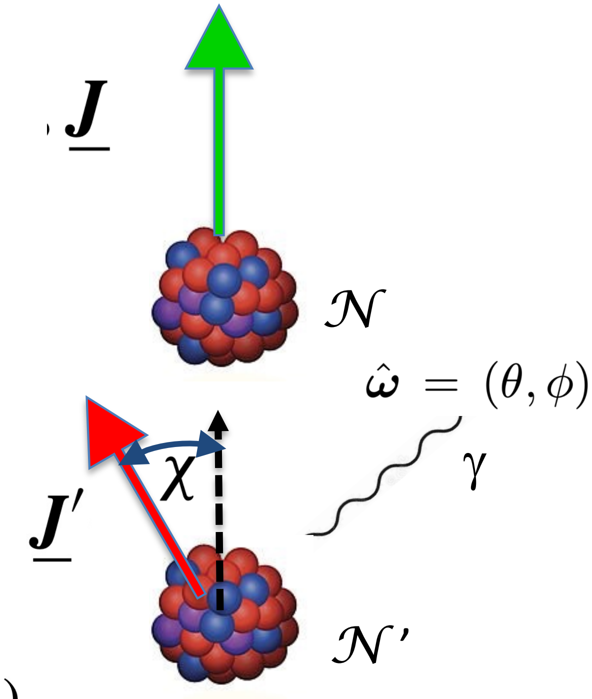
- in the context of *event-by-event* Monte-Carlo simulations — FREYA, …

The emitted photon removes angular momentum

Before emission:

The (expectation value of the) angular momentum is *directed* along the *z* direction:

$$\langle \mathcal{N} | \hat{\boldsymbol{J}} | \mathcal{N} \rangle \ = \ \underline{\boldsymbol{J}} = J\hat{\boldsymbol{z}}$$



After emission:

The (expectation value of the) angular momentum is *tilted* relative to the *z* direction:

$$\langle \mathcal{N}' | \hat{\boldsymbol{J}} | \mathcal{N}' \rangle \ = \ \underline{\boldsymbol{J}}'(\hat{\boldsymbol{\omega}}) = (\underline{J}'_\perp(\theta)\cos\phi,\ \underline{J}'_\perp(\theta)\sin\phi,\ \underline{J}'_z(\theta))$$

Tilting angle $\chi(\theta)$: $\quad \tan\chi = \underline{J}'_\perp(\theta)/\underline{J}'_z(\theta)$

Approximation ("semi-classical"):

The mother state is *maximally aligned* along $\underline{\boldsymbol{J}}$: $\quad |\mathcal{N}\rangle = |\alpha; J, M = J\rangle_{\hat{\boldsymbol{z}}}$

The daughter state is *maximally aligned* along $\underline{\boldsymbol{J}}'(\hat{\boldsymbol{\omega}})$: $\quad |\mathcal{N}'(\hat{\boldsymbol{\omega}})\rangle = |\alpha'; J', J'\rangle_{\hat{\boldsymbol{z}}'}$

$E1$ photon emission

✓ $J'=J$-1: Stretched

Daughter sate:

$$\langle\hat{\boldsymbol{\omega}}_1|\mathcal{N}'\rangle^{E1}_{J-1,h_1} = |\alpha';J-1,J-1\rangle_{\hat{z}}$$

Angular distribution:

$$P_1(\theta_1) \sim d^1_{1,h_1}(\theta_1)^2$$

Tilting: none

$$\underline{J}'_\perp = 0 \quad \Rightarrow \quad \chi = 0.$$

$E1$ photon emission

✓ *J'*=*J*-1: Stretched

Daughter sate:

$$\langle\hat{\boldsymbol{\omega}}_1|\mathcal{N}'\rangle^{E1}_{J-1,h_1} = |\alpha';J-1,J-1\rangle_{\hat{z}}$$

Angular distribution:

$$P_1(\theta_1) \sim d^1_{1,h_1}(\theta_1)^2$$

Tilting: none

$$\underline{J}'_\perp = 0 \quad \Rightarrow \quad \chi = 0.$$

J'=*J*

Daughter state:

$$\langle\hat{\boldsymbol{\omega}}_1|\mathcal{N}'\rangle^{E1}_{J,h_1} = h_1 c_0(\theta_1)|\alpha';J,J\rangle - c_1(\theta_1)e^{i\phi_1}|\alpha';J,J-1\rangle$$

$$c_0 \sim \left[\frac{J}{J+1}\right]^{\frac{1}{2}} h_1 d^1_{0,h_1}(\theta_1),$$

$$c_1 \sim \left[\frac{1}{J+1}\right]^{\frac{1}{2}} d^1_{1,h_1}(\theta_1)$$

Angular distribution:

$$P_1(\hat{\boldsymbol{\omega}}_1) \sim \frac{J}{J+1} d^1_{0,h_1}(\theta_1)^2 + \frac{1}{J+1} d^1_{1,h_1}(\theta_1)^2$$

Tilting:

$$\underline{J}'_\perp(\theta_1) = -h_1\sqrt{2J}c_0c_1, \quad \underline{J}'_z(\theta_1) = Jc_0^2 + (J-1)c_1^2 \quad \Rightarrow \quad \chi(\theta)$$

$E1$ photon emission

✓ ## $J'=J-1$: Stretched

Daughter sate: $$\langle\hat{\omega}_1|\mathcal{N}'\rangle^{E1}_{J-1,h_1} = |\alpha';J-1,J-1\rangle_{\hat{z}}$$

Angular distribution: $$P_1(\theta_1) \sim d^1_{1,h_1}(\theta_1)^2$$

Tilting: none $$J'_\perp = 0 \quad \Rightarrow \quad \chi = 0.$$

$J'=J$

Daughter state: $$\langle\hat{\omega}_1|\mathcal{N}'\rangle^{E1}_{J,h_1} = h_1 c_0(\theta_1)|\alpha';J,J\rangle - c_1(\theta_1)e^{i\phi_1}|\alpha';J,J-1\rangle$$

$$c_0 \sim \left[\frac{J}{J+1}\right]^{\frac{1}{2}} h_1 d^1_{0,h_1}(\theta_1),$$

$$c_1 \sim \left[\frac{1}{J+1}\right]^{\frac{1}{2}} d^1_{1,h_1}(\theta_1)$$

Angular distribution: $$P_1(\hat{\omega}_1) \sim \frac{J}{J+1} d^1_{0,h_1}(\theta_1)^2 + \frac{1}{J+1} d^1_{1,h_1}(\theta_1)^2$$

Tilting: $$J'_\perp(\theta_1) = -h_1\sqrt{2J}c_0c_1, \quad J'_z(\theta_1) = Jc_0^2 + (J-1)c_1^2 \quad \Rightarrow \quad \chi(\theta)$$

$J'=J+1$: Anti-stretched

Daughter state: $$\langle\hat{\omega}_1|\mathcal{N}'\rangle^{E1}_{J+1,h_1} = c_-(\theta_1)e^{-i\phi_1}|\alpha';J+1,J+1\rangle - h_1c_0(\theta_1)|\alpha';J+1,J\rangle + c_+(\theta_1)e^{i\phi_1}|\alpha';J+1,J-1\rangle$$

$$c_- \sim \left[\frac{2J+1}{2J+3}\right]^{\frac{1}{2}} d^1_{-1,h_1}(\theta_1) \qquad c_0 \sim \left[\frac{2J+1}{(2J+3)(J+1)}\right]^{\frac{1}{2}} h_1 d^1_{0,h_1}(\theta_1) \qquad c_+ \sim \left[\frac{1}{(2J+3)(J+1)}\right]^{\frac{1}{2}} d^1_{+1,h_1}(\theta_1)$$

Angular distribution: $$P_1(\hat{\omega}_1) \sim \frac{2J+1}{2J+3} d^1_{-1,h_1}(\theta_1)^2 + \frac{(2J+1)d^1_{0,h_1}(\theta_1)^2}{(J+1)(2J+3)} + \frac{d^1_{1,h_1}(\theta_1)^2}{(J+1)(2J+3)}$$

$$J'_\perp(\theta_1) = -h_1c_0[\sqrt{2J+2}c_- + \sqrt{4J+2}c_+] \qquad J'_z(\theta_1) = (J+1)c_-^2 + Jc_0^2 + (J-1)c_-^2 \quad \Rightarrow \quad \chi(\theta)$$

$E1$-$E1$ photon cascades

$$\langle\hat{\omega}_1\hat{\omega}_2|f\rangle = \sum_{J_1\mu_1J_2\mu_2}\langle J_1M_11\mu_1|J_0J_0\rangle\,\langle J_2M_21\mu_2|J_1M_1\rangle\,d^1_{\mu_1h_1}(\theta_1)\,\mathrm{e}^{i\mu_1\phi_1}d^1_{\mu_2h_2}(\theta_2)\,\mathrm{e}^{i\mu_2\phi_2}|J_2,M_2\rangle$$

If different ΔJ do not interfere: $J_0\to J_1\to J_2$

$$\langle\hat{\omega}_1\hat{\omega}_2|f\rangle_{J_1J_2} \;=\; \sum_{\mu_1=-1}^{\mu_1=+1}\langle J_1M_11\mu_1|J_0J_0\rangle\,d^1_{\mu_1h_1}(\theta_1)\,\mathrm{e}^{i\mu_1\phi_1}\sum_{\mu_2=-1}^{\mu_2=+1}\langle J_2M_21\mu_2|J_1M_1\rangle\,d^1_{\mu_2h_2}(\theta_2)\,\mathrm{e}^{i\mu_2\phi_2}|J_2,M_2\rangle$$

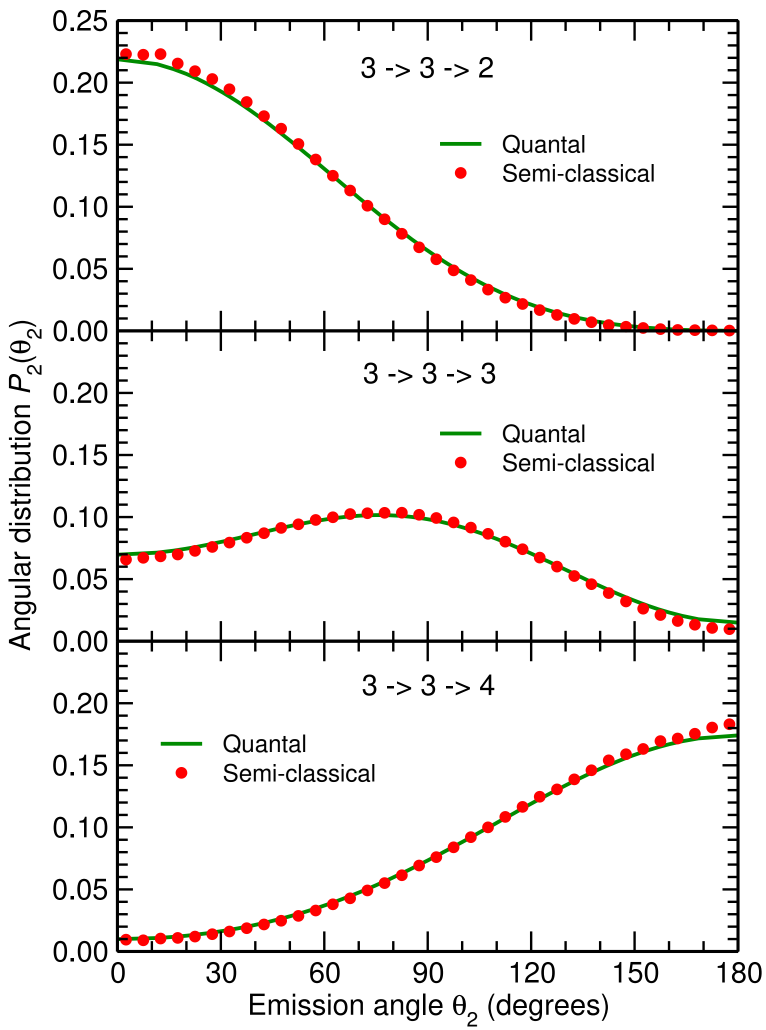
$$\begin{aligned}
(-,-)\;&:\;(J-1,J-1)\to(J-2,J-2),\\
(-,0)\;&:\;(J-1,J-1)\to(J-1,J-2)+(J-1,J-1)\to(J-1,J-1),\\
(-,+)\;&:\;(J-1,J-1)\to(J,J-2)+(J-1,J-1)\to(J,J-1)+(J-1,J-1)\to(J,J);\\
(0,-)\;&:\;(J,J-1)\to(J-1,J-2)+(J,J-1)\to(J-1,J-1)+(J,J)\to(J-1,J-1),\\
(0,0)\;&:\;(J,J-1)\to(J,J-2)+(J,J-1)\to(J,J-1)+(J,J-1)\to(J,J)\\
&\quad+(J,J)\to(J,J-1)+(J,J)\to(J,J),\\
(0,+)\;&:\;(J,J-1)\to(J+1,J-2)+(J,J-1)\to(J+1,J-1)+(J,J-1)\to(J+1,J)\\
&\quad+(J,J)\to(J+1,J-1)+(J,J)\to(J+1,J)+(J,J)\to(J+1,J+1);\\
(+,-)\;&:\;(J+1,J-1)\to(J,J-2)+(J+1,J-1)\to(J,J-1)+(J+1,J-1)\to(J,J)\\
&\quad+(J+1,J)\to(J,J-1)+(J+1,J)\to(J,J)+(J+1,J+1)\to(J,J),\\
(+,0)\;&:\;(J+1,J-1)\to(J+1,J-2)+(J+1,J-1)\to(J+1,J-1)+(J+1,J-1)\to(J+1,J)\\
&\quad+(J+1,J)\to(J+1,J-1)+(J+1,J)\to(J+1,J)+(J+1,J)\to(J+1,J+1)\\
&\quad+(J+1,J+1)\to(J+1,J)+(J+1,J+1)\to(J+1,J+1),\\
(+,+)\;&:\;(J+1,J-1)\to(J+2,J-2)+(J+2,J-1)\to(J+2,J-1)+(J+2,J-1)\to(J+2,J)\\
&\quad+(J+1,J)\to(J+2,J-1)+(J+1,J)\to(J+2,J)+(J+1,J)\to(J+2,J+1)\\
&\quad+(J+1,J+1)\to(J+2,J)+(J+1,J+1)\to(J+2,J+1)+(J+1,J+1)\to(J+2,J+2).
\end{aligned}$$

J_0	M_0	J_1	M_1	μ_1	J_2	M_2
J_0	M_0	J_0-1	M_0-1	+1	J_0-2	M_0-2
				+1	J_0-1	M_0-2
				0	J_0-1	M_0-1
				-1	J_0	M_0-2
				-1	J_0	M_0-1
				-1	J_0	M_0
J_0	M_0	J_0	M_0-1	+1	J_0-1	M_0-2
				0	J_0-1	M_0-1
				+1	J_0	M_0-2
				0	J_0	M_0-1
				-1	J_0	M_0
				+1	J_0+1	M_0-2
				0	J_0+1	M_0-1
				-1	J_0+1	M_0
J_0	M_0	J_0	M_0	+1	J_0-1	M_0-1
				+1	J_0	M_0-1
				0	J_0	M_0
				+1	J_0+1	M_0-1
				0	J_0+1	M_0
				-1	J_0+1	M_0+1
J_0	M_0	J_0+1	M_0-1	+1	J_0	M_0-2
				0	J_0	M_0-1
				-1	J_0	M_0
				+1	J_0+1	M_0-2
				0	J_0+1	M_0-1
				-1	J_0+1	M_0
				+1	J_0+2	M_0-2
				0	J_0+2	M_0-1
				-1	J_0+2	M_0
J_0	M_0	J_0+1	M_0	+1	J_0	M_0-1
				0	J_0	M_0
				+1	J_0+1	M_0-1
				0	J_0+1	M_0
				-1	J_0+1	M_0+1
				+1	J_0+2	M_0-1
				0	J_0+2	M_0
				-1	J_0+2	M_0+1
J_0	M_0	J_0+1	M_0+1	+1	J_0	M_0
				+1	J_0+1	M_0
				0	J_0+1	M_0+1
			$\rightarrow$	-1	J_0+1	M_0+2
				+1	J_0+2	M_0
				0	J_0+2	M_0+1
				-1	J_0+2	M_0+2

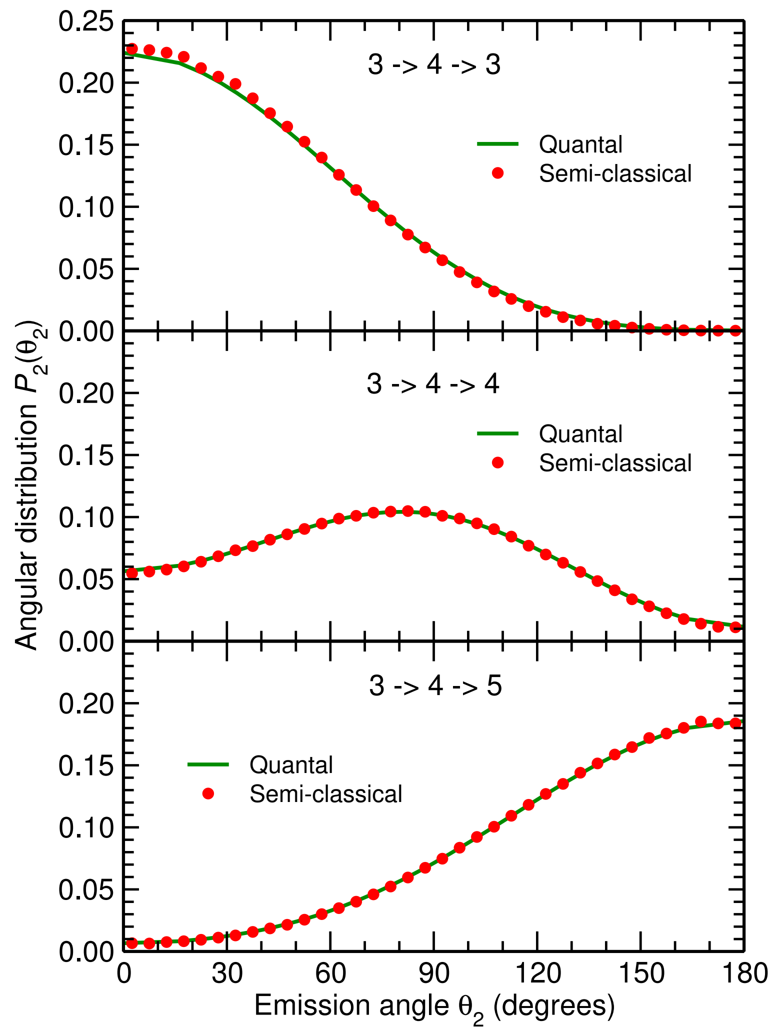
*E*1-*E*1: Angular distribution of the second photon, $dN_2/d\omega_2$

J = 3

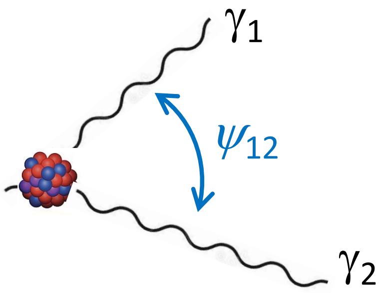
J -> *J* -> *J''*



J -> *J*+1 -> *J''*



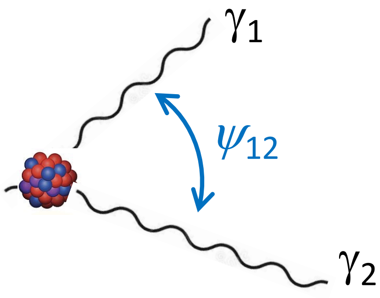
- excellent



Opening angle

$$\cos\psi_{12} = \hat{\boldsymbol{\omega}}_1 \cdot \hat{\boldsymbol{\omega}}_2 = \cos\theta_1 \cos\theta_2 + \sin\theta_1 \sin\theta_2 \cos\phi_{12}$$

Distribution: $P_\psi(\psi) = \int d^2\hat{\boldsymbol{\omega}}_1 d^2\hat{\boldsymbol{\omega}}_2 \delta(\psi_{12} - \psi) P_{12}(\hat{\boldsymbol{\omega}}_1, \hat{\boldsymbol{\omega}}_2)$



Opening angle

$$\cos\psi_{12} = \hat{\boldsymbol{\omega}}_1 \cdot \hat{\boldsymbol{\omega}}_2 = \cos\theta_1 \cos\theta_2 + \sin\theta_1 \sin\theta_2 \cos\phi_{12}$$

Distribution: $P_\psi(\psi) = \int d^2\hat{\boldsymbol{\omega}}_1 d^2\hat{\boldsymbol{\omega}}_2 \delta(\psi_{12}-\psi) P_{12}(\hat{\boldsymbol{\omega}}_1, \hat{\boldsymbol{\omega}}_2)$

Independent emission:

$$P_i(\cos\theta_i) = \sum c_n^{(i)} P_n(\cos\theta_i)\ ,\ i=1,2$$

$$P_\psi^{\rm indep}(\psi_{12}) = 2\sum_n \frac{c_n^{(1)} c_n^{(2)}}{2n+1} P_n(\cos\psi_{12})$$

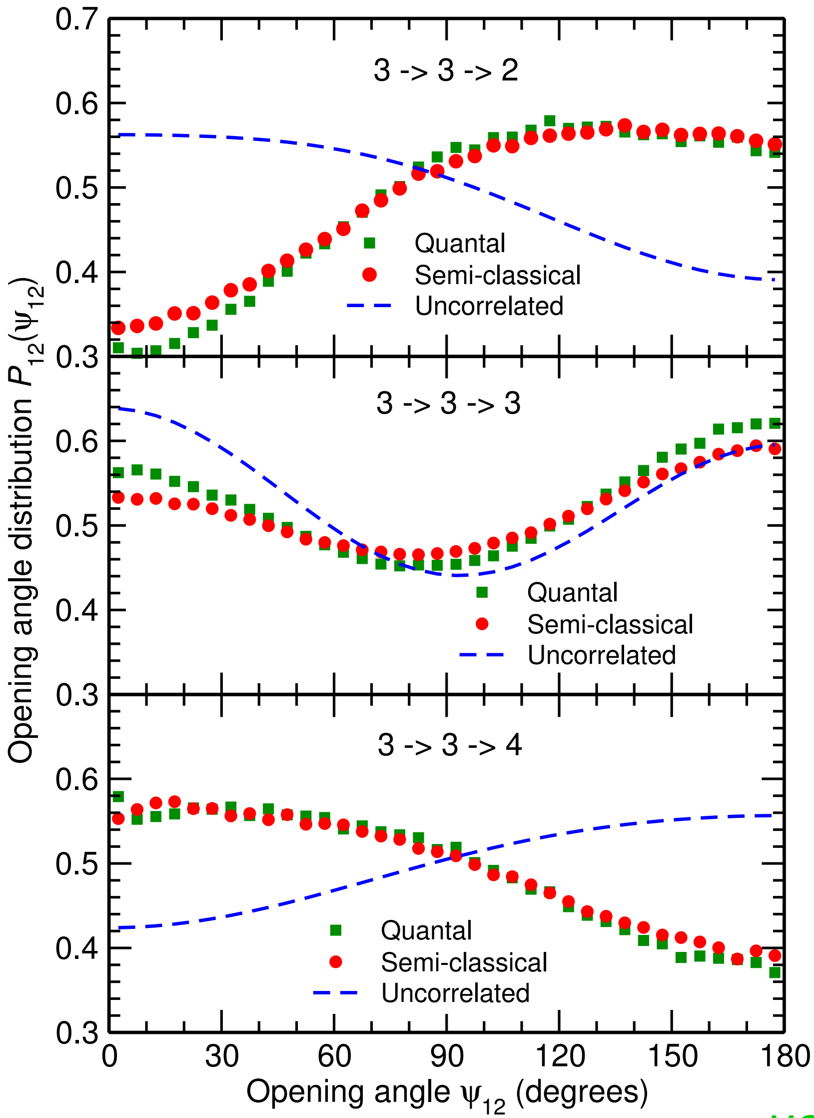
Correlated emission (exact):

$$\begin{aligned}
P_{12}^{--}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 + \tfrac{3}{8}h_1h_2P_1 + \tfrac{1}{40}P_2,\\
P_{12}^{-0}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 + \tfrac{3}{8}\frac{h_1h_2}{J}P_1 - \tfrac{1}{40}\frac{2J-3}{J}P_2,\\
P_{12}^{-+}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 - \tfrac{3}{8}h_1h_2\frac{J-1}{J}P_1 + \tfrac{1}{40}\frac{2J^2-5J+3}{J(2J+1)}P_2;\\
P_{12}^{0-}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 + \tfrac{3}{8}h_1h_2\frac{J^2+J-1}{J(J+1)^2}P_1 - \tfrac{1}{40}\frac{(2J-1)(J^2+J-3)}{J(J+1)^2}P_2,\\
P_{12}^{00}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 + \tfrac{3}{8}h_1h_2\frac{J^2+J-1}{J(J+1)^3}P_1 - \tfrac{1}{40}\frac{(2J-1)(2J^3+J^2-5J-3)}{J(J+1)^3}P_2,\\
P_{12}^{0+}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 - \tfrac{3}{8}h_1h_2\frac{2J^3+5J^2+2J-3}{(2J+3)(J+1)^3J}P_1 - \tfrac{1}{40}\frac{2J-1}{2J+3}\frac{2J^3+J^2-7J+3}{(J+1)^3}P_2;\\
P_{12}^{+-}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 - \tfrac{3}{8}h_1h_2\frac{J^2(J+2)}{(J+1)^3}P_1 + \tfrac{1}{40}\frac{J^2(J+2)(2J-1)[4J^2+8J-5]}{(J+1)^3(2J+1)(2J+3)^2}P_2,\\
P_{12}^{+0}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 - \tfrac{3}{8}\frac{h_1h_2J[2J^2+10J+3]}{(J+1)^2(J+2)(2J+3)}P_1 - \tfrac{1}{40}\frac{J(2J-1)[2J^4+7J^3+5J^2-4J-1]}{(J+1)^3(2J+1)(2J+3)^2}P_2\\
P_{12}^{++}(\cos\psi_{12}) &= \tfrac{1}{2}P_0 + \tfrac{3}{8}h_1h_2\frac{J^2}{(J+1)^2}P_1 + \tfrac{1}{40}\frac{J^2}{(J+1)^2}\frac{(2J-1)^2}{(2J+3)^2}P_2.
\end{aligned}$$

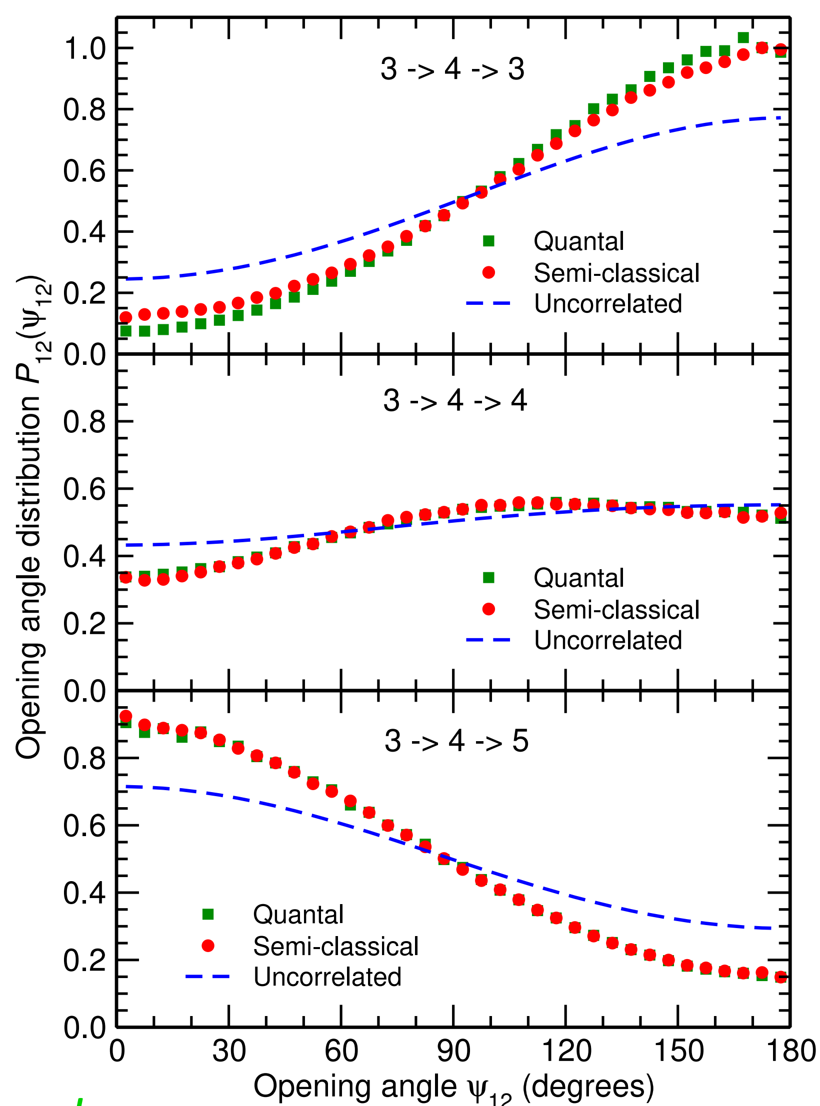
$E1$-$E1$: Opening angle distribution $P_{12}(\psi_{12})$

J = 3

J -> J -> J''



J -> J+1 -> J''



- *very good*

$E2$-$E2$: Angular distribution of the second photon , $dN_2/d\omega_2$

J -> J-1 -> J-3

$$\begin{aligned}\langle\hat{\boldsymbol{\omega}}_1\hat{\boldsymbol{\omega}}_2|f\rangle_{-=} \;=\; & \left[\frac{J-1}{J+1}\right]^{\frac{1}{2}} d^2_{1,h_1}(\theta_1)\,\mathrm{e}^{i\phi_1}\,d^2_{2,h_2}(\theta_2)\,\mathrm{e}^{2i\phi_2}|J-3,J-3\rangle \\ & - \left[\frac{2}{J+1}\frac{2}{J-1}\right]^{\frac{1}{2}} d^2_{2,h_1}(\theta_1)\,\mathrm{e}^{2i\phi_1}\,d^2_{1,h_2}(\theta_2)\,\mathrm{e}^{i\phi_2}|J-3,J-3\rangle \\ & - \left[\frac{2}{J+1}\frac{J-3}{J-1}\right]^{\frac{1}{2}} d^2_{2,h_1}(\theta_1)\,\mathrm{e}^{2i\phi_1}\,d^2_{2,h_2}(\theta_2)\,\mathrm{e}^{2i\phi_2}|J-3,J-4\rangle\end{aligned}$$

$$P_2^{-=}(\hat{\boldsymbol{\omega}}_2) \;=\; \left(\frac{5}{4\pi}\right)^2 \int |\langle\hat{\boldsymbol{\omega}}_1,\hat{\boldsymbol{\omega}}_2|f\rangle_{-=}|^2\, d^2\hat{\boldsymbol{\omega}}_1 \;=\; \frac{5}{4\pi}\left[\frac{J^2-5}{J^2-1}\, d^2_{2,h_2}(\theta_2)^2 + \frac{4}{J^2-1}\, d^2_{1,h_2}(\theta_2)^2\right]$$

$E2$-$E2$: Angular distribution of the second photon , $dN_2/d\omega_2$

J -> J-1 -> J-3

$$\begin{aligned}
\langle\hat{\omega}_1\hat{\omega}_2|f\rangle_{-=} &= \left[\frac{J-1}{J+1}\right]^{\frac{1}{2}} d^2_{1,h_1}(\theta_1)\,\mathrm{e}^{i\phi_1} d^2_{2,h_2}(\theta_2)\,\mathrm{e}^{2i\phi_2}|J-3,J-3\rangle \\
&- \left[\frac{2}{J+1}\frac{2}{J-1}\right]^{\frac{1}{2}} d^2_{2,h_1}(\theta_1)\,\mathrm{e}^{2i\phi_1} d^2_{1,h_2}(\theta_2)\,\mathrm{e}^{i\phi_2}|J-3,J-3\rangle \\
&- \left[\frac{2}{J+1}\frac{J-3}{J-1}\right]^{\frac{1}{2}} d^2_{2,h_1}(\theta_1)\,\mathrm{e}^{2i\phi_1} d^2_{2,h_2}(\theta_2)\,\mathrm{e}^{2i\phi_2}|J-3,J-4\rangle
\end{aligned}$$

$$P_2^{-=}(\hat{\omega}_2) = \left(\frac{5}{4\pi}\right)^2 \int |\langle\hat{\omega}_1,\hat{\omega}_2|f\rangle_{-=}|^2\, d^2\hat{\omega}_1 = \frac{5}{4\pi}\left[\frac{J^2-5}{J^2-1}\, d^2_{2,h_2}(\theta_2)^2 + \frac{4}{J^2-1}\, d^2_{1,h_2}(\theta_2)^2\right]$$

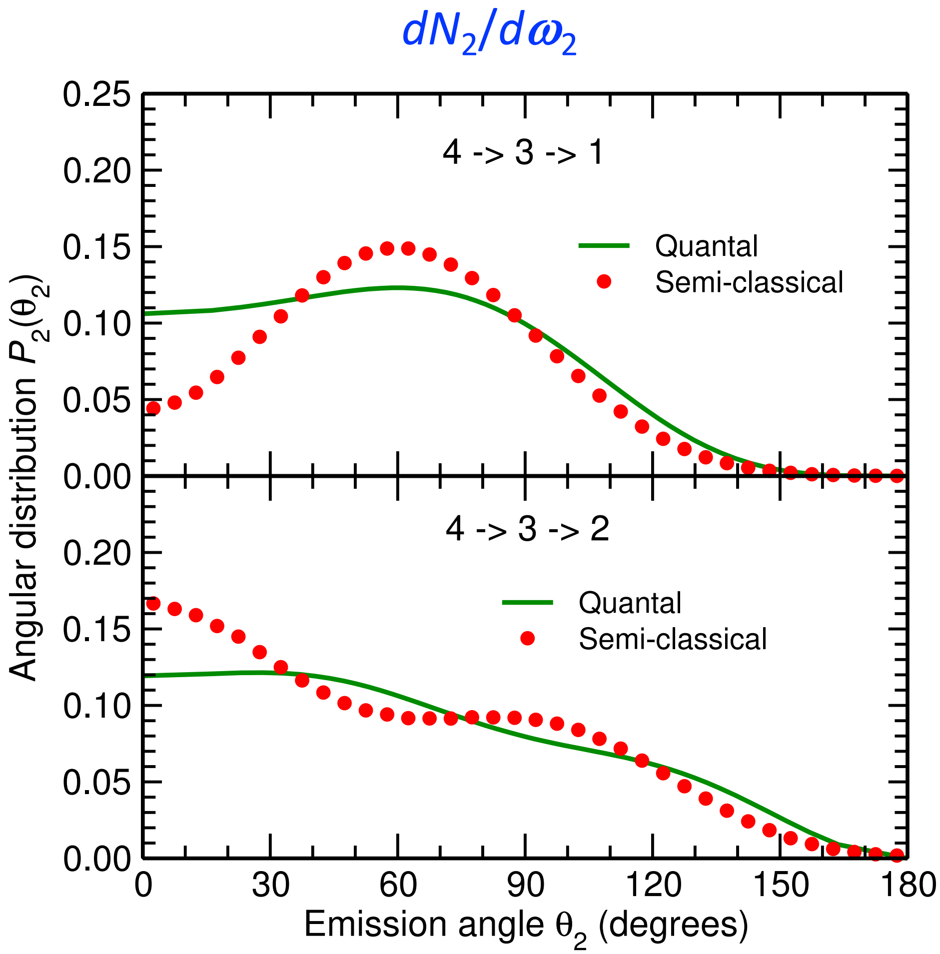
J -> J-1 -> J-2

$$\begin{aligned}
\langle\hat{\omega}_1\hat{\omega}_2|f\rangle_{--} &= \left[\frac{J-1}{J+1}\right]^{\frac{1}{2}}\left[\frac{J-2}{J}\right]^{\frac{1}{2}} d^2_{1,h_1}(\theta_1)\,\mathrm{e}^{i\phi_1} d^2_{1,h_2}(\theta_2)\,\mathrm{e}^{i\phi_2}|J-2,J-2\rangle \\
&- \left[\frac{J-1}{J+1}\right]^{\frac{1}{2}}\left[\frac{2}{J}\right]^{\frac{1}{2}} d^2_{1,h_1}(\theta_1)\,\mathrm{e}^{i\phi_1} d^2_{2,h_2}(\theta_2)\,\mathrm{e}^{2i\phi_2}|J-2,J-3\rangle \\
&- \left[\frac{2}{J+1}\right]^{\frac{1}{2}}\left[\frac{3(J-2)}{J(J-1)}\right]^{\frac{1}{2}} d^2_{2,h_1}(\theta_1)\,\mathrm{e}^{2i\phi_1} d^2_{0,h_2}(\theta_2)\,|J-2,J-2\rangle \\
&- \left[\frac{2}{J+1}\right]^{\frac{1}{2}}\frac{J-4}{[J(J-1)]^{\frac{1}{2}}} d^2_{2,h_1}(\theta_1)\,\mathrm{e}^{2i\phi_1} d^2_{1,h_2}(\theta_2)\,\mathrm{e}^{i\phi_2}|J-2,J-3\rangle \\
&+ \left[\frac{2}{J+1}\right]^{\frac{1}{2}}\left[\frac{2(2J-5)}{J(J-1)}\right]^{\frac{1}{2}} d^2_{2,h_1}(\theta_1)\,\mathrm{e}^{2i\phi_1} d^2_{2,h_2}(\theta_2)\,\mathrm{e}^{2i\phi_2}|J-2,J-4\rangle
\end{aligned}$$

$$P_2^{--}(\hat{\omega}_2) = \frac{5}{4\pi}\left[6(J-2)d^2_{0,h_2}(\theta_2)^2 + (J^3-2J^2-11J+30)d^2_{1,h_2}(\theta_2)^2 + 2(J^2+2J-9)d^2_{2,h_2}(\theta_2)^2\right]\frac{1}{J(J^2-1)}$$

E2: Angular distribution of the second photon

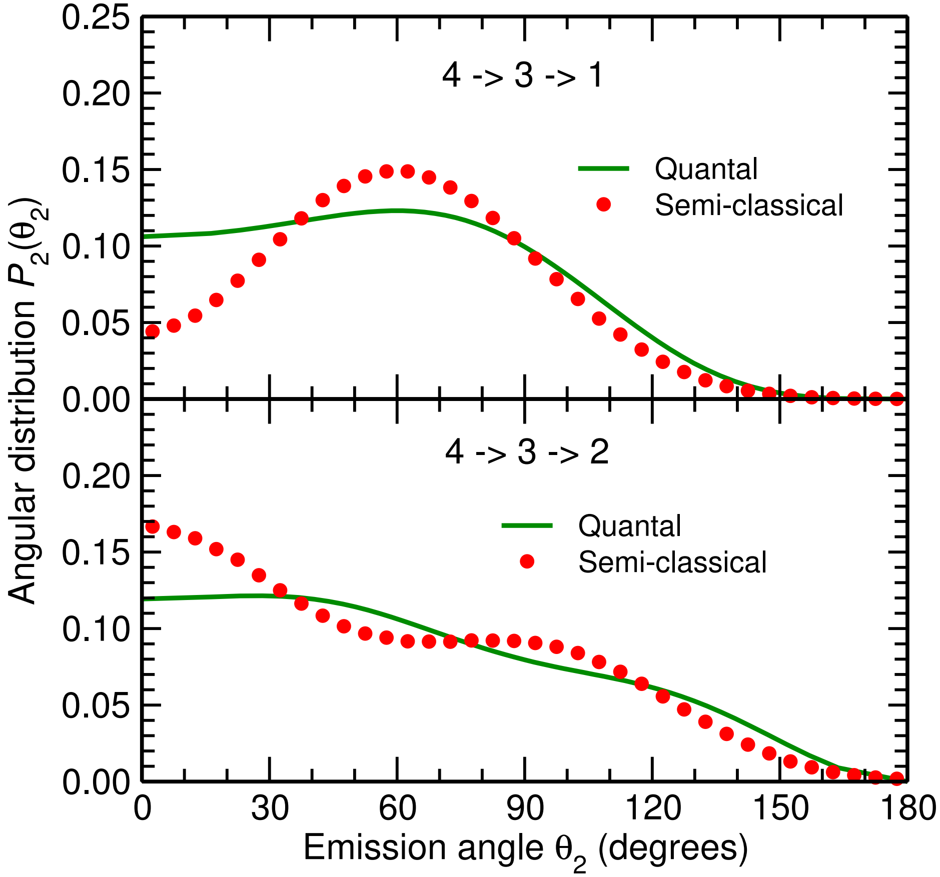
J = 4



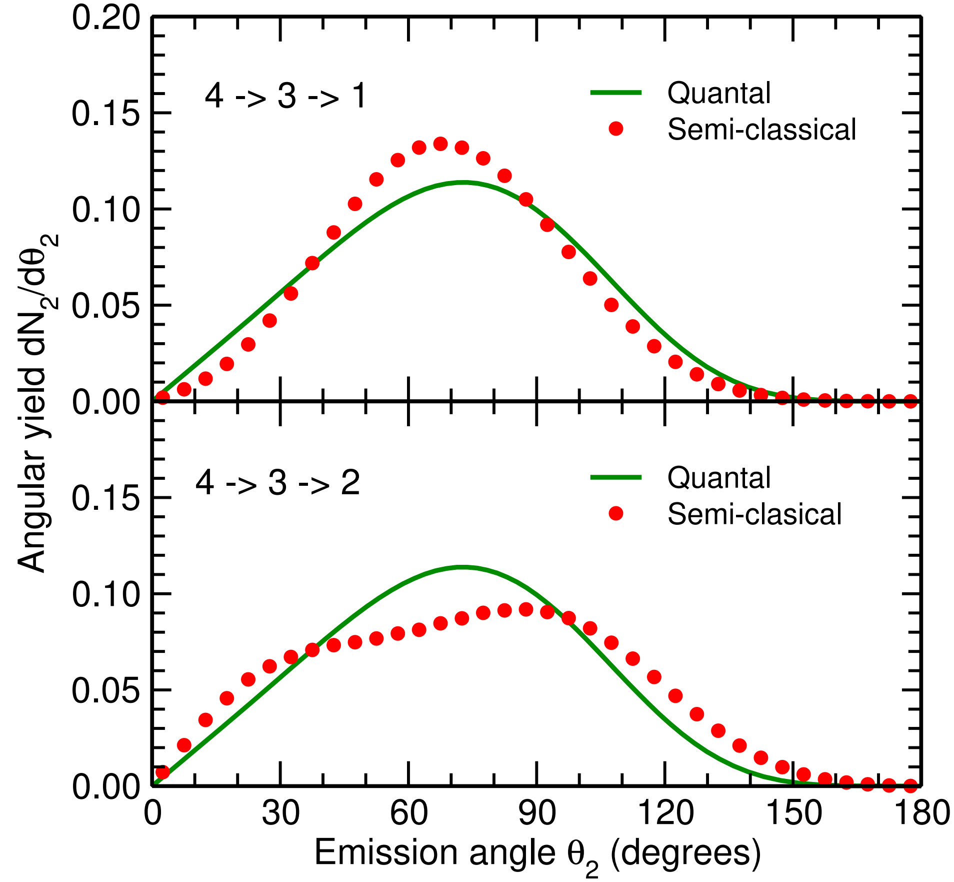
$E2$: Angular distribution of the second photon

J = 4

$dN_2/d\omega_2$



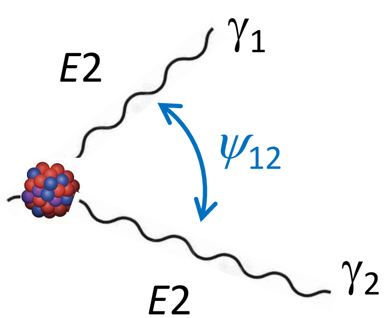
$dN_2/d\theta_2$

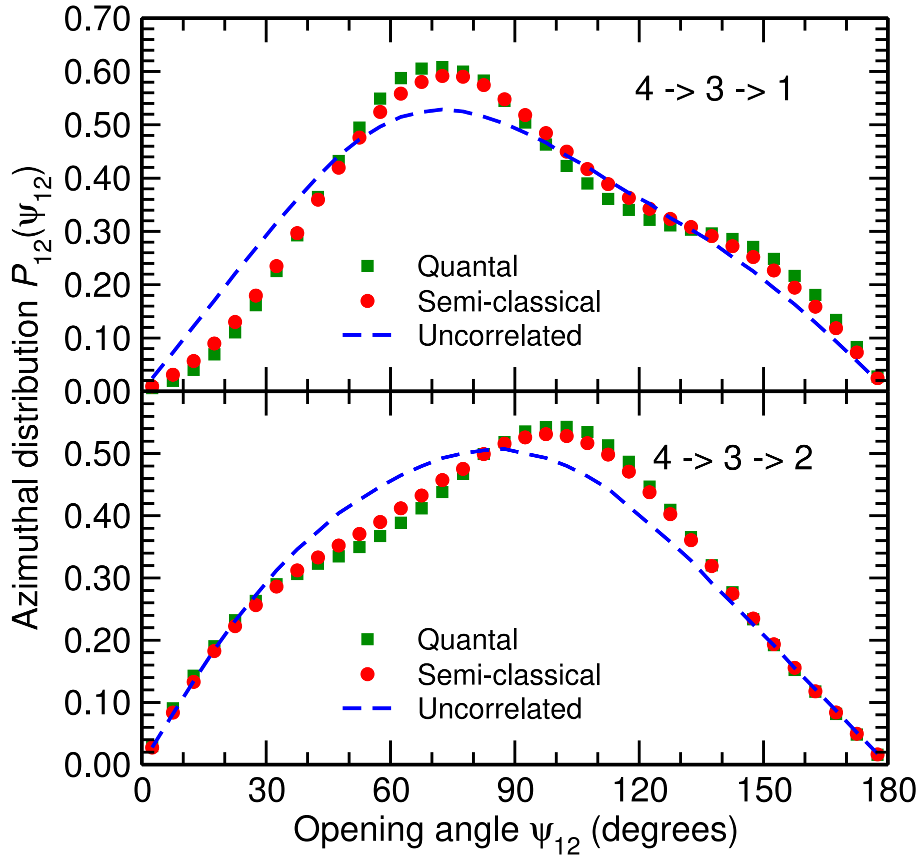


- reasonable

E2-E2: Opening angle distribution $P_{12}(\psi_{12})$

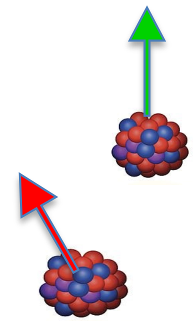
$J = 4$





- excellent

Semi-classical treatment of photon cascades in nuclei



The mother state is *maximally aligned* along $<\mathcal{N}|\ \boldsymbol{J}\ |\mathcal{N}>$

The daughter state is *maximally aligned* along $<\mathcal{N}'|\ \boldsymbol{J}\ |\mathcal{N}'>$

E1 cascades:

Excellent for angular distributions
Very good for angular correlations

E2 cascades:

Reasonable for angular distributions
Excellent for angular correlations

Easy to implement into simulation codes (and fast)
May be useful when using photon angular correlations
to learn about fission fragment angular momenta

Compound-Nuclear Reactions and Related Topics (CNR*24)

Vienna International Centre, 8-12 July 2024

Thank You!

Semi-classical treatment of photon cascades in nuclei

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- based on work done with Thomas Døssing (Niels Bohr Institute, Copenhagen):

J. Randrup and Thomas Døssing, Physical Review C **109**, 054613 (2024)

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