Annexe A: New/Revised Course Content in OBTL+ Format

Course Overview

The sections shown on this interface are based on the templates UG OBTL+ or PG OBTL+
If you are revising/duplicating an existing course and do not see the pre-filled contents you expect in the subsequent sections e.g. Course Aims, Intended Learning Outcomes etc. please refer to Data Transformation Status for more information.

Expected Implementation in Academic Year	AY2025-2026
Semester/Trimester/Others (specify approx. Start/End date)	Semester 2
Course Author * Faculty proposing/revising the course	Leek Meng Lee
Course Author Email	mlleek@ntu.edu.sg
Course Title	Quantum Field Theory
Course Code	PH4509
Academic Units	3
Contact Hours	39
Research Experience Components	Not Applicable

Course Requisites (if applicable)

Pre-requisites	PH3101 – Quantum Mechanics II
Co-requisites	
Pre-requisite to	
Mutually exclusive to	
Replacement course to	
Remarks (if any)	

Course Aims

The course is intended to be a first course in QFT, in which you should, upon completion, gain mastery of essential ideas in relativistic field theory and broadly appreciate how they relate to particle physics and the deep aspects of fundamental physics. The course will enable you to develop an awareness of the plethora of applications in elementary particle physics. It will be a course where you will gather various mathematical methods and various non-interacting bosonic and fermionic field theories, to piece together the formalism for an interacting field theory. You will also learn to solve the interacting field theory perturbatively.

Course's Intended Learning Outcomes (ILOs)

Upon the successful completion of this course, you (student) would be able to:

ILO 1	Manipulate tensors in the context of Special Relativity.
ILO 2	Work with the Path Integral formalism in the context of Quantum Mechanics.
ILO 3	Go through the canonical quantization of the (real and complex) spin-0 Klein-Gordon field theory.
ILO 4	Go through the path integral quantization of Klein-Gordon field theory.
ILO 5	Go through the canonical quantization of the spin-1/2 Dirac fermionic field theory.
ILO 6	Go through the path integral quantization of the Dirac Field theory.
ILO 7	Go through the canonical quantization of Electrodynamics in Coulomb gauge as well as in Lorenz gauge.
ILO 8	Construct interacting field theories via the principle of local gauge invariance.
ILO 9	Generalise the abelian electrodynamics gauge theory to the non-abelian Yang-Mills gauge theory.
ILO 10	Go through the path integral quantization of the non-abelian Yang-Mills gauge theory.
ILO 11	Setup the perturbation framework to handle interacting field theories and consolidate the pertubation series into a set of Feynman diagram rules. Phi-4 interacting theory serves as an example to illustrate the framework.

Course Content

This is a first course in quantum field theory (QFT) where we provide an exposition of basic concepts, mathematical techniques and a sketch of various applications in elementary particle physics. The foundational topics which will be introduced include path-integral formalism in quantum mechanics and QFT, canonical quantization, Green's functions and Feynman diagrams in perturbation theory. We will touch on the application of these concepts to aspects of scalar field theory, fermionic field theory, abelian and non-abelian gauge theories.

Reading and References (if applicable)

a. Das, Ashok. *Lectures on quantum field theory, 2nd Edition*. World Scientific, 2020. ISBN: 978-981-12-2216-0

b. Ryder, Lewis H. *Quantum field theory*. Cambridge university press, 1996. ISBN: 978-0521478144

c. Zee A., 2010, Quantum Field Theory in a Nutshell, Princeton University Press. ISBN: 9781400835324

d. Srednicki M., 2007, Quantum Field Theory, Cambridge University Press. ISBN: 0521864496

e. Greiner W. and Reinhardt J., 1996, Field Quantization, Springer Science. ISBN: 9783642614859

f. Coleman S., 1985, Aspects of Symmetry, Cambridge University Press. ISBN: 978-0521318273

g. Peskin M.E. and Schroeder D., 1995, Introduction to Quantum Field Theory, Westview Press. ISBN: 978-0201503975

NOTE: The above reading comprises the foundational readings for the course and more up-to-date relevant readings will be provided when they are available.

Planned Schedule

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
1	Recasting special relativity into the language of tensor calculus.	1	References and lecture notes	In-person	
2	Derive the path integral formalism in the context of Quantum Mechanics.	2	References and lecture notes	In-person	
3	Setup Klein-Gordon scalar field theory and quantize it by the method of canonical quantization. Then quantize it by the path integral method.	3, 4	References and lecture notes	In-person	
4	Setup the Dirac fermionic field theory and derive its various properties.	5	References and lecture notes	In-person	
5	Subject Dirac field theory to canonical quantization and then subject it to path integral quantization.	5, 6	References and lecture notes	In-person	

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
6	Setup Electrodynamics and subject it to Coulomb gauge and canonical quantization.	7	References and lecture notes	In-person	
7	Subject Electrodynamics to Lorenz gauge and canonical quantization. Then we introduce the local gauge principle and use it to construct interacting Lagrangian terms.	8	References and lecture notes	In-person	
8	Setup non-abelian Yang-Mills field theory by generalizing abelian electrodynamics gauge theory.	9	References and lecture notes	In-person	Midterm 1
9	Subject Yang-Mills field theory to path integral quantization.	10	References and lecture notes	In-person	
10	Setup the interacting framework by deriving the LSZ reduction formula and the formulas for scattering cross section and decay rate.	11	References and lecture notes	In-person	

Week or Session	Topics or Themes	ILO	Readings	Delivery Mode	Activities
11	Setup the interacting Green's function for perturbation and deduce Wick's factorization theorem.	11		In-person	
12	Using phi-4 interacting theory as an example, derive the Feynman diagrams and gather a set of Feynman diagrammatic rules.	11		In-person	
13	Rederive the Feynman diagrammatic rules for phi-4 theory using the path integral method.	11	References and lecture notes	In-person	Midterm 2
14	Project report and presentation	all		Online	

Learning and Teaching Approach

Approach	How does this approach support you in achieving the learning outcomes?
Lecture	During lectures, the teaching approach would be mainly in the form of whiteboard presentation suitable for the nature of this topic (it is mathematically rather intensive and the traditional board work fits best).
Tutorials	During tutorials, students will learn and understand various approaches of solving problems which would assist them to internalize the concepts presented in lectures. Their participation in presenting their own solutions will also refine their communication skills at the same time clarifying their own understanding of the course materials.

Assessment Structure

Assessment Components (includes both continuous and summative assessment)

No.	Component	ILO	Related PLO or Accreditation	Weightage	Team/Individual	Rubrics	Level of Understanding
1	Continuous Assessment (CA): Test/Quiz(Midterm Test 1)	1-5	Not applicable	25	Individual	Analytic	Relational
2	Continuous Assessment (CA): Test/Quiz(Midterm Test 2)	6-11	No applicable	25	Individual	Analytic	Relational
3	Continuous Assessment (CA): Assignment(Homework)	All	Not applicable	25	Individual	Analytic	Relational
4	Continuous Assessment (CA): Project(Report and Presentation)	All	Not applicable	25	Team	Analytic	Relational

Description of Assessment Components (if applicable)

Continuous Assessment (CA) 1 / Midterm Test 1 is a 1hr 30min written paper to assess student's understanding of the first part of the course.
Continuous Assessment (CA) 2 / Midterm Test 2 is a 1hr 30min written paper to assess student's understanding of the second part of the course.
Continuous Assessment (CA) 3 / Assignment: This component is made up of 5 homework sets where students will work on problems that enforce and enhance their understanding.
Continuous Assessment (CA) 4 / Project: This component requires students to read up on a topic that is slightly beyond the course content and write up a report and give a presentation on it.

Formative Feedback

The homework assignments will allow me to understand how each student is progressing along, and for me to correct any misconceptions and identify specific topics which are not well-understood. Feedback will be reflected on their homework scripts and if necessary, extra consultation hours will be arranged to address learning difficulties. During tutorial sessions, students will be invited to present solutions and feedback will be given during their participation. I will also react to their project presentation in terms of encouraging remarks and a critical evaluation of content presented.

NTU Graduate Attributes/Competency Mapping

This course intends to develop the following graduate attributes and competencies (maximum 5 most relevant)

Attributes/Competency	Level
Curiosity	Intermediate
Problem Solving	Intermediate
Sense Making	Advanced

Course Policy

Policy (Academic Integrity)

Good academic work depends on honesty and ethical behaviour. The quality of your work as a student relies on adhering to the principles of academic integrity and to the NTU Honour Code, a set of values shared by the whole university community. Truth, Trust and Justice are at the core of NTU's shared values. As a student, it is important that you recognize your responsibilities in understanding and applying the principles of academic integrity in all the work you do at NTU. Not knowing what is involved in maintaining academic integrity does not excuse academic dishonesty. You need to actively equip yourself with strategies to avoid all forms of academic dishonesty, including plagiarism, academic fraud, collusion and cheating. If you are uncertain of the definitions of any of these terms, you should go to the academic integrity website for more information. On the use of technological tools (such as Generative AI tools), different courses / assignments have different intended learning outcomes. Students should refer to the specific assignment instructions on their use and requirements and/or consult your instructors on how you can use these tools to help your learning. Consult your instructor(s) if you need any clarification about the requirements of academic integrity in the course.

Policy (General)

You are expected to complete all assigned pre-class readings and activities, attend all lectures, tutorial classes punctually and take all scheduled assignments and tests by due dates. You are expected to participate in all tutorial discussions and activities.

Policy (Absenteeism)

Absence Due to Medical or Other Reasons

If you are sick and unable to attend your class / Mid-terms, you have to:

1. Send an email to the instructor regarding the absence and request for a replacement class and make-up midterms.

2. Submit the original Medical Certificate* or official letter of excuse to administrator.

3. Attend the assigned replacement class (subject to availability) and make-up mid-terms.

* The medical certificate mentioned above should be issued in Singapore by a medical practitioner registered with the Singapore Medical Association.

Policy (Others, if applicable)

Diversity and inclusion policy

Integrating a diverse set of experiences is important for a more comprehensive understanding of science.

It is our goal to create an inclusive and collaborative learning environment that supports a diversity of perspectives and learning experiences, and that honours your identities; including ethnicity, gender, socioeconomic status, sexual orientation, religion or ability.

To help accomplish this:

- If you are neuroatypical or neurodiverse, have dyslexia or ADHD (for example), or have a social anxiety disorder or social phobia;

- If you feel like your performance in the class is being impacted by your experiences outside of class;

- If something was said in class (by anyone, including the instructor) that made you feel uncomfortable;

Please speak to your teaching team, our school pastoral officer or a peer or senior (either in-person or via email) about how we can help facilitate your learning experience.

As a participant in course discussions, you should also strive to honour the diversity of your classmates. You can do this by: using preferred pronouns and names; being respectful of others opinions and actively making sure all voices are being heard; and refraining from the use of derogatory or demeaning speech or actions.

All members of the class are expected to adhere to the NTU anti-harassment policy. if you witness something that goes against this or have any other concerns, please speak to your instructors or a faculty member.

Appendix 1: Assessment Criteria for Homework/ Assignments

Each homework assignment consists of a variety of questions relevant to the lecture content. They will be mostly technical questions designed to assist students assimilate various concepts presented in lectures. There will also be a few short reading assignments designed to invite students to critically respond to semi-technical articles written by or about quantum field theorists. The mark percentages for each question will be indicated and the points given to each question will be based not only on the precision of the final answer but also on the validity of the approach.

By mark range

Marks	Criteria
> 90%	Demonstrates very complete understanding of the various conceptual and technical aspects of quantum field theory; be able to solve relevant questions reflecting understanding of the topic at the level of being able to apply to advanced problems in particle theory and condensed matter theory (as described in the intended learning outcomes)
75% to 89%	Demonstrates ability to solve a variety of questions in quantum field theory and a sound awareness of the central principles of QFT. In other words, you have demonstrated the achievement of the learning outcomes in a comprehensive way.
65% to 74%	Able to solve most elementary questions with partially consistent and valid attempts in applying course content to unfamiliar questions. In other words, you have demonstrated the potential to achieve the learning outcomes in time.
50% to 64%	Able to solve only the most basic questions relevant to the course content. Has difficulty in applying ideas to new contexts. Lack of clarity in physical interpretations. In other words, you have demonstrated an achievement of some of the learning outcomes and have some way to go with the others.
< 50%	Unable to solve most basic questions relevant to the course content, and lack of basic mathematical techniques to apply concepts presented in lectures and described in the learning outcomes to new contexts and problems.

Appendix 2: Assessment Criteria for Midterm Tests

Two midterm tests each planned to be 90 minutes, consisting of questions similar in rigor and style to tutorial questions, and the range of questions to appropriately reflect the content coverage of the lectures.

By mark range

Marks	Criteria
> 90%	A complete and impressive demonstration of the achievement of the learning outcomes. Successful and impressive attempts at solving all the questions, including bonus questions. Demonstrates mastery of the various conceptual and technical aspects of quantum field theory; be able to solve relevant questions

	reflecting understanding of the topic at the level of being able to apply to advanced problems in particle theory and condensed matter theory.
75% to 89%	A strong demonstration of the achievement of the learning outcomes Correct solutions to most of the questions in the assignments. Demonstrates ability to solve a variety of questions in quantum field theory and a sound awareness of the central principles of QFT.
65% to 74%	A decent demonstration of the achievement of the learning outcomes. Able to solve most elementary questions with partially consistent and valid attempts in applying course content to unfamiliar questions.
50% to 64%	A superficial demonstration of the achievement of the learning outcomes Able to solve only the most basic questions relevant to the course content. Has difficulty in applying ideas to new contexts. Lack of clarity in physical interpretations.
< 50%	A insufficient demonstration of the achievement of the learning outcomes Unable to solve most basic questions relevant to the course content, and lack of basic mathematical techniques to apply concepts presented in lectures to new contexts and problems.

Appendix 3: Assessment Criteria for Project

The project component's assessment consists of two parts: the report and the presentation. The report will be graded based on the depth and breadth of analysis manifest in the literature review and bonus points will be awarded to the demonstration of original work based on the project theme. In the oral presentation component, the grade will reflect the ability of students to communicate and explain their ideas across to the audience, their response to spontaneous questions and the clarity of their overall presentation.

By mark range

Marks	**Criteria**
> 90%	A complete and impressive demonstration of the achievement of the learning outcomes. Project report indicates excellent understanding of the scientific article(s); demonstrates not only an overall solid understanding of the broad ideas in the literature review but also some of the important concrete details to the extent of being able to reproduce equations and conclusions in the scientific articles; demonstrate ability to critically evaluate articles; demonstrates some form of original work built upon the known results in the literature review. Oral presentation demonstrates clear and strong ability to communicate various concepts in the literature review with high amount of clarity in presentation, a sound understanding of physical ideas and conclusions of

	various scientific articles. Student is able to comment constructively on the importance of various results. Presentation style is interesting and fluent. Able to respond coherently to questions.
70% to 89%	A strong demonstration of the achievement of the learning outcomes Project report demonstrates that the student read and understood most of the concepts presented in the scientific articles. There is some fair attempt in critically responding to the conclusions of the articles and not just a mere summary of facts. Oral presentation shows excellent ability in communicating various concepts at various levels, and genuine understanding of the scientific articles. Able to respond fairly and soundly to most questions.
60% to 69%	A valiant effort to achieve the learning outcomes Project report demonstrates a devoted attempt in covering the ideas presented in the scientific articles, but review lacks in depth and clarity. There is some modest and reasonable attempt in responding to conclusions of various articles more than a cursory summary of the facts presented in the papers, demonstrating some form of original thoughts. Oral presentation shows effort in presenting a summary of results in the various scientific articles; unable to respond to some (basic) questions showing possible lack of rigorous grasp of key ideas in the literature review.
50% to 59%	A weak attempt at achieving the learning outcomes Project report shows a minimal summary of the results of various papers, put together without a strong sense of organization. Very little original response to the content of the articles in the form of critical evaluation. Oral presentation lacks strong structural coherence and inability to convey clearly the results of various articles. But there is a decent attempt to furnish a summary containing basic ideas; unable to respond to most basic questions.
< 50%	An insufficient demonstration of the achievement of the learning outcomes Project report is very poorly written with a depth that is far less than what is expected if basic concepts covered in this course have been properly assimilated. Very little or complete lack of critical evaluations of the papers. Oral presentation is very weak, with signs of confusion indicating a weak grasp of the basic physical ideas in the literature review; unable to respond to basic questions.

Appendix 4: Peer Review for teamwork evaluation

This evaluation form is meant to be filled up by all members in the team. The purpose is to probe team dynamics. Typically, equal marks are awarded to each team member but this form may uncover irresponsible behaviour from certain team members and lead to adjustments in marks being awarded to each team member.

By mark range

Criteria (Weighs)	**Score from 1 to 9*** **(1: Never; 3: Rarely; 5: Occasionally; 7: Frequently; 9: Always)**		
	Member A	Member B	Member C
Member Name			
a. Fulfilling one's responsibility duly (15%)			
Behaved responsibly such as attend meetings punctually and regularly; participate in discussion; complete assigned tasks / roles punctually.	Score from 1 to 9		
	Qualitative comments / reasons		
b. Fulfilling one' responsibilities effectively (25%)			
Behaved and contributed effectively – such as quality of work produced; creativity of ideas; extensiveness of research and thinking.	Score from 1 to 9		
	Qualitative comments / reasons		
c. Managing interpersonal relationships (30%)			
Listened attentively to and sought inputs from others; helped team resolve conflicts and achieved common understanding to function effectively; promoted respect for others and differences; fostered camaraderie.	Score from 1 to 9		
	Qualitative comments / reasons		
d. Providing support to others to achieve goals (30%)			
Behaved fairly and ethically – such as sharing responsibilities and giving credits. Exhibited group citizenship behaviour – such as helping others to learn and complete their work through guidance and encouragement; standing up for others when needed.	Score from 1 to 9		
	Qualitative comments / reasons		

*Score of 1 should be given only when a team member does not really deserve to be awarded any mark for the team assignment (i.e., zero mark) because the member either has not or has barely participated and / or contributed to the team assignment in any meaningful manner.