Gauge Theories of the Standard Model

Professors:
Javier Virto
Jorge Casalderrey
Federico Mescia (coordinador)

Time Schedule: Spring 2022
Mon, Tue, Wed, Thursday.

Particle Physics

Processes & interactions at very high energy (>1GeV)

Quantum field theory

Formalism of quantum physics at high energy

Gauge Theories of the Standard Model

Build and study the quantum theory of present phenomena.

Standard Model L_{SM}

$$L_{eff}(\mu \le M_Z) = L_{gauge}(A_i, \psi_i) + L_{Higgs}^{\Lambda_{UV}}(H, A_i, \psi_i) + \cdots$$

$$L_{gauge} = -\frac{1}{4} F^a_{\mu\nu} F^{a\mu\nu} + i\bar{\psi} D\psi$$

- *Natural only in terms of symmetries*

  $G_g = SU(3) \otimes SU(2)_L \otimes U(1)_Y \rightarrow U(1)_Q$

Higgs and Gravity couplings are not gauge invariant!

Fundamental forces like the electromagnetic, weak and nuclear ones are based on the gauge principle.

Programme:

- The basic objective:

  Study of gauge and Higgs interactions at the quantum level.

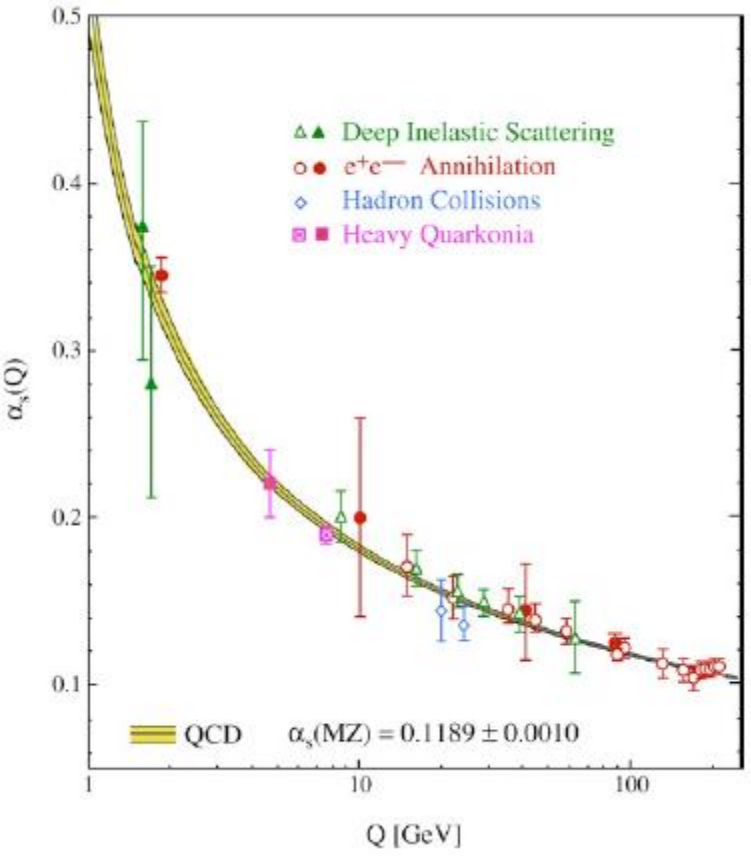
- 3 blocks:

  1) Gauge interactions and their quantization

  2) Focus on strong interactions (QCD)

  3) and electroweak theory -> Higgs mechanism

Asymptotic Freedom and QCD



Quantum field theory

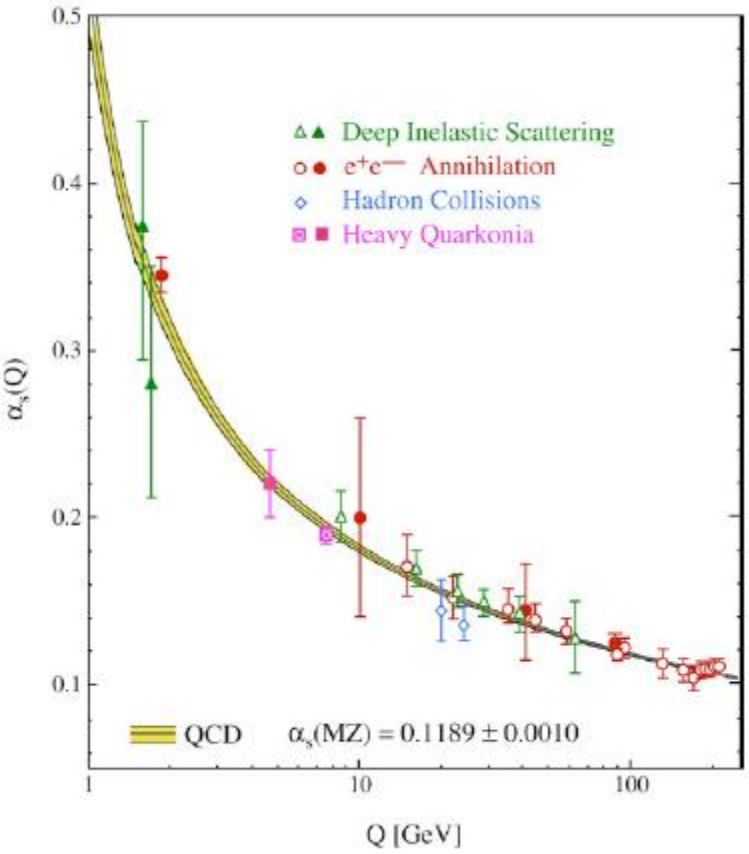
The electric and strong constants are not at all constants. They are function of energy.

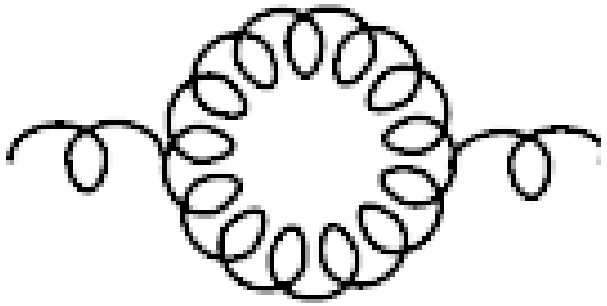
Asymptotic freedom:

- the **strong** coupling is **weak** at high energy
  -> free quarks
- the strong coupling is strong at low energy
  -> confined quarks

Homework

Asymptotic Freedom and QCD





The Nobel Prize in Physics 2004

David J. Gross, H. David Politzer, Frank Wilczek

David J. Gross

H. David Politzer

Frank Wilczek

The Nobel Prize in Physics 2004 was awarded jointly to David J. Gross, H. David Politzer and Frank Wilczek *"for the discovery of asymptotic freedom in the theory of the strong interaction"*.

Quantum Anomalies: Symmetries Yes or No?

Particle Physics & QFT

classical symmetries may not be such at a quantum level

Quantum fluctuations can break symmtries

Quantum Anomalies: Symmetries Yes or No?

☺ **We love anomalies on global symmetries:**
essential to explain nature: $\pi^0 \to \gamma\gamma$.

☹ **We hate anomalies if they break the Gauge symmetries!**

Quantum Anomalies: Symmetries Yes or No?

❖ **Experimentally:** η' mass much larger than the π one

→ **$U(1)_A$** ***is an anomalous symmetry of QCD***

→ θ-*term to the QCD Lagrangian*

$$\mathcal{L}_{\mathrm{QCD}} = \sum_q \bar{q}\left(i\not{D} - m_q e^{i\theta_q}\right) q - \frac{1}{4} G_a^{\mu\nu} G^a_{\mu\nu} - \theta \frac{\alpha_s}{8\pi} G_a^{\mu\nu} \tilde{G}^a_{\mu\nu}$$

Now, QCD violates T and P, namely CP!

➢ **Experimentally:** no CP violation in the strong sector found!

➢ **Theory: new particle axions** $\varphi = (v + H)e^{ia/f_a}$

☺ **Guideline to go Beyond the Standard Model**

Hidden Symmetries: Flavour

$$m_e = m_\nu$$

$$\frac{K \to e\nu}{K \to \nu\nu} = 1?$$

$$\frac{K \to e\nu}{K \to \nu\nu} = 0?$$

Syllabus:

Javier Virto
30 hours

PART I

I Introduction

1.- Euclidean and Minkowski conventions.
2.- Summary of path-integral techniques for a scalar theory.
3.- The effective action and functional methods.
4.- **The phenomenon of spontaneous symmetry breaking**.
5.- Classical gauge invariance in abelian and non-abelian theories.

II Introduction to QCD

1.- Why QCD?
2.- The classical lagrangian of QCD
3.- Global symmetries of QCD and their realization.
4.- The U(1)_A anomaly.
5.- The theta vacuum.
6.- Anomaly cancellation.

III Quantization of gauge theories

1.- Covariant quantization: Faddeev-Popov formalism in QED and Yang-Mills.
2.- Ghosts in Yang-Mills. Feynman rules. Unitarity.
3.- BRST symmetry.
4.- Ward and Slavnov-Taylor identities.
5.- Spontaneous symmetry breaking and renormalizability.
6.- R-gauges and modified Slavnov-Taylor identities.

Syllabus:

Jorge Casalderrey
15 hours

PART II

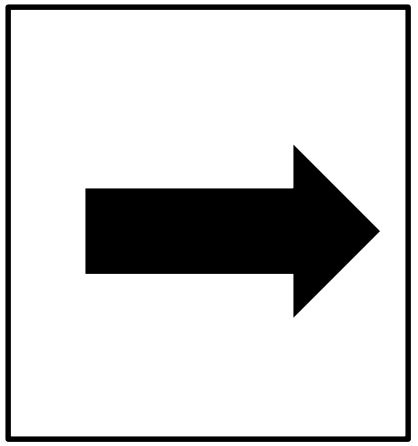
V Radiative corrections in gauge theories

1.- Divergent structure of gauge theories.
2.- Renormalization and counter-terms in QCD.
3.- The meaning of renormalization.
4.- Calculation of the beta function in QCD.
5.- The renormalization group. Fixed points.
6.- The R-observable.
7.- Renormalization ambiguities
and the renormalization group.
8.- Decoupling of heavy quarks.

VI The limits of perturbation theory

1.- Confinement
2.- Infrared divergences. Inclusive and Exclusive processes.
3.- The Operator Product Expansion (OPE).
4.- Power corrections to the R observable.

Syllabus:



PART III

VII Gauge structure of the electroweak theory

1.- Summary of known results.

2.- Gauges and gauge fixing. Physical states.

3.- The Yukawa interaction: Higgs couplings to fermions

VIII The Electroweak Theory beyond tree level

1.- FCNC and the GIM mechanism.

2.- CP symmetry and CP violation in neutral systems.

3.- The Gilman-Wise effective lagrangian.

IX Radiative corrections in the Electroweak theory

1.- Effective couplings

2.- Precision observables.

Federico Mescia
15 hours

Language: English

Evaluation:

- 100% Homework