ECFA Detector R&D Roadmap Status

Phil Allport

On behalf of all those contributing as members of the ECFA Detector R&D Roadmap process Group

Introduction by ECFA Chair

Update of the European Strategy for Particle Physics (cont.)

4. Other essential scientific activities for particle physics

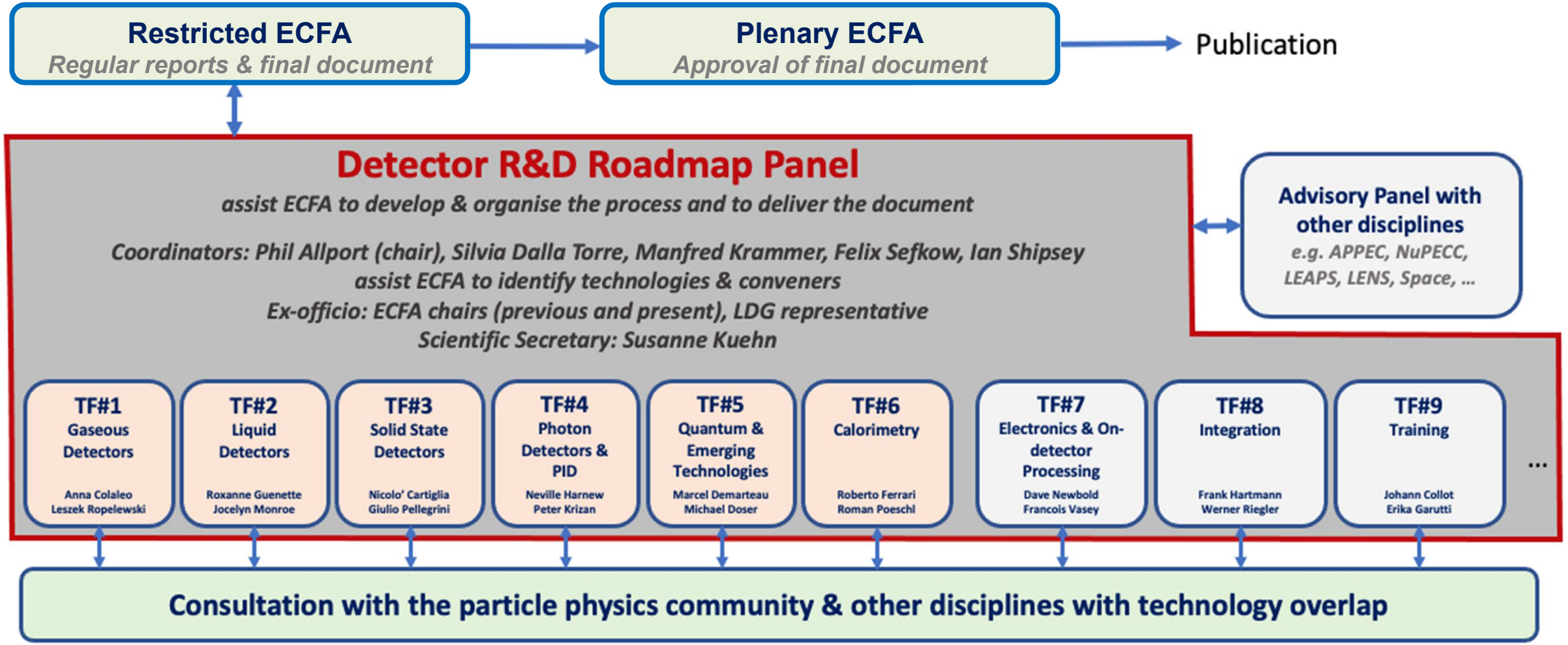
…

C. The ***success of particle physics experiments relies on innovative instrumentation and state-of-the-art infrastructures.*** *To prepare and realise future experimental research programmes, the community must* ***maintain a strong focus on instrumentation. Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities****. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a* ***global detector R&D roadmap*** *that* ***should be used to support proposals at the European and national levels.***

Deliberation Document:
"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. The roadmap should identify and describe a diversified detector R&D portfolio that has the largest potential to enhance the performance of the particle physics programme in the near and long term. …"

Roadmap Organisation

ECFA Detector R&D Roadmap Organisational Structure

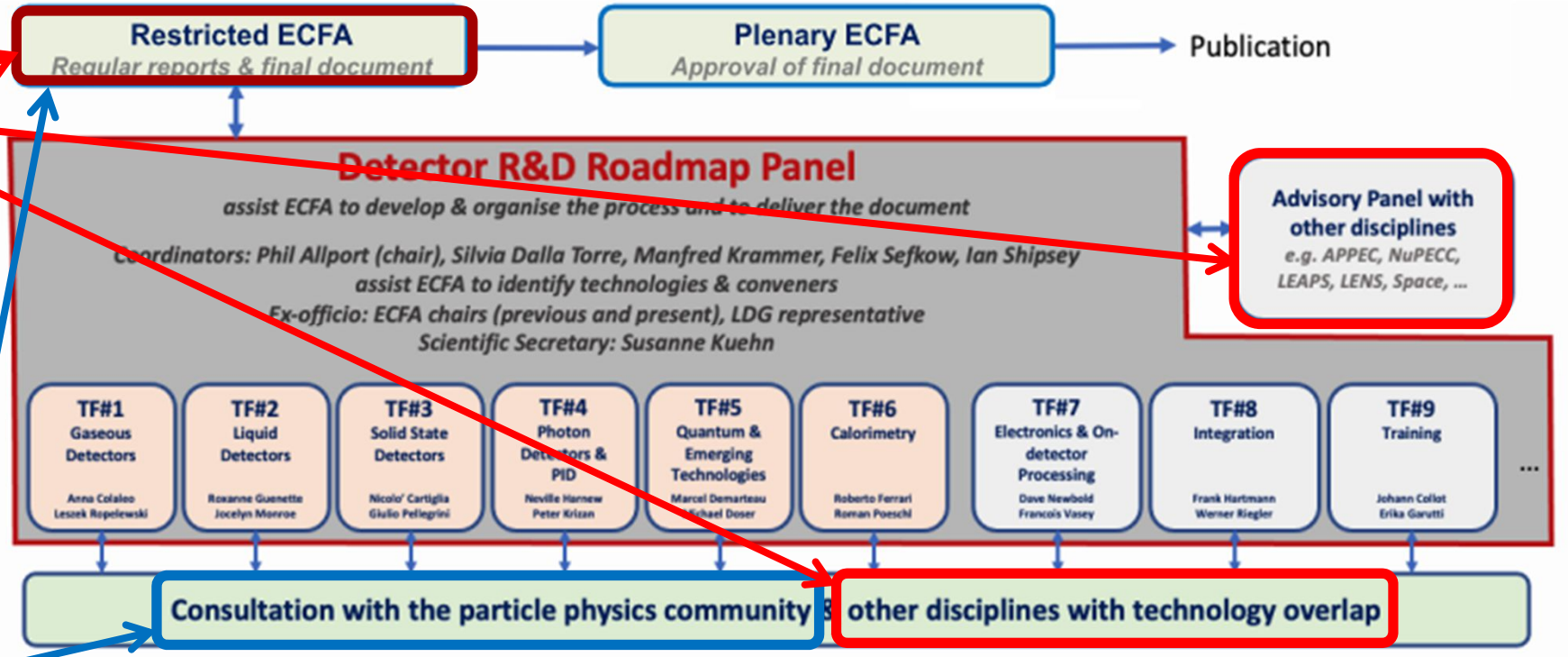


https://indico.cern.ch/e/ECFADetectorRDRoadmap

Roadmap Organisation

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

The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels



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

Organisation for Consultation of Relevant Communities

- Focus on the technical aspects of detector R&D requirements given the EPPSU deliberation document listed "*High-priority future initiatives*" and "*Other essential scientific activities for particle physics*" as input and organise material by Task Force.
- Task Forces start from **the future science programme** to identify main detector technology challenges to be met (both mandatory and highly desirable to optimise physics returns) and estimate the period over which the required detector R&D programmes may be expected to extend.
- Within each Task Force the aim is to propose a time ordered detector R&D programme in terms of **capabilities not currently achievable**.

Grouped targeted facilities/areas emerging from the EPPSU

- **Detector requirements for full exploitation of the HL-LHC (R&D still needed for LS3 upgrades and for experiment upgrades beyond then) including studies of flavour physics and quark-gluon plasma (where the latter topic also interfaces with nuclear physics).**
- **R&D for long baseline neutrino physics detectors (including aspects targeting astro-particle physics measurements) and supporting experiments such as those at the CERN Neutrino Platform.**
- **Technology developments needed for detectors at e^+e^- Higgs-EW-Top factories in all possible accelerator manifestations including instantaneous luminosities at 91.2GeV of up to $5\times10^{36}cm^{-2}s^{-1}$ and energies up to the TeV range.**
- **The long-term R&D programme for detectors at a future 100 TeV hadron collider with integrated luminosities targeted up to $30ab^{-1}$ and 1000 pile-up for 25ns BCO.**
- **Specific long-term detector technology R&D requirements of a muon collider operating at energies going up to 10 TeV and with a luminosity of the order of $10^{35}\,cm^{-2}\,s^{-1}$.**

Grouped targeted facilities/areas emerging from the EPPSU

- **Detector developments for accelerator-based studies of rare processes, DM candidates and high precision measurements (including strong interaction physics) at both storage rings and fixed target facilities, interfacing also with atomic and nuclear physics.**
- **R&D for optimal exploitation of dedicated collider experiments studying the partonic structure of the proton and nuclei as well as interface areas with nuclear physics.**
- **The very broad detector R&D areas for non-accelerator-based experiments, including dark matter searches (including axion searches), reactor neutrino experiments and rare decay processes, also considering neutrino observatories and other interface areas with astro-particle physics.**

- **Facilities needed for detector evaluation, including test-beams and different types of irradiation sources, along with the advanced instrumentation required for these.**
- **Infrastructures facilitating detector developments, including technological workshops and laboratories, as well as tools for the development of software and electronics.**
- **Networking structures in order to ensure collaborative environments, to help in the education and training, for cross-fertilization between different technological communities, and in view of relations with industry.**

- **Overlaps with neighbouring fields and key specifications required for exploitation in other application areas**
- **Opportunities for industrial partnership and technical developments needed for potential commercialisation**

ECFA
European Committee for Future Accelerators

Process and Timeline

Organisation

May 2020
EPPSU mandate to ECFA to develop a roadmap for detector R&D efforts in Europe

Sep 2020
Structure in place with **Detector R&D Roadmap Panel**

Dec 2020
Task Forces active

Website:
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Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
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Task Forces liaise with experts in
- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia

Drafting Roadmap & Feedback

May 2021
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October 2021
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*community feedback via Restricted ECFA delegates and National Contacts
(See https://ecfa.web.cern.ch/restricted-ecfa-composition in back-up)

Process and Timeline

Input session of Future Facilities I
Friday 19 Feb 2021, 13:00 → 18:00 Europe/Zurich

- 13:00 → 13:30 **Detector R&D requirements for HL-LHC** — Speaker: Chris Parkes (University of Manchester (GB)) — ECFA_RD_Parkes_1...
- 13:30 → 14:00 **Detector R&D requirements for strong interaction experiments at future colliders** — Speaker: Luciano Musa (CERN) — MUSA_ECFA_IS_20...
- 14:00 → 14:30 **Detector R&D requirements for strong interaction experiments at future fixed target facilities** — Speaker: Johannes Bernhard (CERN) — Detector R&D requir...
- 14:30 → 14:45 Coffee-Tea Break
- 14:45 → 15:15 **Detector R&D requirements for future linear high energy e+e- machines** — Speaker: Frank Simon (Max-Planck-Institut fuer Physik) — LC_DetRoadmapInp...
- 15:15 → 15:45 **Detector R&D requirements for future circular high energy e+e- machines** — Speaker: Mogens Dam (University of Copenhagen (DK)) — ECFA_Detector_R&D...
- 15:45 → 16:15 **Detector R&D requirements for future high-energy hadron colliders** — Speaker: Martin Aleksa (CERN) — 20210219-ECFA-Det...
- 16:15 → 16:35 **Detector R&D requirements for muon colliders** — Speaker: Nadia Pastrone (Universita e INFN Torino (IT)) — MuonColliders_Dete...

Input session of Future Facilities II
Monday 22 Feb 2021, 14:00 → 18:00 Europe/Zurich

- 14:00 → 14:30 **Detector R&D requirements for future short and long baseline neutrino experiments** — Speaker: Marzio Nessi (CERN) — 21-02-22-ECFA-Neut... 21-02-22-ECFA-Neut...
- 14:30 → 15:00 **Detector R&D requirements for future astro-particle neutrino experiments** — Speaker: Maarten De Jong (Nikhef National Institute for subatomic physics (NL)) — ECFA - Maarten de ... ECFA - Maarten de ...
- 15:00 → 15:30 **Detector R&D requirements for future dark matter experiments** — Speaker: Laura Baudis (University of Zurich) — baudis_ecfa_feb21....
- 15:30 → 15:40 Coffee-Tea Break
- 15:40 → 16:10 **Detector R&D requirements for future rare decay processes experiments** — Speakers: Cristina Lazzeroni (University of Birmingham (GB)), Cristina Lazzeroni (University of Birmingham (GB)) — ECFA_Lazzeroni.pdf
- 16:10 → 16:40 **Detector R&D requirements for future low energy experiments** — Speaker: Dr Alexandre Obertelli (TU Darmstadt) — ECFA_LowEnergyFa...

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May 2021

- 07 May ECFA Detector R&D Roadmap Symposium of Task Force 6 Calorimetry
- 06 May ECFA Detector R&D Roadmap Symposium of Task Force 4 Photon Detectors and Particle Identification Detectors

April 2021

- 30 Apr ECFA Detector R&D Roadmap Symposium of Task Force 9 Training
- 29 Apr ECFA Detector R&D Roadmap Symposium of Task Force 1 Gaseous Detectors
- 23 Apr ECFA Detector R&D Roadmap Symposium of Task Force 3 Solid State Detectors
- 12 Apr ECFA Detector R&D Roadmap Symposium of Task Force 5 Quantum and Emerging Technologies
- 09 Apr ECFA Detector R&D Roadmap Symposium of Task Force 2 Liquid Detectors

March 2021

- 31 Mar ECFA Detector R&D Roadmap Symposium of Task Force 8 Integration
- 25 Mar ECFA Detector R&D Roadmap Symposium of Task Force 7 Electronics and On-detector Processing

Materials from past Symposia, Input Sessions and other components of the ECFA Detector R&D Roadmap Process can be found at https://indico.cern.ch/e/ECFADetectorRDRoadmap

ECFA
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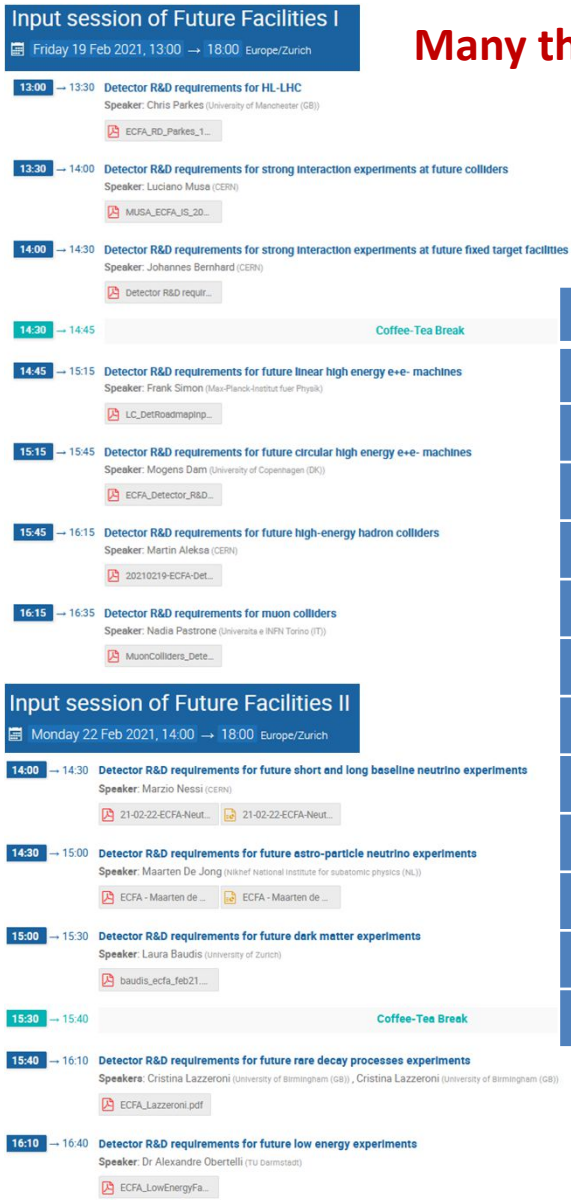
Process and Timeline



Many thanks to Input Session speakers for detailed specifications and continued support for the process

… particularly for checking if there were any unmet detector R&D needs for the ESPP identified programme which may have been overlooked in the symposia programmes.

	Speaker	Presentation Topic
1	Chris Parkes	Detector R&D requirements for HL-LHC
2	Luciano Musa	Detector R&D requirements for strong interaction experiments at future colliders
3	Johannes Bernhard	Detector R&D requirements for strong interaction experiments at future colliders
4	Frank Simon	Detector R&D requirements for future linear high energy e+e- machines
5	Mogens Dam	Detector R&D requirements for future circular high energy e+e- machines
6	Martin Aleksa	Detector R&D requirements for future high-energy hadron colliders
7	Nadia Pastrone	Detector R&D requirements for muon colliders
8	Marzio Nessi	Detector R&D requirements for future short and long baseline neutrino experiments
9	Maarten De Jong	Detector R&D requirements for future astro-particle neutrino experiments
10	Laura Baudis	Detector R&D requirements for future dark matter experiments
11	Cristina Lazzeroni	Detector R&D requirements for future rare decay processes experiments
12	Alexandre Obertelli	Detector R&D requirements for future low energy experiments

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Process and Timeline

There were nine well attended but very intense full-day public meetings through March to May.

The organisers and presenters are to be congratulated on their detailed and comprehensive preparation work.

Task Force	TF7	TF8	TF2	TF5	TF3	TF1	TF9	TF4	TF6
Dates	25/3/21	31/3/21	9/4/21	12/4/21	23/4/21	29/4/21	30/4/21	6/5/21	7/5/21
Unique users	369 + 123 (webcast)	154 + 17 (webcast)	197 + 5 (webcast)	220	504	339	105	207	201
Max. number of concurrent viewers	230 + 123 (webcast)	76 + 17 (webcast)	130 + 5 (webcast)	100	275	191	59	110	115

Common registration for the symposia had logged 1359 participants by the end of the last one.

Received extensive feedback during symposia and after by email.

Surveys were also employed to receive direct inputs from individuals and via RECFA delegates or their National Contacts.

APOD appointed experts consulted where needed by Task Force convenors for advice on developments in their disciplines.

May 2021

- 07 May ECFA Detector R&D Roadmap Symposium of Task Force 6 Calorimetry
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Advisory Panel with Other Disciplines

Organisation name	Contact name
APPEC	Andreas Haungs (Chair)
NuPECC	Marek Lewitowicz (Chair)
LEAPS	Caterina Biscari (Chair)
LENS	Helmut Schober (Chair)
ESA	Guenther Hasinger (Director of Science) Franco Ongaro (Director of Technology, Engineering and Quality)

APPEC: Astro-Particle Physics European Consortium
ESA: European Space Agency
LEAPS: League of European Accelerator-based Photon Sources
LENS: League of advanced European Neutron Sources
NuPECC: Nuclear Physics European Collaboration Committee

Named expert contacts		
APPEC	TF1	Jennifer L Raaf (Fermilab)
	TF2	Manfred Lindner (MPI Heidelberg)
	TF3	Fabrice Retiere (TRIUMF)
	TF4	Tina Pollmann (Nikhef)
	TF5	Harald Lück (Hannover)
	TF6	Federica Petricca (MPI Munich)
	TF7	Marc Weber (KIT)
	TF8	Aldo Ianni (LNGS)
	TF9	Katrin Link (APPEC)
NuPECC	TF1	Laura Fabbietti (TUM Munich)
		Bernhard Ketzer
	TF2	
	TF3	Luciano Musa (CERN)
		Michael Deveaux
	TF4	Eugenio Nappi (INFN Bari)
		Jochen Schwiening
	TF5	: Christian Enss (Heidelberg),
	TF6	Thomas Peitzmann (Utrecht)
		Ulrike Thoma (Bonn)
	TF7	David Silvermyr (Lund)
		Christian J. Schmidt
	TF8	Werner Riegler (CERN)
		Lars Schmitt
	TF9	Michael Deveaux,
LEAPS	Bernd Schmitt (PSI)	
	Fabienne Orsini	
	Steve Aplin (European	
	Heinz Graafsma (DESY)	

Named contacts for each TF where appropriate

Many thanks to these experts for their advice and availability

LENS	TF1	Bruno Guerard (ILL)
	TF2	Manfred Lindner (MPI Heidelberg)
	TF3	
	TF4	
	TF5	Helmut Schober (ILL)
	TF6	
	TF7	Bruno Guerard (ILL)
	TF8	
	TF9	
ESA	TF1	Nick Nelms
	TF2	
	TF3	Brian Shortt
		Nick Nelms
		Giovanni Santin
		Alessandra Constantino Mucio
	TF4	Brian Shortt
		Peter Verhoeve
		Sarah Wittig
		Nick Nelms
		Giovanni Santin
	TF5	Peter Verhoeve
		Sarah Wittig
		Nick Nelms
	TF6	Nick Nelms
	TF7	Joerg Ter Haar
		Christophe Honvault
		Nick Nelms
		Alessandra Constantino Mucio
	TF8	Massimo Braghin
	TF9	Christophe Honvault

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Detector R&D Roadmap
Initial Full Draft

2021 ECFA Detector Research and Development Roadmap

by the European Committee for Future Accelerators
Detector R&D Roadmap Process Group

DISCLAIMER
regarding the version circulated on 2. July 2021

- The references will be homogenized and cross-referencing between chapters will be added.
- The graphics and figure resolutions will be improved, also through professional help with the layout (esp: DRM graphics in each TF section and DRDT figure in conclusions).
- Front and back cover in branding of EPPSU will be added.
- More work intended to make text more concise and section lengths more compatible.
- Further common editing to create greater consistency of language and terms.
- Glossary of common acronyms and abbreviations to be added.

Detector R&D Roadmap Process Group

Task Force convenors, Task Force expert members and Panel members of the ECFA Detector R&D Roadmap Process

Task Force 1 Gaseous Detectors: Anna Colaleo[1], Leszek Ropelewski[2] *(Conveners)*
Klaus Dehmelt[3], Barbara Liberti[4], Maxim Titov[5], Joao Veloso[6] *(Expert Members)*

Task Force 2 Liquid Detectors: Roxanne Guenette[7], Jocelyn Monroe[8] *(Conveners)*
Auke-Pieter Colijn[9], Antonio Ereditato[10,11], Ines Gil Botella[12],
Manfred Lindner[13] *(Expert Members)*

Task Force 3 Solid State Detectors: Nicolo Cartiglia[14], Giulio Pellegrini[15] *(Conveners)*
Daniela Bortoletto[16], Didier Contardo[17], Ingrid Gregor[18,19] Gregor Kramberger[20],
Heinz Pernegger[2] *(Expert Members)*

Task Force 4 Particle Identification and Photon Detectors: Neville Harnew[16],
Peter Krizan[20] *(Conveners)*
Ichiro Adachi[21], Eugenio Nappi[1] Christian Joram[2],
Christian Schultz-Coulon[22] *(Expert Members)*

Task Force 5 Quantum and Emerging Technologies: Marcel Demarteau[23],
Michael Doser[2] *(Conveners)*
Caterina Braggio[24], Andy Geraci[25], Peter Graham[26], Anna Grasselino[27],
John March Russell[16], Stafford Withington[28] *(Expert Members)*

Task Force 6 Calorimetry: Roberto Ferrari[29], Roman Poeschl[30] *(Conveners)*
Martin Aleksa[2], Dave Barney[2], Frank Simon[31],
Tommaso Tabarelli de Fatis[32] *(Expert Members)*

Task Force 7 Electronics: Dave Newbold[33], Francois Vasey[2] *(Conveners)*
Niko Neufeld[2], Valerio Re[29] Christophe de la Taille[34], Marc Weber[35] *(Expert Members)*

Task Force 8 Integration: Frank Hartmann[35], Werner Riegler[2] *(Conveners)*
Corrado Gargiulo[2], Filippo Resnati[2], Herman Ten Kate[36], Bart Verlaat[2],
Marcel Vos[37] *(Expert Members)*

Task Force 9 Training: Johann Collot[38], Erika Garutti[18,39] *(Conveners)*
Richard Brenner[40], Niels van Bakel[9] Claire Gwenlan[16], Jeff Wiener[2],
ex-officio Robert Appleby[41] *(Expert Members)*

The Task Force Convenors join those listed below to compose the Detector R&D Roadmap Panel.

Panel coordinators: Phil Allport[42] *(Chair)*, Silvia Dalla Torre[43], Manfred Krammer[2],
Felix Sefkow[18], Ian Shipsey[16]

Ex-officio Panel members: Karl Jakobs[44] *(Current ECFA Chair)*,
Jorgen D'Hondt[45] *(Previous ECFA Chair)*, Lenny Rivkin[46] *(LDG Representative)*

Scientific Secretary: Susanne Kuehn[2]

[1] INFN Bari, Bari, Italy
[2] CERN, Geneva, Switzerland
[3] Stony Brook University, New York, US
[4] INFN Roma, Rome, Italy
[5] IRFU/DPhP CEA Saclay, Saclay, France
[6] Universidade de Aveiro, Aveiro, Portugal
[7] Harvard University, Cambridge, US
[8] Royal Holloway University of London, London, UK
[9] NIKHEF and University of Amsterdam, Netherlands
[10] Yale University, New Heaven, US
[11] University of Bern, Berne, Switzerland
[12] CIEMAT, Madrid, Spain
[13] MPI Heidelberg, Heidelberg, Germany
[14] INFN Sezione di Turino, Turino, Italy
[15] IMB-CNM-CSIC, Barcelona, Spain
[16] University of Oxford, Oxford, UK
[17] IN2P3-IP2I, Lyon, France
[18] DESY, Hamburg, Germany
[19] University of Bonn, Bonn, Germany
[20] University of Ljubljana and J. Stefan Institute, Ljubljana, Slovenia
[21] KEK, Tsukuba, Japan
[22] University of Heidelberg, Germany
[23] ORNL, Oak Ridge, US
[24] INFN Sezione di Padova, Padova, Italy
[25] Northwestern University, Evanston, US
[26] Stanford University, Stanford, US
[27] FNAL, Batavia, US
[28] University of Cambridge, UK
[29] INFN Sezione di Pavia, Pavia, Italy
[30] IN2P3-IJClab, Paris, France
[31] MPP Munich, Munich, Germany
[32] INFN Milano-Bicocca, Milano, Italy
[33] RAL, Didcot, UK
[34] IN2P3-OMEGA, Palaiseau, France
[35] KIT, Institut für Kernphysik, Karlsruhe, Germany
[36] University of Twente, Twente, Netherlands
[37] IFIC Valencia, Valencia, Spain
[38] IN2P3-LPSC, Grenoble, France
[39] University of Hamburg, Hamburg, Germany
[40] University of Uppsala, Uppsala, Sweden
[41] University of Manchester, Manchester, UK
[42] University of Birmingham, Birmingham, UK
[43] INFN Sezione di Trieste, Trieste, Italy
[44] Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
[45] IIHE, Vrije Universiteit Brussel, Brussels, Belgium
[46] ETH Lausanne and PSI, Villigen, Switzerland

Detector R&D Roadmap

- The sections start from the principle that for the earliest feasible start dates of a proposed facility (including those which are still considered in the EPPSU, but would be mutually exclusive):
  - the basic detector R&D phase is not the time limiting step, i.e. that R&D is started sufficiently early and prioritised correctly to meet the needs of the long-term European particle physics programme in its global context;
  - the outcomes of the R&D programme are able to provide the necessary information on the feasibility and cost of future deliverables to allow such decisions to be made.
- The relevant Task Forces have then identified a set of detector R&D areas which are required if the physics programmes of experiments at these facilities are not to be compromised.
- It is also noted that in many cases, the programme for a nearer-term facility helps enable the technologies needed for more demanding specifications later, providing stepping stones towards these.
- In the text there are developed and defined "Detector R&D Themes" (DRDTs) to highlight the most important drivers for research in each technology area.
- We also defined Detector Community Themes in the context of the training area (TF9).
- These are represented graphically in the following figures and are identified by arrows lasting up to the last currently identified facility for which they are relevant.

The dates used for the above are shown in this diagram have deliberate low precision, and are intended to represent the earliest 'feasible start date' (where a schedule is not already defined), taking into account the necessary steps of approval, development and construction for machine and civil engineering. They do not constitute any form of plan or recommendation, and indeed several options presented are mutually exclusive. Fine-tuning of time-ordering is also still under discussion with the Laboratories Directors Group (see previous presentation). Furthermore, the projects mentioned here are limited to those mentioned in the EPPSU, although it should be noted that detector R&D for other possible future facilities is usually aligned with that for programmes already listed.

Figure 3. Large Accelerator Based Facility/Experiment Earliest Feasible Start Dates

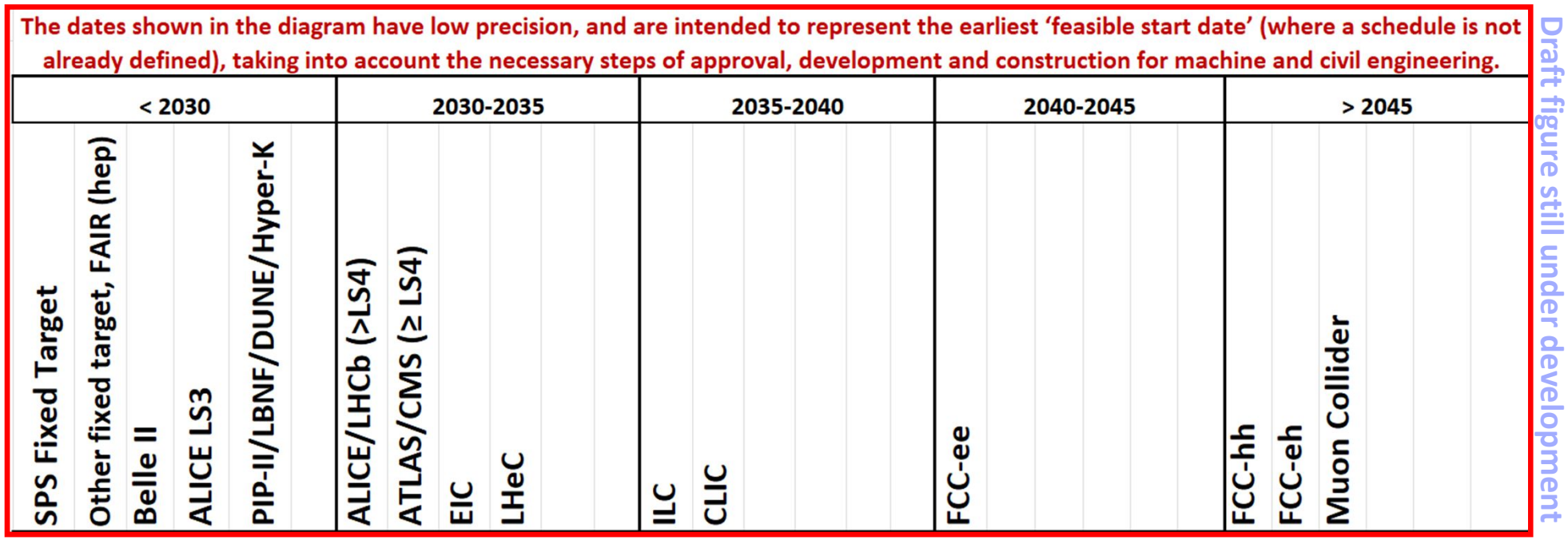
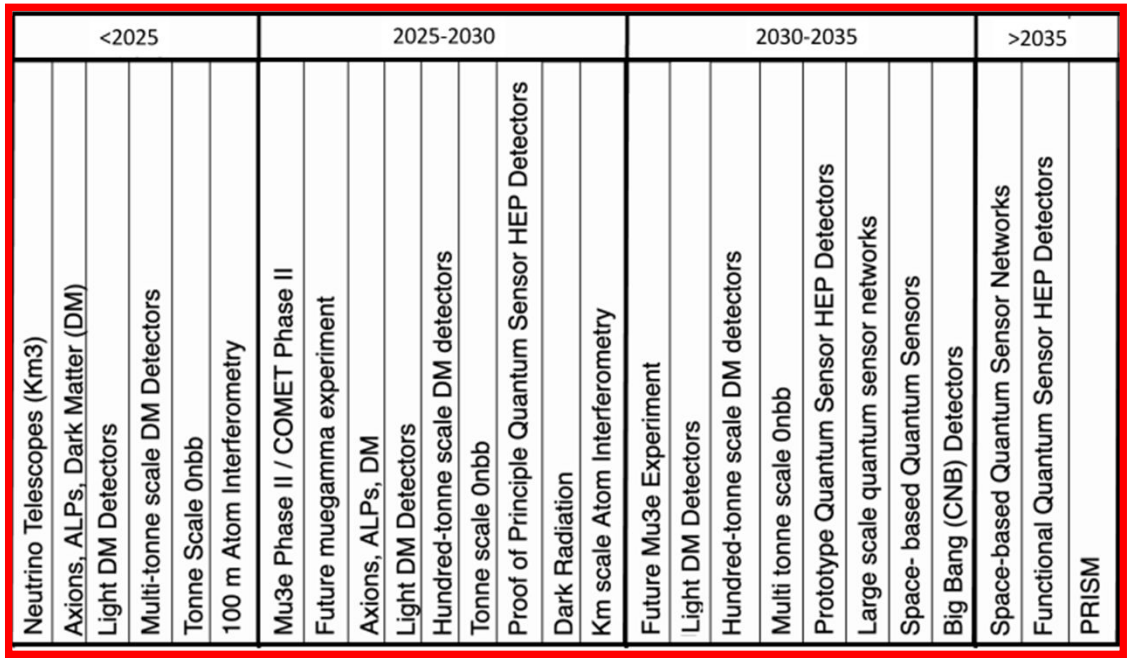


Figure 4. (Representative*) Smaller Accelerator and Non-Accelerator Based Experiments Start Dates



*Not intended at all to be an exhaustive list

In the ECFA Detector R&D Roadmap the focus has been on facilities targeting the properties and interactions of fundamental particles (including those that are undiscovered but theoretically motivated). It is noted that a number of particles increasingly play the role of cosmic messengers for phenomena happening far beyond our own galaxy which provides some of the exciting science opportunities in the neighbouring field of astroparticle physics, but the demanding detector requirements specific to this area are not generally within the scope of this document.

Throughout the document these figures inform the development of the Detector R&D Roadmap with a view to set concrete target timelines for the readiness of the recommended R&D thematic programmes emerging in each Task Force and summarized in the conclusion chapter.

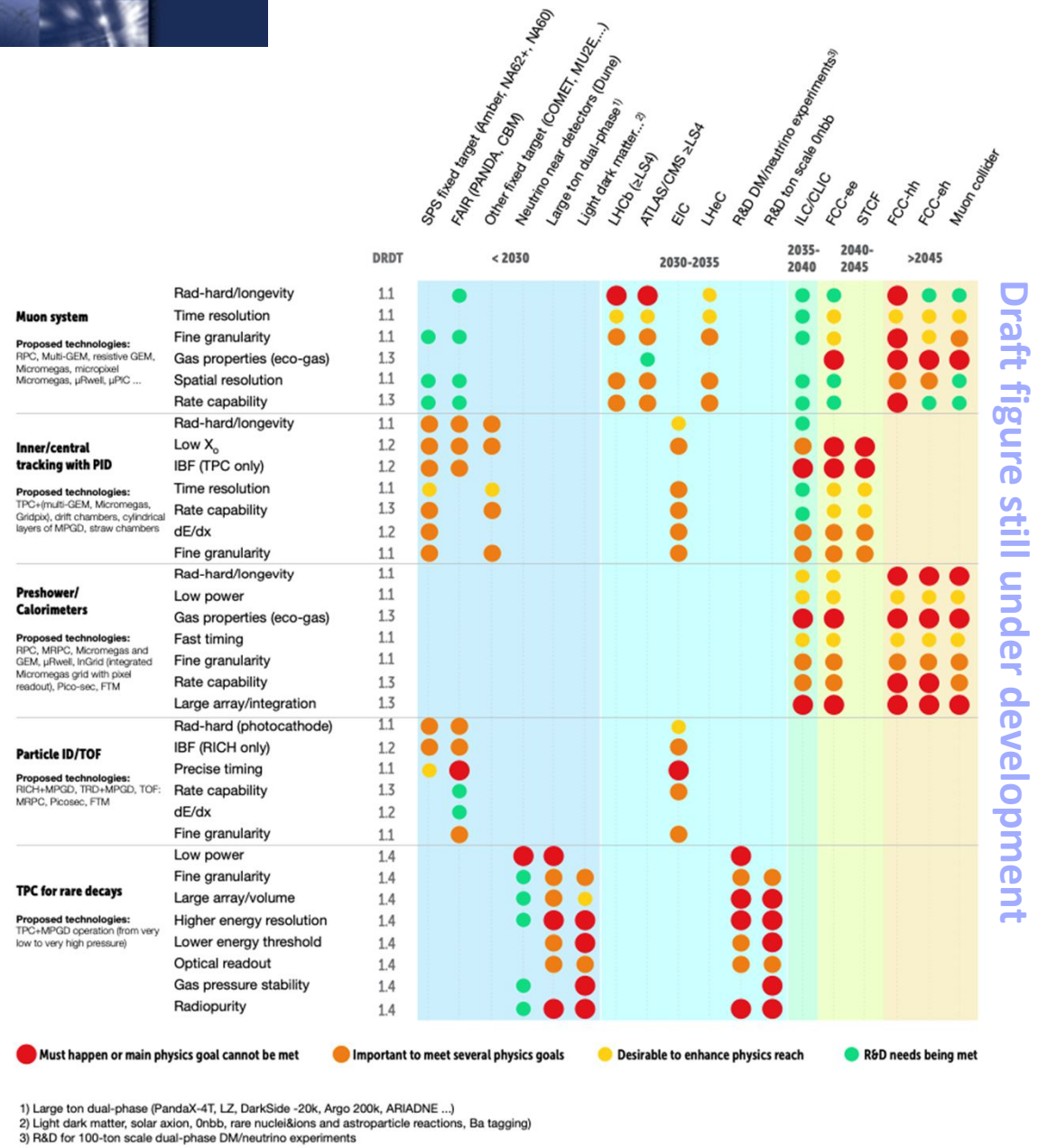
Detector R&D Roadmap

Example figure from Task Force 1
Gaseous Detectors

Note the dots relate to the importance to the listed facilities of the R&D activity not the intensity of effort needed to meet these requirements

- Must happen or main physics goal cannot be met
- Important to meet several physics goals
- Desirable to enhance physics reach
- R&D needs being met

The idea is to illustrate the way requirements could evolve over time to help define the planning for the corresponding detector R&D to ensure the main physics goals of the updated strategy for particle physics do not risk being compromised by detector readiness

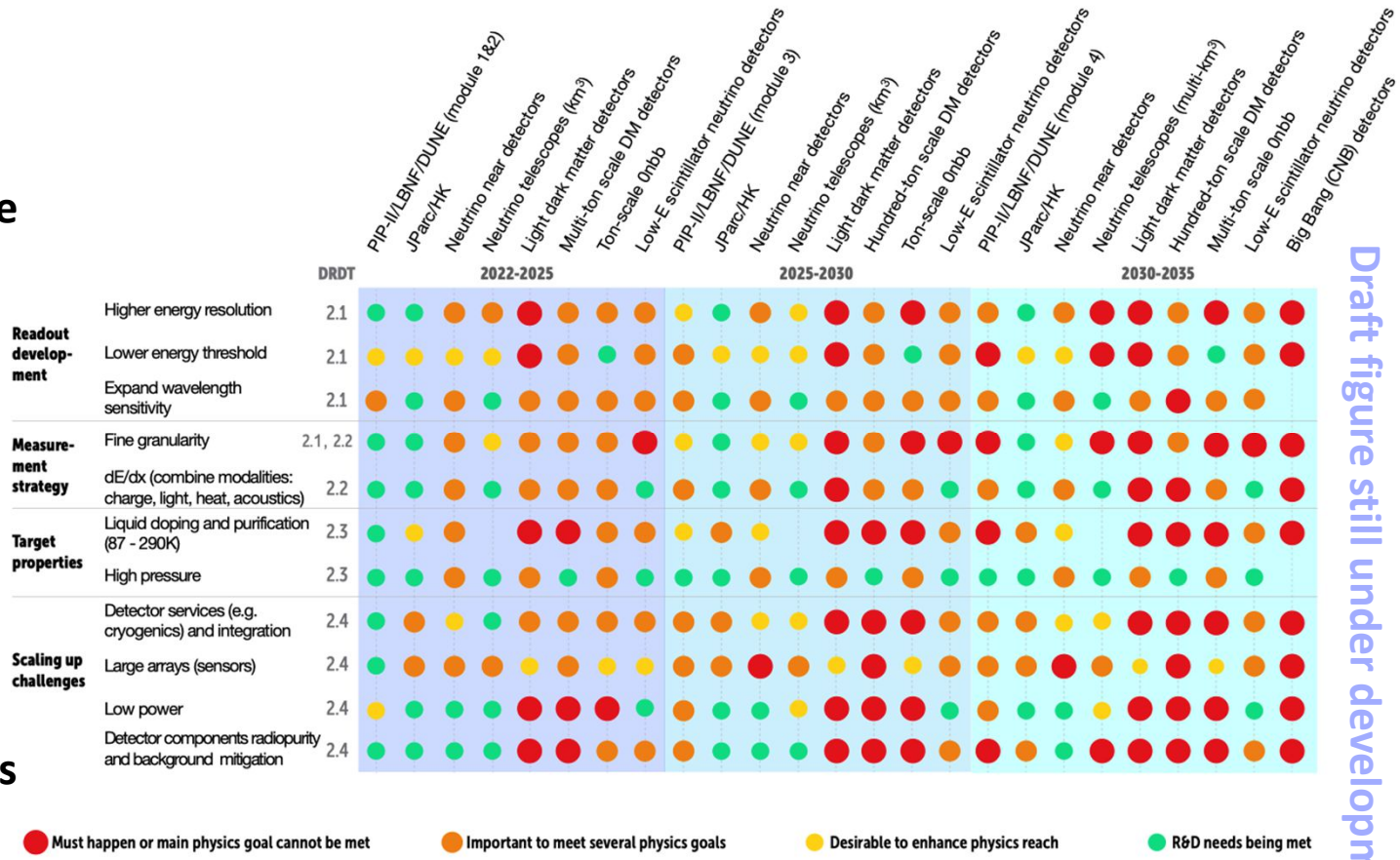


Detector R&D Roadmap

Second example figure from Task Force 2
Liquid Detectors

Note the dots relate to the importance to the listed facilities of the R&D activity not the intensity of effort needed to meet these requirements

- Must happen or main physics goal cannot be met
- Important to meet several physics goals
- Desirable to enhance physics reach
- R&D needs being met



Draft figure still under development

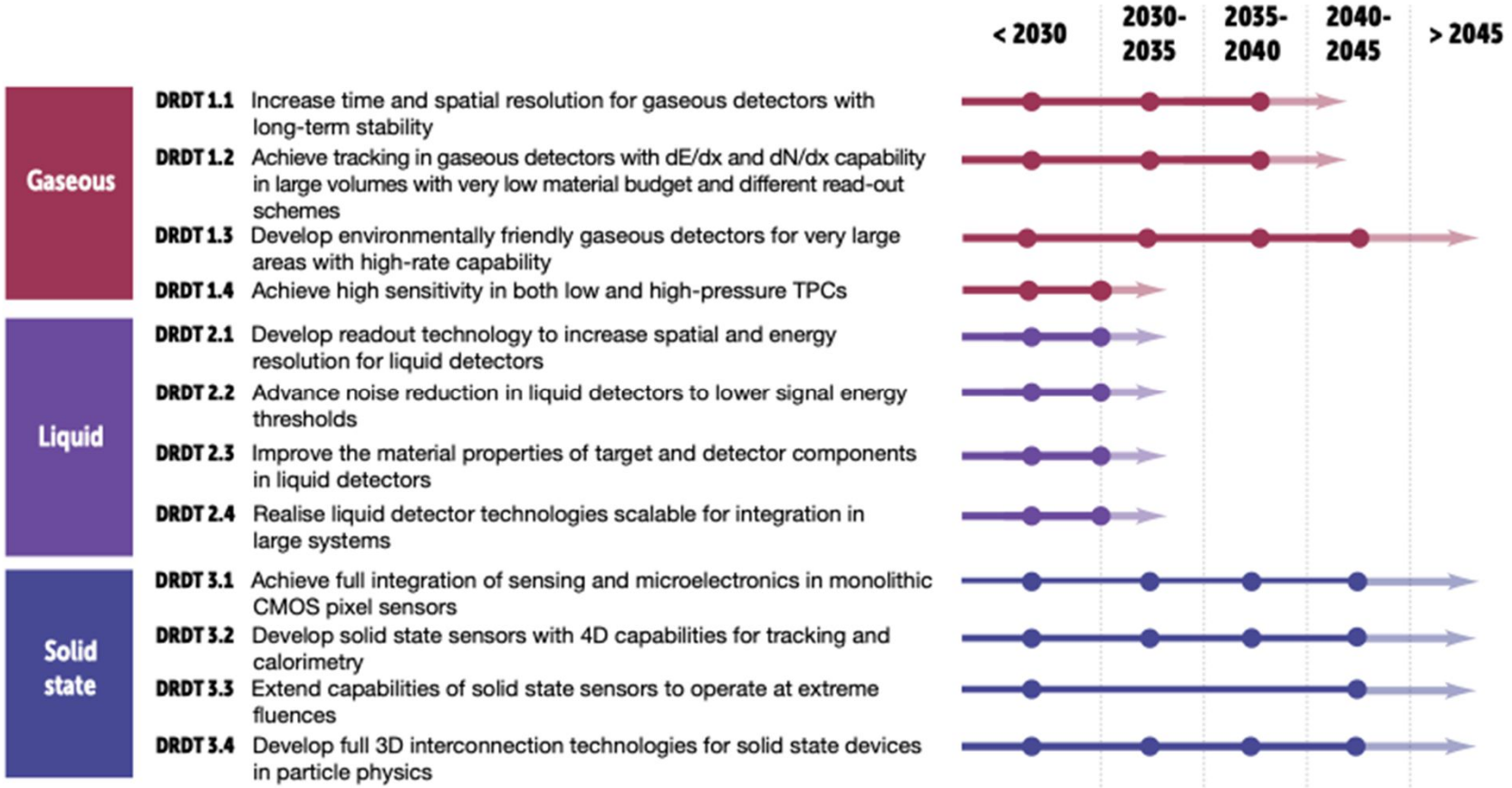
The idea is to illustrate the way requirements could evolve over time to help define the planning for the corresponding detector R&D to ensure the main physics goals of the updated strategy for particle physics do not risk being compromised by detector readiness

Draft figures for other TFs in back-up

Detector R&D Roadmap

- It should be emphasised that the future beyond the end of the arrows is simply not yet defined, not that there is an expectation that R&D for the further future beyond that point will not be needed.
- Stepping stones are shown to represent the R&D needs of facilities intermediate in time.
- The faded region acknowledges the typical time needed between the completion of the R&D phase and the readiness of an experiment at a given facility.

DETECTOR RESEARCH AND DEVELOPMENT THEMES (DRDTs)



Draft figure still under development

Detector R&D Roadmap

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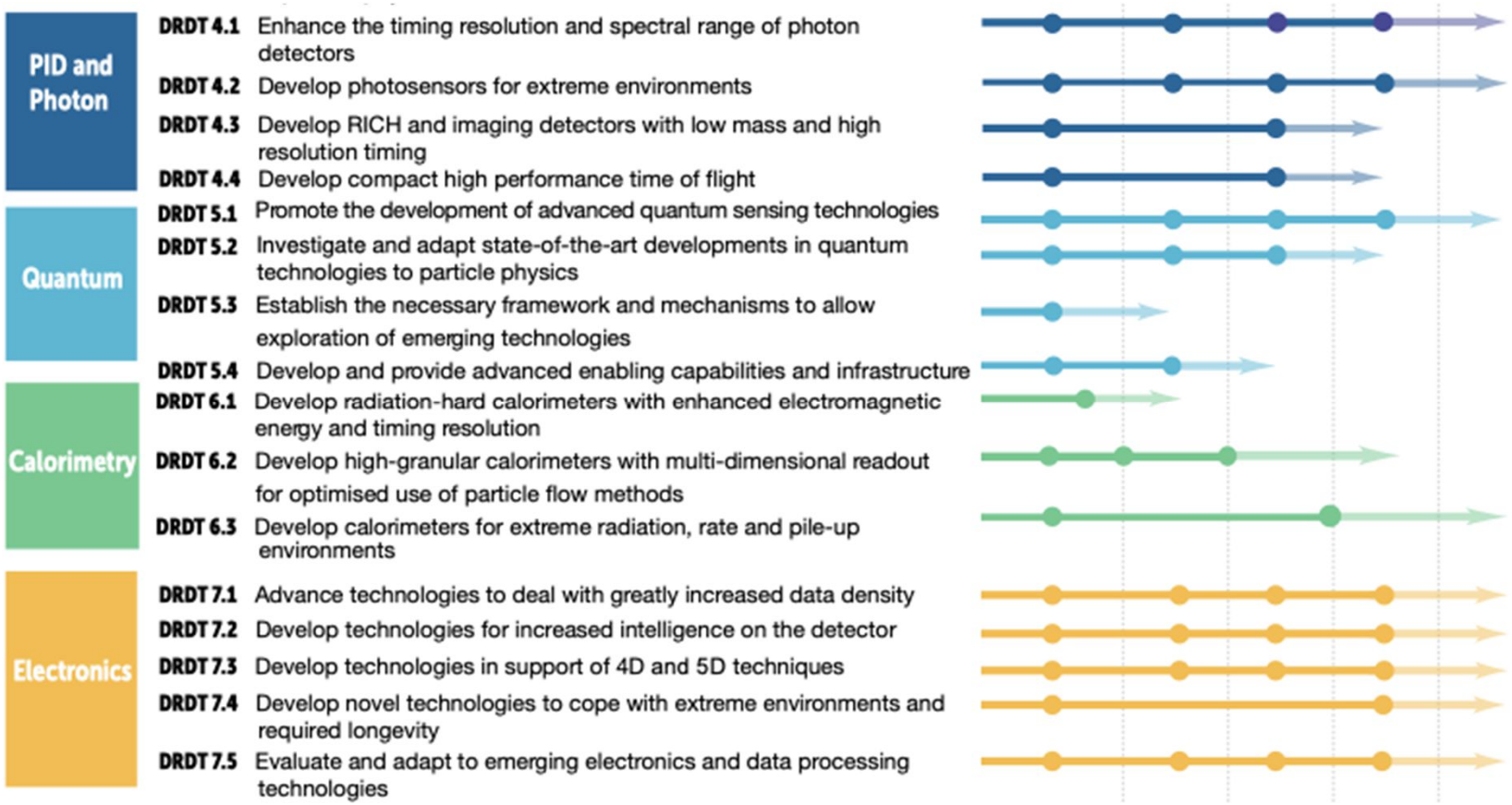

Draft figure still under development

Detector R&D Roadmap

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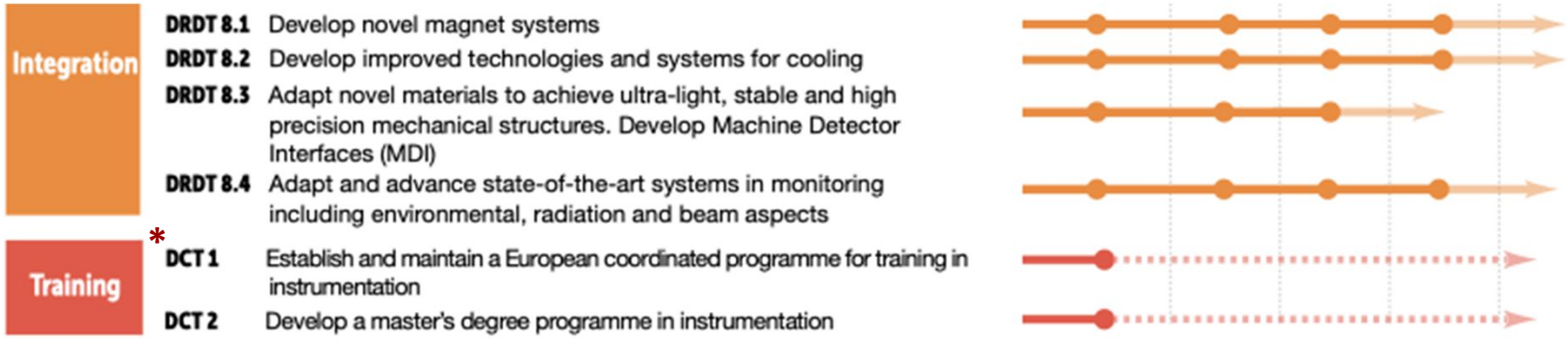

Figure 1: Detector R&D Themes (DRDT) and Detector Community Themes (DCT). Here, except in the DCT case, the final dot position represents the target date for completion of the R&D required by the latest known future facility/experiment for which an R&D programme would still be needed in that area. The time from that dot to the end of the arrow represents the further time to be anticipated for experiment-specific prototyping, procurement, construction, installation and commissioning. Earlier dots represent the time-frame of intermediate "stepping stone" projects where dates for the corresponding facilities/experiments are known. (Note that R&D for Liquid Detectors will be needed far into the future, however the DRDT lines for these end in the period 2030-35 because developments in that field are rapid and it is not possible today to reasonably estimate the dates for projects requiring longer-term R&D. Similarly, the dotted lines for the DCTs indicate that beyond the initial programmes, the activities will need to be sustained going forward in support of the instrumentation R&D activities).

Draft figure still under development

*See also "Results of the 2021 ECFA Early-Career Researcher Survey on Training in Instrumentation", ECFA ECR Panel, *arXiv:2107.05739*

In addition to the Detector R&D Themes described above and discussed in each chapter the following General Strategic Recommendations are made under the following headings.

GSR 1 - Supporting R&D facilities

GSR 2 - Engineering support for detector R&D

GSR 3 - Specific software for instrumentation

GSR 4 - International coordination and organisation of R&D activities

GSR 5 - Distributed R&D activities with centralised facilities

GSR 6 - Establish long-term strategic funding programmes

GSR 7 - 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

Detector R&D Roadmap

GSR 1 - Supporting R&D facilities
It is recommended that the structures to provide Europe-wide coordinated infrastructure in the areas of: test beams, large scale generic prototyping and irradiation be consolidated and enhanced to meet the needs of next generation experiments with adequate centralised investment to avoid less cost-effective, more widely distributed, solutions, and to maintain a network structure for existing distributed facilities, e.g. for irradiation.

GSR 2 - Engineering support for detector R&D
In response to ever more integrated detector concepts, requiring holistic design approaches and large component counts, the R&D should be supported with adequate mechanical and electronics engineering resources, to bring in expertise in state-of-the-art microelectronics as well as advanced materials and manufacturing techniques, to tackle generic integration challenges, and to maintain scalability of production and quality control from the earliest stages.

GSR 3 - Specific software for instrumentation
Across DRDTs and through adequate capital investments, the availability to the community of state-of-the-art R&D-specific software packages must be maintained and continuously updated. The expert development of these packages - for core software frameworks, but also for commonly used simulation and reconstruction tools - should continue to be highly recognised and valued and the community effort to support these needs to be organised at a European level.

GSR 4 - International coordination and organisation of R&D activities
With a view to creating a vibrant ecosystem for R&D, connecting and involving all partners, there is a need to refresh the CERN RD programme structure and encourage new programmes for next generation detectors, where CERN and the other national laboratories can assist as major catalysers for these. It is also recommended to revisit and streamline the process of creating and reviewing these programmes, with an extended framework to help share the associated load and increase involvement, while enhancing the visibility of the detector R&D community and easing communication with neighbouring disciplines .

GSR 5 - Distributed R&D activities with centralised facilities
Establish in the relevant R&D areas a distributed yet connected and supportive tier-ed system for R&D efforts across Europe. Keeping in mind the growing complexity, the specialisation required, the learning curve and the increased cost, consider more focused investment for those themes where leverage can be reached through centralisation at large institutions, while addressing the challenge that distributed resources remain accessible to researchers across Europe and through them also be available to help provide enhanced training opportunities.

GSR 6 - Establish long-term strategic funding programmes
Establish, additional to short-term funding programmes for the early proof of principle phase of R&D, also long-term strategic funding programmes to sustain both research and development of the multi-decade DRDTs in order for the technology to mature and to be able to deliver the experimental requirements. Beyond capital investments of single funding agencies, international collaboration and support at the EU level should be established. In general, the cost for R&D has increased, which further strengthens the vital need to make concerted investments.

GSR 7 - Blue-sky R&D
It is essential that adequate resources be provided to support more speculative R&D which can be riskier in terms of immediate benefits but can bring significant and potentially transformational returns if successful both to particle physics: unlocking new physics may only be possible by unlocking novel technologies in instrumentation, and to society. Innovative instrumentation research is one of the defining characteristics of the field of particle physics. Blue-sky developments in particle physics have often been of broader application and had immense societal benefit. Examples include: the development of the World Wide Web, Magnetic Resonance Imaging, Positron Emission Tomography and X-ray imaging for photon science.

GSR 8 - Attract, nurture, recognise and sustain the careers of R&D experts
Innovation in instrumentation is essential to make progress in particle physics, and R&D experts are essential for innovation. It is recommended that ECFA, with the involvement and support of its Detector R&D Panel, continues the study of recognition with a view to consolidate the route to an adequate number of positions with a sustained career in instrumentation R&D to realise the strategic aspirations expressed in the EPPSU. It is suggested that ECFA should explore mechanisms to develop concrete proposals in this area and to find mechanisms to follow up on these in terms of their implementation. Consideration needs to be given to creating sufficiently attractive remuneration packages to retain those with key skills which typically command much higher salaries outside academic research. It should be emphasised that, in parallel, society benefits from the training particle physics provides because the knowledge and skills acquired are in high demand by industries in high-technology economies.

GSR 9 - Industrial partnerships
It is recommended to identify promising areas for close collaboration between academic and industrial partners, to create international frameworks for exchange on academic and industrial trends, drivers and needs, and to establish strategic and resources-loaded cooperation schemes on a European scale to intensify the collaboration with industry, in particular for developments in solid state sensors and micro-electronics.

GSR 10 – Open Science
It is recommended that the concept of Open Science be explicitly supported in the context of instrumentation, taking account of the constraints of commercial confidentiality where these apply due to partnerships with industry. Specifically, for publicly-funded research the default, wherever possible, should be open access publication of results and it is proposed that the Sponsoring Consortium for Open Access Publishing in Particle Physics (SCOAP^3) should explore ensuring similar access is available to instrumentation journals (including for conference proceedings) as to other particle physics publications.

Conclusions

- The draft document has been prepared by a large team of internationally recognised leaders in this area with access to a much wider pool of other instrumentation experts.
- It has been the product of wide community consultation with very broad participation.
- The first full draft has been iterated with the RECFA delegates and National Contacts with numerous helpful comments received from committees looking at this in a number of countries.
- We also have benefited from very valuable feedback from neighbouring disciplines where there are strong synergies between instrumentation needs.
- The results of that very welcome feedback is now being implemented in an improved version which will then need to be subjected to proper integration into a single document over the Summer with a large number of editorial improvements still to implement but with no major changes to the basic messages communicated here.

Detector R&D Roadmap Process Group

ECFA

European Committee for Future Accelerators

Task Force convenors, Task Force expert members and Panel members of the ECFA Detector R&D Roadmap Process

Task Force 1 Gaseous Detectors: Anna Colaleo[1], Leszek Ropelewski[2] *(Conveners)*
Klaus Dehmelt[3], Barbara Liberti[4], Maxim Titov[5], Joao Veloso[6] *(Expert Members)*

Task Force 2 Liquid Detectors: Roxanne Guenette[7], Jocelyn Monroe[8] *(Conveners)*
Auke-Pieter Colijn[9], Antonio Ereditato[10,11], Ines Gil Botella[12],
Manfred Lindner[13] *(Expert Members)*

Task Force 3 Solid State Detectors: Nicolo Cartiglia[14], Giulio Pellegrini[15] *(Conveners)*
Daniela Bortoletto[16], Didier Contardo[17], Ingrid Gregor[18,19] Gregor Kramberger[20],
Heinz Pernegger[2] *(Expert Members)*

Task Force 4 Particle Identification and Photon Detectors: Neville Harnew[16],
Peter Krizan[20] *(Conveners)*
Ichiro Adachi[21], Eugenio Nappi[1] Christian Joram[2],
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Task Force 5 Quantum and Emerging Technologies: Marcel Demarteau[23],
Michael Doser[2] *(Conveners)*
Caterina Braggio[24], Andy Geraci[25], Peter Graham[26], Anna Grasselino[27],
John March Russell[16], Stafford Withington[28] *(Expert Members)*

Task Force 6 Calorimetry: Roberto Ferrari[29], Roman Poeschl[30] *(Conveners)*
Martin Aleksa[2], Dave Barney[2], Frank Simon[31],
Tommaso Tabarelli de Fatis[32] *(Expert Members)*

Task Force 7 Electronics: Dave Newbold[33], Francois Vasey[2] *(Conveners)*
Niko Neufeld[2], Valerio Re[29] Christophe de la Taille[34], Marc Weber[35] *(Expert Members)*

Task Force 8 Integration: Frank Hartmann[35], Werner Riegler[2] *(Conveners)*
Corrado Gargiulo[2], Filippo Resnati[2], Herman Ten Kate[36], Bart Verlaat[2],
Marcel Vos[37] *(Expert Members)*

Task Force 9 Training: Johann Collot[38], Erika Garutti[18,39] *(Conveners)*
Richard Brenner[40], Niels van Bakel[9] Claire Gwenlan[16], Jeff Wiener[2],
ex-officio Robert Appleby[41] *(Expert Members)*

The Task Force Convenors join those listed below to compose the Detector R&D Roadmap Panel.

Panel coordinators: Phil Allport[42] *(Chair)*, Silvia Dalla Torre[43], Manfred Krammer[2]
Felix Sefkow[18], Ian Shipsey[16]

Ex-officio Panel members: Karl Jakobs[44] *(Current ECFA Chair)*,
Jorgen D'Hondt[45] *(Previous ECFA Chair)*, Lenny Rivkin[46] *(LDG Representative)*

Scientific Secretary: Susanne Kuehn[2]

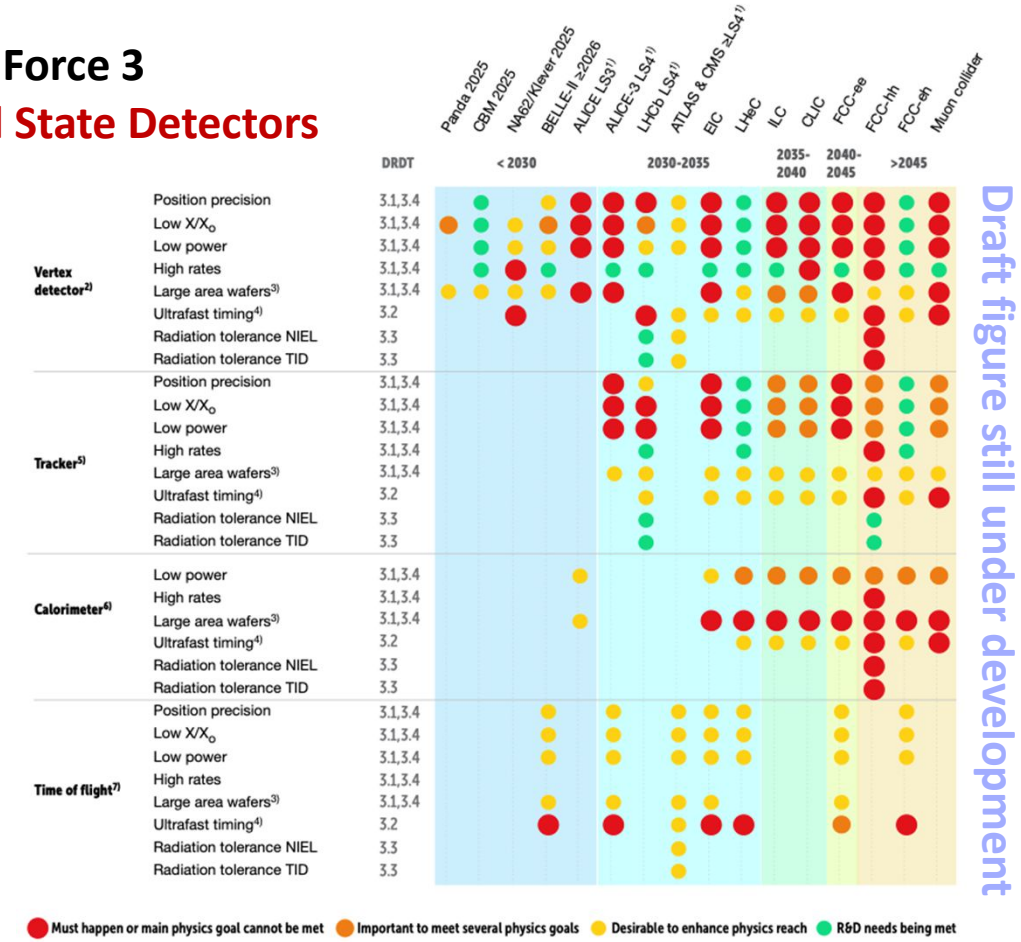
[1] INFN Bari, Bari, Italy
[2] CERN, Geneva, Switzerland
[3] Stony Brook University, New York, US
[4] INFN Roma, Rome, Italy
[5] IRFU/DPhP CEA Saclay, Saclay, France
[6] Universidade de Aveiro, Aveiro, Portugal
[7] Harvard University, Cambridge, US
[8] Royal Holloway University of London, London, UK
[9] NIKHEF and University of Amsterdam, Netherlands
[10] Yale University, New Heaven, US
[11] University of Bern, Berne, Switzerland
[12] CIEMAT, Madrid, Spain
[13] MPI Heidelberg, Heidelberg, Germany
[14] INFN Sezione di Turino, Turino, Italy
[15] CNM-CSIC, Barcelona, Spain
[16] Oxford, Oxford, UK
[17] France
[18] Germany
[19] Stefan Institute, Ljubljana, Slovenia
[24] IN
[25] Northwe
[26] Stanford Un
[27] FNAL, Batavia,
[28] University of Cambrid
[29] INFN Sezione di Pavia, Pav
[30] IN2P3-IJClab, Paris, France
[31] MPP Munich, Munich, Germany
[32] INFN Milano-Bicocca, Milano, Italy
[33] RAL, Didcot, UK
[34] IN2P3-OMEGA, Palaiseau, France
[35] KIT, Institut für Kernphysik, Karlsruhe, Germany
[36] University of Twente, Twente, Netherlands
[37] IFIC Valencia, Valencia, Spain
[38] IN2P3-LPSC, Grenoble, France
[39] University of Hamburg, Hamburg, Germany
[40] University of Uppsala, Uppsala, Sweden
[41] University of Manchester, Manchester, UK
[42] University of Birmingham, Birmingham, UK
[43] INFN Sezione di Trieste, Trieste, Italy
[44] Albert-Ludwigs-Universität Freiburg, Freiburg, Germany
[45] IIHE, Vrije Universiteit Brussel, Brussels, Belgium
[46] ETH Lausanne and PSI, Villigen, Switzerland

Although the final draft is still being worked on, the main conclusions and recommendations will remain as presented here. Thanks are due to the entire ECFA Detector R&D Process Group - along with our gratitude to many additional contributors.

Back-up

Detailed ECFA Timeline

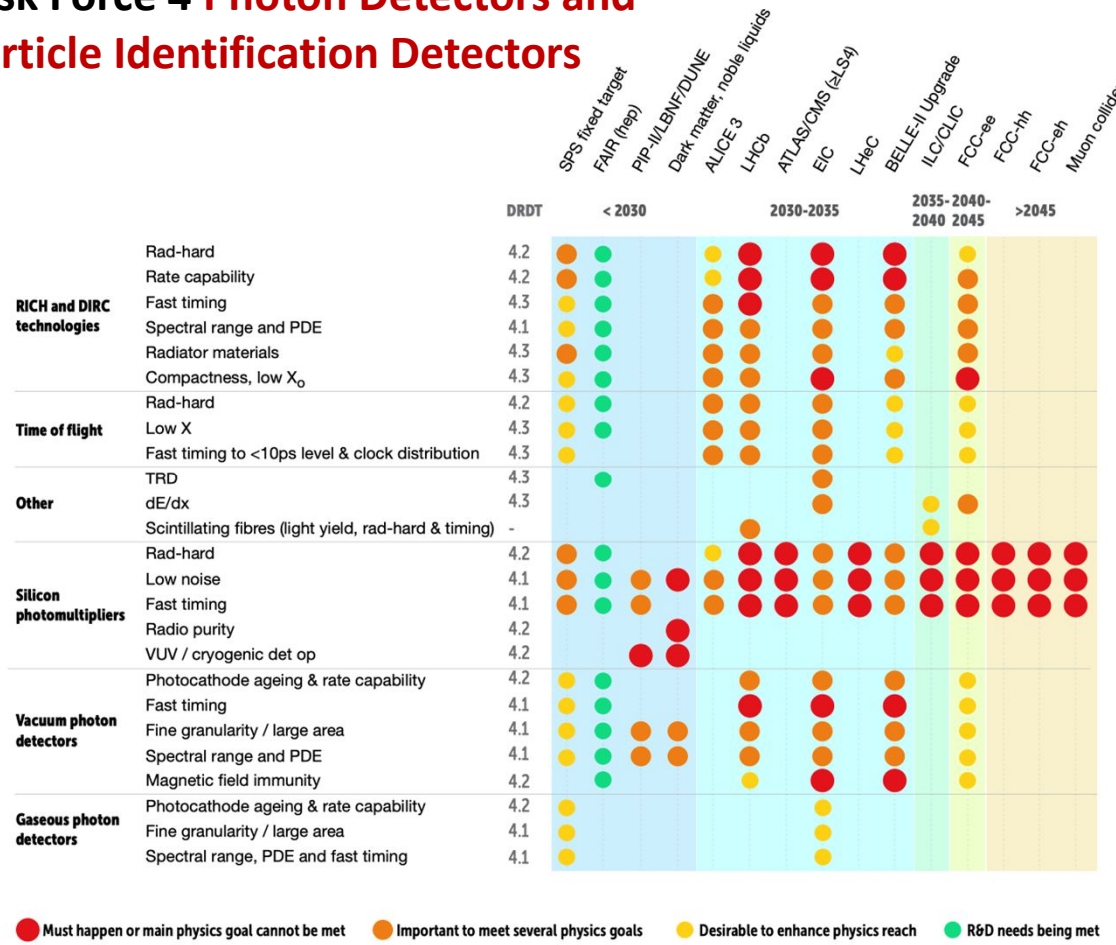
Task Force 3
Solid State Detectors



Draft figure still under development

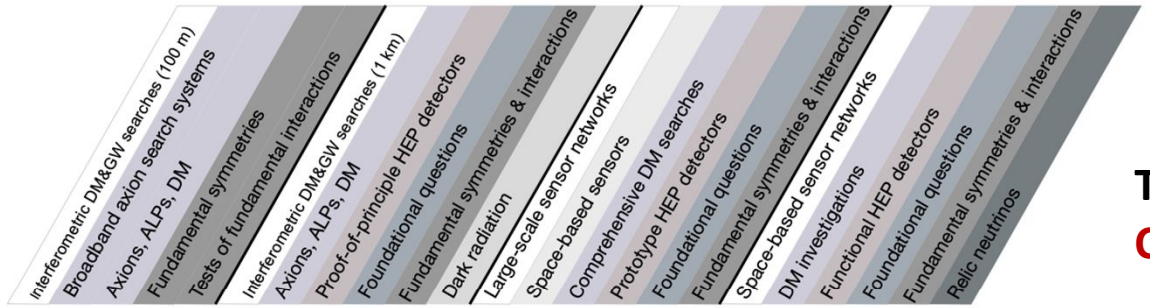
1) HL-LHC Long shutdowns: LS3/LS4 2025/2031 (see https://lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm)
2) LHCb/ATLAS/CMS consider Planar/3D sensors at the time of this document for rates and radiation tolerance. On longer term, pixelated LGADs could be considered for potentially higher timing precision
3) In trackers, coarser longitudinal granularities could be considered for MAPS. Thorough performance and cost comparison with passive CMOS would be needed. Pixelated LGADs could be considered for potentially higher timing precision
4) The size of wafers achievable can depend on technology (industrial process) with a general trend to benefits from larger areas
5) Ultrafast timing refers to ≤100 ps depending on technology and detector purpose
6) Two options exist for calorimetry: pads O(1) mm pitch with analog readout (applying to all technologies) and particle counting digital with MAPS O(50) µm pitch. LGADs could be considered for potentially higher timing precision
7) ToF, as compared to 4D tracking, concerns dedicated layers for very high pile-up, beam induced background or particle identification with highest possible precision. Timing erformance of sensors without amplifcation (MAPS, planar/3D/CMOS passive CMOS) is subject to R&D, while LGADs with amplification are at this stage expected to potentially provide higher precision

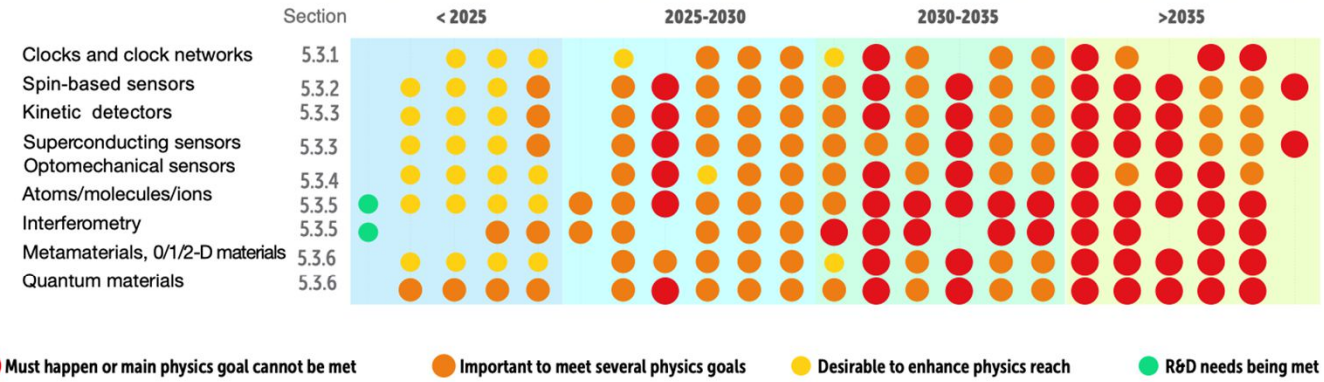
Task Force 4 Photon Detectors and Particle Identification Detectors



Draft figure still under development

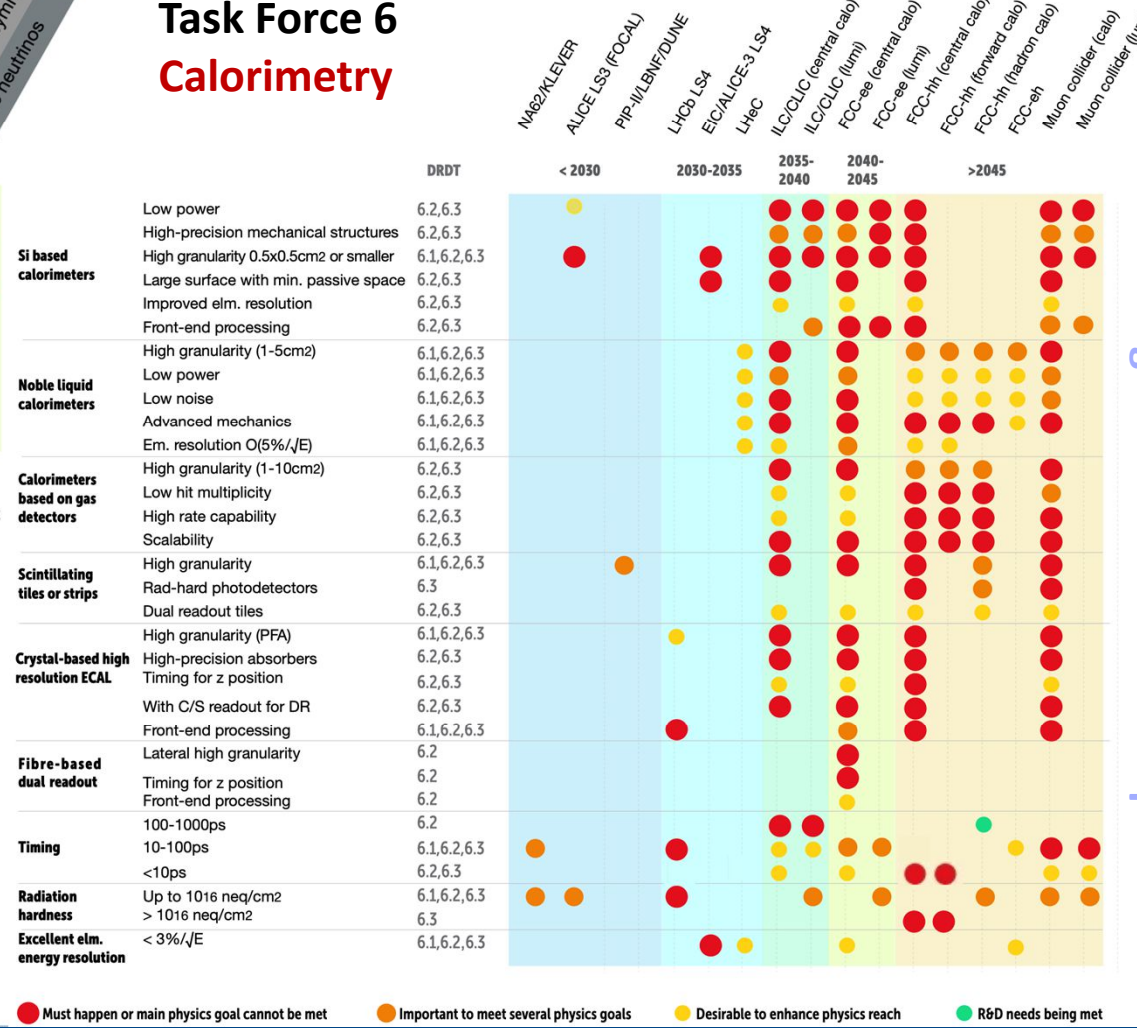
Detailed ECFA Timeline





Task Force 5 Quantum and Emerging Technologies

Task Force 6 Calorimetry



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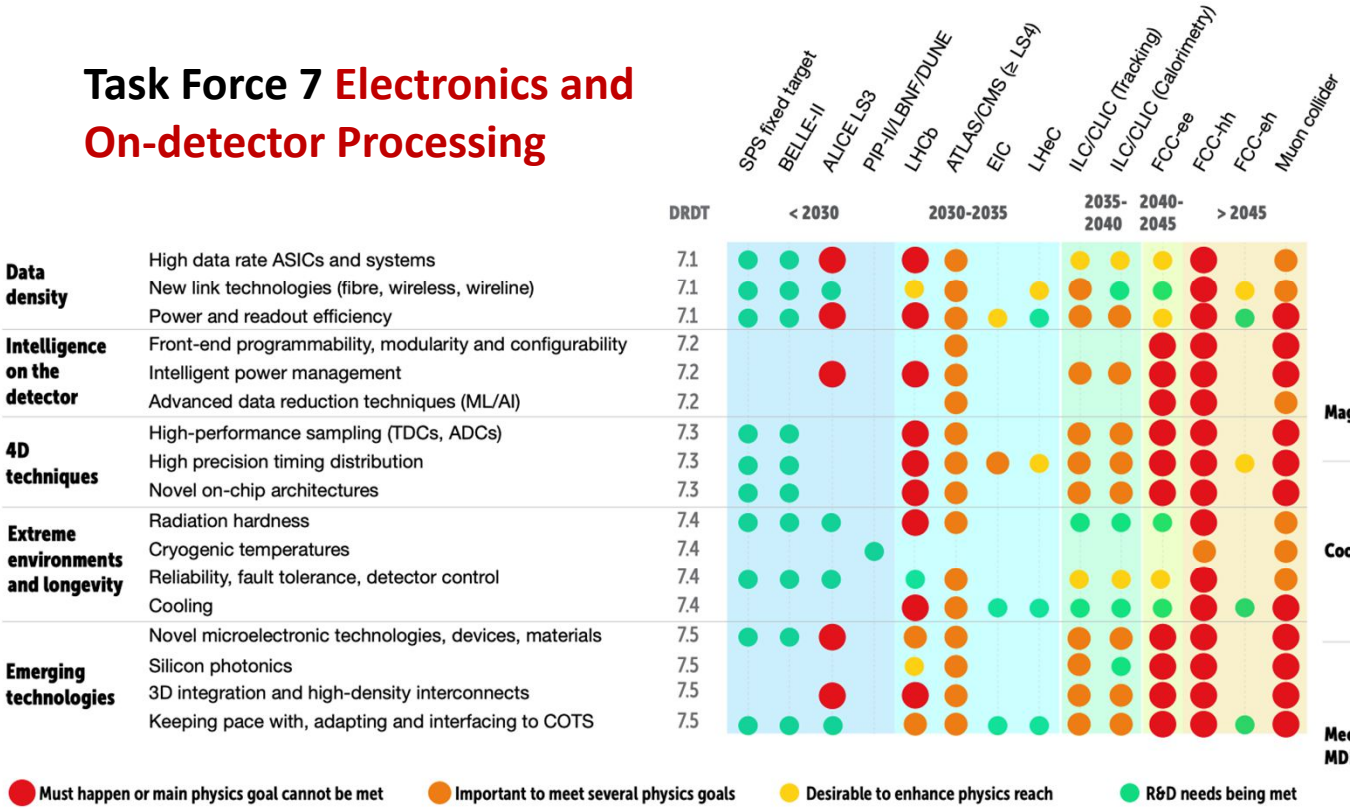
Detailed ECFA Timeline

Task Force 7 Electronics and On-detector Processing



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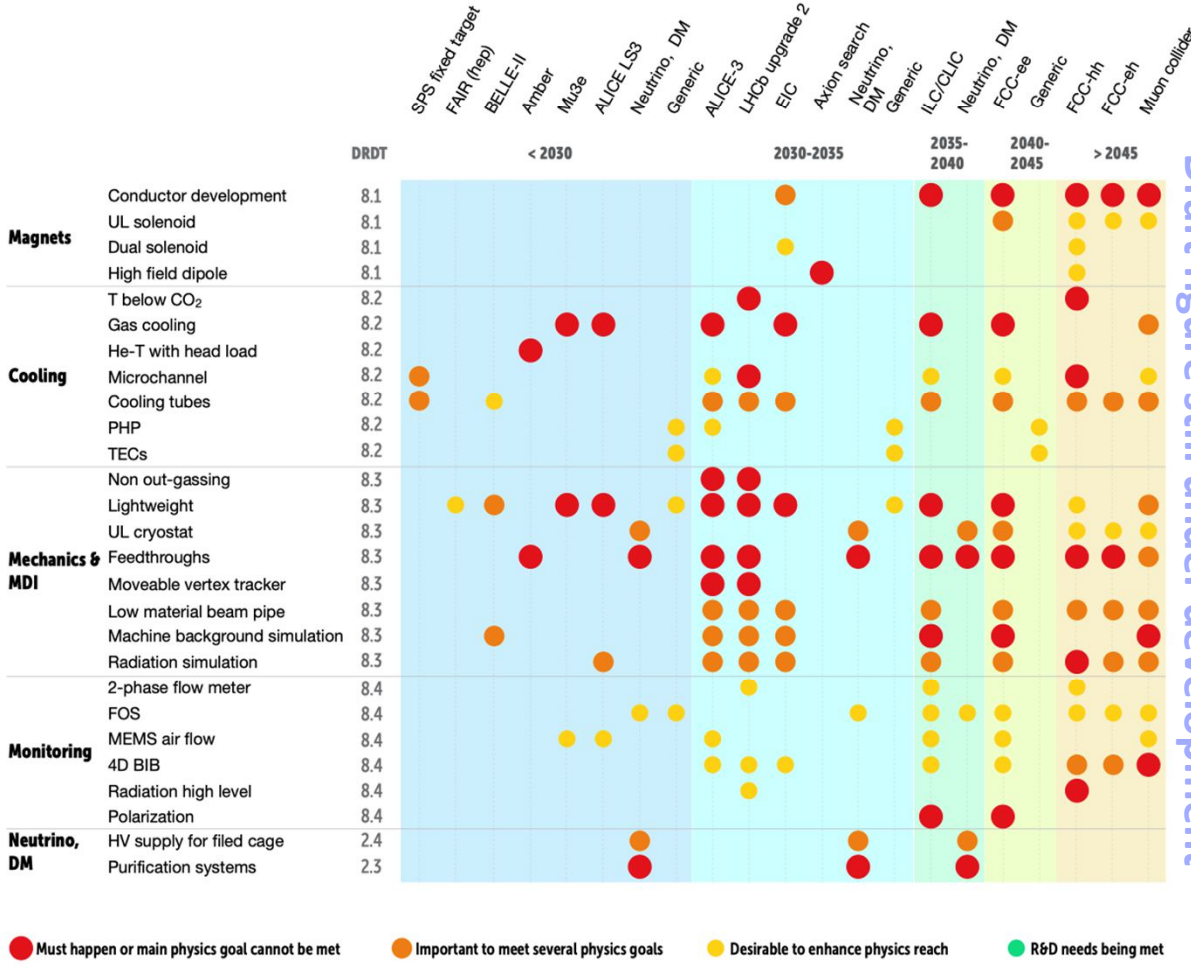
Task Force 8 Integration



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Early Career Researchers

Task Force 9 Training

Results of the 2021 ECFA Early-Career Researcher Survey on Training in Instrumentation

The ECFA Early-Career Researcher (ECR) Panel

July 14, 2021

Anamika Aggarwal[1], Chiara Amendola[2], Liliana Apolinario[3], Jan-Hendrik Arling[*,4], Adi Ashkenazi[5], Kamil Augsten[6], Julien Baglio[7], Evelin Bakos[8], Liron Barak[5], Diogo Bastos[3], Bugra Bilin[9], Silvia Biondi[10], Neven Blaskovic Kraljevic[11], Lydia Brenner[7], Francesco Brizioli[12], Antoine Camper[13], Alessandra Camplani[14], Xabier Cid Vidal[15], Hüseyin Dag[16], Flavia de Almeida Dias[17], Eleonora Diociaiuti[18], Lennart van Doremalen[19], Katherine Dunne[*,20], Filip Erhardt[21], Pedro Fernández Manteca[22], Andrei Alexandru Geanta[23], Stefan Alexandru Ghinescu[23], Loukas Gouskos[7], Andrej Herzan[24], Viktoria Hinger[25], Bojan Hiti[26], Armin Ilg[*,27], Gianluca Inguglia[28], Adrián Irles[*,29], Hendrik Jansen[4], Kateřina Jarkovská[30], Lucia Keszeghova[31], Henning Kirschenmann[32], Sotiroulla Konstantinou[33], Magdalena Kuich[34], Neelam Kumari[35], Katarína Křížková Gajdošová[6], Aleksandra Lelek[36], Jeanette Lorenz[37], Ana Luisa Carvalho[3], Jakub Malczewski[38], Giada Mancini[18], Alexander Mann[37], Laura Martikainen[39], Émilie Maurice[40], Seán Mee[41], Predrag Milenovic[*,42], Vukasin Milosevic[43], Zuzana Moravcova[14], Laura Moreno Valero[44], Louis Moureaux[45], Heikki Mäntysaari[46], Nikiforos Nikiforou[47], Younes Otarid[4], Alex Pearce[7], Michael Pitt[7], Vlad-Mihai Placinta[23], Giulia Ripellino[48], Bryn Roberts[49], Luka Šantelj[50], Steven Schramm[*,51], Mariana Shopova[*,52], Kirill Skovpen[53], Aleks Smolkovič[50], Gamze Sokmen[54], Paweł Sznajder[55], Abigail Victoria Waldron[56], Sarah Williams[*,57], Valentina Zaccolo[58], and Manuel Zeyen[59]

The European Committee for Future Accelerators (ECFA) Early-Career Researchers (ECR) Panel was invited by the ECFA Detector R&D Roadmap conveners to collect feedback from the European ECR community. A working group within the ECFA ECR panel held a Town-hall Meeting to get first input, and then designed and broadly circulated a detailed survey to gather feedback from the larger ECR community. A total of 473 responses to this survey were received, providing a useful overview of the experiences of ECRs in instrumentation training and related topics. This report summarises the feedback received, and is intended to serve as an input to the ECFA Detector R&D Roadmap process.

https://arxiv.org/abs/2107.05739

Restricted ECFA Composition

https://ecfa.web.cern.ch/restricted-ecfa

Chair	Prof. Dr Karl Jakobs	Appointed Jan. 2021
Secretary	Prof. Patricia Conde Muino	Appointed July 2021

Members		
Austria	Dr Manfred Jeitler	Appointed Jan. 2018
Belgium	Prof. Nick van Remortel	Appointed July 2018
Bulgaria	Prof. Plamen Iaydjiev	Appointed Jan. 2016
Croatia	Prof. Mirko Planinic	Appointed July 2020
Cyprus	Prof. Panos Razis	Appointed Oct. 2017
Czech Republic	Dr Marek Tasevsky	Appointed Jan. 2019
Denmark	Prof. Mogens Dam	Appointed Jan. 2018
Finland	Dr Kati Lassila-Perini	Appointed Jan. 2018
France	Dr Jean-Claude Brient	Appointed Jan. 2020
Germany	Prof. Heiko Lacker	Appointed July 2021
Greece	Prof. Paris Sphicas	Appointed July 2018
Hungary	Dr Ferenc Siklér	Appointed Jan. 2021
Italy	Prof. Chiara Meroni	Appointed July 2020
Israel	Prof. Eilam Gross	Appointed Jan. 2018
Netherlands	Prof. Stan Bentvelsen	Appointed Jan. 2015
Norway	Prof. Alexander Read	Appointed Jan. 2018
Poland	Prof. Justyna Łagoda	Appointed Jan. 2021
Portugal	Prof. Patricia Condes Muino	Appointed July 2020
Romania	Dr Alexandru-Mario Bragadireanu	Appointed Jan. 2019
Serbia	Prof. Peter Adžic	Appointed July 2012
Slovakia	Dr Pavol Stríženec	Appointed May 2016
Slovenia	Prof. Marko Mikuž	Appointed July 2018
Spain	Prof. Celso Martinez	Appointed Jan. 2021
Sweden	Prof. David Milstead	Appointed Jan. 2018
Switzerland	Dr Mike Seidel	Appointed Jan. 2019
Turkey	Prof. Mehmet Zeyrek	Appointed July 2018
United-Kingdom	Prof. Max Klein	Appointed Jan. 2021
Ukraine	Prof. Mykola Shul'ga	Appointed July 2018
CERN	Dr Roger Forty	Appointed Sept. 2015
Ex-Officio Members		
CERN	Dr Fabiola Gianotti Prof. Joachim Mnich	Appointed Jan. 2016 Appointed Jan. 2021
LDG	Prof. Dave Newbold	Appointed Jan. 2021
Observers		
EPS-HEPP Board Chair	Prof. Thomas Gehrmann	Appointed Sept. 2019
ApPEC Chair	Dr Andreas Haungs	Appointed Jan. 2021
NuPECC Chair	Prof. Marek Lewitowicz	Appointed March 2018
Russian Federation	Prof. Victor Matveev	Appointed Jan. 2007
Early Career Researchers (ECR)	Lydia Brenner	Appointed Feb. 2021

European Particle Physics Strategy Update

"**Main report**: *"Recent initiatives with a view towards strategic R&D on detectors are being taken by CERN's EP department and by the ECFA detector R&D panel, supported by EU-funded programmes such as AIDA and ATTRACT. Coordination of R&D activities is critical to maximise the scientific outcomes of these activities and to make the most efficient use of resources; as such, there is a clear need to strengthen existing R&D collaborative structures, and to create new ones, to address future experimental challenges of the field beyond the HL-LHC. 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."*

Deliberation document: *"Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels."*

Extracted from the documents of 2020 EPPSU, https://europeanstrategyupdate.web.cern.ch/

Many more details on the roadmap process can be found in past Plenary ECFA presentations and in various talks linked through the web pages at https://indico.cern.ch/e/ECFADetectorRDRoadmap

Detailed ECFA Timeline

- **Draft circulated to RECFA, National Contacts and ECR on 2nd July with deadline for comments on 16th July**
- **Comments received from many of the RECFA members, observers and appointed National Contacts for the ECFA Detector R&D Roadmap process.**
- **Overwhelmingly positive and impressed with the amount of careful work in the sections.**
- **A number of countries have organised a careful reading of the full draft with many detailed comments to each section - which are very helpful and greatly appreciated.**
- **A number of more general comments have been discussed in greater detail on 21st July with a special sub-panel composed of RECFA members with reports back to RECFA and also to Plenary ECFA on 22nd July.**
- **A large number of comments are either being implemented in the text or will be implemented by the individual task forces before the beginning of global editing of the final document begins in mid-August.**
- **Because of timescales for final graphics, printing etc, the electronic text will need to be finalised for October.**
- **The document will need formal approval from ECFA on 19th November to be presented as printed copies to CERN Council on 10th December.**
- **In parallel we will prepare an 8 page "glossy" to accompany this, summarising the main conclusions to be prepared with CERN IR-ECO in a more accessible language and style.**

Links for Roadmap Process

(**https://indico.cern.ch/e/ECFADetectorRDRoadmap**)

https://indico.cern.ch/event/957057/page/21633-mandate (Panel Mandate document)

https://indico.cern.ch/event/957057/page/21653-relevant-documents

https://home.cern/resources/brochure/cern/european-strategy-particle-physics

https://arxiv.org/abs/1910.11775 (Briefing Book)

https://science.osti.gov/-/media/hep/pdf/Reports/2020/DOE_Basic_Research_Needs_Study_on_High_Energy_Physics.pdf

https://ep-dep.web.cern.ch/rd-experimental-technologies (CERN EP R&D)

https://aidainnova.web.cern.ch (linking research infrastructures in detector development and testing)

https://attract-eu.com/ (ATTRACT: linking to industry on detection and imaging technologies)

https://ecfa-dp.desy.de/public_documents/ (Some useful documents from the ECFA Detector Panel)