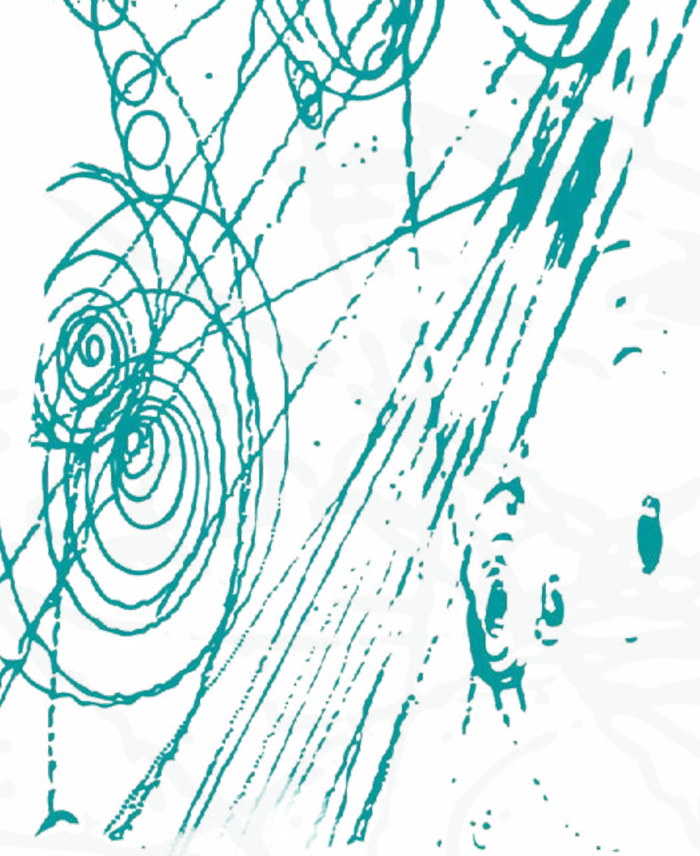
2013

LNF Highlights

INFN
Istituto Nazionale
di Fisica Nucleare
Laboratori Nazionali di Frascati



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Cover
The SPARC accelerator (Photo: Claudio Federici, LNF Information & Documentation Service)

One year of Physics at LNF: 2013

Foreword

2013 has been an intense year of work at LNF.

The DAΦNE collider has undergone an intense program of hardware upgrades and a new interaction region with several brand new detectors has been installed inside the KLOE apparatus.

Many experiments have been carried out, exploiting the unique facilities available at SPARC-LAB.

The NAUTILUS ultracold antenna has continued its hunt for a signal of gravitational waves coming from the outer space.

LNF researchers and technicians have contributed to experiments worldwide, especially at the most powerful and largest particle accelerator of the world, the LHC of CERN.

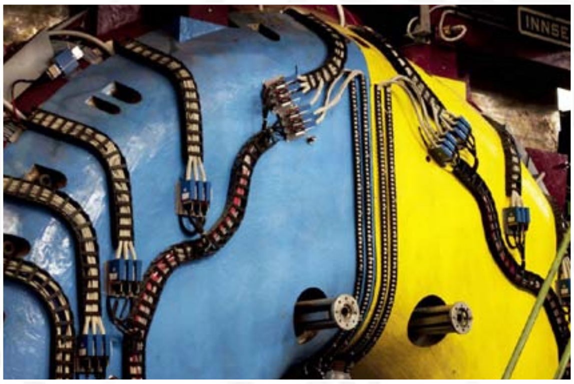
This document focuses on some highlights of the science produced by our Laboratory during this year. They are the result of the total commitment and of the enthusiasm of all the researchers, technicians and administrative staff of LNF, as well as of the unique contribution of the many students and external users visiting the Lab. To all of them goes my warmest thank you.

Umberto Dosselli

Umberto Dosselli
LNF Director

KLOE closes measurements on hadronic cross section

The measurement of the muon magnetic anomaly a_μ obtained by the E821 experiment at the Brookhaven Laboratory has reached a fractional accuracy of 0.54 x 10^{-6} [1]. The reason for measuring with such a high-precision the rate at which muons wobble in a magnetic field is that at this sensitivity level the result would be affected by a large class of new-physics phenomena, probing an energy scale beyond that directly accessible at the Large Hadron Collider. The E821 result differs from the Standard Model (SM) prediction by about three standard deviations.
The main uncertainty on the SM theoretical prediction is related to the hadronic contributions which, at low energy, are not calculable by perturbative QCD and are obtained from a dispersion integral over measured hadronic cross sections.
KLOE pursued a challenging experimental program to provide precision measurements of the hadronic cross section at low energy, addressing the question: is this discrepancy due to the experimental input to the theoretical evaluations? The program has been developed along the years through several measurements, focusing on different experimental issues.
The publication in year 2013 of the paper "Precision measurement of
$\sigma(e^+e^-\to\pi^+\pi^-\gamma)/\sigma(e^+e^-\to\mu^+\mu^-\gamma)$
and determination of the $\pi^+\pi^-$ contribution to the muon anomaly with the KLOE detector" [2] completes the program whose final result is a consistent set of measurements demonstrating a good control of the systematic errors. Running at fixed energy, KLOE was the first experiment exploiting Initial State Radiation (ISR) processes to measure the hadronic cross section below 1 GeV, that accounts for most (75%) of the hadronic contribution to the muon anomaly. From e^+e^- collisions at 1.02 GeV (and 1.0 GeV) produced by the DAΦNE collider of LNF, two pions ($\pi^+\pi^-$) with invariant mass in the interval (0.32-0.97) GeV are generated in association with (0.45-0.02) GeV photons from ISR.



In 2005 and 2008 KLOE published two measurements based on events with the ISR photon emitted at small angle [3, 4].
A measurement with different event topologies and particle spectra, with photons emitted at large angle to reach the $\pi^+\pi^-$ production threshold at s = 0.1 GeV^2, was published in year 2011 [5]. These three measurements of the hadronic cross section $\sigma(e^+e^-\to\pi^+\pi^-)$ cover the interval ($0.1 < M^2_{\pi\pi} < 0.95$) GeV^2, providing consistent results with a combined fractional uncertainty at 1% level. The new analysis of KLOE data [5] in year 2013 directly derives the pion form factor from the bin–by–bin ratio of $e^+e^-\to\pi\pi\gamma$ to
$e^+e^-\to\mu\mu\gamma$ cross sections, from which one derives the two-pion contribution to the muon anomaly in the interval
($0.35 < M^2_{\pi\pi} < 0.95$) GeV^2, $\Delta a_\mu^{\pi\pi} = (385.1 \pm 1.1_{stat} \pm 2.6_{exp} \pm 0.8_{th}) \times 10^{-10}$.
This result is consistent with the previous measurements and has a comparable total experimental uncertainty; however now the theoretical error is reduced by 70%, since inputs from theory affect to the same extent $\pi^+\pi^-$ and $\mu^+\mu^-$ final states, thus canceling out almost entirely in the cross section ratio.

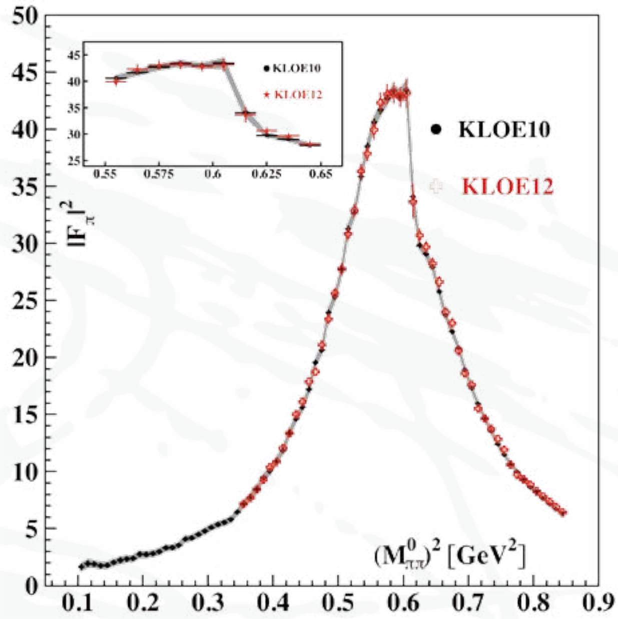
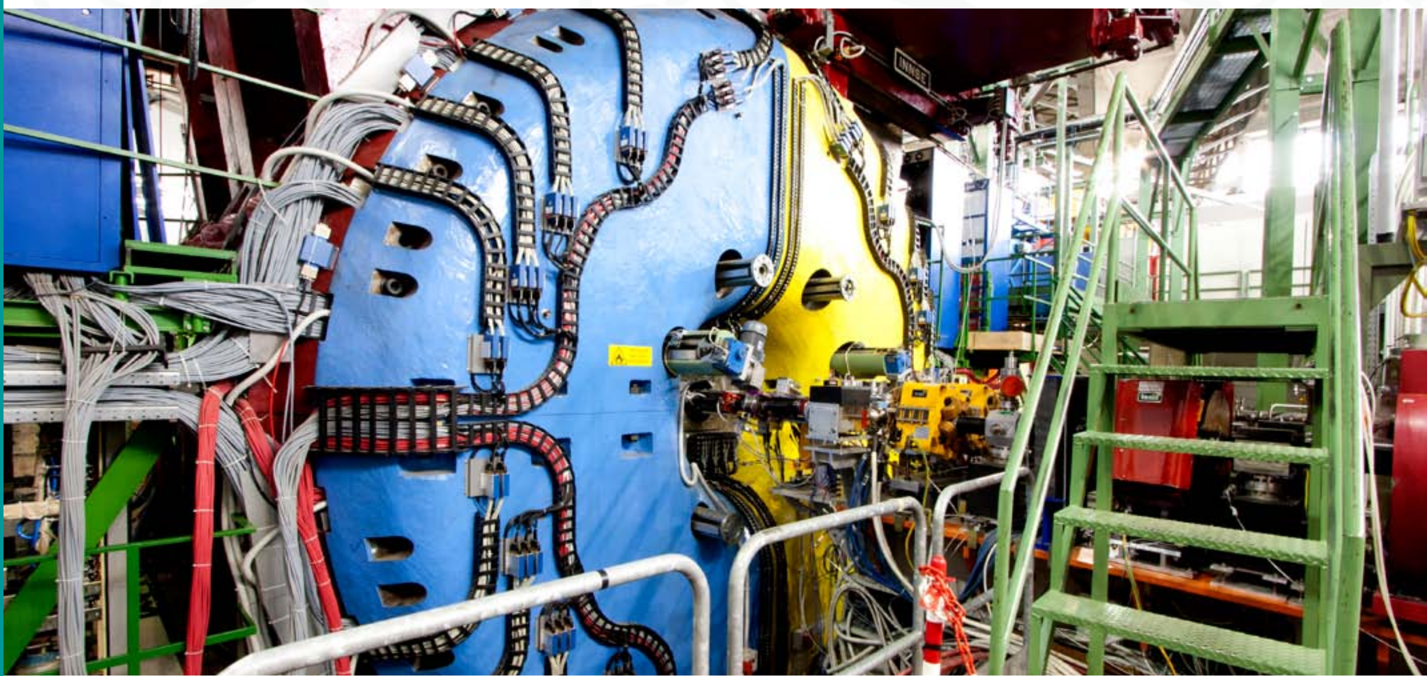


Fig 1 - The pion form factor obtained in this work, KLOE12 (crosses) and from the measurement with the photon at large angle, KLOE10 (points).

The KLOE measurements confirm the three standard deviations discrepancy between SM predictions and the experimental value of a_μ, ruling out any relevant effect of the experimental input to the calculations of the vacuum hadronic polarization, a result in agreement with the other experiments at the e^+e^- colliders, SND [6] and CMD-2 [7] at Novosibirsk, and BaBar [8] at SLAC.



References

[1] G. W. Bennet et al. (Muon g-2 Collaboration), Phys. Rev. D 73, 072003 (2006) (arXiv:hep-ex/0602035).

[2] D. Babusci et al. (KLOE Collaboration), Phys. Lett. B 720, 336 (2013) (arXiv:1212.4524 [hep-ex]).

[3] A. Aloisio et al. (KLOE Collaboration), Phys. Lett. B 606, 12 (2005) (arXiv:hep-ex/0407048).

[4] F. Ambrosino et al. (KLOE Collaboration), Phys. Lett. B 670, 285 (2009) (arXiv:0809.3950 [hep-ex]).

[5] F. Ambrosino et al. (KLOE Collaboration), Phys. Lett. B 700, 102 (2011) (arXiv:1006.5313 [hep-ex]).

[6] M. N. Achasov et al. (SND Collaboration), J. Exp. Theor. Phys. 103, 380 (2006) (arXiv:hep-ex/0605013).

[7] R. R. Akhmetshin et al. (CMD-2 Collaboration), Phys. Lett. B 648, 28 (2007) (arXiv:hep-ex/0610021).

[8] B. Aubert et al. (BaBar Collaboration), Phys. Rev. Lett. 103, 231801 (2009) (arXiv:0908.3589 [hep-ex]).

Low-energy kaon-nucleon/ nuclei interactions studies with SIDDHARTA

In 2013 the final results of the data analyses for various types of kaonic atoms measurements were published by the SIDDHARTA collaboration. The measurements were performed in 2009 at the DAΦNE collider, by using cryogenic gaseous targets and, for the first time, Silicon Drift Detectors (SDD) as fast, high precision X-ray detectors, realized by the collaboration, with support from an European funding within the HadronPhysics project of FP6.

SIDDHARTA combines the best possible low-energy kaons beam, namely the back-to-back charged kaons "beam" delivered by the decay of the Φ-mesons produced at DAΦNE in the electron-positron annihilation processes, with a refined experimental technique which allows to optimize the yield of the studied X-ray transitions. SIDDHARTA, an international collaboration among 8 Institutions from 6 different countries, continues the successful tradition of exotic atoms precision measurements, in particular of kaonic atoms, pioneered by the DEAR collaboration back in the beginning of the century.

The measurements of kaonic atoms are an extremely important tool to unveil the kaon-nucleon interaction at low-energy. By measuring the X-ray transitions to the *1s* fundamental levels in kaonic hydrogen and deuterium one can directly access the strong interaction between the kaon and the nucleon(s) at threshold. This is realized, in practice, by determining the shifts and widths induced by the strong interaction with respect to the purely electromagnetic calculated values. The shifts and widths are then used to obtain the antikaon-nucleon isospin-dependent scattering lengths, which represent fundamental ingredients for the understanding of the low-energy QCD in non-perturbative regime, allowing to achieve a deeper understanding of the chiral symmetry breaking mechanics, with implications going from particle and nuclear physics to astrophysics (equation of state of a neutron star).

SIDDHARTA has already published the most precise measurement ever of the kaonic hydrogen transitions to the fundamental level [1]. Completing the data analyses, in 2013 the final results for the following measurements were published:

- the first preliminary experimental study of the kaonic deuterium ever [2] which allowed to extract an upper limit on the yield of the transitions to the *1s* level: $Y(K_{tot}) < 0.0143$ and $Y(K_{\alpha}) < 0.0039$ (CL 90%), in preparation of the future precision measurement within SIDDHARTA-2;

- the first determination of the X-ray transition yields of low-Z kaonic atoms produced in kapton [3], which will contribute to the understanding of the kaonic atoms cascade process, still largely unknown;

- the strong interactions shifts and yields of the *2p* level for the kaonic helium isotopes (^{3}He and ^{4}He), where kaonic ^{3}He was measured for the first time [4]; these results will allow to better understand the strong interaction effects in the kaon interactions with a many-body system.

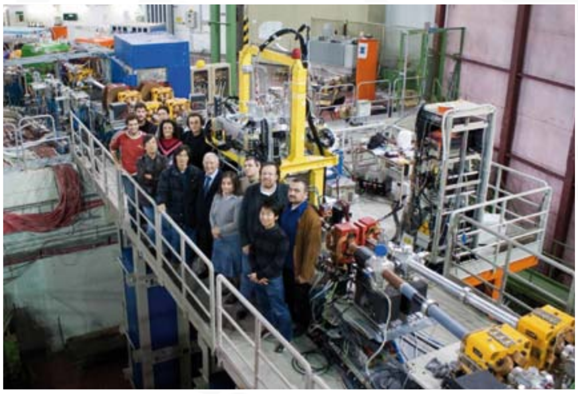


Fig. 1 - Members of the SIDDHARTA Collaboration with the SIDDHARTA setup (November 2009).

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In parallel with the data analyses, within a new collaboration - SIDDHARTA-2 -, largely based on the previous SIDDHARTA one, a new setup is being prepared. There are many new features, including a veto system for the background reduction and new SDD detectors, with a much larger active/total area ratio, successfully tested at the BTF-LNF facility in December 2013. The SIDDHARTA-2 setup is going to be ready to perform unique precision kaonic atoms measurements, starting with the kaonic deuterium one, from 2015 on, exploring new frontiers in the strangeness sector, and contributing to understand the possible role of strangeness in the Universe. The SIDDHARTA and SIDDHARTA-2 scientific programs and detector developments are supported by the HadronPhysics3 project, within the FP7 EU program.

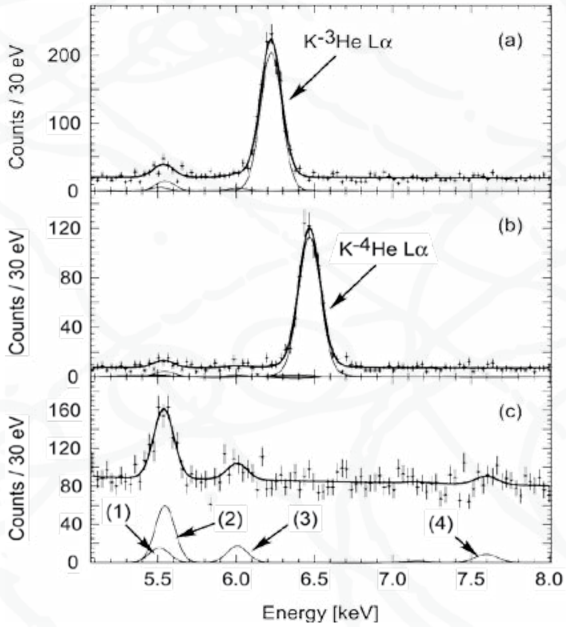


Fig. 2 - X-ray energy spectra of (a) kaonic ^{3}He, (b) kaonic ^{4}He, and (c) kaonic deuterium. The positions of the kaonic ^{3}He and ^{4}He $3d \rightarrow 2p$ transitions are indicated. In (c), (1): K^-C 6 → 5 transition, (2): K^-C 8 → 6 transition, (3): K^-O 7 → 6 transition, and (4): K^-N 6 → 5 transition.

References

[1] M. Bazzi et al. (SIDDHARTA Collaboration), Phys. Lett. B 704, 113 (2011) (arXiv:1105.3090 [nucl-ex]).

[2] M. Bazzi et al. , Nucl. Phys. A 907, 69 (2013) (arXiv:11105.3090 [nucl-ex]).

[3] M. Bazzi et al. (SIDDHARTA Collaboration), Nucl. Phys. A 916, 30 (2013) (arXiv:1306.5912 [nucl-ex]).

[4] T. Ishiwatari et al. (SIDDHARTA Collaboration),to Nucl. Phys. A 914, 305 (2013).

New detectors for KLOE-2 at DAΦNE

A major achievement of the KLOE-2 Collaboration in year 2013 was the successful completion of the detector upgrades followed by the challenging phase of their installation on DAΦNE. The latter has been acknowledged as exemplary for the collaborative efforts taken by the KLOE-2 and the LNF Accelerator Division members.

The KLOE-2 project aims at an upgrade of the existing KLOE detector i) to improve vertex reconstruction near the beam interaction region, ii) to increase the acceptance for low polar angle photons, and iii) to reconstruct particles passing through the DAΦNE final focusing region. A cylindrical tracking chamber based on the Gaseous Electron Multiplier (GEM) technology [1] has been installed between the DAΦNE beam pipe and the big Drift Chamber of KLOE, to track particles closer to their origin; two small stations of LYSO calorimeters [2] have been placed on the beam pipe for the detection of low polar angle photons; the final focusing region has been instrumented with sampling calorimeters composed of five layers of tungsten interleaved with scintillator tiles coupled to fibers that are readout on one side by silicon photomultipliers [3].

The inner tracker is the first cylindrical 3-GEM detector ever built. Planar GEM have been used so far for their excellent performance when exposed to millions of particles per second, per square centimeter (MHz/cm^2). Typical GEMs are made of 50 micrometer thick kapton plastic foils clad in copper on both sides.

A photolithographic process, as the one used for printed circuits, makes 50 micrometer holes at a distance of 140 micrometer, for a density of about 5000 holes/cm^2.

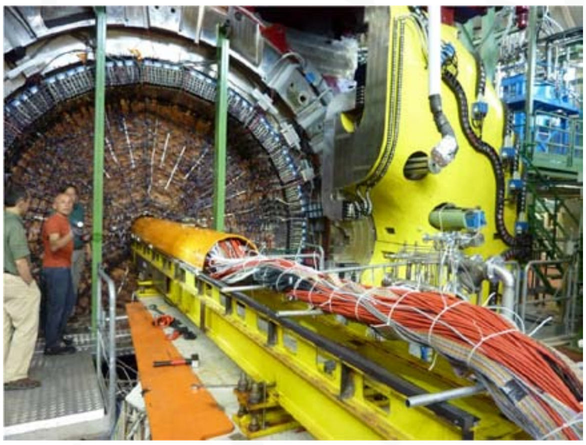


Fig. 1 – The installation of the new KLOE-2 interaction region

The detector is operated with a noble-gas based mixture and a voltage of 300-400 V producing large electric fields in the holes. A particle passing through the detector originates ionization electrons, and each of them creates an avalanche of 100-1000 electrons traversing a single hole. The processing of this detectable signal allows the particle trajectory to be reconstructed.
The novel idea of a Cylindrical GEM was developed at LNF, exploiting the kapton characteristics to build a transparent and compact inner tracker for KLOE-2.
The project has been realized thanks to the fruitful collaboration among INFN divisions of Bari, LNF, Roma, Roma3, and foreign institutions, the TE-MPE-EM workshop at CERN, the IHEP in Beijing, the Jagiellonian University of Krakow, Uppsala University in Sweden and the JINR in Dubna, together with several industries involved on custom electronics and construction tools. The installation of the four layers of triple-GEM detectors is expected to improve, among other issues, precision tests of Quantum Mechanics and CPT invariance with the entangled neutral kaon pairs produced at DAΦNE.

First tests of the detector with circulating beams have shown the feasibility of the data taking and performance studies on cosmic muons demonstrate stable, efficient device operation. KLOE-2 is expected to start regular physics data taking by summer 2014.

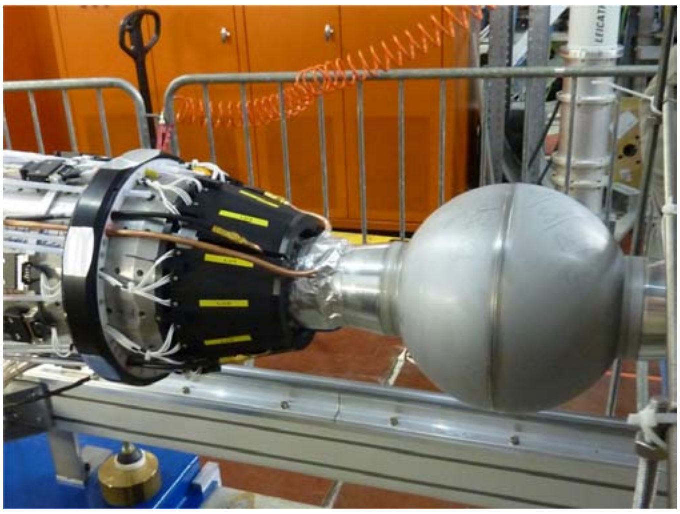


Fig. 2 Details of: (a) the sampling calorimeters and (b) the inner tracker.

References

[1] A. Balla et al., Acta Phys. Pol. Suppl. 6(4), 1053 (2013).

[2] F. Happacher, M. Martini, S. Miscetti, I. Sarra, Nucl. Phys. B. Proc. Suppl. 197, 215 (2009) (arXiv:0906.1157 [physics.ins-det]).

[3] M. Cordelli et al., Nucl. Instrum. Meth. A 617, 109 (2010) (arXiv:0906.1144 [physics.ins-det]).

FLAME laser produces lightning in the atmosphere

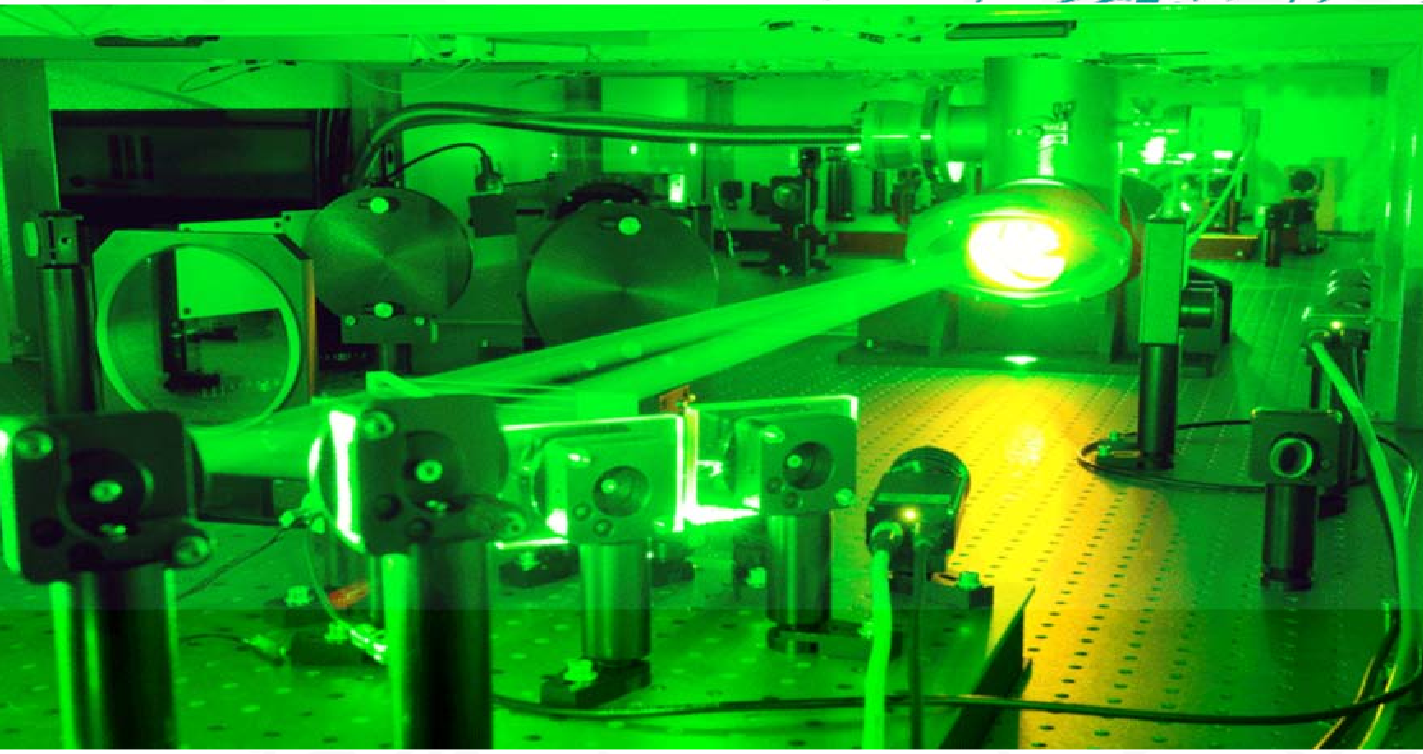


Fig. 1 – The last amplification stage of the laser FLAME.

The study of lightning formation and of the local generation of water droplets, the remote analysis, at different altitudes, of the atmospheric particulate constituents, the understanding of the mechanisms of laser-atmosphere interaction: these are some of the results that can be achieved with the use of ultra powerful laser pulses propagating in the atmosphere.

The use of laser beams as a device to map distant objects is a well known technique known as Lidar (a blend of the two words “Laser” and “Radar”). The first femtosecond white light Lidar experiment in which the sub-PW class laser system FLAME (Frascati Laser for Acceleration and Multidisciplinary Experiments) has been propagated through the free atmosphere of the sky above the Frascati area, was performed during March 2013.

FLAME is a Ti:Sa chirped pulse amplification (CPA) laser chain providing 200 TW pulses of 25 fs duration, at a repetition rate of 10 Hz, and a central wavelength of 790 nm. In these experiments, pulse durations up to 5 ps have been employed.

The laser, a collimated beam of 10 cm diameter was directed by a single mirror into the sky, at an angle of about 60 deg. from vertical (Figure 2). Measurement time slots were specified and allocated in agreement with the air traffic control division of the Roma-Ciampino airport.

During its propagation in the atmosphere, the FLAME laser beam produces a strong supercontinuum emission. This means that the original bandwidth of the laser pulses (60 nm around the central wavelength) broadens extensively reaching the UV region of the spectrum (~ 260 nm). This phenomenon arises from the interplay of non-linear effects triggered by the high intensity of the laser pulses. In particular, when the laser peak power exceeds the critical peak power of about 4 GW (in air at ~ 800 nm) the laser propagation becomes extremely non-linear and a balance between focusing and defocusing effects establishes the filamentation regime, i.e. a self-channeled propagation of the laser pulses.

During this propagation, the pulses are confined within ~ 100 μm along several meters of propagation length and the intensity reaches typically ~ 50 TW/cm^2, thus leading to a strong broadening of the initial pulse spectral bandwidth. For laser peak power far above the critical peak, as it is for FLAME, the laser transverse intensity profile auto-modulates and several number of filaments appears (multiple-filamentation regime). The number of filaments saturates with increasing laser power for a fixed laser transverse profile: for instance, for 100 TW and 100 cm^2 laser peak power and transverse dimension, up to about 1000 filaments can be generated. In this multiple filamentation regime, filaments are accompanied by high intensity regions surrounding them often called “photon bath”.
High-energy, high-power lasers in multiple filamentation regime can be used for several applications, as, for example, to probe from remote distances the atmospheric constituents or to trigger the water droplet formation. In order to properly exploit such powerful laser systems, it is important to study and characterize the non-linear propagation regime at sub-PW lower level in the free atmosphere. This can be done by detecting with standard Lidar techniques, the supercontinuum emission signal and by studying its behavior (efficiency, emission geometry, etc.) for different laser settings. This was the purpose of the experiment carried on at LNF.
These studies proved the importance of the photon bath together with the temporal distribution of the different laser pulse frequency components within the pulse. It has been observed that the maximum efficiency for the visible part of the super continuum emission is obtained for positively chirped pulses (i.e. with longer wavelengths in the leading edge of the pulse and shorter ones in the trailing edge).
On the contrary, negatively chirped pulses (longer wavelengths in the trailing edge and shorter ones in the leading edge of the pulse) are required to optimize the efficiency of the UV portion of the supercontinuum.
This behavior also underlines the strong contribution of the photon bath to the supercontinuum emission.
The experiment showed also that, contrary to observations at lower power, the high intensity in the beam from the laser exit on, allows efficient supercontinuum generation from the photon bath at low altitude ($\leqslant$ 100 m).

In order to shift the filamentation onset to larger distances, the beam would have to be expanded to larger apertures and/or the pulse should be chirped (temporally broadened) to unconventional timescales $\geqslant$ 20 ps for distances $\geqslant$ 250 m.
This research activity has been developed in collaboration with the GAP-Biophotonic group of the University of Geneva.

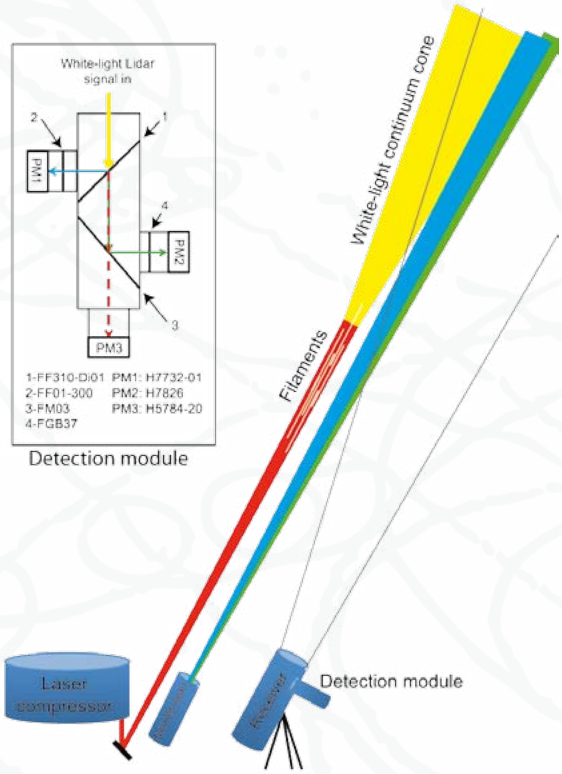


Figure 2 - Schematic layout of the Lidar experiment. The receiver telescope is located ~ 90 cm – 1 m below the FLAME and reference Nd:YAG laser beams. The beam axes lie at a distance of 12 cm to each other. The layout of the detection module is detailed in the inset.

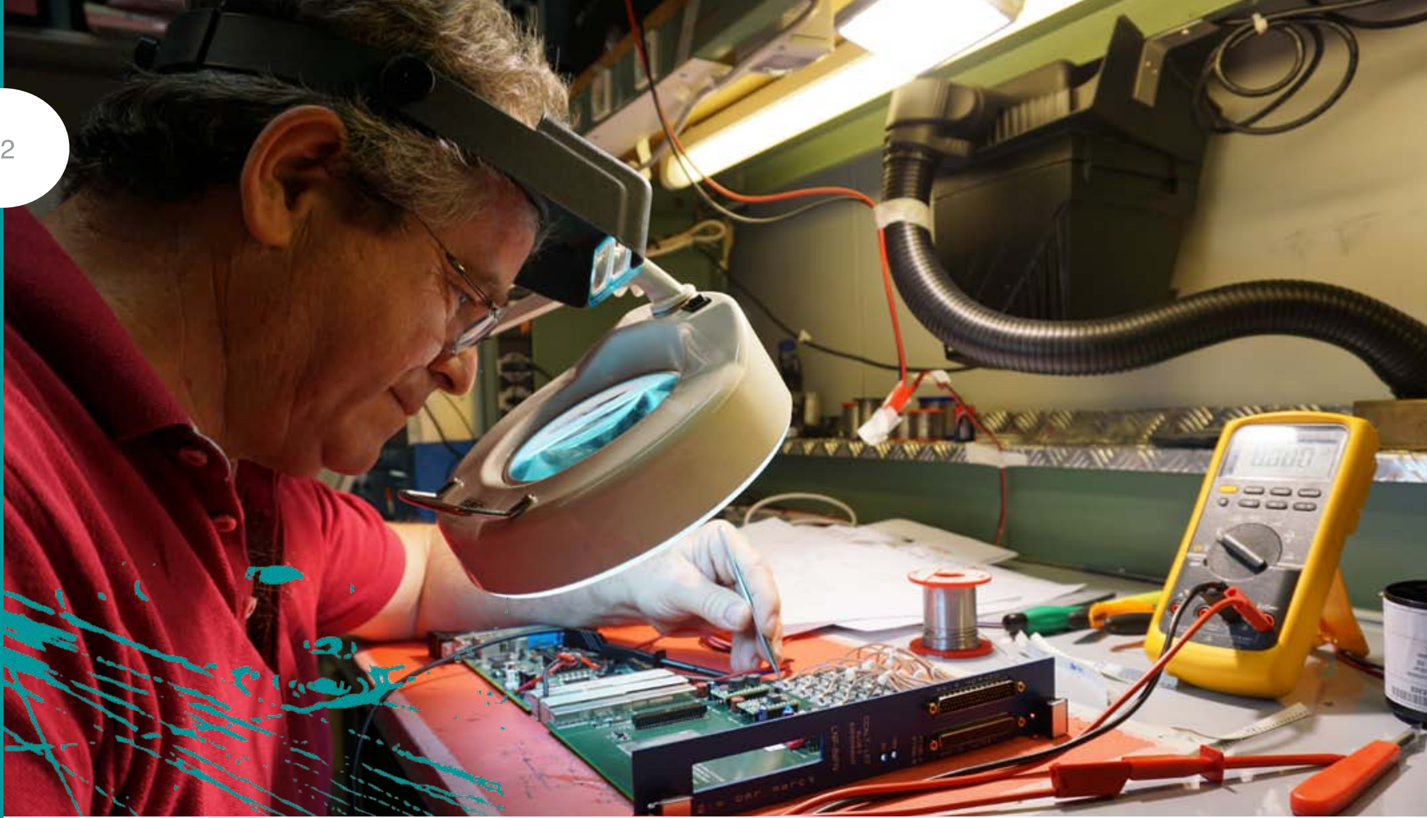
References

[1] M. Petrarca et al., Appl. Phys. B 114, 319 (2014).

AdA becomes historical site of the European Physical Society

We remember 2013 as the year the European Physical Society (EPS) declared AdA (Anello di Accumulazione), the first particle-antiparticle accelerator ever built, Historic Site.
The ceremony took place in the presence of Stefano Di Tommaso, the major of Frascati town, and Guido Fabiani, Councilor for Economical Development in the Region Lazio. During the ceremony, Giorgio Salvini, director of LNF in 1961, and Carlo Bernardini, one of the young physicists involved in the construction of AdA, gave a personal recollection of the main steps of the enterprise and the exciting atmosphere pervading the LNF at that times. The EPS Historic Site plaque was unveiled by the President of INFN, Fernando Ferroni, and the Vice-President of the EPS, Luisa Cifarelli.
The program continued in the afternoon with two events in the Bruno Touschek Auditorium, as a part of the Bruno Touschek Memorial Lectures: Samuel C. C. Ting (MIT, Nobel Prize for Physics 1976) held a seminar on latest results from AMS, and Luigi Rolandi (CERN) gave a public lecture for non-experts and high school teachers and students on the discovery of Higgs boson. All the data and pictures are available at www.lnf.infn.it/edu/AdA_EPSHistoricSite/

INFN president Fernando Ferroni address at the unveiling ceremony.

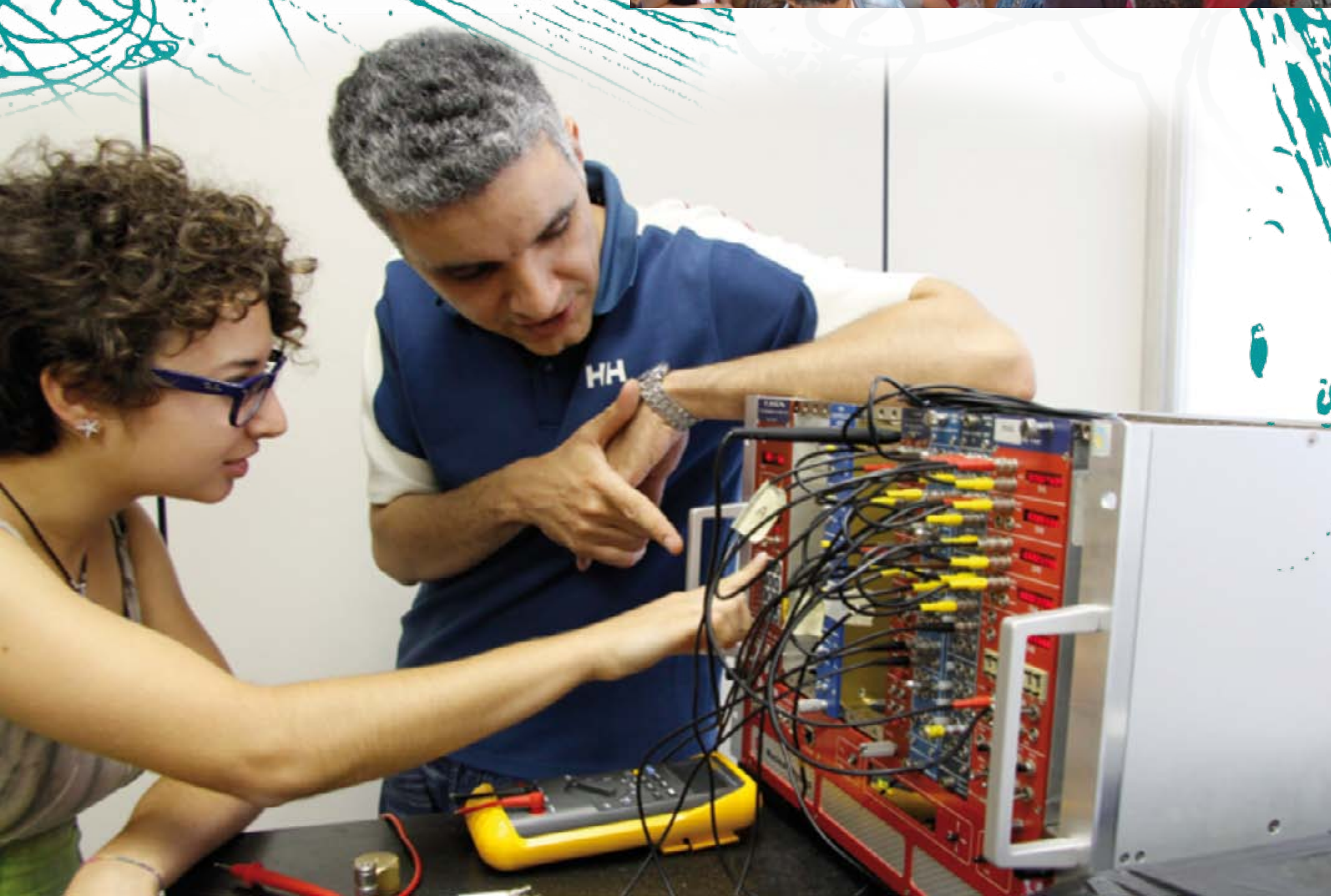


Activities in external laboratories

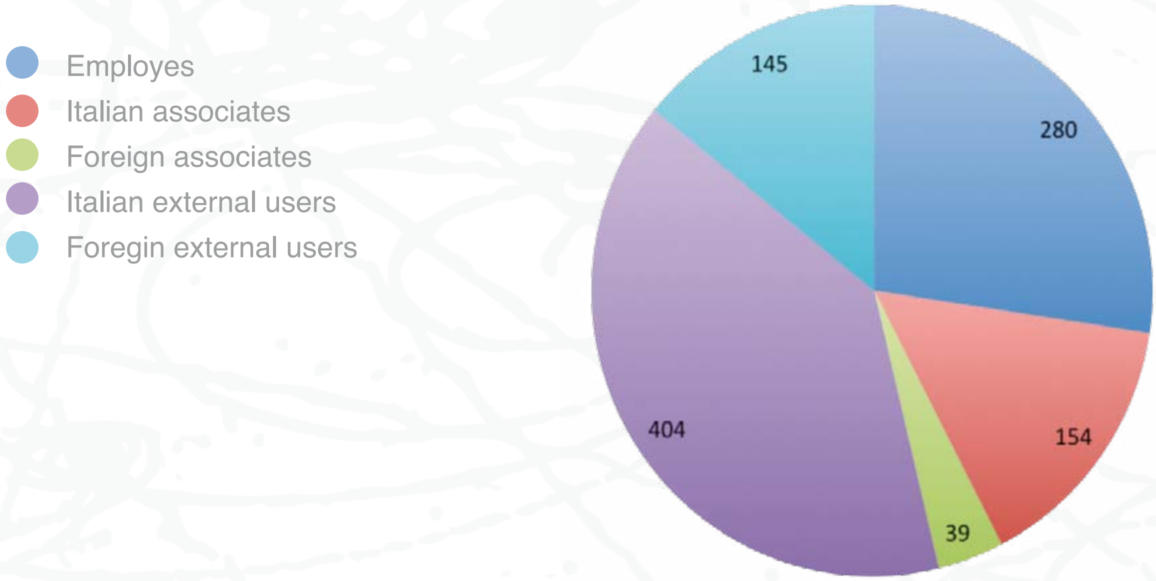
Many LNF researchers actively participate in experiments held in outdoors laboratories.
In particular, LNF contributes to the world-wide scientific enterprise of the Large Hadron Collider, at CERN.
The ATLAS group is involved in the study of the Higgs boson properties. These contributions were made possible also thanks to the reliability and the innovative tools available on the LNF TIER2, where novel analysis methods have been tested for the first time. The group is also deeply involved in the upgrades of the detector for the forthcoming data taking periods.
The main efforts of the CMS group were devoted to the studies and R&D for the future muon system upgrades.
The LNF LHCb team has had a leading role in the analysis which has produced the first evidence for the $B_s \to \mu\mu$ rare decay channel, resulting in the top-cited paper in HEP for 2013.
The ALICE group is leader in the analysis of the jet quenching, in particular for the heavy flavours jets reconstructed by the electromagnetic calorimeter. This detector, which has been partly built at LNF, is still under the group responsability. The group is also involved in the Inner Tracking System upgrade of the spectrometer, setting up the national assembling center for this innovative detector.
An important contribution to the observation of the third tau-neutrino event of the OPERA experiment at the Gran Sasso Laboratory, has come from the LNF team. At LNF it is also located one of the emulsion scanning stations of the experiment.
Important contributions were also given to NA62 at CERN, to BESIII at the BEPC collider in Beijing, to CLAS at JLAB and BaBar at SLAC (USA).

Communication and Outreach activities

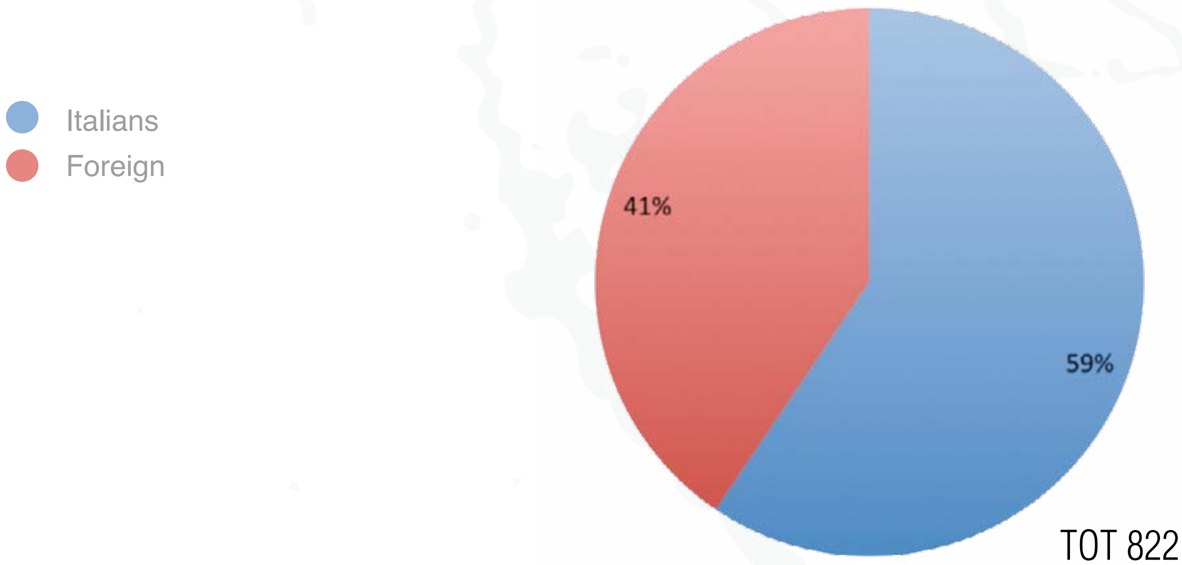
Throughout the year LNF provide basic education in physics by means of a vast outreach program for the general public, teachers and students. In 2013 approximately 9,000 people have benefited from this program.These activities are made possible by the enthusiastic involvement of INFN-LNF people: graduate students, postdocs, researchers, engineers and technicians.
The events are organized both inside - (Visits, Open Day, Physics Lessons, European Researchers Night and special appointments addressed to high school teachers and students such as Incontri di Fisica and Stages) - and outside LNF (Seminars at schools, local libraries, etc).



Distribution of LNF collaborators



Participants to conferences and workshops



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