Mark scheme for Extension Worksheet – Option J, Worksheet 2

1 For appreciable diffraction around an obstacle of linear size d, $\lambda \approx d$; the de Broglie wavelength of the proton is $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{4 \times 10^{-15}}$; $\lambda \approx 2 \times 10^{-19}$ m and this is the order of magnitude of linear size that can be resolved. [3]

2 A charged particle follows a curved path in the bubble chamber; measuring the radius of the curved path; and knowing (or assuming) the charge the value of the momentum of the particle may be determined. [3]

3 The great advantage is that no photographs need to be taken (so no dead time as in the bubble chamber) and the data collected are digital; so that they can be analysed by computer as opposed to the very tedious and long process of photograph analysis by a human. [2]

4 Available energy is the energy that can be used to create new particles out of the vacuum. [1]

5 14 TeV [1]

6 **a** $E = mc^2 + E_K = \left(938 \text{ MeV c}^{-2}\right) \times c^2 + 2500 \text{ MeV} = 3438 \approx 3400 \text{ MeV}$ [1]

b $E_A^2 = 2Mc^2E + (Mc^2)^2 + (mc^2)^2$ where M is the mass of the target and m the mass of the incoming particle and E its total energy. Here E $= m = M\, 938 \text{ MeV c}^{-2}$; so the available energy is

$E_A^2 = 2 \times 938 \times 3438 + (938)^2 + (938)^2 = 2.9 \times 10^3$ MeV [2]

7 $E_A^2 = 2mc^2E + (mc^2)^2 + (mc^2)^2$ where m the mass of the electron and E the total energy of the incoming electron; we must have that $E_A = 4mc^2 (= 4 \times 0.511 = 2.04 \text{ MeV})$; and so $16(mc^2)^2 = 2mc^2E + 2(mc^2)^2 \Rightarrow 14(mc^2)^2 = 2mc^2E \Rightarrow E = 7mc^2 = 3.6$ MeV [3]

8 Collisions in a synchrotron have higher available energy; but lower probability of collision. [2]

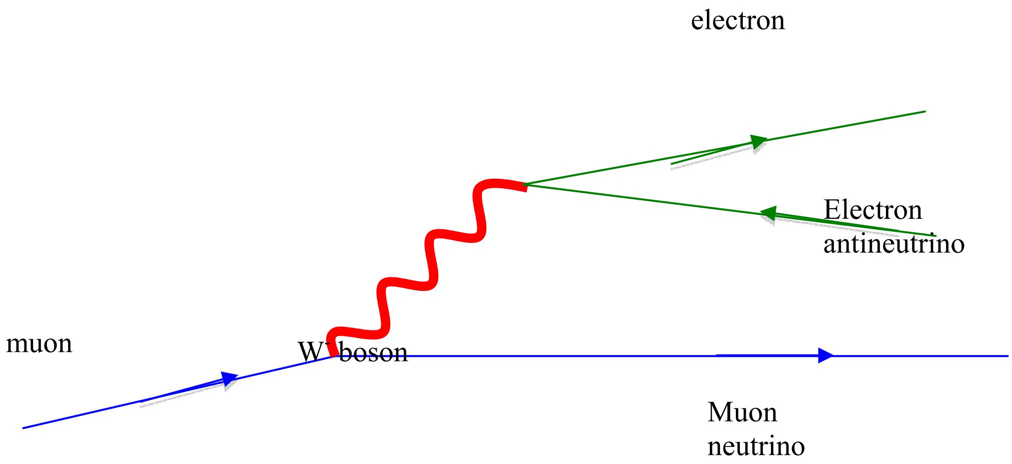
9 A lot of the energy provided is lost as synchrotron radiation by the accelerating particle; so the energy provided is $E + E_{\text{synch.}}$. [2]

10 The main difference is that that masses change. [1]

11 It would violate electron lepton number; and muon lepton number. [2]

12 **a** the reaction is $\mu^- \to e^- + \overline{\nu}_e + \nu_\mu$ for each neutrino. [2]

b A Feynman diagram is:



W^- boson; muon–muon neutrino line; electron–electron antineutrino line [3]

13 **a** hadron [1]

b photon [1]

c lepton [1]

14 Choose three from: quarks exist and gave fractional electric charge; gluons exist and are electrically neutral; there are three types of colour for quarks; quarks behave as free particles when probed at high energies. [3]

15 Asymptotic freedom means that when probed at high energies quarks inside hadrons behave as free particles; evidence for this comes from deep inelastic scattering experiments where the leptons scattering off hadrons appear to be bouncing off loosely connected quarks. [2]

16 $\frac{3}{2}kT \approx 2mc^2$; and so

$$T \approx \frac{4mc^2}{3k} = \frac{4 \times 0.511 \times 10^6 \times 1.6 \times 10^{-19}}{3 \times 1.38 \times 10^{23}} = 7.899 \times 10^9 \approx 8 \times 10^9 \text{ K}$$ [2]

17 It is believed that in the very early universe there was a slightly greater number of particles than antiparticles; particle antiparticles pairs annihilated into photons and photons materialised into particle antiparticle pairs maintaining an equilibrium of the numbers; but as the universe expanded and the temperature dropped (below 8×10^9 K, see previous problem) particle antiparticle pairs continued to annihilate but photons could no longer produce particle antiparticle pairs; and so what has been left behind today is just the excess of particles that were originally present. [4]

