Di-electron Widths of $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ Update

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0 Introduction

This document is a *list* of differences between the EPS/Lattice05/PANIC05 preliminary Γ_{ee} result and the final PRL result up for vote on December 3.

1 Efficiency Determination

1.1 "Visible to Trigger" Part

The top of Table I, page 10, presents the probability that an $\Upsilon(1S)$ hadronic decay will generate at least one trigger track and at least one CBLO cluster (it is "visible"), determined from fit yields to $\pi^+\pi^-$ recoil mass from $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$ decays captured by the TwoTrack trigger (see text). This inferred probability is consistent with 100%, and must be corrected for the part of its probability distribution that is greater than 100%. Because the $\Upsilon(1S)$ events include leptonic decays, and these have a different (greater) probability of being "invisible," we must use the Monte Carlo simulation to correct for this. The first correction was applied incorrectly and the second was omitted in the preliminary results. Applying both correctly changes this number from $(99.45\ ^{+0.34}_{-0.32})\%$ to $(99.59\ ^{+0.29}_{-0.45})\%$.

1.2 "Cascade to Leptons" Correction

In Table II, page 14, the lines labeled "$\Upsilon(2S)$, $\Upsilon(3S)$ cascade to leptons branching fraction" have been recalcuated with more data and a different technique. The same criteria were applied to select decays containing $\Upsilon \to \mu^+\mu^-$, but instead of using a small subset of the $\Upsilon(2S)$ and $\Upsilon(3S)$ data (about a dozen runs), we use the entire $\Upsilon(2S)$ and $\Upsilon(3S)$ datasets, and the continuum subtraction is now derived from the lineshape fit results.

To determine the branching fraction of $\Upsilon(2,3S) \to X\mu^+\mu^-$, we now fit the invariant mass spectrum to a Monte Carlo simulation, as shown in Figure 1. Only the magnitudes of $\Upsilon(2,3S) \to X\mu^+\mu^-$ and $\Upsilon(2,3S) \to \mu^+\mu^-$ are allowed to float: the branching fraction of $X\mu^+\mu^-$ is measured relative to known $\mu^+\mu^-$ branching fractions, with a 10% uncertainty assigned for the fitting technique.

The old values for the branching fractions, $(1.54 \pm 0.36)\%$ and $(1.44 \pm 0.48)\%$, are now $(1.58 \pm 0.16)\%$ and $(1.34 \pm 0.13)\%$, respectively.

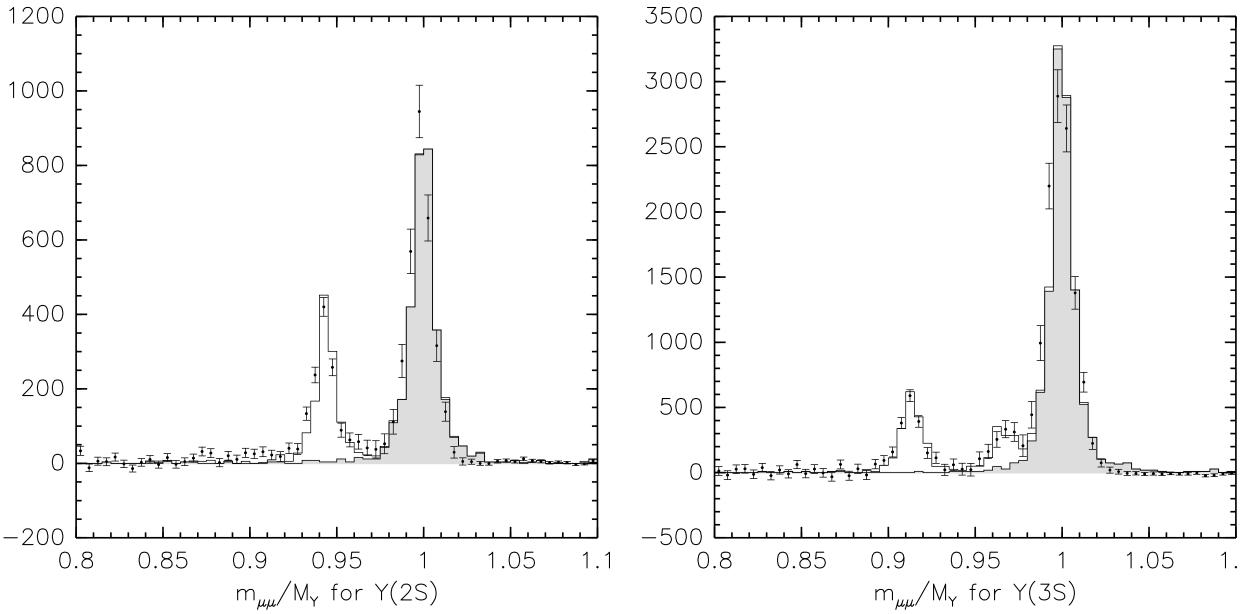

Figure 1: Invariant mass of muon pairs (divided by Υ mass) for $\Upsilon(2S)$ and $\Upsilon(3S)$. Points are data, histograms are Monte Carlo simulations, and shaded area is prompt $\Upsilon \to \mu^+\mu^-$.

2 Point-to-Point Luminosity is Now from Bhabhas

While the preliminary results used $e^+e^- \to \gamma\gamma$ events to determine the luminosity of each point in the scan (and Bhabhas, $e^+e^- \to \mu^+\mu^-$, and $e^+e^- \to \gamma\gamma$ to determine the overall scale), the final results use Bhabhas to determine the luminosity of each point in the scan. This improves the statistical precision by a factor of 2.2, which is especially helpful for determining ratios of Γ_{ee}, which are statistically limited.

This introduces contamination from $\Upsilon \to e^+e^-$, which is readily calculated from the total Υ cross-section, from the lineshape fit. At a given center-of-mass energy E, the number of $\Upsilon \to e^+e^-$ contaminating the Bhabha count is

$$\sigma(E)\mathcal{B}_{ee}\frac{\int_{-0.76}^{0.76}\cos^2\theta\, d\cos\theta}{\int_{-1}^{1}\cos^2\theta\, d\cos\theta}\mathcal{L}(E) \tag{1}$$

where $\sigma(E)$ is the Υ production cross-section (determined from the fit result by a quickly-converging iterative process), $\mathcal{B}_{ee}$ is the e^+e^- branching fraction (we assume $\mathcal{B}_{ee} = \mathcal{B}_{\mu\mu}$), and $\mathcal{L}(E)$ is the integrated luminosity of the point (determined from $\gamma\gamma$). For the $\Upsilon(1S)$, $\Upsilon(2S)$, and $\Upsilon(3S)$, this is a 5%, 2%, and 2% correction at the peak, respectively.

Because we calculate $\sigma(E)$ with our standard fit function, we can easily add the interference term once we know the effective Bhabha cross-section. This term is smaller than the direct $\Upsilon \to e^+e^-$ contamination and negligibly affects the fitted Γ_{ee}.

2.1 Now Sensitive to Variations in Beam Energy Spread

With this new statistical sensitivity, the tall, narrow $\Upsilon(1S)$ peak is now sensitive to 1% variations in beam energy spread. Between March 15 and April 7, 2002, the CESR beam energy spread narrowed by 1.5–1.9%. (See my September 2005 PTA talk for plots.)

This change in beam energy spread was coincident with large changes in the CESR horizontal steerings, and CESRV simulations confirmed that large changes in the electron orbit, corrected by changes in the horizontal steerings, yield a 1% beam energy spread difference. We therefore identified all large changes in horizontal steerings as potential shifts in beam energy spread and fitted the data between them with different beam energy spread values. Every $\Upsilon(3S)$ scan, therefore, has a different beam energy spread parameter, the $\Upsilon(1S)$ has three: Jan 16 – Feb 20 (2002), Feb 27 – Mar 13, and Apr 8 – Apr 10, and the $\Upsilon(2S)$ has a constant beam energy spread for all scans.

2.2 Now Sensitive to Magnitude of Interference Term

In both the preliminary result and the final result, we assume that only $\Upsilon \to q\bar{q}$ interferes with the hadronic continuum. It is conceivable that $\Upsilon \to ggg$ would as well, if the "$\Upsilon \to$ intermediate state $\to$ hadronic final state" process does not factorize. (The third intermediate state, $gg\gamma$, has a distinct high-energy photon and a much smaller rate than $q\bar{q}$ and ggg.) With the additional statistical power, we tested this assumption on the $\Upsilon(1S)$. We effectively fit for the magnitude of the interference term y_{int} by fitting with different y_{int} hypotheses, shown in Figure 2. The fit prefers a y_{int} of 0.0163 ± 0.0044, consistent with $q\bar{q}$-only interference and inconsistent with $|q\bar{q}| + |ggg|$ interference. The fraction of Υ decays f participating in continuum interference is related to y_{int} by $y_{int} \propto \sqrt{f}$, so this fraction is determined to 13% of itself. Varying y_{int} by its uncertainty alters Γ_{ee} by 0.2%.

2.3 Still Insensitive to the Full Width

Our fits are still insensitive to the Υ full width Γ, and its effect on the fitted value of Γ_{ee} is still negligible.

3 Dropped April 3 Scan

The April 3 scan, included in the preliminary result, is dropped in the final result. This scan contains measurements on one side of the peak only and cannot be joined with a more complete scan. This omission reduces χ^2 by 32 (out of 187 constraints) but changes Γ_{ee} by only 0.006%.

4 New Fit Results

The results are plotted in Figure 3. The reduced χ^2, or χ^2/(number of points $-$ degrees of freedom) for $\Upsilon(1S)$ is $240/(203-16) = 1.3$ (0.5% C.L.), for $\Upsilon(2S)$ is $107.2/(75-9) = 1.6$ (0.1% C.L.), and for $\Upsilon(3S)$ is $155/(175-16) = 0.97$ (59% C.L.). Pull distributions versus energy and versus date (Figures 4, 5, and 6) show no obvious trends. (See PRL draft for more discussion.)

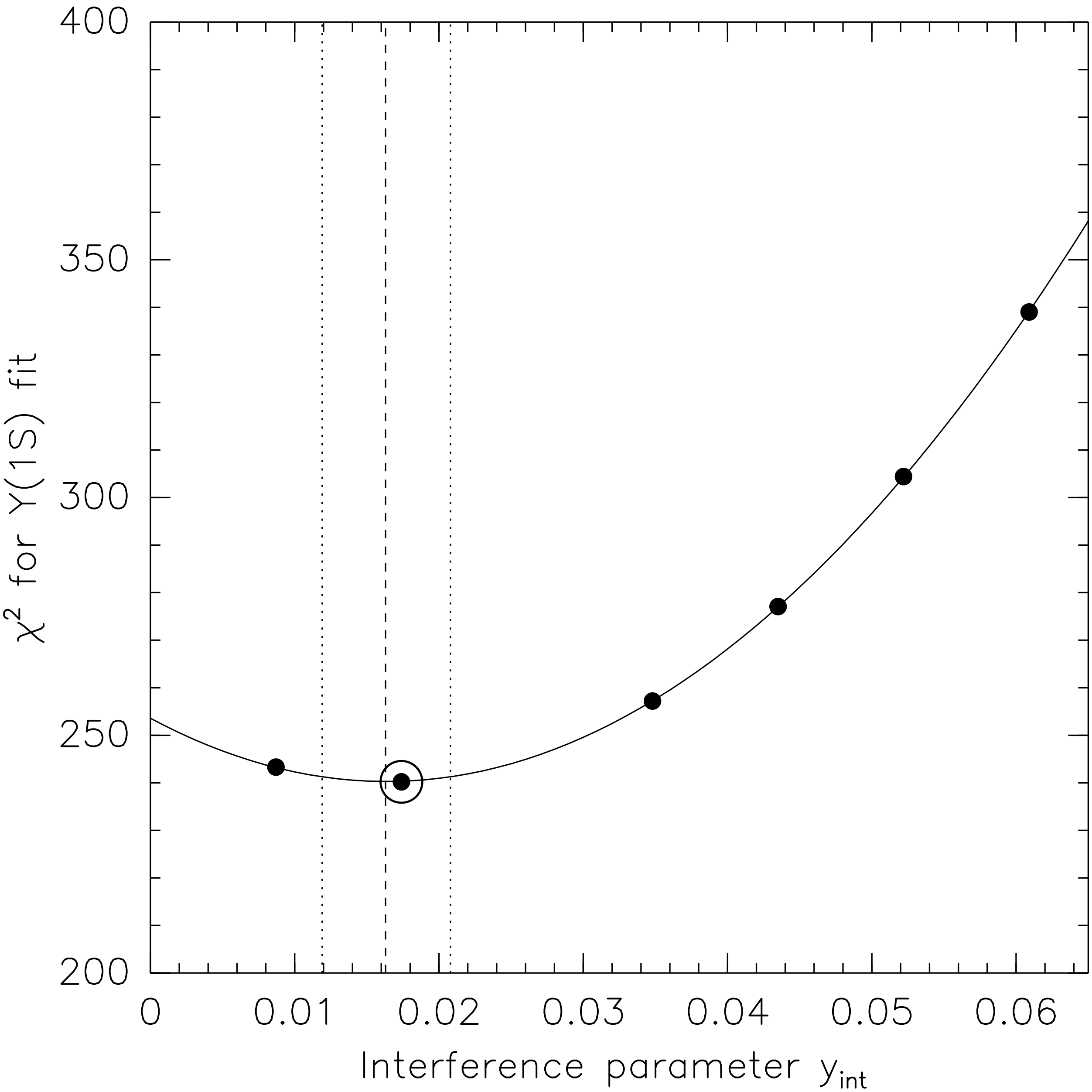

Figure 2: Best-fit χ^2 for $\Upsilon(1S)$ fits with different interference term magnitudes y_{int} (points) and a parabola drawn through them (line). If only $\Upsilon \to q\bar{q}$ interferes with continuum hadrons, $y_{int} = 0.0174$ (circled point), and if all hadronic Υ decays interfere with continuum hadrons, $y_{int} = 0.0560$. Dashed and dotted vertical lines indicate the minimum and +1 intervals of y_{int}.

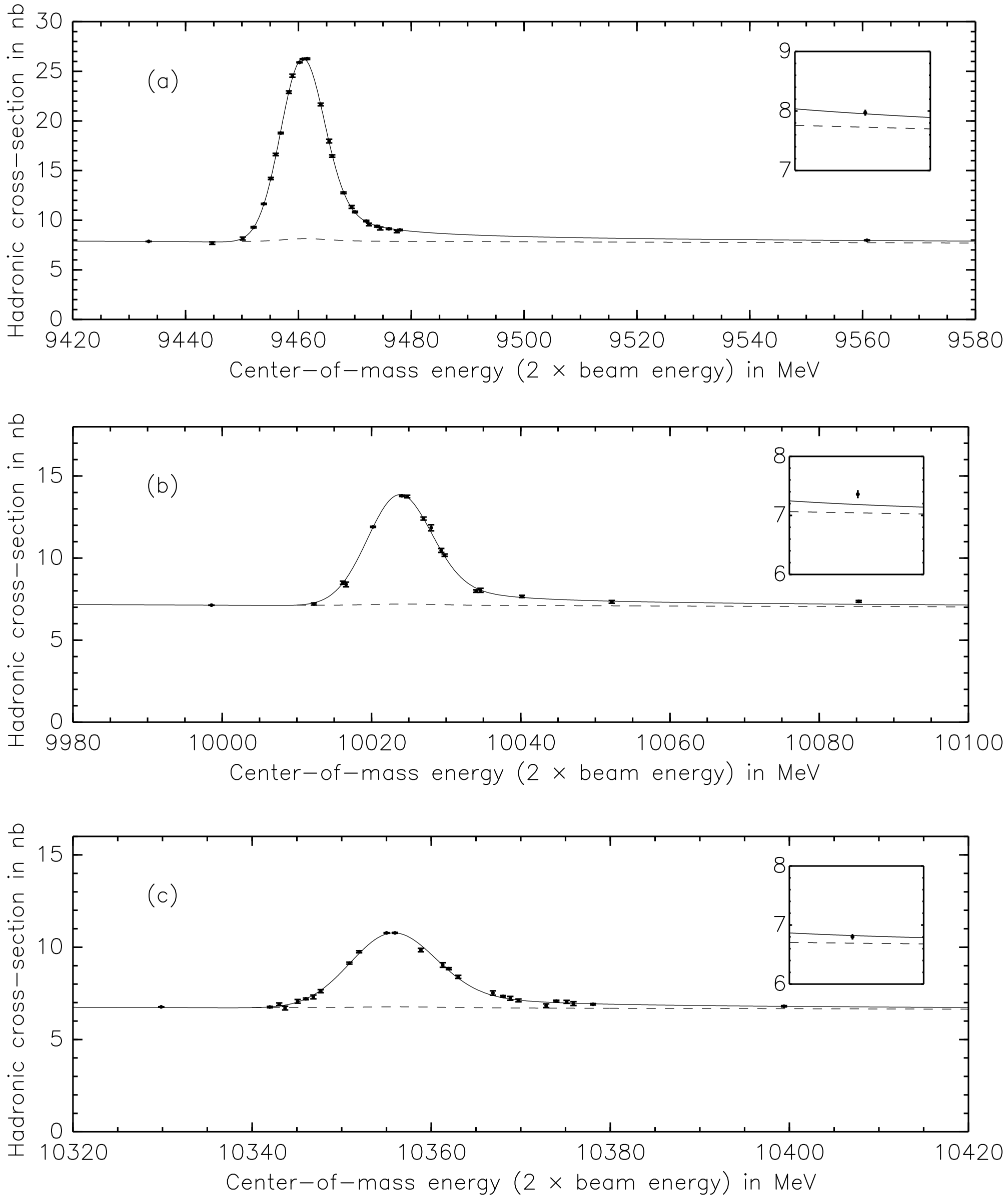

Figure 3: Lineshape fits for (a) $\Upsilon(1S)$, (b) $\Upsilon(2S)$, and (c) $\Upsilon(3S)$. Vertical axis should be "Selected events / nb^{-1}," as data (points) are not corrected for efficiency and contain a flat background contamination from radiative Bhabhas (about half of the continuum). The solid line is the best fit and the dashed line is the sum of all backgrounds. Insets enlarge the high-energy tail point they are placed over. Points within 1 MeV of each other are combined in the plot, but not in the fit.

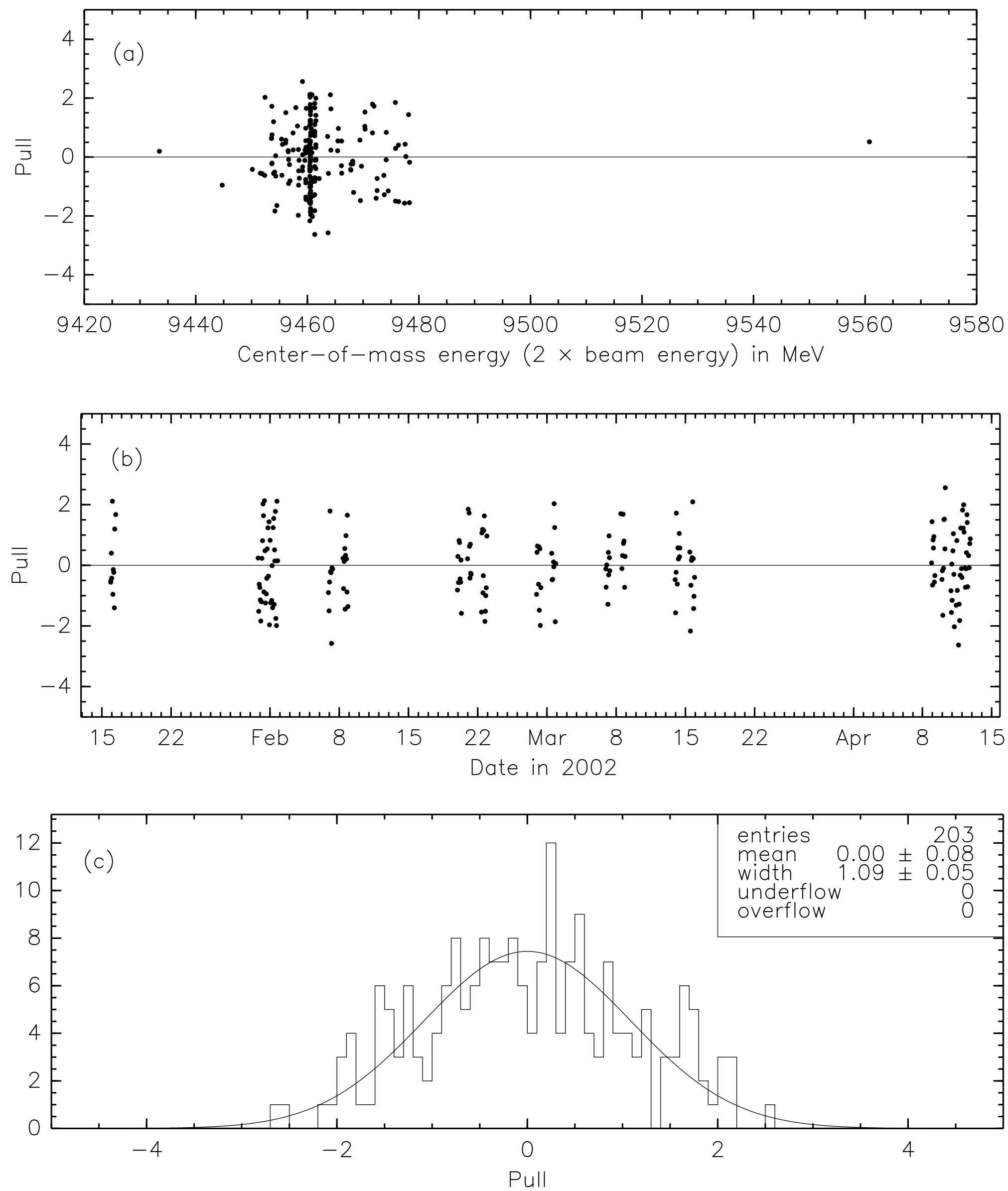

Figure 4: Pulls (fit residual divided by uncertainty) versus (a) energy, (b) date, and (c) as a histogram for the $\Upsilon(1S)$. No points have been combined; this is what was used in the fit.

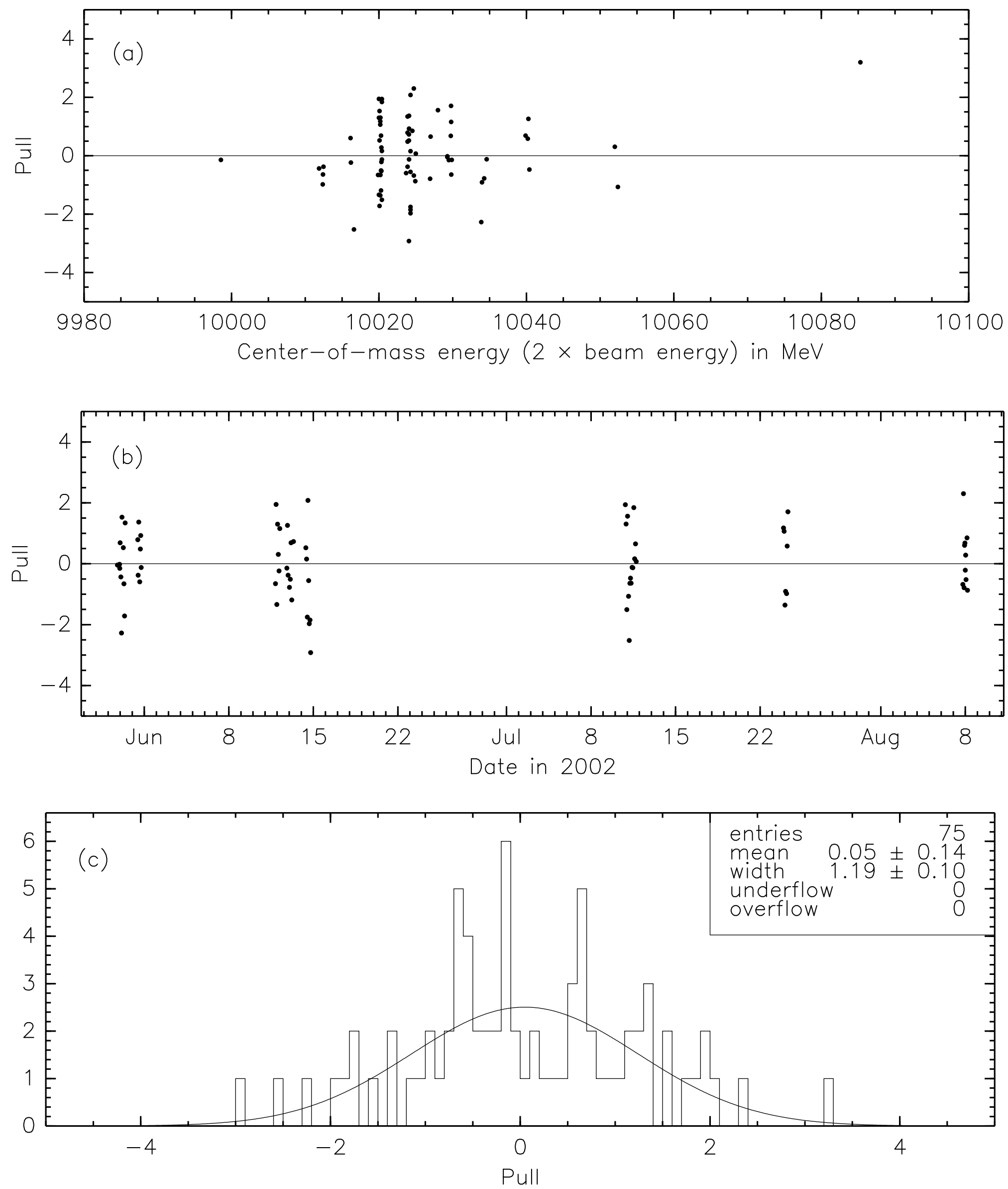

Figure 5: Pulls (fit residual divided by uncertainty) versus (a) energy, (b) date, and (c) as a histogram for the $\Upsilon(2S)$. No points have been combined; this is what was used in the fit.

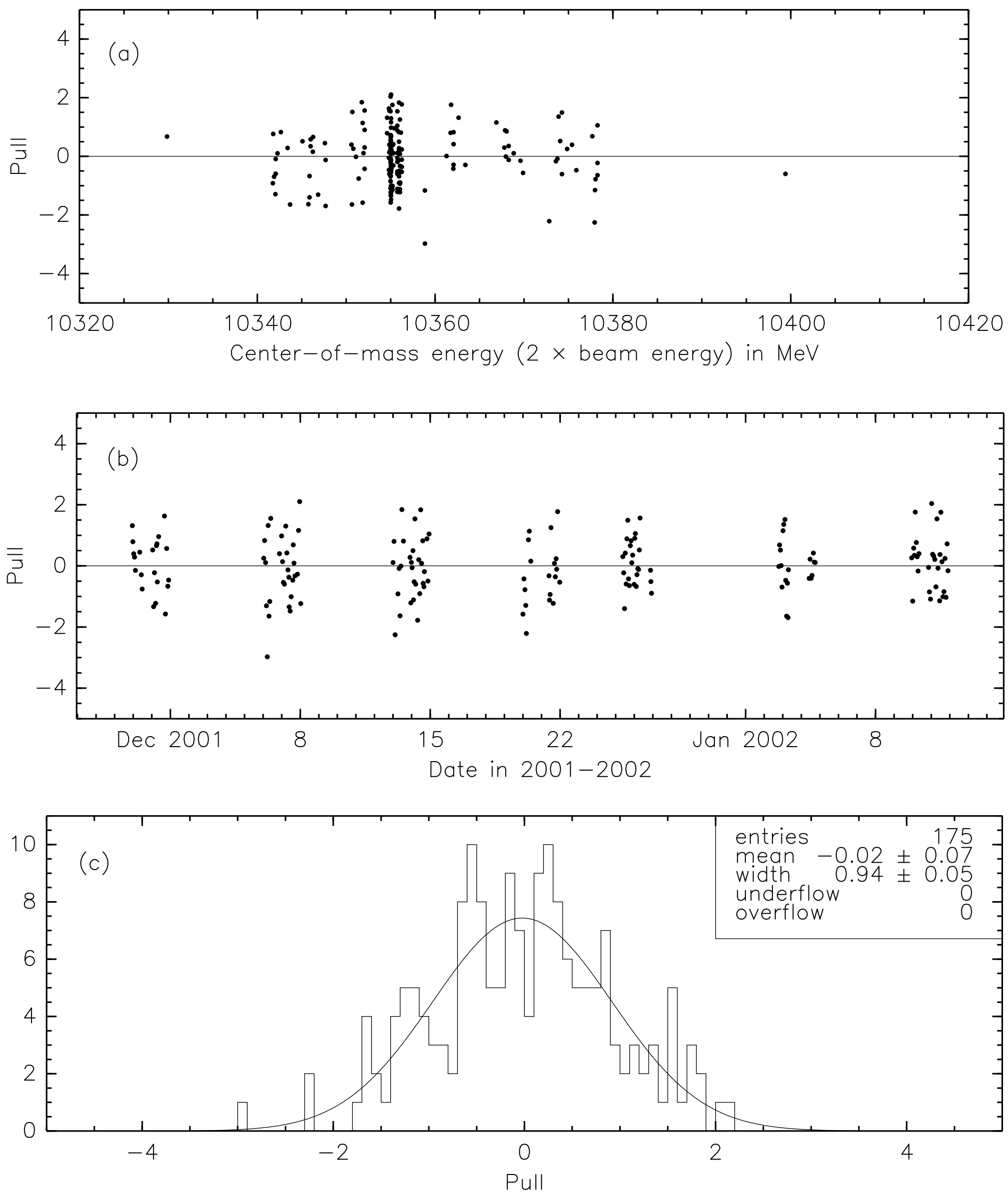

Figure 6: Pulls (fit residual divided by uncertainty) versus (a) energy, (b) date, and (c) as a histogram for the $\Upsilon(3S)$. No points have been combined; this is what was used in the fit.