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Summary of Section "New Accelerators, Detectors, Calculus and New Technologies"

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Summary. — Deployment and development of advanced technologies for accelerators, detectors, electronics and computing is inherent in everyday activity of all research projects and experiments funded by INFN. However, when a part of the research work can be clearly identified as an R&D activity aimed at the development of a new technology or procedure for specific, or a more general, application it is worthwhile to cut it off and manage it as an independent self-consistent experiment. For many of them it is also easy to find applications in other research discipline or industry. In this case it is important to verify the potentiality of the technology, customize it and improve it, in collaboration with the end user, for the specific application.

PACS 41.75.-i – Charged-particle beams.
PACS 41.60.-m – Radiation by moving charges.
PACS 87.19.-j – Properties of higher organisms.
PACS 29.40.-n – Radiation detectors.

1. – Introduction

The National Scientific Committee V is a precursor and incubator for new projects devoted to INFN's experiments: the researchers group develops materials, apparatuses, particle beams, new or improved procedures or, more generally, cutting-edge technologies for experiments in nuclear, sub-nuclear and astro-particle physics. The extreme performances required by new experiments give rise to new techniques for particle acceleration and detection and for advanced computation tools. These results have found broad applications in other fields of science, as well as technology, informatics, health, defense, cultural heritage and environment preservation. The activity of the Scientific Committee develops in the following main items:

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– Particle accelerators

– Particle detectors

– Electronics and software development

– Interdisciplinary applications of INFN cutting-edge techniques.

The program of IFAE Conference parallel session "New Accelerators, Detectors, Calculus and New Technologies" has hosted oral presentation about the news in these areas.

2. – Accelerators

In the search for the fundamental constituents of the matter, physicists investigating the frontier of high-energy physics can rely on a strong partner community of scientists and engineers continuously improving the probes for their experiments by developing more intense and more energetic accelerated particle beams. Particle accelerators performance, basically represented by the beams energy and intensity, shows a constant progress since their first "appearance" in the research laboratories in the first half of the last century. This remarkable progress can be partly attributed to the progress of technologies involved. More likely is the result of the continuous development of new concepts and new solutions moving forward the limit of performance.

The scenario at the end of the first decade of the 21st century is confirming this trend. The largest and most energetic particle accelerator ever, LHC, is ready to be operative at CERN in Geneva. At the other end of the scale, relatively small accelerators became fundamental components for applied research activities. In between, mid-size intermediate-energy accelerators are used for either the development of interdisciplinary research infrastructure, like third-generation synchrotron radiation source or FEL, or the realization of particles "factories" where high-precision measurements of, usually, rare events predicted by the models of elementary particle physics can be performed.

This analysis has been confirmed by the presentations given at IFAE 2009.

The reports also evidenced the relevant contribution to the progress of particle accelerators physic and technology given by the INFN research groups. In the past years, a number of important achievements originated from projects lead by INFN and/or hosted by the INFN national laboratories. At the same time INFN research groups played an important role in large projects coordinated by worldwide international collaborations.

Another remarkable result, implicitly offered by the reports, is the presence of strong links and synergies among the different projects and the important role played by interdisciplinary applications of particle accelerators. The latter, in fact, being usually medium/small size projects, can fill the large temporal gap between the large HEP accelerator projects by providing training opportunities for young scientist, thus preserving and further developing cutting-edge competences over the years.

2·1. *The LHC start-up* [1]. – The date of 10 September 2008 marked the first complete injection tests, rapidly and successfully achieved, and the start of the Beam Commissioning Phase of the LHC. The first days of LHC operation provided remarkable results thanks to the excellent performance of all the key elements of the LHC complex. Unfortunately, after about 10 days of operation, the LHC was subjected to a major stop caused by a faulty interconnection between two magnets in the dipole string. The fault caused severe collateral damages. A task force, mandated to establish the failure sequence, formulated recommendations on two lines: the first one aim at the prevention of initial fault and the second ones aim at the mitigation of consequences.

The principal modification toward prevention of faults is the upgrade of the Quench Protection System (QPS). Main modifications towards mitigation of consequences for an eventual incident are adding extra relief devices in each dipole to reduce pressure build-up in the insulation vacuum and to replace fix clamped flanges by spring loaded clamps.

The operation with beam is expected for end October 2009.

2˙2. *DAΦNE and the high-luminosity test* [2]. – Collisions at DAΦNE, as well as at the other factories, are provided by flat multi-bunch beams colliding under a normalized horizontal crossing angle ψ (also known as Piwinski angle) smaller than 1.

In this context, the only approach to get a higher luminosity consists in reducing the vertical betatron function β_y^* at the IP, increasing the beam intensity and tuning properly beam emittance and transverse beam sizes to keep under control the beam-beam effects. However, since several factors set limits to any further relevant luminosity improvement, a new collision scheme, based on large Piwinski angle and *Crab-Waist* compensation, was proposed and implemented at DAΦNE. The large Piwinski angle, obtained by increasing the horizontal crossing angle and by reducing the transverse horizontal beam size at the IP, reduces beam-beam tune shift in the horizontal plane and it allows for a lower β_y^* value by taking advantage of the shorter longitudinal overlap length between colliding bunches. It also cancels almost completely parasitic beam crossings because the vacuum chambers of the two beams can be separated just after the first low-beta quadrupole in the IR and, finally, betatron and synchro-betatron resonances can be suppressed by means of a couple of *Crab-Waist* sextupoles, installed symmetrically and with a proper phase advance with respect to the IP.

Measurements confirmed the benefit provided by the *Crab-Waist* sextupoles and by the scheme as a whole. In May 2008, after only six months dedicated to machine commissioning, values of luminosity considerably higher ($\sim 30\%$) than those achieved in the past were already measured. The peak luminosity reached the maximum value achieved by now is 4.36 and the present peak luminosity is satisfactorily close to the nominal one predicted by numerical simulations. The single bunch specific luminosity at low currents exceeds by 4 times the best value measured during the past DAΦNE runs. Also daily integrated luminosity is a factor 1.5 higher than before the upgrade. The beam-beam vertical tune shift is now a factor ~ 1.5 higher than the maximum value achieved with the original collision scheme providing further evidence of the *Crab-Waist* sestupoles effectiveness in compensating the bem-beam coupling resonances.

This set of remarkable results confirmed the principle of *Crab-Waist* compensation as a major advance in the field of the beam-beam interaction in lepton colliders.

2˙3. *The SuperB project* [3]. – As a nascent international enterprise and multi-lab effort, *SuperB* aims at the construction of an asymmetric very high luminosity on the Frascati/Tor Vergata Italian area, providing a uniquely sensitive probe of New Physics in the flavour sector of the Standard Model. The luminosity goal of $10^{36}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ can be reached with a new collision scheme tested at DAΦNE (*see previous section*). This novel collision approach allows for very low β and for beam currents and bunch length to be comparable to those of PEP-II and KEKB. A unique feature of the *SuperB* collider is the longitudinal polarization close to the Interaction Point (IP), improving sensitivity for lepton flavor-violating τ decays, for measurement of τ g-2, CP in τ measurements and T violation studies.

After the publication of the Conceptual Design Report last March 2007 the *SuperB* project has started the Technical Design Report (TDR) this Spring 2009. For this purpose lattice design and beam dynamics studies are in progress together with collective effects, R&D studies and parameters assessment.

2˙4. *The future linear collider* [4]. – The high-energy physicists community agrees that LHC physics results need to be complemented, in the future, by experiments done with a high-energy lepton collider. The centre-of-mass energy will be between few hundreds GeV and few TeV depending on the experimental results from LHC. Linear colliders are the only feasible option since the energy reach of circular storage rings is limited by the emission of synchrotron radiation.

For a linear collider with a centre-of-mass energy in the 0.5–3 TeV range one candidate is CLIC (Compact Linear Collider), which aims to reach a peak luminosity in the range of $10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$. CLIC is a normal conducting accelerator with X-Band (12 GHz) high-gradient (100 MV/m) accelerating cavities that will implement the novel scheme of the two beam accerelation (TBA) proposed at CERN few years ago. Part of the R&D for CLIC is done in the CLIC Test Facility (CTF3), which is being constructed at CERN by an international collaboration.

If the required centre-of-mass energy will be in the 200–500 GeV range, following the recommendation by the ITRP International Panel, the linear collider will be based on the superconducting radio-frequency (SCRF) technology. The project called International Linear Collider (ILC) is now under study by an international collaboration. The ILC aims to reach a peak luminosity of $2 \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}$ and is based on 1.3 GHz SCRF TESLA type accelerating cavities.

2˙5. *New diagnostic for ultra-high intense electron beams* [5]. – The problem of measuring and controlling small beam sizes (of the order of tens of μm and smaller) is particularly crucial for Linear Colliders (LC) and linac-driven Free-Electron Lasers where the small beam size, together with high intensity and high charge density, makes non-invasive techniques of large interest as beam diagnostics, both transverse and longitudinal. As non-invasive beam profile monitors, diffraction Radiation (DR) is the most promising candidate for measurement of beam sizes of the order of tens of μm, typical for ILC in the first acceleration stage and XFEL. It is totally non-intercepting, which means that not only high-density beams can be measured, but also that they do not loose their quality. From the analysis of the angular distribution, beam size and angular divergence can be determined, allowing in the beam waist a single shot emittance measurement. Furthermore, by measuring the coherent spectrum it is possible to estimate the bunch length and reconstruct its longitudinal structure.

Results of recent measurements performed at FLASH by INFN scientist in collaboration with DESY confirmed the expectations. Further developments are planned aiming at the definition of a standard diagnostic set-up based on ODR.

2˙6. *Novel acceleration technologies* [6]. – In the past decade, terawatt, table top laser systems based upon chirped pulse amplification have been successfully used in many laboratories world-wide to explore the laser-matter interaction in the ultra-short, ultraintense domain for novel X-ray and γ-ray sources, laser-driven acceleration, inertial fusion energy research through the interaction with gas and solid targets. These results gave strong motivations for the development of new laser infrastructures like HiPER and ELI. The perspective of a practical exploitation of laser-driven acceleration for the future generation of particle accelerators is giving thrust to the development of integrated LINAC and FEL laboratories. The PLASMONX project at INFN-LNF aims at exploiting the FLAME laser system and the 150 MeV SPARC LINAC to explore laser driven particle acceleration in both the self-injection and the external injection scheme. In view of this, a self-injection test experiment (SITE) has been planned to establish the performance of the FLAME laser system and to assess the degree of control of critical laser parameters.

3. – Detectors

3·1. *Dual readout calorimetry* [7]. – An important factor presently limiting the performances of hadronic calorimeters is the presence of large fluctuations in the electromagnetic fraction of the hadronic shower. The dual readout method is a promising new technique to compensate for these fluctuations and consists in measuring, event by event, the electromagnetic fraction by separate detection of the scintillation light component and the Cherenkov light component, the latter being produced by the electromagnetic part of the shower.

The separation of the two light components, demonstrated with fiber calorimeters in the past, can be achieved using homogeneous materials too, because scintillation and Cherenkov light have different time structure and emission spectra.

New crystals from lead tungstate ($PbWO_4$) doped with small fractions of praseodymium or molybdenum are being developed to improve this separation, and the results reported by the DREAM Collaboration from the beam test performed in 2008 are encouraging: both dopings provide significantly different emission spectra for the two components, unlike the case of undoped $PbWO_4$. In particular, the 1% Mo-doped lead tungstate crystal allowed to achieve good separation, despite a severe problem of UV light attenuation.

Further improvements are needed, and will possibly come from the optimization of the doping fraction or from the use of different crystals already in 2009, offering the option to use homogeneous dual readout calorimeters to future experiments.

3·2. *A monolithic pixel detector* [8]. – Silicon pixel detectors for precise particle tracking are the central elements of most major HEP experiments, providing very high space resolution and good time precision.

Presently used pixel detectors are hybrid detectors since the sensor and the readout IC are separate units, linked by bonding. The option to use monolithic detectors in which sensors and readout are integrated in a single monolithic block is very attractive, because it promises to offer lower material budget, lower power consumption, reliable production yield and possibly mass production at low cost.

The recent developments toward implementing 90 nm CMOS technology on moderately doped p-type substrates open the possibility to integrate in a monolithic block standard CMOS readout circuits and sensor diodes with performances comparable to the ones of hybrid detectors: with an adequate thickness of the depletion layer and an external reverse bias to collect the charge by drift and not by diffusion the sensor diodes should provide good S/N ratio and readout speed.

This integration presents many challenges: uniformity of the depletion layer, full collection of the generated charge, shielding of the circuitry, insulation of the high voltage, etc. Preliminary results from simulations seem to indicate that no additional technological step is required to solve these problems.

On the other hand, the high density of metal lines allowed by 90 nm CMOS technology offers the chance to design a new architecture of the front end electronics: apart from the input transistor, housed in the pixel cell, all the rest of the analog and digital electronics may sit in the periphery of the chip, and receive prompt signal from the pixel via an individual metal connection, thus avoiding to distribute digital signals over the entire matrix.

With pixel cells of $100\,\mu\text{m} \times 100\,\mu\text{m}$ and a $10\,\mu\text{m}$ depletion layer the expected S/N ratio is about 25 and the overall power budget is $10\,\text{mW/cm}^2$.

3˙3. *Micro-Pattern Gaseous Detectors* [9]. – Micro-Pattern Gaseous Detectors (MPGDs) are recent but well-established technologies, with applications in HEP, astrophysics and several other fields.

Detectors based on GEMs and Micormegas have been successfully operated for several years by the COMPASS Experiment at CERN, and are nowadays used in the tracking systems of many experiments.

A consistent R&D effort to optimize the MPGD technologies for production of detectors covering very large-areas is however needed to fulfill the requirements of future large scale experiments, as foreseen in the SLHC upgrade and elsewhere.

There is a continuously increasing interest in a number of these R&D activities, which have reported recent progresses, like single mask GEM production, GEM foils splitting, curved GEM production, Bulk Micromega technology, integration of MPGDs with front end electronics, THGEM-based photon detectors, Resistive THGEMs, etc.

The MPGD Community has recently converged in the RD51 Collaboration, with the aim of sharing information, results and experiences, and also steering the R&D efforts: about 350 authors from 57 institutes and 20 countries worldwide have signed the proposal, approved by CERN at the end of 2008.

3˙4. *The upgrade of COMPASS RICH-1* [10]. – The COMPASS Experiment at the CERN SPS, requiring hadron identification in wide momentum and angular ranges, has built and operated since 2001 a large-size RICH detector with a 3 m long C_4F_{10} gas radiator and photon detectors consisting in MWPCs with CsI photocathodes, providing 14 detected photon per ring at saturation and a $2\sigma\pi$-K separation up to $43\,\text{GeV}/c$.

To overcome a problem of limited efficiency in the very forward angular region, due to the high rate of uncorrelated background, a major upgrade of the photon detectors has recently been implemented, including the replacement of the central MWPC's with arrays of MAPMTs coupled to individual fused silica lens telescopes and read out by fast electronics based on the MAD4 preamplifier-discriminator chip and the F1 TDC.

With 56 detected photons per ring at saturation and a 2σ π-K separation above $55\,\text{GeV}/c$ the upgraded RICH-1 is providing really outstanding performances. In order to further improve the rate capability of the detector, limited around 1 MHz per channel by the MAD4, a new front end chip, the CMAD, has been developed and implemented for the 2009 COMPASS run: it is a full-custom ASIC in $0.35\,\mu\text{m}$ CMOS technology, with 8 channels per chip, a low-noise transimpedance preamplifier, programmable gain, individually adjustable threshold levels and low power consumption.

With the CMAD front end the fast photon detection system of COMPASS RICH-1 can now stand rates above 5 MHz per channel.

3˙5. *A THGEM-based photon detector* [11]. – Possible candidates for future large-area RICH photon detectors are THGEMs coupled to a CsI photoconverting layer. THGEMs are electron multipliers derived from the GEM design, with scaled geometrical parameters and manufactured using standard PCB techniques: holes are mechanically drilled on double-layer PCBs.

In order to optimize the geometrical and production parameters, more than 30 different THGEMs have been characterized using X-ray sources, gaining insight in the role of the various parameters.

Very large gains can be achieved when using THGEMs with large rims around the holes, but only THGEMs with small rim (less than 20 μm) offer good gain stability.

The efficiency of photoelectron extraction from a CsI coated THGEM and the efficiency of collection into the THGEM holes have been studied and found to have the behavior predicted by dedicated simulations.

Tests of photon detector prototypes with multilayer THGEMs have been performed using tagged UV light sources in single photon mode: stable operation with gain larger than 10^5 has been obtained.

The time resolution of a prototype has been measured using 600 ps long light pulses and a high-resolution TDC and found to be about 7 ns.

4. – Calculus and new technologies

Advanced technologies for both data acquisition and analysis is a very important aspect of experiments founded by INFN. Generally these activities are part of high-energy physics experiments but there were innovative applications to interdisciplinary fields. In this session there are presented both work purely related to high-energy physics and work in interdisciplinary areas. This parallel session of IFAE Conference has also hosted two presentations involving the bio-medical application.

4˙1. *Comparison of Monte Carlo simulations based on Geant4 and Fluka to the Tile-Cal test beam data* [12]. – Monte Carlo simulation of detector hardware is increasingly important and many aspects of modern experiments demand a reliable software simulation. The work presented by dr. M. Cascella was developed to validate the official simulation chosen by the ATLAS Collaboration (Geant4) against the data acquired during the test beam of ATLAS hadronic calorimeter and to compare Geant4 predictions to those of a completely different software simulation (the Fluka package). Dr. Cascella has submitted a study of the signal produced by charged pions of energies ranging between 20 and 350 GeV in modules of ATLAS Tile Calorimeter. The results from test beam data are compared to the predictions of different Monte Carlo simulations (Geant4 and Fluka). The goal is to assess in a quantitative way how well different Monte Carlo codes can reproduce the distribution of visible energy in the calorimeter and the details of the hadronic shower.

4˙2. *GigaFitter: performances at CDF and perspective for future applications*. – Dr. M. Bucciantonio showed a new track fitter, the GigaFitter, pariculary about performances at CDF and perspective for future applications. The Silicon Vertex Trigger (SVT) at CDF experiment is a Level 2 online trigger that performs online fast and precise track reconstruction. The SVT efficiency is derating while the Tevatron instantaneous luminosity is increasing. A next generation track fitter, the GigaFitter, has to be developed. The GigaFitter reduces the track parameter reconstruction to a few clock cycles and can perform many fits in parallel, thus allowing high-resolution tracking at very high rate. The core of the GigaFitter is implemented in a Xilinx Virtex-5 FPGA chip, rich of powerful DSP arrays. The processor architecture has been developed and preliminary tests have been curried out parasiticaly in SVT to study its capabilities. Preliminary results of timing measurement in the SVT environment are shown.

4˙3. *Medical Image Processing: Automatic Segmentation of Hippocampus* [13]. – Dr. M. Corosu (on behalf of Magic5 Collaboration) presented algorithms designed and tested for the analysis of brain imaging for early diagnosis of Alzheimer's disease. Dementia is a major cause of disability in the developed countries and places. An important public health concern of developed countries is aging of the population and the associated increases in the prevalence of various dementias, particularly Alzheimer's disease (AD). In fact, as life expectancy increases together with the birth rate decrease in industrialized countries, we face a noticeable escalation in population aging and, consequently, a burst in Alzheimer disease incidence. The tragic outcome of this disease and the health system increasing costs render the economical burden often unbearable for the families as well as for the social health networks. Numerous studies have explored the effect of Alzheimer's disease on brain structure. For these reasons, it is of paramount importance to develop strategies and reliable tools for the early assessment of the disease, in the effort to limit its consequences. The objective of this research is to increase the likelihood of early recognition and assessment of Alzheimer Disease so that 1) concern can be eliminated if it is not warranted; 2) treatable conditions can be identified and addressed appropriately; and 3) non-reversible conditions can be diagnosed early enough to permit the patient and family to plan for contingencies such as long-term care. In this work a computational tools for the automatic analysis of Medial Temporal Lobe atrophy starting from large sets of structural MR images is developed. The goal of the research program is to develop and test predictive quantitative models for the analysis of distributed biomedical images using the typical techniques of Physics, such as: massive computationally algorithms, based on statistical mechanics too; analysis of images with high complexity; calculation and use of results on distributed computing infrastructure.

4˙4. *Detectors for the next generation PET scanners* [14]. – Still within interdisciplinary are presented by Dr. S. Marcatili the results about the study of detectors for new PET scanners. Next-generation PET scanners are expected to fulfill very high requirements in terms of spatial, energy and timing resolution. Modern scanner performances are inherently limited by the use of standard photomultiplier tubes. The use of Silicon Photomultiplier (SiPM) matrices have been demonstrated to be optimum candidates for the assessment of PET apparatuses. Their intrinsic features allow for the construction of PET systems with performances far better than those of the modern scanners. A small animal PET prototype is under development in the framework of the INFN project DASiPM. It will provide DOI information and a sub-millimetric spatial resolution at the center of the FOV as predicted by Geant4 simulations and then confirmed by measurements on a smaller version of the final detector module.

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