Okayama, Sept. 26-29, 2005

NuInt05

Nuclear Models and Neutrino Cross Sections

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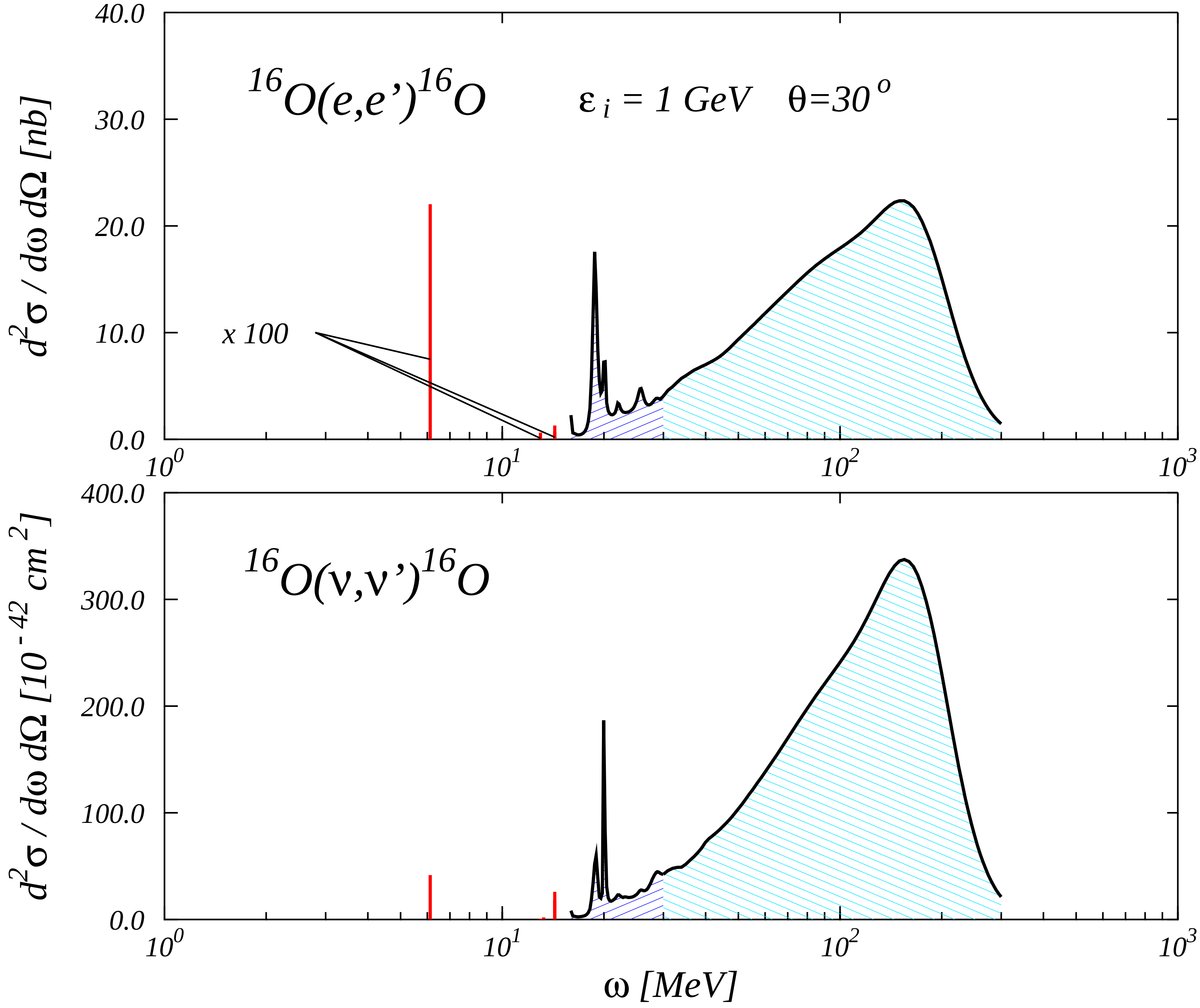


$^{16}O(e,e')^{16}O$
ε_i = 1 GeV θ=30^o
x 100
$d^2\sigma / d\omega\, d\Omega$ [nb]
40.0
30.0
20.0
10.0
0.0
10^0
10^1
10^2
10^3
$^{16}O(\nu,\nu')^{16}O$
$d^2\sigma / d\omega\, d\Omega$ [10^{-42} cm^2]
400.0
300.0
200.0
100.0
0.0
10^0
10^1
10^2
10^3
ω [MeV]

Random Phase Approximation (RPA)

$$|\Psi_n >= Q_n^+ |\Psi_o > \qquad Q_n|\Psi_o >= 0$$

$$Q_n^+ = \sum_{ph} X_{ph}^n \, a_p^+ a_h + \sum_{ph} Y_{ph}^n \, a_h^+ a_p$$

$$W = \sum_{\alpha\beta} w \, a_\alpha^+ a_\beta$$

$$< \Psi_n|W|\Psi_o >= \sum_{ph} X_{ph}^n < p|w|h > - \sum_{ph} Y_{ph}^n < h|w|p >$$

Equations of motion

$$< \Psi_o| \left[\delta Q_n^+ , \left[H^{eff}, Q_n^+ ,\right]\right] |\Psi_o >$$
$$= (E_n - E_o) < \Psi_o| \left[\delta Q_n^+ , Q_n^+\right] |\Psi_o >$$

RPA secular equations

$$\begin{pmatrix} A & B \\ B^* & A^* \end{pmatrix} \begin{pmatrix} X \\ Y \end{pmatrix} = (E_n - E_o) \begin{pmatrix} X \\ -Y \end{pmatrix}$$

$$A_{ph,p'h'} = (\epsilon_p - \epsilon_h)\delta_{ph,p'h'} + < ph'|V^{eff}|hp' > - < ph'|V^{eff}|p'h >$$

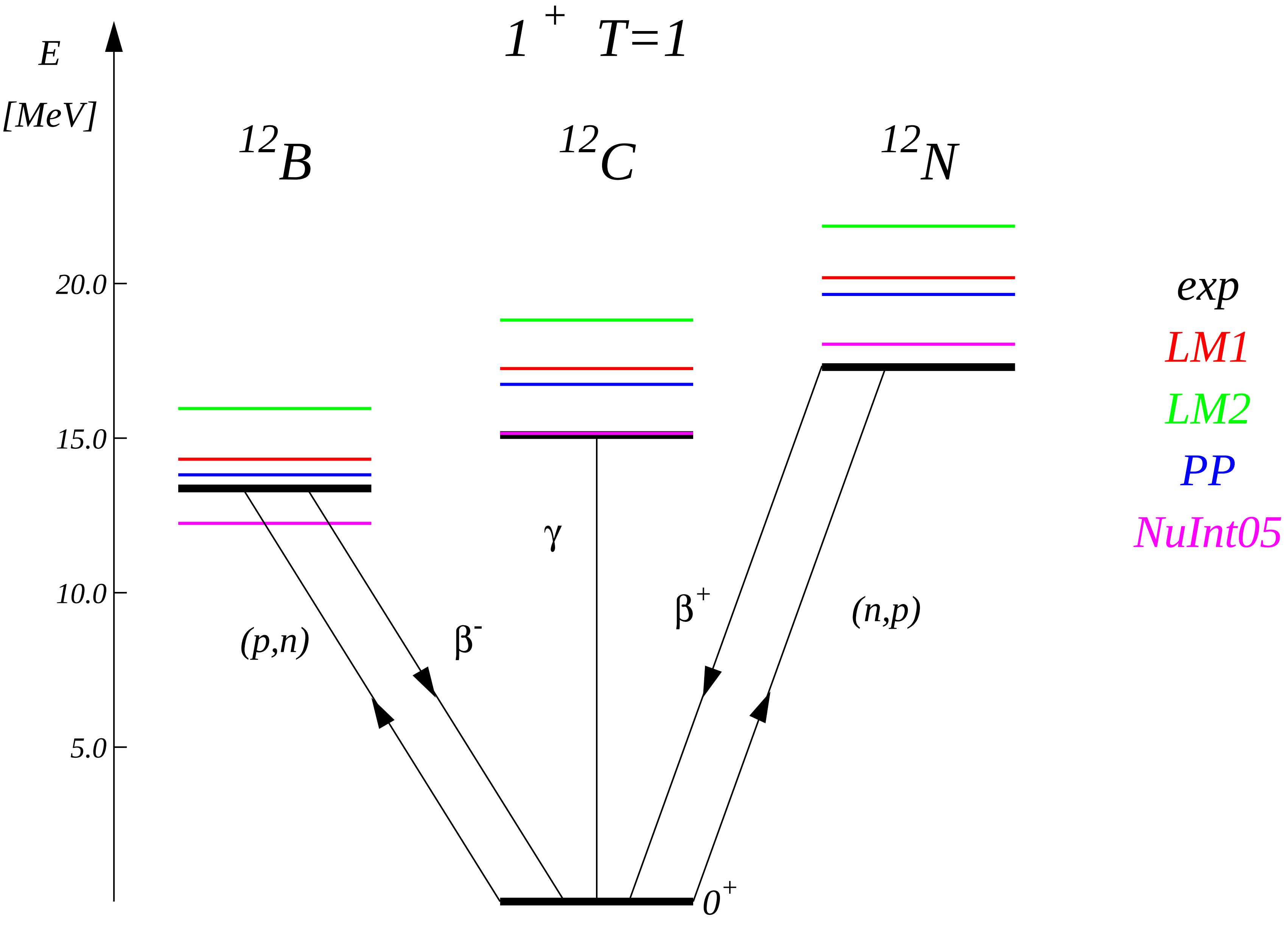
$$B_{ph,p'h'} = < pp'|V^{eff}|hh' > - < pp'|V^{eff}|h'h >$$

		^{12}C		^{16}O	
	MeV	WS	exp	WS	exp
p	1s1/2	-30.90		-29.90	
	1p3/2	-15.76	-15.96	-16.92	-18.44
	1p1/2	-12.95	-1.94	-12.74	-12.11
	1d5/2	2.0		-3.76	-0.60
	2s1/2			-0.89	-0.10
n	1s1/2	-34.04		-33.98	
	1p3/2	-18.92	-18.72	-20.52	-21.81
	1p1/2	-15.06	-4.96	-16.63	-15.65
	1d5/2	-3.88	-1.10	-6.84	-4.14
	2s1/2	-1.96	-1.86	-3.90	-3.27
	1d3/2	1.6		-3.90	-3.27

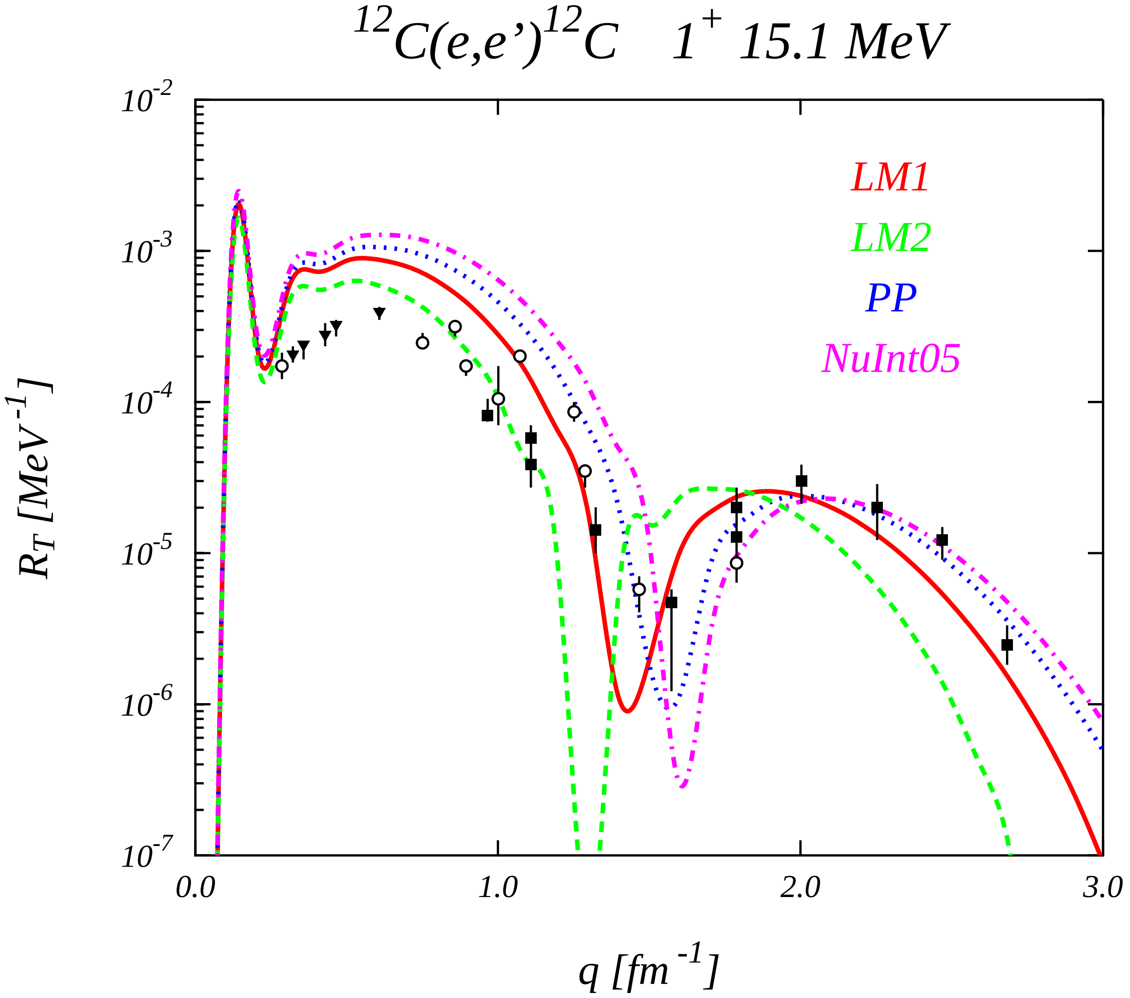
$$
\begin{aligned}
V^{eff}(k,\rho) \;=\; & \mathcal{K}\,[\,F(k,\rho) + F'(k,\rho)\,\vec{\tau}(1)\cdot\vec{\tau}(2) \\
& + \; G(k)\,\vec{\sigma}(1)\cdot\vec{\sigma}(2) \\
& + \; G'(k)\,\vec{\sigma}(1)\cdot\vec{\sigma}(2)\,\vec{\tau}(1)\cdot\vec{\tau}(2)\,]
\end{aligned}
$$

$$
F(k,\rho) = F^{ext}(k,\rho) + \left[F^{int}(k,\rho) - F^{ext}(k,\rho)\right]\frac{\rho(r)}{\rho(0)}
$$

MeV fm^3	F^{ext}	F^{int}	$F'^{\,ext}$	$F'^{\,int}$	G	G'	$\mathcal{K}$ (^{12}C)	$\mathcal{K}$ (^{16}O)
LM1	-740.0	60.4	453.0	453.0	166.1	211.4	0.8	0.865
LM2	-630.0	0.0	450.0	195.0	0.0	300.0	1.0	0.865
PP	-1007.0	-54.7	677.8	201.3	60.0	241.0	1.2	1.030
NuInt05	-740.0	60.4	453.0	302.0	-30.2	51.34	1.0	-



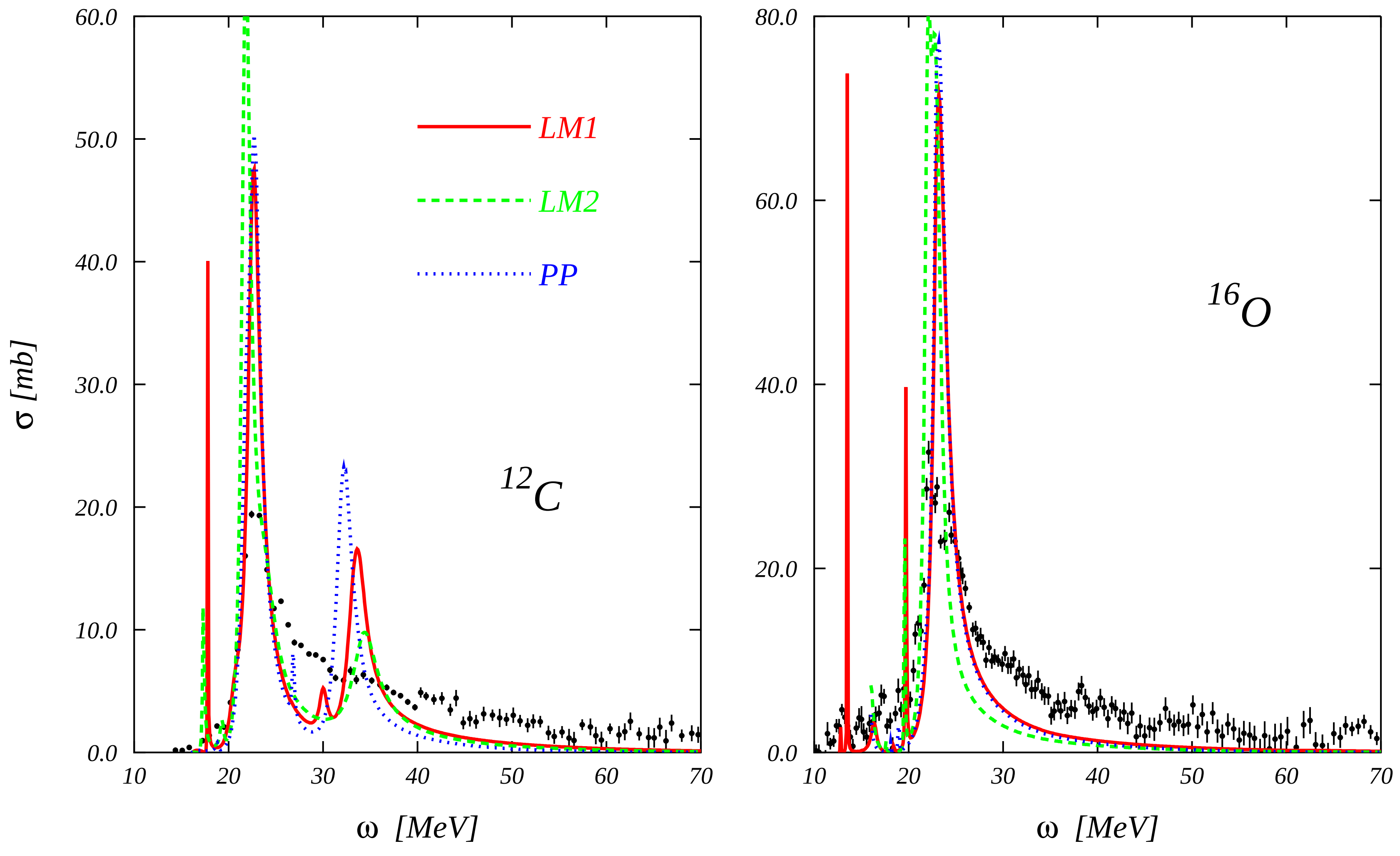
1^+ $T=1$
E
[MeV]
^{12}B
^{12}C
^{12}N
20.0
15.0
10.0
5.0
(p,n)
β^-
γ
β^+
(n,p)
0^+
exp
LM1
LM2
PP
NuInt05



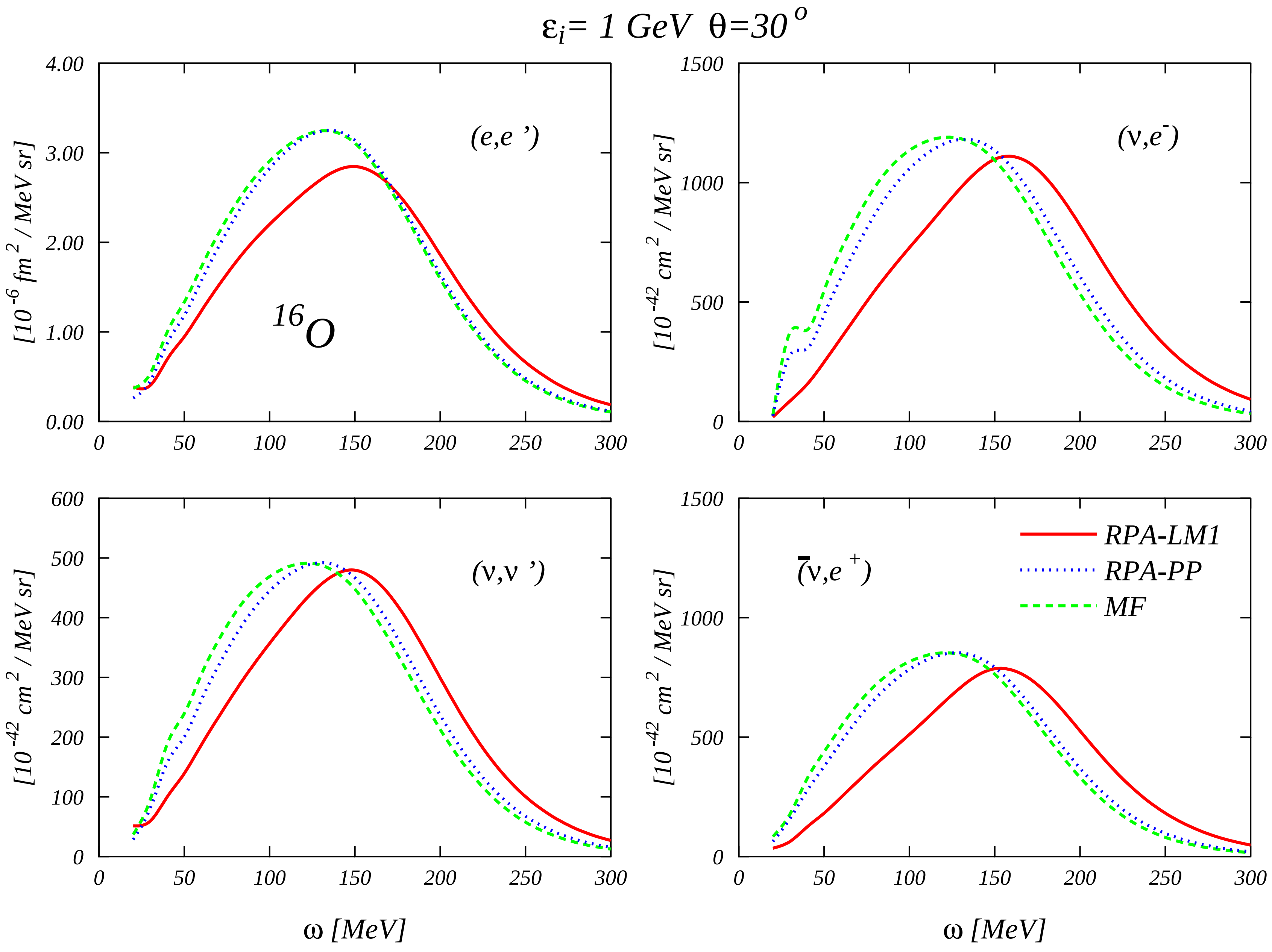
DATA from T.W. Donnelly, J.D. Walecka, I Sick, E.B. Hughes

Phys. Rev. Lett. 21 (1968) 1197.

PHOTOABSORPTION



DATA: J. Ahrens et al., Nucl. Phys. A 251 (1975) 479.



εi= 1 GeV θ=30 o
(e,e ')
16O
(ν,e-)
(ν,ν ')
(ν̄,e +)
RPA-LM1
RPA-PP
MF
[10 -6 fm 2 / MeV sr]
[10 -42 cm 2 / MeV sr]
ω [MeV]

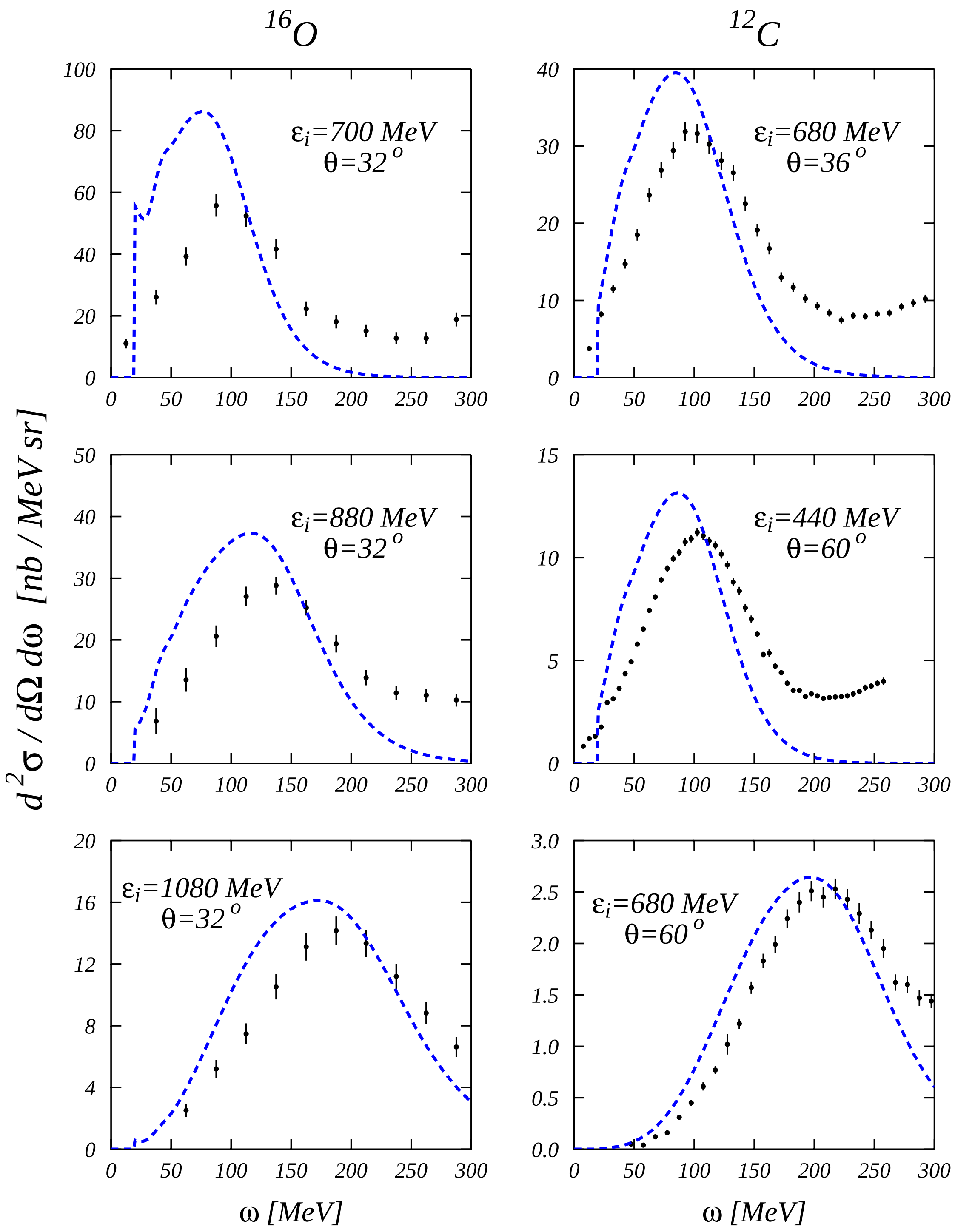
DATA:

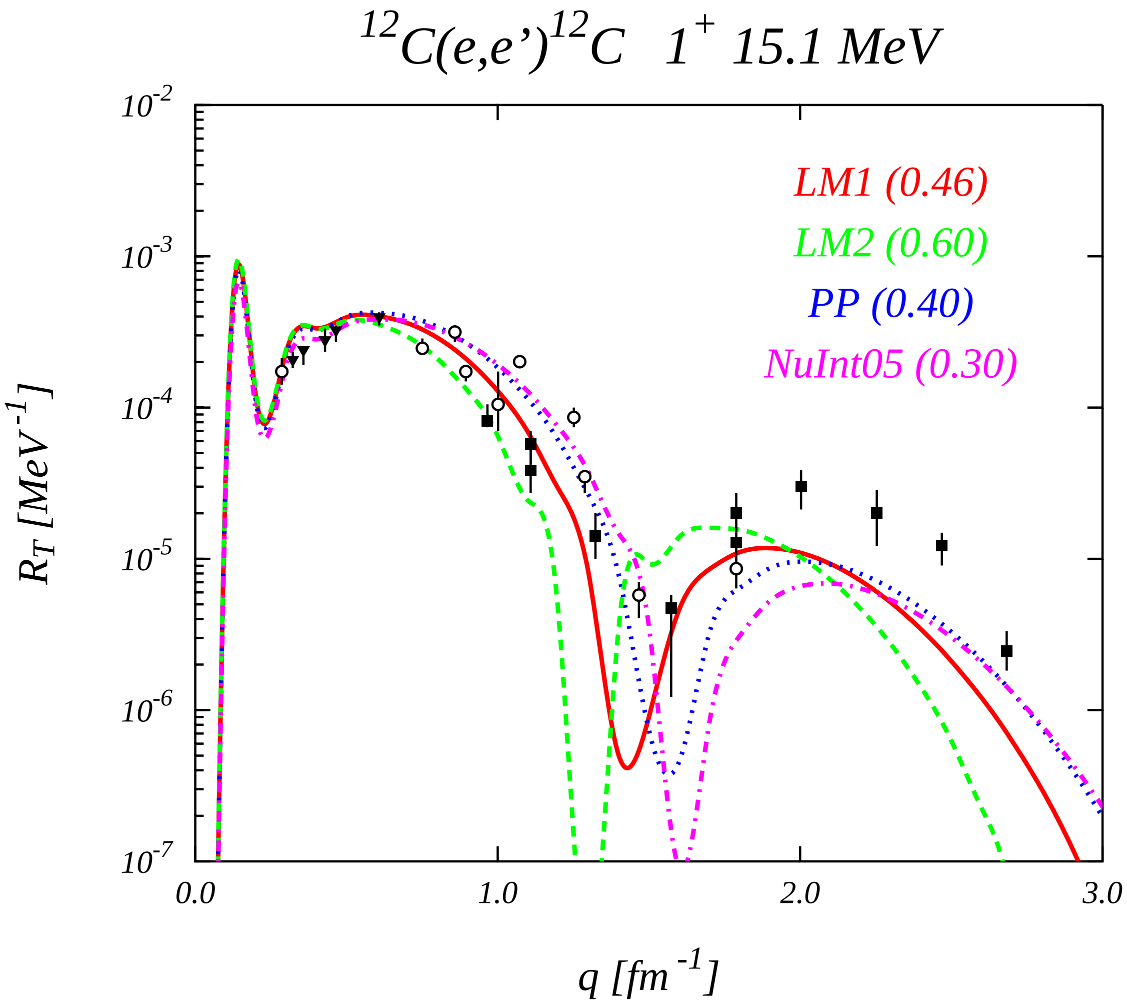
M.Anghinolfi *et al.*,

Nucl. Phys. A 602 (1996) 405.

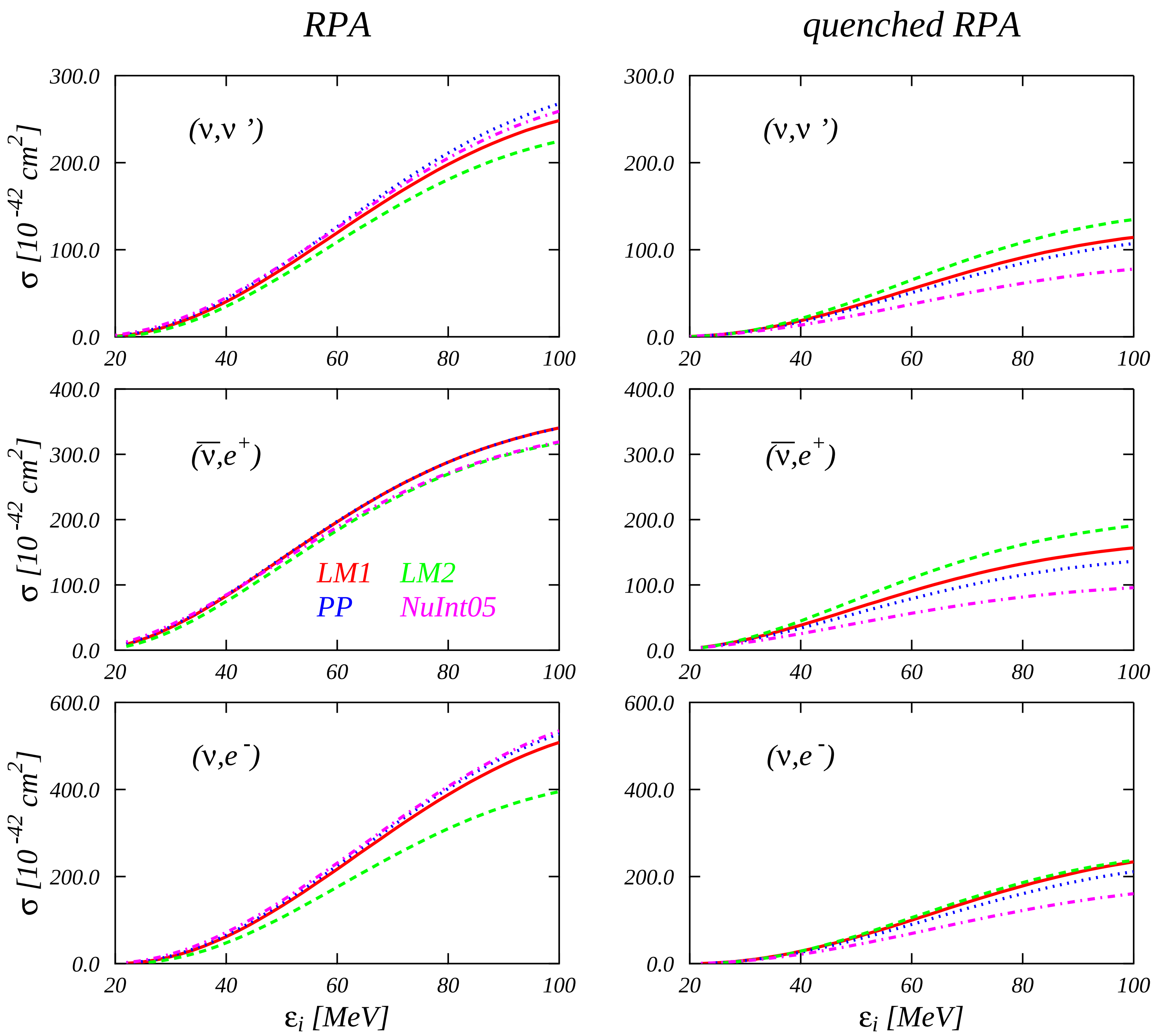
P.Barreau *et al.*,

Nucl. Phys. A 402 (1983) 515.





$^{12}C(e,e')^{12}C$ 1^+ 15.1 MeV
LM1 (0.46)
LM2 (0.60)
PP (0.40)
NuInt05 (0.30)
R_T [MeV^{-1}]
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
0.0
1.0
2.0
3.0
q [fm^{-1}]


RPA
quenched RPA
(ν,ν ')
(ν̄,e⁺)
(ν,e⁻)
σ [10^-42 cm^2]
ε_i [MeV]
LM1
LM2
PP
NuInt05
300.0
200.0
100.0
0.0
400.0
600.0
20
40
60
80
100

Beyond Continuum RPA (FSI)

$$R^{FSI}(q,\omega) = \int_0^\infty dE \; R^{RPA}(q,E)\,[h(E,\omega) + h(E,-\omega)]$$

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

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

$$\Gamma(\omega) = \frac{1}{\omega}\int_0^\omega d\epsilon \; [\gamma(\epsilon+\omega) + \gamma(\epsilon-\omega)]$$

FSI parameters

$$\gamma(\epsilon) = A\left(\frac{\epsilon^2}{\epsilon^2 + B^2}\right)\left(\frac{C^2}{\epsilon^2 + C^2}\right)$$

ε [MeV]	A [MeV]	B [MeV]	C [MeV]
$\leq$ 10.0	6.0	60.0	110.0
$\geq$ 40.0	11.0	20.0	110.0

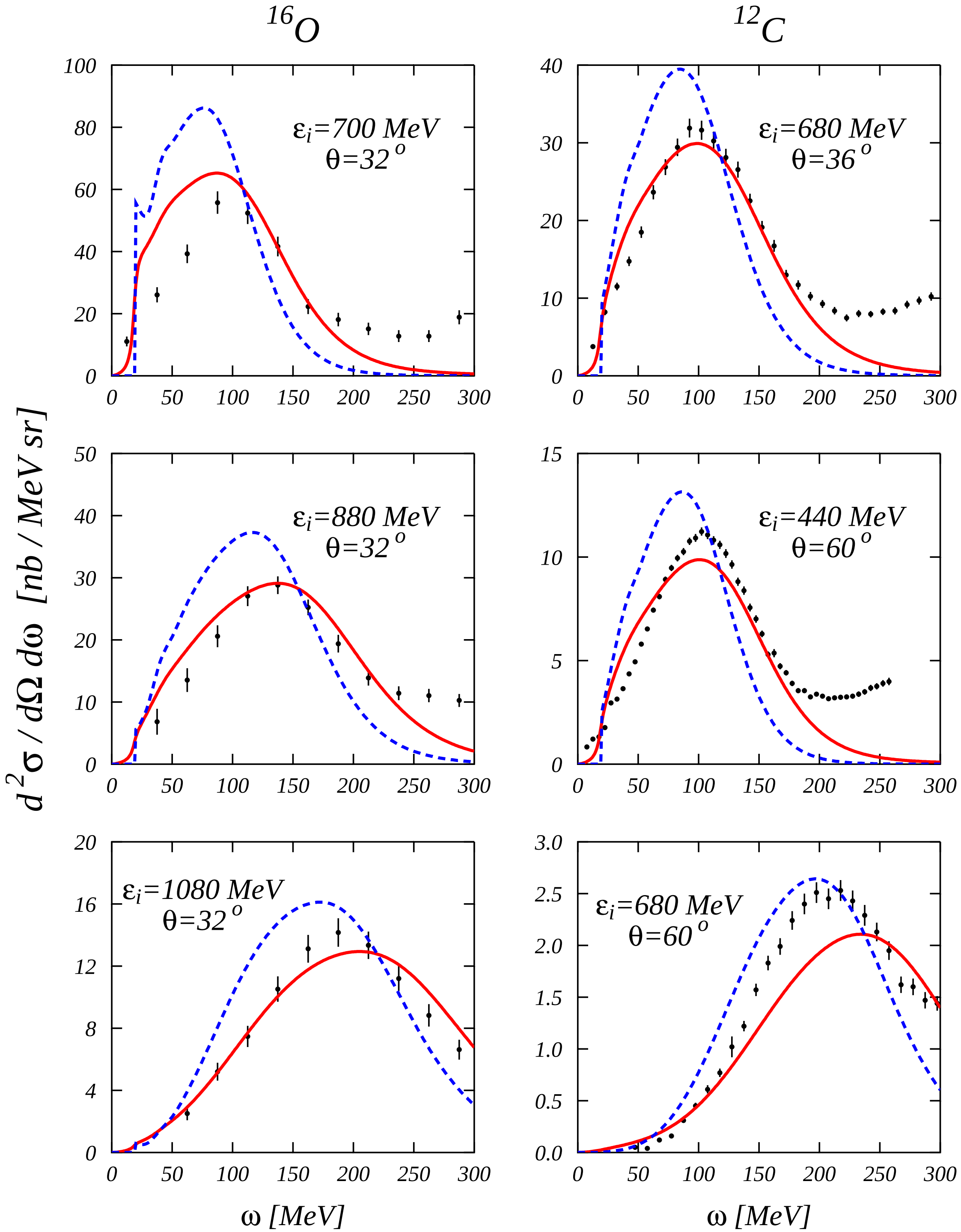
DATA:

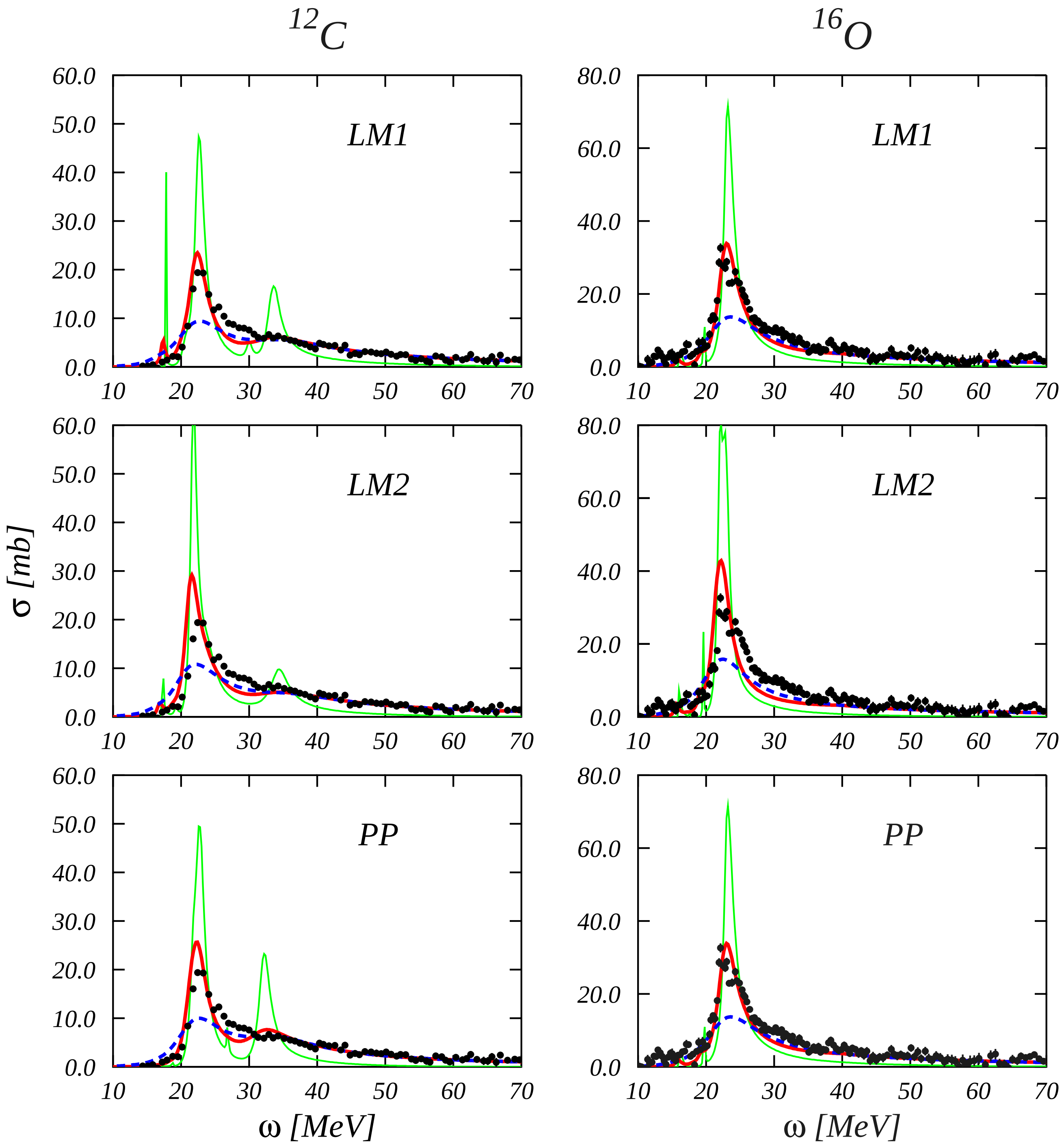
M.Anghinolfi *et al.*,

Nucl. Phys. A 602 (1996) 405.

P.Barreau *et al.*,

Nucl. Phys. A 402 (1983) 515.





^{12}C
^{16}O
LM1
LM2
PP
σ [mb]
ω [MeV]
60.0
50.0
40.0
30.0
20.0
10.0
0.0
80.0
60.0
40.0
20.0
0.0
10
20
30
40
50
60
70

DATA:

(a,b,c) quoted in

E. Kolbe

Nucl. Phys. A

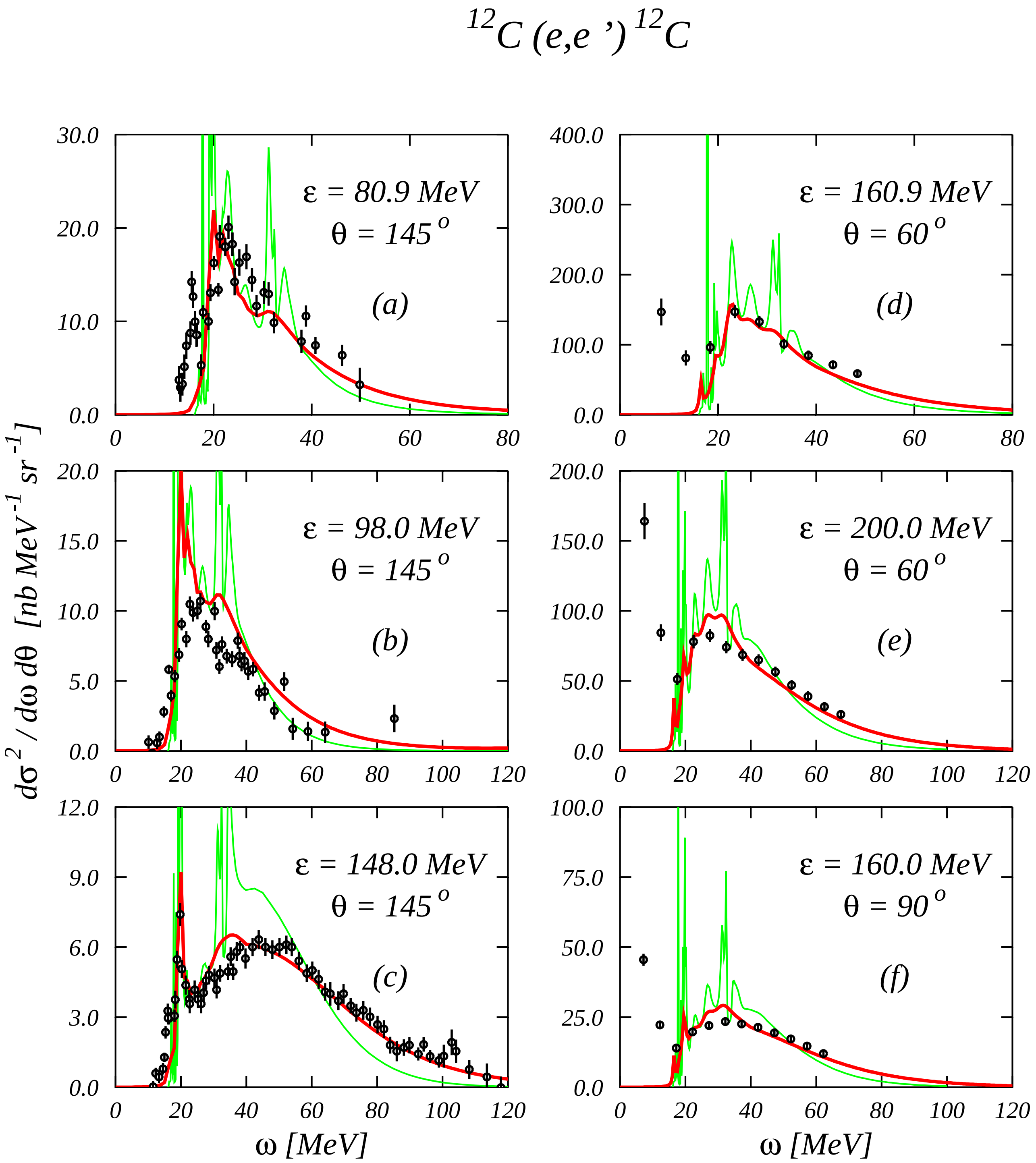
602 (1996) 405.

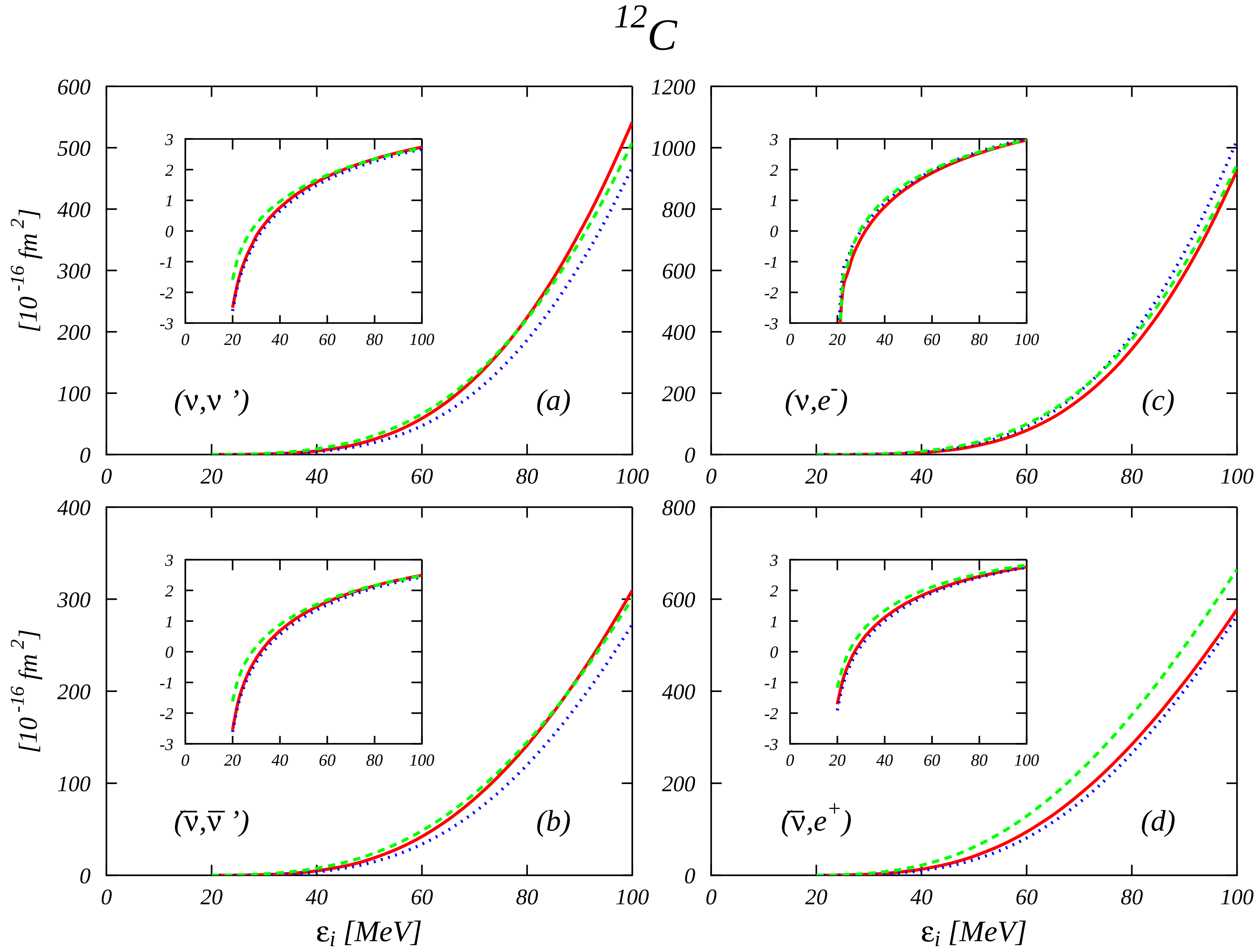
(d,e,f)

P.Barreau *et al.*,

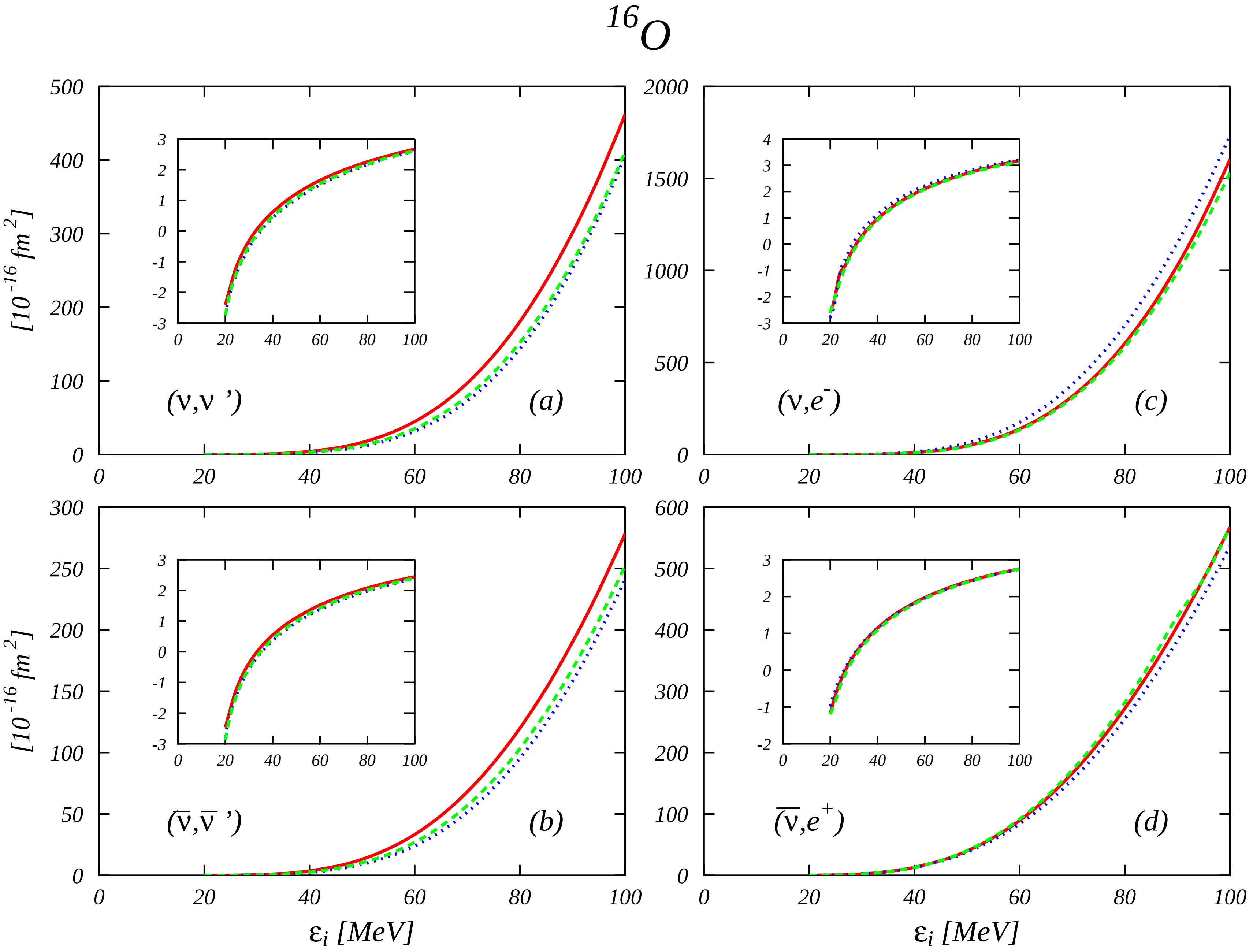
Nucl. Phys. A

402 (1983) 515.

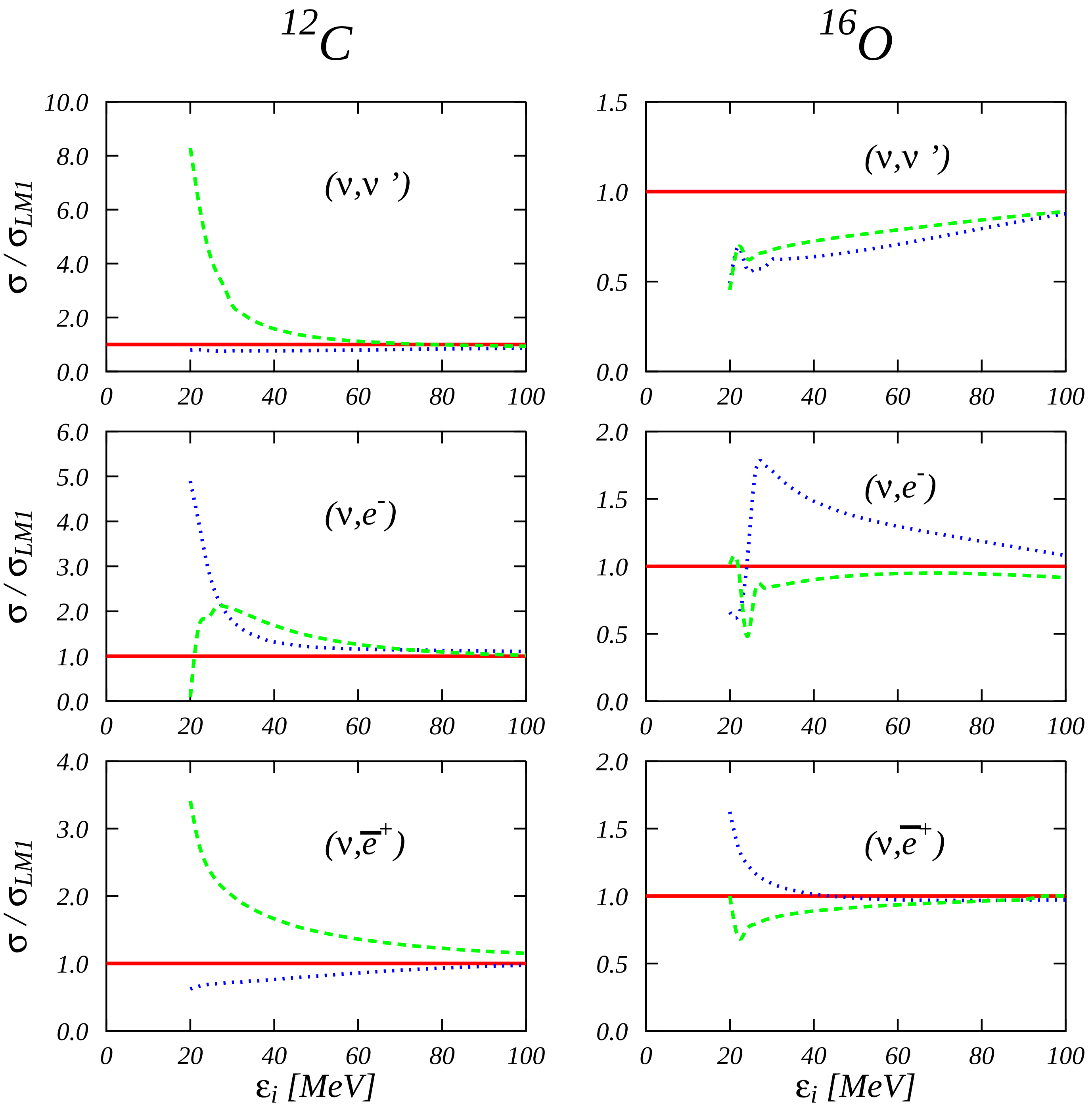




12C
[10^-16 fm^2]
(ν,ν ')
(a)
(ν,e-)
(c)
(ν̄,ν̄ ')
(b)
(ν̄,e+)
(d)
εi [MeV]

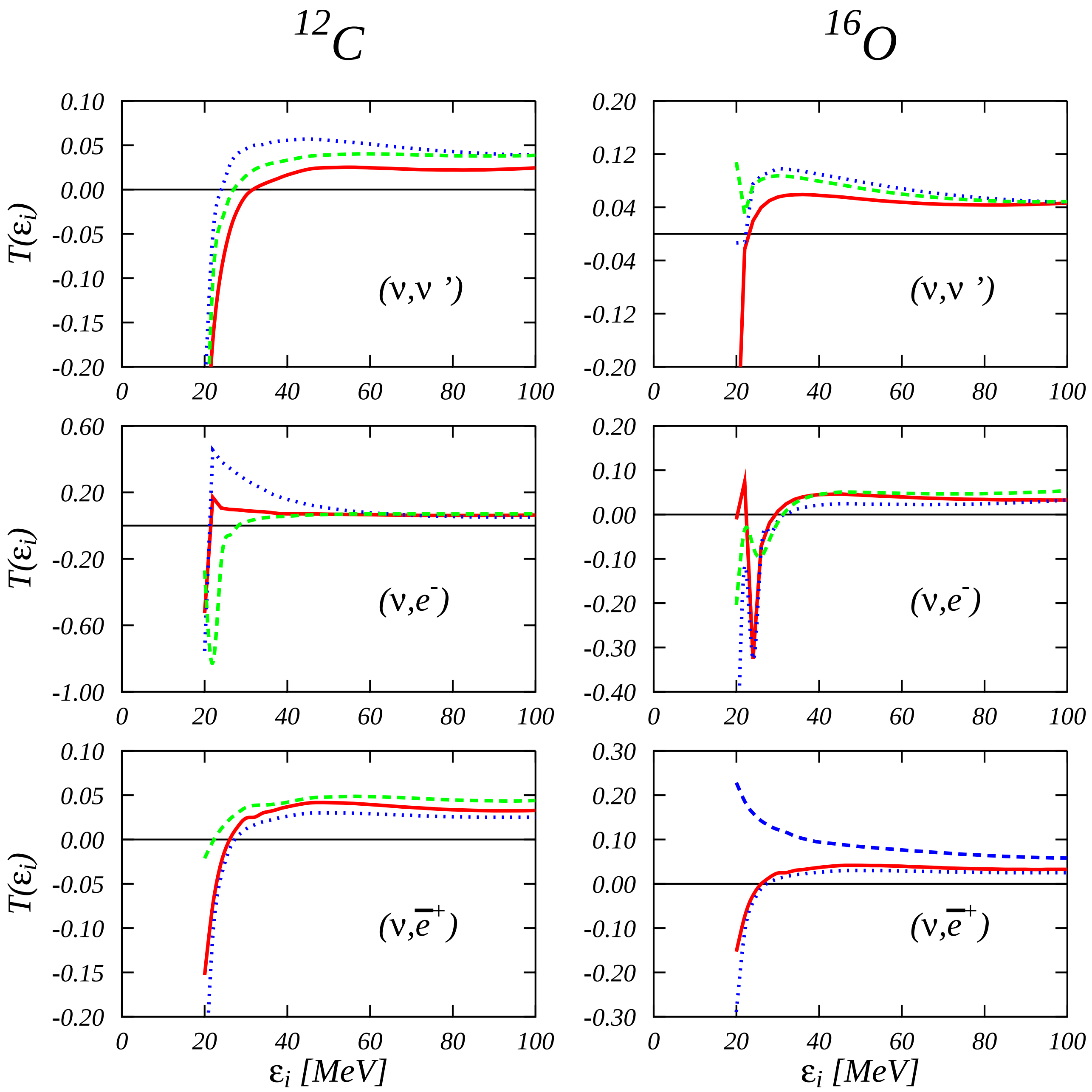


^{16}O
$[10^{-16}\ fm^2]$
(ν,ν')
(a)
$(\bar{\nu},\bar{\nu}')$
(b)
(ν,e^-)
(c)
$(\bar{\nu},e^+)$
(d)
ε_i [MeV]



^{12}C
^{16}O
(ν,ν')
(ν,e^-)
$(\nu,\overline{e}^+)$
(ν,ν')
(ν,e^-)
$(\nu,\overline{e}^+)$
σ / σ_{LM1}
ε_i [MeV]

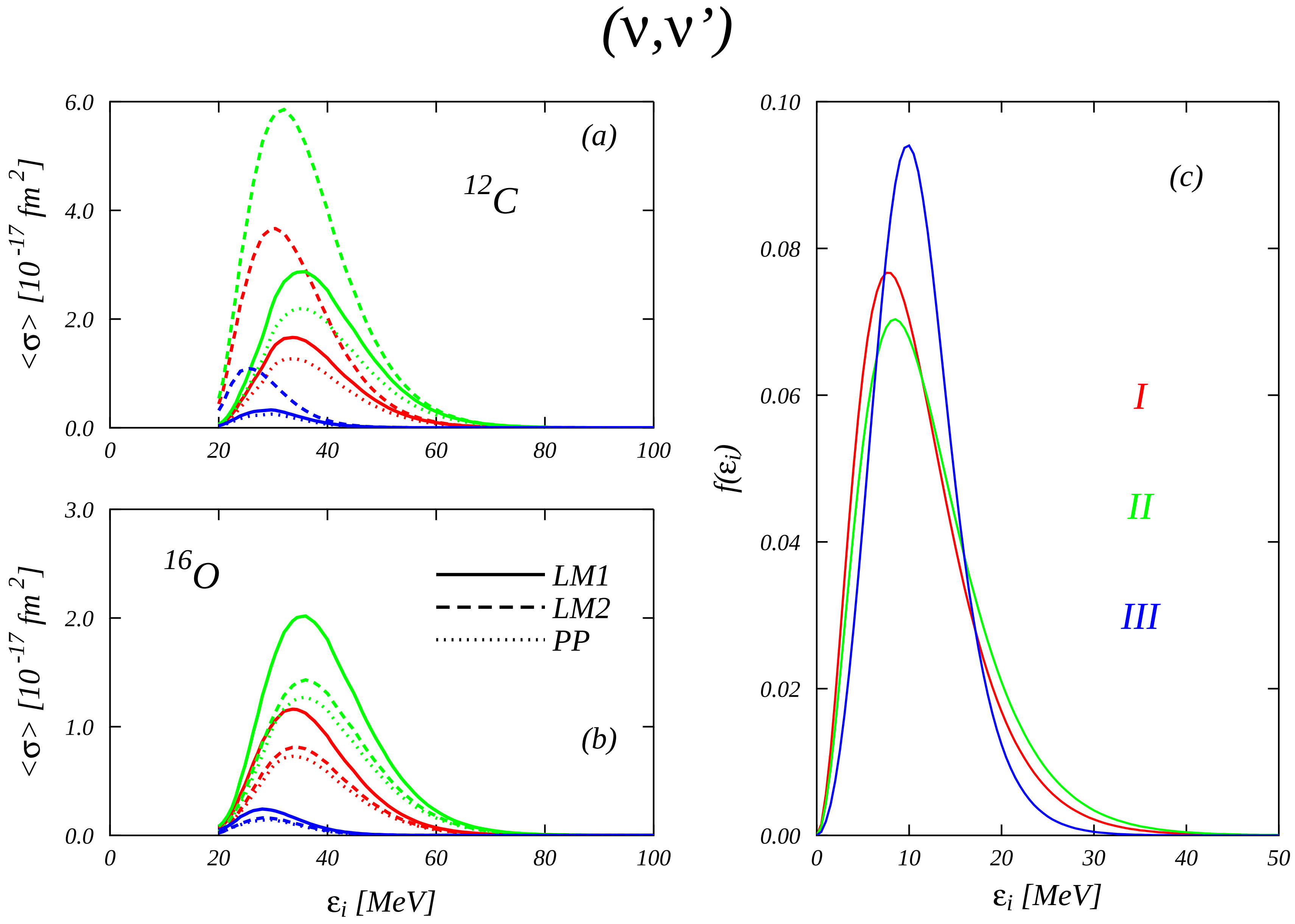
$$T(\epsilon_i) = \frac{\sigma^{RPA} - \sigma^{FSI}}{\sigma^{RPA} + \sigma^{FSI}}$$



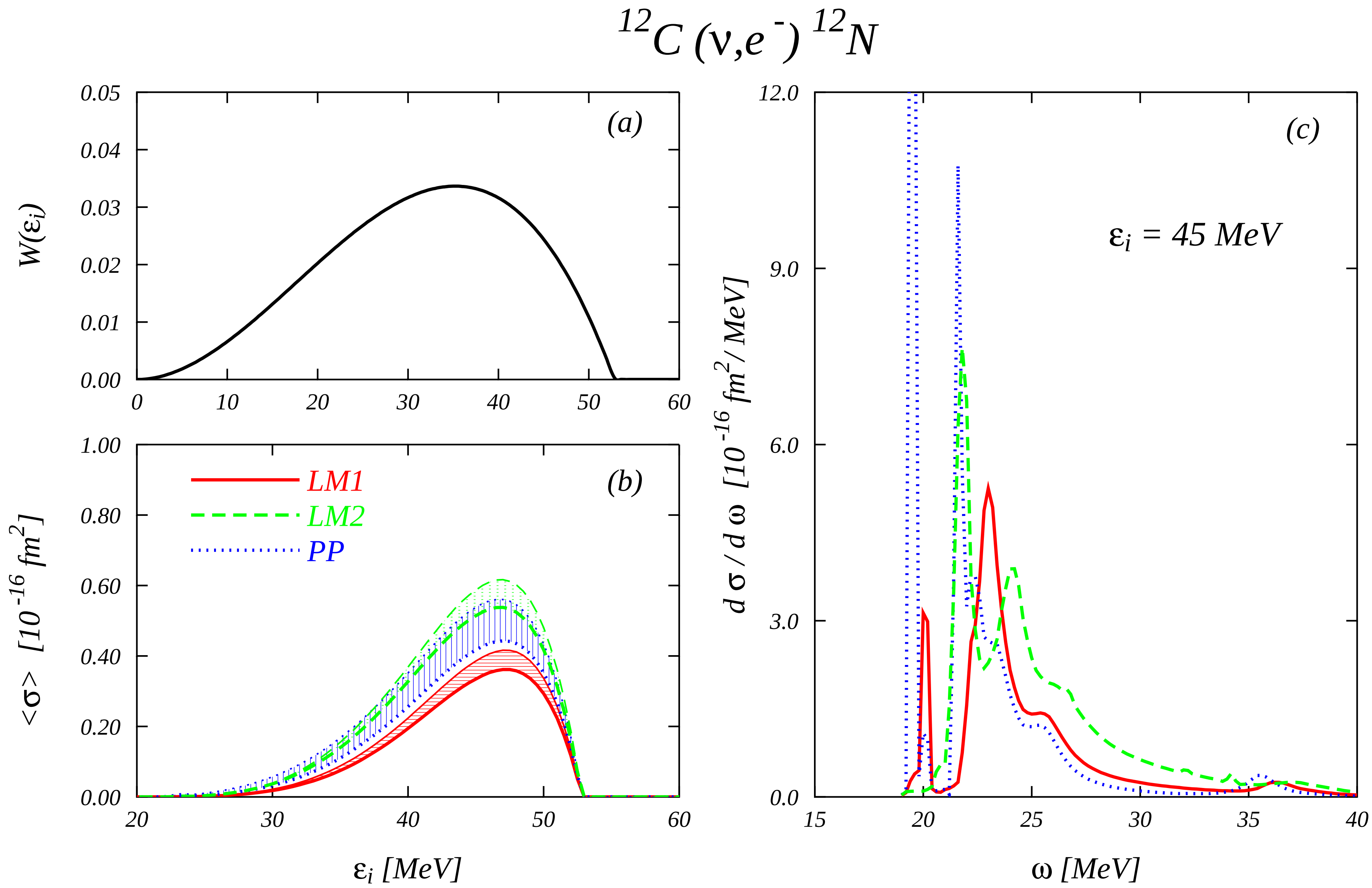
Supernova neutrino fluence

$$f(\epsilon_i) = \mathcal{C}\,\frac{\epsilon_i^2}{1 + exp(\epsilon_i/T - \alpha)}$$

	T [MeV]	α	$< \varepsilon_i >$ [MeV]
I	3.49	0.0	11.0
II	3.80	0.0	12.0
III	2.46	4.0	11.0



(ν,ν')
(a)
^{12}C
<σ> [10^{-17} fm^2]
6.0
4.0
2.0
0.0
0
20
40
60
80
100
^{16}O
LM1
LM2
PP
(b)
3.0
2.0
1.0
0.0
ε_i [MeV]
(c)
$f(\varepsilon_i)$
0.10
0.08
0.06
0.04
0.02
0.00
I
II
III
10
30
50



$^{12}C\ (\nu,e^-)\ ^{12}N$
(a)
$W(\varepsilon_i)$
(b)
LM1
LM2
PP
$<\sigma>\ [10^{-16}\ fm^2]$
ε_i [MeV]
(c)
ε_i = 45 MeV
$d\sigma / d\omega\ [10^{-16}\ fm^2 / MeV]$
ω [MeV]