DRD5:

A global initiative on R&D on quantum sensors and emerging technologies for particle physics*

Michael Doser, Marcel Demarteau (and *many* contributors)

* spanning from very low energy to high energy particle physics

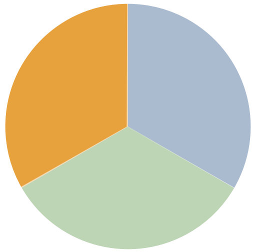
Broad range of application for quantum sensing

Novel designer materials
Extreme sensitivity: candidate techniques for ultra-low interaction energy scales
Gravitational wave detection
Novel types of detectors

Searches for dark matter
Probing of fundamental symmetries (via particle, atomic, molecular EDM's, spectroscopy)
Gravitational waves
Searches for novel couplings

Applied (detectors)

Fundamental physics

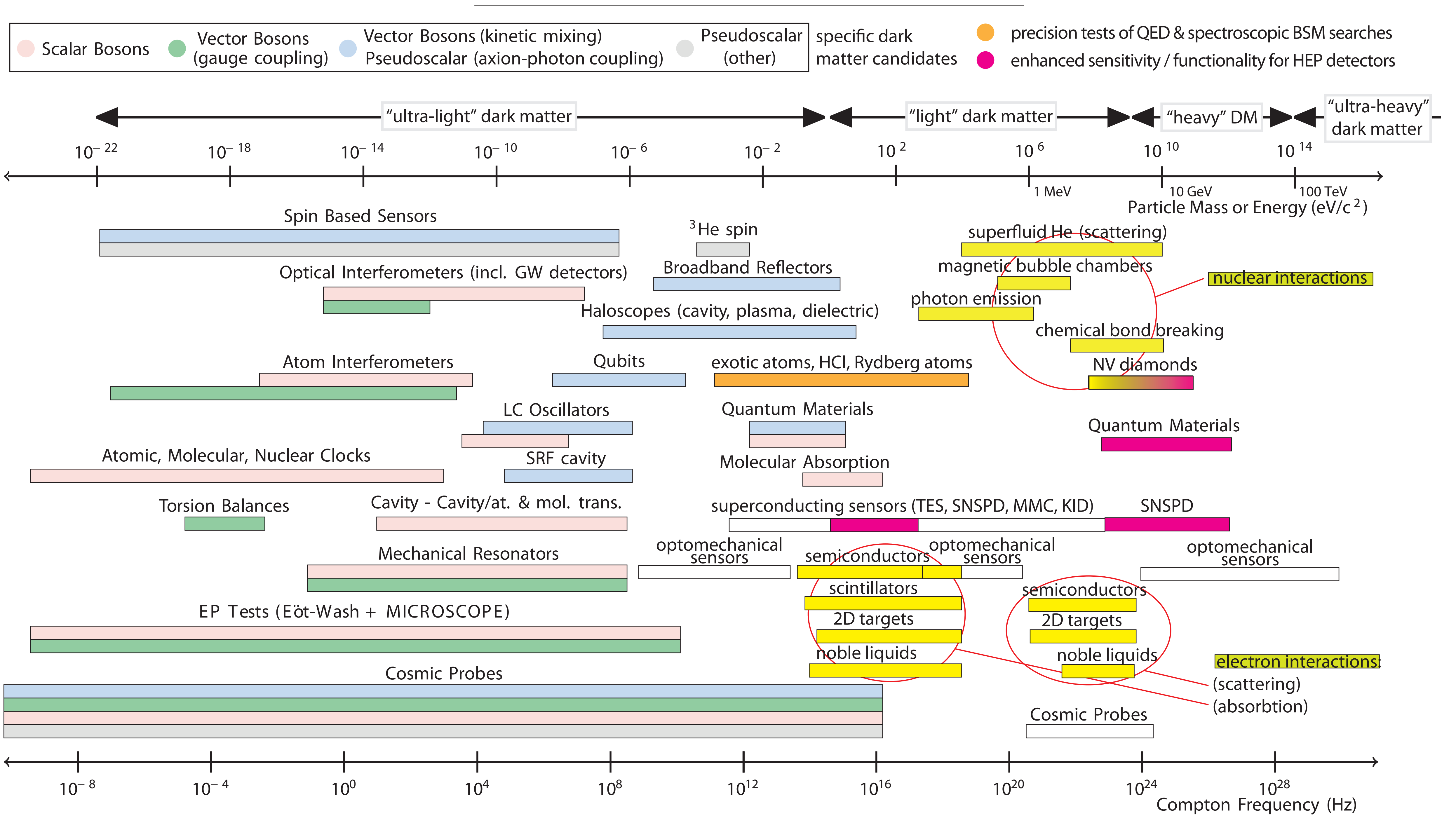


Improved quantum measurements

Tests of fundamental symmetries and interactions
Foundational questions
Exploit full power of Quantum Mechanics

Example: searches for dark matter

Many fundamental physics areas where quantum sensing can have a real impact, but for e.g. UL-DM, QS is essential



Goals of DRD5:

Among the *very* many areas and technologies being worked on worldwide,

- Identify key quantum/emerging technologies (within the ECFA roadmap)

  (*where is collaboration relevant?*)

- Within these, identify key topics which would most benefit the corresponding communities but that are not being addressed because they go beyond what individual groups can tackle

  (*where is collaboration useful?*)

- On these topics, identify groups that are willing to participate in a global collaborative effort

  (*where is collaboration welcome?*)

Challenge 1: non-HEP communities, need to establish trust, mutual interest, benefits for all involved

Challenge 2: need to grow a corresponding community (unlike other DRD's)

Timeline:

2021-2022: ECFA roadmap (*top-down*)

- Identify key quantum/emerging technologies

2023: transform roadmap into proposal (*bottom-up*)

- Identify key figures in the communities → ~30 contributors
- Workshop to identify relevant WP-able groupings (April)
- proto-proposal (September)
- public workshop to fine-tune *WP*'s, *milestones*, *deliverables* (October)
- final proposal formulated and circulated (January '24)
- call for participation (*ongoing*)
- in parallel, constant communication & community building

Our WP deliverables emphasize the initial community building. This forms the necessary basis for the technical specifications that will be required in order to achieve the goal of ultimately producing better devices

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

WP1: Atomic, ionic, nuclear, 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)

(build on existing efforts / roadmaps / interest : involve & mesh with communities such that fundamental physics questions are well integrated)

Visions:

Widely **expanded set of systems and of tools** to form, manipulate and study them (atoms, molecules, ions, trapped nanoparticles; improved production, trapping and cooling techniques)

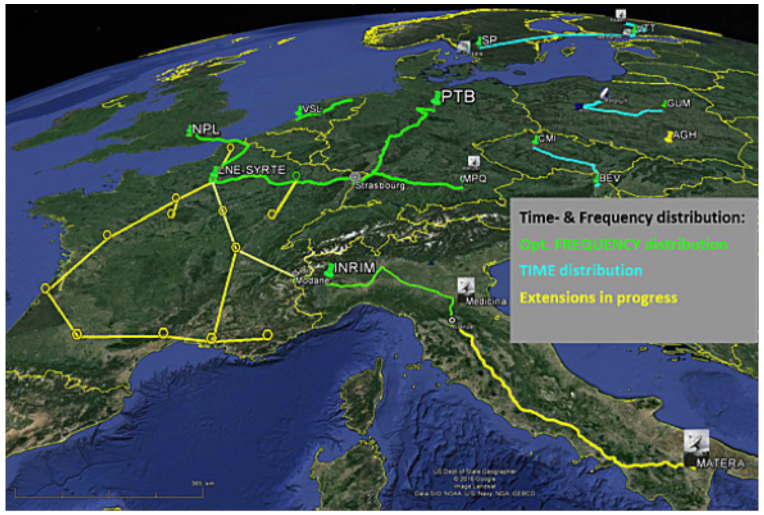
Match (future) experimental precision with **improved precision in theory** for simple 2 or 3 body systems, allowing testing QED, BSM, nuclear properties, fundamental symmetries, in all possible bound systems.

A birds-eye view on the **landscape of well-motivated new physics scenarios** and their effects on different measurements.

At least one **km-scale detector** operational by 2035, and preparation for a space-based atom-interferometry mission

Several orders of magnitude gain in sensitivity by:

- Advance on large momentum transfer techniques
- Increasing the source flux of ultra-cold Rb and Sr atoms
- High repetition rate set-ups
- Deployment of entangled atoms



Global network of high-stability and high-accuracy **clocks**: time-stamping to O(10ps) and distribution of a highly precise continuous clock signals as multiple references

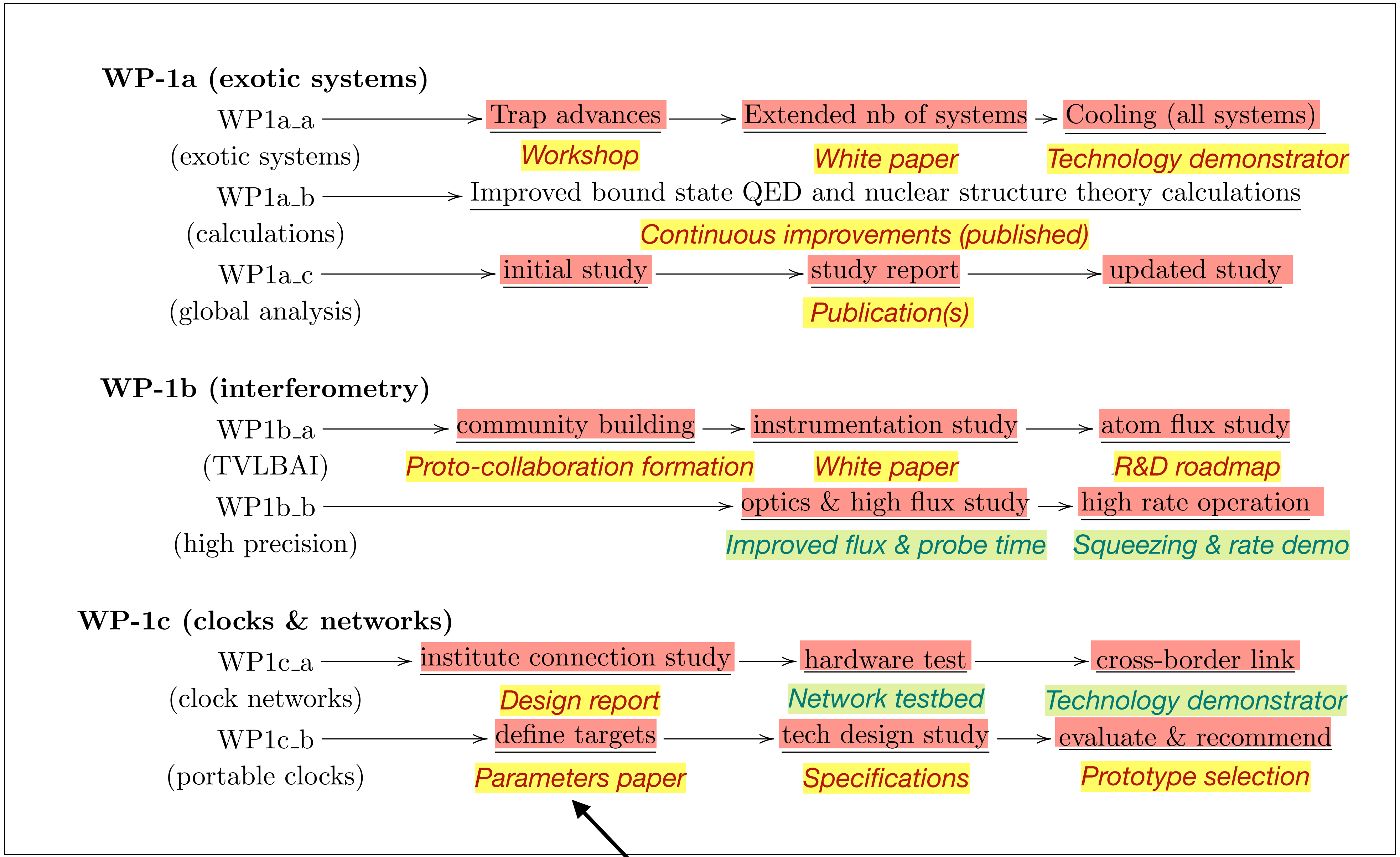
Design and fabrication of **standardized portable references** (neutrals & charged); robust portable trapping systems.

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

Conceptual / organizational developments

Milestones & Deliverables

Technical developments



WP-1a (exotic systems)

WP1a_a (exotic systems)	Trap advances *Workshop*	Extended nb of systems *White paper*	Cooling (all systems) *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 *Publication(s)*	updated study

WP-1b (interferometry)

WP1b_a (TVLBAI)	community building *Proto-collaboration formation*	instrumentation study *White paper*	atom flux study *R&D roadmap*
WP1b_b (high precision)		optics & high flux study *Improved flux & probe time*	high rate operation *Squeezing & rate demo*

WP-1c (clocks & networks)

WP1c_a (clock networks)	institute connection study *Design report*	hardware test *Network testbed*	cross-border link *Technology demonstrator*
WP1c_b (portable clocks)	define targets *Parameters paper*	tech design study *Specifications*	evaluate & recommend *Prototype selection*

Specific example: define the specifications for a real-time clock network

WP2: Quantum materials (0-, 1- & 2-D) materials

(Building blocks for complex nanoscale “quantum materials”)

***WP-2a**: Application-specific tailoring*

Exploring the landscape of possible building blocks of the low dimensional devices:

Quantum dots, nanocrystals, nano-platelets

Nanowires (also WP-3)

Mono-layers, surface deposition, surface treatments (thin films, also of superconductors)

***WP-2b**: Extended functionalities*

Geometries, chemical composition, internal layout, environment: all play a role in shaping the properties of individual elements;

***WP-2c**: Simulations*

Simulation packages need to go beyond the assumption of continuous media (G4) and incorporate processes at the local molecular scale;

Visions:

Optimized engineering for specific applications (e.g. scintillators)

Radiation hardness

Extensive **overview** of what the **design landscape** enables on one hand, and what detector design benefits from.

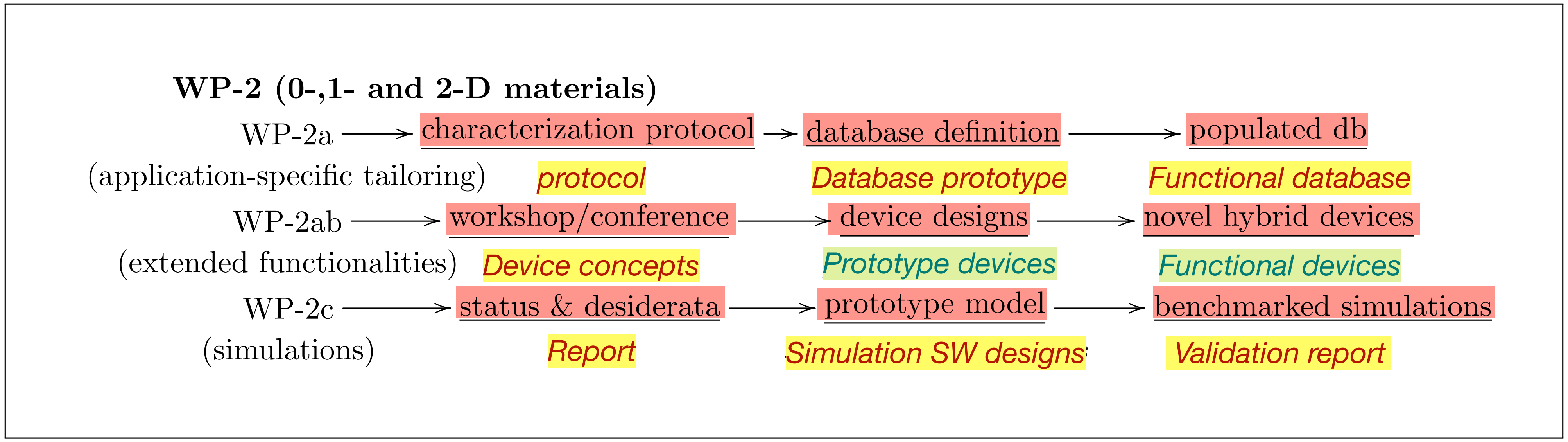
Full understanding of performance requires accounting for interactions between the building blocks and their environment.

Engineering of the building blocks of **arbitrary nanocomposite material**

WP2: Quantum materials (0-, 1- & 2-D) materials

(Building blocks for complex nanoscale “quantum materials”)

Milestones & Deliverables



WP-2 (0-,1- and 2-D materials)

WP-2a	→ characterization protocol	→ database definition	→ populated db
(application-specific tailoring)	*protocol*	*Database prototype*	*Functional database*
WP-2ab	→ workshop/conference	→ device designs	→ novel hybrid devices
(extended functionalities)	*Device concepts*	*Prototype devices*	*Functional devices*
WP-2c	→ status & desiderata	→ prototype model	→ benchmarked simulations
(simulations)	*Report*	*Simulation SW designs*	*Validation report*

WP3: Cryogenic materials, devices & systems

WP-3a: The 4K stage

Optimized, standardized and robust electronics for superconducting devices with minimal degradation of performance (ultra-low-noise amplifiers, arrayable high dynamic range amplifiers, integrated system building blocks, multiplexing for mega-pixel devices)

WP-3b: Cryogenic quantum sensors for particle and photon detection

Improved devices for photon and massive particle detection;

improved modeling of charged-particle impact on full devices;

address need for a forest of high-resolution calibration lines between 50 keV and 300 keV

WP 3c: Resilient integration of superconducting systems

Go beyond rule-of-thumb approaches to allow development, use and scaling up by numerous groups

Visions:

Library of validated modules

Fabrication of **large arrays** of such devices beyond the existing photon sensors

Investigation of role of **high-Tc superconductors** for HEP applications

Optimized, standardized and robust **packaging approaches**; shielding against stray light, EMI, magnetic fields, operation in harsh environments; optimal thermal design

WP3: Cryogenic materials, devices & systems

Milestones & Deliverables

WP-3 (Cryogenic systems)

WP3a → design 4K ASIC → fabrication 4K ASIC → library release
(electronics at the 4K stage) *Tape out* *4K ASIC* *Library*

WP3b → prototype beam tests → specifications → integration in experiment
(calorimetry, tracking) *Characterization* *Test beam* *Operation of multi-channel SC detector in beam*

WP3c → identification of challenges → specification → delivery
(resilient integration) *System design* *Readout developed* *Multi-channel detector system*

WP4: Scaling up Quantum ("bulkification")

***WP-4a**: Massive spin polarized ensembles*

Large ensembles of spin-polarized samples:

***WP-4b**: Hybrid devices*

WP-4b a: Scintillators

WP 4b b: Ensembles of heterostructures

WP-4b c: Heterodox devices

***WP-4c**: Opto-Mechanical Sensors*

Bulk systems of quantum-behavior exhibiting individual elements: levitated nanospheres, levitated torque sensors, arrays of cantilevered detectors, superfluid He sensors whose detection modality (mechanical) is different from the readout modality (optical)

Visions:

Go beyond building blocks

Optimization of polarization:

- Levitated ferromagnetic torque sensors
- Molecules with radio-isotopes (for EDM searches)
- High-spin-polarization “targets” and “scattering planes” for HEP
- High-spin-polarization ensembles for spin-dependent interactions

HEP (Scintillators): full optimization of the complete chain: not just of the quantum dots but also of surface treatments, novel types of scintillators (e.g. quantum wells in semiconductors), embedding materials and photon detection

Composite structures engineered for optimal performance and potentially combining different dimensionalities or compositions or geometries (work-function engineering, fine-tuning of charge transport in gaseous detectors, …)

Novel types of devices that use individual quantum elements to engineer new types of behavior, e.g. QCL coupled to silicon strip detectors.

Optimization of sensors & interconnects

WP4: Scaling up Quantum ("bulkification")

Milestones & Deliverables

WP-4a (spin-polarized ensembles)

WP4a → map of polarizable systems → better polarizability → bulk high polarization

Workshop / report — *Prototype*

WP-4b (Hybrid systems)

WP4b_a → overview of technologies → focus on HEP-relevance → lab/beam tests

(Engineering at the nanoscale) *Report* — *Technology selection*

WP4b_b → tests of existing blocks → engineering proposals → prototype tests

(bulk heterostructures) *Report: outcomes / challenges*

WP4b_c → conceptual studies → feasibility studies → prototypes

(heterodox devices) *Workshop on device concepts*

WP-4c (opto-mechanical sensors)

WP4c → sensor optimization → coherent interconnects → quantum network

Workshop

WP5: Quantum techniques for sensing

***WP-5a**: Squeezing*

- opto-mechanical resonators
- Atom interferometers

Need: versatile and scalable sources of squeezed light

***WP-5b**: Back action evasion*

Develop a *theoretical framework* for implementation in experiments beyond gravitational wave experiments

Perform *proof-of-principle experiments* as validation

***WP-5c**: Entanglement*

(Applicability to HE particle physics?)

***WP-5d**: Optimization of physics reach*

theoretical exploration of landscape

Visions:

Beyond gravitational wave detection: other systems

Extraction of information without modifying the observed system

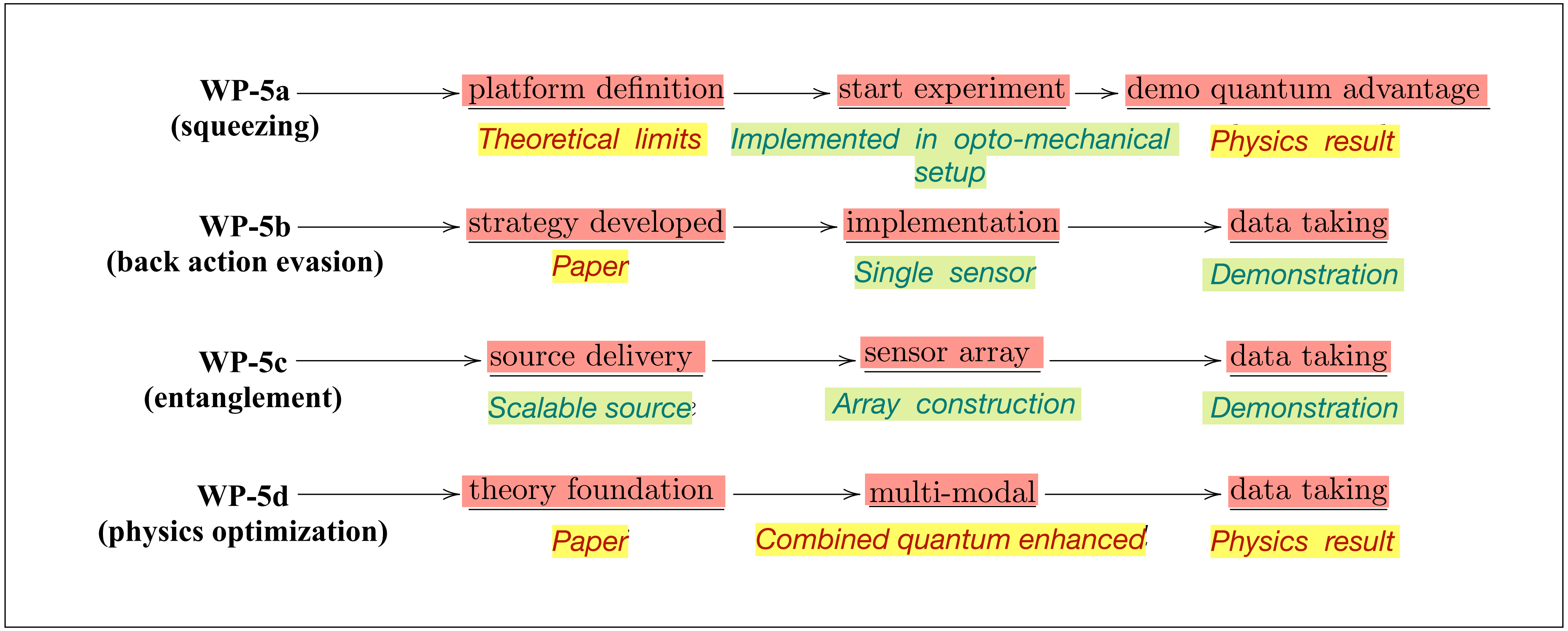
Beyond two-sensor entanglement:

- scaling up to networks of sensors
- distribution of entanglement over networks

How far can one go?

WP5: Quantum techniques for sensing

Milestones & Deliverables



WP-5a **(squeezing)**	platform definition *Theoretical limits*	start experiment *Implemented in opto-mechanical setup*	demo quantum advantage *Physics result*
WP-5b **(back action evasion)**	strategy developed *Paper*	implementation *Single sensor*	data taking *Demonstration*
WP-5c **(entanglement)**	source delivery *Scalable source*	sensor array *Array construction*	data taking *Demonstration*
WP-5d **(physics optimization)**	theory foundation *Paper*	multi-modal *Combined quantum enhanced*	data taking *Physics result*

WP6: Capacity building

***WP-6a**: Education platforms*

Quantum Sensing and Technology Schools

Education based on micro-credentials

***WP-6b**: Exchange platforms*

Cross-disciplinary contacts & exchanges

***WP-6c**: Shared infrastructures*

Optimization of existing facilities

Visions:

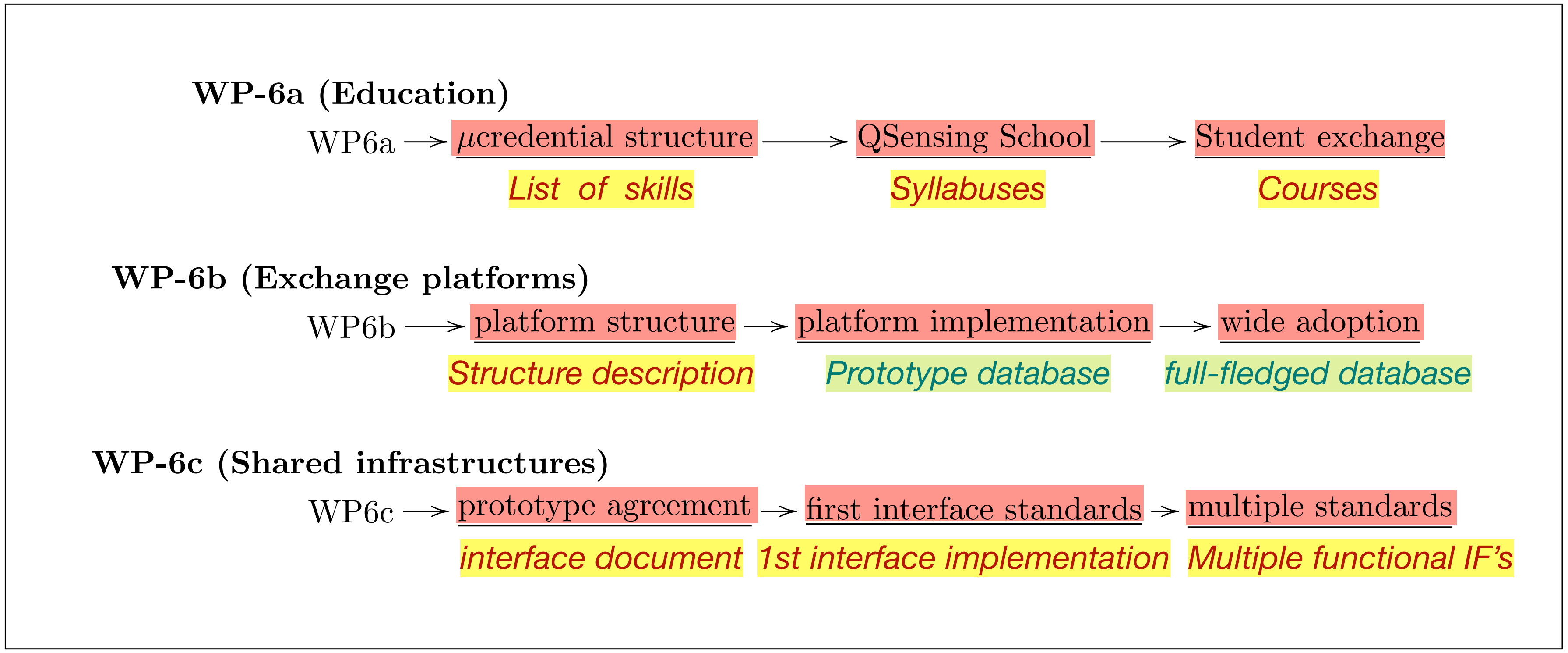
Growing a workforce of quantum technology savvy individuals, both for research and for society

Sharing and exchange of expertise and of research questions / opportunities

Sharing of infrastructures (test beams, dilution refrigerators, fab labs, …) via agreed-upon standardized protocols

WP6: Capacity building

Milestones & Deliverables



WP-6a (Education)

WP6a → μcredential structure → QSensing School → Student exchange

List of skills · *Syllabuses* · *Courses*

WP-6b (Exchange platforms)

WP6b → platform structure → platform implementation → wide adoption

Structure description · *Prototype database* · *full-fledged database*

WP-6c (Shared infrastructures)

WP6c → prototype agreement → first interface standards → multiple standards

interface document · *1st interface implementation* · *Multiple functional IF's*

Cross-WP and DRD synergies

work package	WP-1	WP-2	WP-3	WP-4	WP-5	WP-6
WP 1 (Quantum systems in traps and beams)	-					
WP 2 (Quantum materials: 0-, 1- and 2-D)	?	-				
WP 3 (Superconducting quantum devices)	?	X	-			
WP 4 (Scaled-up bulk systems for mip's)		X	X	-		
WP 5 (Quantum techniques)	X	?	X	?	-	
WP 6 (Capacity building)	X	X	X	X	X	-

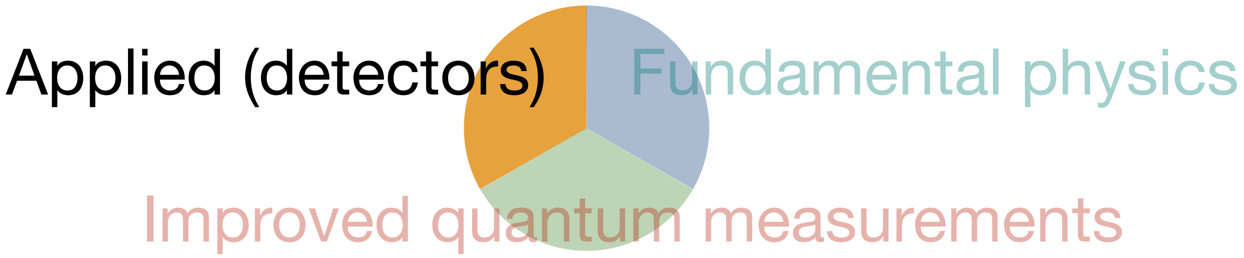
WP-WP cross-influences and impacts

	Gaseous detectors	Liquid detectors	Solid state detectors	Photon detectors & PID	Calorimetry	Electronics/on-detector proc.	Integration	Training
work package	DRD1	DRD2	DRD3	DRD4	DRD6	DRD7	DRD8	DRD9
WP 1 (Quantum systems in traps and beams)	X			X				
WP 2 (Quantum materials: 0-, 1- and 2-D)		X	X		X			
WP 3 (Superconducting quantum devices)			X	X		X		
WP 4 (Scaled-up bulk systems for mip's)			X					
WP 5 (Quantum techniques)								
WP 6 (Capacity building)	X	X	X	X	X	X	X	X

cross-DRD influences and impacts

Potential HEP impact

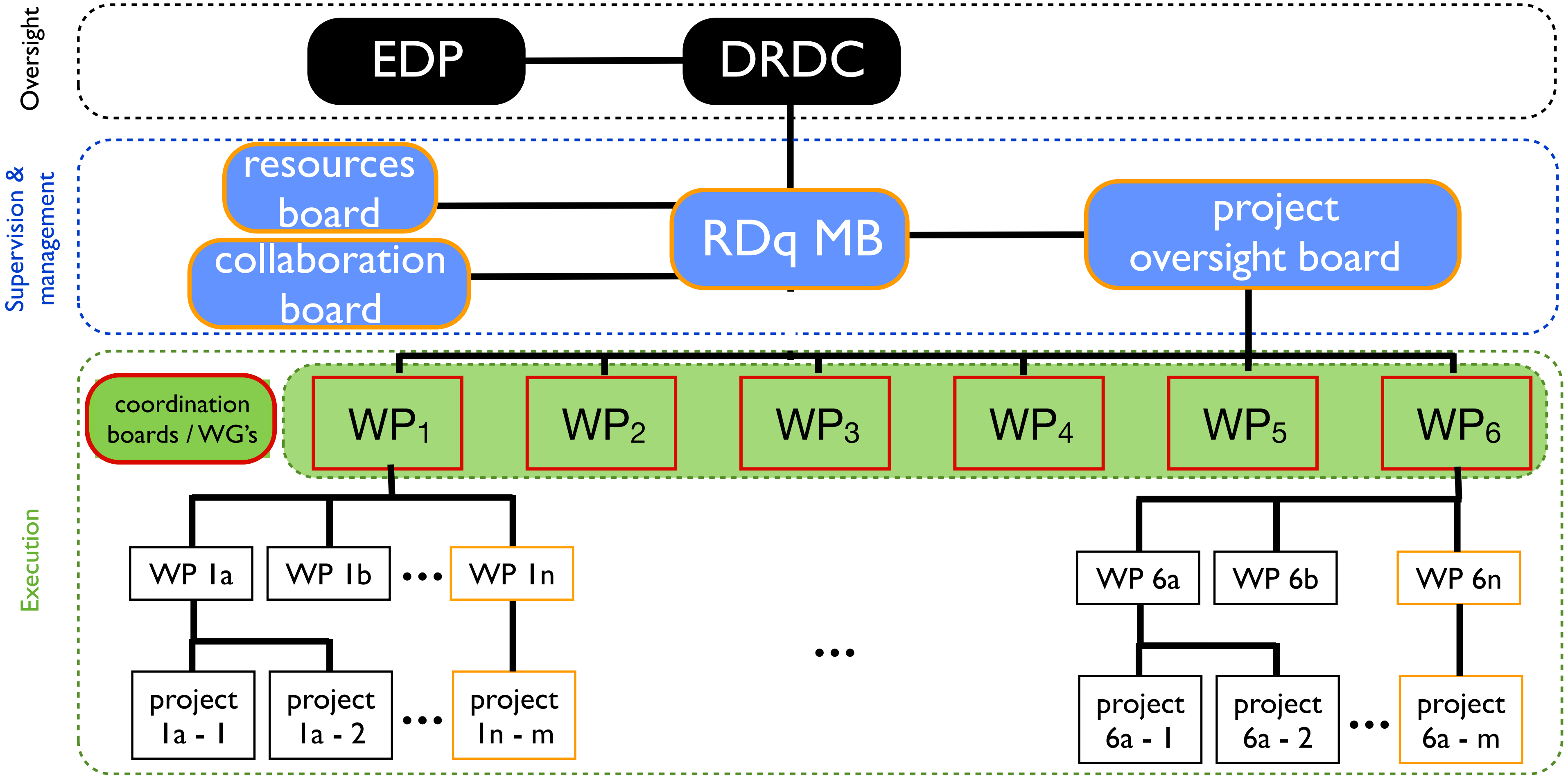
(Colliders, fixed targets)



HEP function / Work package	Tracking	Calorimetry	Timing	PID	Helicity
WP 1 (Quantum systems in traps and beam)	Rydberg TPC	BEC WIMP scattering (recoil)	O(fs) reference clock for time-sensitive synchronization (photon TOF)	Rydberg dE/dx amplifiers	
WP2 (Quantum materials: 0-, 1- and 2-D)	"DotPix"; improved GEM's; chromatic tracking (sub-pixel); active scintillators	Chromatic calorimetry	Suspended / embedded quantum dot scintillators	Photonic dE/dx through suspended quantum dots in TPC	
WP 3 (Superconducting quantum devices)	O(ps) SNSPD trackers for diffractive scattering (Roman pot)	FIR, UV & x-ray calorimetry	O(ps) high Tc SNSPD	Milli- & microcharged particle trackers in beam dumps	
WP 4 (scaled-up bulk systems for mip's)	Multi-mode trackers (electrons, photons)	Multi-mode calorimeters (electrons, photons, phonons)	Wavefront detection (e.g. O(ps) embedded devices)		Helicity detector via ultra-thin NV optically polarized scattering / tracking stack
WP 5 (Quantum techniques)				Many-to-one entanglement detection of interaction	
WP 6 (capacity building)	Technical expertise of future workforce (detector construction); broadened career prospects and thus enhanced attractiveness; cross-departmental networking and collaboration; broadened user base for infrastructure (beam tests, dilution refrigerators, processing technologies)				

(under way; in preparation; under discussion or imaginable applications; long-range potential)

Structure of DRD5:


Oversight

EDP

DRDC

Supervision & management

resources board

collaboration board

RDq MB

project oversight board

Execution

coordination boards / WG's

WP$_1$ WP$_2$ WP$_3$ WP$_4$ WP$_5$ WP$_6$

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

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)

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

96 groups (as of 3.6.2024)

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
Univ. Claude Bernard Lyon

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

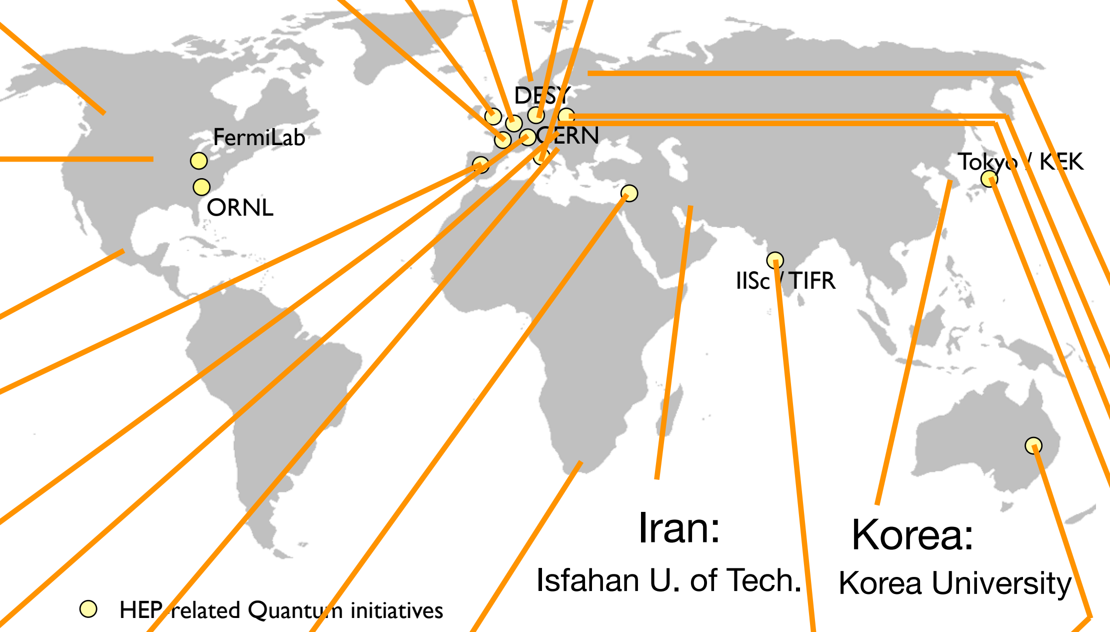
Mexico:
U. de Aguascalientes

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.

Korea:
Korea University

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

Australia:
University of Queensland
University of Western Australia
Swinburne University of Technology

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

Japan:
QUP / KEK
Kyoto University
Tokyo University / ICEPP

Participants per WP and total (as of 3.6.2024)

University / Lab.	Country	WP1	WP2	WP3	WP4	WP5	WP6	People
University of Queensland	**Australia**							1
University of Western Australia	**Australia**				X			1
Swinburne Univ. of Technology	**Australia**			X				3
IQOQI Vienna	**Austria**	X		X	X	X	X	2
McGill University	**Canada**	X			X	X		1
TRIUMF	**Canada**	X				X		1
Institute of Physics, Zagreb	**Croatia**	X						6
Czech Technical University	**Czech Rep.**		X	X				2
VTT	**Finland**	X		X				2
Helsinki Inst. Physics	**Finland**		X		X			8
OBSPM / SYRTE	**France**	X			X	X		1
CNRS-Université Sorbonne Paris Nord	**France**	X			X	X		6
Laboratoire Keller Brossel, Paris	**France**			X				3
University Claude Bernard Lyon1 - CNRS (ILM)	**France**		X		X		X	3
University Ulm	**Germany**	X				X		1
Leibnitz Universität Hannover	**Germany**	X				X		3
PTB	**Germany**	X						2
DESY	**Germany**	X	X	X	X	X	X	21
HU Berlin	**Germany**	X						1
FBH Berlin	**Germany**	X						1
University Düsseldorf	**Germany**	X						1
Universität Bremen / ZARM	**Germany**	X			X			2
TU Darmstadt	**Germany**	X				X		2
KIT, Karlsruhe	**Germany**			X				2
TU Munich	**Germany**			X				3
MPP Garching	**Germany**			X				7
University of Heidelberg	**Germany**		X	X				1
University of Mainz	**Germany**							1
Universität Tübingen	**Germany**				X			1
Semiconductor Lab HLL / MPG	**Germany**			X				4
IITTP, Tirupati	**India**	X						3
Indian Inst. of Science Ed. and Research (IISER),Kolkata	**India**		X		X			6
TIFR, Mumbai	**India**		X	X	X			1
University of SOA, Bhubaneswar	**India**				X			2
Isfahan University of Technology	**Iran**	X	X	X		X	X	7
Technion IIT, Haifa	**Israel**	X		X				1
University / INFN - Florence	**Italy**	X	X		X		X	6
Fondazione Bruno Kessler Trento	**Italy**	X	X	X	X	X	X	13
Univ. of Napoli	**Italy**	X		X				6
University of Pisa and INFN	**Italy**		X	X	X	X	X	10
University / INFN - Pavia	**Italy**		X	X	X	X	X	14
INFN Padova	**Italy**			X				3
INFN LNF	**Italy**			X		X		3
INFN TIFPA (Trento)	**Italy**					X		3
INFN Lecce	**Italy**		X					9
INFN Torino	**Italy**				X	X		11
INFN LNL	**Italy**		X		X			3
INFN Roma 1	**Italy**			X		X	X	6
University / INFN Milano-Bicocca	**Italy**		X	X	X			6

University / Lab.	Country	WP1	WP2	WP3	WP4	WP5	WP6	People
IOM CNR & Elettra Sincrotrone, Trieste	**Italy**		X		X			3
University / Politecnico / INFN - Bari	**Italy**		X			X		10
Univ. Roma 1 (Sapienza)	**Italy**		X					2
Univ. Roma 3	**Italy**		X					1
Univ. of Napoli	**Italy**	X		X				6
CNR-SPIN Institute	**Italy**			X	X			1
INFN Roma Tor Vergata	**Italy**		X	X	X	X		7
University of Camerino	**Italy**		X	X	X			5
QUP / KEK	**Japan**			X			X	4
UTokyo / ICEPP	**Japan**			X		X		2
Kyoto University	**Japan**			X		X		1
Korea University	**Korea**	X						3
Universidad de Aguascalientes	**Mexico**	X						1
University of Groningen	**Netherlands**	X			X	X	X	1
Univ. of Oslo	**Norway**		X			X		2
Warsaw University of Technology	**Poland**	X	X	X	X	X	X	7
National Centre for Nuclear Research in Warsaw	**Poland**	X				X	X	1
National Laboratory FAMO / Torun	**Poland**	X				X	X	3
University of Cape Town	**South Africa**		X					2
University Zaragoza	**Spain**					X		4
IFIC (CSIC - University of Valencia)	**Spain**			X		X		1
University of Lleida	**Spain**	X				X		1
Universidad de Cartagena	**Spain**			X				3
University of Stockholm	**Sweden**							1
University of Geneva	**Switzerland**			X				1
University of Zürich	**Switzerland**			X				7
ETHZ	**Switzerland**	X						1
CERN	**Switzerland**	X	X	X	X	X	X	4
Oxford University	**UK**	X		X		X	X	5
University of Warwick	**UK**	X			X	X		5
University of Birmingham	**UK**	X						2
NPL	**UK**	X						5
University of Southhampton	**UK**	X			X	X		4
Imperial College	**UK**	X		X		X		7
University of Sussex	**UK**	X		X		X		7
Arizona State University	**USA**			X	X			3
University of Arizona	**USA**				X	X		1
UCLA	**USA**	X	X		X	X		2
MIT	**USA**	X						1
Northwestern University	**USA**	X		X	X	X		1
Yale	**USA**	X			X	X	X	2
ORNL	**USA**		X		X	X	X	3
Caltech	**USA**							2
NIST, Time and Frequency Division	**USA**	X						3
LBNL	**USA**	X	X	X	X	X	X	3
Univ. of Delaware	**USA**							1
FNAL	**USA**			X		X		1
SLAC	**USA**	X						1

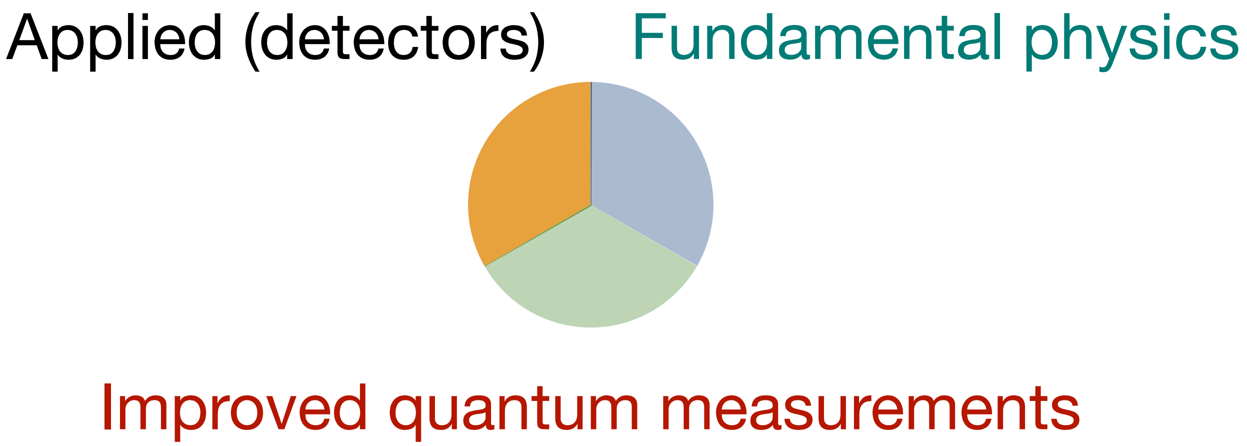
344 participants

Tabulation of FTE / WP

Total number of institutes (as of 3.6.2024): 96

Total number of participants (as of 3.6.2024): 344 (= 100 FTE, assuming 30% scaling)

	FTE	Total number of institutes
WP 1	21	45
WP 2	16	26
WP 3	18	40
WP 4	19	35
WP 5	18	42
WP 6	9	18



Widespread (geographically and community-wise) interest & participation

Conclusions:

- thanks to the involvement of key figures in the different Quantum Sensor and emerging technologies communities, we have identified a number of areas where the DRD5 collaboration can provide an added value to both particle physics and quantum technology activities

- we have formulated WP's, milestones and deliverables in such a form that they are reasonable and acceptable to those communities

- we have started the process of growing a community; this process will require *time* and *trust*, both among the participants, but also from the side of the involved institutions (DRDC, CERN). It is also an ongoing process that will rely on successfully implementing first milestones in form of workshops, reports, agreements *and* technical co-developments

- we believe that the widespread response indicates that this endeavor addresses a real need and can build on an understanding that a CERN-style collaborative approach *can* benefit the different communities, as long as their idiosyncrasies are understood and accommodated

This is a nascent area of research for HEP. Our efforts at this early stage already indicate strong interest from the communities. As is the tradition of CERN, we hope that DRD5 will be embraced by the DRDC given the potential for significant contributions to the field at large