Status of TF5

Anna Grassellino, Marcel Demarteau, Michael Doser,
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Input from:

- input session
- symposium (including requested written contributions from the speakers)
- contributions submitted to TF-5
- ESG-recommendation communities were contacted
- national contacts
- reference materials from BRN, US and UK prior efforts

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Symposium: April 12

14 presentations

first block covering physics landscape

following blocks focusing on technologies

discussion of three important points

ECFA Detector R&D Roadmap Symposium of Task Force 5: Quantum and emerging technologies

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

09:00 → 09:15 Introduction

09:15 → 11:00 science targets – Overview and Landscape

9:15 EDM searches & tests of fundamental symmetries Peter Fierlinger / TU Munich

9:45 Tests of QM [wavefunction collapse, size effects, temporal separation, decoherence]

10:15 Multimessenger detection [including atom interferometer or magnetometer networks] Giovanni Barontoni / Birmingham

10:45 Axion and other DM (as well as non-DM Ultra-light) particle searches Mina Arvanitaki / Perimeter Institute

11:15 → 11:30 Coffee break

11:30 → 12:30 Experimental methods and techniques - Overview and Landscape

11:30 Precision spectroscopy and clocks, networks of sensors and of entangled systems [optical atomic clocks] David Hume / NIST

12:00 Novel ionic, atomic and molecular systems [RaF, multiatomic molecules, exotic atoms] Marianna Safranova / U. Delaware

12:30 → 13:30 Lunch break

13:30 → 16:00 Experimental and technological challenges, New Developments

13:30 Superconducting platforms [detectors: TES, SNSPD, Haloscopes, including single photon detection]

14:00 High sensitivity superconducting cryogenic electronics, low noise amplifiers Stafford Withington / Cambridge

14:30 Broadband axion detection Kent Irwin / Stanford

15:00 Mechanical / optomechanical detectors Andrew Geraci / Northwestern

15:30 Spin-based techniques, NV-diamonds, Magnetometry Dima Budker / Mainz

16:00 → 16:15 Coffee break

16:15 → 18:30 Experimental and technological challenges, New Developments

16:15 Calorimetric techniques for neutrinos and axions potential speaker identified

16:35 Quantum techniques for scintillators potential speaker identified

16:55 Atom interferometry at large scales (ground based, space based) Jason Hogan / Stanford

17:25 → 18:15 Discussion session : discussion points
- Scaling up from table-top systems
- Networking – identifying commonalities with neighboring communities
- Applying quantum technologies to high energy detectors

18:15 → 18:30 Wrap-up

National representatives:

All contacted; replies from a handful, mainly pointing out the lack of overlap of TF5 with ongoing activities.

One encouragement to also address quantum computing. Separate topic & not included in our program explicitly, although speakers were encouraged to mention potential links where appropriate

Communities:

Many of the communities represented at the input session were contacted, but very little overlap could be identified with TF5 focus, with the exception of FCC-eh, who expressed an interest in dialogue in exploring options beyond their base detector design

Neighbouring fields:

Ongoing discussions with some nuclear physics communities. Thoughtful feedback from APPEC regarding gravitational waves, which we did however not consider to be a major part of our focus… peripherally addressed in context of polyvalent detectors

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“Quantum and emerging” technologies

- main focus on *quantum* technologies, with some preference for technologies in use / under development
- only partly included 0/1/2 dimensional materials (nanodots, …)
- did not emphasize low energy particle physics *per se* (m_ν)
- theory guidance to focus on some physics domains
- limited discussion (for now) on “novel” materials (meta-materials, scintillators, …)

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Structure of chapter:

2 Theory context of the science drivers for quantum technologies:

2.1 Dark Sector
2.2 Quantum Mechanics
2.3 Fundamental Interactions

3 Quantum Methodologies and Techniques.
summary of the methodologies and various techniques .....
3.1 Clocks
3.2 Neutrino detectors (TES, bolometers)
3.3 Collective excitations (also phonons), Spins, magnons
3.4 Superconducting approaches (detectors, electronics)
3.5 Optomechanical techniques
3.6 Atoms, Molecules, Ions
3.7 Metamaterials & 0/1/2 dimensional materials

each written by 1-2 experts within TF5

4 Challenges and Priority Research Directions
list of challenges and the promising avenues to pursue .....
4.1 Workforce
4.2 Materials
4.3 Networks of sensors
4.4 Challenges of space-based devices

5 Conclusions & Recommendations

written in common within TF5

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“Matrix’

- categories of matrix not well suited to TF5
- instead, structure as ‘physics target’ vs ‘technology’
- space constraints = concentrate on small numbers of key technologies / physics topics (overlap with section 2)
- complemented by *figure(s)*: physics reach per physics domain and technology; and by *tentative timelines**
- *speakers quite reluctant to predict developments > 5-10 years

domain of physics → ↓ technique	**Axions, ALPs, & other DM candidates**	**fundamental symmetries**	**tests of QM**	**neutrino masses**	**gravity & 5th force**
Superconducting detectors	TES			TES	–
kinetic detectors	bolometers			bolometers	–
Spin-based detection, phonons, rotons, magnetometry					
atomic & molecular systems	excitations via DM scattering, spectroscopy	spectroscopy		^{131}Cs → ^{131}Xe + ν_e	interfe-rometry, spectroscopy
meta- & 0/1/2 D materials					
emerging technologies	hybrid scintillators				

Table 1: Overview of technologies relevant for specific physics topic detailed in section 1

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Time lines

- very specific to individual technologies
- some detector technologies can reliably be extrapolated, others are still very fresh (some didn't exist 10 years ago)
- several natural phases:
  - proof-of-principle comes with first exploration of new phase space
  - improvements to expand phase space
  - consolidation to exploit phase space
- rapidly changing context makes long-term planning challenging (e.g. experiments on nano-satellites)
- importance of emphasizing that in this field, some attempts may not pan out, and others are not on the radar yet → flexibility to shift direction!

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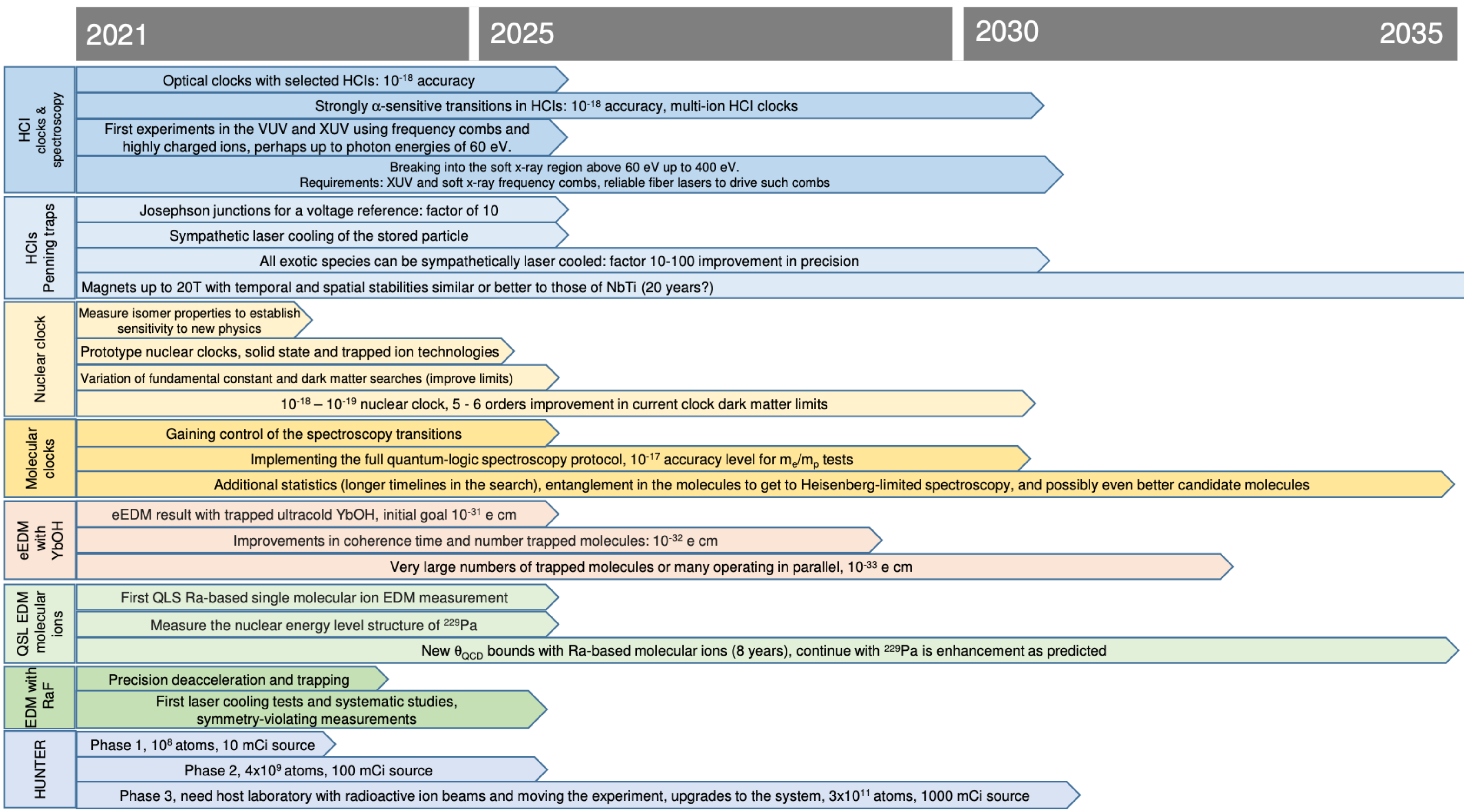
Time line (from very detailed to very tentative)



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“Recommendations’

- many fascinating opportunities in nascent fields
- encourage exploratory approaches
- encourage flexibility
- adapt funding profiles to both exploratory as well as consolidation approaches:
  - exploratory: funding cycle of 3 years, lightweight grant application, “fail early / fail often / proof-of-principle” mindset
  - consolidation: funding cycle of 10 years, after initial proof of principle, requiring full scientific proposal
- importance of interdisciplinarity
  - training not only of early stage researchers but also of established researchers
  - opportunistic (awareness of developments elsewhere - physics or industry)
  - openmindedness towards applications in HEP (requires mutual involvement)

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Summary

- report taking shape, but still a rough draft
- expect to have a preliminary (semi-complete) version by the end of the week
- still discussing the details of what to include, recommendations, figures, …