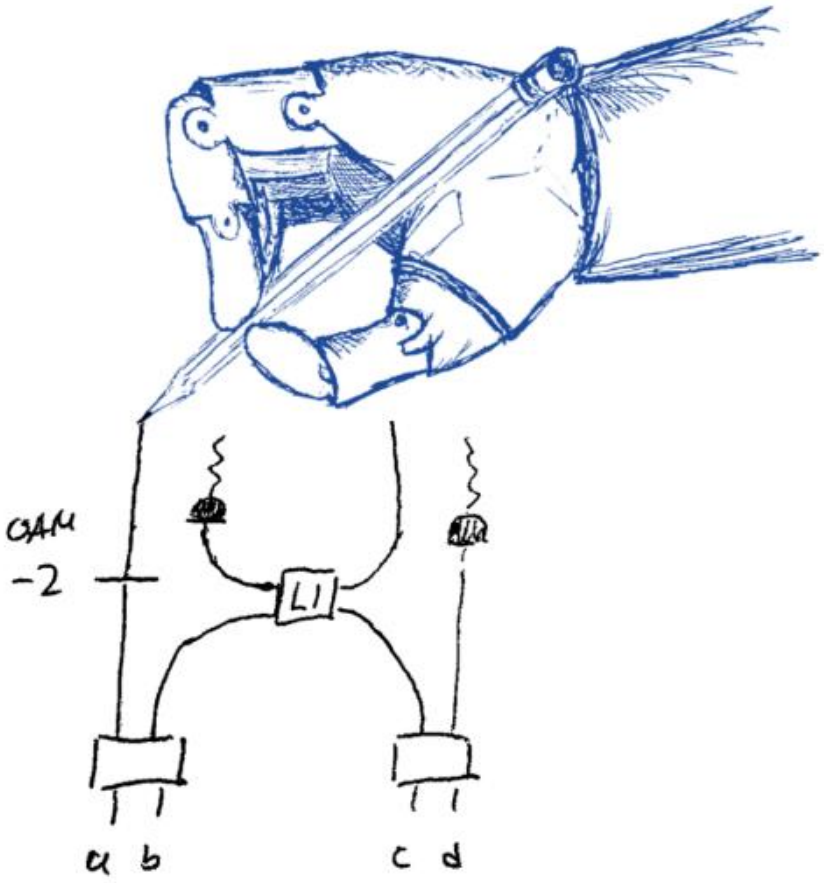
MODE workshop, Valencia, Spain, 24.09.2024

Automated Design of Quantum (and Gravitational Wave) Experiments



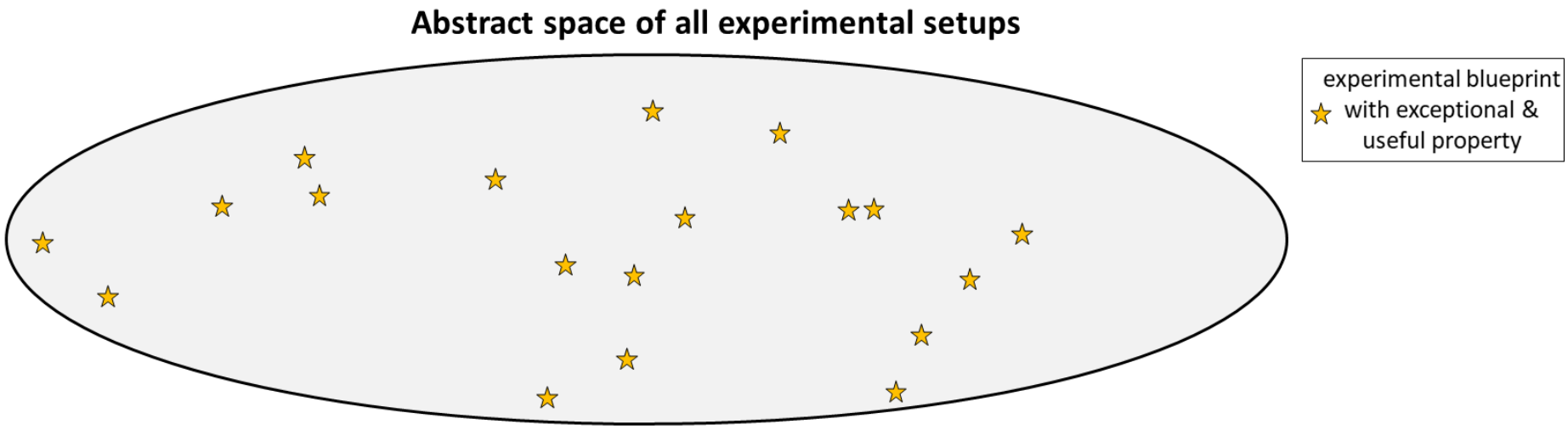
Mario Krenn

Artificial Scientist Lab, Theory Division

@mariokrenn6240

http://mariokrenn.wordpress.com/

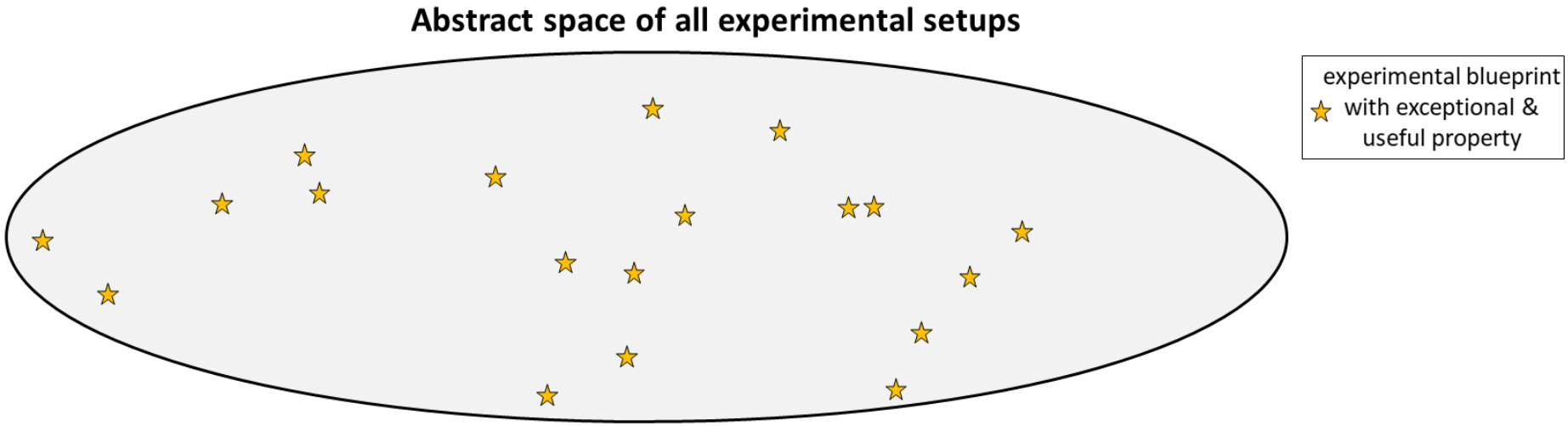
MAX PLANCK INSTITUTE
FOR THE SCIENCE OF LIGHT


Abstract space of all experimental setups
experimental blueprint
with exceptional &
useful property

Some examples: (without symmetry)

3 lasers, 3 BS, 3 detectors: 1000 combinations

5 lasers, 5 BS, 5 detectors: 81,000 combinations (!)



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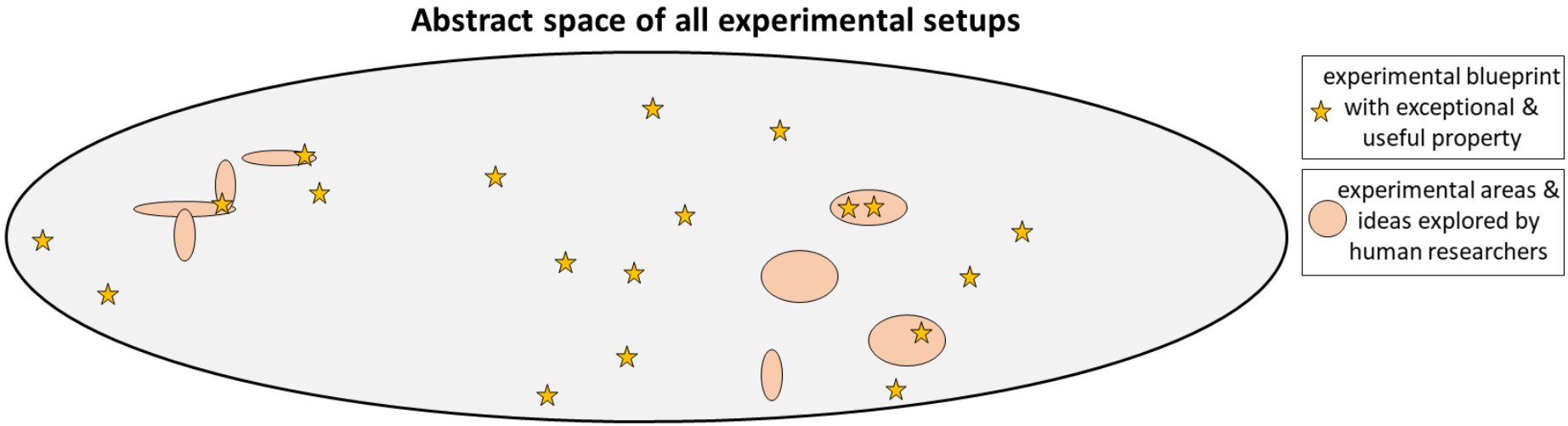

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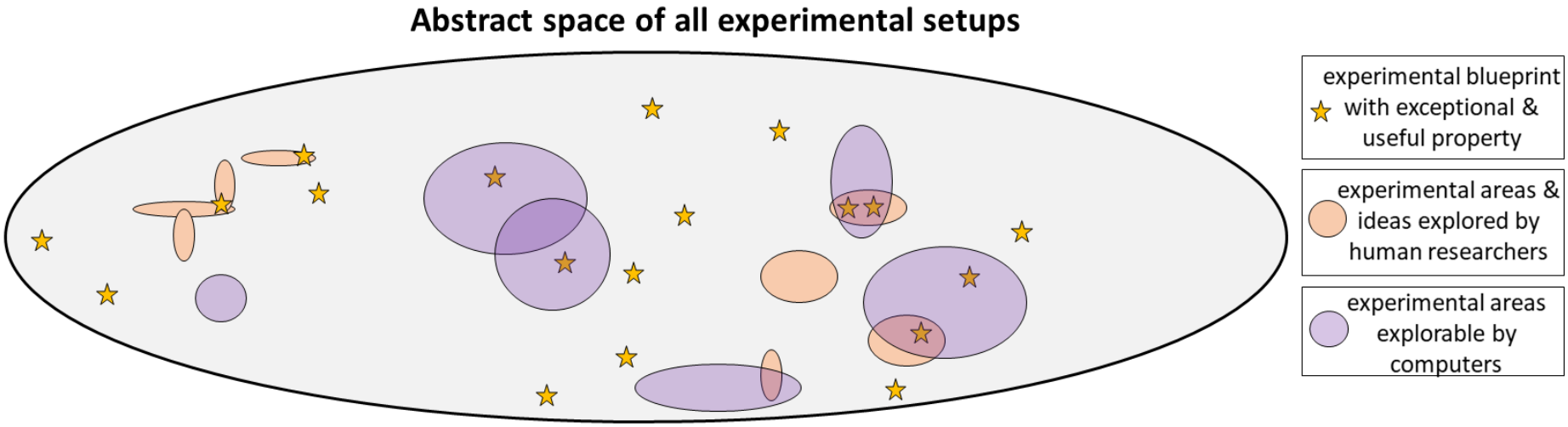

How to design quantum experimental setups?

High-dimensional multipartite entanglement

$$|\psi\rangle_{GHZ-3D} = \frac{1}{\sqrt{3}}\left(|000\rangle + |111\rangle + |222\rangle\right)$$

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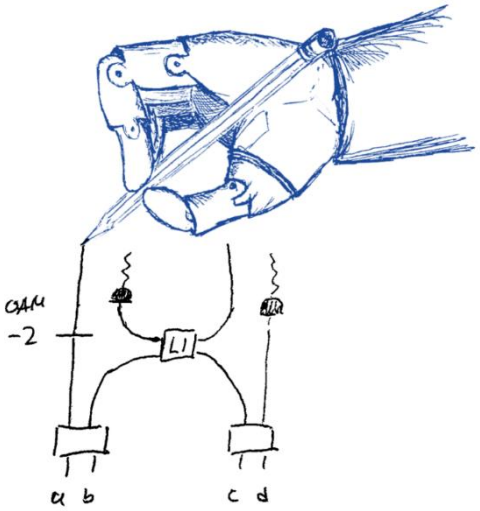

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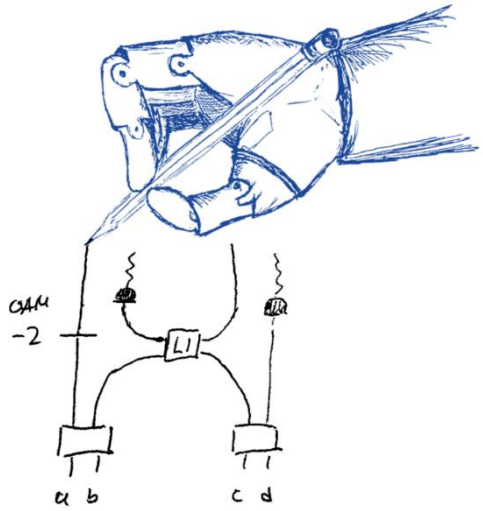
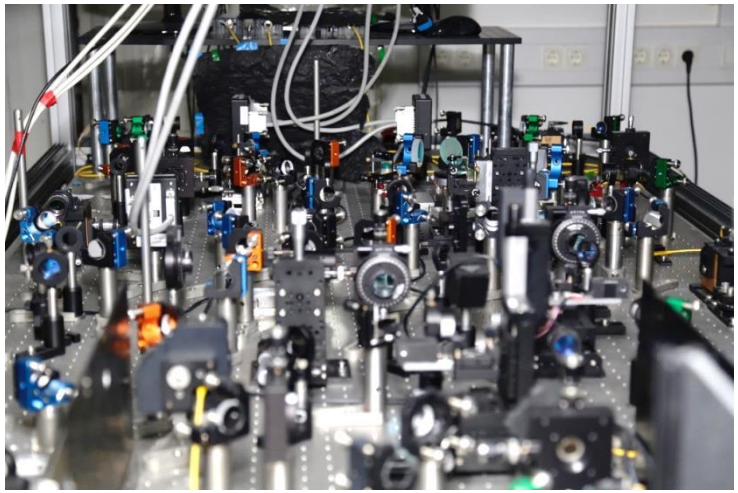
Erhard et al., *Nature Photonics* **12**, 759 (2018)





Krenn, Malik, Fickler, Lapkiewicz, Zeilinger, Automated Search for new Quantum Experiments, *Phys. Rev. Lett.* **116**, 090405 (2016)
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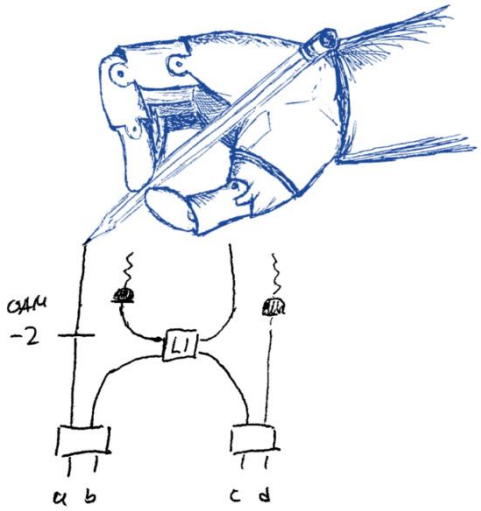

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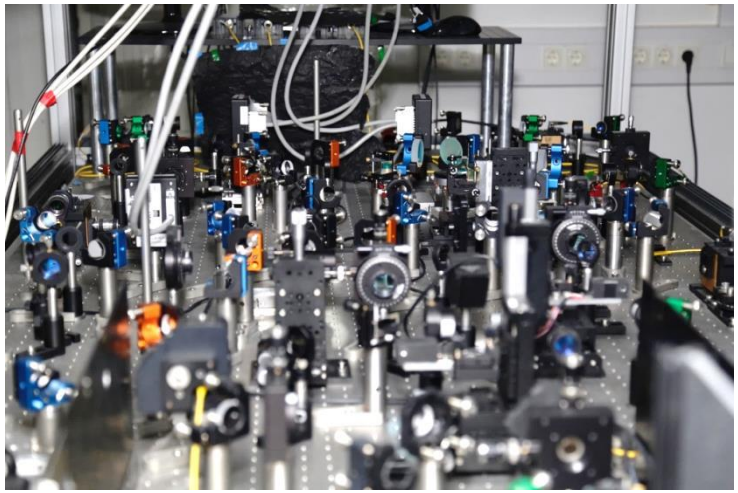

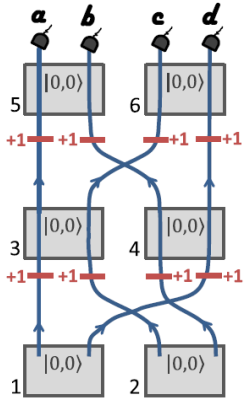

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Mario Krenn

Computer-inspired ideas and concepts

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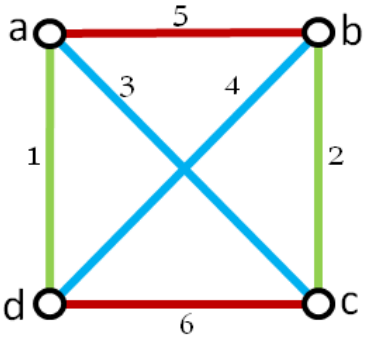

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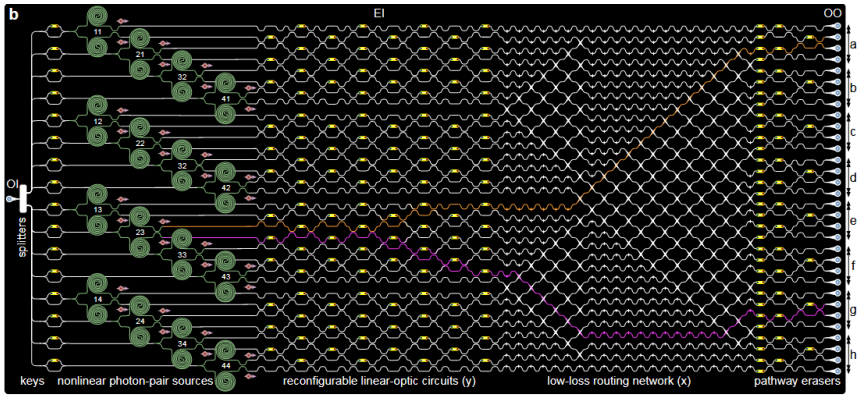
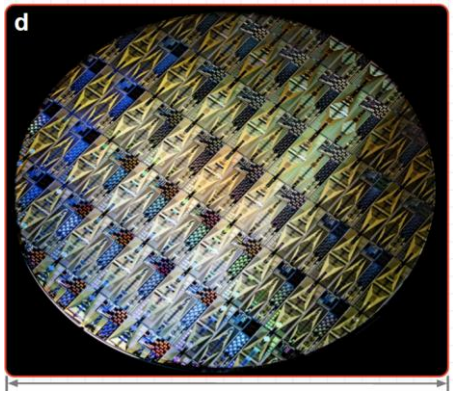
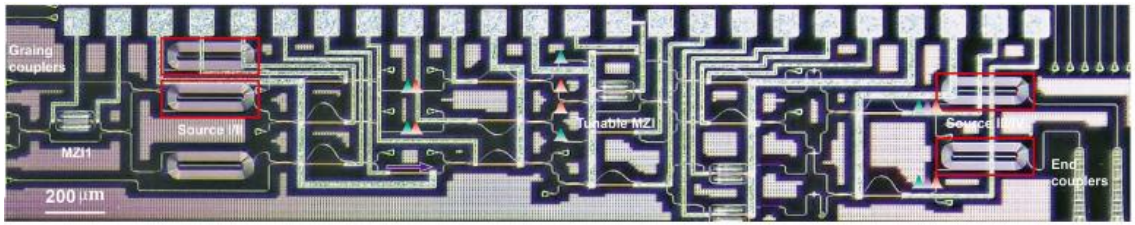
Bao et al., Very-large-scale integrated quantum graph photonics, *Nature Photonics*, **17**, 573 (2023) .







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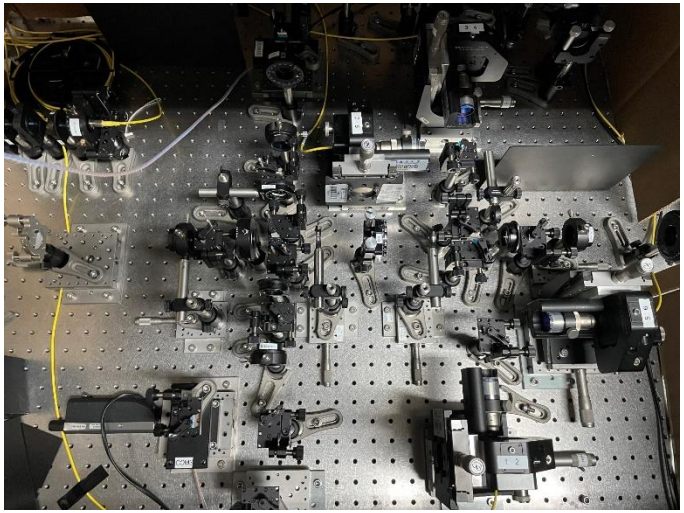

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https://doi.org/10.1088/1402-4896/ab7a35

Perspective

The sounds of science—a symphony for many instruments and voices

Gerianne Alexander[1], Roland E Allen[2], Anthony Atala[3], Warwick P Bowen[4,5], Alan A Coley[6], John B Goodenough[7], Mikhail I Katsnelson[8], Eugene V Koonin[9], Mario Krenn[10,11], Lars S Madsen[5], Martin Månsson[12], Nicolas P Mauranyapin[4], Art I Melvin[10,13], Ernst Rasel[14,15], Linda E Reichl[16], Roman Yampolskiy[17], Philip B Yasskin[18], Anton Zeilinger[10,13] and Suzy Lidström[19,20]

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Highly efficient computer-designed quantum experiments

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Mario Krenn

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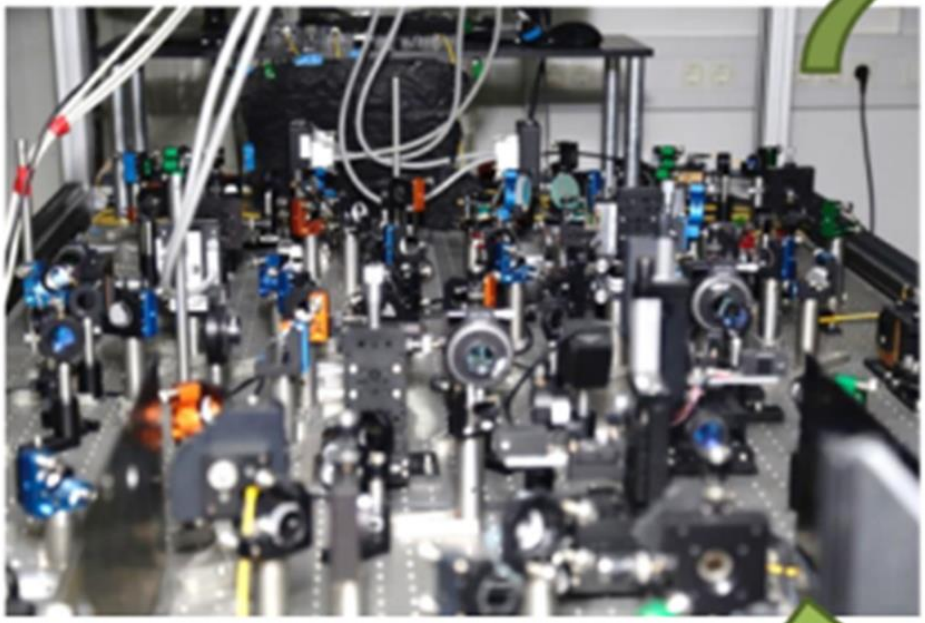
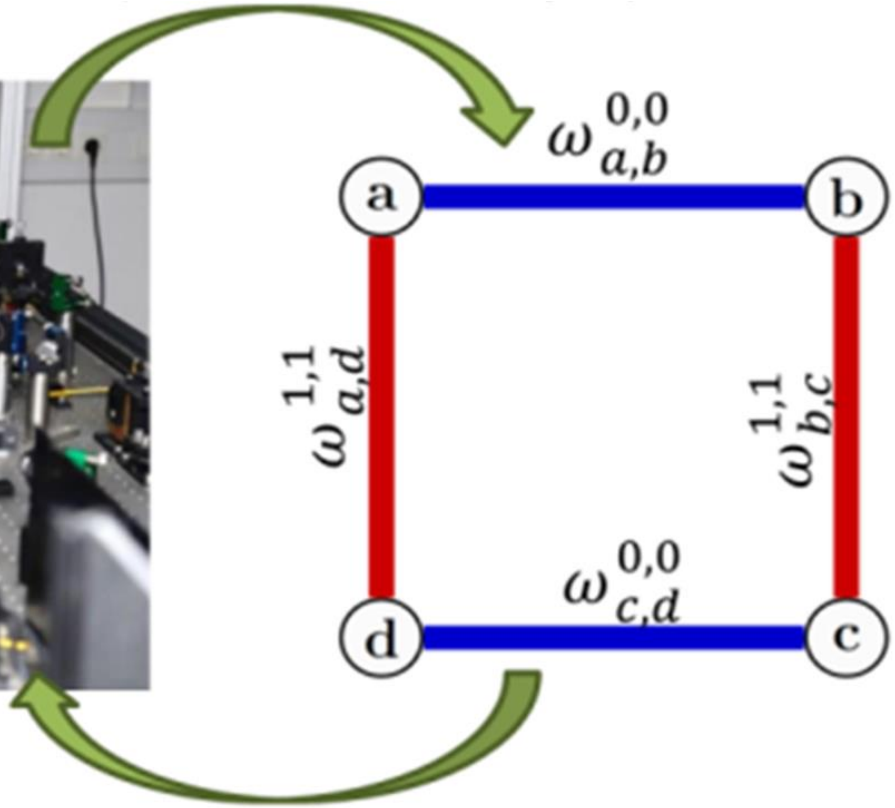
Change Perspective:

New representation -> orders of magnitude speed-up.





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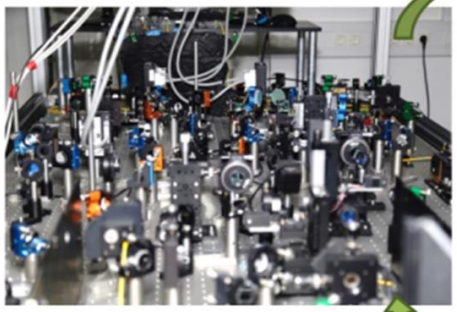
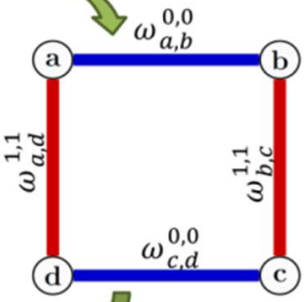
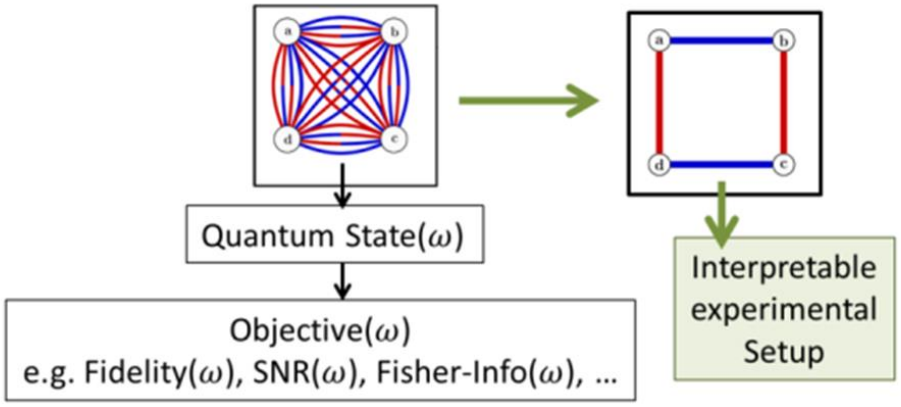
Vertex: Photonic path
Edge: Photon pair
Edge weight: amplitude
Color: Photonic Mode

A) Bridge between quantum experiments and graphs





B) Gradient-based optimization + discrete topological optimization



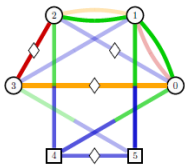
Highly efficient computer-designed quantum experiments

Quantum
the open journal for quantum science

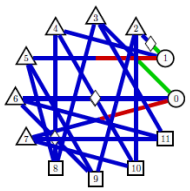
Digital Discovery of 100 diverse Quantum Experiments with PyTheus

Carlos Ruiz-Gonzalez[§1], Sören Arlt[§1], Jan Petermann[1], Sharareh Sayyad[1], Tareq Jaouni[2], Ebrahim Karimi[1,2], Nora Tischler[3], Xuemei Gu[1], and Mario Krenn[1]

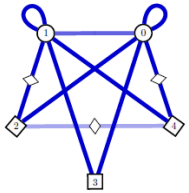
Quantum 7, 1204 (2023).



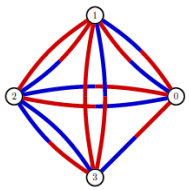
(a) Four-dimensional four-photon GHZ state (overcoming the 3-dimensional barrier for multiphoton entanglement)



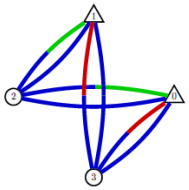
(b) Heralded 3D Bell state with single photons (improves state-of-the-art design by requiring less ancilla photons)



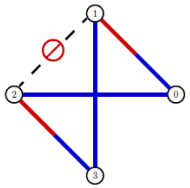
(c) Two-mode five-photon N00N state $|50\rangle + |05\rangle$ (very symmetric shape with an inscribed pentagram)



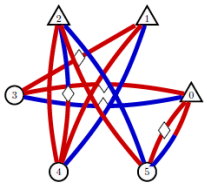
(d) A 4-qubit entangled states with unit coefficients, which requires complex-valued weights for generation



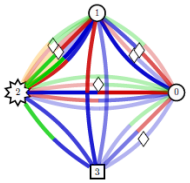
(e) Quantum measurement for a quantum communication task with quantum advantage (Mean King's Problem)



(f) Entanglement swapping without using two Bell states



(g) Toffoli quantum gate without ancilla photons



(h) Mixed state with bound entanglement that can violate a Bell inequality (counterexample to the Peres conjecture from 1999, solved 2014)

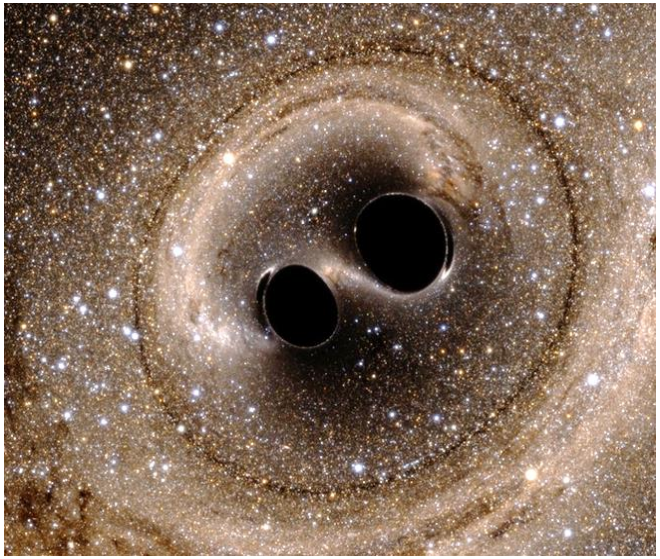
github.com/artificial-scientist-lab/PyTheus

`pip install pytheusQ`

Mario Krenn

AI-driven design of new Gravitational Wave Detectors

with Yehonathan Drori, Rana X. Adhikari (Caltech, LIGO): arXiv:2312.04258



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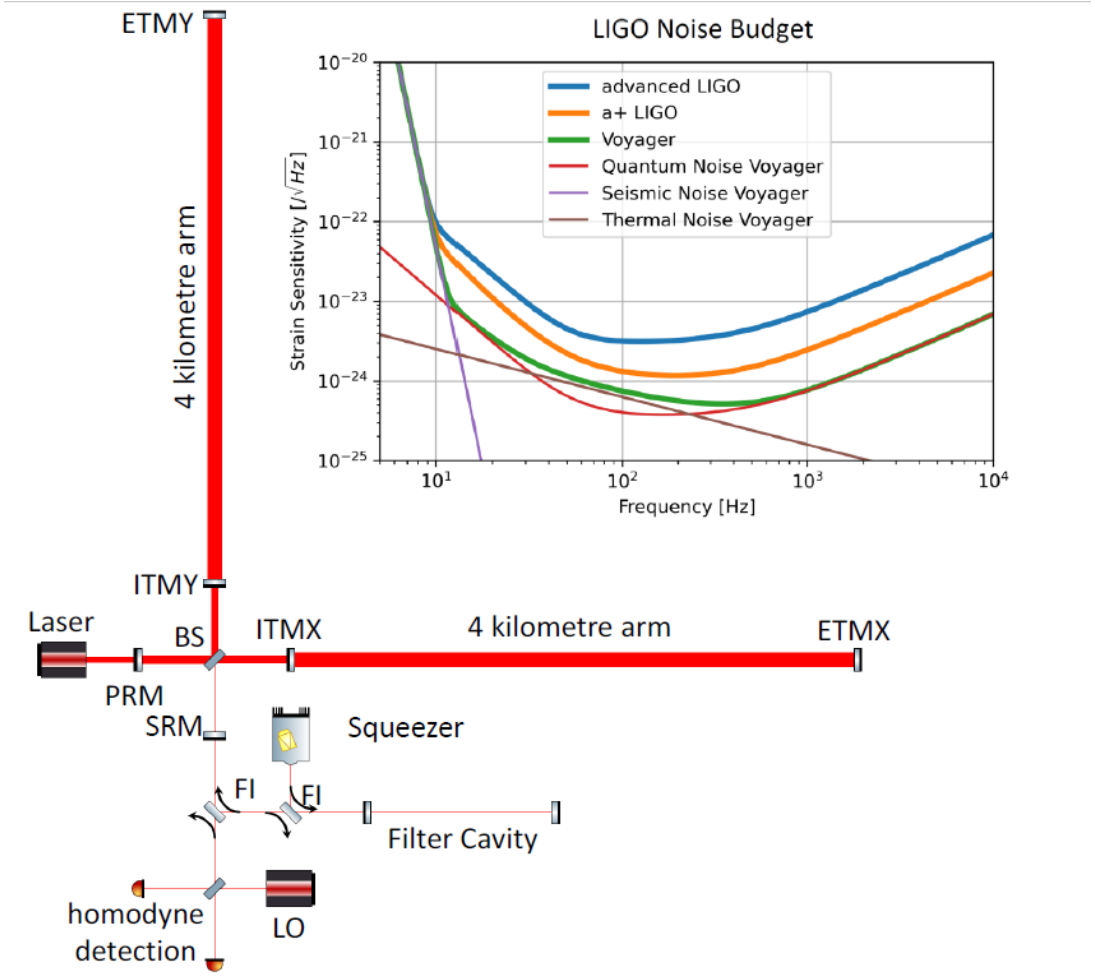
LIGO's next Generation Detector Update: Voyager



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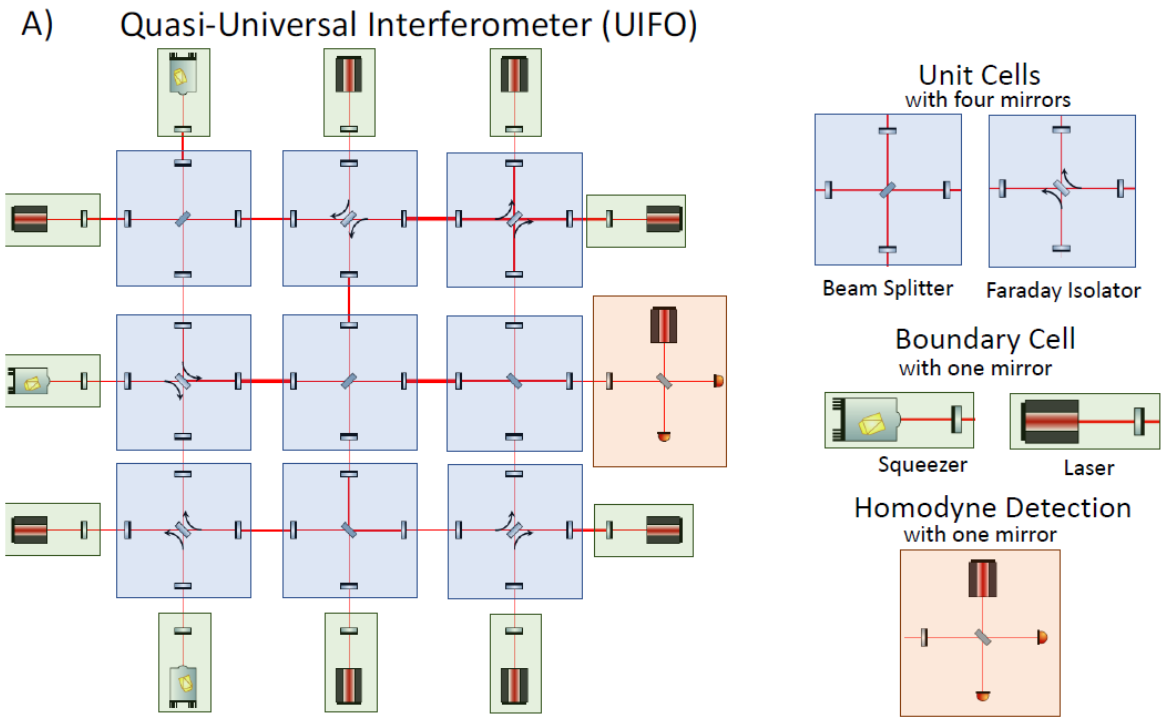

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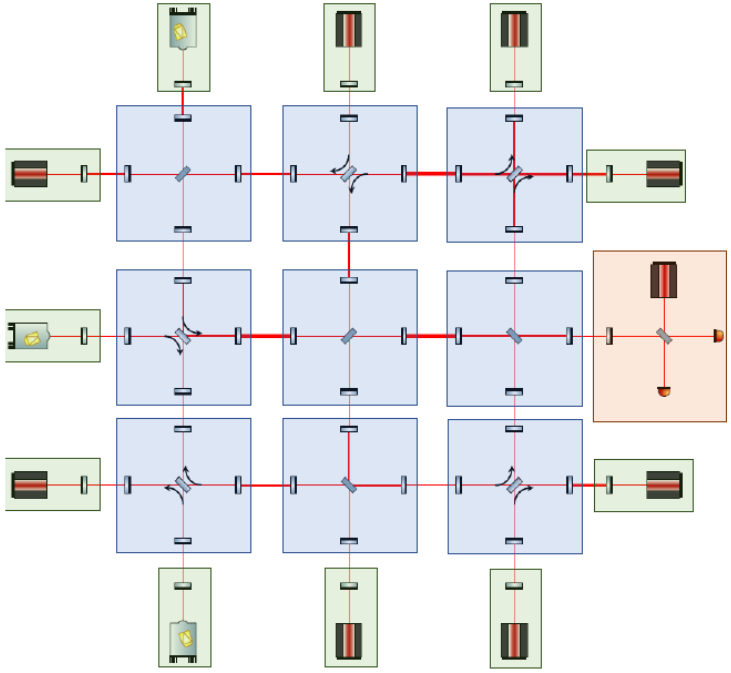
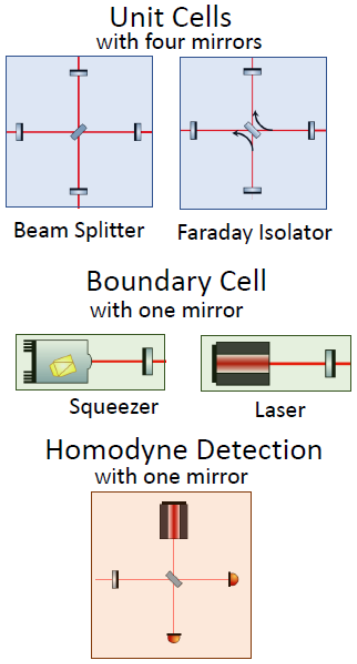
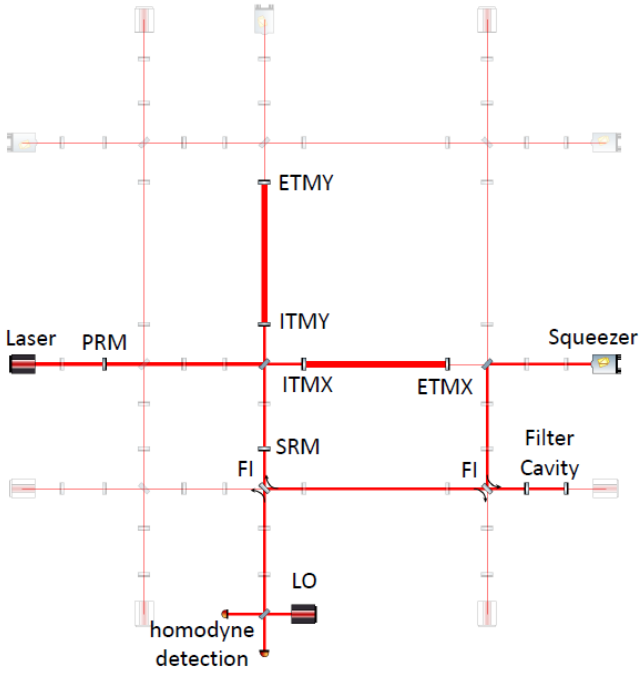
A) Quasi-Universal Interferometer (UIFO)





B) LIGO Voyager in UIFO



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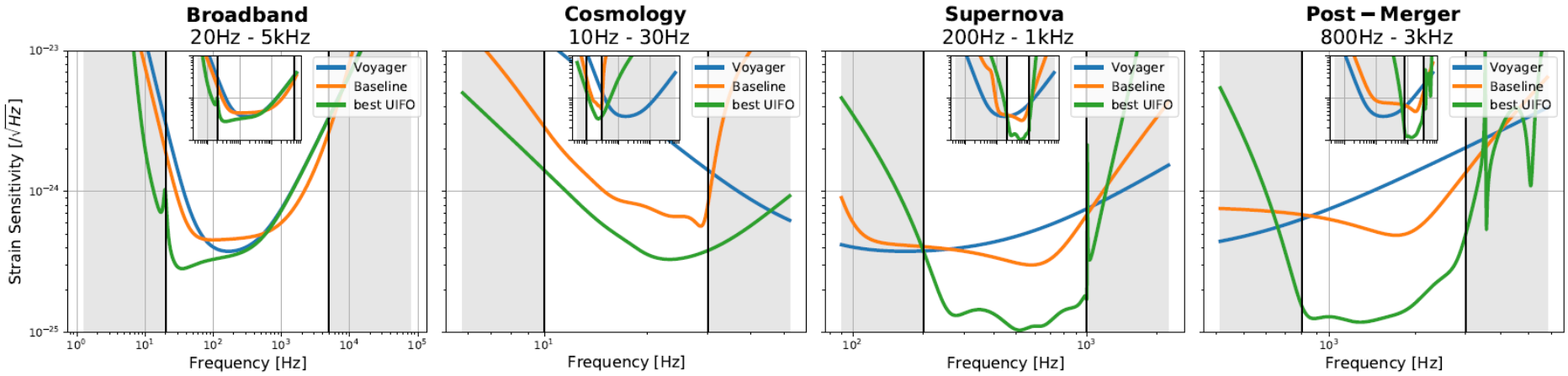

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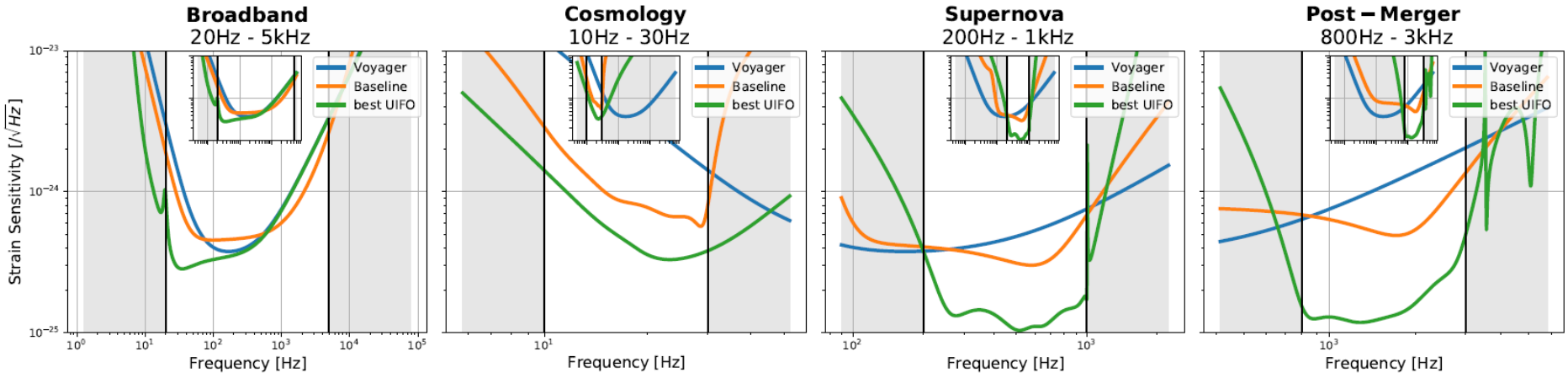

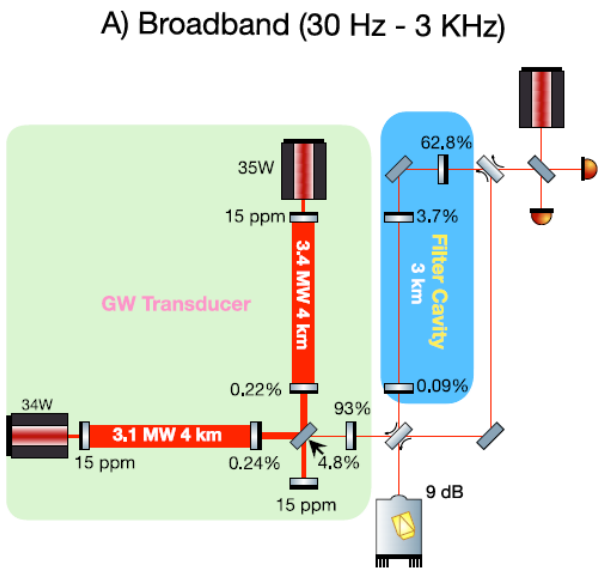

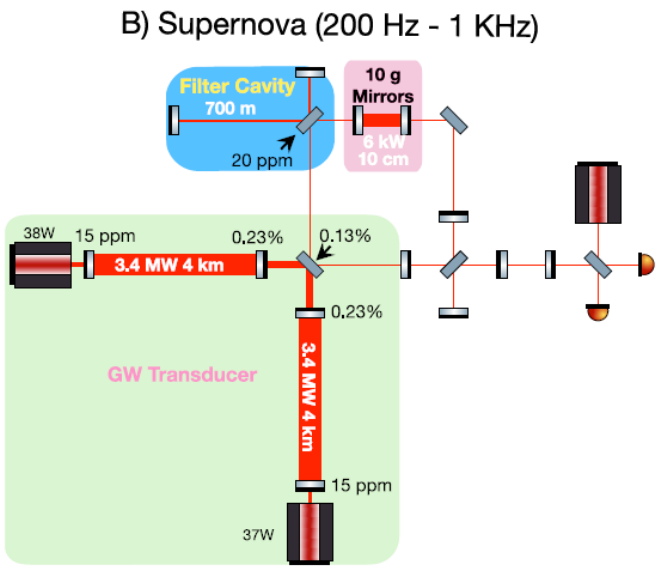

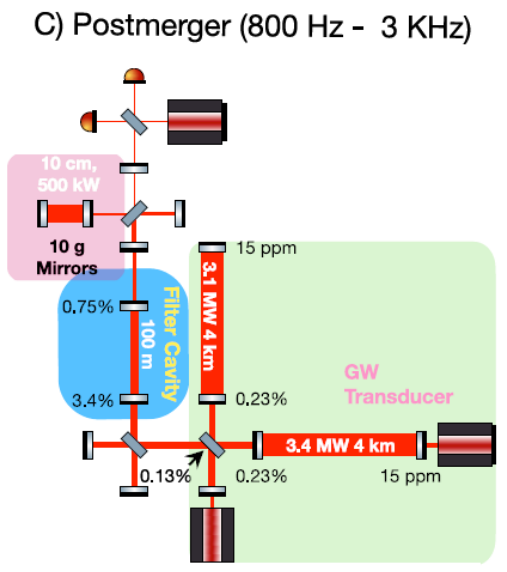

Conclusion

AI-based Quantum Hardware & Experiment Design:

In many domains in physics (*quantum optics, gravitational wave physics, microscopes/telescopes soon*), we have now algorithms for

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The solutions are presented such that

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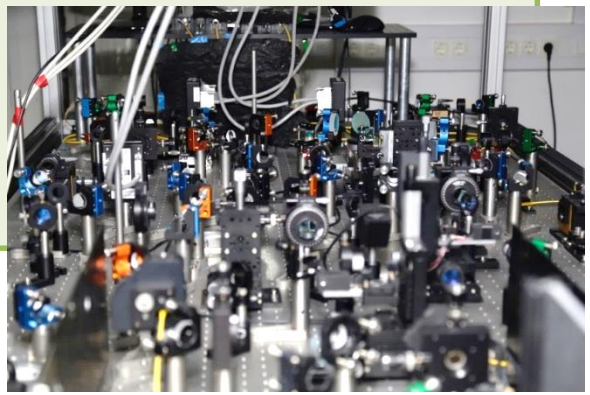

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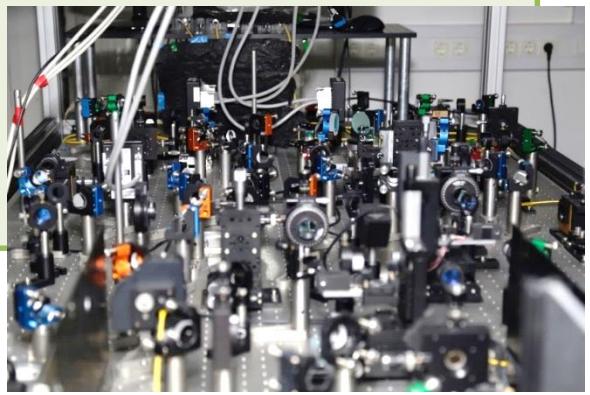

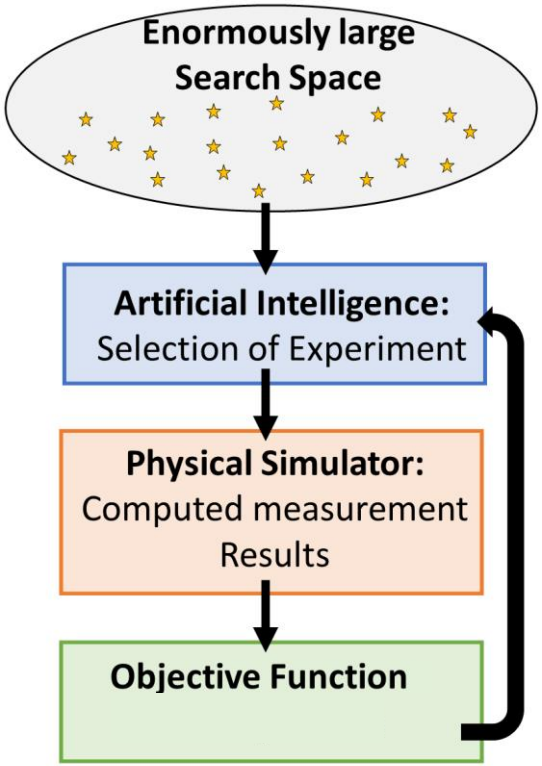

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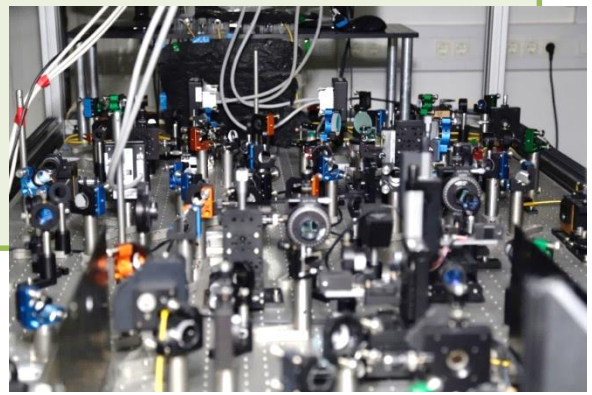

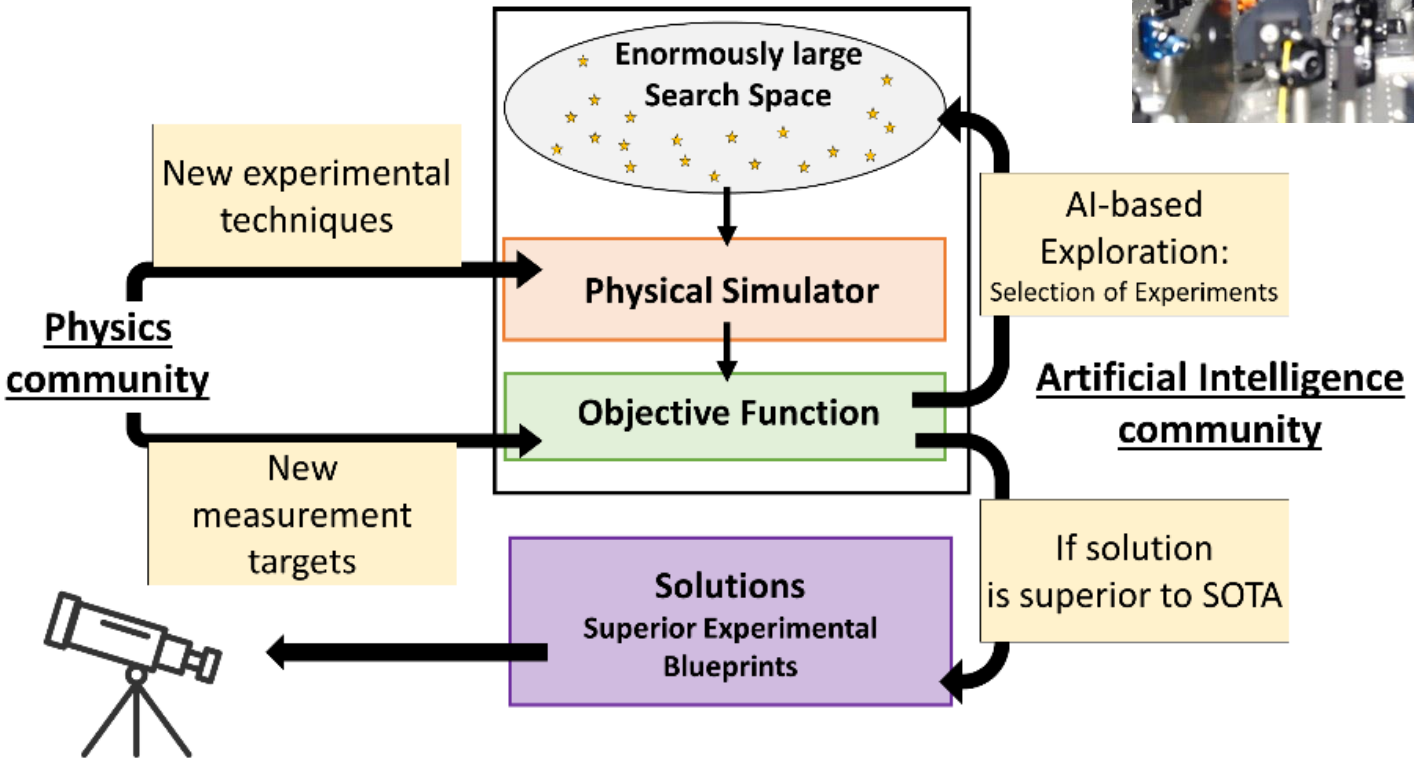

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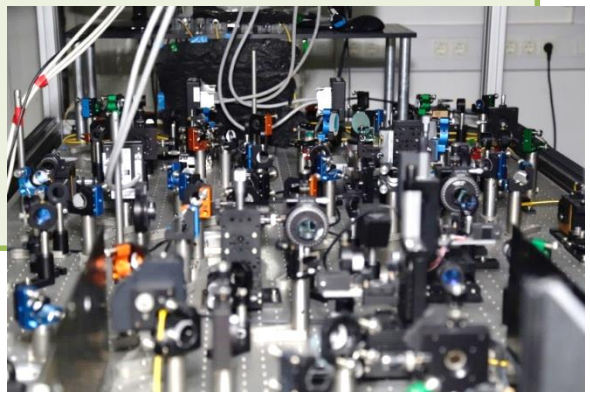

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