NUCLEON RECOIL POLARIZATION IN QUASI-ELASTIC ELECTRON SCATTERING WITH TWO-BODY CURRENTS

[illegible]. Boffi, C. Giusti, F.D. Pacati and M. R.

Polarization experiments

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spin degrees of freedom of the particles involved in the reaction are put in evidence and exploited

⇓

1] New observables → new structure functions

2] Complete determination of scattering amplitudes

Hard task ! (at least one measurement of recoil nucleus polarization)

⇓

Selection of the structure functions more sensitive to the various effects to be explored — F.S.I.

M.E.C. + I.C.

1] General Formalism → polarization observables
structure functions

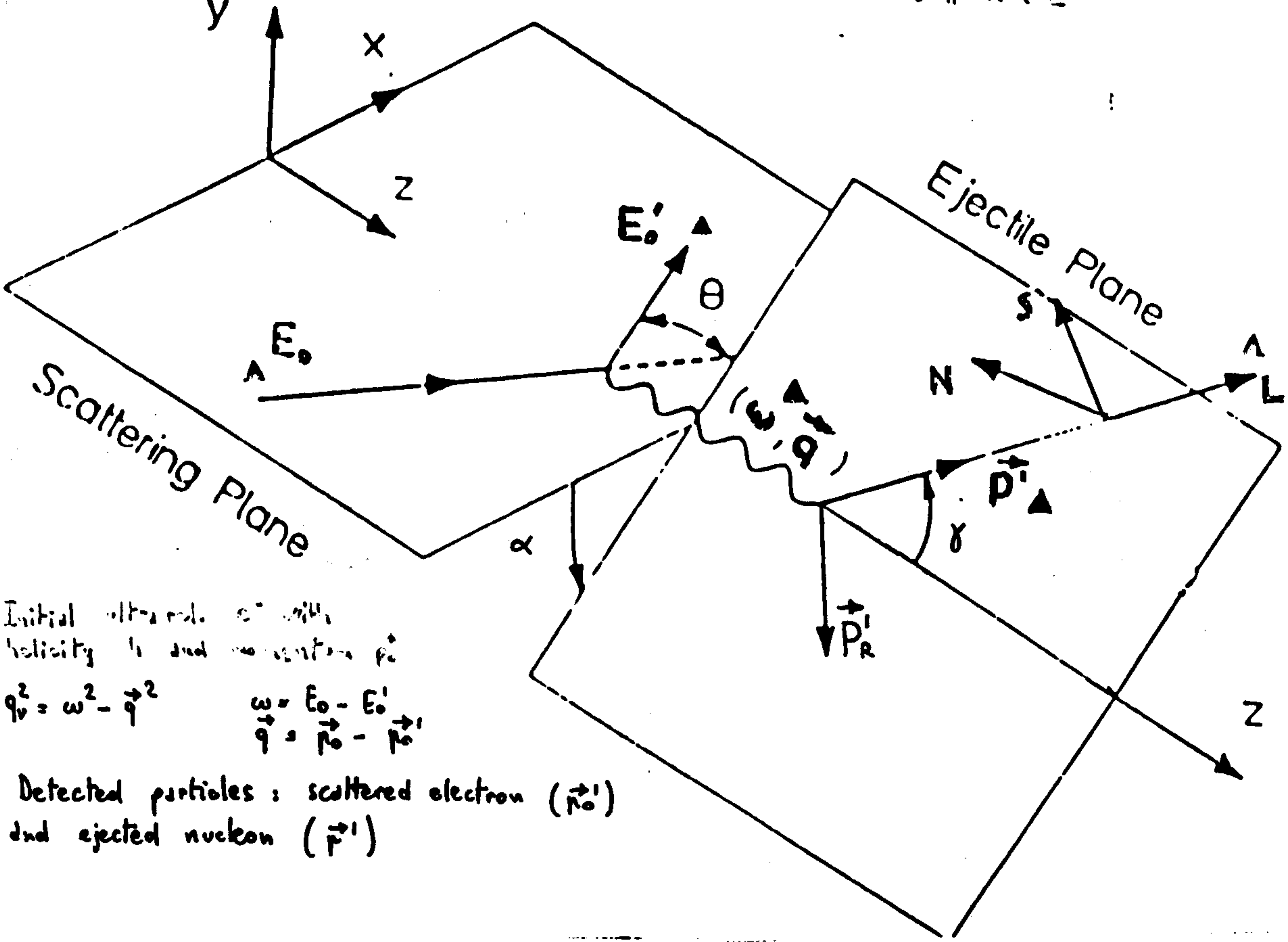
Details of the model

2] Definition of the kinematics

3] Discussion of results for the $(\vec{e}, e'\vec{p})$, $(\vec{e}, e'\vec{n})$ reactions

4] Conclusions and outlooks

$\hat{L} \parallel \vec{p}\,'$
$\hat{N} \parallel \vec{q} \times \vec{p}\,'$
$\hat{S} \parallel \hat{N} \times \hat{L}$



▲ Initial ultra-rel. e⁻ with helicity h and momentum $\vec{p}_0$

▲ $q_\nu^2 = \omega^2 - \vec{q}\,^2$ $\quad \omega = E_0 - E_0'$, $\vec{q} = \vec{p}_0 - \vec{p}_0\,'$

▲ Detected particles : scattered electron ($\vec{p}_0\,'$) and ejected nucleon ($\vec{p}\,'$)

$\vec{e}^- ; h, \vec{p}_e \qquad e'^- ; \vec{p}_o{}' \qquad \vec{N} ; \vec{p}\,', s'$

DWIA + Born Approximation

$$\frac{d\sigma^{h,s'}}{d\vec{p}_o{}'\, d\vec{p}\,'} = \frac{1}{2}\sigma_0 \left[1 + \vec{P}\cdot\vec{\sigma} + h\left(A + \vec{P}'\cdot\vec{\sigma}\right)\right]$$

unpolarized cross section

$$\sigma_0 = K\left[2\varepsilon_L h^u_{00} + h^u_{11} + \sqrt{\varepsilon_L(1+\varepsilon)}\, h^u_{01}\cos\alpha - \varepsilon\, h^u_{1-1}\cos 2\alpha \right]$$

$$K = \frac{e^4}{8\pi^2 q_\nu^2\, p_o'\, p_e\, (\varepsilon - 1)}$$

$$\varepsilon_L = -\frac{q_\nu^2}{\vec{q}^{\,2}}\,\varepsilon$$

$$\varepsilon = \left[1 - 2\frac{\vec{q}^{\,2}}{q_\nu^2}\, tg^2\frac{\theta}{2}\right]^{-1}$$

Electron analyzing power

$$A = \frac{K}{\sigma_0}\sqrt{\varepsilon_L(1-\varepsilon)}\; h'^u_{01}\sin\alpha$$

Vector polarization

$$P^N = \frac{K}{\sigma_0}\left[2\varepsilon_L h^N_{00} + h^N_{11} + \sqrt{\varepsilon_L(1+\varepsilon)}\, h^N_{01}\cos\alpha - \varepsilon h^N_{1-1}\cos 2\alpha\right]$$

$$P^{L,S} = \frac{K}{\sigma_0}\left[\sqrt{\varepsilon_L(1+\varepsilon)}\, h^{L,S}_{01}\sin\alpha - \varepsilon h^{L,S}_{1-1}\sin 2\alpha\right]$$

Polarization transfer coefficient

$$P'^N = \frac{K}{\sigma_0}\sqrt{\varepsilon_L(1-\varepsilon)}\; h'^N_{01}\sin\alpha$$

$$P'^{L,S} = \frac{K}{\sigma_0}\left[\sqrt{1-\varepsilon^2}\, h'^{L,S}_{11} + \sqrt{\varepsilon_L(1-\varepsilon)}\, h'^{L,S}_{01}\cos\alpha\right]$$

$\alpha = 0^\circ, \pi$

$$A = 0$$
$$P^{L,S} = 0$$
$$P'^N = 0$$

The structure functions $h_{\mu\nu}$ are suitable linear combinations of the hadronic tensor

$$W^{\mu\nu}_{ss'} = \overline{\sum_{if}} \langle \psi_f^s | J^\mu | \psi_i \rangle \left(\langle \psi_f^{s'} | J^\nu | \psi_i \rangle \right)^* \delta(E_i - E_f)$$

hadronic matrix elements of electromagnetic current

$$\langle \psi_f^s | J^\mu | \psi_i \rangle = \int d\vec{r}\; e^{i\vec{q}\cdot\vec{r}} \langle \psi_f | J_\mu | \psi_i \rangle e^\mu_{..}$$

↓

helicity amplitudes

$$\vec{e}_0 = (1, 0, 0, 0)$$ longitudinal

$$\vec{e}_{\pm 1} = \left(0, \mp \frac{1}{\sqrt{2}}, \frac{-i}{\sqrt{2}}, 0\right)$$ transverse

} respect to the virtual photon exchanged

Following S. Boffi et.al., Nucl. Phys. A379 (1982) 509

helicity amplitudes

$$\langle \Psi_f | J^{\mu} | \Psi_i \rangle = \int d\vec{r}\, d\vec{r}\,' \, \delta(\vec{r}\,' - \vec{r} - \vec{q}) \, \chi^{(-)*}_{E\alpha}(\vec{r}\,') \, J_\mu(\vec{r}, \vec{r}\,') \, \epsilon^{\mu}_{[illegible]} \, \cdot$$

$$\cdot \, \varphi_{E\alpha}(\vec{r}) \, [S_\alpha(E)]^{1/2}$$

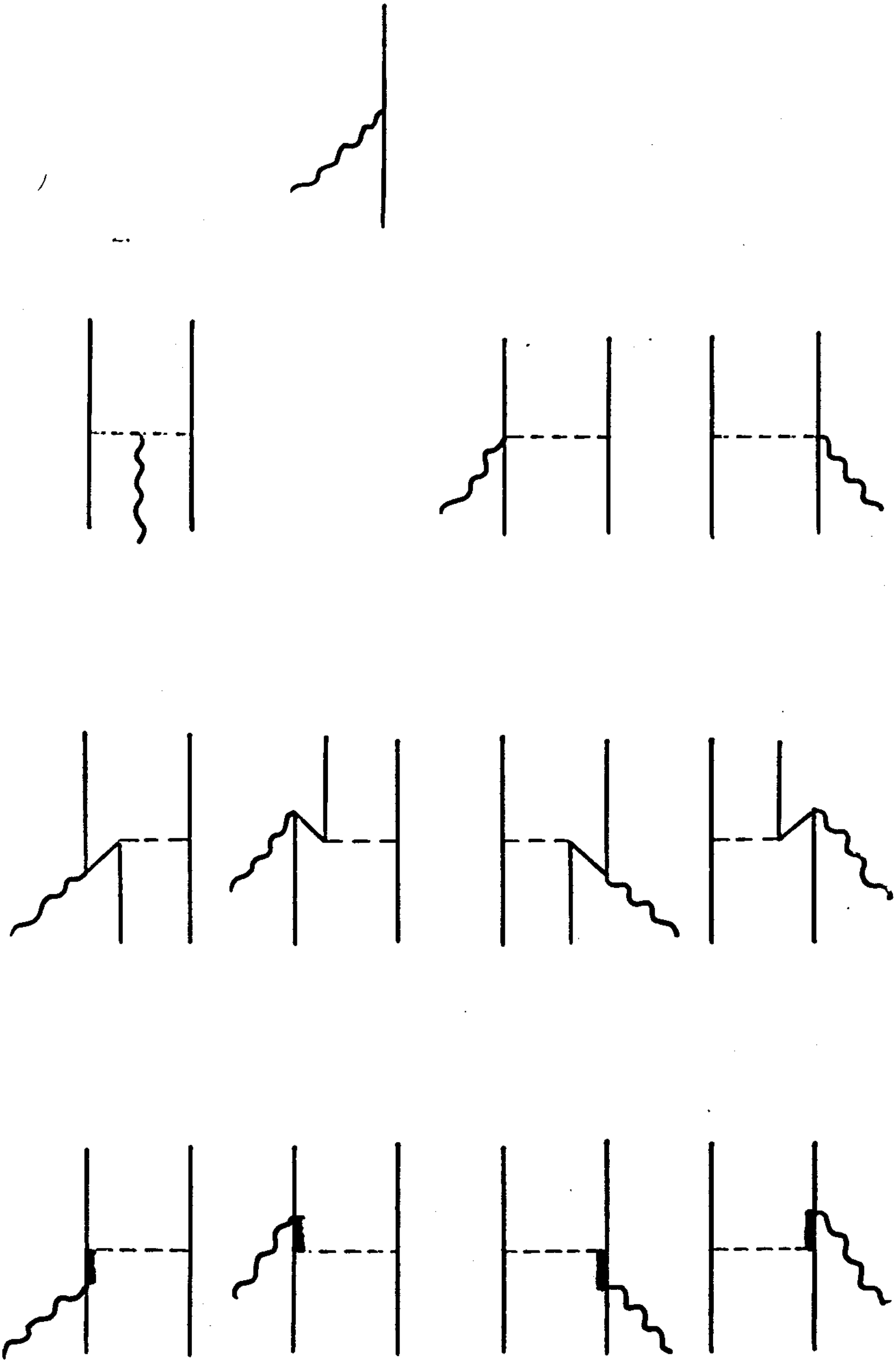
$S_\alpha(E)$ spectroscopic factor for the residual nucleus in $|E\alpha\rangle$

$\varphi_{E\alpha}(\vec{r})$ solution of Feshbach optical potential $\mathcal{H}(E)$ referred to residual nucleus state

$\chi^{(-)}_{E\alpha}(\vec{r}\,')$ solution of Feshbach optical potential $\mathcal{H}^{+}(E+\omega)$ referred to distorted ejectile particle state

$$\chi^{(-)}_{E\alpha}(\vec{r}) \not\perp \varphi_{E\alpha}(\vec{r}) \implies J^{\text{eff.}}_{\mu}(\vec{r}, \vec{r}\,')$$

$$J_\mu(\vec{r}, \vec{r}\,') = j^{(1)}_{\mu}(\vec{r}, \vec{r}\,') - \int d\vec{k}\, j^{(2)}_{\mu}(\vec{r}\,' - \vec{k}, \vec{k} - \vec{r}) \, n(\vec{k}) \, \delta^{\mu}_{i}$$



Kinematics

$(\vec{q},\omega)$ constant :

p' q fixed

γ variable $\longrightarrow$ p variable

p - dependence of $J_\mu(\vec{p},\vec{p}')$

parallel :

$\gamma = 0 \quad p' \parallel q$

p' fixed

q variable $\longrightarrow$ p variable

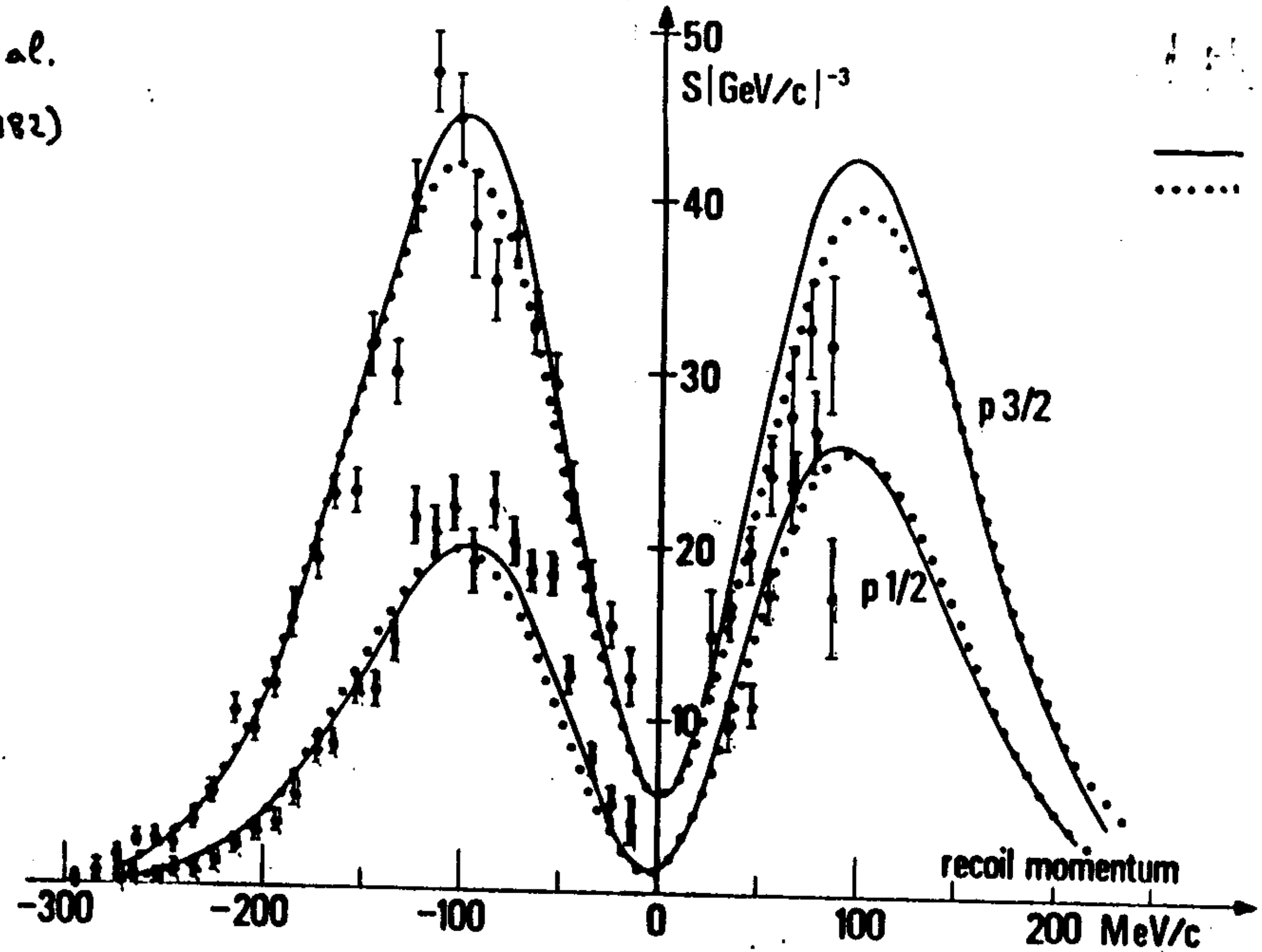
q - dependence of MEC + IC in J_μ
at fixed FSI

Target nucleus ^{16}O knockout from shells with $j=\frac{1}{2}$, $j=\frac{3}{2}$

$E_0 = 700$ MeV	initial electron energy	If not otherwise specified
$T_{p'} = 150$ MeV	ejected nucleon kinetic energy	
$q = 550$ MeV/c	in $(\vec{q},\omega)$ constant kinematics	

$^{16}O(e,e'p)$

M. Bernheim et al.
N.P. A375, 381 (1982)



ϕ p3/2

—— Elton-S. + Jackson-A.

······ Sogny + Jackson-A.

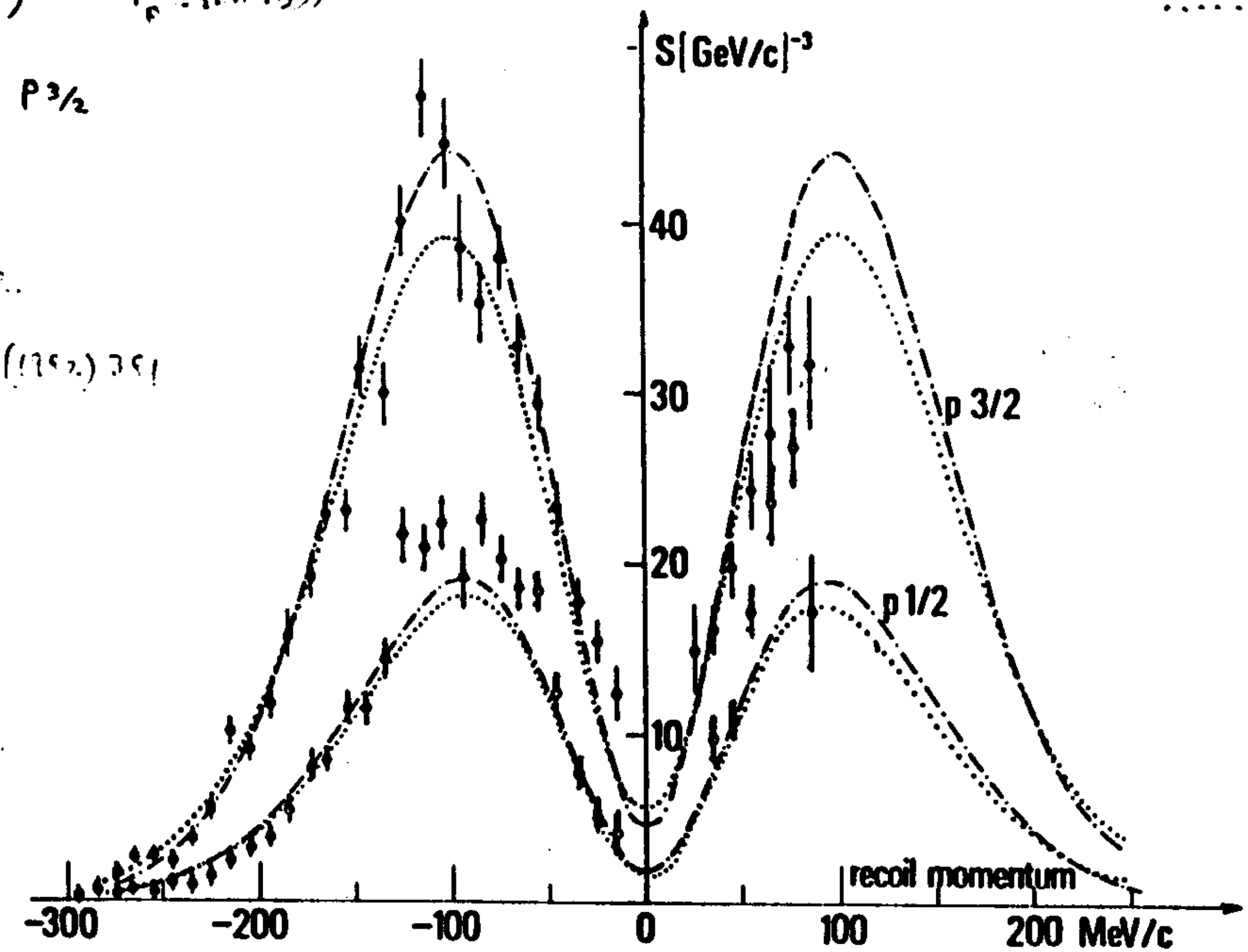
T_p = [illegible]

$^{16}O(e,e'p)$ $T_p = 100$ MeV

$p_{1/2}$ $p_{3/2}$

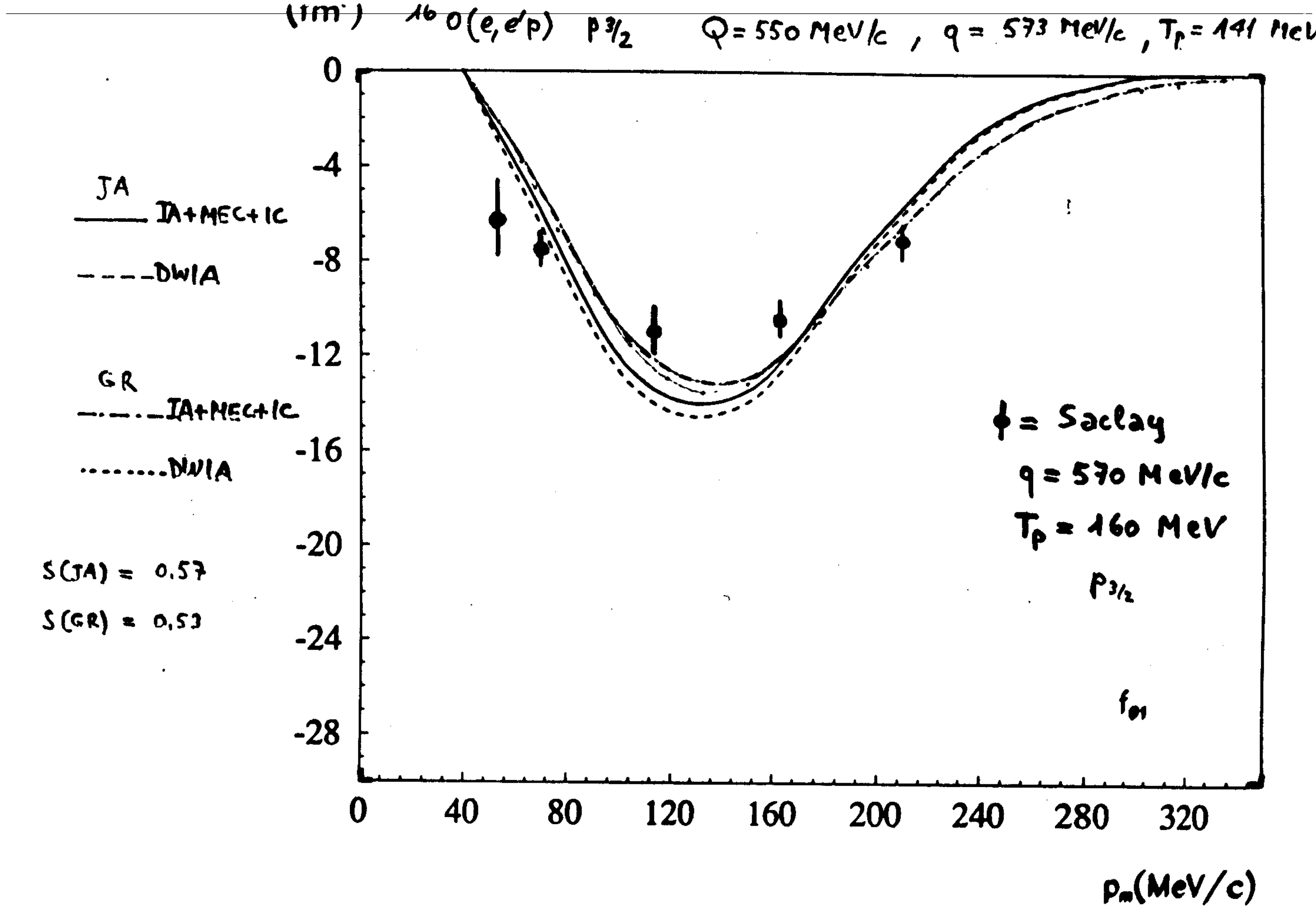
M. Bernheim et al.

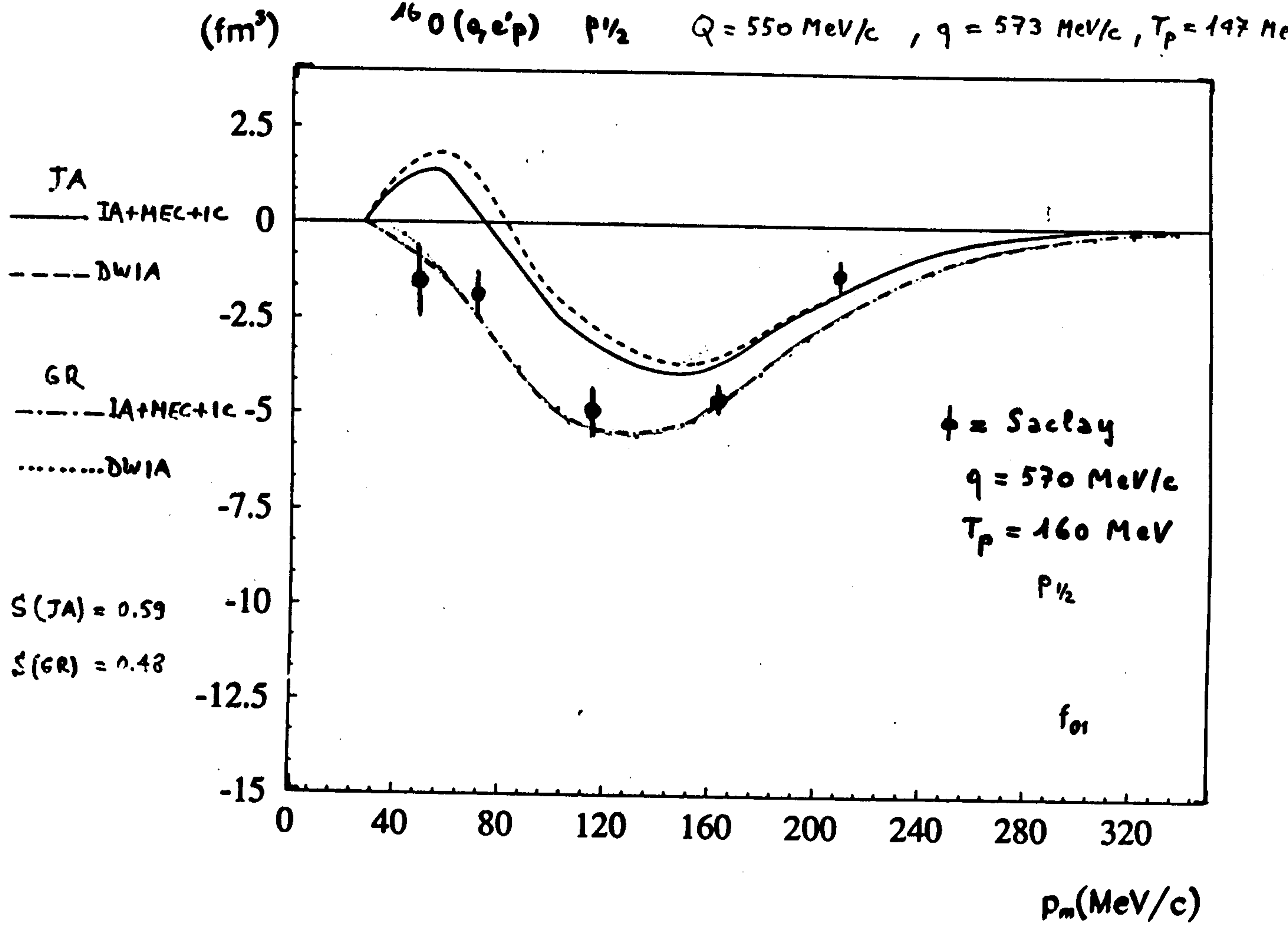
Nucl. Phys. A375 (1982) 381



—·— [illegible]

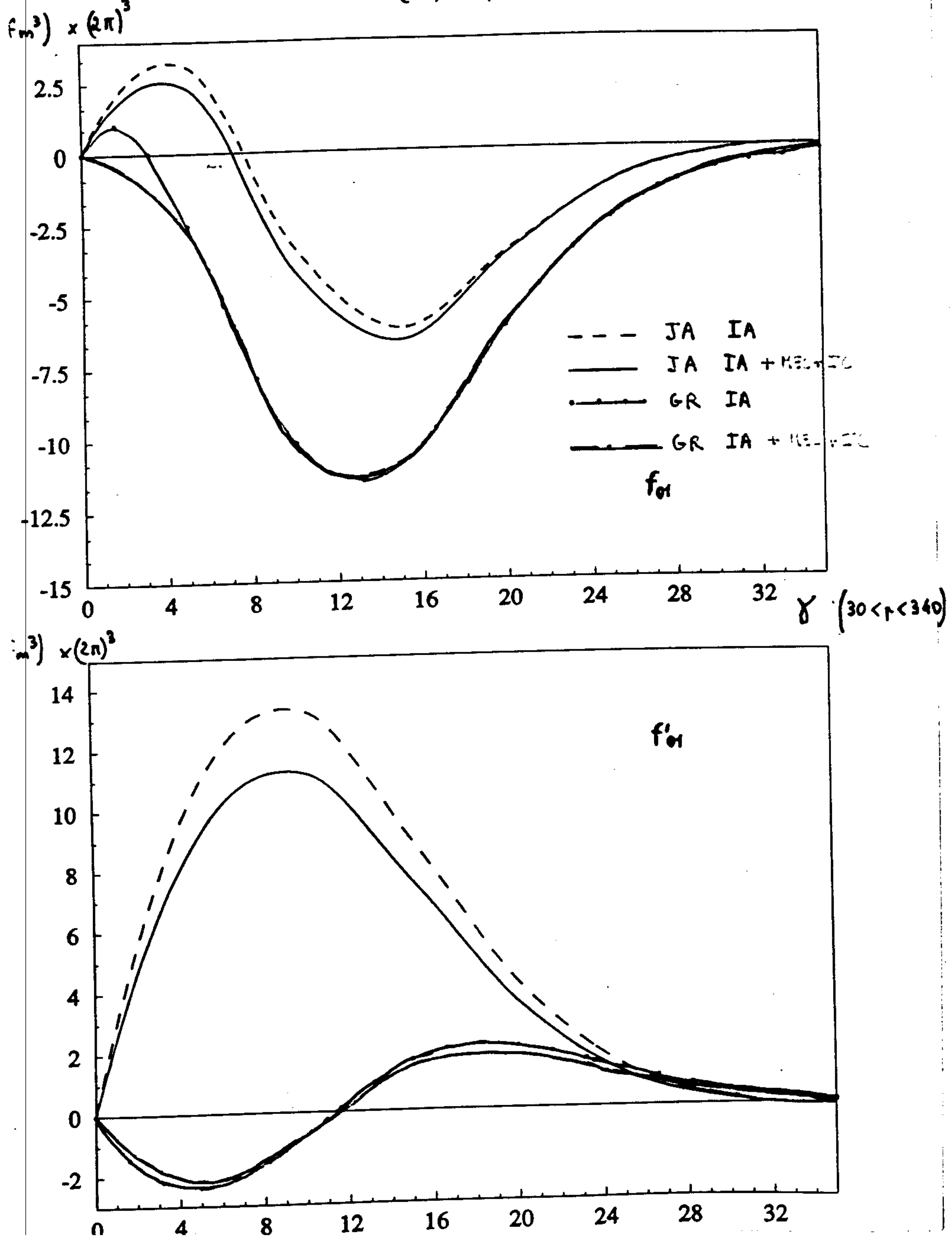
······ GR-GR

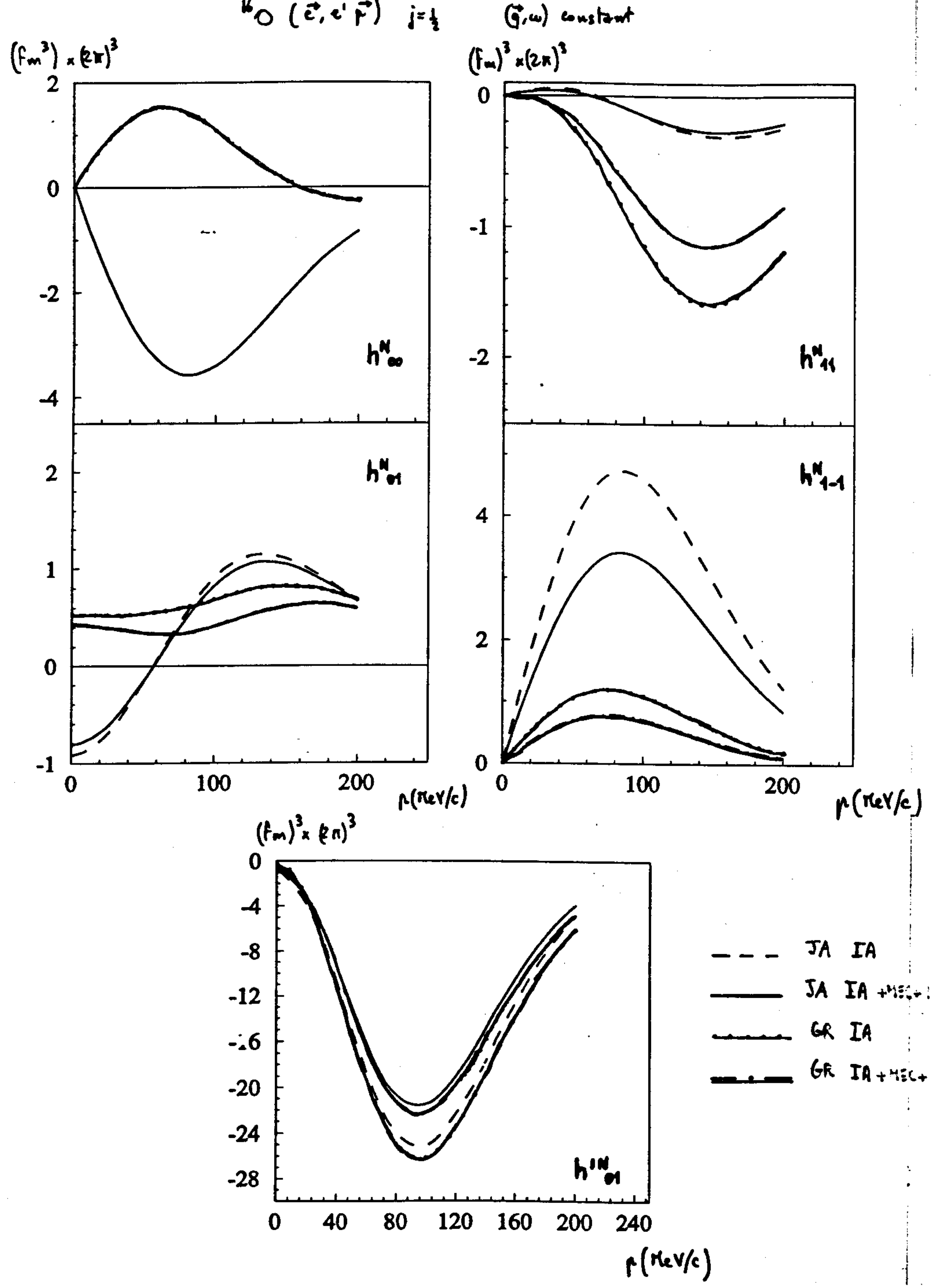

(fm) ¹⁶O(e,e'p) p3/2 Q = 550 MeV/c , q = 573 MeV/c , Tp = 141 MeV
JA
IA+MEC+IC
DWIA
GR
IA+MEC+IC
DWIA
S(JA) = 0,57
S(GR) = 0,53
= Saclay
q = 570 MeV/c
Tp = 160 MeV
p3/2
0
-4
-8
-12
-16
-20
-24
-28
0
40
80
120
160
200
240
280
320
pm(MeV/c)



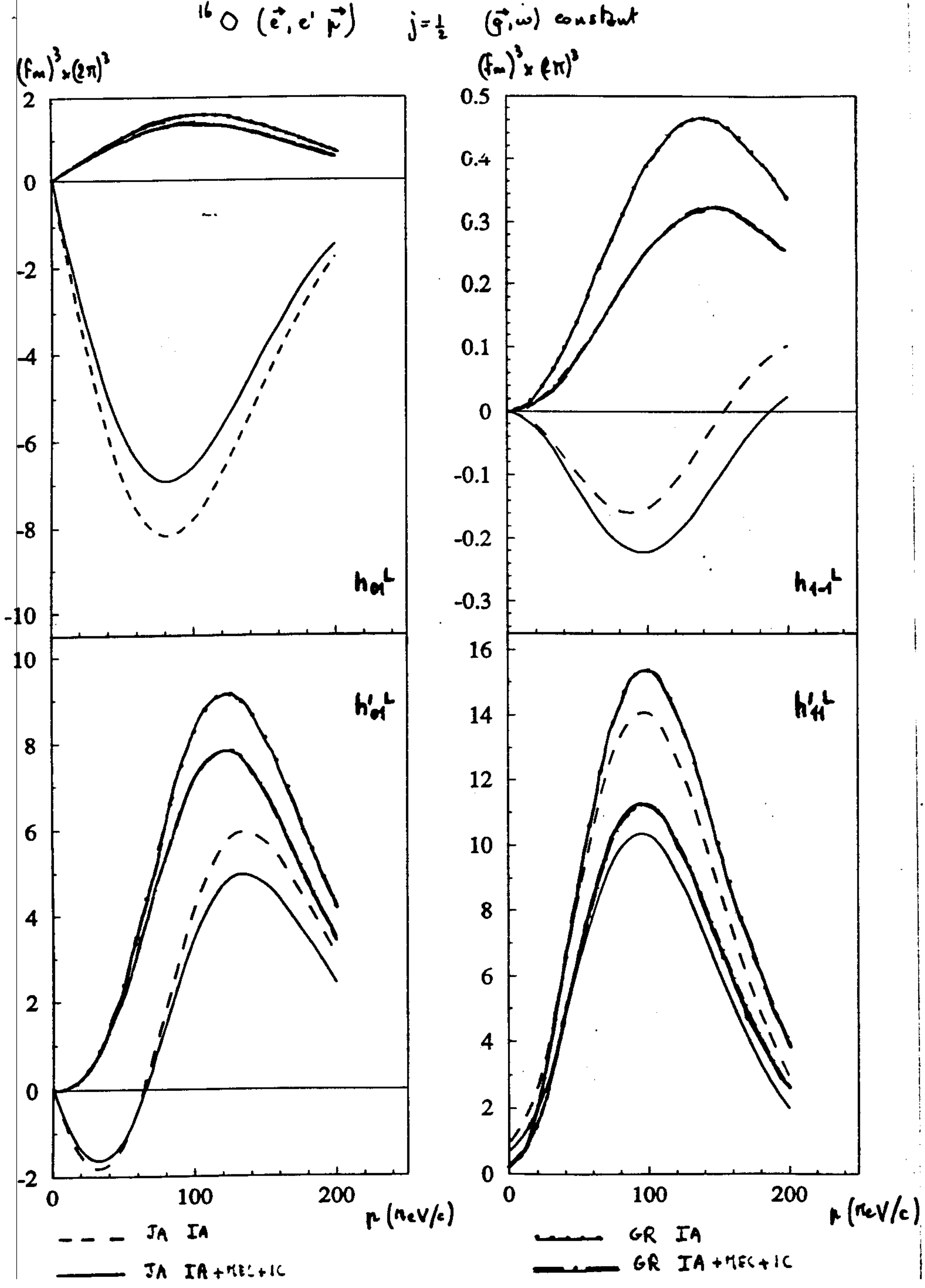
(fm³)
16O(e,e'p) p1/2 Q = 550 MeV/c , q = 573 MeV/c , Tp = 147 Me
JA
IA+MEC+IC
DWIA
GR
IA+MEC+IC
DWIA
S(JA) = 0.59
S(GR) = 0.48
2.5
0
-2.5
-5
-7.5
-10
-12.5
-15
0
40
80
120
160
200
240
280
320
= Saclay
q = 570 MeV/c
Tp = 160 MeV
p1/2
f01
pm(MeV/c)

$^{16}O\ (\vec{e}, e'\ p)$ $j = \frac{1}{2}$ $Q = 550$ MeV/c $T_{p'} = 147$ MeV

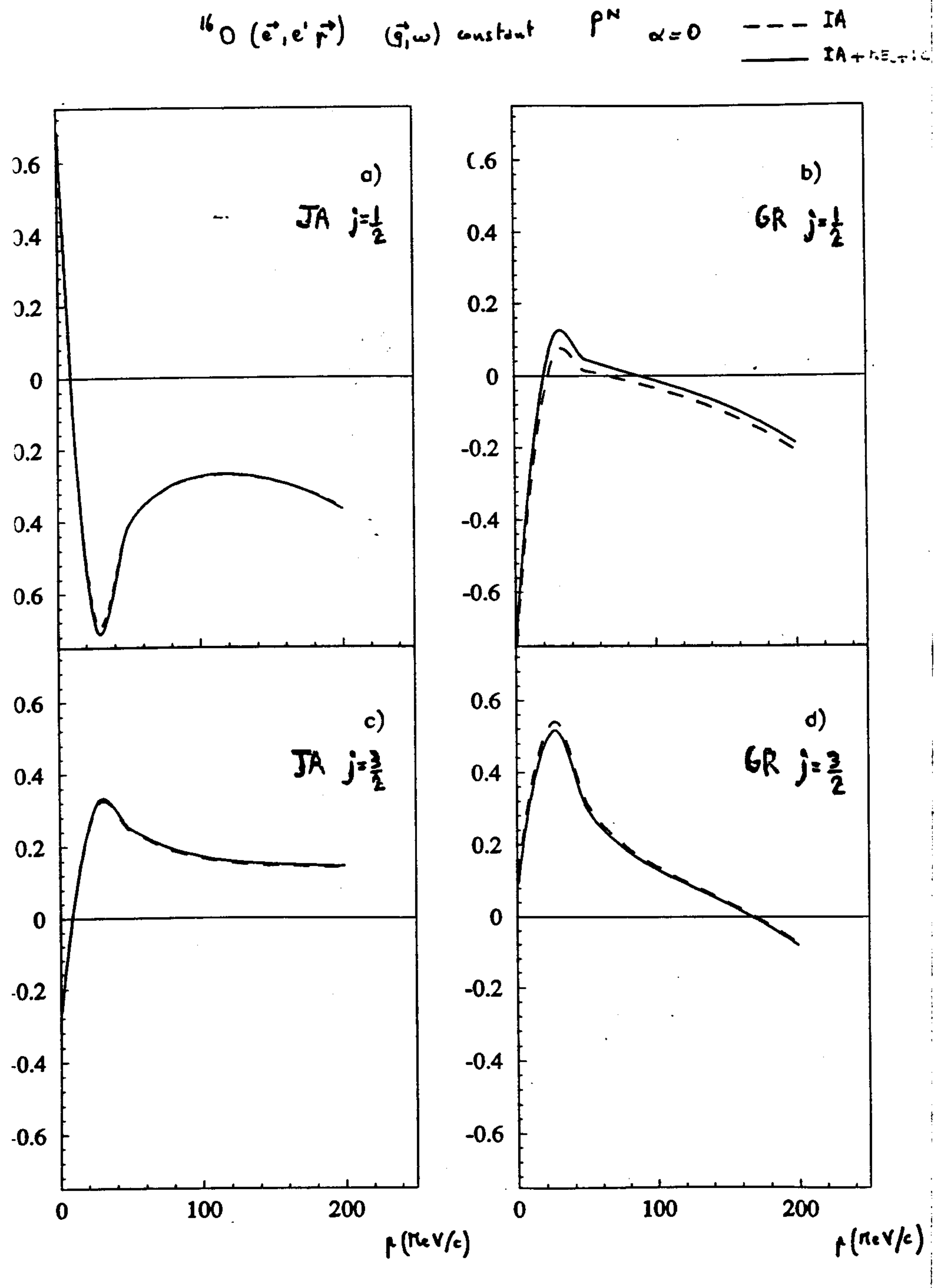




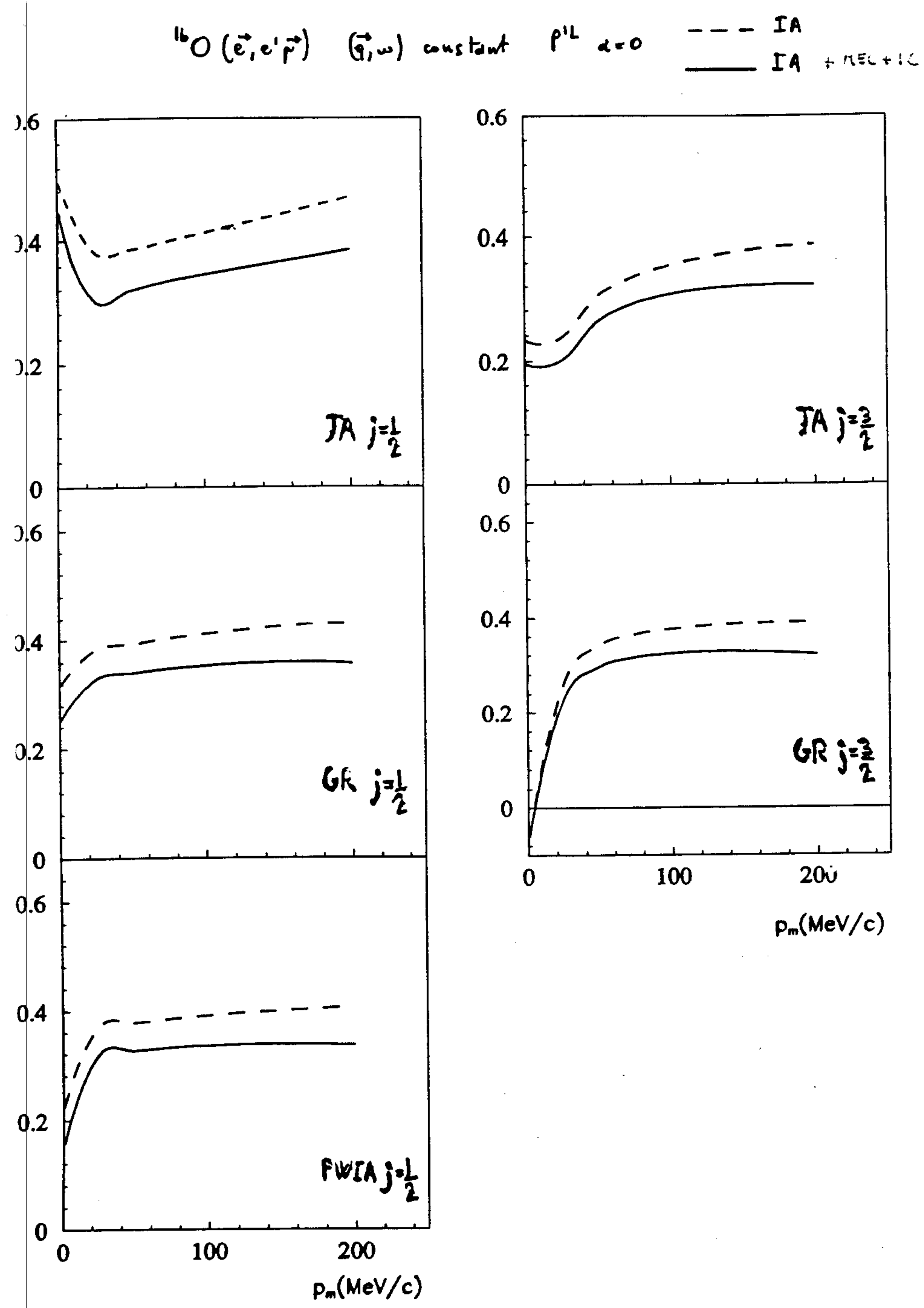
16O (e, e' p) j=1/2
(q, ω) constant
(fm)^3 x (2π)^3
h^N_00
h^N_11
h^N_01
h^N_1-1
h'^N_01
p (MeV/c)
JA IA
JA IA + MEC +
GR IA
GR IA + MEC +



16O (e⃗, e' p⃗) j = 1/2 (q⃗, ω) constant
(fm)^3 x (2π)^3
(fm)^3 x (2π)^3
2
0
-2
-4
-6
-8
-10
h01^L
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
h1-1^L
10
8
6
4
2
0
-2
h'01^L
16
14
12
10
8
6
4
2
0
h'11^L
0
100
200
p (MeV/c)
0
100
200
p (MeV/c)
JA IA
JA IA + MEC + IC
GR IA
GR IA + MEC + IC



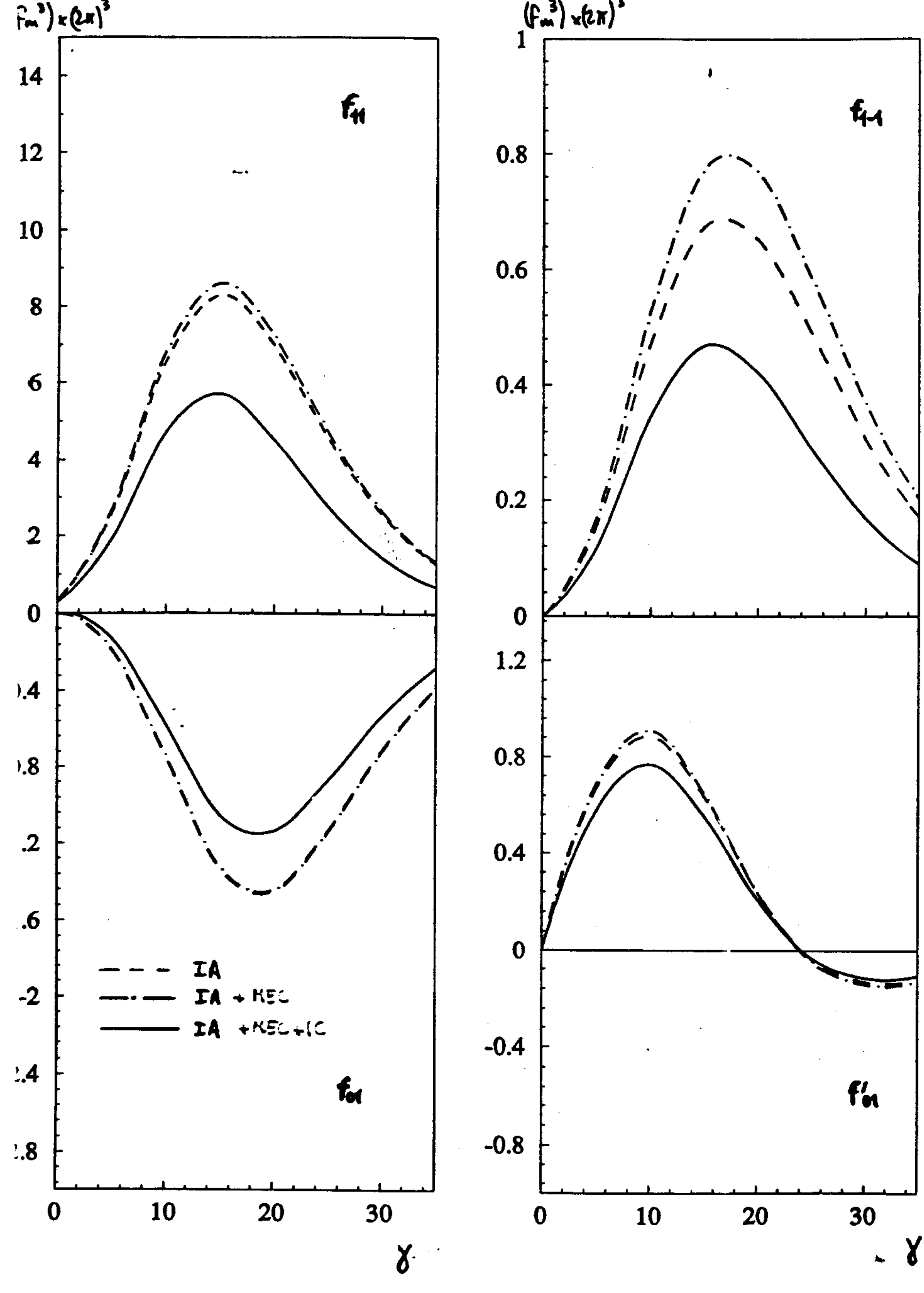
16O (e→, e' p→) (q→, ω) constant ρN α=0
IA
a)
JA j=1/2
b)
GR j=1/2
c)
JA j=3/2
d)
GR j=3/2
0
100
200
p (MeV/c)

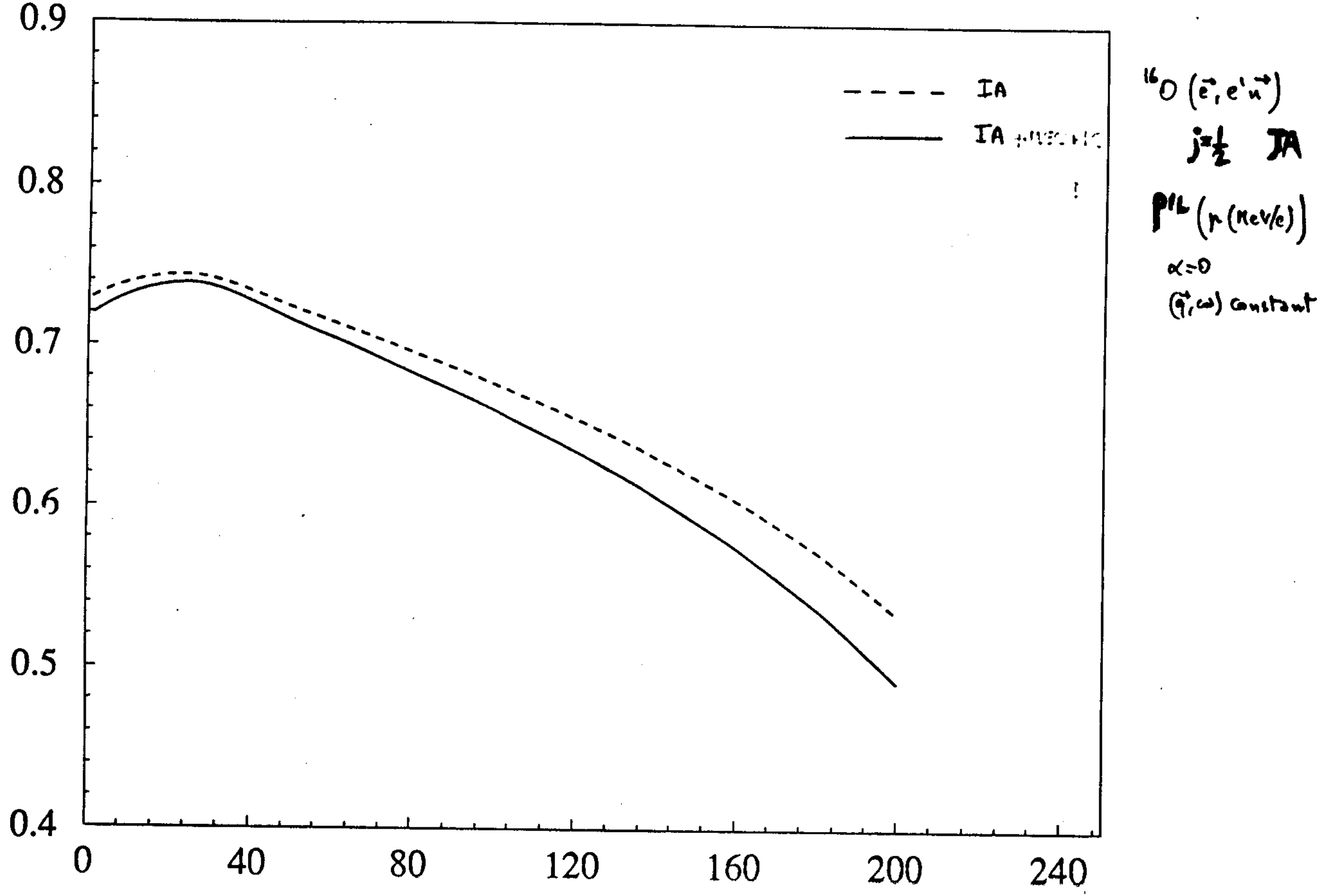


16O (e,e'p) (q,ω) constant ρ'L α=0
IA
IA + MEC + IC
IA j=1/2
IA j=3/2
GR j=1/2
GR j=3/2
PWIA j=1/2
0.6
0.4
0.2
0
100
200
pm(MeV/c)

$^{16}O\ (\vec{e}, e'N)$ $j=\frac{1}{2}$ $(\vec{q}, \omega)$ constant Q=400 MeV/c T_p=68 MeV GR

45 MeV/c < p < 236 MeV/c





0.9
0.8
0.7
0.6
0.5
0.4
0
40
80
120
160
200
240
IA
$^{16}O(\vec{e},e'\vec{n})$
j=1/2 IA
P'L (p (MeV/c))
α=0
($\vec{q}$,ω) constant

Parallel kinematics

$\gamma = 0 \longrightarrow \vec{r}' \parallel \vec{q}$

$$\sigma_0 = K \left(2 \varepsilon_L h^u_{00} + h^u_{11} \right)$$

$$P^N = \frac{K}{\sigma_0} \sqrt{\varepsilon_L (1+\varepsilon)}\, h^N_{01}$$

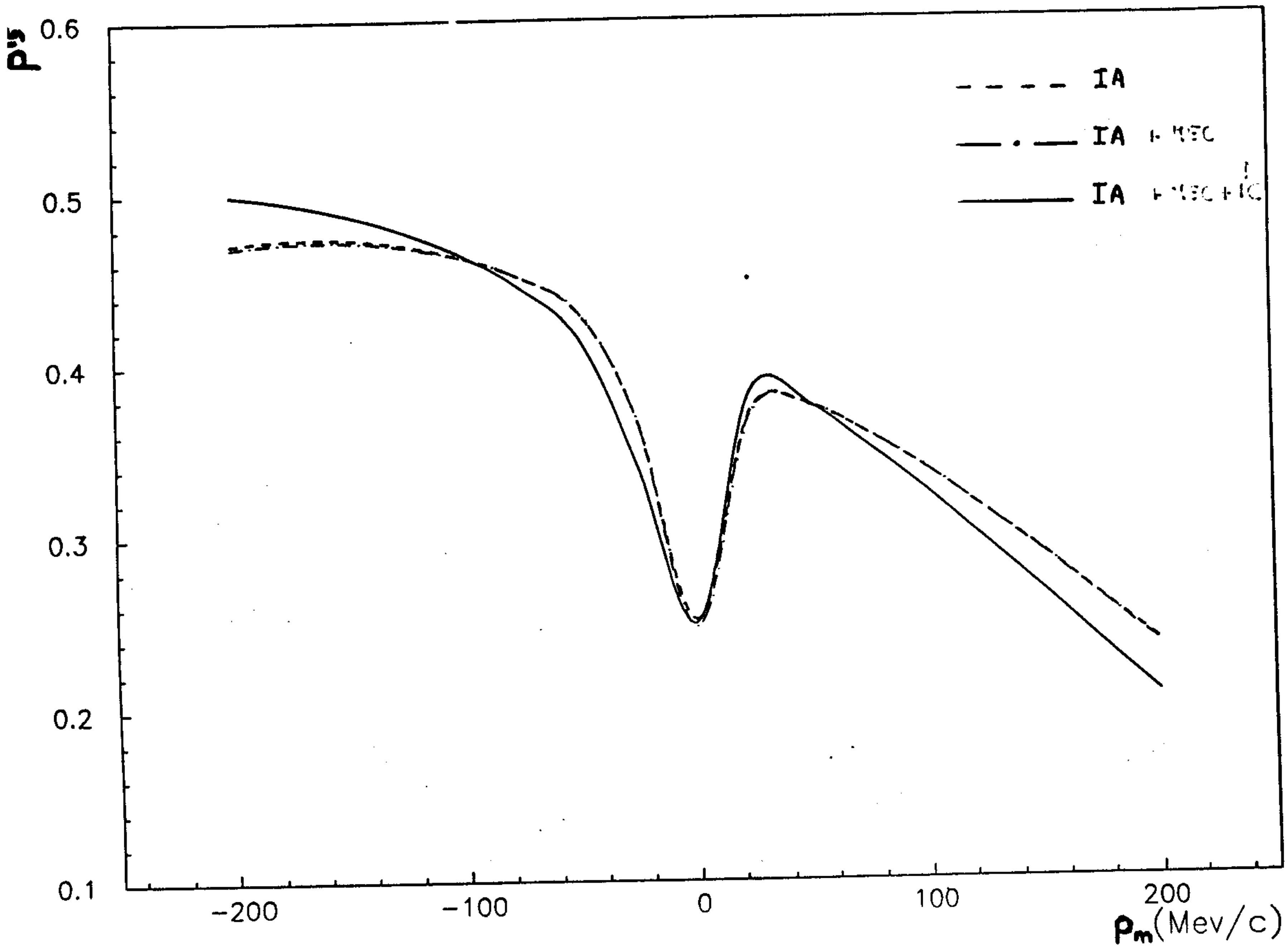
$$P'^L = \frac{K}{\sigma_0} \sqrt{1-\varepsilon^2}\, h'^L_{11} \qquad j=\tfrac{1}{2} \longrightarrow h'^L_{11} \equiv h^u_{11}$$

$$P'^S = \frac{K}{\sigma_0} \sqrt{\varepsilon_L (1-\varepsilon)}\, h'^S_{01}$$

1] Two polarization measurements (P^N, P'^S) only

2] Direct access to structure functions

$^{16}O(\vec{e},e'\vec{p})$ $J=\frac{1}{2}$ parallel 350 MeV/c < q < 750 MeV/c IA



Conclusions

PWIA $\quad\quad$ DWIA

$A, \vec{P} = 0 \longrightarrow A, h^{1N}_{01}$, $\vec{P}, h^{1N;\ldots}_{\mu\nu}$ sensitive to FSI

to IC but effect overwhelmed by FSI

not to MEC (in this model and energy domain)

$(\vec{q},\omega)$ constant kinematics prefereable, because quantities are more sizeable

PWIA $\quad\quad$ DWIA

$\vec{P}' \neq 0 \longrightarrow \vec{P}', h^{1N;\ldots}_{\mu\nu}$ sensitive to IC

not to FSI

not to MEC (In this model and energy domain)

P^{1L} is prefereable, because very sensitive to IC and sizeable in both kinematics [$(\vec{q},\omega)$ constant and parallel] and both knockout reactions [$(\vec{e},e'\vec{p})$; $(\vec{e},e'\vec{n})$]

Non-relativ. DWIA in Born-approximation basically confirmed in quasi-elastic energy region

MEC, IC (small) corrections

Measurement of P^N in coplanar ($\alpha = 0, \pi$) $(\vec{q},\omega)$ constant kinematics $\longrightarrow$ Additional informations on FSI

Measurement of P^{1L} in coplanar $(\vec{q},\omega)$ constant or in parallel kinematics $\longrightarrow$ Test of "Two-body currents model"