Int J Theor Phys (2008) 47: 1316–1321
DOI 10.1007/s10773-007-9566-0

Pion-Muon Asymmetry Revisited

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Received: 23 May 2007 / Accepted: 11 September 2007 / Published online: 2 October 2007

Abstract Long ago an unexpected and unexplainable phenomena was observed. The distribution of muons from positive pion decay at rest was anisotropic with an excess in the backward direction relative to the direction of the proton beam from which it was produced. Although this effect was observed by several different groups with pions produced by different means and detected by different methods, the result was not accepted by the physics community, because it is in direct conflict with a large set of other experiments indicating that the pion is a pseudoscalar particle. It is possible to satisfy both sets of experiments if helicity-zero vector particles exist and the pion is such a particle. Helicity-zero vector particles have direction but no net spin. For the neutral pion to be a vector particle requires an additional modification to conventional theory as discussed herein. An experiment is proposed which can prove that the asymmetry in the distribution of muons from pion decay is a genuine physical effect because the asymmetry can be modified in a controllable manner. A positive result will also prove that the pion is *not* a pseudoscalar particle.

Keywords Pion-muon asymmetry · Helicity zero particles · Anisotropic muon distribution

1 Introduction

First of all, we will discuss in some detail the experimental evidence indicating that pions have an internal direction. After that, we consider a new model for the pion that can accommodate this result and the evidence indicating that the pion is a pseudoscalar.

Fifty years ago after parity non-conservation was discovered in the $\pi^+ \to \mu^+ \to e^+$ chain with an anisotropic angular distribution of electrons from muon decay, experimentalists looked at the distribution of muons from pion decay. (In some cases this was done to check that their method would show an isotropic distribution for a pseudoscalar particle.) To their surprise they found a large anisotropic angular distribution of muons from positive pion decay at rest.

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The history of physics is full of observed phenomena that were later retracted or shown to be invalid by other scientists. However, there are several reasons why this observation (anisotropic angular distribution of muons from pion decay at rest) looks like a genuine physical effect: (1) It was observed by several different groups [1–8], even in one experiment [2] that predated the observation of the anisotropic muon-electron angular distribution; (2) It was observed in pions produced by different methods (proton-proton interactions and kaon decay); (3) It was detected with different apparatus (nuclear emulsions, bubble chambers, and electronic counters [9]); (4) It was observed with repeatable results by one group [1] over many years; and (5) It was almost always detected as a forward-backward asymmetry relative to the pion direction with a surplus in the backward direction.

The results of several other experimental groups [9–15] showed appreciable asymmetry in the muon distributions, but, in summary, they reported that the distributions were isotropic. Most of these negative findings were re-examined by Hulubei et al. [1] showing that "several authors, yielding to general opinion, have formulated negative conclusions in spite of their own positive results."

With regard to the counter experiments of Garwin et al. [9], because of the production and transport of the pions, the pion polarization axis is unknown. Thus they measured the muon asymmetry along x, y, and z axes, detecting small asymmetries along the y and z axes and none along the x axis. If one assumes that the pions have longitudinal polarization (as detected in other experiments), their results indicate a polarization axis in the y–z plane with a measurable asymmetry. No asymmetry is expected along the x-axis for longitudinal polarization perpendicular to that axis.

In the electronic counter experiments of Crewe et al. [16] they did not find any asymmetry, but this is to be expected because they only looked for a transverse polarization while the observed effect is longitudinal polarization along the axis of proton beam at pion creation. Unfortunately, their experimental setup had the pion beam axis almost parallel to the proton beam rather than perpendicular to it.

In a third group of experiments [17–24] the distributions of muons were observed to be isotropic. In order to show that using their techniques would result in an isotropic muon distribution if the pions were not polarized, in 1965, Hulubei et al. [17] performed the experiment again under radically different conditions: the pions were produced in a high magnetic field with an emission angle of 180 degrees. This resulted in an isotropic muon distribution, very different from the earlier one.

A possible explanation for the observed isotropic muon distributions in [18–20] may have been lack of pion polarization. Connolly and Lynch [19] studied photoproduced positive pions. The observed isotropic muon distributions in [21, 22] using pions from kaon decay is puzzling since an asymmetry was observed in the similar, earlier experiments of [3, 9]. Its cause may be related to the unusual asymmetry axes discovered by Osborne [6] in his kaon experiments.

In 1969, Frota-Pessoa [23] reanalyzed the emulsion stacks used in the experiments of Hulubei et al. The apparent goal of this work was to show that the anomaly (anisotropic muon distribution) did not really exist. It is not surprising that he concluded, "the results of two experiments, which seems to be the safe part of scanning of this stack, are in good agreement with isotropy." Hulubei et al. [1] commented on an earlier work by Frota-Pessoa and Margem [24] in that regard, "The experiment was performed on plates from our stack and would therefore seem to be most appropriate for a comparison. Unfortunately, the conclusions drawn in that paper are based on qualitative considerations."

The chance of a statistical fluctuation causing the observe asymmetry is one in 2500 in just one set of experiments [1] and much less when all the experiments are considered.

Hulubei et al. [1] have shown that systematic errors could not have caused the effect. Lattes [4, 5] examined seven possible sources of error and showed that none of then could account for the observed effect.

In attempting to explain the asymmetric muon distribution in the 1960s, scientists [25–27] suggested that it was caused by a new particle (present in the pion beam) with spin but mass degenerate with that of the pion. These attempts were not successful since a spin-1 pion should decay through the electron mode as often as the muon mode and because no other evidence for such pion-like particles was ever found. Cassels [28] noted that other alternatives besides the pion having spin were possible.

How can the many experiments [29–31] showing that pions have spin-0 and the observations [1–8] that pions have a direction be compatible? In a recent paper [32] the author has proposed the existence of helicity-zero particles, and the pion could be such a particle. As formulated, helicity-zero vector particles are similar to pseudoscalar particles because they have no net spin. Whereas the polarization of a spin-1 vector particle is defined by sixteen or more parameters [33], an helicity-zero particle has only longitudinal polarization which agrees with the observed polarization. Since it has zero spin, an helicity-zero vector pion satisfies experimental results such as the large ratio of the π–μ decay mode relative to the π–e decay mode [21, 34] and the observed polarization of muons from pion decay [35].

Experiments [36] have shown that negative pions have zero (or very small) magnetic moment. It was noted in one of the asymmetry experiments [2], that the asymmetry existed in a high magnetic field. Since pion precession due to a magnetic moment should have washed out the observed asymmetry, this experiment indicates small or zero magnetic moment for the positive pions causing the asymmetry. An helicity-zero vector pion would have zero magnetic moment because it has zero net spin.

If charged pions are helicity-zero vector particles, the neutral pion must also be an helicity-zero vector particle. The well-known proofs of Landau [37] and Yang [38] showing that the neutral pion cannot be a vector particle are based on the assumption that a state of two photons must be symmetric under interchange of the photons. Although this assumption seems very reasonable, as discussed in Sect. 6.2 of [39], a state of two *composite* photons need not be symmetric under interchange if the two photons are not identical.

2 Experimental Test

Unlike the previous π–μ asymmetry experiments, we propose an experiment that involves the variation of a parameter to change the asymmetry in a controllable manner. The experiments, described earlier, indicate that pions created in proton-proton interactions are longitudinally polarized in the direction of the proton beam momentum. In order to obtain a polarized beam of pions, Hulubei et al. recommended that the pions should be created outside the accelerator field from a proton beam striking a hydrogen or hydrogen-rich target. As discussed in Sect. 1, pions have zero magnetic moment. Thus their polarization direction after creation will not be affected by a magnetic field.

The experimental test involves varying the angle at which the pions enter the detector (relative to their creation direction) and measuring the angle of peak muon emission. Figure 1 indicates how this might be accomplished. The first magnet before the shielding is used to select the pion energy. The second magnet varies the pion angle and the detector is rotated accordingly. The energy degrader slows the pions so that they will come to rest in the muon-angle detector, which could be emulsions, for example.

With the pion angle set as shown in the diagram, we expect that the detector will record an anisotropic muon distribution with a peak in the backward direction as shown in Fig. 2.

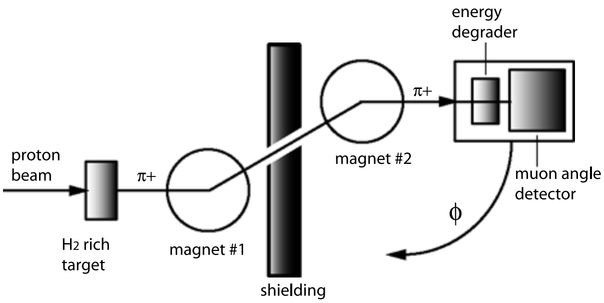

Fig. 1 Illustration of an experimental apparatus for detecting π–μ asymmetry. The detection box should supported is such a way that it can be rotated in a circular arc about the bending axis of the second magnet

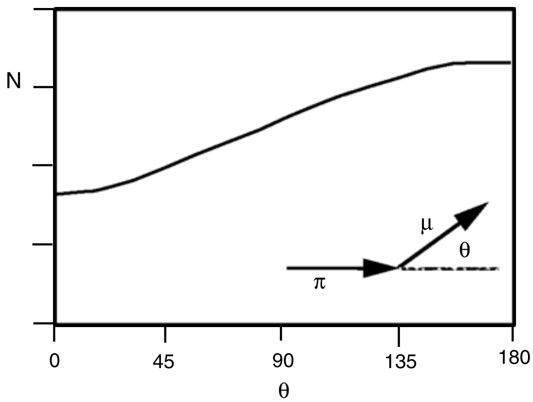

Fig. 2 Expected angular distribution of muons from pion decay. Peak is at 180 degrees from the proton-beam direction (and pion-beam direction for $\phi = 0$)

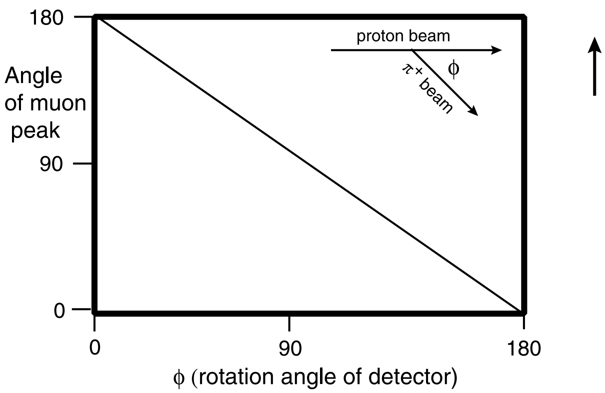

Fig. 3 Expected variation in the angle at which the peak in the muon distribution occurs (as measured relative to pion momentum) as a function of the rotation angle of the detector

This is essentially the experiment of Hulubei et al. [1]. Since the pion-polarization direction is not changed by the magnetic field, varying the angle of pion momentum with the second magnet and rotating the detector thorough an angle ϕ will cause the angle of the muon distribution peak to change as shown in Fig. 3. A result, similar to that in Fig. 3, will be obtained by rotating the detector thorough an angle of $-\phi$. However, the polarization direction for $\phi = -90$ degrees will be opposite to that for $\phi = 90$ degrees, and can provide further evidence of a controllable asymmetry.

3 Conclusion

Over the past forty years no experiment has been performed that explained away the observed π–μ asymmetry [1–15]. If the π–μ asymmetry results [1–15] are not interpreted as evidence of non-zero pion spin, then they are not in conflict with the many experiments showing that the pion has spin 0 [21, 29–31, 34–36]. Furthermore, an experiment in which the asymmetry axis is modified in a controlled manner has been proposed. A positive result from this experiment will prove that the pion is *not* a pseudoscalar particle.

It will be necessary to reconcile a positive result in this π–μ asymmetry experiment with our existing pion knowledge. Although we have pointed out that the main features of the pion can be handled by an helicity-zero-particle model [32], a systematic study is obviously needed. It should be noted that before any pion experiments were performed, Yukawa [40] and others expected that the pion would be a *vector* particle. It is also interesting that experimentally [41], "light vector mesons have been found to populate preferentially in the helicity-zero state."

Acknowledgements This work was inspired by the experimental results of the Romanian Group (H. Hulubei, J.S. Auslander, E.M. Friedlander, and S. Titeica). One has to admire the courage of that Group for their determination to stand by their experimental results over many years in spite of the natural desire of the physics community to resolve or eliminate the anomaly. To satisfy objections to their results, they performed more experiments and made numerous additional checks for systematic errors. In 1965, they even performed the experiment again to show that their method would give an isotropic distribution if the pion beam were unpolarized [17].

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