# What Next Technologies
# (IFD2015 Workshop)
Draft

## 1. Introduction

Italy has been one of the key players in the effort which led to the discovery awarded the 2013 Nobel Prize for Physics, with a highly recognized technological contribution both to the LHC and the experiments.

The top priority of the European Strategy for Particle Physics is the exploitation of the full potential of the LHC including the high-luminosity upgrade of the machine and detectors. To be able to contribute at the international level and to foster common R&D projects the INFN Workshop on Future Detectors for HL-LHC (IFD2014) was held in Trento (March 11-13, 2014) to focus on the upgrades of the experiments for the High Luminosity LHC. The goal was to establish an open framework to discuss and work on new ideas for research and development where expertise can be shared and expand across the different INFN experimental groups. This process aimed to explore and consolidate a constructive interaction within different national research centers, facilities and industry also to better prepare for Horizon2020 applications.

At the same time INFN started the What Next (WN) program, a process based on the open and wide discussion to investigate possible new research ideas and to promote new science-driven experiments. It is clear that new or improved technologies play a crucial role to pave the road towards the necessary breakthrough for possible discoveries.

With this aim IFD2015 in Torino, became the INFN Workshop on Future Detectors (December 16-18, 2015), where the What Next challenge to identify new ideas to be explored was technology-driven exploiting cross synergies coming out from different research groups. The following document presents the highlights and the perspectives for further discussions.

## 2. Overview

One of the main objectives of the IFD2015 Workshop was to bring together the vast INFN Community involved in detector technology development. 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 know-how in detector technology, and to transmit it to the next generations of researchers

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

Some detector (and detector-related) technologies cover an extremely vast spectrum of applications.

One notable example is given by the Micro Pattern Gaseous Detectors (MPGD), which have 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.

Another sensor category that finds virtually ubiquitous application is photosensors. 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), without 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 the 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. 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 wich will benefit from the R&D on new high-temperature superconducting materials. On the other hand, the experience achieved to be compliant 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 locations where the radiation conditions are extreme.

4. Some critical issues for the next physics 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
- Suppress background 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 a final 4D tracking system. 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 guaranty the complete control of the experimental clocks.

2. Along the same line, a further pixelization or increase in granularity is needed in all detectors technology. This push all experimental communities, also the ones traditionally less aggressive under this respect, to develop low mass mechanical support, 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 costs 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:

- reading out cherenkov and scintillation light to increase the calorimeter energy resolution for collider and in space experiments,

- with a dual-phase cryogenic particle detectors to suppress background in dark matter search and with a second bolometer to detect scintillation and Cerenkov light in coincidence with the signal produced in the crystal absorber to reject background in double beta decay experiments.

Also, the importance of excellent front-end electronics, trigger and DAQ has been emphasized in order to achieve the needed performance for 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 still 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.

5. 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 how the 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 that 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 can probably still meet the requirements of HL-LHC, advanced CMOS sensor technologies (either on high-voltage, HV,or high-resistivity, HR, 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 NDAs), 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, these 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.

## 6. Maintaining, developing and transmitting the knowledge

We have to be aware of the importance of maintain and develop detector expertise, and to transmit this know-how 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, shorter scale experiments and R&D

- Rewarding: giving proper recognition of excellence in instrumentation development in careers at universities and research institutions

As Prof. Pier Francesco Manfredi taught us: " a detector must be thought as part of a system" producing the signal to be analyzed to produce final results. Therefore to setup proper experimental apparatus suited to next discoveries it's mandatory to be able to design, commission and exploit together different technologies to be adapted to environmental and aging constraints. We need to form the new generation of experimental physicists!

## 7. 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, are all 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 structure has given (and is still giving) excellent results.

For the next editions of the workshops, 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 period 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 in the future edition is the Technology Transfer, a sector in which INFN made very important progress in the last few years. Developing specific technologies for frontier experiments, INFN continuously transfers large knowledge to our 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. A discussion on how to further improve the effectiveness of the TT and its relevance for our research field and for the nonscientific community, is definitely worth.