

FYS5190 – Supersymmetry

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Schedule

- Lectures Mondays 12.15 & Wednesdays 14.15
 - Held in Kristian Birkeland and V203 until end of November (~ 15 weeks).
- Lecture plan will be posted on the course page in the Schedule (gradually updated).
- Project (30%): Handed in two weeks ahead of exam.
- Exam (70%): Oral exam some time in December. Need to agree on day.

Exams

- Project (30%)
 - Four-page double column essay on chosen topic.
 - In the style of a journal paper.
 - Template will be provided.
- Exam (70%)
 - Oral exam
 - Focused on the main concepts covered in the course and their relationships.

Prerequisites

- Good knowledge of linear algebra (vector space and matrix properties)
- Quantum mechanics (states as a vectors)
- Field theory needed, but can be taken alongside course (quantum fields, field theory Lagrangians, Feynman diagrams)
- Familiarity with some particle physics is highly useful

Curriculum

- Lecture notes are provided (will be continuously updated with links on Schedule). These should suffice for the exam.
 - Some (more or less) useful exercises in the notes.
- Some suggested reading beyond the notes:
 - H.J.W. Müller-Kirsten, A. Wiedemann, *Introduction to Supersymmetry*, World Scientific (2010). Second Edition.
 - S.P. Martin, *A Supersymmetry primer*, <http://arxiv.org/abs/hep-ph/9709356>.
 - F. Quevedo, S. Krippendorfer, O. Schlotterer, *Cambridge Lectures on Supersymmetry and Extra Dimensions*, <http://arxiv.org/abs/1011.1491>.

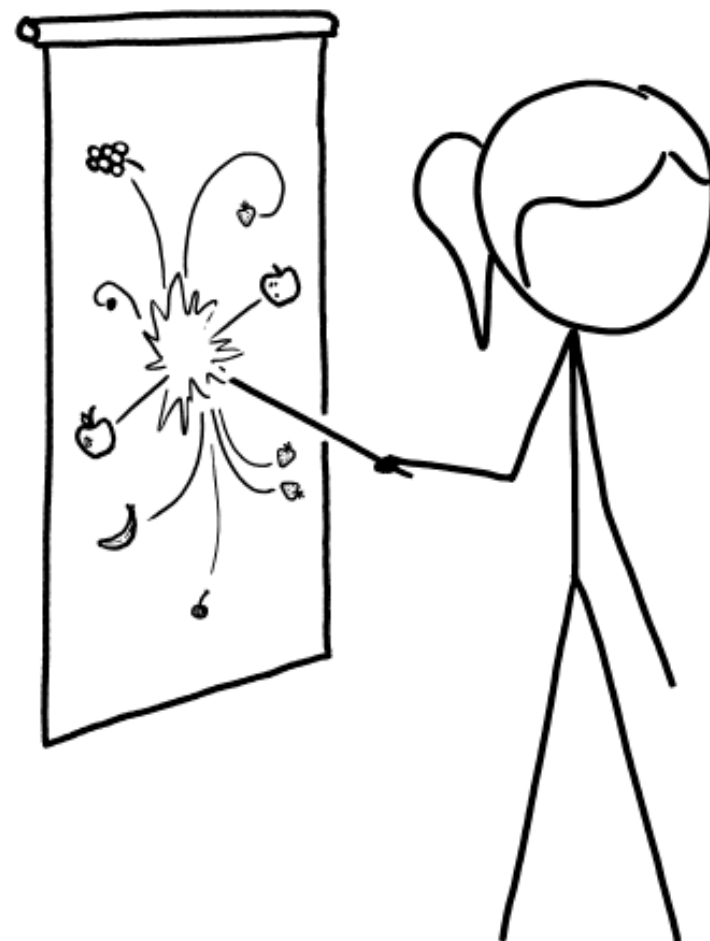
Course content

- Obviously an introduction to supersymmetry (doh!)
 - A (very) popular alternative to the Standard Model
- However, also an introduction to many central concepts in modern high-energy physics
- Part I: A course in the abstract algebraic structure of supersymmetry
 - What symmetry, and why super?
- Part II: *and* a course in the **phenomenology** of supersymmetry
 - How do you discover or falsify supersymmetry?

WHEN TWO APPLES COLLIDE, THEY CAN BRIEFLY FORM EXOTIC NEW FRUIT. PINEAPPLES WITH APPLE SKIN. POMEGRANATES FULL OF GRAPES. WATERMELON-SIZED PEACHES.

THESE NORMALLY DECAY INTO A SHOWER OF FRUIT SALAD, BUT BY STUDYING THE DEBRIS, WE CAN LEARN WHAT WAS PRODUCED.

THEN, THE HUNT IS ON FOR A STABLE FORM.



HOW NEW TYPES OF FRUIT ARE DEVELOPED

- Obviously

- A (very)

- However, a high-energy

- Part I: A co-supersymmetry

- What symmetry

- Part II: an

- How do

s in modern

symmetry

The Standard Model (SM)

three generations of matter (fermions)				interactions / force carriers (bosons)	
	I	II	III		
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
charge	u	c	t	g	H
	up	charm	top	gluon	higgs
spin	$\approx 4.7 \text{ MeV}/c^2$	$\approx 96 \text{ MeV}/c^2$	$\approx 4.18 \text{ GeV}/c^2$	0	
	$-\frac{1}{3}$	$-\frac{1}{3}$	$-\frac{1}{3}$	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
QUARKS	d	s	b	γ	
	down	strange	bottom	photon	
LEPTONS	$\approx 0.511 \text{ MeV}/c^2$	$\approx 105.66 \text{ MeV}/c^2$	$\approx 1.7768 \text{ GeV}/c^2$	$\approx 91.19 \text{ GeV}/c^2$	
	-1	-1	-1	0	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	e	μ	τ	Z	
	electron	muon	tau	Z boson	
	$< 1.0 \text{ eV}/c^2$	$< 0.17 \text{ MeV}/c^2$	$< 18.2 \text{ MeV}/c^2$	$\approx 80.39 \text{ GeV}/c^2$	
	0	0	0	± 1	
	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	
	ν_e	ν_μ	ν_τ	W	
	electron neutrino	muon neutrino	tau neutrino	W boson	
				GAUGE BOSONS VECTOR BOSONS	SCALAR BOSONS

GAUGE BOSONS
VECTOR BOSONS

SCALAR BOSONS

Problems with the SM

- No **dark matter** candidate (neutrinos too light)
- How do you include gravity into the SM?
- Why is there more matter than anti-matter?
- How do neutrinos get mass?
- Why is the mass of the Higgs boson 125 GeV and not 10^{18} GeV?
- Why is the scale of dark energy 10^{-3} eV and not 10^{18} GeV?
- Why is the neutral pion lighter than the charged pion? (the strong CP-problem)

Symmetries

- In Einstein's **special relativity** lengths of four-vectors are invariant under Lorentz transformations:

$$x^\mu \rightarrow x'^\mu = \Lambda^\mu_\nu x^\nu, \quad x'^2 = x^2$$

- This can be extended to the Poincaré symmetry:

$$x^\mu \rightarrow x'^\mu = \Lambda^\mu_\nu x^\nu + a^\mu, \quad (x' - y')^2 = (x - y)^2$$

- **Noether's theorem:**
continuous symmetry $\Leftrightarrow$ conserved quantity
- This is the basis of energy–momentum conservation.

Symmetries

- The Poincaré symmetry is an **external symmetry** (it deals with coordinates)
- SM also has **internal symmetries** (for quantum fields), the **gauge symmetries** representing the three forces
$$SU(3)_c \times SU(2)_L \times U(1)_Y$$
- Two questions asked ~1970:
 - Can the Poincaré symmetry be extended?
 - Can the external and internal symmetries be united?

Rough plan

Part I

- The math behind symmetries: group theory
- The math behind the properties of groups: (Lie) algebras
- The symmetries of the SM: the Poincaré algebra
- How to extend the symmetries of the SM: the superalgebra
- Superspace: an extension of Minkowski space where supersymmetry is manifest
- Superfields: field theory in superspace (here you need QFT!)

Rough plan

Part II

- Construction of Lagrangians for supersymmetry (in general)
- All the neat properties of supersymmetric models
- The Minimal Supersymmetric Standard Model (MSSM)
- The phenomenology of the MSSM
- Dark matter in supersymmetric models