Low Energy Measurements of the Strong Coupling Constant
and the Question of a Light Gluino

L. Clavelli and P.W. Coulter

Dept. of Physics and Astronomy
University of Alabama
Tuscaloosa AL 35487

Abstract

The hadronic width of the J/ψ is anomalously small when compared with that of the Υ in standard QCD in the non-relativistic approximation. We discuss the extent to which current ideas concerning relativistic corrections and/or supplementing QCD with a light gluino can reconcile these measurements with each other and with other low energy data including that from the lattice and from τ decay.

Although precision measurements at the Z pole have yielded information on the electroweak couplings with an error of the order of 0.1%, the experimental value of $\alpha_3(M_Z)$ from LEP has an error of the order of 10%. For instance, we know that

$$\alpha^{-1}(M_Z) = 127.9 \pm 0.2 \quad (1)$$

$$\sin^2 \theta_W(M_Z) = 0.2324 - .005 \cdot \left(m_t^2 / (138 \text{ GeV})^2 - 1 \right) \pm .0003 \quad (2)$$

whereas from LEP studies the current published value [1] of the strong coupling constant is

$$\alpha_3(M_Z) = 0.123 \pm .006 \quad (3a)$$

Analysis of more recent data from LEP may have the effect of bringing this value down significantly, without, however, reducing the error [2]:

$$\alpha_3(M_Z) = 0.108 \pm .012 \quad (3b)$$

Current jet studies at LEP are still plagued by hadronization effects and

SCAN/9408027

CERN LIBRARIES, GENEVA

other systematic errors. The substantial uncertainty in α_3 has had the effect of severely limiting the predictive power of SUSY unification schemes. On the other hand, electron annihilation studies over a range of lower energies allow for a test of the presence of strong non-perturbative effects since these will typically fall off with a power of $\sqrt{s}$ which can then be easily distinguished from the predictions of perturbative QCD which fall off only logarithmically. Two jet measures which were predicted to have negligible non-perturbative effects are the jet mass difference and the integrated energy-energy asymmetry. We discuss current data on these measures and compare the resulting values of $\alpha_3(M_Z)$ with those from quarkonia decays and lattice calculations. The effect of relativistic effects in quarkonia decays and of a possible light gluino are also considered.

The jet (squared) mass difference scaled by the (squared) center of mass energy, s , is an infrared insensitive quantity whose perturbation theory prediction [3] as a function of s is

$$\langle M_h^2 - M_l^2 \rangle / s = 1.05 \frac{\alpha_3(s)}{\pi} \cdot \left(1 + 2.76 \frac{\alpha_3(s)}{\pi} + \dots \right) \quad (4)$$

M_h and M_l are respectively the heavier and lighter jet masses where, by definition, the hadrons are associated with two jets of minimum mass. For this quantity the second order corrections are small and the non-perturbative effects are expected to approximately cancel between the two jet masses. This can be experimentally tested by comparing the experimental results with the QCD prediction and looking for additional power law terms in $\sqrt{s}$. In fact it is found that the energy dependence of this quantity is consistent with perturbative QCD alone; there is no evidence for the presence of power law corrections to eq.4. It would be theoretically discouraging if the non-perturbative contributions to an infrared insensitive quantity had the same logarithmic behavior as the perturbative contributions, thus frustrating any separation. On general grounds (they are higher twist terms) the non-perturbative contributions should fall off as a power of the QCD Λ parameter divided by $\sqrt{s}$. There is very little room in the data for such contributions. We feel therefore that this data gives a reasonable estimate of the strong coupling constant without appreciable uncertainties due to non-perturbative effects. As we shall see the results interpolate well through the quarkonium region and are in reasonable agreement with the lattice

results, which at present are the only quasi-rigorous treatment of non-perturbative effects.

A similarly infrared insensitive quantity is the integrated energy-energy asymmetry.

$$\int_{30^0}^{90^0} d\chi A_{EE}(\chi) = 0.766 \frac{\alpha_3(s)}{\pi} \left(1.0 + 3.59 \frac{\alpha_3(s)}{\pi} \right) , \quad (5)$$

where $A_{EE}(\chi) = E(180^0 - \chi) - E(\chi)$ and $E(\chi)$ is the distribution of the energy-weighted angle χ between the directions of any two particles in the event. Any non-perturbative corrections to this quantity must also be power behaved in $\sqrt{s}$ and no such corrections are found. The CELLO data [4] on these two quantities are plotted in figure 1 versus $\sqrt{s}$. Each result for $\alpha_3(s)$ is extrapolated to M_Z and averaged there assuming standard QCD running with five flavors. These can be compared with a recent precision lattice result [5]

$$\alpha_3(M_Z) = .102 \begin{smallmatrix} +.0029 \\ -.0100 \end{smallmatrix} \quad (\text{Lattice}) \quad . \quad (6)$$

This is consistent with the previous published lattice result [6]. The asymmetric errors quantify the preference of lattice calculations for small values of α_3 . The band of α_3 values shown in figure 1 corresponds to the weighted average of this lattice value with that from the CELLO data

$$\alpha_3(M_Z) = .0965 \begin{smallmatrix} +.002 \\ -.003 \end{smallmatrix} \quad (\text{weighted average}) \quad . \quad (7)$$

We also plot in figure 1 the lattice result in eq. 6 extrapolated to 5 GeV. Eq.(7) is consistent with that obtained in 1984 from earlier experiments on the same jet measures. The most accurate data from the three gluon decays of the 3S_1 vector quarkonia in the non-relativistic approximation are also plotted on figure 1 for comparison. The other quarkonia measurements are consistent with these but have larger errors. The results are taken from [7] but are updated to include the results of the 1994 Particle Data Group averages. In the non-relativistic quark model one finds

$$\alpha_3^0(\mu) = \left[\frac{\Gamma(^3S_1 \rightarrow \text{dissimilar hadrons}) \cdot 81\alpha^2\pi e_q^2}{\Gamma(^3S_1 \rightarrow e^+e^-) \cdot 10 \cdot (\pi^2 - 9)} \right]^{1/3} . \quad (8)$$

The scale μ is chosen so that the next-to-leading order QCD corrections vanish. It takes the natural form of approximately the quark mass. Such a scale choice is usually very close to that defined by the principle of minimum sensitivity. The superscript 0 indicates that α_3^0 is the result of pure perturbative QCD in the non-relativistic heavy quark approximation with no attempt to allow for model-dependent relativistic corrections. We regard it as quite interesting that one can predict the non-strange decay of the Φ meson from perturbative QCD if the strong coupling is as low as eq.7. This was first pointed out in [8]. On the other hand a strong coupling this low is inconsistent with minimal SUSY unification. In [7] it was noted that a gluino of mass 5 GeV or less could restore consistency with unification; this was the first positive indication that the gluino might be light. Other positive indications were noted in [9],[10],and [11]. It is now generally agreed that there are three windows at low energy for the gluino mass [12] and vigorous proposals are being made to close these windows definitively or to discover a light gluino [13]. The current status of these windows is shown in figure 2 which updates the figure of [12] to show the effect of LEP measurements and the Helios result [14]. The latter experiment is a missing energy experiment which complements the Beam Dump results. It, however, is not sensitive to gluinos of mass or lifetime significantly greater than charm. The upper boundary of the ultra low mass gluino window is given by the CUSB [15] result $m_{\tilde{g}} < 0.6 \text{ GeV}$ or $m_{\tilde{g}} > 2.6 \text{ GeV}$. The CUSB experiment searched for mono-energetic photons from Υ decay which could signal the presence of gluinoballs. The theoretical prediction for this rate is governed by the gluinoball wave function at the origin which is somewhat model dependent. The CUSB constraint will become more compelling when the mono-energetic photons associated with the expected glueballs or with the known pseudoscalar mesons are discovered in Υ decay. However, even accepting this result, a very light gluino which should lead to an approximately supersymmetric multiplet of glueballs, gluinoballs, and glueballinos could exist.

The above-noted consistency of light gluinos with SUSY unification, however, required that only the gluino and photino be light. If, as is the case in the minimal supergravity-inspired model, the Winos, Zino, and Higgsinos are also below the Z when the gluino is light, the consistency is destroyed [16] and solutions are only found for $.122 < \alpha_3(Z) < .132$. Although

this is not in disagreement with the LEP data of eq.3a, it causes serious problems for low energy QCD as is obvious from fig.1. Independent of this problem, it was pointed out in [9] that the discrepancy in fig.1 between the J/Ψ and Υ data can be greatly alleviated if the gluino is in the lowest energy window around 0.4 GeV. The possibility that the vector quarkonia can decay into gluino-containing hadrons modifies the quarkonium measurement of $\alpha_3(M_q)$ according to the relation

$$\alpha_3^0(M_q) = \alpha_3(M_q) \left(1 + \frac{3}{\pi} \alpha_3(M_q) R(m_{\tilde{G}}/M_q) \right)^{1/3} \quad (9)$$

where R is a steeply falling function of its argument given by [17]. The result then is that $\alpha_3(M_Z)$ is 0.113 ± 0.003 , significantly higher than eq.7. Another approach to the J/Ψ - Υ discrepancy of fig.1 is to make a linear parametrization of the relativistic corrections of the form [18]

$$\alpha_3^0(M_q) = \alpha_3(M_q) \left(1 - C \langle v^2/c^2 \rangle \right)^{1/3} \quad (10)$$

Here v is the quark velocity in the vector bound state. In a typical potential model

$$\langle v^2/c^2 \rangle = \begin{cases} .23 & \text{for } J/\Psi \\ .077 & \text{for } \Upsilon \end{cases} \quad (11)$$

This is a dangerous procedure for several reasons apart from the model dependence of eq.11. First of all, the fit values of C are greater than 3 implying that the J/Ψ width is reduced by some 70% by "relativistic corrections". This would strongly suggest that quadratic effects are non-negligible and should go in the opposite direction. It is possible to do a quadratic fit which would reconcile the J/Ψ and Υ data without such large corrections. Such a fit could easily bring the quarkonium data into agreement with the jet mass and energy asymmetry data without requiring such large relativistic corrections although then all predictive power from quarkonia is lost. Secondly, if one makes a phenomenological linear parametrization of the relativistic corrections, one must give up hope of understanding the Φ decay, and the Zweig rule at low energies, since the simple linear fit in $\langle v^2/c^2 \rangle$ is not likely to be meaningful. Thirdly, the agreement of the quarkonia data with the lattice results and with the infrared insensitive jet measures is destroyed. In addition the large increase in α_3 at both the bottom quark and charm quark scales in the linear parametrization is not supported by the data

from $GGG/GG\gamma$ branching ratios of vector quarkonia nor by that from the $GG/\gamma\gamma$ branching ratio of the η_c as we will now discuss. Theoretically these ratios are

$$\frac{\Gamma(V \rightarrow GGG)}{\Gamma(V \rightarrow GG\gamma)} = \frac{5}{36\alpha_e^2} \alpha_3^{(\mu)} \left\{ 1 + \frac{\alpha_3^{(\mu)}}{\pi} \left[-2.3 + 0.93 \cdot \beta_0 + \frac{\beta_0}{2} \ln(\mu/M_V) \right] \right\} \quad (12)$$

$$\frac{\Gamma(\eta_c \rightarrow GG)}{\Gamma(\eta_c \rightarrow \gamma\gamma)} = \frac{2}{9\alpha_e^2} \alpha_3^{(\mu)} \left\{ 1 + \frac{\alpha_3^{(\mu)}}{\pi} \left[-0.9 + \frac{20-\pi^2}{3} + \beta_0(4/3 + \ln(\mu/M_{\eta_c})) \right] \right\} \quad (13)$$

where $\beta_0 = 11 - 2n_f/3$ for n_f active quarks. In each case a separate μ can be chosen so that the square bracket in eqs. 12 and 13 vanishes. The results are summarized in table 1.

Table 1

Branching Ratio	experiment	ref.	μ (GeV)	$\alpha_3^0(\mu)$	$\alpha_3^0(M_Z)$
$\Gamma(\Upsilon \rightarrow GGG)/\Gamma(\Upsilon \rightarrow \ell^+ \ell^-)$	32.5 ± 1.3	[19]	4.54	$.181 \pm .002$	$.1045 \pm .0007$
$\Gamma(J/\Psi \rightarrow GGG)/\Gamma(J/\Psi \rightarrow e^+ e^-)$	10.7 ± 0.7	[19]	1.37	$.197 \pm .004$	$.0909 \pm .0008$
$\Gamma(\Upsilon \rightarrow GG\gamma)/\Gamma(\Upsilon \rightarrow GGG)$	$.0279 \pm .0015$	[20]	2.55	$.216 \pm .011$	$.1043 \pm .0024$
$\Gamma(J/\Psi \rightarrow GG\gamma)/\Gamma(J/\Psi \rightarrow GGG)$	$0.10 \pm .04$	[21]	0.80	$.23^{+.16}_{-.06}$	$.089^{+.014}_{-.010}$
$\Gamma(\eta_c \rightarrow GG)/\Gamma(\eta_c \rightarrow \gamma\gamma)$	1470 ± 650	[19]	0.60	$.27 \pm .06$	$.0895^{+.0049}_{-.0101}$

Since the structure of the interactions in the numerators and denominators of eqs. 12 and 13 are identical, these ratios should be insensitive to relativistic corrections. The corresponding values of α_3 are shown, on an expanded scale, in figure 3 in comparison with the values from the quarkonia and lattice data of figure 1. The dashed line in figure 3 corresponds to the value $\alpha_3(M_Z) = 0.108$ which is the 1σ lower limit in the fit of Kobel [18]. In that fit the α_3 values from J/Ψ and Υ are moved above the dashed line by

relativistic corrections ($C \approx 3$). If the radiative to gluonic branching ratios are indeed insensitive to relativistic corrections, it is clear from figure 3 that the value of α_3 from the GGG decay of the Υ cannot rise by as much as would be suggested by a value $C=3$ in eq. 10. In other words, the value of $C \sim 3$ required to reconcile the J/Ψ with the Υ hadronic decay data is disfavored at the 1σ level by the Υ radiative decay. Similarly the data from the J/Ψ and η_c radiative decays, the 4th and 5th rows in table 1, do not support as large an increase in $\alpha_3(m_c)$ as would be implied by the linear fit. The problem, in fact, goes beyond the linear fit. As one can see from figure 3, the discrepancies cannot be resolved by any relativistic corrections to the three gluon decays of J/Ψ and Υ which, as expected, do not affect the radiative branching ratios in table 1. The best one could hope for in this approach would be for the relativistic corrections to increase the α_3 value from the hadronic J/Ψ decays while decreasing that from the hadronic Υ decays. This could be done by adding a quadratic term to the phenomenological relativistic correction of eq. 10. The resulting value of $\alpha_3(M_Z)$ would then be close to eq. 7 although the minimum χ^2 per degree of freedom in such a fit including the radiative decays would still be unacceptably large. As a final note of caution concerning the linear parametrization one should note that, since in such a fit one can trivially reconcile the J/Ψ data with the Υ data (ignoring the radiative data), it begs the question of whether there is some non-standard physics in the low energy region.

A mundane resolution of the puzzle might be to assume that the relativistic corrections also affect the radiative branching ratios in table 1, but a sufficiently large effect would be extremely surprising. At present therefore one should not rule out a "new physics" resolution. On the other hand the fit with a light gluino by itself did not succeed in totally reconciling the J/Ψ 1S data with the Υ . An acceptable fit including the J/Ψ 1S data was found in [9] only by adding in quadrature to the experimental error an extra 10% as a concession to the seeming necessity for some relativistic corrections. We therefore consider a combination of gluino and relativistic corrections writing

$$\alpha_3^0(\mu) = \alpha_3(\mu) \left(1 + \frac{3}{\pi} \alpha_3(\mu) R(m_{\tilde{G}}/M_q) \right)^{1/3} \left(1 - C_1 \langle v^2/c^2 \rangle - C_2 \langle v^2/c^2 \rangle^2 \right)^{1/3} \quad (14)$$

for the Υ and J/Ψ hadronic decay results,

$$\alpha_3^0(\mu) = \alpha_3(\mu) \left(1 + \frac{1}{\pi} \alpha_3(\mu) R(m_{\tilde{G}}/M_q) \right) \quad (15)$$

for the Υ radiative result, and

$$\alpha_3^0(\mu) = \alpha_3(\mu) \left(1 + \frac{2}{\pi} \alpha_3(\mu) R(m_{\tilde{G}}/M_q) \right)^{1/2} \quad (16)$$

for the η_c result. The coefficient of the gluino correction is taken, as an approximation, to be proportional to the difference in the numerator and denominator processes of the number of zeroth order gluons each of which can split into a gluino pair. In these equations α_3^0 is the uncorrected result of table 1 while α_3 is the resulting value of the strong coupling constant in the presence of gluino and relativistic corrections. For each value of $m_{\tilde{G}}$ there is a narrow band of C_1 and C_2 values that will bring the data into reasonable agreement. We have scanned the space of $m_{\tilde{G}}$, C_1 , and C_2 in a Monte Carlo to find these allowed solutions. We require consistency between the J/Ψ and Υ GGG decay data as well as consistency with the $\Upsilon \rightarrow GGG/GG\gamma$ and $\eta_c \rightarrow GG/\gamma\gamma$ branching ratios which are taken to be independent of relativistic corrections. We also require that the relativistic correction to the Υ decay be no larger than that to J/Ψ decay since this correction goes to zero for sufficiently large quark mass. Because of its large experimental uncertainty we do not use in the fit the J/Ψ radiative branching ratio, the 4th row in table 1, although one can see from figure 3 that its inclusion would not qualitatively change our results. Instead we use a constraint from the lattice result.

We turn therefore to consider the effect of light gluinos on the lattice analysis [22]. In this work calculations are made in the zero flavor (quenched) approximation and a correction factor $1 + 2n_f/33 \approx 1.24$ is applied to the resulting α_3 to account for the effect of quark loops. Actually we feel this is an overestimate since it is unlikely that the strange and charm quarks contribute equally with the light flavors. We would find it preferable to replace n_f by the mass dependent β function contribution

$$n_f = \sum_{i=1}^4 n(m_i, m_b) \quad (17)$$

where [23]

$$n(m_i, Q) = 1 - 6 m_i^2/Q^2 + 24(m_i^4/Q^4) \frac{1}{w} \operatorname{arccoth}(w) \quad (18)$$

with

$$w = \sqrt{1 + 4m_i^2/Q^2} \quad (19)$$

This has the effect of reducing the lattice value of $\alpha_3(m_b)$ by about 2%. Similarly the effect of light gluinos can be incorporated by writing

$$\alpha_3(5 \text{ GeV}) = (0.169_{-0.027}^{+0.017}) \left(1 + 2(n_f + 3n(m_{\tilde{G}}/m_b)) / 33 \right) / 1.24 \quad (20)$$

where we have supplied the color-statistics factor of 3 to relate the effect of an octet of color gluinos to that of a single quark flavor. The lattice value of α_3 increases with decreasing gluino mass while the Υ value decreases. The result is that they are consistent only for a very restricted range of gluino masses $m_{\tilde{G}} < 2 \text{ GeV}$.

Thus in our monte carlo, we vary four parameters $\alpha_3(M_Z)$, $m_{\tilde{G}}$, C_1 , and C_2 . For each set of these four parameters we calculate the χ^2 per degree of freedom for the 5 data points represented by the lattice result and the processes of table 1 excluding the J/Ψ radiative decay. Figure 4 shows a scatter plot of $m_{\tilde{G}}$ versus $\chi^2/5$ with the $\alpha_3(M_Z)$ values indicated by shape coding. Solutions are found with $.1047 < \alpha_3(M_Z) < .1231$. Values of $\alpha_3(M_Z)$ in the lowest to highest quadrants of this range are indicated in figure 4 by rectangles, triangles, ovals, and diamonds respectively. The plotted points are a random non-overlapping subset from a random sample of 5000 solutions. The figure represents all possible values of C_1 and C_2 with $0.1 < m_{\tilde{G}} < 5 \text{ GeV}$ and a resulting $\chi^2/5 < 3$. Values of $m_{\tilde{G}}$ above 5 GeV have $\chi^2/5$ above 2.2 and lower values of $\alpha_3(M_Z)$. For $m_{\tilde{G}} > M_Z$ this minimum $\chi^2/5$ corresponds to $\alpha_3(M_Z) = .0985 \pm .0015$ which overlaps well with the result of eq.7. As can be seen from Fig. 4, a $\chi^2/5 < 1$ requires a gluino mass below 0.7 GeV. In figure 5 we show the values of $\alpha_3(1.36 \text{ GeV})$ as a function of the gluino mass with the $\chi^2/5$ values indicated in the shape coding. Solutions are found with $\chi^2/5$ down to 0.54 and the range from this value to 3.0 is divided into quadrants indicated in figure 5 by rectangles, triangles, ovals and diamonds from the lowest to the highest quadrant respectively. The solutions shown are a random non-overlapping subset of the 5000 events used also in figure 4. For $m_{\tilde{G}} < 5 \text{ GeV}$ figure 6 shows the resulting $\chi^2/5$ values as a function of $\alpha_3(M_Z)$. The preferred solutions have $\alpha_3(M_Z) = 0.114 \pm .005$ with $m_{\tilde{G}} < 0.7 \text{ GeV}$.

The constraints on α_3 from τ decay are often quoted in support of an $\alpha_3(M_\tau) \approx 0.33$ which would suggest standard QCD running between M_τ and M_Z [24,25]

and hence the absence of a light gluino. Such a large value of $\alpha_3(M_\tau)$ would be in conflict with the large body of low energy data shown in figures 1 and 3. In fact there are at least three ways to measure the strong coupling in τ decay and the current anomalies in the world average data can be interpreted in terms of an inconsistency in the α_3 values deduced from these various measurements [26]. Thus, on very general grounds, the electronic branching ratio, $B_\tau(e)$, the τ lifetime, τ_τ and the τ single hadron branching ratio, $B_\tau(h)$, are all related by

$$\tau_\tau = B_\tau(e) \tau_\mu \left(\frac{M_\mu}{M_\tau} \right)^5 \quad (21)$$

$$B_\tau(h) = \frac{\tau_\tau}{2M_\mu^2 M_\tau} \left[\frac{M_\pi^3 B_\pi(\mu) (M_\tau^2 - M_\pi^2)}{\tau_\pi (M_\pi^2 - M_\mu^2)^2} + \frac{M_K^3 B_K(\mu) (M_\tau^2 - M_K^2)^2}{\tau_K (M_K^2 - M_\mu^2)^2} \right] \quad (22)$$

Each of these three quantities can be used as a measure of the strong coupling constant through the theoretical expression

$$B_\tau(e) = \left\{ 1.973 + 3.0582 \left[1 + \delta_{pert} + \delta_{n.p.} \right] \right\}^{-1} \quad (23)$$

The perturbative contribution is usually written

$$\delta_{pert} = \left(\frac{\alpha_s}{\pi} \right) + 5.2023 \left(\frac{\alpha_s}{\pi} \right)^2 + 26.366 \left(\frac{\alpha_s}{\pi} \right)^3 + \delta_{h.o.} \quad (24)$$

and usually $\alpha_s(M_\tau)$ is evaluated from the electronic branching ratio of the τ with $\delta_{h.o.}$ taken to be zero or negative and $\delta_{n.p.}$ (the non-perturbative contribution) estimated to be ≈ -0.007 . [24] This leads to the quoted result for $\alpha_3(M_\tau)$ above 0.3. However, in view of the large quadratic and cubic terms in eq. 24, it seems more reasonable to us to write

$$\delta_{pert} = \left(\frac{\alpha_s}{\pi} \right) \left[1 - 5.202 \left(\frac{\alpha_s}{\pi} \right) \right]^{-1} - 0.69 \left(\frac{\alpha_s}{\pi} \right)^3 + \delta_{h.o.} \quad (25)$$

with the residual $\delta_{h.o.}$ assumed negligible. This amounts to assuming that the higher order corrections fall off approximately as a geometric series as suggested by the first two known corrections. Eqs. 25 and 24 are equivalent up to the known order. In addition we neglect $\delta_{n.p.}$ since its current estimate is comparable to unknown fourth order perturbative contributions and the theory of non-perturbative corrections is still highly model dependent. In table 2 we show the values of the three related τ decay parameters in both

the world average data where discrepancies persist and in the ALEPH data where consistency is obtained although the errors are larger. In each case we calculate α_3 using eq. 25 neglecting $\delta_{n.p.}$ and $\delta_{h.o.}$. The weighted means are also given. The data in table 2 are taken from reviews at the 2nd Workshop on τ Lepton Physics. [27, 28]

The inconsistencies in the world average data can be gauged by the discrepancies in the values of α_3 deduced from the three measurements. Until these discrepancies are resolved the small error in the average α_3 may not be reliable. The Aleph data is more self-consistent and therefore its weighted average α_3 may be more meaningful. Extrapolated to 1.36 GeV the resulting value of α_3 is $.300 \pm .018$ in the case of a heavy gluino and $0.289 \pm .016$ in the case of a light gluino. These are two or three standard deviations from the value predicted by good fits to the quarkonium and lattice data as can be seen from figure 5. The τ data could be brought into perfect agreement if the non-perturbative contribution were $\delta_{n.p.} \approx + 0.03$ which is small compared to the perturbative contribution.

Table 2

	World Ave.	ALEPH
$B_\tau(e)$	$.1776 \pm .0015$	$.1820 \pm .0035$
$\alpha_3(M_\tau)$	$.305 \pm .013$	$.264 \pm .034$
τ_τ	295.7 ± 3.2 ps	$294.7 \pm 5.4 \pm 3.0$ ps
$\alpha_3(M_\tau)$	$.274 \pm .018$	$.277 \pm .035$
$B_\tau(h)$	$.1279 \pm .0029$	$.1281 \pm .0034$
$\alpha_3(M_\tau)$	$.243 \pm .041$	$.231 \pm .059$
ave. $\alpha_3(M_\tau)$	$.285 \pm .006$	$.262 \pm .013$
ave. $\alpha_3(M_Z)$	$.1095 \pm .0008$	$.1063 \pm .0020$

Finally we turn to the jet measures. It is known that the presence of light gluinos would raise the value of α_3 required to fit jet measures [11] by about 10%. The actual value of $\alpha_3(M_Z)$ deduced from the CELLO data

in the presence of light gluinos would then be about 0.11.

The current analysis, therefore, suggests two consistent values of $\alpha_3(M_Z)$ depending on whether or not the gluino is light. These are

$$\text{Standard QCD: } \alpha_3(M_Z) = 0.097 \pm 0.003 \quad (26)$$

$$\text{Light Gluino: } \alpha_3(M_Z) = 0.114 \pm 0.005 \quad (27)$$

Both of these are inconsistent with minimal supersymmetric unification predictions (with supergravity inspired soft SUSY breaking) [7, 16] which prefers significantly higher values. We will come back to this in a subsequent publication. An important question, of course, is what is the likelihood that the actual value of the strong coupling constant in standard QCD is significantly greater than eq. 26. Many higher values of α_3 have in fact been reported from jet studies including some quoted in [9] in support of a light gluino but all of these depend on large model-dependent hadronization corrections. Recent LEP values from the Z width are consistent at the 1σ level with both eq. 26 and 27.[2] It is of course possible that, in the future, better understanding of the bound-state corrections to the quarkonia widths and refinements in the lattice calculations may lead to somewhat larger values of $\alpha_3(M_Z)$ but it is unlikely that such effects could lead to consistency between low energy physics and minimal susy unification.

A more physical model for the bound state corrections [29] taking into account one of three possible effects has also recently obtained limited upward corrections to α_3 . Their results are that, in standard QCD,

$$\text{from the } J/\Psi \text{ width: } \alpha_3(M_Z) = .1056 \pm 0.0013 \quad (28)$$

$$\text{from the } \Upsilon \text{ width: } \alpha_3(M_Z) = .110 \pm 0.002 \quad (29)$$

The fact that the value of $\alpha_3(M_Z)$ from the J/Ψ lies below that from the Υ continues to support the possibility of a light gluino.

Comparable numbers have also come from analysis of deep inelastic scattering [30] which arrives at

$$\text{Deep Inel: } \alpha_3(M_Z) = .108 \pm 0.002 \quad (30)$$

These authors find that the deep inelastic data in the presence of a light Majorana gluino requires $\alpha_3(M_Z) = 0.124 \pm 0.001$. This figure, although in agreement with the published LEP analyses leading to eq. 3, is inconsistent

with the jet data and lattice results. The deep inelastic data, if they are currently correctly interpreted, may therefore rule out a gluino in the five GeV mass region. It is not clear whether the effects of an ultra-light gluino (below 0.7 GeV) on the deep inelastic data have been thoroughly analyzed.

A number similar to eq. 30 comes, in the heavy gluino case, from the Brodsky-Lepage-Mackenzie [31] proposal for choice of scale

$$\text{BLM scale choice: } \alpha_3(M_Z) = .107 \pm .003 \quad (31)$$

Similarly, recent lattice work [32] might point to an increase in α_3 , the new preliminary values being about $\alpha_3(M_Z) = 0.110 \pm .004$, two standard deviations from the result of [5]. It is clear from [18] that further analysis of potential model dependence in the lattice calculations may be needed to resolve a possible discrepancy between the lattice values and the values from the jet-mass difference and the energy-energy asymmetry. For the present we regard eqs. 26 and 27 as the best estimates from low energy data of the value of $\alpha_3(M_Z)$ although the current situation is such that an ultimate two to three standard deviation departure from those values would not be totally surprising. This would not affect our major conclusions which are:

1. Current ideas about relativistic corrections in quarkonium decays in the standard model still leave a 2σ - 3σ discrepancy between values of the strong coupling constant from J/Ψ and Υ decay. This discrepancy could be resolved by further progress in understanding relativistic corrections or by new physics such as a light gluino.

2. If there is no new physics in the low energy region, the large body of low energy data that is free of obvious, large, model-dependent effects when taken as a whole prefers values of $\alpha_3(M_Z)$ below 0.11 and perhaps below 0.10.

It is to be hoped that the various analyses will soon come to the point where the data will be clearly inconsistent with either a heavy or a light gluino.

This work was supported in part by the Department of Energy under grant DE-FG05-84ER40141.

REFERENCES

- [1] The LEP Collaborations, Updated Parameters of the Z^0 Resonance from Combined Preliminary Data of the LEP Experiments., CERN preprint PPE/93-157
- [2] ALEPH Collaboration, Cern preprint CERN-PPE/94-30
- [3] T. Chandramohan and L. Clavelli, Nucl. Phys. B184, 365, 1981
L. Clavelli and D. Wyler, Phys. Lett. 103B, 383, 1981
- [4] H.J. Behrend et al., CELLO Collaboration, Z. Phys. C44, 63, 1989
- [5] K. Shilling and G.S. Bali, Wuppertal preprint 1993, hep-lat/9311054
- [6] A. El-Khadra, G. Hockney, A. Kronfeld, and P. Mackenzie, Phys. Rev. Lett. 69, 729, 1992
- [7] L. Clavelli Phys. Rev. D46, 2112, 1992
- [8] L. Clavelli, Proceedings of the 2nd International Symposium on High Energy e^+e^- Interactions, Nashville, TN, AIP Conf. Proceedings #121, R.S. Panvini and G.B. Word, eds, 1984
- [9] L. Clavelli, P.W. Coulter, and K. Yuan, Phys. Rev. D47, 1973, 1993
- [10] M. Jezabek and J. Kuhn, Phys. Lett. B301, 121, 1993
- [11] J. Ellis, D.V. Nanopoulos, and D. Ross, Phys. Lett. B305, 375, 1993
- [12] UA1 Collab. C. Albajar et al., Phys. Lett. B198, 261, 1987
G. Coignet, talk at the 1993 Europhysics Conference, Marseille, 1993
- [13] G. Bhattacharyya and A. Raychaudhuri, Phys. Rev. D49, 1156, 1994
and preprint CERN-TH.7245/94
F. Cuypers, Phys. Rev. D49, 3075, 1994
R. Munoz-Tapia and W.J. Stirling, Phys. Rev. D49, 3763, 1994
C.E. Carlson and Marc Sher, Wm. & Mary preprint WM-93-114, 1993
- [14] T. Akesson et al., HELIOS Collab., Z. Phys. C52, 219, 1991
- [15] CUSB Collaboration, Phys. Lett. B156, 233, 1987
- [16] M. Carena, L. Clavelli, D. Metaliotakis, H.P. Nilles, and C. Wagner, Phys. Lett. B317, 346, 1993
- [17] R. Barbieri, M. Caffo, and E. Remiddi, Phys. Lett. B83, 345, 1979

- [18] P. Mackenzie and P. Lepage, Phys. Rev. Lett. 47, 1244, 1981
W. Kwong, P.B. Mackenzie, R. Rosenfeld, and J.L. Rosner, Phys. Rev. D37
3210, 1988
M. Kobel, Proceedings of the XXVII Rencontre de Moriond, Tran Thanh Van,
ed. 1992
- [19] Review of Particle Properties, Particle Data Group, 1994
- [20] CUSB Collab. , Phys. Lett. B138, 225, 1984
CLEO Collab. , Phys. Rev. Lett. 56, 1222, 1986
ARGUS Collab., Phys. Lett. 199B, 291, 1987
Crystal Ball Collab., Phys. Lett. B267, 286, 1991
- [21] D.L. Scharre et al., Phys. Rev. D23, 43, 1981
- [22] K. Shilling and G.S. Bali, Wuppertal preprint 93-33
G.S. Bali, Talk presented at the XVI Workshop on High Energy Physics,
Sept. 14-17 1993, Protvino, Russia., Wuppertal preprint WUB 93-37
A. El-Khadra, G. Hockney, A. Kronfeld, P. Mackenzie,
Phys. Rev. Lett. 69 729, 1992
- [23] H. Georgyi and H.D. Politzer, Phys. Rev. D14, 1829, 1976
- [24] A. Pich, in Proceedings of the 2nd Workshop on τ Lepton Physics,
ed. K.K. Gan, World Scientific, 1993
- [25] M. Schmelling and R. St.Denis, CERN preprint CERN/PPE 93-193
- [26] L. Clavelli, in Proceedings of the Second Workshop on τ Lepton Physics,
Columbus Ohio 1992, ed. K.K. Gan, World Scientific Press, 1993
- [27] M. Davier, in Proceedings of the 2nd Workshop on τ Lepton Physics,
ed. K.K. Gan, World Scientific, 1993
- [28] S.R. Wasserbaech, in Proceedings of the 2nd Workshop on τ
Lepton Physics, ed. K.K. Gan, World Scientific, 1993
- [29] H.C. Chiang, J. Hüfner, and H.J. Pirner, Phys. Lett. B324, 482, 1994
- [30] J. Blümlein and J. Botts, Phys. Lett. B325, 190, 1994
- [31] S.J. Brodsky and H.J. Lu, preprint SLAC-PUB-6389, 1993
S.J. Brodsky, G.P. Lepage, and P.B. Mackenzie, Phys. Rev. D28, 228, 1983
- [32] P. Mackenzie, Status of Lattice QCD, presented at the Lepton
Photon Symposium, Cornell University, Aug. 10-15, 1993
A. El-Khadra, talk at Lattice 93, Dallas, Oct. 12-16, 1993

Figure Captions

- Fig. 1. The running of the strong coupling constant in standard QCD compared to data on decays of vector strangeonium, charmonium, and bottomonium into dissimilar quarks, jet data, and the lattice result. The solid lines correspond to $\alpha_3(M_Z) = .0985$ and $.0935$.
- Fig. 2. Gluino windows in the space of gluino and squark masses. Hatched areas are disfavored by the indicated experiments. The quarkonium data favors a gluino in the lowest energy window.
- Fig. 3. Lattice and quarkonium data shown on an expanded scale. The radiative quarkonia decays are expected to be insensitive to relativistic corrections.
- Fig. 4. Correlation between the gluino mass and the $\chi^2/5$ for the data of fig. 3 excluding the Φ hadronic decay data and the J/Ψ radiative decay. The shape coding indicates the resulting value of $\alpha_3(M_Z)$ in each solution. See text.
- Fig. 5. Correlation between the gluino mass and the resulting $\alpha_3(1.36 \text{ GeV})$ allowing arbitrary relativistic corrections to the J/Ψ and Υ hadronic decays. The shape coding indicates the χ^2/DoF . Solutions with $\chi^2/5 < 1.15$ are indicated by rectangles. See text.
- Fig. 6. Correlation between $\alpha_3(M_Z)$ and the χ^2/dof values for $m_{\tilde{G}} < 5 \text{ GeV}$. The solutions are plotted as rectangles, triangles, ovals, or diamonds if the gluino mass is in the 1st through 4th quadrants respectively of the range from 0.1 GeV to 5 GeV. Values of $m_{\tilde{G}}$ above this range have $\chi^2/5 > 2.2$ and lower values of $\alpha_3(M_Z)$ (see text).

Figure 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6