TWIST: Measuring the space-time structure of muon decay

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This past year, TWIST completed its final measurements of the muon decay parameters. We find $\rho = 0.74977 \pm 0.00012(\text{stat.}) \pm 0.00023(\text{syst.})$, $\delta = 0.75049 \pm 0.00021(\text{stat.}) \pm 0.00027(\text{syst.})$, and $P_\mu\xi = 1.00084 \pm 0.00029(\text{stat.}) +0.00165 -0.00063(\text{syst.})$, consistent with the Standard Model expectations of ¾, ¾, and 1. The results are summarized in Fig. 1, and have been published in [1].

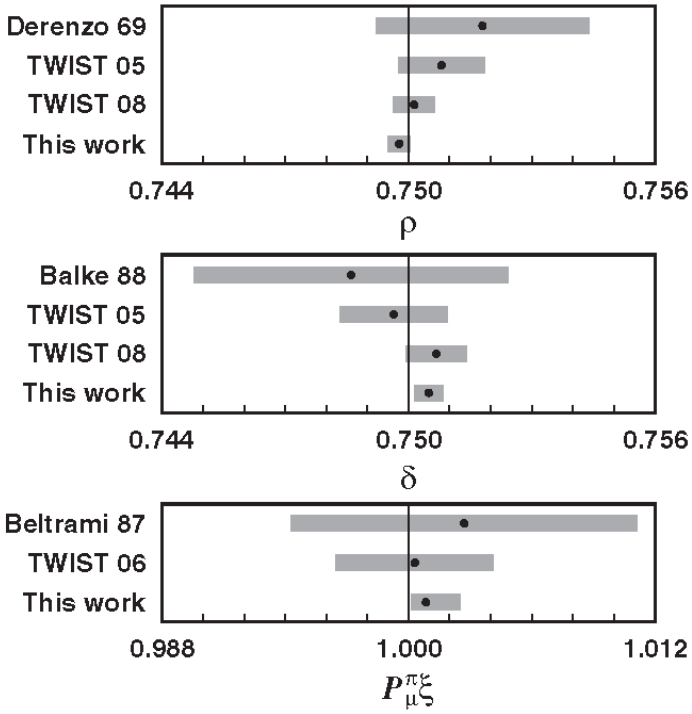

FIG. 1. Final TWIST central values and total uncertainties, together with the intermediate TWIST results and the best pre-TWIST measurements. The vertical lines represent the Standard Model values.

Once the results were finalized, our group explored the implications of the measurements within the Left-Right Symmetric (LRS) model [2]. The LRS model assumes parity violation at low energies arises from a mass splitting between (primarily) left- and right-handed bosons W_1 and W_2. The model parameters include the mass of the heavy W_2 boson, the mixing between the two bosons, the right-handed coupling constant g_R, and the form of the right-handed CKM matrix. The generalized LRS model allows all of these parameters to be free. The manifest LRS model is a special case where the right-handed coupling constant and CKM matrix are assumed to be equal to their left-handed analogs. In LRS models, δ and η retain their Standard Model values, the value of ρ is determined by the $W_1 - W_2$ mixing angle ζ, and the value of $P_\mu\xi$ is determined by the mixing angle, the heavy boson mass m_2, the V_{ud}^R element of the

right-handed CKM matrix, and two CP-violating phases. We developed a method to identify the region of parameter space that is allowed at the 90% level by the TWIST measurements of ρ, δ, and $P_\mu\xi$, including the influence of the parameter correlations. The results are shown in Fig. 2. The TWIST measurements provide the most stringent limits to date within generalized LRS models.

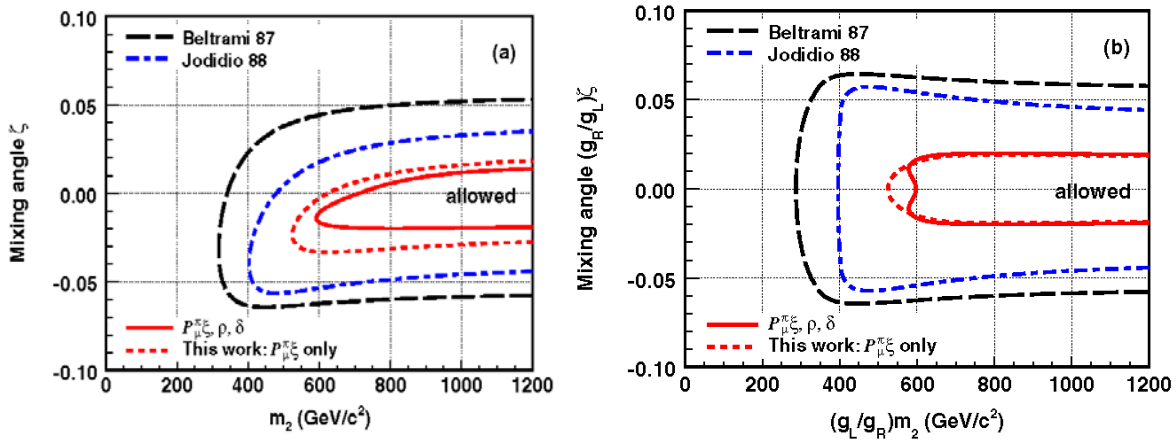

FIG. 2. Allowed regions (90% confidence) for the $W_1 - W_2$ mixing angle and W_2 mass in (left) manifest and (right) generalized LRS models. The red dotted curves show the limits derived using only the final TWIST value for $P_\mu\xi$. The red solid curves show the limits derived from the final TWIST measurements of ρ, δ, and $P_\mu\xi$, including the influence of the parameter correlations.

Our group also updated our previous global analysis of muon decay [3], combining the final TWIST results with a broad range of other measurements. The global analysis sets limits on the weak coupling constants $g^\Gamma_{\varepsilon\mu}$, where Γ specifies the space-time structure of the interaction (*S*, *V*, *T*), and ε and μ specify the chirality of the electron and muon, respectively. Table I presents the final 90% confidence limits, together with the pre-TWIST values [4]. The TWIST measurements provide much stronger constraints on *RR* and *LR* coupling constants that involve right-handed muon interactions. The quantity

Table I. 90% confidence limits on the muon decay coupling constants. The second column shows the pre-TWIST limits.

	Ref. [4]	Final TWIST results
$\lvert g^S_{RR}\rvert$	<0.066	<0.035
$\lvert g^V_{RR}\rvert$	<0.033	<0.017
$\lvert g^S_{LR}\rvert$	<0.125	<0.050
$\lvert g^V_{LR}\rvert$	<0.060	<0.023
$\lvert g^T_{LR}\rvert$	<0.036	<0.015
$\lvert g^S_{RL}\rvert$	<0.424	<0.420
$\lvert g^V_{RL}\rvert$	<0.110	<0.105
$\lvert g^T_{RL}\rvert$	<0.122	<0.105
$\lvert g^S_{LL}\rvert$	<0.550	<0.550
$\lvert g^V_{LL}\rvert$	>0.960	>0.960

Q^{μ}_{R} provides the total probability for a muon to decay via a right-handed interaction. We find Q^{μ}_{R} < 0.00082 with 90% confidence, a factor of 6 reduction compared to the pre-TWIST limit.

A report of the final TWIST results has been published in [1]. The collaboration is preparing two long, archival papers. The first will describe the measurement of $P_{\mu}\xi$; the second will describe the measurements of ρ and δ. The collaboration also plans to publish a search for the two-body decay of the muon, $\mu^{+} \rightarrow e^{+} + X$, where X lives long enough to escape the TWIST detector. The collaboration will disband after those last three papers are published.

[1] R. Bayes *et al*. (TWIST Collaboration), Phys. Rev. Lett. **106**, 041804 (2011).

[2] P. Herczeq, Phys. Rev. D **34**, 3449 (1986).

[3] C.A. Gagliardi, R.E. Tribble, and N.J. Williams, Phys. Rev. D **72**, 073002 (2005).

[4] B. Balke *et al*., Phys. Rev. D **37**, 587 (1988); W. Fetscher and H.-J. Gerber, in S. Eidelman *et al*., Phys. Lett. B **592**, 1 (2004).