Braaten Replies: The Comment by Pumplin[1] criticizes the main result of Ref. 2, that QCD can be used to systematically calculate both the perturbative and nonperturbative corrections to the ratio R for τ decay. Some flaws in his argument will be pointed out below.

Pumplin questions the use of perturbative QCD at the scale $M_\tau^2=3.2$ GeV^2, pointing out that calculations involving parton distributions are generally not extended to a scale lower than $Q^2=5.0$ GeV^2. However, in τ decay the first few power corrections $[(1/M_\tau^2)^n, n=1,2,3]$ to R can be calculated in terms of a few phenomenological "condensate" parameters. In parton calculations, this is not possible for even the first "higher-twist" $(1/Q^2)$ correction because it depends on phenomenological two-parton correlation distributions,[3] which cannot be extracted accurately from experimental data. It is because the power corrections can be calculated and are found to be small that the theoretical prediction for R is expected to be valid at an energy scale as low as M_τ.

There is a separate issue of whether QCD perturbation theory is sufficiently convergent to be useful at any accessible energy. The problem is not that the scale M_τ is too low, because the expansion parameter $\alpha_s(M_\tau)/\pi\simeq\frac{1}{10}$ is indeed small. The estimate of 1% uncertainty given in Ref. 1 was based on the assumption that the coefficient of $(\alpha_s/\pi)^3$ in $R/3$ would be less than 10: $10(\alpha_s/\pi)^3\simeq 1\%$. The coefficient has since been calculated[4] and found to be an order of magnitude larger than anticipated, giving a correction of 10%. This result relies, however, on recent calculation of the order-α_s^3 correction to the ratio R for e^+e^- annihilation,[5] which has not yet been verified by an independent calculation.

Pumplin suggests that the theoretical prediction for R cannot be more accurate than the Shifman-Vainshtein-Zakharov[6] (SVZ) calculations of the parameters of the ρ and a_1 resonances. On the contrary, the prediction for R is necessarily more accurate. The reason is that the ratio R is given by a weighted integral of the hadronic spectrum, which smears the resonances over Q^2. Simply from the uncertainty principle, it is clear that a calculation based on a short-distance expansion should give a more accurate prediction for the integral than for the resonance parameters.

To quantify the error due to resonance effects, Pumplin shows that 10% changes in the ρ and a_1 masses and couplings yield variations in R of several percent, and argues that the error on the theoretical calculation cannot be significantly smaller. However, as pointed out above, such an estimate can only provide an upper bound on the error. Furthermore, he does not take into account the fact that such changes in the resonance parameters would be reflected in the theoretical calculation by large changes in the condensate parameters. For example, if these parameters are extracted from e^+e^- annihilation data, they depend exponentially on the ρ-meson mass.

As a practical test of the validity of the calculation, Pumplin suggests using τ-decay data to calculate phenomenologically the ratio $R(M)$ for a lepton mass $M<M_\tau$, which can then be compared with the M dependence of the theoretical prediction. I believe that this would indeed be a fair test. It can also be carried out independently for the vector part of the hadronic current by using e^+e^- annihilation data.

Finally, I thank Pumplin for pointing out a minor technical error in Ref. 2, along with an embarrassing number of typographical errors.

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[1]J. Pumplin, preceding Comment, Phys. Rev. Lett. **63**, 576 (1989).
[2]E. Braaten, Phys. Rev. Lett. **60**, 1606 (1988).
[3]R. L. Jaffe, Nucl. Phys. **B229**, 205 (1983).
[4]E. Braaten, Phys. Rev. D **39**, 1458 (1988).
[5]S. G. Gorishny, A. L. Kataev, and S. A. Larin, Phys. Lett. B **212**, 238 (1988).
[6]M. A. Shifman, A. I. Vainshtein, and V. I. Zakharov, Nucl. Phys. **B147**, 385 (1979); **B147**, 448 (1979); **B147**, 519 (1979).