Conceptual foundations of QFT
June 1st – June 3rd

Book of abstracts

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Day 1

June 1st

Local measurement and relativistic causality I

State updates in quantum field theory
Chris Fewster
University of York

I will summarise the state updates rules derived in the QFT measurement framework of [1], and their properties, including the resolution of the 'impossible measurement' problem [2]. I will then present work with Christiane Klein on polarisation-sensitive measurements [3] and try to draw some wider conclusions about the role of states in QFT.
[1] Quantum fields and local measurements, CJ Fewster and R Verch, Commun. Math. Phys. 378(2020) 851-889 arXiv:1810.06512 [2] Impossible measurements require impossible apparatus, H Bostelmann, CJ Fewster and MH Ruep, Phys. Rev. D 103 (2021) 025017 arXiv:2003.04660 [3] Coupled Proca theories: Green-hyperbolicity, quantization and applications to polarization measurement, CJ Fewster and CKM Klein, arXiv:2511.11348

No superluminal causal influence in QFT with a local measurement theory
Doreen Fraser
University of Waterloo

In Non-Relativistic Quantum Mechanics (NRQM) with Quantum Measurement Theory, selective measurement operations appear to have superluminal effects. Since non-relativistic theories do not prohibit superluminal causal influence, a natural response is to shift the analysis of selective measurements to QFT. A well-known obstacle to this strategy is the Reeh-Schlieder theorem, which appears to show that "by acting on the vacuum with suitable operations in a terrestrial laboratory, an experimenter can create the Taj Mahal on (or even behind) the Moon!" (Verch 2006). However, this analysis of the Reeh-Schlieder theorem relies on Quantum Measurement Theory for NRQM. We argue that, when local selective measurement operations are represented using the Fewster-Verch (FV) measurement framework, the Reeh-Schlieder theorem no longer entails the possibility of superluminal causal influence. We also briefly comment on how superluminal causal influence is excluded by other local measurement theories for QFT. This talk is based on joint work with Maria Papageorgiou.

What happens when one measures a quantum system in a relativistic setting?
Eduardo Martín-Martínez
University of Waterloo / Perimeter Institute

What happens when one measures a quantum system in a relativistic setting? We will address the challenge of consistently updating quantum states after selective measurements in a relativistic spacetime. Standard updates along the future lightcones preserve causality but break correlations between causally disconnected parties, whereas updates along the past lightcone can either imply retrocausality or not respect the causal propagation of information. We will discuss a minimal extension of multipartite states to encode subsystem-specific contextual information.

Gravity and interpretations of relativistic quantum theory

Black Holes Decohere Quantum Superpositions
Robert Wald
University of Chicago

We show that if a massive body is put in a quantum superposition of spatially separated states, the mere presence of a black hole in the vicinity of the body will eventually destroy the coherence of the superposition. This occurs because, in effect, the gravitational field of the body radiates soft gravitons into the black hole, allowing the black hole to harvest "which path" information about the superposition. A similar effect occurs for quantum superpositions of electrically charged bodies. The effect is very closely related to the memory effect and infrared divergences at null infinity.

A healthier stochastic semiclassical gravity: world without Schrödinger cats
Lajos Diosi
Wigner Research Centre for Physics Budapest

Semiclassical gravity couples classical gravity to the quantized matter in the mean-field approximation, which is problematic for two reasons. It ignores the quantum fluctuation of matter distribution, and it violates the linearity of the quantum dynamics. The first problem can be mitigated by allowing stochastic fluctuations of the geometry, but the second problem lies deep in quantum foundations. Restoration of quantum linearity requires a conceptual approach to hybrid classical-quantum coupling. Studies of the measurement problem and the quantum-classical transition point to a solution. It is based on a postulated mechanism of spontaneous quantum monitoring.

The Relativity of Branching
Guido Bacciagaluppi
Utrecht University

Everettians standardly argue that their view is completely local and therefore applicable without further ado to relativistic QFT. I believe this argument is correct, but leaves open how one should think of 'branching' (whether in a Schrödinger or Heisenberg picture). I argue that there is a naturally invariant notion of branching in Minkowski spacetime and that apparently different descriptions of branching arise as different descriptions of the invariant branching structure due to different choices of simultaneity. (This is very similar to Myrvold's conceptualisation of relativistic collapse.) The relativity of simultaneity thus leads naturally to the relativity of branching.

Day 2

June 2nd

Historical and contemporary perspectives on foundations of QFT

Origins of Axiomatic QFT
Alexander Blum
Caltech

I present an overview of the historical origins of axiomatic QFT, beginning with the prehistory of the 1930s. Here I identify two general programs: von Neumann's quantum theory with infinitely many degrees of freedom and Wigner's relativistic quantum theory. I then discuss how Wigner's program became the basis for the axiomatic program of Wightman and Haag in the 1950s, but then encountered its first stumbling block in a result (Haag's theorem) anticipated by von Neumann. I conclude by presenting some work in progress on the parallel development of the LSZ program and its origins in Heisenberg's S-matrix theory.

How far can we go with divergent series?

James Fraser
Paris 1 Pantheon-Sorbonne University

Perturbative expansions in quantum field theory (QFT) are divergent series, even after renormalization. Some theorists have concluded from this that perturbation theory is entirely irrelevant to the foundations of QFT, and that new non-perturbative methods are needed to understand the content of the theory. Another tradition, which has emerged in stops and starts since the late 1960s, views the divergence of perturbation theory as an opportunity rather than a dead-end. On this second view, the large-order behaviour of the expansion is a source of information about non-perturbative effects and maybe even the key to understanding the content of empirically successful QFTs. I discuss the back and forth between these pessimistic and optimistic perspectives on the foundational mileage of perturbation theory.

Thoughts on semilocal quantum physics

Kasia Rejzner
University of York

Local quantum physics as proposed by Haag and Kastler has for decades remained one of the main axiomatic frameworks used in understanding the foundations of QFT. It is conceptually elegant and mathematically rigorous and is based on the idea that the main building blocks of QFT are algebras of operators assigned to locally compact open regions of spacetime, obeying an appropriate collection of axioms (this is local quantum physics). Recently, this viewpoints has been revisited, when introducing measurements into the game and searching for an operational description thereof. This led to the necessity to look beyond local quantum physics towards a framework that one may describe as semilocal. In this talk, I will review some of the results obtained in collaborations with Fewster, Janssen, Loveridge and Waldron, and I will discuss the perspectives for future research.

Local measurement and relativistic causality II

Facets of relativistic locality

Miklós Rédei
London School of Economics

It is argued in the talk that relativistic locality is not a single condition a quantum physical theory should have in order to be compatible with the underlying causal structure of spacetime but an interconnected web of conditions that only jointly express the causally good behavior of the theory. Four components of this web will be distinguished: spatiotemporal locality, along with three distinct notions of causal locality called "Independence", "Explainability" and "Dynamic". The categorial approach to quantum field theory satisfies spatiotemporal locality, and taking the time slice axiom as the formulation of causal locality "Dynamic" in this framework is uncontroversial. But there are different ways to formulate the causal locality condition "Independence", and it will be seen how some notions of independence and the causal locality condition "Explainability" can be specified in the categorial framework using the concept of operation. Some open questions about the status of some of the operational casual locality conditions are formulated.

Local Measurement and the Type III Property in Algebraic QFT
Noel Swanson
University of Delaware

The fact that local observables in AQFT form type III von Neumann algebras blocks a straightforward application of traditional quantum measurement theory as developed by Davies and Lewis. Over the last decade, Okamura and Ozawa have devised a workable generalization of the Davies-Lewis theory for models of AQFT satisfying the split property and Haag-duality in flat spacetime. They prove that completely positive instruments possessing a certain normal extension property stand in 1-1 correspondence with statistical equivalence classes of measurement processes, and that these special CP instruments are ultraweakly dense in any injective von Neumann algebra. Thus while there are local CP instruments which do not have corresponding measurement processes (unlike the situation in traditional Davies-Lewis theory), they can always be approximated by ones that do. This talk investigates what the Okamura-Ozawa theory can and cannot tell us about local measurement in relativistic QFT. How good is ultraweak approximation? How do we measure global quantities like charge or particle number? Where do local measurement records come from? How do we frame the relativistic measurement problem?

Probing non-equilibrium of relativistic quantum dynamical systems
Rainer Verch
University of Leipzig

In this presentation, two situations related to non-equilibrium for quantum fields in Minkowski spacetime will be investigated: The general result showing that KMS states with respect to different inertial frames are not in the same folium, i.e. cannot be generated from each other by approximately local operations. A consequence is that return-to-equilibrium arguments fail in this situation. This is manifested by the fact that a KMS state defined with respect to some inertial frame is not an equilibrium state in another inertial frame, i.e. for an observer moving with constant velocity relative to the inertial frame in which the system is in thermal equilibrium. An apparently dual situation is that of an Unruh-de Witt detector coupled to a quantum field prepared in a non-equilibrium steady state (NESS), i.e. a state where there is a constant heat flux along a fixed spatial direction. The Unruh-de Witt detector will asymptotically at large times not show a thermal response rate and does not appear to respond to the heat flux under the usual monopole coupling to the quantum field. We conclude that the asymptotic response rate of an Unruh-de Witt detector may be indicative for a folium of states, but not for local properties of individual states in a folium. Based on joint publications with Albert Georg Passegger, Rev. Math. Phys. 37 (2025) 02, 2430009 and Ann. Henri Poincaré (2025), https://doi.org/10.1007/s00023-025-01618-3.

Day 3

June 3rd

The Measurement Problem in Relativistic Quantum Theory

What happens between in and out? Events do.
Charis Anastopoulos
University of Patras

The S-matrix does not capture what QFT is used for. I argue that QFT should be formulated as a statistical theory of events: spacetime-localized macroscopic records on detectors. In practice, this framework works: probabilities are well defined and they single out field correlators as the core objects of QFT. However, causality poses conceptual challenges to a spacetime-localized non-asymptotic notion of an event.

Do we have any viable solution to the measurement problem?
Emily Adlam
Chapman University
TBA

Quantum Reality from Late Time Boundary Conditions: Problems and Possibilities
Adrian Kent
University of Cambridge

I describe an ongoing research programme that aims at realist versions of quantum theory defined via the initial state and asymptotic late time conditions. I explain why these promise a mathematical underpinning to common intuitions about the reality underlying quantum experiments and explore some ways in which these ideas suggest generalizations of quantum theory. I discuss some problems with these ideas and some unusual features (which might also be considered problematic).

Realism about effective field theories

Facets of relativistic locality
David Wallace
University of Pittsburgh

I explore the field-particle relation in quantum field theory (QFT) from an effective-field-theory perspective. In noninteracting or nonrelativistic QFT, field and particle descriptions are exactly dual: field operators act as creation operators for quanta, which behave as particles in the fullest sense. This duality breaks down under relativistic interactions, as seen abstractly in Haag's theorem and concretely in the failure of the creation-operator and zero-quanta interpretations.
A thinner notion of "interacting quanta" survives in weakly-coupled regimes, underpinning familiar heuristics about virtual particles and vacuum fluctuations, but these quanta have unclear localization properties, limited stability, lack robust stability, have properties that are somewhat conventional, and the vacuum (i.e., the field ground state) is not a zero-quanta state but a superposition of states with many different numbers of quanta.
More robust particle notions do exist: localized scattering states (via LSZ) and stable nonrelativistic particles (via NREFT). Both are approximate and regime-dependent, but substantive. I conclude by examining their interrelations and connections to other emergent particle concepts in QFT.

Renormalisation and realism
Jeremy Butterfield
University of Cambridge

For 40-plus years, physicists, especially high-energy physicists, have extolled the "effective field theory" view of quantum field theory. A key idea has been about renormalisation: whatever non-renormalizable interactions may occur at higher energies beyond our reach, their contributions to (the probabilities for) physical processes decline with decreasing energy, and do so rapidly enough that they are negligible at the energies we canreach. Philosophers have picked up on this. Recently, they suggested that this sheds light on the philosophical topic of scientific realism: both how to formulate it, and whether it is right. This talk will report and assess these developments.

Posters

Physics Session

Marcos Morote-Balboae
Nordita

Optimization of entanglement harvesting with arbitrary temporal profiles: the limit of second order perturbation theory— Experimental verification of vacuum entanglement in QFT is hindered by prohibitively small numbers. In this talk we optimize the protocol of entanglement harvesting for two spacelike separated probes that couple to a field in arbitrary temporal regions. Using analytical expressions for smeared propagators, we find optimal compactly supported switching functions that significantly improve the prospects for experimental realization.

Theodora Kolioni
University of Patras

I present an exactly solvable detector–field model that highlights conceptual tensions between relativistic causality and standard open-system descriptions in quantum field theory. Focusing on two Unruh–DeWitt detectors interacting through a quantum field, I examine non-Markovian information transfer, the emergence of correlations, and the conditions under which reduced detector dynamics exhibit apparent non-causal behavior. The analysis revisits classic problems such as Fermi's two-atom paradox and emphasizes the role of observable localization and renormalization in relativistic quantum theories. Rather than proposing new computational techniques, the poster aims to clarify foundational issues concerning causality, locality, and the physical interpretation of entanglement in QFT, and to stimulate interdisciplinary discussion at the interface of physics and philosophy.

Nicolas Boulle
Mid Sweden University

Recent proposals argue that detecting entanglement between two spatially superposed masses could provide evidence for the quantum nature of gravity. Such gravity-induced entanglement (GIE) experiments rely on assumptions about subsystem independence, measurement, and observables inherited from quantum information theory. In this work, we analyze GIE proposals from the perspective of AQFT, distinguishing between operational and algebraic notions of independence. We focus on how gauge constraints and gravitational dressing affect the definition of subsystems, central to the experimental logic. We show that with gravitationally dressed fields, commutation relations between spacelike separated observables can fail, undermining strict Hilbert space factorization. We discuss the consequences for entanglement witnesses, showing that standard bounds can remain valid even when subsystem algebras do not commute. Finally, we estimate the magnitude of dressing-induced violations of microcausality.

Anjana Krishnan
SRM University-AP

Horizon brightened acceleration radiation signifies a unique radiation process and provides a promising framework in exploring acceleration radiation in flat/curved spacetime. Its construction primarily relies on the transition probability of an atom falling through a high-Q cavity while interacting with a quantum field. The HBAR effect has typically been explored in the context of minimal coupling between the atom and the field amplitude. However, the minimally coupled models are affected by the infrared divergences that arise in the massless limit of the quantum fields in (1+1) dimensions. We examine the HBAR process using both the pointlike and finite size detectors coupled with the momentum of the field, which plays a crucial role in naturally resolving IR divergences. Our results show unique features for this setup, including as independence of the transition on the pointlike detector's frequency and the existence of non equilibrium thermodynamic state for a small sized detector.

Philipp Dorau
Universität Leipzig

We illustrate how the semiclassical Einstein equations can be recovered from the relative entropy between coherent states of a quantum field on a bifurcate Killing horizon. Using modular theory, we compute the Araki-Uhlmann relative entropy between the vacuum and a coherent excitation of a quantized scalar field on the Rindler horizon of a local inertial frame, and show that it coincides with the energy flux across this local horizon. Assuming the Bekenstein-Hawking entropy-area law, this relates the relative entropy to a variation of the horizon cross section and, via the Raychaudhuri equation, yields the semiclassical Einstein equations. Our result thus provides a fully quantum field theoretic formulation of Jacobson's thermodynamic derivation of the Einstein equations.

Riccardo Falcone
IQOQI Vienna

We investigate the trade-off between vacuum insensitivity and sensitivity to excitations in finite-size detectors, taking measurement locality as a fundamental constraint. We derive an upper bound on the detectability of vacuum excitation, given a small but nonzero probability of false positives in the vacuum state. The result is independent of the specific details of the measurement or the underlying physical mechanisms of the detector and relies only on the assumption of locality. Experimental confirmation or violation of the inequality would provide a test of the axioms of algebraic quantum field theory, offer new insights into the measurement problem in relativistic quantum physics, and establish a fundamental technological limit in local particle detection.

Adriano Chialastri
SISSA Trieste

The relative entropy between two states is a key concept in quantum information theory and quantum field theory. In the setting of quantum field theory, its computation requires the handling of relative modular Hamiltonians, which have nice general properties, but are typically very difficult to compute explicitly. We can however exploit locality properties of general algebraic QFTs to describe a scheme that allows us to estimate relative modular Hamiltonians for the algebra of some region between two suitable states in terms of the modular Hamiltonian of a reference state on a larger or smaller region, which might be better understood. The applicability of this scheme is directly linked to the absence of superluminal signaling in the sense of Sorkin's paradox. Indeed, if we choose one of the states as our reference state, then any unitary operation that maps it to the second state must be local in Sorkin's sense. This is a joint work with C. Minz and Ko Sanders.

Iman Zabett
University of Vienna

Are Observer-Independent Facts Local?—The Wigner's Friend Crisis in Quantum Field Theory Nested-observer reasoning in non-relativistic QM leads to a fundamental crisis of objectivity. The Local Friendliness no-go theorem proves that L, F, and A, cannot jointly hold — this confirmed experimentally in photonic implementations. We ask whether this crisis persists when the setting is promoted to relativistic QFT. In algebraic QFT, observables are assigned to spacetime regions, and local algebras are typically Type III, lacking the simple projection structure that supports classical facts. Observers cannot be modelled by simple subsystem factorisation and requires split property with sufficient spacetime separation. Using the measurement framework and the observer-locality analysis, the stability of the LF trilemma under this structural reformulation will be investigated. Finally three major interpretational responses will be examined to assess how they fare under relativistic extension.

Philosophy Session

Samuel Fedida
University of Cambridge

We develop foundations for a relational approach to quantum field theory (RQFT) based on the operational quantum reference frames (QRFs) framework considered in a relativistic setting. Unlike other efforts in combining QFT with QRFs, we use the latter to provide novel mathematical and conceptual foundations for the former. We focus on scalar fields in Minkowski spacetime and discuss the emergence of relational local observables and fields from the consideration of Poincaré-covariant frame observables defined over the space of inertial reference frames. We recover a relational notion of Poincaré covariance, with transformations on the system directly linked to the state preparations of the QRF. We introduce and analyse various causality conditions, and construct an explicit example of a covariant scalar relational quantum field which is causal relative to operationally meaningful preparations of a relativistic QRF. Based on arXiv:2507.21601

Karla Weingarten
Radboud University Nijmegen

Making Do and Getting By: A Unifying Classification of Effective Field Theories—Effective field theories (EFTs) are theories that describe phenomena up to an energy cutoff introduced through renormalization, which removes infinities and renders theories predictive while limiting their domain of applicability. The special nature of EFTs and the complex process of renormalization, have prompted considerable work in the area. Philosophers have proposed binary classifications which focus on isolated aspects of EFTs, such as the role of a more fundamental theory or specific renormalization schemes. I argue these approaches overlook that EFTs are the outcome of a multi-step process, and a more holistic approach should be used. I provide a holicistic characterisation of EFTs by considering choices of initial Lagrangian, renormalization procedure, and resulting structure together. This framework unifies existing classifications and accommodates all EFTs commonly used in physics practice.

Alexander Niederklapfer
London School of Economics and Political Science

The consensus in philosophy of physics is that quantum field theories (QFTs) are, at the fundamental level, not about particles. Nevertheless, much of the relevant empirical data is gathered from particle detectors. Reconciling this particle phenomenology with the underlying field-theoretic framework therefore remains an important task in the interpretation of QFTs. I present and defend a philosophically under-explored approach due to Haag and collaborators that aims to define particles in an operational manner and compare it to a more realist approach based on Wallace's (2006) proposal of "effective localisation". Overall, I conclude that Haag's approach leads to the most satisfactory notion of particles currently available. Addressing the curcial notion of localised states, I frame Wallace's "effective localisation" and Haag's almost local operators as two possible ways to deal with the conequences of the Reeh-Schlieder theorem.

India Bhalla-Ladd
University of California-Irvine

Recently, philosophers have proposed to redefine the standard formalization of the cluster-decomposition principle as a dynamical constraint on the interaction Hamiltonian, rather than as the factorization of the S-matrix for spacelike-separated processes [Williams et al. 2023]; these authors are primarily motivated to find a basis-independent formulation of cluster decomposition that captures dynamical isolability rather than isolability from entanglement. In light of the ubiquity of entangled states across spacelike-separated regions in AQFT, I examine how this debate bears on the formalization of cluster-decomposition in locally-covariant algebraic quantum field theory. In particular, it can be shown that the factorization of the S-matrix for operators of disjoint support is equivalent to the Causal Factorization axiom of the time-ordered product [Dutsch 2019]. I offer an analysis of the connection between Williams et al.'s dynamical condition and the Causal Factorization axiom.

Andrea Di Biagio
IQOQI Vienna
Circuit-locality from relativistic locality in scalar—field mediated entanglement-Relativity and quantum information theory use different notions of locality. In relativity, locality is tied to spacetime regions while, in QI, locality is based on the notion of subsystems. What is the precise relation between these notions? In this talk we will investigate this question for a simple quantum field theory model and see how relativistic causality implies subsystem locality—approximately. We will then comment on whether we can expect this result to generalise to more realistic QFTs, and how it relates to no-go theorems about low-energy quantum gravity. Based on https://arxiv.org/abs/2305.05645.

Avraham Levy
University of Haifa

QFT and the measurement problem—The measurement problem in QM arises from the discrepancy between the unitary evolution of states described by the Schrödinger equation and the non-unitary evolution ("collapse") of the state in a measurement process. In QFT there are strong claims suggesting that non-unitary interactions occur in certain elementary processes. We propose that these non-unitary interactions in QFT are the source of the non-unitarity of quantum measurements. We propose (following various versions of Haag's theorem) that in elementary interactions, where the "particles content" of the system is changed, the temporal evolution is non-unitary. These interactions, which are almost instantaneous, lead to a genuine stochastic selection ("collapse") of an outcome subspace that has a distinct "particles content", but can be a superposition of momentum states, spin states, etc. We further argue that in every measurement process there is such a non-unitary stage.

Arnold Neumaier
University of Vienna

Starting with the assumption that a single universal quantum state of a universal *-algebra of relativistic quantum fields uniquely describes all physical details of our universe, a locally Lorentz covariant quantum version of the classical, mechanical universe suggested by Laplace over 200 years ago is given. By reinterpreting some of the mathematical terms of quantum field theory, it provides a fairly common sense single-history, single-world alternative to decoherent histories (Gell-Mann and Hartle) and many-world interpretations (Everett, Wallace), compatible with scientific realism, By giving a mathematically precise meaning to statements involving measurement, the quantum measurement problem is reduced to a rigorously tractable mathematical problem. A route to a possible solution is outlined.

Adamantia Zampeli
ICTQT, University of Gdansk

Causal Quantum Instruments— A notorious problem in quantum theory is the description of temporally or spacetime extended quantum measurements, which is a necessary tool for information extraction. In non-relativistic quantum theory one has to ensure the constraint of operational causality while in spacetime and field theories this becomes even more involved with the demand for locality as well. I discuss a general framework, the positive formalism, that achieves the reconciliation of quantum measurement theory with spacetime theories, the decoherent histories as an instance of it and how the decoherence condition provides us with a way to construct temporal Kraus operators that satisfy operational causality.

Dominic Rhyder
London School of Economics

TBA