Comitato Nazionale per l'Energia Nucleare
ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Firenze
66/3

INFN/BE-66/7
27 Giugno 1966

M. Mandò: A CRITICAL DISCUSSION OF EXPERIMENTAL EVIDENCE FOR ERICSON'S FLUCTUATIONS.
(Invited talk at the Gordon Conference on Photonuclear Reactions, Tilton, 9-13 August 1965)

Reparto Tipografico
dei Laboratori Nazionali di Frascati

Istituto Nazionale di Fisica Nucleare
Sezione di Firenze

INFN/BE-66/7
27 Giugno 1966

M. Mandò: A CRITICAL DISCUSSION OF EXPERIMENTAL EVIDENCE FOR ERICSON'S FLUCTUATIONS. -

(Invited talk at the Gordon Conference on Photonuclear Reactions, Tilton, 9-13 August 1965)

1. INTRODUCTION.

When I was invited to give a talk on the present experimental situation concerning Ericson's fluctuations in photonuclear reactions, it was agreed that the talk would not be restricted to photonuclear reactions; the reason is that photonuclear reactions, even if we include (p,γ) and (α,γ) reactions, do not supply, partly for instrumental and partly for physical reasons, the most simple and convincing examples of Ericson's fluctuations, but rather the most controversial ones. Since, on the other hand, I believe that Ericson's fluctuations play an important, though not always obvious, role also in photonuclear reactions, I'll try to show first, through some of the most significant examples taken from other reactions, the soundness and the extent of the experimental evidence which is by now available to consider the fluctuations as a well established and general feature of nuclear reactions. Later I will try to show, again through some examples, the kind of difficulties one is likely to encounter when trying to extract information from a set of data where fluctuations are present and, finally, I will discuss some cases where fluctuations seem to be present in photonuclear reactions, but the presence of intermediate structure is also suspected and the task to separate them from Ericson's fluctuations, seems to be a very difficult one.

As it has been made clear in the preceding theoretical talk by J. Bondorf, fluctuations in the cross section are more clearly apparent and also more significant when the conditions $\delta E \ll \Gamma \ll D$(x) are satisfied; it is therefore the greatest concern of experimentalists working in this field to make δE as small as possible and to choose the energy interval in a region where the condition $\Gamma \ll D$ of strongly overlapping levels holds good.

Once these conditions have been satisfied, the next task of the experimentalist is to accumulate cross section values (sometimes relative values will also do) in an energy range (ΔE) as wide as possible. This is again another condition if quantitative comparison with the theory is aimed at, as it has also been made clear by Bondorf, as a consequence of the finite coherence width Γ, which amounts to saying that the number of independent values is of the order of $\Delta E / \Gamma$ (see also par. 3).

Finally it is desirable (though not necessary) to get values at different angles and, possibly, to select also the final energy of the emitted particle.

When all this is done, what is the experimental picture before the physicist? This will be apparent from some simple examples, which at the same time will show the great variety of the reactions to which the fluctuation phenomenon applies, as is to be expected from the generality of theoretical arguments.

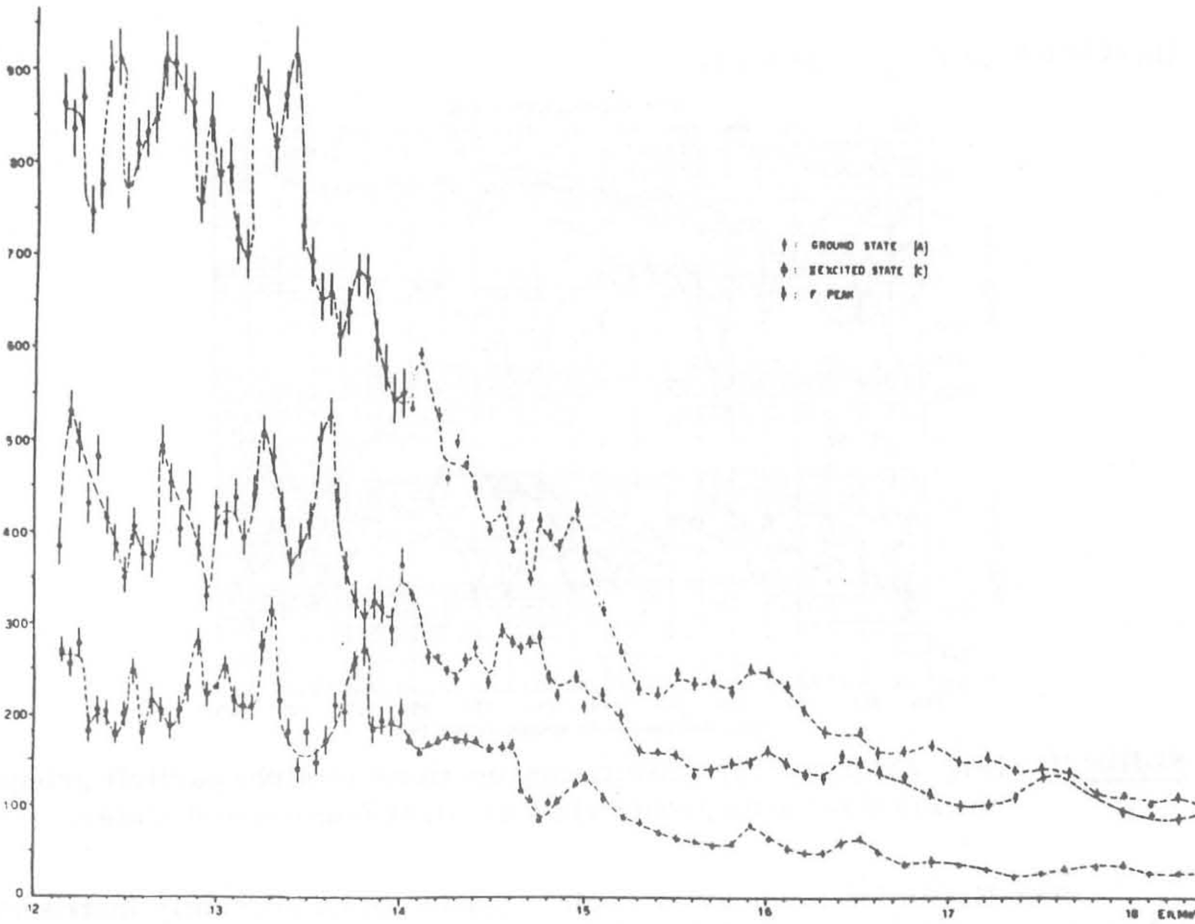
I will show, first of all, the pioneer experimental results on the reaction $Si^{28}(n, \alpha) Mg^{25}$ by the Milan group, who correctly interpreted their results as evidence for Ericson's fluctuations(1), (v. slides 1 and 2)(+).

Next slide (n. 3) shows also a pioneer experiment in this field; it was carried out at OAK RIDGE by M. L. Halbert et al. (2) on the reaction $C^{12}(O^{16}, \alpha) Mg^{24}$; it is interesting to note the presence of fluctuations also in this heavy particle reaction. Another example of heavy particle reaction is supplied by the data of E. Almquist et al. (3) on the reaction $C^{12}(C^{12}, \alpha) Ne^{20}$; their data have, in fact, been shown by J. Bondorf and Leachman(4), to be fully consistent with an interpretation in terms of Ericson's fluctuations.

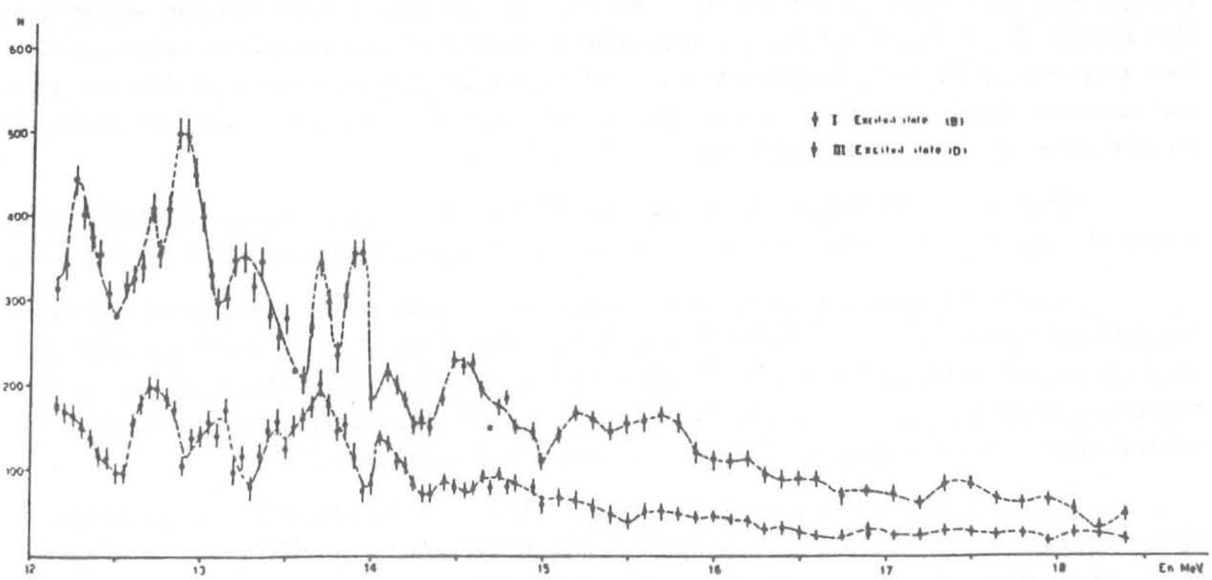
To show the range of atomic weight, in which fluctuations have been observed I'll quote now the results of Temmer et al. (5), of which unfortunately I have no slides. They have observed the phenomenon for compound nuclei as light as Ne^{20} in the reaction $F^{19}(p, \alpha) O^{16}$ at $E_{exc} = 21$ MeV (with a Γ of about 160 KeV) and for as heavy a nucleus as Ni^{60} in the reaction Co^{59}

(x) - Here δE denotes experimental energy resolution, Γ and D, as usual, the average level width and level spacing.

(+) - Figures are given in this paper progressive roman numerals, corresponding to the slides presented at the conference. They reproduce experimental results of various authors; the caption shows in parenthesis also its arab number in the original paper.

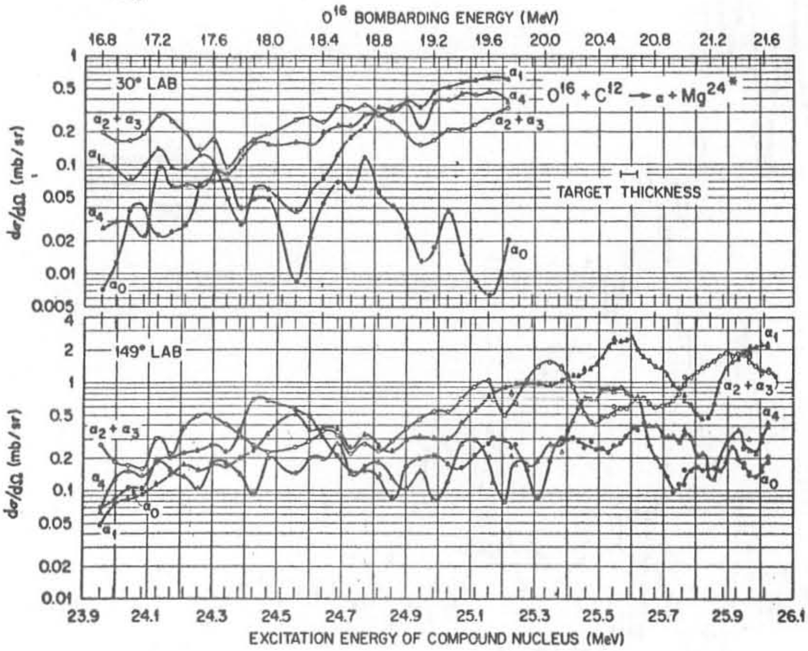


SLIDE I - (Fig. 1 in paper (1c)) - Cross section vs. energy of $Si^{28}(n,\alpha)Mg^{25}$ in arbitrary units for A, C, F, peaks.



SLIDE II - (Fig. 2 in paper(1c)) - Cross section vs. energy of $Si^{28}(n,\alpha)Mg^{25}$ in arbitrary units for B, D, peaks.

$(p, \alpha)Fe^{56}$ at $E_{exc.} = 20$ MeV.



SLIDE III - (Fig. 2 in paper(2)) - Excitation functions for alpha particle groups leaving Mg^{24} in its ground state and first four excited states.

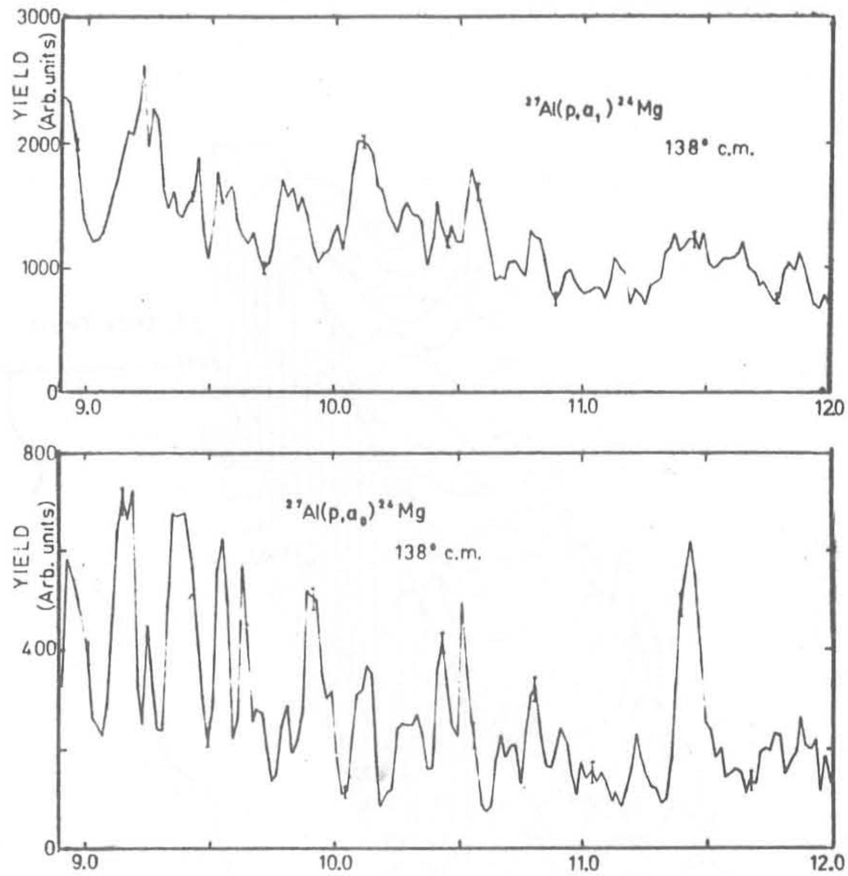
The limitation for heavier nuclei appears to be presently instrumental, because δE is to date difficult to reduce below 2 or 3 KeV at the necessarily high energies required.

Another nice example is shown in the following slide 4, which is taken from a paper by Allardyce et al.[6] at Oxford; here the yield of $Al^{27}(p,\alpha_0)$ and $Al^{27}(p, \alpha_1)$ reaction is shown as a function of proton energy in the range $9 < E_p < 12$ MeV; here the absence of correlation between the two curves is clearly apparent even at a simple inspection; and this is a characteristic feature predicted by Ericson's theory, which would be difficult to account by any other mechanism.

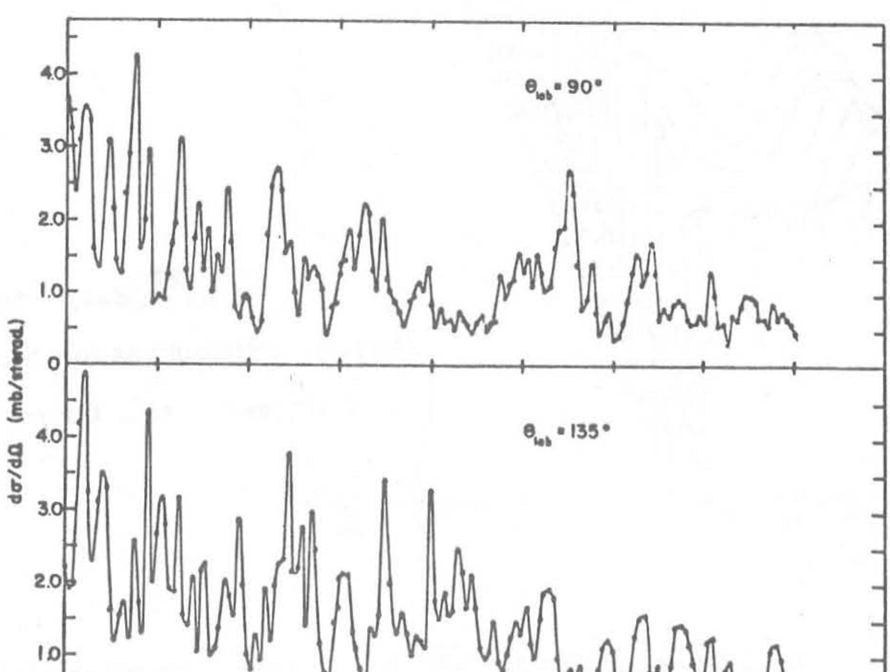
The same reaction $Al(p, \alpha) Mg^{24}$ has also been investigated more recently by a Canberra group[7], with substantial agreement. (v. slide 5).

A most favourite reaction (I believe, mainly for instrumental reasons) has been $Al^{27}(d, \alpha)Mg^{25}$ which has been studied by various groups, at Saclay, Florida and Milan[8]; the slides 6 and 7 show the results of the Saclay group and give a quite vivid picture of the large amount of data which have to be accumulated for an accurate analysis.

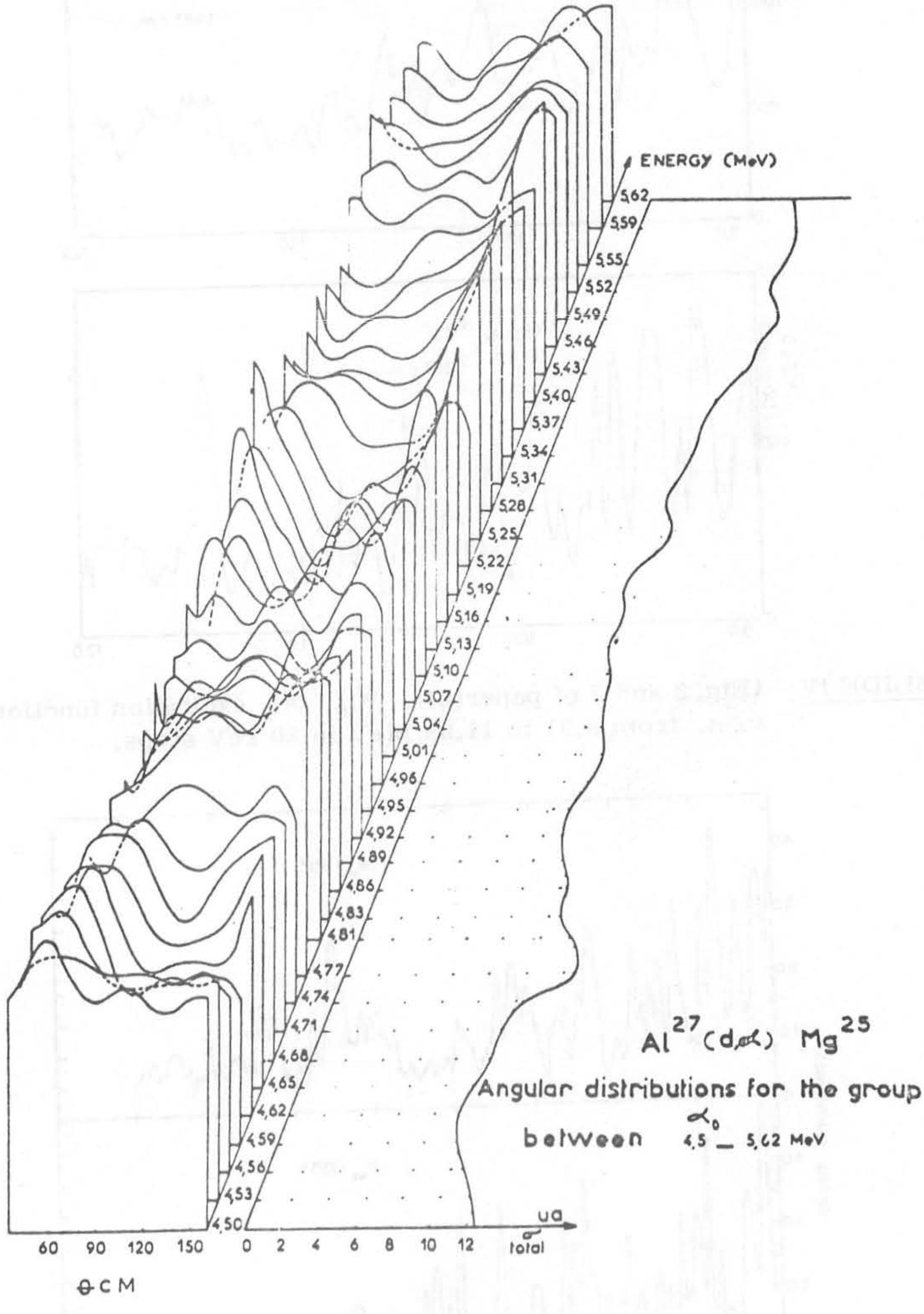
These slides show also a typical effect of Ericson's fluctuations; the angular distributions show very wild differences at different energies; at a given energy they may be strongly peaked in the forward or backward direction, without necessarily implying the presence of direct interactions; the statistical prediction of the compound nucleus mechanism that the angular distribution be symmetric is expected to be(and in fact is) fulfilled only after averaging over a suitably large energy interval.



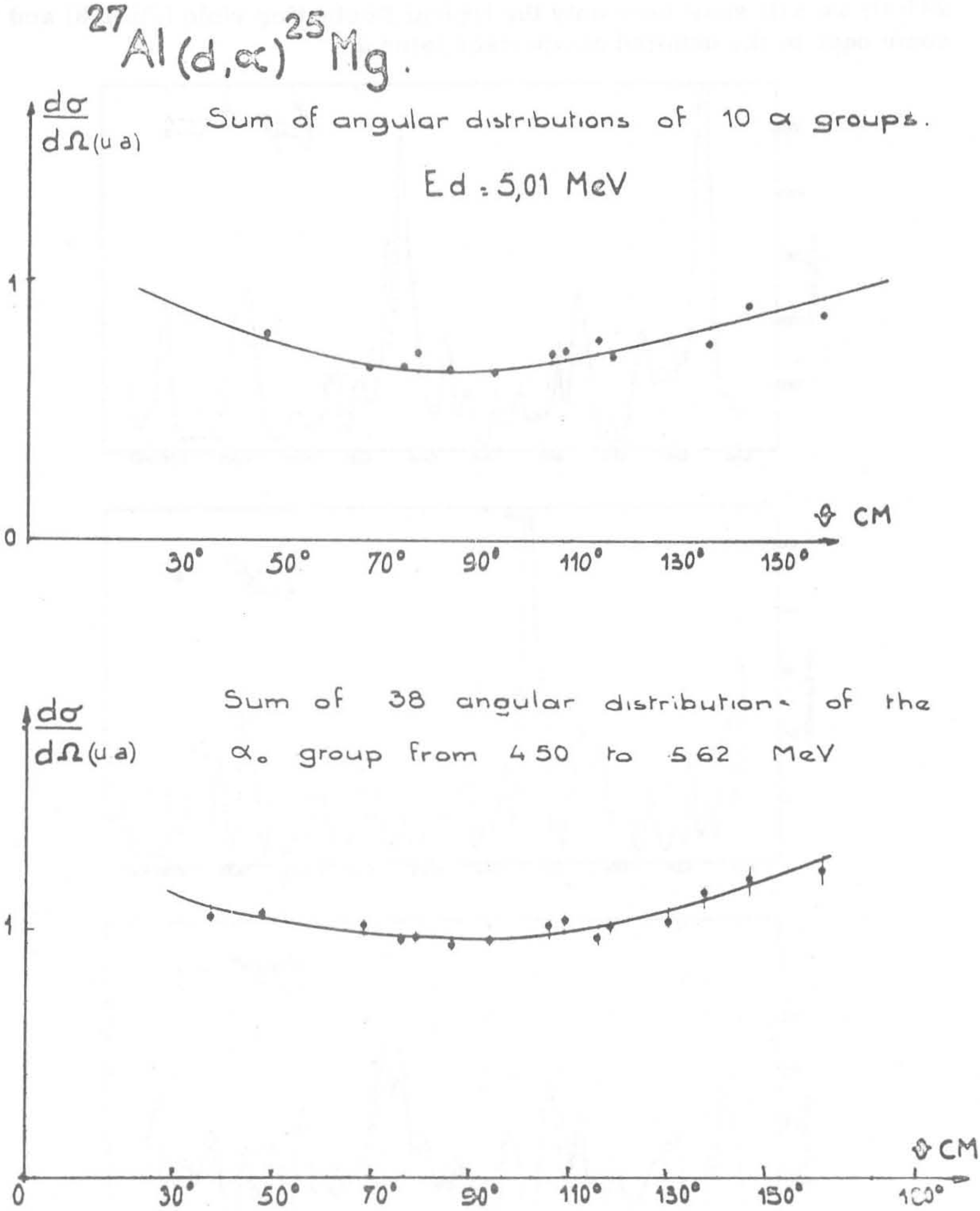
SLIDE IV - (Fig. 2 and 3 of paper(6)) - α_0, α_1 excitation functions at 138^{o} c.m. from 8.91 to 11.99 MeV in 20 keV steps.



SLIDE V - (Fig. 3 in paper (7)) - The $Al^{27}(p,\alpha_0)Mg^{24}(90^o, 135^o)$ excitation functions for alpha particles populating the Mg^{24} ground state at E = 6.0 - 10.0 MeV.

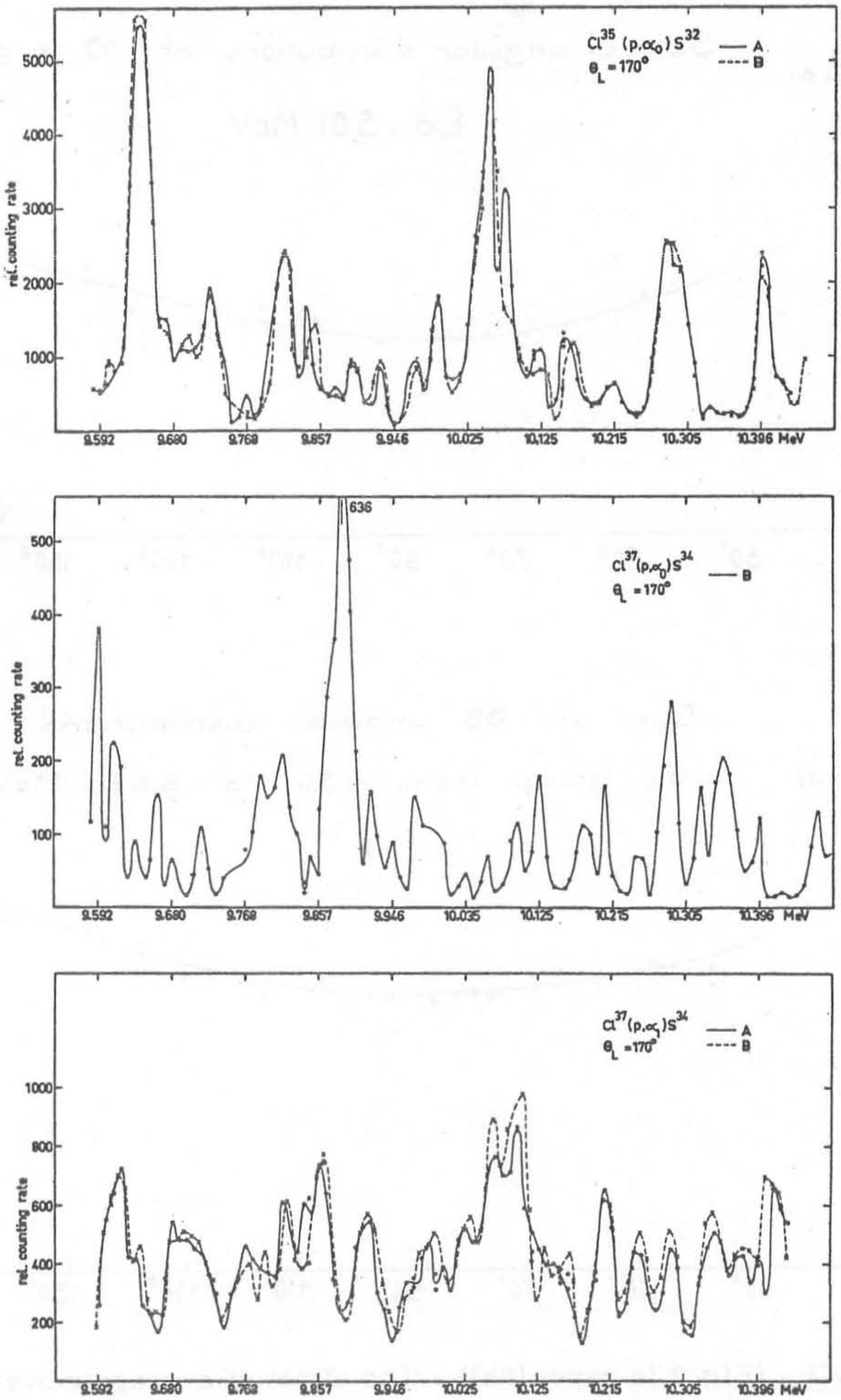


SLIDE VI - (Fig. 2 in paper (8a)) - $Al^{27}(d, \alpha_0)Mg^{25}$ angular distributions for the group α_0 between 4.5 - 5.62 MeV.



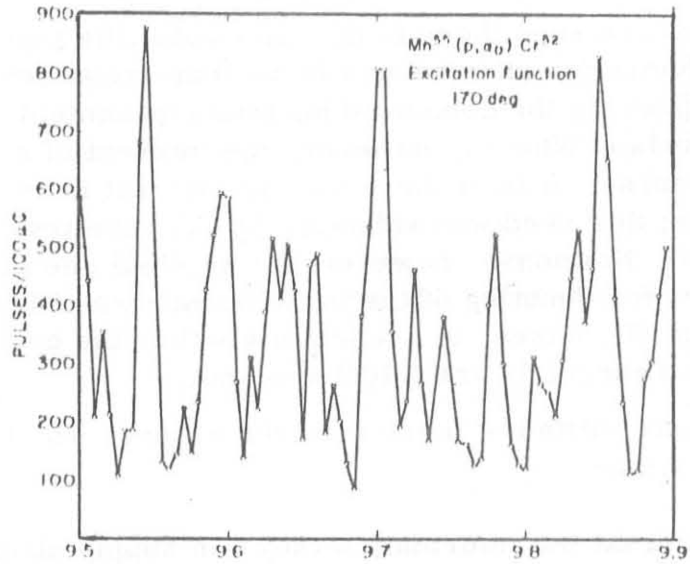
SLIDE VII - (Fig. 3 in paper (8a)) - The effect of averaging over final states or over energy on ang. distributions.

A most extensive and detailed comparison of theory and experiment has been made at Heidelberg for the reactions $Cl^{35}(p, \alpha)S^{32}$ and $Cl^{37}(p, \alpha)$ S^{34}(9); we will show here only the typical fluctuating yield (slide 8) and will come back to the detailed comparison later on.

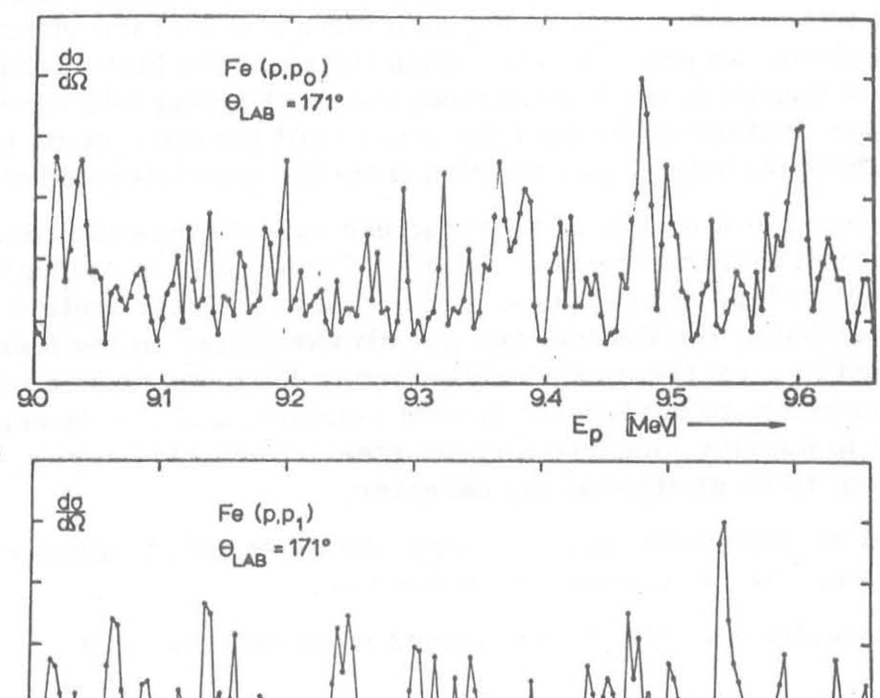


SLIDE VIII - (Fig. 1 in paper (9)) - Excitation functions of some differential cross sections.

Two more examples, for heavier nuclei, are shown by the following slides; slide 9 presents data by VONACH et al.[11] at the Argonne laboratory on the reaction $Mn^{55}(p, \alpha)Cr^{52}$. The estimated value of Γ is about 6-7 keV at E(exc) about 20 MeV. Slide 10 shows a result by the HEIDELBERG group[12] on the reaction $Fe^{56}(p, p_0)$ and $Fe^{56}(p, p_1)$ at $E_{exc.}$ from 15 to 18 MeV; the value of Γ comes out from 3 to 6 keV. This seems to be about the lowest value of Γ which can be observed with the energy resolution available to date. It is also interesting to note that the fluctuation theory applies also to compound elastic and inelastic scattering.



SLIDE IX - (Fig. 1a in paper (11)) - Excitation function for the $Mn^{55}(p, \alpha_0)Cr^{52}$ reaction.



SLIDE X - (Fig. 12 in paper (12)) - Fluctuations in elastic and inelastic scattering of protons in Fe^{56}.

2. THE INTEREST OF THE FLUCTUATIONS PHENOMENON.

After all the examples we have seen,there is no doubt about the fact of the constant presence of the fluctuation phenomenon in nuclear cross section measurements, in the region where the compound nucleus mechanism is also present and the levels overlap. What is, however, the interest of a study on fluctuations? Well, of course, at first there was an interest in verifying the theoretical predictions; this need was enhanced by the unbelievable number of sceptical people(13). Nowadays, however, as we shall see in a moment, there is no more room for doubting of the basic soundness of theory; the only question being, in specific cases, to ascertain whether the conditions for the theory to be applied correctly are fulfilled or not.

The interest, therefore, has shifted to more involved assues, which presently can be of two different kinds:

a) - to extract from the data all the information they can supply about the compound nucleus, mainly the coherence energy Γ and the relative amount of direct intercation y_D;

b) - to eliminate the "noise" produced by statistical fluctuations when looking at intermediate structures; as a matter of fact the effect of fluctuations will always be present, even when the experimental conditions (for instance poor energy resolution) are not the most favourable for a nice observation of the fluctuation themselves; and it will not often be an easy task to separate their statistical contribution from the true intermediate structure.

In the specific case of photonuclear experiments the conditions are generally such that information of the kind mentioned in a) can be best obtained from other type of reactions, and the main interest centers in point b). On the other hand, the fluctuations are always there, in the form of a "noise" and we need to know their exact behaviour to have any chance of properly get rid of them and have confidence in what remains; and this is especially true if we want to ascribe what remains to intermediate structures, which are supposed not to be statistical in character.

Let,us, therefore, examine first the most simple question a) namely how to extract the information from the data.

Basically our information comes from two sources:

A) - The correlation function, for which we refer at the most common form, which was just written on the blackboard by Bondorf, namely

$$C(\varepsilon) = \frac{\langle \sigma(E+\varepsilon)\, \sigma(E) \rangle}{\langle \sigma \rangle^2} - 1 = \frac{1}{N}(1 - y_D{}^2)\, \frac{\Gamma^2}{\Gamma^2 + \varepsilon^2} \tag{1}$$

B) - The probability distribution of cross sections.

It is easily seen that from an accurate correlation curve, we can easily extract Γ and the product $(1/N)(1 - y_D^2)$, N being the so called number of effective channels (and 1/N the so called damping factor); this remains true also when experimental errors and especially the finite range effect are taken into account; though this latter effect may introduce comparatively big errors.

From the probability distribution curve more complete information can, in principle, be extracted, and in particular N and y_D could be obtained separately. Unfortunately, however, the finite range effect introduces such uncertainties that this separation is rarely possible from data collected in actual experiments.

There are, however, some cases in which N can be fairly accurately estimated theoretically; in these cases a well consistent agreement has been obtained between theory and experiment and, besides Γ, also fairly accurate values of y_D have been obtained. It must be borne in mind, however, that in any case, small values of y_D cannot in general be accurately determined, because, in the correlation function, y_D appears in the expression $1-y_D^2$ and even the distribution function is not very sensitive to a small admixture of direct interaction.

3. CONDITIONS FOR A GOOD FLUCTUATION EXPERIMENT AND VERIFICATION OF THE THEORY.

A good fluctuation experiment for the verification of the theory has to fulfil some conditions, arising partly from the theory itself and partly from the need of a significant statistical sample.

We leave aside the basic statistical assumption, which is by now quite well established; it may be said, however, that the fluctuation phenomena have brought, in the end, a good of evidence to establish the hypothesis.

Then the conditions, as already shown by Bondorf, are:

1) - We must work in a region of overlapping levels; theoretically $(\Gamma/D) \gg 1$ but it has been shown that $(\Gamma/D) > 2$ is practically a quite good approximation; (see, f. i., Moldauer(10)).

2) - The energy resolution (δE) of the experiment must be very good, namely $\delta E \ll \Gamma$; the experimental verification is the more straight forward and convincing, the better this condition is satisfied; once, however, one believes in the correctness of the theory, suitable corrections can be applied to get good results up to δE of the order of Γ. It is perhaps important to point out that, while for a good fluctuation experiment the condition $\delta E \ll \Gamma$ or at least $\delta E < \Gamma$ must be fulfilled, the fluctuation phenomenon is only damped

out but is still present when $\delta E > \Gamma$ and it takes $\delta E \gg \Gamma$, to smooth it out completely; we will come back to this question later on.

3) - Large sample size; this means that the energy range ΔE over which measurements are taken must be large compared to Γ ; the larger the better; $\Delta E \gg \Gamma$. This point can hardly be overemphasized; there are many papers on the subject of evaluating the errors introduced by taking all the necessary averages over a finite range (see Böhning, Gibbs, Hall etc.)[14]. As a rule of thumb it may be said that an energy range ΔE is equivalent, owing to the correlation extending over an interval of the order of Γ, to a collection of about $\Delta E/\Gamma$ independent points; accurate evaluation however, shows that the situation is even worse, the relative standard deviation for $\langle\sigma\rangle$ being, e.g., $\sqrt{\pi\Gamma/\Delta E}$.

4) - The theory supposes that the average value of σ is costant over the range ΔE, that is it considers that whatever differences there are from the overall average $\langle\sigma\rangle$, these are due to statistical fluctuations and not to any systematic trend; we will discuss this point in a moment.

5) - A final important point for a good verification is that, whenever possible, many different channels should be measured independently and their cross correlations should be shown, by analysis, to be zero; this is an important part of the verification if the mechanism of the reaction has to be checked, but once one believes in the validity of the theory, the fundamental formulas to gather the information on Γ and y_D can be applied, without bothering about many different channels; another point, which is related to this, but again is not essential, is that the smaller is the number of independent channels that contribute to a given σ, the easier is the verification and application of the theory; in fact for a small number of channels N the fluctuations amplitude is larger and the value of N can often be estimated quite reliably from the theory.

6) - Finally, another point which has been analyzed theoretically, and checked experimentally, is the correlation which exists among the σ's taken at different, but not too distant, angles; though this a subsidiary point in the theory, it has to be kept in mind always; I will not insist on this point and refer to the litterature[15].

Before leaving this general presentation of the main points to be kept in mind when an analysis of fluctuating cross section is attempted, I would like to return to points 3) and 4) because they tend to impose conflicting restrictions and may sometimes make the situation quite difficult.

In fact to get a reasonably significant sample (say $\Delta E = 100\,\Gamma$)[(x)] one should use an energy interval of the order of many MeV in most cases; on the other hand it is difficult to make sure that over so large an interval the ave-

---

(x) - And even this implies, e.g., an error of 17% in $\langle\sigma\rangle$.

rage $\langle\sigma\rangle$ remains truly constant namely does not show a systematic trend; much attention has been given to this problem, from the empirical approach to subdivide the interval into subintervals, to the attempt to get a fairly accurate theoretical extimate of what the average trend of σ (so called local averages) should be (on which the fluctuations would be superimposed or from which the fluctuations should be evaluated). We will only briefly discuss later some of these more difficult cases. See also[16]. For the time being we will be content with the following remark: you should not be surprised to see the big errors that are often reported in fluctuation results; they do not come out of the laziness of the people involved, but are due to intrinsic limitations of the method.

Now suppose all the conditions have been fulfilled, every precaution has been taken, and all the necessary manipulations have been done: what kind of evidence can we offer for the fluctuation theory?

Everybody involved in the field would say: very strong indeed. To convince other people, however, is perhaps more difficult, because the errors are always big, due to the above mentioned finite range effects, so that only a long series of examples can give sure confidence in the comparison experiment-theory; on the other hand the conditions to be fulfilled tends to restrict the number of unquestionable examples.

The comparison experiment-theory can be made on the following points:

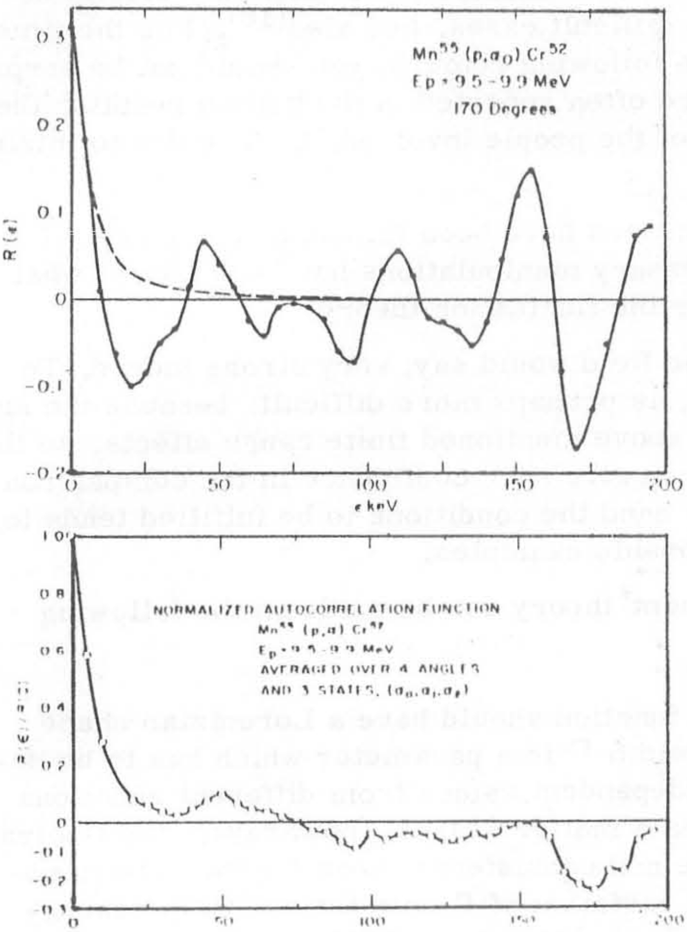
1) - The autocorrelation function should have a Lorentzian shape (though this a minor point); the width Γ is a parameter which has to be determined from the curve, but independent values from different reactions should give consistent results; as a matter of fact, nowadays, the fluctuation analysis in our more secure and consistent source for the determination of Γ values; even the slight variation of Γ with the excitation energy has been determined, while previous estimates could be as far off as a factor 2 o 3;

2) - The cross-correlation between different channels should be zero;

3) - The amplitude of the fluctuations C(0) is expressed by formula (1) as a function of N and y_D; there are, however, some cases in which N can be evaluated theoretically, while y_D can be assumed to be small enough for its square y_D^2 to be neglected with respect to 1, thus allowing a simple estimate of $C(0) \approx 1/N$.

4) - The probability distribution is also predicted by the theory as a function of N and y_D and should be consistent with the values assumed in point 3).

Now for point 1) we have plentiful examples, which are quite convincing if due account is taken of finite range errors, which especially cause the autocorrelation curve to have large fluctuations around zero for high values of $\mathcal{E}$. As for point 2), a part from the strong impression you get when you compare directly the excitation curves to different final levels (as was the case for slide 2 or for slides 3 and 4 taken together), you may evaluate the cross correlation curves.



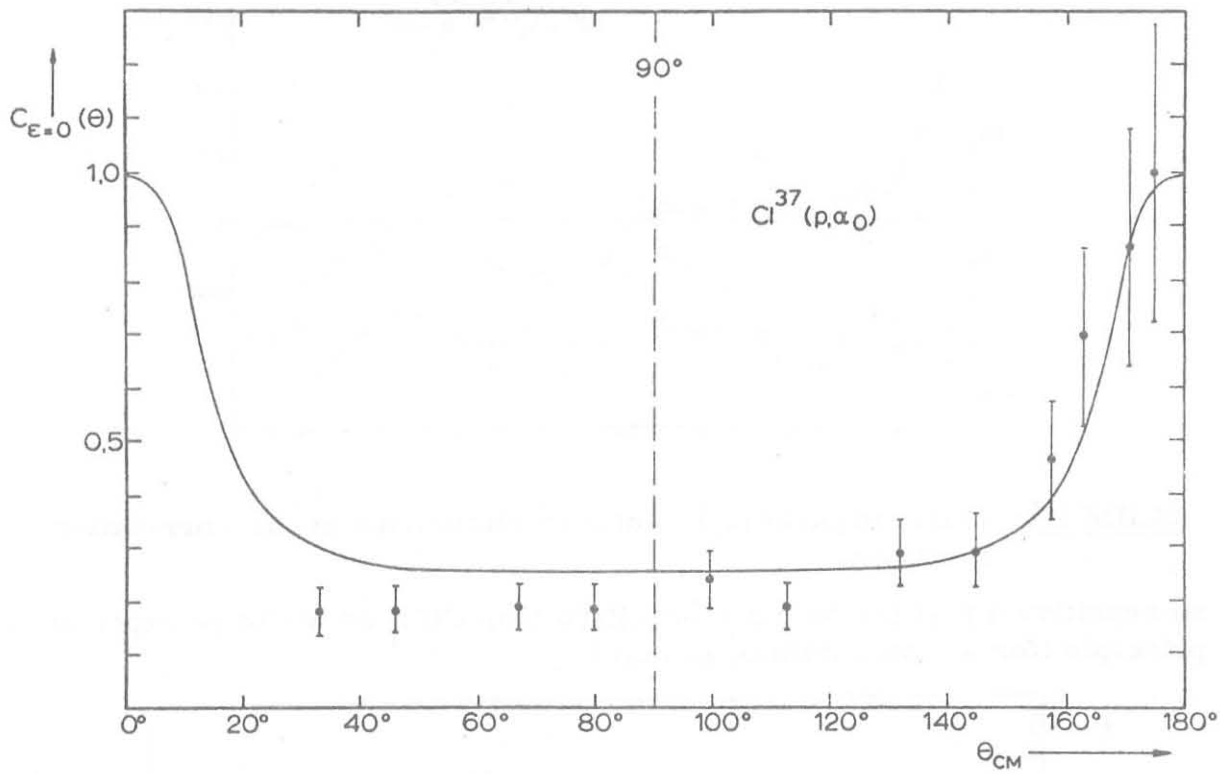
SLIDE XI - (Fig. 1b and 1c in paper (11)) - Autocorrelation functions for a single final state or averaged over angles and states.

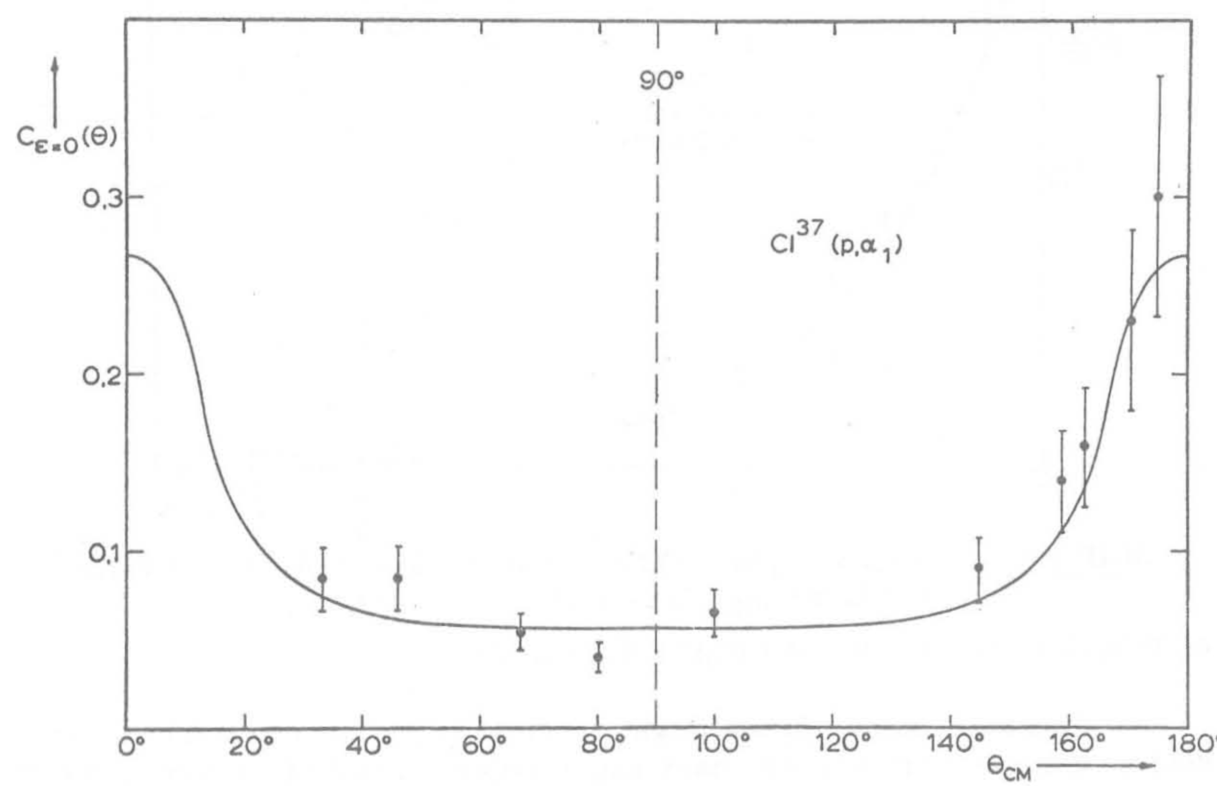
Some autocorrelation and cross correlation curves are shown in slides 11 and 12. After noticing the above mentioned effect of the finite range of the data (and the smoothing of the effect when averaging over many channels, slide 11) one is struck by the neat difference of crosscorrelation and autocorrelation curves, as it should be (slide 12). It must be remarked, however, that in some cases the fluctuations are superimposed on a systematic trend or on a direct effect mechanism and in these cases we may expect that some crosscorrelation among different channels exist, without disproving the existence of large amount of fluctuating cross section.

Point 3 represent perhaps the most stringent test of the theory.

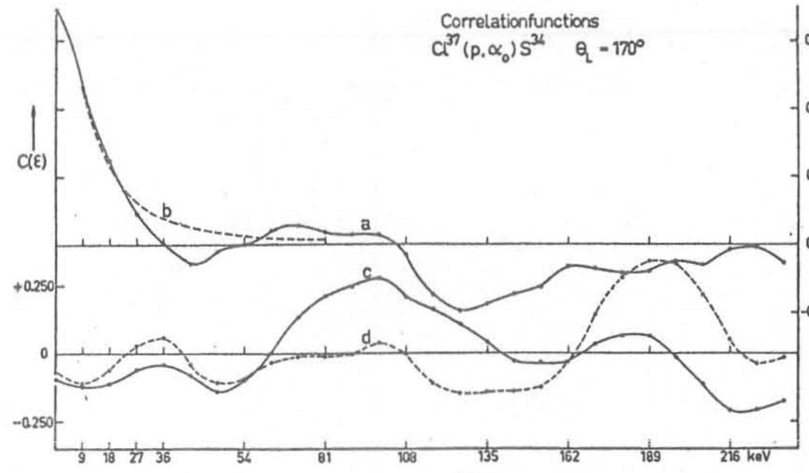
A highly significant example is shown in slide 13 which is taken from a paper by HEIDELBERG group[17]. Here the value of C(0) or the reaction $Cl^{37}(p,\alpha)S^{34}$ is plotted as a function of θ; this means different N, which is theoretically evaluable; (e. g. for a mainly statistical reaction N is expected to be 1 and C(0) also to be 1 around $\theta = 180^{\circ}$ and then to decrease for lower values of θ). The agreement with the prediction of the theory is striking. The errors are not small owing to the finite range effects, but please note that there is no adjusted parameter (not even a normalization factor).

Point 4) can also be checked; as an example we can show slide 14; we can summarize the situation by saying that the analysis is always consistent with the values of y_D and N which give a good fit to C(0); it must be said, however, that this test, owing to finite range effects, is generally not



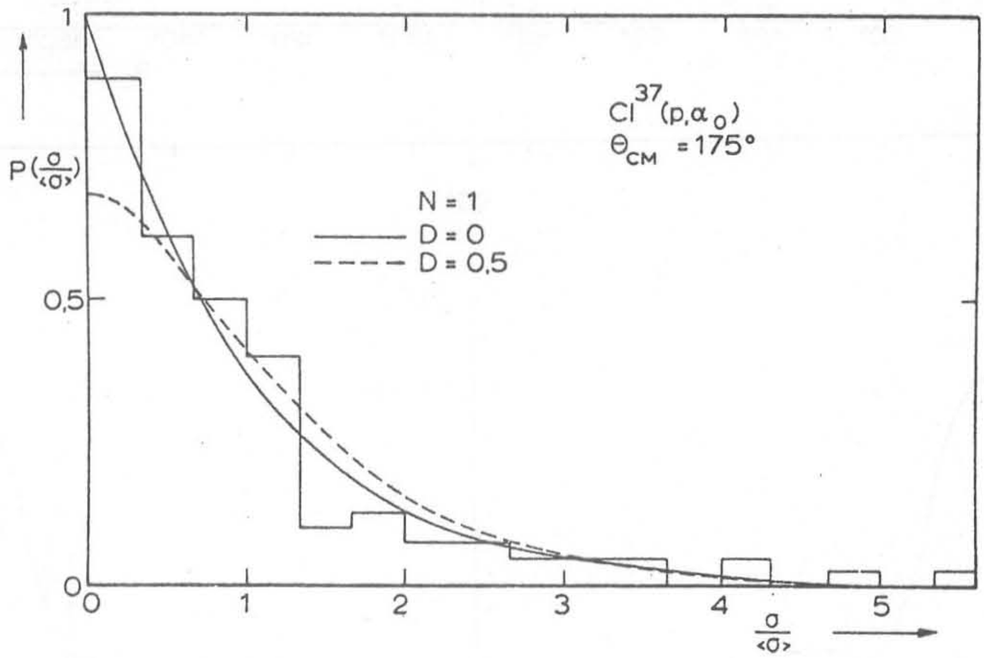


SLIDE XIII - (Fig. 7 in paper (12)) - Comparison of experimental values of the fluctuation amplitude with theoretically expected ones.



SLIDE XII - (Fig. 2 in paper (9)) - Autocorrelation and cross-correlation functions.

so sensitive a test (or no more sensitive than C(0)) as would be expected in principle (for an ideal infinite sample).



SLIDE XIV - (Fig. 8 in paper (12)) - Distribution of measured values of fluctuating cross section.

4. DISCUSSION OF MORE COMPLEX CASES.

As I said, the evidence might, at first sight, appear not be so stringent as it looks to people who have experencied the toil of collecting the data and extracting from them the few graphs I have shown.

However when you think that, by now we have many such examples and that, fortunately enough, there are practically no parameters to be adjusted, the whole picture becomes much brighter. To this you may add that the fluctuation theory follows from quite simple and widely accepted principles. It is true that in most cases the situation is not so simple, but even in the more complex cases, agreement can be found. The manipulation becomes now much more sophisticated (but without introducing a great deal of arbitrariness). These cases, when analyzed into detail (which we cannot possibly do, here), supply as strong and, in my opinion, even stronger evidence for the basic soundness of the theory.

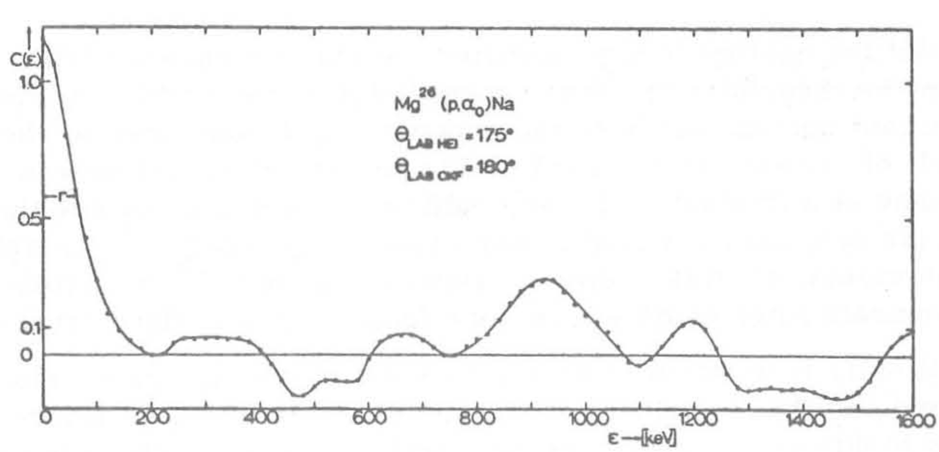
I have, before me, two preprints, (for which I have to thank the authors). These two papers belong exactly to this category of more difficult cases, requiring more sophisticated elaboration and interpretation. They are:

1) - the case of $Mg^{26}(p,\alpha)Na^{23}$ which was studied in a OXFORD - HEIDELBERG collaboration (Allardyce, Dallimore, Hall, Tanner-Richter, von Brentano, Mayer-Kuchcuk)(18);

2) - the case of $Al^{27}(\alpha, p)Si^{30}$ reaction, which is supplied by the LOS ALAMOS Laboratory with the participation of G. Dearnaley from HARWELL(19).

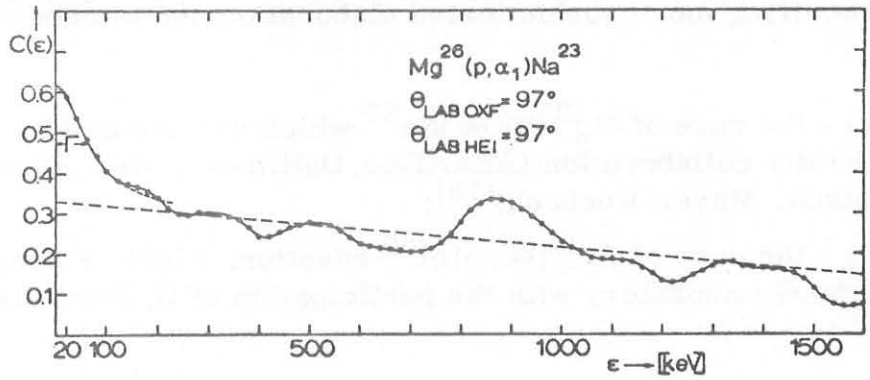
Fortunately enough for me there is here one of the coauthors for each of these paper, namely W. Tanner for the first paper and W. R. Gibbs for the second one, so that anybody curious enough to ask for the many non trivial and not simple details, may address himself to them. I shall only insist on some particular features which appear to me noticeable for the purpose of supplying further evidence for the fluctuation theory.

In the $Mg^{26}(p,\alpha)Na^{23}$ experiment if we look at the autocorrelation function for the ground state at backward angles everything is O.K. (slide 15). But if you look at the first excited state at 97° you get the picture on slide 16.



SLIDE XV - (Fig. 5 in paper (18)) - Autocorrelation function $C(\mathcal{E})$ at the most backward angle for the reaction $Mg^{26}(p,\alpha_0)Na^{23}$.

The autocorrelation function for great $\mathcal{E}$ does not oscillate around zero, but, apparently, around some sloped straight line; this, let us say, anomalous behaviour seems to be rather the rule in this reaction. After a careful analysis of the cospicuous set of data, the authors are able to show that the results can be analyzed in terms of "modulated" noise, the noise being the usual compound nucleus fluctuations, as exactly predicted by the theory, and the modulation being at least partly an intermediate structure. Finally this intermediate structure is cautiously interpreted in term of "doorway states".



SLIDE XVI - (Fig. 6 in paper (18)) - Autocorrelation function $C(\mathcal{E})$ at $\theta_{lab} = 97^{o}$ for the reaction $Mg^{26}(p,\alpha_1)Na^{23*}$.

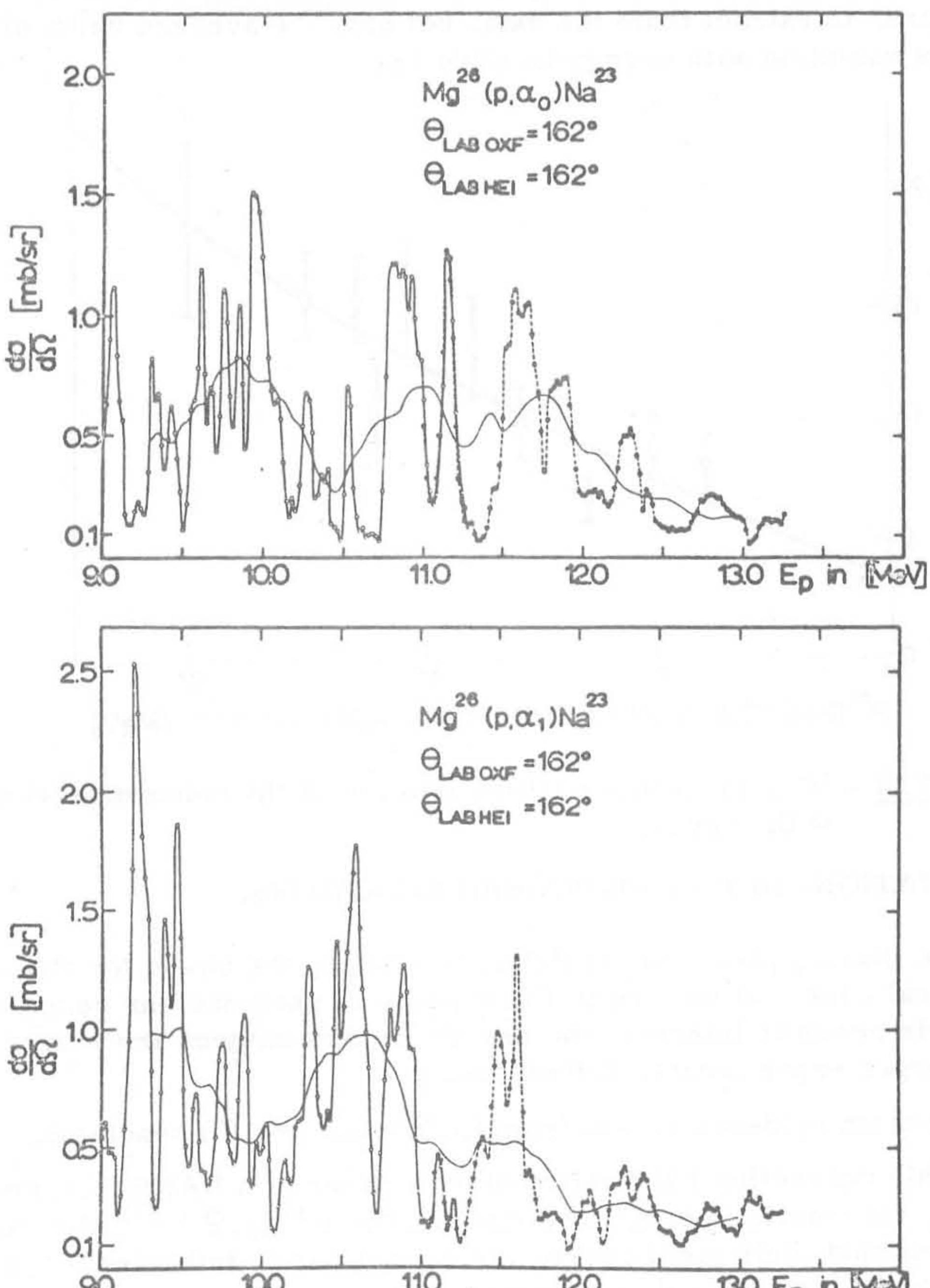
If I can add my personal opinion I agree both with the conclusions and with the caution; the reason is quite simple. To account for the whole set of data by a single parameter, namely a suitable averaging interval (which is not even critical), is a strong indication that

1) - the fine structure is really due to compound nucleus statistical fluctuations.
2) - An intermediate structure is certainly there.

But the caution is also justified because we have too little information from the theorist about these supposed doorway states, to make a really significant comparison with the experiment. I would like to show also what the result of the smoothing is (slide 17) just to emphasize how misleading the first glance at a fluctuating curve could be; in fact you can see that sharp minima in the original curve have been completely absorbed by neighbouring maxima and viceversa; this seems to illustrate quite well the difficulty of the job to separate intermediate structure from the basic fluctuation noise.

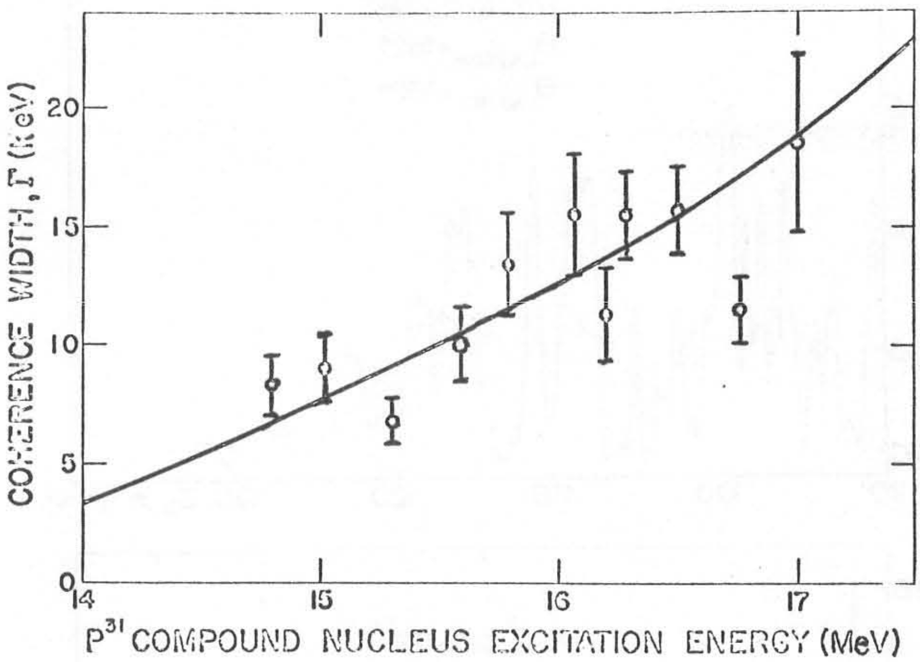
Finally it is worth to have a look at the detailed comparison between the Oxford and the Heidelberg results in the energy region where they overlap: it is highly gratifying to see how well the wildly fluctuating pattern is reproduced in detail.

For the LOS ALAMOS experiment[(19)] I'll show only some results, indicating the high degree of refinement of which a careful fluctuation analysis of a large set of data is nowadays capable.



SLIDE XVII - (Fig. 8 in paper (18)) - Excitation functions for $Mg^{26}(p,\alpha_{0,1})$ Na^{23} superimposed on the cross section averaged over an interval of 600 keV.

As you can see in the slide physicist are now able, in spite of finite range errors, to extract from the data, not only the average value of Γ, but also its variation with energy (v. slide 18).



SLIDE XVIII - (Fig. 11 in paper (19)) Variation of the coherence width Γ with energy.

5. FLUCTUATIONS IN PHOTONUCLEAR REACTIONS.

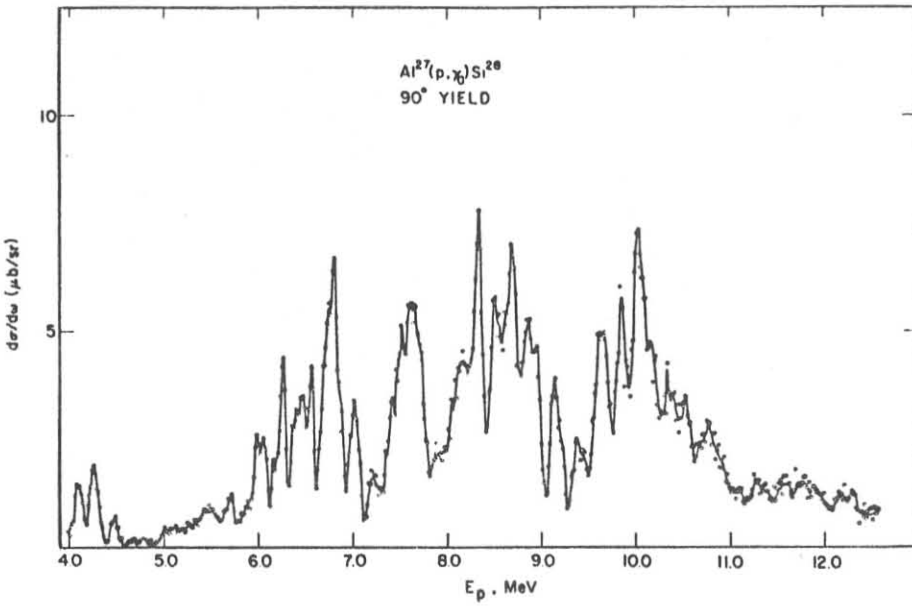
Now, having plead successfully, as I hope, the cause for fluctuations in the general case, let us turn to fluctuations in photonuclear reactions. In spite of their peculiar interest, the results on this subject are scanty, mainly due to larger experimental difficulties.

The main evidence comes from (p, γ) and (α, γ) reactions.

In this connection I'll first mention a paper of a HARWELL group[(20)] (Dearnaley, Gemmell, Hooton and Jones) on the $P^{31}(p, \gamma) S^{32}$ reaction: it is my opinion that their yield curve, for $E_p > 6$ MeV, indicates a typical fluctuation behaviour, though the authors themselves do not accept this interpretation, which was suggested by TANNER (appendix to paper (20)). Since I do not want to enter into a detailed discussion, I will pass to the next case for which I believe the presence of fluctuations is beyound any doubt, though the detailed analysis is much more involved than it looks at first sight, owing to the probable presence of intermediate states.

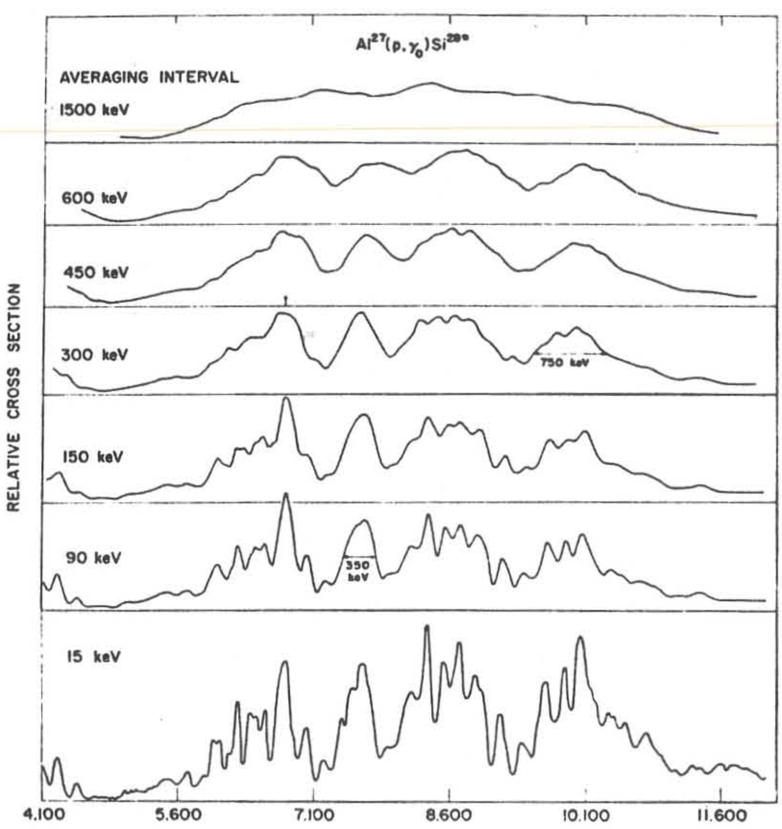
I refer to the papers on $Al^{27}(p, \gamma) Si^{28}$ reaction and $Al(\alpha, \gamma) P^{31}$ reaction (21) (22) by the ARGONNE group. Since four of the five authors are present here, I can dispense with details, though not with the conclusions.

The next slide (19) shows the yield curve, for $Al^{27}(p, \gamma_0) Si^{28}$; it looks



SLIDE XIX - (Fig. 3 in paper (21)) -Differential yield curve for Al^{27} $(p, \gamma_0) Si^{28}$.

quite satisfactory for fluctuation minded people. But now let us try to average the cross section, (thus simulating a bad resolution experiment, please take note) in order to get an idea of the average behaviour, which in the ideal fluctuation experiment should be a constant all over the range. (slide 20). We soon notice not only the appearance of the giant resonance but also some bumps which we are tempted to interpret as intermediate structures, or doorway states, or what you like to call them.

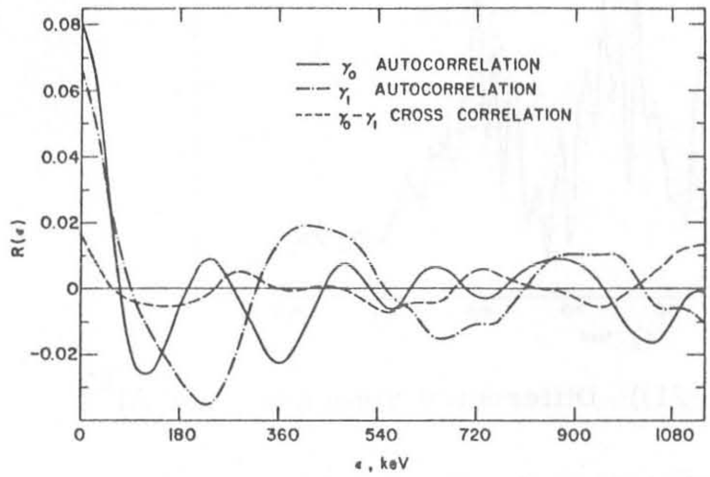


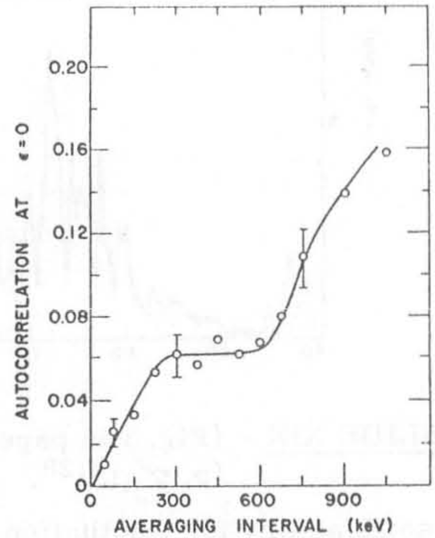
SLIDE XX - (Fig. 12 in paper (21)) - The yield curve for γ_0 for various averaging intervals.

I would like to mention at this point that the four bumps you see, seem to correspond pretty well to bumps in Si^{28} (γ, p) reaction as observed by the MELBOURNE group, whose final results are not yet fully published[23].

It is not an easy job to convert the strong impression you get from this slide (in favour of intermediate structure) in a more objective mathematical statement.

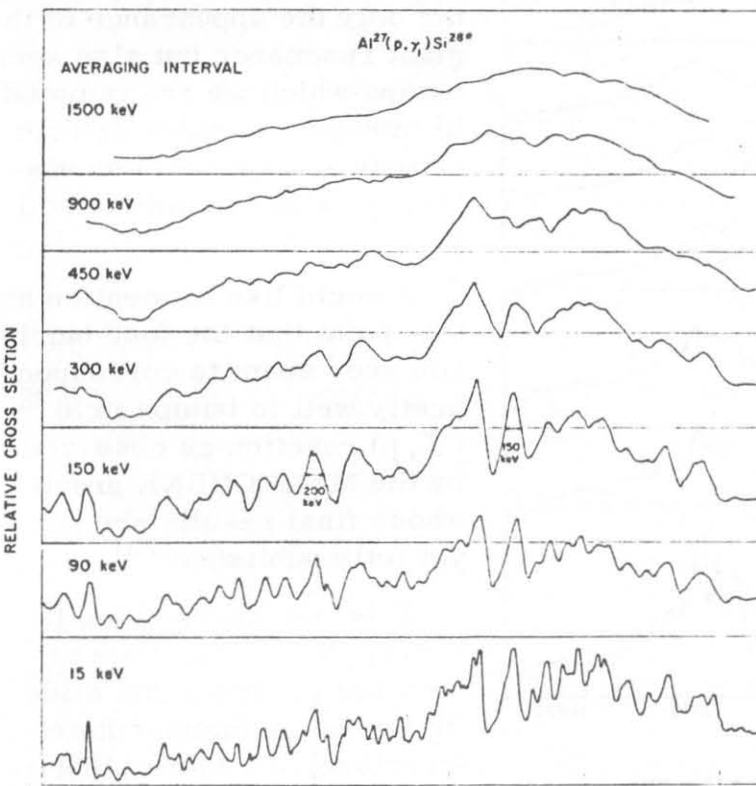
Not to enter into details I summarize my opinion by saying that, I believe that somehow the authors managed to do so; then you can go on with your analysis and find, for instance, the various correlation curves and determine your Γ (see next slide 21); then you try with (p, γ_1) the same





SLIDE XXI - (Fig. 14 and Fig. 15 in paper (21)) - Correlation functions.

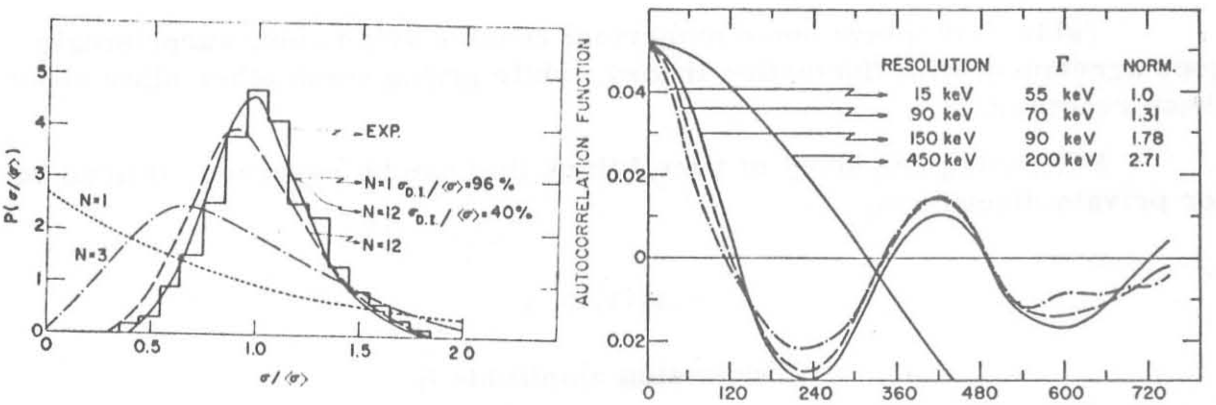
averaging procedure and you don't find the same sort of pattern (see slide 22); that is a pity, because, if you had, then you would have further evidence for intermediate structures; but not having them is not an objection to their existence; I talked this question with some theorist at the Antwerp Conference and they agreed that this is the sort of things that doorway state can pretty well do. Therefore this is a wonderful position for a theorist; if you find correlation, this is evidence for intermediate states, if you don't find it, no worry, this is not against.



SLIDE XXII - (Fig. 13 in paper (21)) - The yield curve for γ_1 for various averaging intervals.

Now, with all this sort of varying average, giant resonance, intermediate structure and so on, what will you expect from a conventional fluctuation analysis? A lot of direct interaction, because this is the name given by fluctuation people to anything else.

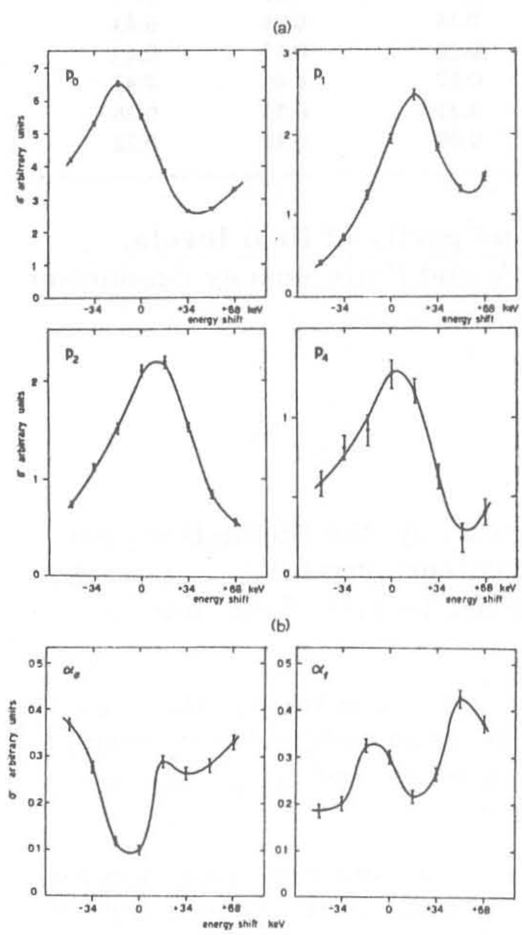
Well, this is exactly what ARGONNE people find by analyzing the probability distribu tion (slide 23, left part): 96% direct interaction. I would like to call this to your attention if you remind the strong fluctuating behaviour, which was



SLIDE XXIII - (Fig. 17 and Fig. 18 in paper (21)) - Probability distributions. Effect of experimental resolution on autocorrelation.

shown in slide 19, because this is typical. In spite of the enormous amount of D.I., the fluctuations show up quite strongly.

Now I'll show that only tiny bit of evidence we were able to get in FLORENCE with a 400 KeV machine about fluctuations in $Si^{28}(\gamma, p)$ and $Si^{28}(\gamma, \alpha)$ reactions. The results have already appeared in Nuclear Physics[24] and I will not go into details. After all I have said about finite range errors, you will be astonished to hear that our range is only about 3 Γ , which by the standard formula means 100% errors. Nevertheless I think the data still contain some information because we observed four proton and two alpha transitions and the hope is that somebody may take up the problem of extending the range; this in fact can be done by using the same reaction but, instead of sending protons on Lithium to get γ-rays, by sending 3.1 MeV Lithium ions on a hydrogen target; the Doppler shift would then allow to cover a range of about 900 keV, that is about 18 Γ. Even leaving aside fluctuations, I think that the experiment could give some interesting information, because, to date, this method supplies the best possible, fairly intense, γ -ray source, which can give a resolution of about 10 KeV.



SLIDE XXIV - (Fig.3 in paper (24)) - Experimental cross sections versus energy for the six transitions $\alpha_0, \alpha_1, p_0, p_1, p_2, p_4$.

Next slide (24) shows the cross sections for the (γ, p_0), (γ, p_1), (γ, p_2), (γ, p_4) and

$(\gamma, \alpha_0)(\gamma, \alpha_1)$ reactions.

Table 1 displays some numerical results which show surprisingly good agreement with fluctuation theory, while giving some other hints about these reactions.

But having run short of time, I think this can be reserved, if need be, for private discussion.

TABLE 1

Fluctuation amplitude $\bar{\bar{\Lambda}}$

Transition a)	Theoretical uncorrected b) E1	Theoretical uncorrected b) E2	Theoretical corrected b) E1	Theoretical corrected b) E2	Observed
$p_0(\frac{3}{2}^+)$	0.82	0.58	0.44	0.31	0.31
$p_1(\frac{1}{2}^+)$	0.71	0.71	0.38	0.38	0.43
$p_2(\frac{3}{2}^+)$	0.68	0.62	0.36	0.33	0.43
$p_4(\frac{3}{2}^+)$	0.97	0.76	0.52	0.40	0.45
$\alpha_0(0^+)$	1.00	1.00	0.53	0.53	0.36
$\alpha_1(2^+)$	0.75	0.72	0.40	0.38	0.28

a) - Values in parentheses show the spin and parity of final levels.
b) - For finite energy interval $\Delta E = 117$ keV and finite energy resolution $\delta E \approx 12$ keV.

6. CONCLUSIONS.

If I may add a word of conclusion I would say: the fluctuations are not likely to give a great help to the photonuclear physicist, all to the contrary; but, because they are there, we need to take them into account.

It is not an altogether easy job to get rid of them, when you aim at intermediate structures. But since anybody nowadays is very fond of intermediate structures, and there are many good reasons to be, this is a difficulty you have got to face and surmount.

If you allow me (a florentine) to give a rather unusual quotation for a physics conference, I will quote Dante (Divine Commedy, Purgatory)[25]. He does not want to cross the flames in order to purify his soul from his sins; Virgil is almost at a loss to convince him, but finally has a brilliant idea and says to Dante "From Beatrice thou art by this wall divided". And Dante jumps across the flames!

Let Beatrice stands for intermediate structures and the dividing wall for the fluctuations and you see what I mean. That's all. Thank you.

BIBLIOGRAPHY.

(1) - a) L. Colli, U. Facchini, I. Iori, G. M. Marcazzan, M. Milazzo and F. Tonolini, Physics Letters 1, 120 (1962).
b) L. Colli, U. Facchini, I. Iori, G. M. Marcazzan, M. Milazzo, E. Saetta Menichella, F. Tonolini, Energia Nucleare 9, 439 (1962).
c) L. Colli, I. Iori, M. G. Marcazzan, M. Milazzo, Physics Letters 2, 12 (1962).
(2) - M. L. Halbert, F. E. Durham, C. D. Moak and A. Zucker, Nuclear Physics 47, 353 (1963).
(3) - a) E. Almquist, I. A. Kuehner, D. Mc Pherson, E. Vogt, Phys. Rev. 136 B86 (1964).
b) D. A. Bromley, J. A. Kuehner, E. Almquist, Phys. Rev. 123, 878 (1961).
c) J. A. Kuehner, J. D. Prentice, E. Almquist, Physics Letters 4, 332 (1963).
(4) - J. P. Bondorf and R. B. Leachman, Matematisk-fysiske Medd. Dan. Vid. Selsk. 34, n. 10 (1965).
(5) - G. M. Temmer, Phys. Rev. Letters 12, 330 (1964).
(6) - B. W. Allardyce, W. R. Graham and I. Hall, Nuclear Physics 52, 239 (1964).
(7) - G. P. Lawrence and A. R. Quinton, Nuclear Physics 65, 275 (1965).
(8) - a) L. Papineau, Hercegnovi Lectures (août 1964).
b) Y. Cassagnou, C. Levi, I. Iori, M. Mermaz, L. Papineau, Physics Letters 2, 93 (1962); 7, 147 (1963); 8, 276 (1964); 9, 263 (1964).
c) I. M. Naqib, R. Gleyvod, N. P. Heydenburg, Nuclear Physics 66, 129 (1965).
d) M. Corti, G. M. Marcazzan, L. Milazzo Colli, M. Milazzo, private communication and in the press.
(9) - P. v. Brentano, J. Ernst, O. Häusser, T. Mayer-Kuckuk, A. Richter and W. v. Witsch, Phys. Letters 9, 48 (1964) and private communication.
(10) - P. A. Moldauer, Phys. Lett. 8, 70 (1964).
(11) - H. K. Vonach, A. Katsanos and J. R. Huizenga, Phys. Rev. Letters 13, 88 (1964).
(12) - Bamberger, Böhning, v. Brentano, Ernst, Harney, Häusser, Kotajima, Mayer Kuckuk, Stephen, Richter, v. Witsch, page 15 and 16 in Tandem Laboratorium Jahresbericht 1964 des Max Planck Institut für Kernphysik in Heidelberg (herausgegeben von W. Hering, 1965/V/4).
(13) - Among the sceptical people the following are to be quoted: K. Tsukada, Tson Jen Lee, Phys. Lett. 11, 141 (1964). Though their objections may partly apply to some of the earlier results (see also W. Breunlich, Antwerp Conference 1965, Contribution 100) it is by now certain that they do not apply to the most recent experiments and that also the earlier results are substantially correct, even if they may need some corrections for a quantitative comparison with the theory and an exact extraction of the parameters Γ and y_D.
(14) - a) M. Böhning, Comptes Rendus du Congrès International de Physique Nucléaire (Paris 2-8 juillet 1964). Contr. 4a/C158 Vol. II, page 697, and also private communication.

b) I. Hall, Physics Letters 10, 199 (1964).
c) W. R. Gibbs, "Finite sample Effects in Nuclear Cross-section Fluctuations". (University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico) in the press and private communication.
(15) - D. M. Brink, R. O. Stephen, N. W. Tanner, Nuclear Phys. 54, 577 (1964).
(16) - G. Pappalardo, Phys. Letters 13, 320 (1964).
- E. Gadioli, Phys. Letters 16, 288 (1965).
(17) - W. vonWitsch, P. von Brentano, T. Mayer-Kuckuk and A. Richter, "The statistical character of the Reaction $^{37}Cl(p, \alpha)^{34}S$ at 20-22 MeV Excitation Energy of the Compound Nucleus". Private communication, to be published.
(18) - B. W. Allardyce, P. J. Dallimore, I. Hall, N. W. Tanner, A. Richter, P. von Brentano, T. Mayer Kuckuk, "An analysis of cross section fluctuations in the reaction $Mg^{26}(p, \alpha)Na^{23}$". Private communication, to be published.
(19) - G. Dearnaley, W. R. Gibbs, R. B. Leachman and P. C. Rogers, "Investigation of the $Al^{27}(\alpha, p)$ Reaction by Cross-Section Fluctuation Studies". Private communication, to be published.
(20) - G. Dearnaley, D. S. Gemmell, B. W. Hooton and G. A. Jones. Nuclear Phys. 64, 177 (1965), with an appendix by N. W. Tanner.
(21) - P. P. Singh, R. E. Segel, L. Meyer Schutzmeister, S. S. Hanna and R. G. Allas, Nuclear Phys. 65, 577 (1965).
(22) - Private communication by R. E. Segel, L. Meyer Schutzmeister and Zeev Vager.
(23) - a) K. H. Lokan, G. R. Hogg, P. H. Cannington, R. J. Stewart, Phys. Letters 11, 73 (1964).
b) P. H. Cannington, R. J. J. Stewart, G. R. Hogg, K. H. Lokan and D. G. Sargood, private communication.
(24) - P. G. Bizzeti, A. M. Bizzeti Sona, M. Bocciolini, G. Di Caporiacco, T. Fazzini and M. Mandò, Nuclear Phys. 63, 161 (1965).
(25) - Dante Alighieri - Divine Comedy - Purgatory - Canto XXVII, verses 36 37 (in the H. F. Cary's translation).