interacting qubits
quantum state transfer
n-iQST

OUTLINE:

- *One-qubit quantum state transfer*
- *Quantum dynamical map & random matrix theory approach to n-iQST*
- *Many-body dynamics in quadratic fermionic models*
- *Applications: n-QST, quantum batteries, entanglement generation*

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L-Università ta' Malta

Quantum Hiking 2019

UNIVERSITÄT BERN

Kovol, July 18, 2019
Quantum Walk

Average fidelity between a pure state and its image

Let $\Phi(\rho) = \rho' = \sum_{i=1}^{M} A_i \rho A_i^{+}$ be a quantum operation (trace preserving, completely positive map in its Kraus form. TP ⇔ $\sum_{i=1}^{M} A_i^{+} A_i = 1$)

fidelity $F(|\psi\rangle, |\varphi\rangle) = |\langle\psi|\varphi\rangle|^2$ ← probability

$|\psi\rangle \in \mathcal{H}_N$ $\quad F(|\psi\rangle, \rho) = \langle\psi|\rho|\psi\rangle$.

$$F(|\psi\rangle\langle\psi|, \Phi(|\psi\rangle\langle\psi|)) = \langle\psi|\,\Phi(|\psi\rangle\langle\psi|)\,|\psi\rangle =$$

$$= \sum_{i=1}^{M} \langle\psi|A_i|\psi\rangle\langle\psi|A_i^{+}|\psi\rangle = \sum_{i=1}^{M} |\langle\psi|A_i|\psi\rangle|^2$$

The average $\langle F(|\psi\rangle\langle\psi|, \Phi(|\psi\rangle\langle\psi|))\rangle_{\psi \in \mathcal{H}_N}$ can be rewritten in term of the Haar measure on $U(N)$

$|\psi\rangle = U|0\rangle$, U random unitary in $U(N)$
↑ arbitrary!

$$\langle F(|\psi\rangle\langle\psi|, \Phi(|\psi\rangle\langle\psi|))\rangle_{\psi} = \Big\langle \sum_{i=1}^{M} |\langle 0|U^{+}A_i U|0\rangle|^2 \Big\rangle_{U \in U(N)} =$$

$$\sum_{i=1}^{M} \langle |(A'_i)_{00}|^2 \rangle_U \;), \quad \text{where } A'_i := U^{+} A_i U$$

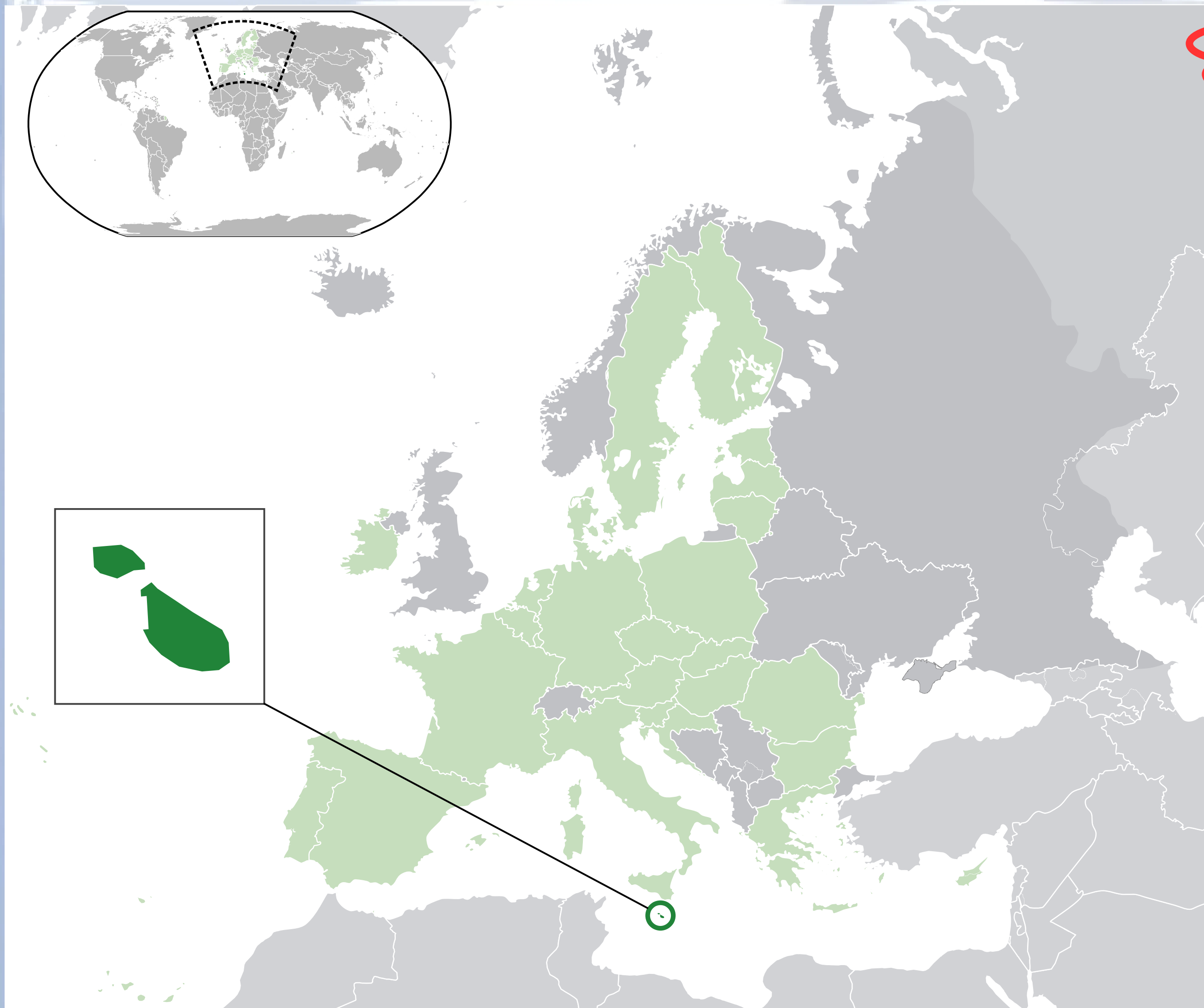
is averaged over the Unitary group $U(N)$

This can be done by know formulae for $\langle |U_{ii}|^2 \rangle_U = 1/N$, and $|U_{ii}|^2 |U_{ij}|^2 = \dots$?

etc. see Mello, J. Phys A. 1988?

www.unibe.ch

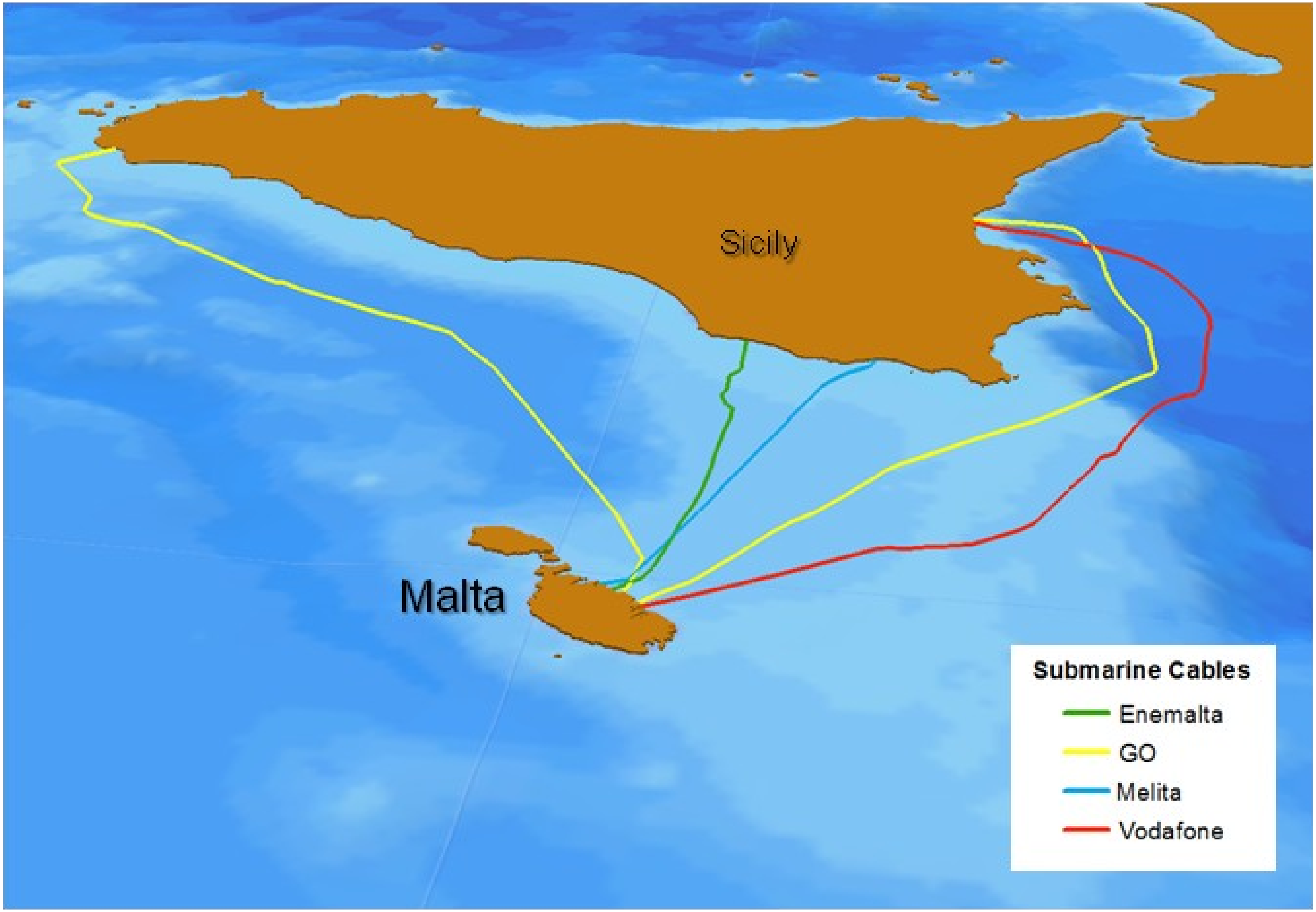
Where is Malta?



Malta:

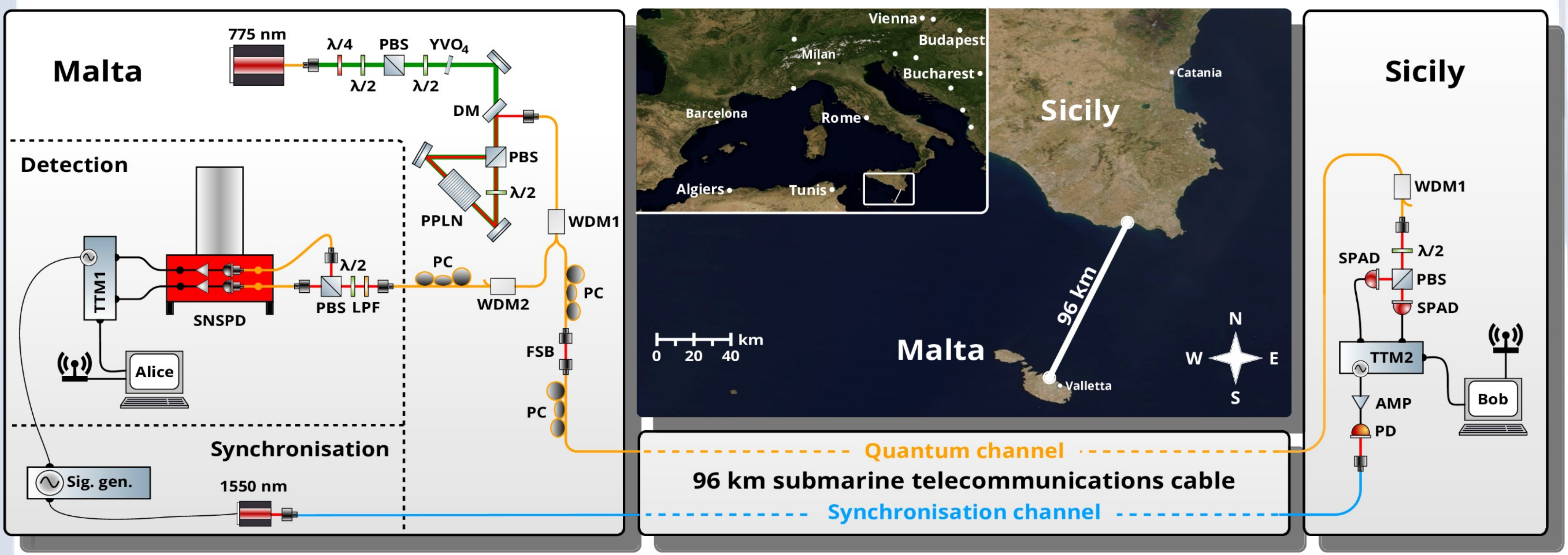
- Area: 316 km^2
- Population: 514564
- Home to the world's oldest, free-standing monument: Ġgantija Temples (~3600 BC)
- Closest countries:
  Italy (93 km)
  Tunisia (~300 km)

Malta and Sicily are connected

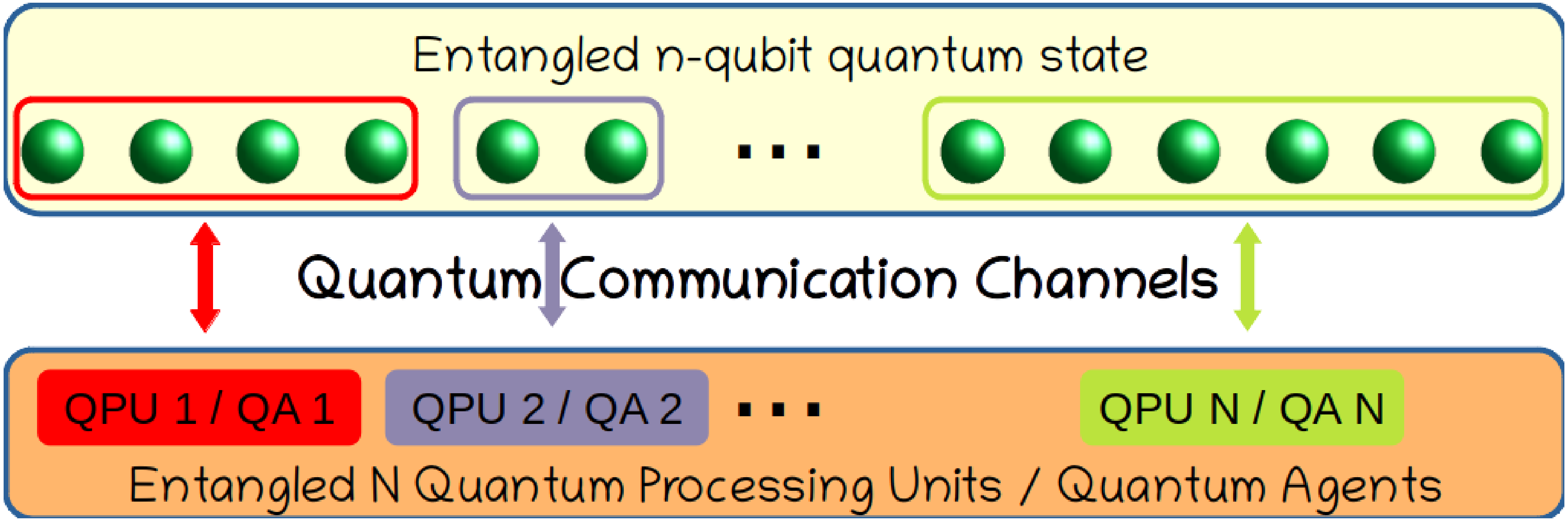


http://quantum.edu.mt/

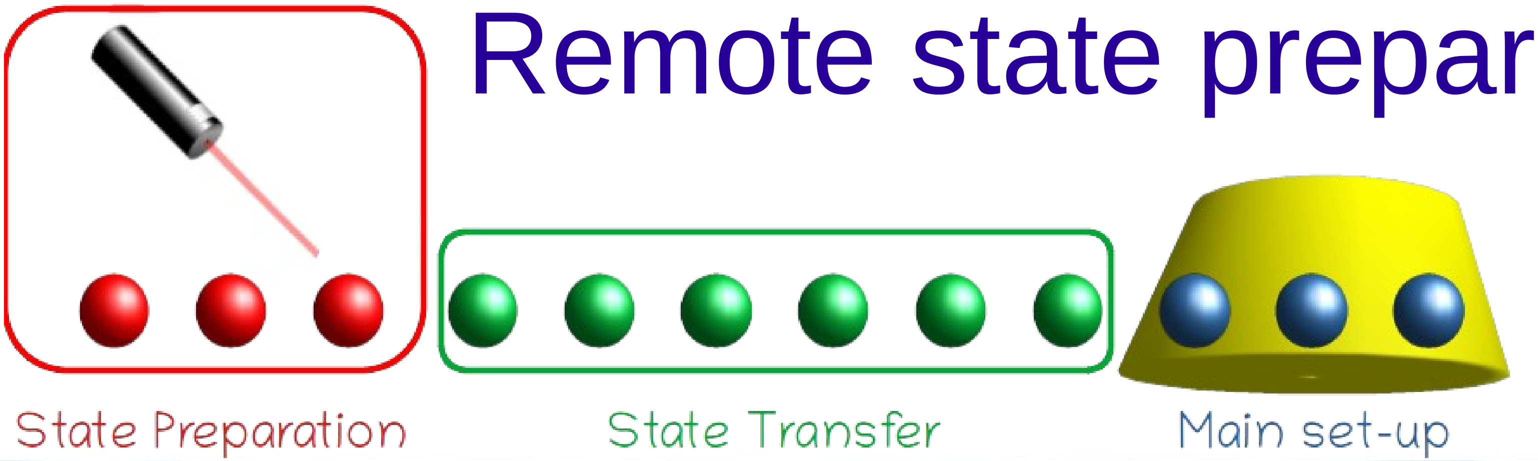
Polarization-entanglement based QKD over a 96 km-long submarine optical fiber



Distributed quantum computing/QKD



Remote state preparation



QUANTUM-STATE TRANSFER (QST)

$$|\Psi\rangle_A |\ldots\rangle \xrightarrow{\mathcal{H}_{QC}} |\ldots\rangle |\Psi\rangle_B$$

INPUT STATE OF THE QUBIT A

OUTPUT STATE OF THE QUBIT B

$$|\Psi\rangle_A = \alpha\,|0\rangle + \beta\,|1\rangle \quad \xrightarrow{\text{time}} \quad \rho_B$$

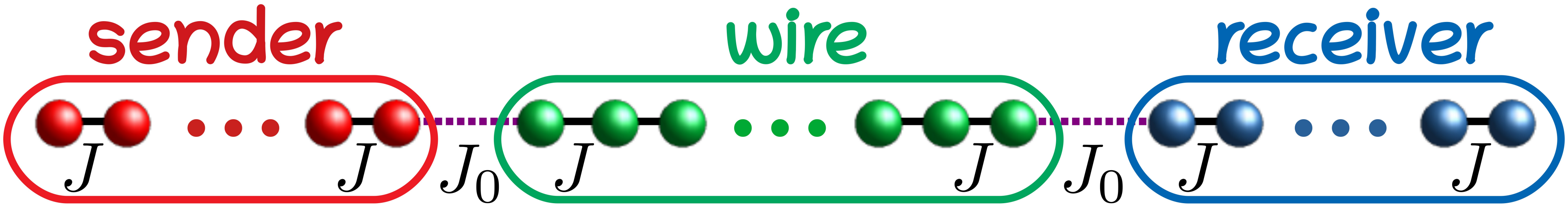
Fidelity

$$\mathcal{F}_{AB} = \langle \Psi_A | \rho_B | \Psi_A \rangle$$

Average Fidelity

$$\overline{\mathcal{F}}_{AB} = \frac{1}{\Omega} \int_\Omega d\Omega \mathcal{F}_{AB}$$

QST via a quantum wire



Aim: Transfer a **<u>many-body *state*</u>** from the **sender** to the **receiver** via a **wire**

$$|\Psi\rangle_s \, |\ldots\rangle \xrightarrow{\hat{H}} |\ldots\rangle \, |\Psi\rangle_r$$

quantum channel: Spin-1/2 XX Hamiltonian

$$\hat{H} = \sum_i^N J_i \left(\hat{S}_i^x \hat{S}_{i+1}^x + \hat{S}_i^y \hat{S}_{i+1}^y \right) + h_i \hat{S}_i^z$$

1D Spin-1/2 XX Hamiltonian - JW mapping – Quadratic, spinless fermion Hamiltonian

$$\hat{H} = \sum_{i=1}^N \frac{J_i}{2} \left(\hat{c}_{i+1}^\dagger \hat{c}_i + \hat{c}_i^\dagger c_{i+1} \right) + h_i \hat{c}_i^\dagger \hat{c}_i$$

n=1 QST IN THE XX MODEL

The single-particle transition amplitude from site s to site r

$$f_s^r(t) = \sum_{k=1}^{N} \langle r| e^{-it\hat{H}} |s\rangle = \sum_{k=1}^{N} e^{-i\omega_k t} \phi_{rk} \phi_{ks}^*$$

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The QST average fidelity depends only on the transition amplitude

$$\bar{\mathcal{F}}_{sr}(t) = \frac{1}{2} + \frac{|f_s^r(t)|}{3} + \frac{|f_s^r(t)|^2}{6}$$

Bose, Phys. Rev. Lett. **91**, 207901 (2003)

n=1 QST IN THE XX MODEL

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$$\mathcal{F}^{cl}_{max} = \frac{2}{d+1}$$

For a qubit (d=2)
the maximum fidelity
achievable by LOCC is
2/3

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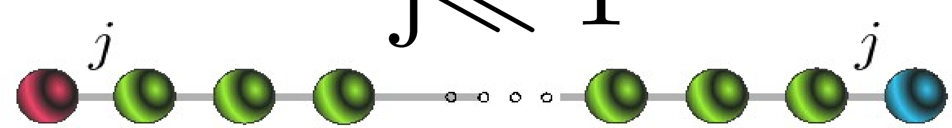
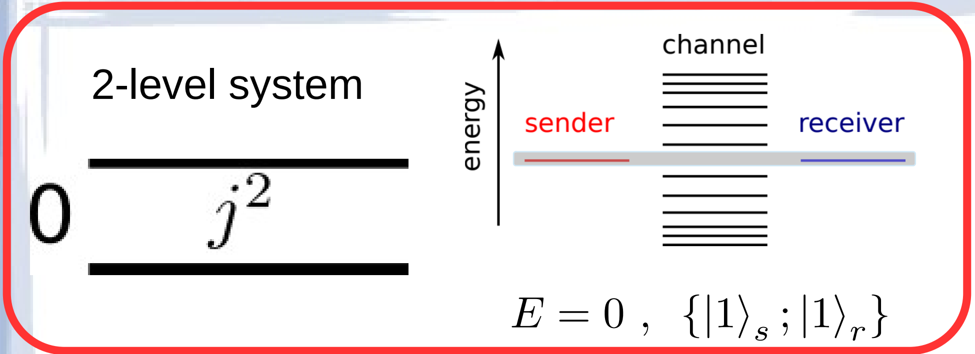
Perturbative couplings

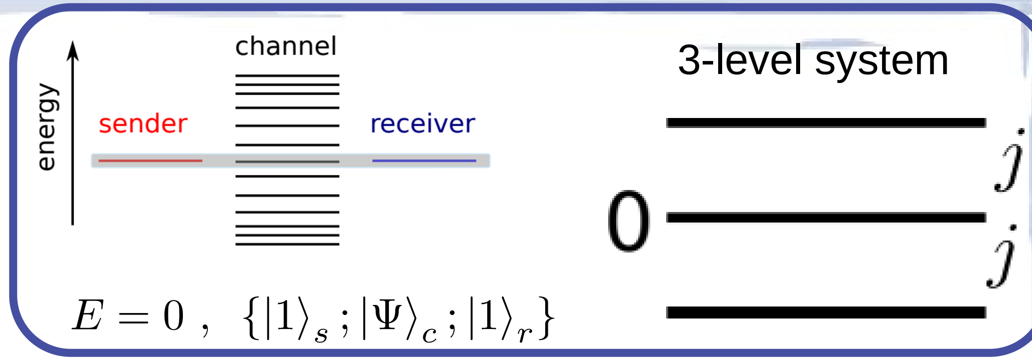
Wójcik et al. Phys. Rev. A **72**, 034303 (2005)
Apollaro and Plastina, Phys. Rev. A **74**, 062316 (2006)
Lorenzo et al., Phys. Rev. A **87**, 042313 (2013)

$\mathrm{j} \ll 1$



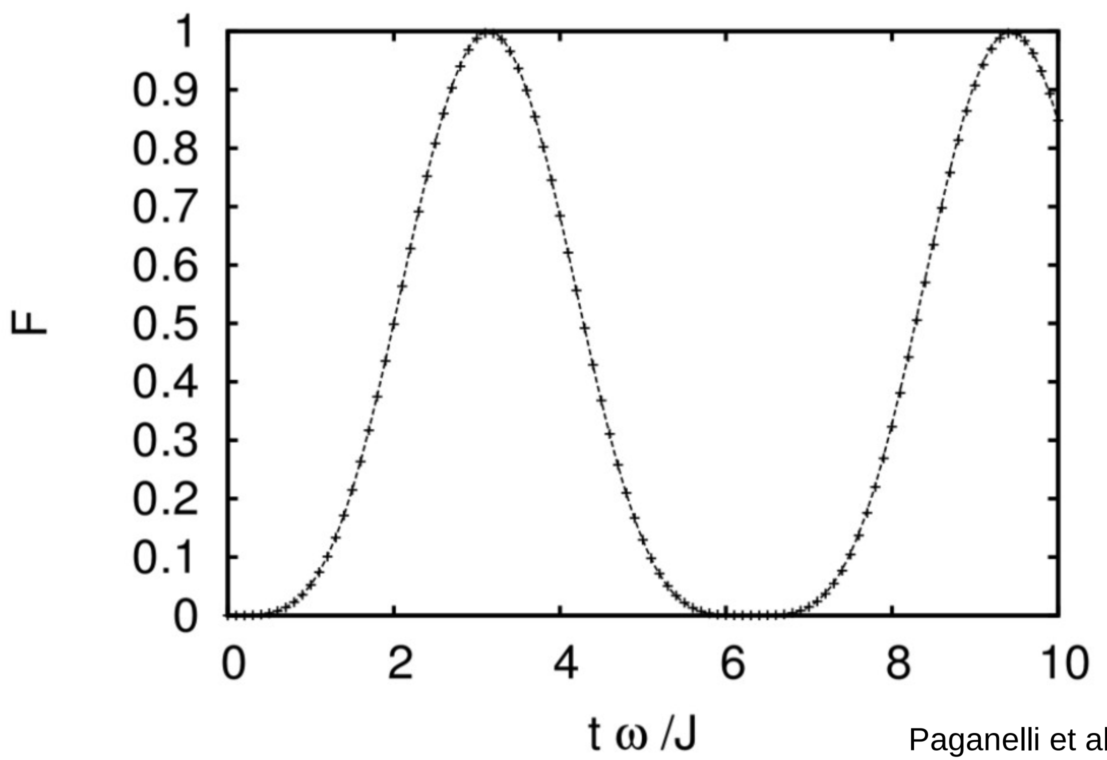
$$\bar{\mathcal{F}}_{sr}(t^*) = 1 - O\left(Nj^2\right) \qquad \begin{cases} t_e^* = j^{-2} & \text{even } N \\ t_o^* = \dfrac{\sqrt{N}}{j} & \text{odd } N \end{cases}$$





Perturbatively Perfect (PP) transfer

Excitation transfer occur via Rabi-like oscillations between the sender and the receiver



Paganelli et al., Phys. Rev. A **87**, 062309 (2013)

A single wire for multiple QIP tasks

Motivations:

- The technological challenge of faithful quantum wire;
- The request of scalability of a quantum computer;
- The short coherence times of the coherent dynamics;
- The protection against environmental intrusions;
- The economical costs of a single quantum wire;
- ...

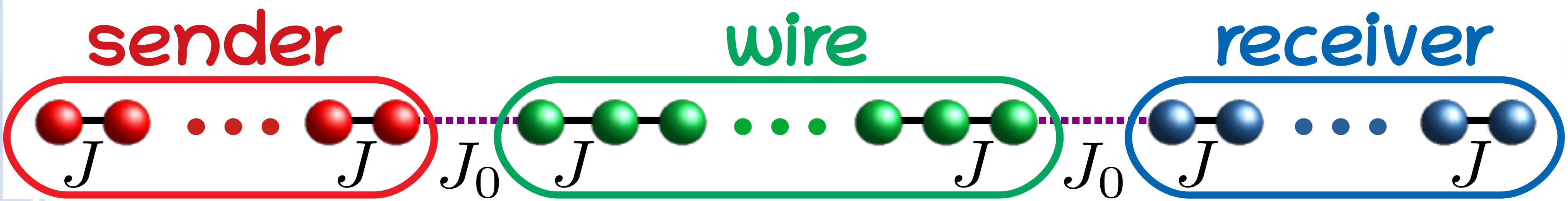
A single channel for multiple QIP tasks

Motivations:

- The technological challenge of faithful quantum wire;
- The request of scalability of a quantum computer;
- The short coherence times of the coherent dynamics;
- The protection against environmental intrusions;
- The economical costs of a single quantum wire;
- ...

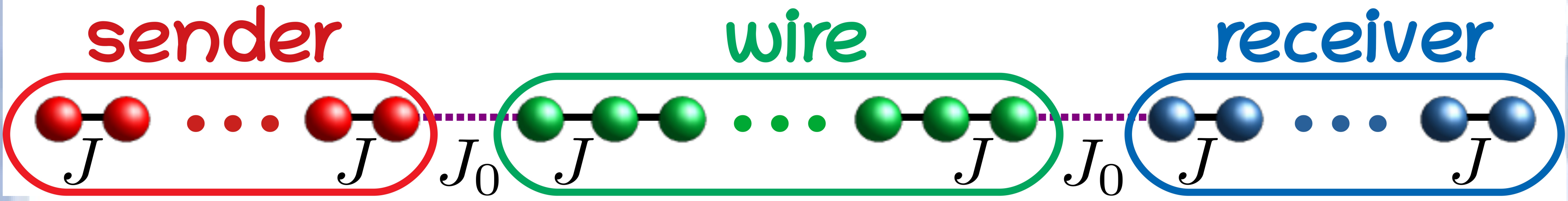
Can perturbative couplings be helpful in this regard?

Task: many-body quantum state transfer



Motivations:
the output of a QIP protocol is a n-qubit state
transfer of multipartite entanglement
many-body properties transfer

Alternative Protocols:
parallel/sequential use of a 1-QST
use of entangled states as QC
PQST QC



$$\langle F \rangle = \frac{1}{\Omega} \int_{\Omega} d\Omega \; F\left(|\Psi\rangle, \rho(t)\right)$$

The problem is to perform the average over all input states
(efficient parametrization of an n-qubit state)

Quantum dynamical map & random matrix theory approach

$$\rho^R = \Lambda[\rho^S] \quad -> \quad \rho^R = \sum_{n,m=0}^{d-1} \sum_{i,j=0}^{d-1} A_{ij}^{nm} a_n a_m^* |i><j|$$

$$F\left(|\Psi\rangle, \rho\right) = \langle \Psi | \rho | \Psi \rangle = \sum_{ijnm=0}^{d-1} a_i^* a_j a_n a_m^* A_{ij}^{nm} \; ,$$

Averages from Random Matrix Theory

$$\left\langle |a_i|^2 \right\rangle = \frac{1}{d}\,, \quad \left\langle |a_i|^4 \right\rangle = \frac{2}{d\,(d+1)}\,, \quad \left\langle |a_i|^2\,|a_j|^2 \right\rangle_{i\neq j} = \frac{1}{d\,(d+1)}$$

Average Fidelity

$$\boxed{\langle F \rangle = \frac{1}{d\,(d+1)} \left(2\sum_{i=0}^{d-1} A_{ii}^{ii} + \sum_{i\neq j=0}^{d-1} A_{ii}^{jj} + 2\Re\left\{ \sum_{i>j=0}^{d-1} A_{ij}^{ij} \right\} \right).}$$

The trivial case $\Phi(t) = \mathbf{I}$, i.e., $A_{ij}^{nm} = \delta_{in}\delta_{jm}$, yielding $\langle F \rangle = 1$.

The LOCC-limit is obtained from the first two contributions to $\langle F \rangle$, which come from those elements of the map A connecting all of the diagonal elements of the density matrices of S and R. The LOCC limit is obtained by setting $A_{ij}^{nm} = \delta_{ij}\delta_{nm}$, yielding $\langle F \rangle = \frac{2}{d+1}$.

The third term, instead, is due to off-diagonal map elements, connecting input to output coherences. It has, thus, a purely quantum origin, and it disappears for a classical map. Its contribution scales as $\frac{d-1}{d+1}$.

Variance of the Fidelity

$$(\Delta F)^2 = \left\langle F^2 \right\rangle - \left\langle F \right\rangle^2$$

$$F^2\left(|\Psi\rangle, \rho\right) = \sum_{ijnmpqrs=0}^{d-1} a_i^* a_j a_n a_m^* a_p^* a_q a_r a_s^* A_{ij}^{nm} A_{pq}^{rs} \ .$$

$$\left\langle F^2 \right\rangle = \frac{1}{d(d(+1)(d+2)(d+3)} \times$$

$$\sum_{i,m,p,s=0}^{d-1} \Big((A_{ii}^{mm} + A_{im}^{im})(A_{pp}^{ss} + A_{ps}^{ps}) + (A_{ii}^{pm} + A_{ip}^{im})(A_{pm}^{ss} + A_{ps}^{ms}) +$$
$$(A_{ii}^{sm} + A_{is}^{im})(A_{pm}^{ps} + A_{pp}^{ms}) + (A_{im}^{pm} + A_{ip}^{mm})(A_{pi}^{ss} + A_{ps}^{is}) +$$
$$(A_{im}^{sm} + A_{is}^{mm})(A_{pi}^{ps} + A_{pp}^{is}) + (A_{ip}^{sm} + A_{is}^{pm})(A_{pi}^{ms} + A_{pm}^{is}) \Big) \ .$$

$$\rho^R = \Lambda[\rho^S]$$

The explicit expression for the dynamical map of a U(1)-symmetric Hamiltonian (where the quantum channel and the receiver is initialized in the fully polarized state)

$$\begin{pmatrix}\rho_{00}\\ \rho_{01}\\ \rho_{02}\\ \rho_{03}\\ \rho_{10}\\ \rho_{11}\\ \rho_{12}\\ \rho_{13}\\ \rho_{20}\\ \rho_{21}\\ \rho_{22}\\ \rho_{23}\\ \rho_{30}\\ \rho_{31}\\ \rho_{32}\\ \rho_{33}\end{pmatrix}_{N-1,N} = \begin{pmatrix}
A^{00}_{00} & 0 & 0 & 0 & 0 & A^{11}_{00} & A^{12}_{00} & 0 & 0 & A^{21}_{00} & A^{22}_{00} & 0 & 0 & 0 & 0 & A^{33}_{00}\\
0 & A^{01}_{01} & A^{02}_{01} & 0 & 0 & 0 & 0 & A^{13}_{01} & 0 & 0 & 0 & A^{23}_{01} & 0 & 0 & 0 & 0\\
0 & A^{01}_{02} & A^{02}_{02} & 0 & 0 & 0 & 0 & A^{13}_{02} & 0 & 0 & 0 & A^{23}_{02} & 0 & 0 & 0 & 0\\
0 & 0 & 0 & A^{03}_{03} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & A^{10}_{10} & 0 & 0 & 0 & A^{20}_{10} & 0 & 0 & 0 & 0 & A^{31}_{10} & A^{32}_{10} & 0\\
0 & 0 & 0 & 0 & 0 & A^{11}_{11} & A^{12}_{11} & 0 & 0 & A^{21}_{11} & A^{22}_{11} & 0 & 0 & 0 & 0 & A^{33}_{11}\\
0 & 0 & 0 & 0 & 0 & A^{11}_{12} & A^{12}_{12} & 0 & 0 & A^{21}_{12} & A^{22}_{12} & 0 & 0 & 0 & 0 & A^{33}_{12}\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & A^{13}_{13} & 0 & 0 & 0 & A^{23}_{13} & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & A^{10}_{20} & 0 & 0 & 0 & A^{20}_{20} & 0 & 0 & 0 & 0 & A^{31}_{20} & A^{32}_{20} & 0\\
0 & 0 & 0 & 0 & 0 & A^{11}_{21} & A^{12}_{21} & 0 & 0 & A^{21}_{21} & A^{22}_{21} & 0 & 0 & 0 & 0 & A^{33}_{21}\\
0 & 0 & 0 & 0 & 0 & A^{11}_{22} & A^{12}_{22} & 0 & 0 & A^{21}_{22} & A^{22}_{22} & 0 & 0 & 0 & 0 & A^{33}_{22}\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & A^{13}_{23} & 0 & 0 & 0 & A^{23}_{23} & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & A^{30}_{30} & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & A^{31}_{31} & A^{32}_{31} & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & A^{31}_{32} & A^{32}_{32} & 0\\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & A^{33}_{33}
\end{pmatrix}\begin{pmatrix}\rho_{00}\\ \rho_{01}\\ \rho_{02}\\ \rho_{03}\\ \rho_{10}\\ \rho_{11}\\ \rho_{12}\\ \rho_{13}\\ \rho_{20}\\ \rho_{21}\\ \rho_{22}\\ \rho_{23}\\ \rho_{30}\\ \rho_{31}\\ \rho_{32}\\ \rho_{33}\end{pmatrix}_{1,2}$$

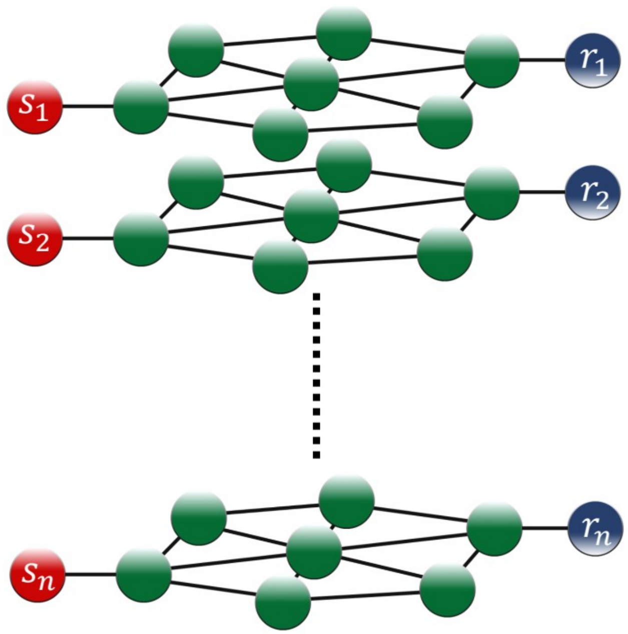
$$A^{00}_{00} = 1\ ,\ \ A^{11}_{00} = 1 - \left|f_1^{N-1}\right|^2 - \left|f_1^{N}\right|^2\ ,\ \ A^{22}_{00} = 1 - \left|f_2^{N-1}\right|^2 - \left|f_2^{N}\right|^2\ ,$$

$$A^{33}_{00} = 1 - \left|f_{12}^{mN-1}\right|^2 - \left|f_{12}^{mN}\right|^2 - \left|f_{12}^{N-1N}\right|^2\ ,$$

$$A^{12}_{00} = -f_1^{N-1}\left(f_2^{N-1}\right)^* - f_1^{N}\left(f_2^{N}\right)^*\ ,\ \ A^{21}_{00} = -f_2^{N-1}\left(f_1^{N-1}\right)^* - f_2^{N}\left(f_1^{N}\right)^*\ ,$$

$\dots$

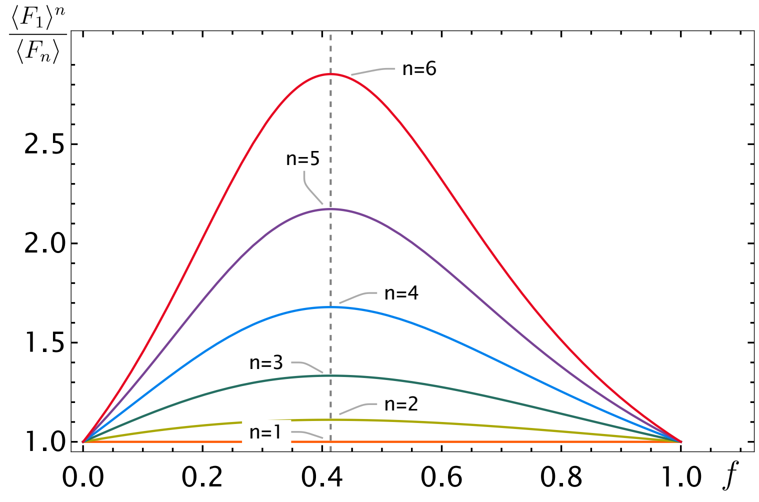
N-QST over independent channels

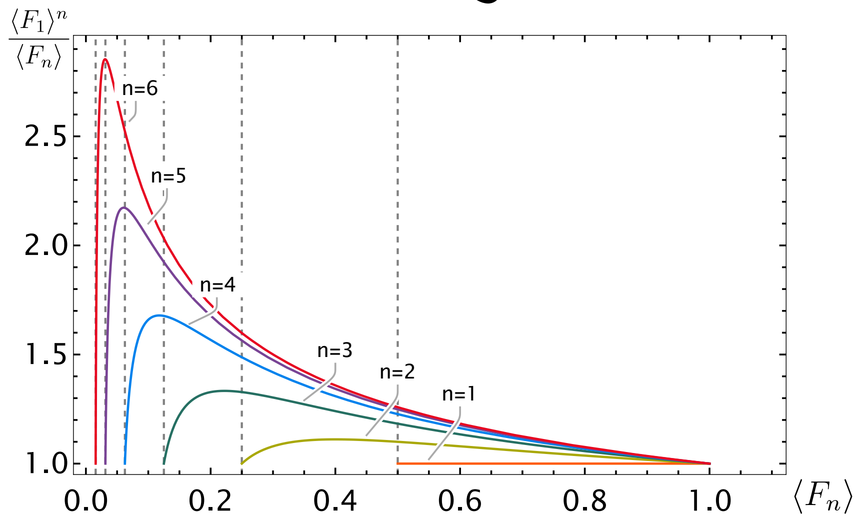


$$\langle F_n \rangle = \frac{1}{d+1} + \frac{1}{d(d+1)} |1+f|^{2n}$$

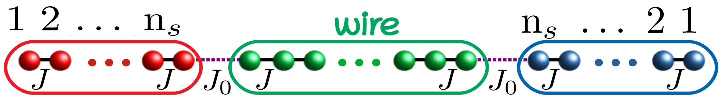
$$\langle F_n \rangle \neq \prod_{i=1}^{n} \langle F_1 \rangle$$

Product states are transferred better than entangled states





many-body dynamics in terms of one-body dynamics in bilinear models



$$\hat{H} = \sum_{i=1}^{N} \frac{J_i}{2}\left(\hat{c}_{i+1}^{\dagger}\hat{c}_i + \hat{c}_i^{\dagger}c_{i+1}\right) + h_i\hat{c}_i^{\dagger}\hat{c}_i \rightarrow \sum_{k=1}^{N}\omega_k\hat{c}_k^{\dagger}\hat{c}_k$$

Mirror-symmetric Hamiltonian:

one-body transition amplitude

$$f_i^j(t) = \sum_{k=1}^{N} e^{-i\omega_k t}\phi_{jk}\phi_{ki}^*$$

- persymmetric matrix
- real (imaginary) for i+j even (odd)
- symmetric spectrum around the center implies

1) $\dfrac{n_s(n_s+1)}{2}$ distinct elements

2) one's on the main and skew diagonal

3) $\left\lceil \dfrac{n_s}{2} \right\rceil$ distinct terms on the main diagonal

many-body transition amplitude matrix

$$\mathcal{F}_{n_s}^{n_r} = \begin{pmatrix} f_1^{n_s}(t) & f_1^{n_s-1}(t) & \cdots & f_1^1(t) \\ f_2^{n_s}(t) & \cdots & \cdots & f_2^1(t) \\ \vdots & & \ddots & \vdots \\ f_{n_s}^{n_s}(t) & & \cdots & f_{n_s}^1(t) \end{pmatrix}$$

n_s-excitations transition probability

fermions	bosons
$\left\lvert\det(\mathcal{F}_{n_s}^{n_s})\right\rvert^2$	$\left\lvert\mathrm{perm}(\mathcal{F}_{n_s}^{n_s})\right\rvert^2$

n-excitation transfer in U(1) & bilinear models

$$\mathcal{F} = \begin{pmatrix} f_1^1 & f_1^2(t) & \cdots & f_1^{N-4} & f_1^{N-3} & f_1^{N-1} & f_1^N \\ f_2^1 & \cdots & \cdots & f_2^{N-4} & f_2^{N-3} & f_2^{N-2} & f_2^N \\ f_3^1 & \cdots & \cdots & f_3^{N-4} & f_3^{N-3} & f_3^{N-2} & f_3^N \\ f_4^1 & \cdots & \cdots & f_4^{N-4} & f_4^{N-3} & f_4^{N-2} & f_4^N \\ \vdots & & \ddots & & & \vdots & \\ f_N^1 & & & & \cdots & f_N^N & \end{pmatrix}$$

n=1

n=2

n=3

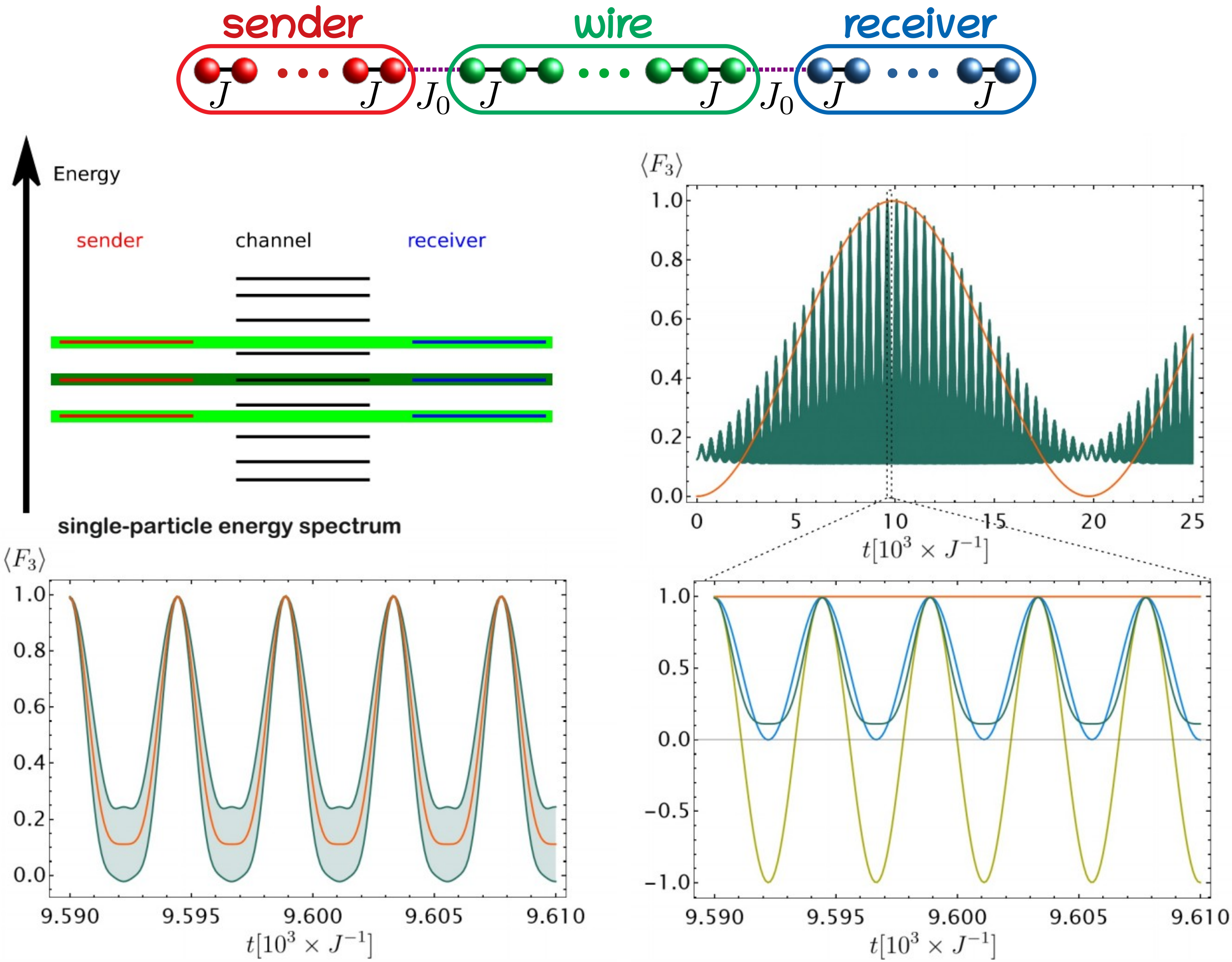
n=4

n-excitation transfer amplitude is given by the determinant (permanent) of the submatrix for fermions (bosons).

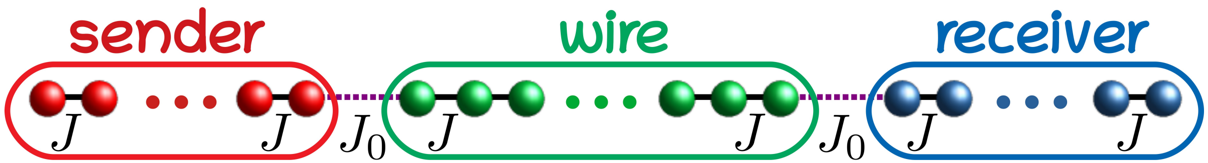
Average n-iQST

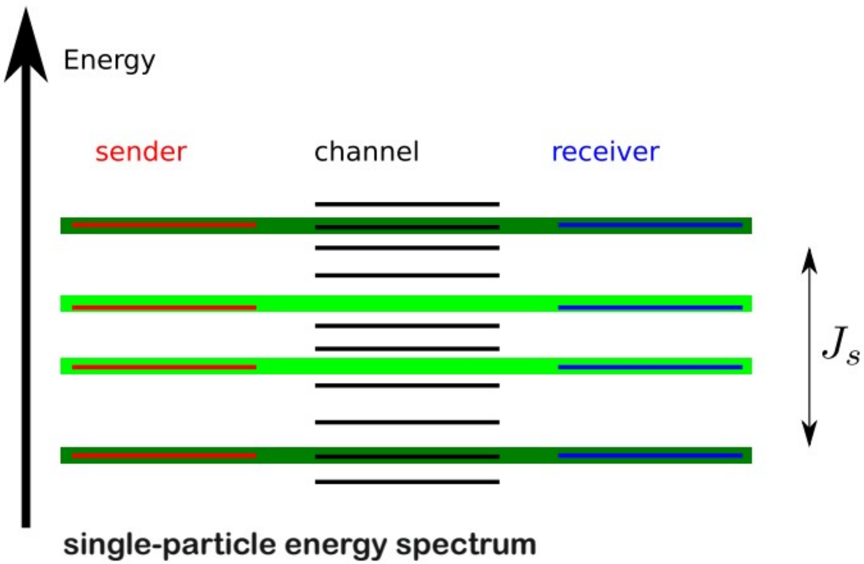
$$\langle F_n \rangle = \frac{1}{d+1} + \frac{1}{d\,(d+1)} \left| 1 + \sum_S f_S^S \right|^2 .$$

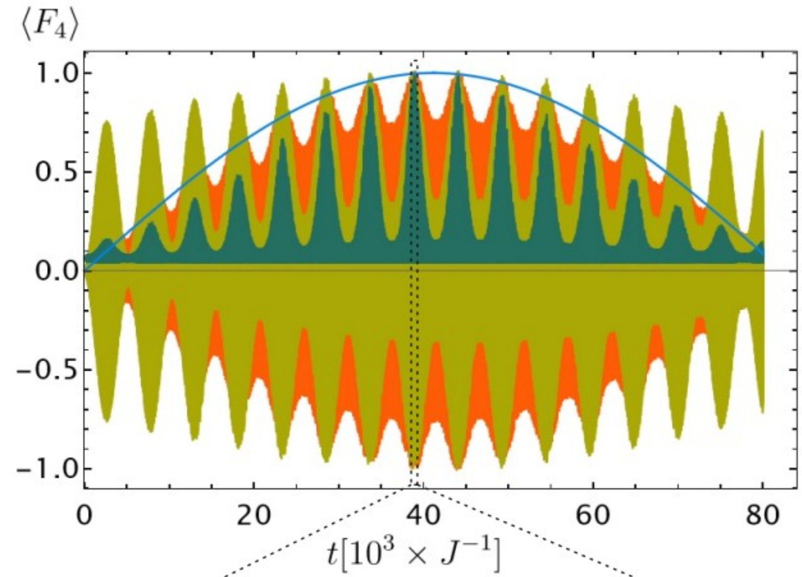
3-iQST

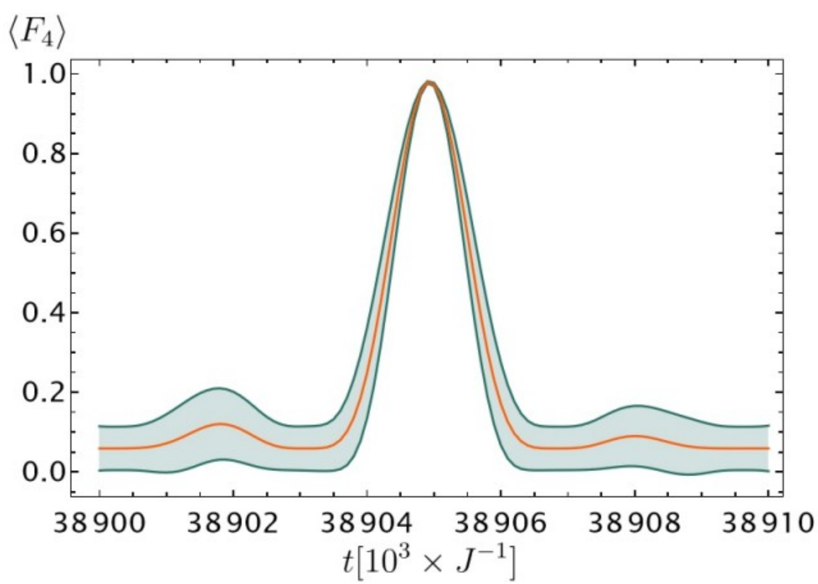

sender
wire
receiver
J
J_0
Energy
sender
channel
receiver
single-particle energy spectrum
$\langle F_3 \rangle$
$t[10^3 \times J^{-1}]$

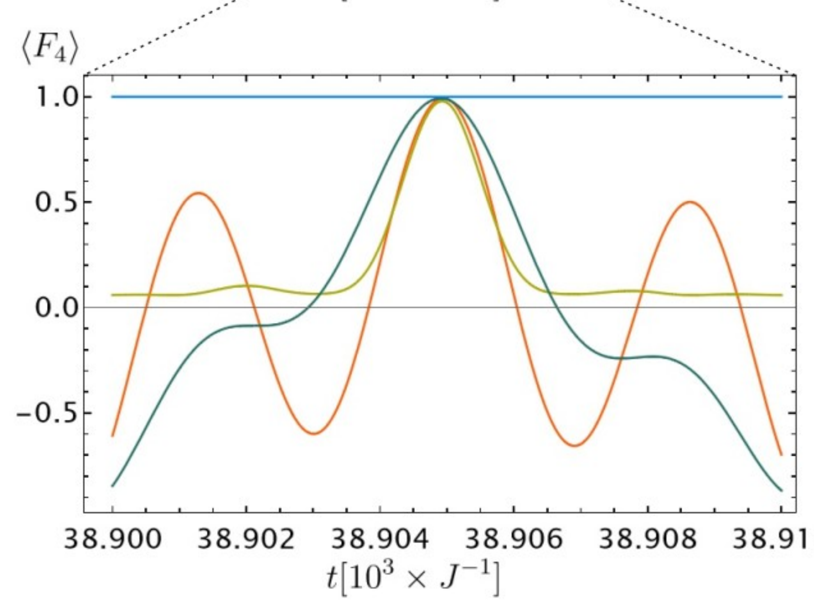
4-iQST


sender
wire
receiver
J
J_0

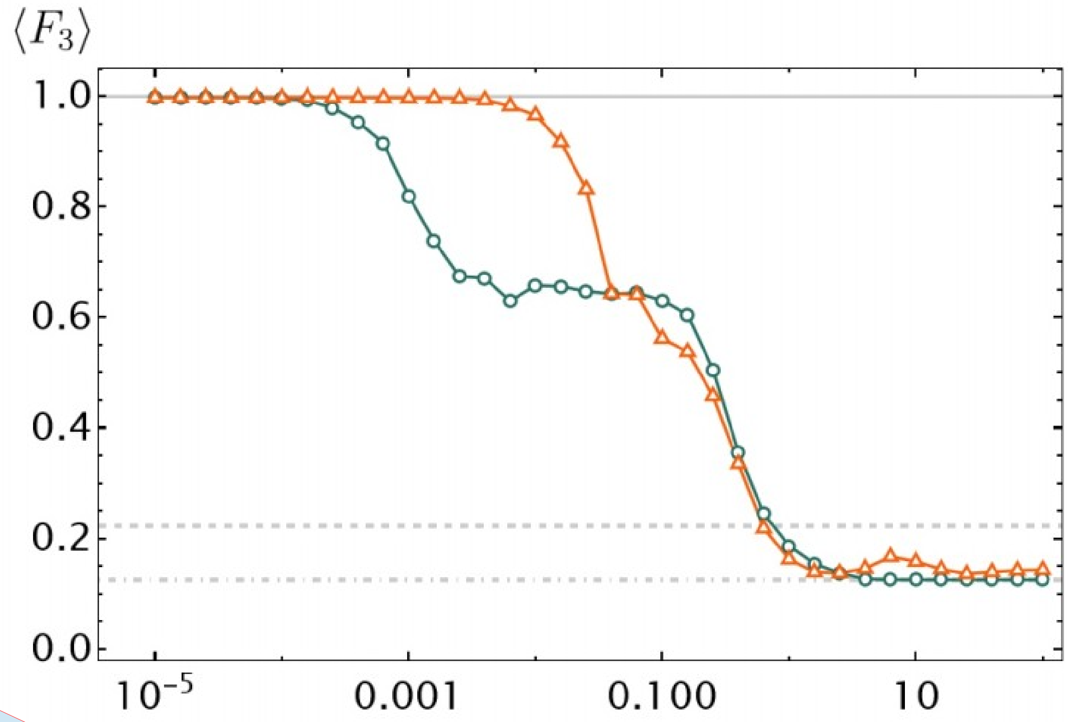

Energy
sender
channel
receiver
J_s
single-particle energy spectrum


$\langle F_4 \rangle$
$t[10^3 \times J^{-1}]$


$\langle F_4 \rangle$
$t[10^3 \times J^{-1}]$

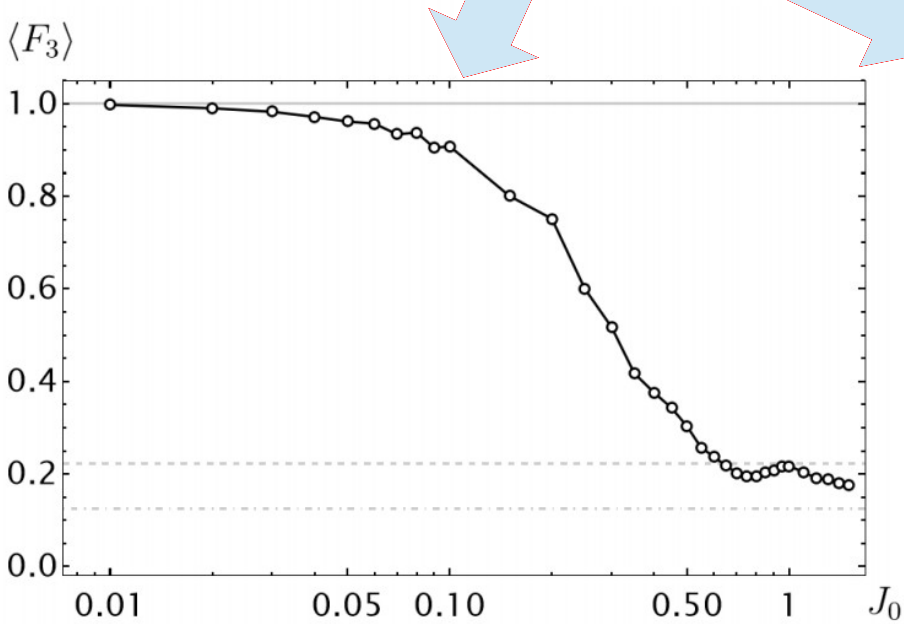

$\langle F_4 \rangle$
$t[10^3 \times J^{-1}]$

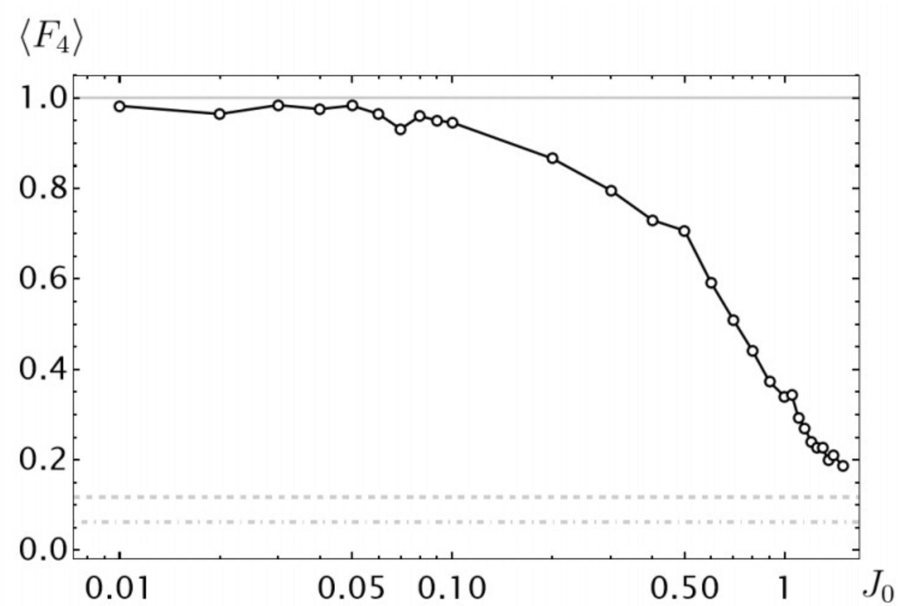
Effect of disorder in the wire

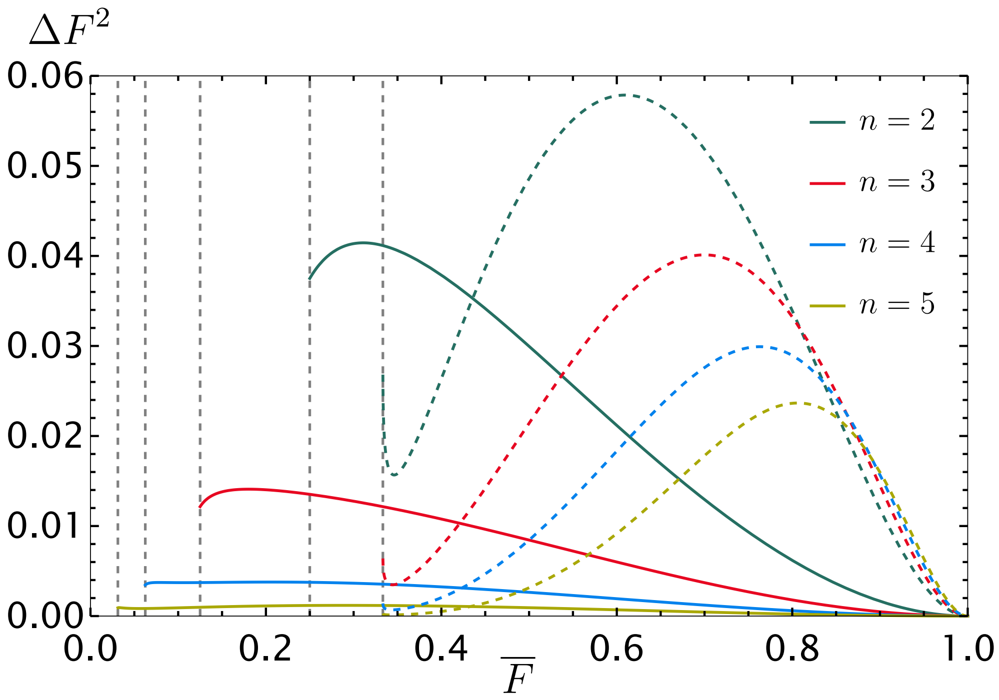


And

Imperfections in the weak couplings

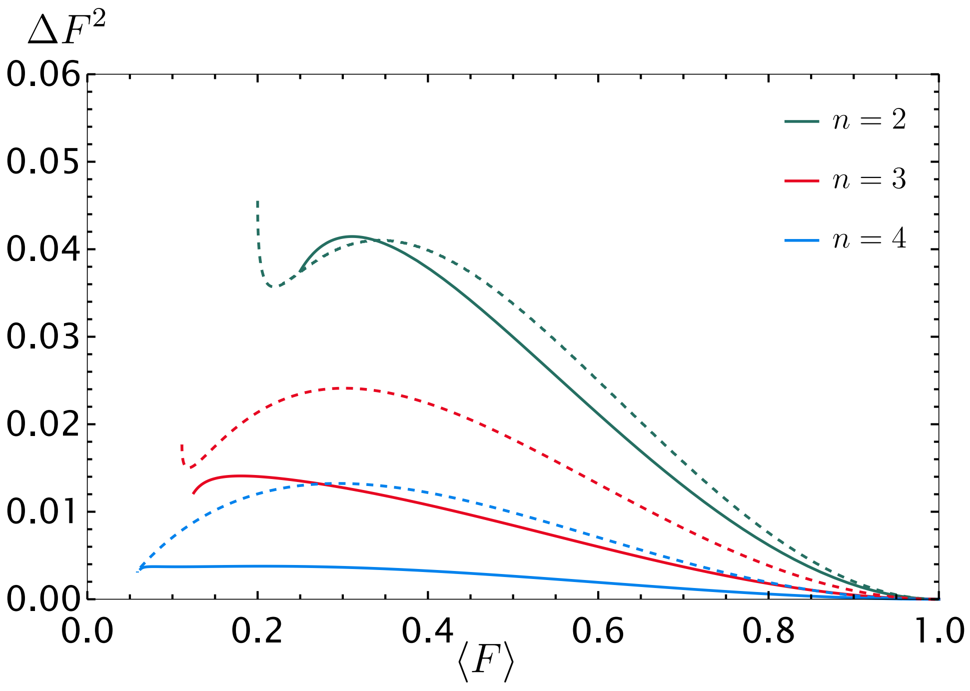






Variance vs average fidelity (n-QST) across independent channels for product states (dotted lines) and arbitrary states (continuous lines)

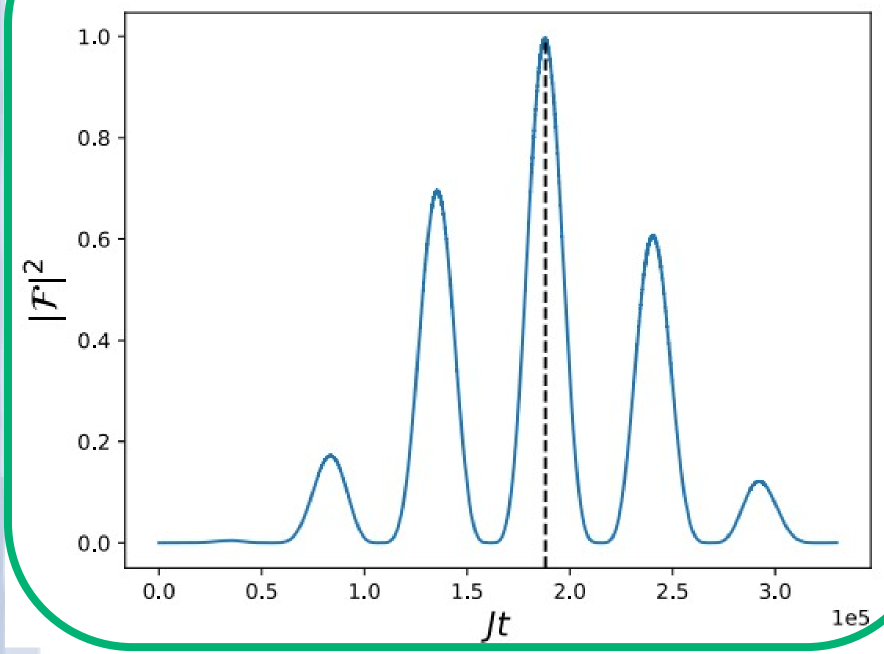
Variance vs average Fidelity for independent channels (continuous lines)
and for an interacting channel (dotted lines)



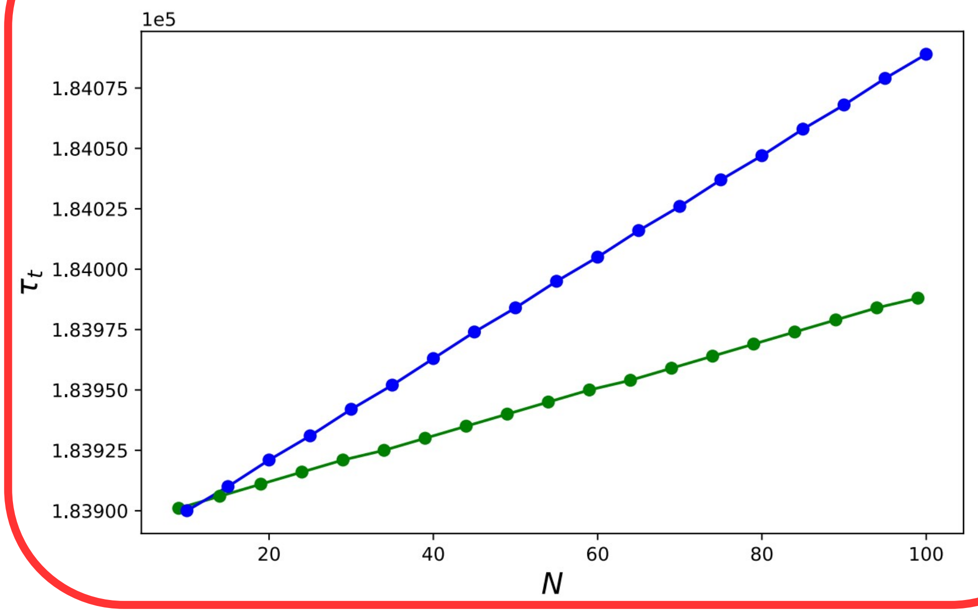
Length of wires that are equivalent mod(number of senders) have the same behaviour w.r.t. excitation transfer

Number of Excitations	Number of Resonant Modes	Length of the wire
1	0 1	$2n$ $2n+1$
2	0 0 2	$3n$ $3n+1$ $3n+2$
3	0 1 0 3	$4n$ $4n+1$ $4n+2$ $4n+3$
4	0 0 0 0 4	$5n$ $5n+1$ $5n+2$ $5n+3$ $5n+4$
5	0 1 2 1 0 5	$6n$ $6n+1$ $6n+2$ $6n+3$ $6n+4$ $6n+5$

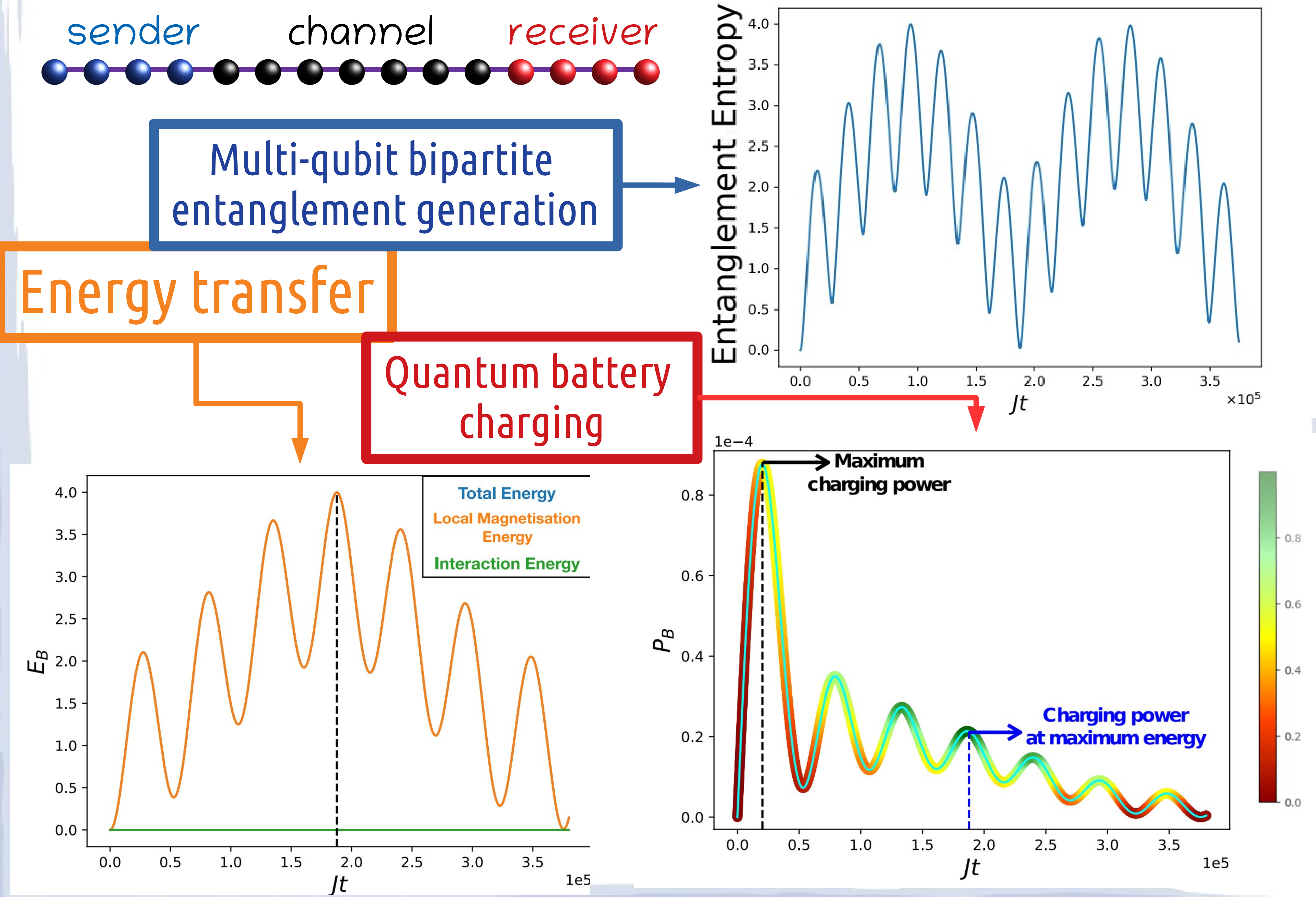
Fidelity of 4-excitation transfer



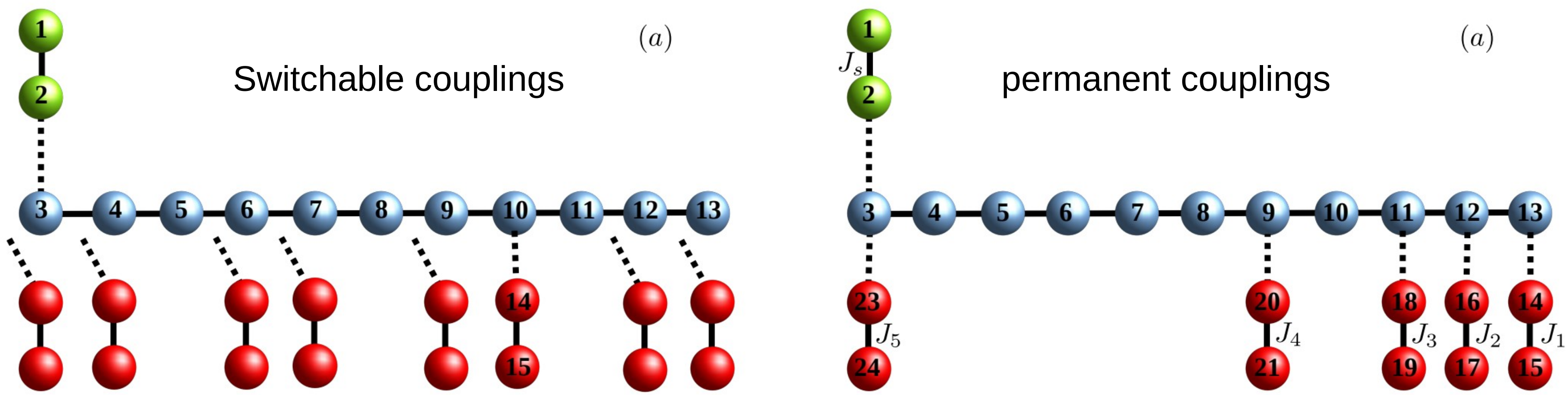
Linear increase of the transfer time with N



n-particle dynamics useful for:

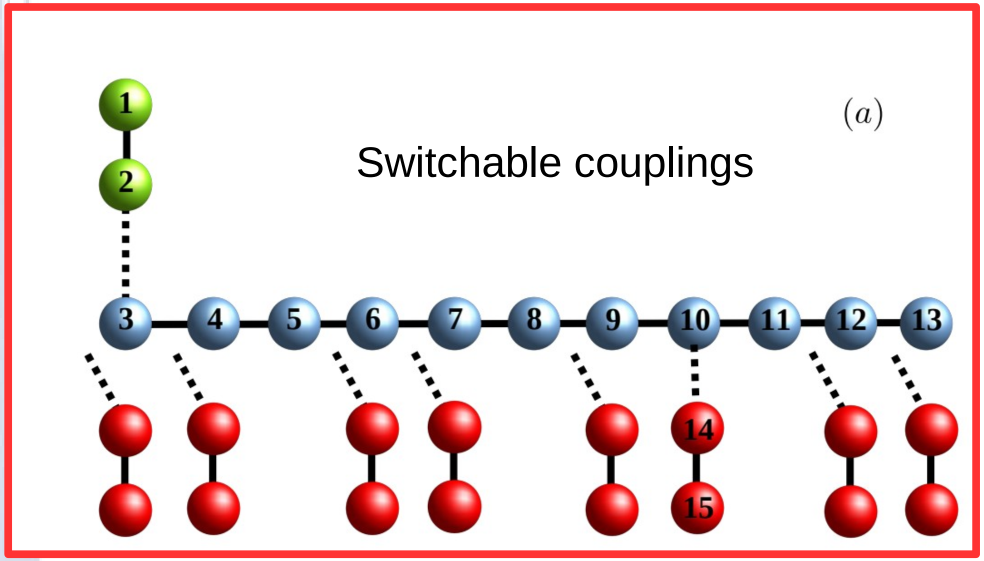


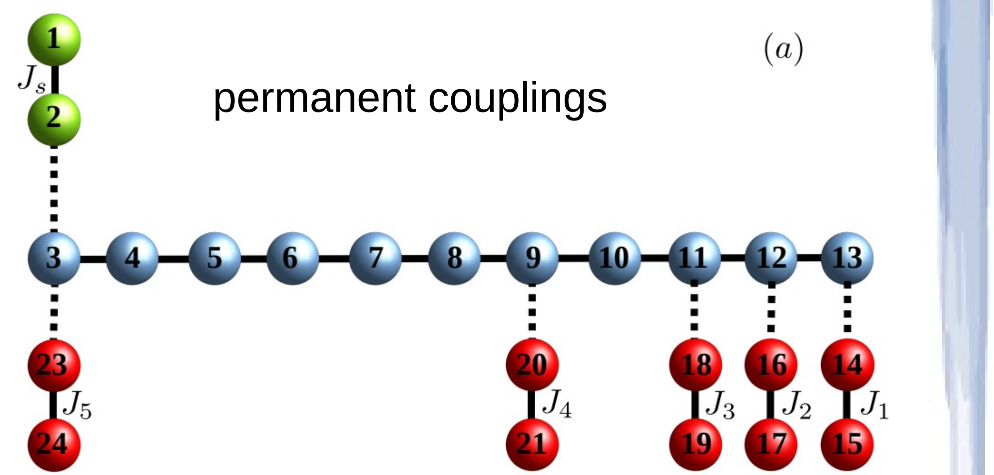
2-particle routing in network configuration:



<u>*NB: in the case of spin-1/2 particles, the JW transformation can not be applied*</u>

2-particle routing in network configuration:

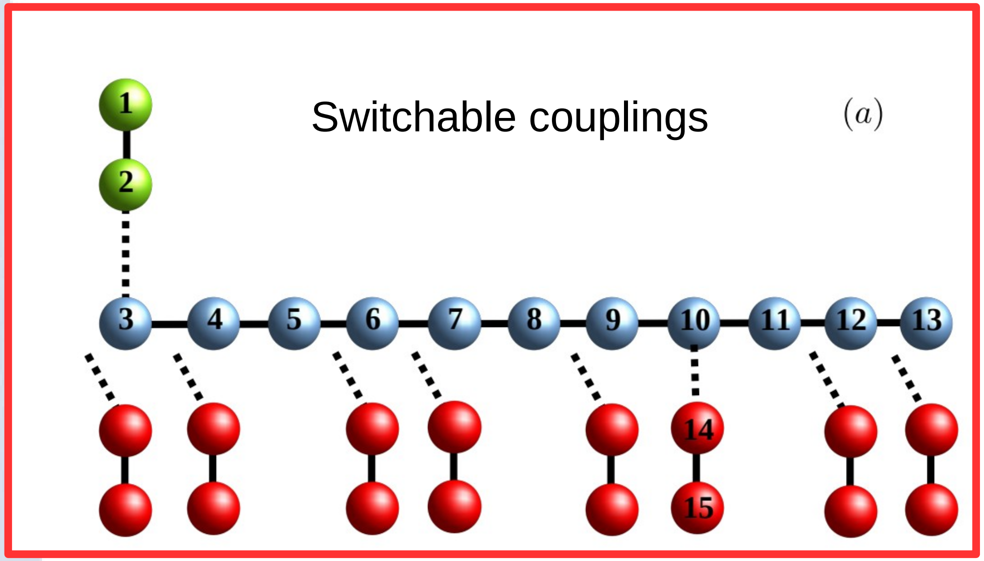


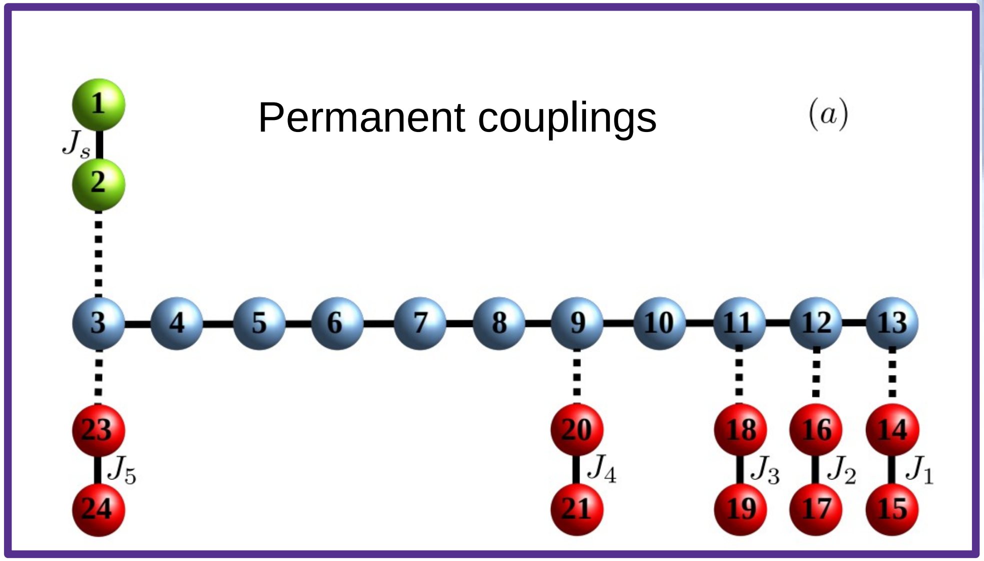


NB: in the case of spin-1/2 particles, the JW transformation can not be applied

- Length of wire n_w=3n+2
  (fulfills the energy resonance condition);
- Postion of the switchable couplings $n_r \neq 2n+1$
  (fulfills the equal-amplitude condition);
- Perturbatively perfect 2-excitation transfer in $O(J_0^{-1})$ time for every contact point.

2-particle routing in network configuration:

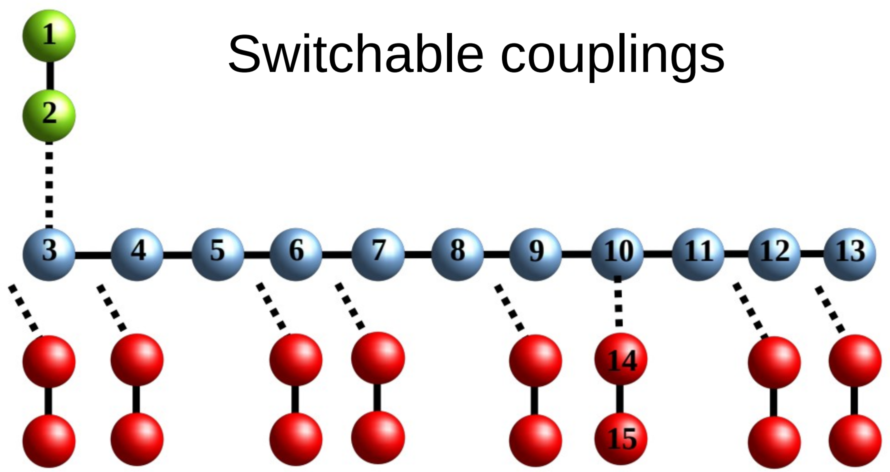


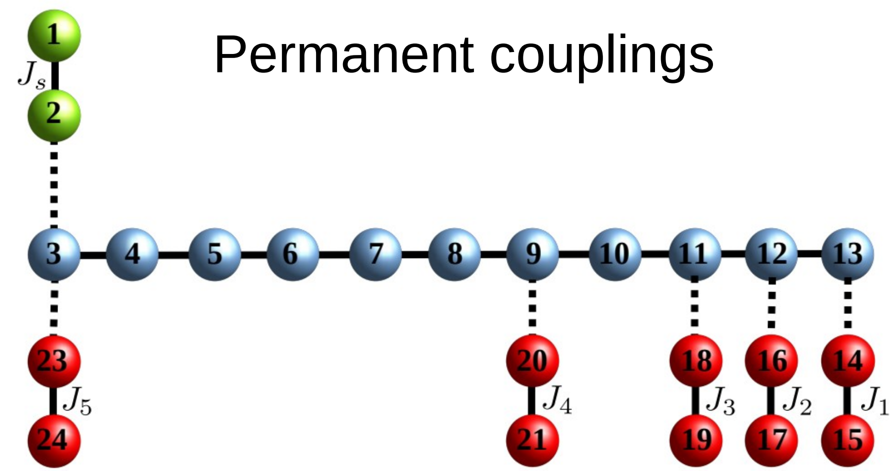


NB: in the case of spin-1/2 particles, the JW transformation can not be applied

- $n_w/2$-even $(n_w-1)/2$-odd possible receivers
- postion of the permanent couplings depending on J_i (fulfills the equal-amplitude condition);
- Perturbatively perfect 2-excitation transfer in $O(J_0^{-1})$ time for every contact point.

2-particle routing in network configuration:





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- $n_w/2$-even $(n_w-1)/2$-odd possible receivers
- postion of the permanent couplings depending on J_i (fulfills the equal-amplitude condition);
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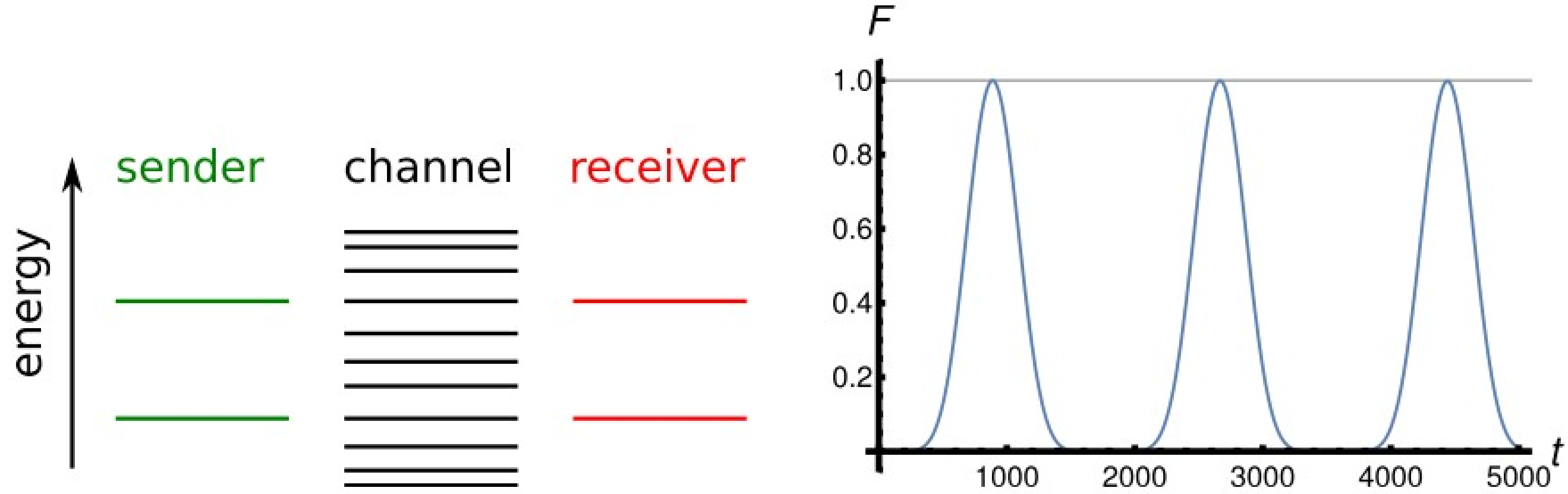
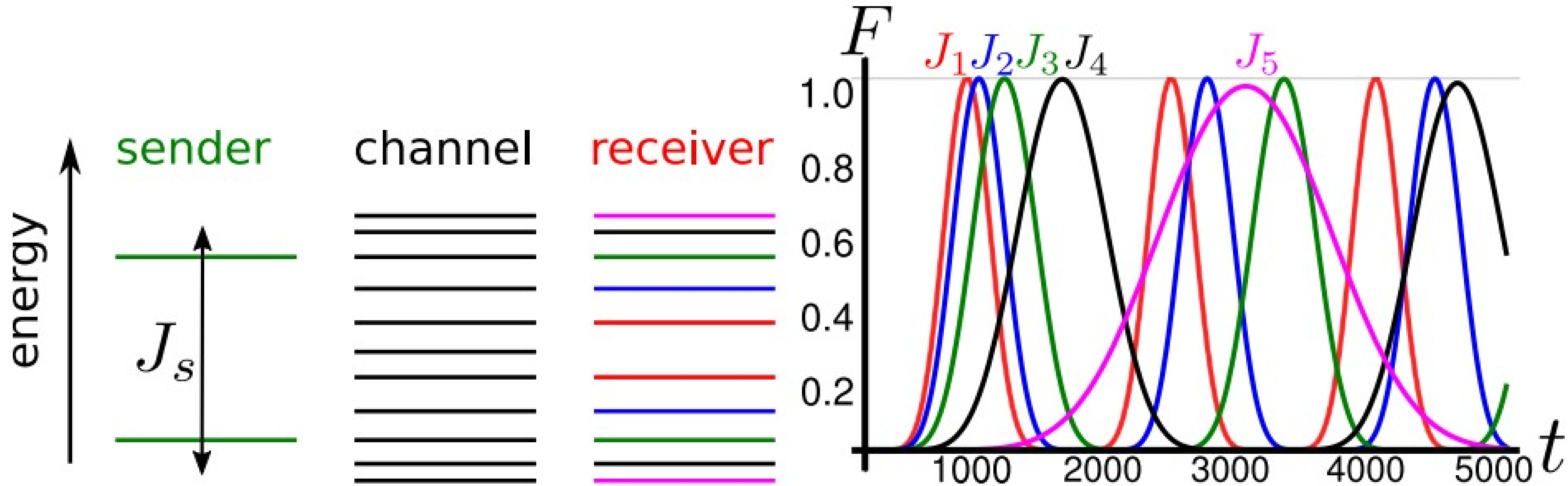
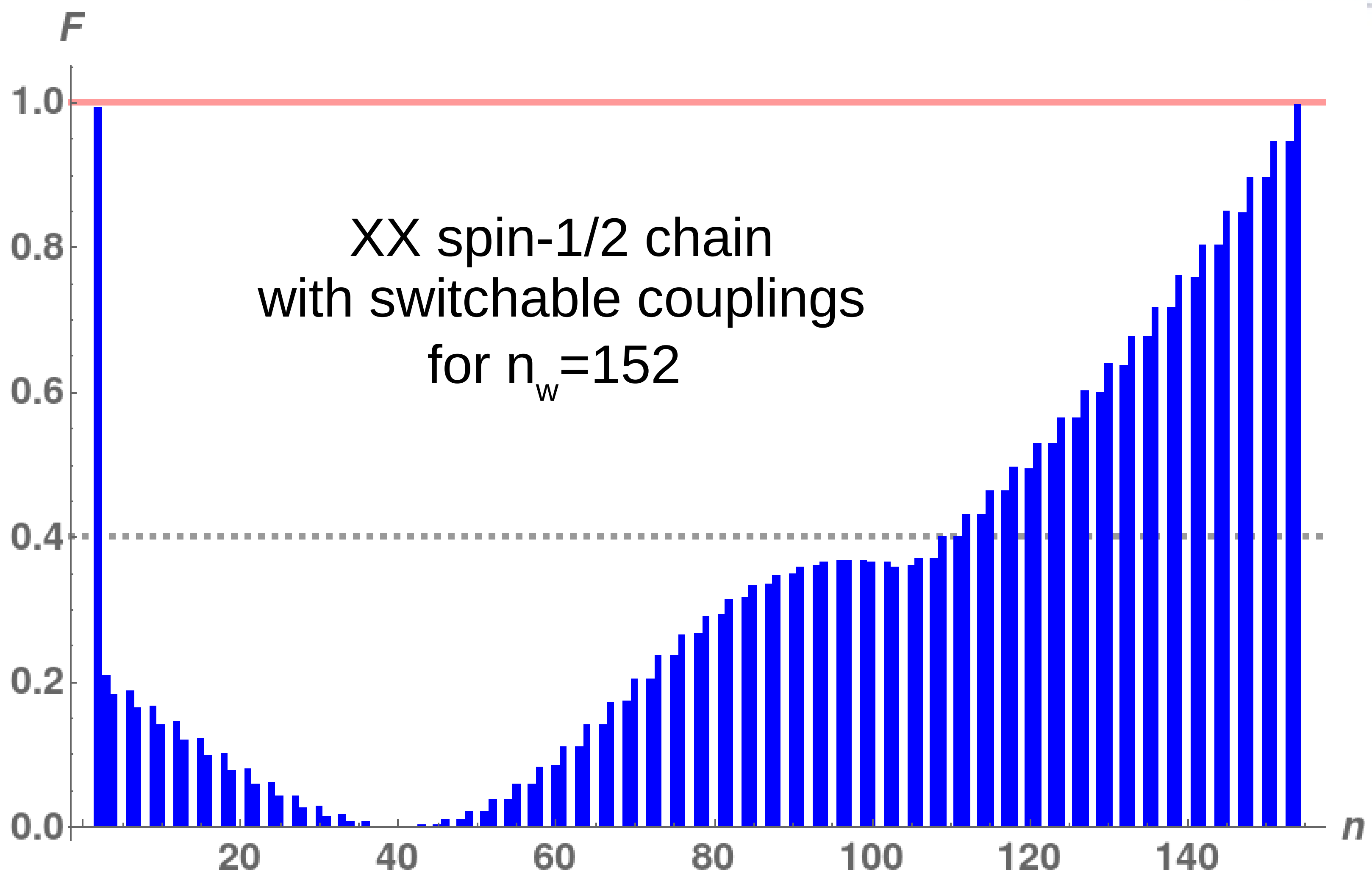
k	J_r	n_r
1	$\frac{\sqrt{3}-1}{2}$	1,11
2	1	1,2,4,5,7,8,10,11
3	$\sqrt{2}$	1,3,5,7,9,11
4	$\sqrt{3}$	1,5,7,11
5	$\frac{\sqrt{3}+1}{2}$	1,11

Switchable couplings



Permanent couplings





Questions:

- Does the protocol work for very long chains? I.e., is there a regime where the dynamics is governed by the single-particle spectrum?
- Is there any analogy between spin dynamics and (interacting) fermion/boson dynamics?

CONCLUSIONS

- n-QST vs. n-iQST
- First and second moment of the fidelity PDF
- Applications to quantum batteries and multi-qubit bipartite entanglement generation

Outlooks:

- PDF of fidelity
- n-iQST for arbitrary n
- Characterisation of multipartite entanglement generation

Quantum transfer of interacting qubits, T. J. G. Apollaro, S. Lorenzo, F. Plastina, M. Consiglio, Karol Zyczkowski, https://doi.org/10.48550/arXiv.2205.01579

Quantum map approach to entanglement transfer and generation in spin chains, S. Lorenzo, F. Plastina, M. Consiglio, T. J. G. Apollaro https://arxiv.org/abs/2112.02348

Perturbatively-perfect many-body transfer, Chetcuti, Sanavio, Lorenzo, Apollaro, New J. Phys. **22**, 033030 (2020)

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Francesco Plastina

Claudio Sanavio

Mirko Consiglio

Salvatore Lorenzo

THANK YOU FOR YOUR ATTENTION

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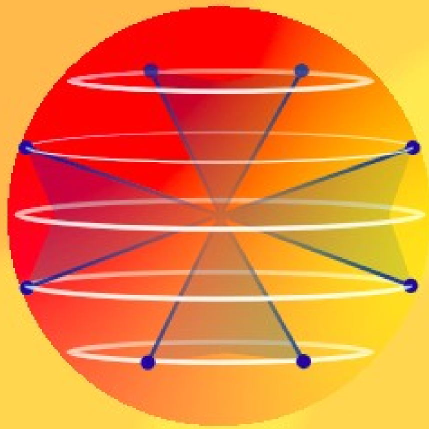

Malta, September 5–9 2022

Speakers

Massimo Palma (University of Palermo)
Steve Campbell (University College Dublin)
John Goold (Trinity College Dublin)
Mark Mitchison (Trinity College Dublin)
Sabrina Maniscalco (Algorithmiq, University of Helsinki)
Marcus Huber (TU Wien, IQOQI, Atominstitut)
Yelena Guryanova (IQOQI)
Zoe Holmes (EPFL)
Elisa Bäumer (IBM Quantum)
Bob Coecke (Quantinuum)