Tera-Days: Attività INFN e prospettive per la radiazione THz e le sue applicazioni

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Book of Abstracts

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Imaging with a Talbot interferometer using THz radiation

Author: Augusto Marcelli[1]

[1] *LNF*

Corresponding Author: augusto.marcelli@lnf.infn.it

THz radiation is already used for spectroscopy and imaging applications. In particular, several imaging techniques have been already considered at these wavelengths for industrial and security applications, each one with specific advantages and drawbacks. Indeed, thanks to the high penetration of the THz radiation, a condition similar to X-ray radiation, it is possible to consider different optical layouts working at extremely long wavelengths.

We present here a novel THz imaging system based on the Talbot interferometry layout, a powerful method already established in the x-ray domain. Taking advantage of the non-ionizing nature of the THz waves, it may allow collection of images overcoming drawbacks of x-rays. Using a quite simple setup based on one or to gratings it is possible to demonstrate that both phase and amplitude information of an object can be simultaneously obtained within a large field of view. However, contrary to a X-ray Talbot interferometry, the best spatial resolution of a Talbot Interferometer in the THz range is in the micrometre range, mainly limited by the wavelength used. Actually, the field of view of this THz imaging system is comparable to the beam size and may reach dimensions of few cm. Associated to a tomo-synthesis method, such instrument could also obtain three dimensional phase and amplitude information in a short time, e.g., within ps to ms with no dose. Moreover, this optical layout overcomes the limitations of extremely long scans or of complex optical layouts as required by the imaging of large objects.

An imaging device in THz domain may offer many opportunities in materials science and in particular, in biological and medical studies, possibly enabling the continuous monitoring of a living system because of the lack of dose released to the sample under investigation. Coupled to a high flux free electron laser (FEL) source a THz-based Talbot interferometer should be able to resolve very tiny difference in the refraction index and the transmission of a sample. The main limitations of this approach remain the maximum available spatial resolution and the maximum sample thickness that can be probed.

In the framework of the Bilateral Cooperation Agreement between Italy and Japan of the Italian Ministry of Foreign Affairs (MAE) for the years 2017-2019 we are already working to perform the first test of a Talbot interferometer in the THz energy domain using the FEL's available at the Institute of Scientific and Industrial Research (ISIR) of the Osaka University.

Acknowledgments. This research is a joint collaboration among the Institute of High Energy Physics of Beijing, the University of Science and Technology of China at Hefei and the Istituto Nazionale di Fisica Nucleare. A.M. acknowledge the great contributions over the years of Qiyue Hou, Kai Zhang, Peiping Zhu and Ziyu Wu.

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Detection of microwave photons with superconducting qubits for axion searches

Author: Claudio Gatti[1]

Co-author: Fabio Chiarello [2]

[1] *LNF*

[2] *IFN-CNR*

Corresponding Author: claudio.gatti@lnf.infn.it

An elegant solution to the strong CP problem, proposed in 1977 by Peccei and Quinn, implies the existence of a new neutral boson called the Axion. Axions could explain the presence of cold dark matter in our Universe. Microwave cavity experiments looking for galactic axions (ADMX, QUAX) need to push their sensitivity beyond the quantum limit of amplifiers by means of single-photon counters in the microwave region (10-30 GHz). Superconducting qubits provide an interesting option: a photon in a cavity can change the state of a coupled qubit, and this is detected performing spectroscopy on the qubit-cavity system. In this talk we will discuss status and prospects for this technique.

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The SPARC_LAB THz Source

Author: Enrica Chiadroni[1]

[1] *LNF*

Corresponding Author: enrica.chiadroni@lnf.infn.it

High peak power THz radiation with tunable spectral bandwidth is produced at SPARC_LAB as coherent radiation (CR) from relativistic, short (~100 fs) electron bunches. The characterization of the CR spectrum serves both as powerful longitudinal diagnostics of electron bunches that drive Free-Electron Lasers and plasma-based accelerators, and as intense source of THz radiation for studying ultra-fast and non-linear phenomena. The generation techniques of the SPARC_LAB THz source and its application, together with future perspectives, will be presented.

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High-Intensity Terahertz Sources for New Physics at Low-Energy

Author: Stefano Lupi[1]

[1] *ROMA1*

Corresponding Author: stefano.lupi@roma1.infn.it

Terahertz (THz) and Sub-THz High-Intensity Radiation (1 THz=33 cm-1=4 meV=300 microns), represents a new frontier in low-energy physics with applications ranging from Dirac electrons in graphene and 2-Dimensional exotic electronic systems, astrophysics, security and biomedical and cultural heritage imaging.

In this talk I will review the existing and new THz and sub-THz sources, their main characteristics and some experiments at the border between high-energy physics and condensed matter.

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A possible novel Terahertz Detection based on Tunable nanometric Nb islands Flux Array Device

Author: Daniele Di Gioacchino[1]

[1] *LNF*

Corresponding Author: daniele.digioacchino@lnf.infn.it

D. Di Gioacchino, C. Gatti, A. Marcelli, S. Lupi, M. Lankhorst and N. Poccia

We recently assembled a nanometric pattern of niobium islands as a controllable regular fluxon-array used to investigate the phase transitions of stable and metastable states (vortex insulator-vortex metal state) in competing regular vortex configurations [1].
This system shows the evidence of Shapiro steps at gigahertz frequencies [2]. Such device has suggested the possibility to design a conceptually new radiation detector with unique properties [3]. These pattern structures of size 80 µm x 80 µm made by 300 X 300 Nb islands were realized on a silicon/silicon oxide substrate where a metallic gold template has been grown with four contacts. On this 'template' the array of niobium superconducting islands was realized with a period of ~270 nm. The island diameter is 220 nm, the separation 47 nm and the island thickness 45 nm.
An applied magnetic field in the range 0-100 mT can induce the localization of different magnetic-vortex arrays between the superconducting islands, because of the weak superconductivity proximity effect. Different period 'Josephson vortex flux lattice configuration' (JV) can be selected using this applied magnetic field. The thickness and the separation of the superconducting Nb islands were comparable to the London penetration depth ⊠L≈90nm at T=0 K, so that a strong inductive coupling was achieved between junctions.
JV can scatter electromagnetic waves and when their fast motion with velocity v exceeds a certain threshold vmin in the Flux flow regime has been observed an e.m. emission in the THz-range [4], i.e. the velocity exceeds the lowest characteristic velocity of the Josephson plasma wave. In this process a Cerenkov-type radiation is emitted and can interacts with the periodic flux array itself. An incident THz wave can resonantly excite the surface Josephson plasma wave at certain angles between the incident wave and the sample surface. This results in a strong increase of the absorption of THz wave in the sample and of the resonant peak of the sample resistance [5,6]. A simple I-V technique may control the dynamic state of the superconducting system.
The goal is to test this new nano-sized superconducting device as a Terahertz radiation detector under a magnetic field and vs. temperature.

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Fundamental Physics at THz and sub-THz / 7

STAX, a search for axion-like particles with sub-THz photons

Authors: Antonio Davide Polosa[1]; Gianluca Cavoto[1]; Paolo Spagnolo[2]

Co-authors: Angelo Cruciani [1]; Marco Vignati [1]

[1] *ROMA1*
[2] *PI*

Corresponding Author: gianluca.cavoto@roma1.infn.it

An improved detection scheme for a light-shining-through-wall (LSW) experiment for axion-like particle searches is introduced. Extremely intense photon fluxes (from 100 kW to 1MW) from sources at frequencies in the sub-THz range are sent in an intense magnetic field where a photon to axion-like particle conversion is possible. A single photon detector in this frequency domain based on a superconducting phase transition edge sensor is proposed. High quality factor Fabry-Perot cavities in the microwave domain (Q ≈ 104-105), both on the photon-axion conversion and photon regeneration side are used to increase the sensitivity.
The present exclusion limits based on laboratory experiments for axion-like particles searches might be improved by at least four orders of magnitude for axion masses ≤ 0.01 meV.

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THz emission from the interaction of ultra-short laser pulses with thin solid targets

Authors: Domenico Delle Side[1]; Vincenzo Nassisi[2]

Co-authors: Fabio Paladini [2]; Giovanni Buccolieri [2]

[1] *LE*
[2] *Università del Salento*

Corresponding Author: domenico.delleside@le.infn.it

The interaction of an ultra-short laser pulse at relativistic intensities is known to produce plasmas composed by hot electrons and energetic ions. The characteristics of the energy transfer from the laser pulse to the plasma components are completely different from longer pulse situations and give rise to a wide range of new phenomena. Among these, terahertz radiation generation is one of the less explored. Several authors already observed the presence of pulsed THz fields in ultra-high-power short pulse interaction with solid targets [1-3]. Using TPX lenses, pyroelectric and electro-optical detectors, we propose an investigation aimed at unveiling the relation between such non-equilibrium process and the resulting equilibrium-plasma. This could be of great interest for predicting the properties of the ion beams generated during the interaction of ultra-high intensity laser pulses with thin targets. Indeed, these setups are currently seen as a promising technology for next-generation tabletop particle accelerators.

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Studio dell'accoppiamento ottico di rivelatori veloci con risonatori a metamateriali selettivi alle frequenze THz

Author: Sara Cibella[1]

Co-authors: Guido Torrioli [2]; Roberto Leoni [3]

[1] *Istituto di Fotonica e Nanotecnologie CNR*

[2] *Istituto di Fotonica e Nanotcnologie, CNR*

[3] *Istituto di fotonica e nanotecnologie, CNR*

Corresponding Author: roberto.leoni@ifn.cnr.it

Si mostreranno i risultati ottenuti nello sviluppo di rivelatori superconduttori selettivi in frequenza che operano a frequenze THz. Il nostro approccio prevede l'integrazione di un hot electron bolometer (HEB), realizzato con un layer ultra sottile di nitruro di niobio (NbN) (3-5 nm), con un risonatore LC . Come è noto, il nitruro di niobio è il materiale di riferimento per la fabbricazione di rivelatori di singolo fotone a lunghezze d'onda telecom inoltre, a causa del basso tempo di "escape" dei fononi nel substrato (30-60 ps), risulta essere anche il layer superconduttore più adatto per la realizzazione di "phonon cooled hot electron bolometers", rivelatori termici in cui il processo di raffreddamento del dispositivo è dominato dalla fuga dei fononi nel substrato rendendoli rivelatori non solo molto sensibili ma anche estremamente veloci nel intervallo di frequenze THz. I phonon cooled HEB, usati come rivelatori diretti mostrano infatti proprietà eccellenti se confrontati con altri rivelatori veloci di radiazione THz . Questi rivelatori, pur avendo dimensioni molto inferiori della lunghezza d'onda della radiazione incidente, sono accoppiati otticamente in modo efficiente e sono stati caratterizzati a T~3 K in un refrigeratore pulse tube e caratterizzati con laser a cascata quantica e sorgenti di corpo nero mediante uno spettrometro FTIR.

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The 250 GHz CARM source project at the ENEA-Frascati Research Center

Author: giuseppe dattoli[1]

[1] *ENEA*

A new coherent source of FEL type is under development at ENEA frascati.
The proposed device is a Coherent Auto-Resonance Maser (CARM) operating at 250 GHz, the proposal initially framed within the context of fusion research programs, has been originally conceived to provide a source for additional plasma heating. The peculiarity of the radiation, the frequency range and the intensity opens the way to other types of applications including high gradient accelerating RF fields and a source for dark matter research, as well.
We present the operating mechanisms of the device, the relevant analogies and differences with ordinary FEL devices and Gyrotrons, the timeline of the project, and the critical points.

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SIMAP: A project on Thz kinetic inductance detectors (KID) based on high-Tc superconductors.

Author: Jose' Guillermo Garcia Lorenzana[1]

[1] *ROMA1*

Corresponding Author: jose.lorenzana@roma1.infn.it

I will present the SIMAP project proposal conceived within a collaboration among researchers from the INFN-cryogenic detectors laboratory, the ISC-CNR, IFN-CNR, and the Sapienza physics department. The aim of the project is to realize a prototype KID based on a high-Tc superconductor with the aim of lowering the operational costs for commercial applications in fields as medicine, astronomy, and security. I will discuss the challenges and advantages that can arise from this kind of materials.

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Laser driven THz pulses and accelerator technology

Author: Massimo Petrarca[1]

[1] *"Sapienza" University of Rome and Roma1-INFN*

Corresponding Author: massimo.petrarca@roma1.infn.it

In the last few years the possibility to produce high intensity THz pulses and high gradient electric fields ~40 MV/cm has been reported.
The same period of time can be considered as the dawn of acceleration schemes relying on laser-produced THz fields.
Even though the proposed acceleration methodologies triggered a certain interest of the accelerator scientific community, the results are not yet competitive with the conventional technology.
Nevertheless thanks to the strong development of lasers and laser-related technologies there is a window of great hope that soon THz driven acceleration can have an important role in this field.

In this talk, I will give and overview of the THz driven experiments that have been reported in literature in the latest few years as well as the most promising laser technologies to produce strong THz field. I will also discuss about the possibility to locally increase and shape the THz field produced by nowadays technology and I will discuss some perspective for THz driven acceleration that can be tested in the short term.

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THz response of innovative materials and metamaterials, metadevices and metasurfaces

Author: Antonello Andreone[1]

Co-author: GianPaolo Papari [1]

[1] *Physics Department, University of Naples "Federico II" and INFN Naples Unit*

Corresponding Author: andreone@unina.it

Terahertz Time Domain Spectroscopy (THz-TDS) is a powerful tool for investigating the electrodynamic response of any kind of material and/or metamaterial.
Using THz radiation (0.3-10 THz) one can retrieve in direct way essential information on material properties such as the refractive index and conductivity. These quantities are both described in terms of the complex dielectric function that TDS can provide through the coherent investigation of the modulus and phase of the transmitted signal.
In contrast with natural materials, metamaterials (MM) have a response tailored by the geometrical features and periodicity of the unit cell (meta-atom). The structure and specific features of the sub-wavelength elements and their coupling type and strength define their electromagnetic properties and functionalities. Metamaterials are commonly employed to design novel electro-optical devices with well-defined transmission/reflection signatures.
We will present here a brief overview on the on-going activities at the University of Naples "Federico II" using TDS in the range 0.1-4 THz.
We will first show, using a mean field theory, the capability of this technique into extracting electrodynamic information (through a mean field theory) of samples in thin film or bulk form, including polymeric nanocomposites.
On the metamaterial side, we will present results obtained on a number of passive and active metadevices and metasurfaces (i.e., planar metamaterials), aimed at exploiting exotic properties such as negative refraction, sub-diffraction imaging, enhanced transmission, cloaking, diffuse scattering, etc.

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THz waveguide characterization of amorphous carbon for the Compact Linear Collider

Author: Antonello Andreone[1]

Co-authors: Andrea Passarelli [2]; GianPaolo Papari [1]; Giovanni Rumolo [3]; Hannes Bartosik [3]; Maria Rosaria Masullo [4]; Vittorio Giorgio Vaccaro [1]

[1] *Physics Department, University of Naples "Federico II" and INFN Naples Unit*

[2] *Tecnische Universität Darmstadt and CERN*

[3] *CERN*

[4] *INFN Naples Unit*

Corresponding Author: andreone@unina.it

Amorphous Carbon (aC) is used to prevent or limit the insurgence of an electron cloud in the accelerator vacuum chamber. Since in the Compact Linear Collider (CLIC) small bunches are used, a full electromagnetic characterization of the amorphous carbon conductivity is needed in the high frequency region (millimeter wave range and above), where no literature data are available.
Material characterization at high frequencies usually consists in the study of the electromagnetic response of a standard waveguide where the sample under test is placed or deposited.
This method however lacks accuracy when the material is in thin film form, and it is not very reliable for frequencies exceeding the sub-mm range. Besides that, aC has to be deposited with thickness not larger than 1-2 μm on steel substrate, which makes difficult to extract the material parameters.
An alternative idea is to carry out measurements using a Time-Domain coherent THz Spectrometer (TDS). Under specific conditions, placing a sample in the optical path of the TDS allows to measure the transmission or reflection properties and to retrieve the complex response function. In the case of aC coatings, the simple THz reflection measurement in air usually doesn't provide enough sensitivity to see the difference when the sample is not present. To circumvent this problem, the electromagnetic characterisation of the material can be carried out in a circular waveguide specifically designed, having a very thin central layer where aC is deposited on both sides. This configuration ensures a simple and controlled deposition of the material under test, in contrast with a standard rectangular waveguide. In order to efficiently collect the THz signal, the waveguide is connected to two horn antennas on both sides.
We will present the design and fabrication of the circular waveguide, the study of the best optical configuration in free space and the optimization of data retrieval procedure from the signal transmitted through the waveguide in the frequency range 0.1 − 1 THz and above.

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Nonlinear optical effects and third-harmonic generation in superconductors: Cooper pairs versus Higgs mode contribution

Author: Tommaso Cea[1]

Co-author: Lara Benfatto [2]

[1] *IIT*

[2] *ISC - CNR*

Corresponding Author: tommaso_cea@libero.it

The recent observation of a transmitted THz pulse oscillating at three times the frequency of the incident light paves the way to a powerful protocol to access resonant excitations in a superconductor. Here we show that this nonlinear optical process is dominated by light-induced excitation of Cooper pairs, while the collective amplitude (Higgs) fluctuations of the superconducting order parameter give in general a negligible contribution. We also predict a nontrivial dependence of the

signal on the direction of the light polarization with respect to the lattice symmetry, which can be tested in systems such as, e.g., cuprate superconductors.

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Design and Electrical Performance of the Kinetic Inductance Detectors of the OLIMPO experiment

Author: Alessandro Paiella[1]

Co-authors: Alessandro Coppolecchia [1]; Elia Stefano Battistelli [1]; Fabio Columbro [2]; Francesco Piacentini [1]; Giuseppe D'Alessandro [3]; Ivan Colantoni [4]; Luca Lamagna [1]; Maria Gabriella Castellano [4]; Paolo De Bernardis [1]; Philip Mauskopf [5]; Samuel Gordon [5]; Silvia Masi [1]

[1] *Sapienza and ROMA1*

[2] *Dipartimento di Fisica, Sapienza*

[3] *Dipartimento di Fisica - Sapienza*

[4] *IFN-CNR*

[5] *Arizona State University*

Corresponding Author: alessandro.paiella@roma1.infn.it

In this contribution, we are going to show the design and the electrical performance of the horn-coupled lumped element kinetic inductance detectors (LEKIDs) for the OLIMPO experiment. OLIMPO is a balloon borne mission, devoted to the study of the largest structures in the Universe, by detecting the Sunyaev-Zel'Dovich effect of the Comsic Microwave Background (CMB) photons crossing clusters of galaxies. The multi-band focal planes (centered at 0.15, 0.20, 0.35 and 0.48 THz), large aperture telescope (2.6 m),
photometric and spectrometer configuration (OLIMPO is equipped with a plug-in differential Fourier transform spectrometer) make OLIMPO able to characaterize all the components of the Sunyaev-Zel'dovich effect with unprecedented precision. The design of the LEKIDs has been optimized to cope with a wide range of optical loadings (corresponding to both photometric and spectrometric configurations). The electrical characterization of the LEKID arrays was performed in the OLIMPO cryostat, at a temperutare around 300 mK and under a constant optical load lower than 500 fW. The readout electronics is a customized ROACH-2 coupled to a MUSIC DAC/ADC board. The averaged reasponsivities for the arrays, measured from the phase readout, are 1.18×10^(11) rad/W for the 0.15 THz array, 4.10×10^(10) rad/W for the 0.20 THz array, 1.09×10^(12) rad/W for the 0.35 THz array, and 4.41×10^(11) rad/W for the 0.48 THz array. Therefore, measuring the spectral noise density for each pixels of the arrays, whose average values are 2.5×10^(−5) rad/sqrt(Hz) for the 0.15 THz array, 3.6×10^(−5) rad/sqrt(Hz) for the 0.20 THz array, 5.1×10^(−5) rad/sqrt(Hz) for the 0.35 THz array, and 1.9×10^(−9) rad/sqrt(Hz) for the 0.48 THz array, we obtained the values of the averaged electrical noise equivalent power (NEP) over all the arrays: 2×10^(−16) W/sqrt(Hz), 9×10^(−16) W/sqrt(Hz), 5×10^(−17) W/sqrt(Hz), and 4×10^(−17) W/sqrt(Hz) respectively for the four OLIMPO arrays.

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Sensors and Readout Electronics for High Brilliance Terahertz Radiation

Author: Michele Caselle[1]

Co-authors: Andreas Kopmann [1]; Anke-Susanne Mueller [1]; Erik Bründermann [1]; Johannes Steinmann [1]; Lorenzo Rota [1]; Marc Weber [1]; Matthias Balzer [1]; Meghana Patil [1]; Miriam Brosi [1]

[1] *Karlsruhe Institute of Technology*

Corresponding Author: michele.caselle@kit.edu

The ANKA storage ring can generate brilliant coherent synchrotron radiation (CSR) in the THz range due to a dedicated low-αc -optics with reduced bunch lengths. At higher electron currents the emission of CSR is not stable, but occurs in powerful bursts caused by micro-bunching instabilities. This intense THz radiation is very attractive for users. However, the reproducibility of the experimental conditions is very low due to those power fluctuations. For the investigation of multi-bunch dynamics of the electrons in the storage ring, novel THz detectors and ultra-fast readout electronics have been developed and commissioned at different accelerators machines: ANKA [1], Eu-XFEL [2], ELBE [3] and DELTA [4]. An overview of the status of high intensity THz sources and activities within the machine physics German community will be presented. Pico- and femto-second beam diagnostic systems including THz sensor and electronics technologies will be deeply discussed.

Summary:

The synchrotron radiation source ANKA is located in Karlsruhe, Germany. The user facility is based on an electron storage ring with a circumference of 110.4 meters and is being operated by the Karlsruhe Institute of Technology. For a few years special user operation with reduced bunch length in the order of few picoseconds is available and offered to the research community. In this mode, high brilliant coherent synchrotron radiation (CSR) is generated in the THz band. Moreover, above a certain current threshold, a coherent modulation of the longitudinal particle distribution (micro-bunching) occurs due to CSR impedance. This particle dynamics effect changes the characteristics of the CSR tremendously.
Due to progress in the multi-bunch readout electronics development at KIT, a completely new type of measurement was realized at ANKA. New superconductor film detectors and new readout electronics have been developed at KIT and then installed in other accelerator facilities in Germany.
To detect and study the emission characteristics of CSR in the THz range over multiple revolutions several detector systems based on superconductor film layers have been developed. The first generation of THz detector was based on Niobium nitride (NbN) detectors with a response time of less than 165 ps. The new generation of detector is based on thin Yttrium barium copper oxide (YBCO) superconductor film with an intrinsic response time down to 1 ps.
The KAPTURE readout system opens up a new possibility to monitor all bunches in a synchrotron storage ring over an unlimited number of turns. The system was successfully commissioned and tested in a real measurements environment in 2013. KAPTURE is used as ANKA and DELTA to follow turn-by-turn bursting behavior of the generated THz radiation. This novel diagnostic tool is used to explore the fundamental physical mechanism of their generation and thus on the long term to improve the stability of the emitted CSR.
The KALYPSO system has been developed to measure the longitudinal bunch profile and its instabilities during the emission of CSR. Thanks to its high frame-rate (2.7 MHz) it allows continuous monitoring of the beam dynamics with femtosecond resolution (down to 300 fs). The system was successfully tested in real measurements in 2014/2015 and is permanently installed at ANKA, XFEL, DELTA and ELBE.

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Activity Status at LNF-INFN on the high accelerating gradient

Authors: Augusto Marcelli[1]; Bruno Spataro[1]; Giovanni Castorina[1]

[1] *LNF*

Corresponding Author: giovanni.castorina@lnf.infn.it

To enhance the maximum gradient achievable with a normal-conducting RF powered structures for

particle beam accelerators, an intense activity of design, simulations, characterization of materials, technologies, construction and experimental tests of linear accelerating structures at high power is going on at INFN-LNF since a decade. Several studies have been carried out on hard linear accelerating devices such as electroforming, soft bonding, electron beam welding manufactured devices, all methods alternative to the standard brazing in order to improve the electromagnetic properties of X band accelerating structures. In addition to build RF structures we also performed calculations on novel mode launchers for the next generation of photo-injectors, parallel coupling designs etc.. In this presentation we report the status of the RF activities at INFN-LNF from S-band to W-band of interest also for THz applications and recent results regarding new RF copper structures operated at cryogenic temperatures.

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THz applications of Synchrotron Radiation at the Sinbad Infrared beamline at Dafne.

Author: Mariangela Cestelli Guidi[1]

[1] *LNF*

Corresponding Author: mariangela.cestelliguidi@lnf.infn.it

The LFN DaFne storage ring is a powerful source for Synchrotron Radiation (SR) in the FAR IR/THz domain (20µm-1mm). The brilliance of SR in this region is up to three order of magnitude higher than standard sources, opening the possibility to perform experiment in the solid, liquid and gas phase with application from material science to biology and chemistry. Case studies of experiments that are currently performed at Sinbad are presented.

Combining the properties of THz and Near IR radiation, together with MIR molecular spectroscopy (2-20 µm), new perspectives of applications for biomedical tissues analysis and skin cancer diagnosis are explored.