

**TP - IV**

***Theoretical Particle Physics  
Laboratory  
(LPTP)***

***Riccardo Rattazzi***

# Relativity

instantaneous action at a distance is not possible

need **fields** permeating all of space

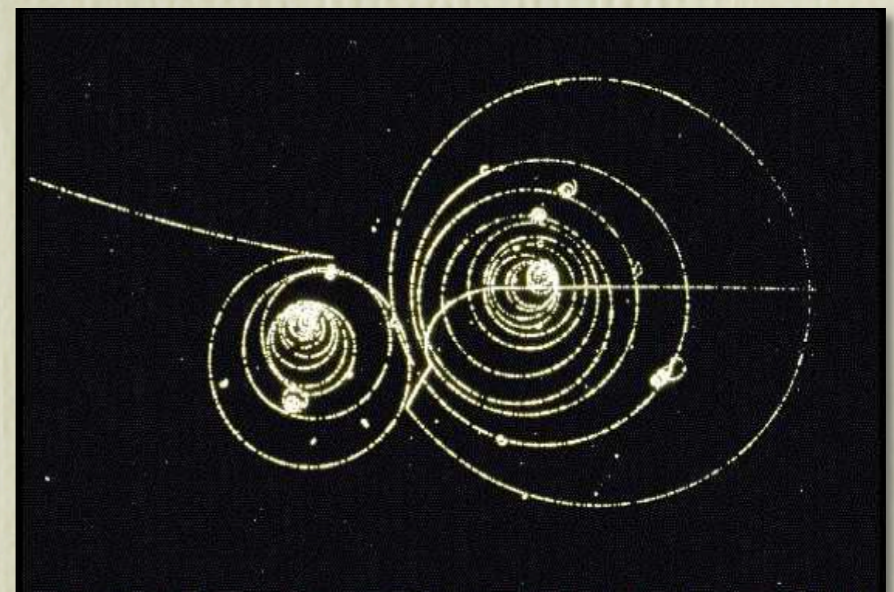
interaction carried by waves in the fields



# Quantum Mechanics

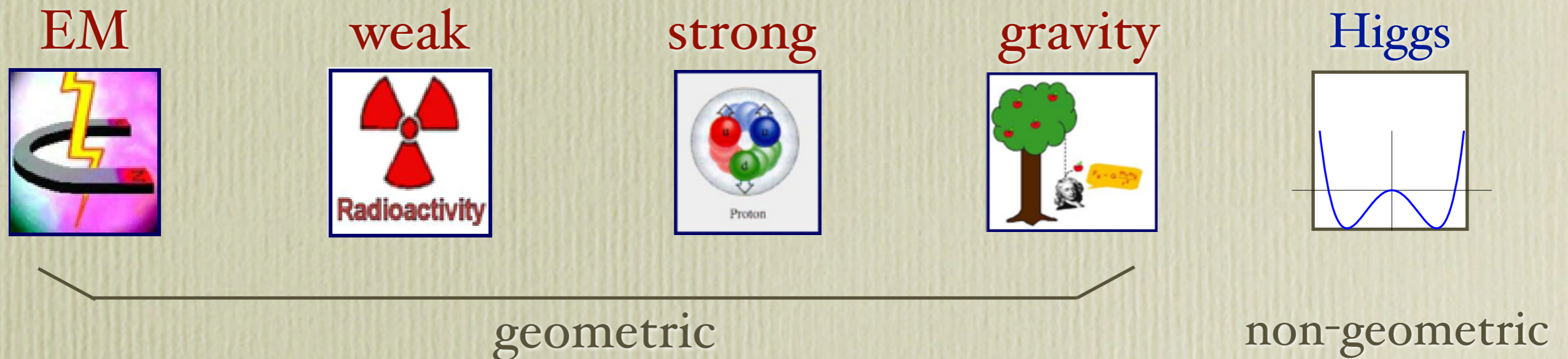
Discrete nature of microworld

wave of smallest intensity:  
**particle**





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

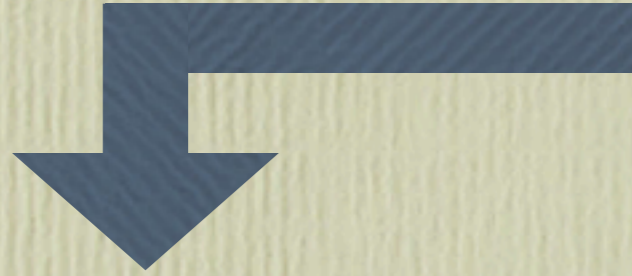


- Most precisely tested theory in science (electron gyromagnetic ratio, 1ppb)
- Atomic and Nuclear physics “just” complex corollaries of simple principles  
 ...yet big mysteries persist (and deepened with Higgs discovery)

# The mysteries (some of them)

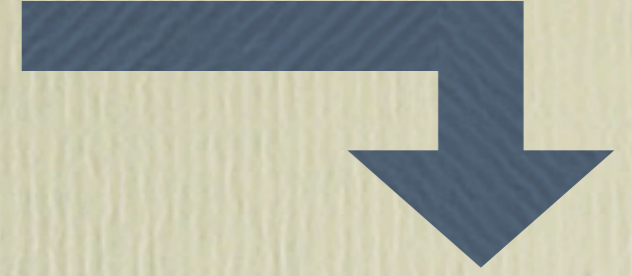
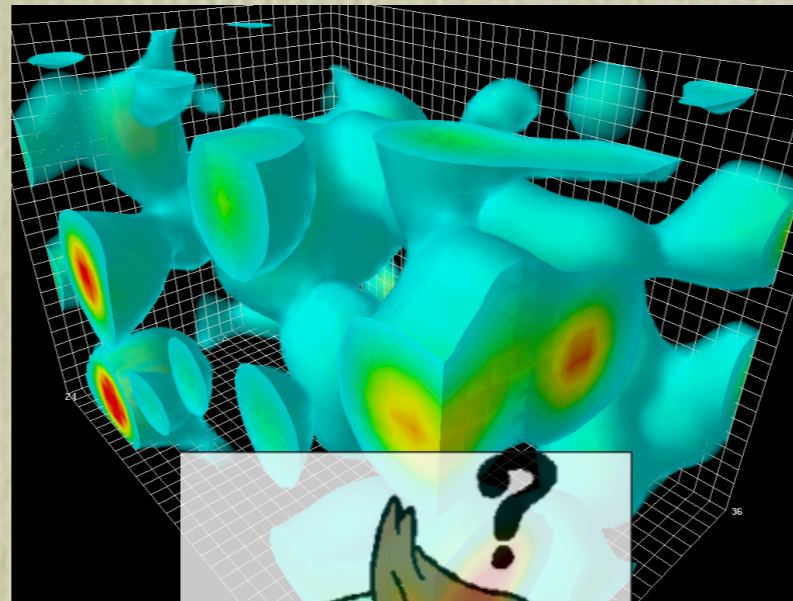
- The origin of matter/antimatter symmetry in the universe
- What is Dark Matter made up of?
- ....
- ....
- The incredible properties of the vacuum

Quantum mechanically the vacuum is very active



Higgs force  
range less than  
 $10^{-30}$  cm

*(Hierarchy puzzle)*



Universe's "size"  
less than  
 $10^{-4}$  cm

*(Dark Energy puzzle)*

...well, unless some fundamental parameters are tuned  
to an insane accuracy

***What are we missing?***

Partial answers may come from the explorations of the Fermi scale at the LHC and future machines and from cosmological observations

Deeper answer will probably only come from a radical reformulation of basic principles

There is still a lot to learn on Quantum Field Theory

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

[arXiv:2011.00037](http://arxiv.org/abs/2011.00037)

[arXiv:0811.2197](http://arxiv.org/abs/0811.2197)

[hep-ph/0703164](http://hep-ph/0703164)

[arXiv:1909.01269](http://arxiv.org/abs/1909.01269)

[arXiv:1501.03845](http://arxiv.org/abs/1501.03845)

[hep-th/0602178](http://hep-th/0602178)

[arXiv:1204.5221](http://arxiv.org/abs/1204.5221)

[arXiv:1902.05936](http://arxiv.org/abs/1902.05936)

[arXiv:0807.0004](http://arxiv.org/abs/0807.0004)

[hep-th/0512260](http://hep-th/0512260)

- ◆ Symmetry in QM & Particle Physics  
*Lie Groups, selection rules, spacetime symmetries...*

M-I

- ◆ A little “project” at the end  
*Ex.: Grand Unification, Quark Model, Supersymmetry, ...*
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- ◆ Quantum Field Theory at work  
*S-matrix and Feynman diagrams, Fundamental processes, ...*

M-II

- ◆ A less little “project” at the end  
*Ex.: Standard Model and open problems*
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- ◆ Courses
  - *Gauge Theories and the Standard Model*
  - *Advanced Quantum Field Theory*
  - *Conformal Field Theory and Gravity*

M-III

- ◆ Preparation to Master Project

# Prerequisites

## **Necessary**

- Quantum Field Theory I & II
- Relativity and Cosmology I & II
- Quantum Mechanics III and IV

## **Suggested**

- Statistical Physics III
- Solid State III



# The group next fall

- Riccardo Rattazzi, professor, Scuola Normale Sup., Pisa, 1990
- Tim Cohen, CERN/EPFL professor, PhD University of Michigan, 2011
- Brian Henning, postdoc, PhD Berkeley University, 2015
- Majid Ekhterachian, postdoc, PhD University of Maryland 2021
- Stefan Stelzl, PhD Technical University Munich, 2022
- Eren Firat (PhD 2025)
- Filippo Nardi (PhD 2025)