



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

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.”*



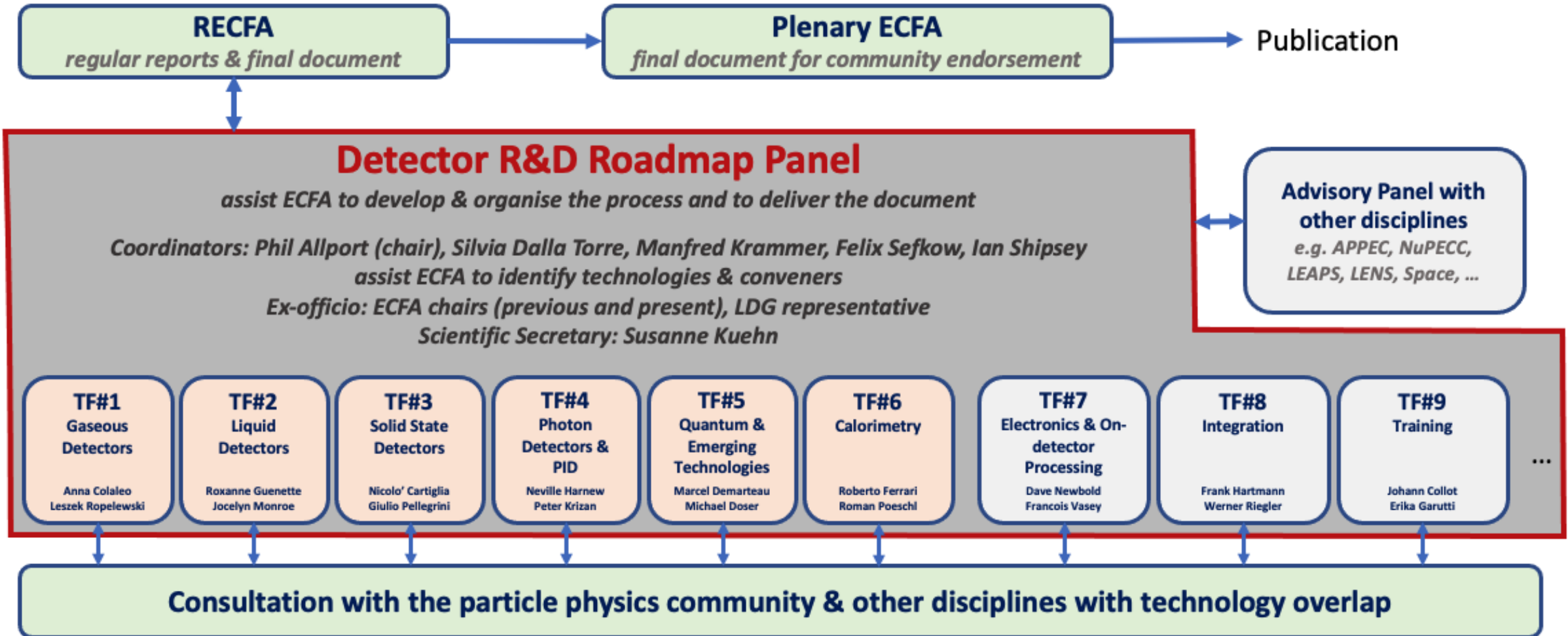
Deliberation document: *“Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development 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/>

For previous presentations on the Detector R&D Roadmap see Plenary ECFA: Jorgen D’Hondt (13/7/20) & Susanne Kuehn (20/11/20) (<https://indico.cern.ch/event/933318/> & <https://indico.cern.ch/event/966397/>)

More roadmap process details at: <https://indico.cern.ch/e/ECFADetectorRDRoadmap>

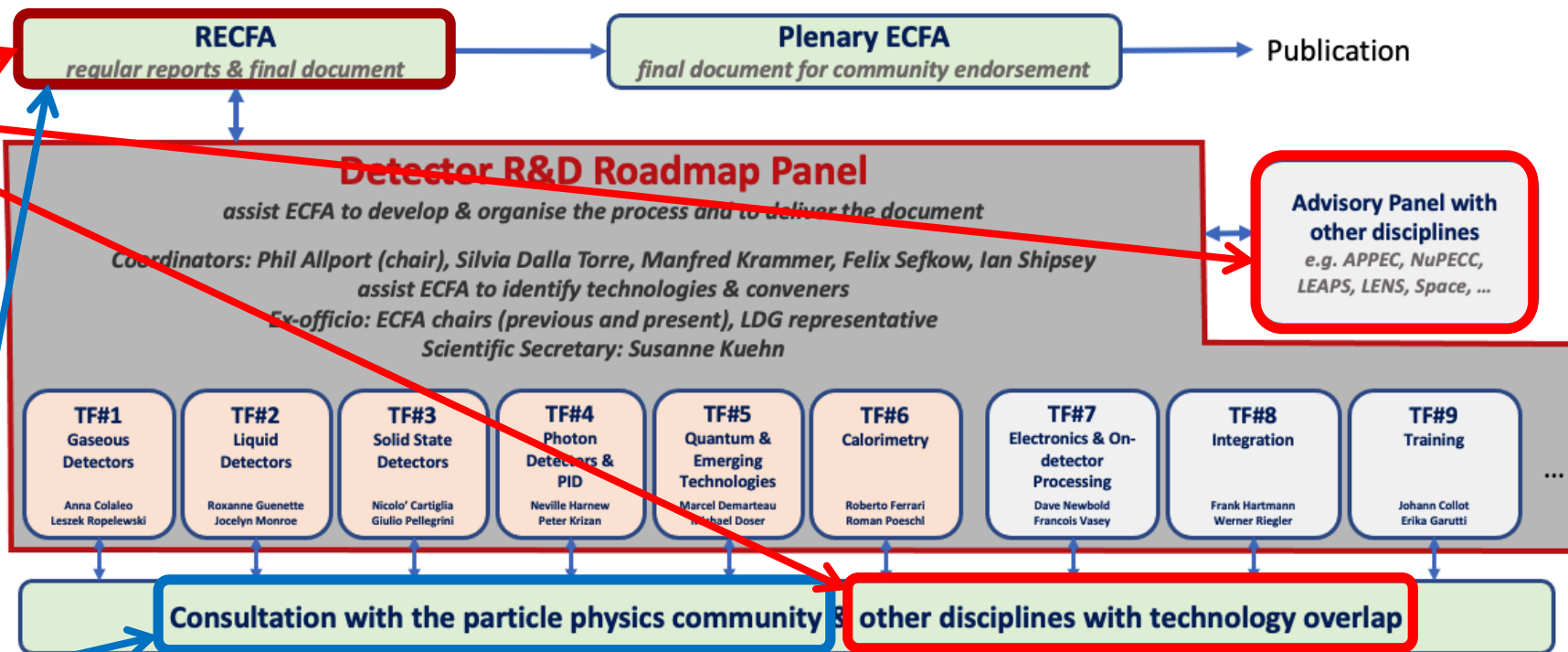
Organization for Consultation of Relevant Communities



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

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>

Organization for Consultation of Relevant Communities

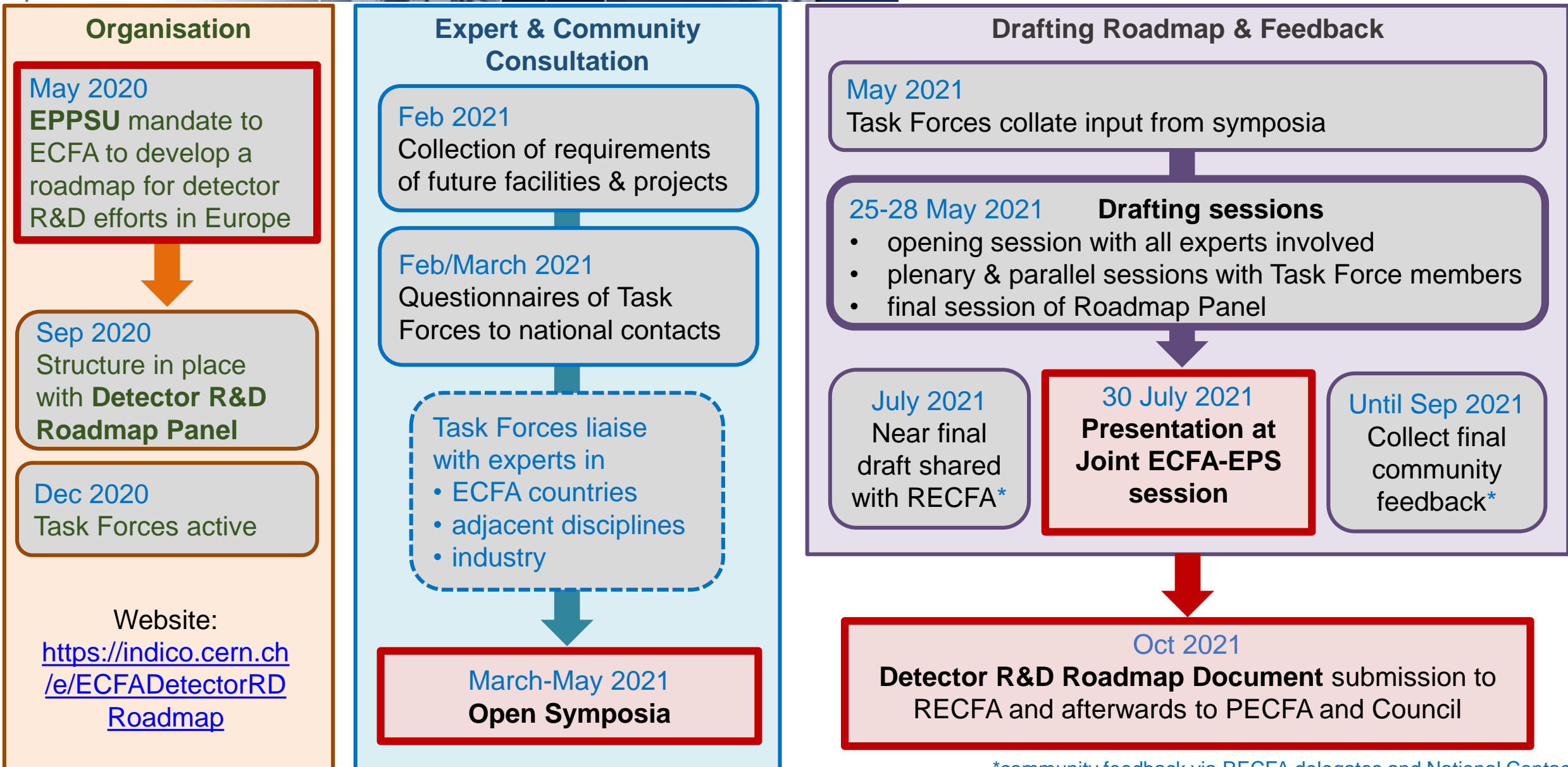
- Focus on the technical aspects of detector R&D requirements given the EPPSU deliberation document listed “*High-priority future initiatives*” and “*Other essential scientific activities for particle physics*” as input and organise material by Task Force.
- Task Forces start from **the future science 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 $5 \times 10^{36} \text{cm}^{-2} \text{s}^{-1}$ 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 $10^{35} \text{cm}^{-2} \text{s}^{-1}$.

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**



*community feedback via RECFA delegates and National Contacts

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**
Speaker: 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...

Expert & Community Consultation

Feb 2021
Collection of requirements of future facilities & projects

Feb/March 2021
Questionnaires of Task Forces to national contacts

Task Forces liaise with experts in

- ECFA countries
- adjacent disciplines
- industry

March-May 2021
Open Symposia

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>

Input Session speakers have provided invaluable input material and continued support for the process

They were particularly asked to check if there were any unmet detector R&D needs for the ESPP identified programme which may have been overlooked in the symposia programmes

Input session of Future Facilities I

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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...

	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

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

The feedback received shows the painstaking preparation work by the organisers and presenters was well appreciated.

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.

Significant further contributions by email after the symposia

Surveys were also employed to receive direct inputs from individuals and via ECFA 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
- 06 May ECFA Detector R&D Roadmap Symposium of Task Force 4 Photon Detectors and Particle Identification Detectors

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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>

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)

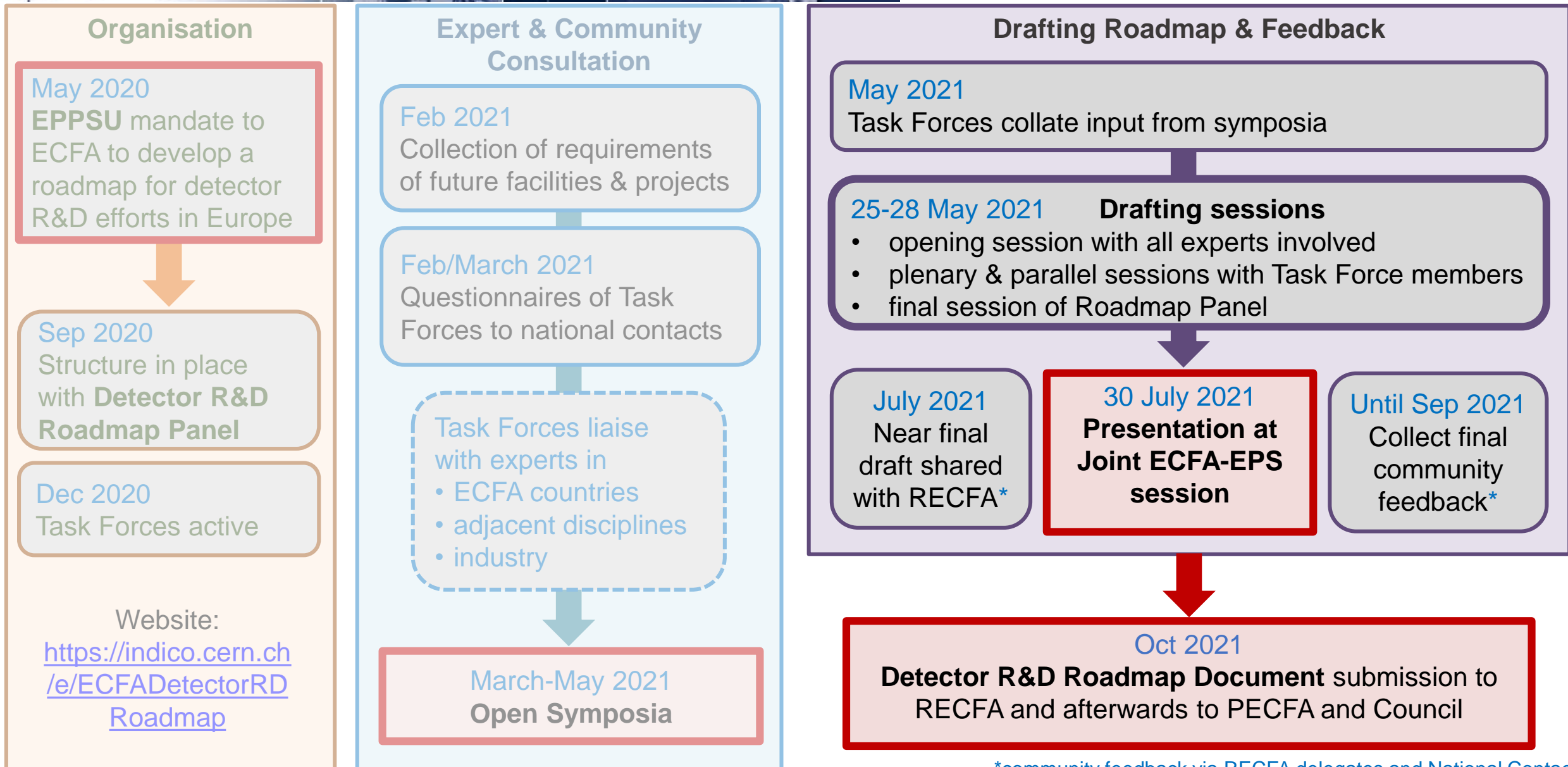
APPEC: Astro-Particle Physics European Consortium
ESA: European Space Agency
LEAPS: League of European Accelerator-based Photon Sources
LENS: League of advanced European Neutron Sources
NuPECC: Nuclear Physics European Collaboration Committee

Named expert contacts			
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	Heinz Graafsma (DESY)	Heinz.graafsma@desy.de	

Named contacts for each TF where appropriate

The Panel thanks these experts for their advice and availability

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	TF4		
	TF5	Helmut Schober (ILL)	schober@ill.fr
	TF6		
	TF7	Bruno Guerard (ILL)	guerard@ill.fr
	TF8		
	TF9		
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		Nick Nelms	Nick.Nelms@esa.int
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		Nick Nelms	Nick.Nelms@esa.int
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	Nick Nelms	Nick.Nelms@esa.int	
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TF9	Christophe Honvault	Christophe.Honvault@esa.int	



*community feedback via RECFA delegates and National Contacts

2021 ECFA Detector Research and Development Roadmap

ECFA

European Committee for Future Accelerators

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.

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

Task Force 1 Gaseous Detectors: Anna Colaleo¹, Leszek Ropelewski² (*Convenors*)
Klaus Dehmelt³, Barbara Liberti⁴, Maxim Titov⁵, Joao Veloso⁶ (*Expert Members*)

Task Force 2 Liquid Detectors: Roxanne Guenette⁷, Jocelyn Monroe⁸ (*Convenors*)
Auke-Pieter Colijn⁹, Antonio Ereditato^{10,11}, Ines Gil Botella¹²,
Manfred Lindner¹³ (*Expert Members*)

Task Force 3 Solid State Detectors: Nicolo Cartiglia¹⁴, Giulio Pellegrini¹⁵ (*Convenors*)
Daniela Bortoletto¹⁶, Didier Contardo¹⁷, Ingrid Gregor^{18,19}, Gregor Kramberger²⁰,
Heinz Pernegger² (*Expert Members*)

Task Force 4 Particle Identification and Photon Detectors: Neville Harnew¹⁶,
Peter Krizan²⁰ (*Convenors*)
Ichiro Adachi²¹, Eugenio Nappi¹, Christian Joram²,
Christian Schultz-Coulon²² (*Expert Members*)

Task Force 5 Quantum and Emerging Technologies: Marcel Demarteau²³,
Michael Doser² (*Convenors*)
Caterina Braggio²⁴, Andy Geraci²⁵, Peter Graham²⁶, Anna Grasselino²⁷,
John March Russell¹⁶, Stafford Withington²⁸ (*Expert Members*)

Task Force 6 Calorimetry: Roberto Ferrari²⁹, Roman Poeschl³⁰ (*Convenors*)
Martin Aleksa², Dave Barney², Frank Simon³¹,
Tommaso Tabarelli de Fatis³² (*Expert Members*)

Task Force 7 Electronics: Dave Newbold³³, Francois Vasey² (*Convenors*)
Niko Neufeld², Valerio Re²⁹, Christophe de la Taille³⁴, Marc Weber³⁵ (*Expert Members*)

Task Force 8 Integration: Frank Hartmann³⁵, Werner Riegler² (*Convenors*)
Corrado Gargiulo², Filippo Resnati², Herman Ten Kate³⁶, Bart Verlaet²,
Marcel Vos³⁷ (*Expert Members*)

Task Force 9 Training: Johann Collot³⁸, Erika Garutti^{18,39} (*Convenors*)
Richard Brenner⁴⁰, Niels van Bakel⁹, Claire Gwenlan¹⁶, Jeff Wiener²,
ex-officio Robert Appleby⁴¹ (*Expert Members*)

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

Panel coordinators: Phil Allport⁴² (*Chair*), Silvia Dalla Torre⁴³, Manfred Krammer²,
Felix Sefkow¹⁸, Ian Shipsey¹⁶

Ex-officio Panel members: Karl Jakobs⁴⁴ (*Current ECFA Chair*),
Jorgen D'Hondt⁴⁵ (*Previous ECFA Chair*), Lenny Rivkin⁴⁶ (*LDG Representative*)

Scientific Secretary: Susanne Kuehn²

¹ INFN Bari, Bari, Italy

² CERN, Geneva, Switzerland

³ Stony Brook University, New York, US

⁴ INFN Roma, Rome, Italy

⁵ IRFU/DPPh 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 Haven, US

¹¹ University of Bern, Berne, Switzerland

¹² CIEMAT, Madrid, Spain

¹³ MPI Heidelberg, Heidelberg, Germany

¹⁴ INFN Sezione di Torino, Torino, 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

- Draft circulated to RECFA, National Contacts and ECR on 2nd July with deadline for comments on 16th July
- Comments received from: Austria, Bulgaria, Croatia, Czech Republic, Denmark, France, Germany, Greece, Hungary, Italy, Portugal, Serbia, Sweden, Spain, UK, CERN, APECC and NuPECC
- Overwhelming positive and impressed with the amount of careful work in the sections
- From several countries there has been quite a careful reading with many already detailed comments to sections which are very helpful.
- A number of more general comments have been discussed in greater detail on 21st July with a special RECFA sub-panel ([Jean-Claude Brient](#), [Karl Jakobs](#), [Manfred Jeitler](#), [Marko Mikuz](#), [Mogens Dam](#), [Roger Forty](#)) as also reported to RECFA this morning by [Manfred Jeitler](#).
- 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 endorsement by RECFA on 19th November to go 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.

- **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 we 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 figure and are identified by arrows lasting up to the last currently identified facility for which they are relevant.**

DETECTOR RESEARCH AND DEVELOPMENT THEMES (DRDTs)

- As explained in detail in the text, the future beyond the end of the arrows is simply not known 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 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.

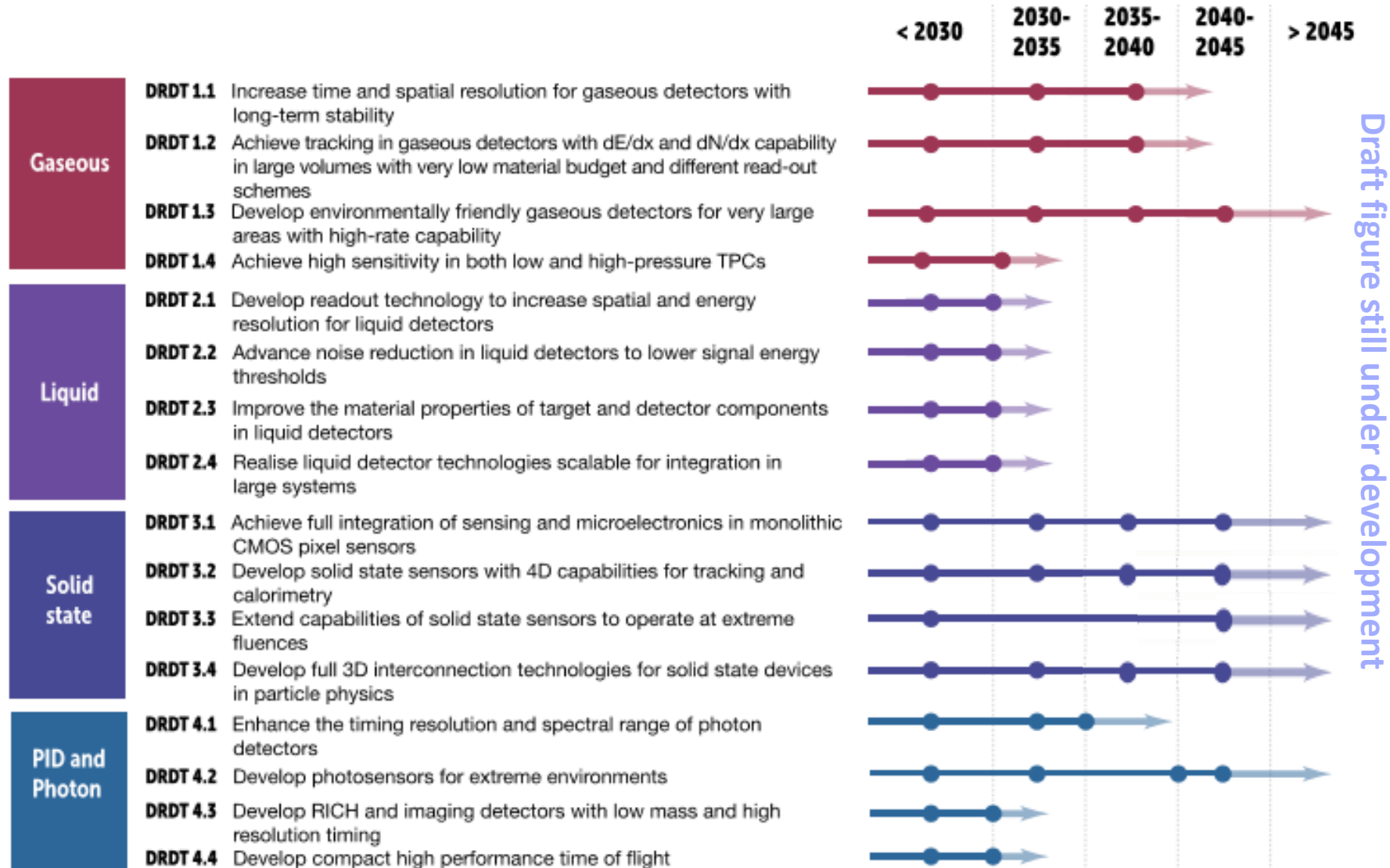




Figure 1: Detector R&D Themes (DRDT) and Detector Community Themes (DCT). Here, except in the DCT case, the final dot position represents the target date for completion of the R&D required by the latest known future facility/experiment for which an R&D programme would still be needed in that area. The 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).

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. 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

The dates shown in the diagram have 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.

	< 2030	2030-2035	2035-2040	2040-2045	> 2045
SPS Fixed Target					
Other fixed target, FAIR (hep)					
Belle II					
ALICE LS3					
PIP-II/LBNF/DUNE/Hyper-K					
ALICE/LHCb (>LS4)					
ATLAS/CMS (≥ LS4)					
EIC					
LHeC					
ILC					
CLIC					
FCC-ee					
FCC-hh					
FCC-eh					
Muon Collider					

Draft figure still under development

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

<2025	2025-2030	2030-2035	>2035
Neutrino Telescopes (Km3)			
Axions, ALPs, Dark Matter (DM)			
Light DM Detectors			
Multi-tonne scale DM Detectors			
Tonne Scale Onbb			
100 m Atom Interferometry			
Mu3e Phase II / COMET Phase II			
Future meugamma experiment			
Axions, ALPs, DM			
Light DM Detectors			
Hundred-tonne scale DM detectors			
Tonne scale Onbb			
Proof of Principle Quantum Sensor HEP Detectors			
Dark Radiation			
Km scale Atom Interferometry			
Future Mu3e Experiment			
Light DM Detectors			
Hundred-tonne scale DM detectors			
Multi tonne scale Onbb			
Prototype Quantum Sensor HEP Detectors			
Large scale quantum sensor networks			
Space- based Quantum Sensors			
Big Bang (CNB) Detectors			
Space-based Quantum Sensor Networks			
Functional Quantum Sensor HEP Detectors			
PRISM			

Draft figure still under development

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.

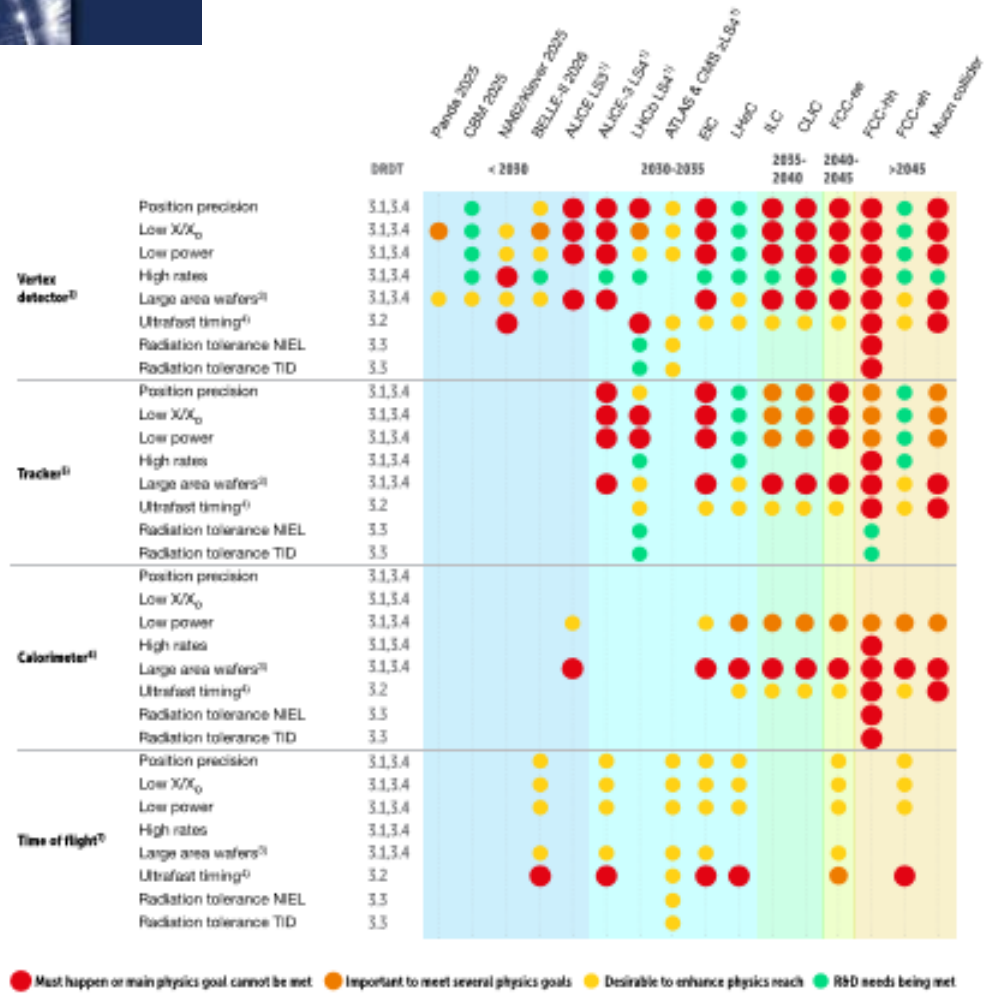
Throughout the document these figures inform the development of the Detector R&D Roadmap with a view to set concrete target timelines for the readiness of the recommended R&D thematic programmes emerging in each Task Force and summarized in the conclusion chapter.

Example figure from the Task Force 3 **Solid State 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



Draft figure still under development

1) LSS/LB4
 2) LHCB/ATLAS/CMS consider Planar3D 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 (1) mm pitch with analog readout (applying to all technologies) and particle counting digital with MAPS (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 performance of sensors without amplification (MAPS, planar3D/Cmos passive CMOS) is subject to R&D, while LGADS with amplification are at this stage expected to potentially provide higher precision



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

The issues of open access in appropriate journals and around intellectual property have also been raised and are expected to form the basis of an additional recommendation

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 creative 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.



- 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 and numerous comments received from committees looking at this in a number of countries.
- 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 improvement still to implement but with no major changes to the basic messages communicated here.
- At the ECFA Session of next week's EPS meeting these main conclusions will be presented to the community for discussion and further feedback.



(<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)