Version 2: fixed typo in Exercise 2

COMPUTING METHODS FOR PHYSICS
12 FEBRUARY 2020

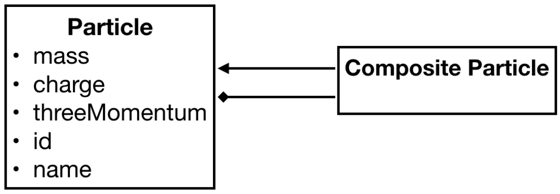
You must submit your exam by following the instruction at http://www.roma1.infn.it/people/rahatlou/cmp/

Higgs Decay Chain (C++) (20 pt)

The goal is to use the Composite Pattern to generate the following decay chains for the Higgs boson.

$$H \to \gamma\gamma$$
$$H \to ZZ$$
$$Z \to e^+e^-/\mu^+\mu^-$$

`Particle` is characterised by its mass, three vector of its momentum (use your Vector3D), electric charge and an integer id number (see page 5 of particle data group), and a name.



`CompositeParticle` has a list of children. Provide the appropriate constructors, setters and accessors, and member functions. It should be possible to do the following

```
CompositeParticle h1(…);
Particle g1(…), g2(…);
h1.add(&g1); h1.add(&g2);

CompositeParticle h2(…), z1(…), z2(…);
h2.add(&z1); h2.add(&z2);
Particle ele(…), pos(…), mup(…), mum(…);
z1.add(&ele); z1.add(&pos);
z2.add(&mu); z2.add(&mum);

h1.setMomentum( Vector3D(0,0, 50.) );
h2.setMomentum( Vector3D(0,0, 100.) );
```

Here **`setMomentum`** is a polymorphic member function

- for a **`CompositeParticle`** it must correctly generate the 2-body decay kinematics for its children and assign the three momentum to them (please make sure energy and momentum are conserved)
- for a **`Particle`** it simply sets its three momentum

Generate 10000 Higgs decays to two photons with the Higgs momentum **`(0,0,pz)`** in the lab reference frame. Extract **`pz`** from a Gaussian distribution with mean of 50 GeV and width of 10%.

Plot the distribution of the opening angle between the two photons in a histogram.

Generate 10000 Higgs decays to two Z bosons with the Higgs momentum **`(0,0,pz)`** in the lab reference frame. Extract **`pz`** from a Gaussian distribution with mean of 100 GeV and width of 20%. Use the nominal Z mass (91 GeV) for the first Z boson and a mass of 31 GeV for the second Z boson (z2)

Plot the distribution the momentum (magnitude of the three momentum) for the children of the two Z bosons (electron, positron, and the 2 muons).

Which of the 4 children has the lowest average momentum ?

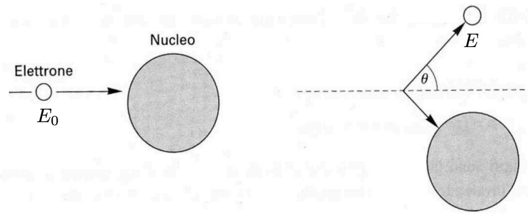
In order to check the correct implementation of your code, you can compute the invariant mass of the Higgs bosons and of the Z bosons and verify that you indeed obtain their nominal mass (125 GeV for Higgs).

Use the ROOT libraries for random generation and plotting.

Provide **`{Particle,CompositeParticle,Vector3D}.{hh,cc}`** for evaluation. Submission of **`app.cc`** is not mandatory. You might be asked to write a test application during the oral discussion to test your classes.

Evaluation will be based on: successful compilation, correct use of C++ syntax, return type and arguments of functions, data members and interface of classes, unnecessary void functions, use of unnecessary C features, correct mathematical operations, correct physics units, correct kinematics for 2-body decay, meaningful plots, correct implementation of polymorphic functions and the Composite Pattern.

Elastic Backscattering (python) (10 pt)



In the elastic scattering of a charged particle on a nucleus, the energy of the scattered particle depends on the scattering angle

$$E(\theta) = \frac{E_0}{1 + \frac{E_0}{M}(1 - cos\theta)}$$

where E_0 is the energy of the incident particle and M is the mass of the target nucleus. In this example we assume the target is made of water (H_2O).

Provide the plot of the distribution E(θ) as a function of the incident energy for E_0 between 1 MeV and 10 GeV and $\theta = 90^\circ$ ·

Provide the plot of the distribution E(θ) as a function of θ energy for E_0 = 1 GeV.

We want to study the fraction of backscattered particles (particles with $\theta > 90^\circ$) as a function of energy for different types of beam.

Simulate 10^6 scatterings for each type of particles: electrons, protons, alpha particles, and ^{12}C ions. The energy E_0 of the beam has an exponential distribution between 1 MeV and 10 GeV, with N(10 GeV)/N(1 MeV) = 0.1.

Compute and print the fraction of backscattered particles for each type of particles.

- You can either integrate E(θ) (easier)
- or generate θ according to E(θ) and then count

Provide a plot showing this fraction as a function of the incident particle mass.

What happens to the distribution if the target is heavy water (D_2O) ?

Proper use of numpy arrays will be an important evaluation criterio. Evaluation will be based on use of python features and data structures, comprehensions (instead of C-style for loops), NumPy objects, labels, units, clarity ad correctness of plots.