Introduction to Modern Physics and to the LNF-INFN Activities

INSPYRE 2016
International School on modern Physics and Research
QUANTUM LEGACY
15-19 February 2016

Catalina Curceanu
LNF-INFN
The School is open for students in their last year(s) of high school/college coming from all European countries. Organized in lectures and experiments on Modern Physics and its applications in Society. The official language is going to be English.
After 100 years of General Relativity...

Imagine travelling through space on a beam of light at the speed of light.

Albert Einstein, theory of relativity, gravity, velocity, energy, mass, speed, time, \( E=mc^2 \)
Discovery of the gravitational waves (14 Sept. 2015 -> 11 Feb 2016)
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Discovery of the gravitational waves (14 Sept. 2015 - > 11 Feb 2016) – talk Viviana Fafone (19th feb)
NAUTILUS at LNF-INFN
Towards quantum gravity?
1 miliardo a. l.
The INFN promotes, coordinates and performs scientific research in the sub-nuclear, nuclear and astroparticle physics, as well as the research and technological development necessaries to the activities in these sectors, in strong connection with the University and in the framework of international cooperation and confrontation.
1951
4 University Sections
Milano, Torino, Padova, e Roma

1957
Laboratori Nazionali di Frascati

Frascati
Laboratori del Sud (Catania)

19 Sections
11 Related Groups
4 National Laboratories
What are the activities performed at Laboratori Nazionali di Frascati?

Fundamental research

• Studies of the ultimate matter structure
• Search for gravitational waves
• Developments of theoretical models

• Development and construction of particle detectors
• Studies and development of accelerating techniques
• Material studies and bio-medical research with the synchrotron light
• Development and support for computing systems and nets
How we see differently sized objects:
The atom in the beginning of '900

The Thompson's atom

Quantum mechanics - atom

Rutherford e Bohr - atom

The nucleus today

The nucleus structure
The Standard Model

Fermions

Quarks
- u (up)
- c (charm)
- t (top)
- d (down)
- s (strange)
- b (bottom)

Leptons
- νₑ (electron-neutrino)
- νₑ (mu-neutrino)
- νₑ (tau-neutrino)
- e (electron)
- μ (muon)
- τ (tau)

Bosons
- g (gluon)
- γ (photon)
- W (boson)
- Z (boson)

Matter families

I
II
III

Higgs boson

Gravitation
The “Opera ghost”
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<td><strong>Total Staff</strong></td>
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<td>of which:</td>
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<tr>
<td>Researchers</td>
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<td>57</td>
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<td>Italian</td>
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Frascati electrosynchrotron 1959-1975
Observing on fixed target

- Matter is mainly empty
- All those particles which did not interact get lost
- Energy loss by moving the center of mass
- Target is complex
First Frascati’s idea

- The non-interacting particles can be re-used in the successive rounds
- Collisions are performed in the center of mass frame
- The circulating particles can be either elementary or complex (nuclei or atoms)
Second Frascati’s idea

\[ E = 2m_\tau c^2 \]

\[ E = m c^2 \]

Bigger the energy is, more and more particles can be studied.
Matter-antimatter colliders

LEP al CERN di Ginevra 1988

LHC at Cern (pp)
Out of the electron–positron collisions the Φ meson can be produced; it decays immediately in other two particles, the $K$-mesons (kaons). The kaons can be both neutrals or charged.

The $K$ are the particles used by the three experiments, DEAR, FINUDA and KLOE, to reach their scientific goals. The DAΦNE luminosity allows to produce about 10000 $K$ in a second.
The DEAR experiment investigates the strong force by studying the kaonic atoms (in which a $K^-$ is substituting an atomic electron).

**Kaonic hydrogen**

$2p \rightarrow 1s (K_\alpha)$ X ray of interest

The DEAR experiment investigates the strong force by studying the kaonic atoms (in which a $K^-$ is substituting an atomic electron).
Could strangeness play a role in neutron stars?
KLOE
(K LOng Experiment)

KLOE studies the differences between matter and antimatter in the kaon decay processes.

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KLOE2
(K LOng Experiment)
Synchrotron light (DAΦNE-luce)
Laser of high power (> 100 TW), able to produce pulses of 6 J in 20 fs at 10 Hz

FLAME: Frascati Laser for Acceleration and Multidisciplinary Experiments

Started
December 2010

1) If FLAME beam is injected into a gas the electrons inside get highly accelerated (new acceleration technique)

2) If FLAME beam is colliding head-on with an electron beam (SPARC) an intense source of X rays is produced
1) New acceleration technique

In few cm electrons get accelerations as in present accelerators of hundred meters

L’impulso laser produce nel plasma un’onda di scia simile a quella che lascia dietro di sè un’imbarcazione

Su quest’onda parte degli elettroni del plasma acquistano energia come un surfista che cavalca un’onda.

In few cm electrons get accelerations as in present accelerators of hundred meters
Electron beams from Linac (SPARC) with energies about 25-50 MeV collide with FLAME beam

Resulting in monochromatic X ray beams with energies between 20 and 800 keV.

Medical diagnosis and material science
Fig. 3 – Confronto fra una mammografia monocromatica (sinistra) con una tradizionale (destra).
Gravity force

Distortion of space-time
The electromagnetic waves are produced by an electric charge in movement.

Gravitational waves: an analogy

Gravitational waves are produced by masses in movement….
Gravitational waves

The gravitational waves have an intensity $10^{40}$ times smaller than the electromagnetic one.
Search for gravitational waves: NAUTILUS

- Supernova in our Galassia $h=10^{-18}$
- Supernova in Virgo $h=10^{-21}$
- Thermal noise @ $T=300$ K, $\Delta L=10^{-16}$ m
- Thermal noise @ $T=3$ K, $\Delta L=10^{-17}$ m
- Thermal noise @ $T=300$ mK $\rightarrow \Delta L=10^{-18}$ m

\[ \frac{\Delta L}{L} \approx h \]

vibrations in the bar
(for $A_l$, $L=3$ m, $f=915$ Hz)
Large Hadron Collider
Higgs Decay to Photons

Rare decay in SM

LHC detectors have been optimized to find this peak!
The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs "for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider" – Francois Englert, Peter Higgs
Einstein – last black-board
Dark Energy 73%

Dark Matter 23%

“Normal Matter” 4%
Alcubierre Warp Drive:

\[ \psi = - \alpha \text{Tr}(K) \]

Alcubierre Warp Drive: stretches spacetime in a wave causing the fabric of space ahead of a spacecraft to contract and the space behind it to expand.

The ship can ride the wave to accelerate to high speeds and time travel.
Einstein quotes

There are two ways to live: you can live as if nothing is a miracle; you can live as if everything is a miracle.

Try not to become a man of success, but rather try to become a man of value.
Laboratori Nazionali di Frascati