# TP - IV

# *Theoretical Particle Physics Laboratory (LPTP)*

*Riccardo Rattazzi*

# Relativity

instantenous action at a distance is not possible

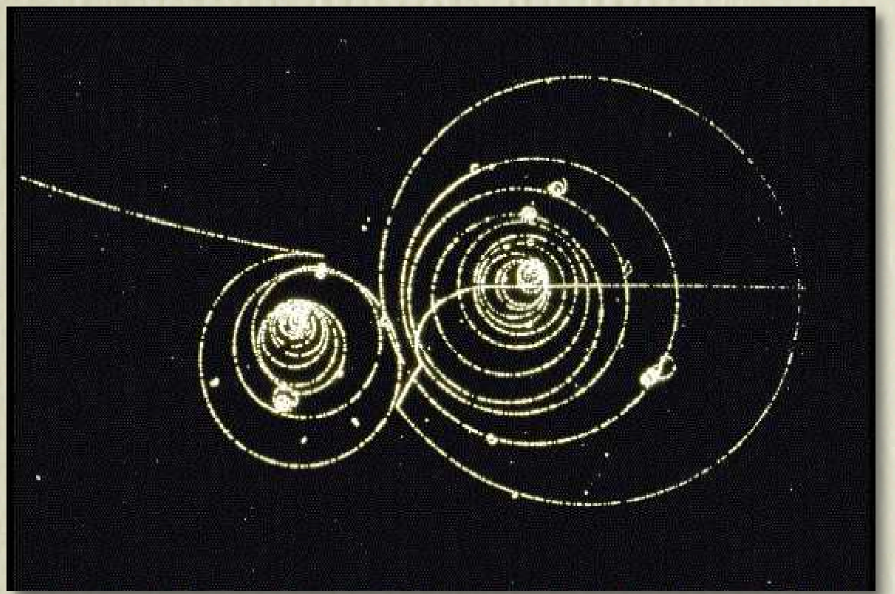
need **fields** permeating all of space

interaction carried by waves in the fields

# Quantum Mechanics

Discrete nature of microworld

wave of smallest intensity: **particle**



Relativity → **Quantum Field Theory** ← Quantum Mechanics

Explanation of existence of matter, forces and their properties

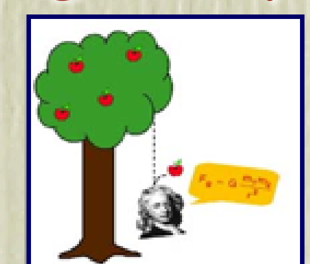
Standard Model: specific QFT describing/explaining *basically* all that we see

EM

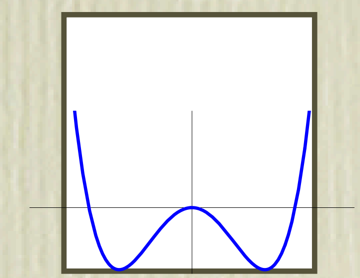
weak


strong


gravity



Higgs



geometric (EM, weak, strong, gravity)

bizarre (Higgs)

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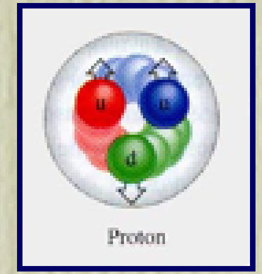
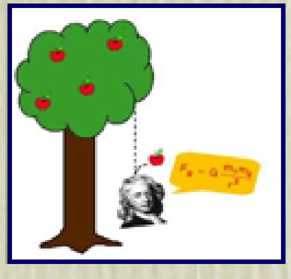



gravity



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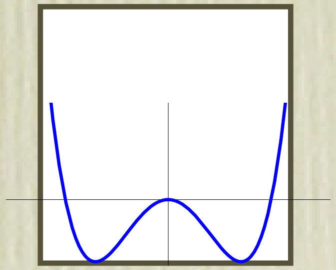


geometric (EM, weak, strong, gravity) — bizarre (Higgs)

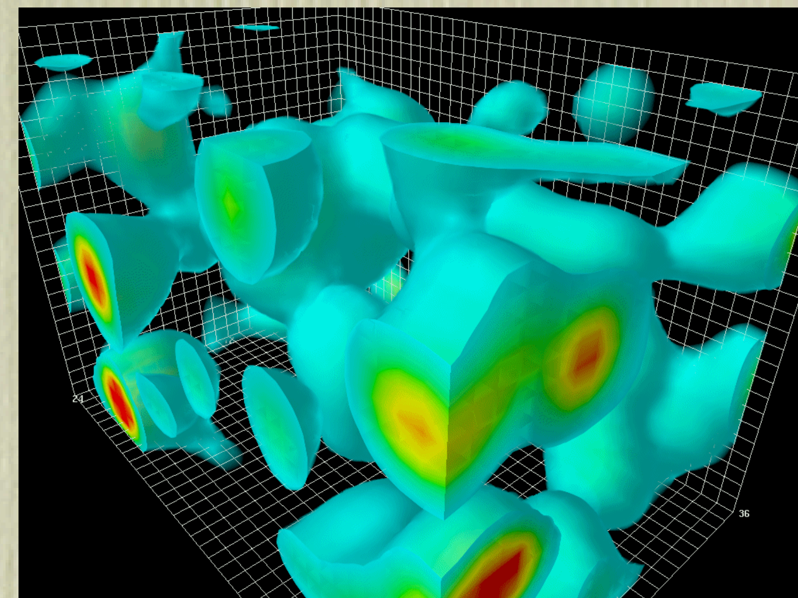
- Most precisely tested theory in science (g-2 of electron, 1ppb)
- Atomic and Nuclear physics “just” complex corollaries of simple principles
- Satisfies all particle physics tests so far

...yet big mysteries persist (and deepened with Higgs discovery)

# The mysteries (some of them)

- The origin of matter/antimatter symmetry in the universe
- What is Dark Matter made up of?
- ....
- ....
- The incredible properties of the vacuum

# Quantum mechanically the vacuum is very active



Higgs force and its boson should plausibly be confined to distances of order $10^{-30}$ cm
***(Hierarchy puzzle)***

The curvature radius of universe should plausibly be less than $10^{-3}$ mm
***(Dark Energy puzzle)***

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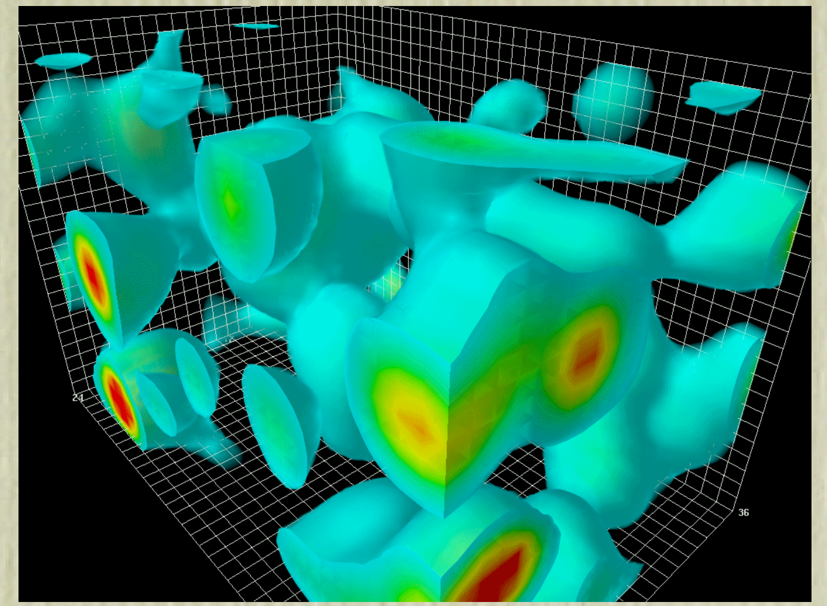

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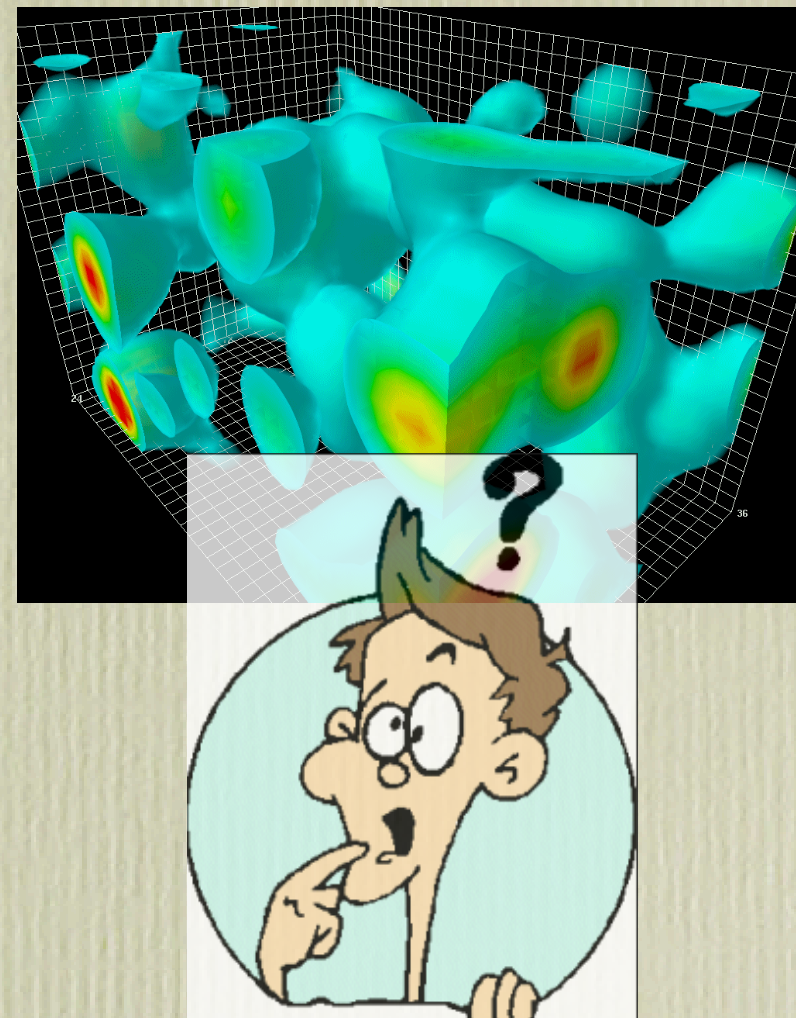

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***(Hierarchy puzzle)***

The curvature radius of universe should plausibly be less than $10^{-3}$ mm

***(Dark Energy puzzle)***

Observation of Higgs boson and extreme smallness of Dark Energy imply two parameters of fundamental physics are somehow tuned to an insane accuracy

# ***WHY?***

Partial answers may come from the explorations of the Fermi scale at the LHC and future machines and from cosmological observations
(is there Supersymmetry? is the Higgs boson an elementary particle?)

Deeper answer will probably only come from a radical reformulation of the basic notions of space-time and quantum mechanics
(string theory?)

There is still a lot to learn (and a lot is being learned lately) on the properties of Quantum Field Theory

see for instance the articles on http://inspirehep.net//

arXiv:1909.01269 arXiv:1902.05936 arXiv:1204.5221

arXiv:0811.2197 arXiv:1501.03845 arXiv:0807.0004

hep-ph/0703164 hep-th/0602178 hep-th/0512260

Master semester I

✦ Symmetry in QM & Particle Physics

*Lie Groups, selection rules, spacetime symmetries...*

✦ A little "project" at the end

*Ex.: Grand Unification, Quark Model, Supersymmetry, ...*

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Master semester II

✦ Quantum Field Theory at work

*S-matrix and Feynman diagrams, Path Integral, ...*

✦ A less little "project" at the end

*Ex:. Standard Model and open problems,*
*conformal field theory, ... , some crazy stuff*

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Master semester III

✦ Courses

- *Gauge Theories and the Standard Model*
- *Advanced Quantum Field Theory*
- *Conformal Field Theory and Gravity*

✦ Preparation to Master Project

# Prerequisites

## Necessary

- Quantum Fields I & II
- Relativity and Cosmology I & II
- Quantum Mechanics III and IV

## Recommended

- Statistical Physics III and Solid State III

# Rules (normally)

## semester I: up to 3 people are accepted.

Goal: to acquire the methodology (computations!!!) and the physical intuition to formulate and solve problems in theoretical physics. Study on books. Lots of exercises. Communal discussions in weekly meetings. Short seminar and brief written report at the end.

## semester II

Same as semester 7, but with more substantial individual project towards the end of the semester. Study also on scientific articles. Short seminar and written report at the end.

## semester III:

3 advanced courses.
Preparation to master project by studying a subject on scientific articles

## semester IV

Master project

# The group (next fall)

- Riccardo Rattazzi, professor, Scuola Normale Sup., Pisa, 1990
- Andrea Wulzer, CERN/EPFL professor, PhD S.I.S.S.A., 2005
- Matt Walters, postdoc, PhD Johns Hopkins University, 2014
- Angelo Esposito, postdoc, PhD Columbia University, 2018
- Siyu Chen (PhD 2022), Lorenzo Ricci (PhD 2022)
  Gil Badel (PhD 2022), Alfredo Glioti (PhD 2021)

## Recent PhD students

- Jan Mrazek, thesis 2011: high school teacher, Lausanne
- Alessandro Vichi, thesis 2011: Berkeley U., CERN, SNF/EPFL and Pisa University (professor)
- Duccio Pappadopulo, thesis 2012: Berkeley U., New York U., Bloomberg LP NY
- Andrea Thamm, thesis 2014: Mainz U., CERN, University of Melbourne (professor)
- Lorenzo Vitale, thesis 2016: Boston University, G-research London
- Davide Greco, thesis 2017: Credit Suisse, Zurich
- Gabriel Cuomo, thesis 2020: Simons Center for Geometry and Physics, Stony Brook, NY

EPFL
master students

- 2008/09 : Diego Becciolini (Southampton, PhD), Gregoire Gallet, Valentin Hirschi (EPFL, PhD)
- 2009/10 : Pascal Borel, David Pfefferlé (EPFL, PhD)
- 20010/11: Damien Favre
- 20011/12: Johnny Espin (Nottingham, PhD), Sacha Jorg
- 2012/13 : Fabrizio Rompineve (Heidelberg PhD), Max Carrel, Thibaud Vantalon (Hamburg PhD), Florent Baume (Heidelberg PhD)
- 2013/14 : Luca Delacretaz (Stanford PhD)
- 2014/15 : Sebastian Bruggisser (Hamburg PhD), Michele Oliosi (Kyoto, PhD), Tony Mercuri, Emil Rotilio, Simon Loewe (Cornell PhD)
- 2015/16: Olivier Simon, Fiona Seibold (ETH, PhD), Virgile Lahu
- 2016/17: Giulia Albonico (Oxford), Gil Badel (EPFL), Laetitia Laub (Bern)
- 2017/18: Romain Soguel (Jena), Jann Zosso (ETH)
- 2018/19 Emma Geoffray (Heidelberg), Stephane Bajeot (SISSA), Aurelien Dersy (Harvard)
- 2019/20 Florian Rouge, Alexandre Farquet