Marciana Marina (Elba), June, 21- 25, 2010

Effective nuclear many-body theories

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Effective theory

$$H|\Psi> = E|\Psi> \qquad H^{\text{eff}}|\Psi^{\text{eff}}> = E|\Psi^{\text{eff}}>$$

$$H = H_0 + H_1 \qquad H_0 P|\Psi> = \omega P|\Psi> \qquad P^2 = P \qquad Q = I - P$$

$$\left[H_0 + P\left(H_1 + H_1 Q \frac{1}{E - H_0 - QH_1Q} QH_1\right)P\right] P|\Psi> = EP|\Psi>$$

$$\left[H_0 + V^{\text{eff}}(E)\right] P|\Psi> = EP|\Psi>$$

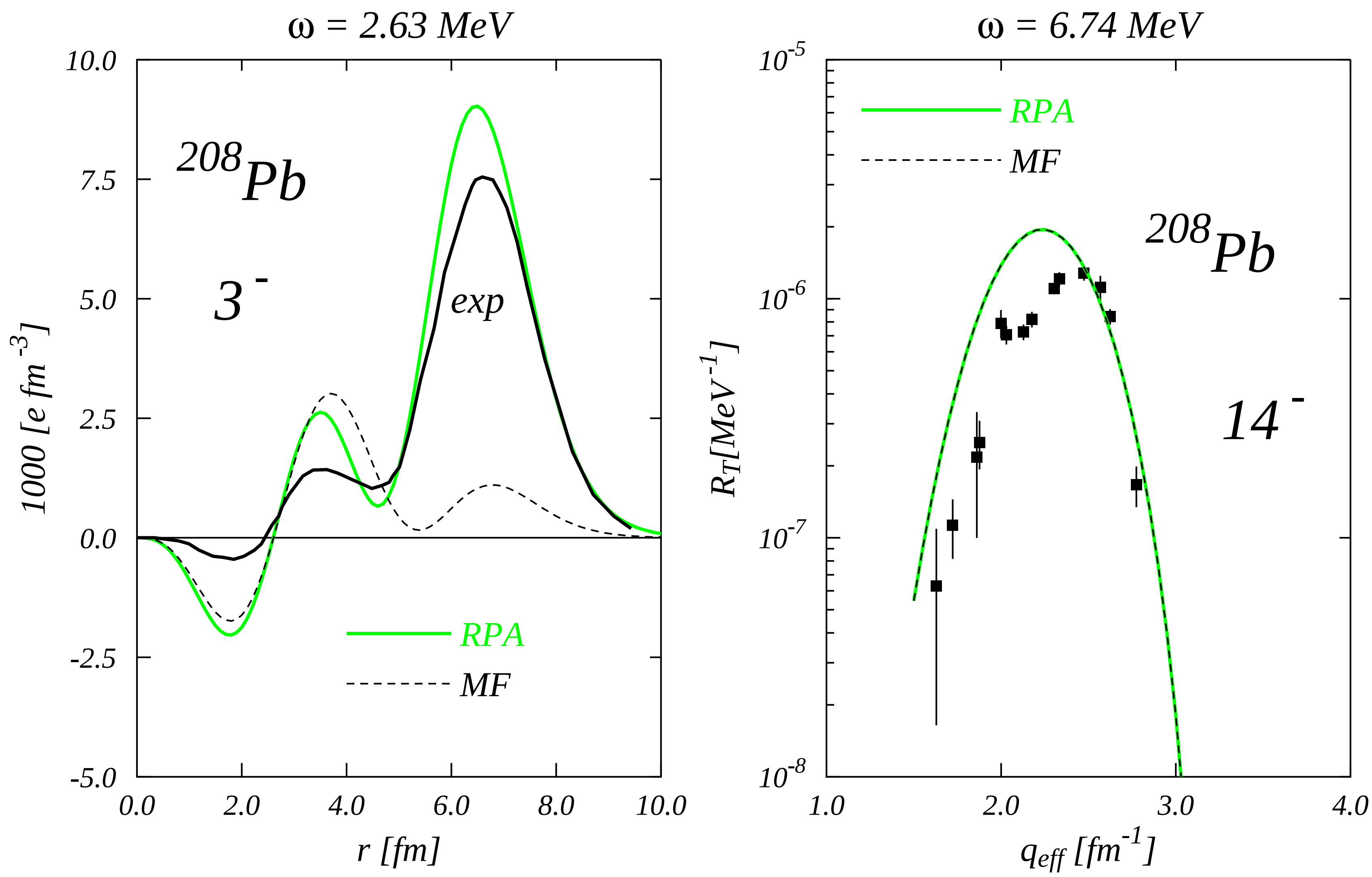
Effective hamiltonian depends on the choice of H_0

Effective hamiltonian depends on the energy E

Phenomenological Random Phase Approximation (RPA) calculations

- Single particle wavefunctions from Woods-Saxon potentials.
- Experimental single particle energies (when available)
- Effective nucleon-nucleon interaction chosen to reproduce some empirical quantity.

The input changes for each nucleus.



3^- data: D. Goutte et al., Phys. Rev. Lett. 45 (1980) 1618

14^- data: J. Linchtenstadt et al., Phys. Rev. C 20 (1979) 497

Self-consistent RPA calculations

Single particle bases taken from Hartree-Fock (HF) calculations
The same interaction is used in HF and RPA

A unique interaction for all the nuclei

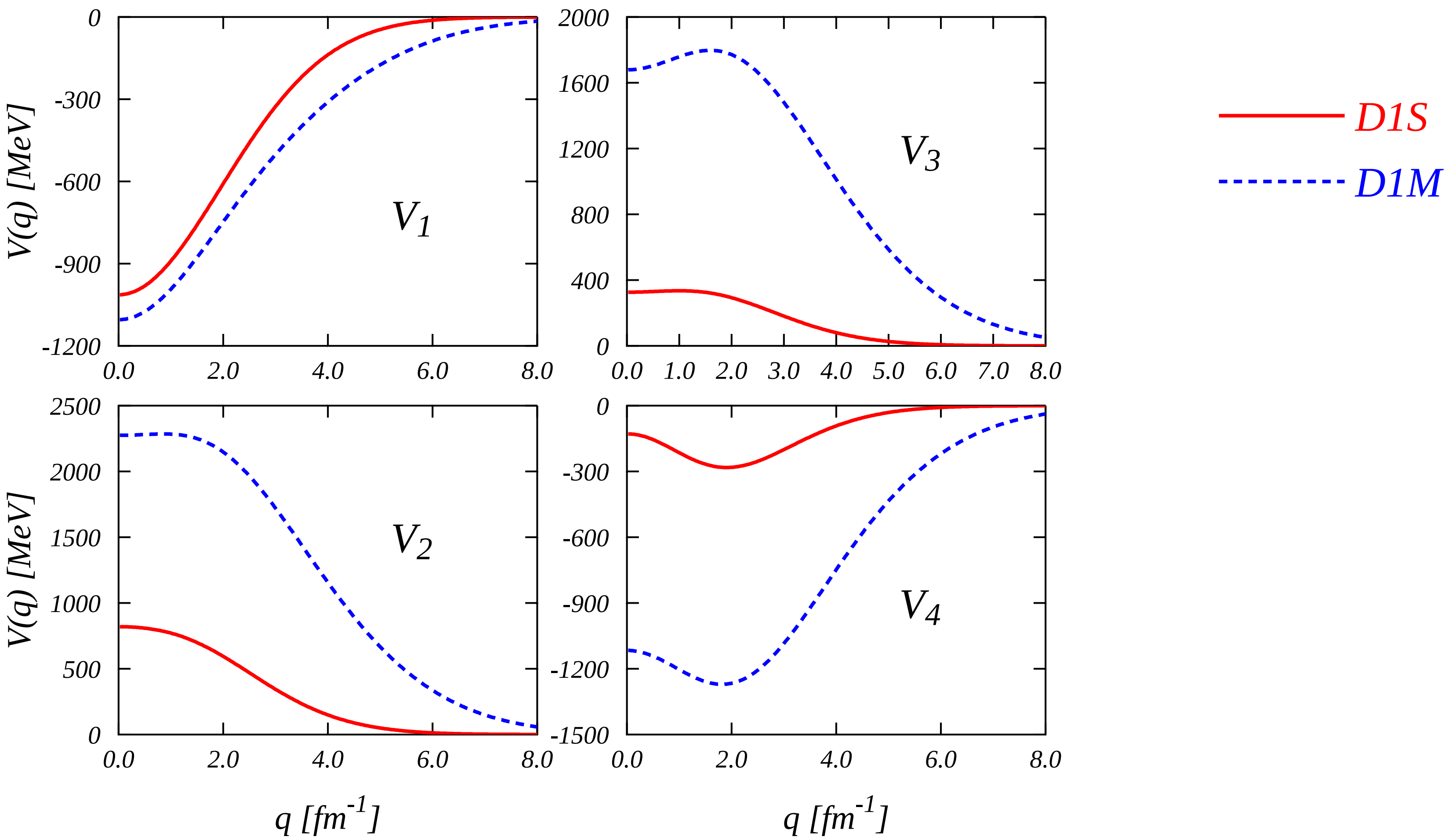
Our choice

- Gogny-like interactions
- finite range
- zero-range Spin-Orbit term
- zero-range Density dependent term
- 14 parameters chosen with a fit of about 2000 nuclear binding energies and 700 charge radii.

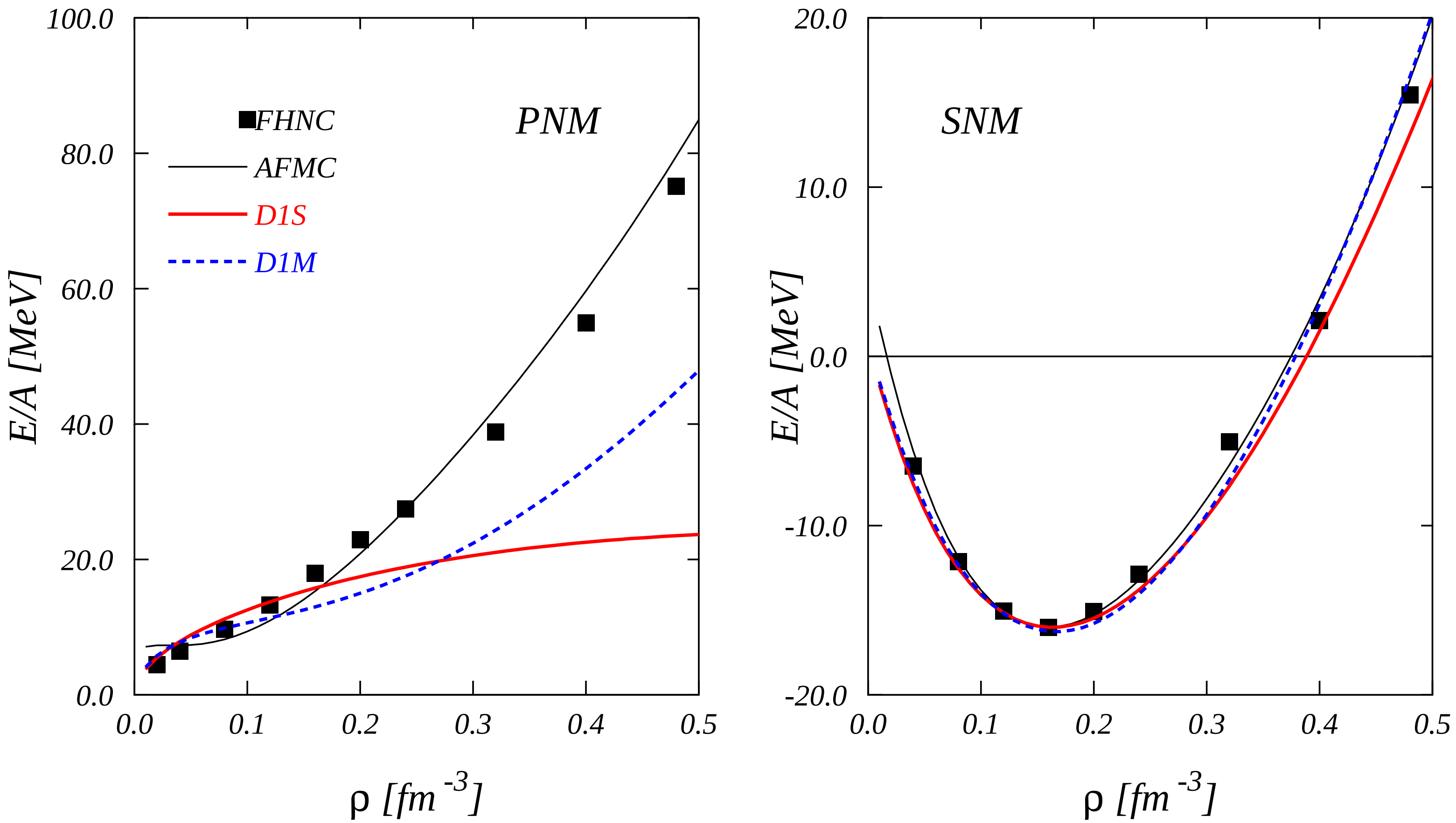
Two parameterizations

-D1S: J. F. Berger et al., Comp. Phys. Comm. 63 (1991) 365

-D1M: S. Goriely et al,: Phys. Rev. Lett. 102 (2009) 252501

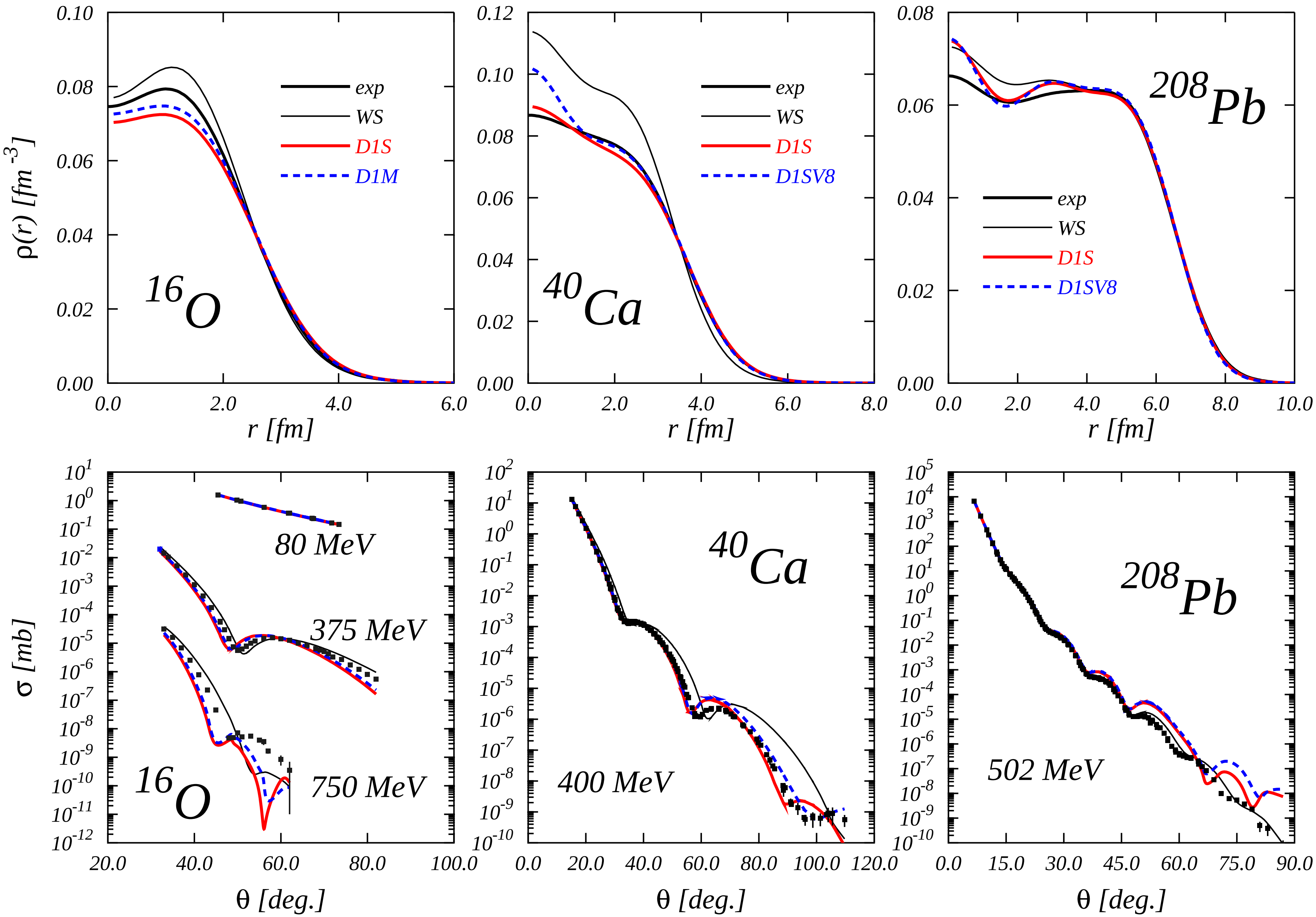


V(q) [MeV]
V(q) [MeV]
q [fm⁻¹]
q [fm⁻¹]
V1
V2
V3
V4
D1S
D1M

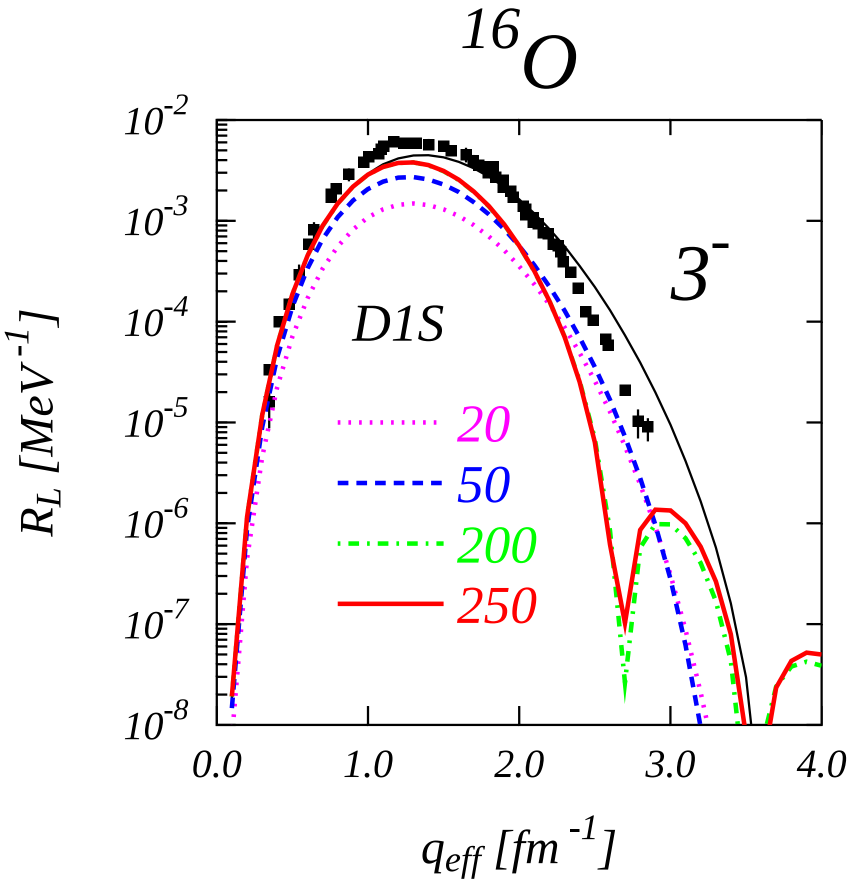


FHNC: A. Akmal et al., Phys Rev C 58 (1998) 1804

AFMC: S. Gandolfi et al., Mon. Not. Roy. Astron. Soc. 404 (2010) L35



ρ(r) [fm -3]
r [fm]
exp
WS
D1S
D1M
D1SV8
16O
40Ca
208Pb
σ [mb]
θ [deg.]
80 MeV
375 MeV
750 MeV
400 MeV
502 MeV



$\epsilon_{ph}^{\max}$ [MeV]	ω [MeV]
20.0	9.11
50.0	8.55
200.0	7.87
250.0	7.85
exp	6.13

Data: T. N. Buti et al., Phys. Rev. C 33 (1986) 755

Continuum in RPA

(A pedagogical and simplified presentation)

$$(\epsilon_p - \epsilon_h - \omega) X_{ph}(\epsilon_p) + \sum_{p'h'} \int d\epsilon_{p'}\, v_{ph,p'h'}(\epsilon_p, \epsilon_{p'}) X_{ph}(\epsilon_p') = 0$$

Definition of a new unknown

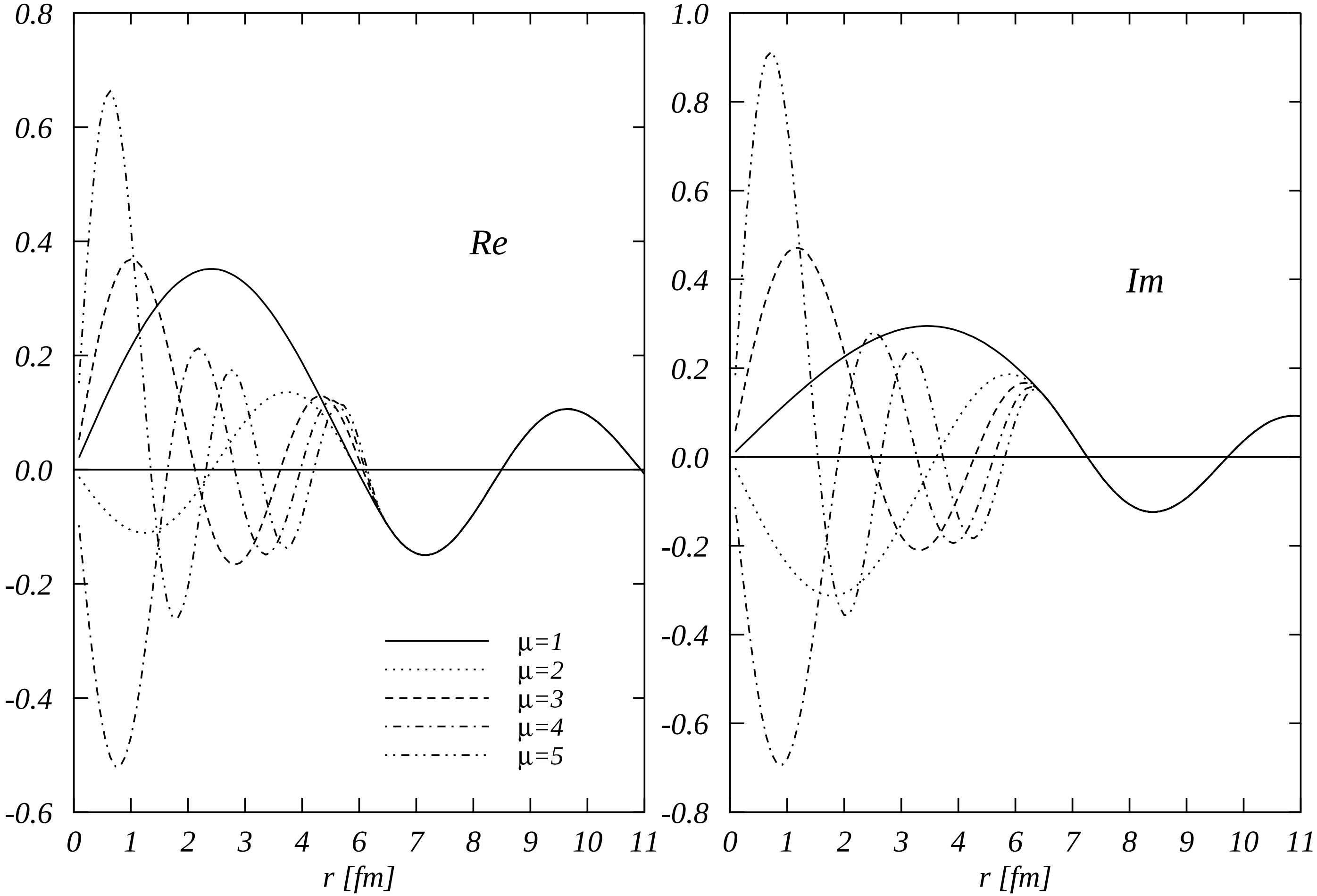
$$f_{ph}(r) = \int d\epsilon_p X_{ph}(\epsilon_p) R_p(r, \epsilon_p)$$

A new equation to be solved

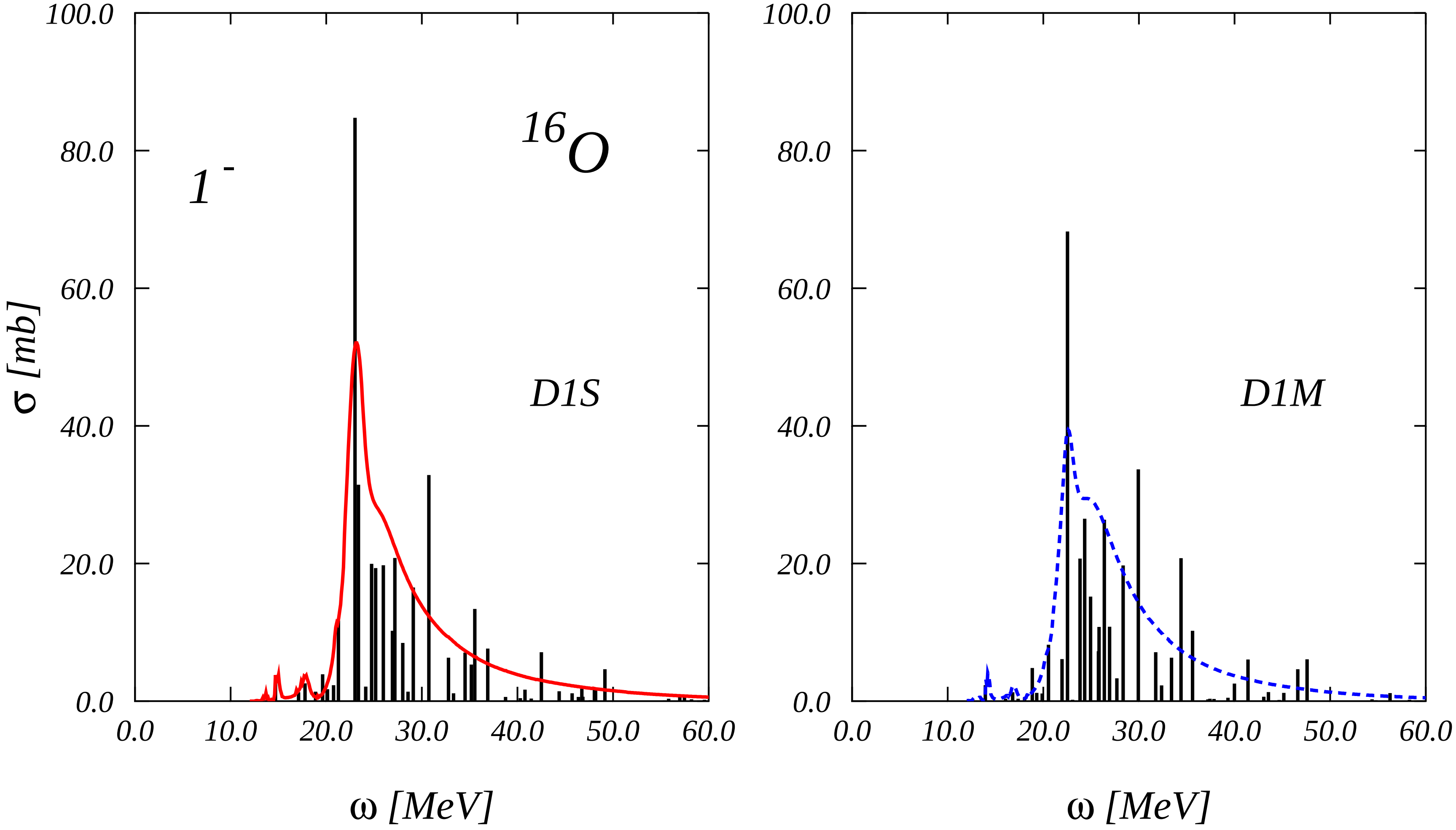
$$0 = -\frac{\hbar^2}{2m} \nabla^2 f_{ph}(r) + U(r) f_{ph}(r) - \int dr' r'^2 W(r, r') f_{ph}(r') - (\epsilon_h + \omega) f_{ph}(r)$$
$$- \sum_{p'h'} \int dr' r'^2 \left[R^*_{h'}(r') v^{\text{dir}}(r, r') R^*_h(r) f_{p'h'}(r') - R^*_{h'}(r') v^{\text{exc}}(r, r') R^*_h(r') f_{p'h'}(r) \right]$$

Expansion of $f_{ph}(r)$ on a Sturm-Bessel functions basis

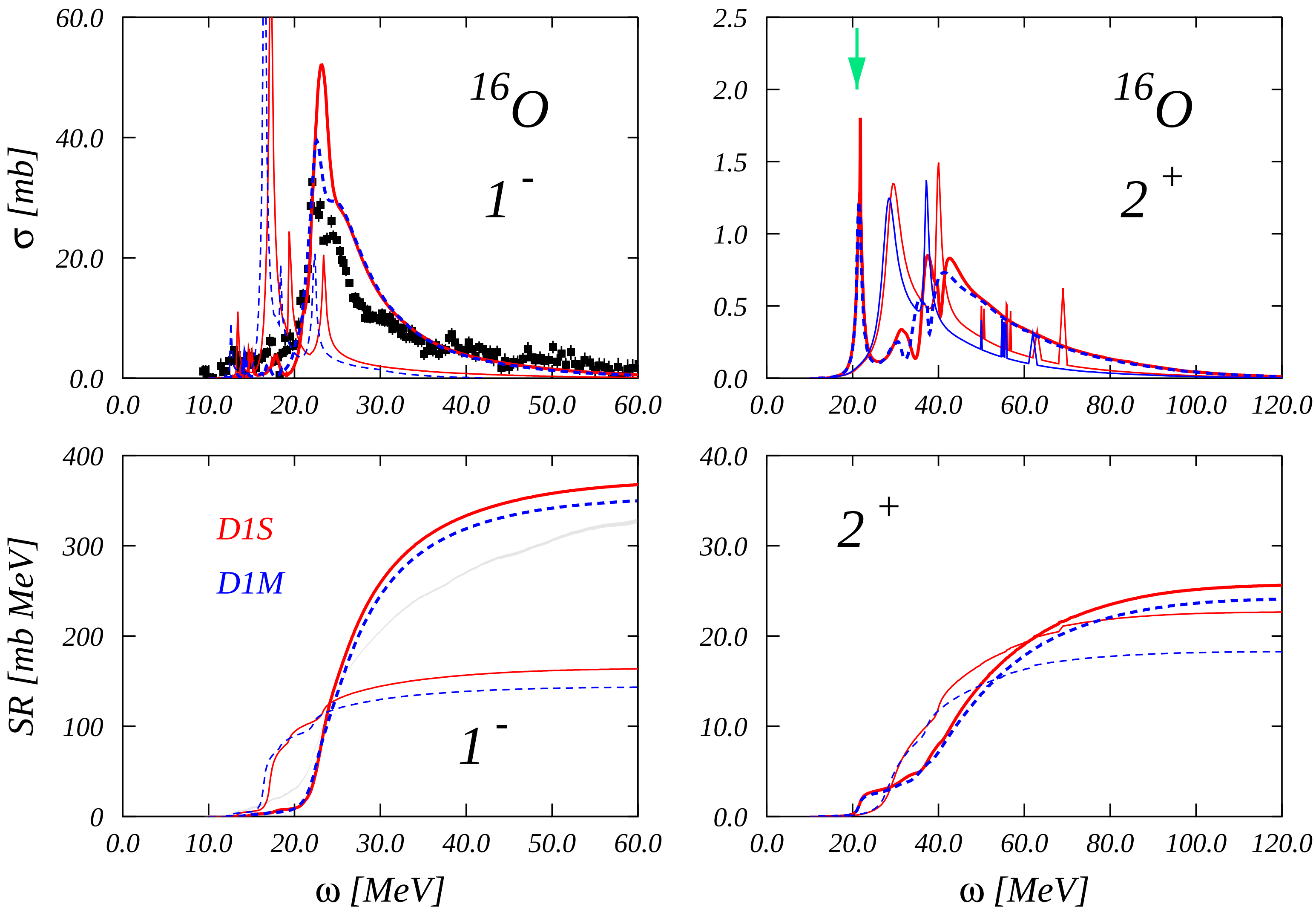
Sturm-Bessel functions



ϵ=30 MeV, $l = 1$, $j = 3/2$, ^{16}O

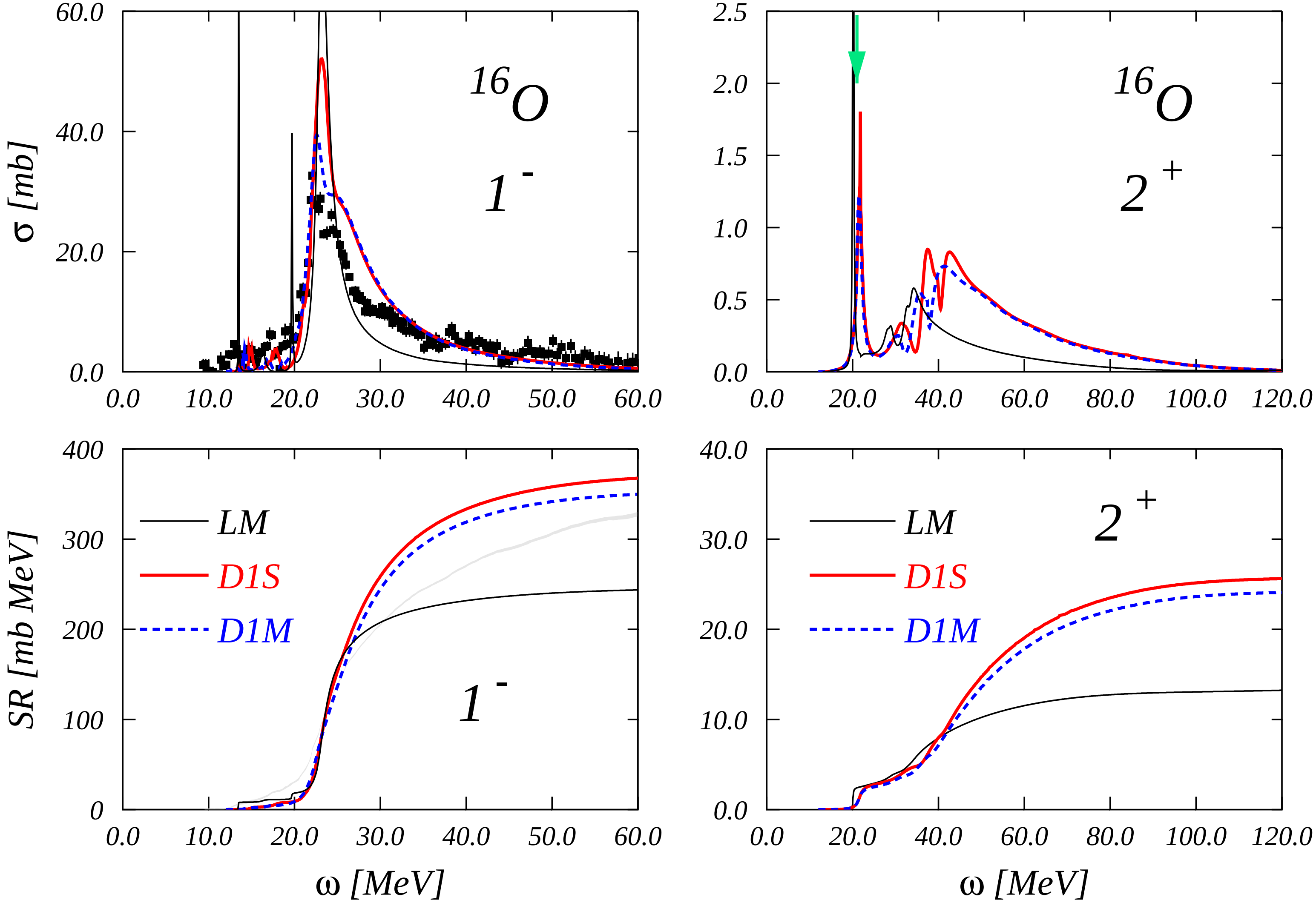


Centroid energies in MeV					
$\epsilon_{ph}^{\mathrm{max}}$	20	50	200	250	cont.
D1S	24.06	27.80	28.27	28.25	28.58
D1M	24.74	27.82	28.25	28.23	28.57



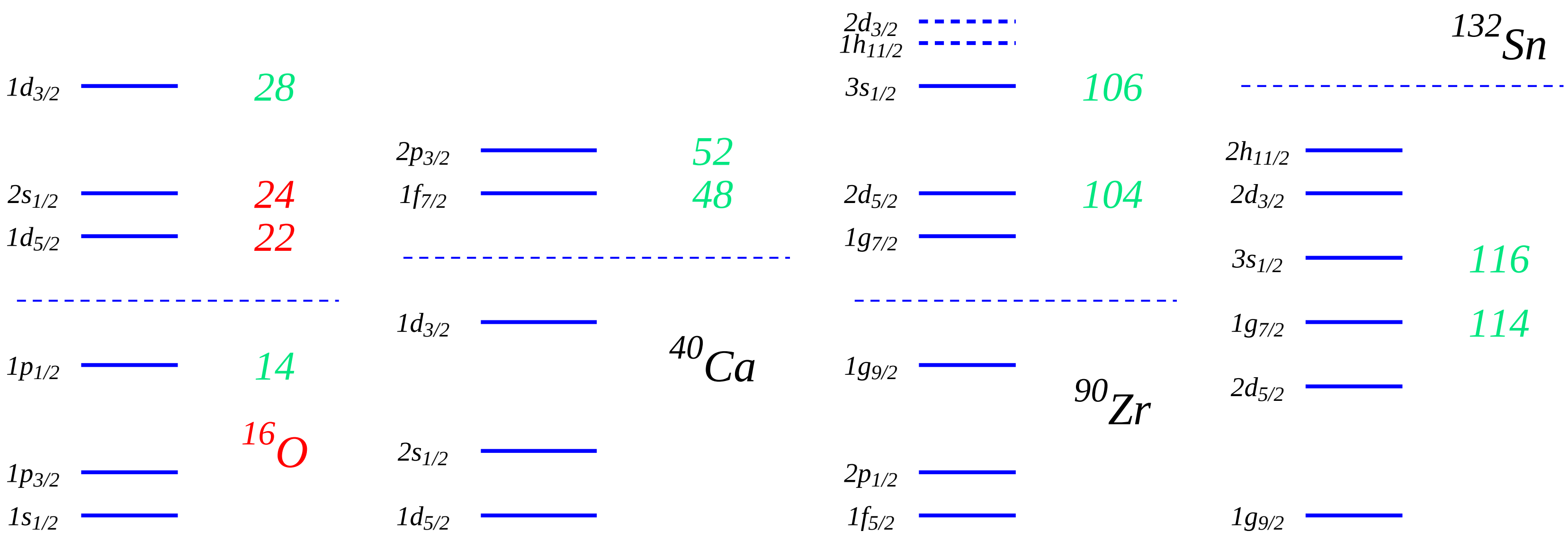
1^- data: J. Ahrens et al., Nucl. Phys. A 251 (1975) 479.

2^+ data: K. T. Knöpfke et al., Phys. Rev. Lett. 35 (1975) 779

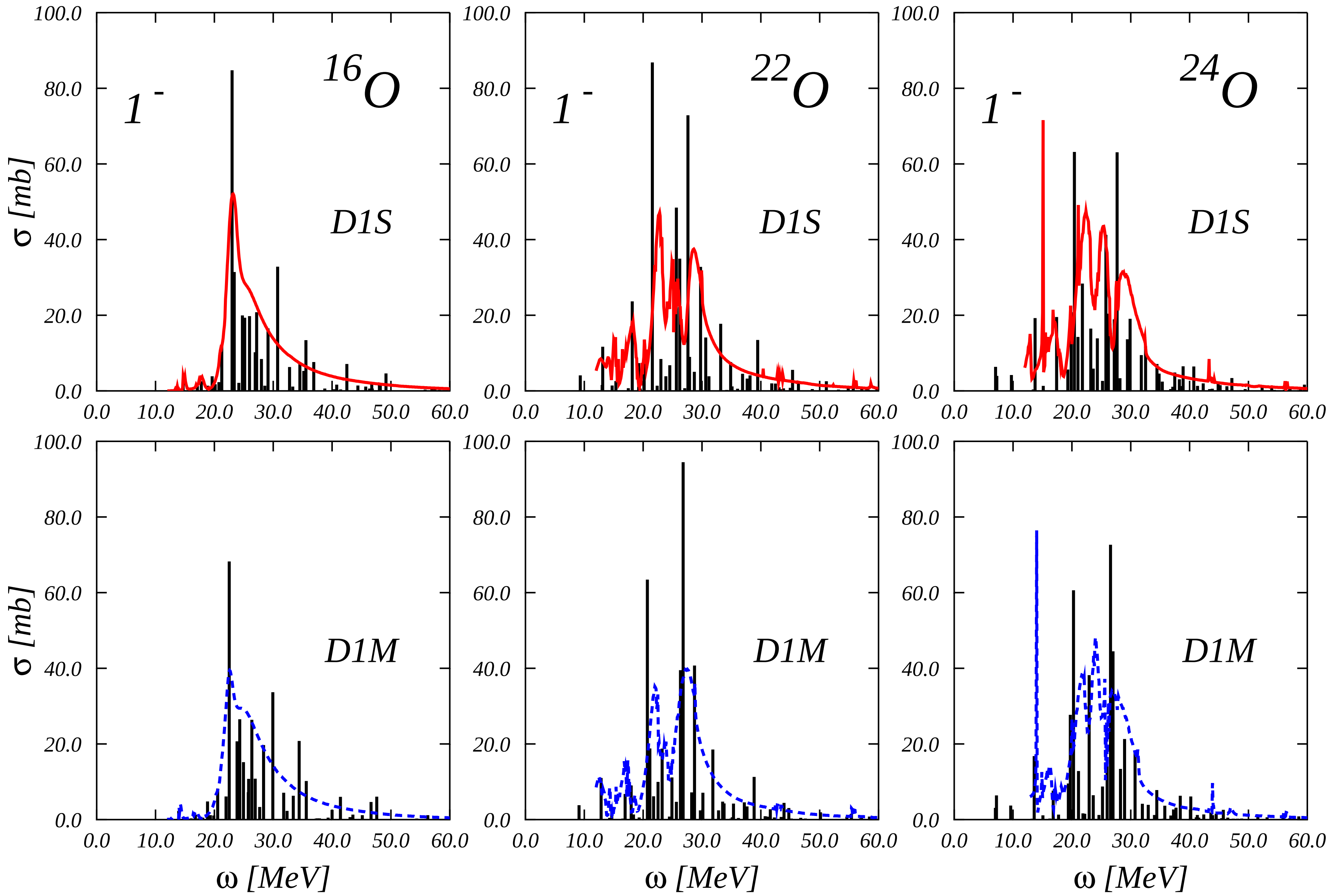


1^- data: J. Ahrens et al., Nucl. Phys. A 251 (1975) 479.

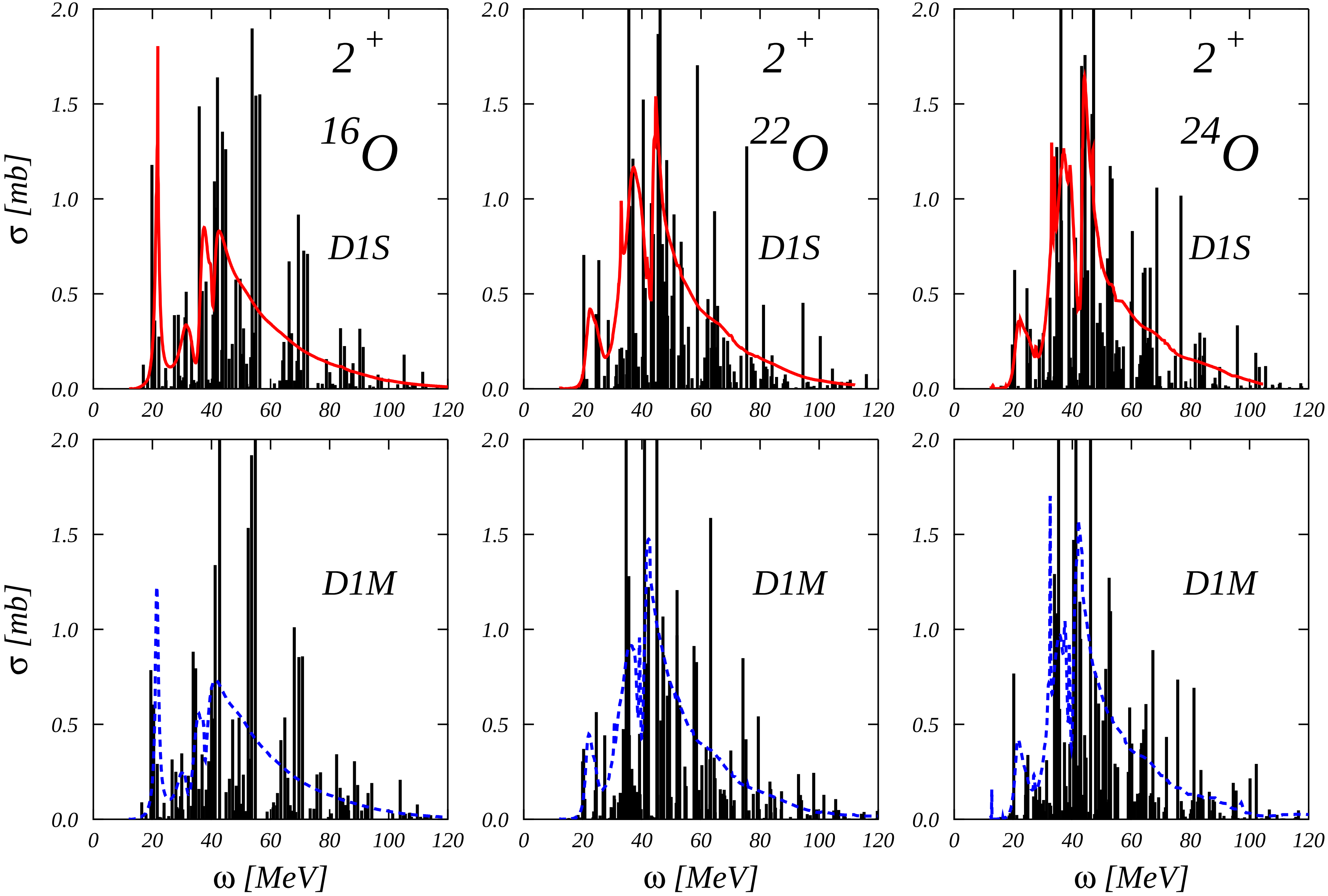
2^+ data: K. T. Knöpfke et al., Phys. Rev. Lett. 35 (1975) 779



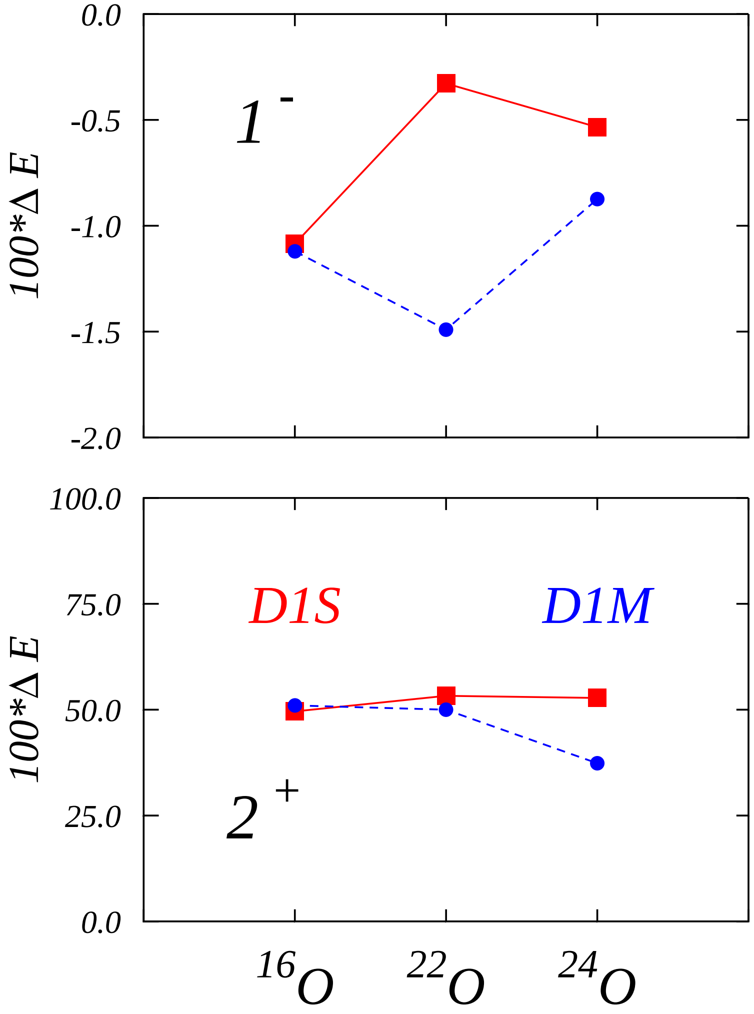
1d3/2
28
2s1/2
24
1d5/2
22
1p1/2
14
16O
1p3/2
1s1/2
2p3/2
52
1f7/2
48
1d3/2
40Ca
2s1/2
1d5/2
2d3/2
1h11/2
3s1/2
106
2d5/2
104
1g7/2
1g9/2
90Zr
2p1/2
1f5/2
132Sn
2h11/2
2d3/2
3s1/2
116
1g7/2
114
2d5/2
1g9/2



1^-
^{16}O
^{22}O
^{24}O
D1S
D1M
σ [mb]
ω [MeV]
0.0
20.0
40.0
60.0
80.0
100.0
10.0
30.0
50.0



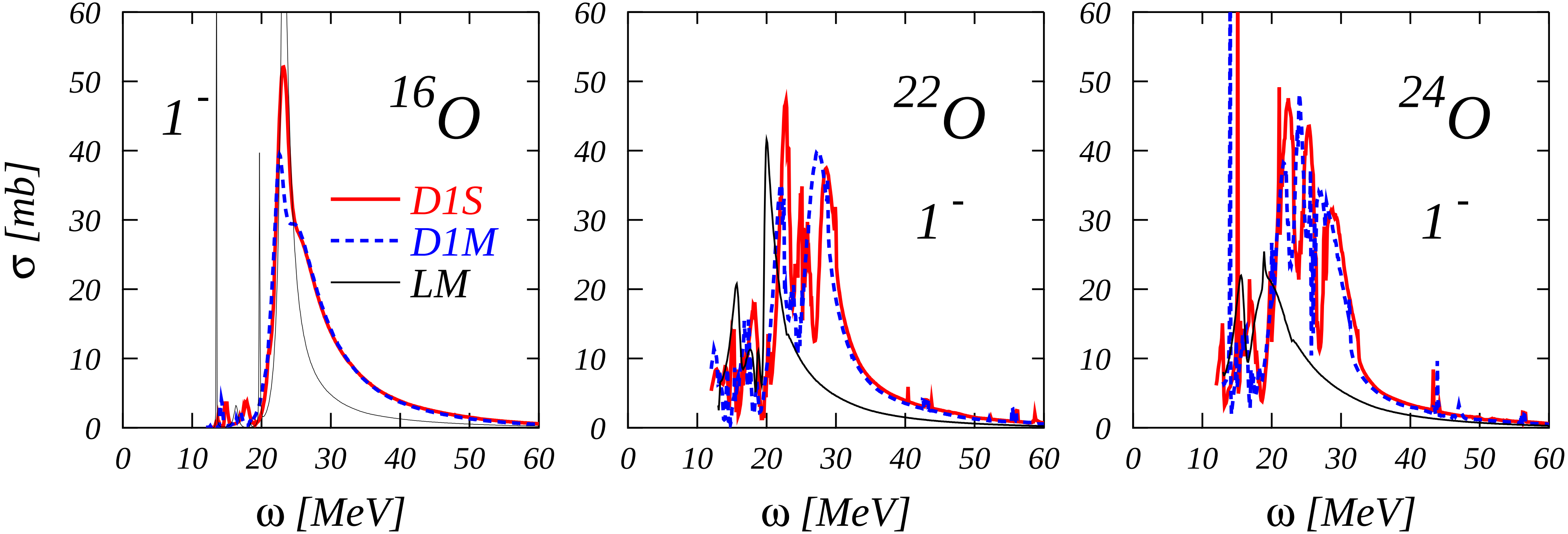
2⁺
16O
22O
24O
D1S
D1M
σ [mb]
ω [MeV]
0.0
0.5
1.0
1.5
2.0
0
20
40
60
80
100
120



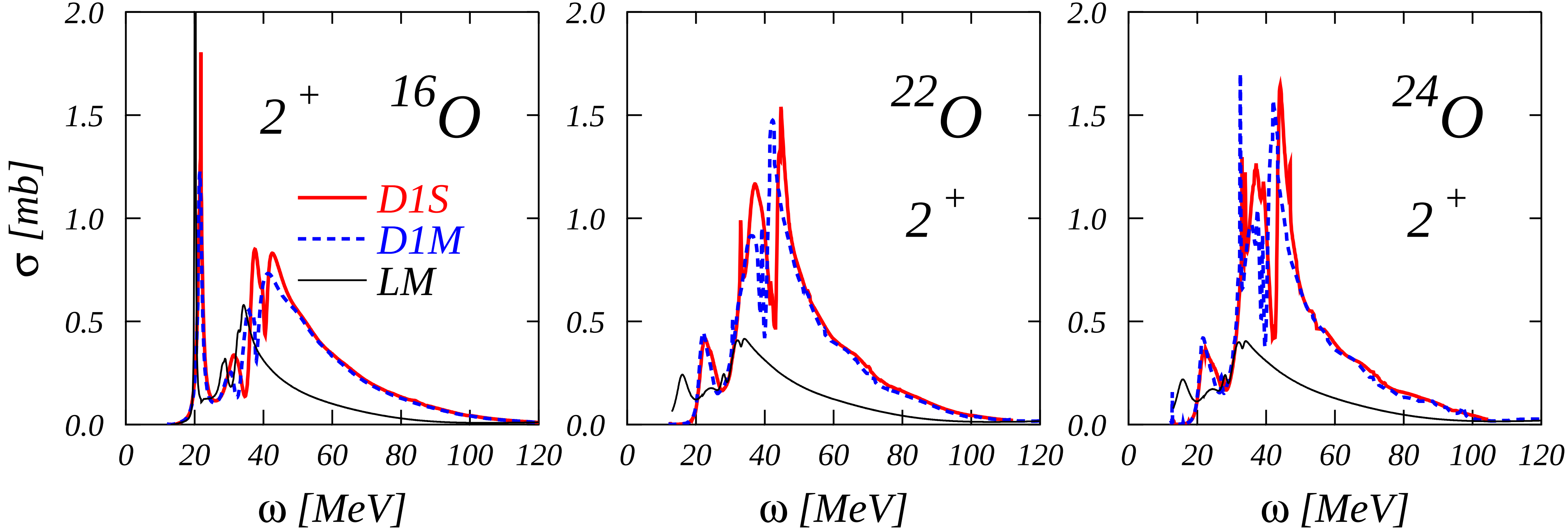
$$\Delta E = \frac{E^{\text{dis}} - E^{\text{con}}}{E^{\text{con}}}$$

Centroid energies in MeV

	^{16}O	^{22}O	^{24}O
1^-			
D1S(dis)	28.27	27.34	26.08
D1S(con)	28.58	27.43	26.18
D1M(dis)	28.24	27.09	25.99
D1M(con)	28.56	27.50	26.31
2^+			
D1S(dis)	67.99	68.77	67.54
D1S(con)	45.45	44.87	44.21
D1M(dis)	69.09	67.50	60.07
D1M(con)	45.76	45.00	43.74



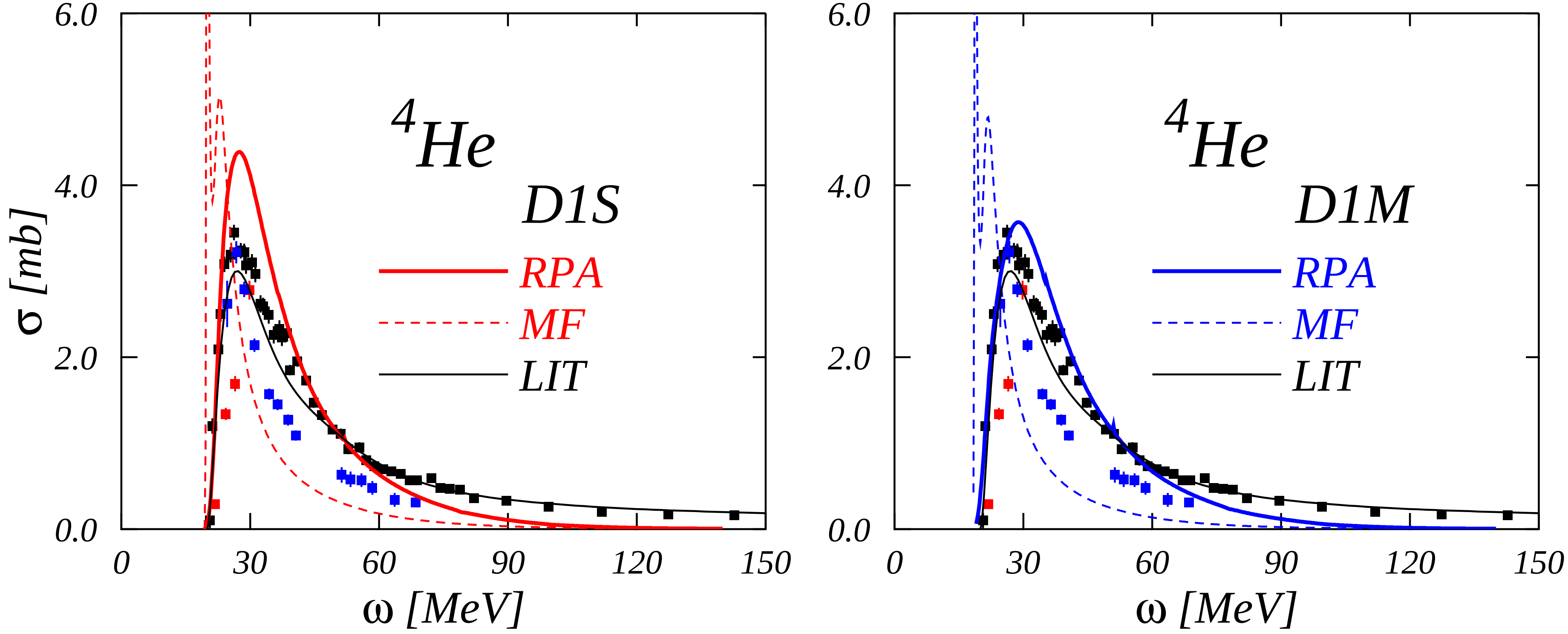
Centroid energies in MeV			
	D1S	D1M	LM
^{16}O	28.58	28.56	26.00
^{22}O	27.43	27.50	23.52
^{24}O	26.18	26.31	23.60



Centroid energies in MeV			
	D1S	D1M	LM
^{16}O	45.45	45.76	40.19
^{22}O	44.87	45.00	43.70
^{24}O	44.21	43.74	44.86

^{4}He

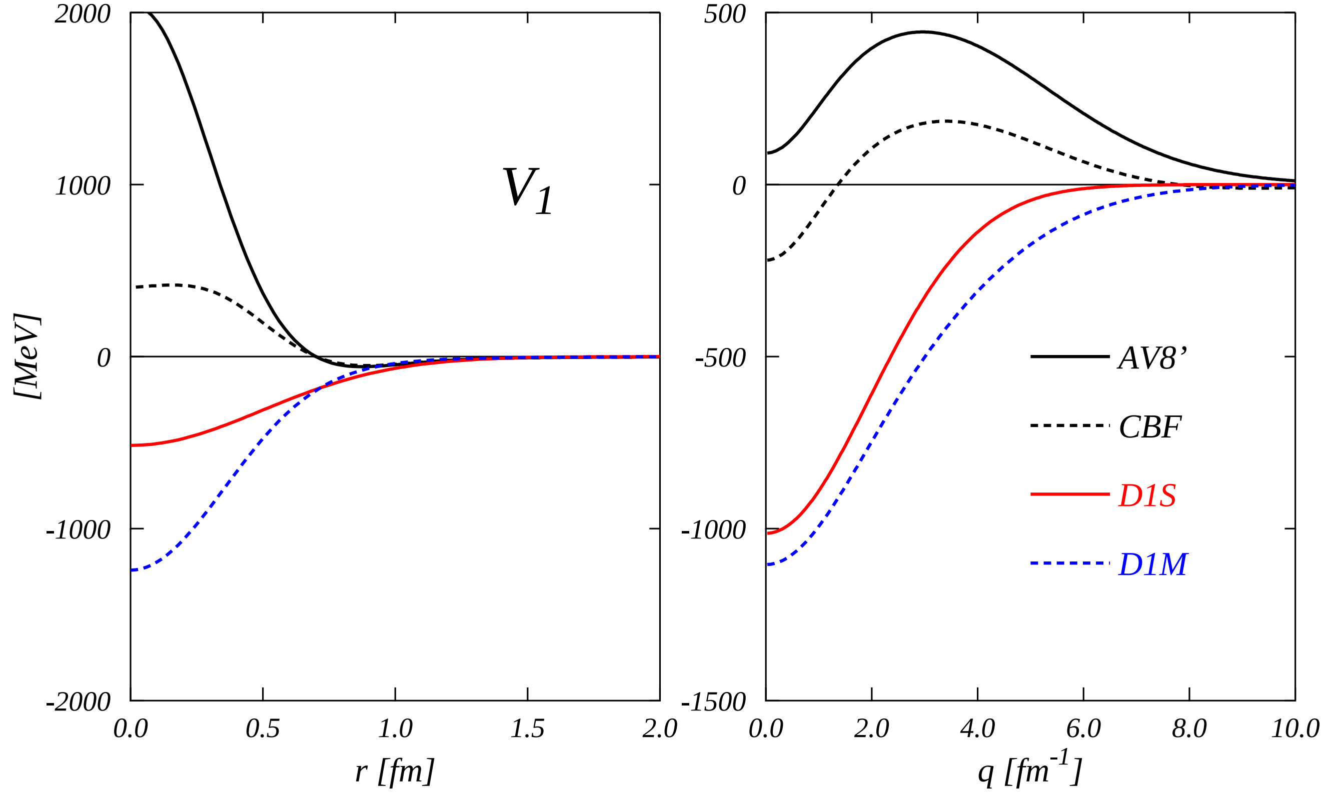
E(D1S)= 30.28 MeV E(D1M)= 29.54 MeV



Data: T. Shima et al., Phys. Rev. C 72 (2005) 044004, B. Nilsson et al., Phys. Lett. B 626 (2005) 65, Yu. M. Arkatov et al. Yad. Konst. 4 (1979) 55.

LIT: D. Gazit at al., Phys. Rev. Lett. 96 (2006) 112301, G. Orlandini, priv. comm.

Scalar terms of the interaction



CBF correlation from

F. Arias de Saavedra, C. Bisconti, G. Co' and A. Fabrocini, Phys. Rep. 450 (2007) 450