2015

LNF Highlights

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Laboratori Nazionali di Frascati

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One year of Research at LNF: 2015

Foreword

In 2015, the scientific life of the Laboratory has been rich in achievements that are only partially described in this report. After a slow start-up, the DAΦNE collider finally reached new world record luminosities and very high operation efficiency, which will allow the KLOE2 experiment to reach, by 2017, the required amount of data on tape. In the meantime, the SPARC_LAB laboratory has started to operate a plasma cell in order to investigate innovative accelerator techniques. Frascati is an important partner in a large European project (EUPRAXIA), just approved as part of the H2020 program, fostering the construction of a large facility in Europe. A major step for the ELI-NP gamma source in Romania has been achieved, assembling in Frascati the accelerating elements of the low energy section of the project. Upgrade projects for the Beam Test Facility have been approved, not only to provide more opportunities to users, but also to host in 2017 a new experiment, PADME, which is looking for new particles in the Dark Sector. LHC experiments have started the preparation for Phase 1 upgrades: muon chambers, silicon sensors and micro-pattern detectors will be built in our clean rooms. As in the previous years, a strong activity in outreach has been pursued to communicate science, particularly to motivate students and teachers in their educational scientific paths. Since August 2015, I was nominated Director of the Laboratory of Frascati. The history of the Lab, more than 60 years old, is full of success and achievements. I feel honoured and charged with a great responsibility, but also relieved, knowing the great qualities of the Lab personnel

Pierluigi Campana

LNF Director

Searching for Dark Photons at Frascati

Galaxies in our universe are rotating with a speed that the gravity generated by their observable matter could not allow. This leads scientists to believe that there might be something not yet directly detected that is giving these galaxies extra mass, generating the extra gravity they need to stay intact. This unknown matter has been called "dark matter" since it is not interacting electromagnetically, and it does not absorb, reflect or emit light, making it extremely hard to spot. The standard model of cosmology indicates that the total mass–energy of the universe contains 4.9% ordinary matter, 26.8% dark matter and 68.3% dark energy.

Many experiments have been proposed to detect dark matter particles through non-gravitational means (see fig. 1). One of these is PADME (Positron Annihilation into Dark Matter Experiment), which will be built at the Frascati Laboratory.

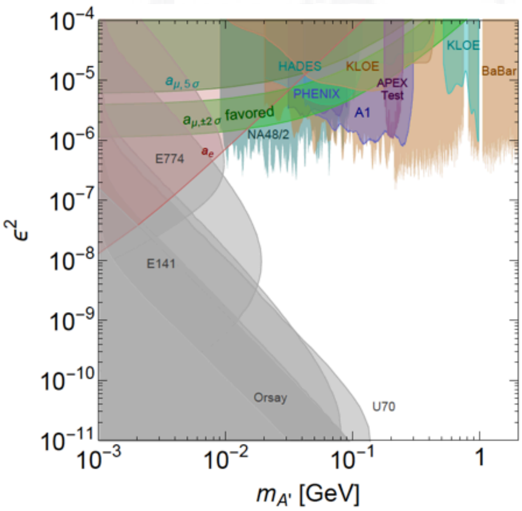


Fig. 1 Current exclusion limits and prospects for dark photon search. The colored areas represent explored region and report the indication of the corresponding experiment. Picture has been adapted from [1].

PADME aims to look for a dark photon, in the mass range 1 MeV/c^2 to 20-30 MeV/c^2, studying electron-positron annihilations. The key elements of the experiment are: a positron beam, with well defined and easily tunable parameters coming from the LINAC of the DAΦNE accelerator complex; a thin active target, capable of monitoring the interaction point; a vacuum region for avoiding spurious positron interactions; a sweeping magnet, with the additional task of measuring the momentum of the interacting positrons, thus improving the rejection of the background events; and a fine-segmented, high-resolution detector, for detecting the photons. In order to reduce the background rate in the inner part, this apparatus has a central hole, shadowed by a smaller, fast "small angle" second detector. Figure 2 shows a CAD schematic drawing of the PADME layout. The red circle on the right represents the target, followed by a dipole magnet. The light blue segmented object on the left side of the picture is the electromagnetic calorimeter to detect the photons.

To realize such a project a collaboration has been formed in 2015. It consists of INFN researchers from LNF and the Lecce unit, from "La Sapienza" Rome University, and from Sofia University. Their aim is to complete the design and the construction of the experiment by the end of 2017 and to collect 10^{13} positrons on target in a period of 1–2 years, allowing to reach a sensitivity ~ 10^{-3} (labelled ε in fig. 1) for dark photons with mass down to ≈ 26 MeV/c^2.

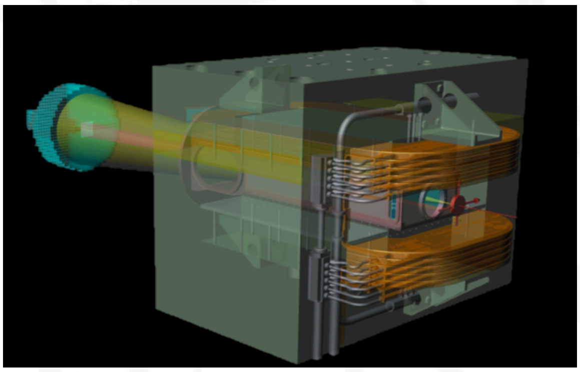


Fig. 2 CAD drawing of the proposed layout of the PADME experiment (see text for more details).

References: [1] The PADME Collaboration, "The PADME experiment Technical Proposal", Ed. by V. Kozhuharov, M. Raggi and P. Valente, INFN-SC-16-02/LNF.

DAΦNE operation: a year of successes

DAΦNE, the LNF electron-positron collider, is the only phi-factory in the world. In September 2015, it started the II run aimed at delivering, in about 9 months, a data sample of the order of 1.5 pb^{-1} to the KLOE-2 detector.

During this period, DAΦNE achieved record performances in terms of instantaneous as well as integrated luminosity:

Instantaneous luminosity	$L \approx 2.18 \times 10^{32}\ cm^{-2}s^{-1}$
Best hourly delivered integrated luminosity	$L_{\int 1h} \approx 0.63\ pb^{-1}$
Best 24 hours delivered integrated luminosity	$L_{\int 24h} \approx 14.\ pb^{-1}$
Best weekly delivered integrated luminosity	$L_{\int week} \approx 76.3\ pb^{-1}$
Best monthly delivered integrated luminosity	$L_{\int month} \approx 280\ pb^{-1}$

Instantaneous luminosity is the highest ever measured with the KLOE detector. It exceed by 45% the best value measured during the I run in 2005, when the machine operated on the base of a conventional collision scheme. This remarkable result has been obtained thanks to the innovative and unique Crab-Waist collision scheme, developed and tested at DAΦNE and now used, for the first time, with a detector including a high intensity solenoidal field strongly perturbing the machine optics.

Maximum daily integrated luminosity is comparable with the best value achieved during the Crab-Waist test run with the table top SIDDHARTA detector, and has been measured during routine data taking.

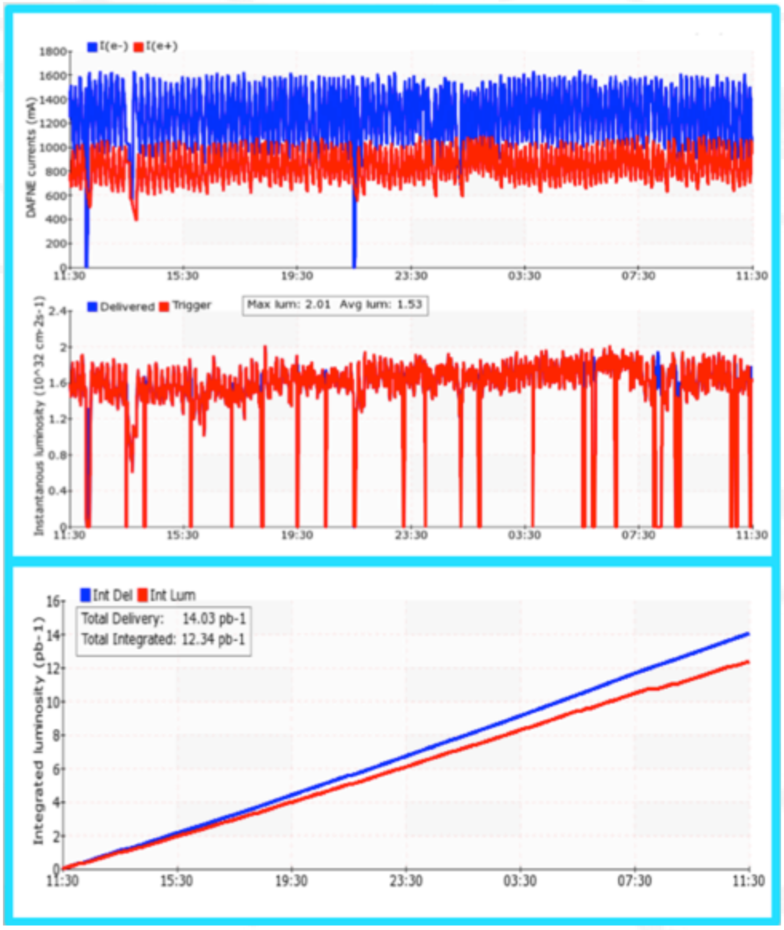


Fig. 3 Plots showing the performance of the DAΦNE collider during one day of operation.

The background, hitting the experimental apparatus, has been studied in detail and considerably reduced. The component due to the electron beam in particular is now compatible with an efficient detector data taking, thanks to the optimization made to the main rings working point. This goal has been achieved almost two months in advance with respect to the agreed schedule! A real challenge for all the staff that operates the accelerator.
DAΦNE performances profited from a wise operation planning, essential in maintaining stable and reproducible machine conditions, and from the continuous analysis and optimization of the collective effects affecting the high intensity colliding beams. The latter was implemented adiabatically, while delivering data to the KLOE-2 experiment.

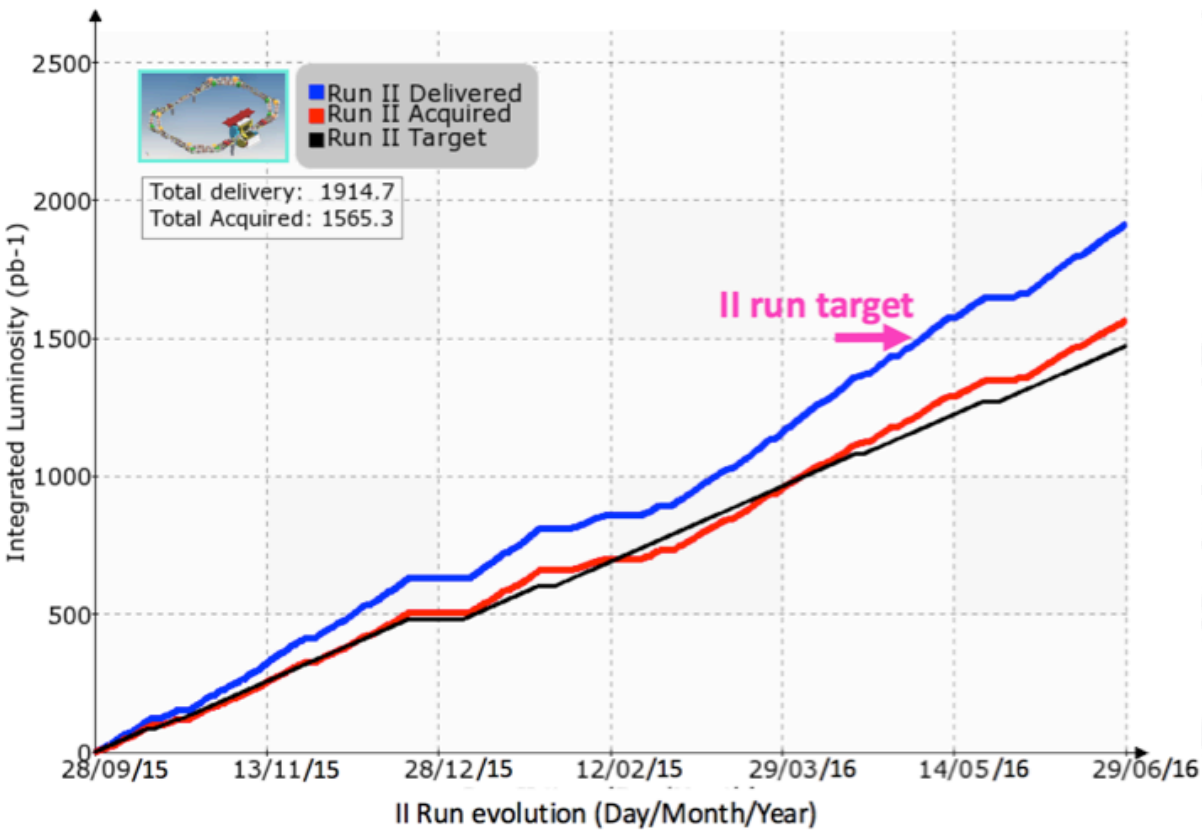


Fig. 4 Plots showing the evolution of the integrated luminosity at DAΦNE.

Still, the full potential of the new KLOE-2 interaction region based on the Crab-Waist collision scheme has not yet been exploited, and there are plans in the coming months of conducting several studies and implement optimization intended to reach higher luminosity performances.
Other than the KLOE-2 data taking, the ultimate luminosity achievable at DAΦNE is crucial for the research and development in the field of circular colliders. In fact, the design study of several new circular colliders includes the Crab-Waist collision scheme as a main design concept.

References: [1] M. Zobov, et al., "Simulation of Crab-Waist Collisions in DAFNE with KLOE-2 Interaction Region",IEEE Transaction on Nuclear Science, VOL:63, Issue:2, April 2016.
[2] C. Milardi, et al., 'DAFNE Consolidation Program and Operation with the KLOE-2 Detector",
ICFA Beam Dyn. Newslett. 67 (2015) 8-20.
[3] D. Alesini, et al., "DAFNE Gamma-Ray Factory", IEEE Transaction on Nuclear Science, VOL:63, Issue:2, April 2016.
[4] A. Valishev et al., "Numerical analysis of Parasitic Crossing Compensation with Wires in DAFNE", Proceedings, 6th International Particle Accelerator Conference (IPAC 2015): Richmond, Virginia, USA, May 3-8, 2015.

Particle rare decays: a powerful test of the Standard Model

The Standard Model (SM) of particle physics defines the fundamental constituents of matter and their interactions via the strong, electromagnetic and weak forces. It provides precise predictions for measurable quantities that can be tested experimentally.

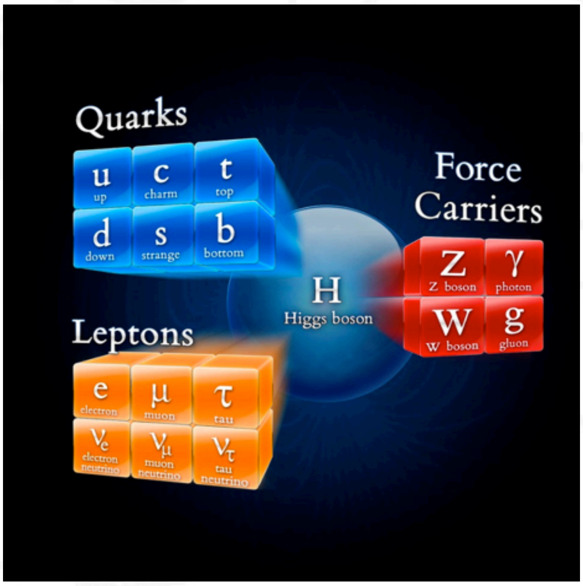


Fig. 5 The fundamental particles of the Standard Model are the quarks, leptons, and force-carriers [1].

Experimental particle physicists have been testing the predictions of the SM with increasing precision since the 1970s, and in the course of the past few decades the SM has passed critical exams. Nowadays, the picture drawn by the SM of our Universe is very solid, but cannot be considered complete since it does not give an explanation to some deep questions like, for instance, the existence of dark matter, and the origin of the present asymmetry between matter and antimatter that were equally abundant after the Big Bang.

Many theories have been proposed to modify the SM in order to provide solutions to these open questions: in order to understand which one is correct, experimental tests are needed. Particles known as B-mesons were common in the aftermath of the Big Bang, although absent from the Universe today since they are unstable and subject to decaying rapidly into other particles. The probabilities, or branching fractions, of some B-mesons decaying into two oppositely charged muons (μ^+ and μ^-) are especially interesting because of their sensitivity to new theories extending the SM.

The Standard Model predicts that $B^0_s \to \mu^+ \mu^-$ and $B^0 \to \mu^+ \mu^-$ decays are very rare, with about four of the former occurring for every billion B^0_s mesons produced, and one of the latter occurring for every ten billion B^0 mesons. Therefore, a difference from the predictions in the observed branching fractions would provide a direction in which the SM would have to be extended.

Before the Large Hadron Collider (LHC) at CERN started operating, no evidence for these decay modes had been found. Upper limits on the branching fractions were one order of magnitude above the SM predictions. At LHC, B-mesons are abundantly produced in the proton-proton head-on collisions, and they are one of the main topics under study at the CERN experiments.

The CMS (Compact Muon Solenoid) and LHCb (Large Hadron Collider beauty) collaborations have performed a joint analysis of the data of the Run I (the first period of LHC data taking) that resulted in a publication on one of the most prestigious scientific journal: Nature.

LHCb is an experiment set up specifically to study B-mesons. CMS is one of the two experiments (ATLAS is the other) that aims at detecting and investigating the Higgs boson with high precision. They are different in concept and size, but they can be regarded as two different attempts to understand space, time, matter... exploring an environment that reproduces the Universe in its early phase, allowing to perform the previously mentioned tests of the SM.

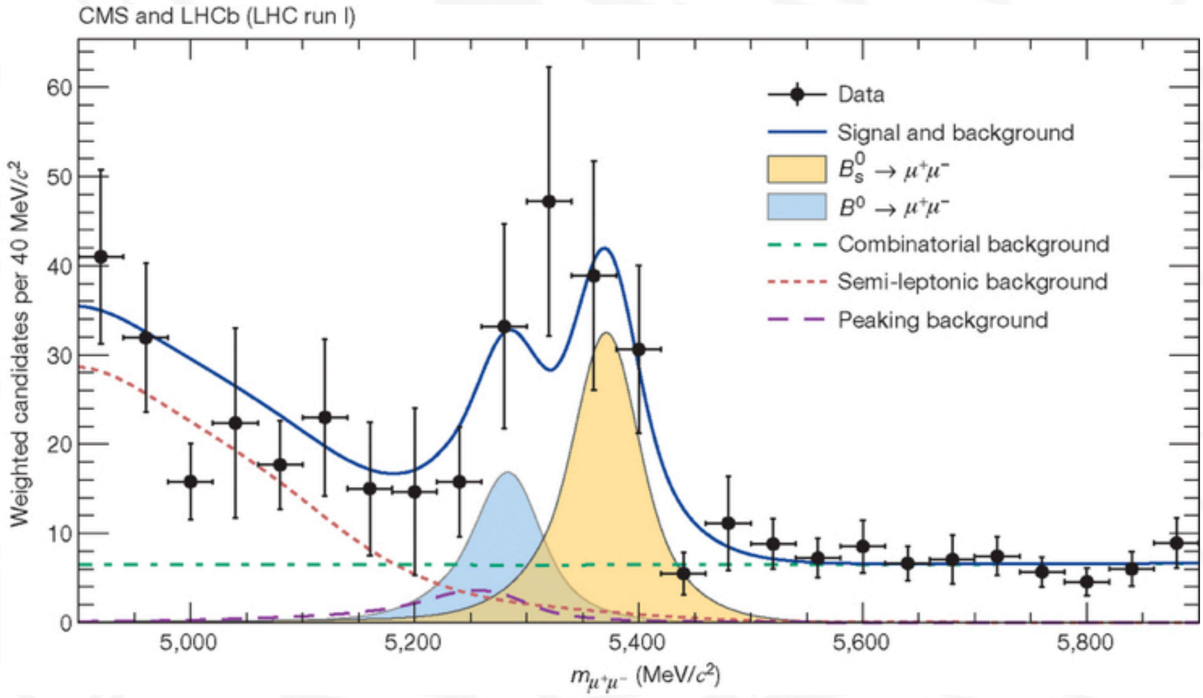


Fig. 6 Observation of the rare B-mesons decay from the combined analysis of CMS and LHCb data [2].

The joint LCHb and CMS paper [2] reports the first observation of the $B_s^0 -> \mu^+ \mu^-$ decay, with a statistical significance exceeding six standard deviations, and the best measurement so far of its branching fraction. Furthermore, it shows the first evidence for the $B^0 -> \mu^+ \mu^-$ decay with a statistical significance of three standard deviations.

The LNF groups participating in CMS and LHCb were prominently involved in the analyses that led to these results. “2015 has been an exciting year,” said Matteo Palutan, the LNF leader of the LHCb group. “This joint result announced last May, delimits precisely the parameter region in which new models can exist. All candidate models of physics beyond the Standard Model will now have to demonstrate their compatibility with these important measurements”.
The LHCb and CMS experiments have resumed data taking in June 2015 with proton-proton collisions at a centre-of-mass energy of 13 TeV. “We expect to double the production rates for B_s^0 and B^0 mesons in the future,” said Luigi Benussi, the LNF leader of the CMS group. “Therefore we plan on reaching further improvements in the precision of these crucial measurements”.

References
[1] http://www.particleadventure.org
[2] The CMS and LHCb collaborations, Nature 522 (2015) 68.

Robotic exploration of Mars

Establishing if life ever existed on Mars is one of the pressing scientific questions of our time. To address this important goal, the European Space Agency (ESA) has established the ExoMars program to investigate the Martian environment and to test new technologies paving the way for a future Mars sample return mission in the 2020's.
The first step of this program is represented by the Trace Gas Orbiter (TGO) plus an Entry, Descent and landing demonstrator Module (EDM), known as Schiaparelli, launched on March 14, 2016. The name Schiaparelli, for the module that represent the Italian contribution to the enterprise, was selected in honor of the Italian astronomer Giovanni Schiaparelli who was the first to ever draw a map of the Red Planet.

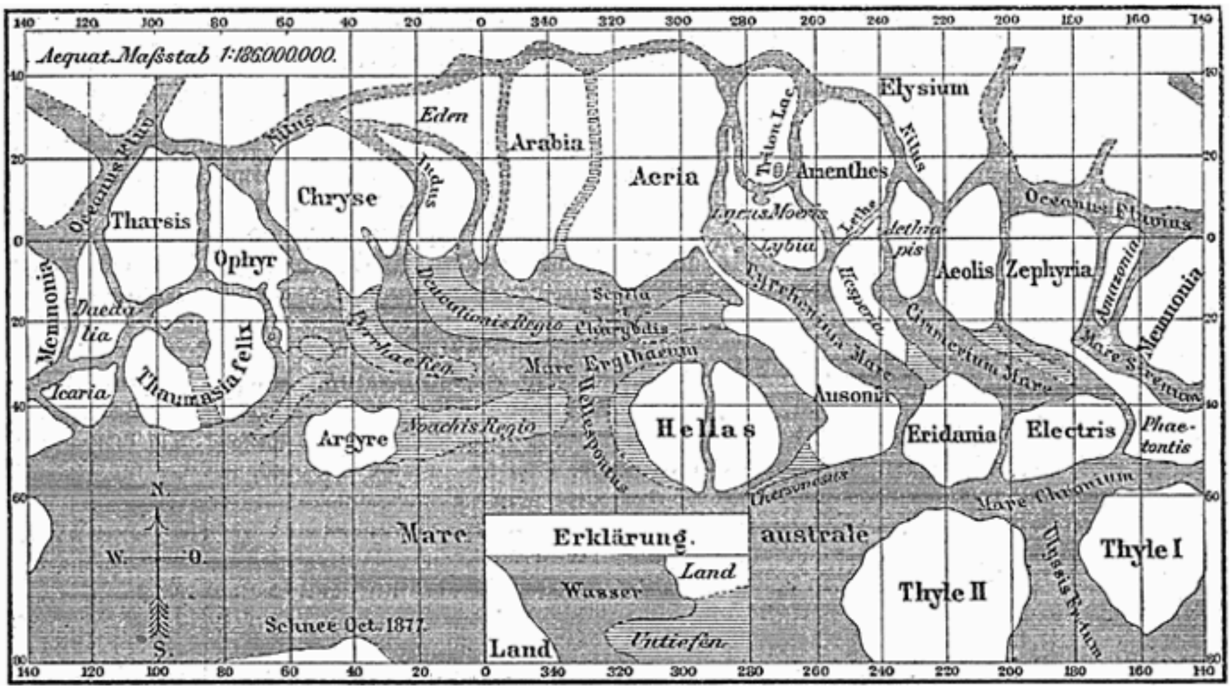


Fig. 7 Map of the Mars surface drawn in 1888 by the Italian astronomer Giovanni Schiaparelli.

The TGO carries scientific instruments to detect and study atmospheric trace gases, such as methane. Schiaparelli contains sensors to evaluate the lander's performance as it descends, and additional sensors to study the environment at the landing site. One of these sensors is the INRRI (Instrument for landing-roving laser retroreflector Investigations), designed and build at the SCF_Lab of the Frascati Laboratory.
INRRI is a very compact and lightweight Corner Cube laser Retroreflector (CCR). It is dome shaped, with a diameter of about 54mm and a weight of only 25g (see fig. 8). INRRI is attached to the zenith-facing surface of Schiaparelli and has an unobstructed view of the Martian sky, which is essential, since it will enable Schiaparelli to be located, using laser ranging, from Mars orbiters.

INRRI is not the only creature of the SCF_LAB. This technological infrastructure for space qualification has been carrying out, since 2003, an intense program of research in cooperation with the major space agencies: NASA, ASI and ISRO. The laboratory is located inside an 85 m^2 class 10.000 Clean Room (ISO 7) and replicates a realistic outer space environment that can be used to test and develop devices meant for space explorations.
The main focus of the SCF_LAB is laser ranging: a technique to measure spatial positions with high accuracy, using laser pulses and special mirrors called retro-reflectors. “Our key experimental innovation is the capabillity of correlating the optical response with the temperature distribution of retroreflector payloads,” said Simone dell’Agnello, the team-leader of the SCF_LAB. “This capability provide unique pre-launch performance validation of retroreflectors, allowing to optimize ranging efficiency and signal-to-noise conditions”.
INRRI will be the first passive laser reflector on the surface of Mars and the first to ever go further than the Moon. It should also be the first of a series of micro-reflectors carried on board of future landers or rovers, that will go together to form a Mars Geophysical Network (MGN): a network of reference points for taking geodesic measurements and conducting General Relativity tests on Mars. In the long term, MGN could become a precision positioning network similar to the one created using laser retroreflectors on the Apollo and Lunokhod moon missions.
The Schiaparelli module will land on the surface of the Red Planet after a journey of about seven months. Scientific analyses will therefore begin on the DREAMS (Dust characterization, Risk assessment and Environment Analyser on the Martian Surface) weather station. This is another Italian instrument, developed by ASI with engineering support from CISAS (“G. Colombo” University Space Activities and Research Centre) and the scientific direction Observatory of Napoli. INRRI, contrary to other scientific devices that are employed in this mission, is a passive instrument. Thus, it will continue to work for years after the short life of the EDM and of its active instruments. It will therefore be the only survivor of the mission, keeping Schiaparelli’s memory alive and extending the positive effect of ExoMars to everyone.

Lastly, the INRRI could possibly be used as a new primary precision geodetic reference point on Mars: a sort of Martian Greenwich.

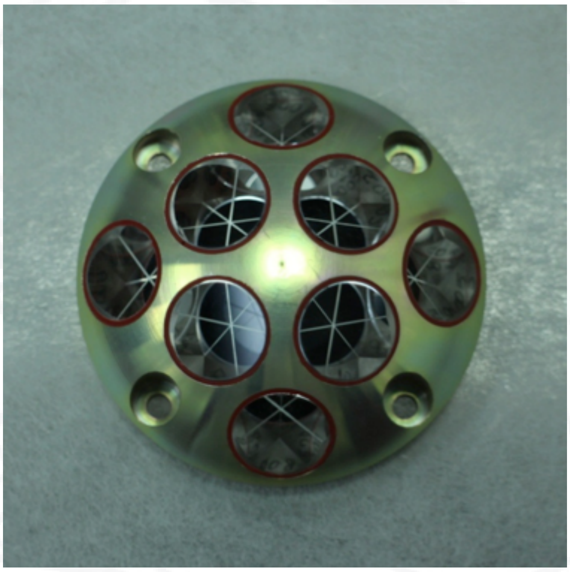


Fig. 8 Photo of the INstrument for landing - Roving laser Retroreflector Investigations (INRRI) carried on the ExoMars 2016 Schiaparelli entry descent and landing demonstrator module. INRRI has been designed and built at the SCF_Lab of Frascati.

Beam Driven Plasma Acceleration at SPARC_LAB

According to Stephen Hawking: "Particle accelerators are the closest things we have to time machines" [1]. In fact, high-energy collisions of particles inside an accelerator recreate the conditions that governed the moments just after the Big Bang, allowing physicists to look back into the past: almost 14 billions years ago.
To reach this ambitious goal, a lot of energy and space is needed. The Large Hadron Collider (LHC), the world's largest and most powerful particle accelerator, to accelerate protons at a 0.999999991 speed of light, needs a tunnel of 27 kilometers. In order to plan more powerful accelerators, it is mandatory to achieve an improvement in energy gain: new technologies, that will allow to accelerate particles more and in smaller spaces, are needed.

Plasma acceleration opens a possible path to development of more cost-effective accelerators for the 21th century, and the SPARC_LAB at Frascati is on the forefront of this kind of research. It hosts an accelerator, SPARC, able to produce and accelerate up to 150 MeV electron beams with record brightness, and a powerful laser, FLAME, a Ti:Sa Chirped Pulse Amplification (CPA) laser chain providing 200 TW pulses of 25 fs duration, with a repetition rate of 10 Hz, and a central wavelength of 790 nm.

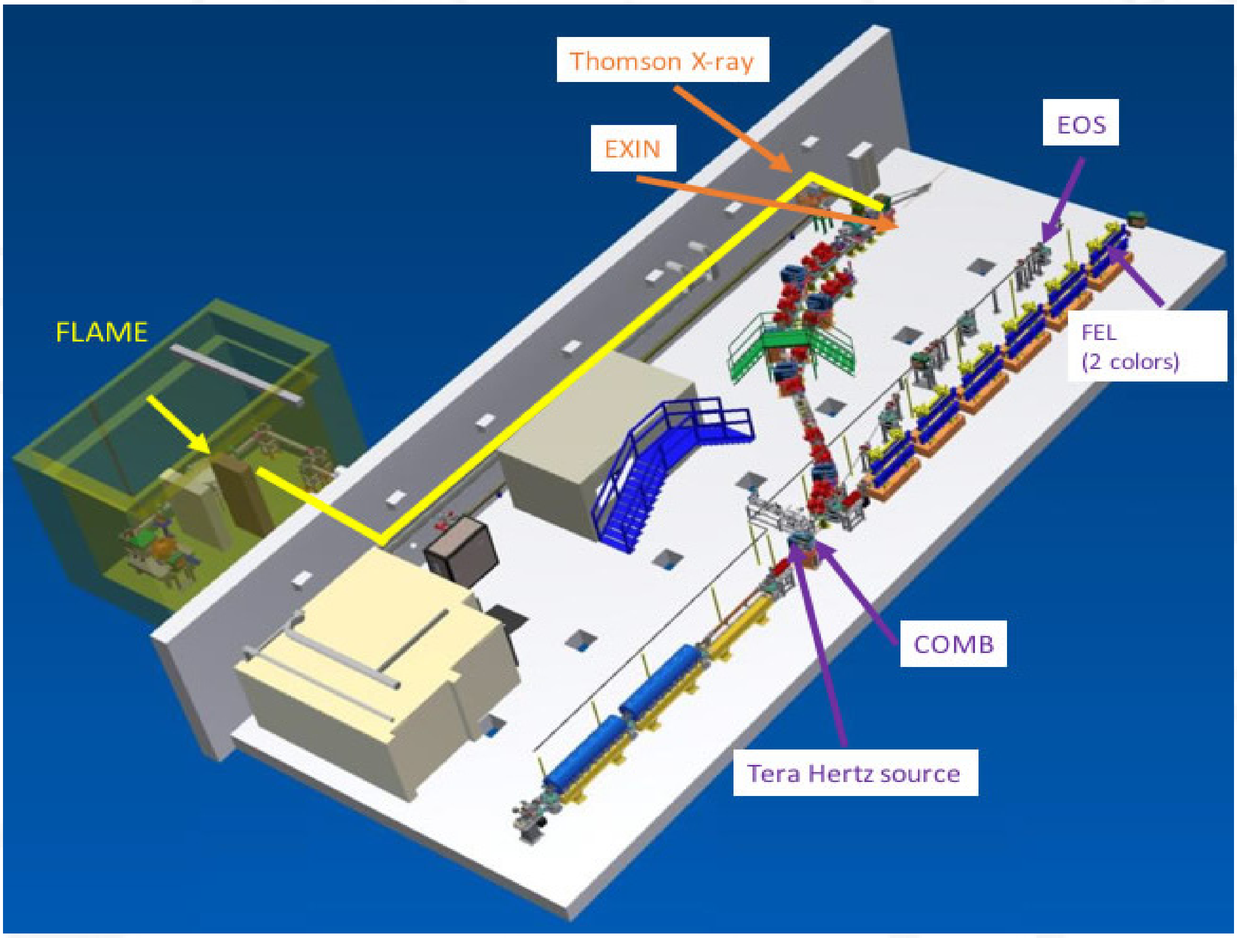


Figure 9 Schematic view of the SPARC facility.

In 2015 at the SPARC_LAB the experiment SL_COMB has been successfully started. The goal is to accelerate high brightness electron beams with resonant plasma wakefields (PWFA). A train of high brightness electron bunches, with THz repetition rate (called comb beam), is properly generated at the cathode, and manipulated through the velocity bunching technique, in order to be injected in a H_2-filled plasma discharge capillary. The train of driver bunches separated by a plasma wavelength λ_p (in our case to 1 ps) resonantly excites a plasma wake, which accelerates a trailing witness bunch injected at the accelerating phase.
The vacuum chamber for PWFA experiments has been realized, vacuum tested and installed (see fig. 10) at the SPARC_LAB.

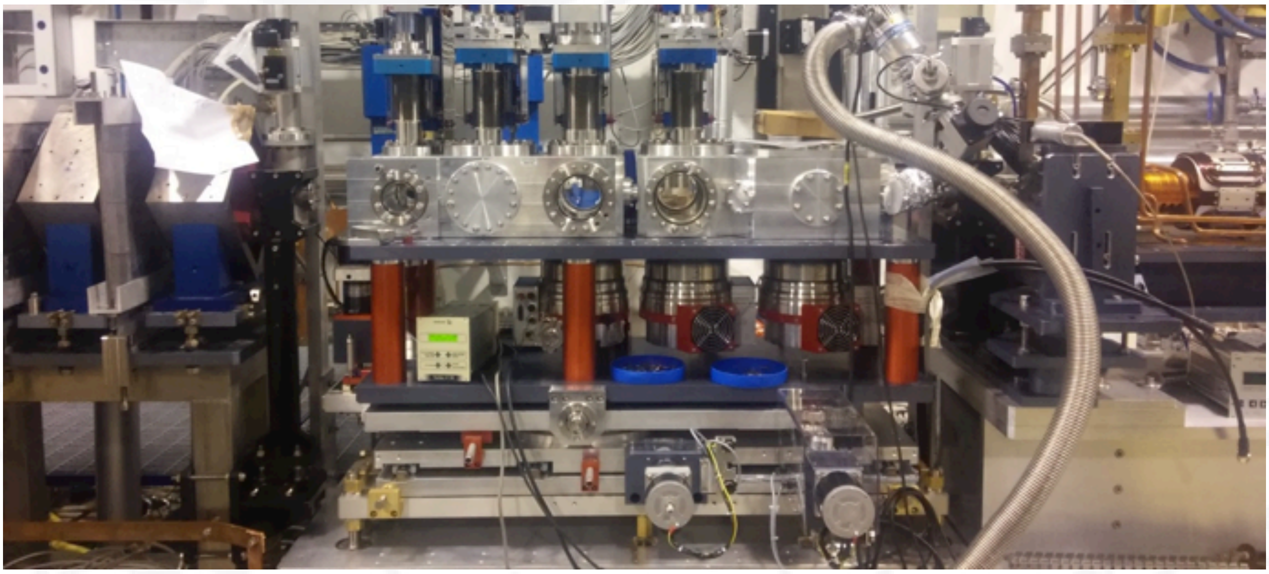


Figure 10 PWFA chamber installed at the end of the SPARC linac.

The capillary is filled with hydrogen at 10 mbar (~100mbar outside the chamber). A valve opens for a few ms (~5 ms) letting gas flow inside. A discharge of ~20kV and 200A ionizes the gas. First tests of the discharge circuit for plasma generation from H_2-filled capillaries have been performed in laboratory (see fig. 11).

Figure 11 Screenshot of the discharge-driven plasma.

This is just a first step, but the results are very promising. The final goal will be to have accelerating structures of a few centimeters replacing the present – meter long – RF structure.

[1] S. Hawking, Daily Mail, 27 April 2010.

EDIT 2015: The International School on experimental techniques took place at LNF

EDIT – Excellence in Detectors and Instrumentation Technologies – is an International School addressed to young researchers, in their graduate studies or in their first year as post docs, seeking to acquire a deeper knowledge on the major aspects of detectors and instrumentation technologies for fundamental research.

Figure 12 Photo of the EDIT 2015 school students and teachers.

The school series has been inaugurated at CERN in 2011 under the direction of Ariella Cattai and the supervision of an International Advisory Panel of eminent scientists.

The objective of the school is to give young researcher a chance to practice on state of the art technology of the particle physics field. This goal is achieved by providing a diversified program that integrates topical academic courses, with hands-on laboratories. This practice-oriented approach is particularly profitable for physicists with limited hardware experience, as they can explore the performance and limitations of the technologies which are used routinely in sub-atomic physics experiments. Furthermore, more experienced participants can extend their knowledges beyond their immediate circle to a broader view, favoring strong skills in understanding the operation of particle detectors and fostering innovative ideas on R&D and data treatment.

EDIT 2015 has been the 4th of the series – previous editions were taking place at the Fermi National Accelerator Laboratory in Batavia, IL, USA in 2012, and at the KEK Laboratory in Tsukuba, Japan in 2013 – and has been hosted by the National Laboratory of Frascati on October 20th-29th, 2015. "Compared to the previous editions, we have now tried to enlarge the spectrum of activities proposed," said the school director Paola Gianotti. "During the ten days of the school, we offered each student the possibility to participate in two laboratory courses". Not only the school format, but also the range of topics addressed in this edition has been broadened. For the first time students had the possibility to manipulate electrons on a real accelerator beam line, experiencing firsthand all the problems of beam dynamics. "It was a pity that not all of the students could take part in all of the laboratory activities. In each one there were things to learn," said André Cortez, one of the students that awarded the best poster prize. In fact, aside from the training, the participants were also invited to present their own work in an evening poster session.

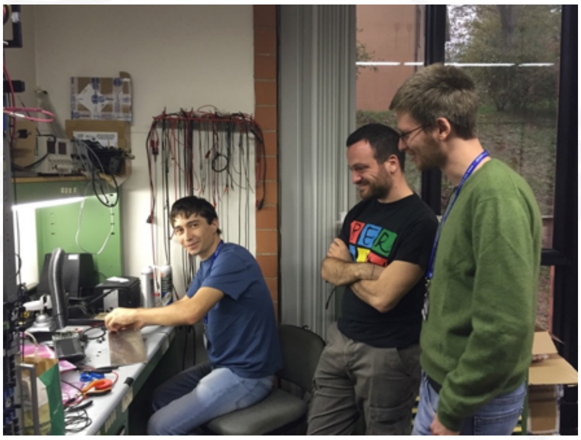


Figure 13 EDIT school students during the laboratory course.

The organization of the EDIT school has been a challenging enterprise. "To host 55 students, we had to involve almost 100 researchers, some of whom were coming from other laboratories around Europe," said Paola Gianotti. But LNF is used to ambitious outreach activities and everything worked smoothly. The Laboratory outreach service organizes regularly a wide spectrum of activities for different kinds of audience: school students and teachers, general public. In 2015 around 10.000 people visited the laboratory during the Open Day, the Public Lectures taking place along the year, and the European Researchers' Night.

LNF Outreach activities

Since many years LNF has been active in the field of scientific dissemination. 2015 has been proclaimed International Year of Light and for this occasion the outreach program of LNF has been enriched with a vast program of events for the general public, teachers and students. "Along the year, around 10.000 people entered the LNF premises," said Rossana Centioni, coordinator of the LNF outreach service, "2200 just for the Open Day on Saturday May 23rd.

This was only one of the numerous occasions to enter the LNF: visits to the Laboratory are a well-established tradition for students, and not only Italian students; seminars and public lectures were held every month by eminent personality of science; during the European Researchers' Night a series of all ages events was organized, featuring conferences, guided tours of the experimental facilities, scientific exhibitions, theatre plays and experimental physics lessons. The realization of such a wide program was possible thanks to the enthusiastic involvement of the LNF personnel, including graduate students, post-docs, technicians and administrative, that always react positively to any new proposal.

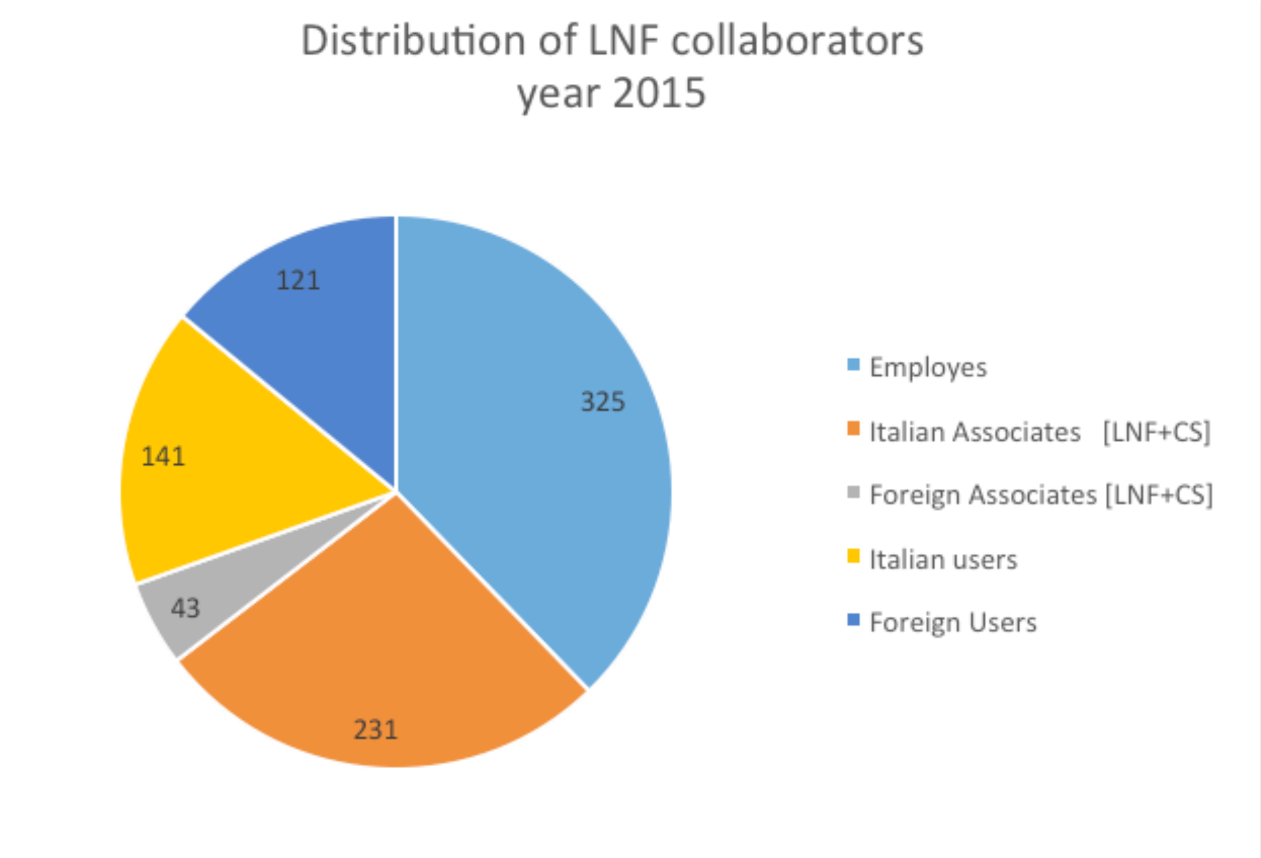
Figure 14 Some students of the International School on Modern PhYsics (INSPYRE2015) with their tutor.

LNF in numbers

The LNF personnel, at the end of 2015, consists of 325 units, 56 of which have a fixed term contract, plus 274 associate members. Among these, there are university and PhD students, young post-Docs and employees from universities or other research institutions. Associate members work alongside staff members and likewise take part in the laboratory's activities. Tab. 1 shows the division of the LNF personnel among the different profiles.

	Staff	Temp.	Tot.
Researchers	74	9	83
Engineers	40	20	60
Administrative employees	31	10	41
Technicians	124	17	141
Tot.	269	56	325

Table 1 LNF personnel at December 2015.



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