Tutorial 3

(1) Draw a Feynman diagram using as few vertices as possible (i.e. leading order) for the process:
$\gamma+\gamma \rightarrow \gamma+\gamma$.

(2) State which of the following reactions/decays can take place. State the force or forces which can mediate the process if that information is not written next to the process. If the processis forbidden state a conservation law which forbids it.

$(i)\ \Lambda^0 \rightarrow p+\pi^- \quad (ii)\ p \rightarrow \Sigma^+ + \pi^0$

$(iii)\ \Omega^- \rightarrow \Xi^0 + \pi^-$ (strong) $(iv)\ e^- + \gamma \rightarrow e^-$

$(v)\ e^+ + e^- \rightarrow K^+ + K^- \quad (vi)\ \pi^+ + p \rightarrow \Delta^{++}$

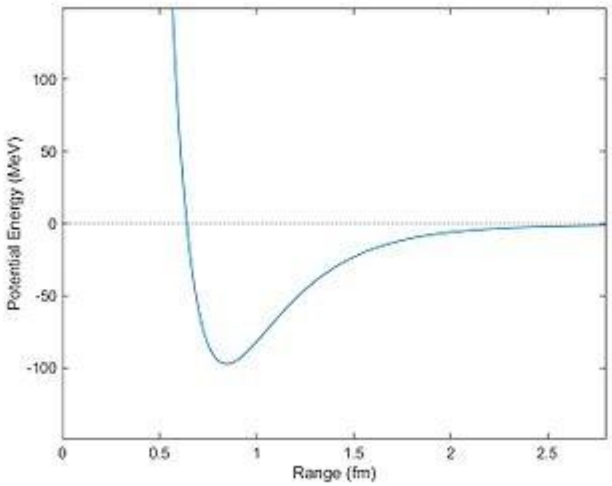
(3) The Υ consists of a $b\bar{b}$ and has a mass around 9460 MeV/c^2 and a lifetime $\sim 10^{-20}$s.With this information what can you deduce about the mass of of the B-meson with quark content $u\bar{b}$?

(4) At the Minos experiment, a beam of muon neutrinos is fired 750km from the Fermilab Laboratory in Chicago to the SOUDAN mine in Minnesota. The purpose of the experiment is to see if any are lost via conversion to electron neutrinos. Sketch the expected energy spectrum of muon neutrinos at the SOUDAN detector if :

$$\sin^2(2\theta) = 0.9\ ;\ \Delta m^2 = 0.003\ \frac{\text{eV}}{c^2}.$$

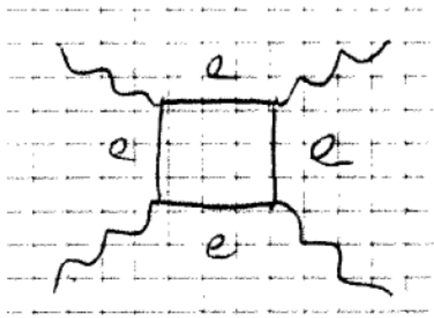
Assume that there exist only two types of neutrinos (electron and muon) and that the neutrinos have energies between 1-5 GeV and have a flat energy distribution (like a "top hat") in Chicago.

5 The potential between two nucleons in a nucleus as a function of the distance between the nucleons is given below.
Sketch how the force between the nucleons depends on distance apart.
Estimate the force between the nucleons at a separation of 1.2 fm.

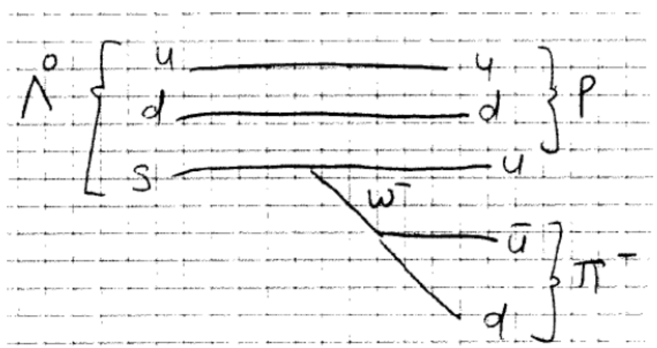


(1)

$\gamma + \gamma \rightarrow \gamma + \gamma$



(2) (i) $\Lambda^0 \rightarrow p + \pi^-$: weak force.



(ii) $p \rightarrow \Sigma^+ + \pi^0$: forbidden since it violates energy conservation

mass$\left[\Sigma^+ + \pi^0\right]$ > mass$[p]$

(iii) $\Omega^- \to \Xi^0 + \pi^-$ (strong)

Forbidden as a strong reaction since strangeness is violated.

$\Omega^- \equiv sss \quad S = -3 \quad ; \quad \Xi^0 \equiv uss \quad S = -2 \quad ; \quad \pi^- \equiv d\bar{u} \quad S = 0$

$\Rightarrow \Delta S = 1$

(iv) $e^- + \gamma \to e^-$

Forbidden since energy conservation is violated.

This can be seen by considering the reaction taking place in the centre-of-mass frame i.e. the frame of the e^- which would be at rest after absorbing a photon.

$e^- + \gamma$: Energy before=$E_e + E_\gamma$

Since $E_e = \gamma m_e > m_e$ and $E_\gamma > 0 \Rightarrow E_e + E_\gamma > m_e$.

In our chosen reference frame the electron is at rest after absorbing the photon

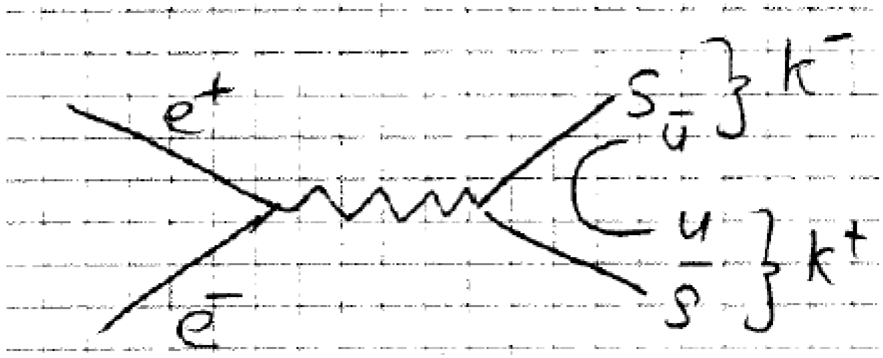
$\Rightarrow$ Energy after=m_e.

The laws of physics are invariant to a change in inertial reference frames.

If a reaction can happen in one frame the same reaction can take place in another frame (with different momenta etc. of course).

(v) $e^+ + e^- \rightarrow K^+ + K^-$

Allowed as an electromagnetic or weak process + strong (hadronisation)
Not strong of course for the annihilation part- gluons don't couple to leptons.



(vi) $\pi^+ + p \rightarrow \Delta^{++}$

Allowed as a strong, electromagnetic or weak process.
The strong contribution would, however, dominate.

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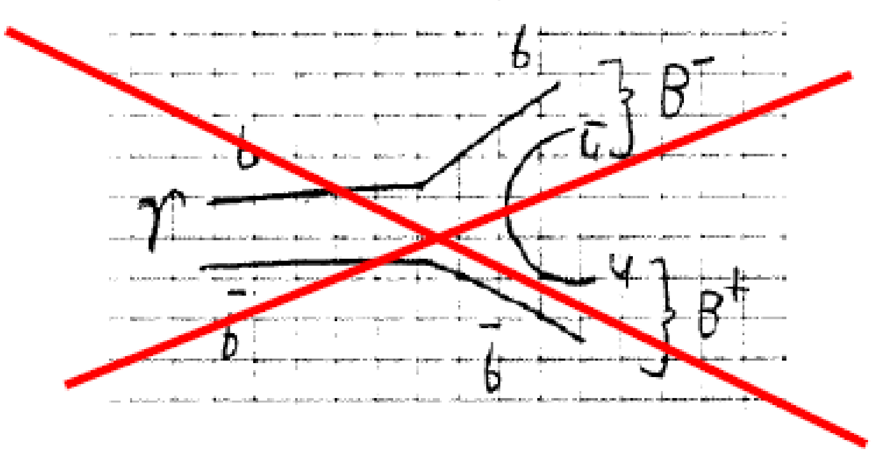
$\Upsilon(b\bar{b})$

Expect strong decay to B^+ and B^- as per diagram.



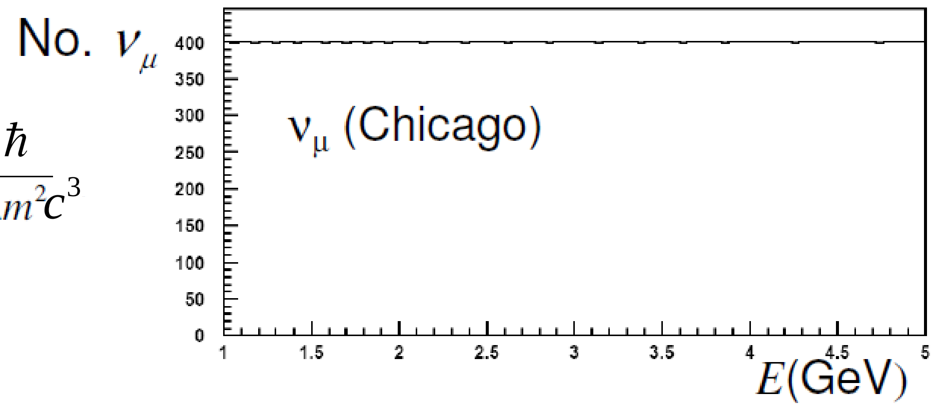
However, $\tau \sim 10^{-20}$s $\Rightarrow$ preferred decay impossible.

$\Rightarrow m_{B^+} > \left[\frac{m_\Upsilon}{2} \sim 4730 \text{ GeV}\right]$

In fact $m_{B^+} \sim 5279$ GeV.

4 Lecture 3: two component neutrino oscillations.

Probability that muon neutrino has converted to an electron neutrino after travelling a distance L.

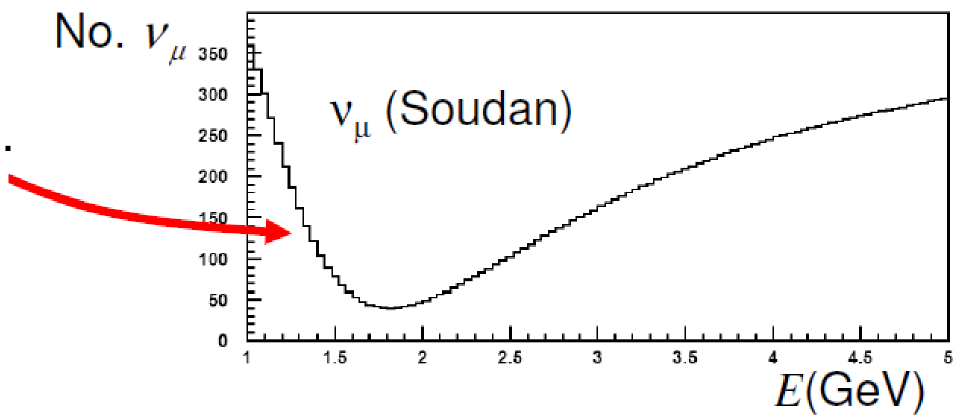


$$P\left(\nu_\mu \to \nu_e\right) = \sin^2 2\theta \sin^2 \frac{L}{L_0} \quad ; \; L_0 = \frac{E\,\hbar}{1.27\,\Delta m^2 c^3}$$

Units: distances L, L_0 in km; Δm^2 in eV^2.

$$P\left(\nu_\mu \to \nu_e\right) = 1.0 - \sin^2 2\theta \sin^2 \frac{L}{L_0}$$

Plot with values given in the question.



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$\bar{F} = -\dfrac{\partial U}{\partial r}\,\hat{r}$ Estimate the gradient.

Sketch of the force F is given below.

Eg at $r \sim 1.2$ fm $F = \dfrac{60\times10^{6}\times1.602\times10^{-19}}{0.6\times10^{-15}} \sim 2\times10^{4}$ N (attractive)