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

Peter Krizan & **Christian Joram**
JSI Ljubljana CERN

Community Meeting

16 and 17 May 2023

Many thanks to Neville Harnew for quite a few slides.

Welcome at CERN

- Community meeting of groups and individuals active in the field of photodectors and Particle ID (+ SciFi trackers)
- Towards an R&D collaboration (DRD4) as outlined in the ECFA Roadmap process.
- DRD4 shall bundle and boost R&D avtivities in the above fields, in order to achieve the performance needed for the next generation of high energy physics experiments and upgrades.
- Common R&D may accelerate progress, avoid duplication, give access to infrastructure, train people, lower the cost...

Peter Križan

- University of Ljubljana and J. Stefan Institute
- Flavour physics and detectors
  - ARGUS @DESY
  - HERA-B @DESY: RICH with MaPMTs and C_4F_{10}
  - Belle @KEK: silicon strip vertex detector
  - Belle II: spoke, technical coordinator, Cherenkov detectors ARICH and TOP
  - Applications in medical imaging: Cherenkov based TOF-PET
- Photon detectors
  - MaPMTs, MCP-PMT, HAPD, SiPM
- Editor NIMA (2010-2022)

Why am I here?

- ECFA Roadmap, co-convener of TF4 (together with Neville Harnew).
- With Christian given the mandate to launch a D(etector)RD Collaboration on Photodetector and PID
- Co-coordinator of the Photodector working group of the 2019 US DOE HEP-Instrumentation BRN effort
- Technical coordinator of Belle II (2015-2020)

Christian Joram

- CERN, since 1994
- Detector physicist
  - DELPHI RICH
  - LHCb, RICH R&D
  - ATLAS ALFA, Scint. Fibre tracker
  - LHCb SciFi, Scint. Fibre tracker
  - AXIAL PET
- Photodetectors
  - HPD, MAPMT, SIPM, also digital

Why am I here?

- ECFA Roadmap, expert in TF4
- Peter and I were given the mandate to launch this Detector R&D (DRD) Collaboration
- Helped to launch RD50 and RD51 collaborations
- Coordinator of EU MC network MC-PAD
- Coordinator of CERN Detector R&D Programme
- Editor of NIM A

Tentative Programme for Community Meeting

Tue, 16/05, morning, 0.5h

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

Session Photodetection,
- SiPM, SPAD, PMT, MCP 12 talks

Session Technologies
- **Materials**
- **Software**

3 talks

Session Particle ID 6 talks
- RICH/DIRC
- TOF/TORCH

Social dinner

Wed, 17/05

Session 'blue sky', special, etc. 3 talks

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

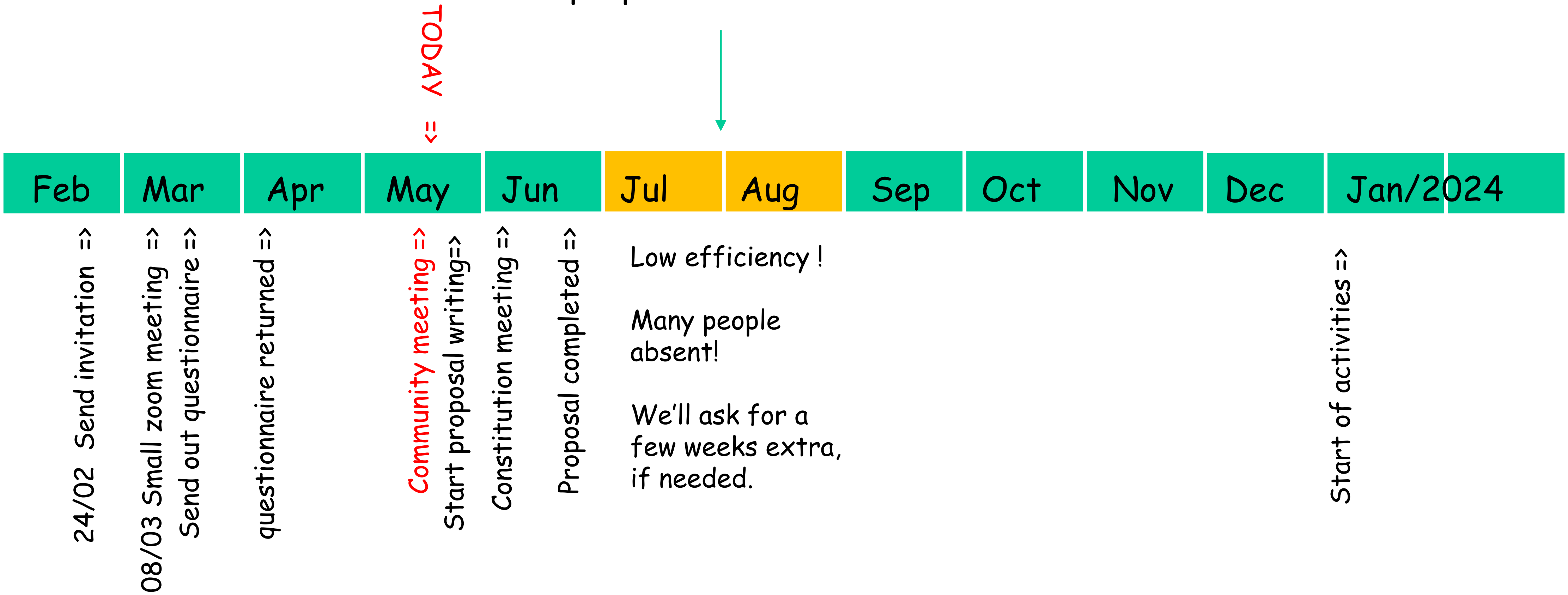
Session Organisation 2
- Structure of DRD4
- Which WPs? Scopes ?
- Financial
- Common projects

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

DRD4: timeline

DRD4 Timeline

31.07.2023
Official deadline for
proposal submission



24/02 Send invitation =>

08/03 Small zoom meeting =>

Send out questionnaire =>

questionnaire returned =>

Community meeting =>

Start proposal writing=>

Constitution meeting =>

Proposal completed =>

Low efficiency !

Many people
absent!

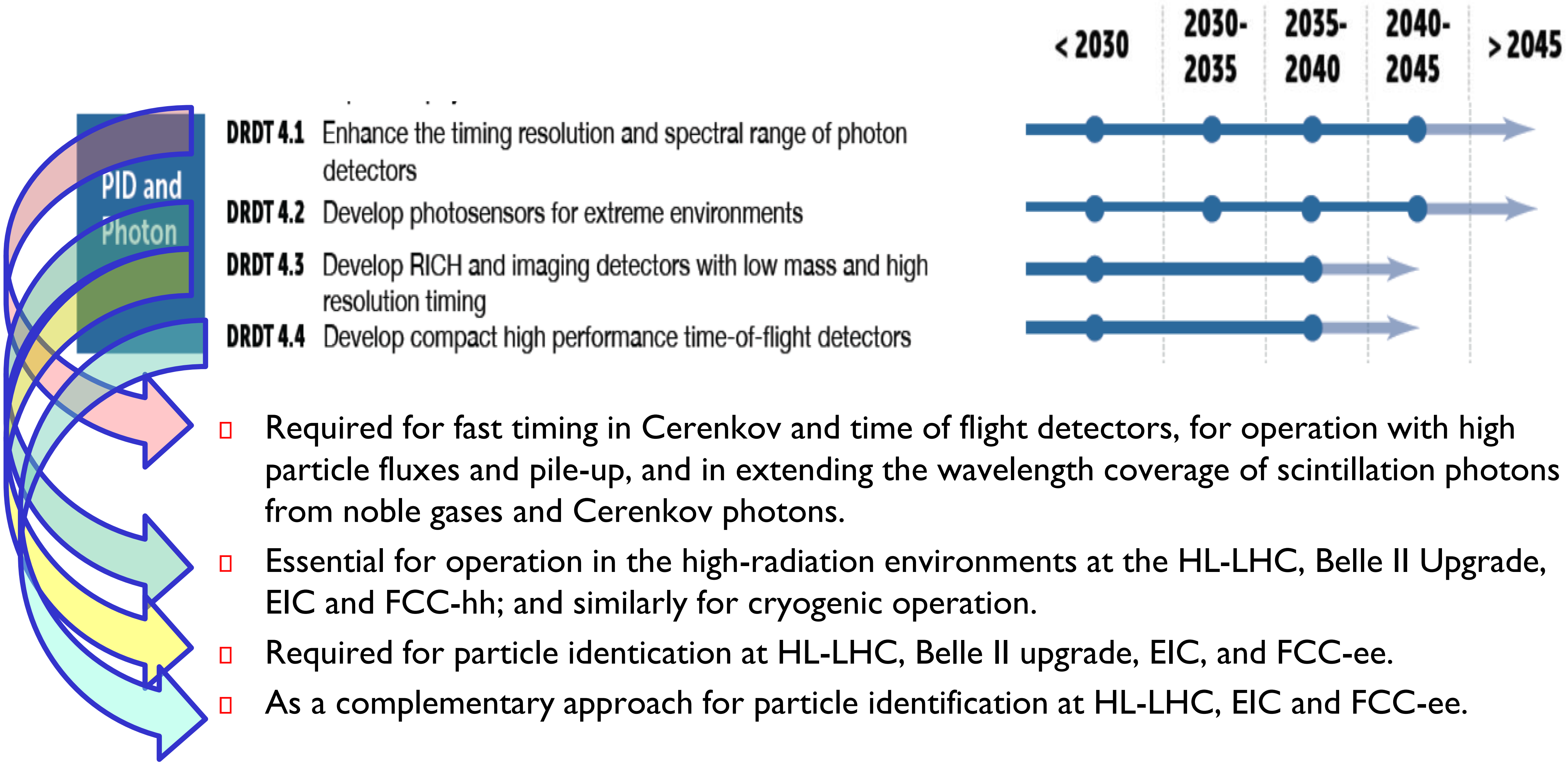
We'll ask for a
few weeks extra,
if needed.

Start of activities =>

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/ » 91 registrations so far (55 present) » 24 abstracts » 40 partipants to dinner
31 July 2023	**Ultimate deadline for submission of proposal** » 20 pages, based on Roadmap 'book'

DRD4 - Detector Research and Development Themes



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; and similarly for cryogenic operation.
- Required for particle identication at HL-LHC, 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

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/cm^2), 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 drive the performance needs of DIRC detectors.
  - DIRC detectors need to extend to 3 sigma pi/K separation @ 7-8 GeV/c (with TOP correction)
- R&D to make DIRC readout more compact, expand momentum reach, develop for endcap operation. Improvements in focusing designs, emphasizing spatial resolution.
- Develop quartz technology, surface quality is essential ((sub)-nm surface roughness) is a major cost driver, lower price.
- Photon detection - fast timing performance is essential (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 ~50ps. Gaseous detectors: multigap RPCs to <50ps with micro pattern gas detectors (MPGDs).
  - Silicon detectors : Low gain avalanche diodes (LGADs) important to the GPDs, FCC-hh etc, timing to10 ps.
  - Large area MCPs (to 15ps): LAPPDs. Instrumenting large area surfaces.
  - Cherenkov (DIRC)-based detectors eg. TORCH detector (LHCb, TauFV, kaon) with 3 sigma pi/K separation to 10 GeV/c at 10m.
- Future R&D challenges
  - Quartz technology (as for DIRC)
  - 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)
- Requirement for other vacuum devices and gaseous photon detectors in backup slides

Microchannel plate PMTs

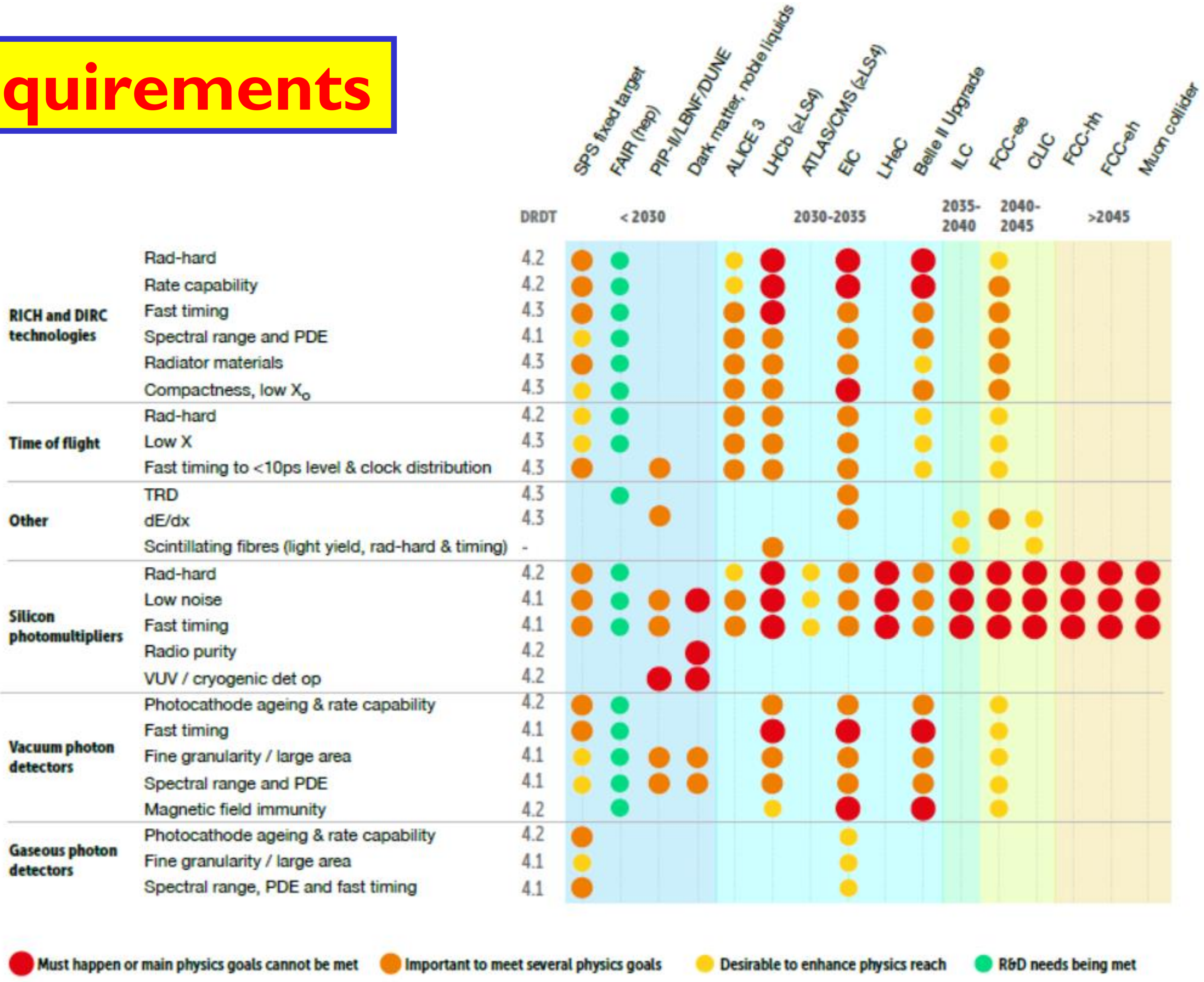
- MCP-PMTs proposed extensively for RICH detectors and TOF
  - Several suppliers : eg. LAPPD (large area) and Photonis/ Hamamatsu/ Photek (compact, tunable granularity)
  - State of the art currently ~20ps timing resolution
- R&D requirements
  - Large area coverage, cheaper cost for tiling large areas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

Radiation hard SiPMs : a key technology

- SiPMs are photosensors of choice for many applications – HL-LHC & FCC-hh mainly drive the HEP technology limits
- Important features are their compactness, low operation voltage, robustness to magnetic fields and reasonable price
- Timing, radiation tolerance, low backgrounds are key :
  - 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 now becoming the detector of choice for RICH and DIRC-type detectors (LHCb, ALICE, EIC, FCC-ee etc). And also calorimetry.
    - High QE around 50-60% in the visible (350-600 nm)
    - However high dark count rates 10-100 kHz mm^{-2} at room temperature need to improve towards 1 Hz mm^{-2}
    - Rad hardness : lose sensitivity to single photons at around 1x10^{11} n cm^{-2} eq. need to improve (1x10^{14} n cm^{-2} eq @ CMS ; 10^{17}-10^{18}@ FCC-hh !)
    - Fast timing response – significantly below 100 ps (aspire to 10 ps or below for time resolution)
    - Small cell sizes which are tuneable – integration of large systems (cooling etc) important
    - Note requirements for single photon detection and calorimeters (with many photons) could be conflicting

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.



		DRDT	< 2030				2030-2035						2035-2040	2040-2045		>2045		
			SPS fixed target	FAIR (hep)	PIP-II/LBNF/DUNE	Dark matter, noble liquids	ALICE 3	LHCb (≥LS4)	ATLAS/CMS (≥LS4)	EIC	LHeC	Belle II Upgrade	ILC	FCC-ee	CLIC	FCC-hh	FCC-eh	Muon collider
RICH and DIRC technologies	Rad-hard	4.2	🟠	🟢			🟡	🔴		🔴		🔴		🟡				
	Rate capability	4.2	🟠	🟢			🟡	🔴		🔴		🔴		🟠				
	Fast timing	4.3	🟠	🟢			🟠	🔴		🟠		🟠		🟠				
	Spectral range and PDE	4.1	🟡	🟢			🟠	🟠		🟠		🟠		🟠				
	Radiator materials	4.3	🟠	🟢			🟠	🟠		🟠		🟡		🟠				
	Compactness, low X_0	4.3	🟡	🟢			🟠	🟠		🔴		🟠		🟠				
Time of flight	Rad-hard	4.2	🟡	🟢			🟠	🟠		🟠		🟡		🟡				
	Low X	4.3	🟡	🟢			🟠	🟠		🟠		🟡		🟡				
	Fast timing to <10ps level & clock distribution	4.3	🟠		🟠		🟠	🟠		🟠		🟡		🟡				
Other	TRD	4.3		🟢						🟠								
	dE/dx	4.3			🟠					🟠			🟡	🟠	🟡			
	Scintillating fibres (light yield, rad-hard & timing)	-						🟠					🟡		🟡			
Silicon photomultipliers	Rad-hard	4.2	🟠	🟢			🟡	🔴	🟡	🟠	🔴	🟠	🔴	🔴	🔴	🔴	🔴	🔴
	Low noise	4.1	🟠	🟢	🟠	🔴	🟠	🔴	🟡	🟠	🔴	🟠	🔴	🔴	🔴	🔴	🔴	🔴
	Fast timing	4.1	🟠	🟢	🟠		🟠	🔴	🟡	🟠	🔴	🟠	🔴	🔴	🔴	🔴	🔴	🔴
	Radio purity	4.2				🔴												
	VUV / cryogenic det op	4.2			🔴	🔴												
Vacuum photon detectors	Photocathode ageing & rate capability	4.2	🟠	🟢				🟠		🟠		🟠		🟡				
	Fast timing	4.1	🟠	🟢				🔴		🔴		🔴		🟡				
	Fine granularity / large area	4.1	🟡	🟢	🟠	🟠		🟠		🟠		🟠		🟡				
	Spectral range and PDE	4.1	🟡	🟢	🟠	🟠		🟠		🟠		🟠		🟡				
	Magnetic field immunity	4.2		🟢				🟡		🔴		🔴		🟡				
Gaseous photon detectors	Photocathode ageing & rate capability	4.2	🟠							🟡								
	Fine granularity / large area	4.1	🟡							🟡								
	Spectral range, PDE and fast timing	4.1	🟠							🟡								

🔴 Must happen or main physics goals cannot be met 🟠 Important to meet several physics goals 🟡 Desirable to enhance physics reach 🟢 R&D needs being met

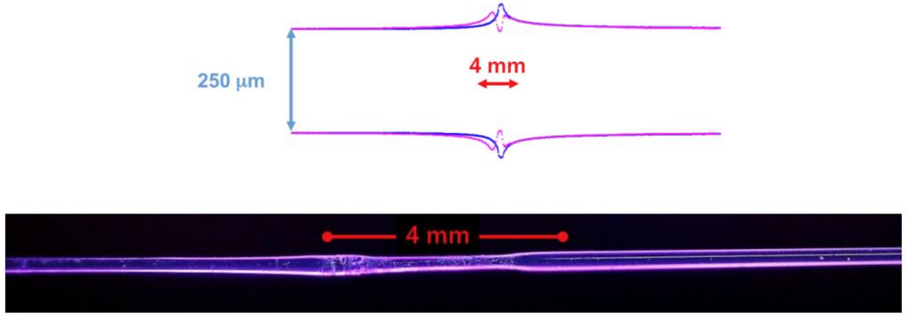
Summary of recommendations

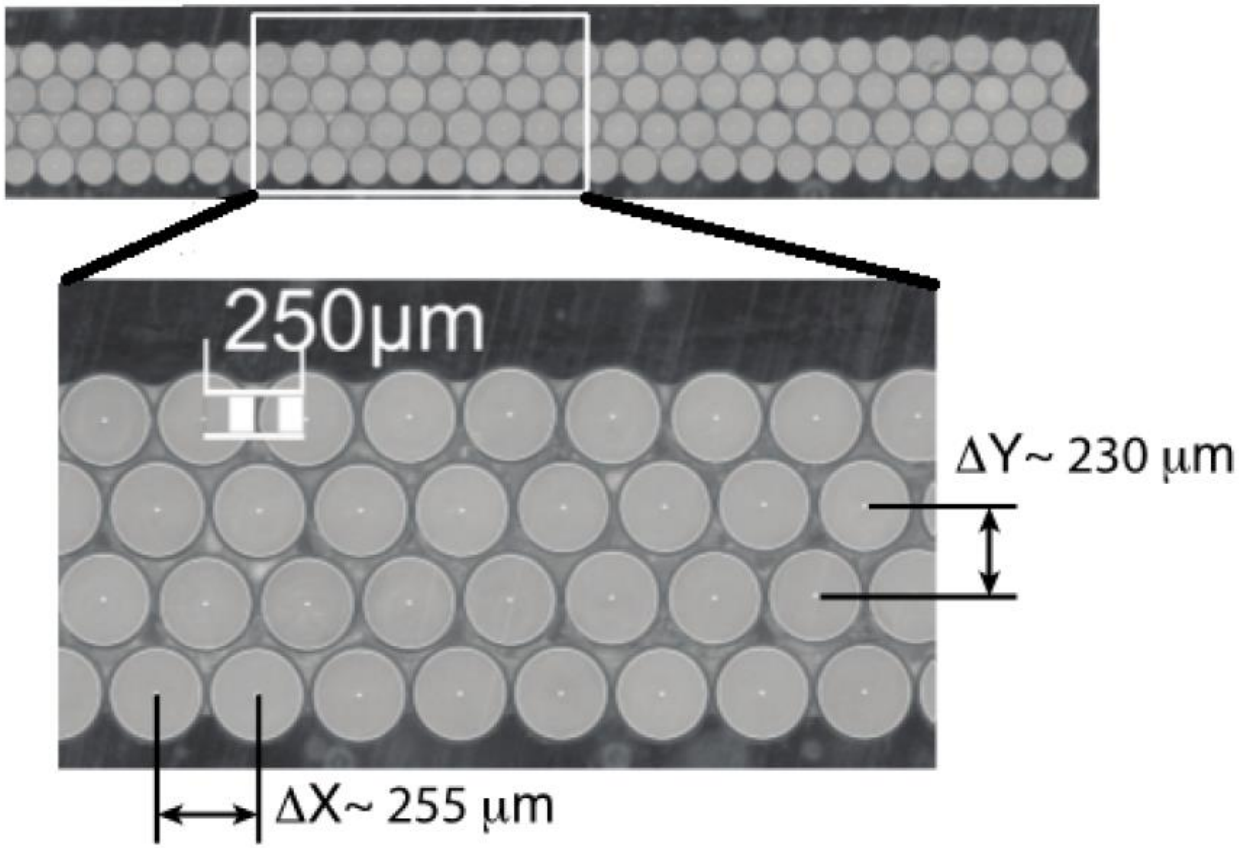
- DRDT 4.1 : Enhance the timing resolution and spectral range of photon detectors
  - Next 5 years : Advances in SiPMs for fast timing, uv sensitivity and rad hardness. Light collection systems
  - MCP-PMTs improved QE & collection efficiencies, granularity and large areas.
  - Next 10 years : Incremental 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

Scintillating fibre trackers

- Decision by ECFA Roadmap officials : DRD4 shall include Scintillating Fibre (SciFi) trackers
- We weren’t aware.

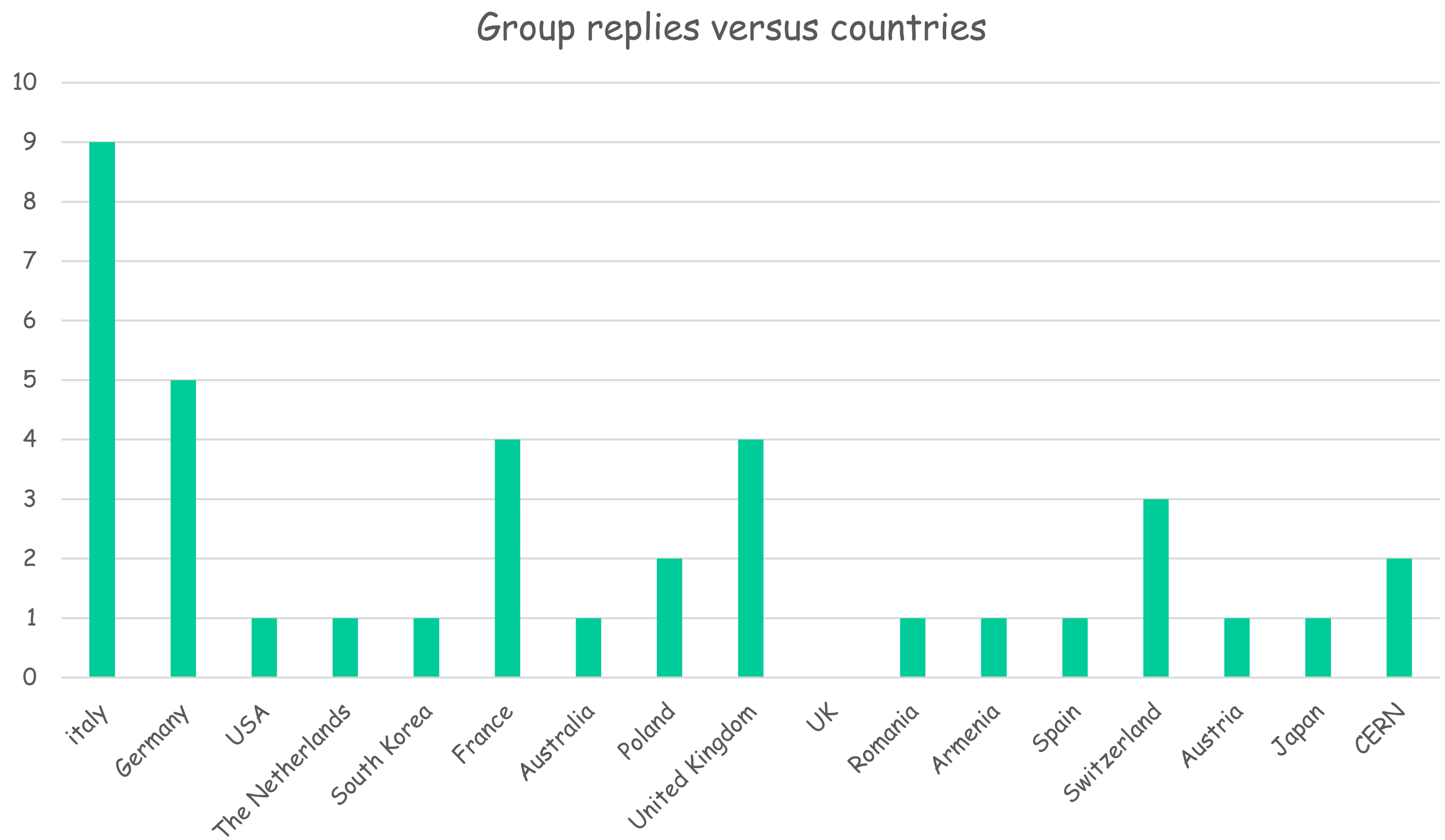
- Recent examples: LHCb SciFi, Mu3e
- Possible R&D goals
  - Higher light yield
  - Longer attenuation length
  - More radiation hardness
  - Better geometrical parameters (no bumps)
  - Effective mat production technology





Quick analysis of returned surveys

ECFA TF-4 Survey : 40 groups replying



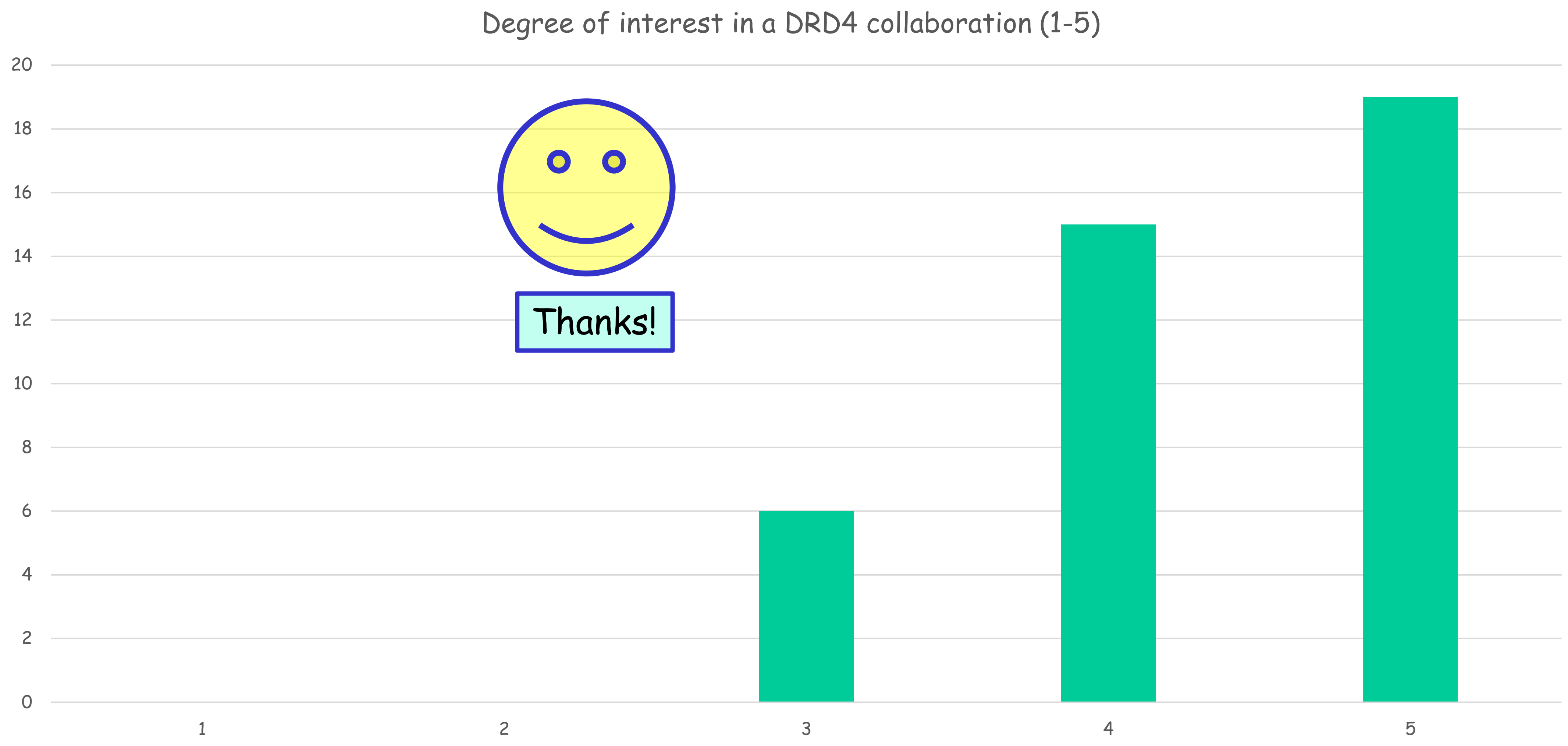
Replying Groups (40)

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

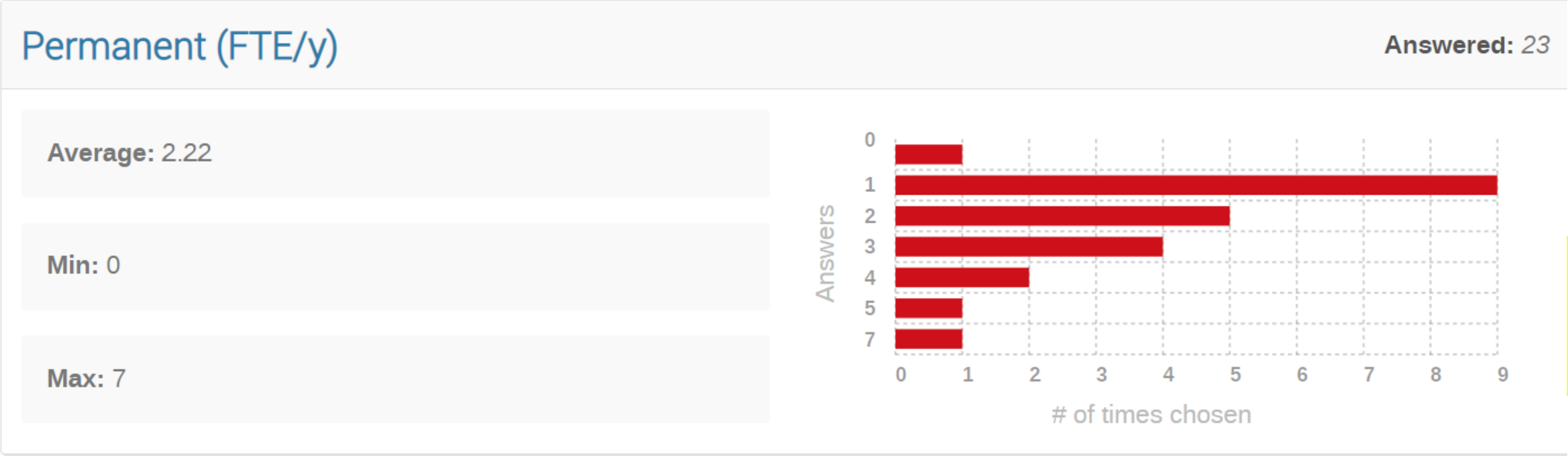
Involved experiments (double countings not removed)

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 resposibility)
Electron Ion Collider/ hpDIRC
Belle II, ARICH
DUNE, ATLAS, MoEDAL
lhcb

Degree of interest in a DRD4 collaboration



ECFA TF-4 Survey. Personnel resources. Groups replying (23)



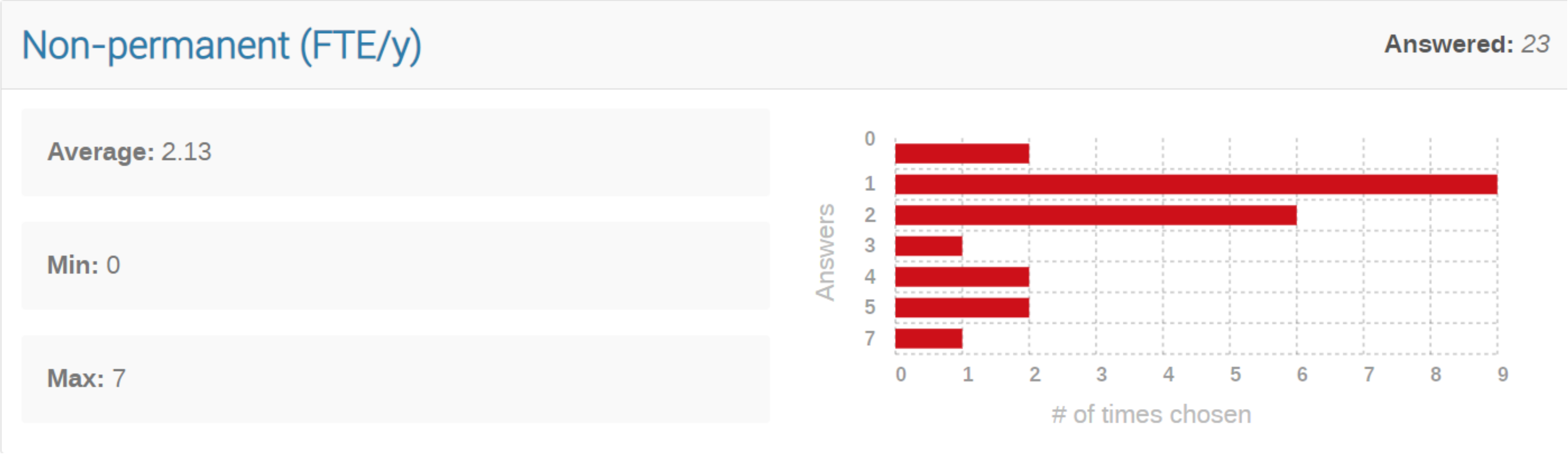
Permanent (FTE/y)

Answered: *23*

Average: 2.22

Min: 0

Max: 7



Non-permanent (FTE/y)

Answered: *23*

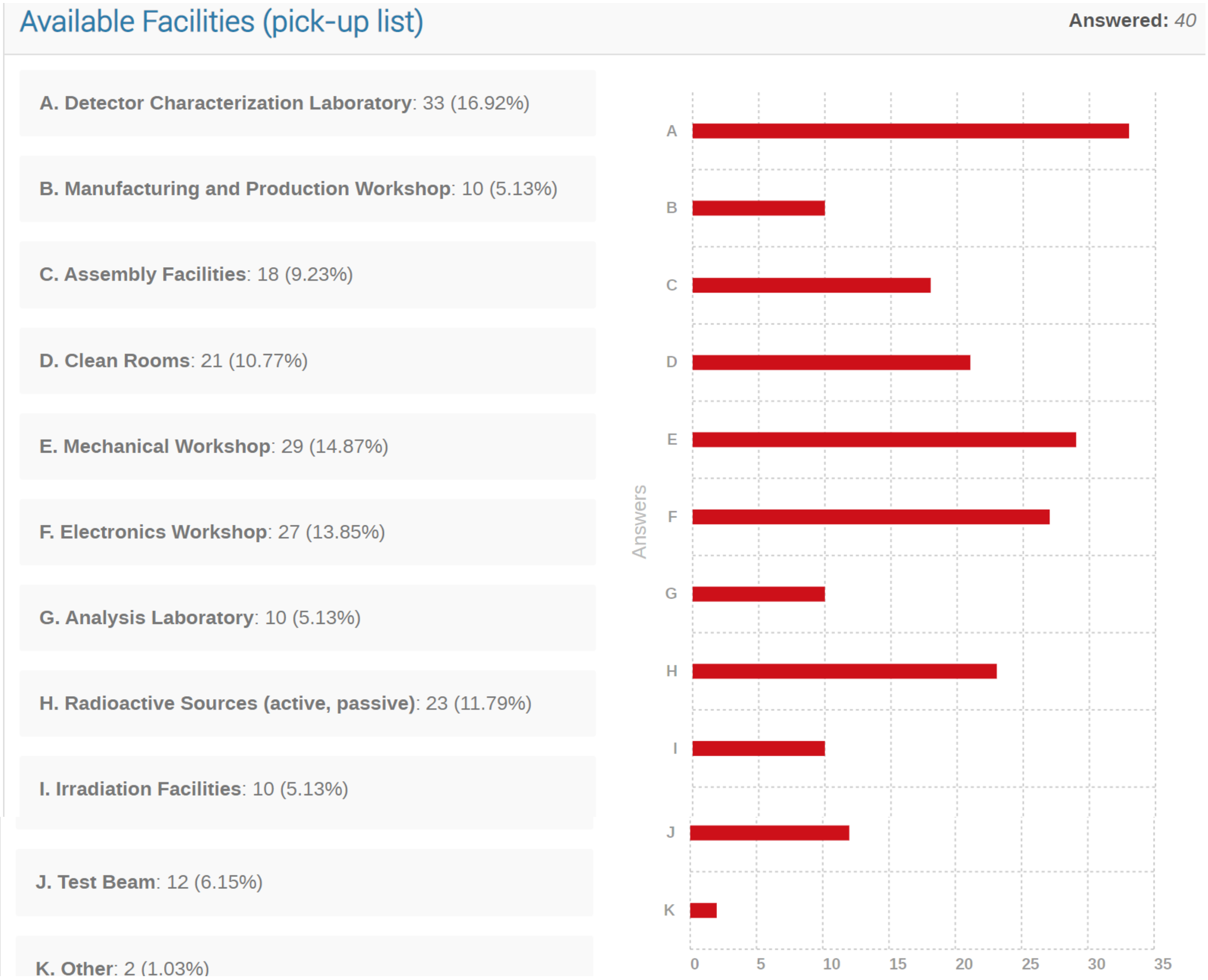
Average: 2.13

Min: 0

Max: 7

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

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%)

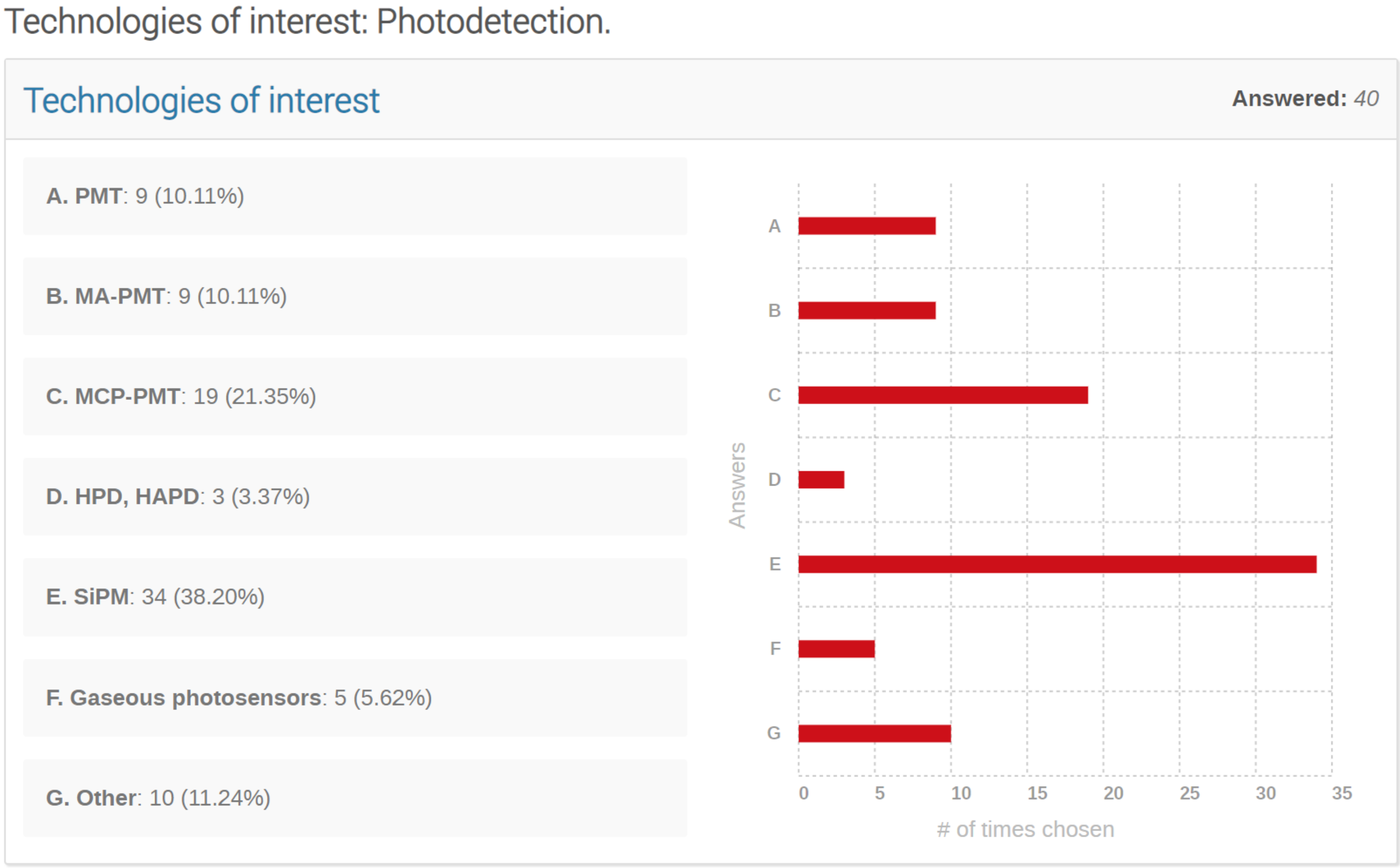
H. Radioactive Sources (active, passive): 23 (11.79%)

I. Irradiation Facilities: 10 (5.13%)

J. Test Beam: 12 (6.15%)

K. Other: 2 (1.03%)

Technologies of Interest (Photodetection)



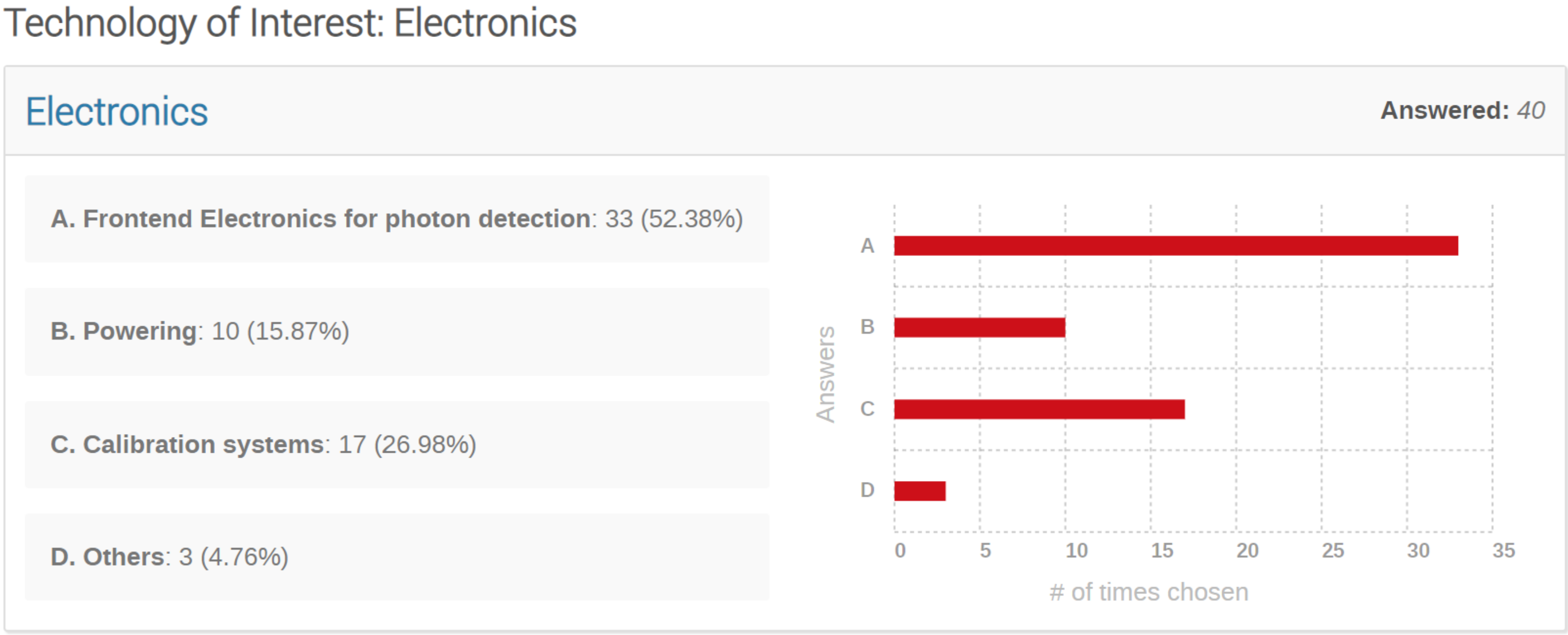
Technologies of interest: Photodetection.

Technologies of interest

Answered: *40*

- **A. PMT**: 9 (10.11%)
- **B. MA-PMT**: 9 (10.11%)
- **C. MCP-PMT**: 19 (21.35%)
- **D. HPD, HAPD**: 3 (3.37%)
- **E. SiPM**: 34 (38.20%)
- **F. Gaseous photosensors**: 5 (5.62%)
- **G. Other**: 10 (11.24%)

Technology of Interest: Electronics



Technology of Interest: Electronics

Electronics

Answered: *40*

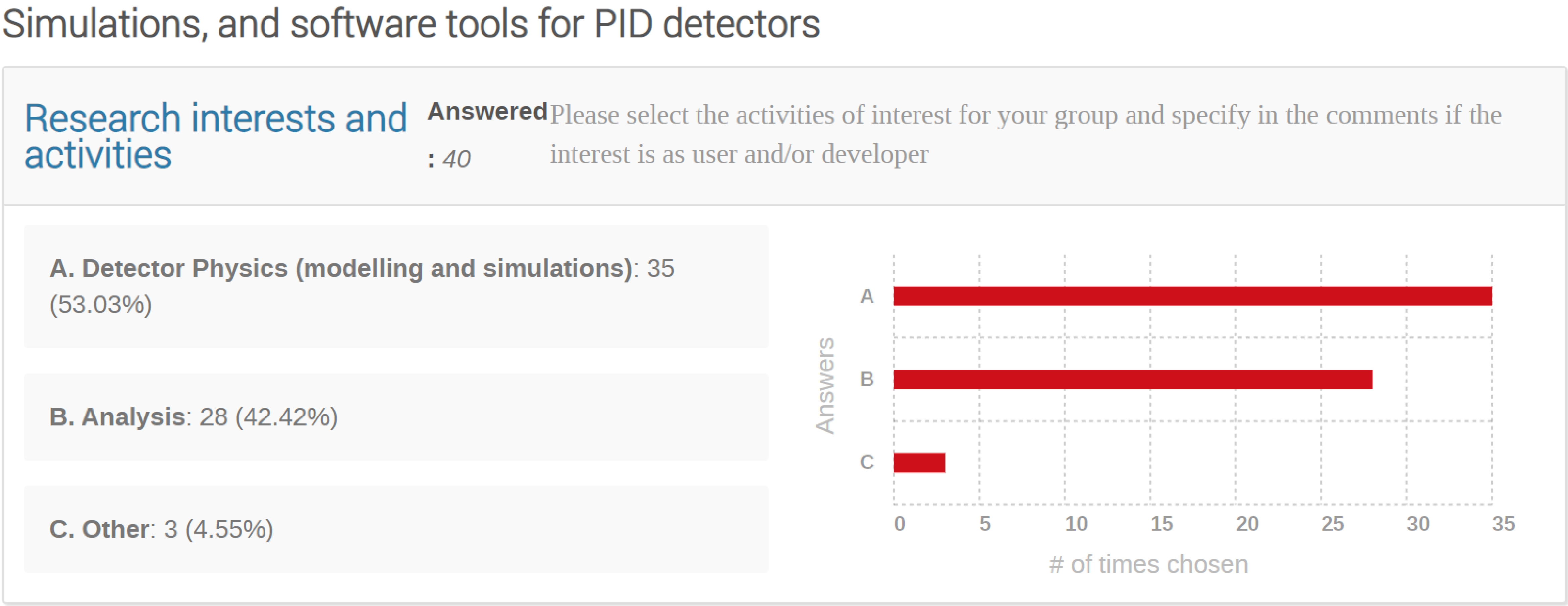
A. Frontend Electronics for photon detection: 33 (52.38%)

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*

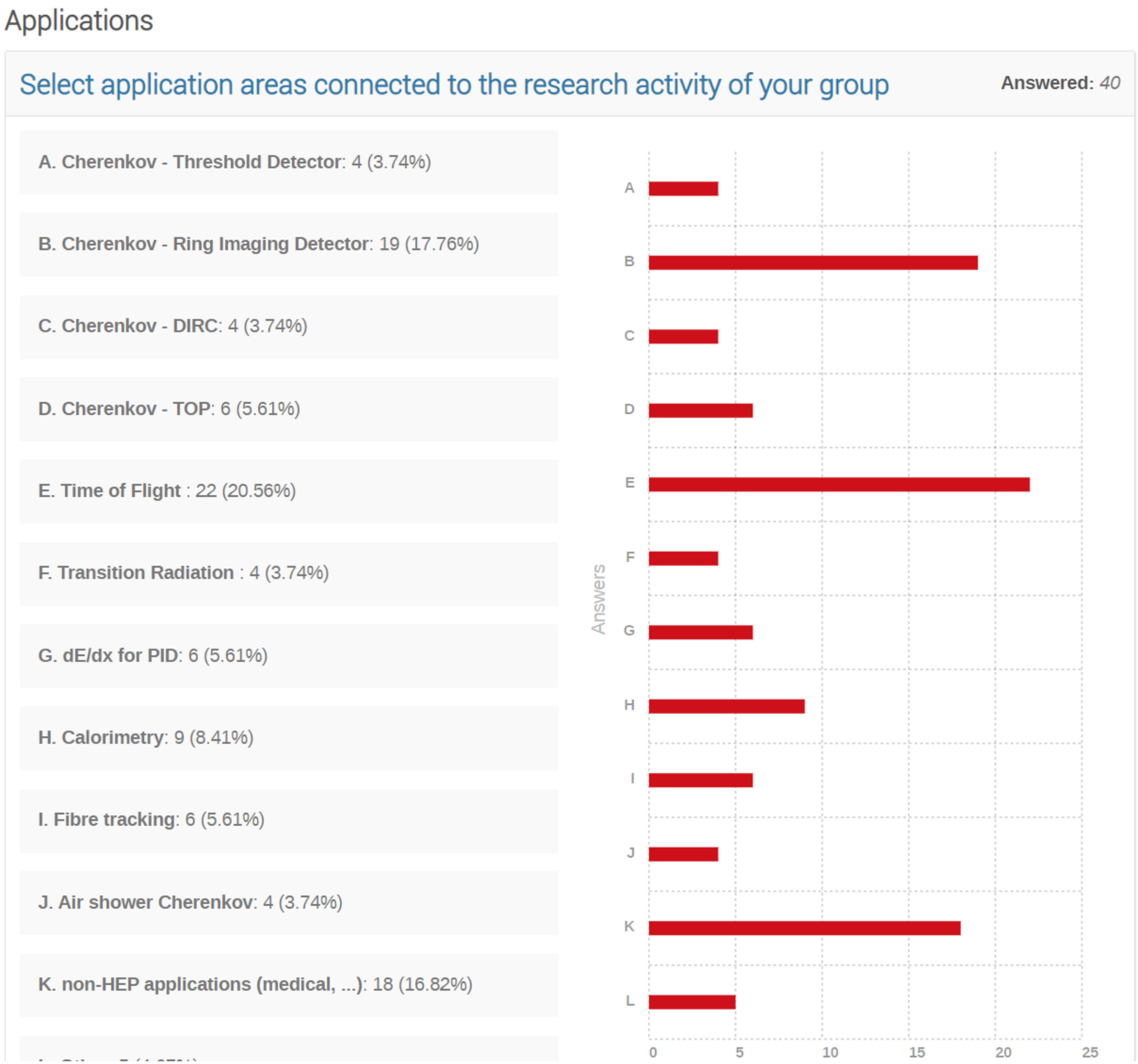
Please select the activities of interest for your group and specify in the comments if the interest is as user and/or developer

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%)
- L. Other: 5 (4.67%)

Tentative Programme for Community Meeting

Tue, 16/05, morning, 0.5h

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

Session Photodetection,
- SiPM, SPAD, PMT, MCP 12 talks

Session Technologies
- **Materials**
- **Software**

3 talks

Session Particle ID 6 talks
- RICH/DIRC
- TOF/TORCH

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Wed, 17/05

Session 'blue sky', special, etc. 3 talks

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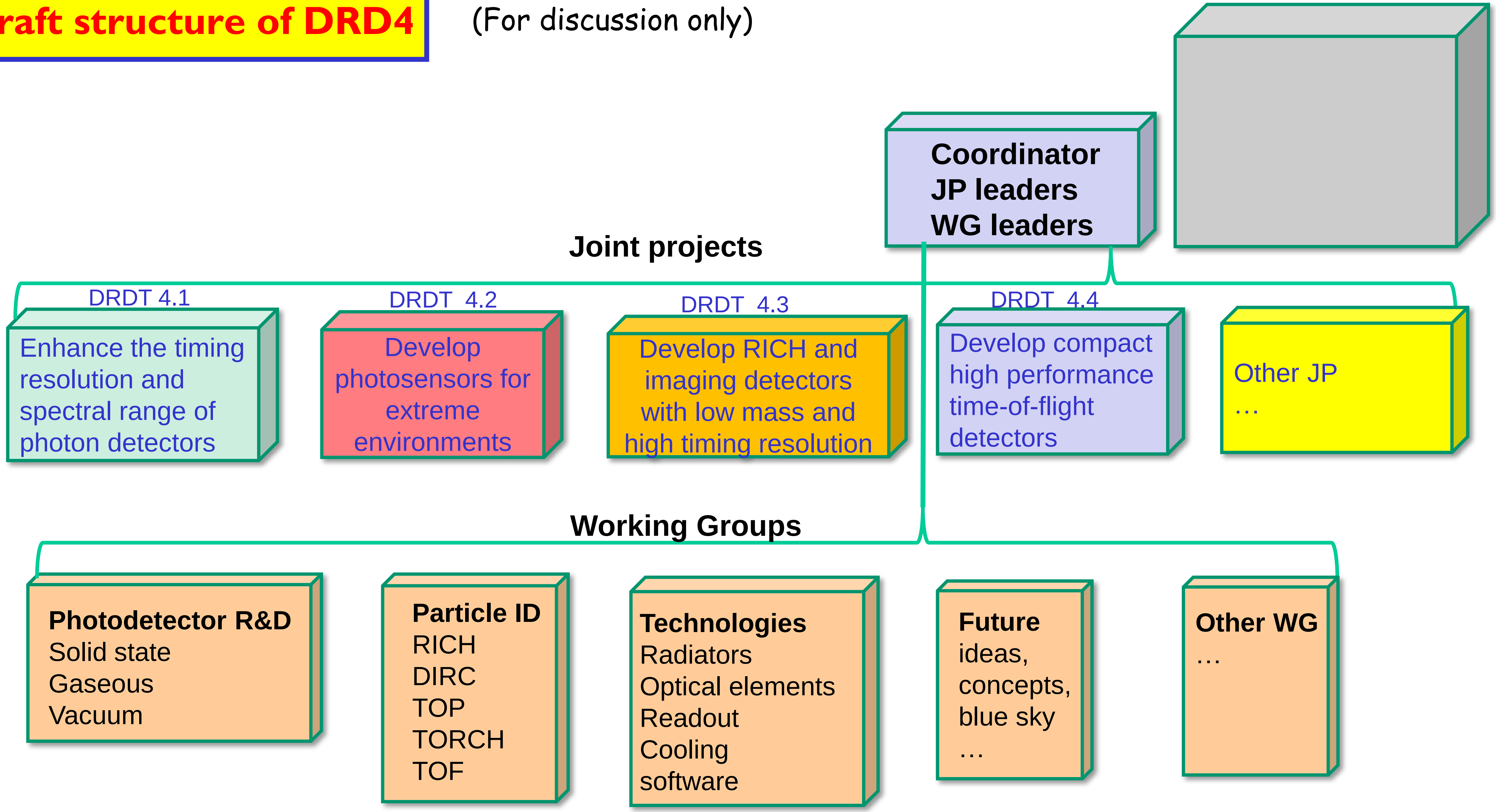
SPARE SLIDES

Draft structure of DRD4

(For discussion only)



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

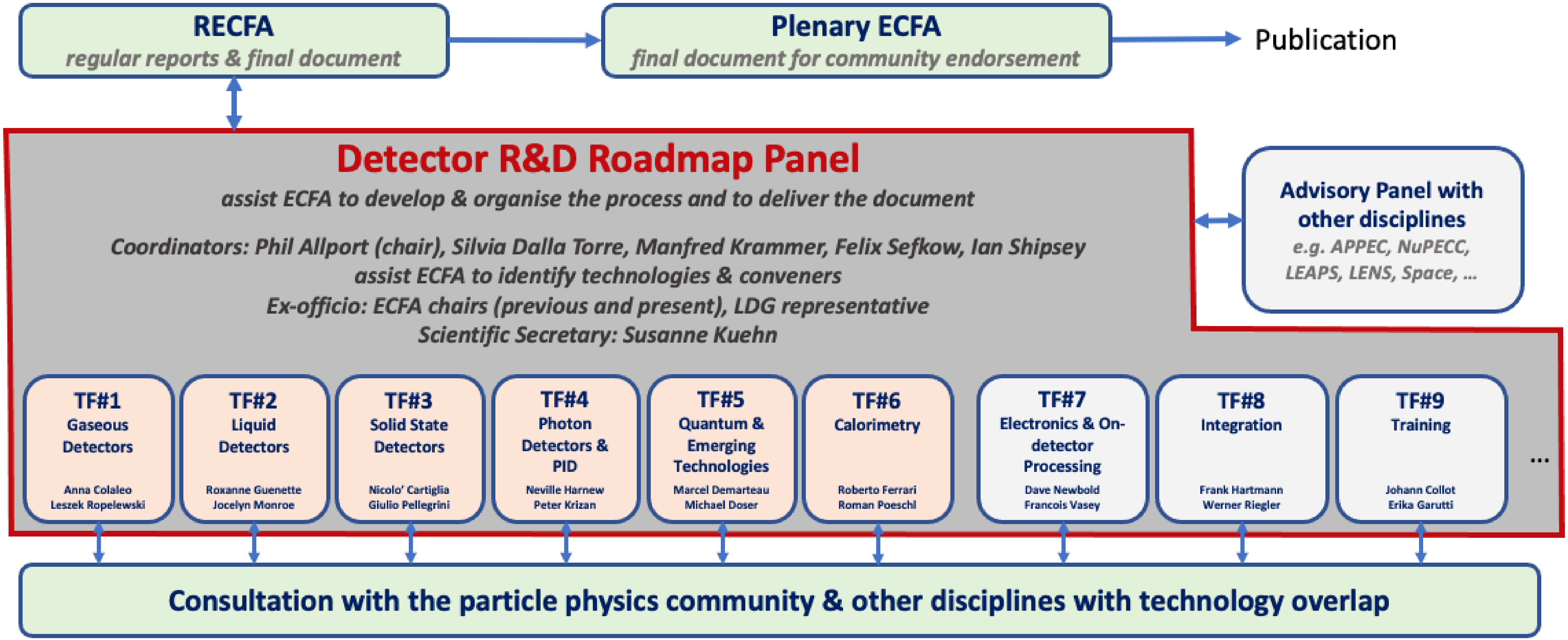
Particle ID
RICH
DIRC
TOP
TORCH
TOF

Technologies
Radiators
Optical elements
Readout
Cooling
software

Future
ideas,
concepts,
blue sky
…

Other WG
…

Organisation of Detector R&D Roadmap



RECFA
regular reports & final document

Plenary ECFA
final document for community endorsement

Publication

Detector R&D Roadmap Panel

assist ECFA to develop & organise the process and to deliver the document

Coordinators: Phil Allport (chair), Silvia Dalla Torre, Manfred Krammer, Felix Sefkow, Ian Shipsey
assist ECFA to identify technologies & conveners
Ex-officio: ECFA chairs (previous and present), LDG representative
Scientific Secretary: Susanne Kuehn

Advisory Panel with other disciplines
e.g. APPEC, NuPECC, LEAPS, LENS, Space, …

TF#1 Gaseous Detectors — Anna Colaleo, Leszek Ropelewski

TF#2 Liquid Detectors — Roxanne Guenette, Jocelyn Monroe

TF#3 Solid State Detectors — Nicolo' Cartiglia, Giulio Pellegrini

TF#4 Photon Detectors & PID — Neville Harnew, Peter Krizan

TF#5 Quantum & Emerging Technologies — Marcel Demarteau, Michael Doser

TF#6 Calorimetry — Roberto Ferrari, Roman Poeschl

TF#7 Electronics & On-detector Processing — Dave Newbold, Francois Vasey

TF#8 Integration — Frank Hartmann, Werner Riegler

TF#9 Training — Johann Collot, Erika Garutti

…

Consultation with the particle physics community & other disciplines with technology overlap

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

< 2030	2030-2035	2035-2040	2040-2045	> 2045
SPS fixed target Other fixed target, FAIR (hep) Belle II ALICE LS3 PIP-II/LBNF/DUNE/Hyper-K	ALICE 3 LHCb (≥ LS4) EIC LHeC	ILC	FCC-ee CLIC	FCC-hh FCC-eh Muon Collider

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