Quantum Detectors
for particle physics

(focus on applying quantum sensors to *both* "HEP" *and* low energy particle physics)

M. Doser, CERN

CEA_Saclay, Jan. 2025

Clarification of terms

Some words on the landscape

Quantum sensors for low energy particle physics

Quantum sensors for high energy particle physics

(low energy) particle detectors:

quantum sensors register a change of quantum state caused by the interaction with an external system:

- transition between superconducting and normal-conducting
- transition of an atom from one state to another
- change of resonant frequency of a system (quantized)

} highly sensitive and highly specific sensors for minute perturbations of the environment in which they operate

Then, a "quantum sensor" is a device, the measurement (sensing) capabilities of which are enabled by our ability to manipulate and read out its quantum states.

and because the commensurate energies are very low, unsurprisingly, quantum sensors are ideally matched to low energy (particle) physics;

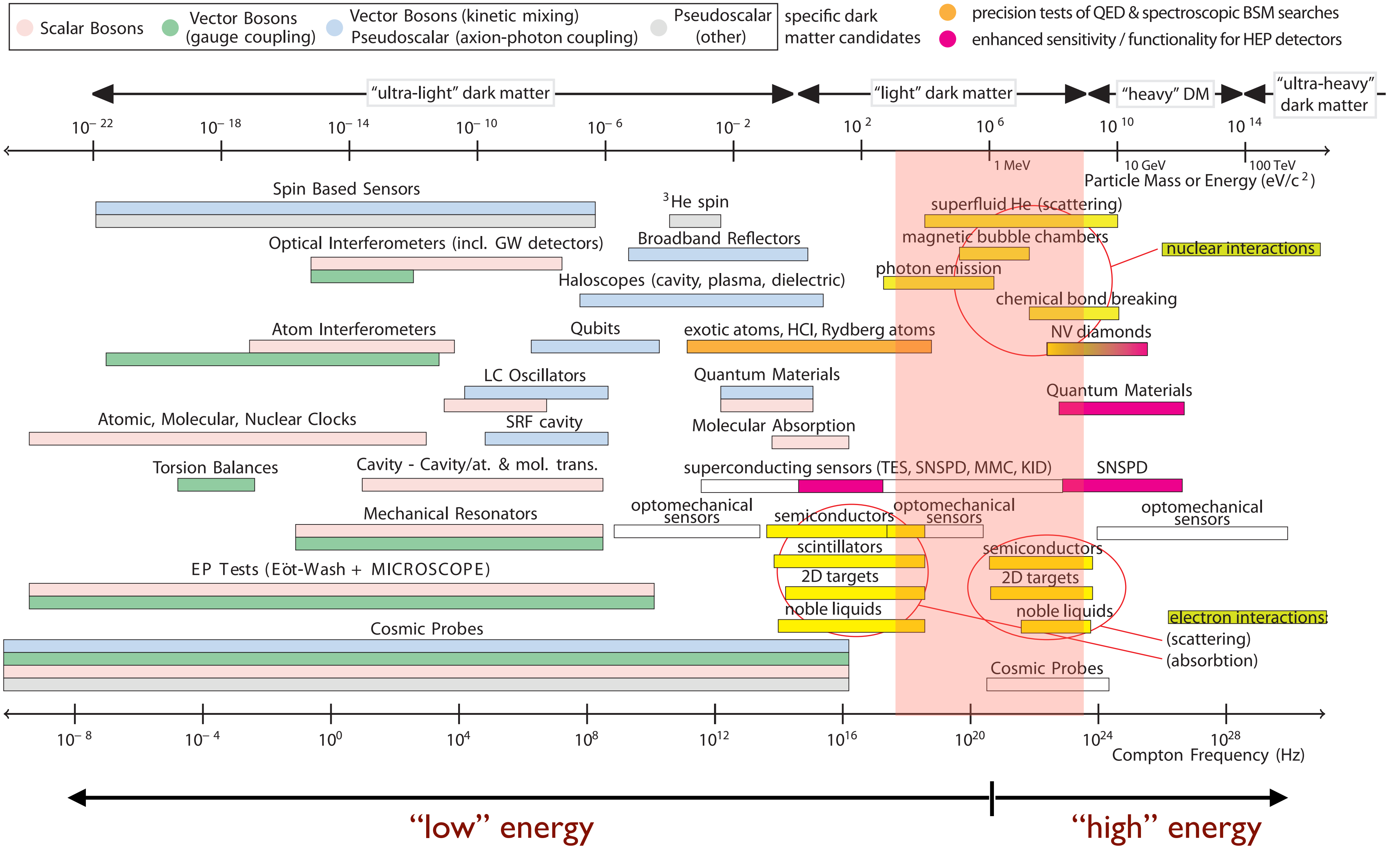
→ focus on activities in both in low energy and high energy particle physics

(I will *not* however be talking about entanglement and its potential applications)

bottom line: measure result of *a single* individual interaction

quantum sensing & particle physics

Ranges of applicability of different quantum sensor techniques to searches for BSM physics



quantum sensors & particle physics: what are we talking about?

quantum technologies

1. superconducting devices (TES, SNSPD, …) / cryo-electronics
2. spin-based, NV-diamonds
3. optical clocks
4. ionic / atomic / molecular
5. optomechanical sensors
6. metamaterials, 0/1/2-D materials

domains of physics

- search for NP / BSM
- Axions, ALP's, DM & non-DM UL-particle searches
- tests of QM — wavefunction collapse, decoherence
- EDM searches & tests of fundamental symmetries
- *Development of new detectors*

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

https://indico.cern.ch/event/999818/

Many initiatives related to HEP world-wide;

Three initiatives at CERN:

- CERN Quantum Technology Initiative
- Physics Beyond Colliders
- R & D on quantum sensors for particle physics

CERN quantum initiative

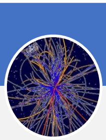
https://quantum.web.cern.ch/

focus on technology

quantum sensing & particle physics

CERN QUANTUM TECHNOLOGY INITIATIVE

⑥



- Assess the **areas of potential quantum advantage** in HEP applications (QML, classification, anomaly detection, tracking)
- Develop **common libraries of algorithms, methods, tools**; benchmark as technology evolves
- Collaborate to the development of shared, **hybrid classic-quantum infrastructures**

Computing & Algorithms

- Identify and develop techniques for **quantum simulation** in collider physics, QCD, cosmology within and beyond the SM
- Co-develop quantum computing and sensing approaches by providing **theoretical foundations** to the identifications of the areas of interest

Simulation & Theory

- Develop and promote **expertise in quantum sensing** in low- and high-energy physics applications
- Develop quantum sensing approaches with emphasis on **low-energy particle physics measurements**
- Assess **novel technologies and materials** for HEP applications

Sensing, Metrology & Materials

currently: 3 PhD's

- **Co-develop CERN technologies relevant to quantum infrastructures** (time synch, frequency distribution, lasers)
- Contribute to the **deployment and validation of quantum infrastructures**
- Assess requirements and **impact of quantum communication on computing applications** (security, privacy)

Communications & Networks

https://quantum.web.cern.ch/

CERN quantum initiative (v2)

(1.2024-12.2028)

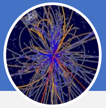
focus on technology

quantum sensing & particle physics

QUANTUM
TECHNOLOGY
INITIATIVE

DRD5 WP's

① ③ ⑥



- Objective 2.1a: Exotic atoms as qubits and Dark Matter sensors (Rydberg states characterisation, spectroscopy; atom interferometry; entangled Rydberg states as quantum demonstrators for qubits)
- Objective 2.2a: RF cavities and coating for axion searches; designing, building and operating a tuneable RF cavity for axion and GW searches
- Objective 2.2b.1: Development of a multi-qubit demonstrator platform (cryogenic infrastructure and RF cavity technology; design intermediate control software layer)
- Objective 2.3a: Quantum Sensors and Quantum Data Acquisition (TES as quantum sensors for millicharged DM searches in beam dumps, test bed for Quantum DAQ)

Core goals

- Objective 2.1b: Evaluation of the interplay between interferometric inertial sensors and cosmology to improve understanding of properties of Dark Matter and sources of GWs
- Objective 2.2b.2: Develop device-aware algorithms for qubits with SRF cavities
- Objective 2.3b: Cryogenic veto system, tuneable low-energy deposit calibration set-up; Monte Carlo simulation for tracks of backgrounds and signals, pushing the modeling towards low-energy deposits

Extended objectives

- Objective 2.1c: Benchmark and comparison of Rydberg states as qubits in prototype systems
- Objective 2.2b.3: Investigate scaling behavior of multiple qubits
- Objective 2.3c: Read-out-free detection & DAQ via entanglement between TES voxels and another system; machine-learning-based anomaly detection of millicharged DM particles in TES

Long term objectives

focus on physics

@ CERN: PBC, large low energy physics community…

https://indico.cern.ch/event/1002356/ PBC technology annual workshop 2021 (focus on quantum sensing)
https://indico.cern.ch/event/1057715/ PBC technology mini workshop: superconducting RF (Sep. 2021)

Initial experiments with quantum sensors world-wide
→ rapid investigation of new phase space

→ scaling up to larger systems, improved devices
  → expanding explored phase space

→ particles, atoms, ions, nuclei: tests of QED, symmetries

→ RF cavities: axion searches

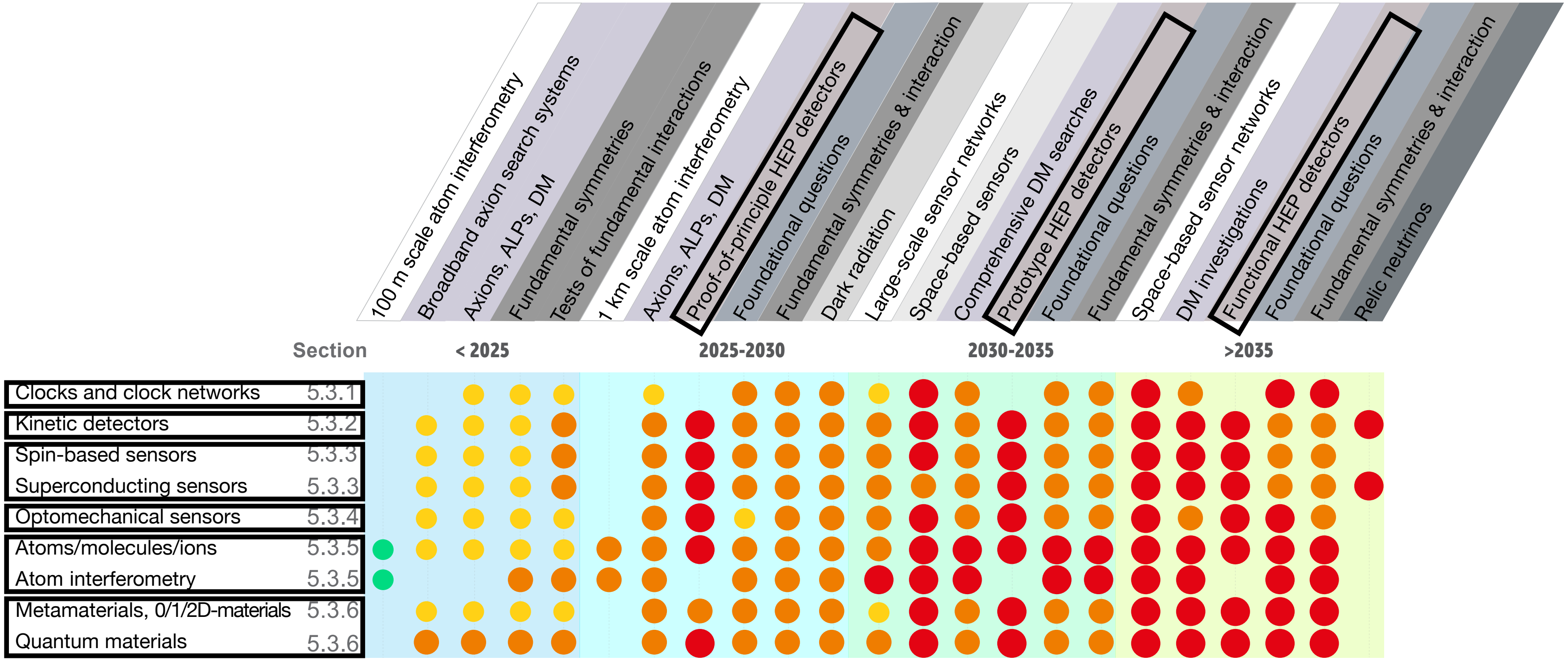
→ atom interferometers: DM searches

RECFA Detector R&D roadmap 2021

https://cds.cern.ch/record/2784893

Chapter 5: Quantum and Emerging Technologies Detectors

focus on physics *and* technology



① ② ③ ④ ⑤ ⑥

Section		< 2025					2025-2030						2030-2035						>2035					
		100 m scale atom interferometry	Broadband axion search systems	Axions, ALPs, DM	Fundamental symmetries	Tests of fundamental interactions	1 km scale atom interferometry	Axions, ALPs, DM	Proof-of-principle HEP detectors	Foundational questions	Fundamental symmetries & interaction	Dark radiation	Large-scale sensor networks	Space-based sensors	Comprehensive DM searches	Prototype HEP detectors	Foundational questions	Fundamental symmetries & interaction	Space-based sensor networks	DM investigations	Functional HEP detectors	Foundational questions	Fundamental symmetries & interaction	Relic neutrinos
Clocks and clock networks	5.3.1			🟡	🟡	🟡		🟡		🟠	🟠	🟠	🟡	🔴	🟠		🟠	🟠	🔴	🟠		🔴	🔴	
Kinetic detectors	5.3.2		🟡	🟡	🟡	🟠		🟠	🔴	🟠	🟠	🟠	🟠	🔴	🟠	🔴	🟠	🟠	🔴	🔴	🔴	🟠	🟠	🔴
Spin-based sensors	5.3.3		🟡	🟡	🟡	🟠		🟠	🔴	🟠	🟠	🟠	🟠	🔴	🟠	🔴	🟠	🟠	🔴	🔴	🔴	🟠	🟠	
Superconducting sensors	5.3.3		🟡	🟡	🟡	🟠		🟠	🔴	🟠	🟠	🟠	🟠	🟠	🟠	🔴	🟠	🟠	🔴	🔴	🔴	🟠	🟠	🔴
Optomechanical sensors	5.3.4		🟡	🟡	🟡	🟡		🟠	🔴	🟡	🟠	🟠	🟠	🔴	🟠	🔴	🟠	🟠	🔴	🟠	🔴	🔴	🟠	
Atoms/molecules/ions	5.3.5	🟢	🟡	🟡	🟡	🟡	🟠	🟠	🔴	🟠	🟠	🟠	🟠	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	🔴	
Atom interferometry	5.3.5	🟢			🟠	🟠	🟠	🟠		🟠	🟠	🟠	🔴	🔴	🔴		🔴	🔴	🔴	🔴		🔴	🔴	
Metamaterials, 0/1/2D-materials	5.3.6		🟡	🟡	🟡	🟡		🟠	🟠	🟠	🟠	🟠	🟡	🔴	🟠	🔴	🟠	🟠	🔴	🔴	🔴	🔴	🔴	
Quantum materials	5.3.6		🟠	🟠	🟠	🟠		🟠	🔴	🟠	🟠	🟠	🟠	🔴	🟠	🔴	🟠	🟠	🔴	🔴	🔴	🔴	🔴	

🔴 **Must happen or main physics goals cannot be met** 🟠 **Important to meet several physics goals** 🟡 **Desirable to enhance physics reach** 🟢 **R&D needs being met**

Proposal for DRD5: R&D on quantum sensors

Roadmap topics → Proposal themes → Proposal WP's

Roadmap topics

Proposal WP's

Sensor family → Work Package ↓	clocks & clock networks	superconducting & spin-based sensors	kinetic detectors	atoms / ions / molecules & atom interferometry	opto-mechanical sensors	nano-engineered / low-dimensional / materials
WP1 *Atomic, Nuclear and Molecular Systems in traps & beams*	X			X	(X)	
WP2 *Quantum Materials (0-, 1-, 2-D)*		(X)	(X)		X	X
WP3 *Quantum superconducting devices*		X				(X)
WP4 *Scaled-up massive ensembles* (spin-sensitive devices, hybrid devices, mechanical sensors)		X	(X)	X	(X)	X
WP5 *Quantum Techniques for Sensing*	X	X	X	X	X	
WP6 *Capacity expansion*	X	X	X	X	X	X

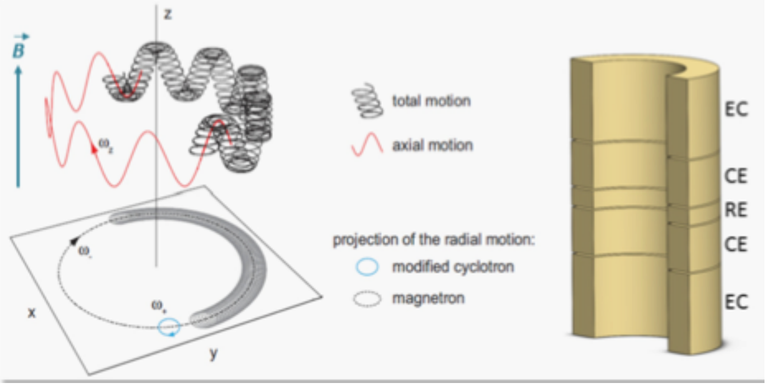
Ensure that all sensor families that were identified in the roadmap as relevant to future advances in particle physics are included

WP → sub-WP → sub-sub-WP

particles, atoms, ions, nuclei:

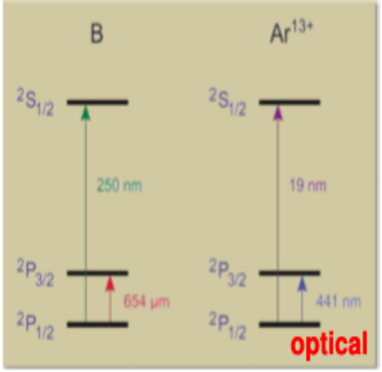
tests of QED, T-violation, P, Lorentz-violation, DM searches

HCI's in Penning traps



Scaling with a nuclear charge Z

Binding energy ~ Z^2
Hyperfine splitting ~ Z^3
QED effects ~ Z^4
Stark shifts ~ Z^{-6}



K. Blaum et al., Quantum Sci. Technol. 6 014002 (2021)

eEDM's in molecules

nuclear clock (^{229}Th)

molecular / ion clocks

Quantum Sensors for New-Physics Discoveries

https://iopscience.iop.org/journal/2058-9565/page/Focus-on-Quantum-Sensors-for-New-Physics-Discoveries

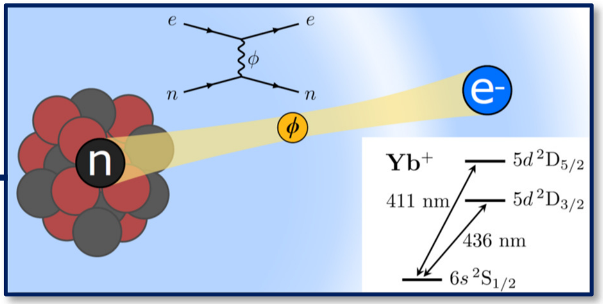
ECFA Detector R&D Roadmap Symposium of Task Force 5 Quantum and Emerging Technologies

https://indico.cern.ch/event/999818/ Marianna Safronova (University of Delaware)

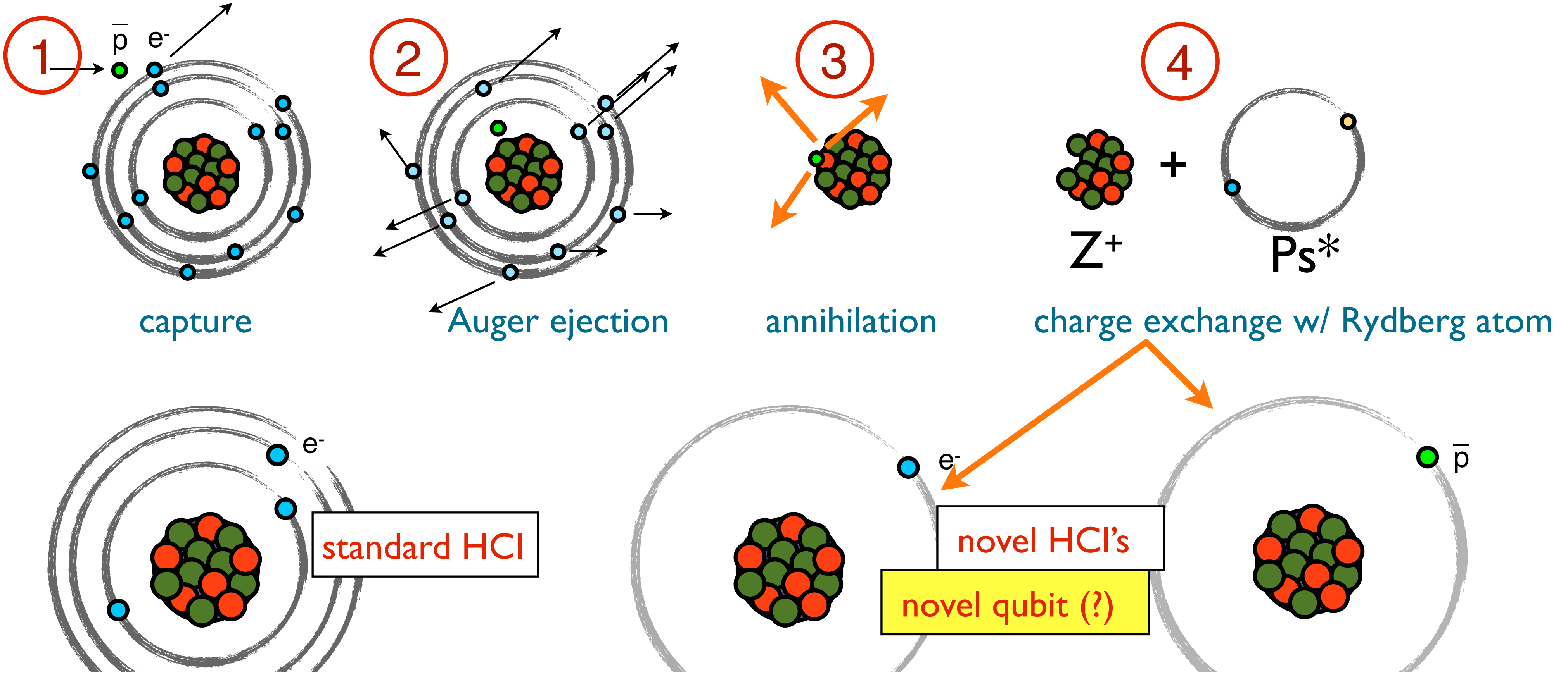
Quantum sensors for new particle physics experiments: Penning traps

HCIs: **much larger** sensitivity to variation of α and dark matter searches then current clocks

- Searches for the variation of fundamental constants
- Tests of QED: precision spectroscopy
- Fifth force searches: precision measurements of isotope shifts with HCIs to study non-linearity of the King plot



Antiprotonic atoms → novel HCI systems



capture

Auger ejection

annihilation

charge exchange w/ Rydberg atom

standard HCI

novel HCI's

novel qubit (?)

HCI (stable), (Z-n)+

HCI*(stable or unstable), (Z-1)+

HCI*(stable or unstable), (Z-1)+

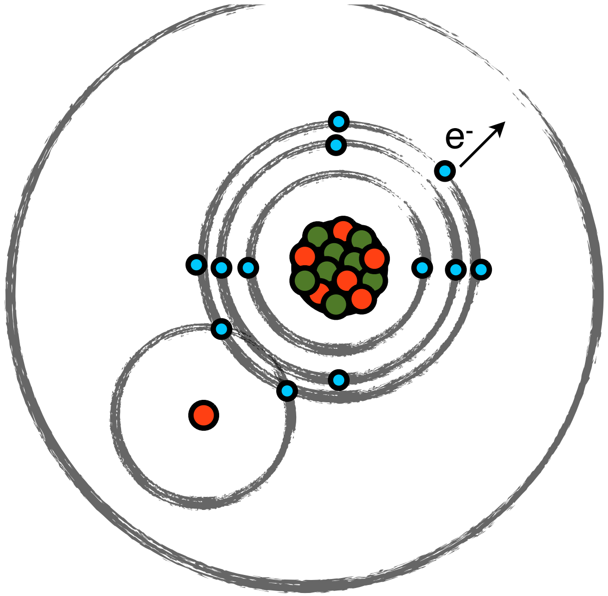
M. Doser, Prog. Part. Nucl. Phys, (2022), https://doi.org/10.1016/j.ppnp.2022.103964

Quantum sensors for new particle physics experiments: Penning traps

Antiprotonic Rydberg atoms: exotic couplings, similar approach as spectroscopy of muonic atoms, CPT tests

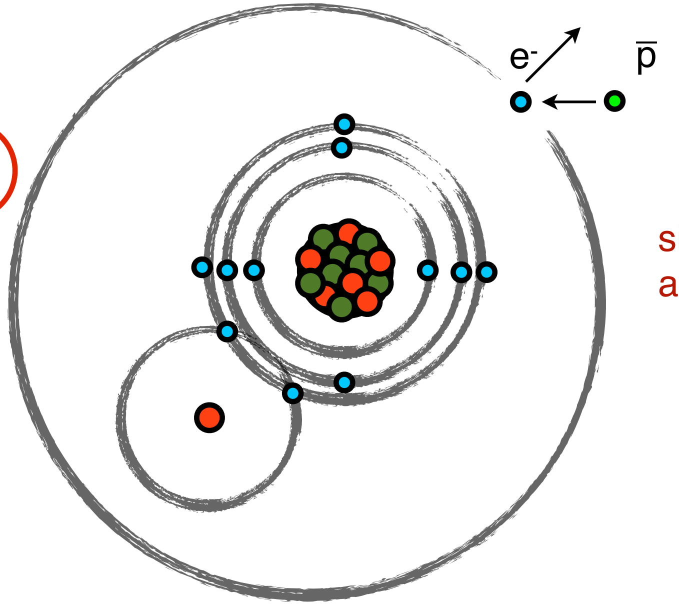
Antiprotonic Rydberg molecules: $\bar{p}$EDM?

①



Rydberg excitation

②

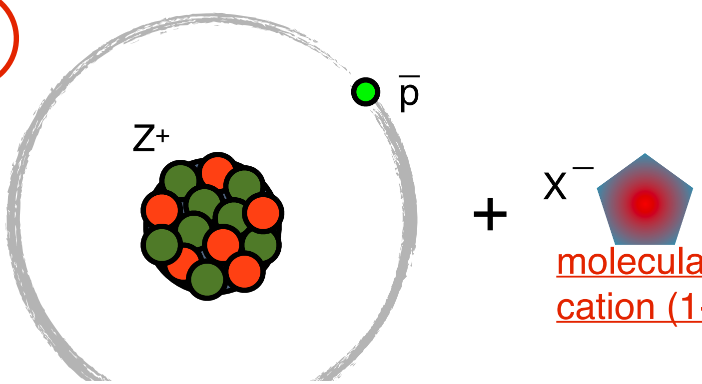


charge exchange

similar approach
as eEDM in molecules

Antiprotonic Rydberg molecular ions: $\bar{p}$EDM

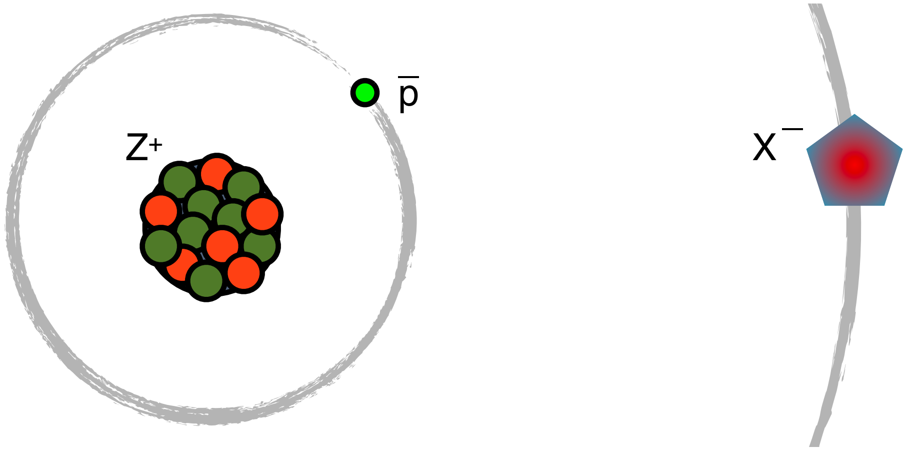
①



molecular
cation (1-5)⁻

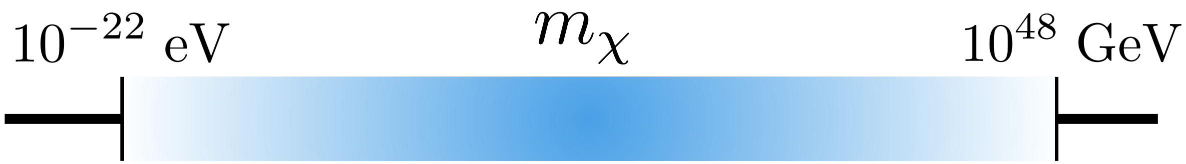
$\bar{p}$ H-like HCI, (Z-1)+

②



Superconducting sensors: RF cavities

Axions, ALP's, DM & non-DM UL-particle searches

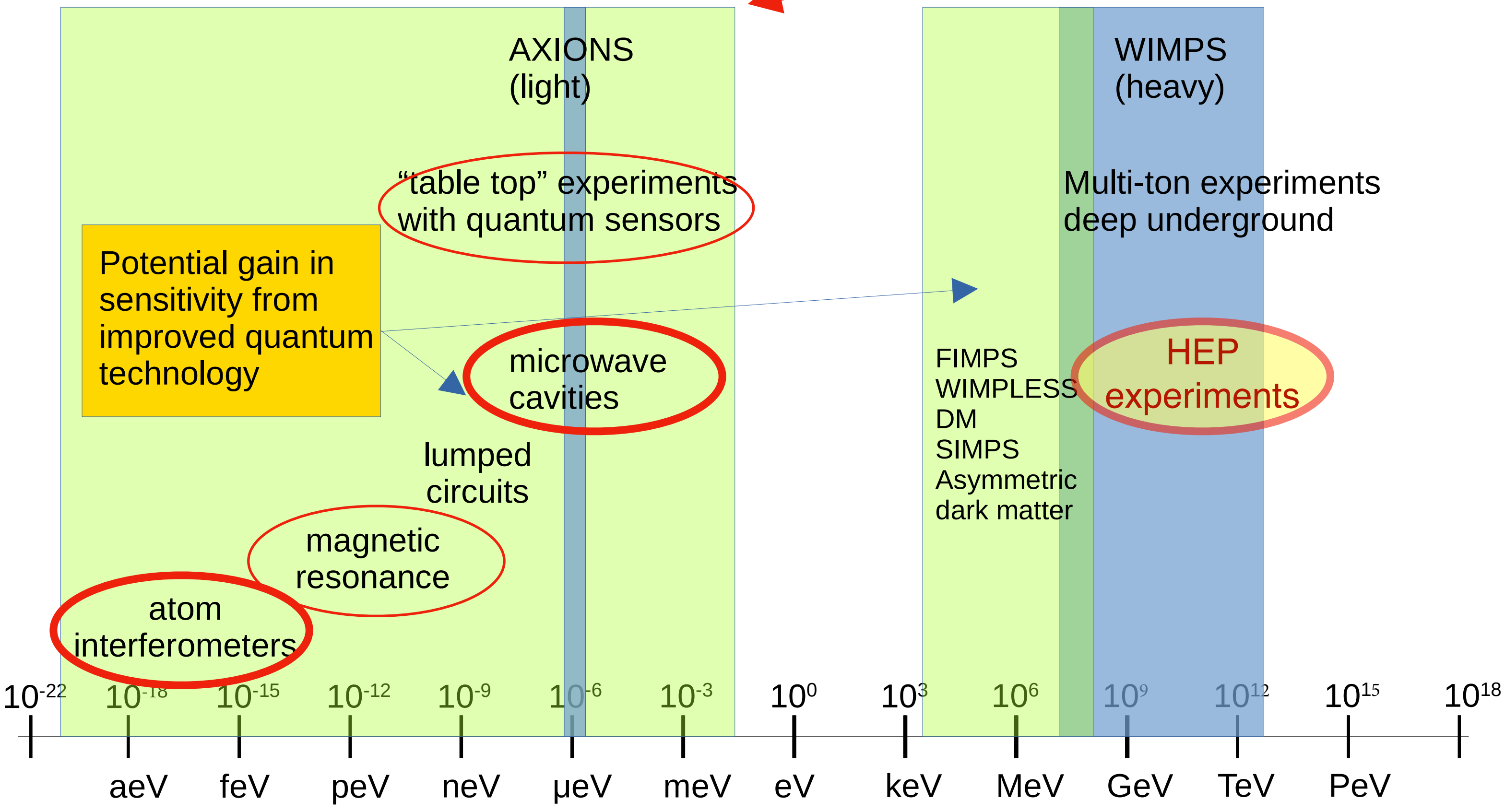


cavity size = axion size

axion mass = unknown

$$F \sim g_{a\gamma}^2 m_A^2 B^4 V^2 T_{sys}^{-2} G^4 Q,$$

system noise temperature
cryo-amplifiers JJPA


AXIONS
(light)

"table top" experiments
with quantum sensors

Potential gain in sensitivity from improved quantum technology

microwave
cavities

lumped
circuits

magnetic
resonance

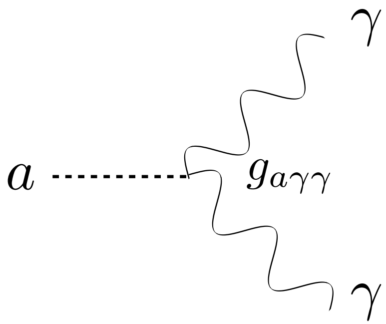
atom
interferometers

WIMPS
(heavy)

Multi-ton experiments
deep underground

FIMPS
WIMPLESS
DM
SIMPS
Asymmetric
dark matter

HEP
experiments



(but not only…)

Axion heterodyne detection

problem: cavity resonance generally fixed

Conceptual Theory Level Proposal:

A. Berlin, Raffaele Tito D'Agnolo, S. Ellis, C. Nantista, J. Nielson, P. Schuster, S. Tantawi, N. Toro, K. Zhou, *JHEP* 07 (2020) 07, 088

A. Berlin, Raffaele Tito D'Agnolo, S. Ellis, K. Zhou, arXiv:2007.15656

$$F \sim g_{a\gamma}^2 m_A^2 B^4 V^2 T_{sys}^{-2} G^4 Q,$$

figure of merit

axion mass

cavity volume

Resonant cavities possible down to μeV; below that, need huge volume

→ frequency conversion: driving "pump mode" at ω_0 ~ GHz allows axion to resonantly drive power into "signal mode" at $\omega_1 \sim \omega_0 \pm m_a$

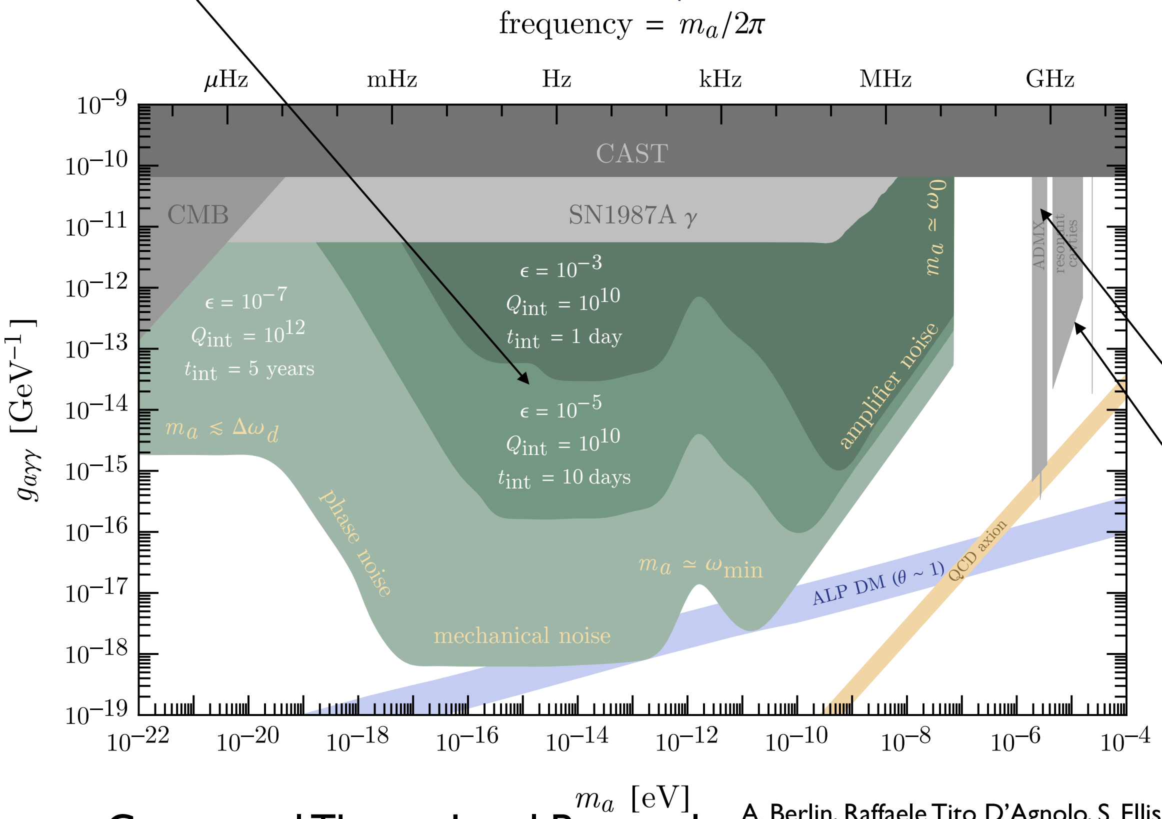
→ scan over axion masses m_a = slight perturbation of cavity geometry, which modulates the frequency splitting $\omega_0 - \omega_1$

→ superconducting RF cavities

Axion heterodyne detection

$Q_{\rm int} \gtrsim 10^{10}$ achieved by DarkSRF collaboration
(sub-nm cavity wall displacements)

A. Grassellino, "SRF-based dark matter search: Experiment," 2019. https://indico.fnal.gov/event/19433/session/2/ contribution/2/material/slides/0.pdf



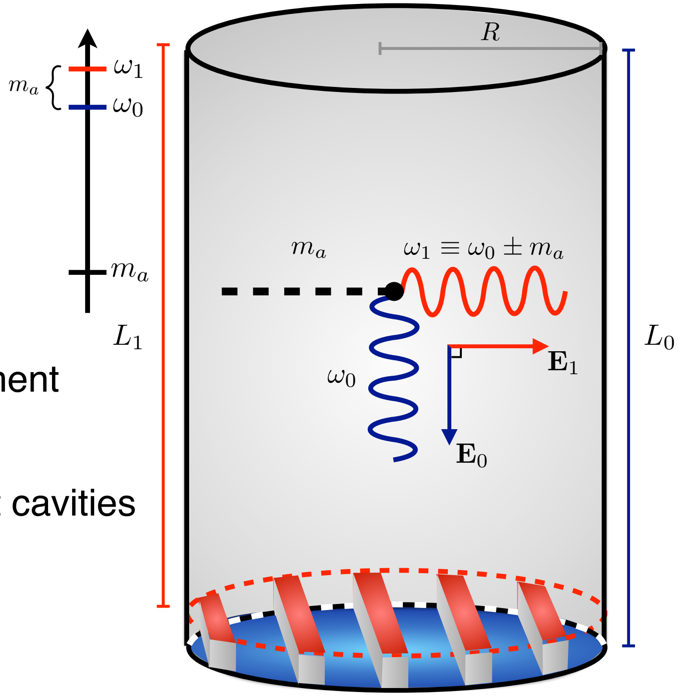
ADMX experiment

resonant cavities

problem: cavity resonance generally fixed

Resonant cavities possible down to μeV;
below that, need huge volume

driving "pump mode" at $\omega_0 \sim$ GHz allows axion to resonantly drive power into "signal mode" at $\omega_1 \sim \omega_0 \pm m_a$



(a) Cartoon of cavity setup.

Conceptual Theory Level Proposal:

A. Berlin, Raffaele Tito D'Agnolo, S. Ellis, C. Nantista, J. Nielson, P. Schuster, S. Tantawi, N. Toro, K. Zhou, *JHEP* 07 (2020) 07, 088

Asher Berlin, Raffaele Tito D'Agnolo, Sebastian A. R. Ellis, Christopher Nantista, Jeffrey Neilson, Philip Schuster, Sami Tantawi, Natalia Toro, Kevin Zhou, https://arxiv.org/abs/1912.11048

"The cavity is designed to have two nearly degenerate resonant modes at ω_0 and $\omega_1 = \omega_0 + m_a$. One possibility is to split the frequencies of the two polarizations of a hybrid HE_{11p} mode in a corrugated cylindrical cavity. These two polarizations effectively see distinct cavity lengths, L_0 and L_1, allowing ω_0 and ω_1 to be tuned independently."

Needed! : major developments on integrated cryoelectronics (4K)

AION: atom interferometer (start small, ultimately → space)

L. Badurina et al., AION: An Atom Interferometer Observatory and Network, JCAP 05 (2020) 011, [arXiv:1911.11755].

Where does this fit in? Go after 10^{-20} eV < m_a < 10^{-12} eV,

but also topological DM, ultralight DM, gravitational waves, Lorentz invariance, ...

atom interferometry at macroscopic scales: arXiv:2201.07789v1 [astro-ph.IM] 19 Jan 2022

MIGA France

AION UK

ZAIGA China

CERN? shafts (100~500 m ideal testing ground), cryogenics, vacuum, complexity…

MAGIS Fermilab

M. Abe, P. Adamson, M. Borcean, D. Bortoletto, K. Bridges, S. P. Carman et al., Matter-wave Atomic Gradiometer Interferometric Sensor (MAGIS-100), arXiv:2104.02835v1.

MAGIS collaboration, Graham PW, Hogan JM, Kasevich MA, Rajendran S, Romani RW. Mid-band gravitational wave detection with precision atomic sensors. arXiv:1711.02225

satellite missions:

ACES (Atomic Clock Ensemble in Space): April 2025

ESA mission for ISS

two on-board clocks rely on atomic transitions in the microwave domain

probe time variations of fundamental constants, and to perform tests of the Lorentz-Violating Standard Model Extension (SME). Possibly topological dark matter

pathfinder / technology development missions: ~2030

I-SOC: key optical clock technology (laser cooling, trapping, optical resonators) for space; Sr optical lattice clock / Sr ion clock; microwave and optical link technology;

FOCOS (Fundamental physics with an Optical Clock Orbiting in Space): Yb optical lattice clock with 1×10^{-18} stability

AION: ~2045 satellite mission

AEDGE: ~2045 satellite mission

El-Neaj, Y.A., Alpigiani, C., Amairi-Pyka, S. *et al*. AEDGE: Atomic Experiment for Dark Matter and Gravity Exploration in Space. *EPJ Quantum Technol*. **7**, 6 (2020). https://doi.org/10.1140/epjqt/s40507-020-0080-0 typically not obvious, given that most detectors rely on detecting the product of many interactions between a particle and the detector (ionization, scintillation, Čerenkov photons, …)

handful of ideas that rely on quantum devices, or are inspired by them. not necessarily used as quantum detectors per se, but rather their properties to enhance / permit measurements that are more difficult to achieve otherwise

main focus on tracking / calorimetry / timing / novel observables / PU ...

closely related: nanostructured materials

→ Frontiers of Physics, M. Doser et al., 2022
doi: 10.3389/fphy.2022.887738

these are not fully developed concepts, but rather the kind of approaches one might contemplate working towards

very speculative!

Metamaterials, 0 / 1 / 2-dimensional materials (quantum dots, nanolayers)

ultra-fast scintillators based on perovskytes

chromatic calorimetry (QDs)

active scintillators (QCL, QWs, QDs) 5.3.6 *

GEMs (graphene)

Atoms, molecules, ions

5.3.5 *

Rydberg TPC's

Spin-based sensors

5.3.3 *

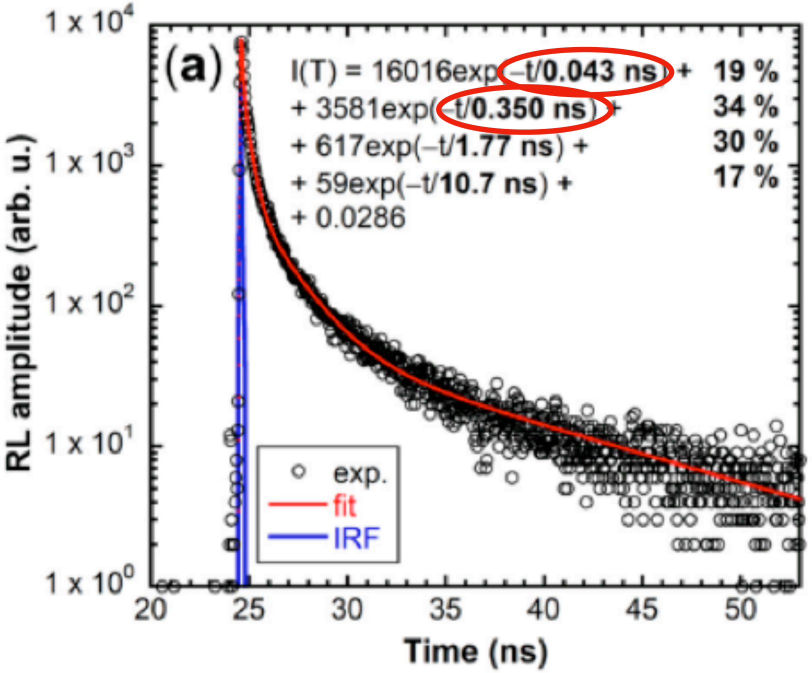
helicity detectors

* https://cds.cern.ch/record/2784893

Superconducting sensors

Quantum dots: timing

Etiennette Auffray-Hillemans / CERN



Scintillation decay time spectra from $CsPbBr_3$ nanocrystal deposited on glass

K. Decka et al., Scintillation Response Enhancement in Nanocrystalline Lead Halide Perovskite Thin Films on Scintillating Wafers. Nanomaterials 2022, 12, 14. https://doi.org/ 10.3390/nano12010014

ZnO:Ga embedded in SiO_2 or polystyrene

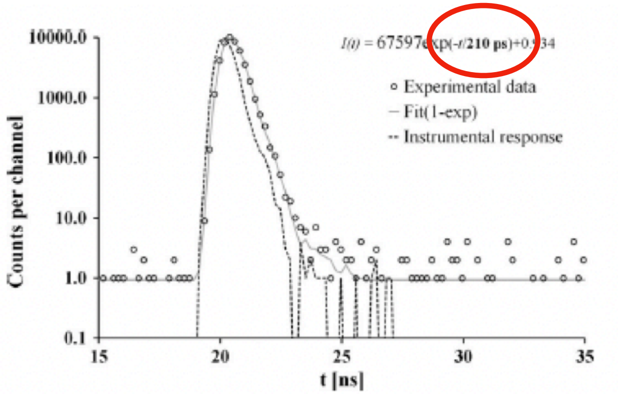
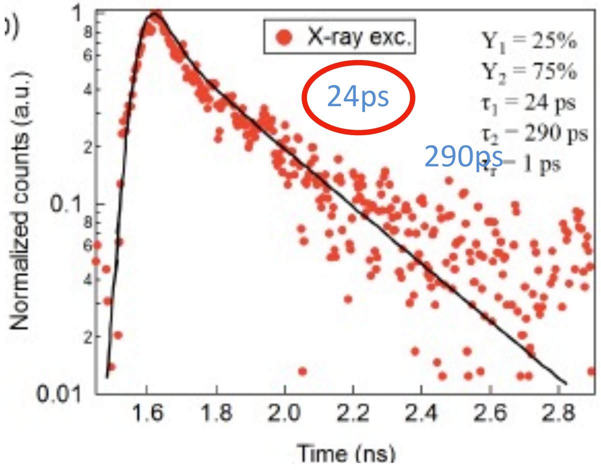


Fig. 9. Photoluminescence decay of ZnO:Ga sample at room temperature. Excitation nanoLED 339 nm, emission wavelength set at 390 nm. Decay curve is approximated by the convolution of instrumental response (also in figure) and single exponential function $I(t)$ provided in the figure.

Lenka Prochazkova et al., Optical Materials 47 (2015) 67–71

CdSe nanoplatelet,



24ps

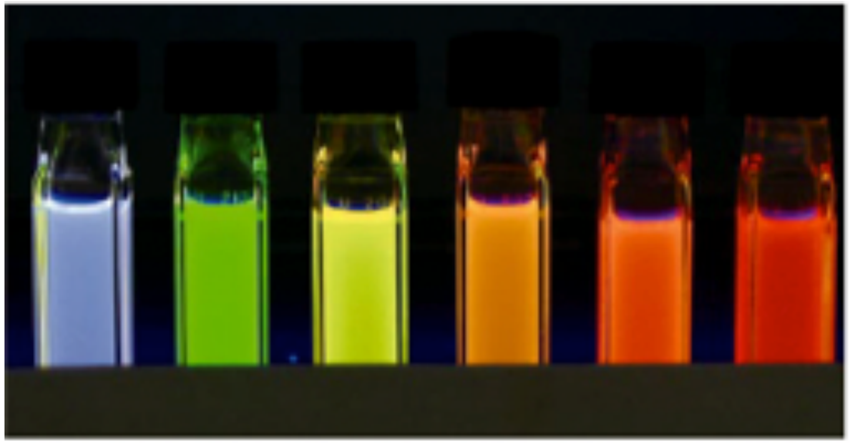
290ps

J. Grim et al., *Nature Nanotechnology,* **9**,2014, 891–895
R. Martinez Turtos et al., 2016 JINST_11 (10) P10015

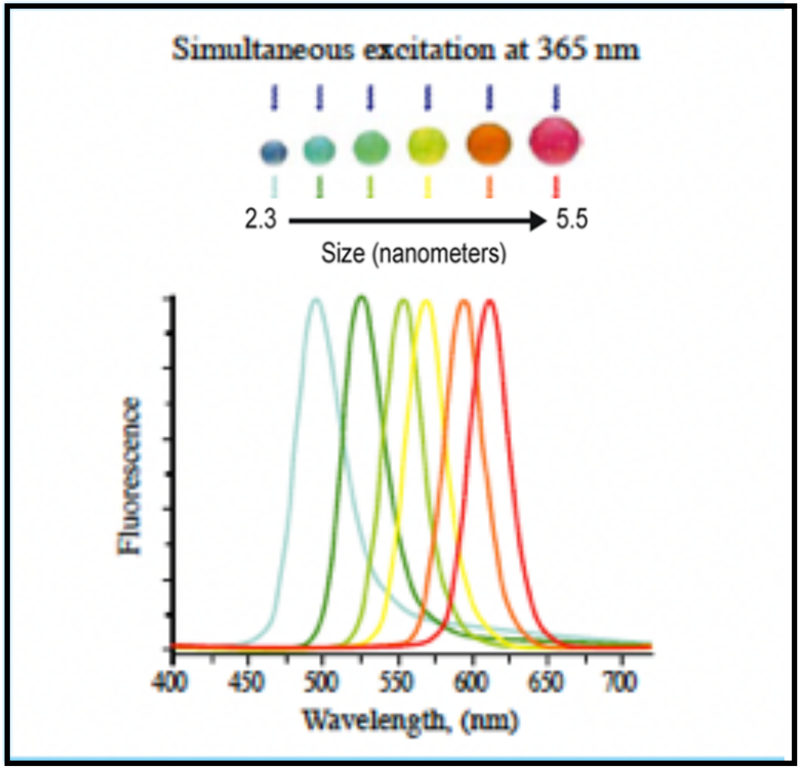
Concerns: integrated light yield (need many photons to benefit from rapid rise time)

Quantum dots: chromatic tunability

Etiennette Auffray-Hillemans / CERN



Hideki Ooba, "Synthesis of Unique High Quality Fluorescence Quantum Dots for the Biochemical Measurements," AIST TODAY Vol.6 , No.6 (2006) p.26- 27

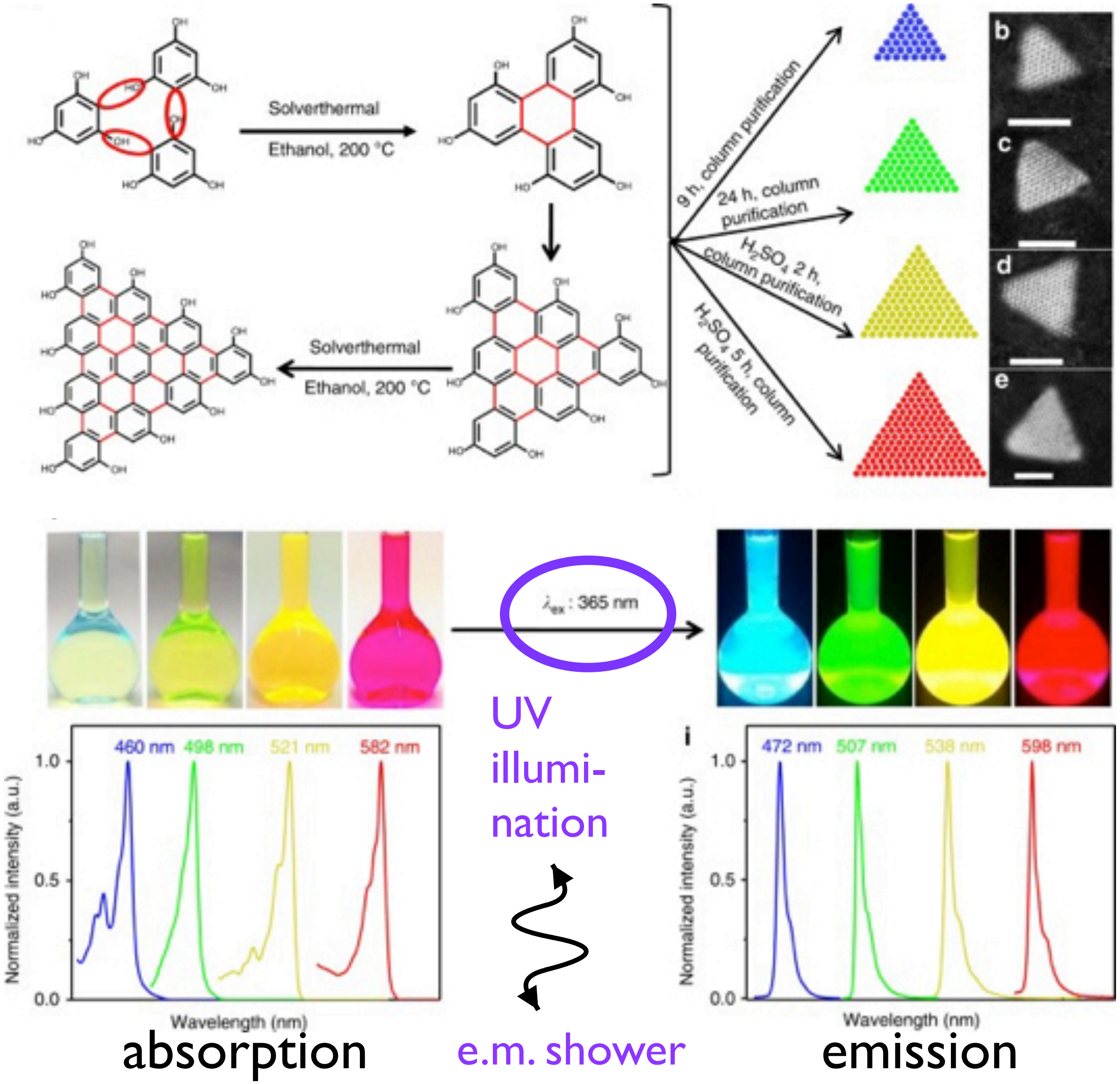


chromatic tunability → optimize for quantum efficiency of PD (fast, optimizable WLS)

deposit on surface of high-Z material → thin layers of UV → VIS WLS

embed in high-Z material ? two-species (nanodots + microcrystals) embedded in polymer matrix?
→ quasi continuous VIS-light emitter (but what about re-absorbtion?)

Quantum dots: chromatic calorimetry



F. Yuan, S. Yang, et al., Nature Communications 9 (2018) 2249

idea: seed different parts of a "crystal" with nanodots emitting at different wavelengths, such that the wavelength of a stimulated fluorescence photon is uniquely assignable to a specific nanodot position

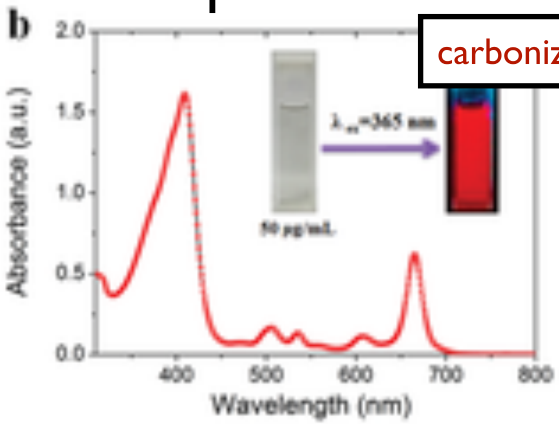
requires:

- narrowband emission (~20nm)
- only absorption at longer wavelengths
- short rise / decay times

select appropriate nanodots

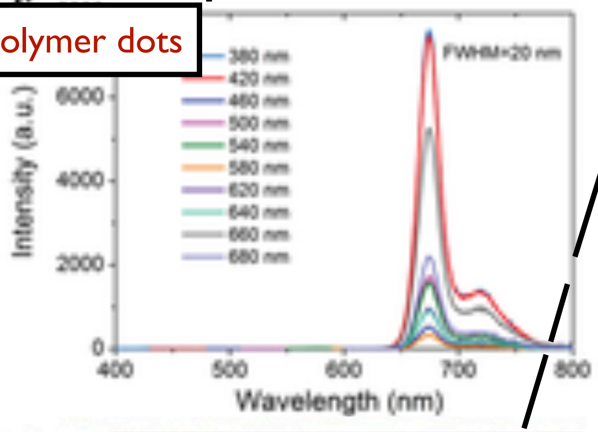
e.g. triangular carbon nanodots

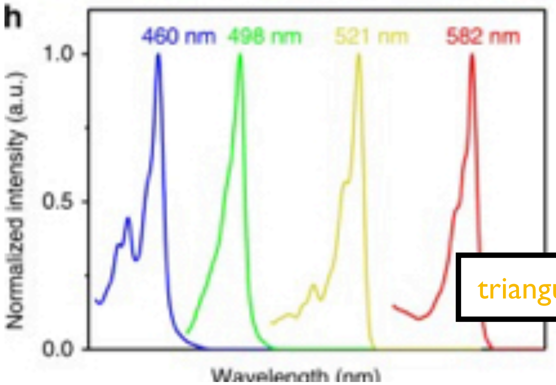
absorption spectrum



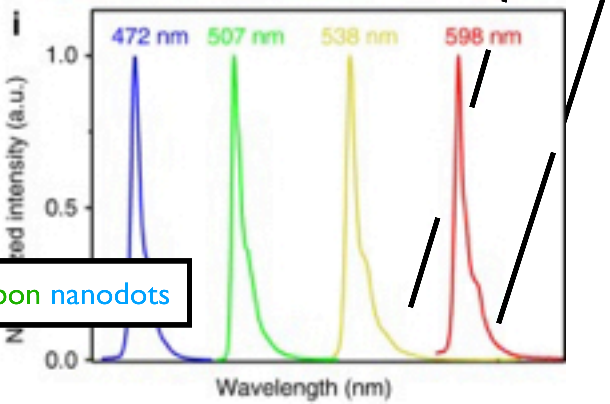
carbonized polymer dots

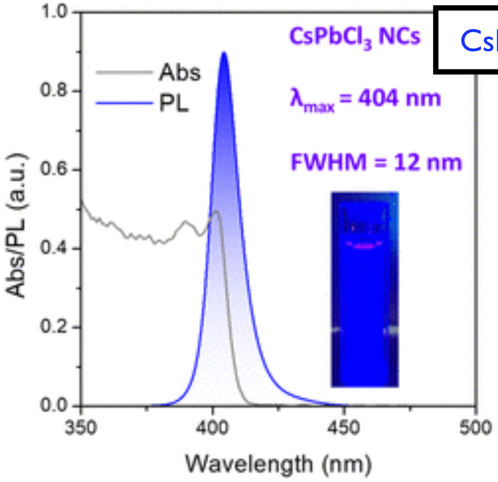
emission spectrum





triangular carbon nanodots





$CsPbCl_3$ nanocrystals

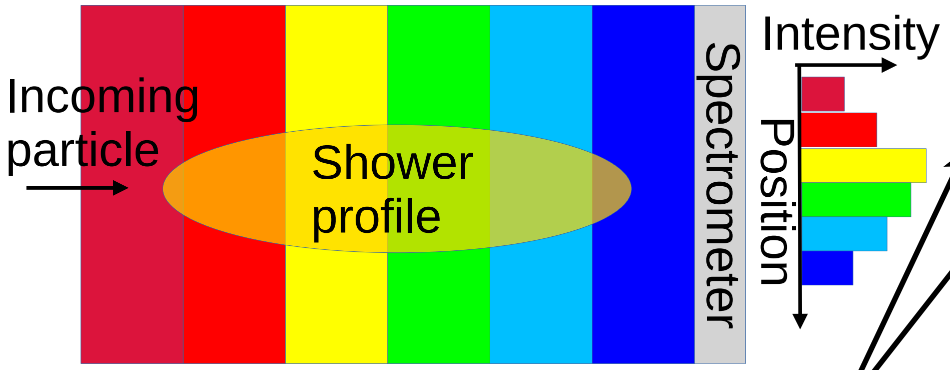
leftmost nanodots:
absorb wavelengths < 650 nm
emit at > 680 nm

next band:
absorb wavelengths < 590 nm
emit at > 590 nm

…

rightmost nanodots:
absorb wavelengths < 410 nm
emit at > 420 nm

if high-Z substrate transparent in 400-700 nm, then no re-absorption of emitted light



(shower profile via ***spectrometry***)

Monochromators + PD?

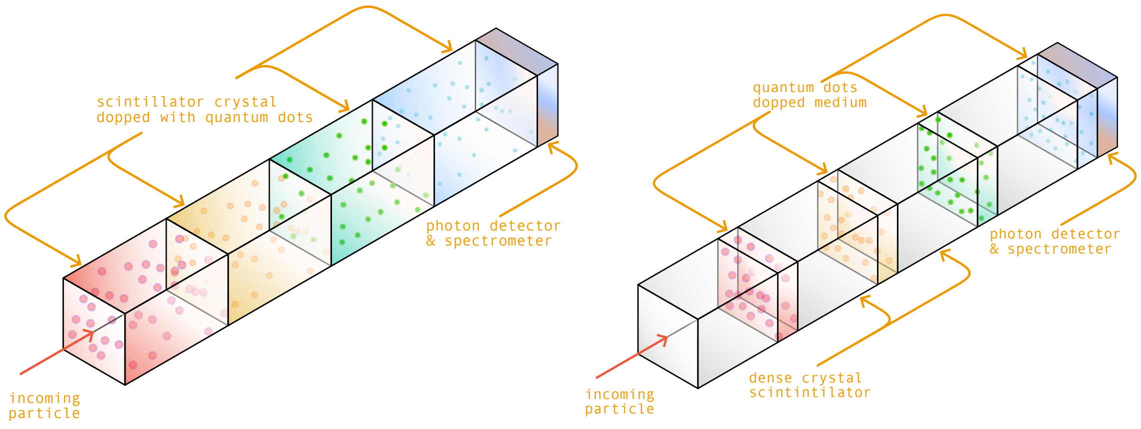
Y.T. Lin & G. Finlayson, Sensors 23, 4155 (2023)

Metalenses?

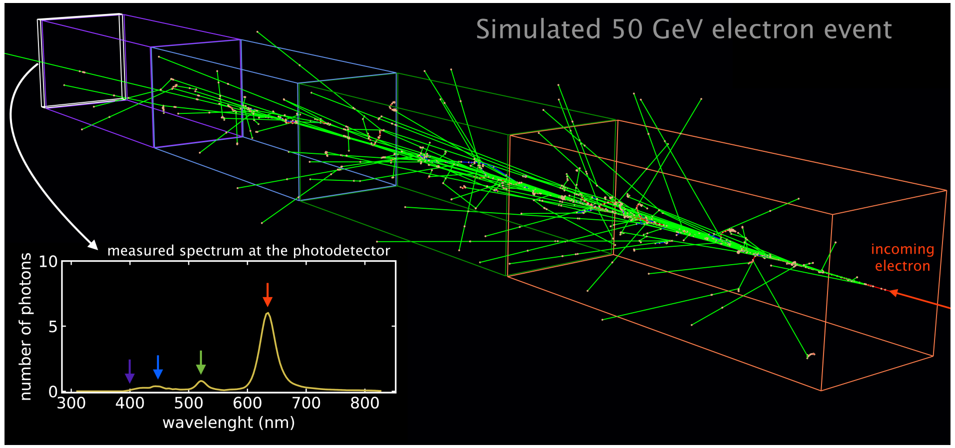
M. Khorasaninejad & F. Capasso, Science 358, 6367 (2017)

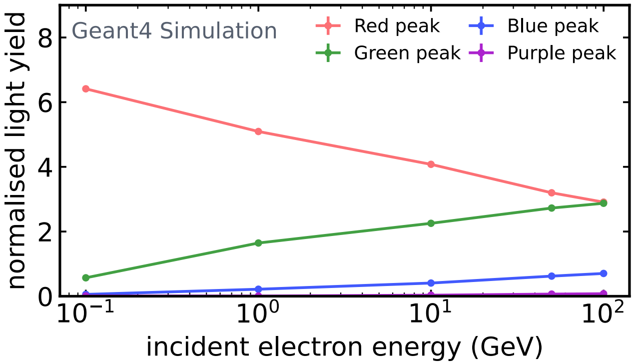
This slide courtesy Devanshi Arora, CALOR'24

Quantum sensors for high energy particle physics



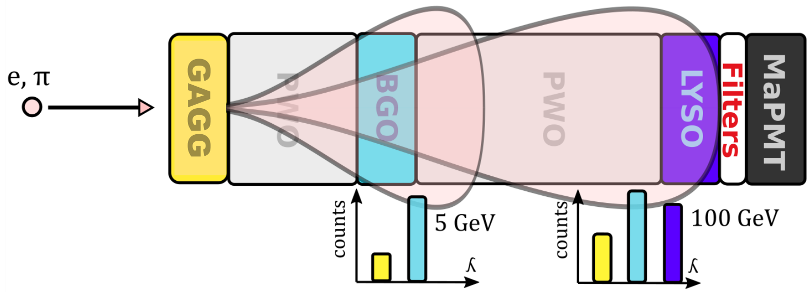
courtesy Y. Haddad, N U, Boston, USA



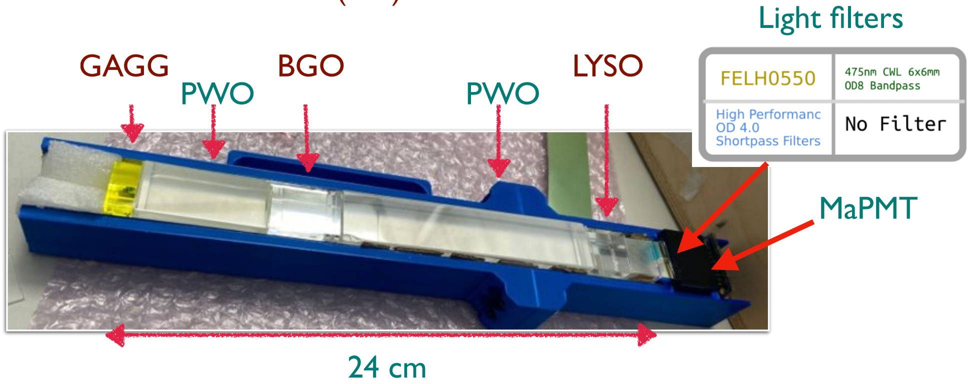


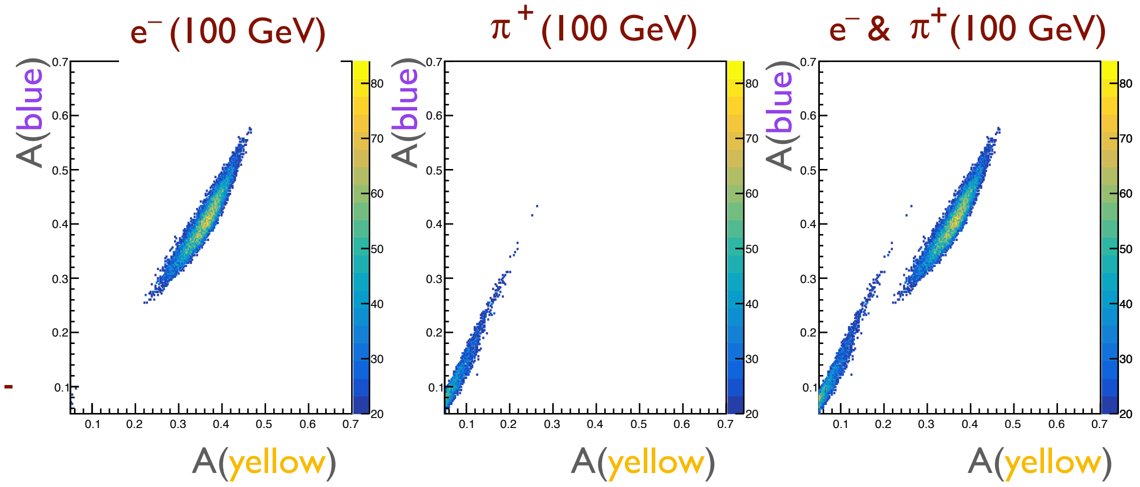
"Chromatic" energy measurement

"Chromatic" electron - pion discrimination



Beam test results (SPS) 2023



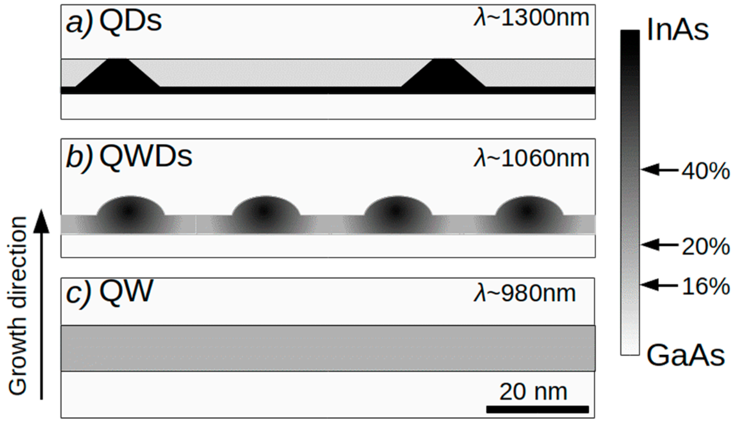


86% "chromatic" electron - pion discrimination

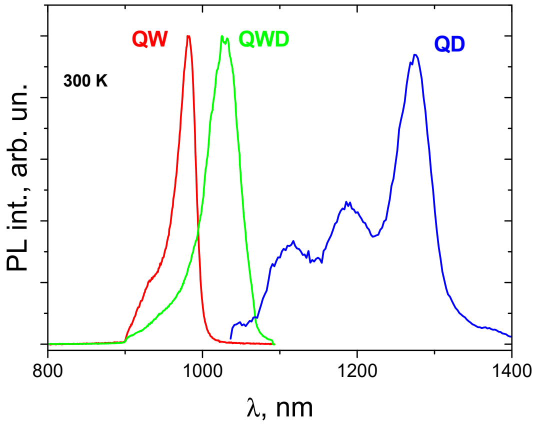
Active scintillators (QWs, QDs, QWDs, QCLs)

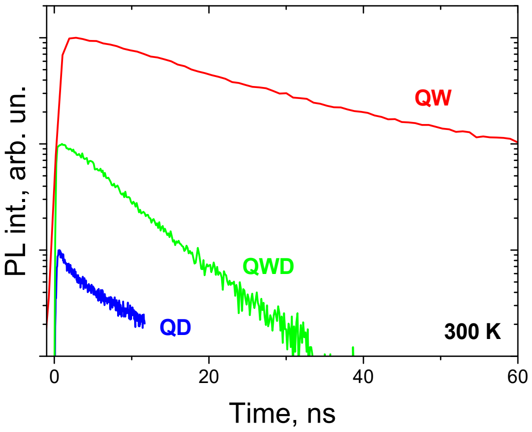
standard scintillating materials are passive
- can not be amplified
- can not be turned on/off
- can not be modified once they are in place

is it possible to produce active scintillating materials?
- electronically amplified / modulable
- pulsed / primed
- gain adapted in situ

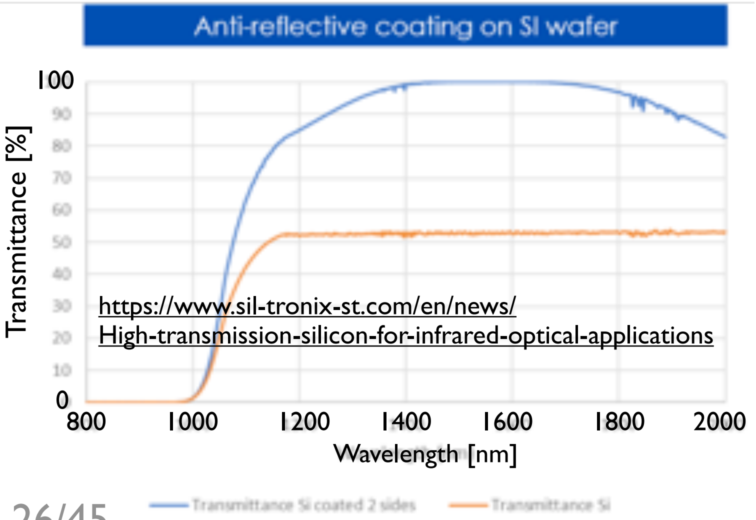


existing QD's, QWD's are elements of optoelectronic devices, typically running at 10 GHz, quite insensitive to temperature





Light Emitting Devices Based on Quantum Well-Dots, Appl. Sci. 2020, 10, 1038; doi:10.3390/app10031038



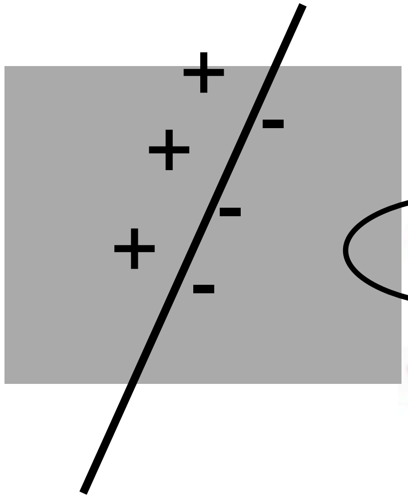
https://www.sil-tronix-st.com/en/news/High-transmission-silicon-for-infrared-optical-applications

Emission in IR! Silicon is ~transparent at these wavelengths… Can this IR light be transported *through* a tracker to outside PDs?

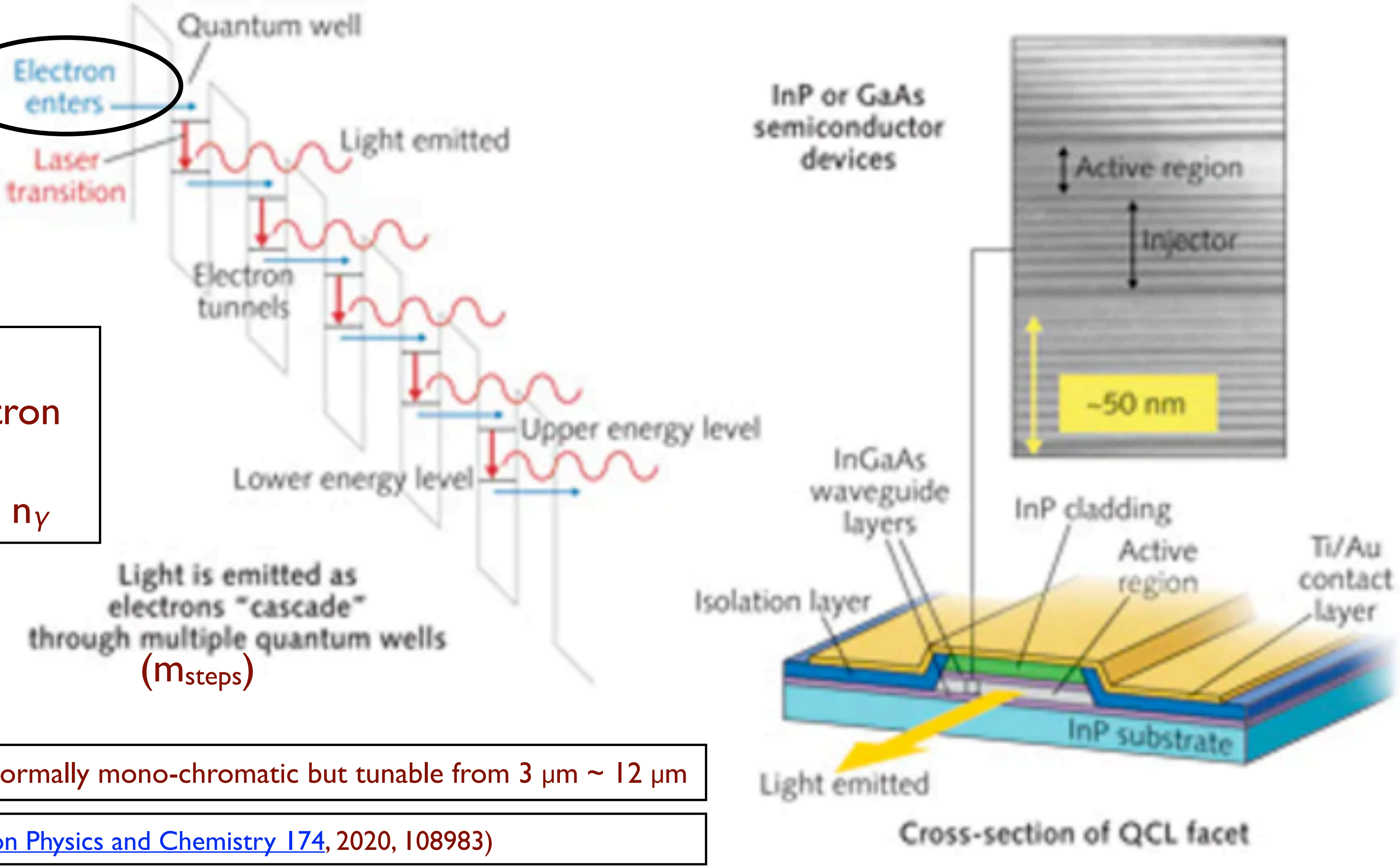
QD's are radiation resistant

R. Leon et al., "Effects of proton irradiation on luminescence emission and carrier dynamics of self-assembled III-V quantum dots," in IEEE Transactions on Nuclear Science, 49, 6, 2844-2851 (2002), doi: 10.1109/TNS.2002.806018.

Active scintillators (QCLs, QWs, QDs, QWDs)



https://www.laserfocusworld.com/test-measurement/spectroscopy/article/16556856/quantumcascade-lasers-qcls-enable-applications-in-ir-spectroscopy



(m_{steps})

Couple bulk semi-conductor to electron injection layer:

$n_e \longrightarrow m_{steps} \times n_\gamma$

Emitted light is IR~THz, normally mono-chromatic but tunable from 3 μm ~ 12 μm

Radiation resistant (Radiation Physics and Chemistry 174, 2020, 108983)

Quantum dots and wells:

https://arxiv.org/abs/2202.11828

submicron pixels

DoTPiX

= single n-channel MOS transistor, in which a buried quantum well gate performs two functions:

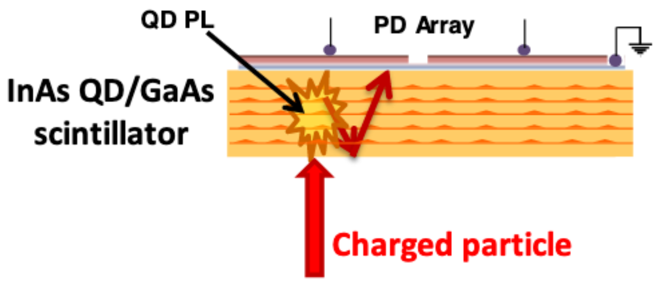
- as a hole-collecting electrode and
- as a channel current modulation gate

A charged particle enters the GaAs bulk, producing electron-hole pairs. The electrons are then quickly trapped by the positively charged InAs quantum dots (QDs). The QDs undergo photoluminescence (PL) and emit photons that travel through the medium (GaAs absorption edge at 250 nm). The emitted photons are collected by a immediately adjoining photodiode (PD) array.

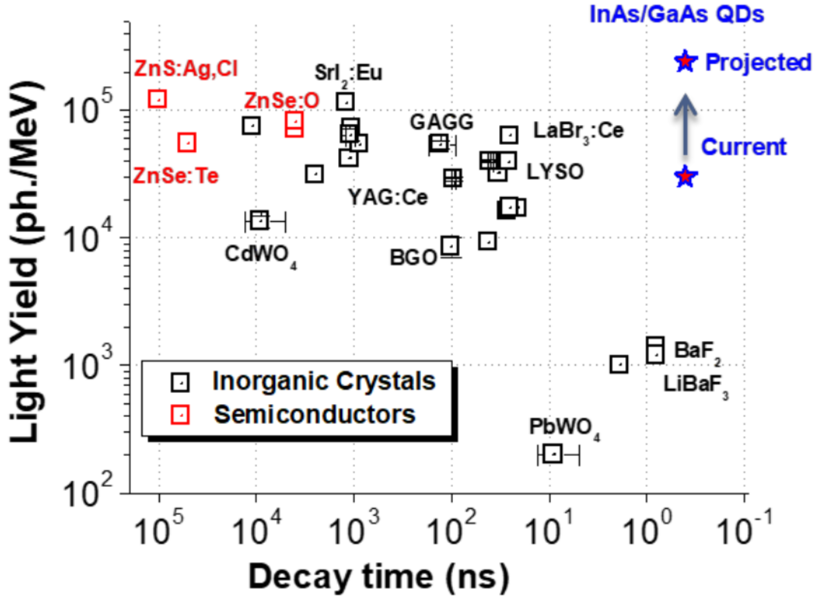
Novel Sensors for Particle Tracking: a Contribution to the Snowmass Community Planning Exercise of 2021, M.R. Hoeferkamp et al., arXiv:2202.11828

scintillating (chromatic) tracker

https://link.springer.com/article/10.1557/s43580-021-00019-y



IR emission from InAs QD's integrated PD's (1-2 μm thick)



Metamaterials, 0 / 1 / 2-dimensional materials (quantum dots, nanolayers)

ultra-fast scintillators based on perovskytes

chromatic calorimetry (QDs)

active scintillators (QCL, QWs, QDs) 5.3.6

GEMs (graphene)

Atoms, molecules, ions

5.3.5

Rydberg TPC's

Spin-based sensors

5.3.3

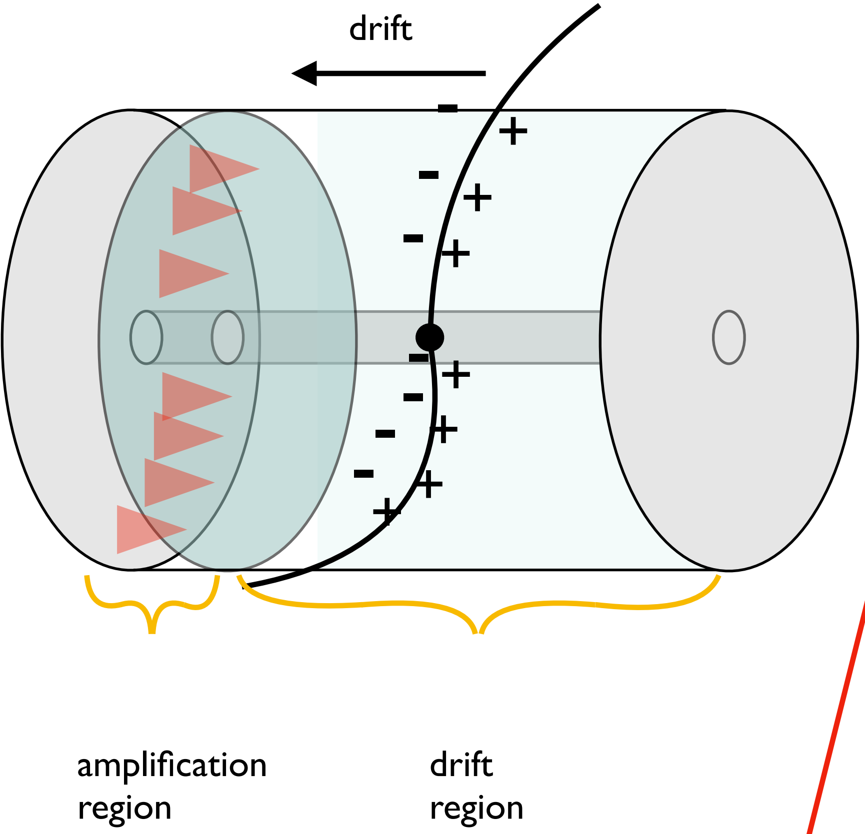
helicity detectors

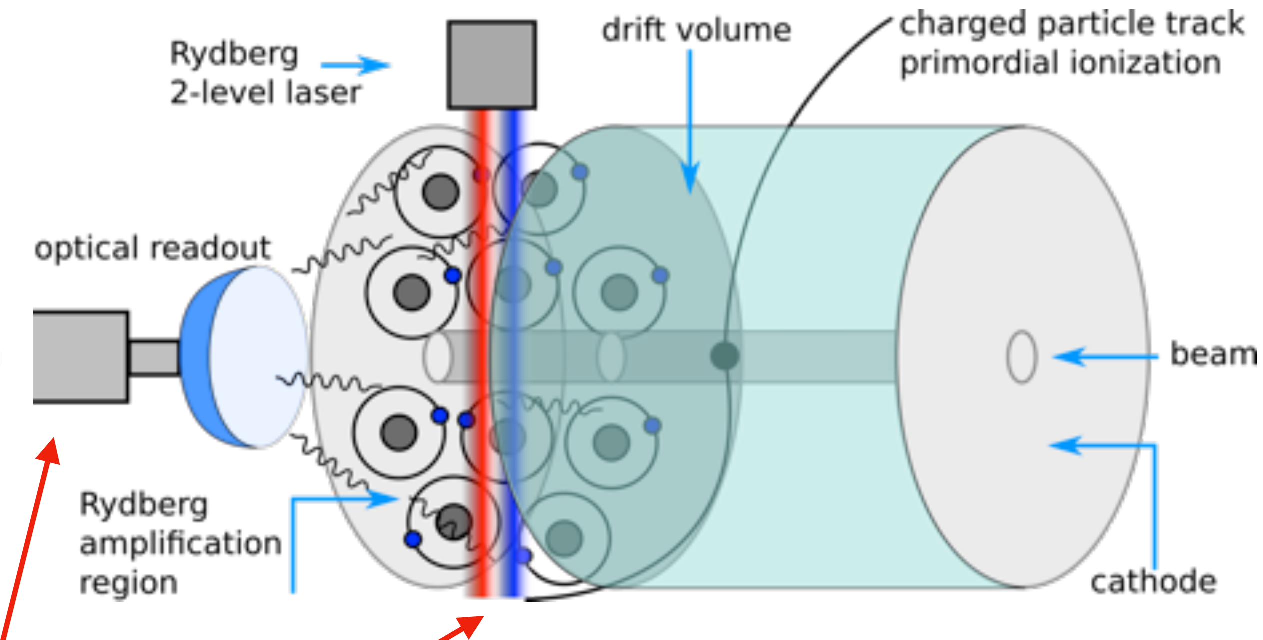
Superconducting sensors

Rydberg atom TPC's

Georgy Kornakov / WUT

Act on the amplification region





enhanced electron signal through "priming" of gas in amplification region: ⟶ effective reduction of ionization threshold of gas in amplification region ⟶ higher electron yield

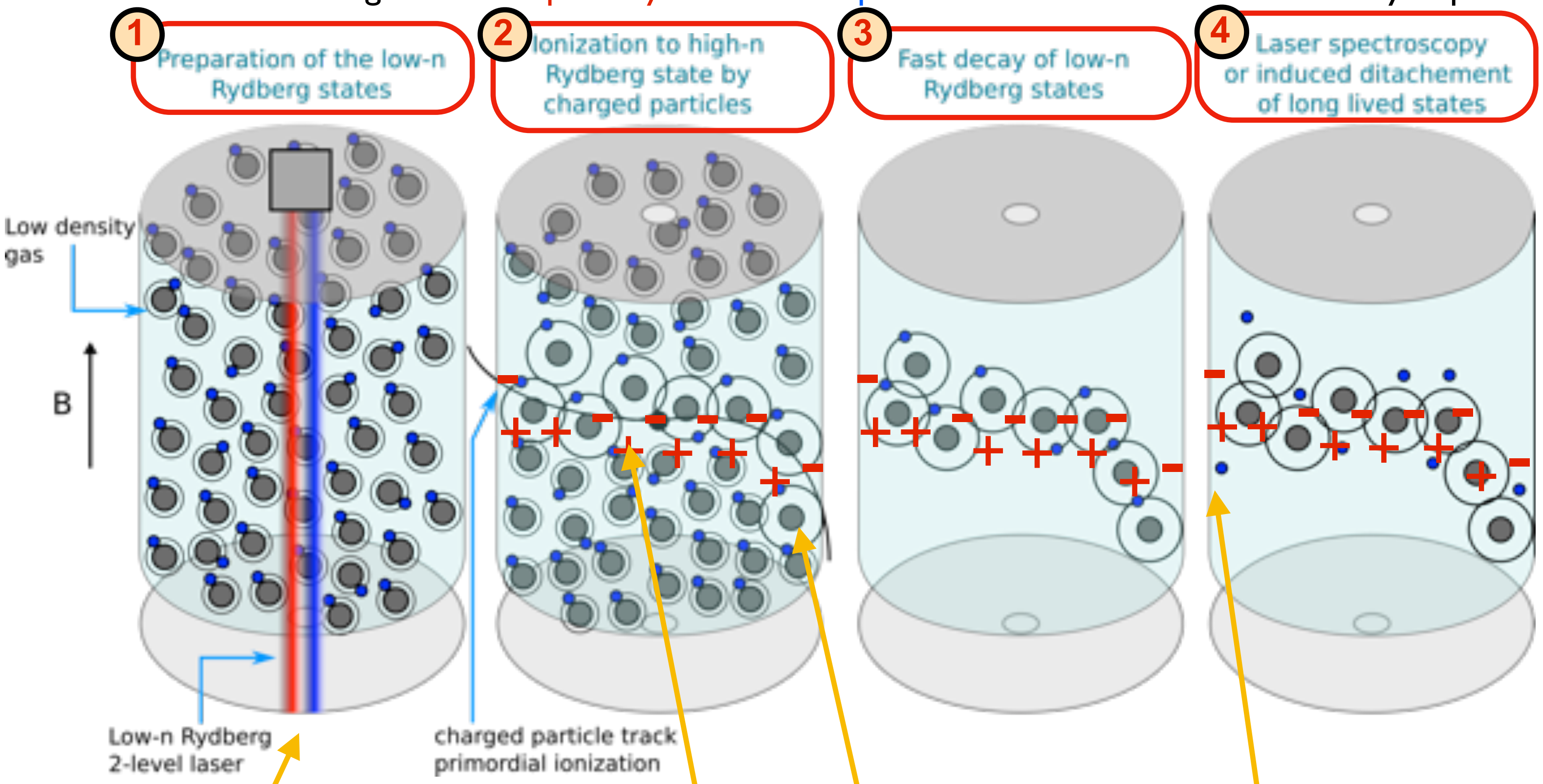
Rydberg atoms can serve to up-convert THz / GHz radiation into the optical regime ⟶ optical R/O of avalanche intensities

Rydberg atom TPC's

Georgy Kornakov / WUT

Act on the drift region

principle carries over to drift region:
enhanced electron signal through "priming" of gas in drift region:
effective reduction of ionization threshold of gas in amplification region
increased dE/dx through standard primary ionization + photo-ionization of atoms excited by mip's



reduction of ionization and atomic excitation threshold

ionization + excitation;
natural decay of unmodified atoms

photo-ionization of excited atoms

Metamaterials, 0 / 1 / 2-dimensional materials (quantum dots, nanolayers)

- ultra-fast scintillators based on perovskytes
- chromatic calorimetry (QDs)
- active scintillators (QCL, QWs, QDs) 5.3.6
- GEMs (graphene)

Atoms, molecules, ions

5.3.5

- Rydberg TPC's

Spin-based sensors

5.3.3

- helicity detectors

Superconducting sensors

HEP

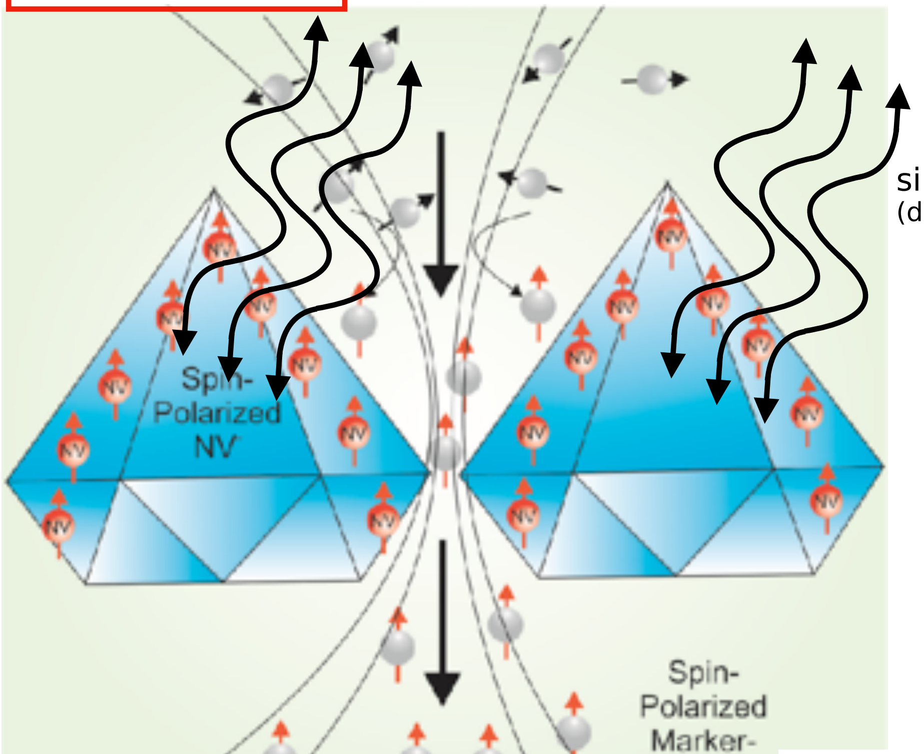
optically polarizable elements: Nitrogen-vacancy diamonds (NVD)

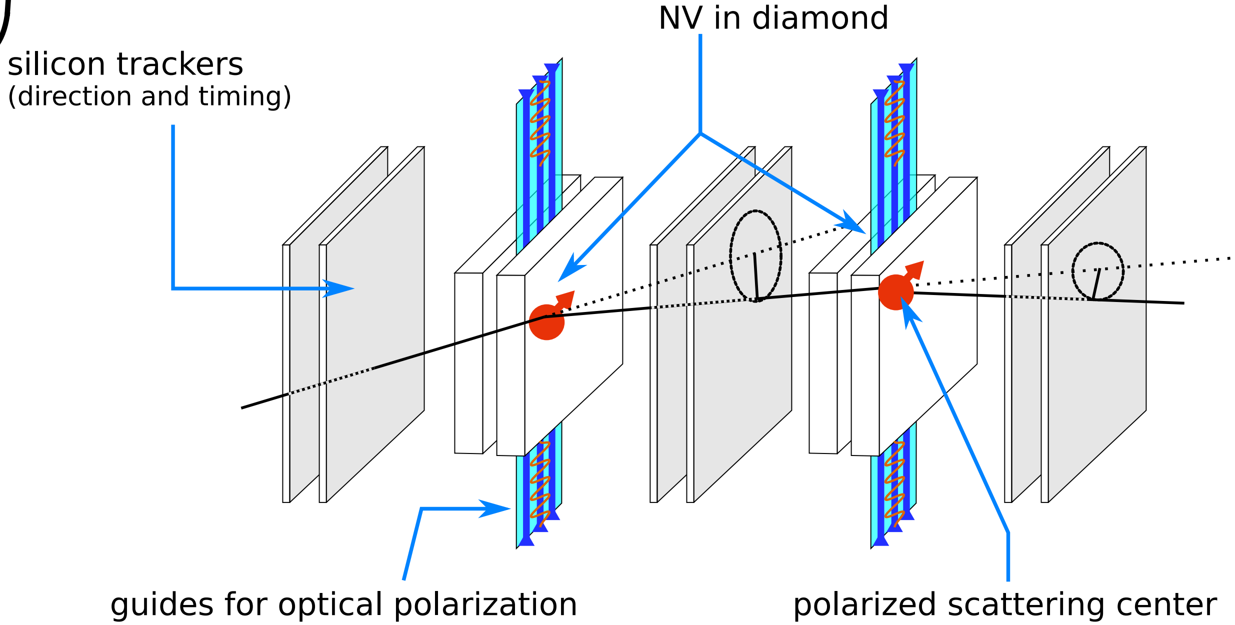
Georgy Kornakov / WUT

spin-spin scattering for helicity determination: usually with polarized beams and/or polarized targets

introduce polarized scattering planes to extract track-by-track particle helicity

$10^{16} \sim 10^{18}$ / cm^3

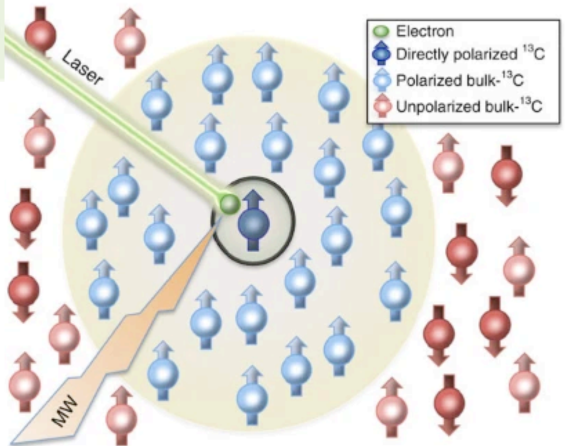




© Dr. Christoph Nebel, Fraunhofer IAF

https://www.metaboliqs.eu/en/news-events/MetaboliQs_PM_first_year.html

Diamond plates of up to 8 × 8 mm^2 in size, fabricated by Element Six



Local and bulk ^{13}C hyperpolarization in nitrogen-vacancy centred diamonds at variable fields and orientations, G. Alvarez et al., *Nature Communications* **6**, 8456 (2015)

https://www.nature.com/articles/ncomms9456

x 10^2

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Atoms, molecules, ions

5.3.5

Rydberg TPC's

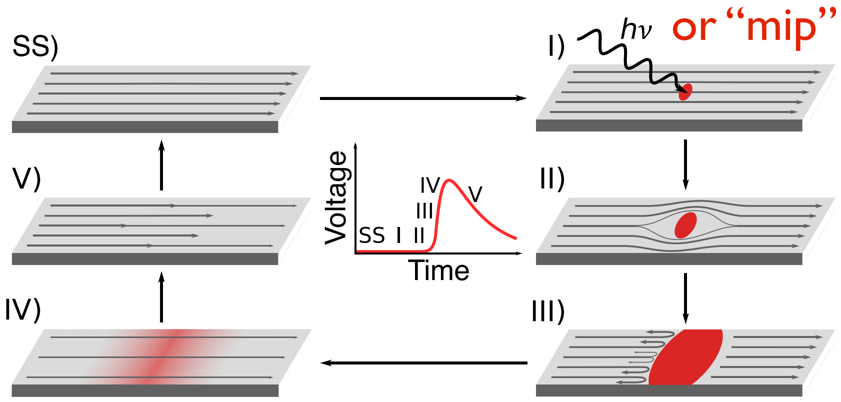
Spin-based sensors

5.3.3

helicity detectors

Superconducting sensors

Extremely low energy threshold detectors: SNSPD



SNSPD's Near term future

Parameter	SOA 2020	Goal by 2025
Efficiency	98% @ 1550nm	>80 % @10μm
Energy Threshold	0.125 eV (10 μm)	12.5 meV (100 μm)
Timing Jitter	2.7 ps	< 1ps
Active Area	1 mm^2	100 cm^2
Max Count Rate	1.2 Gcps	100 Gcps
Pixel Count	1 kilopixel	16 megapixel
Operating Temperature	4.3K	25 K

Snowmass2021 - Letter of Interest

Superconducting Nanowire Single-Photon Detectors

Contact Information:
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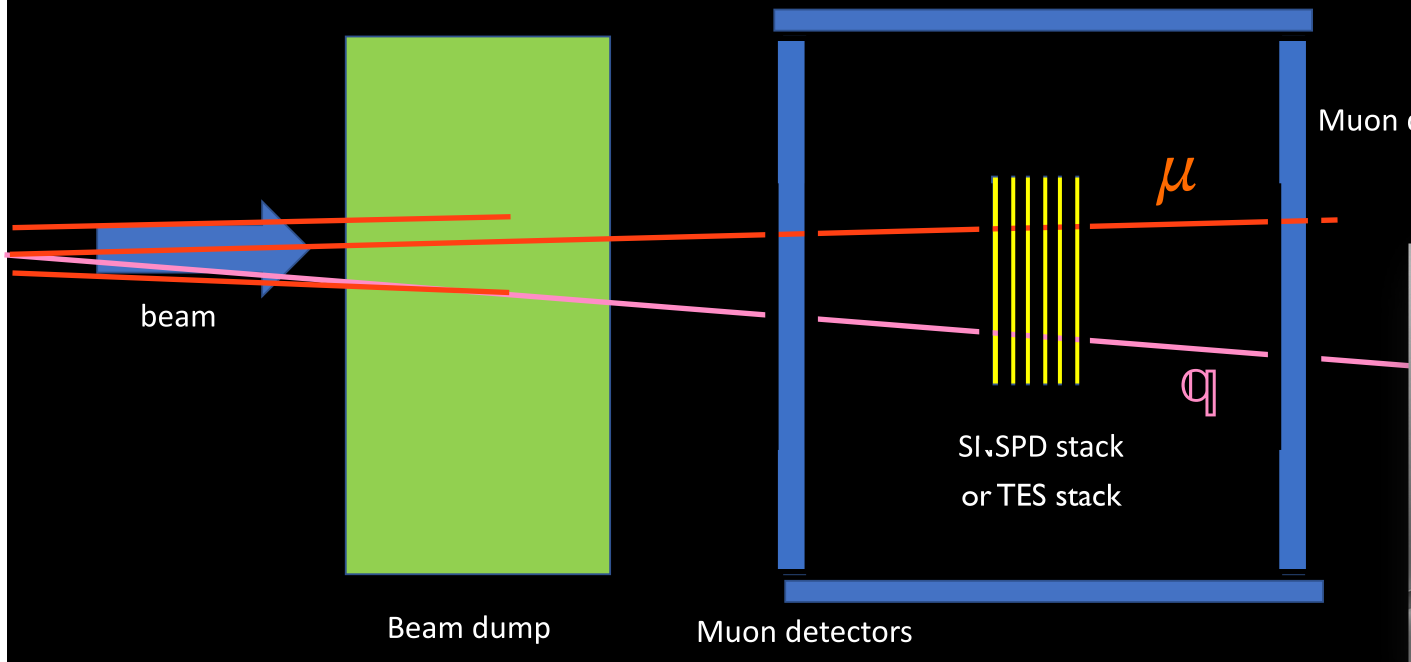
Jeff Chiles, jeffrey.chiles@nist.gov
Sae Woo Nam, saewoo.nam@nist.gov
Valentine Novosad, novosad@anl.gov
Boris Korzh, bkorzh@jpl.nasa.gov
Matt Shaw, mattshaw@jpl.nasa.gov

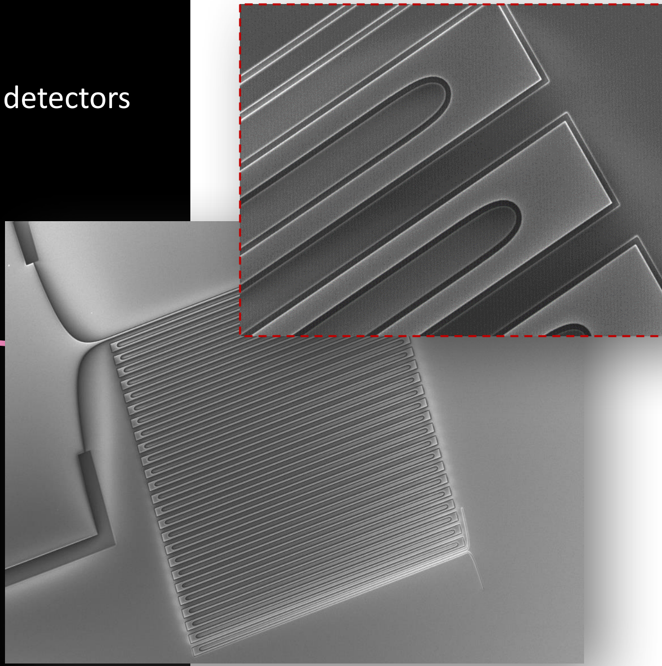
Moving to SC strips conventional lithography → scale up
Development towards SC SSPM

Search for Beyond Standard Model milli-charged particles?



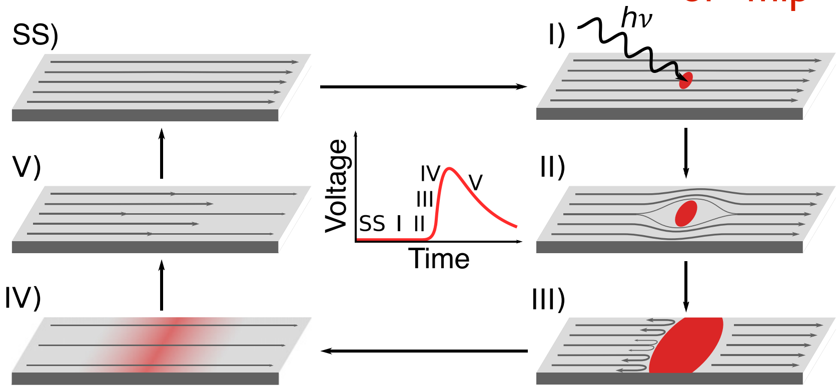
mip: ~20 keV/100 μm

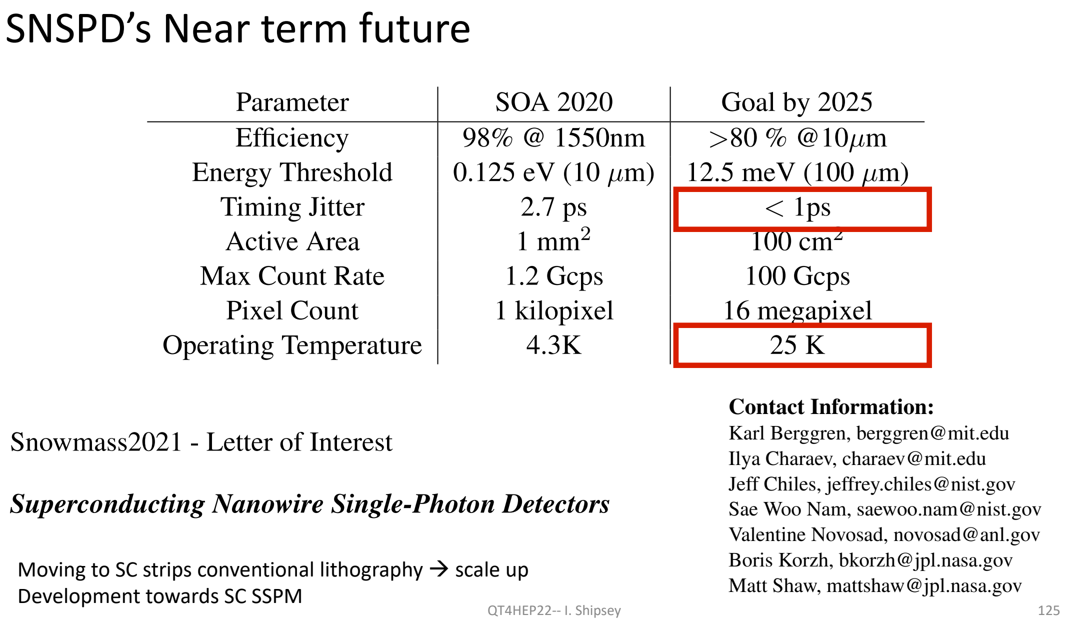
x 10^6 sensitivity



Extremely fast detectors: SNSPD

or "mip"





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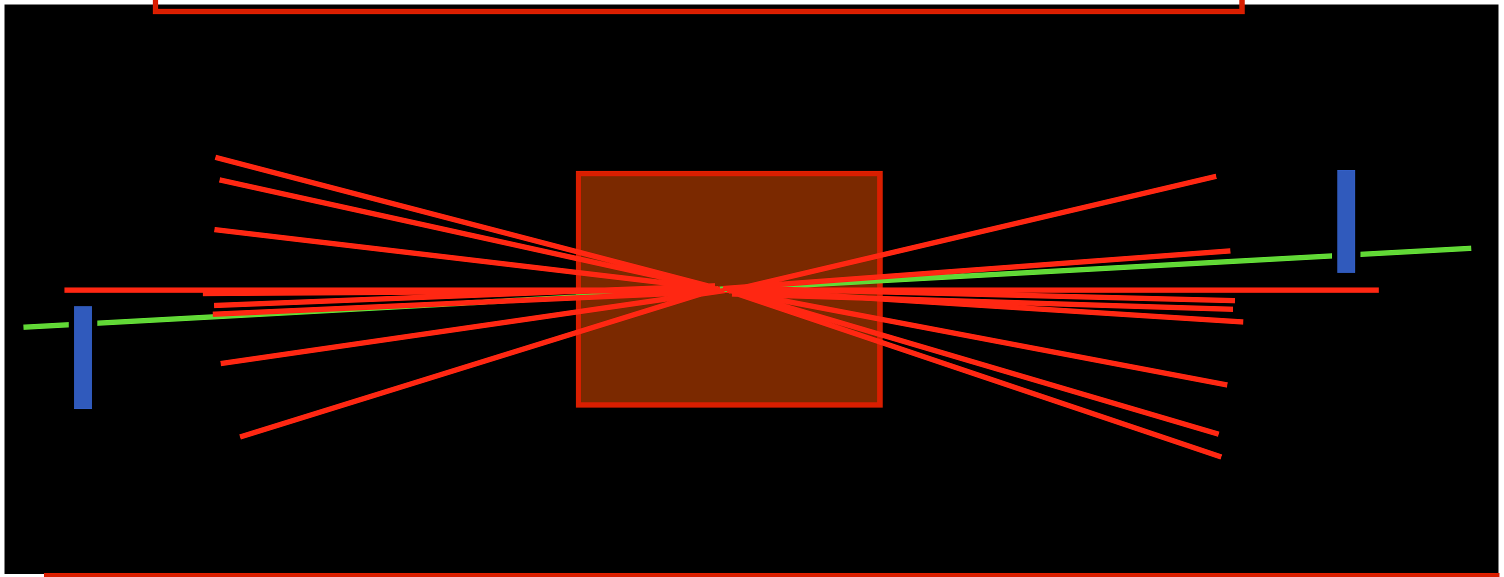
Moving to SC strips conventional lithography → scale up
Development towards SC SSPM

QT4HEP22-- I. Shipsey

125

diffractive scattering via ps-resolution tracking in Roman pots



@ 2.8 K

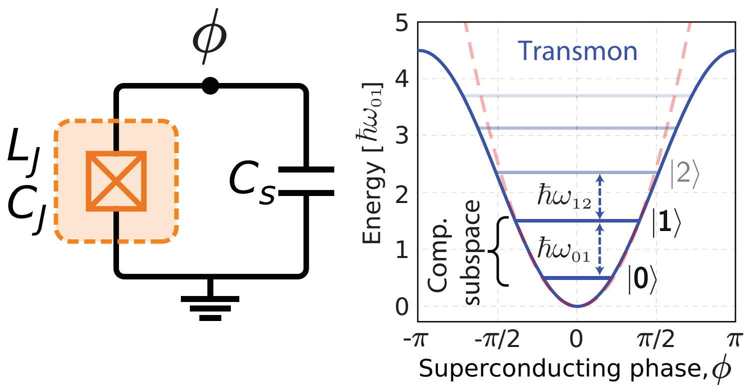
arXiv:2312.13405v2
[physics.ins-det]
5 Apr 2024

low energy particle physics: dark count rate is critical !
high energy particle physics: dark count rate is not a problem: high Tc is imaginable

Beyond existing sensors: using (superconducting) qubits

commonly used qubits: transmons

Josephson junction qubit



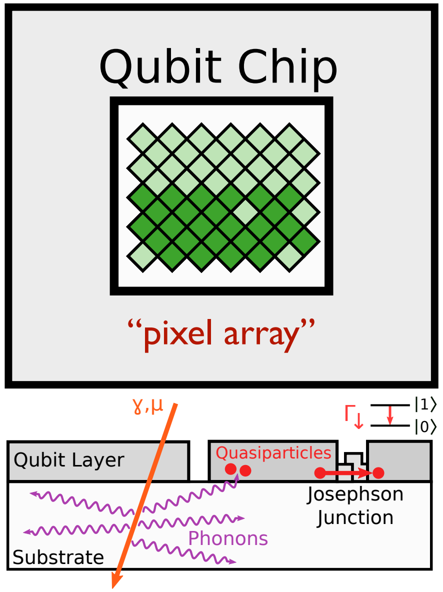
variant of a harmonic oscillator (with numerous equally-spaced energy levels):

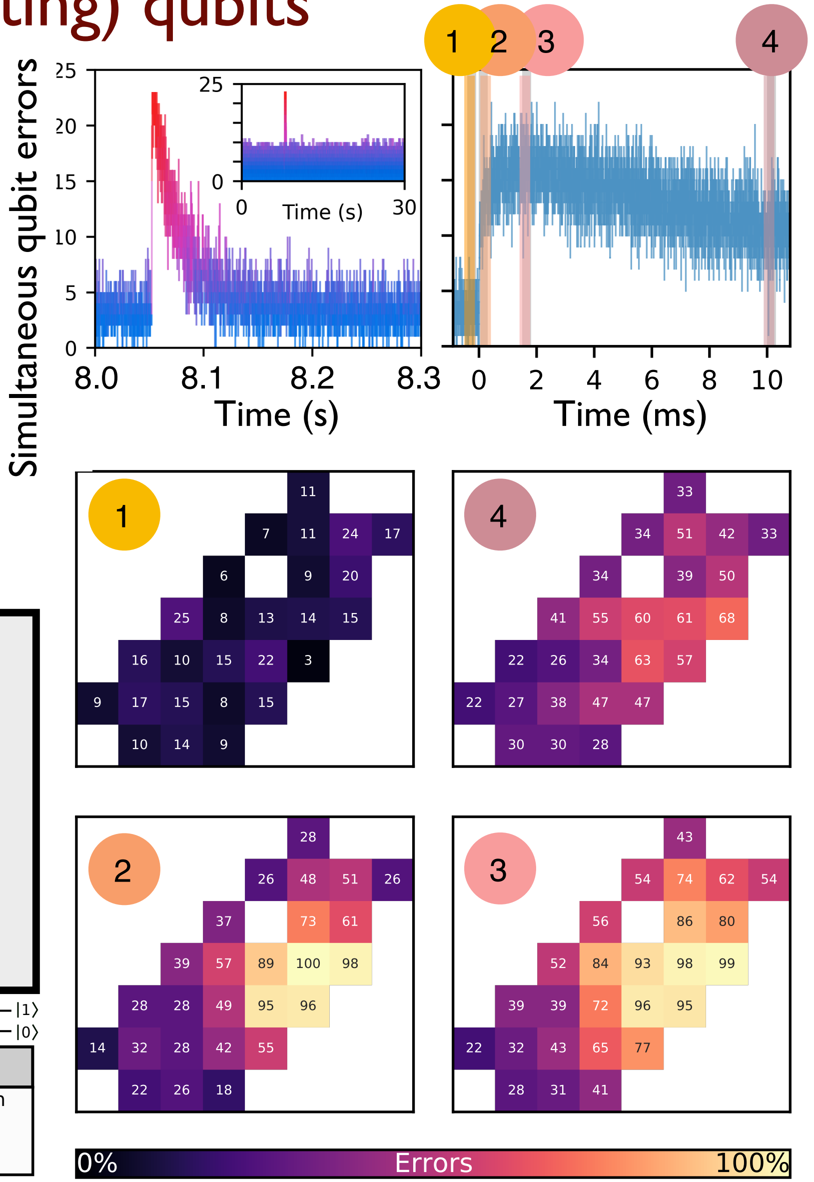
need to be able to define a computational subspace consisting of only two energy states (usually the two-lowest energy eigenstates) in between which transitions can be driven without also exciting other levels in the system: $|0\rangle$ and $|1\rangle$

Energy scale: 25μeV (cosmic: 0.1~1 MeV)

A quantum engineer's guide to superconducting qubits,
P. Krantz et al., https://arxiv.org/pdf/1904.06560

Google Sycamore processor (Quantum Computer)





Correlated errors in neighboring qubits in a 26 qubit sub-array: cosmic ray "tracker"

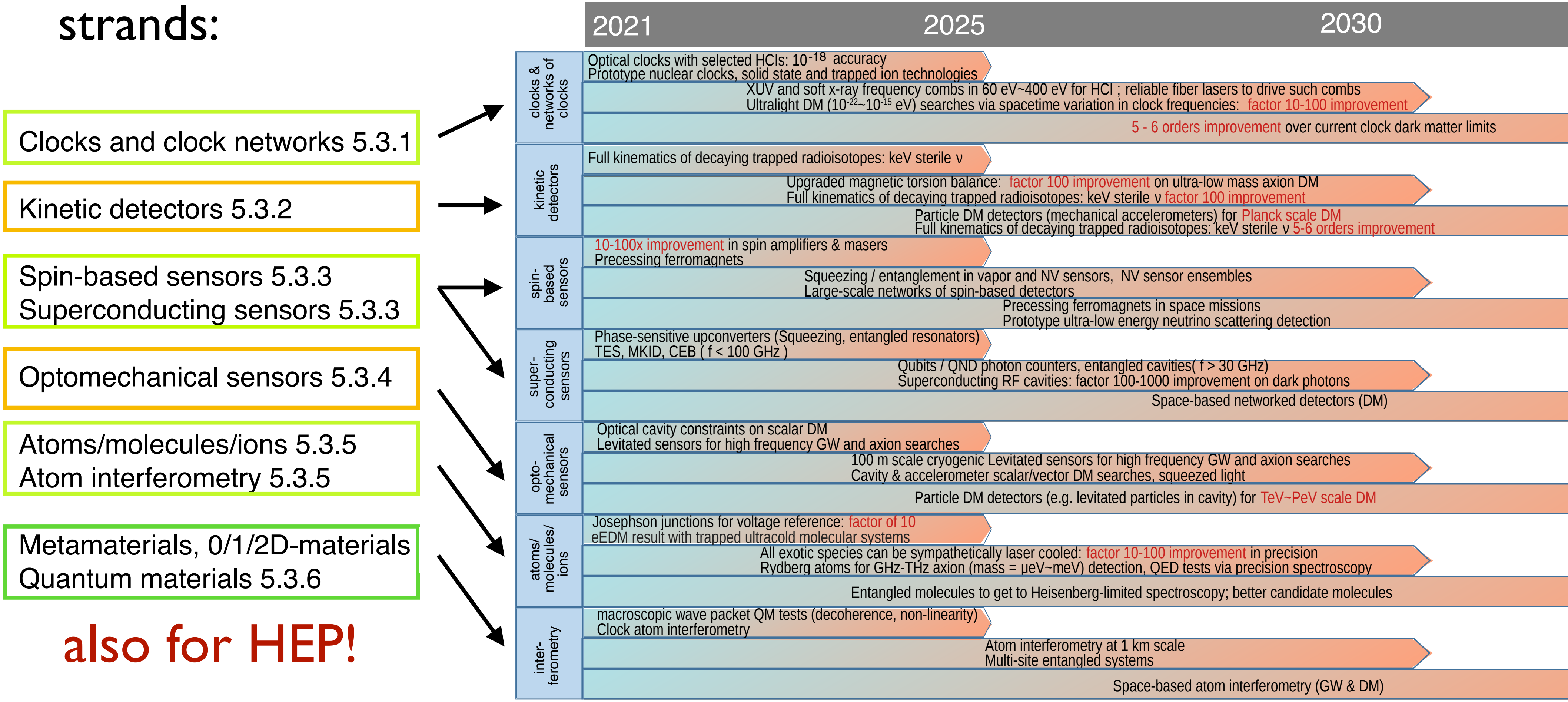
McEwen et al., Nature 118, 107 (2022) arXiv:22014.05219

This slide stolen from Daniel Baxter, IDM, L'Aquila, 2024

What's next?

These potential applications of quantum sensors also in HEP require dedicated R&D to evaluate their potential and feasibility.

In line with the RECFA R&D roadmap, it makes sense to consider a quantum-sensing R&D program that brings together the following strands:



Clocks and clock networks 5.3.1

Kinetic detectors 5.3.2

Spin-based sensors 5.3.3
Superconducting sensors 5.3.3

Optomechanical sensors 5.3.4

Atoms/molecules/ions 5.3.5
Atom interferometry 5.3.5

Metamaterials, 0/1/2D-materials
Quantum materials 5.3.6

2021 2025 2030

clocks & networks of clocks
Optical clocks with selected HCIs: 10^{-18} accuracy
Prototype nuclear clocks, solid state and trapped ion technologies
XUV and soft x-ray frequency combs in 60 eV~400 eV for HCI ; reliable fiber lasers to drive such combs
Ultralight DM (10^{-22}~10^{-15} eV) searches via spacetime variation in clock frequencies: factor 10-100 improvement
5 - 6 orders improvement over current clock dark matter limits

kinetic detectors
Full kinematics of decaying trapped radioisotopes: keV sterile ν
Upgraded magnetic torsion balance: factor 100 improvement on ultra-low mass axion DM
Full kinematics of decaying trapped radioisotopes: keV sterile ν factor 100 improvement
Particle DM detectors (mechanical accelerometers) for Planck scale DM
Full kinematics of decaying trapped radioisotopes: keV sterile ν 5-6 orders improvement

spin-based sensors
10-100x improvement in spin amplifiers & masers
Precessing ferromagnets
Squeezing / entanglement in vapor and NV sensors, NV sensor ensembles
Large-scale networks of spin-based detectors
Precessing ferromagnets in space missions
Prototype ultra-low energy neutrino scattering detection

super-conducting sensors
Phase-sensitive upconverters (Squeezing, entangled resonators)
TES, MKID, CEB (f < 100 GHz)
Qubits / QND photon counters, entangled cavities(f > 30 GHz)
Superconducting RF cavities: factor 100-1000 improvement on dark photons
Space-based networked detectors (DM)

opto-mechanical sensors
Optical cavity constraints on scalar DM
Levitated sensors for high frequency GW and axion searches
100 m scale cryogenic Levitated sensors for high frequency GW and axion searches
Cavity & accelerometer scalar/vector DM searches, squeezed light
Particle DM detectors (e.g. levitated particles in cavity) for TeV~PeV scale DM

atoms/ molecules/ ions
Josephson junctions for voltage reference: factor of 10
eEDM result with trapped ultracold molecular systems
All exotic species can be sympathetically laser cooled: factor 10-100 improvement in precision
Rydberg atoms for GHz-THz axion (mass = μeV~meV) detection, QED tests via precision spectroscopy
Entangled molecules to get to Heisenberg-limited spectroscopy; better candidate molecules

inter-ferometry
macroscopic wave packet QM tests (decoherence, non-linearity)
Clock atom interferometry
Atom interferometry at 1 km scale
Multi-site entangled systems
Space-based atom interferometry (GW & DM)

also for HEP!

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- Spin-based sensors 5.3.3
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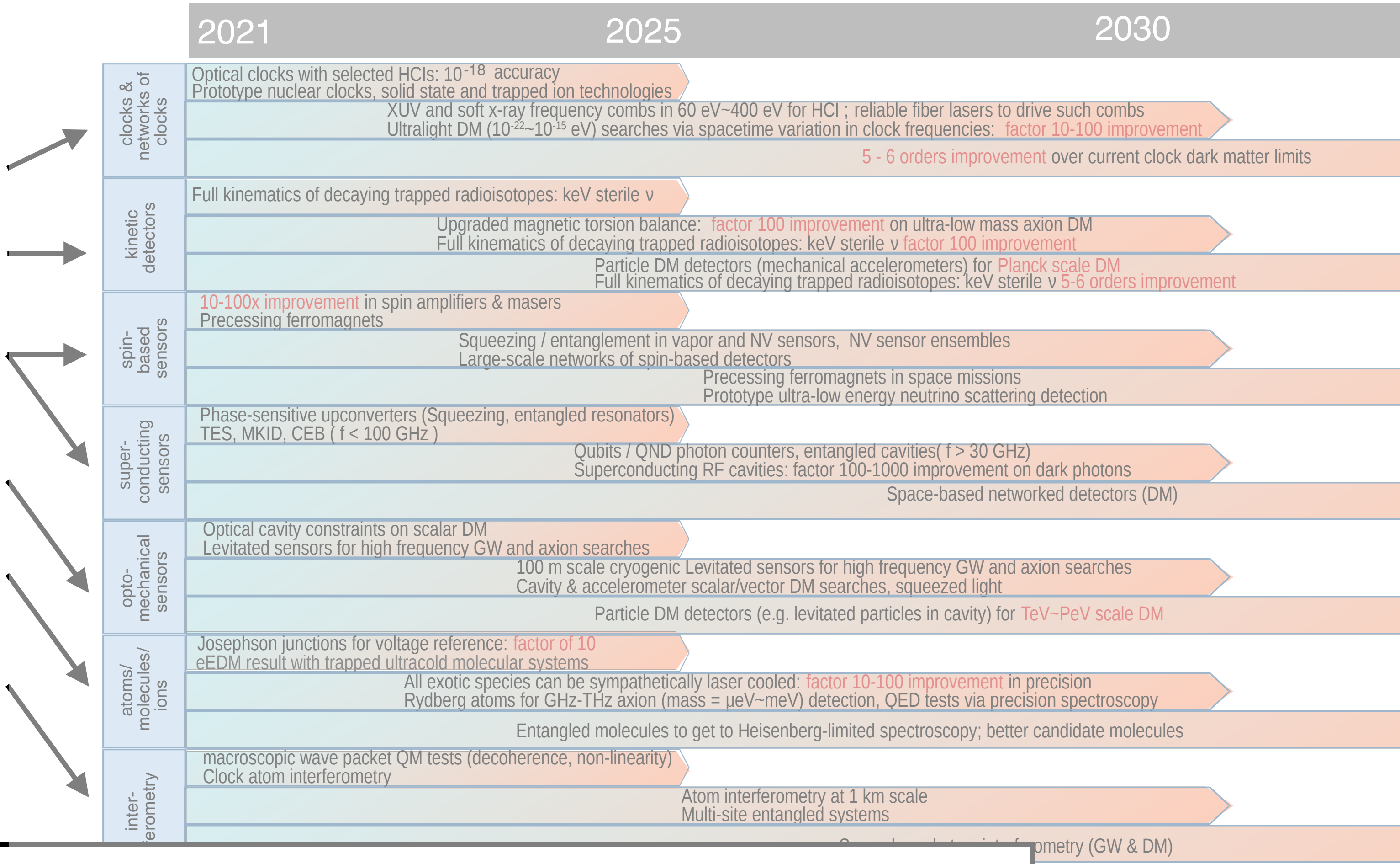
  Quantum materials 5.3.6



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Prototype ultra-low energy neutrino scattering detection

Phase-sensitive upconverters (Squeezing, entangled resonators)
TES, MKID, CEB (f < 100 GHz)

Qubits / QND photon counters, entangled cavities(f > 30 GHz)
Superconducting RF cavities: factor 100-1000 improvement on dark photons

Space-based networked detectors (DM)

Optical cavity constraints on scalar DM
Levitated sensors for high frequency GW and axion searches

100 m scale cryogenic Levitated sensors for high frequency GW and axion searches
Cavity & accelerometer scalar/vector DM searches, squeezed light

Particle DM detectors (e.g. levitated particles in cavity) for TeV~PeV scale DM

Josephson junctions for voltage reference: factor of 10
eEDM result with trapped ultracold molecular systems

All exotic species can be sympathetically laser cooled: factor 10-100 improvement in precision
Rydberg atoms for GHz-THz axion (mass = μeV~meV) detection, QED tests via precision spectroscopy

Entangled molecules to get to Heisenberg-limited spectroscopy; better candidate molecules

macroscopic wave packet QM tests (decoherence, non-linearity)
Clock atom interferometry

Atom interferometry at 1 km scale
Multi-site entangled systems

Space-based atom interferometry (GW & DM)

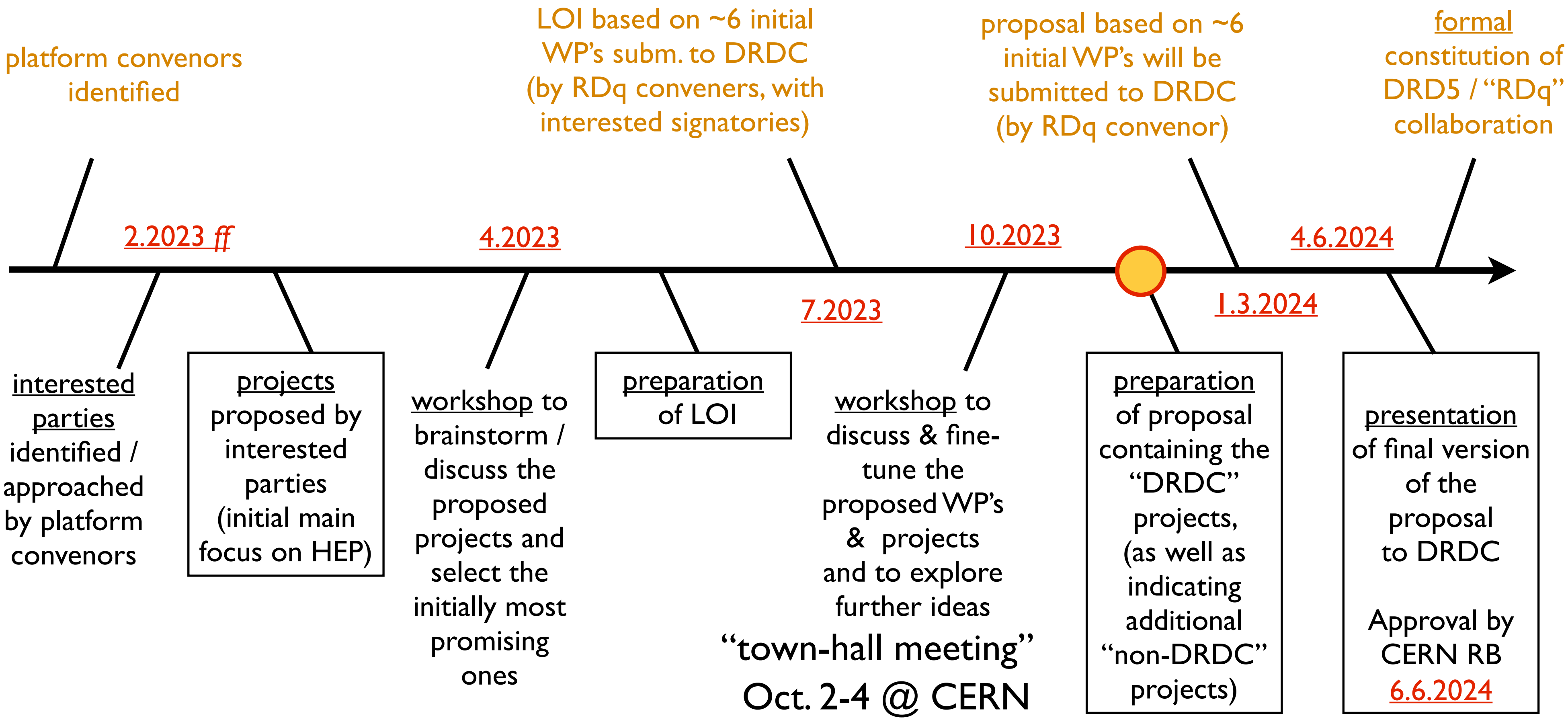
also for HEP!

next step: implementation of ECFA detector R&D pgm

timeline

Two goals:

- preparation of a proposal (LoI, White Paper) for detector R&D
- formation of a global collaboration (Europe, Americas, Asia)



platform convenors identified

2.2023 ff

interested parties identified / approached by platform convenors

projects proposed by interested parties (initial main focus on HEP)

4.2023

workshop to brainstorm / discuss the proposed projects and select the initially most promising ones

preparation of LOI

LOI based on ~6 initial WP's subm. to DRDC (by RDq conveners, with interested signatories)

7.2023

10.2023

workshop to discuss & fine-tune the proposed WP's & projects and to explore further ideas

"town-hall meeting"
Oct. 2-4 @ CERN

preparation of proposal containing the "DRDC" projects, (as well as indicating additional "non-DRDC" projects)

proposal based on ~6 initial WP's will be submitted to DRDC (by RDq convenor)

1.3.2024

4.6.2024

presentation of final version of the proposal to DRDC

Approval by CERN RB 6.6.2024

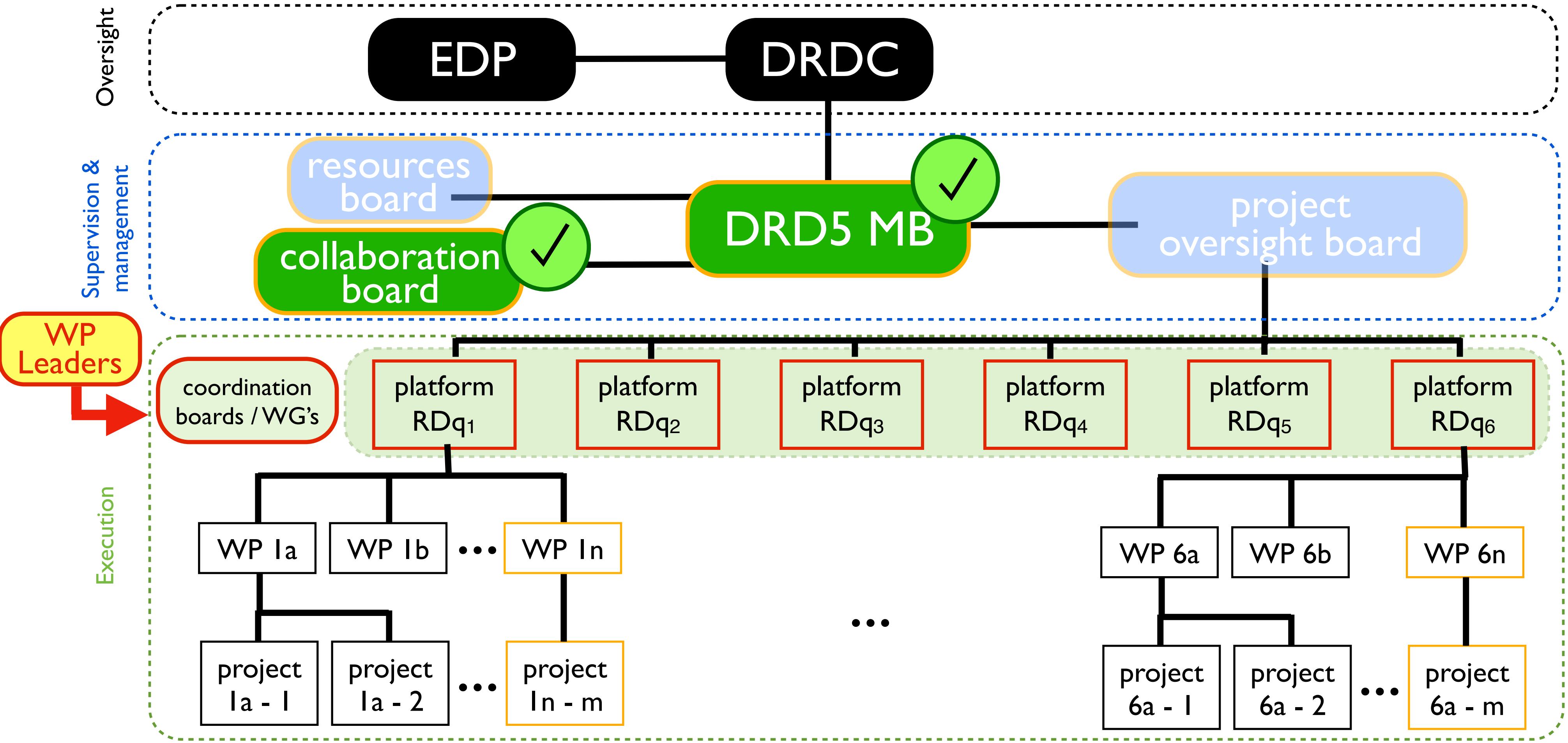
formal constitution of DRD5 / "RDq" collaboration

call for wide participation in DRD5

DRD5: WP's and structure

WP's & structure

WP1	Exotic systems in traps & beams (HCI's, molecules, Rydberg systems, clocks, interferometery, …)
WP2	Quantum materials (0-, 1-, 2-D) (Engineering at the atomic scale)
WP3	Quantum superconducting systems (4K electronics; MMC's, TES, SNSPD, KID's/…; integration challenges)
WP4	Scaling up to macroscopic ensembles (spins; nano-structured materials; hybrid devices, opto-mechanical sensors,…)
WP5	Quantum techniques for sensing (back action evasion, squeezing, entanglement, Heisenberg limit)
WP6	Capability expansion (cross-disciplinary exchanges; infrastructures; education)



Oversight

EDP

DRDC

Supervision & management

resources board

collaboration board ✓

DRD5 MB ✓

project oversight board

Execution

WP Leaders

coordination boards / WG's

platform RDq1

platform RDq2

platform RDq3

platform RDq4

platform RDq5

platform RDq6

WP 1a

WP 1b

…

WP 1n

project 1a - 1

project 1a - 2

…

project 1n - m

…

WP 6a

WP 6b

WP 6n

project 6a - 1

project 6a - 2

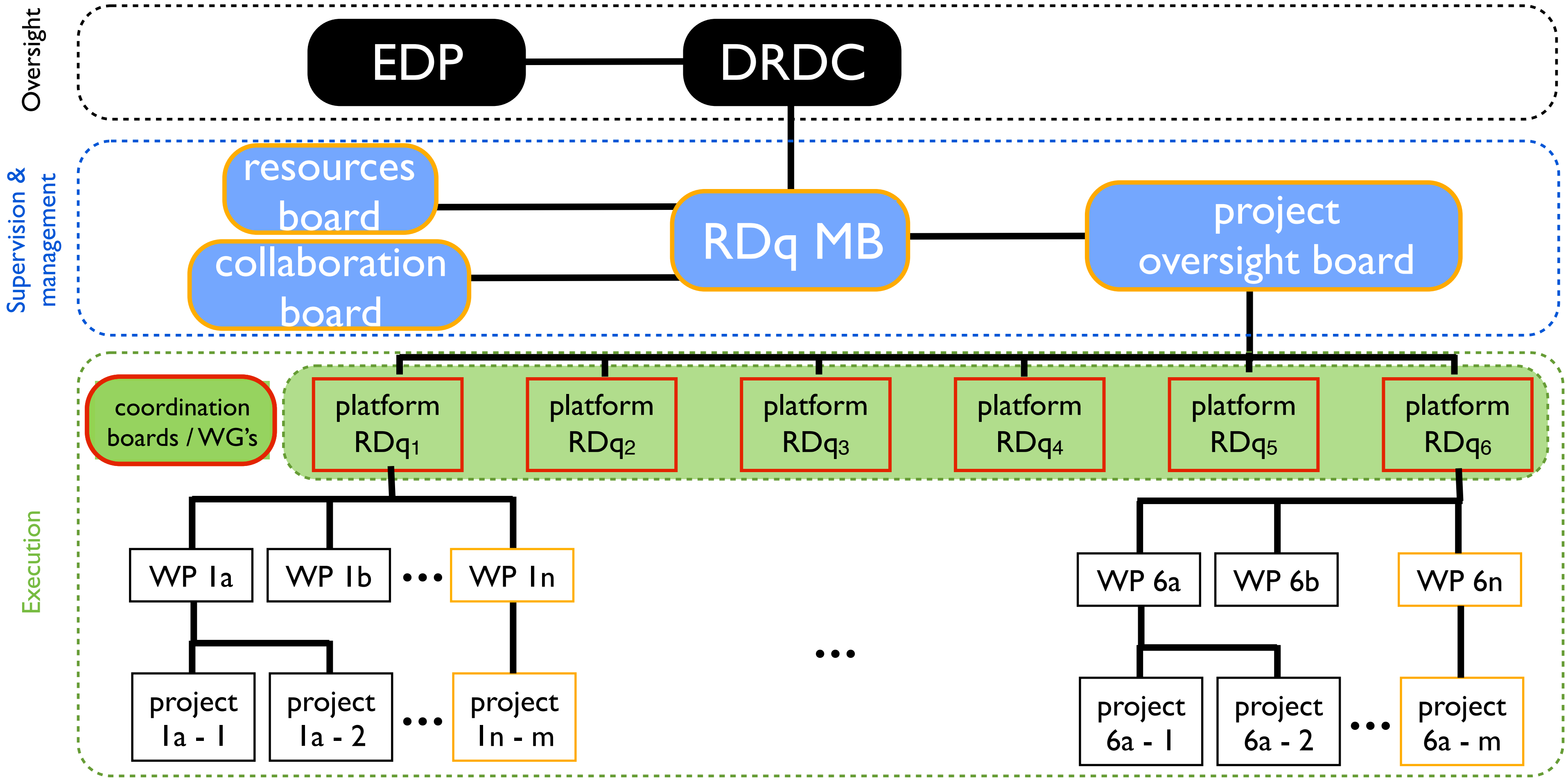
…

project 6a - m

(WP's may be mono-site or multi-site but carry the responsibility to shepherd the spread-out activities related to their specific projects)

WP's & structure

WP1	Network, signal & clock distribution (clock network; std. 'portable' clocks)
WP2	Exotic systems in traps & beams (HCI's, Rydberg systems & molecules; beam-beaker-beam)
WP3	Cryogenic systems (4K electronics; TES/KID's/...; integration challenges)
WP4	Theory (bound state calculations; Heisenberg limit; parameter space comparators)
WP5	Scaling up to macroscopic ensembles (spins; nano-structured materials; ...)
WP6	Capability driven design (cross-disciplinary exchanges; test infrastructure; education)



(platforms may be mono-site or multi-site but carry the responsibility to shepherd the spread-out activities related to their specific WP)

WP1: Atomic, ionic, nuclear and molecular systems and nanoparticles in traps and beams

WP-1a : Exotic systems in traps and beams

WP-1a_a: extension and improved manipulation of exotic systems

WP-1a_b: Bound state calculations

WP-1a c: Global analysis in the presence of new physics

WP-1b : Atom Interferometry

WP-1b a: Terrestrial Very-Long-Baseline Atom Interferometry Roadmap

WP-1b b: High-Precision Atom Interferometry

WP-1c: Networks, Signal and Clock distribution

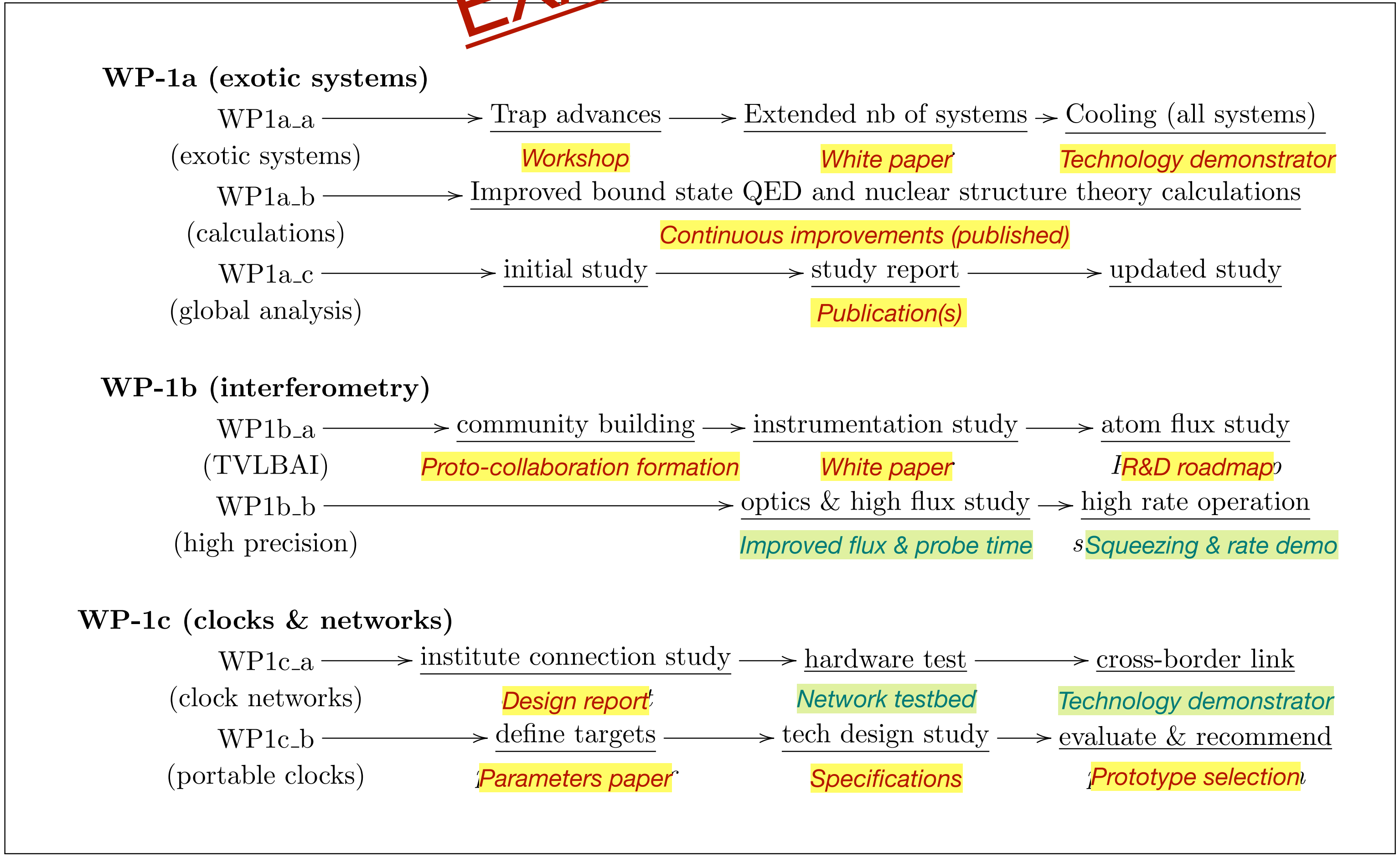
WP-1c a: Large-scale clock network

WP-1c b: Portable references and sources

cross-WP activity

(Time and frequency distribution via space)

EXAMPLE



WP-1a (exotic systems)

WP1a_a (exotic systems) → Trap advances → Extended nb of systems → Cooling (all systems)

Workshop · White paper · Technology demonstrator

WP1a_b (calculations) → Improved bound state QED and nuclear structure theory calculations

Continuous improvements (published)

WP1a_c (global analysis) → initial study → study report → updated study

Publication(s)

WP-1b (interferometry)

WP1b_a (TVLBAI) → community building → instrumentation study → atom flux study

Proto-collaboration formation · White paper · R&D roadmap

WP1b_b (high precision) → optics & high flux study → high rate operation

Improved flux & probe time · Squeezing & rate demo

WP-1c (clocks & networks)

WP1c_a (clock networks) → institute connection study → hardware test → cross-border link

Design report · Network testbed · Technology demonstrator

WP1c_b (portable clocks) → define targets → tech design study → evaluate & recommend

Parameters paper · Specifications · Prototype selection

WP1: Atomic, ionic, nuclear and molecular systems and nanoparticles in traps and beams

WP-1a : Exotic systems in traps and beams

WP-1a_a: extension and improved manipulation of exotic systems

WP-1a_b: Bound state calculations

WP-1a c: Global analysis in the presence of new physics

WP-1b : Atom Interferometry

WP-1b a: Terrestrial Very-Long-Baseline Atom Interferometry Roadmap

WP-1b b: High-Precision Atom Interferometry

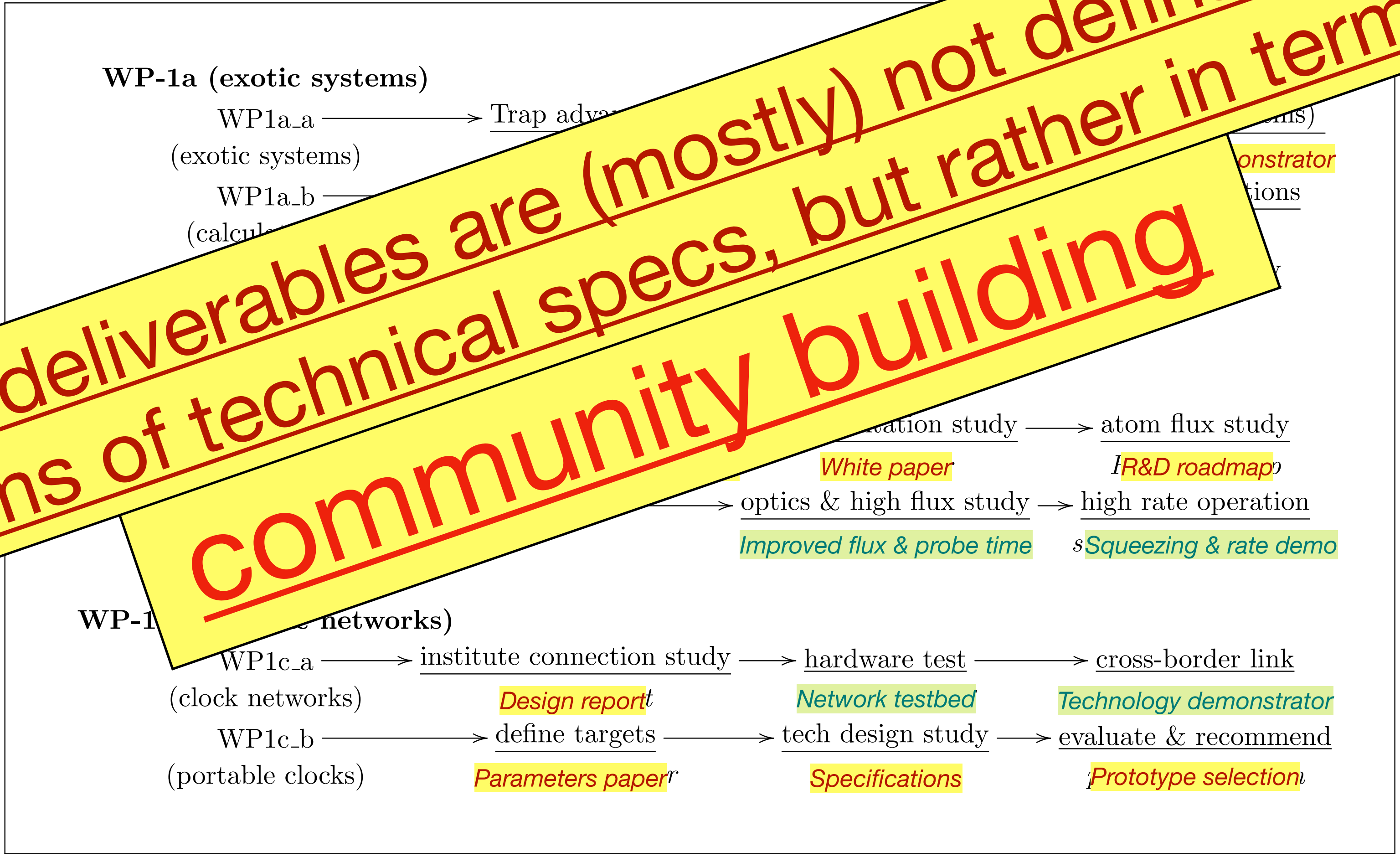
WP-1c: Networks, Signal and Clock distribution

WP-1c a: Large-scale clock network

WP-1c b: Portable references and

cross-WP activity

(Time and frequency distribution via spa



WP-1a (exotic systems)

WP1a_a (exotic systems) → Trap adva … ns)

onstrator

WP1a_b (calcul … tions

ation study → atom flux study

White paper · R&D roadmap

→ optics & high flux study → high rate operation

Improved flux & probe time · Squeezing & rate demo

WP-1 networks)

WP1c_a (clock networks) → institute connection study → hardware test → cross-border link

Design report · Network testbed · Technology demonstrator

WP1c_b (portable clocks) → define targets → tech design study → evaluate & recommend

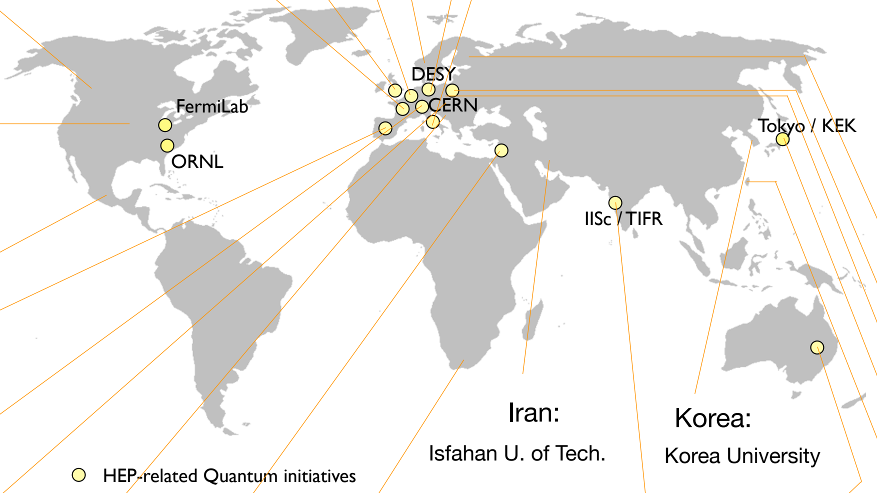
Parameters paper · Specifications · Prototype selection

Our deliverables are (mostly) not definable in terms of technical specs, but rather in terms of

community building

DRD5: 100 involved groups

(and another 10 in discussions)



UK:
- Oxford University
- Univ. of Warwick
- Univ. of Birmingham
- NPL
- Imperial College
- Univ. of Southhampton
- Univ. of Sussex

France:
- SYRTE / OBSPM
- CNRS - U. Sorbonne Paris Nord
- LKB
- ILM - University Lyon 1

Canada:
- McGill Univ.
- TRIUMF

USA:
- UCLA
- ORNL
- Northwestern Univ.
- Caltech
- MIT
- Arizona State Univ.
- Yale
- Univ. of Arizona
- NIST
- LBNL
- Univ. of Delaware
- FNAL
- SLAC

Mexico:
- U. de Aguascalientes

Spain:
- U. de Zaragoza
- U. de Cartagena
- U. de Valencia
- U. de Lleida

Switzerland:
- U. of Geneva
- U. of Zürich
- CERN
- ETHZ

Netherlands:
- U. of Groningen

Norway:
- Oslo University

Austria:
- IQOQI Vienna

Croatia:
- Inst. of Physics, Zagreb

Israel:
- Technion, Haifa

South Africa:
- U. of Cape Town

Iran:
- Isfahan U. of Tech.

India:
- IITTP, Tirupati
- IISER, Kolkata
- TIFR, Mumbai
- University SOA Bhuvaneswar

Korea:
- Korea University

Australia:
- University of Western Australia
- Swinburne University of Technology

Taiwan:
- Academia Sinica & NTU

Germany:
- PTB
- Univ. Ulm
- Leibnitz Univ. Hannover
- KIT, Karlsruhe
- TU München
- DESY
- MPP Garching
- HU Berlin
- FBH Berlin
- Univ. Heidelberg
- Univ. Tübingen
- Univ. Düsseldorf
- Univ. Mainz
- Univ. Bremen / ZARM
- Semiconductor Lab HLL / MPG
- TU Darmstadt

Italy:
- U. of Pisa & INFN
- U. of Pavia
- U. of Firenze
- U. of Milano-Bicocca
- Fondazione Bruno Kessler, Trento
- IOM CNR, Elettra Sincrotrone, Trieste
- Univ. of Bari / INFN
- INFN Padova
- Univ. Roma 1 & 3
- Univ. Napoli
- INFN Roma Tor Vergata
- INFN LNF
- INFN Trento (TIFPA)
- INFN Torino
- INFN LNL
- INFN Lecce
- INFN Roma Tor Vergata
- U. of Camerino

Finland:
- Helsinki Inst. of Physics
- VTT

Poland:
- Warsaw TU
- Nat. Centre Nucl. Research / Warsaw
- Nat. Lab. FAMO / Torun

Czech Republic:
- Czech Tech. University
- University West Bohemia

Japan:
- QUP / KEK
- Kyoto University
- Tokyo University / ICEPP
- University of Shizuoka

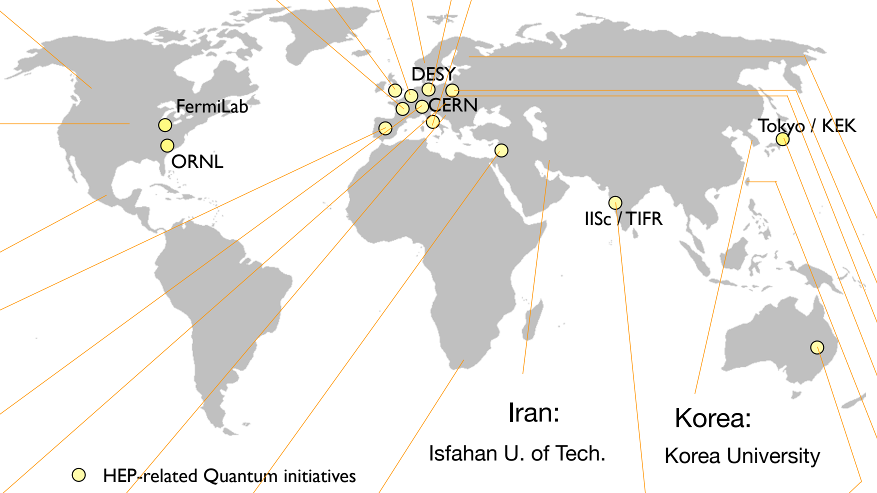
DRD5: 100 involved groups

(and another 10 in discussions)

Collaboration currently being ramped up, combines diverse communities, including HEP.

Many novel developments that benefit both quantum technologies and particle physics.

Open to all interested parties (and it's free to join!)



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U. de Valencia
U. de Lleida

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U. of Geneva
U. of Zürich
CERN
ETHZ

Netherlands:
U. of Groningen

Norway:
Oslo University

Austria:
IQOQI Vienna

Croatia:
Inst. of Physics, Zagreb

Israel:
Technion, Haifa

South Africa:
U. of Cape Town

India:
IITTP, Tirupati
IISER, Kolkata
TIFR, Mumbai
University SOA Bhuvaneswar

Iran:
Isfahan U. of Tech.

Korea:
Korea University

Australia:
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Leibnitz Univ. Hannover
KIT, Karlsruhe
TU München
DESY
MPP Garching
HU Berlin
FBH Berlin
Univ. Heidelberg
Univ. Tübingen
Univ. Düsseldorf
Univ. Mainz
Univ. Bremen / ZARM
Semiconductor Lab HLL / MPG
TU Darmstadt

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Nat. Lab. FAMO / Torun

Czech Republic:
Czech Tech. University
University West Bohemia

Japan:
QUP / KEK
Kyoto University
Tokyo University / ICEPP
University of Shizuoka

thank you!

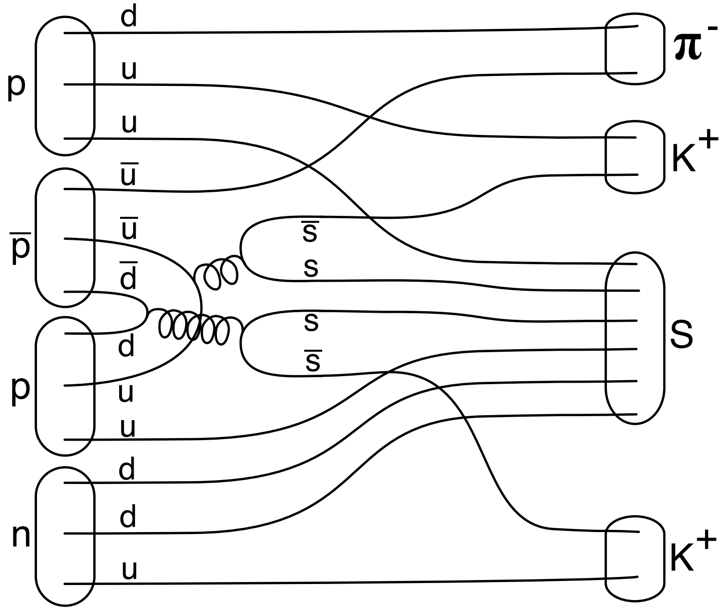
AE$\bar{g}$IS : a novel dark matter search

***sexaquark: uuddss bound state** (m ~ 2m$_p$) [Glennys Farrar* https://arxiv.org/abs/1708.08951*]*

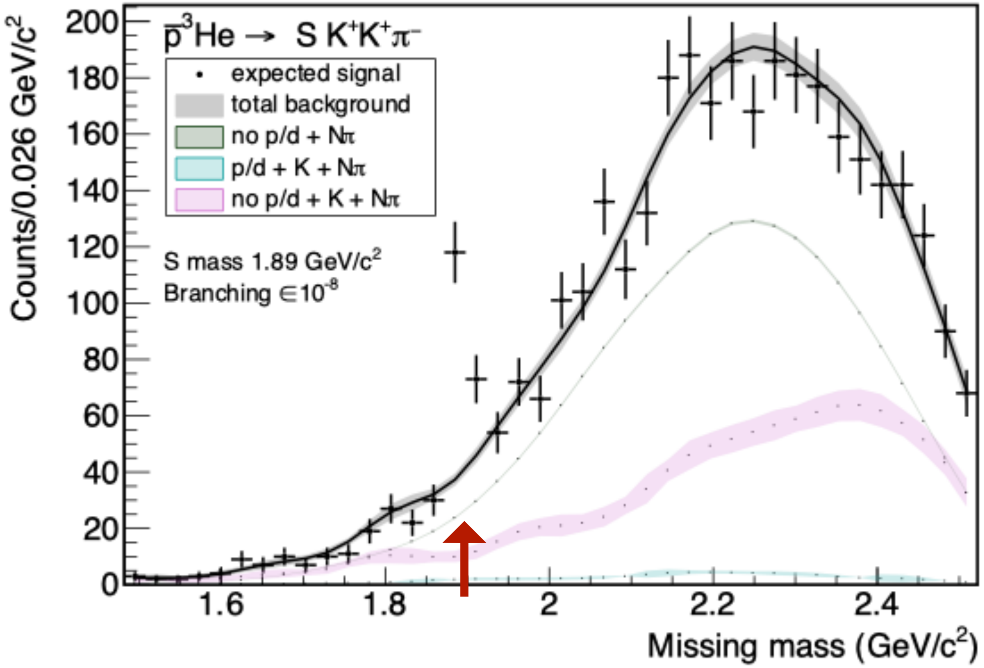
not excluded by prior searches for similar states (among them, the H dibaryon) in the GeV region
astrophysical bounds can be evaded
standard model compatible (uuddss bound state)

formation reaction:
$(\bar{p}\ ^3\text{He})^* \longrightarrow S(uuddss) + K^+K^+\pi^-$

$S = +2,\ Q = +1$



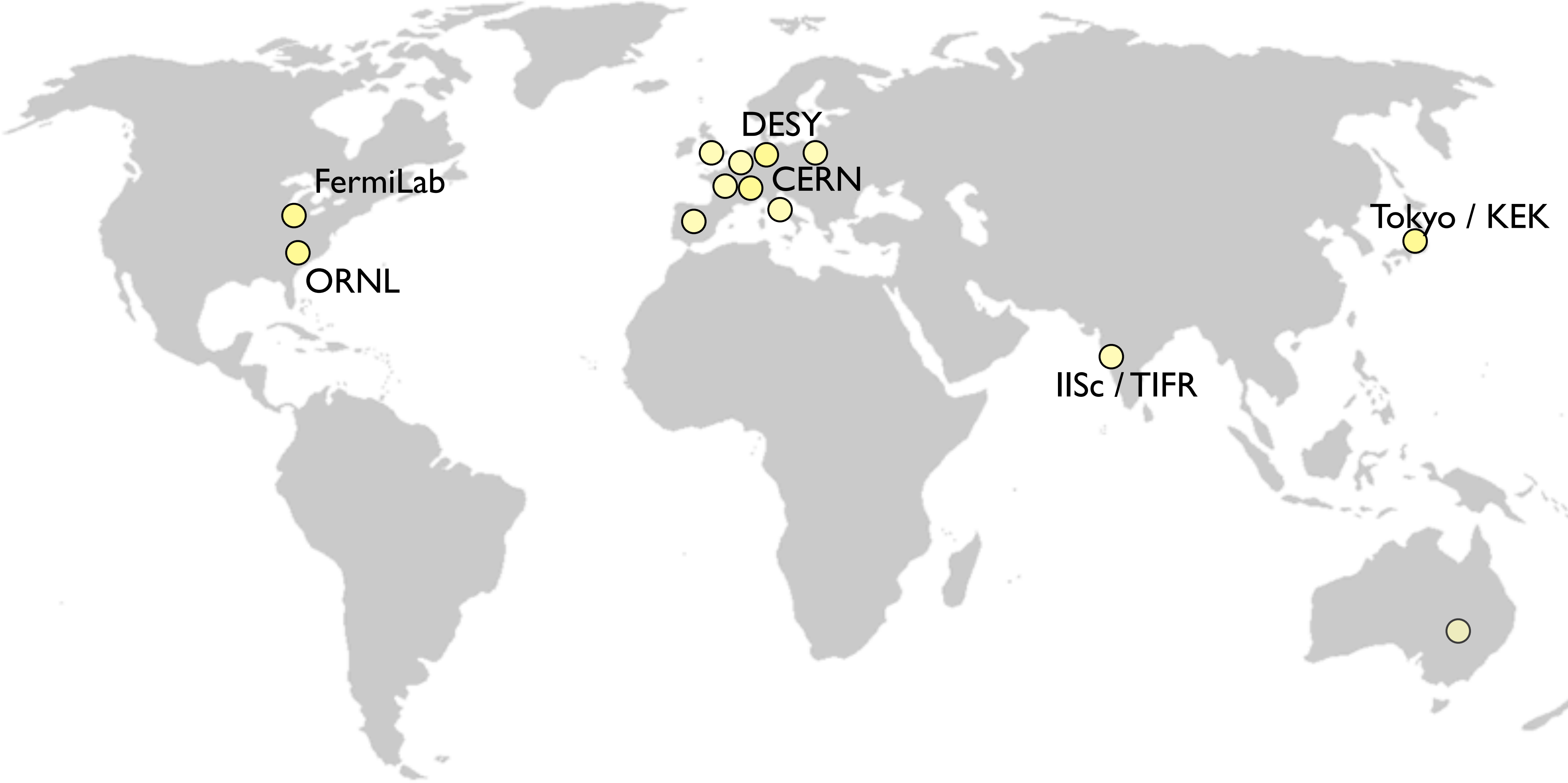
Geant-4 simulation



→ ***in-trap formation of antiprotonic atoms***
charged particle tracking, PID
detection of spectator p, d

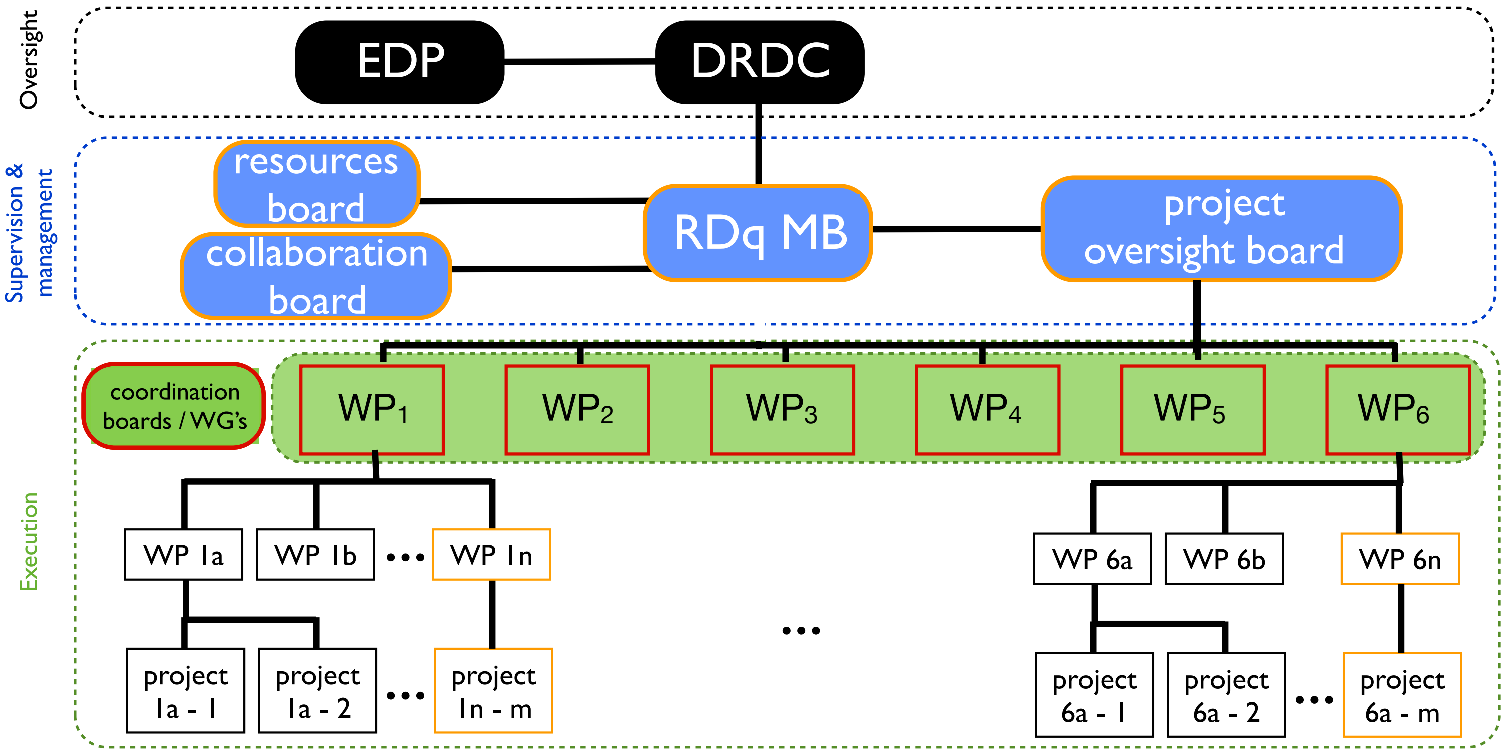
→ ***sensitivity down to 10^{-9}***

possible WP coordination sites



● interested groups from Quantum Technologies
or HEP-related Quantum initiatives

Structure of DRD5:



Membership is free (no common fund contributions)! (Only for academics! industry?)

Simple membership access (via request to CB) / leave (inform CB) processes;

WP's are coordinated as WG's

MB, POB, WG coordinators: by election through CB (1 institute = 1 vote) (Attention to balance!)
(sub-WP coordinators are appointed by WP coordinator)

MB = spokesperson, deputy, CB, RB and POB chairs

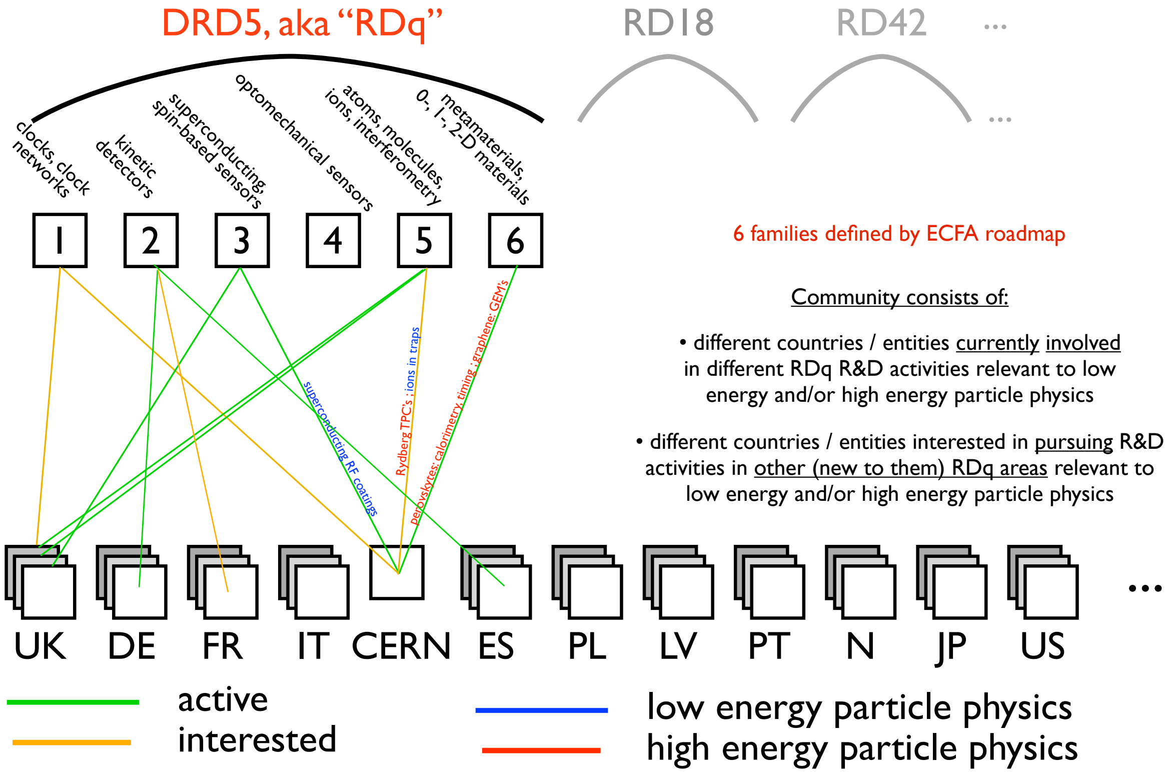
* CB: collaboration board; MB: management board; POB: project oversight board; RB: resources board; WG: working group for a specific Work Package

timeline

next step: implementation of ECFA-wide R&D pgm

define structure of implementation of TF5:

- formal collaboration (“DRD5”, a.k.a. “RDq”)
- consists of 6 families of quantum technologies, each with many sub-activities and sub-collaborations



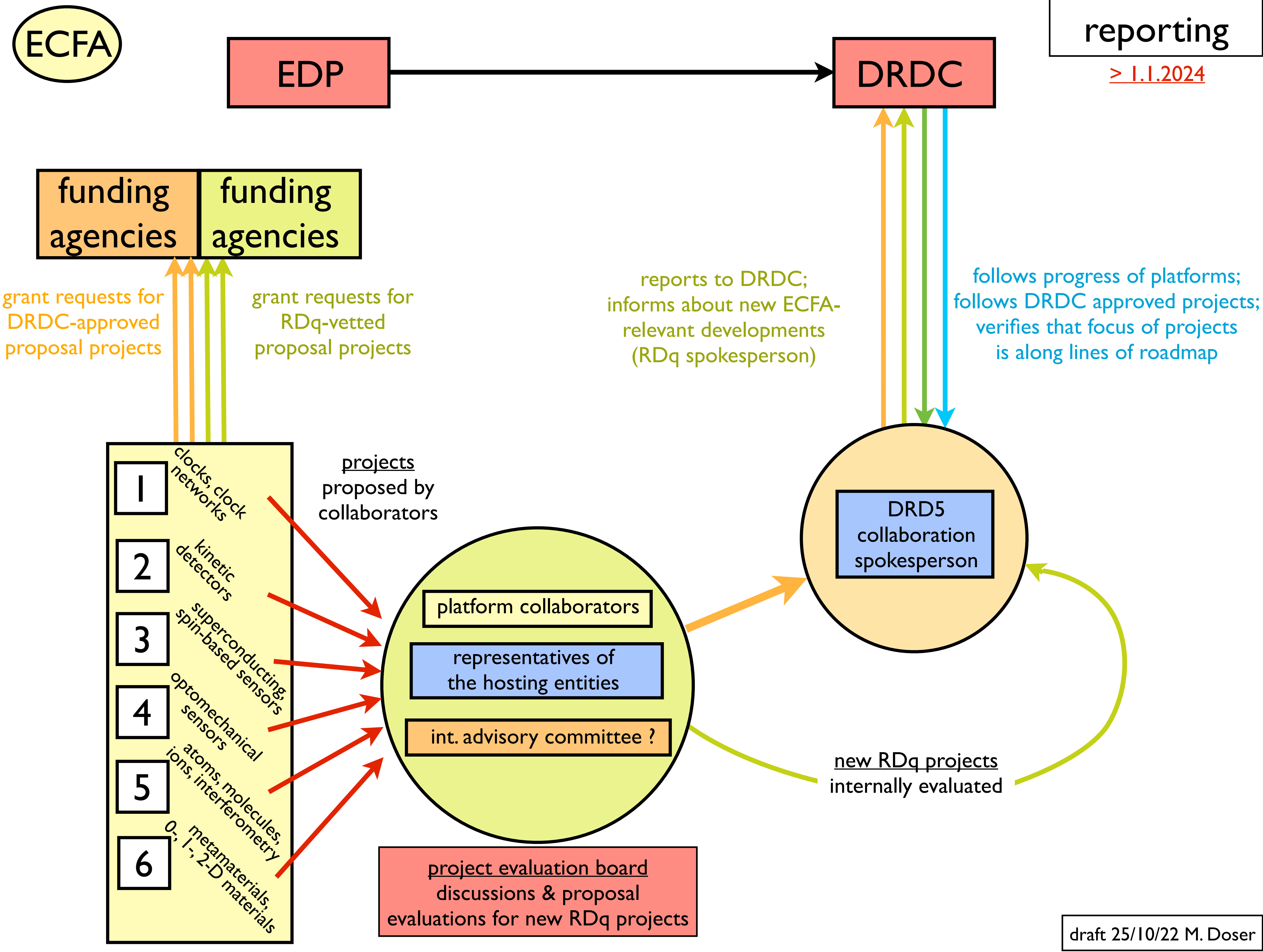
6 families defined by ECFA roadmap

Community consists of:

- different countries / entities currently involved in different RDq R&D activities relevant to low energy and/or high energy particle physics
- different countries / entities interested in pursuing R&D activities in other (new to them) RDq areas relevant to low energy and/or high energy particle physics

- spread load by hosting families in several platforms / institutions

draft 25/10/22 M. Doser



ECFA

EDP

DRDC

reporting

> 1.1.2024

funding agencies

funding agencies

grant requests for DRDC-approved proposal projects

grant requests for RDq-vetted proposal projects

reports to DRDC; informs about new ECFA-relevant developments (RDq spokesperson)

follows progress of platforms; follows DRDC approved projects; verifies that focus of projects is along lines of roadmap

1 clocks, clock networks

2 kinetic detectors

3 superconducting, spin-based sensors

4 optomechanical sensors

5 atoms, molecules, ions, interferometry

6 metamaterials, 0-, 1-, 2-D materials

projects proposed by collaborators

platform collaborators

representatives of the hosting entities

int. advisory committee ?

project evaluation board
discussions & proposal evaluations for new RDq projects

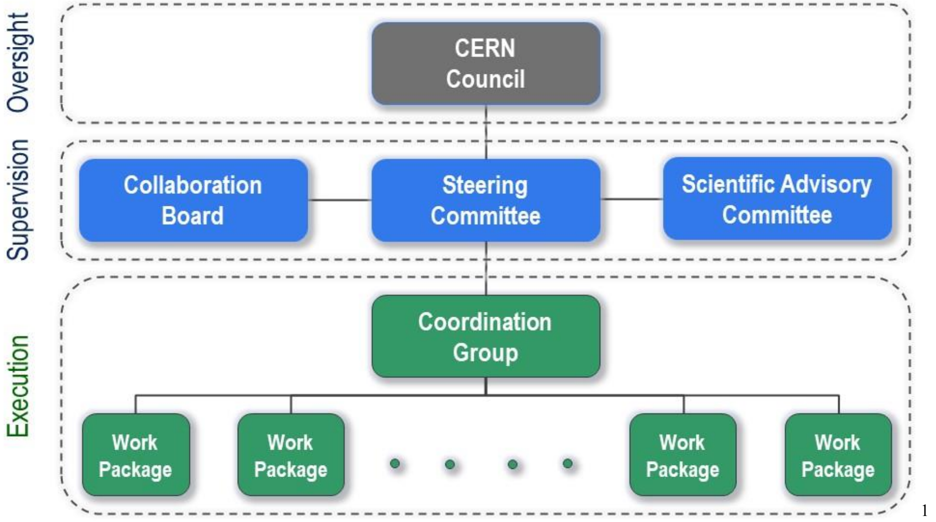
DRD5 collaboration spokesperson

new RDq projects internally evaluated

draft 25/10/22 M. Doser

structure of RDq

example from FCC



Oversight

CERN Council

Supervision

Collaboration Board

Steering Committee

Scientific Advisory Committee

Execution

Coordination Group

Work Package

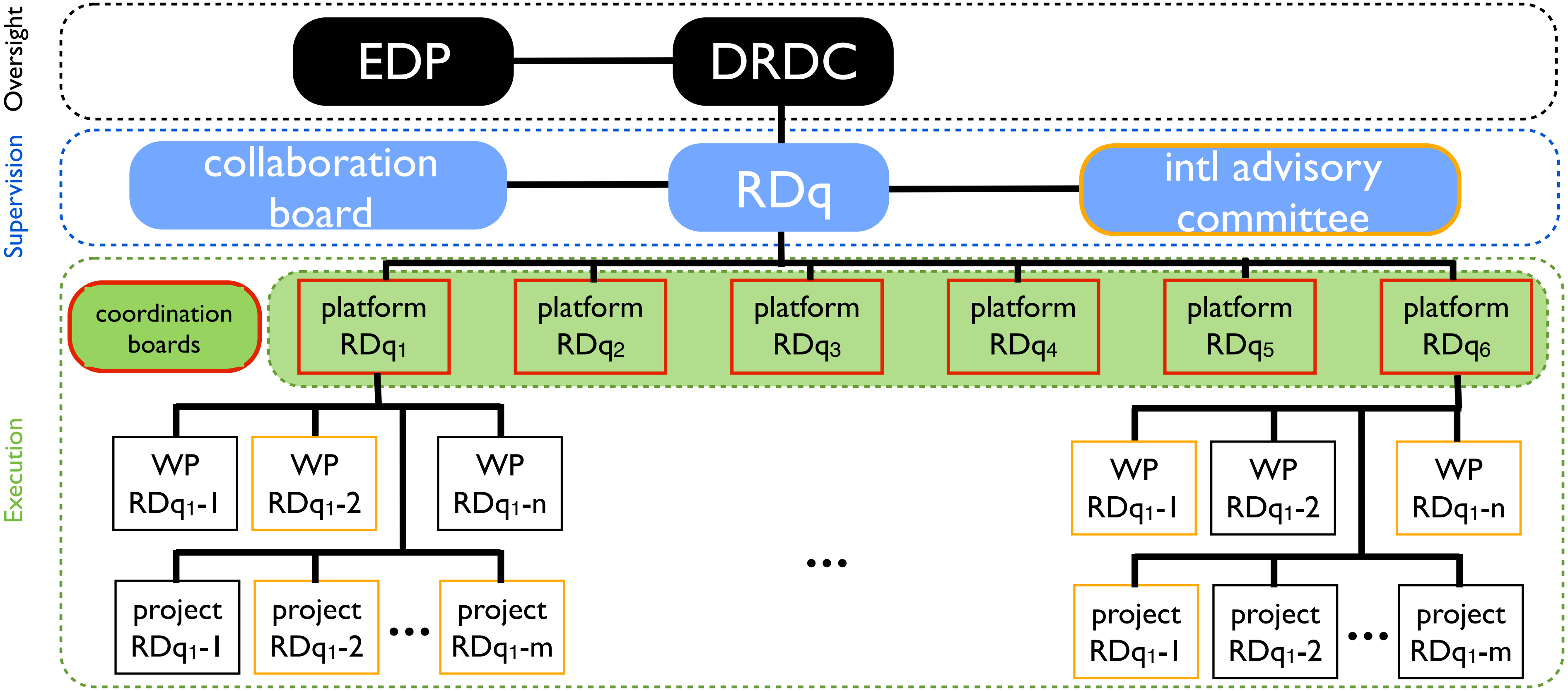
Work Package

Work Package

Work Package

1

https://fcc.web.cern.ch/Documents/Organisation/FCC-1409051000-JGU_GovernanceStructure_V0200.pdf



Oversight

EDP

DRDC

Supervision

collaboration board

RDq

intl advisory committee

Execution

coordination boards

platform RDq$_1$

platform RDq$_2$

platform RDq$_3$

platform RDq$_4$

platform RDq$_5$

platform RDq$_6$

WP RDq$_1$-1

WP RDq$_1$-2

WP RDq$_1$-n

project RDq$_1$-1

project RDq$_1$-2

…

project RDq$_1$-m

…

WP RDq$_1$-1

WP RDq$_1$-2

WP RDq$_1$-n

project RDq$_1$-1

project RDq$_1$-2

…

project RDq$_1$-m

draft 25/10/22 M. Doser

Open symposium organized by TF5

Anna Grassellino, Marcel Demarteau, Michael Doser, Caterina Braggio, Stafford Withington, Peter Graham, John March-Russel, Andrew Geraci

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

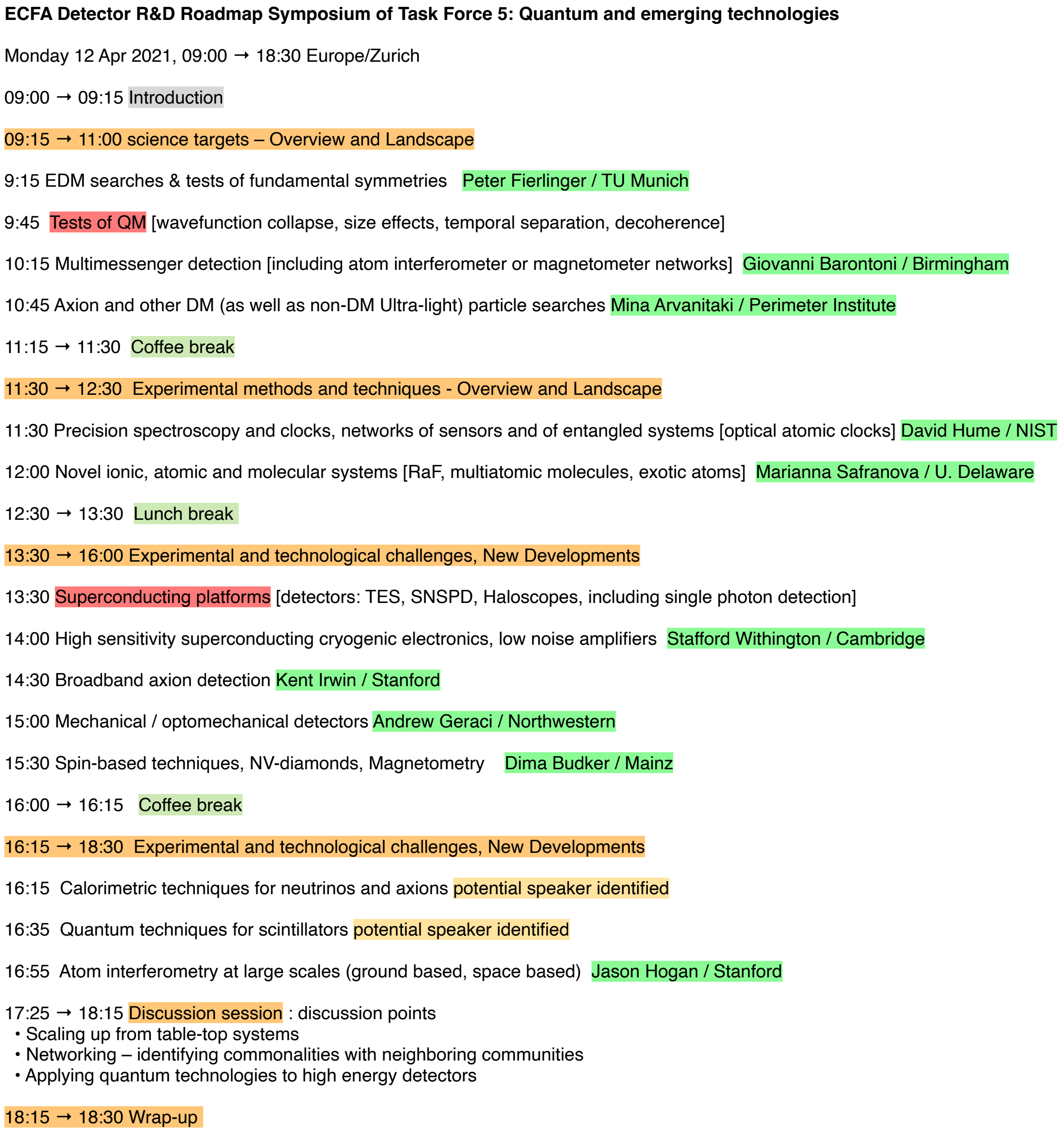
Symposium: April 12, 2021 https://indico.cern.ch/event/999818/

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

Quantum Technologies for High Energy Physics (QT4HEP) (Nov. 1-4, 2022)

https://indico.cern.ch/event/1190278/timetable/

topics chosen to overlap with
CERN focus and expertise

Applications of superconducting technologies to particle detection Caterina Braggio (Univ. Padova (IT))	DM searches via RF, superconducting electronics, coatings, cavities
Scaling up of atomic interferometers for the detection of dark matter Oliver Buchmuller (Imperial College (GB))	AION, MAGIS, ... DM searches via atom interferometers in vertical shafts
Applying traps and clocks to the search for new physics Piet Schmidt (Univ. Hannover / PTB (DE))	AD, ISOLDE: symmetry & BMS tests via precision spectroscopy
Applications of quantum devices to HEP detectors Ian Shipsey (University of Oxford (GB))	Quantum systems for HEP (novel or enhanced detectors)
Molecular systems for tests of fundamental physics Steven Hoekstra (Univ. Groeningen (NL))	AD, ISOLDE: symmetry & BMS tests via precision spectroscopy
Development of detectors for ultra-low energy neutrinos Gianluca Cavoto (Sapienza Universita e INFN, Roma I (IT))	neutrino physics at the low energy frontier (CNB)