Quantum@Trento

Organization

Management Board:

Lorenzo Pavesi, UniTN scientist in charge
Gianluigi Casse, FBK scientist in charge
Iacopo Carusotto, CNR scientist in charge
Franco Dalfovo, WP1 coordinator
Enrico Blanzieri, WP2 coordinator
Luciano Serafini, WP3 coordinator
Jochen Wambach, WP4 coordinator
Alberto Quaranta, WP5 coordinator
Georg Pucker, WP5 coordinator

Advisory Board:

Tommaso Calarco, University of Ulm, Germany, Germany
Alain Aspect, Institute d'Optique, France
Daniel Esteve, CEA-Saclay, France
Peter Zoller, IQOQI, Innsbruck

Francesco Pederiva
Physics Department, University of Trento
INFN - TIFPA

Workshop

ADVANCES IN MANY-BODY THEORIES: FROM FIRST PRINCIPLE METHODS TO QUANTUM COMPUTING AND MACHINE LEARNING
ECT* November 2-6 ,2020

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Long tradition of studies in fundamental quantum physics and quantum information

- Activity carried out at ECT* in the field of quantum information, in particular by T. Calarco and D. Binosi, since the early 2000. Coordination of several European projects.
- Theoretical and, more recently, experimental studies in the frame of confined quantum gases in the BEC group at the Physics Department of UNTIN and CNR/INO.
- Experimental research in QI with optical devices carried out at the NanoScience Lab at the Physics Dept. of UNITN in collaboration with FBK for at least 15 years.

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Q@TN

UNIVERSITÀ DI TRENTO

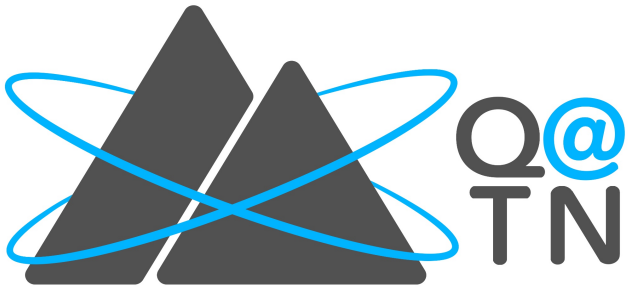
FONDAZIONE BRUNO KESSLER

Consiglio Nazionale delle Ricerche

RECENTLY QUANTUM INFORMATION AND QUANTUM COMPUTING GAINED MOMENTUM

INCREASE IN THE NUMBER OF RESEARCHERS, DEPARTMENTS, AND INSITUTIONS INVOLVED IN QI AND QC

FINANCIAL CONTRIBUTION FROM DIFFERENT SOURCES



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CASSA DI RISPARMIO DI TRENTO E ROVERETO

PROVINCIA AUTONOMA DI TRENTO

Good quantum science requires a synergistic effort!

- Collaboration between groups concerned in the theoretical and experimental development of fundamental quantum physics and technological developments.
- Provide better visibility at national and international level, increase the probability of accessing to significant funding from EU sources
- Training of a young generation of researchers with transdisciplinary competences (there is for example a Transdisciplinary Program at Ph.D. level including 18 graduate students from different University Departments and FBK, partly funded with specific fellowships)
- Possible construction of a shared experimental facility.

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Q@TN RESEARCH

- WP1 – Fundamental quantum science: Franco Dalfovo (DF)
- WP2 – Quantum communication: Enrico Blanzieri (DISI)
- WP3 – Quantum computing: Luciano Serafini (FBK-ICT)
- WP4 – Quantum simulations: Jochen Wambach (FBK-ECT*)
- WP5 – Future sensors and metrology: Georg Pucker (FBK-CMM) and Alberto Quaranta (DII)

Important activity in the perspective of enabling quantum simulations in the NISQ era

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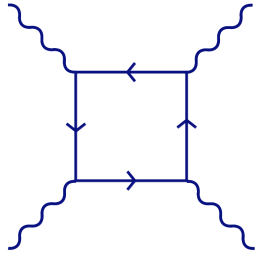
Quantum Fluids of Light

Light beam composed by a huge number of photons

- in vacuo photons travel along straight line at c
- (practically) do not interact with each other
  (first scattering evidence ATLAS @ LHC, 2017)
- undergrad optics typically dominated by single-particle physics

Photon – photon interaction: non-linear optics



- Spatial confinement → effective photon mass
  ~ 1ev, to be compared to GeV of proton
- $\chi^{(3)}$ nonlinearity → photon-photon interactions
  via exchange of virtual electron-hole pair:
  e^-/e^+ rest mass replaced by e^-/h energy
  (energy gap of solid) → 10^{36} fold stronger

$$\sigma \sim \alpha^4 \frac{\hbar^2}{m^2c^2}\left(\frac{\hbar\omega}{mc^2}\right)^6$$

(Iacopo Carusotto et al, CNR-INO)

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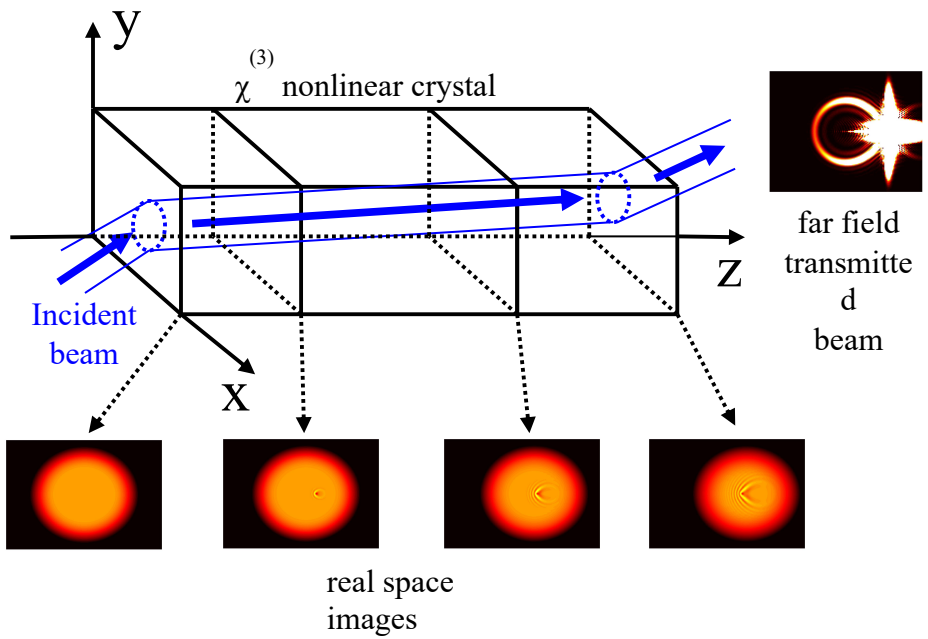
EU-FETFLAG *PhoQuS* project "Photons for Quantum Simulation" (Quantum Flagship)

Goal: develop applications of quantum fluids of light as a platform for quantum simulation

Trento BEC group involved in the theoretical study of quantum simulations using a new concept of quantum fluid of light, first developed within the Grande Progetto PAT "SiQuro"

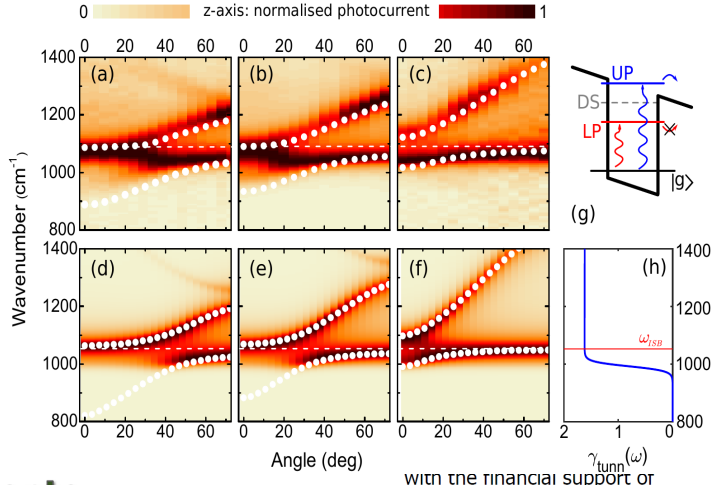


EU-FET-OPEN *MirBose* project "Mid- and far-IR opto-electronic devices based on BEC"

Goal: develop new coherent light sourcesbased on quantum fluids of intersubband polaritons

BEC Center is the only theoretical node of the project:

- support to experiments by partner groups,
- develops new theoretical concepts
- characterizes new devices



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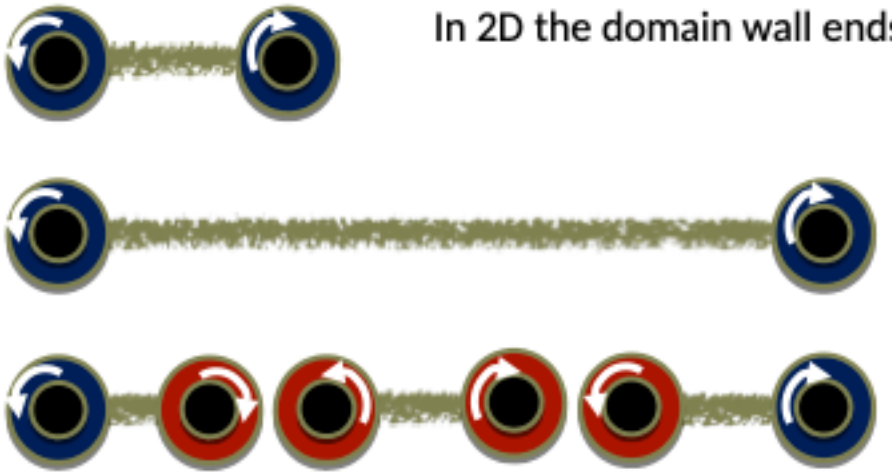
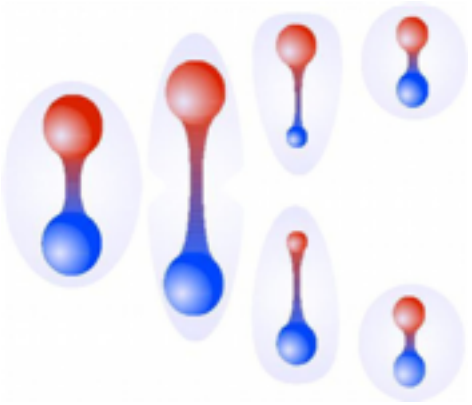
Condensed matter analog of color confinement in QCD



In 2D the domain wall ends with vortices

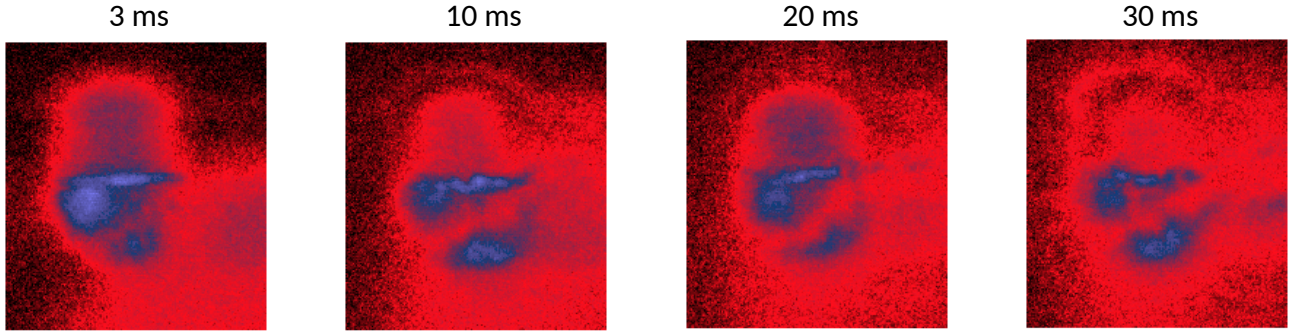
Suppose we can stretch the pair...
at some point we will get to a
too energetic configuration...
domain wall snaps



Rabi coupled Bose-Einstein condensates

Tylutki et al., PRA **93**, 043623 (2016)

Time evolution of the domain wall



Gabriele Ferrari – Physics Dept. UNITN

INFN Istituto Nazionale di Fisica Nucleare

FISh

Fundamental Interactions Simulations with quantum gases

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Research activities Hauke group – Synthetic Quantum Systems Theory

Quantum technologies

- Quantum simulation (synthesize many-body models)
- Quantum sensing (outperform classical detectors)
- Quantum annealing (solve hard classical problems on qu. device)

Quantum many-body systems

Strongly correlated matter

- magnetic materials
- topological phases of matter
- quantum out-of-equilibrium dynamics
- lattice gauge theories
- entanglement in many-body systems

Synthetic quantum systems

- ultracold atoms
- trapped ions
- superconducting qubits
- photonic devices …

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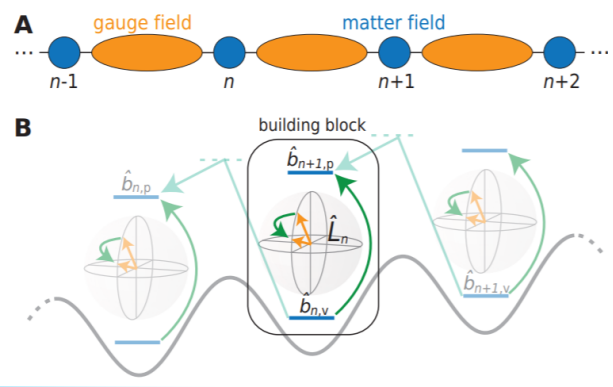
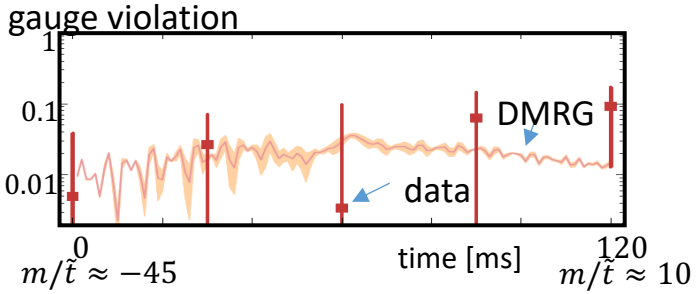
Quantum simulation of lattice gauge theories

Realizations in cold atoms etc

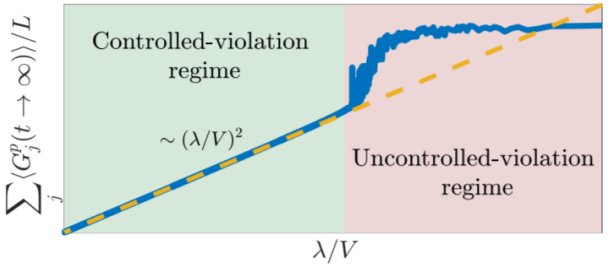


Mil, Zache, Hegde, Xia, Bhatt, Oberthaler, Hauke, Berges, Jendrzejewski ***Science* 367**, 1128-1130 (2020)

Reliability



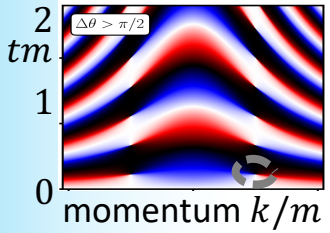
Yang, Sun, Ott, Wang, Zache, Halimeh, Yuan, Hauke, Pan, arXiv:2003.08945, accepted in ***Nature*** (2020)



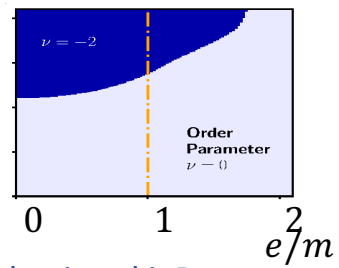
Halimeh, Hauke, ***Phys. Rev. Lett.* 125**, 030503 (2020)

Observable phenomena

Phase



Topological invariant



Zache, Mueller, Schneider, Jendrzejewski, Berges, Hauke, ***Phys. Rev. Lett.* 122**, 050403 (2019)

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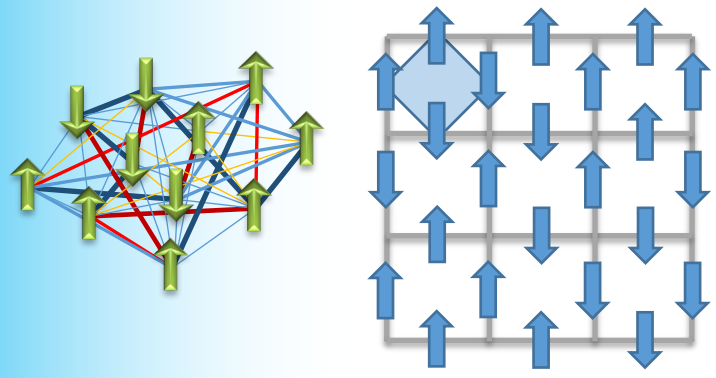
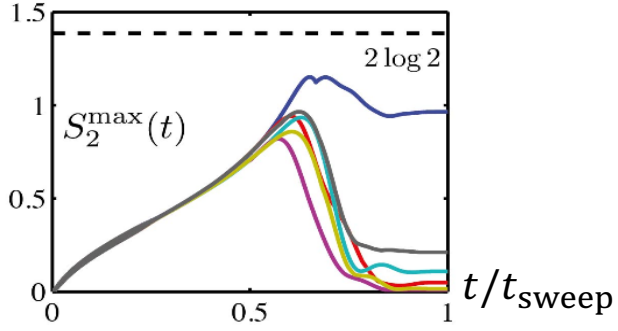
Quantum annealing

Theoretical ideas to improve hardware abilities



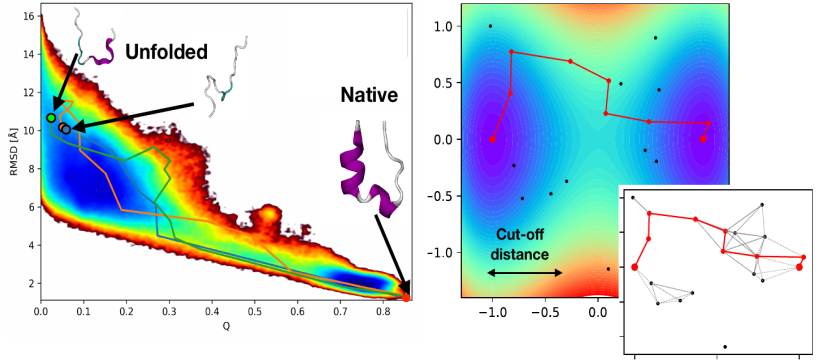
Lechner, Hauke, Zoller,
***Science Advances* 1,** e1500838 (2015)

Entanglement as resource



Hauke, Bonnes, Heyl, Lechner,
***Frontiers in Physics* 3**, 21 (2015)

Implementation algorithms



Hauke, Mattiotti, Faccioli,
arXiv:2007.13788 (2020)

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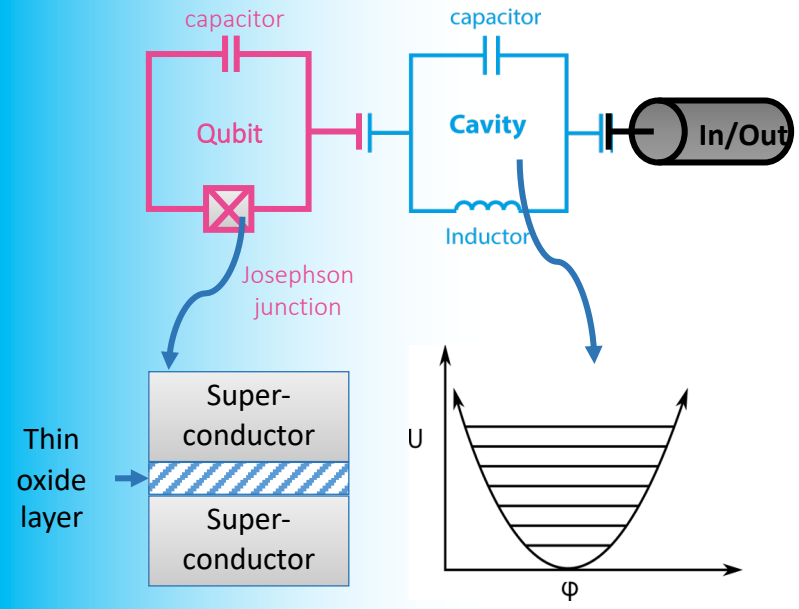
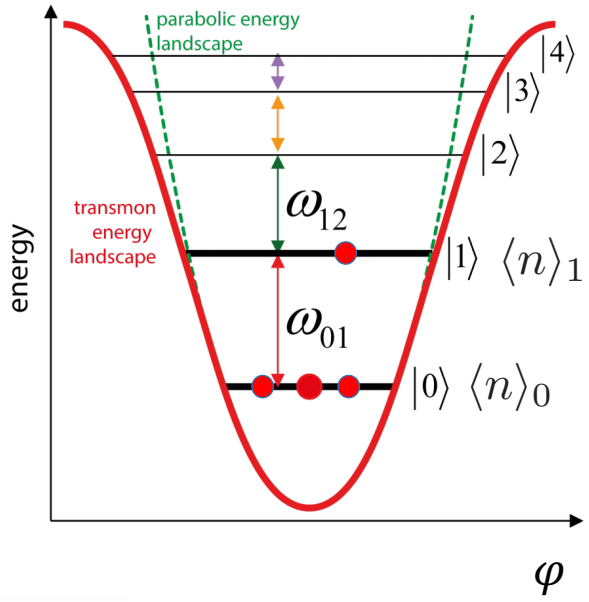
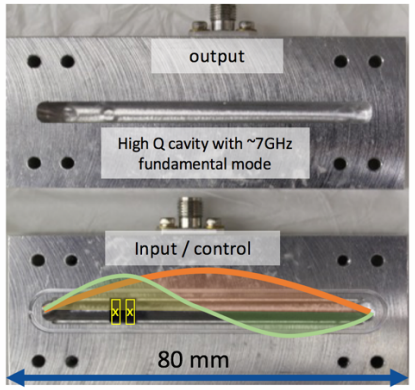
Dynamics of nuclear reactions via optimal control





External "control" signal

$$U(t,\alpha) = \mathcal{T} e^{-i\int_0^t dt'[\hat{H}_0 + f(t',\alpha)\hat{H}_c]}$$



V. Amitrano, J. Dubois, K. Kravvaris, P. Luchi, W. E. Ormand, F.P., S. Quaglioni, Y. Rosen, F. Turro, K. Wendt, X. Wu

JOINT LLNL-UNITN INITIATIVE

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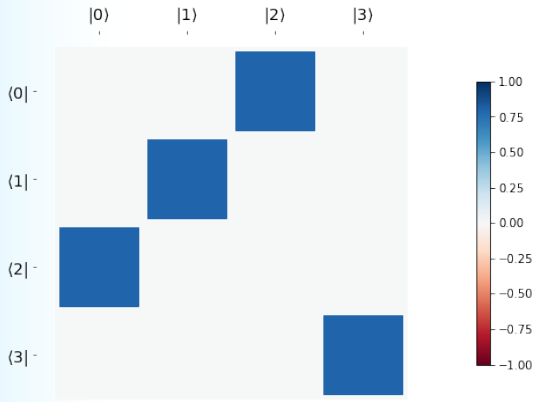
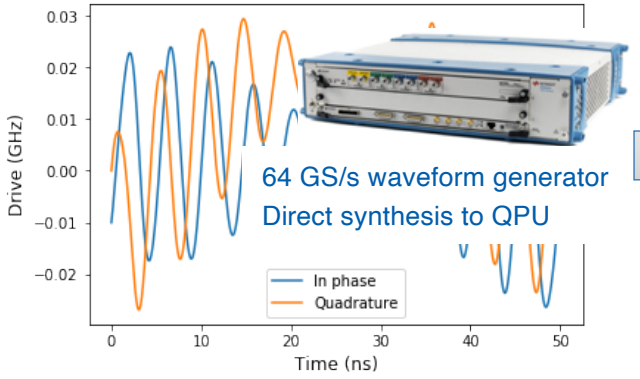
Dynamics of nuclear reactions via optimal control

$$U_{targ} \cong \mathcal{T}\exp\left\{-\frac{i}{\hbar}\int_0^{\tau} H_d + H_c(\tau')d\tau'\right\}$$

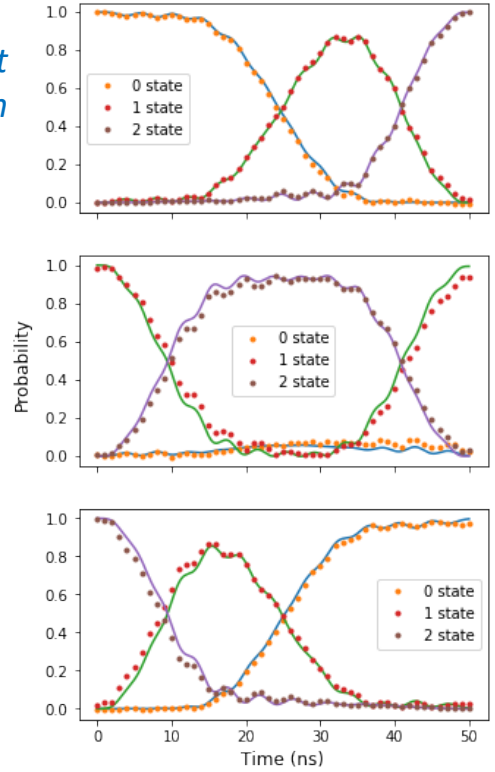


Target gate: 0 – 2 swap



Solved 50ns Optimized Control Drive of the target gate (using GRAPE)

Experiment vs simulation



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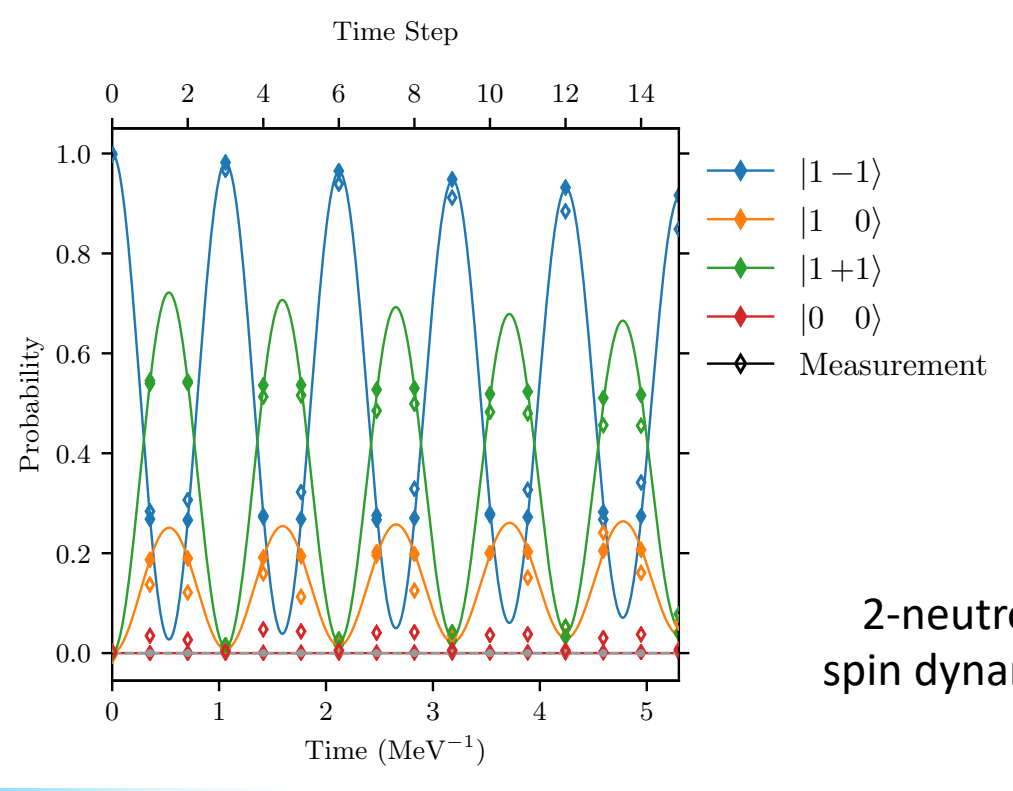
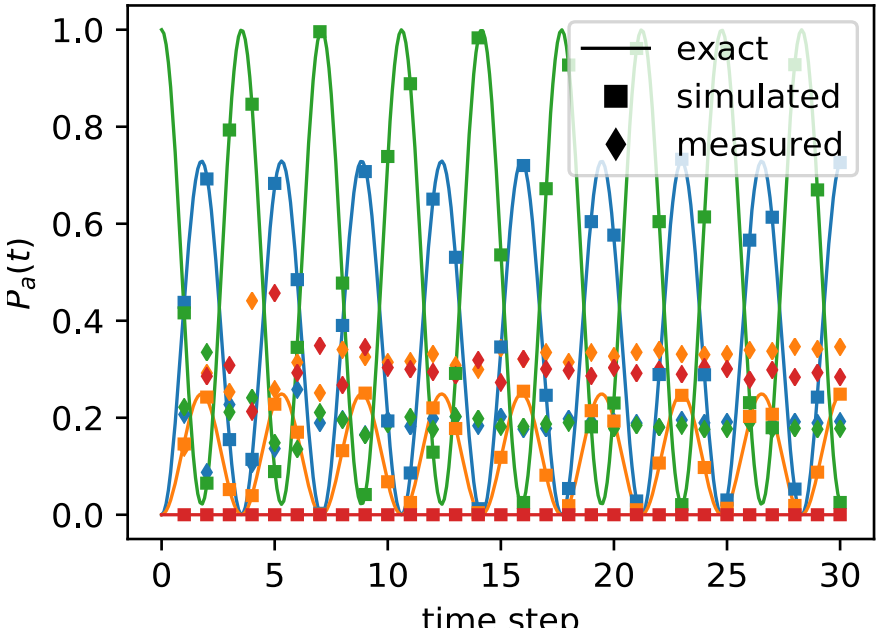
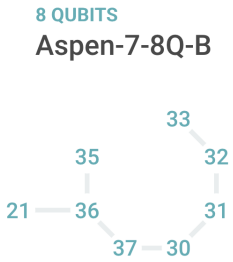
Dynamics of nuclear reactions via optimal control



2-neutron spin dynamics

Control-centric (LLNL quantum testbed)





Gate-centric (Rigetti-Aspen)

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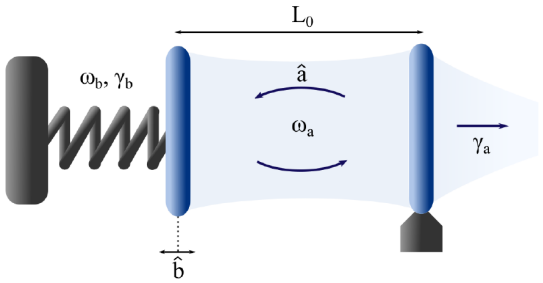
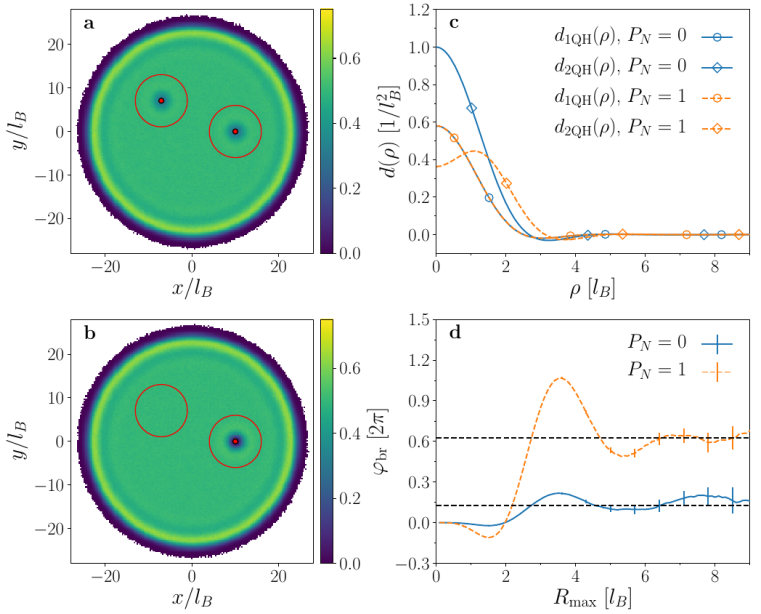
Many other projects….

SIQURO

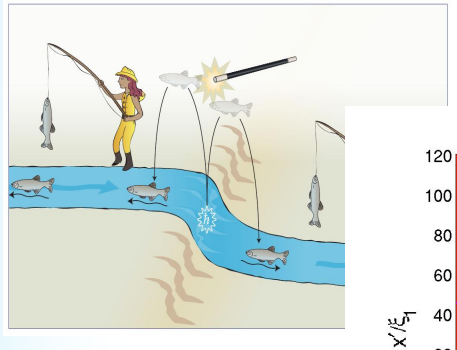
On silicon chip quantum optics for quantum computing and secure Communications (L. Pavesi – NSL)



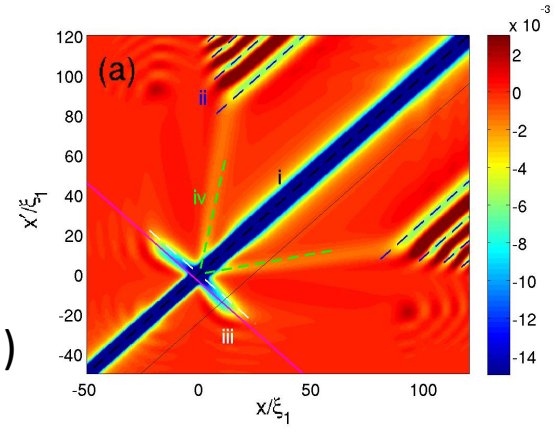
Cirquit-QED simulation of Casimir effect (Carusotto, Margesin)

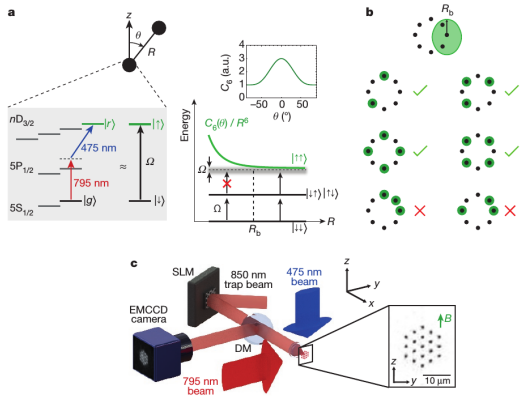


Topological photonics (Carusotto)



Analog Models of Gravity (Carusotto-Rinaldi)





A. Browaeys et al., Nature 534, 667 (2016)

Strontium Rydberg Atoms (Ferrari)

And more!

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Punchlines

- The path towards practical quantum computing needs a synergetic, transdisciplinary effort.
- Quantum simulation vs. quantum computing: in the NISQ era it is necessary to broaden our schemes and find new ways of thinking of a computation…
- The border between theory and experiment is quite thin (as it was in the very early days of standard computing, first and of supercomputing later!)
- Q@Tn wants to pursue this collaborative scheme and exploit the local lively scientific environment.

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