"Particle physics" Course Syllabus

《粒子物理学（英文)》课程教学大纲

I. Basic Information

Name	Particle physics	Course Code	PHYS3128
Course Category	Required course	Majors	Physics
Credit	3	Total Hours	3
Instructors	Tianyi Cai(蔡田怡) Sheng Ju(睢胜)	Date	2021.9
Textbooks	David Griffiths，Introduction to Elementary Particles，2th Edition, Wiley-VCH, 2008		

II. Teaching aim

1） Overall objectives:

Elementary particle physics addresses the question, 'What is matter made of?' at the most fundamental level - which is to say, on the smallest scale of size. It's a remarkable fact that matter at the subatomic level consists of tiny chunks, with vast empty spaces in between. Even more remarkable, these tiny chunks come in a small number of different types (electrons. protons. neutrons, pi mesons, neutrinos. and so on), which are then replicated in astronomical quantities to make all the 'stuff' around us. And these replicas are absolutely perfect copies - not just 'pretty similar', like two Fords coming off the same assembly line, but utterly indistinguishable. You can't stamp an identification number on an electron, or paint a spot on it - if you've seen one, you've seen them all. This quality of absolute identicalness has no analog in the macroscopic world. (In quantum mechanics it is reflected in the Pauli exclusion principle.) It enormously simplifies the task of elementary particle physics: we don't have to worry about big electrons and little ones, or new electrons and old ones - an electron is an electron is an electron. It didn't have to be so easy.

2） Course objectives:

1. Basic concepts of Particles and elementary particle dynamics including

photon, mesons, antiparticles, neutrinos, the Quark model, Quantum Electrodynamics and Quantum Chromodynamics.

2. Application of concepts and rules including Relativistic Kinematics, Symmetries, Bound States, The Feynman Calculus, Quantum Electrodynamics, Electrodynamics and Chromodynamics of Quarks, Weak Interactions and Gauge Theories.

3) Corresponding relationship between curriculum objectives, graduation requirements and curriculum content

Table I. Correspondence between course objectives, course contents and graduation requirements

Course objectives	**Corresponding course content**	**Corresponding graduation requirements**
Course objective 1	Chapter 1 Historical Introduction to the Elementary Particles Chapter 2 Elementary Particle Dynamics Chapter 7 Quantum Electrodynamics Chapter 8 Electrodynamics and Chromodynamics of Quarks	Graduation requirement 2: master the basic knowledge, basic physical experiment methods and experimental skills related to mathematics and physics, and have the ability to solve problems, explain or understand physical laws by using physical theories and methods. Graduation requirement 3: understand the frontier and development of physics, the physical thought in new technology, and be familiar with the impact of new discoveries, theories and technologies in physics on society. Graduation requirements 8: have the awareness

		of independent learning and lifelong learning and the ability to adapt to the society.
Course objective 2	Chapter 3 Relativistic Kinematics Chapter 4 Symmetries Chapter 5 Bound States Chapter 6 The Feynman Calculus Chapter 9 Weak Interactions	Graduation requirement 2: master the basic knowledge, basic physical experiment methods and experimental skills related to mathematics and physics, and have the ability to solve problems, explain or understand physical laws by using physical theories and methods. Graduation requirements 7: have the ability of subject research, design, data processing and academic exchange. Graduation requirements 8: have the awareness of independent learning and lifelong learning and the ability to adapt to the society.

III. Contents

Chapter One: Historical Introduction to the Elementary Particles

1. Teaching aims

Know how the various particles were first discovered, and how they fit into the overall scheme of things;

Know some of the fundamental ideas that dominate elementary particle theory.

2. Keypoints and Difficulties

Keypoints: Particles

Difficulties: Antiparticles

3. Contents

1.1 The Classical ERA (1897-1932)

1.2 The Photon (1900-1924)

1.3 Mesons (1934-1947)

1.4 Antiparticles (1930-1956)

1.5 Neutrinos (1930-1962)

1.6 Strange Particles (1947-1960)

1.7 The Eightfold Way (1961-1964)

1.8 The Quark Model (1964)

1.9 The November Revolution and Its Aftermath (1974-1983 and 1995)

1.10 Intermediate Vector Bosons (1983)

1.11 The Standard Model (1978-?)

4.Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5.Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

1. If a charged particle is undeflected in passing through uniform crossed electric and magnetic fields E and B (mutually perpendicular and both perpendicular to the direction of motion), what is its velocity? If we now turn off the electric field, and the particle moves in an arc of radius R, what is its charge-to-mass ratio?

2. How many different meson combinations can you make with 1, 2, 3, 4, 5, or 6 different quark flavors? What's the general formula for n flavors?

3. How many different baryon combinations can you make with 1, 2, 3, 4, 5, or 6, different quark flavors? What's the general formula for n flavors?

4. Using four quarks (u, d, s, and c), construct a table of all the possible baryon species. How many combinations carry a charm of +1? How many carry charm +2, and +3?

5. Same as Problem 4, but this time for mesons.

Chapter Two: Elementary Particle Dynamics

1. Teaching aims

Know the fundamental forces by which elementary particles interact, and the Feynman diagrams we use to represent these interactions.

2. Keypoints and Difficulties

Keypoints: Forces; Interactions

Difficulties: Quantum Electrodynamics

3. Contents

2.1 The Four forces

2.2 Quantum Electrodynamics (QED)

2.3 Quantum Chromodynamks (QCD)

2.4 Weak Interactions

2.4.1 Neutral

2.4.2 Charged

2.4.2.1 Leptons

2.4.3 Quarks

2.4.4 Weak and Electromagnetic Couplings of W and Z

2.5 Decays and Conservation Laws

2.6 Unification Schemes

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems：

1. Calculate the ratio of the gravitational attraction to the electrical repulsion between two stationary electrons. (Do I need to tell you how far apart they are?)

2. Determine the mass of the virtual photon in each of the lowest-order diagrams for Bhabha scattering (assume the electron and position are at rest). What is its velocity? (Note that these answers would be impossible for real photons.)

Chapter Three: Relativistic Kinematics

1. Teaching aims

   Know the basic principles, notation, and terminology of relativistic kinematics.

2. Keypoints and Difficulties

   Keypoints: Lorentz Transformations; Collisions

   Difficulties: Collisions

3. Contents

   3.1 Lorentz Transformations

   3.2 Four-vectors

   3.3 Energy and Momentum

   3.4 Collisions

   3.4.1 Classical Collisions

   3.4.2 Relativistic Collisions

   3.5 Examples and Applications

4. Teaching method

   Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

1. Half the muons in a monoenergetic beam decay in the first 600 m. How fast are they going?

2. How much more does a hot potato weigh than a cold one (in kg)?

3. Particle A, at rest, decays into three or more particles: A→ B + C + D + ⋯.

(a) Determine the maximum and minimum energies that B can have in such a decay, in terms of the various masses.

(b)Find the maximum and minimum electron energies in muon decay, $\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$.

Chapter Four: Symmetries

1. Teaching aims

Know some general remarks about the mathematical description of symmetry (group theory) and the relation between symmetry and conservation laws (Notther's theorem);

Take up the case of rotational symmetry and its relation to angular momentum and spin;

Consider 'discrete' symmetries - parity, charge conjugation, and time reversal.

2. Keypoints and Difficulties

Keypoints: Symmetries

Difficulties: Flavor Symmetries

3. Contents

4.1 Symmetries. Groups. and Conservation Laws

4.2 Angular Momentum

4.2.1 Addition of Angular Momenta

4.2.2 Spin $\frac{1}{2}$

4.3 Flavor Symmetries

4.4 Discrete Symmetries

4.4.1 Parity

4.4.2 Charge Conjugation

4.4.3 CP

4.4.3.1 Neutral Kaons

4.4.3.2 CP Violation

4.4.4 Time Reversal and the TCP Theorem

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

1. Work out the symmetry group of a square. How many elements does it have? Construct the multiplication table, and determine whether or not the group is Abelian.

2. Suppose you had two particles of spin 2, each in a state with $S_z = 0$. If you measured the total angular momentum of this system. given that the orbital angular momentum is zero, what values might you get, and what is the probability of each? Check that they add up to 1.

Chapter Five: Bound States

1. Teaching aims

Know the nonrelativistic theory of two-particle bound states - hydrogen (e^-p^+), positronium (e^-e^+), charmonium ($c\bar{c}$), and bottomonium ($b\bar{b}$).

2. Keypoints and Difficulties

Keypoints: The Schrodinger Equation

Difficulties: Hydrogen

3. Contents

5.1 The Schrodinger Equation

5.2 Hydrogen

5.2.1 Fine Structure

5.2.2 The Lamb Shift

5.2.3 Hyperfine Splitting

5.3 Positronium

5.4 Quarkonium

5.4.1 Charmonium

5.4.2 Bottomonium

5.5 Light Quark Mesons

5.6 Baryons

5.6.1 Baryon Wave Functions

5.6.2 Magnetic Moments

5.6.3 Masses

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

1. Work out all of the hydrogen wave functions for n = 2. using Equation 5.12. (How many are there?)

$$\left\{\left(\frac{2}{na}\right)^3 \frac{(n-l-1)!}{2n[(n+l)!]^3}\right\}^{1/2} e^{-r/na}\left(\frac{2r}{na}\right)^l L_{n-l-1}^{2l+1}\left(\frac{2r}{na}\right) Y_l^{m_l}(\theta,\phi)e^{-iE_n t/\hbar} \quad (5.12)$$

2. Construct the (singlet) color wave function for mesons, analogous to Equation 5.60.

$$\psi(\text{color}) = (rgb - rbg + gbr - grb + brg - bgr)/\sqrt{6} \quad (5.60)$$

Chapter Six: The Feynman Calculus

1. Teaching aims

   Know the quantitative formulation of elementary particle dynamics.

2. Keypoints and Difficulties

   Keypoints: Decays; Scattering

   Difficulties: Cross Sections

3. Contents

   6.1 Decays and Scattering

   6.1.1 Decay Rates

   6.1.2 Cross Sections

   6.2 The Golden Rule

   6.2.1 Golden Rule for Decays

   6.2.1.1 Two-particle Decays

   6.2.2 Golden Rule for Scattering

   6.2.2.1 Two-body Scattering in the CM Frame

   6.3 Feynman Rules for a Toy Theory

   6.3.1 Lifetime of the A

   6.3.2 A + A → B + B Scattering

   6.3.3 Higher-order Diagrams

4. Teaching method

   Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

   Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems:

1. Consider the collision 1 + 2 →3 + 4 in the lab frame (2 at rest) with particles 3 and 4 massless. Obtain the formula for the differential cross section.

$$\left[\textit{Answer}: \ \frac{d\sigma}{d\Omega} = \left(\frac{\hbar}{8\pi}\right)^2 \frac{S|\mathcal{M}|^2|\mathbf{p}_3|}{m_2|\mathbf{p}_1|(E_1 + m_2c^2 - |\mathbf{p}_1|c\cos\theta)} \right]$$

2. Calculate $d\sigma/d\Omega$ for $A + A \rightarrow B + B$, in the CM frame, assuming $m_B = m_C = 0$. Find the total cross section, σ.
3. Find $d\sigma/d\Omega$ and σ for $A + A \rightarrow B + B$ in the lab frame. (Let E be the energy, and p the momentum, of the incident A. Assume $m_B = m_C = 0$.) Determine the nonrelativistic and ultrarelativisitic limits of your formula.

Chapter Seven: Quantum Electrodynamics

1. Teaching aims

   Know the Dirac equation, the Feynman rules for quantum electrodynamics, learn useful calculational tools, and derive some of the classic QED results.

2. Keypoints and Difficulties

   Keypoints: Dirac equation; Feynman Rules
   Difficulties: Cross Sections and Lifetimes

3. Contents

   7.1 The Dirac Equation

   7.2 Solutions to the Dirac Equation

   7.3 Bilinear Covariants

   7.4 The Photon

   7.5 The Feynman Rules for QED

   7.6 Examples

   7.7 Casimir's Trick

   7.8 Cross Sections and Lifetimes

   7.9 Renormalization

4. Teaching method

   Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

   Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problem

1. Show that Equation 7.17 satisfies Equation 7.15

$$\{\gamma^{\mu},\gamma^{\nu}\} = 2g^{\mu\nu} \tag{7.15}$$

$$\gamma^0 = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \quad \gamma^i = \begin{pmatrix} 0 & \sigma^i \\ -\sigma^i & 0 \end{pmatrix} \tag{7.17}$$

2. (a)Derive Equations 7.70 (iandiv) from Equation 7.73.

$$\left\{ \begin{array}{llll} \text{(i)} & \nabla \cdot \mathbf{E} = 4\pi\rho & \text{(iii)} & \nabla \cdot \mathbf{B} = 0 \\ \text{(ii)} & \nabla \times \mathbf{E} + \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} = 0 & \text{(iv)} & \nabla \times \mathbf{B} - \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} = \frac{4\pi}{c}\mathbf{J} \end{array} \right\} \tag{7.70}$$

$$\partial_{\mu} F^{\mu\nu} = \frac{4\pi}{c} J^{\nu} \tag{7.73}$$

(b)Prove Equation 7.74 from Equation 7.73.

$$\partial_{\mu} J^{\mu} = 0 \tag{7.74}$$

3. Derive the amplitudes (Equation 7.133 and 7.134) for pair annihilation, e+ + e-→γ+γ.

$$\mathscr{M}_1 = \frac{g_e^2}{(p_1 - p_3)^2 - m^2c^2} \bar{v}(2)\not{\epsilon}_4(\not{p}_1 - \not{p}_3 + mc)\not{\epsilon}_3 u(1) \tag{7.133}$$

$$\mathscr{M}_2 = \frac{g_e^2}{(p_1 - p_4)^2 - m^2c^2} \bar{v}(2)\not{\epsilon}_3(\not{p}_1 - \not{p}_4 + mc)\not{\epsilon}_4 u(1) \tag{7.134}$$

Chapter Eight: Electrodynamics and Chromodynamics of Quarks

1. Teaching aims

Understand two important examples: the production of hadrons in electron-positron collisions (Section 8.1), and elastic electron-proton scattering (Section 8.2);

Study chromodynamics: the Feynman rules (Section 8.3), color factors (Secticn 8.4), pair annihilation in QCD (Section 8.5), and asymptotic freedom (Section 8.6).

2. Keypoints and Difficulties

Keypoints: Collisions; Scattering; Chromodynamics
Difficulties: Chromodynamics

3. Contents

8.1 Hadron Production in e^+e^- Collisions

8.2 Elastic Electron-Proton Scattering

8.3 Feynman Rules For Chromodynamics

8.4 Color Factors

8.4.1 Quark and Antiquark

8.4.2 Quark and Quark

8.5 Pair Annihilation in QCD

8.6 Asymptotic Freedom

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems

1. (a)Derive Equation 8.1, from the Feynman rules for QED.

(b)Obtain Equation 8.2 from Equation 8.1

(c)Derive Equation 8.3 from Equation 8.2

(d)Derive Equation 8.4 from Equation 8.3

$$\mathcal{M} = \frac{Qg_e^2}{(p_1+p_2)^2}[\overline{v}(p_2)\gamma^\mu u(p_1)][\overline{u}(p_3)\gamma_\mu v(p_4)] \tag{8.1}$$

$$\langle|\mathcal{M}|^2\rangle = \frac{1}{4}\left[\frac{Qg_e^2}{(p_1+p_2)^2}\right]^2 \mathrm{Tr}[\gamma^\mu(\not{p}_1+mc)\gamma^\nu(\not{p}_2-mc)] \times\mathrm{Tr}[\gamma_\mu(\not{p}_4-Mc)\gamma_\nu(\not{p}_3+Mc)] \tag{8.2}$$

$$\langle|\mathcal{M}|^2\rangle = 8\left[\frac{Qg_e^2}{(p_1+p_2)^2}\right]^2 [(p_1\cdot p_3)(p_2\cdot p_4)+(p_1\cdot p_4)(p_2\cdot p_3) +(mc)^2(p_3\cdot p_4)+(Mc)^2(p_1\cdot p_2)+2(mc)^2(Mc)^2] \tag{8.3}$$

$$\langle|\mathcal{M}|^2\rangle = Q^2 g_e^4 \left\{1 + \left(\frac{mc^2}{E}\right)^2 + \left(\frac{Mc^2}{E}\right)^2 + \left[1 - \left(\frac{mc^2}{E}\right)^2\right]\left[1 - \left(\frac{Mc^2}{E}\right)^2\right]\cos^2\theta\right\} \quad (8.4)$$

2. Derive Equation 8.70, starting from Equation 8.69.

$$\mathcal{M}_3 = i\overline{v}(2)c_2^\dagger\left[-i\frac{g_s}{2}\lambda^\delta\gamma_\sigma\right]u(1)c_1\left[-i\frac{g^{\sigma\lambda}\delta^{\delta\gamma}}{q^2}\right]\{-g_s f^{\alpha\beta\gamma}[g_{\mu\nu}(-p_3+p_4)_\lambda + g_{\nu\lambda}(-p_4-q)_\mu + g_{\lambda\mu}(q+p_3)_\nu]\}[\epsilon_3^\mu a_3^\alpha][\epsilon_4^\nu a_4^\beta] \quad (8.69)$$

$$\mathcal{M}_3 = i\frac{g_s^2}{4}\frac{1}{p_3\cdot p_4}\overline{v}(2)[(\epsilon_3\cdot\epsilon_4)(\not p_4 - \not p_3) + 2(p_3\cdot\epsilon_4)\not\epsilon_3 - 2(p_4\cdot\epsilon_3)\not\epsilon_4]u(1) \times f^{\alpha\beta\gamma}a_3^\alpha a_4^\beta(c_2^\dagger\lambda^\gamma c_1) \quad (8.70)$$

Chapter Nine: Weak Interactions

1. Teaching aims

Stating the Feynman Rules for the coupling of leptons to $w^{\pm}$, and treat three classic problems in some detail: beta decays of the muon, the neutron, and the charged pion;

Consider the coupling of quarks to W±, which brings in the Cabibbo angle, the GIM mechanism, and the Kobayashi-Maskawa matrix;

State the Feynman rules for coupling quarks and leptons to the Z^0, and the final section sketches the Glashow-Weinberg-SaIam electroweak theory.

2. Keypoints and Difficulties

Keypoints: Weak Interactions
Difficulties: Charged Weak Interactions of Quarks

3. Contents

9.1 Charged leptonic Weak Interactions

9.2 Decay of the Muon

9.3 Decay of the Neutron

9.4 Decay of the Pion

9.S Charged Weak Interactions of Quarks

9.6 Neutral Weak Interactions

9.7 Electroweak Unification

9.7.1 Chiral Fermion States

9.7.2 Weak Isospin and Hypercharge

9.7.3 Electroweak Mixing

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems

1. What is the average value of the electron energy in muon decay?

[*Answer* : $(7/20)m_{\mu}c^2$]

2. Calculate the ratio of the decay rates $K^- \rightarrow e^- + \bar{\nu}_e$, and $K^- \rightarrow \mu^- + \bar{\nu}_{\mu}$. Compare the observed branching ratios.

Chapter Ten: Gauge Theories

1. Teaching aims

Know the 'gauge theories' that describe all elementary particle interactions;

Begin with the Lagrangian formulation of classical mechanics, and proceed to Lagrangian field theory, the principle of local gauge invariance, the notion of spontaneous symmetry-breaking, and the Higgs mechanism (which accounts for the mass of the W's and the Z).

2. Keypoints and Difficulties

Keypoints: Lagrangian Formulation
Difficulties: IDA Yang-Mills Theory

3. Contents

10.1 Lagrangian Formulation of Classical Particle Mechanics

10.2 Lagrangians in Relativistic Field Theory

10.3 Local Gauge Invariance

10.4 IDA Yang-Mills Theory

10.5 Chromodynamics

10.6 Feynman Rules

10.7 The Mass Term

10.8 Spontaneous Symmetry-breaking

10.9 The Higgs Mechanism

4. Teaching method

Teaching; Group Discussion; Autodidacticism under the guidance of the teacher

5. Comments

Carefully prepare lessons, prepare students and make preparations before class; In the teaching process, we pay attention to cultivating students' creative thinking, take students as the main body and enhance students' sense of participation; Corresponding exercises and supplementary exercises after class.

Problems

1. Show that any Hermitian 3 x 3 matrix can be written as a linear combination of the unit matrix and the eight Gell-Mann matrices (Equation 10.76)

$$H = \theta 1 + \lambda \cdot a \quad (10.76)$$

IV. Class hour allocation

Table II. Specific contents of each chapter and class hour allocation table

Chapter	Chapter content	Class hour allocation
Chapter One	Historical Introduction to the Elementary Particles	Two Weeks, 4 Hours

Chapter Two	Elementary Particle Dynamics	Two Weeks, 4 Hours
Chapter Three	Relativistic Kinematics	Two Weeks, 4 Hours
Chapter Four	Symmetries	Two Weeks, 4 Hours
Chapter Five	Bound States	Two Weeks, 4 Hours
Chapter Six	The Feynman Calculus	Two Weeks, 4 Hours
Chapter Seven	Quantum Electrodynamics	Two Weeks, 4 Hours
Chapter Eight	Electrodynamics and Chromodynamics of Quarks	Two Weeks, 4 Hours

V. Teaching progress

Table III. Teaching schedule

Week	Date	Chapter	Content	Teaching hours	Requirements	Remarks
1		Chapter One	The Classical ERA; The Photon; Antiparticles	Two	Problem	
2		Chapter One	Strange Particles; The Eightfold Way; The Quark Model	Two	Problem	
3		Chapter Two	The Four forces; Quantum Electrodynamics (QED); Quantum Chromodynamks (QCD)	Two	Problem	
4		Chapter Two	Weak Interactions	Two	Problem	

5		Chapter Three	Lorentz Transformations; Four-vectors; Energy and Momentum	Two	Problem	
6		Chapter Three	Collisions	Two	Problem	
7		Chapter Four	Symmetries; Angular Momentum	Two	Problem	
8		Chapter Four	Spin; Parity	Two	Problem	
9		Chapter Five	The Schrodinger Equation; Hydrogen; The Lamb Shift; Hyperfine Splitting	Two	Problem	
10		Chapter Five	Positronium; Quarkonium; Charmonium; Baryons	Two	Problem	
11		Chapter Six	Decays and Scattering; The Golden Rule	Two	Problem	
12		Chapter Six	Two-particle Decays; Golden Rule for Scattering	Two	Problem	
13		Chapter Seven	The Dirac Equation; Bilinear Covariants	Two	Problem	

14		Chapter Seven	The Photon; The Feynman Rules for QED	Two	Problem	
15		Chapter Eight	Elastic Electron-Proton Scattering	Two	Problem	
16		Chapter Eight	Color Factors; Pair Annihilation in QCD	Two	Problem	

VI. Textbook and References

Textbooks：David Griffiths，Introduction to Elementary Particles，2th Edition, Wiley-VCH, 2008

References：

1. Kane, Gordon, Modern Elementary Particle Physics, Cambridge University Press, 2019

VII. Teaching method

1. Fully leverage the educational role of theoretical physics courses, establish a solid foundation in mathematical and physical principles, and emphasize the inclusion of cutting-edge scientific content. Enrich the teaching materials in a progressive manner, integrating courses such as particle physics, quantum mechanics, and electromagnetism. Focus on complex quantum model systems at the forefront of interdisciplinary research to cultivate scientific thinking abilities and research innovation skills.

2. Combine chalkboard and PowerPoint presentations, taking advantage of both traditional and modern teaching methods. Utilize a combination of lectures, discussions, and flipped classroom approaches for teaching.

3. Integrate relevant innovation projects, train students’ ability to solve complex problems through thematic seminars, literature research, and group collaboration, among other activities.

4. Utilize information technology: Create an information-based teaching environment that combines offline classroom teaching, making the teaching format interactive. For example, use an online platform to distribute quizzes

in real-time to assess teaching effectiveness and assist in activities such as flipped classrooms and thematic seminars.

VIII. Assessment method and evaluation method

[1] Corresponding relationship between curriculum assessment and curriculum objectives

Table IV. Correspondence between course assessment and course objectives

Course objectives	Key points of assessment	Assessment method
Course objectives1	Related teaching content	The regular assessment + the midterm exam + the final exam
Course objectives2	Related teaching content	The regular assessment + the midterm exam + the final exam

[2] Appraising method

[1] Appraising method

Multifaceted assessment: from in-class to out-of-class, from final exams to process-oriented assessments, from in-class activities to project-based assessments, etc. Utilize an information-based app to export pre-class, in-class, and post-class learning data, along with out-of-class thematic discussions, process-oriented assessments, and closed-book exams. Calculate the final grade based on weighted scores.

The regular assessment (assignments, discussions, etc.) accounts for 20%, the midterm assessment accounts for 20%, and the final assessment accounts for 60% of the total grade.

[2] Analysis of assessment proportion and achievement degree of curriculum objectives

Table V. Analysis of assessment proportion and achievement degree of curriculum objectives

考核占比 / 课程目标	平时	期中	期末	总评达成度
Course objectives1	40%	40%	40%	Degree of achievement

Course objectives2	60%	60%	60%	for Course Objective 1 = {0.2 x regular performance score for Objective 1 + 0.2 x the midterm exam score for Objective 1 + 0.6 x the final exam score for Objective 1} / Total score for Objective 1. Degree of achievement for Course Objective 2 = {0.2 x regular performance score for Objective 2 + 0.2 x the midterm exam score for Objective 2 + 0.6 x the final exam score for Objective 2} / Total score for Objective 2. Overall degree of achievement = 0.4 x Degree of achievement for Course Objective 1 + 0.6 x Degree of achievement for Course Objective 2.

[3] Scoring criteria

Course objectives	Scoring criteria				
	90-100	80-89	70-79	60-69	＜60
	优	良	中	合格	不合格
	A	B	C	D	F
Course objectives 1	Demonstrate a comprehensive understanding of the basic concepts of particles and	Show a solid understanding of the basic concepts of particles and elementary	Demonstrate a satisfactory understanding of the basic concepts of particles and	Exhibit a limited understanding of the basic concepts of particles and	Lack a sufficient understanding of the basic concepts of particles and

Course objectives	Scoring criteria				
	90-100	80-89	70-79	60-69	＜60
	优	良	中	合格	不合格
	A	B	C	D	F
	elementary particle dynamics, including photon, mesons, antiparticles, neutrinos, the Quark model, Quantum Electrodynamics (QED), and Quantum Chromodynamics (QCD). Provide clear explanations, demonstrate the interconnections between these concepts, and apply them to various contexts within particle physics.	particle dynamics, including photon, mesons, antiparticles, neutrinos, the Quark model, QED, and QCD. Provide accurate explanations and demonstrate the ability to apply these concepts in different situations within particle physics.	elementary particle dynamics, including photon, mesons, antiparticles, neutrinos, the Quark model, QED, and QCD. Provide basic explanations and show some ability to apply these concepts within particle physics.	elementary particle dynamics, including photon, mesons, antiparticles, neutrinos, the Quark model, QED, and QCD. Provide incomplete or inaccurate explanations and show limited ability to apply these concepts within particle physics.	elementary particle dynamics, including photon, mesons, antiparticles, neutrinos, the Quark model, QED, and QCD. Unable to provide accurate explanations or apply these concepts effectively within particle physics.
Course objectives 2	Demonstrate an excellent application of particles and elementary particle dynamics, including Relativistic Kinematics, Symmetries, Bound	Show a solid application of particles and elementary particle dynamics, including Relativistic Kinematics, Symmetries, Bound States, The	Demonstrate a satisfactory application of particles and elementary particle dynamics, including Relativistic Kinematics, Symmetries,	Exhibit a limited application of particles and elementary particle dynamics, including Relativistic Kinematics, Symmetries,	Lack a sufficient application of particles and elementary particle dynamics, including Relativistic Kinematics, Symmetries,

Course objectives	Scoring criteria				
	90-100	80-89	70-79	60-69	＜60
	优	良	中	合格	不合格
	A	B	C	D	F
	States, The Feynman Calculus, QED, Electrodynamics and Chromodynamics of Quarks, Weak Interactions, and Gauge Theories. Show a deep understanding of these concepts and their interconnections, and effectively apply them to analyze and solve complex problems within the field of particle physics.	Feynman Calculus, QED, Electrodynamics and Chromodynamics of Quarks, Weak Interactions, and Gauge Theories. Demonstrate a good understanding of these concepts and their applications, and effectively apply them to analyze and solve problems within the field of particle physics.	Bound States, The Feynman Calculus, QED, Electrodynamics and Chromodynamics of Quarks, Weak Interactions, and Gauge Theories. Show a basic understanding of these concepts and their applications, and apply them to analyze and solve problems to some extent within the field of particle physics.	Bound States, The Feynman Calculus, QED, Electrodynamics and Chromodynamics of Quarks, Weak Interactions, and Gauge Theories. Show a partial understanding of these concepts and have limited ability to apply them to analyze and solve problems within the field of particle physics.	Bound States, The Feynman Calculus, QED, Electrodynamics and Chromodynamics of Quarks, Weak Interactions, and Gauge Theories. Unable to provide accurate explanations or apply these concepts effectively within the field of particle physics.