Gauge Theories for the Standard Model

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Relativity + Quantum Mechanics + Causality + Cluster Decomposition

= **Quantum Field Theory**

Lorentz-Invariant S-matrix + Unitarity + massless particles

= **Gauge Theory** (for spin 1)

= **General Relativity** (for spin 2)

(Weinberg 1964)

It seems we do not have a choice!!

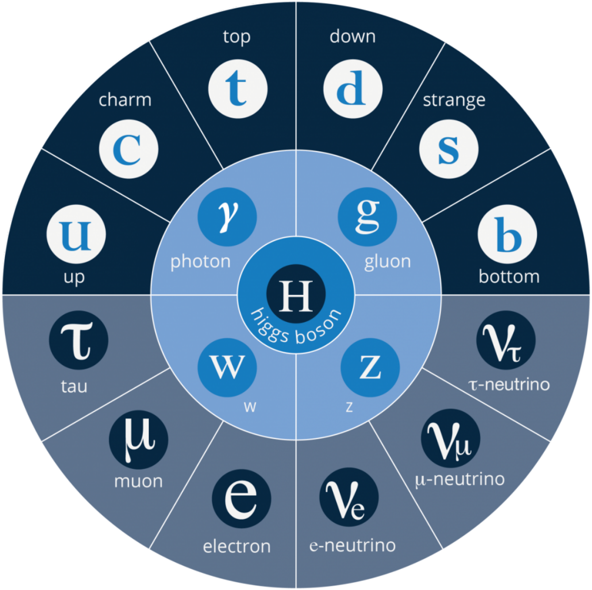
The above + Observed particle content

= Standard Model of Particle Physics:

A **Renormalizable Gauge Quantum Field Theory** with the following ingredients:

1. Gauge group $\mathcal{G}_{\text{SM}} \equiv SU(3)_c \times SU(2)_L \times U(1)_Y$.
2. Spontaneous symmetry breaking (SSB) of $\mathcal{G}_{\text{SM}}$ down to $SU(3)_c \times U(1)_{\text{em}}$ via the vacuum spectation value of a single $SU(2)_L$ doublet.
3. Three families of Matter fermions in specific representations of $\mathcal{G}_{\text{SM}}$.

	Q	u	d	L	e	H
$SU(3)_c$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{3}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{1}$
$SU(2)_L$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{1}$	$\mathbf{2}$	$\mathbf{1}$	$\mathbf{2}$
$U(1)_Y$	$1/6$	$2/3$	$-1/3$	$-1/2$	-1	$1/2$


top
t
down
d
charm
c
strange
s
u
up
γ
photon
g
gluon
b
bottom
H
higgs boson
τ
tau
W
w
Z
z
ντ
τ-neutrino
μ
muon
νμ
μ-neutrino
e
electron
νe
e-neutrino

OBJECTIVE

The purpose of this course is

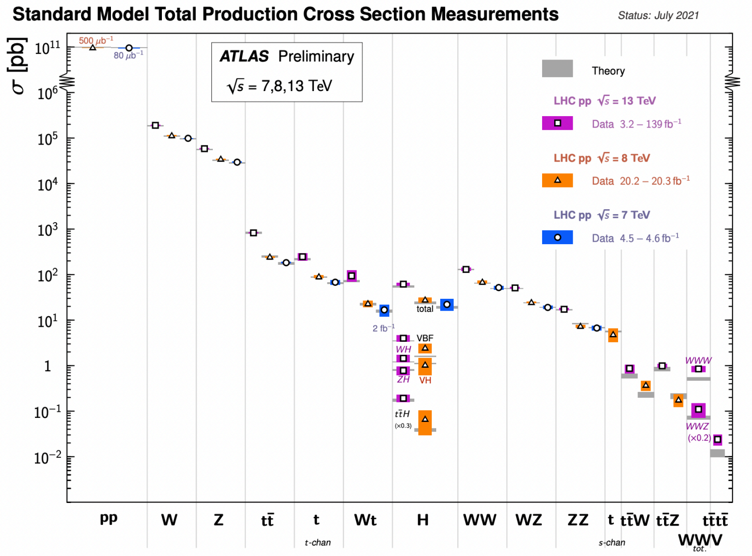
To understand the SM in detail at the **quantum** level

Of course, this will imply understanding a wider (quite general) set of gauge theories with

- different gauge groups
- different patterns of SSB, and
- different field content

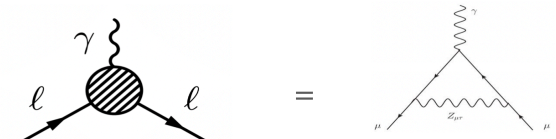
Thus we will also be able to understand e.g. **Grand Unified Theories** such as Georgi-Glashow's $SU(5)$.

The Standard Model is **A-MA-ZING**



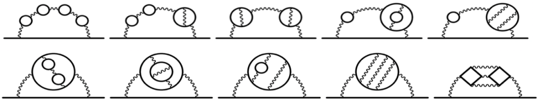
The Standard Model is **A-MA-ZING**

- Muon Magetic Moment:



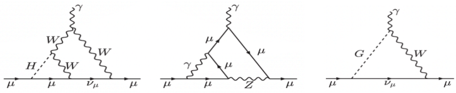
(Schwinger 1948)

+



(QED up to 5 loops)

+



(Electroweak and Higgs)

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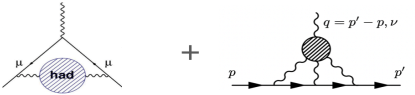


(Hadronic VP and LbL (QCD))

The Standard Model is **A-MA-ZING**

- Muon Magetic Moment: (known to parts-per-billion)

$$a_\mu = (g_\mu - 2)/2$$

Exp	0.00116592089
Schwinger 1948	$\alpha/2\pi = 0.00116140000$
QED (5 loops)	0.00116584719
Electroweak	0.00000000154
Hadronic VP	0.00000006845
Hadronic LbL	0.00000000092
Total SM	0.00116591810

Current status: $a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = 0.00000000279(76)$ BSM???

STRUCTURE OF THE COURSE

PART I: 25 hrs (Javier Virto)

Gauge Theories with and without SSB, and their quantization

PART II: 13 hrs (Jorge Casalderrey)

Renormalization and Quantum Chromodynamics

PART III: 13 hrs (Federico Mescia)

Electroweak Theory and Higgs

STRUCTURE OF THE COURSE

PART I: 25 hrs (Javier Virto)

Gauge Theories with and without SSB, and their quantization

1. Massless spin-1 particles and Gauge Symmetry
2. Non-Abelian Gauge Theory
3. Quantization of Yang-Mills Theory
4. Gauge Theories with Spontaneous Symmetry Breaking
5. QFT Anomalies

PART II: 13 hrs (Jorge Casalderrey)

Renormalization and Quantum Chromodynamics

6. Radiative corrections in Gauge Theory
7. The limits of perturbation theory

PART III: 13 hrs (Federico Mescia)

Electroweak Theory and Higgs

8. Gauge structure of Electroweak Theory
9. The Electroweak Theory beyond tree level
10. Radiative corrections in Electroweak Theory

YOU WILL LEARN ...

- Why we need Gauge Symmetry
- Why some Gauge Theories have *ghost* particles ...
- What happens when the quantum vacuum is not gauge invariant
- Why quantum mechanics breaks some global symmetries !! ...
- ... and why it does **not** break gauge symmetry within the SM !!
- Why QCD is asymptotically free (explicitly!)
- Why Flavor-changing processes are loop-mediated, and the GIM mechanism
- Why pions are Goldstone bosons, and why $\pi^0 \to 2\gamma$ occurs
- AND MUCH MORE...

EVALUATION

For the **evaluation** there will be several problem *hand-outs* during the course.

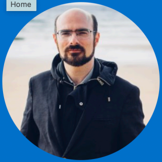
The final grade will be based on these hand-outs, in the proportion

$$\text{Grade} = 50\%\ \text{(Part I)} + 25\%\ \text{(Part II)} + 25\%\ \text{(Part III)}$$

There will be **no final exam**.

INSTRUCTORS

Home



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