Towards an R&D collaboration for PD and PID (DRD4)

Peter Krizan and Christian Joram
JSI Ljubljana CERN

Community Meeting

16 and 17 May 2023

Many thanks to Neville Harnew for quite a few slides.

Tentative Programme for Community Meeting

Tue, 16/05, morning, 1h

- Introduction, the Roadmap, purpose of the meeting, timeline, results of survey

Session Photodetection, 2h
- 2 talks 20' + 10'
- 4 talks 10' + 5'

Session Particle ID, 2h
- RICH/DIRC 4 talks
- TOF/TORCH 2 talks

Session Technologies, 1-2h

Social dinner

Wed, 17/05, morning, 1h

Session 'blue sky' etc.
- superconductive

Session Organisation 1
- Introduction
- Presentation of groups and their interests

Session Organisation 2
- Structure of DRD4
- Which WPs? Scopes ?
- Financial
- Common projects

Session Organisation 3
- Proposal, content, timeline, signatories
- Contributors

Draft structure of DRD4

(For discussion only)

Board of Institutes

Coordinator
JP leaders
WG leaders

Joint projects

- 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 timing resolution
- DRDT 4.4 – Develop compact high performance time-of-flight detectors
- Other JP …

Working Groups

- **Photodetector R&D**: Solid state, Gaseous, Vacuum
- **Particle ID**: RICH, DIRC, TOP, TORCH, TOF
- **Technologies**: Radiators, Optical elements, Readout, Cooling, software
- **Future**: ideas, concepts, blue sky …
- **Other WG** …

DRD4 Collaboration Proposal – layout
following a suggested template

Abstract

Introduction (objectives of the DRD4 collaboration)
(make use of the introduction of the TF4 chapter in the RD Roadmap, shortened)

Scope of the DRD4 Research Work

Planning technology area 1: DRDT 4.1 - Enhance timing resolution and spectral range of photon detectors
(including a task/deliverable synoptic, resources and list of contributing institutes)

Planning technology area 2: DRDT 4.2 - Develop photosensors for extreme environments:
(including a task/deliverable synoptic, resources and list of contributing institutes)

DRD4 Collaboration Proposal – layout 2

Planning technology area 3: DRDT 4.3 - Develop RICH and imaging detectors with low mass and high resolution timing.

(including a task/deliverable synoptic, resources and list of contributing institutes)

Planning technology area 4: DRDT 4.4 - Develop compact high performance time-of-fight detectors.

(including a task/deliverable synoptic, resources and list of contributing institutes)

Common simulation tools and test facilities

Partnerships (industrial, other research areas, other applications)

Networking and training

Proposal for the collaboration structure

Table 1: timeline

Timeline of milestones and major deliverables per DRDT and technology					
Deliverables or milestones in appropriate years	**2024**	**2025**	**2026**	**2027-2029**	**≳ 2030**
DRDT 1					
Technology 1	List of deliverables in year due (if any)				
...					
Technology n	List of deliverables in year due (if any)				
...					
DRDT n					
Technology 1	List of deliverables in year due (if any)				
...					
Technology n	List of deliverables in year due (if any)				

Timeline of FTE per DRDT and technology					
Total FTE estimated to be required to deliver the outlined R&D programme	**2024**	**2025**	**2026**	**2027-2029**	**≳ 2030**
DRDT 1					
Technology 1	Total required FTE				
...					
Technology n	Total required FTE				
...					
DRDT n					
Technology 1	Total required FTE				
...					
Technology n	Total required FTE				

Timeline of Materials and Services (non-FTE) Funding per DRDT and technology					
Total non-FTE funds estimated to be required to deliver the outlined R&D programme	**2024**	**2025**	**2026**	**2027-2029**	**≳ 2030**
DRDT 1					
Technology 1	Total requried funds				
...					
Technology n	Total requried funds				
...					
DRDT n					
Technology 1	Total requried funds				
...					
Technology n	Total requried funds				

Table 1 Timeline of Key Deliverables plus Milestones and Associated Required Resources

Table 2: institutional involvement

List of deliverables per technology and DRDT				
List of Contributing Institutes	**Technology 1**	**...**	**...**	**Technology n**
DRDT 1	List of contributors			
...				
DRDT n	List of contributors			

Table 2 List of Institutes in Matrix of Technology Area vs DRDT

Table 3: available and requested resources - confidential

	Timeline of FTE per DRDT and technology			
Estimate of expected total FTE from existing sources (not requiring new "strategic" support)	2024	2025	2026	≳ 2027
DRDT 1				
Technology 1	Total estimated FTE from existing sources			
...				
Technology n	Total estimated FTE from existing sources			
...				
DRDT n				
Technology 1	Total estimated FTE from existing sources			
...				
Technology n	Total estimated FTE from existing sources			
	Timeline of Materials and Services (non-FTE) Funding per DRDT and technology			
Estimate of expected total non-FTE funds from existing sources (not requiring new "strategic" funding)	2024	2025	2026	≳ 2027
DRDT 1				
Technology 1	Total estimated funds from existing sources			
...				
Technology n	Total estimated funds from existing sources			
...				
DRDT n				
Technology 1	Total estimated funds from existing sources			
...				
Technology n	Total estimated funds from existing sources			
	Timeline of FTE per DRDT and technology			
Estimate of total R&D programme FTE (sum of existing and hoped for given realistic assumptions)	2024	2025	2026	≳ 2027
DRDT 1				
Technology 1	Total number of FTE proposed			
...				
Technology n	Total number of FTE proposed			
...				
DRDT n				
Technology 1	Total number of FTE proposed			
...				
Technology n	Total number of FTE proposed			
	Timeline of Materials and Services (non-FTE) Funding per DRDT and technology			
Estimate of total R&D programme non-FTE funding (sum of existing and hoped for given realistic assumptions)	2024	2025	2026	≳ 2027
DRDT 1				
Technology 1	Total funding proposed			
...				
Technology n	Total funding proposed			
...				
DRDT n				
Technology 1	Total funding proposed			
...				
Technology n	Total funding proposed			

Table 3 Confidential Compilation of Available and Required Resources

Table 4: community input estimates

Proposed DRD input request to the community per DRDT				
Description/timeline/resources	**Technology Deliverable 1**	**...**	**...**	**Technology deliverable n**
DRDT 1				
Description of technology				
Strategic program(s) target				
Performance target				
Planned date, 2024-2025-2026, 2027-2029, ≳ 2030				
Existing R&D framework and/or list of contributors				
Description of contribution to the technology deliverable				
FTE contributions already covered or expected to continue				
"Materials" funding already covered or expected to continue				
Proposed FTE that would be needed to cover longer term strategic aspirations (≳ 2027)				
Proposed "Materials" that would be needed to cover longer term strategic aspirations (≳ 2027)				
...				
DRDT n				
Description of technology				
Strategic program(s) target				
Performance target				
Planned date, 2024-2025-2026, 2027-2029, ≳ 2030				
Existing R&D framework and/or list of contributors				
Description of contribution to the technology deliverable				
FTE contributions already covered or expected to continue				
"Materials" funding already covered or expected to continue				
Proposed FTE that would be needed to cover longer term strategic aspirations (≳ 2027)				
Proposed "Materials" that would be needed to cover longer term strategic aspirations (≳ 2027)				

Table 4 Suggested Template to Collect Community Input estimates. (A technology deliverable is a contribution to a physical object, it can be a component or a dedicated study prepared in collaboration with other contributors.)

SPARE SLIDES

DRDT 4.1 : Enhance the timing resolution and spectral range of photon detectors

- Next 5 years : Advances in SiPMs for fast timing, uv sensitivity and rad hardness. Light collection systems
- MCP-PMTs improved QM, & collection efficiencies, granularity and large areas.
- Next 10 years : Incremental improvements to gaseous photon detectors, granularity and fast timing.

DRDT 4.2 : Develop photosensors for extreme environments

- Next 5 years : Improve radiation tolerance of SiPMs. Radiation pure for cryo systems.
- MCP-PMTs improve detector ageing and high-rate performance
- Improve photocathode ageing and rate capability for gaseous detectors
- Next 20 years : Further advances in SiPMT rad hadness a couple of orders of magnitude beyond 1×10^{14} n_{eq}/cm^2

DRDT 4.3 : Develop RICH and imaging detectors with low mass and high timing resolution

- Next 5 years : Picosecond timing, greenhouse-friendly radiator gases, cheaper quartz amd transparent aerogels
- Next 10 years : Compact RICH systems with low X_0 (pressurised systems).

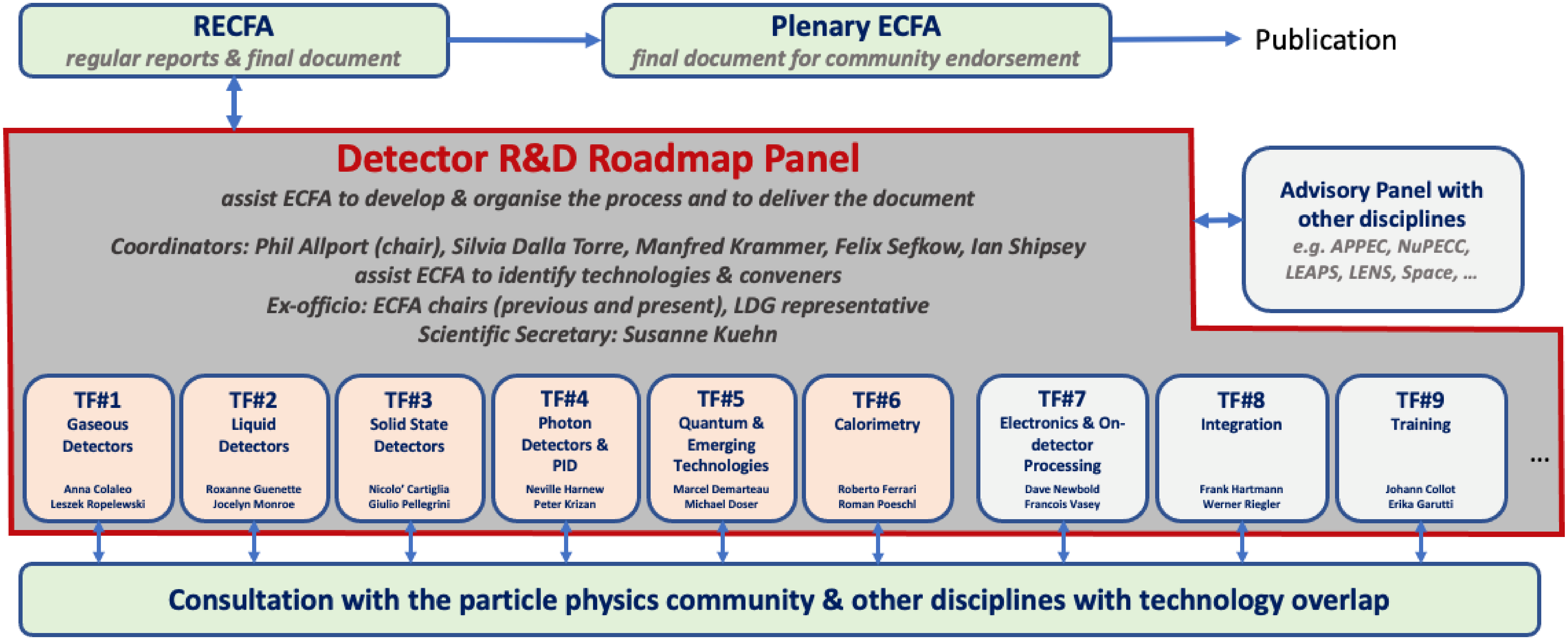
DRDT 4.4 : Develop compact high performance time-of-flight detectors

- Picosecond timimg, high granularity photosensors with long lifetime and high-rate capabilities

Pursue “blue sky” R&D activities

- Solid state photon detectors from novel materials
- Cryogenic superconducting photosensors
- Gaseous photon detectors for visible light
- Metamaterials to give tune-able refractive indices

Organisation of Detector R&D Roadmap



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

Facility requirements : Particle Identification

Projects	Timescale	RICH (high and low momentum PID)	Time of flight and DIRC	RPC technologies	TRD & dE/dx
Panda/CBM (Fair/GSI)	2025	✓	✓	✓	
NA62/KLEVER/TauFV	2025	✓	✓		
ALICE	2026-27 (LS3) – 2031 (LS4)	✓	✓	✓	✓
Belle-II	2026	✓	✓		
Neutrino long baseline	2027				
LHCb	2031 (LS4)	✓	✓		
ATLAS-CMS	2031 (LS4) - 2035 (LS5)				
Non accelerator & particle astro	--				
EIC	2031	✓	✓		
ILC	2035				
CLIC	2035				
FCC-ee	2040	✓	✓		✓
Muon-collider	> 2045				
FCC-hh	> 2050				

Facility requirements : Photon Detectors

Projects	Timescale	SiPM technology	MCP-PMT technology	Large diameter PMT technology	Scintillating fibres & new scintillating materials	CCDs & superconducting devices
Panda/CBM (Fair/GSI)	2025	✓	✓			
NA62/KLEVER/TauFV	2025	✓	✓			
ALICE	2026-27 (LS3) – 2031 (LS4)	✓	✓			
Belle-II	2026		✓			
Neutrino long baseline	2027	✓		✓	✓	
LHCb	2031 (LS4)	✓	✓		✓	
ATLAS-CMS	2031 (LS4) - 2035 (LS5)	✓				
Non accelerator & particle astro	--	✓		✓	✓	✓
EIC	2031	✓	✓		✓	
ILC	2035	✓			✓	
CLIC	2035	✓			✓	
FCC-ee	2040	✓	✓		✓	
Muon-collider	> 2045	✓				
FCC-hh	> 2050	✓				

Large accelerator-based facility/experiment earliest feasible start dates

Smaller accelerator and non-accelerator-based experiments start dates

Family of vacuum-based photodetectors

A number of photon detector types have evolved from the classic photomultiplier concept :

- Micro-channel plate detectors (MCP-PMTs)
  - Several suppliers : eg. LAPPD (large area) and Photonis/ Hamamatsu/ Photek (compact, tunable granularity) – see next slide
- Photo-multipliers (including large areas)
  - Improvements needed to increase radio-purity (factor 5-10), UV response & QE
- Multianode (MaPMTs)
- Hybrid avalanche photon detectors (HAPDs)
- Hybrid HPDs, V-SiPMT …. etc

Gas-based photodetectors

- Gaseous Photon Detectors (GPDs) represent an effective solution for instrumenting large imaging surfaces (up to several square metres) in high magnetic felds.
- Need to develop GPDs based on Micro Pattern Gaseous Detector (MPGD) structures which allow photon conversions at few 10's of micron level.
  - Further R&D to improve the photocathode lifetime (GHz rates for EIC), the PDE, radiation hardness and time resolution in the few ps range (PICOSEC-Micromegas Detector Development); challenging extension to the visible spectral range.
- Search for UV-sensitive materials more radiation-hard and chemically inert than CsI.
  - Carbon based photocathodes
- Develop compact GPD systems with integrated electronics for imaging applications
  - InGrid - Micromegas integrated in a Timepix
- R&D for alternative hydrocarbon-free gas mixtures
- GPDs for cryogenic applications
  - Detection of both scintillator light and ionization

SiPMs : R&D technology requirements

- A non-exhaustive list – different applications, different requirements:
  - Improved radiation hardness (1x10^{14} n cm^{-2} eq @ CMS ; 10^{17}-10^{18}@ FCC-hh !)
  - Improved dark count rates towards 1 Hz mm^{-2} (driven by low light-level experiments) and reduced after pulsing
  - Improved timing characteristics (aspire to 10 ps or below for time resolution)
  - Increasing photon detection efficiency for single-photons : fill factor and spectral range into the UV & IR
  - Cryogenic operation of SiPMs : improved cooling systems (to reduce dark noise), @ -50 °C
  - Optimised SiPM systems - large-area integration with cooling
  - Optimised optical couplings. development of micro-lenses/filters.
  - New materials for SiPMTs (eg SiC, GaN, InGaN, AlGaN)
  - Improved dynamic range (driven by calorimetry)
  - Improved cross talk
  - Cheaper solutions for SiPMs (eg CMOS) for large area applications and high pixel density. Analogue vs. Digital
  - Improving pulse shape discrimination (neutrinos and non-accelerator); development of corresponding r/o electronics
  - High radioactive-purity for underground experiments, better than a few Bq/kg depending on material
  - Cell size, dynamic range, fill factor.

PID with dE/dx, TRD

- dE/dx resolution around 5% is routinely reached, in excellent conditions and with accurate calibration. Possible improvements
  - dE/dx resolution ~ 5.4% $(LP)^{-0.37}$ with L length in m, P pressure in bar; the interest in the P term is renewed where excellent PID is needed together with a large mass of the gas (TPC-as-a-target). R&D topics: suitable gas mixtures for high-P operation, light pressure-containment vessels.
  - Cluster counting: dN_{cl}/dx resolution is potentially better than dE/dx (by a factor of 2). Cluster counting requires fast electronics and sophisticated counting algorithms, or alternative readout methods. It has the potential of being less dependent on other parameters. Cluster counting in time, cluster counting in space; R&D topics: wave-form sampling FEE with FPGA processing, 2D micropattern read-out.
- TRD: employed in several experiments, ATLAS, ALICE, AMS, CBM, EIC
  - Gas TRDs a mature instrument for PID at high energies. Due to the overlapping of the TR signal with the ionization, a precise knowledge (and simulation) of dE/dx is a must.
  - GEMs are making their way in the technique
  - An attempt has been made to improve cluster counting by means of a GridPix. Some improvement is possible, although not drastic. Potential improvement may be reached by differentiating the response to X-ray photons and to particle ionization→ Extensive R&D required!
  - TRD imaging (e.g., with Timepix3)? (for hadron PID at very high energies)

Superconducting photodetectors

- Single photon detection technologies with superconductors
- Superconducting detectors for UV-midIR photons
  - TES: Transition Edge Sensor
  - SNSPD: Superconducting Nanowire Single Photon Detector
  - MKID: Microwave Kinetic Inductance Detector
- Example: nanowire detectors for dark matter detection; dark photons
- Work in progress relevant to HEP applications

Novel optical materials for fiber trackers

- Scintillating fibres:
  - A cost-effective way of instrumenting large areas for charged particle tracking at relatively low material budget. With the availability of small-pitch SiPM arrays, high resolutions are possible (LHCb SciFi tracker upgrade)
- Further advances in the technology, e.g. for a second upgrade of the tracker envisaged for the High-Luminosity LHC:
  - Optimize photo-sensor and optical fibers need to be optimised for a higher light yield, allowing for smaller diameters and thus higher precision and improved radiation tolerance.
- Open issues:
  - Radiation tolerance, speed, emission spectrum
- Innovative materials: Nanostructured-Organo-silicon-Luminophores (NOL) scintillators:
  - Exhibit stronger and faster light output than presently achieved.
  - Decay time: NOL fibres are almost a factor 2 (6) faster than the best blue (green) standard fibres, which makes them very interesting for time critical applications
  - Radiation hardness (X-rays to a dose of 1 kGy): damage is as expected on a level comparable to reference fibres

Proposed implementation timeline

- **Starting now** : the R&D Roadmap Task Forces will organise open meetings to establish the scope and scale of the communities wishing to participate in the new DRD activities. DRD conveners and team of experts identified. Where the R&D area has a DRDT already in operation, these need to be involved from the beginning.
- **Q4 2022 :** Outline structure and review mechanisms agreed by CERN Council.
- **Through 2023 :** mechanisms to be agreed with funding agencies, preparing for DRD collaboration funding requests.
- **By Spring 2023 :** the DRDC mandate to be formally defined with CERN management; Core DRDC membership appointed.
- **Through early Summer 2023 :** Conveners and experts prepare DRD proposals with work package structure which are then submitted.
- **Q4 2023 :** DRD collaborations receive formal approval from CERN Research Board.
- **Q1 2024 :** The new DRDs come into existence and operational for ongoing review of DRDs. R&D programmes underway.
- **Through 2024 :** collection of MoU signatures to take place, with defined areas of interest per institute.
- **2024-2026 :** Ramp up of new strategic funding and R&D activities in parallel to completion of current deliverables.