HEP AND QIS&T

High Energy Physics Advisory Panel

Gaithersburg Marriott Washingtonian Center
9751 Washingtonian Boulevard
Gaithersburg, MD 20878

November 29-30, 2018

Thanks to many FNAL ppl (Panagiotis, Joe, Brenna, Cristian…) Kent Irwin SLAC/Stanford Chris Tully, Kathryn Zurek, Matt Shaw (JPL), Neil Sinclair (Caltech/Harvard) ++

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FROM LAST YEAR'S HEPAP

2017-2018

Quantum Information Science (QIS)

- **QIS identified as a national (interagency) and Office of Science priority**
- **HEP QIS emphasis (both near-term and long-term) is on:**
  - P5 science drivers – exploiting entanglement and QIS technology
  - New computational and foundational techniques via QIS
  - Advancing the national QIS enterprise
- **Approach: Interdisciplinary partnerships via connections with other SC programs and/or other federal agencies**
- **Areas of focus for HEP research via coordinated partnerships:**
  - Quantum Computing and Foundational QIS
    - Simulations, entanglement, algorithms, machine learning, data analysis on qubit systems
  - Quantum Sensor Technology
    - Sensors developed in alignment with qubit technology that expand the measurement ranges for experiments
  - Experiments Exploiting Quantum Entanglement
    - New windows on research utilizing QIS foundations, tools, and techniques
- **Reports available at:**
  - http://science.energy.gov/hep/community-resources/reports/
- **Program Manager: Lali Chatterjee**

Quantum Information Science in DOE-SC

ASCR	BES	HEP	NP
Quantum algorithms; uncertainty quantification and verification & validation methods; software stack; quantum networks	Synthesis, characterization, theory, modeling, and instrumentation to advance quantum materials & chemical phenomena	Black hole physics; quantum gravity and quantum error correction; fundamental aspects of entanglement	Isotopes and trapped ions for quantum devices; lattice quantum chromodynamics

Quantum Field Theory and Topology

Control of Quantum Phenomena

- SC Unique Strengths
  - Intellectual capital accumulated for more than a half-century
  - Successful track record of forming interdisciplinary yet focused science teams for large-scale and long-term investments
  - Demonstrated leadership in launching internationally-recognized SC-wide collaborative programs

HEP Motivations and Thrust Areas in QIS

- **Fundamental High Energy Physics and QIS** III
  - Foundational Concepts and related experiments, including:
    - Convergent development of Black Hole physics, Quantum Error Correction, holographic duality
  - Field Theory/Analogue Simulations using QI and entanglement, including:
    - Perturbative QCD models exploiting QI, de Sitter space, & gauge duality
    - Tensor Networks/ Gauge symmetries
    - Field theories, including lattice gauge theories
  - Entanglement/QIS based Experiments for P5 science drivers I
    - Exploiting superposition, entanglement, and squeezing
- **Quantum Computing for HEP**
  - Data analysis techniques, algorithms for HEP computations and modelling
- **Quantum Controls & Sensor Technology**
  - Controls, qubits, and other technology to advance dark universe & space time sensors
  - Advancing QIS technology using HEP expertise and capabilities II

DARK MATTER & QUANTUM SENSORS

TESTIMONY IN CONGRESS MAY 2017

- New ideas to search for dark matter particles call for novel superconducting, semiconducting, graphene, superfluid helium and other exotic and novel quantum materials. Remarkably we are adapting technologies developed for quantum computers in HEP as sensors for dark matter searches, pushing further the advancement of those technologies.

FNAL & QIS

PAC JULY 2017

- Fermilab rolls QIS/HEP exploratory program (Physics Advisory Committee)

Fermilab
Physics Advisory Committee Report
Sanford Laboratory, July 5-9, 2017

NATURE PUBLICATION OCT 19 2017

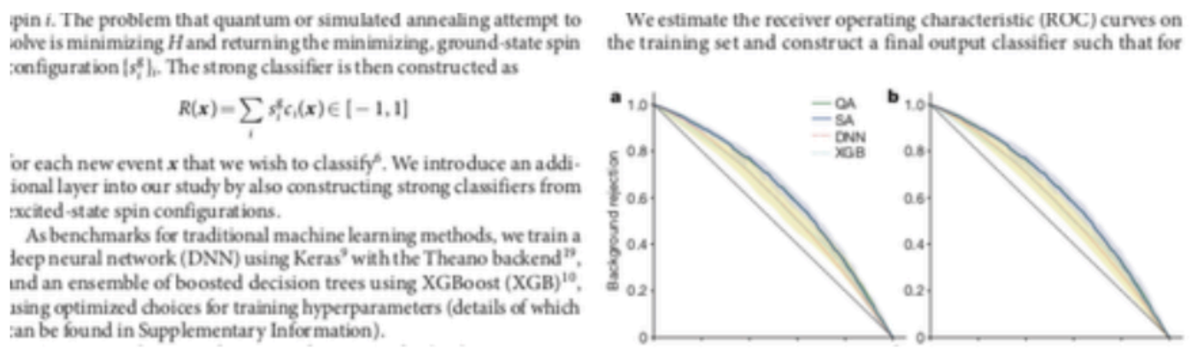
QUANTUM MACHINE LEARNING? : CS-Y DATA TECHNOLOGIES

"PERHAPS A QUANTUM DEEP LEARNING NETWORK CAN BE TRAINED MORE EFFICIENTLY, E.G. USING A SMALLER TRAINING SET. WE DON'T KNOW. WE'LL HAVE TO TRY IT TO SEE HOW WELL IT WORKS." J. PRESKILL

LETTER

doi:10.1038/nature24047

Solving a Higgs optimization problem with quantum annealing for machine learning



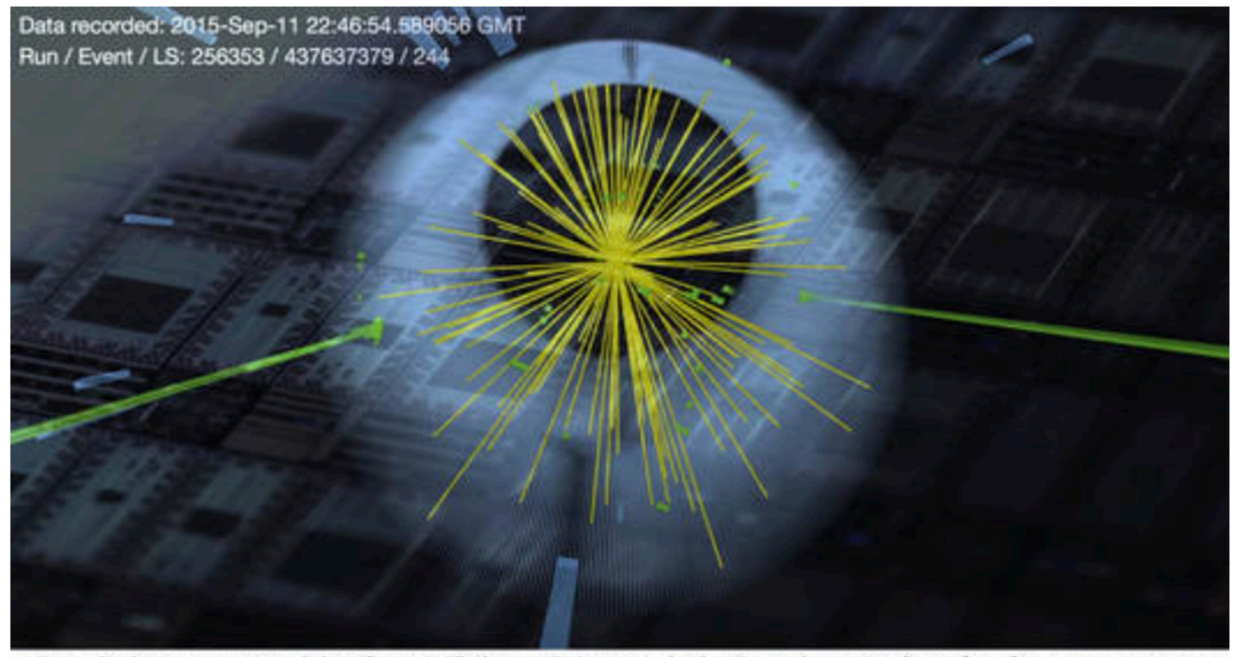
October 18 2017 | Nature Paper Extended Summary & FAQ

LETTER

doi:10.1038/nature24047

Solving a Higgs optimization problem with quantum annealing for machine learning

October 18 2017 | Nature Paper Summary



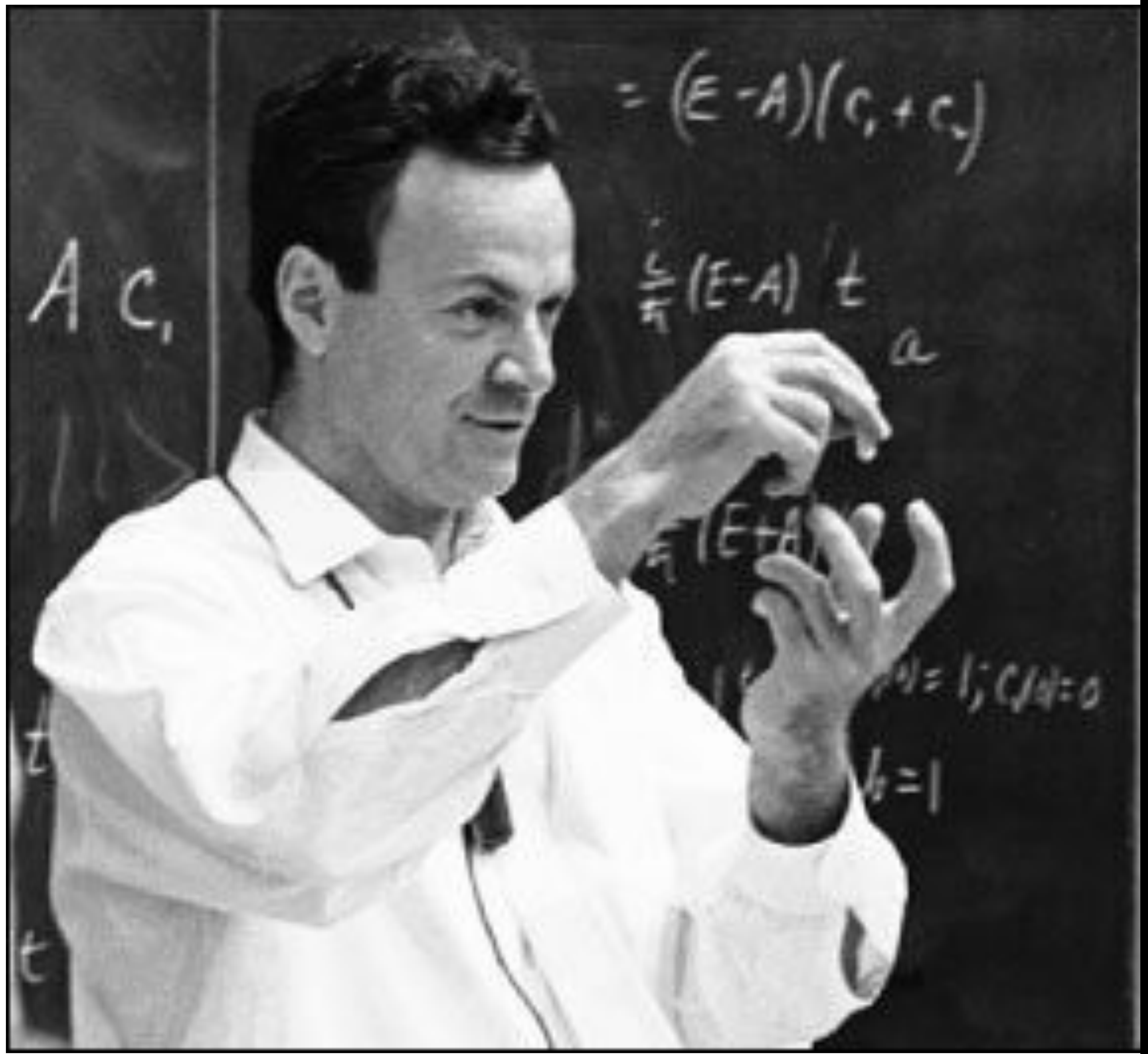
Higgs di-photon event candidate from LHC data collisions overlaid with a schematic of a wafer of quantum processors

2017 | A physics-based computation approach solves a Higgs optimizatio

Richard Feynman 1981

"Nature isn't classical, dammit, and if you want a simulation of nature, you'd better make it quantum mechanical"

- First person to propose the idea of quantum computing and explain it's potential importance



Quantum Information Science R&D and initiatives (academic, government, industry) are springing around the world in the 21st century

Quantum computing in the NISQ Era

The (noisy) 50-100 qubit quantum computer is coming soon.
(*NISQ = noisy intermediate-scale quantum*.)

NISQ devices cannot be simulated by brute force using the most powerful currently existing supercomputers.

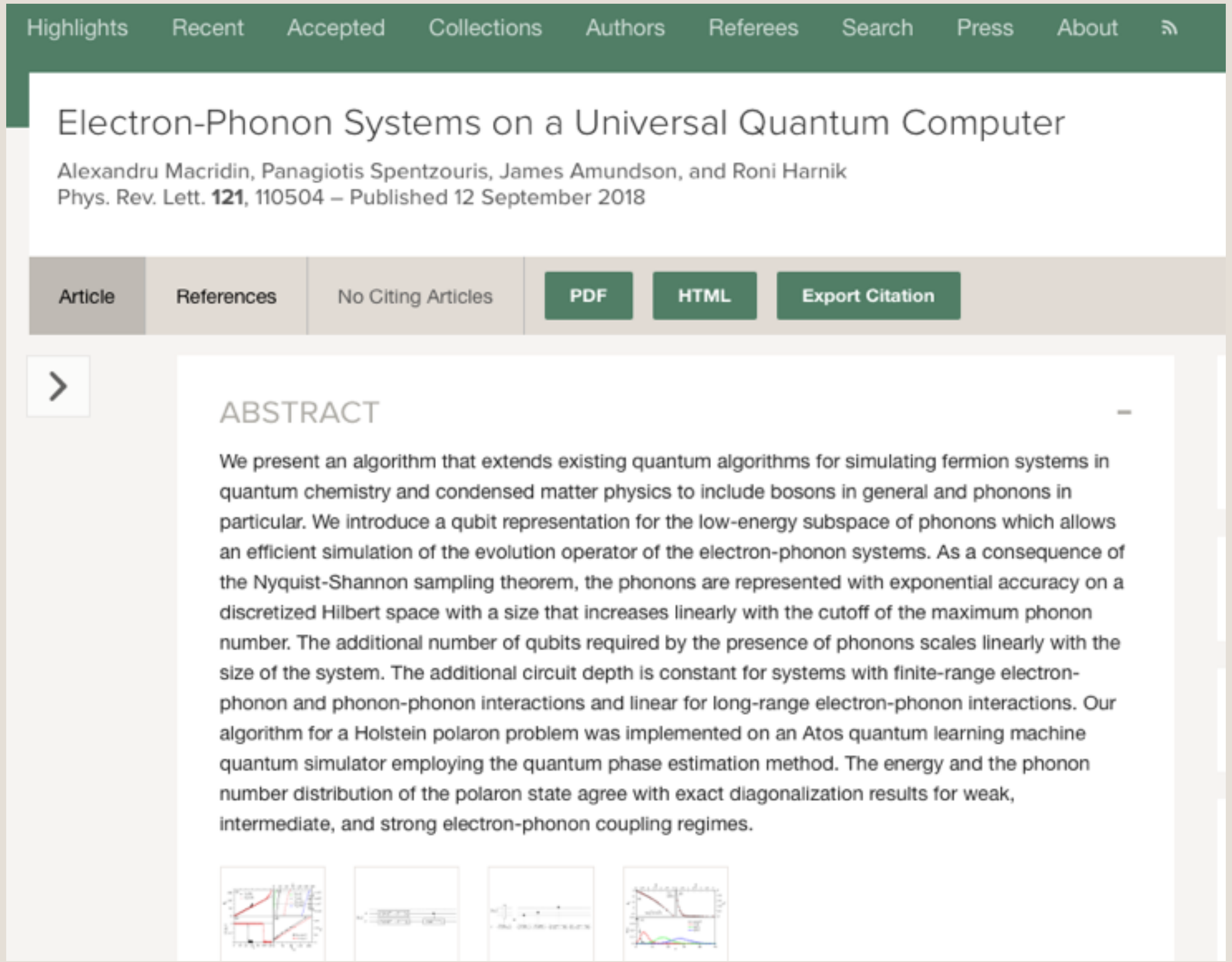
Noise limits the computational power of NISQ-era technology.

NISQ will be an interesting tool for exploring physics. It *might* also have useful applications. But we're not sure about that.

NISQ will not change the world by itself. Rather it is a step toward more powerful quantum technologies of the future.

Potentially transformative scalable quantum computers may still be decades away. We're not sure how long it will take.

HEP APPLICATIONS ON NISQ QUANTUM COMPUTERS: FROM FERMIONS TO BOSONS TO GAUGE THEORIES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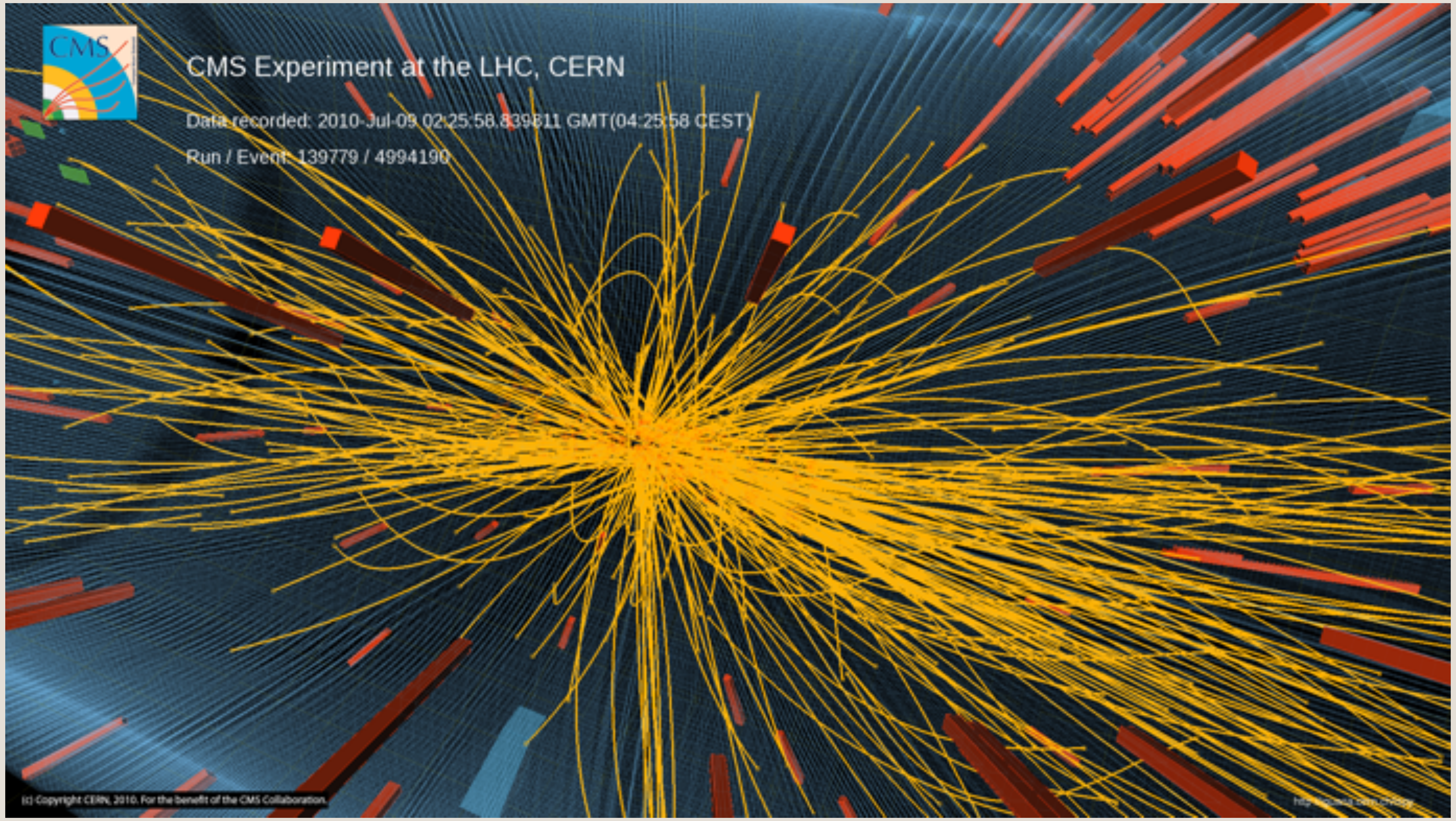
Electron-Phonon Systems on a Universal Quantum Computer

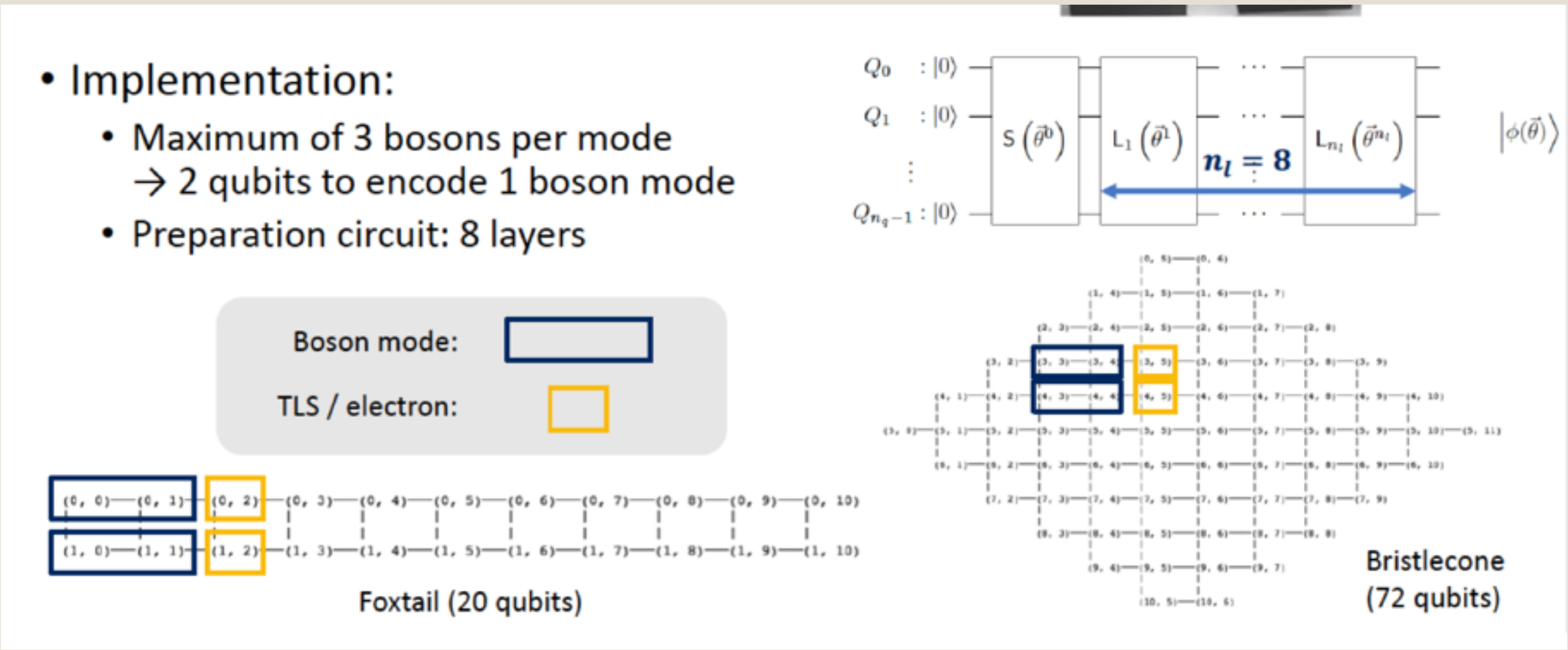
Alexandru Macridin, Panagiotis Spentzouris, James Amundson, and Roni Harnik
Phys. Rev. Lett. **121**, 110504 – Published 12 September 2018

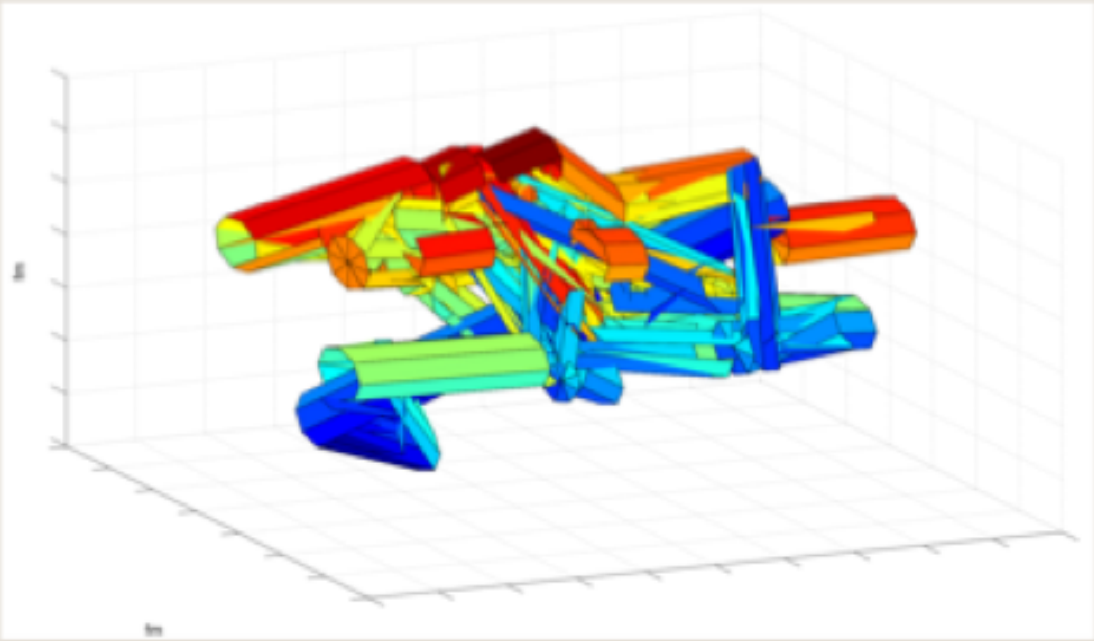
Article | References | No Citing Articles | PDF | HTML | Export Citation

ABSTRACT

We present an algorithm that extends existing quantum algorithms for simulating fermion systems in quantum chemistry and condensed matter physics to include bosons in general and phonons in particular. We introduce a qubit representation for the low-energy subspace of phonons which allows an efficient simulation of the evolution operator of the electron-phonon systems. As a consequence of the Nyquist-Shannon sampling theorem, the phonons are represented with exponential accuracy on a discretized Hilbert space with a size that increases linearly with the cutoff of the maximum phonon number. The additional number of qubits required by the presence of phonons scales linearly with the size of the system. The additional circuit depth is constant for systems with finite-range electron-phonon and phonon-phonon interactions and linear for long-range electron-phonon interactions. Our algorithm for a Holstein polaron problem was implemented on an Atos quantum learning machine quantum simulator employing the quantum phase estimation method. The energy and the phonon number distribution of the polaron state agree with exact diagonalization results for weak, intermediate, and strong electron-phonon coupling regimes.







Color reconnections in LHC collisions

QC WORKSHOP@FNAL

DECEMBER 2017

Come to Fermilab's first quantum computing workshop – Dec. 6-7

November 30, 2017 | Stefan Prestel

Share Tweet G+ Email

Stefan Prestel

The topic of quantum computing has been popping up in particle physics news lately. In October, Caltech announced that a technique involving machine learning was able to tease out a Higgs boson signal from a mountain of data, work that was supported by INQNET, a program for accelerating quantum technologies. And earlier this year, the University of Chicago, Argonne and Fermilab launched the Chicago Quantum Exchange to explore the potential of quantum computing in diverse scientific disciplines.

It's a good time for those of us interested in both high-energy physics and the potential of quantum computing to exchange ideas about how we can connect the two fields. To that end, Fermilab is hosting from Dec. 6-7 a workshop titled "Near-Term Applications of Quantum Computing." Registration is free, and all are welcome to attend.

We've designed the workshop to explore whether high-energy physics can offer test case problems for quantum computers, and we expect attendees to help identify problems that lend themselves to experiments that are feasible on quantum computers (including analog systems) in the near term.

Experts will present on topics such as software tools for large-scale quantum computing and simulating quantum field theories on quantum computers.

The University of Southern California's Daniel Lidar, one of the workshop speakers, will give the Fermilab Colloquium that week: "Adventures in quantum optimization with noisy qubits."

Sign up now for the workshop. We hope to see you in Curia II on Dec. 6 and 7!

Stefan Prestel is a scientist in the Fermilab Theory Department and one of the workshop co-organizers.

Tagged: computing, meeting, quantum computing

One day HEP/QC workshop @Fermilab

Near-term Applications of Quantum Computing

chaired by Walter Giele (Fermilab), Prestel Stefan (Fermilab), James Simone (Fermilab), Marcela Carena (Fermilab), Joseph Lykken (Fermilab), Kiel Howe (Fermilab)

from Wednesday, December 6, 2017 at **08:00** to Thursday, December 7, 2017 at **19:30** (US/Central)
at **Fermilab - Wilson Hall (Curia II)**
Fermi National Accelerator Laboratory Batavia, IL

Description This meeting will bring together a small group of experts in high energy physics and quantum computing. The focus is to identify problems and algorithms that are expected to be feasible on quantum computing systems in the near term.

In particular, we hope to:

- discuss how different disciplines have cast their problems of interest into a form amenable to quantum computing
- discuss the complexity of problems that have been addressed with state-of-the art quantum architectures
- learn how quantum computing ties into the HEP computing model, and how existing code frameworks, languages and toolkits could be leveraged for HEP computing
- understand how current challenges in HEP computing / calculations (machine learning, dynamics of strongly interacting field theories and scattering amplitudes,experimental event reconstruction bottlenecks) could benefit from quantum algorithms and architectures, and how HEP could provide benchmark problems for quantum computers.

Material: Internet Info | Travel Info

Go to day

Wednesday, December 6, 2017

08:40 - 09:00 Welcome and Introduction *20'*
Speakers: Dr. Joseph Lykken (Fermilab), Dr. Marcela Carena (Fermilab)
Material: Slides

09:00 - 10:00 Quantum Computing Testbed Approaches *1h0'*
Until recently, the term "applied quantum computing" was best used as an answer to the question "What is a good example of an oxymoron?" Now, however, quantum computing hardware with significant capabilities is on the very near horizon. I describe how we at Fermilab are taking a testbed the topic of applied quantum computing. Even though the killer application for quantum computing in high energy physics has yet to be developed, I describe the steps we are taking toward identifying and implementing quantum solutions to high energy physics problems.
Speaker: Dr. James Amundson (Fermilab)
Material: Slides

10:00 - 11:00 Machine Learning of a Higgs Decay Classifier via Quantum Annealing *1h0'*
In this talk, we describe how we used quantum and classical annealing (probabilistic techniques for approximating the global maximum or minimum of a given function) to solve a Higgs-signal-versus-background machine learning optimization problem, and mapped it to a problem of finding the ground state of a corresponding Ising spin model. We build a set of weak classifiers based on the kinematic observables of the Higgs decay photons, which we then use to construct a strong classifier. This strong classifier is highly resilient against overtraining and against errors in the correlations of the physical observables in the training data, which may result from the use of event generators in high-energy physics. We show that the resulting quantum and classical annealing-based classifier systems perform comparably to the state-of-the-art machine learning methods that are currently used in particle physics for this test case. However, in contrast to these methods, the annealing-based classifiers are simple functions of directly interpretable experimental parameters with clear physical meaning. The annealer-trained classifiers demonstrate some advantage over traditional machine learning methods for small training datasets. Given the relative simplicity of the algorithm and its robustness to error, this technique may find application in other areas of experimental particle physics, such as real-time decision making in event-selection problems and provides a proof of principle for future work on machine learning applications of quantum and digital annealing machines.
Speaker: Joshua Job (University of Southern California)
Material: Slides

11:00 - 11:15 Break (Art Gallery)
11:15 - 12:15 Statistical Analysis of Quantum Computing Experiments *1h0'*
Speaker: Dr. Yazhen Wang (University of Wisconsin, Madison)
Material: Slides

such classes, and for further definitive assessments of scaling advantages using current and future quantum annealing devices.
Speaker: Dr. Daniel Lidar (University of Southern California)
Material: Slides

10:00 - 11:00 Quantum Information for Fundamental Physics *1h0'*
The tried-and-true method for probing fundamental physics is to measure scattering probabilities with colliders. Recent advances in quantum information-based theory and experimental technologies suggest new methods for understanding elementary physics. In this vein, I will discuss some results on the quantum structure of scattering states, and sketch some preliminary ideas about trying to use novel information-theoretic observables and techniques to explore fundamental theories at energies accessible in labs today.
Speaker: Dr. Daniel Carney (NIST / University of Maryland)
Material: Slides

11:00 - 11:15 Break
11:15 - 12:15 Simulating Quantum Field Theories on Quantum Computers *1h0'*
In some regimes, such as strong coupling, quantum field theory dynamics are difficult to simulate using conventional techniques. In this talk I will describe my joint work with John Preskill and Keith Lee developing quantum algorithms for simulating quantum field theories. I will also comment on potential applications of near-term "pre-threshold" quantum computers to quantum field theory problems.
Speaker: Dr. Stephen Jordan (NIST / University of Maryland)
Material: Slides

12:15 - 13:30 Lunch (Fermilab Cafeteria)
13:30 - 14:30 Quantum Simulations of Abelian and non- Abelian Gauge Theories *1h0'*
Besides lattice QCD in particle physics, strongly coupled gauge theories arise, for example, in the condensed matter physics of spin liquids, or in the quantum information theory of Kitaev's toric code, which is a Z(2) lattice gauge theory. Numerical simulations of gauge theories on classical computers, in particular, at high fermion density or in out-of-equilibrium situations, suffer from severe sign problems that prevent the importance sampling underlying Monte Carlo calculations. Quantum simulators are accurately controllable quantum devices that mimic other quantum systems. They do not suffer from sign problems, because their hardware is intrinsically quantum mechanical. Recently, trapped ions, following a laser-driven stroboscopic discrete time evolution through a sequence of quantum gate operations, have been used as a digital quantum simulator for particle-anti-particle pair creation in the Schwinger model. Analog quantum simulators, on the other hand, follow the continuous time-evolution of a tunable model Hamiltonian. Using ultra-cold atoms in optical lattices, analog quantum simulators have been designed for Abelian and non-Abelian lattice gauge theories. Their experimental realization is a challenge for the foreseeable future, which holds the promise to access the real-time dynamics of string breaking, the out-of-equilibrium decay of a false vacuum, or the evolution of a chiral condensate after a quench, from first principles. Quantum link models which realize gauge theories including QCD not with classical fields but with discrete quantum degrees of freedom, are ideally suited for implementation in quantum matter. For example, alkaline-earth atoms, whose nuclear spin represents an SU(N) degree of freedom, naturally embody fermionic rishon constituents of gluons. CP(N-1) models, which are toy models for QCD, can be quantum simulated in a similar way via SU(N) quantum spin ladders.
Speaker: Dr. Uwe-Jens Wiese (University of Bern)
Material: Slides

14:30 - 15:30 Quantum Simulating Lattice Gauge Theories with Optical Lattices *1h0'*
Optical lattices have been used successfully to quantum simulate the Bose-Hubbard model. We briefly review recent proposals to use similar procedures for lattice gauge theories. The long term objectives are to deal with sign problems and the real time evolution, which is not possible with classical computations. We introduce a gauge-invariant formulation of the Abelian Higgs model in 1+1 dimensions obtained with the tensor renormalization group method. We propose an approximate realization using cold atoms in an optical lattice with a ladder structure. Recently developed Rydberg's atom manipulations allow to create nearest neighbor interactions with the desired strength. An experimental proof of principle would be to try first simpler examples: the Ising and O(2) models. We report on recent progress in this direction.
Speaker: Yannick Meurice (U. of Iowa)

Three days HEP/QS workshop Sept 12-14 2018 @Fermilab

Next steps in Quantum Science for HEP
from **Wednesday, September 12, 2018 (08:00)** to **Friday, September 14, 2018 (19:30)**

: Sessions / : Talks : Breaks

Wednesday, September 12, 2018

AM	**08:30**	**Session 1** (until 10:05)
	08:30	Welcome - Marcela Carena (Fermilab)
	08:40	Fermilab Quantum Science Program - Joseph Lykken (Fermilab) Slides
	09:00	Formulating Gauge Theories for a Quantum Computer - David B. Kaplan (INT, University of Washington) Slides
	09:40	Guass's Law and Hilbert Space Constructions for U(1) Lattice Gauge Theories - Jesse Stryker (University of Washington) Slides
	10:05	--- Coffee Break ---
	10:35	**Session 2** (until 12:30)
	10:35	Simulating quantum and classical field theories with a quantum computer - Stephen Jordan (NIST / University of Maryland) Slides
	11:15	Linear Response on a Quantum Computer - Joe Carlson (LANL) Slides
	11:40	Quantum Simulations at Google - Zhang Jiang (Google, inc) Slides
	12:05	Quantum Computing for Feynman Integral Reduction - Joshua Isaacson Slides
	12:30	--- Lunch ---
PM	**13:45**	**Session 3** (until 15:30)
	13:45	What we've learned about gravity from quantum error correction - Daniel Harlow (MIT) Slides
	14:25	Quantum Information Techniques in High Energy Physics - Ning Bao (Berkeley)
	15:05	Quantum Teleportation at Fermilab - Neil Sinclair (Caltech) Maria Spiropulu Slides
	15:30	--- Coffee Break ---
	16:00	**Quantum Computing and the Entanglement Frontier** (until 17:00)
	16:00	Colloquium: Next Steps in Quantum Science for HEP - John Preskill (Caltech)

Thursday, September 13, 2018

08:45	**Session 4** (until 10:40)
08:45	Tensor Network and Cold Atoms Methods for Lattice Gauge Theories - Erez Zohar (Max Planck Institute of Quantum Optics) Slides
09:25	Universal Features of the Polyakov Loop in Quantum Simulations of the Abelian Higgs Model - Judah Unmuth-Yockey (Syracuse University) Slides
09:50	Digitization of Scalar Fields for NISQ-Era Quantum Computing - Natalie Klco (University of Washington) Slides
10:15	An Operator Algebra Approach to Entropy Spread and Quantum Chaos - Nicholas LaRacuente (University of Illinois at Urbana-Champaign) Slides
10:40	--- Coffee Break ---
11:05	**Session 5** (until 12:20)
11:05	Contracting Tensor Network on a Noisy Quantum Computer - Isaac Kim (Stanford University) Slides
11:30	Tensor Networks for Fine-Graining Lattice Gauge Theory, and Also Path Integral Geometry - Ashley Milsted (Perimeter Institute for Theoretical Physics) Slides
11:55	Approaching Lattice Gauge Theories with Matrix Product States and Gaussian States - Stefan Kuehn (Perimeter Institute for Theoretical Physics) Slides
12:20	--- Lunch ---
13:20	**Session 8** (until 14:25)
13:20	Trapped-ion systems for Quantum Simulation of Lattice Gauge Theory - Guido Pagano (University of Maryland) Slides
13:45	A lower bound method for Hamiltonian simulation based on quantum marginals and its relation to quantum information - Nick Rubin (Rigetti) Slides
14:25	**Tutorial** (until 16:25) (Hornet's Nest (8th Floor))
14:25	Refresher Tutorial - Adam Lyon (Fermilab) Slides
15:25	Cirq Intro - Craig Gidney (Google) Slides
16:25	--- Coffee Break ---
16:40	**Tutorial** (until 19:25) (Hornet's Nest (8th Floor))
16:40	OpenFermion Intro - Kevin Sung (Google) Slides
17:40	--- Break ---
17:55	Programming and Experiments

Friday, September 14, 2018

08:30	**Tutorial** (until 10:30) (Hornet's Nest (8th Floor))
08:30	OpenFermion-Cirq VQE Hands On Tutorial - Kevin Sung (Google) Slides
10:30	--- Coffee Break ---
10:45	**Session 6** (until 12:45)
10:45	The IBM-Q Initiative as a Resource for HEP Quantum Computing - Patrick Dreher (NC State University) Slides
11:25	Fermionic Systems and Quantum Computing - Antonio Mezzacapo (IBM)
12:05	A Universal Training Algorithm for Quantum Deep Learning - Guillaume Verdon (Institute for Quantum Computing) Slides
12:45	--- Lunch ---
13:45	**Session 7** (until 15:30)
13:45	Quantum Link Lattice Field Theory - Richard C. Brower (Boston University) Slides
14:10	TBD: Quantum Simulation of Field Theories - Martin Savage (Institute For Nuclear Theory) Slides
14:50	Closing Remarks - John Preskill (Caltech) Slides
15:30	--- Wine & Cheese ---
16:00	**Fermilab Joint Experimental-Theoretical Physics Seminar** (until 17:00)
16:00	Entanglement in Gauge Theories - Sandip Trivedi (Tata Institute for Fundamental Research)

@CERN 2 days QC/HEP workshop November 5-6 2018

Quantum Computing for High Energy Physics workshop

from **Monday, 5 November 2018 (08:30)** to **Tuesday, 6 November 2018 (18:50)**
CERN (Main Auditorium)

: Sessions / : Talks : Breaks

5 Nov 2018

AM	09:00	Opening - Dr Federico Carminati (CERN) (500-1-001 - Main Auditorium) — QC-Meeting.pdf, QC-Meeting.pptx, Recording
	09:10	Introduction - Dr Eckhard Elsen (CERN) (500-1-001 - Main Auditorium) — Introduction Quantum Computing Nov 2018.pdf, Recording
	09:40	CERN openlab - Dr Alberto Di Meglio (CERN) (500-1-001 - Main Auditorium) — CERN openlab QC Workshop 2018.pdf, CERN openlab QC Workshop 2018.pptx, Recording
	10:10	Introduction to Quantum Computing - Prof. Simone Montangero (Università di Padova) (500-1-001 - Main Auditorium) — Montangero_CERN.pdf, Recording
	10:40	--- Coffee Break ---
	11:00	Quantum Computing at INTEL - Dr Astrid Elbe (Intel) (500-1-001 - Main Auditorium) — Intel QC 5 Nov 2018 Astrid Elbe final.pdf, Recording
	11:30	Quantum Computing at Strangeworks - Dr Andrew Ochoa (Strangeworks) (500-1-001 - Main Auditorium) — QCatSW-02_Ochoa.pdf, Recording
PM	12:00	Quantum Computing at D-Wave - Dr Bo Ewald (D-Wave) (500-1-001 - Main Auditorium) — CERN 18 11 5_Ewald.pdf, CERN 18 11 5_Ewald.pptx, Recording
	12:30	--- Lunch Break ---
	14:00	The ATLAS Physics challenge at the HL-LHC and ideas about Quantum Computing - Heather Gray (LBNL) (500-1-001 - Main Auditorium) — hgray_quantumcomputing.pdf, Recording
	14:30	Quantum Computing at Barcelona Supercomputing Center / Qilimanjaro - Dr Jose Ignacio Latorre Sentis (Barcelona Supercomputing Center) (500-1-001 - Main Auditorium) — 18-CERN-algorithms_Latorre.pdf, Recording
	15:00	Computing models and resource needs for ATLAS and CMS during HL_LHC - Tommaso Boccali (Universita & INFN Pisa (IT)) (500-1-001 - Main Auditorium) — quantum computing atlas and cms Nov 2018.pdf, quantum computing atlas and cms Nov 2018.pptx, Recording
	15:30	--- Coffee Break ---
	16:00	LHCb Run 3 Computing Model - Marco Cattaneo (CERN) (500-1-001 - Main Auditorium) — 20181105_LHCbComputingModel-QCWkshop.pdf, Recording
	16:30	Classification with Quantum Annealing on the D-Wave System - Dr Jean-Roch Vlimant (California Institute of Technology (US)) (500-1-001 - Main Auditorium) — Recording, vlimant_DW-OpenLab_Nov18.pdf
	17:00	NEQsys – The Northeast Quantum Systems Center supporting research and services in support of real applications - Dr Kerstin Kleese Van Dam (BNL) (500-1-001 - Main Auditorium) — BNL - CERN Quantum Workshop Talk 2018.pdf, Recording
	17:30	Quantum Communication Networks and the Quantum Flagship - Prof. Robert Thew (University of Geneva) (500-1-001 - Main Auditorium) — Recording, Thew CERN QCompConf.pdf
	18:00	--- Dinner Break ---
	20:00	Piano Concert - Mr Jérôme Kus (500-1-001 - Main Auditorium)

6 Nov 2018

09:00	Quantum Computing at IBM - Tavernelli Ivano (IBM) (500-1-001 - Main Auditorium) — CERN_Tavernelli4_I.pdf, Recording
09:30	Quantum Computing at Microsoft - Dr Stephen Jordan (Microsoft) (500-1-001 - Main Auditorium) — QC_at_Microsoft_CERN3.pdf, Recording
10:00	ProjectQ - Mr Damien Steiger (ETHZ) (500-1-001 - Main Auditorium) — projectq_cern_steiger.pdf, Recording
10:30	--- Coffee Break ---
11:00	Quantum Computing at Google - Kevin Kissell (Google Cloud Office) (500-1-001 - Main Auditorium) — CERN 2018 Quantum Talk_Kissell.pdf, Recording
11:30	Reinforcement learning approach for fast qubit control - Andrey Ustyuzhanin (Yandex School of Data Analysis (RU)) (500-1-001 - Main Auditorium) — Deep RL for fast qubit control_3.pdf, Recording
12:00	Quantum Variational AutoEncoder - Dr Walter Vinci (D-Wave) (500-1-001 - Main Auditorium) — QC_for_HEP.pdf, Recording
12:30	--- Lunch Break ---
14:00	Prime numbers and quantum computers - Dr Gérman Sierra (CSIC-UAM) (500-1-001 - Main Auditorium) — Recording, Sierra-Primes-QC-18.pdf
14:30	Digital quantum computation of fermion-boson interacting systems - Dr Alexandru Macridin (FNAL) (500-1-001 - Main Auditorium) — macridin_fb_cern2018.pdf, Recording
15:00	Quantum Computing at Rigetti - Dr Will Zeng (Rigetti Computers) (500-1-001 - Main Auditorium) — CERN (Nov 2018).pdf, Recording
15:30	--- Coffee Break ---
16:00	FNAL Quantum Program - Panagiotis Spentzouris (Fermilab) (500-1-001 - Main Auditorium) — FermilabProgram_CERN.pdf, Recording
16:30	Preliminary Development on HEP Data Analysis Using Quantum Computing based on IBM Qiskit (progress report) - Dr Wen Guan (University of Wisconsin/Madison) (500-1-001 - Main Auditorium) — Quantum machine learning for hep- VERSION 3(1).pdf, Recording
17:00	Round Table on Quantum Computing - Federico Carminati (CERN) (500-1-001 - Main Auditorium) — Recording


Think different.
DOWNTOWN CAR WASH

DETECTING THE THE DARK UNIVERSE

CALTECH COLLOQUIUM OCTOBER 2016 : SOURCE KATHRYN ZUREK

QUANTUM SENSORS FOR HEP IN THE DARK MATTER LANDSCAPE

1 meV | 1 eV | 1 keV | 1 MeV | 1 GeV | 100 GeV

DM mass

Absorption

Polar Crystals

Dirac Materials

Super-conductors

Superfluid Helium

Semiconductors

SuperCDMS

DAMIC, SENSEI

Graphene

Traditional WIMP

XENON1T

LZ

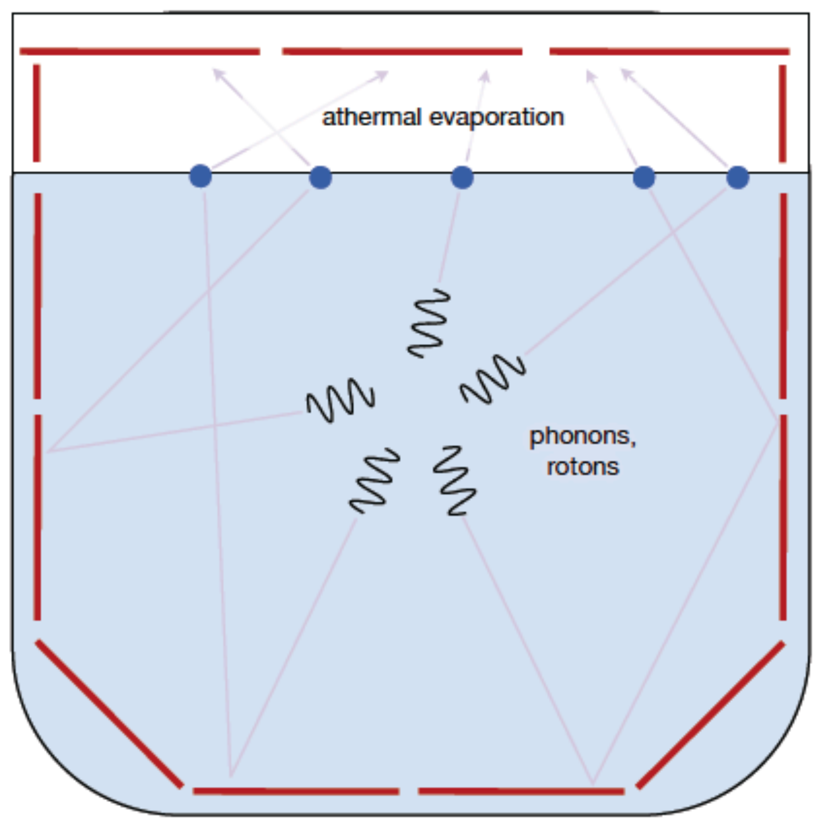
QCD axion, "ultralight frontier"

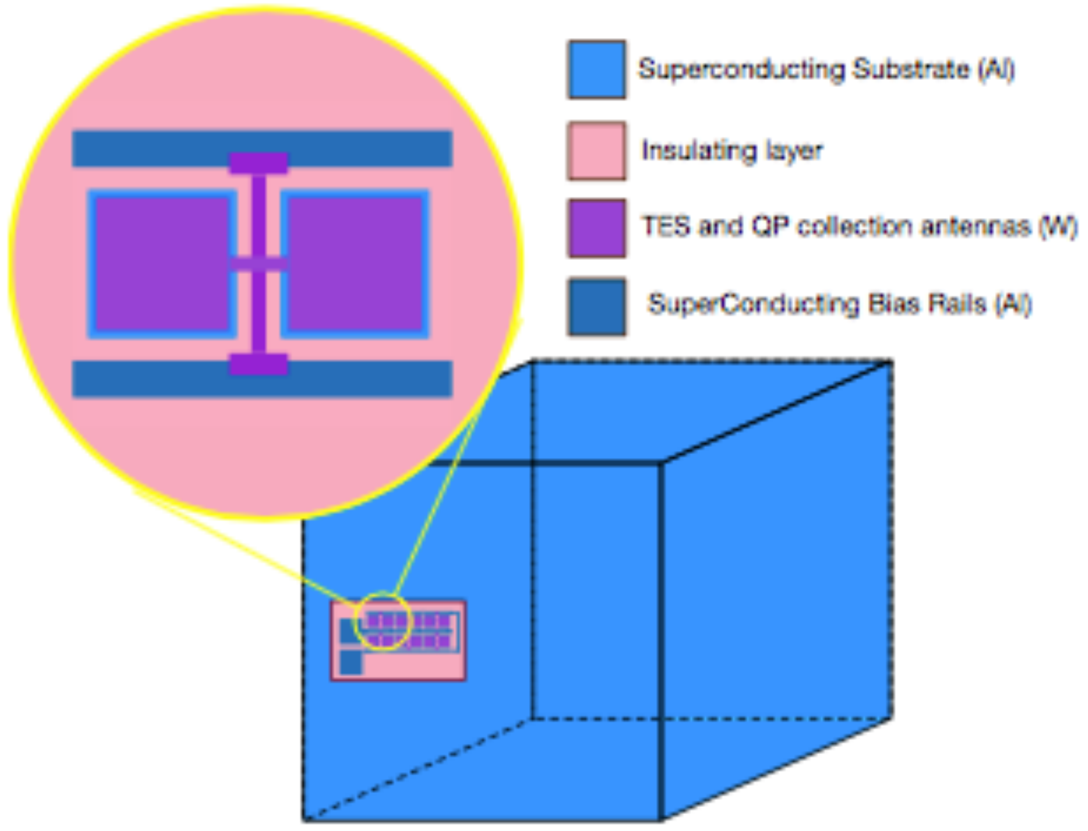
~meV energy resolution

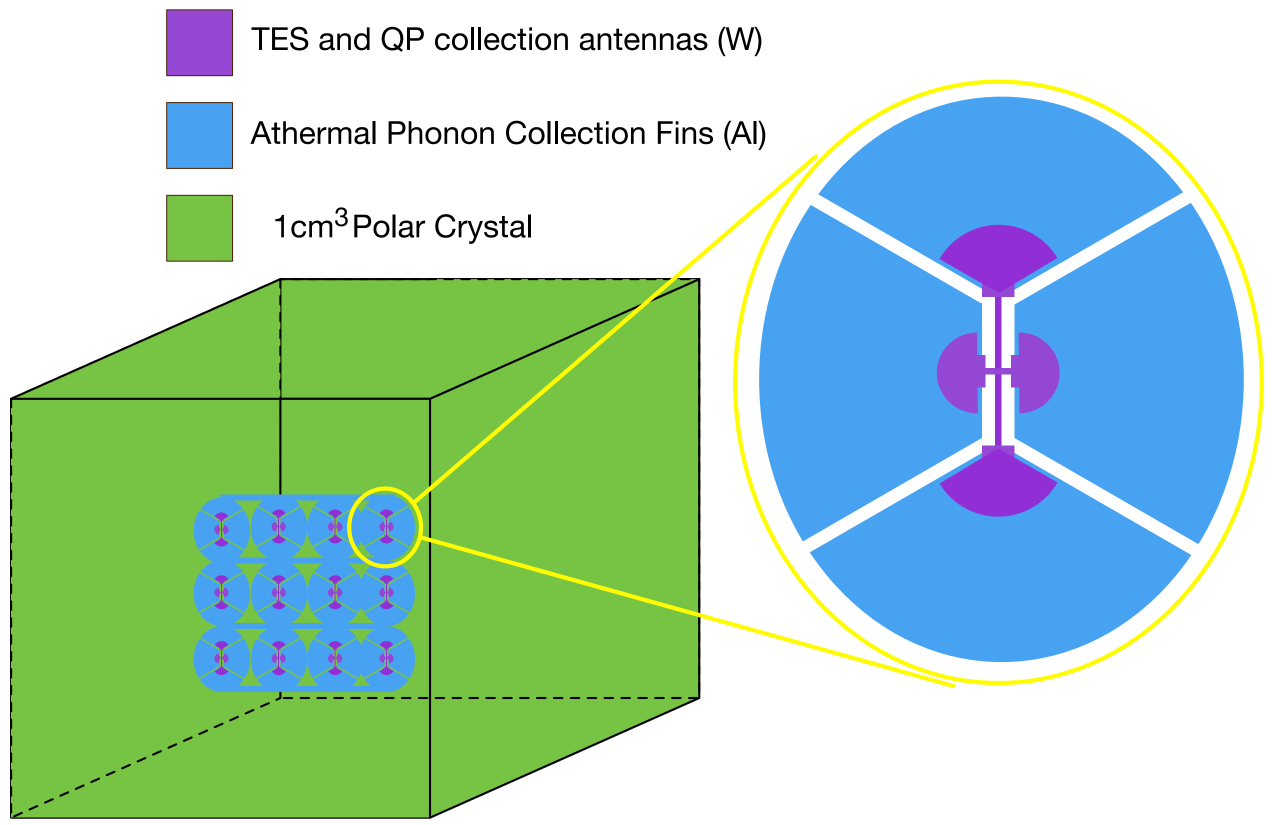
~eV energy resolution

~keV energy resolution

QUANTUM SENSORS PORTABLE TO A WIDE RANGE OF THESE TARGETS







GOING LOW IN THE X-AXIS

- New ideas for dark matter detection!
- Moving beyond nuclear recoils into phases of matter crucial to access broader areas of DM parameter space
- Target diversity essential. graphene, superconductors, semiconductors, helium ….. Weyl semi-metal?
- Fun interplay between HET and condensed matter

SYMMETRY BREAKING AND COMPLEXITY

Nambu (1960)

The importance of Spontaneous Symmetry Breaking

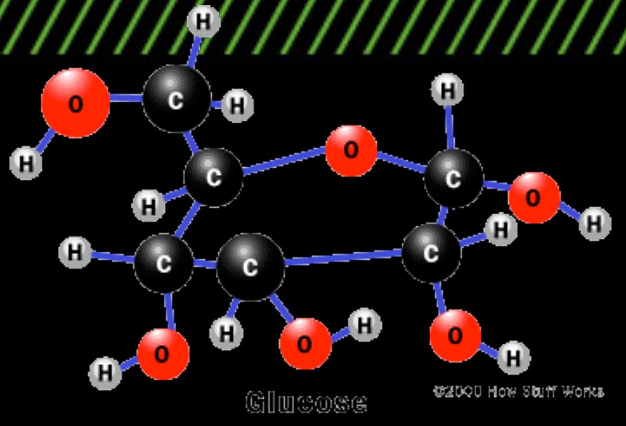
Nobel Lecture: Spontaneous symmetry breaking in particle physics: A case of cross fertilization*

Yoichiro Nambu

Physical system	Broken symmetry
Ferromagnets	Rotational invariance (with respect to spin)
Crystals	Translational and rotational invariance (modulo discrete values)
Superconductors	Local gauge invariance (particle number)

- Apply condensed matter ideas to **particle physics**
- **Now the quantum vacuum is the "medium"**

SYMMETRY BREAKING AND COMPLEXITY



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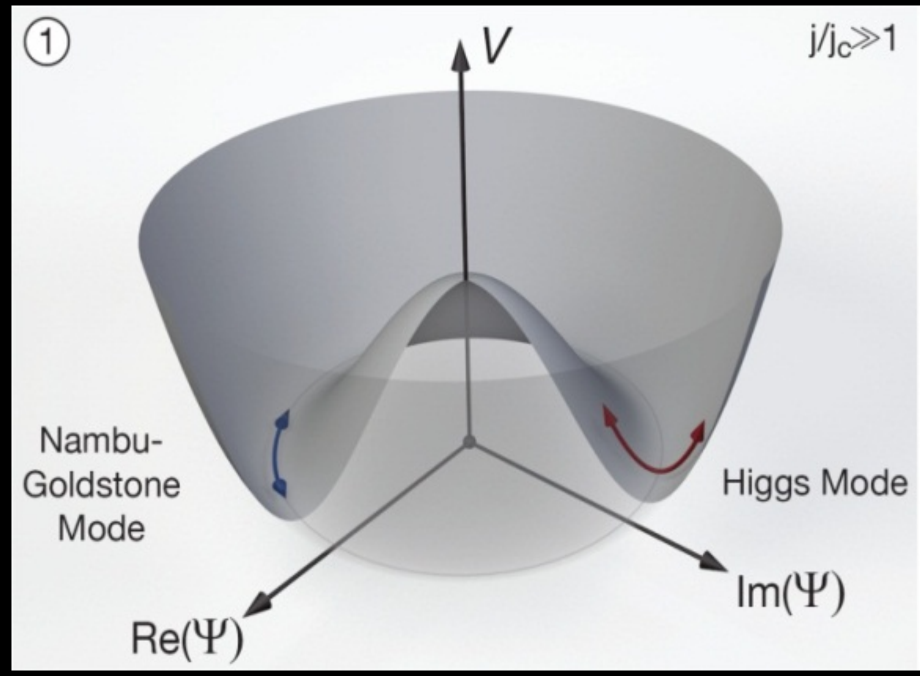
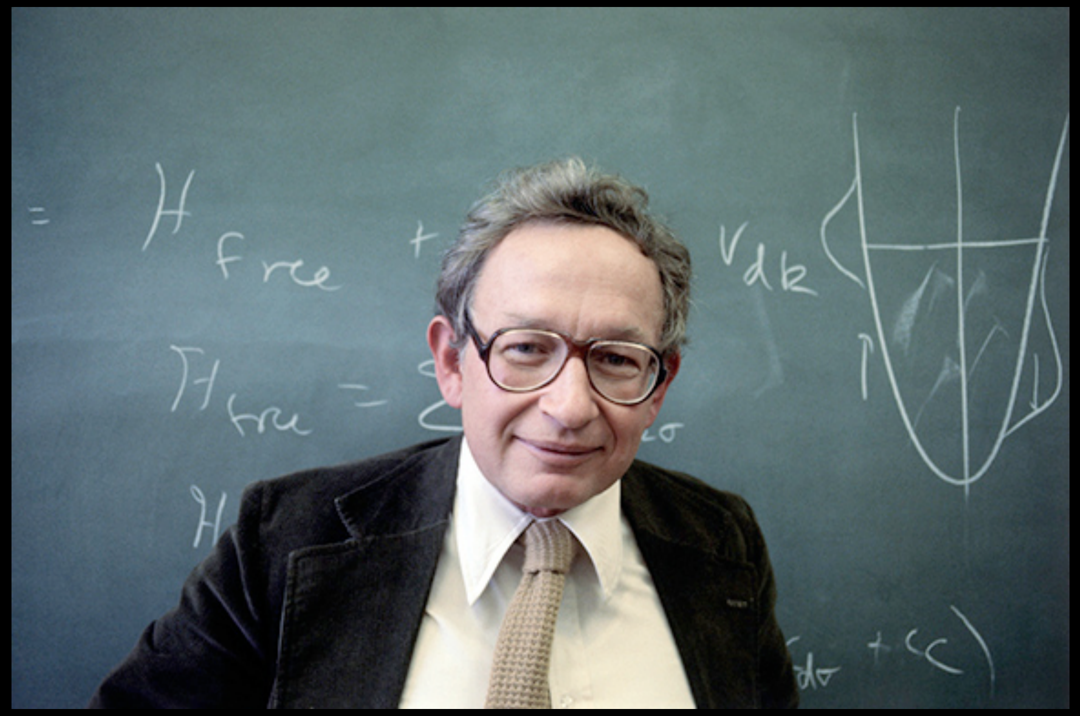
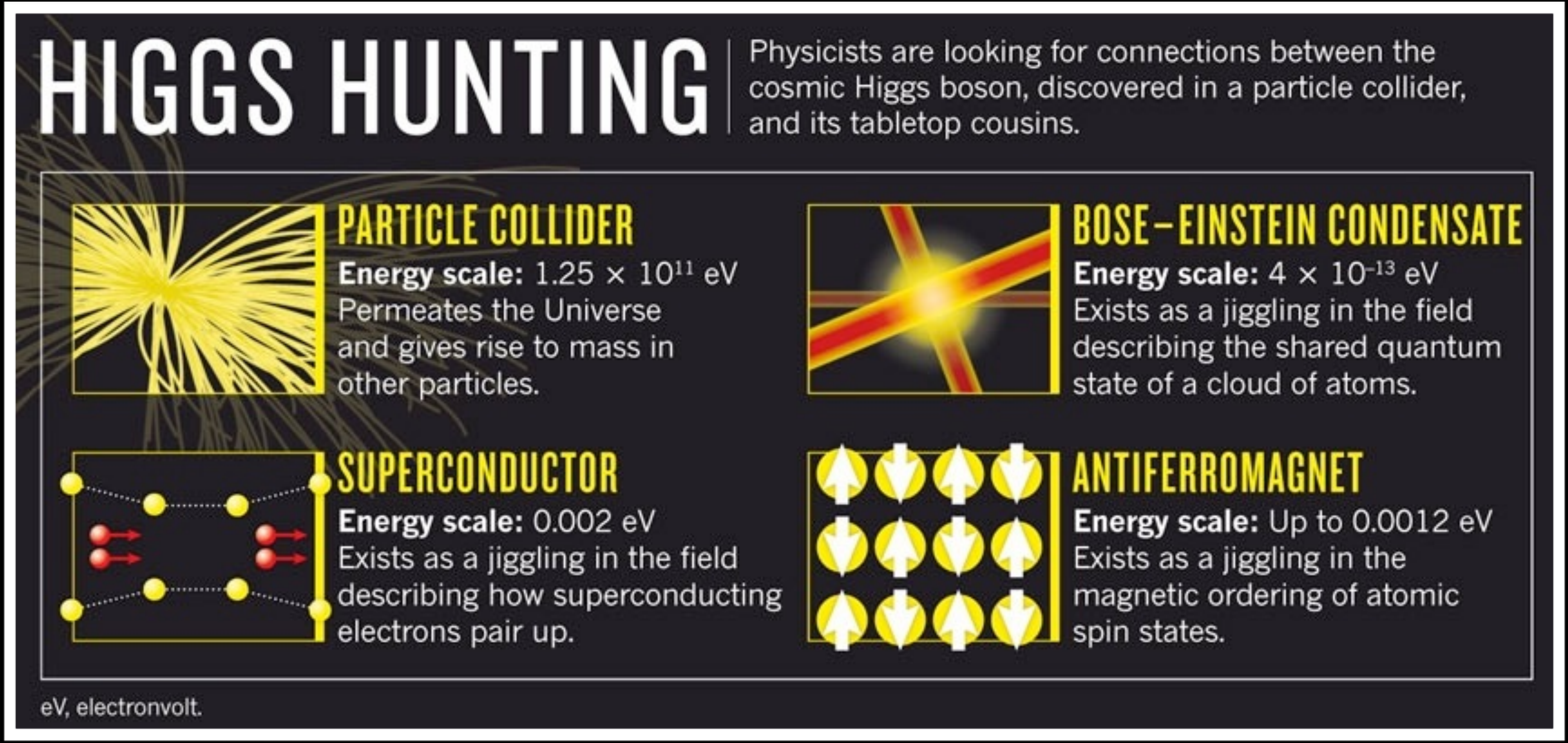




- Apply condensed matter ideas to **particle physics**
- **Now the quantum vacuum is the "medium"**

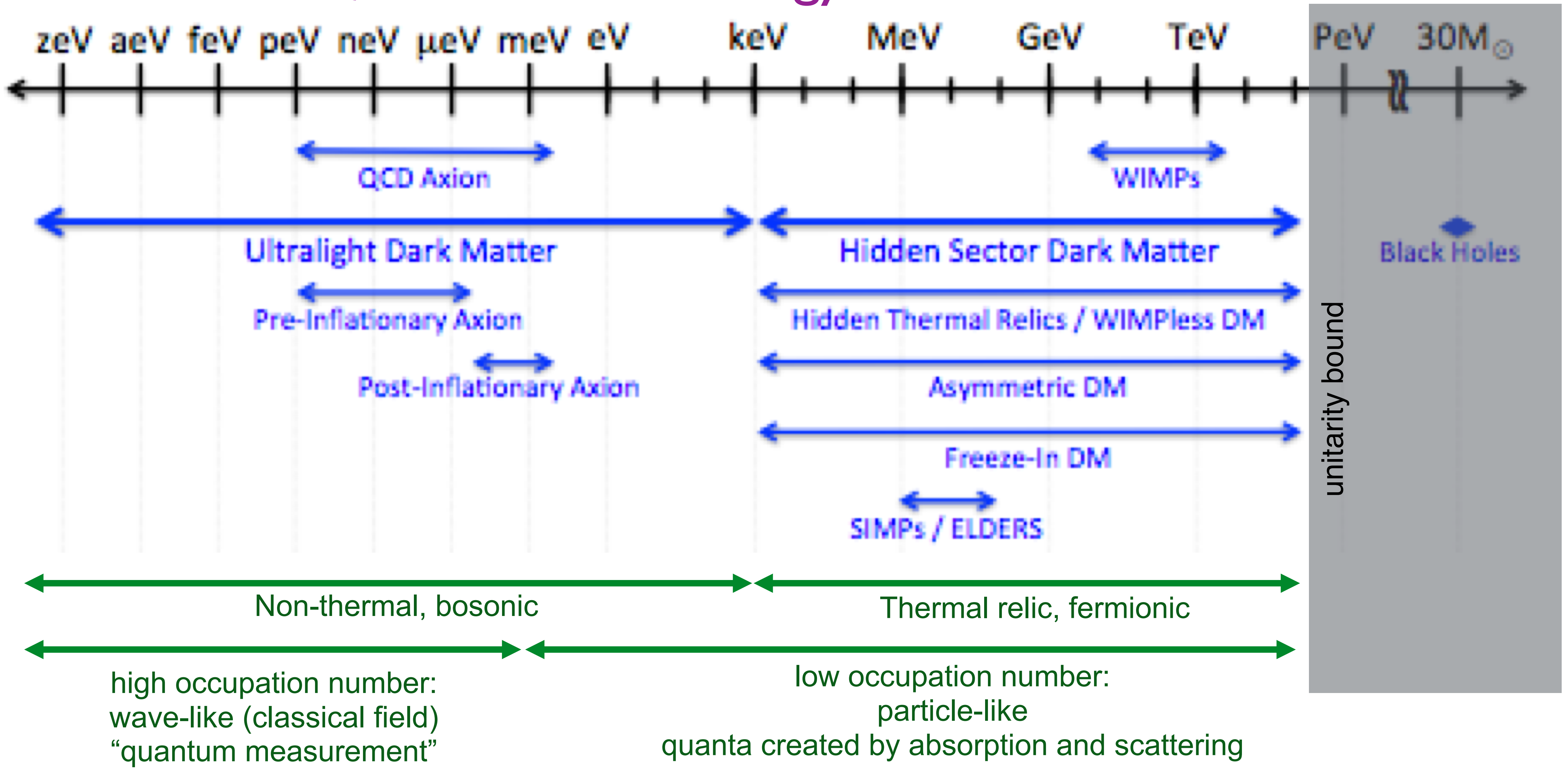
- ***The quantum vacuum*** is like a many-body system
- As Phillip Anderson emphasized in his 1972 article "**More is Different**", **spontaneous symmetry breaking is a property of "large" systems**

SYMMETRY BREAKING DYNAMICS



"light" Higgs bosons states were discovered in niobium-selenide superconductors in 1981

Quantum Technology for Dark Matter



US Cosmic Visions DM 2017 summarized the new, expanded landscape for DM

Two regimes for quantum technologies:

High occupation number = wave-like (classical field) regime: R&D on technologies needed to make "quantum-limited" measurements of classical fields (e.g., atom interferometry, NMR, EM waves)

Low occupation number = particle-like regime: R&D on technologies needed to measure creation of individual quanta that are coherent quantum mechanical modes (e.g., phonons, quasiparticles)

Quantum Sensors for Low Occupation Number, Low-Mass DM

Scattering of thermal relic DM down to warm-DM observational bound (few keV)

Current technologies can reach to

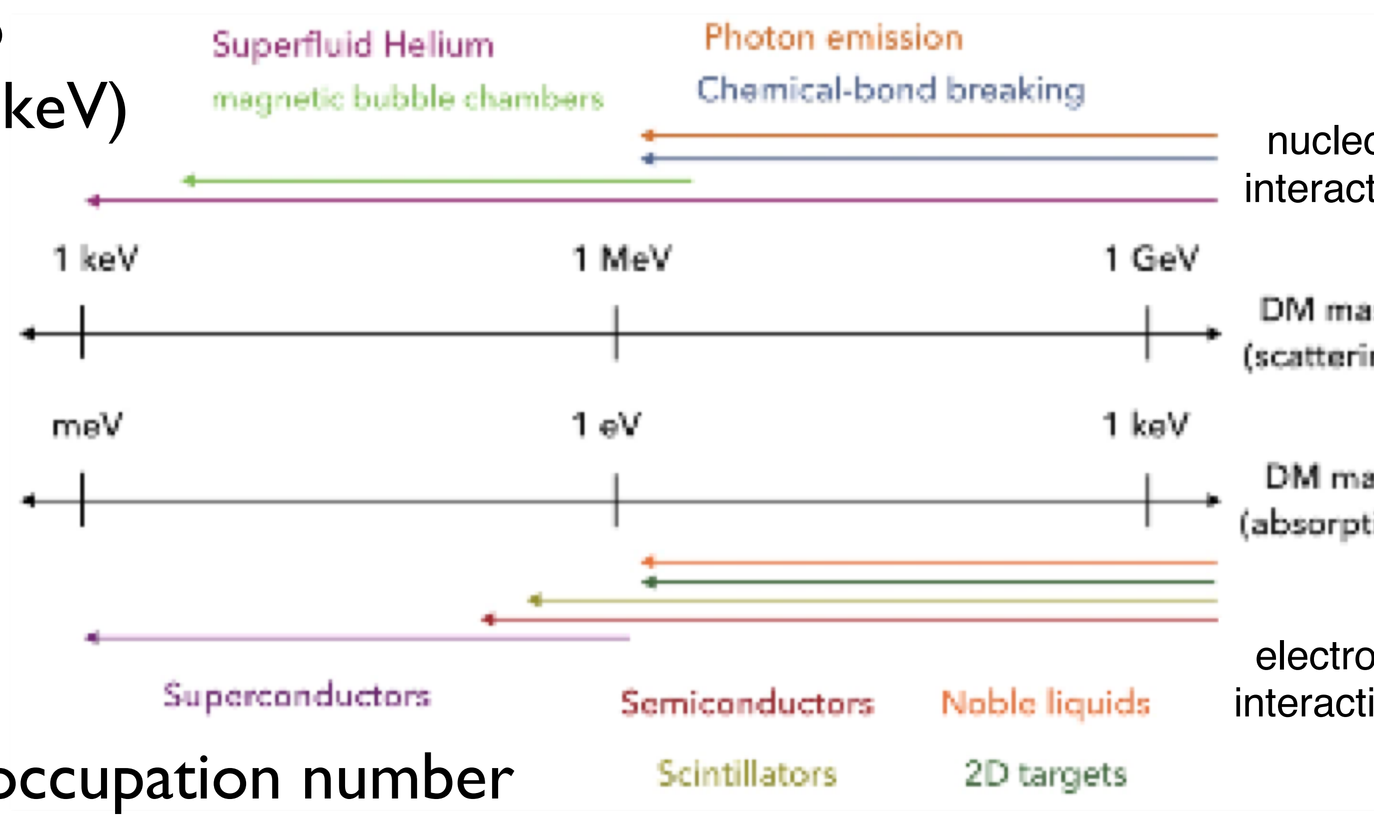
50 MeV nucleon interaction (scattering)

1 MeV electron interaction (scattering)

Absorption of non-thermal relic DM (photon or axion-like) meV-keV

Current technologies can reach to

1 eV absorption



Covering full parameter space for low occupation number DM requires new technologies to sense sub-eV depositions

At these energies, deposition excites coherent modes: fundamentally *quantum* phenomena

e.g., phonons, quasiparticles in superconductors, rotons in LHe, almost gap-less Dirac materials

R&D required to reach sensitivity to detect single coherent quanta at meV energies

Phonons, quasiparticles already employed (e.g., SuperCDMS)

Need to push currently available superconducting sensor technologies to single-quantum detection

transition-edge sensors (TESs) used in SuperCDMS: mature, but need to demonstrate sensitivity scaling

microwave kinetic inductance detectors (MKIDs) under dev't but needs bigger push than to date

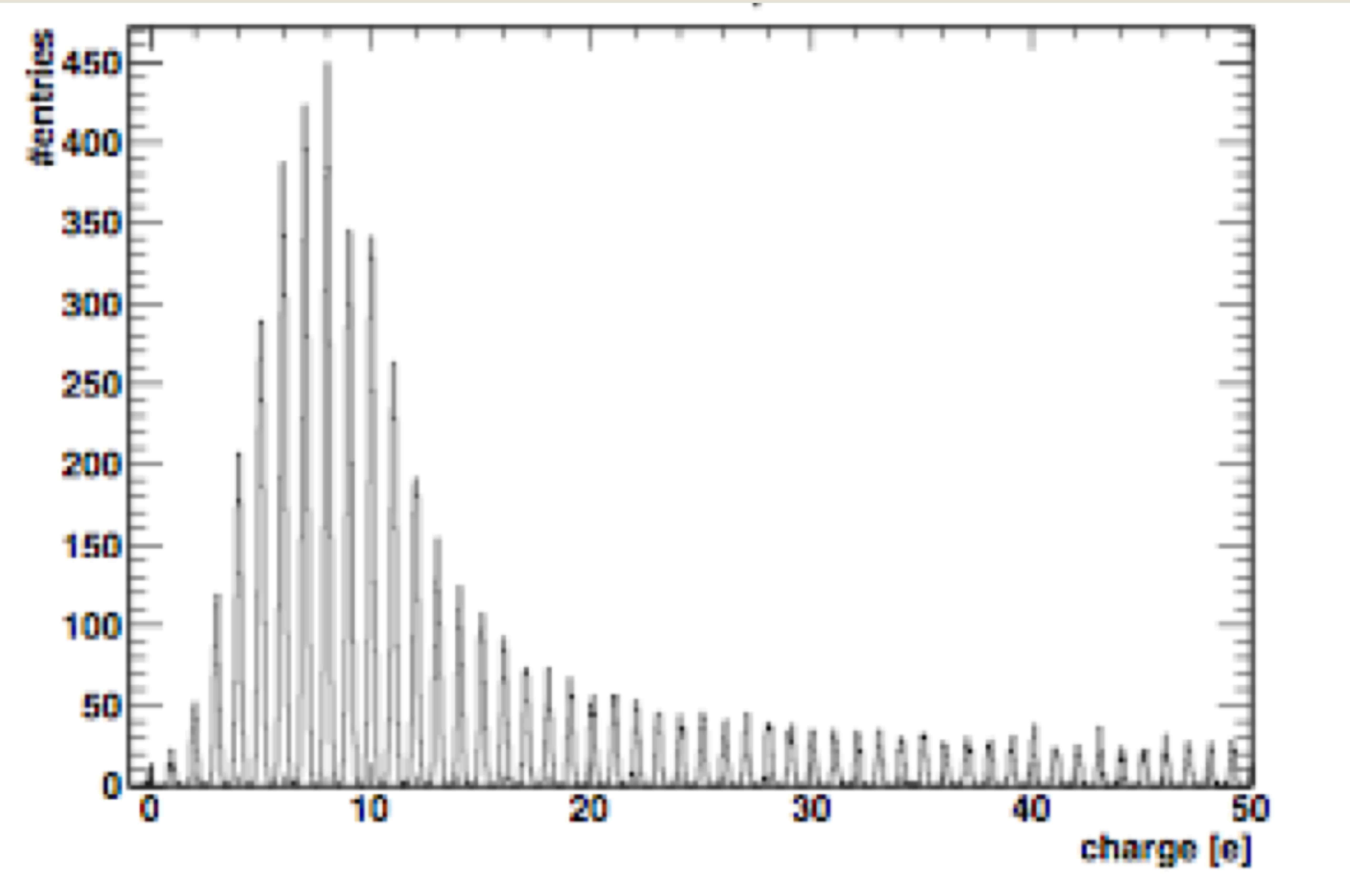
Need to develop new technologies that may have better sensitivity; e.g., Dirac materials

Potential for synergy with "quantum measurement"

e.g. quantum-limited amplifiers necessary for readout of some quantum sensors

CCD'S ⇒ SKIPPER-CCDS W/ SUB-SHOT NOISE

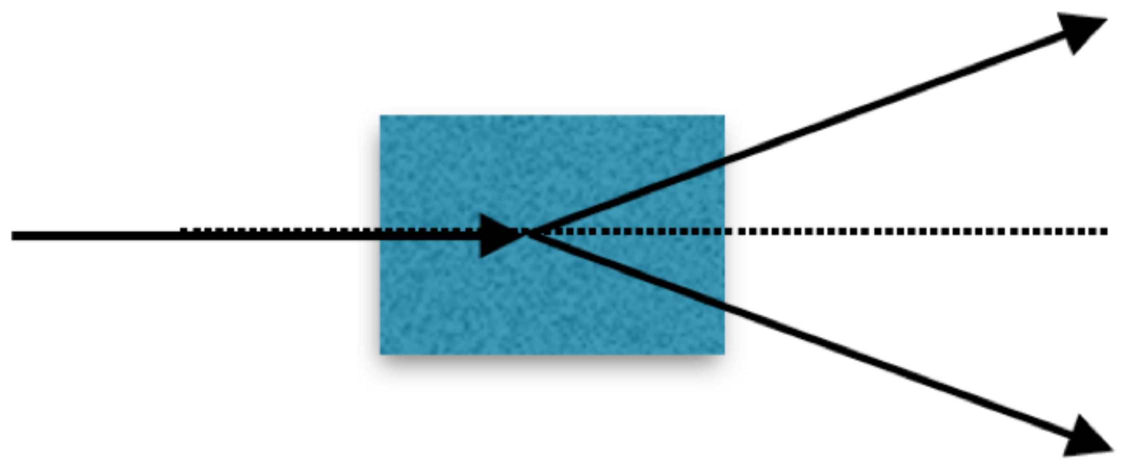
DARK SECTOR SEARCHES



- Can count from 0 to ~1000 photons. No internal gain in the sensor means no additional noise factor. Skipper-CCD will be truly able to explore the sub-shot noise fluctuations.
- 1. Validate noise fluctuations
- 2. Optimize readout speed and dynamic range
- 3. Use for dark photon searches

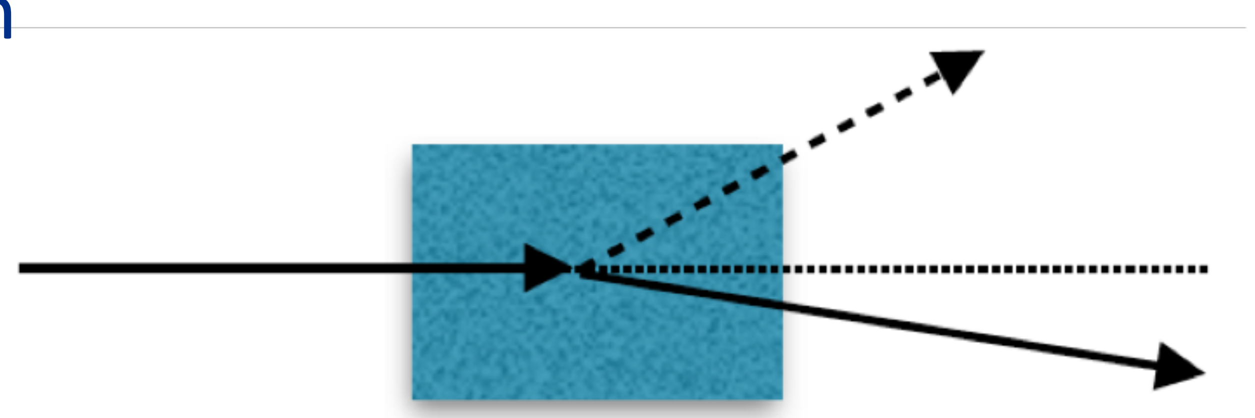
CCD'S ⇒ SKIPPER-CCDS W/ SUB-SHOT NOISE

DARK SECTOR SEARCHES

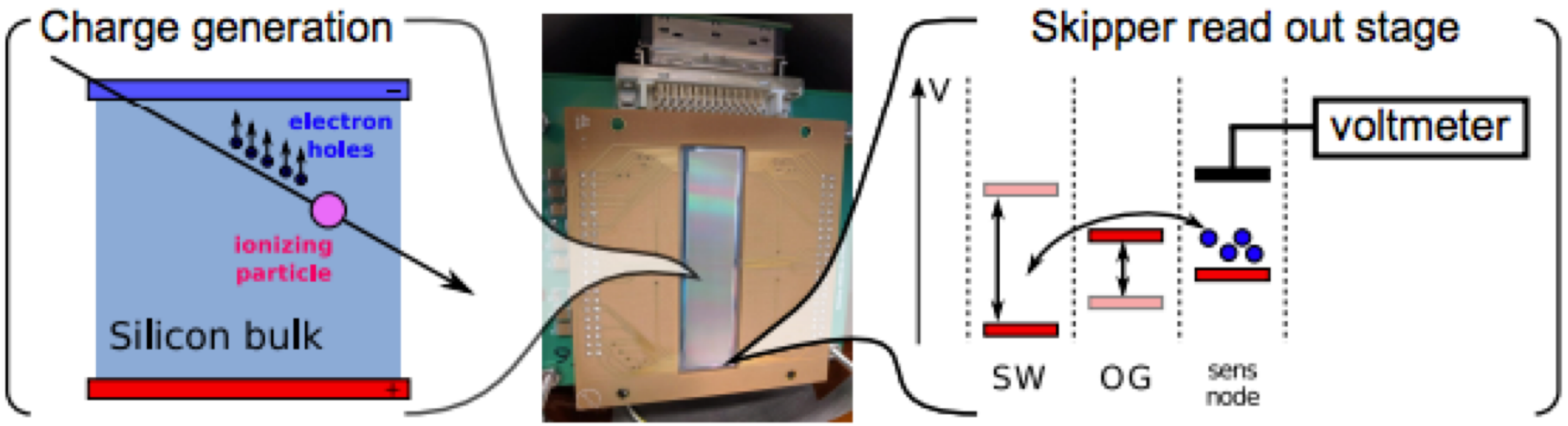


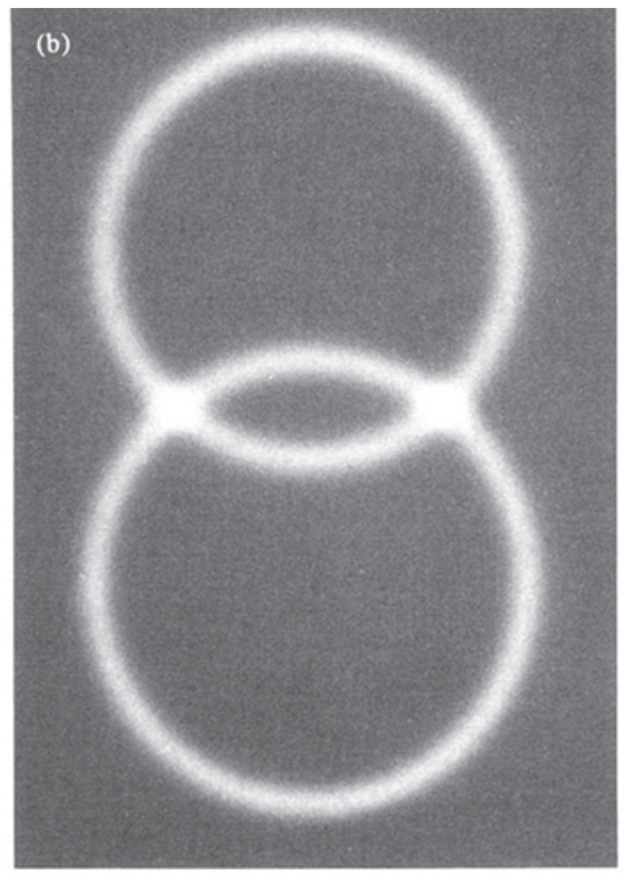
Spontaneous Parametric Down Conversion **(SPDC):** down-converted photons are entangled in angle and energy.

Emission angle and energy determined by the phase matching conditions and the crystal's index of refraction.



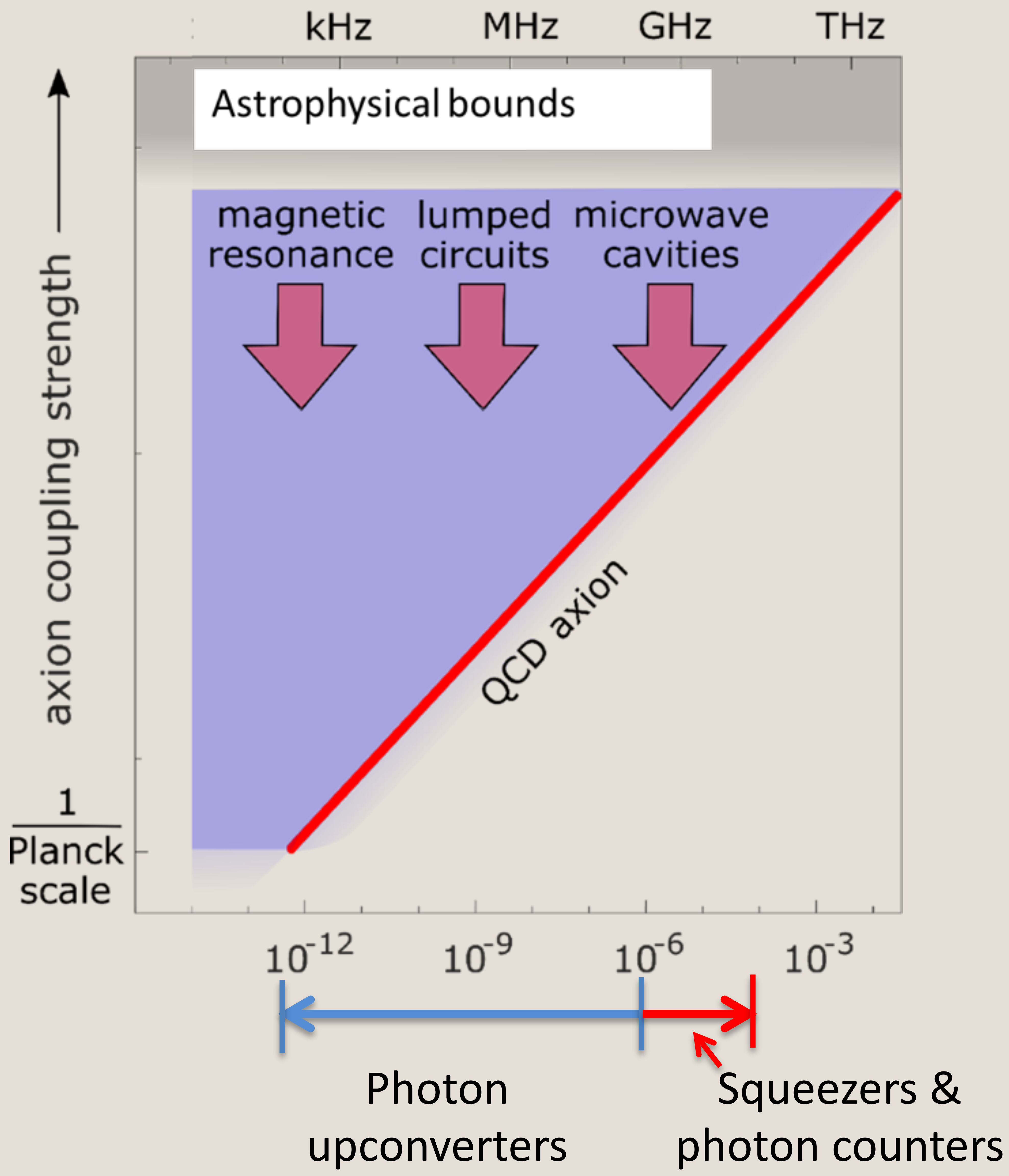
The index of refraction of the dark photon is significantly different, thus the angle of the visible photon is also significantly different for a given energy.





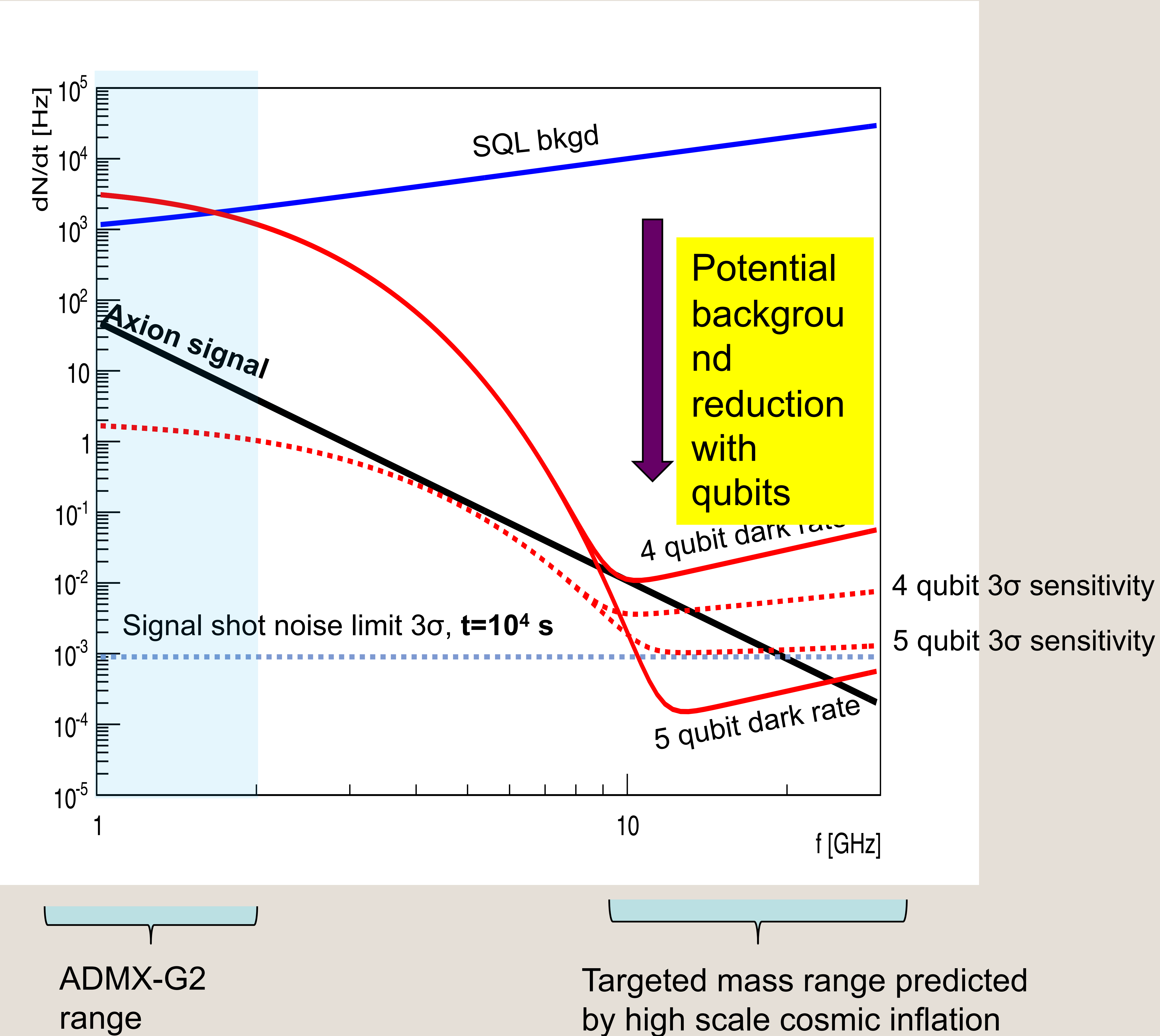
AXIONS

- Different quantum sensors are needed to probe the QCD axion in different frequency ranges:
- • peV - ueV: Photon upconverters (with both NMR spin and lumped circuits)
- • ueV - ~10 ueV : Parametric amplifiers with squeezing
- •~10 ueV - ~100 ueV : Qubit-based photon counters
- <u>It is not possible to fully probe the QCD axion band without quantum sensors operating below the quantum limit.</u>



EXAMPLE AXION

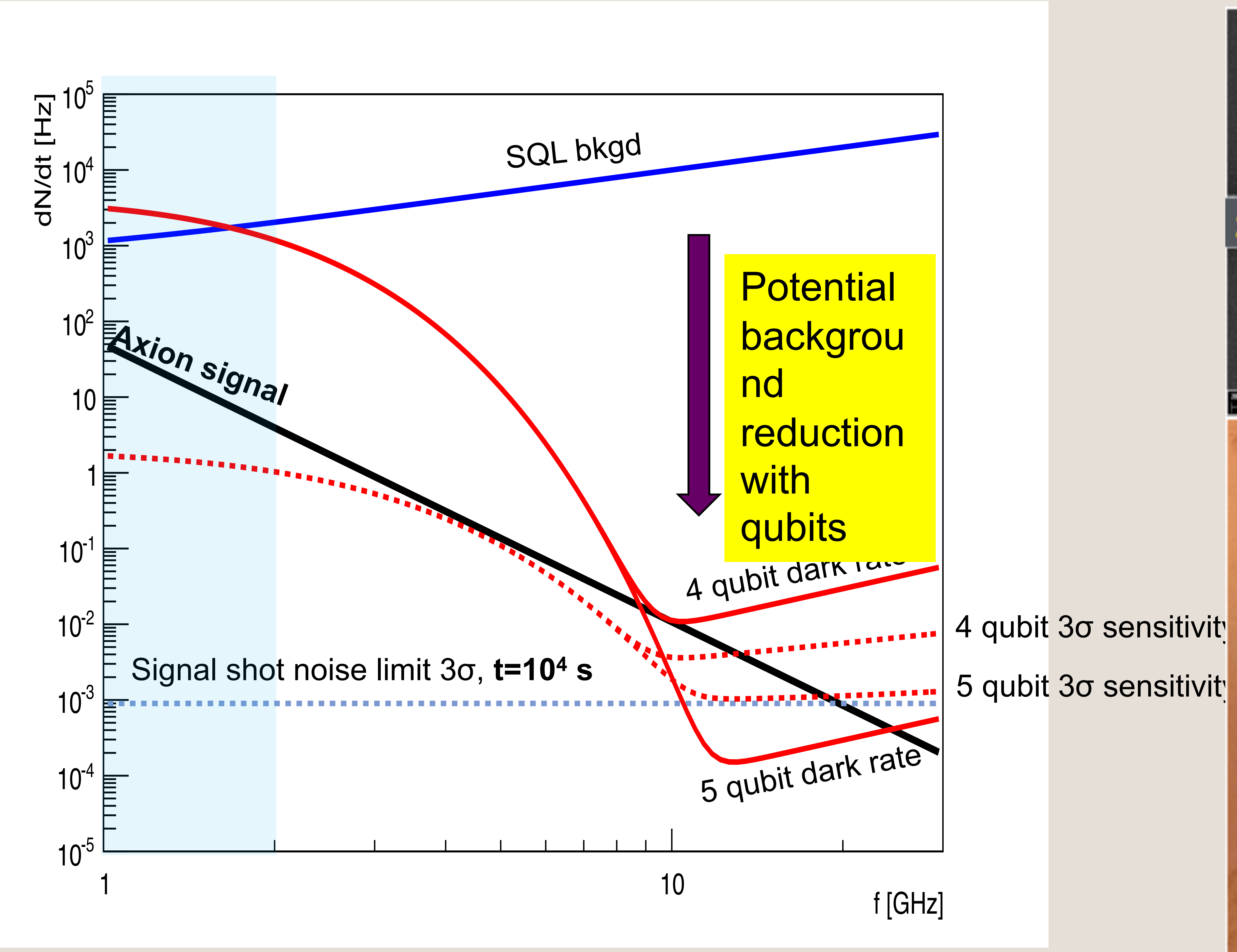
SC QUBITS AS QUANTUM-NON-DEMOLITION SINGLE PHOTON COUNTERS



- Sensitivity of current axion dark matter experiments (ADMX, HAYSTAC) is limited by zero-point readout noise – the standard quantum limit of phase resolving amplifiers
- Qubit detectors measure only photon wave amplitude but not phase evades SQL bound
- Count photons via the qubit's Stark frequency shift (= Lamb shift due to real photons).

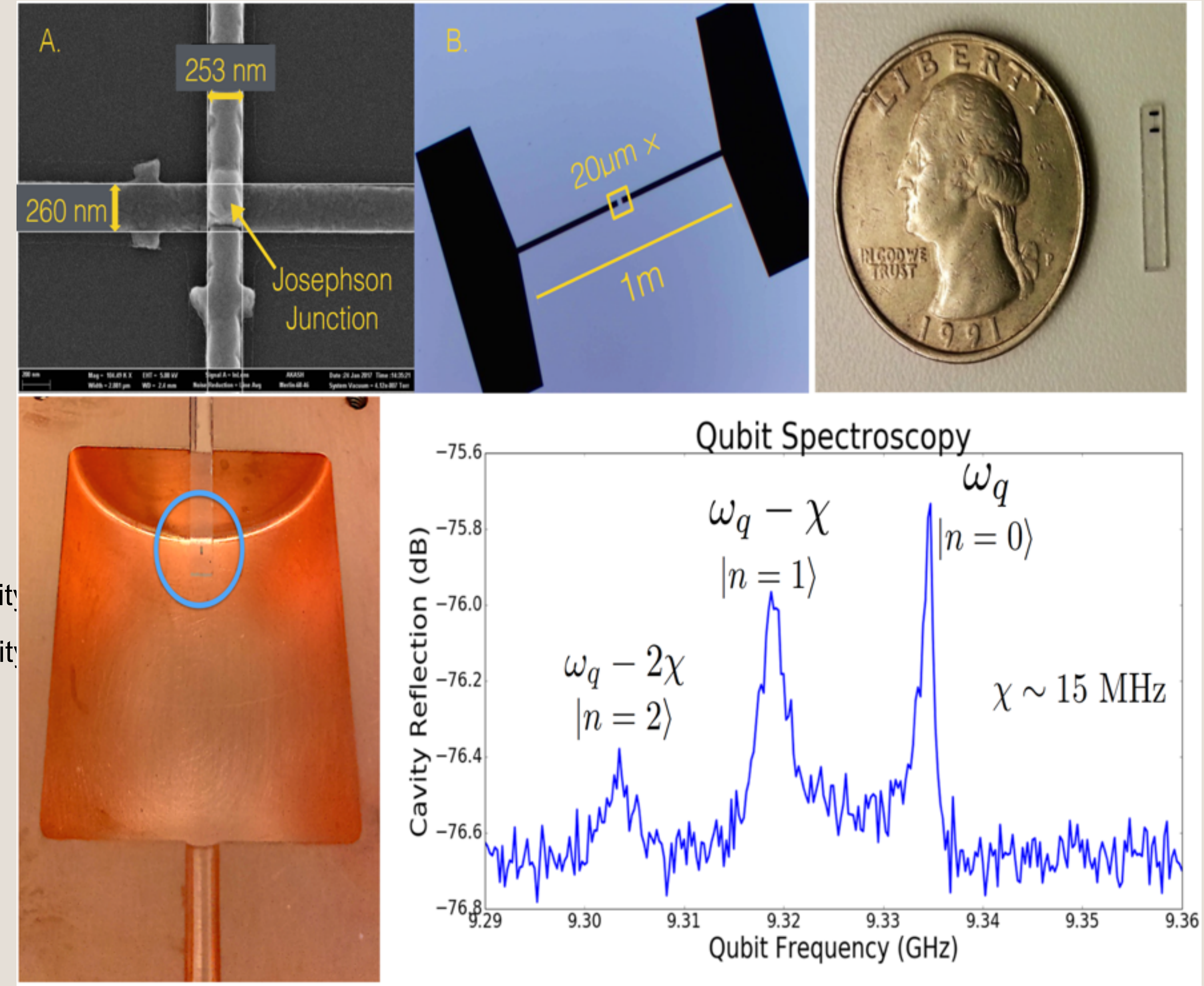
EXAMPLE AXION

SC QUBITS AS QUANTUM-NON-DEMOLITION SINGLE PHOTON COUNTERS



ADMX-G2 range

Targeted mass range predicted by high scale cosmic inflation



source: Fermilab

EXAMPLE AXION

INFRASTRUCTURE

- Multiple sub-Kelvin test stands – dilution refrigerators, adiabatic demagnetization, He3 fridges
  - Supports DOE projects including ADMX-G2, SPT-3G
  - R&D on MKIDs, superconducting qubits
- SiDet bubble chamber pit undergoing full renovation to house new LDRD-funded axion test stand
  - Large dilution refrigerator + 14 T cryogen-free magnet
  - 2018 DOE Early Career award to Daniel Bowring for axion sensor development
- Cryogenic, RF, and magnet engineering departments support both projects and R&D

Rakshya Khatiwada, ADMX L2 manager for cold electronics, assembling a prototype cryogenic package for quantum amplifiers at Fermilab's SiDet facility

EXAMPLE AXION

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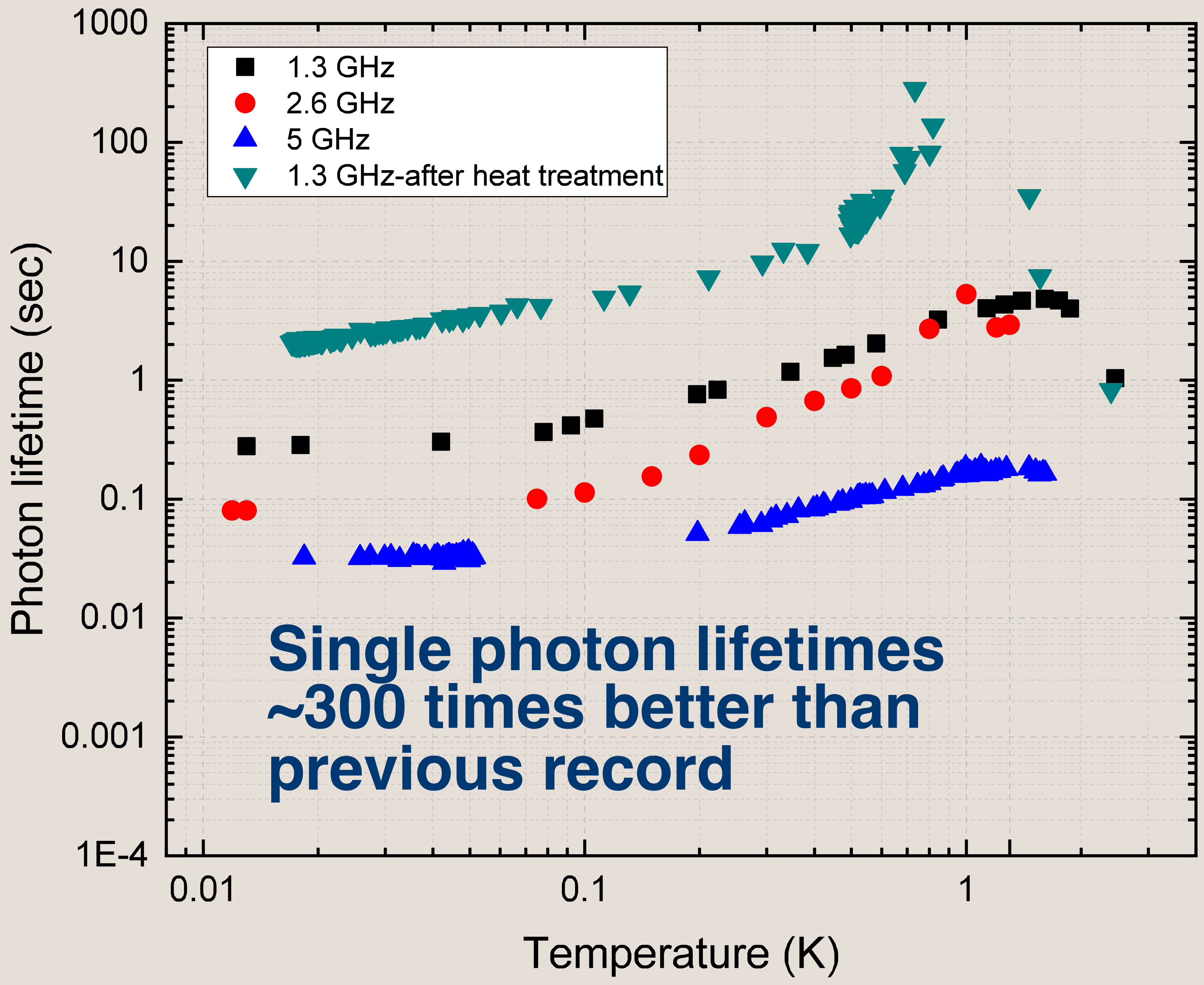
- Record high-Q niobium cavities extend qubit lifetimes, enable milliKelvin dark photon searches

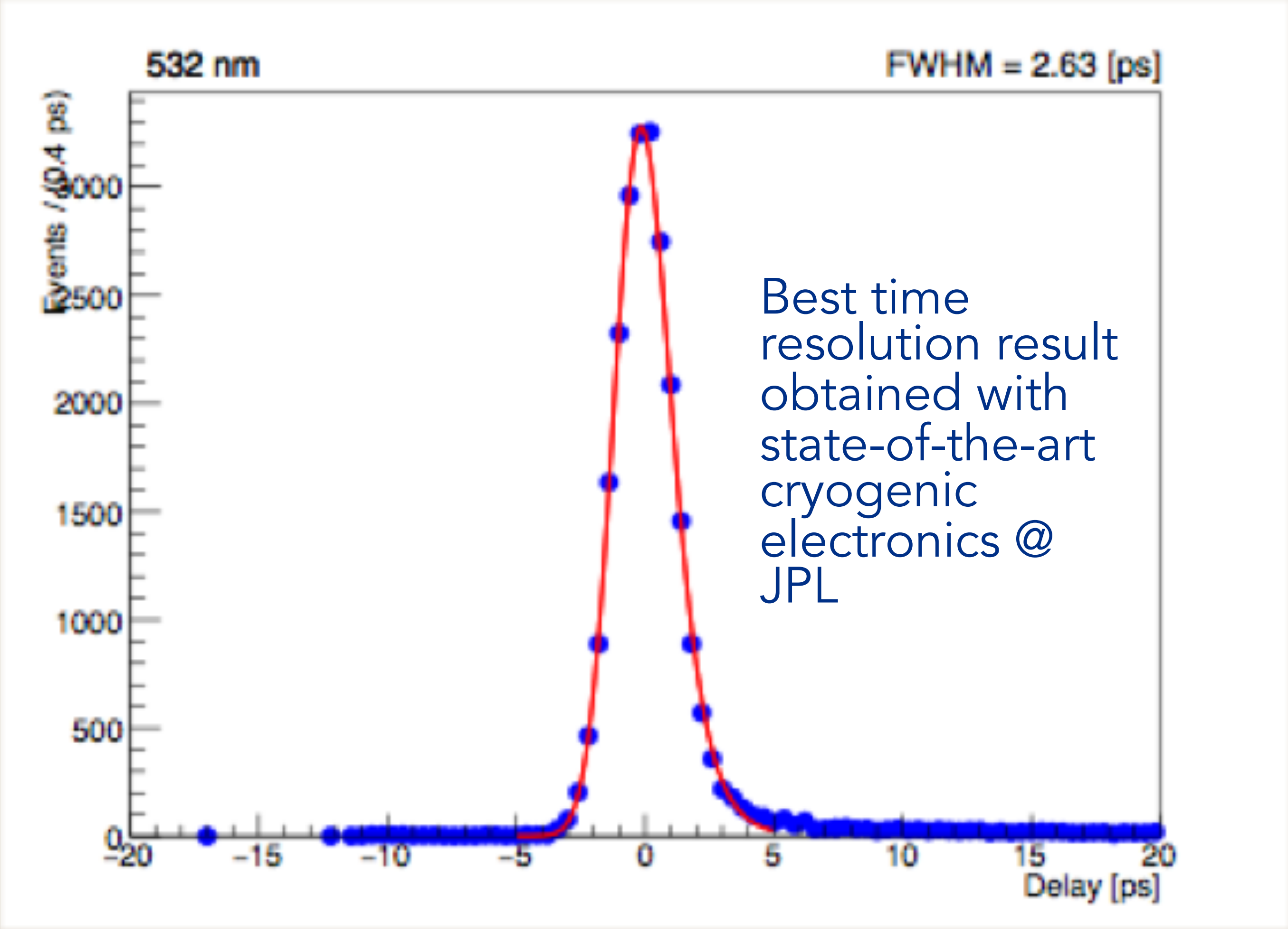


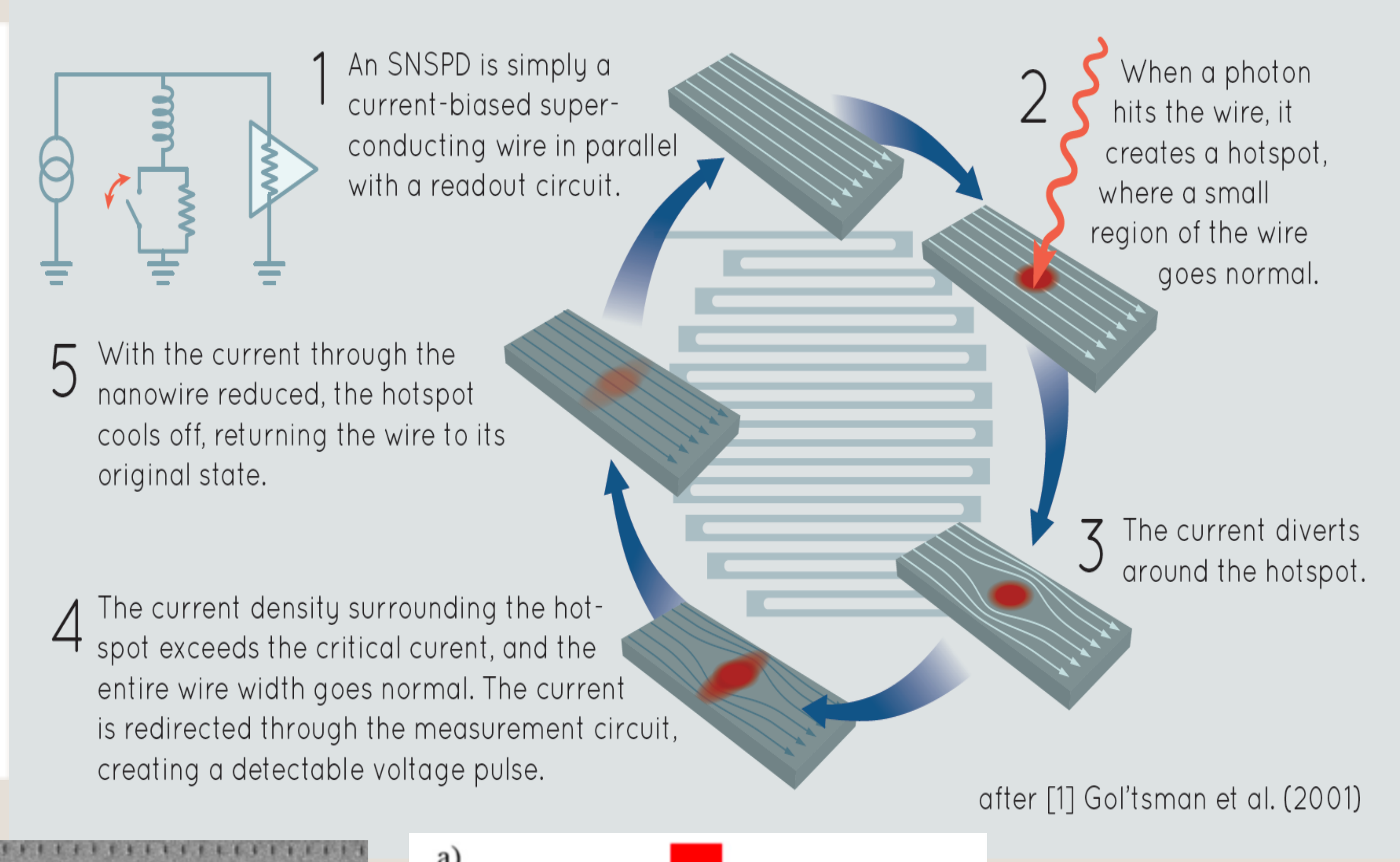
A. Romanenko, R. Pilipenko, S. Zorzetti, D. Frolov, M. Awida, S. Posen, A. Grassellino, arXiv:1810.03703

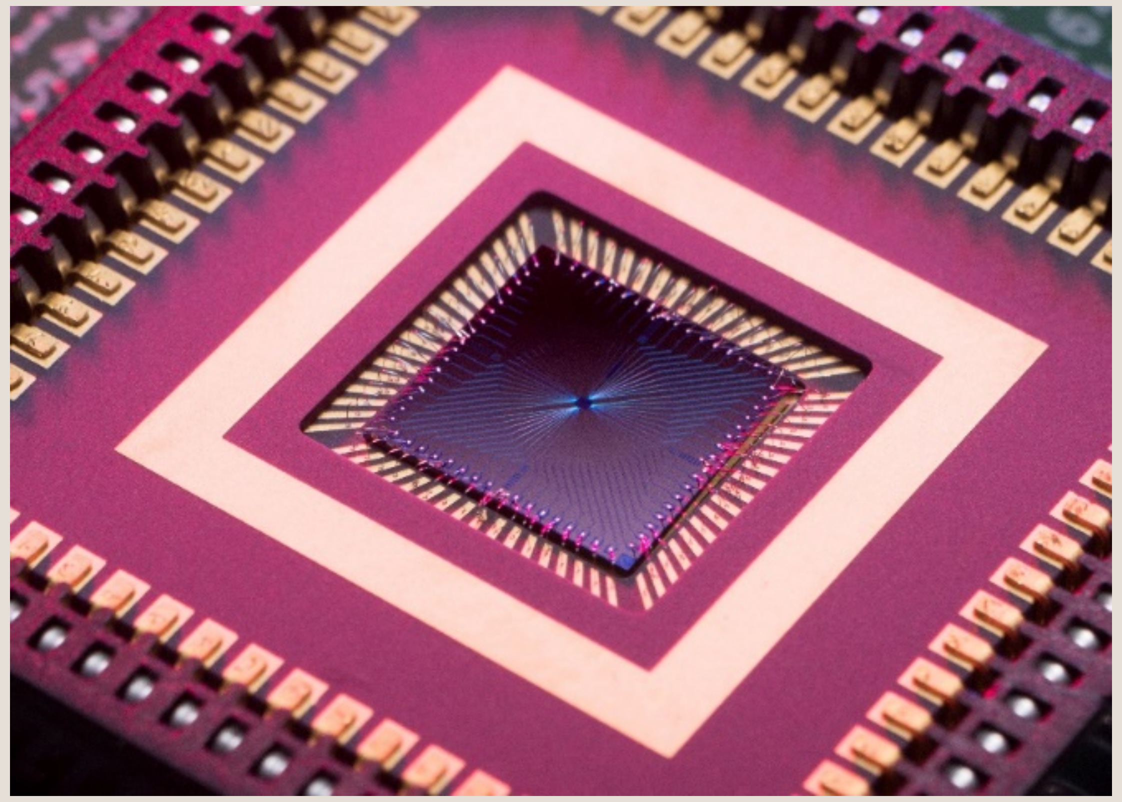
CRYO-ELECTRONICS

FAST/LOW NOISE

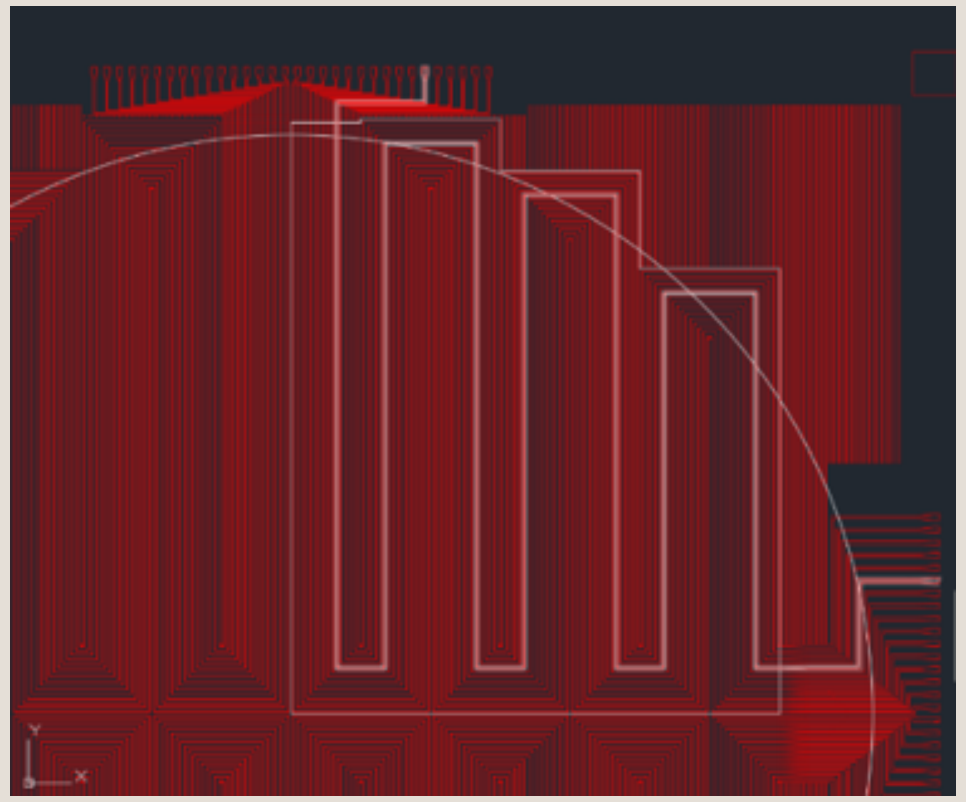
3RD GEN SNSPDS



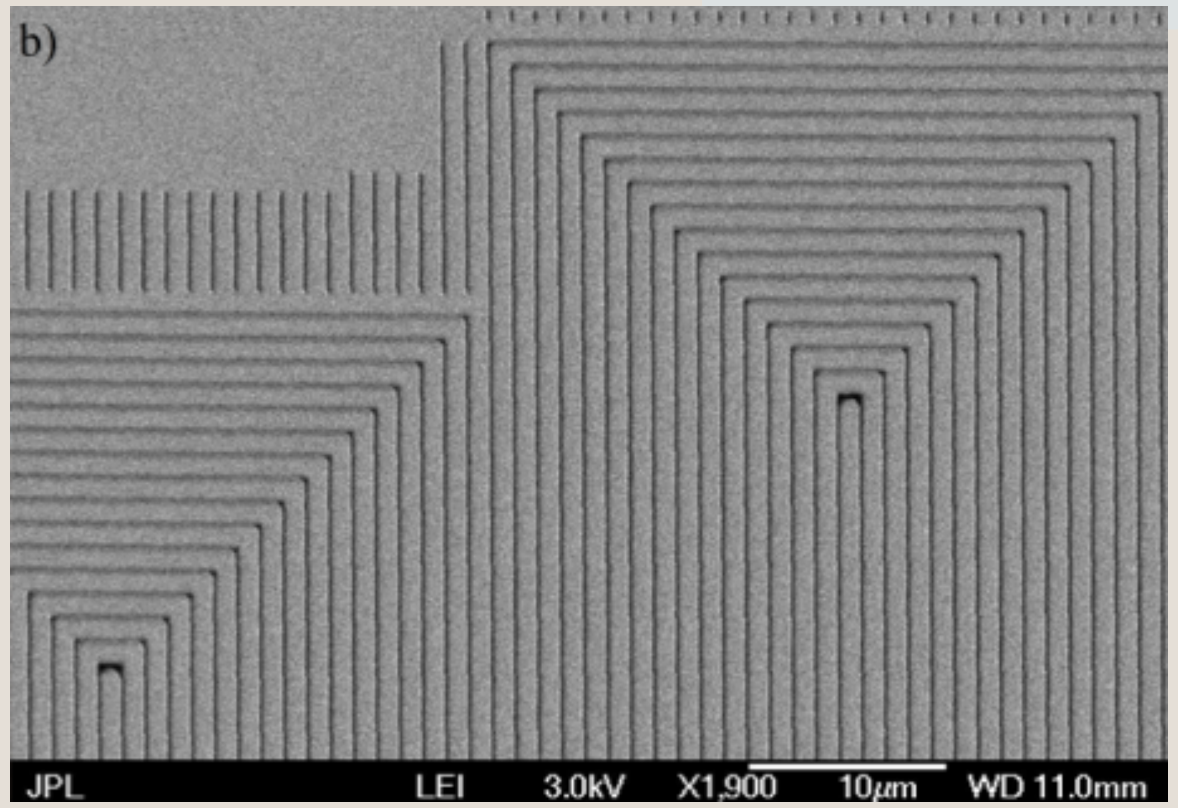




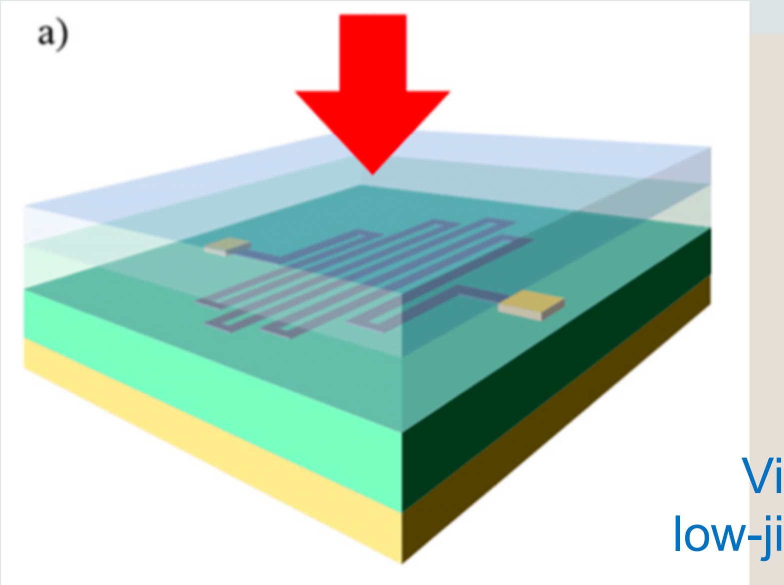
Packaged 64-pixel SNSPD array



Nanowire Sensor Element



Electron Microscope Image of Sensor Elements



Vision for an efficient, low-jitter differential SNSPD

Vision for an efficient, low-jitter differential SNSPD

inqnet

Alliance for Quantum Technologies

- •SNSPDs are the most advanced detectors available for time-resolved single photon counting from the UV to the mid-infrared •Require 1-4 Kelvin operating temperature •SNSPDs are designed, fabricated, and tested at the JPL Microdevices Laboratory •Currently being infused into the ground receiver for the DSOC project •JPL has demonstrated SNSPDs with world-record performance in multiple metrics * Detection Efficiency: 93% at 1550 nm (collaboration with NIST) * Timing Jitter: 2.7 ps FWHM (collaboration with MIT) -Active Area: 320 μm diameter (for DSOC project) Maximum Count Rate: 1.2 Gcps @ 3 dB saturation (for DSOC project).

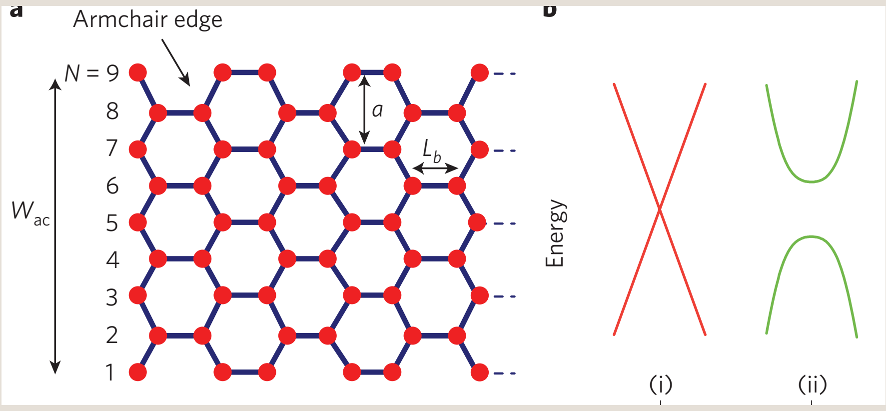
Source: C. Tully AAAS2018, PTOLEMY G3

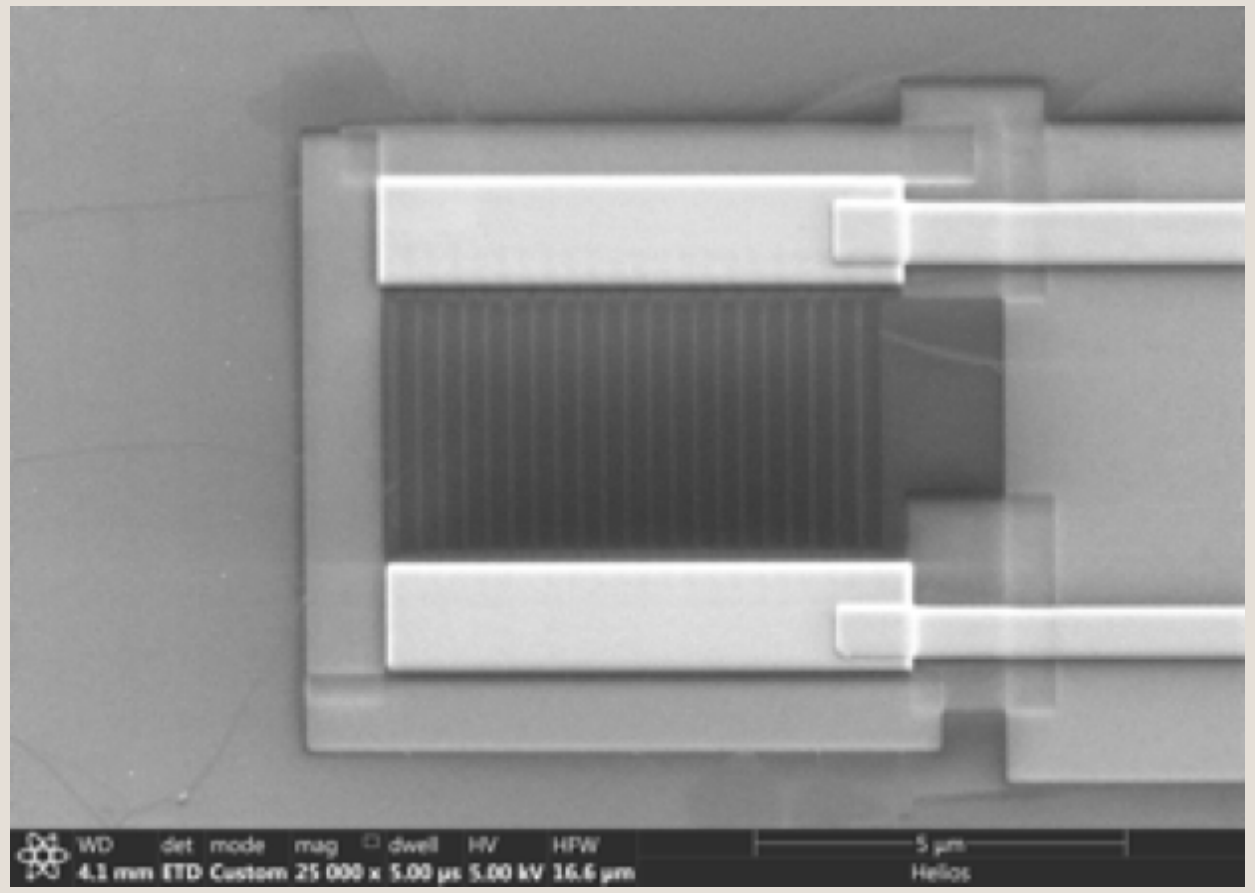
GRAPHENE FET FOR SINGLE ELECTRON DETECTION

DIRECTIONAL DARK MATTER, NEUTRINOS

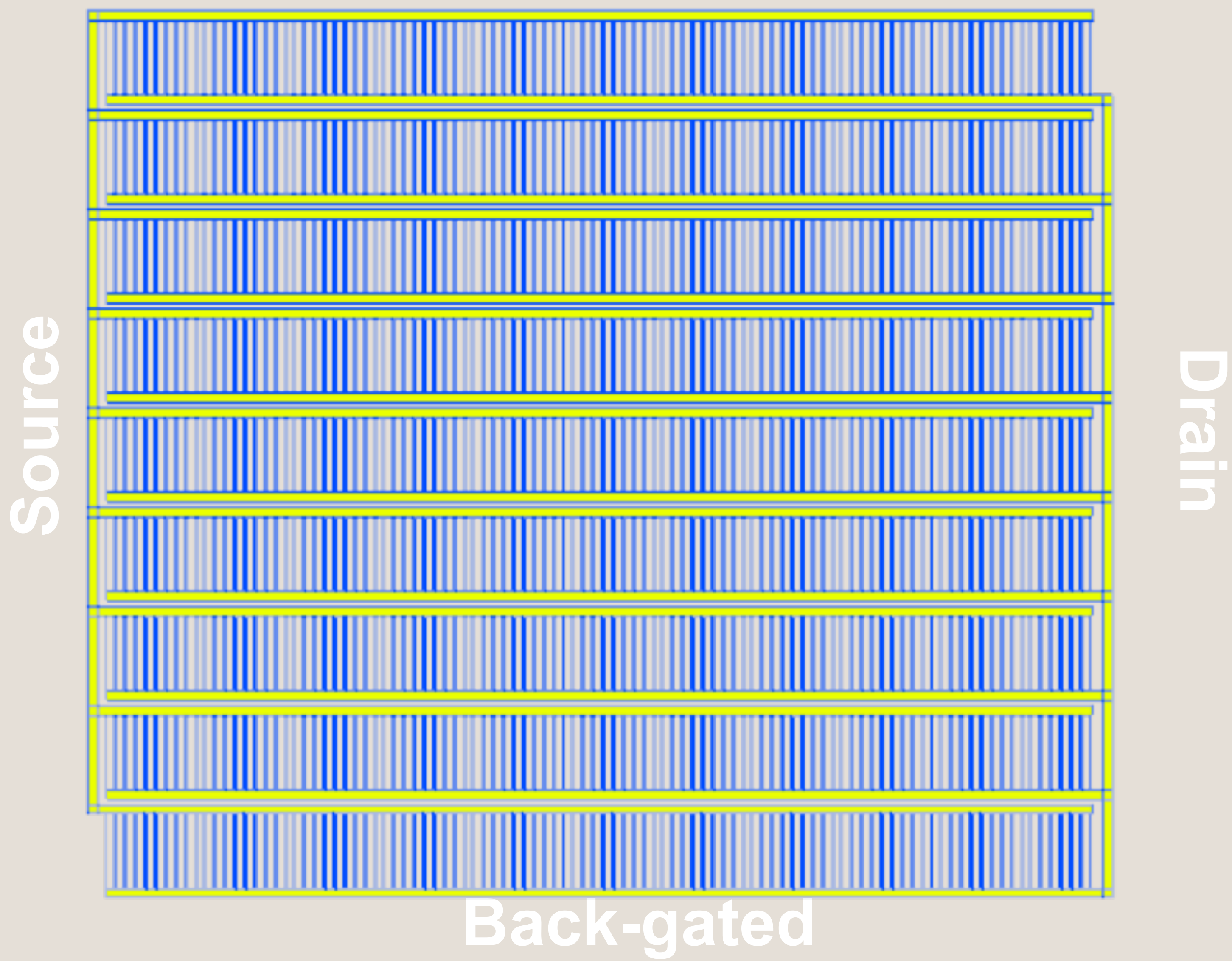
Principles of Operation:

- Tunable meV band gap set by nanoribbon width (Egap ~ 0.8eV/width[nm])





- Large jump in conductivity (~10^{10} charge carriers) relative to charge neutrality point under the field-effect from a single electron scatter



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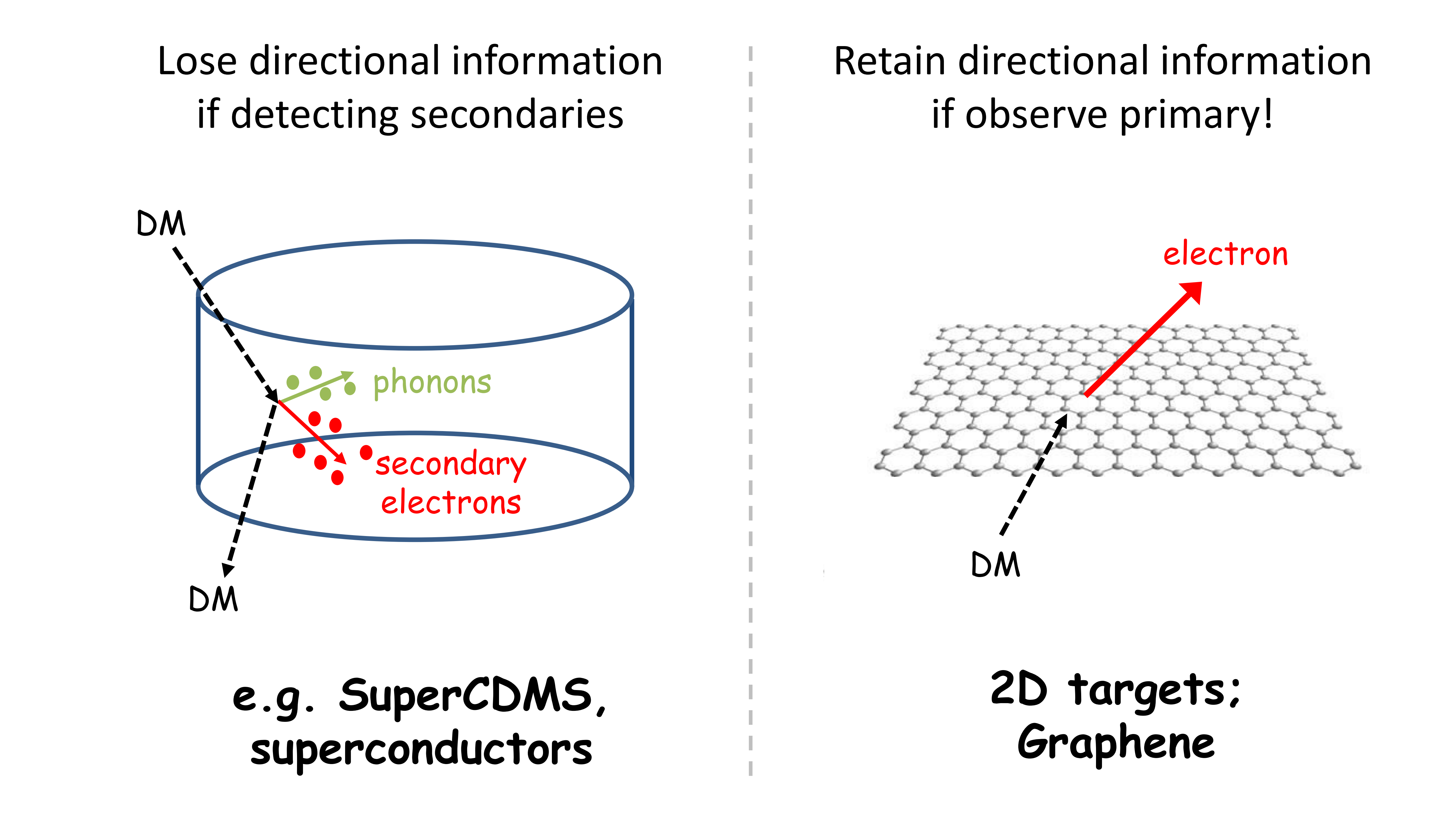


- To eject electron: $E_{\mathrm{eject}} = E_b + \Phi \sim \mathrm{eV}$

cryo-electronics readout in the RF

Source: Sunil Golwala

QUANTUM TECHNOLOGY FOR COSMOLOGY

CMB-S4 CONCEPT DEFINITION TASK FORCE REPORT

Table 2: Instrument configuration satisfying the measurement requirements.

Science	Item	20	30	40	85	95	145	155	220	270	Total
		Frequency [GHz]									
r	**14 x 0.5-m cameras**										
	# detectors	…	260	470	17 k	21 k	18 k	21 k	34 k	54 k	168 k
	Angular resolution [FWHM]		77′	58′	27′	24′	16′	15′	11′	8.′5	
	1 x 6-m telescope										
	# detectors	130	250	500	…	25 k	25 k	…	8.7 k	8.7 k	68 k
	Angular resolution [FWHM]	11′	7.′0	5.′2	…	2.′2	1.′4	…	1.′0	0.′8	
N_{eff}											
	2 x 6-m telescopes										
	# detectors	290	640	1.1 k	…	50 k	50 k	…	17 k	17 k	136 k
	Angular resolution [FWHM]	11′	7.′0	5.′2	…	2.′2	1.′4	…	1.′0	0.′8	

Table 3: Assessment of most significant project risks across subsystems. Risks are ordered from highest (top) to lowest (bottom). Pre-project investment is prioritized by risk and schedule.

Subsystem	Risk	Mitigation
Readout	Integrated performance (MUX factor, noise)	Develop multiple readout technologies with orthogonal technical risks, and downselect.
Detectors	Array production	Develop and validate processes, yield, and throughput at multiple fabs.

CMB-S4: synergy potential

- CMB Stage 3 experiments regularly deploy detectors limited by statistical noise on the quiescent optical power received (photon noise = shot+Bose noise)
- CMB-S4 challenge is to build and read out the large detector counts required: **300k detectors needed to achieve all science goals**
- Some of the technical options overlap well with “quantum measurement” technologies

Source: Sunil Golwala

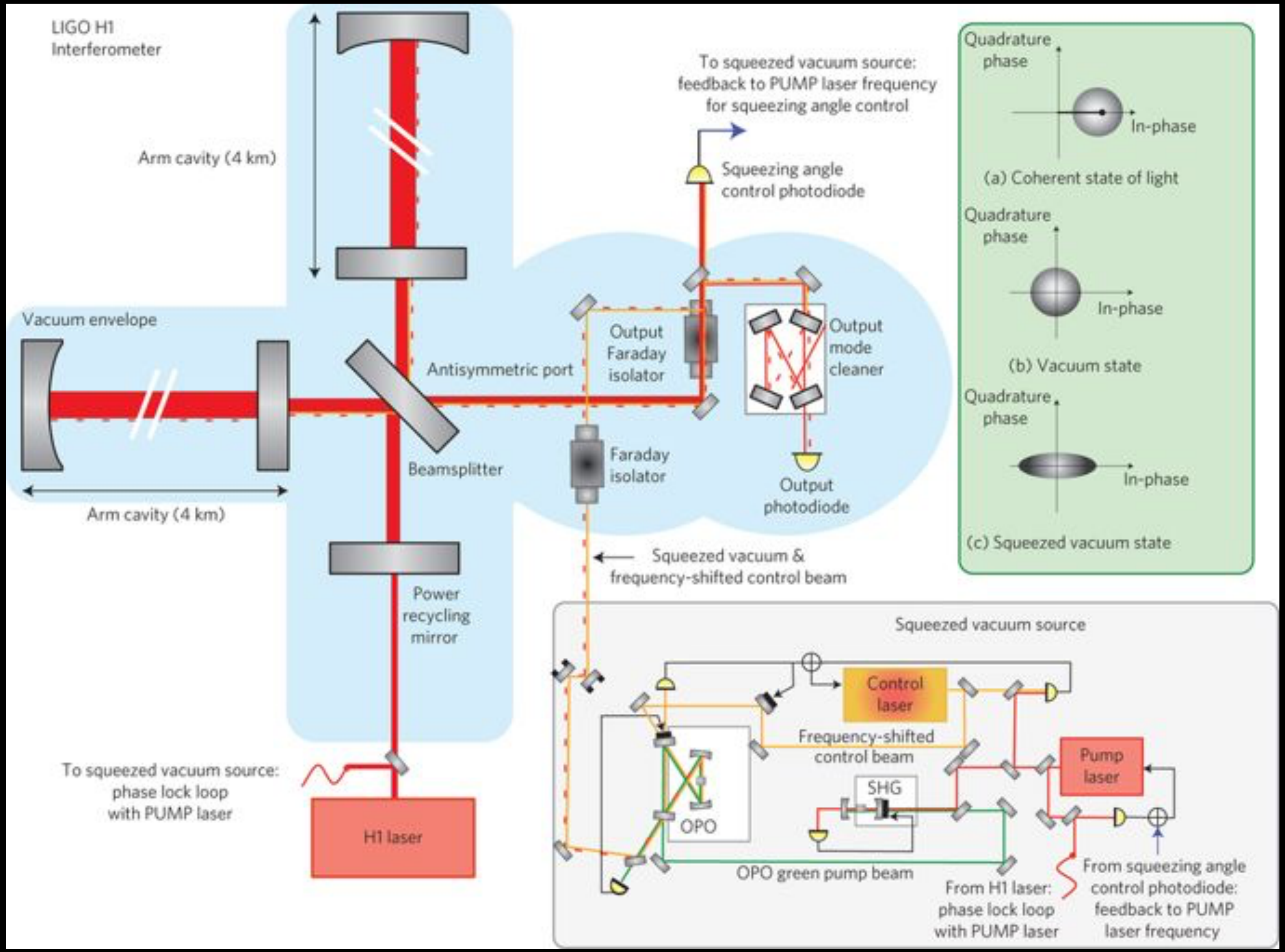
QUANTUM TECHNOLOGY FOR COSMOLOGY

INTEGRATION & SCALING CHALLENGES

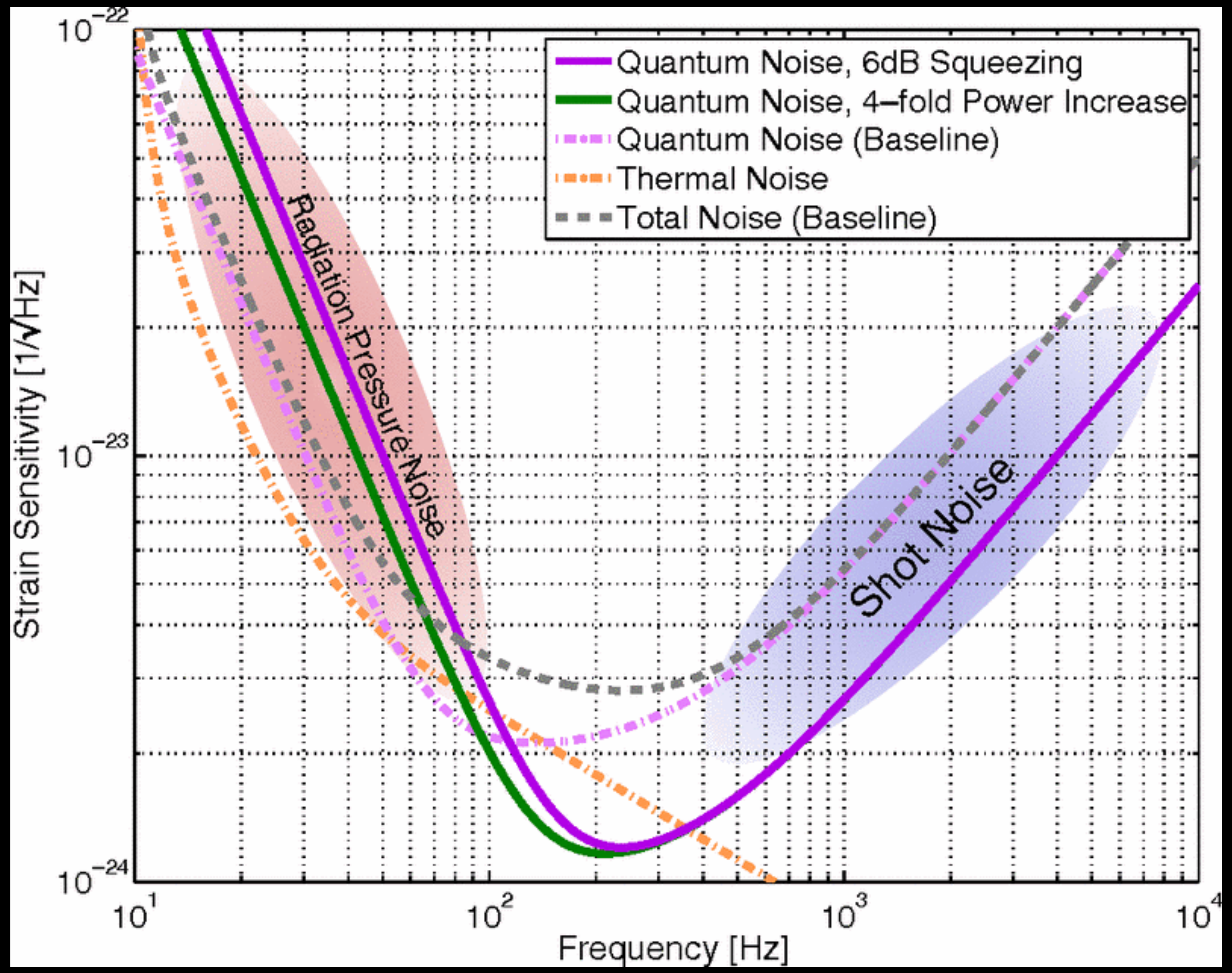
- Scale-up challenges foreshadow those expected for QIS technologies:
  - How to achieve with QIS technologies the scale developed for semiconductors over the last 50 years?
- Future optical surveys for dark energy: speculation on possible synergies
  - Imaging (post-DES, LSST): Quantum sensor technologies may provide spectral information now obtained via filters
  - Spectroscopy (post-BOSS, DESI): Quantum sensor technologies may enable more efficient, more compact spectrographs to survey more objects to improve statistical uncertainties

INTERFEROMETRY

VICKY K. LIGO STORY



LIGO H1
Interferometer
Arm cavity (4 km)
Vacuum envelope
Arm cavity (4 km)
Antisymmetric port
Beamsplitter
Power
recycling
mirror
To squeezed vacuum source:
phase lock loop
with PUMP laser
H1 laser
To squeezed vacuum source:
feedback to PUMP laser frequency
for squeezing angle control
Squeezing angle
control photodiode
Output
Faraday
isolator
Output
mode
cleaner
Faraday
isolator
Output
photodiode
Squeezed vacuum &
frequency-shifted control beam
Quadrature
phase
In-phase
(a) Coherent state of light
Quadrature
phase
In-phase
(b) Vacuum state
Quadrature
phase
In-phase
(c) Squeezed vacuum state
Squeezed vacuum source
Control
laser
Frequency-shifted
control beam
Pump
laser
SHG
OPO
OPO green pump beam
From H1 laser:
phase lock loop
with PUMP laser
From squeezing angle
control photodiode:
feedback to PUMP
laser frequency



Quantum Noise, 6dB Squeezing
Quantum Noise, 4−fold Power Increase
Quantum Noise (Baseline)
Thermal Noise
Total Noise (Baseline)
Radiation Pressure Noise
Shot Noise
Strain Sensitivity [1/√Hz]
Frequency [Hz]
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
10^{4}

ATOM INTERFEROMETRY (AMO MEETS HEP, GRAVITY, QG…)

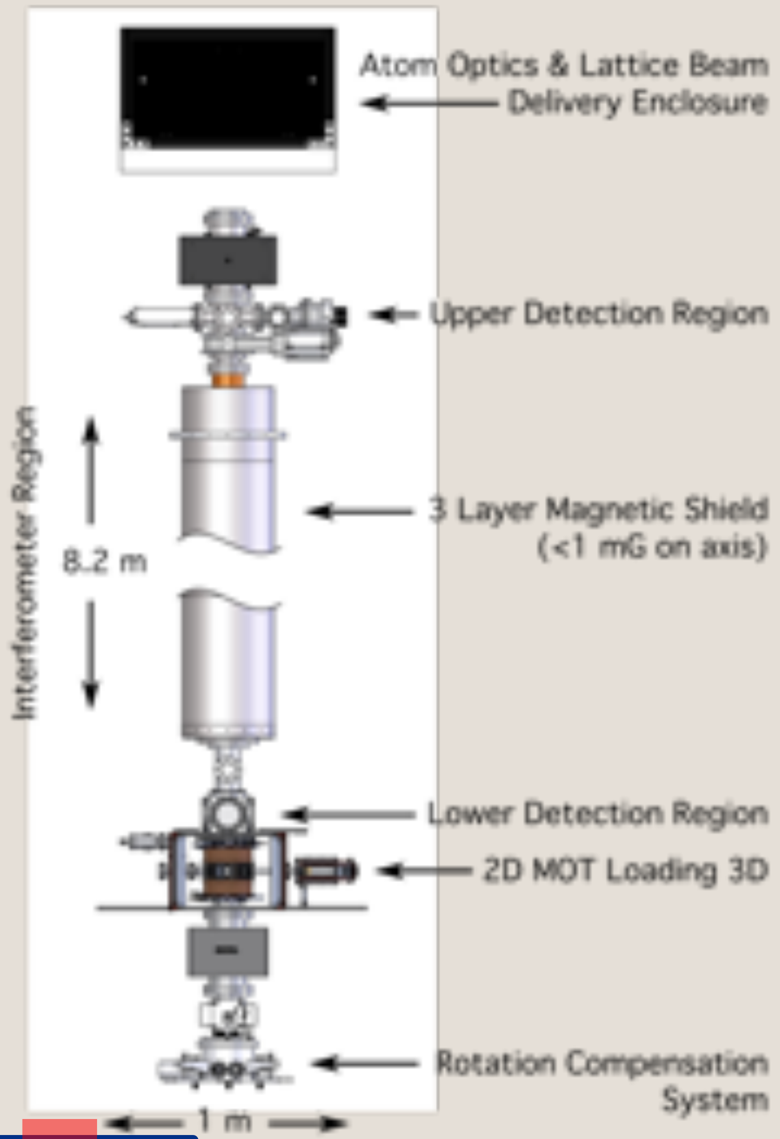
EXAMPLE MAGIS-100

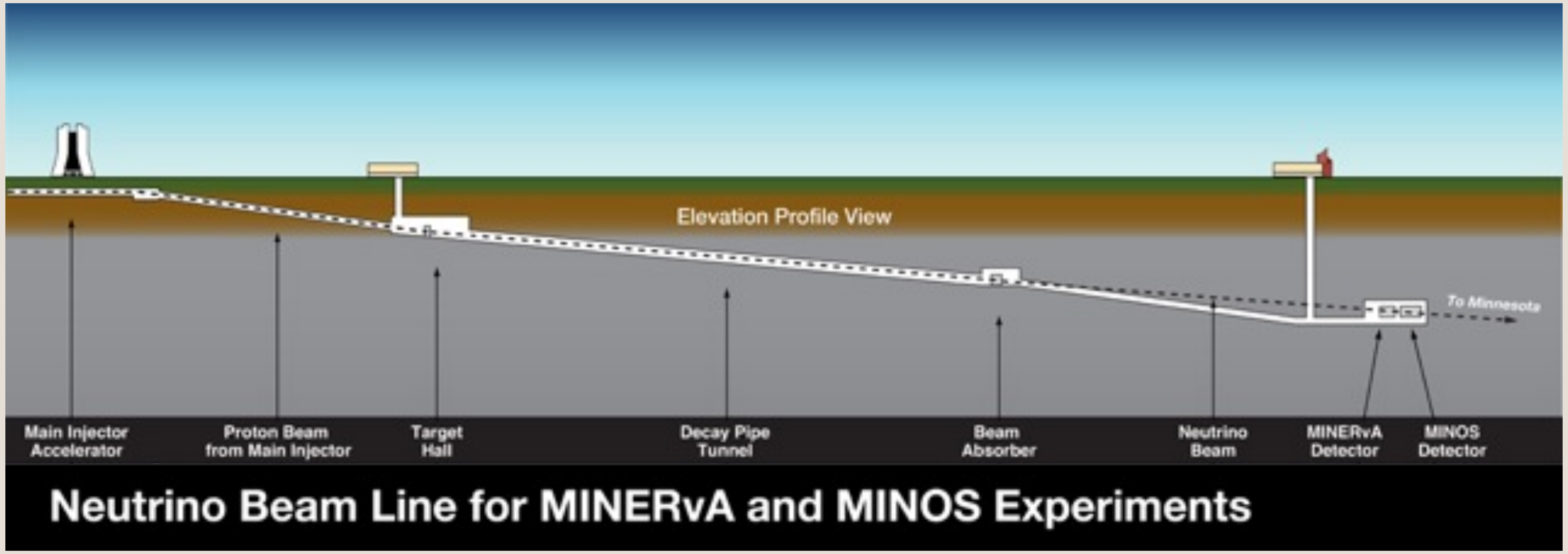
- Time-dependent signals caused by ultra-light dark matter candidates (dilaton, ALP, relaxion …)
- Dark matter that affects fundamental constants: electron mass, fine structure constant
- Time-dependent EP violations from B-L coupled dark matter
- New forces
- Space-time deformations / Quantum Gravity

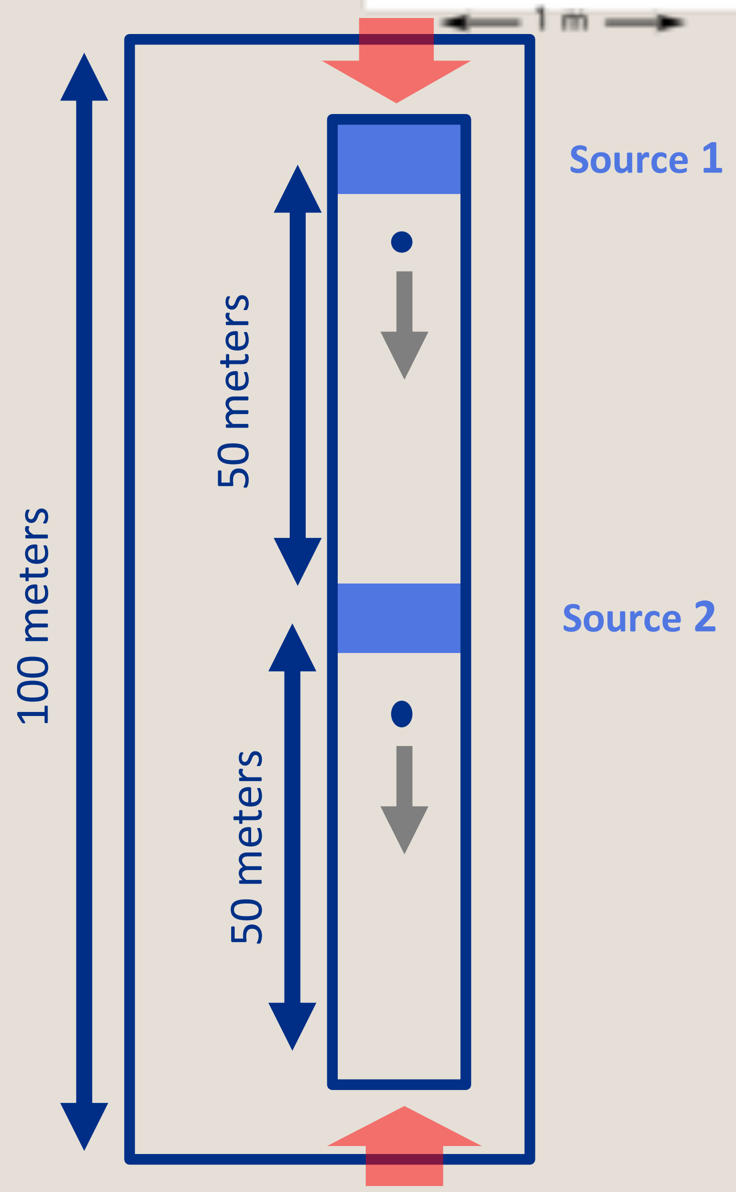
ATOM INTERFEROMETRY (AMO MEETS HEP, GRAVITY, QG…)

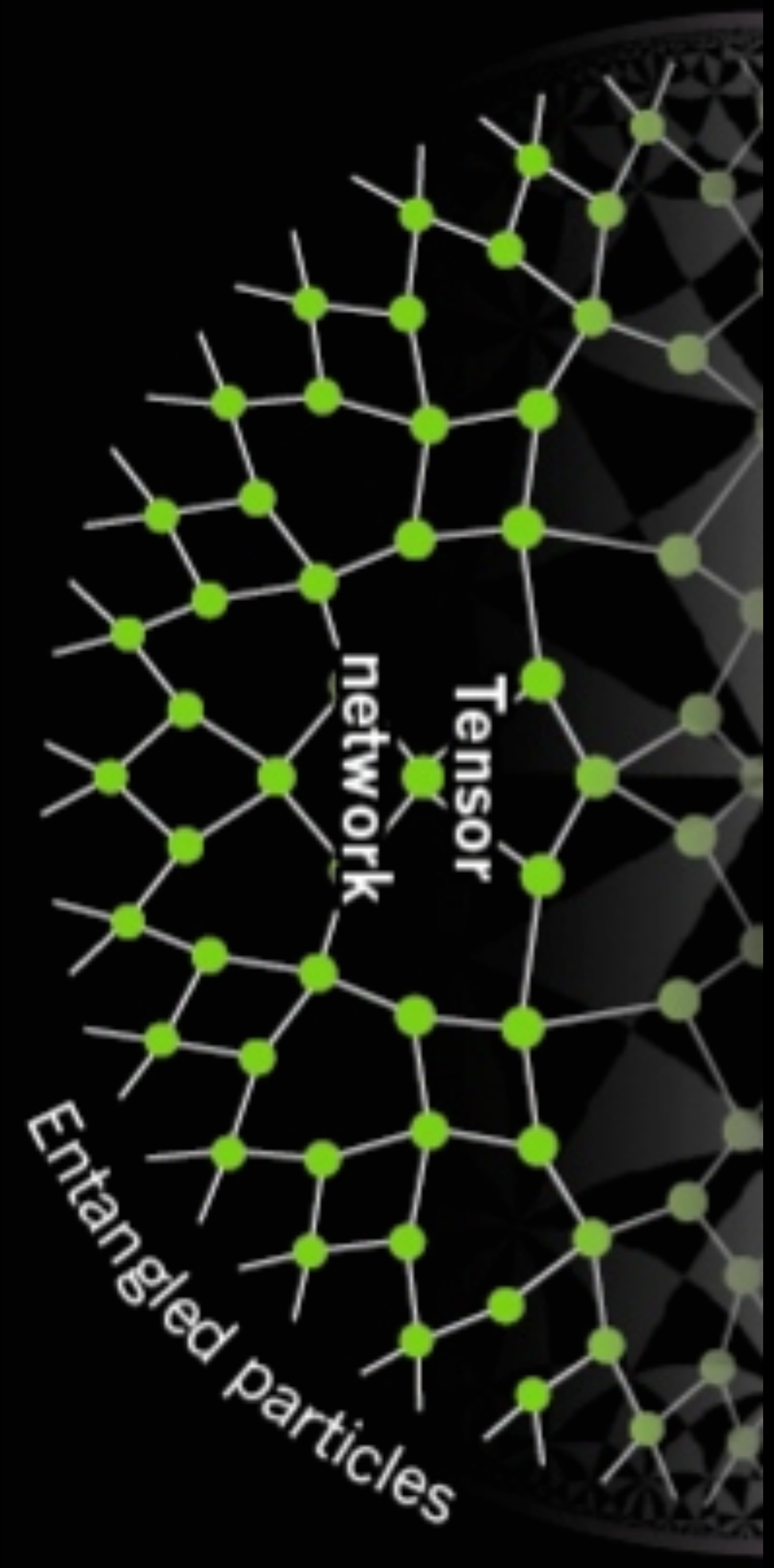
EXAMPLE MAGIS-100: QUANTUM GRADIOMETER

- Compare multiple cold atom ensembles separated by a 100 meter baseline
- Laser pulses implement atom interferometry
- Science signal is differential phase between interference patterns
- Differential measurement suppresses many sources of common noise and systematic errors
- Proof-of-concept using the Stanford 10m scale prototype

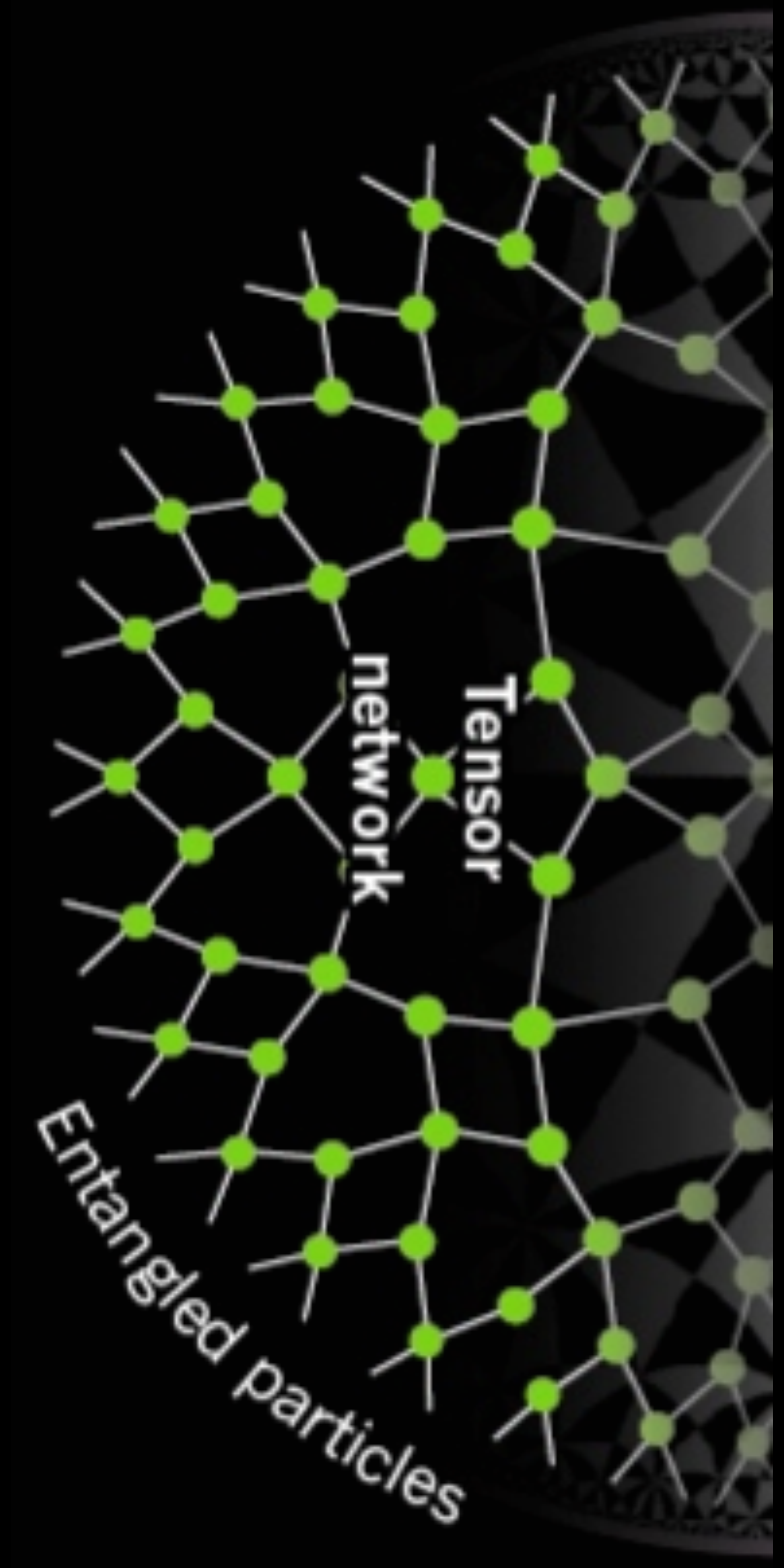








GRAVITY
SPACE-TIME
HACKING



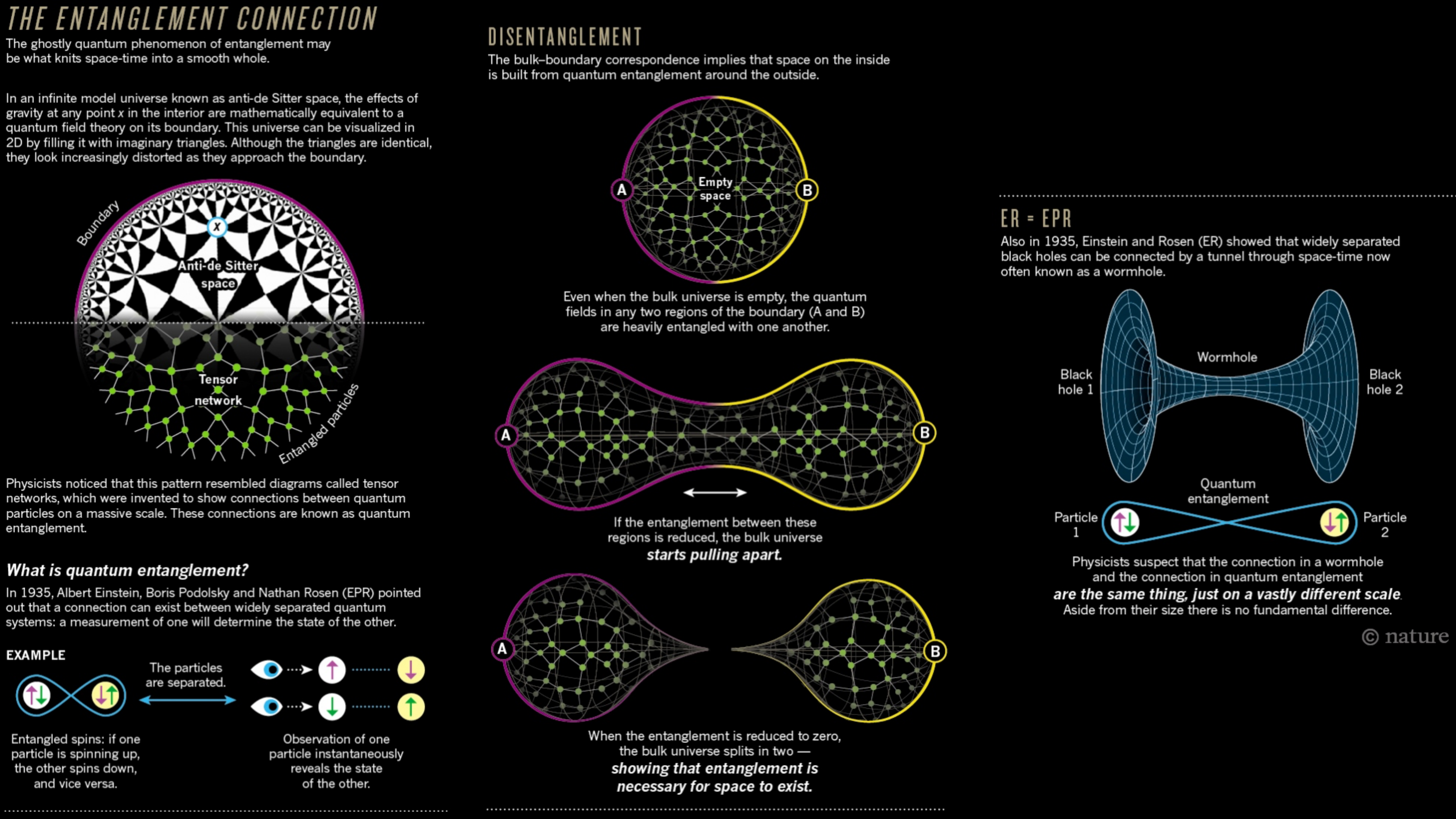
GRAVITY
SPACE-TIME
HACKING

http://www.nature.com/news/the-quantum-source-of-space-time-1.18797

NATURE | NEWS FEATURE

The quantum source of space-time

Many physicists believe that entanglement is the essence of quantum weirdness — and some now suspect that it may also be the essence of space-time geometry.



https://www.nature.com/news/the-quantum-source-of-space-time-1.18797

Wormholes as Quantum Channels

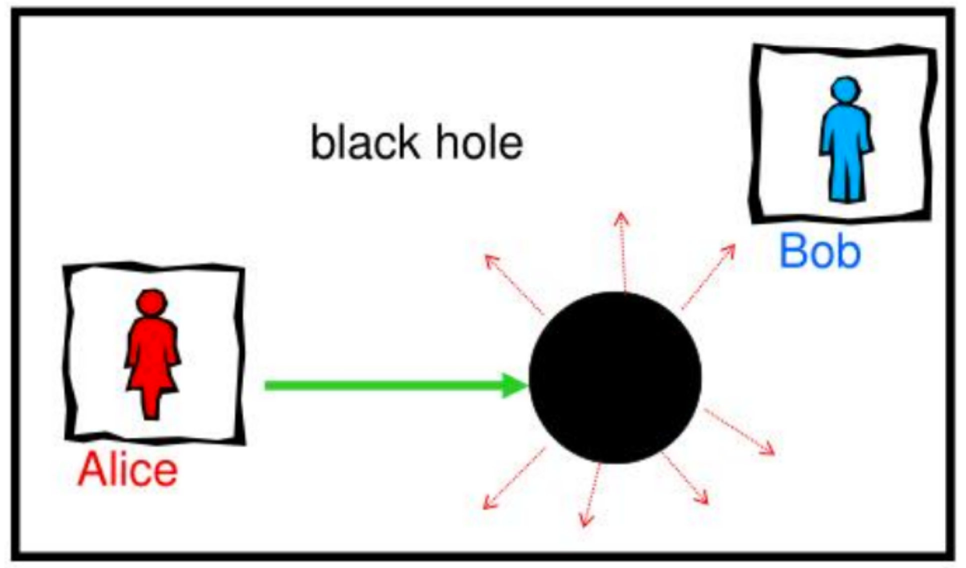
based mostly on arXiv:1808.05963 w/ Aidan Chatwin-Davies, Jason Pollack, and Grant Remmen

Ning Bao

Caltech Seminar
November 27th, 2018

Teleportation and black holes

In a classic paper, John Preskill and Patrick Hayden considered what happens when Alice throws her diary into a black hole, and Bob tries to recover its contents by patiently collecting photons of Hawking radiation



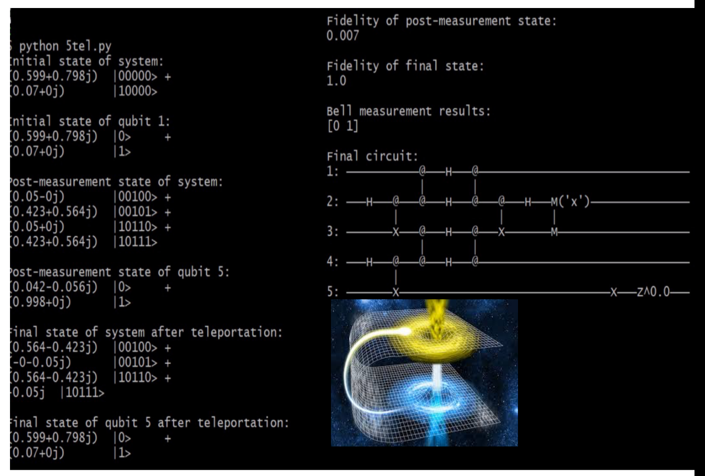
The information in the diary is quickly entangled with whatever else is inside the black hole

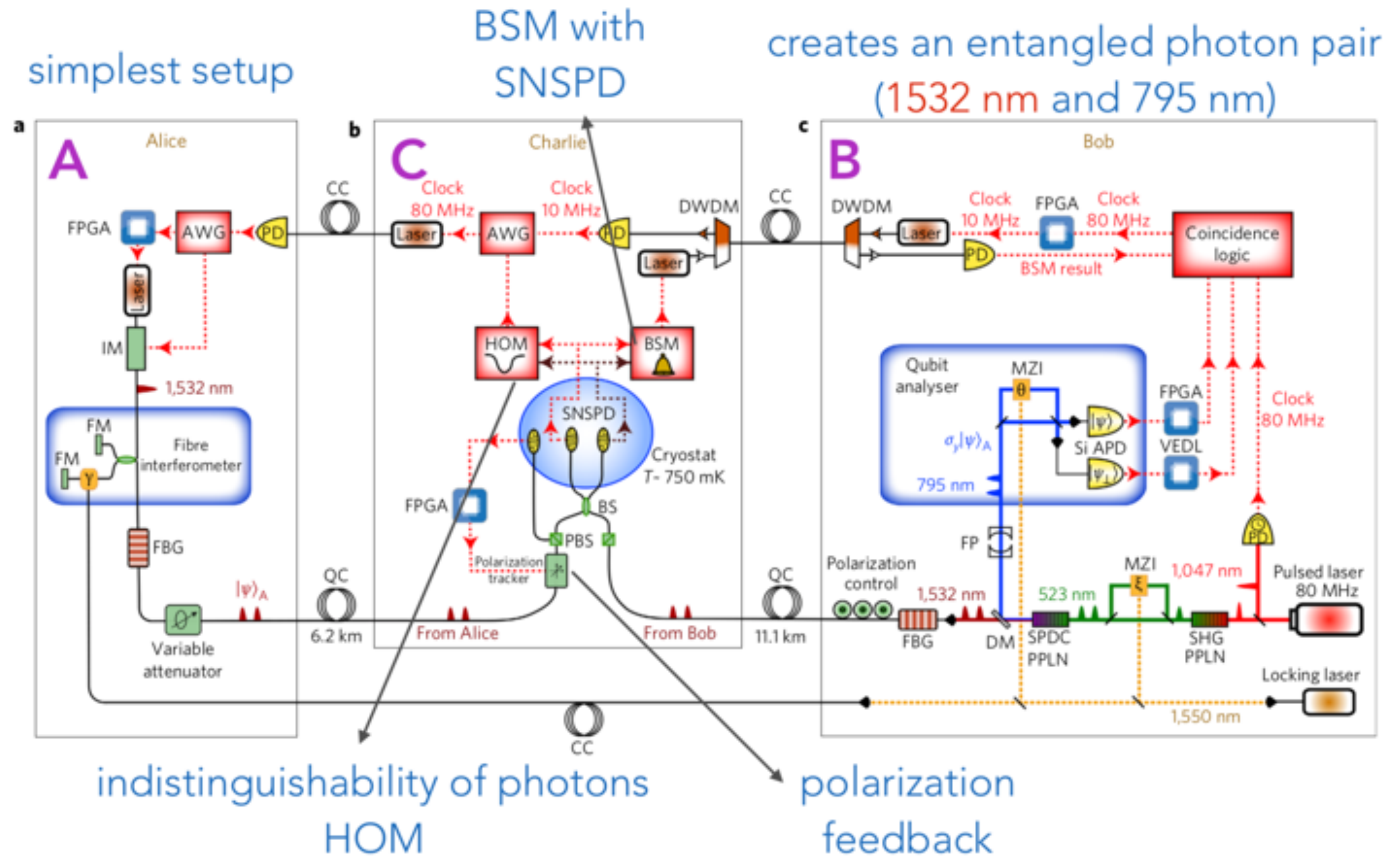
And Bob can retrieve it through quantum teleportation

Wormhole teleportation

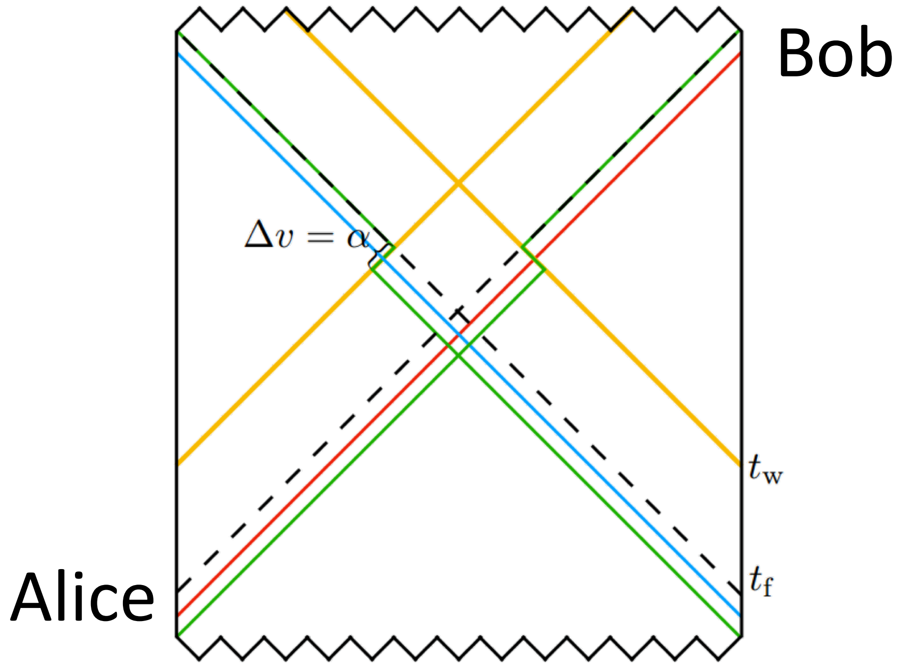
- Recent theoretical work shows that a pair of entangled black holes would be connected by a **wormhole**
- A traveler jumping into one black hole would appear at the other one
- This has been shown to be **a special kind of quantum teleportation**, that should be reproducible for smaller quantum systems in the lab
- At Fermilab we are developing the technology required for wormhole teleportation experiments

P. Gao, D. Jafferis, A. Wall, "Traversable wormholes via a double trace deformation", arXiv:1608.05687.
J. Maldacena, D. Stanford, Z. Yang, "Diving into traversable wormholes", arXiv:1704.05333.
L. Susskind and Y. Zhao, "Teleportation through the wormhole", arXiv:1707.04354.





- We can now proceed to actually consider the process of sending an excitation through the wormhole from a QI perspective.



Theory Colloquium

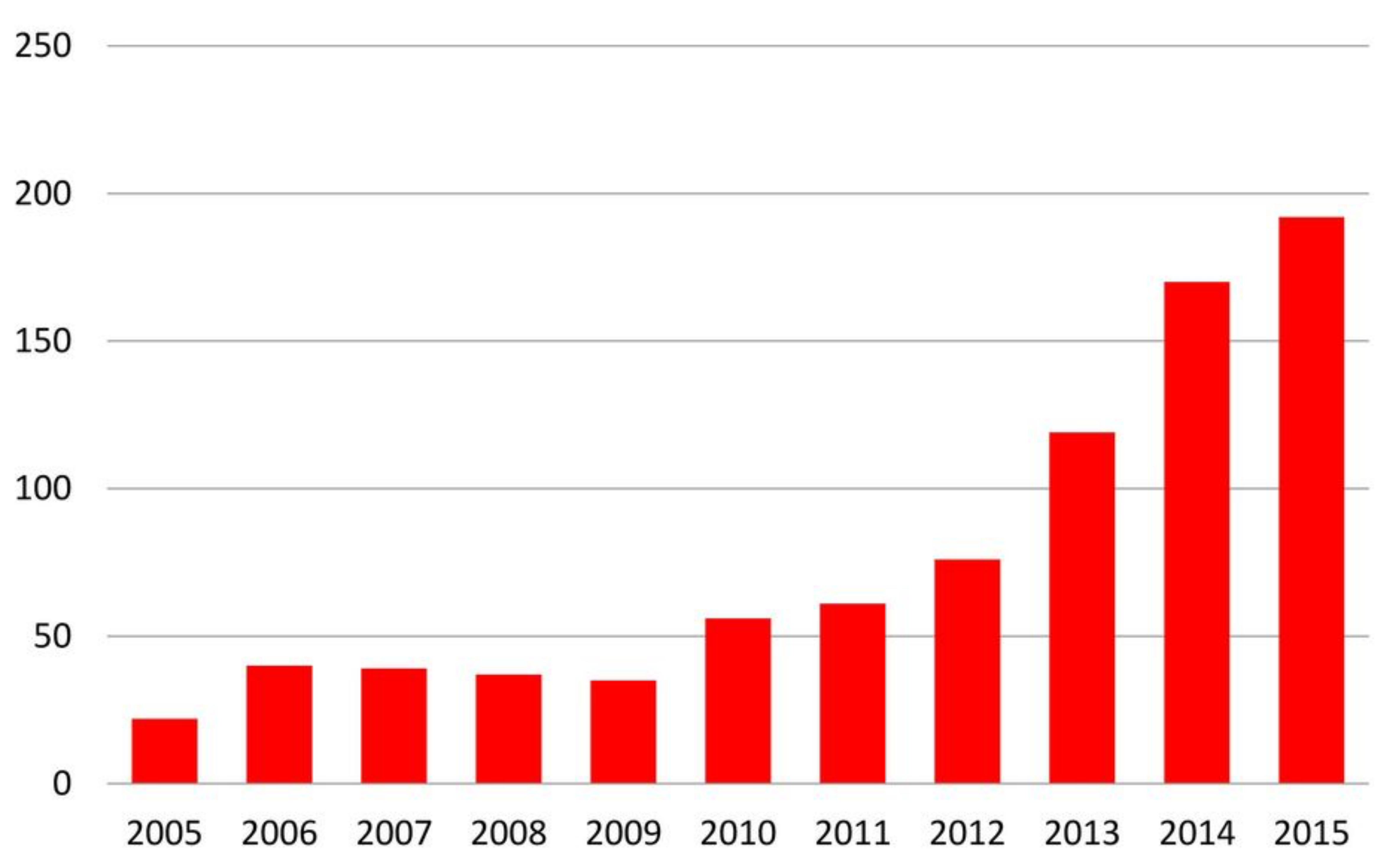
Is Quantum Gravity Observable in Gravitational Wave Interferometers?

by Kathryn Mary Zurek (University of California Berkeley (US))

Wednesday 28 Nov 2018, 14:00 → 16:00 Europe/Zurich

4-3-006 - TH Conference Room (CERN)

hep-th papers with “entanglement” in the title



arXiv.org > quant-ph > arXiv:1707.00025

Quantum Physics

Quantum limits to gravity estimation with optomechanics

Federico Armata, Ludovico Latmiral, A.D.K Plato, M.S. Kim

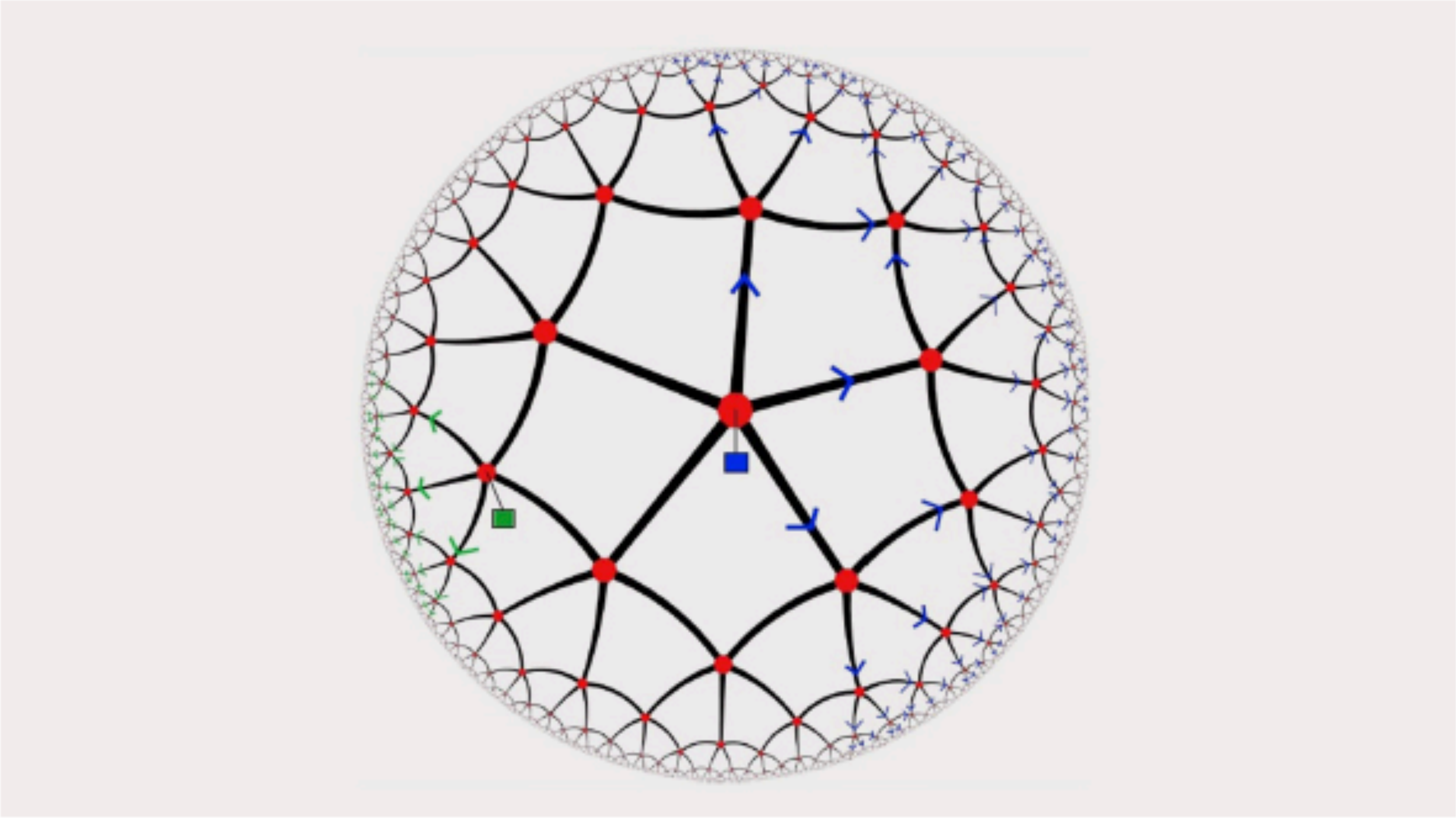
(Submitted on 30 Jun 2017 (v1), last revised 12 Oct 2017 (this version, v3))

We present a table-top quantum estimation protocol to measure the gravitational acceleration g by using an optomechanical cavity. In particular, we exploit the non-linear quantum light-matter interaction between an optical field and a massive mirror acting as mechanical oscillator. The gravitational field influences the system dynamics affecting the phase of the cavity field during the interaction. Reading out such phase carried by the radiation leaking from the cavity, we provide an estimate of the gravitational acceleration through interference measurements. Contrary to previous studies, having adopted a fully quantum description, we are able to propose a quantum analysis proving the ultimate bound to the estimability of the gravitational acceleration and verifying optimality of homodyne detection. Noticeably, thanks to the light-matter decoupling at the measurement time, no initial cooling of the mechanical oscillator is in principle demanded.

Comments:	7 pages, 3 figures
Subjects:	**Quantum Physics (quant-ph)**; Mesoscale and Nanoscale Physics (cond-mat.mes-hall); Optics (physics.optics)
Journal reference:	Phys. Rev. A 96, 043824 (2017)
DOI:	10.1103/PhysRevA.96.043824
Cite as:	arXiv:1707.00025 **[quant-ph]**
	(or **arXiv:1707.00025v3 [quant-ph]** for this version)

It from Qubit: Simons Collaboration on Quantum Fields, Gravity and Information

https://www.simonsfoundation.org/mathematics-physical-sciences/it-from-qubit/



Developments over the past ten years have shown that major advances in our understanding of quantum gravity, quantum field theory and other aspects of fundamental physics can be achieved by bringing to bear insights and techniques from quantum information theory. Nonetheless, fundamental physics and quantum information theory remain distinct disciplines and communities, separated by significant barriers to communication and collaboration. Funded by a grant from the Simons Foundation, "It from Qubit" is a large-scale effort by some of the leading researchers in both communities to foster communication, education and collaboration between them, thereby advancing both fields and ultimately solving some of the deepest problems in physics. The overarching scientific questions motivating the collaboration include:

Does spacetime emerge from entanglement?

Do black holes have interiors?

Does the universe exist outside our horizon?

What is the information-theoretic structure of quantum field theories?

Can quantum computers simulate all physical phenomena?

How does quantum information flow in time?

Message to members of the APS Division of Quantum Information
Approved by Mark Byrd, DQI Secretary/Treasurer

Dear Members,

It is now official: the Topical Group on Quantum Information has officially become the Division of Quantum Information!

The executive committee would like to thank the members for their membership, participation in, and support of, the Topical Group. Without you, our Division would not have come to be. Please continue to recruit and participate to help continue to strengthen our Division.

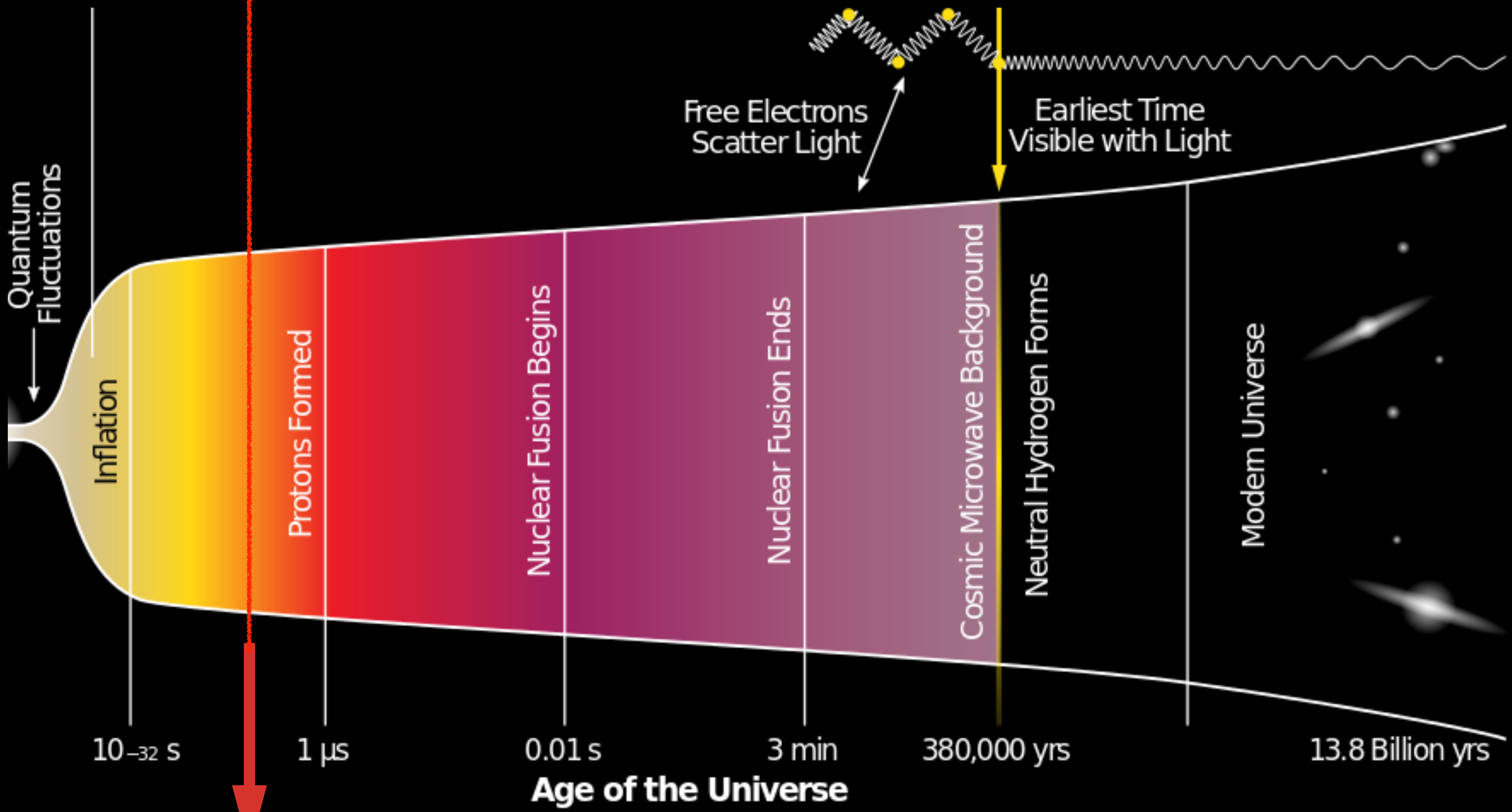
Who writes "QIS" papers?

CMP, Nano, material scientists, AMO, NP, Beams, HEP, BES, Comp, Math, string…

Division of Quantum Information

The Topical Group of Quantum Information was officially established as a Division in 2017. The mission of the Division of Quantum Information is to promote the advancement and diffusion of knowledge concerning the physics of quantum information, computing, fundamental concepts, and foundations. The Division will serve as a focus for theoretical and experimental research in these and related areas. Research topics of direct interest include quantum entanglement, quantum communication, quantum cryptography, quantum algorithms and simulations, physical implementations of qubits, quantum error correction, fault-tolerant quantum computation, quantum measurements, open quantum systems, quantum coherence, control of quantum dynamics, the quantum-classical correspondence, and the conceptual and mathematical foundations of quantum theory.

▸ Full Mission Statement



Higgs : 10^{-11}s
0.00000000001 seconds, 10^{15} K,
10^{11} eV

From breaking the EW ... quantum cosmos

http://bicepkeck.org/visuals.html


Connections: Quarks to the Cosmos
Quantum Fluctuations
Inflation
10–32 s
Higgs :
0.00000000001 s
From breaking the EW quantum vacuum to the quantum cosmos

WORKFORCE

ITFROMQUBIT ANECDODAL DATA

QIS/HEP THEORISTS TRAINED ITFROMQUBIT

2017 : 10 candidates for 3 (academic/lab) jobs

2018 : 15 candidates for 4 jobs

2019: 20 candidates for x(<=4) jobs

Pileup of excellent candidates — industry can will absorb them— esp. the ones that more on the I (CS-y) trained. These are the ppl that can teach the next cycles of grad students.

Some thinking is needed on the HEP/QIS trained ppl in terms of careers

OPPORTUNITY & RISK

HEP & QIS

Opportunity: new tools for larger phase space exploration in HEP

Risk : HEP program must be strong for HEP/QIS intersections to grow and flourish

Challenge : Sociology and Culture Dictionaries $\Rightarrow$ Physics, Math, Astro/Cosmo, Engineering melting pot

Intersections of Quantum Information Science with High Energy Physics

Abstract

Quantum Information Science intersections with High Energy Physics have been developing over the last few years. Cross fertilization of ideas and expertise across many intersecting research areas have contributed to the confluence of research on black hole physics, information theory, holographic correspondence, computational complexity, and quantum error corrections leading to new understanding of the quantum universe and potential quantum technology. HEP-QIS intersections provide the intellectual stimulus for entanglement-based field theory models, tensor networks, and innovative techniques for addressing de-coherence. At the intersection of QIS/HEP science and technology are new techniques for instrumentation, detectors, data transfer, and quantum communications that exploit superposition, entanglement, and/or squeezing for HEP experiments. This includes in particular the tools and theoretical ideas necessary for detecting very faint signals from the dark matter sector, as well as from other new physics beyond the standard model. In this workshop we will interweave theoretical and experimental topics emerging at the boundaries and intersections of QIS and HEP and explore synergies and complementarities.

Introduction/Synthesis

The last several years has seen an explosive growth in the intersection between high energy physics and quantum information science. This growth has occurred both in theoretical domains – such as the connection between black holes and holography and a purely information theoretic description of spacetime – and in areas of application of QIS measurement techniques to the search for physics beyond the Standard Model.

The workshop seeks to bring people together from diverse areas of interest, with the goal of stimulating new bridges between QI and HEP, and between those pondering deep theory issues and those developing remarkable new experimental techniques. Closing these gaps will engender opportunities to uncover new physics beyond the standard model. While the QI and HEP communities have begun to recognize their joint areas of interest, standard meeting formats are a poor fit for connecting communities that need to form a common scientific language. An ACP program is much better adapted to the sort of discussion that will stimulate new ideas and new connections.

Below we describe theree thursts that generate intereactions and enthusiasm in the relevant dynamic fields.

1 Black hole physics, information theory and holographic correspondence

The relation between quantum entanglement and the geometry of spacetime is leading to profound new understanding of quantum gravity and holography. Quantum information theoretic descriptions of gravitational phenomena have been found in the context of the AdS/CFT duality: fast scrambling in the sense of quantum chaos is dual to falling through the horizon of a black hole, the encoding of bulk excitations in terms of boundary variables has error correction properties, the growth of complexity of quantum states is related to the growing size of the dual geometry, descriptions of black hole interiors using an approximate analog of Tomita Takesaki theory, and a duality between traversable wormholes and quantum teleportation. These are also related to important applications of quantum information science to the study of quantum field theories, in which the quantification of patterns of entanglement has led to new understanding and proofs of quantum positive energy conditions and renormalization group monotonicity. Furthermore, this relationship gives a geometric interpretation of quantum entanglement, and may provide a novel internal description of quantum phenomena, such as the wormhole gravitational dual of quantum teleportation.

ACP Summer 2019 Proposal

2 Quantum Metrology

Quantum metrology is an emerging topic in quantum information science that 1.) counts the resources needed to sense a weak signal, 2.) gives precise meaning to a measurement operating at a quantum limit, and 3.) describes how such limits can be circumvented. It will have profound influence for the next generation of high energy physics experiments that probe fundamental interactions at energies above the TeV scale. In particular, searches for low-energy relic fields associated with phase transitions at a very high energy scale have emerged as one of the few ways to probe such high energy scales. The axion of quantum chromodynamics (QCD) is the most prominent of these hypothetical fields, but they are a generic feature of string theories, which predict axion-like particles and dark photons. These experiments attempt to sense ever-present but weakly coupled fields by detecting their action on an oscillatory system that has been well-isolated from its environment, such as: superconducting resonant circuits, microwave cavities, or electron and nuclear spin ensembles. Through recent progress in quantum sciences, it is now possible to resolve the zero-point motion of these high-quality oscillators, and consequently, to search for these fields at a rate limited by fundamental quantum noise. But by deploying precision quantum metrology methods, such as squeezing and back action evasion, searches with a sensitivity many times better than the quantum limit would be possible. This would make many more theories of dark matter, inflation, and the early universe testable, heralding a new era of laboratory tests of fundamental physics.

3 Probes of Physics Beyond the Standard Model and Quantum Sensing

Traditional searches for dark matter (in particular the WIMP) has focused on a classical process – hard scattering of DM from nuclei treated as classical billiard balls – to detect DM. As DM searches have moved beyond the WIMP, HEP has begun to interact with and leverage developments in QIS-directed fields in novel ways. This is nowhere more evident than in quantum metrology techniques to detect light DM, in some cases acting as a DM wave (e.g. axions) and in some cases as a particle (e.g. asymmetric dark matter). In order to detect the whispers, the development of extremely sensitive quantum devices, such as SQUIDs, quantum non-demolition measurements of photons (e.g. from axions) with a transmon qubit, transition edge sensors (TESs) and microwave kinetic inductors (MKIDs) are crucial. At the same time, the development of these devices leads to new opportunities for DM interactions with the target that leverages quantum coherence. Recent examples include detection of dark photons via a resonant LC circuit, detection of light bosons with a super-radiance-type effect, and axion detection with qubits. The development of new ideas will benefit from the direct interaction of theorists working in searching for new physics beyond the Standard Model with those working to develop quantum measurement devices.

Kathryn Zurek
Daniel Jafferis
Konrad Leonard
MS

74 ppl signed up
May12-27 off-season Summer Aspen Workshop