- I am Tim Evans, Theory Group
- WEB PAGE: Theoretical Physics - PG Study - MSC - Info for Graduates
- Office Hours: 2016 Tue, Fri 10am 14609

- Rapid Feedback: 2016
  - Jonathan Baird
  - Even weeks
    - Hand in level 3 office WEDS
    - Presentation Friday
  - Except Week 2
    - Hand in Mon
    - Presentation Thurs.
  - NOT for assessment, written feedback only
    - I nominate 2 or 3 Qs each week

- Problem Sheets
  - Must do = *
  - Should do (No mark)
  - Optional (log) #(!)

- Exams: Issued at end
  - No changes expected except Fermions
Natural Units

For relativistic examples we will use natural units for length, time, mass

\[ c = \hbar = 1\ ]\  \text{where } \begin{cases} \hbar c & = \text{LT}^{-1} \\ \hbar & = \text{L}^2\text{MT}^{-2} \end{cases} \]

- This means we can measure length, time, mass and hence energy (E=mc²) in terms of **one** unit.
- In particle physics they use eV

Metro. & Spacetime

\[ g_{\mu\nu} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix} \]

\[ x^\mu y_\mu = x^0 y_0 - x^1 y_1 - x^2 y_2 - x^3 y_3 \]

We will usually assume 4+3 dimension space-time

**Convention** Repeated Indices = Sum

\[ a_\mu b^\mu = \sum_i a_i b_i = \vec{a} \cdot \vec{b} \]

\[ \text{Vector} \]

\[ \text{Also } \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \end{pmatrix} \]

\[ \text{Matrix} \]
WHY Quantum Theory?

- World is NOT classical (Newton, deterministic, ...)
- On smallest scales we see QUANTUM effects
e.g. photoelectric effect, superfluidity/conductivity
- Classical world only appears as long distance &
  
  long time averages, typically bigger than atomic
  
  
  - Compton wave length \( \lambda = \frac{h}{mc} \) sets scale for
  
  Q \Leftrightarrow \text{CE} \text{ transition}

Why not Quantum Mechanics (QM)?

MANY PARTICLES

QM describes one particle \( \int | \psi|^2 \, dx = 1 \)

or a few particles,

\[ \int \psi_{x_i}^* \psi_{x_i} \, dx = 1, \ldots, N \]

where \( x_i, p_i = \text{position, momentum of} \)

\( i \)-th particle

Language of

FIRST QUANTISATION \( \psi, \bar{\psi} \)

WAVES - \( \gamma \)

- QFT is QM for \( \infty \) number of particles

best is a better language notation

SECOND QUANTISATION \( \gamma, \bar{\gamma} \)

Needed because:

- Relativity allows particle production
  
  if energy \( E \geq \text{mass } m \)

  \( \Rightarrow \) Quantum fluctuations can allow

  states of many (infinite) numbers of

  \( \text{particles AND superpositions with} \)

  \( \text{different numbers} \)

- Condensed matter have "holes & massless"
  
  modes leading to similar issues
QFT is more than QM

There are subtle mathematical differences between QM for FINITE # particles & QFT = QM for INFINITE # particles

These lead to STRIKING new phenomena in QFT vs QM

In particular SYMMETRY BREAKING - Higgs = CONDENSATES - BEC condensons = SUPERFLUID/SUPERA CONDUCTIVITY
What is a field?

**Classified (function)**
A field is a quantity defined at every point of space & time

\[ \phi_a(x, t) \in \mathbb{R}^4 \text{ (classical)} \]

Labels coming from space-time symmetry
- Typically greek alphabet

"Internal Symmetries"
- Typically Latin alphabet

We will focus on scalar fields
= Spin 0
which don't have such labels

A crude/poor picture is that the more stuff (energy/particles/charge) at some point the larger \( \phi \) is.

\( \phi \) is NOT directly measurable

\[ |\phi(x, t)|^2 \neq \text{Probability density} \]

It is a tool

\[ \phi \approx \text{particle} \]

(at best)

e.g., we work with \( \phi \) an operator in QFT not a \( \mathbb{R} \) valued function \( \phi \)

Expectation value

e.g., \( A^\mu(x, t) \) is the classical field used to represent photons in QED

\( E(x, t) \) & \( B(x, t) \) are familiar electric magnetic
\[ A^\mu(x, \xi) \] is four-vector potential

\( \phi, A \) used as the classical field for photons in QED

**N.B.** Electrostatic field, NOT potential scalar field!

- \( E(x, \xi) \) is the electric field
- \( B(x, \xi) \) "Magnetic"

\[
E = -\frac{\partial A^0}{\partial \xi} - \frac{1}{2} \frac{\partial A}{\partial x} \quad B = \nabla \times A
\]

\[20/1, 11/10/11\]

\[13, 11/10/15\]

\[6, 16/10/16\]