Graduate Studies in Accelerator Physics: thesis topics

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Dip. di Fisica, ”Sapienza” Univ. di Roma

Book of Abstracts

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Extremely compact and high gradient laser-based THz-driven accelerators

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In the framework of novel acceleration techniques the following topics are available as PhD dissertation concerning the Research and Development activities toward the generation of an extremely compact and high gradient laser-based THz-driven accelerators.

• Study the possibility to strongly accelerate electron bunches exploiting high gradient THz filed.

• Study the high energy, high power broadband THz laser pulse generation

Both theoretical and experimental work is required and will be assigned to the students depending on their skills and interest.

Part of the experimental work can be carried out at LNF-INFN and /or at CERN

Activity :

1) Research and Development activity aiming to generate high energy broadband THz pulses by optimizing the optical rectification process and coherent controlling multiple THz pulses.

2) Theoretical/numerical and experimental studies to optimize the THz propagation in capillaries with the aim to produce an extremely compact high gradient THz-driven linac section.

3) Theoretical/numerical and experimental studies of high energy high power (>30TW) laser pulse propagation in gasses with the aim to produce an high energy (>1mJ) broadband THz source.

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Summary:

In the framework of novel acceleration techniques, PhD dissertations concerning the Research and Development activities toward the generation of an extremely compact and high gradient laser-based THz-driven particle accelerators are available.

The Research and Development is dedicated to:

1) the development of an high intensity THz source,

2) the coupling of the THz radiation in a capillary structure in order to produce an high gradient compact linac .

3) proof of principle of the THz-driven linac acceleration.

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Implementation of RFKO and multi-energy extraction at CNAO

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The Centro Nazionale di Adroterapia Oncologica, CNAO, in Pavia is one of the few centers worldwide where radiotherapy can be delivered with both protons and carbon ions.
The core of the CNAO is a small synchrotron capable of producing proton beams in the energy range 60-250 MeV and carbon ion beams in the energy range 120-400 MeV/u.
The beams are slowly extracted from the synchrotron by a third integer resonant scheme in which particles are driven into the resonance in energy by a betatron core.
A second extraction mechanism, called RFKO, is going to be implemented in the near future. In this alternative scheme the particles are driven into the resonance in amplitude by a transverse resonant noise. This scheme is more suitable to a multi-energy extraction process in which the particles remaining in the accelerator, when all the particles required for a given energy have been delivered, are accelerated to the following required energy without the need for a new injection.
When the RFKO will be working the CNAO synchrotron will have two extraction systems present at the same time on the same machine and this will give a unique opportunity to make a comparison of the two systems under the same conditions.
The selected candidate will participate to the aforementioned activities contributing to both theoretical aspects and hardware implementation.
The work will be carried out in Pavia.

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FCC Interaction Region design: machine detector interface

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CERN has recently launched the ambitious project of the Future Circular Collider. The same 100 km tunnel will host a hadron-hadron collider with pp collisions at 100-TeV center-of-mass energy (FCC-hh) and e+e- collisions up to 350-GeV center-of-mass energy (FCC-ee). The two colliders should be built in the same tunnel as was for LEP and LHC. This challenging design study involves a worldwide collaboration with great accelerator physics experts on all the different fields.
INFN is involved in the FCC study in both machines, and it also participates to EuroCirCol, the European project funded by EU under Horizon 2020 for some aspects of FCC-hh study.
One of the key issues of these two colliders is the Interaction Region design, in fact, the Machine Detector Interface group has to ensure that the two beams produce the desired luminosity in the experiments. Low backgrounds induced in the detectors are one of the challenges of this enterprise, that would be the world's largest and most powerful collider.
The PhD thesis would focus on the Machine Detector Interface aspects, contributing to optimize the Interaction Region design.
The activity will be to develop particle tracking studies for the main beam loss effects, relevant for the interaction regions design. Possibility of Benchmark tools with existing colliders, like the LHC for the FCC-hh studies and SuperKEKB for FCC-ee.

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Novel approach for low emittance muon beams

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The traditional approach for the design of a muon collider is based on the production of muons by means of an intense proton source. One of the most critical issues of this design is the cooling of the muons emerging from the hadronic interactions in the target. Some basic designs now exist, however, the final cooling stage for a multi−TeV muon collider needs further R&D.
An alternative approach, called Low Emittance Muon Collider (LEMC), has been recently proposed. It is based on muon pair production by a positron beam impinging on electrons at rest in a target. The main advantage of the new scheme is that the muons produced in the e+e- to μ+μ− process are constrained into a very small longitudinal and transverse phase space region. LEMC provides a "naturally"cooled muon beam with high laboratory lifetime. If successful, the new technology could lead to very compact machines yielding high precision measurements of the Higgs mass and width and would allow the exploration of the multi TeV region with a much lower level of investments relative to current projects.
To asses the feasibility of the novel technique we propose to study some of the most crucial issues of the new approach, in particular the choice of the target, and the most appropriate accelerator optics to allow large momentum acceptance for the positron storage ring. We plan to perform detailed simulations and to validate some of the studies with experimental tests.

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Plasma driven Free Electron Lasers

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A novel type of accelerator technology making use of plasma wakefields promises gradients as high as some tens of GeV per meter. This would allow much smaller accelerator facilities that could be used for a wide range of fundamental and applied research applications. A relevant milestone towards the complete demonstration of the plasma wakefield acceleration concept is the integration of the high gradient plasma modules within a short wavelength Free Electron Laser (FEL) user facility. The PhD student will join the efforts of the ENEA-Frascati group in the simulations, design and optimization of the FEL driven by the electron beam coming from the plasma acceleration module at the SPARC_LAB facility at the INFN-LNF. In particular, these studies include the beam transport and matching into the present undulators section as well as the research and development on short period undulators based on new concept technologies such as RF and Optical undulators. This work is also propedeutical for the design study of the world's first multi-GeV plasma based facility, carried by the European Plasma Research Accelerator with Excellence in Applications (EUPRAXIA) Consortium.

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Development of a simulation code for design and optimization of bunch-by-bunch feedback systems dedicated to circular lepton accelerators

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Goal of the thesis work is to develop a model to study stored lepton beam and bunch-by-bunch feedback behavior. The beam model will be based on parameters from future or existing circular accelerators. It will implement circular accelerator concepts for describing beam behavior and instability. The feedback model will be used to design a system able to damp the instabilities and it will be based on F.I.R filter theory. Both models should be most likely implemented in Matlab and/or Simulink language. Interfaces to other models written in FORTRAN or C/C++ are possible. A good knowledge of the dynamic system theory is required to characterize the beam+feedback system. Feedback stability criteria as well as zero-pole-gain model must be known. Matlab Control System Toolbox can be used as basic development tool. Linux and C/C++ working knowledge is also welcome.

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Development of a real time bunch by bunch feedback system based on FPGA technology aimed at stabilizing beam motion in circular lepton accelerators

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Goal of the thesis work is to develop a real time feedback system based on FPGA technology. Signals from each bunch are acquired, digitally converted and stored in dedicated memory space to produce individual feedback correction kick at each bunch passage. F.I.R. filters have to be implemented in FPGA based boards to stabilize the beam motion. Digital electronics, FPGA programming, VHDL and/or Verilog, C/C++, Matlab knowledge is required. Linux working experience is also welcome.

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Bent crystals for high energy beam steering

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Charged particle beams can be manipulated with crystals thanks to a variety of phenomena usually refered as crystal channeling. For instance, few mm long bent crystals can provide a deflection of the CERN LHC beam equivalent to a 300 T dipole magnet. Several application are envisaged, ranging from the LHC crystal collimation to crystal-aided slow extraction. Particles can be redirected to secondary targets where various processes of hadron-nuclei interactions can be studied.
In collaboration with CERN, a program of study of use of crystals on circular machine is currently on-going, including crystal characterization, beam monitor and absorber devices constructions, and MC simulations.

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Study and mitigation of collective effects and in HL - LHC and FCC-hh. (LNF).

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In future proton accelerators at the energy frontier an essential component that can influence their final characteristics in terms of luminosity and intensity requires the understanding and control of collective effects. Such possible effects are due to the interaction between the accelerated beam with some of the electrons present within the accelerators. Such electrons (mainly of low energy) are emitted (also by photoemission) from the accelerator metallic walls. This thesis focuses on the study of this phenomenon. Experiments to unveil all of the material properties governing such electrons production will be studied in details. To this end, the candidate will work within an international context (in close collaboration with CERN and other international laboratories) and will use an "ad hoc"Material and surface science laboratory, at the National Laboratories in Frascati. An essential part of this study will require a deep understanding of electron production and gas desorption phenomena from cold walls once bombarded by photons, electrons and / or ions. This study will try to exactly simulate what will take place in real accelerators conditions.

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Study of the thermal load induced by Synchrotron radiation in Future circular colliders (FCC-hh) and potential cures to make more them more sustainable.

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In future proton accelerators at the energy frontier an important show-stopper could be represented by their sustainability. Installation as well as running costs should be kept under stringent control. One of the most significant item, in this context, is represented by energy consumption costs. Present estimates shows that most of the expected energy consumption will be devoted to control the thermal load induced by synchrotron light inside the superconducting magnets, operating at low temperature. It is well known that the lower is the temperature at which an heat load must be dissipated, the more this operation becomes expensive. The subject of this thesis focuses on the study of an innovative proposal, which allows to transfer the heat load from the low temperatures dipole regions to warm areas of the machine. This would significantly reduce FCC-hh energy consumption, rendering it sustainable. Interested applicants will participate to an international collaboration, which involves CERN and other European Synchrotron Radiation facilities in addition to the one in operation at the Frascati National Laboratories. Validation of an highly reflective system carrying the light-induced power away from the cold walls into room temperature areas could represent a key solution to this complex problem. This study will require the development of computational and experimental skills to study and qualify various materials and thin coatings, using techniques ranging from synchrotron radiation spectroscopy, thin films technology, X ray reflectivity etc.

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Installation, test and preliminary commissioning of the ELI-NP Compton Gamma ray source

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An advanced source of Gamma-ray photons is under construction in Magurele (Bucharest, Romania) in the context of the ELI-NP Research Infrastructure. The photons will be generated by Compton back-scattering in the collision between a high quality electron beam and a high power laser. The machine is expected to achieve an energy of the gamma photons tunable between 1 and 20 MeV with a narrow bandwidth (0.3%) and a high spectral density (104 photons/sec/eV).
In this framework it is available a PhD dissertation mainly devoted to the experimental activity on LINAC installation, commissioning of RF plants and accelerating structures, diagnostics systems, photocathode laser and preliminary test with beam related to measurements of dark current, beam dimensions, emittance, energy, energy spread and position along the first part of the LINAC.
The activity is mainly experimental and requires a broadband knowledge of the overall accelerator systems from accelerating structures to RF power sources, laser and diagnostics with the development of dedicated mathematical tools for measurements acquisition, elaboration of images and signals and error analysis.

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Design and test of a full C-band high gradient photo-injector for high brightness electron beams with the new technology of clamped structures

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The use of radiofrequency C-Band accelerating structures for electron acceleration and production of high quality beams has been recently proposed and adopted in several linac project all over the world. The current projects foreseen the use of an S-band injector combined with a C-band linac booster like in the ELI-NP project. A full C-band injector that combines a C-band high rep. rate RF gun with C-band accelerating structures is the next and definitive step in the C-band photo-injector design. The research activity foresees different phases:

- design of a new type of travelling wave C-band gun that allow to reach accelerating field on the cathode above 150 MV/m

-beam dynamics simulations including solenoids for beam emittance compensation to optimize the working point at different regimes

-mechanical design of the RF gun for the realization of a prototype structure with the novel proposed technique of clamping without brazing

-RF test and characterization of the RF gun prototype.

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High level applications for the ELI NP GBS project

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EuroGammas is a consortium of top-level European scientific institutions and companies, lead by INFN (Istituto Nazionale di Fisica Nucleare) to provide the design, installation and commissioning of the most innovative light source in the world, to be deployed in the upcoming years in Romania.

This new international research infrastructure will provide a broad range of science covering new nuclear physics, astrophysics, fundamental high field physics as well as applications in nuclear materials, radioactive waste management, material science and life sciences.
The Gamma Beam System of ELI–NP will produce brilliant, quasi–monochromatic gamma–ray beams via Inverse Compton Scattering (ICS) of short laser pulses on relativistic electron beam pulses. The scattered radiation is Doppler upshifted and is forward focused in a narrow, polarized, tunable beam.
The gamma–ray beam at ELI–NP will be characterized by large spectral density of about 104 photons/s/eV, narrow bandwidth(< 0.5%) and tunable energy from 200 keV up to about 20 MeV.
The Gamma Beam System is a state-of–the–art equipment employing techniques and technologies at the limits of the present–day's knowledge. ELI-NP is the most powerful of the new generation of light sources that will stem all over the world.
Physics PhD student to work on high level applications development and study machine physics for the ELI-NP Gamma Beam System (GBS) within the Beam Dynamics and Commissioning working groups of the EuroGammas collaboration, located at INFN Laboratori Nazionali di Frascati.

You will be part of the team responsible for the development of high level applications for the GBS. This involves developing a "virtual accelerator"on which the tools needed for commissioning the real machine will be developed and tested. It will be possible then to test such tools on the actual machine during its commissioning or in partnership with other LINAC-based facilities (SPARC, Fermi@Elettra⋯).
The accelerator model will be developed through the MATLAB Middle Layer toolbox and the elegant simulation codes: these two instruments are the state-of-the-art codes for developing model-independent tools for machine commissioning and operation.
Throughout the job the student will have the opportunity to learn first-hand about the whole range of physics to operate an innovative 5th generation user-oriented light source facility.

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Development of a new tracking device for characterization and monitoring of ultra fast neutron beams

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Nowadays, there is a great concern about high energy neutron fields owing to the increasing number of high energy accelerators in research and medicine and the special consideration given to the occupational exposure to cosmic radiation. In order to study the physics of neutron interactions in these applications (dosimetry, radiation protection, effects in electronics, etc) well-characterized neutron fields for high energies are needed. The project of the construction of a Quasi Mono-energetic Neutron beam (QMN) with energies above 100 MeV has been lunched at TIFPA in Trento. The MONDO detector, a tracker for ultra-fast neutrons, exploits the elastic interactions (single ES and double ES) of the neutrons in a compact matrix of thin scintillating fibers; the tracking and the energy measurement of the recoil protons allow to study the energy spectra and the flux of the incoming neutrons. The subject of this Ph.D. thesis will be the realization of a monitor for neutron beam exploiting the MONDO detector and the integration of such a device in the Trento QM neutron beam facility.

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Beam dynamics and collective effects for the upgrade of the CERN Proton Synchrotron

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In the framework of the upgrade program of CERN accelerator complex, with a goal of reaching in LHC a luminosity 10 times higher and double the beam energy, a critical point could be the beam current limit due to the electromagnetic fields produced by the interaction of the beam with the surrounding environment. These fields are particularly important for high intensity beams because they can perturb the nominal trajectory of the beam by modifying the guiding external fields up to a level to generate beam instabilities.

For the CERN Proton Synchrotron some issues related to collective effects are observed and need further studies, in particular for its upgrade program:

1) a transverse instability is observed at the transition energy. This instability is explained with the present impedance model of the machine, but further investigation is necessary, also to optimize the gamma-jump used to cross the transition in order to reduce the instability growth rate. This work foresees Machine Development sessions at CERN and simulations with a CERN code.

2) a longitudinal feedback has been installed to counteract the dipolar coupled bunch instability due to the 10 MHz cavities. Some quadrupolar oscillations are however observed, and they need to be well understood.

3) the transverse impedance model of the machine that has been developed in the last years needs to be improved in order to explain the machine betatron tune shift at different values of chromaticity.

The thesis activity will be based at the Department of Basic and Applied Science for Engineering of La Sapienza, but some periods at CERN for MD sessions and discussions are foreseen.

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Benefits of barrier buckets during the transfer of fixed target beams with application to the BDF facility beams

For a future intensity increase of the fixed-target beam in the accelerator complex at CERN (BDF, SHiP, etc.), new techniques to reduce beam loss must be explored. A major fraction of the losses during extraction of the coasting beam from the PS towards the SPS originates from badly kicked particles. A line density depletion, synchronized with the extraction kickers, would allow to significantly decrease these losses. The Finemet wideband cavity recently installed in the PS as a longitudinal feedback kicker could also serve to study a longitudinal gap in the beam by generating a so-called barrier bucket. In the framework of a doctoral student work, the benefits of these barrier bucket RF system for fixed target beams should be evaluated in the PS and SPS accelerators. This will be complemented by hardware developments to operate the existing Finemet cavity as a prototype barrier RF system and machine development studies.

The thesis activity will be based at CERN and application for a PhD grant at CERN is open.

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Beam dynamics in present and future circular lepton colliders

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DAFNE is one of the seven colliders operating in the world. The main part of the accelerator complex consists of two distinct rings implementing collisions between electron and positron beams at the energy of F-resonance, 1.02 GeV in the center of mass. The present luminosity achieved at DAFNE is by two orders of magnitude higher than the one obtained at other colliders operating in the same energy range.
Careful beam dynamics studies such as vacuum chamber design with low beam coupling impedance, suppression of different kinds of beam instabilities, investigation of beam-beam interaction, optimization of the beam nonlinear motion have been the key ingredients that have helped to reach this remarkable result.
Many novel ideas concerning accelerator physics have been proposed and or tested experimentally at DAFNE for the first time. It is the case of parasitic beam-beam interaction suppression by current-carrying wires, beam collisions with negative momentum compaction factor, electron cloud mitigation with dedicated electrodes, wigglers with "wiggling"poles, strong RF focusing of interacting beams, and many others.
However, the most outstanding contribution of DAFNE to the physics of colliders is the innovative concept of interacting beams, called Crab Waist (CW) collision scheme. It has been proposed at LNF INFN and successfully tested at DAFNE in operational conditions providing luminosity for two different experimental detectors, SIDDHARTA and KLOE-2. The high efficiency of the CW scheme in increasing luminosity and its relatively easy implementation led it to become a basic design concept for several new projects. The list of the new machines includes: SuperKEKB, a B-factory already under commissioning in Japan, SuperC-Tau, a collider proposed at Novosibirsk, CEPC, the Higgs Factory under study in China, and FCC-ee the new 100-km electron-positron machine which is part of the CERN ambitious FCC project.
The proposed PHD thesis aims at studying beam dynamics and its interplay with the beam-beam interaction for the DAFNE configuration based on the Crab Waist collision scheme and including the KLOE-2 detector. The purpose of this work is twofold: to push DAFNE luminosity to its ultimate limit, and achieve a detailed comprehension of the collider limiting factors. Moreover, the experimental studies undertaken at the Frascati F-factory will be of primary interest for all the other communities working at the design of future colliders based on the Crab Waist approach.
The research program includes experimental and simulation activities to be done at the Frascati laboratori (LNF) of INFN.

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Design and realization of an RF impedance measurement system at cryogenic temperature

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The beam screen of the FCC will make use of innovative technologies, either for beam impedance mitigation (HTS coatings) or for the suppression of the electron cloud phenomenon (amorphous-carbon coating or laser surface structuring). Assessing the properties of real-scale prototypes in terms of RF impedance, in a frequency range relevant for the FCC at cryogenic temperature and eventually in presence of a multi-T magnetic field, is a necessary condition for the success of the study. Realizing such an impedance test system is a challenge which will allow developing diverse competencies in the fields of radiofrequency, material and surface science, vacuum technology, cryogenics.

The PhD student will first carry out the RF design of a prototype test facility, based on the coaxial two-rods configuration, follow-up its manufacturing and verify its performance first at room temperature and then at cryogenic temperature. In a second stage, and based on the earlier results, the PhD student will carry out the design of the final facility which should be integrated into a cryostat fit for an 11 T magnet, supervise its construction, commission it and bring it into routine operation.

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Sviluppo di beam monitors basati su rivelatori timepix per studi di manipolazione di fasci con cristalli

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L'estrazione o la collimazioni di fasci circolanti tramite il channeling su cristalli risulta sempre più promettente e necessaria per gli acceleratori di nuova generazione.
La messa a punto dei cristalli e lo sviluppo del software e hardware per il loro corretto posizionamento all'interno dell'acceleratore richiede una diagnostica molto sofisticata e radiation resistent.
Rivelatori al silicio e diamante letti da Timepix si sono rivelati
molto utili a tal scopo ottenendo ottimi risultati nei recenti test al SPS del CERN.

Summary:

Negli ultimi due anni e' stato messo a punto dal gruppo UA9 di Farscati un sistema di diagnostica basato su tecnologia Timepix installati in 3 Roman Pots dell'SPS al CERN.
Il sistema di acquisizione e' stato sincronizzato con la radiofrequenza SPS e permette il monitoraggio del fascio circolante fino a 100 giri senza tempi morti.
Recentemente e' stato installato un nuovo rivelatore basato su timepix3 che permette di allungare questi tempi di misura.

Durante alcuni beam test sono stati effettuati studi di nuovi dispositivi Timepix-quad che permettono di realizzare dei telescopi portabili per test di cristalli.

C'è un interesse quindi da parte dei gruppi acceleratori CERN di continuare la collaborazione nei prossimi anni.

L'attività prevista nei prossimi anni:
•Miglioramento del software di acquisizione
•Analisi delle preformance timepix vs timepix3
•Analisi dei dati presi nel 2018 su SPS e test beam
•Test dei cristalli da installare in SPS e LHC tra 2 anni
•Sviluppo di rivelatori basati su timepix radiation hard (diamondpix)
•Realizzazione di un telescopio basato su rivelatori timepix

In allegato le slide presentate durante la riunione italiana di UA9 del Giugno 2018.

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Terahertz Acceleration of Particles

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Recently INFN approved a project in the Department of Physics of Sapienza for developping a Terahertz high-intensity sub-picosecond source to be used for unconventional schemes of electron acceleration. A PhD thesis is avalaible at the Teralab laboratory (Prof. Stefano Lupi) of the Department of Physics of Sapienza on this argument.

Summary:

The TERA (THz-ERA) project financed by the italian National Institute for Nuclear Physics (INFN) is dedicated to the development of innovative terahertz technology with the following goals:

1) The development of a highly intense THz source with an associated electric field of 50 MV/cm based on the conversion of near-infrared laser radiation at lower frequency through either optical rectification and two-colors air plasma mechanisms;
2) Novel THz detectors and active polarizer devices;
3) Cavities for particle acceleration through the THz electric field.

These goals are the key components required to develop in the near future an all-THz based compact accelerator and at the same time are the mains elements for a multi-disciplinary use of THz radiation in other fields of research in line to the European THz road map.

In this framework a PhD Thesis is opened in the Roma-La Sapienza INFN section, and we are looking for a highly-motivated student. The Thesis includes the developping of the terahertz source and the simulation of the acceleration cavity and their coupling. Non linear optics and ultrafast laser will be routinely used in the thesis developement.
We extected that at the end of this thesis the PhD student will be expert in non linear optics, laser technology, THz acceleration and more in general in THz new technologies spending this expertise in several laboratories in Europe and USA.

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Machine layout for the search of electric dipole moments of heavy baryons at the LHC

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A novel experiment for the study of electromagnetic moments of short-lived baryons at the LHC has been recently proposed. The machine layout is based on a crystal kicker deflecting protons from the beam halo towards a fixed-target, where baryons are produced and channeled in a long-bent crystal. In collaboration with CERN, feasibility studies and simulations of the LHC machine will be carried on to determine the optimal layout for the proposed experiment.

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muon accumulator ring study for a muon collider

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Very low emittance muon beams can be produced by direct annihilation of about 45 GeV positrons on atomic electrons in a thin target. With such a muon beam source, a mu+ mu- collider can be designed in the multi-TeV range at very high luminosities. In this scheme two muon accumulator rings are foreseen to recollect the muon bunches that will be injected in the collider.
We propose to design the layout of a large momentum acceptance isochronous ring that aims to maximise the performances of a low emittance muon collider.
The work will be performed at the Frascati national laboratories of INFN in collaboration with ESRF and CERN.

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Positron source for a low emittance muon collider

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Very low emittance muon beams can be produced by direct annihilation of about 45 GeV positrons on atomic electrons in a thin target. With such a muon beam source, mu+ mu- collider can be designed in the multi-TeV range at very high luminosities.
An high intensity positron source is needed to produce muons with this method.
The present record positrons production rate has been reached at the SLAC linac SLC. We propose to study a scheme to allow and embedded positron generation compatible.
The work will be performed at La Sapienza in collaboration with LNF and LAL.

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design of a Multi-TeV muon collider ring

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Very low emittance muon beams can be produced by direct annihilation of about 45 GeV positrons on atomic electrons in a thin target. With such a muon beam source, a mu+ mu- collider can be designed in the multi-TeV range at very high luminosities.
A design of the muon collider ring is very challenging as it requires very low emittance.
We propose to study an optics for such ring.
The work will be performed at the Frascati National Laboratory of INFN in collaboration with ESRF and CERN.