CTA Preworkshop Exercise on Particle Physics

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1). From the class called "solver", construct a new class for solving the 2 to 2 scattering ($a+b \to c+d$) for a general set of momenta in an arbitrary frame of reference where all masses involved are not identical, i.e., $m_a \neq m_b \neq m_c \neq m_d$

Hint: Apart from figuring out the logistic of how each parameters flows into functions, don't forget to change the t-channel and u-channel equations. The threshold condition must also be modified accordingly.

2). From the class called "random_generator", construct another class of generator producing a set of particles with probability density depending on a power law of the energy, namely

$$P_k(E) = NE^{-k}, \text{where } \; E_{min} \leq E \leq E_{max} \tag{1}$$

where $k \geq 0$ is a non-negative number and $E_{min} \neq 0$. The normalisation factor, N, is chosen appropriately from the condition

$$N = (\int_{E_{min}}^{E_{max}} E^k dE)^{-1} \tag{2}$$

Then convince yourself by plotting the probability density and energy bin in log-log scale.

Hint: There is no instant density function you can call from either numpy or scipy (as far as I know). The workaround is to assume that the probability density of E^{-k} is uniform from the range

$$E_{min}^{-k} \leq E^{-k} \leq E_{max}^{-k} \tag{3}$$

3). The Greisen Zatsepin Kuzmin limit (GZK limit): Considering the ultra-high energetic cosmic ray protons scattering off from the Cosmic Microwave Background (CMB) photons creating π^0 meson:

$$p + \gamma \to p + \pi^0 \tag{4}$$

We will simulating this effect on the distribution of cosmic rays as follows:

- Construct a set of protons with energy distributed by the power law with $k = 3$. The range for distribution can be chosen arbitrarily.
- Construct a set of photons with mean energy = 2.73 K (here you might either choose a tiny spread in energy distribution or a set of equal energy photons for an approximation. Also please don't forget the natural unit system in order to convert K to GeV)
- Randomly pair up proton and photon from both distributions where the final particles are proton and π^0 meson with mass 135 MeV.
- Measure the energy distribution of the final outcome of the proton and plot the log-log scale of probability vs energy. Compare the plot before and after collision. Finally comment on the scale at which the threshold happens.

  Hint: You can figure out the threshold analytically before doing the simulation. This would probably help you in finding the correct scales involved in the problem.