Collective Properties of the Low Energy Dipole Response in the Relativistic RPA

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Relativistic Mean Field Theory

THE NUCLEUS $\Rightarrow$ system of **Dirac nucleons** coupled to exchange **mesons** and **photon** through an effective Lagrangian

- **σ -meson** $\Rightarrow$ strong medium-range attraction
- **ω -meson** $\Rightarrow$ strong short-range repulsion
- **$\vec{\rho}$ -meson** $\Rightarrow$ couples to the isovector baryon current
- **photon** $\Rightarrow$ electromagnetic interaction

The Effective Lagrangian Density:

$$
\begin{aligned}
\mathcal{L} \; = \; & \bar{\psi}\,(i\gamma\cdot\partial - m)\,\psi \; + \; \frac{1}{2}(\partial\sigma)^2 - U(\sigma) \; - \; g_\sigma\bar{\psi}\sigma\psi \\
& - \; \frac{1}{4}\Omega_{\mu\nu}\Omega^{\mu\nu} \; + \; \frac{1}{2}m_\omega^2\omega^2 - \; \frac{1}{4}\vec{\mathrm{R}}_{\mu\nu}\vec{\mathrm{R}}^{\mu\nu} + \frac{1}{2}m_\rho^2\vec{\rho}^{\,2} \; - \; \frac{1}{4}\mathrm{F}_{\mu\nu}\mathrm{F}^{\mu\nu} \\
& - \; g_\omega\bar{\psi}\gamma\cdot\omega\psi \; - \; g_\rho\bar{\psi}\gamma\cdot\vec{\rho}\vec{\tau}\psi \; - \; e\bar{\psi}\gamma\cdot A\frac{(1-\tau_3)}{2}\psi
\end{aligned}
$$

The Nonlinear σ Self-Interaction:

$$
\boxed{U(\sigma) = \tfrac{1}{2}m_\sigma^2\sigma^2 \; + \; \tfrac{1}{3}g_2\sigma^3 + \tfrac{1}{4}g_3\sigma^4}
$$

Relativistic Random Phase Approximation

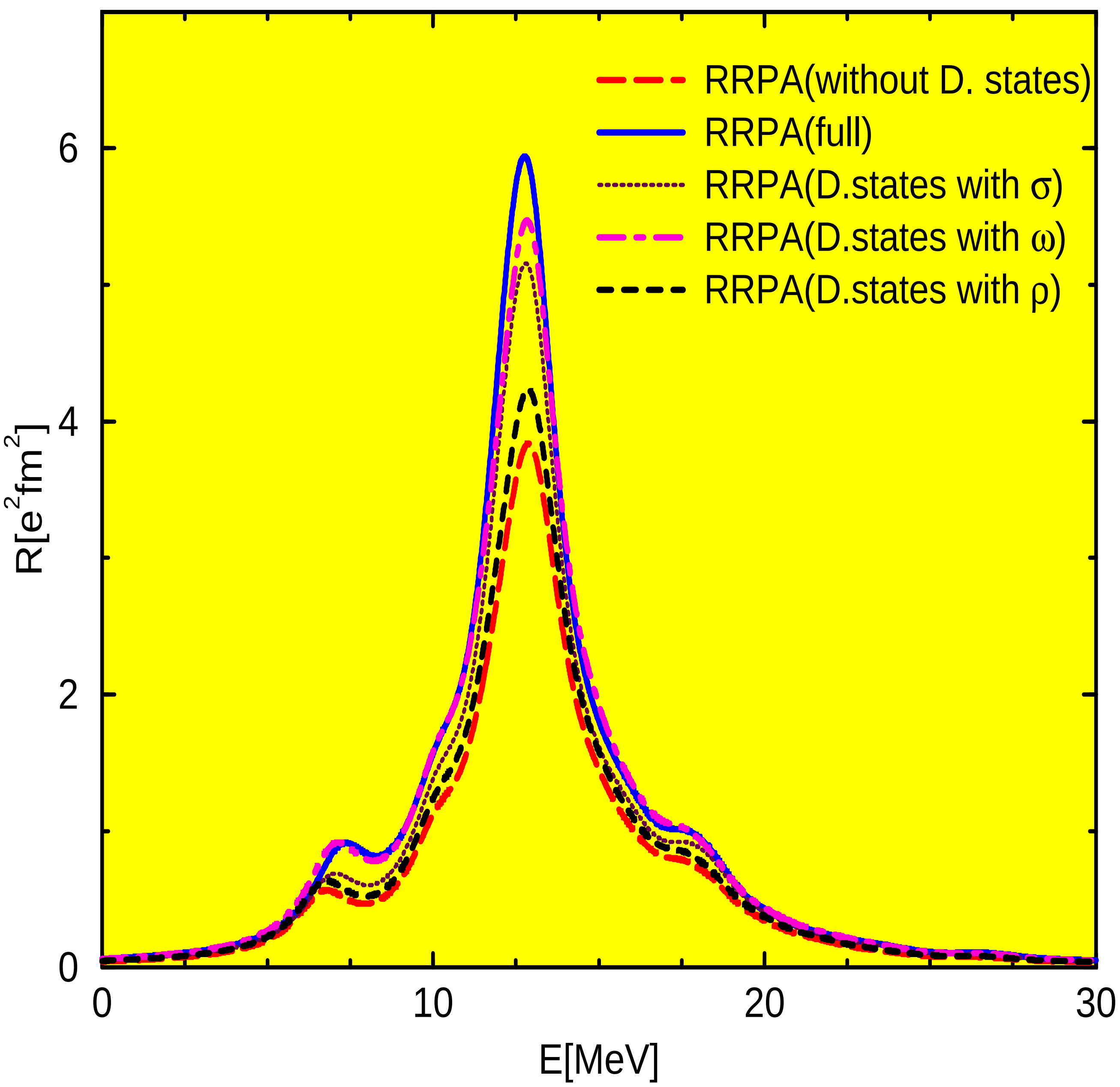
$$\begin{pmatrix} A^J & B^J \\ B^{*J} & A^{*J} \end{pmatrix} \begin{pmatrix} X^{\nu,JM}_{\tilde{p}h} \\ Y^{\nu,JM}_{\tilde{p}h} \end{pmatrix} = \omega_\nu \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \begin{pmatrix} X^{\nu,JM}_{\tilde{p}h} \\ Y^{\nu,JM}_{\tilde{p}h} \end{pmatrix}$$

$$A^J_{j_{\tilde{p}}j_h,j_{\tilde{q}}j_i} = \left(\epsilon_{j_{\tilde{p}}} - \epsilon_{j_h}\right) \delta_{j_{\tilde{p}}j_{\tilde{q}}} \delta_{j_h j_i} + V^J_{j_{\tilde{p}}j_i j_h j_{\tilde{q}}}$$

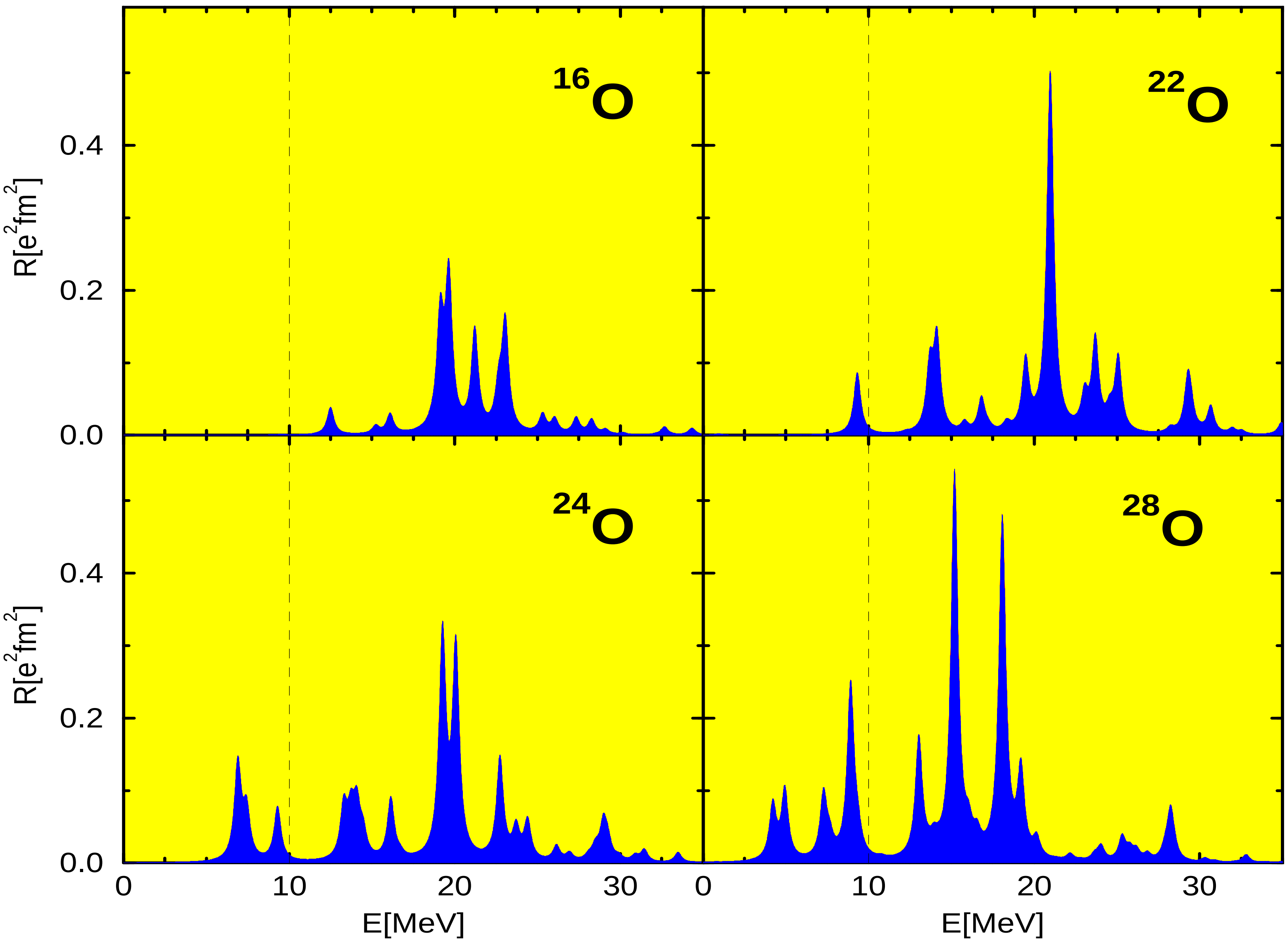
$$B^J_{j_{\tilde{p}}j_h,j_{\tilde{q}}j_i} = (-1)^{j_{\tilde{q}} - j_i + J} V^J_{j_{\tilde{p}}j_{\tilde{q}} j_h j_i}$$

- **Relativistic two body interaction includes both particle-hole and antiparticle-hole pairs**

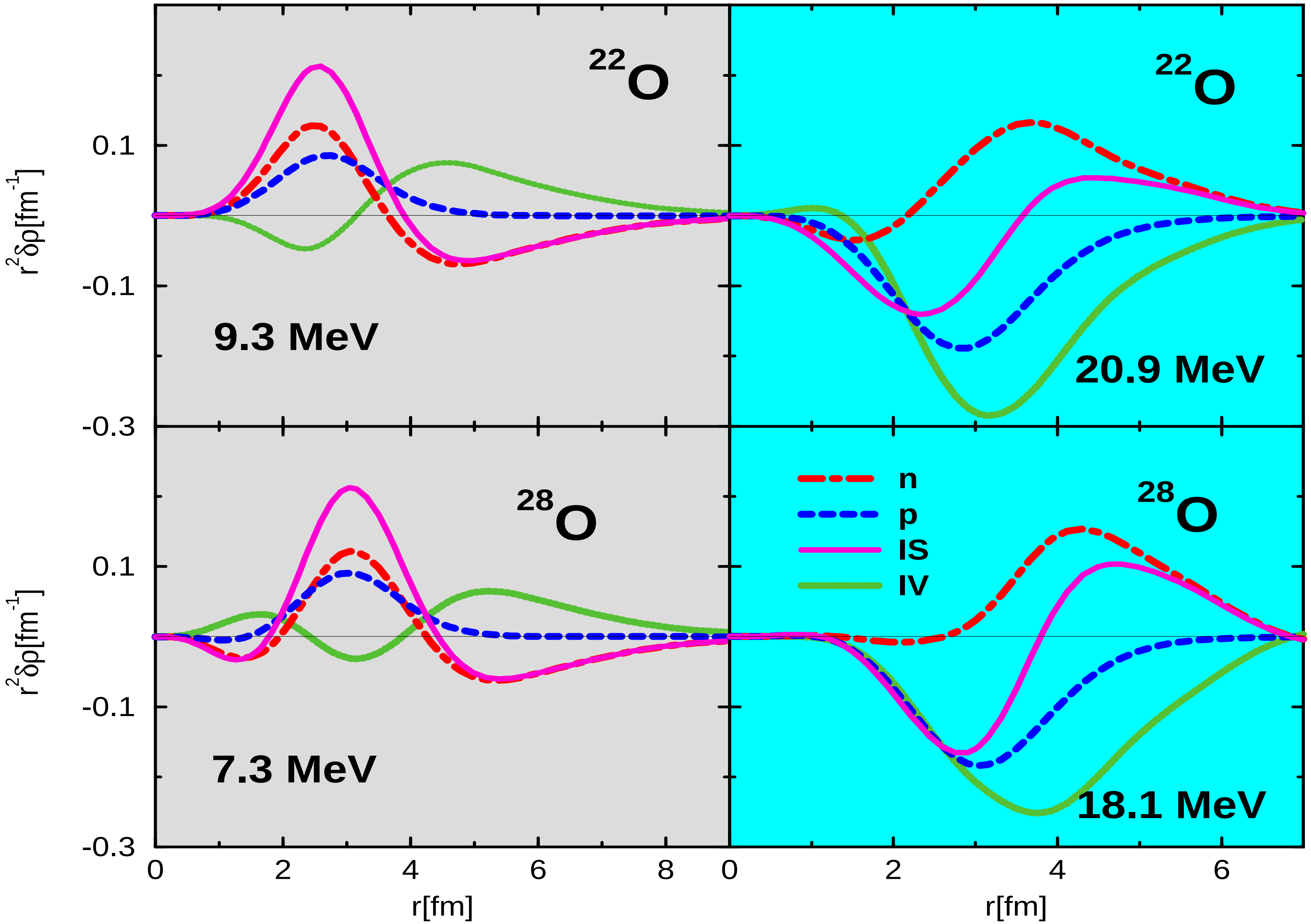
Isovector Dipole Strength Distribution in ^{208}Pb



IV Dipole Strength Distributions in Oxygen Isotopes



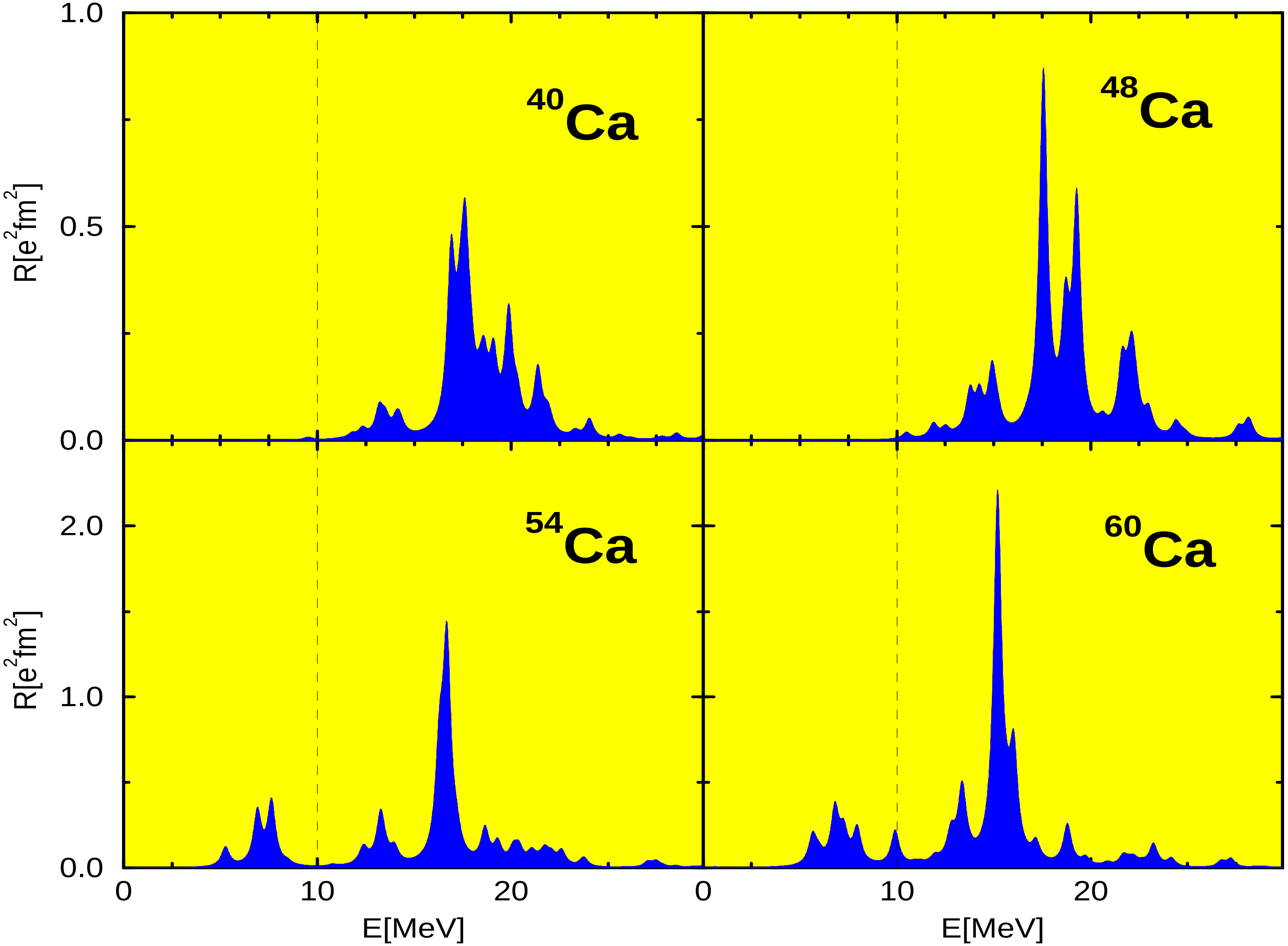
Transition Densities of the Low-energy Soft Modes and Giant Dipole Resonances in Oxygen Isotopes



- **Structure of the main peaks in the low-energy region of the isovector strength distribution in ^{28}O**

E[MeV]	EWSR[%]	neutron $p-h$ configuration
4.2	0.9	$(92\%\ 1d_{3/2} \rightarrow 2p_{3/2})$
4.9	1.4	$(91\%\ 1d_{3/2} \rightarrow 2p_{1/2})$ $(\ 6\%\ 1d_{3/2} \rightarrow 2p_{3/2})$
7.3	1.9	$(92\%\ 2s_{1/2} \rightarrow 2p_{3/2})$
8.9	6.3	$(71\%\ 1d_{3/2} \rightarrow 1f_{5/2})$ $(16\%\ 1d_{5/2} \rightarrow 1f_{7/2})$ $(\ 3\%\ 1d_{5/2} \rightarrow 2p_{3/2})$

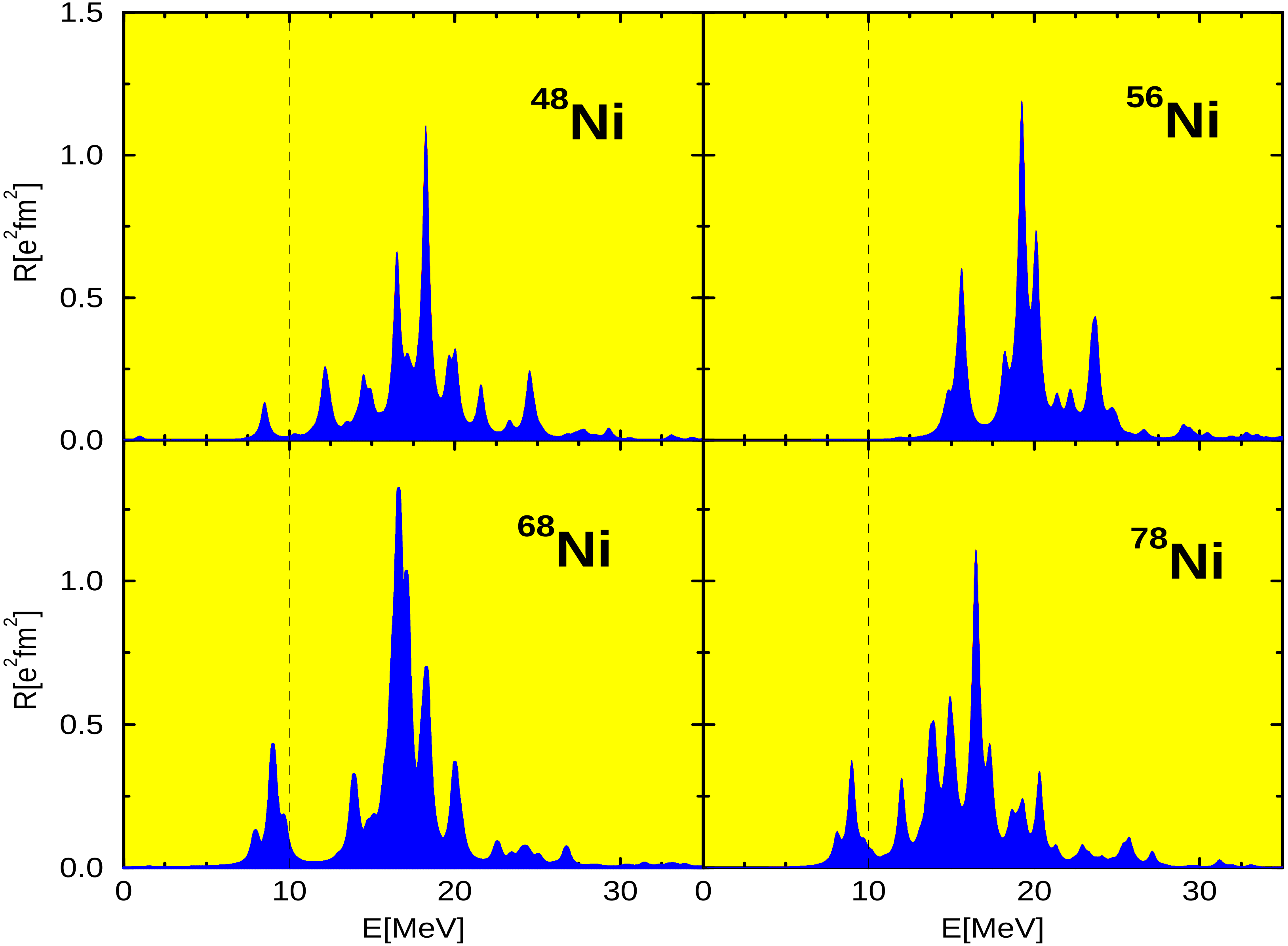
IV Dipole Strength Distributions in Calcium Isotopes



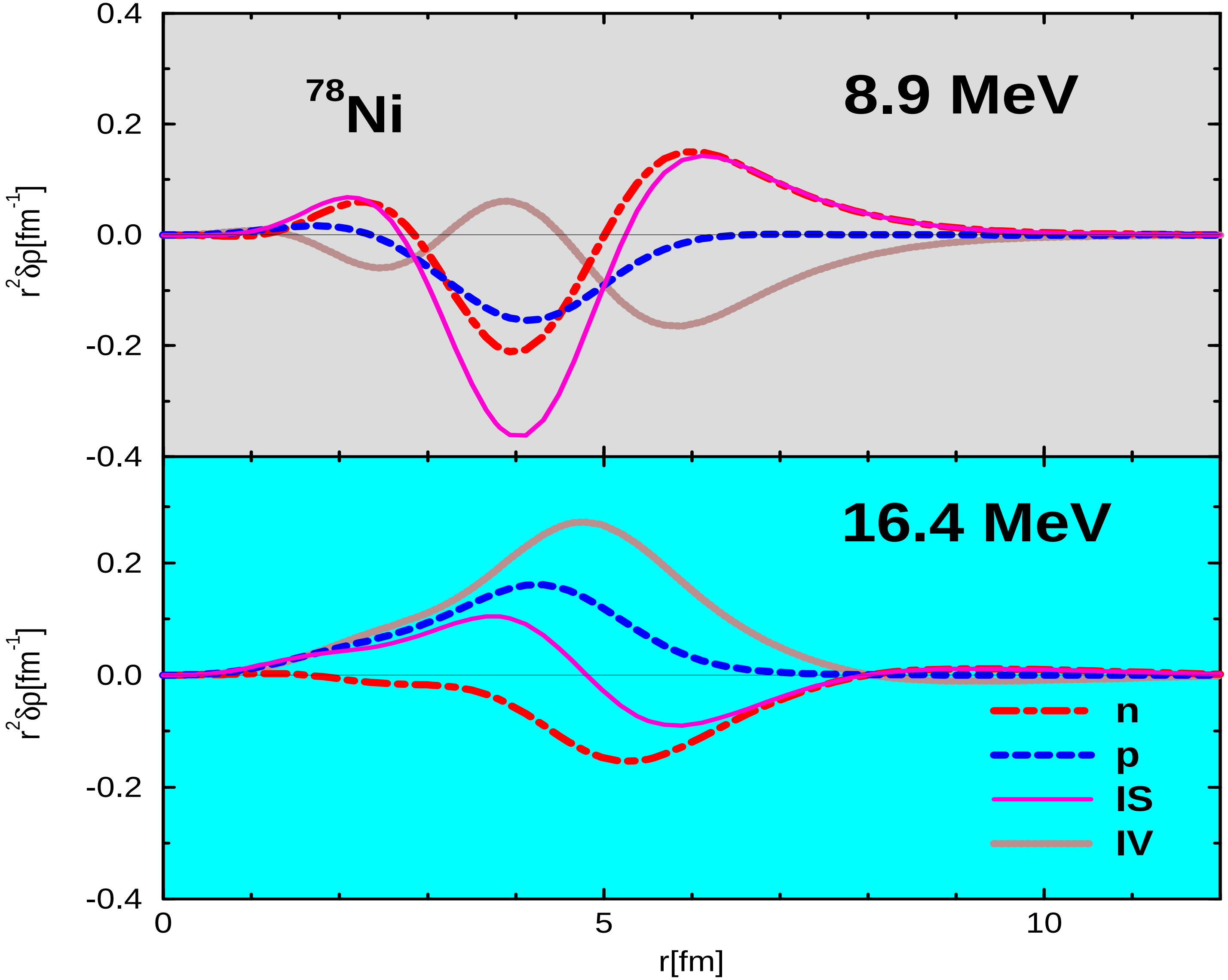
- Contributions of the **neutron p-h configurations** to the RRPA amplitude of the low-lying states in ^{60}Ca

E[MeV]	EWSR[%]	$p-h$ config.
5.7	1.2	$93.1\%\ 2p_{1/2} \to 3s_{1/2}$ $3.6\%\ 1f_{5/2} \to 2d_{5/2}$
6.8	2.6	$82.8\%\ 1f_{5/2} \to 2d_{3/2}$ $6.1\%\ 1f_{5/2} \to 2d_{5/2}$ $3.1\%\ 1f_{7/2} \to 1g_{9/2}$ $2.3\%\ 2p_{3/2} \to 2d_{5/2}$ $1.1\%\ 2p_{3/2} \to 3s_{1/2}$
7.3	1.6	$49.3\%\ 2p_{1/2} \to 2d_{3/2}$ $41.3\%\ 2p_{3/2} \to 3s_{1/2}$ $3.2\%\ 1f_{5/2} \to 2d_{3/2}$ $1.5\%\ 2p_{3/2} \to 2d_{5/2}$
7.9	2.0	$83.8\%\ 2p_{3/2} \to 2d_{5/2}$ $5.7\%\ 1f_{5/2} \to 2d_{3/2}$ $3.5\%\ 1f_{7/2} \to 1g_{9/2}$ $2.4\%\ 1f_{5/2} \to 1g_{7/2}$
9.9	2.1	$57.7\%\ 1f_{5/2} \to 1g_{7/2}$ $22.0\%\ 1f_{7/2} \to 1g_{9/2}$ $3.3\%\ 1f_{7/2} \to 2d_{5/2}$

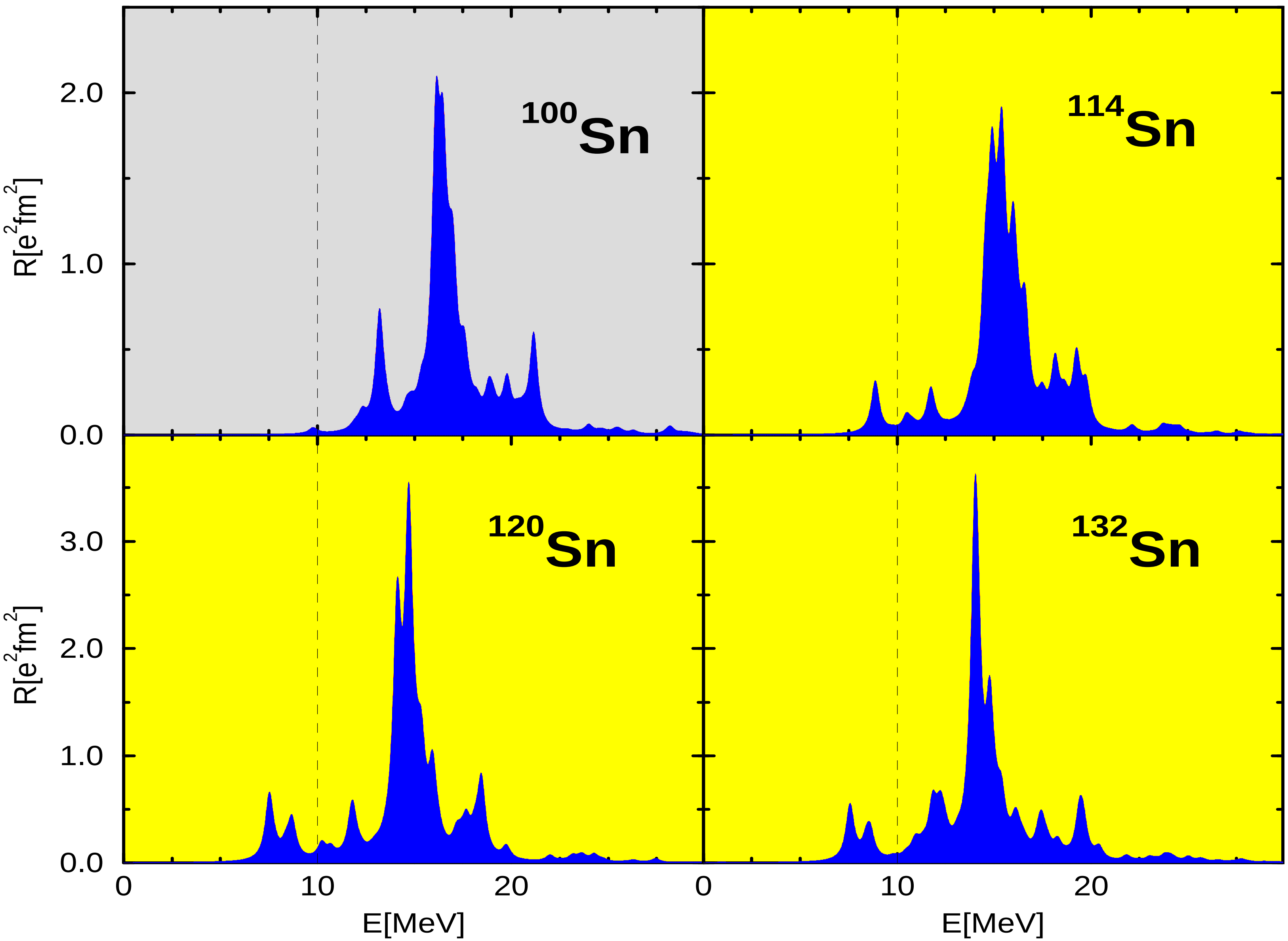
IV Dipole Strength Distributions in Nickel Isotopes



- Transition Densities of the **Low-energy Soft Mode** and **Giant Dipole Resonance** in ^{78}Ni



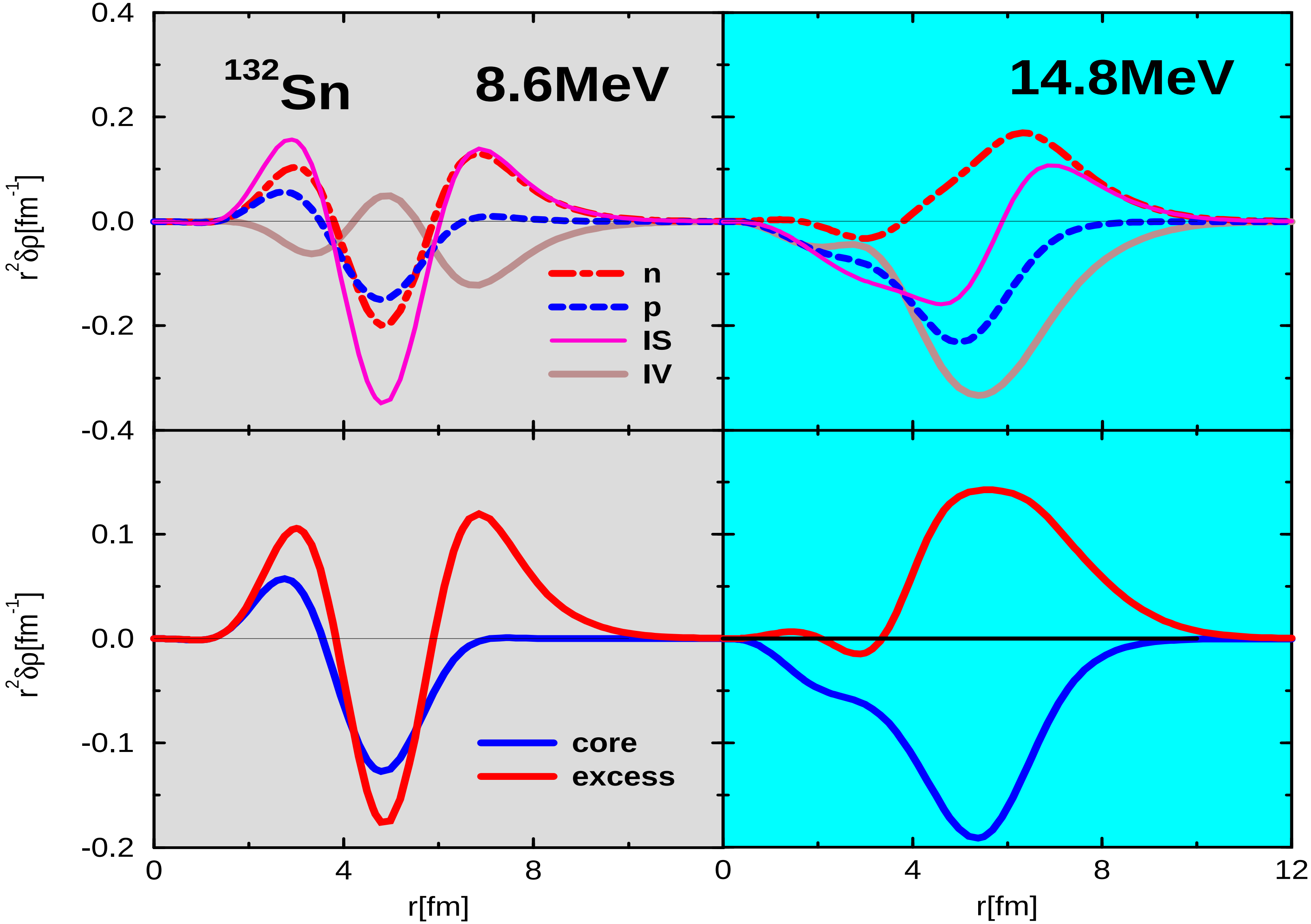
IV Dipole Strength Distributions in Tin Isotopes



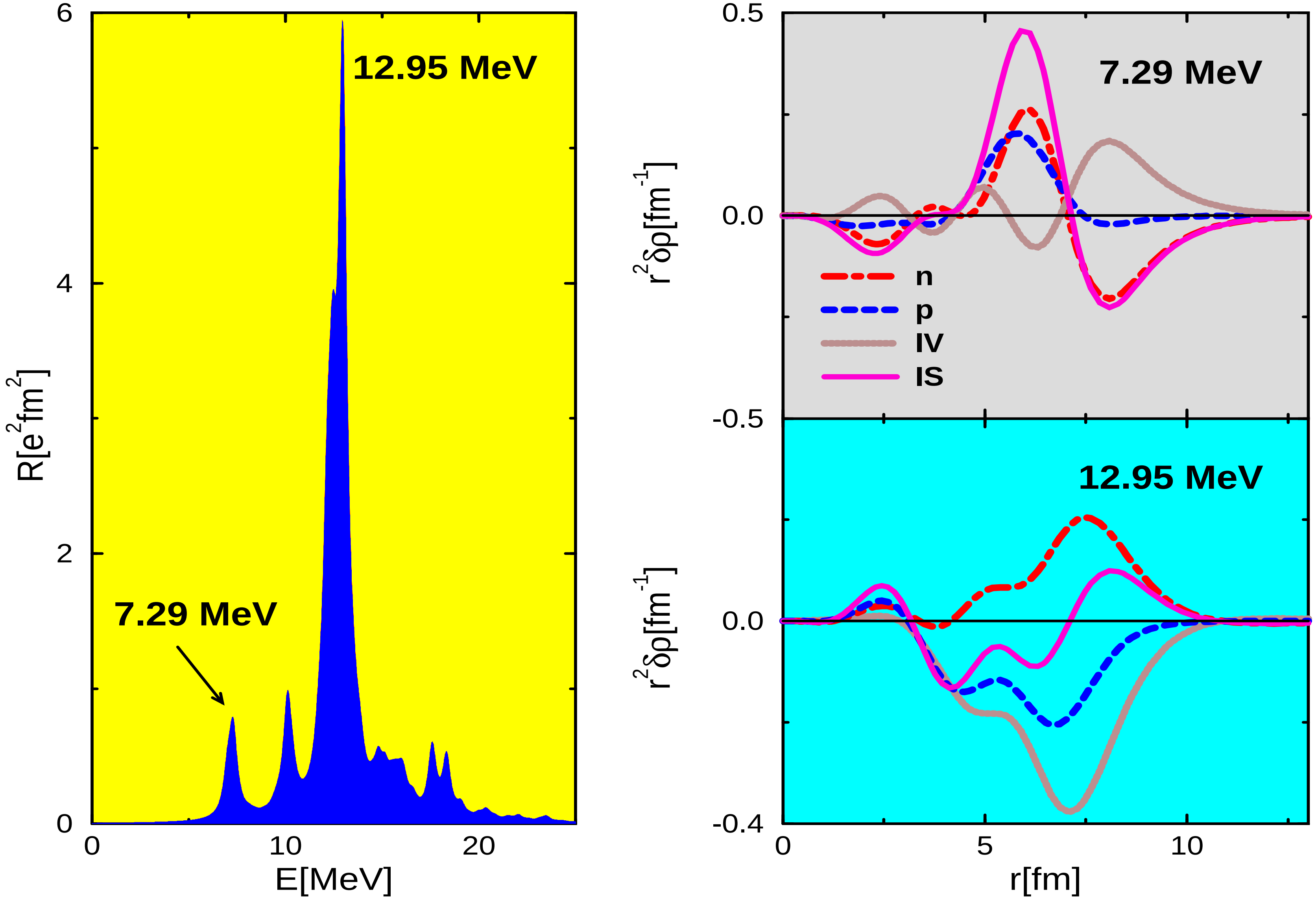
- **Distribution of the neutron particle-hole configurations for the state at 9.0 MeV (4.3% EWSR) in ^{68}Ni and at 8.6 MeV state (1.4% EWSR) in ^{132}Sn**

^{68}Ni at 9.0 MeV	^{132}Sn at 8.6 MeV
26.1% $1f_{5/2} \to 2d_{5/2}$	28.2% $2d_{3/2} \to 2f_{5/2})$
22.9% $2p_{3/2} \to 2d_{5/2}$	21.9% $2d_{5/2} \to 2f_{7/2}$
11.3% $1f_{7/2} \to 1g_{9/2}$	19.7% $2d_{3/2} \to 3p_{1/2}$
10.3% $2p_{1/2} \to 2d_{3/2}$	10.5% $1h_{11/2} \to 1i_{13/2}$
10.0% $1f_{5/2} \to 2d_{3/2}$	3.5% $2d_{5/2} \to 3p_{3/2}$
8.2% $2p_{3/2} \to 3s_{1/2}$	1.9% $1g_{7/2} \to 2f_{5/2}$
1.4% $2p_{1/2} \to 3s_{1/2}$	1.5% $1g_{7/2} \to 1h_{9/2}$
1.0% $1f_{5/2} \to 1g_{7/2}$	0.6% $1g_{7/2} \to 2f_{7/2}$
0.3% $1s_{5/2} \to 3d_{3/2}$	0.6% $2d_{3/2} \to 3p_{3/2}$

Contributions to the Transition Densities from the proton-neutron core and the excess neutrons in ^{132}Sn

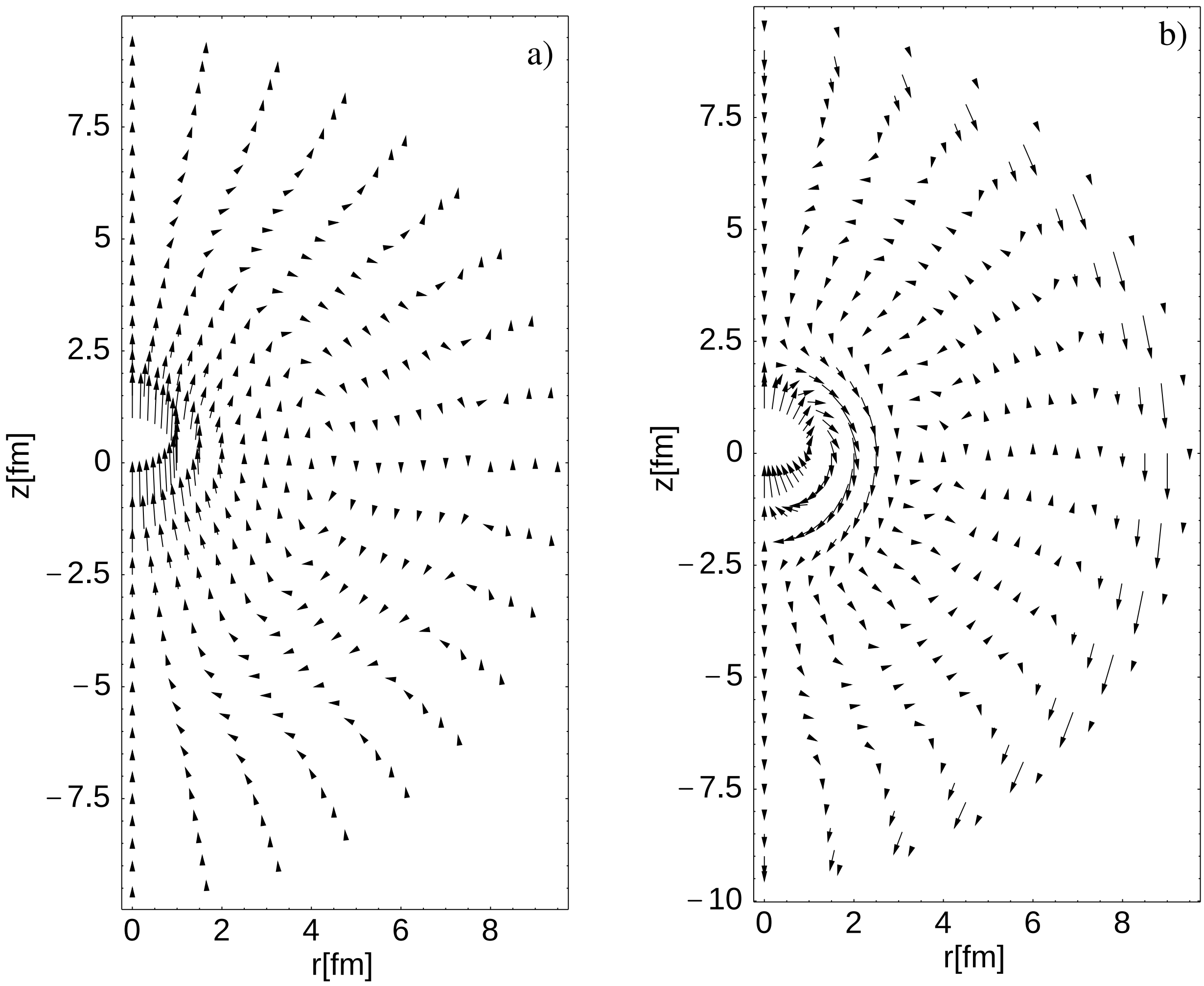


IV Dipole Strength for ^{208}Pb and Transition Densities for the peaks at 7.29 MeV and 12.95 MeV



- **Velocity distributions** for the **pygmy state** at 7.29 MeV in ^{208}Pb

- The Velocity Field of the **proton-neutron core** (Z,N$\leq$82)(a) is separated from the contribution of the **excess neutrons** (82$<$N$\leq$126)(b)



- **Transition densities of the pygmy (7.29 MeV) and the giant resonance (12.95 MeV) states in ^{208}Pb.**
- **The contributions of the excess neutrons ($82 < N \leq 126$), and of the proton-neutron core ($Z,N \leq 82$) are displayed separately**