Call 2021
Final Evaluation

QUANTERA
DECADE OF IMPACT 2016-2026

EQUIP

Error Correction for Quantum Information Processing

Valentin Savin

https://equip-quantera.github.io/website/

COLLABORATION (overview)

DISCIPLINES

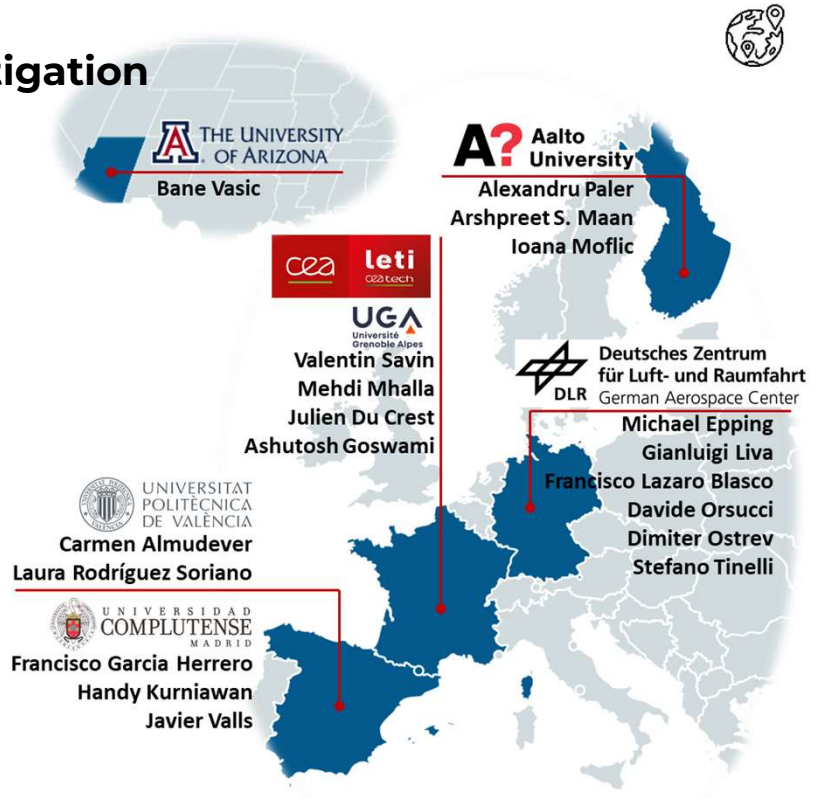
Quantum error correction & error mitigation

- Quantum information & software
- Quantum computer architecture
- Classical/quantum coding theory
- Hardware/ VLSI engineering

QUALITY OF COOPERATION

- Plenary meetings (3/year)
- Short term research visits
- Multipartner publications

  (~25% of the project publications)



CHALLENGES

Quantum Error Mitigation and Error Correction for NISQ

- Develop techniques to deal with errors in NISQ devices including **error-aware compilation** of quantum circuits, quantum **error mitigation** methods, and **low-qubit overhead QEC** protocols

Quantum Error Correction for LSQ

- Investigate **quantum LDPC codes** as a promising approach to scalable FTQC, offering high encoding rates and low-overhead error correction
- Develop new approaches to accurate and **hardware friendly decoding of quantum codes**, with a focus on the design of new iterative **message-passing based decoders** for **quantum LDPC codes**
- Explore approaches to FT quantum computation relying on **quantum polar codes**

Proof of Concept, Validation, and Evaluation

- Demonstrate the effectiveness of the proposed solutions through **proof-of-concept implementations**

ACHIEVEMENTS

Quantum Error Mitigation and Error Correction for NISQ

- **SW-based error mitigation techniques to reduce the noise in syndrome measurements** via a calibration experiment and a post-processing step
- Developed **models to predict error rates from calibration data**, enabling **noise-aware compilation with up-to-date error information** despite queuing delays in cloud-based quantum platforms
- **Machine learning based tools for automating the compilation of fault-tolerant quantum circuits** and for the detection and correction of errors within the circuit **based on flag qubits**

Proof of Concept, Validation, and Evaluation

- Versatile **framework and software platform** for **evaluating and comparing software-based error mitigation techniques**, enabling the integration of novel error-aware compilation methods and automated benchmarking against state-of-the-art approaches; **accessible through GitHub**

ACHIEVEMENTS

Quantum Error Correction for LSQ

- **Quantum LDPC codes from intersection subsets**, which been shown to outperform codes from other families with similar parameters
- **Theoretical analysis of message-passing decoders**, providing new insights into their intrinsic limitations for the toric code
- **Decoding algorithms** and post-processing techniques to handle the degeneracy of quantum LDPC codes with low computational complexity (stabilizer inactivation, check-agnosia, layered, **GARI**), improving **state-of-the-art performance in both decoding accuracy and hardware efficiency**.
- **Neural-network-based decoding strategies**, including machine-learning MP algorithms that remain scalable with code size and offer implementation-friendly structures
- Demonstrated **quantum polar codes for fault-tolerant error correction**, improving by three orders of magnitude on the error rate of a surface code with similar parameters

Proof of Concept, Validation, and Evaluation

- **HW-prototyping and validation of QEC decoders** through
  FPGA-based platform: validation of MP-based decoders, including **GARI**
  GPU-based platform: validation of GNN-based decoder
- **Software simulators**, accessible on GitHub

ACHIEVEMENTS (highlight)

GARI: the **state-of-the-art** decoder for **decoding correlated errors in QLDPC codes**

nature communications

Article

https://doi.org/10.1038/s41467-026-70556-3

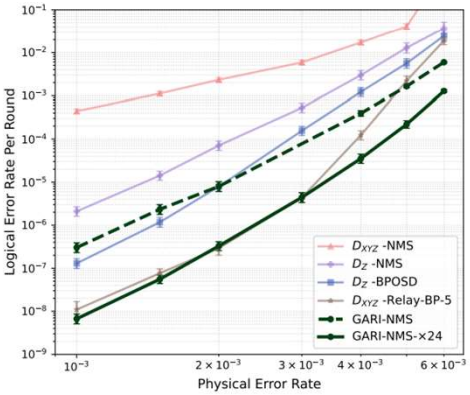
Decoding correlated errors in quantum LDPC codes

Received: 28 October 2025

Accepted: 2 March 2026

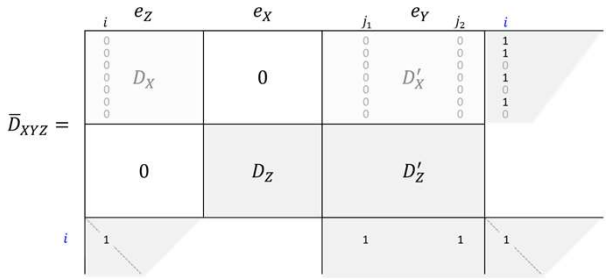
Arshpreet Singh Maan[1], Francisco Miguel Garcia Herrero[2], Alexandru Paler[1] & Valentin Savin[3,4]

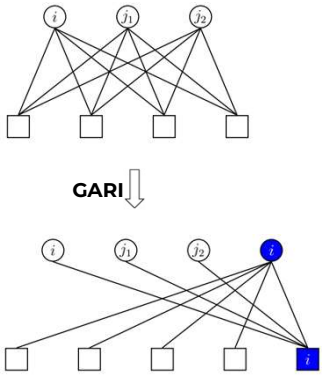
[1]Aalto University, Espoo, Finland. [2]Universidad Complutense de Madrid, Madrid, Spain. [3]Université Grenoble Alpes, CEA-Léti, Grenoble, France.

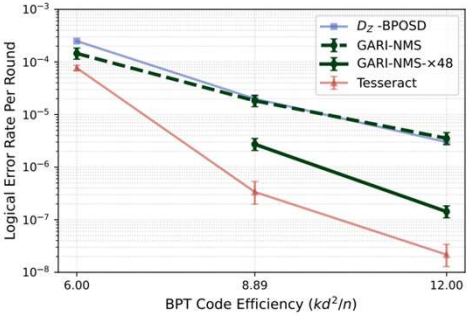


(c) [[144,12,12]] code, Stim circuit from [32]

Graph Augmentation and Rewiring for Inference (GARI)







ACHIEVEMENTS (highlight)

GARI: the **state-of-the-art** decoder for **decoding correlated errors in QLDPC codes**

nature communications

Article

https://doi.org/10.1038/s41467-026-70556-3

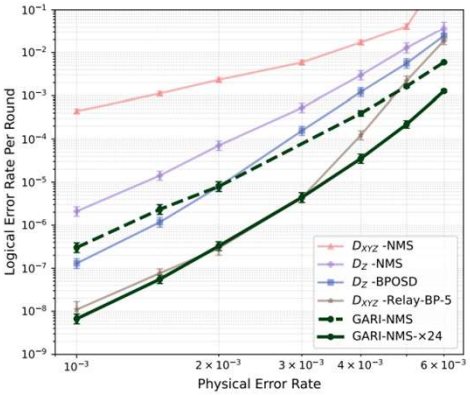
Decoding correlated errors in quantum LDPC codes

Received: 28 October 2025

Accepted: 2 March 2026

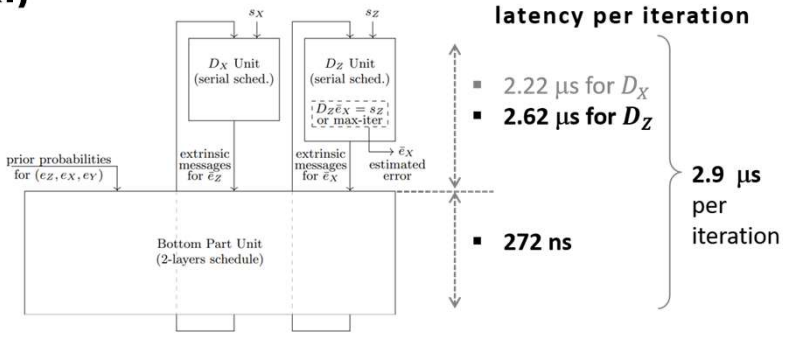
Arshpreet Singh Maan[1], Francisco Miguel Garcia Herrero[2], Alexandru Paler[1] & Valentin Savin[3,4]

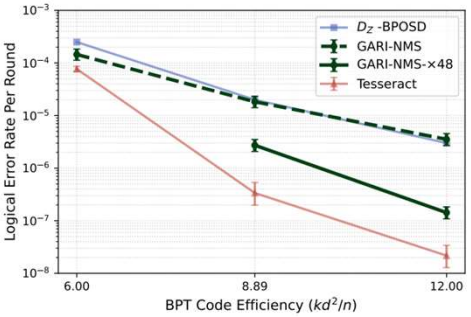
[1]Aalto University, Espoo, Finland. [2]Universidad Complutense de Madrid, Madrid, Spain. [3]Université Grenoble Alpes, CEA-Léti, Grenoble, France.



(c) [[144,12,12]] code, Stim circuit from [32]

Graph Augmentation and Rewiring for Inference (GARI)





ACHIEVEMENTS (highlight)

GARI: the **state-of-the-art** decoder for **decoding correlated errors in QLDPC codes**

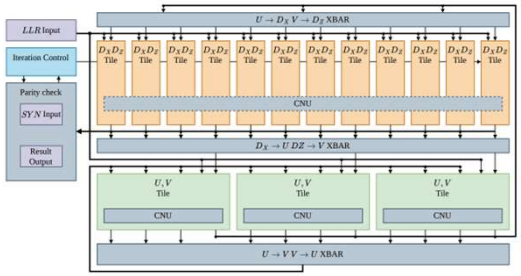
A Scalable FPGA Architecture for Real-Time Decoding of Quantum LDPC Codes Using GARI

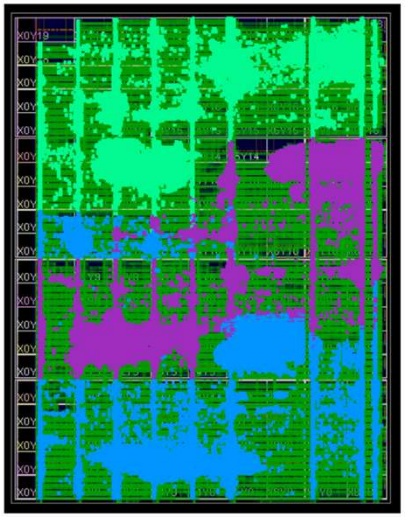
Daniel Báscones[1], Arshpreet Singh Maan[2], Valentin Savin[3] and Francisco Garcia-Herrero[1]

[1] Complutense University of Madrid, Madrid, Spain, {danibasc, francg18}@ucm.es
[2] Aalto University, Espoo, Finland, arshpreet.maan@aalto.fi
[3] Quobly, Grenoble, France, valentin.savin@quobly.io

arXiv:2605.01035v1 [quant-ph] 1 May 2026

Proc. of IEEE QCE'26, Toronto, September 2026





- Proposed architecture can accommodate **three decoders** for **correlated errors** for the gross code on **one single FPGA**

  ⇒ vs. a single instance of an uncorrelated decoder for RelayBP [arXiv:2510.21600]

- **Average latency of 596 ns per decoding round @p=0.001**

SCIENTIFIC OUTPUTS

PUBLICATIONS AND PRESENTATIONS (highlights)

- **38 publications, 25% involving multiple partners**
  Nature Communications
  npj Quantum Information
  IEEE Transactions on Information Theory
  IEEE Journal on Selected Areas in Information Theory
  IEEE Information Theory Magazine
  IEEE Software
  Quantum
  Physical Review A
  ...

- **30+ presentations at seminars, workshops, panels, and online events**
  Scientific seminars in academia and industry
  Invited talks at workshops and panel participation
  Online media and popular press

SCIENTIFIC OUTPUTS

PATENTS (obtained and pending)

2 patents (already obtained)

NUMBER OF BACHELOR, MASTER AND PhD THESES
prepared under the QuantERA Project

5 MSc Students

6 PhD Students

IMPACT (potential users)

RELEVANT **INDUSTRY BRANCH**

- **Quantum computing hardware, control systems and software**
  QEC/FTQC, quantum processor control, compilation and error mitigation

KEY COMMERCIALLY RELEVANT **APPLICATIONS**

- **Noise-aware compilation and error mitigation** for NISQ quantum computing
- **Real-time QEC decoders** for integration into quantum-processor control units
- **FPGA/GPU-based QEC validation and emulation** for development and benchmarking of QEC decoders

POTENTIAL **END USERS**

- **Quantum hardware & control:** IQM, Quantum Machines, Qblox, PlanQC
- **QEC software:** Riverlane
- QC companies with in-house QEC & control stacks

IMPACT (RRI aspects)

EDUCATION AND PUBLIC ENGAGEMENT

- 30+ presentations at seminars, workshops, panels, and online events

- **Organization of Workshop and Scientific Seminars**

Three Workshops on Quantum Resource Estimation — June 18, 2023; September 11, 2024; September 5, 2025

Four Workshops as part of IEEE Quantum Week

Practical Quantum Error Correction and Fault-tolerant Quantum Computing: a Full-stack Approach	September 17, 2023
Towards Error Correction within Modular Quantum Computing Architectures	September 15, 2024
Quantum Error Correction: Pathways to Scalability	September 2, 2025
Quantum Error Correction: Quantum LDPC Codes	September 15, 2026

Dagstuhl Seminar on "Classical-Quantum Synergies in the Theory and Practice of Quantum Error Correction" — May 20-23, 2024

Dautreppe Seminar on Quantum Science and Technologies (doctoral training school) — October 6-8, 2025

IMPACT (RRI aspects)

ACTIONS ON GENDER EQUALITY

- **Gender Balance**

  PIs: 1/5 women ; Total Participants: 6/29 women

- **Invited presentation at Women in Science Day in Iran**

  Online event to celebrate and empower women in science.

  It aims to encourage and support the professional growth of women in science, facilitate international scientific collaborations, and create a platform for knowledge exchange

- **Presentation at Girls4stem event**

  Aimed at promoting STEM (Science, Technology, Engineering, Mathematics) vocations, especially among girls, through the organisation of dissemination activities

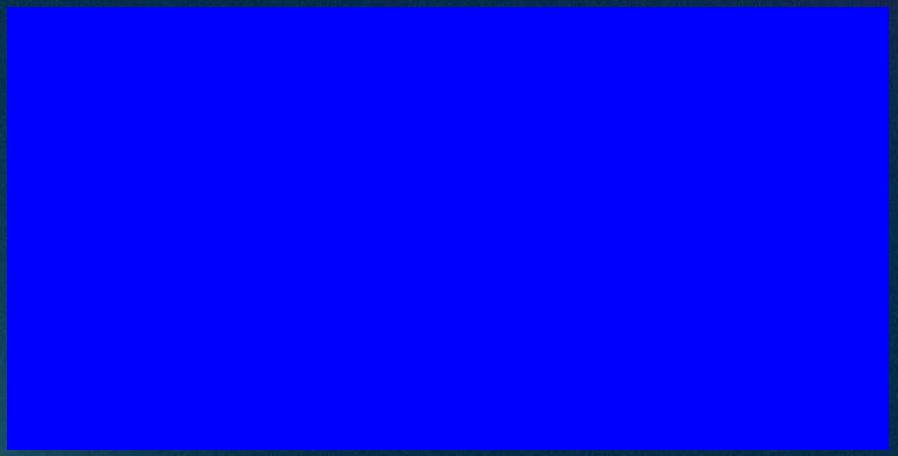
OPEN SCIENCE

- All project publications are available through **gold open access** (open-access journals) or **green open access** (e.g., via arXiv), with **links to public repositories containing the associated code and data**, where applicable

WHAT'S NEXT

Our collaboration continues:

- **On the GARI decoder:** new preprint coming soon
- **Co-supervision of PhD students:** continued beyond the end of EQUIP
- **Workshop organization:** we plan to continue organizing the Quantum Error Correction workshop at IEEE Quantum Week
- **New project proposals:** ongoing and forthcoming submissions



Co-funded by
the European Union