2016 - NPP

Quarks: $\overset{I}{\begin{pmatrix} u \\ d \end{pmatrix}} \overset{II}{\begin{pmatrix} c \\ s \end{pmatrix}} \overset{III}{\begin{pmatrix} t \\ b \end{pmatrix}}$ Anti-Quarks $\overset{I}{\begin{pmatrix} \bar{u} \\ \bar{d} \end{pmatrix}} \overset{II}{\begin{pmatrix} \bar{c} \\ \bar{s} \end{pmatrix}} \overset{III}{\begin{pmatrix} \bar{t} \\ \bar{b} \end{pmatrix}}$

Leptons $\overset{I}{\begin{pmatrix} e^- \\ \nu_e \end{pmatrix}} \overset{II}{\begin{pmatrix} \mu^- \\ \nu_\mu \end{pmatrix}} \overset{III}{\begin{pmatrix} \tau^- \\ \nu_\tau \end{pmatrix}}$ Antileptons $\overset{I}{\begin{pmatrix} e^+ \\ \bar{\nu}_e \end{pmatrix}} \overset{II}{\begin{pmatrix} \mu^+ \\ \bar{\nu}_\mu \end{pmatrix}} \overset{III}{\begin{pmatrix} \tau^+ \\ \bar{\nu}_\tau \end{pmatrix}}$

Charges: u, c, t charge $= +\frac{2}{3}$ $\bar{u}, \bar{c}, \bar{t}$ charge $= -\frac{2}{3}$

d, s, b charge $= -\frac{1}{3}$ $\bar{d}, \bar{s}, \bar{b}$ charge $= +\frac{1}{3}$

e^-, μ^-, τ^- charge $= -1$ e^+, μ^+, τ^+ charge $= +1$

$\nu_e, \nu_\mu, \nu_\tau, \bar{\nu}_e, \bar{\nu}_\mu, \bar{\nu}_\tau$ charge $= 0$

→ Must not be violated, must be equal before & after decay

2a) Due to conservation of energy: $E^2 = m^2c^4 + p^2c^2$. Even for a particle at rest, $E = mc^2$, the mass must be conserved, and so the mass ~~for~~ of a decaying particle must be ~~exceed the~~ less than the mass of decayed particles, otherwise energy is not conserved.

b) uud

c) i) $E_{com} = 2E_{beam}$ $\qquad W^2c^4 = \left(\sum_i^N E_i\right)^2 - \left(c\sum_i^N p_i\right)^2$

$2 \times 6500 = 13{,}000\,\text{GeV} = 13\,\text{TeV}$

ii) As protons have much lower mass than protons so would have a lower centre of mass energy. Also ~~they~~ they do not have to overcome the coulomb barrier

↳ protons annihilate

3a) ~~$E^2 = (\gamma M_0c^2)^2$~~ $+$ ~~$p = \gamma\beta M$~~ $E^2 = (\gamma M_0c^2)^2 + (\gamma\beta M)^2 = \gamma^2\left[(M_0c^2)^2 + (\beta M)^2\right] = M_0^2c^4 + p^2c^2$, $\beta = \frac{v}{c}$, $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$

b) As solutions to this are $E = \pm\gamma\sqrt{(M_0c^2)^2 + (\beta M)^2}$, the negative values led to the idea of particles travelling backwards in time, i.e. anti-particles

→ positive ods travel forward in time

c) ~~antiproton~~ positron was first discovery of antiparticle

d) The tracks in the cloud chamber curved according to a magnetic field which enabled the determination of charge (by following the trajectory). Opposite curve to electron in cloud chamber

4a) · a_s = Surface Term. This reduces the binding energy as nucleons on the surface of the nucleus do not have ~~any~~ other nucleons to bind to so reduces the overall binding energy. ↳ Fewer on surface

b) · Heavy nuclei contain more neutrons on average. This is due to coulomb repulsion of protons so there is a preference towards ~~neutron heavy nuclei~~. This is explained by the coulomb term, ~~a_c~~. → Result of Asymmetry term, a_a

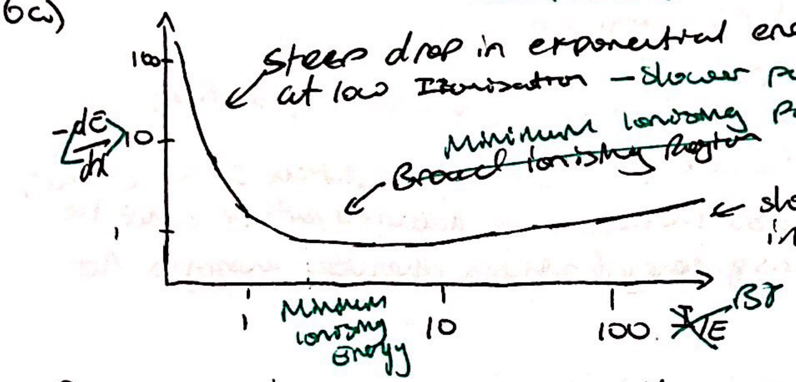
5a) • Scintillator
• Photomultiplier tube (PMT)
• Geiger Müller Detector

• Vertex & tracking detectors
• electromagnet Calorimeter
• Hadronic Calorimeter
• Muon Detector
} LHC

b). Muons are weakly interacting and have a low decay probability ~~so~~ ~~of~~ and ~~so~~ are very penetrating so are not much detected in the ~~electronic~~ electromagnet calorimeter but in muon chambers. Pions are ~~det~~ absorbed and detected in the electromagnet calorimeters. ↳ Muons traverse whole detector, detected on last part. • Pions deposit in HCAL, charged have track

c). b-jets leave tracks in the electromagnet calorimeter and deposit energy in the hadronic calorimeter. Their curvature can also be detected by magnetic fields.
↳ B-jets are longer lived, decay a few mm away. Can be reconstructed from displaced secondary vertex.

6a)

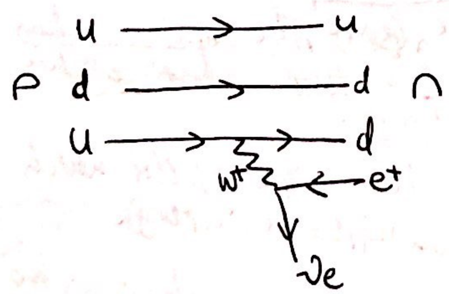


b) A proton loses more energy at this region as ionisation is the resonant energy type over bremsstrahlung rather than a pion which is more likely to lose energy via bremsstrahlung than ionisation.

$p = 1\,GeV/c$, $p = mv$

$v = \frac{p}{m}$ • Proton is slower, loses more energy at low energies.

7a) i) ~~A~~ $p \to n + e^+ + \nu_e$. Allowed
uud udd



→ Neither is charge : $p + p \to p + \bar{p} + \pi^0$

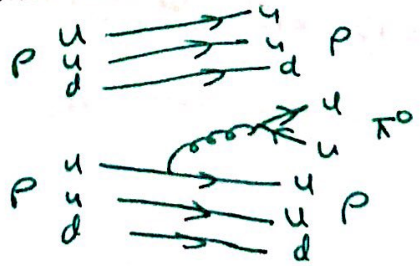
ii) forbidden, violates baryon number ~~and mass conservation~~

iii) ~~Forbidden, violates mass conservation~~

iv) ~~$p + p \to \pi^0 + \pi^+ + \pi^+$ Allowed~~
~~uud uud $u\bar{u}$ $u\bar{d}$ $u\bar{d}$~~

Allowed

$p + p \to p + p + \pi^0$



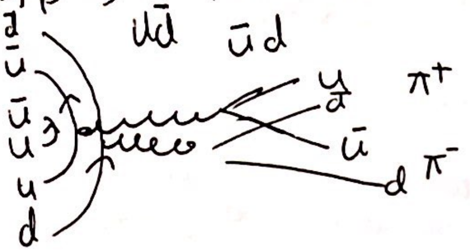
②

~~$p + p \to \pi^0 + \pi^+ + \pi^+$~~ ~~Allowed.~~

uud uud $u\bar{u}$ $u\bar{d}$ $u\bar{d}$ forbidden. Baryon number not conserved

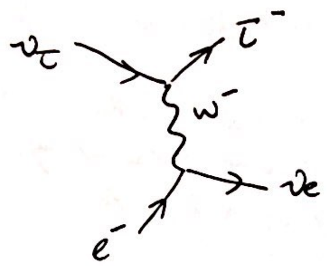
v) $p + \bar{p} \to \pi^+ + \pi^-$ Allowed

$u\bar{d}$ $\bar{u}d$



vi) ~~τ~~ → forbidden. Muon lepton number not conserved

vii) Allowed



b i) ~~$A \to p^+$~~

$p \to n + e^+ + \nu_e$

~~^{18}O~~ ^{17}O

ii) $T_{1/2} = 109.8$

$A = \frac{N}{\tau}$ $\Rightarrow$ $\frac{N}{2} = N e^{-T_{1/2}/\tau}$

$\ln 2 = \frac{T_{1/2}}{\tau}$

$\tau = \frac{T_{1/2}}{\ln 2} = \frac{109.8 \times 60}{\ln 2} = 9435.225\ s$

$A = \frac{N_A}{\tau} = \frac{6.02 \times 10^{23}}{9435.225} = 6.38 \times 10^{19}$ decays/s

5 minutes $= 5 \times 60 = 300s$

$\Rightarrow 6.38 \times 10^{19} \times 300 = 1.91 \times 10^{22}$ positrons

~~iii) $^{18}F \to {}^{17}O + n + e^+ + \nu_e$~~

iii) $^{18}F \rightarrow ^{17}O + n + e^+ + \nu_e$

neutrino has negligible mass

$18.000938 - 16.9991317 - 1 - \frac{0.511}{931.5} = 1.257 \times 10^{-3} u$

$= 1.1715 \text{ MeV} \approx 1.87 \times 10^{-13} J$

8a). As the decay occurs very fast and so the particle does not travel far before decaying. Hence only small widths are able to be probed.

b) ~~It appeared tha~~ It was previously assumed the proton was only made of 3 quarks, uud. However it appeared that the ~~energy~~ cross section measured would vary depending on how energetically it was probed.

~~I~~ So this model was changed to a dynamic one with a 'sea of quarks' ~~which~~ ~~exist~~ and gluons floating about and interacting, with the quarks constantly forming $q\bar{q}$ pairs and annihilating. And so the simple model was updated.

c i) $P = (E_p + E_e, p_p + p_e)$

$E_e = 70$ GeV, $E_p = 7000$ GeV

$P^2 = (E_p + E_e)^2 - (p_p + p_e)^2$

$= E_p^2 + E_e^2 + 2E_pE_e - p_p^2 - p_e^2 - 2p_pp_e$

$E_p \sim p_p$ $\quad$ $E_e \sim p_e$

$(p \gg M)$

$= 2E_pE_e(1 - \cos\theta)$ ~~the~~

head on collision, $\theta = 180°$

$= ~~E_e E_p~~ \; 4E_pE_e$

$P = 2\sqrt{E_pE_e} = 2\sqrt{7000 \times 70} = 1400$ GeV/c

ii) • ~~The frequency of pulses of particles~~

• The number of particles per bunch

• ~~The velocity of the particles in~~ a bunch

• N.o of colliding bunches

• N.o of particles per bunch

• Cross-sectional area of the beams

• Frequency beams circulate the ring

$\pi^+ \rightarrow \mu^+ \nu_\mu$

$P_i = (M_\pi, 0)$ $\quad P_f = (E_\mu + E_\nu, p_\mu + p_\nu)$

$P_i^2 = P_f^2$

$M_\pi^2 = (E_\mu + E_\nu)^2 - (p_\mu + p_\nu)^2$

$= E_\mu^2 + \cancel{E_\nu^2} + 2E_\mu E_\nu - p_\mu^2 - \cancel{p_\nu^2} - 2\vec{p}_\mu \cdot \vec{p}_\nu$

$(p_\nu \sim E_\nu)$

$E_\mu^2 = m_\mu^2 + p_\mu^2$

$= m_\mu^2 + 2E_\mu E_\nu - 2 p_\mu \cdot E_\nu = m_\mu$

$\cancel{m_\pi^2 - m_\mu^2 = 2E_\nu (E_\mu - p_\mu)}$

$M_\pi^2 - m_\mu^2 = 2(E_\mu E_\nu - p_\mu E_\nu)$

$= 2(E_\mu E_\nu - p_\mu E_\nu \cos\theta)$ $\quad p_\mu \sim E_\mu$, $p \gg m$, $\cos\theta = -1$

$= 2(2E_\mu^2)$

$\sqrt{\frac{M_\pi^2 - m_\mu^2}{4}} = E_\mu = \sqrt{\frac{139.57^2 - 105.7^2}{4}} = 45.57$ MeV

Initial: $(E_{\pi^+}, 0)$

After: $(E_\mu, -\vec{p})$, $(E_{\nu_\mu}, \vec{p})$

$P_i^2 = P_f^2$

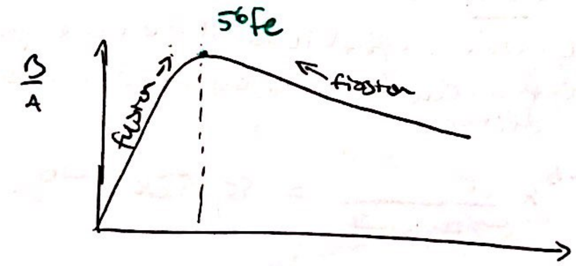
$P_i = P_\mu + P_\nu$

$P_\mu = P_i - P_\nu$

$P_\mu^2 = (P_i - P_\nu)^2$

Rearrange etc –

ei)



• increases rapidly for low nucleon (spikes for magic numbers), then slowly decrease

ii) • Fusion is possible for $A < 56$, as this is the maximum binding energy per nucleon. Nuclei fuse up to here and beyond this, it is not energy beneficial to fuse as the binding energy per nucleon does not increase.

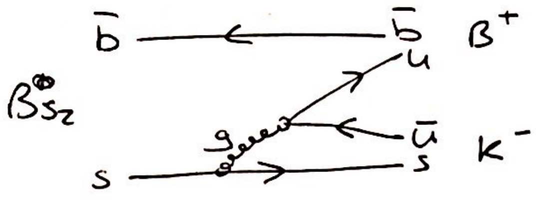
This is the process of two smaller nuclei joining to form a larger nuclei, releasing energy in the process

• Fission is a larger nucleus splitting apart to smaller nuclei releasing energy in the form of kinetic energy and heat from its daughter particles and emitted neutrons so releases energy as the binding energy per nucleon increases. • Total binding energy is larger, total energy is smaller, rest is released as KE

iii) $2 \times 2.224 - 8.482 = \underline{-4.034 \text{ MeV}}$

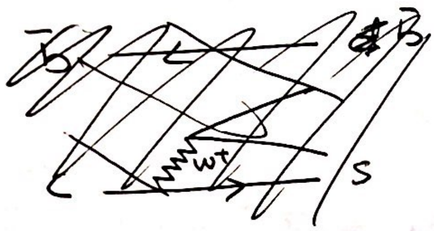
a) i) $B^0_{s2} \rightarrow B^+ + K^-$

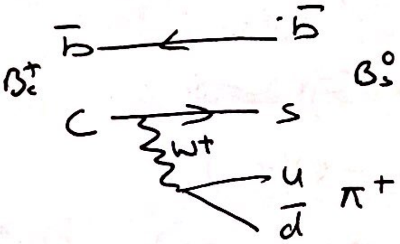
$\bar{b}s \quad \bar{b}u \quad s\bar{u}$



ii) $B_c^+ \rightarrow B_s^0 + \pi^+$ 　　 uct $+$

$\bar{b}c \quad \bar{b}s \quad u\bar{d}$ 　　 ds b $-$





b) i) occurs through ~~strong~~ strong

ii) occurs through weak

c) · B^0_{s2} as ~~gluon~~ strong force decay faster than weak force which is much more strongly interacting as their intermediatory particles have mass.

· weak depends on Q-value $\sim Q^5$

· Lifetime is proportional to the inverse square of the coupling constant, which causes decay

d) B^+, $c\tau = 450\,\mu m$

B^0_{s2}, $p = 10$ GeV/c $= \beta\gamma m$

$$\boxed{L = c\tau\beta\gamma} = 450 \times 10^{-6} \times \frac{10}{5279 \times 10^{3}} = 8.52 \times 10^{-10}\,m$$

e) $B^0_{s2} \rightarrow B^+ + K^-$

$$P^2_{B^0_{s2}} = (P_{B^+} + P_{K^-})^2$$

$$M_{B^0_{s2}} = P^2_{B^+} + P^2_{K^-} + 2P_{B^+} \cdot K^- \qquad M \gg P$$

$$= M_B^2 + M_{K^-}^2 + 2(E_{B^+}E_{K^-} - P_B P_K)$$

$(E_B+E_K)^2 - (P_B+P_K)^2$

$E_B^2+E_K^2+2E_BE_K - P_B^2 - P_K^2 - 2P_B\cdot P_K$

$= M_B^2 + M_K^2 + 2(E_BE_K - \cancel{2}P_B\cdot P_K) = M_{B_{s2}}^2$

$M_{B_{s2}}^2 - M_B^2 - M_K^2 = \cancel{2\!\!\!\!2}\ 2(E_BE_K - \vec{P}_B\cdot\vec{P}_K)$

$E^2 = M^2 + P^2$

$\cancel{M_{B_{s2}}^2 - M_B^2 - M_K^2 = 2(E_BE_K - \sqrt{E_B^2-M_B^2}\cdot\sqrt{E_K^2-M_K^2})}$

$\boxed{E_B = M_B = E_B+E_K \quad E_B = M_B - E_K}$

$\boxed{P_B = -P_K = P}$

$\Rightarrow M_{B_s}^2 - M_B^2 - M_K^2 = 2[(M_B - E_K)E_K + P^2]$

$= 2[M_BE_K - \cancel{E_K^2} + \cancel{E_K^2} - M_K^2]$

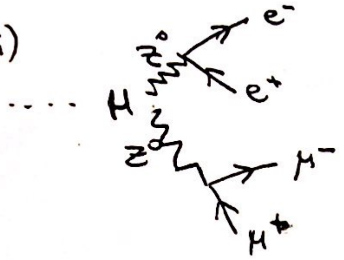
$$\frac{M_{B_s}^2 - M_B^2 - \cancel{M_K^2} + \cancel{2}M_K^2}{2M_B} = E_K$$

$$= \frac{M_{B_{s2}}^2 - M_B^2 + M_K^2}{2M_B} = E_K$$

- ~~Convert to other one lorentz~~
- Convert to the particle frame via Lorentz transform

f) $\frac{P}{[GeV]} \approx 0.3 \frac{B}{[T]} \frac{r}{[M]}$

) ai)



ii) 3 4 6eV/c^2

b) 1 bn = 10^{-28} m^2

$\sigma = 20{,}000$ fb

$20{,}000 \times 10 = 2\times10^{5}$ collisions

$$\left(\left(\frac{3.36}{100}\right)^2 + \left(\frac{3.36}{100}\right)^2\right) \times 2\times10^5 = \cancel{451}584$$

$0.027 \times (0.0336 + 0.0336) \times 2\times10^5$

0.027

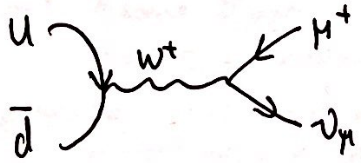
~~0.027~~ bosons

H

0.973 not Z bosons

c) No, Higgs boson couples to mass and photons are massless

d) $\pi^+ \rightarrow \mu^+ + \nu_\mu$



e) The rate of decay is supressed as the ~~electron~~ positron mass is much smaller, so would need a much greater velocity and therefore, the ~~rate of~~ $\mu^+\nu_\mu$ is preferred.

f)

g)

h)