QCD Vacuum Structure and Confinement

Monday, 26 August 2024 - Friday, 30 August 2024

Book of Abstracts

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Were there any anomalies in the gluon jets in ALEPH?

Author: Inkyu Park[1]

[1] *University of Seoul, Department of Physics (KR)*

According to the Abelian decomposition of QCD, there is a theoretical prediction that gluons can be classified into two types, each exhibiting distinct experimental signatures. The optimal setting for experimental verification of this theory is a clean environment such as the LEP, rather than the LHC. We have investigated whether there were any anomalies observed already in the gluon jets recorded in the ALEPH experiment and revisited the analyses with the archived ALEPH data. In this presentation, we will show our latest updates on our study on the gluon jet properties in ALEPH.

2

Dual Theory of Decaying Turbulence

Author: Alexander Migdal[1]

[1] *New York University, Abu Dhabi*

We have found an infinite dimensional manifold of exact solutions of the Navier-Stokes loop equation for the Wilson loop in decaying Turbulence in arbitrary dimension d > 2. This solution family is equivalent to a fractal curve in complex space Cd with random steps parametrized by N Ising variables σi = ±1, in addition to a rational number p q and an integer winding number r, related by Σ σi = qr. This equivalence provides a dual theory describing a strong turbulent phase of the Navier Stokes flow in Rd space as a random geometry in a different space, like ADS/CFT correspondence in gauge theory. From a mathematical point of view, this theory implements a stochastic solution of the unforced Navier-Stokes equations. For a theoretical physicist, this is a quantum statistical system with integer-valued parameters, satisfying some number theory constraints. Its long-range interaction leads to critical phenomena when its size N ⟶ ∞ or its chemical potential μ ⟶ 0. The system with fixed N has different asymptotics at odd and even N ⟶ ∞, but the limit μ ⟶ 0 is well defined. The energy dissipation rate is analytically calculated as a function of μ using methods of number theory. It grows as ν/μ 2 in the continuum limit μ ⟶ 0, leading to anomalous dissipation at μ ∝ √ ν ⟶ 0. The same method is used to compute all the local vorticity distribution, which has no continuum limit but is renormalizable in the sense that infinities can be absorbed into the redefinition of the parameters. The small perturbation of the fixed manifold satisfies the linear equation we solved in a general form. This perturbation decays as t −λ , with a continuous spectrum of indexes λ in the local limit μ ⟶ 0. The spectrum is determined by a resolvent, which is represented as an infinite product of 3 ⊗ 3 matrices depending of the element of the Euler ensemble.

3

How Large is the Space of Covariantly Constant Gauge Fields

Author: Georgios Savvidis[1]

[1] *Nat. Cent. for Sci. Res. Demokritos (GR)*

The covariantly constant gauge fields are solutions of the sourceless Yang-Mills equation and represent classical vacuum fields. We found that the moduli space of the covariantly constant gauge

fields is infinite-dimensional and is therefore much larger than the space of constant chromomagnetic fields. These solutions represent a space lattice of non-perturbative magnetic flux tubes/vertices oriented in the opposite directions, each of which has a Dirac quantum flux. The geometrical structure of the solutions is self-sustaining without presence of any Higgs field support. They are similar to a condensate of the Nielsen-Olesen magnetic flux tubes of opposite orientations. The solutions have a non-vanishing Hopf invariant density.

4

Conformal symmetry of the Nambu-Goto string

Author: Yuri Makeenko[1]

[1] *Niels Bohr Institute*

I consider a generalization of the Liouville action which corresponds to the Nambu-Goto string like the usual Liouville action corresponds to the Polyakov string. The two differ by higher-derivative terms which are negligible classically but revive quantumly. I exactly solve the four-derivative case and argue that conformal symmetry of the Nambu-Goto string in 4 dimensions is described by the (4,3) minimal model.

5

Explorations in Metric-Affine Quadratic Gravity

Author: Kyriakos Tamvakis[1]

[1] *University of Ioannina*

Abstract: It is a common assumption that well below the Planck scale gravity can be treated classically in the framework of General Relativity. Nevertheless, the quantum interactions of gravitating matter fields are expected to generate modifications in the Einstein-Hilbert action. Such modifications are non-minimal couplings of scalar fields to curvature or quadratic curvature terms. It has been known that in the framework of the Einstein- Hilbert action the standard (metric) formulation is entirely equivalent to the Palatini (or metric-affine) formulation in which the connection is an independent dynamical variable in addition to the metric. Nevertheless, in the presence of the above non-minimal terms the two formulations yield different theories, possibly with additional gravitational degrees of freedom. We consider metric-affine gravity coupled to scalar fields in the presence of the above non-minimal terms, derive the equivalent metric theory and its resulting particle content and discuss applications to inflation.

6

Einstein - Cartan gravity and the early Universe

Author: Mikhail Shaposhnikov[1]

[1] *École Spéciale de Lausanne*

Abstract. It is well-known since the works of Utiyama and Kibble that the gravitational force can be obtained by gauging the Lorentz group, which puts gravity on the same footing as the Standard Model fields. The resulting theory - Einstein-Cartan gravity - happens to be very interesting. I

will overview the construction of this theory and discuss its applications in particle physics and cosmology.

7

On calculating the mass-gap in Yang-Mills Theory

Author: Paul Romatschke[1]

[1] *University of Colorado, Boulder*

Abstract: The existence and mass-gap of Yang-Mills theory in 3+1 dimensions is an open Millennium Prize problem. In this lecture, I point out the curious similarities between the SU(2) mass gap and the superfluid gap in non-relativistic atomic systems when using an exact mathematical rewriting of the Yang-Mills Lagrangian. This may (or may not) constitute a new route towards calculating the mass-gap in Yang-Mills theory.

8

Timecrystalline vortices, anyons and the Poincaré index formula

Author: Antti Niemi[1]

[1] *Nordic Institute for Theoretical Physics*

I start by an update of vortices, as described by the Gross-Pitaevskii (GP) equation, explaining why there is room for new phenomena. First I describe what a time crystal is in Hamiltonian context. Then, I show that minimal energy solutions of GP equation behave like a time crystal. Furthermore, I show that as a consequence vortices of GP equation have anyonic exchange. I conclude with a topological analysis of multi-vortex systems and their Kosterlitz-Thouless transition, using the Poincaré index formula. At the end, I comment on three dimensional extensions such as closed and possibly knotted vortex lines.

9

Vacuum Energy and Dark Dimension

Author: Vincenzo Branchina[1]

[1] *University of Catania*

Abstract: According to the recently proposed dark dimension (DD) scenario, we might well live in a 5D universe with one compact extra dimension, whose mesoscopic (micrometer) size is dictated by the measured value of the cosmological constant. Considering the contributions to the vacuum energy from the Standard Model (that lives on a 4D-brane) and from the bulk, in the talk I discuss different aspects of this proposal, and investigate on the viability of the scenario .

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Cosmology of composite dynamics: dark matter, phase transitions and gravitational waves

Author: Roman Pasechnik[1]

[1] *Lund University*

Abstract:In this talk, I briefly overview recent progress in strong coupling dynamics at finite temperatures and its cosmological implications in SU(N) gauge theories, with and without fermions. In a confining pure Yang-Mills theory of dark sector, the scalar glueballs are considered as possible candidates for Dark Matter. To predict the relic abundance of glueballs for the various gauge groups and scenarios of thermalisation of the dark gluon gas, we employ a thermal effective theory that accounts for the strong-coupling dynamics in agreement with lattice simulations. In a QCD-like theory with N_f flavours, the Polyakov-loop Improved Linear Sigma Model in the Cornwall-Jackiw-Tomboulis formulation is employed to investigate the chiral phase transition in regimes that can mimic QCD-like theories incorporating in addition composite dynamics associated with the effects of confinement-deconfinement phase transition. We show that strong first-order phase transitions occur for weak effective couplings of the composite sector leading to gravitational-wave signals potentially detectable at future experimental facilities.

11

Abelian Decomposition of QCD and Two Types of Gluons

Author: Yongmin Cho[1]

[1] *Seoul National University*

We review the Abelian decomposition of QCD and discuss the physical implications of the decomposition. The Abelian decomposition decomposes the gluon potential to the restricted part which contains the non-topological Maxwellian Abelian potential which describes the color neutral neurons and the topological Diracian potential which describes the non-Abelian monopole, and the valence part which describes the colored chromons. It allows us to calculate the QCD effective potential gauge independently and demonstrate the monopole condensation as the physical vacuum of QCD. It allows us to decompose the QCD Feynman diagrams in such a way that the color conservation is explicit. It generalizes the quark and gluon model to the quark and chromon model in which the chromons become the constituent gluons of hadron, which clarifies the glueball picture of the hadron spectroscopy greatly.

Most importantly, the Abelian decomposition is not just a theoretical proposition. It can be verified by experiment. It tells that there are two types of gluons, the color neutral Abelian neurons which play the role of the binding gluon and the gauge covariant colored chromons which play the role of the constituent gluon. We show how to verify the existence of the two types of gluons, the neurons and chromons, experimentally by reanalyzing the old ALEPH and CMS gluon jet data.

12

Flux Tubes and Confinement in Lattice Quantum Chromodynamics.

Author: Leonardo Cosmai[1]

[1] *Istituto Nazionale di Fisica Nucleare*

Abstract: Color confinement is a fundamental non-perturbative aspect of Quantum Chromodynamics (QCD). Despite decades of research and numerical lattice simulations, a complete understanding

of this phenomenon has remained elusive. Although a rigorous mathematical proof is still lacking, efforts to understand confinement could hold significant value for comprehending broader aspects of QCD, such as the phase diagram. In this talk, following a brief general introduction, we will focus on the study of flux tube structures on the lattice, exploring them as a manifestation of color confinement.

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Electroweak Strings in the Standard Model

Author: Pengming Zhang[1]

[1] *Sun Yat-sen University, Zhuhai*

Abstract : Both electroweak monopole and electroweak string could exist in the standard model. In this talk we will argue that the existence of the electroweak Cho-Maison monopole indicates the existence of the electroweak string in the standard model made of monopole-antimonopole pair separated infinitely apart, which carry the quantized magnetic flux $4\pi n/e$. We show how to construct such quantized magnetic flux string solution. Our result strongly indicates that genuine fundamental electromagnetic string could exist in nature which could actually be detected.

14

On the Schrodinger/dipole CFT correspondence

Author: Georgios Georgiou[1]

[1] *NKUA, Athens*

Abstract: We will discuss a new integrable example of the AdS/CFT correspondence with Schrodinger symmetry. The supergravity solution depends on two parameters and is obtained by marginally deforming the internal space of the Schrodinger background through a series of TsT transformations. On the field theory side, we identify the dual field theory. Using the Landau-Lifshitz coherent state approach, we reproduce from field theory the dispersion relation of a certain point-like string. We also calculate the Wilson loop, describing the quark/anti-quark potential at strong coupling. Finally, based on the string spectrum of strings in the pp-wave limit, we make an educated guess for the exact, in the 't Hooft coupling, dispersion relation of the magnon excitations in the original doubly deformed background.

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Everlasting Savvidy Vacuum

Author: Stefan Evans[1]

[1] *Helmholtz-Zentrum Dresden-Rossendorf*

Abstract: We apply the recently developed everlasting i.e. asymptotically interacting approach [1] to the Savvidy Yang-Mills spin-1 effective action. The everlasting fields extend the usual perturbative Schwinger-Dyson polarisation series creating a nested fraction sum which removes the infrared Landau pole [2]. We compare the resulting running coupling to recent lattice results which exhibit a finite infrared limit. Seeking to introduce the QCD confinement scale we begin the study of a magnetic Sauter step structure in both spin-1 and spin-1/2 actions. The combined actions encode quark

mass,
chromo-magnetic field strength and the degree of inhomogeneity modelled by the Sauter step sharpness - their interplay is needed to determine how the confinement scale emerges from the vacuum structure.

[1] SE, J. Rafelski, Everlasting interaction: polarization summation without a Landau pole, arXiv: 2311.00891 [hep-ph]
[2] SE, J. Rafelski, Everlasting Savvidy vacuum, in preparation.

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