Proposal for a mini-workshop: Computing $\sigma(DD \to \alpha\pi^0)$

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The running lifetime of the IUCF Cooler has been extended to allow two experiments to run: one [1] is the measurement of the cross section for the reaction $DD \to \alpha\pi^0$. A non-zero value could provide a verification of QCD and for the effective field theory approach to handling QCD, and a determination of the light quark mass difference $m_d - m_u$. The potential importance of the measurement requires a very carefully executed computation of the cross section which involves different kinds of expertise. The mini-workshop could enable the creation of the necessary collaboration by identifying and bringing together theorists interested in participating.

We discuss the implications of the experiment in more detail. The first is that charge symmetry is broken if $\sigma(DD \to \alpha\pi^0) \neq 0$. Charge symmetry [2] is an approximate symmetry of QCD. If one ignores electromagnetic corrections and the mass difference between u and d quarks, then the Lagrangian is invariant under the interchange of $u \leftrightarrow d$. The presence of the small breaking of charge symmetry, CSB, is felt in hadronic mass differences, such as that between the neutron and proton, in the mass differences between mirror nuclei, and in the IUCF and TRIUMF measurements of n, p analyzing power differences in elastic scattering.

The relation between the $DD \to \alpha\pi^0$ process and the fundamental theory is that QCD predicts strong CSB in π^0 interactions. The most general Lagrangian which respects unitarity, has correct properties under cluster decomposition and which has the same symmetry as QCD should give the same results as QCD [3]. The light quark mass difference term of QCD is the third component of a chiral four vector [4], and the corresponding hadronic chiral Lagrangian $\delta\mathcal{L}$ includes a term of the form

$$\delta\mathcal{L} = -\frac{B}{4f_\pi^2}\, \bar{N}\boldsymbol{\tau}\cdot\boldsymbol{\phi}\, N\phi_3, \tag{1}$$

where f_π =93 MeV, $B \propto m_d - m_u \approx 3-4$ [2,4] MeV, and $\boldsymbol{\phi}$ is the isovector pion field operator. Weinberg [4] showed that the difference between $\pi^0 p$ and $\pi^0 n$ scattering lengths was huge, and studied the relation between B and $m_d - m_u$. The influence of this term in the production of a π^0 occurs when a virtual pion of any charge is scattered into an on-mass-shell π^0 via the term $\delta\mathcal{L}$. It is very likely that $\delta\mathcal{L}$ dominates CSB π^0 production. We studied, with Niskanen [5], the effects of $\delta\mathcal{L}$ for the reaction $pn \to d\pi^0$ for near-threshold kinematics. Here the CSB signal is any asymmetry of the π^0 angular distribution about center of mass angles of 90°. Our result is that the influence of $\delta\mathcal{L}$ gives an asymmetry that is about three times as large as the other effects he previously included [6]. However, the largest of those effects occurs for CSB in the amplitude for producing P-wave pions, which would not contribute to the reaction $DD \to \alpha\pi^0$. The net result is that, to an excellent degree of approximation,

$$\sigma(DD \to \alpha\pi^0) \propto (m_d - m_u)^2. \tag{2}$$

It is necessary to accurately compute the proportionality constant of Eq. (2). We believe that there are real uncertainties and technical challenges which can be surmounted. One needs to be concerned with initial and final state interactions, and the computation of the matrix element using good D and α wave functions. The pion production operator needs to be carefully computed for our dominant mechanism involving Eq. (1), and the other mechanisms. While the difficulties involved in computing the matrix element are not severe, a successful effort will require that expert members of different fields be involved.

A list of theorists we would like to attract to this enterprise includes: J. Carlson, C.-Y. Cheung, A. Gardestig, J. Gasser, C. Hanhart, T.-S. Harry Lee, U.-G. Meißner, F. Myhrer, J. Niskanen, R. Schiavilla, C. Wilkin. We hope and expect, that advertisement as an INT activity will lead to others joining. In addition, the IUCF experimentalists want to participate (at IUCF expense).

Given the time scales involved in both experimental and theoretical efforts, the workshop would be most useful if carried out in the Spring 2001.

A successful measurement and computation of the cross section for $DD \to \alpha\pi^0$ could provide a verification of QCD and for the effective field theory approach to handling QCD. Furthermore, a determination of the light quark mass difference $m_d - m_u$ is possible. There is a tremendous potential benefit of such an experiment. The participation of the INT, by supporting this workshop, could significantly enhance the chance for success.

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