Quantum Foundations Workshop

June 21-22, Dipartimento di Fisica, via A. Bassi 6 Pavia
Room **109** ground floor

Website: www.qubit.it

For information:
alessandro.bisio@unipv.it
alessandro.tosini@unipv.it

WORKSHOP DAY 1: June 21

09:00 – 10:00	**Gábor Hofer-Szabó** Inst. of Phil. of the Hungarian Academy of Sciences, Budapest *Quantum mechanics as a representation of classical conditional probabilities*
10:00 – 10:30	Coffee Break
10:30 – 11:30	**Francesco Buscemi** Nagoya University *Reverse Data-Processing Theorems, Bayesian Structures, and the Flow of Information*
11:30 – 12:30	**Arkady Plotnitsky** Purdue University, West Lafayette *Three Great Divorces of Quantum Theory: Reality from Realism, Probability from Causality, and Locality from Relativity*
12:30 –	Lunch
16:00 – 17:00	**Lynden K. Shalm** University of Toronto *A strong loophole-free test of local realism* (Dep. Seminar in Aula Giulotto)
20:00	*Social dinner*

WORKSHOP DAY 2: June 22

09:00 – 10:00	**Masanao Ozawa** Nagoya University *Soundness and Completeness of Mean Errors for Quantum Measurements*
10:00 – 10:30	Coffee Break
10:30 – 11:30	**Pablo Arrighi** Aix-Marseille University and ENS de Lyon *TBA*
11:30 – 12:30	**Marco Genovese** INRM, Turin *Weak measurements: from sequential weak values to protective measurements*
12:30 –	Lunch
16:00 – 17:00	**Andrei Khrennikov** Linnaeus University, Växjö *Possibility to agree on disagree from quantum information and decision making*

LIST OF ABSTRACTS

Gábor Hofer-Szabó Inst. of Phil. of the Hungarian Academy of Sciences, Budapest

Quantum mechanics as a representation of classical conditional probabilities

The aim of the talk is somewhat anti-parallel to the research project of the QUIT Group where one is looking for the reconstruction of quantum mechanics from information-theoretic first principles. In our talk we follow an opposite, bottom-up route. We will investigate how the formalism of quantum mechanics can be reconstructed in an empiricist way that is based purely on classical conditional probabilities representing measurement outcomes conditioned on measurement choices.

Francesco Buscemi Nagoya University

Reverse Data-Processing Theorems, Bayesian Structures, and the Flow of Information

Suppose that two random variables X and Y are connected by a process (transition matrix or CPTP map) mapping X in Y. Then, the data-processing inequality states that the information content of Y never exceeds that of its parent X, thus providing a necessary condition for the existence of a process from X to Y. A reverse data-processing theorem aims to the converse, namely, to give a set of sufficient conditions for the existence of a process (i.e., a stochastic relation) between two random variables by looking solely at their information content. In this talk, I review some recent results in this direction and discuss few scenarios in which reverse data-processing theorems play a fundamental role -- in particular, Markov processes, open quantum systems dynamics, and generalized resource theories.

Arkady Plotnitsky Purdue University, West Lafayette

Three Great Divorces of Quantum Theory: Reality from Realism, Probability from Causality, and Locality from Relativity

This paper considers three great divorces, indicated in my title, of quantum theory, from quantum mechanics to quantum theory, at least in some interpretations-- reality from realism, probability from causality, and locality from relativity. It is of course crucial, and is indeed the main point, that reality, probability, and locality are still strictly maintained by quantum theory. The divorce, or perhaps thus far, only a separation between locality and relativity in quantum theory is rarely considered but is important, especially in considering the possibility of fundamental physics "beyond quantum", for example, in particular beyond quantum field theory in its current form, for example, is considering quantum gravity. Whether such a "beyond-quantum theory" will continue to remain divorced at least from realism and causality (a divorce of locality from relativity is somewhat different matter) or will reconcile with both, as Einstein famously wanted, is a matter of conjecture and, at this stage, of a probabilistic assessment, a bet, on one's part. What is responsible for such a bet, or a theory of such a bet, may itself mirror the epistemology of quantum theory insofar as it may require a divorce from realism and causality. Locality is a strictly physical matter, but the questions of realism and causality (and both are linked in term) extend well beyond physics.

Lynden K. Shalm University of Toronto (Dep. Seminar in Aula Giulotto)

A strong loophole-free test of local realism

81 years ago Einstein, Podolsky, and Rosen published a paper with the aim of showing that the wave function in quantum mechanics does not provide a complete description of reality. The gedanken experiment showed that quantum theory, as interpreted by Niels Bohr, leads to situations where distant particles, each with their own "elements of reality", could instantaneously affect one another. Such action at a distance seemingly conflicts with relativity. The hope was that a local theory of quantum mechanics could be developed where individual particles are governed by elements of reality, even if these elements are hidden from us. This concept is known as local realism.

In 1964 John Bell, continuing Einstein's line of investigation, showed that the predictions of quantum mechanics are fundamentally incompatible with any local realistic theory. Bell's theorem has profoundly shaped our modern understanding of quantum mechanics, and lies at the heart of quantum information theory. However, all experimental tests of Bell's theorem have had to make assumptions that lead to loopholes.

This past year, a loophole-free violation of Bell's 1964 inequalities, a 'holy grail' in the study of the foundations of quantum mechanics for half a century, was finally achieved by three different groups. Here I will present the loophole-free Bell experiment carried out at the National Institute of Standards and Technology that requires the minimal set of assumptions possible. We obtain a statistically significant violation of Bell's inequality using photons that are space-like separated, and therefore forbidden by relativity from communicating. Local realism,as defined by Bell, is dead.

Masanao Ozawa Nagoya University

Soundness and Completeness of Mean Errors for Quantum Measurements

The notion of root-mean-square (rms) error for measurements, originally introduced by Gauss, is a well-established notion for the mean error of a measurement in classical physics.

Since a universally valid uncertainty relation was obtained for measurement errors in 2003, the problem of extending the notion of rms error to quantum measurements has attracted considerable attention.

Here, we introduce basic requirements for quantum generalizations of the classical rms error including the soundness and the completeness requirements, and show that the rms of the noise operator satisfies the soundness condition. We also show there are several ways to modify this definition to satisfy the completeness condition and discuss their physical significances.

Marco Genovese INRM, Turin

Weak measurements: from sequential weak values to protective measurements

Measurements are the very basis of Physics. In quantum mechanics they assume even a more fundamental role since observables can have undetermined values that "collapse" on a specific one only when a strong measurement (described by a projection operator) is done. Furthermore, a crucial feature of quantum measurement is that measuring one observable completely erases the information on the corresponding conjugate one (e.g. measurement of position erases information about impulse).

Nevertheless, in quantum mechanics other kind of measurements beyond projective ones are possible. For example, there is the possibility to overcome collapse through a weak measurements (i.e. though an interaction sufficiently weak not to collapse the state).

A first example are weak values [1], introduced in [2] and firstly realized in [3]. They have been used for addressing fundamental questions [4], as contextuality, but are also a tool for quantum metrology allowing high-precision measurements, as tiny spin Hall effect [5] or small beam deflections [6] and characterization of states [7].

One of the most intriguing properties of weak values is that, since they do not collapse the wave function, they can permit to gather simultaneous information of non-commuting observables [8].
A second example is offered by protective measurement where in a single measurement information about the average value can be gathered [10].
In this talk, after a general introduction to weak measurements, we discuss the first experimental results on sequential weak values, i.e. a joint measurement of the weak value of (incompatible) polarizations of a single photon, discussing future applications.
Then, we present an experiment addressed to explore the connection between weak values and contextuality following the theoretical proposal of Ref. [9]. A clear violation of the inequality proposed in [9] is achieved satisfying all the theoretical requests of [9], unequivocally demonstrating the contextual nature of weak values.
Finally, we present and discuss the first demonstration of a protective measurement.

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Pablo Arrighi Aix-Marseille University and ENS de Lyon
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Andrei Khrennikov Linnaeus University, Växjö
Possibility to agree on disagree from quantum information and decision making
The celebrated Aumann theorem states that if two agents have common priors, and their posteriors for a given event E are common knowledge, then their posteriors must be equal; agents with the same priors cannot agree to disagree. The aim of this note is to show that in some contexts agents using a quantum probability scheme for decision making can agree to disagree even if they have the common priors, and their posteriors for a given event E are common knowledge. We also point

to sufficient conditions guaranteeing impossibility to agree on disagree even for agents using quantum(-like) rules in the process of decision making. A quantum(-like) analog of the knowledge operator is introduced; its basic properties can be formulated similarly to the properties of the classical knowledge operator defined in the set-theoretical approach to representation of the states of the world and events (Boolean logics). However, this analogy is just formal, since quantum and classical knowledge operators are endowed with very different assignments of truth values. A quantum(-like) model of common knowledge naturally generalizing the classical set-theoretic model is presented. We illustrate our approach by a few examples; in particular, on attempting to escape the agreement on disagree for two agents performing two different political opinion polls. We restrict our modeling to the case of information representation of an agent given by a single quantum question-observable (of the projection type). A scheme of extending of our model of knowledge/common knowledge to the case of information representation of an agent based on a few question-observables is also presented and possible pitfalls are discussed.