QSNET: Networked Quantum Sensors

22nd March 2019
National Physical Laboratory

Welcome to NPL

NPL
National Physical Laboratory

UK's National Measurement Institute

- Develop and maintain primary standards
- Measurement solutions for business and government
- 600 Research scientists

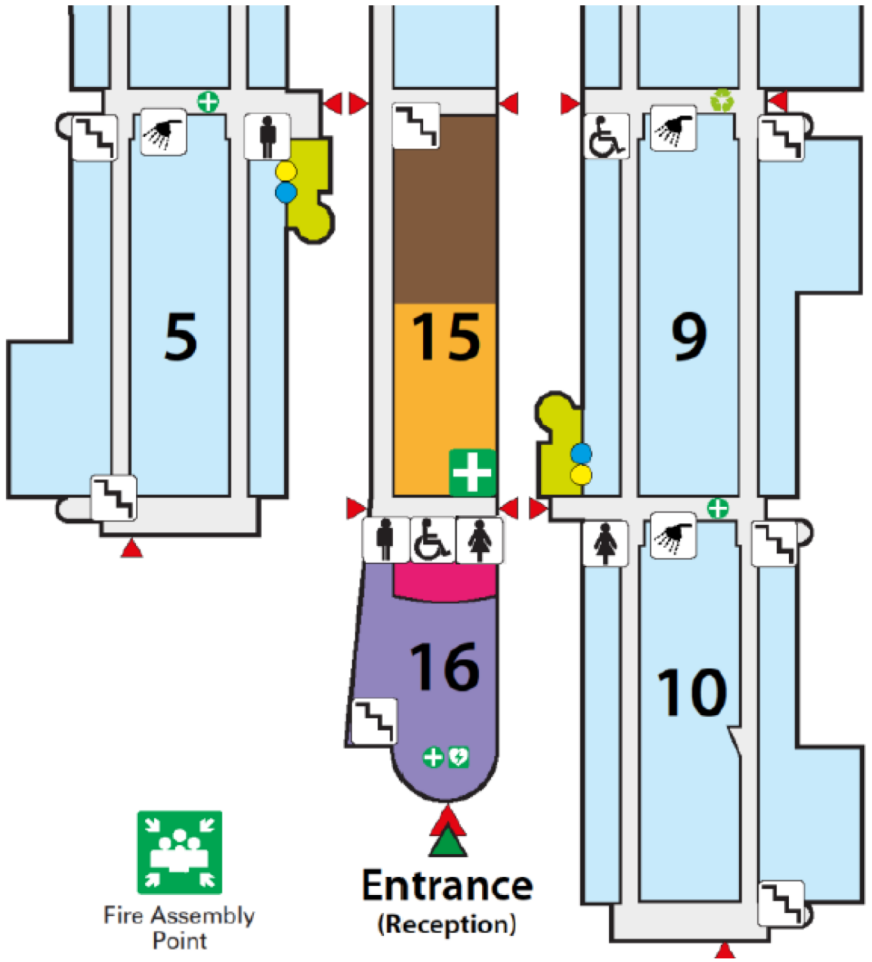
- Time & Frequency:
  - Maintain UK's time scale
  - Operate Cs primary frequency standards
  - Develop next-generation optical atomic clocks
  - Develop compact clocks for commercial applications

Advanced Quantum Metrology Lab

NPL
National Physical Laboratory

Housekeeping

- Fire assembly point
- Toilets



New Opportunities

- Industrial Strategy Challenge Fund (ISCF) – Wave 2 challenges launched, open call for Wave 3 ideas
- Global Challenges Research Fund (GCRF) – up to £200 million of the £1.5 billion total collective fund unallocated
- **Strategic Priorities Fund (SPF)** – £755 million over three years, bids from any BEIS-funded research and development organisation
- Talent Fund – £300 million over three years
- Commercialisation Fund – £108 million
- Strength in Places Fund – £115 million over three years for collaborative bids between research organisations and business to support regional growth
- **Fund for International Collaboration** – £110 million over three years

Strategic Priorities Fund Wave 1

STFC submitted five bids for Wave 1 (spend starting in 2018/19)

- **Artificial Intelligence for the National Facilities at Harwell**: £11.62 million
- **CLARA**: £29.1 million
- **Digital Twinning**: £19.43 million - STFC £13.4 million
- **DiRAC-3**: £36.85 million
- **Extreme Photonics Applications Centre**: £81.2 million, including £10 million from MOD

In addition, we were required to submit evidence on why it is not feasible to fund these from our existing programme

Science & Technology Facilities Council

News, Updates, Timeline

- QSNET 4-page document circulated in December
  - outline of QSNET theme, opportunities, draft timescales and costings
  - objectives for the first funding, also longer-term
- From STFC+EPSRC, a staged programme is implied for projects
  - National phase w/ initial (competitive?) results (2.5 to 3 year)
  - International phase targeting world-leading results (another 3 year)
  - Money (or timescales) not yet clear for next stage
- Lots of activity behind the scenes…
  - *December:* Four-page outline document, NPL+STFC+EPSRC phone meeting, meetings @ Durham w/theorists & STFC, bid submitted to UKRI
  - *January:* Bid reviewed by UKRI, more meetings with STFC, Second QSFP meeting Oxford
  - *February:* QSNET kickoff, Quantum and other SPF bids to BEIS
  - *March:* Meeting with STFC's Jason Green; waiting for BEIS/ministers to action the SPF bids (Brexit delay?)

TIMELINES (FROM 2018 QSFP WORKSHOP)

UKRI (STFC+EPSRC) Timeline

mid Nov 18: Draft template complete

Dec 18: UKRI submission, incl. £40M for QSFP

March 19: Funding awarded

April 19: Official grant start date

May 19: STFC issue open call

June 19: call closes

"Opportunities" Grant timeline

Draft cases collected, sent to STFC

Dec 2018: Project outlines collected, request support for workshop & travel

Jan: Projects meet to "cross-fertilise, give feedback, merge if required, last chance of any late-breaking new ideas"

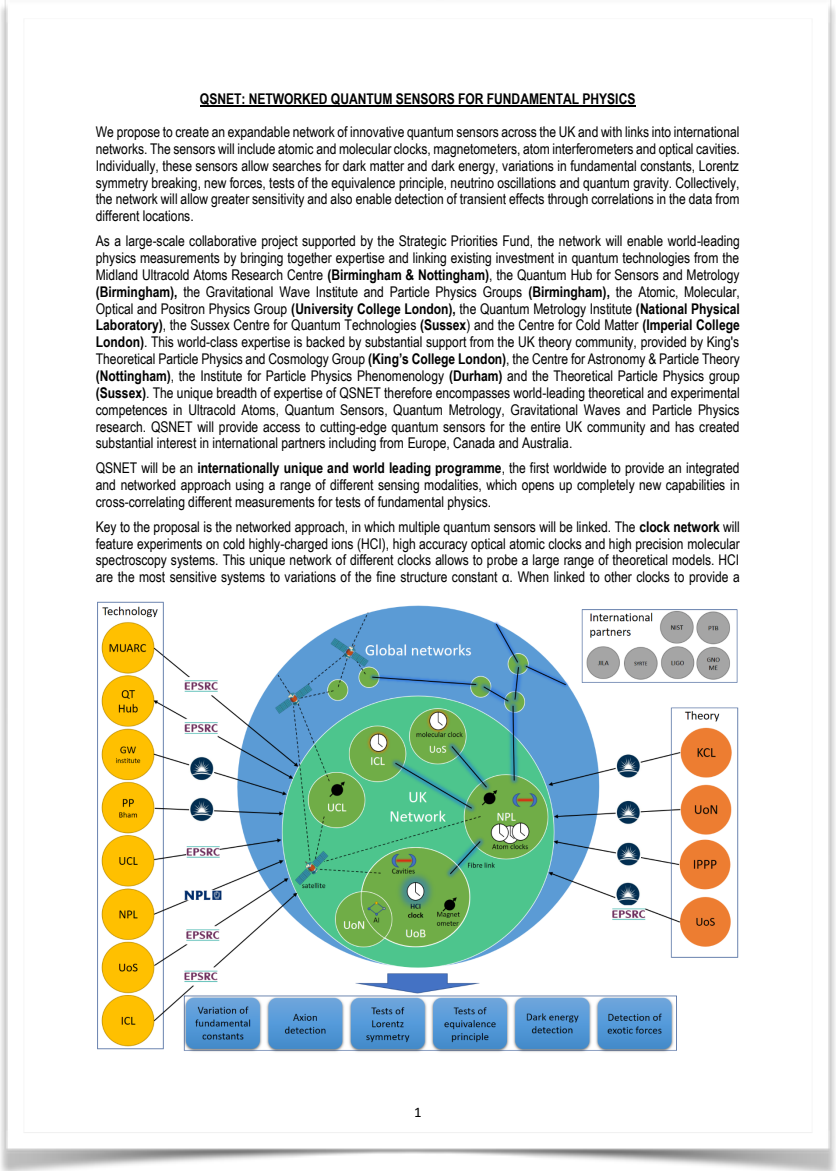
End Mar 2018: Draft review by IRB (…and grant ends)

End April 2018: Final review by IRB, formal costings initiated

May: Projects meet, review proposals, bid to STFC for funding, backed by IRB

QSNET OUTLINE PROPOSAL (2018)

- Submitted to STFC & QSFP; outlines consortia bid of 9 institutes (~12 groups) for £19.1M
- Expandable network of innovative quantum sensors to searches for “dark matter and dark energy, variations in fundamental constants, Lorentz symmetry breaking, new forces, tests of the equivalence principle, neutrino oscillations and quantum gravity”.
- Originally planned to include atomic and molecular clocks, magnetometers, atom interferometers and optical cavities.
- Network will allow greater sensitivity and detection of transient effects through correlations in the data from different locations.



QSNET: NETWORKED QUANTUM SENSORS FOR FUNDAMENTAL PHYSICS

We propose to create an expandable network of innovative quantum sensors across the UK and with links into international networks. The sensors will include atomic and molecular clocks, magnetometers, atom interferometers and optical cavities. Individually, these sensors allow searches for dark matter and dark energy, variations in fundamental constants, Lorentz symmetry breaking, new forces, tests of the equivalence principle, neutrino oscillations and quantum gravity. Collectively, the network will allow greater sensitivity and also enable detection of transient effects through correlations in the data from different locations.

As a large-scale collaborative project supported by the Strategic Priorities Fund, the network will enable world-leading physics measurements by bringing together expertise and linking existing investment in quantum technologies from the Midland Ultracold Atoms Research Centre **(Birmingham & Nottingham)**, the Quantum Hub for Sensors and Metrology **(Birmingham),** the Gravitational Wave Institute and Particle Physics Groups **(Birmingham),** the Atomic, Molecular, Optical and Positron Physics Group **(University College London),** the Quantum Metrology Institute **(National Physical Laboratory)**, the Sussex Centre for Quantum Technologies **(Sussex)** and the Centre for Cold Matter **(Imperial College London)**. This world-class expertise is backed by substantial support from the UK theory community, provided by King's Theoretical Particle Physics and Cosmology Group **(King's College London)**, the Centre for Astronomy & Particle Theory **(Nottingham)**, the Institute for Particle Physics Phenomenology **(Durham)** and the Theoretical Particle Physics group **(Sussex)**. The unique breadth of expertise of QSNET therefore encompasses world-leading theoretical and experimental competences in Ultracold Atoms, Quantum Sensors, Quantum Metrology, Gravitational Waves and Particle Physics research. QSNET will provide access to cutting-edge quantum sensors for the entire UK community and has created substantial interest in international partners including from Europe, Canada and Australia.

QSNET will be an **internationally unique and world leading programme**, the first worldwide to provide an integrated and networked approach using a range of different sensing modalities, which opens up completely new capabilities in cross-correlating different measurements for tests of fundamental physics.

Key to the proposal is the networked approach, in which multiple quantum sensors will be linked. The **clock network** will feature experiments on cold highly-charged ions (HCI), high accuracy optical atomic clocks and high precision molecular spectroscopy systems. This unique network of different clocks allows to probe a large range of theoretical models. HCI are the most sensitive systems to variations of the fine structure constant α. When linked to other clocks to provide a

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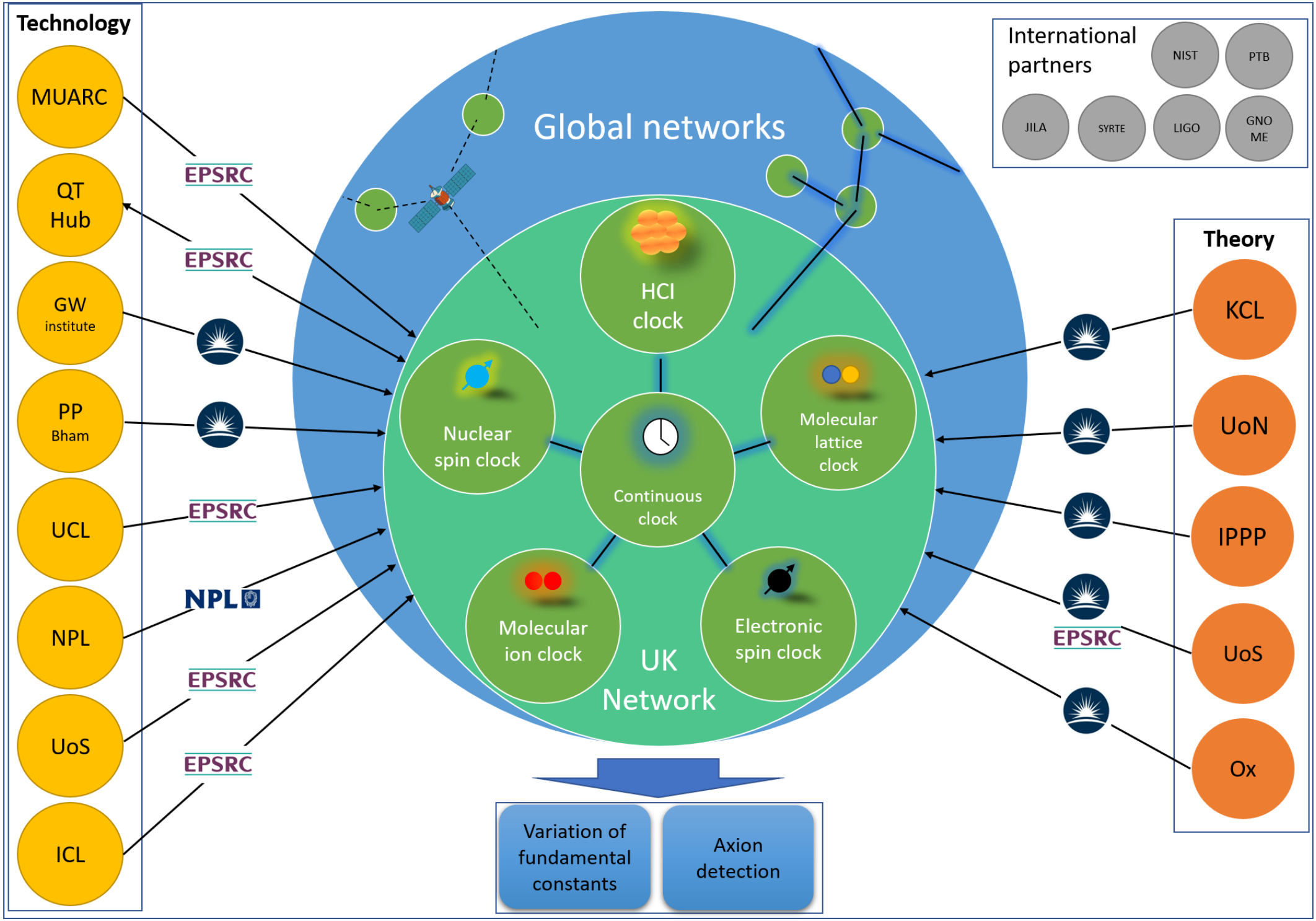
Technology
MUARC
QT Hub
GW institute
PP Bham
UCL
NPL
UoS
ICL
EPSRC
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NPL
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EPSRC
Global networks
HCI clock
Nuclear spin clock
Molecular lattice clock
Continuous clock
Molecular ion clock
Electronic spin clock
UK Network
International partners
NIST
PTB
JILA
SYRTE
LIGO
GNOME
Theory
KCL
UoN
IPPP
UoS
Ox
EPSRC
Variation of fundamental constants
Axion detection

"Quantum Sensor" Projects

- Summary of Quantum projects from 4-page summaries and presentations

	Project	Years 1-2	Year 3	Total 1st	Total 2nd	Total
Low-mass Particles in the Hidden Sector	1	3.8	0.8	**4.5**	7.0	11.5
MaQS: Macroscopic quantum superpositions for BSM	2	3.9	1.9	**5.8**	4.8	10.6
AION: Atom Interferometer Observatory and Network	3	5.8	2.9	**8.7**	8.8	17.5
Absolute Neutrino Mass	4	3.4		**3.4**	3.8	7.2
Quantum Simulators of Fundamental Physics	5	1.2	0.5	**1.7**	2.3	4.0
QSNET: Networked Quantum Sensors for Fundamental Physics	6	14.9	4.3	**19.1**	8.6	27.7
Fifth Force and Dark Matter using Precision Atomic Spectroscopy	7	4.3	1.1	**5.4**	10.0	15.4
Fundamental physics from precision studies of exotic atoms	8	6.3		**6.3**	2.8	9.1
LIST: Lorentz Invariance Space Test	9	3.3	0.9	**4.3**	0.7	5.0
				59.2	**48.7**	**107.9**

AGENDA FOR QSNET MEETING @ NPL

9:30 - Welcome coffee

10:00 - Welcome
Rachel Godun, Steven Worm, Giovanni Barontini

10:30 - Highly Charged Ion Clocks
Steven King

11:15 - Magnetometers and Fundamental Physics
Arne Wickenbrock

12:00 - Lunch

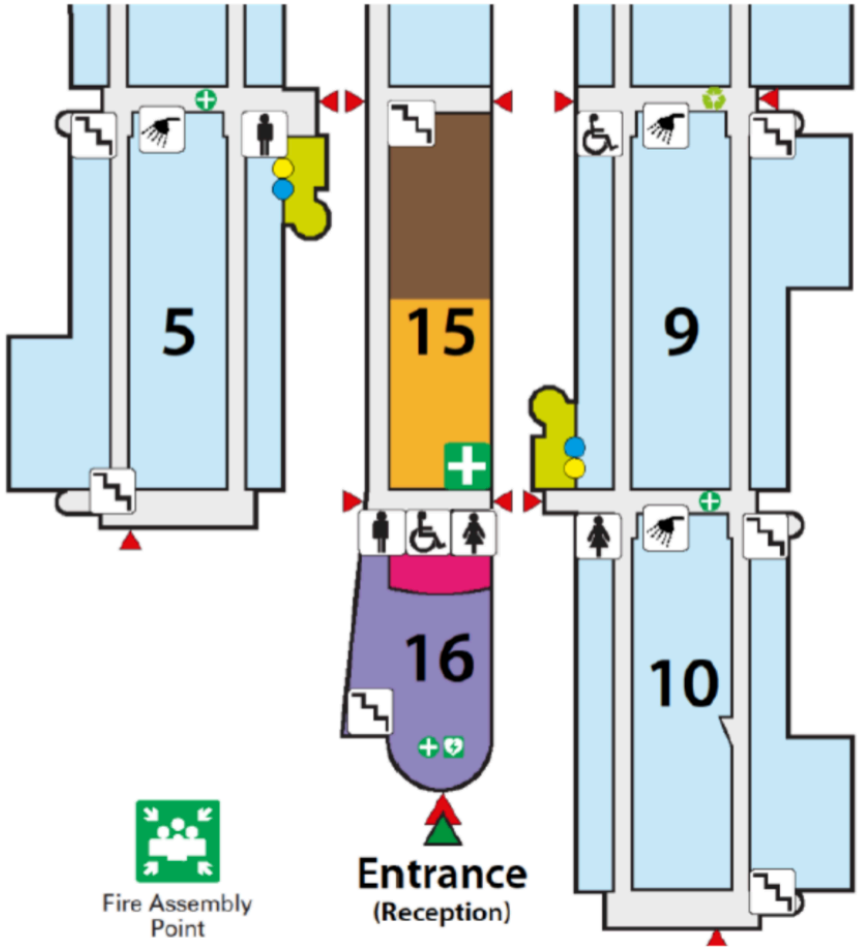
13:00 - Discussion Session 1 - Clocks, HCI
Giovanni Barontini

14:00 - Discussion Session 2 - Spin clocks
Witold Chalupczak

15:00 - Break

15:30 - Discussion Session 3 - Theory and Wrapup
(all)

16:00 - Finish



Meeting: G15-CS5, NPL