European Survey on Detector R&D

Phil Allport, Ariella Cattai, Silvia Dalla Torre, Doris Eckstein, Els Koffeman, Lucie Linssen, Laurent Serin, Arno Straessner

(The ECFA Detector Panel http://ecfa-dp.desy.de)

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During Summer 2018, the ECFA Detector panel launched a survey in order to collect input from physicists and engineers, from master students to senior researchers, involved in astro-particle, neutrino, nuclear and particle physics activities in Europe. This survey intended to provide key insight for the preparation of a document by the Panel for the ongoing Update of the European Strategy for Particle Physics, follow-up discussions and compilation of the "Briefing Book" in 2019/2020. Here, a statistical analysis of the answers is compiled.

The survey consisted of 30 questions (referred to as Q1 to Q30, to be found in the Appendix) and collected some 700 replies from people whose position at the home institutes are reported in the Tab. 1.

Position at home institute	% replies
Professor	28
Physicist (permanent position)	36
Engineer (permanent position)	8
PostDoc Physics	11
PostDoc Engineer	1
PhD student Physics	8
PhD student Engineer	1
Master student Physics	1
Master student Engineer	0
Other	6

Table 1: Position at the home institutes of the people replying to the survey (Q2).

The age distribution of the people replying to the survey is plotted in Fig. 1.

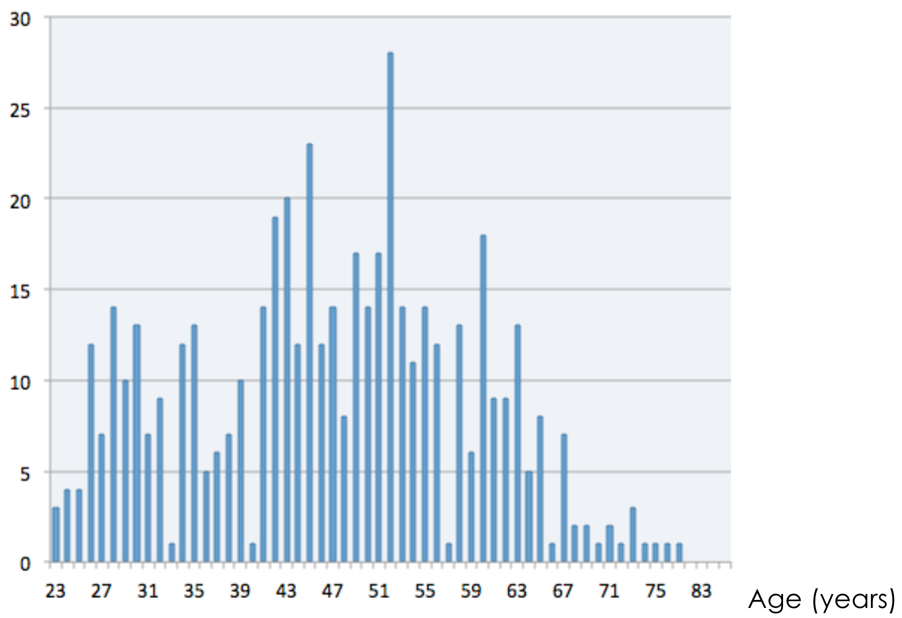

Fig 1: Age distribution of the people replying to the survey (Q1).

87% (=616/704) of the respondents are involved in various R&D activities while the remaining 13% (=88/704) are not (Q5). The reasons for not working on R&D are being reported in Tab.2. Multiple answers were possible and the results are normalised to the number of replies.

Reasons not to be involved in R&D	% replies
Other interests	58
Do not feel competent	25
No time available	36
No funding available	11
Does not bring credit for my career	11
Other	20
	>100

Table 2: 13% of people replying to the survey are not involved in R&D for different reasons *(multiple answers were allowed, Q6.)*

Researchers involved, or not, in R&D activities belong to different categories of expertise as reported in Tab. 3.

	Researchers involved in R&D (%)	Researchers NOT involved in R&D (%)
Professors	17	30
Physicists (permanent position)	33	40
Engineers (permanent position)	7	10
PostDoc Physics	19	10
PostDoc Engineers	2	1
PhD students Physics	15	7
PhD students Engineer	0	1
Master students Physics	1	1
Master students Engineers	0	0
Other	5	1

Table 3: Expertise of the 87% (13%) of respondents who are (not) involved in R&D activities (Q2, Q5).

296 team leaders reported number and degree of expertise of the FTEs working in their teams (Q15). Other 320 respondents indicated the percentage of time that they dedicate to R&D (Q14). All these values were taken into consideration for estimating the total number of FTEs (~2900) represented by this survey. In obvious cases data were corrected for double counting. The statistic of this survey is summarised in Tab. 4. The percentage of FTEs belonging to different categories of expertise is summarised in Tab. 5.

	Number
Total respondents on Sept. 15th	704
Respondents actively involved in R&Ds	616
Team Leaders	296
Total number of FTEs from the 616 respondents	2932
Total number of FTEs when removing obvious cases of double counting	2890

Table 4: Statistic of respondents, number of team leaders and number of FTEs (Q14, Q15).

Categories	% of FTEs involved in R&D
Professors	2
Physicists (permanent position)	24
Engineers (permanent position)	18
PostDoc	13
PhD students	19
Other students	10
Technicians	13

Table 5: Percentage of 2890 FTEs belonging to different categories of expertise (Q14, Q15).

This survey represents the work of ~2900 FTEs from 37 countries (Q3) distributed as in Fig. 2. The statistic includes the contributions from FTEs from non-European countries but working on European projects. The colour code in Fig. 2 follows the CERN nomenclature.

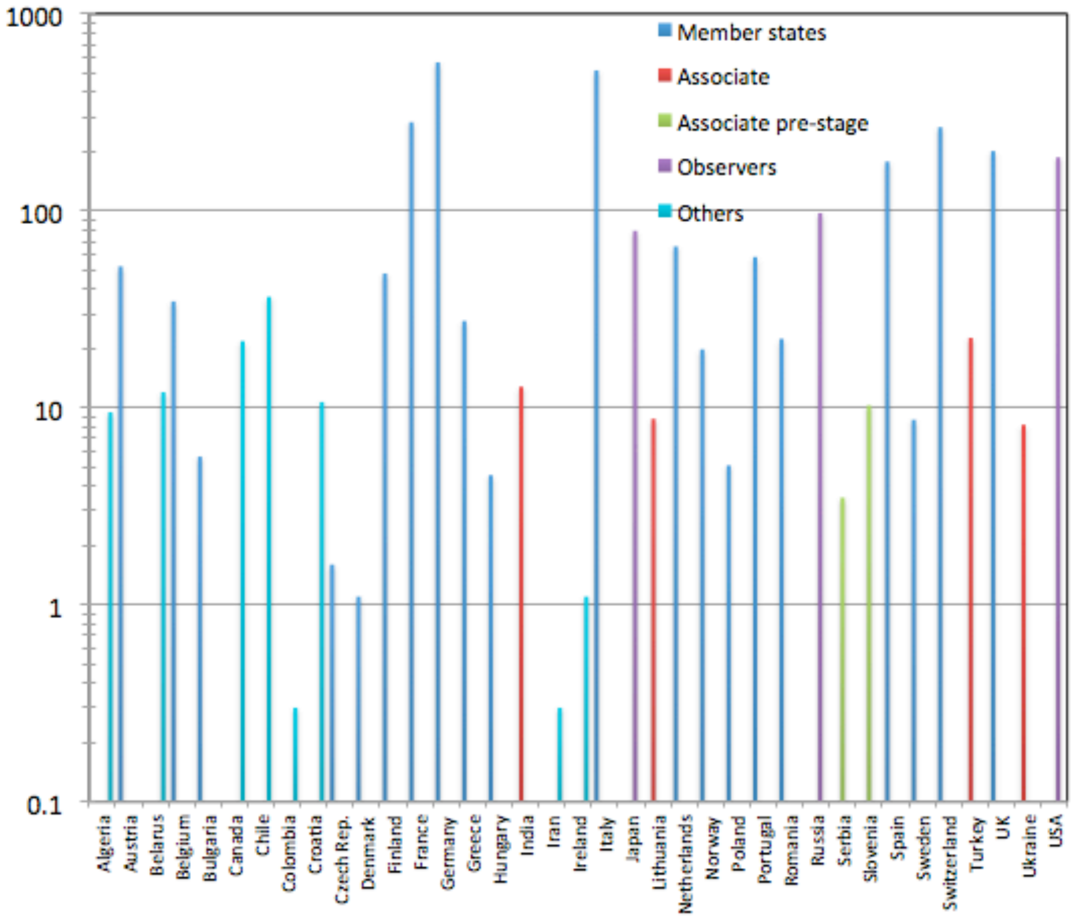

Fig. 2: Distribution of FTEs in 37 states who are engaged in R&Ds for European projects (Q3, Q5).

R&Ds activities are performed in the context of experiments belonging to the branches of physics as reported in Tab. 6. Multiple answers were possible and we received 540 replies (Q17).

	% of replies
Astroparticle Physics	19
Neutrino Physics	17
Nuclear Physics	19
Particle Physics	72
Other branches of fundamental physics	12
Other	8
	>100

Table 6: Major branches of Physics in which detector R&D is performed normalised to the number of people who responded to the survey *(multiple answers possible, Q17)*.

The affiliations of 2900 FTEs are distributed as in Fig. 3. The affiliation "other" mainly includes researchers working for national Institutes, public research centers and private companies.

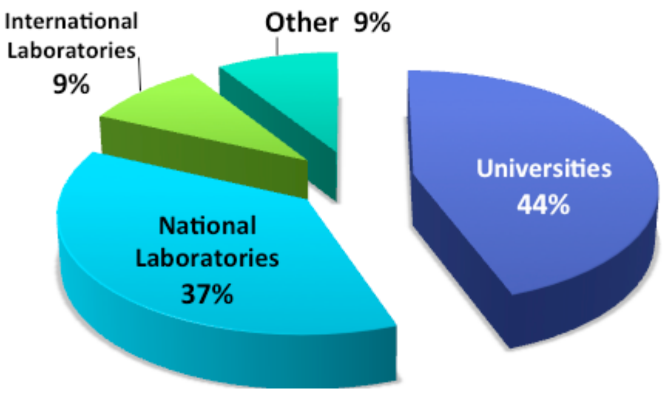

Fig. 3: Affiliations of FTEs (Q4).

Only some 300 respondents out of the 616 who stated to be involved in R&D activities indicated the percentage of time that they invest in R&Ds. Results are reported in the Tab. 7.

	<5%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Professors	2	22	24	30	10	24	5	7	3	1	2
Physicists	1	9	16	17	5	24	8	12	15	5	3
Engineers		2	2	3	2	3	1	3	1	1	1
PostDoc Physics	1	1	1			3			8		2
PostDoc Engineer									1		
Other		4	2	1	1	1	1	1	1		4

Table 7: Number of researchers, with different expertise, who dedicate a certain percentage of time to R&D (Q14).

The survey offered the possibility to choose among several categories of detector R&Ds, technologies and electronics activities. The percentages of FTEs working in the different specializations are presented in Tab. 8 and Tab. 9.

Detectors categories	% of FTE
Vertex detectors	15
Trackers	23
Detectors for Particle Identification	14
Calorimetry	15
Timing detectors	12
Highly specialized instrumentation for Neutrino searches	7
Highly specialized instrumentation for Astroparticle	7
Other *(gamma spectrometry, neutron detection, dosimeter, beam monitors, gravitational waves……..)*	5

Table 8: Percentage of FTEs working in major detectors R&D categories (Q8).

Detectors technologies	% of FTE
Gaseous detectors	15
Semi-conductors	35
Scintillators and crystals	12
Photo-detectors	12
Cryogenic (liquid) detectors	3
Cerenkov detectors	3
Highly specialized mechanics	8
Detector specific software	10
Other (*TES – RF related - bolometers, opto-mechanical sensors – MEMS, laser, photonics, magnets, quantum sensors ……..)*	2

Table 9: Percentage of FTEs working in major detectors R&D technologies (Q9).

The survey investigated the interest in electronics R&D via two specific questions: Q11 *(If you are doing R&D on Front End electronics. Which technology are you using?)* and Q12 *(If you are you doing R&D on electronics, in which branch are you working?)*. Multiple answers were allowed.

- Q11 had 375 multiple entries from 230 respondents
- Q12 had 494 multiple entries from 255 respondents
- Some people replied to both Q11 and Q12; being 311 the number of researchers who replied to, at least, one single question,

The percentage of involvement in the different field of electronics is reported, for the two normalizations, in Tabs. 10 and 11.

Activities on Front-End electronics	% Normalised to multiple entries (869)	% Normalised to number of respondents (311)
Monolithic integrated silicon detectors	10	27
FE ASIC for hybrid semi-conductor detectors	11	31
FE ASIC for gaseous detectors	6	17
FE ASIC for calorimetry	5	13
FE ASIC for fast data links, optical links	3	9
FE ASIC for monitoring, slow control and timing	3	9
3D electronics integration	1	4
Other (Front End for noble liquid, scintillators, HPG, PMT, SiPM, …., testing systems, systems design, SQUID……._	4	10

Table 10: Involvement in R&D on Front-End electronics *(multiple answers possible, Q10)*.

Activities on electronic domains	% Normalised to multiple entries (869)	% Normalised to number of respondents (311)
FPGA firmware	14	38
On-detector & optoelectronics	16	45
Off-detector & Trigger	10	29
Off-detector & processing	9	26
Powering	7	19
Other *(RF data transmission, services & integration,….)*	1	2

Table 11: Involvement in R&D on different electronics domains *(multiple answers possible, Q12)*.

160 researchers (~25%) are involved in R&D on the Front End electronics technologies listed in Fig. 4. Multiple entries were possible for this question (Q11); data are normalised to the respondents to the question.

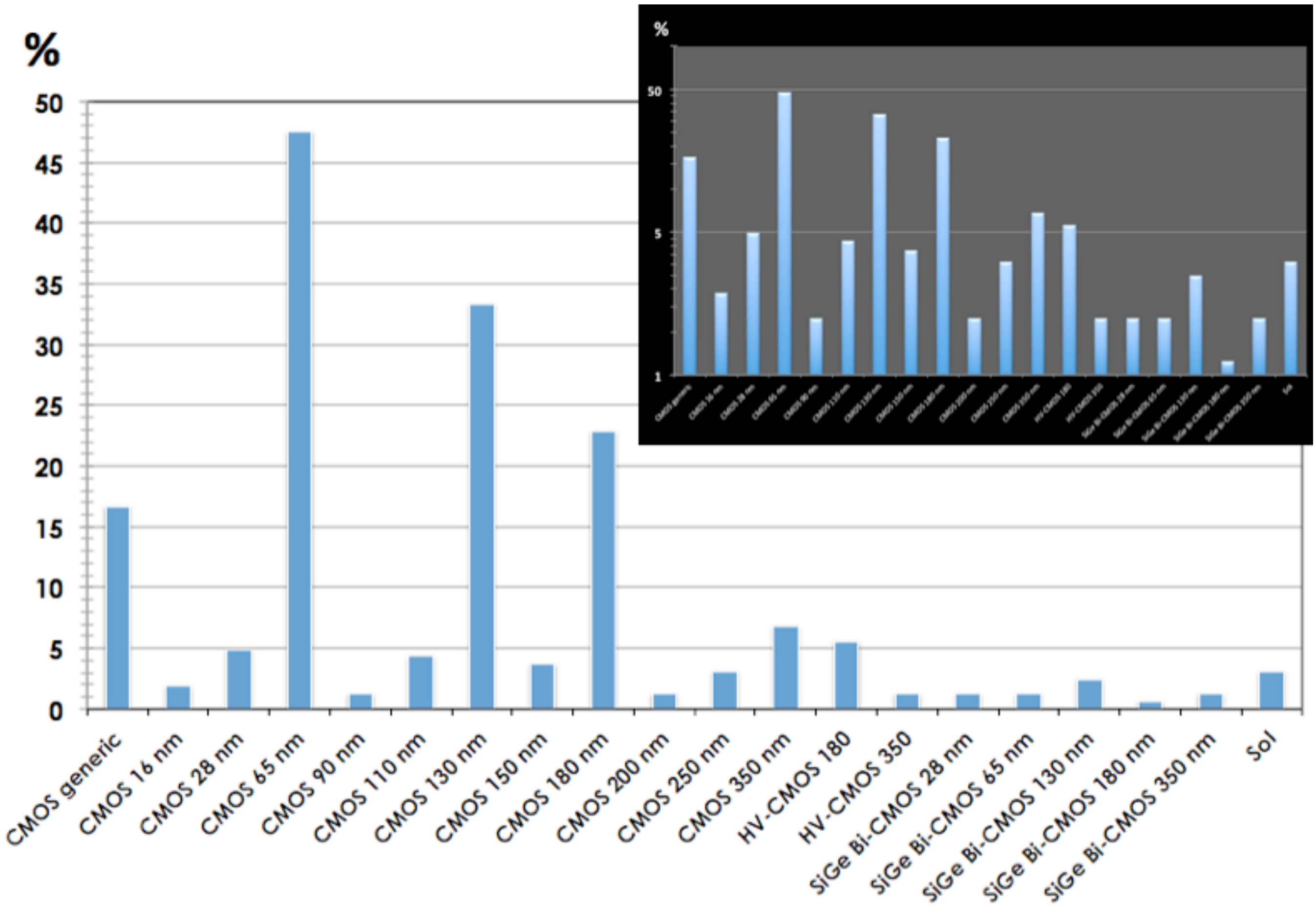

Fig. 4: Main technologies pursued on Front End electronics by 160 researchers (Q11). (Note linear scale of principal plot, logarithmic scale in the insert)

537 researchers (~88%) are, as well, involved in characterization, integration and performance optimization studies (Q13). The activities are reported in the Tab. 12.

ACTIVITIES	% normalised to number of respondents (537)
Beam tests	66
Ageing studies	21
Radiation hardness tests	44
Quality control / Quality assurance	42
Cooling	19
Services and integration	34
Software development for detector simulations	37
Software development for detector performance assessment	38
Other *(design, Integration, production, trigger optimization, DAQ, alignment, radiopurity checks, development with industries,*	5
	>100

Table 12: Sub-activities in which researchers are involved *(multiple answers possible, Q13)*.

Fig. 5 shows the FTEs involvement in research activities within consortia (AIDA, RD#....), or in experiments (ATLAS, ALICE.......) or as freelance (Q16). Data are normalized to the number of FTEs.

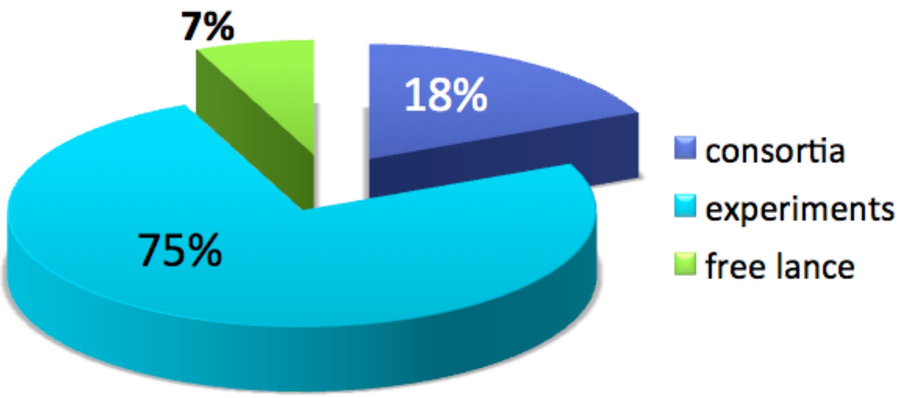

Fig. 5: Percentage of FTEs working within consortia (18%), experiments (75%) or as freelance (7%) normalized to the number of FTEs (Q16).

78 % of respondents (Q18) perceive that their R&Ds activities are suited also for applications outside fundamental physics as described in Tab. 13. Multiple answers were allowed and data are normalized to the number of respondents.

Domains	% Respondents
Dosimetry	26
Civil security	18
Cultural heritage	10
Medical	65
Nuclear control	25
Other *(Photon science, geophysics, vulcanology, industry, magnets related, muon & large tomography, data handling, space, agriculture, optics, precision metrology, marine biology, environmental, high-tech engineering, telecommunications,….)*	18
	>100

Table 13: Domains, outside fundamental physics, that are perceived as possible fields of research in which R&Ds can be applied *(multiple answers possible Q18).*

Roughly 50% of R&Ds are carried out in partnership with industry (Q19). In this population, in 50% of the cases the collaboration with industries is restricted to the R&Ds; in 34% of the cases industries are exploited only for the mass production. In the remaining 16% of the cases, the collaboration with industries covers both the R&D and production phases. These results, normalized to the number of respondents (589), are summarized in Tab. 14.

R&D in partnership with industry			
YES			NO
51 %			49%
For R&D	For mass production	Both	
50%	34%	16%	

Table 14: Partnership between R&Ds and industries (Q19).

As summarized in Tab. 15, in 32% of R&Ds, exploitations or technology transfer strategies are embedded in the programs (Q20). When a technology transfer strategy is possible, almost 70% of the groups feel that they do not get enough support to solve financial, manpower, technical and legal problems (Q21).

Possibility of technology transfer and consequent supports		
YES		NO
32 %		68%
Get support from TT	No support from TT	
31%	69%	

Table 15: Strategies for technology transfers or exploitations are embedded in 32% of R&Ds but the support for their actuation happens only in 31% of the cases (Q20, Q21).

R&Ds are reviewed and funded by the agencies reported in the Tab.16 and 17 respectively. Multiple answers were possible and data are normalized to the number of respondents (Q22, Q23).

Agency	% Respondents
Associated experiment or Collaboration	48
International agency (ECFA, LHCC.....)	29
National agency	68
Not aware	8
Other	0.5
	>100

Table 16: Agencies reviewing the R&D projects *(multiple answers possible, Q22)*.

Agency	% Respondents
International funding program	13
EU funding program	32
National funding agency	71
Home Institute	52
Not aware	5
Other *(Mainly private or industry)*	1
	>100

Table 17: Agencies funding the R&D projects *(multiple answers possible, Q23)*.

We investigated if groups performing R&Ds receive enough support in terms of manpower, funds, access to common infrastructure and irradiation facilities (Q24). The results, normalised to the number of respondents (approximately 570), are reported in Tab. 18a and Tab. 18b.

	Manpower		Funds		Access to test beam	
Categories	YES (%)	NO (%)	YES (%)	NO (%)	YES (%)	NO (%)
Professors	9	21	14	16	21	2
Physicists (perm. pos.)	14	23	21	16	29	3
Engineers (perm. pos.)	3	6	5	4	6	0.4
PostDoc Physics	3	7	7	3	8	0.4
PostDoc Engineers	0	1	1	0.2	1	
PhD students Physics	2	3	4	1	4	0.4
PhD students Engineer	0.4	0 .2	0.4	0.2	0.6	
Other	3.2	3.2	3	3 .4	5	0.6
Total	34.6%	62.9%	53.7%	43.6%	73.5 %	6.5 %
Not applicable	2.5 %		2.7 %		20 %	

Table 18a: Support for resources, funds and test beam available to R&Ds (Q24).

	Test beam infrastructures		Infrastructures for irradiation facilities	
Categories	YES (%)	NO (%)	YES (%)	NO (%)
Professors	20	3	16	3
Physicists (perm. pos.)	27.4	4	23	2
Engineers (perm. pos.)	5	0.6	6	0.4
PostDoc Physics	7	0.7	6	0.4
PostDoc Engineers	0.7		0.8	
PhD students Physics	4	0.6	3	0.6
PhD students Engineer	0.6		0.6	0.2
Other	4	1	4	1
Total	68%	10%	60%	7.5%
Not applicable	22 %		32%	

Table 18b: Support for infrastructures of test beams and irradiation facilities available to R&Ds (Q24).

In this latest analysis, the entry "NOT applicable" has an important weight especially for what concern the "irradiation facilities", subject of study for only very specific R&Ds. Hence, we think it is justify to analyse these data also excluding the responses "NOT applicable. Results for data normalised to the number of respondents are reported in Tab. 18c.

Manpower (550 entries)		Funds (550 entries)		Access to test beam (430 entries)		Test beam infrastructures (415 entries)		Irradiation facilities (355 entries)	
YES	NO	YES	NO	YES	NO	YES	NO	YES	NO
35 %	65 %	55 %	45 %	92 %	8 %	88 %	12 %	89 %	11 %

Table 18c: Available support to R&D for what concerns: manpower resources, funds, test beams access, test beam infrastructures and irradiation facilities (Q24).

According to this survey, the R&D in Europe is reasonably organized centrally, but it should be better coordinated among the fundamental physics communities (Q25). This is expressed in Tab.19. Data are normalised to the number of respondents.

	Need to be better/more centrally organized		Need to be coordinated among the fundamental physics communities	
Categories	YES (%)	NO (%)	YES (%)	NO (%)
Professors	14.1	14.3	22	7.3
Physicists (perm. pos.)	20	18	27.7	9
Engineers (perm. pos.)	5	5	7.1	2.4
PostDoc Physics	4.6	5.6	9	1.4
PostDoc Engineers	0.4	0.4	0.2	0.6
PhD students Physics	3	2.4	5	0.4
PhD students Engineer	0.2	0.6	0.6	0.2
Other	2.4	3.4	5.5	1.6
Total	50 %	50 %	77 %	23 %

Table 19: Organization of R&D in Europe *(normalized to respondents Q25).*

The opportunities for PhD students and/or PostDocs to contribute to detector R&D was investigated (Q27). Data, normalised to the number of respondents are reported in Tab. 20, 65% of the people responding to the survey believe that there are enough opportunities. Nonetheless the 35% who replied negatively, underlined that it is needed to:

- Give better recognition for the students working on R&D
- Consider R&D activities as rewarding as physics analysis and grant equal opportunities towards a career
- Increase specific grants for technical R&D
- Address the issue that students have poor perspectives towards a permanent position in case they uniquely perform detector R&D.

	Opportunities to contribute to R&D	
Categories	YES (%)	NO (%)
Professors	19.8	9.4
Physicists (perm. pos.)	24.7	13.7
Engineers (perm. pos.)	5.2	3.5
PostDoc Physics	6.4	3.7
PostDoc Engineers	0.5	0.2
PhD students Physics	4.2	1.7
PhD students Engineer	0.5	0.2
Other	3.8	2.5
Total	65.2	34.8 %

Table 20: Opportunities for students and PostDoc to contribute to R&Ds (Q27).

59% of the people responding to the survey claim that training in detector R&D is sufficiently actuated (Q28). Nonetheless, those who replied negatively underlined four main points:

- For R&D it is important to have a broad view. Opportunities to gather experience on various detector technologies are limited.
- In large experiments, there are very few and narrow windows of opportunity for doing interesting R&D work; after the design era, the R&D work becomes more and more specialized, industrialized, and less and less appropriate as a thesis topic.
- Students/Postdocs often lack basic knowledge in electronics, mechanics, software and instrumentation. University training is often insufficiently oriented towards these technical aspects and as a consequence it is difficult to attract young people to work in R&D fields.
- Restricted budget.

Concerning the perceived perspective for job/career opportunities for detector R&D experts in different domains (Q29), the respondents provided the results reported in Tab 21.

	YES (%)	No (%)
In research field	39	61
In industry	66	34
In tertiary sector, requiring advanced software development skills	80	20

Table 21: Perceived perspective for job/careers for detector R&D experts (Q29).

380 respondents expressed their opinion on what they believe to be the most promising R&Ds for the next decade (Q26). The results are reported in Tab. 22.

Most promising future R&Ds	# answers (380 total)
3D integration	3
4D tracking	14
Advanced simulation tools	2
Advanced TPC	4
Artificial intelligence / Machine Learning	16
Autonomous and adaptive detectors.	2
Bolometer	1
Broadband data transmission	2

CMOS HV-MAPS monolithic	24
Cooling	2
Cryogenic detectors and devices	7
Directional (dark matter) detectors	3
Fast (tracker) triggers (online)	16
Fast detectors/electronics	13
Fast inorganic (photonic) crystals	4
Fast links	2
Gamma ray detectors (TOF PET, tracking…..)	6
High energy resolution	13
High granularity imaging calorimetry	21
High rate capability	14
Large area detectors	9
Liquid noble detectors	1
Low cost	8
Low mass detectors & services	11
Low power consumption in detector systems/electronics,	14
MPGD (with new readout)	4
Neutron detection	2
New material - metamaterials	5
Photon detection	1
Photonics	4
PID TOF	12
Precise energy measurements	25
Precise position resolution	63
Precision timing	**210**
Prompt time stamps	2
Qdots	1
Rad Hard	29
Real time processing of large data set	6
Robustness, reliability	6
Room temperature high resolution gamma ray detectors	2
Silicon photomultipliers	10
Single photon	3
wakefield driven beams	1
water-based liquid scintillators	2
wireless data transmission	4
X-ray detection in large area	1

Table 22: Perceived most promising future R&Ds (Q26).

APPENDIX

2018 Survey on Detectors R&D activities across the Physicists Communities

We would be very grateful if you could complete this survey that intends to gather information on the current state-of-the-art in detector R&D for physics at the energy, intensity and cosmic frontiers.

The survey will contribute to assessing the deployment and strength of R&D activities in astro-particle, neutrino, nuclear and particle physics in Europe. It will also aim to elucidate opportunities created by current and emerging technologies and the potential for greater synergies between R&D activities.

Answers to this survey will provide key insight for the preparation of a document by the ECFA Detector Panel for the ongoing Update of the European Strategy for Particle Physics, follow-up discussions and compilation of the "Briefing Book" in 2019/2020.

The survey solicits input from physicists and engineers, from master students to senior researchers, involved in astro-particle, neutrino, nuclear and particle physics activities in Europe.

1. **About you**
    - Name (optional):
    - Age:

2. **About your position at your home Institution**
    - Professor
    - Physicist (permanent position)
    - Engineer (permanent position)
    - PostDoc Physics
    - PostDoc Engineer
    - PhD student Physics
    - PhD student Engineer
    - Master student Physics
    - Master student Engineer
    - Other (please specify)

3. **Location of Home Institution**
    - City/Town:
    - Country:

4. **Home Institution Type**
    - University
    - National Laboratory
    - International Laboratory
    - Other (please specify):

5. **Are you currently involved or have recently been involved in detector R&D activities?**
    - o Yes
    - o No
    - o Other (please specify):

6. **If you are NOT involved in detector R&D activities: what are the reasons? After answering this question, you can proceed to Q28 at the end of the survey. Thank you for your contribution.**
    - o Other interests
    - o Do not feel competent
    - o No time available
    - o No funding available
    - o Does not bring credit for my career
    - o Other (please specify):

7. **What are the main objectives of your R&D?**

8. **Which is your main topic in detector R&D? (multiple choices are welcome, if related to the same R&D projects mentioned in question 7)**
    - o Vertex detectors
    - o Trackers
    - o Detectors for Particle Identification
    - o Calorimeters
    - o Timing detectors
    - o Neutrino detectors
    - o Astroparticle detectors
    - o Other detectors (please specify):

9. **On which technology or technologies are you working?**
    - o Gaseous detectors
    - o Semi-conductors
    - o Scintillators and crystals
    - o Photo-detectors
    - o Cryogenic (liquid) detectors
    - o Cerenkov detectors
    - o Highly specialized mechanics
    - o Detector specific software
    - o Other (please specify):

10. **If you are doing R&D on front end electronics, in which branch are you working?**
    - o Monolithic integrated silicon detectors
    - o FE ASIC for hybrid semi-conductor detectors
    - o FE ASIC for gaseous detectors
    - o FE ASIC for calorimetry
    - o FE ASIC for fast data links, optical links
    - o FE ASIC for monitoring, slow control and timing
    - o 3D electronics integration
    - o Other (please specify):

11. **If you are doing R&D on Front End electronics. Which technology are you using (CMOS, BiCMOS, … , 180, 130, 65, 28 nm …..)?**

12. **If you are you doing R&D on electronics, in which branch are you working?**

    - o FPGA firmware
    - o On-detector & optoelectronics
    - o Off-detector & Trigger

- Off-detector & processing
- Powering
- Other (please specify):

13. Are you involved in the following aspects:

- Beam tests
- Ageing studies
- Radiation hardness tests
- Quality control / Quality assurance
- Cooling
- Services and integration
- Software development for detector simulations
- Software development for detector performance assessment
- Other (please specify):

14. Give your personal % of working time dedicated to R&D

15. If you are a team leader: please enter the number of FTE staff, in your team/project and at your home Institution, dedicated to detector R&D activities

- Engineers
- PhD Students
- Physicists
- Post Doc
- Other students
- Technicians

16. Is a large fraction of your R&D carried out within a Consortium, such as an RD collaboration (RD50, RD51.....), a European project (AIDA-2020,…), ... ?

- Yes
- No
- If YES, please specify

17. Is your R&D carried out in the context of an experiment in:

- Astroparticle Physics (please indicate the experiment):
- Neutrino Physics (please indicate the experiment):
- Nuclear Physics (please indicate the experiment):
- Particle Physics (please indicate the experiment):
- Is any of your R&D applicable to another branch of fundamental physics?
- Other (please indicate)

18. Is any of your R&D suited to applications outside fundamental physics?

- Sorry, no applications
- Dosimetry
- Civil security
- Cultural heritage
- Medical
- Nuclear Control
- Other (please specify)

19. Is your R&D carried out in partnership with industry?

- YES, for R&D
- YES, for mass production
- NO
- Comment:

20. Is there an exploitation or technology transfer strategy typically embedded in your R&D programmes?

- o YES
- o NO
- o Comment:

21. Do you get enough support for the transfer of technology (financial, manpower, legal, market research …)?

- o YES
- o NO
- o Comment:

22. Which sort of agency is usually reviewing your R&D projects?

- o Associated experiment or Collaboration
- o International agency (ECFA, LHCC, …)
- o National agency
- o I am not aware
- o Other (please specify):

23. Financial aspects: is your R&D funded by:

- o Home Institute
- o National funding agency or section
- o EU funding program
- o International funding program
- o I am not aware
- o Other (please specify):

24. Is your R&D in receipt of adequate resources?

- o Manpower (YES, NO, not applicable)
- o Budget (YES, NO, not applicable)
- o Access to test beams facilities (YES, NO, not applicable)
- o Infrastructure at the test beams (YES, NO, not applicable)
- o Access to test irradiation facilities (YES, NO, not applicable)
- o Comment:

25. Should the R&D in Europe:

- o be better/more centrally organized (YES, NO)
- o be coordinated with other fundamental physics communities (YES, NO)
- o Comment:

26. What do you believe to be promising R&D for the next decade ? (For instance, ultimate position resolution detectors, precise time resolution detectors, energy measurement detectors….)

27. Is there enough opportunity for PhD students/postdocs to contribute to detector R&D?

- o YES
- o NO
- o If NO, how can it be improved?

28. Are there sufficient opportunities for training in detector R&D?

- o YES
- o NO
- o Comment:

29. Is there enough job/career perspective for detector R&D experts?

- o In research field (YES, NO)

- In industry (YES, NO)
- In tertiary sector, requiring advanced software development skills (YES, NO)
- If NO, what are the obstacles?

30. Thank you for completing this survey.

Your further considerations regarding the situation for detector R&D are most welcome; please add them in the space below or contact ECFA Detector Panel at ecfa-dp@desy.de