Homework/Labs

1. WIRED- Great exercise with real data!
    a. http://hands-on-cern.physto.se/hoc_v21en/index.html
    b. WIRED is a Java script using real data
    c. Neutral particles shown as straight lines
    d. The key to identifying electrons, positrons and photons is to look for energy depositions in the EM-calorimeter. (This calorimeter can be turned on and off)
    e. A muon leaves a track in the track detector and a mark (a cross) in the muon detector. (This detector can be turned on and off)
    f. Sometimes one can guess if there were neutrinos in an event by comparing the collision energy to the detected energy. Usually these can't be detected.
    g. A quark will create a jet of many particles. Such a jet of particles usually consists of ten or more particles.
    h. Tau particles will also decay before they can be seen in the detector. A tau particle decays into 1 or 3 charged particles plus a number of neutral particles. If several neutral particles are created, the decay will result into a mini-jet resembling the quark jets. However, the mini-jet from the tau particle has fewer particles, less than ten.

   In this section (http://hands-on-cern.physto.se/hoc_v21en/index.html) you can look at animated sequences of events were a Z particle decays into different kinds of particles.

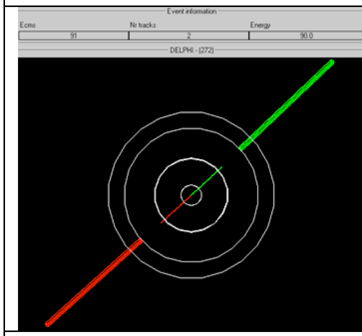
    i. A Z particle can decay into either two electrons, two muons, two tau particles, two neutrinos or into two quarks. See examples below.
    j. With the help of WIRED, measure how often the different decays occur (branching ratio) and compare the results with the theoretical predictions below
    k. For example to calculate the branching ratio for 5 electron events (out of 100 analyzed), this means that the Z particle decays into electrons in 5/(100/0.80) = 4%. Assume 20% of the events are neutrino events that can't be detected, hence the 100/0.8

The following types of decays should be counted. Notice that at least 100 events should be analyzed. These go fast, especially if done in the classroom where a team of 2 or 3 is responsible for 10 events.

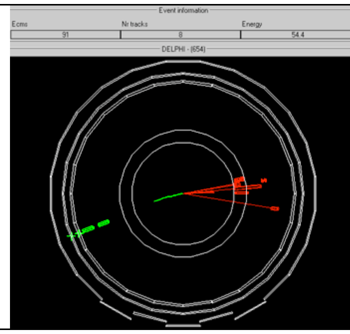
Electon	Tau	2-Jet	3-Jet	4 or more Jets
# of events	# of events	# of events	# of events	# of events

Examples of Z particle decay

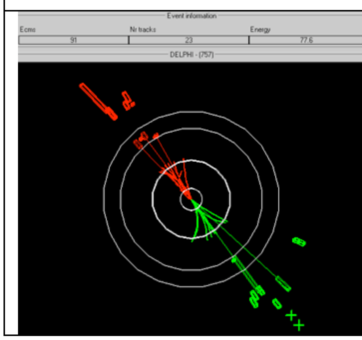
2-Electrons
Large bars show energy in E&M detector



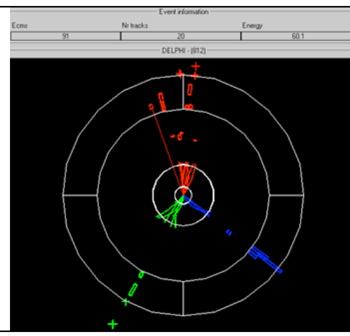
2-Tau particles



Quark and muon (2-jets)



Quark and Gluon (3-jets)
Red, green and blue bars shown in the Hadron detector



Theoretical values for the branching ratios of the Z particle:

Leptonic decays	Branching ratio	Quark decays	Branching ratio*
2 neutrinos	20 %	Total	69,9 %
2 electrons	3,67 %	2 jets	~ 40 %
2 muons	3,67 %	3 jets	~ 24 %
2 tau particles	3,67 %	4 or more jets	~ 6 %

* Only the total branching ratio for quarks is a value from the Standard Model. The individual numbers of the branching ratios for events with different number of jets are experimental values.

2. For teachers with access to a small radio telescope, I would highly suggest the following exercise. A small radio telescope can also be built for ~$5000. http://www.haystack.mit.edu/edu/undergrad/srt/SRT%20Projects/rotation.html

This is really cool experiment as students can calculate the missing mass or our Milky Way Galaxy. Teachers and students could also travel to the National Radio Astronomy Observatory in Greenbank, WV. At the NRAO, students can measure galactic rotation curves on a 4 m radio telescope, demonstrating the missing mass of our galaxy. http://www.gb.nrao.edu. A really great experience!

3. Find attached a homework sheet for http://particleadventure.org

4. How fast must a proton be moving to reach an energy of 7 TeV? Put in terms of xc, where $0<x<1$. Relativistic affects must be taken into account.

$m_p = 1.67262158\times10^{-27}$ kg
c = 299792458 m/s
1 joule = $6.24150974 \times 10^{18}$ electron volts
$\gamma=(1 - v^2/c^2)^{-1/2}$

Solution:
Let v=xc
$E = 7$ TeV $= 7\text{x}10^{12}$ eV $= 1.121523524 \text{ x } 10^{-6}$ J
$E=m_p\gamma c^2= 1.67262158\text{x}10^{-27} *[1-(v^2/c^2)]^{-1/2}*c^2$
$[1-(v^2/c^2)^{1/2}] = 1.340388565\text{x}10^{-4}$
$1-x^2= 1.796641506\text{x}10^{-8}$
x = +/-0.999999991
v=0.999999991c

6. A cyclotron is the simplest type of particle accelerator. Two 'D' chambers sit between a pair of electromagnets with some radius R. For a cyclotron operating with an electromagnetic of radius, R = 0.3 m, and a field strength of B = 2 T, find:
a. the frequency of the alternating source required to accelerate the proton
b the maximum energy gained by these protons

Solution:
Assume nonrelativistic motion

$q = 1.602176463\text{x}10^{-19}$ C
B = 2 T
$m_p = 1.67262158\times10^{-27}$ kg
c = 299792458 m/s

$\nu = qB/2\pi m_p=1.602176463\text{x}10^{-19}(2)/[2(3.14159265)\ 1.67262158\times10^{-27}]$
ν = 30.49 MHz

$T_{max}=1/2m_pv^2=(qBR)^2/2m_p=(1.602176463x10^{-19}(2)0.3)^2/2(1.67262158\times10^{-27})$
1 joule = $6.24150974 \times 10^{18}$ eV
$T_{max}=1.38122843x10^{-12}$ J = 8.521 MeV

7. Estimate the time it takes for a 7 TeV proton to travel a circular path with a circumference of 27 km.

Solution:

Assume the proton is traveling the speed of light.
time = distance/c = 27 km/3x10^5 km/s = 90 μs

8. Estimate the height of a cube needed to hold 50,000 tons of water used in the Super Kamiokande experiment. (Neutrino detection)

Solution:
1 short ton = 907.18474 kilograms
ρ_{H2O}=1000 kg/m^3
Mass = 4.546x10^7 kg
Volume = 4.546x10^4 m^3

Each side of a cube would need to be 35.7 m or 117 ft

9. Estimate the temperature in a gas of particles such that the thermal energy, kT, is high enough to make the electromagnetism and the weak force appear as a single phenomenon. (Symmetry Breaking) Assume this occurs at around 100 GeV.

Solution:

k_B = 8.617 343x10^{-5} eV·K^{-1}
T = 100 Gev/k_B = 1.2x10^{15} K
This answer can be compared with the first slide in the lecture

10. Assume binding energies can be neglected. Find the masses of the up (u) and down (d) quark from the masses of the proton and neutron. m_p = 938.3 MeV/c^2 m_n= 939.6 MeV/c^2. The proton is composed of two up and one down quark. The neutron is composed of one up quark and two down quarks. Are your answers reasonable? Why or why not. Look up the actual mass of the up and down quark.

Solution:

$m_p = 2\ m_u + m_d$
$m_n = m_u + 2m_d$

Two equations, two unknowns yields

m_u = 312.3 MeV/c^2
m_d = 313.7 MeV/c^2