8. Conclusions

The angular distribution parameter λ measures how well a perturbative treatment of charmonium and the constituent antiproton and proton works. If charmonium could be completely treated perturbatively and the energy scale is high enough, then this parameter should be one. We have determined the angular distribution parameter to be in accordance with the world average for the J/Ψ, and both the J/Ψ and Ψ' are produced via the helicity one channel over 80% of the time.

There are a few reasons why the angular distribution parameter is not one in the charmonium system, especially for the J/Ψ. Principally this is due to the energy at which charmonium is produced. The production process indeed probes distances in the confinement region of the interquark potential between the valence quarks of the proton and between the charm and anti-charm quarks. When the interquark distance is smaller, a pure perturbative treatment is more appropriate.

The theoretical derivation of the angular distribution parameter is far from complete. Higher-order Feynman diagrams can still be included, and it is unclear whether one may model the distribution amplitudes in the same way at

charmonium energies than at top quark energies. One may also argue about the charmonium potential used in the derivation and the appearance of multi-quark Fock states in the proton. Nevertheless, recent theoretical predictions are quite consistent with experimental results.

Figure 8.1 compares the angular distribution parameter derived in this thesis respectively with previous theoretical expectations for the J/Ψ shown in Chapter 5. The value of $0.63 \pm 0.18 \pm 0.05$ is consistent with most of the theoretical predictions to within 1σ, although the predictions of Brodsky-Lepage and Gari -Stefanis lie outside the 1σ window.

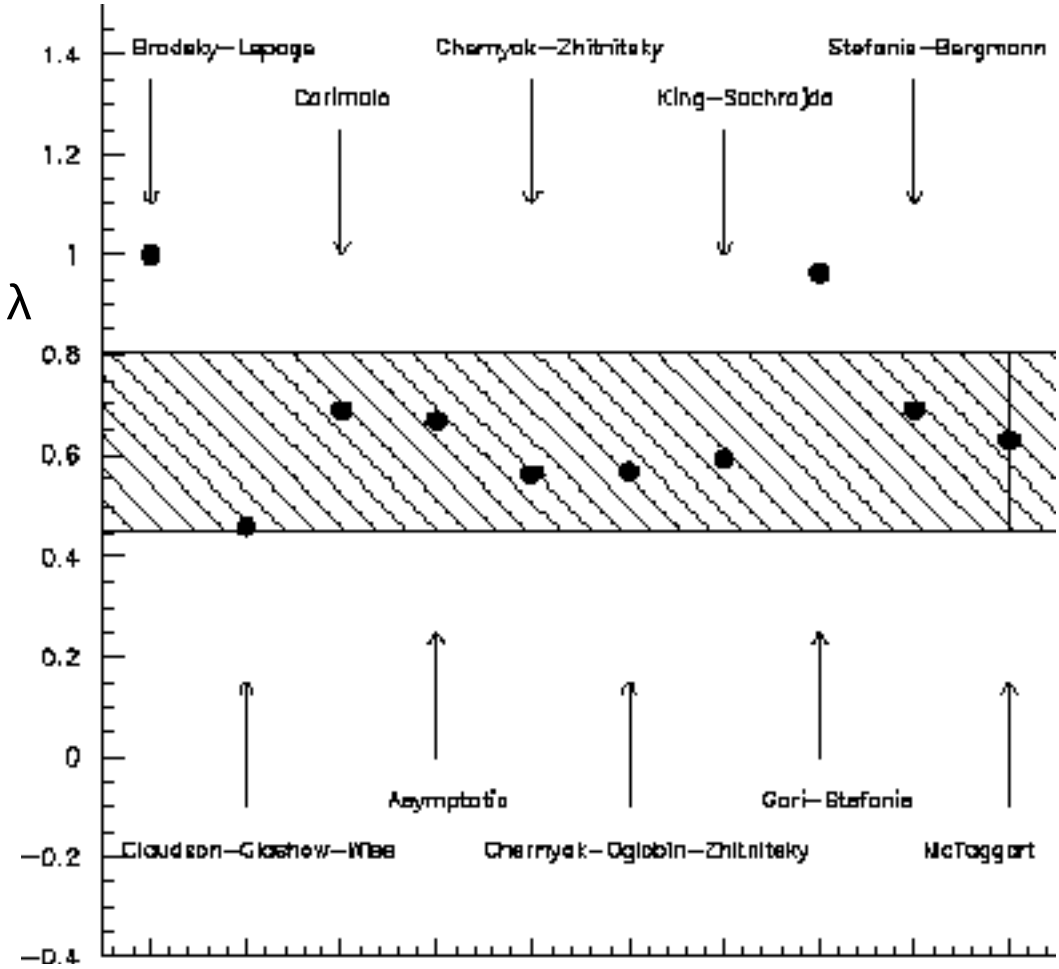

Figure 8.1: Comparison of thesis value with the theoretical predictions for the angular distribution parameter λ at the J/Ψ.

Figure 8.2 likewise compares the thesis value for the Ψ' with the various theoretical models. In this case, the thesis value again agrees with all the predictions for the Ψ' to within 1 σ. Again, the values of Brodsky-Lepage, and Gari-Stefanis lie outside the 1 σ window.

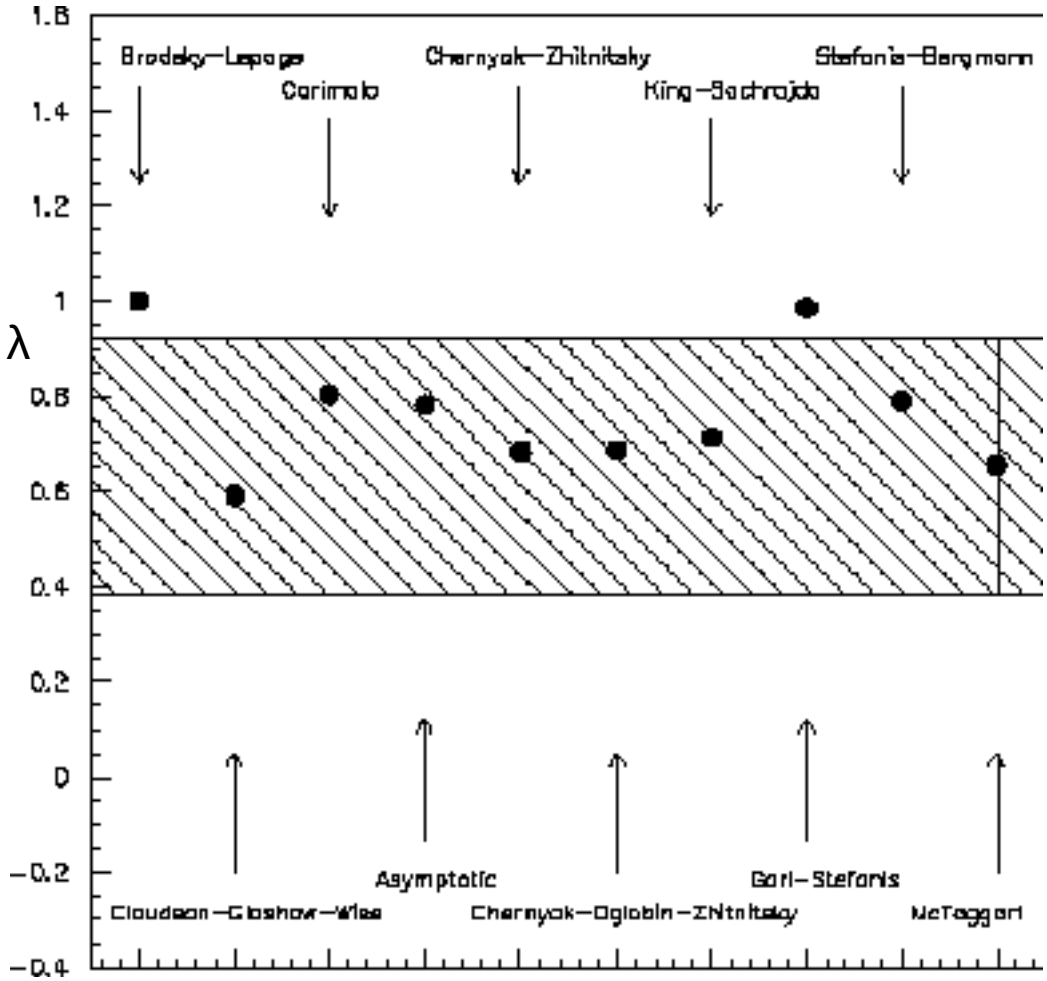

Figure 8.2 : Comparison of thesis value with the theoretical predictions for the angular distribution parameter λ at the Ψ'.

In Figure 8.3 one may contrast the thesis value for the J/Ψ with previous experiments (see Table 7.3). The thesis value of 0.63 ± 0.18 ± 0.05 agrees with both the world average of 0.63 ± 0.08 and lies within the errors of all the previous experiments except Mark I. Moreover, the proton-antiproton annihilation method (from e760 and e835) is consistent with the electron-

positron method of charmonium production at the J/Ψ, where λ is derived from the decay of charmonium into $p\bar{p}$.

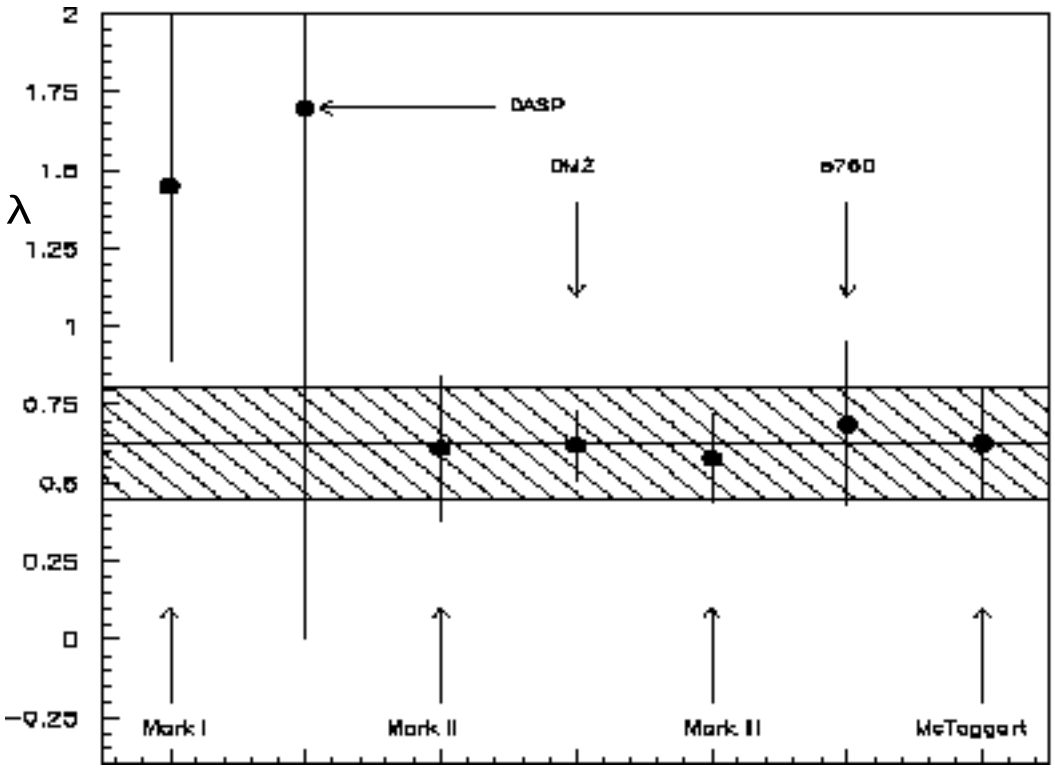

Figure 8.3 : Comparison of thesis value with previous experimental data for the angular distribution parameter λ at the J/Ψ.

In conclusion, the experimental values presented in this thesis for the angular distribution parameter are consistent within errors with most of the theoretical models and with the current world experimental average. However , the theoretical extremes of either a pure perturbative system or of a system where spin-flip amplitudes are negligible are mildly inconsistent with the results at both the J/Ψ and the Ψ'. Hence spin dynamics and the confinement term in

the QCD potential have an effect.

Increased statistics and a value for the width to $p\bar{p}$ would help to favor one particular theory, since the thesis values match several predictions equally well. However it appears that the heterotic treatment of Stefanis-Bergmann[85] agree better with both the thesis values for the angular distribution parameter and the quoted widths to $p\bar{p}$ (see Tables 5.1 and 5.2), which are not determined from the thesis sample. In this instance, non-perturbative effects in the formation of the proton (or dissolution thereof) represented by the quark distribution amplitudes become important.

The hypothesis that the angular distribution parameter, which links $p\bar{p}$ annihilation to charmonium production, increases as the formation energy increases (which is predicted by QCD) cannot be excluded by the data presented in this thesis. However, this behavior must be resolved by more data at the Ψ', since the thesis values of the angular distribution are also consistent with the angular distribution parameter remaining constant, or nearly constant, over the course of the charmonium system.

The final values of the angular distribution parameter derived in this thesis for the exclusive decays of J/Ψ and Ψ' into e+e- from proton-antiproton annihilation are:

$$\lambda(J/\Psi) = 0.63 \pm .18 \text{ (statistical)} \pm .05 \text{ (systematic)}$$
$$\lambda(\Psi') = 0.66 \pm .27 \text{ (statistical)} \pm .03 \text{ (systematic)}$$