A NATURE'S PREFERENCE

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Prologue

Our cosmic journey begun two months ago. Now filled with mind adventures in particle physics, like Odysseus's comrades we would like to come to our Ithaca-CERN to experience how all these could apply to reality. From this experience we hope to take away the knowledge of checking by the scientific method even the most imaginative ideas about the Cosmos.

Weak force keeps the Sun and the other stars glowing and gives life to life. Studying the history of particle physics we found out that weak force was the motive power for major discoveries in CERN: pion decay to electron, neutral currents, W and Z and recently Higgs boson. So in relation to 60th anniversary of CERN we decided to propose an experiment related to a peculiar property of weak force, namely its preference to left-handed particles and right-handed antiparticles.

Theoretical Considerations

When spin has the same direction with the particle motion, we say the particle has right-handed helicity. Otherwise the helicity is left-handed.

The helicity of a massive particle can be swapped depending on the reference frame we observe the particle. While nature prefers to do business only with left handed particles and right handed antiparticles, for massive states the distinction between left-handed and right-handed depends on the speed of the observer. However if a particle is massless, and therefore ought to travel always with the speed of light, it is not any more possible to swap its perceived momentum and will have constant helicity fixed for its entire life. Neutrino seems to be this kind of particle.

Experimental Considerations

We will use a particle beam provided by CERN to create neutrinos and study experimentally their left-handed helicity. Neutrinos are hard to detect since they interact only weakly with matter. However we can infer their properties by studying the accompanying charged leptons produced simultaneously with the neutrinos in decays of charged pions:

$$\pi^+ \to e^+ + \nu$$
$$\pi^+ \to \mu^+ + \nu$$

Using as proxy the easily detectable antimuons and positrons, together with the spin and energy-momentum conservation, we can infer the properties of the invisible neutrinos that will escape from the experimental area.

Spin Conservation

Since charged pion has spin 0, the spin of its decay products should also sum up to 0. If the positron and antimuon didn't have any mass, they would be always left handed (like the neutrinos) and the charged pions wouldn't be allowed to decay, due to spin conservation. However positron and antimuons have a small mass of 0.511 MeV/c^2 and 105.7 MeV/c^2 respectively. The reaction is therefore allowed and the ratio between the number of positrons to the number of antimuons is theoretically predicted to be:

$$R = \frac{N(\pi^+ \to e^+ + \nu)}{N(\pi^+ \to \mu^+ + \nu)} = 1.2 \times 10^{-4} \tag{1}$$

If nature didn't have any preference for left-handed particles we would have $R = 1$. Therefore measuring $R < 1$ at CERN will demonstrate that indeed nature prefers left-handed particles and the neutrinos are bound to be always left-handed.

Experimental Setup

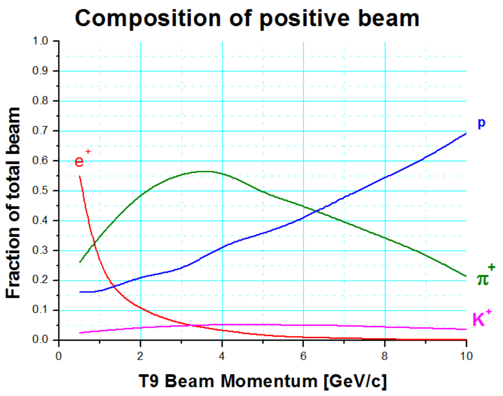

Figure 1

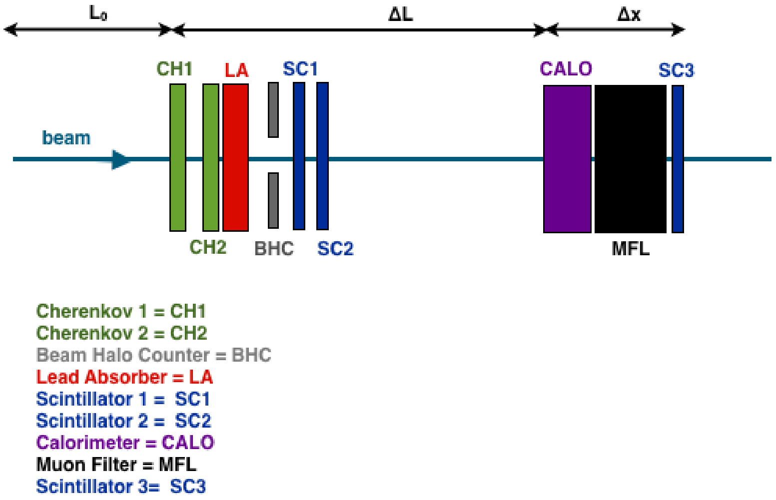

Figure 2

We chose to work initially with the positive beam and if time allows, we may repeat the measurement with a negative beam. The reasons for this choice are: a) the positive beams contains a larger multiplicity 10^6 of particles per burst than the negative beam, and thus will allow to record more decays b) positron component of the beam (Fig. 1) is very small and decreases as function of beams momentum and therefore this will not spoil the measurement of R.

The logic behind the experimental setup (Fig. 2) is as follows. In the entrance of the experimental area, two Cherenkov counters will be used to identify the pions and discriminate them against other particles contaminating the beam. The lead absorber that follows just after the two Cherenkov counters, will secure that no positrons that escaped from identification are passing into the experimental area. A beam halo counter may be used to further veto parasitic particles that may contaminate the beam. The two scintillators SC1 and SC2 when fire simultaneously together with the pion identification information from the Cherenkov counters, will signal that a pion enters the experimental area. A fraction of the identified pions that enter inside the experimental area will spontaneously decay before the calorimeter (muon filter) which is placed in L (L+x) distance away from first Cherenkov counter CH1. A positron coming from the decay of a pion will be totally absorbed in the calorimeter, while a muon will just pass through it leaving only a negligible amount of energy. If the calorimeter measures an energy deposit higher than a threshold, say half of beams energy, then we classify this event as a pion decaying to a positron and an electron neutrino candidate. If instead the calorimeter doesnt records any significant energy, but the third scintillator behind the muon filter (iron block that absorbs all but the antimuon and its neutrino) has a signal consistent with the time of flight for a distance of L+x, then we categorize this event as a pion that decayed to a antimuon plus a muonic neutrino.

The above setup will hopefully allow us to show that $R < 1$. If time allows, we can repeat the experiment with other beam energies and possible also the negative beam, to show that the effect is energy and charge independent. Ultimately, kaons can also be used to study the same effect, but to stay realistic a bare minimum goal of just showing the case of a positive charged pion beam will be sufficient for the purpose of this exercise.

An Open Question

In reality, neutrinos are not absolutely massless but only extremely light. Which would be the required experimental precision in the measurement of R in order to be sensitive to effects induced by the small but non-zero neutrino masses ?

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