Searches for Light New Physics with *BABAR*

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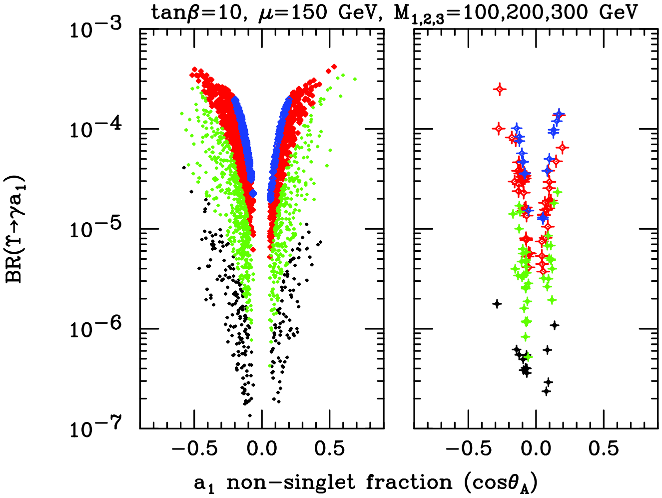
Motivation

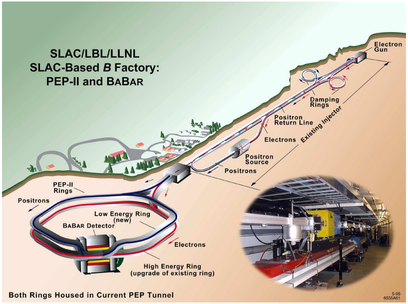
- A light Higgs A^0 ($< 2M_B$) is predicted for extensions of SM such as the nMSSM (Phys. Rev. Lett. **95**, 041801 [2005])
  - $\Upsilon(nS) \to \gamma A^0$ is allowed
- Branching fractions can be significant depending on the model parameters
  - $B(A^0 \to f\bar{f}) \propto m_f^2/tan^2\beta$ for up-type fermions
  - $B(A^0 \to f\bar{f}) \propto m_f^2 tan^2\beta$ for down-type fermions

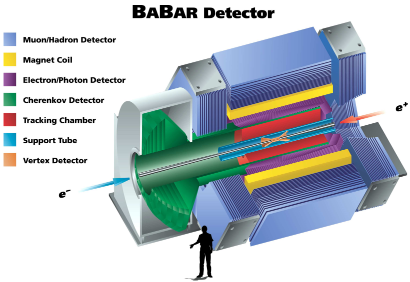
Branching Fractions of $\Upsilon \to \gamma A^0$ for nMSSM



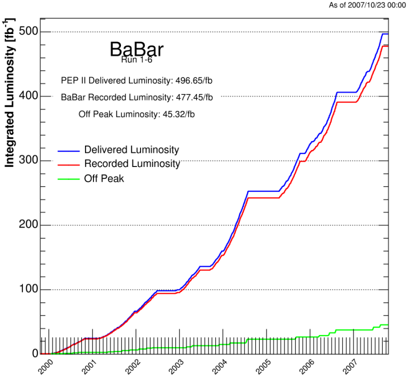
Dermisek *et al*, Phys. Rev. D **76**, 051105 (2007)

PEP-II and the *BABAR* Experiment



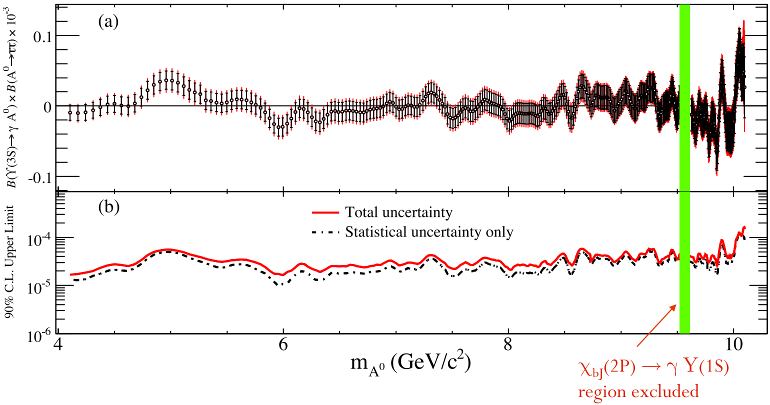


Samples at *BABAR*



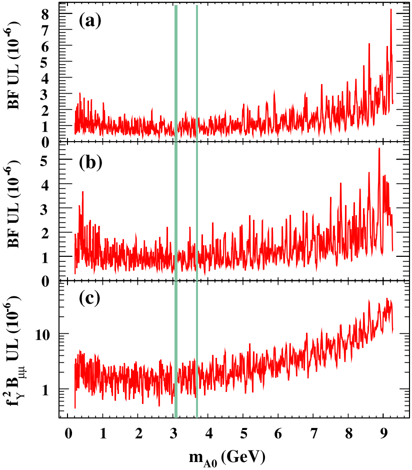
- Data collected:
  - 465 M $B\overline{B}$ pairs at $\Upsilon(4S)$ from 1999–2007
  - 27.9 fb^{-1} at $\Upsilon(3S) \Rightarrow$ 121 M events
  - 13.6 fb^{-1} at $\Upsilon(2S) \Rightarrow$ 98 M events

Search for $A^0 \to \tau^+\tau^-$ in $\Upsilon(3S)$ Data



BABAR collaboration, Phys. Rev. Lett. **103**, 181801 (2009)

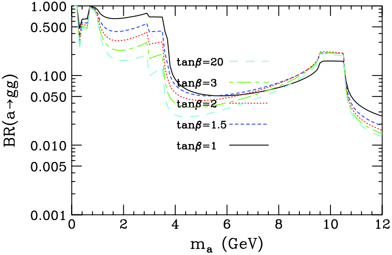
Search for $A^0 \to \mu^+\mu^-$ in $\Upsilon(2S)$ and $\Upsilon(3S)$ Data

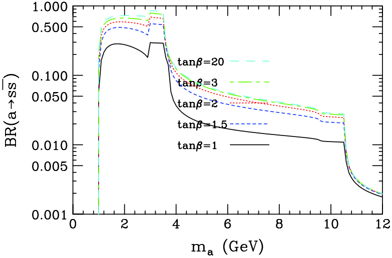


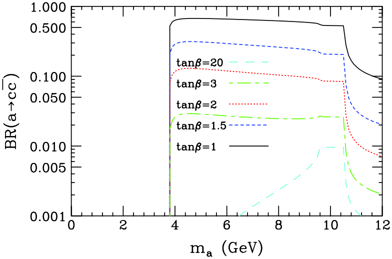
BABAR collaboration, Phys. Rev. Lett. **103**, 081803 (2009). J/ψ and $\Upsilon(2S)$ resonances (shaded areas) are excluded from the search.

Search for hadronic decays of the A^0

$A^0 \to$ hadrons can be the dominant decay mode depending on the mass of A^0 and $tan\beta$







Dermisek & Gunion, Phys. Rev. D **81**, 075003 (2010)

Event Reconstruction Strategy for $A^0 \to$ hadrons Study

The event is reconstructed in the following manner:

1. Highest energy photon is the radiative photon of the decay
2. Four-momenta of the remaining particles are added to reconstruct the A^0:
   2.1 $K_S^0 \to \pi^+ \pi^-$, where $m_{K_S^0}$ is within a K_S^0 mass window
   2.2 proton, $K^{\pm}$, $\pi^{\pm}$ mass assigned using charged hadron ID
   2.3 $\pi^0 \to \gamma\gamma$, where m_{π^0} is within a π^0 mass window and π^0 satisfies an energy cut
   2.4 any leftover γ

Event Selection Criteria

Event selection criteria are as follows:

- Radiative photon energy $E_\gamma > 2.5\,\mathrm{GeV}$ for $\Upsilon(3S)$ and $E_\gamma > 2.2\,\mathrm{GeV}$ for $\Upsilon(2S)$
- At least two charged tracks for the A^0 decay
- The radiative photon and all A^0 decay products must come from a common vertex
- Event rejected if the radiative photon can be combined with any other γ in the event to give a π^0 or an η meson
- $e^+e^- \to \gamma\ e^+e^-$ or $e^+e^- \to \gamma\ \mu^+\mu^-$ events are rejected

The analysis takes two parallel paths:

- *CP*-all: no assumptions on the *CP* nature of the A^0
- *CP*-odd: A^0 is assumed to be *CP*-odd $\Rightarrow$ no $A^0 \to \pi^+\pi^-$ or $A^0 \to K^+K^-$

Backgrounds

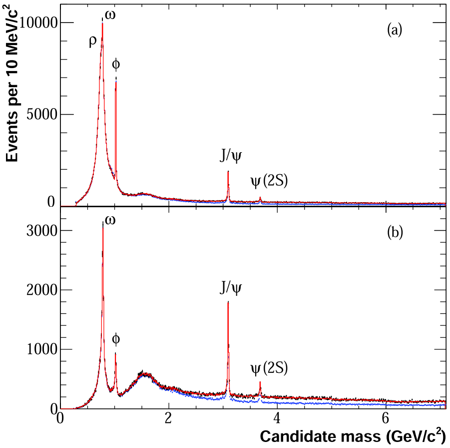
Main backgrounds include:

- continuum: ISR production of resonances ($e^+e^- \rightarrow \gamma\ M$) or non-resonant modes ($e^+e^- \rightarrow \gamma\ X$)
- Υ radiative decay
- A γ from π^0 decay at high A^0 mass can fake the radiative photon

$\Upsilon(4S)$ and offpeak data are used as continuum sample

- $B\overline{B}$ events do not pass selection

Candidate Mass Spectrum

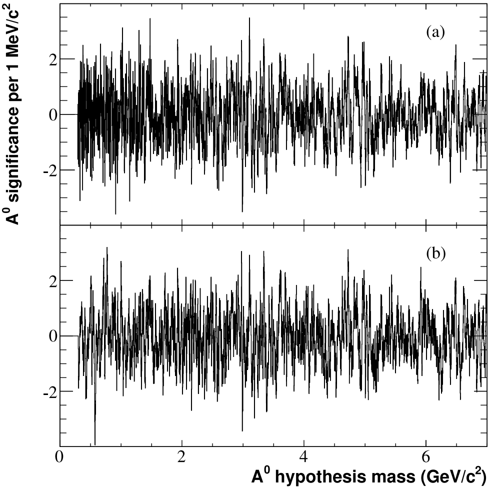


Candidate mass spectrum for (a) *CP*-all (371,740 events) and (b) *CP*-odd (171,136 events) overlaid with background fit and scaled continuum data

A^0 Signal Determination

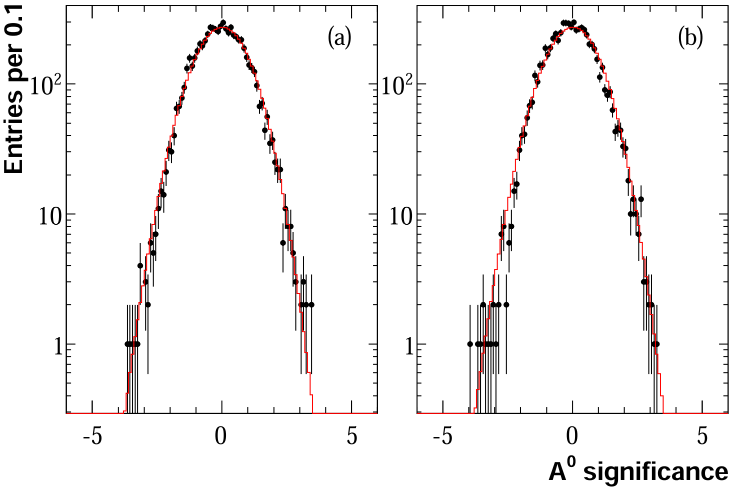
- The number of A^0 signal in a particular mass window centered at m_i is the number of events minus the background
- Background events consist of:
  - Continuum component scaled with a normalization factor
  - Five light resonances as observed by CLEO in the study of $\Upsilon(1S) \to \gamma h^+ h^-$: $f_0(980)$, $f_2(1270)$, $f_2^{'}(1525)$, $f_0(1710)$ and $f_4(2050)$ (Phys. Rev. D **73**, 032001 (2006))
  - Non-resonant $\Upsilon(nS) \to \gamma X$ decays
- A^0 significance is defined to be the number of events divided by the uncertainties; it is plotted in candidate mass bins

A^0 Signal Significance



Statistical significance as a function of candidate mass for (a) *CP*-all and (b) *CP*-odd.

A^0 Signal Significance (cont'd)



Histogram for statistical significances for (a) *CP*-all and (b) *CP*-odd. Red line is predicted by toy MC for no signal.

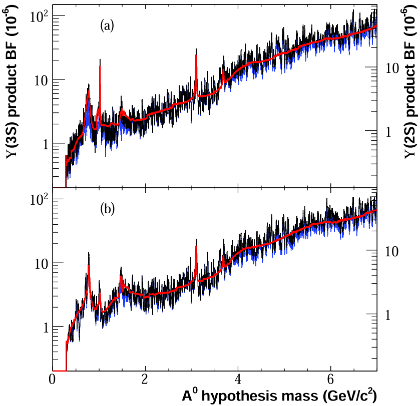
Systematic Errors

- Uncertainty of efficiency mainly comes from A^0 decay modes
  - A^0 can decay into $s\bar{s}$, $c\bar{c}$ and gg in this study. Uncertainty is estimated by varying the fractions of the final decay modes.
- Uncertainties in backgrounds are obtained by:
  - comparing fixed/ floating continuum scaling factor
  - including/ omitting light resonances in the fit

Significance and Upper Limits

- Candidate mass at which the most significant "signal" occurs:
  - *CP*-all: 3.5σ at $3.107\,\mathrm{GeV}/c^2$ (stat. only)
    2.9σ at $1.295\,\mathrm{GeV}/c^2$ (stat. + syst.)
  - Larger fluctuations occur in 33% of simulated experiments
  - *CP*-odd: 3.2σ at $0.772\,\mathrm{GeV}/c^2$ (stat. only)
    3.1σ at $4.727\,\mathrm{GeV}/c^2$ (stat. + syst.)
  - Larger fluctuations occur in 63% of simulated experiments
- Can also calculate 90% C.L. upper limits on $\mathrm{B}[\Upsilon(3S) \to \gamma A^0]{\cdot}\mathrm{B}(A^0 \to \text{hadrons})$ and $\mathrm{B}[\Upsilon(2S) \to \gamma A^0]{\cdot}\mathrm{B}(A^0 \to \text{hadrons})$ assuming that the same matrix element describes both $\Upsilon(3S)$ and $\Upsilon(2S)$ decays

Upper Limits vs. A^0 Hypothesis Mass



Upper limits of $\mathrm{B}[\Upsilon(nS) \to \gamma A^0]\cdot\mathrm{B}(A^0 \to \text{hadrons})$ as a function of A^0 hypothesis mass in the (a) *CP*-all and (b) *CP*-odd, overlaid with predictions from simulated experiments and limits from statistical errors only.

Conclusions

- *BABAR* has performed searches for light Higgs with data collected at the $\Upsilon(3S)$ and $\Upsilon(2S)$ resonances
- No observations of the light Higgs have been made at the searches
- 90% CL upper limits on the product branching fraction $B(\Upsilon(nS) \to \gamma A^0) \cdot B(A^0 \to \text{hadrons})$ are from 1×10^{-6} at $0.3\,\mathrm{GeV}/c^2$ to 8×10^{-5} at $7\,\mathrm{GeV}/c^2$

Papers

- "Probing next-to-minimal-supersymmetric models with minimal fine tuning by searching for decays of the Υ to a light *CP*-odd Higgs boson", Phys. Rev. D **76**, 051105(R) (2007)
- "Search for a low-mass Higgs boson in $\Upsilon(3S) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$ at *BABAR*", Phys. Rev. Lett. **103**, 181801 (2009)
- "Search for dimuon decays of a light scalar boson in radiative transitions $\Upsilon \to \gamma A^0$", Phys. Rev. Lett. **103**, 081803 (2009)
- "Search for hadronic decays of a light Higgs boson in radiative decays $\Upsilon \to \gamma A^0$". To be submitted to Phys. Rev. Lett.