Dark Sector Physics

PPAP, Nov 20th 2020

John March-Russell
Oxford/Perimeter Institute/Stanford

Physics case for Dark Sector research is overwhelming

- We *know* Dark Matter exists - morally multi-component

massive neutrinos

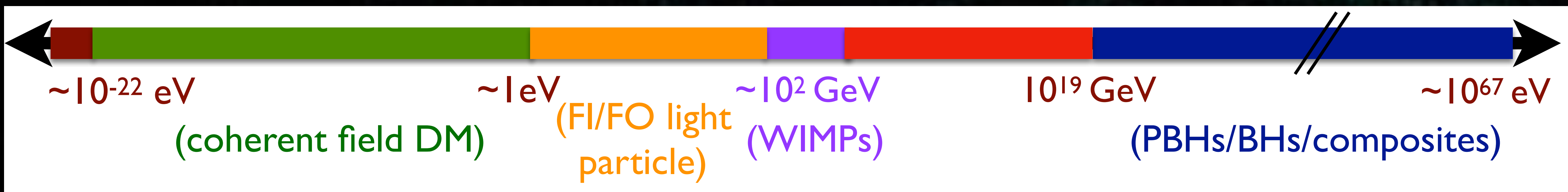
black holes

fundamentally new massive field/ particle/composite/sector...

↓

itself very likely multi-component if we look carefully (sub-dominant components carry vital information too)

The Dark Matter Landscape
(bosonic)



there are currently `theoretically favoured' regimes but constraints allow ~90 decades in mass to have >1% fraction of DM

- A very wide range of types of DM with many different couplings to SM, and different phenomenology
- Shouldn't look just in one place or with one technique

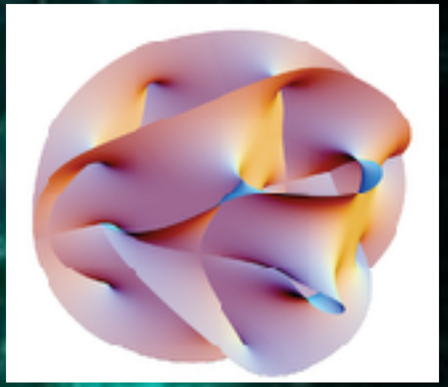
(and again, a sub-component of DM might be the most interesting)

Additionally:

- *Dark radiation* is a target for dark sector searches

  predicted *cosmic neutrino background* & any new source of DR (dark photon, or conformal sector, or `hot' gravitons,...)

- Most theories underlying the SM possess new *light* states which are feebly coupled

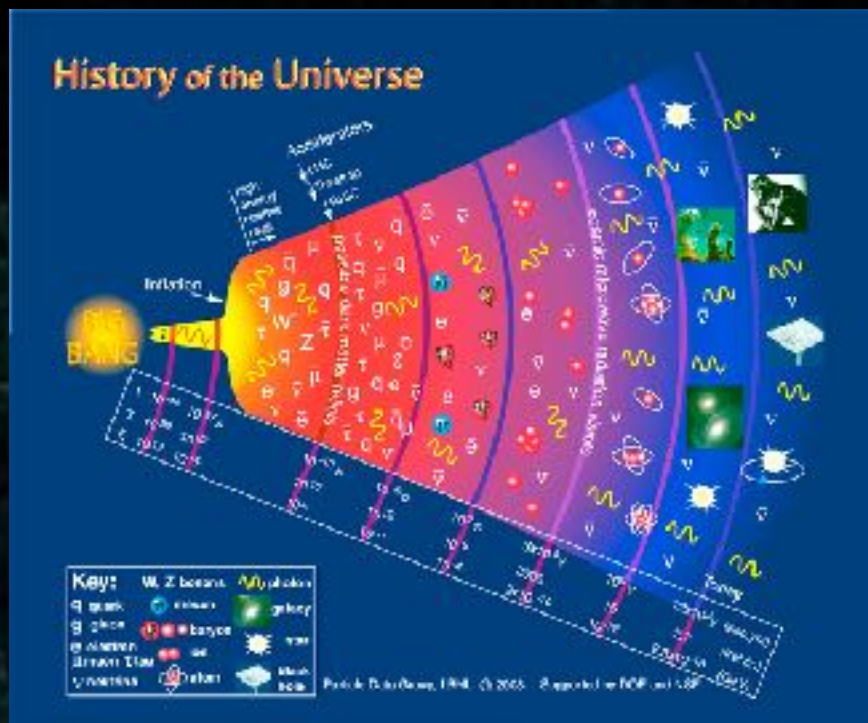


  such forces and/or particle states which are *not DM* are also targets for dark sector searches - need to *sense* & *source*

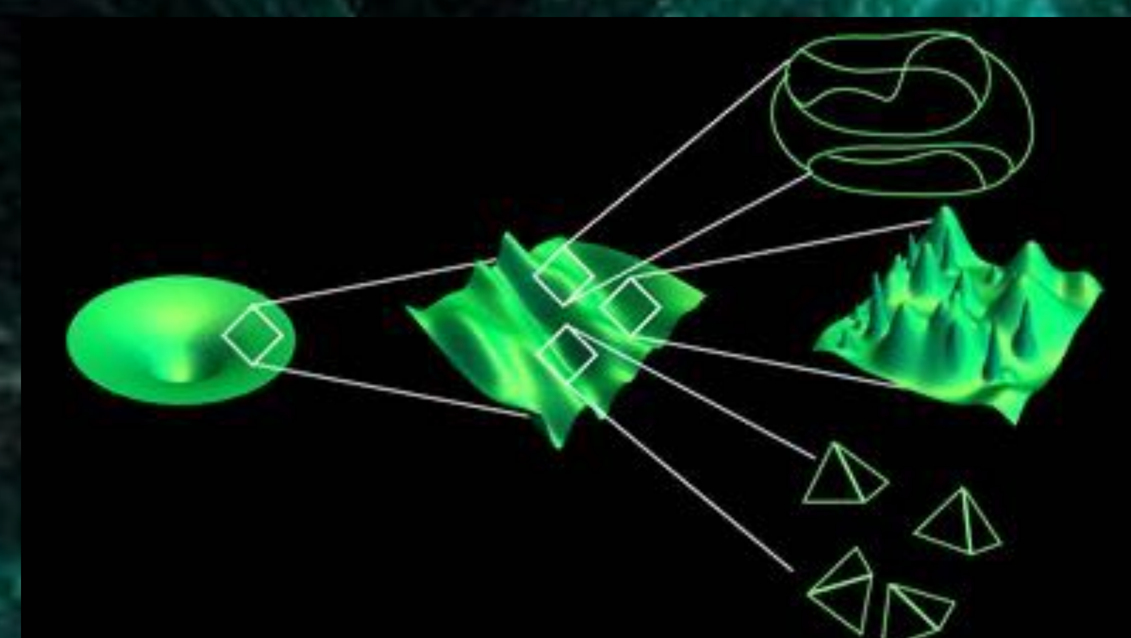
- Dark physics weakly/feebly coupled to SM could either *solve great SM puzzles or give clues*

  matter asymmetry, CP violation, hierarchy problem, flavour,...

DM/DR gives window to
earliest epochs of our universe



Light, feebly-coupled states give
info about *smallest distances*

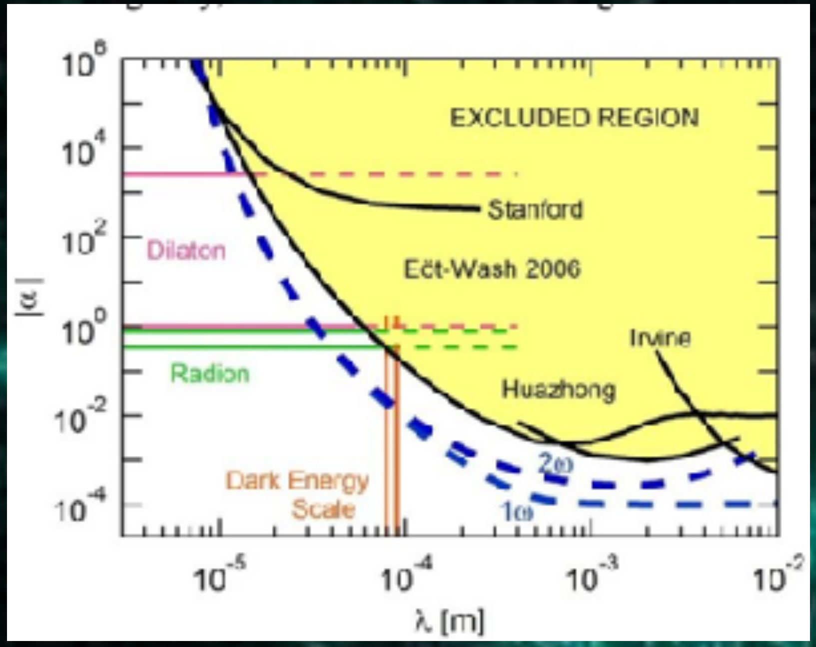


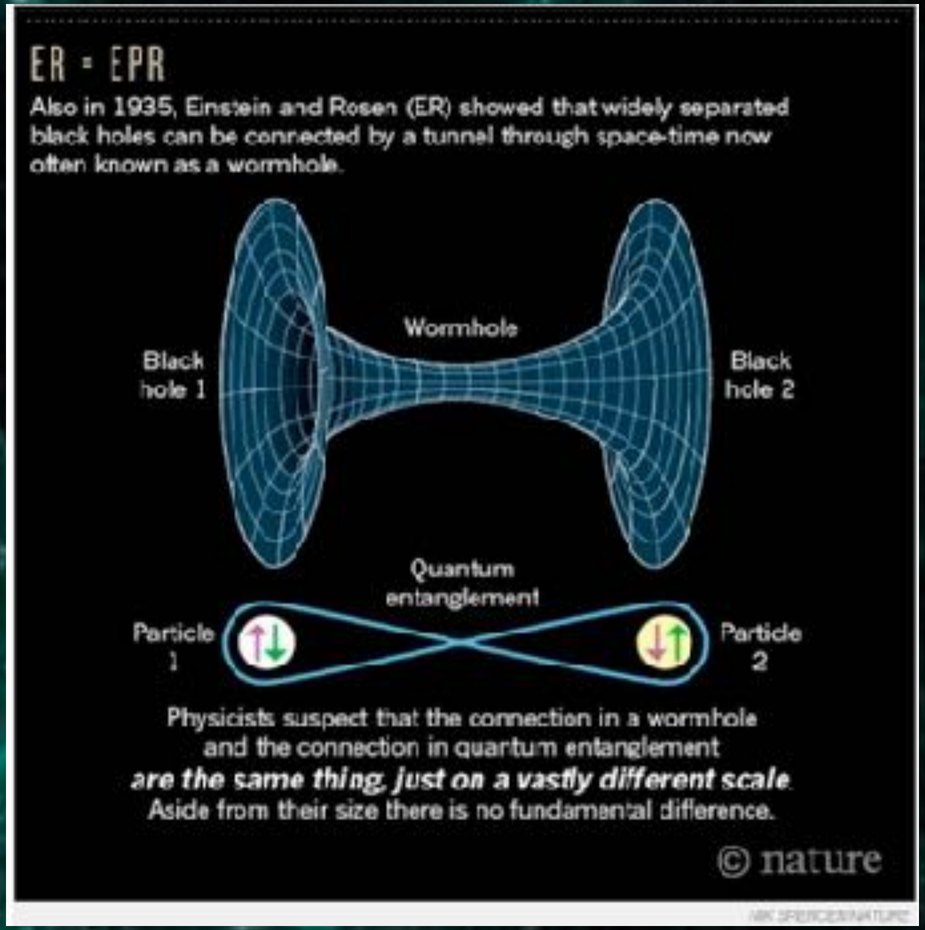
Gravitation

- *Dark Energy* (or equivalent) presents huge puzzle for our understanding of fundamental physics

- *Gravity itself* presents huge puzzle for our understanding of fundamental physics - likely deep links to quantum entanglement & quantum computation

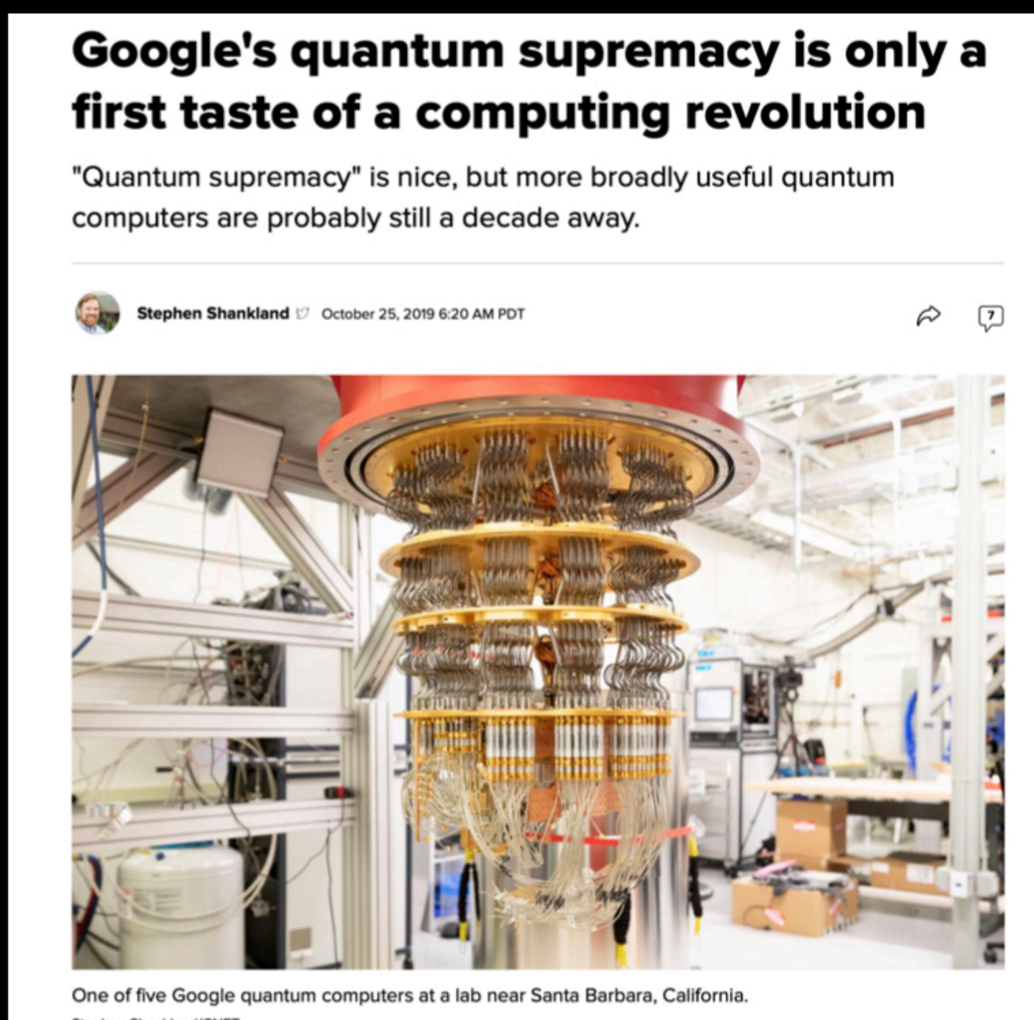
- Must investigate gravity on *every length scale, including interplay with QM*





Quantum 2.0

- There is a growing realization that we at the dawn of the Second Quantum Revolution.
- **First Quantum Revolution**: exploitation of the quantum nature of matter to build devices
- **Second Quantum Revolution**: engineering of large quantum systems to build devices using the quantum nature of matter; control of full quantum system at the individual level



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

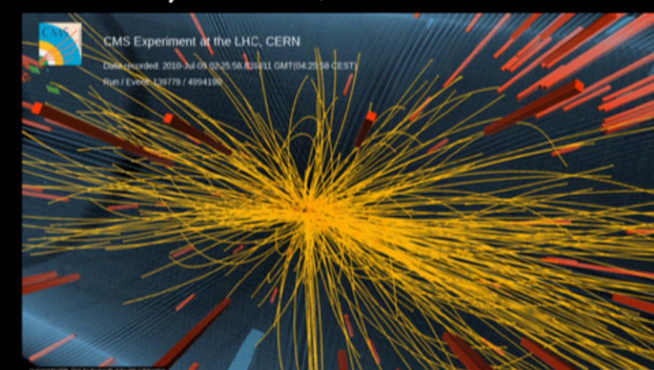
"Quantum supremacy" is nice, but more broadly useful quantum computers are probably still a decade away.

Stephen Shankland October 25, 2019 6:20 AM PDT

One of five Google quantum computers at a lab near Santa Barbara, California.

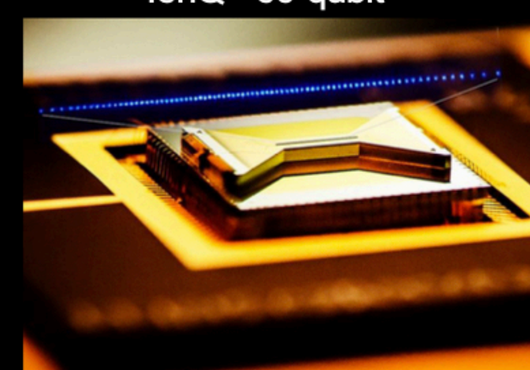
Stephen Shankland/CNET

AI, ML on Quantum annealer



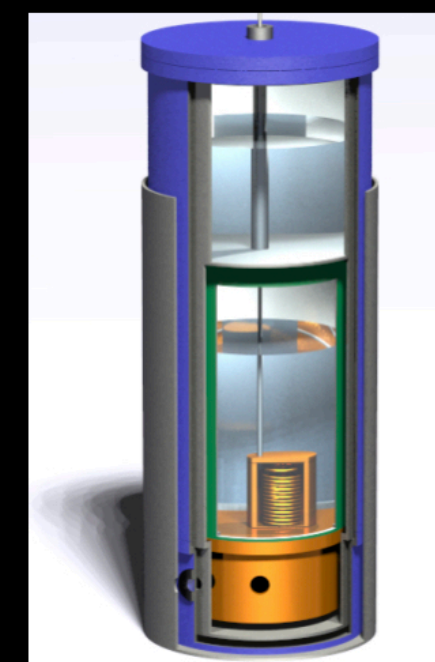
Nature 550 (2017) 375

IonQ >60-qubit



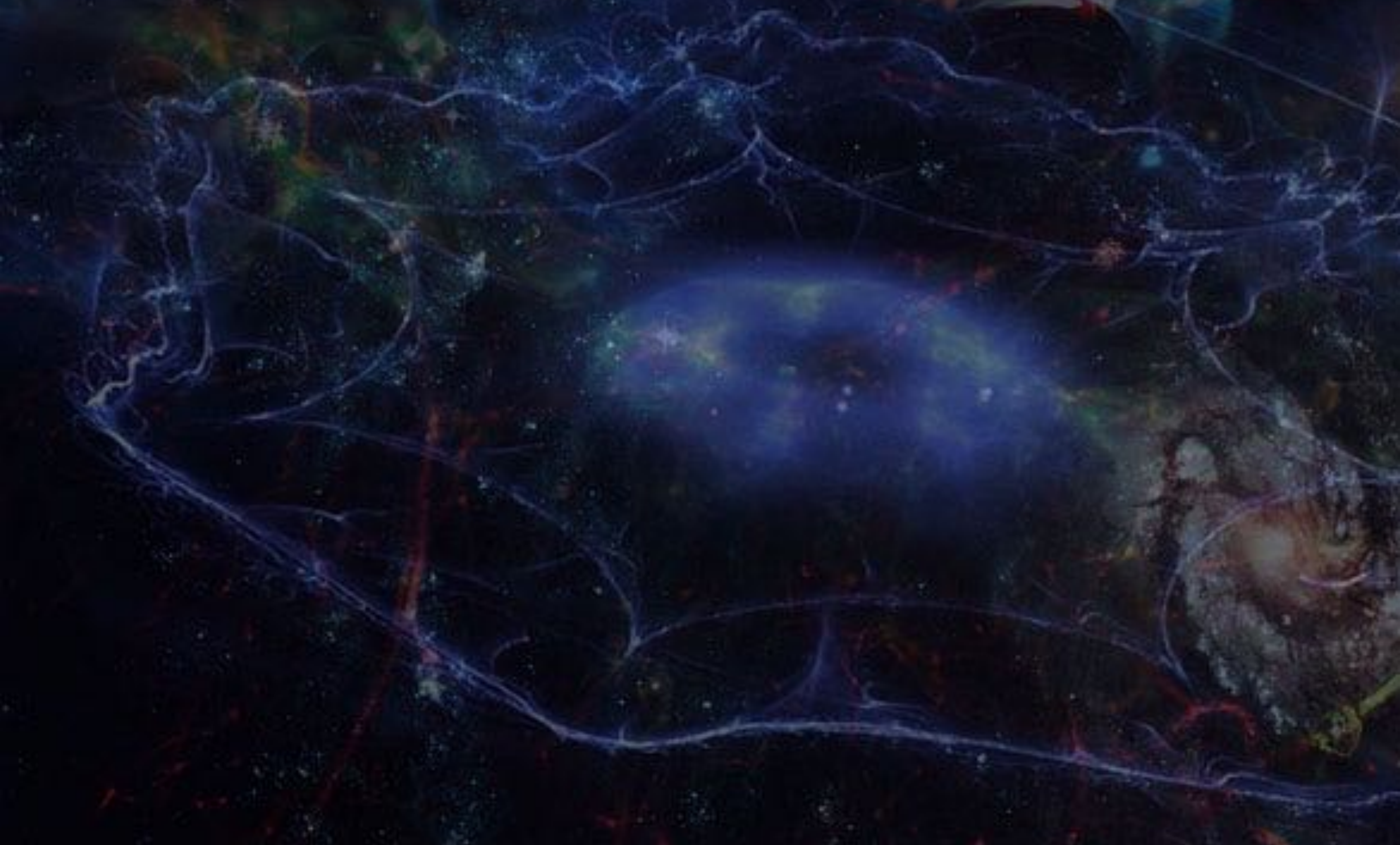
arXiv:1902.10171

Atomic clocks

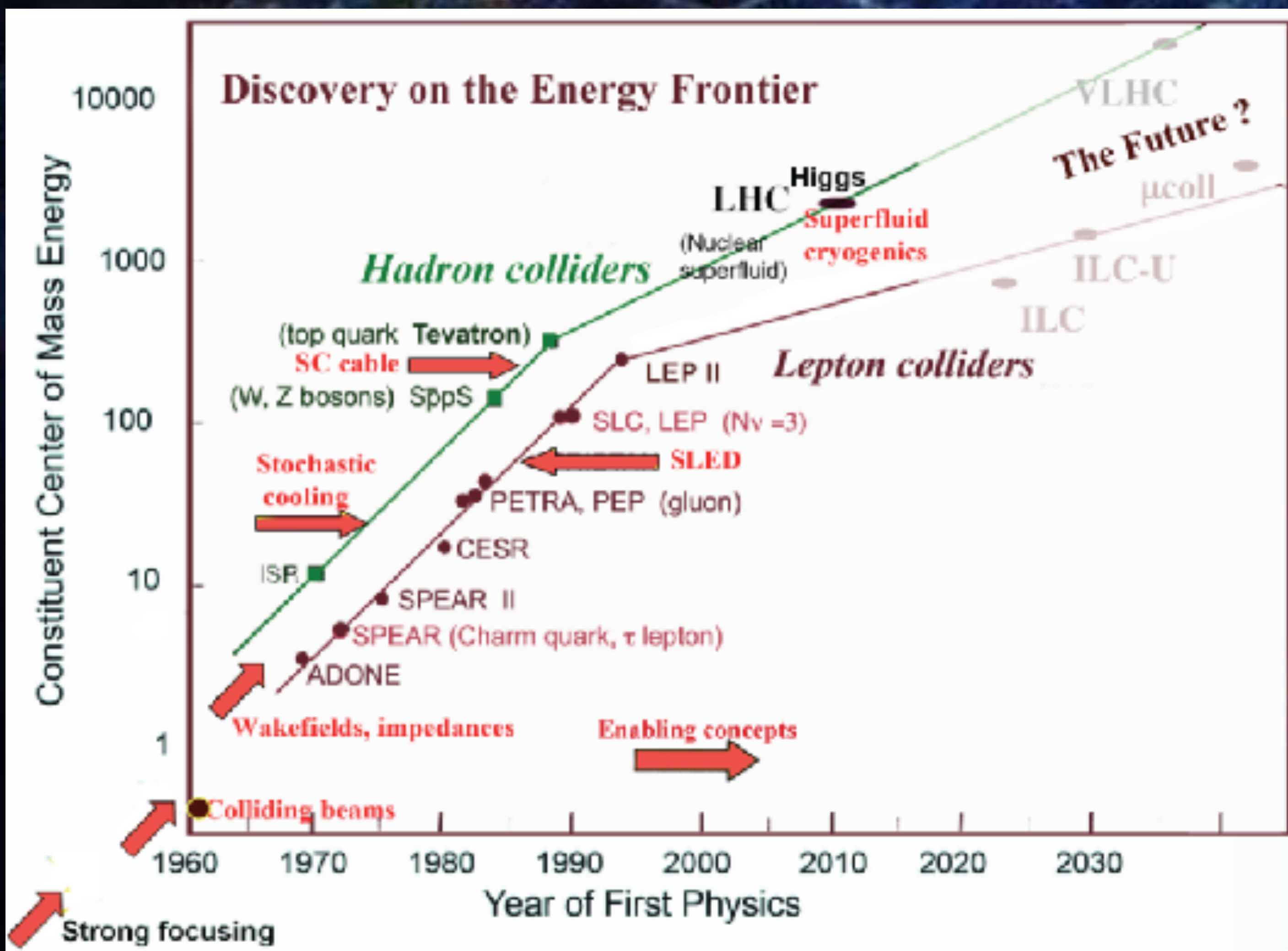


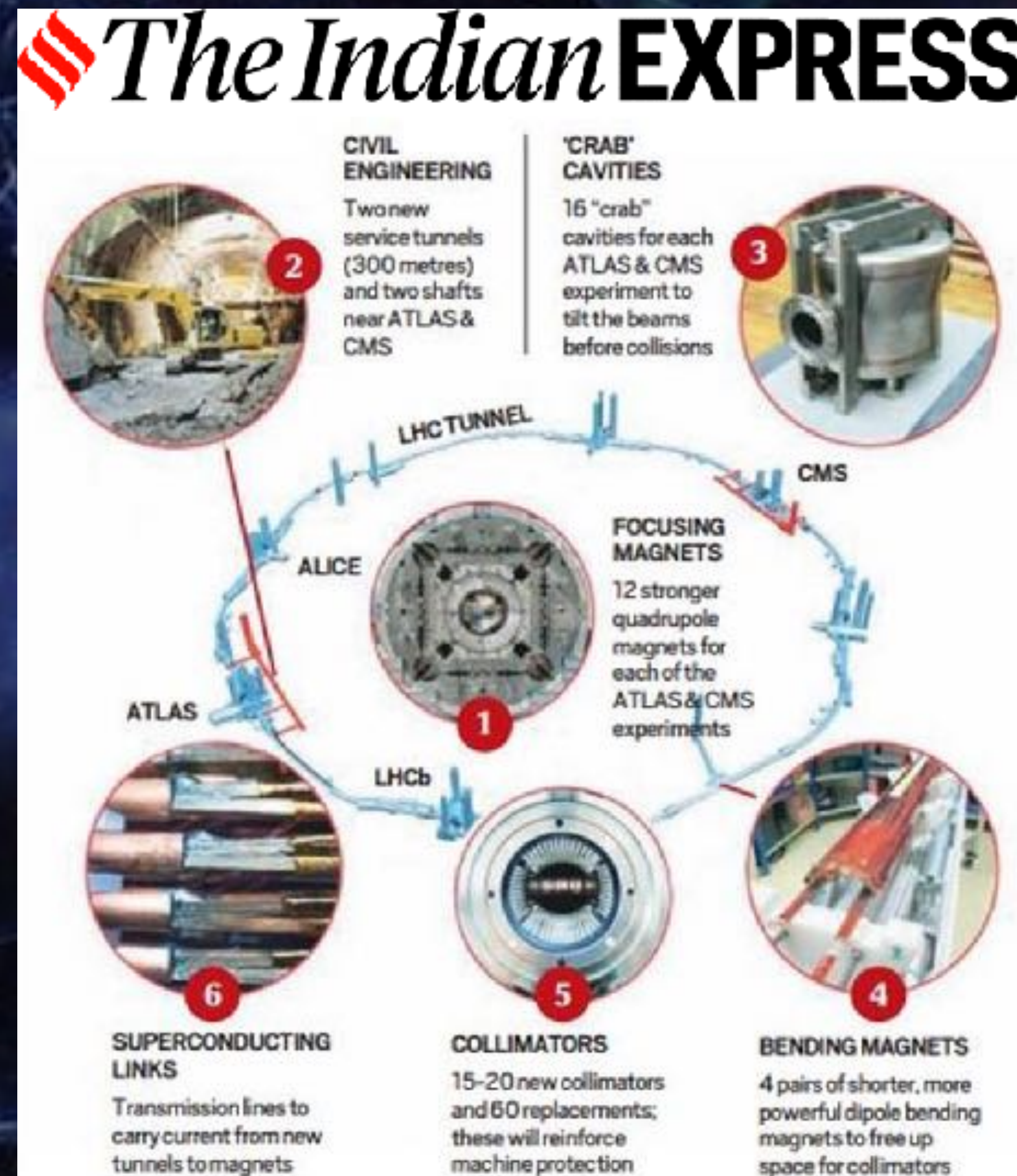
Nature (564) 87 (2018)

Dark Sector program promises a multi-decade+ effort with multiple major discoveries



Primary effort to investigate fundamental physics needs to be the continued exploration of the energy frontier





Dark Sector program is *complementary and mutually beneficial*

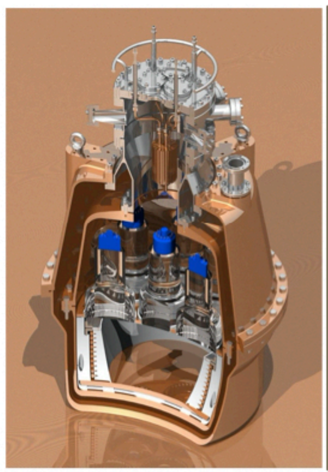
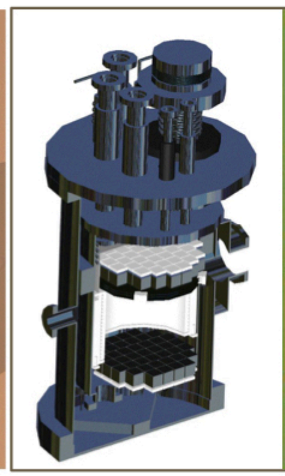
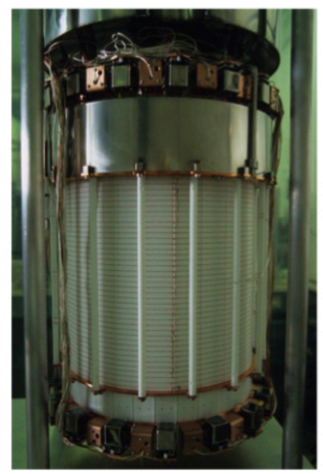
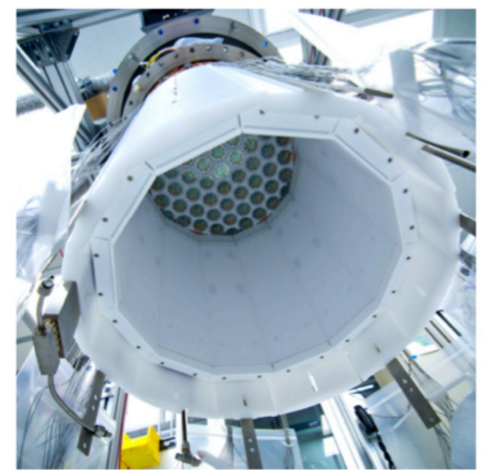
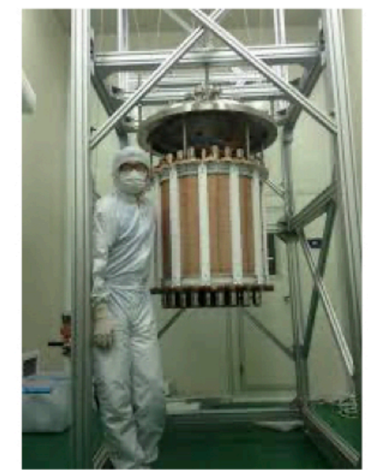
UK is in leadership position - as I'll outline

Totally clear that going forward this area needs to be a full & continuing part of UK's fundamental science effort

Current status:

Particle DM searches (*sans* QTFP)

Liquid xenon TPCs

ZEPLIN-II	XENON10	ZEPLIN-III	XENON100	LUX	PANDAX-II	XENON1T
						
31 kg (7.2 kg)	15 kg (5 kg)	12 kg (7 kg)	62 kg (34 kg)	250 kg (100 kg)	580 kg (362 kg)	2,000 kg (1,042 kg)
2007	2007	2008	2010	2013	2016	2017
6.6×10^{-43} cm^2	8.8×10^{-44} cm^2	8.1×10^{-44} cm^2	3.4×10^{-44} cm^2	3.4×10^{-46} cm^2	2.5×10^{-46} cm^2	7.7×10^{-47} cm^2

UK pioneered the xenon technology with the ZEPLIN programmes…

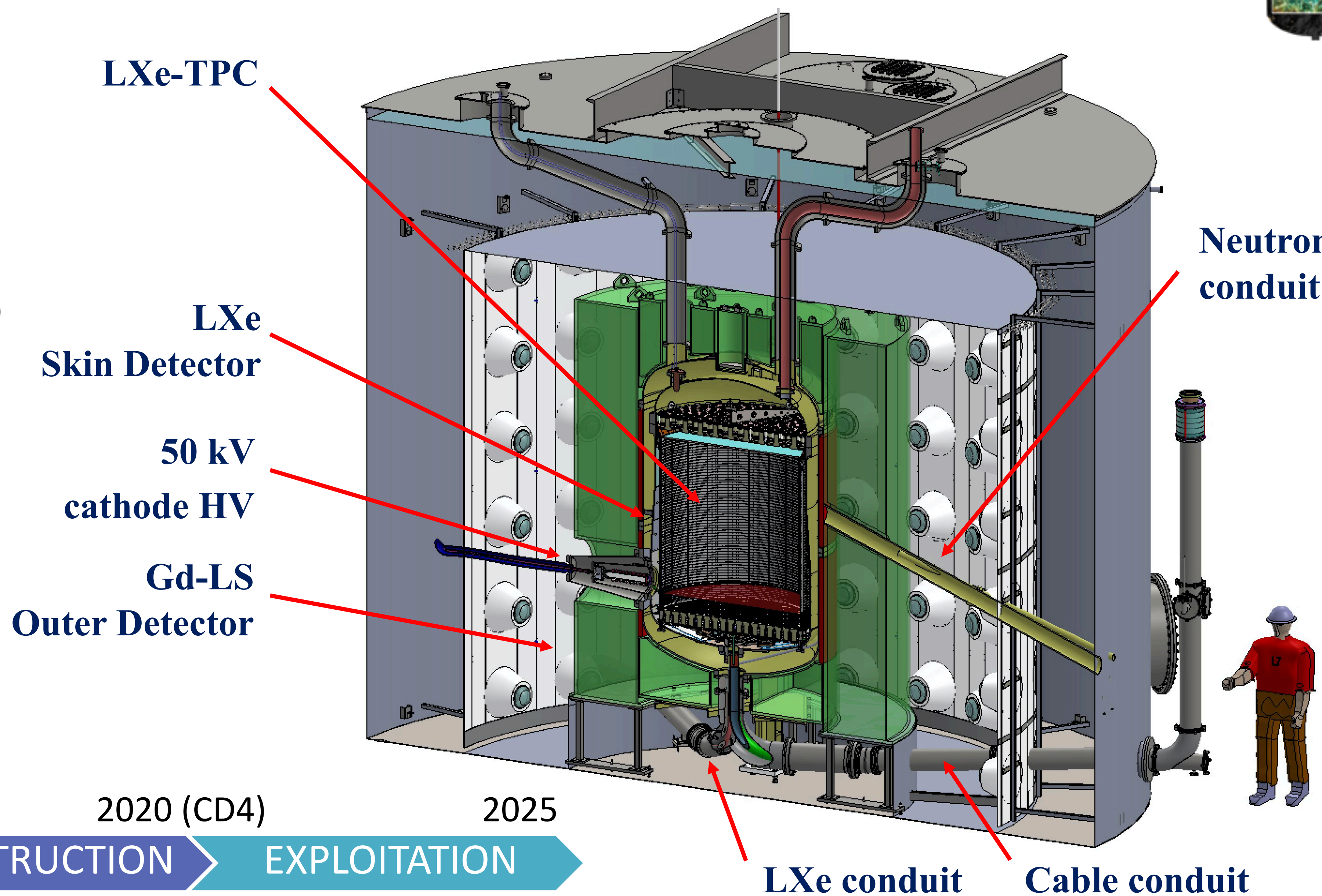
Slide credit: Chris McCabe (KCL)

THE LUX-ZEPLIN (LZ) EXPERIMENT

LZ detector(s)

- 7-tonne LXe-TPC
- 2-tonne LXe Skin Detector
- 17-tonne Outer Detector (Gd-loaded liquid scintillator)

25x more sensitive than Xenon1T



LZ Technical Design Report: arXiv:1703.09144
LZ WIMP sensitivity: arXiv:1802.06039
LZ 0NBB sensitivity: arXiv:1912.04248

2012 | 2015 (CD1) | 2020 (CD4) | 2025

DESIGN → CONSTRUCTION → EXPLOITATION

Slide credit: Henrique Araujo (LZ/Imperial)

Imperial College London
H. Araújo (A), A. Vacheret (A), T. Sumner (A), B. Lopez Paredes (PDRA), K. Oliver-Mallory (PDRA), Z. Tong (PG), A. Baker (PG), T. Marley (PG), A. Chiang (PG) +GridPP team: D. Colling (A), A. Richards (E), S. Fayer (E), D. Bauer (E)

Rutherford Appleton Laboratory
P. Majewski (S), M. van der Grinten (S), E. Holtom (E), A. Khazov (S), S. Balashov (S), A. Kaboth (S/A), +GridPP: C. Brew (E)

Edinburgh University
A. Murphy (A), X. Liu (PDRA), T. Davison (PG), E. Leason (PG). A. Nguyen (PG)

University College London
C. Ghag (A), J. Dobson (A/ERF), T. Fruth (PDRA), U. Utku (PG), N. Angelides (PG), O. Jahangir (PG), I. Khurana (PG), R. James (PG)

Oxford University
H. Kraus (A), K. Palladino (A), A. Cottle (PDRA), A. Stevens (PG), E. Gibson (PG), M. Tan (PG), N. Fearon (PG), A. Al-Musalhi (PG)

Sheffield University
V. Kudryavtsev (A), D. Tovey (A), E. Korolkova (PDRA), P. Rossiter (PG), A. Naylor (PG)

University of Liverpool
S. Burdin (A), W. Turner (PDRA), S. Powell (T), P. Sutcliffe (E), A. Baxter (PG), E. Fraser (PG)

University of Bristol
H. Flaecher (A), L. Kreczko (PDRA), B. Krikler (PDRA), S. Eriksen (PG), C. Wright (PG)

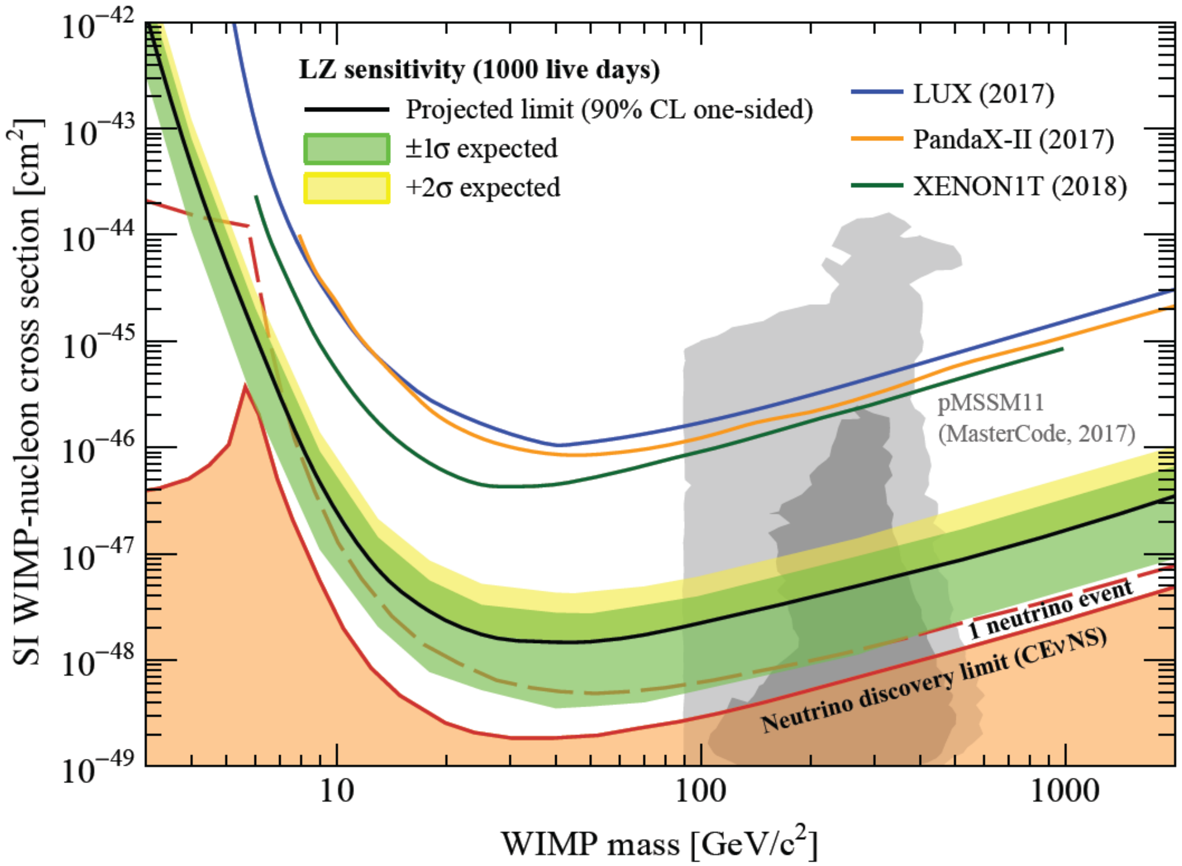
Royal Holloway, University of London
A. Kaboth (A), D. Santone (PDRA), J. Palmer (PG)

58 MEMBERS
16 ACADEMICS
11 POSTDOCS/PHYS
7 ENGINEERS/TECHS
24 PHD STUDENTS

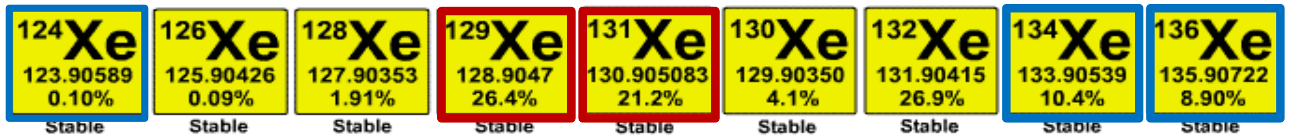
Slide credit: Henrique Araujo (LZ/Imperial)

PHYSICS HIGHLIGHTS: WIMPS & NEUTRINOS

- Aiming for leading SI sensitivity above a few GeV, 1.6×10^{-48} cm^2 @40 GeV
- WIMP-n and WIMP-p SD sensitivity – in fact, most NonRel-EFT operators
- Extension to sub-GeV masses with non-standard analyses (e.g Migdal effect)



Xenon family photo: a portfolio of opportunities



- **Coherent Elastic Neutrino-Nucleus Scattering**
  LZ can detect several neutrino fluxes via CEνNS:
  - ≳40 events from B-8 solar neutrinos
  - ~100 events from a supernova at 10 kpc
- **Searches for 0νββ in Xe-136**
  - Goal: to demonstrate the potential of this scalable technology, exploit fully in a "G3 observatory"

Slide credit: Henrique Araujo (LZ/Imperial)

THE ROAD AHEAD

LUX-ZEPLIN (LZ)

- Construction completed, commissioning now: data from 2021
- 1,000 live days by 2025

Xenon Futures R&D

- Towards a global Gen-3 Rare Event Observatory at 50-100 tonne scale
- Final design/construction from ~2023/24, data from ~2028/29

Boulby Feasibility Study

- Could the UK host a next-generation DM and/or $0\nu\beta\beta$ experiment?
- Reporting early/mid 2021

- If DM is GeV-TeV particles this technology (& the UK) will be on to it
- And plenty of other physics opportunities too!

UK continues its Xe leadership role via LZ at SURF and in possible future G3 observatory. Entering exploitation phase of LZ...

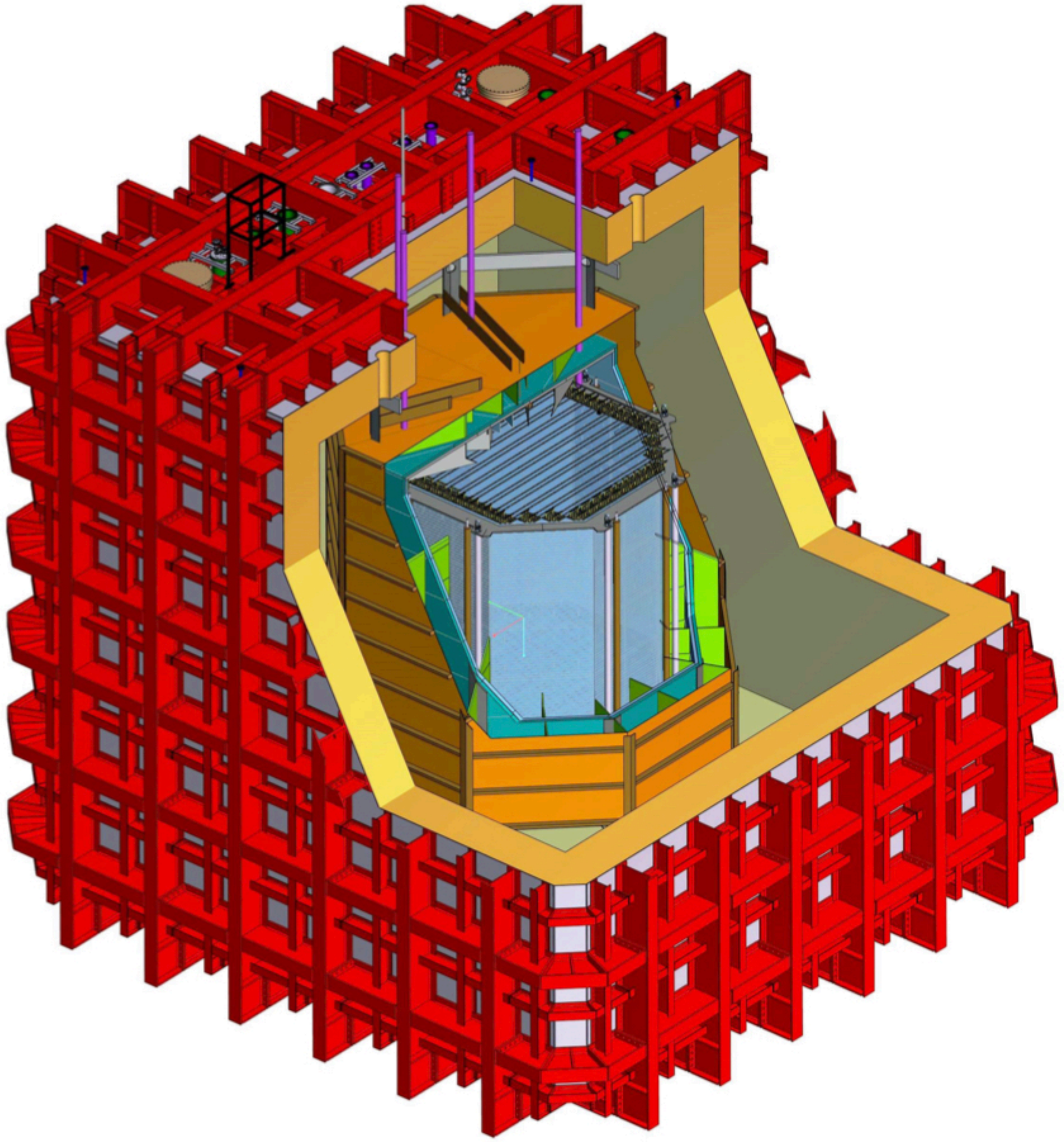
Liquid Argon TPCs

DEAP-3600 (running)

DarkSide-50 (running)

miniCLEAN

ArDM



DarkSide-20k
2022~

~300 tonnes

ARGO
2029~

Slide credit: Chris McCabe (KCL)

UK proposal to PPRP for participation in DarkSide-20k

Case for support: silicon detector development for the low-background frontier

P. Agnes[e], D. Britton[i], D. G. Cerdeno[b], M. Fairbairn[c], M. French[f], J. Heymes[g], J. Lipp[f], M. Malek[l], K. Mavrokoridis[j], A. Mitra[n], J. Monroe[e,*], K. Nikolopoulos[h], J. Nowak[d], S. Peeters[m], D. D. Price[k], Y. Ramachers[n], M. Soman[g], A. M. Szelc[k], J. Vossebeld[j], J. Walding[e], M. O. Wascko[a]

a: Imperial College London, South Kensington, London SW7 2BU, UK

b: IPPP, Durham University, South Rd, Durham DH1 3LE, UK

c: Kings College London, Strand, London WC2R 2LS, UK

d: Lancaster University, Bailrigg, Lancaster LA1 4YW, UK

e: Royal Holloway, University of London, Egham Hill, Egham, TW20 0EX, UK

f: Rutherford Appleton Laboratory, Chilton, Didcot OX11 0DE, UK

g: The Open University, Walton Hall, Milton Keynes MK7 6AA, UK

h: University of Birmingham, Birmingham B15 2TT, UK

i: University of Glasgow, University Avenue, Glasgow G12 8QQ, UK

j: University of Liverpool, Liverpool L69 3BX, UK

k: University of Manchester, Oxford Rd, Manchester M13 9PL, UK

l: University of Sheffield, Western Bank, Sheffield S10 2TN, UK

m: University of Sussex, Falmer, Brighton, BN1 9RH, UK

n: University of Warwick, Coventry CV4 7AL, UK

DarkSide-20k

Global collaboration: >350 physicists, 11 countries, >55 institutes

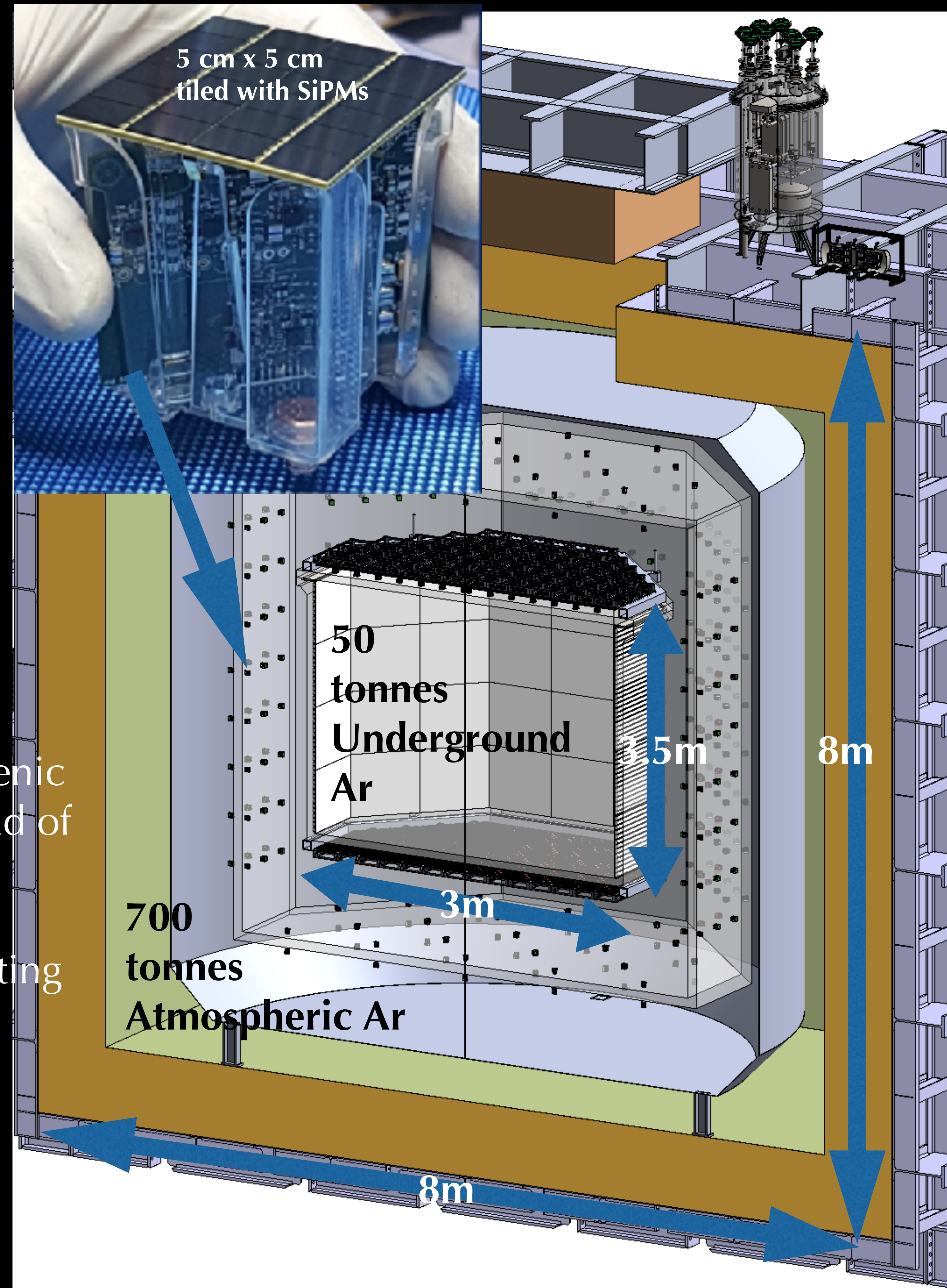
50 t liquid Underground Ar (UAr) dark matter target, inside a 700 t liquid Atmospheric Ar (AAr) outer detector

Gran Sasso Underground Laboratory (LNGS) (outside L'Aquila, IT)

Two key innovations:

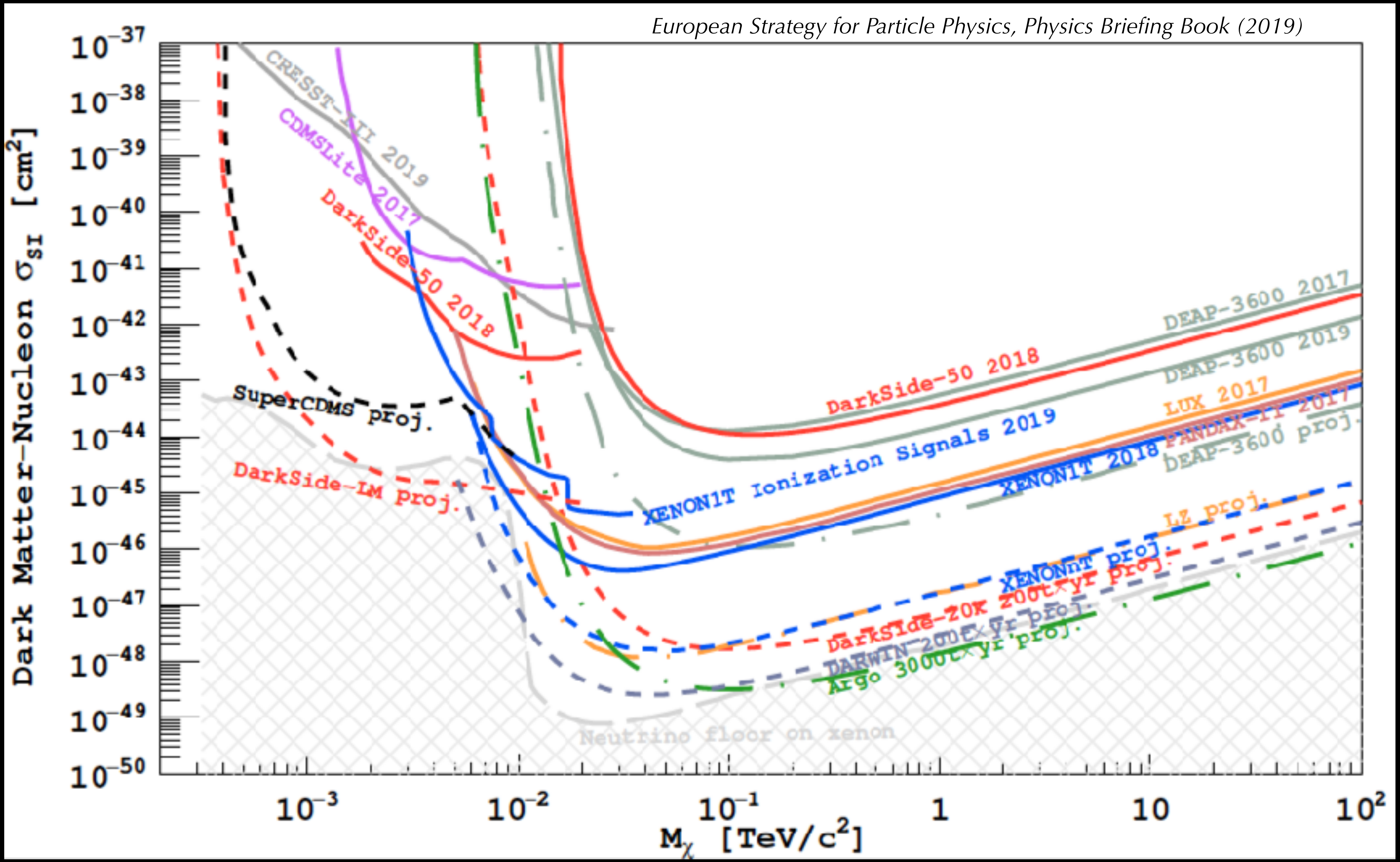
1. first large-scale use of large-area cryogenic Si photon detection modules instead of PMTs.
2. liquid AAr outer detector to veto the limiting background: neutrons

UK: deliver outer detector photosensors, building on UK Si detector infrastructure



Direct Detection Context

main challenge: rejecting background interactions at ~keV energies and below, while scaling up…



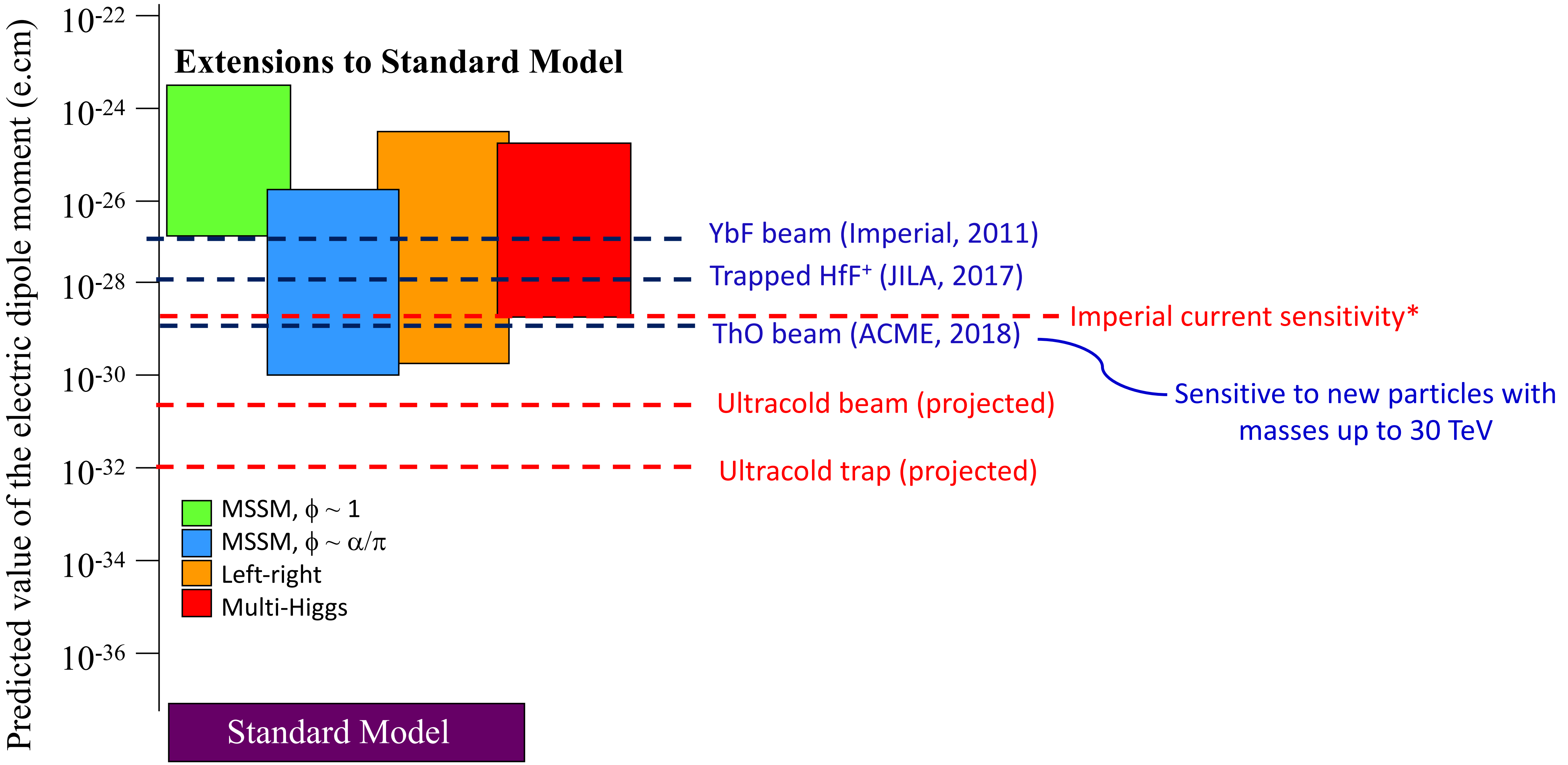
Current status:

Tests of fundamental symmetries: EDMs
(again *sans* QTFP for now)

Electric Dipole Moment searches

Electron EDM – current status and projections

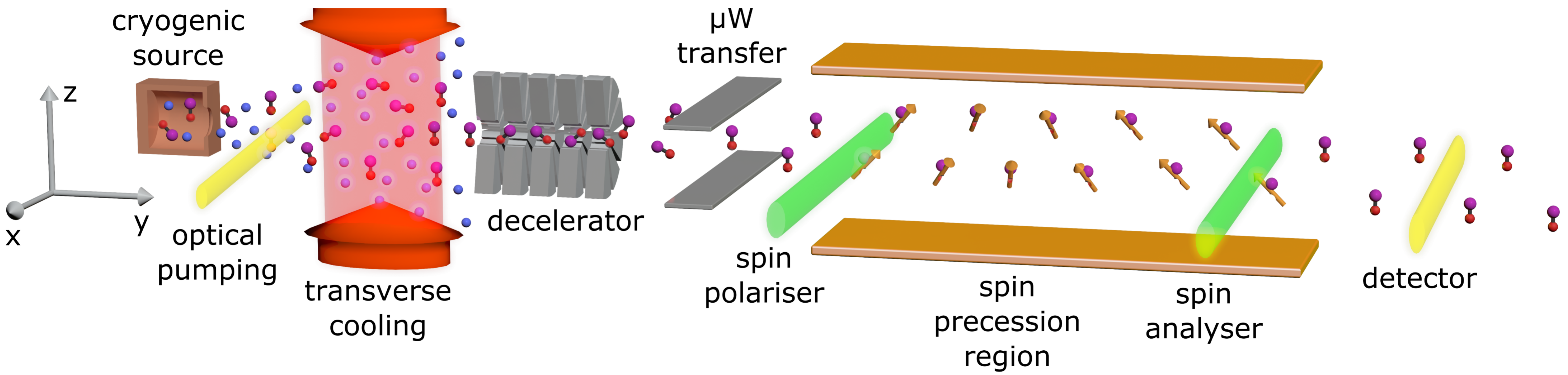
All current competitive experiments are done using polar molecules



*New. J. Phys. 22, 053031 (2020)

Slide credit: Maurits Van der Grinten (PPD/STFC)

Ultracold eEDM: new apparatus being built at Imperial



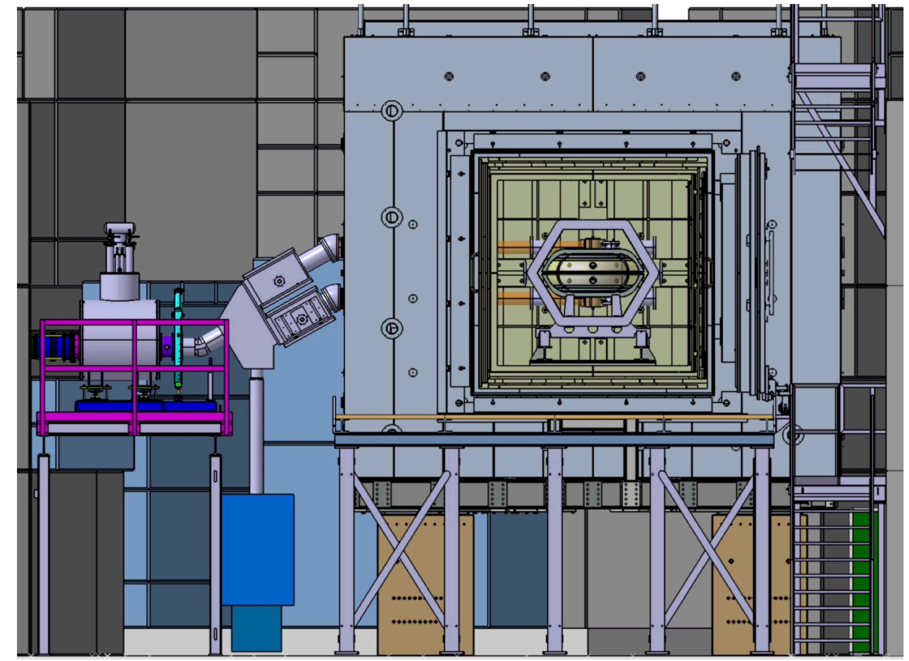
- New method based on molecules cooled to 50 microkelvin – massively improves spin coherence time
- Imperial group is the world leader in developing this new method
- Oct 2018 - Oct 2022: build apparatus and demonstrate eEDM sensitivity at 10^{-30} e.cm level
- Funded through a PPRP project (joint STFC & EPSRC funding) with additional support from Templeton, Royal Society, EU…
- Apparatus development is on schedule; key techniques all demonstrated
- Beyond 2022: measure eEDM at 10^{-30} e.cm level, and push towards 10^{-31} e.cm. Not yet funded

Slide credit: Maurits Van der Grinten (PPD/STFC)

neutron EDM searches: PSI

- Sussex/RAL-developed UCN/Hg comagnetometer apparatus upgraded on PSI UCN source
  - new world leading nEDM limit published in 2020, $d_n = (0.0 \pm 1.1_{stat} \pm 0.2_{syst}) \times 10^{-26} e\text{cm}$
  - 5x reduction in systematic error
- next generation: n2EDM
  - expect commissioning in 2021, $\sigma(d_n) \sim 10^{-27} e\text{cm}$ in 500 days
  - best placed to maintain world leading limit or reach discovery
  - UK/Sussex contributions to leakage current monitors, atomic magnetometry, and systematics analysis

PAUL SCHERRER INSTITUT PSI



Slide credit: Maurits Van der Grinten (PPD/STFC)

UK EDMx community is substantial and growing

- Imperial College (eEDM)
- UCL (mu/pEDM)
- Birmingham University (mu/pEDM)
- Sussex University (nEDM)
- University of Liverpool (mu/pEDM)
- RAL-PPD (nEDM)

Current status:

2nd Quantum Revolution & QTFP

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)

Slide credit: Ian Shipsey (Oxford)

Slide credit: Ian Shipsey (Oxford)

QUEST DMC

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

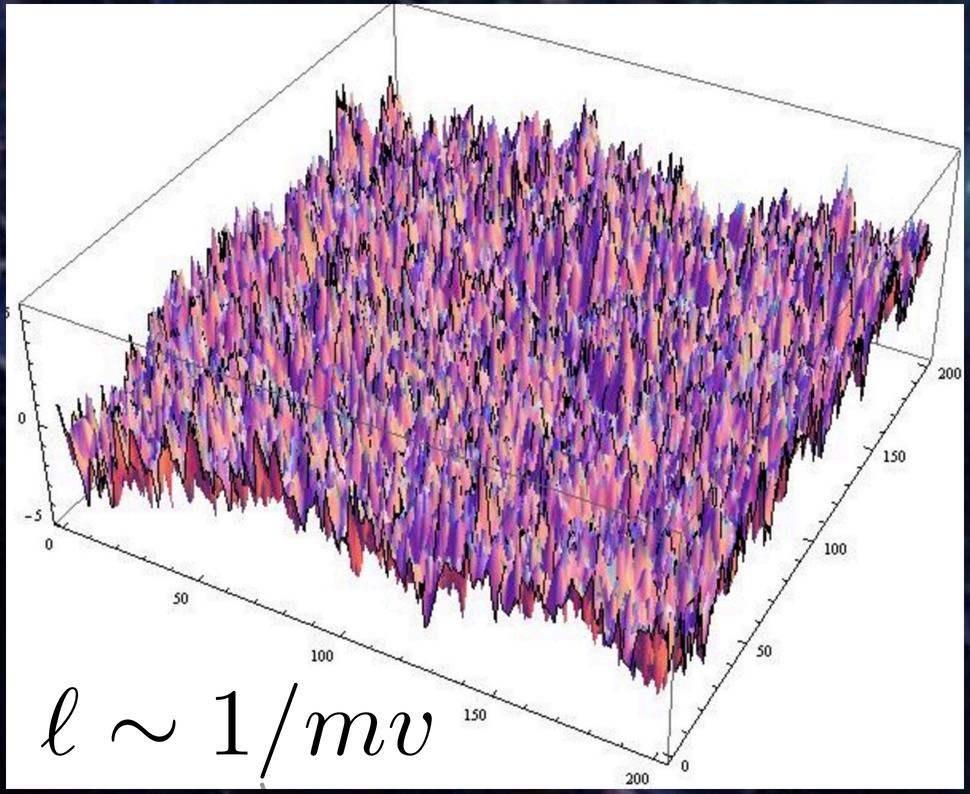
Quantum Technologies for Fundamental Physics selected proposals: QUEST-DMC + six that were developed by the community activities supported by the STFC Opportunities Award

Slide credit: Ian Shipsey (Oxford)

Five+ of the funded QTFP bids are connected to DM search

Quantum technologies are *essential*

The ultra-light DM mass regime (axions, dark photons, moduli...): a partially-coherent random field



correlation length

$$\frac{\delta\omega}{\omega} \sim \frac{m_a v^2/2}{m_a} \sim 10^{-6}$$

resonant enhancement in detection is possible

What kind of bosons?

Naturalness. Structure set by symmetries.

Spin 0

Axions and other goldstone bosons

Easy to get in many UV theories

Spin 1

Anomaly free Standard Model couplings

Electromagnetism

$\left(\frac{a}{f_a} F\tilde{F}\right)$

usual searches

$(m_a \sim \text{GHz})$

Nuclear Force

$\left(\frac{a}{f_a} G\tilde{G}\right)$

QCD Axion

Nuclear Spin

$\left(\frac{\partial_\mu a}{f_a} \bar{N}\gamma^\mu \gamma_5 N\right)$

General Axions

Nuclear Spin

$\left(\frac{F'_{\mu\nu}}{f_a} \bar{N}\sigma^{\mu\nu} N\right)$

Dipole moment

Electro-magnetism

$\left(\epsilon F' F\right)$

Kinetic Mixing

Nucleon Current

$\left(g A'_\mu J^\mu_{B-L}\right)$

B-L

new searches

$$\text{Dark Matter} \implies a = a_0 \cos(m_a t)$$

$$\text{yr}^{-1} \lesssim \omega \lesssim 10\text{THz}$$

Slide credit: Peter Graham (Stanford)

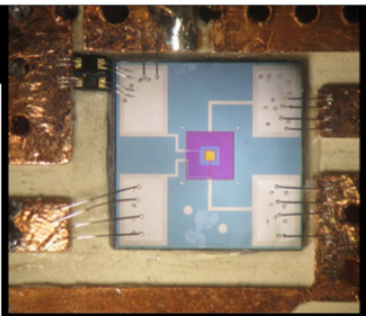
Quantum Sensors for the Hidden Sector

Sheffield, Cambridge, Oxford, RHUL, Lancaster, UCL, NPL, Liverpool

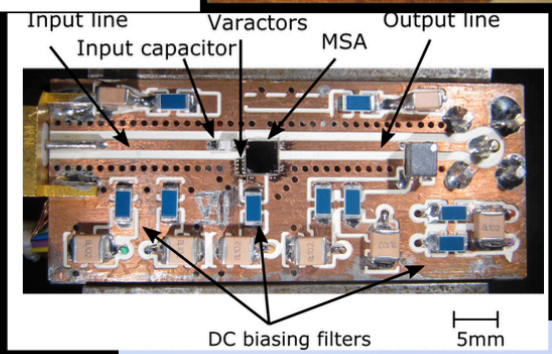
- A search for axions/ALPs using resonant conversion to microwave photons in high magnetic fields
- Initial focus on QCD axion, mass range 25-40μeV
- Collaboration with U.S. Axion Dark Matter eXperiment group, who operate the worlds most sensitive axion search, ADMX.
- **Ambition to build a UK high field (8T) low temperature (10mK) facility at Daresbury.**

World-leading QCD axion/ ultra-light DM searches possible in accessible mass range(s)

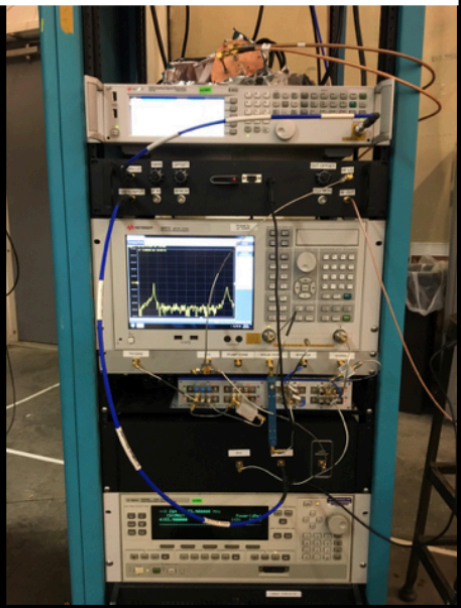
ADMX SQUID washer



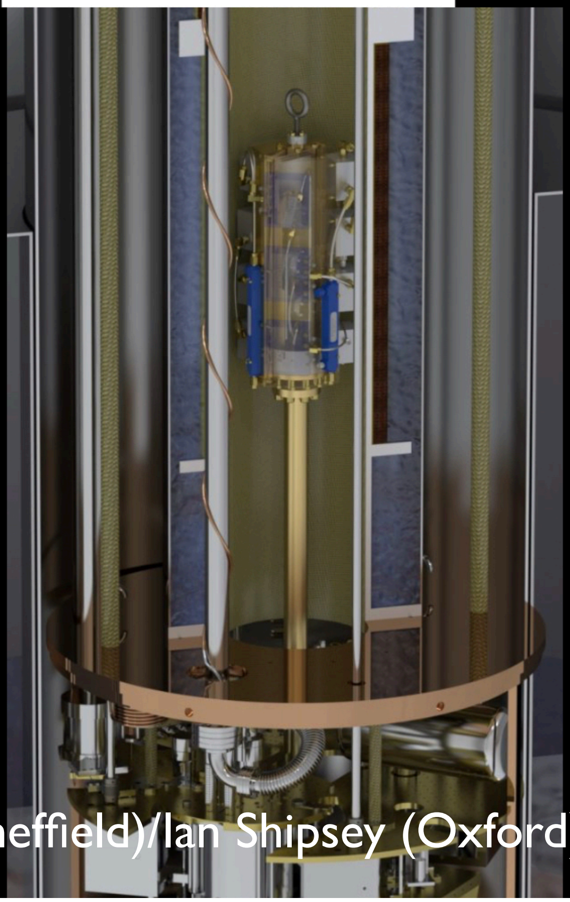
ADMX Microwave SQUID amplifier



Resonant feedback test

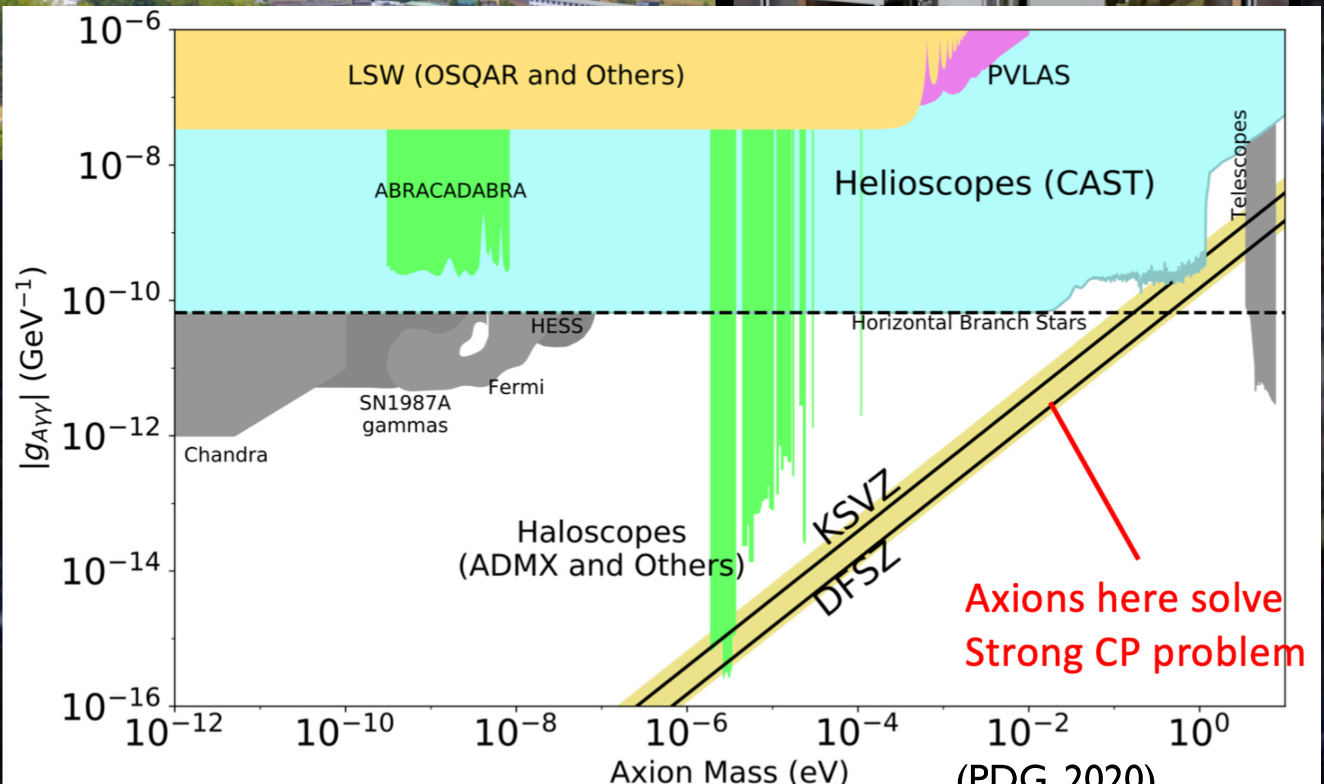


ADMX SQUID housing



Daresbury Lab

Slide credit: Ed Daw (Sheffield)/Ian Shipsey (Oxford)

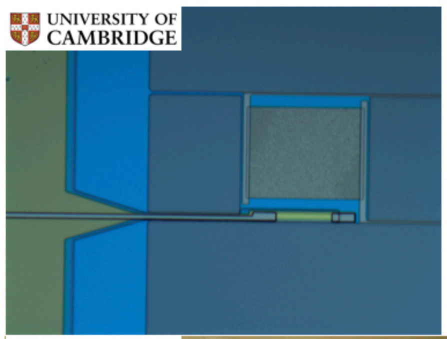


(PDG, 2020)

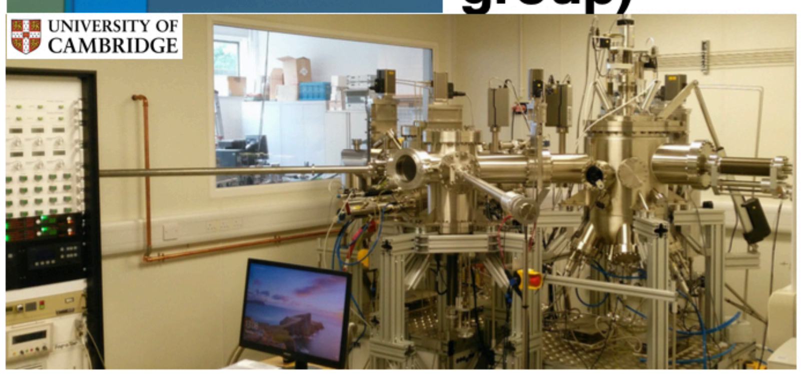
Quantum Electronics

QSHS groups are world leading in quantum electronics and quantum systems design critical to searches for axions and ALPS

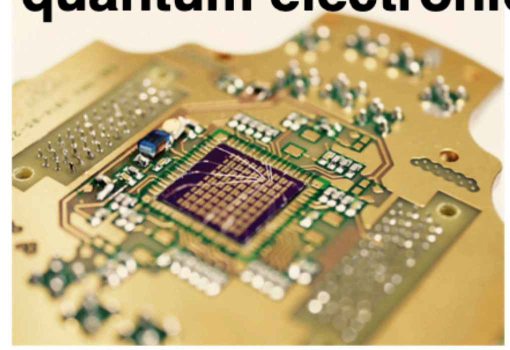
Josephson, Travelling Wave Parametric Amplifiers, Bolometric detectors, and Qubits



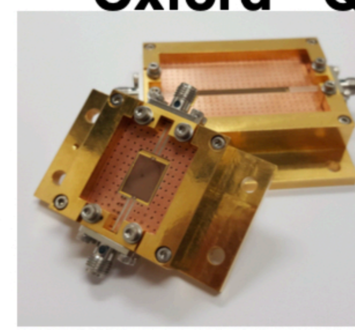
Cambridge (Withington group)

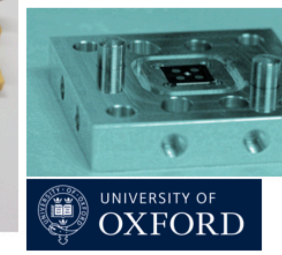


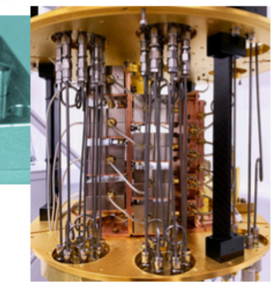
Lancaster - device physics, low noise quantum electronics



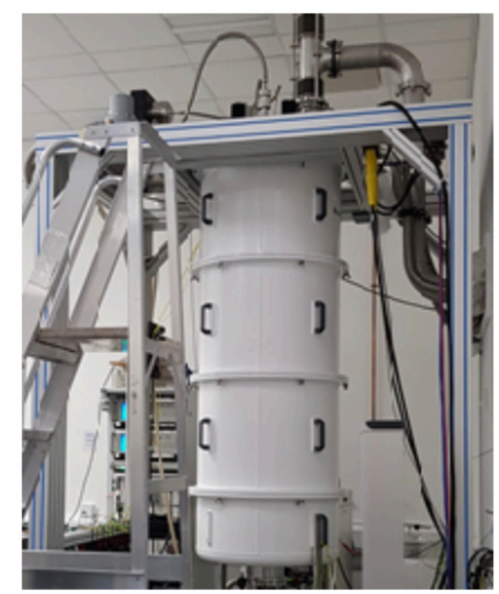
Oxford - QuBits and SIS mixer expertise, Leek, Tan



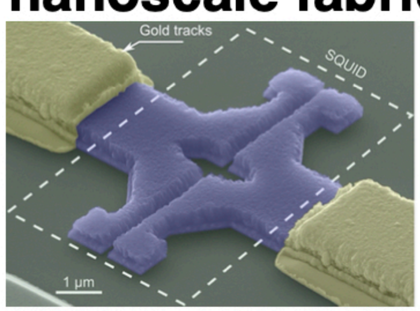


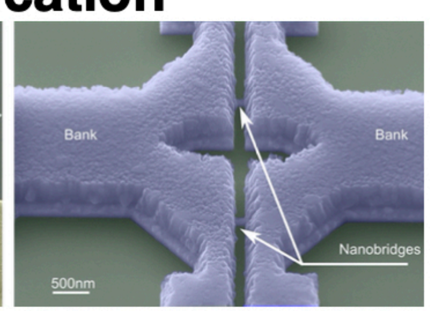


NPL- Hao, Lewis, Gallup Squids, high field facilities

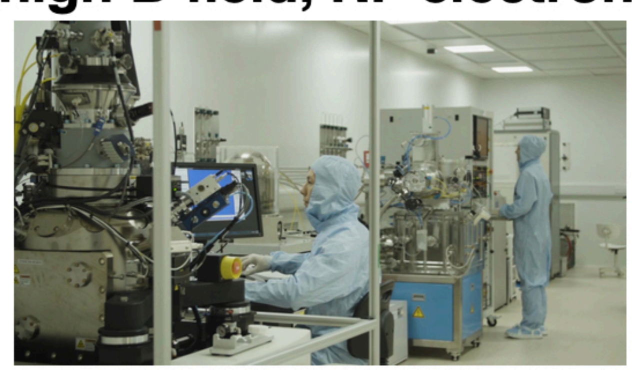


UCL (Romans) SQUIDS, nanoscale fabrication



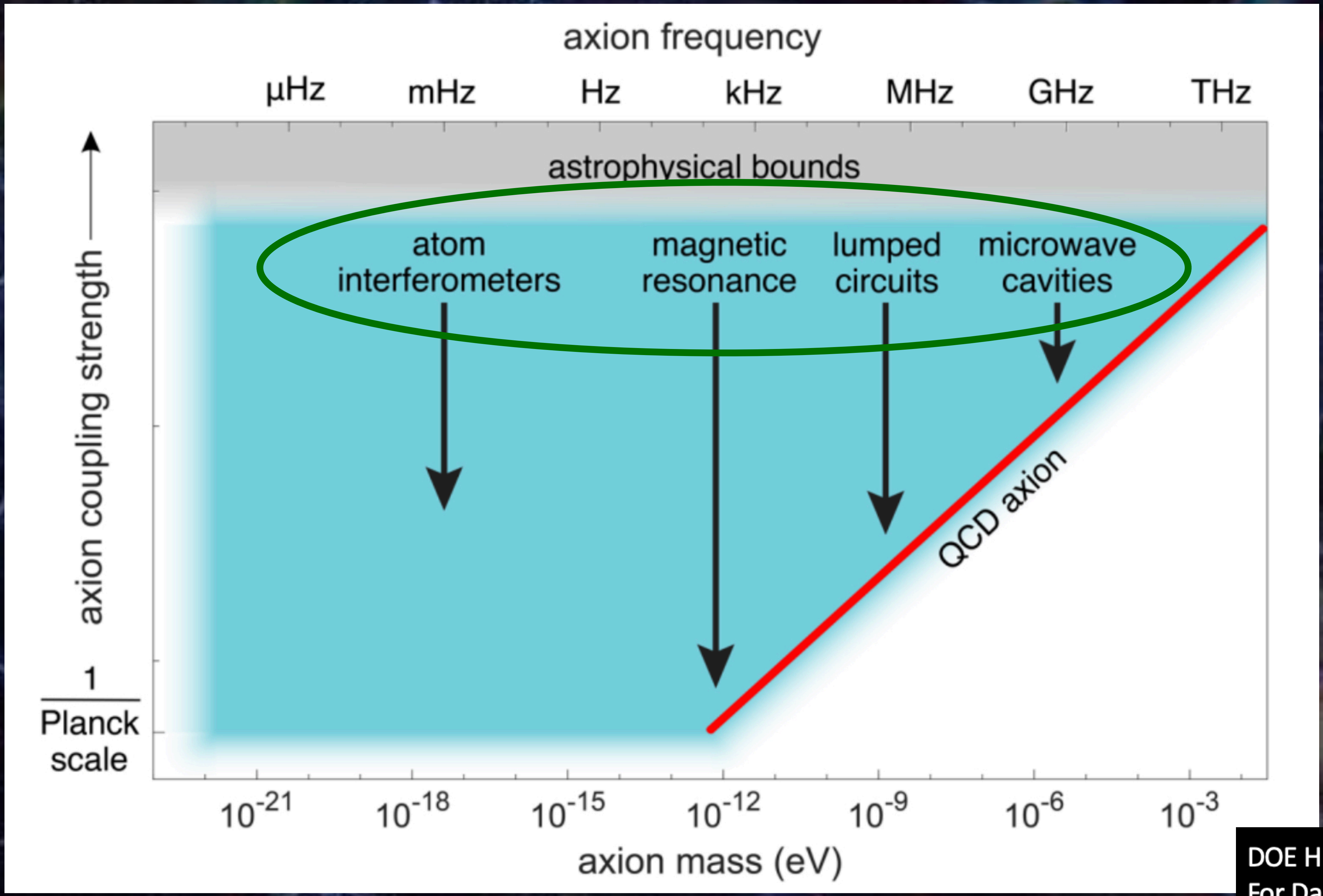


RHUL (Meeson)-fabrication, high B field, RF electronics



Slide credit: Ed Daw (Sheffield)

Whole variety of quantum-enhanced technologies important...

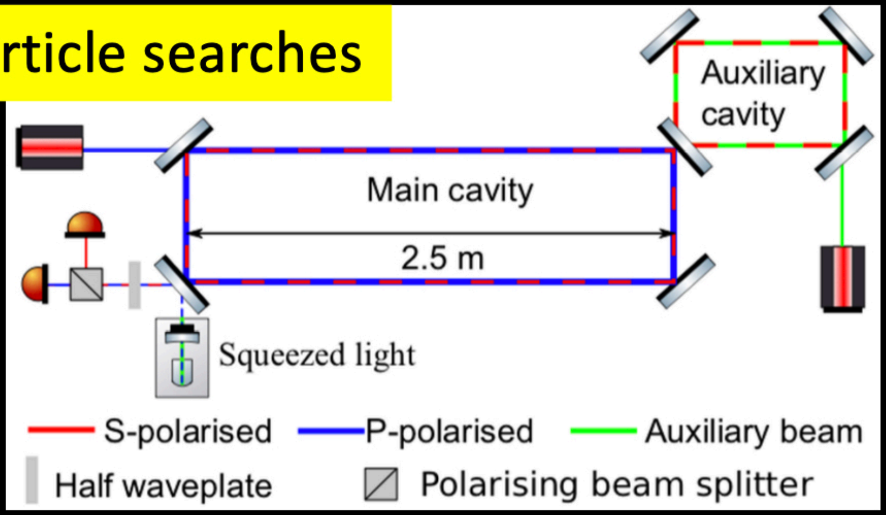


DOE HEP BRN
For Dark Matter
Small Projects
New Initiatives

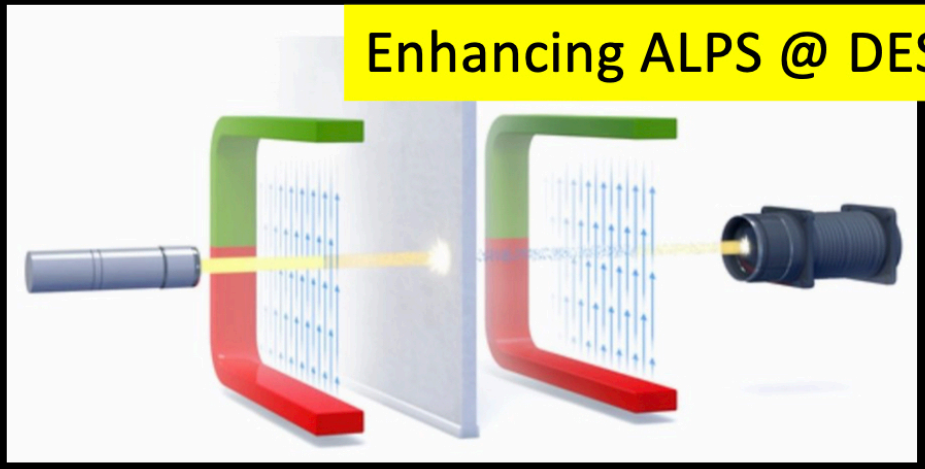
Quantum-enhanced Interferometry

Vincent Boyer (Birmingham), Animesh Datta (Warwick), Katherine Dooley (Cardiff),
Hartmut Grote (Cardiff, PI), Robert Hadfield (Glasgow), Denis Martynov (Birmingham, Deputy PI)
Haixing Miao (Birmingham), Stuart Reid (Strathclyde)

Axion-like particle searches

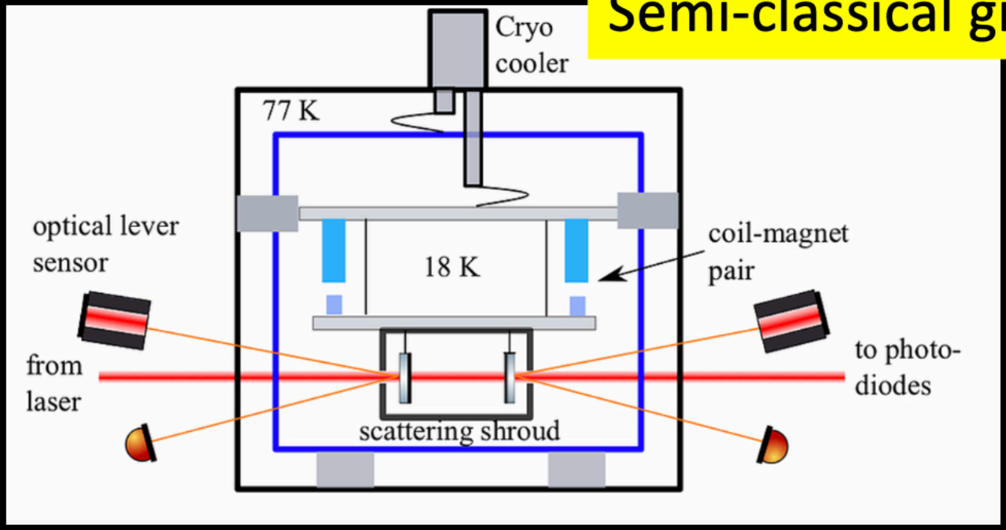


Enhancing ALPS @ DESY



Quantization of space time

Semi-classical gravity

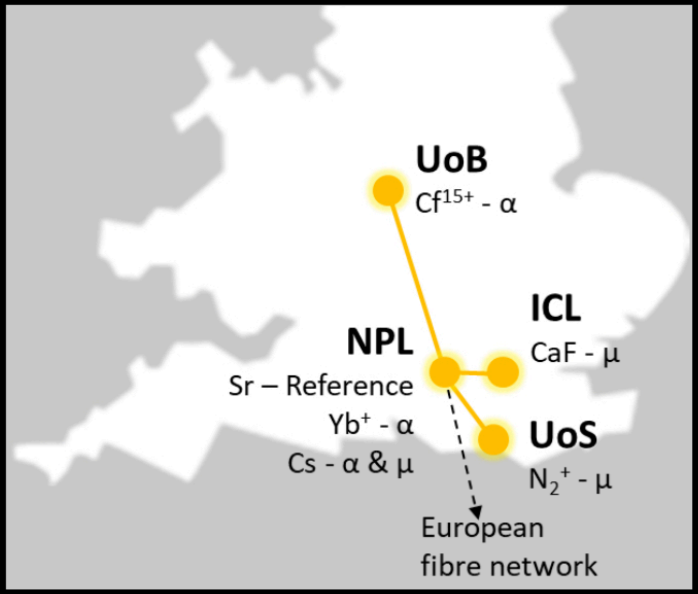


Slide credit: Hartmut Grote (Cardiff)/Ian Shipsey (Oxford)

A network of clocks for measuring the stability of fundamental constants

G. Barontini, V. Boyer, X. Calmet, M. Chung, N. Fitch, R. Godun, J. Goldwin, V. Guarrera, I. Hill, M. Keller, J. Kronjaeger, H. Margolis, C. Mow-Lowry, P. Newman, L. Prokhorov, B. Sauer, M. Schioppo, M. Tarbutt, A. Vecchio, S. Worm

The aim of the consortium is to build a community that will achieve unprecedented sensitivity in testing variations of the fine structure constant, $\boldsymbol{\alpha}$, and the proton-to-electron mass ratio, $\boldsymbol{\mu}$. This in turn will provide more stringent constraints on a wide range of fundamental and phenomenological theories beyond the Standard Model and on dark matter models. The ambition of the QSNET consortium will be enabled by a unique network that connects a number of complementary quantum clocks across the UK



Clock	WP	Variations of fund. Constant
Ion clock Yb^+ (467 nm)	1	**α**
Atomic clock Sr (698 nm)	1	**Stable reference**
Atomic clock Cs (32.6 mm)	1	**μ**
Highly-charged ion clock Cf^{15+} (618 nm)	2	**α**
Molecular clock CaF (17 μm)	3	**μ**
Molecular ion clock N_2^+ (2.31 μm)	3	**μ**

Slide credit: Giovanni Barontini (Birmingham)/Ian Shipsey (Oxford)

Oscillating Fundamental Constants from DM

eg, for the electron mass $\left(1 + d_{m_e} \frac{\phi}{M_{pl}}\right) m_e \bar{\psi}_e \psi_e$

$$\frac{\delta m_e}{m_e} \approx \frac{d_{m_e} \phi_o}{M_{Pl}} \cos(m_\phi t)$$

$$= 6 \times 10^{-13} \cos(m_\phi t) \frac{10^{-18} \text{ eV}}{m_\phi} \frac{d_{m_e}}{1}$$

Fractional variation set by square root of DM abundance

(recall $m_a^2 a_0^2 \simeq \rho_{DM}$)

also gives apparent violation of Lorentz-invariance, etc....

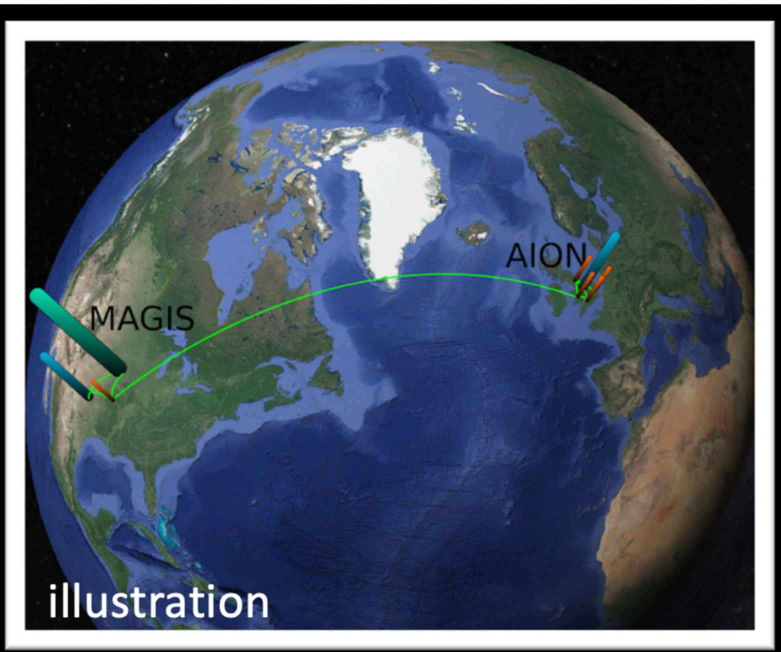
The AION Project

A UK Atom Interferometer Observatory and Network

to explore Ultra-Light Dark Matter and Mid-Frequency Gravitational Waves.

L. Badurina[1], S. Balashov[2], E. Bentine[3], D. Blas[1], J. Boehm[2], K. Bongs[4], D. Bortoletto[3], T. Bowcock[5], W. Bowden[6,*], C. Brew[2], O. Buchmueller[6], J. Coleman[5], G. Elertas[5], J. Ellis[1,$,&], C. Foot[3], V. Gibson[7], M. Haehnelt[7], T. Harte[7], R. Hobson[6,*], M. Holynski[4], A. Khazov[2], M. Langlois[4], S. Lellouch[4], Y.H. Lien[4], R. Maiolino[7], P. Majewski[2], S. Malik[6], J. March-Russell[3], C. McCabe[1], D. Newbold[2], R. Preece[3], B. Sauer[6], U. Schneider[7], I. Shipsey[3], Y. Singh[4], M. Tarbutt[6], M. A. Uchida[7], T. V-Salazar[2], M. van der Grinten[2], J. Vossebeld[4], D. Weatherill[3], I. Wilmut[7], J. Zielinska[6]

[1]Kings College London, [2]STFC Rutherford Appleton Laboratory, [3]University of Oxford, [4]University of Birmingham, [5]University of Liverpool, [6]Imperial College London, [7]University of Cambridge



Project executed in national partnership with **UK National Quantum Technology Hub in Sensors and Timing, Birmingham, UK,** and international partnership with **The MAGIS Collaboration and The Fermi National Laboratory, US**

Slide credit: Olivier Buchmuller (Imperial)/Ian Shipsey (Oxford)

Imperial College London

The AION Programme consists of 4 Stages

- **Stage 1:** to build and commission the 10 m detector, develop existing technology and the infrastructure for the 100 m.
- **Stage 2:** to build, commission and exploit the 100 m detector and carry out a design study for the km-scale detector.
  - AION was selected in 2018 by STFC as a high-priority medium-scale project.
  - AION will work in equal partnership with MAGIS in the US to form a "LIGO/Virgo-style" network & collaboration, providing a pathway for UK leadership.

Stage 1 is now funded with about £9M by the QTFP Programme and other sources and Stage 2 (~£10M) could be placed at national facility in Boulby or Daresbury (UK), possibly also at CERN (France/Switzerland).

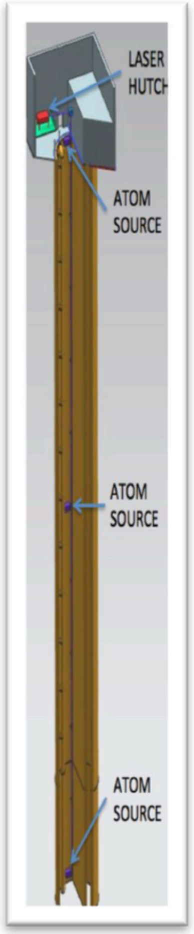
- **Stage 3:** to build a kilometre-scale terrestrial detector.
- **Stage 4**: long-term objective a pair of satellite detectors (thousands of kilometres scale) [AEDGE proposal to ESA Voyage2050 call]
  - AION has established science leadership in AEDGE, bringing together collaborators from European and Chinese groups (e.g. MIGA, MAGIA, ELGAR, ZAIGA).

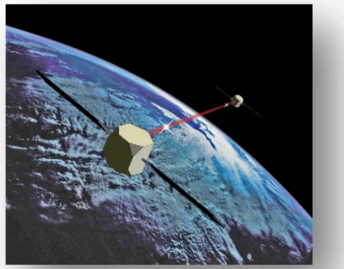
Stage 3 and 4 will likely require funding on international level (ESA, EU, etc) and AION has already started to build the foundation for it.

L ~ 10m

L ~ 100m

L ~ 1km



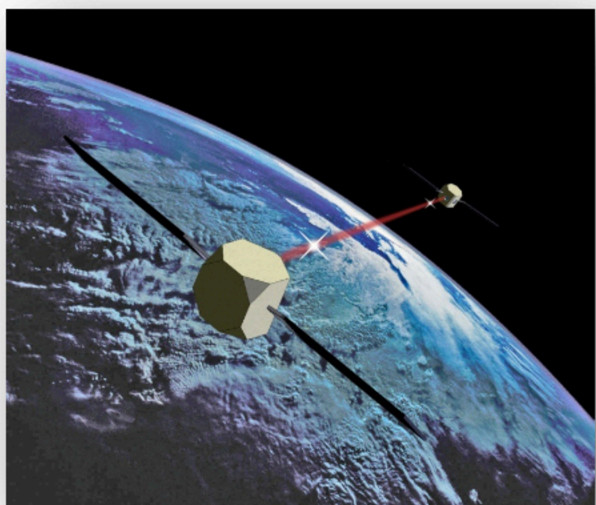


AION Project: UK HEP FORUM 2020

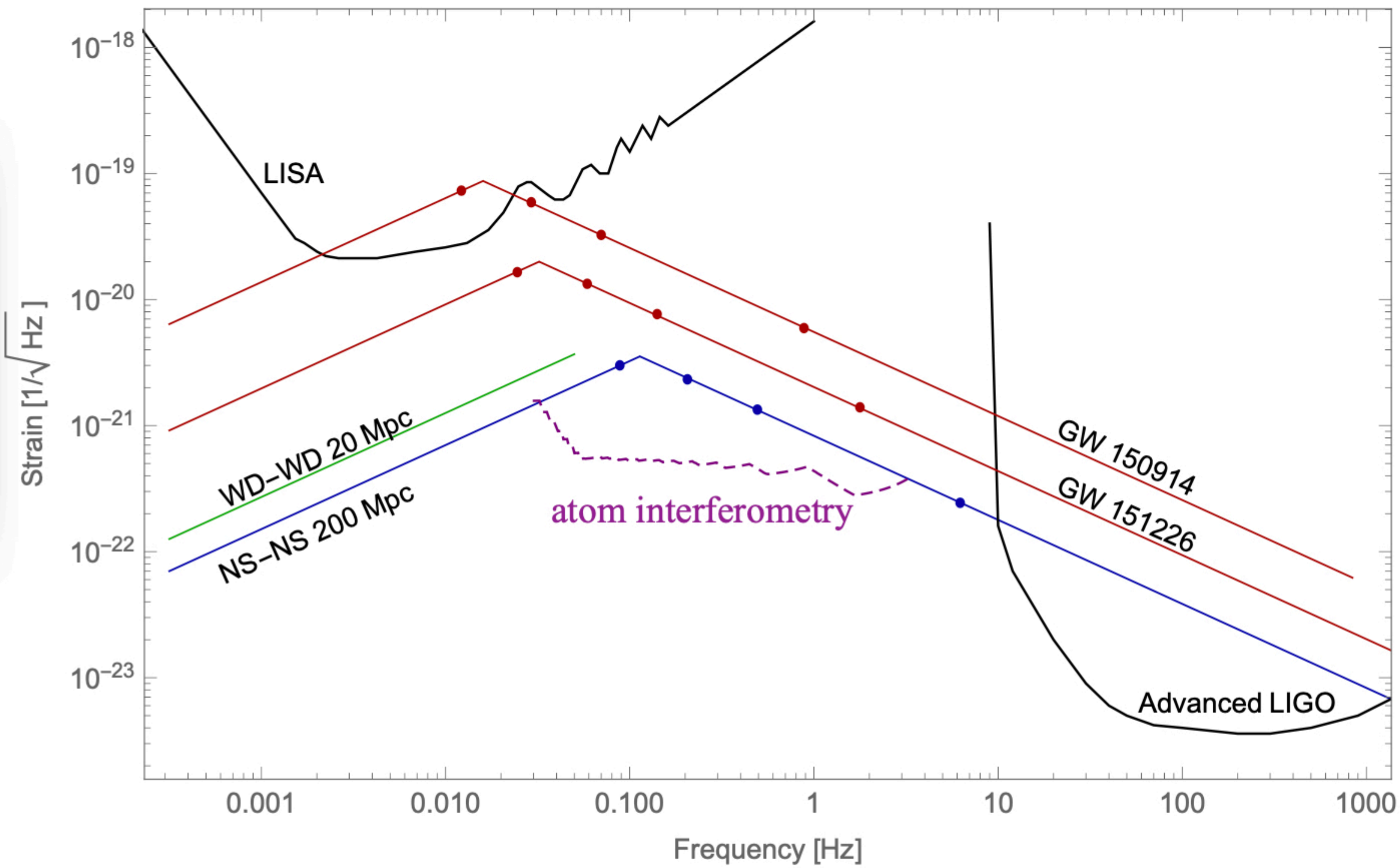
Slide credit: Olivier Buchmuller (Imperial)

Atom Interferometry for Gravitational Waves

Atoms could access mid-frequency band



earth orbit allows polarization measurement with single detector



for example this band allows:

- observe new sources
- localize and predict BH and NS binary mergers for other telescopes to observe
- good measurement of BH spins

Slide credit: Peter Graham (Stanford)

And in light particle-DM regime…

Quantum Enhanced Superfluid Technologies for Dark Matter and Cosmology, QUEST –DMC

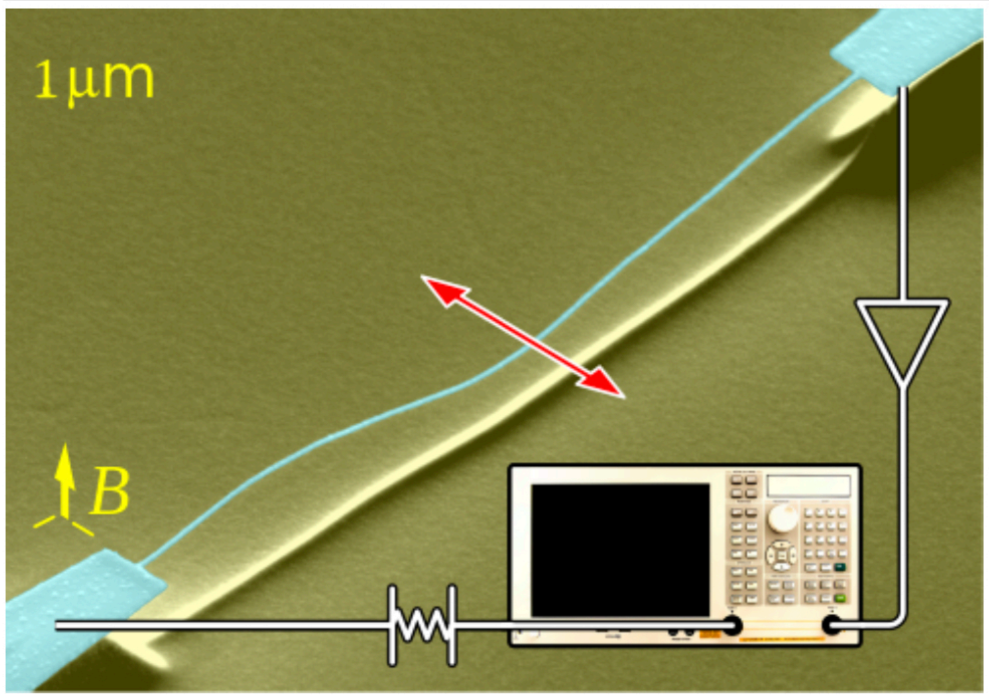
ROYAL HOLLOWAY UNIVERSITY OF LONDON

Lancaster University

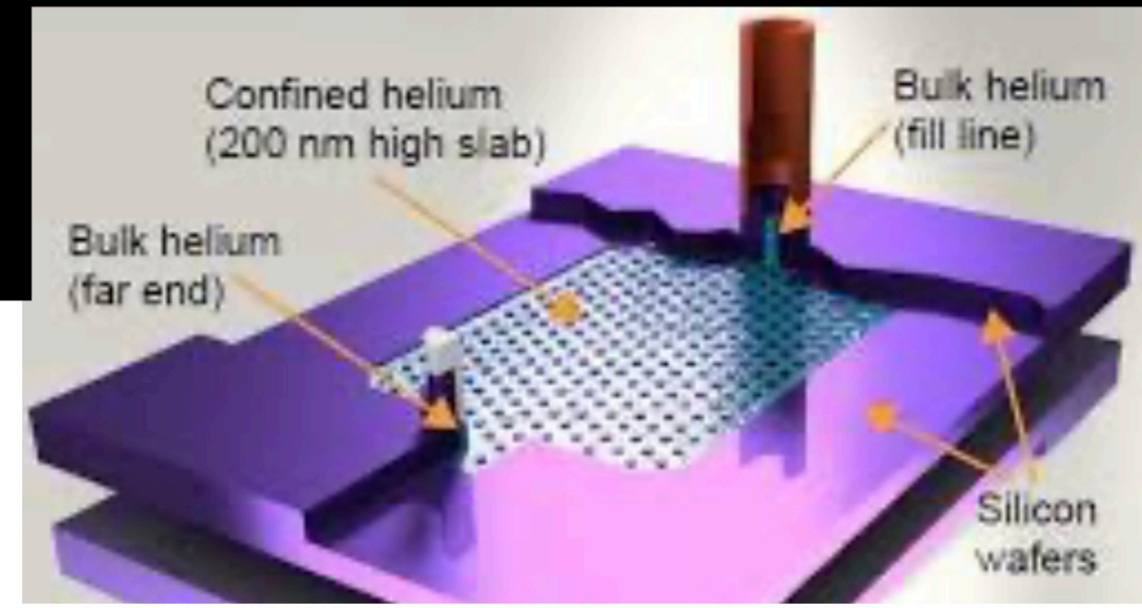
University of Sussex

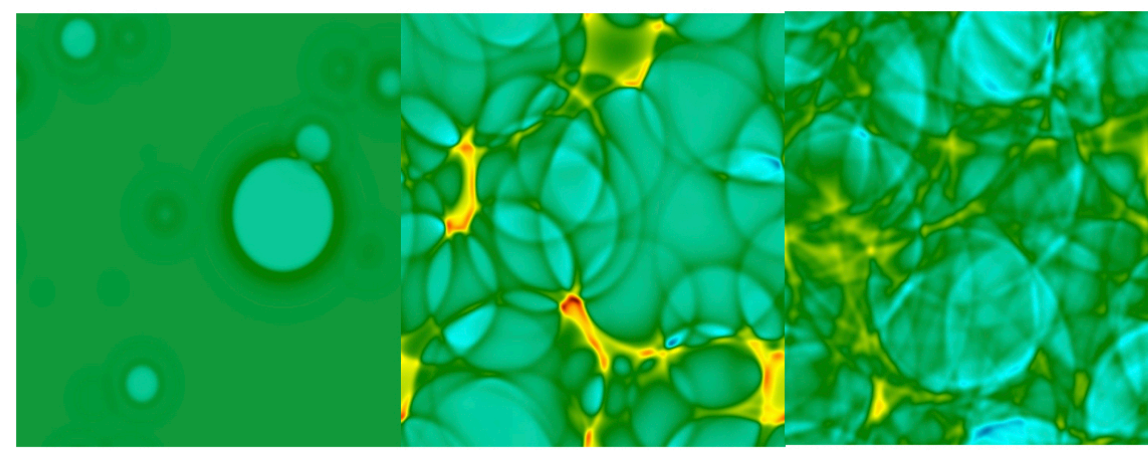
UNIVERSITY OF OXFORD

Detection of sub-GeV dark matter with a quantum-amplified superfluid ^{3}He calorimeter.



Phase transitions in extreme matter





UK HEP Forum 2020, 9-11 November 2020, See Andrew Casey's talk

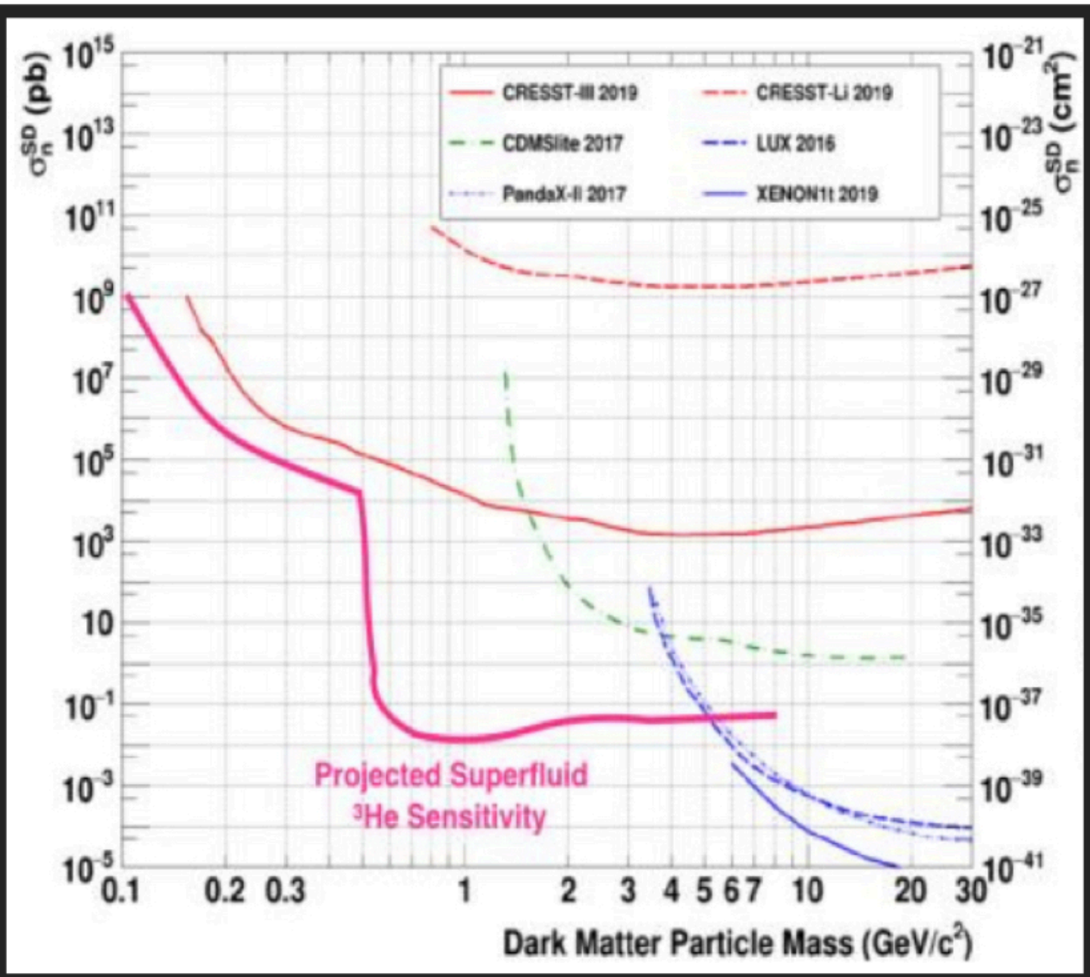
Slide credit: Andrew Casey (RHUL)/Ian Shipsey (Oxford)

Search regime highly motivated by asymmetric DM

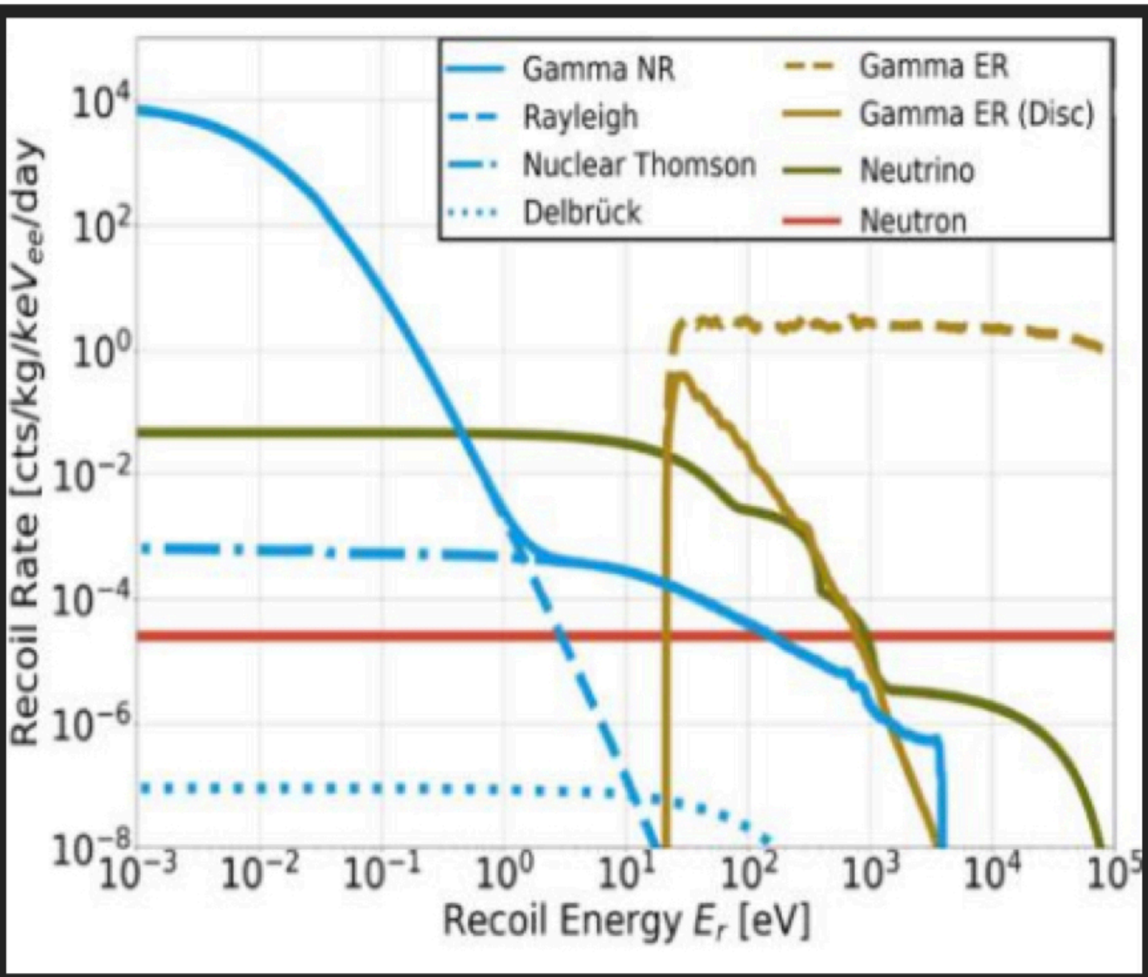
WP1: Detection of sub-GeV dark matter with a quantum-amplified superfluid ^{3}He calorimeter

Prof Jocelyn Monroe

New mass regime, sensitivity to spin-dependent interactions, predict 10 eV threshold.



A. H. Abdelhameed *et al.* (CRESST Collaboration) Phys. Rev. D **100**, 10200 (2019)



Hertel et al. Phys. Rev. D 100, 092007 (2019)

Slide credit: Andrew Casey (RHUL)

Building a community: essential for creation of QTFP

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

Slide credit: Ian Shipsey (Oxford)

CERN?

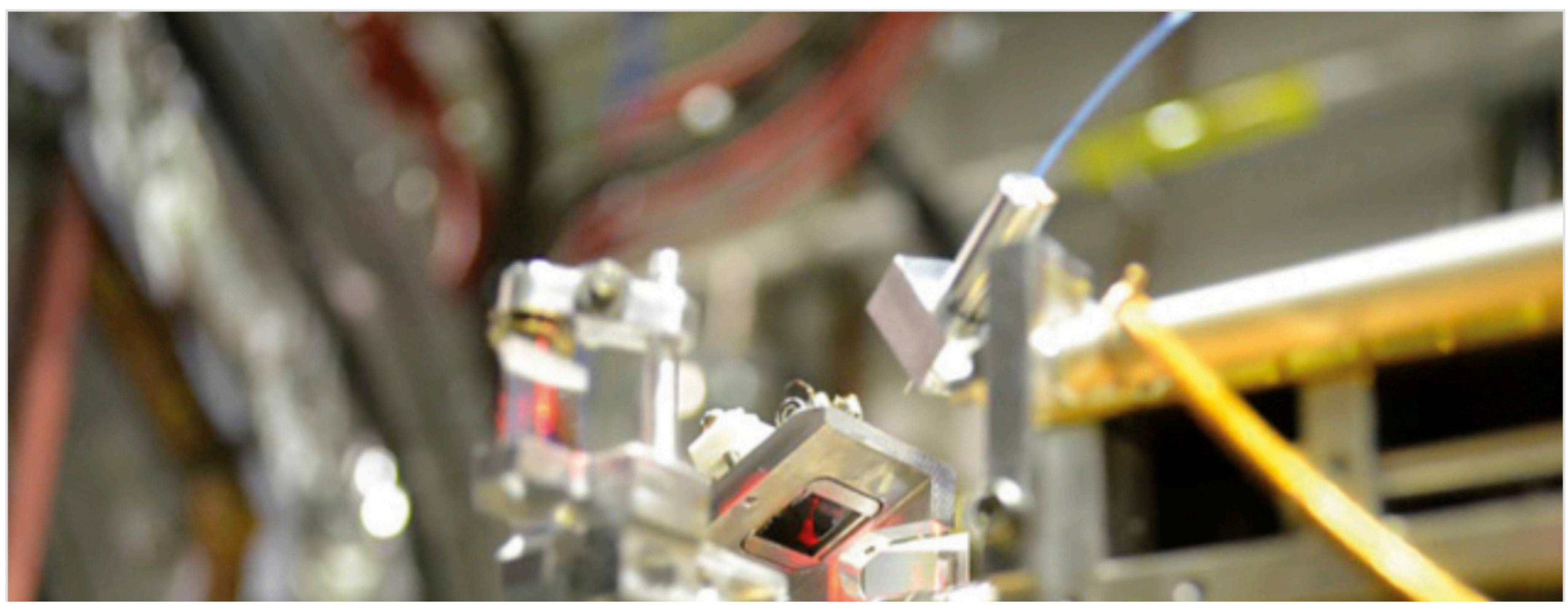
CERNCOURIER | Reporting on international high-energy physics

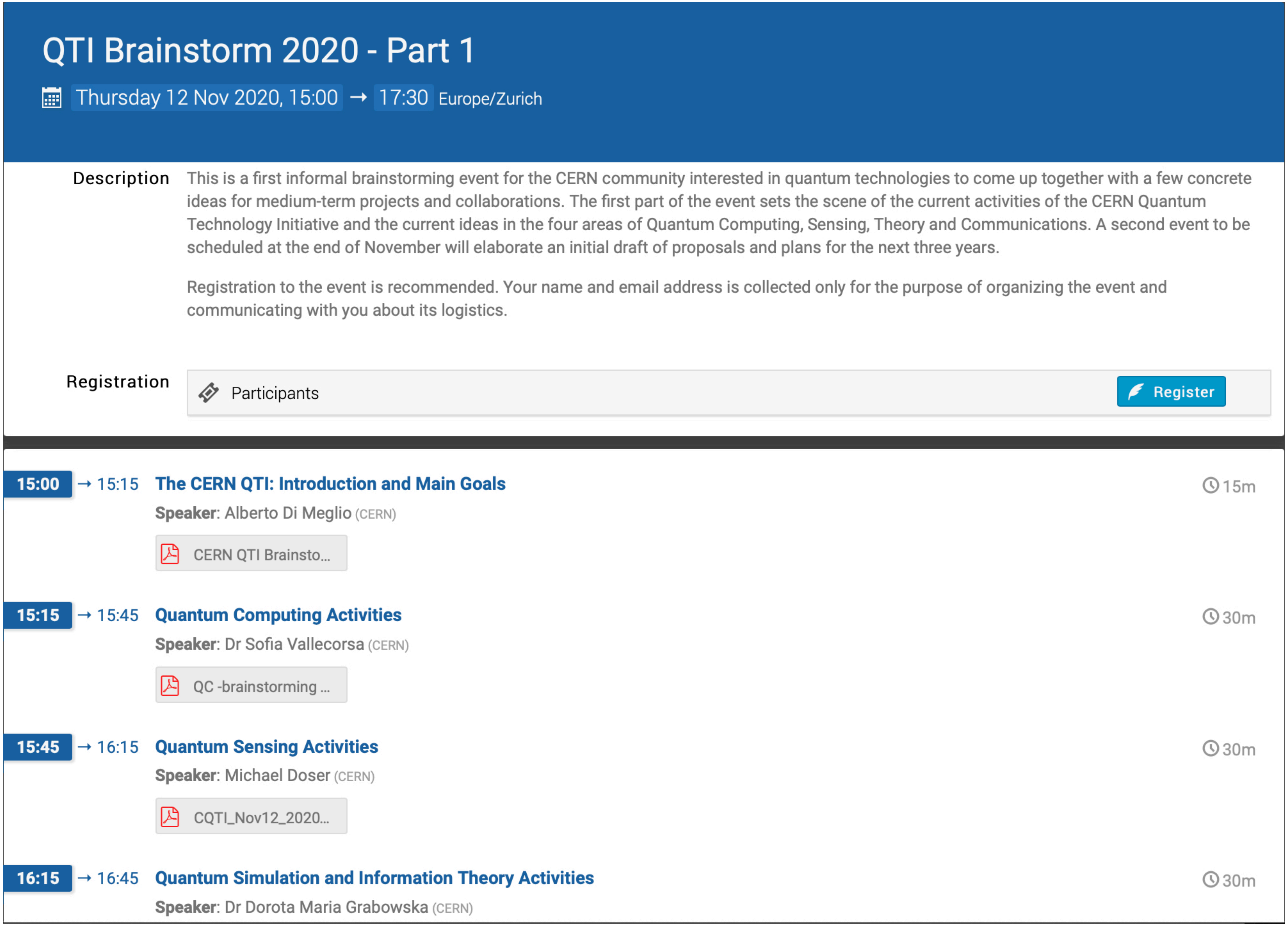
COMPUTING | OPINION

CERN and quantum technologies

25 September 2020

CERN's new quantum technology initiative has the potential to enrich and expand its challenging research programme, says Alberto Di Meglio.





QTI Brainstorm 2020 - Part 1

Thursday 12 Nov 2020, 15:00 → 17:30 Europe/Zurich

Description This is a first informal brainstorming event for the CERN community interested in quantum technologies to come up together with a few concrete ideas for medium-term projects and collaborations. The first part of the event sets the scene of the current activities of the CERN Quantum Technology Initiative and the current ideas in the four areas of Quantum Computing, Sensing, Theory and Communications. A second event to be scheduled at the end of November will elaborate an initial draft of proposals and plans for the next three years.

Registration to the event is recommended. Your name and email address is collected only for the purpose of organizing the event and communicating with you about its logistics.

Registration Participants Register

15:00 → 15:15 **The CERN QTI: Introduction and Main Goals** 15m
Speaker: Alberto Di Meglio (CERN)
CERN QTI Brainsto...

15:15 → 15:45 **Quantum Computing Activities** 30m
Speaker: Dr Sofia Vallecorsa (CERN)
QC -brainstorming ...

15:45 → 16:15 **Quantum Sensing Activities** 30m
Speaker: Michael Doser (CERN)
CQTI_Nov12_2020...

16:15 → 16:45 **Quantum Simulation and Information Theory Activities** 30m
Speaker: Dr Dorota Maria Grabowska (CERN)

- From presentations and discussion status pretty clear: CERN wants to be involved, *but searching for direction. UK can & should provide this!*

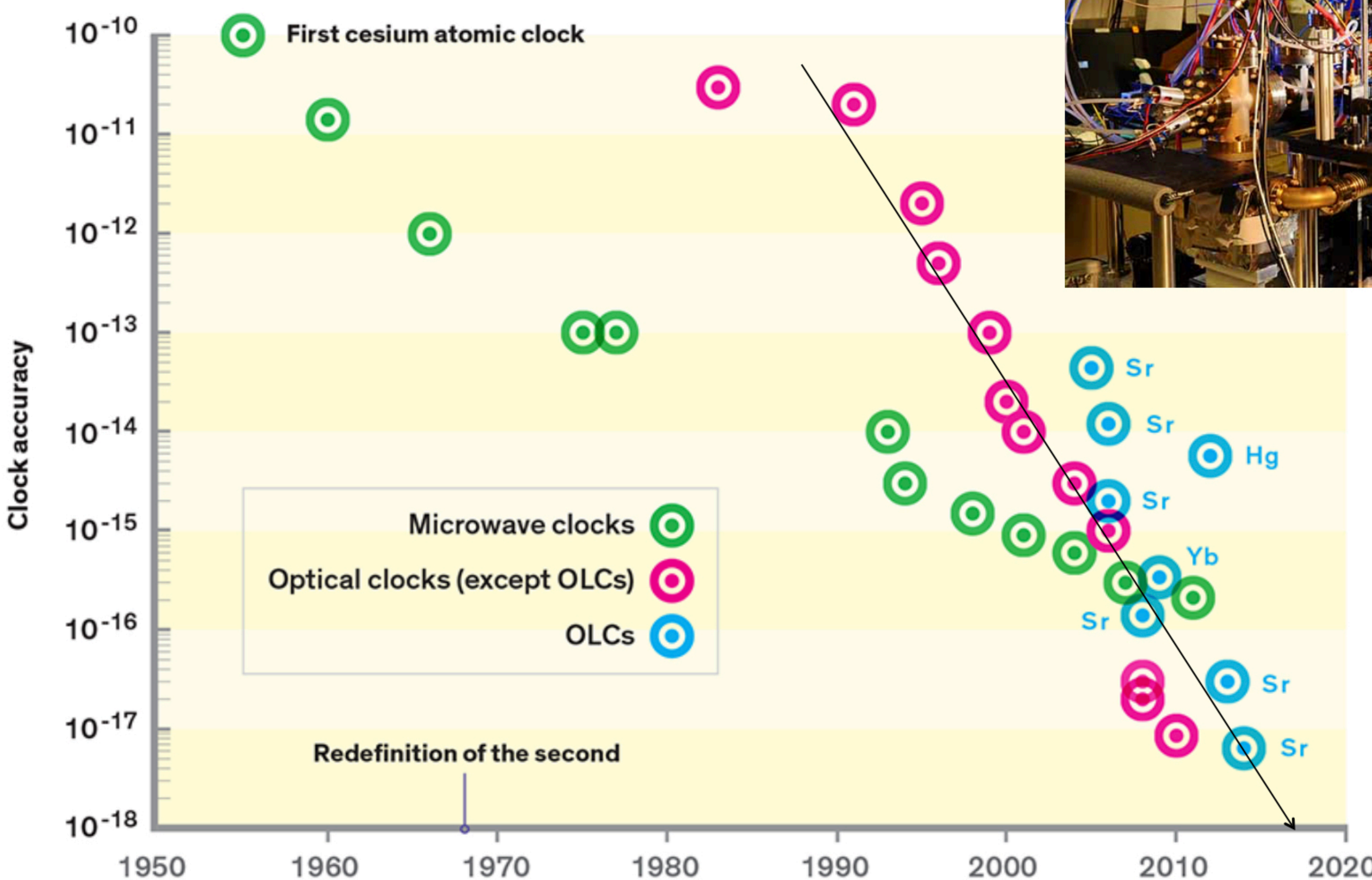
Multi-decade+ program with multiple major discoveries beckons!

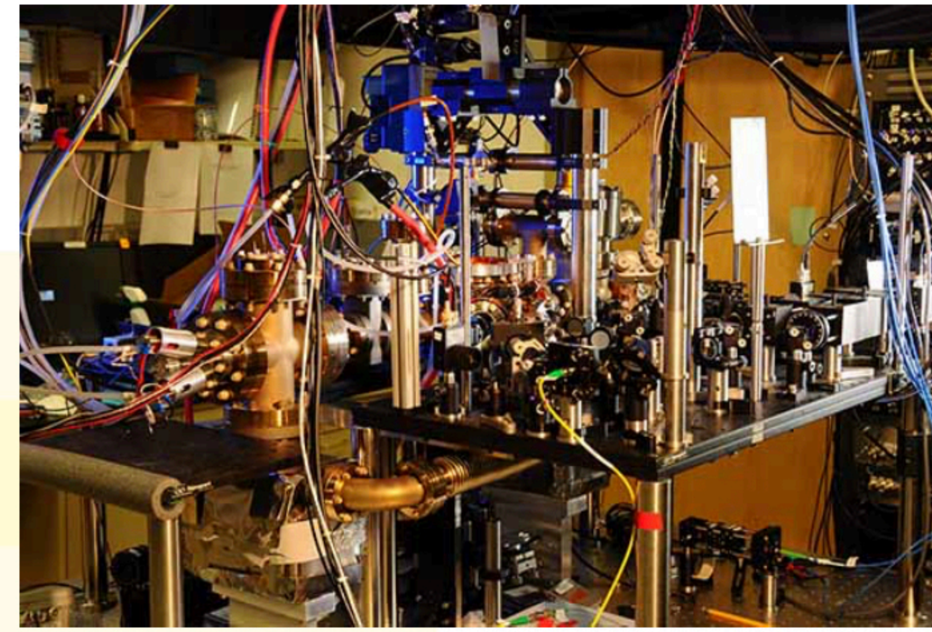
Have engaged our fellow physicists in other fields, significantly growing the community working in fundamental particle physics. *Increasing the size of the pie to everyone's benefit*

Need to continue UK's leadership and get even better

BACKUP SLIDES

Atomic Clock Sensitivity





current technology already allows many new searches, and will improve by orders of magnitude

Slide credit: Peter Graham (Stanford)

Main Aims of G3-Xe R&D

- Development of scalable VUV-SiPM array: possible alternative for PMT readout.
  Major technical progress recently, develop UK capability and operational experience.

- Exploration and evaluation of options for VUV-SiPM readout technologies to reduce cable count and meeting the background requirements of a G3 instrument.
  Address the main challenge of SiPM readout head on.

- Advanced radio-assay techniques to ensure technical developments meet stringent radiopurity requirements to achieve G3 sensitivity.
  Major campaign needed, as we conducted for PMT development (ZEPLIN, LZ).

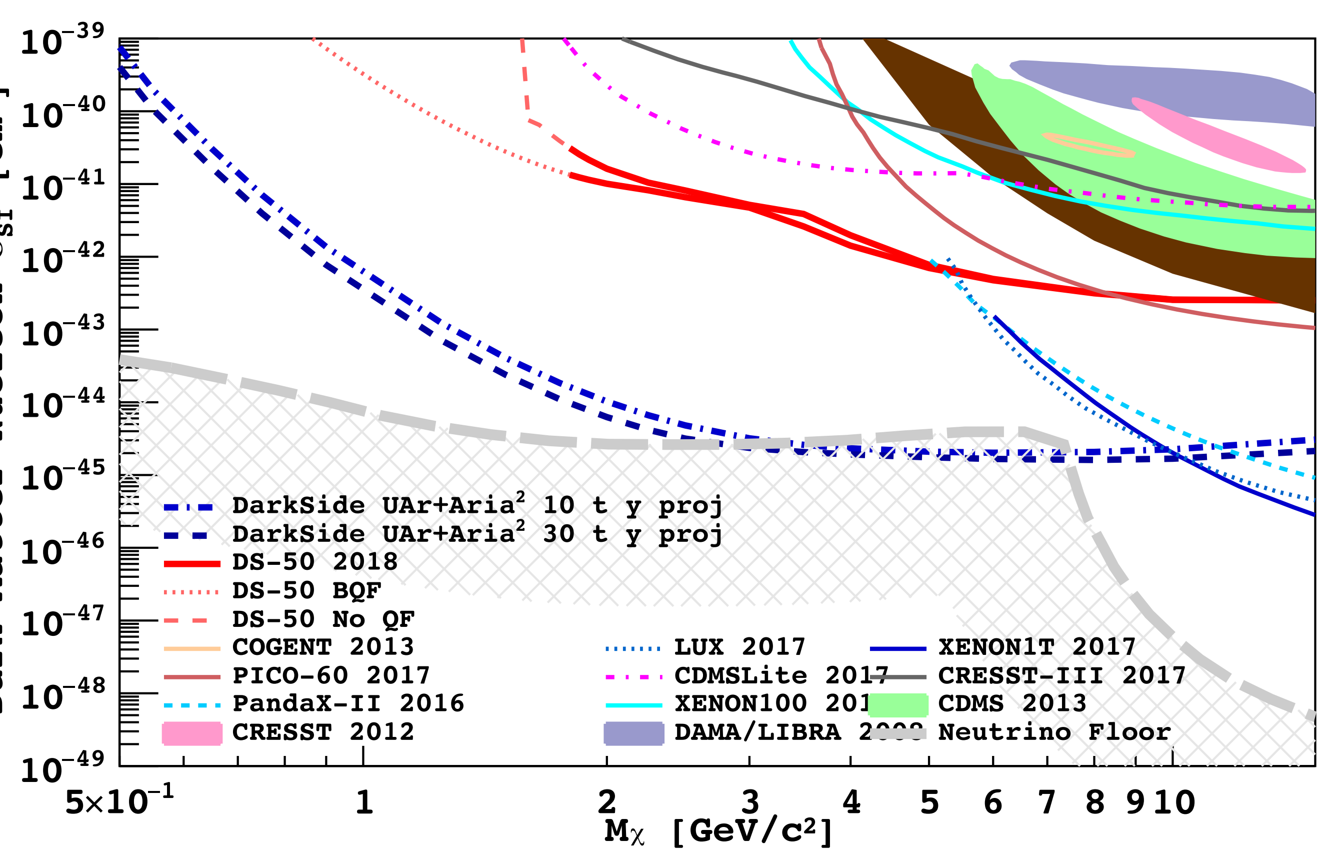
- First observation of Migdal effect from nuclear scattering: major impact on DM field.
  Already important in the field: but are experimental Migdal rates as predicted?

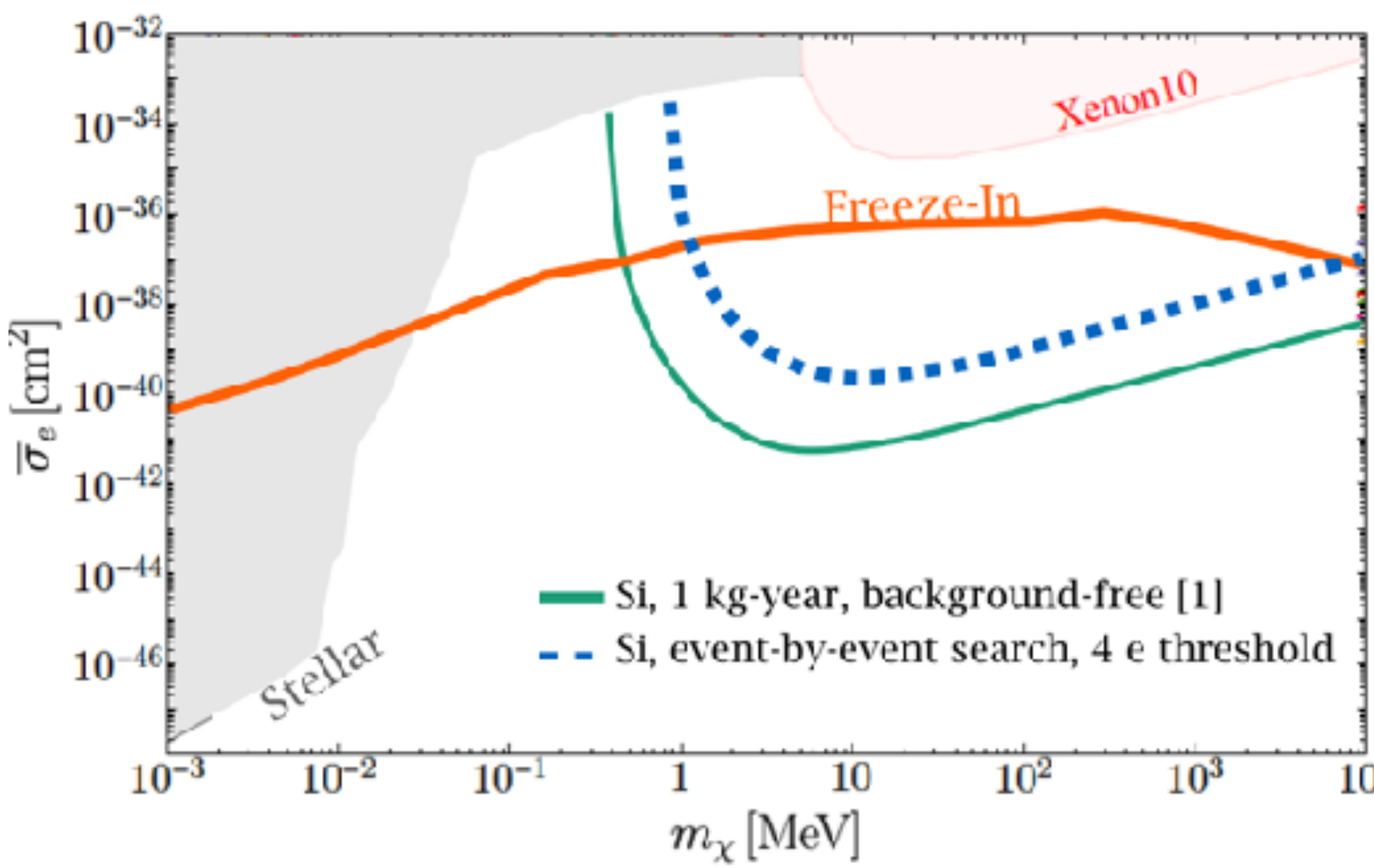
Low Mass Dark Matter Opportunities Enabled by SiPMs

1. Expanded dark matter cross section reach: ~proportional to background

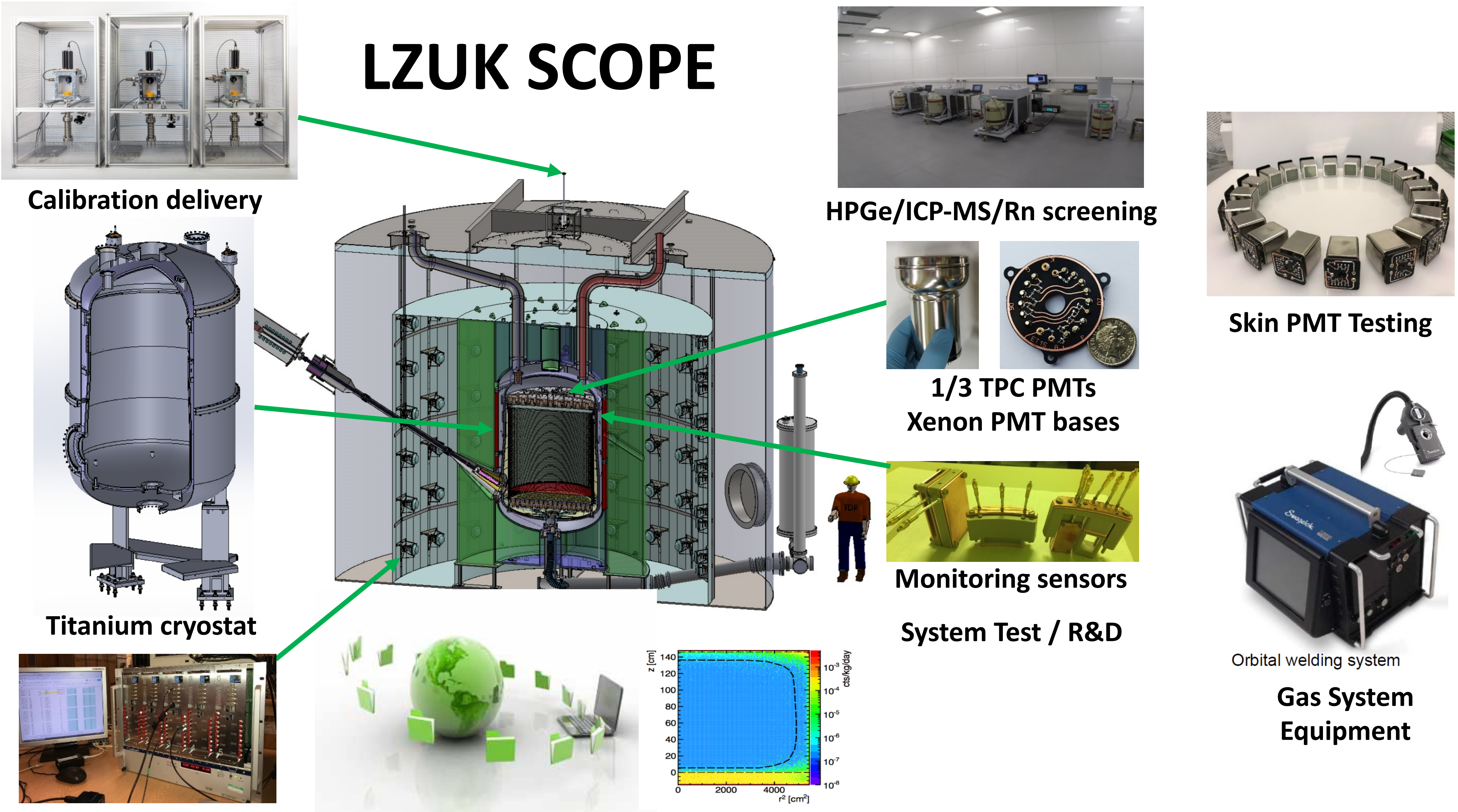
2. Expanded dark matter mass range:

- lighter targets are better for low mass dark matter (below left) — reach **GeV** mass range
- access to dark matter search *in* the Si target (below, right) — opens up **MeV** mass range
- sidereal modulation potential using the Si target *(Heikinheimo et al., Phys. Rev. D 99, 103018 (2019))*
    - energy threshold to liberate a charge carrier in Si depends on orientation of recoil relative to crystal symmetry axis — gives rise to sidereal modulation in rate





LZUK SCOPE

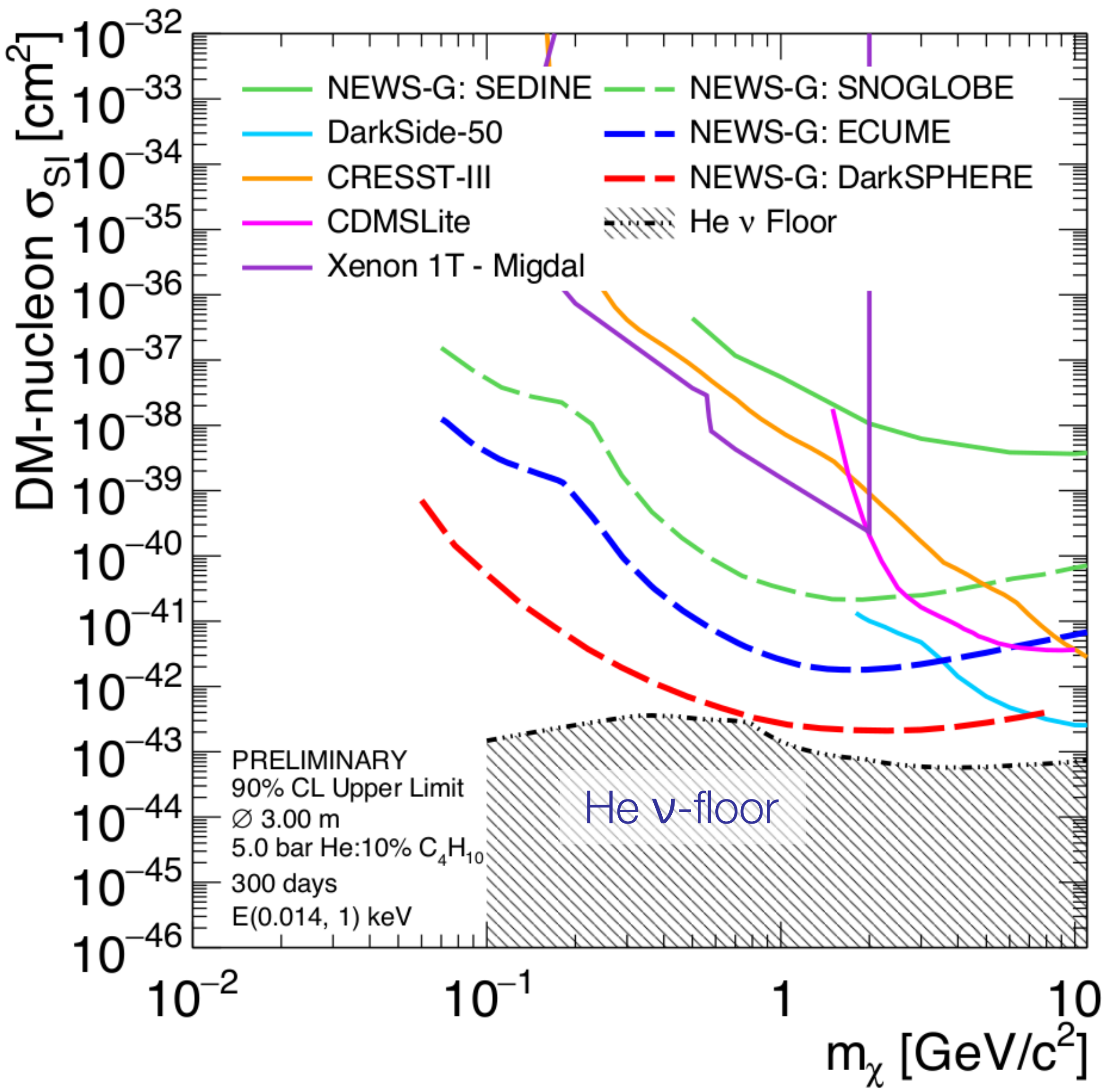


Slide credit: Henrique Araujo (LZ/Imperial)

XenonFutures: R&D FOR A GLOBAL RARE EVENT OBSERVATORY (Phase 2)

Henrique Araújo, Sergey Burdin, Jim Dobson, Henning Flaecher, Chamkaur Ghag, Maurits van der Grinten, Asher Kaboth, Hans Kraus (PI), Vitaly Kudryavtsev, Pawel Majewski, Christopher McCabe, Alex Murphy, Tim Sumner, Dan Tovey, Antonin Vacheret

NEWS-G will produce increasingly radio-pure, scaled-up detectors over the next 5+ years

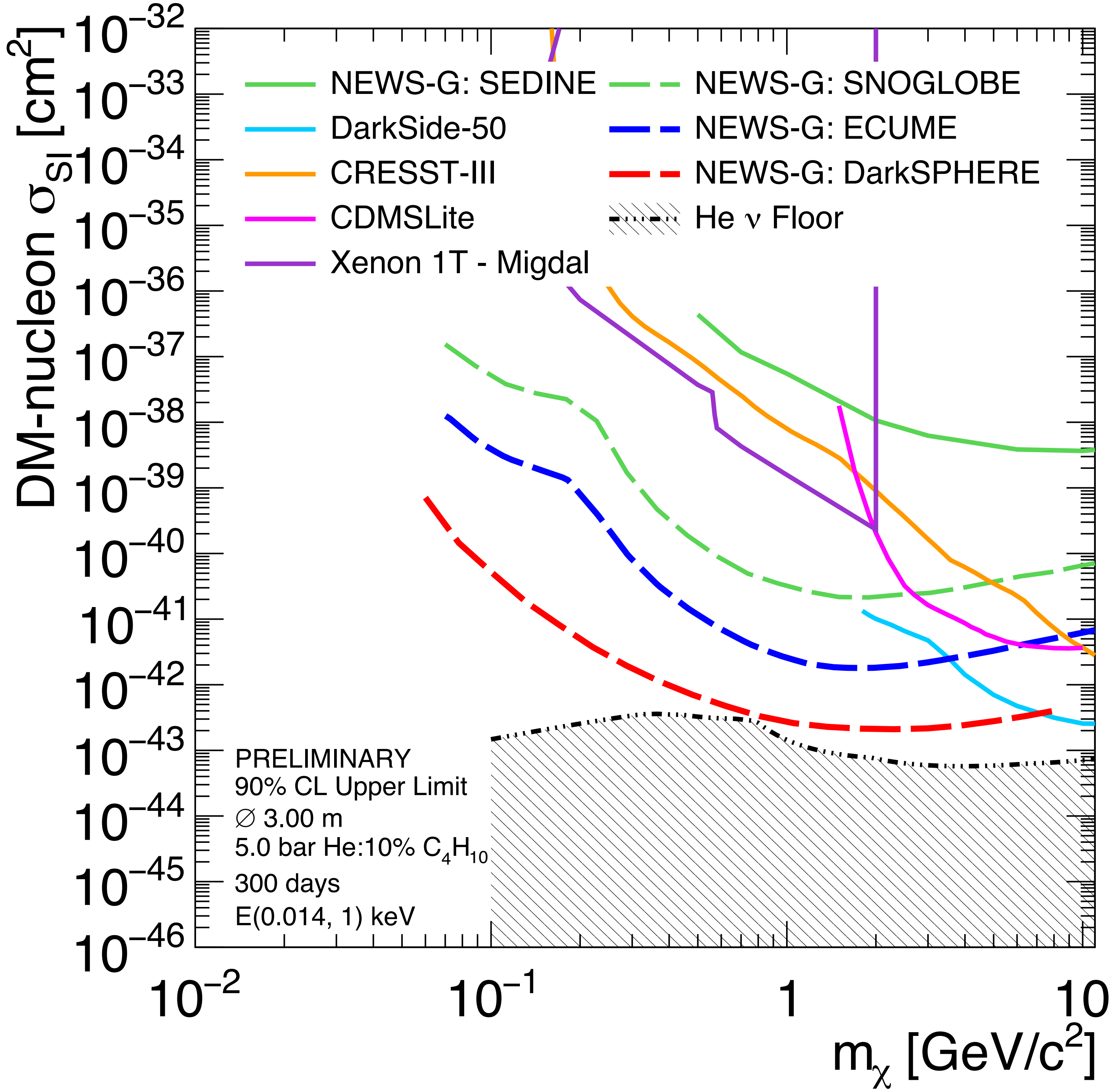


General assumptions:
F= 0.2, θ = 0.12,
SRIM quenching factor,
ROI: 14 eV_{ee} - 1 keV_{ee}

NEWS-G SNOLAB:
Ne + 10% CH_4, 1 bar (1.04 kg)
Background: 1.78 dru
Exposure: 20 kg.days
Optimum Interval Method [13]

NEWS-G ECUME:
Ne + 10% CH_4
Background: 0.3 dru
Exposure: 200 kg.days
Optimum Interval Method [13]

DarkSPHERE:
He + 10% C_4H_{10}, 5 bars (26.8 kg)
Background: 0.02 dru
Exposure: 300 days
Binned Likelihood

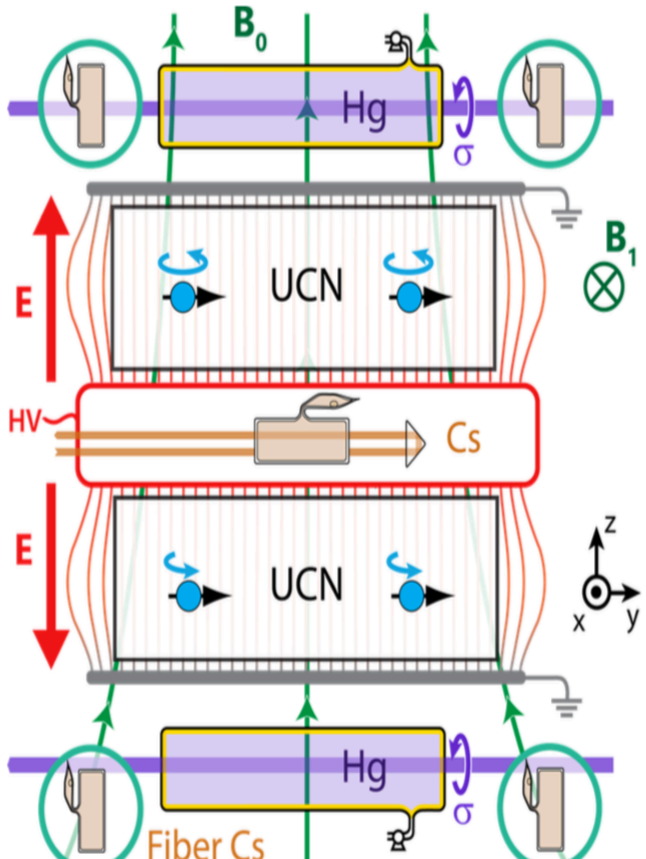


NEWS-G: SEDINE
DarkSide-50
CRESST-III
CDMSLite
Xenon 1T - Migdal
NEWS-G: SNOGLOBE
NEWS-G: ECUME
NEWS-G: DarkSPHERE
He ν Floor
PRELIMINARY
90% CL Upper Limit
∅ 3.00 m
5.0 bar He:10% C_4H_{10}
300 days
E(0.014, 1) keV
DM-nucleon σ_{SI} [cm^2]
m_χ [GeV/c^2]

Cryogenic neutron EDM R&D

PanEDM – two stage programme towards a cryogenic nEDM (ILL/TUM/RAL/PNPI+US institutes)

- Will provide a next generation nEDM experiment following the room temperature era
- Super-thermal ultracold neutron source "SuperSUN" constructed:
  - room temperature, UCN produced through SuperSun
  - cryogenic experiment – to start five years beyond



- RT stage to reach 4 x10^{-27} e·cm sensitivity per 100 days run.
- cryogenic experiment to reach sub-10^{-27} e·cm

EDM chambers/magnetometry in place

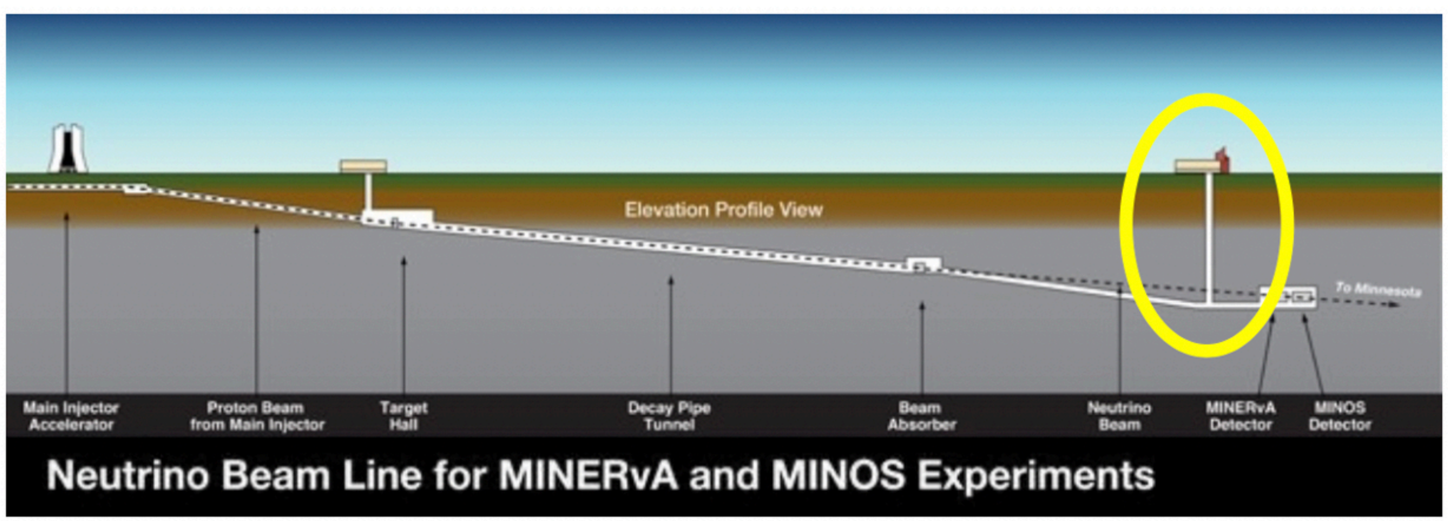
Expect that future of nEDM will go through European Spallation Source (ESS)

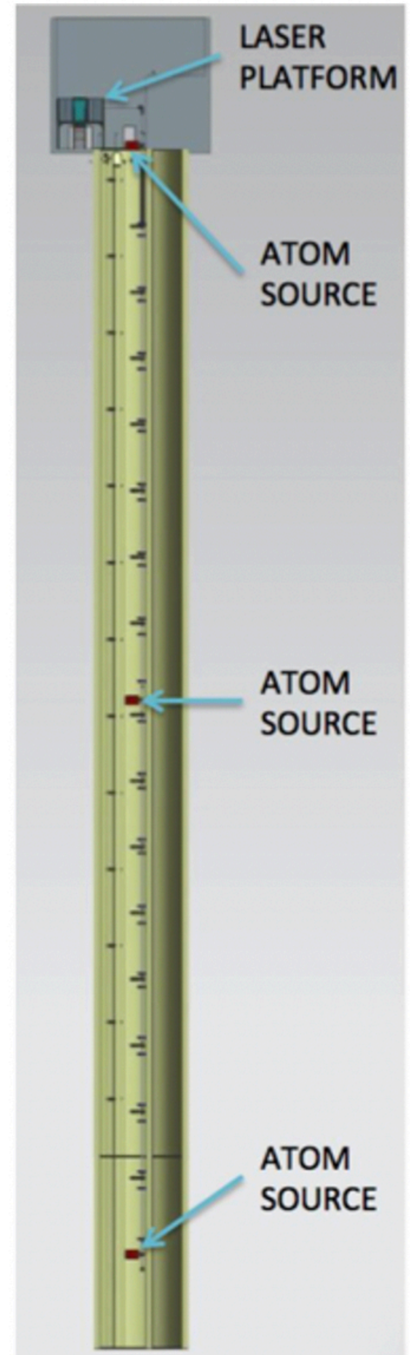
Slide credit: Maurits Van der Grinten (PPD/STFC)

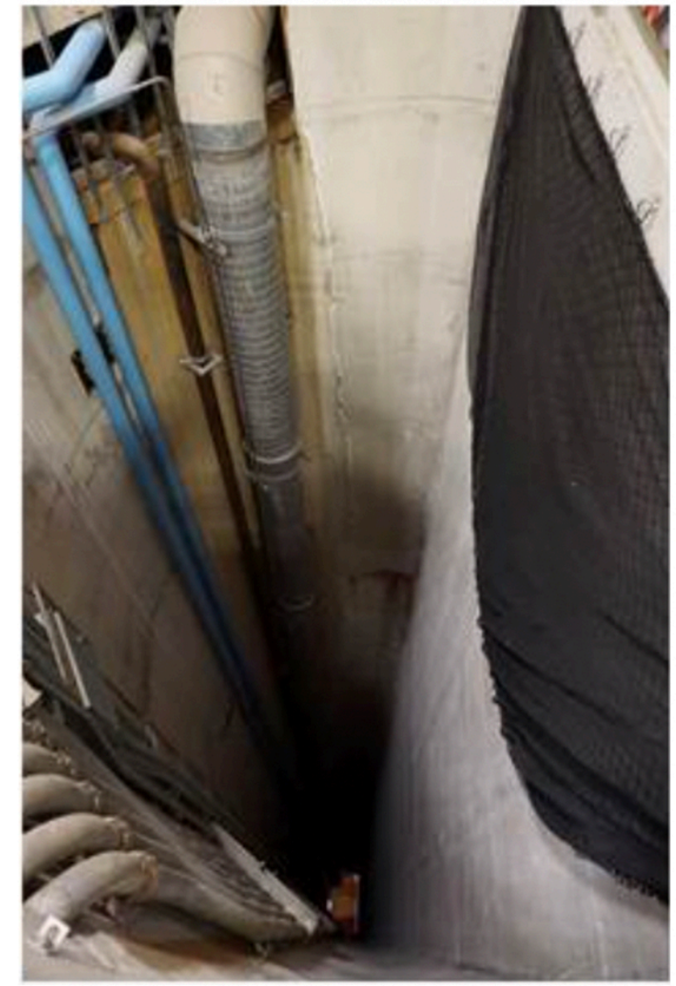
Also now significant involvement in MAGIS-100

MAGIS-100 @ Fermilab

- 100m baseline – MINOS access shaft
  - 3 interferometers
- Scalar Dark Matter Detection with MAGIS
  - Affects fundamental constants (m_e and α)
  - altering atomic energy level separation
- gravitational wave measurements
  - Use same configuration







UK Contribution via the AION programme

UNIVERSITY OF LIVERPOOL

UNIVERSITY OF OXFORD

UNIVERSITY OF CAMBRIDGE

Slide credit: Jon Coleman (Liverpool)

MAGIS-100 @ Fermilab

- 100m baseline – MINOS access shaft
  - 3 interferometers
- Scalar Dark Matter Detection with MAGIS
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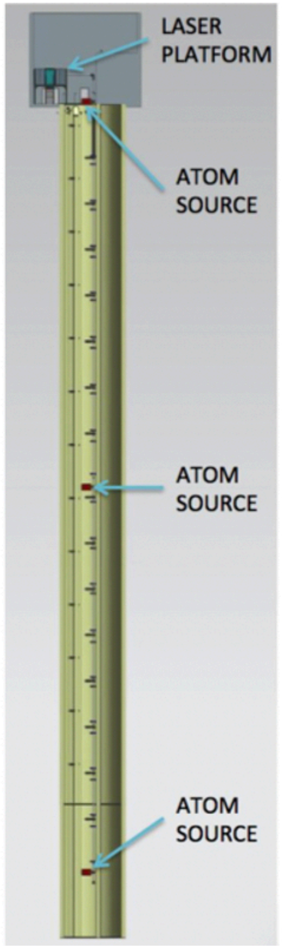
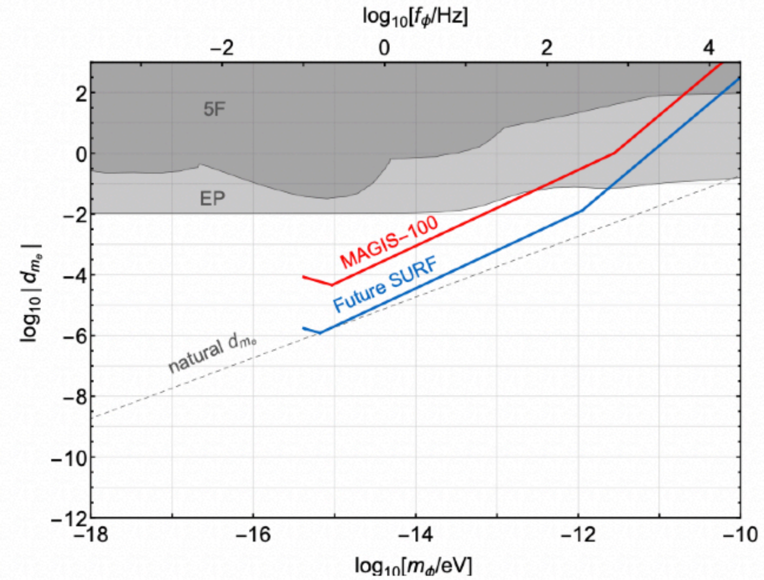
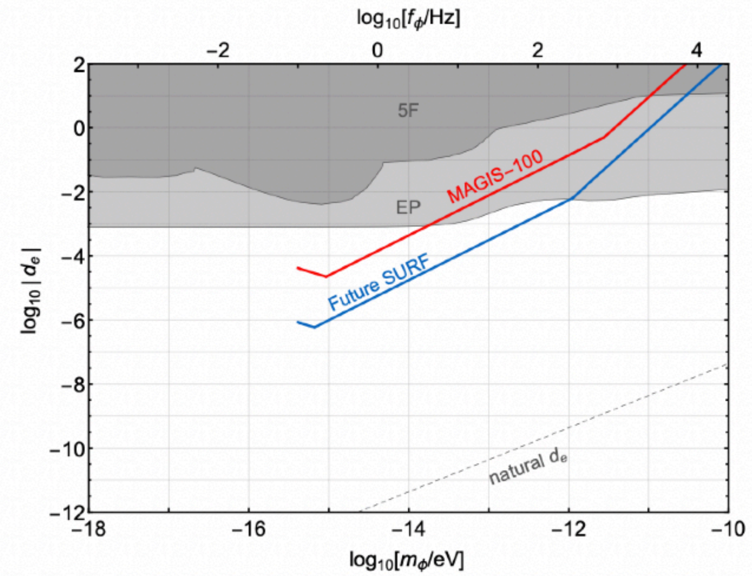
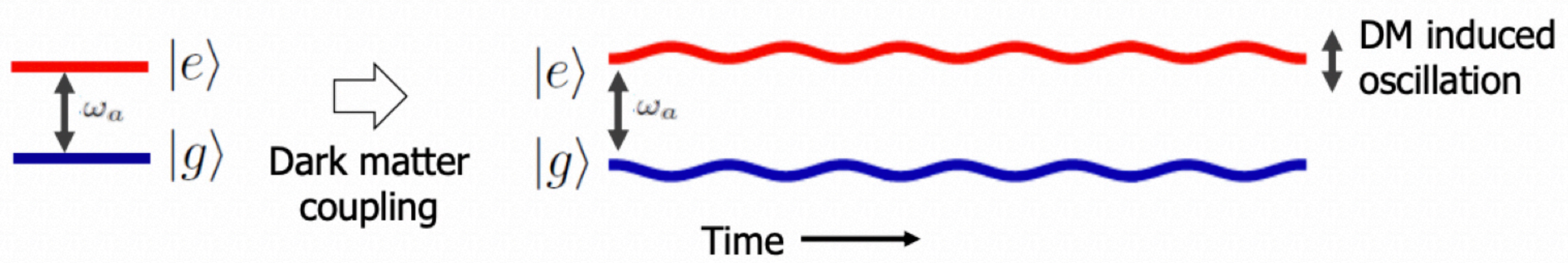
UK Contribution via the AION programme









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