Obligatory Assignment I

27.02.2016 to be delivered BY 10.03.2016 @ 12:15
per email (pdf), or at the secretariat (ekspedisjon), or handed to me

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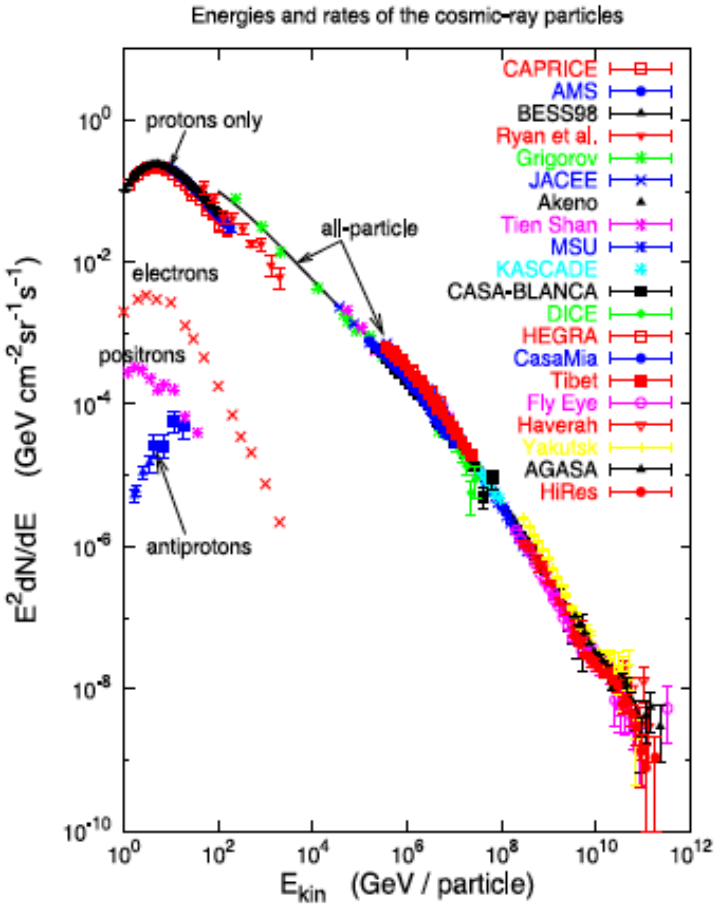
FYS 3510 Subatomic physics with applications in astrophysics

I. Relativistic kinematics

1. In the LHC at CERN, 2 proton beams will head-on with energies E_p=7TeV.
   a) What is the centre of mass (CM) energy?
   b) What energy would be needed to produce the same CM energy with a proton beam on a fixed hydrogen target?
   c) How does this energy compare with cosmic ray energies? Read supplement 1.1 “Cosmic rays and Astroparticle physics”.
   d) How are muons produced in the atmosphere? What is the expected ratio of detected muon- to electron-neutrinos on Earth?



2. The neutral pion decays to two photons ($\pi^0 \rightarrow \gamma\gamma$) with a branching ratio of 98.8%.
   a) What is the minimum opening angle between the photons? Apply to a pion with momentum 100 GeV? $m_{\pi 0}$=135 MeV.
   b) Compare to a Higgs boson of similar momentum and decay $H \rightarrow \gamma\gamma$. m_H=125 GeV.

II. Relativistic kinematics and Rutherford Scattering

1. In a collider experiment, Λ baryons can be identified from the decay $\Lambda \rightarrow \pi^- p$ that gives rise to a displaced vertex in a tracking detector. In a particular decay, the momenta of the π^- and p are measured to be 0.75 GeV and 4.25GeV respectively, and the opening angle between the tracks is 9^o. m_{π^-}=139.6MeV; m_p=938.3 MeV.
   a) Calculate the mass of the baryon.
   b) On average, baryons of this energy are observed to decay at a distance of 0.35m from the point of production. Calculate the lifetime of the Λ.
   c) Which interaction is responsible for the decay? Justify.

2. Briefly "derive" and explain the Rutherford scattering formula (QM derivation)
   a) What is the minimum impact parameter needed to deflect 7.7 MeV α particles from gold nuclei by at least 1^o?
   b) What about by at least 30^o?
   c) What is the ratio of probabilities for deflection of $\theta > 1^o$ relative to $\theta > 30^o$?

III. Allowed and forbidden processes

1. Which of the 9 processes to the right are allowed and which are forbidden?
   a) If allowed, draw the Feynman graph and state which interaction is at work.
   b) For allowed decays check that interaction type and lifetime are compatible.
   c) If forbidden, give the reasons.

2. Read Supplement 5.1: "Baryon Number Conservation: the Search for Proton Decay"
   a) Briefly explain the concepts of lepton and baryon number conservations
   b) Discuss baryon number violation within Grand Unification and the possibility of proton decay through the process $p \to e^+\pi^0$
   c) What is the experimental signature?
   d) Bonus question: Can you write down one or two Feynman diagrams of the decay.

1. $e^+e^- \to \nu_e\bar{\nu}_e$
2. $n \to p\pi^-$
3. $e^+e^- \to \gamma\gamma\gamma$
4. $\Lambda^0 \to pe^-\bar{\nu}_e$
5. $\nu_\mu\bar{n} \to \mu^- p$
6. $\mu^+ \to e^+\nu_e\bar{\nu}_\mu e^+e^-$
7. $\nu_e e^- \to \nu_e e^-$
8. $e^+e^- \to W^+W^-$
9. $\Delta^{++} \to p\pi^+$

Remarks

- *Important remarks*
  - *In answering the following questions, use as much as possible your own reasoning, alternative methods, …*
  - *Once you have delivered the assignment some students might be asked to solve one question each in front of the class*
- *Compulsory assignments*
  - *It is necessary to deliver all assignments and get them approved*
    - *to be qualified for the final exam*
    - *to have CERN travel expenses (partly) covered*