

Fundamental interactions

Course information

M. Sozzi

Dipartimento di Fisica – Università di Pisa



UNIVERSITÀ DI PISA

M.Sozzi - Fundamental Interactions - Università di Pisa



Dipartimento di Fisica "E. Fermi"
UNIVERSITÀ DI PISA

Generalities

Duration:

9 CFU (about 54h of class lectures), first semester

Language:

The course is in English. If all students so desire, lectures can be in Italian.
All the course material is in English.

Contact:

Main instructor: Prof. Marco Sozzi (marco.sozzi@unipi.it)

Information:

e-learning platform (<https://elearning.df.unipi.it/course/view.php?id=312>)

You are supposed to signup there: all information, news and announcements will be channeled through that (check your email account!)

Course topics

This course is mandatory for the curriculum of "Physics of Fundamental Interactions"

The goal is to allow a basic quantitative understanding of the the physics of elementary particles and of their interactions, from the phenomenological and experimental point of view, including the ability to estimate *qualitatively and quantitatively* processes and experiments.

It tries to cover (almost) **all topics** at a **basic level**, to provide students a wide understanding of the field and its language.

Other courses go in more detail on some of the topics.

Must learn how to apply your knowledge to real problems and obtain numerical answers.
You should work out completely the examples and problems in the course and in books!

Relation to other courses

Assume bachelor degree completed

No previous knowledge of particle physics is assumed

Essential pre-requisites: quantum mechanics, modern physics ("Fisica 3")

Important for a deeper understanding: quantum field theory ("Fisica teorica 1")

Further learning:

General: particle physics, astroparticle physics, fundamental interactions laboratory

Methods: analisi statistica dei dati, computing methods for experimental physics and data analysis, instrumentation for fundamental interactions physics

Specific topics: simmetrie discrete, recent highlights in fundamental interactions, fisica delle onde gravitazionali, fisica ai collisionatori adronici, fisica dei neutrini

Links to all courses and presentation of the different curricula:

<https://www.df.unipi.it/didattica/laurea-magistrale/presentazione/>

Tools

Several formal tools are required for computations or to solve problems. The course focus is phenomenological and experimental, but such tools must be known.

- **Fisica teorica 1** provides most of the formal justification for the computations: since most students follow the two courses at the same time, we'll introduce some ideas
 - in an euristic way (with limited formal derivation) or in alternative ways, and
 - stress the fundamental concepts to help understanding their deeper meaning and you may catch up on the formal side when things are discussed there.
- **Relativistic kinematics** is one topic you've seen multiple times and you think you know well: evidence shows this is often not the case, and exams are failed on this: you don't really know something if you cannot apply it on a real problem.
- A minimum of **group theory** will be introduced here (but the theory of angular momentum in QM must be known).

Overlaps

Several topics are discussed in different courses with

- different level of depth
- different mathematical tools
- different emphasis or perspectives

e.g. Introduzione alla fisica subnucleare (bachelor degree), Fundamental Interactions, Particle Physics, Fisica Teorica, etc...

We'll try to minimize repetitions of specific topics, but

"You don't understand anything until you learn it more than one way"
(Marvin Minsky)

Lectures

Lectures are in presence only, you are warmly invited to attend.

The available lecture slots for AA 2026/27 are:

Monday: 10.30 – 13.30 Room G1

Tuesday: 10.30 – 13.30 Room A1

We won't use *all* such slots: trying to reduce the load by having 2h lectures when possible

All information on the detailed calendar will be on the e-learning site and might change

We will agree on exact starting/end time and pauses during long lectures

Some lectures with exercises by Prof. Francesco Forti (francesco.forti@unipi.it)

No fixed time slots for lectures and exercises

Will sometimes provide homework problem assignments

Lectures content

Class lectures are not meant to be a recitation of textbook material but rather to provide additional insight, explanation, comment and supplement, thus

The material provided is only intended as a guide and supplement on the discussed topics:

- It is not the main study material
- Student are supposed to use (at least one of) the suggested books

We'll try to reduce the amount of straightforward algebra (most easily followed from textbooks) in the lectures, but rather stress the important assumptions, concepts and conclusions, to help students focus on the ideas and path, and avoid losing the forest for the trees by getting lost in formal aspects. Still, derivations must be fully understood.

Exams

Exam sessions follow the standard pattern:

one session in each of: June – July – September – January – February

Sessions for working students to be requested

Other specific needs can be considered

In case of impediments on specific dates (*i.e.* other exams) inform the instructor early enough

The exam consists in a **written entry test** in presence,

followed by an **oral discussion**, usually on the same or next day

Questions and exercises are on all topics discussed (check the course program!)

If the result of the test is at least "sufficient" you can take the oral exam, but a low grade in the test often correlates to the final grade

A self-evaluation test (not relevant for final evaluation) might be foreseen

Material

Lectures are based on hand-written notes on electronic whiteboard

Some lectures are accompanied by slides

Both will be made available to students on the e-learning site soon after the lecture and are not for redistribution

There will be no "text-book-like" course notes: all topics are treated on so many excellent books, and students are assumed to be mature enough to use published material

Some original articles will be available for gaining some further historical insight (copyrighted material for self-study, do not share) [not required for the exam]

Problems from past exams are also available online

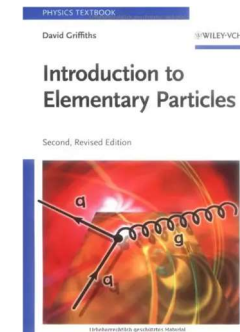
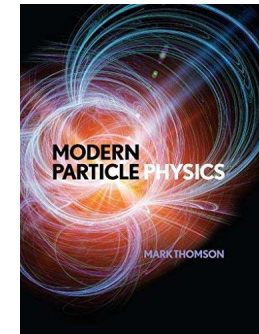
Material from previous years' courses is also available

Bibliography

Many excellent books exist on particle physics

A couple of recommended ones:

- Thomson, *Modern Particle Physics*, Cambridge UP [part of it]
- Griffiths, *Introduction to Elementary Particles*, Wiley



Some other good ones at the level of this course:

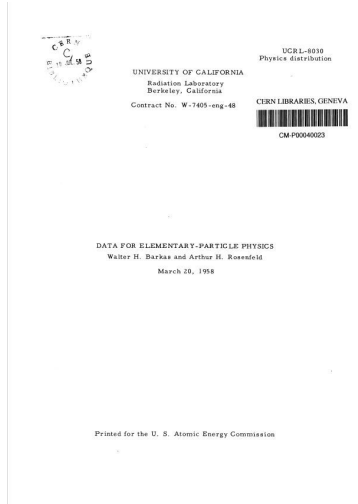
- Barr et al., *Particle physics in the LHC era*, Oxford UP
- Martin, Shaw, *Particle physics*, Wiley

And a special one:

- Cahn, Goldhaber, *The experimental foundations of particle physics*, Cambridge UP

Several more books can be suggested when needed or on request

The RPP



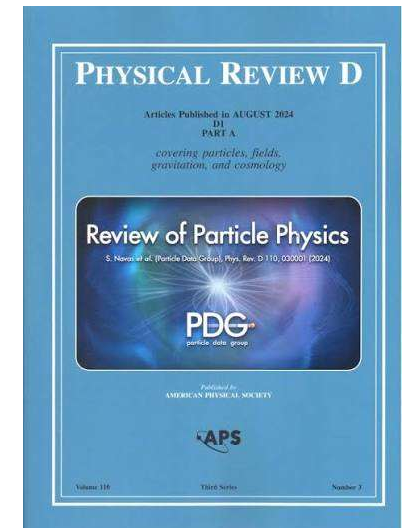
1958: W. Barkas and A. Rosenfeld publish a 20-page report "Data for elementary-particle physics at the University of California Radiation Laboratory

Birth of the "Rosenfeld tables" and wallet cards compiled at the Lawrence Berkeley Laboratory



Arthur Rosenfeld
(1926-2017)

The Review of Particle Properties is published bi-annually by the Particle Data Group, a collaboration of 250 people, is now a 1300-page book which references 14681 articles also available online (<https://pdg.lbl.gov>). It is the authoritative source of information and contains 118 (tough but complete) reviews on several topics



A few warm suggestions

Avoid the standard student errors:

- being satisfied with muddled half-comprehension
- believing something is already well known
- forgetting past topics from earlier courses
- copying homework or relying on AI
- not going through to the end of a problem, not reaching the numerical result
- not attending classes
- not keeping up to pace and failing to follow lectures
- being fearful of asking questions
- being shy about getting teacher's help

A few general considerations on the teaching approach

A simplified view of (particle) physics

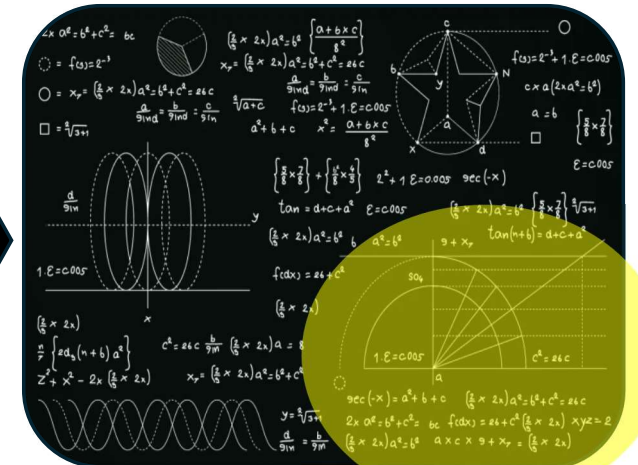
NATURE



MEASUREMENTS



MODELS

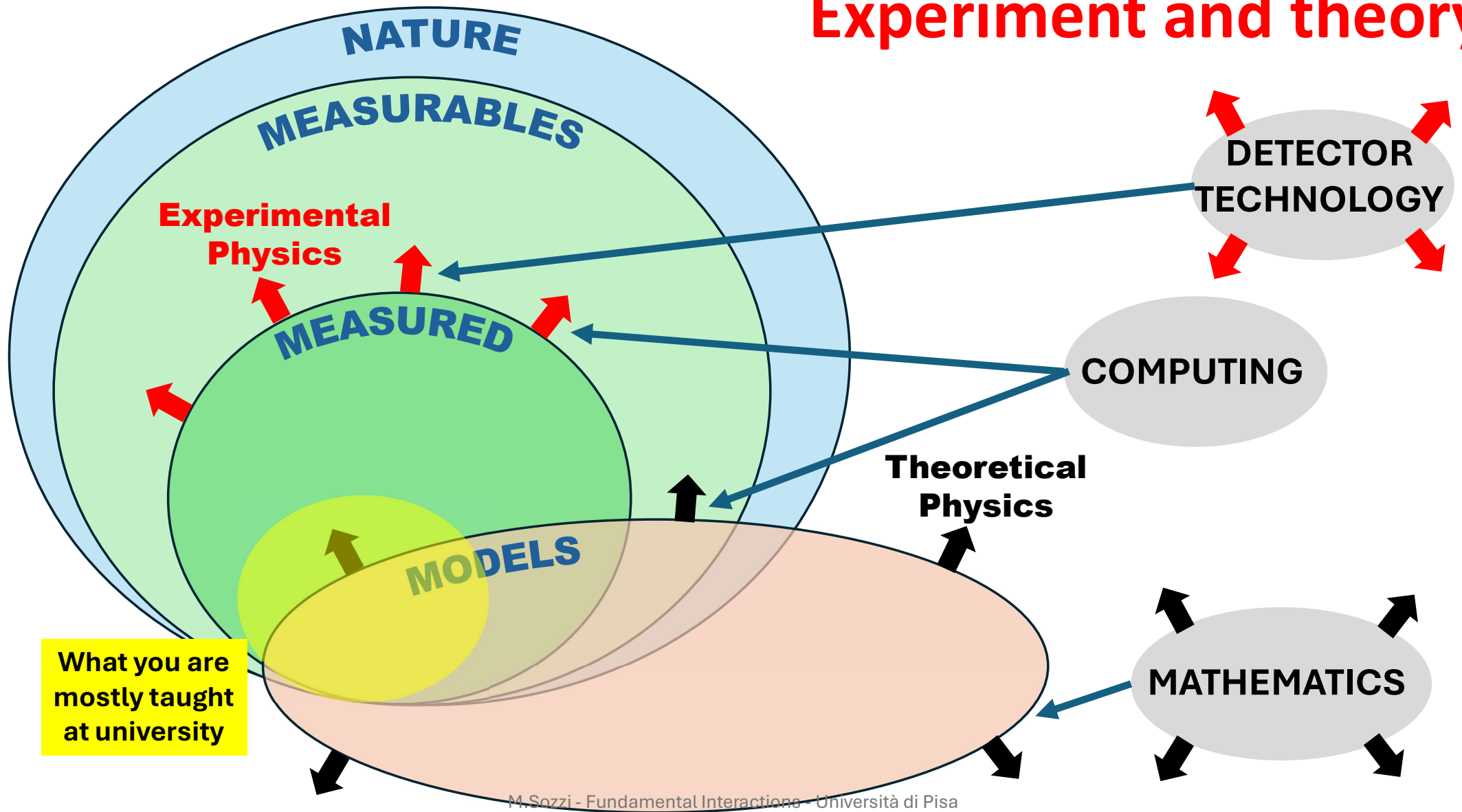


**Experimental
Physics**

**Theoretical
Physics**

**What you are
mostly taught
at university**

Experiment and theory



The lessons of history

A historical approach to the discoveries is relevant for different reasons:

- it illustrates how science progresses (a history of trial and error, and frequent mistakes)
- it provides a hint of how to do science (which is almost never taught)
- it is required for understanding why things were done as they were (needed for research)
- it allows to appreciate the empirical nature of physics, and the deep intellectual content of experimental physics (which students are rarely allowed to appreciate)

But such approach might be overwhelming for students learning a new subject the first time

- ingenuity can often be appreciated only in relation to the current understanding and current technology, which changes with time
- delving into wrong ideas and concepts might confuse students and take too much time

We'll not provide a true historical account in this course, but still discuss in some detail a few crucial experiments to give a feeling of the above

But...

Be aware that, overall, you'll usually continue to be fed the WRONG impression that

- most of the intellectual content of physics lies in some nice and satisfactory mathematical derivation, usually the only surviving one among many wrong ones
- great ideas come "out of the blue" by somebody thinking hard (it did happen, but very rarely and not in a vacuum)
- measurement is more or less a trivial "practical" thing (it's not: successful experiment design is one of the most challenging endeavours, and requires a deep understanding of very many parts of physics)

Some medicine for that:

- Cahn, Goldhaber - The experimental foundations of particle physics - Cambridge UP (online at <https://archive.org/details/CahnGoldhaberExperimentalFoundationsOfParticlePhysics>)
- Telegdi - Mind over matter - CERN lecture (online on the course pages)