PH4442 Advanced Particle Physics 2025/26
Lecture Week 1

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- General course information
- Overview of Particle Physics
- Relativity
- Introduction to relativistic QM

Course info

Lectures Fridays 2-5 in Tolansky 125.

Exam (May): 2.5 hour written exam, worth 80% of final mark.

5 problem sheets (in total 20% of mark):

Problem sheets due Mondays at 2 p.m. in weeks 4, 6, 8, 10, 12 (i.e. Monday after end of term).

Usual late policy: lose 10% if <1 day late, otherwise no credit unless agreed in advance with course leader.

Unless exception agreed, solutions must be handwritten, scanned and submitted through moodle.

You are allowed (encouraged) to discuss the coursework with fellow students, but solutions must represent your own work and must be written up independently. Cases of plagiarism or collusion are subject to the College policy in Student Handbook.

Books, notes, etc.

Lecture notes will cover most of the material and will be released as they become ready.

Some books:

I.J.R. Aitcheson and A.J.G. Hey, *Gauge Theories in Particle Physics*, 4th ed., CRC Press, 2021 (open access, link on moodle).

Mark Thomson, *Modern Particle Physics*, CUP, 2013.
Online resources:
https://www.hep.phy.cam.ac.uk/~thomson/MPP/ModernParticlePhysics.html

The starting point for PH4442 is the year-3 course PH3520 or equivalent. You should be familiar with the material in the PH3520 lecture notes (on moodle and here).

Other papers, slides, etc., will be linked on moodle.

Course outline

Lecture week

1-2	Relativistic QM, Klein-Gordon and Dirac Eqs. non-rel. limit, EM interactions, rel. covariance.
3-4	Interpreting negative energy states, propagators, Feynman rules, e^- scattering, trace theorems.
5-6	Cross sections, decay rates. Weak interactions, helicity, chirality, $\pi \to \mu\nu$ decay
7	Neutrino physics
8-9	Electroweak Standard Model, gauge invariance, Higgs mechanism
10-11	QCD, hadronization, jets. LHC physics: partons, $pp \to$ dijets, exotics, Higgs, top, BSM

All of Particle Physics (abridged)

Cast of characters:

Fermions
("matter")

Lepton			Charge
ν_e	ν_μ	ν_τ	0
e^-	μ^-	τ^-	-1

Quark			Charge
u	c	t	$2/3$
d	s	b	$-1/3$

interact with
bosons

Boson	Spin	Charge	Interaction
Photon (γ)	1	0	Electromagnetic
$W^\pm$	1	± 1	Weak
Z	1	0	Weak
Gluon (g)	1	0	Strong
Higgs (H)	0	0	(Weak)

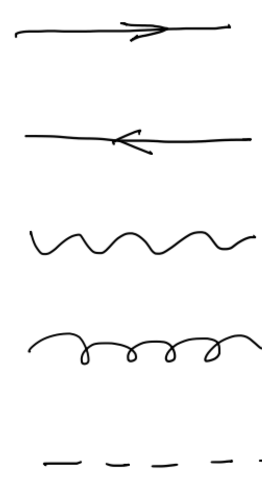
The Standard Model

Cast of characters

+	quantum mechanics	particles created/destroyed, QM $\longrightarrow$ Quantum Field Theory
+	relativity	Special relativity (no gravity)
+	gauge symmetry	Determines interactions
+	25 free parameters	Masses, couplings,...

= The Standard Model (SM) ~Agrees with all exp. data

Theoretical Framework

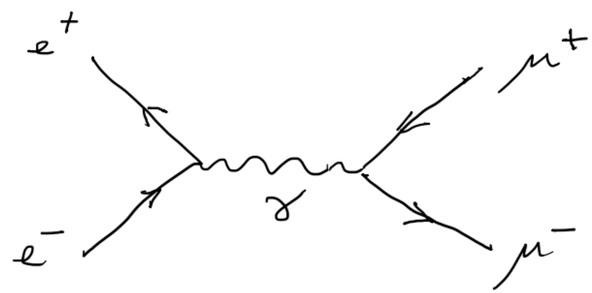


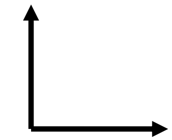
Particle reaction

→ Feynman diagrams

→ QM amplitudes

Example: $e^+e^- \to \mu^+ \mu^-$





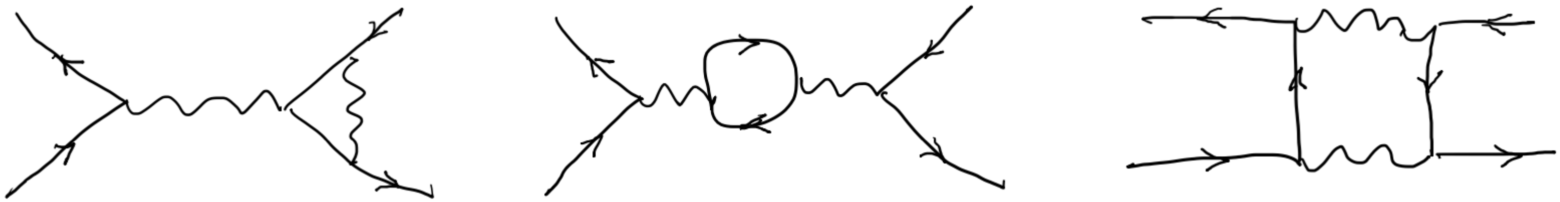
Amplitude:

$$\mathcal{M} = i\frac{e^2}{s}\left[\overline{v}(p_2, s_2)\gamma_\mu u(p_1, s_2)\right]\left[\overline{u}(p_{3,3})\gamma^\mu v(p_4, s_4)\right]$$

Get this from the diagram almost by inspection.

Higher orders, observables,...

If a reaction can proceed via more than one intermediate path, there is an amplitude for each path:



More particle vertices $\longrightarrow$ smaller contribution

Total amplitude = sum of amplitudes for each path: $\mathcal{M} = \sum_i \mathcal{M}_i$

Probability of reaction (cross section, decay rate) $\propto |\mathcal{M}|^2$

Particles created/destroyed $\longrightarrow$ Quantum Field Theory (hard); shortcut via Feynman-Stückelberg interpretation of negative energies; bring in some QFT later in course.