

IS THE PENTAQUARK THE ONLY JUSTIFICATION FOR RESEARCH ON KN PHYSICS?*

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(Received July 2, 2007)

The talk is intended to motivate the use of DAΦNE-2 running at the ϕ peak as an intense, clean source of low-momentum charged and neutral kaons. It covers a few open problems still unsolved after more than twenty-five years and the physics (some of it still novel) that could be learned only in this way. And, of course, the answer to the above question is NO.

PACS numbers: 11.55.Fv, 13.75.Jz, 28.50.Nv, 36.10.Gv

1. Introduction: about history (and philosophy).

In the last few years the interest for kaon physics has significantly increased. The possibly most spectacular reason for this revival of interest for the understanding of kaon–nucleon interaction has been the suggestion of the

* Presented by G. Violini at The Final EURIDICE Meeting “Effective Theories of Colours and Flavours: from EURODAΦNE to EURIDICE”, Kazimierz, Poland, 24–27 August, 2006.

possible existence of a pentaquark reported in 2003 by the LEPS/SPring8 group in Japan [1]. However, after a couple of years new experimental results [2] cast serious doubts [3] on the existence of such a state.

The fact that usually one makes reference to a theoretical prediction about the possible existence of such a state [4] might cover the fact that experimentally there had already been some indication of that sort. About thirty years ago a bump in K^+N total cross sections in the 1 GeV/ c region prompted much interest about the possibility of existence of a resonant state which would not fit a classification in either an **8** or **10** representation of $SU(3)_f$. Investigations by phase-shift analyses of K^+N scattering did not lead to a conclusive evidence, although some of the solutions actually exhibited a resonant behaviour in the energy region where the “pentaquark” was supposed to lie [5]. It has however to be remarked that the widths of those putative resonances were significantly larger than the one usually assigned to the pentaquark, although a recent analysis of K^+N has suggested that only a very small width would be compatible with the data [6].

It is to be noted that, having those old results been almost forgotten, the claim of the discovery of a pentaquark was something unexpected, and although linked to a theoretical prediction, it was not the result of a dedicated, systematic search. One could argue that if in the eighties the machines producing medium-energy (for the scales of that time) kaons had not been turned off, probably the consequent deeper knowledge of KN interaction could have helped in understanding better such an unexpected (at least by most) phenomenon. This is recognized in Hicks’ review [7] and it is interesting to note that it also underlines the fact that for this purpose even the (relatively) good K^+N data require new, better experiments.

A different situation is related to the increasing attention to kaon physics originated by the starting of operation at DAΦNE, where a systematic research program is carried out.

As it is well known, during the first phase of DAΦNE’s activity three experiments have been performed. On the ground of fundamental physics, KLOE seems to be the one probing more basic problems, since its goal is the study of tiny effects of CP violation in the decays of neutral kaons. The other two, FINUDA and DEAR, are devoted to the study of, respectively, hypernuclei and kaonic atoms; but, for what concerns FINUDA, one should recall its possibility of taking K_L charge exchange data on the hydrogen of its plastic scintillators, following a proposal by Olin [8].

One of the main results of DEAR is the solution of the long-standing puzzle of the character of low-energy K^-p interaction, by giving a definite confirmation that it is repulsive [9], in agreement with all the analyses of the available low-energy K^-N data. It has a strict connection with the main aspect of this talk.

The analogy between this and the pentaquark issue is that they give a common lesson: the experimental knowledge we have of KN physics at lab. momenta below 1 GeV/ c is poor and based on old data.

2. A look into possible futures at DAΦNE

Even comparing at a glance KN and πN total cross sections [10] is enough to confirm this statement, and this fact reflects in turn on the knowledge of the parameters of the KN interaction (scattering lengths, coupling constants, sigma terms), much worse than that of the $SU(3)_f$ -related πN ones.

One could argue that, despite this difference in quality, it has been possible to analyze kaon data in a coherent way, extracting the relevant information, and describing it in terms of a few parameters: however, this is only partially true, because, for example, the calculation of KN sigma terms by dispersive methods [11] is affected by substantial uncertainties, and the coupling constants involving strange particles have much larger errors than those of the $S = 0$ sector. So that the success of the comparison of their values with $SU(3)_f$ predictions, usually claimed in particle physics textbooks, is not so evident. Table I¹ offers an order-of-magnitude estimate of the uncertainties for several couplings accessible through dispersive analyses.

TABLE I

Coupling constant	$g_{\pi NN}^2$	$g_{K\Lambda p}^2$	$g_{K\Sigma N}^2$	$g_{\pi\Lambda\Sigma}^2$	$g_{\pi\Sigma\Sigma}^2$
SU(3) prediction	g^2	$\frac{1}{3}(1+2\alpha)^2 g^2$	$(1-2\alpha)^2 g^2$	$\frac{4}{3}(1-\alpha)^2 g^2$	$4\alpha^2 g^2$
uncertainty	a few %	10 %	30 %	100 %	100 %

The scope of this talk is to review the description of KN interactions at low energies, and to put in evidence a number of problems which still exist and which can only be solved by new experiments, most of which are within the reach of DAΦNE.

We shall not give many technical details, since there are several papers by our group where they are exhaustively presented [12]. Our purpose is to show, mainly to our experimental colleagues, that with a little effort one could have a much better understanding of this branch of physics. It is interesting to note that indeed some experimental proposals for the future of DAΦNE are taking into account these ideas [13, 14].

¹ Here $\alpha = f/(f+d)$ is a typical parameter of the theory, due to the existence of two $\mathbf{8}$ representations in the $\mathbf{8} \otimes \mathbf{8}$ product.

KN reactions are described by four isospin amplitudes, two for each strangeness sector. The $S = +1$ sector is well described by an S -wave scattering length approximation in both isospin channels (see Table II), being the P -wave significant only in the $I = 0$ channel from about 300 MeV/ c on.

TABLE II

$I = 1$	about -0.3 fm	(minor variations if an effective range is included)
$I = 0$		very small (between -0.1 and 0.2 fm)

The situation is much more complicated for the $S = -1$ sector, due to the presence of several coupled channels. Some fifty years ago Dalitz and Tuan proposed a formalism that in its simplest application (scattering lengths) succeeded in predicting the existence of a resonance below the elastic threshold, the $\Lambda(1405)$ [15]. Few years later, a more complicated multichannel version of this formalism including S -, P - and D -waves was used to analyze data up to about 0.5 GeV/ c [16]. As for today, the latter is one of the best, model-free analysis available for these systems².

A characteristic of this formalism is that the continuation of the parametrization to the unphysical regions automatically includes the correct theoretical behaviour at $\pi\Lambda$ and $\pi\Sigma$ thresholds.

The understanding of the interaction in the low-energy region is not exempt of problems, and this cannot be surprising insofar it is evident that no formalism can replace the scarce quality of (or even the lack of) the experimental data it aims to describe.

Before going to mention some of these problems, it is appropriate to recall that the lowest energy where (poor) data exist lies tens of MeV/ c above the region that could be studied using DAΦNE kaons.

The first problem we would like to mention, put in evidence a few years ago by some of us, is that dispersion relations for πY scattering indicate that something might go wrong in Kim's multichannel parametrization.

For the youngest colleagues who may be not too familiar with this tool broadly used in KN physics during the sixties and seventies, we recall that the analyticity of the scattering amplitude as function of the energy can be used not only to test the consistency of the values of the forward differential cross sections with the total cross sections (and through this the validity of causality at short distances), but also to determine the values of the coupling constants of the particles involved [17]. This application has a long history in the case of KN physics, where it was used as a test of $SU(3)_f$ symmetry, and, as we have shown in Table I, the different quality of pion and kaon data shows up in the relative uncertainties of the corresponding couplings.

² One of us (P.M.G.) happened to share exactly this point of view with none else but the late R.H. Dalitz at a breakfast in Frascati on the occasion of "DAΦNE '95".

Going back to πY interactions, one can use the πY amplitudes provided by the multichannel parametrization of $S = -1$ KN scattering to determine, by conventional dispersion relations, the values of the $\pi Y Y'$ couplings [18]. Their values, far from being constant, turned out to depend quite strongly on the energy at which the relations were evaluated: this behaviour was clearly signalling that something was not all-right either with the method (which however was quite successful in all other cases) or with at least one of the higher- ℓ partial waves. Figures 1 through 3 summarise nicely those results.

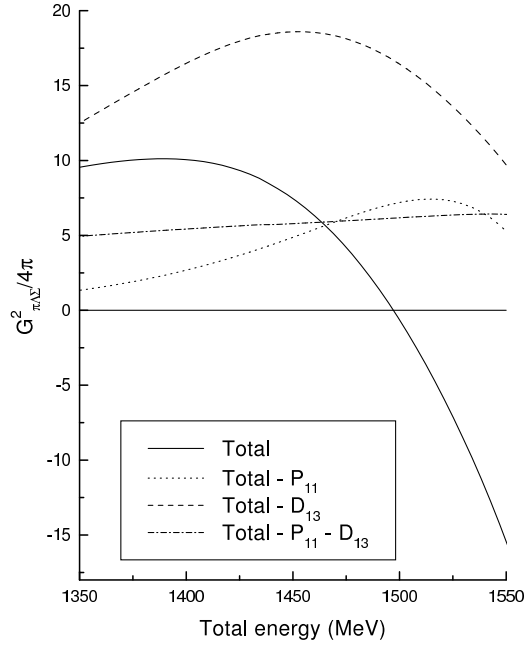


Fig. 1. $G_{\pi\Lambda\Sigma}^2/4\pi$ from $\pi\Lambda \rightarrow \pi\Lambda$.

A second problem concerns the characteristic feature of $\bar{K}N$ system, namely the existence of $S = -1$ resonances below the elastic threshold, the $\Sigma(1385)$ and the $\Lambda(1405)$. Our knowledge about them is limited, and comes mostly from production experiments and only in part from the extrapolation below threshold of the low-energy $\bar{K}N$ data. It must be observed that this region is inaccessible only to scattering experiments on hydrogen, but can be explored either in associate production or by experiments on nuclear targets, when part of the incoming kaon momentum can be carried out by the spectator nucleons [19]. For ^4He (the gas filling KLOE's wire chamber), final state interactions *in the inelastic channels* should not be a taxing problem due to the weak binding in nuclear states with $A \leq 3$.

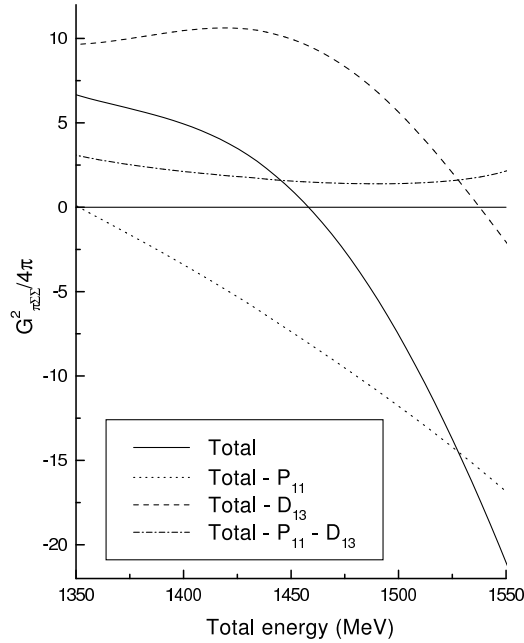


Fig. 2. $G^2_{\pi\Sigma\Sigma}/4\pi$ from $\pi\Sigma \rightarrow \pi\Sigma$ and $\pi\Lambda \rightarrow \pi\Lambda$.

Because of the possibility of exploring deeply the unphysical regions, experiments on nuclei would allow to improve our knowledge of the $\Sigma(1385)$ and $\Lambda(1405)$ resonances, and particularly to clarify the nature of the latter, on which much discussion exists in the literature, and it has even been proposed the possibility that it is actually the result of the confluence of two resonant states [20]; it is to be remarked however that the only *phenomenological* support to this hypothesis comes from a poor analysis [21] of a low-statistics experiment [22], and that related measurements could be performed with much higher statistics at DAΦNE.

Recently, two groups [23,24] have investigated this matter and the consistency of K^-p scattering length with KEK [25] and DEAR [9] measurements of the $1s$ K^-p atomic level shift. We shall not insist again on the fact that the experiments that led to attribute attractive character to the K^-N low-energy interactions go again back to the infamous eighties [26].

Both these groups make use of an approach based on chiral SU(3) symmetry, and their results leave still open several puzzling questions. In particular, Oller *et al.* [23] find two classes of solutions, one of which disagrees with DEAR measurements [9] (even if it is compatible with the less accurate KEK data [25]). Borasoy *et al.* [24] criticize the consistency of the first solution with fundamental principles of scattering theory and prefer a KEK type solution.

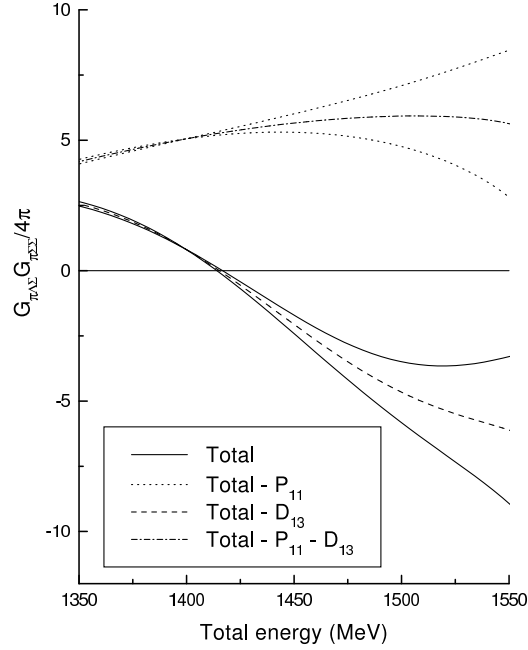


Fig. 3. $G_{\pi\Lambda\Sigma}G_{\pi\Sigma\Sigma}/4\pi$ from $\pi\Lambda \rightarrow \pi\Sigma$.

These studies do not therefore question the repulsive character of the interaction, yet they suggest a reflection. The idea of using theoretical constraints in K^-N analyses is not new, and it can be found in the literature in many variants (see, for instance, Ref. [27]); in particular it is implicit in a list of several current elements of interest for these reactions, among which chiral symmetry is quoted in the first place [28].

One can always try to constrain a fit by imposing the validity of the hypotheses to be eventually tested: however, in this way one is substituting the knowledge of experimental data of adequate quality and statistics with a theoretical (possibly well founded, but still theoretical) prejudice. This is not accidental, because this branch of physics has been plagued by the absence of new experimental results for more than twenty years, during which theoretical research has made much progress, especially with low-energy, QCD-inspired methods. Our point of view is that the desirable, sounder procedure would be to try and gain better experimental data, that could be used to test the validity of any given approach.

As a matter of fact, it is clear that new good experiments could easily provide better and more abundant data than those which, *faute de mieux*, could be used for example by Oller *et al.* (94 data points, referring to six reactions and in a very limited energy region). Obviously this does not

pretend to be a criticism to Oller's approach, but only a reminder that the scarcity of data on KN scattering is a direct consequence of the closing down of the machines where those data could have been produced.

In the last two decades a number of proposals of new facilities were debated (*e.g.* the European Hadron Facility [29] and KAON at TRIUMF [30]), but did not materialize for several — even political — reasons, and the few remaining kaon beams were barely enough to keep alive hypernuclear and exotic-atom physics.

One could still take advantage of the fact that, with the starting of DAΦNE's operations, the situation has changed, at least potentially, for the better. Although understandably the goals of the experiments carried out at DAΦNE during the first phase of its existence were not the improvement of our understanding of KN interactions, our group has repeatedly [12, 19] stressed that the experiments running there could also indirectly collect many events which could shed light on the above problems, from K^- interactions and K_L charge-exchange (and regeneration) both on ^4He and H. Furthermore, DAΦNE (running at the ϕ -resonance peak) is unique for exploring directly an energy region where otherwise the currently existing data would only allow to infer the behaviour of the scattering amplitudes via extrapolations from the higher-energy region.

Indeed DAΦNE's monochromatic charged (neutral) kaons are produced at momenta of about 127 (110) MeV/ c , making possible (via the energy losses in the detector) to explore the region down to about 90 MeV/ c , and there are at least two reasons for doing so. First, that region is sensitive to the details of the opening of the $\bar{K}^0 n$ channel; second, the possibility of collecting *in the same experimental conditions* data from K^+ , K^- and K_L^0 allows for an accurate, simultaneous isotopic spin analysis of different reactions in either S sector.

In fact, since K^-N and K^+N are described by four isospin amplitudes, the consideration of the charge exchange and regeneration amplitudes beside the elastic scattering amplitudes (which in principle are sufficient to determine completely the four amplitudes) leads to a set of overdetermined data (Table III).

TABLE III

$S = -1$	$I = 0$	$K^-p - \frac{1}{2}K^-n$
$S = -1$	$I = 1$	K^-n
$S = +1$	$I = 0$	$K^+n - \frac{1}{2}K^+p$
$S = +1$	$I = 1$	K^+p
$S = -1$	Ch. exch.	$K^-p - K^-n$
$S = +1$	Ch. exch.	$K^+p - K^+n$
Regeneration	on H	$K^-n - K^+n$

A byproduct of this overdetermination is that the possibility of studying the regeneration on hydrogen would provide an information for a combination of Kn amplitudes free of the need of taking into account the neutron Fermi motion [31]. Better regeneration data would also be able to improve considerably the determination of $g_{K\Sigma N}^2$ [32].

In this connection one should observe that the interest for the region very close to elastic threshold may lead to overstating the importance of S -waves, but P -waves should not be neglected, and for several good reasons, such as the possibility of understanding of the nature of $\Lambda(1405)$ through their interference with the S -waves, and of studying kaonic helium, an expected development of DEAR's program [33].

Until now we have insisted on the very low-energy region; however it should not be ignored that also the intermediate region is far from being fully understood. Beside the problem of the pentaquark, in that region one faces the problem of the many missing Σ and Λ states, and moreover the continuation of the most popular phase-shift analysis [34] is unable to reproduce the structure below threshold, so that its matching with the low-energy parametrizations is not exempt of ambiguities.

Last but not least, one can expect new data from JPARC, as well as at very high energy from new accelerators [35], with secondary beams having energies of a few GeV, when these facilities will be operating.

In order to be prepared to reach a coherent description of at least the low energy interaction one should exploit DAΦNE: this will allow to reliably use such description to test theoretical models that possibly can be later incorporated in the fits (with the caveat that a clear distinction between experimental data and theoretical inputs should not be forgotten).

At DAΦNE one could expect about 10^7 two-body and 10^5 three-body final-state events per year. Even taking into account some reduction in these figures due to different causes of particle losses, the rates achieved would be orders of magnitude above those of the lowest-energy available data of thirty years ago, or of the few, more recent experiments. Moreover the possibility of studying by nuclear targets the region below threshold might allow the analyses to take effectively into account the existence of the $\pi\pi\Lambda$ channel, whose threshold is in that region.

The fact that the emphasis of this talk is on strong interactions should not prevent us from making an additional comment on the possibilities offered by DAΦNE in the area of radiative captures, where one can expect $10^4 - 10^5$ events/year, and actually determine these BR for the $\Lambda(1405)$.

In conclusion, we insist on the value of systematic research, that for kaon–nucleon physics would fill a serious gap of information: with DAΦNE at present or higher luminosity, operating at the ϕ peak, we would have a great opportunity to carry on a program of this kind and it would really be — perhaps unrecoverable — a loss if this opportunity were not fully exploited.

One of us (G.V.) would like to express his gratitude to the Centro de Modelamiento Matemático of the Universidad de Chile for its hospitality when the text of this talk was prepared.

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