Detector technologies (my personal view)

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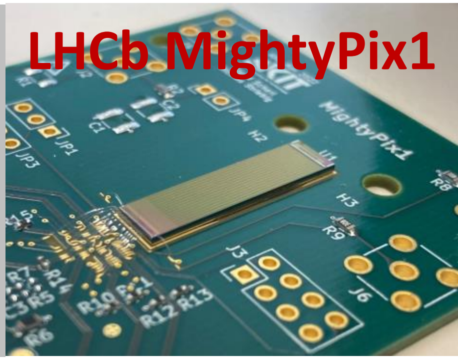
My background

Dr. Eva Vilella
UKRI Research Fellow
University of Liverpool

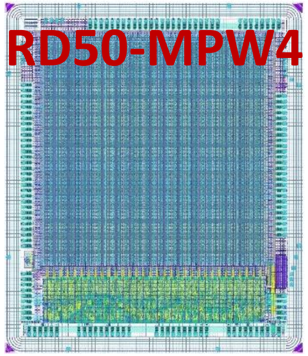
PhD @ Barcelona	2010 – 2013
PDRA @ Liverpool	2014 – 2019
Future Leaders Fellow @ Liverpool	2019 – now

- Mostly High Voltage CMOS sensors R&D (chip design and evaluation)
  - LHCb Mighty Tracker Upgrade
  - CERN-RD50 CMOS Working Group (ie generic R&D), which I started and lead
  - proton EDM
  - ATLAS ITk Upgrade
  - Mu3e



- For my PhD I worked on an avalanche photodiode sensor prototype
  - ILC
  - CLIC

  and developed IP for a readout chip for DEPFET sensors
  - Belle II



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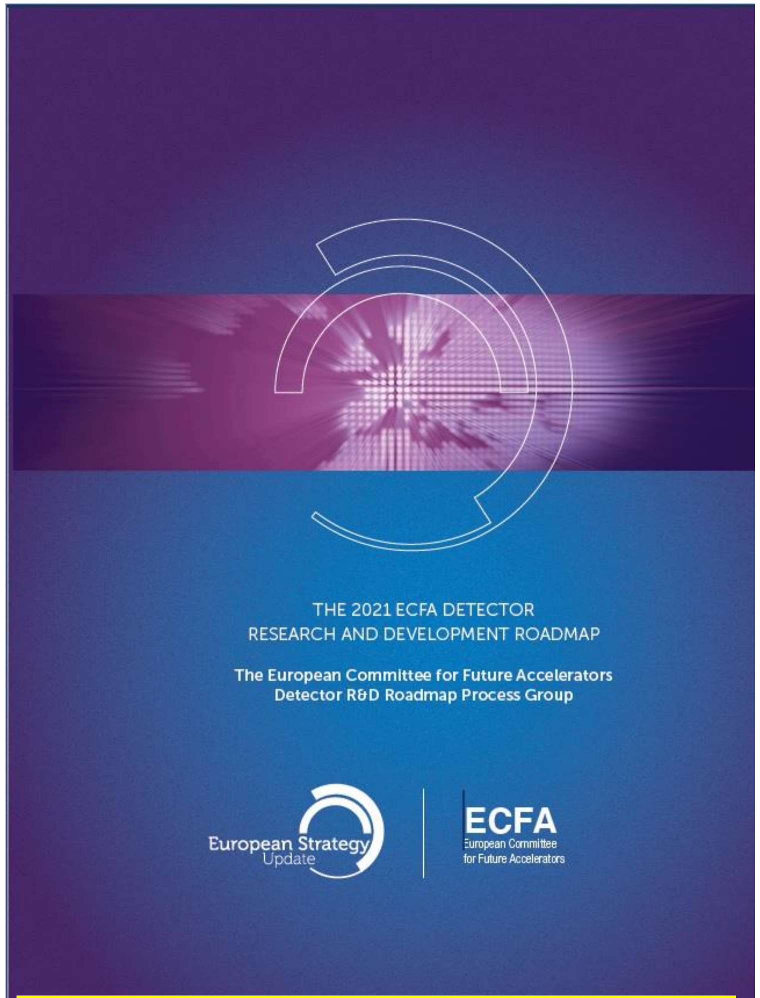
2021 ECFA Detector R&D Roadmap

- Developed by the community to balance the detector R&D efforts in Europe
- Highlighted the need for a new R&D phase in the form of Detector Research and Development (DRD) collaborations
- To enhance the performance of the particle physics programme in the near and long term



https://cds.cern.ch/record/2784893

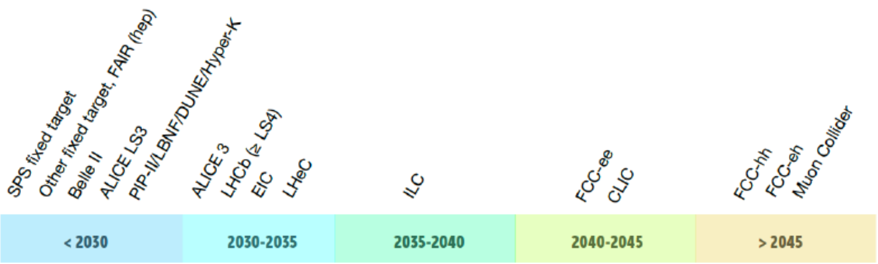
Detector Research and Development Themes (DRDTs)

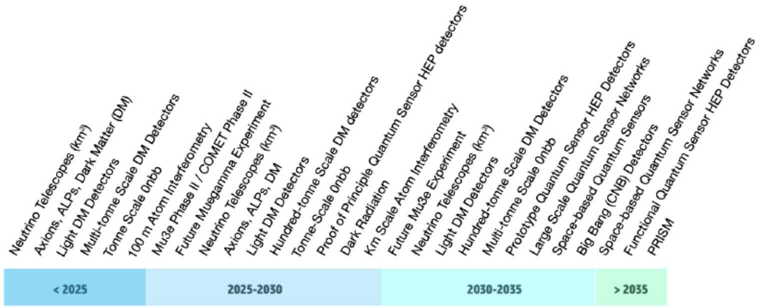
From 01.01.2024

- The roadmap identified several R&D themes
- Critical to achieve the scientific programme in the ESPP (European Strategy for Particle Physics)
- Derived from the technological challenges that need to be overcome for the scientific potential of the future facilities

Gaseous	DRDT 1.1	Improve time and spatial resolution for gaseous detectors with long-term stability
	DRDT 1.2	Achieve tracking in gaseous detectors with dE/dx and dN/dx capability in large volumes with very low material budget and different read-out schemes
	DRDT 1.3	Develop environmentally friendly gaseous detectors for very large areas with high-rate capability
	DRDT 1.4	Achieve high sensitivity in both low and high-pressure TPCs
Liquid	DRDT 2.1	Develop readout technology to increase spatial and energy resolution for liquid detectors
	DRDT 2.2	Advance noise reduction in liquid detectors to lower signal energy thresholds
	DRDT 2.3	Improve the material properties of target and detector components in liquid detectors
	DRDT 2.4	Realise liquid detector technologies scalable for integration in large systems
Solid state	DRDT 3.1	Achieve full integration of sensing and microelectronics in monolithic CMOS pixel sensors
	DRDT 3.2	Develop solid state sensors with 4D-capabilities for tracking and calorimetry
	DRDT 3.3	Extend capabilities of solid state sensors to operate at extreme fluences
	DRDT 3.4	Develop full 3D-interconnection technologies for solid state devices in particle physics
PID and Photon	DRDT 4.1	Enhance the timing resolution and spectral range of photon detectors
	DRDT 4.2	Develop photosensors for extreme environments
	DRDT 4.3	Develop RICH and imaging detectors with low mass and high resolution timing
	DRDT 4.4	Develop compact high performance time-of-flight detectors
Quantum	DRDT 5.1	Promote the development of advanced quantum sensing technologies
	DRDT 5.2	Investigate and adapt state-of-the-art developments in quantum technologies to particle physics
	DRDT 5.3	Establish the necessary frameworks and mechanisms to allow exploration of emerging technologies
	DRDT 5.4	Develop and provide advanced enabling capabilities and infrastructure
Calorimetry	DRDT 6.1	Develop radiation-hard calorimeters with enhanced electromagnetic energy and timing resolution
	DRDT 6.2	Develop high-granular calorimeters with multi-dimensional readout for optimised use of particle flow methods
	DRDT 6.3	Develop calorimeters for extreme radiation, rate and pile-up environments
Electronics	DRDT7.1	Advance technologies to deal with greatly increased data density
	DRDT7.2	Develop technologies for increased intelligence on the detector
	DRDT7.3	Develop technologies in support of 4D- and 5D-techniques
	DRDT7.4	Develop novel technologies to cope with extreme environments and required longevity
	DRDT7.5	Evaluate and adapt to emerging electronics and data processing technologies
Integration	DRDT 8.1	Develop novel magnet systems
	DRDT 8.2	Develop improved technologies and systems for cooling
	DRDT 8.3	Adapt novel materials to achieve ultralight, stable and high precision mechanical structures. Develop Machine Detector Interfaces.
	DRDT 8.4	Adapt and advance state-of-the-art systems in monitoring including environmental, radiation and beam aspects
Training	DCT 1	Establish and maintain a European coordinated programme for training in instrumentation
	DCT 2	Develop a master's degree programme in instrumentation

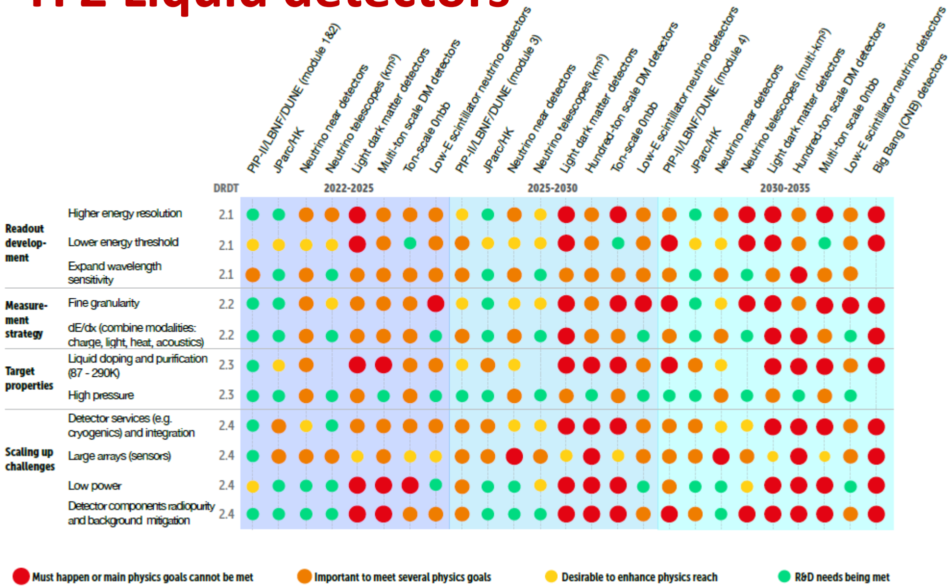
Experiments timeline and DRDTs technological challenges



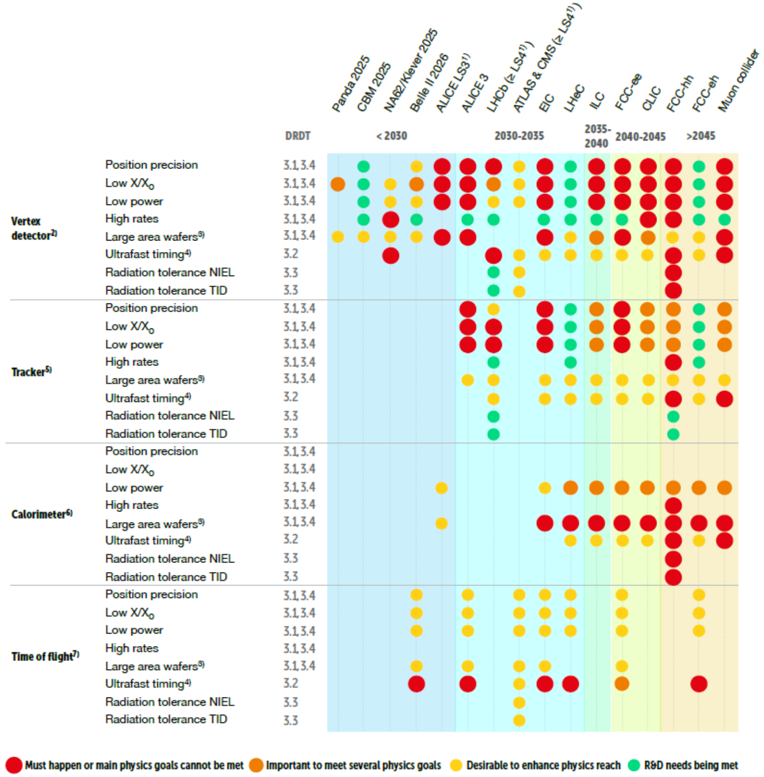


TF1 Gaseous detectors

TF2 Liquid detectors



TF3 Solid state detectors



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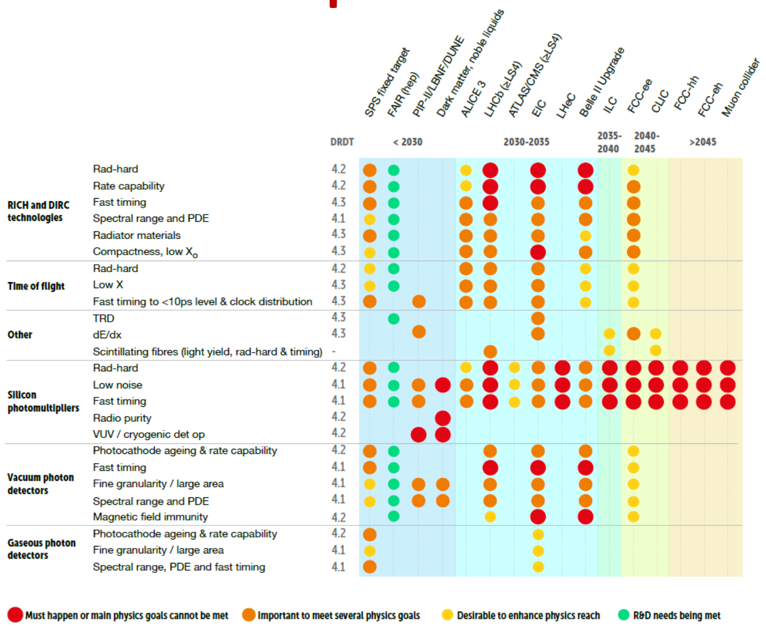
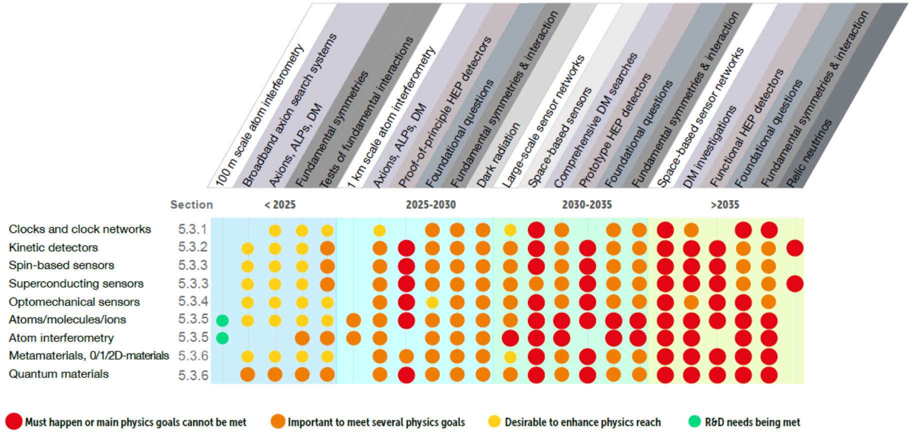
Experiments timeline and DRDTs technological challenges

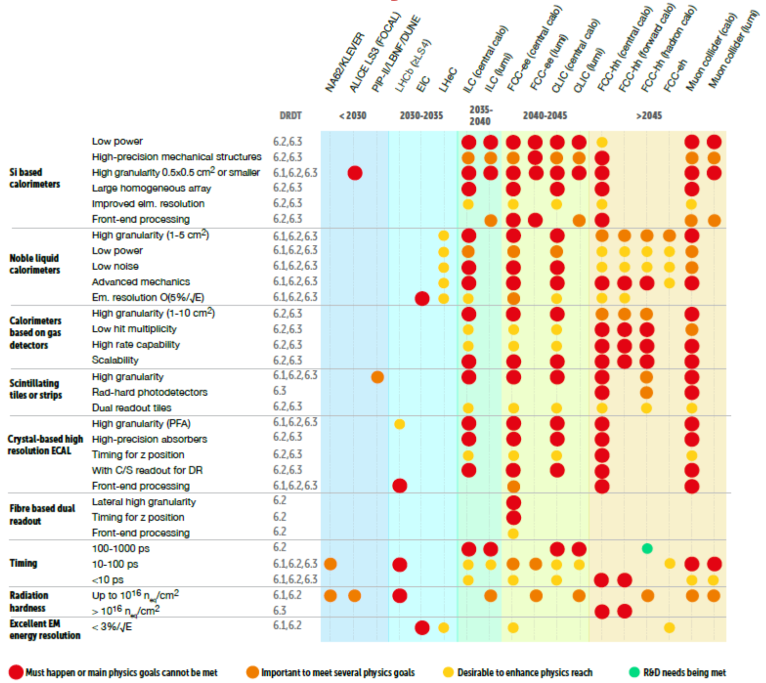
TF4 PID and photon



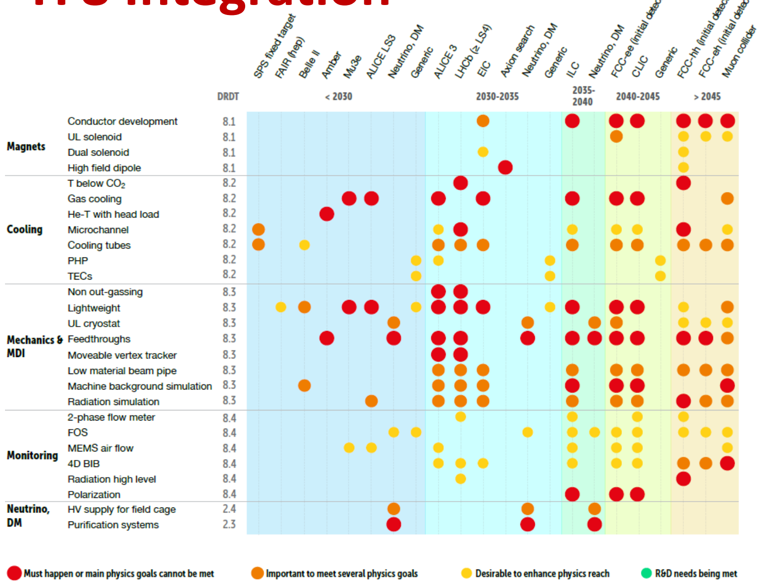
TF5 Quantum



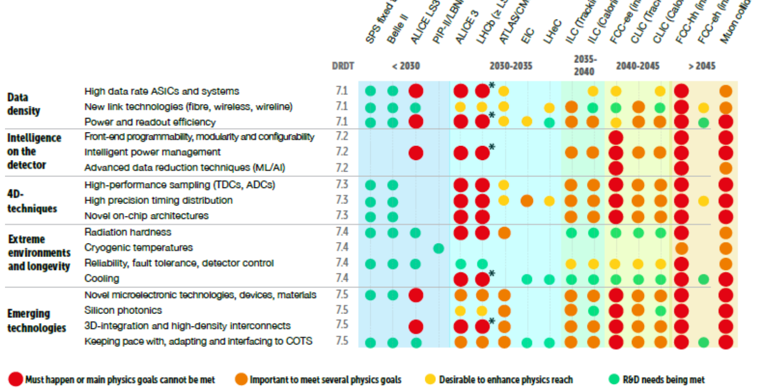
TF6 Calorimetry



TF8 Integration



TF7 Electronics



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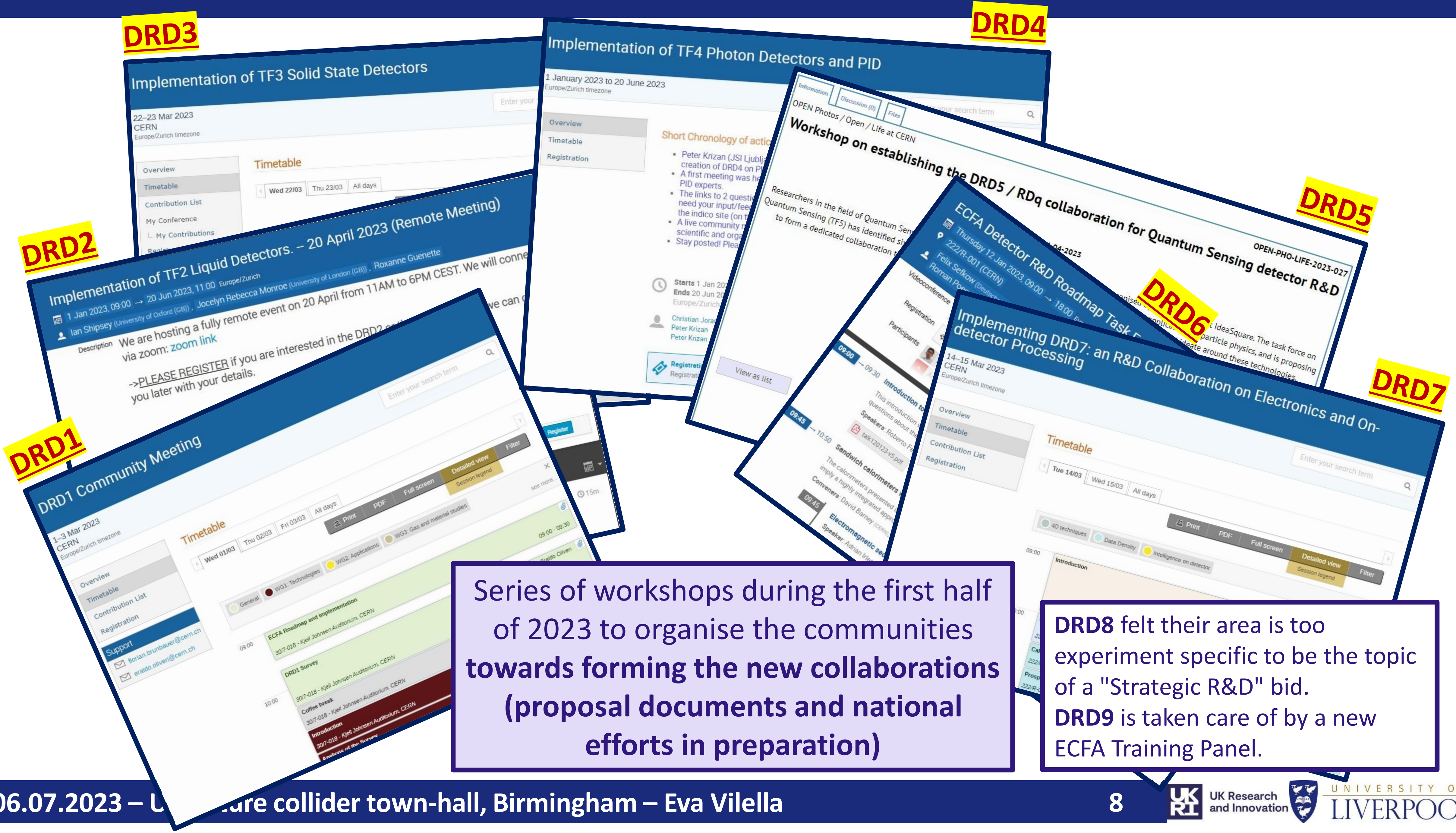
Solid state detectors (TF3) – An example

Challenging specifications
Staged R&D programme
Stepping stones

	"Technical" Start Date	< 2030			2030 -2035		2035 -2040	2040 - 2045			
		ALICE LS3	Belle II CBM	NA62	LHCb, ATLAS, CMS (≳ LS4)[7]	ALICE 3 - EIC	ILC	FCC-ee	CLIC		
MAPS	technology node[1]	65 nm - stitching	65 nm - stitching			28 nm		≲ 28 nm		≃ 10 nm	≲ 28 nm
	pitch	10 - 20 µm	10 - 20 µm			pitch ≲ 10 µm for σ_{hit} ≲ 3 µm in VD					
					Reduce z-granularity in TK - pad granularity in analog Cal.						
	wafer size[2]	12"	12"			12"					
	rate[3]		O(100) MHz/cm^2						5 GHz/cm^2	30 GHz/cm^2	
	ultrafast timing[4]				σ_t ≲ 100 ps					σ_t ≲ 20 ps	
	radiation tolerance				3 x 10^{15} neq/cm^2					10$^{18(16)}$ neq/cm^2 VD/Cal.(Trk)	
Planar/3D/Passive CMOS	technology node[1]				ASIC 28 nm	ASIC 28 nm		ASIC ≲ 28 nm		ASIC ≃ 10 nm	ASIC ≲ 28 nm
	pitch				≲ 25 µm in VD	≲ 10 µm for σ_{hit} ≲ 3 µm in VD					
					≲ 50 µm for σ_{hit} ≲ 10 µm in Trk						
	wafer size[2]					12"					
	rate[3]				6 GHz /cm^2					30 GHz/cm^2	
	ultrafast timing[4]			σ_t ≃ 50 - 100 ps		σ_t ≲ 100 ps				σ_t ≲ 20 ps	
	radiation tolerance				6 x 10^{16} neq/cm^2					10$^{18(16)}$ neq/cm^2 VD/Cal.(Trk)	
LGADs	technology node[1]						ASIC 28 nm	ASIC ≲ 28 nm		ASIC ≃ 10 nm	
	pitch			≃ 300 µm (100% fill facor)	≲ 50 µm (100% fill facor)	same as for other technologies with ultimate pitch ≲ 10 µm for σ_{hit} ≲ 3 µm in VD					
	wafer size[2]				> 3"	12"					
	rate[3]				6 GHz /cm^2					30 GHz/cm^2	
	ultrafast timing[4]				σ_t ≲ 30 ps	σ_t ≃ 20 ps (PID)	σ_t ≲ 20 ps VD/Trk/Cal.	σ_t ≲ 10 ps PID	σ_t ≲ 20 ps VD/Trk/Cal.	σ_t ≲ 20 ps VD/Trk/Cal.	
	radiation tolerance				≳ 5 x 10^{15} neq/cm^2					10$^{18(16)}$ neq/cm^2 VD/Cal.(Trk)	
backend processing	sensor thickness[5]	< 50 µm MAPS	< 50 µm MAPS		< 150 µm Plan/3D/Pas. < 50 µm LGADs	< 50 µm MAPS, Planar/3D/Passive CMOS, LGADs					
	3D integration[6]										



Series of workshops during the first half of 2023 to organise the communities **towards forming the new collaborations (proposal documents and national efforts in preparation)**

DRD8 felt their area is too experiment specific to be the topic of a "Strategic R&D" bid.
DRD9 is taken care of by a new ECFA Training Panel.

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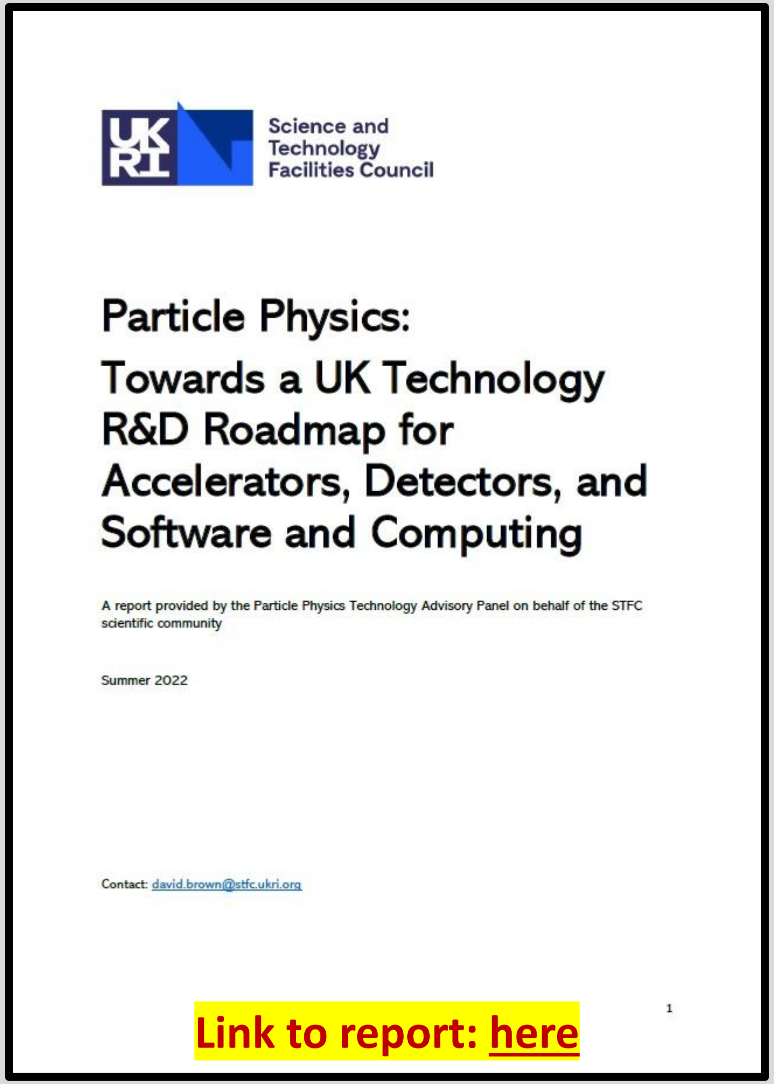
UK Particle Physics Technology Advisory Panel (PPTAP)

- Developed by the STFC scientific community
- To coordinate the UK response to the European Committee on Future Accelerators (ECFA) and European Laboratory Directors Group (ELDG) R&D roadmaps
- To provide a report for STFC's Technology and Accelerator Advisory Board (TAAB) on developing a coherent response to the European activities


Science and Technology Facilities Council

Particle Physics:

Towards a UK Technology R&D Roadmap for Accelerators, Detectors, and Software and Computing

A report provided by the Particle Physics Technology Advisory Panel on behalf of the STFC scientific community

Summer 2022

Contact: david.brown@stfc.ukri.org

1

Link to report: here

PPTAP report

Table 2: Strengths, weaknesses, opportunities, and obstacles analysis of the UK accelerator and detector particle physics community regarding current and potential technology R&D

Strengths	Weaknesses
Multiple including, beam dynamics, RF systems, beam instrumentation, feedback and control, plasma, surface science ERL, muons, permanent magnets, thin-film SRF, mm-wave & THz, particle sources	Links with industry under-developed Discontinuity in funding projects
Multiple including DAQ, Silicon, Quantum	Approach to dependencies not joined up (performance requirements) Lack of investment in electronics Quantum – no project/facility to scale up
Well-established expertise Leadership roles Training and hands-on opportunities Well-established track record of R&D in a number of areas Strong input into R&D roadmaps Integration Software and computing expertise	Lack of access to R&D facilities/beamlines Disparate small groups in some areas (novel acceleration, calorimetry, integration, gaseous detectors) Lack of career paths for technical experts Lack of coordinated computing & software training Little early TRL collaboration with industry

Opportunities	Obstacles
Expertise in areas of growing importance (thin film, ERL, permanent magnets, MM-wave, sustainable design) STFC facilities (CLARA, EPAC) leading to international opportunities (EuPRAXIA) Future UK facilities (UK XFEL, ISIS II)	
Expertise in essential, as yet unfilled and needed, areas	
International R&D underway Low-cost test stands and bench-top experiments Long-standing experienced communities (DAQ, integration, beam dynamics) Leadership building from expertise (muon, ERL, beam dynamics) Partnership with industry Greater coordination of computing and software training and expertise	Little UK R&D underway Funding – often just project related, lack of investment for co-creation and early-stage R&D Industry not well plugged in Overall cost of end goal Sustainability of end goal

Accelerators	Detectors	Both

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The PPTAP report… (my take-home messages)

- **… encourages a shift from the current funding model of experiment-construction-project driven Accelerators, Detectors, Software and Computing technology R&D to that of technology R&D driven programmes.**
  - A desire for longer-term stable funding for technology R&D
  - A different and broader approach to detector R&D to complement the construction project funding might be beneficial
- … notes that the traditional approach that understandably focuses on the science drivers, and the projects delivering these, were **missing the opportunities of creating technology synergies that could enhance science delivery, skills development, and career trajectories.** The financial constraints of recent years have further aggravated this by concentrating R&D into construction projects, where there is limited time and capacity, thereby restricting cross fertilisation, and potentially squeezing out early-stage innovation.
- … says that **cross-experimental R&D projects can be beneficial**, allowing the sharing of expertise and producing enhanced solutions for the same cost.

Early-stage R&D

PRD call for applications 2015

STFC has announced a call for applications to the Projects Research and Development scheme (PRD). Applications should be submitted by the deadline of July 29th2015 and will be reviewed at a meeting of the PPRP Panel on October 28/29 2015. STFC intends to allocate a total of around £1.0 Million. It is expected that most grants will start no earlier than 1 April 2016.

The PRD scheme is intended to develop the capabilities needed to underpin UK science and technology leadership in future Science and Technology Facilities Council projects and gives industry the opportunity, in collaboration with approved research organisations, to apply directly to the STFC for funding for research and development.

The PRD scheme provides funding for research and development projects which enable STFC to deliver the science programme objectives in the areas of particle physics, particle astrophysics, nuclear physics and astronomy. Please note that proposals for project specific R&D, or small upgrades for space instruments and missions, fall within the remit of theUK Space Agency.

More details of the STFC PRD scheme, including an updated guide for applicants can be found on our PRD webpage.

Early-stage research and development scheme 2023

Opportunity status:	Closed
Funders:	Science and Technology Facilities Council (STFC)
Funding type:	Grant
Maximum award:	£600,000
Publication date:	10 May 2023
Opening date:	11 May 2023 9:00am UK time
Closing date:	1 June 2023 5:00pm UK time

Apply for funding to the early-stage research and development scheme.

You must be based at a UK research organisation eligible for early-stage research and development funding and send an expression of interest notification.

The full economic cost of your project can be up to £600,000. STFC will fund 80% of the full economic cost.

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Guidance on good research

Good research resource hub

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Non-collider experiments… don't shoot me

Mu3e

DarkSide-20K

LEGEND

g-2

MAGIS-100

T2K / Super-k / Hyper-K

LZ

proton EDM / muon EDM

CTA

Watchman

SNO+

Apologies if I missed your favourite non-collider experiment

SBND / DUNE

My concerns

- We are safe (?) until ~2035… then what?
- What do we need to do now to be safe then?
- Concentrate on R&D for the next big thing?
- Look for smaller non-collider experiments?
- Money
  - Also for blue-sky detector R&D
- People
  - How do we maintain our very much skilled hardware people?
  - How do we transfer their knowledge and expertise to the next generation?
  - How do we keep the next generation interested?