Theoretical particle physics at UZH

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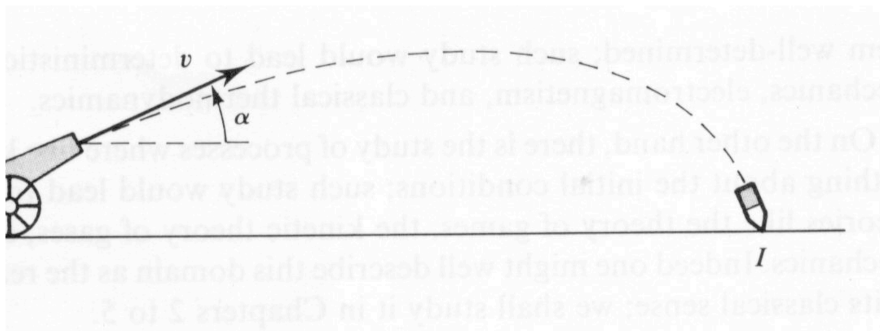
Introduction

Classical mechanics



drives our everyday life in the macroscopic world:
- space and time are absolute
- material bodies have motion and trajectories uniquely determined by external agents (forces) and initial conditions

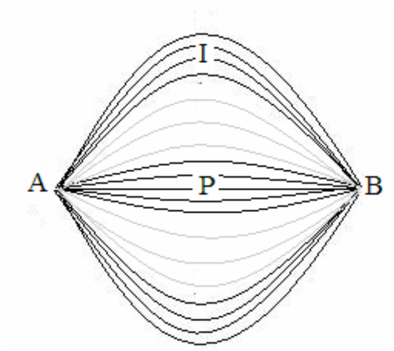
Electromagnetism

electromagnetic phenomena described by Maxwell equations: electromagnet waves

They are just approximations !

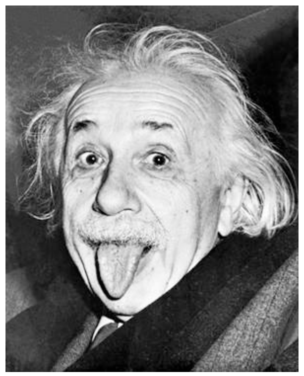
Introduction

Quantum mechanics



The deterministic laws of classical mechanics are not valid in the subatomic world:
- loss of the concept of trajectory
- all trajectories contribute to the quantum amplitude
- uncertainty principle

Theory of relativity

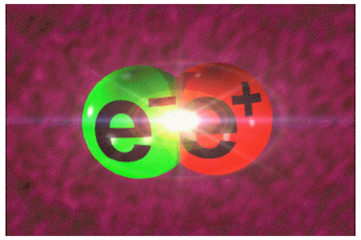


The laws of classical mechanics hold only for speeds much smaller than the speed of light
- space and time are not absolute
- speed of light is the maximum

....

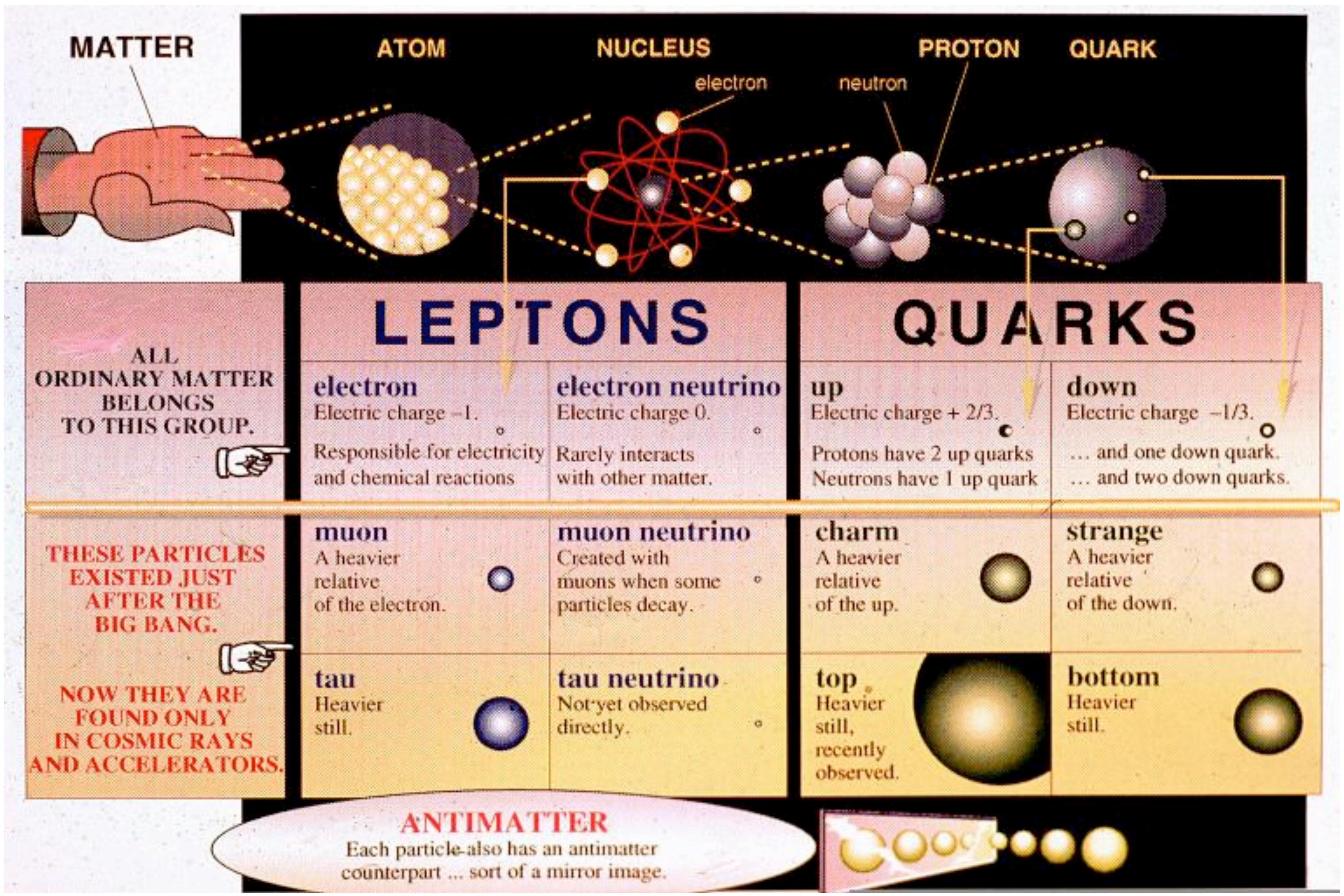
Quantum field theory

Foundation of the theory of elementary particles:
indestructible particles replaced by quantum fields
implies the existence of antiparticles



The Standard Model

The theory that successfully describes elementary particles and their interactions over a huge range of scales



+ mediators of strong and electroweak forces

massless gluons and photon

heavy W and Z bosons

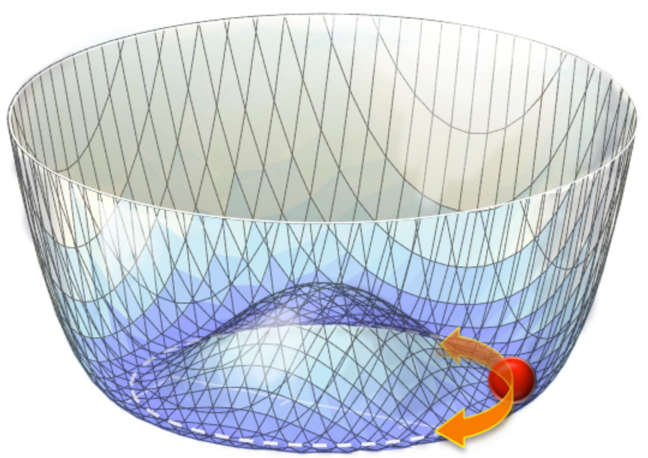
Symmetry breaking

The theory we have outlined is based on specific symmetry principles and requires all particles to be massless

Why are the W and Z bosons so heavy while the photon and the gluon are massless ?

→ **Higgs hypothesis**

The beautiful symmetries of the theory are preserved but they are broken by the vacuum

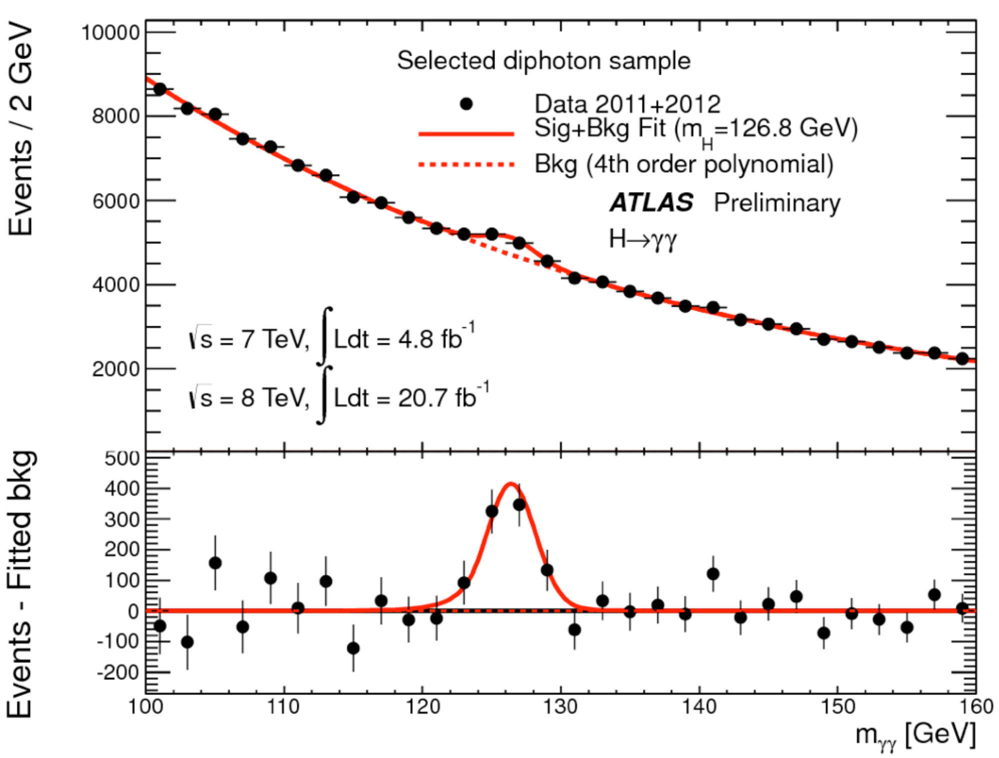


The proposed implementation requires a new particle: Higgs boson

What is the Higgs boson ?

- It was the missing piece in our current understanding of the physics of the subatomic world

- It explains the origin of mass

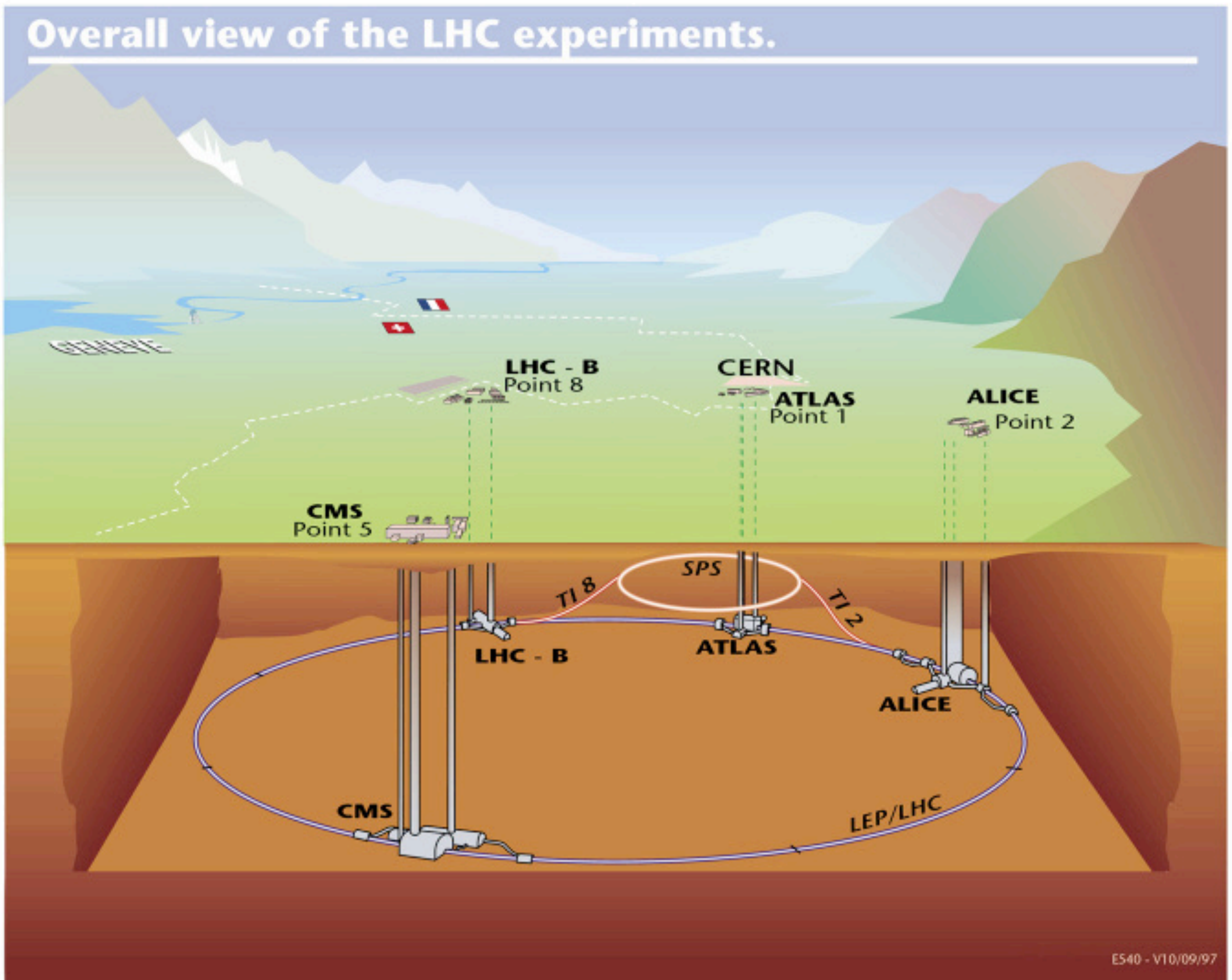


It appears as a (small) peak in certain event distributions

Nobel prize in physics 2013 !

The Large Hadron Collider (LHC)

LHC is a proton-proton collider operating at energies never reached before: very successful runs at 7, 8 and 13 TeV (billions of eV !)



Built in a 27 km tunnel outside Geneva at the border between France and Switzerland: replaced LEP

Largest and most complex instrument ever built

Power consumption: 120 MW

How many events ?

The number of Higgs events to be expected is given by the number of collisions multiplied by the production probability

LHC experimentalists tell us the number of collisions

Theorists try to compute the production probability as precisely as possible

Crucial to measure the Higgs properties

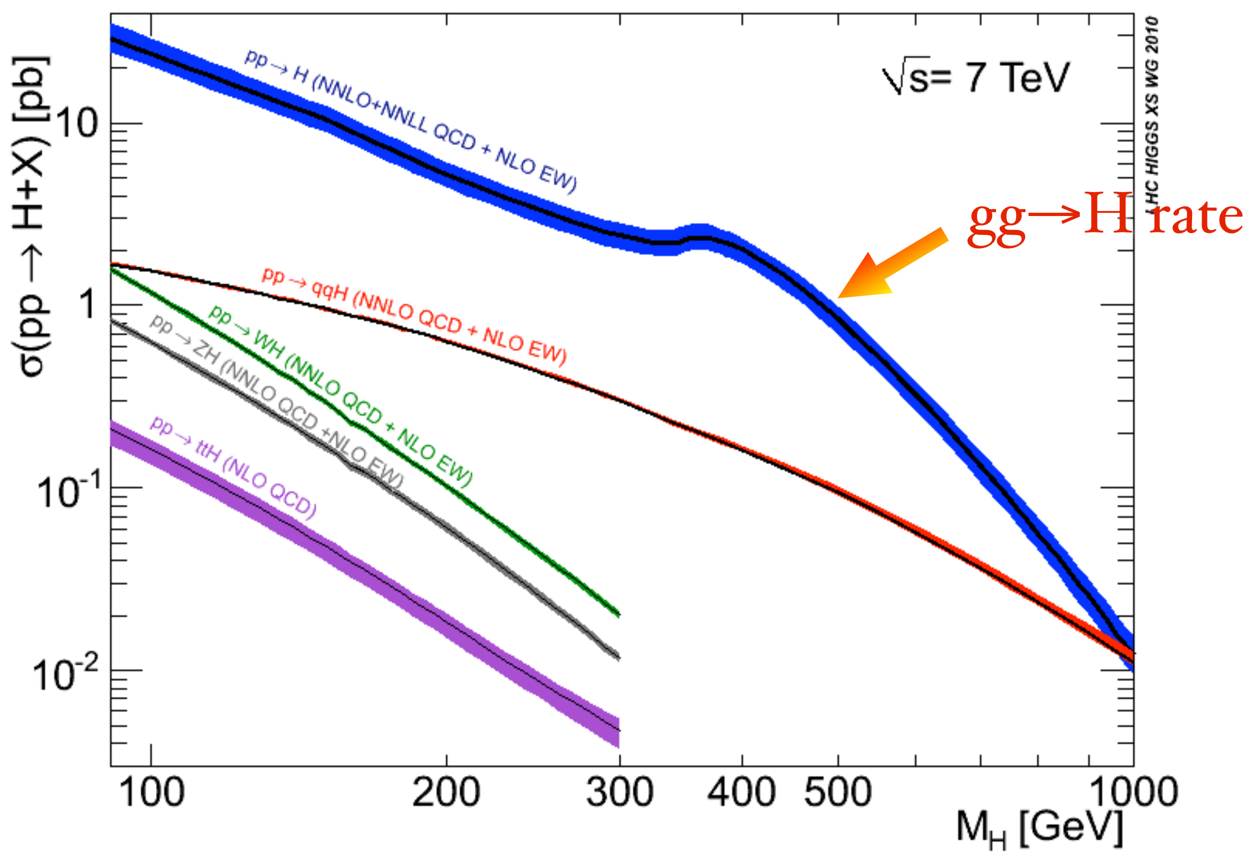
Gehrmann, Grazzini, Pozzorini

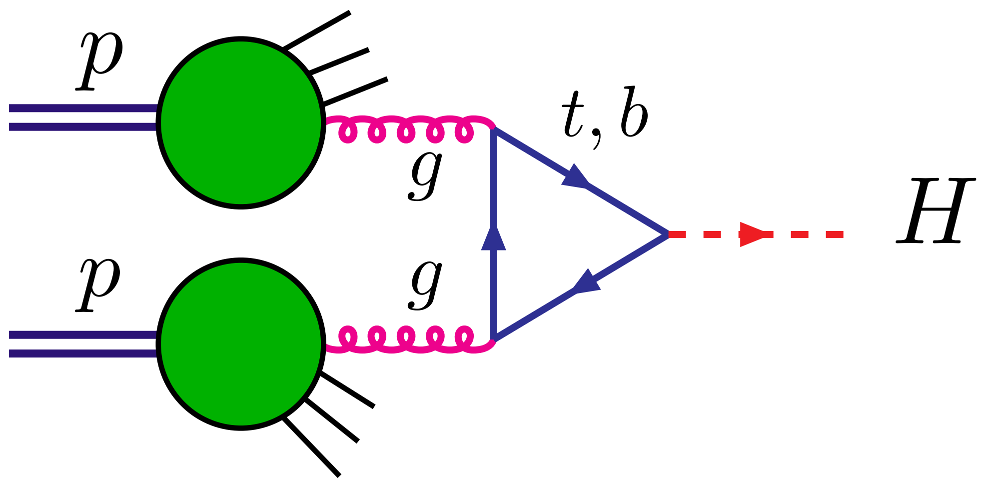
How many events ?

According to the quantum theory Production probability = | Amplitude | ^{2}

All contributing processes must be considered

Main production mechanism is gluon fusion through a heavy quark loop



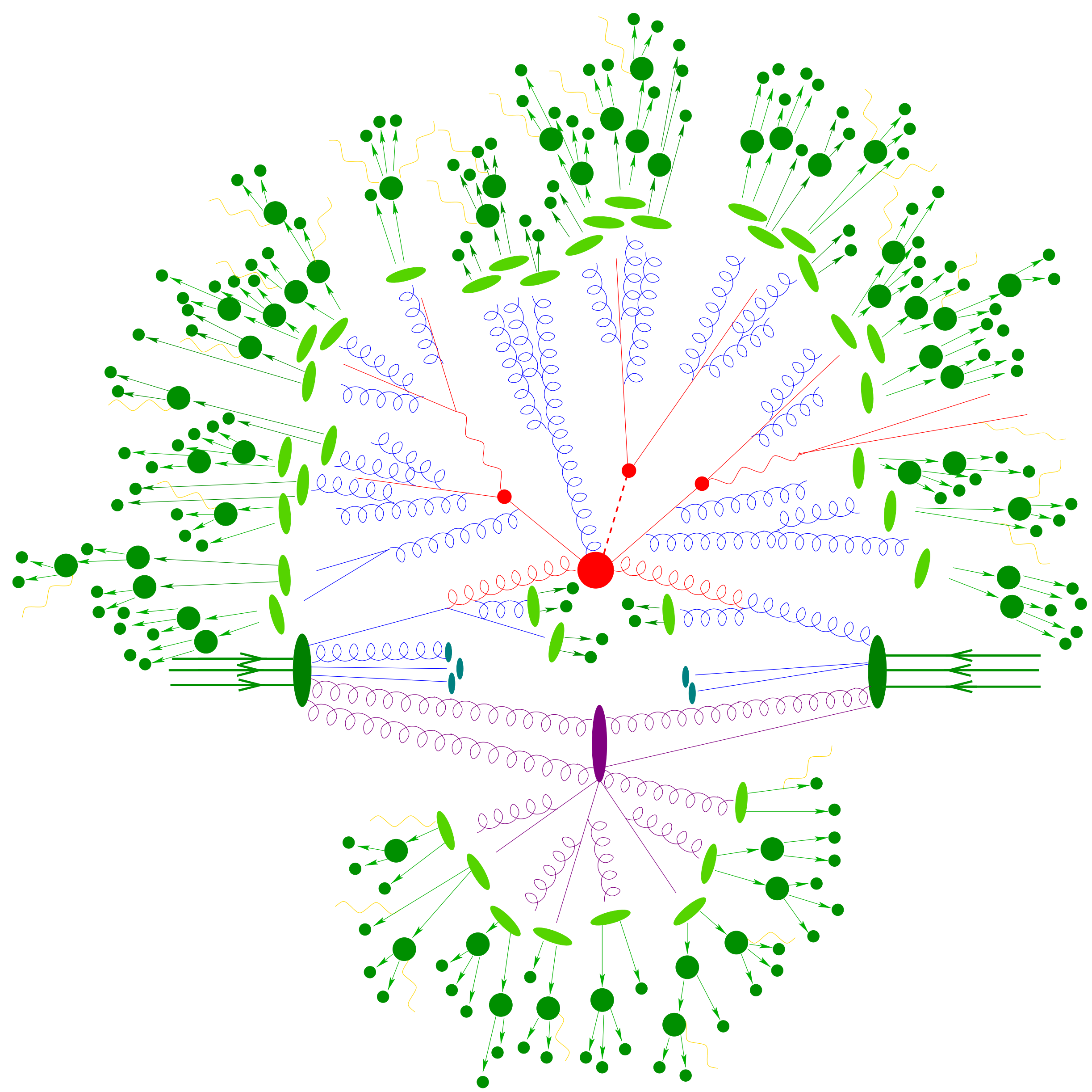


Theoretical prediction used by experiments are based on sophisticated computations

Gehrmann, Grazzini, Pozzorini

Numerical simulations

Computations implemented in numerical tools that simulate the real events observed by the experiments

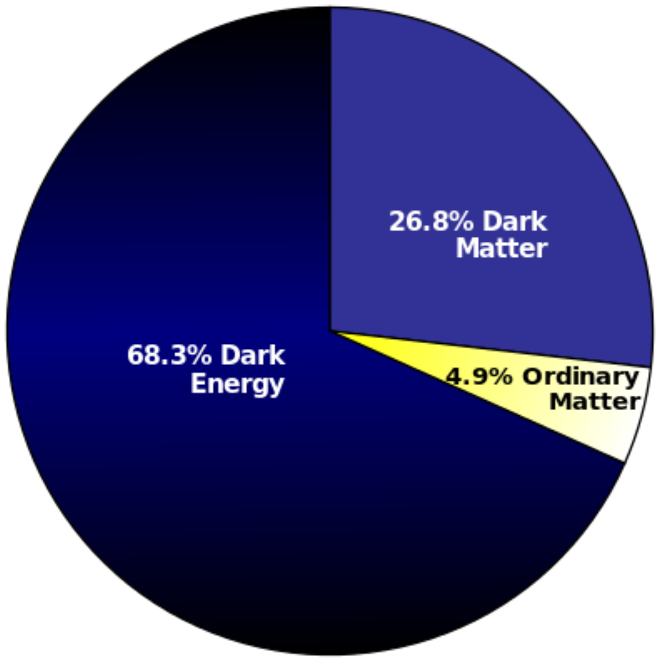


Gehrmann, Grazzini, Pozzorini

Beyond the Standard Model

Despite its success the Standard Model cannot be the ultimate theory of nature

- It does not describe the gravitational interactions



- It does not have a dark-matter candidate

- It does not explain the huge hierarchy between the electroweak scale (~ 100 GeV) and the Planck scale (~10^{19} GeV) at which gravity ultimately becomes relevant

How can we go beyond ?

Beyond the Standard Model

Three main strategies:

1) Construct an explicit theory beyond the Standard Model

Standard Model → Enlarge the symmetry group and add new matter content → Compare to experimental data

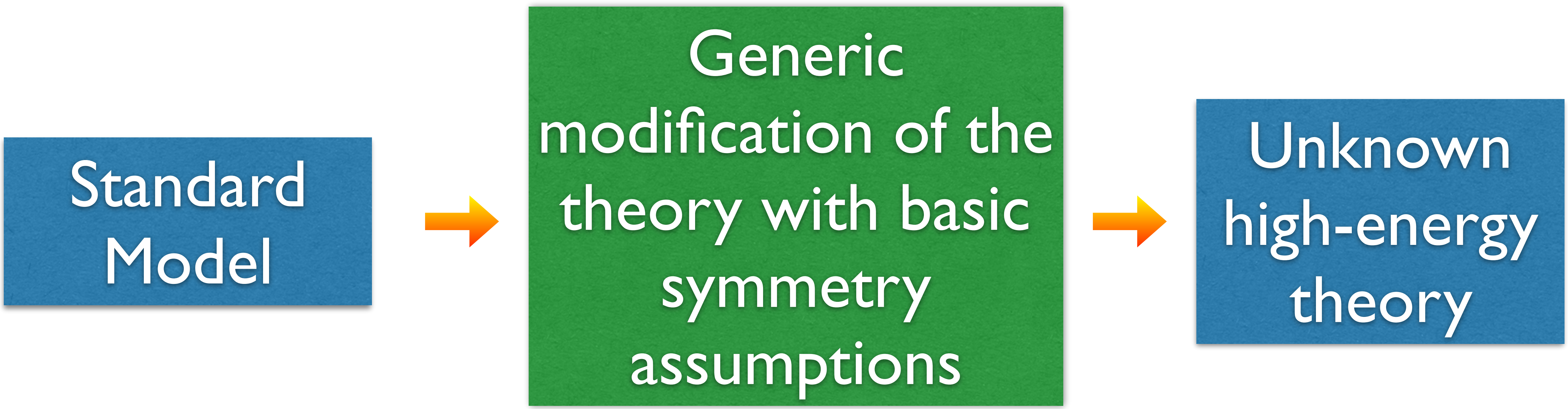
Here we must check whether the theory is consistent with the tight constraint from the experimental data

Isidori

Beyond the Standard Model

Three main strategies:

2) Effective field theories



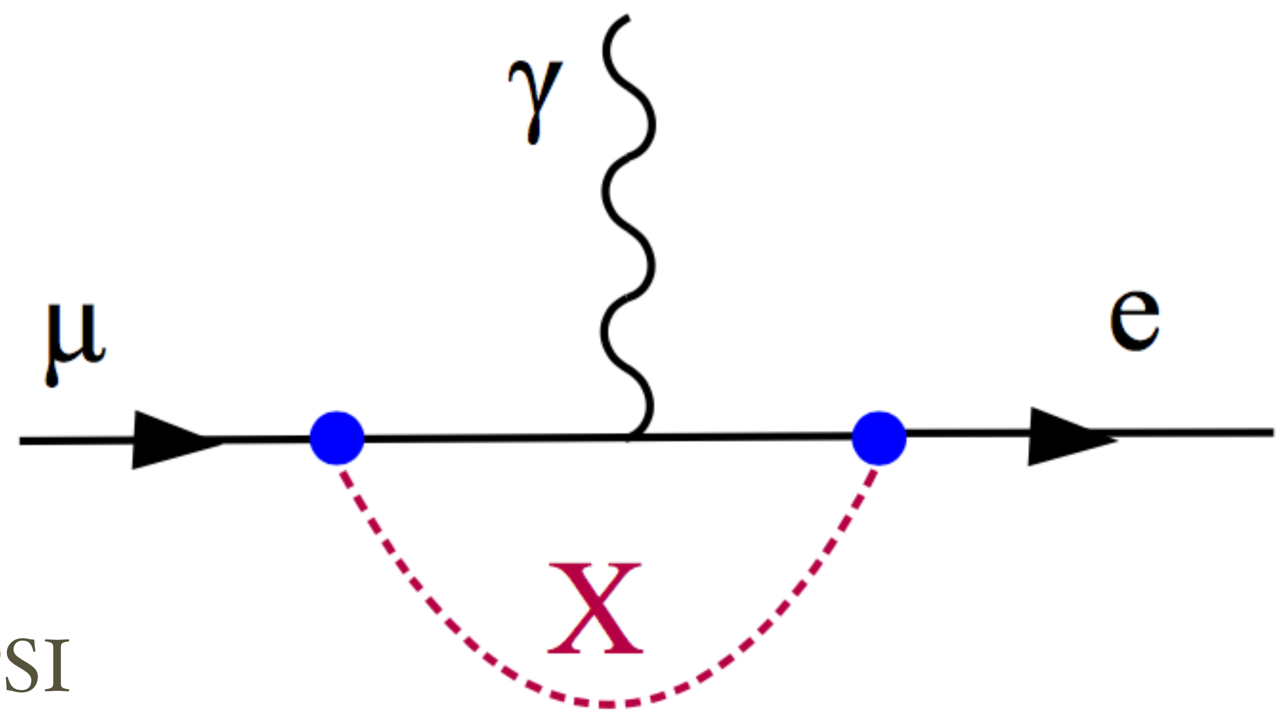
Typically formulated as an expansion in E/Λ, where E is the energy at which the modified theory is formulated and Λ is the new physics scale

Grazzini, Isidori, Signer

Beyond the Standard Model

Three main strategies:

3) Study of rare low-energy processes



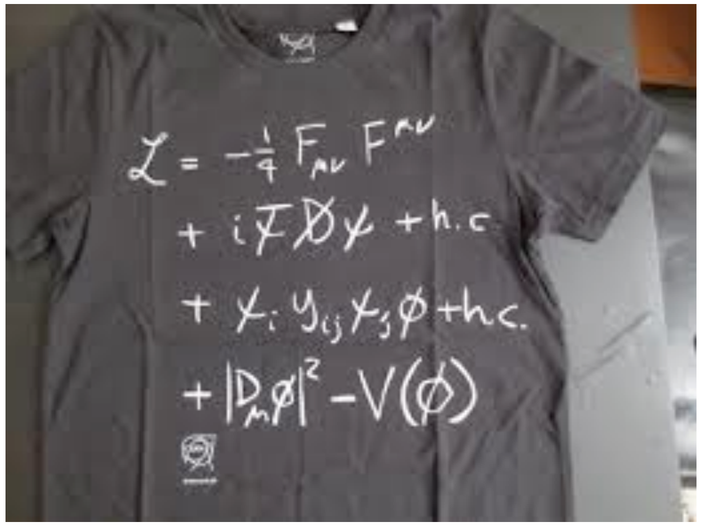
Close connection with LHCb and PSI experiments

Hints on possible new physics can be obtained by studying specific processes that are either strongly suppressed or forbidden in the Standard Model

Isidori, Signer

Things you can learn

- Quantum field theory methods and the Standard Model of particle physics



- Algebraic manipulation (Mathematica, Maple, Form.....)

- Programming (C++, Fortran....)

- Simulation codes

…..and maybe help shaping the future in this field !