name: **group:**

Exercise Sheet 2 – Particle Physics – SS 2016

hand in: Tue 3rd May (after the lecture or at INF 226, 3.104 by 4 pm)

2.1 Interaction of Particles with Matter (5 points)

Estimate the kinetic energy of the following particles after their material interactions:

a) a muon with $E_{kin} = 400\text{MeV}$ transverses a 10 cm iron target
b) a proton with $E_{kin} = 200\text{MeV}$ transverses a 20 cm iron target
c) a charged pion with $E_{kin} = 1\text{GeV}$ transverses a 20 cm iron target

2.2 Event Displays (5 points)

LEP was running at the Z resonance when events in this exercise were recorded, thus all reactions are of the type: $e^+e^- \to Z \to ....$ As the lecture will discuss later in more detail, single quarks can never be detected, however they form jets of many particles (mostly pions) that can be detected. The symbols in the event displays are explained in the following figure.

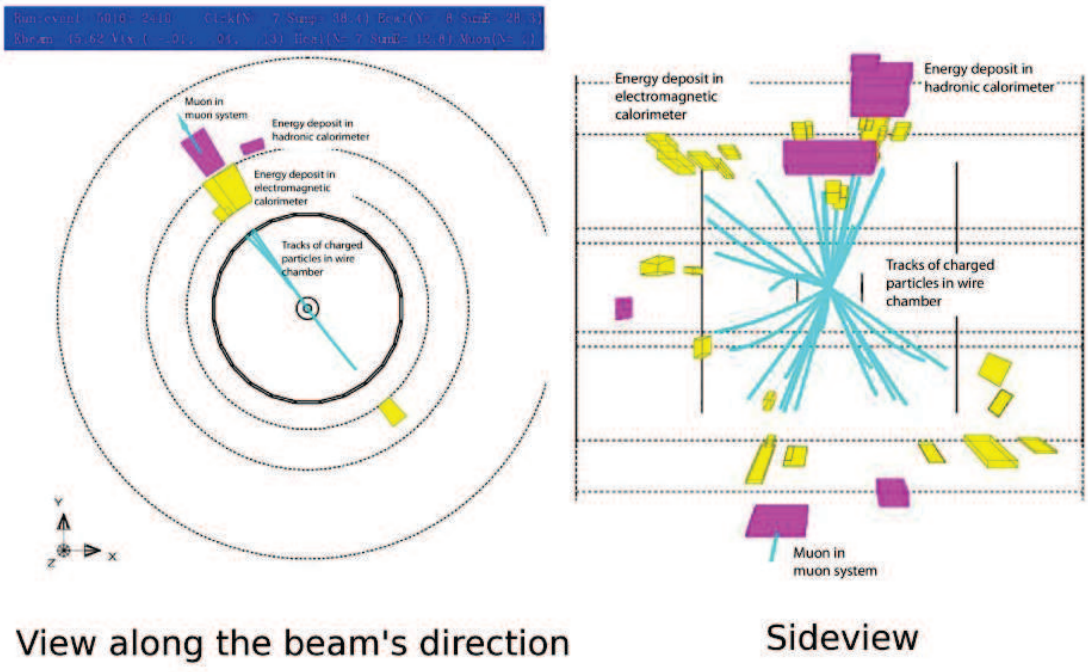
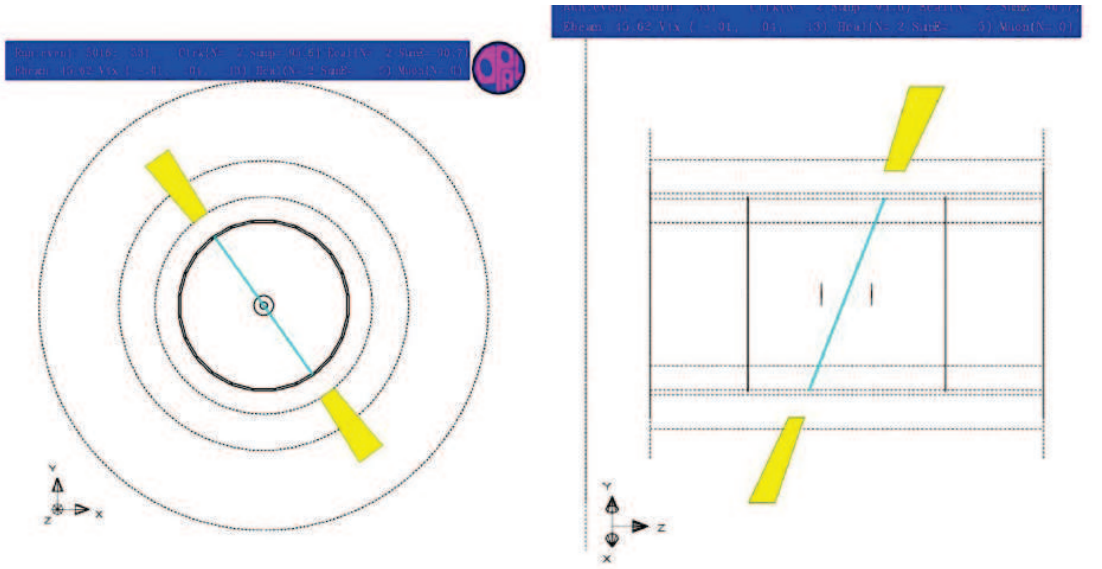
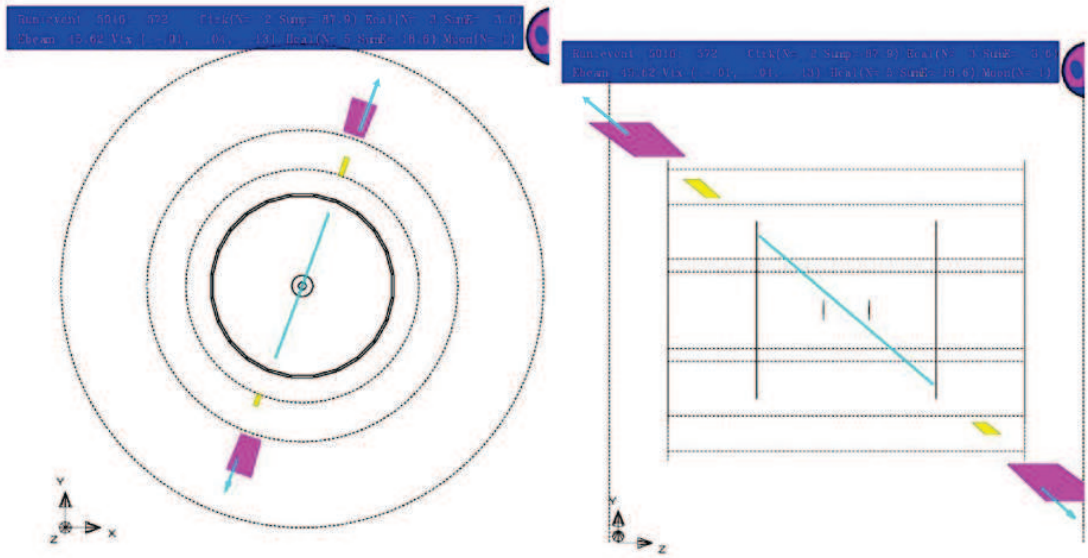
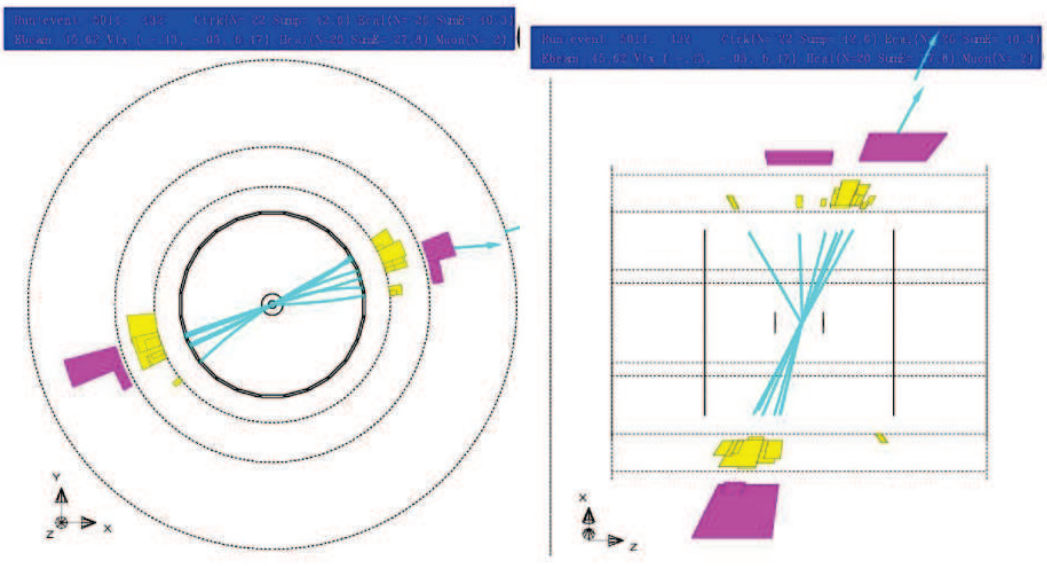


Figure 1: Illustrative example of an event display. The view along the beam's direction and sideview show different events in this figure only!

a) Look at the following event displays from the OPAL detector at the electron-positron collider LEP. Write down the final state particles and draw the corresponding Feynman diagram.



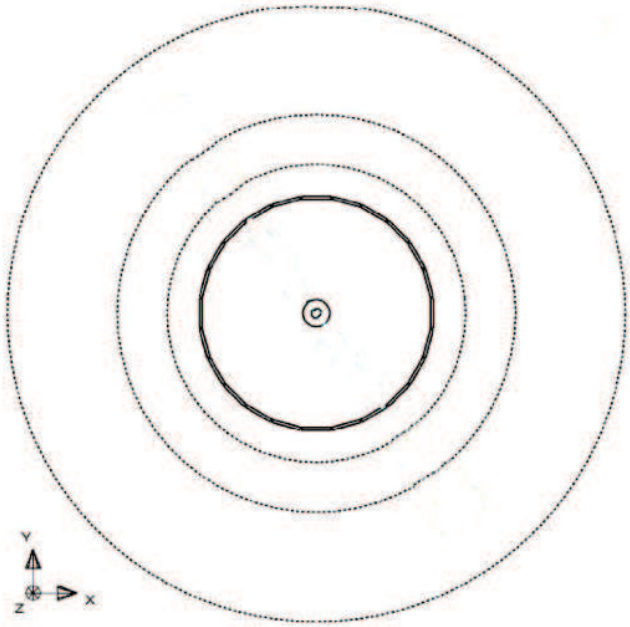




b) Sketch how the following particles being produced at the center of the detector would look like in an event display:

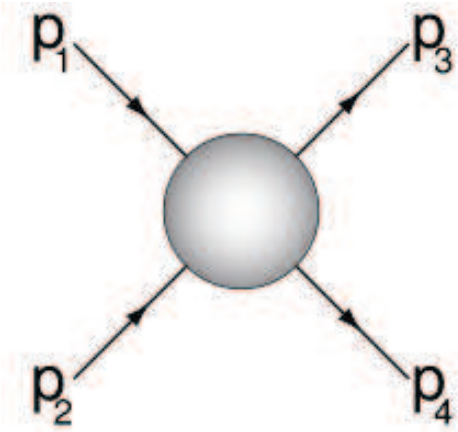
- a photon
- a proton
- a neutron

Follow the scheme (colors, etc.) from above and label the particles.



2.3 Mandelstam Variables and Scattering angle (5 points)

Two particles (1 and 2) scatter and produce two outgoing particles (3 and 4)



With p_i denoting the 4-momentum vector of particle i, the following three variables are defined (Mandelstam variables):

$$s := (p_1 + p_2)^2, t := (p_1 - p_3)^2, u := (p_1 - p_4)^2$$

a) Calculate $s + t + u$.

b) Prove the following relations for the case that the masses of all particles vanish ($m_i = 0$). The angle θ^* is the angle between the flight directions of particles 1 and 3 in the center-of-mass frame: $\theta^* = \angle(\vec{p}_1^*, \vec{p}_3^*)$.

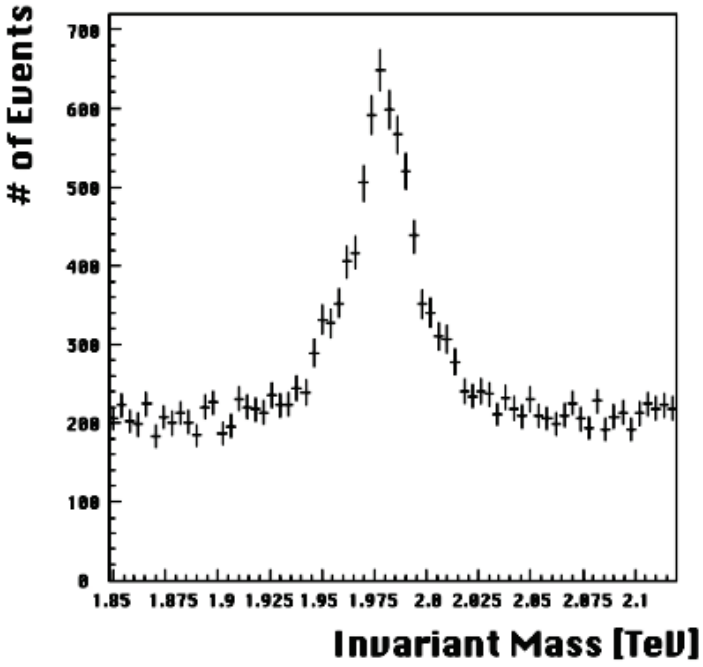
$$\frac{t^2+u^2}{s^2} = \frac{1+\cos^2\theta^*}{2}$$

$$t = -s\frac{1-\cos\theta^*}{2}$$

$$u = -s\frac{1+\cos\theta^*}{2}$$

2.4 Resonance (5 points)

In the year 2027 scientist finally succeeded to build and operate a circular $\mu^+\mu^-$ collider with a center-of-mass energy of $\sqrt{s} = 10$TeV. Shortly afterwards, a new resonance was discovered among the decay products of the $\mu^+\mu^-$ annihilation. A preliminary invariant mass distribution is shown:



a) How are the decay width Γ and the lifetime τ related?

b) Estimate the mass, decay width and lifetime of the new state (Remember, in natural units 1 $\text{GeV}^{-1} = 6.58 \times 10^{-25}$s

c) The data shown in the mass distribution corresponds to data-taking of one month (10^6s). For this period, the machine people reported an average luminosity of $10^{32} cm^{-2} s^{-1}$. Give an estimate of the cross section (in barns) to produce the new state in $\mu^+\mu^-$ annihilations. Assume that the detection of the new events is 100% efficient.