Lanzhou University
12 September 2014

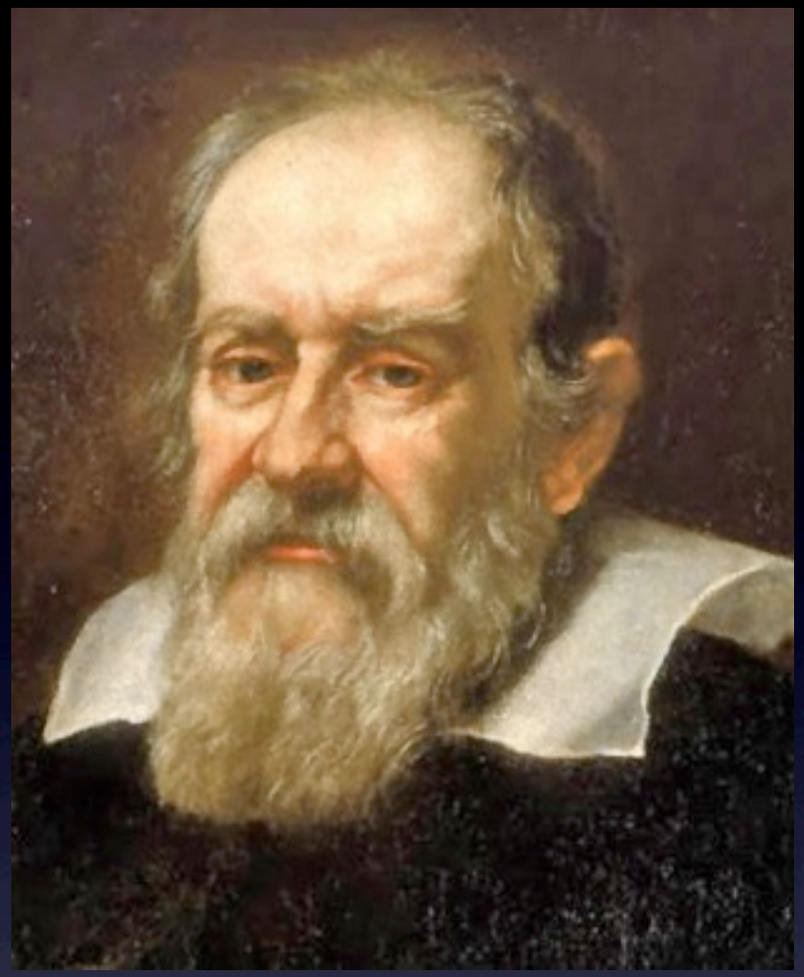
# The Birth of Modern Physics: Galileo, Fermi & Today

I. Galileo Galilei (1564-1642)

II. Enrico Fermi (1901-1954)

III. Physics Today

K. Konishi (Univ. Pisa/INFN, Pisa)



Galileo Galilei (1564-1642)

Born in Pisa 15th Feb. 1564
in Casa Ammannati (~440 m dal Dep. Phys. Univ.Pisa !)

Student at the Univ. Pisa (medicine) (1581-)

Discover isochronism of pendulum
(1583) Beigins study of mechanics

Chair of Mathematics Univ. Pisa (1588-92)
Study of hydrostatics (Archimede!) (1588)

Chair of Mathematics at Univ. Padua (1592-1610)

Telescope, phases and mountains of the moon, Satellites of Jupitor, phases of Mercury, solar spots, Milky way

The first Mathematian and Physicist Univ. Pisa (1610-)

Sidereus Nuncius (1610)

Dialogo sopra i due massimi sistemi del mondo
Ptolemaic vs Copernican views (1632)

Discussions and demonstrations around the two world views, in the form of dialogues among three noblemen in a Tuscan villa : a book one can still buy in ordinary bookshops, in the original language

Condemned by the Roman Church to recant the Copernican view (1634)

Under house arrest until his death

● Pope Jean Paul II admits that Galileo's condemnation was a "tragic error" (1992 !)

# Galileo: founding father of modern physics and cosmology

- Experimental physicist:
  - experimental method based on observations;
  - construction of measuring devises
  (telescope (8x, 20x), inclined plane for measuring the falls of objects, etc.)

- Theoretical physicist:
  - summarizing the observational facts as "laws"
  (law of "inertia"; law of parabolic and circular motions; law of free fall of bodies )
  - Language in which the Book of Nature is written: Mathematics *
  - Theoretical method of reasoning *

Establish New Cosmology (Copernican) (Ticho-Brahe, Kepler, Copernicus)

Recognition of the fact that the celestrial bodies and terrestrial bodies are made of the same materials and governed by the same law of physics (Newton)

Galileo, against Aristotle's philosophy, says:

" io veramente stimo il libro della filosofia

esser quello che perpetuamente ci sta aperto innanzi a gli occhi ;

ma perché è scritto in caratteri diversi da quelli del nostro alfabeto , non può esser da

tutti letto : e sono i caratteri di tal libro triangoli , quadrati , cerchi , sfere , coni , piramidi

ed altre figure matematiche , attissime per tal lettura " .

" I really consider the true book of philosophy being the one that is perpetually open

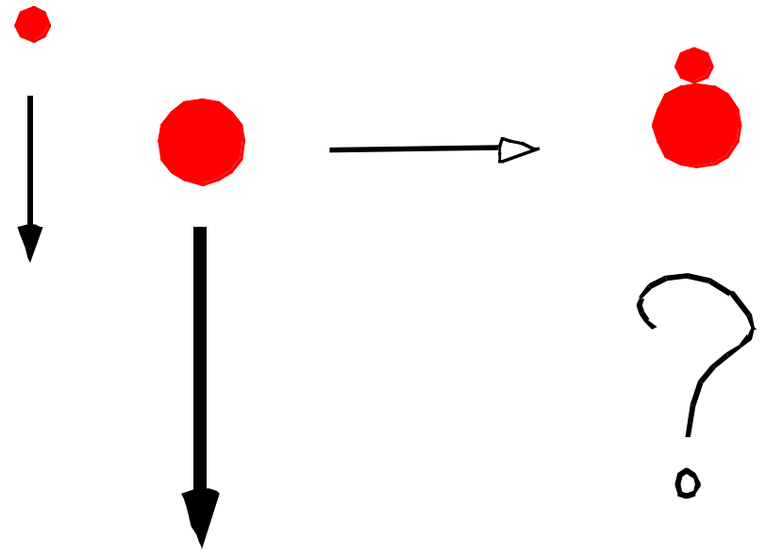
before our eys; but since it is written in characters different from our alphabets it cannot be read

by everybody; they are triangles, squares, circles, spheres, cones, pyramids and other

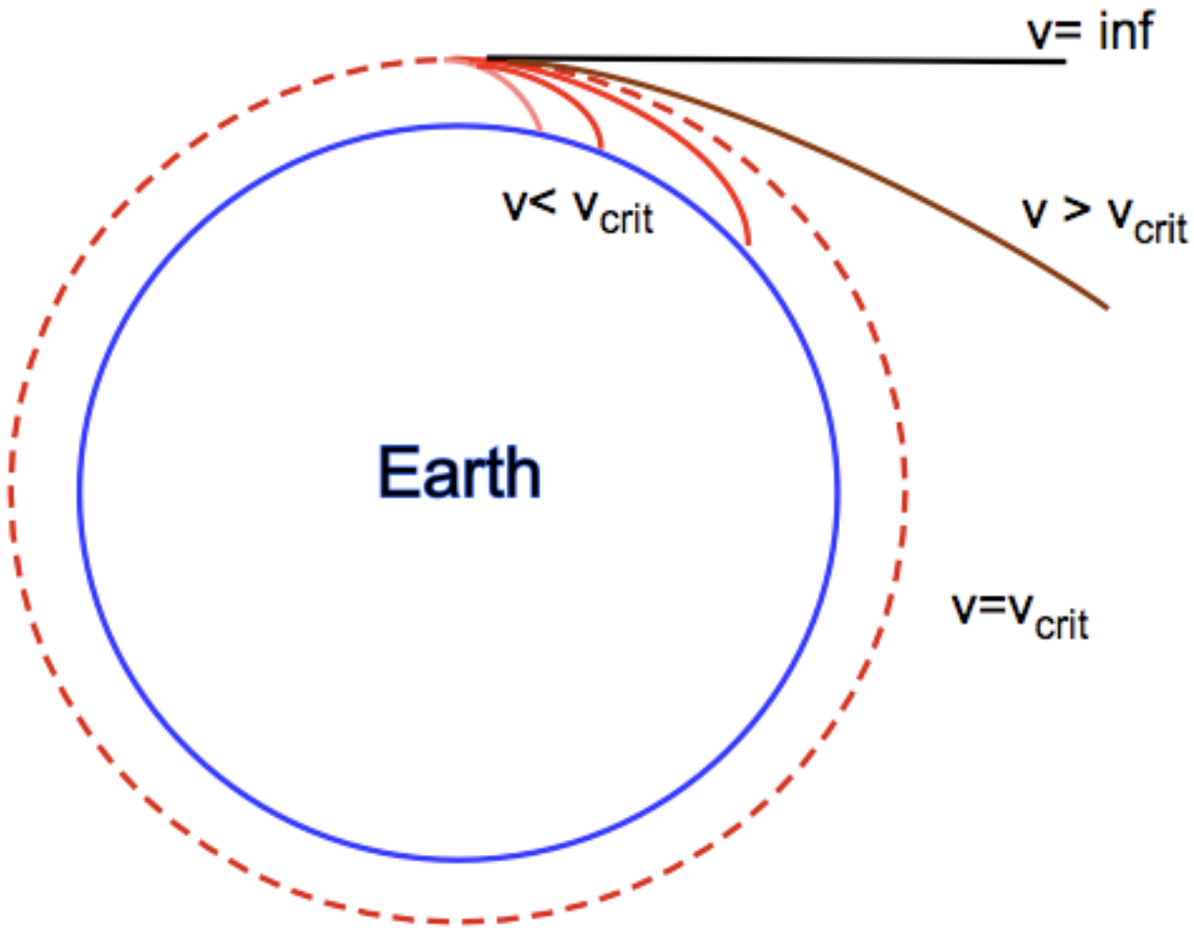
mathematical figures, sophisticated for such reading "

That is, to read the book of Nature one must learn mathematics!

# Power of reasoning



Contradiction unless the light and heavy masses fall together




there must be a critical velocity $v=v_{crit}$ such that the stone will continue to travel around the Earth

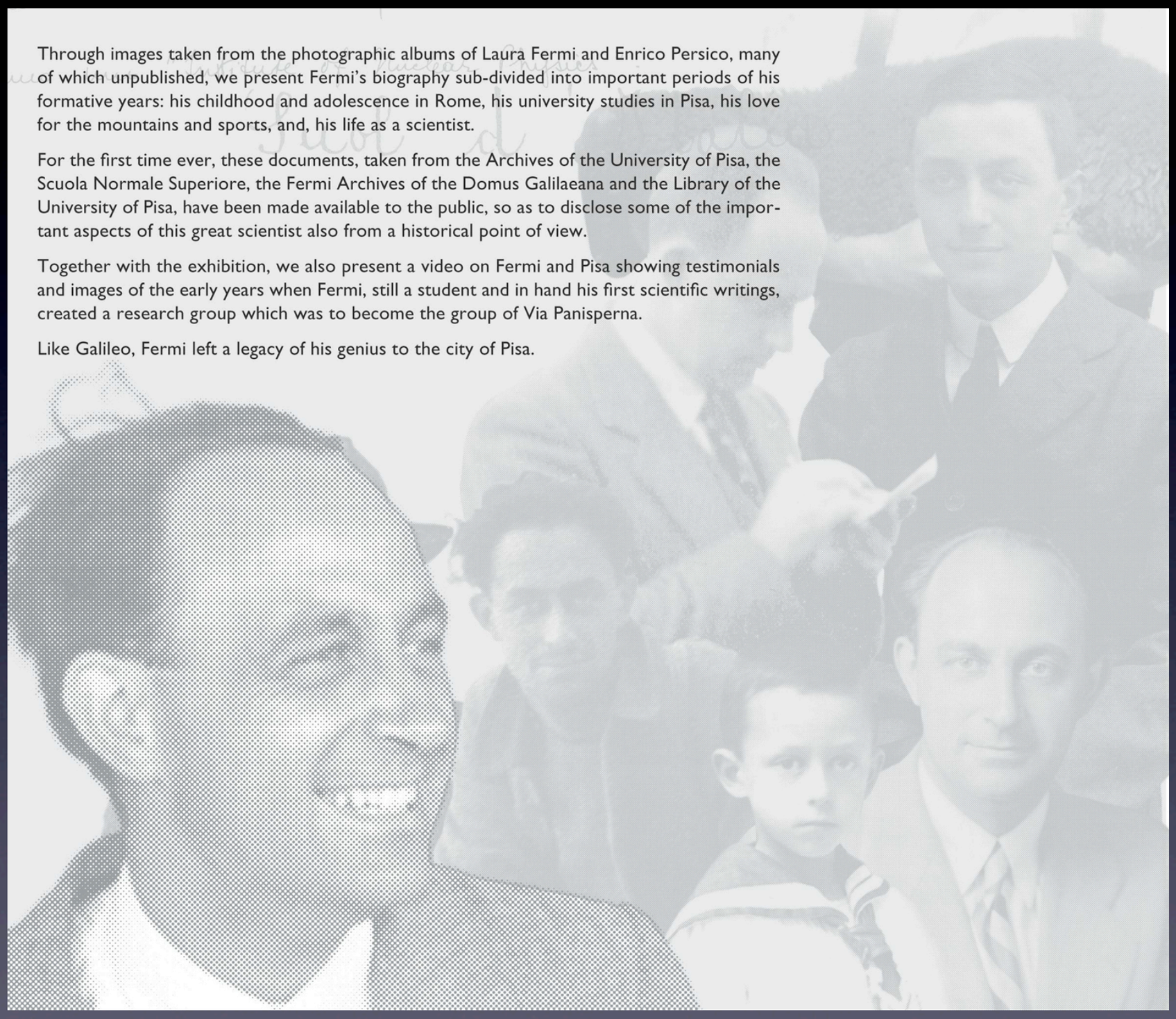
# Enrico Fermi (1901-1945)

Through images taken from the photographic albums of Laura Fermi and Enrico Persico, many of which unpublished, we present Fermi's biography sub-divided into important periods of his formative years: his childhood and adolescence in Rome, his university studies in Pisa, his love for the mountains and sports, and, his life as a scientist.

For the first time ever, these documents, taken from the Archives of the University of Pisa, the Scuola Normale Superiore, the Fermi Archives of the Domus Galilaeana and the Library of the University of Pisa, have been made available to the public, so as to disclose some of the important aspects of this great scientist also from a historical point of view.

Together with the exhibition, we also present a video on Fermi and Pisa showing testimonials and images of the early years when Fermi, still a student and in hand his first scientific writings, created a research group which was to become the group of Via Panisperna.

Like Galileo, Fermi left a legacy of his genius to the city of Pisa.



Enrico Fermi a 17 anni.

Enrico Fermi

o as follows: «*I have*
*for a week, doing noth-*
*wake up very late and*
*r 5 games of bowls,*
*clear day and I could*
*lmost like being in the*

e at Ladispoli and
s an excellent swim-
ling: «*This morning*
*that he would like*
*e wrote to Persico in*
*e before leaving for the*

o the mountains: to
Ovindoli, Moena di

rrived in Val Gardena
kers and a tyrolese
alked at the head of
alf hour three minutes
out of breath and he
art, stronger than all
i was all made up of
nuscles were stronger
cise and prompt, his

ta Cristina – he wrote
with Rasetti, we went
, to the Adamello
we went back to
ar».

Enrico Fermi (kneeling) with his friends.

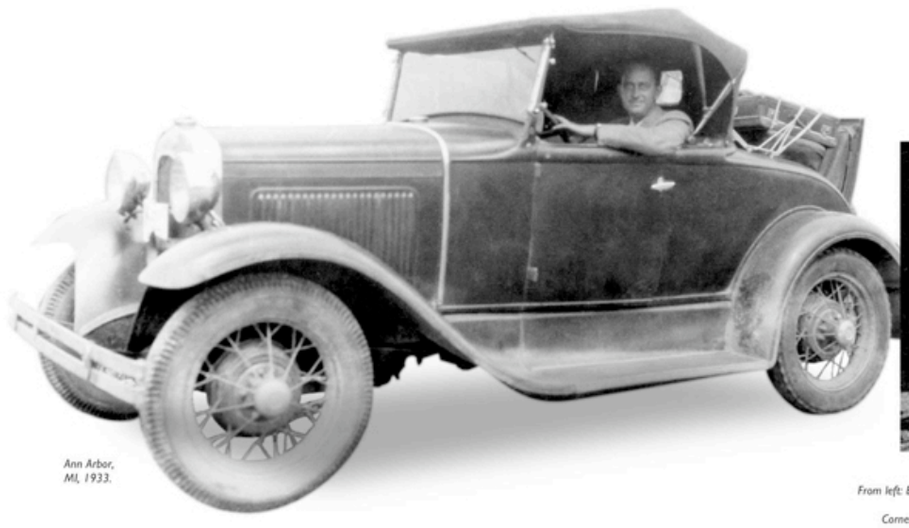
Enrico Fermi and Enrico Persico (busy with the car), Laura and a friend.

Enrico and Laura Fermi with friends.

Fermi on Monte Cavo, 1923.

Fermi and Persico.

From right: Enrico Fermi, Enrico Persico, Emilio Segrè. Ostia, 1927.



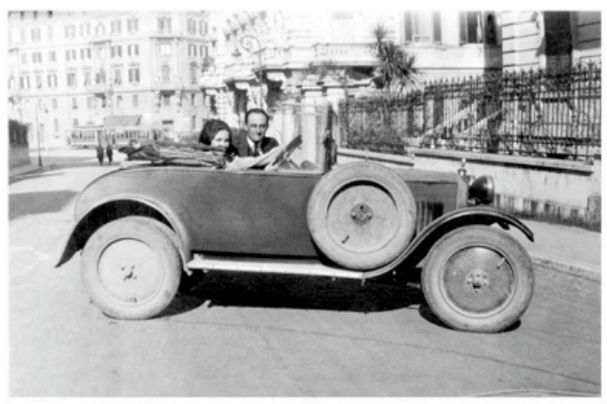
Ann Arbor, MI, 1933.

From left: Persico, Maria and Enrico Fermi. Monte Cavo, 1923.

Enrico Fermi at the lake with friends.

Seated from right: Fermi, Persico, Segrè. Ostia, 1927.

A rough route.

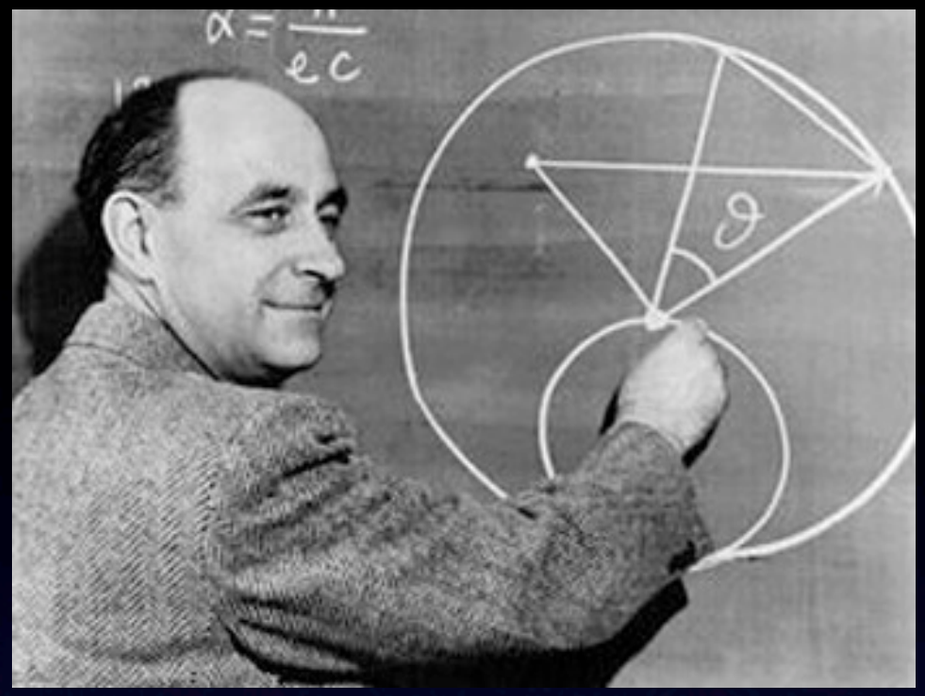


Enrico and Laura Fermi, in front of the Capon's, in the yellow bébé Peugeot. Rome, 1928.

From left: Enrico and Laura Fermi, a friend and Enrico Persico.

From left: Emma Castelnuovo, a friend, Libera Trevisani Levi-Civita, Cornelia Trevisani, with Fermi and Persico at the far right.

From left: Maria Fermi, a friend and Enrico. Monte Cavo, 1923.



Enrico Fermi (1901-1954)

Born in Rome 29th Sept. 1901

Enter Scuola Normale Superiore of Pisa
/ University of Pisa (1919);
1919-1921 : dedicates himself to the study of
general relativity, quantum mechanics and atomic physics

Publishes first two articles (1921)

Visit to Göttingen 23

Visit to Leiden, c/o Ehrenfest (1924)

Article on Fermi-Dirac statistics (1926)

Fails to win a position
in Cagliari (1926)

Wins the first chair of theoretical physics in Univ. Roma (1926)
(Corbino)

1926-1937 Golden period of Istituto di Via Panisperna
(Fermi, Rasetti, Persico, Amaldi, Majorana, Segré, Pontecorvo ... ...)

Quantum mechanics
formulated by
Heisenberg, Born, Bohr,
Pauli, Dirac, Schrödinger
(1924-27)

From atomic physics to nuclear physics, to high-energy physics

theory of β-ray ('34), slow neutrons, discovery of new elements, neutrinos ....

After Nobel prize, Fermi moves to US (anti-hebrew law in fascist Italy) 1938

At the news of discovery of nuclear fission (Hahn-Strassmann),
Fermi realized immediately the possibility of chain reactions

First nuclear reactor (uranium combustion) at Chicago university (1942)

Manhattan project

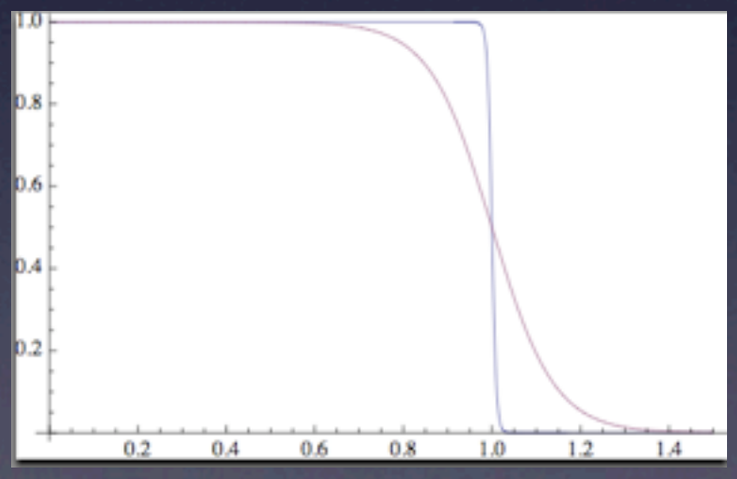
# Work of Enrico Fermi, theoretical and experimental physicist

- Quantum mechanics / atomic physics:
  - Fermi's golden rule
  - Thomas-Fermi statistical model of atoms
  - Fermi-Dirac statistics

$$N_{\mathbf{p}} = \frac{1}{e^{(\epsilon_{\mathbf{p}}-\mu)/kT}+1}$$

- Statistical mechanics / condensed matter physics
  - Fermi distribution; Fermi's degenerate gas
  - Electrons in metals

$$\mu(T=0) = \epsilon_F$$




- Nuclear physics - high-energy physics
  - neutrons, study of radioactivity
  - application of chain nuclear reactions; reactor
  - theory of beta decay : basis of the theory of weak interactions

# Fermi-Dirac Statistics:
## part of building principles of Quantum Mechanics

- Notion of symmetries
  (homogeneity in time ⇨ energy conservation;
  homogeneity in space ⇨ momentum conservation; etc. )
  fundamental role in quantum mechanics as well as in class. mechanics

- Statistics : symmetries under exchange of identical particles

In Quantum Mechanics, wave functions must be:

- symmetric if the particles have integer spins (s=0, 1, 2, ... )
  (Bose-Einstein statistics) (bosons)
- antisymmetric if the particles have half-integer spins (s=1/2, 3/2, ... )
  (Fermi-Dirac statistics) (fermions)

$$\psi(\xi_1, \xi_2) = \pm\psi(\xi_2, \xi_1), \qquad \xi = (\mathbf{r}, \sigma)$$

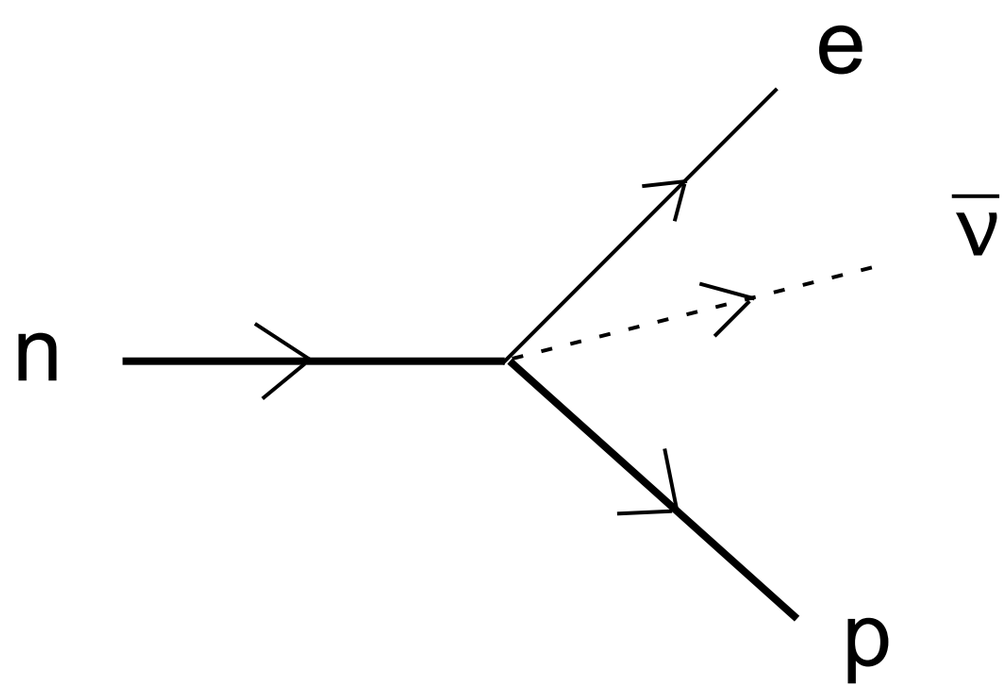
e.g., two electrons (spin 1/2)

$|\uparrow\rangle|\uparrow\rangle, \quad |\downarrow\rangle|\downarrow\rangle, \quad (|\uparrow\rangle|\downarrow\rangle + |\downarrow\rangle|\uparrow\rangle)/\sqrt{2}$ ⇨ orbital wave fn antisymmetric

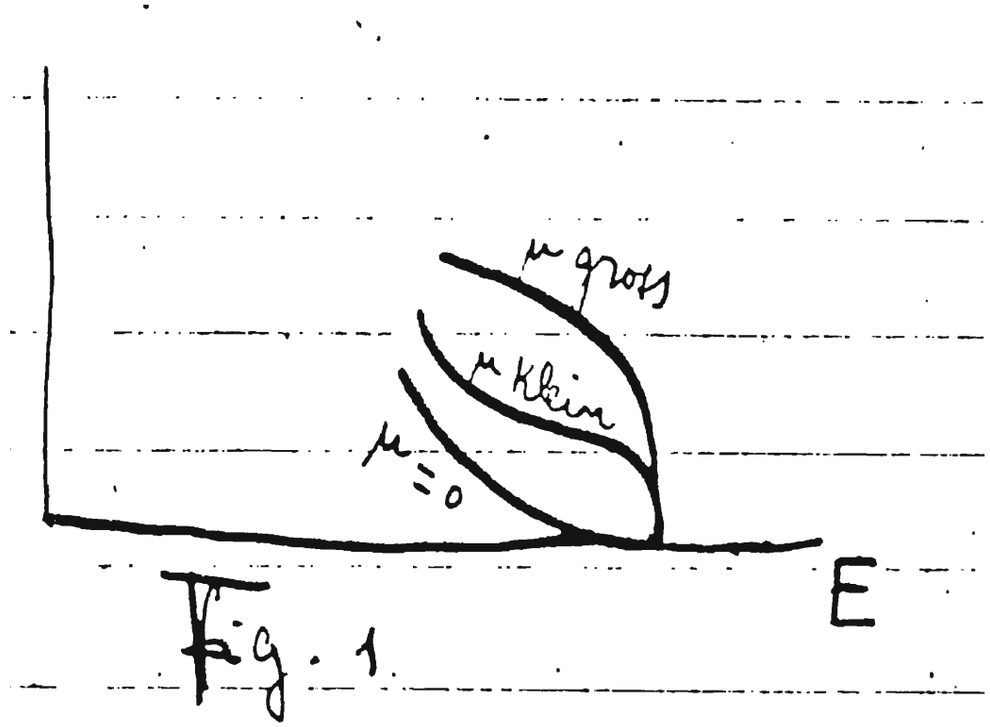
$(|\uparrow\rangle|\downarrow\rangle - |\downarrow\rangle|\uparrow\rangle)/\sqrt{2}$ ⇨ orbital wave fn symmetric

Each atomic "orbit" can contain only two electrons ⇨ periodic table of elements

# Fermi interactions (weak interactions)




Theory of beta decay (1934)
(refused by Nature, appeared in Nuovo Cimento)

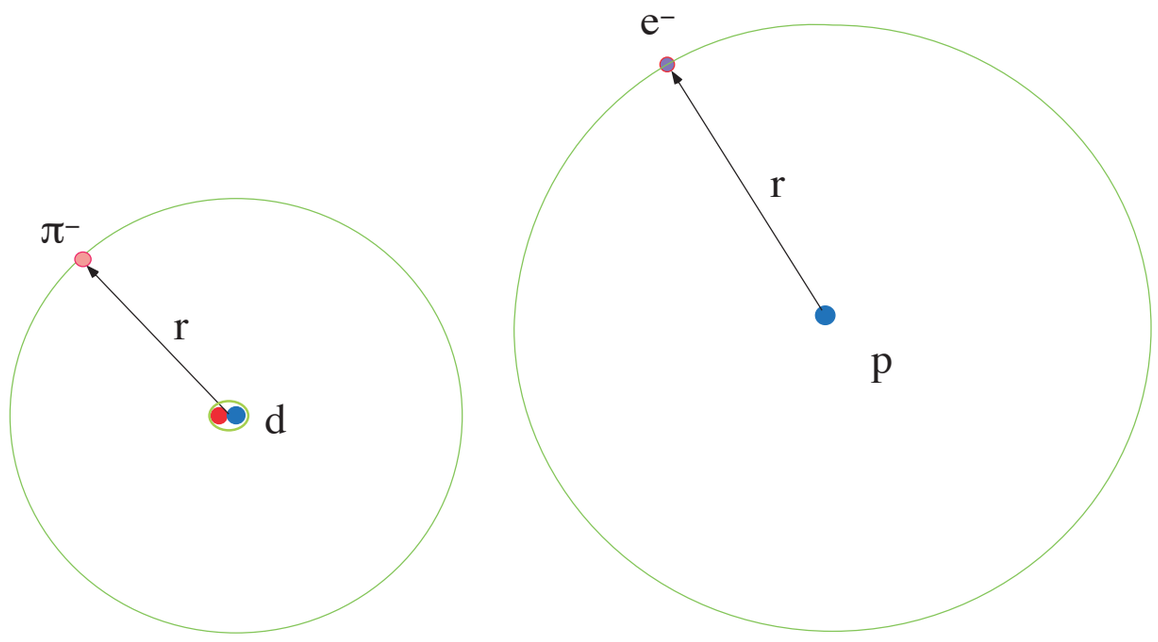



The Fermi constant

$$\mathcal{L} = G_F\, \bar{\psi}_p(x)\psi_n(x)\bar{\psi}_e(x)\psi_\nu(x) + h.c.$$

By the way... the original Fermi's idea for determining the neutrino mass from the endpoint of the electron spectrum turns out to be too difficult. The existence of nonvanishing neutrino masses was established at SuperKAMIOKANDE in atmospheric neutrinos -- neutrino oscillation* -- experiments (1998) * B. Pontecorvo

# By the way... a puzzle?




pi-deuterium

hydrogen

pi-deuterium decays via $\pi^- + d \to n + n.$

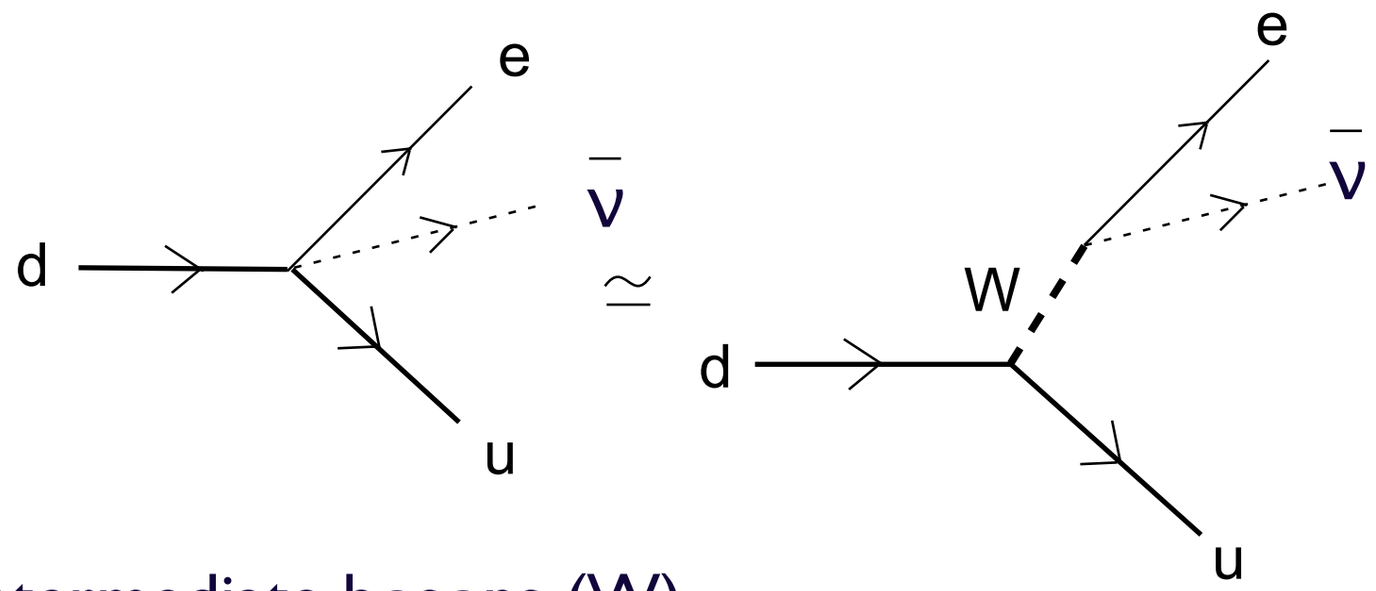
hydrogen atom (fortunately) does not decay via $e^- + p \to n + \nu$

Why?

# From Fermi' theory to Electroweak (GWS) theory

Glashow-Weinberg-Salam, 1968-72

Fermi interactions as local interactions among quarks and leptons




$M_W = 80\ GeV/c^2$

requires Higgs mechanism

Intermediate bosons (W)

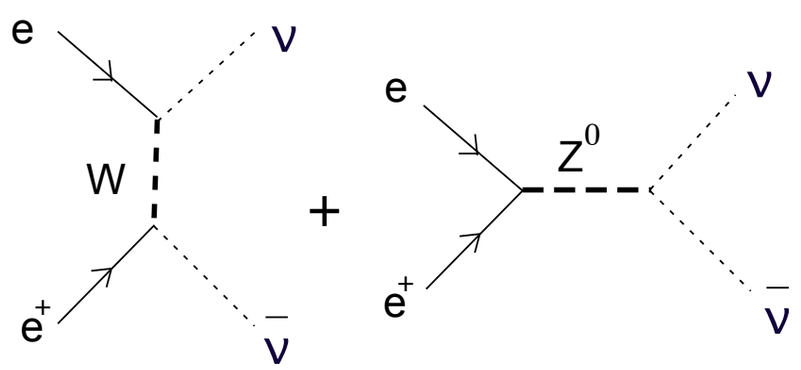
Quark-lepton universality (Cabibbo, Kobayashi, Maskawa)

Parity violation : $d \rightarrow d_L$ , $u \rightarrow u_L$ , $e \rightarrow e_L$

World not left-right symmetric!

Not enough! needs *)
$W^{\pm}$ and $Z^0$ and H

⇨ Renormalizable $(SU(2)xU(1))_{GWS}$ gauge theory of quarks, leptons and W,Z and γ gauge bosons!



# The standard model of strong and electroweak interactions ('70-'74)

QCD = quantum chromodynamics

Glashow-Weinberg-Salam theory

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\mathcal{D}\psi + |\mathcal{D}\phi|^2 + g_Y\, \bar{\psi}\phi\psi + \lambda(|\phi|^2 - v^2)^2$$

| $SU(3) \times SU(2) \times U(1)$ | quarks, leptons | Higgs boson | Yukawa interactions | Higgs scalar potential |
|---|---|---|---|---|
| gluons, W, Z, $\gamma$ | | | | |

**All** described by non-Abelian local gauge theories (Yang-Mills type theories)

Not quite!

C.N. Yang, R. Mills, (1954)

⇒ Deep unification underling the working of Nature ('t Hooft)

Discovery of W, Z bosons at CERN SPS-converted
$\bar{p}$ - p collider (1983)

Carlo Rubbia (Pisa, CERN) and Simon van der Meer (CERN)
share Nobel Prize (1984)

**Table: Quarks and their charges**

| Quarks | | | $SU_L(2)$ | $U_Y(1)$ | $U_{EM}(1)$ |
|---|---|---|---|---|---|
| $\begin{pmatrix} u_L \\ d'_L \end{pmatrix}$, | $\begin{pmatrix} c_L \\ s'_L \end{pmatrix}$, | $\begin{pmatrix} t_L \\ b'_L \end{pmatrix}$ | $\underline{2}$ | $\frac{1}{3}$ | $\begin{pmatrix} \frac{2}{3} \\ -\frac{1}{3} \end{pmatrix}$ |
| $u_R$, | $c_R$, | $t_R$ | $\underline{1}$ | $\frac{4}{3}$ | $\frac{2}{3}$ |
| $d_R$, | $s_R$, | $b_R$ | $\underline{1}$ | $-\frac{2}{3}$ | $-\frac{1}{3}$ |

Discovery of the top quarks (M = 170 GeV/$c^2$ ) at CDF experiment at Fermilab, Chicago (1995)
Physics led by Pisa group (Bellettini, Ristoro, Menzione*)

* 2008
Panofsky prize

## Table: Quark masses

| $u$ (MeV) | $c$ (GeV) | $t$ (GeV) | $d$ (MeV) | $s$ (MeV) | $b$ (GeV) |
|---|---|---|---|---|---|
| $1.5 - 4$ | $1.15 - 1.35$ | $174.3 \pm 5.1$ | $4 - 8$ | $80 - 130$ | $4.1 - 4.4$ |

$$|p\rangle = |uud\rangle, \quad |n\rangle = |udd\rangle,$$
$$m_p = 938.272\,\mathrm{MeV}/c^2, \quad m_n = 939.565\,\mathrm{MeV}/c^2,$$

## Table: Lepton masses

| $\nu_e$ (eV) | $\nu_\mu$ (MeV) | $\nu_\tau$ ( MeV) |
|---|---|---|
| $< 3$ | $< 0.19$ | $< 18.2$ |

| $e$ (MeV) | $\mu$ (MeV) | $\tau$ (MeV) |
|---|---|---|
| $0.51099892 \pm 4 \cdot 10^{-8}$ | $105.658369 \pm 9 \cdot 10^{-6}$ | $1776.99 \pm 0.26$ |

## Table: Gauge boson masses

| photon | gluons | $W^{\pm}$ (GeV) | $Z$ (GeV) |
|---|---|---|---|
| 0 | 0 | $80.425 \pm 0.038$ | $91.1876 \pm 0.0021$ |

**Table 24.10**

## Table: Neutrino masses

| $\nu_e$ | $\nu_\mu$ | $\nu_\tau$ |
|---|---|---|
| $\Delta_{12}\, m^2 = (6-9) \cdot 10^{-5}\ \mathrm{eV}^2$ | | |
| $\Delta_{23}\, m^2 = (1-3) \cdot 10^{-3}\ \mathrm{eV}^2$ | | |

**Table 24.11** Solar neutrinos and reactor (SNO, SuperKamiokande, KamLAND) experiments give the first results. Atmospheric neutrino data and the long baseline experiment (SuperKamiokande, K2K) provide the second. The mixing angle relevant to the solar and reactor neutrino oscillation is large, $\tan^2\theta_{12} \sim 0.40^{+0.10}_{-0.07}$, while the one related to the atmospheric neutrino data is maximal, $\sin^2 2\theta_{23} \sim 1$. Cosmological considerations give $\sum m_{\nu_i} < O(1\,\mathrm{eV})$.

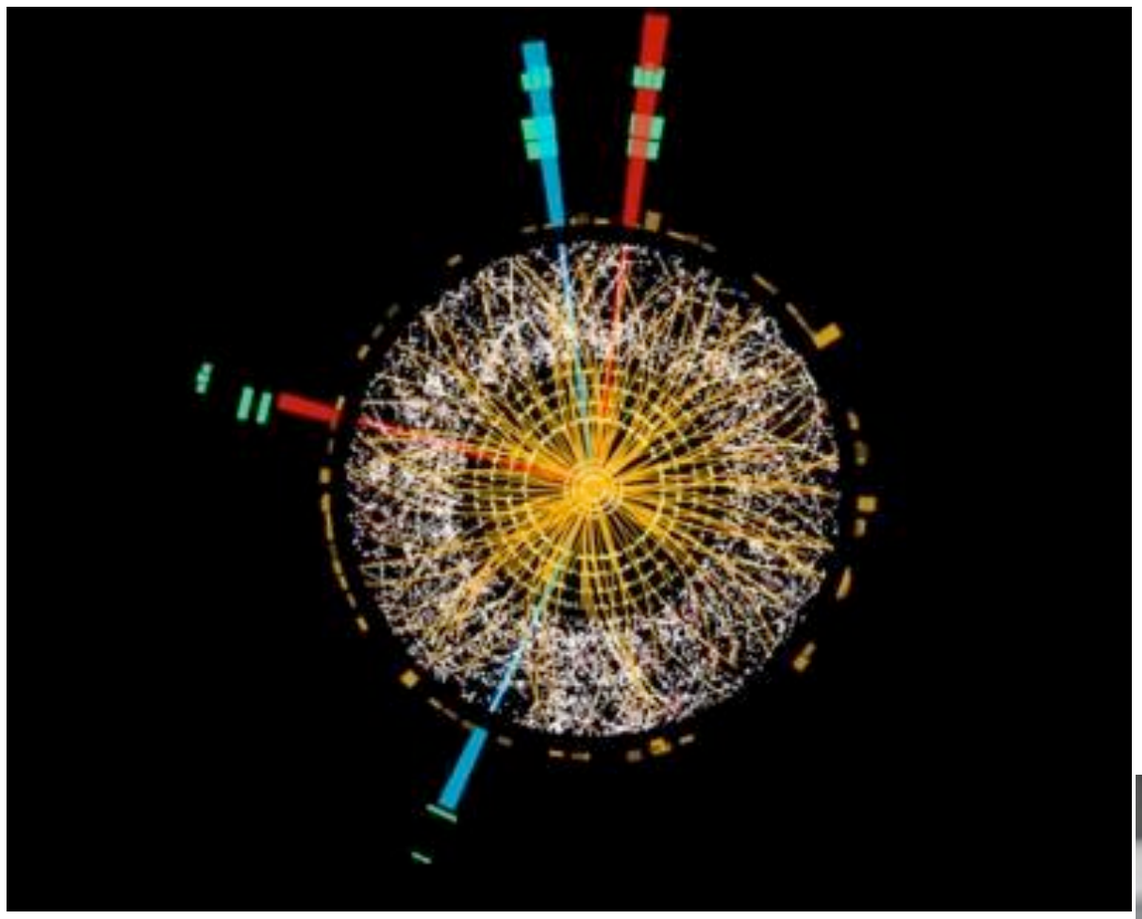
# AND
# Discovery of the Higgs particle
(2012, ATLAS & CMS at LHC, CERN)

**Table: The Higgs boson**

| Higgs (GeV) |
|---|
| 126 |

Table 1:

Peter Higgs and Francoise Englert, Nobel Prize (2013)



7 May 2012 (Atlas)

F. Englert and P. Higgs, CERN July 2013

So:

• Discovery of the Higgs scalar fills in the last missing entity of the elementary particles Table today (the deg. freedom of $SU(3)_{QCD}$ x $(SU(2)xU(1))_{EW}$ theory) and completes our understanding of the fundamental interactions

...., or, does it?

• Neutrino masses require something else ( $\nu_R$ ?)

• Naturalness problem; supersymmetry, compositeness, extra dimensions, ...? No hints so far at LHC

• Have we discovered the first elementary scalar (spin 0) particle in Nature?

• Dark matter require something else

• Understanding of mass ratios require some new principles?

• Dark energy ?

• etc. etc. etc.

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- Three "melodies" of 20th Century Theoretical Physics:

  "Quantization, Symmetries and Phase Factors"  (C.N. Yang 2002)

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Information paradox; black-hole entropy

- New principles? New paradigm? Holographic principles?

Origin of universe?

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- Gravity and quantum mechanics: quantum gravity?
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- New principles? New paradigm? Holographic principles?
- String theory? ( From "Theory of Everything" to "Theory for Everything" ? )

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  Information paradox; black-hole entropy Origin of universe?
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- String theory? ( From "Theory of Everything" to "Theory for Everything" ? )
- Cosmology: accelerating universe,
  dark matter, dark energy

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