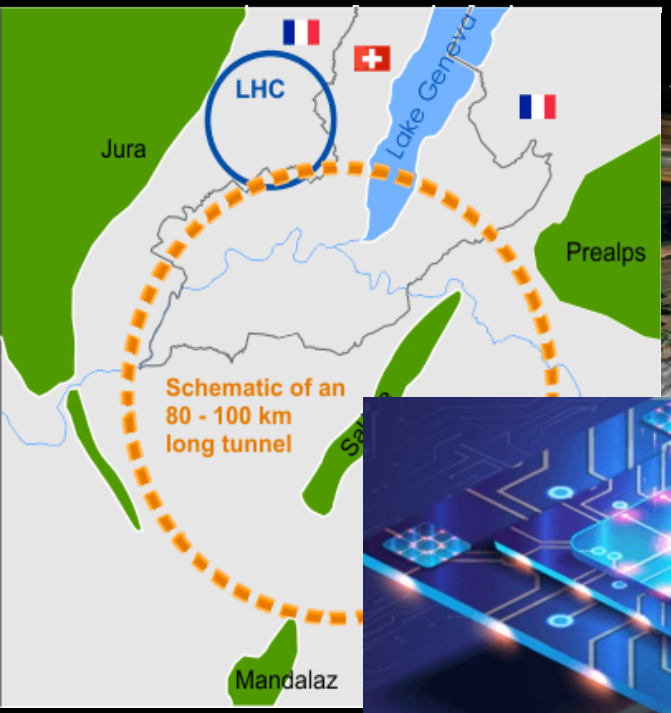
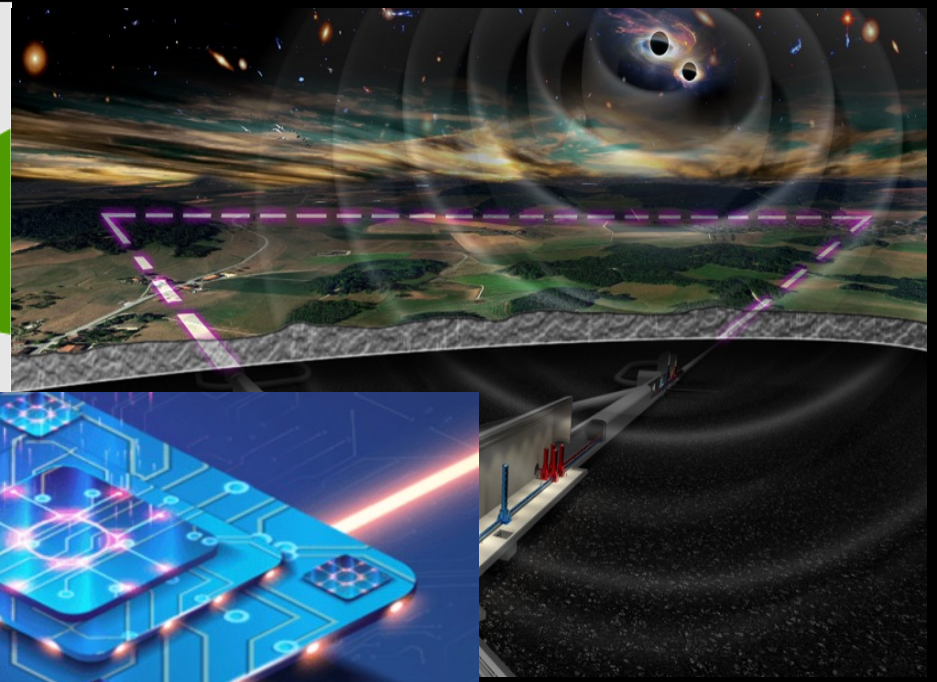
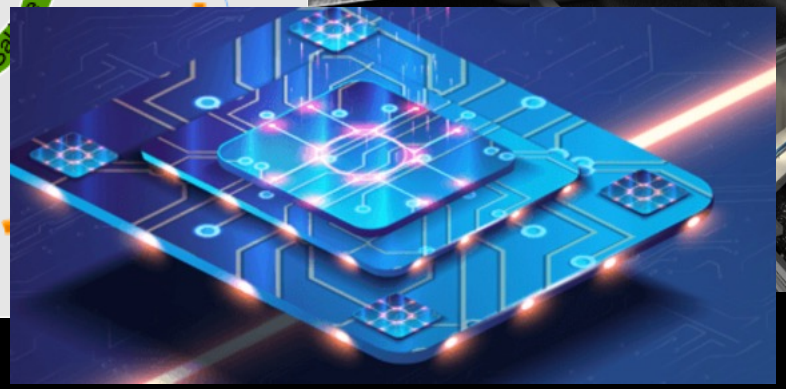
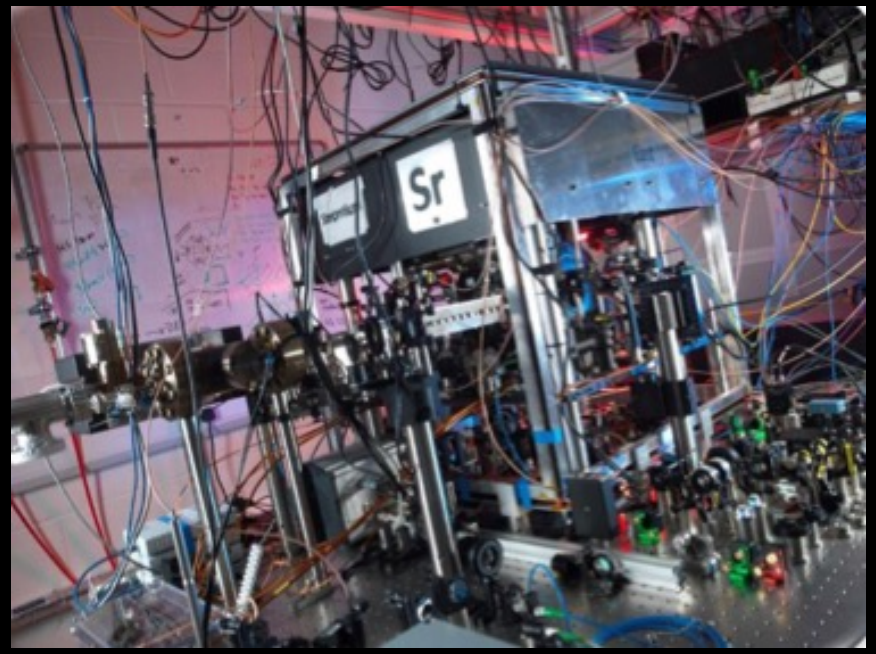
The Great Questions in Fundamental Physics and the Detector Technologies to Address them via the ECFA Detector Roadmap









Ian Shipsey,
Oxford University
(ECFA Roadmap co-coordinator)

Opportunities for Discovery

Many mysteries to date go unanswered including:

The mystery of the Higgs boson

The mystery of Neutrinos

The mystery of Dark Matter

They mystery of Dark Energy

The mystery of quarks and charged leptons

The mystery of Matter – anti-Matter asymmetry

The mystery of the Hierarchy Problem

The mystery of the Families of Particles

The mystery of Inflation

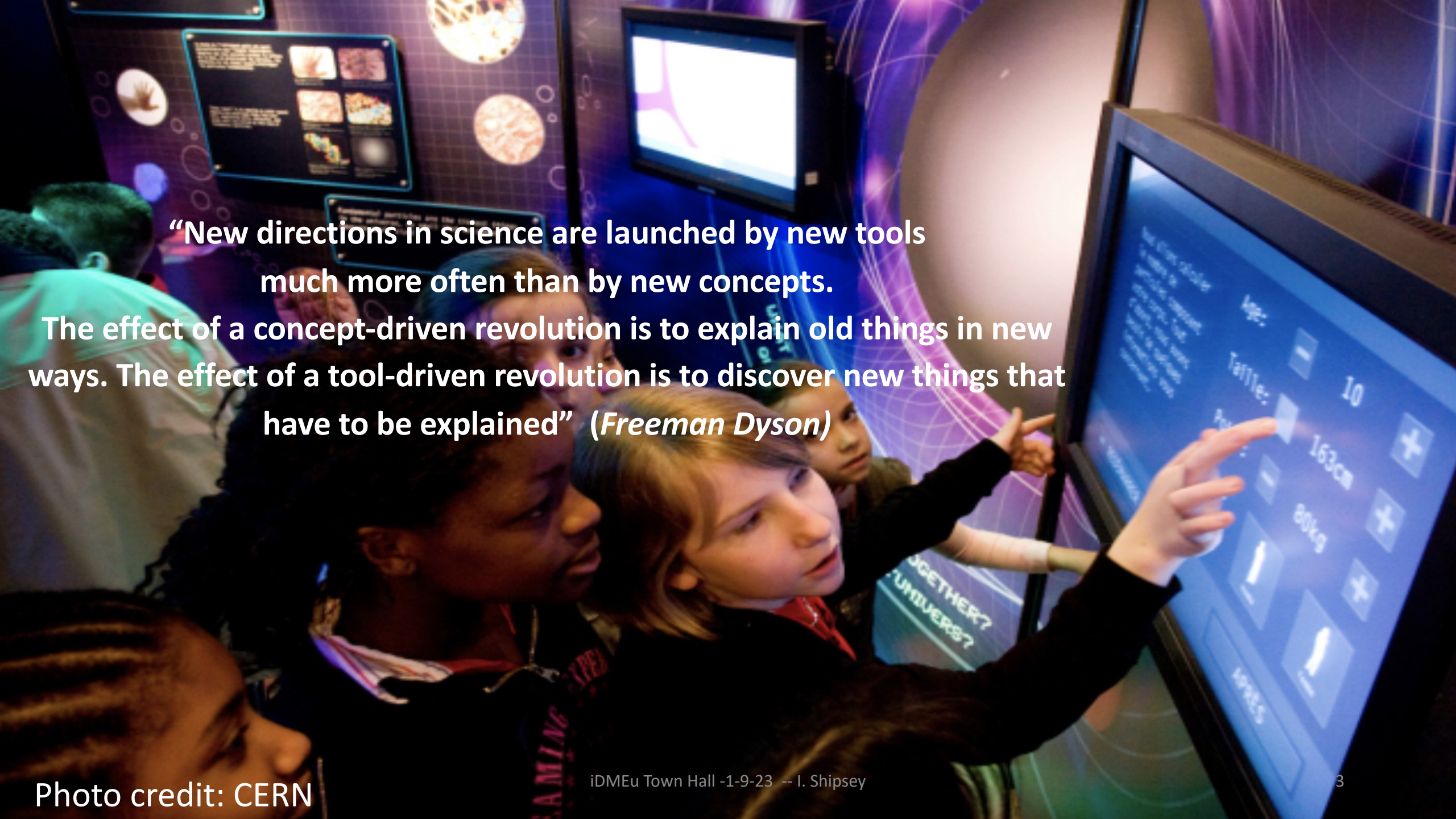
The mystery of Gravity

How do quarks and gluons give rise to the properties of nuclei

The mystery of the origin and engine of high energy cosmic particles

Multiple theoretical solutions – experiment must guide the way

We are very much in a data driven era for which we need new tools!



“New directions in science are launched by new tools much more often than by new concepts. The effect of a concept-driven revolution is to explain old things in new ways. The effect of a tool-driven revolution is to discover new things that have to be explained” (*Freeman Dyson)*

Photo credit: CERN

“Measure what is measurable, and make measurable what is not so” (*Galileo Galilei)*

Photo credit: CERN

Most recent European Strategies

the large …

weblink

2017-2026 European Astroparticle Physics Strategy

… the connection …

weblink

Long Range Plan 2017 Perspectives in Nuclear Physics

… the small

weblink

2020 Update of the European Particle Physics Strategy

Are community driven strategies outlining our ambition to address compelling open questions

Guidance for funding authorities to develop resource-loaded research programmes

the update of the European Strategy for Particle Physics, recognizing the primacy of instrumentation, called on the community via ECFA to define a global detector R&D roadmap

Most recent European Strategies

the large …

weblink

2017-2026 European Astroparticle Physics Strategy

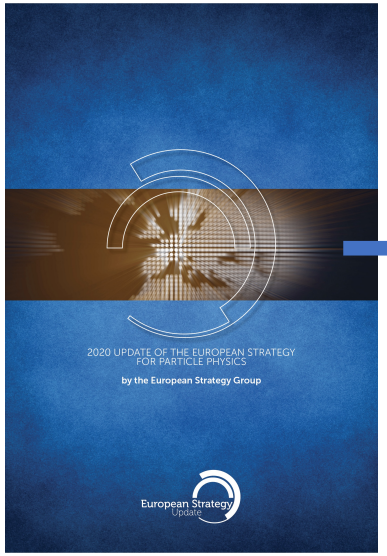
… the connection …

weblink

Long Range Plan 2017 Perspectives in Nuclear Physics

… the small

weblink

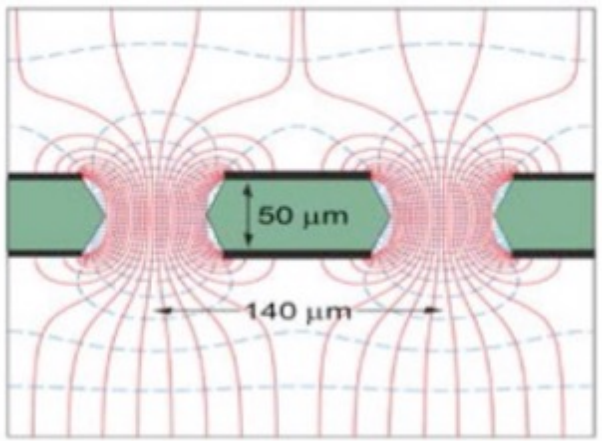


2020 Update of the European Particle Physics Strategy

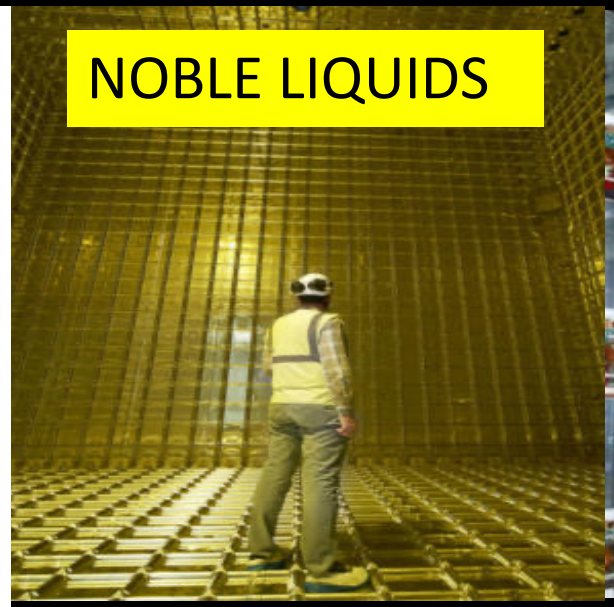
ECFA Detector R&D Roadmap

Technology Classification for the ECFA R&D Roadmap

GASEOUS



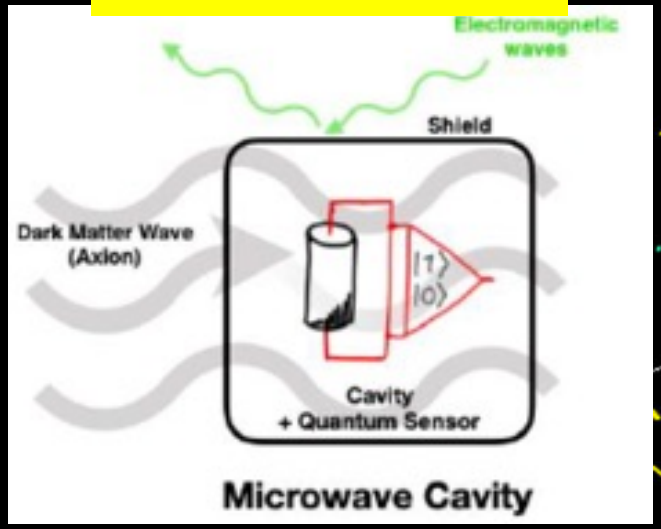
NOBLE LIQUIDS



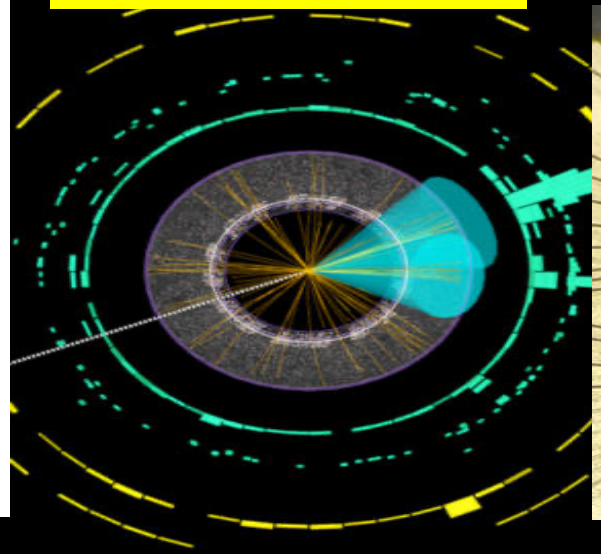
SOLID STATE

PHOTODETECTORS

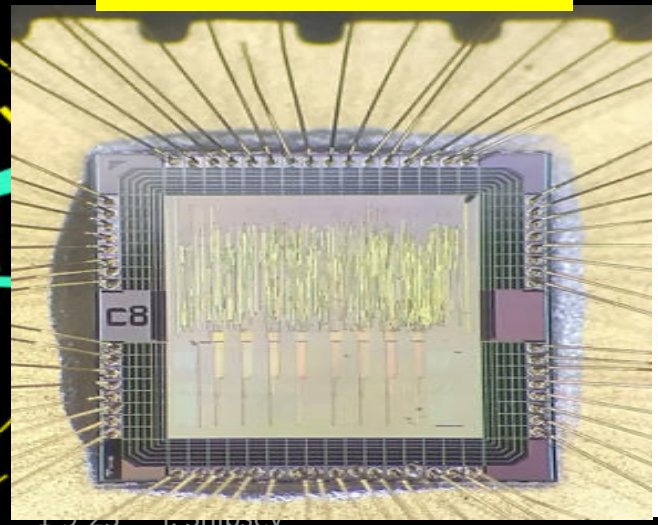
QUANTUM



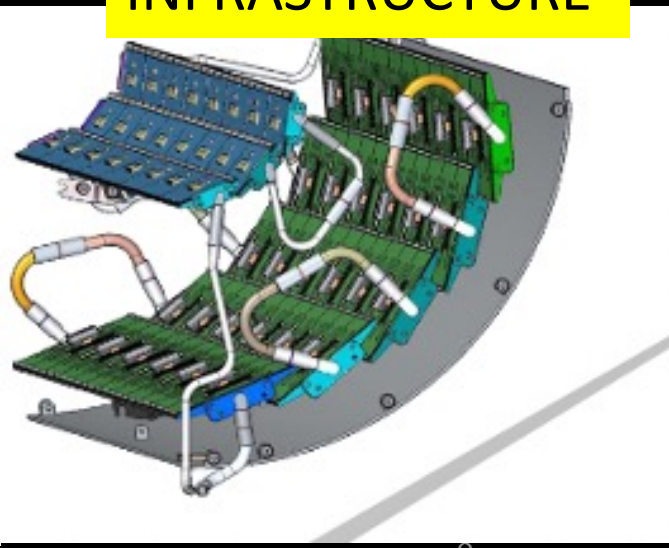
CALORIMETER



ELECTRONICS

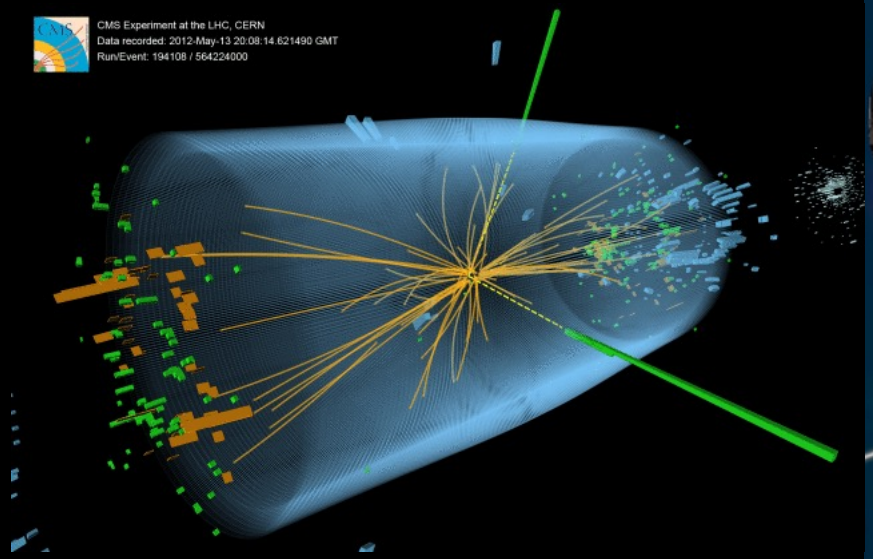


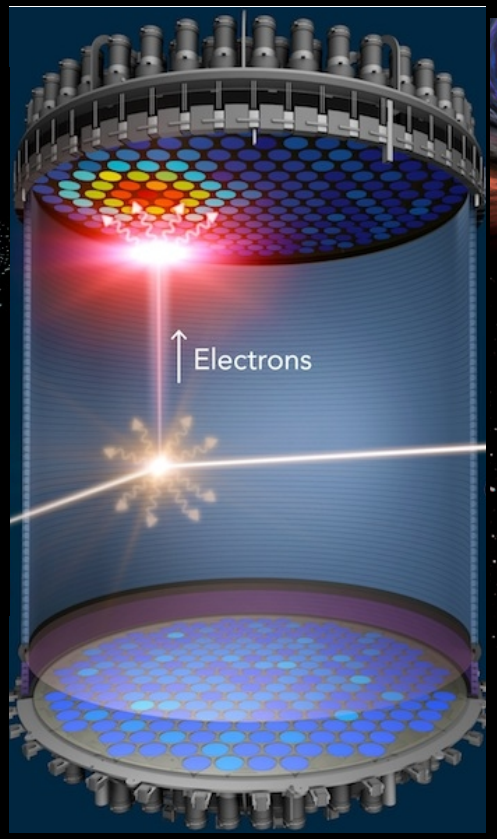
INFRASTRUCTURE

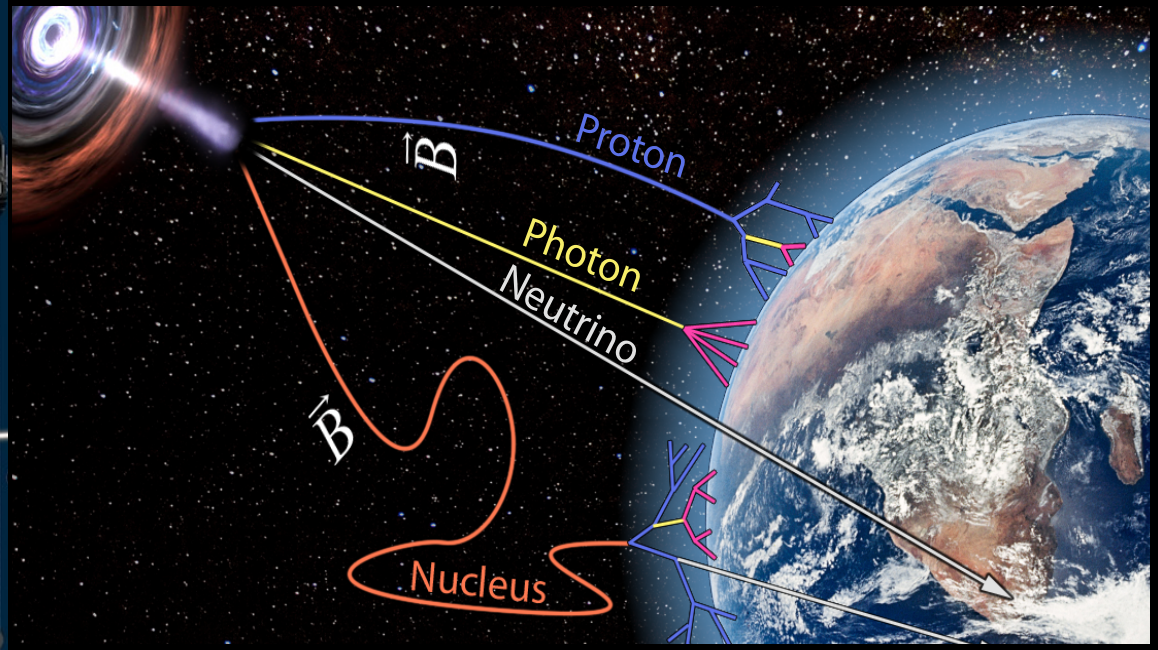


Our Technologies: synergy & broad applicability

- The technologies we develop are broadly applicable across PP NP and APP & synergistically developed







ECFA Detector R&D Roadmap

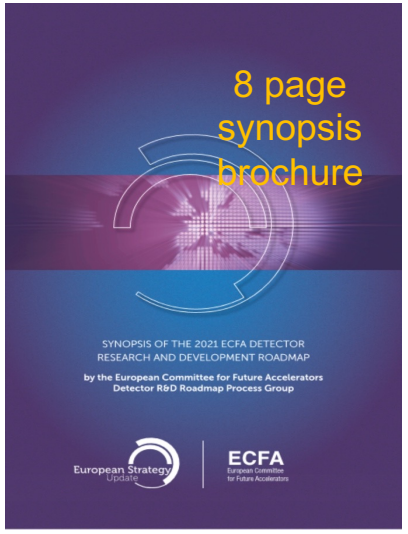
- Given the future physics programme, identify **the main technology R&D to be met so that detectors ar not the limiting factor for the timeline.**
- Detector context considered:

- Full exploitation of LHC
- Long baseline neutrinos
- Detectors for future Higgs-EW-Top factories (in all manifestations)
- Long term vision for 100 TeV hadron collider

- Future muon colliders
- Accelerator setup for rare decays/dark matter
- Experiments for precision QCD
- Non accelerator experiments (reactor neutrinos, double beta decay, dark matter)

Process organised by Panel and nine Task Forces with input sessions and open symposia with wide community consultation (1359 registrants)

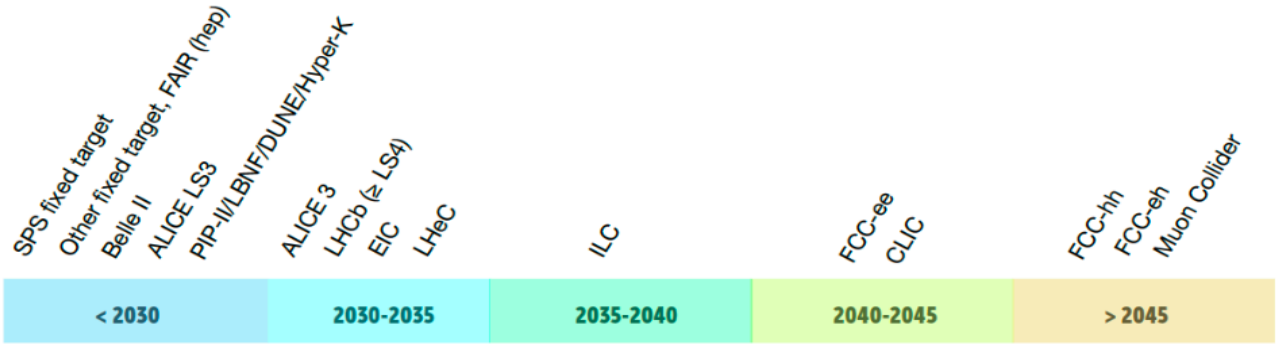
Main Document published (approval by RECFA at 19/11/21) and 8 page synopsis brochure prepared for less specialised audience

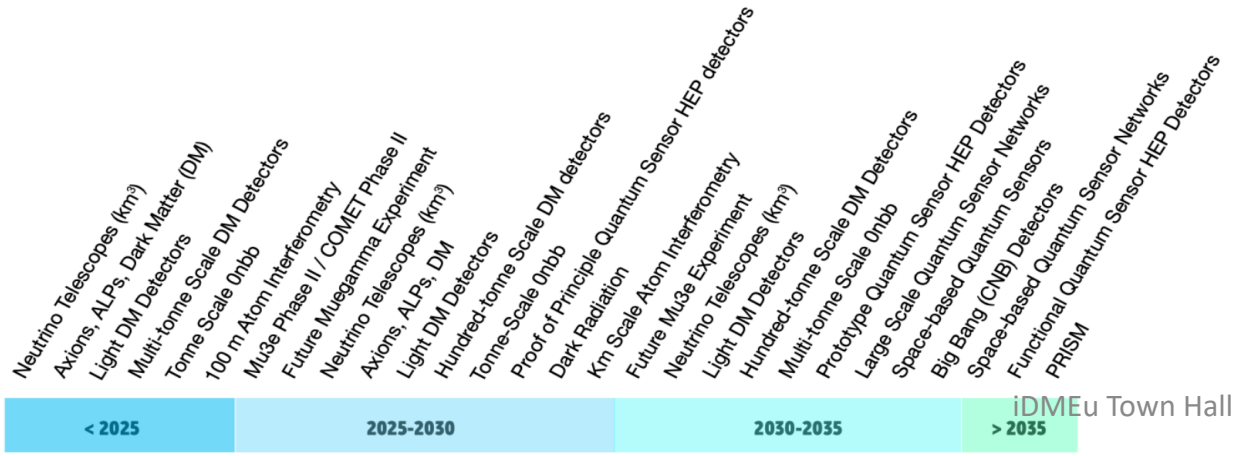


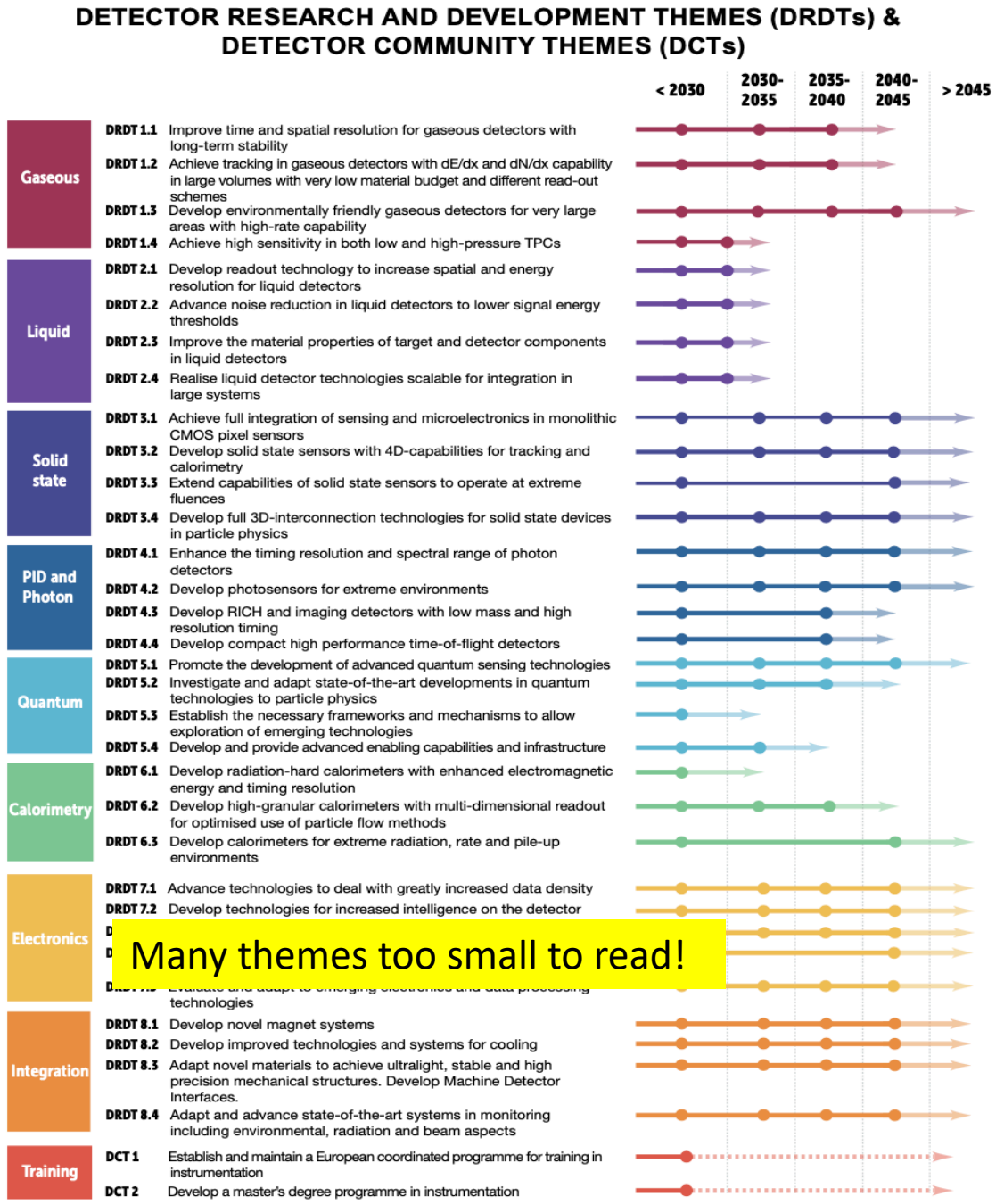
ECFA Detector R&D Roadmap Panel web pages at: https://indico.cern.ch/e/ECFADetectorRDRoadmap
Documents CERN-ESU-017: 10.17181/CERN.XDPL.W2EX

Roadmap Document Structure

Within each Task Force (one for each technology area + training) the aim is to propose a time ordered detector R&D programme by Detector Research and Development Themes (DRDT) in terms of **capabilities not currently achievable**.



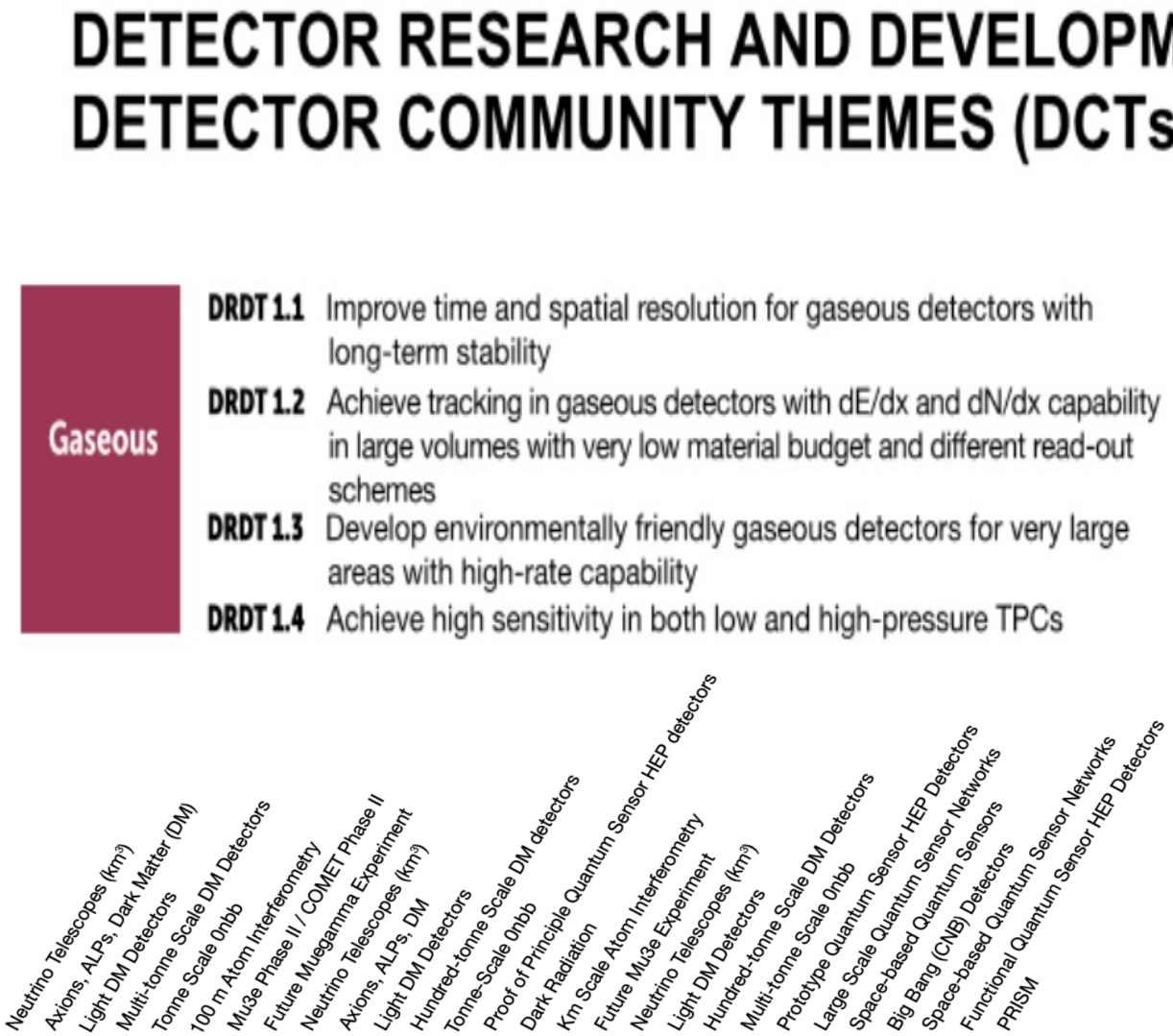


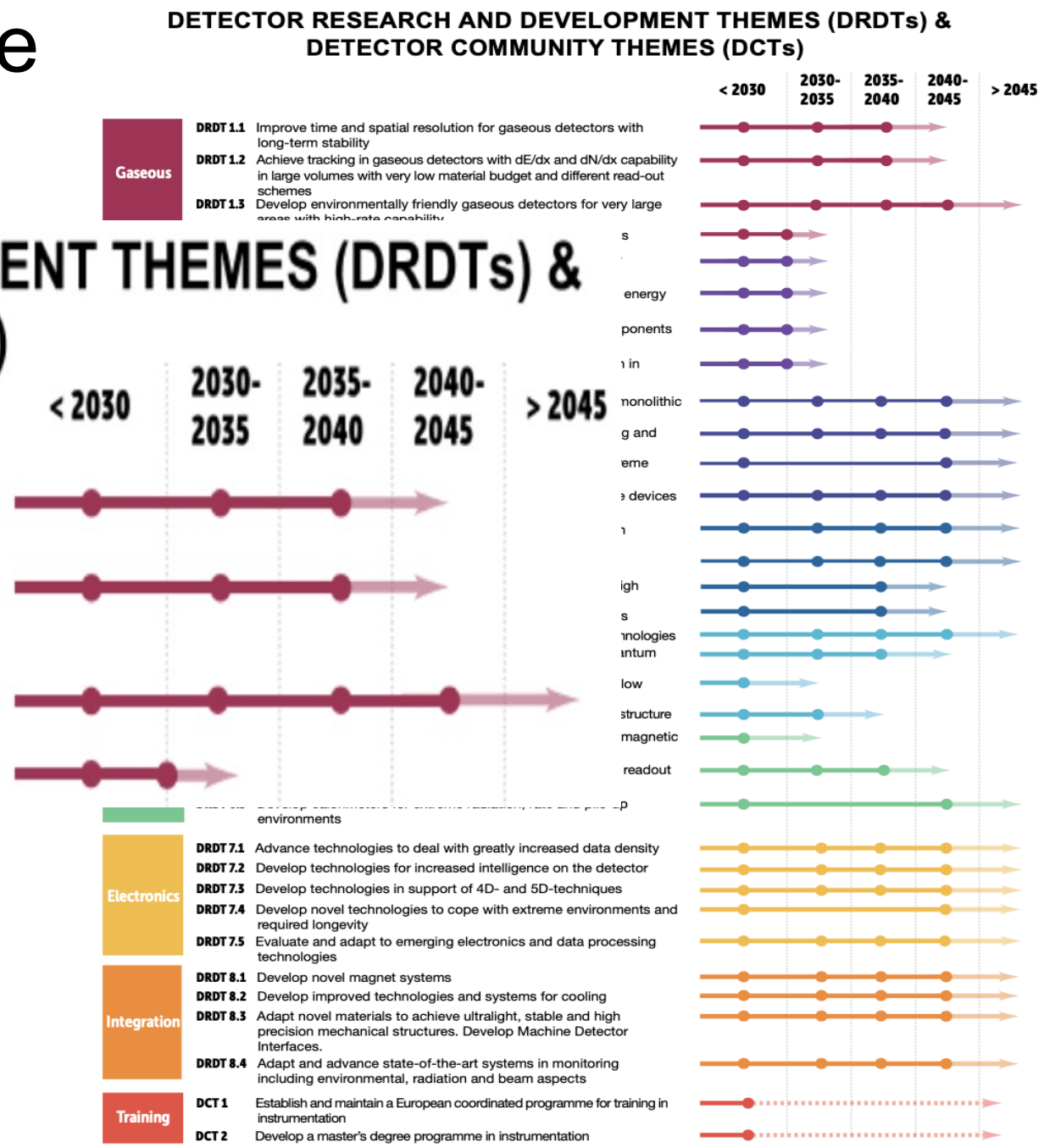


Many themes too small to read!

Roadmap Document Structure

Within each Task Force the aim is to propose a time ordered detector R&D programme by





Gaseous detectors

Are ubiquitous

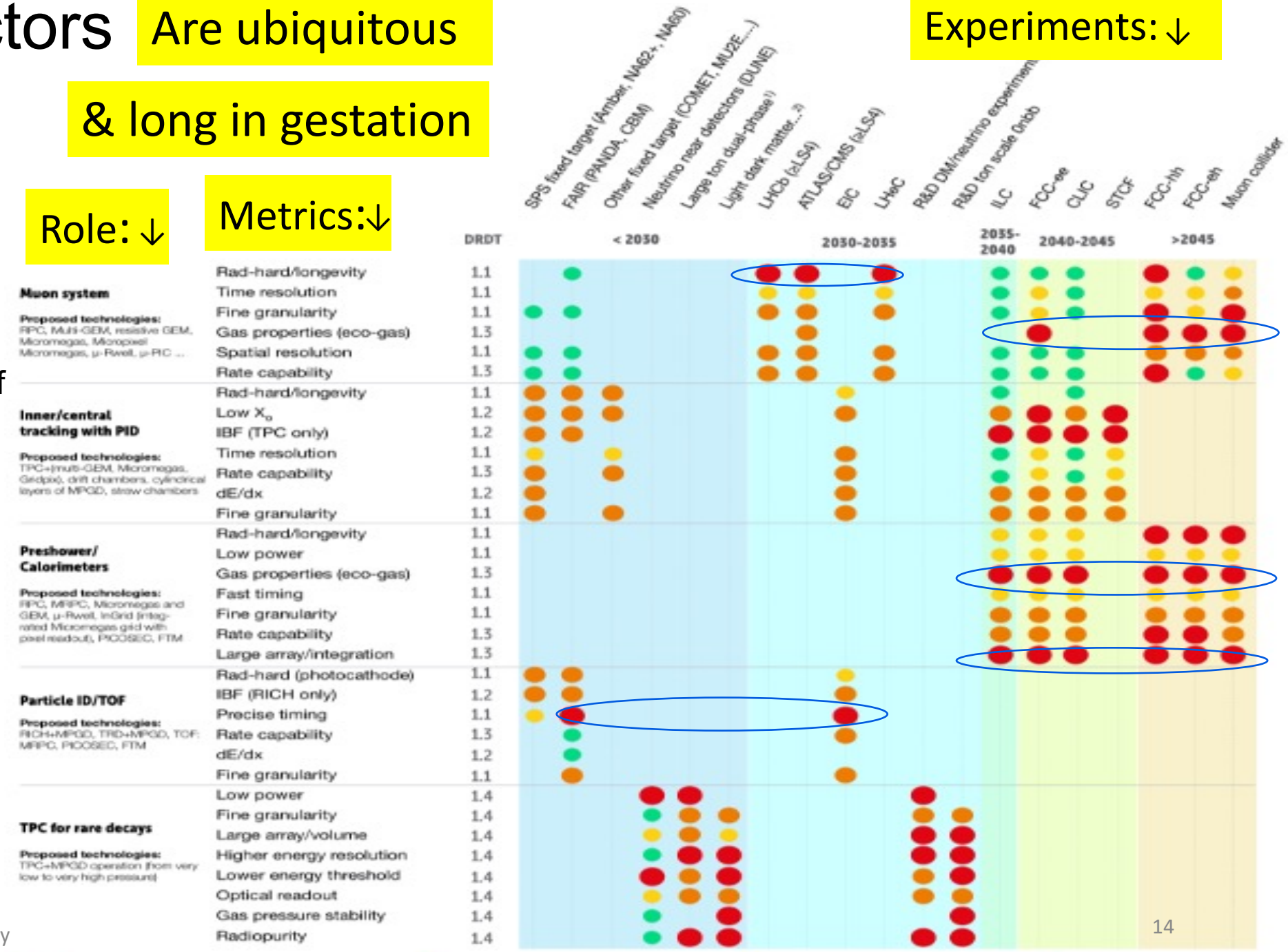
& long in gestation

Experiments: ↓

- **Detector Readiness Matrices of each Task Force chapter** focus on the extent to which the R&D topic is *mission critical* to the programme rather than the intensity of R&D required
  - Must happen or main physics goals cannot be met
  - Important to meet physics goals
  - Desirable to enhance physics reach
  - R&D need being met

Role: ↓

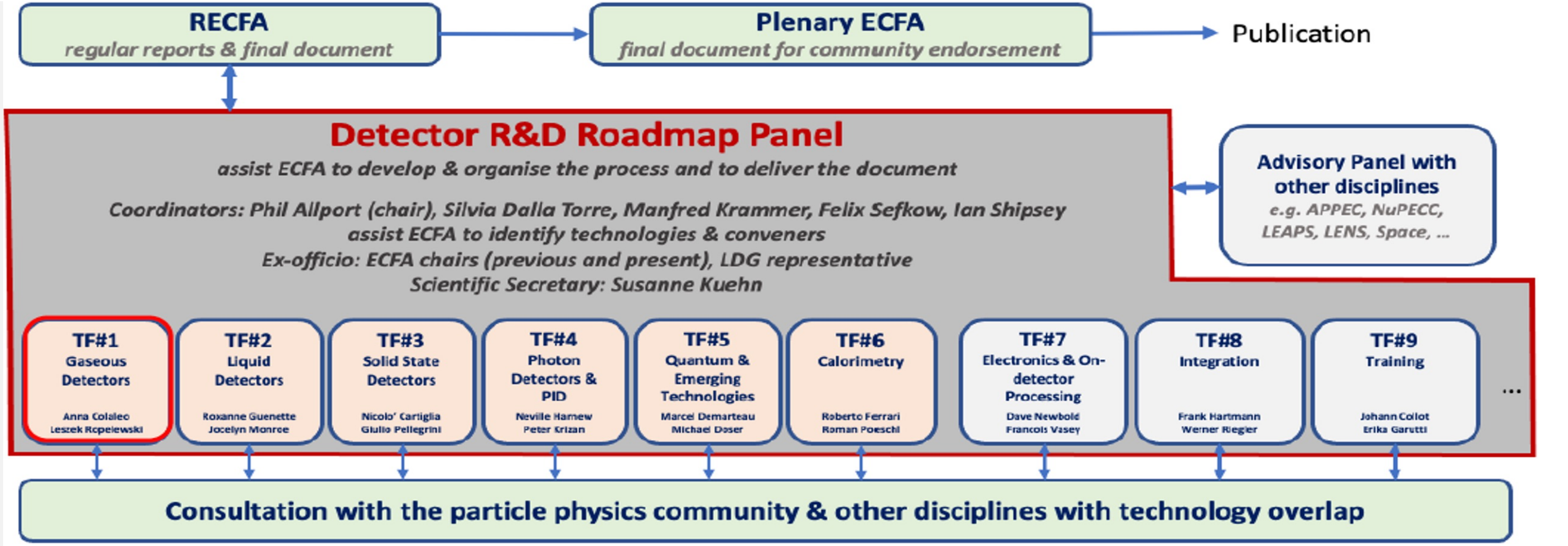
Metrics: ↓



Steps toward a long term detector R&D program

2019 — ESPP update (HEP strategic projects) — 2021 — ECFA DRD proposals — 2024 — ESPP update

Granada Symposium (WGs and Physics Briefing Book) — 2020 — ECFA detector R&D roadmap (TF & workshops community driven) — 2023 — DRD MoUs (collaborations active) — 2026-27

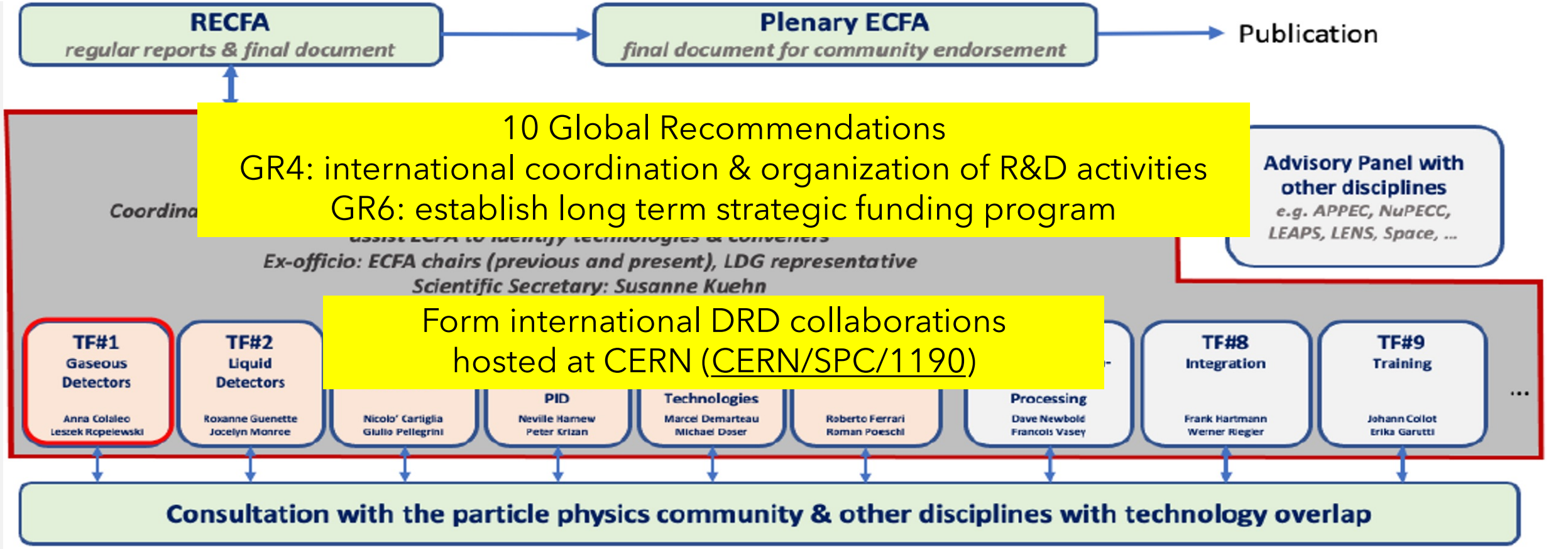


an accelerator R&D roadmap was also prepared in 2021 by the Laborartory Directors Group

Steps toward a long term detector R&D program

2019 — ESPP update (HEP strategic projects) — 2021 — ECFA DRD proposals — 2024 — ESPP update

Granada Symposium (WGs and Physics Briefing Book) — 2020 — ECFA detector R&D roadmap (TF & workshops community driven) — 2023 — DRD MoUs (collaborations active) — 2026-27

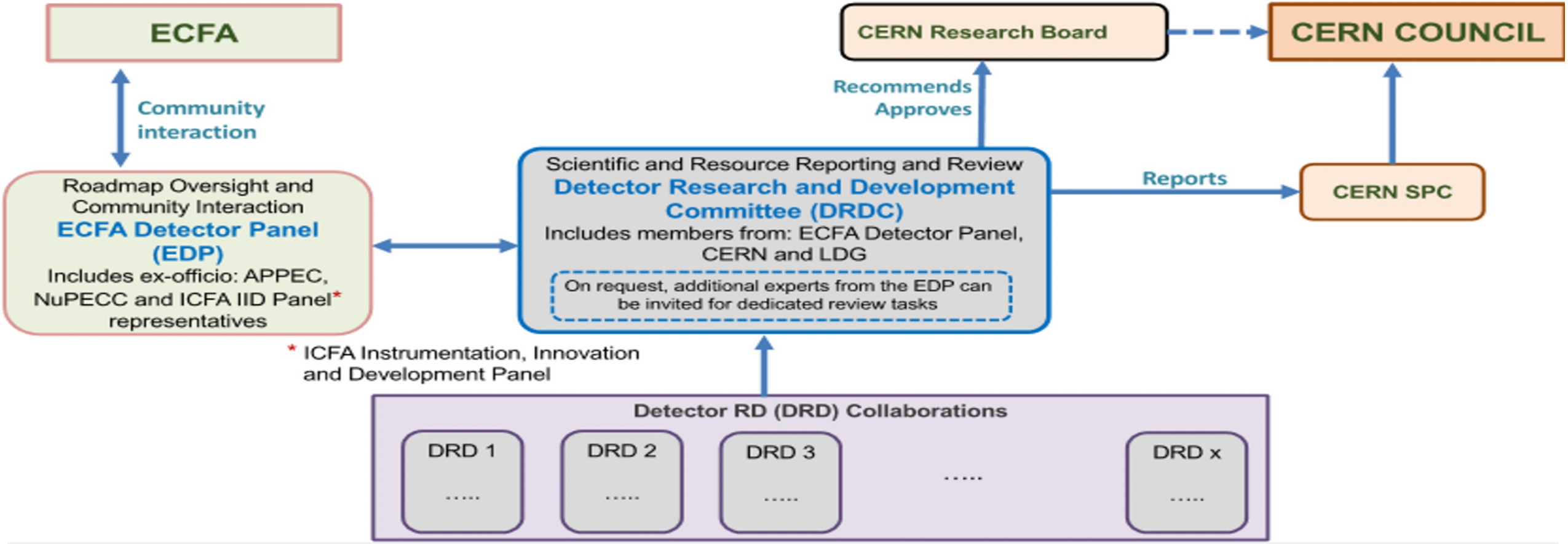


an accelerator R&D roadmap was also prepared in 2021 by the Laborartory Directors Group

Framework for DRD collaborations

similar to general conditions for execution of experiments at CERN

with a dedicated Detector R&D review Committee and MoU with Funding Agencies



EDP provides input on DRD proposals to the DRDC* in terms of roadmap priorities
it follows up achievements and evolution from experiment concept groups for update of the rodmap

* through its co-chairs, appointed members in the DRDC or via topic-specific experts in the conduct of the DRDC reviews

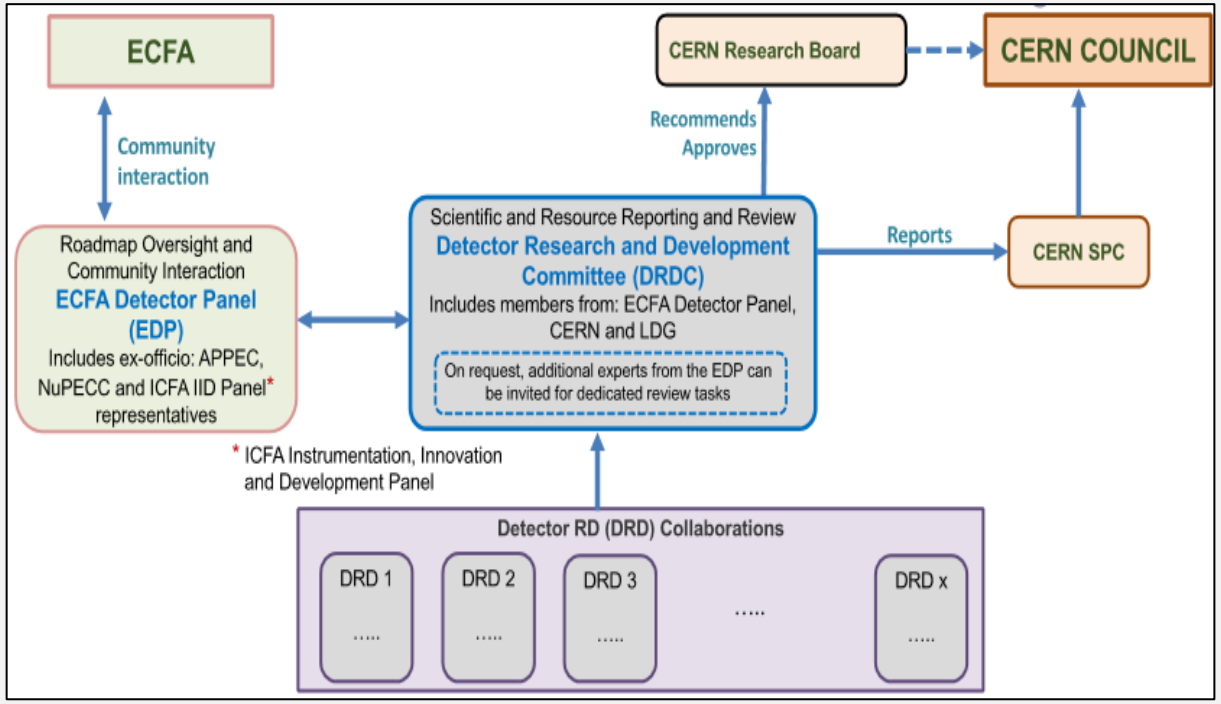
Framework for DRD collaborations

similar to general conditions for execution of experiments at CERN

with a dedicated Detector R&D review Committee and MoU with Funding Agencies

Co-chairs:	Phil Allport (Birmingham) Didier Contardo (IP2I Lyon)
Scientific secretary:	Doris Eckstein (DESY)
Gaseous Detectors:	Silvia Dalla Torre (Torino)
Liquid Detectors:	Inés Gil Botella (CIEMAT, Madrid)
Solid State Detectors:	Doris Eckstein (DESY) Phil Allport (Birmingham)
PID & Photon Detectors:	Roger Forty (CERN)
Quantum and emerging Technologies.:	Steven Hoekstra (Groningen)
Calorimetry:	Laurent Serin (IJCLab)
Electronics:	Valerio Re (Bergamo)
Ex Officio:	Karl Jakobs (ECFA Chair) Ian Shipsey (ICFA Detector Panel)
Observer for APPEC	Aldo Ianni (INFN, LNGS)
Observer for NuPECC	Eugenio Nappi (INFN, Unit of Bari)

ECFA Detector Panel



BERGAUER, Thomas	HEPHY, Vienna, **Chairperson**
Members	
BENTVELSEN, Stan	NIKHEF
BRESSLER, Shikma	Weizmann Institute of Science
BUDKER, Dimitry	Helmholtz Institute Mainz and Johannes Gutenberg
FORTY, Roger	CERN
GEMME, Claudia	INFN and University, Genoa
GIL BOTELLA, Ines	CIEMAT
MERKEL, Petra	Fermilab
PESARESI, Mark	Imperial College
SERIN, Laurent	IJCLab - Laboratoire de physique des 2 infinis
Ex-officio	ECFA Detector Panel (EDP) Chair

DRDC membership

EDP provides input on DRD proposals to the DRDC* in terms of roadmap priorities
it follows up achievements and evolution from experiment concept groups for update of the rodmap

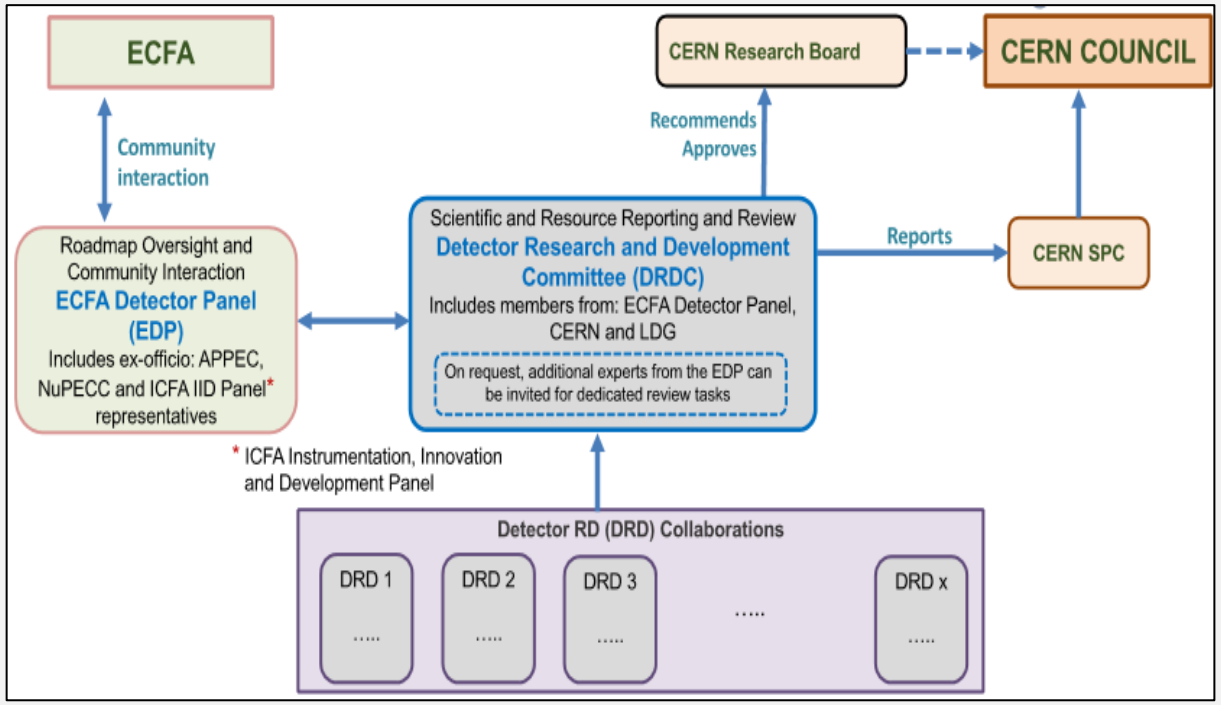
* through its co-chairs, appointed members in the DRDC or via topic-specific experts in the conduct of the DRDC reviews

Framework for DRD collaborations

similar to general conditions for execution of experiments at CERN

with a dedicated Detector R&D review Committee and MoU with Funding Agencies

Co-chairs:	Phil Allport (Birmingham) Didier Contardo (IP2I Lyon)
Scientific secretary:	Doris Eckstein (DESY)
Gaseous Detectors:	Silvia Dalla Torre (Torino)
Liquid Detectors:	Inés Gil Botella (CIEMAT, Madrid)
Solid State Detectors:	Doris Eckstein (DESY) Phil Allport (Birmingham)
PID & Photon Detectors:	Roger Forty (CERN)
Quantum and emerging Technologies.:	Steven Hoekstra (Groningen)
Calorimetry:	Laurent Serin (IJCLab)
Electronics:	Valerio Re (Bergamo)
Ex Officio:	Karl Jakobs (ECFA Chair) Ian Shipsey (ICFA Detector Panel)
Observer for APPEC	Aldo Ianni (INFN, LNGS)
Observer for NuPECC	Eugenio Nappi (INFN, Unit of Bari)



BERGAUER, Thomas	HEPHY, Vienna, **Chairperson**
Members	
BENTVELSEN, Stan	NIKHEF
BRESSLER, Shikma	Weizmann Institute of Science
BUDKER, Dimitry	Helmholtz Institute Mainz and Johannes Gutenberg
FORTY, Roger	CERN
GEMME, Claudia	INFN and University, Genoa
GIL BOTELLA, Ines	CIEMAT
MERKEL, Petra	Fermilab
PESARESI, Mark	Imperial College
SERIN, Laurent	IJCLab - Laboratoire de physique des 2 infinis
Ex-officio	ECFA Detector Panel (EDP) Chair

DRD collaborations aim to ensure that R&D readiness is not a primary project schedule driver

5 proposals and 2 LoIs submitted this month to DRDC

9 months preparation - community driven with workshops and calls for contributions

ECFA roadmap panel guidance and templates to prepare documentation

interim leadership: roadmap TF teams and leaders of current R&D programs

CERN RD50 (rad. hard semiconductors), RD51 (MPGDs), RD42 (diamond), RD18 (crystals)*, CALICE, AIDAInnova…

DRD areas were defined in the ECFA detector roadmap

mapping technology & systems R&D to needs of HEP strategic projects

future experiments (including upgrades) at large accelerator facilities

future experiments 1st , 2nd, 3rd generations small accelerators, nuclear reactors, cosmic rays

gaseous - solid state - photon and PID - calorimeter

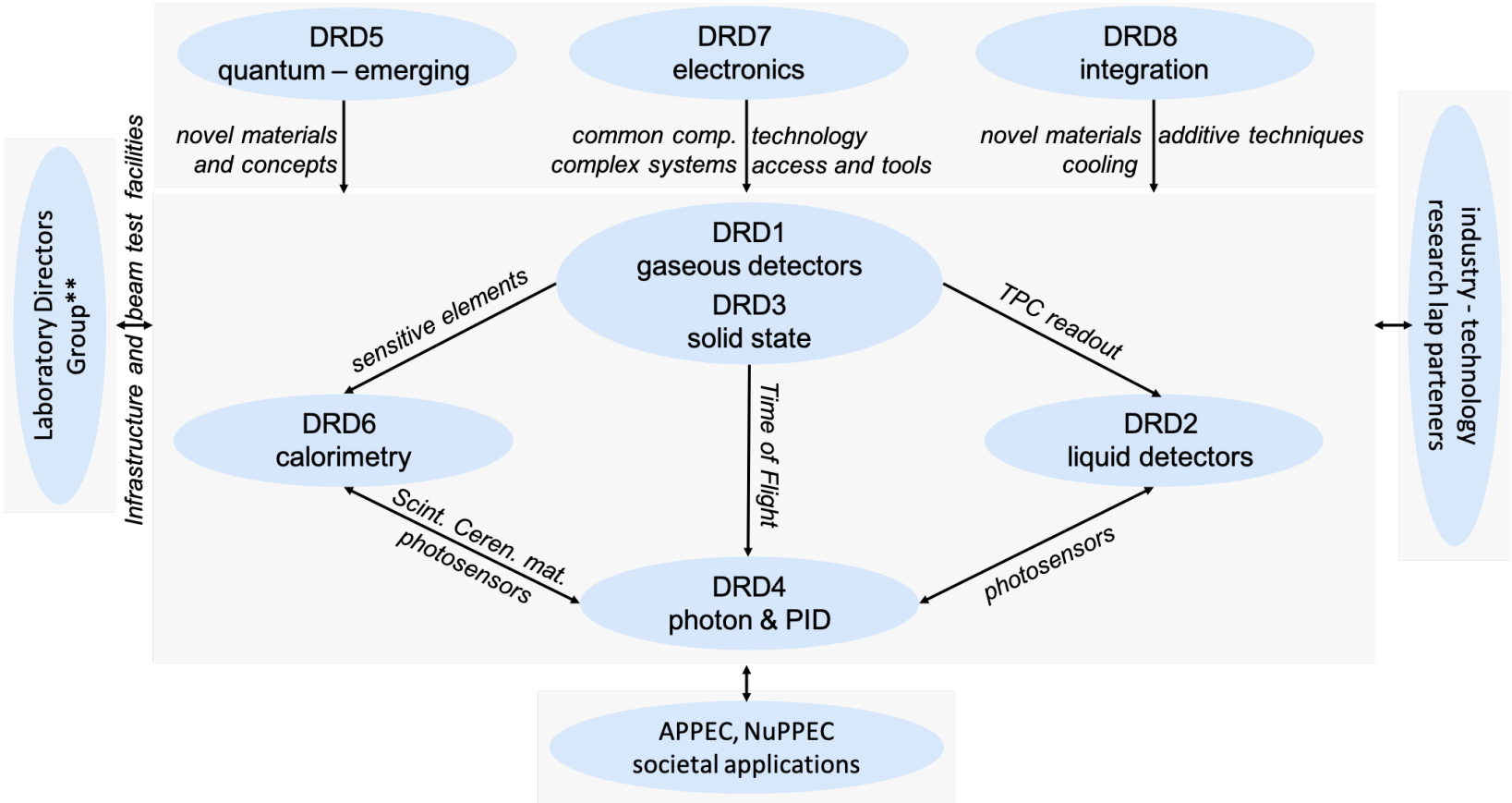
liquid - quantum and emerging technologies

electronics and on-detector processing - integration - training and career

range of strategic project dates are as understood in 2021 at the time of the roadmap preparation

Execution programs consider links across DRDs and external

typical hierarchy is technology areas* - Work Packages - deliverables & milestones
needs/availability of irradiation & beam test facilities is being investigated in conjunction with LDG**

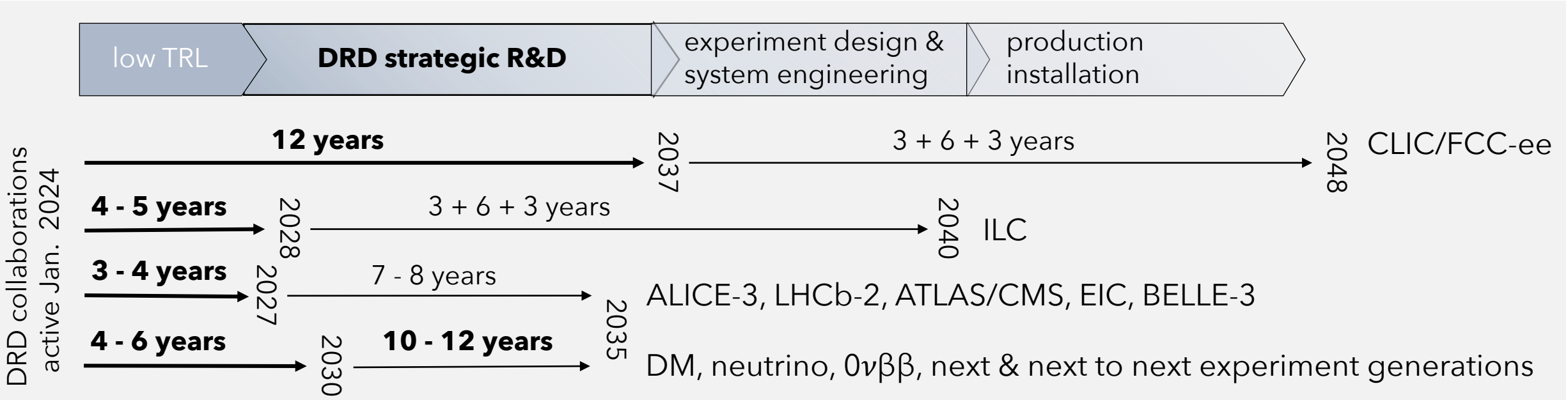


** can be technology elements entering several systems, specific system components and/or full systems depending on DRD area*
*** CEA/Irfu-France, CERN-EU, CIEMAT-Spain, DESY-Germany, IJCLab-France, LNF-Italy, LNGS-Italy, Nikhef-Netherlands, PSI-Switzerland, STFC/Daresbury-UK, STFC/RAL-UK*
**** DRD8 still under discussion see slide 32*

Planning is dynamic

driven by strategic project timelines and R&D progress

- Considering low TRL* becoming strategic & timeline to enter specific experiment designs



timelines beyond DRD phase vary with systems and project scales, other accelerator projects with less well defined timeline would also benefit from DRDs

- Presently focusing on a 1st phase of 3 - 4 years, identifying decision points & transitions
  - stepping stones earlier strategic programs
  - iterations toward longer term goals: new technologies - new materials – ultimate radiation tolerance
- Synchronizing supply of components for prototypes across DRDs

* *Technology Readiness Level defined by NASA,, low TRL also often referred as "blue sky"*

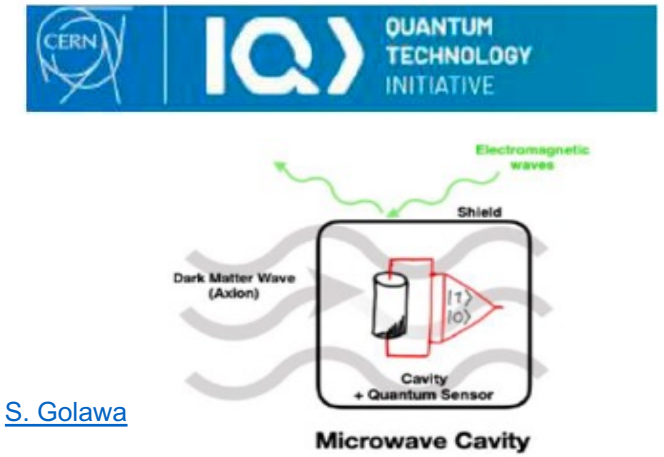
DRD collaboration organization and resources

- Organization framework described in proposals
  - management, committees and Working Group structure
    - building on WGs set-up in preparation of proposals
    - including contact persons to other related DRD areas
  - place/status of partners, industrial and from other fields
- Human resources and budget
  - in public document
    - list of institutes willing to contribute to various Technology Areas
    - estimate of human and funding resources required to achieve the TA goals
  - Confidential to DRDC to evaluate feasibility of the programs
    - current level of human and funding resources expected to be available/prolongated
    - new resources being requested to achieve the strategic scope
    - preliminary "money matrix" of potential funding per Funding Agency

- ➢ MoUs for 1st phase (3-4 years) will be prepared in 2024 for agreement with FAs
  - resources are at this stage only those expected to be considered by Funding Agencies
  - funding will remain within institutes supported by FAs
  - an updating process to follow DRD progress and project timelines will be established by CERN
- ➢ Ramp-up of funding needs with time can be expected to access new technologies

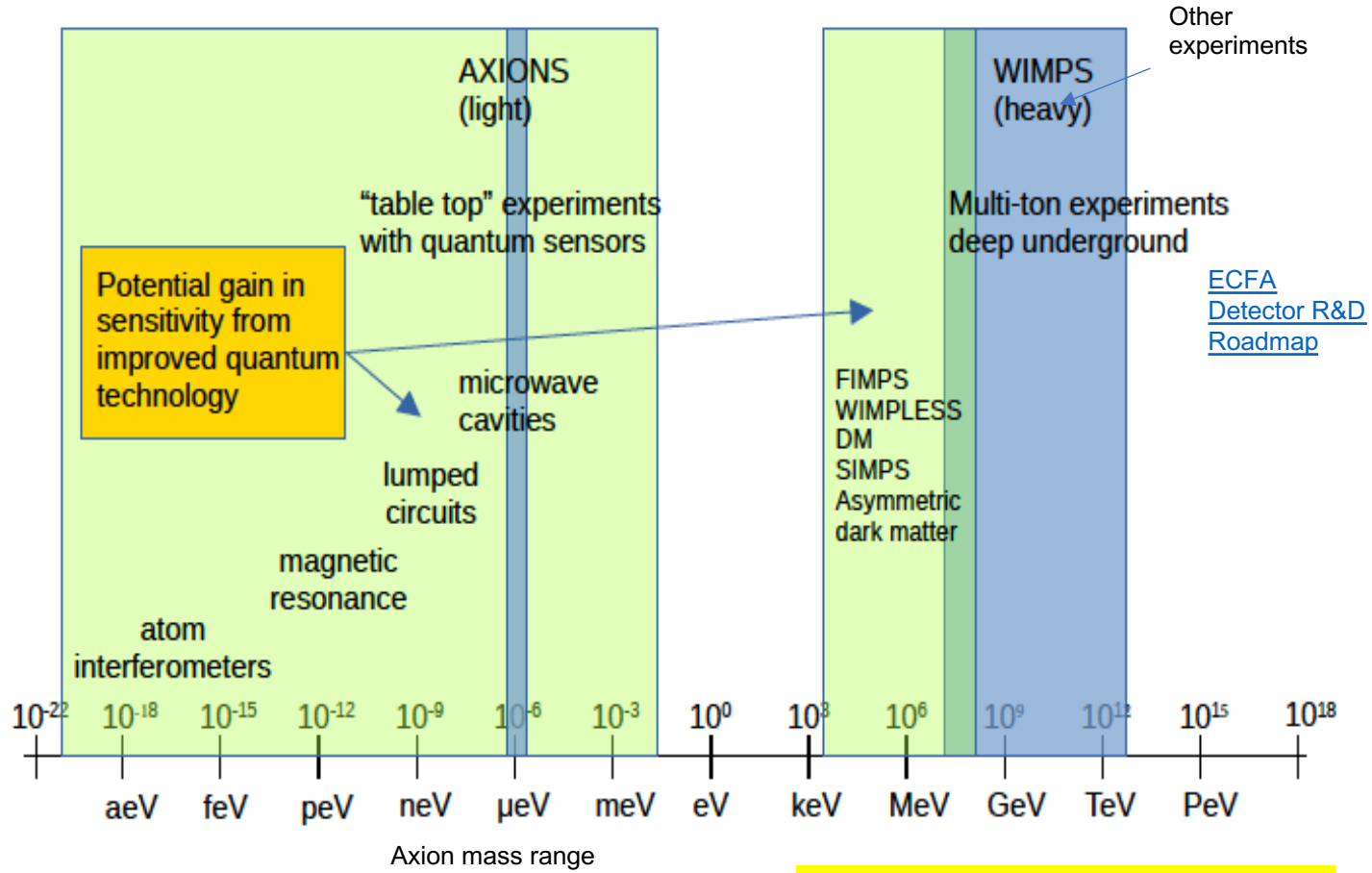
Quantum and emerging technologies

- **Quantum Technologies are a rapidly emerging area** of technology development to study fundamental physics
- The ability to engineer quantum systems to improve on the measurement sensitivity holds great promise
- **Many different sensor and technologies being investigated**: clocks and clock networks, spin-based, superconducting, optomechanical sensors, atoms/molecules/ions, atom interferometry, …
- Several initiatives started at CERN, DESY, FNAL, US, UK, …



S. Golawa

Example: potential mass ranges that quantum sensing approaches open up for Axion searches & other light particles



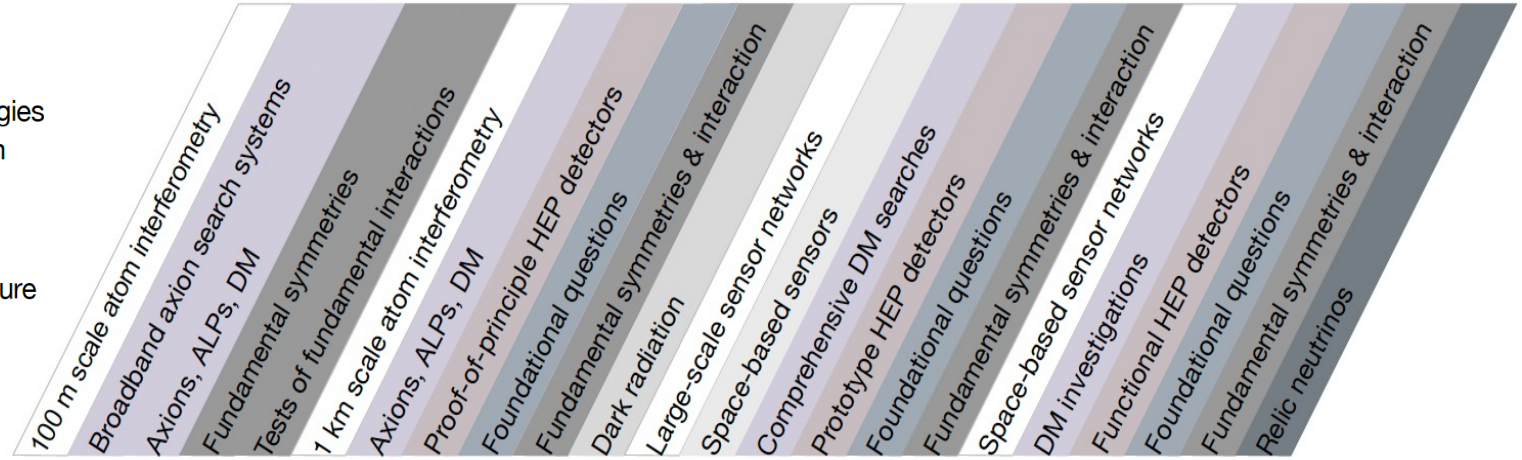
ECFA Detector R&D Roadmap

Blue: now
Light green: with quantum

DRD5 Quantum Sensors and emerging technologies

Sensors with high sensitivity and precision, nano/meta/heterogenous materials enabling new experimental concepts, so far applications in EDM, DM, neutrino, 0$\nu\beta\beta$ searches, fundamental forces, including gravity

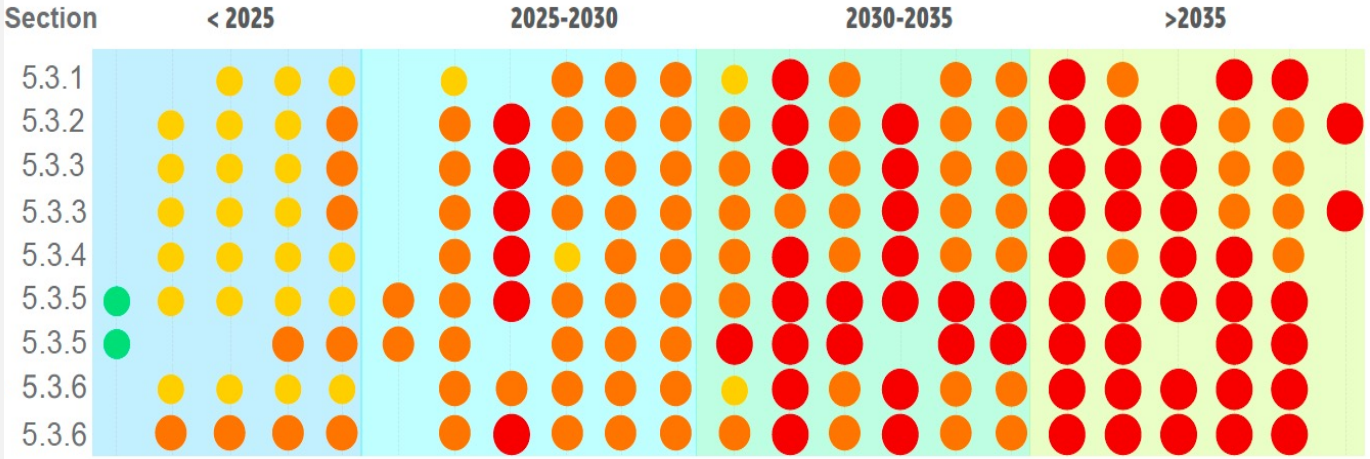
DRDT 5.1 Promote the development of advanced quantum sensing technologies
DRDT 5.2 Investigate and adapt state-of-the-art developments in quantum technologies to particle physics
DRDT 5.3 Establish the necessary frameworks and mechanisms to allow exploration of emerging technologies
DRDT 5.4 Develop and provide advanced enabling capabilities and infrastructure



Implementation white paper/LoI

Technology Areas
sensor families

- Clocks and clock networks
- Kinetic detectors
- Spin-based sensors
  Superconducting sensors
- Optomechanical sensors
- Atoms/molecules/ions
  Atom interferometry
- Metamaterials, 0/1/2D-materials
  Quantum materials



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

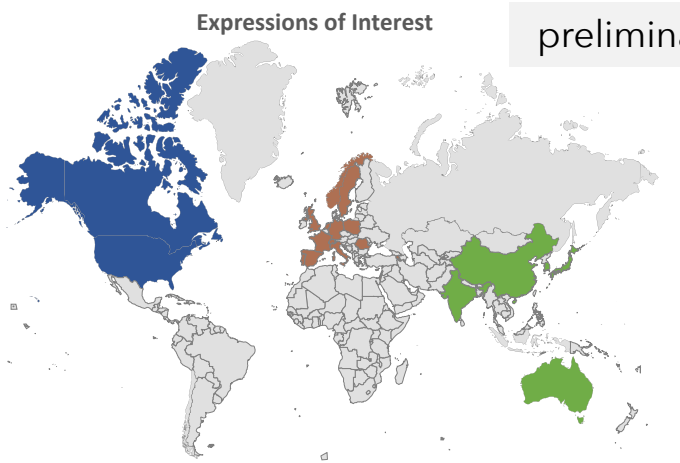
DRD5: Quantum & emerging technologies

40 institutes in 15 countries, 25 proposed contributions

conveners: Marcel Demarteau, Michael Doser

White Paper / LoI being submitted to DRDC

identify WPs suitable for community & collaborative effort building*



preliminary

- WP1: Network of atomic clocks and global sub-ns time stamping - portable reference
- WP2: Exotic systems in traps and beam
- WP3: Cryogenic systems solid state superconducting materials - electronics - integration
- WP4: Theory
- WP5: Scaling to larger systems preserving quantum properties
- WP6: Capability driven design

community meeting October 2-4

** driver of the program at this stage rather than a sensor or project dedicated approach*

drd5 / rdq - implementation

homepage | drd5/rdq collaboration | jobs

https://doser.web.cern.ch

what's this about?

The implementation of the ECFA detector R&D roadmap for quantum sensing for particle physics is planned to proceed in several steps: first a workshop among conveners, then the writing of a White Paper (evolving draft) based on this workshop, but with involvement of the different communities interacting with the conveners, then the drafting of a Letter of Interest based on the White paper and to be submitted to a CERN scientific committee, the DRDC in September, 2023. A document describing the process can be found here. If you are interested, please sign up here for regular updates by email.

A workshop to prepare the proposal for submission by the end of the year will take place at CERN from Oct. 2-4.

The six quantum sensing families that form part of the ECFA detector R&D roadmap are:
- clocks and clock networks
- kinetic detectors
- superconducting and spin-based sensors
- optomechanical sensors
- atoms, ions, molecules and atom interferometry
- metamaterials, 0-,1-,2-dimensional materials

A workshop on these different families (represented both by the conveners themselves, as well as based on the submissions to a call for contributions) took place at CERN from April 2-5, 2023. The outcome of this workshop is two-fold:

Minutes of the workshop. These minutes provide an overview of the presentations and discussions surrounding the many activities in the field of quantum technologies and related areas, and highlight some possible Work Packages (WP's) for the implementation phase.

White Paper (in the process of being written). This White Paper is structured around these WP's and is geared towards preparing a LOI that structures these activities within a proto-collaboration, named DRD5 / RDq.

who's who?

Conveners of the first ECFA quantum sensing implementation workshop (Apr. 2-5, 2023, CERN)

Hiroki Akamatsu, Etiennette Auffray, Caterina Braggio, Florian Brunbauer, Shion Chen, Martino Calvo, Marcel Demarteau, Michael Doser, Christophe Dujardin, Andrew Geraci, Arindam Ghosh, Glen Harris, David Hume, Derek Jackson, Jeroen Koelemeij, Georgy Kornakov, Stefan Maier, Alberto Marino, Tanja Mehlstäubler, Alessandro Monfardini, Ben Ohayon, Nancy Paul, Sadiq Rangwala, Florian Reindl, Mariana Safronova, Swati Singh, Stafford Withington, Steven Worm

Co-ordinators of the implementation process

Marcel Demarteau, Michael Doser

how about some links?

- ECFA roadmap
- RDq structure, process and timeline
- Jobs
- Upcoming conferences on Quantum Sensing
- description of the process / FAQ
- list of all co-conveners
- didactical resources

Outlook

Forming DRD collaborations → strong interest in the international community

preparation of the scientific programs shows the interest of a global endeavor
to investigate best and cost-effective technical solutions for future HEP projects

Having DRD collaboration status similar to experiments is welcome

it values work in detector instrumentation and innovation
it provides mechanisms for the sustained funding needed to access & develop new technologies

Next step is to establish the DRD collaboration organization

forming the Collaboration Boards of institutes – new contributors are welcome
To find out more: https://indico.cern.ch/event/957057/page/27294-implementation-of-the-ecfa-detector-rd-roadmap

credit

Didier Contardo, Phil Allport, Karl Jakobs
Silvia Dalla Torre, Manfred Kramer, Susanne Kuehn, Felix Sefkow, Ian Shipsey
Anna Colaleo, Leszek Ropelewski, Roxanne Guenette, Jocelyn Monroe, Nicolo Cartiglia, Giulio Pellegrini, Peter Krizan, Christian Joram, Marcel Demarteau, Michael Doser, Roberto Ferrari, Roman Poeschl, Dave Newbold, Francois Vasey
and registered participants: 294 DRD1 - 173 DRD2 - 488 DRD3 - 222 DRD4 -140 DRD5 - 233 DRD6 – 183 DRD7