Search for Production of Invisible Final States in Single-Photon Decays of Υ(1S)

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Motivation

- There's compelling astrophysical evidence for the existence of dark matter, which amounts to about one-quarter of the total energy density in the Universe.
- Yet there's no experimental information on the particle composition of dark matter.
- A class of new physics models, motivated by astroparticle observations, predicts a light component of the dark matter spectrum.
- The bottomonium system of Υ states is an ideal environment to explore these models.

Motivation

- Transitions Y(3S)->pi+pi-Y(1S) and Y(2S)->pi+pi-Y(1S) offer a way to cleanly detect the production of Y(1S) mesons, and enable searches for invisible or nearly invisible decays of the Y(1S).

- Such decays would be a telltale sign of low-mass, weakly interacting dark matter particles.

- The standard model process Y(1S)->gam+nunu is not observable at the present experimental sensitivity. An observation of Y decays with significant missing energy would be a sign of new physics, and could shed light on the spectrum of dark matter particles x.

  Current 90% confidence level BF upper limit: of order 10^-3

- B(Y(1S)->xx) is estimated to be as large as (4-18)*10^-4, while B(Y(1S)->gam+xx) is in range 10^-5 - 10^-4.

  < 3.0*10^-4

- B(Y(1S)->gam+A0) is predicted to be as large as 5*10^-4, depending on mA0 and couplings. If there’s also a low-mass neutralino with mass mx<mA0/2, the decays of A0 would be predominantly invisible.

Signal Channel

- Y(1S)->gam+invisible, characterized by a single energetic photon and a large amount of missing energy and momentum.
    - Y(1S)->gam+A0, A0->invisible
    - Y(1S)->gam+xx

Data Set

- Sample corresponding to an integrated luminosity of 14.4 fb-1 collected on the Y(1S) resonance with the BABAR detector at PEP-II asymmetric-energy e+e- collider at the SLAC National Accelerator Laboratory —- (98.3+-0.9)*10^6 Y(2S) decays

- Sample of 28 fb^-1 accumulated on the Y(3S) resonance for studies of the continuum backgrounds

- For selection optimization, they also use 1.4fb^-1 and 2.4fb^-1 data sets collected about 30MeV below the Y(2S) and Y(3S) resonances, respectively.

Event Selection

- Hardware-based L1 trigger accepts single-photon events if they contain at least one EMC cluster with energy above 800MeV. A collection selects a pair of low-momentum pions.

- A software-based L3 trigger accepts events with a single EMC cluster with the center-of-mass E>1GeV, if there's no charged track with transverse momentum pT>0.25GeV originating from the e+e- interaction region. L3 accepts events that have at least one track with pT>0.2GeV.

- An offline filter accepts events that have exactly 1 photon with energy E>1GeV, and no tracks with momentum p>0.5GeV. A nearly independent filter accepts events with 2 tracks of opposite charge, which from a dipion candidate with recoil mass between 9.35 and 9.60 GeV.

Event Selection

- 2 oppositely charged tracks
- 1 single energetic photon with E>=0.15GeV in central part of the EMC(-0.73<costhe<0.68)
- Additional photons with E<=0.12GeV can be present so long as their summed laboratory energy is less than 0.14GeV.
- They require that both pions be positively identified with 85-98% efficiency for real pions, and a mis-identification rate of <5% for low-momentum electrons and <1% for kaons and protons.
- Pion candidates are required to form a vertex with $x^2<20$ displaced in the transverse plane by at most 2 mm from the e+e- interaction region.
- pT<0.5GeV, rejecting events if any track has p>1GeV

Event Selection

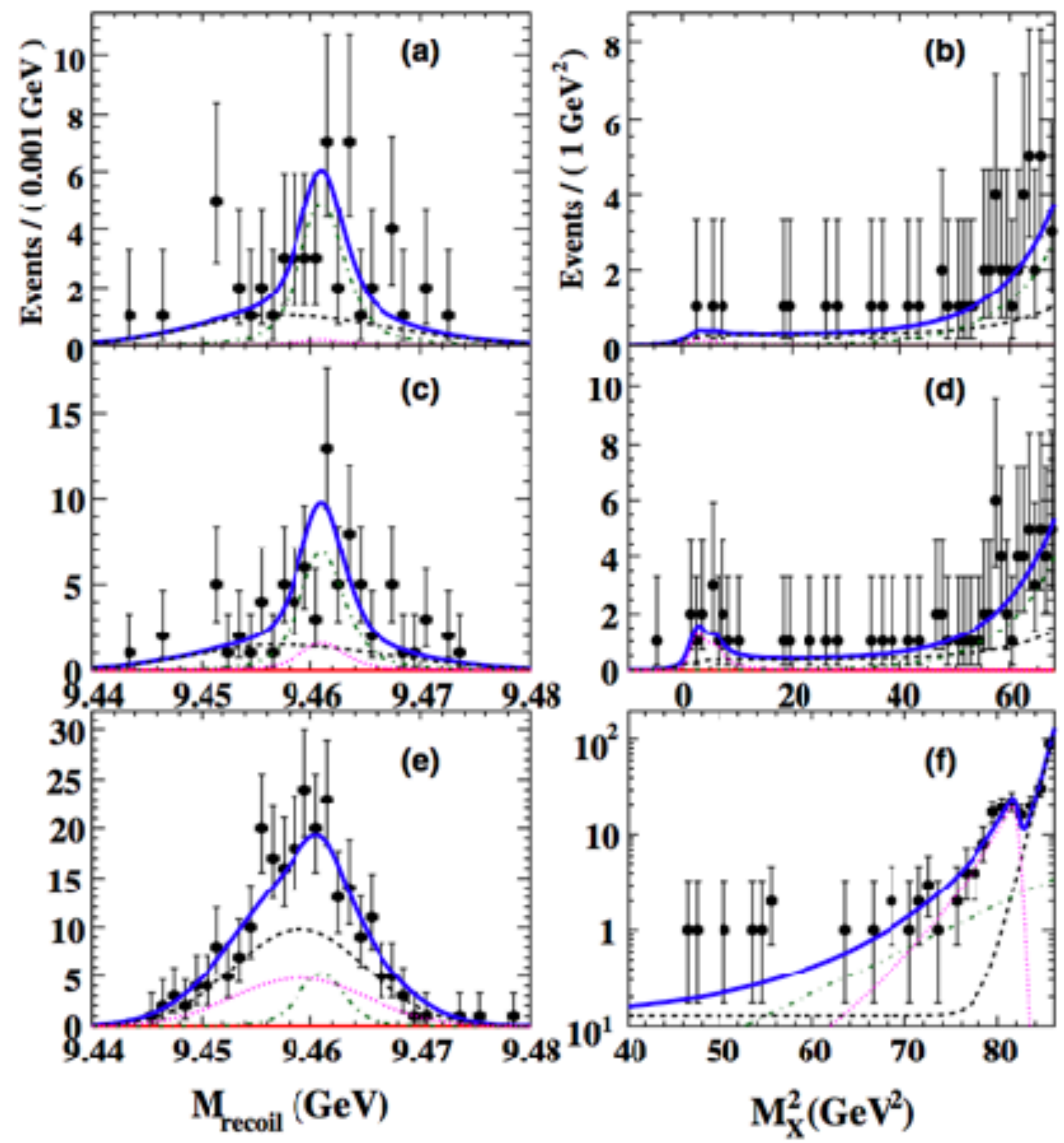

FIG. 1 (color online). Projection plots from the fit with $N_{\rm sig} = 0$ onto (a,c,e) $M_{\rm recoil}$ and (b,d,f) M_X^2. (a,b) Low-mass region with IFR veto, (c,d) low-mass region without IFR veto, (e,f) high-mass region. Overlaid is the fit with $N_{\rm sig} = 0$ (solid blue line), continuum background (black dashed line), radiative leptonic $\Upsilon(1S)$ decays (green dash-dotted line), and (c,d) radiative hadronic $\Upsilon(1S)$ decays or (e,f) η' background (magenta dotted line).

Event Selection

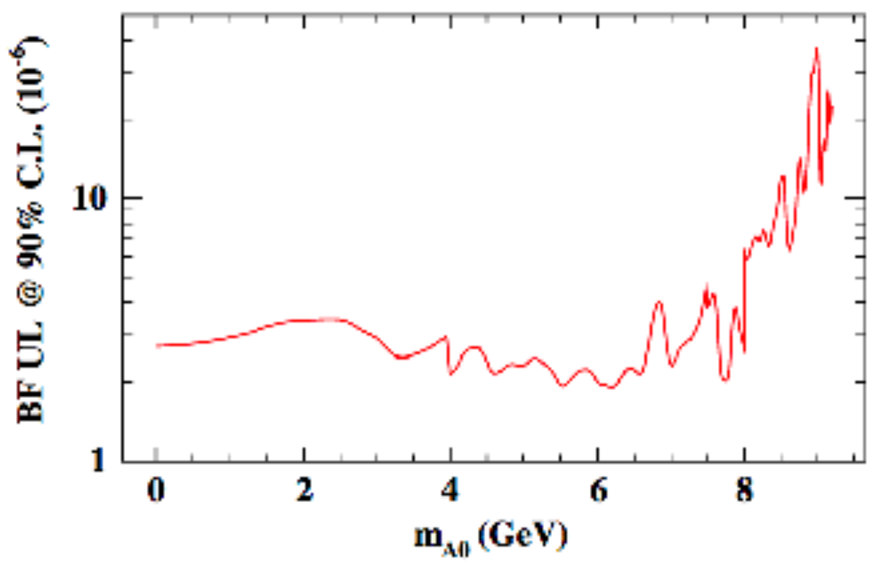

FIG. 2 (color online). Ninety percent C.L. upper limits for $\mathcal{B}(\Upsilon(1S) \to \gamma A^0) \times \mathcal{B}(A^0 \to \text{invisible})$.

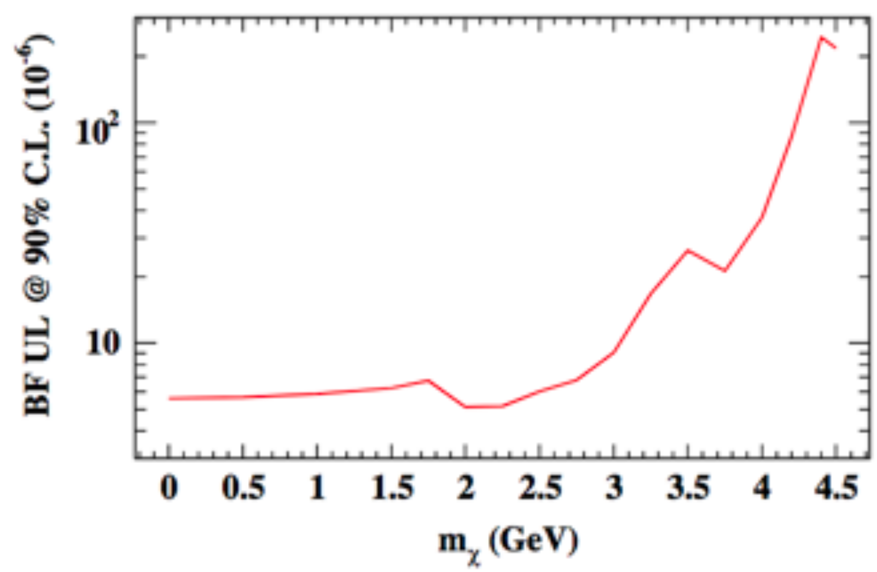

FIG. 3 (color online). Ninety percent C.L. upper limits for $\mathcal{B}(\Upsilon(1S) \to \gamma\chi\bar{\chi})$.

Summary

In summary, we find no evidence for the single-photon decays $\Upsilon(1S) \to \gamma + \text{invisible}$, and set 90% C.L. upper limits on $\mathcal{B}(\Upsilon(1S) \to \gamma A^0) \times \mathcal{B}(A^0 \to \text{invisible})$ in the range $(1.9\text{–}4.5) \times 10^{-6}$ for $0 \leq m_{A^0} \leq 8.0$ GeV, $(2.7\text{–}37) \times 10^{-6}$ for $8 \leq m_{A^0} \leq 9.2$ GeV, and scalar A^0. We limit $\mathcal{B}(\Upsilon(1S) \to \gamma\chi\bar{\chi})$ in the range $(0.5\text{–}24) \times 10^{-5}$ at 90% C.L. for $0 \leq m_\chi \leq 4.5$ GeV, assuming the phase-space distribution of photons in this final state. Our results improve the existing limits by an order of magnitude or more, and significantly constrain [26] light Higgs boson [13] and light dark matter [8] models.