

Selected Abstracts from Physical Review D

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Solutions to the solar neutrino anomaly. Naoya Hata, *Institute for Advanced Study, Princeton, New Jersey 08540*; Paul Langacker, *Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania 19104*. (Received 2 June 1997)

We present an updated analysis of astrophysical solutions, two-flavor MSW solutions, and vacuum oscillation solutions to the solar neutrino anomaly. The recent results of each of the five solar neutrino experiments are incorporated, including both the zenith angle (day-night) and spectral information from the Kamiokande experiment, and the preliminary super-Kamiokande results. New theoretical developments include the use of the most recent Bahcall-Pinsonneault flux predictions (and uncertainties) and density and production profiles, the radiative corrections to the neutrino-electron scattering cross section, and new constraints on the Ga absorption cross section inferred from the gallium source experiments. From a model-independent analysis, arbitrary astrophysical solutions are excluded at the 99.4% C.L. and more than 98% C.L. even if one ignores any one of the three classes of experiment, relaxes the luminosity constraint, or allows more suppression of the ${}^7\text{Be}$ than ${}^8\text{B}$ flux. The data are well described by large and small mixing angle two-flavor MSW conversions, MSW conversions into a sterile neutrino with small mixing, or vacuum oscillations. We also present MSW fits for nonstandard solar models parametrized by an arbitrary solar core temperature or arbitrary ${}^8\text{B}$ flux. [S0556-2821(97)01422-7] [Phys. Rev. D **56**, 6107 (1997)]

How neutrino oscillations can induce an effective neutrino number of less than three during big bang nucleosynthesis. R. Foot and R. R. Volkas, *School of Physics, Research Centre for High Energy Physics, The University of Melbourne, Parkville 3052, Australia*. (Received 4 June 1997)

Ordinary-sterile neutrino oscillations can generate significant neutrino asymmetry in the early Universe. In this paper we extend this work by computing the evolution of neutrino asymmetries and light element abundances during the big bang nucleosynthesis (BBN) epoch. We show that a significant electron-neutrino asymmetry can be generated in a way that is approximately independent of the oscillation parameters δm^2 and $\sin^2 2\theta$ for a range of parameters in an interesting class of models. The numerical value of the asymmetry leads to the prediction that the effective number of neutrino flavors during BBN is either about 2.5 or 3.4, depending on the sign of the asymmetry. Interestingly, one class of primordial deuterium abundance data favors an effective number of neutrino flavors during the epoch of BBN of less than 3. [S0556-2821(97)03822-8] [Phys. Rev. D **56**, 6653 (1997)]

New singularities in nonrelativistic coupled channel scattering. I. Second order. N. N. Khuri, *Department of Physics, The Rockefeller University, New York, New York 10021*; Tai Tsun Wu, *Gordon McKay Laboratory, Harvard University, Cambridge, Massachusetts 02138-2901 and Theoretical Physics Division, CERN, CH-1211 Geneva 23, Switzerland*. (Received 7 May 1997)

New and surprising singularities are found in the forward scattering amplitude for nonrelativistic potential scattering with coupled channels. In the simplest case of two coupled channels, these singularities appear when the energy difference between the two channels is larger than the inverse range of the potential. They are similar to singularities recently discovered by one of us for potential scattering on $R^3 \otimes S^1$. [S0556-2821(97)03923-4] [Phys. Rev. D **56**, 6779 (1997)]

New singularities in nonrelativistic coupled channel scattering. II. Fourth order. N. N. Khuri, *Department of Physics, The Rockefeller University, New York, New York 10021*; Tai Tsun Wu, *Gordon McKay Laboratory, Harvard University, Cambridge, Massachusetts 02138-2901 and Theoretical Physics Division, CERN, CH-1211 Geneva 23, Switzerland*. (Received 7 May 1997)

We consider a two-channel nonrelativistic potential scattering problem, and study perturbation theory in fourth order for the forward amplitude. The main result is that the new singularity demonstrated in second order in the preceding paper I also occurs at the same point in fourth order. Its strength is again that of a pole. [S0556-2821(97)04023-X] [Phys. Rev. D **56**, 6785 (1997)]

Pion production from baked-Alaska disoriented chiral condensate. G. Amelino-Camelia, J. D. Bjorken, and S. E. Larsson, *Theoretical Physics, University of Oxford, 1 Keble Road, Oxford OX1 3NP, United Kingdom*. (Received 30 June 1997)

We study the various stages of the evolution of chiral condensates disoriented via the "baked-Alaska" mechanism, in which the condensates are described as the products of external sources localized on the light cone. Our analysis is based on the classical equations of motion of either the linear or the nonlinear σ model. We use the associated framework of coherent states and, especially, their source functions to make the connection to the distribution functions for the produced particles. We also compare our classical approach with a mean-field calculation which includes a certain class of quantum corrections. [S0556-2821(97)07123-3] [Phys. Rev. D **56**, 6942 (1997)]

Asymptotic limits and the structure of the pion form factor. John F. Donoghue and Euy Soo Na, *Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003*. (Received 8 January 1997)

We use dispersive techniques to address the behavior of the pion form factor as $Q^2 \rightarrow \infty$ and $Q^2 \rightarrow 0$. We perform the matching with the constraints of perturbative QCD and chiral perturbation theory in the high-energy and low-energy limits, leading to four sum rules. We present a version of the dispersive input which is consistent with the data and with all theoretical constraints. The results indicate that the asymptotic perturbative QCD limit is approached relatively slowly, and give a model-independent determination of low-energy chiral parameters. [S0556-2821(97)02123-1] [Phys. Rev. D **56**, 7073 (1997)]

Heavy quark expansion and universal form factors in the quark model. Dmitri Melikhov, *Nuclear Physics Institute, Moscow State University, Moscow, 119899, Russia.* (Received 20 June 1997)

Meson transition amplitudes of the vector, axial-vector, and tensor quark currents are analyzed within the dispersion formulation of the constituent quark model. The form factors in the decay region are given by relativistic double spectral representations through the wave functions of the initial and final mesons. We perform a heavy quark expansion of the quark-model mesonic matrix elements with a next-to-leading-order accuracy and demonstrate that matching this expansion to the heavy quark expansion in QCD requires subtractions in the double spectral representations for the form factors and allows fixing the subtraction terms. The Isgur-Wise function and next-to-leading-order universal form factors are calculated. [S0556-2821(97)01721-9] [Phys. Rev. D **56**, 7089 (1997)]

Two-loop corrections to the electromagnetic vertex for energies close to threshold. A. H. Hoang, *Department of Physics, University of California, San Diego, La Jolla, California 92093-0319.* (Received 19 June 1997)

Two-loop contributions to the electromagnetic form factors are calculated in the kinematic regime close to the fermion-antifermion threshold. The results are presented in an expansion in the velocity β of the fermions in the c.m. frame up to next-to-next-to-leading order in β . The existence of a new Coulomb singularity logarithmic in β , which is closely related to the $O(\alpha^2 \ln \alpha)$ corrections known from positronium decays, is demonstrated. It is shown that due to this Coulomb singularity $O(\alpha^2)$ relativistic corrections to the non-relativistic cross section of heavy-fermion-antifermion pair production in e^+e^- annihilation cannot be determined by means of conventional multiloop perturbation theory. [S0556-2821(97)05123-0] [Phys. Rev. D **56**, 7276 (1997)]

From deep inelastic scattering to photoproduction: A unified approach. G. Kerley and G. Shaw, *Department of Physics and Astronomy, Schuster Laboratory, University of Manchester, Manchester M13 9PL, United Kingdom.* (Received 21 July 1997)

The strikingly different high energy behaviors of real photoabsorption cross sections with $Q^2=0$ and the low x proton structure function at large Q^2 are studied from a laboratory frame viewpoint, in which the x and Q^2 dependence reflects the space-time structure of the interaction. This is done using a simple model which incorporates hadron dominance, but attributes the striking enhancement

observed at DESY HERA at very low x and high Q^2 to contributions from heavy long-lived fluctuations of the incoming photon. Earlier published predictions of the model for the then unknown behavior of the structure function at small x and intermediate Q^2 are shown to be strikingly confirmed by recent experimental data. A simultaneous analysis of real photoabsorption data and structure function data for $0 \leq x < 0.1$ and $0 \leq Q^2 \leq 15 \text{ GeV}^2$ is then reported. An excellent fit is obtained, with all parameters in the restricted ranges allowed by other physical requirements. [S0556-2821(97)02523-X] [Phys. Rev. D **56**, 7291 (1997)]

Evidence for eikonal zeros in the momentum transfer space. P. A. S. Carvalho and M. J. Menon, *Instituto de Fisica "Gleb Wataghin," Universidade Estadual de Campinas, Unicamp 13083-970 Campinas, SP, Brazil.* (Received 7 July 1997)

We present the results of fitting elastic pp differential cross section data at $23.5 \leq \sqrt{s} \leq 62.5 \text{ GeV}$ with a novel analytic parametrization for the scattering amplitude. Making use of a fitting method, the errors from the free parameters are propagated to the imaginary part of the eikonal in the momentum transfer space. A novel systematic study of the effects coming from data at large momentum transfer is also performed. We find statistical evidence for the existence of eikonal zeros in the interval of momentum transfer $5-9 \text{ GeV}^2$. [S0556-2821(97)05323-X] [Phys. Rev. D **56**, 7321 (1997)]

Cosmic-ray double-core γ -family events at ultrahigh energies. Z. Cao, *Institute of Theoretical Science and Department of Physics, University of Oregon, Eugene, Oregon 97403*; L. K. Ding and Q. Q. Zhu, *Cosmic Ray Laboratory, Institute of High Energy Physics, Academia Sinica, Beijing 100039, People's Republic of China*; Y. D. He, *Department of Physics and Space Science Laboratory, University of California, Berkeley, California 94720 and Nuclear Science Division and Institute for Nuclear and Particle Astrophysics, Lawrence Berkeley National Laboratory, Berkeley, California 94720.* (Received 26 June 1996)

We present a detailed account of our analysis on ultrahigh-energy cosmic-ray double-core γ -family events observed in emulsion chambers at mountain levels. Extending the leading-order perturbative QCD jet calculations for hadron-hadron collisions to hadron-nucleus collisions by including nuclear effects, we performed a Monte Carlo simulation of cosmic-ray particle interaction and propagation in the atmosphere. We find a significant excess of event rates at large transverse momenta with respect to our prediction based on perturbative QCD. The excess cannot be accounted for by a compositeness model of quarks with a characteristic energy scale lower limit $\Lambda_c > 1.4 \text{ TeV}$ or a possible value of $\Lambda_c \approx 1.6 \text{ TeV}$ from the CDF at the Fermilab Tevatron. We discuss possible onset of new physics indicated by the large discrepancy at $E_{\text{lab}} \sim 10^4 - 10^5 \text{ TeV}$, an energy region beyond the reach of existing colliders but within the range of future hadron colliders such as the proposed Large Hadron Collider at CERN. [S0556-2821(97)06823-9] [Phys. Rev. D **56**, 7361 (1997)]

Three-neutrino mixing and combined vacuum oscillations and MSW transitions of solar neutrinos. Q. Y. Liu, *Scuola Internazionale Superiore di Studi Avanzati, I-34013 Trieste, Italy*; S. T. Petcov *Scuola Internazionale Superiore di Studi Avanzati, I-34013 Trieste, Italy and Istituto Nazionale di Fisica Nucleare, Sezione di Trieste, I-34013 Trieste, Italy.* (Received 24 February 1997)

Assuming three-flavor neutrino mixing takes place in vacuum, we investigate the possibility that the solar ν_e take part in MSW transitions in the Sun due to $\Delta m_{31}^2 \sim (10^{-7} - 10^{-4}) \text{ eV}^2$, followed by long wavelength vacuum oscillations on the way to the Earth, triggered by Δm_{21}^2 (or Δm_{32}^2) $\sim (10^{-12} - 10^{-10}) \text{ eV}^2$, Δm_{31}^2 and Δm_{21}^2 (Δm_{32}^2) being the corresponding neutrino mass squared differences. The solar ν_e survival probability is shown to be described in this case by a simple analytic expression. Depending on whether the vacuum oscillations are due to Δm_{21}^2 or Δm_{32}^2 there are two very different types of interplay between the MSW transitions and the vacuum oscillations of the solar ν_e . Performing an analysis of the most recently published solar neutrino data we have found several qualitatively new solutions of the solar neutrino problem of the hybrid MSW transitions + vacuum oscillations type. The solutions differ in the way the pp , ${}^7\text{Be}$ and ${}^8\text{B}$ neutrino fluxes are affected by the transitions in the Sun and the oscillations in vacuum. The specific features of the new solutions are discussed. One of the distinctive predictions of the hybrid MSW + vacuum oscillation solutions found is the existence of strong and very characteristic distortions of the spectrum of ${}^8\text{B}$ neutrinos. [S0556-2821(97)00321-4] [Phys. Rev. D **56**, 7392 (1997)]

Study of the day-night effect for the Super-Kamiokande detector. II. Electron spectrum deformations and day-night asymmetries. M. Maris, *Scuola Internazionale Superiore di Studi Avanzati, Trieste, Italy and INFN, Sezione di Pavia, Pavia, Italy*; S. T. Petcov *Scuola Internazionale Superiore di Studi Avanzati, Trieste, Italy. and INFN, Sezione di Trieste, Trieste, Italy.* (Received 23 May 1997)

Using the results of a high precision calculation of the solar neutrino survival probability for Earth crossing neutrinos in the case of the MSW $\nu_e \rightarrow \nu_{\mu(\tau)}$ transition solution of the solar neutrino problem, performed in an earlier study, we derive predictions for the one-year-averaged day-night (D-N) asymmetry in the deformations of the e^- spectrum to be measured with the Super-Kamiokande detector, and for the D-N asymmetry in the energy-integrated one-

year signal in this detector. The asymmetries are calculated for the solar ν_e crossing the Earth mantle only, the core, and the (mantle + core) for a large representative set of values of the MSW transition parameters Δm^2 and $\sin^2 2\theta_V$ from the "conservative" MSW solution region obtained by taking into account possible uncertainties in the values of the ${}^8\text{B}$ and ${}^7\text{Be}$ neutrino fluxes. The effect of the uncertainties in the value of the bulk matter density and in the chemical composition of the core on the D-N asymmetry predictions is studied. It is shown, in particular, that for $\sin^2 2\theta_V \leq 0.013$ the one-year average D-N asymmetry for neutrinos crossing the Earth core can be larger than the asymmetry for (only mantle crossing + core crossing) neutrinos by a factor of up to six. Iso-(D-N) asymmetry contours in the $\Delta m^2 - \sin^2 2\theta_V$ plane for the Super-Kamiokande detector are derived in the region $\sin^2 2\theta_V \geq 10^{-4}$ for only mantle crossing, core crossing, and (only mantle crossing + core crossing) neutrinos. The dependence of the D-N asymmetry in the three data samples on the recoil- e^- energy threshold is also investigated. Our results indicate that the Super-Kamiokande experiment might be able to test the $\sin^2 2\theta_V \leq 0.01$ region of the MSW solution of the solar neutrino problem by performing selective D-N asymmetry measurements. [S0556-2821(97)05921-3] [Phys. Rev. D **56**, 7444 (1997)]

Remark on the Burkhardt-Cottingham and generalized Gerasimov-Drell-Hearn sum rules for the neutron. J. Soffer, *Centre de Physique Théorique, CNRS, Luminy, Case 907, F-13288 Marseille Cedex 9, France*; O. V. Teryaev, *Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, 141980 Dubna, Russia.* (Received 27 March 1997)

A description of the generalized Gerasimov-Drell-Hearn sum rule for the neutron is suggested, using its relation to the Burkhardt-Cottingham sum rule. [S0556-2821(97)06119-5] [Phys. Rev. D **56**, 7458 (1997)]