QNP 2012

April 16-20, 2012
Palaiseau (France)

Sixth International Conference on Quarks and Nuclear Physics

40 years of development of Quantum Chromodynamics

ÉCOLE POLYTECHNIQUE ParisTech

ABSTRACT BOOK

PARALLEL SESSION

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Rare Meson Decays and Transition Form Factors

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The physics program with the WASA detector at the COSY accelerator pursues symmetry breaking processes by studying rare decays of the light unflavored mesons as well as the determination of electro-magnetic transition form factors. The WASA facility is a 4π detector system, designed to study the hadronic production and the decays of light mesons. A high density pellet target combined with the high intensity beams of the Cooler Synchrotron COSY provide luminosities which allow studies of rare processes.

Among the cases to be discussed are the three-pion decays of η and ω mesons which hold important information for chiral perturbation theory. At low energies, the dynamics of pseudoscalar Goldstone bosons is successfully described by chiral perturbation theory. New strategies are being explored to describe processes at higher energies with additional degrees of freedom. Leading–order calculations for two–body decays and decays of vector mesons to three pseudoscalar mesons are already available.

The study of the conversion decays of pseudoscalar and vector mesons aim at the precise determination of fundamental hadron properties, here, the transition form factors. The knowledge of form factors is needed for the interpretation of the g-2 and $\pi^0 \to e^+e^-$ experiments. The case of the $\omega \to \pi^0 e^+e^-$ decay provides unique information about the form factor in the time-like region where the two vector particles (the ω and the intermediate virtual photon) have an invariant mass squared significantly greater than zero. The puzzling issue has been that the transition form factor for the ω meson seems to deviate strongly from vector meson dominance predictions whereas pseudoscalar meson decays involving dileptons typically agree with vector meson dominance, for example, $\pi^0 \to \gamma e^+e^-$ and $\eta \to \gamma\mu^+\mu^-$. Here, both theoretical and experimental advances have recently been made.

Determination of ChPT low energy constants from a precise description of $\pi\pi$ scattering threshold parameters

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We present preliminary results on the determination of the values of the one and two-loop low energy constants appearing in the Chiral Perturbation Theory calculation of pion-pion scattering [1, 2, 3, 4]. For this we use a recent and precise determination [5], using the Froissart-Gribov representation, of scattering lengths and slopes that appear in the effective range expansion. In this work we provide new sum rules and the values for these coefficients up to third order in the expansion. Our results are relatively consistent with previous determinations but already seem to hint at the presence of higher order contributions, which we have considered as systematic uncertainties.

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Bounds on the spacelike pion electromagnetic form factor from analyticity and unitarity

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We use the recently measured accurate *BABAR* data [1] on the modulus of the pion electromagnetic form factor, $F_\pi(s)$, up to an energy of 3 GeV, the $I = 1$ P-wave phase of the $\pi\pi$ scattering amplitude up to the $\omega - \pi$ threshold [2], the pion charge radius known from Chiral Perturbation Theory, and the recently measured JLAB value of F_π [3] in the spacelike region at $s = -2.45\text{GeV}^2$ as inputs in a formalism [4] that leads to bounds on F_π in the intermediate spacelike region. We compare our constraints with perturbative QCD [5, 6] and the results of several theoretical models for the non-perturbative contributions proposed in the literature [7, 8, 9, 10].

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Factorization of chiral logarithms in the pion form factors

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The recently proposed hard-pion chiral perturbation theory [1, 2, 3] predicts that leading chiral logarithmsfactorize with respect to the energy dependence in the chiral limit. This claim has been successfullytested in the pion form factors up to two loops in chiral perturbation theory. We present an analyticalexplanation of this factorization property at two loops, on the basis of the dispersive representationof the form factors. We also discuss factorization of leading chiral logarithms beyond two loops.

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Tests of ChPT in Primakoff Reactions at COMPASS

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Chiral Perturbation Theory effectively describes QCD at low energies, expressing the dynamics in terms of m_π, f_π and higher-order low-energy constants. These have been adjusted to experimental results, e.g. on pion-pion scattering, and lead to predictions of quantities such as the pion polarizabilities or 2 pion production cross-sections.

The COMPASS experiment at CERN [1] is a unique tool for measurements of these quantities in pion-photon reactions, occurring in the Coulomb field of heavy nuclei with a high-energetic pion beam. The status of the polarizability determination via $\pi^-\gamma \to \pi^-\gamma$ is presented. The second focus is placed on the measurement of the cross-section $\pi^-\gamma \to 3\pi$ below 5 m_π, extracted through partial-wave analysis methods [2].

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Extraction of S-wave πN scattering lengths from data on pionic atoms

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For many years a combined analysis of pionic hydrogen and deuterium atoms has been known as a good tool to extract information on the isovector and especially on the isoscalar S-wave πN scattering length [1]. However, given the smallness of the isoscalar scattering length, the analysis becomes useful only if the pion-deuteron scattering length is controlled theoretically to a high accuracy comparable to the experimental precision. To achieve the required few-percent accuracy one needs theoretical control over all isospin conserving 3-body $\pi NN \to \pi NN$ operators up to one order before the contribution of the dominant unknown $4N\pi\pi$ contact term. This term appears at next-to-next-to-leading order in Weinberg counting. In addition, one needs to include isospin violating effects in both two-body (πN) [2] and three-body (πNN) operators. In this talk we discuss the results of the recent analysis [3] where these isospin conserving and violating effects have been carefully taken into account. Based on this analysis, we present the up-to-date values of the S-wave πN scattering lengths. Using the πN scattering lengths as an input we apply the Goldberger-Miyazawa-Oehme sum rule to extract the pion-nucleon coupling constant.

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NN interactions from Chiral Dynamics and the N/D method. Chiral Efective Field Theory for Nuclear Matter

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We report on the recent developments of a new effective field theory for nuclear matter. We present first the nuclear matter chiral power counting that takes into account both short- and long-range inter-nucleon interactions. It also identifies non-perturbative strings of diagrams, related to the iteration of nucleon-nucleon interactions, which have to be re-summed. The methods of unitary chiral perturbation theory has been shown to be a useful tool in order to perform those resummations. Results up to next-to-leading order for the ground state energy per particle of nuclear matter, the in-medium chiral quark condensate, pion-weak axial couplings and pion self-energy are discussed. We also apply the resulting nuclear matter equation of state for discussing the maximum mass allowed for neutron stars. Its precise value depends on details of the nuclear matter equation of state about which we are much more certain thanks to recent progress in low-energy effective theories. The discovery of a two-solar mass neutron star, near that maximum mass, when analyzed with modern equations of state, implies that Newton's gravitational constant in the star cannot exceed its value on Earth by more than 8% at 95% confidence level. This is a remarkable leap of ten orders of magnitude in the gravitational field intensity at which the constant has been constrained. Finally, we also discuss the application of the N/D method to study chiral nucleon-nucleon (NN) interactions. Interestingly, this method allows one to obtain NN partial waves free of regulator dependence. We will review on the list of Refs. [1, 2, 3, 4].

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Two-nucleon scattering in nuclear effective field theory with perturbative chiral two-pion exchange

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In this talk I consider the two-nucleon system from the effective field theory viewpoint. In particular, I address the problem of constructing a sensible expansion of the scattering amplitude that is able to reconcile the requirements of (i) renormalizability, (ii) the existence of a well-defined power counting at the level of observable quantities and (iii) phenomenological success. Using the proposal of Nogga, Timmermans and van Kolck [1] as a starting point, I show how these conditions can be met by perturbatively renormalizing the chiral two pion exchange contributions to the nuclear force. The explicit next-to-next-to-leading order (N^2LO) computations show that the present scheme leads to a good description of the phase shifts [2, 3], comparable with the results obtained in the Weinberg counting at the same order [4, 5], but free of the usual inconsistencies generated by the full iteration of chiral nuclear forces [6]. Further aspects of the theory, such as the convergence rate, the expansion parameter, or the power counting in deuteron reactions, will be briefly discussed [7].

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$1/N_c$ - Chiral Perturbation Theory in the One-Baryon Sector

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We study the ground state baryons in an expansion which combines both the $1/N_c$ and Chiral Perturbation Theory expansions. We analyze baryon self-energies, meson-baryon couplings and axial current corrections to NLO in both expansions for the baryon octet and decuplet. In particular the renormalization and the issues of non-commutativity of the $1/N_c$ and chiral expansions are discussed in detail. Possible relevance for understanding recent lattice results with varying quark masses is discussed as well.

Investigating the thermodynamics and susceptibilities of the $(2+1)$ Polyakov Quark Meson Model

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We consider the $(2 + 1)$ flavor Polyakov Quark Meson Model (PQM) and study the effect of including fermion vacuum fluctuations on the thermodynamics and phase diagram [1]. The variation of the thermodynamic quantities across the phase transition region becomes smoother. This results in better agreement with the lattice QCD (LQCD) data. The critical end point is pushed into higher values of the chemical potential. We then go on to study the fluctuations (correlations) of conserved charges in PQM upto sixth (fourth) order [2]. Comparison is made with LQCD wherever available and overall good qualitative agreement is found, more so for the case of the normalised susceptibilities. Our study provides a solid basis for the use of PQM as an effective model to understand the topology of the QCD phase diagram.

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The weak $\Delta S = 1$ ΛN interaction with effective field theory

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The relation between the low energy constants appearing in the effective field theory (EFT) description of the $\Lambda N \to NN$ transition potential and the parameters of the one-meson-exchange model previously developed is obtained. We extract the relative importance of the different exchange mechanisms included in the meson picture by means of a comparison to the corresponding operational structures appearing in the effective approach. The ability of this procedure to obtain the weak baryon-baryon-meson couplings for a possible scalar exchange is also discussed.

The talk will be based in the low order EFT approach of Ref. [1]. Higher order contributions will also be presented.

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Roy-Steiner equations for pion-nucleon scattering

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Starting from hyperbolic dispersion relations, we derive a closed system of Roy-Steiner equations for pion-nucleon scattering that respects analyticity, unitarity, and crossing symmetry. We work out analytically all kernel functions and unitarity relations required for the lowest partial waves. In order to suppress the dependence on the high-energy regime we also consider once- and twice subtracted versions of the equations, where we identify the subtraction constants with subthreshold parameters. Assuming Mandelstam analyticity we determine the maximal range of validity of these equations. As a first step towards the solution of the full system we cast the equations for the $\pi\pi \to \bar{N}N$ partial waves into the form of a Muskhelishvili-Omnès problem with finite matching point, which we solve numerically in the single-channel approximation. We investigate in detail the role of individual contributions to our solutions and discuss some consequences for the spectral functions of the nucleon electromagnetic form factors.

Soft spectator scattering in the nucleon form factors at large Q^2 within the SCET approach

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The proton form factors at large momentum transfer are dominated by two contributions which are associated with the hard and soft rescattering respectively. Motivated by a very active experimental form factor program at intermediate values of momentum transfers, $Q^2 \sim 5 - 15\text{GeV}^2$, where an understanding in terms of only a hard scattering mechanism cannot yet be expected, we investigate in this work the soft spectator scattering contribution using soft collinear effective theory (SCET). Within such description, the form factor is characterized, besides the hard scale Q^2, by a hard-collinear scale $Q\Lambda$, which arises due to presence of soft spectators, with virtuality Λ^2 ($\Lambda \sim 0.3 - 0.5$ GeV), such that $Q^2 \gg Q\Lambda \gg \Lambda^2$. In case of nucleon FFs the soft spectator scattering mechanism contributes at leading power accuracy and therefore it must be considered in the systematic QCD factorization approach. We discuss how to generalize the well known Brodsky-Lepage collinear factorization in order to include the soft spectator contribution using the SCET technique. We carefully investigated the factorization of the soft and collinear modes in this case and demonstrate that even for the FF F_1 the pure collinear factorization could not be valid due to the mixing of the soft and collinear contributions. As a result this allows one to put specific constrains on the end-point behavior of the nucleon distribution amplitude.

HQET sum rules for quark-gluon three-body components in the B meson

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We discuss the heavy-quark effective theory (HQET) parameters, λ_E and λ_H, which correspond to matrix elements representing quark-gluon three-body components in the B-meson wavefunction [1, 2, 3, 4, 5, 6]. We derive the QCD sum rules for $\lambda_{E,H}$ calculating the new higher-order corrections to the relevant operator product expansion in the HQET, i.e., the order α_s radiative corrections to the Wilson coefficients associated with the dimension-5 quark-gluon mixed operator, and the power corrections due to the dimension-6 four-quark operators. We find that the new radiative corrections significantly improve the stability of the corresponding Borel sum rules and lead to the reduction of the values of $\lambda_{E,H}$. We also discuss the renormalization-group improvement for the sum rules and present update on the values of $\lambda_{E,H}$. The detail is reported in our recent paper [7].

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Three-nucleon contact interaction at the next-to-leading order

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A satisfactory description of bound and scattering states of the three-nucleon (3N) system is still lacking [1], contrary to what happens in the two-nucleon case. In the framework of chiral effective theory, it is possible that a realistic 3N interaction will require the inclusion of subleading contact terms, which are unconstrained by chiral symmetry. We construct the minimal 3N contact Lagrangian imposing all constraints from the discrete symmetries, Fierz identities and Poincaré covariance, and show that it consists of 10 independent operators [2]. Prospects for a determination of the associated low-energy constants from experimental data will be discussed.

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