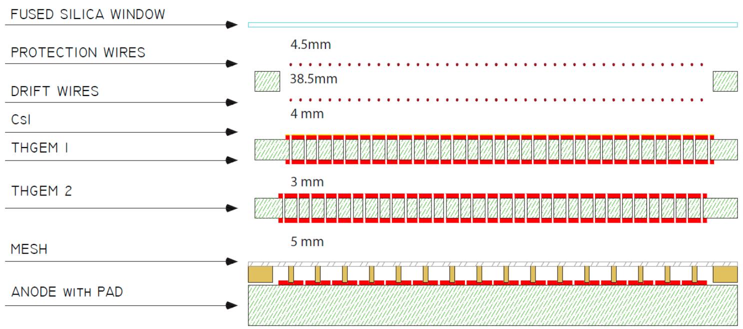
PHOTODETECTORS

DRD1 survey analysis

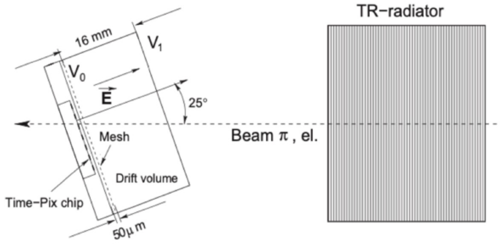
P. Gasik
(GSI/FAIR)

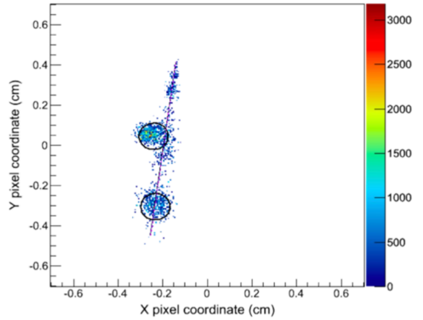


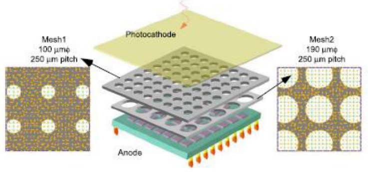
Challenges

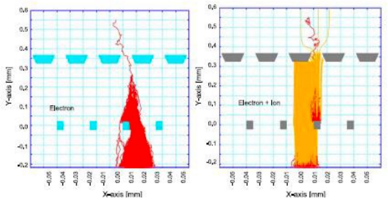
- Reduce the photon feedback generated in the multiplication process which leads to spurious signals;
- Reduce the IBF rate because the ion bombardment destroys the proportional chamber and limits the lifetime of the detector (R&D line in common with TPC needs, DRDT 1.2)
- Improve the detector performance in terms of spatial and time resolution, along with fast response in order to open the way to high-rate capabilities and precision measurements (DRDT 1.1).

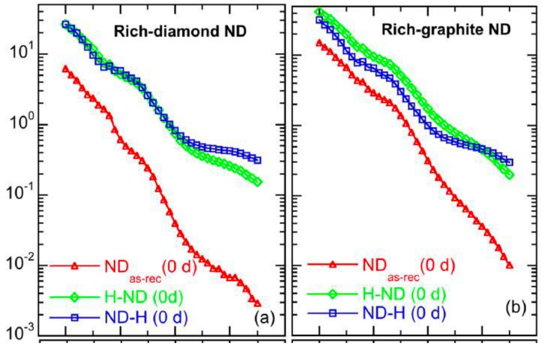
Facility	Technologies	Challenges	Most challenging requirements at experiment
Hadron and nuclear physics (EIC, AMBER, PANDA and CMB@FAIR)	**Gaseous-RICH** with MPGD-based photon detector **TRD** with GEM or GridPix	- **RICH:** Compact, single photon detection, high gain, fine spatial and time resolution, eco-friendly gas radiator, high pressure; limited IBF, novel photoconverters - **TRD:** cluster counting technique, heavy gas for X-ray absorption, TRD photon -dE/dx separation.	**(EIC-gaseous RICH)** 1 meter of radiator gas High-gain: 10^5 - 10^6 Spatial resolution: O(1mm pitch) Time resolution (even with small signals) $\lesssim$ 1n Tolerance to magnetic field (1.5 - 3 T) Rad-hardness up to 10^{11} neq/cm² option: High Pressure-Rich: Ar @ 3.5 bar **(EIC-TRD)** compactness 10^{-2} rejection in 20-30 cm improved MIP/x-ray identification
Higgs-EW-Top Factories (ee) (FCC-ee/CepC)	**Gaseous-RICH** with MPGD-based photon detector	- **RICH:** Compact, single photon detection, high gain, fine spatial and time resolution, eco-friendly gas radiator, high pressure, limited IBF, novel photoconverters	**(Gaseous-RICH):** High-gain: 10^5 - 10^6 Spatial resolution O(1mm pitch) Time resolution (even with small signals) $\lesssim$ 1ns





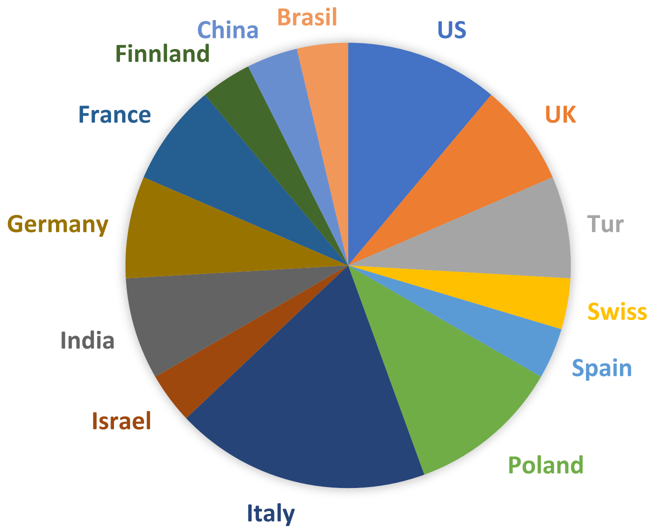


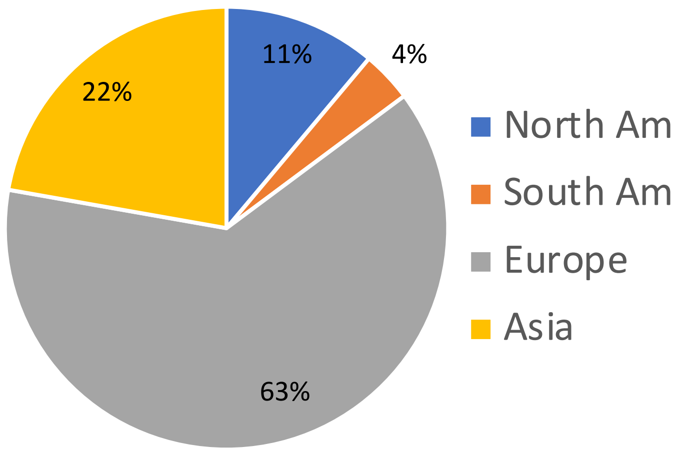


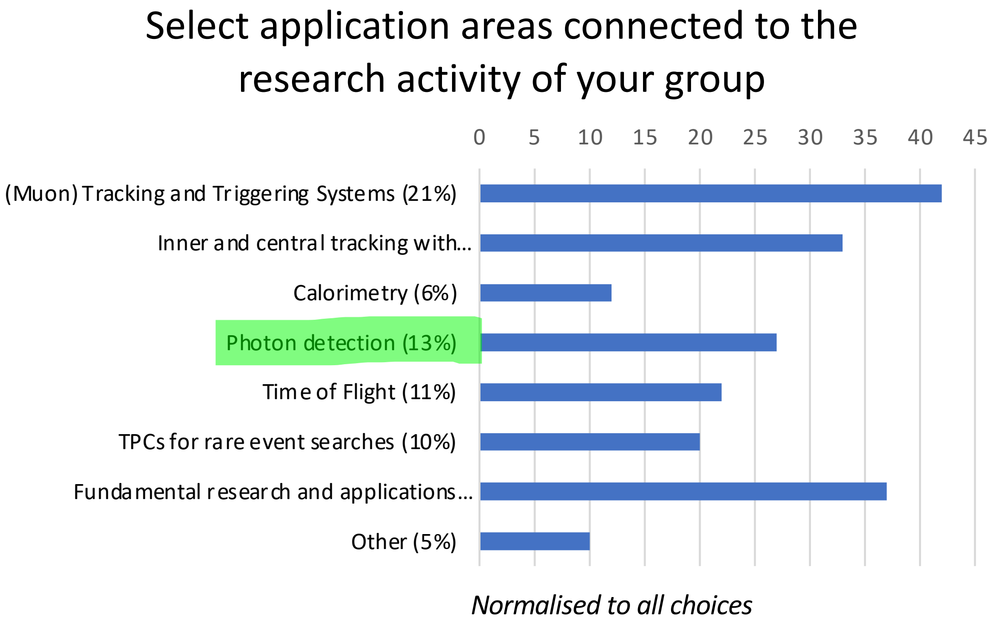


Survey for photodetectors

- 40 % of institutes interested in this application
- 3 % (2 institutes) are interested solely in photon detection (inc. beyond HEP applications)





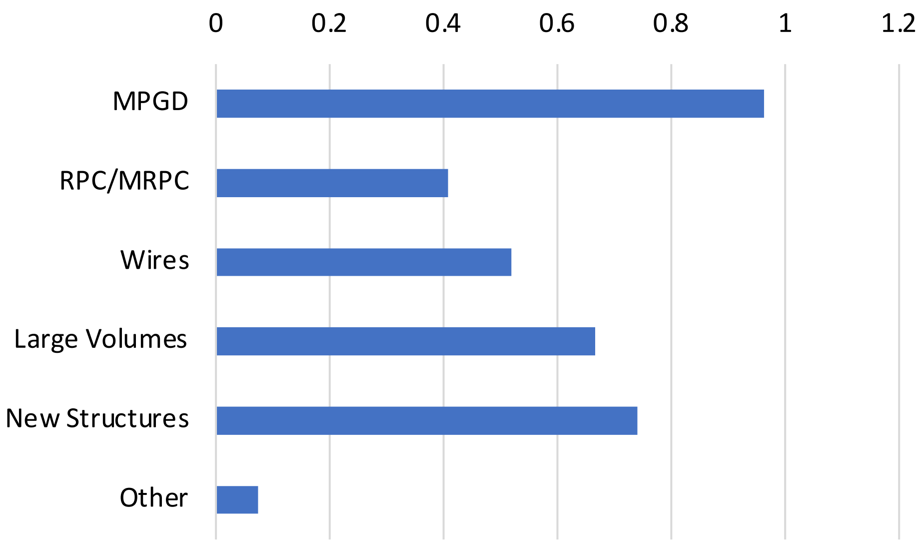


- Photodetectors chosen without any specific topic: 5
- Photo-topic chosen without photo technology of interest: 1

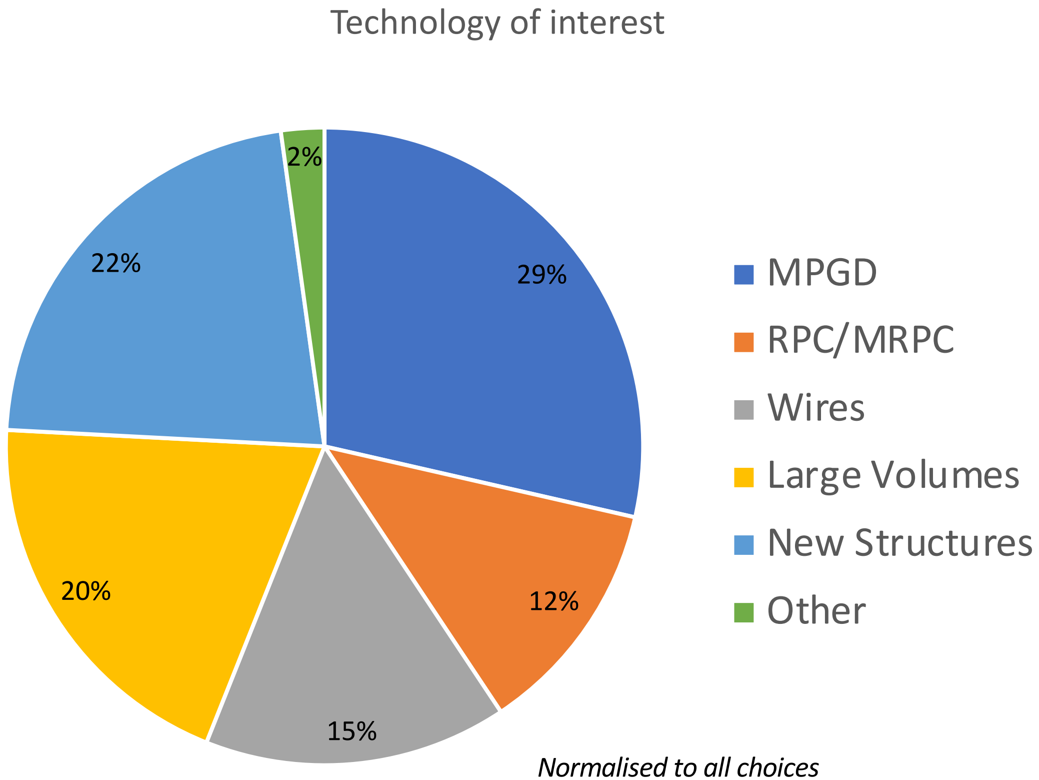
Technologies of interest at the photo-institutes

- Technology specific for photo detectors:

MPGDs based (from comments)



Normalised to no. institutes



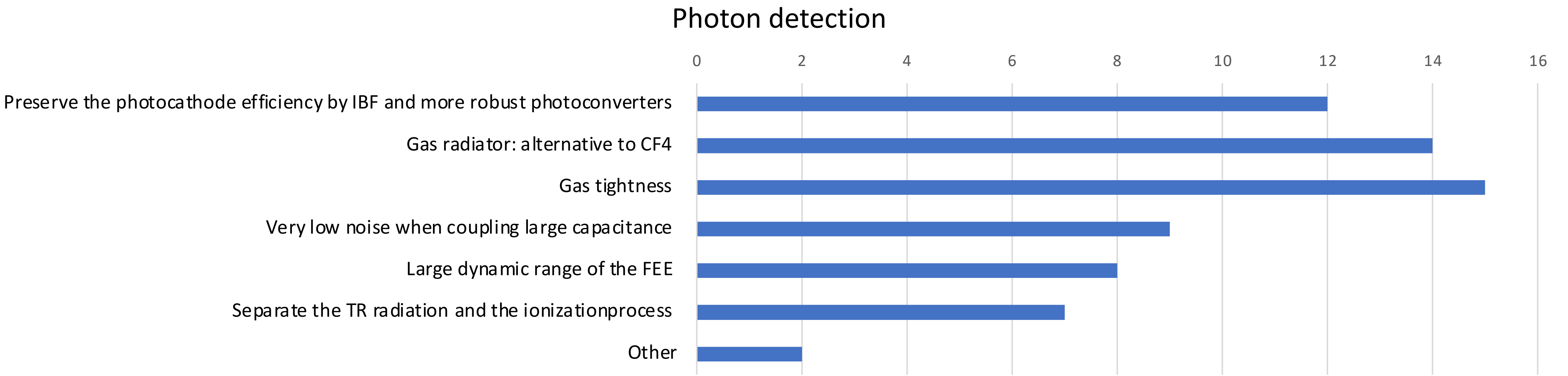
Normalised to all choices

Specific topics

Please provide specific research activities of interest for your group:

- Preserve the photocathode efficiency by IBF and more robust photoconverters
- Gas radiator: alternative to CF_4
- Gas tightness
- Very low noise when coupling large capacitance
- Large dynamic range of the FEE
- Separate the TR radiation and the ionization process
- Other

Specific topics



All topics covered, to some extend…

The case where the primary scintillation in the detector needs to be detected is perhaps not very fitting here but I found no better place. I chose the bullets that relate to that, where the word 'radiator' would need to be changed to 'scintillator'.

X-ray detection!

direct VUV detection. image intensifiers, VUV optics. applications of TPX4 cameras for TPC readout

-

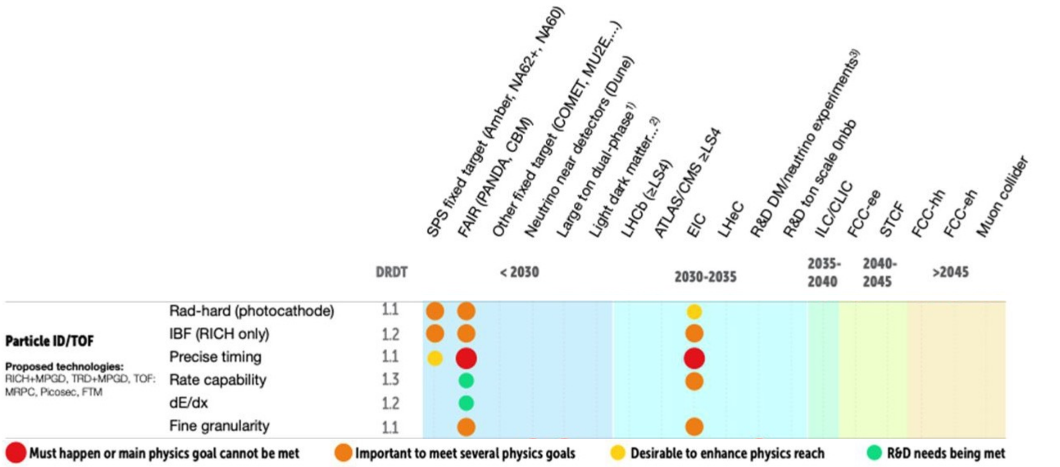
presently mainly soft X-ray.

There is some interest in the topics marked above at GSI, although the investigations have not been pushed that way so far.

Topics of interest or under study in the group, though not necessarily connected to the specific application.

Specific comments

ECFA Roadmap challenges



- Photocathodes
  - Expression of interest (ageing, material studies)
  - IBF minimization, robust photoconverters, photocathode characterization
  - Photocathodes and solid converter studies clearly indicated by photodetector institutes in WG3 survey
- Gas radiator – no specific comments
- Gas tightness
  - EoI to participate in dev.
- FEE – no specific comments to photodetectors
  - WG5 survey: clear indication to develop wide dynamic range FEE; some interest in low-noise FEE
- TRD
  - No specific mention of TRD at all apart from 7 interested sites

Photon detection

- Preserve the photocathode efficiency by IBF and more robust photoconverters
- Gas radiator: alternative to CF4
- Gas tightness
- Very low noise when coupling large capacitance
- Large dynamic range of the FEE
- Separate the TR radiation and the ionization process
- In TRD use of cluster counting technique and improve it by means of a InGrid

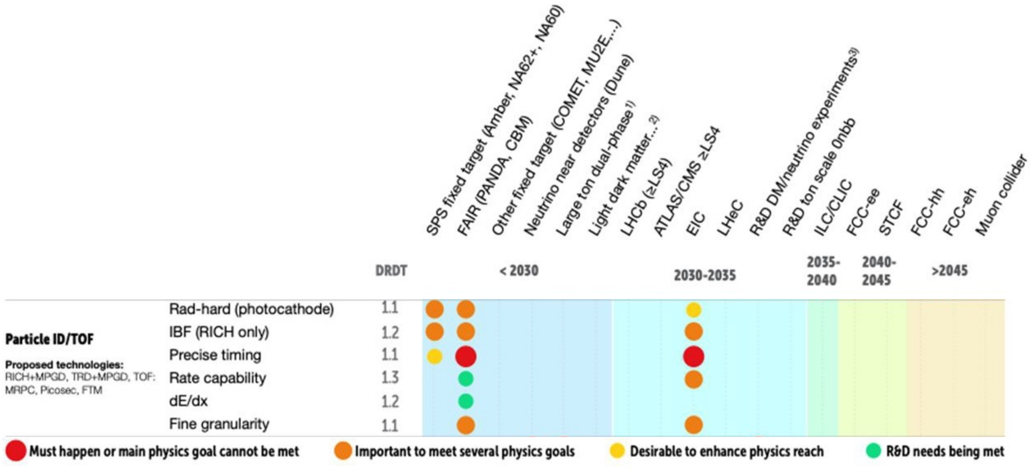
Particular activities in the community, assets

Assets that can support the collaboration:

- A large variety of photodetector developments:
  - MPGD single-photon detectors (THGEM, MMG, CsI)
  - MPGD single-photon detectors for medical imaging (THGEM+MM)
  - Visible range photodetectors
  - MPGD RICH, HBD
- A large variety of material studies
  - Fast photodetectors with innovative photocathode substrates
  - Photoconverters compatible with operation in gas detectors (hydrogenated nanodiamonds)
- Optical readout experience
- Existing infrastructure
  - Photocathode characterization systems (QE, aging vs IBF)
  - Coating facilities
  - Photodetector development platforms

Assets that the collaboration can support (working groups):

- Detector production facilities
- Establish common production and test standards
- Characterisation and understanding of detector physics
- Simulation framework



Resources

- 6 (22%) institutes declared a plan to submit requests for a new strategic R&D budget
- 10 (37%) institutes declared they do not plan to submit requests for additional budget
- No comment specifying the application

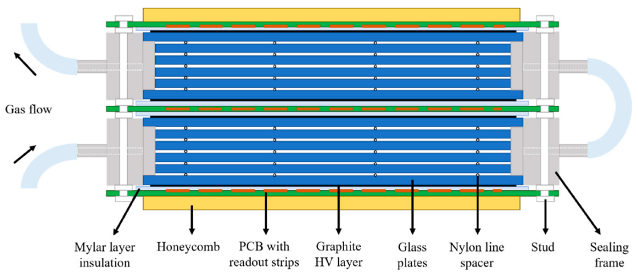
- Same for no. personnel (no discussion of who is working on the given application)

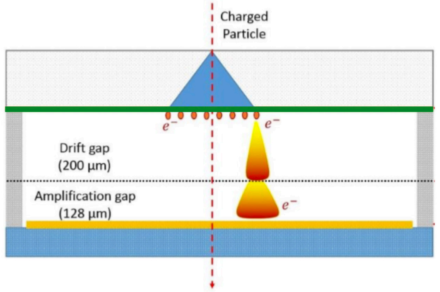
Time of Flight

DRD1 survey analysis

D. Gonzalez Diaz (USC)
P. Gasik (GSI/FAIR)

TOF challenges



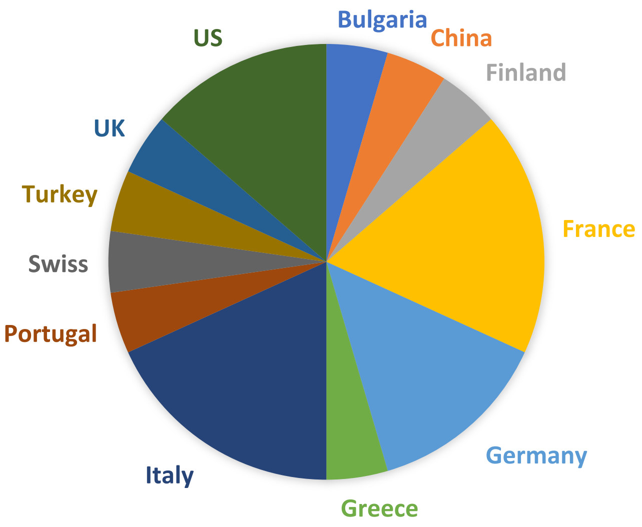


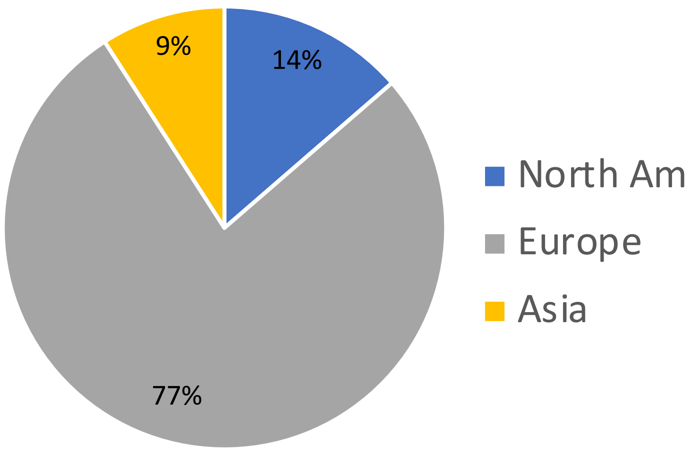
- Keep uniform response, in terms of high rate capability and time resolution (DRDT 1.1), over a large TOF detector area while operating with eco-friendly gases(DRDT 1.3).
- R&D has to continue towards an ultimate time resolution of 20 ps.
  - **MRPCS**: this can be achieved by reducing the thickness of the gas gaps O(100 um) and by increasing the number of gaps ($\mathcal{O}$(10)) to maintain high efficiency. A rate capability up to 100 kHz/cm^2, necessary for systems in high radiation environments, could be achieved by thinner (better signal induction), and low resistive electrodes (order of 10^7 Ωm).
  - **PICOSEC**, FTM: requires, in particular, identifying less expensive materials (radiators for PICOSEC) and very precise mechanical stability and uniformity. Synergetic to photodetectors: development of robust photocathodes by exploration of novel materials and photoconverter protection, stable operation, IBF optimization
- In addition, time resolution below 15-20 ps is comparable to the avalanche jitter level, requiring novel very low-noise front-end electronics. The development of dedicated low-noise electronics coping with high input capacitance and large dynamic range requirements is thus essential

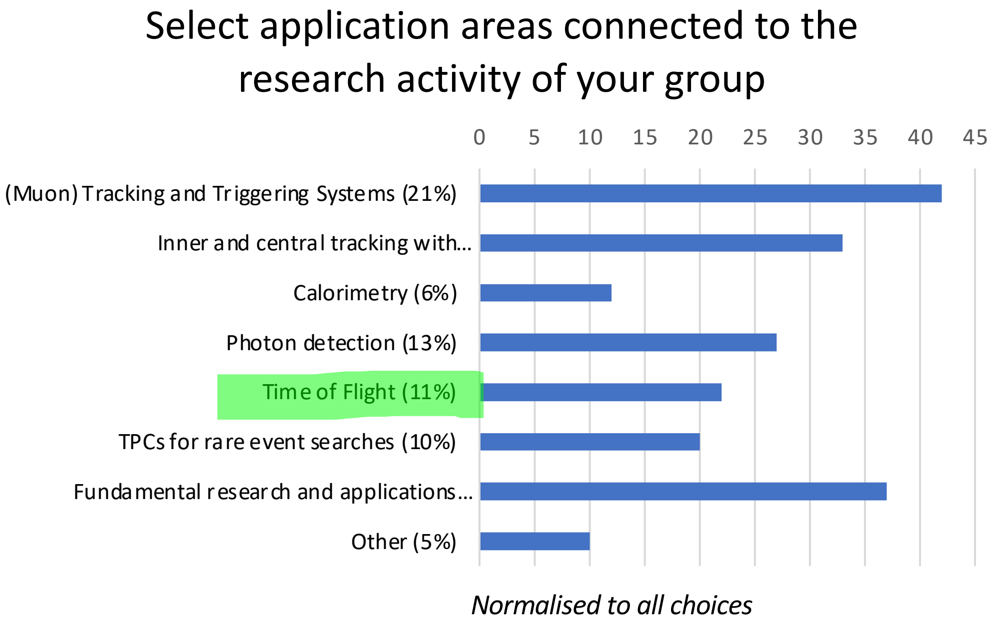
Facility	Technologies	Challenges	Most challenging requirements at experiment
Hadron and nuclear physics (CMB@FAIR, SOLID@JLAB, CEE@HIRFL-CSR)	MRPC, MPGD with precise timing (PICOSEC, FTM)	Rate capability, radiation hardness, large area detectors, new material, eco-gas, thinner structures, FEE, system time distribution	**(CMB)** Max Rate = 30 kHz/cm² Full system time resolution < 80 ps Occupancy < 5% Full system area = 120 m² ~100.000 channels, low power electronics

Survey

- 32% of institutes marked TOF as an application of interest
- Usually together with (muon) tracking and triggering systems





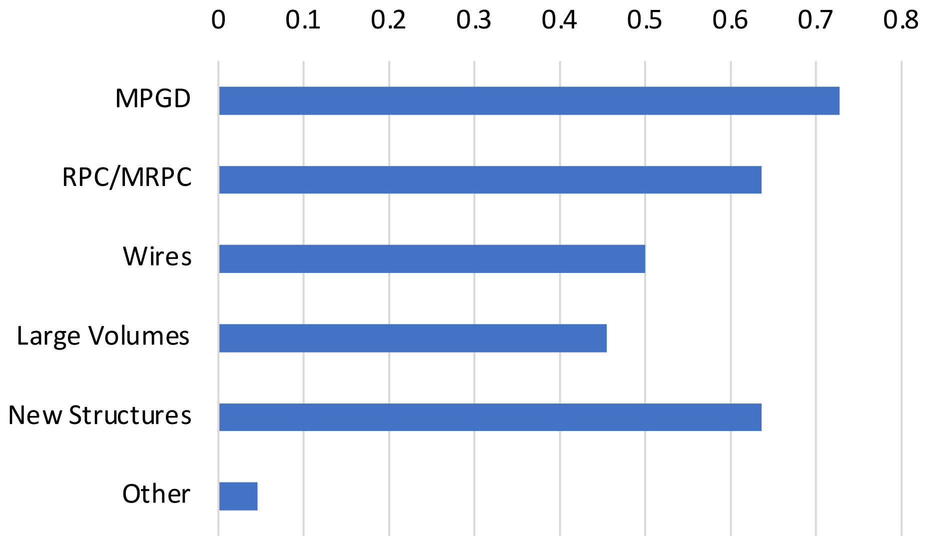


- Photodetectors chosen without any specific topic: 1
- Photo-topic chosen wothout photo technology of interest: 3

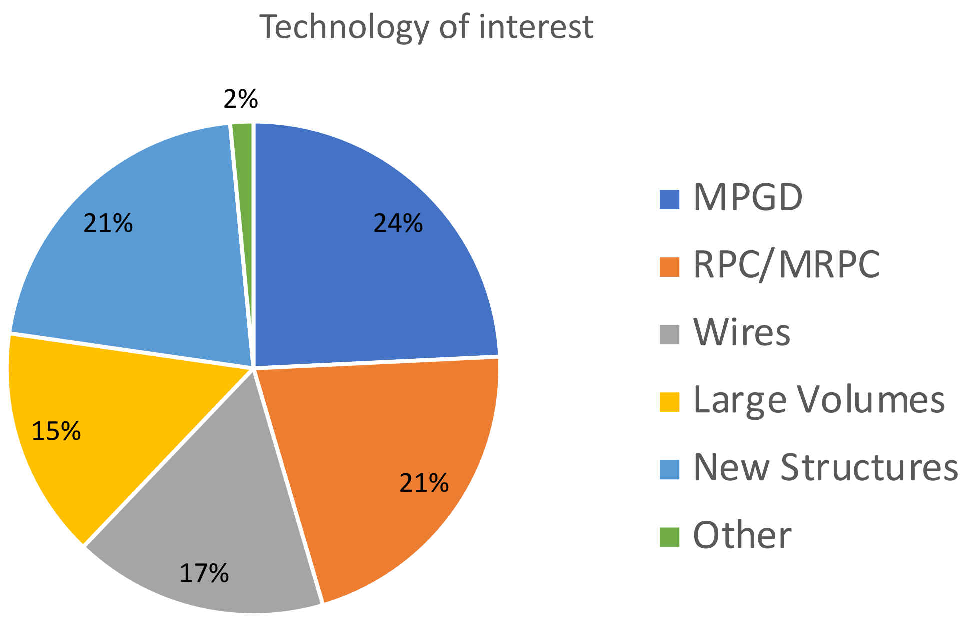
Technologies of interest at the TOF-institutes

- Technology specific for TOF detectors:

PICOSEC, MRPC (from comments)



Normalised to no. institutes



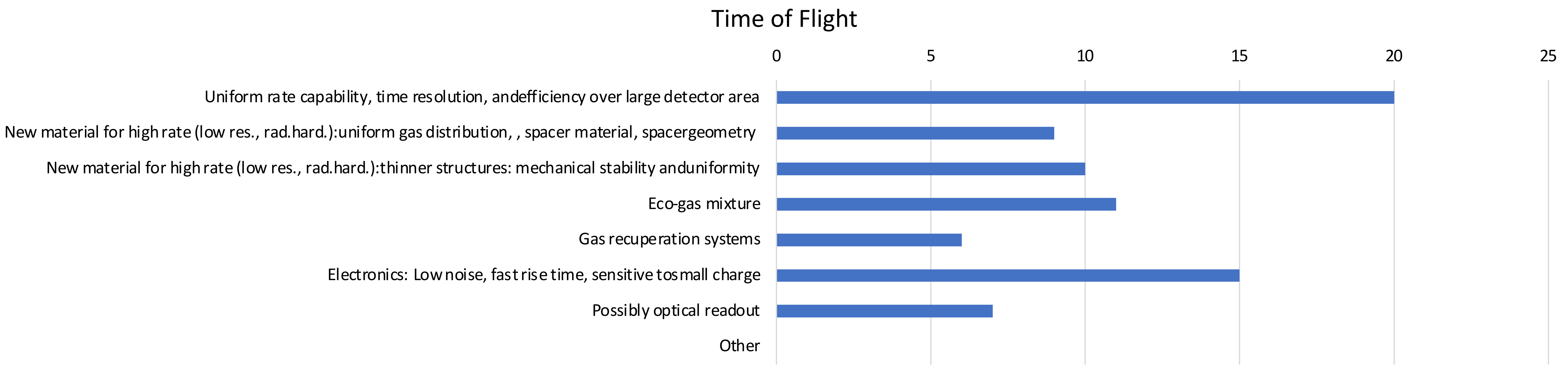
Normalised to all choices

Specific topics

Please provide specific research activities of interest for your group:

- Uniform rate capability, time resolution, and efficiency over large detector area
- New material for high rate (low res., rad.hard.): uniform gas distribution, spacer material, spacer geometry
- New material for high rate (low res., rad.hard.): thinner structures: mechanical stability and uniformity
- Eco-gas mixture
- Gas recuperation systems
- Electronics: Low noise, fast rise time, sensitive to small charge
- Possibly optical readout
- Other

Specific topics



All topics covered, to some extend…

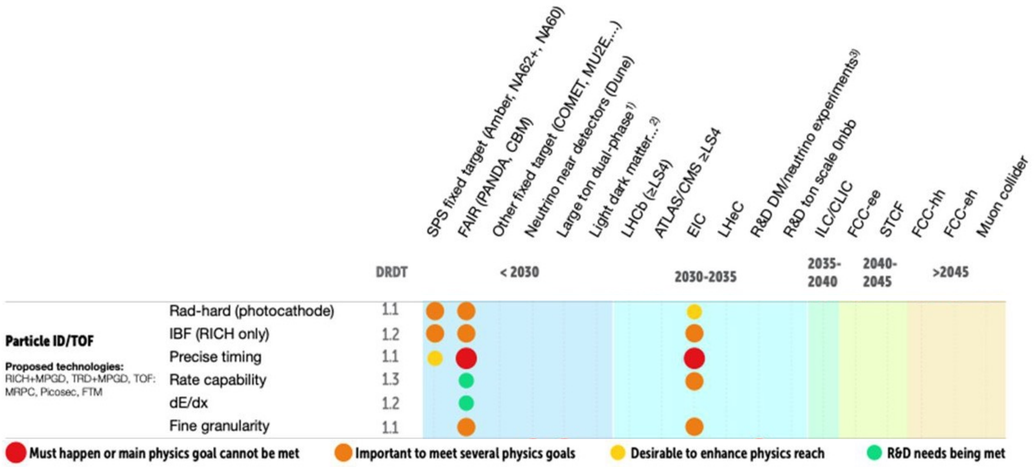
Specific comments

Comments/Notes
Answered: *2*

For timing our interest is in the R&D aiming for the best results with mpgd with single stage amplification, but always in the order of O(ns)

Topics of interest or under study in the group, though not necessarily connected to the specific application.

ECFA Roadmap challenges



Rate capability, timing challenge

- 1-2 references to CBM, No obvious reference to SPS or EIC.
- Many references to ns-level technology (RPC, MPGD, wires, straws)
- Several references to MRPC, and clear interest, but very few groups seem to be strong players below the 100 ps landmark (probably just 3!)
- Several references to picosec, one reference to gas + pixel readout.

Gas and material studies:

- Cross-analysis with WG3 show TOF institutes are particularly interested in gas ageing and radiation hardness studies
- new gas mixtures are under test in order to find low-GWP solutions for saturated-avalanche operational mode;
- Interest in resistive materials as well as photocathodes and solid converters (PICOSEC)
- gas recuperation systems ➞ 6 positive answers, no particular comments. Need to investigate institute-wide for developing standards (WG3!)

FEE

- Clear correlation with precision timing and high rate capabilities (WG5 survey)

TOF
• Uniform rate capability and time resolution over large detector area • New material for high rate (low resistivity, radiation hardness) - uniform gas distribution - thinner structures: mechanical stability and uniformity • Eco-gas mixture • Electronics: Low noise, fast rise time, sensitive to small charge • Possibly optical readout • Precise clock distribution and synchronization over large area

Assets

- **Assets that can support the collaboration:**
  - Familiarity with fast timing systems techniques (know-how):
  - How to handle cross-talk, impedance matching, noise, PSA...
  - Learning from (and using) existing electronics.
  - New resistive layers investigated with material science divisions

- **Assets that the collaboration can support (working groups):**
  - **WG1**: ToF developments largely overlaps with muon triggering (WG1 - RPC, MRPC technology)
  - **WG3**: Studies of eco-friendly gases. Recuperation systems → set standards; might help enormously many groups that struggle with costs
  - **WG4**: Simulation of Space-Charge
  - **WG5**: improvement of electronics characteristics (S/N, BW), common electronics seems possible, but requires discussions.
  - **WG6**: MRPC workshops

Resources

- 9 (41%) institutes declared a plan to submit requests for a new strategic R&D budget
- 6 (27 %) institutes declared they do not plan to submit requests for additional budget
- No comment specifying the application

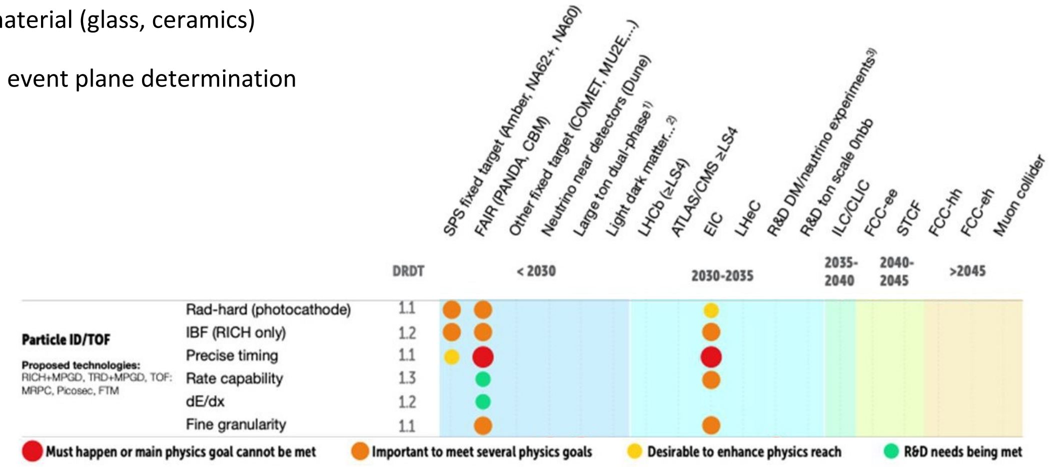
- Same for no. personnel (no discussion of who is working on the given application)

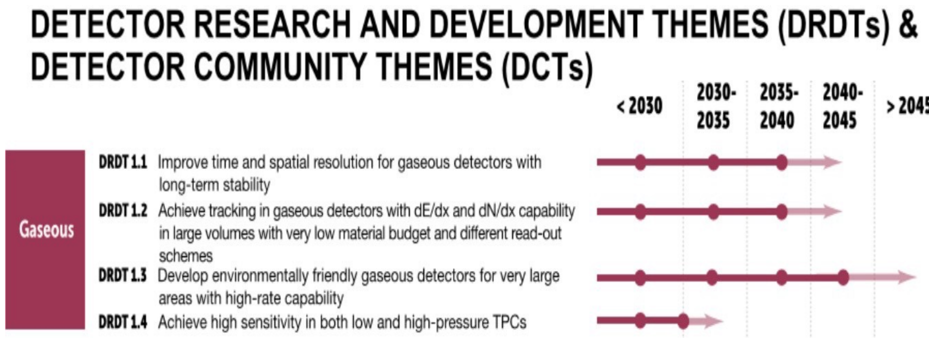
Possible synergies?

(personal view)

Possible synergies, WPs

- **Large-area MPGD-based timing detectors**
- **Ultra high-rate MRPC development**
  - rate capability up to 100 -150 kHz/cm^2, time resolution down to 50 ps
  - use of MRPC technology in single cell/channel layout; very thin (< 0.5 mm) and low resistivity (≤ 10^{10} Ωcm) material (glass, ceramics)
  - Use case: usage in high rate high multiplicity environment for start time by measuring reaction products and event plane determination
- **Medical applications (beyond HEP)**
  - Single photon MPGD-based detector for medical imaging
  - Developments of detectors for PET or CT Imaging applications.
- **WPs related to the development of photocathodes**
  - Cherenkov-based timing detectors, Visible light detectors
  - IBF suppression, discharge protection
- **WPs related to the development of resistive materials**
  - Probably essential for most TOF detectors in the long run (high field/gain operation need)
  - Low resistivity glass for timing MRPCs
  - DLC-based RPCs
- **TRD: differentiate response to X-ray and ionization; TRD with dN/dx?**





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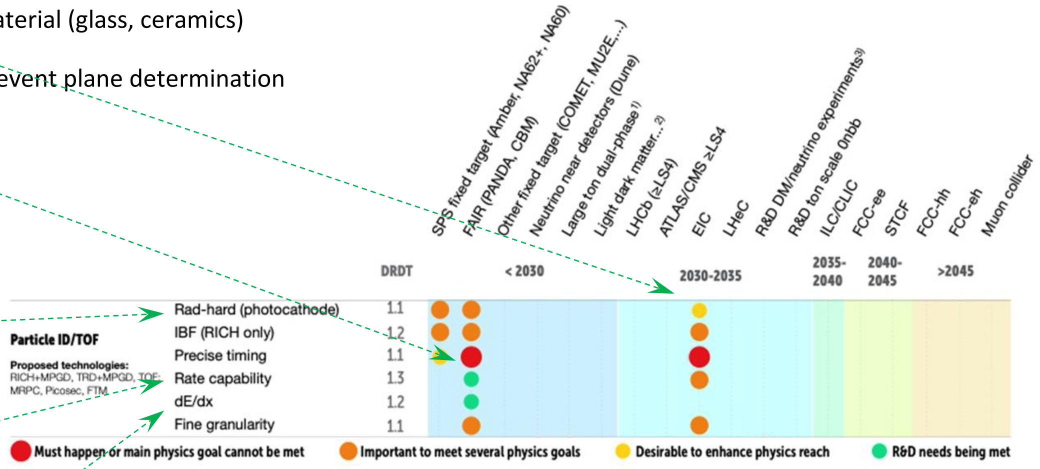

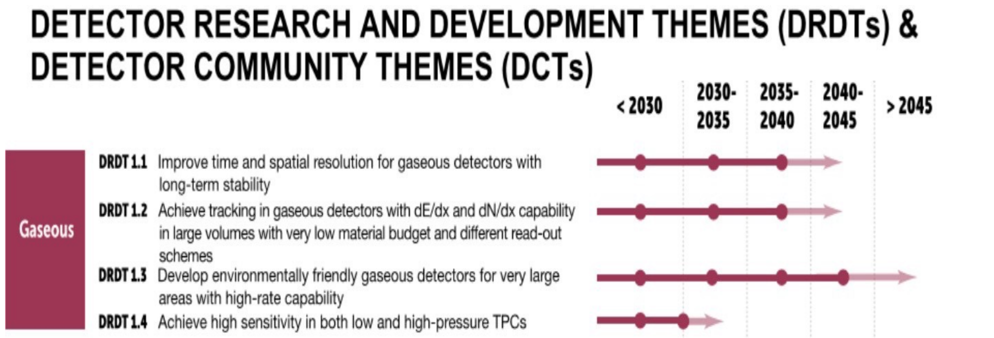

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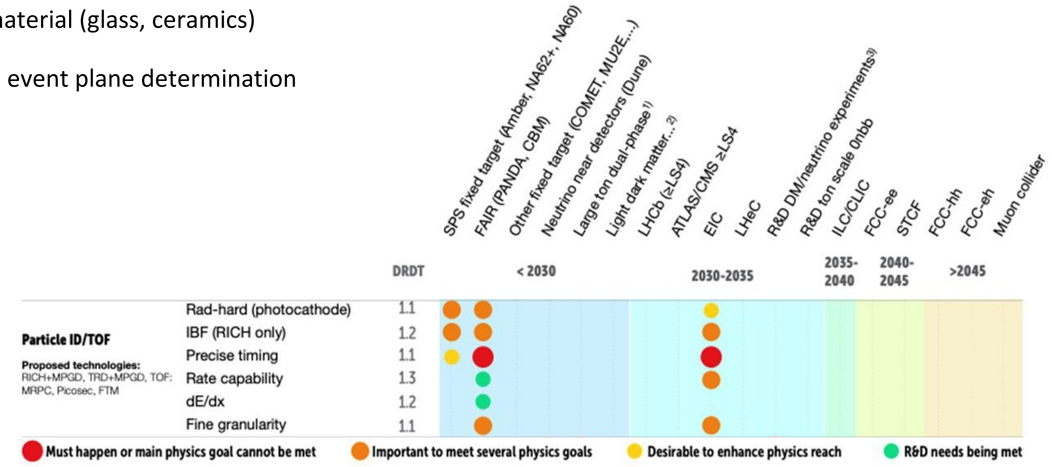
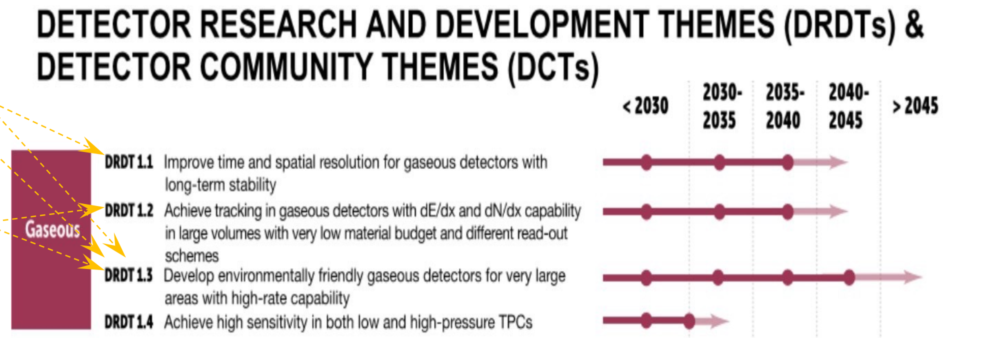




BACKUP

DRD1 WG2 - Applications

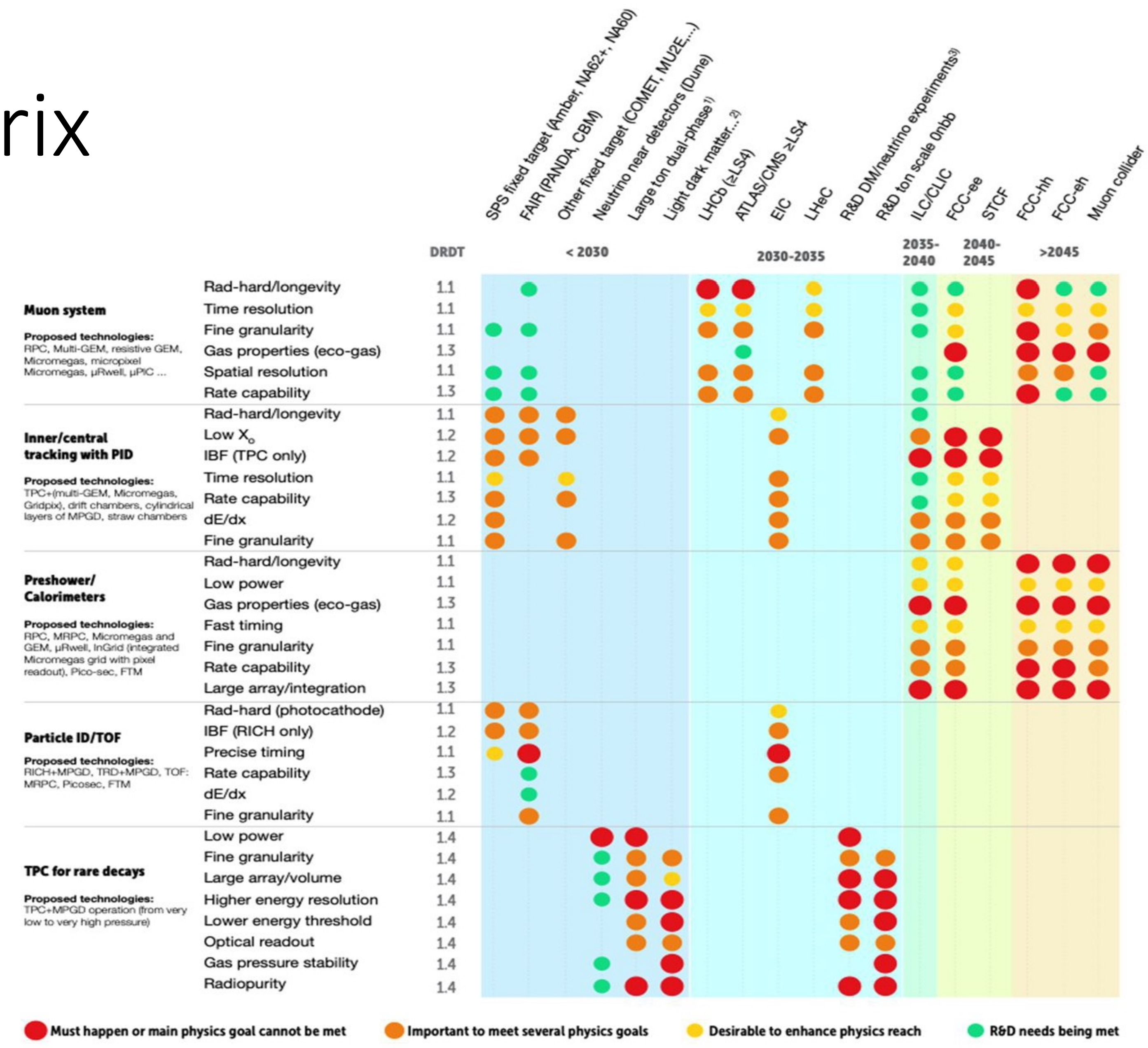
Conveners:

F. Garcia, P. Gasik, F. Grancagnolo, D. Gonzalez Diaz, G. Aielli, G. Pugliese,

and A. Colaleo, M. Titov for the ECFA part

17.02.2022

ECFA matrix

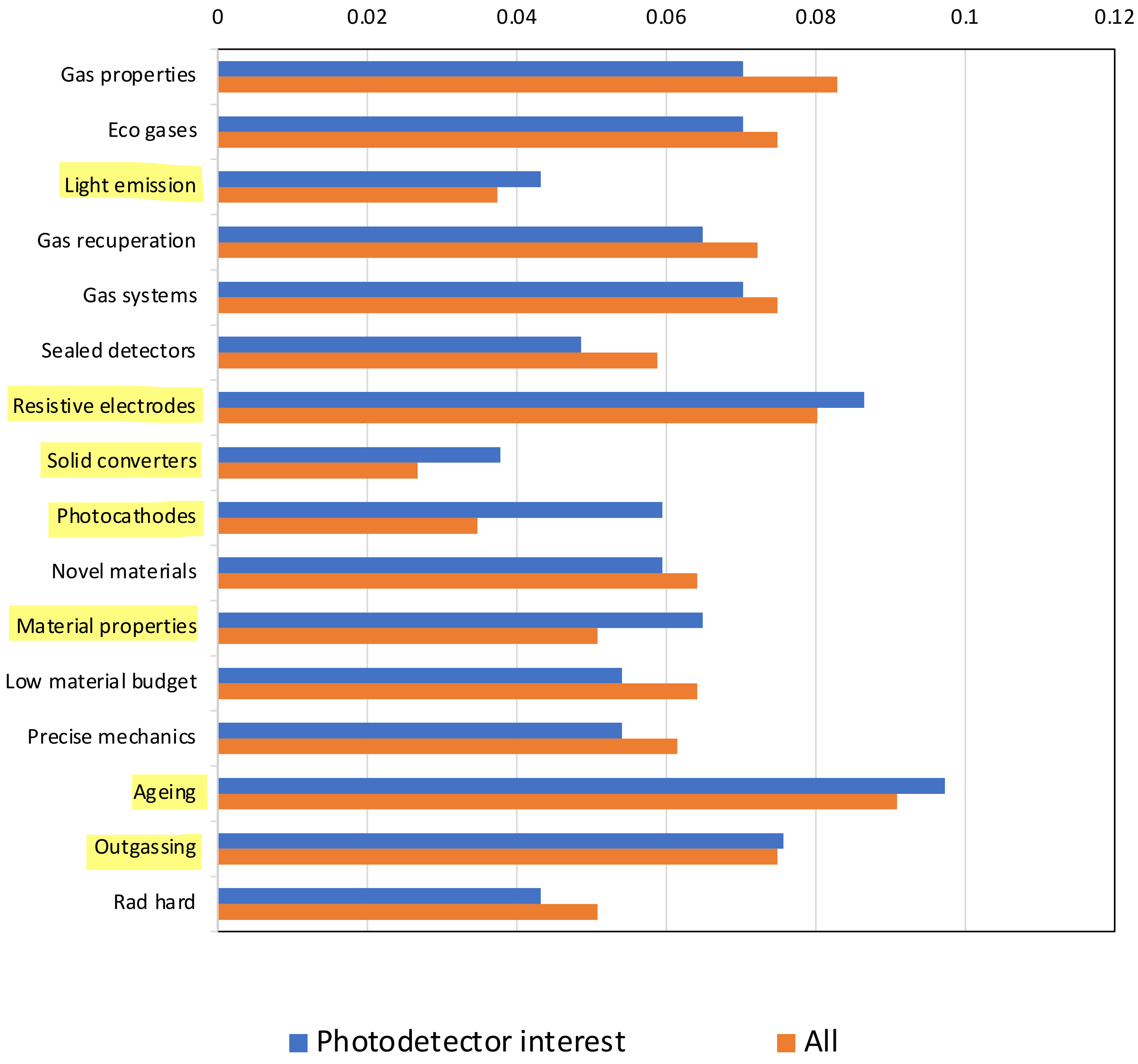


1) Large ton dual-phase (PandaX-4T, LZ, DarkSide -20k, Argo 200k, ARIADNE ...)
2) Light dark matter, solar axion, 0nbb, rare nuclei&ions and astroparticle reactions, Ba tagging)
3) R&D for 100-ton scale dual-phase DM/neutrino experiments

ECFA roadmap table 1.8

Muon System	Inner and Central tracking	Calorimetry	Photon detection	TOF	Rare decays
● Radiation hardness and stability of large area up to integrated charges of hundreds of C/cm2: - aging issues and discharges; ● Operation in a stable and efficient manner with incident particle flows up to ~10 MHz/cm2: - miniaturisation of readout elements needed to keep occupancy low ● Manufacturing, on an industrial scale, large detectors at low cost, by means of a process of technological transfer to the industry and identifies processes transferable to industries ● Identification of eco-friendly gas mixture and mitigation of the issue related to the operation with high WGP gas mixture: - gas tightness;gas recuperation system;accessibility for repairing ● Study of resistive materials (RPC and MPGD): - higher gain in a single multiplication layer, with a remarkable advantage for assembly, mass production and cost - new material and production techniques for resistive layers for increasing the rate capability ● Thinner layers and mechanical precision over large area	**Drift chambers** ● High rate, unique volume, high granularity, low mass ● Hydrocarbon-free mixture for long-term and high-rate operation ● Prove the cluster counting principle with the related electronics ● Mechanics: new wiring procedure, new wire materials ● Integration: accessibility for repairing **TPC** ● R&D on detector sensors to suppress the IBF ratio ● Optimize IBF together with energy resolution ● Gain optimization: IBF, discharge stability ● Uniformity of the response of the sensors ● Gas mixture: stability, drift velocity, ion mobility, aging ● Influence of Magnetic field on IBF ● High spatial resolution ● Very low material budget (few %) ● Mechanics: thickness minimization but robust for precise electrical properties for stable drift velocity ● Integration: cooling of electronics **Straw chambers** ● Ultra-long and thin film tubes ● “Smart“ designs: self-stabilized straw module, compensating relaxation ● Small diameter for faster timing, less occupancy, high rate capability ● Reduced drift time, hit leading times and trailing time resolutions, with dedicated R&D on the electronics ● PID by dE/dx with “standard“ time readout and time-over-threshold ● 4D-measurement: 3D-space and (offline) track time ● Over-pressurized tubes in vacuum: control the leakage rate to maintain the shape	● Uniformity of the response of the large area and dynamic energy range ● Optimization of weights for different thresholds in digital calorimeters ● Rate capability in detectors based on resistive materials: resistivity uniformity, discharge issue at high rate and in large area detector ● R&D on sub-ns in active elements: resolution stables over wide range of fluxes ● Gas homogeneity and stable over time ● Eco-friendly gas mixture for RPC ● Stability of the gas gain: fast monitoring of gas mixture and environmental conditions ● Mechanics: - large area needed to avoid dead zone: limitation on size and planarity of PCB is an issue - multi-gap with ultra-thin modules: very thin layer of glass and HPL electrodes, gas gap thickness uniformity few micron	● Preserve the photocathode efficiency by IBF and more robust photoconverters ● Gas radiator: alternative to CF4 ● Gas tightness ● Very low noise when coupling large capacitance ● Large dynamic range of the FEE ● Separate the TR radiation and the ionization process ● In TRD use of cluster counting technique and improve it by means of a InGrid	● Uniform rate capability and time resolution over large detector area ● New material for high rate (low resistivity, radiation hardness) - uniform gas distribution - thinner structures: mechanical stability and uniformity ● Eco-gas mixture ● Electronics: Low noise, fast rise time, sensitive to small charge ● Possibly optical readout ● Precise clock distribution and synchronization over large area	● Radio-purity of the materials ● Low background ● High granularity ● For large volume detectors: transparency over large distance ● Pressure stability and control ● Electronics with large dynamic range and flexible configuration. ● Self-trigger capability ● Low noise electronics ● Fast electronics ● Optical readout

Photons vs gas relevant topics

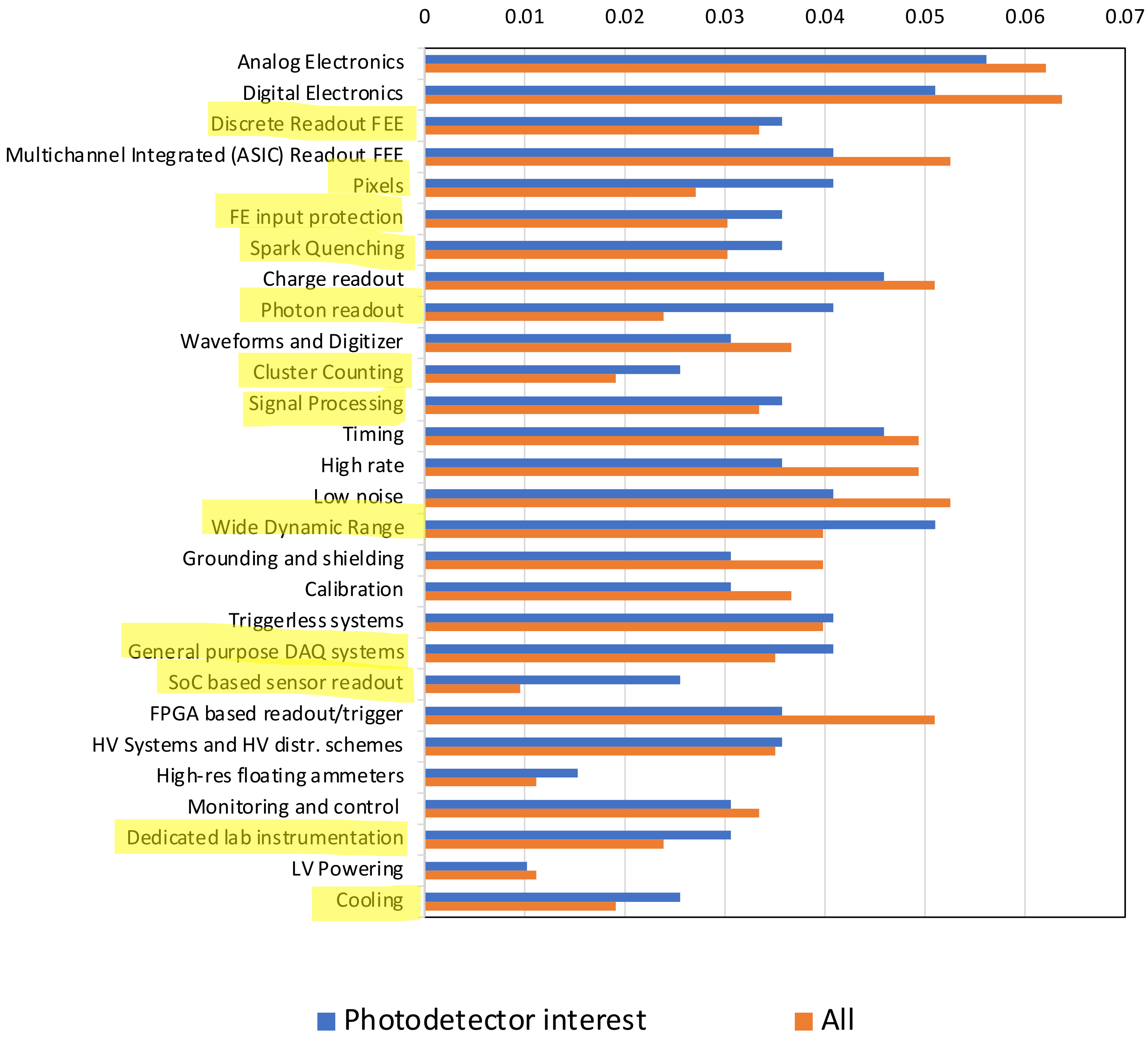


+ 3 institutes are interested in solid converters and photocathodes

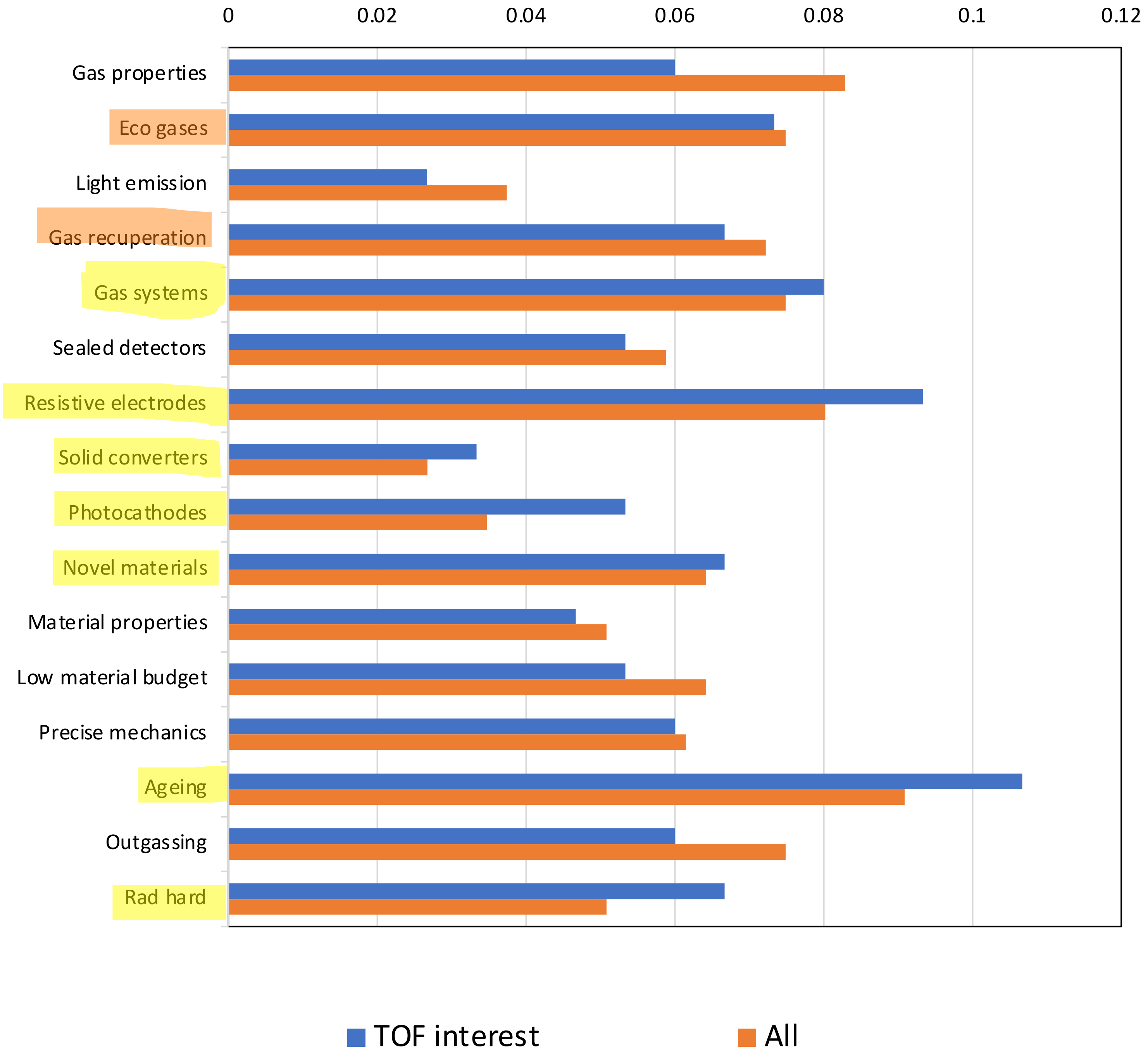
But did not choose photo detectors as application of interest (<1 %)

Photons vs FEE relevant topics

Research interest



TOF vs gas relevant topics



TOF vs FEE relevant topics

Research interest