Department of Physics & Astronomy
Module Report
Semester 1, 2016-17

<u>Course Title</u>: Particle Physics
<u>Module</u>: PHY304
<u>Lecturer(s)</u>: Chris Booth
<u>Number of students</u>: 104 (excluding those not present for exam)

<u>General Comments</u>: There were no major changes to the course this year. The printed course booklet was again produced, instead of using separate handouts for each topic. The expanded topic of quark symmetry in baryons was continued. There were 21 lectures plus two revision & problem classes, one just before the exam. Five assessed homeworks were set fortnightly, with unassessed problem sheets in the intervening weeks. The use of a feedback sheet for each homework, discussing common problems and errors, was continued.

<u>Problems Experienced</u>: None.

<u>Coursework Performance</u>: (5 homeworks) This was generally performed well. Students appeared to appreciate that it gave them practice in kinematic calculations, in particular. Most students attempted all questions, though two handed in no homeworks, two did only 1 of the 5 and another 3 did only 2. A few students handed work in late and were penalised. The average mark overall was good, at 73%.

<u>Exam Performance</u>:
Exam performance was slightly better than recent years'. The main weaknesses displayed were inadequate explanations (mentioning a few facts without explaining any connections) and faulty logical reasoning, e.g. in explaining the relationship between observations and theories.

Question 1 (compulsory short answers) – most sections were well answered. When describing quarks and leptons, the same information was often given twice – e.g. the fact that they have spin ½ and are fermions were not considered separate properties, and neither was the fact that only quarks are coloured and only they experience the strong interaction. Labelling of the Feynman diagram was often inadequate or wrong. The worst answer was for the symmetry of two-pion states, where symmetry and parity were not properly distinguished, while many assumed bosons obeyed the P.E.P. or discussed quark symmetry (in baryons!) rather than boson symmetry. The question was probably too easy, with average mark 14.3 out of 20 (72%).

Question 2 (quark symmetry, allowed reactions) – an unpopular question. Very few people answered the question as set! Even the first, bookwork, section was poorly answered, with people confusing the symmetry of baryons with that of the quarks that make them up. The second section was often ignored, or if answered wave-functions were not given, and it was not the two light quarks that were considered. In contrast, the final part on allowed interactions was done very well, with many perfect attempts. Average 7.1/15 (47%) for 25 attempts.

Question 3 (Cabibbo theory, decay kinematics) – a popular question. The first, book-work, section was done very poorly. Though many mentioned quark eigenstates, few people explained how weak decays occur in Cabibbo theory. Almost everyone gave approximate values for the CKM matrix element (which was not asked in this section), while few defined the matrix or explained the relationship between mixing and decay amplitudes. Although the kinematic calculation was almost identical to a homework, almost everyone made the problem immensely complicated by squaring every expression in sight! Average 8.1/15 (54%) for 73 answers.

Question 4 (colour, confinement, invariant mass) – a popular question. Generally well answered, though when discussing the ejection of a quark from a hadron, there was often no explanation of why the production of a $q\bar{q}$ pair reduced the energy in the field. Calculations of total momentum were often wrong or involved unnecessary consideration of components. Average 8.1/15 (54%) for 76 answers.

Question 5 (Form factor, 4-momentum transfer) – surprisingly unpopular for a "standard" question! The FF was calculated well, but no-one managed to take the q=0 limit. (Several people found the value of q making $F(q)$=0!) Many confused 4-momenum and 3-momentum. Average 8.2/15 (55%) for 33 answers.

Overall average 62.4% on exam, 64.1% including homeworks; 5 students failed; 36 first class marks.

<u>Answers to numerical and similar questions</u>

1 e) Hypercharge of strange quark is $-^2/_3$.

1 f) Weak interaction, as strangeness is not conserved.

1g) $\Xi^- = ssd$; $\pi^- = d\bar{u}$.

1h) Muon energy is 258 MeV.

2c)i) Electromagnetic – photons involved (all qu. nos. conserved).

2c)ii) Forbidden – τ lepton number not conserved.

2c)iii) Weak – change of strangeness by 1 unit.

2c)iv) Strong – hadrons involved, all qu. nos. conserved.

2c)v) Forbidden – change of strangeness by 2 units.

2c)vi) Forbidden – change of strangeness by 2 units.

2c)vii) Strong – hadrons involved, all qu. nos. conserved.

2c)viii) Weak – involvement of neutrinos (all qu. nos. conserved).

3 c) Maximum pion energy is 2.13 GeV.

4 c) Yes – invariant mass consistent with Λ.

5c) $F(0)=1$.

<u>Responses to Questionnaire comments</u>

Satisfaction with the module is generally high, with many positive comments on the handout material, homeworks and feedback, and the support provided for individual questions, which is very gratifying. Some suggested that the homeworks were (too?) easy, while others that they were difficult. They were a progression, becoming gradually more advanced. It is disturbing that a significant fraction of the class never picked up the feedback sheets or model answers to help them with subsequent problems. There was a suggestion of more worked examples in lectures, which I will consider. Someone asked that "questions and answers be shared with the whole class" – this was done, via the web page, and e-mail reminders about this were sent out.

It is true that the lecture notes contain gaps in derivations or explanations. This is deliberate and is actually highlighted at the appropriate points in the notes, as I believe it aids the learning and remembering of mathematical material when it is presented fresh in lectures with personal notes being taken.

One person asked for more explanation of the theory. I am not sure what was wanted, but this may be addressed by the plan to include more quantum mechanics background. Someone asked for an introduction to the standard model to be included – I thought I had given 21 lectures on this! There were other requests for additional content, but to avoid the course being rushed I doubt if this is practical.

<u>Planned Revisions for next session</u>: More quantum mechanics background to be included in the course book.

Course work deadlines and return of marked work

All work was handed out and required on the dates indicated at the start of the semester on the Third Year timetable. Each piece of work was returned with comments one week after being handed in.

Feedback was provided by comments written on the marked scripts, a specimen solution for each question and a "feedback sheet" containing comments on common errors, easier approaches etc.

Work	Given out	Handed in	Returned to students
Homework 1	28th Sep.	5th Oct.	12th Oct.
Homework 2	12th Oct.	19th Oct.	26th Oct.
Homework 3	26th Oct.	2nd Nov.	16th Nov.
Homework 4	16th Nov.	23rd Nov.	30th Nov.
Homework 5	30th Nov.	7th Dec.	14th Dec.

C N Booth
24th January 2017