PHY 554. Homework 1.

Handed: September 6
Return by: September 13
Bring solution to class or send solutions to vladimir.litvinenko@stonybrook.edu

HW 1.1 (3 points): Find available energy (so called C.M. energy) for a head-on collision of electrons and protons in two electron-hadron collisions:

(a) CEBAF collides 12 GeV electrons with protons at rest (the rest energy of proton is 0.938257 GeV);
(b) LHeC ep plans to collide 60 GeV electrons with 7 TeV protons.

HW 2.1 (2 points): Electron ion collider (EIC) will be built in Brookhaven National Lab to collider 18 GeV electrons with 275 GeV protons and 100 GeV/u heavy ions. It will be located in RHIC tunnel with circumference of 3834 m.

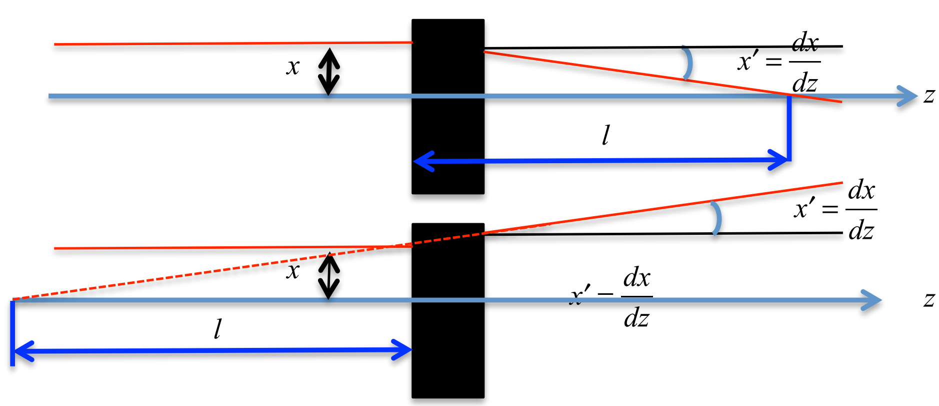
(a) 1 point: What will be bending radius of 275 GeV protons in EIC dipole magnets with magnetic field of 3.8 T?
(b) 1 point: What average magnetic field is required to turn 18 GeV electrons with the same radius?

HW 1.3 (2 points): For a classical microtron with orbit factor k=1 and energy gain per pass of 1.022 MeV and operational RF frequency 1.5 GHz (1.5 x 10^9 Hz) find required magnetic field. What will be radius of first orbit in this microtron?
Hint: Note that rest energy of electron with γ=1 is 0.511 MeV. This is energy gain per pass will define available n numbers in eq. (2.6)

HW 1.4 (5 point): Let's first determine an effective focal length, *F*, of a paraxial (e.g. small angles!) focusing object (a black-box) as ratio between a parallel displacement of trajectory at its entrance to corresponding change of the angle at its exit (see figure below):

$$F = -\frac{x}{x'}; x' \equiv \frac{dx}{dz}$$

see figure below for



Let consider a doublet of two thin lenses: a focusing (F) and defocusing (D) lenses with equal but opposite in sign focal length F with center separated by distance L as in Fig. 1.

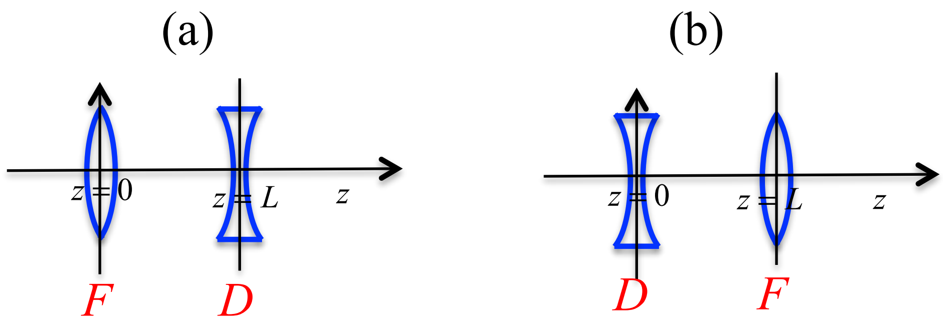


Fig.1. Two combinations of a doublet: *FD* and *DF*.

1. (3 points) Show through a calculation of the ray trajectory that the focal lengths of *FD* and *DF* doublets are equal and given by following expression:

$$F_{eff} = \frac{F^2}{L}$$

2. (2 points) The ray (trajectory) parallel to the axis is entering the FD or DF system of lenses. Using you calculation of the trajectories in *FD* and *DF* doublets, determine location of to the ray crossing the axis and find their difference between *FD* and *DF* doublets. Since a quadrupole focusing in horizontal plane is defocusing in vertical plane - and visa versa – by solving this your find astigmatism of a doublet built from two quadrupoles, i.e. difference between locations of the focal planes for horizontal and vertical direction of motion.

P.S. Definition (picture) of thin lens: