STUDY OF PION STRUCTURE THROUGH PRECISE MEASUREMENTS OF THE $\pi^+ \to e^+\nu\gamma$ DECAY

D. POČANIĆ*, for the PIBETA Collaboration

Department of Physics, University of Virginia,
Charlottesville, VA 22904-4714, USA
**E-mail: pocanic@virginia.edu*
http://pibeta.phys.virginia.edu

We have measured radiative pion $\pi^+ \to e^+\nu\gamma$ (RPD), and muon $\mu^+ \to e^+\nu\bar{\nu}\gamma$ (RMD) decays, over broad phase space regions using the PIBETA detector. Preliminary results of fits to integral and differential RPD distributions yield the axial and vector pion form factors of $F_A = 0.0116(1)$, and $F_V = 0.0262(11)$, respectively, with a first ever evaluation of their q^2 dependence. We have evaluated $B(\mu^+ \to e^+\nu\bar{\nu}\gamma) = 4.40(9) \times 10^{-3}$ for $E_\gamma > 10\,\mathrm{MeV}$ and $\theta_{e\gamma} > 30°$. We have extracted a new upper bound on the Michel decay parameter $\bar{\eta} \leq 0.033$ (at 68 % C.L.). Our results are in excellent agreement with the Standard Model.

Keywords: pion decays, meson properties, muon decays

1. The PIBETA Experiment and Its Motivation

Thanks to their theoretical simplicity, experimental study of rare decays of light mesons, the pion in particular, leads to improved precision of basic Standard Model (SM) parameters. Muon decays further benefit from the leading-order absence of hadrons. The PIBETA experiment[1,2] at the Paul Scherrer Institute (PSI), Switzerland, focused on the study of rare π and μ decays, primarily the pion beta decay,[3] $\pi^+ \to \pi^0 e^+\nu$, with data acquisition runs in 1999–2001 and 2004. Here we report preliminary results of the pion and muon radiative decay data analysis.

2. Radiative Pion Decay $\pi^+ \to e^+\nu\gamma$

Standard Model with a pure V$-$A electroweak sector requires only two pion form factors, F_A and F_V, to describe the non-QED part of the RPD amplitude. The vector form factor is strongly constrained by the CVC hypothesis to $F_V = 0.0259\,(9)$. Analysis of our 1999-2001 data set comprising over 40 k

RPD events yielded a fourfold improvement in precision of F_A, albeit with a large deficit of low-E_e events,[4] prompting a dedicated experiment in 2004. Detailed results of the 2004 run are available in Ref. 5. We are currently reanalyzing the combined 1999–2001 and 2004 data sets, comprising over 70 k RPD events, with these preliminary best-fit values:

$$F_A = 0.0116\,(1)\,, \quad F_V = 0.0262\,(11)\,, \quad \text{and} \quad a = 0.066\,(20)\,, \qquad (1)$$

where a accounts for the $q^2(\bar{e}\nu)$ dependence of $F_V(q^2) = F_V(0)(1 + a \cdot q^2)$, never before measured. Following the χPT ansatz of Ref. 6, we set $F_A(q^2) \equiv F_A(0)$. Our preliminary result provides the most accurate experimental determination to date of the pion polarizability:

$$\alpha_E = (6.24 \times 10^{-4}\,\text{fm}^3) \cdot \frac{F_A}{F_V} = (2.80 \pm 0.03) \times 10^{-4}\,\text{fm}^3\,. \qquad (2)$$

3. Radiative Muon Decay $\mu^+ \to e^+\nu\bar{\nu}\gamma$

The 2004 PIBETA data set accumulated more than 4×10^5 RMD events, which has enabled us to measure the branching ratio, with the restrictions $E_\gamma > 10\,\text{MeV}$ on the photon energy and $\theta_{e\gamma} > 30^\circ$ on the positron–photon opening angle.[7] Our preliminary result is

$$B(\mu^+ \to e^+\nu\bar{\nu}\gamma) = [4.40 \pm 0.02\,(\text{stat.}) \pm 0.09\,(\text{syst.})] \times 10^{-3}\ . \qquad (3)$$

This represents a fourteenfold improvement in precision over the previous world average.[8] The best fit for the branching ratio is found for

$$\bar{\eta} = -0.084 \pm 0.050(\text{stat.}) \pm 0.034(\text{syst.})\,, \quad \text{or,} \quad \bar{\eta} < 0.033\ (68\%\ \text{C.L.})\,. \qquad (4)$$

All of the above results are in excellent agreement with the SM predictions. Both RPD and RMD will be studied further in the PEN experiment.[9]

References

1. D. Počanić *et al.*, *A Precise Measurement of the $\pi^+ \to \pi^0 e^+\nu$ Decay Rate*, PSI Experiment R-89-01, (Dec. 1991), `http://pibeta.phys.virginia.edu`.
2. E. Frlež *et al.*, *Nucl. Instrum. Meth. in Physics Research A* **526**, 300 (2004).
3. D. Počanić *et al.*, *Phys. Rev. Lett.* **93**, 181803 (2004).
4. E. Frlež *et al.*, *Phys. Rev. Lett.* **93**, 181804 (2004).
5. M. A. Bychkov, Ph.D. thesis, (University of Virginia, 2005).
6. C. Q. Geng, I-Lin Ho, and T. H. Wu, *Nucl. Phys. B* **684**, 281 (2004).
7. B. A. VanDevender, Ph.D. thesis (University of Virginia, 2005).
8. S. Eidelman *et al.*, *Phys. Lett. B* **592**, 1 (2004).
9. V. A. Baranov *et al, Precise Measurement of the $\pi^+ \to e^+\nu$ Branching Ratio*, PSI Expt. R-05-01, (Jan. 2006), `http://pen.phys.virginia.edu`.