Granada, 17/11/2004

Interacción neutrino-nucleo

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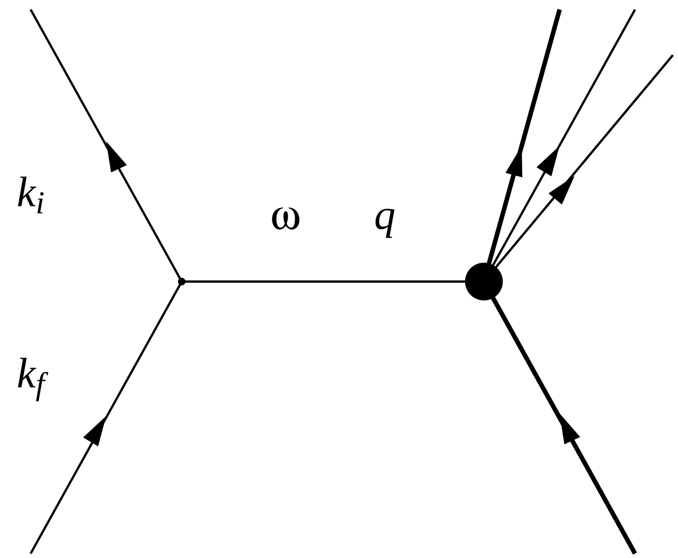
$$e \longrightarrow \gamma_\mu$$

$$\nu \longrightarrow \gamma_\mu(1-\gamma_5)$$

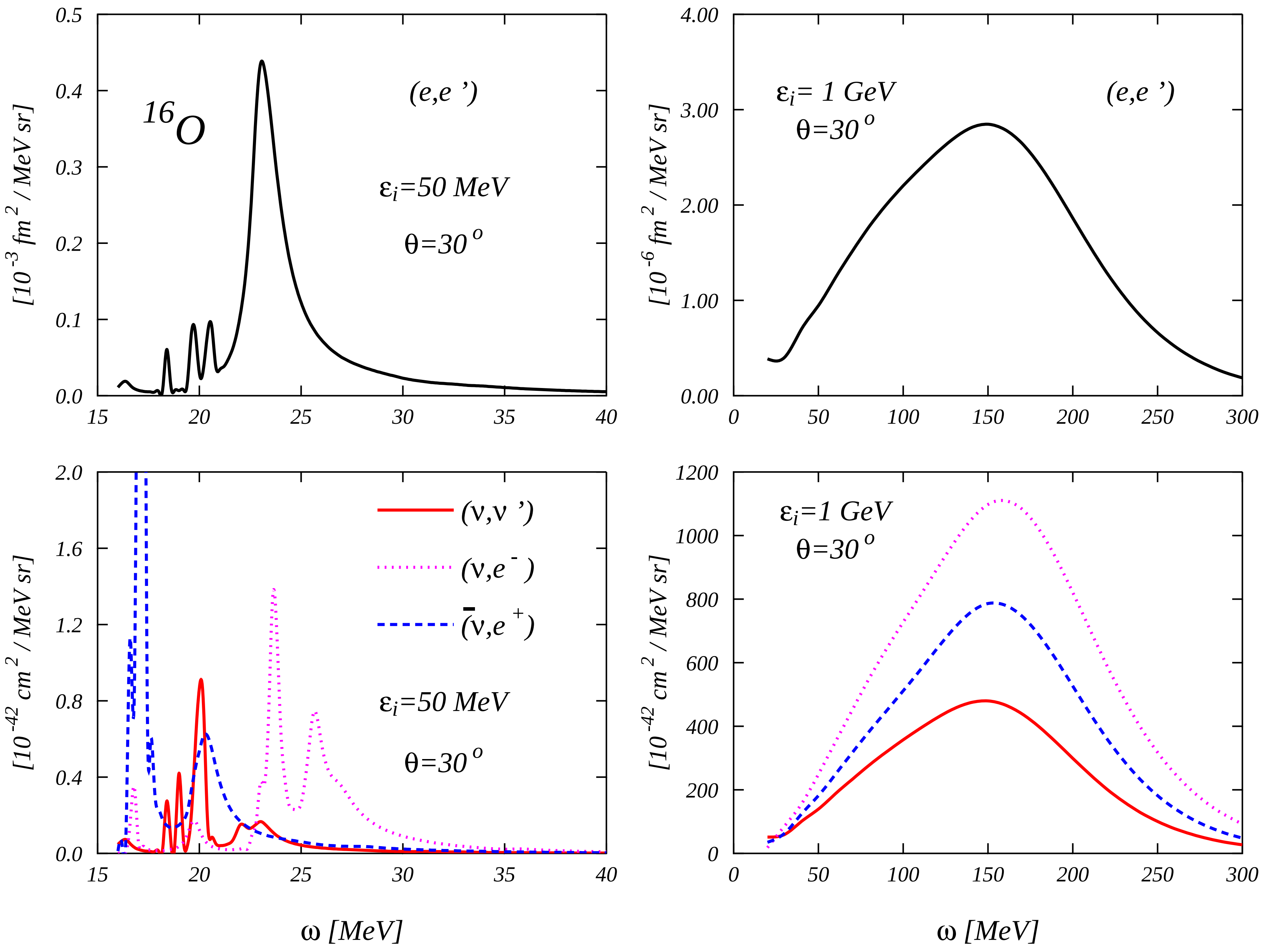


$$\left(\frac{d^2\sigma}{d\Omega\, d\omega}\right)_e = \sigma_M \left[v_L R_L + v_T R_T\right]$$

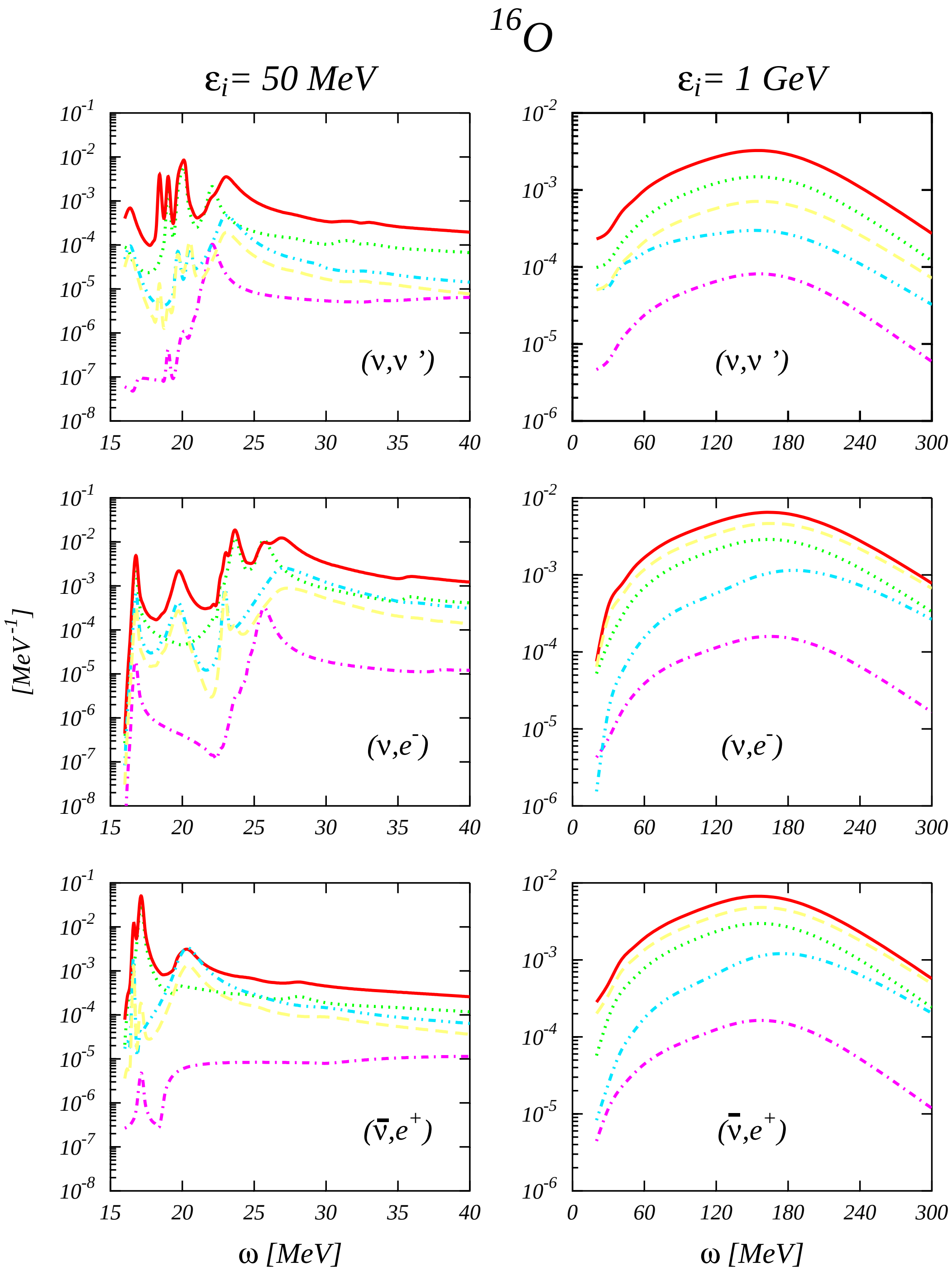
$$\left(\frac{d^2\sigma}{d\Omega\, d\omega}\right)_\nu = G^2 \frac{|\mathbf{k}_f|}{\epsilon_i} \left[\sigma_L + \sigma_T\right]$$

$$\sigma_L = l_v \sum_J | < J_f || \mathcal{M}_J^V || J_i > |^2$$
$$+ l_{00} \sum_J | < J_f || \mathcal{M}_J^A || J_i > |^2$$
$$- l_{33} \sum_J | < J_f || \mathcal{L}_J^A || J_i > |^2$$
$$+ l_{03} \sum_J 2Re < J_f || \mathcal{M}_J^A || J_i >< J_f || \mathcal{L}_J^A || J_i >^*$$

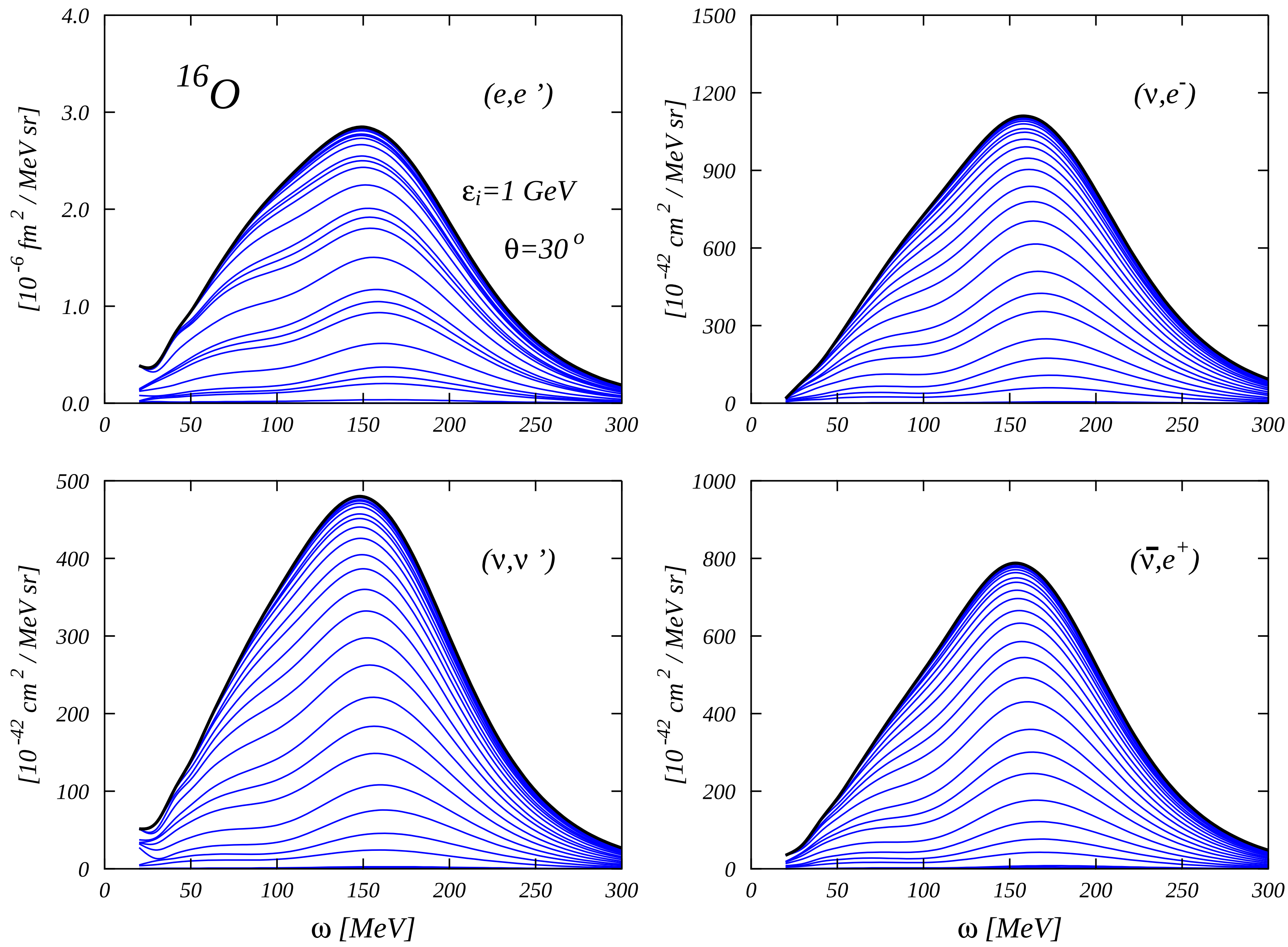
$$\sigma_T = l_+ \left[\sum_J | < J_f || \mathcal{J}_J^V || J_i > |^2 + \sum_J | < J_f || \mathcal{J}_J^A || J_i > |^2 \right]$$
$$\mp l_- \sum_J 2Re < J_f || \mathcal{J}_J^A || J_i >< J_f || \mathcal{J}_J^V || J_i >^*$$



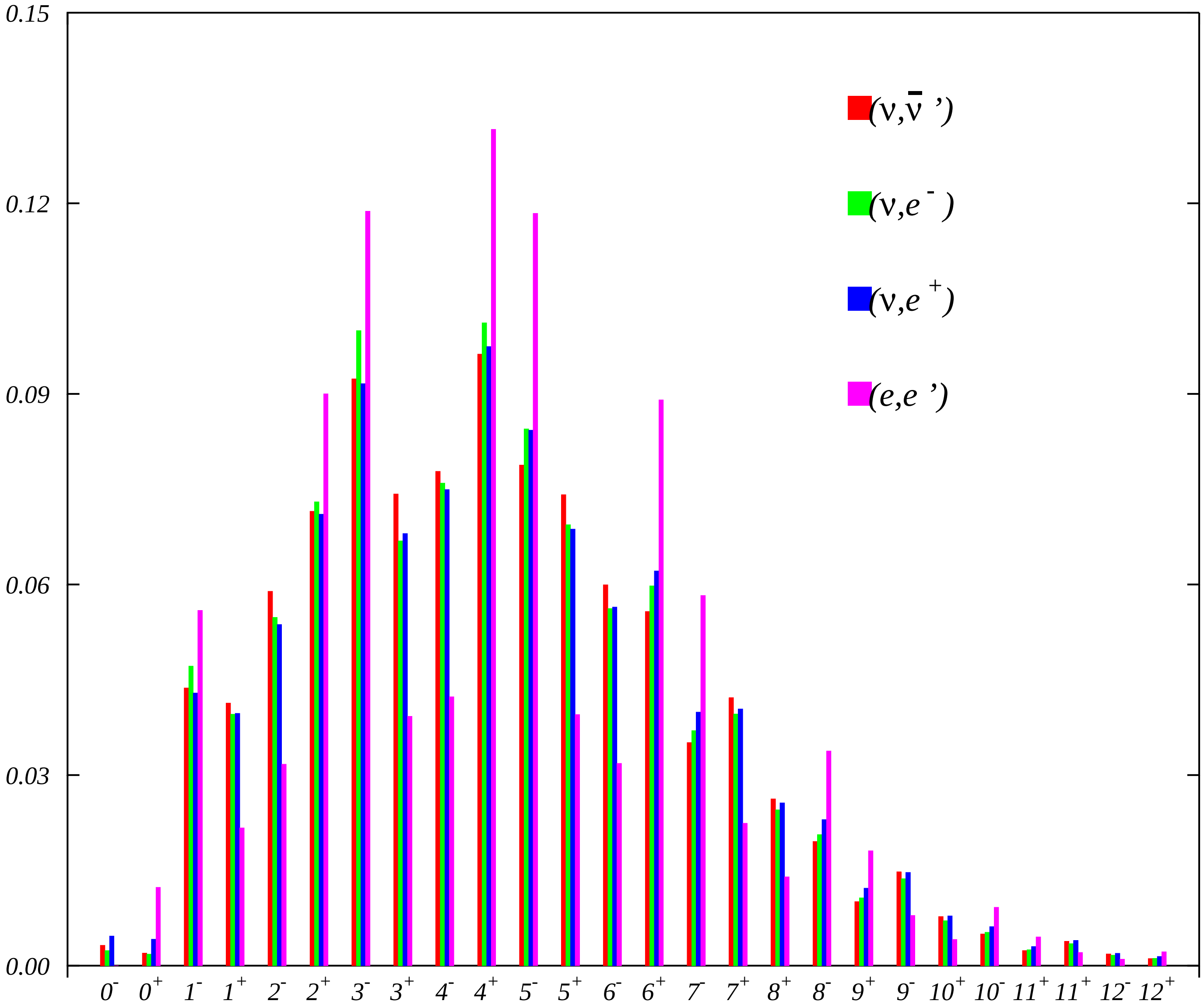
^{16}O
(e,e ')
ε_i=50 MeV
θ=30 ^{o}
ε_i= 1 GeV
θ=30 ^{o}
(e,e ')
(ν,ν ')
(ν,e$^-$)
($\bar{\nu}$,e$^+$)
ε_i=50 MeV
θ=30 ^{o}
ε_i=1 GeV
θ=30 ^{o}
[10^{-3} fm^2 / MeV sr]
[10^{-6} fm^2 / MeV sr]
[10^{-42} cm^2 / MeV sr]
[10^{-42} cm^2 / MeV sr]
ω [MeV]
ω [MeV]



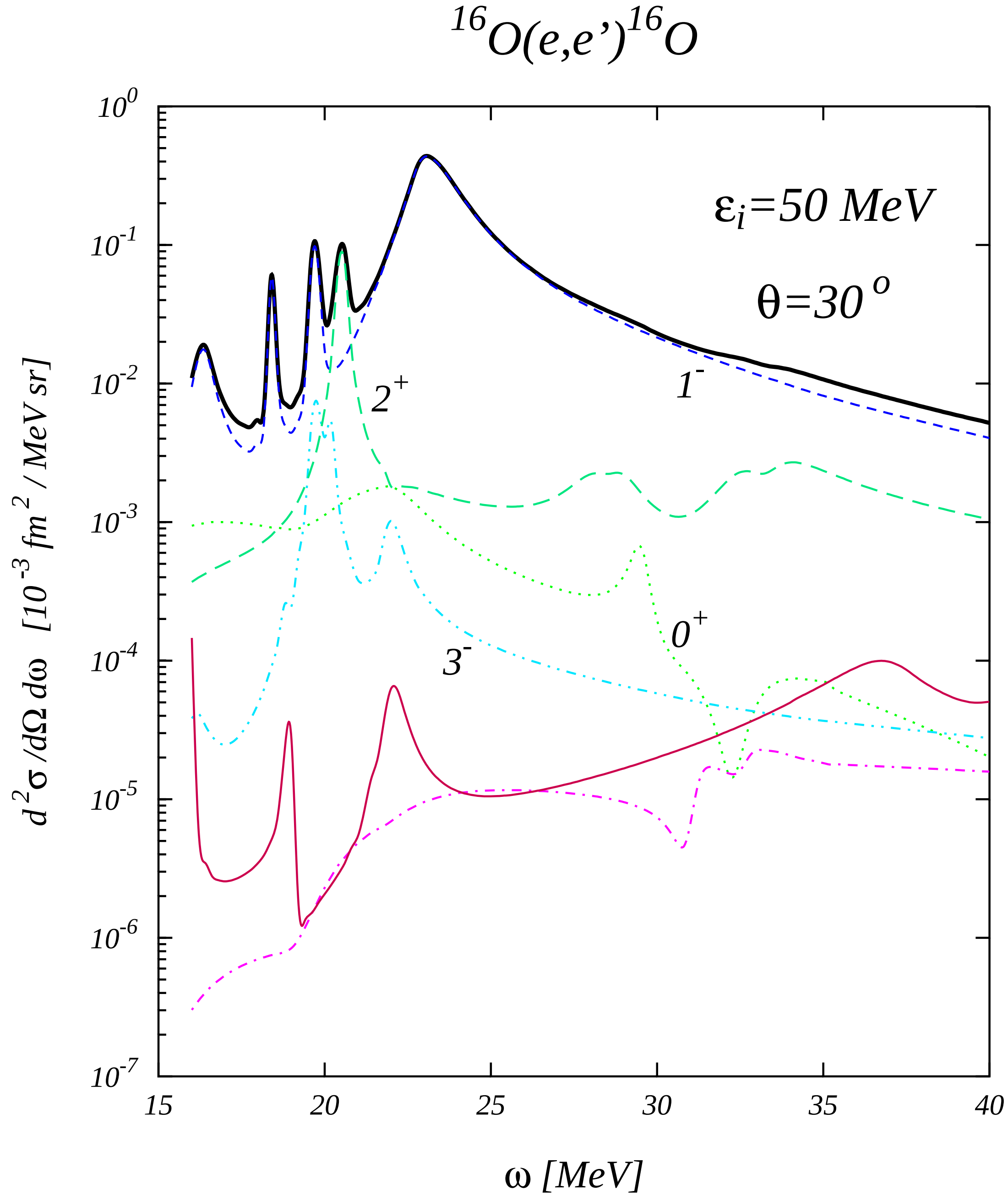
^{16}O
ε_i= 50 MeV
ε_i= 1 GeV
(ν,ν')
(ν,e^-)
$(\bar{\nu},e^+)$
[MeV^{-1}]
ω [MeV]



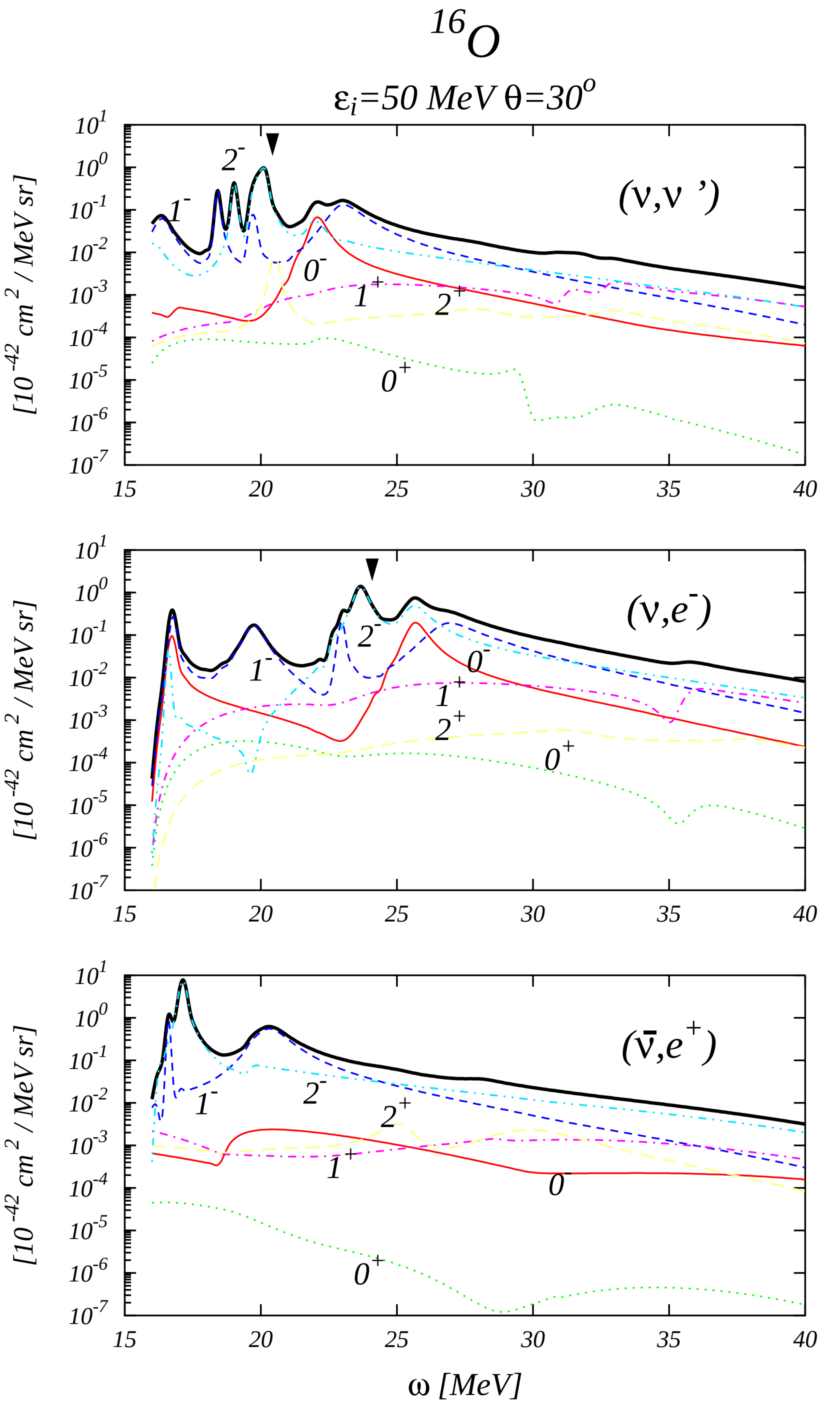
^{16}O
(e,e ')
ε_i=1 GeV
θ=30 ^{o}
[10 $^{-6}$ fm ^{2} / MeV sr]
(ν,e$^-$)
[10 $^{-42}$ cm ^{2} / MeV sr]
(ν,ν ')
($\bar{\nu}$,e$^+$)
ω [MeV]



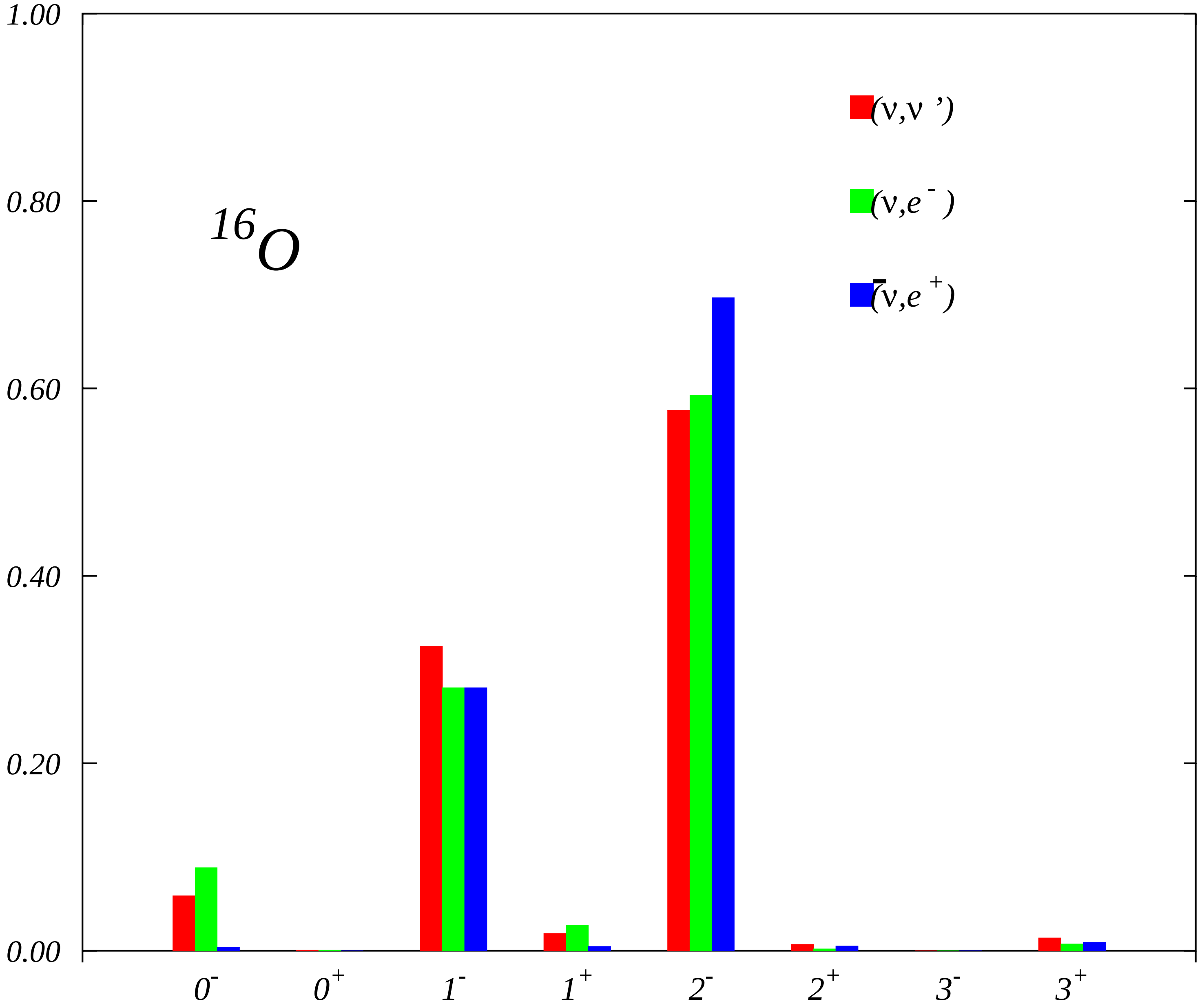
0.15
0.12
0.09
0.06
0.03
0.00
$(\nu,\bar{\nu}')$
(ν,e^-)
(ν,e^+)
(e,e')
0^- 0^+ 1^- 1^+ 2^- 2^+ 3^- 3^+ 4^- 4^+ 5^- 5^+ 6^- 6^+ 7^- 7^+ 8^+ 8^- 9^+ 9^- 10^+ 10^- 11^+ 11^+ 12^- 12^+

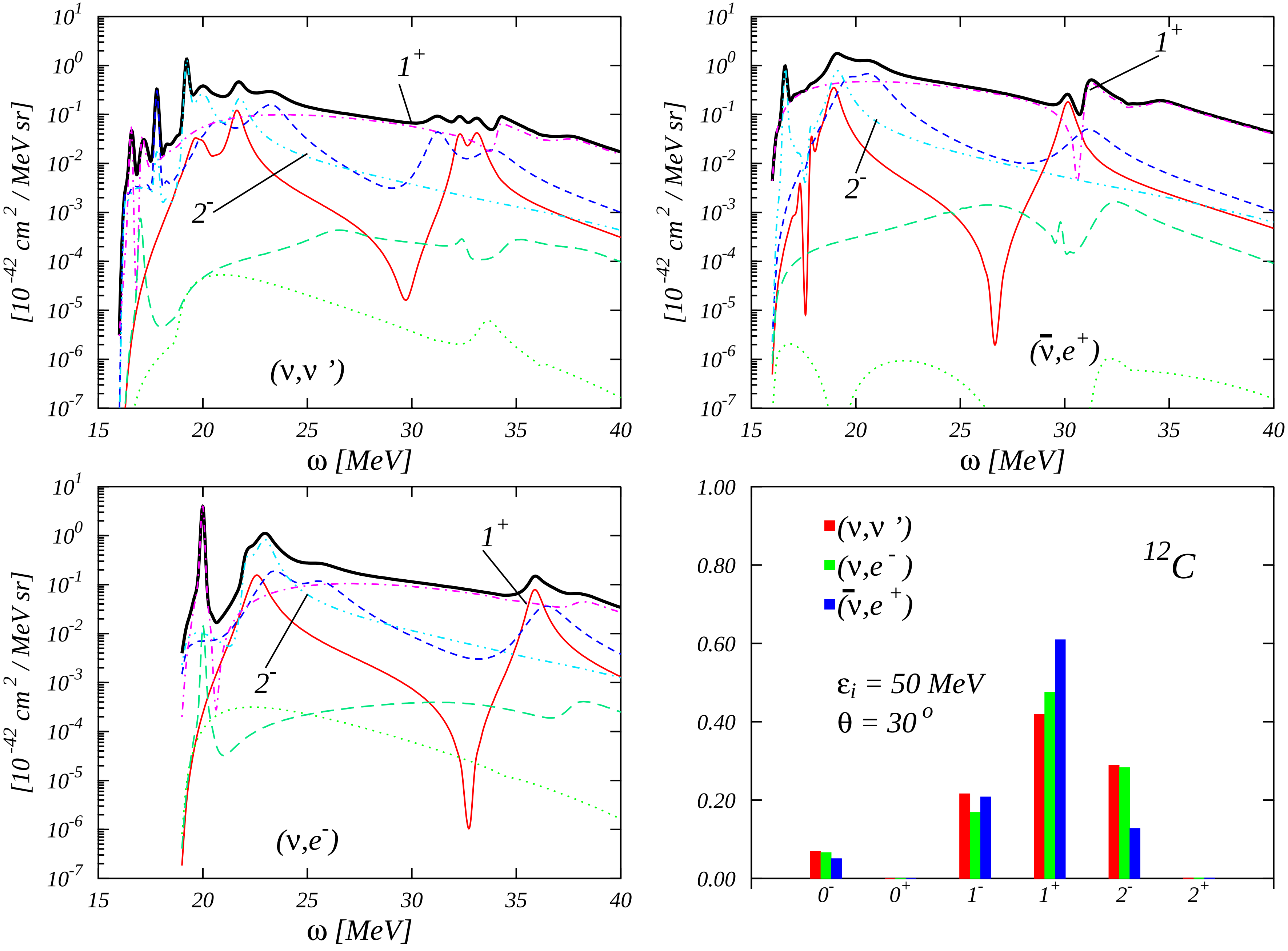


$^{16}O(e,e')^{16}O$
ε_i=50 MeV
θ=30 ^{o}
$d^2\sigma/d\Omega\, d\omega$ [10^{-3} fm^2 / MeV sr]
ω [MeV]
1^-
2^+
0^+
3^-
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
15
20
25
30
35
40

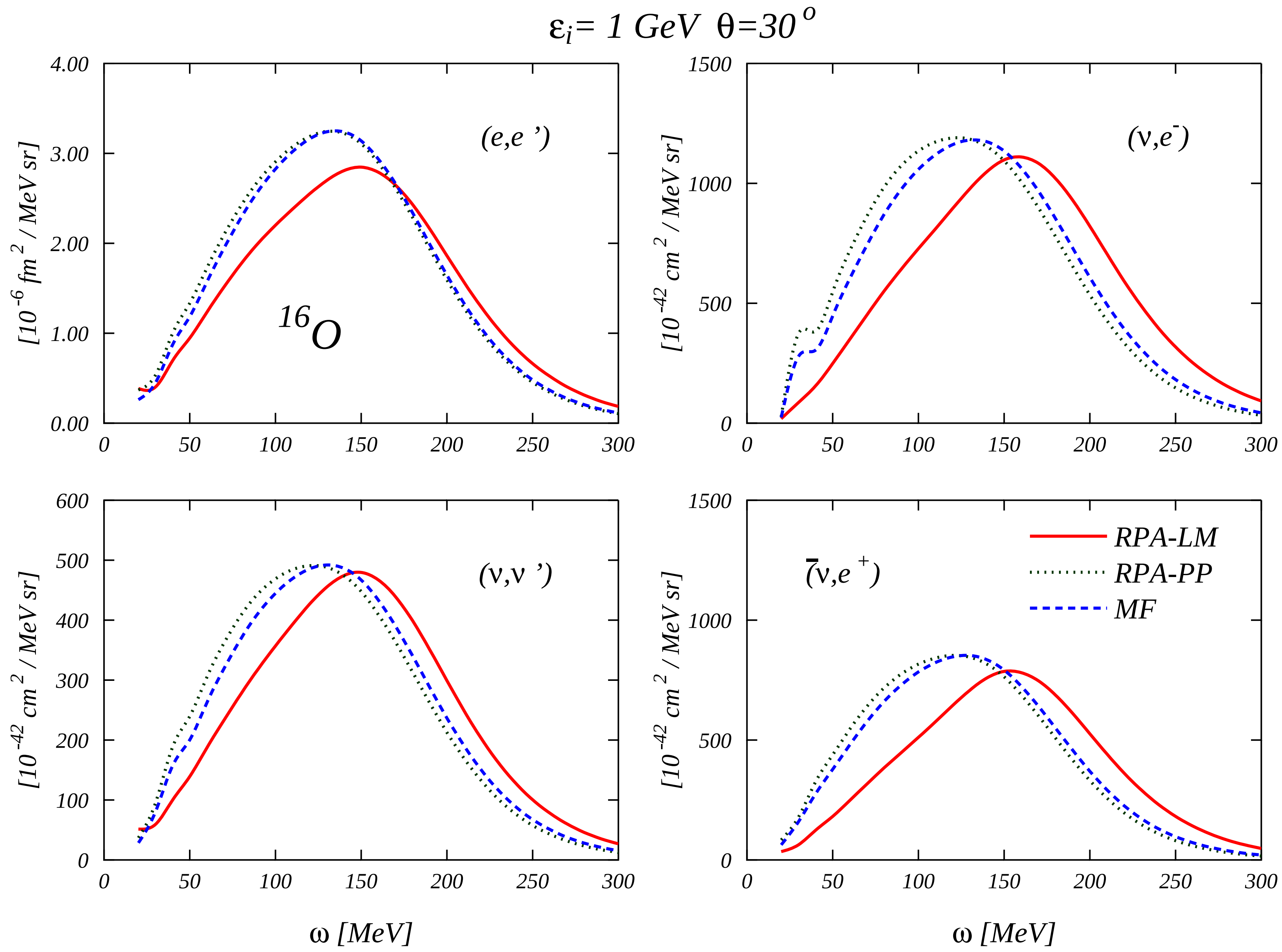


^{16}O
ε_i=50 MeV θ=30°
(ν,ν ')
(ν,e⁻)
($\bar{\nu}$,e⁺)
[10⁻⁴² cm² / MeV sr]
ω [MeV]

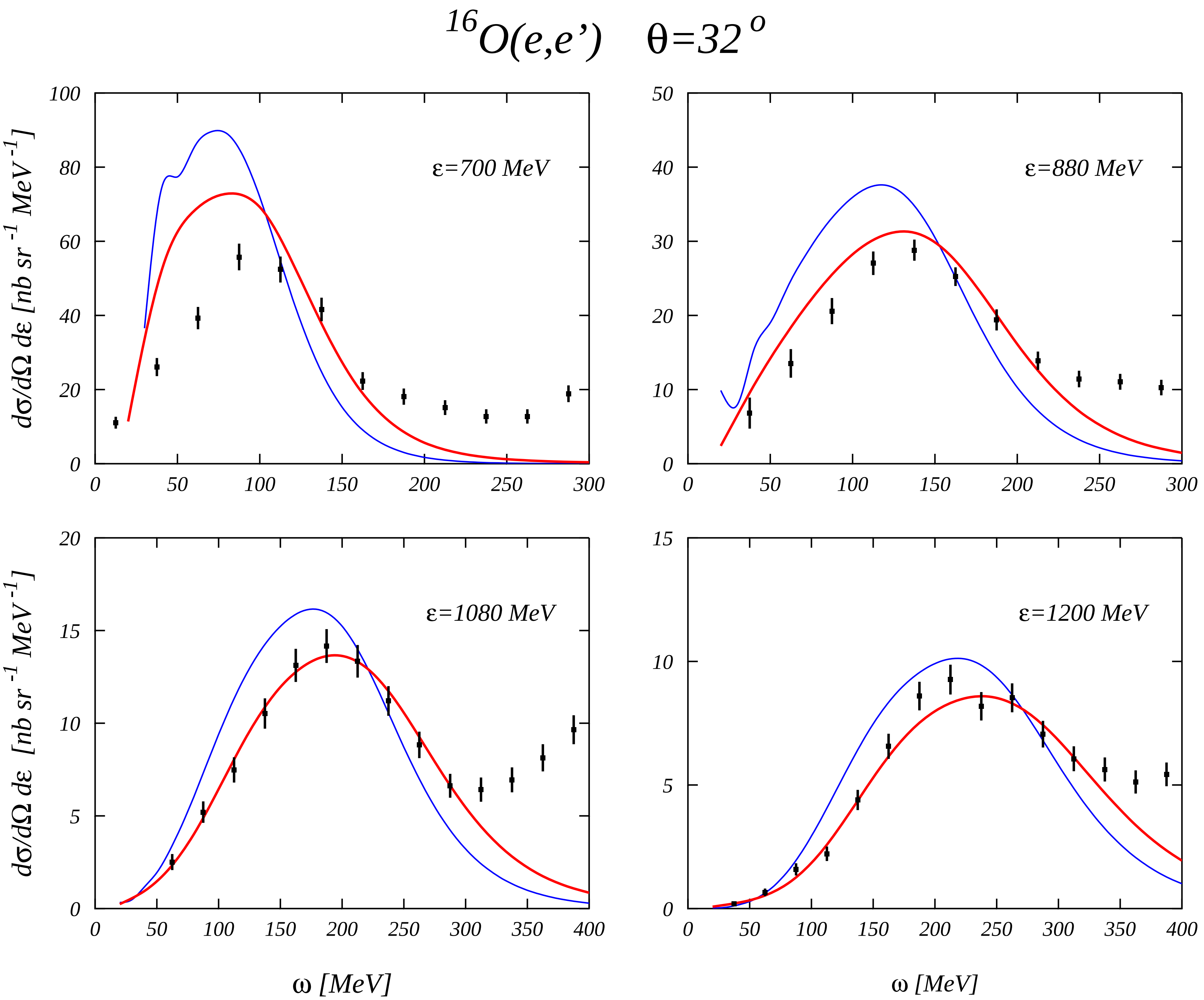

1.00
0.80
0.60
0.40
0.20
0.00
^{16}O
(ν,ν')
(ν,e^-)
$(\bar{\nu},e^+)$
0^-
0^+
1^-
1^+
2^-
2^+
3^-
3^+



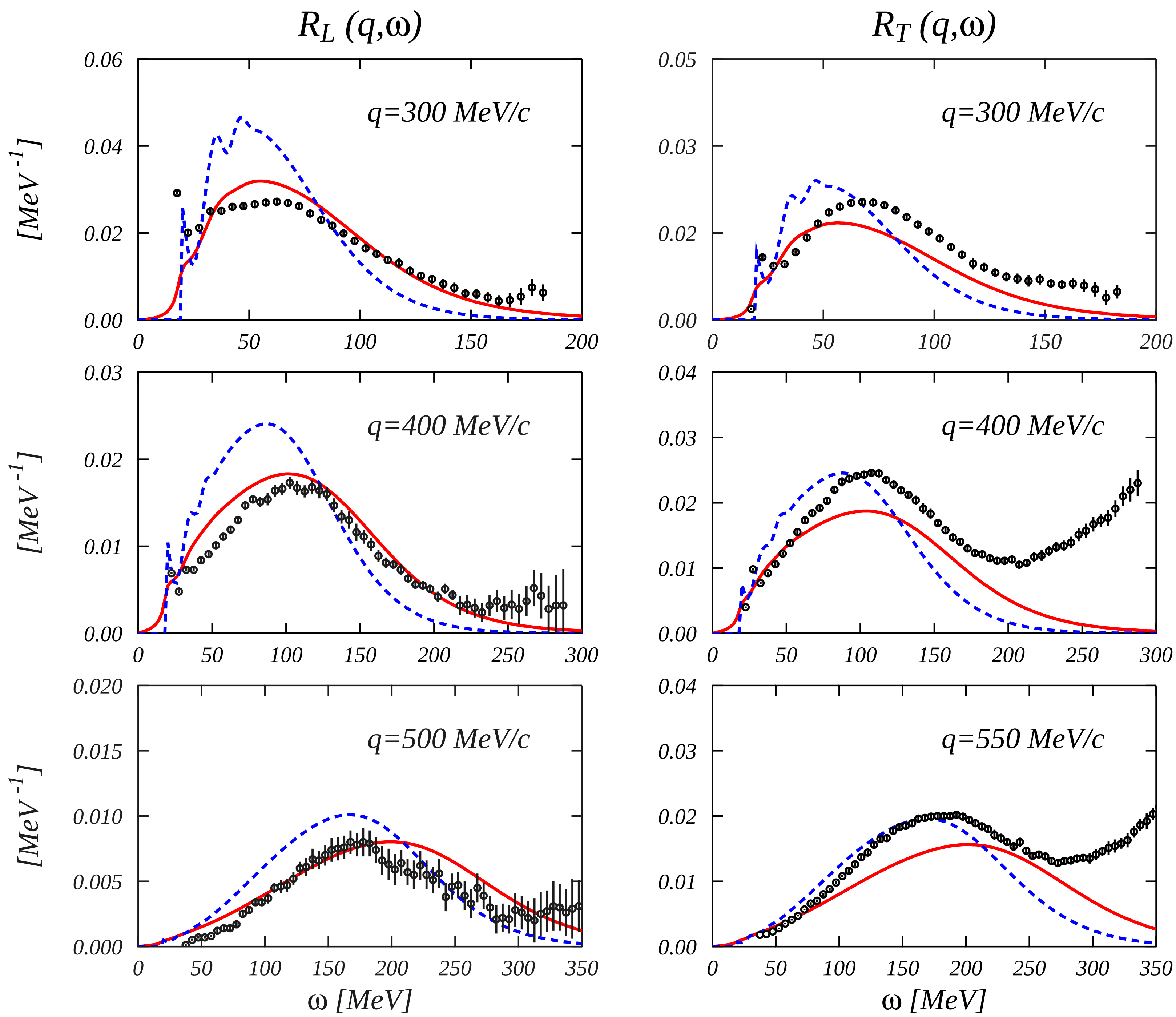
(ν,ν ')
(ν̄,e+)
(ν,e-)
1+
2-
[10-42 cm2 / MeV sr]
ω [MeV]
(ν,ν ')
(ν,e -)
(ν̄,e +)
12C
εi = 50 MeV
θ = 30 o
0- 0+ 1- 1+ 2- 2+

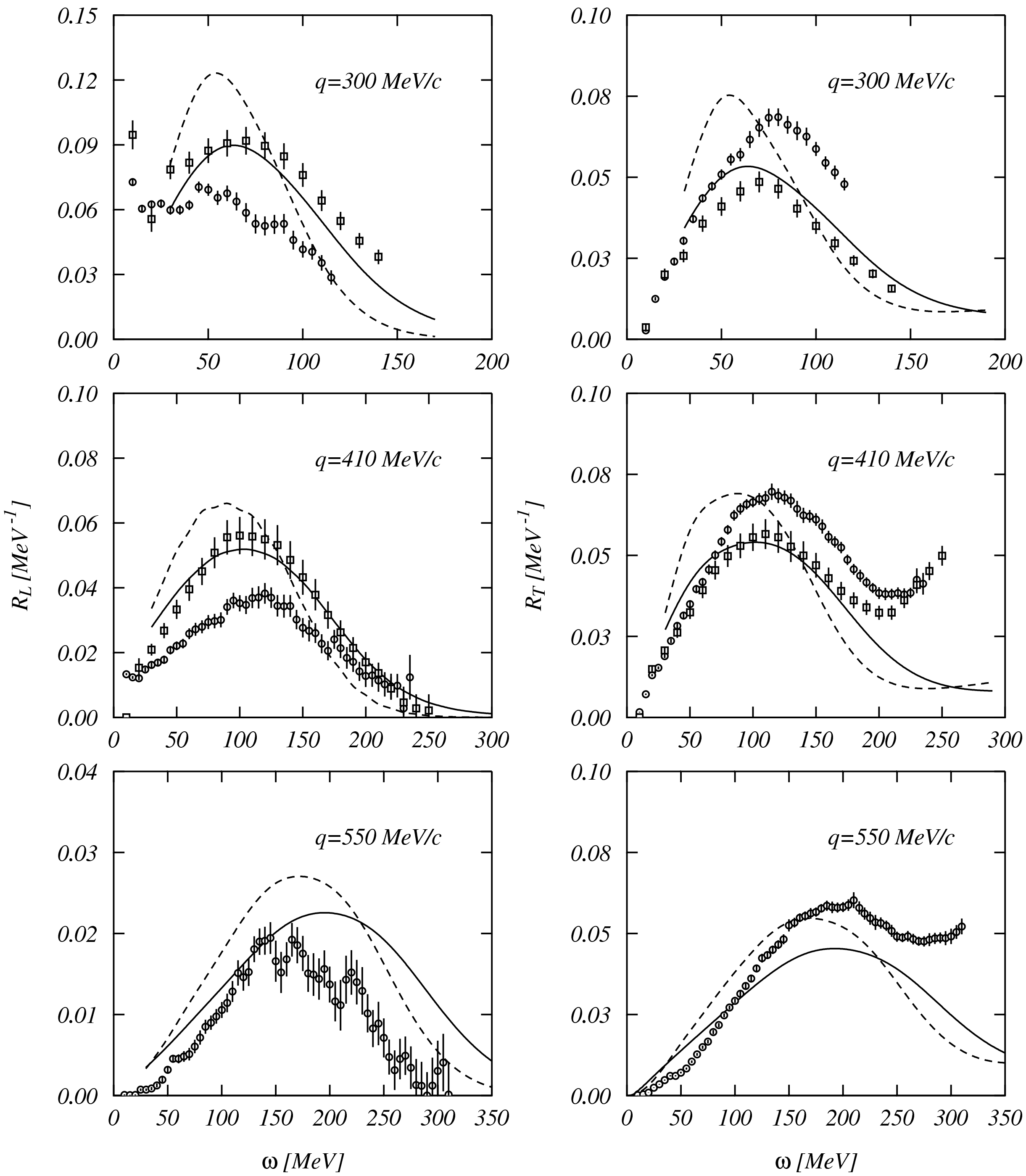


ε_i= 1 GeV θ=30°
(e,e ')
^{16}O
(ν,e⁻)
(ν,ν ')
($\bar{\nu}$,e⁺)
RPA-LM
RPA-PP
MF
[10^{-6} fm^2 / MeV sr]
[10^{-42} cm^2 / MeV sr]
ω [MeV]
0.00
1.00
2.00
3.00
4.00
0
500
1000
1500
100
200
300
400
600
50
150
250



$^{16}O(e,e')$ θ=32 o
ε=700 MeV
ε=880 MeV
ε=1080 MeV
ε=1200 MeV
dσ/dΩ dε [nb sr -1 MeV -1]
ω [MeV]


$R_L\ (q,\omega)$
$R_T\ (q,\omega)$
q=300 MeV/c
q=300 MeV/c
q=400 MeV/c
q=400 MeV/c
q=500 MeV/c
q=550 MeV/c
[MeV^{-1}]
ω [MeV]
ω [MeV]



q=300 MeV/c
q=300 MeV/c
q=410 MeV/c
q=410 MeV/c
q=550 MeV/c
q=550 MeV/c
R_L [MeV^-1]
R_T [MeV^-1]
ω [MeV]
ω [MeV]

$$H = H_0 + H_1 \qquad\qquad H_0|\Phi_n >= E_n|\Phi_n >$$

$$S^0(|\mathbf{q}|,\omega) = \frac{1}{\pi} Im \sum_{n,n'} < \Phi_0|\mathcal{O}^+(\mathbf{q})|\Phi_n >$$

$$\left[\frac{1}{E_n\delta_{n,n'} - \omega - i\eta} + \frac{1}{E_n\delta_{n,n'} + \omega + i\eta}\right] < \Phi_{n'}|\mathcal{O}(\mathbf{q})|\Phi_0 >$$

$$S(|\mathbf{q}|,\omega) = \frac{1}{\pi} Im \sum_{n,n'} < \Phi_0|\mathcal{O}^+(\mathbf{q})|\Phi_n >$$

$$\left[\frac{1}{E_n\delta_{n,n'} - \omega - \Sigma_{n,n'}(\omega) - i\eta} + \frac{1}{E_n\delta_{n,n'} + \omega - \Sigma_{n,n'}(-\omega) + i\eta}\right]$$

$$< \Phi_{n'}|\mathcal{O}(\mathbf{q})|\Phi_0 >$$

$$\Sigma_{n,n'}(\omega) \rightarrow \Sigma(\omega)\delta_{n,n'} \rightarrow \Delta(\omega) - \frac{i}{2}\Gamma(\omega)$$

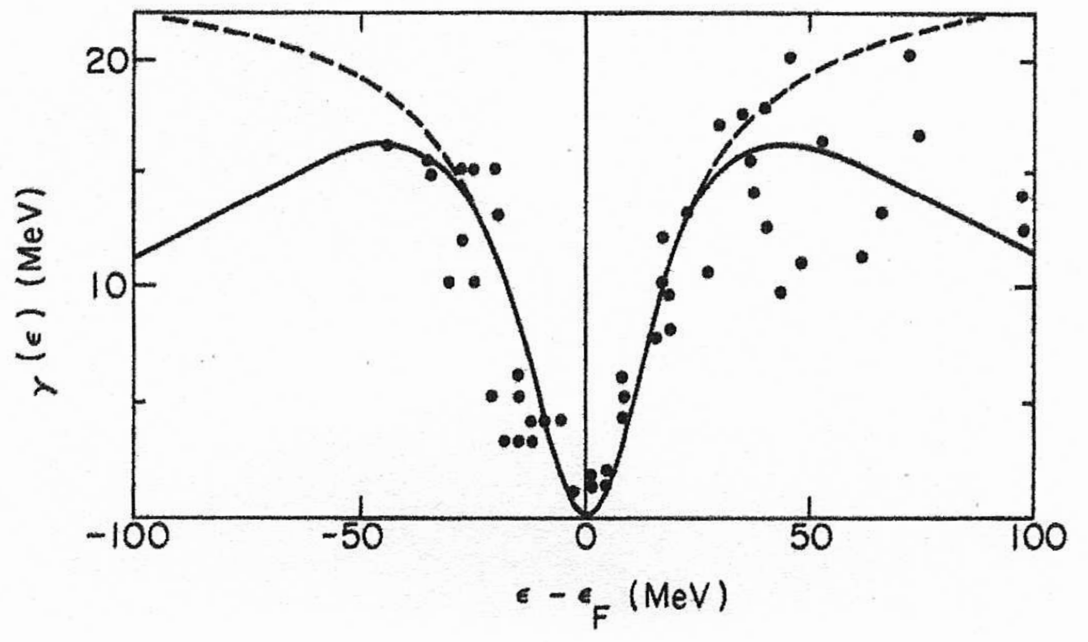
$$S(|\mathbf{q}|,\omega) = \int_0^\infty dE \;\; S^0(|\mathbf{q}|,E)\left[\rho(E,\omega) + \rho(E,-\omega)\right]$$

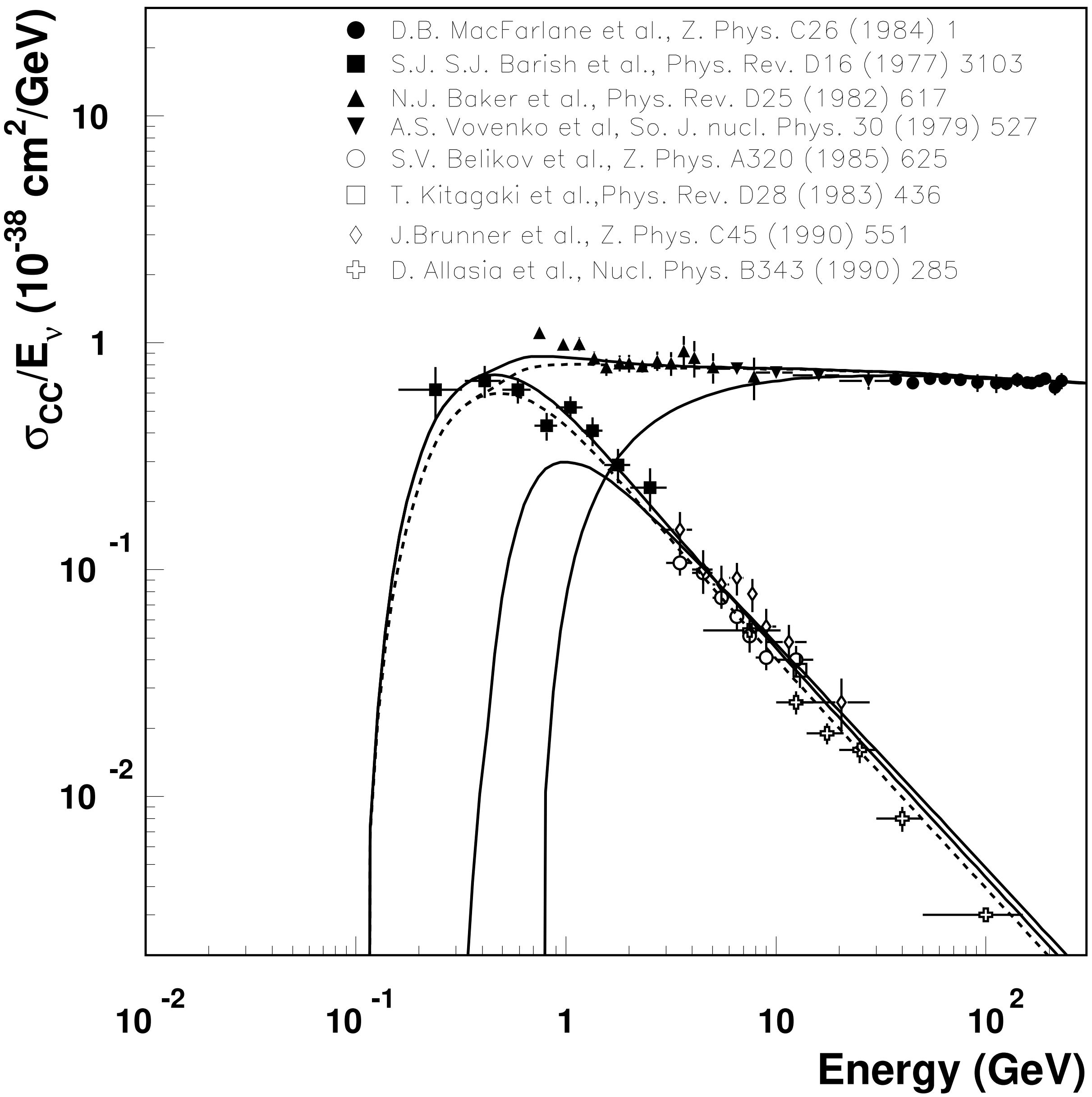
$$\rho(E,\omega) = \frac{1}{2\pi}\frac{\Gamma(\omega)}{[E-\omega-\Delta(\omega)]^2 + [\Gamma(\omega)/2]^2}$$

$$\Delta(\omega) = \frac{1}{2\pi}P\int_0^\infty d\omega' \; \frac{\Gamma(\omega')}{\omega'-\omega}$$

$$\Gamma(\omega) \sim \frac{1}{\omega}\int_0^\omega d\epsilon\,[\gamma(\epsilon_F + \epsilon + \omega) + \gamma(\epsilon_F + \epsilon - \omega)]$$

$$\gamma(\epsilon) = A_\Gamma \left(\frac{\epsilon^2}{\epsilon^2 + B_\Gamma{}^2}\right)\left(\frac{C_\Gamma{}^2}{\epsilon^2 + C_\Gamma{}^2}\right)$$





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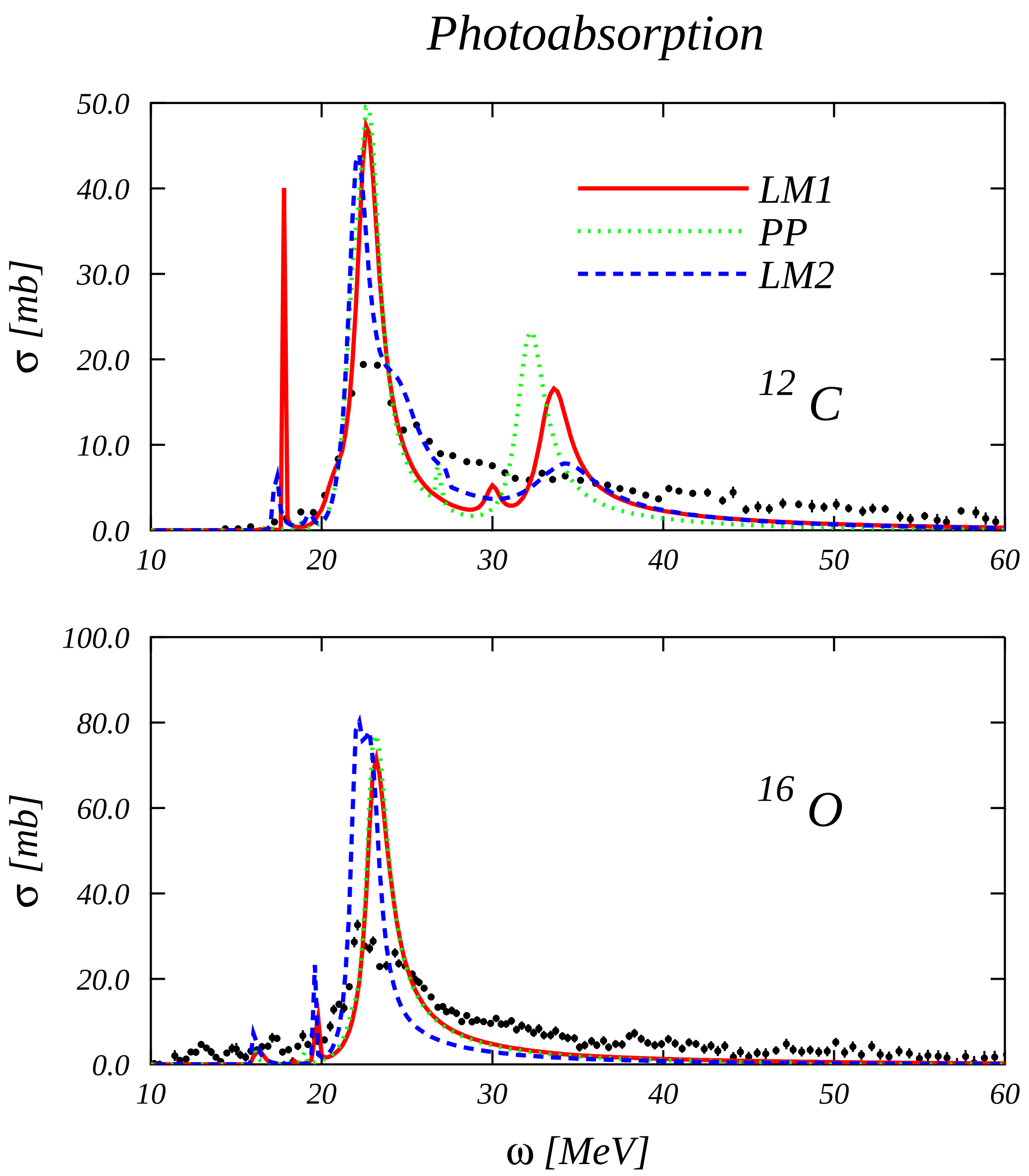
$$V(r_{12}) = C_o \;\; [\;\; f(r_{12}) + f'(r_{12})\vec{\tau}_1 \cdot \vec{\tau}_2$$
$$+ \;\; g(r_{12})\vec{\sigma}_1 \cdot \vec{\sigma}_2 + g'(r_{12})\vec{\sigma}_1 \cdot \vec{\sigma}_2 \vec{\tau}_1 \cdot \vec{\tau}_2 \;]$$

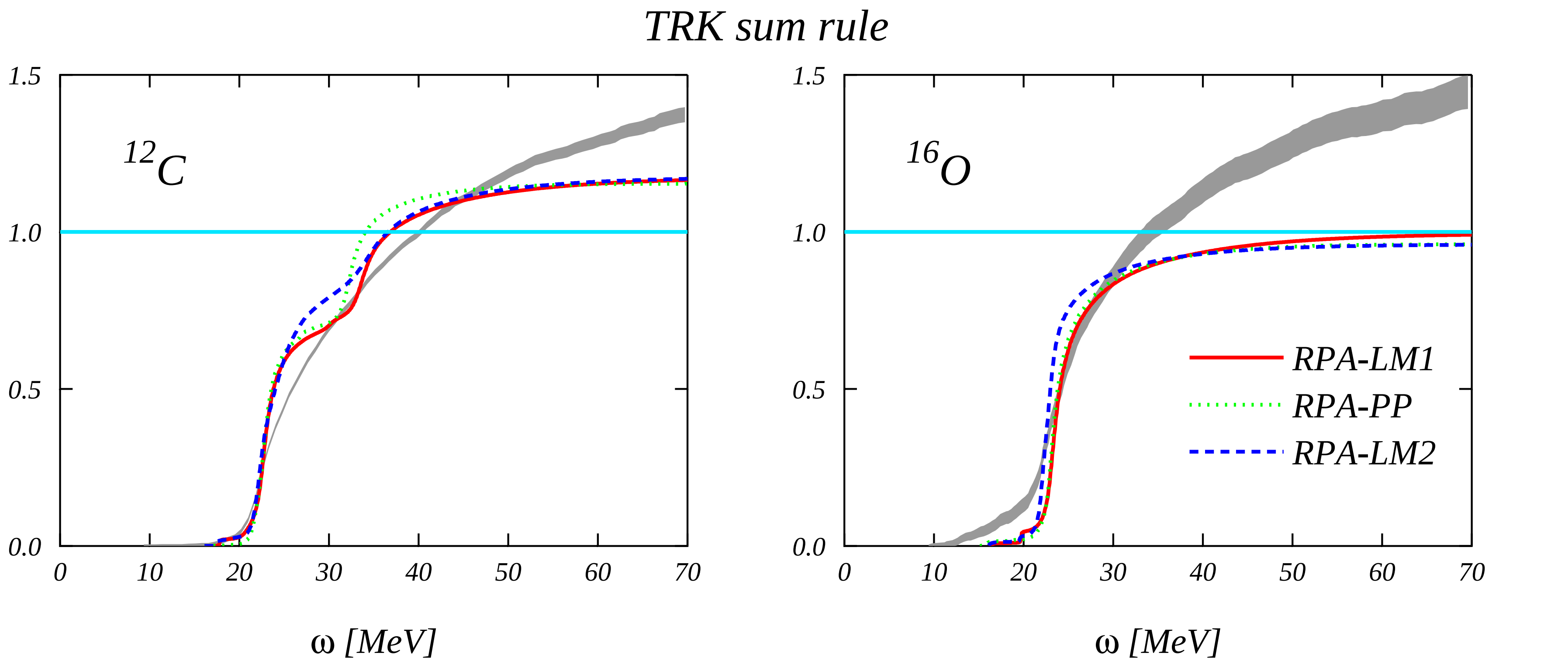
Units $C_o = \pi^2 \hbar^2 / k_F m$

$$k_F = 1.36 fm \rightarrow C_o = 302 MeV fm^3$$

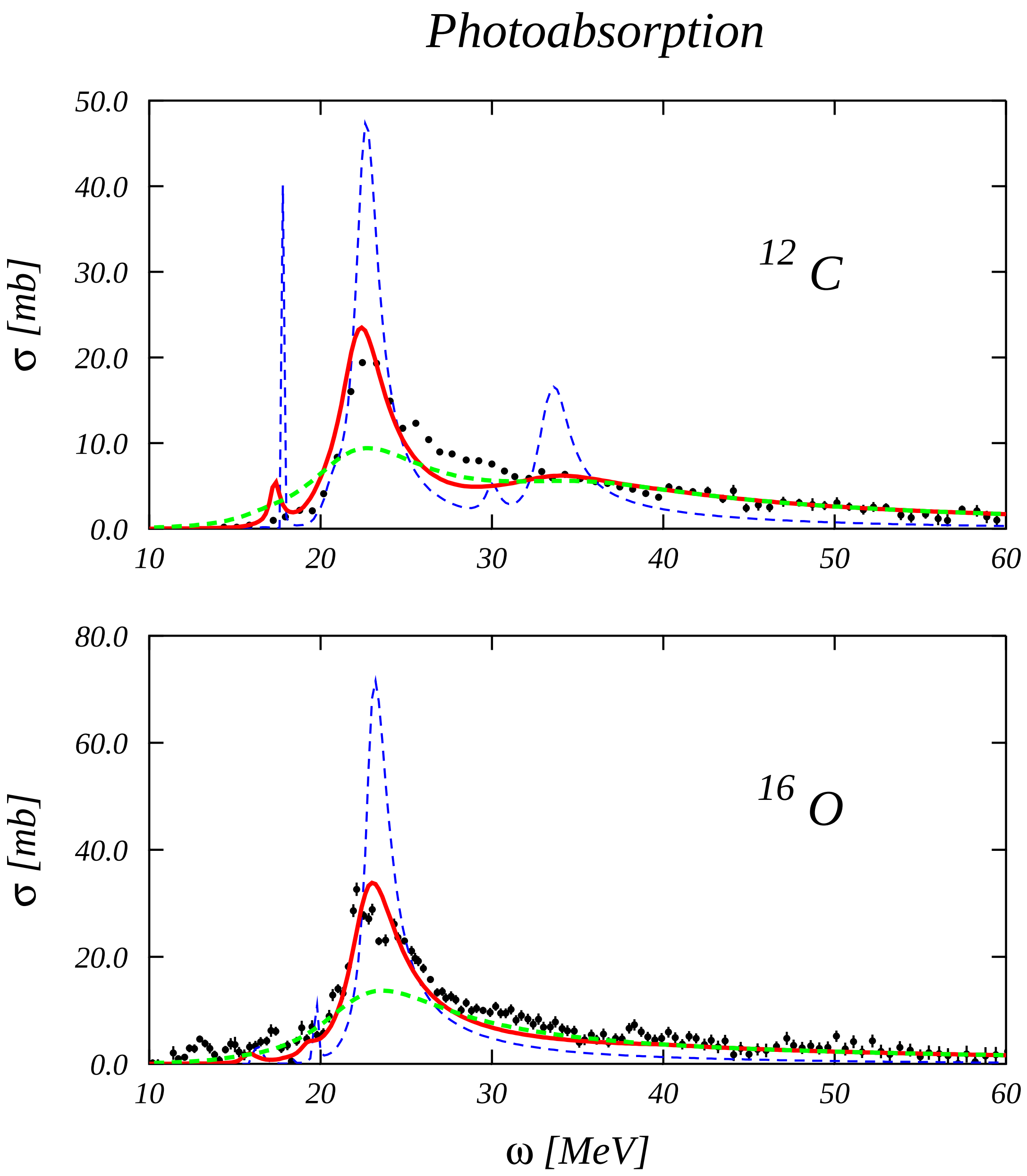
	f_o^{int}	f_o^{ext}	${f'}_o^{int}$	${f'}_o^{ext}$	g_o	g'_o	R (^{12}C)	R (^{16}O)	3^- (^{16}O)
LM1	-2.45	0.2	1.5	1.5	0.55	0.7	0.8	0.865	6.16
LM2	-2.08	0.0	1.5	0.65	0.0	1.0	1.2	0.865	6.16
PP	-3.33	0.18	2.24	0.66	0.2	0.8	1.2	1.030	6.15



Photoabsorption
50.0
40.0
30.0
20.0
10.0
0.0
σ [mb]
LM1
PP
LM2
12 C
10
20
30
40
50
60
100.0
80.0
60.0
40.0
20.0
0.0
σ [mb]
16 O
10
20
30
40
50
60
ω [MeV]



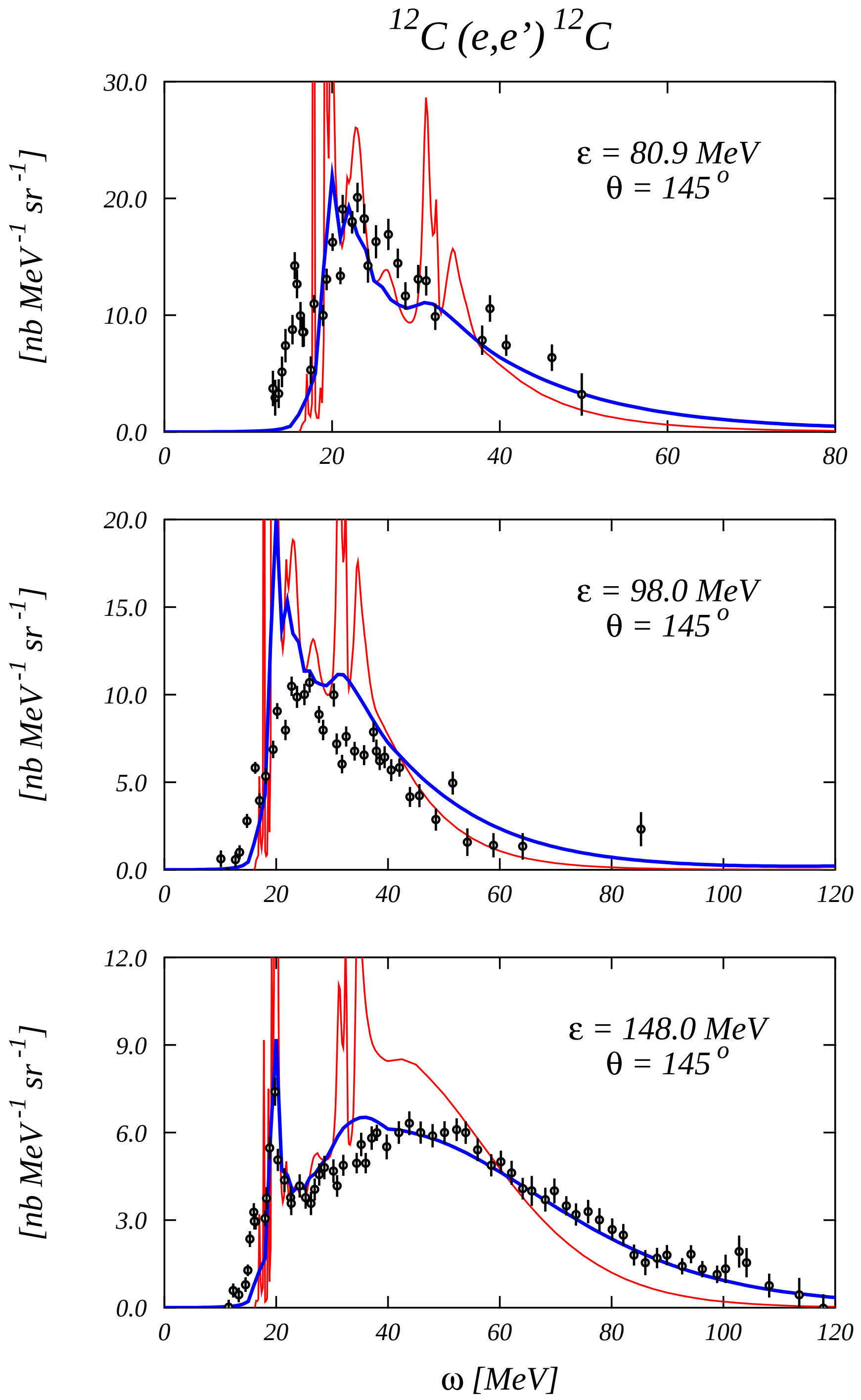
TRK sum rule
1.5
1.0
0.5
0.0
^{12}C
0
10
20
30
40
50
60
70
ω [MeV]
^{16}O
RPA-LM1
RPA-PP
RPA-LM2



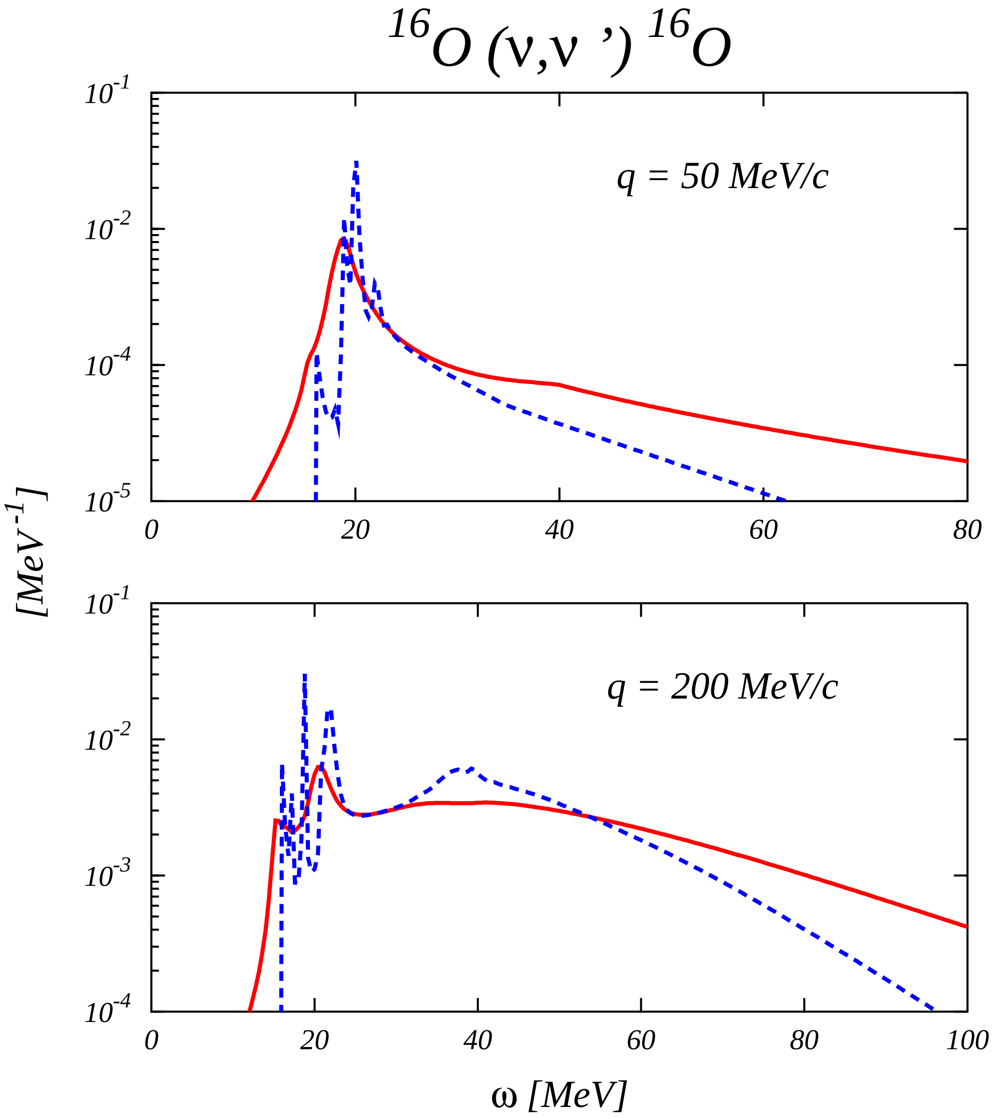
Photoabsorption
σ [mb]
50.0
40.0
30.0
20.0
10.0
0.0
10
20
30
40
50
60
12 C
80.0
60.0
40.0
20.0
0.0
16 O
ω [MeV]

$$\gamma(\epsilon) = A_{\Gamma}(\epsilon)\left(\frac{\epsilon^2}{\epsilon^2 + B_{\Gamma}(\epsilon)^2}\right)\left(\frac{C_{\Gamma}(\epsilon)^2}{\epsilon^2 + C_{\Gamma}(\epsilon)^2}\right)$$

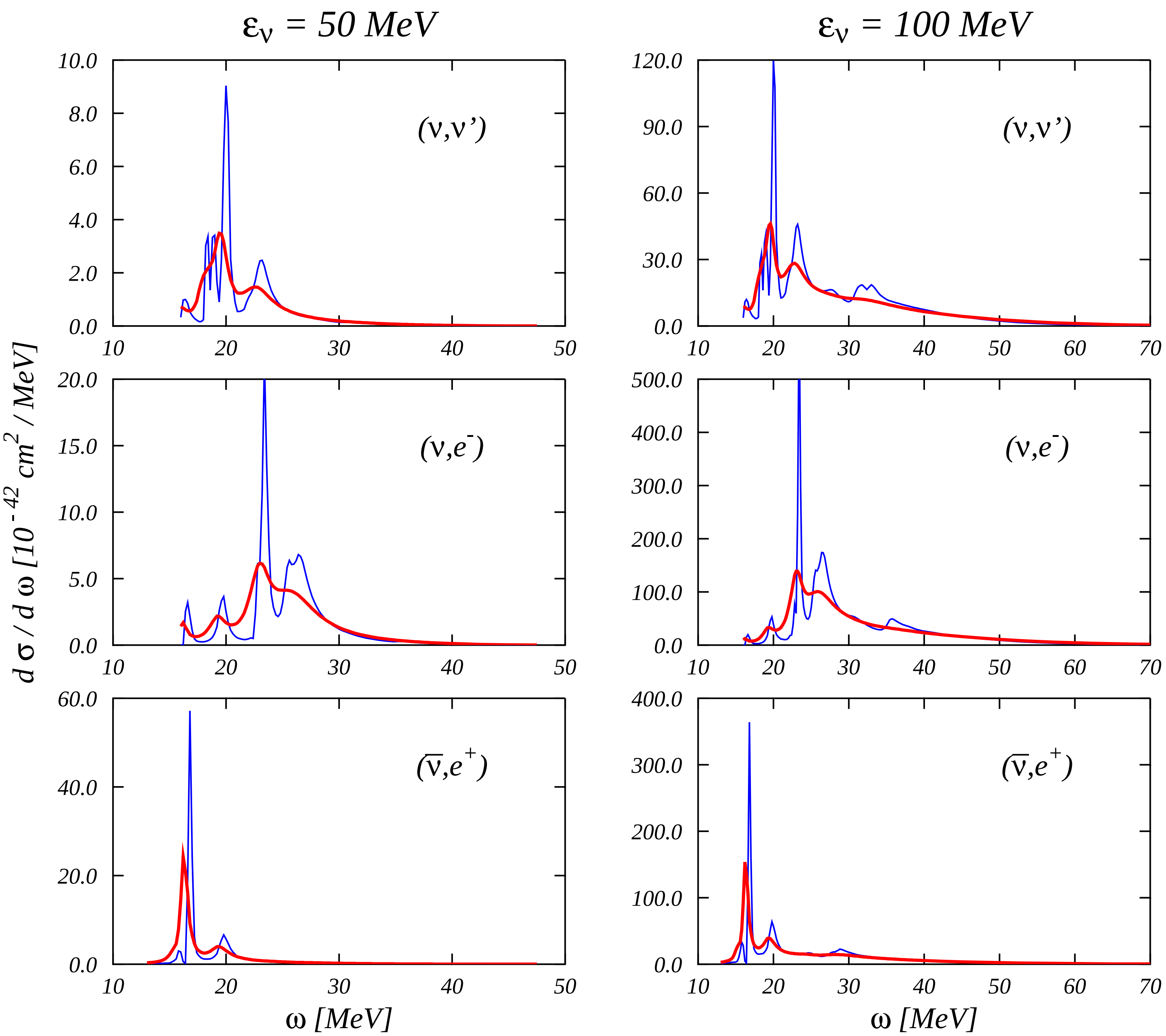
ϵ	10.0	40.0
A_{Γ}	6.0	11.0
B_{Γ}	60.0	20.0
C_{Γ}	110.0	110.0
m^*/m	1.0	0.85



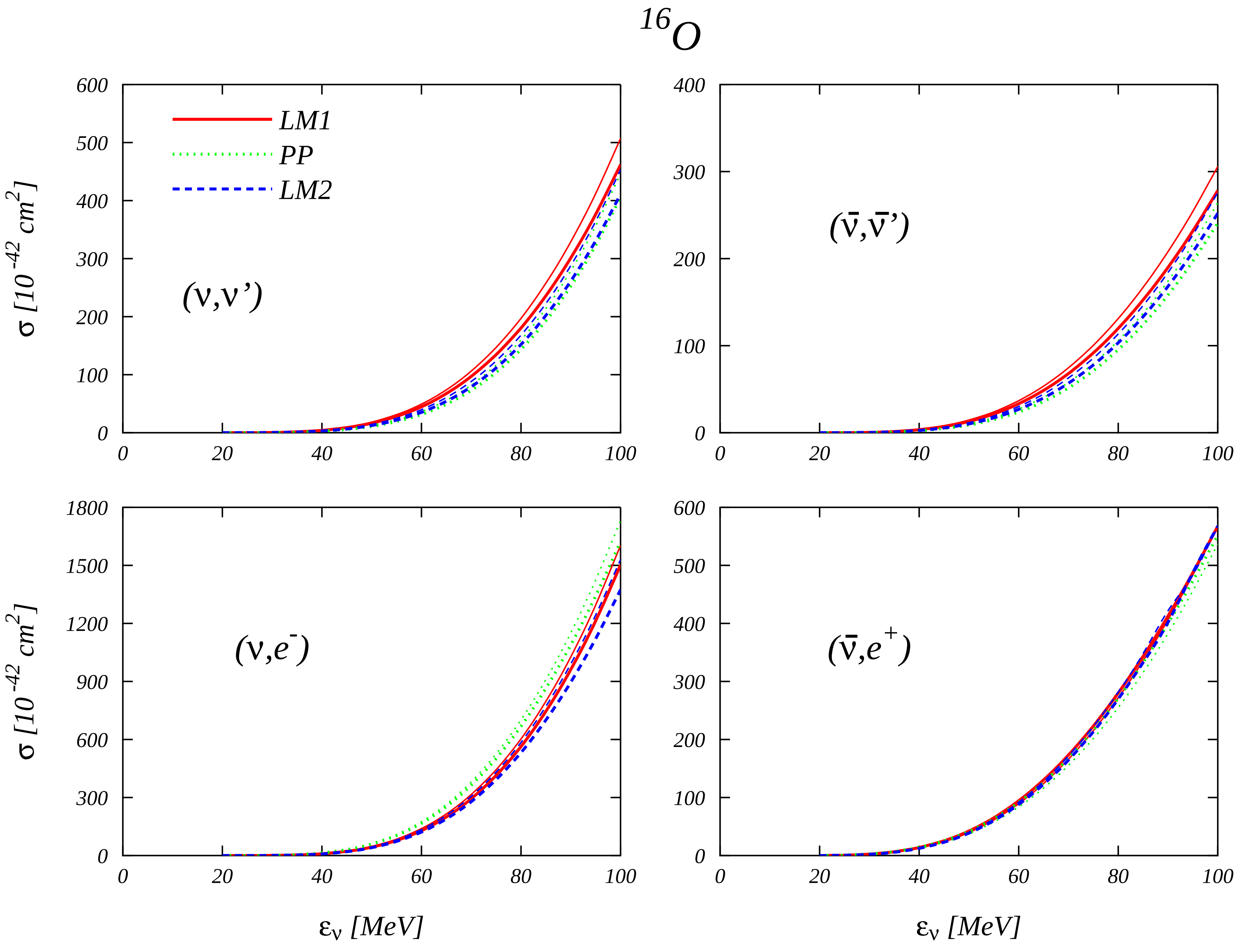
$^{12}C\ (e,e')\ ^{12}C$
ε = 80.9 MeV
θ = 145 o
ε = 98.0 MeV
θ = 145 o
ε = 148.0 MeV
θ = 145 o
[nb MeV -1 sr -1]
ω [MeV]



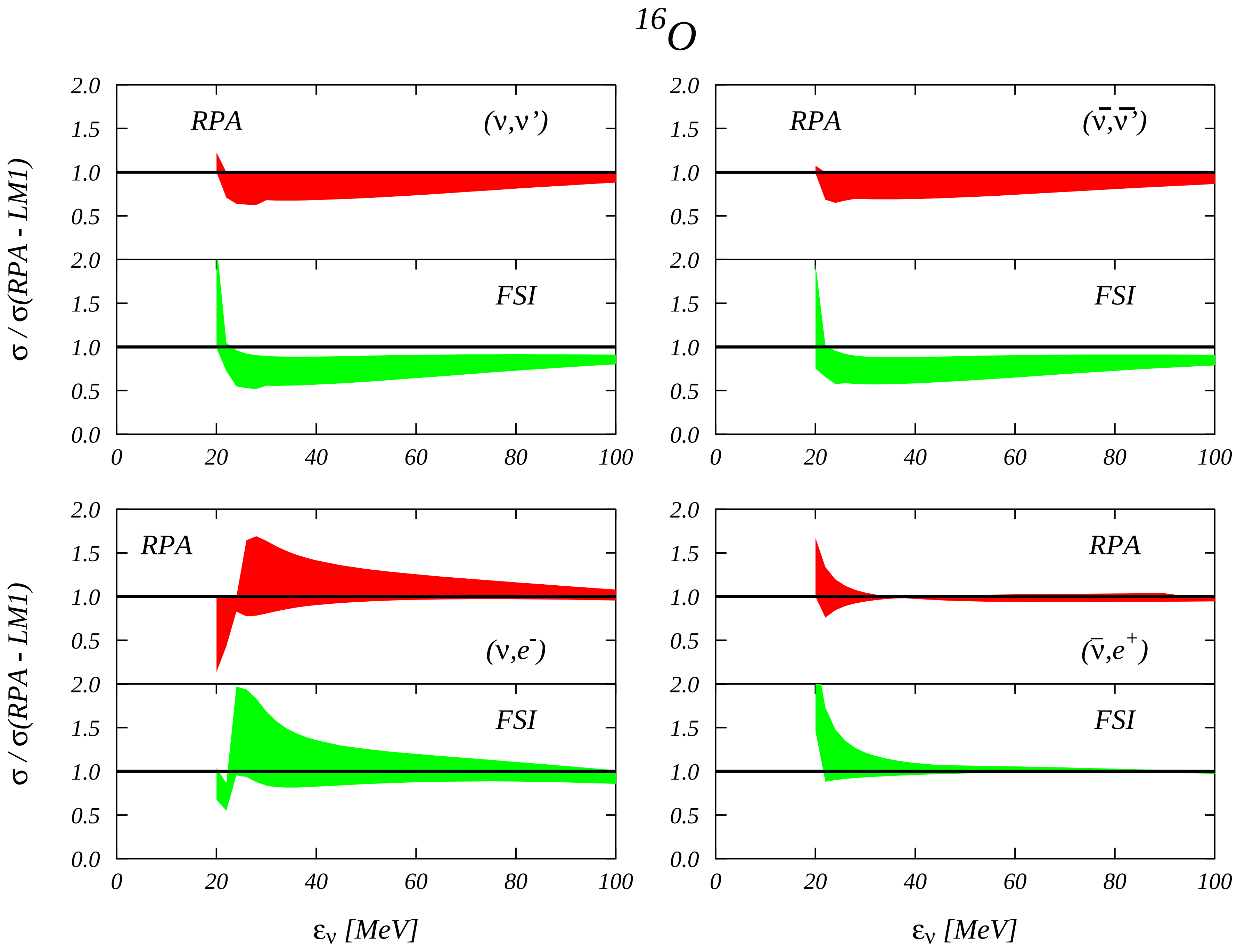
$^{16}O\ (\nu,\nu\ ')\ ^{16}O$
q = 50 MeV/c
q = 200 MeV/c
[MeV^{-1}]
10^{-1}
10^{-2}
10^{-4}
10^{-5}
10^{-3}
0
20
40
60
80
100
ω [MeV]



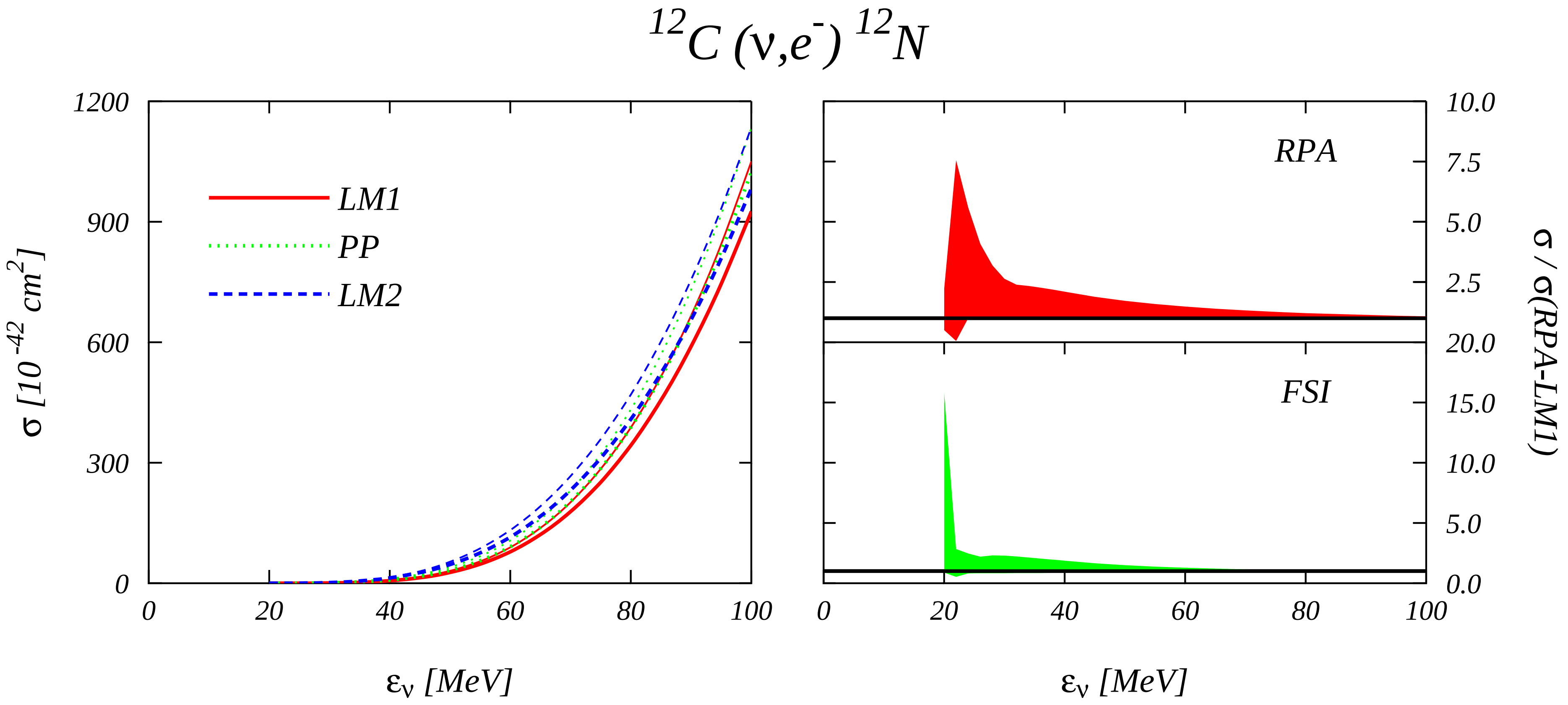
ε_ν = 50 MeV
ε_ν = 100 MeV
(ν,ν')
(ν,e^-)
$(\bar{\nu},e^+)$
$d\sigma / d\omega \; [10^{-42}\, cm^2 / MeV]$
ω [MeV]



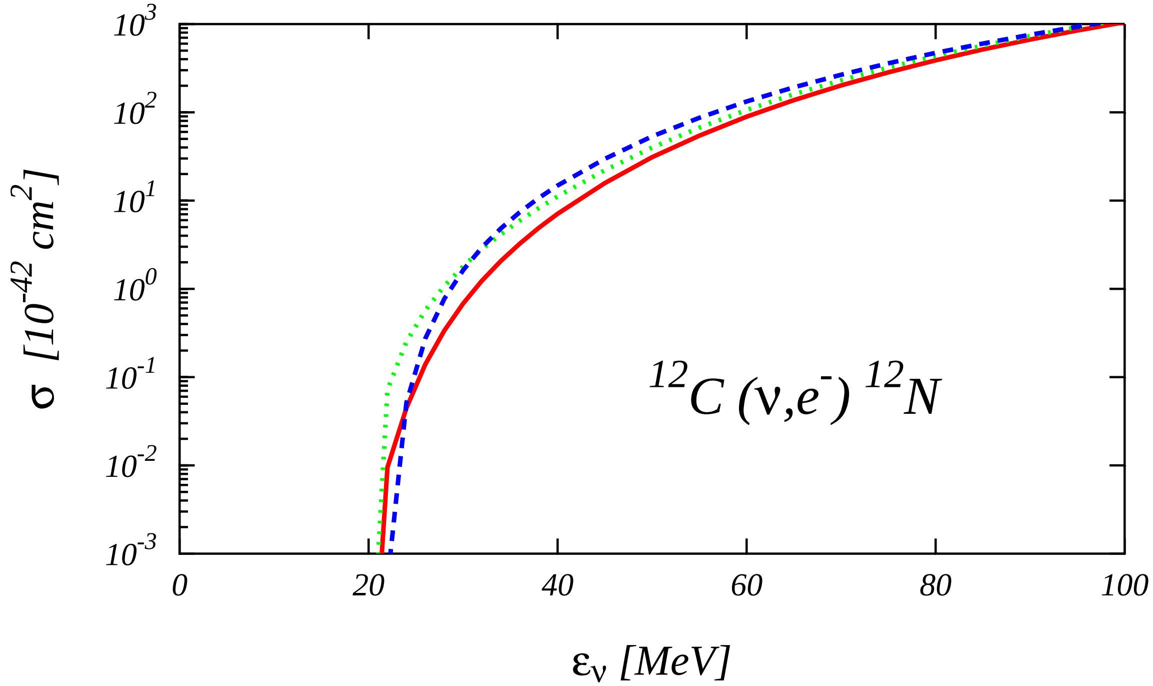
^{16}O
LM1
PP
LM2
(ν,ν')
($\bar{\nu}$,$\bar{\nu}$')
(ν,e⁻)
($\bar{\nu}$,e⁺)
σ [10^{-42} cm^2]
ε_ν [MeV]



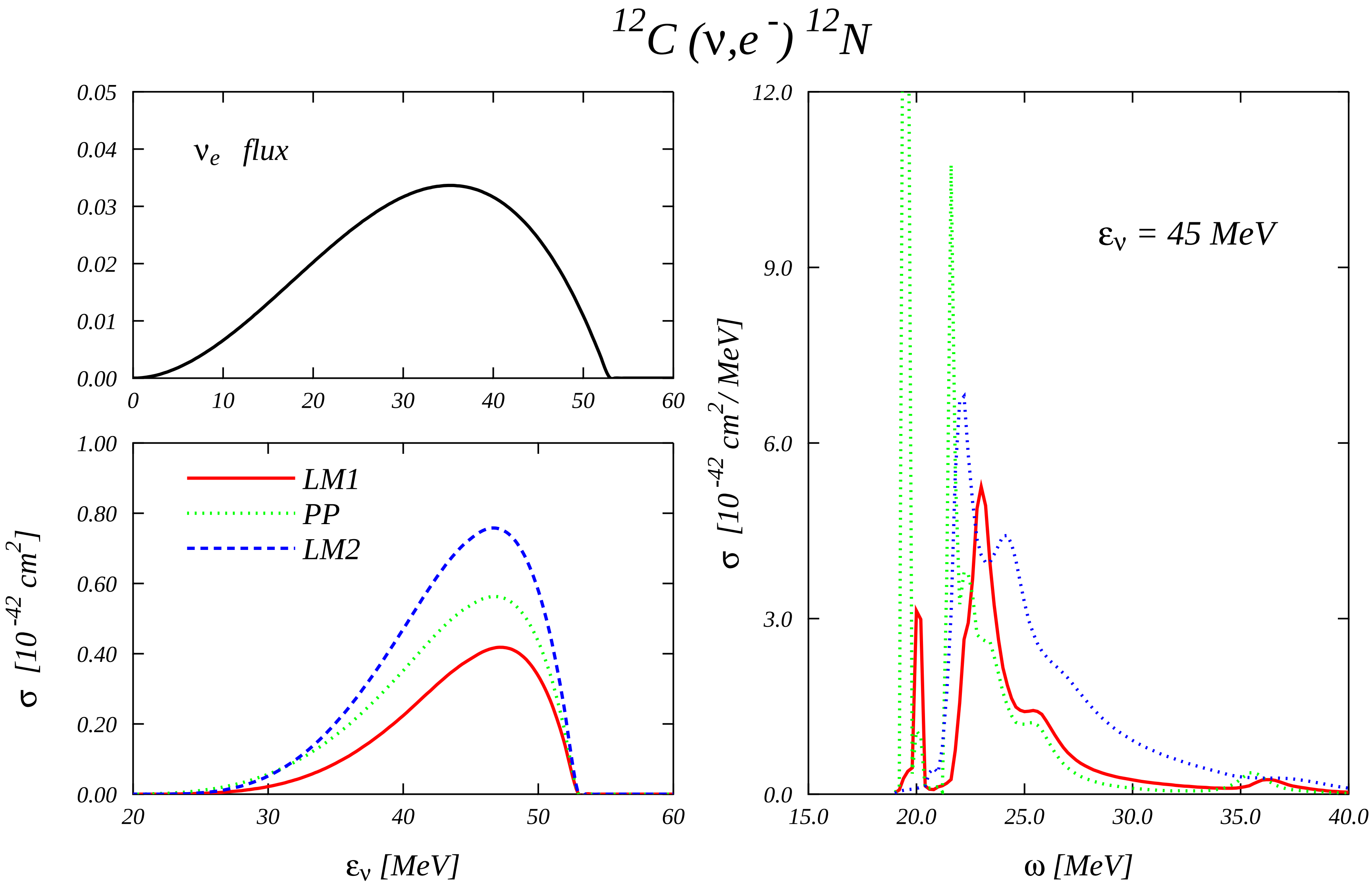
^{16}O
RPA
(ν,ν')
FSI
RPA
$(\bar{\nu},\bar{\nu}')$
FSI
RPA
(ν,e^-)
FSI
RPA
$(\bar{\nu},e^+)$
FSI
$\sigma / \sigma(RPA - LM1)$
ε_ν [MeV]
0.0
0.5
1.0
1.5
2.0
0
20
40
60
80
100



$^{12}C\,(\nu,e^-)\,^{12}N$
LM1
PP
LM2
σ [10^-42 cm^2]
1200
900
600
300
0
0
20
40
60
80
100
ε_ν [MeV]
RPA
FSI
σ / σ(RPA-LM1)
10.0
7.5
5.0
2.5
20.0
15.0
10.0
5.0
0.0



10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
σ $[10^{-42}\ cm^2]$
0
20
40
60
80
100
ε_ν [MeV]
$^{12}C\ (\nu,e^-)\ ^{12}N$



$^{12}C\,(\nu,e^-)\,^{12}N$
ν_e flux
0.05
0.04
0.03
0.02
0.01
0.00
0
10
20
30
40
50
60
LM1
PP
LM2
σ $[10^{-42}\ cm^2]$
1.00
0.80
0.60
0.40
0.20
0.00
20
30
40
50
60
ε_ν [MeV]
ε_ν = 45 MeV
σ $[10^{-42}\ cm^2/\ MeV]$
12.0
9.0
6.0
3.0
0.0
15.0
20.0
25.0
30.0
35.0
40.0
ω [MeV]

$$\sigma = 10^{-42} cm^2$$

	LM1	LM2	PP	exp
RPA	5.18	10.00	7.70	$\sim$ 15
FSI	4.49	8.89	5.77	

Conclusions

- More e-m data required

- Quasi-elastic

- Giant resonance excitation
  - N-N interaction
  - sum rules
  - effects beyond RPA