

Phys 3101 Syllabus (10955, Fall 2021):

Particle Physics Phenomenology: The Making of the Standard Model & Beyond

1 Introduction

1.1 Particles Physics Phenomenology & the Standard Model

2 Nuclear beta Decay

2.1 Nuclear beta Decay

- a. 2-body/3-body kinematics: Pauli's neutrino
- b. Current-current interaction: Fermi's theory
- c. Cabibbo angle & the nucleon structure
- d. Charged current, Parity violation & $V - A$ interactions
- e. The "Weak boson" W^\pm , low energy effective theory

2.2 Double beta decay

- a. Neutrino mass: Dirac or Majorana?
- b. Double β -decay & neutrinoless double β -decay

3 The Neutral $K^0 - \bar{K}^0$ System

3.1 The "strangeness"

- a. $K^0 - \bar{K}^0$ mixing & the mass difference
- b. K_{long} & K_{short} & CP-violation

3.2 A 4th quark & more

- a. The Glashow-Iliopoulos-Maiani mechanism

4 The “Charm”: November Revolution

4.1 J/ψ : surprise, surprise!

- a. A narrow resonance
- b. Potential model
- c. D -mesons and weak decay: Spectator Model

4.2 τ lepton: yet another surprise

5 “Jets” & More

5.1 A new quantum number & a new particle

- a. Color in SU(3)
- b. “3-jets events”: gluons

5.2 QCD dynamics

- a. Asymptotic freedom: running coupling
- b. Infrared confinement: hadron masses
- c. Quark/gluon fragmentation
- d. Partonic picture of hadrons

6 The “Beauty”

6.1 “Oops - Leon!” Υ

- a. Yet another narrow resonance
- b. B -meson lifetime
- c. Heavy quark effective field theory

6.2 CKM mixing and CP violation

- a. The Cabibbo-Kobayashi-Maskawa paradigm
- b. Heavy flavor physics
- c. Flavor anomalies at B -factories

7 The Weak Currents & W^\pm/Z Bosons

7.1 Weak neutral currents & the need of a Z boson

- a. The “Electro-Weak unification” and the weak neutral current
- b. Discovery of W^\pm/Z weak bosons

7.2 A massive electroweak gauge theory

- a. A massive vector boson
- b. Bad high-energy behavior of the massive EW theory

8 The “top”

8.1 The late arrival and surprises

- a. The top-quark discovery
- b. The heaviest of all: a bare quark

9 The Higgs mechanism and the Higgs boson

9.1 Electroweak symmetry breaking

- a. Spontaneous symmetry breaking and the Higgs mechanism
- b. Linear & non-linear realization of the gauge symmetry
- c. Fermion mass generation

9.2 The Standard Model as a precision theory

- a. Z -factories and precision EW physics
- b. Higgs boson discovery & its properties

9.3 More questions than answers

- a. Who gives Higgs a mass?
- b. An elementary particle or composite?
- c. Vacuum stability?

- d. Fermion mass hierarchy and mixing

10 Neutrino mass and mixing

10.1 Neutrinos: the Ghostly particles

- a. Neutrino oscillations
- b. Neutrino mass revisited: Dirac or Majorana?
- c. The “see-saw” mechanisms

11 Beyond the Standard Model

11.1 From observations

- a. The origin of neutrino mass
- b. Particle dark matter
- c. Matter-antimatter imbalance
- d. Cosmological constant or dark energy

11.2 From theoretical considerations

- a. Stability of the EW scale versus the Planck Scale
- b. Gauge force unification
- c. Larger space-time symmetry
- d. String theory & quantum gravity