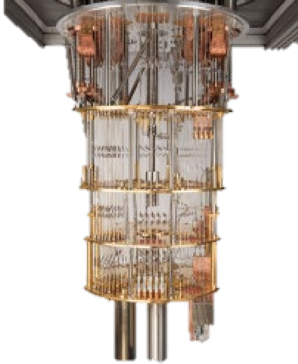

# Quantum Technologies EC

## & Benchmarking June 2024

**Oscar Diez**

**Head of Quantum Computing**

HPC and Quantum Technologies Unit

European Commission

QUANTUM FLAGSHIP

European Commission

# Strategic Pillars of the EU Quantum Ecosystems

RESEARCH BASED

HORIZON EUROPE


2021-2027

INFRASTRUCTURES

DIGITAL EUROPE

## Flagship

**Bring** quantum **technologies** from the **lab** to the **market** and consolidate European scientific **leadership** in quantum research

Fundamental R&D

Technology Supply

## Advanced Digital Skills

Develop short term **training courses** and **Master's programmes** in key capacity areas

## From Lab to Market

Pilot Lines & Testing Facilities

## Q Sensing Deployment

**Build** and **deploy** Quantum sensing devices

Quantum Gravimeters

Quantum MRIs

## European Chips Act

Bolster Europe's competitiveness & resilience in semiconductors & **quantum chips** including production facilities & Quantum Fund

## EuroQCI

**Build** and **deploy** in the next decade a certified secure pan-European end-to-end QCI for **cybersecurity services**

QKD Infrastructure

## EuroQCS

**Build** and **deploy** an infrastructure for high performance computing and **quantum computing**

HPC with Accelerators

Stand-alone Q Computers

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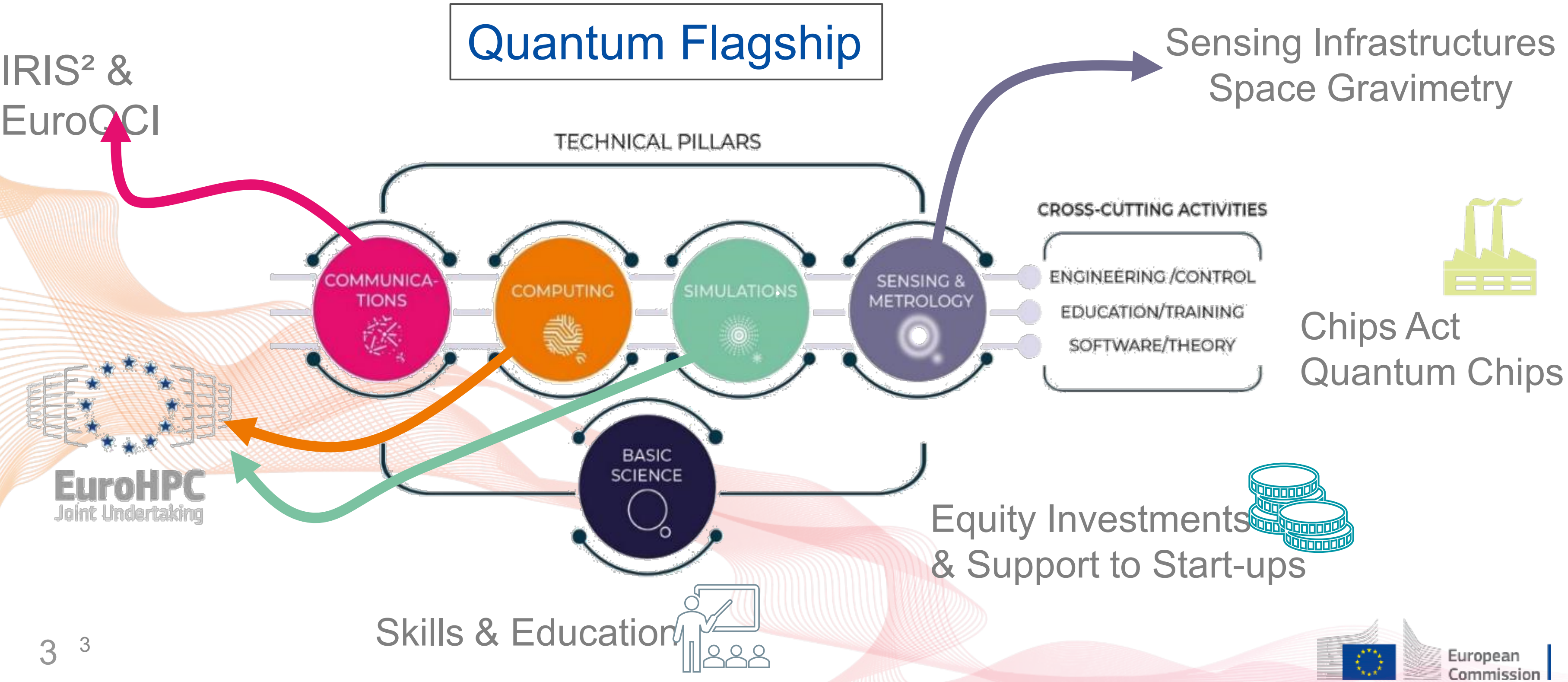
# Quantum Ecosystem Strategic pillars



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# Quantum Flaghip Ramp-up phase

**computers**

- OpenSuperQPlus — superconducting qubits
- AQTION — trapped ion qubits
- microQC — trapped ion qubits
- QLSI — silicon qubits
- QUANTUM FLAGSHIP — European Flagship Quantum Technologies

**simulators**

- Qombs — cold atoms
- PASQuanS2 — cold atoms and trapped ions
- PhoQuS (Photons for Quantum Simulation) — photons
- SQUARE — trapped ions (simulation and universal QC)

**software**

- <NE|AS|QC> — software applications

**telecoms**

- QIA Quantum Internet Alliance — repeater network, interface with qubits
- CiViQ — QKD on photonics, telcos
- UNIQORN (Affordable Quantum Communication for Everyone) — system on chip
- QMiCS — IPC micro-waves
- QRANGE — QRNG, CMOS SPADs
- S2QUIP — photonic
- 2D·SIPC — photonic

**sensing**

- ASTERIQS — NV centers
- Metabolight — IRM & NV centers
- macQsimal — cold atoms
- iqClock — optical clock
- PhoG — photons

Olivier Ezratty 2023

# Quantum Communications

## Flagship: from ramp - up to tech demo

Projects started under Horizon Europe (from 2022):

→ **FPA QIA** (7y) → full-stack prototype network
→ **FPA QSNP** (7y) → further develop & deploy quantum cryptography
→ **RIA HyperSpace** → entangled photons for long-distance space Qcomm
→ …

**Bringing technology to full maturity**:
→ Performance/functionality improvements
→ Industrialisation; towards market uptake

# EU Wide QT Network: First Step

EuroQCI

- Integrated **satellite and terrestrial** system spanning the whole EU for ultra-secure exchange of cryptographic keys
- Part of the EU Secure Connectivity Programme (**IRIS²**)

→ **Deployments**

***Terrestrial** segment

→ DIGITAL: **6 industrial & 26 national projects**, **CSA**

→ Ongoing: **procurement for QKD testing & evaluation**

→ 2024+: CEF **call for cross-border connections** / OGS

***Space** segment

→ Eagle-1

→ SAGA




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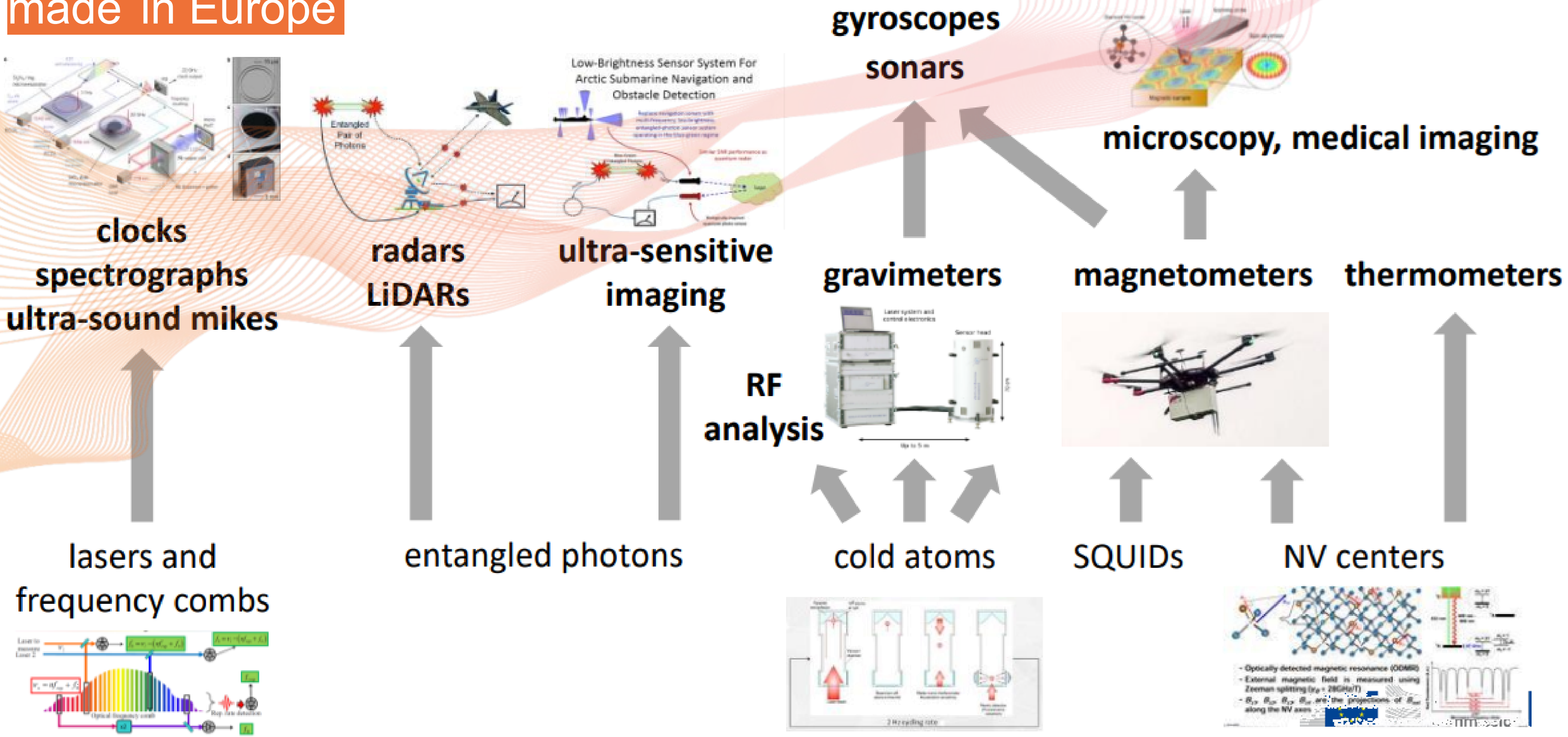
# Quantum Sensing

## Quantum-secured networks and quantum internet made in Europe




a map of various quantum sensing basic technologies and use cases. (cc) Olivier Ezratty, 2021-2023

# Quantum Sensing Deployment

**Developing and deploying a network of Quantum Gravimeters in Europe (HORIZON, IA)**

- Demonstrate the advantage of quantum gravimeters in innovative operational settings (onboarded, networks)
- Procure the gravimeters and operate them for real-world use cases
- Opening/closing dates TBC depending on adoption of amended WP

**AI in support of Quantum-Enhanced Metabolic Magnetic Resonance Imaging Systems**
Digital Europe, SME support action

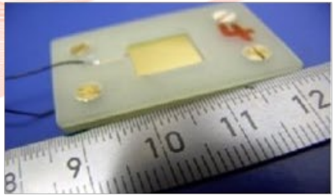
- Leverage sensing precision of quantum metabolic MRI for innovation in disease detection, diagnosis and treatment (e.g. of cancer or neurological diseases)
- Demonstrate the advantage of quantum technologies and AI together
- Support industrial innovation by becoming lead users of these technologies and opening up new markets
- Deployment in two phases (pre-clinical and clinical)

# Quantum Chips in the Chips Act

## Chips for Europe Initiative – Overview

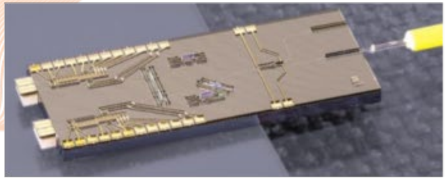
# High diversity of quantum chips

Computing: **Superconducting qubits** and parametric amplifier (for control and readout of qubits)

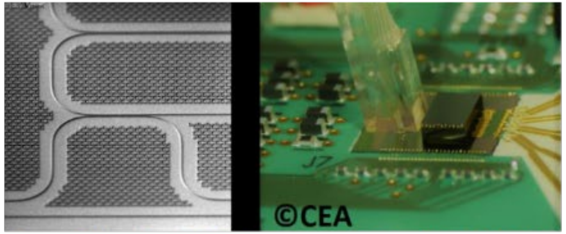


Sensing/Communication/Computing: Diamond growth, defect implantation (**NV-Center**), characterization

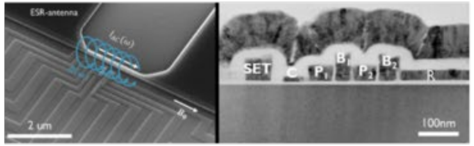
Computing/Sensing: (Left) **Trapped ions Paul trap**, (Right) **Chip ion trap**



Communication: Polarization coding **BB84 transmitter PIC**



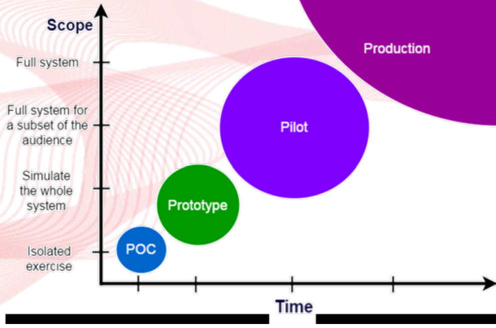

Communication/Computing: (Left) SEM view of a **silicon photonic circuit** for entangled photon generation (Right) Packaging of **photonic integrated circuits** with fiber array and electronic chip on top

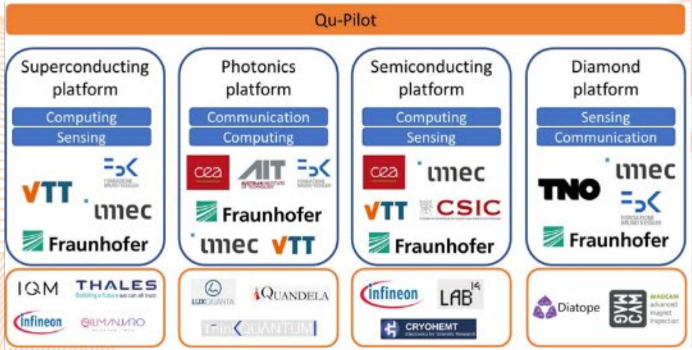


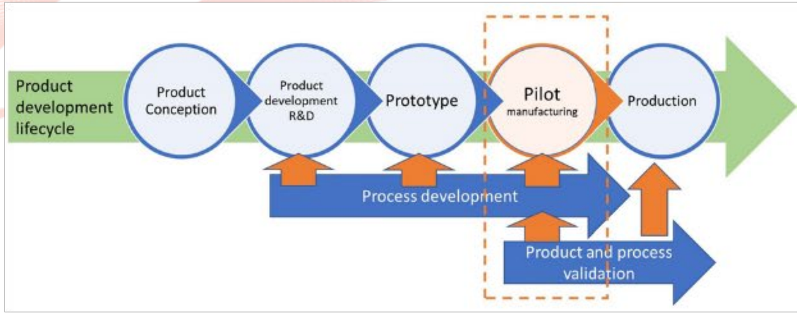

Computing: **Silicon spin qubit** cell with ESR manipulation unit: top view (left) and cross-section (right)

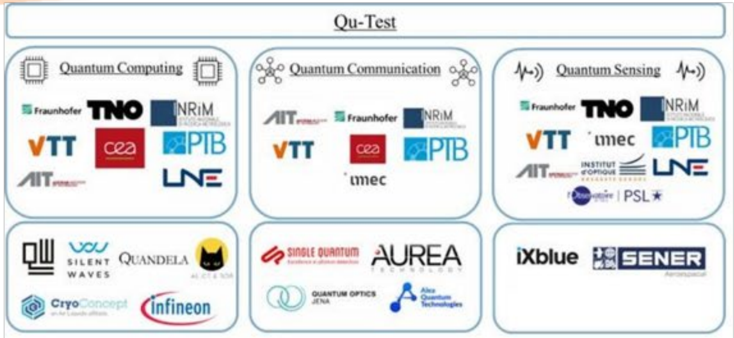
# Pilot lines & Testing Facilities

## Quantum Flagship Projects

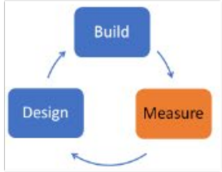



Engineering cycle of QT devices



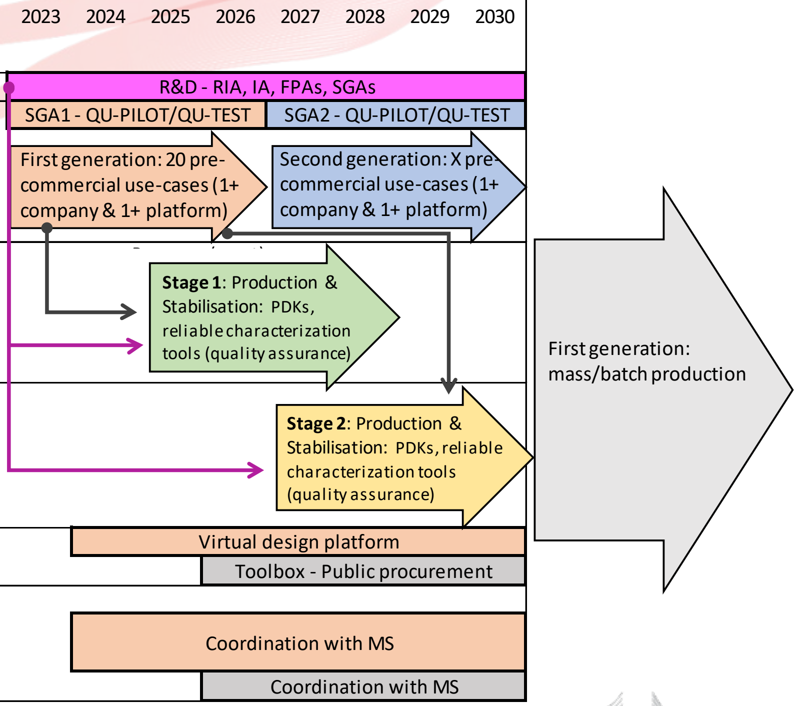

Measure to **improve** prototyping and **design**

# Quantum Chips Act

## Draft Roadmap



| Phase | Action | Target | Funding | WP |
|---|---|---|---|---|
| R&D | **QT Flagship R&D projects** | R&D community | HE | |
| | **Experimental Pilot Lines (high-flexibility, low-volume)** | | HE | |
| | - Superconducting platform (computing, sensing) | RTO + Industry Partner | HE | |
| | - Photonics platform (communication, computing) | RTO + Industry Partner | HE | |
| | - Semiconductor platform (computing, sensing) | RTO + Industry Partner | HE | |
| | - Diamond platform (sensing, communication) | RTO + Industry Partner | HE | |
| PILOT (PRODUCTION) LINES | **Industrial (stability) Pilot Lines (stage 1)** | | | WP24 |
| | Stability use-case 1 (PDK) | RTO + Industry Partner | CA | |
| | Stability use-case 2 (PDK) | RTO + Industry Partner | CA | |
| | Stability Trapped Ions (PDK) | RTO + Industry Partner | CA | |
| | **Industrial (stability) Pilot Lines (stage 2)** | | | WP26 |
| | Stability use-case 4 (PDK) | RTO + Industry Partner | CA | |
| | Stability use-case 5 (PDK) | RTO + Industry Partner | CA | |
| | Stability use-case 6 (PDK) | RTO + Industry Partner | CA | |
| DESIGN | **Basic design tools (for R&D at low TRL)** | Licence acquisition | CA | WP24 |
| | **Advanced design tools (commercial products)** | Industry | CA | WP26 |
| COMP. CENTRES | **Competence centres** | | | |
| | - Training for QT/microelectronics design skills | MS | CA | WP24 |
| | - Support on design-to-manufacture transition | MS | CA | WP24 |
| | - Support on advanced design tools | MS | CA | WP26 |





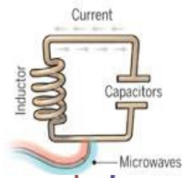

* This implies the implementation of multiple use-cases, including materials (Al, Nb, Si, Ge, etc.) and …??
Dates here are intended "starting of project", i.e. the launching of the calls is 1 year in advance
In most cases 1.5 years is needed from setting up the pilot line and to actually "produce"

# Quantum Computing and Simulation

## Continue funding, diversifying and deploying

# Quantum Computing in the EU Now

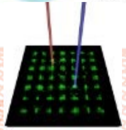
Superconducting




IQM, QuTech, QILIMANJARO, QUANTWARE, ALICE & BOB

OpenSuperQPlus

Neutral Atoms

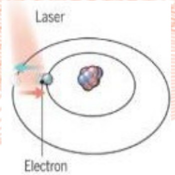


PASQAL, planqc

EuRyQa

PASQuanS2

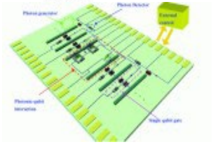
Trapped Ions




AQT, eleQtron, JÜLICH Forschungszentrum

MILLENION QUANTUM

Photonics (PICs)



QUIX QUANTUM, QUANDELA, QANT

QPIC 1550 Quantum Photonic Integrated Circuits

QU-PIC, QLASS

Spins /Quantum Dots

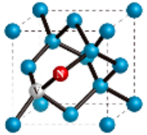

SemiQon, QuTech, siquance, imec

QLSI

IGNITE

QLSI2

NV Centers



XEED, SaxonQ

SPINUS

European Commission

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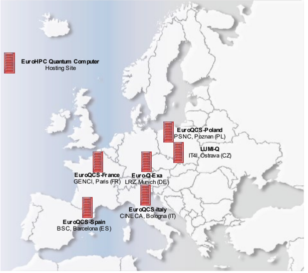
# EuroHPC EuroQCS




## Interfacing Quantum Computers with HPC

| | 2019 & 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
|---|---|---|---|---|---|---|---|---|
| **HPC Infrastructure** | pre-exascale + petascale HPC systems | Several petascale, pre-exascale systems and exascale HPC systems | | | | exascale and post-exascale HPC systems | | |
| **Quantum Infrastructure** | **quantum simulators** interfacing with HPC systems | 1st generation of **quantum computers** + **quantum simulators** interfacing with HPC systems | | | | 2nd generation of **quantum computers** + **quantum simulators** | | |

**Hardware connection between classical supercomputers and quantum computers** → **Use the quantum computer as an accelerator for the supercomputer** → **Develop a software platform for seamless programming of the hybrid system** → **Test and validate hybridisation in key applications** →

**Priority use cases**

- **Climate modelling**
- **New materials (batteries)**
- **Drug simulation**

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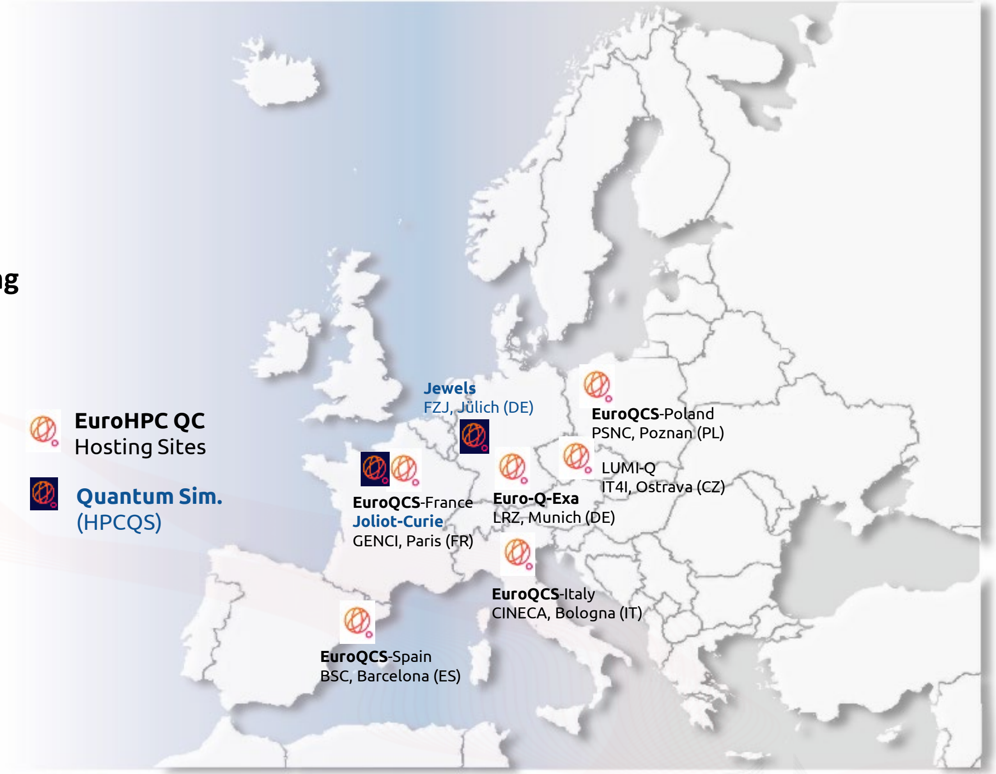
# EuroHPC QCS Infrastructure

- 2 Quantum Simulators* (100+ Qubits)
  - Jülich: *Jewels – PASQAL QS* (*Germany*)
  - GENCI: *Joliot-Curie – PASQAL QS* (*France*)

➢ Both systems will be delivered in January 2024

- **6 Selected Hosting "Entities" (Consortia of 30 participating countries)**
  - Euro-Q-Exa, *superconducting Qubits* (DE)
  - LUMI-Q, *superconducting Qubits* (CZ)
  - EuroQCS-Spain, *superconducting Qubits* (ES)†
  - EuroQCS-Italy, *neutral atom Qubits* (IT)*
  - EuroQCS-Poland, *trapped ion Qubits* (PL)
  - EuroQCS-France, *photonic Qubits* (FR)

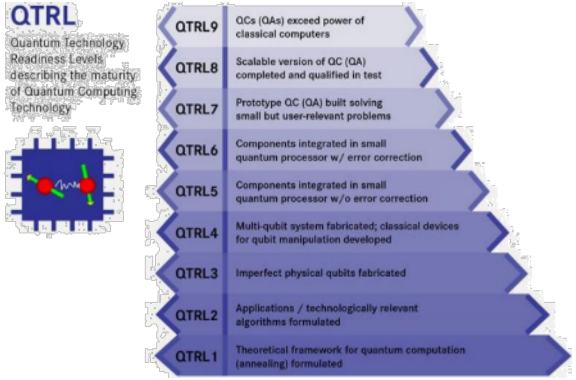
- Total investment > **140 Million EUR**






*) Analogue Quantum Simulator †) Analogue Quantum Annealer

# QC in Supercomputer Centres




- Quantum computers could perform certain calculations **much faster** or with more **precision than classical computers** due to their parallel processing capabilities.

- Use **less energy for certain computations** because they reduce the need for multiple iterations of an algorithm, unlike classical computers that might need billions of cycles for the same task.

# QEC

# European Quantum Excellence Centres


in quantum computing and simulation applications, for **science** and **industry** to:

1. Accelerate discovery of new quantum-oriented applications and fostering of their knowledge and uptake
2. Develop technology-agnostic quantum applications for end-users
3. Integrate quantum/classical applications

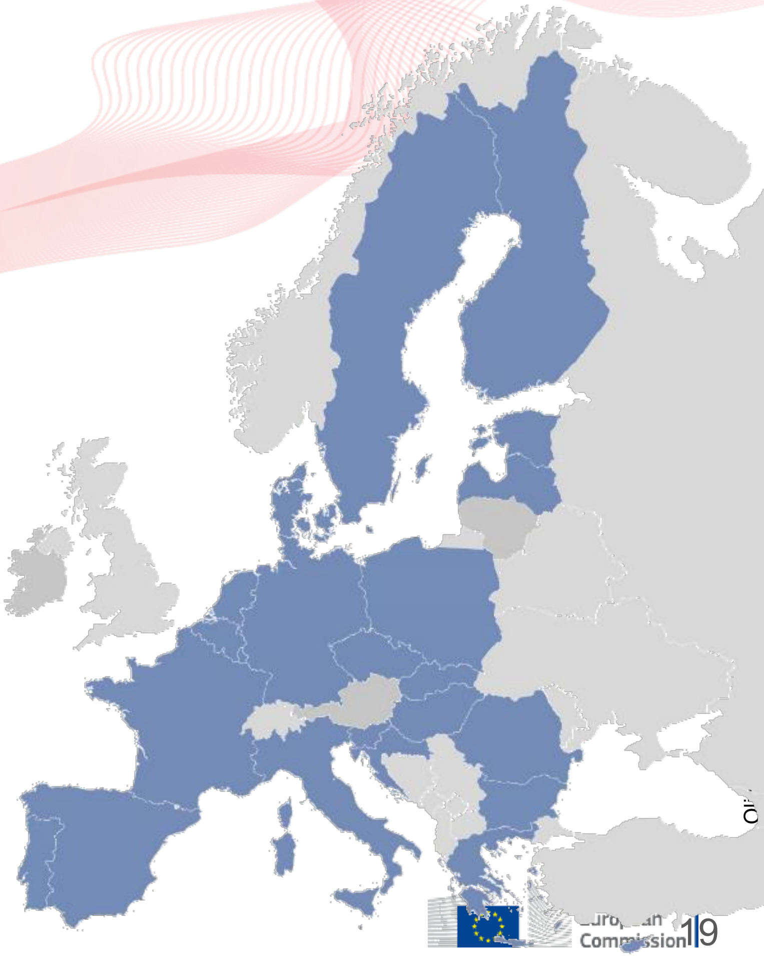
[European Quantum Excellence Centres (QECs) in applications for science and industry - European Commission (europa.eu)]

European Commission

# Quantum Declaration

## Signatories of the QUANTUM DECLARATION

**Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Luxembourg, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden** recognise the strategic importance of quantum technologies for the scientific and industrial competitiveness of the EU and commit to collaborating on the development of a world-class quantum technology ecosystem across Europe, with the ultimate aim of making Europe the 'quantum valley' of the world, the leading region globally for quantum excellence and innovation.





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# The EU Strategy

## … to make Europe *the quantum valley of the world*

**Leadership in Quantum Technology**

- Technolog
y
roadmap
- Basic
Researc
h
- Quantum
Internet
- Terrestrial &
Space
Infrastructure
s

**Leadership in Quantum Ecosystem**

- Industrializatio
n (Quantum
chips)
- Supply
Chain
Independenc
- Quantum
Fund for EU
Entrepreneurshi
p

**Enablers**

- Talent
Skills
- Internationa
l
Cooperatio
- Standardizatio
n

**Coordination and Governance**

- Synergies
with
Member
States
- Governanc
e

# Benchmarking Quantum Computing and Simulation

## EU Perspective



European Commission

# QC Benchmarking Why is crucial?

| Aspect | Description | Current Challenges | Helps on | Examples |
|---|---|---|---|---|
| **Performance Evaluation** | Provides objective metrics **for comparing quantum hardware and algorithms**. Validates claims of quantum advantage through standardized measurements. | Developing universally accepted benchmarks, variability in results due to different quantum hardware | Objective comparison, guiding improvements | IBM Quantum Volume, Quantum LINPACK, Atos, QuTech, **Compare to existing systems** |
| **Progress Tracking** | **Tracks technological advancements** and encourages continuous improvement. | Continuous advancements needed to maintain progress, high costs of development | Identifies technological milestones, fosters innovation | Improvements in qubit fidelity, coherence time advancements, **progress in Q Flagship projects** |
| **Resource Allocation** | Guides **investments and prioritizes research** based on benchmark outcomes. | Efficient allocation of funds, ensuring promising technologies are not overlooked | Informed investment decisions, prioritization of impactful research | **Investments in QC technologies via European Quantum Flagship** |
| **Standardization and Interoperability** | Promotes **consistent and reliable performance measurements**. Ensures compatibility across systems. | Lack of universal standards, varying technical specifications across different systems | Consistency in evaluation, interoperability between different systems | IEEE standards for quantum computing, Quantum Flagship initiatives, **EU Standardisation efforts**, ETSI |
| **Market and Industry Development** | **Assesses commercial readiness** and facilitates industry collaboration. | Balancing innovation with commercial viability, scaling up production | Encourages market growth, promotes industry collaboration | Commercial readiness assessments by firms like IQM and Pasqal. **Procurement via EuroHPC JU** |
| **Technical Insights** | Evaluates **algorithm efficiency and identifies advancements** in error correction. | Complexity in developing efficient quantum algorithms, high error rates | **Guides software and hardware co-design**, improves algorithm performance | Evaluation of VQE for chemistry by Jülich, QAOA for optimization by European research consortia |
| **Policy and Strategic Planning** | **Informs policy decisions with data-driven insights** and aids strategic roadmaps for quantum initiatives. | Ensuring policy keeps pace with technological advances, aligning with international standards | **Data-driven policy making, strategic alignment of resources** | European Quantum Flagship's SRIA, EU Chips Act integration, EuroHPC JU procurement QC |



European Commission

# QC vs Classical Targeted Quantum Advantage?

**Speed**

by solving specific problems faster, leveraging superposition and entanglement, as seen with Shor's algorithm for factorization and Grover's algorithm for searches.

**Precision**

by offering higher precision in simulations, enhancing fields like materials science and pharmaceuticals, evident in accurate molecular modeling and linear equation solutions.

**Energy Efficient**

by performing large-scale computations more energy-efficiently, with quantum annealing reducing the energy footprint compared to classical methods, benefiting data centers.

**Scalability**

measures how quantum systems maintain efficiency as they grow, crucial for benchmarking their potential in real-world applications. Effective scalability supports larger datasets and complex computations

# HPC vs QC Benchmarking

| **Aspect** | **High-Performance Computing (HPC)** | **Quantum Computing (QC)** |
|---|---|---|
| **Objective** | Measure performance of parallel computing systems. | Measure performance of quantum processors and algorithms. |
| **Key Metrics** | FLOPS (Floating-point operations per second), bandwidth, latency. | Qubits, quantum volume, gate fidelity, coherence time. |
| **Common Benchmarks** | LINPACK, HPCG (High Performance Conjugate Gradients). | Quantum Volume, Q-score, random circuit sampling, quantum supremacy tests. |
| **Challenges** | **Scalability, energy efficiency, communication overhead.** | Error rates, qubit connectivity, quantum decoherence. |
| **Focus** | Maximizing computational speed and efficiency. | **Achieving and proving quantum advantage, error correction.** |
| **Standardization** | Well-established standards and benchmarks. | **Still developing, with diverse approaches and metrics.** |
| **Hardware Dependency** | **Comparatively low (more standardized hardware).** | **High (due to different types of quantum computers).** |
| **Use Cases** | Weather simulation, astrophysics, bioinformatics. | Quantum chemistry, optimization problems, cryptography. |
| **Community Involvement** | Broad involvement from academia, industry, and government. | Increasingly broad but currently more **concentrated in academia and specific industry labs.** |
| **Tooling and Software** | **Mature tools** for performance analysis and optimization. | **Emerging tools**, often specific to platforms like Qiskit, Cirq, etc. |

- Develop consistent and reliable performance **evaluation standards**.
- Create benchmarks for objective **comparisons of different systems**.
- Use benchmarks to **identify and address system bottlenecks**.
- Establish clear performance metrics to **guide investments and market development.**
- Foster **international collaboration and competition** through standardized benchmarks.
- Ensure benchmarks are **applicable to a wide range of use cases**.
- **Continuously update benchmarks** to keep pace with technological advancements.

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# Types of QC Benchmarks

Systems benchmark ⟷ Application benchmark

| Origin | IBM | | Sandia National Laboratories | UC Berkeley / Berkeley Lab | Atos | QED-C | Super.tech |
|---|---|---|---|---|---|---|---|
| **Benchmark** | Quantum Volume | Circuit Layer Ops / Second (CLOPS) | Mirror Circuits | Quantum LINPACK | Q-Score | App-Oriented Suite | SupermarQ Suite |
| **Basis** | Maximum size of square quantum circuits that can be implemented | Speed in executing layers of a parameterized model circuit | Executing quantum circuits forward and backward | Performance in a prerequisite task for linear algebra | Performance in solving a standard optimization problem | Executing common quantum algorithms / programs | Executing common quantum algorithms / programs plus error correction |
| **Pros** | ✓ Inclusive measure of performance<br>✓ Practical measure of noise<br>✓ Cannot be "gamed" with classical improvements | ✓ Evaluates speed of whole-machine operations<br>✓ Covers quantum-classical latency | ✓ Captures significant error sources outside of gate error rates<br>✓ The forward-backward "mirror" execution makes the benchmarks easily verifiable | ✓ Predicts efficacy in scientific computing applications | ✓ Predicts efficacy in optimization applications | ✓ Targeted toward practical applications<br>✓ Evaluates whole-machine operations | ✓ Targeted toward practical applications<br>✓ Evaluates whole-machine operations<br>✓ Scalable for post-supremacy testing |
| **Cons** | ✕ Non-square circuits can be predicted only directionally<br>✕ Applies only to near-term quantum computers | ✕ May not measure speed in all applications<br>✕ No distinction between classical and quantum improvements | ✕ Indirect measure of application performance | ✕ Less useful for comparing computers that "pass" the test<br>✕ Restricted to linear algebra | ✕ Restricted to optimization | ✕ Applies only to near-term quantum computers<br>✕ No distinction between open and closed systems<br>✕ No distinction between classical and quantum improvements | ✕ No distinction between classical and quantum improvements<br>✕ No distinction between open and closed systems |

EVOLUTION

BCG, https://www.bcg.com/publications/2022/value-of-quantum-computing-benchmarks, FEBRUARY 23, 2022

Source: IBM; Sandia National Laboratories; UC Berkeley; American Physical Society; Atos; Quantum Economic Development Consortium; Super.tech; BCG analysis.

## App/Algorithmic Benchmarks

- Quantum Speedup by comparing classical and quantum algorithms
- Specific Algorithms like Shor's algorithm, Grover's algorithm, etc.

## Hardware/System Benchmarks

- Qubit Count
- Fidelity, error rates, coherence times
- Gate Speed

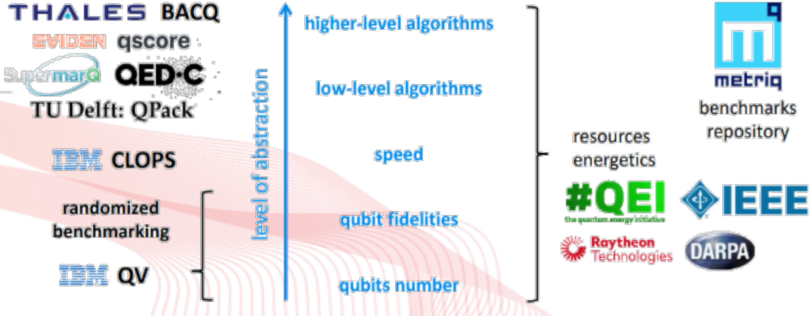


*Figure 852: the various levels of abstraction in quantum computing benchmarking. (cc) Olivier Ezratty, 2023.*

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# Some EU QC Benchmarks

| Origin | Benchmarks | Basis | Consortium |
|---|---|---|---|
| Germany | BenchQC | - Quantum machine learning, Physics simulation, combinatorial optimization<br><br>- Evaluation of both the classical and quantum parts of the computing. | BMW Group, ML Reply, Optware Quantinum, Fraunhofer Inst. (IKS, IIS) |
| France | BACQ | - Optimization, linear system solving, quantum physics simulation, prime factorization<br><br>- Aggregation and analysis of multiple metrics (computational and energetic) | LNE, Thales, CEA, CNRS, EVIDEN (ATOS), Teratec |
| The Netherlands | TNO project | - Q-Score methodology extension (hardware and applications) | TNO |
| The Netherlands | QPack | - Quantum Approximate Optimization Algorithm (QAOA) and Variational quantum eigensolver (VQE)<br><br>- Aggregation of multiple metrics. | TUDelft |
| EVIDEN | Q-Score | - Single score for the effectiveness of solving standard problems (MAXCUT optimization problem) | EVIDEN (ATOS) |
| Europe | Qu-Test | - Supporting open testing and experimentation for quantum technologies in Europe.<br><br>- Establishing measurement capabilities for characterization and testing.<br><br>- Developing harmonized measurement protocols for agreed key characteristics. | 12 RTOs and National Metrology Institutes from NL, FI, BE, DE, AT, FR, IT and 12 industrial companies |

- Different National and Industry benchmarks
- Focuses on practical applications in industry and academia.
- Features methodologies for error correction and noise resilience.
- Includes real-world testing for algorithm efficiency.
- Helps companies evaluate quantum readiness.
- Plans to expand benchmarks to include diverse quantum models.


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# QC Benchmarking

## Developing Benchmarks

- **Toolkit (Catalogue) Benchmarking Model**
  - Combines holistic and component-specific metrics to **choose as needed**.
  - From Applications, Algorithms, System level or Hardware
- **Standardization of Metrics**
  - Common metrics and methodologies
  - **Unifies efforts**, aligns strategies
- **Inclusivity of Emerging Technologies (Evolving)**
  - **Flexible** criteria for new technologies and HPC/QC integration
- **Sustainable & Energy Efficient Benchmarks**
  - Reflects global emphasis on **sustainability**
- **Industry & Academic Collaboration**
  - Encouraging joint **industry-academic** partnerships
  - Ensures robust, applicable, industry-relevant benchmarks



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# QC Benchmarking Catalogue/Sets

User-Friendly Benchmark Selection

## Catalogue (living DB) of current benchmarks that can be consulted online, filter by criteria:

- Level (application, system, hardware)
- Only quantum/HPC integrated
- Use cases (material science, finance optimization…)
- Technologies (Agnostic, trapped ions, superconducting,…)
- Responsible of the benchmark
- Code (link to github) and how to run it (or adapt it)

## Benchmark Sets (Suites)

- Select a set of predefine benchmarks/metrics based on the requirements from the user





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# QC Benchmarking Toolkit/Catalogue

| Benchmark Nameg | Level | Only quantum/HPC integrated | Use cases | Technologies | Responsible of the benchmark | Code (link to github) and how to run it (or adapt it) | Benchmark Set |
|---|---|---|---|---|---|---|---|
| Benchmark 1 | application | Only quantum | finance optimization | photonic | Atos (EU) | link | Financial Portfolio Optimization |
| Benchmark 2 | system | HPC integrated | logistics optimization | topological | Rigetti | link | Logistics and Supply Chain Management |
| Benchmark 3 | hardware | Only quantum | climate modeling | neutral atoms | Pasqal (EU) | link | Climate Modeling |
| Benchmark 4 | application | HPC integrated | pharmaceuticals | color-center | Oxford Quantum Circuits (EU) | link | Pharmaceutical Development |
| Benchmark 5 | application | HPC integrated | quantum machine learning, physics simulation, combinatorial optimization | Agnostic | BMW Group, ML Reply, Optware Quantum, Fraunhofer Inst. (IKS, IIS) | link | Quantum Machine Learning |
| Benchmark 6 | system | Only quantum | optimization, linear system solving, quantum physics simulation, prime factorization | Agnostic | LNE, Thales, CEA, CNRS, EVIDEN (ATOS), Teratec | link | Linear System Solving |
| Benchmark 6 | hardware | HPC integrated | hardware and applications | Agnostic | TNO | link | Hardware and Applications |
| Benchmark 7 | application | HPC integrated | Quantum Approximate Optimization Algorithm (QAOA), Variational Quantum Eigensolver (VQE) | trapped ions | TUDelft | link | Quantum Optimization |
| Benchmark 8 | system | Only quantum | solving standard problems (MAXCUT optimization problem) | Agnostic | EVIDEN (ATOS) | link | Standard Problem Solving |

EXAMPLE



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# QC Benchmarking What Europe should do?


**Establish a Coordination Forum**: Create a **single forum to unify various European benchmarking initiatives**, facilitating collaboration and consistency.

**Promote Exchange and Collaboration**: Encourage interaction between **standardization** and benchmarking activities to harmonize efforts EU and internationally.

**Define a Support Programme**: Develop an EU-level program to **support R&D** with a cross-disciplinary approach, involving both academia and industry.

**Fund and Support Infrastructure**: Allocate funding and resources to build the necessary infrastructure for comprehensive benchmarking efforts.

**Facilitate Access to Quantum Machines**: Use EuroHPC to provide researchers access to quantum computers for benchmark development and testing, ensuring the creation of quantitative and objective benchmarks.

TOP 500 The List.

**Encourage Public-Private Partnerships**: Foster partnerships between public institutions and private companies to drive innovation and practical applications of benchmarks. **Facilitate Co-desing** (Apps/Users - HW)

**Regular Review and Updates**: Implement a system for the regular review and updating of benchmarks to **keep pace with evolving technological advancements**.

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# EQTC 2024

## Lisbon 18 - 20 November

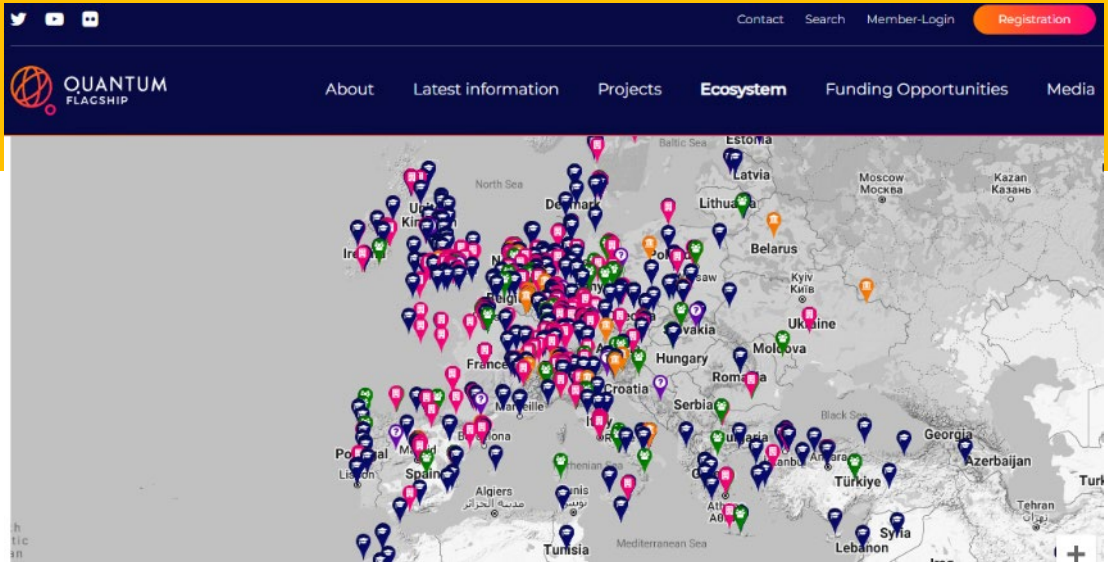
**EQTC – European Quantum Technologies Conference**
**18-20 November 2024, Lisbon, Portugal**





[Highlights from EQTC 2023 | LinkedIn]

# Thank you
# more info in qt.eu



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# Backup Slides

# Types QC Benchmarks Low level

| what and whom | what | pros | cons | timing / adoption |
|---|---|---|---|---|
| **IBM quantum volume** | breath/depth computing capacity, 2^#qubits | simple qualifier of qubits quality | doesn't work in advantage regime due to emulation needs requirements | published in 2019 IBM, Quantinuum |
| **Cisco MBQC quantum volume** | computing capacity for MBQC CV photon qubits | adapted to photon qubit using a different model than circuit based models | to be adapted to direct variable photons MBQC model | proposed in 2022 by Cisco |
| **IBM CLOPS** | circuit layers operations per seconds | complements QV for speed | N/A | announced in November 2021 |
| **cycle benchmarking** | qubits entanglement evaluation | useful to benchmark qubits quality | limited to one low-level feature | 2019, Canada, Denmark and Austria universities |
| **scalable benchmarks for gate-based QC** | six low-level structured circuits tests | tested 21 configurations from IBM, IonQ and Rigetti | low-level benchmark not usage based | published in 2021 QuSoft, Cambridge, Caltech |
| **PQF (photonic quality factor)** | assess performance of linear optics single photons multimode QPUs | covers many NISQ photon qubit implementations | limited to a specific photonic qubit configuration | published in 2022 by Quandela |
| **entanglement-based volumetric benchmark** | estimate size of maximum entangled qubit state | entanglement is a key feature of quantum acceleration | narrow and not usage oriented | proposed in 2022 par DoE Oak Ridge et al |

*Figure 844: low level benchmarking proposals. (cc) Olivier Ezratty, 2022.*

# Types QC Benchmarks Application level

| | what and whom | what | pros | cons | timing / adoption |
|---|---|---|---|---|---|
| multiple use cases | **scalable benchmarks for gate-based QC** | six low-level structured circuits tests | tested 21 configurations from IBM, IonQ and Rigetti | low-level benchmark not usage based | published in 2021 QuSoft, Cambridge, Caltech |
| multiple use cases | **QED-C supported benchmark** | set of low-level algorithms benchmarks | breadth of use cases | complicated visualization | published in 2021 QED-C, Princeton, HQS, QCI, IonQ, D-Wave, Sandia Labs |
| multiple use cases | **IonQ Algorithmic Qubits** | $\min(\#\text{qubits}, \sqrt{\#gates})$ | run on different use cases | a bit complicated | published in 2020 and refined in 2022, IonQ |
| multiple use cases | **SupermarQ from Super.tech** | suite of applications benchmark | also handles error correction benchmarking | | published in March 2022, Intel and Amazon |
| multiple use cases | **Qpack by TU Delft** | three sets of problems (Max-Cut, TSP, DSP) | measure differents metrics | Adoptions | proposed in April 2022 |
| single use cases | **Atos Q-score** | maximum size of solvable MAXCUT problem size | application need oriented works in advantage regime hardware independant | limited to MAXCUT problems marketing & adoption | published in 2020 Atos, be be expanded to other algos |
| single use cases | **DoE ORNL** | chemical simulation | works on existing superconducting hardware | limited to three 2-atom molecules simulations | published in 2020 DoE |
| single use cases | **Zapata benchmark for fermionic quantum simulations** | one-dimensional Fermi Hubbard model (FHM) VQE running on NISQ | tested on Google Sycamore with its tunable couplers | narrow use case | proposed in March 2020 |

*Figure 845: application level benchmarking proposals, either multiple or singe cases. (cc) Olivier Ezratty, 2022.*

# Types QC Benchmarks Other benchmarks

| what and whom | what | pros | cons | timing / adoption |
|---|---|---|---|---|
| **Unitary Fund Metriq** | repository of benchmark results | N/A | N/A | announced in May 2022 |
| **DARPA project** | SWAP (size-weight-application-power) | hardware-agnostic and resource estimates | N/A at this point | awarded in 2022 to Raytheon BBN |
| **IEEE QC Perf Metrics & Perf Benchmarking PAR** | gate-based QC benchmarking | ongoing standardization project | | submission in Oct 2023 completion in Oct 2024 |
| **Quantum Energy Initiative** | QC energetics benchmarking consolidated approach, QGreen500 proposal could consolidate cryogeny benchmarks | methodology (MNR) to optimize QC energetics, first analysis done with superconducting qubits | research and industry must build coordination around this goal | joint research/industry Quantum Energy Initiative launched in 2022. IEEE Working Group P3329 launched in 2023. |
| **BACQ** | application and low-level full-stack benchmarking proposal. | covers many use cases and figures of merit. Includes energetics performance. | participants are so far only from the France quantum ecosystem. | project launched in 2023 by CEA, CNRS, Thales, Teratec and LNE. |

*Figure 846: other benchmarks proposals. (cc) Olivier Ezratty, 2022-2023.*

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# Applications where Quantum Technologies could offer Advantages

**Quantum Computing:**

**Drug discovery** through molecular modeling, **optimization problems in logistics and manufacturing**, and cryptography.

Integrate quantum computers with classical computing systems like HPC supercomputers

**Quantum Sensing and Metrology**:

Enhanced precision in sensors for applications ranging from magnetic field detection to gravimeters, enabling advancements in areas such as **navigation, medical imaging, and geological exploration**.

**Quantum Communication:**

Secure communication channels based on **quantum key distribution (QKD)** technologies, offering superior security against potential cyber threats. New services with **Quantum Internet.**