Exercise 2

FYSC22

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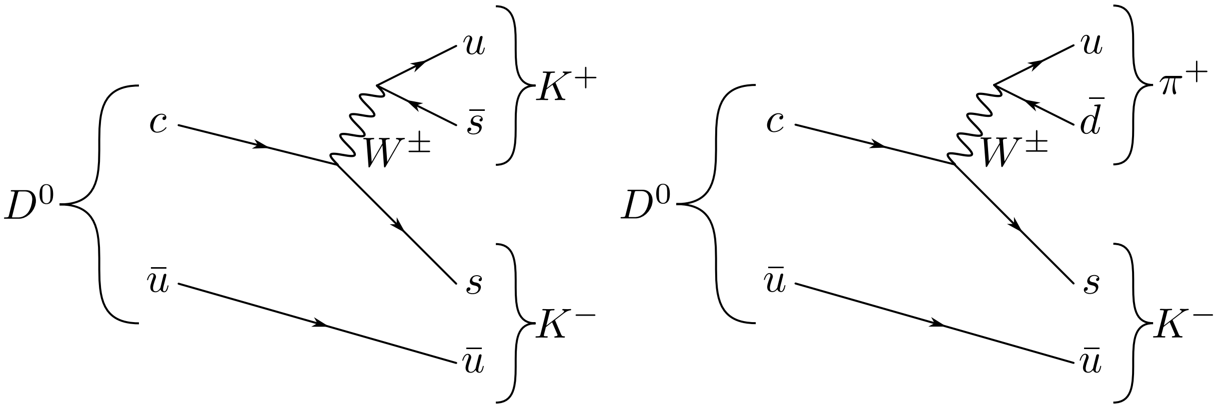
1 D^0 Decays



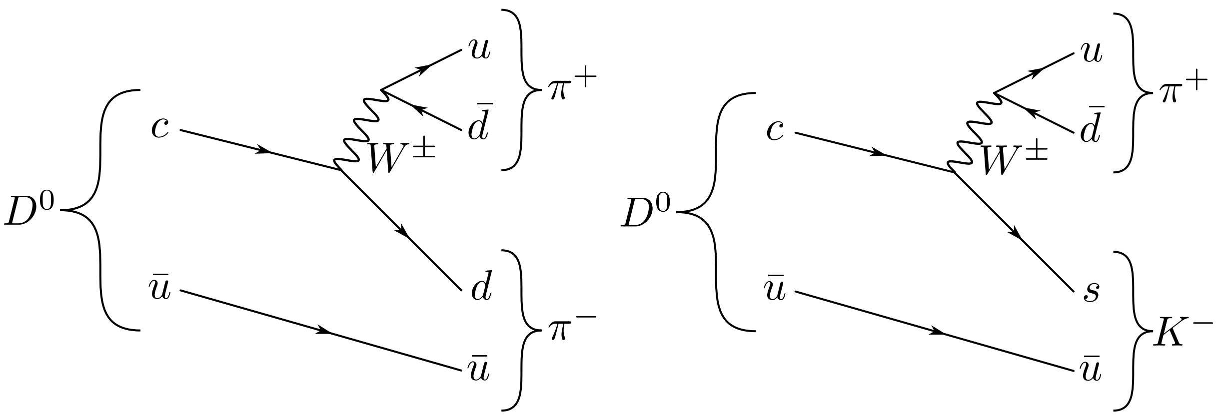
(a) $D^0 \to K^+K^-$ (b) $D^0 \to K^-\pi^+$

Figure 1: Feynman diagrams for the decays $D^0 \to K^+K^-$ and $D^0 \to K^-\pi^+$.

a) The only vertex that differs between these decays are the $\bar{s}uW^\pm$-vertex and the $\bar{d}uW^\pm$-vertex. The CKM matrix elements are $|V_{us}| = 0.2243(8)$ and $|V_{ud}| = 0.973\,73(31)$. Thus

$$\frac{\Gamma(D^0 \to K^+K^-)}{\Gamma(D^0 \to K^-\pi^+)} = \frac{|V_{us}|^2}{|V_{ud}|^2} = 0.0531(4), \tag{1}$$

and the value found in [1] is 0.1033(13), which is a ratio of 51.4(7) %.



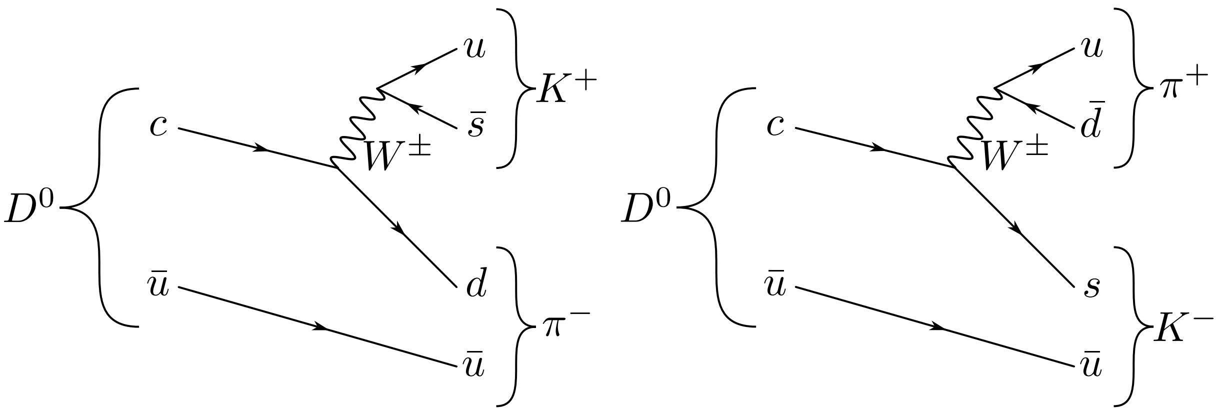
(a) $D^0 \to \pi^+\pi^-$ (b) $D^0 \to K^-\pi^+$

Figure 2: Feynman diagrams for the decays $D^0 \to \pi^+\pi^-$ and $D^0 \to K^-\pi^+$.

b) The only vertex that differs between these decays are the $cdW^{\pm}$-vertex and the $csW^{\pm}$-vertex. The CKM matrix elements are $|V_{cd}| = 0.221(4)$ and $|V_{cs}| = 0.975(6)$. Thus

$$\frac{\Gamma(D^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = \frac{|V_{cd}|^2}{|V_{cs}|^2} = 0.0514(20), \tag{2}$$

and the value found in [1] is 0.0368(5) which is a ratio of 140(6) %



(a) $D^0 \to K^+\pi^-$ (b) $D^0 \to K^-\pi^+$

Figure 3: Feynman diagrams for the decays $D^0 \to K^+\pi^-$ and $D^0 \to K^-\pi^+$.

c) The vertices that differs are the $u\bar{s}W^{\pm}$-vertex, $u\bar{d}W^{\pm}$-vertex, $cdW^{\pm}$-vertex, and $csW^{\pm}$-vertex. The CKM matrix elements are mentioned in a) and b). Thus

$$\frac{\Gamma(D^0 \to K^+\pi^-)}{\Gamma(D^0 \to K^-\pi^+)} = \frac{|V_{cd}|^2 \times |V_{us}|^2}{|V_{cs}|^2 \times |V_{ud}|^2} = 0.002\,73(11), \tag{3}$$

and the value found in [1] is 0.003 79(18) which is a ratio of 72(4) %.

2 Concepts in Particle Physics

a) The experimental evidence of quarks comes mainly from high energy particle collisions. In particular deep inelastic scattering, where by shooting electrons at high speeds on protons and neutrons and measuring how the electron scatters. If the proton and neutrons where elementary particles and did not contain quarks, we would expect a relatively elastic scattering on the 'surface of the atom'. Instead one measured inelastic scattering and angles which showed scattering inside of the hadron, that is, the electron scattering on the quarks on the inside.

b) The main experimental evidence is the production of three jets in particle collisions. Especially the electron positron annihilation at DESY in Hamburg 1979. When colliding the particles in high energy they release jets of hadrons. Since quarks come only in pairs one would expect to always see an even number of jets. However, if there is an odd number of jets it suggests that there is another particle as well, this is what was found.

c) They are related due to flavor mixing which couples the flavor eigenstates (d^f, s^f, b^f) and $(\nu_e, \nu_\mu, \nu_\tau)$ to the mass eigenstates (d, s, b) and (ν_1, ν_2, ν_3), respectively. They can be described as a rotation with the help of a rotation matrix, the CKM-matrix for quarks and the PMNS-matrix for neutrinos. What this essentially means is that the flavor eigenstates is described as a superposition of the mass eigenstates.

d) From the electroweak theory the $W^\pm$ and Z^0 bosons as well as the photon should all be massless. However, experiments showed that only the photons was massless and the other particles had mass. The Higgs mechanism solves this by giving mass to the the $W^\pm$ and Z^0 bosons, as well as quarks and leptons, but not neutrinos, their mass is not explained by the standard model. The quantum particle associated with the Higgs field and Higgs mechanism, is the Higgs boson. Similar to how the electromagnetic field has photons as a quantum particle, the Higgs field has the Higgs boson.

3 Higgs Physics

a) First let

$$V(\eta) = \mu^2|\eta(\mathbf{r},t)|^2 + \lambda|\eta(\mathbf{r},t)|^4 \tag{4}$$

and the perform the transformation

$$\eta(\mathbf{r},t) \to \eta(\mathbf{r},t)e^{i\beta} \tag{5}$$

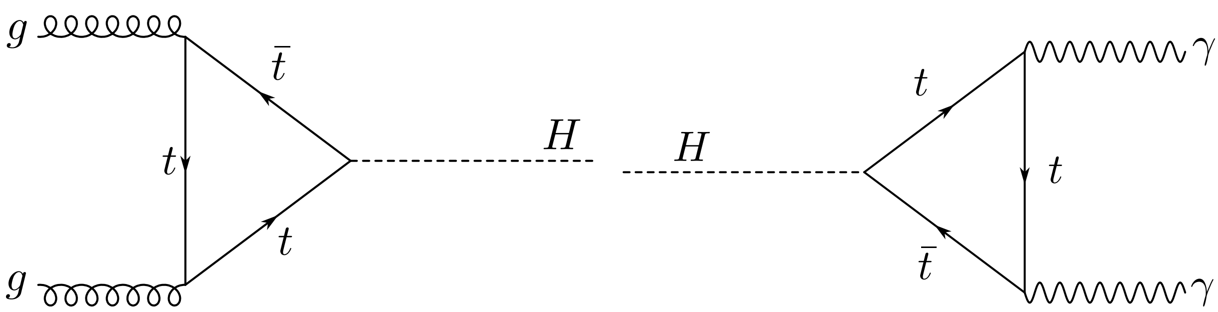
now the first equation becomes

$$V(\eta) = \mu^2\left|\eta(\mathbf{r},t)e^{i\beta}\right|^2 + \lambda\left|\eta(\mathbf{r},t)e^{i\beta}\right|^4 = \mu^2|\eta(\mathbf{r},t)|^2 \times \left|e^{i\beta}\right|^2 + \lambda|\eta(\mathbf{r},t)|^4 \times \left|e^{i\beta}\right|^4 \tag{6}$$

$$= \mu^2|\eta(\mathbf{r},t)|^2 \times 1^2 + \lambda|\eta(\mathbf{r},t)|^4 \times 1^4 = \mu^2|\eta(\mathbf{r},t)|^2 + \lambda|\eta(\mathbf{r},t)|^4. \tag{7}$$

We get the exact same as before the transformation. Thus it is $V(\eta)$ is invariant under the transformation Eq. (5).

b) Firstly an electric field separates the electron from a hydrogen atom and thus creating free protons. Then along the accelerator an electric field oscillates from positive to negative which accelerates the particle forward. By controlling the frequency the particles come as bunches instead of a continuous stream.



(a) $gg \to H$ (b) $H \to \gamma\gamma$

Figure 4: Feynman diagrams for Higgs production and Higgs decay resulting in two gammas.

c)

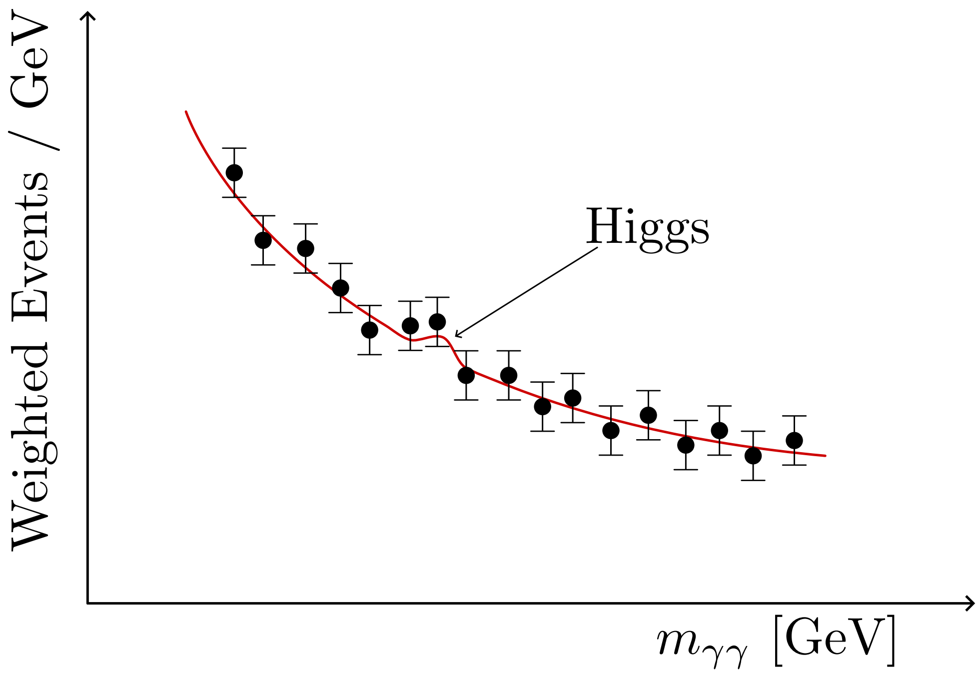


Figure 5: Higgs detection by gamma.

d)

4 Multi-Purpose Detectors

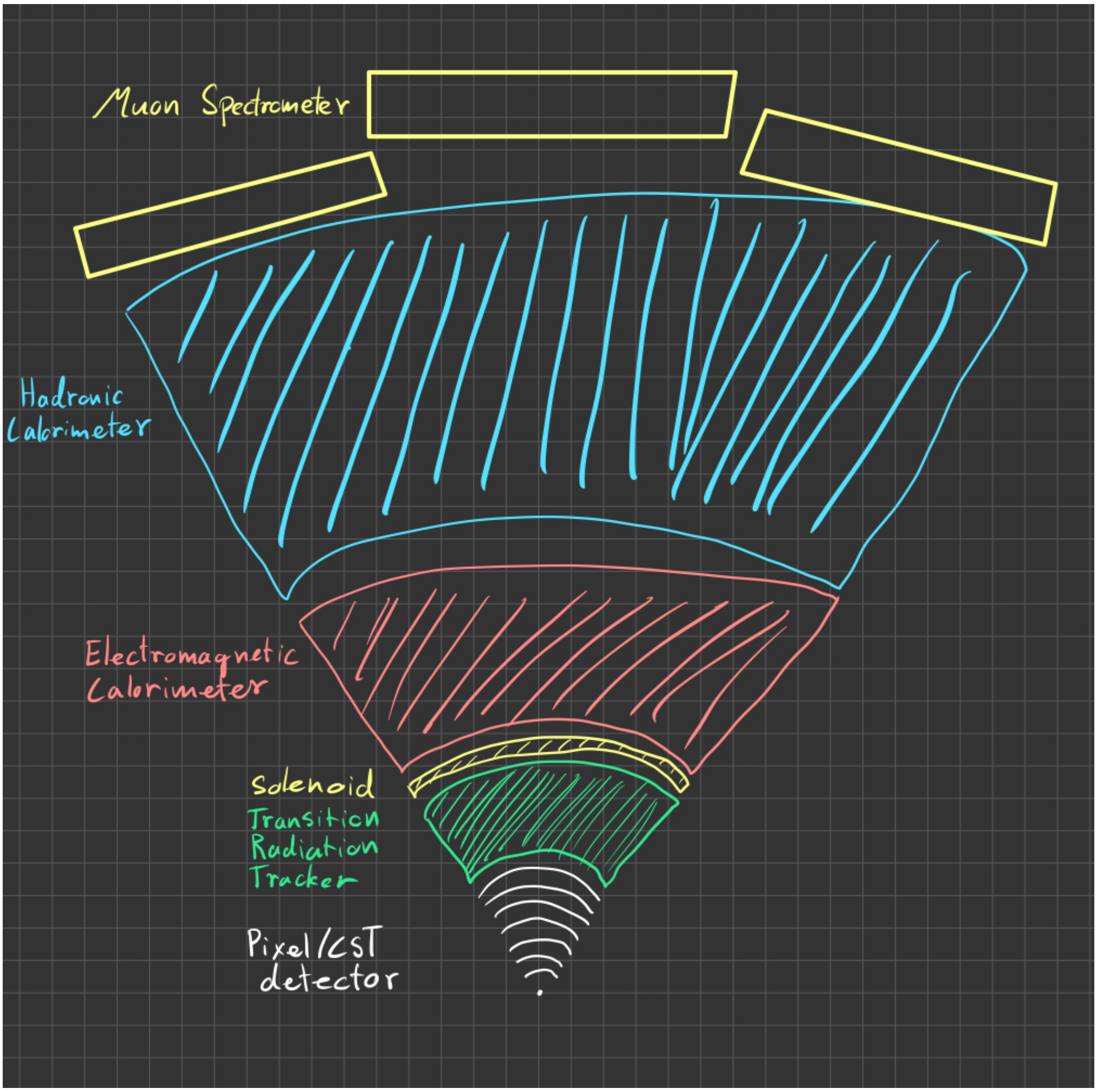


Figure 6: The 'onion' layout of a generic multi-purpose detector.

a)

b) The Pixel/CST tracker and the Transition radiation tracker measures the direction, momentum, and charge of electrically charged particles which are produced in the collisions of hadrons inside the accelerator. The solenoid bends charged particle to measure the momentum of them. The electromagnetic calorimeter measures the energy of particles which are interacting electromagnetically. The hadronic calorimeter measures the energy of hadrons. The muon spectrometer are used to detect muons and measure the muon's properties.

c) Photons doesn't show upp in the tracker since they are not charged, but showers in the electromagnetic calorimeter. Muons go almost straight through the detector showing up in all section, bending a little and being are also measured by the muon spectrometer. Charged hadrons bends from the solenoid, shows up in the tracker, and shows up, but goes through the electromagnetic calorimeter and then showers in the hadronic calorimeter. Neutral hadrons go straight to the hadronic calorimeter and showers there.

d) The candidate $pp \to 2$ jets is most likely Figure 2 and 4. Since there are two large showers in the hadronic calorimeter and they are 180 degrees apart.

The candidate $Z \to \mu\mu$ is most likely Figure 1. There are two directions where muons are detected in the muon spectrometer. Thus we should have a reaction with 2 muon products.

The candidate $J/\Psi \to ee$ is most likely Figure 3. There are two showers in the electromagnetic calorimeter, which matches the reactions with two electrons.

The candidate $W \to \mu\nu_\mu$ has no figure with a good match. We would want a detection in muon spectrometer along one line, and nothing more.

References

[1] R. L. Workman and Others, "Review of Particle Physics," *PTEP*, vol. 2022, p. 083C01, 2022.