3rd Annual Niels Bohr Institute MSc. Student Symposium

Friday, 14 June 2024 - Friday, 14 June 2024

H.C. Ørsted Institute

Book of Abstracts

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Read-out and data acquisition system development for FoCal-H

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In a letter of intent published by the ALICE collaboration in 2020, the proposal to integrate a new Forward Calorimeter (FoCal) as the forthcoming upgrade to ALICE was outlined. In this proposal, it was detailed that this new detector, FoCal, should be comprised of two sub-detectors. These would be an electromagnetic calorimeter (FoCal-E) and a hadronic calorimeter (FoCal-H), and the responsibility of designing, building, and testing these sub-detectors would be carried out by dierent research groups connected to ALICE.
The ALICE group at the University of Copenhagen has since the beginning spearheaded the development of the hadronic calorimeter, FoCal-H, whose first prototype was built and subsequently tested in September 2020. In these early tests, a readout system based upon the CAEN A1702 FEB was utilized, but after encountering numerous issues, this system was discarded. In the development of the second prototype of FoCal-H, an array of different readout solutions have been considered. Despite having issues with the A1702 FEBs from manufacturer CAEN, their newer model, the DT5202 FEB, was acquired and tested in conjunction with prototype II in numerous beam tests over the course of 2022 and 2023. Throughout these beam test it became clear that although not as bad as its predecessor, the CAEN DT5202 would not be a contender for the role of read out system for the final iteration of FoCal-H. Since a commercially available read-out system no longer seemed possible, the attention of the group turned to custom-made read-out systems based on two different ASICS, the VMM3a and the H2GCROC. After both of these ASICS had shown great potential in initial tests in the spring and summer of 2023, fully-fledged readouts for prototype II were planned for tests during the beam test of September 2023 along with the DT5202 that would act as a benchmark system. However, due to issues in the construction of the H2GCROC read-out boards, the test of this particular system had to be postponed, leaving only the VMM3a hybrid boards to be held up against the CAEN DT5202 FEBs.
Through extensive analysis of the data acquired using these different readout systems assessing the capabilities of the different boards, including among other parameters their sensitivity, consistency, and energy resolutions. Based on the results of this evaluation, the VMM3a hybrid boards must be deemed to be on par with if not superior to the CAEN DT5202 in every category, despite not having been tested as rigorously. However, whether the VMM is to remain the favorite will be addressed during the upcoming beam test at the end of May for which the readout board based on the H2GCROC is scheduled to be ready for test. Also during this beam test the CAEN DT5202 might receive a lifeline in the form of the CAEN DT5215 collector board, a new device designed to handle the input of multiple CAEN FEBs at once.

Field of study:

Quantum Physics

Supervisor:

Ian G. Bearden

Poster session: Enjoy the posters! / 3

Analyzing Neutron Scattering Data on the Excitations in the Spin 1 Haldane System NENP

Author: Dorothy Xiaoyu Wang[None]

Co-authors: Goran Nilsen ; Jacques Ollivier ; Kim Lefmann [1]; Sonja Holm-Dahlin [2]; Toby Perring

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A 1D chain of antiferromagnetic spin systems is a critical topic in quantum many-body physics. Theory has predicted that different spins (S) would result in different behaviors. Here, I will focus on the excitations of the Spin 1 Haldane system in the ground state.

In the S=1 system, both experiments and theories indicate that the ground state is topological and that there is a spin gap, Delta, in the dispersion. Some experiments have been conducted previously with neutron spectroscopy on the IN5 spectrometer, ILL, on the compound NENP by co-supervisor Sonja Holm-Dahlin. The data shows spin gaps at Delta and 2 Delta, and it has been speculated that either double scattering of magnons, multiple scattering, or a combination of both contribute to these gaps.

In my thesis project, I conducted a detailed analysis on the previous data taken at IN5 using Horace, a tool designed for analyzing time-of-flight neutron inelastic scattering data. By masking signals such as Bragg peaks and phonons, I isolated the magnetic scattering signals. It is expected to observe single-magnon gaps at odd k and double-magnon gaps at even k along the chain axis. From the reduced data, I approximated the Haldane gap energy. After performing a series of data deductions, I concluded the cause of the observed gaps and calculated the contribution of double-magnon scattering based on the result.

Field of study:

Physics of Complex Systems

Supervisor:

Kim Lefmann (Co-supervisor: Sonja Holm-Dahlin)

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Adhesive Bonding of GaAs with Embedded Charge-tunable Indium Arsenide Quantum Dots to a Silicon Substrate

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The integration of multiple materials in a nanophotonic chip is an effective way of fulfilling the many demands put on photonic quantum information technology. In this work, we present the heterogeneous integration of a p-i-n-i-n-doped Gallium Arsenide die with embedded Indium Arsenide quantum dots onto a Silica surface of a Silicon wafer. We present measurements of tunable single-photon emissions from the photonic circuits fabricated from this die and the results of new fabrication parameters for the grating couplers to and from the chip. Dots are shown to be in line with emissions from similar chips with a tunable range on par with other diode structures. We finally present a new concept for a nanophotonic circuit using the TM mode to excite the emitter and simulations of the expected efficiency of such a coupling. While more measurements are to come, so far indications are that high-quality integrated photon sources could be within reach with our method.

Field of study:

Quantum Physics

Supervisor:

Leonardo Midolo

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ML in the Dating of Greenland Ice Cores: A GRU Method for Automated Annual Layer Identification

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Our understanding of past climate and the mechanisms that drive climate change can be improved through analysis of the excellent palaeoclimatic data available in the Greenland ice cores, but such insights depend on having an established chronology of the ice core. Therefore, the dating of ice cores is an essential part of palaeoclimatic science. However, this dating is often carried out by manual identification, which is both time-consuming and somewhat subjective.

A GRU Encoder-Decoder model for automatic annual layer identification is developed. The GRU provides a sigmoid output, which is then used to find annual layer positions with a peak detection algorithm. The method is applied to the ice cores NGRIP, GRIP and DYE-3 using the manually identified layer positions from GICC05 and GICC21 as targets in training. These annual layer positions, together with reference horizons from stratigraphic markers, are used for evaluating predictions from the model. The model can be used for validation of existing counts, and with further development for predicting annual layer positions in shorter ice-core sections with uncertain annual layers.

Field of study:

Earth & Climate Physics

Supervisor:

Sune O. Rasmussen, Troels C. Petersen

Poster session: Enjoy the posters! / 6

SALSA Virtual A virtual neutron scattering instrument

Author: Daniel Christensen[1]

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In this work, we present a digital twin of the stress imaging neutron scattering instrument SALSA. This digital twin aims to correctly predict SALSAs neutron beam characteristics at sample position. This twin was made, by implementing a bent perfect crystal monochromator in the soft-

ware package McStas, and then used McStas to recreate the instrument setup of SALSA. we then performed experiments to validate the instrument setup, and found that the digital twin correctly recreates the general tendencies of the experiments.

Field of study:

Physics of Complex Systems

Supervisor:

Kim Lefmann

Poster session: Enjoy the posters! / 7

Sub-GeV Dark Matter and Proton Interaction in the Active Galactic Nucleus NGC 1068.

Author: Andreas Knage[1]

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Observations of high-energy neutrinos from the active galactic nucleus NGC 1068 suggest the acceleration of cosmic rays in the vicinity of the central supermassive black hole (corona) 1. These high-energy cosmic-rays can collide either with gas or with photon fields, producing charged and neutral pions. The decay of neutral pions leads to a gamma-ray flux, which in other sources has been used to test proton-dark-matter interactions 2 (DM-cooling). However, in NGC 1068 gamma-rays are strongly attenuated and not directly visible. The decay of charged pions produces instead neutrinos, presumably explaining the signal observed by IceCube.

I test the presence of proton-dark-matter interactions using this neutrino signal. Such interactions can distort the proton energy distribution, and in turn modify the neutrino signal observed by IceCube. In practical terms, I determine the expected proton spectrum, both in the standard scenario and in the case with proton-dark-matter interactions, by solving the transport equation (Fokker-plank equation, a second order PDE), using a leaky box model with parameters informed by the observations. I treat the proton-DM interaction as a cooling in the transport equation. The proton-DM interaction is derived by assuming a gauge theory with a heavy mediator(gauge boson) for the proton-DM interaction. I treat the proton-dark-matter cross section as a parameter free to vary. By comparing the resulting spectra (from solving the transport equation) with the IceCube observations, we can extract limits on how large the proton-dark-matter cross section can be to remain in agreement with the measurements. While this scenario has been analyzed in previous work 3, I go beyond the simplifying assumptions made there, such as neglecting the inelastic component of the proton-dark-matter scattering, and I will consider variability in the results based on the uncertainty in the astrophysical parameters and acceleration mechanisms within the corona.
interaction.

As for now I have solved the transport equation and so gotten the proton spectrum with and without elastic DM-cooling. Soon I will include inelastic scattering and derive the neutrino spectrum. This is what I can present off the project. Though I know what to do for the rest of the project, it is yet to be done.
The DM-proton interaction was derived by assuming Dirac fermion DM particles interacting with protons via a scalar mediator with a mass much larger than the transfer momentum $q^2 = 2mT$.
Recently a new paper came out using a DM candidate with mass $m_{DM} < m_A/2$ in the sub-GeV range, which can either be a complex scalar Φ or a Dirac fermion ψ, that couples to the dark photon A. I may use this model instead to derive the DM-p interaction. As for that I may also present this model at the symposium

Field of study:

Astrophysics

Supervisor:

Mauricio Bustamante

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Gravitational Lensing Effect in Triple Black Hole System

Author: Yan Yu[None]

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The origin of the binary black hole is one of the most charming, cutting-edge, and active Astrophysical topics. One of the possible formation channels is dynamical formation under the effect of another compact object, during which a triple system must exist. To test the existence of the third object, we focus on the gravitational lensing effect on the Gravitational Waves emitted from the binary system. When we consider the binary as the gravitational source and the third object as the lens, the amplification factor which is a function of both frequency and position will show differences under different source parameter combinations and orbital types when the source is inside the defined obvious lensing window, which will help us infer the source information and separate different orbits. This work mainly focuses on the magnification difference between circular and straight orbits with different incoming directions under low-velocity conditions.

Field of study:

Astrophysics

Supervisor:

Johan Samsing & Troels Harmark

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Tidal response of black holes

Author: Edgars Karnickis[1]

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Tidal Love numbers encode gravitational response to external tidal fields generated by companions. These depend on the structure of the gravitating object, such as a black hole or a neutron star, and in a binary coalescence are measurable in the last stages of the inspiral before the merger. Quite strikingly, the black hole tidal Love numbers are zero. By now, they have been calculated for Schwarzschild, Reissner-Nordstrom, and Kerr black holes. Several of these calculations are reviewed here. Special emphasis is given to the case of Kerr black holes, where the Love numbers have been a matter of debate. Zero tidal and nonzero dissipative Love numbers for Kerr black holes have been obtained. This computation, however, relies on a specific regularisation scheme, namely analytic continuation in the harmonic quantum numbers. Here, the response of the Kerr-Newman black holes to charged scalar field perturbations is described. This is used to obtain the Kerr Love numbers for scalar field perturbations in the zero-charge limit. The black hole charge serves as a regularisation parameter and, unlike the analytic continuation approach, this procedure is physically

well-defined. Zero tidal and nonzero dissipative Love numbers are obtained in full agreement with the method of analytic continuation.

Field of study:

Quantum Physics

Supervisor:

David Pereñiguez, Vitor Cardoso

Poster session: Enjoy the posters! / 10

Investigating physical parameters of protostellar systems

Authors: Anton Mol[1]; Krisha Shah[1]; Majid Uzbak[None]

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Over the recent years our ability to model and observe young stars has increased dramatically, enabling the compilation of large catalogues of observed and in silico protostars. We have learned that accretion discs form immediately when a star is born, and that the first planets may form already while the star is still embedded inside a large, cold, and dusty envelope during the first million years. This thesis is a three part project, including observational analysis, computational modelling, and machine learning. Each individual part contributes with its own methods to collaboratively create a better understanding of the protostellar systems and their environments.
The observational part focuses on using necessary tools to analyse the binary protostellar system's primary star, Ced110-IRS4A. We build an understanding of which physical properties can be extracted from the data, their limitations, and how they best can be compared to the large scale models of young stellar objects.
The modelling part focuses on extracting relevant physical parameters from the large scale MHD models of the protostellar systems, as well as creating synthetic images of the model through the means of radiative dust transfer models. The post processing will facilitate exploring what are the driving physical processes in star formation and give a better foundation for understanding and interpreting related observations.
The machine learning part enables a comparative analysis of synthetic and observed protostellar systems via similarity-based deep convolutional learning. By leveraging Deep Learning algorithms, we can reliably find similar images of these systems based on a similarity metric, defined by physical parameters extracted from the simulated systems. This results in a pipeline that ultimately estimates best-guesses for the physical parameters of observed protostellar systems.

Field of study:

Astrophysics

Supervisor:

Jes K. Jørgensen & Troels Haugbølle

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Dense Molecular Gas Tracers in Nearby Seyfert Galaxies

Author: Miranda Andersen[None]

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Dense gas tracers are not commonly observed in AGNs. The purpose of this project was to determine if the kinematics of the dense gas move in Keplerian orbits or are sensitive to out-flows/inflows as seen with CO gas. If the dense gas has ordered motion, it can possibly be used to measure the mass of the central black hole.
In this project I analyse the dense molecular gas tracers in the centre of four nearby Seyfert galax-ies measured by ALMA. For all four galaxies in our pilot study sample, CO gas is present, where two galaxies show rotation and two show signs of outflows.
I only detect dense gas (HCN, HCO+, CS, C2H) in one galaxy, NGC 4253. The question is if galaxy is special?
In my poster, I will present the data and characterise the dense gas dynamics and kinematics and discuss its implications.

Field of study:

Astrophysics

Supervisor:

Marianne Vestergaard

Poster session: Enjoy the posters! / 12

Topological Data Analysis of Phase Transitions in Soft Active Matter Systems

Author: Frederik Mols[1]

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This thesis explores the application of algebraic topological methods, particularly persistent homology, in the analysis of models within statistical, condensed matter, and active matter systems. The primary goal is to classify phase transitions in soft active matter systems characterized by topological defects. Building on preliminary studies using the XY-model as a reference, we propose to use the variance of the Wasserstein distance between persistence diagrams of positively and negatively charged topological defects as a phase transition indicator.

We further hope to extend this approach by:

-Validating the method against other classical models with topological defects or solitons.
-Generalizing the methodology to dimensions higher than two.
-Rigorously proving that this method can reliably indicate phase transitions.

This research seeks to provide a novel topological perspective on phase transitions in complex physical systems.

Field of study:

Physics of Complex Systems

Supervisor:

Amin Doostmohammadi, Martin Cramer Pedersen

Poster session: Enjoy the posters! / 13

Full Spectrum Modeling in AGN Galaxies Using Penalized Pixel-Fitting

Author: Freja Amalie Nørby[1]

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The goal is to create BPT diagrams for nearby Active Galactic Nuclei (AGN). These diagrams, named after Baldwin, Phillips, and Telervich, are a set of nebular emission line diagrams used to distinguish the ionization mechanism of nebular gas. Using these we can map the gas on a large scale within galaxies and identify regions where we have AGN feedback, and help us understand AGNs'role in the chemical and structural evolution of galaxies. Inspired by the methods in MUSE observations of a changing-look AGN I: The re-appearance of the broad emission lines (Raimundo et al., 2019), I want to replicate the results exclusively using the Penalized Pixel-Fitting (pPXF) method developed by Cappellari (2023).

Field of study:

Astrophysics

Supervisor:

Marianne Vestergaard

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Vortex States and Boundary Theories in Topological Spin-Triplet Superconductors

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Most unconventional superconductors are characterized by a non-trivial momentum structure of the Cooper pair wave function, represented by an explicit momentum dependence in the superconducting order parameter. A key challenge to understanding the fundamental nature of unconventional superconductivity is thus to establish the symmetry of this momentum dependence.

For spin-triplet superconductors, the Cooper pair wave function is symmetric in spin, so by the Pauli principle it must be of odd-parity in momentum space. Odd-parity spin-triplet superconductors are characterized by the appearance of zero-energy bound states on the boundaries of the material, due to the topological nature of the superconducting order parameter. Another signature is the appearance of zero-energy Majorana bound states at the core of superconducting vortices.

The recently discovered material UTe2 is a possible candidate for spin-triplet superconductivity. In addition, it may spontaneously break time-reversal symmetry upon entering the superconducting state, condensing into a chiral phase. While probing the momentum dependence of the Cooper pairs has proven to be extremely challenging due to the small energy scales of the material, recent experiments have shown progress utilizing a superconducting Scanning Tunnelling Microscopy (STM) tip to probe the surface of the material.

In this work, we will investigate the possible observable signatures of the different candidate phases considered for UTe2. Specifically, we will calculate the surface density of states in a superconducting phase with a vortex, to investigate whether this could in principle be used to distinguish between different superconducting orders, using STM measurements, or other experiments sensitive to the surface density of states.

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Vortex States and Boundary Theories in Topological Spin-Triplet Superconductors

Author: Hans Christiansen[1]

[1] *NBI*

Corresponding Author: hans.christiansen@nbi.ku.dk

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Field of study:

Quantum Physics

Supervisor:

Brian