DRD7 Perspective on R&D for ASICs and Electronics

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On behalf of the DRD7 steering committee

9 Nov 2023

Introductory Observations and Questions

- Electronics is ubiquitous in HEP experiments and strategically important for their future developments
- Technology and tools evolve fast and are increasingly complex and expensive
- Engineering effort is difficult to recruit and retain

- How can we keep profiting from state-of-the-art electronics?
  - How can we remain above critical mass?
  - How can we maintain accesses to Hi-end technology and tools?
  - How can we reconcile the shortening technology cycles with the increasing detector development time?

- How can we become more visible as a community, to attract the necessary resources and deliver the next-generation systems?

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Agenda

DRD7: an R&D collaboration for electronic systems

1. EPPS priorities, ECFA Detector R&D roadmap, DRD7 implementation
2. Projects portfolio
3. Outlook

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EPPSU & ECFA Roadmap Process

Strategy approved by CERN SPC and Council in June 2020

https://europeanstrategyupdate.web.cern.ch/

https://indico.cern.ch/e/ECFADetectorRDRoadmap

- European Particle Physics Strategy Update
  - » The European Strategy for Particle Physics is the cornerstone of Europe's *decision-making* process for the *long-term future* of the field.
  - » The latest update of the Strategy was approved by the CERN Council at its June 2020 Meeting. It places *priority on the successful completion of the High-Luminosity LHC*, and begins to map out the potential landscape for research in Europe in the post LHC era.
  - » The Strategy update recommends a so-called *Higgs factory* as the highest priority to follow the LHC, while pursuing a technical and financial feasibility study for a next-generation *hadron collider* in parallel, in preparation for the long-term.
  - » recommended that "Organised by ECFA, a roadmap should be developed by the community to balance the *detector R&D efforts* in Europe, taking into account progress with emerging technologies in adjacent fields".
  - » Recommended that a similar process be followed for *R&D on accelerator technologies*.

Roadmap

Roadmap endorsed by CERN SPC and Council on 10 Dec 2021
https://indico.cern.ch/event/957057/page/23281-the-roadmap-document

ECFA
European Committee for Future Accelerators

Gaseous

- **DRDT 1.1** Improve time and spatial resolution for gaseous detectors with long-term stability
- **DRDT 1.2** Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes
- **DRDT 1.3** Develop environmentally friendly gaseous detectors for very large areas with high-rate capability
- **DRDT 1.4** Achieve high sensitivity in both low and high-pressure TPCs

Liquid

- **DRDT 2.1** Develop readout technology to increase spatial and energy resolution for liquid detectors
- **DRDT 2.2** Advance noise reduction in liquid detectors to lower signal energy thresholds
- **DRDT 2.3** Improve the material properties of target and detector components in liquid detectors
- **DRDT 2.4** Realise liquid detector technologies scalable for integration in large systems

Solid state

- **DRDT 3.1** Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
- **DRDT 3.2** Develop solid state sensors with 4D-capabilities for tracking and calorimetry
- **DRDT 3.3** Extend capabilities of solid state sensors to operate at extreme fluences
- **DRDT 3.4** Develop full 3D-interconnection technologies for solid state devices in particle physics

PID and Photon

- **DRDT 4.1** Enhance the timing resolution and spectral range of photon detectors
- **DRDT 4.2** Develop photosensors for extreme environments
- **DRDT 4.3** Develop RICH and imaging detectors with low mass and high resolution timing
- **DRDT 4.4** Develop compact high performance time-of-flight detectors

Quantum

- **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

Calorimetry

- **DRDT 6.1** Develop radiation-hard calorimete… energy and timing resolution
- **DRDT 6.2** Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods
- **DRDT 6.3** Develop calorimeters for extreme radiation, rate and pile-up

Electronics

- **DRDT 7.1** Advance technologies to deal with greatly increased data density
- **DRDT 7.2** Develop technologies for increased intelligence on the detector
- **DRDT 7.3** Develop technologies in support of 4D- and 5D-techniques
- **DRDT 7.4** Develop novel technologies to cope with extreme environments and required longevity
- **DRDT 7.5** Evaluate and adapt to emerging electronics and data processing technologies

Integration

- **DRDT 8.2** Develop improved technologies and systems for cooling
- **DRDT 8.3** Adapt novel materials to achieve ultralight, stable and high precision mechanical structures. Develop Machine Detector Interfaces.
- **DRDT 8.4** Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects

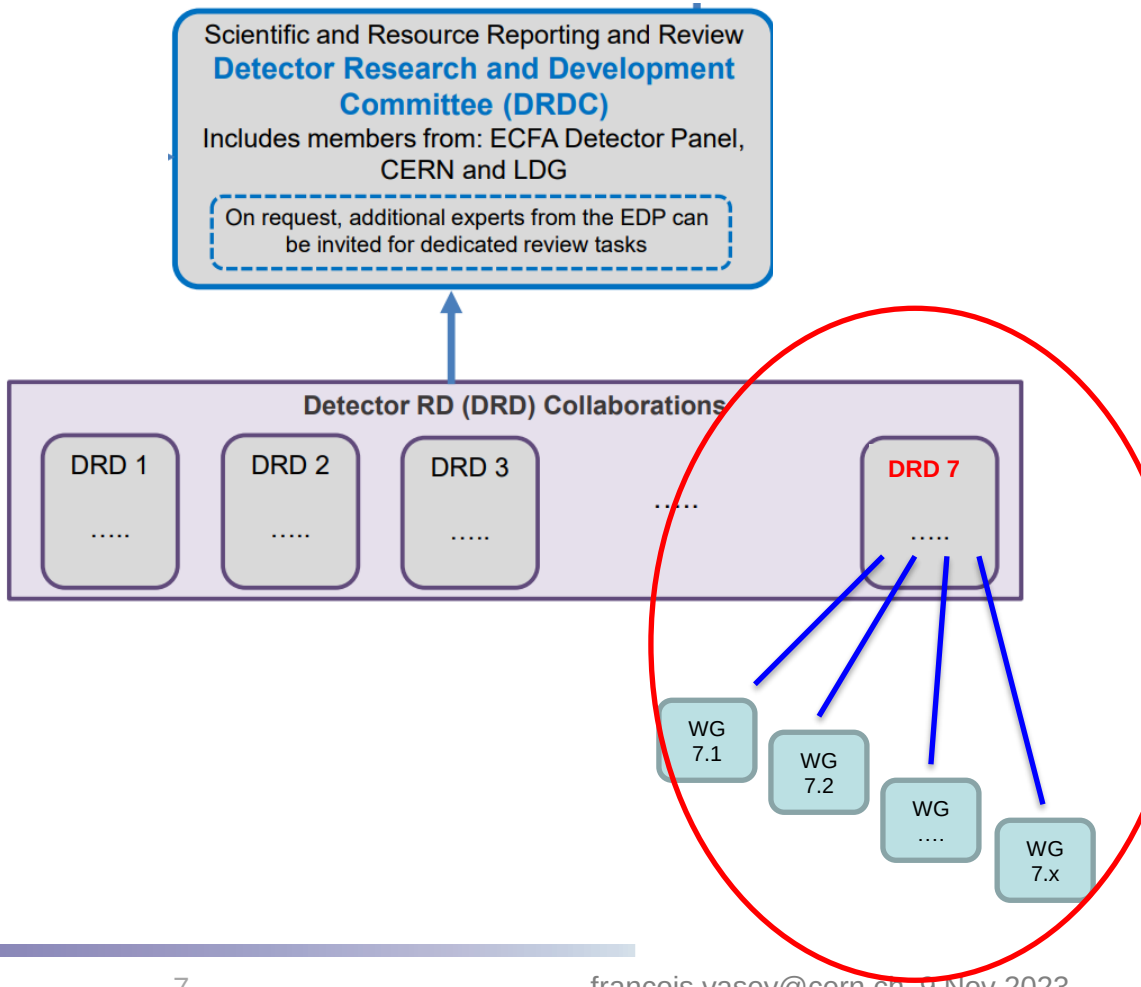
Training

- **DCT 1** Establish and maintain a European coordinated programme for training in instrumentation
- **DCT 2** Develop a master's degree programme in instrumentation

Implementation

Implementation plan endorsed by CERN SPC and Council in Sep 2022

- Collaborations anchored at CERN
- One per technology area (as highlighted by Roadmap Task Forces)
  - TF7 > DRD7, electronics
- Subdivided into Working Groups
  - Mapped to priority themes (DRDTs)
- Community-driven approach
- Prioritized strategic R&D
- Reporting to DRDCommittee



DRD7: R&D collaboration for electronic systems

Letter of Intent sent to DRDC on 15 Sep 2023

- DRD7 is organized in 7 Working Groups representing the roadmap priorities
  - WG7.1 Data Density & Power Efficiency
  - WG7.2 Intelligence on-Detector
  - WG7.3 4D & 5D Techniques
  - WG7.4 Extreme Environments
  - WG7.5 Backend Systems & COTS

  Original Roadmap Themes
  - WG7.6 Complex Imaging ASICs & Technologies
  - WG7.7 Tools and Technologies
- Each WG hosts a set of projects to implement its priority theme
  - Projects meet predefined criteria:
    - Address novel, ambitious, and transformative topics (consistent with the priorities of the Detector R&D Roadmap), with an appropriate risk appetite
    - Have clearly presented objectives, scope, deliverables, and work plan
    - Are pursued by a well-defined set of participating institutes, with clear responsibility assignments and an appropriate leadership and management structure
    - Possess adequate resources and skills to conduct the proposed development over the entire project timeline
  - Projects are encouraged to be transverse, multi-institutional, system-level, etc.
- Project contributors are the DRD7 collaborators
- Each WG animates one or several forums where contributors and observers meet and exchange ideas on running projects as well as on other topics of interest

DRD7 Letter of Intent

- 64 institutes in 15 countries, over 100 FTEs
- 16 projects in 6 working groups

Preliminary, 15 Sep 2023

Country/Institute
Austria
Graz University of Technology, Institute of Electronics
Canada
Université de Sherbrooke
France
Aix Marseille Univ, CNRS/IN2P3, CPPM
CEA IRFU Saclay
CEA Leti
IN2P3 - LPSC Grenoble
IP2I Lyon
Laboratoire de Physique de Clermont - LPC
LP2I Bordeaux IN2P3 CNRS
LPSC Grenoble
OMEGA
IPHC Strasbourg
Germany
Bergische Universität Wuppertal
Deutsches Elektronen-Synchrotron (DESY)
Fachhochschule Dortmund, University of Applied Sciences and Arts
Forschungszentrum Jülich
Karlsruhe Institute of Technology (KIT)
Max-Planck-Society Semiconductor Laboratory
RWTH Aachen University, Physics Institute IB
University of Bonn, Physikalisches Institut
Italy
INFN Bologna
INFN Padova, Università di Padova
INFN Pavia
INFN Perugia
INFN Pisa
INFN Torino
Scuola Superiore Sant'Anna Pisa
Università degli Studi di Milano and INFN Sezione di Milano
University of Bergamo / INFN Pavia
University of Perugia, Dipartimento di Ingegneria
University of Trento
Japan
KEK, High Energy Accelerator Research Organization
Netherlands
Nikhef
Poland
University of Krakow AGH
Romania
IFIN-HH Bucharest
South Korea
DGIST
GWNU
Spain
CIEMAT
Galician Institute for high energy physics (IGFAE)
Instituto de Física Corpuscular (IFIC) Valencia
Instituto de Física de Cantabria (IFCA)
Instituto de Microelectrónica de Barcelona (IMB-CNM)
Instituto Tecnológico de Aragón (ITAINNOVA)
Universidad de Oviedo
Sweden
Uppsala university
Switzerland
CERN
Paul Scherrer Institut (PSI)
University of Geneva, DPNC
United Kingdom
Imperial College
UKRI-STFC Rutherford Appleton Laboratory
University of Birmingham
University of Bristol
University of London Royal Holloway
University of Manchester
University of Warwick
University of Oxford; Rutherford Appleton Laboratory
USA
Argonne National Laboratory
Fermilab
SLAC National Accelerator Laboratory
University of Minnesota

Agenda

DRD7: an R&D collaboration for electronic systems

1. EPPS priorities, ECFA Detector R&D roadmap, DRD7 implementation
2. Projects portfolio
   - Proposed by contributing (=collaborating) institutes
   - Meets R&D roadmap priorities
   - Not exhaustive
3. Outlook

WG 7.1: Data density & power efficiency

7.1.a Silicon Photonics Transceiver Development

- Medium-speed variant (4λ x 25Gbps), and low-speed variant for cryogenic applications
  - Design of PIC, driver, TIA
  - Environmental characterization
  - Packaging
  - Fiber coupling, integration and testing

7.1.b Powering Next Generation Detector Systems

- High efficiency, low material budget
  - High Voltage CMOS and GaN
  - 28nm CMOS DCDC resonant converter IP
  - High efficiency shunt LDO regulator
- Parallel and Serial Powering
  - System-level characterization
  - Radiation hardness and reliability

7.1.c Wireless Data and Power Transmission

- Multi-hop free space optical data transmission
  - System-level analysis, demonstrators, custom design and full chain evaluation
- Exploration of wireless power transmission

WG 7.2: Intelligence on-detector

7.2.a eFPGA, Programmable Logic Array IP (TBC)

- Study and comparison of open frameworks
- Radiation hardening and characterization
- Development of software and infrastructure for synthesis and mapping of user-code

7.2.b Radiation-tolerant RISC-V processor and SoC platform

- Enabling reconfigurable, retargetable ASICs
  - Abstract design methodology
  - Reusable, standardized IP blocks
  - Control processor (RISCV) and framework
  - Programmable, flexible logic blocks

7.2.c Virtual electronic system prototyping

- High-level description of system, front-end to back-end
  - Specification and performance modeling
  - Reference for verification
  - Virtual prototyping

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WG 7.3: 3D & 4D techniques

7.3.a High performance TDC and ADC blocks at ultra-low power

- Medium/high resolution, multi-channel ADC @40MS/s,
- High precision, multi-channel TDC (10ps)
  - Experts' platform for sharing, comparing and benchmarking ideas, designs and ASICs

7.3.b Time measurement and distribution

- Characterization, simulation and calibration of timing sources
  - Develop and compare procedures
  - Study and implement standard/generic solutions
- Timing distribution techniques and systems
  - Explore limits of COTS components
  - Investigate and compare alternatives
  - Develop protocols for precise & deterministic clock distribution

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WG 7.4: Extreme Environments

7.4.a Modeling and development of cryogenic CMOS PDKs

- TSMC 65nm or 28nm
  - Parameter extraction down to 4K
  - Development of mixed-signal cold-IPs
  - Characterization and documentation of developed IP blocks
  - Demonstrator cryo-chip

7.4.b Radiation resistance of advanced CMOS nodes

- Rolling survey of technologies
  - Focusing on specific nodes (i.e.7nm finfets or 3nm LGAA), or specific effects (low dose rate, NIEL scaling, noise, …)
  - New material systems (GaN, SiGe, ...)
  - Facilities and qualification protocols for ultra-high doses

7.4.c Cooling and cooling plates

- Ceramics cooling plates
  - Fabrication and validation of high-pressure resistance, leak tightness, and performance
- Microchannel cooling
  - Fabrication of silicon interposers with integrated cooling, signal, and power routing
  - Full integration with CMOS sensor

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WG 7.5: Backend systems & COTS

7.5.a COTS architectures, tools and IPs

- Benchmark common TDAQ algorithms/workflows
  - Define figures of merit
  - Develop optimized reference implementations
  - Maintain knowledge and community-led repository

7.5.b No backend, direct 100GbE rad-tol solutions from FE to DAQ

- Feeding directly COTS switches
  - NICs or DAQ processors
- Feeding intermediate COTS-based aggregators
  - Low latency bridge to COTS switch

7.5.c Generic backend board (TBC)

- Critically review specificities of DAQ systems in HEP
  - Slow custom links from frontend, interfaces to custom timing system, additional monitoring and configuration data streams, inline processing, etc.
- Compare, discuss and benchmark performance of parallel developments
  - Explore possibility of establishing a common X-experiments base in hardware, firmware and software
  - Review form factors available for future developments and recommend common platform

WG 7.6: Complex imaging ASICs & Technologies

7.6.a Common access to selected CMOS imaging technologies and IP blocks

- Tower-180nm, LFoundry-110nm, TPSCo-65nm
  - Provide efficient and affordable access to technologies
  - Develop and distribute PDKs and IPs
  - Manage legal and commercial frameworks
  - Share test results

7.6.b Common access to 3D and advanced integration

- Access to research or commercial facilities mastering chiplets, 2.5/3D and Si-photonics integration
  - TSV, RDL, interposers, C2C, C2W and W2W bonding
- Development and prototyping of demonstrators
  - Mechanical and electrical characterization

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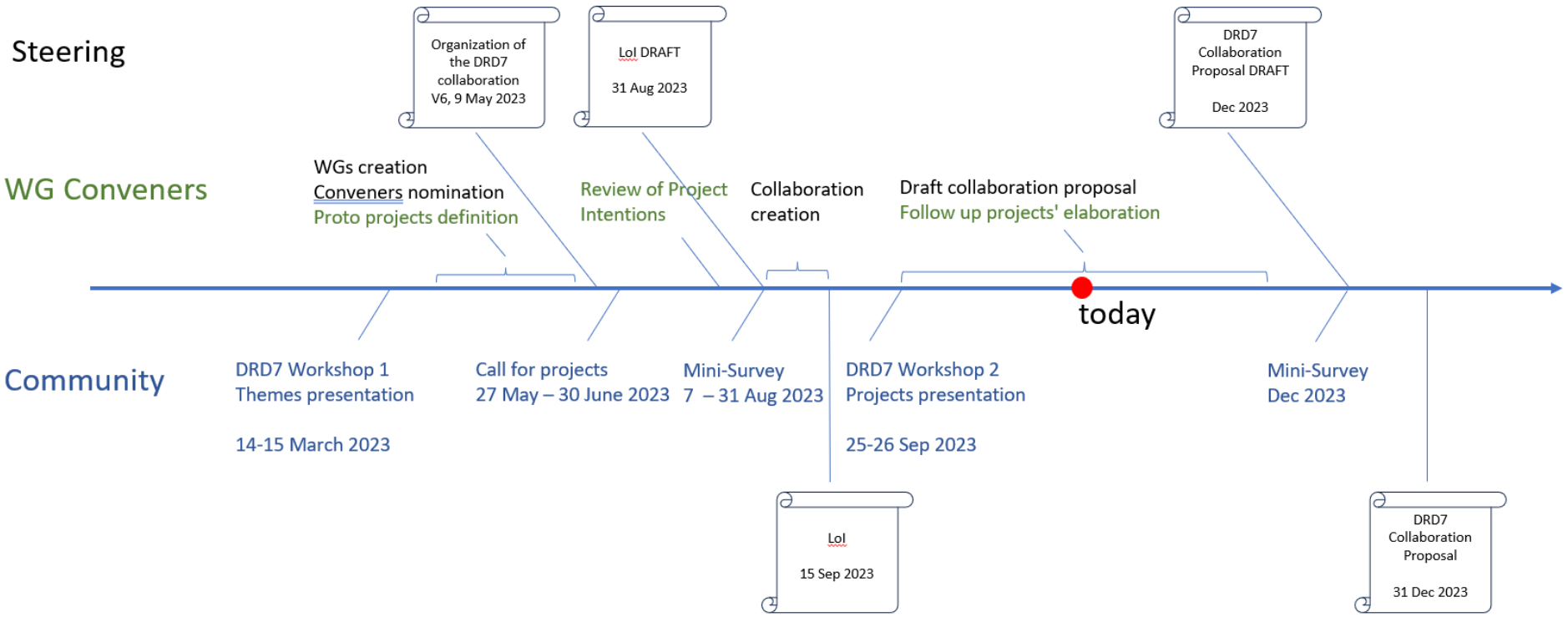
DRD7 organization timeline



Outlook

- The vital importance of electronics to High Energy Physics is acknowledged at the highest levels
  - Innovation in hardware and software will disrupt the way we build detectors
  - Complexity in technologies and tools will disrupt the way we work
- An R&D program must address the above two points, keeping in mind that:
  - No team can cover the full spectrum
  - Collaboration is key to survival
  - Electronics will be both enabling and limiting our ambitions
- R&D lines must build on:
  - Focused expertise and strategic goals
  - Above-critical-mass teams
  - Mid-term applications
- For very complex electronics projects, an improved collaborative model is required
  - a new balance is being sought between central institutions and distributed resources
  - as case study, a hub model for ASIC developments is under discussion
  - A project for DRD7.7 WG (tools and technologies) ?
- DRD7 supports 16 strategic R&D projects in electronics
  - DRD7 collaborators are the project contributors
  - Forums and workshops are organized to share knowledge and exchange ideas with broader community (observers)
  - Collaboration proposal due to be submitted by end-2023
  - New call for projects/contributors expected by end-2024 …and in subsequent years
- A looser framework for collaborating with US institutes who cannot directly contribute could be based on DRD7-forums

References

- EPPS strategy update 2020: https://indico.cern.ch/event/957057/
- ECFA Detector R&D: https://indico.cern.ch/event/957057/
- ECFA DRD Roadmap: https://indico.cern.ch/event/957057/page/23281-the-roadmap-document
- DRD7 LoI: attached to this indico agenda : https://indico.slac.stanford.edu/event/8288/sessions/584/#20231109
- 1st DRD7 workshop: https://indico.cern.ch/event/1214423/timetable/#20230314
- 2nd DRD7 workshop: https://indico.cern.ch/event/1318635/timetable/#20230925

Additional material

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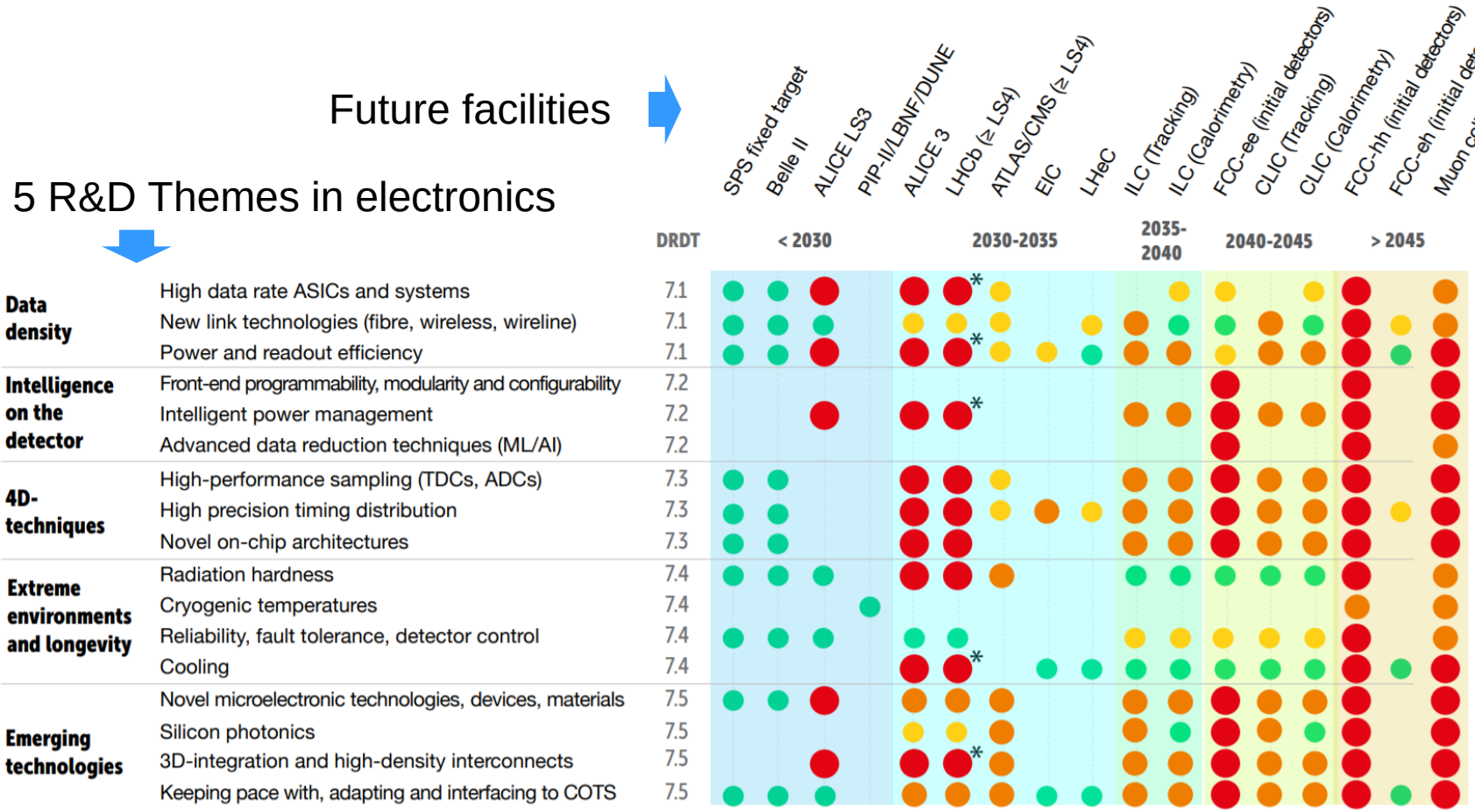
TF7 Recommendations

a) Detector R&D Themes, Electronics

Future facilities

5 R&D Themes in electronics



DRD7 structure

- Collaboration Board: representatives of participating institutes
- Steering Committee: to be appointed
- Technical Committee:WG7.x conveners+steering committee