Specific Initiatives BELL & QUANTUM
from fundamental research to quantum technologies

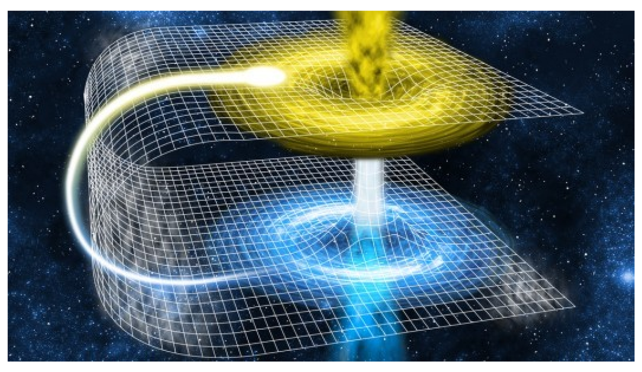
Quantum Mechanics shows us, with its fantastic science-fiction phenomena, that the nature of the physical world is truly very different from what everyday experience tells us…
But our mind still manages to understand and use it!
Quantum Mechanical Technology has changed the world since the middle of the last century: **electronics, nuclear energy, semiconductors, LASER, Magnetic Resonance Imaging**…Unfortunately also **atomic weapons.**
Quantum Science will change the world even more, even faster and, as far as research at the TIFPA is concerned, in a pacific way:
Quantum computers, quantum secure communications, quantum sensors, quantum AI are coming.

BELL Research Network

(Cosenza, Genova, Milano, Pavia, TIFPA, Trieste; National Head: Angelo Bassi Trieste)

The TIFPA team of BELL focuses on

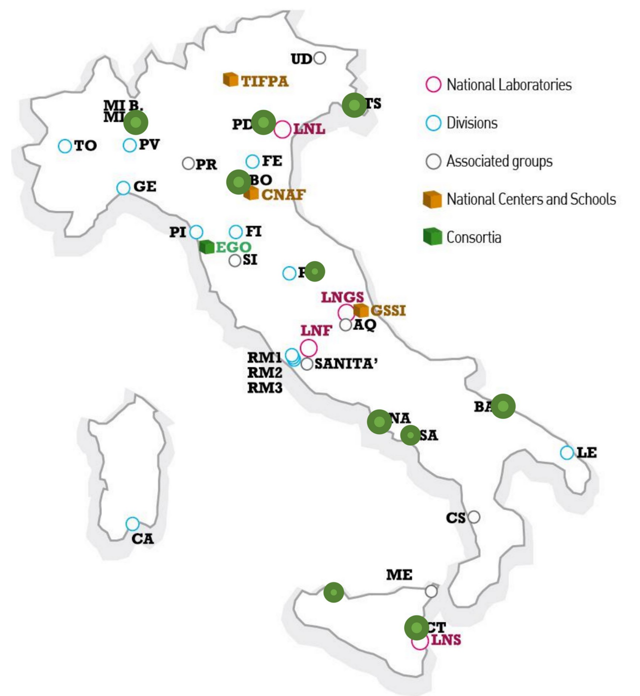
- **Foundational, axiomatic, mathematical topics of Quantum Theories**
- **Algebraic Quantum Field Theory in Curved Spacetime**
- **Rigorous Integral Functional**
- **Rigorous Quantization Procedures**
- **Mathematical and foundational aspects of Quantum Information.**



QUANTUM Research Network

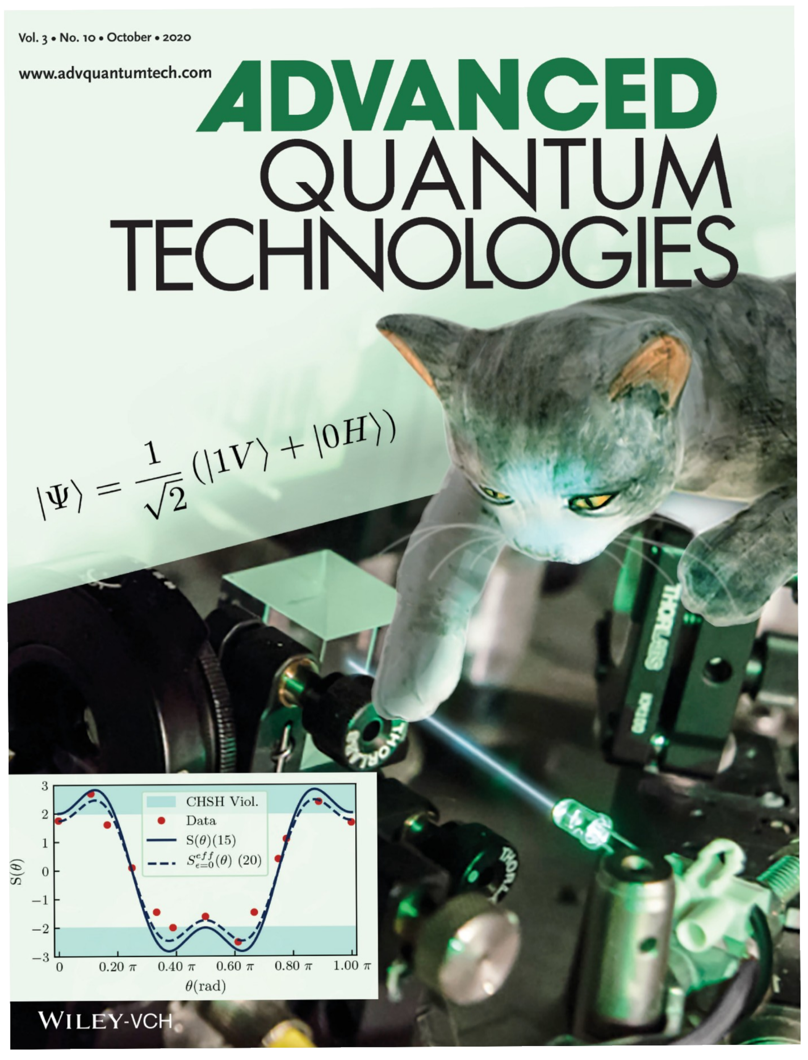
(Bari, Bologna/Camerino, Catania/Palermo, Milano, Napoli/Salerno, Padova, TIFPA, Trieste; National Head: Stefano Mancini)

- **Entanglement**: Discover the fundamental role of quantum correlations in many-body systems
- **Quantum simulation**: Exploit quantum devices to solve strongly correlated quantum models
- **Quantum control**: Exploit quantum effects to achieve unprecedented control



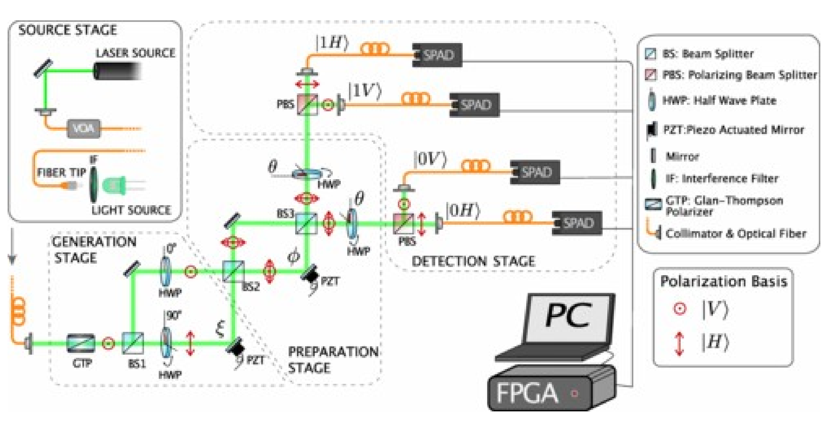
Example Activities

In **single-particle entanglement** two degrees of freedom of a single particle, e.g., momentum and polarization of a single photon, are entangled. Single-particle entanglement is a resource that can be exploited both in quantum communication protocols and in experimental tests of **noncontextuality** based on the **Kochen-Specker theorem**. Here we show that single-particle entangled states of single photons can be produced from attenuated classical sources of light. To experimentally certify the single-particle entanglement, we perform a Bell test, observing a violation of the Clauser, Horne, Shimony, and Holt inequality. We show that single-particle entanglement can be achieved even in a classical light beam. This demonstrates that cheap, compact, and low-power photon sources can be used to generate single-particle entangled photons which could be a resource for quantum technology applications.



S. Azzini et al., Single-Particle Entanglement, Adv. Quantum Technologies, Volume3, Issue10, (2020)

The notion of **position for a quantum relativistic particle** is one of the most elusive notions of modern physics. There is a number of no-go theorems (Hegerfeldt, Malament, Busch, Halvorson-Clifton…). It sems that no notion of spatial localization can exist for quantum relativistic particles. However physicists see tracks of particles at CERN! This is a deep conceptual issue which is currently investigated by some researchers of TIFPA .



M. Pasini et al. Phys. Rev. A 102, 063708 (2020)

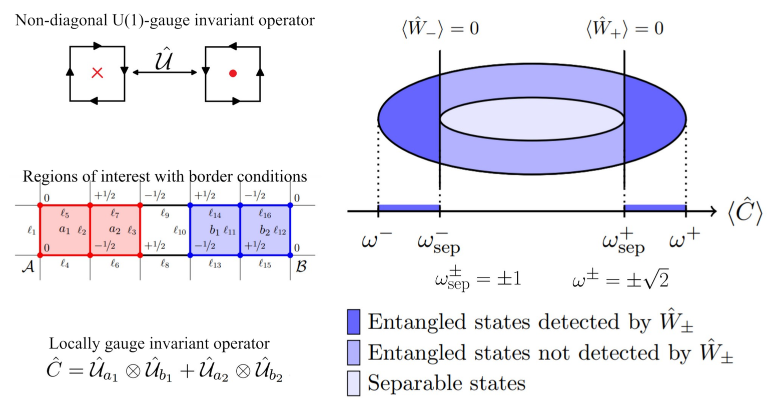
Example Activities

Gauge theories are fundamental to many fields of physics including the standard model, paradigms of quantum computing, and condensed matter physics.

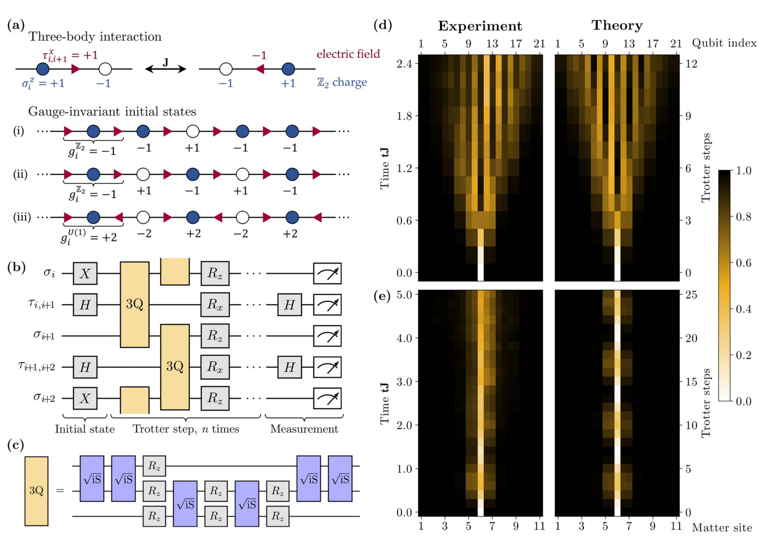
Entanglement in gauge theories does not follow the usual paradigm:

- Gauge symmetries cause the Hilbert space to split into superselection sectors (SSs).
- Gauge invariant operators can not access coherences among different SSs.

We develop a scheme that takes these into account, in order to **witness and certify entanglement in lattice gauge theories.**



V. Panizza et al., J. High Energ. Phys. 2022, 196 (2022)



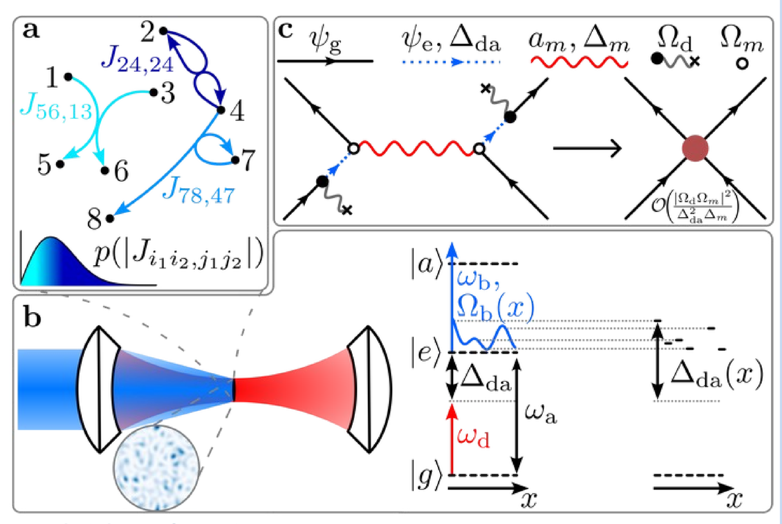
J. Mildenberger et al., arXiv:2203.08905

Despite their importance, the numerical study of gauge theories is intricate, rendering them highly rewarding targets for **quantum simulation**.

- We implement the dynamics of a lattice gauge theory on a superconducting qubit quantum processor.
- To **control errors and noise in the quantum hardware**, the employment of several mitigation techniques proves pivotal.
- Such implementations provide stringent tests and important stimuli for development of quantum-computing hardware.

The **Sachdev–Ye–Kitaev (SYK) model** is a solvable system providing insights into strongly correlated materials and quantum gravity via holography.

- SYK is an all-to-all connected system of interacting fermions with random couplings, making realizations extremely challenging.
- We propose a feasible **implementation in the cavity quantum electrodynamics platform**, which controllably retrieves the physics of the SYK model.
- The implementation provides important stimuli also to theory, for example what experimentally relevant modifications of the SYK model mean in the dual gravity theory.



P. Uhrich et al., arXiv:2303.11343
SERI project Holograph