Particle Physics 1: Exercise 3

Exercise 1

Treating the π^0 as a $u\bar{u}$ bound state, draw the Feynman diagrams for:

(a) $\pi^0 \to \gamma\gamma$

(b) $\pi^0 \to \gamma e^+ e^-$

(c) $\pi^0 \to e^+ e^- e^+ e^-$

(d) $\pi^0 \to e^+ e^-$

By considering the number of QED vertices present in each decay, *estimate* the relative decay rates taking $\alpha = 1/137$.

Exercise 2

Explain why it is not possible to construct a valid Feynman diagram using the Standard Model vertices for the following processes:

1. $\mu^- \to e^+ e^- e^+$
2. $\nu_\tau + p \to \mu^- + n$
3. $\nu_\tau + p \to \tau^+ + n$
4. $\pi^+ + \pi^- \to n + \pi^0$

Exercise 3

Tungsten has a radiation length of $\mathrm{X}^0 = 0.35\,\mathrm{cm}$ and a critical energy of $\mathrm{E_c} = 7.97\,\mathrm{MeV}$. Roughly what thickness of tungsten is required to fully contain a 500 GeV electromagnetic shower from an electron?

Exercise 4

The CPLEAR detector consisted of: tracking detectors in a magnetic field of 0.44 T; an electromagnetic calorimeter; and Čerenkov detectors with a radiator of refractive index $n = 1.25$ used to distinguish $\pi^\pm$ from $K^\pm$.
A charged particle travelling perpendicular to the direction of the magnetic field leaves a track with a measured radius of curvature of $\mathrm{R} = 4\,\mathrm{m}$. If it is observed to give a Čerenkov signal, is it possible to distinguish between the particle being a pion or a kaon?

Exercise 5

Draw the scheme of interaction of a photon (~ GeV) and a detector with a magnetic field. Assume that the detector has a typical multi-layer structure with (from the innermost to the outermost subdetector): tracking detectors, ECAL, HCAL and muon chambers.
Draw the same scheme also for the other particles: $e^\pm$, p, n , $\pi^\pm$, π^0, $\mu^\pm$.

Exercise 1

Treating the π^0 as a $u\bar{u}$ bound state, draw the Feynman diagrams for:

(a) $\pi^0 \to \gamma\gamma$ 98.8 %.

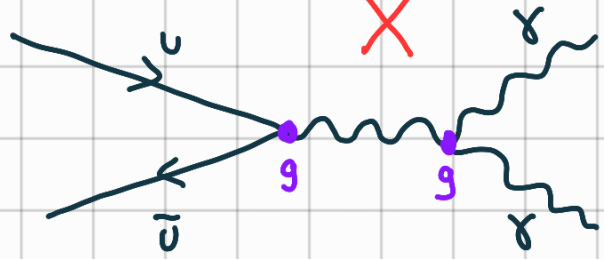
(b) $\pi^0 \to \gamma e^+ e^-$ 1.2 %.

(c) $\pi^0 \to e^+e^-e^+e^-$ 3×10^{-5} %.

(d) $\pi^0 \to e^+e^-$ 6×10^{-8} → Not only dependent on vertices numbers

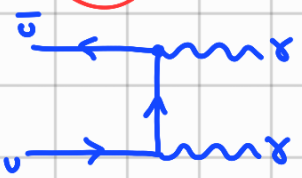
By considering the number of QED vertices present in each decay, *estimate* the relative decay rates taking $\alpha = 1/137$.

a)



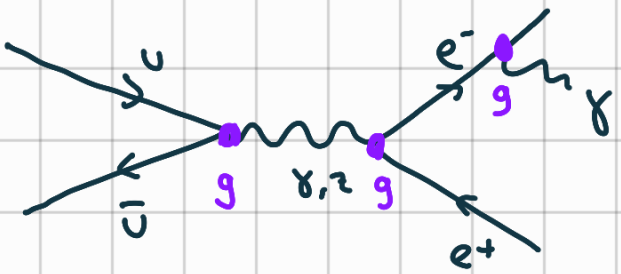
→ cannot happen since γ has no mass, no CENTER of MASS in the photon part

$a^2 \propto g_W^2$

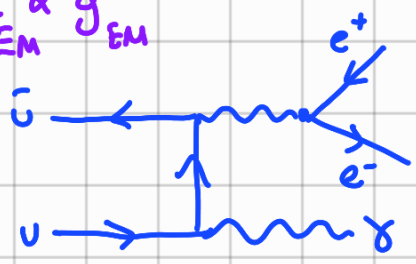


g_{strong}
g_{EM}
g_{weak} ↑

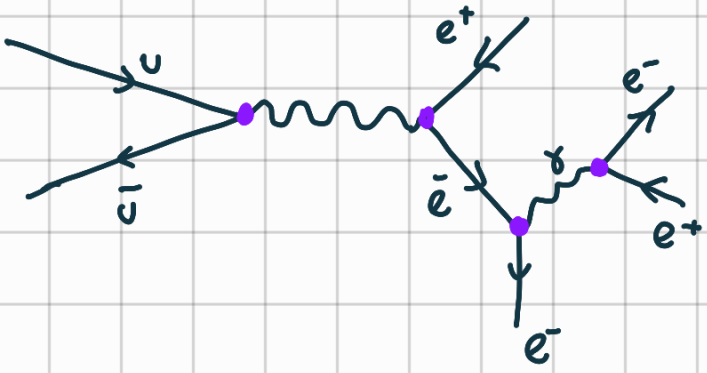
b)



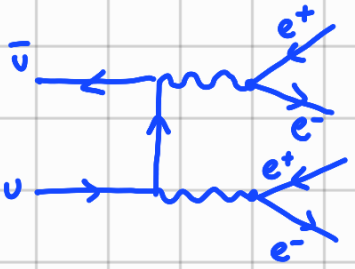
$a_{EM}^3 \propto g_{EM}^3$



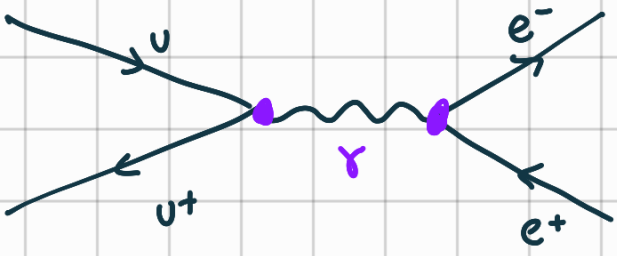
c)



$a_{EM}^4 \propto g_{EM}^4$



d)



$a_{EM}^2 \propto g_{EM}^2$

$a_{EM}^2 > a_W^2 > a_{EM}^3 > a_{EM}^4$

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2. $\nu_\tau + p \to \mu^- + n$
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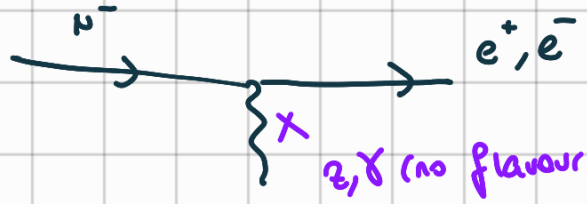
$p = uud$ $\quad n = udd$

$\pi^+ = u\bar{d}$ $\quad \pi^- = \bar{u}d$ $\quad \pi^0 = \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$

1)



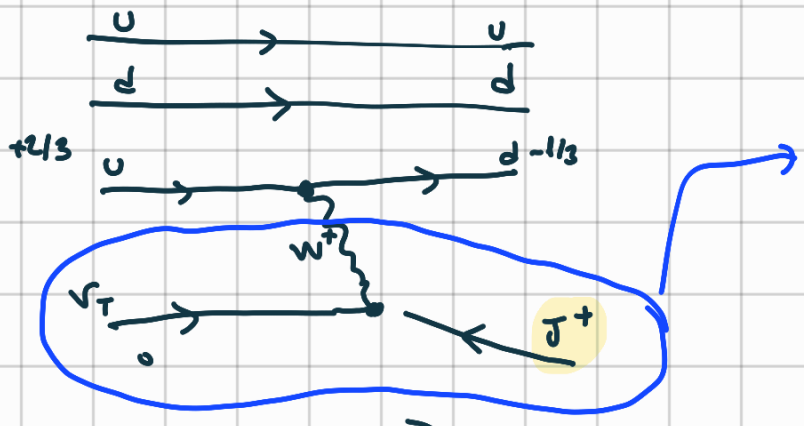
Z, γ (no flavour change)

W (μ^- , ν_{μ^-})

Conservation of muon and electron numbers!

2) $\nu_\tau + p \to \mu^- + n$

$\nu u d$ $\quad udd$



Leptons only couple to the corresponding weak eigenstate neutrino flavour.

??

Turning a particle into an antiparticle

NO SUCH VERTICES EXIT!

3) possible? X

4) $u\bar{d} + \bar{u}d \to udd + \frac{u\bar{u} - d\bar{d}}{\sqrt{2}}$

Net numbers of particles and antiparticle must be CONSTANT acc. to SM!

Exercise 3

Tungsten has a radiation length of $X^0 = 0.35$ cm and a critical energy of $E_c = 7.97$ MeV. Roughly what thickness of tungsten is required to fully contain a 500 GeV electromagnetic shower from an electron?

$$x = \frac{\ln(E/E_c)}{\ln 2} \simeq \frac{\ln\left(\frac{500 \times 10^9 \text{ eV}}{7.97 \times 10^6 \text{ eV}}\right)}{\ln 2} \simeq 15.94 \simeq 16$$

$$\text{Thickness} = x \cdot X^0 = 16 \times 0.35 \text{ cm} = 5.6 \text{ cm}$$

Exercise 4

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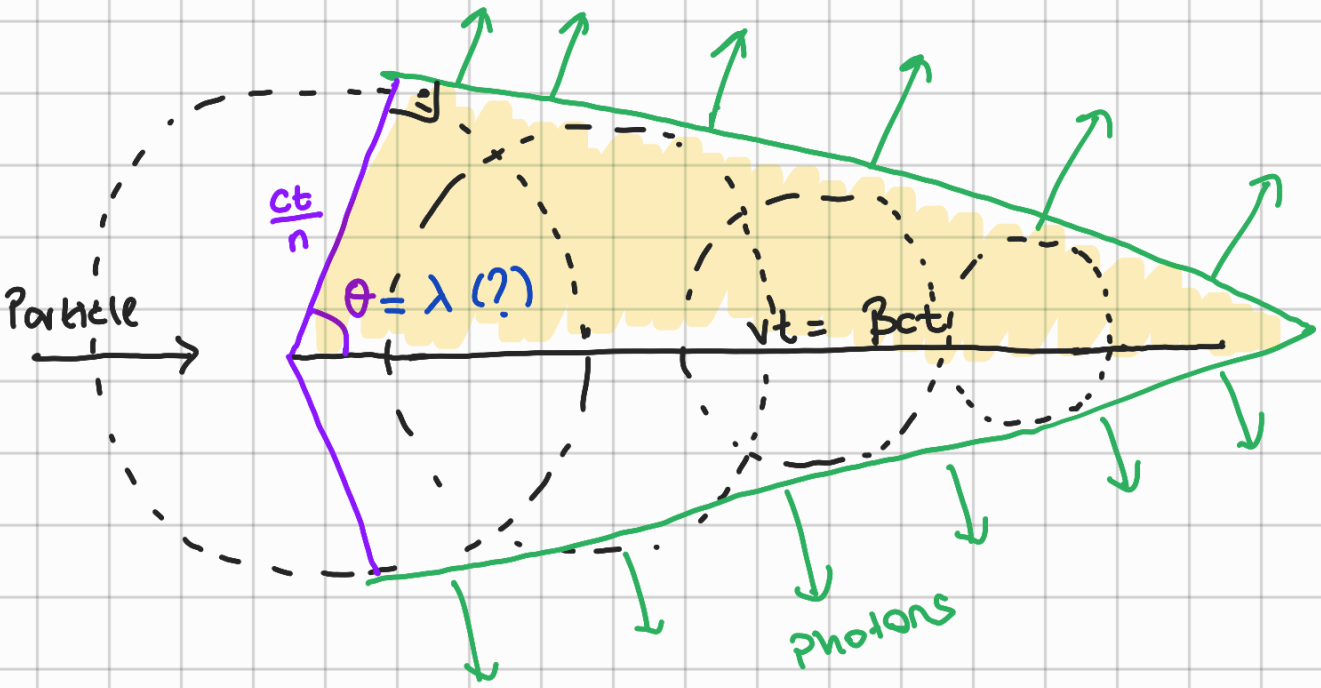
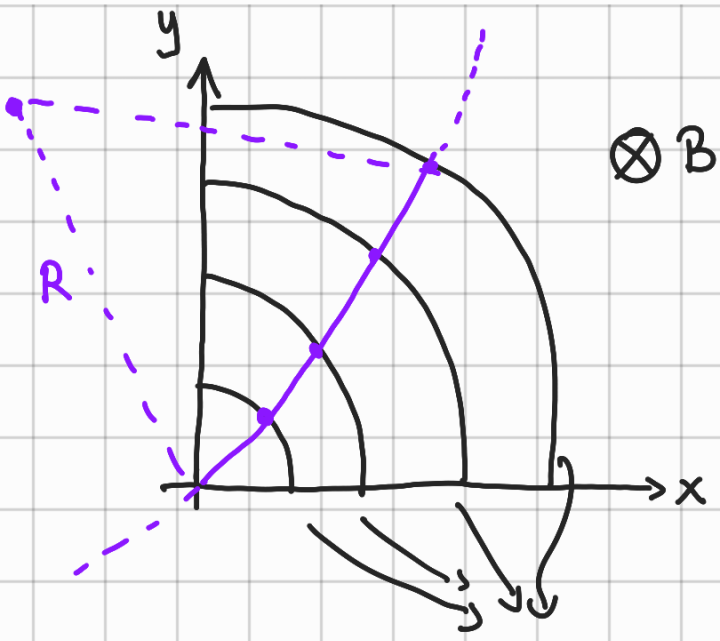
A charged particle travelling perpendicular to the direction of the magnetic field leaves a track with a measured radius of curvature of R = 4 m. If it is observed to give a Čerenkov signal, is it possible to distinguish between the particle being a pion or a kaon?



$B = 0.44\,T$ $\quad n = 1.25$



Several cylindrical surfaces of silican wafers

$p\cos\lambda = 0.3\ B \cdot R = 0.3 \times 0.44\,T \times 4\,m$

$= 528\ MeV/c$

$p = \gamma\beta m$

$m_\pi = 140\ MeV$

$\beta_\pi = \frac{p}{E} = \frac{p}{\sqrt{p^2+m^2}} = 0{,}967$

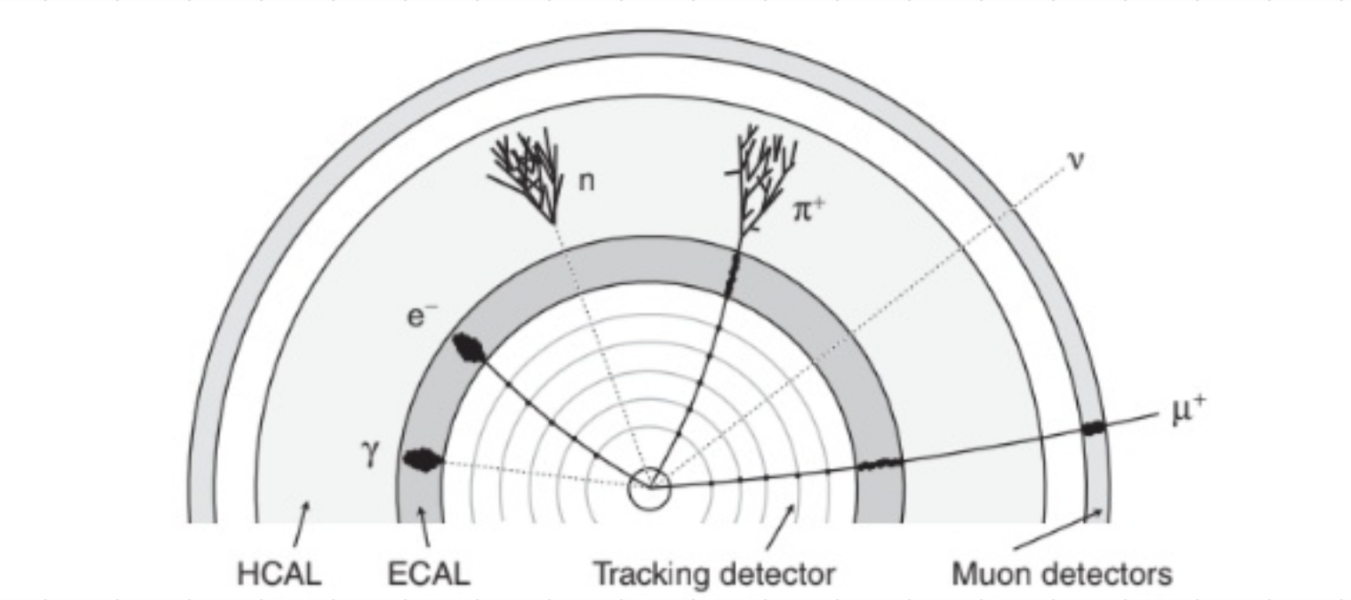
$m_k = 494\ MeV$

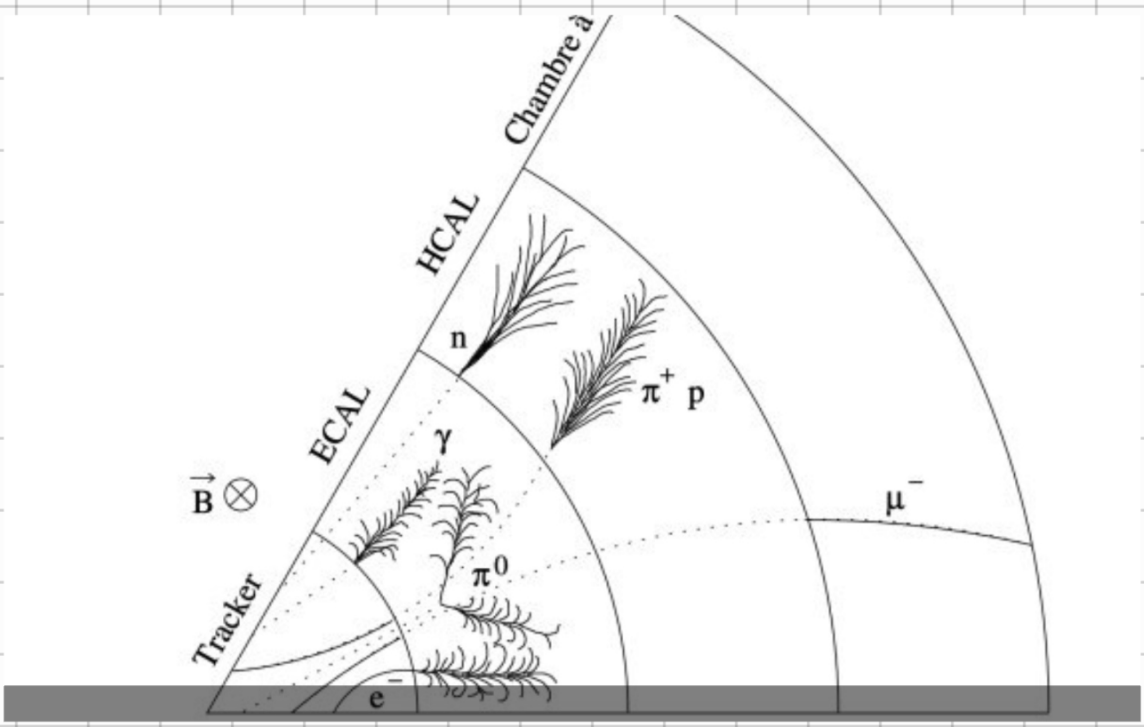
$\beta_k = \frac{p}{E} = 0{,}730$

$\beta > \frac{1}{n} = \frac{1}{1.25} = 0.8$

Thus π has Čerenkov radiation and k has not.

Exercise 5


n
π+
ν
e−
γ
μ+
HCAL
ECAL
Tracking detector
Muon detectors


Chambre à
HCAL
ECAL
Tracker
B
n
π+ p
γ
μ−
π0
e−