

DRD4 plans for photon detectors and PID

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**With thanks to Peter Krizan
and Christian Joram**

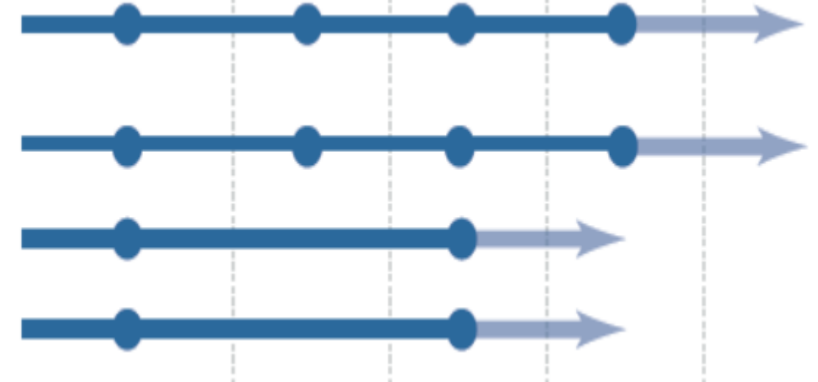
**Meeting of the ECFA WG3:
Topical workshop on calorimetry, PID and photodetectors**

Outline of talk

- Reminder of important R&D DRD4 (Task Force 4) activities addressed in the ECFA roadmap
 - ◆ PID technologies
 - ◆ Photon detectors
- Summary of recommendations from the roadmap
- Status of DRD4 implementation

DRD4 - Detector Research and Development Themes

< 2030 2030-2035 2035-2040 2040-2045 > 2045



- 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

- Required for fast timing in Cerenkov and time of flight detectors, for operation with high particle fluxes and pile-up, and in extending the wavelength coverage of scintillation photons from noble gases and Cerenkov photons.
- Essential for operation in the high-radiation environments at the HL-LHC, Belle II Upgrade, EIC and FCC-hh; in PID and in calorimetry.
- Required for particle identification at HL-LHC (LHCb, ALICE), Belle II upgrade, EIC, and FCC-ee.
- As a complementary approach for particle identification at HL-LHC, EIC and FCC-ee.

RICH, DIRC and TOF detector technologies

- Focus on RICH, DIRC and TOF technologies
- Requirements for dE/dx and TRD are summarised in backup slides

RICH technologies : key R&D areas

- RICH geometries
 - ◆ The HL-LHC has possibly the most demanding requirements for next generation of RICH detectors eg. LHCb.
 - ◆ Hermetic experiments (eg FCC-ee, EIC) need RICH detectors with a total length shorter than a meter.
Possibility of pressurizing noble gases to several bars
 - ◆ The use of lightweight mirrors (CF technology), light collection systems, concentrators – smart optics design
- Radiator materials
 - ◆ Gas radiators : to develop **green gases** as an alternative to fluorocarbons (C_4F_{10} or CF_4).
 - ◆ Solid, crystal & aerogel radiators (tunable refractive index, larger tiles, higher photon yield).
 - ◆ Meta-materials, photonic crystals, capable to match refractive indices at low and high momentum.
- Photon detectors and readout
 - ◆ Need large-area **single-photon detectors** capable of sustaining high counting rates (few MHz/cm²), improved photon detection efficiency, a total ionizing dose up to a few Mrad, timing resolution of the order of few tens of ps. Granularities of mm-level pixel size.
 - ◆ Need to develop SiPMs and MCP-PMTs, solid photocathodes in micro-pattern gaseous detectors (MPGDs)
 - ◆ **Timing absolutely crucial to the new generation of RICHes (<50 ps precision) for background rejection and vertex association.**

DIRC and TOP detectors : key R&D areas

- Applications are for flavour and heavy-ion physics, where PID is essential. e.g. Panda, Belle-II, EIC, Gluex.
 - ◆ DIRC detectors need to extend to 3 sigma pi/K separation @ 7-8 GeV/c with time-of-propagation (TOP) correction
- R&D to make DIRC readout more compact, expand momentum reach, develop for endcap operation, improvements in focusing designs.
- Develop quartz technology. Surface quality is essential ((sub)-nm surface roughness) and is a major cost driver, lower price.
- Photon detection – single-photon fast timing performance is essential (10's of ps level). SiPMs, MCP-PMTs. Improved photon detector granularity; radiation tolerance, lifetime, low noise, photon sensitivity.

TOF technologies : key R&D areas

- TOF provides complimentary PID for high energy machines. Future applications, e.g. Panda/CBM, Na62/TauLV, ALICE, LHCb, ATLAS/CMS, EIC, FCC ...
- ToF methods
 - ◆ Scintillators to ~ 50 ps.
 - ◆ Gaseous detectors: multigap RPCs to < 50 ps with micro pattern gas detectors (MPGDs).
 - ◆ Silicon detectors : Low gain avalanche diodes (LGADs) important to the GPDs, FCC-hh etc, timing to 10 ps.
 - ◆ Large area MCPs (to 15ps): LAPPDs. Instrumenting large area surfaces.
 - ◆ Cherenkov (DIRC)-based detectors eg. TORCH detector with 15ps per track resolution (LHCb, TauFV, kaon) with 3 sigma pi/K separation to 10 GeV/c at 10m.
- Future R&D challenges
 - ◆ Cheaper polished quartz technology (as for DIRC) essential
 - ◆ Photon detection - fast timing performance essential (~ 10 ps level). SiPMs, MCP-PMTs LGADs.
 - ◆ R&D essential for timing (clock) distribution.

Photon Detector Technologies

- Focus on MCP-PMTs and SiPMs for PID and calorimetry
- Requirements for other vacuum devices and gaseous photon detectors summarised in backup slides

Microchannel plate PMTs : key R&D areas

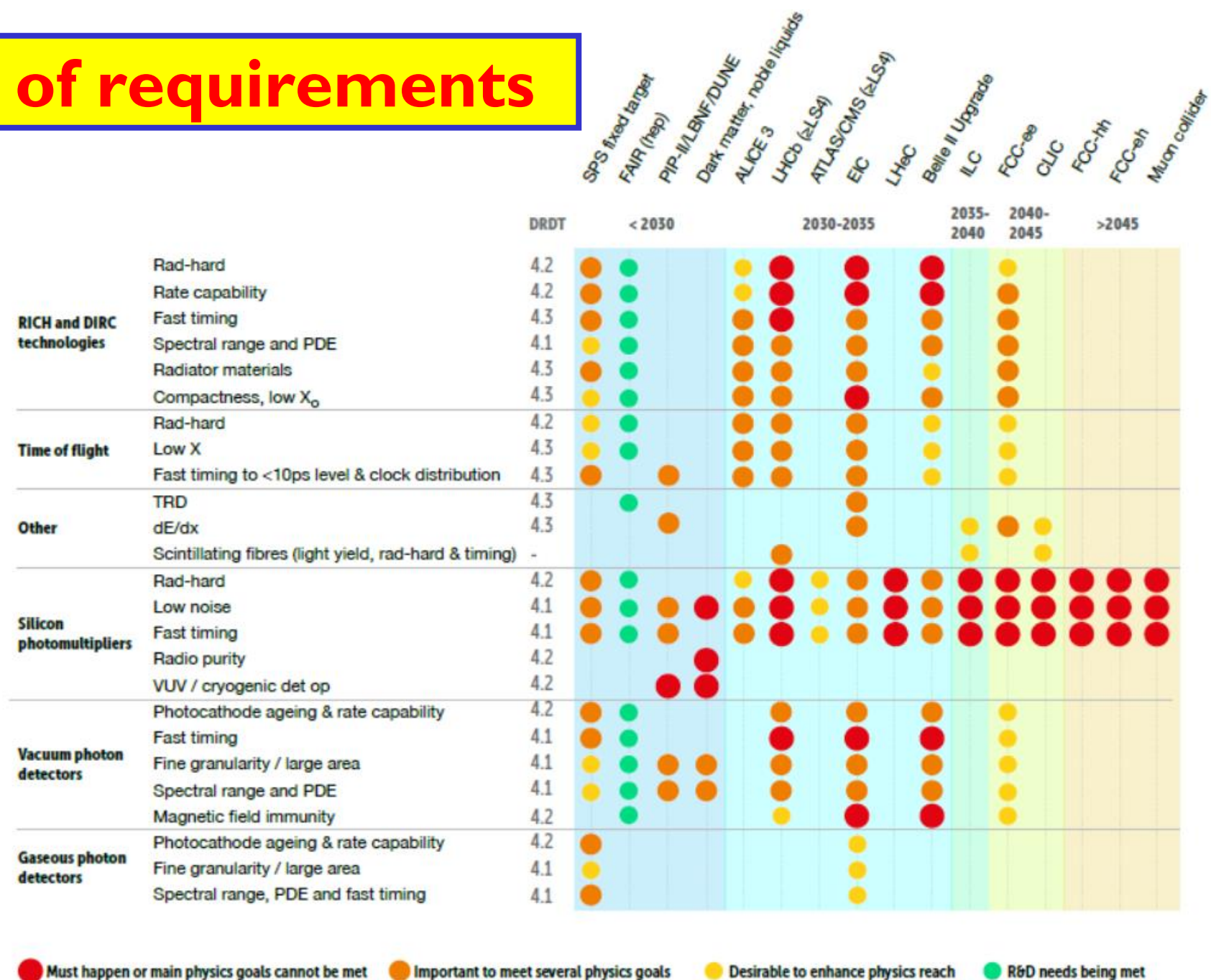
- MCP-PMTs proposed extensively for RICH detectors and TOF
 - ◆ Several suppliers : eg. LAPPD (large area) and Photonis/ Hamamatsu/ Photech (compact, tunable granularity)
 - ◆ State of the art currently ~ 20 ps timing resolution
- R&D requirements
 - ◆ Large area coverage, cheaper cost for tiling large areas (LAPPD)
 - ◆ Customised granularity (for DIRC-type detectors, TOF) -128 pixels over 2-inch tube size
 - ◆ Current rate limitation around $10^5/\text{cm}^2$ - need to improve rate capabilities ($> \text{MHz}$)
 - ◆ Improved integrated charge capabilities (several factors above current state of the art $\sim 20 \text{ C}/\text{cm}^2$)
 - ◆ Operating gain currently $10^6 - 10^7$. Electronics to facilitate operation at a $\sim \text{few} \times 10^5$ operation to reduce integrated charge
 - ◆ Improvements in QE, CCE need to come.

SiPMs : a key technology

- SiPMs are photosensors of choice for many applications – HL-LHC & FCC-hh mainly drive the HEP technology limits
 - ◆ They have wide applications for scintillating fibres, calorimeters, neutrinos and DM experiments (pulse shape discrimination), noble liquid detectors (eg MEG-II with LXe), gamma ray astronomy
 - ◆ SiPMs are now becoming the detector of choice for PID devices : RICH and DIRC-type detectors (LHCb, ALICE, EIC, FCC-ee etc). And for calorimetry.
- Important features are their compactness, low operation voltage, robustness to magnetic fields, reasonable price and high QE around 50-60% in the visible (350-600 nm)
- Timing, radiation tolerance, low backgrounds are key :
 - High dark count rates currently $10\text{-}100\text{ kHz mm}^{-2}$ at room temperature. Need to improve towards 1 Hz mm^{-2}
 - Rad hardness : lose sensitivity to single photons at around $1 \times 10^{11}\text{ n cm}^{-2}\text{ eq}$. Need to improve ($1 \times 10^{14}\text{ n cm}^{-2}\text{ eq}$ @ CMS ; $10^{17}\text{-}10^{18}$ @ FCC-hh !)
 - Fast timing response – now below 100 ps (aspire to 10 ps or better for time resolution for multiphotons)
 - Small cell sizes which are tuneable – integration of large systems (cooling etc) important
 - Note that DRD requirements for PID (single photon detection) and calorimeters (with many photons) could be in conflict

Overall summary of requirements

- A chart was produced showing the timeline of categories of experiments employing PID and photon detectors together with R&D tasks.
- The colour coding is linked to the potential impact on the physics programme of the experiment.
 - ◆ Red, largest dot : Must happen or main physics goals cannot be met;
 - ◆ Orange, large dot : Important to meet several physics goals;
 - ◆ Yellow, medium dot : desirable to enhance physics reach;
 - ◆ Green, small dot : R&D needs are being met;
 - ◆ Blank : no further R&D required or not applicable.



DRD4 plans for photon detectors and

Summary of recommendations

- 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 $1 \times 10^{14} \text{ n}_{\text{eq}}/\text{cm}^2$
- 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 timing, 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

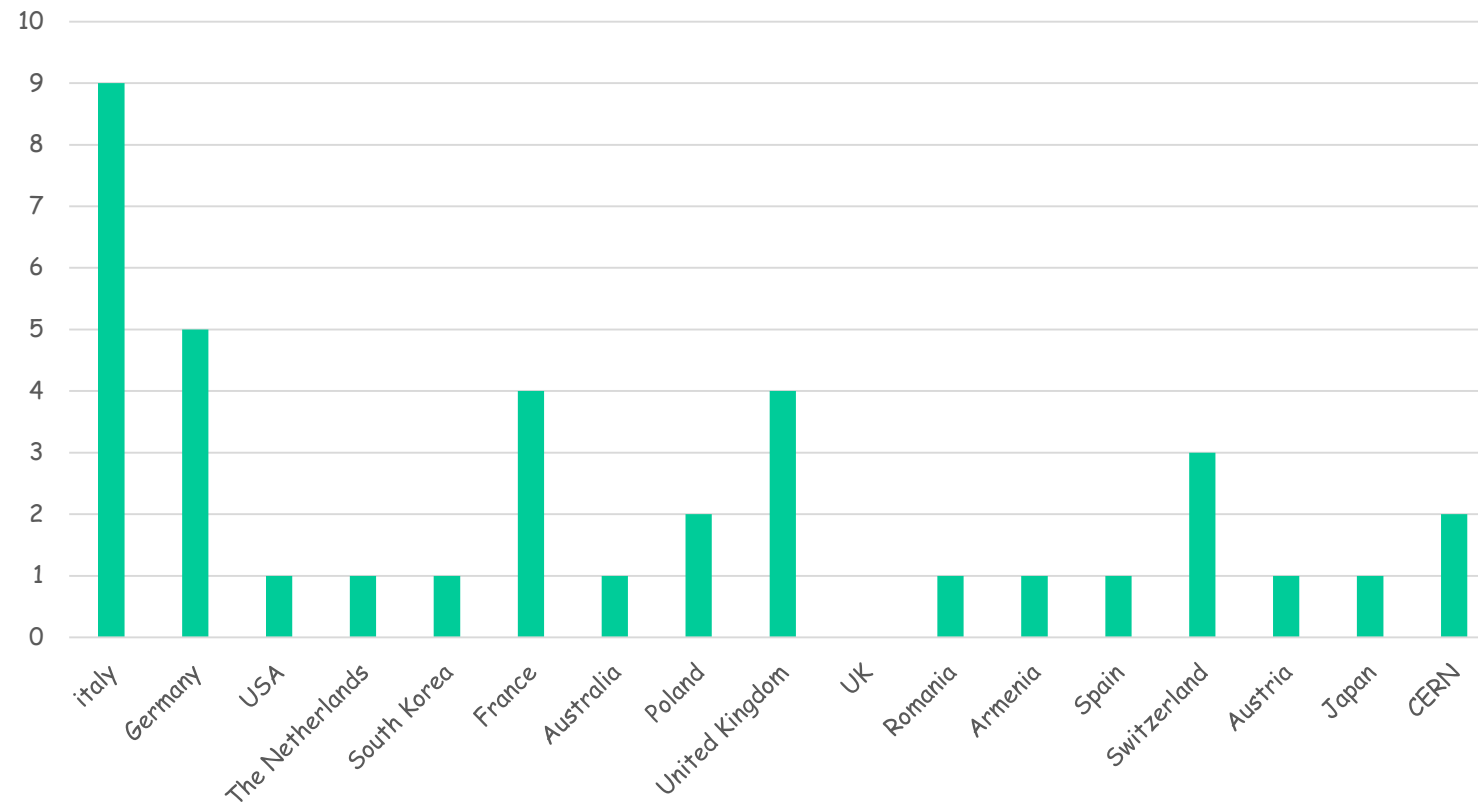
Towards DRD4 implementation

Community meeting and survey schedule

- **8 March 2023** **Small meeting (zoom) with representatives of major experiments and groups (~20 participants)**
 - » <https://indico.cern.ch/event/1263718/>
- **April 2023** **Survey conducted : 40 groups and 43 individuals**
 - » Many small groups, many experiments
- **16 – 17 May 2023** **TF-4 community meeting**
 - » <https://indico.cern.ch/event/1263731/>
 - » 70 registrations so far
 - » 21 abstracts

ECFA TF-4 Survey : 40 groups replying

Group replies versus countries



Replying Groups (40)

*INFN Rome 1 and CREF
Bergische Universität Wuppertal
INFN Padova
GSI Helmholtzzentrum fuer Schwerionenforschung GmbH, Darmstadt,
Germany
Georgia State University
infn
School of Physics and Astronomy, Monash University
Seoul National University
University of Warwick
IRFU, CEA
INFN Bari
INFN Bari
European Space Agency (ESA/ESTEC)
STFC - RAL
Institute of Plasma Physics and Laser Microfusion
CERN
IFIN-HH
IJCLab
INFN Milano Bicocca
Particle Therapy Research Center, University Medical Center Groningen*

*LHCb TORCH R&D project
A. I. Alikhanyan National Science Laboratory (Yerevan Physics Institute)
AANL
ICCUB // University of Barcelona
DESY, Hamburg
University Giessen, Germany
CERN
Institut des 2 infinis de Lyon
INFN
KM3NeT Collaboration
AstroCeNT / Nicolaus Copernicus Astronomical Center of the Polish
Academy of Sciences
ISTITUTO NAZIONALE DI FISICA NUCLEARE, Division of Ferrara
DESY
Fondazione Bruno Kessler
University of Oxford
The Catholic University of America
Queen Mary University of London
Aix-Marseille Univ, CNRS/IN2P3, CPPM, imXgam research team
Innsbruck University, NRNU MEPhI Moscow
Belle II, ARICH at KEK
CERN*

Involved experiments (multiple entries not removed)

ePIC at EIC

RICH - CBM (Compressed Baryonic Matter)

PANDA/FAIR, GlueX/JLab, ePIC/BNL

fairtel

HERD R&D

Belle II

LHCb Upgrade II (TORCH)

ALICE-TOF, CALICE-SDHCAL, AIDAinnova

CALIPSO group, ClearMind project

N/A

LHCb / TORCH, also photon detectors for other applications relevant to DRD1 and DRD2

Space radiation environments and effects

LHCb

RF Timer

Future e+e- Higgs Factory

LHCb

LHCb, CTA, HERD, PETVISION

DUNE, Solar, LEGEND-200, LEGEND-1000

Real-time in vivo verification of proton therapy (RIVER)

TORCH

CBM RICH (with Univ. Wuppertal, GSI)

KM3NeT

PICMIC

CMS and CALICE

ALICE3

Detector developmet for high luminosity experiments (LHCb and 4DPHOTON projects)

ILD

LHCb and TORCH and ARC

ClearMind (French ANR), TEMPORAL (French PIA), TIARA (French PCSI)

Ongoing contacts / projects / discussions are related to CMS, LHCb and ALICE.

DarkSide-20k, DarkSide-LowMass, ARGO, 3DPi

ATLAS/TRT (main responsibility)

Electron Ion Collider/ hpDIRC

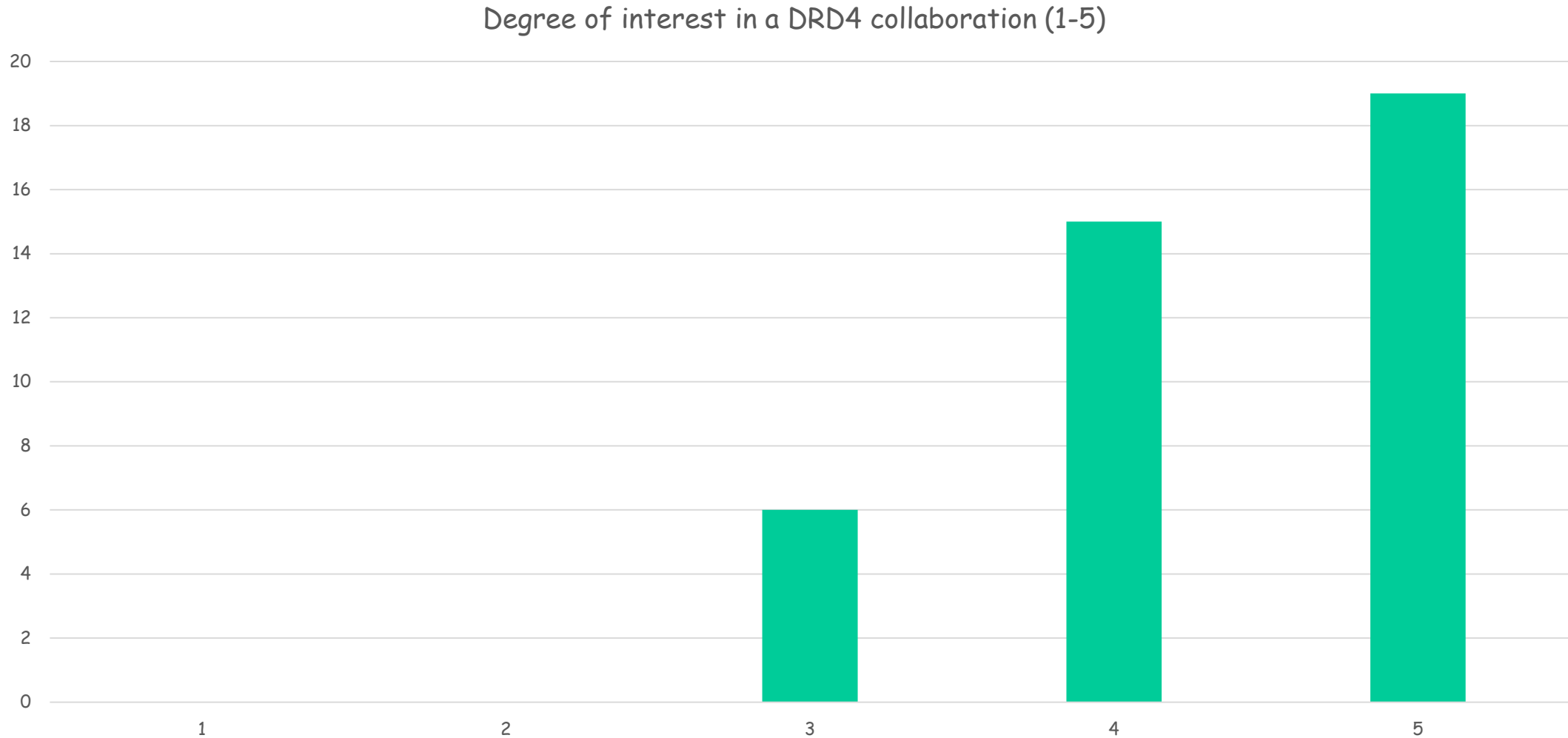
Belle II, ARICH

DUNE, ATLAS, MoEDAL

lhcb

It seems that DRD4 will have to deal with major experiments, but also many relatively small groups with a fragmented landscape of experimental requirements.

Degree of interest in DRD4 collaboration



ECFA TF-4 Survey. Personnel resources. 23 Groups replies

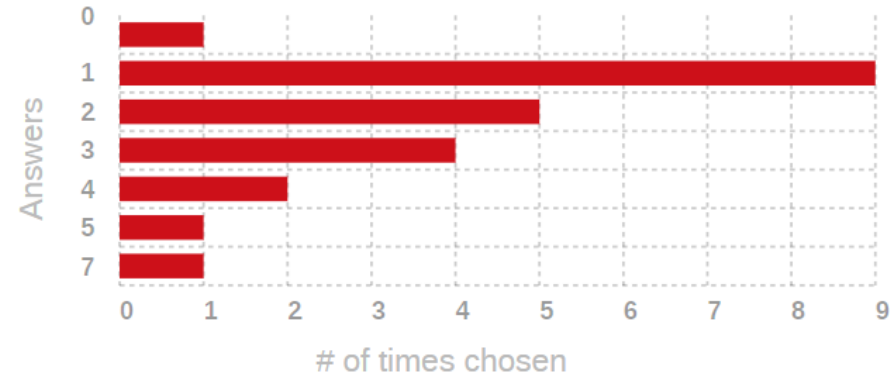
Permanent (FTE/y)

Answered: 23

Average: 2.22

Min: 0

Max: 7



Optimistic picture. Interface didn't allow to enter 0.x FTE. And only half groups answered.

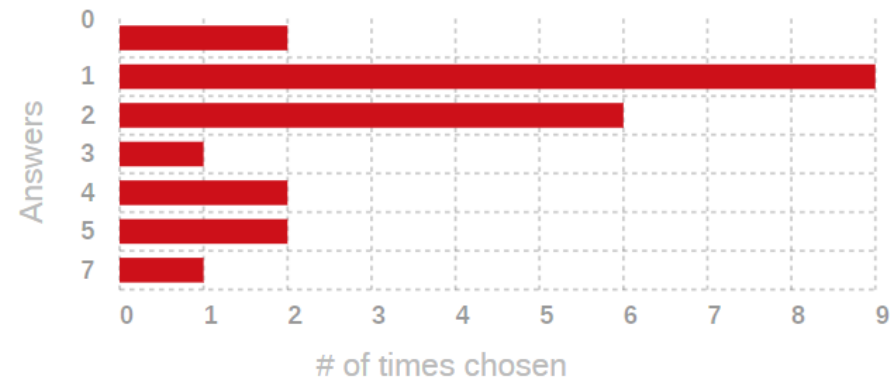
Non-permanent (FTE/y)

Answered: 23

Average: 2.13

Min: 0

Max: 7



Available facilities

Available Facilities (pick-up list)

Answered: 40

A. Detector Characterization Laboratory: 33 (16.92%)

B. Manufacturing and Production Workshop: 10 (5.13%)

C. Assembly Facilities: 18 (9.23%)

D. Clean Rooms: 21 (10.77%)

E. Mechanical Workshop: 29 (14.87%)

F. Electronics Workshop: 27 (13.85%)

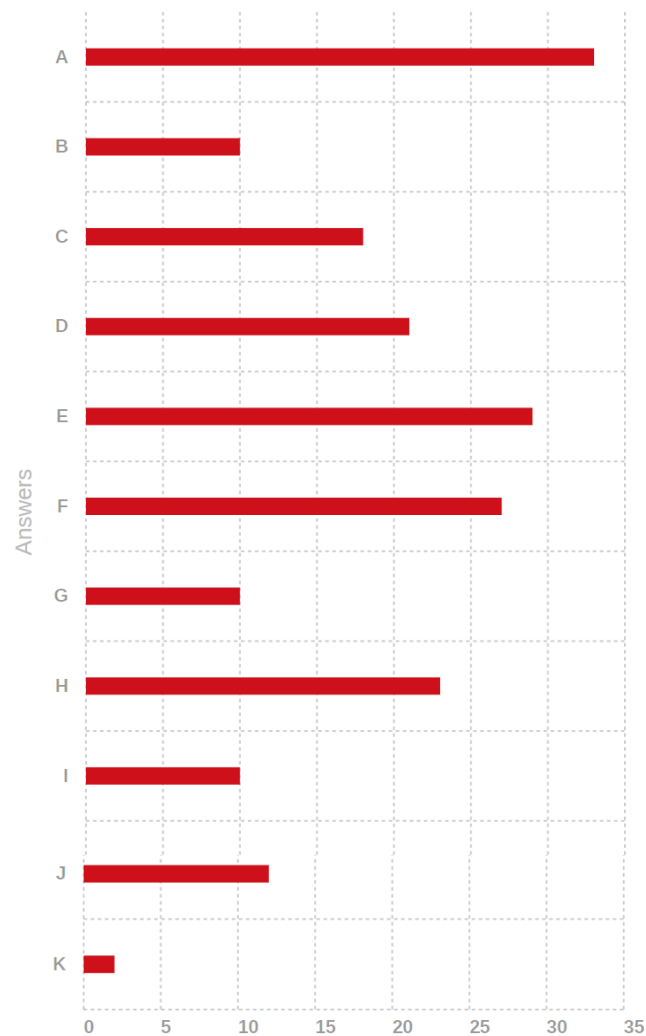
G. Analysis Laboratory: 10 (5.13%)

H. Radioactive Sources (active, passive): 23 (11.79%)

I. Irradiation Facilities: 10 (5.13%)

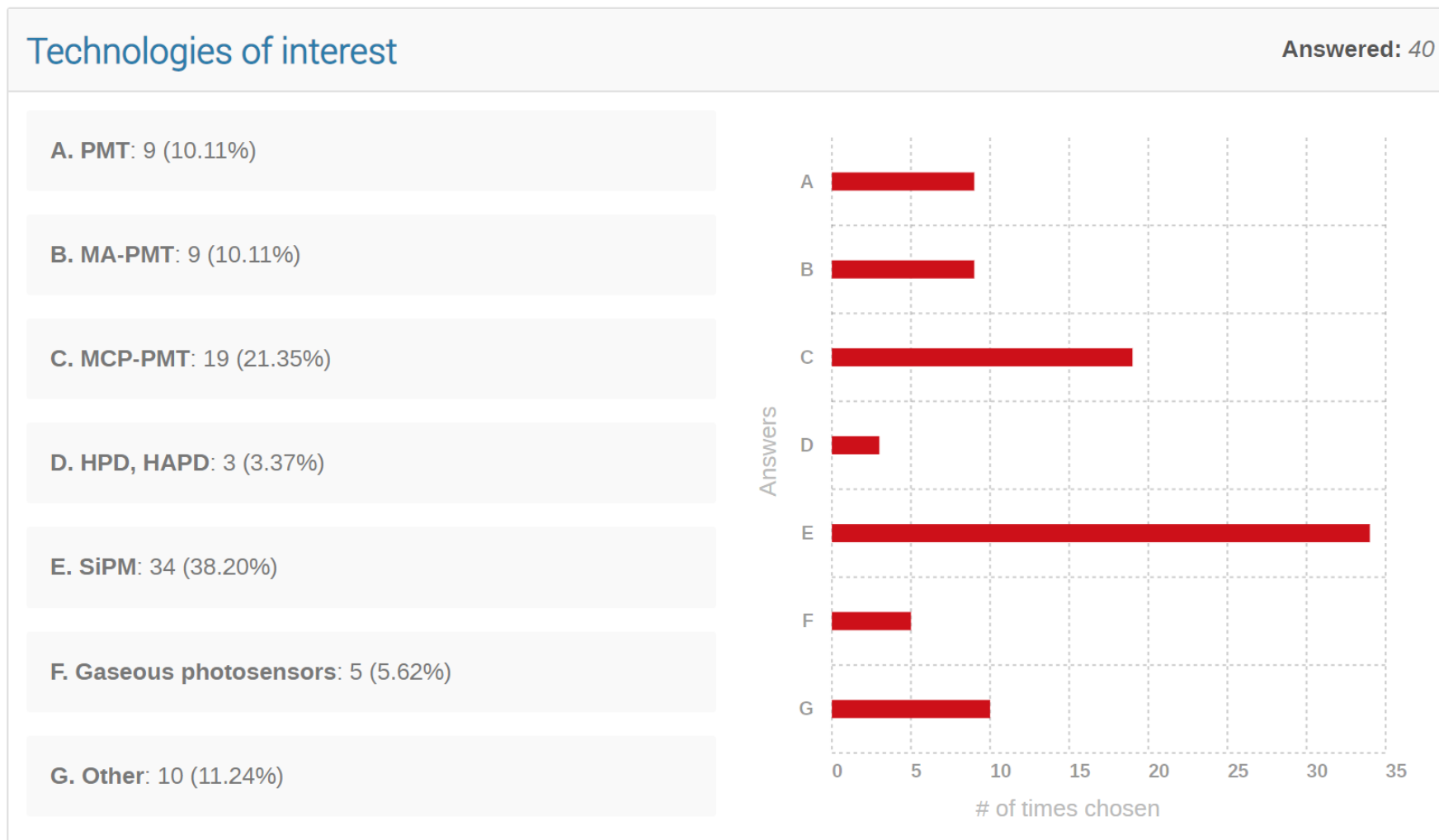
J. Test Beam: 12 (6.15%)

K. Other: 2 (1.03%)



Technologies of interest (Photodetection)

Technologies of interest: Photodetection.



Technology of interest: Electronics

Technology of Interest: Electronics

Electronics

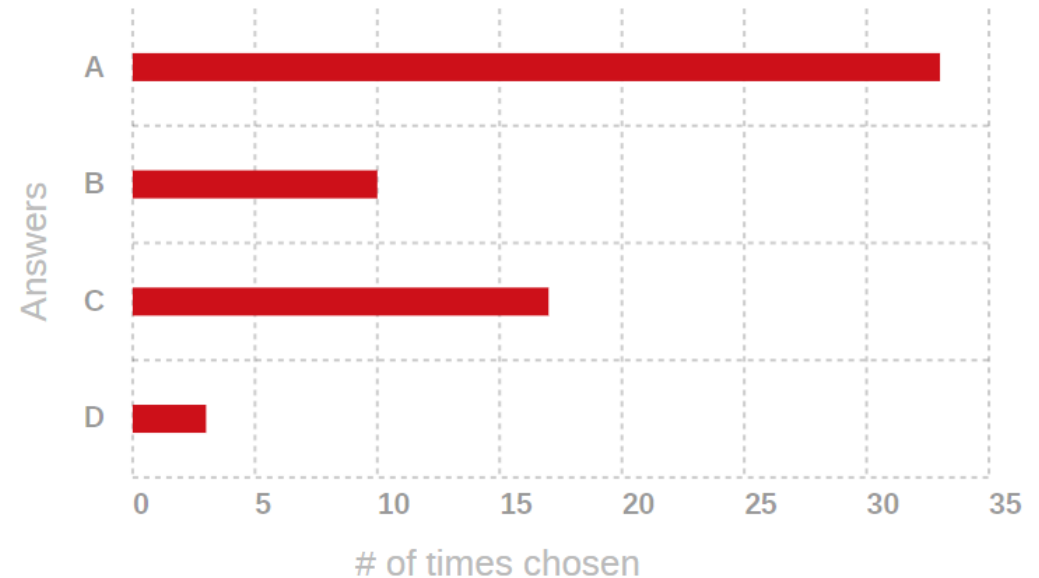
Answered: 40

A. Frontend Electronics for photon detection: 33 (52.38%)

B. Powering: 10 (15.87%)

C. Calibration systems: 17 (26.98%)

D. Others: 3 (4.76%)



Simulation and software tools

Simulations, and software tools for PID detectors

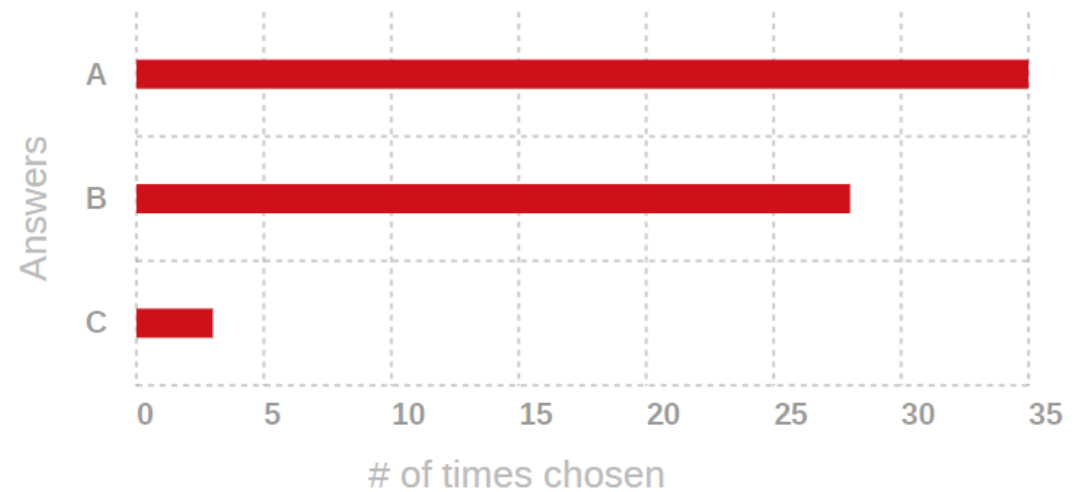
Research interests and activities

Answered : 40 Please select the activities of interest for your group and specify in the comments if the interest is as user and/or developer

A. Detector Physics (modelling and simulations): 35 (53.03%)

B. Analysis: 28 (42.42%)

C. Other: 3 (4.55%)



Applications

Applications

Select application areas connected to the research activity of your group

Answered: 40

A. Cherenkov - Threshold Detector: 4 (3.74%)

B. Cherenkov - Ring Imaging Detector: 19 (17.76%)

C. Cherenkov - DIRC: 4 (3.74%)

D. Cherenkov - TOP: 6 (5.61%)

E. Time of Flight : 22 (20.56%)

F. Transition Radiation : 4 (3.74%)

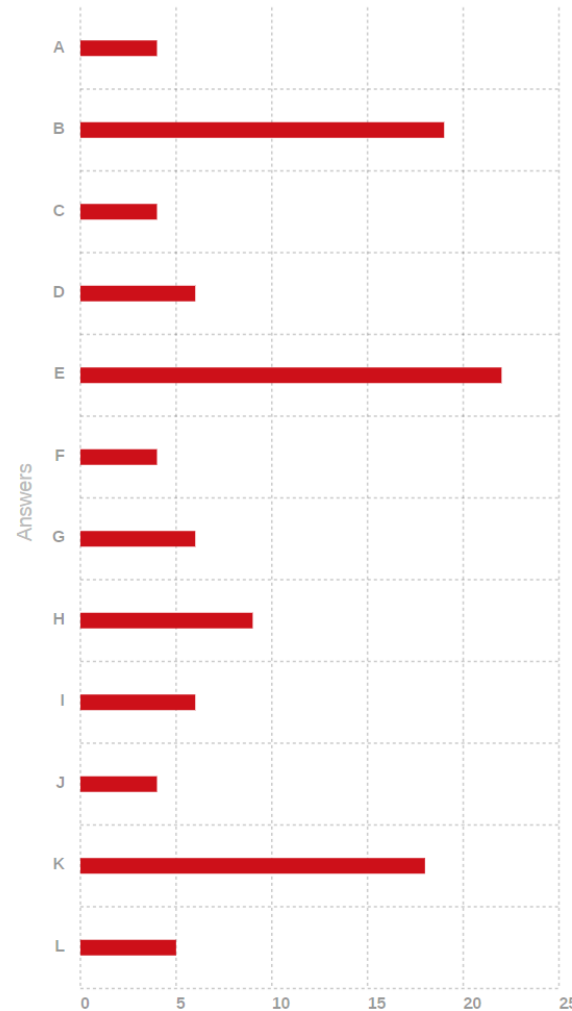
G. dE/dx for PID: 6 (5.61%)

H. Calorimetry: 9 (8.41%)

I. Fibre tracking: 6 (5.61%)

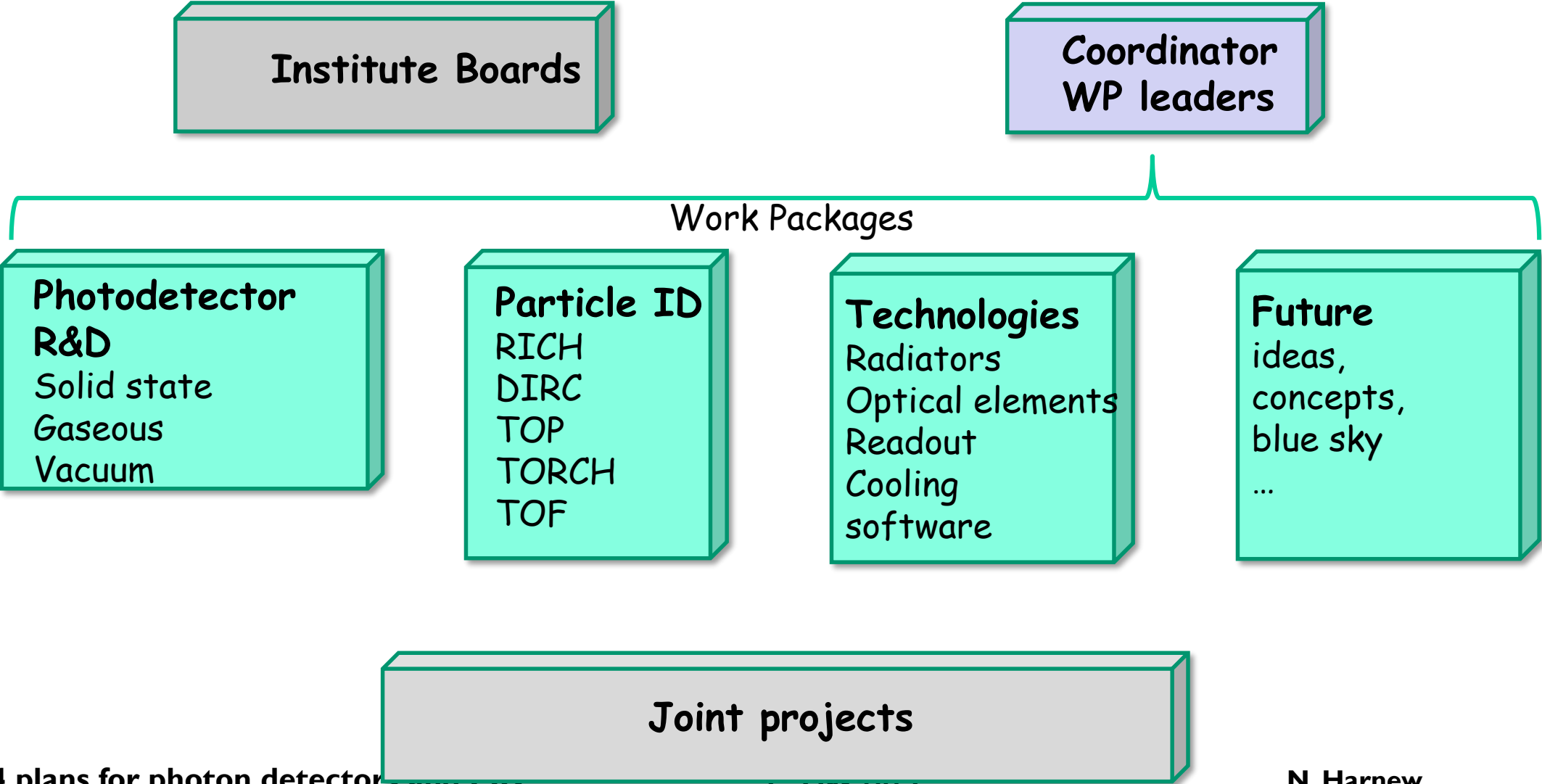
J. Air shower Cherenkov: 4 (3.74%)

K. non-HEP applications (medical, ...): 18 (16.82%)



Draft structure of DRD4: Photodetectors and Particle ID

(For discussion only)



Tentative Programme for Community Meeting

Tue, 16/05 all day

- 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

<https://indico.cern.ch/event/1263731/>

Wed, 17/05 all day

Session 'blue sky' etc.

- superconductive

Session Organisation 1

- Presentation of groups and their interests

Session Organisation 2

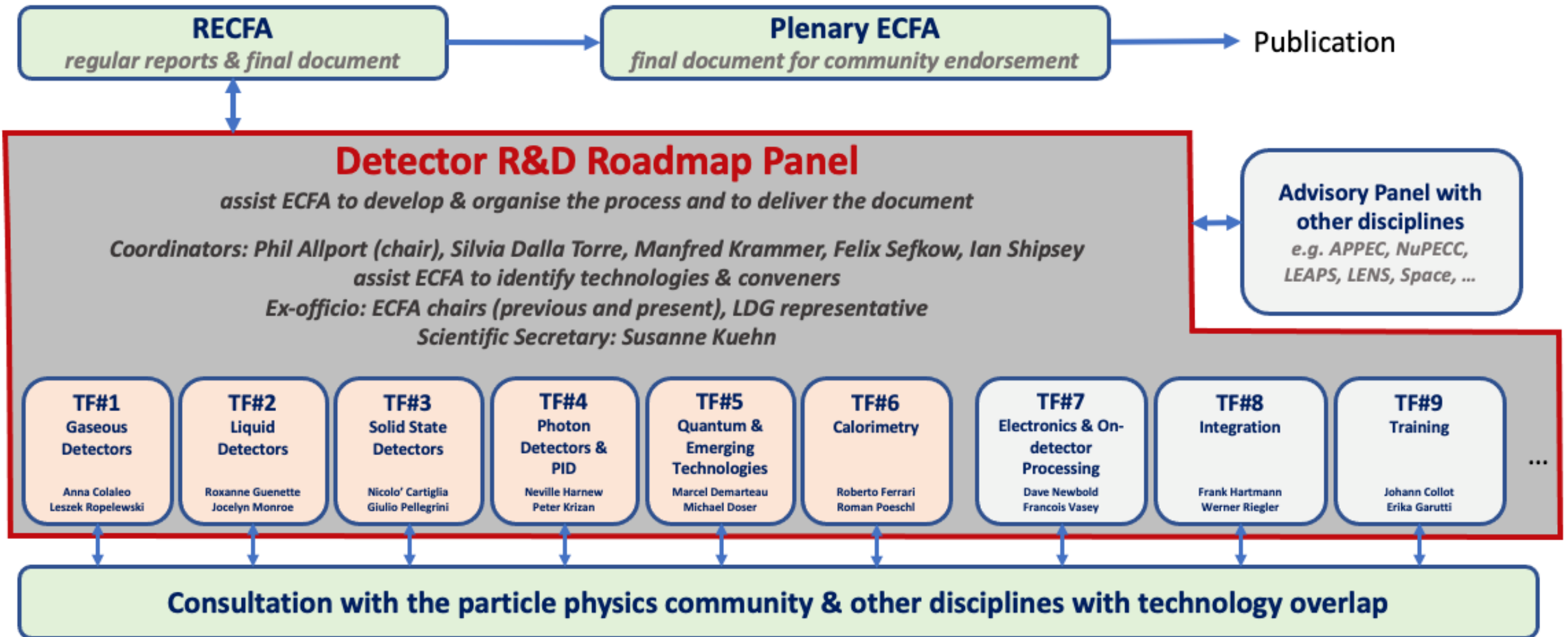
- Structure of DRD4
- Which WPs? Scopes ?
- Financial
- Common projects

Session Organisation 3

- Proposal, content, timeline, signatories
- Contributors

SPARE SLIDES

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	✓	✓	✓	
NAG2/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	✓	✓			
NAG2/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 fields.
- 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 Csl.
 - ◆ 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 (1×10^{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 $\sim 5.4\% (LP)^{-0.37}$ 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.