UK Research
and Innovation

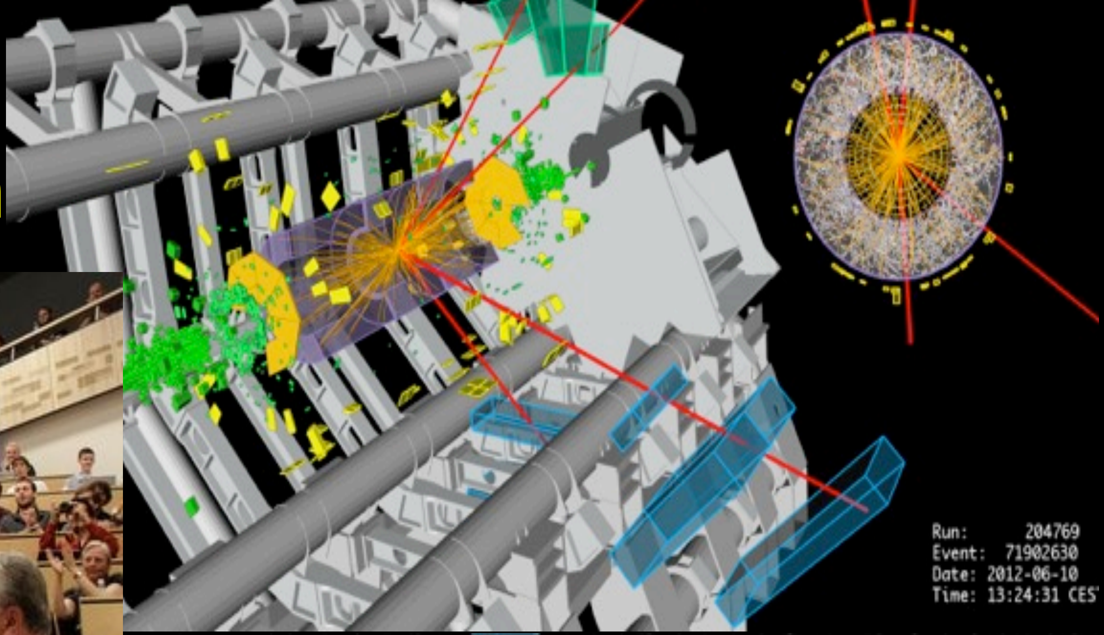
Quantum Technologies for Fundamental Physics

The Science & The Quantum Technologies Landscape

Ian Shipsey

2012.7.4

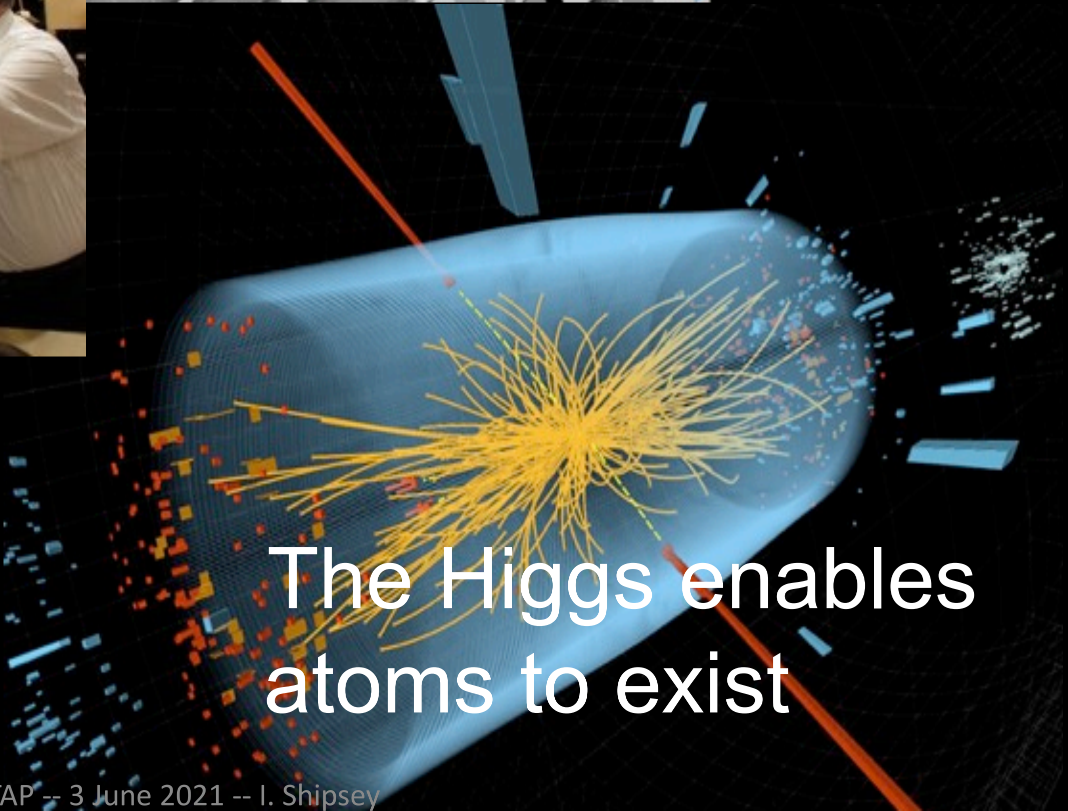
discovery of Higgs boson



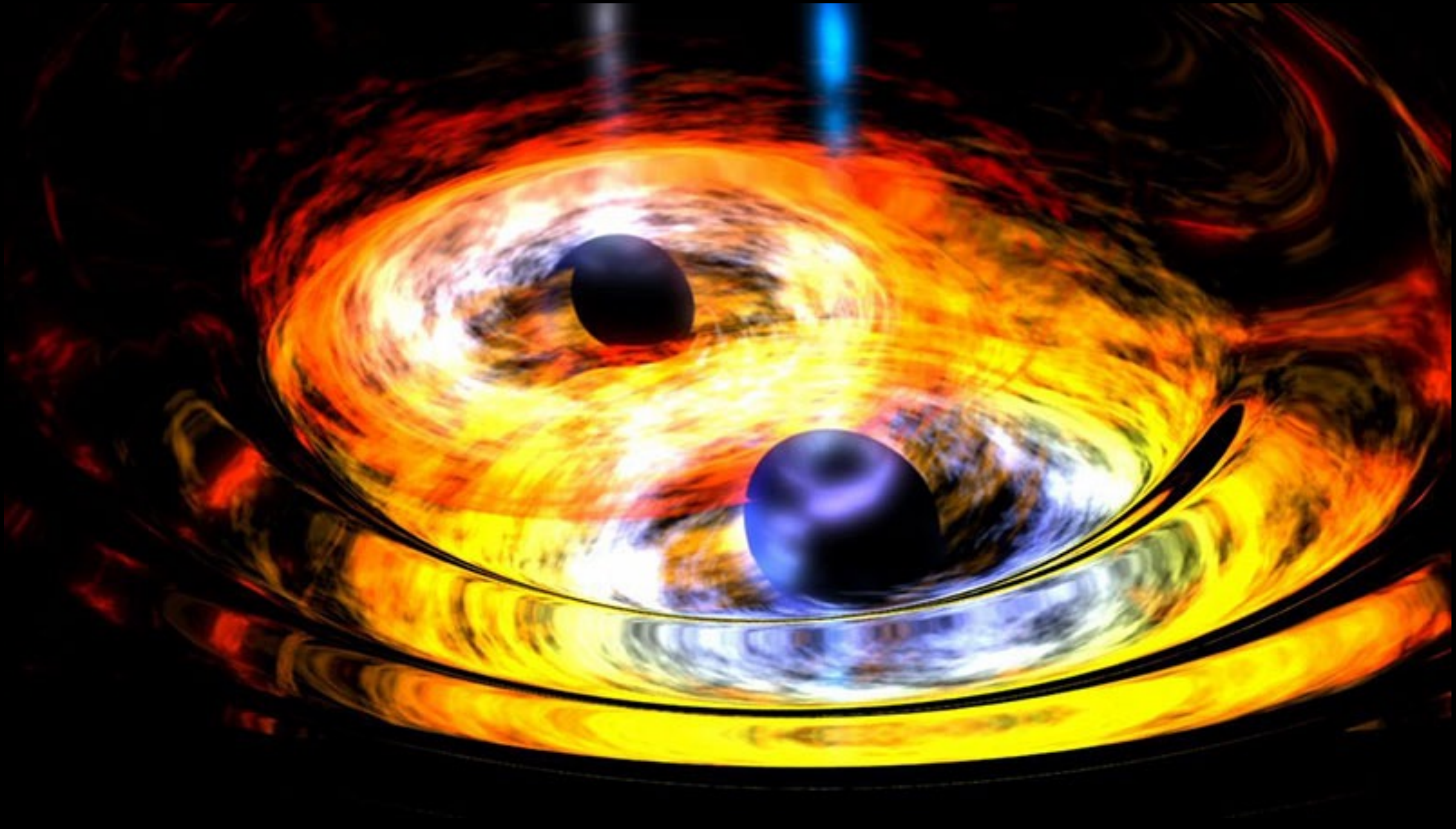
theory : 1964

design : 1984

construction : 1998



Detection of gravitational waves
LIGO February, 2016



Opportunities for Discovery

Many mysteries to date go unanswered including:

The mystery of the Higgs boson

The mystery of Neutrinos

The mystery of Dark Matter

They mystery of Dark Energy

The mystery of quarks and charged leptons

The mystery of Matter – anti-Matter asymmetry

The mystery of the Hierarchy Problem

The mystery of the Families of Particles

The mystery of Inflation

The mystery of Gravity

Based on an original slide by F. Gianotti

Outstanding Questions in Particle Physics *circa* 2011

Quarks and leptons:
- ❑ why 3 families ?
- ❑ masses and mixing
- ❑ *CP* violation in the lepton sector
- ❑ matter and antimatter asymmetry
- ❑ baryon and charged lepton number violation

EWSB
- ❑ Does the Higgs boson exist?

Physics at the highest E-scales:
- ❑ how is gravity connected with the other forces ?
- ❑ do forces unify at high energy ?

Dark matter:
- ❑ composition: WIMP, sterile neutrinos, axions, other hidden sector particles, ..
- ❑ one type or more ?
- ❑ only gravitational or other interactions ?

Neutrinos:
- ❑ ν masses and and their origin
- ❑ what is the role of $H(125)$?
- ❑ Majorana or Dirac ?
- ❑ *CP* violation
- ❑ additional species → sterile ν ?

The two epochs of Universe's accelerated expansion:
- ❑ primordial: is inflation correct ? which (scalar) fields? role of quantum gravity?
- ❑ today: dark energy (why is Λ so small?) or gravity modification ?

Based on an original slide by F. Gianotti

Outstanding Questions in Particle Physics *circa* 2021

... there has never been a better time to be a particle physicist!

Higgs boson and EWSB
- ❑ m_H natural or fine-tuned ?
- → if natural: what new physics/symmetry?
- ❑ does it regularize the divergent $V_L V_L$ cross-section at high $M(V_L V_L)$? Or is there a new dynamics ?
- ❑ elementary or composite Higgs ?
- ❑ is it alone or are there other Higgs bosons ?
- ❑ origin of couplings to fermions
- ❑ coupling to dark matter ?
- ❑ does it violate CP ?
- ❑ cosmological EW phase transition

Quarks and leptons:
- ❑ why 3 families ?
- ❑ masses and mixing
- ❑ *CP* violation in the lepton sector
- ❑ matter and antimatter asymmetry
- ❑ baryon and charged lepton number violation

Physics at the highest E-scales:
- ❑ how is gravity connected with the other forces ?
- ❑ do forces unify at high energy ?

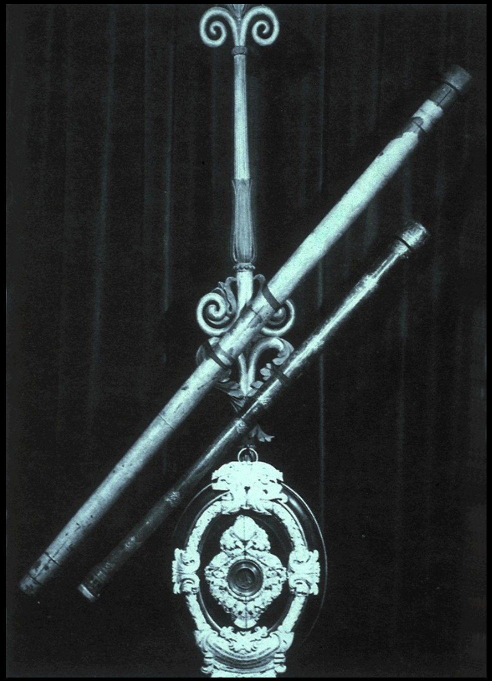
Dark matter:
- ❑ composition: WIMP, sterile neutrinos, axions, other hidden sector particles, ..
- ❑ one type or more ?
- ❑ only gravitational or other interactions ?

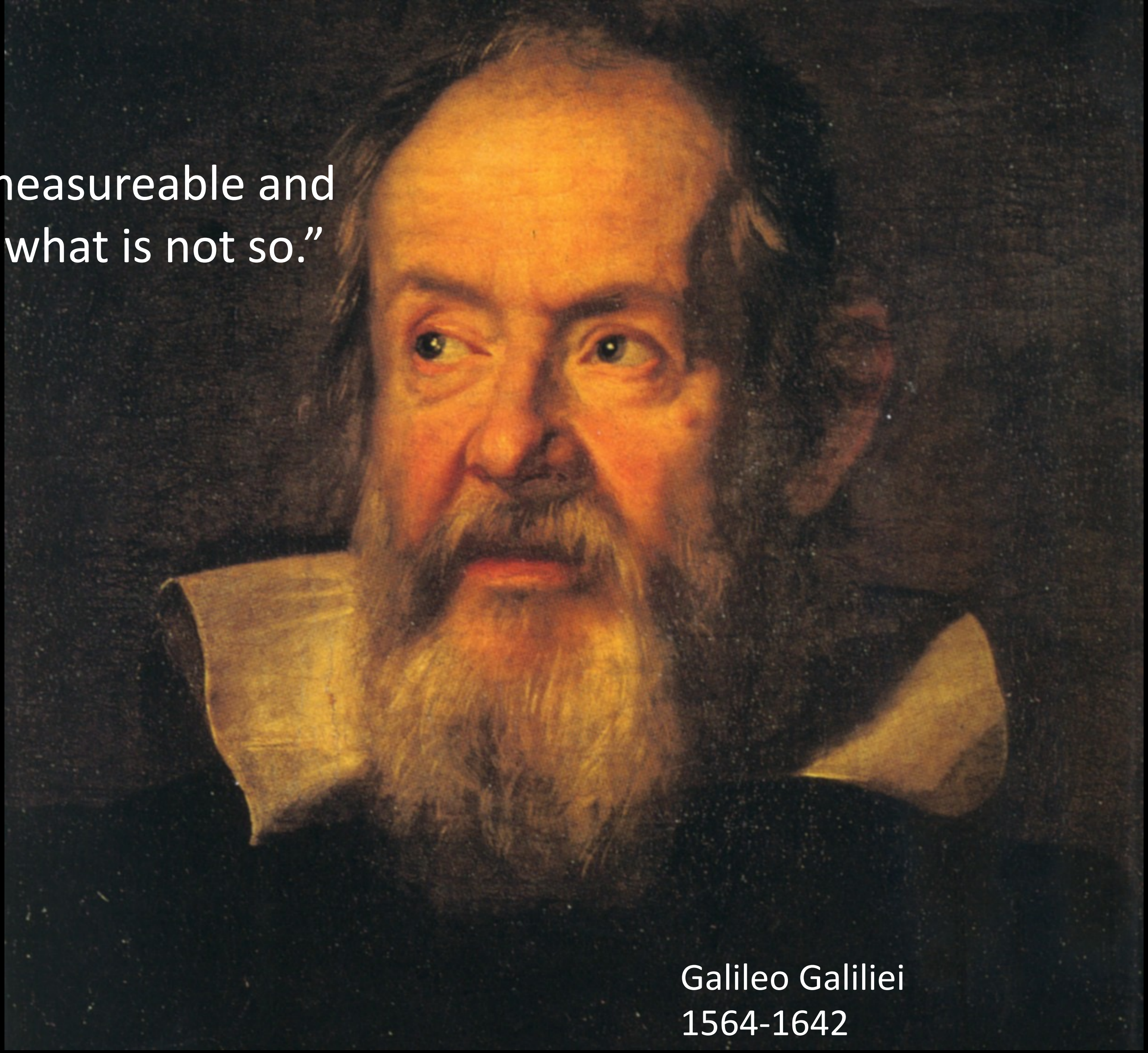
Neutrinos:
- ❑ ν masses and and their origin
- ❑ what is the role of *H*(125) ?
- ❑ Majorana or Dirac ?
- ❑ *CP* violation
- ❑ additional species → sterile ν ?

The two epochs of Universe's accelerated expansion:
- ❑ primordial: is inflation correct ? which (scalar) fields? role of quantum gravity?
- ❑ today: dark energy (why is Λ so small?) or gravity modification ?

We are in a data driven era

“Measure what is measureable and make measureable what is not so.”





Galileo Galiliei
1564-1642

Instrumentation: The Great Enabler

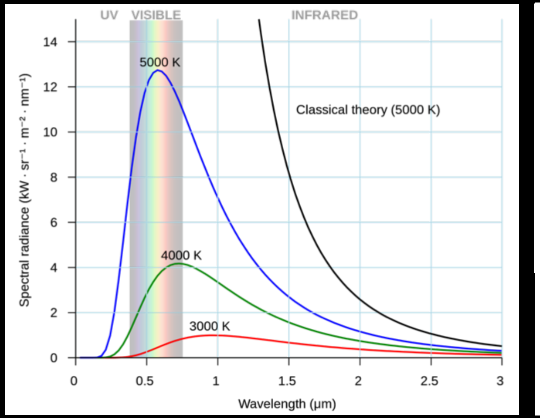
"New directions in science are launched by new tools much more often than by new concepts.

The effect of a concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained"

Freeman Dyson

Tools i.e. precision instruments are key to discovery when exploring new territory Quantum 2.0 provides new tools

Quantum 1.0



Blackbody Radiation

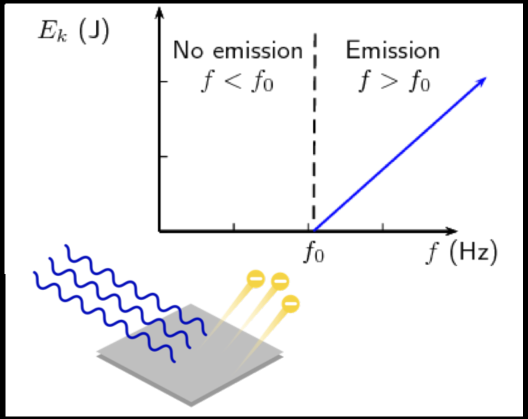
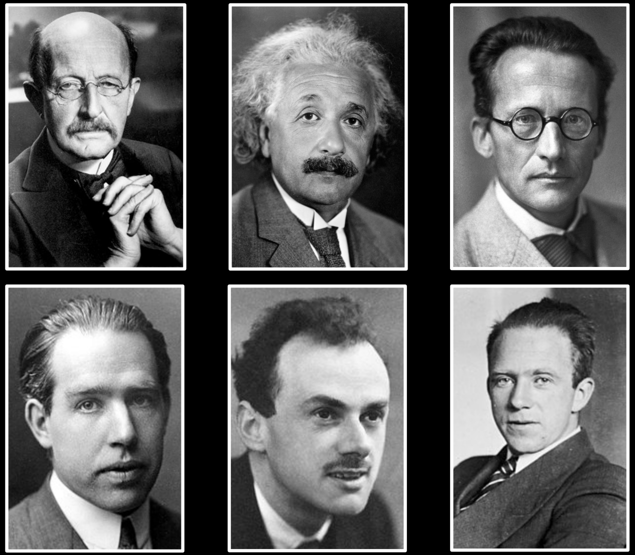
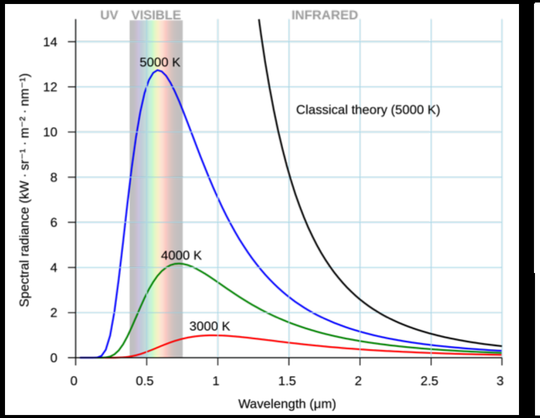


Photo-electric Effect

Quantum Mechanics



Quantum 1.0



Blackbody Radiation

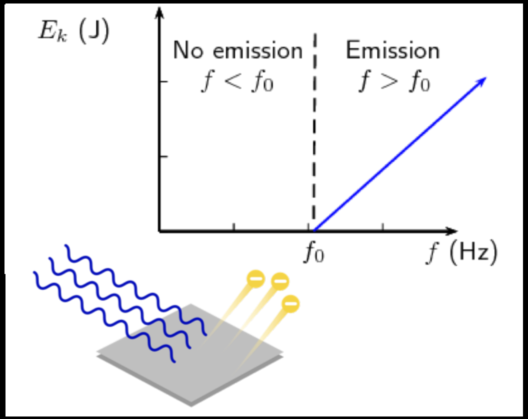
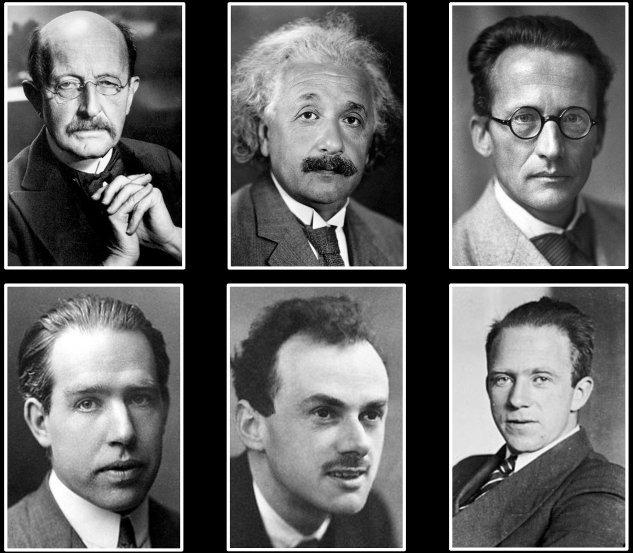


Photo-electric Effect

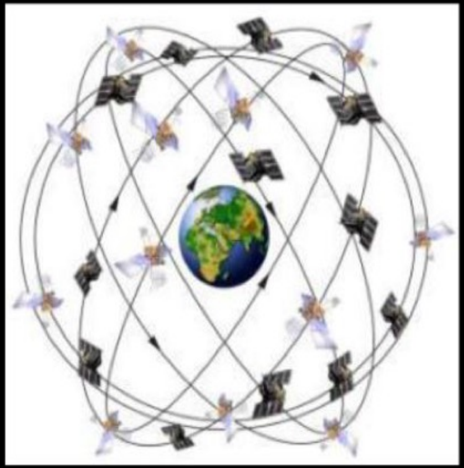
Quantum Mechanics



Exascale Computing

Laser Technology

Magnetic Resonance Imaging

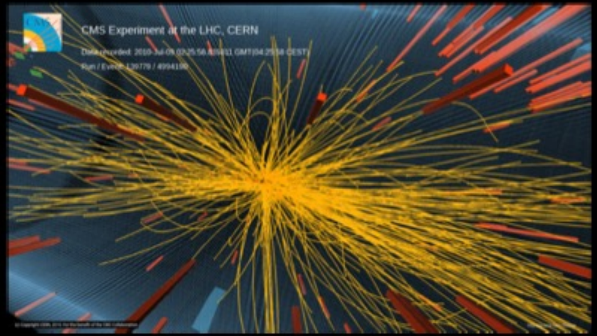


Global Positioning System

Quantum 2.0

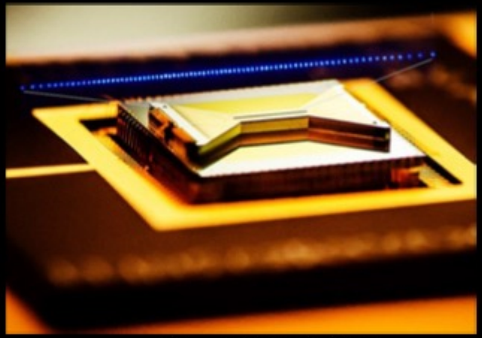
The First Quantum Revolution: exploitation of quantum matter to build devices
Second Quantum Revolution: engineering of large quantum systems with full control of the quantum state of the particles, e.g. entanglement

AI, ML on Quantum annealer



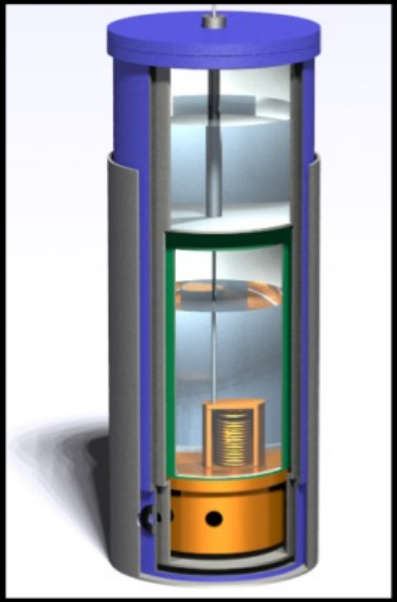
Nature 550 (2017) 375

IonQ >60-qubit



arXiv:1902.10171

Atomic clocks



Nature (564) 87 (2018)

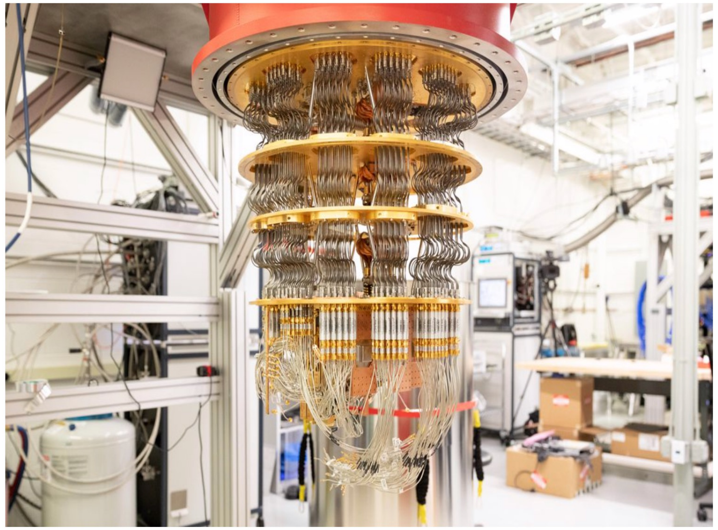
Quantum 2.0

The First Quantum Revolution: exploitation of quantum matter to build devices
Second Quantum Revolution: engineering of large quantum systems with full control of the quantum state of the particles, e.g. entanglement

Google's quantum supremacy is only a first taste of a computing revolution

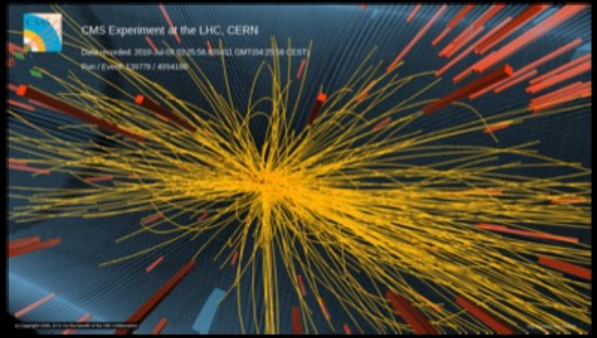
"Quantum supremacy" is nice, but more broadly useful quantum computers are probably still a decade away.

Stephen Shankland October 25, 2019 6:20 AM PDT



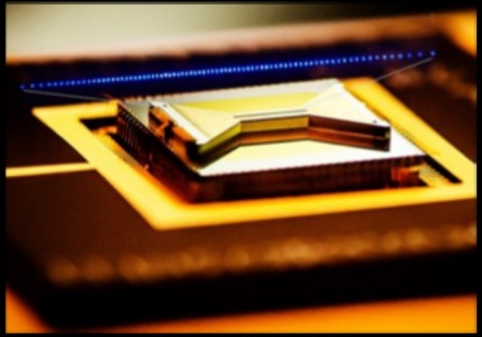
One of five Google quantum computers at a lab near Santa Barbara, California.
Stephen Shankland/CNET

AI, ML on Quantum annealer



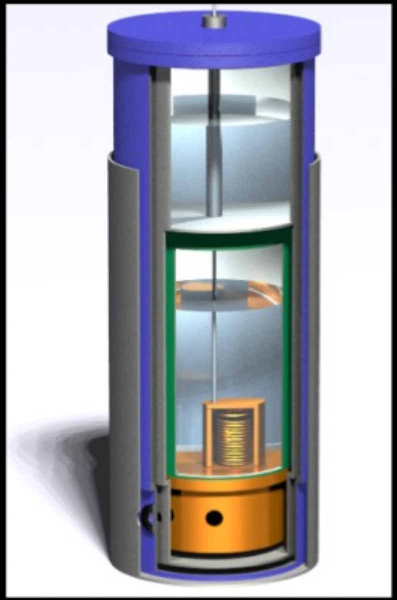
Nature 550 (2017) 375

IonQ >60-qubit



arXiv:1902.10171

Atomic clocks



Nature (564) 87 (2018)

"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical," Feynmann (1981).

You can approximate nature with a simulation on a classical computer, but Feynman wanted a quantum computer that offers the real thing, a computer that "will do exactly the same as nature,"

What if?

Quantum Internet

Quantum Artificial Neural Network

Quantum Liquid Crystals

Quantum Mind Interface

Quantum enabled searches for dark matter

Quantum Gravity

The Confluence

Particle Physics, Particle Astrophysics
& cosmology has many
unanswered questions

The Confluence

Quantum technologies offer new ways to look at the universe

The Confluence

A perfect match

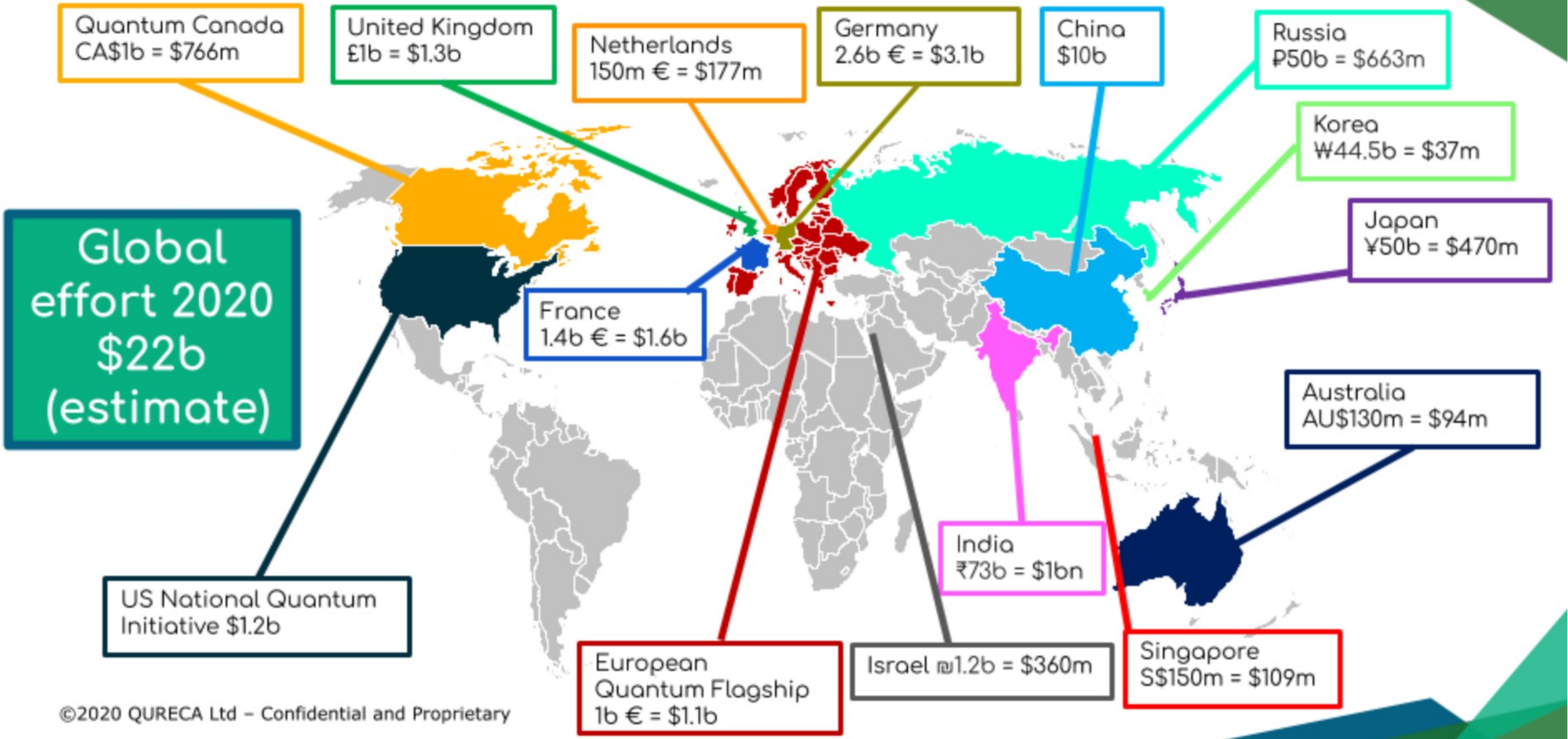
Building a science case: essential for creation of QTFP

The Confluence

A perfect match at a perfect time!

Building a science case: essential for creation of QTFP

Quantum Technologies Public Funding Worldwide



UK National Quantum Technology Program (NQTP)

- *Phase 1 2015-2019, Phase 2 2020-24 (total investment Phase 1+2= £1B)*
- *Phase 2 investments:*
  - *Industry led projects to drive innovation and commercialisation of QT (£173m over 6 years)*
  - Renewal of the QT Research Hubs (£94m over 5 years)
  - Research training portfolio (£25m over 5 years)
  - Quantum Sensors for Fundamental Physics programme (£40m over 4 years)
  - National Quantum Computing Centre to drive development in this new technology and place us at the forefront of this field (£77m over 5 years)

NQTP essential for creation of QTFP

Based on original slides from Ian Walmsley & Peter Knight

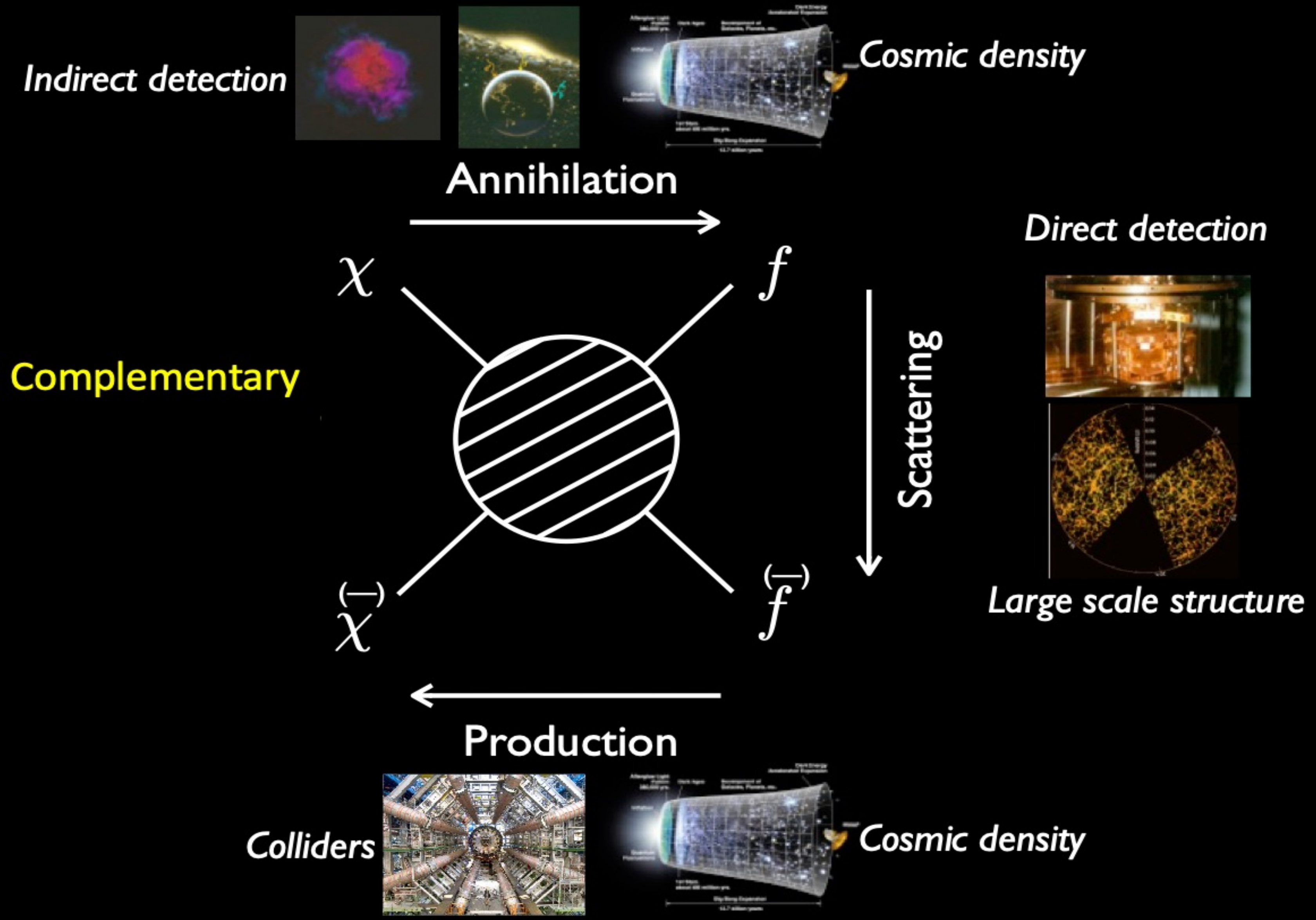
Building a community: essential for creation of QTFP

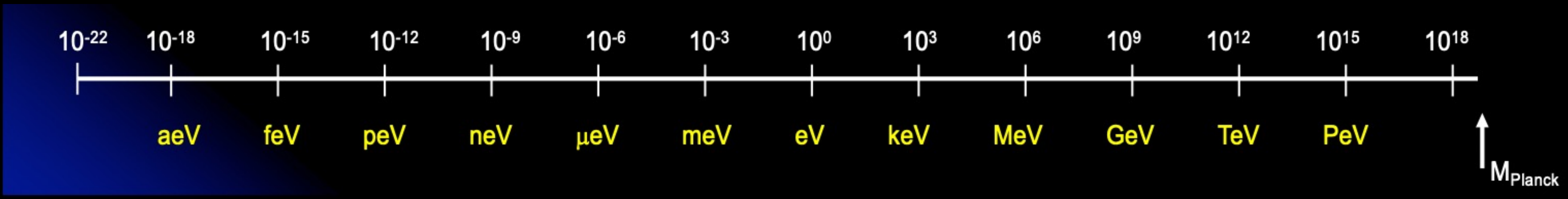
Quantum Technologies for Fundamental Physics Community Workshop October 2018 Oxford
>140 from EPSRC & STFC in attendance

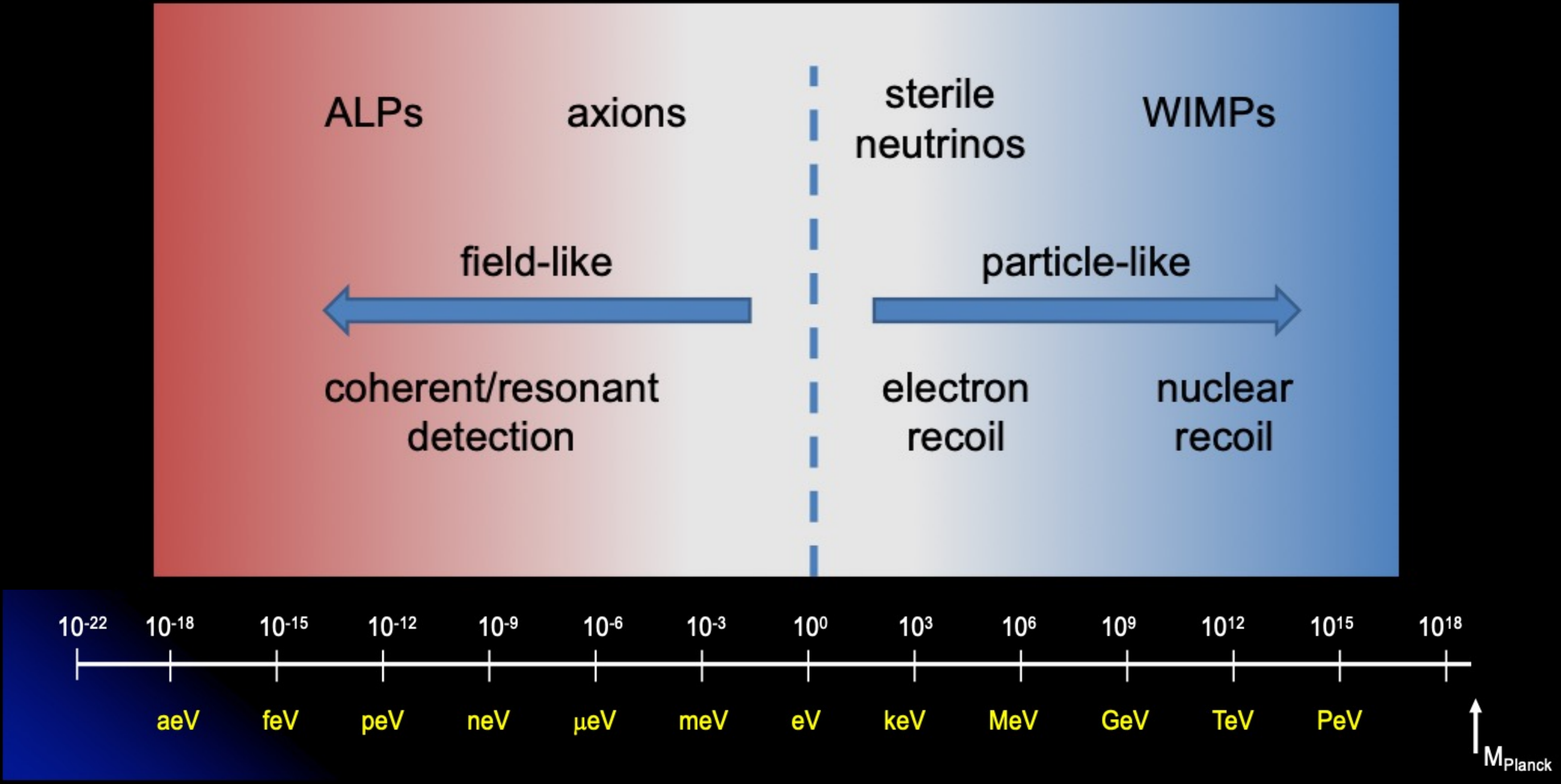
Quantum Technologies and Particle Physics

- The nature of dark matter

Dark Matter Experimental approaches




10^{-22}
10^{-18}
10^{-15}
10^{-12}
10^{-9}
10^{-6}
10^{-3}
10^{0}
10^{3}
10^{6}
10^{9}
10^{12}
10^{15}
10^{18}
aeV
feV
peV
neV
μeV
meV
eV
keV
MeV
GeV
TeV
PeV
M_{Planck}


ALPs
axions
sterile neutrinos
WIMPs
field-like
particle-like
coherent/resonant detection
electron recoil
nuclear recoil
10^{-22} 10^{-18} 10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 10^{0} 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18}
aeV feV peV neV μeV meV eV keV MeV GeV TeV PeV
M_{Planck}

Dark Matter Search Strategy

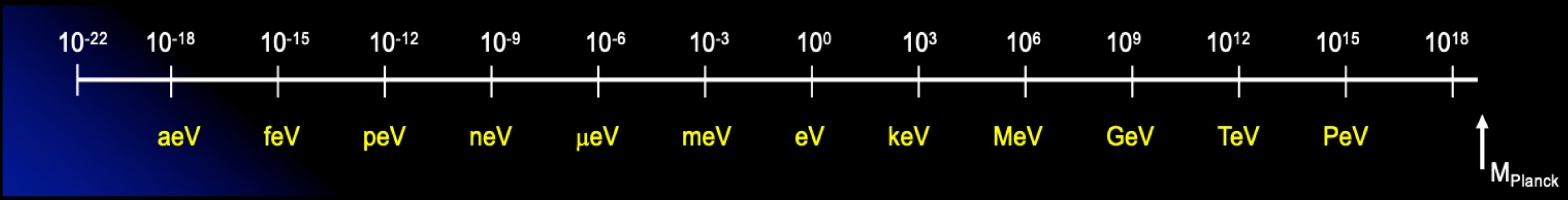
The two theoretically best-motivated candidates:

AXIONS (light)

"table top" expts with quantum sensors

WIMPS (heavy)

Multi-ton expts deep underground



Dark Matter Search Strategy

The two theoretically best-motivated candidates:

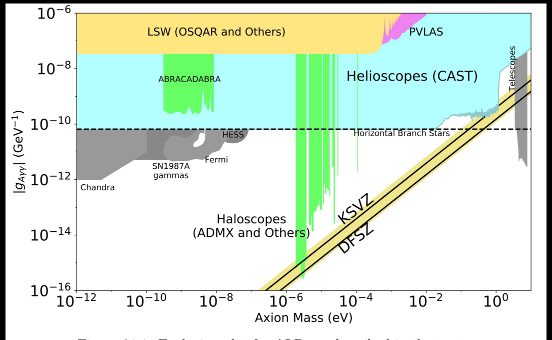
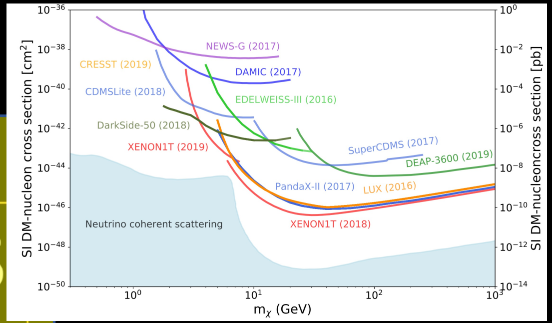


Figure 91.1: Exclusion plot for ALPs as described in the text.

AXIONS (light)

"table top" expts with quantum sensors

WIMPS (heavy)



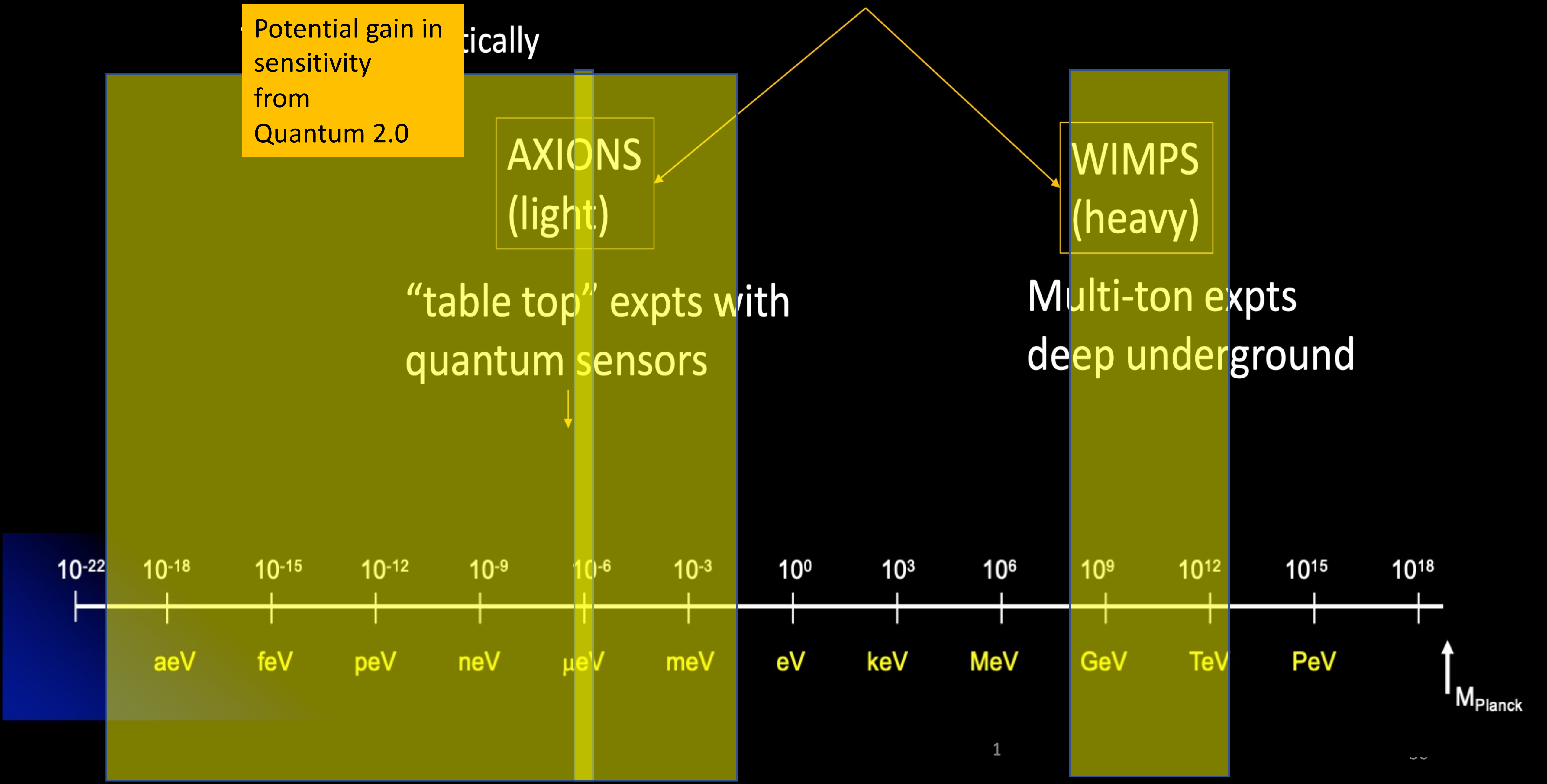
Multi-ton expts deep underground

10^{-22} 10^{-18} 10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 10^{0} 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18}

aeV feV peV neV μeV meV eV keV MeV GeV TeV PeV

M_{Planck}

Dark Matter Search Strategy



Dark Matter Search Strategy

Potential gain in sensitivity from Quantum 2.0

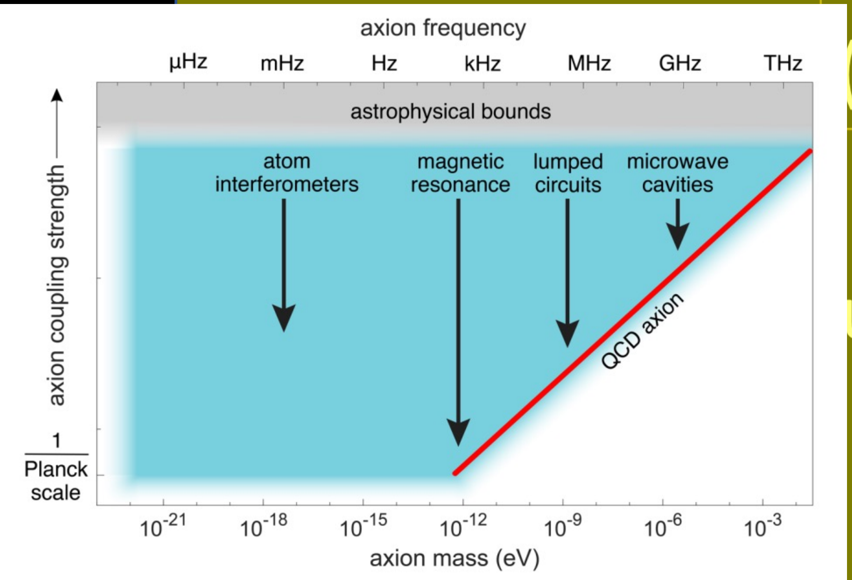
…tically

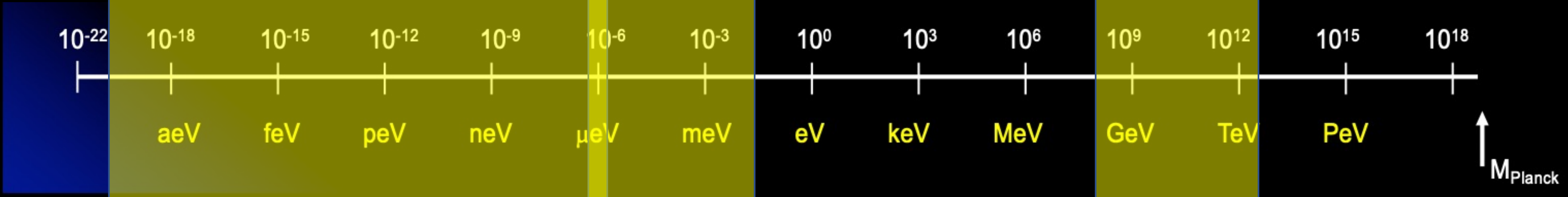
AXIONS (light)

…top" expts with …um sensors

WIMPS (heavy)

Multi-ton expts deep underground





Quantum Technologies and Particle Physics

- The nature of dark matter
- The earliest epochs of the universe at temperatures >> 1TeV
- The existence of new forces
- The violation of fundamental symmetries
- The possible existence of dark radiation and the cosmic neutrino background
- The possible dynamics of dark energy
- The measurement of neutrino mass
- Tests of the equivalence principle
- Tests of quantum mechanics
- A new gravitational wave window to the Universe:
  - LIGO sources before they reach LIGO band
  - Multi-messenger astronomy: optimal band for sky localization
  - Cosmological sources

23-25 March 2017:

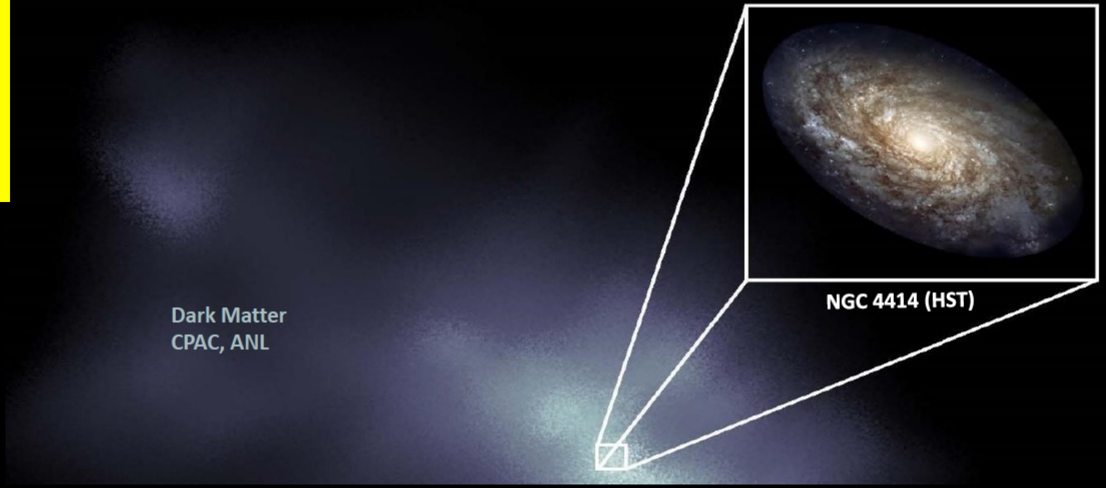
"U.S. Cosmic Visions: New Ideas in Dark Matter" workshop, focusing "… on the science case for additional new small-scale projects in dark-matter science that complement the G2 program …" Comprehensive (exhaustive) report.

14 July 2017:

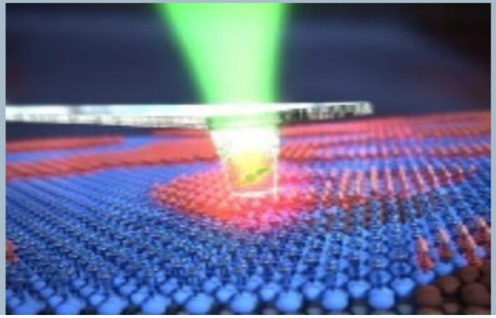
Cosmic Visions Report published (1707.04591). 113 pages. 254 signatories from 112 Institutions (US, Australia, Austria, Canada, Denmark, Germany, Israel, Italy, Japan, Korea, Russia, Switzerland, Taiwan, UK).

Basic Research Needs (BRN) Study for Dark-Matter Small Projects
(preliminary report to HEPAP 30 November 2018)

Increased awareness of the promising application of quantum sensing as one way to the search for dark matter is widespread



APS-DPF Coordinating Panel for Advanced Detectors Interdisciplinary workshop



Workshop on Quantum Sensing

12-14 December 2017
Argonne, Building 240
US/Central timezone

https://indico.fnal.gov/event/ANLHEP1246/

Quantum Sensing for High Energy Physics

Report of the first workshop to identify approaches and techniques in the domain of quantum sensing that can be utilized by future High Energy Physics applications to further the scientific goals of High Energy Physics.

Organized by the Coordinating Panel for Advanced Detectors of the Division of Particles and Fields of the American Physical Society

arXiv:1803.11306v1 [hep-ex]

March 27, 2018

, Malcolm Boshier (LANL), Marcel Demarteau (ANL, co-chair) Maurice Garcia-Sciveres (LBNL) Salman Habib (ANL), Hannes Irwin (Stanford), Akito Kusaka (LBNL), Joe Lykken (FNAL), phael Pooser (ORNL), Sergio Rescia (BNL), Ian Shipsey (Oxford, co-chair), Chris Tully (Princeton).

the first workshop dedicated to **Quantum Sensors for High Energy Physics**, which was influential (and cited in the House Science and Technology Report) in the creation of the US DOE **QS-HEP** program QuantISED for which funds were first awarded in August 2018.

US Initiative including QuantiSED

DOE Office of Science High Energy Physics QIS Core Research
QuantISED (Quantum Information Science Enabled Discovery)

The High Energy Physics (HEP) Program Mission is:

To understand how the universe works at its most fundamental level

It is implemented via projects, facilities, and research & technology programs

Science Drivers were identified with community input https://www.usparticlephysics.org/ as

Higgs Boson, Neutrino Mass, Dark Matter, Cosmic Acceleration, and Explore the Unknown

The HEP QuantISED effort explores the universe via interdisciplinary partnerships between HEP and QIS communities through the topics:

A: Cosmos and Qubits

B: Foundational QIS-HEP Theory and Simulation

C: Quantum Computing for HEP

D: QIS-based Quantum Sensors

E: Research Technology for QIST

F: QuantISED (Small) Experiments exploring P5 science drivers using QIS tools & techniques

(QuantISED was publicly competed in 2018 and 2019 and is part of the DOE Office of Science QIS Initiative)

https://science.osti.gov/hep/Research/Quantum-Information-Science-QIS

QuantISED is in many respects the analogue of QTFP

In the US National Quantum Initiative

CONGRESS.GOV   Advanced Searches | Browse

Search Tools | Support | Sign In

Legislation | Congressional Record | Committees | Members

Legislation   Examples: hr5, sres9, "health care"

MORE OPTIONS

Home > Legislation > 115th Congress > H.R.6227

Subscribe   Share/Save   Site Feedback

H.R.6227 - National Quantum Initiative Act

115th Congress (2017-2018)

LAW   Hide Overview ✖

Sponsor: Rep. Smith, Lamar [R-TX-21] (Introduced 06/26/2018)

Committees: House - Science, Space, and Technology I Senate - Commerce, Science, and Transportation

Committee Meetings: 06/27/18 10:00AM

Committee Reports: H. Rept. 115-950

Latest Action: 12/21/2018 Became Public Law No: 115-368. (TXT I PDF) (All Actions)

Roll Call Votes: There has been 1 roll call vote

Tracker:

Introduced > Passed House > Passed Senate > Resolving Differences > To President > **Became Law**

More on This Bill

Constitutional Authority Statement

CBO Cost Estimates [1]

Subject — Policy Area:

Science, Technology, Communications

View subjects »

Came into law December, 2018
Directed the creation of 5 DOE Quantum Science Centers (including FNAL)
& 6 NSF multidisciplinary Quantum Research Centers

Quantum Sensors for Fundamental Physics

The bid was made by STFC/EPSRC December 20, 2018. This requested the funding to create the new programme (£40M/ 3 years)

Feedback: The QSFP consortium has been essential to demonstrating the interdisciplinary interest & formation of a community . Without it there would have been no credible bid.

STFC Opportunities Funding had been awarded QSFP to build a community and consortium and to prepare for the call. We supported more than a dozen workshops that facilitated the formation of teams and the development of proto-proposals around key experiments that targeted the new programme, we also hosted a school in January 2020

We also engaged with the international community who gave feedback on our ideas

The call opened 9/19 closed 12/19 many excellent proposals submitted by the community 11 from QSFP and many more not associated with QSFP

QSFP | UK Institutions | Partners | International Institutions | Workpackages | QSFP Organization

WP1

Using Quantum Technology to Search for Low-mass Particles in the Hidden Sector

Participants/Collaborators ›
Join this group ›

WP2

MaQS (pronounced "Max") **Macroscopic quantum superpositions for physics beyond the standard model**

WP2 workshop slides ›
Participants/Collaborators ›
Join this group ›

WP3

AION A UK Atom Interferometer Observatory and Network

Join this group ›

WP4

Absolute neutrino mass

Participants/Collaborators ›
Join this group ›

WP5

Quantum Simulators of Fundamental Physics

Participants/Collaborators ›
Join this group ›

WP6

QSNET Networked Quantum Sensors for Fundamental Physics

Join this group ›

WP7

Searches for a Fifth Force and Dark Matter using Precision Atomic Spectroscopy

Join this group ›

WP8

Fundamental physics from precision studies of exotic atoms

Participants/Collaborators ›
Join this group ›

WP9

LIST – Lorentz Invariance Space Test

Participants/Collaborators ›
Join this group ›

WP10

Quantum sensors for fundamental physics: Collective quantum excitations as quantum sensors

Participants/Collaborators ›
Join this group ›

WP11

QI: Quantum-enhanced Interferometry for New Physics

QUEST DMC

QSFP UK Institutions Partners International Institutions **Workpackages** QSFP Organization

QT FP

WP1

Using Quantum Technology to Search for Low-mass Particles in the Hidden Sector

Participants/Collaborators ›
Join this group ›

WP3

AION A UK Atom Interferometer Observatory and Network

Join this group ›

WP4

Absolute neutrino mass

Participants/Collaborators ›
Join this group ›

WP5

Quantum Simulators of Fundamental Physics

Participants/Collaborators ›
Join this group ›

WP6

QSNET Networked Quantum Sensors for Fundamental Physics

Join this group ›

WP11

QI: Quantum-enhanced Interferometry for New Physics

Quantum Technologies for Fundamental Physics selected proposals: QUEST-DMC + six that were developed by the community activities supported by the STFC Opportunities Award

QSFP UK Institutions Partners International Institutions Workpackages QSFP Organization

QUEST DMC

Andrew Casey

WP1

Using Quantum Technology to Search for Low-mass Particles in the Hidden Sector

Participants/Collaborators ›
Join this group ›

Ed Daw

WP3

AION A UK Atom Interferometer Observatory and Network

Join this group ›

Oliver Buchmueller

WP4

Absolute neutrino mass

Participants/Collaborators ›
Join this group ›

Ruben Saakyan

WP5

Quantum Simulators of Fundamental Physics

Participants/Collaborators ›
Join this group ›

Silke Weinfurtner

WP6

QSNET Networked Quantum Sensors for Fundamental Physics

Join this group ›

Giovanni Barontini

WP11

QI: Quantum-enhanced Interferometry for New Physics

Hartmut Grote

QT FP

Quantum Technologies for Fundamental Physics selected proposals: QUEST-DMC + six that were developed by the community activities supported by the STFC Opportunities Award

An excellent review

IOP Publishing Quantum Sci. Technol. 4 (2019) 040502 https://doi.org/10.1088/2058-9565/ab4346

Quantum Science and Technology

Quantum Technologies for Fundamental Physics funds originated from the Strategic Priorities fund and It is part of the National Quantum Technologies Programme

PERSPECTIVE

UK national quantum technology programme

Peter Knight and Ian Walmsley

Imperial College London SW72AZ, United Kingdom

Keywords: quantum, imaging, timing, communication, sensors, computing

CrossMark

OPEN ACCESS

PUBLISHED
29 October 2019

NQTP Phase 2 – 2019 onwards

Further investment into the National Programme

- **Ensuring UK research leadership:** Renewal and refresh of the QT Research Hubs (£94M over 5 years)
- **Commercialisation and industrialisation of QT:** industry led projects to drive innovation and commercialisation (£153M over 6 years, ISCF)
- **Delivering skilled people:** investment in research training (£25M over 5 years)
- **Enhancing national capabilities:** National Quantum Computing Centre to drive development in this new technology and place us at the forefront of this field (£93M over 5 years)
- **Science as a customer of QT:** A focussed research programme aimed at demonstrating how the application of QT will advance the understanding of fundamental physics questions (£40M over 3 years)

Slide credit Sir Peter Knight

Education The QTFP School

QSFP school 2021

6-17 September 2021
remote
Europe/London timezone

School Committee
QSHS Ed Daw
QI Hartmut Grote
QSimFP Silke Weinfurtner
AION Oliver Buchmueller
QUEST-DMC Jocelyn Monroe (tbc)
QTNM Rubin Saakyan
QSNET Giovanni Barontini
Martin Bauer John Ellis Ian Shipsey

QTFP Activities

Workshops

An annual QTFP workshop organized jointly with STFC & EPSRC will be open to the entire UK EPSRC and STFC community (including the funded projects and those not funded). An opportunity to present new ideas from the UK community and from leading international researchers researchers.

An online platform is being developed

Public Engagement Projects

Engagement with Industry – Photonex, NQTP Technology Showcase

Integrating into the NQTP through deepening relationship Hubs and the program more generally

QTFP Community Committee

NQTP Peter Knight

NQTP-Hubs Kai Bongs

QSHS Ed Daw & Stafford Withington

QI Hartmut Grote & Denis Martynov

QSimFP Silke Weinfurtner & Ruth Gregory

AION Oliver Buchmueller & John Ellis

QUEST-DMC Jocelyn Monroe & Mark Hindmarsh

QTNM Rubin Saakyan & Ling Hao

QSNET Giovanni Barontini & Xavier Calmet

Theory Martin Bauer, John March-Russell

EPSRC & STFC Community Reps to be added

Ian Shipsey

THE EUROPEAN STRATEGY UPDATE CALLED FOR A DETECTOR R&D ROADMAP – A TASKFORCE ON QUANTUM SENSORS & OTHER INNOVATIVE TECHNOLOGIES IS ONE OF NINE

CERN HAS A NASCENT QUANTUM PROGRAMME

FERMILAB HAS BEEN CHOSEN AS A DOE QUANTUM SCIENCE CENTER

THE FIRST DOE REVIEW OF THE FUTURE OF THE US NATIONAL INSTRUMENTAITON PARTICLE PHYISCS RESEARCH PROGRAMME HAS IDENTIFED AN AMBITIOUS PROGRAMME OF QUANTUM SENSOR RESEARCH

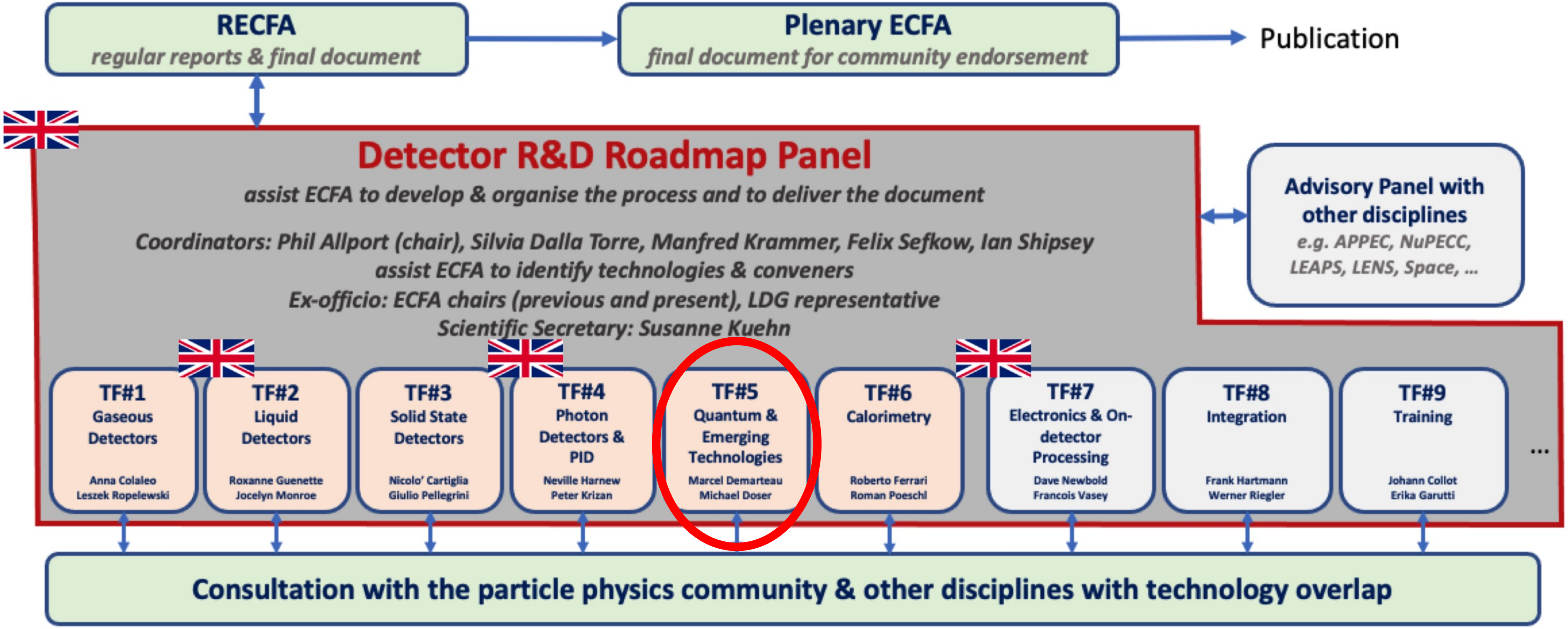
QUANTUM TECHNOLOGIES FOR PARTICLE PHYSICS WILL BE A PROMINENT PLAYER FOR THE NEXT SEVERAL DECADES

THE ESSENTIAL INGREDIENTS THAT HAVE MADE QTFP POSSIBLE ARE:

- COMPELLING SCIENCE
- QUANTUM REVOLUTION 2.0
- THE NATIONAL QUANTUM TECHNOLOGY PROGRAM
- A STRONG COMMUNITY

THERE IS EXCITING SCIENCE AHEAD

ECFA Roadmap Panel Structure



https://indico.cern.ch/e/ECFADetectorRDRoadmap

Summary of Detector R&D Roadmap Process

Expert & Community Consultation Phase completed

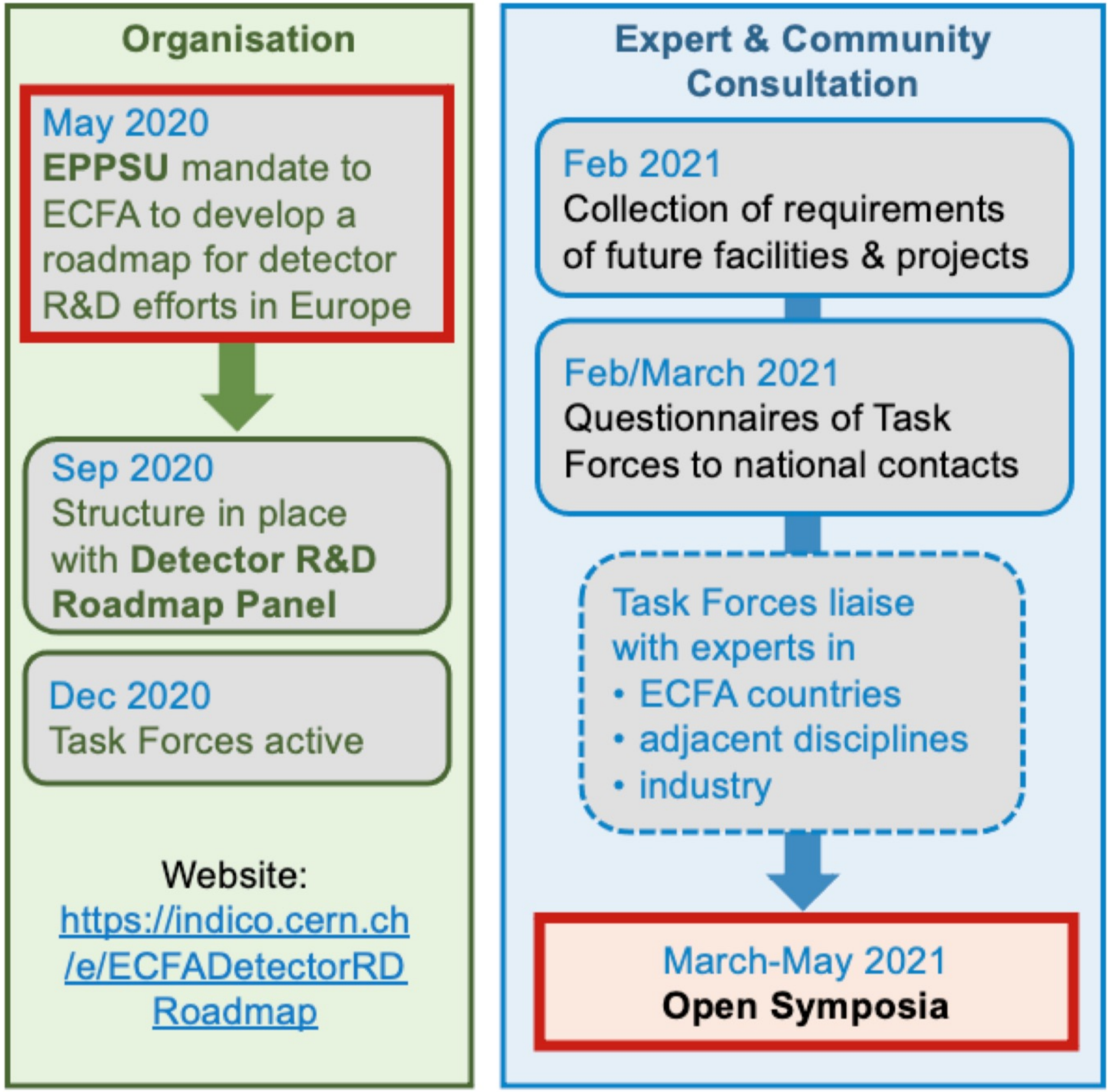
- All **Open Symposia** took place between 27th March and 7th May

  https://indico.cern.ch/event/957057/program

- In total 1366 registered participants

- "Most popular" sessions:
  TF3 (Solid state det.) (504 participants, 275 concurrent views)
  TF7 (Electronics) (492 participants, 353 concurrent views)

- Registration will be used to get future updates (asked for consent of people)
  https://indico.cern.ch/event/957057/registrations/70781/



ECFA Detector R&D Roadmap Symposium of Task Force 5 Quantum and Emerging Technologies

Monday 12 Apr 2021, 09:00 → 18:30 Europe/Zurich

Marcel Demarteau (Oak Ridge National Laboratory), Marcel Demarteau (Fermilab), Michael Doser (CERN)

09:15 → 11:15 **Science targets - Overview and Landscape**
Convener: Michael Doser (CERN)

- **09:15** **EDM searches & tests of fundamental symmetries**
  Speaker: Peter Fierlinger (TUM)
  electric_dipole_mo...
- **09:45** **Tests of QM [wavefunction collapse, size effects, temporal separation, decoherence]**
  Speaker: Angelo Bassi (Department of Physics - University of Trieste)
  QM_Tests_compre...
- **10:15** **Multisensor and networked detection**
  Speaker: Giovanni Barontini (Birmingham)
  ECFA_networks.pdf
- **10:45** **Axion and other DM, non-DM Ultra-light particle searches**
  Speaker: Mina Arvanitaki (Perimeter Institute)
  ECFAApril2021.pdf

11:30 → 13:00 **Experimental methods and techniques - Overview and Lanscape**
Convener: Marcel Demarteau (Oak Ridge National Laboratory)

- **11:30** **Spin-based techniques, NV-diamonds, Magnetometry**
  Speaker: Dima Budker (Mainz)
  ECFA_instrumentat...
- **12:00** **Novel ionic, atomic and molecular systems [RaF, tests in multiatomic molecules, exotic atoms]**
  Speaker: Marianna Safronova (Univ. Delaware)
  2021-Safronova.pdf
- **12:30** **Quantum-limited Metrology with Optical Clocks**
  Speaker: David Hume (NIST)
  Hume_ECFA.pdf | Hume_ECFA.pptx

14:00 → 16:00 **Experimental methods and techniques - New Developments**
Convener: Michael Doser (CERN)

- **14:00** **High sensitivity superconducting cryogenic electronics, low noise amplifiers, TES**
  Speaker: Stafford Withington (Cambridge)
  ECFA talk - Withingt... | ECFA talk - Withingt...
- **14:30** **Superconducting platforms for sensing and computing**
  Speaker: Alexander Romanenko (FNAL)
  ECFA_DetectorBRN... | ECFA_DetectorBRN...
- **15:00** **Quantum Acceleration of Axion Detection**
  Speaker: Kent Irwin (Stanford)
  20210412 Irwin EC...
- **15:30** **Mechanical / optomechanical detectors**
  Speaker: Andrew Geraci (Northwestern)
  Geraci_OptomechD... | Geraci_OptomechD...

16:15 → 18:30 **Experimental and technological challenges**
Convener: Marcel Demarteau (Oak Ridge National Laboratory)

- **16:15** **Low energy techniques for neutrinos and axions**
  Speaker: Loredana Gastaldo (KIP)
  Gastaldo_ECFA_v4....
- **16:45** **Quantum scintillation materials**
  Speaker: Etiennette Auffray Hillemans (CERN)
  EAuffray_ECFAQua...
- **17:15** **Atom interferometry at large scales (ground based, space based)**
  Speaker: Jason Hogan (Stanford)
  ECFA-hogan.pdf | ECFA-hogan.pptx
- **17:45** **Discussion session**
  - Technical challenges and barriers
  - Scaling up from table-top systems
  - Applying quantum technologies to high energy detectors

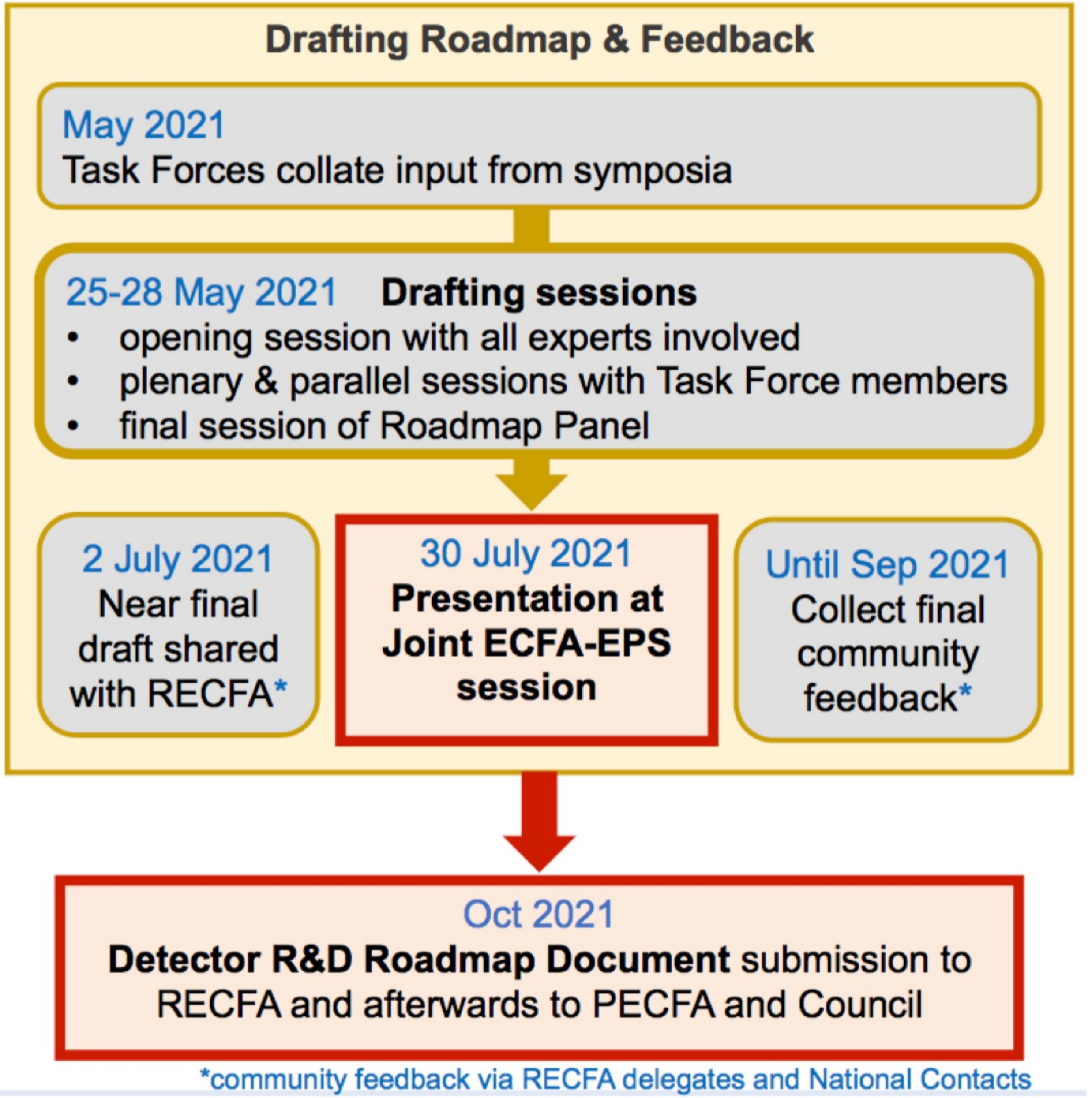
Summary of Detector R&D Roadmap Process (cont.)

- **Drafting Session during week 25 – 28 May**
  Worked very well, stressful due to full online format, but interactions between TFs really needed and fruitful

- Major issues addressed:

  - Agreed on main priorities ("Detector Research Themes") in the different technology areas
  - Identified overlap, transversal activities
  - Finalise layout of the various chapters
  - Discussion of common timeline with LDG for large high-priority projects

- **Finalisation of "near final draft" during June**, will be shared with RECFA by 2nd July



THE EUROPEAN STRATEGY UPDATE CALLED FOR A DETECTOR R&D ROADMAP – A TASKFORCE ON QUANTUM SENSORS & OTHER INNOVATIVE TECHNOLOGIES IS ONE OF NINE

CERN HAS A NASCENT QUANTUM PROGRAMME

FERMILAB HAS BEEN CHOSEN AS A DOE QUANTUM SCIENCE CENTER

THE FIRST DOE REVIEW OF THE FUTURE OF THE US NATIONAL INSTRUMENTAITON PARTICLE PHYISCS RESEARCH PROGRAMME (September, 2020) HAS IDENTIFED AN AMBITIOUS PROGRAMME OF QUANTUM SENSOR RESEARCH

QUANTUM TECHNOLOGIES FOR PARTICLE PHYSICS WILL BE A PROMINENT PLAYER FOR THE NEXT SEVERAL DECADES

THE ESSENTIAL INGREDIENTS THAT HAVE MADE QTFP POSSIBLE ARE:

- COMPELLING SCIENCE
- QUANTUM REVOLUTION 2.0
- THE NATIONAL QUANTUM TECHNOLOGY PROGRAM
- A STRONG COMMUNITY

THERE IS EXCITING SCIENCE AHEAD

QSHS Quantum Sensing for the Hidden Sector

UNIVERSITY OF CAMBRIDGE

Lancaster University

The University Of Sheffield.

NPL National Physical Laboratory

UNIVERSITY OF OXFORD

ROYAL HOLLOWAY UNIVERSITY OF LONDON

UNIVERSITY OF LIVERPOOL

UCL

ADMX

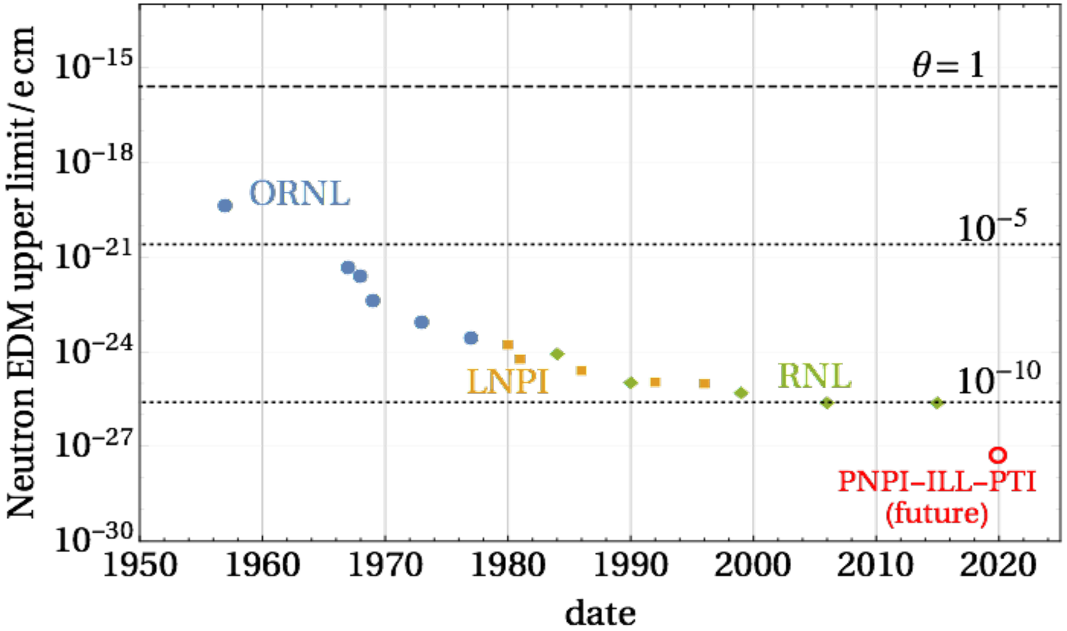
A portion of our work is in collaboration with the U.S. Axion Dark Matter eXperiment collaboration.

Hidden sector dark matter

- The nature of dark matter is one of the important questions in modern physics.
- Light hidden sector fields make compelling dark matter.
- The same fields can solve outstanding problems with the standard model.
- Probably the best motivated particle is the QCD axion.

DARK MATTER PROBLEM

STRONG CP PROBLEM



- Our central aim is to build, in the UK, the world's leading facility for quantum measurements in the hidden sector.
- In the first 3.5 years, we will focus on demonstration of technology, with the axion as our primary science goal. Modelling indicates that 20-40 μeV is the most probable mass range. It is unexplored.

Axion Detectors and the Current Landscape

SUPERCONDUCTING QUANTUM ELECTRONICS:
- SQUIDs
- Josephson Parametric Amplifiers
- Travelling Wave Parametric Amplifiers
- Bolometers
- Qubits / QuBit arrays

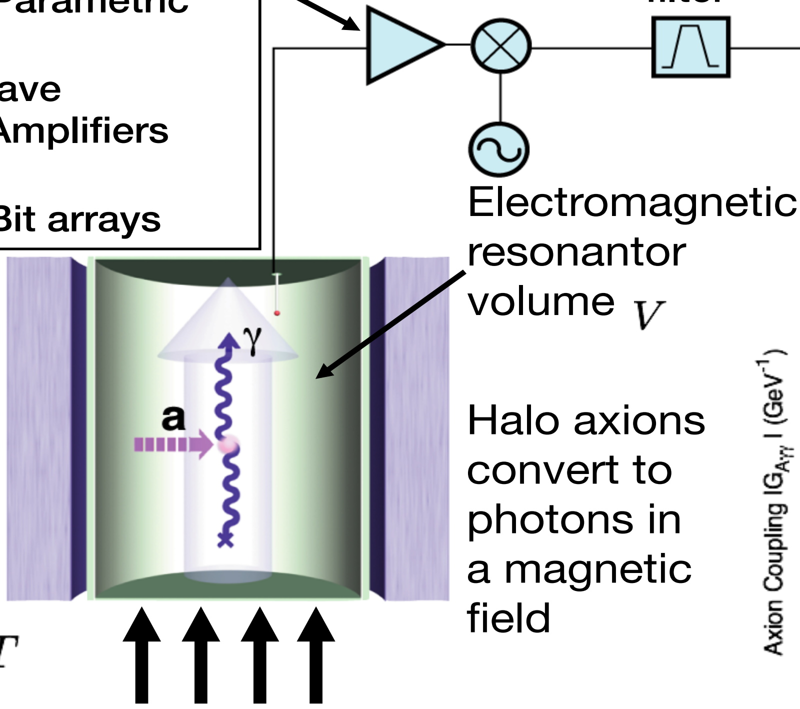
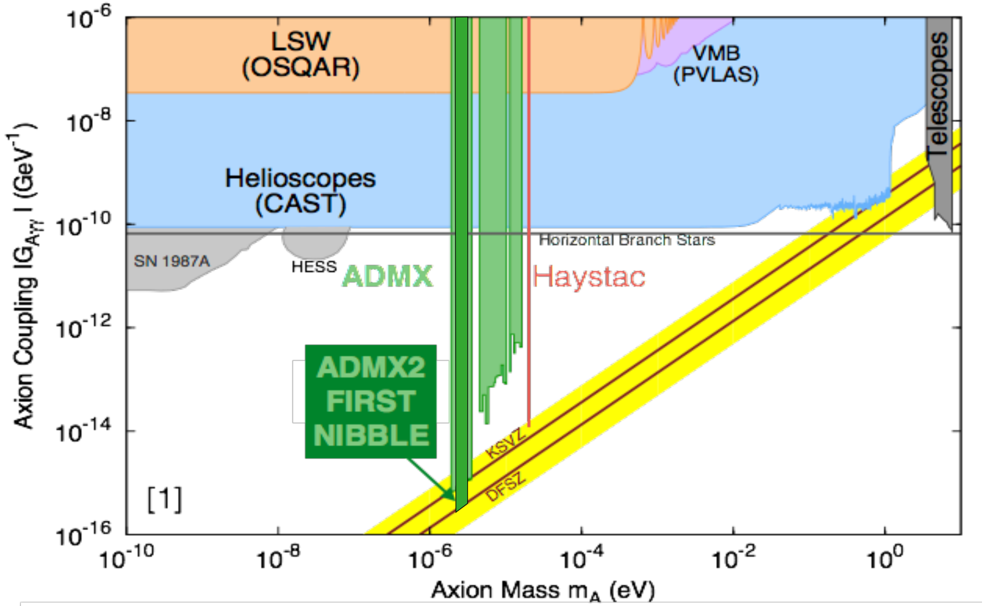


Figure of merit for detector sensitivity: $\frac{B^2 V}{T}$

Current experimental landscape

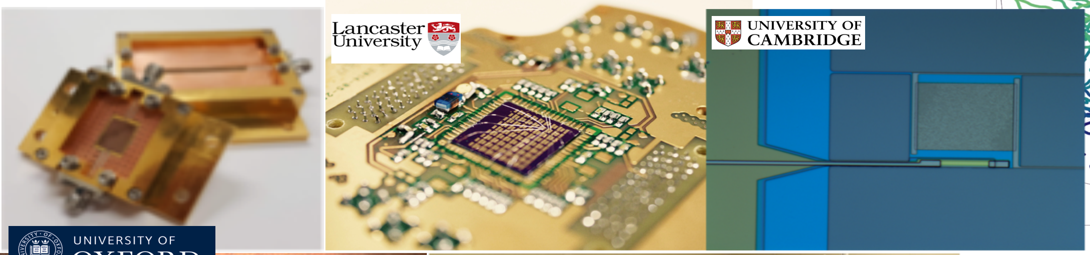


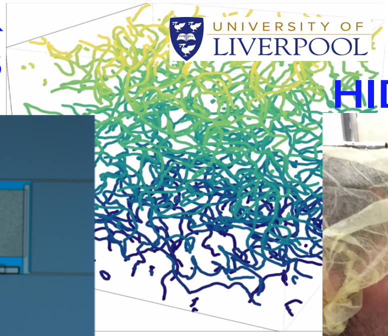
- Non resonant experiments have broad mass coverage, but insufficiently sensitive to detect QCD axions.
- Resonant experiments much more sensitive. ADMX is the only experiment to have probed a broad range of existing axion models. However, mass coverage too slow. Can speed up: 1. By using a new generation of quantum electronics; 2. By using a larger, higher field magnet; 3. Using multiple resonators in parallel.

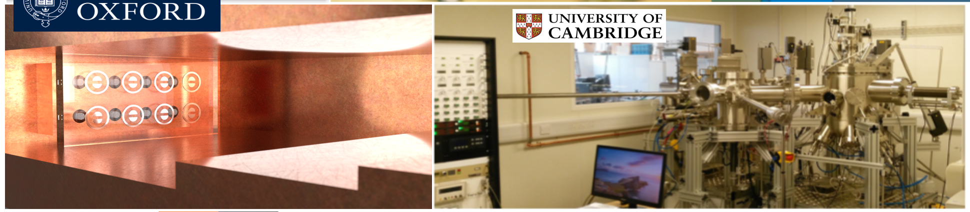
Expertise:

QUANTUM ELECTRONICS

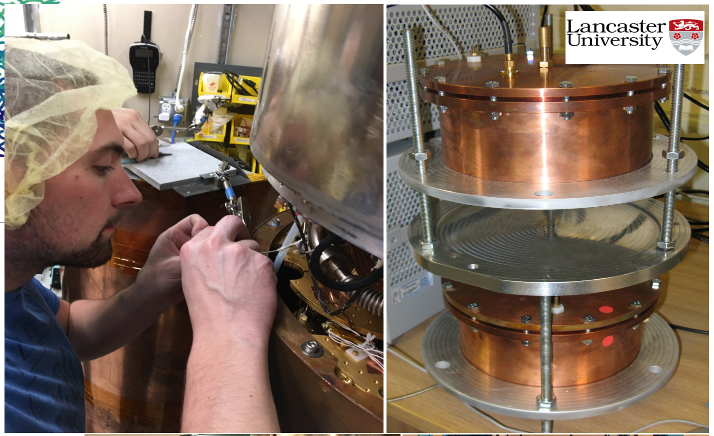
THEORY & SIMULATIONS



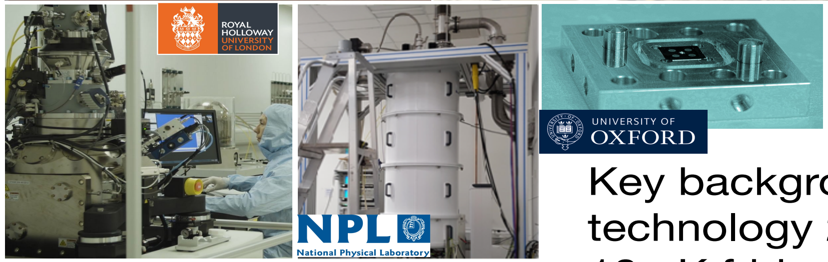




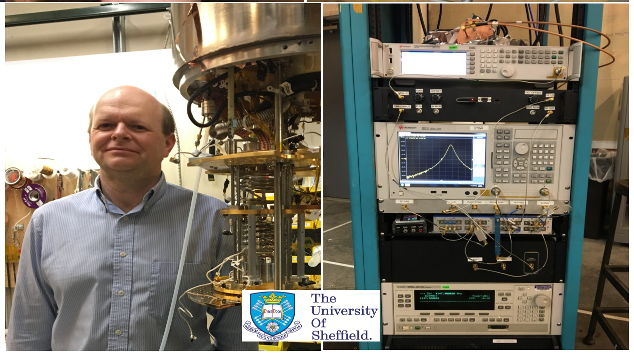
HIDDEN SECTOR SEARCHES



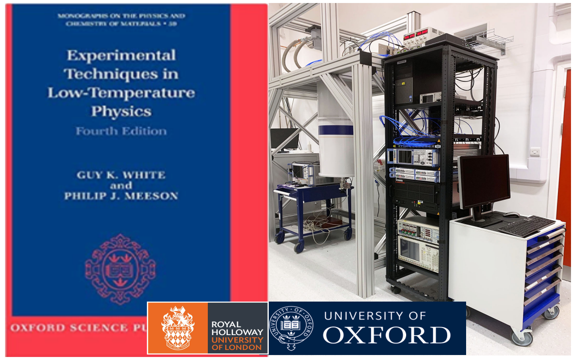
Key background technology 1: large magnets



Key background technology 2: 10mK fridges



VACUUM & CRYOGENICS



RESONANT MICROWAVE ELECTRONICS