RESULTS FROM AN EVOLUTIONARY CUSB

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ABSTRACT

A progress report on the first BGO calorimeter in high energy physics, CUSB-II, is given. Preliminary results on the fine splitting of the χ_b' states obtained in early 1986, using CUSB-II, are presented. Included in here also are the recent limits obtained from CUSB-I on axions and from CUSB-I.5 on Higgs and gluinos.

INTRODUCTION

The CUSB-I detector was a NaI-Pb glass calorimeter, located in the North Area of CESR, which operated continuously from 1979 to mid 1984, mapping out during its lifetime: six $^3S_1(b\bar{b})$, six $^3P_{2,1,0}(b\bar{b})$ and two $(b\bar{d})$ states[1]. Recognizing that we have exhausted the possibilities of this fine instrument [despite it having achieved the designed resolution of $3.8\%/E^{1/4}$(GeV)], in 1984 we began the first step of its upgrade by removing the inner strip chamber used for tracking and putting in the latter's place a quadrant of BGO crystals. In this configuration (CUSB-I.5) we ran at the peak of the Υ(1S) energy for an integrated luminosity of 22 pb^{-1}, and obtained a whole series of limits on new particles[2]. In December 1985 we finished installing the whole complement 360 BGO crystals which constitute the heart of the new CUSB: CUSB-II. Early this year we had a short run on the Υ(3S). I will begin by presenting the most recent results from CUSB-I and CUSB I.5, then give a brief description and status report on CUSB-II, and end with a first look at the new data on the fine splitting of the χ_b' states.

1. THE RECURRENT AXION

In 1978 Weinberg[3)] and Wilczek[4)] (WW) pointed out that the Peccei-Quinn[5)] (PQ) mechanism proposed to avoid strong CP violation requires the existence of a pseudoscalar which they called "axion". In the original implementation of the WWPQ axion the PQ symmetry is supposed to be broken by the same VEV's which break the electroweak symmetry. In such a case the coupling of the axion to all fermions is uniquely determined up to an arbitrary parameter X for up like quarks and 1/X for down like quarks and charged leptons, where X is the ratio of the VEV of the two neutral Higgs in the model. The mass of this axion is ~75(X+1/X)keV. Such axions were completely ruled out by searches in J/ψ[6)] and Υ[7)] radiative decays, independent of X.

The recent observation at GSI[8)] of a ≈400keV positron signal in heavy ion collision has been interpreted as the production and decay of an axion of mass $2m_e+2\times400\approx1.8$ MeV. In the original WW model this corresponds to X- or 1/24, and a lifetime of the axion of $\approx10^{-12}$s, a result which is still incompatible with J/ψ and Υ searches. Since the scale breaking of the PQ symmetry is unknown, lifetimes as low as 10^{-13}sec are acceptable without creating inconsistencies with other pieces of physics such as the g-2 value of the electron. But in such case the J/ψ and Υ searches would have failed to observe the decay of $\Upsilon(J/\psi)\rightarrow a+\gamma$ where the axion escapes undetected.

A search[9)] for Υ radiatively decaying into a short lived axion was made using CUSB-I. We obtain a negative result with varying sensitivity depending on the axion lifetime, see figure 1. For lifetimes of the order of 2×10^{-13}sec where our experiment has the least sensitivity, the experimental limit for $B(\Upsilon\rightarrow\gamma a)$ is $<2\text{-}5\times10^{-3}$; while for such lifetimes assuming the WW model it is predicted to be of the order of 20%, totally in contradiction with our experiment. Thus, we again exclude the existence of an axion which couples to b quarks with a strength greater then 10% of its coupling to electrons and down quarks.

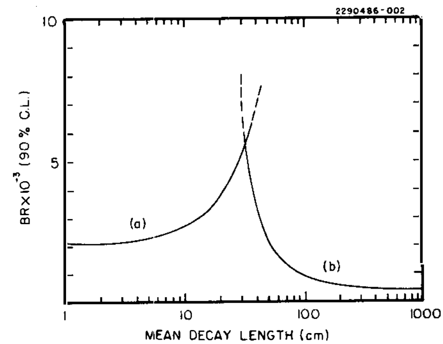

Figure 1. $B(\Upsilon\rightarrow a\gamma)$ versus Mean Decay Length (CUSB).

2. LIMITS ON THE HIGGS BOSON MASS

In the SM with only one Higgs doublet, there was a unique prediction for the branching ratio $B(T\to\gamma+H)$, the Wilczek formula[10]. This has lately been modified by including first order radiative QCD corrections which reduced the expected branching ratio by ~ a factor of two. CUSB[11] had previously reported, assuming the Wilczek formula, exclusion of Higgs bosons of masses less than 4 GeV. With the QCD radiative corrections, the limit would barely hold at the 60% CL. However, if there were more than one Higgs doublet, the branching ratio is modified by the ratio of the VEV's ($<\phi_1>/<\phi_2>$). Therefore we reinterpret our limit on the Higgs' mass as a function of this ratio, figure 2.

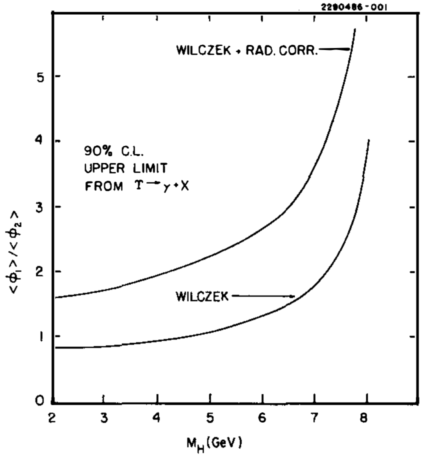

Figure 2. Limits on the Higgs Mass.

3. LIMITS ON GLUINO MASS

Interest in supersymmetry continues unabated among physicists, despite complete lack of experimental evidence for the existence of *sparticles*. Searches for gluinos in particular have been performed at e^+e^- colliders and in beam dumps, yielding negative results, usually expressed as lower limits on the gluino mass in terms of some other *sparticles*[12]. At Kyoto, Farrar[13] pointed out that while beam dump experiments are usually quoted for limits of $m_{\tilde{g}} > 2$ to 3 GeV, these limits hold true only for a small range of $m_{\tilde{q}}$. Furthermore, for the low gluino mass region ($m_{\tilde{g}} < 2$ GeV), there was virtually no range of allowed $m_{\tilde{q}}$ for which the $m_{\tilde{g}}$ are excluded. We have remedied in good part this situation by having performed a search for low mass bound gluino states by searching for monochromatic γ signals. Our negative result translates into the range of excluded $M_{\tilde{g}}$ shown in figure 3.

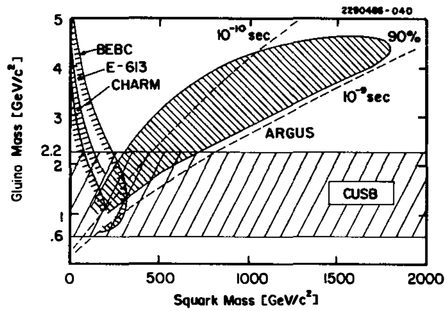

Figure 3. Gluino Masses Excluded by CUSB I.5.

4. THE CUSB-II DETECTOR†

For the second generation of Υ physics experiments, we needed a spectrometer with improved photon resolution and perfect projective geometry. To accomplish these purposes we need more radiation lengths (λ_0), no inactive materials, while retaining the longitudinal segmentation and source imbedding features of CUSB-I, occupying the radial space 10cm< r <25cm. These are possible using bismuth germanate crystals (BGO), because despite its lower light output than NaI, its better material properties, including that of being nonhydroscopic, allows us to fit 12 λ_0's of BGO with ideal geometry into the available space.

Each element has trapezoidal cross section and subtends 10^o in ϕ and 45^o to 90^o (or 90^o to 135^o) in θ. Five such elements, of increasing size, form one ϕ-θ sector; Each crystal is viewed at one end by a miniature photomultiplier tube (p.m.), permanently glued on. All crystals are uniform, in light response, to better than 2% across their length (some after compensation, most as delivered from the Shanghai Institute of Ceramics). Teflon and aluminized mylar wrapping (less than three mils thick) maximize light output and remove optical cross talk. Figure 4 shows one polar half of the BGO assembly (180 elements) viewed from the free crystal end. One notes 5 free standing concentric rings, constructed in a time honored (Roman Arch) method. Figure 5 shows the crystal assembly viewed from the phototube end.

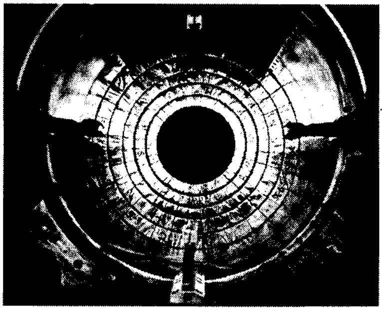

Figure 4. Crystal End View of BGO.

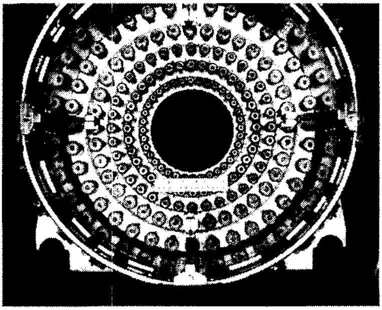

Figure 5. Phototube End View of BGO.

All CUSB calibration is done in real time during data taking with sources which are imbedded between crystal layers. The online calibration is accomplished by having a dual signal path, such that two different sensitivity channels measure collision events and source signals. The complete calibration cycle for all crystals is ≤ 30min. We have achieved ≤0.1% channel to channel calibration and can achieve ≈ 1-2% absolute calibration as checked with Bhabha events and shower leakage calculations. See next section.

5. PRELIMINARY RESULTS.

In figure 6 we show a first comparison of the relative bhabha energy resolution between CUSB-I and CUSB-II. Indeed the BGO array provided the expected improvement of a factor of two. A fit to this preliminary BGO spectrum yields a $\sigma_E/E \approx 1.2\%$ for the upper half of the peak.

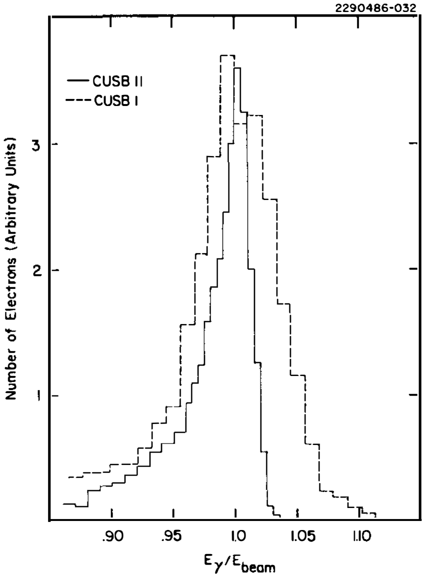

Figure 6. The Bhabha Energy Resolution of CUSB-I and CUSB-II.

5.1 $B_{\mu\mu}$ of the T(3S)

The second excited state of the bound ($b\bar{b}$) system, the T(3S) was first resolved in 1980 at CESR[14]. However, the total integrated luminosity accumulated on this resonance has been small, <15 pb^{-1}. As a result, some fundamental properties such its branching ratio into a muon pair ($B_{\mu\mu}$) was poorly known. Using CUSB-II this spring we improved the knowledge on this quantity by ≈ a factor of 5. We obtain:

$$B_{\mu\mu}[T(3S)] = 0.016 \pm 0.003.$$

This value is preliminary until we finish our calculation of the systematic errors. This value is in agreement with that which is obtained from scaling using $B_{\mu\mu}[T(1S)]$[15].

5.2 Fine Splitting of the χ_b's

The χ_b' states were discovered by CUSB-I in 1982[16] from observations of the photons (γ_1, γ_2) resulting from transitions between the triplet S and triplet P states: $3^3S_1 \rightarrow \gamma_1 2^3P_{2,1,0} \rightarrow \gamma_1\gamma_2 1(2)^3S_1$. Refer to level diagram, Figure 7. The γ_1's were observed in our inclusive photon spectra, and both γ_1 and γ_2 were

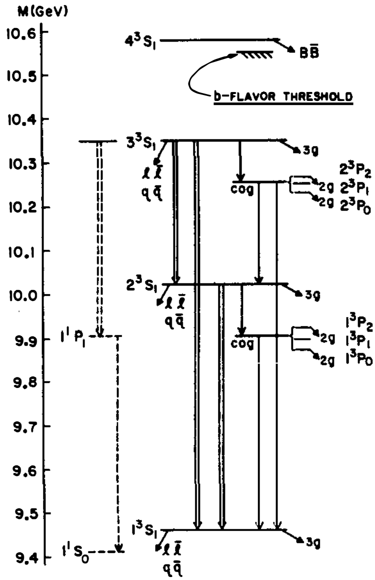

Figure 7. Bound T($b\bar{b}$) Level Diagram.

observed in events where the final $^3S_1$ states decayed into a pair of muons or electrons (="exclusive" events). With CUSB-I we did not have sufficient resolution to resolve between the γ_1's which came from the T(3S) to the J=2 and J=1 χ_b' lines in either the inclusive photon spectrum or in the "exclusive" events. Neither were we able to see the γ_2's in the inclusive photon spectrum.

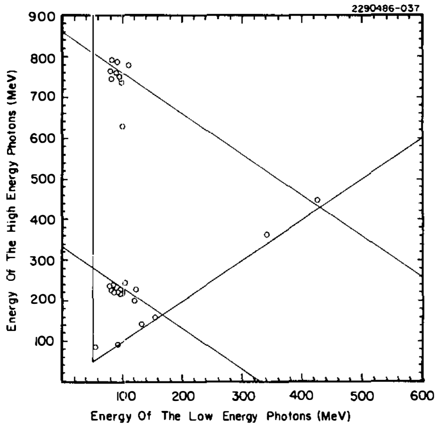

Figure 8. Scatter Plot, γ_{high} vs γ_{low}.

From a preliminary analysis of our run on the T(3S) this spring with CUSB-II we obtained ≈ 30 "exclusive" events. The scatter plot of the high energy γ versus the low energy γ, figure 8, show two distinct clustering, the upper and lower clusters corresponding to T(1S) and T(2S) final states respectively. The projection of figure 8 onto the lower energy photon axis, figure 9, demonstrates visibly that now the χ_b''s J=2 and J=1 lines are fully resolved.

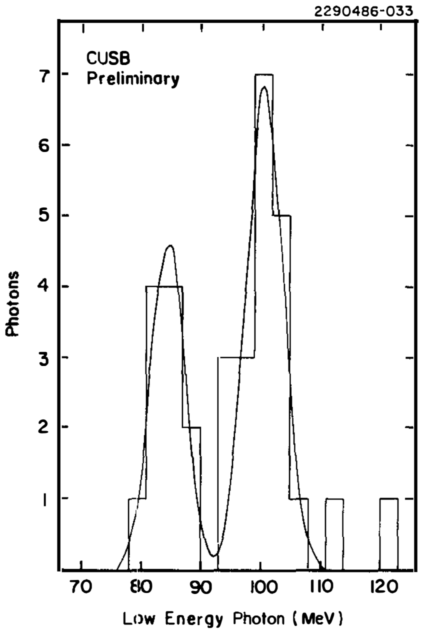

Figure 9. γ_1 Energy Distribution from "exclusive" Events.

The inclusive photon spectrum situation is complicated by the large multiplicity contained in an T(3S) event. Energy clusters tend to overlap each other and we have to optimize a photon algorithm which can select clean isolated clusters originating from photons without losing too much efficiency. We are still working on this problem. However, it is encouraging that our first preliminary inclusive spectrum from CUSB-II, figure 10, shows definite, distinct structures that, after background subtraction (figure 11), we can identify: the first three are the γ_1's, and the second two are γ_2's ending in T(2S) and T(1S). The width of these lines are also as predicted from our MonteCarlo (MC) simulation, shown in figure 12. Finally, our preliminary analysis indicates complete agreement between CUSB-II and our published CUSB-I numbers for the photon energies and E1 transition rates.

In conclusion, our first run with CUSB-II fully vindicates our choice of BGO for the calorimetry. We need to complete the ancillary parts such as a vertex chamber for tracking and insertion of a layer of silicon strips at the shower maximum for θ shower centroid localising. Then we expect to commence our search for the singlet states (indicated by the short dashed lines in figure 7) of the $\Upsilon(b\bar{b})$ system.

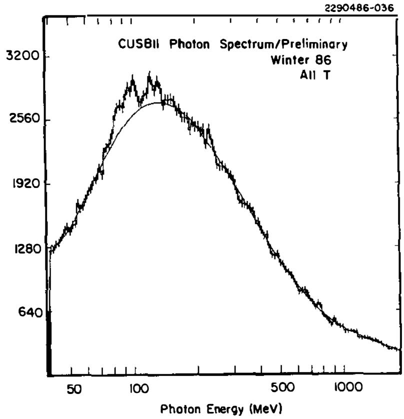

Figure 10. Inclusive γ Spectrum.

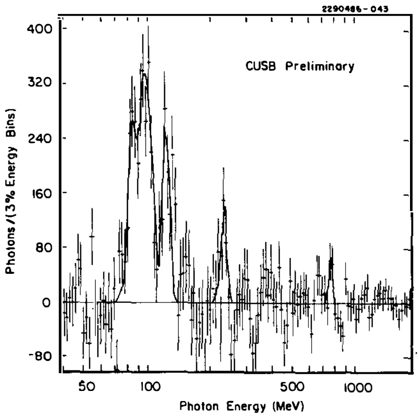

Figure 11. Inclusive γ spectrum signal.

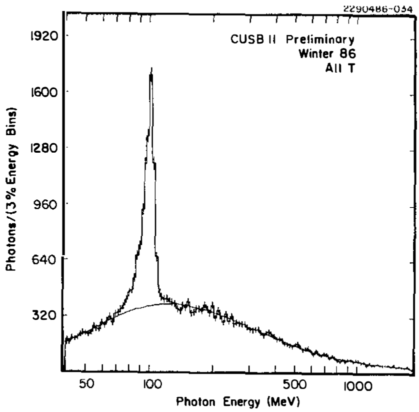

Figure 12. MC BGO Resolution.

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