Entanglement Days 2018
Budapest

organizers:
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26-28 September, 2018

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Entanglement Days workshops

Quantum entanglement plays a central role in quantum physics, and it is an important resource in quantum information processing and quantum metrology. Due to recent technological breakthroughs, even macroscopic entangled states can be created, giving a basis to study large-scale entanglement theoretically in more and more complex systems.

Entanglement Days workshops were organized twice before, in the Wigner Research Centre for Physics of the Hungarian Academy of Sciences. Advertized on the national level, the workshops gathered together researchers working on entanglement, quantum foundations and related topics in Hungary. Due to the considerable success of the national workshops, this year we decided to organise an international event.

Our present three-day workshop covers several topics on entanglement theory and quantum foundations, such as entanglement criteria, quantum nonlocality and Bell inequalities, fundamental questions in quantum physics, quantum metrology, spin squeezing, and experiments in cold gases and photons. The invited speakers of the event are

Iagoba Apellaniz (Bilbao)
John Calsamiglia (Barcelona)
Otfried Gühne (Siegen)
Felix Huber (Siegen)
Marcus Huber (Vienna)
István Kovács (Boston)
Wiesław Laskowski (Gdansk)
Michał Oszmaniec (Gdansk)
Christian Schilling (Oxford)
Jens Siewert (Bilbao)
Tamás Vértesi (Debrecen)
Giuseppe Vitagliano (Vienna)
Mario Ziman (Bratislava)
Karol Życzkowski (Kraków)

We are looking forward to seeing you at the workshop. We hope that it serves as a stimulating opportunity for fruitful collaborations, and it will also be a joyful personal experience.

With best wishes,

Géza Tóth, Zoltán Zimborás, Szilárd Szalay and János Asbóth.

The webpage of the workshop is https://indico.kfki.hu/event/entdays2018.
In case of any question, please feel free to contact us via entdays@wigner.mta.hu.

Timetable

Wednesday 26.09

08:00: Registration, possibly setting up posters

09:00: Marcus Huber†, *Entanglement certification*
09:45: Jens Siewert*, *Distribution of entanglement and correlations in all finite dimensions*
10:15: Alexander Streltsov, *Quantum state redistribution with local coherence*

10:35: Coffee break

11:05: Felix Huber*, *Codes of maximal distance and highly entangled subspaces*
11:35: Zahra Raissi, *Constructing k-uniform states of non-minimal support*
11:55: Nikolai Wyderka, *Constraining the correlations in multi-qubit systems*

12:15: Lunch break

14:00: Karol Życzkowski†, *Multipartite entanglement and combinatorial designs*
14:45: Giuseppe Vitagliano*, *Su(d) spin squeezing and many-body entanglement detection with uncertainty relations*

15:15: Coffee break

15:45: Michał Oszmaniec*, *Efficient classical simulation of lossy boson sampling via separable states*
16:15: Borivoje Dakic, *Single-copy entanglement detection*
16:35: Máté Farkas, *Certifying an irreducible 1024-dimensional photonic state using refined dimension witnesses*

17:00: Poster session, with emphasis on the odd-numbered posters.

Thursday 27.09

09:00: Otfried Gühne†, *Quantum steering and the geometry of the EPR-argument*
09:45: Wiesław Laskowski*, *Disproving hidden variable models with spin magnitude conservation*
10:15: Remigiusz Augusiak, *Self-testing of two-qutrit systems*

10:35: Coffee break

11:05: John Calsamiglia*, *Quantum change-point and anomaly detection*
11:35: Miguel Navascues, *The limits of large quantum systems*
11:55: Albert Aloy, *Device-independent witnesses of entanglement depth from two-body correlators*

12:15: Conference photo and lunch break

14:00: Mario Ziman*, *Dynamics of entanglement*
14:30: Laurin Ostermann, *Subradiance via entanglement in atoms with several independent decay channels*
14:50: Lukas Knips, *Genuine multipartite entanglement detection without reference frames*

15:10: Coffee break

15:40: István Kovács*, *Universal critical behavior in the entanglement entropy of the quantum Ising model*
16:10: Jordi Tura i Brugués, *Bounding the set of classical correlations of a many-body system*
16:30: Balázs Dóra, *Momentum-Space Entanglement in Luttinger Liquids*

17:00: Poster session, with emphasis on the even-numbered posters.

Friday 28.09

09:00: Tamás Vértesi†, *Useful correlations from bound entangled states*
09:45: Iagoba Apellaniz*, *Gradient magnetometry with entangled atomic ensembles*
10:15: Gael Sentís, *Bound entangled states fit for robust experimental verification*

10:35: Coffee break

11:05: Matthias Kleinmann, *Signaling in Bell Experiments*
11:25: Péter Vrana, *The asymptotic spectrum of LOCC transformations*
11:45: Jan Naudts, *Challenges in non-commutative information geometry*

12:05: Lunch break

14:00: Christian Schilling*, *Introduction into fermionic correlation and applications in quantum chemistry*
14:30: Adam Sawicki, *Quantum entanglement from single particle information*
14:50: Tamás Geszti, *Nonlinear unitary quantum collapse model with self-generated noise*
15:10: Péter Vecsernyés, *An effective dynamical model for selective measurement of observables in discrete quantum systems*

†invited plenary talks, *invited talks

Participants

1. **Albert Aloy**, The Institute of Photonic Sciences, Castelldefels, Spain
2. **Iagoba Apellaniz**, University of the Basque Country, Bilbao, Spain
3. **Rayssa Bruzaca de Andrade**, Technical University of Denmark, Copenhagen
4. **János Asbóth**, Wigner Research Centre for Physics, Budapest, Hungary
5. **Remigiusz Augusiak**, Center for Theoretical Physics, Warsaw, Poland
6. **László Bacsardi**, Budapest University of Technology and Economics, Hungary
7. **Gergely Barcza**, Wigner Research Centre for Physics, Budapest, Hungary
8. **Aleksandr Berezutskii**, Skolkovo Institute of Science and Technology, Moscow, Russia
9. **Fabian Bernards**, University of Siegen, Germany
10. **Tulio Brito Brasil**, University of Sao Paulo, Brazil
11. **Wojciech Bruzda**, Jagiellonian University, Kraków, Poland
12. **John Calsamiglia**, Autonomous University of Barcelona, Spain
13. **Borivoje Dakic**, Institute for Quantum Optics and Quantum Information, Vienna, Austria
14. **Lajos Diósi**, Wigner Research Centre for Physics, Budapest, Hungary
15. **Balázs Dóra**, Budapest University of Technology and Economics, Hungary
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17. **Mariami Gachechiladze**, University of Siegen, Germany
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22. **Felix Huber**, University of Siegen, Germany
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58. **Christian Schilling**, University of Oxford, England
59. **Gael Sentís**, University of Siegen, Germany
60. **Jens Siewert**, University of the Basque Country, Bilbao, Spain
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67. **Eleftherios Tselentis**, Swiss Federal Institute of Technology in Zurich
68. **Jordi Tura i Brugués**, Max Planck Institute of Quantum Optics, Garching, Germany
69. **Géza Tóth**, Wigner Research Centre for Physics, Budapest, Hungary and University of the Basque Country, Bilbao, Spain
70. **Gábor Vattay**, Eötvös Loránd University, Budapest, Hungary
71. **Péter Vecsernyés**, Wigner Research Centre for Physics, Budapest, Hungary
72. **Giuseppe Vitagliano**, Institute for Quantum Optics and Quantum Information, Vienna, Austria
73. **Péter Vrana**, Budapest University of Technology and Economics, Hungary

74. **Tamás Vértesi**, Institute for Nuclear Research, Debrecen, Hungary
75. **Yukun Wang**, National University of Singapore
76. **Miklós Werner**, Budapest University of Technology and Economics, Hungary
77. **Nikolai Wyderka**, University of Siegen, Germany
78. **Li Xinhui**, National University of Singapore
79. **Mario Ziman**, Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia
80. **Zoltán Zimborás**, Wigner Research Centre for Physics, Budapest, Hungary
81. **Karol Życzkowski**, Jagiellonian University, Kraków, Poland

updated list of actual participants

Abstracts of talks

Device-independent witnesses of entanglement depth from two-body correlators

Albert Aloy (The Institute of Photonic Sciences, Castelldefels, Spain)
Joint work with J. Tura, F. Baccari, A. Acín, M. Lewenstein, R. Augusiak.

We present how to derive device-independent witnesses of entanglement depth out of Bell inequalities that are constrained by symmetry and involving at most 2-body correlation functions. The problem gets reduced to finding the k-producible bounds of such Bell inequalities. Having the symmetric 2-body Bell inequalities as building blocks allows us to devise two complementary computational methods that find the desired k-producible bound and check its optimality. Furthermore, we are able to find an analytical expression that works in the thermodynamic limit. Finally, the witnesses can be adapted to be experimentally tested with collective measurements and its second moments.

A. Aloy, J. Tura, F. Baccari, A. Acín, M. Lewenstein, R. Augusiak, arXiv:1807.06027 [quant-ph] (2018).

Gradient magnetometry with entangled atomic ensembles

Iagoba Apellaniz (University of the Basque Country, Bilbao, Spain)

We study gradient magnetometry with an ensemble of atoms with arbitrary spin. In the framework of quantum metrology, the quantum Fisher information gives us the achievable precision for the estimation of the unknown parameter, in this case the gradient of the magnetic field. The theory tells us that in order to overcome the classical precision bound of an estimation the system must be entangled. We consider the case of a very general spatial probability distribution function. For quantum states that are invariant under homogeneous magnetic fields, we need to measure a single observable to estimate the gradient. On the other hand, for states that are sensitive to homogeneous fields, the simultaneous measurement of two observables is needed, as the homogeneous field must also be estimated. This leads to a two-parameter estimation problem. We present a method to calculate precision bounds for gradient estimation for different configurations of the spatial state including a permutationally invariant probability distribution function, which can model an atomic ensemble when the particles cannot be addressed individually. Our model can take into account even correlations between particle positions.

Self-testing of two-qutrit systems

Remigiusz Augusiak (Center for Theoretical Physics, Warsaw, Poland)
Joint work with A. Acín, F. Baccari, J. Kaniewski, A. Salavrakos, I. Supic, J. Tura.

Bell inequalities are an important tool in device-independent quantum information processing because their violation can serve as a certificate of relevant quantum properties. Probably the best known example of a Bell inequality is due to Clauser, Horne, Shimony and Holt (CHSH), defined in the simplest scenario involving two dichotomic measurements, whose all key properties are well understood. While there have been many attempts to generalise it to higher-dimensional quantum systems, quite surprisingly, most of them turn out to be difficult to analyse. In particular, the maximal quantum violation—a key quantity for most device-independent applications—remains unknown except for the simplest cases. Here we propose a new generalisation of the CHSH Bell inequality which preserves several of its attractive features: the maximal quantum value can be computed analytically and can be achieved by the maximally entangled states and mutually unbiased bases. These inequalities involve d measurement settings, each having d outcomes with d being an arbitrary prime number. We then show that in the three-outcome case our Bell inequality can be used for self-testing of the maximally entangled state of two-qutrits and three mutually unbiased bases at each site. Yet, we demonstrate that in the case of more outcomes, their maximal violation does not allow for self-testing in the standard sense. The ability to certify high-dimensional MUBs makes them attractive from the device-independent cryptography point of view.

D. Mayers, and A. Yao, Proc. 39th Ann. Symp. on Foundations of Computer Science (FOCS) , 503 (1998).
T. H. Yang and M. Navascues, Phys. Rev. A **87**, 050102(R) (2013).
A. Coladangelo, K. T. Goh, V. Scarani, Nat. Comm. **8**, 15485 (2017).
H. Buhrman and S. Massar, Phys. Rev. A **72**, 052103 (2005).

Quantum change-point and anomaly detection.

John Calsamiglia (Autonomous University of Barcelona, Spain)
Joint work with G. Sentís, R. Muñoz-Tapia.

We present two hypotheses testing problems where the hypotheses to be discriminated differ in the positions of a change or anomaly suffered on a string of qubits. We study the role played by quantum correlations in the n-qubit measurement and in the probe states used in the optimal detection scheme. The first problem is a quantum extension of the change-point detection, a pivotal task is statistical analysis that aims at identifying the moment when a sequence of observed data changes its underlying probability distribution. We study a quantum instance of this problem where a source emits quantum particles in a default state, until a point where a mutation occurs that causes the source to produce a different state [1,2]. The problem is then to find out where the change occurred. The second problem is that of quantum anomaly detection [3] where now the change occurs in a singlequbit of the string whose position is unknown.In anomaly detection we also consider the extension from sources to general quantum channels, i.e. we study the problem of identifying a malfunctioning device from a sequence of n devices that perform a default fixed operation.

1. G. Sentís, E. Bagan, J. Calsamiglia, G. Chiribella, and R. Muñoz-Tapia, Phys. Rev. Lett. **117**, 150502 (2016).
2. G. Sentís, J. Calsamiglia, and R. Muñoz-Tapia, Phys. Rev. Lett. **119**, 140506 (2017).
3. M. Skotiniotis, R. Hotz, J. Calsamiglia, and R. Muñoz-Tapia, arXiv:1808.02729 [quant-ph] (2018).

Single-copy entanglement detection

Borivoje Dakic (Institute for Quantum Optics and Quantum Information, Vienna, Austria)

A main focus of current practical quantum information research is on the generation of large-scale quantum entanglement involving many particles with the goal of achieving real applications of quantum technologies. An important instance of this challenge is the verification problem: how to reliably certify the presence of quantum resources, in particular quantum entanglement. The plausibility of standard verification schemes (for example, based on entanglement witnesses) is questionable, since they require repeated measurement on large ensemble of identically prepared copies, which is highly demanding to achieve in practice when dealing with large-scale entangled quantum systems. In this talk, I will present our recent work [1] where we develop a novel method by formulating verification as a decision procedure, i.e. entanglement is seen as the ability of quantum system to answer certain “yes-no questions”. We show that for a variety of large quantum states even a single copy suffices to detect entanglement with a high probability by using local measurements. For example, a single copy of a 24-qubit linear cluster state suffices to verify entanglement with more than 95% confidence. Our method is applicable to many important classes of states, such as cluster states or ground states of local Hamiltonians in general.

1. A. Dimic, and B. Dakic, npj Quantum Information **4**, 11 (2018).

Momentum-Space Entanglement in Luttinger Liquids

Balázs Dóra (Budapest University of Technology and Economics, Hungary)

Luttinger liquids (LLs) arise by coupling left- and right-moving particles through interactions in one dimension. This most natural partitioning of LLs is investigated by the momentum-space entanglement after a quantum quench using analytical and numerical methods. We show that the momentum-space entanglement spectrum of a LL possesses many universal features both in equilibrium and after a quantum quench. The largest entanglement eigenvalue is identical to the Loschmidt echo, i.e. the overlap of the disentangled and final wavefunctions of the system. The second largest eigenvalue is the overlap of the first excited state of the disentangled system with zero total momentum and the final wavefunction. The entanglement gap is universal both in equilibrium and after a quantum quench.

Certifying an irreducible 1024*-dimensional photonic state using refined dimension witnesses*

Máté Farkas (University of Gdansk, Polnad)

We report on a new class of dimension witnesses, based on quantum random access codes, which are a function of the recorded statistics and that have different bounds for all possible decompositions of a high-dimensional physical system. Thus, it certifies the dimension of the system and has the new distinct feature of identifying whether the high-dimensional system is decomposable in terms of lower dimensional subsystems. To demonstrate the practicability of this technique we used it to experimentally certify the generation of an irreducible 1024-dimensional photonic quantum state. Therefore, certifying that the state is not multipartite or encoded using non-coupled different degrees of freedom of a single photon. Our protocol should find applications in a broad class of modern quantum information experiments addressing the generation of high-dimensional quantum systems, where quantum tomography may become intractable.

Nonlinear unitary quantum collapse model with self-generated noise

Tamás Geszti (Eötvös Loránd University, Budapest, Hungary)

A deterministic nonlinear model of quantum collapse is presented, in which randomness emerges during the measurement process, from deterministic chaotic dynamics of the detectors.The treatment is based on a minimally nonlinear von Neumann equation, containing a self-adjoint skew-symmetric structure, with a split scalar product of coordinate and momentum operators over the configuration space, decomposing into a sum over remote parts of the measurement setup.

The microscopic states of the detectors act as a nonlocal set of hidden parameters, controlling individual outcomes.The model is shown to display pumping of weights between setup-defined basis states, with a single winner randomly selected and the rest collapsing to zero. Through stochastic modelling, based on Pearle's "gambler's ruin" scheme, outcome probabilities are shown to obey Born's rule under a no-drift or "fair-game" (martingale) condition. This fully reproduces quantum statistical predictions, implying that the model satisfies the non-signaling requirement.

T. Geszti, J. Phys. A: Math. Theor. **51**, 175308 (2018).

Quantum Steering and the Geometry of the EPR-Argument

Otfried Gühne (University of Siegen, Germany)
Joint work with C. Budroni, A. C. S. Costa, C. Nguyen, H.-V. Nguyen, J.-P. Pellonpää and R. Uola.

Steering is a type of quantum correlations which lies between entanglement and the violation of Bell inequalities. In this talk, I will first give an introduction into the topic. Then, I will discuss three results on steering: First, I will explain the connection to joint measurability. Second, I will show how entropic uncertainty relations can be used to derive steering criteria. Finally, I will present an algorithmic approach to characterize the quantum states that can be used for steering. With this, one can decide the problem of steerability for two-qubit states.

R. Uola, C. Budroni, O. Gühne, and J.-P. Pellonpää, Phys. Rev. Lett. **115**, 230402 (2015).
A. C. S. Costa, R. Uola, and O Gühne, arXiv:1710.04541 [quant-ph] (2017).
C. Nguyen, H-V. Nguyen, and O. Gühne, arXiv:1808.09349 [quant-ph] (2018).

Codes of Maximal Distance and Highly Entangled Subspaces

Felix Huber (University of Siegen, Germany)
Joint work with M. Grassl.

We present new bounds on the existence of quantum maximum distance separable codes (QMDS): the length n of all non-trivial QMDS codes with local dimension D and distance d is bounded by $n \leq D^2 + d - 2$. We obtain their weight distribution and present additional bounds that arise from Rains' shadow inequalities. Our main result can be seen as a generalization of bounds that are known for the special cases of stabilizer QMDS codes and absolutely maximally entangled states, and confirms the quantum MDS conjecture in the special case of distance-three codes. Because the existence of QMDS codes is directly linked to that of highly entangled subspaces (in which every vector has uniform r-body marginals) of maximal dimension, our methods directly carry over to address questions in multipartite entanglement.

Entanglement certification

Marcus Huber (Institute for Quantum Optics and Quantum Information, Vienna, Austria)

Often described as the principal feature distinguishing quantum mechanics from classical physics and the topic of this conference, entanglement theoretically constitutes a ubiquitous feature of many-particle and high-dimensional Hilbert spaces [1,2]. Due to vast size of the corresponding Hilbert spaces, however, actually certifying quantum entanglement remains a challenging task that is nonetheless often necessary or at least beneficial for the functionality of quantum information protocols. In this talk, I will review the basic definitions of entanglement and corresponding certification methods, with a special focus on high-dimensional Hilbert spaces and multipartite quantum states. I will show how, even with limited data and measurement capacity, suitable methods for certifiying quantum entanglement can be developed and briefly report on our recent experiments exploring high-dimensional spatial and temporal entanglement in Vienna [3,4].

1. M. Huber, L. Lami, C. Lancien, A. Müller-Hermes, arXiv:1802.04975 [quant-ph] (2018).
2. C. Lancien, O. Gühne, R. Sengupta, and M. Huber, J. Phys. A: Math. Theor. **48**, 505302 (2015).
3. F. Steinlechner, S. Ecker, M. Fink, B. Liu, J. Bavaresco, M. Huber, T. Scheidl, and R. Ursin, Nat. Comms. **8**, 15971 (2017).
4. J. Bavaresco, N. H. Valencia, C. Klöckl, M. Pivoluska, P. Erker, N. Friis, M. Malik, and M. Huber, Nature Physics , DOI:10.1038/s41567-018-0203-z (2018).

Signaling in Bell Experiments

Matthias Kleinmann (University of Siegen, Germany)

Bell tests were originally designed to enable the exclusion of local hidden variable models. However, their relevance goes beyond this and high violations of Bell inequalities have many applications, for example, in randomness generation, entanglement quantification, or self-testing. Then, the specific value and its experimental reliability are an important concern. We analyze typical photonic setups and find that those setups are susceptible to systemic errors. These errors can be easily revealed by testing the nonsignaling conditions. We also present a set of experiments with polarization-entangled photons in which we demonstrate approaches to avoid the sources of these systematic errors, allowing us to establish a reliable estimate for the Bell parameter.

Genuine Multipartite Entanglement Detection without Reference Frames

Lukas Knips (Max Planck Institute of Quantum Optics, Garching, Germany)

Entanglement is a fascinating feature of quantum systems and one of the key resources for quantum information processing. In order to detect and quantify entanglement, thus attesting the prepared system to be a useful resource, sophisticated methods are required. The toolbox, I am going to present and illustrate using experimental results, encompasses a method which allows to easily construct non-linear witnesses to detect genuine multipartite entanglement with only two measurement settings. In a different approach, entanglement can be detected in an adaptive way. Finally, I will show a technique based on randomized measurements, not demanding any a priori information. Moreover, this method does not even require the knowledge of the actual measurement directions, but can be applied in scenarios where local reference frames are either hard to measure or may drift over time.

Universal critical behavior in the entanglement entropy of the quantum Ising model

István Kovács (Northeastern University, Boston, USA)

It is a long standing aim to understand and control quantum entanglement at large scales. We will summarize recent results on the disordered quantum Ising model, probably the best understood interacting quantum system. The entanglement entropy of this model is calculated efficiently by the strong disorder renormalization group method, providing asymptotically exact results in any dimensions. We find that the area law is always satisfied, but there are analytic corrections due to edges. More interesting is the contribution arising from corners of the subsystem, which is logarithmically divergent at the critical point with a universal prefactor, independently of the form of disorder. As a step towards practical applications, we will extend these results for the interface between a disordered and clean subsystem as well as for models with long-ranged interactions. Due to its favorable entanglement structure, the disordered quantum Ising model can also be the basis of scalable quantum network architectures, resulting in complex network topologies.

Disproving hidden variable models with spin magnitude conservation

Wiesław Laskowski (University of Gdansk, Poland)

The squares of the three components of the spin-s operators sum up to $s(s+1)$. However, a similar relation is rarely satisfied by the set of possible spin projections onto mutually orthogonal directions. This has fundamental consequences if one tries to construct a hidden variable (HV) theory describing measurements of spin projections. We propose a test of local HV-models in which spin magnitudes are conserved. These additional constraints imply that the corresponding inequalities are violated within quantum theory by larger classes of states than in the case of standard Bell inequalities. We conclude that in any HV-theory pertaining to measurements on a spin one can find situations in which either HV-assignments do not represent a physical reality of a spin vector, but rather provide a deterministic algorithm for prediction of the measurement outcomes, or HV-assignments represent a physical reality, but the spin cannot be considered as a vector of fixed length.

Challenges in Non-Commutative Information Geometry

Jan Naudts (Universiteit Antwerpen)

A new approach to quantum information geometry is followed. the emphasis is shifted from a manifold of strictly positive density matrices to a manifold of faithful quantum states on the C*-algebra of bounded linear operators. In addition, ideas from the parameter-free approach to information geometry are adopted. The underlying Hilbert space is assumed to be finite-dimensional. In this way technicalities are avoided.

J. Naudts, Entropy **20**, 472 (2018).

The limits of large quantum systems

Miguel Navascues (Institute for Quantum Optics and Quantum Information, Vienna, Austria)
Joint work with S. Singh and A. Acín.

As quantum technologies develop, we acquire control of an ever-growing number of quantum systems. Unfortunately, current tools to certify non-classical properties of quantum states, such as entanglement and nonlocality, are just practical for systems of a very modest size, of around 4 sites. Our approach to solve this "many-body quantum information problem" consists in devising linear witnesses which admit an exact tensor network state representation. The resulting method allows us to certify entanglement, Bell nonlocality and supra-quantum Bell nonlocality in networks with hundreds of sites in a matter of seconds.

Subradiance via entanglement in atoms with several independent decay channels

Laurin Ostermann (University of Innsbruck, Austria)
Joint work with M. Hebenstreit, B. Kraus, H. Ritsch.

Spontaneous emission of atoms in free space is modified by the presence of other atoms in close vicinity inducing collective super- and sub-radiance. For two nearby atoms with a single decay channel the entangled antisymmetric superposition state of the two single excited states will not decay spontaneously. No such excited two-atom dark state exists, if the excited state has two independent optical decay channels of different frequencies or polarizations. However, we show that for an excited atomic state with $N-1$ independent spontaneous decay channels one can find a highly entangled N-particle dark state, which completely decouples from the vacuum radiation field. It does not decay spontaneously, nor will it absorb resonant laser light. Mathematically, we see that this state is the only such state orthogonal to the subspace spanned by the atomic ground states. Moreover, by means of generic numerical examples we demonstrate that the subradiant behavior largely survives at finite atomic distances including dipole-dipole interactions.

M. Hebenstreit, B. Kraus, L. Ostermann, and H. Ritsch, Phys. Rev. Lett. **118**, 143602 (2017).

Efficient classical simulation of lossy boson sampling via separable states

Michał Oszmaniec (National Quantum Information Centre, Gdansk, Poland)

We explore the possibility of efficient classical simulation of linear optics experiments under the effect of particle losses. Specifically, we investigate the canonical boson sampling scenario in which an n-particle Fock input state propagates through a linear-optical network and is subsequently measured by particle-number detectors in the m output modes. Our classical simulation scheme is based on approximating lossy photonic states by particle-separable states, for which the output statistics of boson sampling can be efficiently simulated. We examine two models of losses. In the first model a fixed number of particles is lost. We prove that in this scenario the output statistics can be well approximated by an efficient classical simulation, provided that the number of photons that is left grows slower than $\sqrt{n}$. In the second loss model, every time a photon passes through a beamsplitter in the network, it has some probability of being lost. For this model the relevant parameter is s, the smallest number of beamsplitters that any photon traverses as it propagates through the network. We prove that it is possible to approximately simulate the output statistics already if s grows logarithmically with m, regardless of the geometry of the network. The latter result is obtained by proving that it is always possible to commute s layers of uniform losses to the input of the network regardless of its geometry, which could be a result of independent interest. We believe that our findings put strong limitations on future experimental realizations of quantum computational supremacy proposals based on boson sampling.

M. Oszmaniec, D. J. Brod, arXiv:1801.06166 [quant-ph] (2018).

Constructing k-uniform states of non-minimal support

Zahra Raissi (The Institute of Photonic Sciences, Castelldefels, Spain)
Joint work with Ch. Gogolin, A. Riera and A. Acin.

A pure quantum state of n subsystems each having local dimension q is called k-uniform, if all k-qudit reductions of the whole system are maximally mixed. These states form a natural generalization of n qudits EPR and GHZ states which belong to the class 1-uniform states. The k-uniform states are known to play an important role in quantum information processing when dealing with many parties. They are useful for multipartite teleportation and in quantum secret sharing. These states have also deep connections with apparently unrelated areas of mathematics such as combinatorial designs and structures, classical error correcting codes (CECC), and quantum error correcting codes (QECC).

The Schmidt decomposition shows that a state can be at most $\lfloor n/2 \rfloor$-uniform, i.e., $k \leq \lfloor n/2 \rfloor$. The $\lfloor n/2 \rfloor$-uniform states are called Absolutely Maximally Entangled states or AME states for short. We describe that there can be a direct correspondence between a given CECC and k-uniform state of minimal support if there exists a coordinate such that any k symbols of the codewords can be taken as message symbols. One aspect of this connection can provide a framework to develop a stabilizer formalism and produce an orthonormal basis of a given k-uniform state. We also study the description of these k-uniform states within the graph state formalism. We show the graphical representation for the state constructed from a CECC form a bipartite graph.

We propose a systematic method to construct a set of non-minimal support k-uniform states. We show that these states have better parameter compare to the k-uniform states that are obtained from the CECCs. More precisely we show, for given n and local dimension q, if both k-uniform state of minimal support and non-minimal support exist, the two states are not local unitary equivalent. In an analogous fashion, we construct a set of Pauli strings that generate a stabilizer group that stabilizes a given k-uniform state of non-minimal support. Also, we compare the graphical representation of the k-uniform state of minimal support and non-minimal support.

Quantum entanglement from single particle information

Adam Sawicki (Center for Theoretical Physics, Warsaw, Poland)
Joint work with M. Kus, T. Maciazek and M. Oszmaniec.

Despite considerable interest in recent years, understanding of quantum correlations in multipartite finite dimensional quantum systems is still incomplete. I will consider a simple scenario in which we have access to the results of all one-particle measurements of such system. The aim is to understand how much information about quantum correlations is encoded in this data. It turns out that mathematically consistent way of studying this problem involves methods that are used in classical mechanics to describe phase spaces with symmetries. In this talk I will review these methods and show their usefulness to our problem.

Introduction into fermionic correlation and applications in quantum chemistry

Christian Schilling (University of Oxford, England)
Joint work with Ö. Legeza, Sz. Szalay and Z. Zimborás.

We provide an introduction into the concept of correlation for systems of identical fermions. In that context, we emphasize the role of algebras of observables for the notion of entanglement and distinguish between mode/orbital and particle correlations. The operational meaning of common correlation measures is discussed and the significance of the particle number and number parity superselection rules is stressed. We then apply those concepts in quantum chemistry to explore and quantify the structure of molecular ground states. On the one hand, this will provide insights into the bonding character of molecules and on the other hand, it will facilitate more efficient implementations of DMRG in a quantum chemical context. As a prime example, and to illustrate the quantum chemists' perspective on correlations, we will study in detail the dissociation limit of the hydrogen molecule, leading to the notion of static and dynamic correlation. We then explain how this separation of correlation relates to the thermal robustness of the total correlations.

Bound entangled states fit for robust experimental verification

Gael Sentís (University of Siegen, Germany)

Preparing and certifying bound entangled states in the laboratory is an intrinsically hard task, due to both the fact that they typically form narrow regions in the state space, and that a certificate requires a tomographic reconstruction of the density matrix. Indeed, the previous experiments that have reported the preparation of a bound entangled state relied on such tomographic reconstruction techniques. However, the reliability of these results crucially depends on the extra assumption of an unbiased reconstruction. We propose an alternative method for certifying the bound entangled character of a quantum state that leads to a rigorous claim within a desired statistical significance, while bypassing a full reconstruction of the state. The method is comprised by a search for bound entangled states that are robust for experimental verification, and a hypothesis test tailored for the detection of bound entanglement that is naturally equipped with a measure of statistical significance.

We apply our method to families of states of 3×3 and 4×4 systems, and find that the experimental certification of bound entangled states is well within reach.

G. Sentís, J. N. Greiner, J. Shang, J. Siewert, M. Kleinmann, arXiv:1804.07562 [quant-ph] (2018).

Distribution of entanglement and correlations in all finite dimensions

Jens Siewert (University of the Basque Country, Bilbao, Spain)
Joint work with Ch. Eltschka, F. Huber, O. Gühne.

We present a family of correlations constraints that apply to all multipartite quantum systems of finite dimension. The size of this family is exponential in the number of subsystems. We obtain these relations by defining and investigating the generalized state inversion map. This map provides a systematic way to obtain local unitary invariants of degree two in the state and, surprisingly, is directly linked to the shadow inequalities proved by Rains [IEEE Trans. Inf. Theory 46, 54 (2000)]. The constraints are stated in terms of linear inequalities for the linear entropies of the subsystems and hold for arbitrary mixed states. For pure quantum states they turn into monogamy relations that constrain the distribution of bipartite entanglement among the subsystems of the global state.

Quantum state redistribution with local coherence

Alexander Streltsov (Gdansk University of Technology, Poland)
Joint work with A. Anshu, R. Jain.

Quantum entanglement and coherence are two fundamental resources for quantum information processing. Recent results clearly demonstrate their relevance in quantum technological tasks, including quantum communication and quantum algorithms. In this talk I discuss the role of quantum coherence for quantum state redistribution, a fundamental task where two parties aim to relocate a quantum particle by using a limited amount of quantum communication and shared entanglement. We give general bounds for the resource rates required for this process, and show that these bounds are tight under additional reasonable constraints, including the situation where the receiving party cannot use local coherence. While entanglement cannot be directly converted into local coherence in our setting, we show that entanglement is still useful for local coherence creation if an additional quantum channel is provided, and the optimal protocol for local coherence creation for any given amount of quantum communication and shared entanglement is presented.

A. Anshu, R. Jain, and A. Streltsov, arXiv:1804.04915 [quant-ph] (2018).

Bounding the set of classical correlations of a many-body system

Jordi Tura i Brugués (Max Planck Institute of Quantum Optics, Garching, Germany)
Joint work with M. Fadel.

We present a method to certify the presence of Bell correlations in experimentally observed statistics, and to obtain new Bell inequalities. Our approach is based on relaxing the conditions defining the set of correlations obeying a local hidden variable model, yielding a convergent hierarchy of semidefinite programs (SdP's). Because the size of these SdP's is independent of the number of parties involved, this technique allows to characterize correlations in many-body systems. As an example, we illustrate our method with the experimental data presented in [Science 352, 441 (2016)].

M. Fadel and J. Tura, Phys. Rev. Lett. **119**, 230402 (2017).

An effective dynamical model for selective measurement of observables in discrete quantum systems

Péter Vecsernyés (Wigner Research Centre for Physics, Budapest, Hungary)

It is argued that infinite degrees of freedom causes not only the existence of inequivalent representations and even different phases of the corresponding quantum algebras but also leads to non-unitary, non-linear, and probabilistic effective dynamics of selective measurements. The probability (relative frequency) of the measurement outcomes is thought to be equal to the relative volume of the attractor regions in the initial state space of the combined system (measured system and the measuring device) with respect to the effective non-linear dynamics.

Although the exact treatment of the measurement process is hopeless one may try to describe the measurement results as asymptotic states of a dynamical process, where the non-unitarity of time evolution arises as an effective description of the interaction of the measured system with the measuring device.

We present an effective two-step toy dynamics of the measurement of a self-adjoint observable $A \in M_n(\mathbb{C})$: the first step is the non-selective measurement or decoherence, which is known to be described by the linear, deterministic Lindblad equation. The second step is a process from the resulted decohered state to a pure state, which is described by an effective non-linear "randomly chosen" toy model dynamics, where the pure states arise as asymptotic fixed points, and their emergent probabilities are the relative volumes of their attractor regions.

P. Vecsernyés, J. Math. Phys. **58**, 102109 (2017).

SU(d) *spin squeezing and many-body entanglement detection with uncertainty relations*

Giuseppe Vitagliano (Institute for Quantum Optics and Quantum Information, Vienna, Austria)
Joint work with P. Hyllus, I. Apellaniz, I. L. Egusquiza and G. Tóth.

We present our recent results on the relation between (generalizations of) spin squeezing and manybody entanglement geometry. For spin higher than 1/2, we study different possible generalizations of spin squeezing, by considering the larger algebra of SU(d) collective operators for d-level particle systems. We present a set of necessary conditions for fully separable states of N qudits and show the analogy between such conditions and the general method of entanglement detection based on local uncertainty relations. We show that geometrically our set of conditions encloses a convex set of points in a certain space of average two-body correlations and prove that for $N \gg 1$ such set is filled by states decomposed in a certain pseudo-separable form. We also study states that are outside of this set and define a SU(d)-squeezing entanglement parameter, interpreted as a signed distance from it. Finally, we study what states can be detected with our parameter, focusing especially on thermal states of SU(d) mean-field models, thereby finding examples of thermal states that are SU(d)-squeezed but not spin-squeezed (i.e., SU(2)-squeezed) and vice-versa.

1. G. Vitagliano, P. Hyllus, I. L. Egusquiza and G. Tóth, Phys. Rev. Lett. **107**, 240502 (2011).
2. G. Vitagliano, I. Apellaniz, I. L. Egusquiza and G. Tóth, Phys. Rev. A **89**, 032307 (2014).
3. SU(d)-squeezing and many-body entanglement geometry in finite-dimensional systems (in preparation)

The asymptotic spectrum of LOCC transformations

Péter Vrana (Budapest University of Technology and Economics, Hungary)
Joint work with A. K. Jensen.

Motivated by the study of the arithmetic complexity of matrix multiplication, V. Strassen introduced the partially ordered semiring of tensors and used its properties to prove that asymptotic degeneration is characterized by monotone additive and multiplicative functions into the nonnegative reals. The collection of such functions is called the asymptotic spectrum. We show that a similar construction can be performed with pure multipartite states, where the partial order is defined via trace-nonincreasing local operations and classical communication. The

corresponding asymptotic preorder means that a given state can be transformed into another one with a prescribed converse error exponent. This implies that the trade-off between the transformation rate and the error exponent is also characterized by an asymptotic spectrum. For bipartite states we determine the spectral points and thus obtain an explicit formula, generalizing a result of Hayashi et al.

A. K. Jensen, and P. Vrana, arXiv:1807.05130 [quant-ph] (2018).

Useful correlations from bound entangled states

Tamás Vértesi (Institute for Nuclear Research, Debrecen, Hungary)
Joint work with G. Tóth, K. Pál, and N. Brunner.

Bound entanglement is a curious form of quantum correlation: bound entangled states require entanglement to produce them, however, they are so noisy that no pure state entanglement can be distilled from them. Since many tasks in quantum information require pure state entanglement, it became an open problem for which tasks bound entanglement can be a useful quantum resource. In this talk we show two such applications: quantum metrology and Bell nonlocality. In particular, it is shown that bound entangled states can outperform separable states in linear interferometers, and they can give rise to Bell nonlocality from which true randomness can be certified. Powerful iterative methods are presented to find such bound entangled states.

K. F. Pál, T. Vértesi, Phys. Rev. A **96**, 022123 (2017).
G. Tóth and T. Vértesi, Phys. Rev. Lett **120**, 020506 (2018).
T. Vértesi and N. Brunner, Nat. Commun. **5**, 5297 (2014).

Constraining the correlations in multi-qubit systems

Nikolai Wyderka (University of Siegen, Germany)

The set of correlations between particles in multipartite quantum systems is larger than those in classical systems. Nevertheless, it is subject to restrictions by the underlying quantum theory. We explore these restrictions in the case of multi-qubit systems, where one of the strategies is to divide all correlations into two components, depending on the question of whether they involve an odd or an even number of particles. For pure multiqubit states we prove that these two components are inextricably interwoven and often one type of correlations completely determines the other.

Dynamics of entanglement

Mario Ziman (Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia)

In this semi-tutorial talk I will introduce the elementary concepts used to characterize the behavior of quantum entanglement under quantum evolution (especially the local ones) and review the achieved results and open questions.

Multipartite entanglement and combinatorial designs

Karol Życzkowski (Jagiellonian University, Kraków, Poland)

We shall start with a short introduction to entanglement of multipartite pure quantum states. The Bell states are known to be maximally entangled among all two-qubit quantum states. The GHZ states maximize the 3-tangle and some other measures of entanglement of three-qubit systems, as their one-party reductions are maximally mixed.

What are the most entangled states for quantum systems consisting of N systems with d levels each? On one hand the answer may depend on the entanglement measure used. On the other hand, already for four-qubit system there are no states, such that any of its two-party reduction, with respect to any possible splitting, is maximally mixed. We show that such states exist for four qutrits and some other higher dimensional systems.

Construction of these stronly entnagled multipartite quantum states is shown to be linked with qeneralized combinatorial designes: quantum orthogonal arrays and quantum Latin squares.

Abstracts of posters

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1. *Study of steering in the TROPO above threshold.*

Rayssa Bruzaca de Andrade (Technical University of Denmark, Copenhagen)
Joint work with T. B. Brasil, B. Marques, M. Martinelli, P. Nussenzveig.

Einstein, Podolsky and Rosen (EPR) introduced in their famous paper [1] that entangled systems have correlations between position and momenta that it is not possible to be predicted classically. It became known as EPR paradox and it can be evidenced by EPR steering tests [2] as a form to confirm entanglement between two [3] or more systems [4]. The optical parametrical oscillator is a source of entangled states of light, the emitted beams are represented by Gaussian states and their quantum correlations can be used in different quantum information protocols. In order to explore the behavior of a triply-resonant optical parametric oscillator (TROPO) above threshold using the steering criterion in the model developed by Reid [2], we theoretically study the criterion of inference for bipartite quadratures: between the twin beams or between one of the twin beams and the pump beam. In addition, we analyzed the inference between the three modes, through the bipartition pump mode and combination of sum quadrature of the twin beams. Steering is a figure of merit of quantum secret sharing protocols [5], for example. In this way, we will perform the steering criterion for different bipartition and may find one that is more suitable in experimental setup based on priors works [6].

1. A. Einstein, B. Podolsky, and N. Rosen., Phys. Rev. **47**, 777 (1935).
2. M. D. Reid., Phys. Rev. A **40**, 913 (1989).
3. A. S. Villar, L. S. Cruz, K. N. Cassemiro, M. Martinelli, and P. Nussenzveig., Phys. Rev. Lett. **95**, 243603 (2005).
4. Run Yan Teh Qihuang Gong Qiongyi He Jiri Janousek-Hans-Albert Bachor Margaret D. Reid and Ping Koy Lam Seiji Armstrong, Meng Wang, Nature Physics **11**, 167172 (2015).
5. C. Branciard, E. G. Cavalcanti, S. P. Walborn, V. Scarani, and H. M. Wiseman., Phys. Rev. A **85**, 010301 (2012).
6. A. S. Coelho, F. A. S. Barbosa, J. E. S. Cesar, A. S. Villar, K. N. Cassemiro, M. Martinelli, and P. Nussenzveig, Science **326**, 823 (2009).

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2. *Chemical bonds from the perspective of two- and multi-orbital correlations*

Gergely Barcza (Wigner Research Centre for Physics, Budapest, Hungary)

Quantum information theory (QIT) emerged in physics as standard technique to investigate the effective model of interacting quantum systems. The success of the

method arises the question what we can learn from QIT applying it to molecules as quantum systems [1]. By the rigorous analysis of the central quantities of standard QIT, which describes bonding purely in terms of two-orbital correlations, we can identify and distinct various bonding situations, e.g., covalent bond, donor-acceptor dative bond, multiple bond, charge-shift bond [2].

In order to give a better description of more complicated multiple bonds and aromaticity, we introduce the genuine multiorbital correlation theory, consisting of a framework for handling the structure of multiorbital correlations, a toolbox of true multiorbital correlation measures, and the formulation of the multiorbital correlation clustering. These make it possible to quantify the correctness of the associated "naive" bonding picture. As proof of concept, we apply the theory for the investigation of the bond structures of several standard and "unique" molecules. We show that the non-existence of well-defined multiorbital correlation clustering provides a reason for debated bonding picture of the dicarbon [3].

1. E. Fertitta, B. Paulus, G. Barcza, Ö. Legeza, Phys. Rev. B **90**, 245129 (2014).
2. T. Szilvási, G. Barcza, Ö. Legeza, arXiv:1509.04241 [physics.chem-ph] (2015).
3. Sz. Szalay, G. Barcza, T. Szilvási, L. Veis. Ö. Legeza, Sci. Rep. **7**, 2237 (2017).

3.

Aleksandr Berezutskii (Skolkovo Institute of Science and Technology, Moscow, Russia)

Consider a symmetric quantum state on an n-fold product space, that is, the state is invariant under permutations of the n subsystems. We examine the application of several ideas in classical invariant theory as they apply to the SLOCC (stochastic local operations and classical communication) classification of qubit quantum states.

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4. *Properties and Generalisations of Daemonic Ergotropy*

Fabian Bernards (University of Siegen, Germany)
Joint work with M. Kleinmann and O. Gühne.

Daemonic Ergotropy quantifies the extractable energy from a state of a system S with respect to a Hamiltonian if an ancilla A that may be correlated with S can be measured first [1]. We extend the original definition of daemonic ergotropy to allow for generalised measurements and provide a multipartite generalisation. We propose a see-saw algorithm to find an optimal measurement and give analytical results for some classes of states.

1. G. Francica, J. Goold, F. Plastina and M. Paternostro, npj Quant. Inf. **3**, 12 (2017).

5. *Multipartite entanglement for 6-level systems: Euler problem of 36 (quantum) officers*

Wojciech Bruzda (Jagiellonian University, Kraków, Poland)

The problem of existence of absolutely maximally entangled states AME$(4, 6)$ of size six, is studied. Any four-party pure state which is maximally entangled with respect to three possible symmetric partitions of the Hilbert space is called AME. A unitary matrix U of order N^2 is called 2–unitary, if its partial transpose U^{T_2} and the reshuffled matrix U^R, are also unitary. For $N = 3, 4, 5$ and any $N > 6$ there exist a pair of orthogonal Latin squares of order N, which imply 2-unitary permutations matrices of size N^2. Such bi-partite quantum gates are distinguished, as they maximize the entangling power among all unitary matrices of a given size. For $N = 6$, the non-existence of any 2-unitary permutation matrix of order 36 is directly related to the famous problem of 36 officers by Euler and follows from the non-existence of two mutually orthogonal Latin squares of size six. The more general question, whether there exists a 2-unitary matrix of size $N^2 = 36$ (not necessarily a permutation) remains still open. The permutation matrix P_{36} which gives the highest value of entangling power among all permutation matrices was analyzed by Clarisse, Ghosh, Severini and Sudbery (2005). In this work we improve their result by constructing a unitary matrix U_{36} with a larger entangling power.

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6. *Benchmarking two-walker interference in a quantum walk simulator*

Aurél Gábris (Czech Technical University in Prague)
Joint work with Thomas Nitsche, Linda Sansoni, Sonja Barkhofen, Igor Jex, Christine Silberhorn.

Discrete time quantum walks (DTQW) in the single walker regime are well-known to offer a quadratic speedup over classical random-walk based algorithms. Employing multiple walkers and their interactions in an algorithm is expected to allow us to attain the quantum advantage. Our proposal for test the ability of a 1D quantum walk setup to exploit genuine multi-partite quantum effects employs a discrete analogon of the well-known Hong–Ou–Mandel (HOM) experiment. We apply the discretisation to the HOM interference scenario where the initial photonic wave packets are separated in two orthogonal polarisations of the same spatial mode. While we rely on the terminology of optics, the results are applicable to any DTQW platform.

7. *Changing the circuit-depth complexity of measurement-based quantum computation with hypergraph states*

Mariami Gachechiladze (University of Siegen, Germany)
Joint work with O. Gühne and A. Miyake.

The circuit model of quantum computation defines its logical depth or "computational time" in terms of temporal gate sequences, but the measurement-based model could allow totally different time ordering and parallelization of logical gates. We introduce a deterministic scheme of universal measurement-based computation, using only Pauli measurements on multi-qubit hypergraph states generated by the Controlled-Controlled-Z (CCZ) gates. In contrast to the cluster-state scheme where the Clifford gates are parallelizable, our scheme enjoys massive parallelization of CCZ and SWAP gates, so that the computational depth grows with the number of global applications of Hadamard gates, or, in other words, with the number of changing computational bases. An exponentially-short depth implementation of an N-times Controlled-Z gate illustrates a novel trade-off between space and time complexity.

M. Gachechiladze, O. Gühne, A. Miyake, arXiv:1805.12093 [quant-ph] (2018).

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8. *The bilinear-biquadratic model on the complete graph*

Dávid Jakab (Wigner Research Centre for Physics, Budapest, Hungary)
Joint work with G. Szirmai and Z. Zimborás.

The bilinear-biquadratic (BLBQ) model is the generalization of the spin-1/2 Heisenberg model to spin-1 systems with the most general rotation invariant nearest-neighbor spin interaction. Its Hamiltonian is given by

$$H_{\mathrm{BLBQ}} = \sum_{\langle i,i \rangle} \Big(\cos(\gamma)(\mathbf{S}_i \dot{\mathbf{S}}_j) + \sin(\gamma)(\mathbf{S}_i \dot{\mathbf{S}}_j)^2 \Big)$$

where $\mathbf{S}_i$ denotes the spin operator, and the sum is over neighboring sites $\langle i, i \rangle$ of the underlying lattice. The parameter γ determines the signs and relative strength of the bilinear and biquadratic terms. We study this model on the complete graph of N sites, i.e., when each spin is interacting with every other spin with the same strength. Because of its complete permutation invariance, this Hamiltonian can be rewritten as the linear combination of the quadratic Casimir operators of $\mathfrak{su}(3)$ and $\mathfrak{su}(2)$. Using the representation theory of Lie groups, we explicitly diagonalize the Hamiltonian and map out the ground-state phase diagram of the model. Furthermore, the complete energy spectrum, with degeneracies, is obtained analytically for any number of sites.

D. Jakab G. Szirmai and Z. Zimborás, J. Phys. A **51**, 105201 (2018).

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9. *Entanglement between random and clean quantum spin chains*

Róbert Juhász (Wigner Research Centre for Physics, Budapest, Hungary)
Joint work with I. Kovács, G. Roósz, F. Iglói..

The entanglement entropy in clean, as well as in random quantum spin chains has a logarithmic size-dependence at the critical point. Here, we study the entanglement of composite systems that consist of a clean and a random part, both being critical. In the composite, antiferromagnetic XX chain with a sharp interface, the entropy is found to grow in a double-logarithmic fashion $\mathcal{S} \sim \ln\ln(L)$, where L is the length of the chain. We have also considered an extended defect at the interface, where the disorder penetrates into the homogeneous region in such a way that the strength of disorder decays with the distance l from the contact point as $\sim l^{-\kappa}$. For $\kappa < 1/2$, the entropy scales as $\mathcal{S}(\kappa) \simeq (1-2\kappa)\mathcal{S}(\kappa = 0)$, while for $\kappa \geq 1/2$, when the extended interface defect is an irrelevant perturbation, we recover the double-logarithmic scaling. These results are explained through strong-disorder RG arguments.

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10. *Quantum state matching of qubits via measurement-induced nonlinear transformations*

Orsolya Kálmán (Wigner Research Centre for Physics, Budapest, Hungary)
Joint work with T. Kiss.

We consider the task of deciding whether an unknown qubit state falls in a prescribed neighborhood of a reference state. We assume that several copies of the unknown state are given and apply a unitary operation pairwise on them combined with a postselection scheme conditioned on the measurement result obtained on one of the qubits of the pair. The resulting transformation is a deterministic, nonlinear map in the Hilbert space. We derive a class of these transformations capable of orthogonalizing nonorthogonal qubit states after a few iterations. These nonlinear maps orthogonalize states which correspond to the two different convergence regions of the nonlinear map. Based on the analysis of the border (the so-called Julia set) between the two regions of convergence, we show that it is always possible to find a map capable of deciding whether an unknown state is within a neighborhood of fixed radius around a desired quantum state. We analyze which one- and two-qubit operations would physically realize the scheme. It is possible to find a single two-qubit unitary gate for each map or, alternatively, a universal special two-qubit gate together with single-qubit gates in order to carry out the

task.

J. M. Torres, J.Z. Bernád, G. Alber, O. Kálmán, and T. Kiss, Phys. Rev. A **95**, 023828 (2017).
O. Kálmán, and T. Kiss, Phys. Rev. A **97**, 032125 (2018).
O. Kálmán, T. Kiss, and I. Jex, arXiv:1808.08151 [quant-ph] (2018).

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11. *Genuine multipartite qudit entanglement does not need multipartite correlations*

Waldemar Kłobus (University of Gdansk, Polnad)
Joint work with W. Laskowski, T. Paterek, M. Wieśniak, H. Weinfurter.

We derive a general method by which for any multipartite qudit state it is possilbe to contruct its "counterpart state" so that the proper mixture of the two produces a state with no multipartite correlation functions. We then provide examples of states that exhibit genuine multipartite entanglement, even though their respective highest-order correlaion funcions vanish. The method works for any odd number of parties and is easily generalized to arbitrary dimensions of qudits. Furthermore, our procedure serves as an effective method for eliminating all correlation functions for any given odd number of parties.

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12. *Continuous phase-space representations for finite-dimensional quantum states*

Bálint Koczor (Technical University Munich, Germany)
Joint work with R. Zeier, and S. J. Glaser.

Continuous phase-space representations, including Wigner functions, have become a powerful tool for describing, analyzing, and tomographically reconstructing quantum states in quantum optics and beyond. We present a unified approach to continuous phase-space representations of a single spin (or equivalently bosonic qubit states), which highlights their relations and tomography [1]. We also construct their differential star product, which then allows us to calculate quantum dynamics directly in the phase space [2]. The quantum-optics case is naturally recovered in the large-spin limit. We finally consider coupled qubit systems and construct their Wigner functions [3]. The corresponding differential star product enables us to predict phase-space dynamics of coupled qubit systems. We illustrate our results with multiple examples.

1. B. Koczor, R. Zeier, and S. J. Glaser, arXiv:1711.07994 [quant-ph] (2017).
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3. B. Koczor, R. Zeier, and S. J. Glaser, arXiv:1612.06777 [quant-ph] (2016).

13. *Optimal steering inequalities from generalized entropic uncertainty relations*

Tamás Kriváchy (University of Geneva, Switzerland)

We establish a general connection between entropic uncertainty relations, EPR steering, and joint measurability. Specifically, we show how to derive steering inequalities starting from a broad class of entropic uncertainty relations. This allows us to construct steering inequalities based on Rényi entropy, which are optimal in many scenarios. Considering steering tests where Alice performs two noisy measurements, our inequalities exactly recover the noise threshold for steerability. This is the case for qubit 2-outcome measurements, as well as for mutually unbiased bases in any dimension, using here min-entropy and max-entropy. This shows that easy-to-evaluate quantities such as entropy can optimally witness steering, despite the fact that they are coarse-grained representations of the underlying statistics.

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14. *Bipartite unitary gates and billiard dynamics in the Weyl chamber*

Tomasz Linowski (Warsaw University, Poland)

Long time behavior of a unitary quantum gate U, acting sequentially on two subsystems of dimension N each, is investigated. We derive an expression describing an arbitrary iteration of a two-qubit gate making use of a link to the dynamics of a free particle in a 3D billiard. Due to ergodicity of such a dynamics an average along a trajectory V^t stemming from a generic two-qubit gate V in the canonical form tends for a large t to the average over an ensemble of random unitary gates distributed according to the flat measure in the Weyl chamber – the minimal 3D set containing points from all orbits of locally equivalent gates.

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15. *On Universal Bipartite-Entanglement-Witness In A Measurement-Device-Independent Way*

Arindam Mallick (Wigner Research Centre for Physics, Budapest, Hungary)

Experimental detection of entanglement of an arbitrary state of a given bipartite system is crucial for exploring many areas of quantum information processing. But such a detection should be made in a device-independent way if the preparation process of the state is considered to be faithful, in order to avoid detection of a separable state as an entangled one. The recently developed scheme of detecting bipartite entanglement in a measurement-device-independent way [Phys. Rev. Lett. 110, 060405 (2013)] does require information about the state. Here, by using Auguisiak et al.'s universal entanglement witness scheme for two-qubit states [Phys. Rev. A 77, 030301 (2008)], we provide a universal entanglement detection scheme for detecting NPT-ness (negative under partial transpose) of two-qudit states in a measurement-device-independent way. We conjecture that no such universal entanglement witness scheme exists for PPT (positive under partial transpose) entangled states. Arindam Mallick

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16. *Nonclassical states of light in a nonlinear Michelson interferometer*

Bijoy Mathew (Indian Institute of Science Education and Research Thiruvananthapuram, India)
Joint work with A. Shaji.

It has been shown that nonlinear detection schemes can provide improved resolutions than linear ones for the same amount of resources. We study such a scenario for a nonlinear Michelson interferometer setup embedded in a gas with Kerr nonlinearity and nonclassical states of light. The better resolution gained through the nonlinear strategy is found to be quite sensitive to photon loss effects within the interferometer.

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17. *Investigation of multipartite correlations in spin chains with matrix product state approach*

Mihály Máté (Wigner Research Centre for Physics, Budapest, Hungary)
Joint work with Szilárd Szalay, Örs Legeza.

The simplest model showing the properties of the Haldane phase is the widely studied bilinear-biquadratic spin chain in a given range of the phase space. At a special point this model, known as AKLT model, is integrable and its ground state gives the simplest structure among matrix product states (MPS). In my poster, among other spin chains, the one-dimensional bilinear-biquadratic model is investigated using the density matrix renormalisation group method. This is the most powerful tool to study strongly correlated spin chains, based on the MPS representation of the wave function. Pair correlation and entanglement of spins are widely studied in strongly correlated systems, now we consider the multipartite correlations using bipartite as well as multipartite notions. The decay exponents for multipartite correlations are determined in the different intervals of phase spaces (e.g. critical-, dimerised-, Haldane phase) for various spin chains.

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18. *Optical fields to control ultracold atomic/molecular collisions*

Andrea Orbán (Institute for Nuclear Research, Debrecen, Hungary)
Joint work with O. Dulieu and N. Bouloufa-Maafa.

Research focusing on the formation of ultracold atomic and molecular quantum gases is a continuously expanding field due to its potentials in many different applications such as quantum-controlled chemistry or quantum simulation. The aim of our theoretical work is to suppress inelastic or reactive processes between colliding particles in ultracold quantum gases. We plan to couple by optical field, detuned to the blue, the initial colliding particle state to a repulsive, excited one preventing the particles to come close to each other. Due to the extremely small collisional energies it is possible to address a single repulsive channel thus ensuring a full control of the suppression efficiency. To be able to select a well defined molecular state we have developed a model to determine the hyperfine structure of excited molecular states at short range [1]. We will present our results in case of the $^{39}K^{133}Cs$ molecule.

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19. *Quantum state discrimination of three-level systems via non-linear protocol*

Pavlo Pyshkin (Wigner Research Centre for Physics, Budapest, Hungary)
Joint work with O. Kálmán and T. Kiss.

The correct discrimination between non-orthogonal quantum states is one of the important tasks in modern quantum computation and quantum control. A crucial ingredient of such methods is to have an ensemble of identical quantum systems for implementing unambiguous QSD [1,2,3]. Measurement-induced non-linear dynamics is experimentally feasible in quantum optics [4], and as it was shown in [1,3] that non-linear quantum transformations may be a possible way for implementing QSD in two-level quantum systems. In this report we describe a proposal which can be used for QSD of a special kind in three-level quantum systems. We propose a probabilistic quantum protocol to realize a nonlinear transformation of qutrit states, which by iterative applications on ensembles can be used to distinguish two types of pure states. The protocol involves single-qutrit and two-qutrit unitary operations as well as post-selection according to the results obtained in intermediate measurements.

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20.

Grzegorz Rajchel (Centre for Theoretical Physics, Warsaw, Poland)

We introduce the notion of robust Hadamard matrices of order n, such that their projections onto any 2-dimensional subspace spanned by the vectors of the computational basis are Hadamard.The existence of such matrices (real or complex) is established for all even dimension n smaller than 22, and also for infinitely many larger dimensions, for which symmetric conference matrices exist. The existence of a robust Hadamard matrix of order n allows us to construct an equi-entangled basis in $n \times n$ quantum system which consists of n^2 vectors of the same degree of entanglement. Furthermore, we analyze the structure of the set $\mathcal{U}_n$ of unistochastic matrices, which contains bistochastic matrices B such that $B_{ij} = |U_{ij}|^2$, where U is unitary. We show that for $n = 4$ the center of $\mathcal{U}_4$ belongs to its boundary, which is not the case for $n = 2, 3$ and $n = 5, ..., 15$.

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21. *Mutual uncertainty, conditional uncertainty and strong sub-additivity*

Sheikh Sazim (Harish-Chandra Research Institute, Allahabad, India)

We introduce a new concept called as the mutual uncertainty between two observables in a given quantum state which enjoys similar features like the mutual information for two random variables. Further, we define the conditional uncertainty as well as conditional variance and show that conditioning on more observable reduces the uncertainty. Given three observables, we prove a “strong sub-additivity” relation for the conditional uncertainty under certain condition. As an application, we show that using the conditional variance one can detect bipartite higher dimensional entangled states. The efficacy of our detection method lies in the fact that it gives better detection criteria than most of the existing criteria based on the geometry of the states. Interestingly, we find that for N-qubit product states, the mutual uncertainty is exactly equal to $N - \sqrt{N}$, and if it is other than this value, the state is entangled. We also show that using the mutual uncertainty between two observables, one can detect non-Gaussian steering where Reid’s criteria fails to detect. Our results may open up a new direction of exploration in quantum theory and quantum information using the mutual uncertainty, conditional uncertainty and the strong sub-additivity for multiple observables.

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22. *On multipartite entanglement and multipartite correlations*

Szilárd Szalay (Wigner Research Centre for Physics, Budapest, Hungary)

We briefly review the partial separability based classification of mixed states of multipartite quantum systems of arbitrary number of subsystems. We show how this structure boils down in the case when not entanglement but correlation is considered. As special cases, we consider the notions of k-separability and k-producibility (as well as their correlation versions), reveal how these are dual to each other, and discuss some consequences. We also give the corresponding multipartite correlation and entanglement monotones, being the natural generalizations of mutual information, entanglement entropy and entanglement of formation, showing the same structure as the classification (multipartite monotonicity).

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23. *Short time behavior of quantum evolutions on graphs*

Balázs Endre Szigeti (Eötvös Loránd University, Budapest, Hungary)
Joint work with G. Homa, Z. Zimborás, and N. Barankai.

We analyze the short-time asymptotics of continuous time quantum walks (CTQW) on finite, simple graphs. In two recent studies, it was shown that for small times, the continuous time classical diffusion process uses the graph's shortest paths for propagation of high probability: The short-time asymptotics of the entries of the heat kernel corresponding to a pair of nodes follows a power law whose exponent is the usual combinatorial distance of the nodes. Borrowing their arguments, we show that the short-time asymptotics of the entries of the mixing matrix of the CTQW with symmetric tight-binding Hamiltonian follows a power law as well, but with a doubled exponent which is independent of the on-site potential. Consequently, the short-time asymptotics of CTQW depends only on the topological properties of the graph and in all instances it is slower than its classical counterpart. We also discuss several surprising phenomena in the short-time asymptotics of time-dependent quantum walks.

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24. *Entanglement witnesses from arbitrary observables*

Konrad Szymański (Jagiellonian University, Kraków, Poland)

The problem of determination whether a given mixed state is entangled can be approached from different perspectives, including analysis of correlations between

subsystems, properties of partial transpose, or usage of entanglement witnesses. In this work we present a method of determination an entanglement witness from an arbitrary multipartite, finite-dimensional qubit observable: given X, λ is determined such that the negative expectation value of $X + \lambda \mathrm{id}$ indicates entangled state. The result is produced in a deterministic time, albeit the complexity is exponential in number of subsystems, owing to the NP-hardness of the problem. It is possible to increase the accuracy arbitrarily, in the limit reconstructing entanglement witness with expectation value equal to 0 for some nonentangled state. The procedure is applied in analysis of random observables drawn from GUE ensemble.

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25. *Device-independent Purity Characterization and its Application*

Yukun Wang (National University of Singapore)
Joint work with K. T. Goh, L. C. Wen.

The purity of a quantum state quantifies the degree of knowledge and control over its preparation. It is known that one can extract quantitative bounds on the relative entropy of coherence and the coherent information using the purity of the state. As such, purity is intricately related to other valuable resources in quantum information processing, namely, coherence and entanglement.

However, being a non-linear function of the state, the purity of a quantum state is usually computed from its full density matrix despite depending only on a small number of its parameters. However, to obtain the full density matrix, quantum state tomography is required. Such procedure requires a large number fully characterized measurements that scales with the dimension of the quantum state.

Here, we present a device-independent approach to obtain lower bounds on the purity of the quantum states. Our main result dictates that the amount of certifiable purity is directly related to its violations of some Bell inequalities, such as the Clauser-Horne-Shimony-Holt (CHSH) inequality and the Mermin inequalities. Moreover, using explicit families of quantum states and measurements, we proved that such lower bound is tight.

In future work, we will investigate if the tight lower bound on purity would improve the existing lower bounds on entanglement and coherence in the device-independent framework.

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26.

Li Xinhui (National University of Singapore)

Self-testing refers to a device-independent way to uniquely identify the state and the measurement for uncharacterized quantum device. However, all the known criteria for self-testing of multipartite states involve knowledge of the full correlations. Is it possible to self-test some multipartite states based only on marginal information? In this paper, we consider this problem and self-test some classes of multipartite states by marginal information using numerical analysis by NPA hierarchy on quantum set. Firstly, we show that W state can be self-tested by three measurements each part and each measurement has two outcomes. On the other hand we strongly suspect that the correlation is not exposed in the terminology of convex geometry. Secondly, as a generalization of W state, we extend it to a family three-qubit state with one parameter and prove this family three-qubit state can be self-tested by the same measurements with W state by marginal information. At last, we give an example that self-test three-qubit state by a sub-correlation Bell inequality with two measurements each part.