Particle Physics

Dr Victoria Martin, Spring Semester 2012

Lecture 5: Quantum Electrodynamics

(The Electromagnetic force, quantised)

- ★Fermion currents
- ★Spin-1 Bosons
- ★$e^- \mu^- \to e^- \mu^-$

Announcements

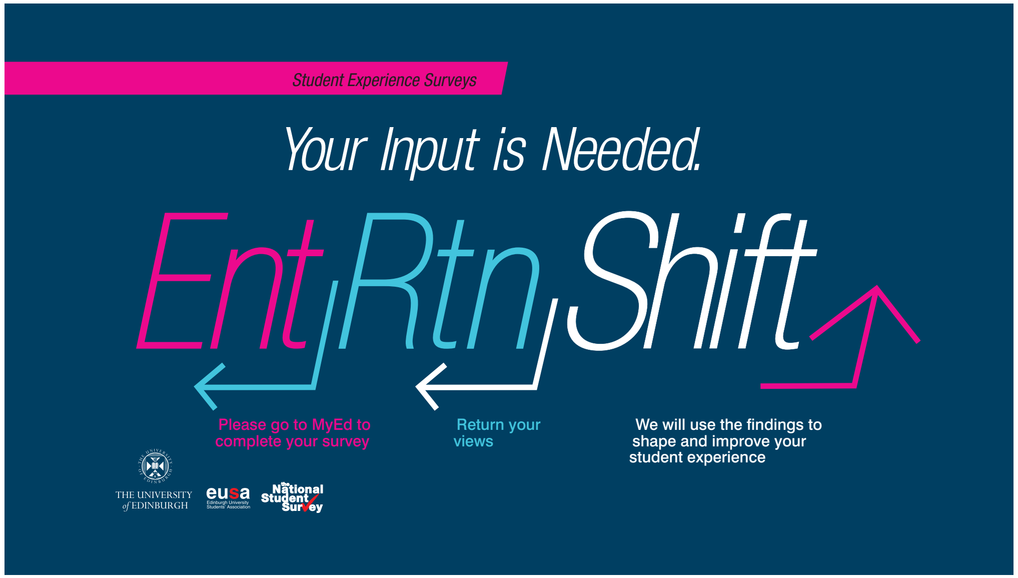
- Lectures as usual this week.

- Next week:
  - lecture on Tuesday only.
  - No lecture on Friday 8th February.
  - Tutorial next week mainly for catch up.

- Tutorial sheet solutions and notes are in preparation.

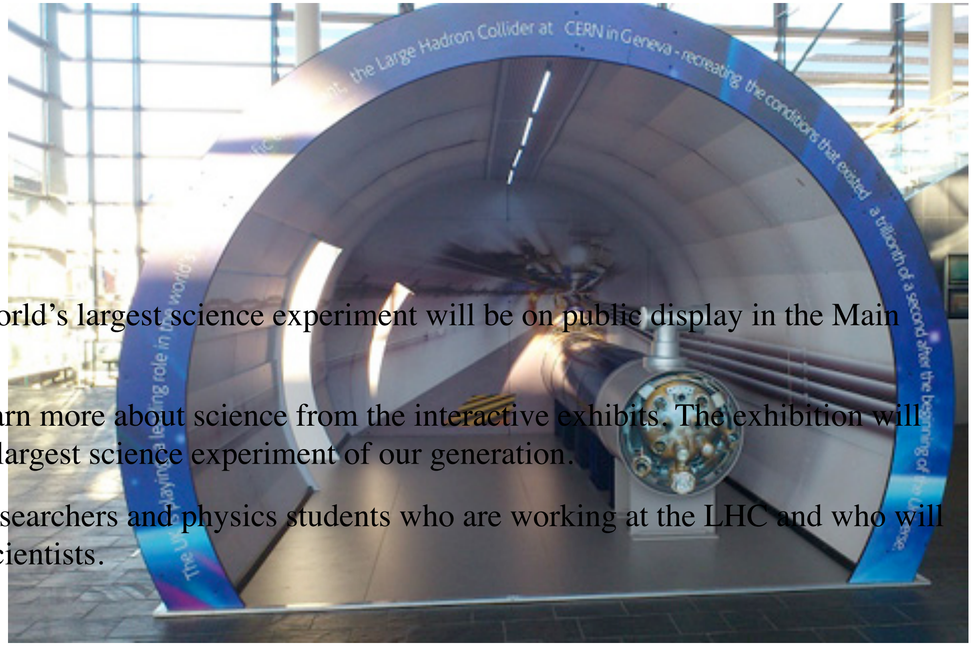
- Notes from last year are online.
  - ➡ Linked from course web page.
  - ➡ Last year's notes cover the same material, but are a bit verbose...

Student Surveys



LHC in the Parliment

http://www.scottish.parliament.uk/visitandlearn/58283.aspx



Saturday 2 February 2013 - Friday 8 February 2013

Main Hall, Free Exhibition

A travelling exhibition showcasing the Large Hadron Collider (LHC), the world's largest science experiment will be on public display in the Main Hall of the Scottish Parliament.

Visitors can walk through a life size model of part of the LHC tunnel and learn more about science from the interactive exhibits. The exhibition will help create a sense of what it's like to be a particle physicist working on the largest science experiment of our generation.

Visitors will also have the opportunity to meet some of the UK's top LHC researchers and physics students who are working at the LHC and who will be available to answer questions and help to inspire the next generation of scientists.

Associated Events

Explore Your Universe - Saturday 2 February

Come along and get involved with the fantastic new family show brought to you by Dynamic Earth as part of the Explore Your Universe project in partnership with the Science and Technologies Facilities Council (STFC) and the Association of Science and Discovery Centres (ASDC). Find out what our world is made of, discover what can be found inside an atom and experiment with making your own electricity! You will also have the chance to see a cloud chamber in action and even make your very own particle to take home with you. Admission is free and will run within normal opening hours.

CERN Lecture - Thursday 7 February

Dr Aidan Robson from the University of Glasgow will be giving a free lecture on CERN, the Large Hadron Collider and his part working on the world's largest scientific experiment. The lecture will begin at 7.00pm. If you wish to take a look at the 'LHC on Tour' exhibition beforehand, please arrive approximately 30 minutes prior to the start.

Notation

- Today we can't avoid using the metric tensor $g_{\mu\nu}$.

$$g_{\mu\nu} = \begin{pmatrix} +1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

- If take the scalar product of two four-vectors, we actually implicitly use the metric tensor:

$$a \cdot b = a_\mu b^\mu = g_{\mu\nu} a^\nu b^\mu = +1 \times (a^0 b^0) - 1 \times (a^1 b^1) - 1 \times (a^2 b^2) - 1 \times (a^3 b^3)$$

- The factors of $+1$ and -1 are due to the metric tensor.

- The important parts today: if we have two four-momentum vectors with different indices $g_{\mu\nu}$ makes the scalar product: e.g. $a^\nu\, b^\mu\; g_{\mu\nu} = a^\nu\, b_\nu = a \cdot b$

The Adjoint Spinor

- Need to define a **fermion current, *j*,** for use in Feynman diagrams.

$$\psi = \begin{pmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \\ \psi_4 \end{pmatrix} \qquad \psi^\dagger = (\psi^*)^T = (\psi_1^*, \psi_2^*, \psi_3^*, \psi_4^*)$$

- $\psi^\dagger\psi$ is not invariant under Lorentz transformations (Spinors are not vectors!)

- Define an **adjoint spinor**, $\bar{\psi} \equiv \psi^\dagger\gamma^0$ $\quad \bar{\psi} \equiv \psi^\dagger\gamma^0 = (\psi_1^*, \psi_2^*, -\psi_3^*, -\psi_4^*)$

- $\bar{\psi}\psi$ **is** invariant under Lorentz transformation

$$\bar{\psi}\psi = (\psi_1^*, \psi_2^*, -\psi_3^*, -\psi_4^*) \begin{pmatrix} \psi_1 \\ \psi_2 \\ \psi_3 \\ \psi_4 \end{pmatrix} = \psi_1^*\psi_1 + \psi_2^*\psi_2 - \psi_3^*\psi_3 - \psi_4^*\psi_4$$

Fermion Currents

- 16 Lorentz invariant quantities can be defined from spinors.

- Each describes a different kind of fermion currents (fermion lines of Feynman diagrams)

scalar:	$\bar{\psi}\psi$
pseudo-scalar:	$\bar{\psi}\gamma^5\psi$
vector:	$\bar{\psi}\gamma^\mu\psi$
axial-vector:	$\bar{\psi}\gamma^\mu\gamma^5\psi$
tensor:	$\bar{\psi}\frac{i}{2}(\gamma^\mu\gamma^\nu - \gamma^\nu\gamma^\mu)\psi$

- Look forward: we will see "vector minus axial vector" currents are important in the Standard Model

vector – axial-vector: $\frac{1}{2}(\bar{\psi}\gamma^\mu\psi - \bar{\psi}\gamma^5\gamma^\mu\psi) = \bar{\psi}\gamma^\mu\frac{1}{2}(1-\gamma^5)\psi$

The Photon

- The photon is described by Maxwell's Equations:

$$\vec{\nabla}\cdot\vec{E}=\rho \qquad \vec{\nabla}\cdot\vec{B}=0$$

$$\vec{\nabla}\times\vec{E}=-\frac{\partial\vec{B}}{\partial t} \qquad \vec{\nabla}\times\vec{B}-\frac{\partial\vec{E}}{\partial t}=\vec{j}$$

- Maxwell's equations can be re-written as (see Griffiths section 7.4)

$$\partial^2 A^\mu = \frac{4\pi}{c} j^\mu \qquad \begin{array}{l} A^\mu = (V,\vec{A}) \text{ with } \vec{B}=\vec{\nabla}\times\vec{A} \\ j^\mu = (c\rho,\vec{j}) \end{array}$$

- A^μ is the electromagnetic four-potential and j^μ is the electromagnetic four-current

- The solutions are $A^\mu = \varepsilon^\mu(s)\, e^{-ip\cdot x}$ where $\varepsilon^\mu(s)$ is the **polarisation vector** (s is helicity)

- Three possible spin orientations along photon direction of travel $s = +1, 0, -1$
  - $s = +1$ corresponds to a right-handed helicity
  - $s = -1$ corresponds to a left-handed helicity

  } **transverse** polarisation states (left and right circular polarisation)

  - $s = 0$ is the **longitudinal** polarisation state (does not exist for a real photon; does exists for W and Z and virtual photons)