# UK-QFT XI

# Report of Abstracts

https://indico.cern.ch/e/uk-qft-xi

Abstract ID : **1**

# Decoherence and entropy generation in an open quantum scalar-fermion system with Yukawa interaction

## Content

We have studied the decoherence mechanism in a fermion and scalar quantum field theory with the Yukawa interaction in the Minkowski spacetime, using the non-equilibrium effective field theory formalism appropriate for open systems. The scalar field is treated as the system whereas the fermions as the environment. As the simplest realistic scenario, we assume that an observer measures only the Gaussian 2-point correlator for the scalar field. The cause of decoherence and the subsequent entropy generation is the ignorance of information stored in higher-order correlators, Gaussian and non-Gaussian, of the system and the surrounding. Using the 2-loop 2-particle irreducible effective action, we construct the renormalised Kadanoff-Baym equation, i.e., the equation of motion satisfied by the 2-point correlators in the Schwinger-Keldysh formalism. These equations contain the non-local self-energy corrections. We then compute the statistical propagator in terms of the 2-point functions. Using the relationship of the statistical propagator with the phase space area, we next compute the von Neumann entropy, as a measure of the decoherence or effective loss of information for the system. We have obtained the variation of the entropy with respect to various relevant parameters. We also discuss the qualitative similarities and differences of our results with the scenario when both the system and the environment are scalar fields.

**Primary author:** JOSHI, Nitin (IIT Ropar)

**Co-authors:** Dr BHATTACHARYA, Sourav (IIT Ropar); Ms KAUSHAL, Shagun (IIT Ropar)

Abstract ID : **2**

# Analysis of phases of scalar field theories in thermal Anti-de Sitter Spaces

## Content

**Abstract**: The primary ingredient for studying the phases of a quantum field theory is the effective action. Though obtaining an exact form is beyond the scope of the existing techniques, approximate expressions using perturbative methods which to the leading order involve computation of one-loop determinants are available. In the talk which is based on our paper [1], I will first describe a method for computing one-loop partition function for scalar field on thermal $AdS_{d+1}$ for arbitrary $d$ that reproduces results known in the literature. The derivation is based on the method of images and uses the eigenfunctions of the Laplacian on Euclidean $AdS$. Employing these results, I will then discuss the phases of scalar field theories in thermal $AdS_{d+1}$ spaces for $d = 1, 2, 3$. We will analyze theories with global $O(N)$ symmetry for finite as well as large $N$. The symmetry-preserving and symmetry-breaking phases will be identified as a function of the mass-squared of the scalar field ($m^2$) and temperature ($T = 1/\beta$) in the $\beta$-$m^2$ parameter space. It will also be seen that the sign of the regularized volume of thermal $AdS_{d+1}$ plays a crucial role in the qualitative nature of the phase diagrams. As was shown for zero temperature in [2], we will confirm that for a finite temperature theory in $AdS$ there occurs a symmetry breaking phase in two dimensions, which is in contrast to the flat space where the Coleman-Mermin-Wagner theorem prohibits continuous symmetry breaking [3, 4]. We will also see that unlike the flat space, there exists a region in $AdS$ space where both the symmetry breaking and symmetry preserving phases coexist. In a particular case of $AdS_3$ the symmetry gets broken at high temperatures.

**References**:

[1] A. Kakkar and S. Sarkar, "On partition functions and phases of scalars in AdS," JHEP **07** (2022), 089 doi:10.1007/JHEP07(2022)089 [arXiv:2201.09043 [hep-th]].

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[3] N. D. Mermin and H. Wagner, "Absence of ferromagnetism or antiferromagnetism in one-dimensional or two-dimensional isotropic Heisenberg models," Phys. Rev. Lett. **17** (1966), 1133-1136 doi:10.1103/PhysRevLett.17.1133.

[4] S. R. Coleman, "There are no Goldstone bosons in two-dimensions," Commun. Math. Phys. **31** (1973), 259-264 doi:10.1007/BF01646487

**Primary authors:** KAKKAR, ASTHA (DEPARTMENT OF PHYSICS AND ASTROPHYSICS, UNIVERSITY OF DELHI, DELHI - 110007, INDIA); SARKAR, SWARNENDU (DEPARTMENT OF PHYSICS AND ASTROPHYSICS, UNIVERSITY OF DELHI, DELHI - 110007, INDIA)

Abstract ID : **3**

# Black hole entropy from quantum mechanics

## Content

I will discuss a holographic duality between a family of seven dimensional supersymmetric black holes and superconformal quantum mechanics on the moduli space of SU(N) Yang-mill instantons. The duality predicts a particular exponential growth of degeneracy of BPS states of the quantum mechanics which must reproduce the black hole horizon formula. This exponential growth has been proven rigorously in the case of U(1) instantons and we have good evidence for the growth in the SU(N) case.

**Primary authors:** Dr MOULAND, Rishi (University of Cambridge); Prof. NICHOLAS, Dorey (University of Cambridge); ZHAO, Boan (University of Cambridge)

Abstract ID : **4**

# Cylinder quantum field theories at small coupling

## Content

I will discuss a novel duality between 2D theory of fields on the cylinder and 1D theory of particles. In particular, any 2D scalar field theory compactified on a cylinder and with a Fourier expandable potential V is equivalent, in the small coupling limit, to a 1D theory involving a massless particle in a potential V and an infinite tower of free massive Kaluza-Klein (KK) modes. Moving slightly away from the deep IR region has the effect of switching on interactions between the zero mode and the KK modes, whose strength is controlled by powers of the coupling, hence making the interactions increasingly suppressed. Using the corresponding worldline theory, it is possible to compute the torus (one-loop) partition function, which, at leading order, is invariant under a T-duality transformation that maps the radius of the cylinder to its inverse and rescales it by the square of the Schwinger parameter of the cylinder. It turns out that his behavior is a universal feature of cylinder QFTs. The talk is based on my paper with A. Dogaru:
https://link.springer.com/article/10.1007/JHEP10(2022)110

**Primary author:** CAMPOS DELGADO, Ruben

**Co-author:** DOGARU, Andrei (University of Bucharest)

Abstract ID : **5**

# From the tabletop to the Big Bang: Quantum simulators of false vacuum decay

## Content

False vacuum decay (FVD) plays a vital role in many models of the early Universe, with important implications for inflation, the electroweak vacuum, and gravitational waves. However, it is also a highly non-perturbative and non-equilibrium process which is challenging to model theoretically, with existing Euclidean methods relying on numerous assumptions that have yet to be empirically tested.

An exciting route forward is to use laboratory experiments which undergo transitions analogous to FVD, allowing nature to simulate all of the relevant physics for us. In this talk, I will discuss ongoing work to develop such analogue FVD experiments within the Quantum Simulators for Fundamental Physics (QSimFP) program. In particular, I will present numerical lattice simulations of ultracold atom systems undergoing FVD, and discuss outstanding challenges in using upcoming experimental data to understand the early Universe.

**Primary author:** JENKINS, Alexander C (University College London)

Abstract ID : **6**

# Vortex nonminimally coupled to Einstein gravity in $AdS_3$: phase transition at critical coupling $\xi_c$

## Content

The Nielsen-Olesen vortex is a non-perturbative solution in quantum field theory in 2+1 dimensions that is topologically stable and composed of a complex scalar field and a gauge field. In this work we will consider the vortex non-minimally coupled to Einstein gravity with a negative cosmological constant ($AdS_3$ background). It is natural to add a non-minimal coupling term $\xi\, R\, ||^2$ to the gravitating vortex because it preserves gauge invariance (here R is the Ricci scalar and $\xi$ a dimensionless constant). This term leads to a novel feature: there exists a critical coupling $\xi_c$ where the vacuum expectation value (VEV) of the scalar field is zero for $\xi \geq \xi_c$ but becomes nonzero as $\xi$ crosses below $\xi_c$ and the gauge symmetry is spontaneously broken. We show that the VEV near the critical coupling has a power law behaviour proportional to $|\xi - \xi_c|^{1/2}$. Therefore $\xi_c$ can be viewed as the analog of the critical temperature $T_c$ in Ginzburg-Landau mean-field theory where a second-order phase transition occurs below $T_c$ and the order parameter has a similar power law behaviour $|T{-}T_c|^{1/2}$ near $T_c$. The critical coupling exists only in an $AdS_3$ background; it does not exist in a Minkowski background (topologically a cone). However, the deficit angle of the asymptotic conical spacetime depends on $\xi$ and is no longer determined solely by the mass; remarkably, a higher mass does not necessarily yield a higher deficit angle. We end by discussing how quantum matter fluctuations modifies the potential by logarithmic corrections leading to a departure from mean-field theory.

**Primary author:** EDERY, Ariel

Abstract ID : **7**

# Unified description of corpuscular and fuzzy scalar dark matter

## Content

We derive coupled equations for self-interacting scalar dark matter, which can include both a condensed, low momentum ‘’fuzzy” component and one with higher momenta that may be described as a collection of classical particles. We do this from first principles, using the Schwinger-Keldysh path integral and the corresponding Feynman diagrams in a perturbative expansion. The resulting coupled equations consist of a modified Gross-Pitaevskii equation describing the condensate, a kinetic equation describing the higher momentum modes (the ‘’particles”), and the Poisson equation for the gravitational potential sourced by the two components. We show that this model contains known models of dark matter and cold atom physics in some limits.

**Primary authors:** Dr PROUKAKIS, Nick (Newcastle University); Dr RIGOPOULOS, Gerasimos (Newcastle University); SOTO, Alex (Newcastle University)

Abstract ID : **10**

# Echo of the Dark: Gravitational Waves from Dark SU(3) Yang-Mills Theory

## Content

We analyze the phase transition in improved holographic QCD to obtain an estimate of the gravitational wave signal emitted in the confinement transition of a pure SU(3) Yang-Mills dark sector. We derive the effective action from holography and show that the energy budget and duration of the phase transition can be calculated with minor errors. These are used as input to obtain a prediction of the gravitational wave signal. To our knowledge, this is the first computation of the gravitational wave signal in a holographic model designated to match lattice data on the thermal properties of pure Yang-Mills.

**Primary author:** RAMBERG, Nicklas (Johannes gutenberg universität Mainz)

**Co-authors:** MORGANTE, Enrico (JGU Mainz); SCHWALLER, Pedro

Abstract ID : **11**

# Integrability treatment of AdS/CFT orbifolds

## Content

The integrability program provides powerful tools to determine the spectrum of holographic theories. The development of these tools and the generalisation to a wider scope of theories go hand in hand. In particular, non-supersymmetric versions of AdS/CFT can be accessed, which is a first step towards more realistic models of QCD and could shed some light on SUSY-breaking mechanisms needed for phenomenology.
We discuss the simple case of orbifolds of $AdS_5 \times S^5$ and the dual $\mathcal{N} = 4$ super Yang-Mills theory. We explain how the orbifolding features in the various integrability techniques and demonstrate this for two simple $\mathbb{Z}_2$-orbifolds. When we break supersymmetry completely, we expect tachyons to appear on both sides of the duality and we comment on their implications and potential matching through AdS/CFT.

**Primary author:** SKRZYPEK, Torben (Imperial College London)

Abstract ID : **12**

# Causality in the EFT of gravity

## Content

Effective field theory (EFT) is a theory-agnostic approach to understanding how high-energy phenomena would manifest in our low-energy universe. It is an expansion in higher-dimension operators built out of light fields with unknown coefficients. These coefficients can either be constrained through experiment or by demanding consistency with theoretical expectations, such as causal wave propagation. In dynamical gravitational EFTs, where there is no globally defined lightcone, defining causality is a nuanced problem. In this talk, using Gauss-Bonnet gravity as an example, I will explain why the recently introduced "infrared" causality is the correct criterion for determining consistency of low-energy EFTs. The crucial ingredient will be properly identifying the "regime of validity" of the EFT expansion, and recognising that it is only sensible to ask whether it is causal within that regime. Based on arXiv:2112.05031.

**Primary author:** MARGALIT, Aoibheann

Abstract ID : **13**

# How to find the Feynman Rules from any scalar-tensor theory and not collapse in the process

## Content

The ability to represent perturbative expansions of interacting quantum field theories in terms of simple diagrammatic rules has revolutionised calculations in particle physics. However, in the case of extended theories of gravity, deriving this set of rules requires linearization of gravity, perturbation of the scalar fields and multiple field redefinitions, making this process very time-consuming and model dependent. In this talk, I will motivate and present FeynMG, a Mathematica extension of FeynRules that automatizes this calculation, allowing for the application of quantum field theory techniques to scalar-tensor theories.

**Primary author:** SEVILLANO, Sergio

**Co-authors:** COPELAND, Ed (Nottingham University); Dr MILLINGTON, Peter (University of Manchester); SPANNOWSKY, Michael (IPPP Durham)

Abstract ID : **15**

# Perturbative approach to non-perturbative phenomena of quantum knot invariants

## Content

A group-theoretical structure in the perturbative expansion for the Wilson loops in the 3d Chern-Simons theory with SU(N) gauge group is developed in symmetric approach. An image of a map called sl(N) weight system from the algebra of chord diagrams to the center of the universal enveloping algebra ZU(sl(N)) is studied. Elements of the image – group factors, were known only up to the 6-th order in some representations. We present the group factors in arbitrary representation up to the 9-th order. Developed methods have wide applications. In particular, these methods allow us to compute the Vassiliev invariants of higher orders, prove the existence of the recently discovered tug-the-hook symmetry of the colored HOMFLY polynomial and provide a combinatorial description of the HOMFLY group factors which turned to be just a deformation of already developed combinatorial description of the Alexander group factors. Moreover, one can apply the determination of the group structure of the colored HOMFLY polynomials to research of properties of their specialities. Namely, we provide some sort of generalization of the one-hook scaling property for the Alexander polynomials to any representation R, and also present a method for constructing recursive relations for the Jones polynomials and apply it to the special case of torus knots T[2,2k+1]. And the final interesting implementation of the discovered HOMFLY group structure is the discussion of the Vogel theorem of not distinguishing chord diagrams by weight systems coming from semisimple Lie (super)algebras.

**Primary author:** LANINA, Elena (Moscow Institute of Physics and Technology)

**Co-authors:** Dr SLEPTSOV, Alexey (Moscow Institute of Physics and Technology); Mr TSELOUSOV, Nikita (Moscow Institute of Physics and Technology)

Abstract ID : **16**

# The analytic wavefunction

## Content

In recent years there has been an increasing interest in the interplay between amplitudes and cosmological correlators, in particular in the use of amplitudes techniques to constrain cosmological correlators. In this talk, I will give an overview of the formalism of the wavefunction of the universe and how it relates to cosmological correlators. After this, I will review the success of the S-matrix programme in studying the analytic properties of the amplitude of scattering A(s,t) in a gapped theory. Among the many results, I will focus on the sum rules for Wilson coefficients, which relate the coefficients in an EFT expansion with an integral of the UV completion of the theory. To incorporate the sum rules to the wavefunction of the universe framework, we define off-shell wavefunction coefficients whose analytic structure is fixed by its tree-level diagrams. The resulting sum rules encapsulate a larger set of Wilson coefficients than those from amplitudes. Finally, I will address future research in the rich interplay between amplitudes and cosmology.

**Primary author:** AGUI SALCEDO, Santiago (University of Cambridge)

Abstract ID : **17**

# Introduction to the worldline formalism of QFT

## Content

This talk will provide an introduction to the first quantised "worldline approach" to quantum field theory. Here, physical information is encoded in path integrals over relativistic point particle trajectories. The path integrals typically lead to "Master Formulae" for scattering amplitudes that combine multiple Feynman diagrams.

I will review the historic development of the worldline formalism before presenting some of its recent successes, specifically in the context of non-perturbative gauge transformations and applied to QED in external background fields.

**Primary author:** EDWARDS, James (Univeristy of Plymouth)

Abstract ID : **8**

cal N=4$supersymmetricYang-Millsthermodynamicstoorder\lambda^{\frac{5}{2}}$ from effective field theory

## Content

The free energy density of $calN = 4$ supersymmetric Yang-Mills theory in four space-time dimensions is derived through order $\lambda^{\frac{5}{2}}$ in the ‘t Hooft coupling $\lambda$ at finite temperature using effective-field theory methods. The contributions to the free energy
density at this order come from the hard scale $T$ and the soft scale $\sqrt{\lambda}T$.The effects of the scale $T$ are encoded in the coefficients of an effective three-dimensional
field theory that is obtained by dimensional reduction at finite temperature. The effects of the electric scale $\sqrt{\lambda}T$ are taken into account by perturbative calculations in the effective theory.

**Primary author:** TANTARY, Ubaid (Kent State University, Kent Ohio, USA)

Abstract ID : **18**

# A dynamical formulation of ghost-free massive gravity

## Content

The ghost-free massive gravity theory of de Rham, Gabadadze and Tolley (dRGT) has attracted a lot of attention since its formulation over a decade ago. Many studies have looked at its consequences for cosmology, and explored various limits in which the theory simplifies. However, until now few attempts have been made at numerically simulating its full non-linear equations, as an explicit dynamical formulation, analogous to the ADM formulation of GR, was not known.

In this talk, based on work with de Rham, Tolley and Wiseman, I will introduce the history and nuances of the formulation of massive gravity. I will then outline a dynamical formulation for the minimal and next-to-minimal dRGT models with a flat reference metric, explicitly identifying the phase-space variables, their associated momenta, as well as the evolution and constraint equations. I will go over the construction of initial data, which, like in GR, must still obey the Hamiltonian and momentum constraints. Finally, the techniques developed will be applied to perform numerical spherically symmetric gravitational collapse of scalar field matter for the minimal model, finding generically that this model breaks down before any large curvatures can appear.

**Primary author:** KOŻUSZEK, Jan

Abstract ID : **19**

# Scale separation in AdS vacua and holography

## Content

The existence of AdS vacua in string theory with a parametric separation between the Hubble scale and the Kaluza-Klein scale of the extra dimensions is an open question, and holography is a promising tool to tackle this. I will discuss some remarkable features of the holographic CFT duals of the DGKT vacua, which are candidate AdS vacua with parametric scale separation.

**Primary author:** APERS, Fien (University of Oxford)

Abstract ID : **20**

# NEC violation: Tunnelling versus Casimir effect

## Content

Tunneling between degenerate vacua is allowed in a finite volume, and leads to a non-extensive symmetric ground state. This talk displays how this leads to a violation of the Null Energy Condition for small enough temperatures, assuming a continuous set of momenta in the finite volume containing the field. Taking into account discrete momenta can modify this picture, and is achieved by adding the Casimir energy to the tunneling-induced ground state energy. Focusing on zero-temperature, it is shown that these non-trivial effects compete when the typical size of the box containing the field is of the order of the particle's Compton wavelength.

**Primary authors:** Prof. ALEXANDRE, Jean (King's College London); BACKHOUSE, Drew