* M. Bernheim, J.F. Danel, J.E. Ducret, J.M. Le Goff,
L. Lakehal-Ayat, A. Magnon, C. Marchand, J. Mougey,
J. Morgenstern, S. Turck-Chieze, P. Vernin, A. Zghiche
SACLAY, DPHN, FRANCE

* S. Frullani, F. Garibaldi, F. Ghio, M. Iodice
SANITA, INFN, ITALY

* G.P. Capitani, E. De Sanctis
LNF, FRASCATI, INFN, ITALY

* M. Brussel
U. ILLINOIS, U.S.A.

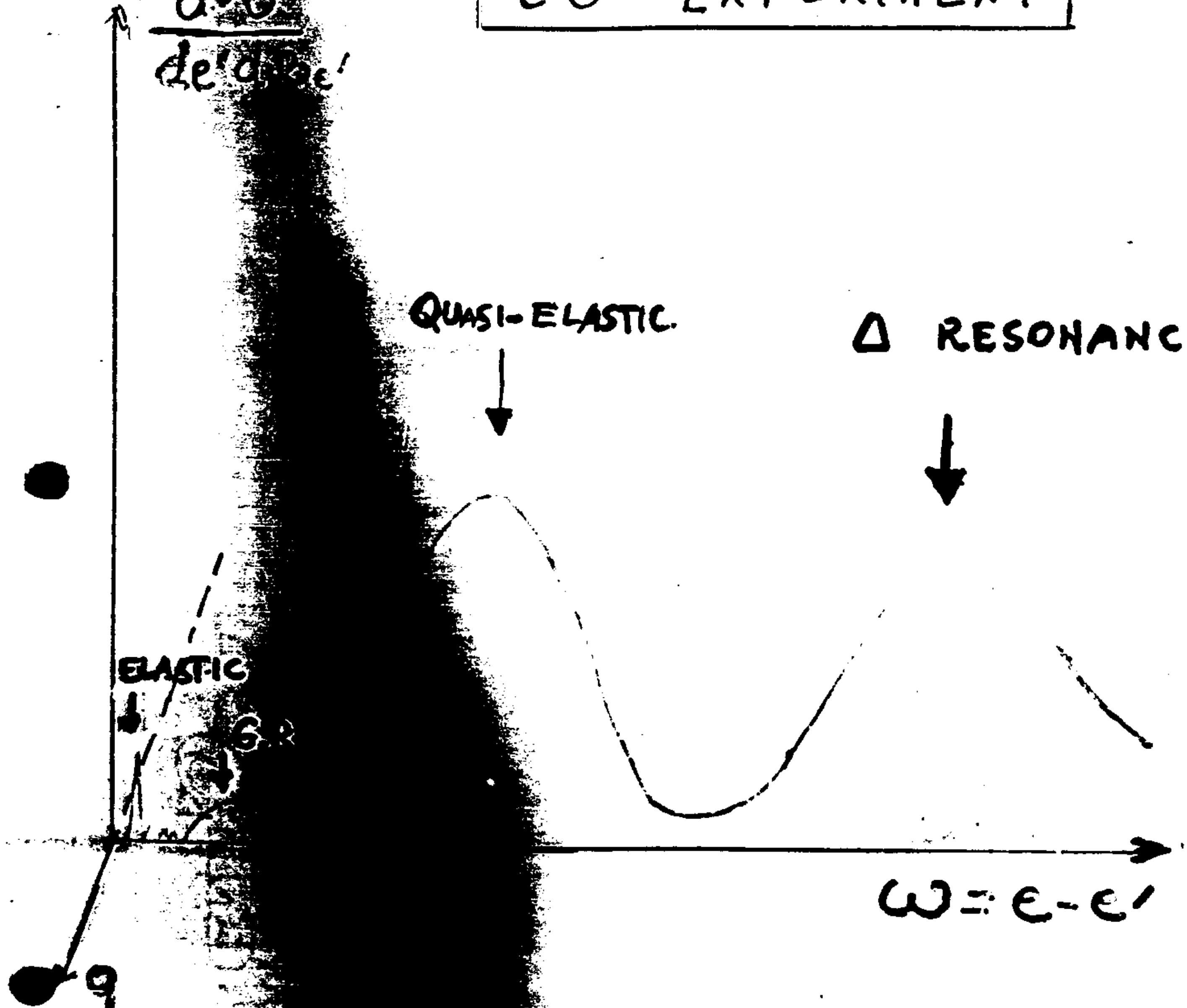
* H.E Jackson
ANL, ARGONNE, U.S.A.

* Z.E. Meziani
U STANFORD, U.S.A.

* J. Le Rose, J. Mougey, S. Nanda, A. Saha, P. Ulmer
CEBAF, U.S.A.

* C. Perdrisat, V. Punjabi
WILLIAM and MARY, U.S.A.

ee' EXPERIMENT



e' ELECTRON ENERGY TRANSFER

$\vec{q}$ $\vec{e}'$ ELECTRON MOMENTUM TRANSFER

QUASI-ELASTIC SCATTERING AND MEDIUM EFFEC

QUASI ELECTRON SCATTERING IS DOMINATED BY ONE SINGLE NUCLEON KNOCK-OUT.

THIS REACTION IS SUITABLE TO STUDY PROPERTIES OF THE NUCLEON INSIDE THE NUCLEAR MEDIUM.

FOR THAT PURPOSE WE HAVE MEASURED THE LONGITUDINAL AND THE TRANSVERSE RESPONSES IN COINCIDENCE $ee'p$ AND IN INCLUSIVE ee' EXPERIMENTS

THESE RESULTS WERE OBTAINED FOR NUCLEON MOMENTA $p < 200$ MeV CORRESPONDING TO THE MEAN FIELD REGIME

WE HAVE FOUND FOR THE TRANSVERSE RESPONSE A RESULT VERY SIMILAR FOR THE PROTON INSIDE AND OUTSIDE THE NUCLEAR MEDIUM FOR ELECTRON MOMENTUM TRANSFER q UP TO 500 MeV/c

FOR THE LONGITUDINAL RESPONSE WE OBSERVE A q DEPENDENCE WITH A SLOPE WHICH IS COMPATIBLE WITH THE FREE NUCLEON BUT WITH A SMALLER STRENGTH. THIS LACK IN STRENGTH INCREASE WITH THE MASS NUMBER.

- IN ADDITION TO NUCLEONIC DEGREES OF FREEDOM, WE CAN HAVE:

- VIRTUAL PION DEGREES OF FREEDOM: EXCHANGE CURRENTS

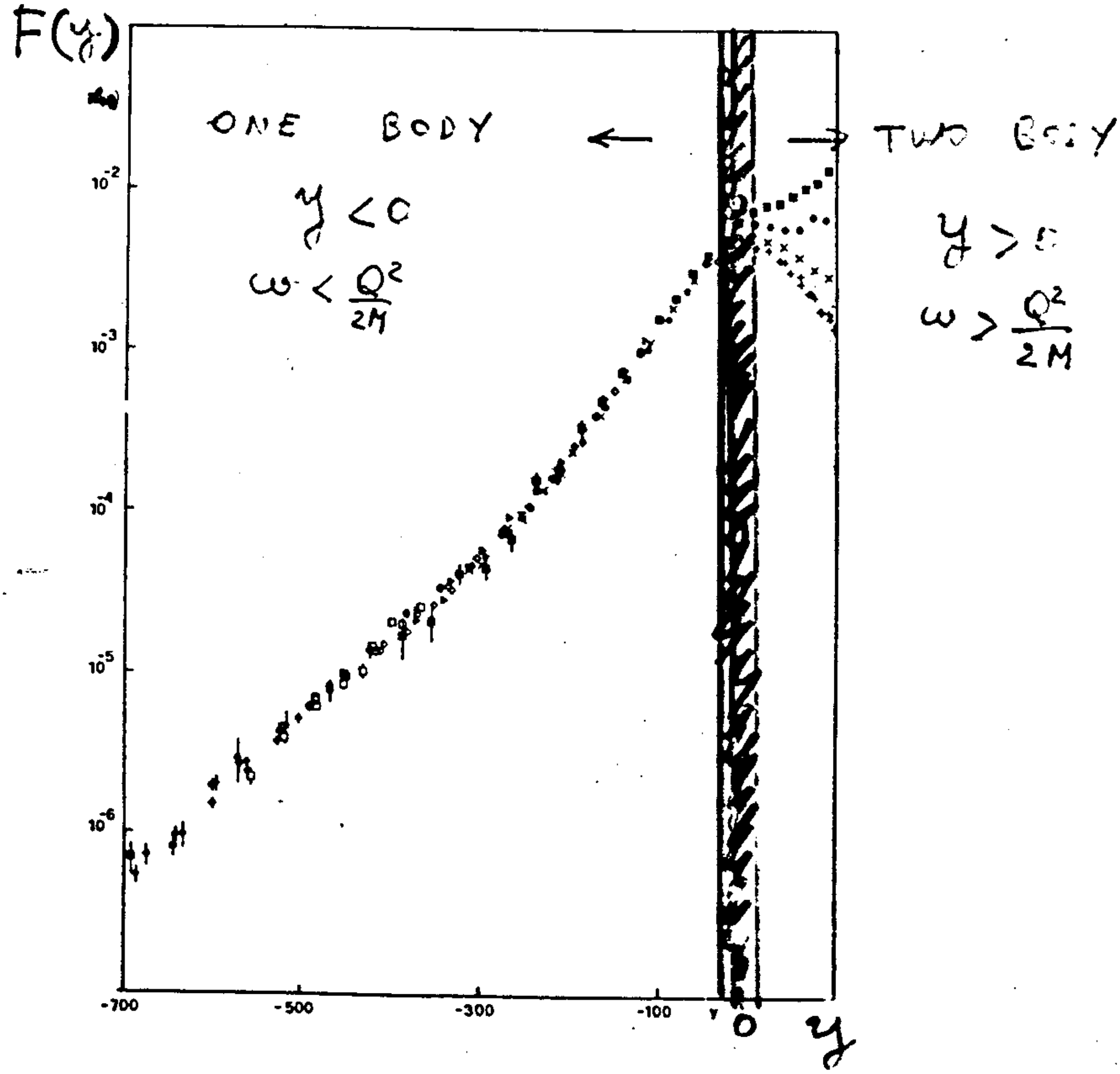
- REAL PION DEGREES OF FREEDOM ONLY ABOVE PION ELECTROPRODUCTION THRESHOLD.

- THESE NEW DEGREES OF FREEDOM ARE ESSENTIALLY TRANSVERSE.

  THE LONGITUDINAL RESPONSE FUNCTION SEEMS MORE SUITABLE FOR STUDYING THE NUCLEONIC DEGREES OF FREEDOM

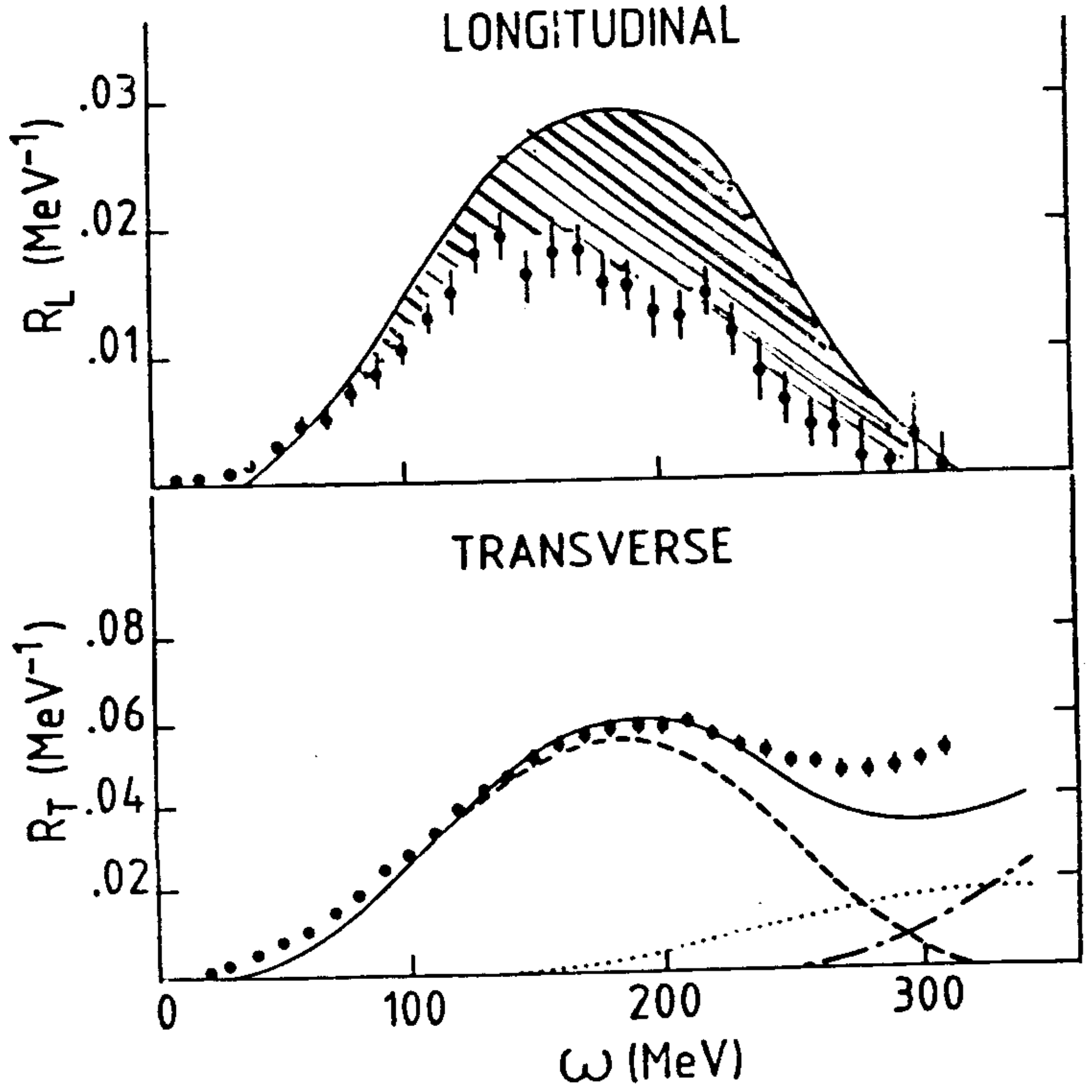
^3He (ee')

S.L.A.C. D. DAY & al.
PHYS. REV. LETT 45, 871 (1980)



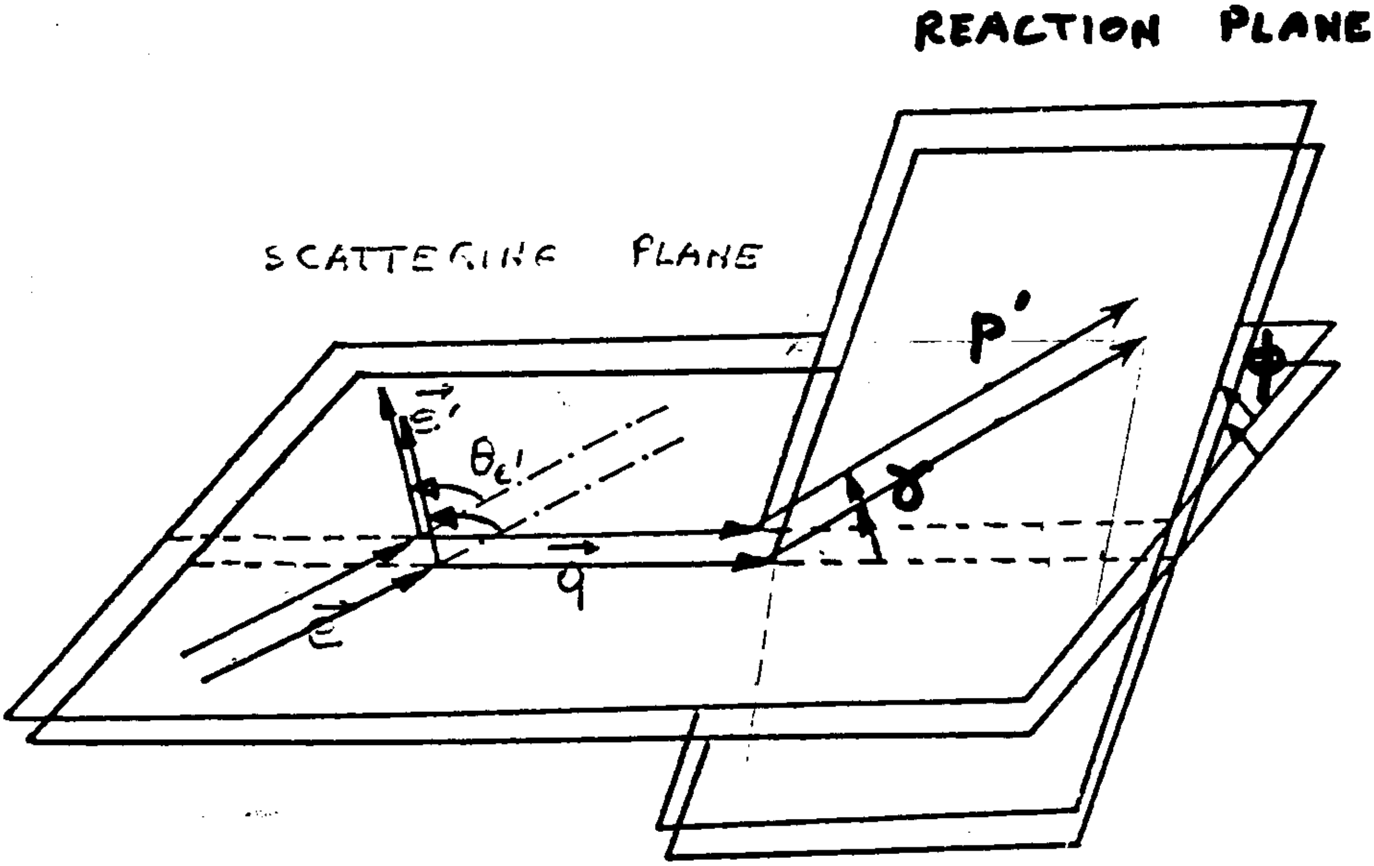
SACLAY
([illegible])

^{40}Ca (ee')
$|\vec{q}|$ = 550 MeV/c



- - - - QUASI-ELASTIQUE
.... COURANTS D'ECHANGE MESIQUES
-·-·- ELECTROPRODUCTION DE PIONS
—— TOTAL

ee'p EXPERIMENT



ee'p EXPERIMENT

DEFINITIONS

$\theta_{e'}$ → ELECTRON SCATTERING ANGLE

$\vec{q}$ → 3-MOMENTUM TRANSFER

ω → ENERGY TRANSFER

$\vec{p}$ → PROTON INITIAL MOMENTUM

$\vec{p}'$ → PROTON FINAL MOMENTUM

$\vec{p}_R = \vec{q} - \vec{p}'$ → RECOIL MOMENTUM

γ → ANGLE BETWEEN $\vec{p}'$ AND $\vec{q}$

ϕ → ANGLE BETWEEN THE ELECTRON SCATTERING PLANE AND THE REACTION PLANE

$$E_m = M^*_{A-1} + m - M_A = \omega - T_{p'} - T_R$$

IS THE MISSING ENERGY
OR REMOVAL, OR SEPARATION ENERGY

$\vec{q}, \omega, \vec{p}_R, E_m$

ARE COMPLETELY DETERMINED

BY THE EXPERIMENT

ee'p CROSS-SECTION
1st BORN APPROXIMATION

NO ELECTRON DISTORTION

$$\frac{d^6\sigma}{d\varepsilon' \, d\Omega_{e'} \, dT_{p'} \, d\Omega_{p'}} = \Gamma \, \sigma_\gamma$$

Γ : VIRTUAL PHOTON FLUX

$$\sigma_\gamma = \sigma_T + \varepsilon \, \sigma_L + \varepsilon \cos 2\phi \, \sigma_{TT} + [\varepsilon(\varepsilon+1)]^{1/2} \cos\phi \, \sigma_{TL}$$

TRANSVERSE (σ_T), LONGITUDINAL (σ_L), INTERFERENCE (σ_{TT}, σ_{TL})

$\varepsilon(\theta)$: ELECTRON POLARIZATION PARAMETER

$\varepsilon \to 1$ for $\theta \to 0°$ $\quad$ $\varepsilon \to 0$ for $\theta \to 180°$

σ_T, σ_L, σ_{TT}, σ_{TL} ARE FUNCTIONS OF ω, q, p', p_R,

IF THE PROTON IS EMITTED IN THE DIRECTION OF THE ELECTRON MOMENTUM TRANSFER

$$\sigma_{TT} = \sigma_{TL} = 0$$

$$\boxed{\sigma_\gamma = \sigma_T + \varepsilon(\theta)\,\sigma_L}$$

INCLUSIVE EXPERIMENT

WE DETECT ONLY THE SCATTERED ELECTR

$$S_L = \int \sigma_L \, d\vec{p}' \, dE_m$$

$$S_T = \int \sigma_T \, d\vec{p}' \, dE_m$$

$$\int \cos\phi = \int \cos 2\phi = 0$$

NO MORE INTERFERENCE TERMS

$$\frac{d^3\sigma}{d\epsilon' \, d\Omega_{e'}} = \Gamma \left(S_T + \varepsilon(\theta) S_L \right)$$

INSTEAD OF S_L AND S_T
IT IS OFTEN USED :

$$R_L = \frac{q^2}{4\pi^2 \alpha q_\gamma^2} S_L$$

$$R_T = \frac{q}{2\pi^2 \alpha} S_T$$

WE CAN DEFINE REDUCED RESPONSES

$$\tilde{R}_L = \frac{1}{Z} \frac{q_\mu^4}{q^4} R_L \qquad \tilde{R}_T = \frac{2M^2}{q^2} \frac{1}{Z\mu_p^2 + N\mu_N^2}$$

FOR INDEPENDENT PARTICLE MODE LIKE FERMI GAS MODEL AND NUCLEONIC DEGREES OF FREEDOM

$$\tilde{R}_L \equiv \tilde{R}_T$$

LONGITUDINAL SUM RULE

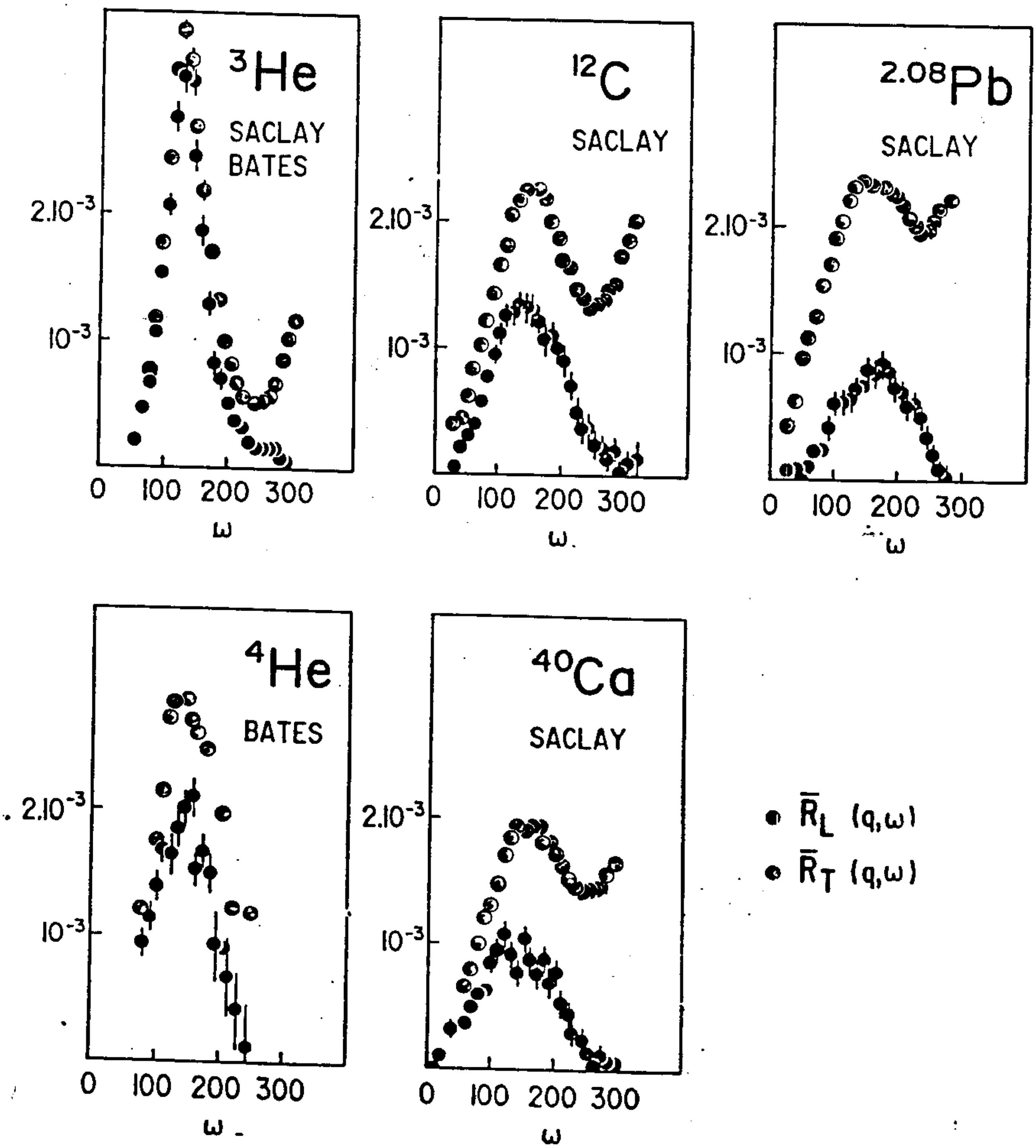
$$S_L(q) = \frac{1}{Z} \int \frac{R_L(q,\omega)}{G_E^2} d\omega$$

$$S_L(q) = 1 - C(q)$$

↑ TWO BODY CORRELATIONS

REDUCED RESPONSE FUNCTIONS

$q = 500 MeV/c$

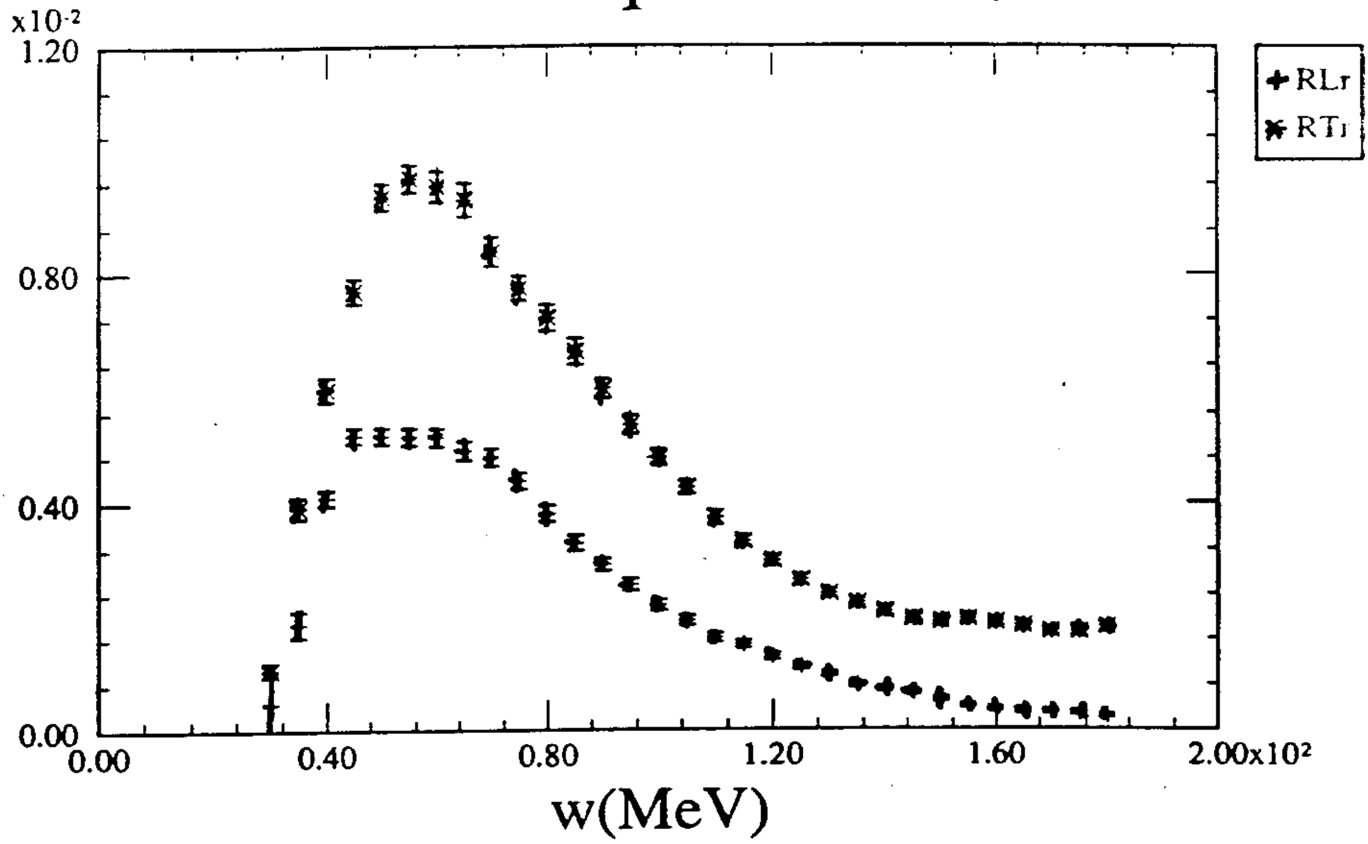


^4He (ee')

SACLAY

J.F. DANEL et al

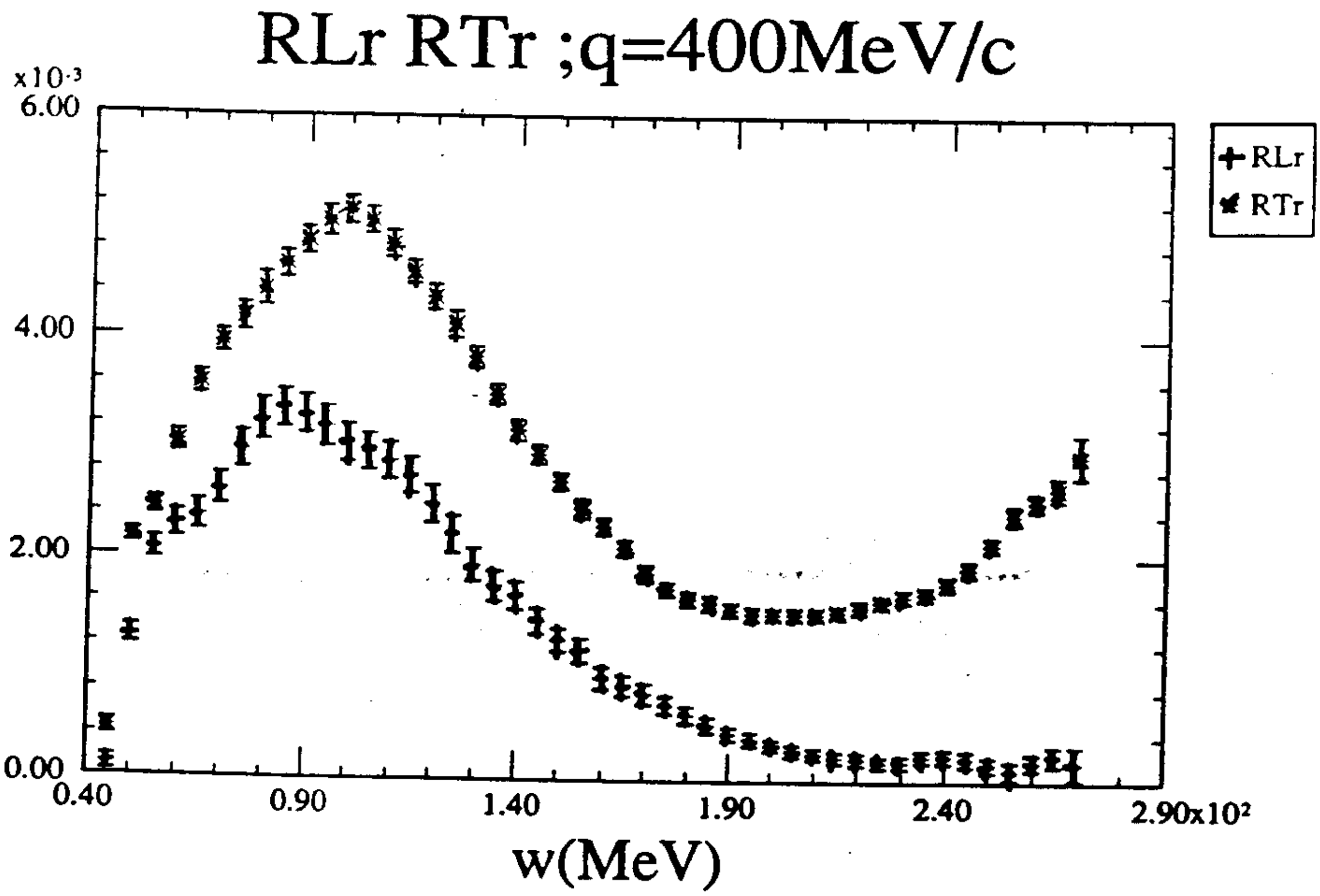
RLr RTr :q=300MeV/c



^4He (ee')

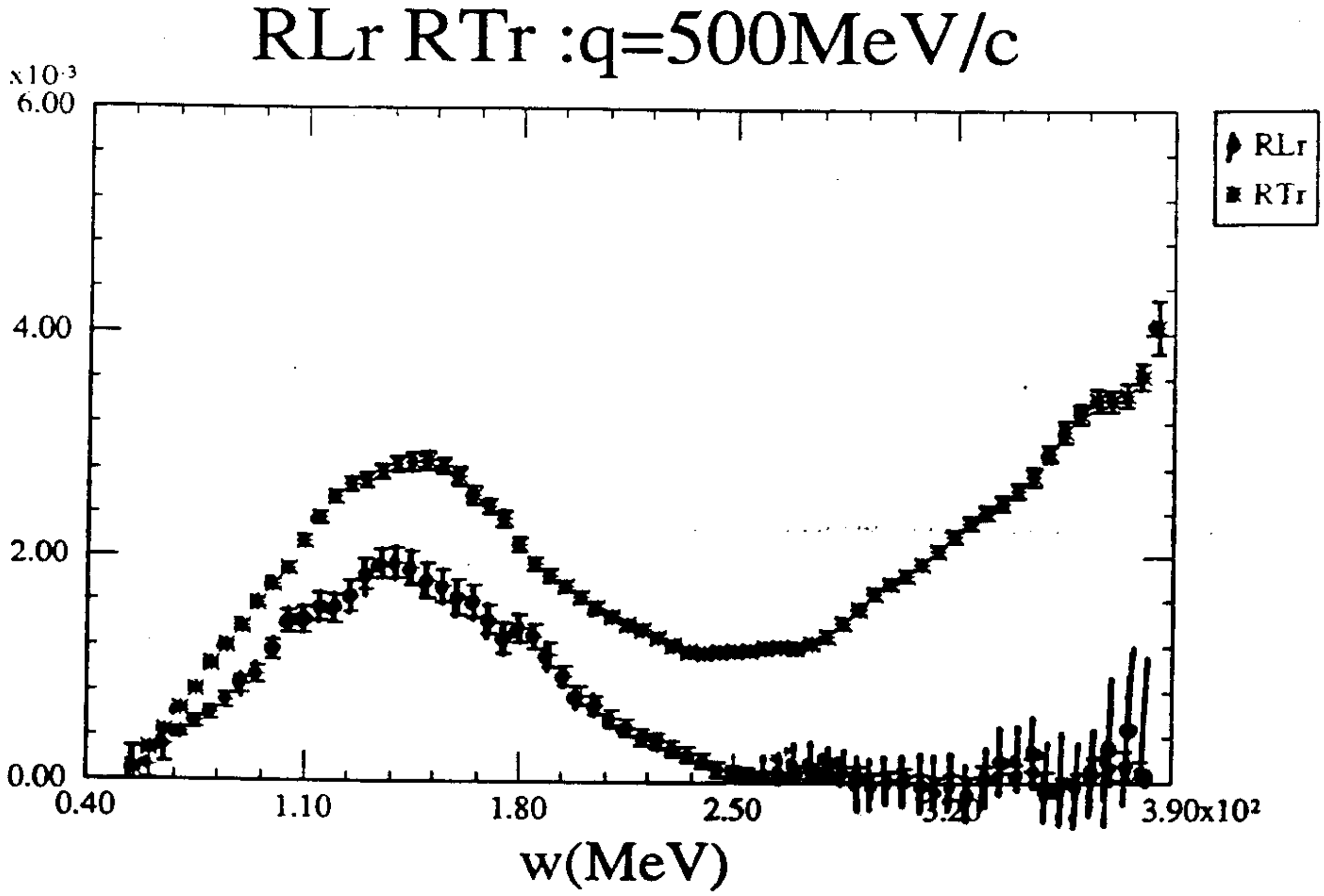
SACLAY

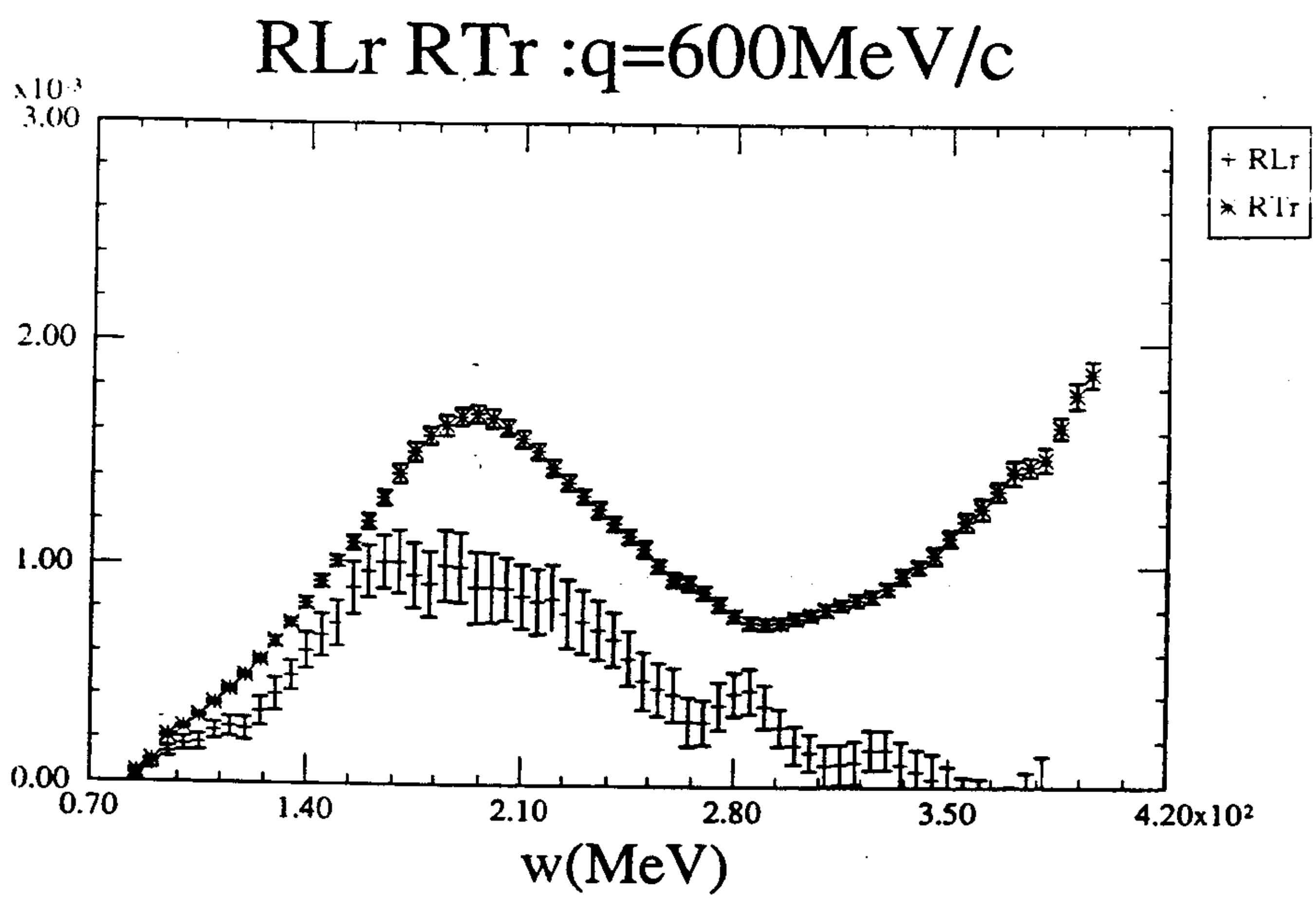
J.F. DANEL et al



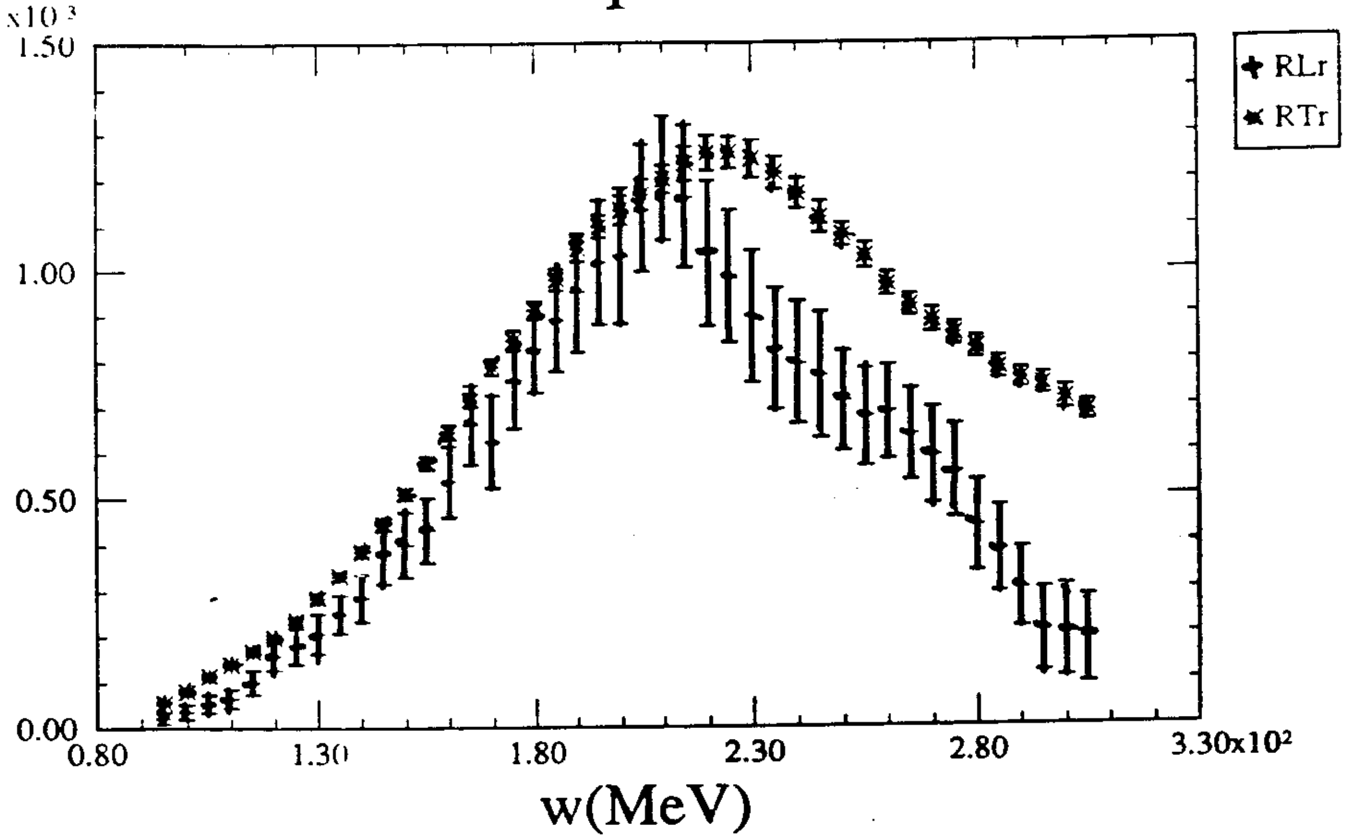
^{4}He (ee')

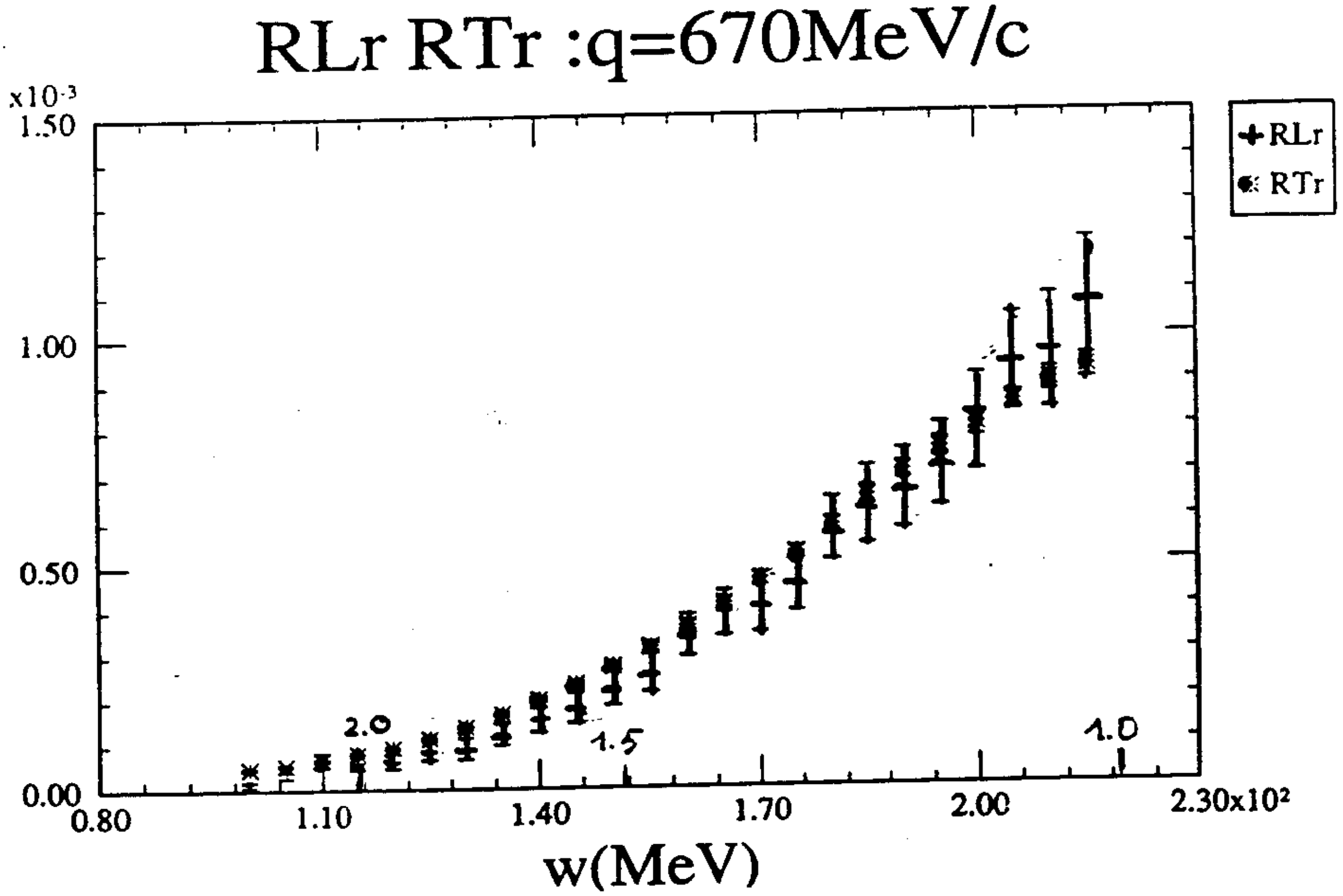
SACLAY
J.-F. DANEL et al.



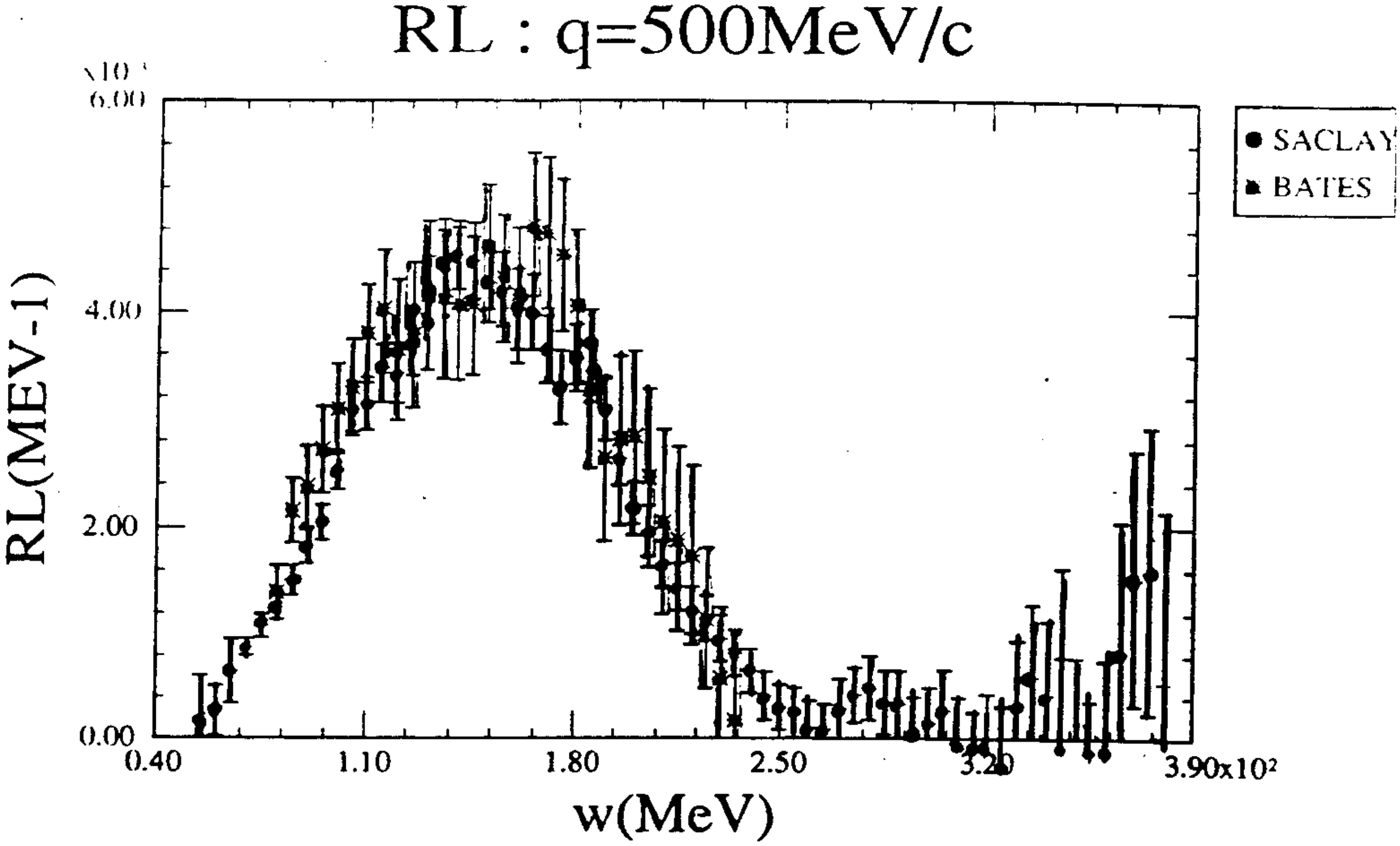

RLr RTr :q=600MeV/c
x10⁻³
3.00
2.00
1.00
0.00
0.70
1.40
2.10
2.80
3.50
4.20x10²
w(MeV)
+ RLr
* RTr

RLr RTr :q=640MeV/c




RLr RTr :q=670MeV/c
x10-3
1.50
1.00
0.50
0.00
0.80
1.10
1.40
1.70
2.00
2.30x10²
w(MeV)
RLr
RTr
2.0
1.5
1.0

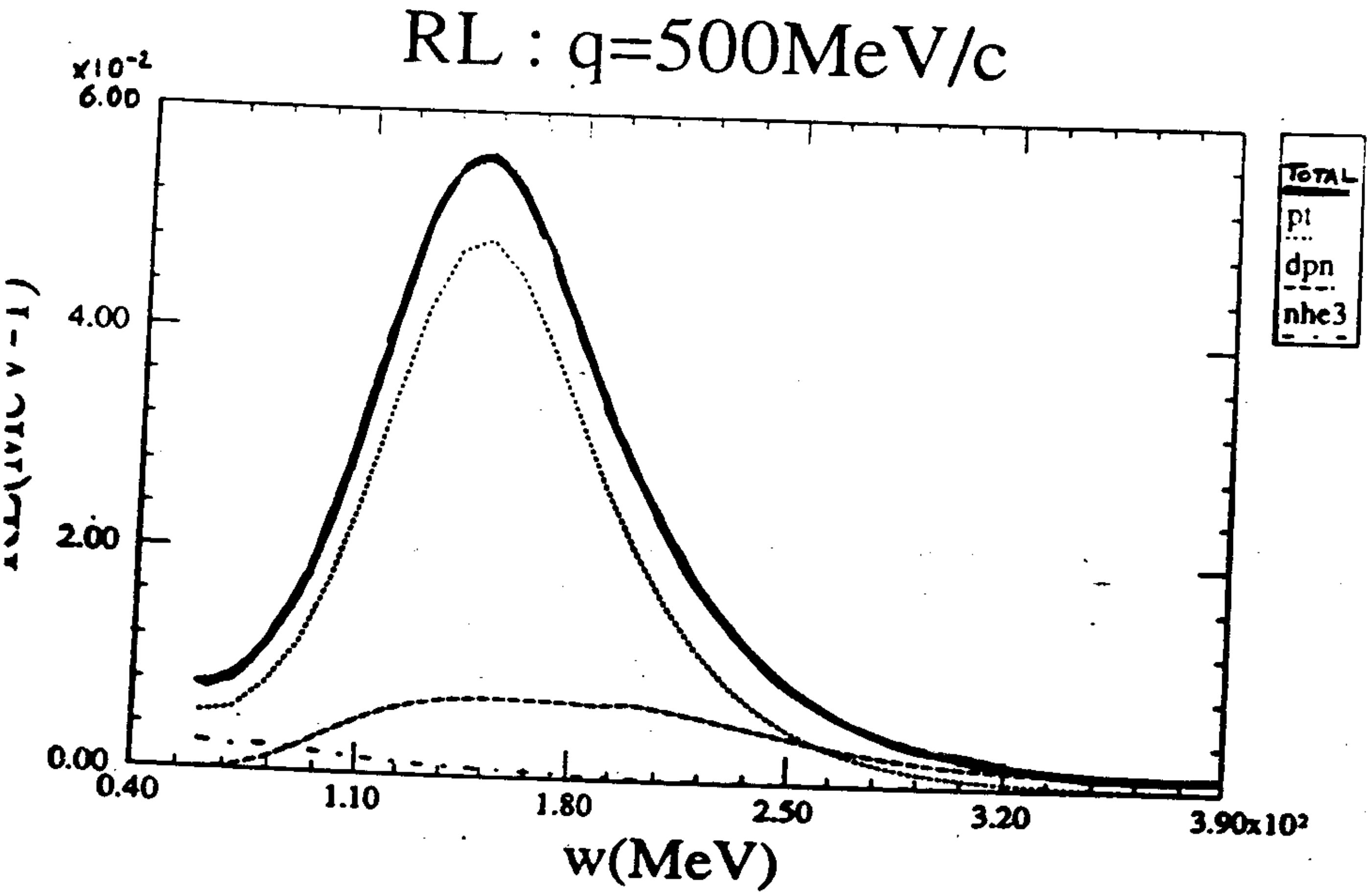
$^4He\,(e\,e')$



RL : q=500MeV/c
x10⁻³
6.00
4.00
2.00
0.00
RL(MEV-1)
0.40
1.10
1.80
2.50
3.20
3.90x10²
w(MeV)
SACLAY
BATES

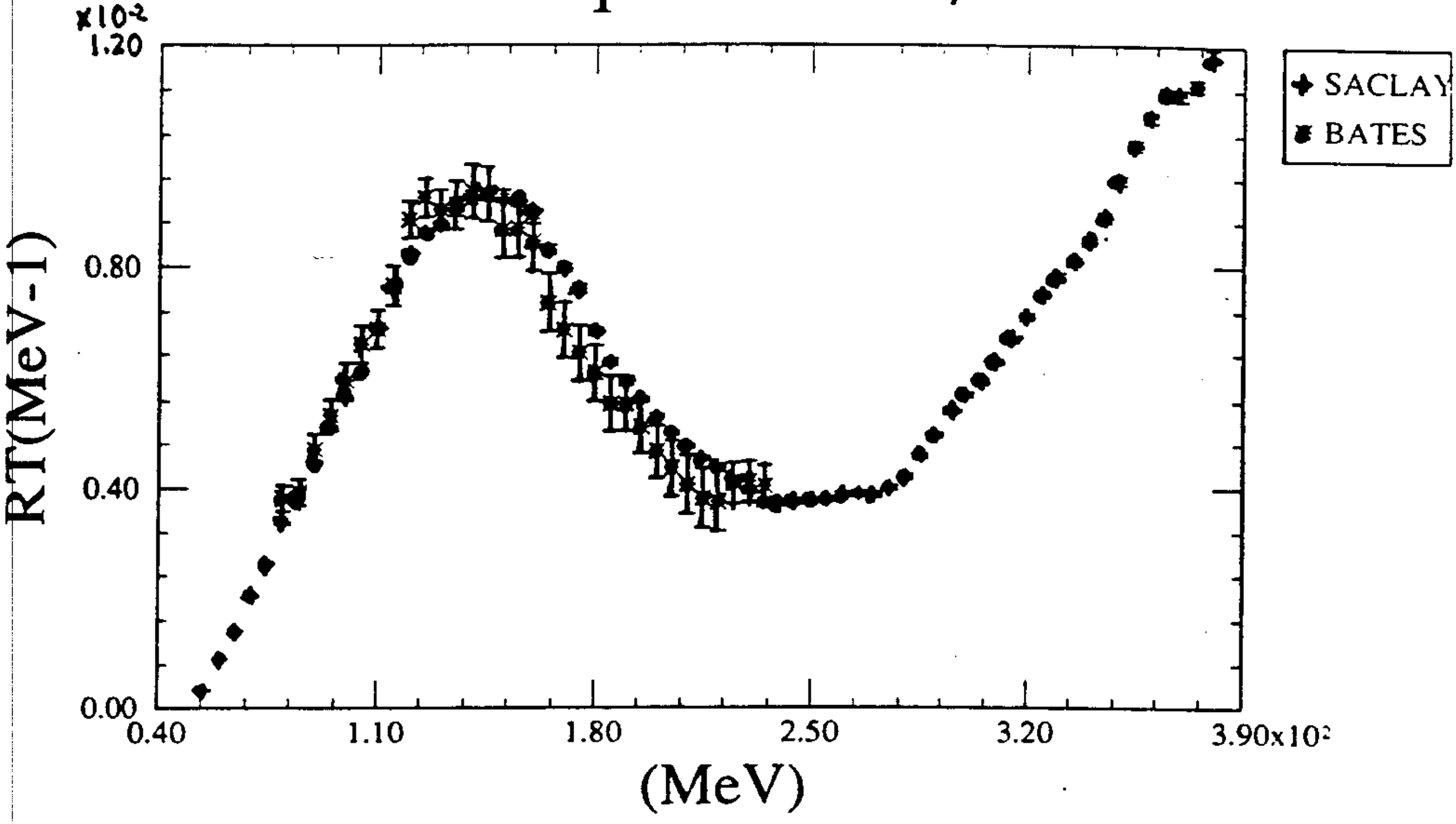
$^4He\ (ee')$

J.M. LAGET CALCULATIONS



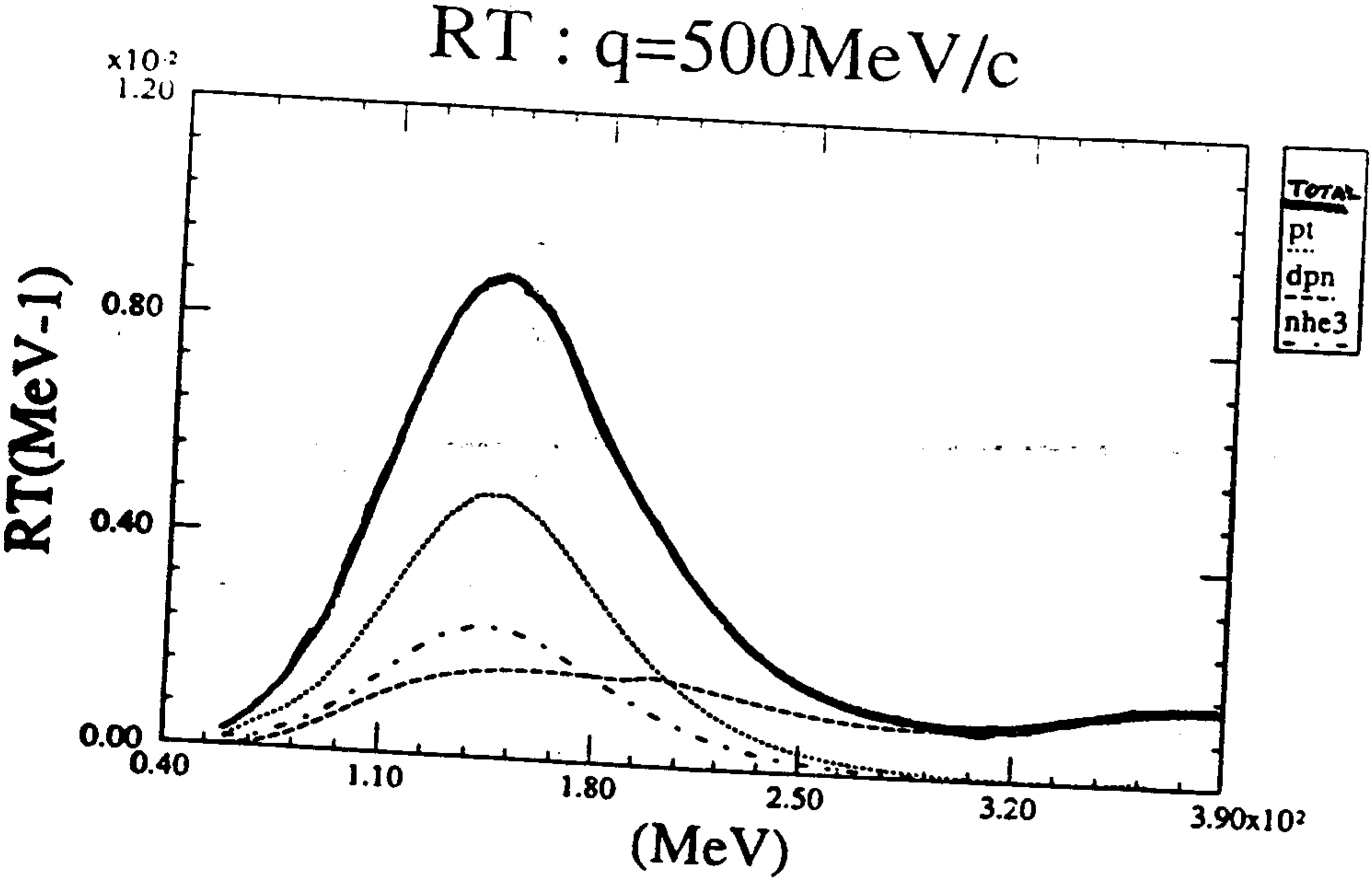
^{4}He (ee')

RT : q=500MeV/c



^4He (ee')

J.M. LAGET CALCULATIONS



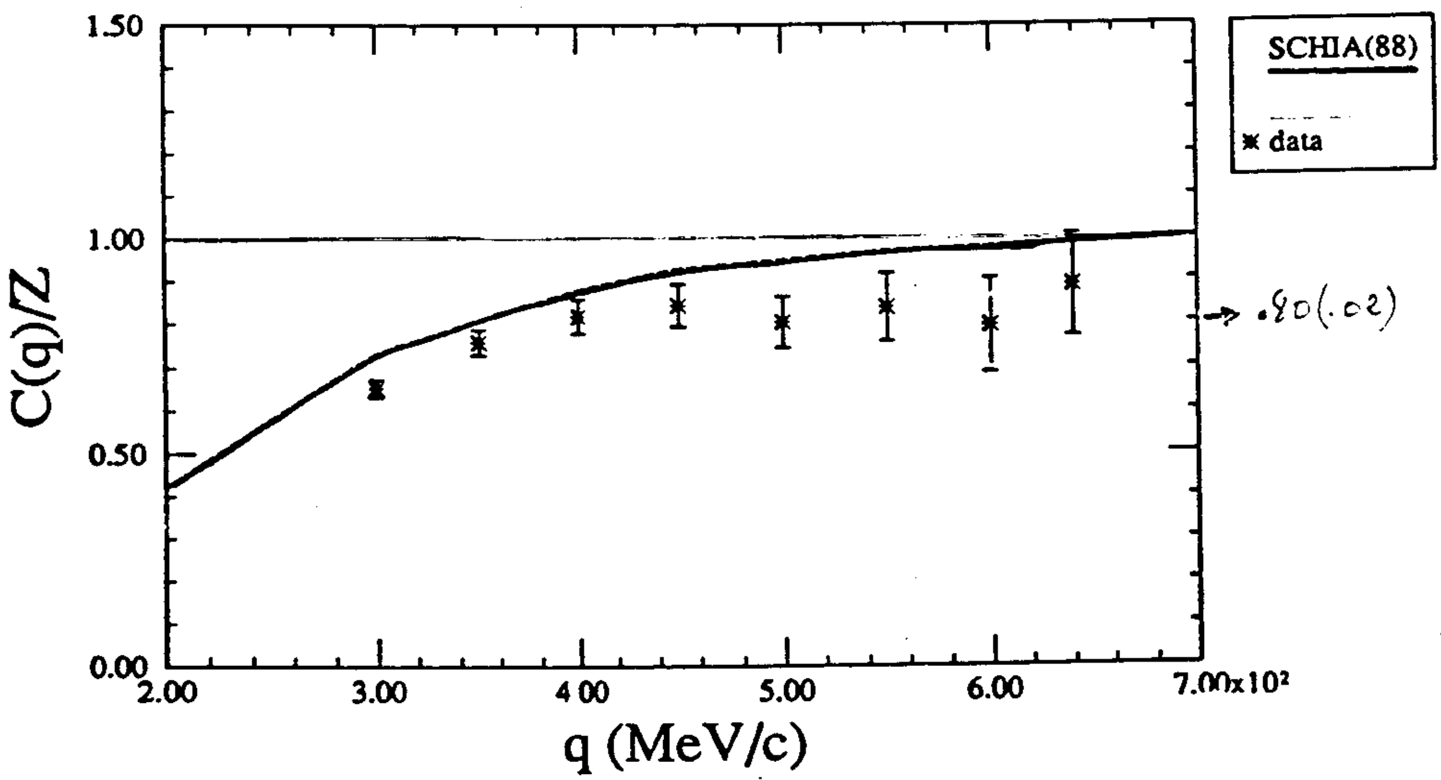
RÈGLE DE SOMME

COULOMBIENNE

$$C(|\vec{q}|) = \int_{\omega > \omega_{elas}} d\omega \; \frac{R_L(|\vec{q}|, \omega)}{\tilde{G}_E^2}$$

$\tilde{G}_E = G_E$ [illegible] / [illegible]

: facteur de forme électrique du nucléon libre (Simon et al)



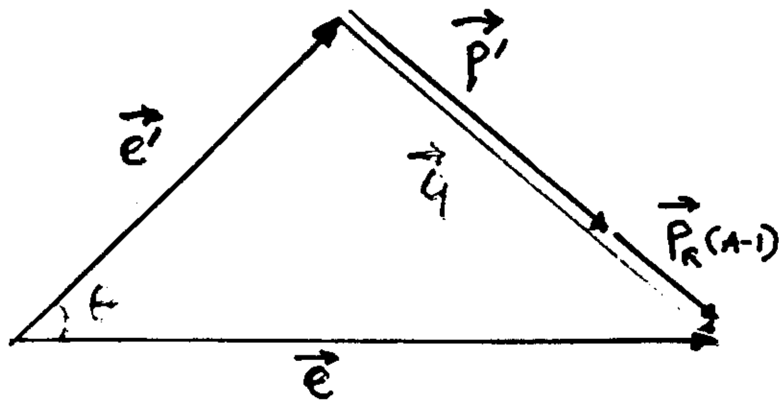
IN INCLUSIVE EXPERIMENTS, WE AVERAGE OVER THE MOMENTUM AND THE SEPARATION ENERGY OF THE NUCLEON.

ON THE OTHER HAND, EVEN IF THE SINGLE NUCLEON KNOCK-OUT, DOMINATES, WE ARE MIXING OTHER CHANNELS.

TO BE MORE SPECIFIC WE HAVE DONE EE'P EXPERIMENTS WITH SEPARATION OF THE DIFFERENT STRUCTURE FUNCTIONS TO SELECT THE ONE SINGLE PROTON KNOCK-OUT.

IN SUCH EXPERIMENT, WE MAKE THIS SEPARATION FOR A GIVEN REMOVAL ENERGY AND A GIVEN MOMENTUM OF THE PROTON.

IN THIS EXPERIMENT, WE DETECT THE PROTON IN THE DIRECTION OF THE ELECTRON MOMENTUM TRANSFER



THE CROSS-SECTION IS GIVEN BY:
(1st BORN APPROXIMATION).

$$\frac{d^6\sigma}{d\varepsilon' \, d\Omega_{e'} \, dT_{p'} \, d\Omega_{p'}} = \Gamma \left[\sigma_T(q, \omega, p', p_R) + \varepsilon(\theta) \, \sigma_L(q, \omega, p', p_R) \right]$$

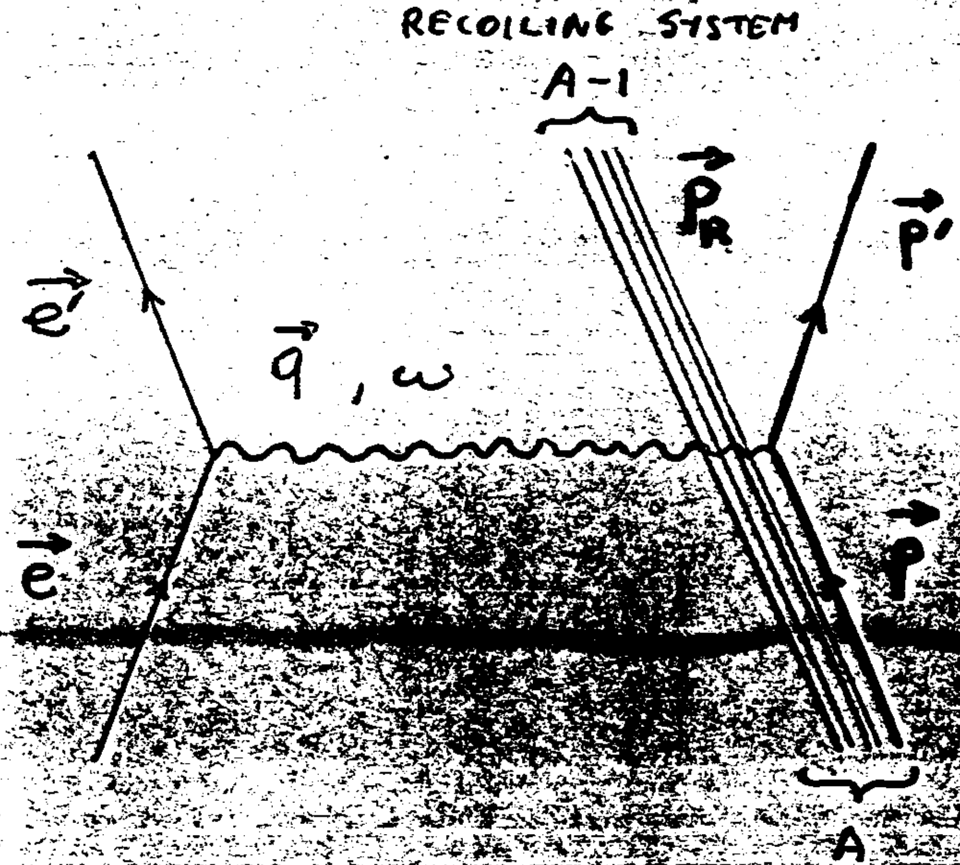
TRANSVERSE RESPONSE

LONGITUDINAL (COULOMB) RESPONSE

Γ : VIRTUAL PHOTON FLUX

$\varepsilon(\theta)$: ELECTRON POLARIZATION PARAMETER

PLANE WAVE IMPULSE APPROXIMATION P.W.I.A.



THE VIRTUAL PHOTON IS ABSORBED BY A SINGLE NUCLEON IN A NUCLEUS WITH MASS A. THE REMAINING SYSTEM WITH MASS A-1 IS SPECTATOR AND RECOILS WITH A MOMENTUM

$$\vec{P}_R = -\vec{p}$$

P. W. I. A.

WE CAN EXPRESS THE ELECTRON – [illegible] CROSS SECTION BY AN EXPRESSION SIMILAR TO THE ELECTRON – NUCLEUS CROSS SECTION

$$\sigma^{ep} = \Gamma \left[\sigma_T^{ep} + \varepsilon \, \sigma_L^{ep} \right]$$

IN P.W.I.A. THE ELECTRON – NUCLEU[S] CROSS – SECTION FACTORIZES:

$$\frac{d^6\sigma}{d\epsilon' d\Omega_e' \, dT_{p'} d\Omega_{p'}} = \sigma^{ep} \times S(E_m, \vec{p})$$

WHERE $S(E_m, \vec{p})$ IS THE SPECTRAL FUNCTI[ON] WHICH GIVES THE PROBABILITY TO FIN[D] A PROTON WITH A MOMENTUM $\vec{p}$ AND A SEPARATION ENERGY E_m IN THE INITIAL NUCLEUS

P. W. I A. IMPLIES :

$$\frac{\sigma_L}{\sigma_L^{ep}} = S_L^{EXP} = \frac{\sigma_T}{\sigma_T^{ep}} = S_T^{EXP} = S(E_m, p)$$

CORRECTIONS TO [illegible]

FOR LIGHT NUCLEI : D, T, ^3He, ^4He

F.S.I. AND E.C. CAN BE

CALCULATED MICROSCOPICALLY

SEE : LAGET, ARENHÖVEL, CIOFI, SCHIAVILLA, TJON ...

FOR MEDIUM AND HAVY NUCLEI,

F.S.I. ARE TAKEN INTO ACCOUNT

BY OPTICAL MODEL

SEE : BOFFI, GIUSTI, PACATI

ONE CAN DEFINE AN EXPERIMENTAL

SPECTRAL FUNCTION :

$$S^{exp} = \frac{\sigma^{exp}}{\sigma^{ep}}$$

FROM THEORETICAL CALCULATIONS

WITHOUT AND WITH F.S.I. AND E.C., WE GET

σ^{PWIA} AND σ^{th}

WE OBTAIN THE CORRECTED

SPECTRAL FUNCTION :

$$S^{CORR} = S^{EXP} \times \frac{\sigma^{PWIA}}{\sigma^{FULL}}$$

FOR EXPERIMENTS WHERE THE RESPONSE FUNCTIONS ARE SEPARATED, WE DEFINE

S_α^{exp}, S_α^{corr} WHERE $\alpha = L, T, LT, TT$

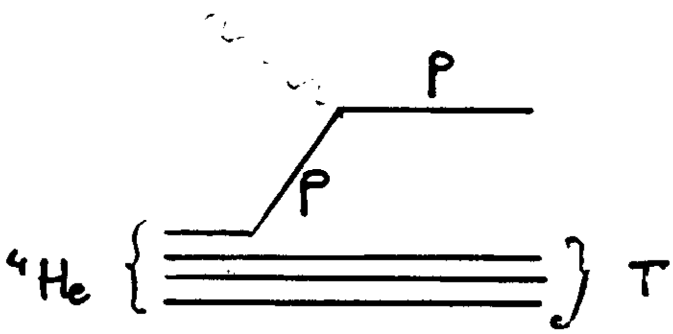
AND WE HAVE

$$S_\alpha^{corr} = S_\alpha^{exp} \times \frac{\sigma_\alpha^{PWIA}}{\sigma_\alpha^{FULL}}$$

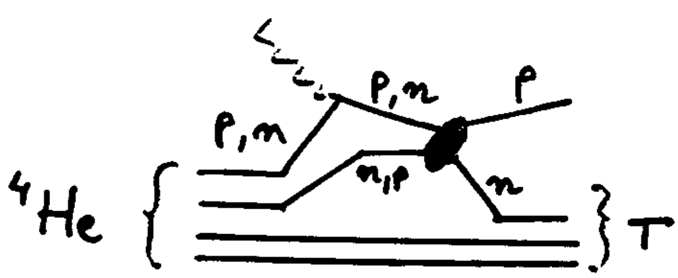
$^{4}He\ (ee'p)\ ^{3}H$

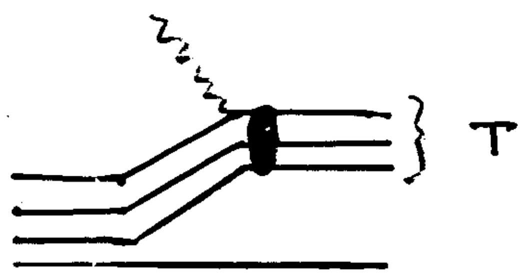
LAGET CALCULATIONS

IMPULSE APPROXIMATION

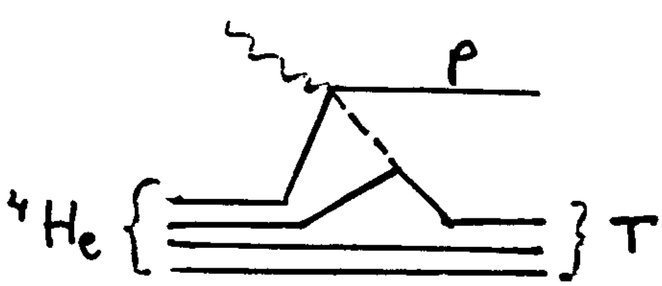


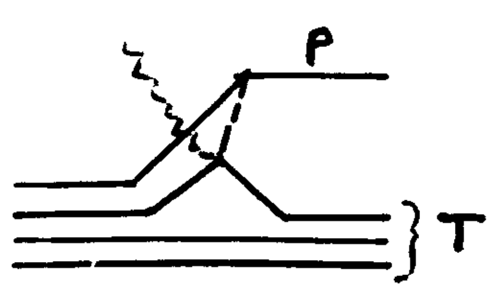
RESCATTERING





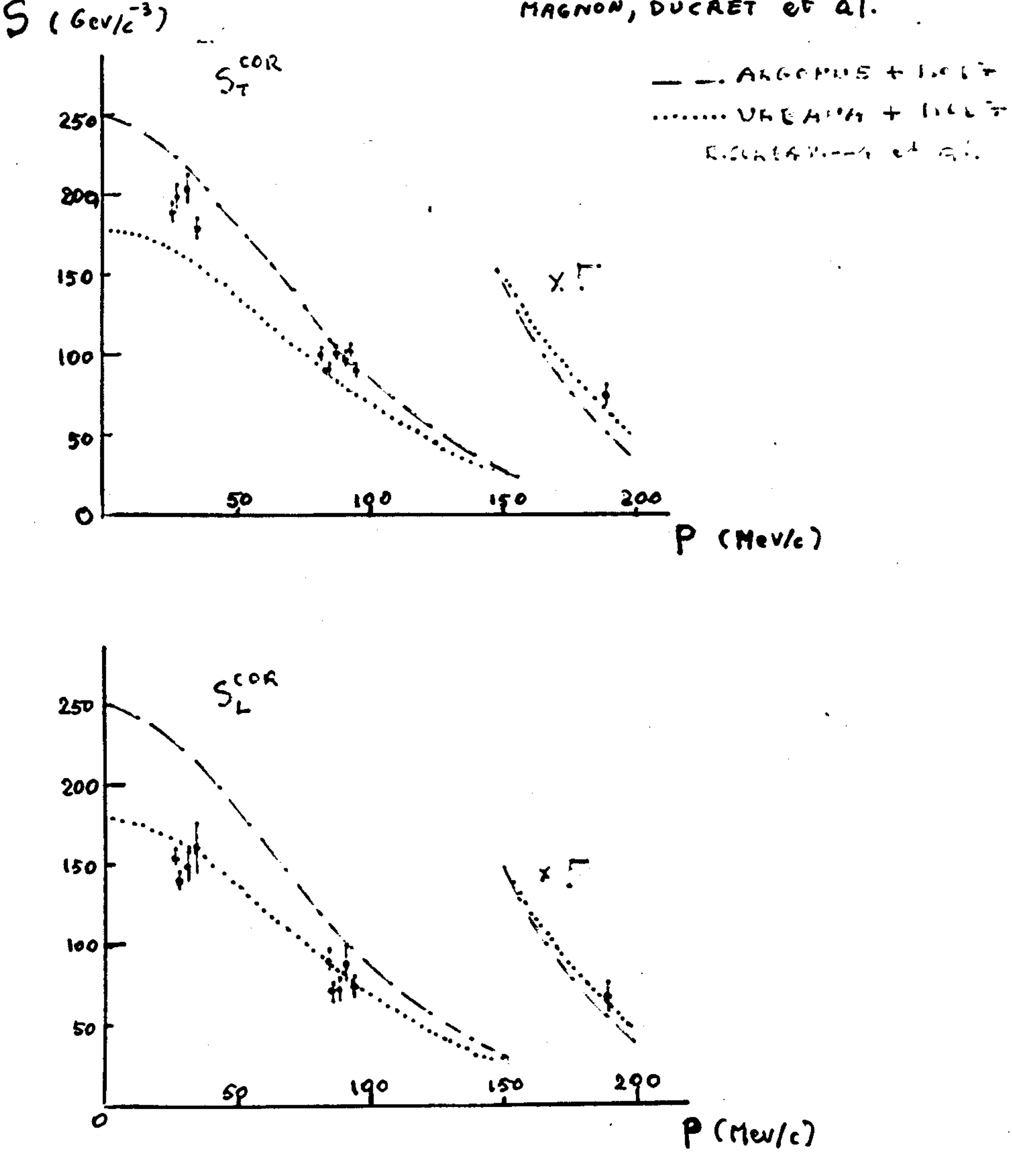
MESON EXCHANGE

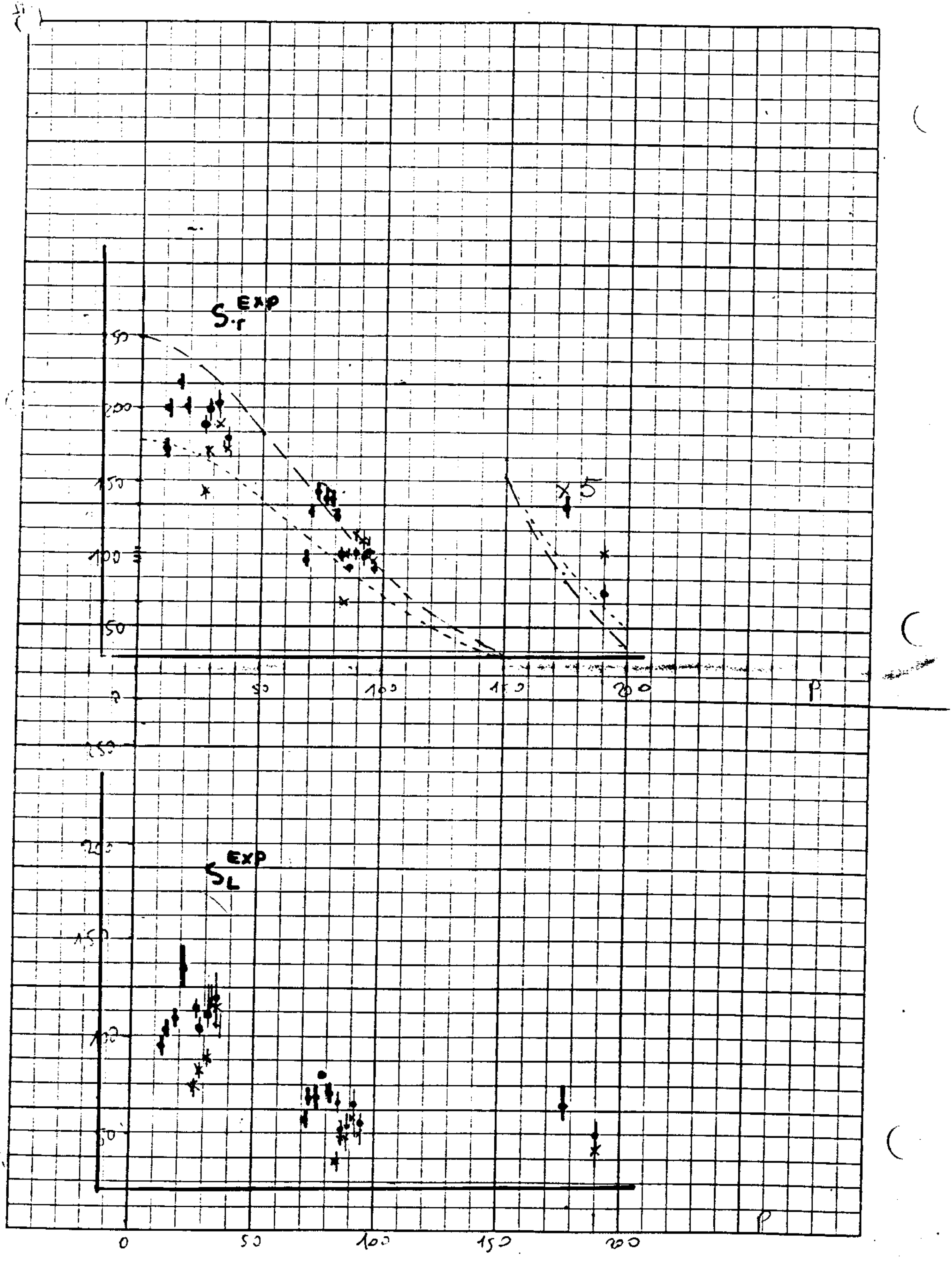




$^4He(ee'p)^3H$

SACLAY 1990
MAGNON, DUCRET et al.

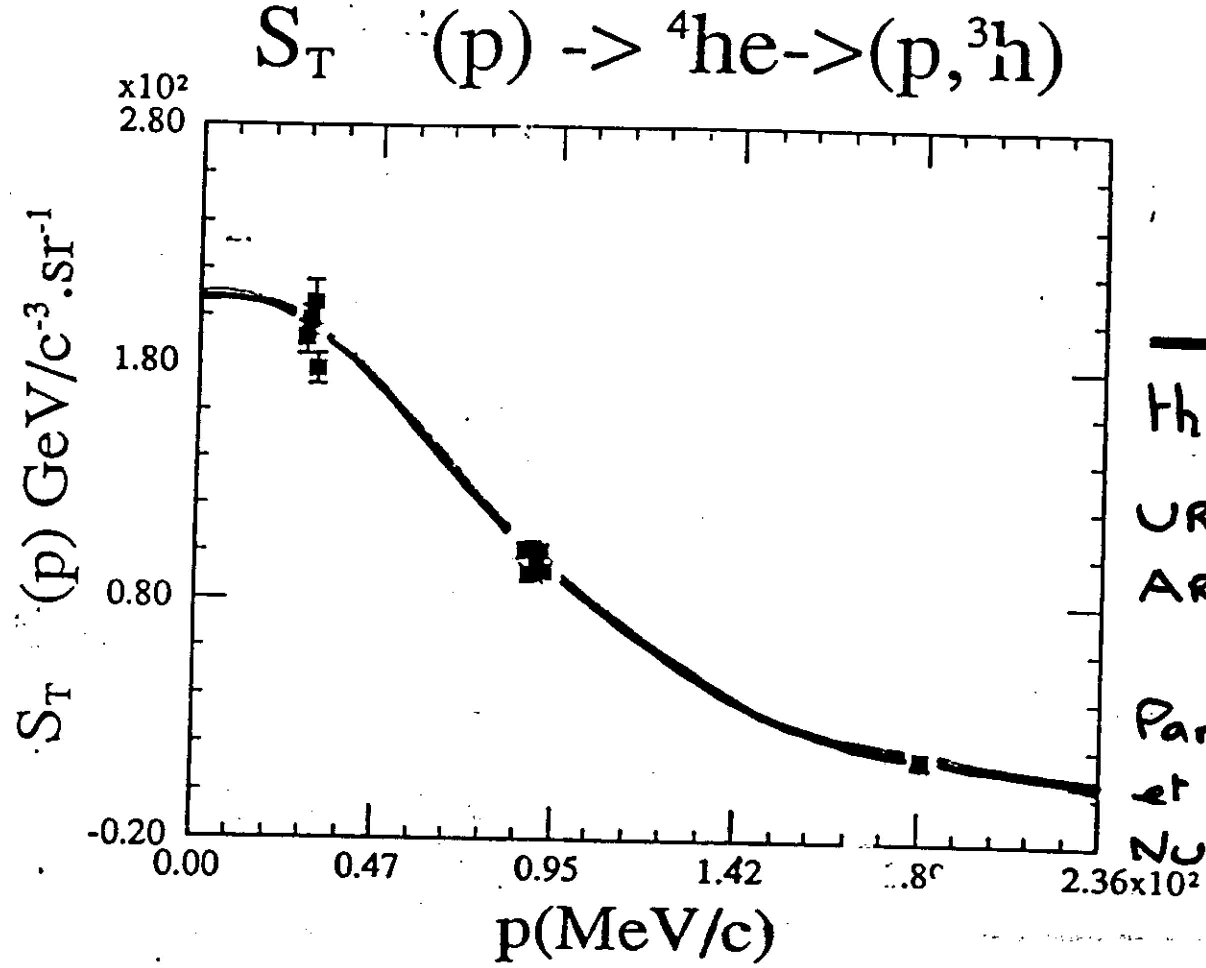



S_T^{EXP}
200
150
100
50
× 5
P
S_L^{EXP}
150
100
50
0
50
100
150
200
P

^4He RADIUS

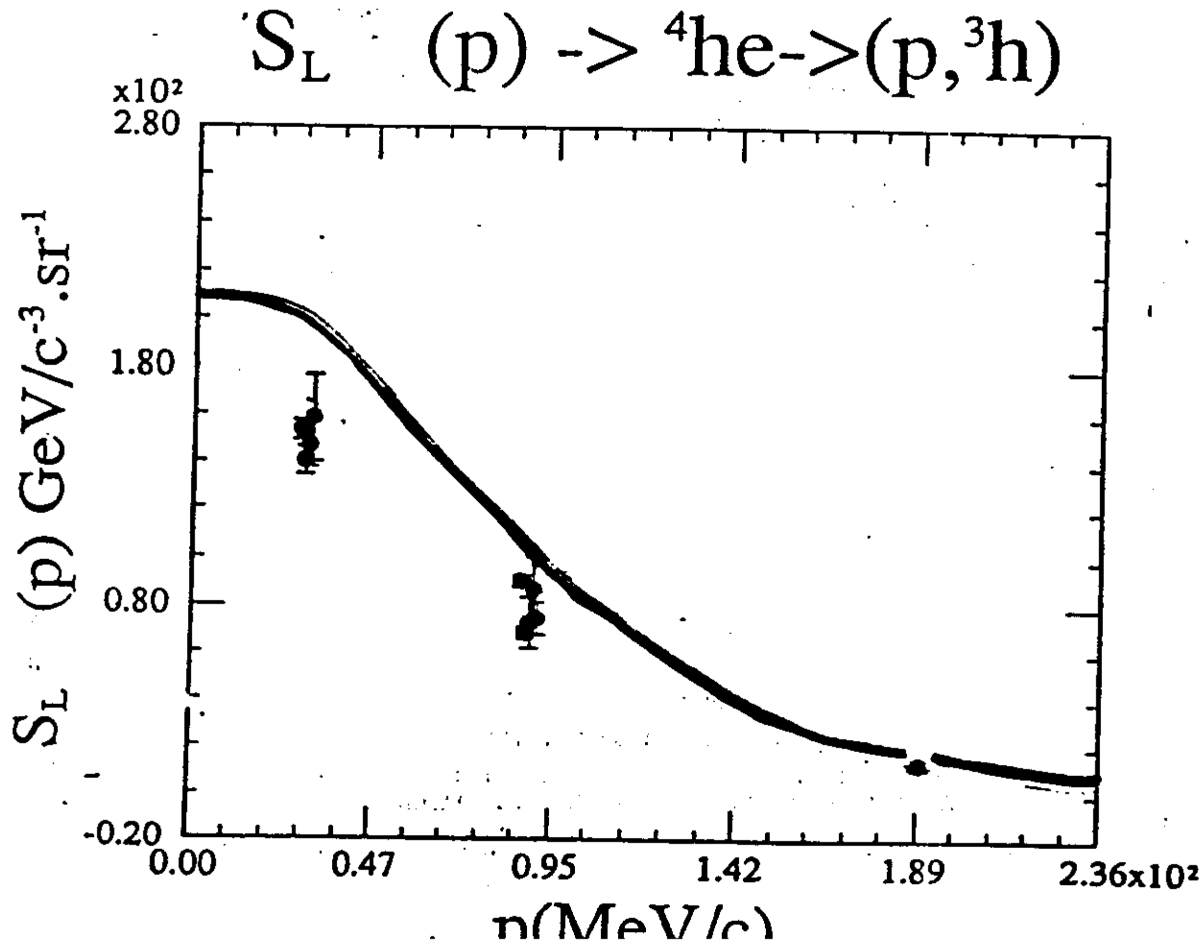
URBANA + MOD 7	1.62 fm
ARGONNE + MOD 7	1.71 fm
EXPERIMENTAL VALUE	1.67 fm

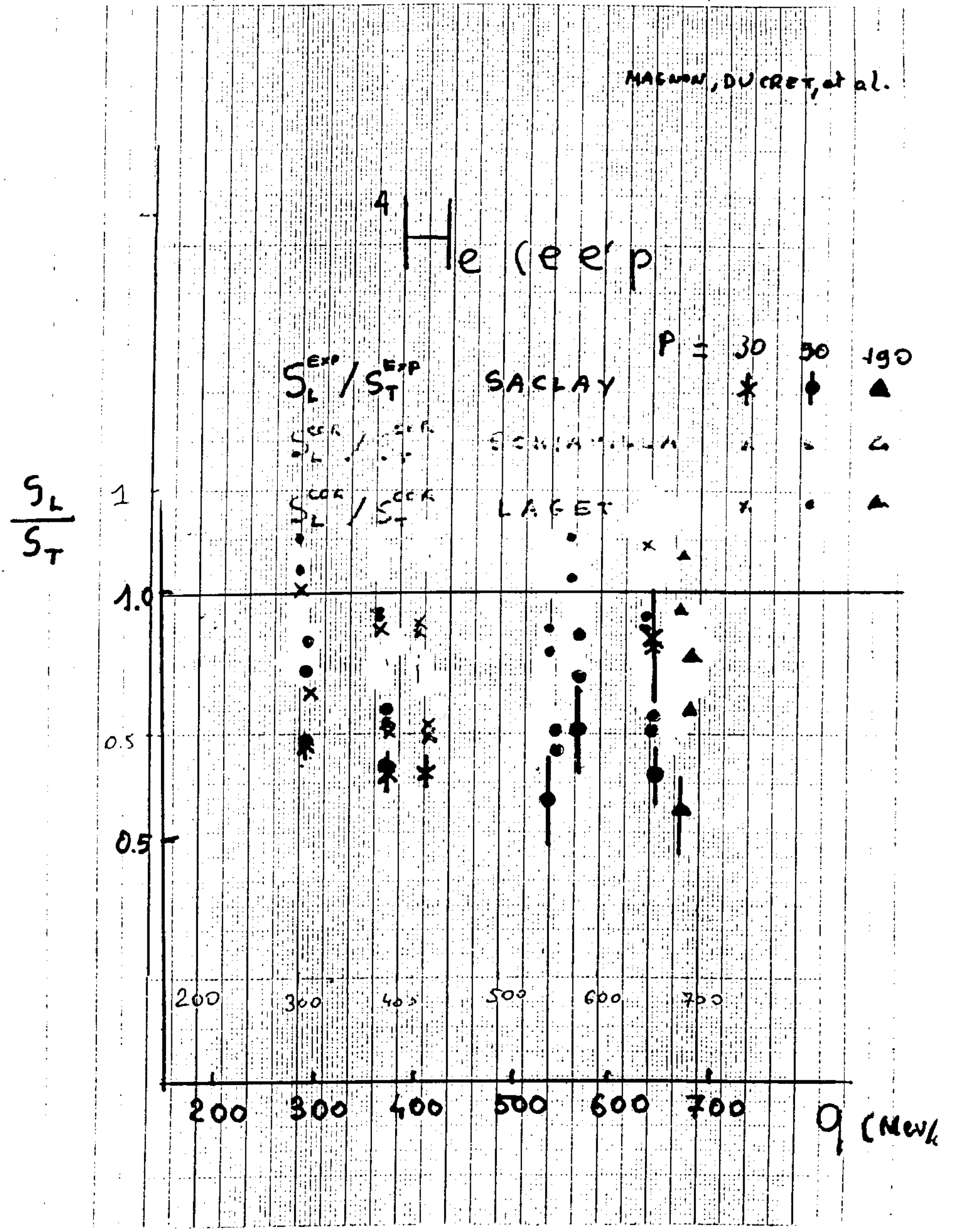
A. Magnon et al PHYS LETT B222 (1989)
J.E Ducret



théorie
URBANA/
ARGONNE

Pandharipande et al.
Nucl Phys A449 (1986)



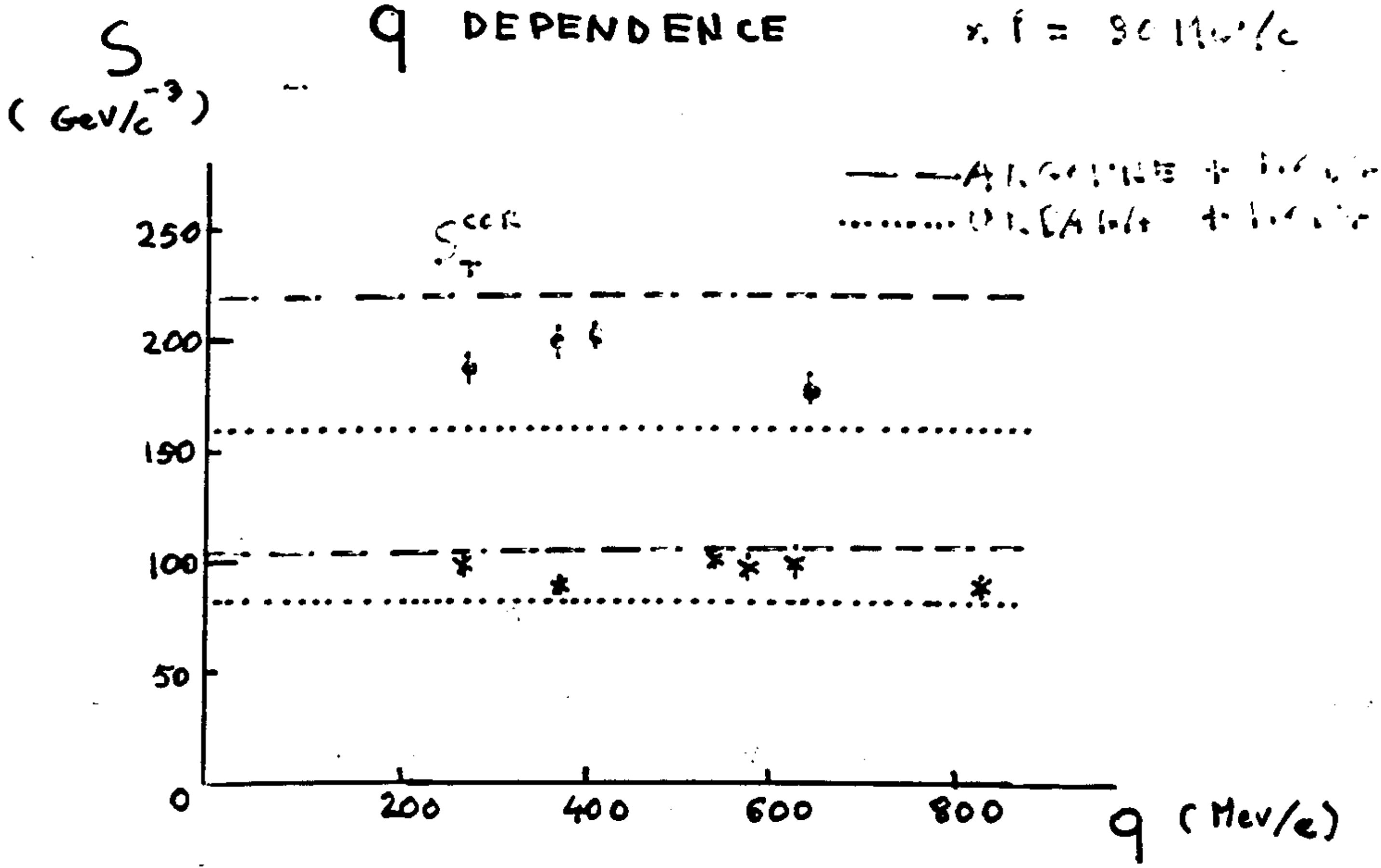

MAGNON, DUCRET, et al.
4He (e e' p)
P = 30 90 190
S_L^EXP / S_T^EXP SACLAY
S_L^CCK / S_T^CCK LAGET
S_L / S_T
1.0
0.5
200 300 400 500 600 700
q (MeV/c)

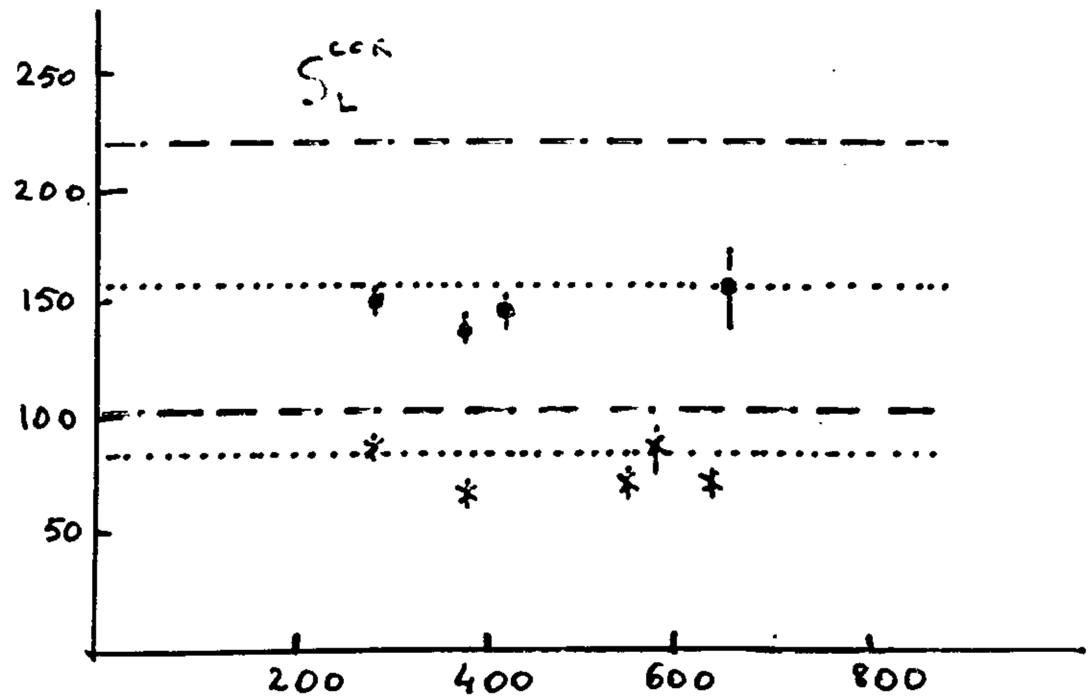
$^4He(ee'p)^3H$

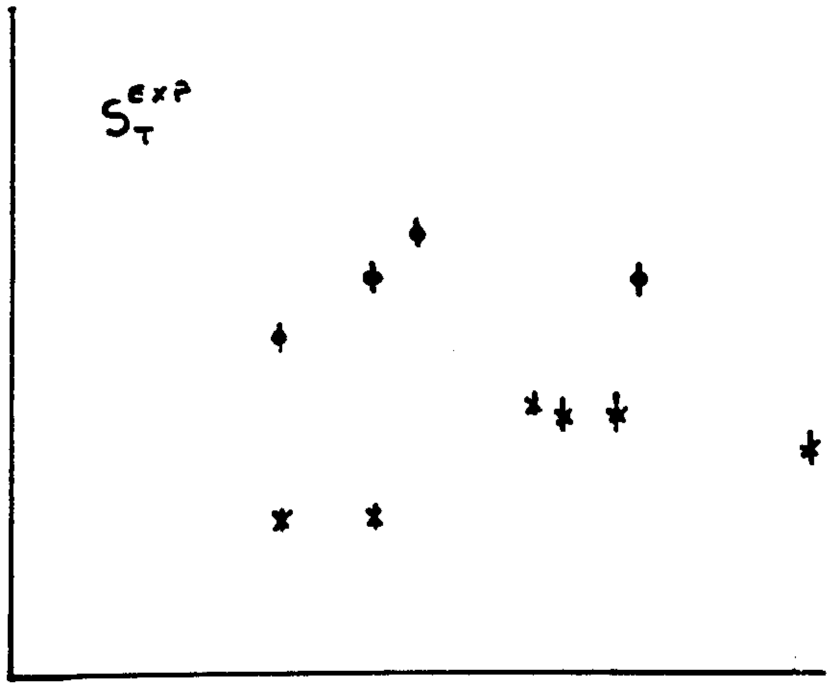
SACLAY 1990
MAGNON, DUCRET et al.

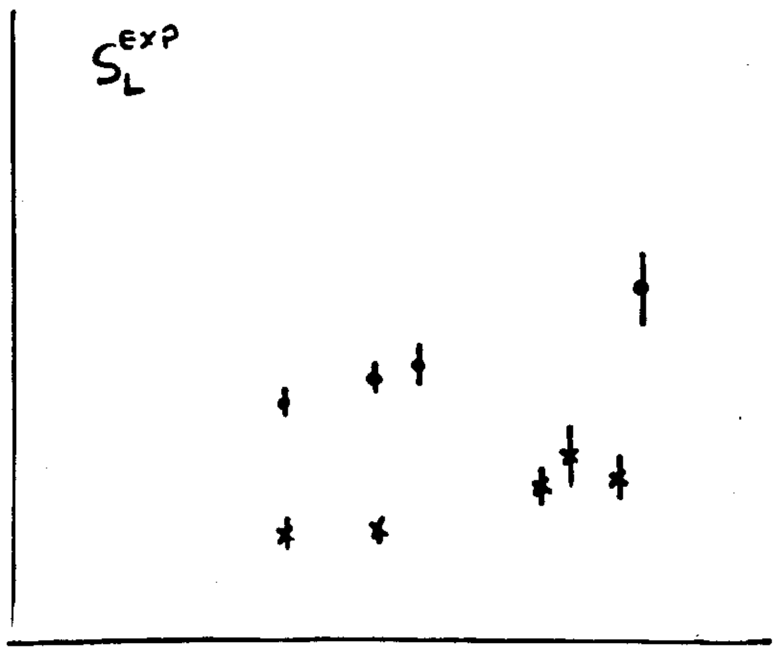
q DEPENDENCE

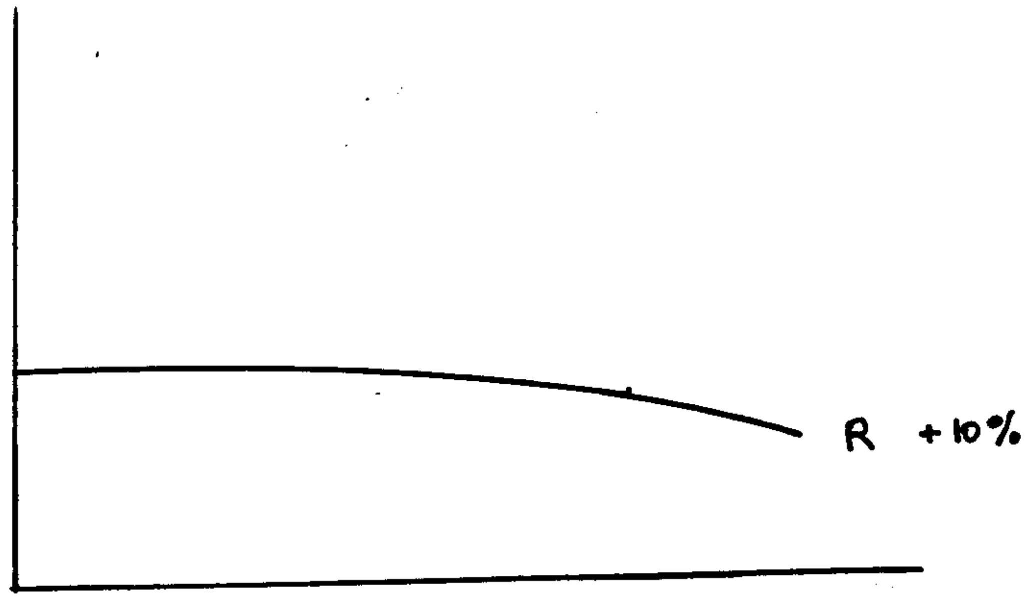
• p = 30 MeV/c
x. p = 90 MeV/c

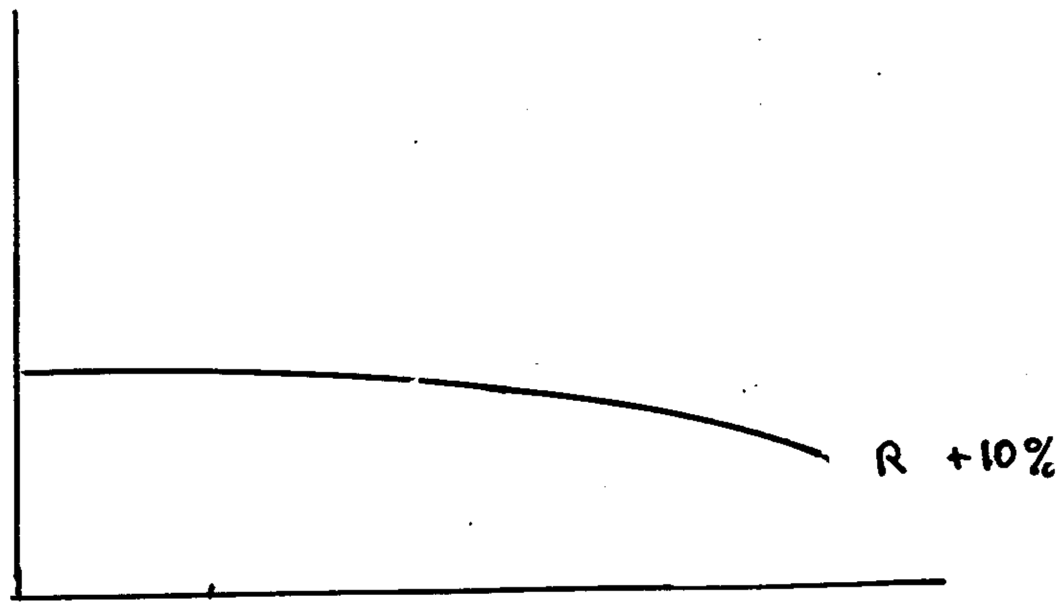





S_T^{exp}


S_L^{exp}

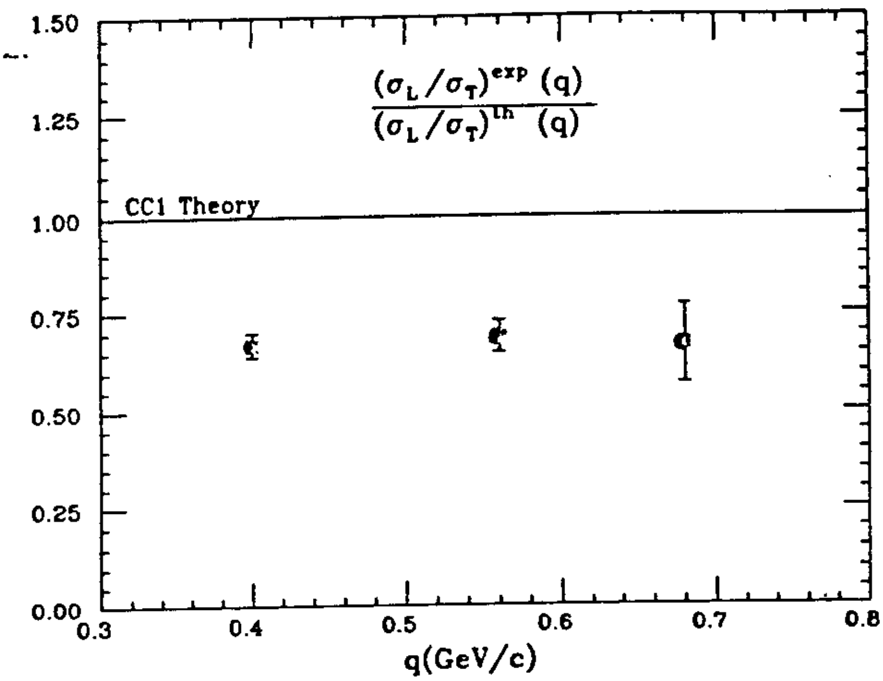

R +10%


R +10%

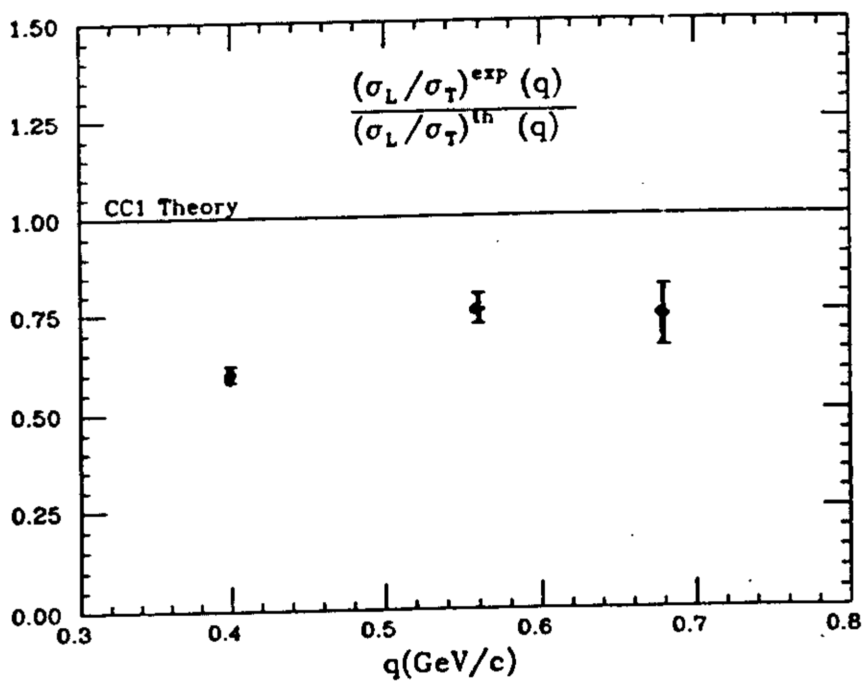
SACLAY EXPERIMENT

F. GHIO et al.

^{6}Li(e,e'p) – 1p Knockout



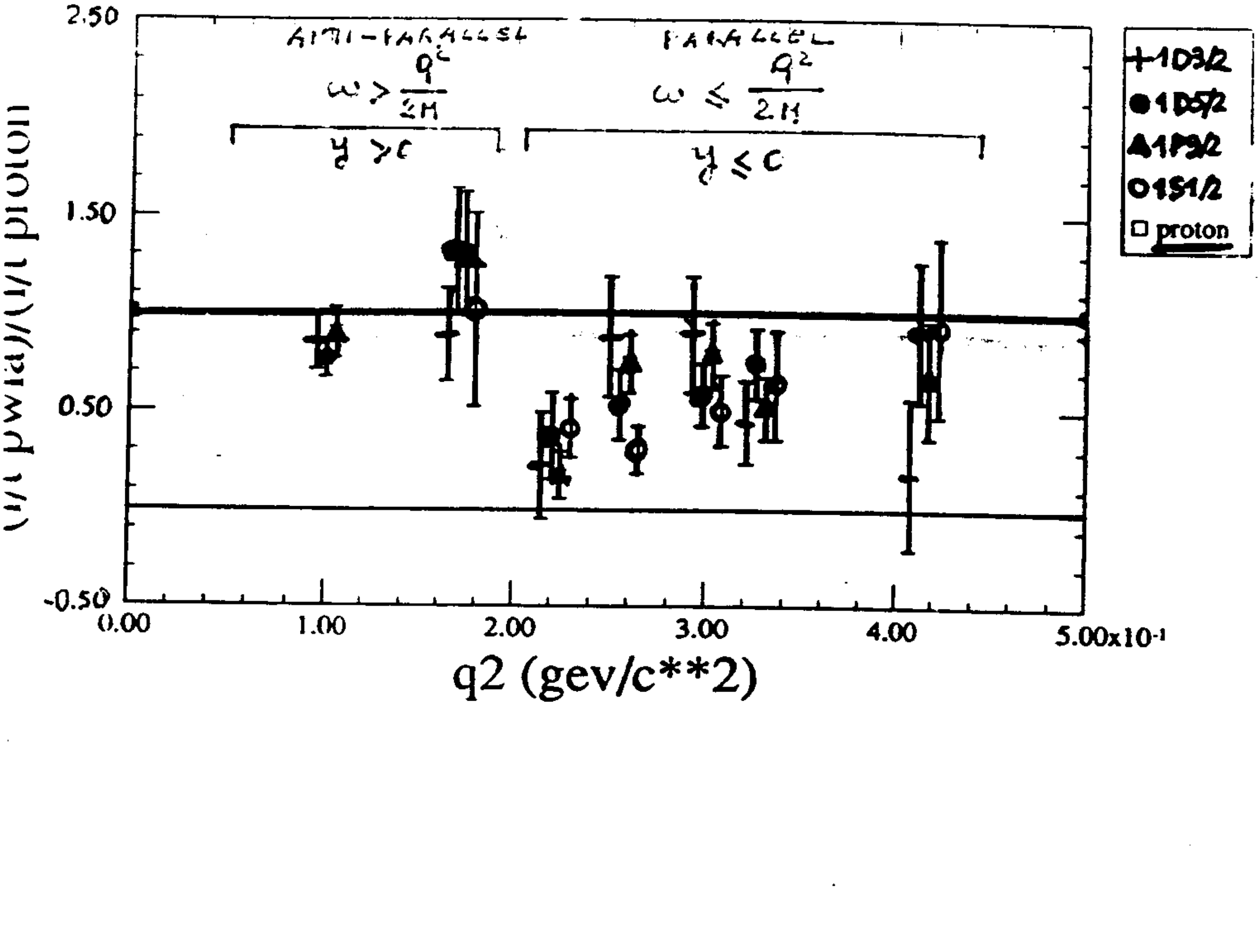
^{6}Li(e,e'p) – 1s Knockout



SACLAY

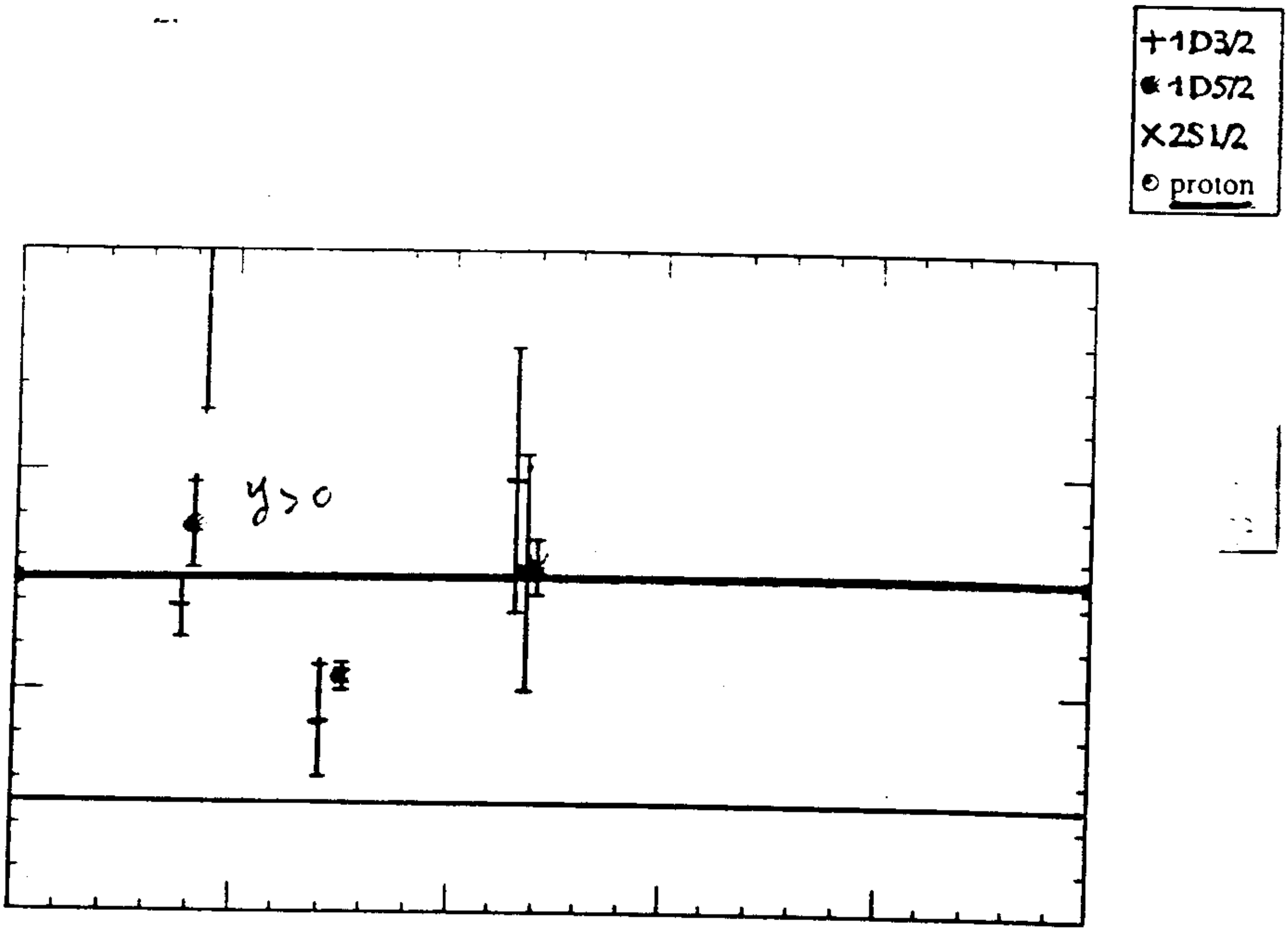
D. REFFAY-PIKEROEN et al.

40Ca lt separation



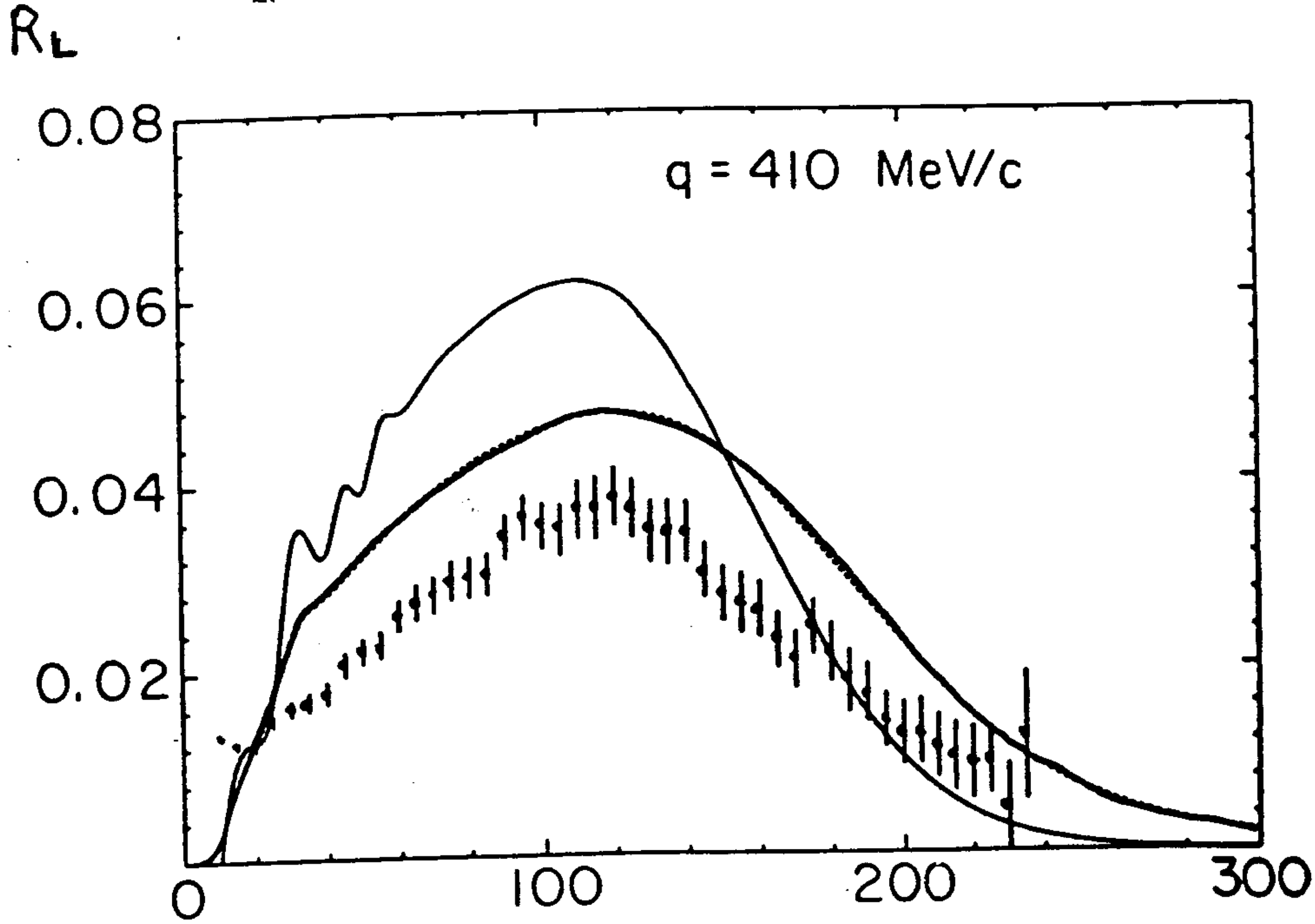
NIKHEF

H. J. BULTEN et al.



^{40}Ca (ee')

LONGITUDINAL RESPONSE



⸸ SACLAY EXPERIMENT

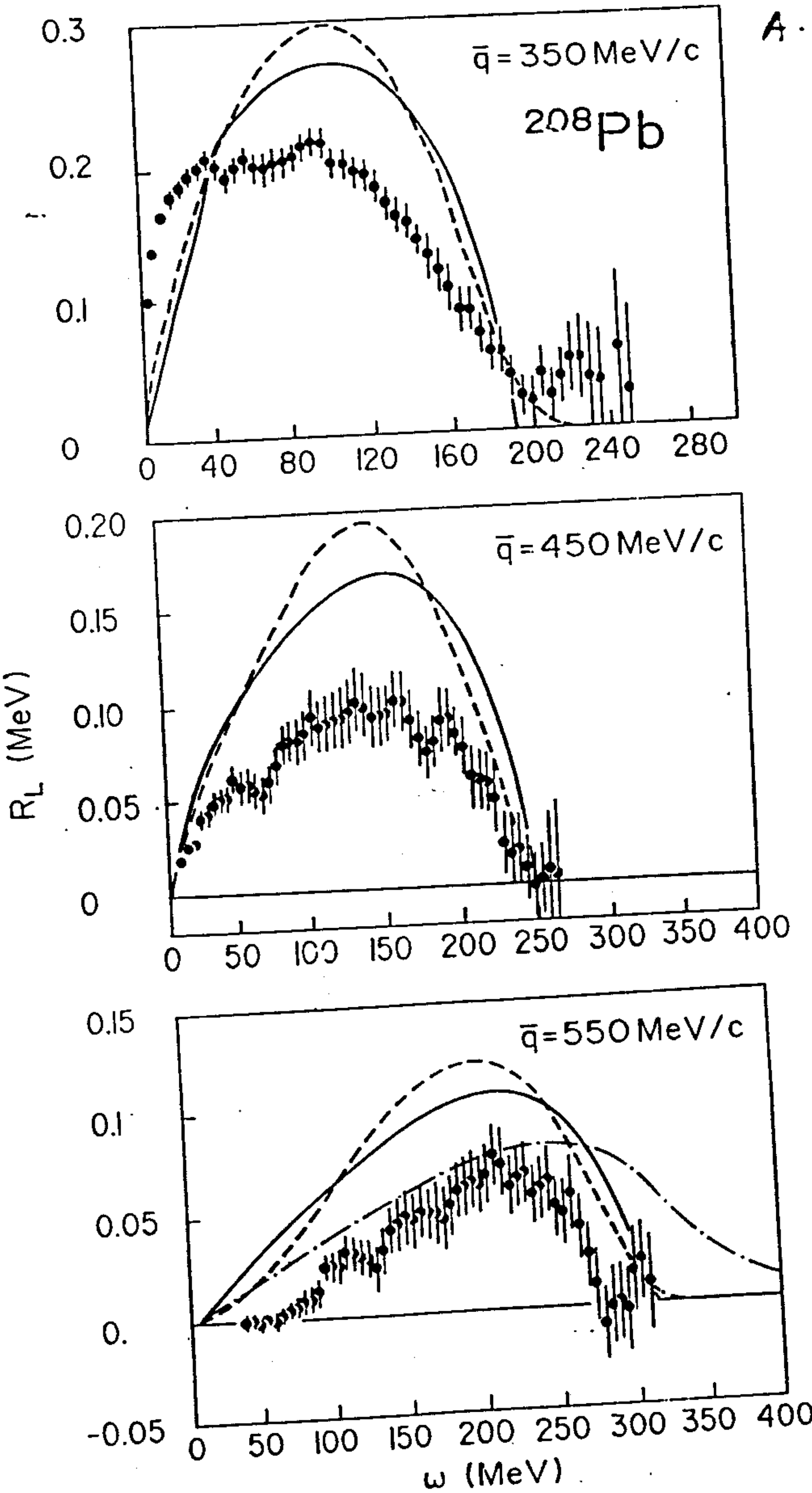
—— R.P.A $m^* = m$

—— R.P.A $m^* = 0.85\,m$ + damping factor (2p-2h)

G. Cò et al.

Pb (ee') L/T SEPARATION

SACLAY
A. ZGHICHE et al.



——— RELATIVISTIC FERMI GAS M. TRAINI

- - - - HARTREE-FOCK M. TRAINI

—·— WITH CORRELATIONS S. FANTONI et al.

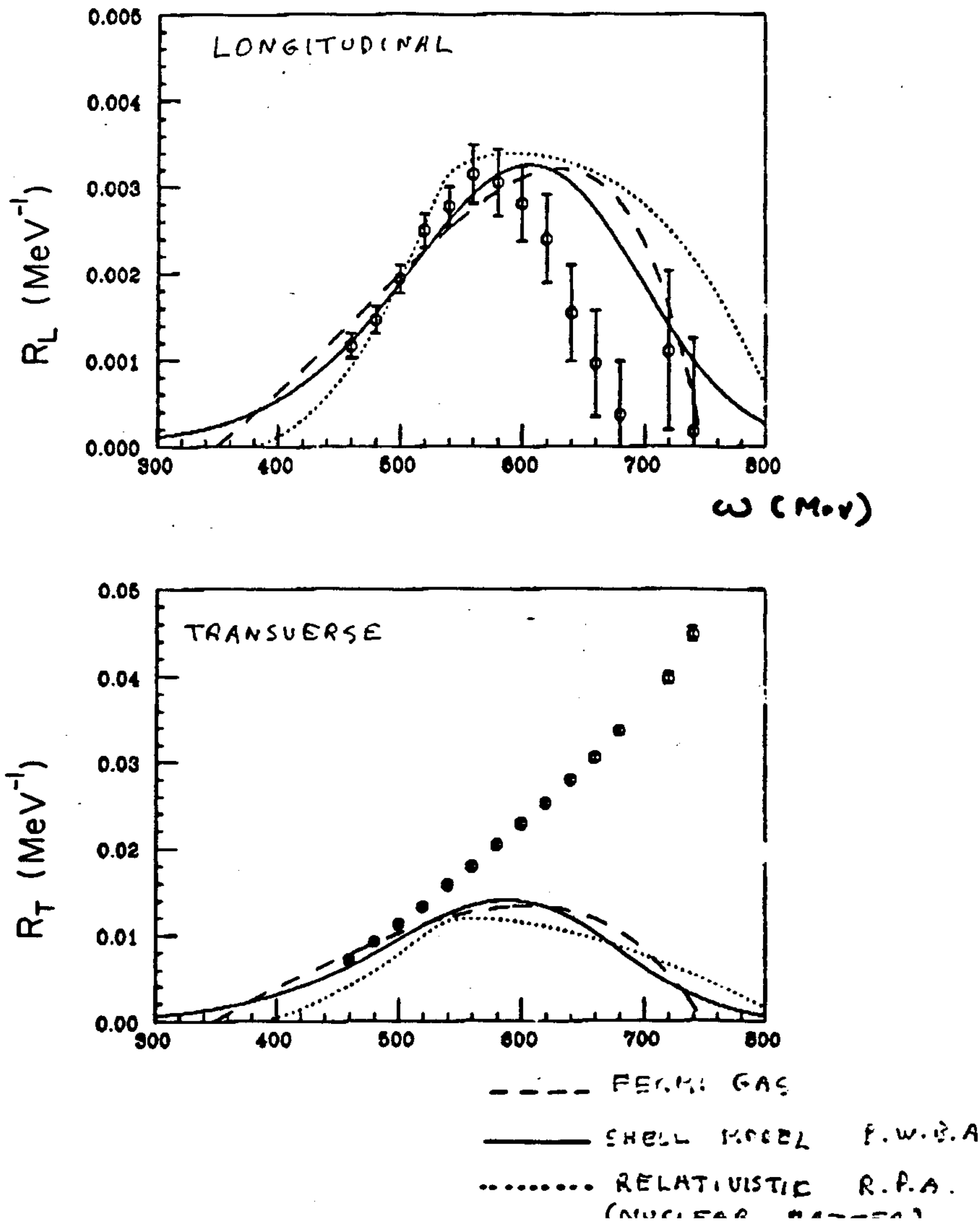
^{56}Fe (ee')

S.L.A.C EXPERIMENT

J.P. CHEN et al.

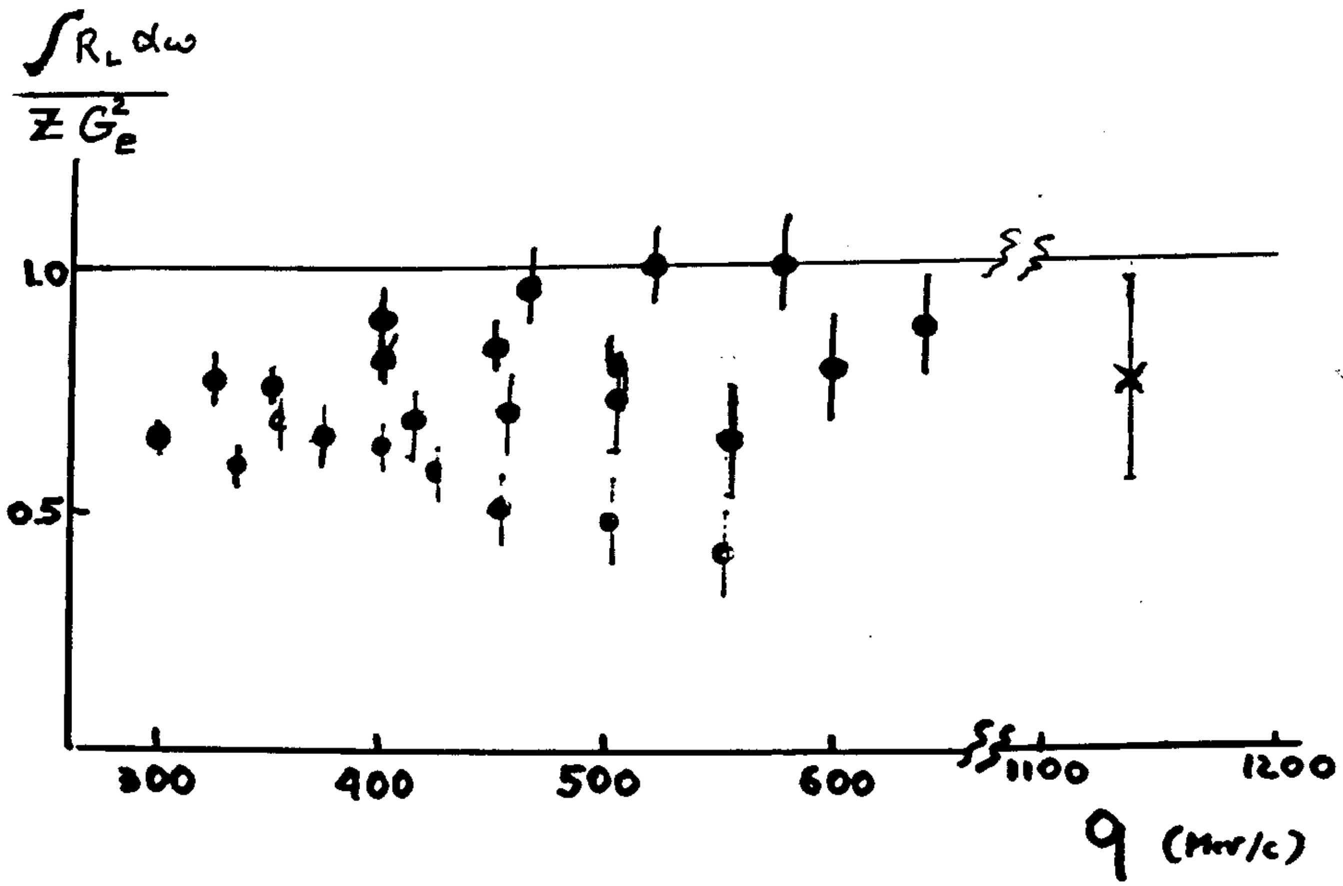
Z.E. MEZIANI

$q = 1140$ MeV



LONGITUDINAL SUM RULE

- ● ^{3}He SACLAY
- ● ^{4}He SACLAY
- ● ^{56}Fe SACLAY
- x ^{56}Fe S.L.A.C.
- o ^{208}Pb SACLAY



SUMMARY

* SINGLE NUCLEON KNOCK-OUT DOMINATES QUASI-ELASTIC ELECTRON SCATTERING

* CORRELATIONS ARE IMPORTANT OR SIGNIFICATIVE UNTIL $\simeq$ 500 MeV/c

* RELATIVISTIC EFFECTS ARE NOT VERY IMPORTANT IN HARTREE-FOCK CALCULATIONS. RELATIVISTIC RPA CALCULATIONS ARE IN PROGRESS

* CONCERNING THE ELECTRON-PROTON INTERACTION INSIDE THE NUCLEUS

- THE TRANSVERSE COMPONENT VARIES WITH q THE FREE ONE

- THERE IS A LACK OF STRENGTH IN THE LONGITUDINAL RESPONSE WHICH INCREASES WITH A
  THE SLOPE OF THE VARIATION WITH q IS COMPATIBLE WITH THAT OF THE FREE PROTON

NUCLEAR AND MOMENTUM TRANSFER DEPENDENCE OF QUASI-ELASTIC ee'p REACTION AT LARGE MOMENTUM TRANSFER

S.L.A.C NE 18 PROPOSAL

R. McKEOWN, R. MILNER SPOKESMEN

STUDY OF Q^2 AND A DEPENDANCE OF THE ee'p CROSS-SECTION ON ^{12}C, ^{56}Fe, ^{197}Au

AND COMPARE TO DIFFERENT MODELS FOR FINAL STATE INTERACTION.

$$1\ GeV/c^2 < Q^2 < 7\ GeV/c^2$$

FINAL STATE INTERACTION MODELS:

$\sigma^{eff} \approx 40$ mb GLAUBER TYPE CALCULATION

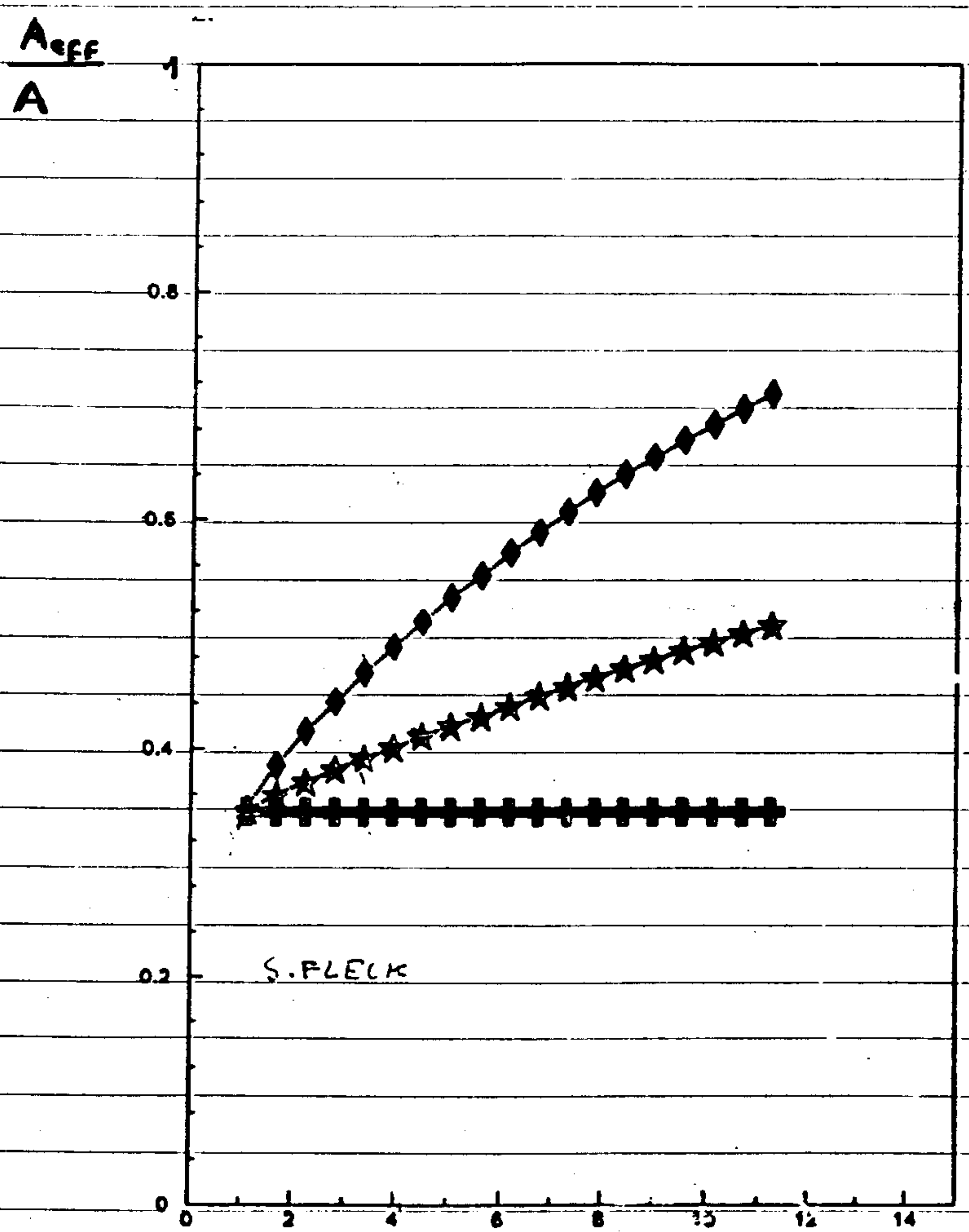
$\sigma^{eff} \propto z^2$ PARTON MODEL

$\sigma^{eff} \propto z$ QUANTUM DIFFUSION Perturbative Q

z is the distance from the point where the hard interaction occurs

COLOUR TRANSPARENCY

^{56}Fe (ee'p)

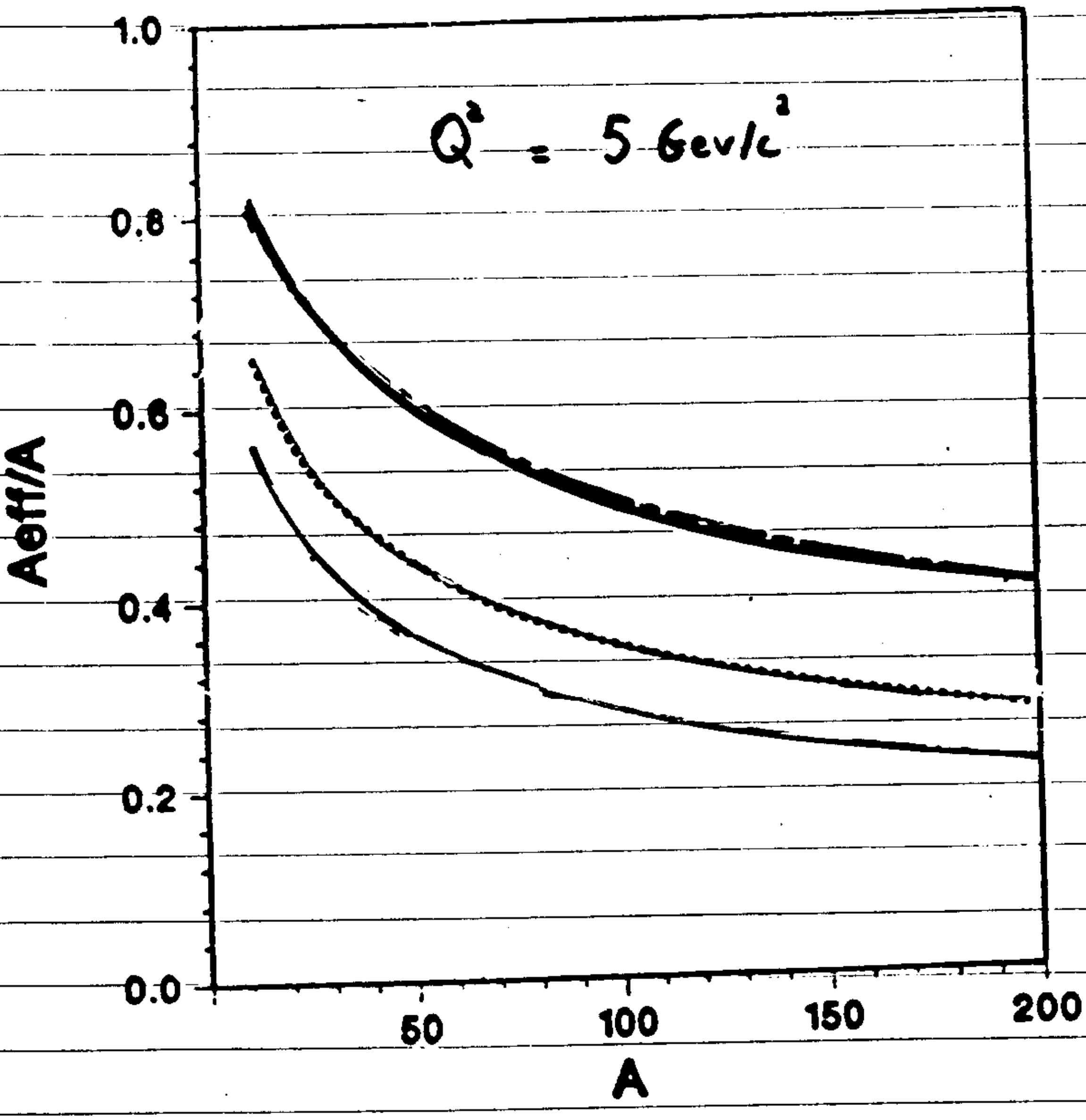


Q^2 $(GeV/c)^2$

- ┼┼┼ GLAUBER TYPE CALCULATIONS
- ✱✱✱ QUANTUM DIFFUSION
- ♦♦♦♦ NAIVE PARTON MODEL

SEE FARRAR et al. P.R.L. 61, 686 (1988)

COLOUR TRANSPARENCY



GLAUBER TYPE CALCULATIONS

QUANTUM DIFFUSION

NAIVE PARTON MODEL

FARRAR et al. PRL 61, 686 (1988)