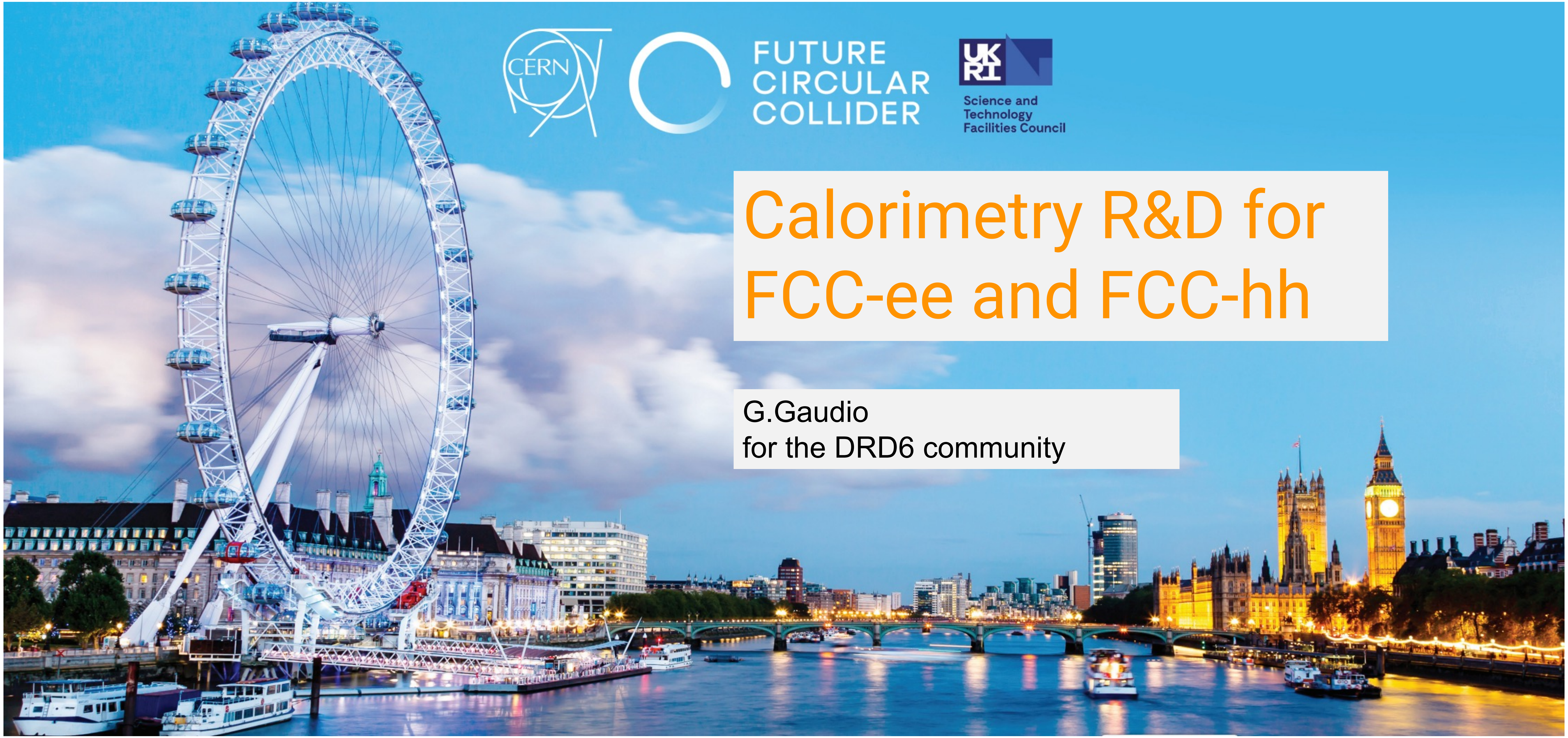


CERN FUTURE CIRCULAR COLLIDER
UKRI Science and Technology Facilities Council

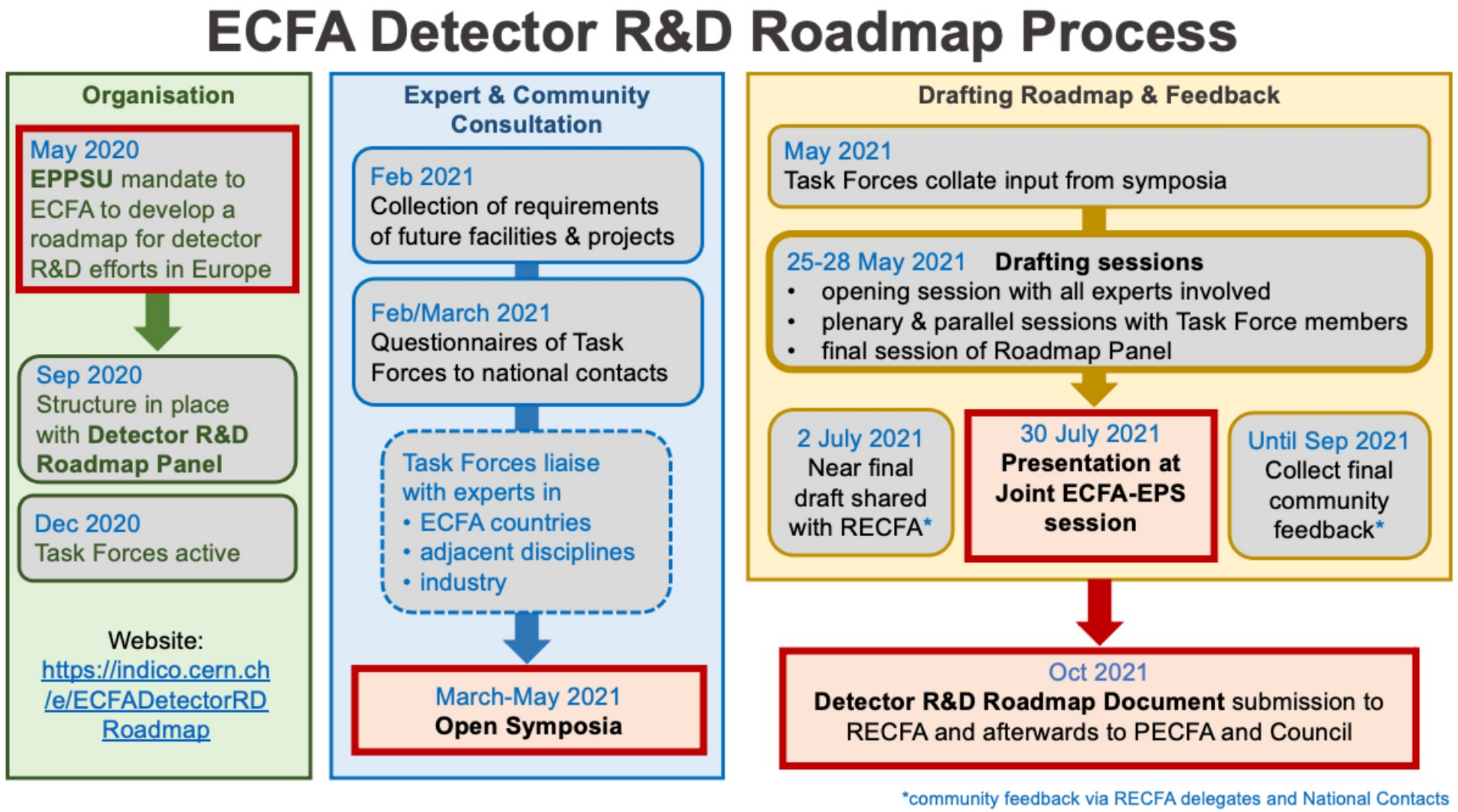
Calorimetry R&D for FCC-ee and FCC-hh

G.Gaudio
for the DRD6 community

ECFA

From roadmap to the DRD6 collaboration

European Strategy Update



Calorimetry Identified Key Technologies and R&D Tasks

Key technologies and requirements are identified in Roadmap

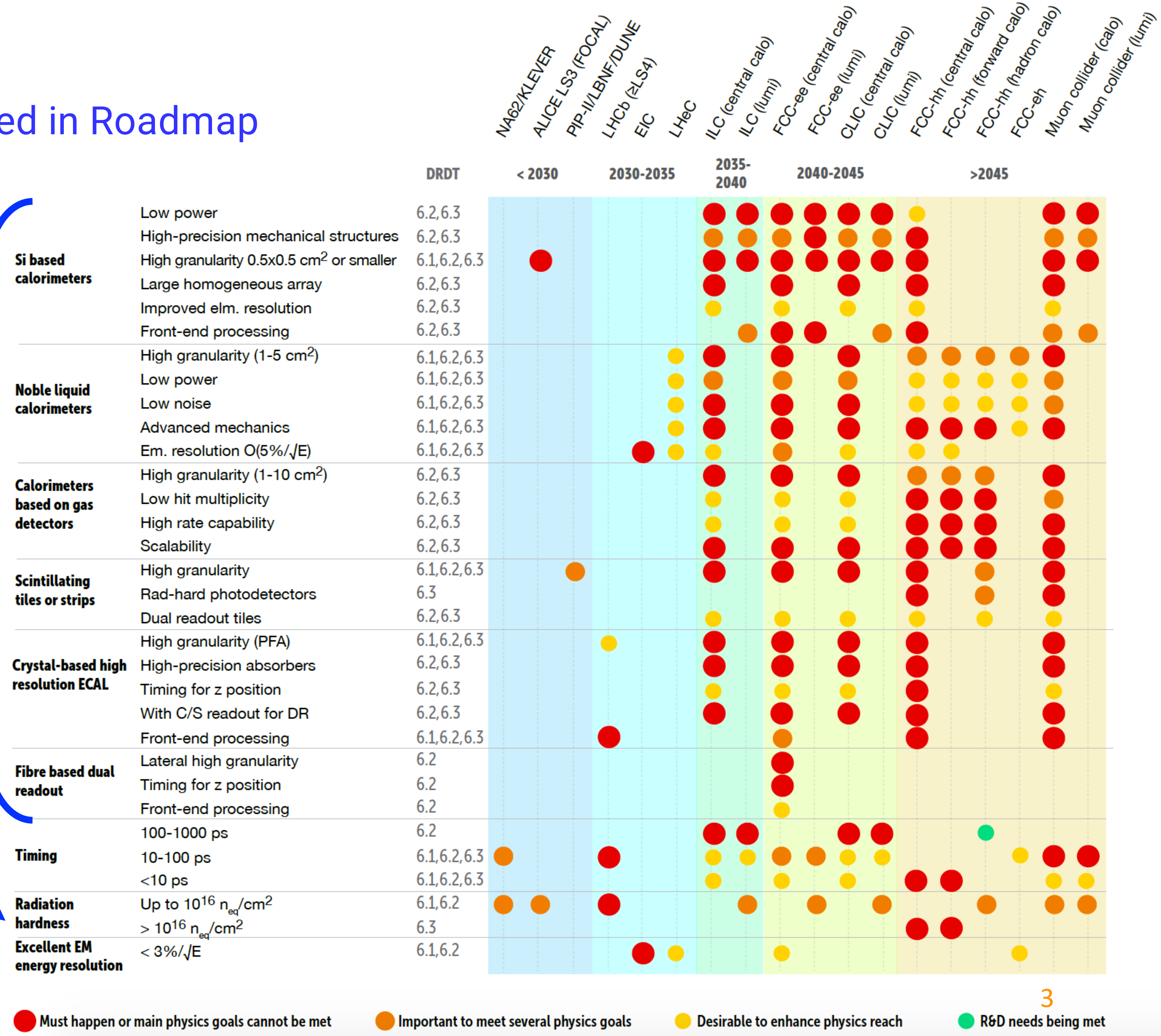
- Si based Calorimeters
- Noble Liquid Calorimeters
- Calorimeters based on gas detectors
- Scintillating tiles and strips
- Crystal based high-resolution ECALs
- Fibre based dual readout

R&D should in particular enable

- Precision timing
- Radiation hardness

R&D Tasks are grouped into

- Must happen
- Important
- Desirable
- Already met



ECFA

The Community meetings & input proposal

European Strategy Update

1st Community Meeting
https://indico.cern.ch/event/1212696/

ECFA Detector R&D Roadmap Task Force 6: Calorimetry Community Meeting

Thursday 12 Jan 2023, 09:00 → 18:00 Europe/Rome

222/R-001 (CERN)

Felix Sefkow (Deutsches Elektronen-Synchrotron (DE)), Felix Sefkow (DESY), Roberto Ferrari (INFN Pavia (IT)), Roberto Ferrari, Roman Poeschl (Université Paris-Saclay (FR))

2nd Community Meeting
https://indico.cern.ch/event/1246381/

ECFA Detector R&D Roadmap Task Force 6: 2nd Calorimetry Community Meeting

Thursday 20 Apr 2023, 09:00 → 18:00 Europe/Rome

40/S2-A01 - Salle Anderson (CERN)

Gabriella Gaudio (Dipartimento di Fisica Nucleare e Teorica), Roberto Ferrari (INFN Pavia (IT)), Roman Poeschl (Université Paris-Saclay (FR))

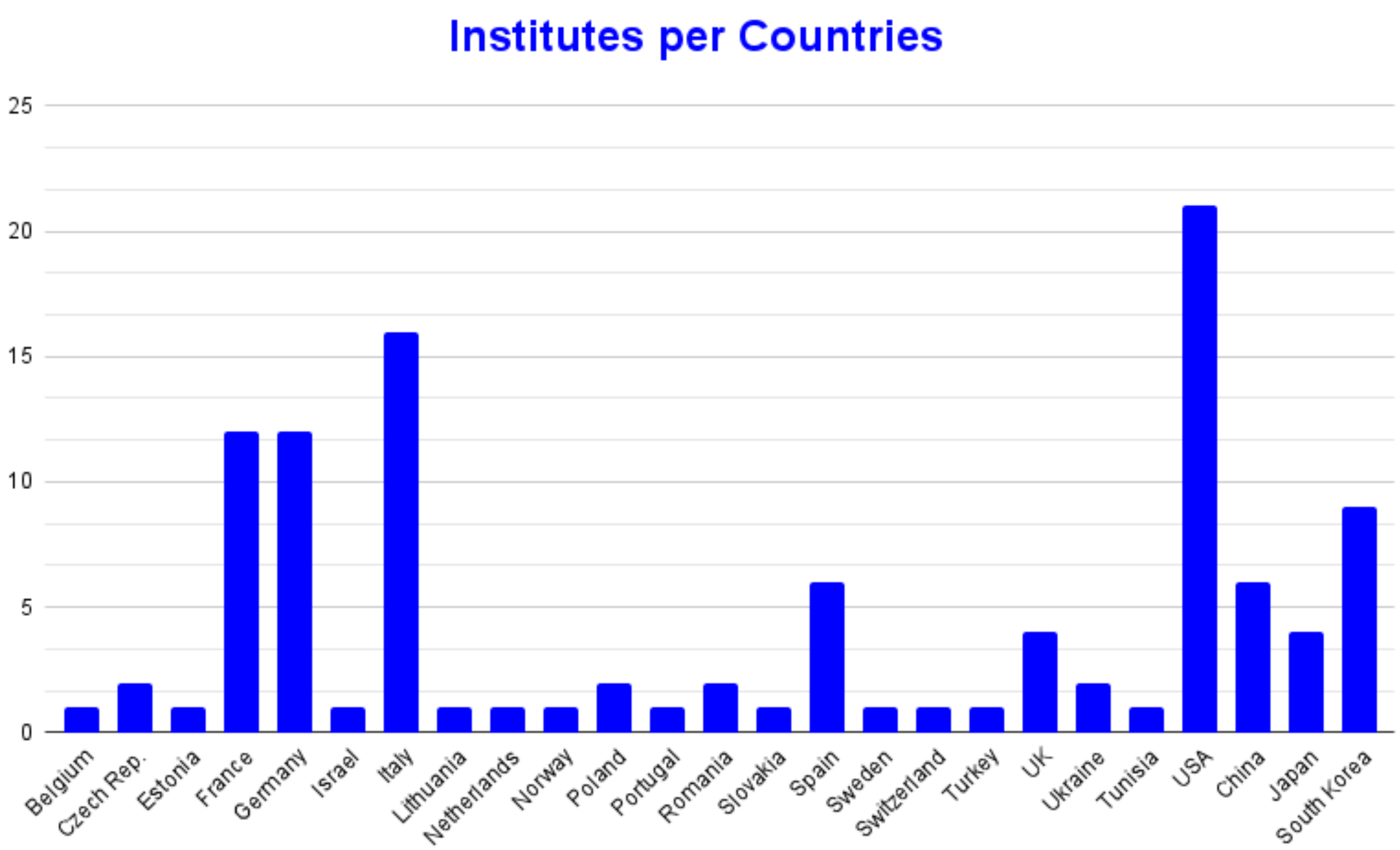
Launch of Input proposal collection

- mid-February – April 1st
- Scientific proposal of what need to be built and tested in the next 3 (2024-2026) - 6 (2027-2029) years
- Description and timeline
- Objectives:
  - Milestones
  - Deliverables
- List of participating Institutes/Labs with short description
- Confidential information on resources

ECFA

Proposal Submission Statistics

European Strategy Update

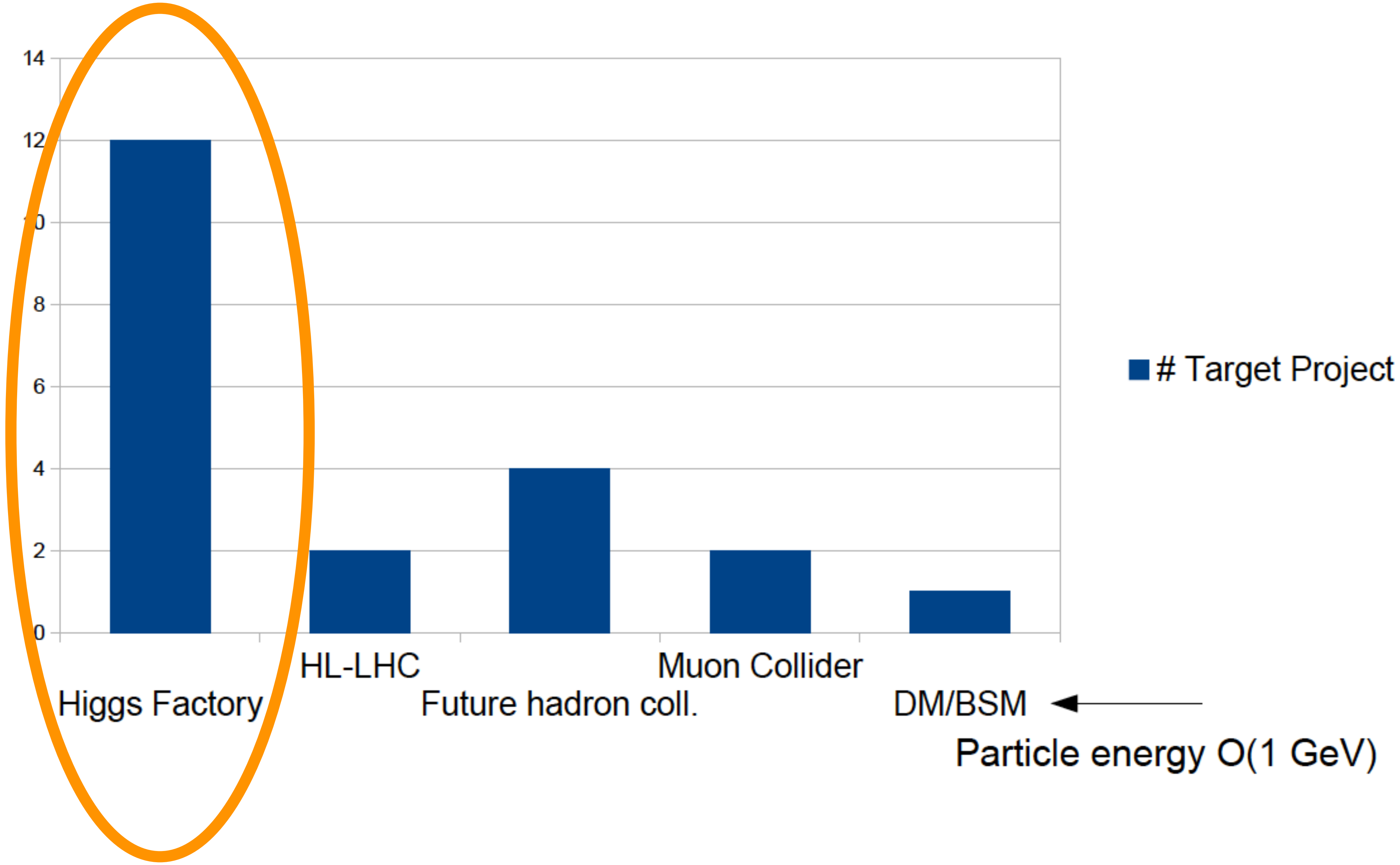


23 proposals received: geographical distribution

- 25 countries
- 110 institutes
  - 2 collaborations: MODE and Glass Scintillator Collaboration

Proposal Submission Statistics

Technologies relevant for FCC will be covered by DRD 6



- Higgs factories dominate
  - HF includes heavy flavor that target superb elm. energy resolutions
- (Already now) orientation towards future hadron collider and muon collider

DRD6 scientific organization

WORK AREAS:

- TRACK 1 — Sandwich calorimeters with fully embedded Electronics
- TRACK 2 — Liquified Noble Gas calorimeters
- TRACK 3 — Optical calorimeters

TRANSVERSAL ACTIVITIES: (common collaboration interest & liaison with other DRD)

- Materials
- Photodetectors, Electronics and DAQ
- Testbeam Facilities
- Detector Physics, simulation, algorithm and software tools
- Industrial Connections and technological transfer

Track 1: Sandwich calorimeters with fully embedded elx

DRD6 Track 1

System aspects

Electronic, mechanical, thermal integration

Larger prototypes demonstrating system-level aspects of the technology - incl. fully embedded electronics

Sensor aspects

Development of calorimeter-specific sensors and materials

Test and performance studies of individual elements / cells

links to Track 3, other DRDs

Front-end & TDAQ

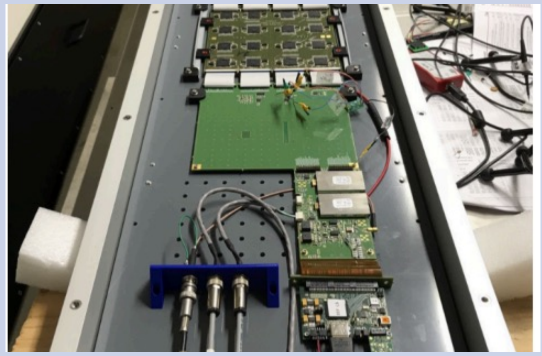
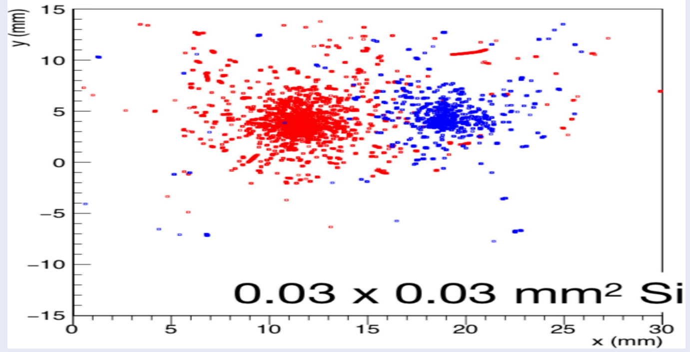
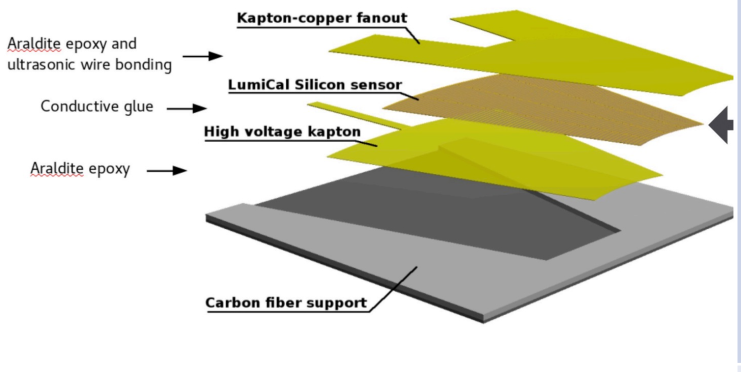
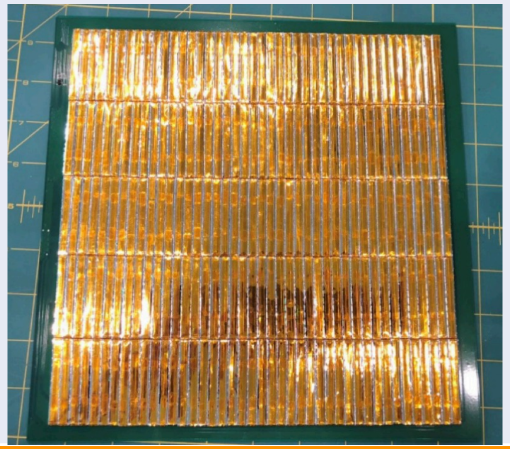
FE Electronics (incl. ASICs), data flow, control, trigger and general back-end solutions

links to transversal track 3, possibly DRD7

Overall system optimization

Simulation studies to establish main performance criteria with system relevance, including timing, granularity, compactness and TDAQ concepts

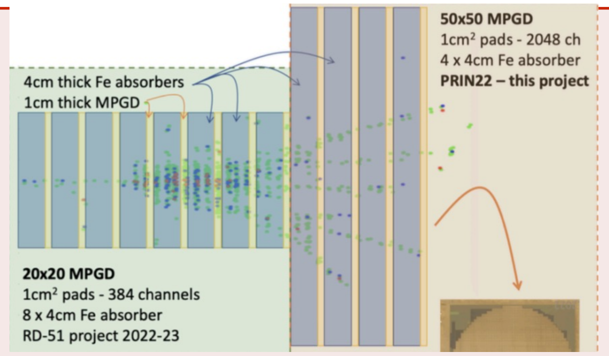
Track 1: Sandwich calo with fully embedded elx - ECAL

SiW ECAL	A SiW-ECAL using silicon pad sensors with analog readout Builds on CALICE SiW ECAL technological prototype Extension of current prototype for continuous readout, reduction of power consumption and cooling, • Study of the addition of timing,	
DECAL Digital ECAL based on MAPS	A MAPS-based digital Silicon-Tungsten ECAL, Building on current DECAL and EPICAL projects. Establish requirements of a sensor dedicated for digital calorimetry and design of next-generation sensor with calorimeter-specific optimisation	
Highly Compact ECAL	Highly compact electromagnetic calorimeter with semiconductor sensors, R&D on Si and GaAs sensors, including optimisation of readout integration • Development of thin conductive gluing. Development of readout electronics. Mechanics with minimal tolerances	
Highly Granular Scintillator-strip Calorimeter	A tungsten-scintillator-strip (with SiPM readout) calorimeter . Engineering study for large-scale production • Timing performance Scintillator material • Scintillator strip design • Active cooling system • Mechanical structure and services	

Track 1: Sandwich calo with fully embedded elx - HCAL

MPGD-based Hadronic Calorimeter

Inspired by CALICE DHCAL & SDHCAL •
Using MPGDs (examples uRWELL, resistive Micromegas) for higher-rate environments

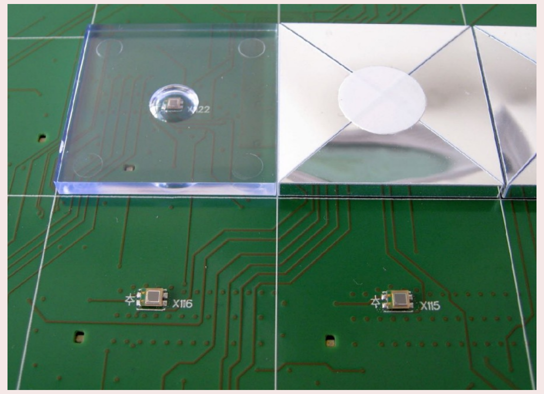


T-SDHCAL

A RPC-based semi-digital HCAL with timing capability
Builds on CALICE SDHCAL technological prototype.
Simulation studies extending to time information • Study and development of cooling and cassette concepts • Fast timing electronics

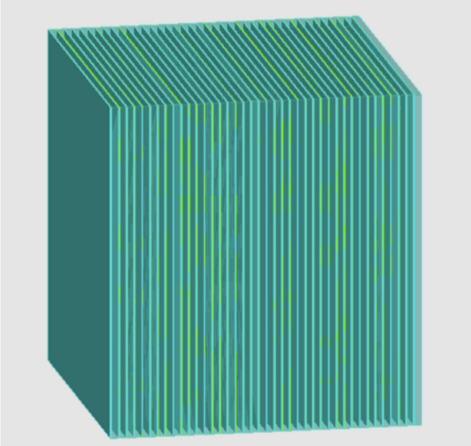
SiPM-on-Tile AHCAL

SiPM-on-tile / steel HCAL
Builds on CALICE AHCAL Technological Prototype.
Extension of current detector concept to circular colliders with continuous readout snd higher data rate • re-evaluate need for cooling • re-optimisation of detector to ensure optimal performance while respecting new constraints

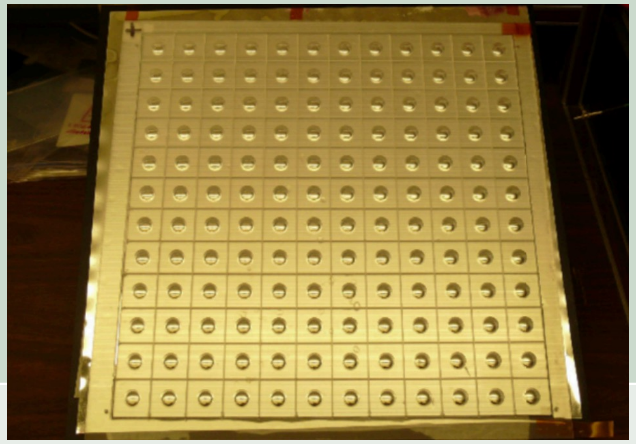
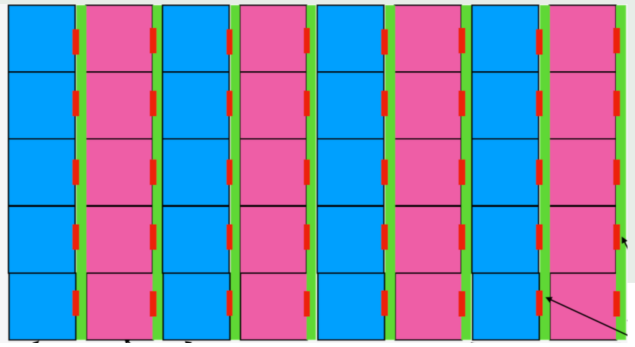


Highly Granular HCAL with Glass Scintillator Tiles

A variation of the CALICE AHCAL concept:
Using glass scintillator tiles instead of plastic • Increased sampling fraction - with the potential for improved energy resolution.
R&D of scintillator material: high density, high light yield, low cost



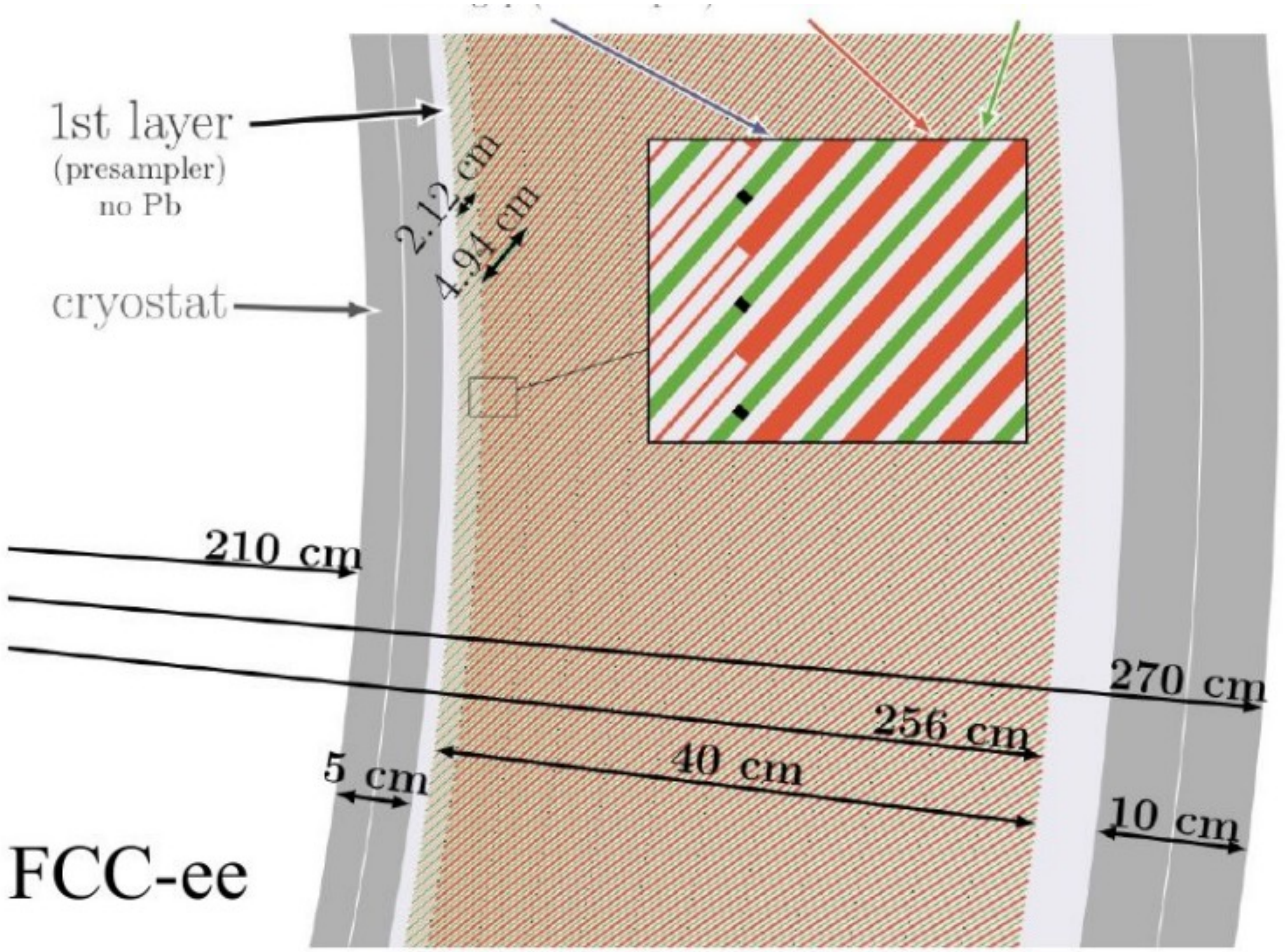
Track 1: Sandwich calo with fully embedded elx - HCAL

ADRIANO3 Triple Readout Calorimeter	Extension of ADRIANO2 (fully active granular dual readout calorimeter) to three readout modes. High-density glass as Cherenkov Medium (and absorber) • Plastic scintillator tiles • RPCs. optimization of the construction technique in terms of: • light yield, RPC efficiency, timing resolution, and cost	
Double Readout Sandwich Calorimeter	Concept for an (almost) fully active hadron calorimeter • Alternating layers of heavy scintillator (PWO) and Cherenkov medium (lead glass) Each read out by embedded SiPMs	

Track 2: Liquified Noble Gas calorimeters

- An appealing option for precision measurements
  - Good energy resolution
  - High(-ish) granularity achievable
  - Radiation hardness for hadron colliders
  - Linearity, uniformity, long-term stability
- Ambitious R&D plans
  - High granularity noble liquid calo
  - Optimization for PFlow reconstruction
  - Designing for improved energy resolution
    - Achieving very low noise
    - Lightweight cryostats to minimize X0

Excellent solution for small systematics



Track 2: Liquified Noble Gas calorimeters

- Develop the calo design
  - Study design solutions for endcaps
  - Study general performance in simulation, in combination with some HCAL concept
  - Optimize granularity
- Build a first prototype and measure performance in testbeam
  - Need to design and optimize electrodes, absorbers
  - Readout electronics
  - Can then be refined to test further developments / new ideas

4 Work Areas

1. General design and expected performance
2. Readout electrodes
3. Readout electronics
4. Mechanical studies and prototype

Track 3: Optical Calorimeters

Scintillator based sampling calorimeters

Scintillating Tile HCAL
for FCC-hh, FCC-ee

Dual Readout Fiber Calorimeter
for Higgs Factories

R&D on Spaghetti (EM) Calorimeter technologies for LHCb Upgrade II, Higgs factories, FCC-hh

Fast-timing, ultracompact, radiation hard, EM calorimetry (*RADiCAL*)
for FCC-hh

High sampling fraction EM calorimeter with crystal grains (*GRAiNITA*) for FCC-ee

Homogeneous EM crystal calorimeters

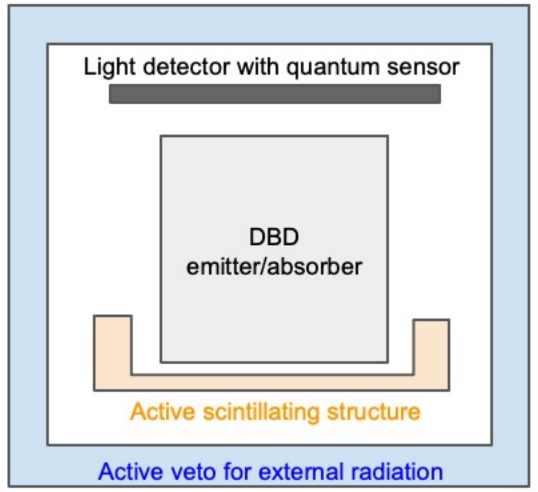
Maximum Information Crystal Calorimeter for Higgs Factories

High Granularity Crystal Calorimeter for Higgs Factories

Fast, segmented Crystal calorimeter for Muon Collider (*CRILIN*)

Large mass cryogenic calorimeters

Large mass cryogenic calorimeters
for neutrinoless double beta decay



Large mass cryogenic calorimeters operated in a double read-out configuration (heat+light)
whole system operated in vacuum at 10 mK, radiopurity of materials, quantum detectors

ScintCal: **Scintillator** material for future calorimeters

Track 3: Optical Calorimeters

Scintillator based sampling calorimeters

Scintillating Tile HCAL for FCC-hh, FCC-ee

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Fast, segmented Crystal calorimeter for Muon Collider (*CRILIN*)

Large mass cryogenic calorimeters

Large mass cryogenic calorimeters for neutrinoless double beta decay

ScintCal: **Scintillator** material for future calorimeters

Commonalities:

- Use of SiPMs
- Particle-Flow Friendly approach
- Targeting 10-100 ps timing precision

Track 3: Optical Calorimeters

Scintillator based sampling calorimeters

Scintillating Tile HCAL
for FCC-hh, FCC-ee

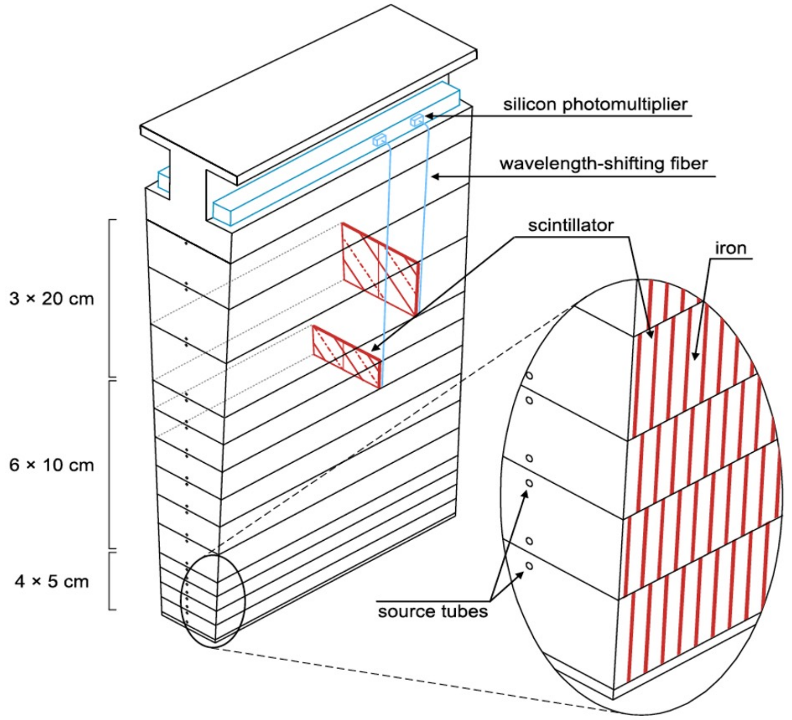
Dual Readout Fiber Calorimeter
for Higgs Factories

R&D on Spaghetti (EM) Calorimeter technologies for LHCb Upgrade II, Higgs factories, FCC-hh

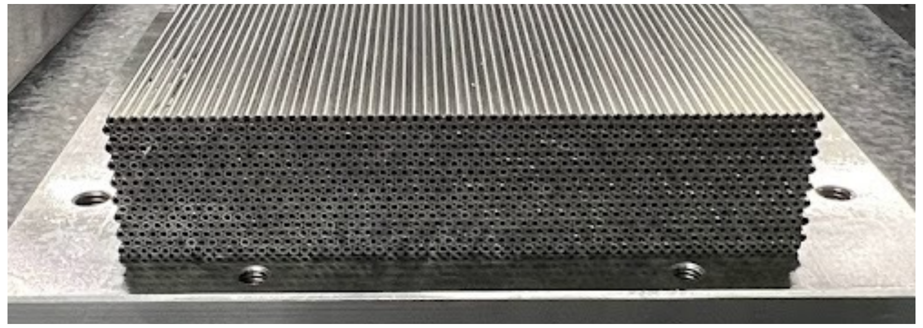
Fast-timing, ultracompact, radiation hard, EM calorimetry (*RADiCAL*) for FCC-hh

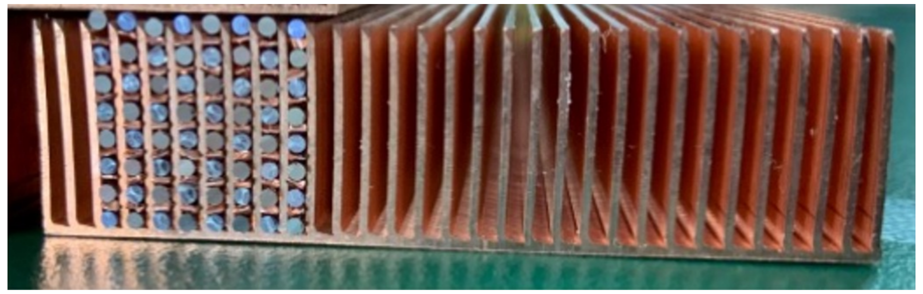
High sampling fraction EM calorimeter with crystal grains (*GRAiNITA*) for FCC-ee

Hadron calorimeter with scintillating tiles and WLS fibre readout and SiPMs
Cost-effective production of tiles, radiation hardness for FCC-hh
Organic scintillating tiles, Steel (+Pb for FCC-hh) absorber



High resolution Electromagnetic and hadronic calorimeter
Organic scintillating fibres in brass or steel absorber(different solutions under development),
SiPM or MCP-PMT photon detectors integration of a large number of SiPMs





Track 3: Optical Calorimeters

Scintillator based sampling calorimeters

Scintillating Tile HCAL
for FCC-hh, FCC-ee

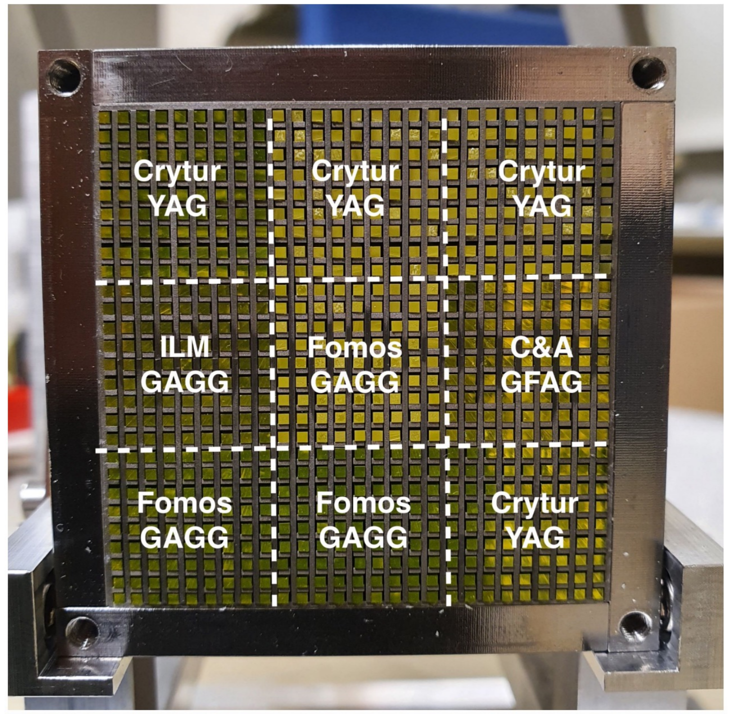
Dual Readout Fiber Calorimeter
for Higgs Factories

R&D on Spaghetti (EM) Calorimeter technologies for LHCb Upgrade II, Higgs factories, FCC-hh

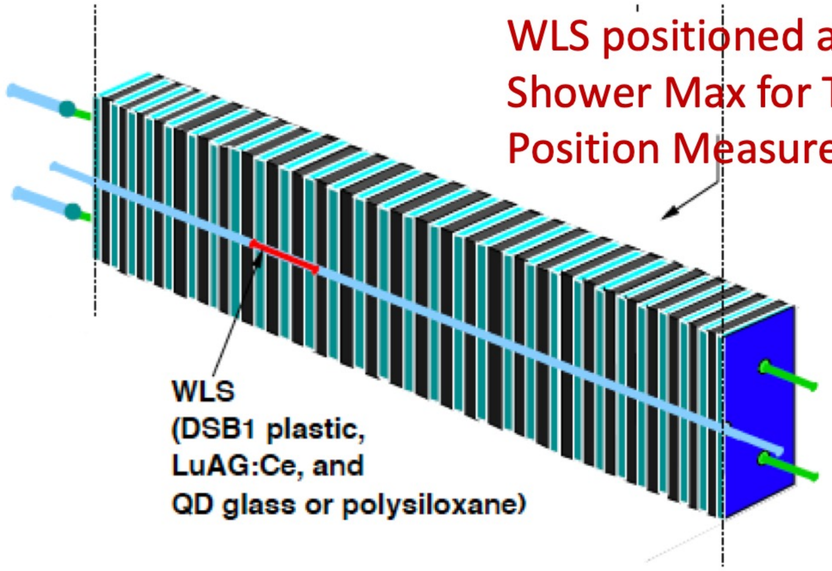
Fast-timing, ultracompact, radiation hard, EM calorimetry (*RADiCAL*) for FCC-hh

High sampling fraction EM calorimeter with crystal grains (*GRAiNITA*) for FCC-ee

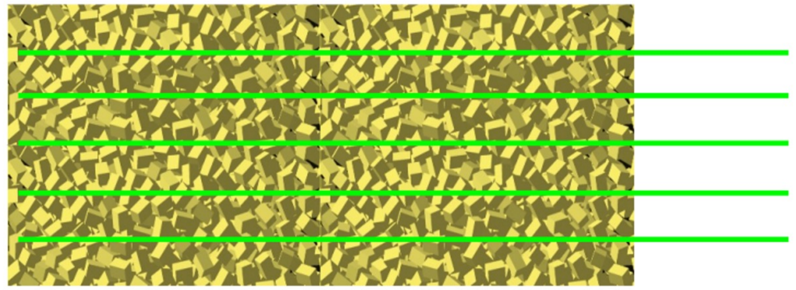
SpaCal (ECAL made of scintillating fibres in dense absorbers) with O(10-20) ps time resolution
Radiation-hard (and radiation-tolerant) scintillating fibres
Crystal or organic fibres in lead or tungsten absorber, hollow light guides, PMT/SiPM photon detectors, SPIDER ASIC for timing



Radiation-hard EM calorimeter with 10%/√E energy resolution and 25 ps timing resolution
Radiation-hard WLS filament and SiPM
Shashlik/type ECAL modules with tungsten absorber and LYSO:Ce tiles, WLS (full-length or in showe maximum),



Innovative technique inspired by Shashlyk-type calorimeters. Extremely fine granularity. Grain of scintillator in dense liquid

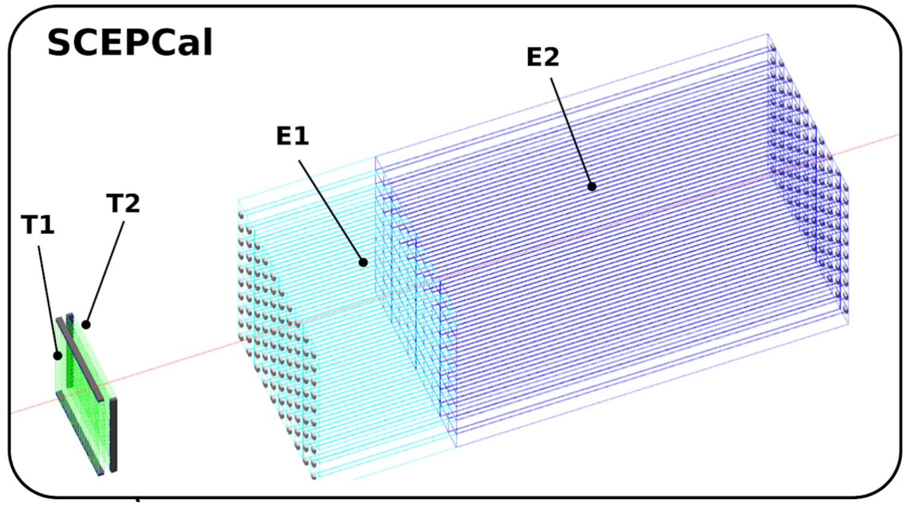


Track 3: Optical Calorimeters

Homogeneous EM crystal calorimeters

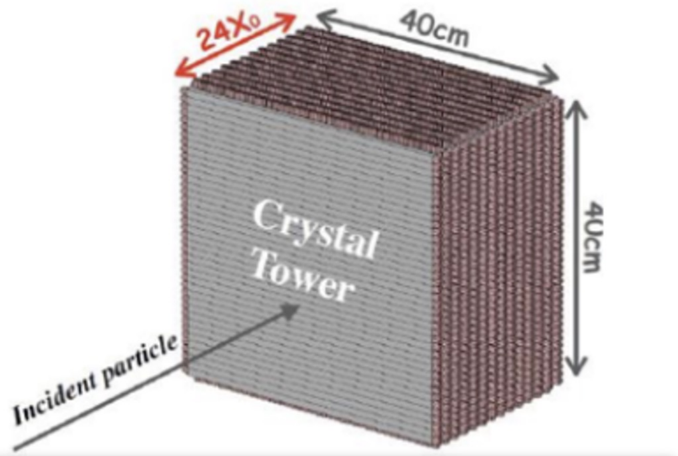
Maximum Information Crystal Calorimeter for Higgs Factories

Homogeneous EM calorimeter based on segmented crystals with SiPMs readout and dual-readout capability Simultaneous readout of scintillation and cherenkov light signals from the same active element (heavy inorganic scintillator) High density scintillating crystals with good cherenkov yield instrumented with dedicated optical filters and SiPMs



High Granularity Crystal Calorimeter for Higgs Factories

Highly granular EM crystal based calorimeter to exploit maximum potential of PFA algorithms Integration (readout, minimize gaps, material budget), reconstruction driven by grid layout High density scintillating crystals with double-ended SiPM readout

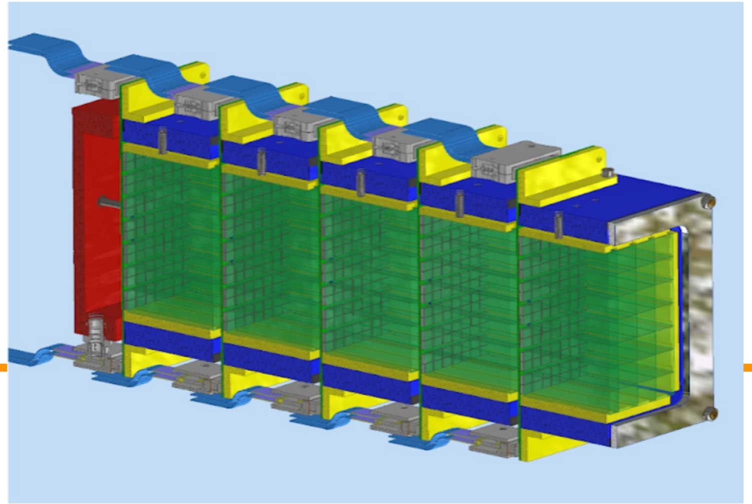


EM calorimeter module: a grid of ~1x1x40cm³ crystal bars

Fast, segmented Crystal calorimeter for Muon Collider (*CRILIN*)

Radiation tolerant design of a longitudinally segmented crystal EM calorimeter (10%/√E) for mitigation of beam induced background at muon colliders.

Very harsh radiation environment for SiPMs, high rate of operation, large beam induced background (BIB) Lead fluoride (PbF_2) crystals, each readout with 2 channels consisting of a pairs of SiPMs connected in series



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DRD6 scientific organization

European Strategy Update

WORK AREAS:

TRACK 1

Sandwich calorimeters with fully embedded electronics

TRACK 2

Liquified Noble Gas calorimeters

TRACK 3

Optical calorimeters

TRANSVERSAL ACTIVITIES: (common collaboration interest & liaison with other DRD)

Materials

Photodetectors, Electronics and DAQ

Testbeam Facilities

Detector Physics, simulation, algorithm and software tools

Industrial Connections and technological transfer

Transversal activity: Material

- Materials
- Photodetectors, Electronics and DAQ
- Testbeam Facilities
- Detector Physics, simulation, algorithm and software tools
- Industrial Connections and technological transfer

Common to all the proposals:
Find the best suitable material for the dedicated application

R&D on various scintillators and wavelength shifters needed

ScintCal proposal in Track 3, is the core of this transversal activity

Optimization of materials (e.g. for radiation hardness, decay time, collection of Cherenkov light, mass production)

Technology: Inorganic and organic scintillators, glasses, ceramics, quantum materials

Next 3+ year goals: Clear overview of the state-of-the-art materials and propose scintillators with mass scale production capability for future collider experiments

Transversal activity: Photodetector, Electronics and DAQ

- Materials
- Photodetectors, Electronics and DAQ
- Testbeam Facilities
- Detector Physics, simulation, algorithm and software tools
- Industrial Connections and technological transfer

- SiPM's appear in almost all the proposal for Optical and scintillating based calorimeters
  - consequence of the high-granularity requirement
- Trends for Calorimeter Readout
  - On-detector embedded electronics, low-power multi-channel ASICs
    - Challenges : #channels, low power, digital noise, data reduction
  - Off-detector electronics: fibre/crystal readout
    - Challenges : low power, data reduction
  - Digital calorimetry: MAPs, RPCs…
    - Challenges : #channels, low power, data reduction
- Proposal for Common ASIC Development
- Circular Collider Higgs Factory requires specific R&D for continuous running (especially important for fully embedded electronics calorimeters)

Transversal activity: test beam facility

Materials

Photodetectors, Electronics and DAQ

Testbeam Facilities

Detector Physics, simulation, algorithm and software tools

Industrial Connections and technological transfer

2024 2027 2030

- Input-proposals reveal (relatively) little need at the beginning
  - Start with prototypes that are either existing or currently under construction
  - Benefitting from AIDAinnova and EUROLABS funding
- Relatively high density of beam tests with new (large scale) prototypes after 2025
- The large scale beam tests will be preceded by smaller scale beam tests
  - Individual layers smaller systems before "mass production"

The importance of beam tests during detector development cannot be underrated

Calorimeters are typically large objects

- A beam test is similar to a small experiment
- Difficult for facility managers to schedule calorimeter beam tests
- No concurring running with other devices possible
- Takes lots of expertise to carry out a successful beam test campaign
- Implies use of infrastructure

Possible issue with beam line shut down in 2026 – 2027 (2028) when many large scale prototype will become available
Follow up needed

Transversal activity: Software Needs

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European Strategy Update

- Materials
- Photodetectors, Electronics and DAQ
- Testbeam Facilities
- Detector Physics, simulation, algorithm and software tools
- Industrial Connections and technological transfer

- Particle Flow Algorithms:
  - mentioned in 17/23 proposals (also in non-native PF-calorimeters)
  - High-granularity ⟺ PFA
- Geant4 Simulation:
  - needed to optimise detector design and interpret data
- Machine (Deep) Learning
  - widely used to reconstruct complicated final states
  - thoughts to have on-board intelligence in FE elx
  - used to optimize detectors?
- Common test beam software?
  - what about a “plug-n-play” SW for data acquisition? Eudaq?

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Next Steps toward DRD6 collaboration

European Strategy Update

- Identify "monitorable" items
  - These are the ones that will be mainly reviewed
  - As of today quite a long list of milestones and deliverables in input-proposals
    - These will have to be condensed and aligned
    - ... but they are useful for internal monitoring
- Type of deliverables?
- Overall goal is studying feasibility of calorimeter technologies for future facilities
- One type of deliverable is prototypes
- Some prototypes could be completed early (2024-2026)
- Further deliverables could be specification/design studies on:
  - ASICs
  - Photodetectors
  - Materials
  - Software
  - Integration strategies

Building the collaboration

- Draft of DRD Proposal ongoing – it will be circulated among proponents in the second half of june
- End of July 2023 – Submission of DRD Calo proposal
- Summer/Early Autumn
  - Implementation of feedback from proposal review
  - Detailed structure of work areas and transversal activities
  - Consolidation of organisation
    - Management structure
    - Including roadmap on assigning names to the different boxes
  - Understanding of which kind of documents do we need (MoU/MoA) and when
  - Maybe a 3rd Community Meeting
- 1 st January 2024 – DRD on Calorimetry in place

Backup

Proposal Submission Statistics

23 proposals received: track distribution

- track 1: 8 (10) proposals
- track 2: 1 proposal
- track 3: 12 (10) proposals
- track 4: 2 proposals

Calo type(*)

- ECAL: 11
- HCAL: 7
- BOTH: 4

Calo type (**)

- Homogeneous: 5
- Sampling: 13
- BOTH: 4

23 proposals received: geographical distribution

- 25 countries
- 4 geographical areas
  - Europe: 19 countries
  - Africa: 1 country
  - America: 1 country
  - Asia: 4 countries

(*) Doesn't apply to Cryogenic DBD proposal
(**) Doesn't apply to Common ASIC proposal

Roadmap implementation

- ECFA Roadmap Coordination group has worked out a proposal
  P. Allport, S. Dalla Torre, J. D'Hondt, K. Jakobs, M. Krammer, S. Kühn, F. Sefkow and I. Shipsey

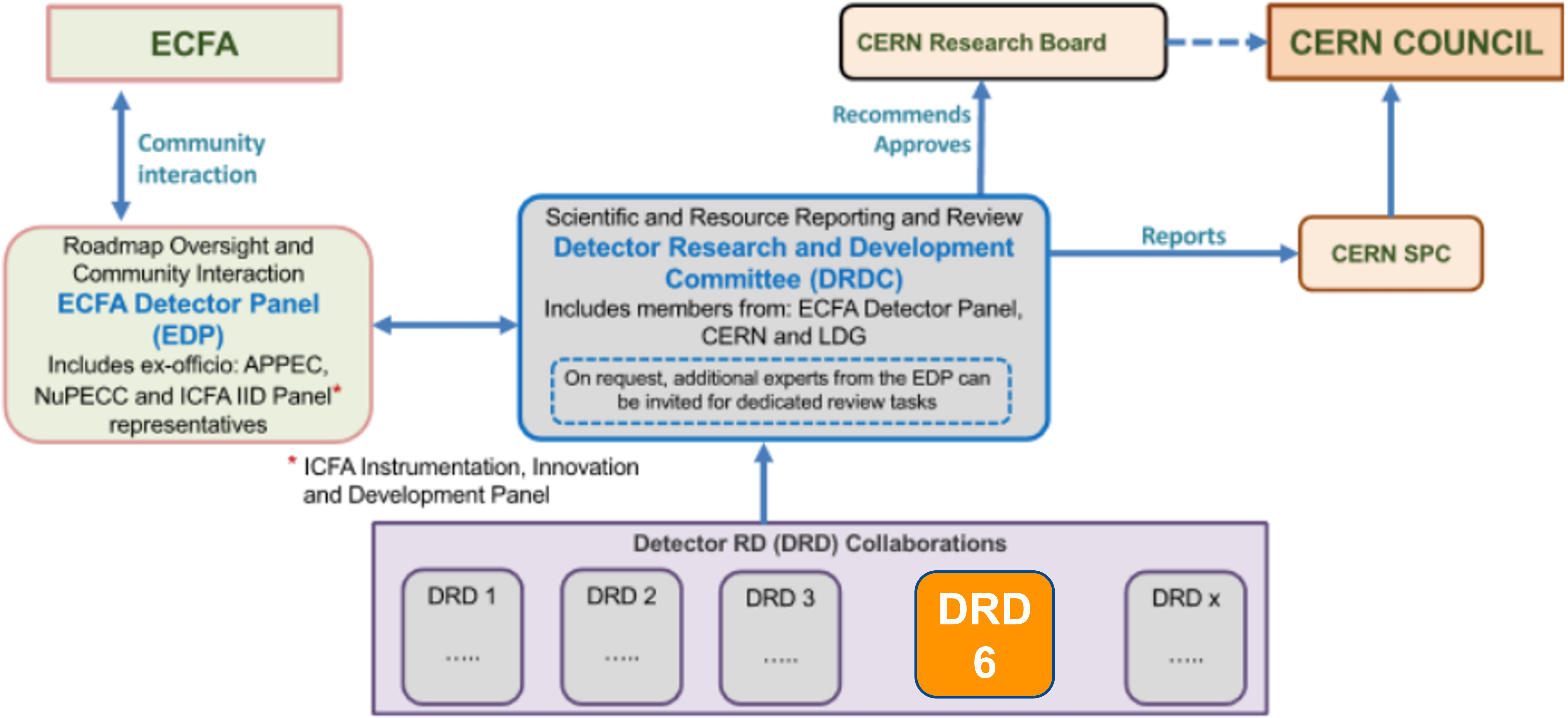
- Document sent to and **endorsed by CERN Council** in September 2022 (CERN/SPC/1190)

- Main outcomes are
  - the **organization of the Detector R&D** in form of **DRD Collaborations**,
  - the overall Organization of the detector R&D
  - an outline of the way towards the formation of the DRD

- DRD will have a CERN recognition but they **will not be** CERN Collaborations ("anchored at CERN")
- Significant participations by non-European groups is explicitly welcome and needed

- The progress and the R&D will be overseen by a DRDC that is assisted by ECFA

ECFA Future Organization of Detector R&D (in Europe)



Toward DRD – Suggested implementation timeline

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European Strategy Update

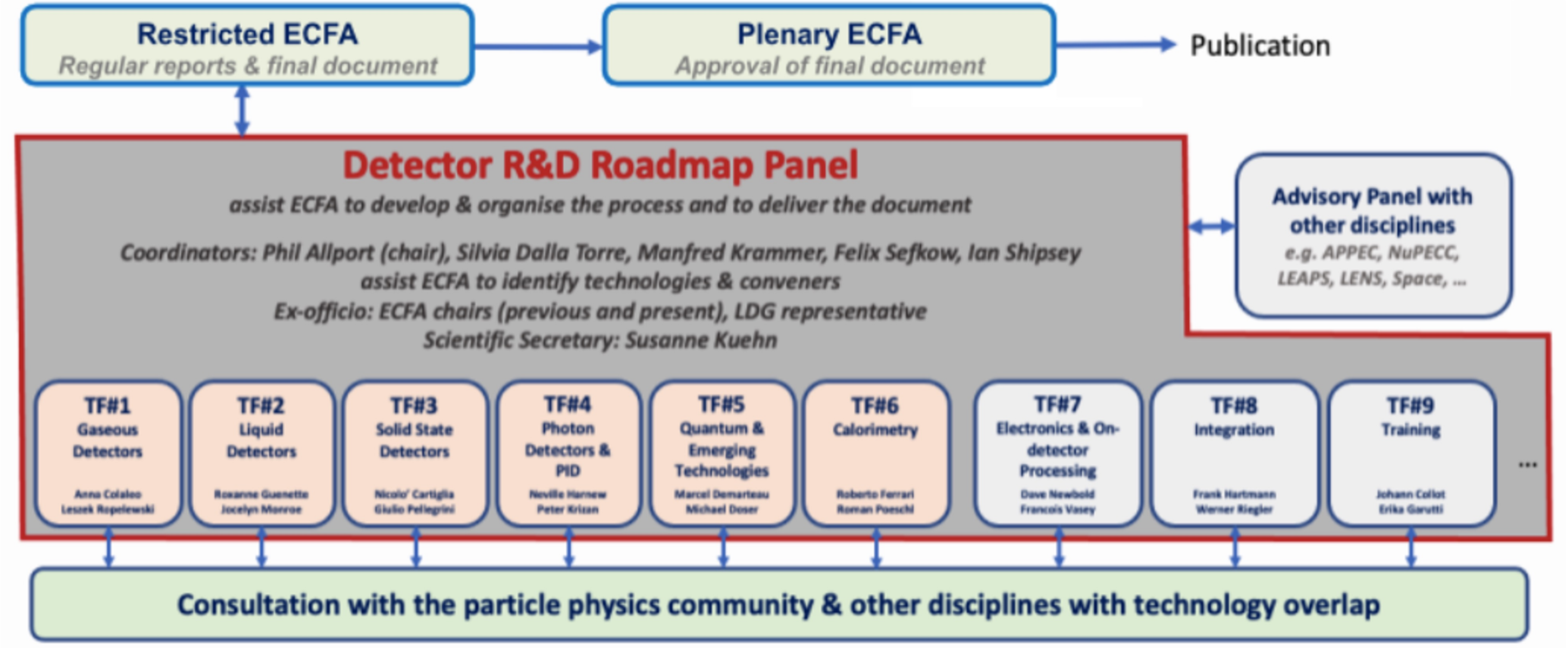
Through 2023, mechanisms will need to be agreed with funding agencies in parallel to the process below for country specific DRD collaboration funding requests for Strategic R&D and for developing the associated MoUs.

Q4 2022	Outline structure and review mechanisms agreed by CERN Council. Detector R&D Roadmap Task Forces organise **community meetings** to establish the scope and scale of community wishing to participate in the corresponding new DRD activity. (Where the broad R&D topic area has one or more DRDTs already covered by existing CERN RDs or other international collaborations these need to be fully involved from the very beginning and may be best placed to help bring the community together around the proposed programmes.)
Q1 2023	**DRDC mandate formally defined** and agreed with CERN management; Core DRDC membership appointed; and EDP mandate plus membership updated to reflect additional roles.
Q1-Q2 2023	**Develop the new DRD proposals** based of the detector roadmap and community interest in participation, including light-weight organisational structures and resource-loaded work plan for R&D programme start in 2024 and ramp up to a steady state in 2026.
Q3 2023	**Review of proposals by DRDC** leading to recommendations for formal establishment of the DRD collaborations.
Q4 2023	DRD Collaborations receive formal **approval from CERN Research Board**.
Q1 2024	New structures operational for ongoing review of DRDs and R&D programmes underway.

Through 2024, collection of MoU signatures

K. Jakobs, ECFA Meeting November 2022

Roadmap Organization



9 Taskforces including TF6 on Calorimetry
Central events: Symposia
TF6 Symposium https://indico.cern.ch/event/999820/
More on roadmap process https://indico.cern.ch/event/957057/

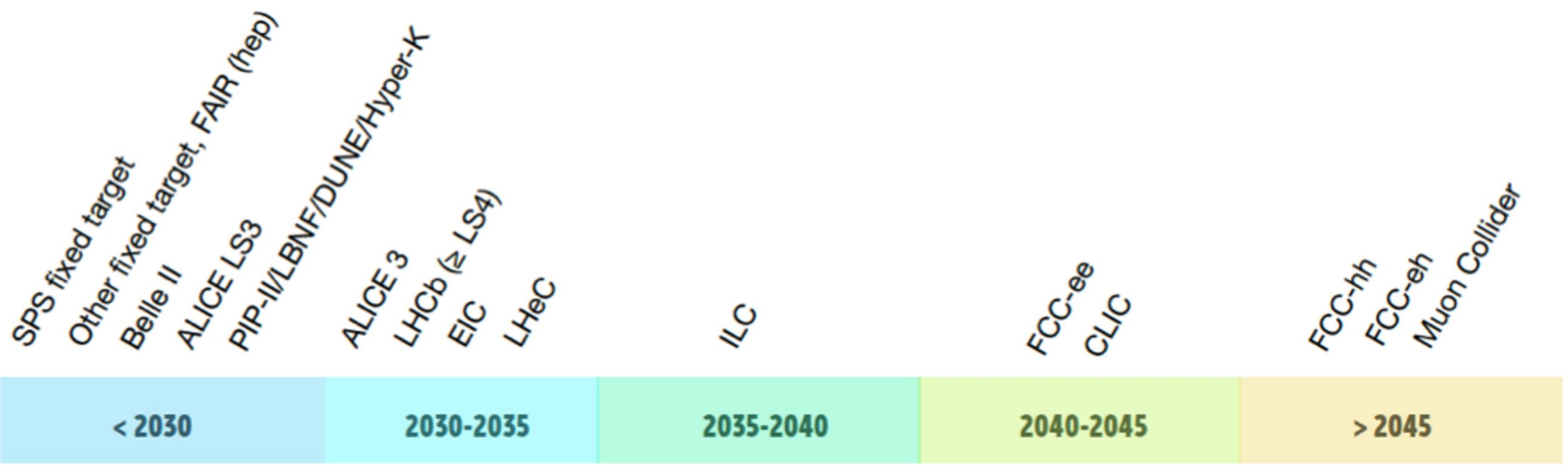
The Roadmap document and process

ECFA R&D Roadmap
- CERN-ESU-017 https://cds.cern.ch/record/2784893
- 248 pages full text and 8 page synopsis

Endorsed by ECFA and presented to CERN Council in December 2021

- The Roadmap has identified
- General Strategic Recommendations (GSR)
- Detector R&D Themes (DRDT) for each of the taskforce topics
- Concrete R&D Tasks

Timescale of projects as approved by European Lab Director Group (LDG)



Guiding principle: Project realisation must not be delayed by detectors

General Strategic Recommendations

GSR1- Supporting R&D facilities

GSR2- Engineering support for detector R&D

GSR3- Specific software for instrumentation

GSR4- International coordination and organisation of R&D activities

GSR5- Distributed R&D activities with centralised facilities

GSR6- Establish long-term strategic funding programmes

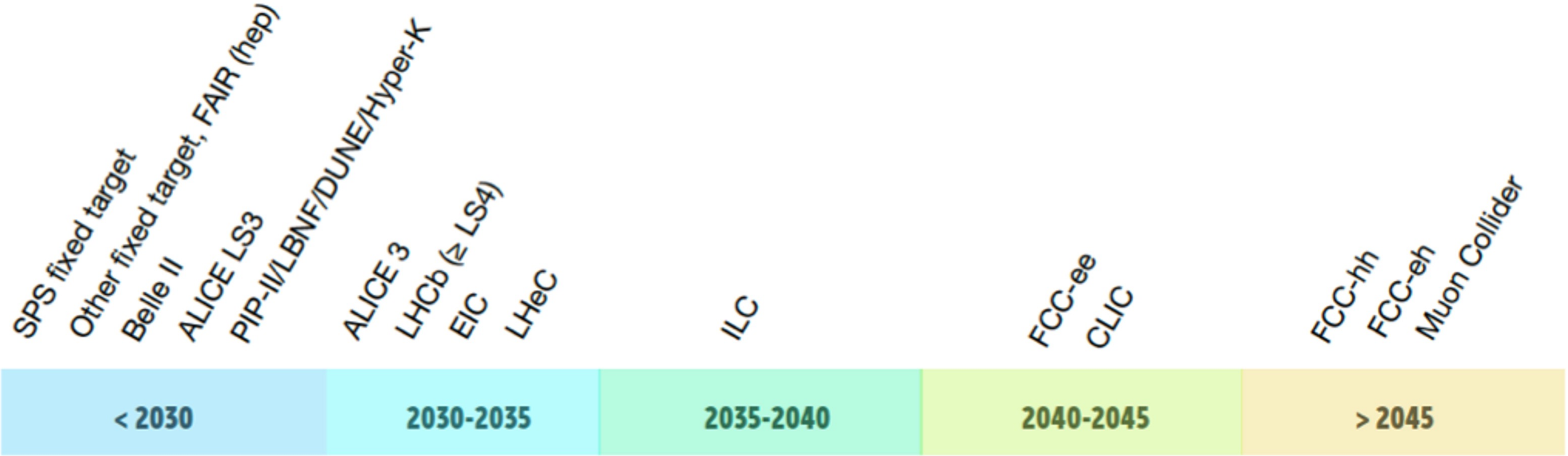
GSR7- Blue-sky R&D

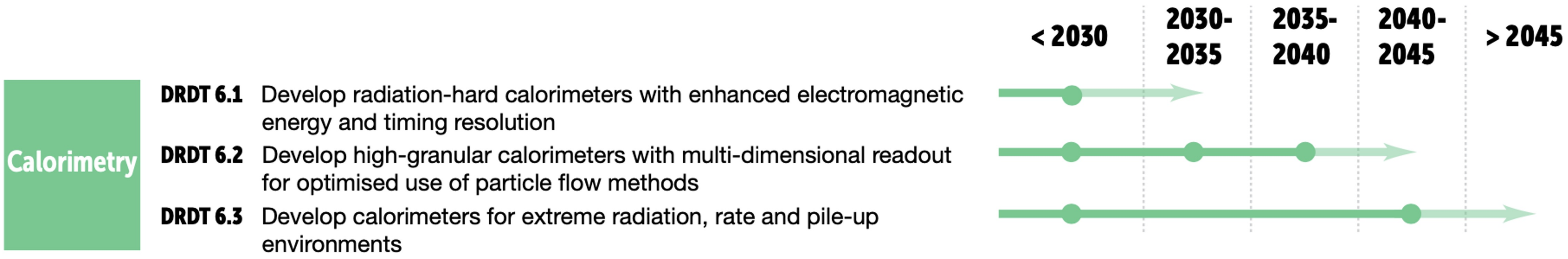
GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts

GSR 9 - Industrial partnerships

GSR 10 - Open Science

Future Facilities and DRDT for Calorimetry





- The DRDT and the provisional time scale of facilities set high-level boundary conditions
- Both as well as the GSR should be taken into account when formulating the R&D proposal(s)