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IFD2015: conclusive remarks and perspectives

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In 2013, INFN started the What Next (WN) program, a process based on open and wide scientific discussions to investigate possible new research ideas and to promote new science-driven experiments. It is clear that new or improved technologies will play a crucial role to pave the road towards the necessary breakthrough for possible discoveries. Within this framework, the INFN Workshop on Future Detectors (IFD2015) was organized to identify and discuss new ideas, to be explored in a technology-driven approach and exploiting synergies amongst different research groups. This paper summarizes the highlights and the perspectives for further discussion.

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1. Overview

One of the main objectives of the IFD2015 Workshop was to bring together the vast INFN Community involved in detector technology development [1]. Cross-fertilization and diffusion of key information amongst the community are strategic items: the continuous contraction of the available resources in the last years clearly implies that we cannot afford duplications of R&D efforts, and that a synergistic approach is mandatory to keep pace with the future challenges.
Going into more details, some strategic items have emerged from many in-depth discussions that occurred during the Workshop:

- The importance of the collaboration with the industries
- The importance of the collaboration with other Research Institutes
- The importance to preserve and develop the current knowledge in detector technology, and to transmit it to the next generations of researchers.

2. Cross-fertilization of detector R&D in different fields

Some detector (and detector-related) technologies cover an extremely vast spectrum of applications.
The Micro Pattern Gaseous Detectors (MPGD) gives a notable example, having been subject to intense R&D in the last years. The performance achievable today by the different detectors belonging to the MPGD "family" (MICROMEGAS, GEM, etc.) make them an extremely interesting option for a variety of applications in different research fields: High Energy Physics, Nuclear Physics, Neutron Detection, Rare Event experiments (as R/O elements of TPCs), Interdisciplinary applications [2].
Another sensor category that finds virtually ubiquitous application is photosensors [3]. Photosensors are the key element in a variety of detection systems, spanning from Calorimetry in High-Energy Physics (particularly, concerning HL-LHC), to Large Detector Arrays for indirect charged cosmic-ray (EAS) or gamma-ray measurement (Large-Area telescope arrays), to large-area neutrino experiments, to rare events experiments (DM and/or neutrinoless double-beta decay), not forgetting medical imaging (e.g. PET). Tremendous improvements have been recently achieved in all the main areas of R&D, i.e. vacuum-based, gas-based and solid state photosensors. The success in pushing further the state-of-the-art of photosensor performance will be one of the keys for the success of the next generation of experiments in all these areas. Just to mention an example, a great effort is being pursued on the LAPPDs, which show great promise both for scientific (e.g. for light-based large area neutrino detectors) and industrial applications.
Space is another sector that can benefit from detector R&D in different fields [4]. For instance, a next generation of space-based experiments for direct measurement of cosmic charged particles and gamma-ray spectra can be envisaged by developing both new large acceptance and high-granularity calorimeters (for calorimetric measurements of comic-ray nuclei up to the "knee") and new magnetic spectrometers which will benefit from the R&D on new high-temperature superconducting materials. On the other hand, the experience achieved to comply with the stringent conditions required for detectors operating in space (radiation tolerance and reliability

as examples) can be very useful to design and build detectors at colliders, in areas where the radiation conditions are extreme.

3. Some critical issues for the next physics challenges

The open questions we are facing both at the high-energy frontier as well as in the neutrino sector and in cosmology indicate some clear avenues of investigation, which require significant advancements that only new technologies can offer. In particular, we point to three selected challenges:

1. The need for excellent time resolution is emerging as a key element in many physics cases:

- HL-LHC pile-up mitigation in tracking, calorimetry and forward systems.
- Background suppression in muon collider and intensity frontier experiments.
- Second coordinate determination in large area and large volume detectors.
- TOF for PET and neutron spectroscopy.

R&D efforts to reach less than 1 ns (scintillators), about 100 ps (gas) and about 10 ps (solid state and photosensor) frontiers are being actively carried out for sensors, front-end electronics and large system time synchronization with the very ambitious goal of building a 4D tracking system (see e.g. [5], [6]). It is also important to access very high precision clocks, so to allow time measurements compatible with the time resolution obtained with state-of-the-art particle detectors. In this field, the partnership with other Italian Research Institutes can permit to access the best timing technologies, able to guarantee the complete control of the experimental clocks.

2. Along the same line, a further pixelization or increase in granularity is needed in all detector technologies. This requirement is pushing all experimental communities, also those traditionally less aggressive under this respect, to develop low mass mechanical supports, low mass cooling systems, low mass electrical cables, advanced electrical interconnections, in-chip local intelligence, ultra-high bandwidth optical links and sophisticated data acquisition systems. At the same time, in all this new generation of experiments, the physics reach requires larger areas or volumes at an affordable cost and several crucial experiments need detectors an order of magnitude more radiation resistant.

3. Another mandatory technological challenge is the detection of a signal in two complementary ways for the same active volume. This goal is physics driven and it is pursued by very different ideas:

- Simultaneous read-out of Cherenkov and scintillation light to increase the energy resolution of hadron calorimeters for collider and space experiments;

- Dual-phase cryogenic particle detectors to suppress background in dark matter search and with an additional bolometer to detect scintillation and Cerenkov light in coincidence with the signal produced in the crystal absorber, in order to allow background rejection in double beta decay experiments.

In addition, the importance of excellent front-end electronics, trigger and DAQ has been emphasized in order to achieve the required performance of the detection system. In this respect, greater design complexity requires shared tools and knowledge. The effort done by the CHIPIX65 experiment, which brought together more than 20 VLSI designers to cope with the development of the pixel electronics for ATLAS and CMS for HL-LHC, is definitely commendable. When discussing the choice of the microelectronics technologies for our experiments, we have anyway to keep in mind that the HEP "market" is (and will remain) a dwarf compared with consumer electronics; therefore, it is necessary to pursue the best possible synergies with the industrial R&D and to take advantage of favorable conditions. Another important issue, particularly for future collider experiments, will be the integration of as much intelligence as possible already at the detector/front-end level, in order to dramatically reduce the amount of data transmitted to the back-end electronics, therefore significantly increasing the throughput of the experiment.

4. New technologies and the importance of strategic collaborations.

The importance of the technological collaboration with Industries and other Research Institutes can be further exemplified. For instance, it has been underlined that industrial collaboration is of paramount importance in the development of advanced MPGDs. The projects to develop SiC detectors currently running in CSN5 are very good examples of strategic collaboration between INFN, other research Institutes (CNR, in this case) and external companies. Another example is given by the development of the pixel sensors for HL-LHC tracking systems, which have already a strong impact in other strategic research fields such as in advanced FEL. While hybrid pixel detectors probably can still meet the requirements of HL-LHC, advanced CMOS sensor technologies (either on high-voltage or high-resistivity substrates) are emerging as possible viable alternatives. A close collaboration with the foundries, giving to our researchers full access to the technologies (within clearly defined Non-Disclosure Agreements), is obviously a necessary condition to successfully develop innovative sensors.

Another interesting point concerns the development of sensors based on new technologies (e.g. nanostructures, graphene, etc.) While for gas and solid-state (particularly silicon) detectors INFN can be considered as a world leader, those other technologies "belong" to other Research Institutes. For example, new sensors based on materials like SiC, Graphene, Carbon/Metal Nano Wires, new and highly radio-pure scintillating materials (to name only a few) can open up exciting possibilities for the next generation of many fundamental physics experiments.

5. Maintaining, developing and transmitting the knowledge.

We have to be aware of the importance of maintaining and developing detector expertise, and to transmit this knowledge to young researchers. The brilliant achievements of the INFN detector community are not automatically reproducible by the next generation(s). Three elements appear essential and should be pursued by INFN:

- Training: organizing and stimulating participation in instrumentation schools.
- Experimenting: encouraging young experimentalists to do hands-on detector work especially in smaller and shorter time-scale experiments and R&D.
- Rewarding: giving proper recognition of excellence in instrumentation development in careers at Universities and Research Institutions.

6. Conclusions and outlook

The evaluation of the IFD2015 Workshop is, in our opinion, extremely positive. The wide and "transversal" participation of researchers belonging to different INFN communities, the large number of young colleagues, the in-depth physics discussions that originated from the perspective of how to face difficult experimental challenges, have all been clear indicators of this success.

Within INFN, we have lots of knowledge, competence and mastery of the technology in many different detector areas. We have also many high-level infrastructures (laboratories, mechanical workshops, clean rooms, etc.) distributed in our Units/National Laboratories. This working model has given (and is still giving) excellent results.

For the next editions of the Workshop, we envisage to keep the most successful aspects: transversal involvement of the INFN community, bottom-up approach, a program that favors the participation for the whole duration of the Workshop.

In addition, to promote the collaboration with Research Institutes and Companies, it is crucial to involve people outside INFN to get a mutual understanding of the experience and technological capabilities.

An important argument to discuss and analyze in the future edition is Technology Transfer, a sector in which INFN made very important advancements in the last few years. By developing specific technologies for frontier experiments, INFN continuously transfers large knowledge to the industrial partners, strongly increasing their competitiveness and technological expertise. The enormous amount of knowledge that was and is developed inside the INFN laboratories often gives a strong boost to many activities in which industries are involved, providing important improvements. It looks definitely worthwhile to deepen the discussion on how to further enhancing the effectiveness of the Technology Transfer and its relevance for both our research field and the non-scientific community.

References

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