Qpurpose’s advanced Quantum Mathematics approach to build Quantum enhanced Software Solutions for Industry

요르겐 엘레가드 앤더슨 (Jørgen Ellegaard Andersen)

(QM-SDU, Qpurpose)

QM, SDU & QPURPOSE

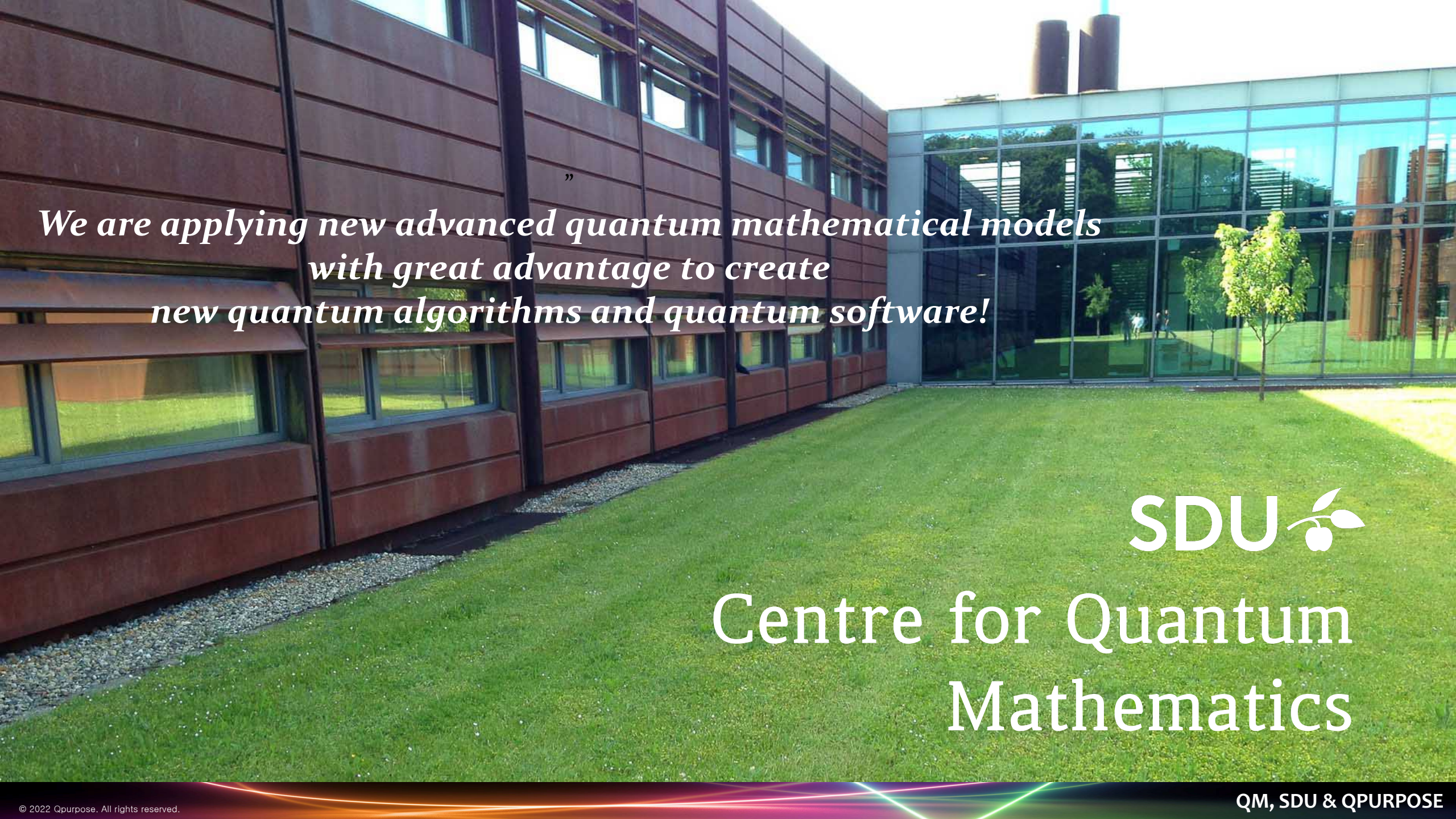
- PhD fra Oxford Universitet 1992 i Kvantematematik
- Professor ved University of California, Berkeley 5 år, 1992-2001
- Clay Professor ved Harvard University 2001-2002
- Professor og Centerleder ved Aarhus Universitet 27 år, 1992-2019
  - 220 Mill kr. i forskningsmidler > 2 gange nummer 2 i Danmark
  - Danmark Grundforskningsfond center i Kvantematematik 2012-2019
  - European Research Council Synergy Bevilling 2019-2025

ERC Evaluation:
"This is a superb team. It is hard to imagine a stronger one"
- Ranked absolute top among all proposals for that call!

- Professor og Centerleder ved Syddansk Universitet, 2019-
  - Permanent Center for Kvantematematik (QM) ved SDU 2019-
  - Danish Institute of Advanced Studyies, Chair i kvantematematik 2019-
  - Simons collaboration grant 2022-2026
  - Leder af SDU kvante-Hub 2023-
- Founder and CEO Qpurpose 2021-

Jørgen Ellegaard Andersen

Prof. and Director of Center for Quantum Mathematics
Danish Institute for Advanced Study
University of Southern Denmark
CEO and founder, Qpurpose



The International Advisory Board of QM

Includes 6 Fields Medalists, Analog of a Nobel Prize in Mathematics

10 absolute top international researchers from Harvard, Oxford, Caltech, Berkeley, Institute of Advanced Study in Princeton, College de France, IHES Paris and Bonn.

QM Team, *hired from the best universities in the world: Berkeley, Harvard, Duke, Oxford, ETH, etc.*

Professors


Prof., Centre Director,
Jørgen Ellegaard Andersen


Prof. Vivek Shende


Assoc. Prof. Du Pei


Assist. Prof. Shan Shan

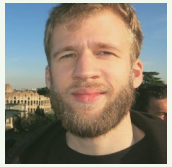

Assist. Prof. Fabian Haiden


Assist. Prof. Nadia Ott

Administration

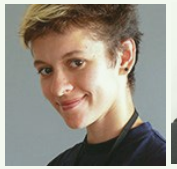

Centre Administrative Manager
Jane Jamshidi

Post Docs


William Elbæk Mistegaard


Konstantin Wernli


Nezhla Aghaei


Daria Poliakova


Ikshu Neithalath


Bingyu Zhang


Alexei Latyntsev


Gard Olav Helle


Adrian Petr


Greyson Potter


Guillermo Barajas Ayuso


Guillem Cazassus


William Olsen


Muyang Liu

PhD Students


Tim Henke

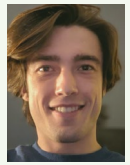

Calvin Pfeifer


Santiago Quintero de los Rios


Zhongyu Zhang


Matthias Scharitzer


Shomrik Bhattacharya


Samuel Hindson


Siva Tej Pindiprolu


Jöel Beimler

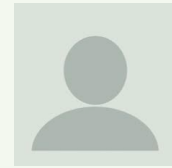

Devon Stockall


Yuki Matsubara

Student Programmers


Anne Louise Grønnemose


Adam Wolkowyski


Jakob Blaabjerg Møller

Plus 20 more incomming summer 2024

Research funds obtained by Center for Quantum Mathematics (QM) 2019-2023:

40 Million €

Synergy Grants

SIMONS FOUNDATION

D·IAS

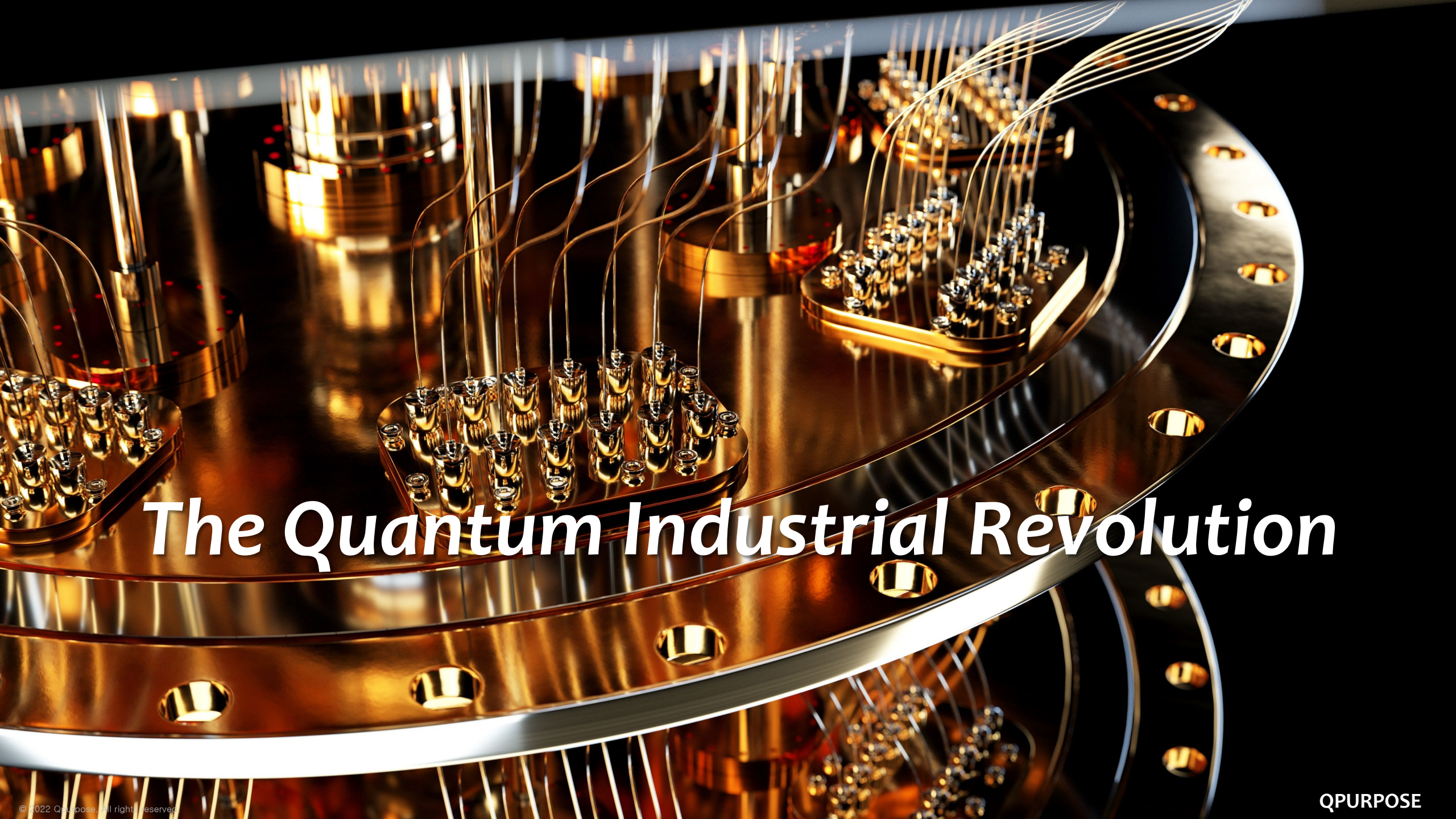
Innovationsfonden

VILLUM FONDEN

CARLSBERG FOUNDATION

novo nordisk fonden
Benefitting people and society

Danmarks Grundforskningsfond
Danish National Research Foundation



The Quantum Industrial Revolution

QPURPOSE

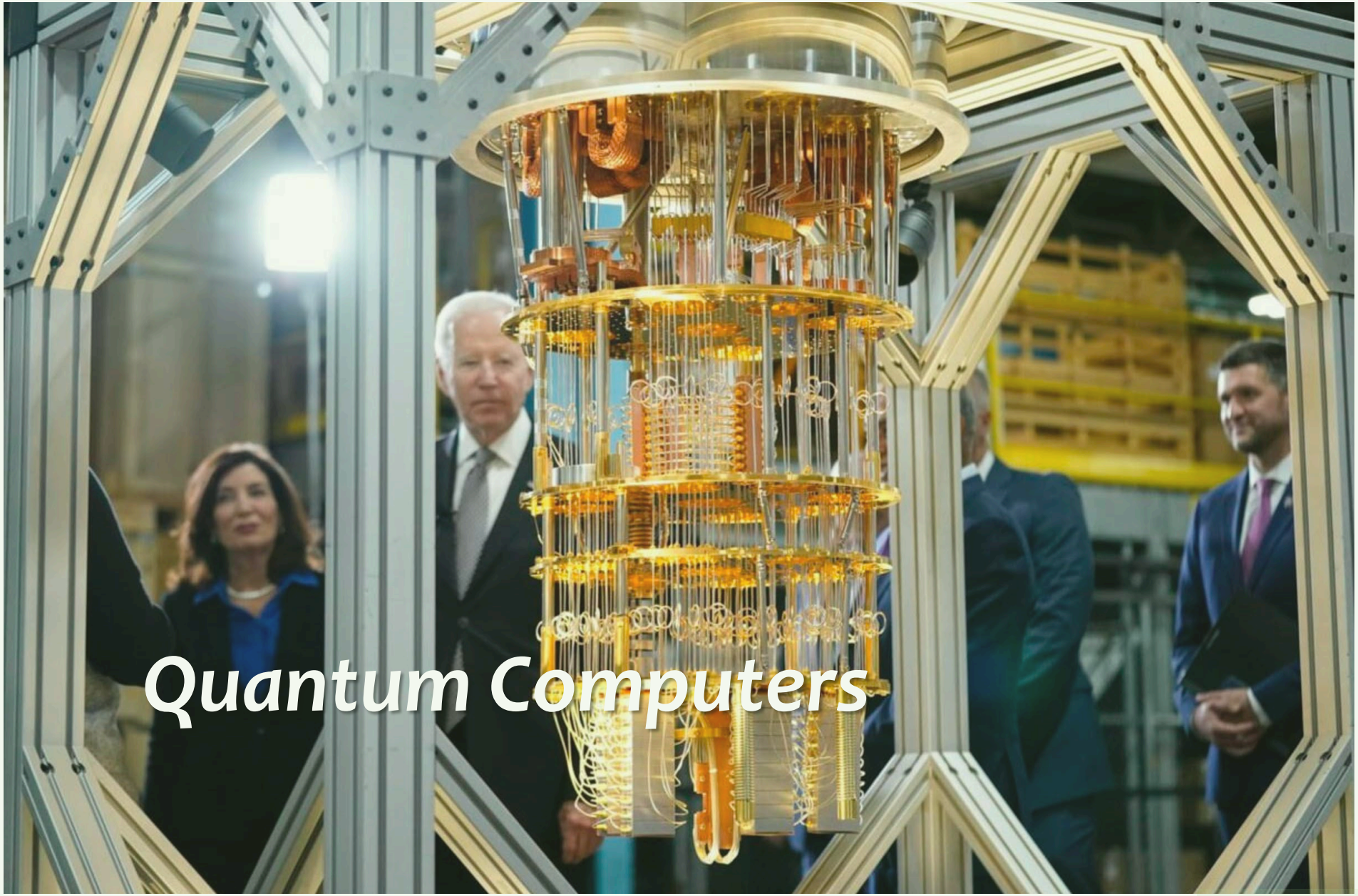


Foto: Andrew Harnik/AP/Ritzau Scanpix

Foto: Andrew Harnik/AP/Ritzau Scanpix

Nye uddannelse: Quantum Computing

Uddannelses- og Forskningsministeriet

Prækvalifikation af videregående uddannelser - Kvantecomputing

Direkte adgangsgivende bacheloruddannelser
Følgende bachelorgrader er direkte adgangsgivende til kandidatuddannelsen:

- Matematik, fysik, datalogi fra Syddansk Universitet
- Matematik, fysik, datalogi fra Københavns Universitet
- Matematik, fysik, datalogi fra Aarhus Universitet
- Matematik, fysik, datalogi fra Aalborg Universitet
- Kunstig Intelligens fra Syddansk Universitet
- Kunstig Intelligens og Data, DTU
- Data Science, ITU
- Tilsvarende dansk eller international bacheloruddannelse*

Ministeren

Uddannelses- og Forskningsministeriet

Rektor Jens Ringsmose

Kære Jens Ringsmose

På baggrund af gennemført prækvalifikation af Syddansk Universitets ansøgning om godkendelse af ny uddannelse er der truffet følgende afgørelse:

Godkendelse af ny kandidatuddannelse i Quantum Computing (Odense)

Afgørelsen er truffet i medfør af § 20, stk. 1, nr. 1 i bekendtgørelse om akkreditering af videregående uddannelsesinstitutioner og godkendelse af videregående uddannelser (nr. 1558 af 2. juli 2021 med senere ændringer).

Det er en forudsætning for godkendelsen, at uddannelsen og dennes studieordning opfylder uddannelsesreglerne, herunder bekendtgørelse nr. 2285 af 1. december 2021 om universitetsuddannelser tilrettelagt på heltid (uddannelsesbekendtgørelsen) med senere ændring.

Godkendelsen sker under forudsætning af, at pladserne på den nye uddannelse oprettes under hensyntagen til rammen for tilgang af internationale studerende.

Da Syddansk Universitet er positivt institutionsakkrediteret, gives godkendelsen til umiddelbar oprettelse af uddannelsen.

18. april 2024

Uddannelses- og Forskningsministeriet

Børsgade 4
Postboks 2135
1015 København K
Tel. 3392 9700
ufm@ufm.dk
www.ufm.dk

CVR-nr. 1680 5408

Ref.-nr.
2024 - 8619

Kandidat - Kvantecomputing - Syddansk Universitet

Institutionsnavn: Syddansk Universitet
Indsendt: 31/01-2024 20:53
Ansøgningsrunde: 2024-1
Status på ansøgning: Indsendt
Download den samlede ansøgning
Læs hele ansøgningen

Ansøgningstype
Ny uddannelse

Udbudssted
Odense

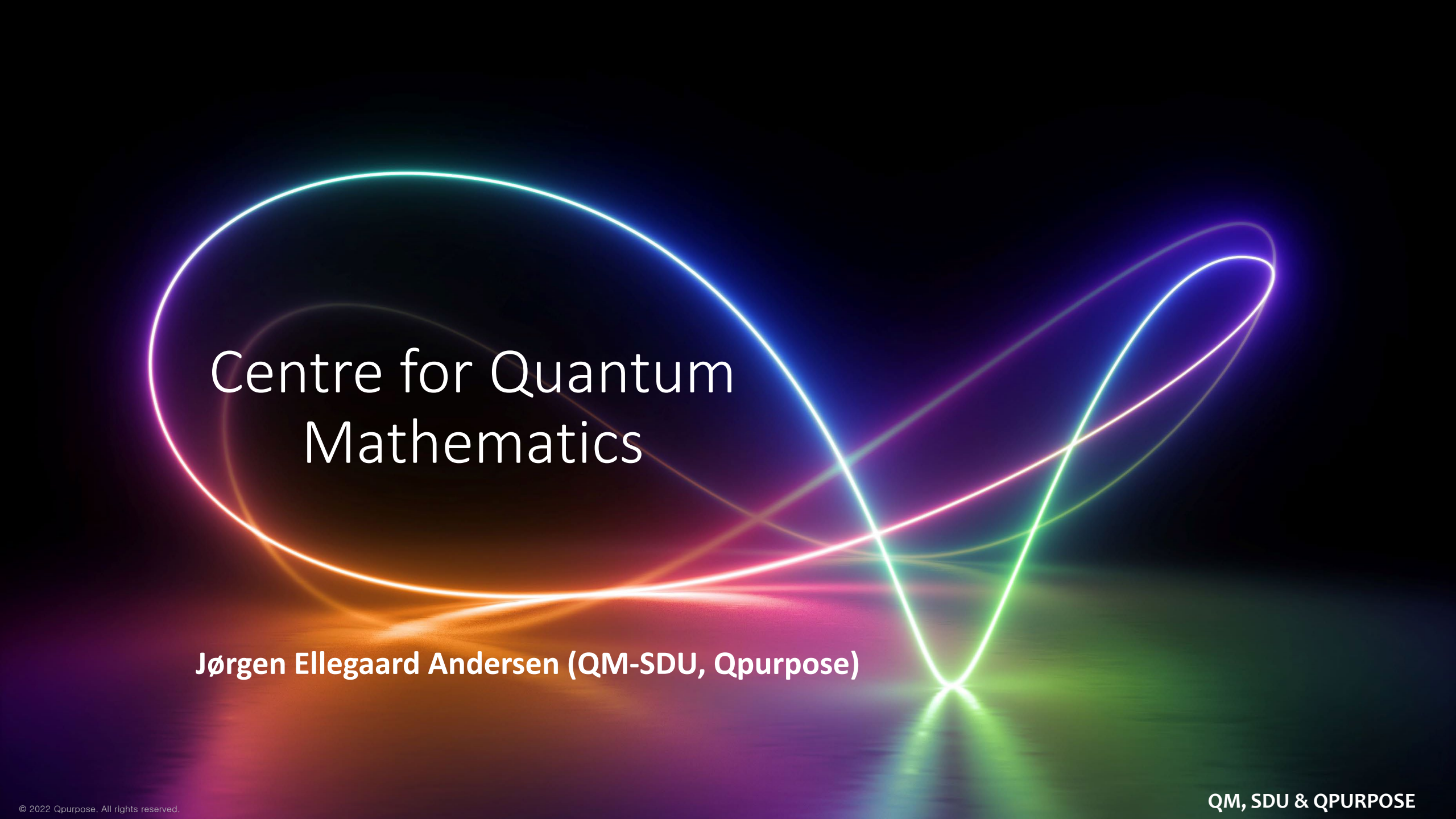
Informationer på kontaktperson for ansøgningen (navn, email og telefonnummer)
AC-fuldmægtig Camilla Katrine Hollmann, camkat@sdu.dk, +45 65 50 18 58, Det Naturvidenskabelige Fakultetssekretariat, SDU samt SDUs prækvalifikations mailbox praekval@sdu.dk

Er institutionen institutionsakkrediteret?
Ja

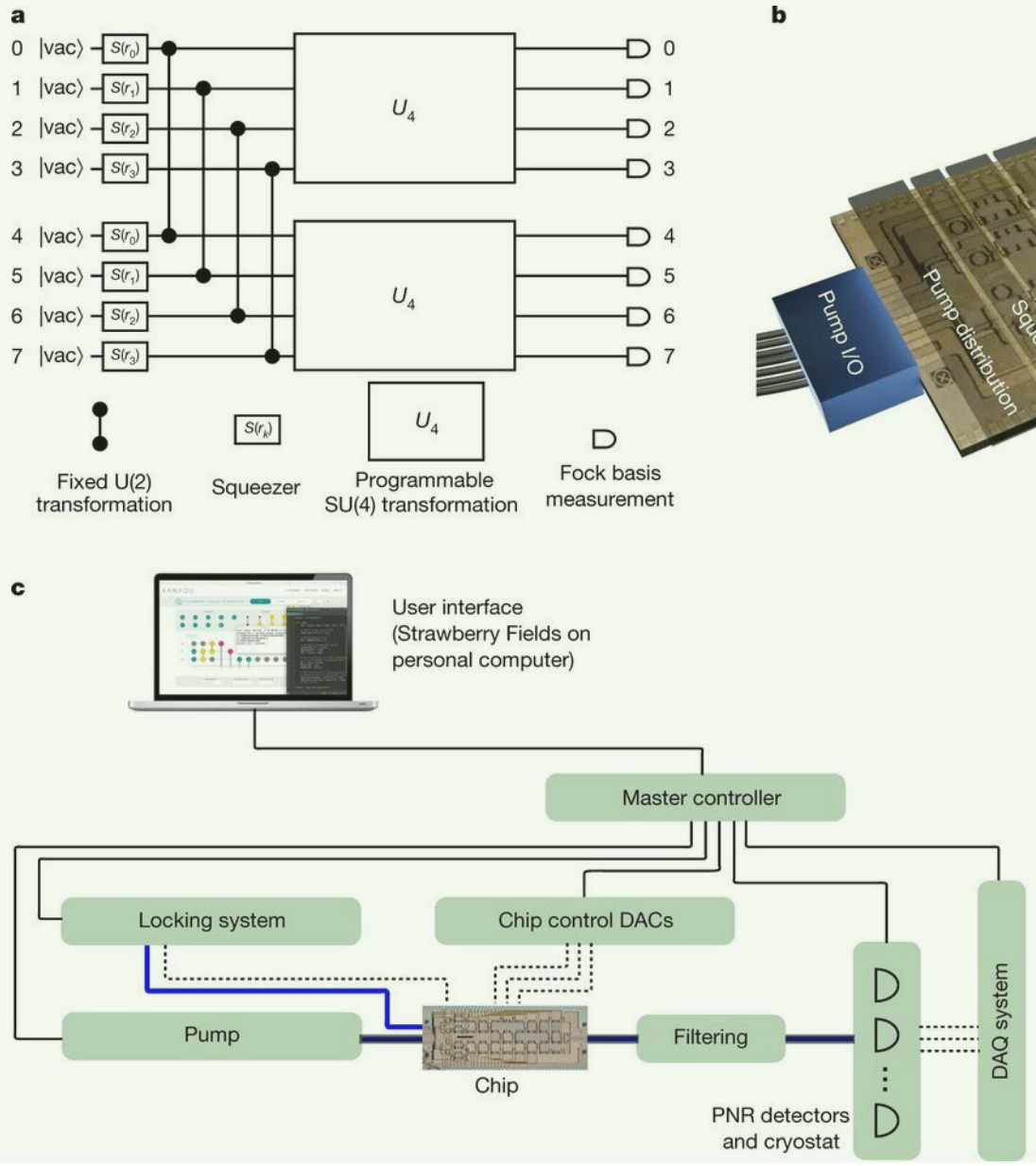
Er der tidligere søgt om godkendelse af uddannelsen eller udbuddet?
Nej

Uddannelsestype
Kandidat

Uddannelsens fagbetegnelse på dansk
Kvantecomputing



QM, SDU & QPURPOSE



We have gotten an 3 Mill. € EU-grant:
”CLUSTEC”, where we design and develop ”in silico” GBS and other optical quantum computers platforms joint with leading Hardware teams from EU. Qpurpose is responsible for the software design and development.

CV QKD

First deployment in Denmark of advanced national quantum systems in a versatile network that supports real-life applications of Quantum Key Distribution (QKD).

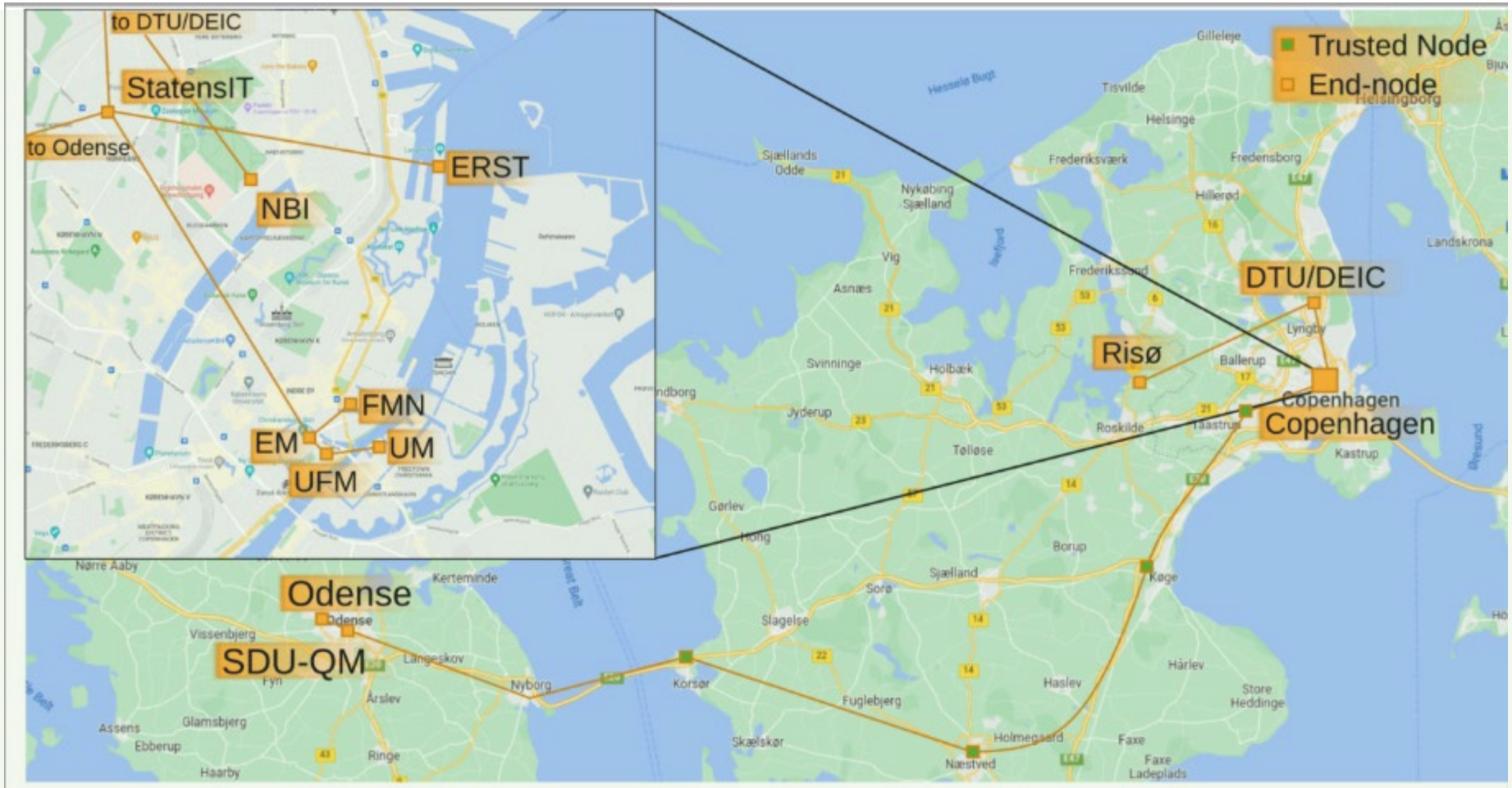
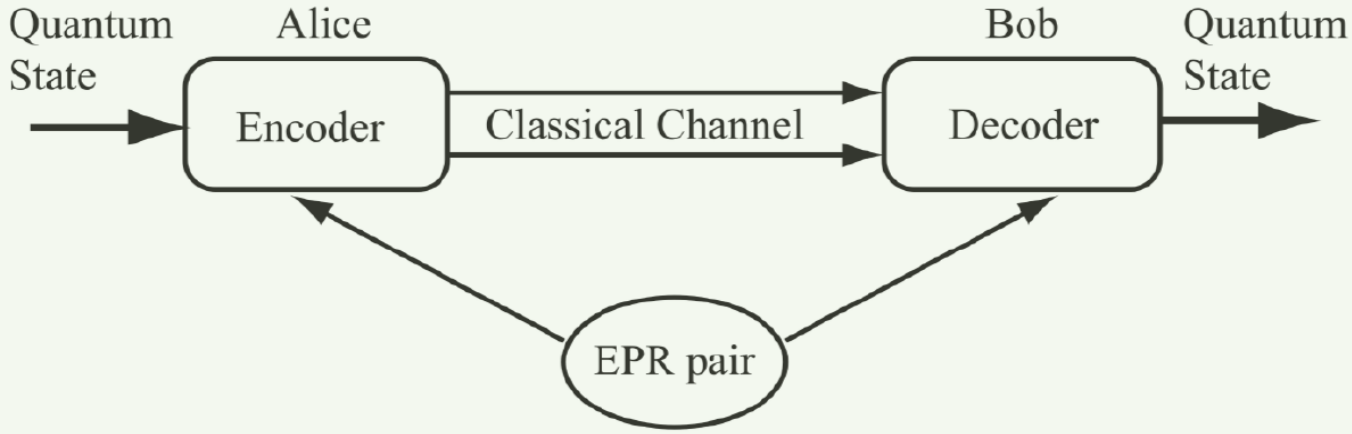
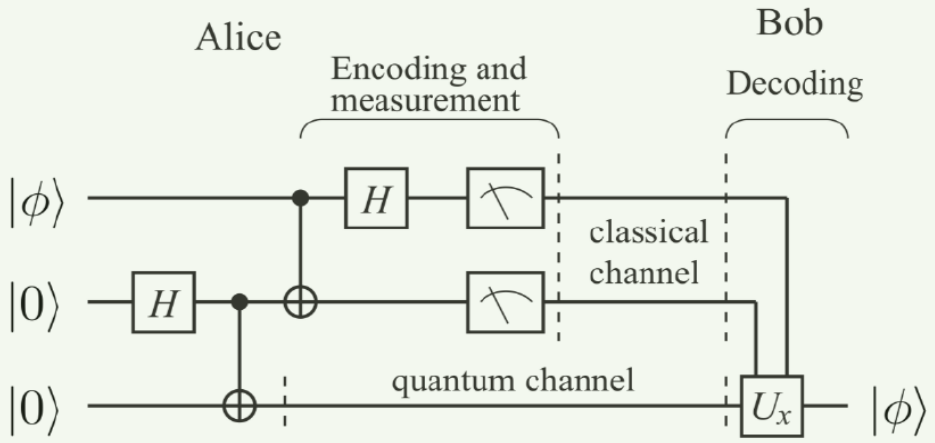


Figure 1: EM: Ministry of Industry, Business and Financial Affairs, ERST: the Danish Business Authority, UM: Ministry of Foreign Affairs of Denmark, UFM: Ministry of Higher Education and Science, FMN: Danish Ministry of Defence, Statens IT: the IT service provider of the public authorities, DEIC: Danish e-infrastructure cooperation, DTU: Technical University of Denmark, SDU: University of Southern Denmark, NBI: Niels Bohr Institute, Copenhagen University.

Funded by Digital Europe Program



EPR pair $|\Psi_{EPR}\rangle = \frac{1}{\sqrt{2}}(|00\rangle + |11\rangle)$.



received bits	Bob's state	decoding
00	$a\|0\rangle + b\|1\rangle$	I
01	$a\|1\rangle + b\|0\rangle$	X
10	$a\|0\rangle - b\|1\rangle$	Z
11	$a\|1\rangle - b\|0\rangle$	Y

TopQC2X

Lead Partner: Centre for Quantum Mathematics (QM), SDU

Prof. Jørgen Ellegaard Andersen, Project lead

Assoc. Prof. Du Pei

Assistant Prof. Shan Shan

SDU

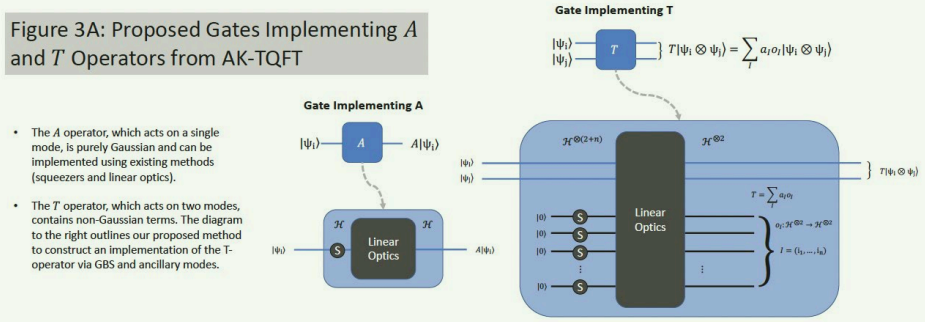
Partner 2: Quantum Physics and Information Technology (QPIT), DTU

Prof. Ulrik Lund Andersen

Assoc. Prof. Jonas Schou Neergaard-Nielsen

DTU

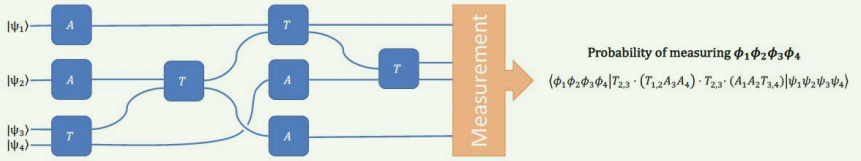
Figure 3A: Proposed Gates Implementing A and T Operators from AK-TQFT



- The A operator, which acts on a single mode, is purely Gaussian and can be implemented using existing methods (squeezers and linear optics).
- The T operator, which acts on two modes, contains non-Gaussian terms. The diagram to the right outlines our proposed method to construct an implementation of the T-operator via GBS and ancillary modes.

Figure 3B: Example Quantum Circuit Using AK-TQFT A and T Operators

- The implementations of the A and T operators from Figure 3A can be combined to build quantum circuits.



Let τ be an ideal triangulation of a punctured surface $\Sigma_{g,s}$ and $M = 2g - 2 + s > 0$ the number of ideal triangles.

The Andersen-Kashaev TQFT at level N induces a representation of the Ptolemy groupoid of $(L^2(\mathbb{R}) \otimes \mathbb{C}^N)^M$.

Explicit formulas for $N = 1$: $(\mathbf{q}f)(q) = q \cdot f(q), \qquad \mathbf{p} = \frac{1}{2\pi i}\frac{\partial}{\partial q}$

$$A = \exp(3\pi i \mathbf{q}^2)\exp(\pi i(\mathbf{p}+\mathbf{q})^2)\colon L^2(\mathbb{R}) \to L^2(\mathbb{R})$$

$$\mathbf{T} = \mathbf{T}_{12} = \exp(2\pi i \mathbf{p}_1\mathbf{q}_2)\Phi^{-1}(\mathbf{q}_1 + \mathbf{p}_2 - \mathbf{q}_2)\colon L^2(\mathbb{R})^2 \to L^2(\mathbb{R})^2$$

with Φ Faddeev's quantum dilogarithm

$$\Phi_b(z) = \exp\left(\int_C \frac{e^{-2izw}\,dw}{4w\sinh bw\sinh b^{-1}w}\right).$$

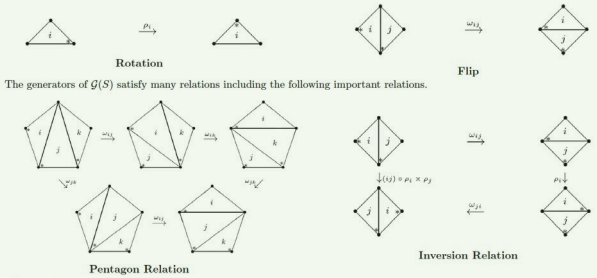
Theorem (Andersen-Kashaev, 2012, 2014, 2018)

Sending $\rho_i \to A_i$ and $\omega_{ij} \mapsto \mathbf{T}_{ij}$ defines a (projective) representation of the Ptolemy groupoid on $(L^2(\mathbb{R}))^M$

ICM 2018 RIO DE JANEIRO

Figure 2A: Ptolemy Groupoid Generators and Relations

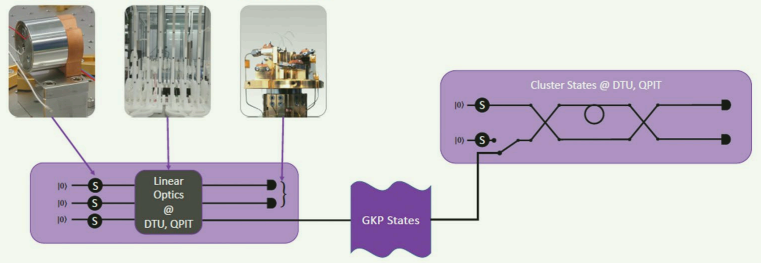
The Ptolemy Groupoid $\mathcal{G}(S)$ of a surface S consists of certain maps of (ideal) triangulations, where each triangle has a marked corner denoted by $\star$ and a label i. The maps are generated by ρ_i and $\omega_{i,j}$ given as follows.



The generators of $\mathcal{G}(S)$ satisfy many relations including the following important relations.

For more details, see [P12, AK12c].

Photonics Hardware at DTU, QPIT



Major research achievements

Expert in **Quantum Topology**, **Geometric Quantitation**, and in particular **quantization of moduli spaces.**

Known in particular for:

- **Asymptotic Faithfulness** of the Witten- Reshetikhin-Turaev (WRT) **quantum representations of mapping class groups** (*Annals of Math.*)
- The **Andersen-Ueno isomorphism** verifying the **Witten conjecture** regarding the **conformal field theory** construction of the **WRT-TQFT** (*Inventiones*)
- The **Andersen-Kashaev construction** of the **Complex Chern-Simons QFT** (*Proc. of ICM*).

= The mathematical foundation of topological quantum software

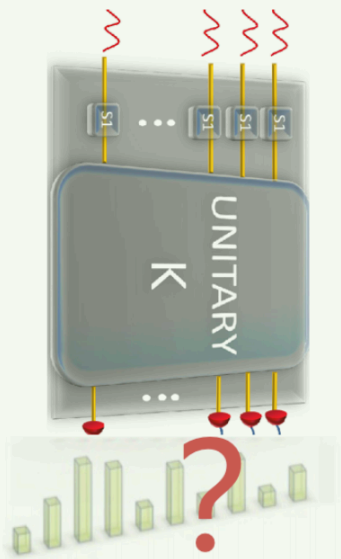
GBS a special-purpose photonic quantum computer

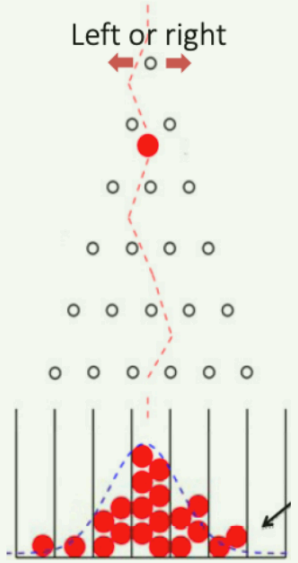
GBS prepares a *m*-mode Gaussian state by shooting squeezed state of light into a linear interferometer and measures the number of photons in each output mode.

Output: $\bar{n} = (n_1, \ldots, n_m)$

n_i is the number of photons measured at the i-th mode.

E.g.: $(0, 0, 4, 5, 6, 3, 0, 0)$
$(1, 0, 2, 5, 7, 1, 1, 1)$
$(1, 1, 5, 3, 2, 0, 3, 3)$





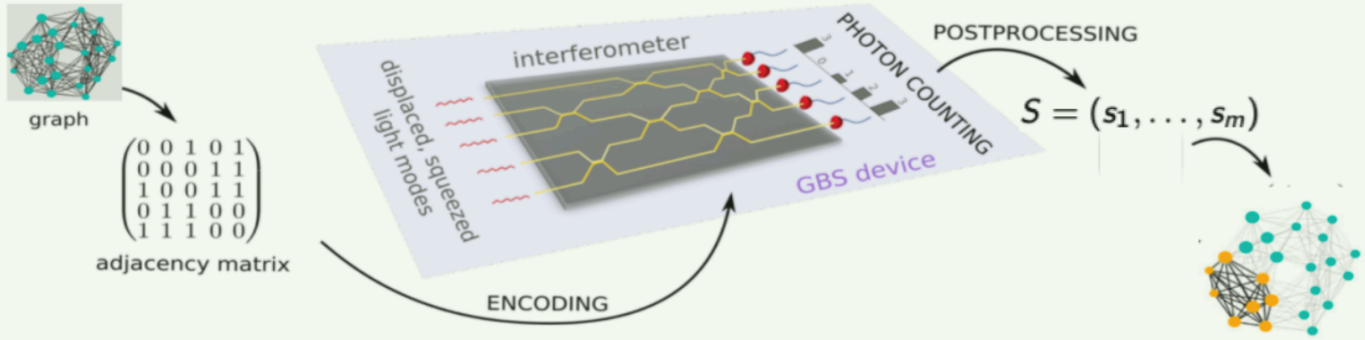
Theoretical hardness of sampling GBS

→ **Theorem (Aaronson-Arkhipov 2011):**
To sample exactly from the GBS distribution is not efficiently solvable by a classical computer, unless $P^{\#P} = BPP^{NP}$ and the polynomial hierarchy collapses.

→ **Sketch of proof:**
If there is efficient classical algorithm to simulate GBS distribution
Then one can approximate the matrix hafnian to within a multiplicative factor ($\#P$-hard) in BPP time with an NP oracle.
By Toda's theorem $P^{\#P} = BPP^{NP}$.

→ The hardness of sampling **approximately** from the GBS distribution is also known under some mild conjecture

Use GBS to find the largest clique



- Let G be a graph with adjacency matrix A.
- Samples of GBS have uniquely determine subgraphs of G through the matrix A_S
- The probability distribution of the GBS samples

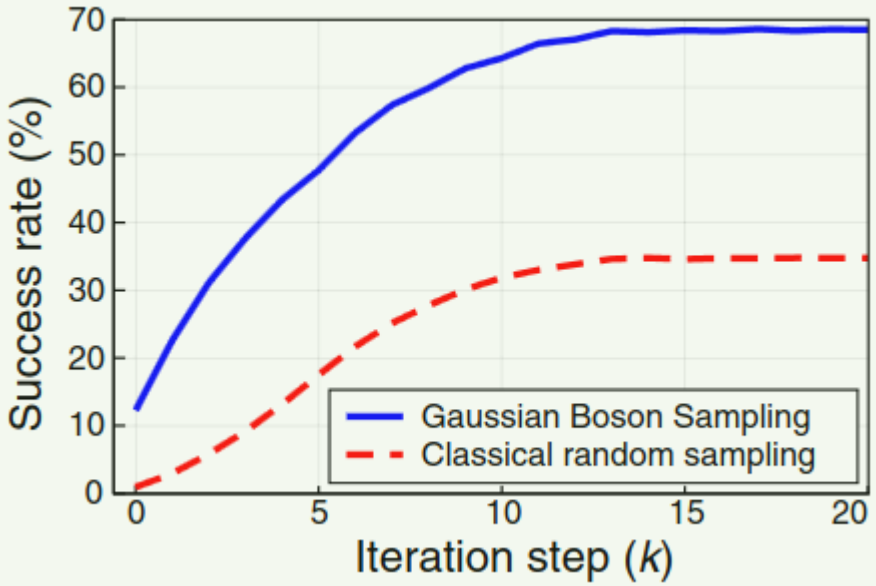
$$Pr(S) \propto |\mathrm{Haf}(A_S)|^2$$

- Dense subgraphs have large $\mathrm{Haf}(A_S)$. Therefore, GBS samples dense subgraphs with high probability.

• Con: no proven quantum advantage

The paper claimed that the success rate in finding the maximum clique after greedily shrinking and expanding is significantly higher compared to starting with a random subgraph.

- There are no proven guarantees for an actual speed up.
- The numerical simulation is done on a small binding graph.
- The comparison does not use the best classical algorithm for finding the maximum clique.

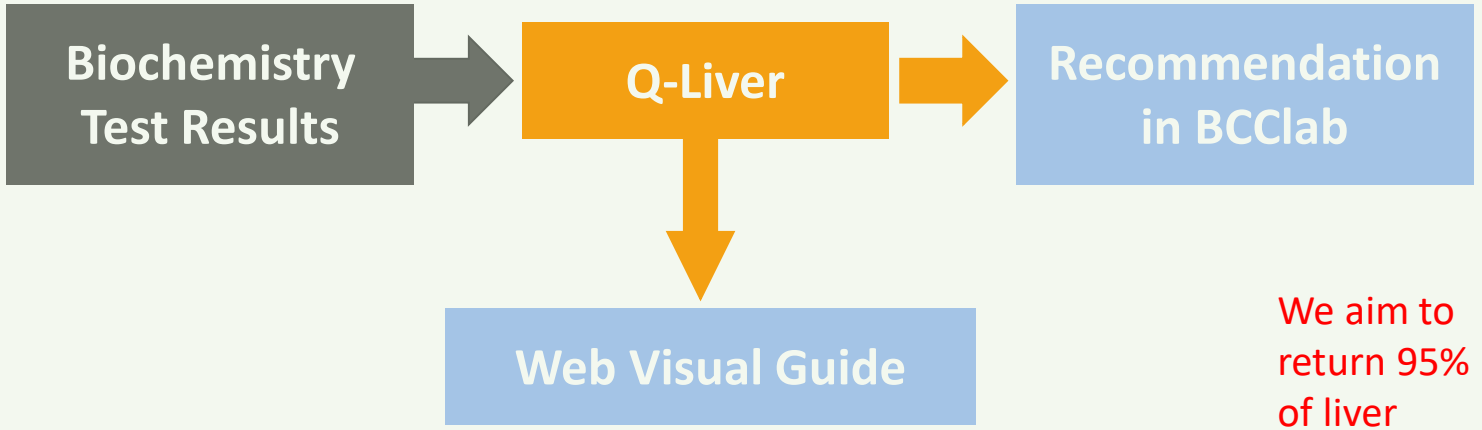


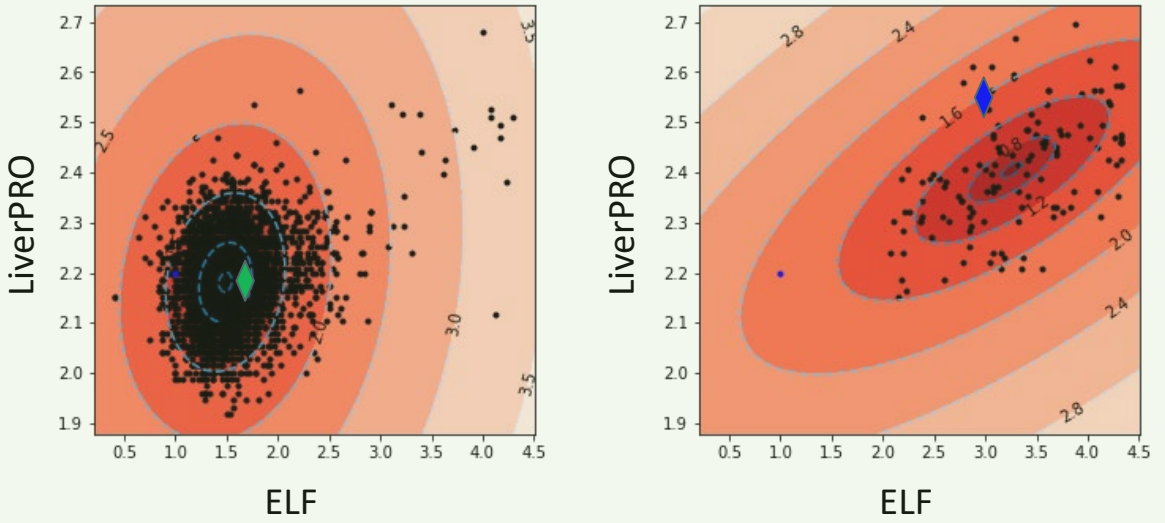
Use QC to optimize clinical referral pathway

Q-LIVER

(2 Mil DKK, Innovation Fund, 2023-25)

Qpurpose is responsible for developing and testing the quantum-enhanced ML tool for rapid evaluation of newly referred patients





We aim to return 95% of liver patients back to primary care without secondary care Treatment!

Our approach: Gaussian Weighted Integrals

We want to compute

$$\mu = \int_{\mathbb{R}^N} f(x)h(x)dx.$$

$f : \mathbb{R}^N \to \mathbb{R}$ take the form

$$f(x) = \sum_{k=0}^{K} \sum_{|I|=k} a_I x^I, \qquad a_I \in \mathbb{C}.$$

Let $I = (i_1, \ldots, i_N)$ and $|I| \equiv i_1 + i_2 \cdots + i_N$.

h is the zero-centered Gaussian probability density function with covariance matrix B (real, symmetric and positive definite.

$$h(x) = (2\pi)^{N/2} (\det B)^{1/2} \exp\left(-\frac{1}{2} x^\intercal B^{-1} x\right).$$

When N is large, this is a difficult problem to solve exactly.

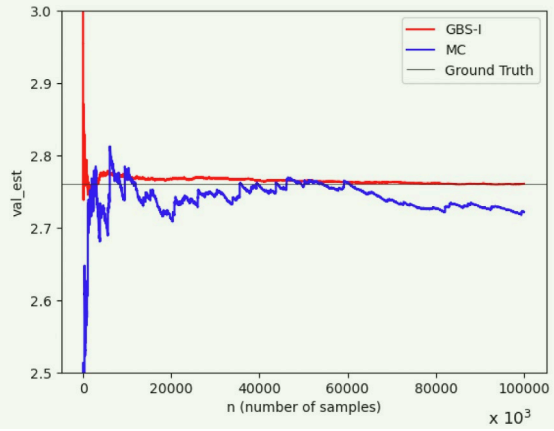
Gaussian Boson Sampling

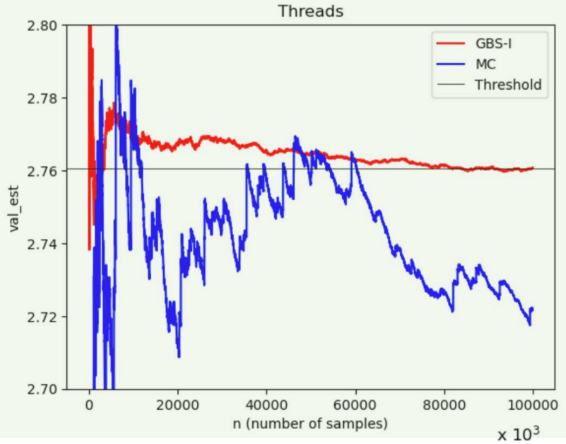
We can prove exponential speed up over the Monte Carlo method.

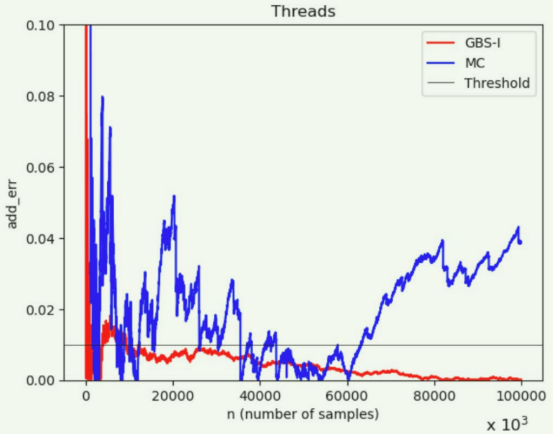
Our Main Result

Theorem (J.E.Andersen & S.Shan)

There is an infinite dimensional space of a_l's and B's such that $\mathcal{E}_n^{g-P}$ and $\mathcal{E}_n^{g-I}$ can reduce n exponentially compared to the standard Monte Carlo estimator $\mathcal{E}_n^{MC\text{-}S}$







Only our imagination will limit our applications of quantum computing!

Centre for Quantum Mathematics & Qpurpose

Jørgen Ellegaard Andersen (QM-SDU, Qpurpose)

Qpurpose clients

... consist of a diverse portfolio of leading businesses in Denmark.
We use advanced mathematics, quantum inspired algorithms and true quantum algorithms to help them optimize their operation.

SDU

QM

QPURPOSE

Finance
Insurance

JYSKE BANK

Danske Bank

MSCI

atp

Renewable energy

Ørsted

CIP
Copenhagen Infrastructure Partners

kamstrup

COWI

Other leading Danish or International partners

MAERSK

novo nordisk®

Danfoss

KPMG

NVIDIA

Samarbejde med MSCI

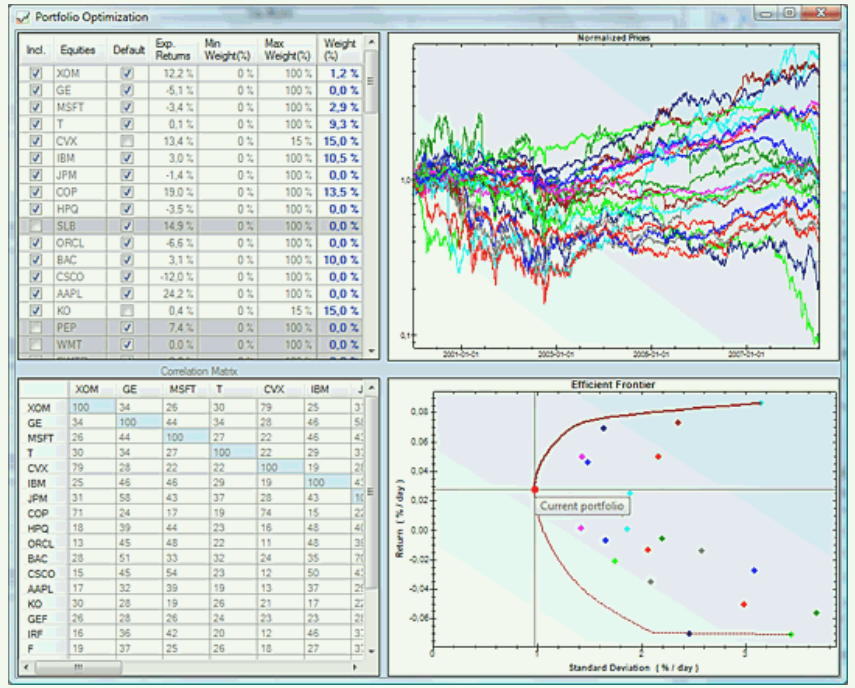
- Vi arbejder sammen med MSCI, verdens ledende firma inden for “**investment decision support tools and services”.**

- Industriens nuværende tilgang er:

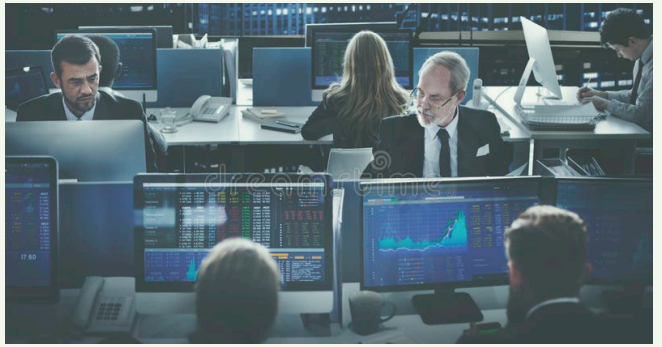
    - Monte Carlo metoder kombineret med forskellige AI teknikker som alle er beregningstunge og ikke top effektive.

- Vores innovation er:
    - Udvikling af en nye algorithmer ved hjælp af **advanceret Kvantematematik**.
    - Fordele: Stor speed up på beregningstiden og langt mere precise løsninger for deres pricing og risk analysis inkluderende estmater for “higher moments”.

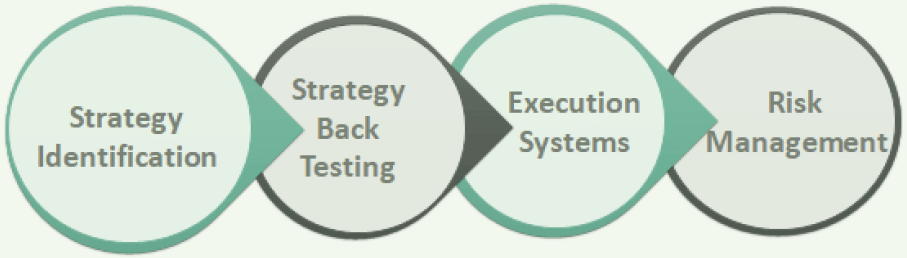
MSCI



JYSKE BANK



QPURPOSE hjælper med:



- Hurtigere og bedre Quantitative Strategy værktøjer

- Bedre og hurtigere analyseværktøj for trading teams

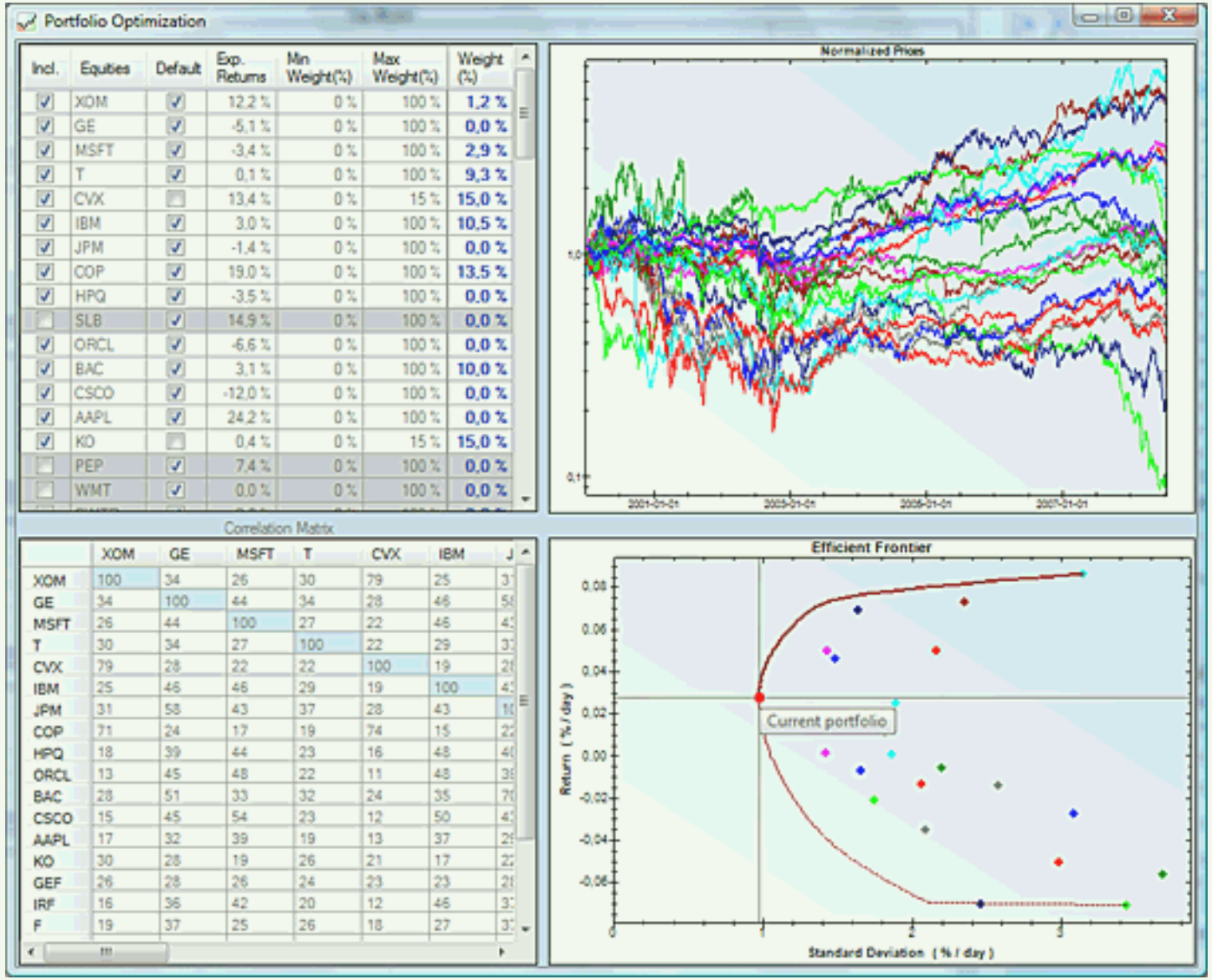
- Mere præcise og hurtigere risiko vurdering

- Forbedre automatiserede kunde behandling

JYSKE BANK

Simulating price of multiple financial derivatives.

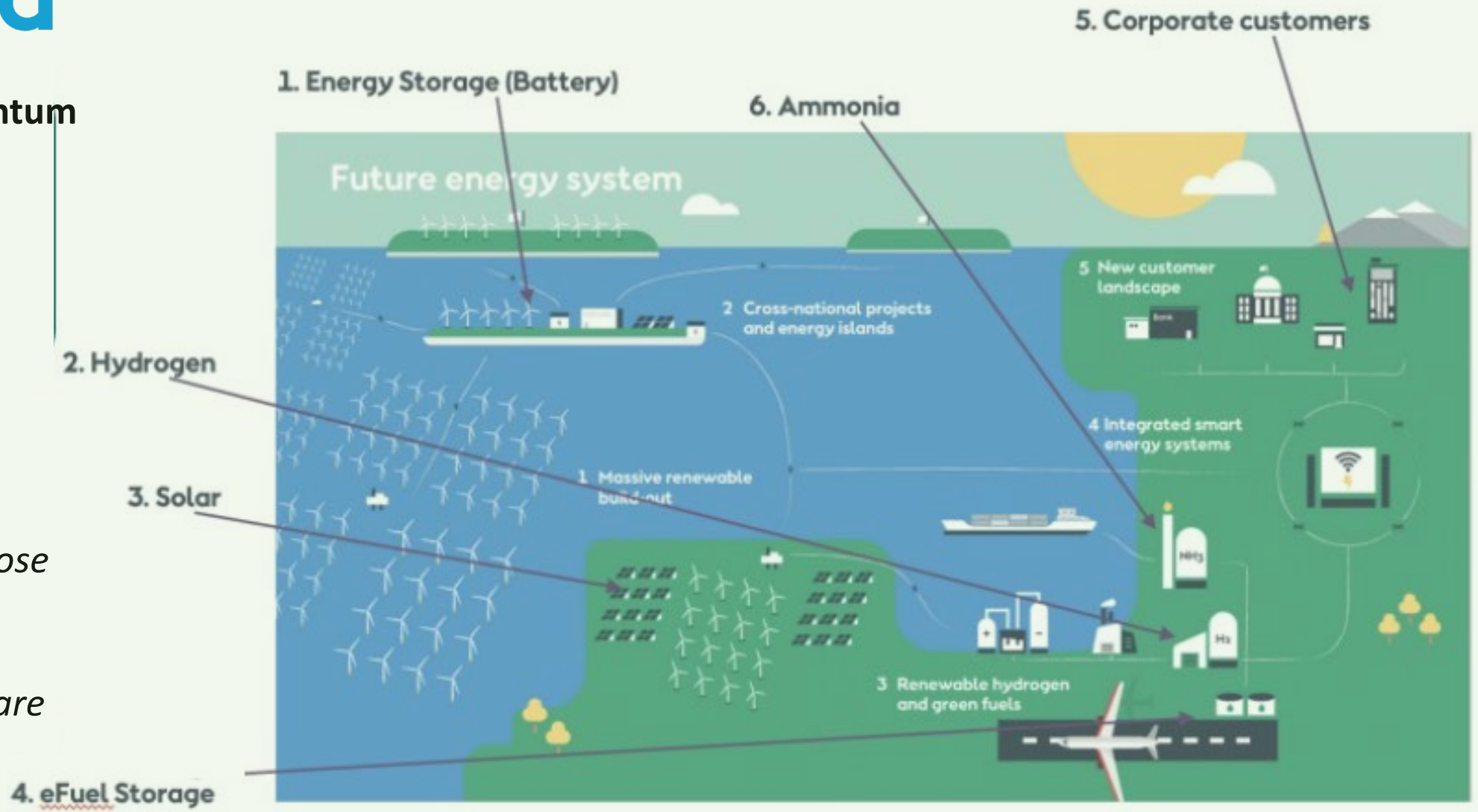
Quantum algorithms will provide major speed up in the solutions of their pricing and risk analysis.



Ørsted

Qpurpose is developing Quantum Software solving energy dispatch optimization problems, which provides major speed up and much better optimization.

This gives Qpurpose fantastic opportunities to develop Q-software for this industry worldwide.



Projects for the DEA and EnergyNet in Denmark

Energistyrelsen

ENERGINET

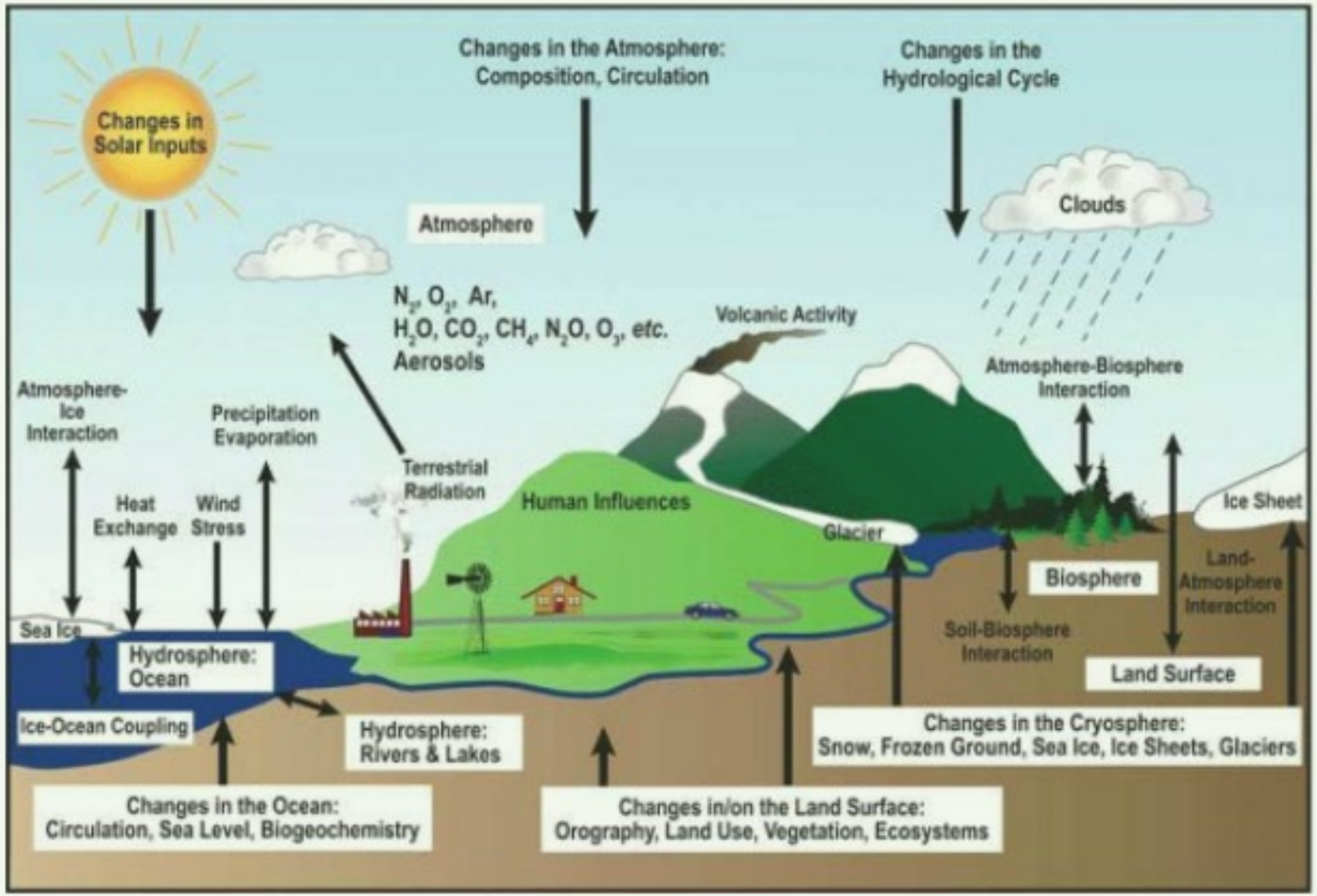
Danmarks Meteorologiske Institut

Small changes accumulate over time

Complex interaction of many systems!

Interdependent nonlinear effects!

Quantum computing can speed up the modeling and the simulation process.



We can also make supply chains climate-smart

The Quantum Software core, which Qpurpose is developing for dispatch optimization and climate modeling/weather prediction turns out to be equally applicable to supply chain optimization, which is of great importance for mitigation of climate problem.

1

Research

- Molecular docking, Dosing optimization, Disease understanding

2

Development

- Patient pharmacogenetic modeling, Site selection optimization

3

Production and Supply chain

Route/network optimization, Dynamic inventory optimization

4

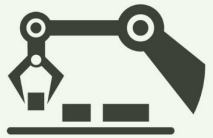
Market access

- Advanced forecasting; Automatic drug recommendations

ENERGY

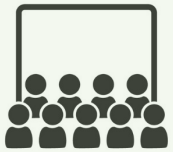
TELECOMMUNICATIONS

CHEMICALS



MANUFACTURING

AUTOMOTIVE



ENTERTAINMENT

BANKING

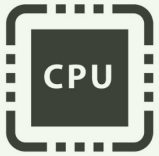
LOGISTICS

INSURANCE

GOVERNMENT

HOSPITALITY

AEROSPACE



ELECTRONICS

RETAIL

LIFE SCIENCES

UTILITIES

PHARMACEUTICAL

RESOURCES

HIGH TECH

INFORMATION TECHNOLOGY

QPURPOSE