Muon Collider detectors in the Detector R&D Roadmap

DRD – Implementation of Detector R&D Roadmap –
approved by CERN Council September 2022 – coordinated by ECFA
CPAD initiative – new detector research U.S. consortia –
presented @ BNL April P5 Town Hall

Nadia Pastrone
INFN TORINO
International MUON Collider Collaboration

IMCC Annual Meeting
IJCLAB – Orsay – June 19, 2023

EU Strategy ➔ Accelerator/Detector R&D Roadmap

International MUON Collider Collaboration

Muon Collider Working Group

Jean Pierre Delahaye (CERN), Marcella Diemoz (INFN-IT),
Ken Long (Imperial College-UK), Bruno Mansoulie (IRFU-FR),
***Nadia Pastrone** (INFN-IT) **(chair),** Lenny Rivkin (EPFL & PSI-CH), Daniel Schulte (CERN),*
Alexander Skrinsky (BINP-RU), Andrea Wulzer (EPFL & CERN-CH)

de facto it was the seed for a renewed international effort till 2020

***European* Strategy Update – June 19, 2020**: **High-priority future initiatives** [..]

3 ! High-priority future initiatives

In addition to the high field magnets the **accelerator R&D roadmap** could contain:

[..] an **international design study** for a **muon collider**, as it represents a **unique opportunity** to achieve a ***multi-TeV energy domain*** *beyond the reach of* e^+e^- *colliders*, and potentially within a *more compact circular tunnel* than for a hadron collider. The **biggest challenge** remains to produce an intense beam of cooled muons, but *novel ideas are being explored.*

CERN Laboratory Directors Group (LDG) established an Accelerator R&D roadmap

to carry out R&D and construction and operation of demonstrators

To facilitate implemention of the European Strategy LDG decided (July 2 2020) to:

Agree to start building the collaboration for international muon collider design study

➔ **International Muon Collider Collaboration kick-off virtual meeting**

(>260 participants) https://indico.cern.ch/event/930508/

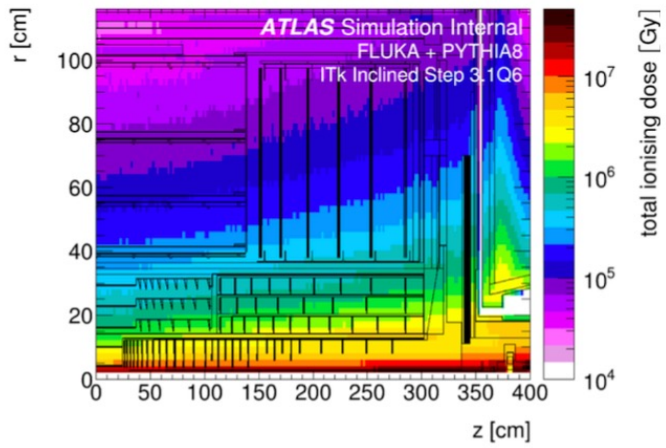
July 3rd, 2020

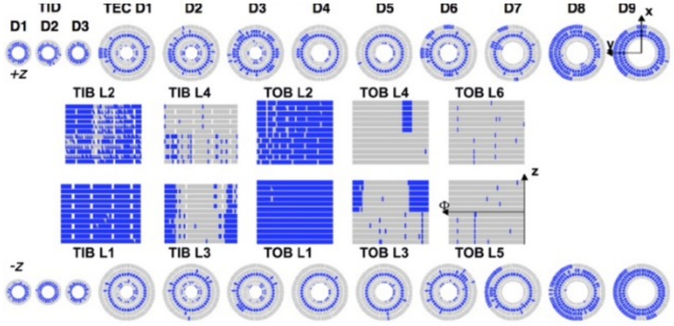
Priority: HL_LHC

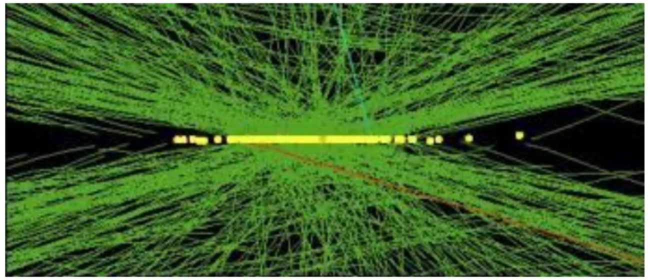
TECHNICAL MOTIVATION FOR DETECTOR UPGRADE

- **The HL-LHC will reach instantaneous luminosities up to 7.5 x nominal and will and operate for a ~ decade.**
- **The current ATLAS and CMS detectors cannot realize the physics opportunities presented by 3000 fb^{-1} of data expected during the HL-LHC era:**
  - **Accumulated radiation dose makes sub-detectors inoperable.**
    - Need for radiation hard sensors and electronics.
  - **High instantaneous luminosities lead to complex events (200 pileup collisions per bunch crossing).**
    - Need for high granularity, 4D information, redundancy.
  - **Rate plus complexity lead to x10 data volume.**
    - Need for faster readout ASICs and next generation TDAQ.

(plus paradigm shift in software and computing)







Detector Requirements for a multi-TeV Muon Collider Experiment

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Direct searches
Pair production, Resonances, VBF, Dark Matter, …

High-rate measurements
Single Higgs, self coupling, rare and exotic Higgs decays, top quarks, …

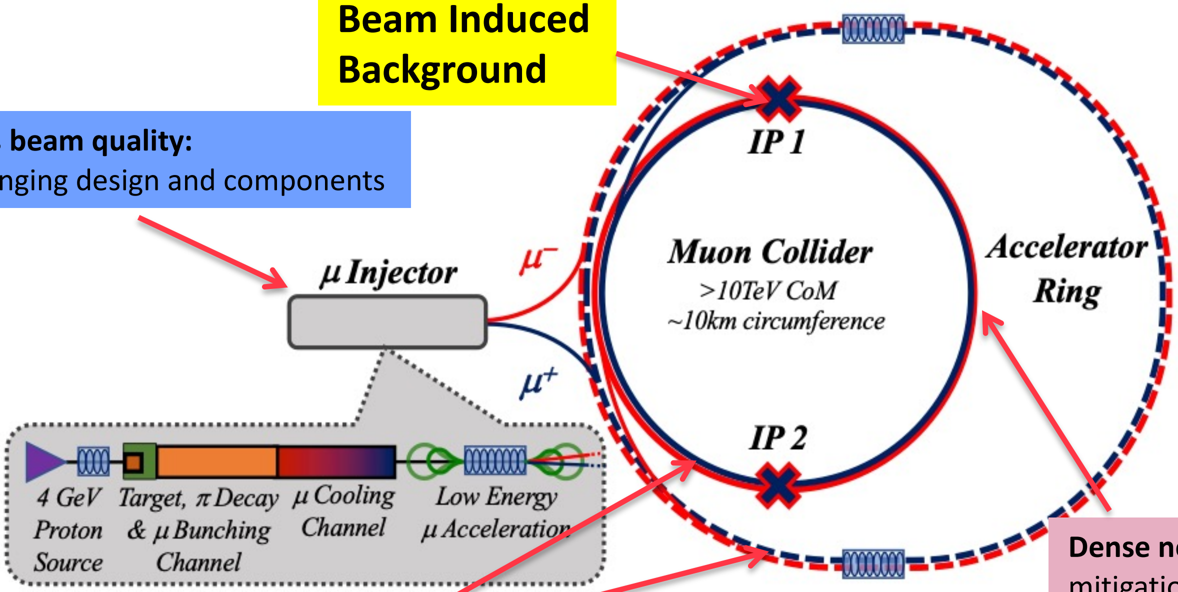
High-energy probes
Di-boson, di-fermion, tri-boson, EFT, compositeness, …

Muon physics
Lepton Flavor Universality, b → sμμ, muon g-2, …

10+ TeV completely new regime to explore!

Beam Induced Background

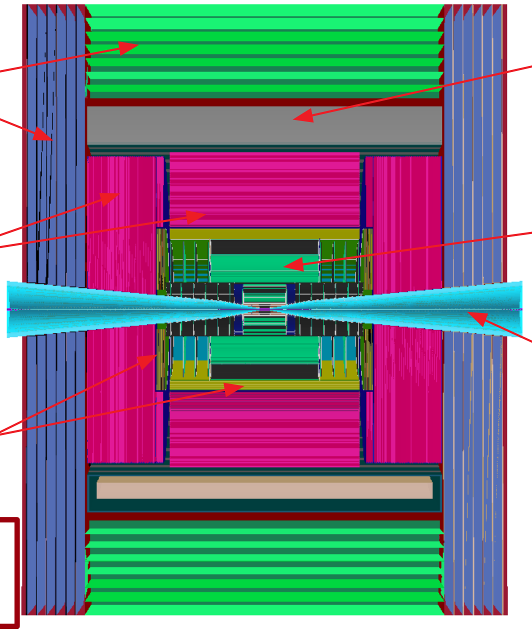
Drives **beam quality:**
challenging design and components



Dense neutrino flux mitigation and site

Cost and **power** consumption drivers, limit energy reach
e.g. 30 km accelerator for 10/14 TeV, 10/14 km collider ring

Proton driver production as baseline



B = 3.57 T to be studied and tuned

CLIC Detector technologies adopted with important tracker modifications to cope with Beam Induced Background

Full simulation conceptual design @ 1.5 and 3 TeV
➔ More R&D on technologies required @ 10+ TeV

under LDG, coordination formed

IMCC collaboration

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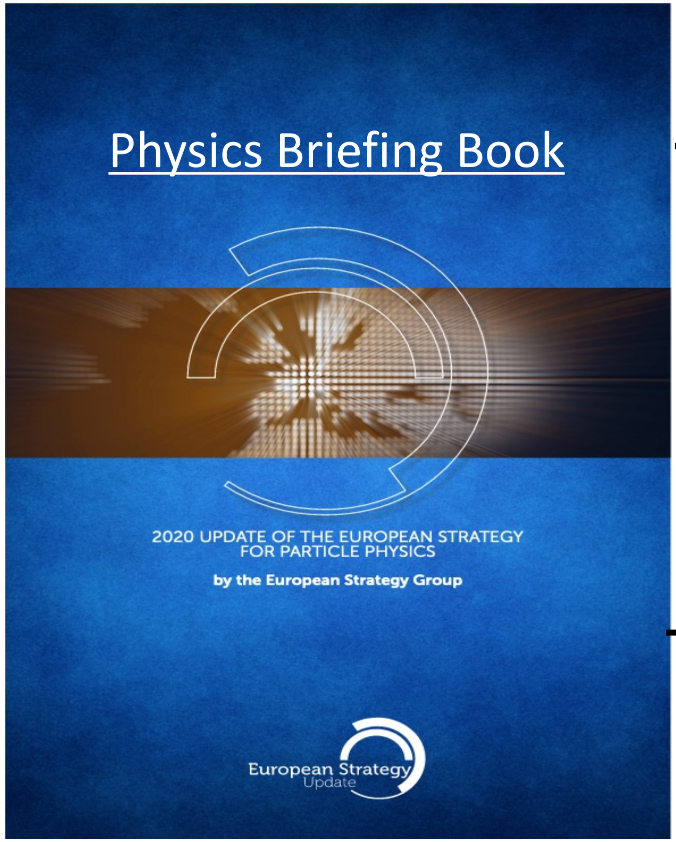
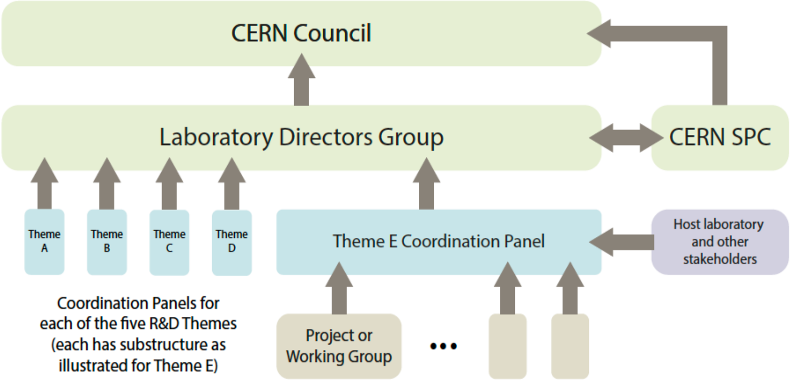
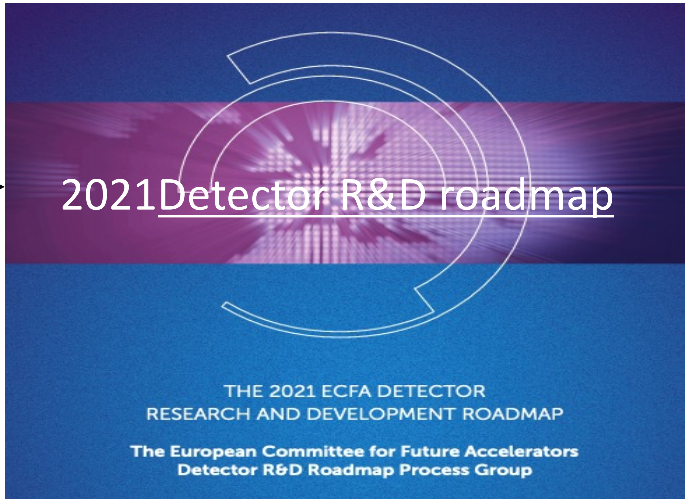




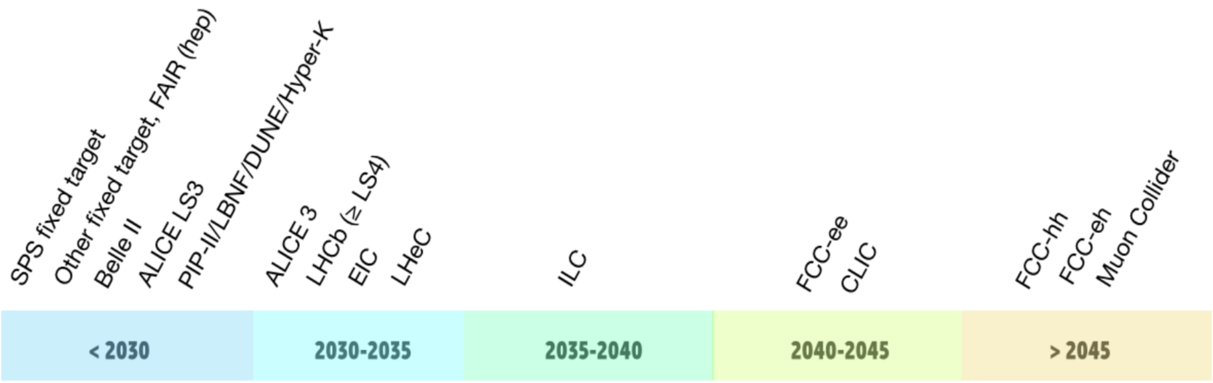
High-Field Magnets - Radiofrequency Structures – Muon Beams - Energy Recovery Linacs -Plasma Acceleration



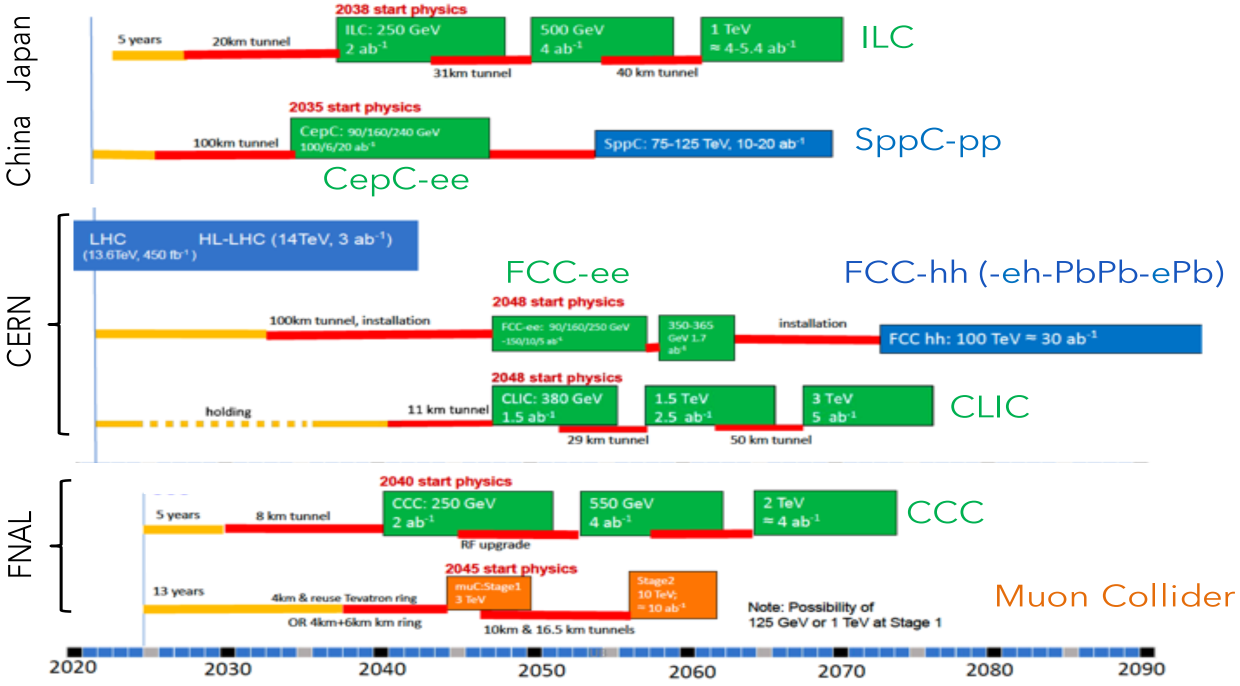
under ECFA, on-going

ECFA detector R&D roadmap goal

establish needs to fulfil strategic programs identified by the ESPP update



Detector R&D Roadmap



Snowmass future collider planning schedule

preparation construction - physics ee hh μμ

Unique lattice – MDI – Beam Induced Background

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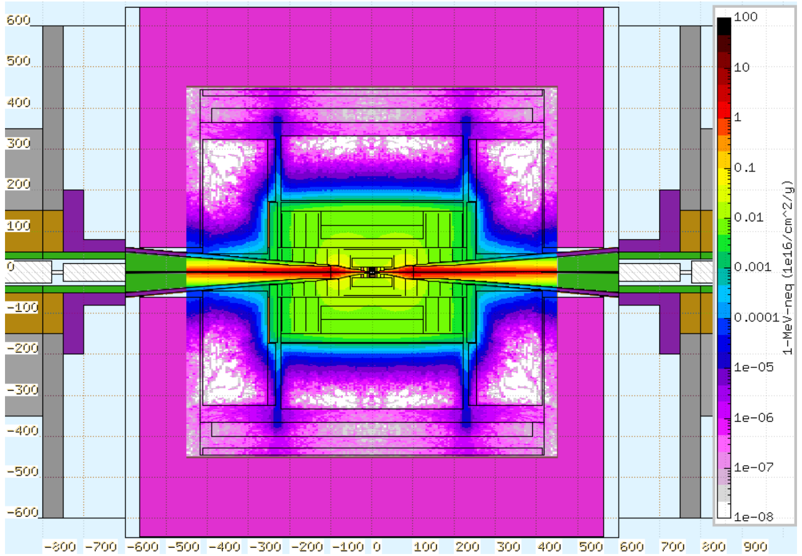
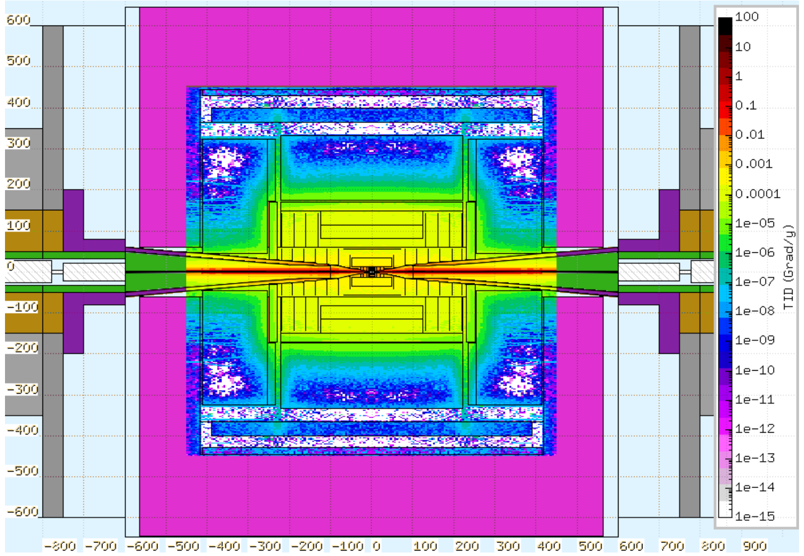
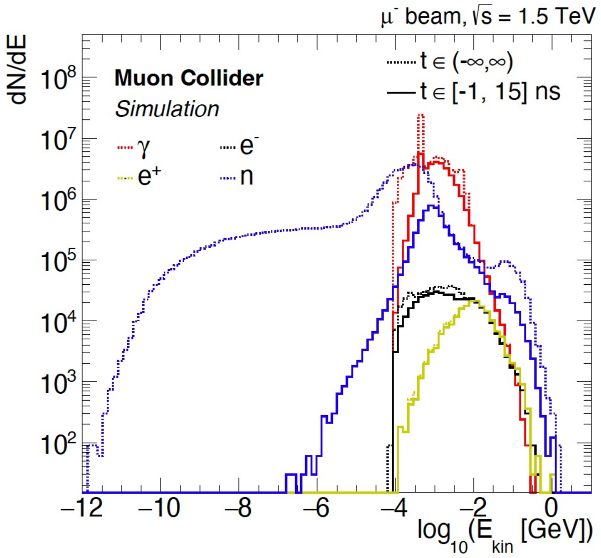


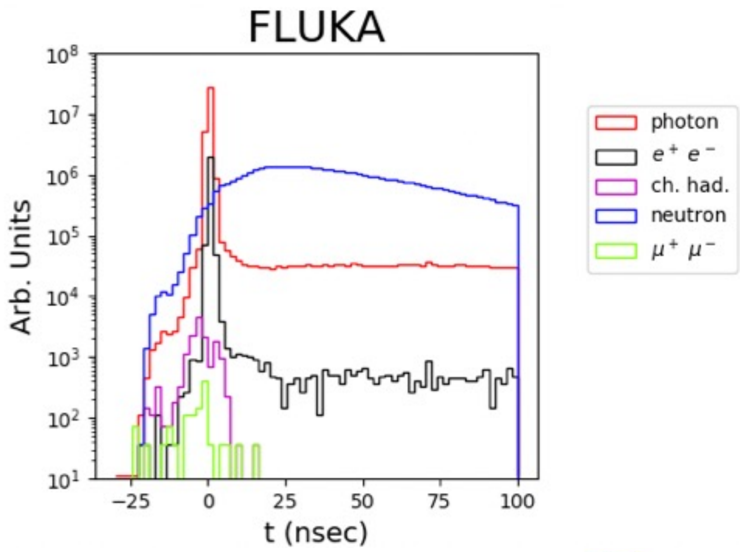
$1\ MeV\ n_{eq}$
fluence/year @ 3 TeV



TID/year @ 3 TeV

The machine elements, MDI and interaction region must be properly designed and optimized @ each collider energy

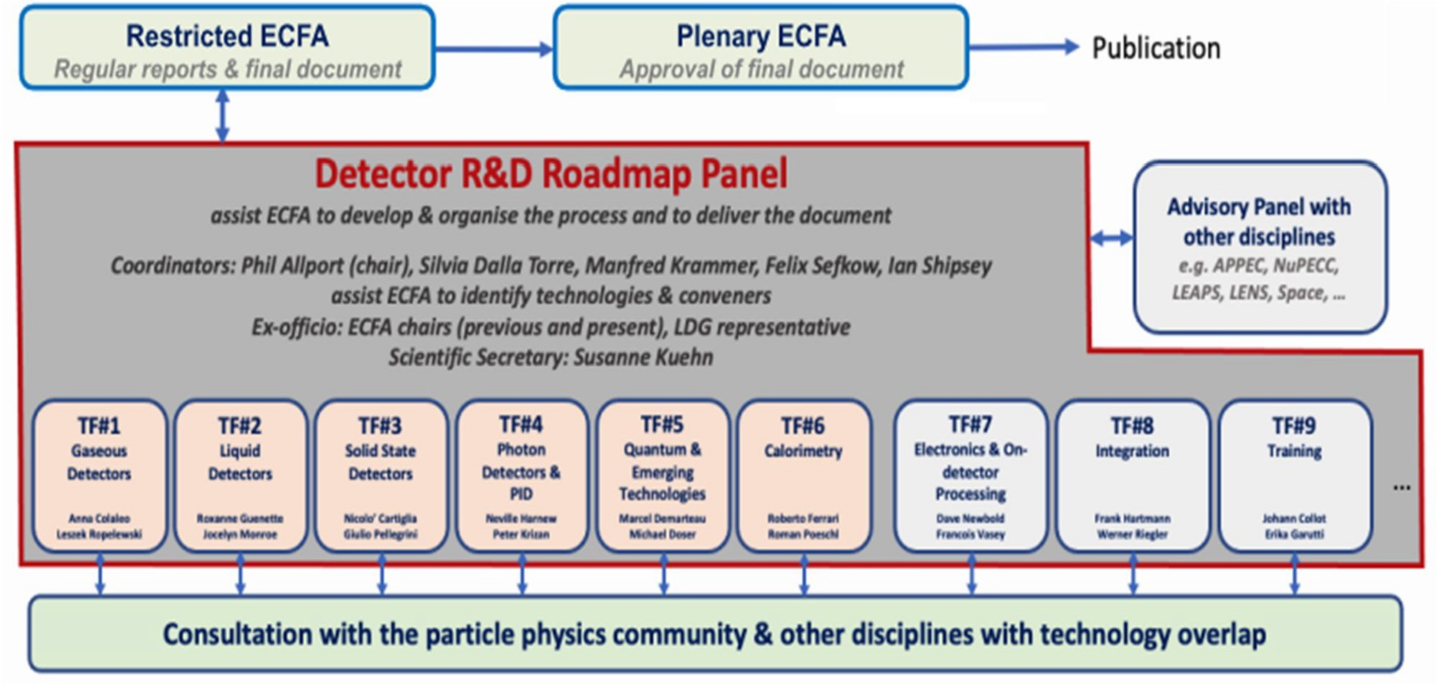




Detector Research and Development – DRD
international collaborations anchored at CERN: implementation

ECFA Detector R&D Roadmap

Full document



ECFA Detector Panel Members

International MUON Collider Collaboration

EDP Home / Members /

Members

Detector Panel Members

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

Snowmass process → P5 Town Hall

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Instrumentation Frontier Topical Groups

Quantum Sensors (IF01)
Photon Detectors (IF02)
Solid State Detectors and Tracking (IF03)
Trigger and DAQ (IF04)
Micro Pattern Gas Detectors (IF05)
Calorimetry (IF06)
Electronics/ASICS (IF07)
Noble Elements (IF08)
Cross Cutting and System Integration (IF09)
Radio Detection (IF10)

Input documents:

- DOE Detector R&D BRN Report
- 2021 ECFA Detector R&D Roadmap

Summary Report: arXiv:2209.14111

A strong need for much increased technology development, in preparation for the next big step in facilities and experiments while we exploit the ones we are currently developing/building

Snowmass process ➔ P5 Town Hall

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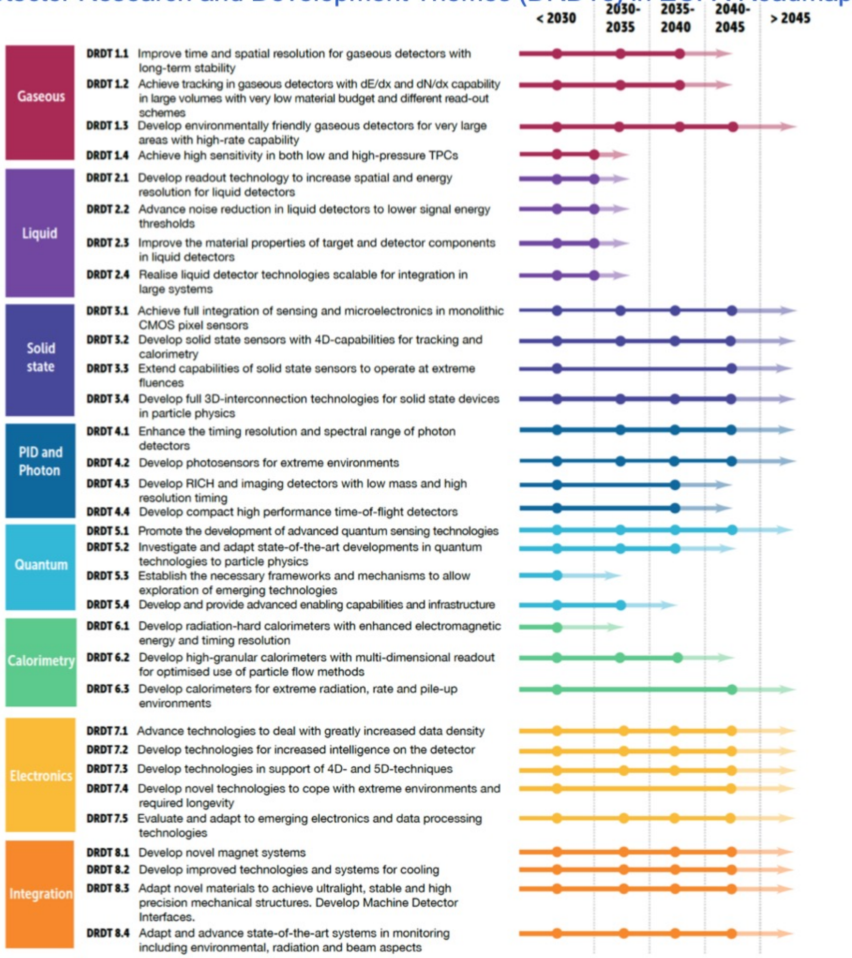
Exciting Technology Challenges Ahead

Priority Research Directions (PRDs) in BRN Report

	PRD: Priority Research Direction	Grand Challenge
Calorimetry	PRD 1: Enhance calorimetry energy resolution for precision electroweak mass and missing-energy measurements	1
	PRD 2: Advance calorimetry with spatial and timing resolution and radiation hardness to master high-rate environments	1,4
	PRD 3: Develop ultrafast media to improve background rejection in calorimeters and particle identification detectors	1,3,4
Nobles	PRD 4: Enhance and combine existing modalities to increase signal-to-noise and reconstruction fidelity	1,2
	PRD 5: Develop new modalities for signal detection	1
	PRD 6: Improve the understanding of detector microphysics and characterization	1
Photodetectors	PRD 7: Extend wavelength range and develop new single-photon counters to enhance photodetector sensitivity	1,3
	PRD 8: Advance high-density spectroscopy and polarimetry to extract all photon properties	2,3
	PRD 9: Adapt photosensors for extreme environments	2,4
	PRD 10: Design new devices and architectures to enable picosecond timing and event separation	1,2,4
	PRD 11: Develop new optical coupling paradigms for enhanced or dynamic light collection	1,2,3
Quantum	PRD 12: Advance quantum devices to meet and surpass the Standard Quantum Limit	1,3
	PRD 13: Enable the use of quantum ensembles and sensor networks for fundamental physics	1,2
	PRD 14: Advance the state of the art in low-threshhold quantum calorimeters	1,3
	PRD 15: Advance enabling technologies for quantum sensing	1,2,3
ASIC	PRD 16: Develop process evaluation and modeling for ASICs in extreme environments	3,4
	PRD 17: Create building blocks for Systems-on-Chip for extreme environments	1,4
SolidState	PRD 18: Develop high spatial resolution pixel detectors with precise high per-pixel time resolution to resolve individual interactions in high-collision-density environments	1,4
	PRD 19: Adapt new materials and fabrication/integration techniques for particle tracking	2,3
	PRD 20: Realize scalable, irreducible-mass trackers	2,3
TDAQ	PRD 21: Achieve on-detector, real-time, continuous data processing and transmission to reach the exascale	2,4
	PRD 22: Develop technologies for autonomous detector systems	2
	PRD 23: Develop timing distribution with picosecond synchronization	1
Xcut	PRD 24: Manipulate detector media to enhance physics reach	1,3
	PRD 25: Advance material purification and assay methods to increase sensitivity	1,2,3,4
	PRD 26: Addressing challenges in scaling technologies	2,3

Detector Research and Development Themes (DRDTs) in ECFA Roadmap



U.S. Detector R&D – CPAD

Coordinating Panel for Advanced Detectors

International MUON Collider Collaboration

Marina Artuso Syracuse University
@ P5 Town Hall Meeting BNL April 12, 2023

Planning Detector Research Consortia

To sign up go to More Information

RD	Topic	Mailing list	Current subscribers
RDC1	Noble elements Detectors	cpad_rdc1@fnal.gov	43
RDC2	Photodetectors	cpad_rdc2@fnal.gov	62
RDC3	Solid State Tracking	cpad_rdc3@fnal.gov	71
RDC4	Readout and ASICs	cpad_rdc4@fnal.gov	64
RDC5	Trigger and DAQ	cpad_rdc5@fnal.gov	28
RDC6	Gaseous Detectors	cpad_rdc6@fnal.gov	29
RDC7	Low-background detectors	cpad_rdc7@fnal.gov	38
RDC8	Quantum and Superconducting Sensors	cpad_rdc8@fnal.gov	62
RDC9	Calorimetry	cpad_rdc9@fnal.gov	46
RDC10	Detector Mechanics New		JUST ADDED

Picosecond timing across technologies consortium is under consideration

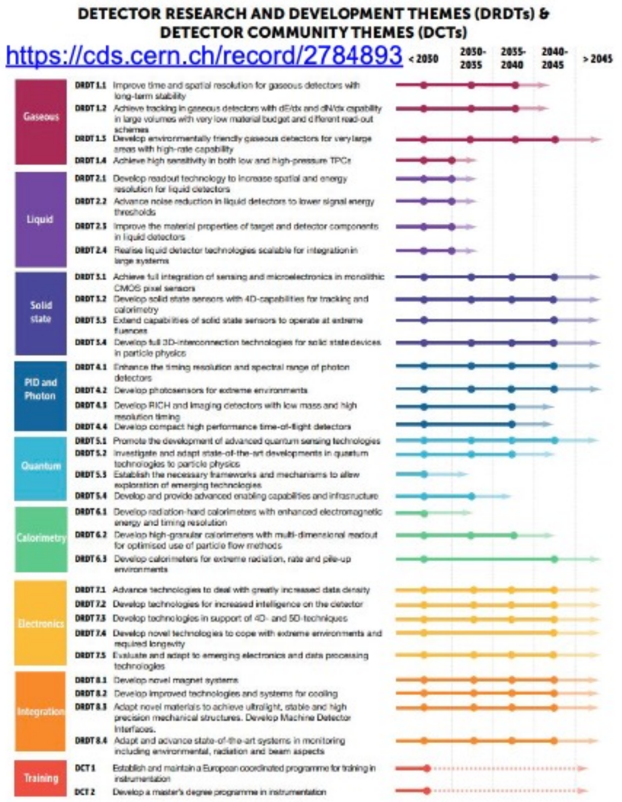
- Develop and maintain the critical and diverse technical workforce
- **Double the US Detector R&D budget over the next five years, and modify existing funding models to enable R&D consortia along critical key technologies for the planned long-term science projects, sustaining the support for such collaborations for the needed duration and scale.**

Instrumentation R&D

- DOE Detector R&D BRN Report, Snowmass Instrumentation Report – US;
- 2021 ECFA Detector R&D Roadmap – Europe.

ECFA initiative to establish new detector R&D “groups” (DRD”X”).
CPAD initiative planning new detector research consortia (RDC”X”).
The two initiatives closely connect in structure and objectives.

RD	Topic
RDC1	Noble elements Detectors
RDC2	Photodetectors
RDC3	Solid State Tracking
RDC4	Readout and ASICs
RDC5	Trigger and DAQ
RDC6	Gaseous Detectors
RDC7	Low-background detectors
RDC8	Quantum and Superconducting Sensors
RDC9	Calorimetry
RDC10	Detector Mechanics



ECFA detector R&D content

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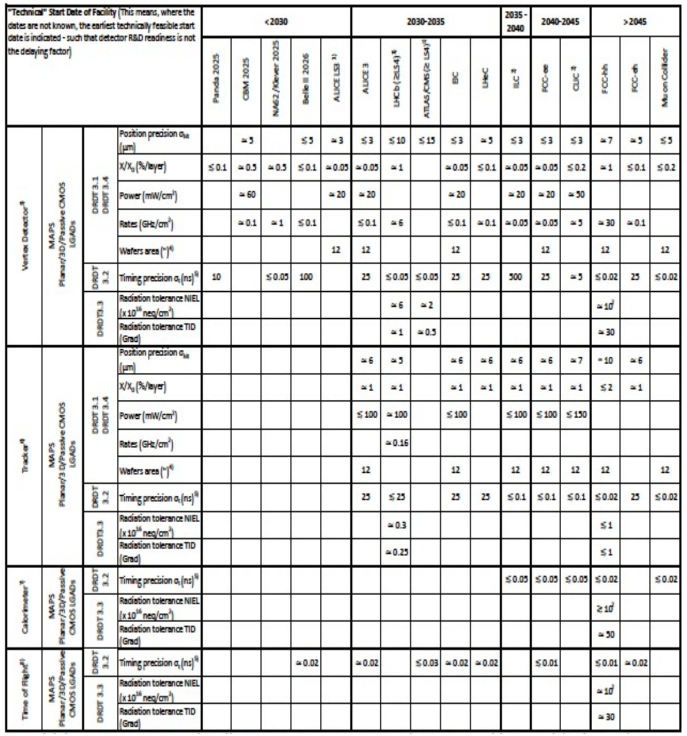
ball park performance targets → needs/benefits for physics reach → detector R&D Themes

ex. TF3 Solid State Detector
Systems and technology options



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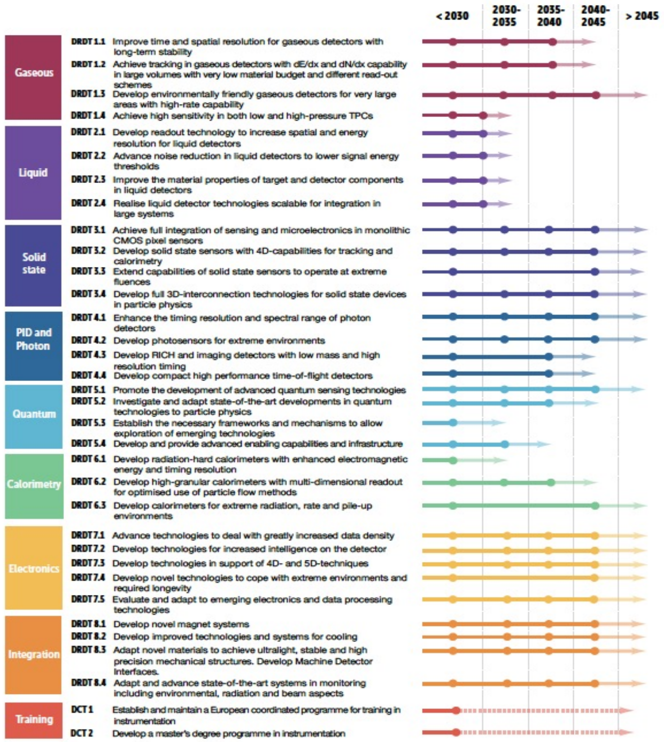


10 General Recommendations to achieve outlined goals, two about execution

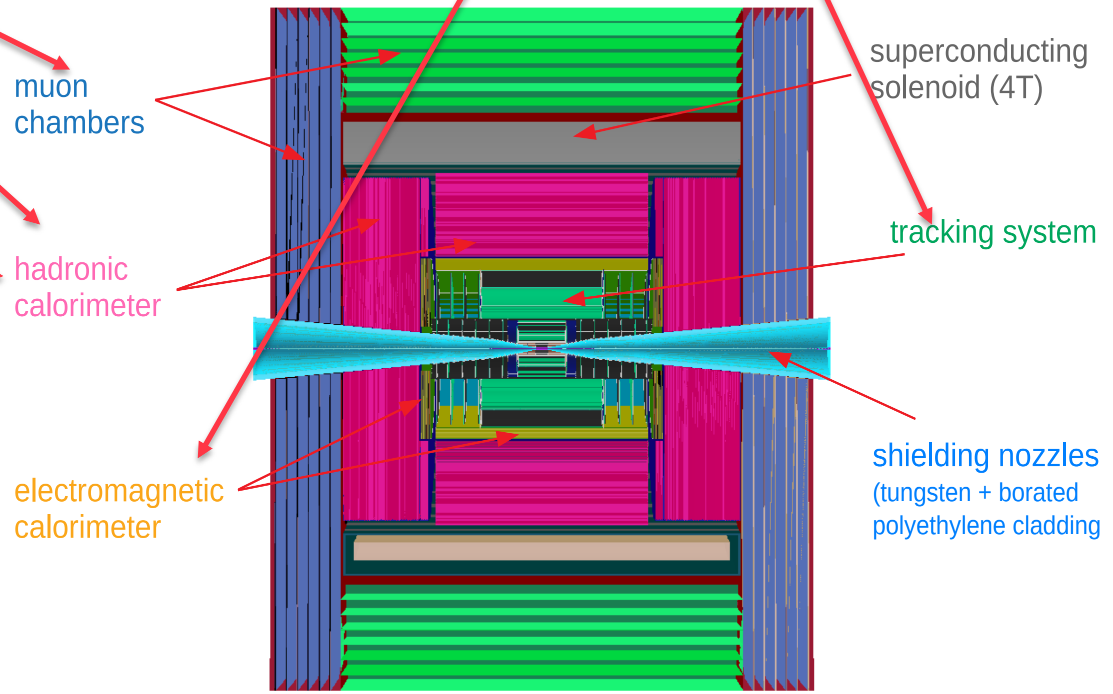
GR4: international coordination and organization of R&D activities

ensure red dots are fulfilled and orange achieved to the best by the program need-dates

GR6: establish long term strategic funding program

Detector Research and Development – DRD

- **DRD1 – Gaseous Detectors   <<==   RD5**
- **DRD3 – Solid State Detectors << == RD50-42**
- **DRD4 – Photon Detectors and PID**
- **DRD6 – Calorimetry**



- **DRD7 – Electronics and On-detector Processing   <<==   RD53**
- (DRD8 – Integration) ➔ not implemented – includes MDI – detector magnet
- (DRD9 – Training) ➔ included in others / Starting

- *DRD2 – Liquid Detectors*
- *DRD5 – Quantum and Emerging Technologies*

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Update ECFA roadmap

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- 200 days/year
- collision rate 100 kHz

"Technical" Start Date of Facility (This means, where the dates are not known, the earliest technically feasible start date is indicated - such that detector R&D readiness is not the delaying factor)				< 2030					2030-2035					2035 - 2040	2040-2045		> 2045		
				Panda 2025	CBM 2025	NA62/Klever 2025	Belle II 2026	ALICE LS3 [1]	ALICE 3	LHCb (≥LS4) [1]	ATLAS/CMS (≥ LS4) [1]	EIC	LHeC	ILC [2]	FCC-ee	CLIC [2]	FCC-hh	FCC-eh	Muon Collider
Vertex Detector [3]	MAPS Planar/3D/Passive CMOS LGADs	DRDT 3.1 DRDT 3.4	Position precision σ_{hit} (μm)		≃ 5		≲ 5	≃ 3	≲ 3	≲ 10	≲ 15	≲ 3	≃ 5	≲ 3	≲ 3	≲ 3	≃ 7	≃ 5	≲ 5
			X/X_0 (%/layer)	≲ 0.1	≃ 0.5	≃ 0.5	≲ 0.1	≃ 0.05	≃ 0.05	≃ 1		≃ 0.05	≲ 0.1	≃ 0.05	≃ 0.05	≲ 0.2	≃ 1	≲ 0.1	≲ 0.2
			Power (mW/cm^2)		≃ 60			≃ 20	≃ 20			≃ 20		≃ 20	≃ 20	≃ 50			
			Rates (GHz/cm^2)		≃ 0.1	≃ 1	≲ 0.1		≲ 0.1	≃ 6		≲ 0.1	≃ 0.1	≃ 0.05	≃ 0.05	≃ 5	≃ 30	≃ 0.1	
			Wafers area (") [4]					12	12			12			12		12		12
		DRDT 3.2	Timing precision σ_t (ns) [5]	10		≲ 0.05	100		25	≲ 0.05	≲ 0.05	25	25	500	25	≃ 5	≲ 0.02	25	≲ 0.02
		DRDT 3.3	Radiation tolerance NIEL ($x 10^{16}$ neq/cm^2)							≃ 6	≃ 2						≃ 10^2		
			Radiation tolerance TID (Grad)							≃ 1	≃ 0.5						≃ 30		
Tracker [6]	MAPS Planar/3D/Passive CMOS LGADs	DRDT 3.1 DRDT 3.4	Position precision σ_{hit} (μm)						≃ 6	≃ 5		≃ 6	≃ 6	≃ 6	≃ 6	≃ 7	≃ 10	≃ 6	
			X/X_0 (%/layer)						≃ 1	≃ 1		≃ 1	≃ 1	≃ 1	≃ 1	≃ 1	≲ 2	≃ 1	
			Power (mW/cm^2)						≲ 100	≃ 100		≲ 100		≲ 100	≲ 100	≲ 150			
			Rates (GHz/cm^2)							≃ 0.16									
			Wafers area (") [4]						12			12		12	12	12	12		12
		DRDT 3.2	Timing precision σ_t (ns) [5]						25	≲ 25		25	25	≲ 0.1	≲ 0.1	≲ 0.1	≲ 0.02	25	≲ 0.02
		DRDT 3.3	Radiation tolerance NIEL ($x 10^{16}$ neq/cm^2)							≃ 0.3							≲ 1		
			Radiation tolerance TID (Grad)							≃ 0.25							≲ 1		
Calorimeter [7]	MAPS Planar/3D/Passive CMOS LGADs	DRDT 3.2	Timing precision σ_t (ns) [5]											≲ 0.05	≲ 0.05	≲ 0.05	≲ 0.02		≲ 0.02
		DRDT 3.3	Radiation tolerance NIEL ($x 10^{16}$ neq/cm^2)														≳ 10^3		
			Radiation tolerance TID (Grad)														≃ 50		
Time of Flight [8]	MAPS Planar/3D/Passive CMOS LGADs	DRDT 3.2	Timing precision σ_t (ns) [5]				≃ 0.02		≃ 0.02		≲ 0.03	≃ 0.02	≃ 0.02		≲ 0.01		≲ 0.01	≃ 0.02	
		DRDT 3.3	Radiation tolerance NIEL ($x 10^{16}$ neq/cm^2)														≃ 10^2		
			Radiation tolerance TID (Grad)														≃ 30		

≲ 5
≲ 0.05
min possible
≈ 0.5
TBD best
≲ 0.03
≈ 0.1/y
≈ 0.1/y
7 tran / 90 long
0.2 total tracker
min possible
0.02
TBD best
≲ 0.06
≈ 0.01/y
≈ 0.001/y
< 0.2 arr / < 0.1 integ
≈ 0.05/y
≈ 0.0001/y

TOF not yet considered

Last reference paper: Towards a Muon Collider

Values are indicative of performance targets and of operating conditions relevant to R&D. The latter are reported for the regions most exposed to radiation. Empty cells indicate either that projects are not

Muon Collider Detector R&D

Solid-State Detectors (TF3/DRD3, RDC3)

- Radiation-hard silicon detectors with O(10ps) timing resolution
- Integrated or hybrid design

Calorimetry (TF6/DRD6, RDC9)

- High-granularity (transverse and longitudinal); good radiation hardness
- good timing resolution and low integration time (esp. ECAL)
- Scintillator or Silicon-based sampling; Crilin: semi-homogenous w/ SiPMs readout

Gaseous Detectors (TF1/DRD1, RDC6)

- Mostly Muon spectrometer: micromegas, GEM, etc.. focus on good timing resolution, sustainable gas mixtures

Photon-Detectors and PID (TF4/DRD4, RDC2)

- Less explored so far, but PID can offer additional physics oportunities

Electronics (TF7/DRD7, RDC4)

- Radiation-hard ASIC design (HL-LHC levels)
- Small feature size for more complex on-chip processing (tracker, calo?)

Trigger and DAQ (RDC5)

- Triggerless readout requires large real-time data handling

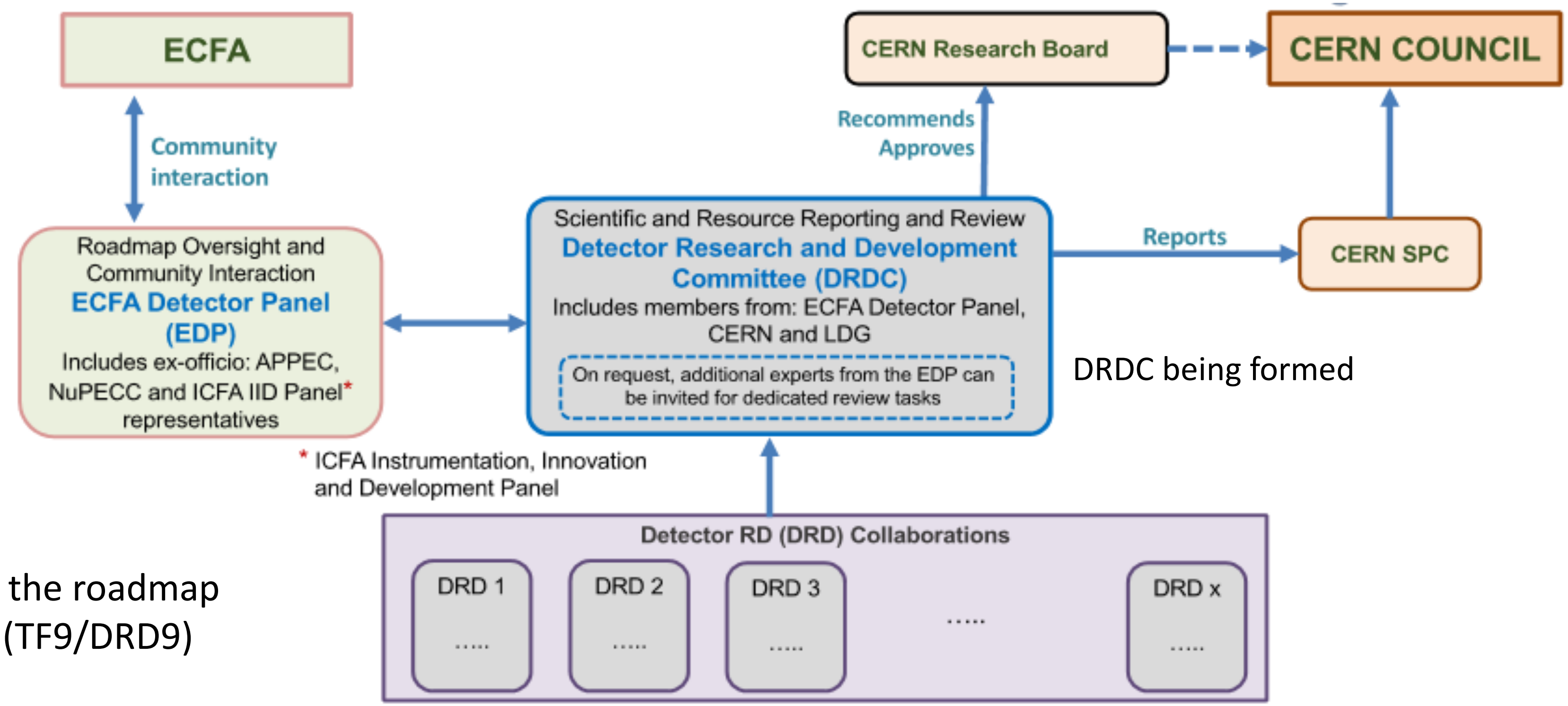
Detector Mechanics (RDC10)

- Lightweight structures, nozzle support design,

<u>Proposal</u> to implement the roadmap GR4 and GR6 approved by CERN Council Sep. 2022

form DRD international collaborations anchored at CERN with a status similar to experiments:
DRDC scientific review committee*, Funding Agency MoU agreements, Resources Review Board

EDP <u>hosted at DESY</u> : interface to experiments, vetting scope, goals & milestones, acting as expert members in DRDC



DRDC being formed

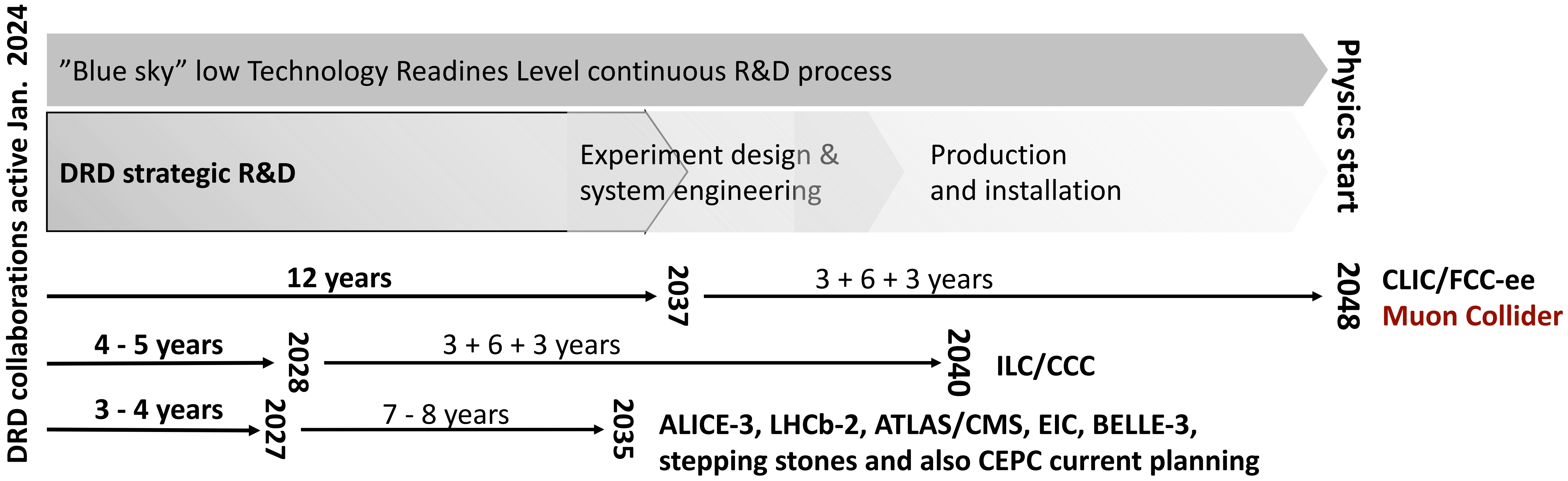
TFx/DRDx are areas identified by the roadmap
a coordination panel for training (TF9/DRD9)

DRD proposals to DRDC end-July 2023, collaborations active Jan. 2024, MoUs prepared/signed by FAs in 2024**

** Review frequency will de defined by the DRDC, it could typically be every 2 years*
*** TF7/DRD7 and TF5/DRD5 only LoI in July, full proposal end-2023 /beginning 2024, TF8/DRD8 possibly a forum under discussion*

Timeline considerations for DRD planning

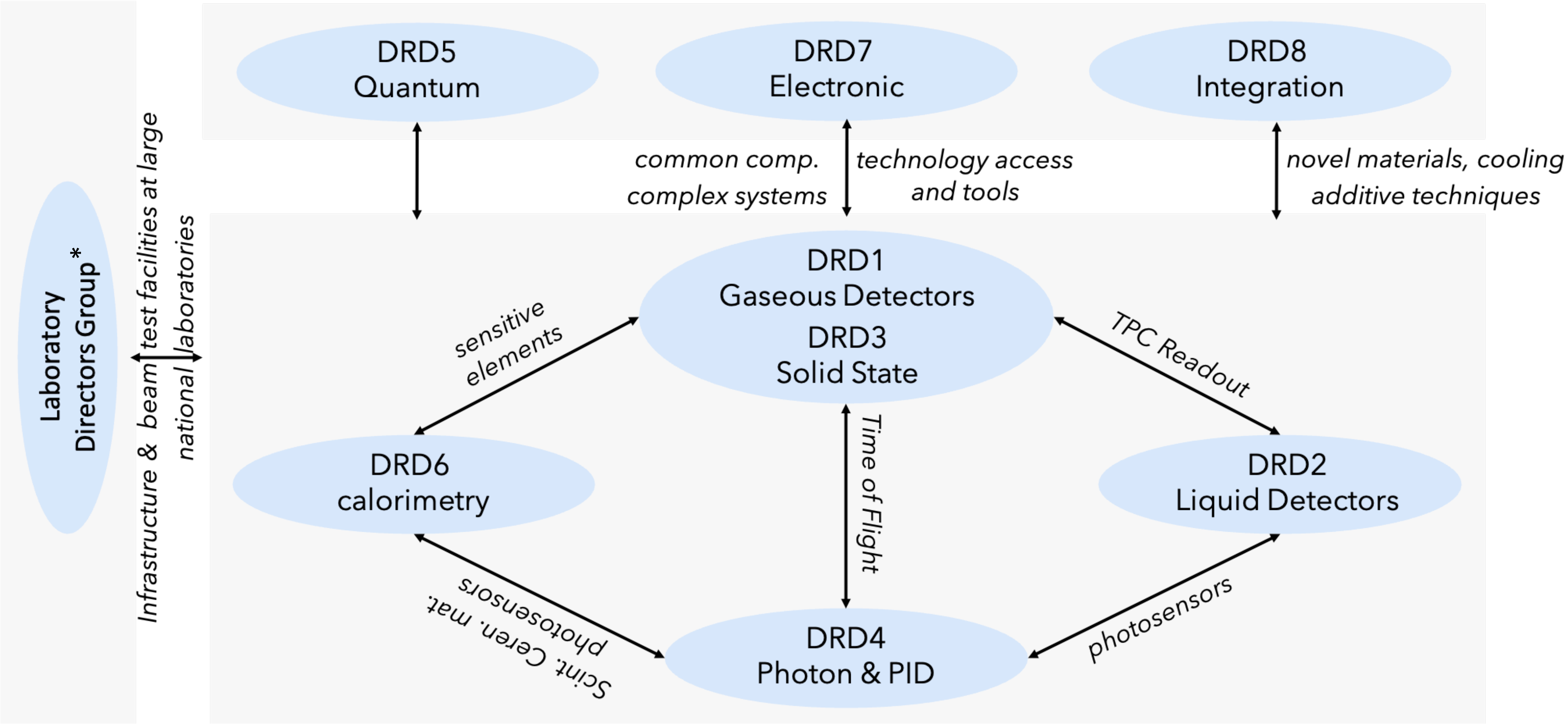
*when technical solutions must be handled to strategic projects**



** ballpark timelines for future colliders, smaller scale projects mostly upgrades of existing experiments with fixed LS4 timeline for HL-LHC*

Topical considerations to establish DRD planning

interplay between DRDs



direct the community contributions to Work Packages and resources in proper DRD(s)

** LNF - Italy, STFC/Daresbury - UK, CIEMAT - DESY, Germany, STFC/RAL - UK , LNGS - Italy, F.CEA/Irfu – France, IJCLab – France, Nikhef - Netherlands, PSI - Switzerland*

DRD proposals scientific content

technology Work Packages planning
deliverables - milestones

transverse activities planning
simulation/characterization tools, beam test facilities, industrial partnership, dissemination & networking

Work Packages & technology options

DRD3.1 Monolithic CMOS	Phase-1: sensors with 3 µm position precision, sensors with timing precision 20 ps, readout architectures for 100 MHz/cm^2, radiation tolerance 10^16 neq/cm^2 NIEL and 500 MRad						Phase-2: 4D tracking <3 µm and <20 ps precisions, O (1) GHz/cm^2 rates		Phase-3: 4D tracking <1 µm and <10 ps precisions, O(50) GHz/cm^2 rates, radiation tolerance 10^18	
Timeline	2024	2025		2026	2027-28		2029-2034		≳ 2035	
Work Packages	Deliverable	Deliverable	Milestones MPW1.1	Deliverable	Deliverable	Milestones MPW1.2 MPW1.3	Deliverable	Milestones	Deliverable	Milestones
WP1 position precision technology and design parameters	preprare MPW1.1 submit MPW1.1	preprare MPW1.2 qualify MPW1.1	M1 Q4-2025 establish position precision versus pitch, sensor active thickness and readout mode (digital/binary)	submit MPW1.2 qualify MPW1.2	preprare MPW1.2 qualify MPW1.1	M5 handle technical opions for ALICE-3, LHCb, BELLE-3, IEC VD, CT, TL engineering runs M6 deliver SoA sensors for beam area infrastrcuture M7 deliver SoA sensors for DRD6 HGCal protoypes	technology nodes ≲ 65 nm wafer size ≳ 12'' 3D interconnection non Si-materials	handle technical options for lepton colliders (ILC, C3, CLIC, FCC-ee, MC)	technology nodes ≲ 16 nm wafer size ≳ 12'' 3D interconnection non Si-materials	handle technical options for hadron colliders
Technology 1	specifications MWP1.1	specifications MWP1.2			specifications MWP1.3					
...										
Technology n										
WP2 timing precision technology and design parameters	preprare MPW1.1 submit MPW1.1	preprare MPW1.2 qualify MPW1.1	M2 Q4-2025 establish timing precision versus electrode size and pitch, sensor active thickness, w/o/ and w/ amplification	submit MPW1.2 qualify MPW1.2	preprare MPW1.2 qualify MPW1.1					
Technology 1	specifications MWP1.1	specifications MWP1.2			specifications MWP1.3					
...										
Technology n										
WP3 readout architecture features common to DRD7	preprare MPW1.1 submit MPW1.1	preprare MPW1.2 qualify MPW1.1	M3 Q4-2025 qualified IP blocks, optimised architecture for power dissipation in selected functions of WP1 - WP2	submit MPW1.2 qualify MPW1.2	preprare MPW1.2 qualify MPW1.1					
Technology 1	specifications MWP1.1	specifications MWP1.2			specifications MWP1.3					
...										
Technology n										
WP4 radiation tolerance	preprare MPW1.1 submit MPW1.1	preprare MPW1.2 qualify MPW1.1	M4 establish SoA radiation tolerance of different designs and technologies	submit MPW1.2 qualify MPW1.2	selected from WP1.2					
Technology 1	specifications MWP1.1	specifications MWP1.2			specifications MWP1.3					
...										
Technology n										
Interconnection and data transfer common to DRD3/DRD7	preprare prototypes for 3D integration									
Integration common to DRD3/DRD8	cooling systems, light mechanical designs, sytem prototypes									
Non-silicon materials common to DRD3/DRD7	qualify radiation tolerance									
Simulation and characterization common to DRD3	develop and test simulation models, develop tools and telescopes									

not contractual ex. Monolithic CMOS DRD3.1

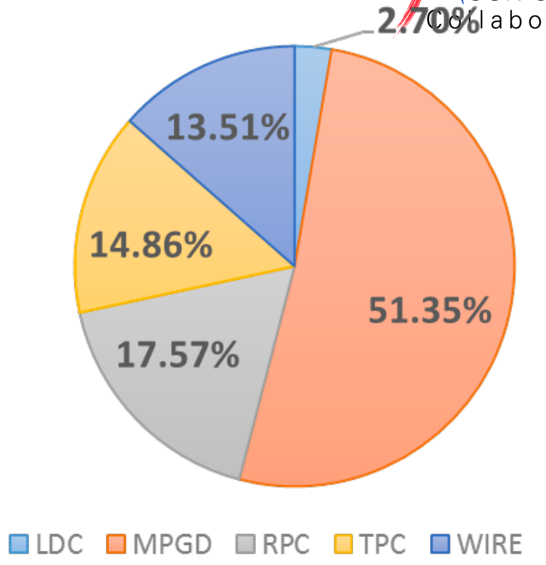
1st period typically 3-4 years
targeting stepping stone programs (slide 8)

previsions
toward longer term strategic projects

programs will evolve* with experiment requirements & R&D progress including blue sky growing TRL

DRD1 Gaseous Detectors program & community building status

conveners: Anna Colaleo, Leszek Ropelewski, 292 people registered



Organized in 8 working groups to develop the R&D program

- WG1 : technologies MPGDs, RPC, Wires, TPC, DCH
- WG2 : applications muon tracking and triggering, Central Tracking with PID, Photon Detection, ToF, High Granularity Calorimetry, TPC for rare event searches
- WG3 : gas and material studies
- WG5 : electronic components
- WG6 : detector production
- WG7 : common test facilities
- WG8 : training and dissemination

Detailed survey in each WG to assess community interests

- 74 contributions presented at 1st community meeting

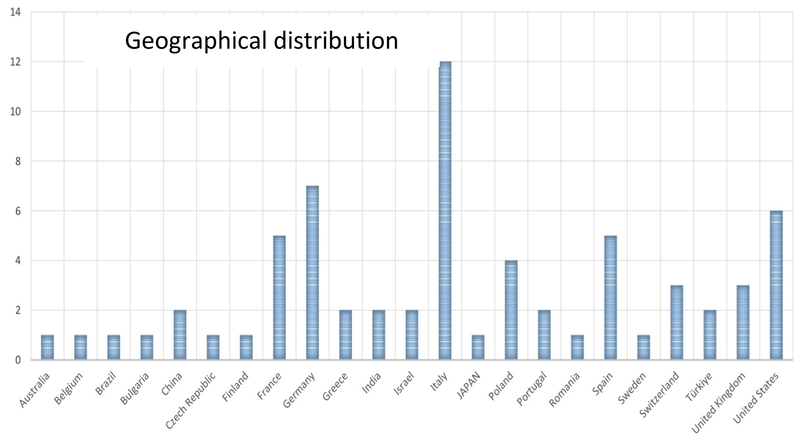
Planning of technology Work Packages (deliverable/milestones)

- on-going mapping of needs and aspirations of the community

Discussion of collaboration structure on-going

- proper arrangement of technology and transverse activities

DRD1 proposal draft at 2nd community meeting



Colors indicative of Technology areas versus transverse activities

DRD3 Solid State Detectors program & community building status

conveners: Nicolo Cartiglia, Giulio Pellegrini, 484 people registered

Organized in 8 working groups to develop the R&D program

- WG1 : Monolithic CMOS sensors
- WG2 : sensors for tracking and calorimetry (Hybrid, LGADs)
- WG3 : radiation damage and ultrahigh fluence
- WG5 : characterization techniques, facilities
- WG6 : non silicon based detectors
- WG7 : Interconnect and device fabrication
- WG8 : dissemination and outreach

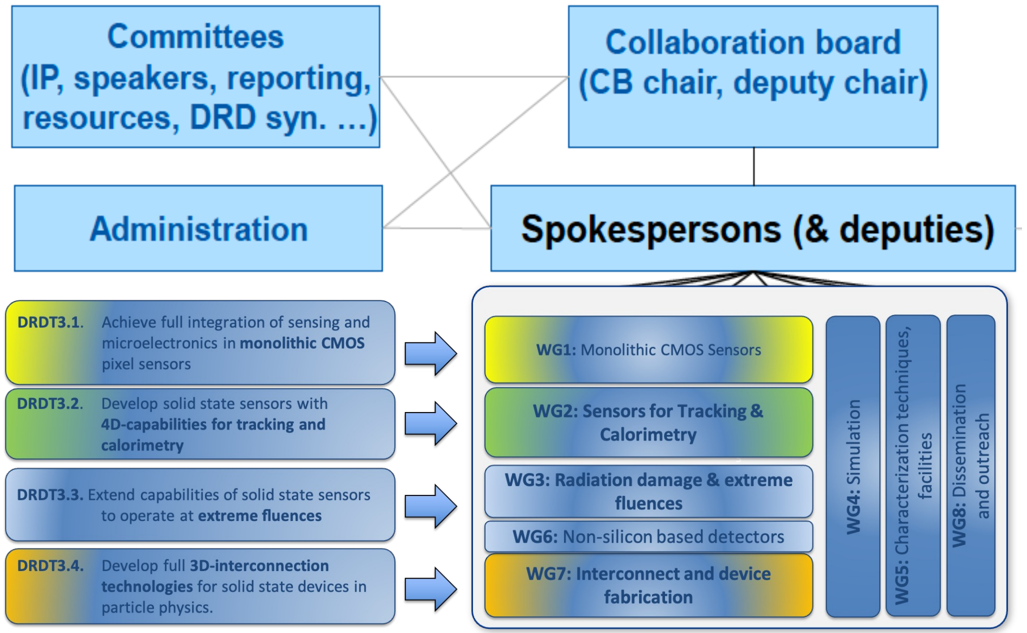
Survey to assess community interests

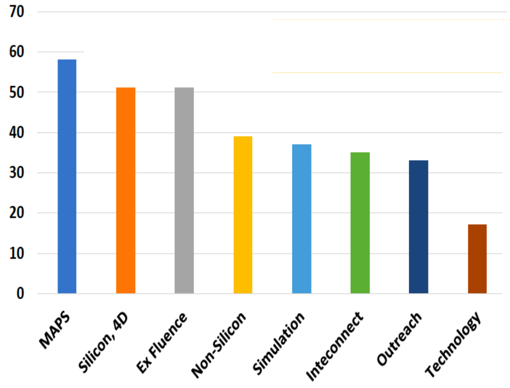
- 88 contributions presented at 1st community meeting

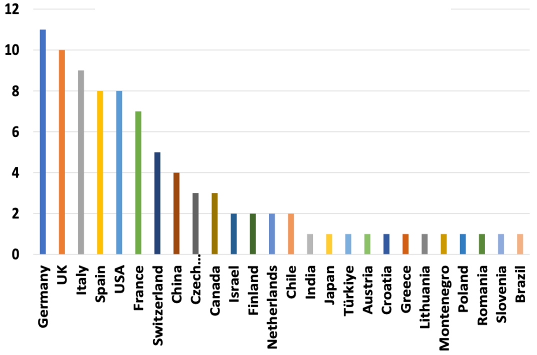
Planning of technology Work Packages (deliverable/milestones)

- on-going mapping of needs and aspirations of the community

DRD3 proposal draft beginning of June

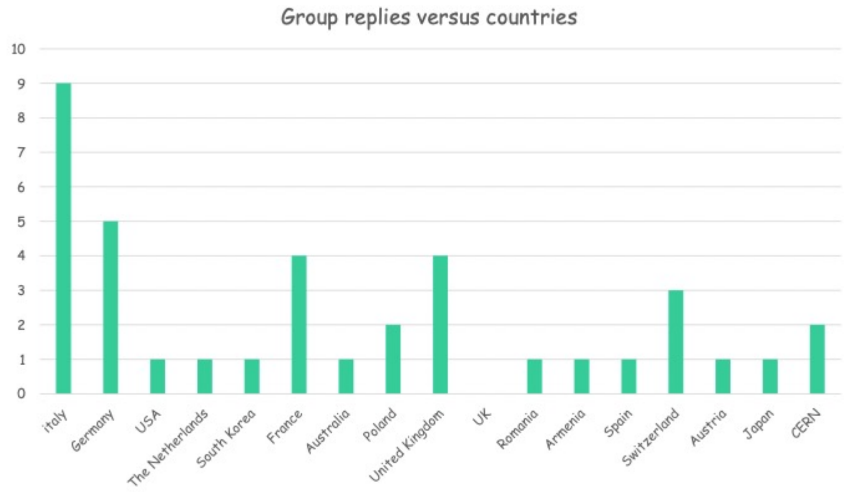






DRD4 Photon Detectors and PID program & community building status

conveners: Peter Krizan, Christian Joram, 217 people registered



4 Technology areas identified in coordination meeting

- WG1 : photodetector (SiPM, SPADs, PMT/MCP-PMT, Gas)
- WG2 : particle ID (RICH/DIRC/TOP,TORCH/ToF)
- WG3 : technologies (radiators, optical elements, readout, cooling, software)
- WG4 : emerging technologies (novel materials and concepts…)

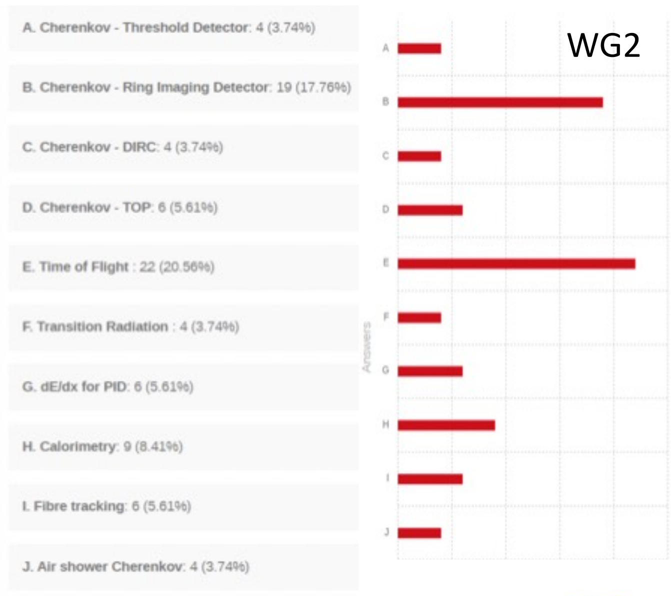
Survey to assess community interests

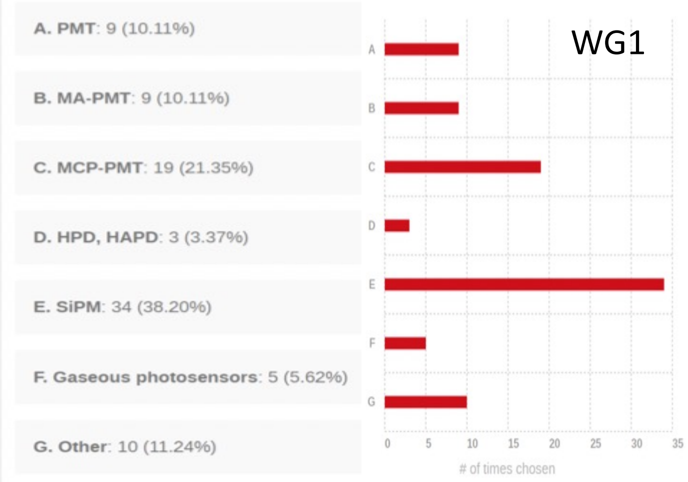
- 40 contributions

Planning of technology Work Packages (deliverable/milestones)

- 1st community meeting this week 16 – 17 May

DRD4 proposal draft end-June





DRD6 Calorimetry program & community building status

conveners: Roberto Ferrari, Roman Pöschl, 232 people registered

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Organized in 4 working groups to develop the R&D program (1st community meeting)

- WG1 : full integrated sampling calorimeters
- WG2 : liquified Noble Gas calorimeters
- WG3 : optical calorimeters
- WG4 : transverse activities

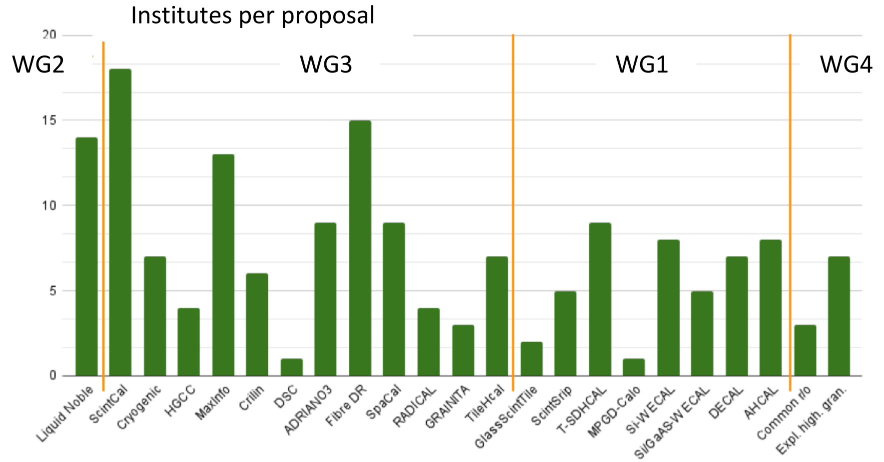
Survey to assess community interests

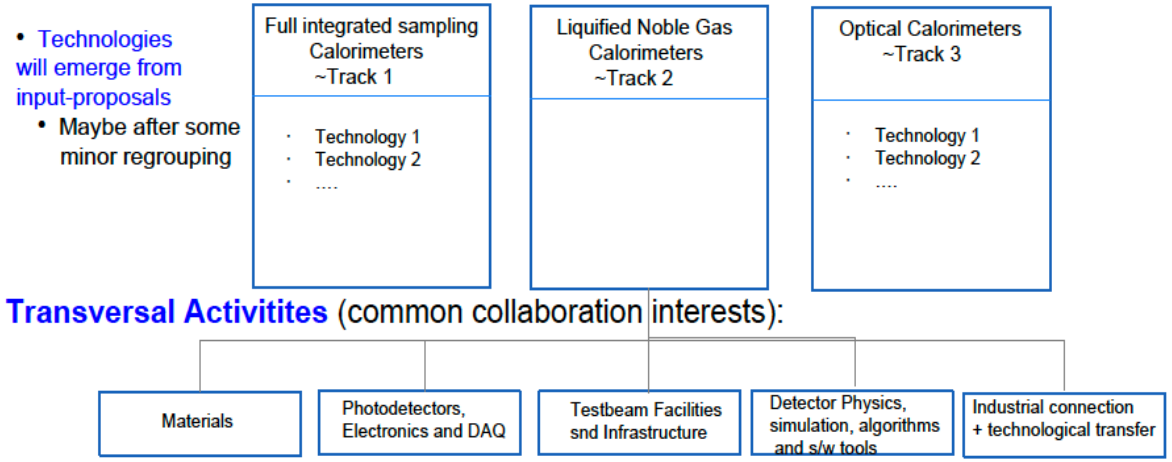
- 23 contributions, 110 institutes, presented at 2nd community meeting

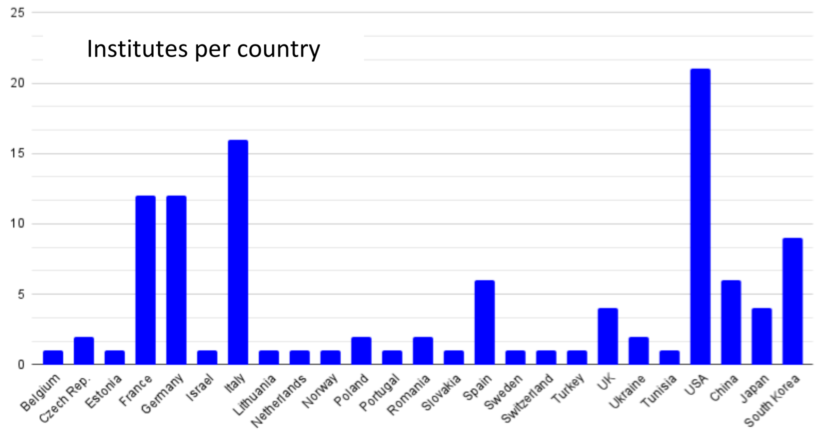
Planning of technology Work Packages (deliverable/milestones)

- on-going mapping of needs and aspirations of the community

DRD6 proposal draft beginning of June

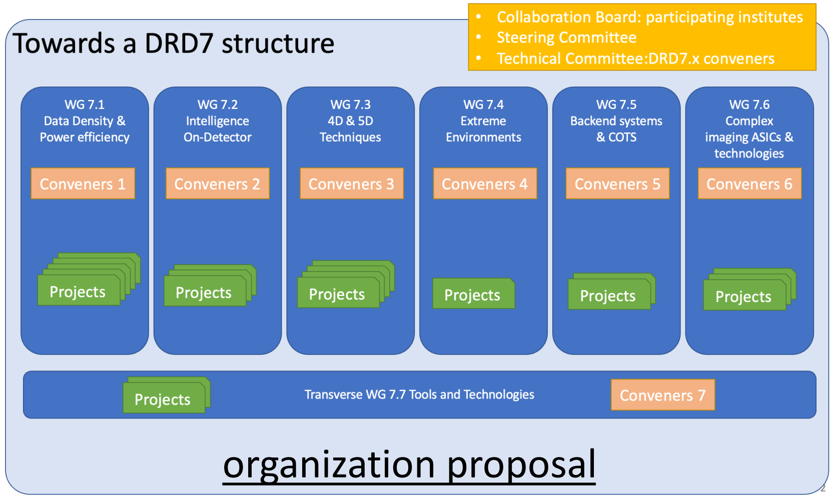






DRD7 electronics and on-detector processing program & community building status

conveners: Francois Vasey, Dave Newbold, 183 people registered



Technology areas identified at 1st community workshop

- WG1 : data density and power efficiency
- WG2 : intelligence on the detector
- WG3 : 4D and 5D techniques
- WG4 : extreme environments
- WG5 : backend systems and cots
- WG6 : complex imaging ASICs and technologies
- WG7 : provision access to tools and technologies (vendors)

Interaction with other DRDs

- DRDs provide specification, planning, production and characterisation of prototypes with relevant RH and funding
- DRD7 review specifications and designs, develop and provision common IP, components, and subsystems, deliver common, generic, complete components / systems, when big or complex

Work organisation proposal being investigated

- Tiered/platform structure of competences (with appropriate sharing of human resources with other DRDs)

Next steps

- May-June collect expressions of interest in specific projects, define common plans and interface to other DRDs
- July DRD7 LoI indicating broad scope, composition and resource needs scale
- September 2nd community workshop to discuss Work Packages
- December proposal submitted to DRDC including resources

Step forward - synergies

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- ✓ A lot of work to discuss proposals, organize strategic R&D, mantaing resources for blue-sky R&D
- ✓ Different level of maturity in each DRD
- ✓ The milestones will be shared so each institute can still commit for contributions
- ✓ Needed existing/missing infrastructures are under survey at DRD and institutes/national laboratories level
- ✓ Strong synergies among present upgrading and future projects to be exploited for R&D on common technologies

Thanks to Didier Contardo for the discussions and slides

Overall process and timeline to form the DRD collaborations*

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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.

** Presentation of K. Jakobs at the SPSC on Sept. 27, 2022 (private communication)*

DRD proposals resources and organization structure

demonstrate programs can reasonably be achieved

Public documents will contain:

- list of institutes willing to contribute to each WP
- scale of human and funding resources required to achieve each WP
- management, committees and working group organization

Confidential material on resources in support of programs will be submitted to the DRDC

- sum of resources (HR and funding) currently expected to be available
- sum of new strategic resources sought
- initial money matrix of contributions per Funding Agency

It is expected that institutes will have entered into negotiations with their Funding Agency to ensure that the assumptions on additional strategic support can be considered (although not guaranteed before MoU 1st agreements*)

- *it is foreseen that MoUs will be regularly updated as the R&D programs evolve (with a frequency to be agreed between CERN and Fas)*

Plans for training (TF9)

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The conclusions of the detector R&D roadmap document (https://cds.cern.ch/record/2784893) explicitly stress the need to train and maintain a work force in instrumentation for particle physics, targeting, with the highest priority, graduate students and Early Career Researchers (ECR). One of the two "Detector Community Themes" (DCTs) that emerged from the deliberations of the training task force (TF9), calls for the **creation of a dedicated panel in this area under the auspices of ECFA**, in consultation with organisations or communities representing neighbouring disciplines and ICFA. The role of this coordination panel would primarily be to enhance the synergies between existing training programmes and stimulate the creation of complementary ones where relevant, in particular multidisciplinary schools or academia-industry-joined training programmes. The second equally important DCT sets out as a goal the creation of a European master's degree programme in HEP instrumentation, to also be a potential responsibility of this proposed panel to help coordinate.

During the roadmap process it realised that there was a mutual interest to also involve training in accelerators and to support cross-disciplinary activities with this area. As a result, the recommendations state that the same panel should also coordinate the synergies between HEP instrumentation and accelerator training provision.

→ ECFA Training Panel

The membership of this panel could encompass that of the detector roadmap R&D TF9 group, plus one more expert on training in accelerators, plus a representative of ICFA, a representative of APPEC, a representative of NuPECC and a representative of the ECFA ECR Panel.

** Presentation of K. Jakobs (ECFA Chair) at the SPSC on Sept. 27, 2022 (private communication)*

DRD collaboration proposal preparation

under ECFA roadmap panel (slide 3), with TF experts and existing program conveners*

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- TF1/DRD1 Gaseous Detectors https://indico.cern.ch/event/1214405/
- TF2/DRD2 Liquid Detectors https://indico.cern.ch/event/1214404/
- TF3/DRD3 Solid State Detectors https://indico.cern.ch/event/1214410/
- TF4/DRD4 Photon Detectors and PID https://indico.cern.ch/event/1214407/
- TF5/DRD5 Quantum and Emerging Technologies https://indico.cern.ch/event/1214411/
- TF6/DRD6 Calorimetry https://indico.cern.ch/event/1213733/
- TF7/DRD7 Electronics and On-detector Processing https://indico.cern.ch/event/1214423/
- TF8/DRD8 Integration https://indico.cern.ch/event/1214428/
- TF9/DRD9 Training https://indico.cern.ch/event/1214429/

Wide consultation with the community**, workshops & surveys to establish program & contributions

** ex. current CERN RD which mandate end end-2023 and will become part of the new wider scope DRD collaborations:*
RD51 (MPGDs) in TF1/DRD1, RD50 (radiation hard semiconductors) & RD42 (diamond) in TF3/DRD3, RD18 (crystals) in TF4/DRD4 and TF6/DRD6

*** Subscription to follow the process and to contribute at the links*

DRD2 Liquid Detectors program & community building status

conveners: Roxanne Guenette, Jocelyn Rebecca Monroe, Ian Shipsey, 168 people registered

Technology areas identified in coordination meeting

- WG1 : charge readout
- WG2 : light readout
- WG3 : target properties
- WG4 : scaling-up

Planning of technology Work Packages

- 1st community meeting

Survey to assess community interests and WP deliverables/milestones on-going

DRD2 proposal draft early-June

WPs	WG1	WG2	WG3	WG4
	1.1: Pixels	2.1: Increased sensor QE	3.1: Doping & isotope loading	4.1: Radiopurity & bkg mitigation
	1.2: Electroluminescence & charge amplification	2.2: WLS & increasing light collection	3.2: Purification	4.2: Detector & target procurement/production
	1.3: Dual (charge + light)	2.3: Improved sensors for LS/Water	3.3: Light emission & transport	4.3 Large-area readout
	1.4: Charge to light		3.4: Microphysics & characterization	4.4: Material properties
	1.5: Ion detection			

DRD5 Quantum and emerging technologies program & community building status

conveners: Michael Doser, Marcel Demarteau, Ian Shipsey, 164 people registered

Proposal to organize WGs define in expert workshop Apr.

- WG1 : clocks, clock networks
- WG2 : kinetic detector
- WG3 : superconducting spin based sensors
- WG4 : optomechanical sensors
- WG5 : atoms, molecules, ions, interferometry
- WG6 : meta materials 0-1-2D materials

Next steps

- circulate minutes of workshop with seeds of Work Package
- circulate white paper to organise WGs
- July submit LoI to DRDC with initial projects and resource needs scale
- September 1st community meeting to tune WP proposal
- January 2024 submit proposal to DRDC

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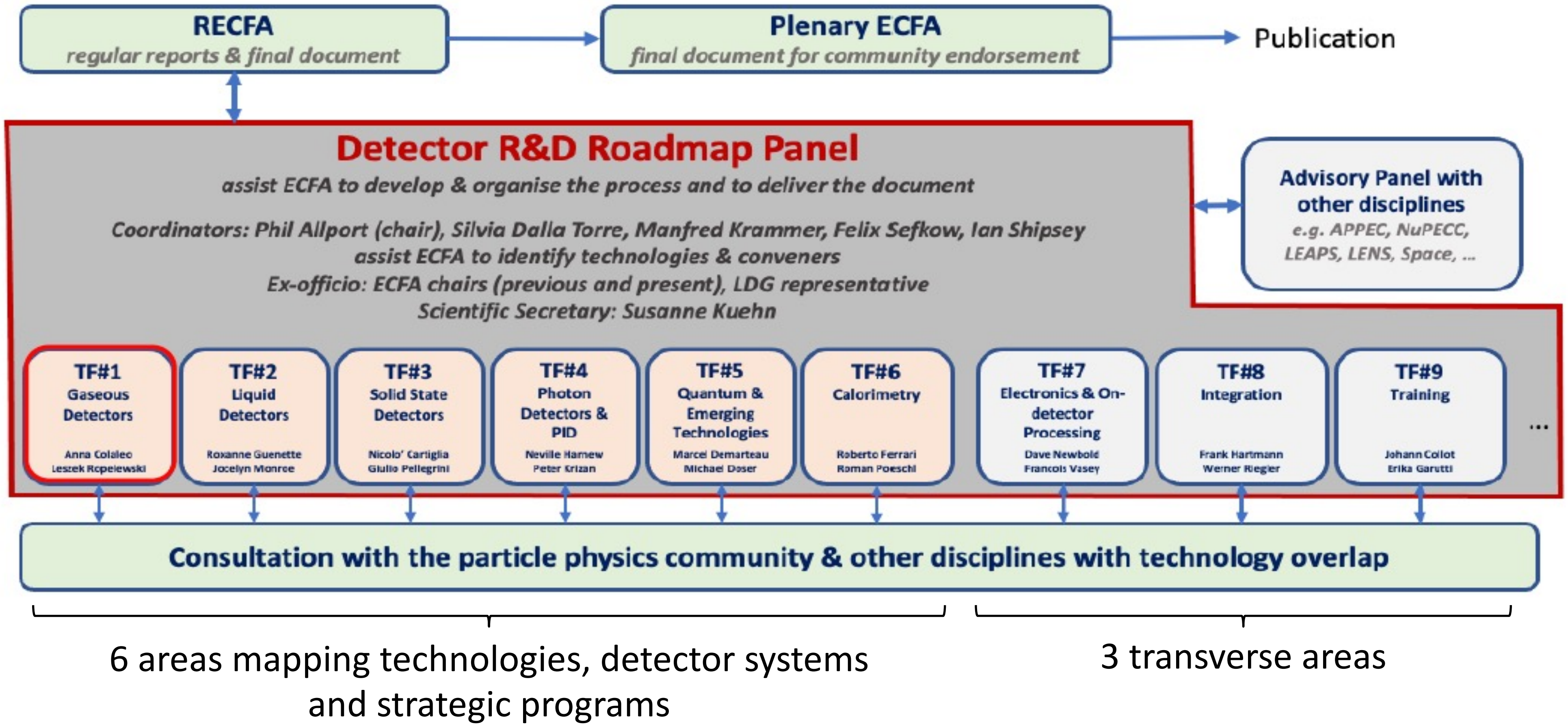
extras

ECFA detector R&D roadmap preparation

9 Task Forces organizing wide consultation of the community* through questionnaires and symposia**



* Nuclear Physics and AstroParticle (including Gravitational Wave) not considered in the roadmap, but NuPPEC and ApPEC invited to follow the process, also joint ECFA - NuPECC - ApPEC seminars in 2019 - 2022 to develop common instrumental projects

** great source of information on requirements for future experimental programs and State or the Art detector R&D, also US CPAD workshop 2022

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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

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, for example in cooperation with the ICFA Instrumentation Panel.

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.