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NUCLEON-NUCLEON INTERACTION FROM PION-NUCLEON PHASE SHIFT ANALYSIS

The NN peripheral partial waves

R. VINH MAU*, J.M. RICHARD, B. LOISEAU, M. LACOMBE**, W.N. COTTINGHAM***

Division de Physique Théorique†, Institut de Physique Nucléaire †† and Laboratoire de Physique Théorique et Hautes Energies††, Paris.

ABSTRACT

The low energy peripheral nucleon-nucleon partial wave phase parameters are calculated from our present knowledge of pion-pion and pion-nucleon phase shifts. The results are compared with phenomenological energy independent and energy dependent phase shift analyses.

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** Faculté des Sciences de Reims, 51 - Reims (France).

*** H.H. Wills Physics Laboratory - University of Bristol, Bristol (G.B.)

† Laboratoire associé au Centre National de la Recherche Scientifique

†† Postal address : Tour 16 - 11, Quai St-Bernard - 75230 Paris Cedex 05 (France)

DISCLAIMER

This letter is part of a series of papers which through dispersion theory correlate the low and intermediate energy data on pion-pion, pion-nucleon and nucleon-nucleon scattering. The dispersion relations which are used incorporate both Mandelstam analyticity and Regge asymptotic behaviour.

In a previous paper[1], the long and intermediate range contributions to the nucleon-nucleon scattering amplitude were calculated from our knowledge of pion-pion and pion-nucleon phase shifts. As a first step, this amplitude was used in ref.(1) to derive a theoretical nucleon-nucleon potential. Here, from this same amplitude, we calculate directly the low energy peripheral partial wave phase parameters, in particular, we restrict ourselves to total angular momentum $J\geq 2$ and laboratory kinematic energy less than 425 MeV.

The relevant formulas for the nucleon-nucleon amplitude are given in ref.(1) and the phase parameters are calculated from it by standard techniques[2]. However, for the low energies that concern us here, our calculated scattering amplitude does not automatically satisfy the unitarity condition and small unitarity corrections have to be made before the phase parameters can be calculated. We find that most of the phase parameters are not sensitive to any of the unitarization procedures that we have examined, which are : the "geometrical", the K matrix and a shortest path procedures.

The inputs of this calculation are the same as those of ref.(1) and to remind the reader, we list them below in order of decreasing reliability.

(i) The one-pion exchange and the "fourth order" contributions which are uniquely determined by the pion-nucleon coupling constant.

(ii) The "double spectral contributions" which depend upon the πN phase shift analyses. We consider the CERN experimental and the Glasgow A solutions which represent maximum differences in pion-nucleon inputs.

(iii) "The subtraction functions in the isospin (-) amplitude". These are related to the exchange of two pion in a P state and are known to be dominated by ρ meson exchange which, from several model calculations [3],[4] seems to be well determined. We use here the model of Höhler, Strauss and Wunder[3].

(iv) The "subtraction function in the isospin (+) state". This is given by the $N\bar{N}\to 2\pi$ S-wave amplitude which, in turn, is related to the pion-pion S-wave phase shift. We use two models

a) the solution of ref.(4) obtained from a resonant $\pi\pi$ S-wave and refered to here as R.

b) the solution of ref.(5) which corresponds to a non-resonant $\pi\pi$ S-wave and called here NR.

(v) The ω-exchange which represents part of the three-pion-exchange. The overall coupling of the ω to nucleons is not well determined. We take

$$G_\omega^T/G_\omega^V = -0.12 \text{ and } \frac{(G_\omega^V)^2}{4\pi} = 4.65$$

which follows from the above quoted ρ coupling constant, SU(3) prediction and isoscalar nucleon magnetic moment.

The results for the high ($J\geq 2$) partial wave phase parameters unitarized by the K matrix method are displayed in figs.(1) to (19). The two different πN phase shift analyses (CERN and GLASGOW) and the two solutions for the $\pi\pi$ S-wave (NR and R) give rise to the four curves denoted by C+NR, C+R, G+NR, G+R. We also plot the contributions from the one-pion-exchange (OPE) alone and with the fourth order (OPE+4th). The results are compared with the phenomenological energy independent and energy dependent phase shift analyses of ref.(6).

It can be seen from the figures that in the energy range considered, one can draw the following conclusions :

i) In most cases, the results obtained from the CERN and GLASGOW πN phase shift analyses differ very little, especially for energies less than 200 MeV. Only the low partial waves, show some differences and then only at energies greater than 250 MeV.

ii) When compared to phenomenology, our results, in most cases, give a significant improvement to OPE, and, in many cases an appreciable improvement to OPE+4th. This is especially true at the higher energy,

iii) the results are sensitive to the model of the $N\bar{N}\to 2\pi$ S-wave amplitude. Although the graphs favour the non resonant $\pi\pi$ S-wave phase shift the calculation depends only on the modulus of the amplitude and not directly on the phase. Also, our calculation depends on the ω coupling constant G_{ω}^{V} which is taken here from SU(3) prediction. However, an increase of this constant would improve somewhat the fit of the resonant S-wave model.

iv) Of the nineteen calculated phase parameters thirteen high partial waves (fig.1 to 13) are in good agreement with the Livermore phase shift analysis[6] over the whole energy range. The two exceptions ($^1H_5$, $^3G_5$) are in the isospin T=0 which is only accessible in neutron-proton scattering. Experimentally they are not too well determined and our calculation actually fits much better a previous Livermore phase shift analysis[7].

v) We also calculate waves as low as P and D waves. For the D-waves ($^3D_3$, $^1D_2$, $^3D_2$), the agreement is satisfactory below 200 MeV but not for higher energies. However, at these higher energies, the uncertainties of our unitarization procedure are in this case significant. The $^3P_2$ wave (fig.19) is in qualitative agreement with phenomenology.

Brown and Durso, Chemtob and Riska [8] have made similar calculations to ours. However, as pion-nucleon scattering input they have only considered the low lying nucleon resonances in a narrow width approximation, also their input of $N\bar{N}\to\pi\pi$ S-waves is based on soft pion considerations and is similar to our NR solution. The phase parameters that they show are in qualitative agreement with ours. All of these results show important contributions from uncorrelated two-pion-exchange.

This uncorrelated two-pion-exchange is calculated here in the framework of dispersion relations from the presently known properties of π mesons. Our aim was not to achieve a best fit of the nucleon-nucleon data. It was rather an attempt to relate independent pieces of information from different branches of meson physics. The fact that we have obtained, without agjusting any parameter, a good consistency between experimental data on the π-nucleon, $\pi\pi$ and nucleon-nucleon systems does give us confidence in the dispersion relation approach to the fundamental problem of nucleon-nucleon interaction. Conversely, within the same framework, better nucleon-nucleon data will help in removing some ambiguities of the π-nucleon or $\pi\pi$ interactions.

ACKNOWLEDGEMENT

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FIGURE CAPTIONS

Figs 1 to 19 The NN phase parameters versus laboratory kinematic energy

- OPE : one pion exchange contribution
- OPE + 4th : one pion exchange contribution + the "fourth order contribution"
- C + R = CERN πN phase shifts + resonant ππ S-wave
- G + R = GLASGOW πN phase shifts + resonant ππ S-wave
- C + NR= CERN πN phase shifts + non resonant ππ S-wave
- G + NR= GLASGOW πN phase shifts + non resonant ππ S-wave

CERN solution is only drawn when it differs appreciably from GLASGOW solution.

- Shaded area : energy dependent phase shift analysis of ref.(6) with its uncertainties.
- Points : energy independent phase shift analysis of ref.(6).

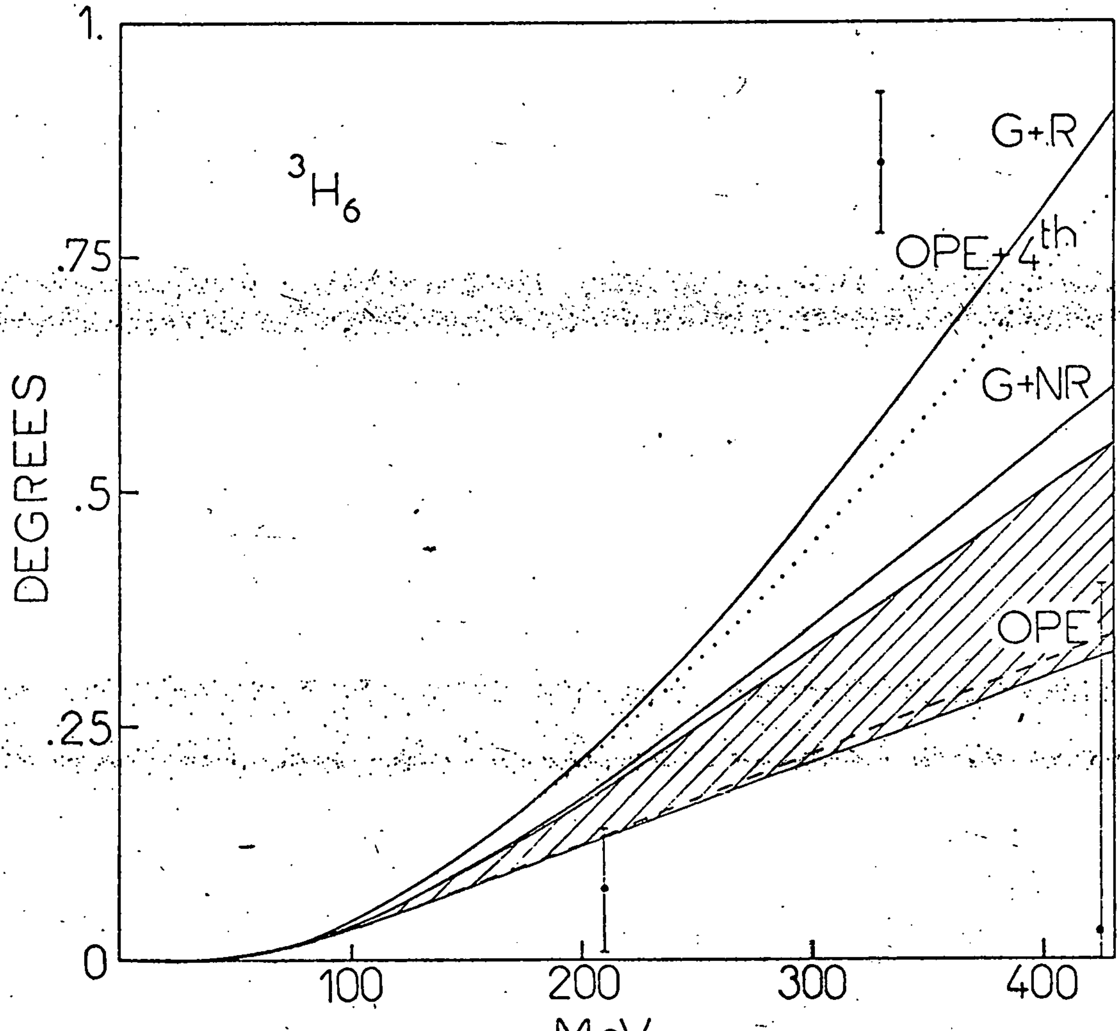
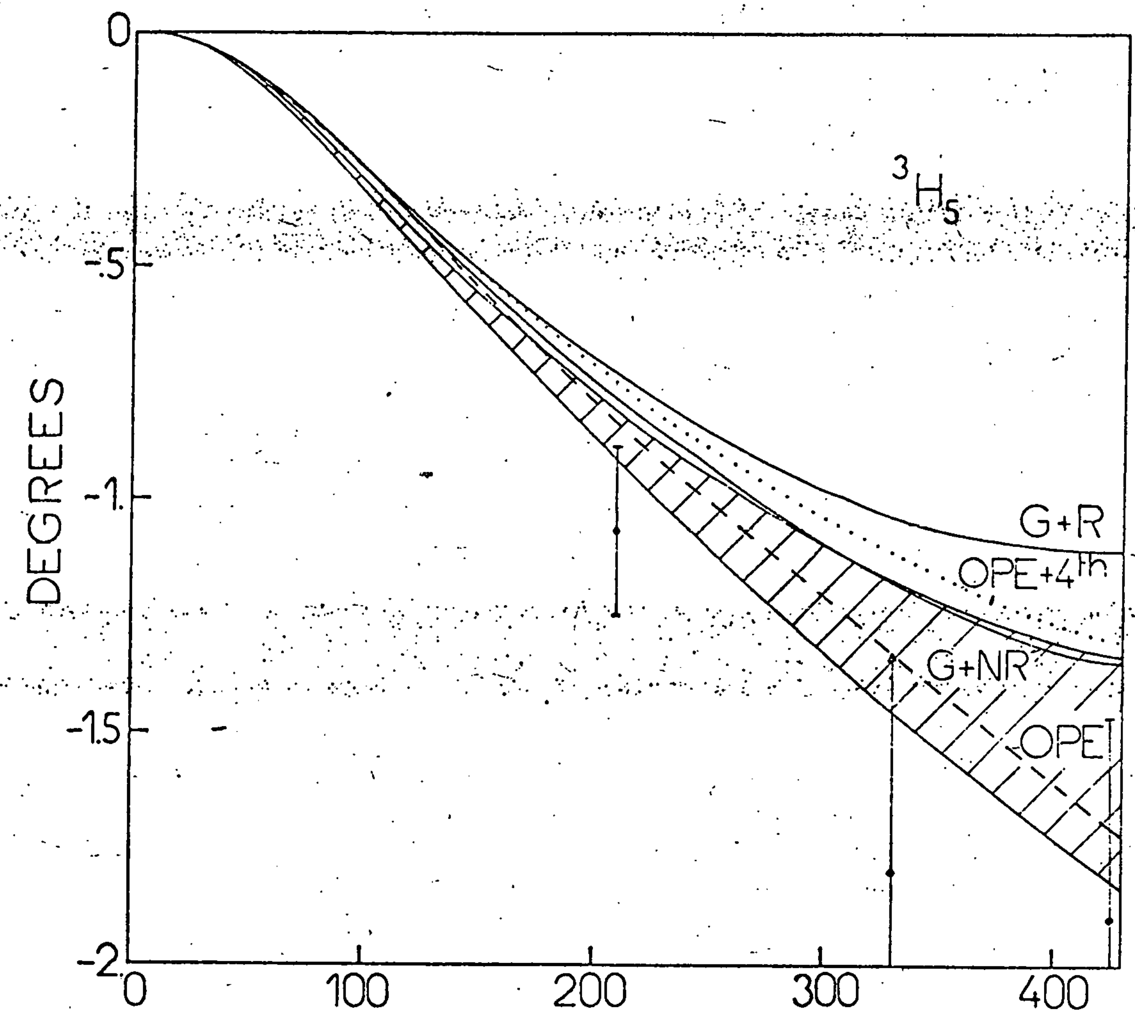


Fig.1



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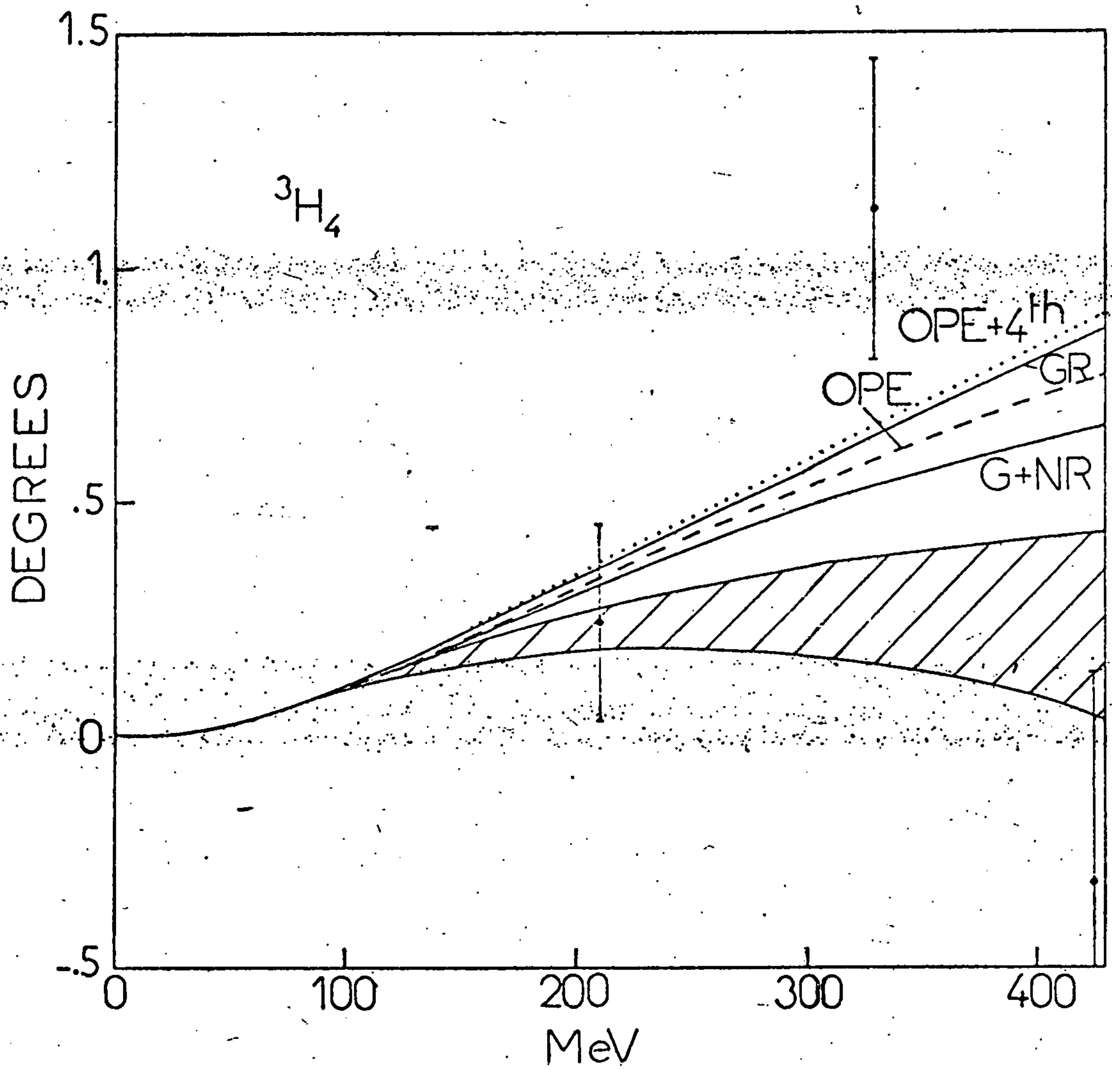

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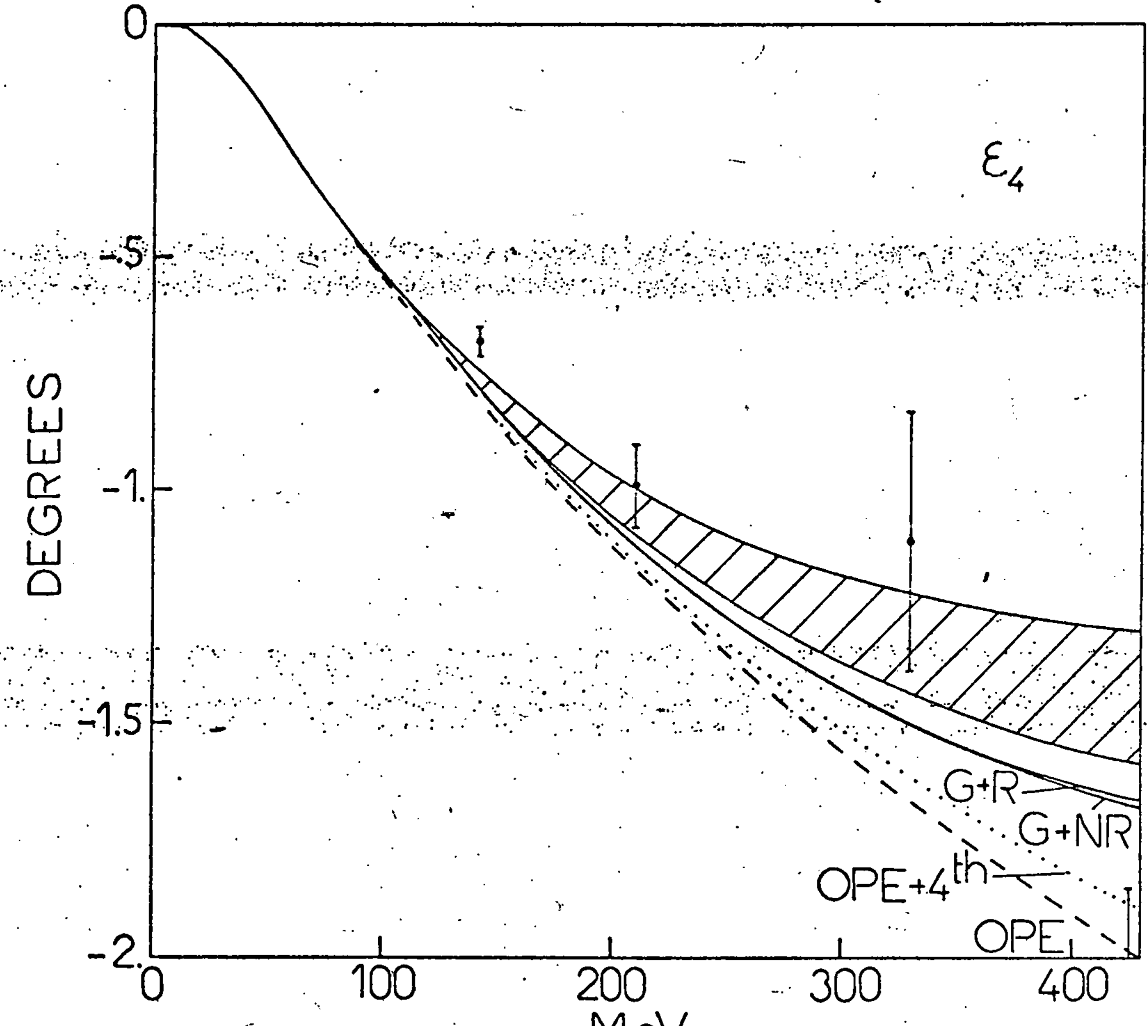

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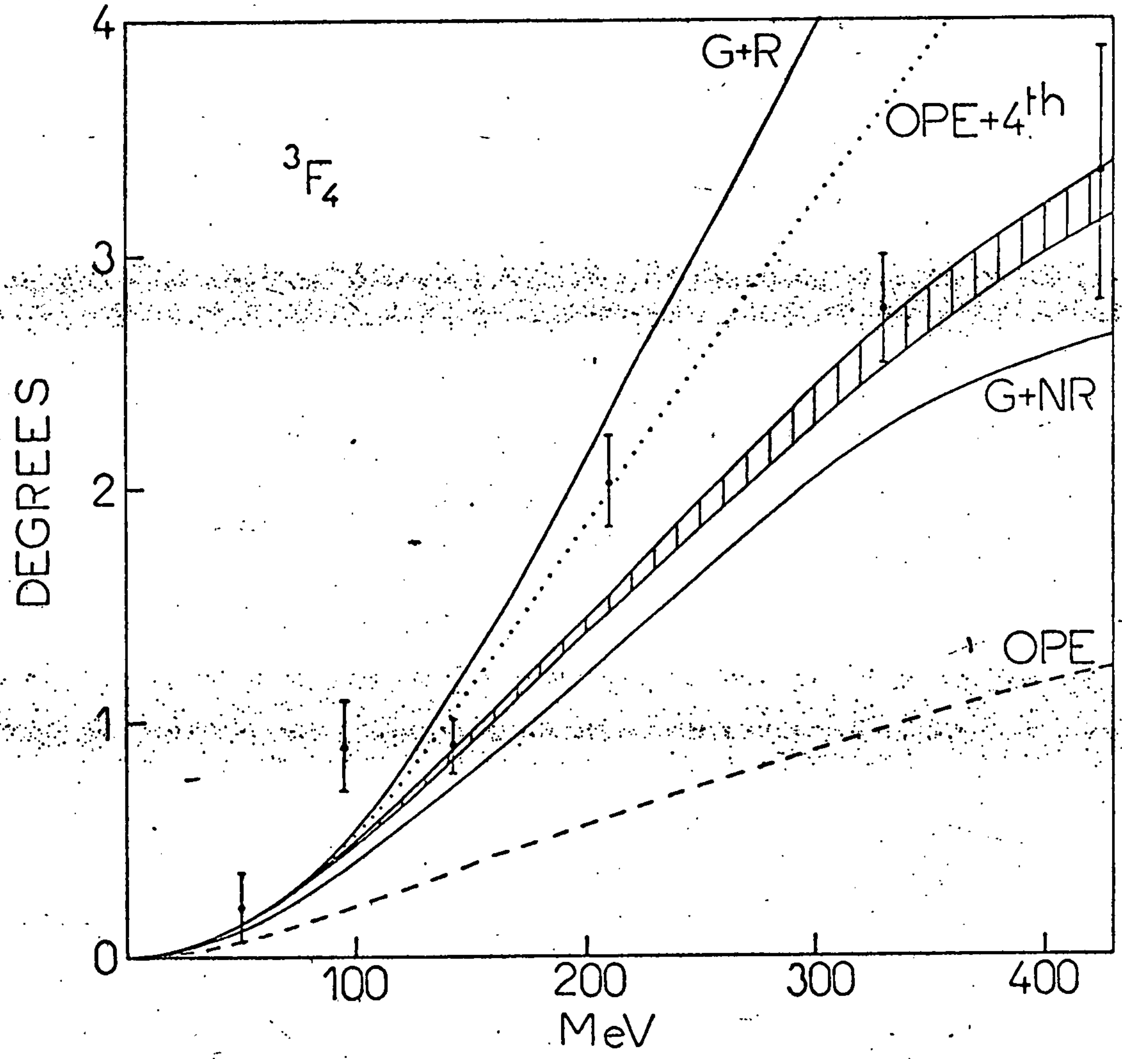

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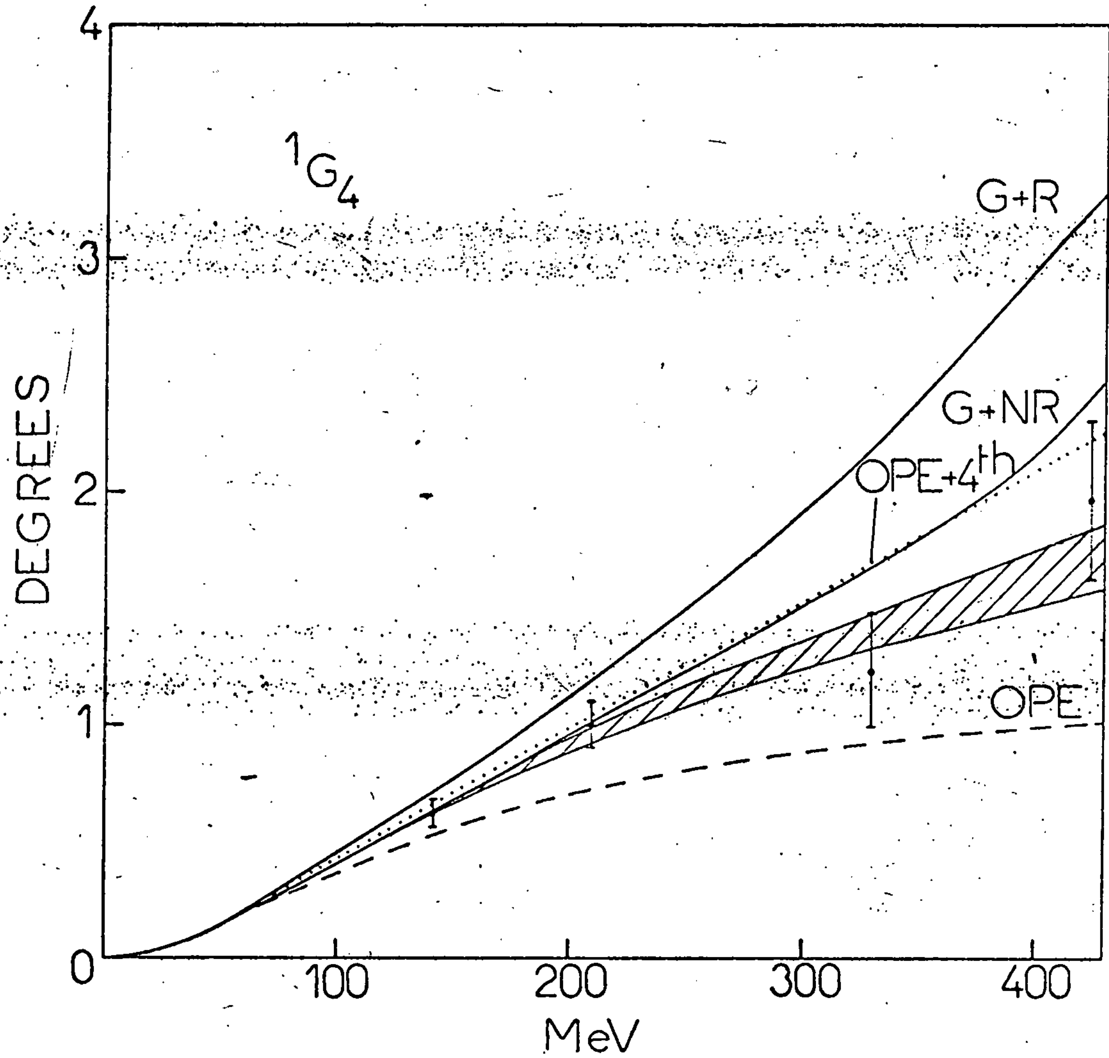

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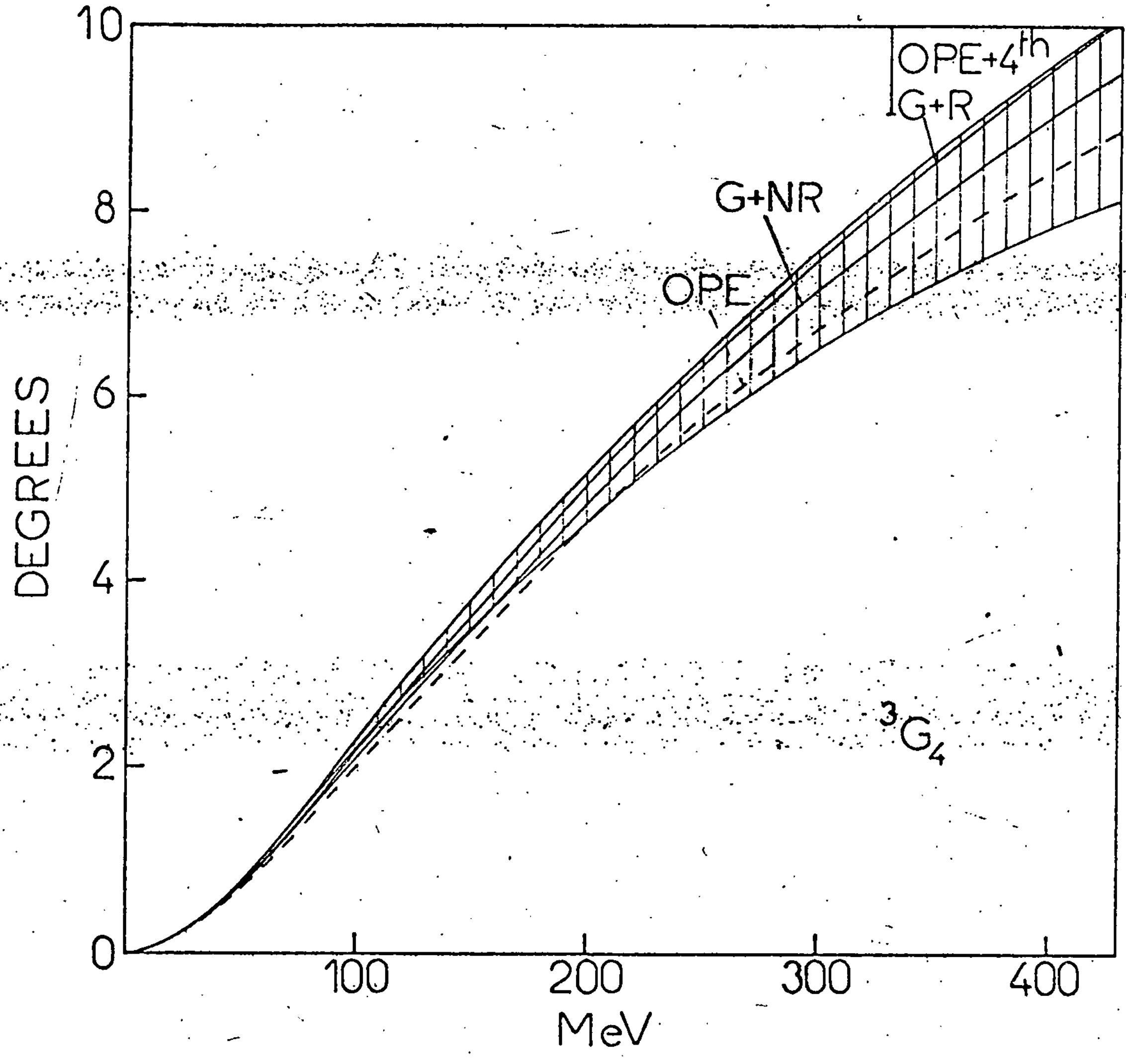

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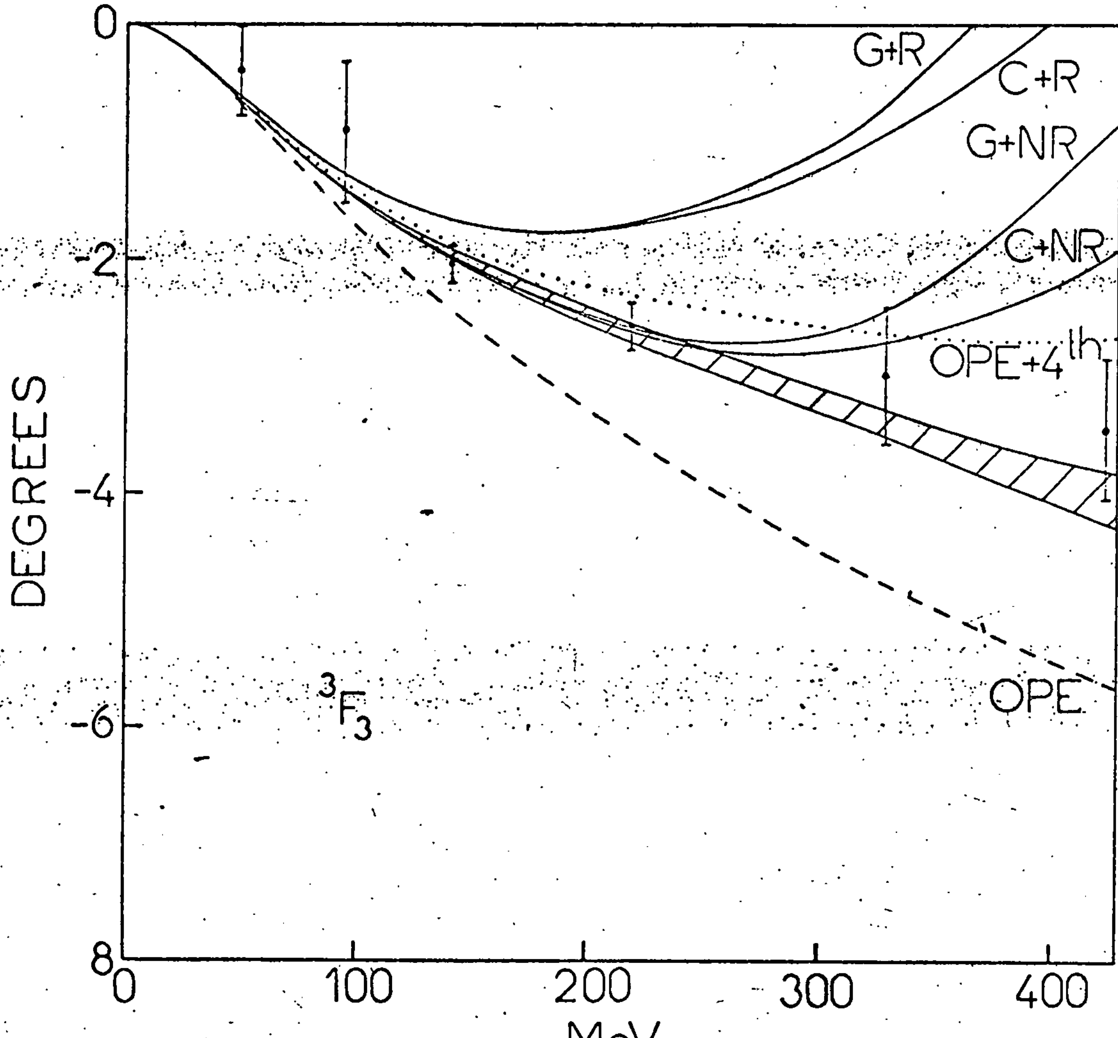
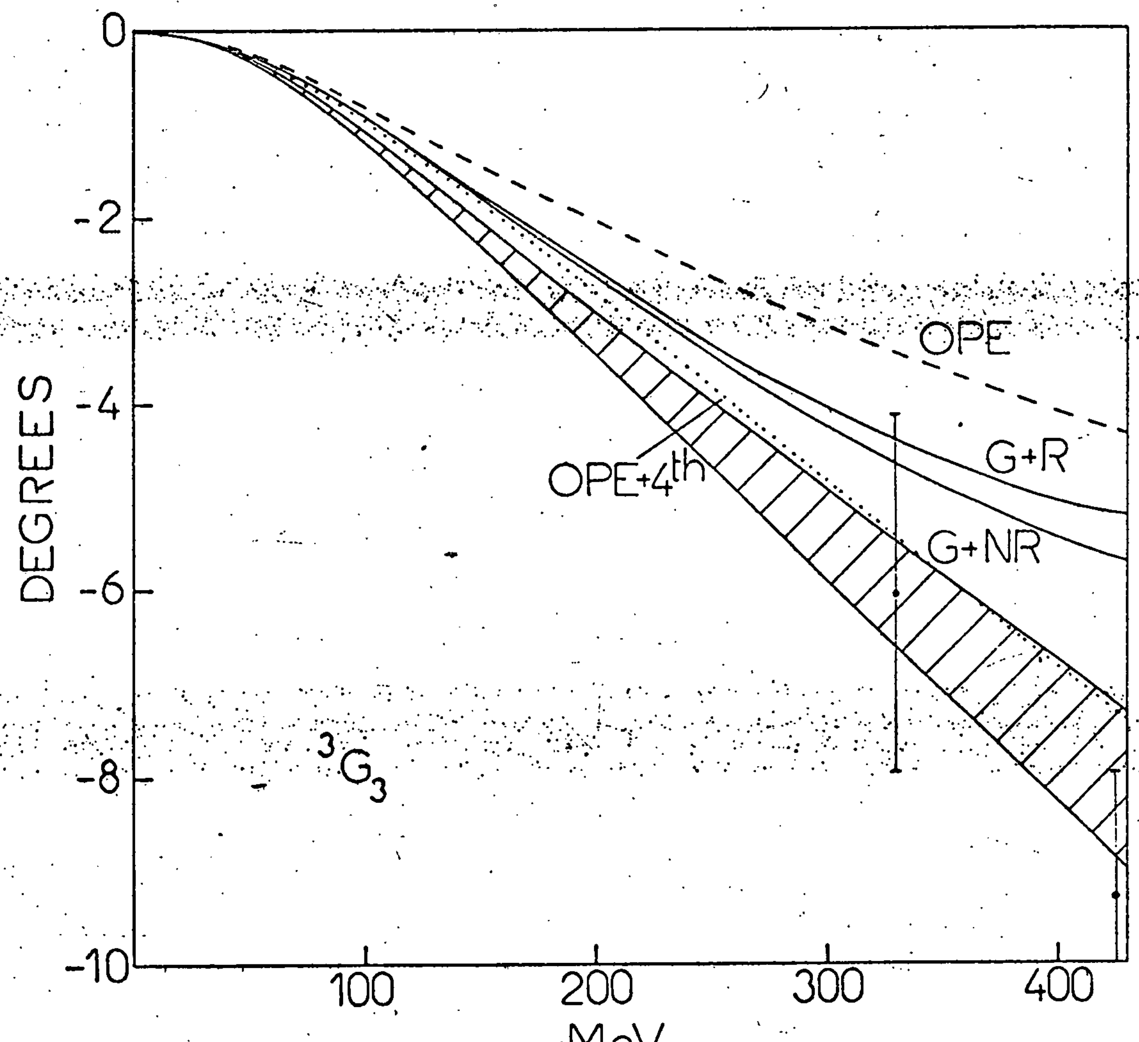


0
-2
-4
-6
8
DEGREES
G+R
C+R
G+NR
C+NR
OPE+4th
OPE
$^3F_3$
0
100
200
300
400
MeV

Fig. 8



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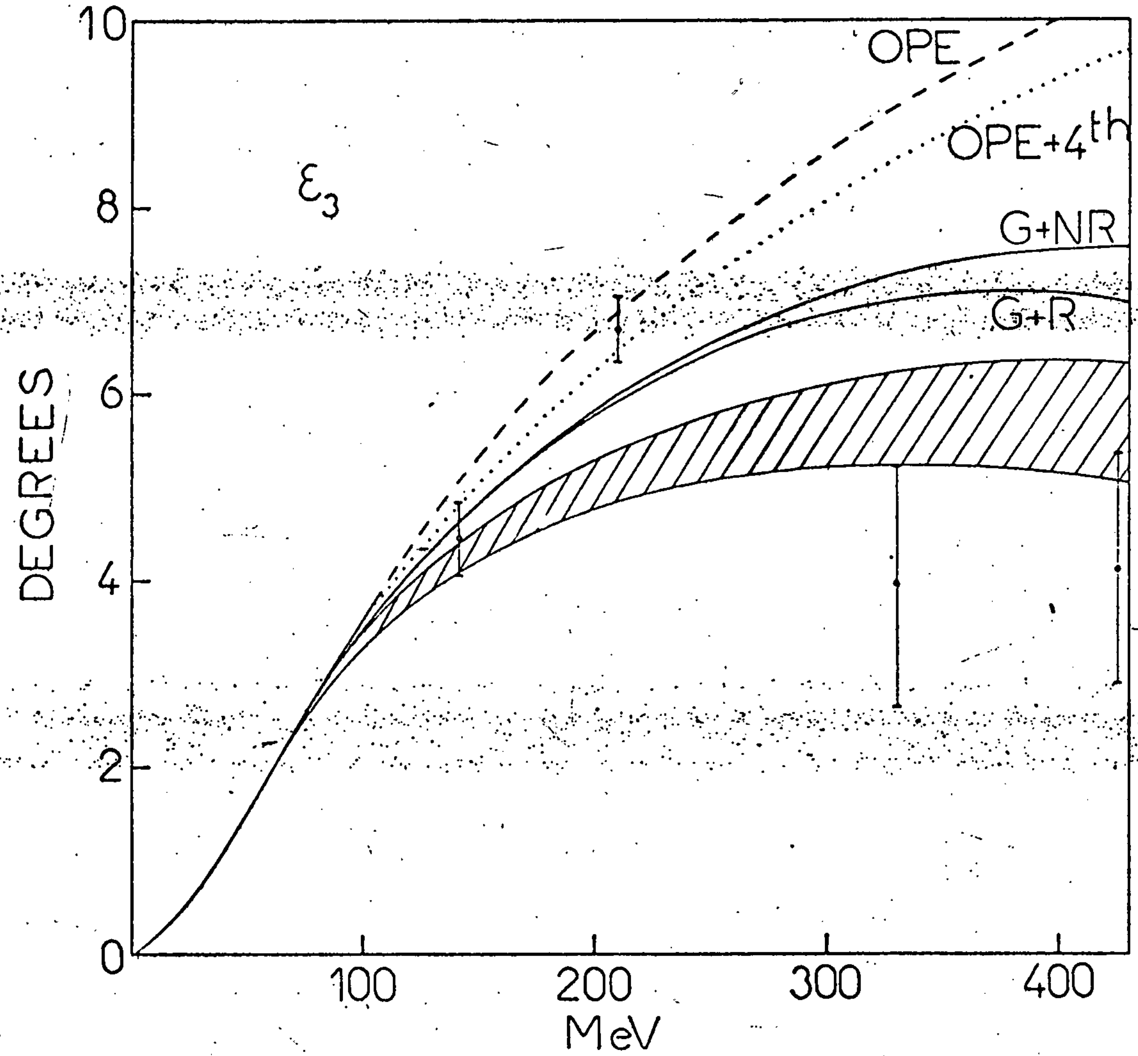

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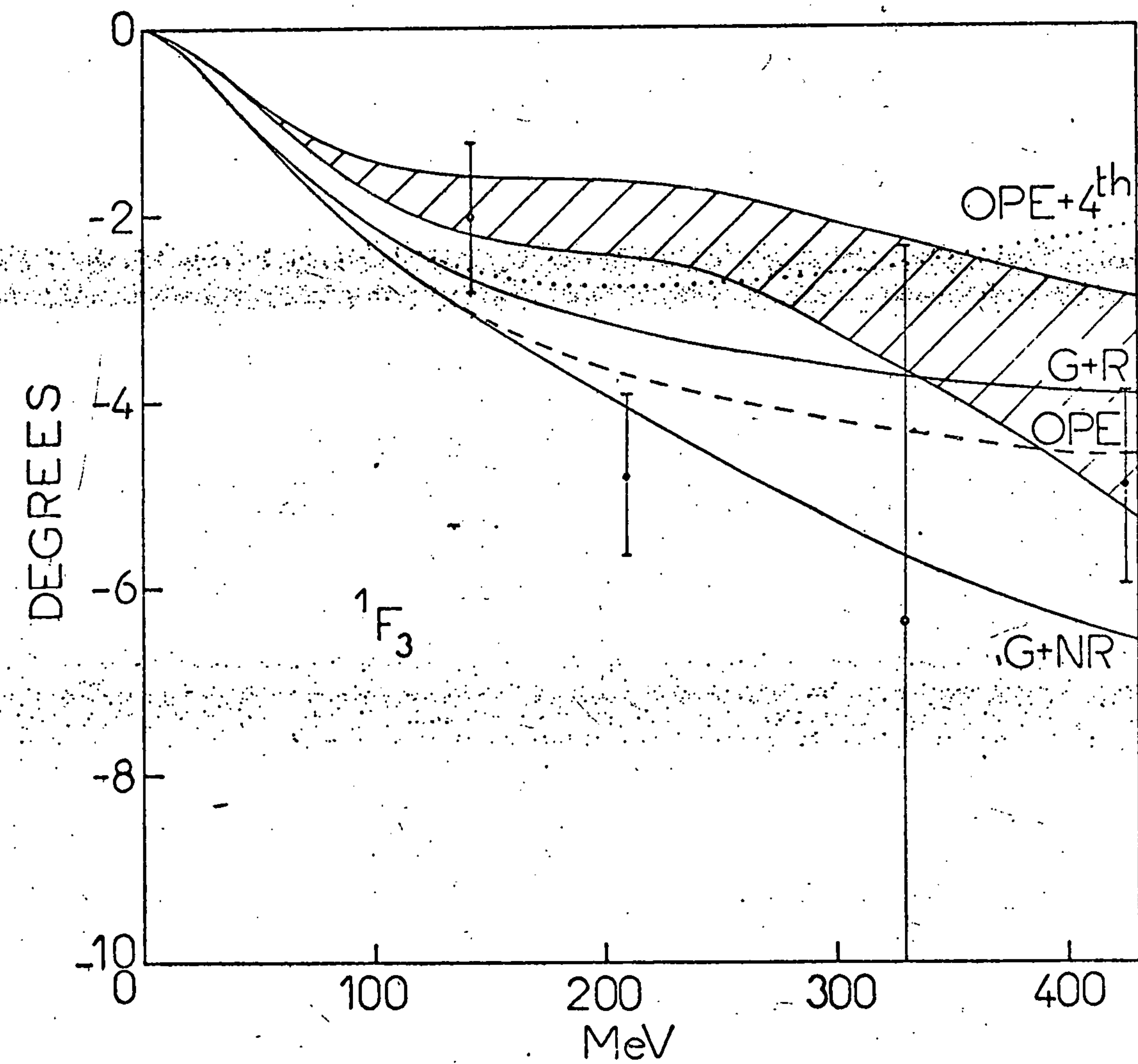

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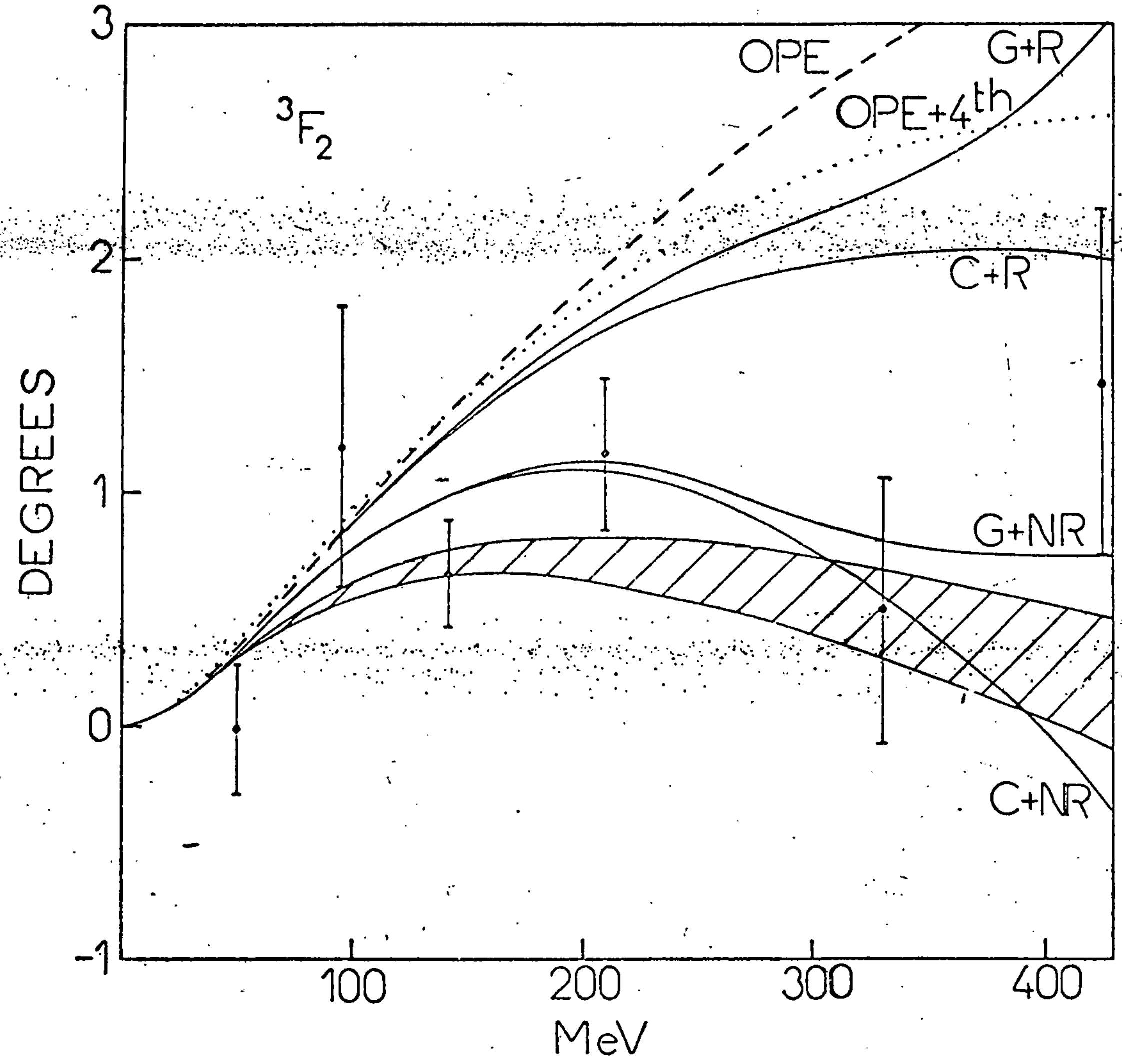

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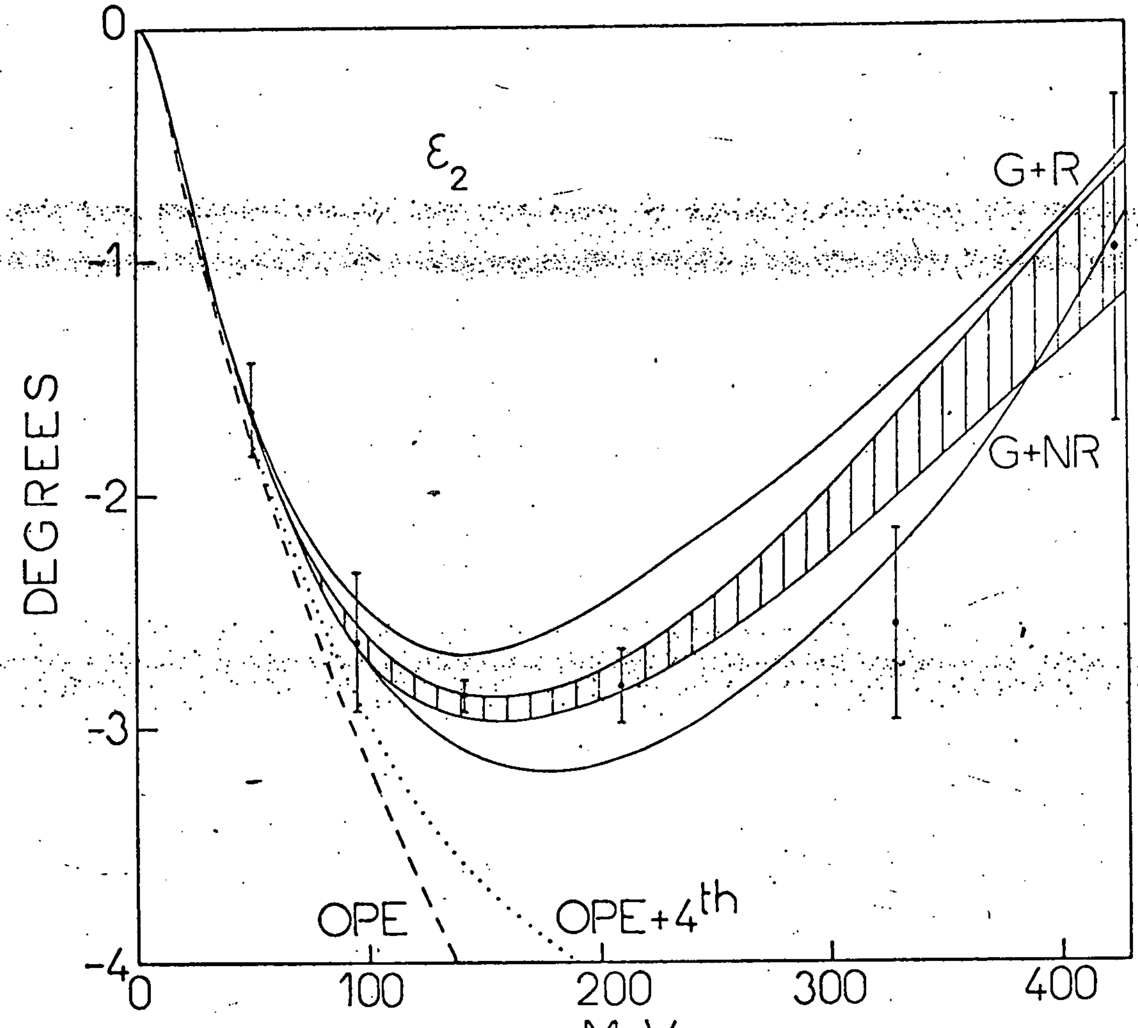
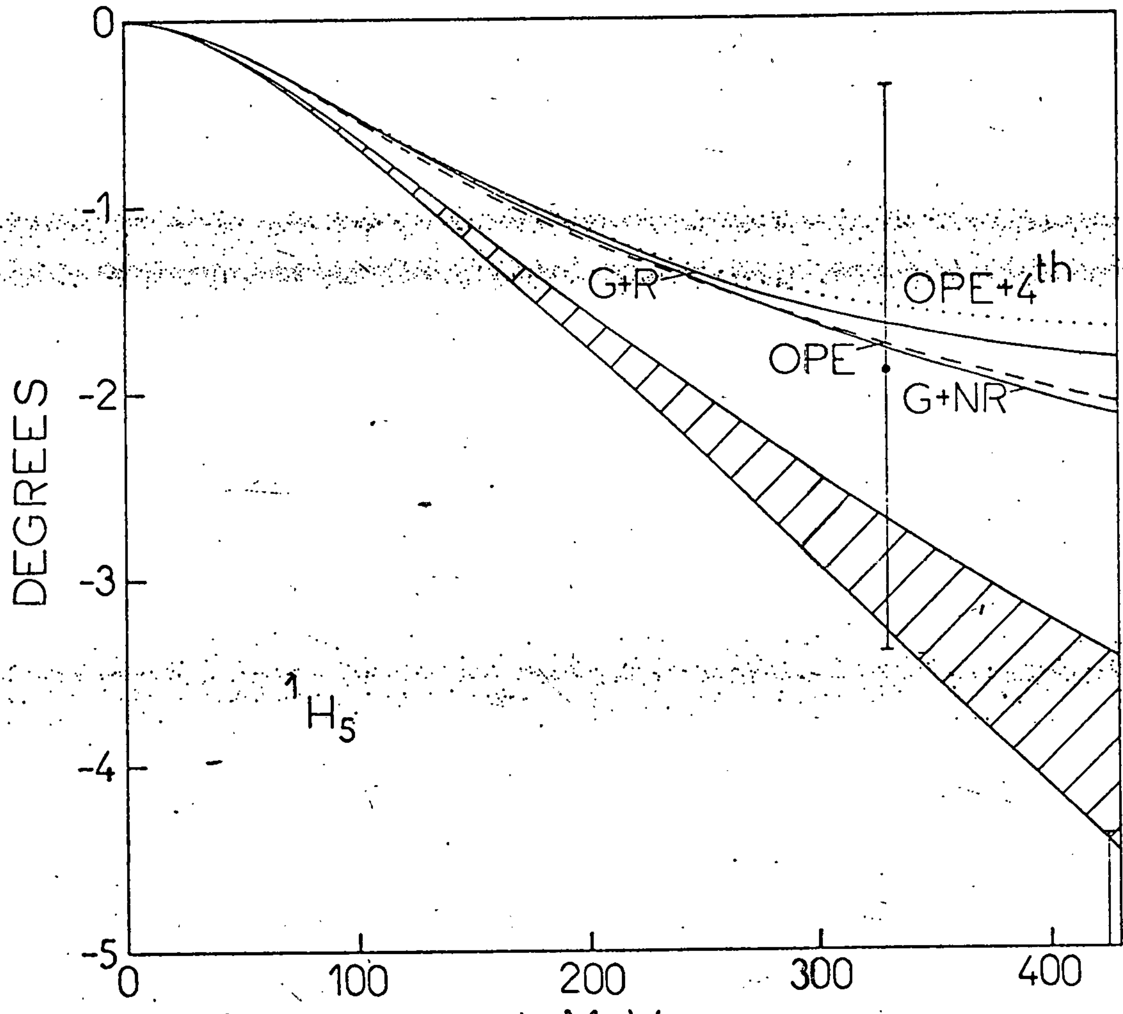


0
-1
-2
-3
-4
DEGREES
ε_2
G+R
G+NR
OPE
OPE+4th
0
100
200
300
400
MeV

Fig. 13



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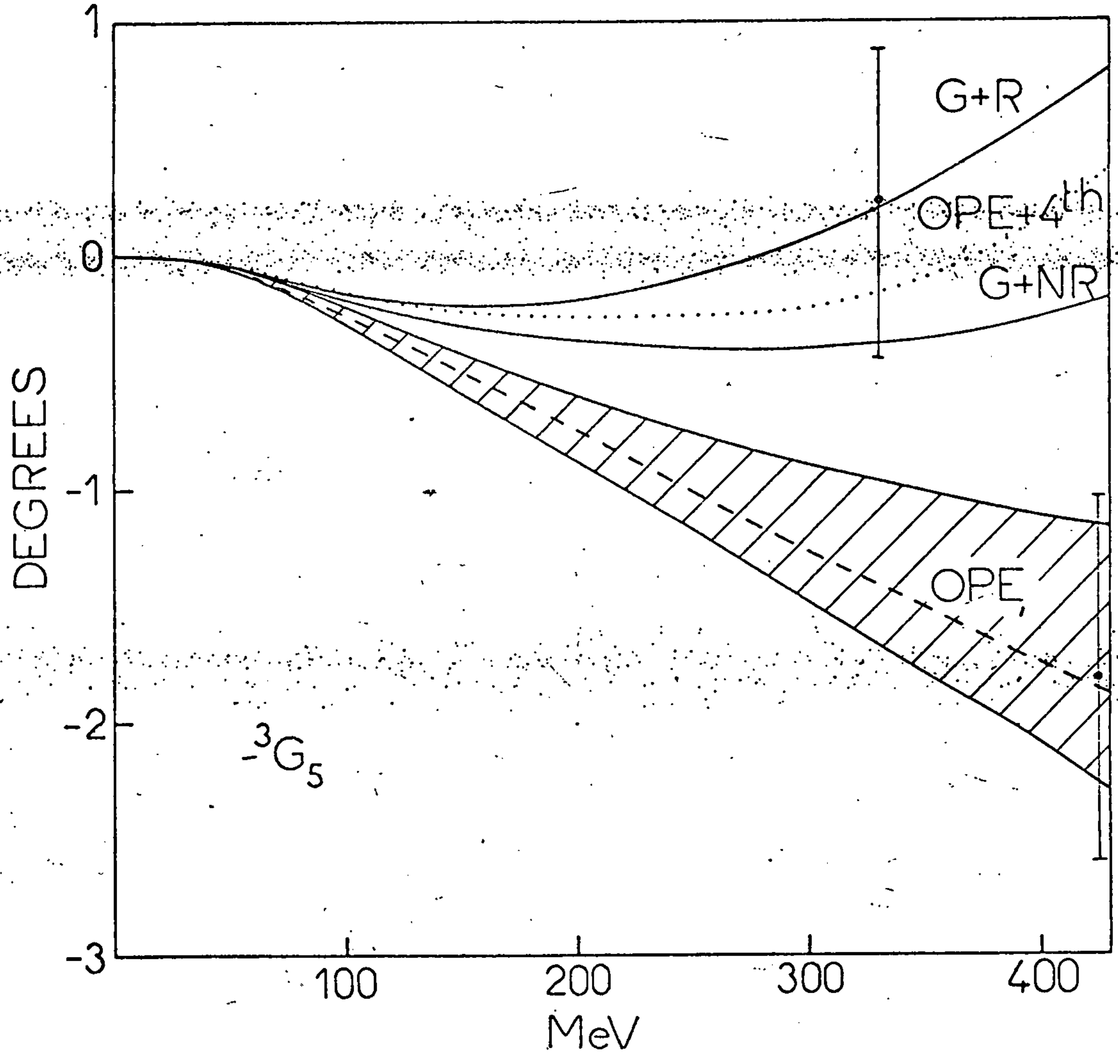

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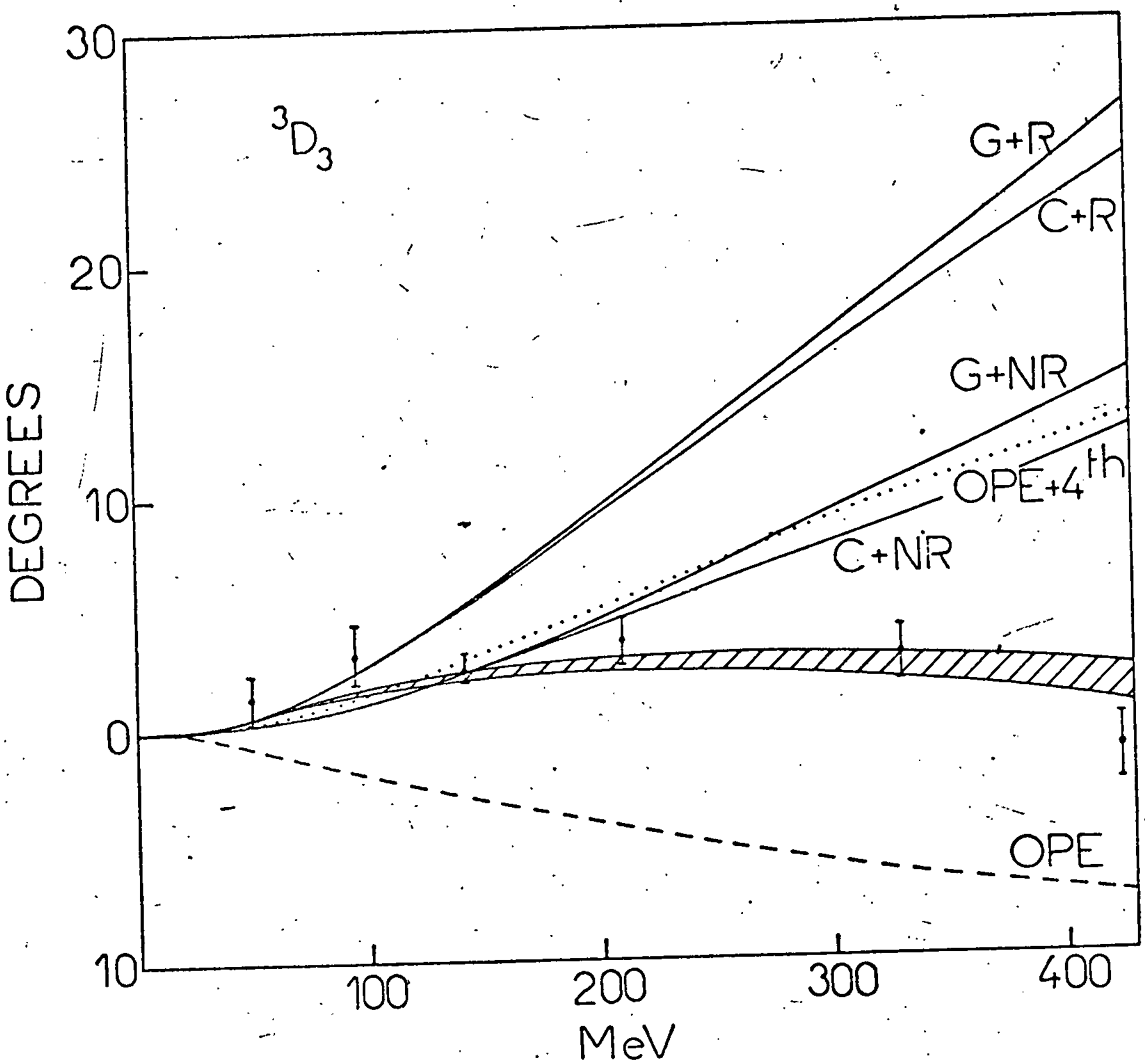
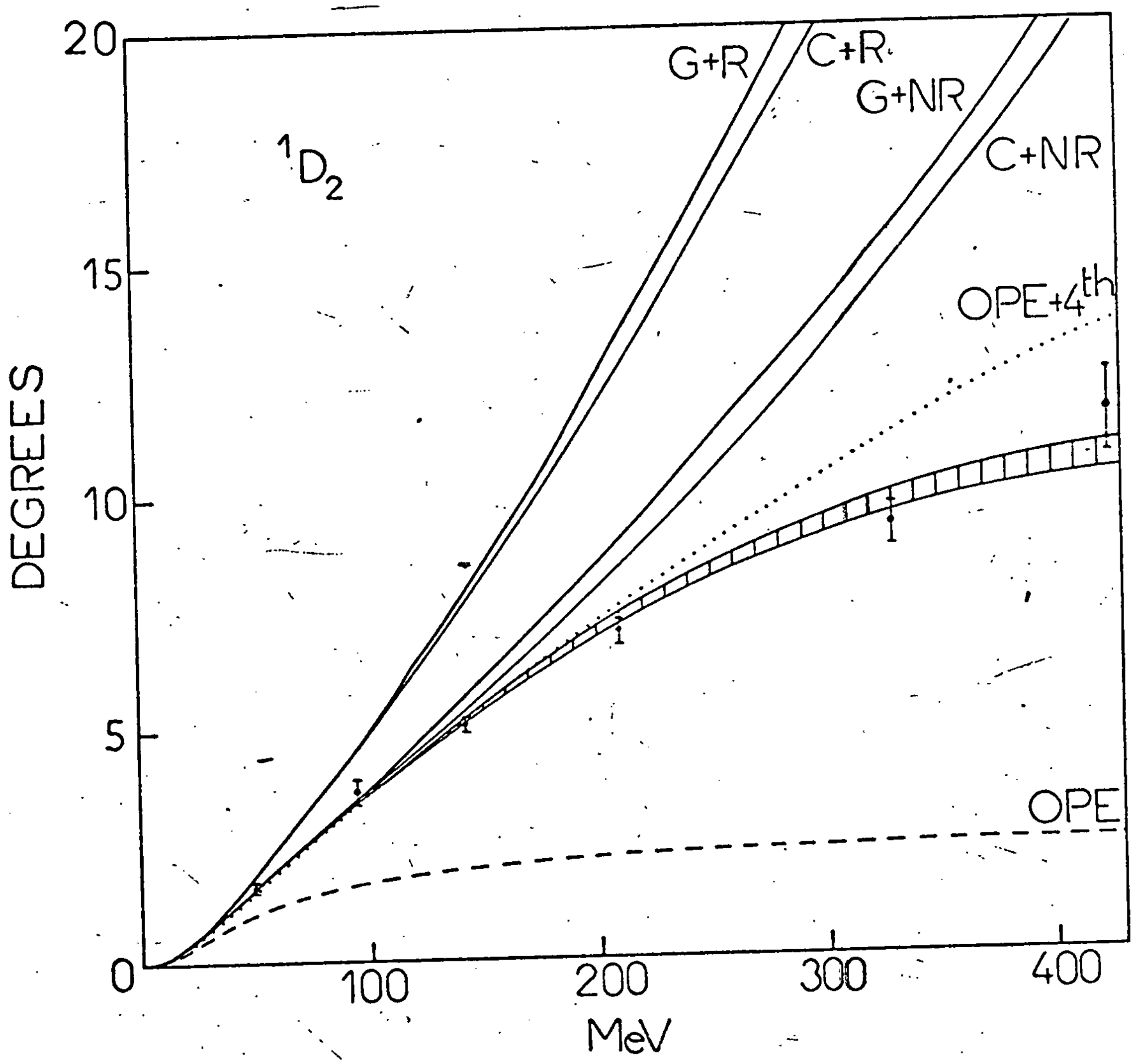


$^3D_3$
G+R
C+R
G+NR
OPE+4th
C+NR
OPE
DEGREES
30
20
10
0
10
100
200
300
400
MeV

Fig. 16



20
15
10
5
0
100
200
300
400
DEGREES
MeV
$^1D_2$
G+R
C+R
G+NR
C+NR
OPE+4th
OPE

Fig. 17

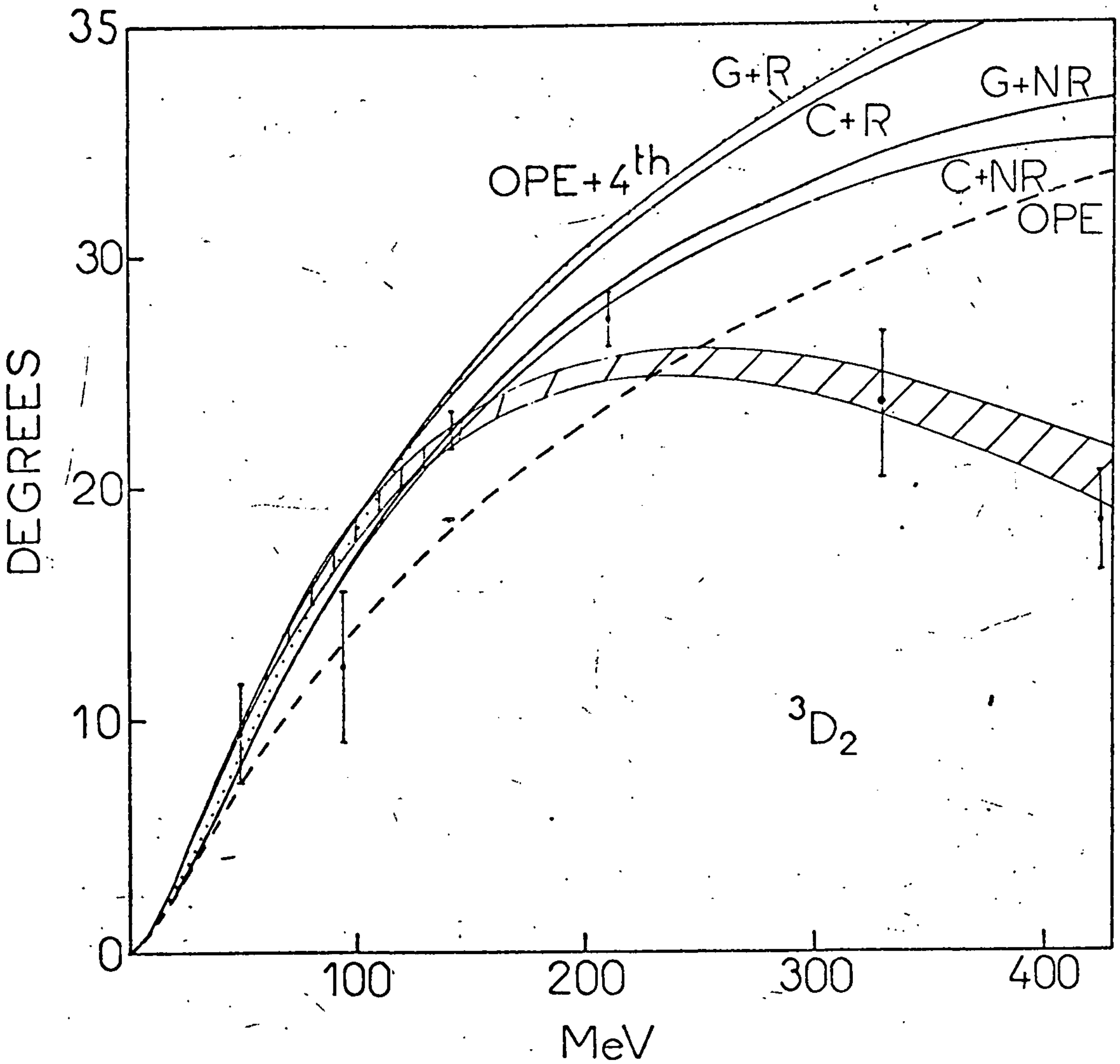
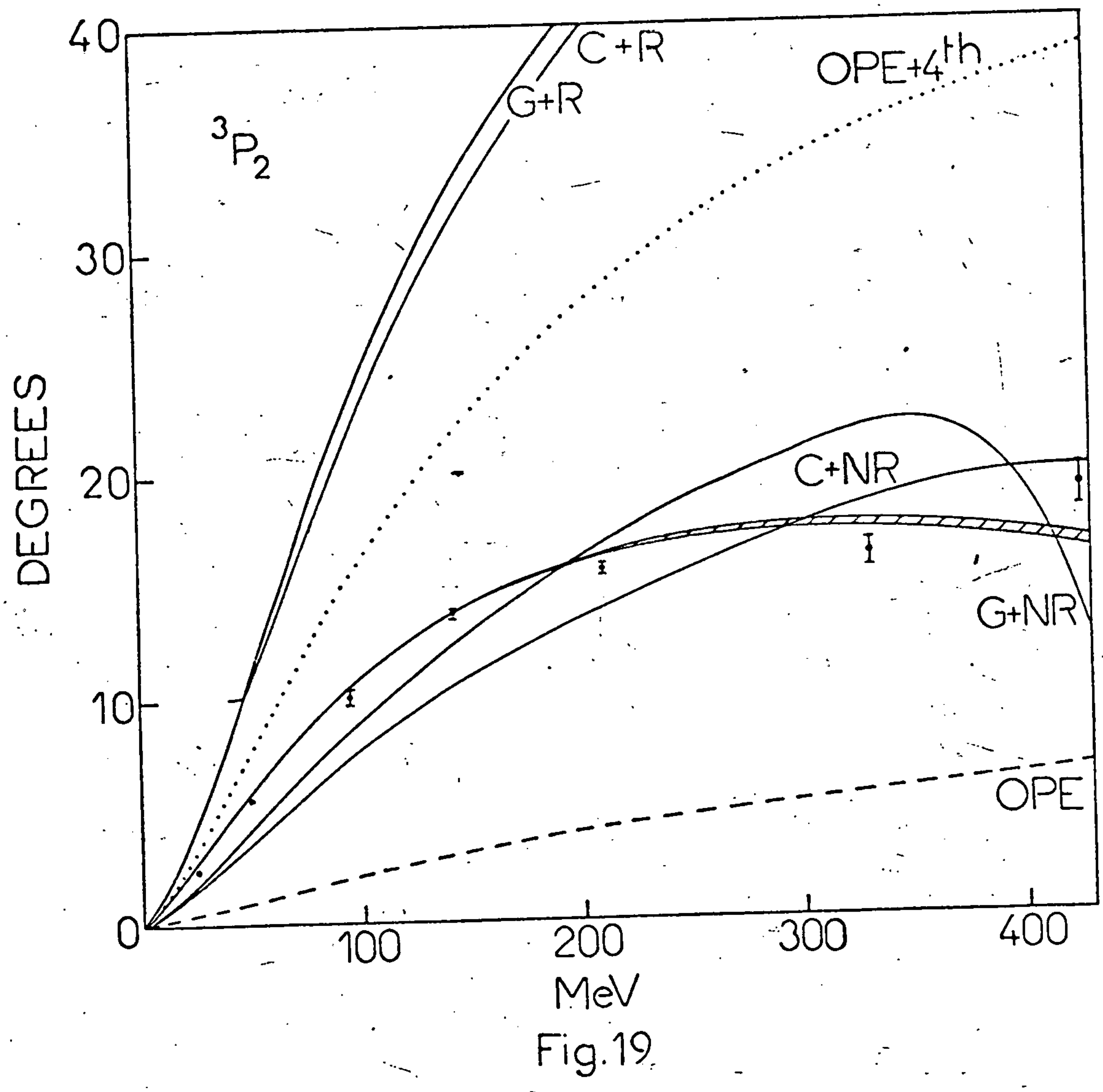

35
30
20
10
0
100
200
300
400
DEGREES
MeV
G+R
C+R
G+NR
OPE+4th
C+NR
OPE
3D2

Fig. 18



40
30
20
10
0
100
200
300
400
MeV
DEGREES
$^3P_2$
C+R
G+R
OPE+4th
C+NR
G+NR
OPE

Fig.19