Searches for light Higgs bosons at BABAR

Christopher Hearty
University of British Columbia / IPP

12-Aug-2011

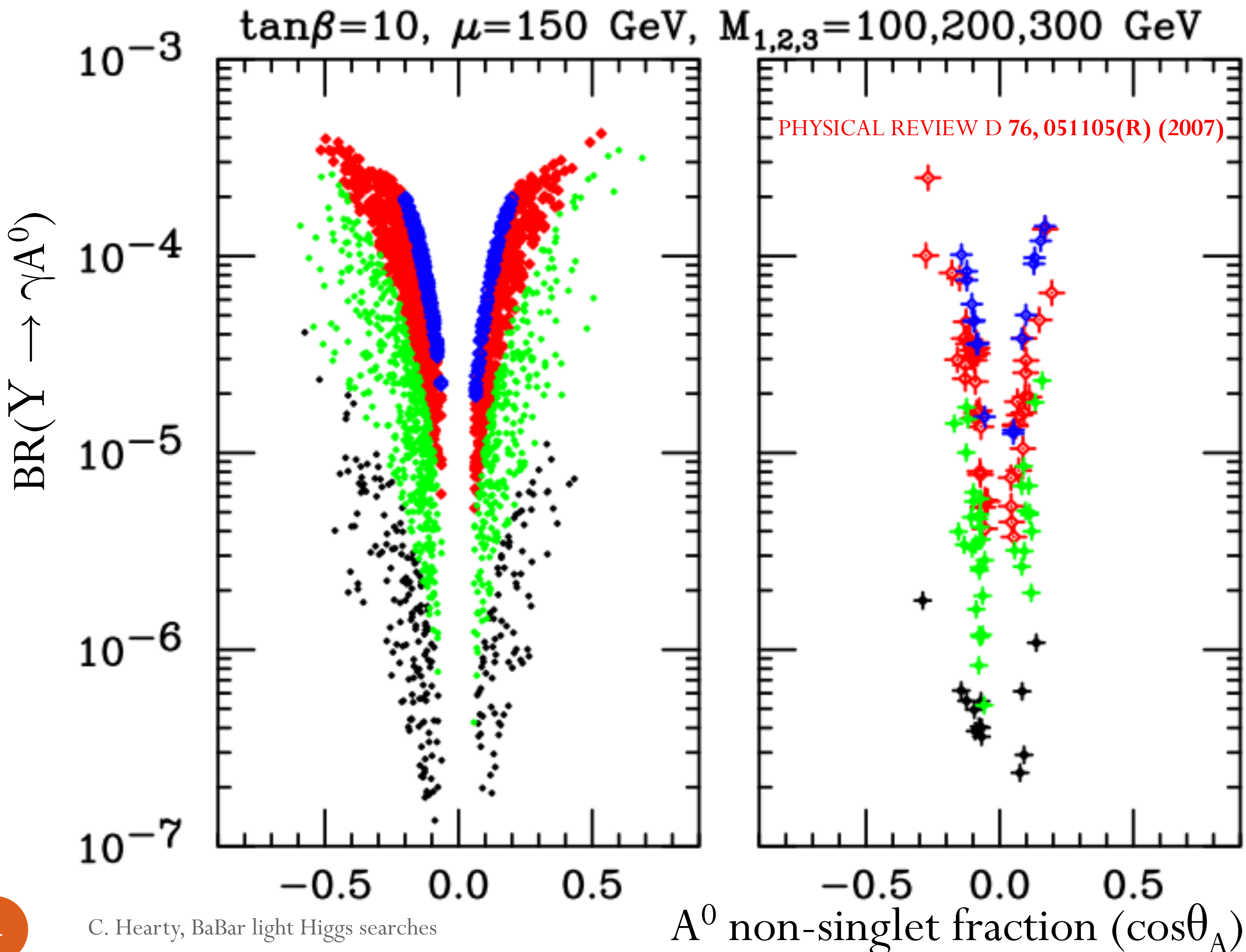
Division of Particles and Fields
Brown University, August 2011

BaBar

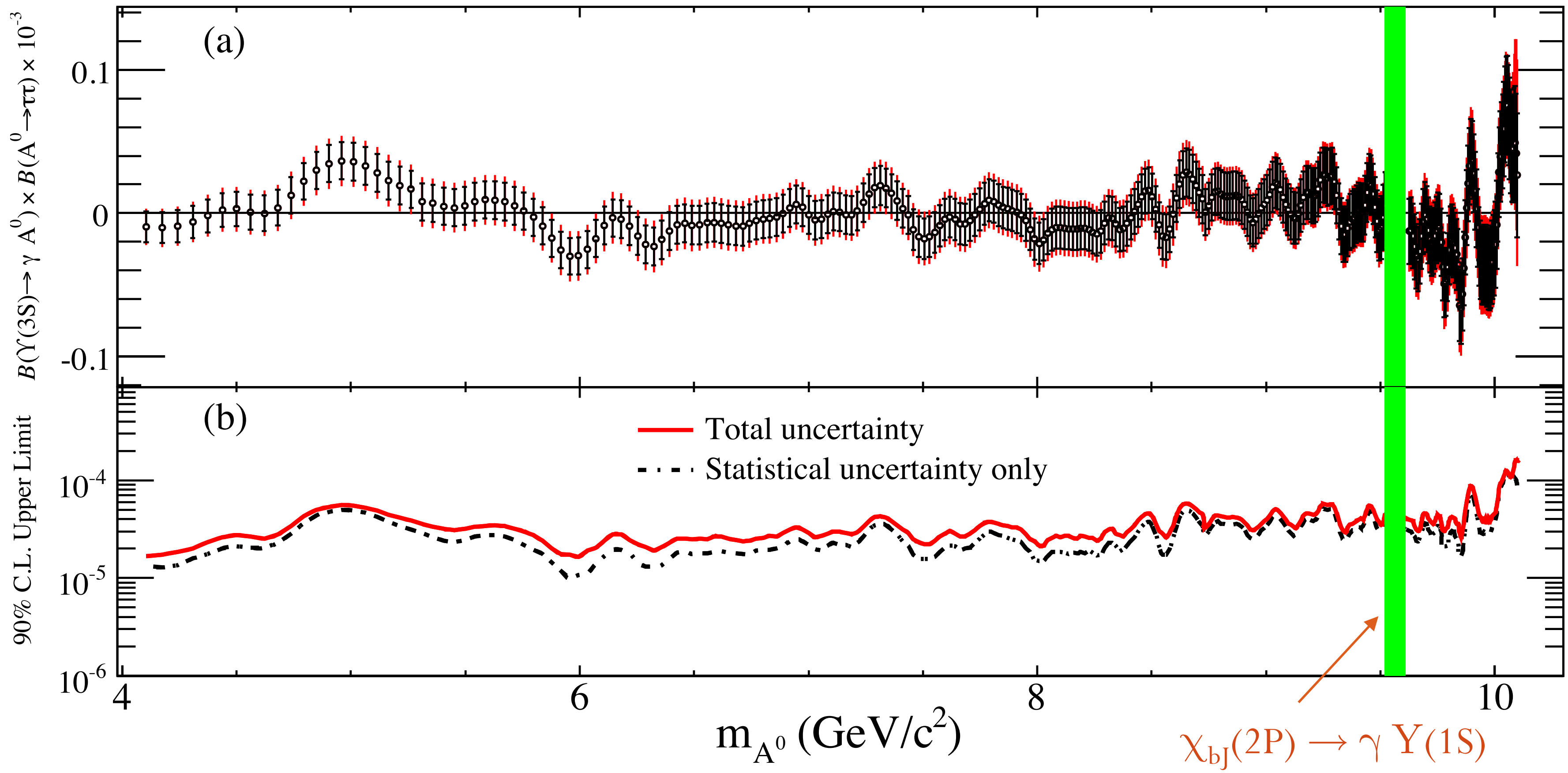
- BaBar collected 465M $B\bar{B}$ pairs at the $\Upsilon(4S)$ from 1999 – 2007 at the PEP-II e^+e^- collider located at the SLAC national laboratory.
- Also collected $\Upsilon(2S)$ and $\Upsilon(3S)$ data in 2008, the focus of this talk.
  - $(98.3 \pm 0.9) \times 10^6$ $\Upsilon(2S)$ ($13.6\ \mathrm{fb}^{-1}$)
  - $(121.3 \pm 1.2) \times 10^6$ $\Upsilon(3S)$ ($27.9\ \mathrm{fb}^{-1}$)

Light Higgs bosons

- A light Higgs ($< 2\cdot M_B$) expected in extensions to the SM such as nMSSM, enabling $\Upsilon(nS) \to \gamma A^0$
  - R. Dermisek and J.F. Gunion, Phys. Rev. Lett. 95, 041801 (2005).
- Branching fractions are predicted to be relatively large, depending on underlying model parameters.
- $$B\left(A^0 \to f\bar{f}\right) \propto m_f^2 / \tan^2\beta \quad \text{up-type fermions}$$
  $$B\left(A^0 \to f\bar{f}\right) \propto m_f^2 \tan^2\beta \quad \text{down-type fermions}$$


tanβ=10, μ=150 GeV, $M_{1,2,3}$=100,200,300 GeV
PHYSICAL REVIEW D 76, 051105(R) (2007)
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
BR($\Upsilon \rightarrow \gamma A^0$)
−0.5
0.0
0.5
−0.5
0.0
0.5
A^0 non-singlet fraction ($\cos\theta_A$)

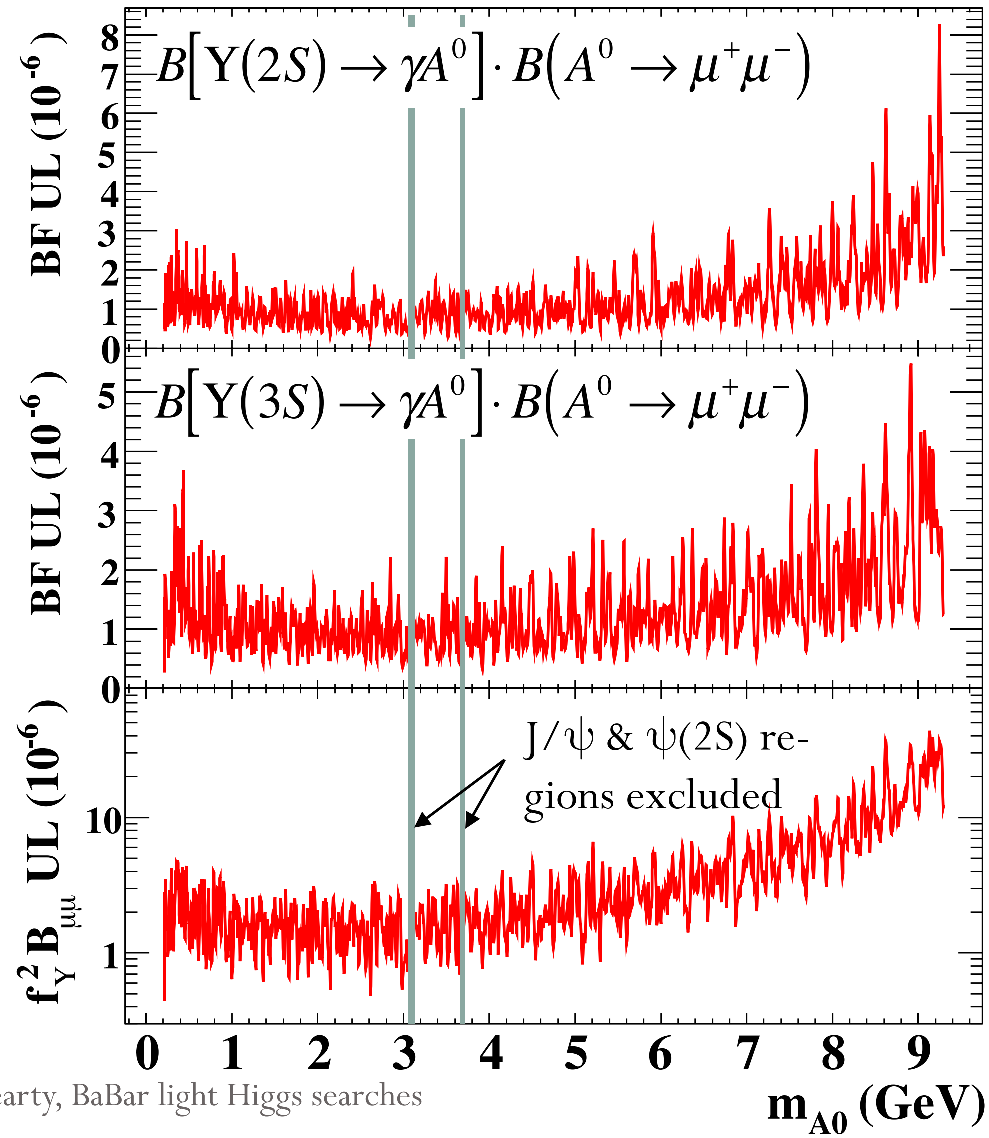
Search for $A^0 \rightarrow \tau^+ \tau^-$ in $\Upsilon(3S)$ data



$\chi_{bJ}(2P) \rightarrow \gamma\, \Upsilon(1S)$
region excluded

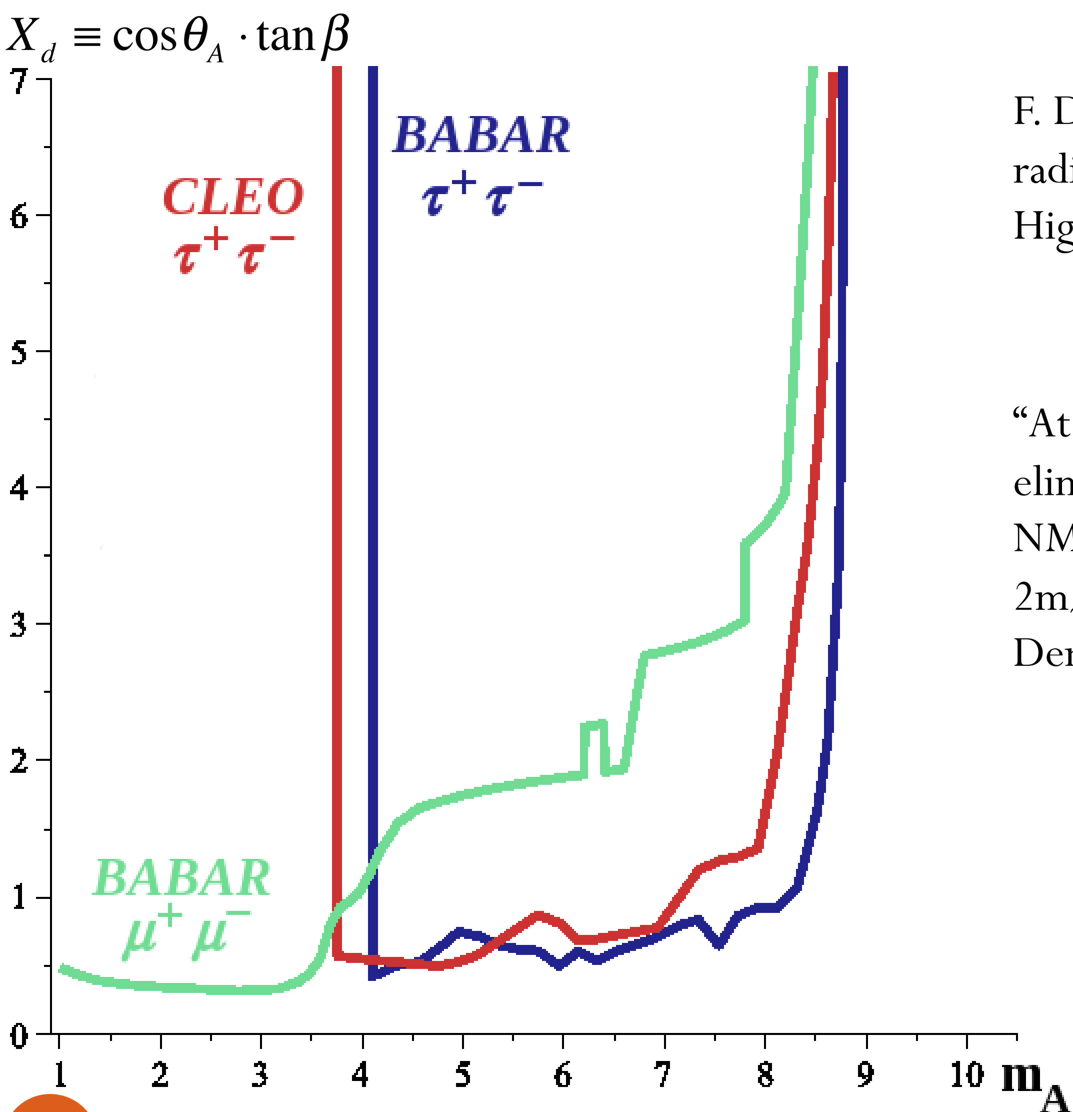
BaBar collaboration, Phys. Rev. Lett. 103, 181801 (2009)

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



BaBar collab., Phys. Rev. Lett. 103, 081803 (2009)

The BABAR measurements to leptonic final states have excluded much, but not all, of the parameter space.



F. Domingo, "Updated constraints from radiative Υ decays on a light CP-odd Higgs", 1010.4701 [hep-ph] (2010).

"At $\tan\beta = 3$, the $\mu^+\mu^-$ final state data eliminates more than 4/5 of the NMSSM models points in the $m_{a1} < 2m_\tau$ mass range"
Dermisek and Gunion PRD 81, 075003

Lepton universality in 1S decays

- Apparent violation of lepton universality would arise if the radiative photon is not observed in

  $$\Upsilon(1S) \to \gamma\, A^0, \quad A^0 \to \ell^+\ell^-$$

  or $$\Upsilon(1S) \to \gamma\, \eta_b,\ \eta_b \to A^0 \to \ell^+\ell^-$$

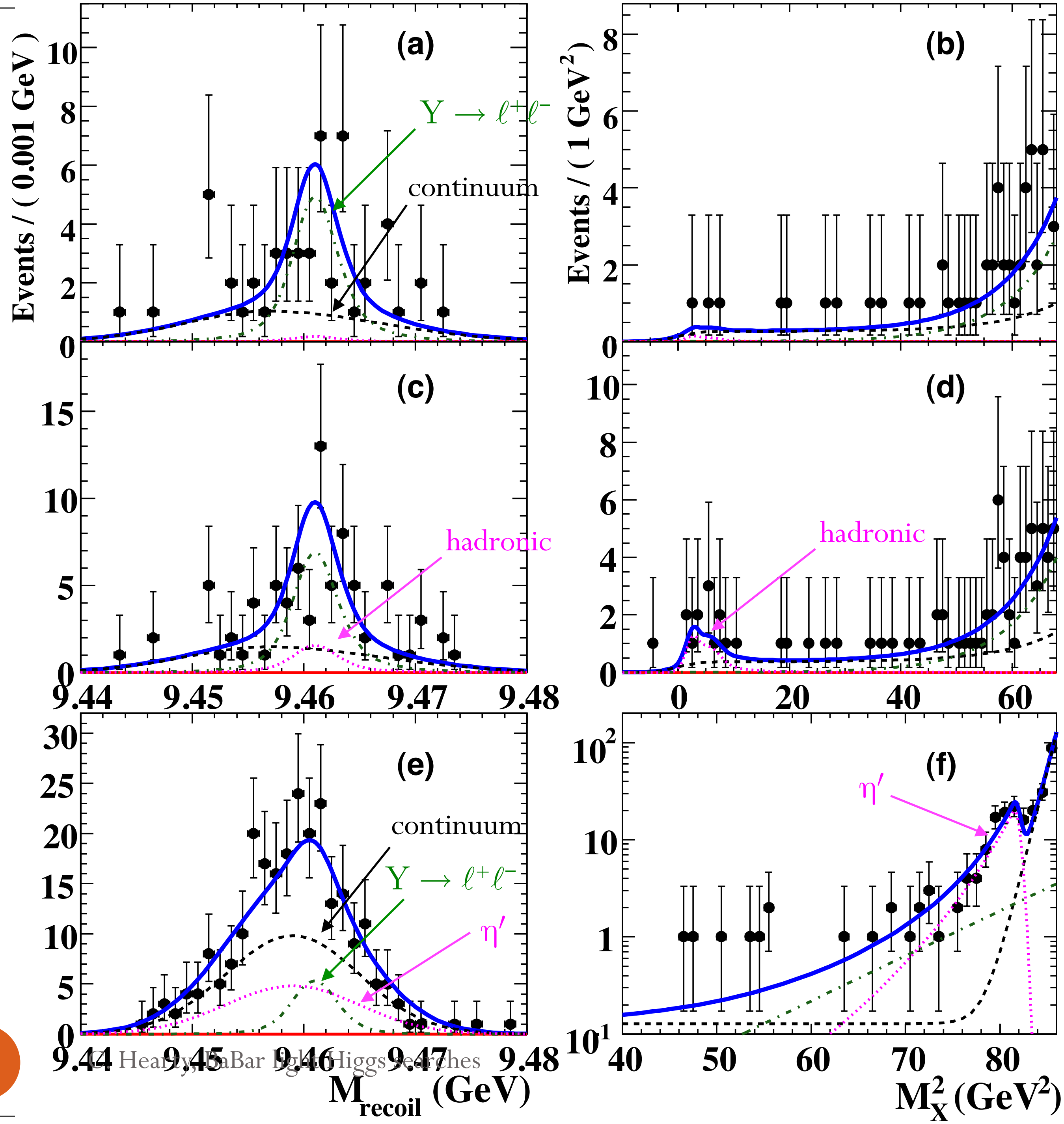
  - η_b and A^0 have the same quantum numbers $J^{PC} = 0^{-+}$
- $\Upsilon(3S) \to \pi^+ \pi^- \Upsilon(1S) \qquad (4.4\%)$
- $\Gamma_{\Upsilon(1S)\to\tau^+\tau^-} / \Gamma_{\Upsilon(1S)\to\mu^+\mu^-} = 1.005 \pm 0.013 \pm 0.022$

  vs SM expectation of 0.992

BaBar collab., Phys. Rev. Lett. 104, 191801 (2010)

Invisible decays of the A^0

- $\Upsilon(2S) \rightarrow \pi^+\pi^- \Upsilon(1S)$ (18.1%)
  - $\Upsilon(1S) \rightarrow \gamma A^0$, $A^0 \rightarrow$ invisible
  - or $\Upsilon(1S) \rightarrow \gamma \chi\chi$ dark matter
- Trigger is important. Single photon $E^*>1$ GeV special for $\Upsilon(2,3S)$ running, or di-pion (low efficiency) .
- Use $\pi^+ \pi^-$ to suppress continuum [non-$\Upsilon(1S)$] backgrounds.
- Other backgrounds:
  - leptonic: $\Upsilon(1S) \rightarrow \gamma \ell^+\ell^-$ ($\ell^+\ell^-$ not detected)
  - hadronic: $\Upsilon(1S) \rightarrow \gamma M$, $M \rightarrow K_L K_L$ or n n
  - η': 2γ production of η', $\eta' \rightarrow \gamma \pi^+\pi^-$
- Fit mass recoiling against $\pi^+\pi^-$ ($\approx M_{\Upsilon(1S)}$) and missing mass squared (M^2_A or $M^2_{\chi\chi}$)

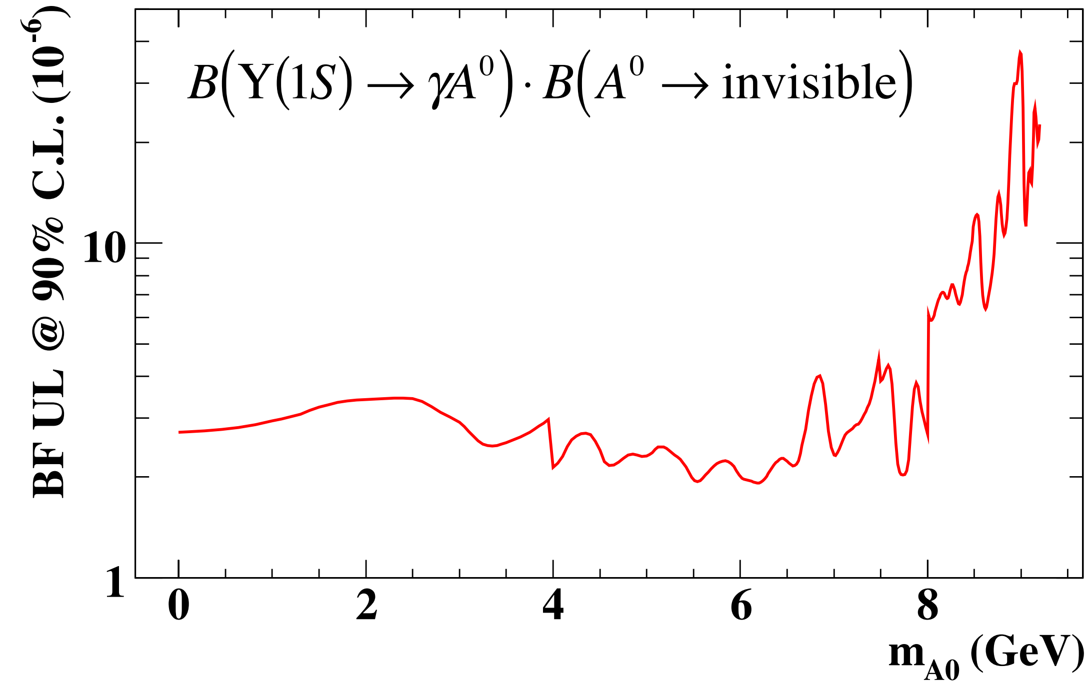


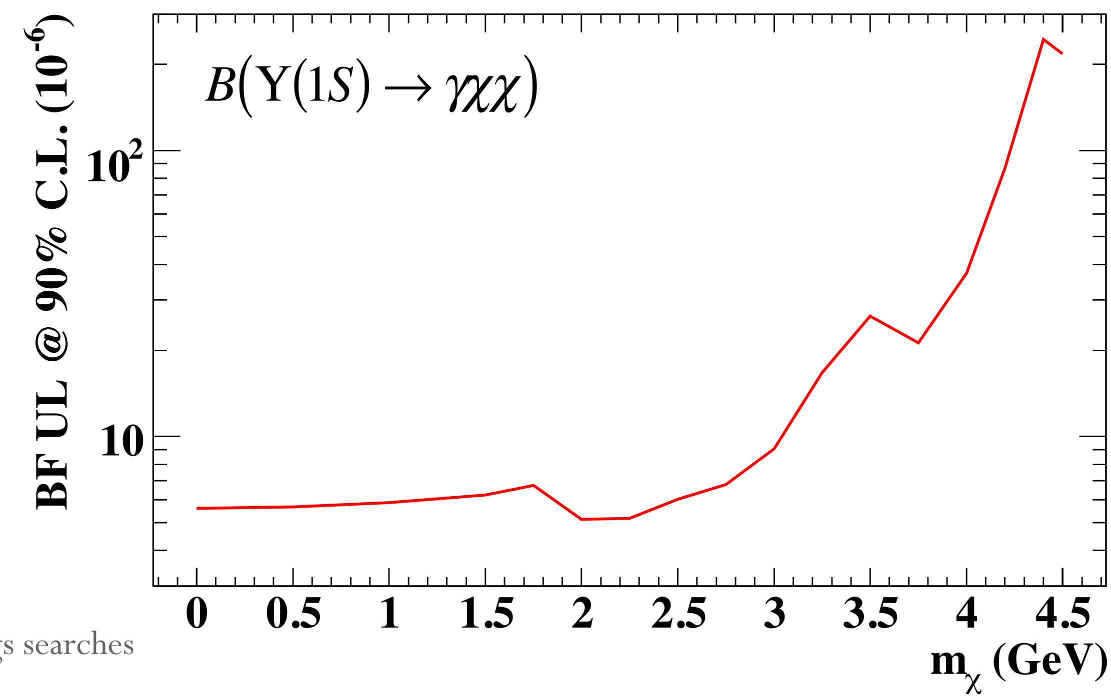
$M_{A0} < 8$ GeV/c^2

$M_{A0} < 8$ GeV/c^2
Cuts loosened to enhance hadronic backgrounds in (c) and (d)

$7.5 < M_{A0} < 9.2$ GeV/c^2

BaBar collab., Phys. Rev. Lett. 107, 021804 (2011)

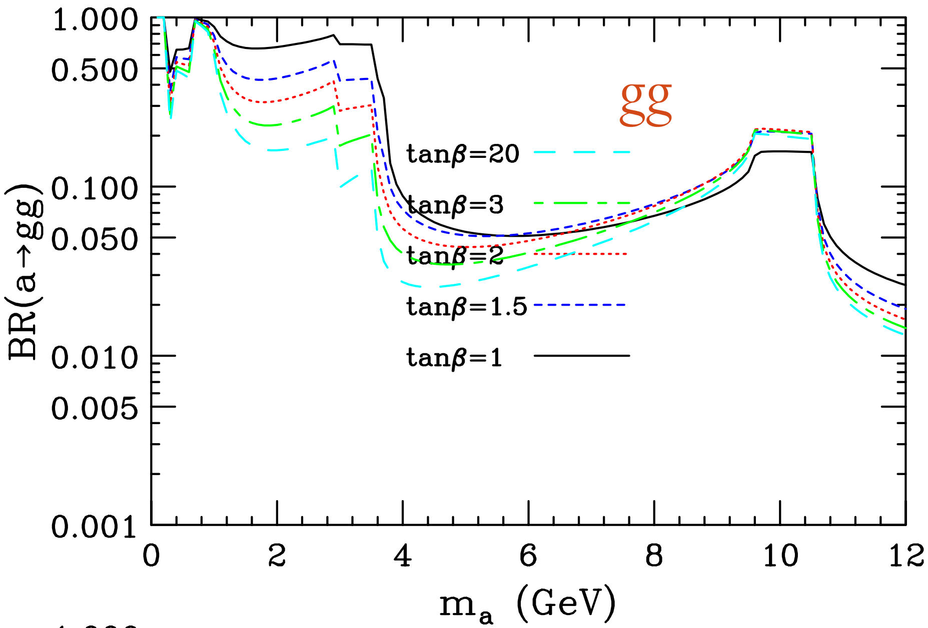


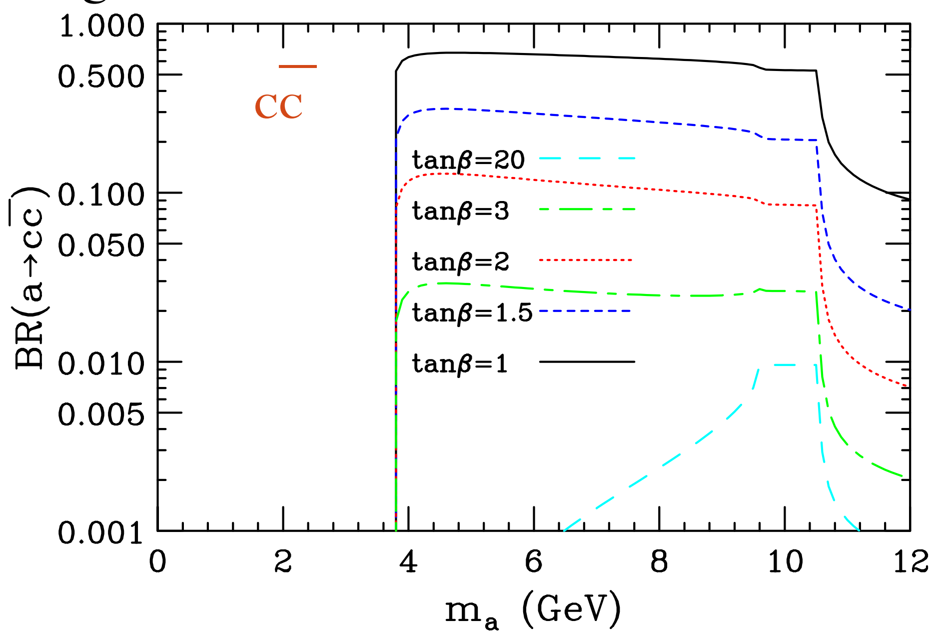


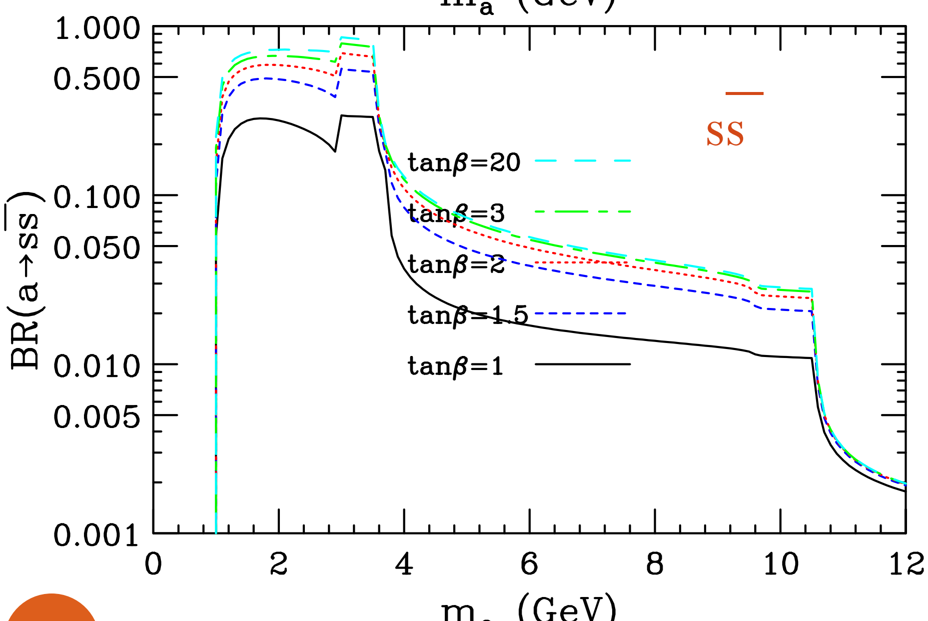
Search for hadronic decays of the A^0

- Hadronic decays of the A^0 can be dominant depending on mass and $\tan\beta$.

A^0 hadronic decay branching fractions for various tanβ



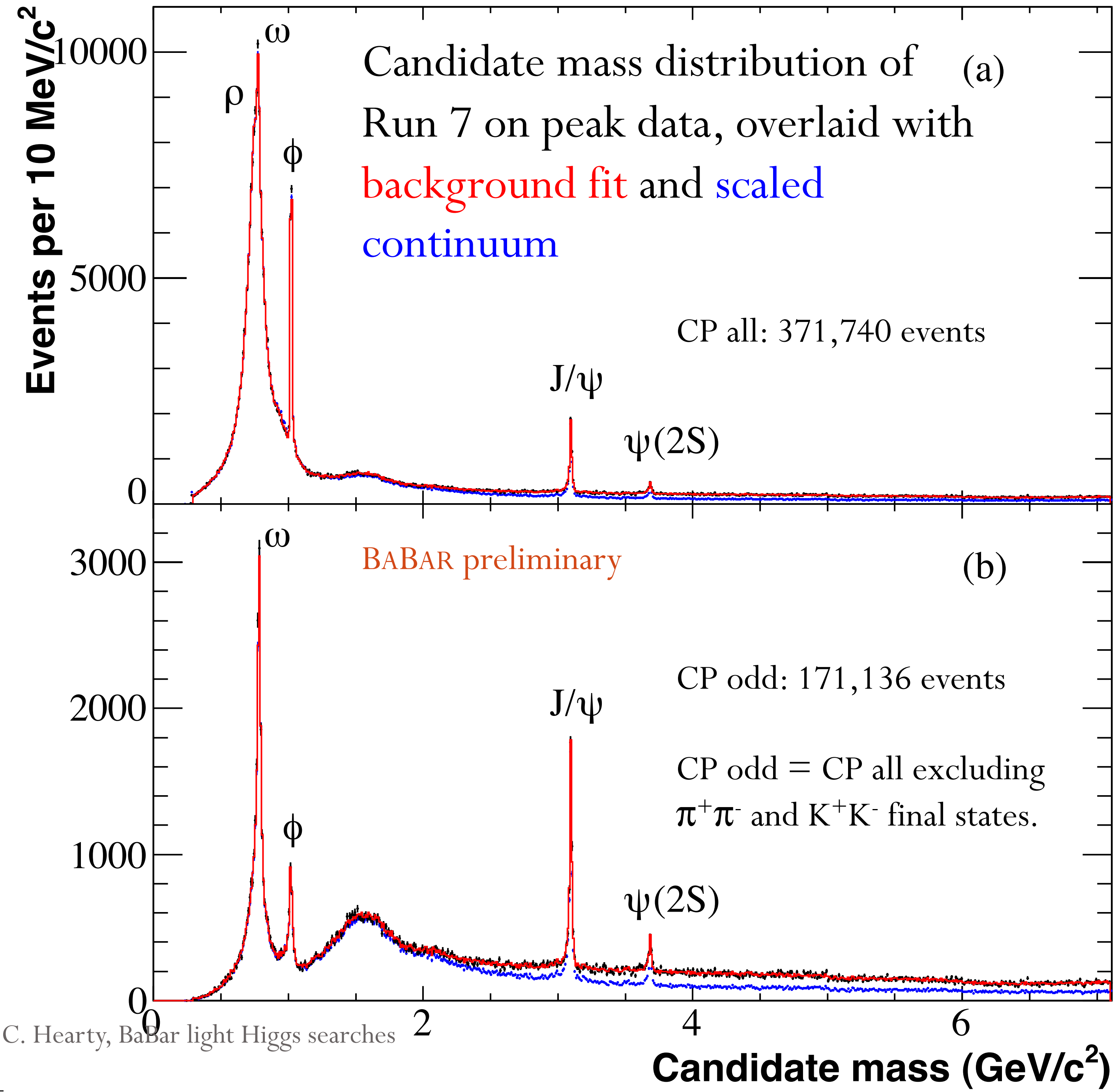




R. Dermisek and J. F. Gunion, "New constraints on a light CP−odd Higgs boson and related NMSSM ideal Higgs scenarios", Phys. Rev. D 81, 075003 (2010).

Analysis method

- Look for narrow resonances in A^0 mass spectrum from fully reconstructed $\Upsilon(2S,3S) \to \gamma A^0$ events.
  - Assume A^0 is CP odd, or make no assumption ("CP all")
- PID & kinematics reject $e^+e^- \to \gamma e^+e^-$ and $\gamma\, \mu^+\mu^-$
- Remaining backgrounds:
  - continuum: ISR production of resonances ($e^+e^- \to \gamma$ M) or non-resonant ($e^+e^- \to \gamma$ X)
  - Υ radiatve decay, resonant ($\Upsilon \to \gamma$ M) and non-resonant ($\Upsilon \to \gamma$ X)
  - at high A^0 mass, π^0 decay can fake radiative photon.
- Use $\Upsilon(4S)$ and offpeak data as a continuum sample.
  - $B\overline{B}$ events do not pass selection.

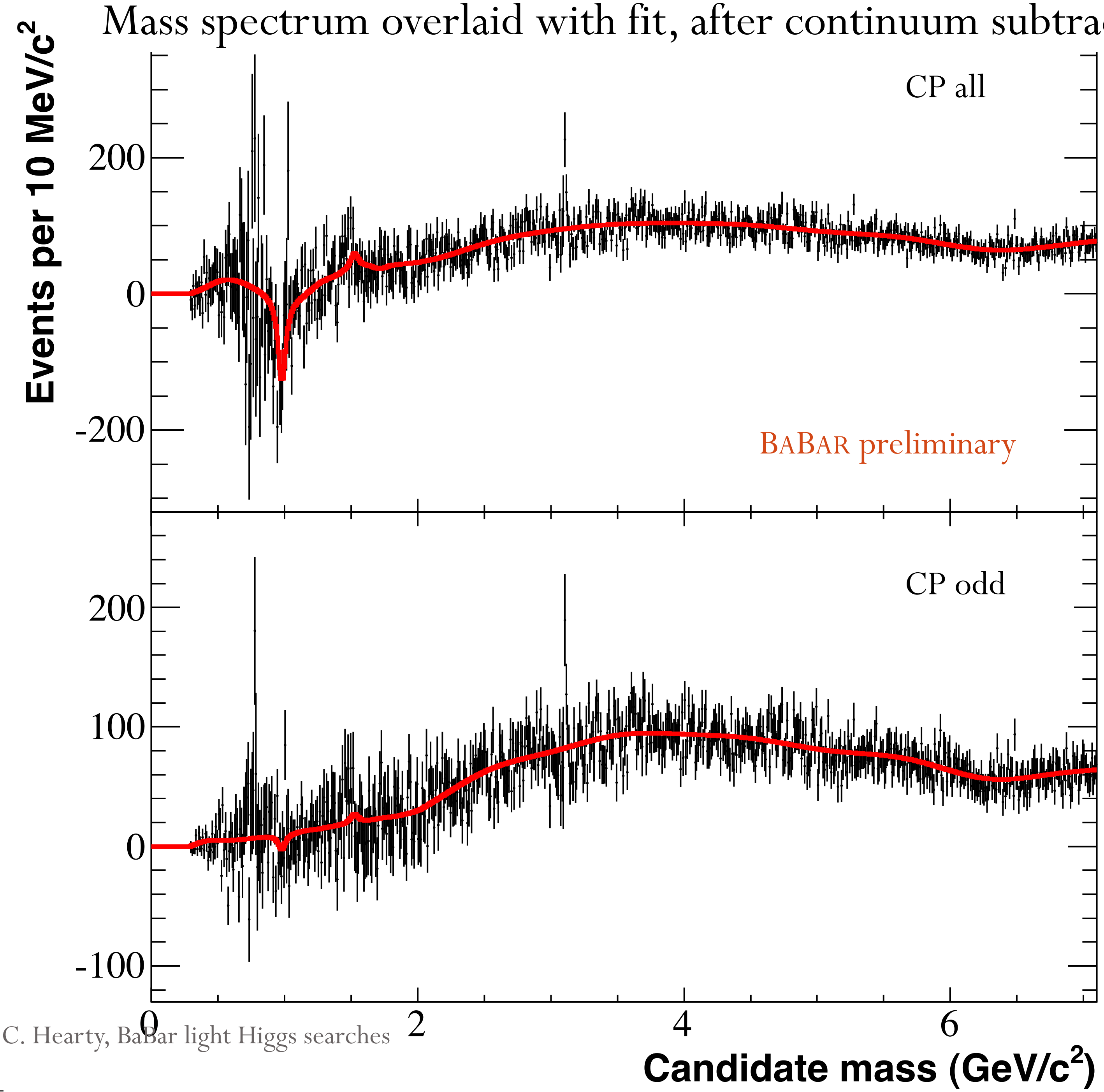


Candidate mass distribution of Run 7 on peak data, overlaid with background fit and scaled continuum
(a)
CP all: 371,740 events
BABAR preliminary
(b)
CP odd: 171,136 events
CP odd = CP all excluding $\pi^+\pi^-$ and K^+K^- final states.
ρ
ω
φ
J/ψ
ψ(2S)
Events per 10 MeV/c^2
Candidate mass (GeV/c^2)

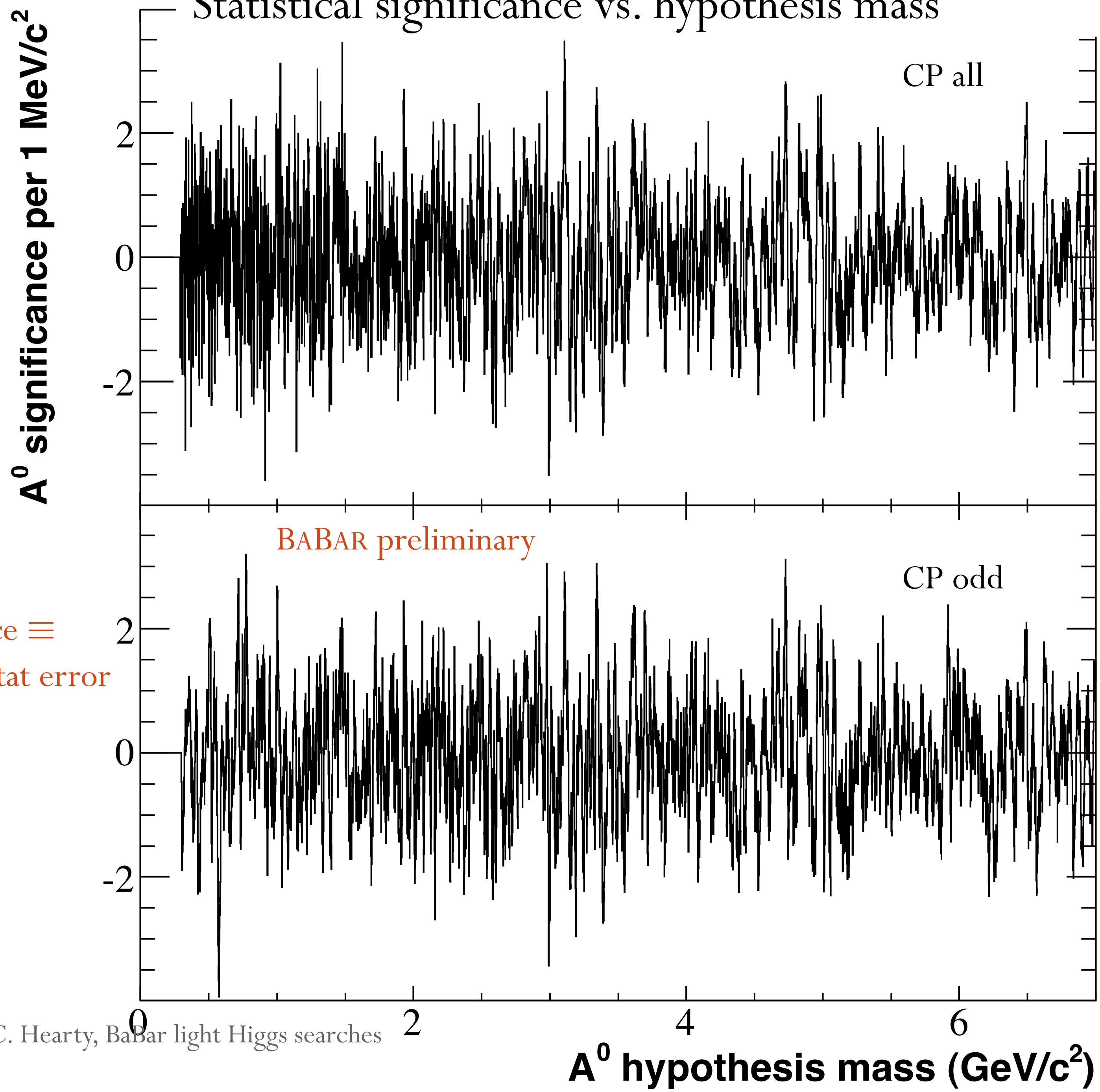
Higgs signal

- Higgs signal at a particular mass hypothesis is the number of events in a mass window centered on m_i minus the estimated background events in that window.
- Number of background events comes from a fit to the candidate mass distribution with three components:
  - Continuum component of fit has one parameter, C_N, which scales the mass spectrum of the continuum data.
  - Five light resonances ~seen by CLEO in $\Upsilon(1S) \rightarrow \gamma\, h^+h^-$
  - Smooth curve for non-resonant $\Upsilon(nS) \rightarrow \gamma\, X$ decays

Mass spectrum overlaid with fit, after continuum subtraction

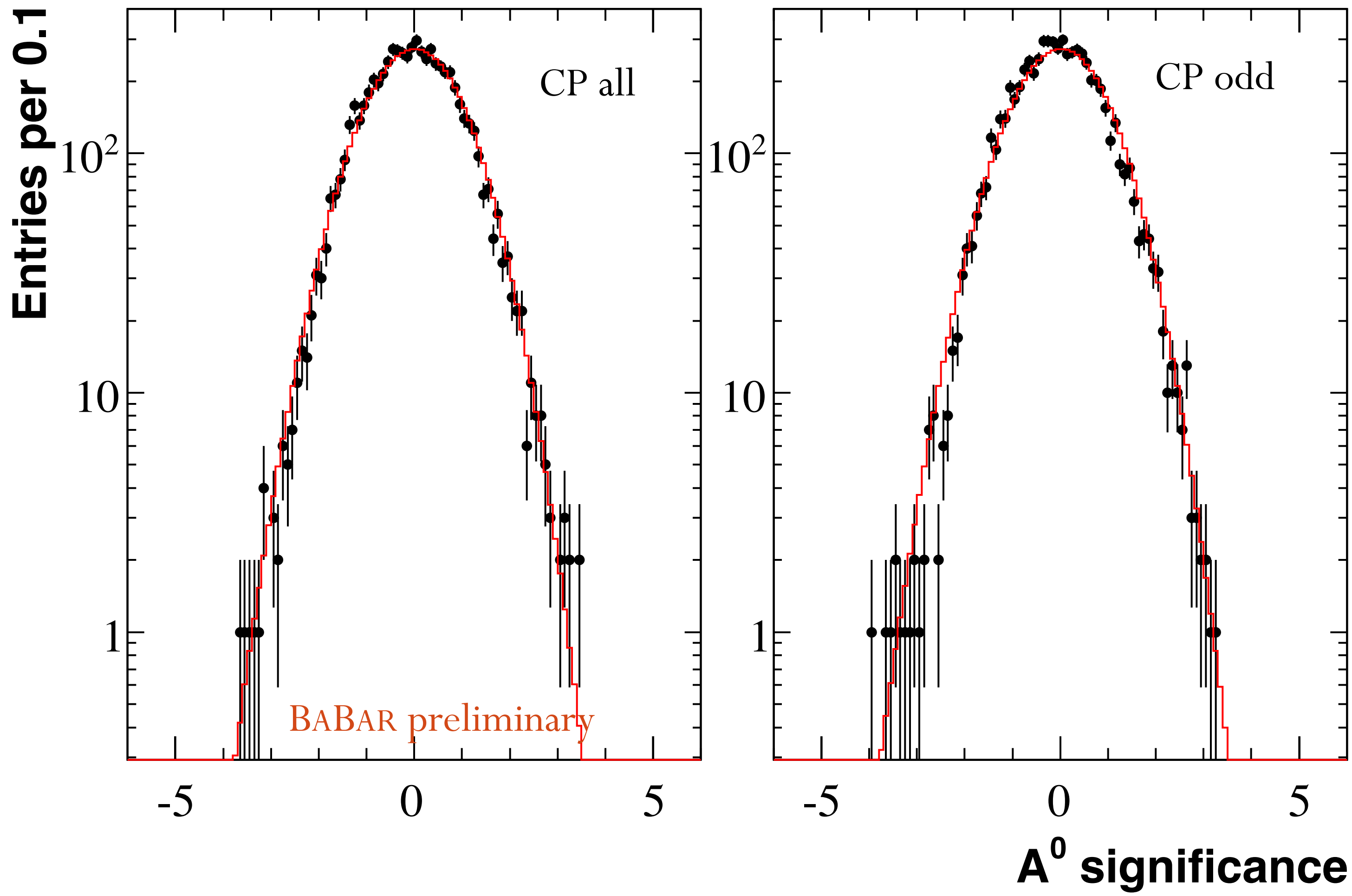


Statistical significance vs. hypothesis mass



significance ≡ events / stat error

Histogram of the 6720 (CP all) or 6711 (CP odd) values of statistical significance from the previous plot overlaid (in red) with distribution predicted by Toys for no signal



Systematic errors

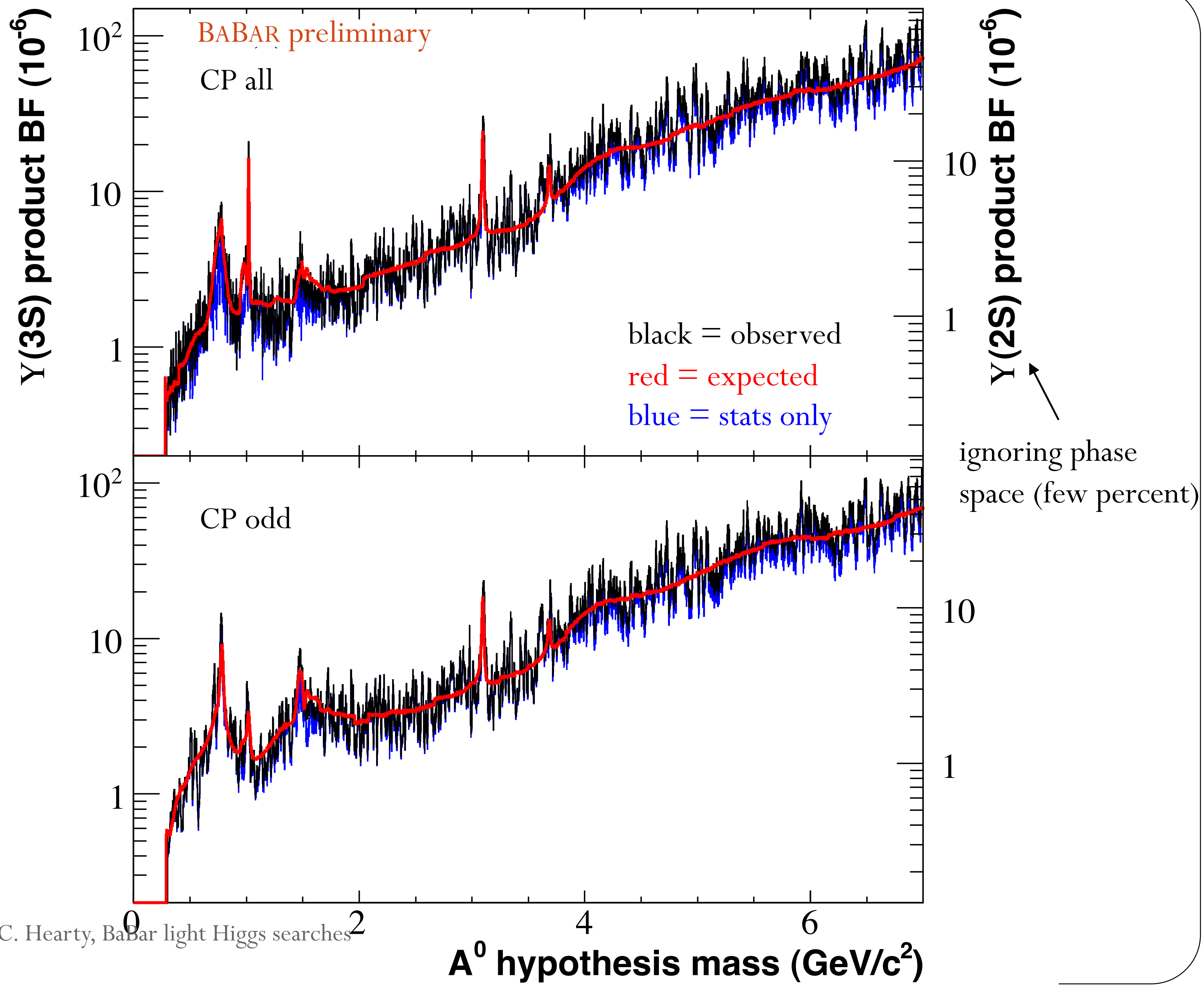
- Primary efficiency uncertainty is in the A^0 decay modes.
- Uncertainties on backgrounds by comparing fixed and floating continuum scaling factor, and by varying light resonances included in the fit.

Most significant signals

- CP all: 3.5σ at 3.107 GeV/c^2 (statistics only)
  2.9σ at 1.295 GeV/c^2 (stats + systematics)
  - 33% of Toy MC experiments have larger fluctuations
- CP odd: 3.2σ at 0.772 GeV/c^2 (statistics only)
  3.1σ at 4.727 GeV/c^2 (stats + systematics)
  - 63% of Toy MC experiments have larger fluctuations

Upper limit calculation

- Calculate of 90% CL upper limits on $B[\Upsilon(3S) \rightarrow \gamma A^0] \cdot B(A^0 \rightarrow \text{hadrons})$ and $B[\Upsilon(2S) \rightarrow \gamma A^0] \cdot B(A^0 \rightarrow \text{hadrons})$ assuming that the same matrix element describes both 2S and 3S decays.


BABAR preliminary
CP all
CP odd
black = observed
red = expected
blue = stats only
Υ(3S) product BF (10^-6)
Υ(2S) product BF (10^-6)
A^0 hypothesis mass (GeV/c^2)
ignoring phase space (few percent)

Conclusions

- The $\Upsilon(2S)$ and $\Upsilon(3S)$ data collected by BaBar has produced searches for light Higgs production in a variety of modes, but unfortunately, no observations.
- This data set continues to be exploited for standard model quarkonium studies.
  - See "Recent BABAR Studies of Bottomonium States" by V. Ziegler in this morning's Hadron Spectroscopy session.
- Other new physics searches are in the pipeline.

BaBar papers in this talk

- "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).
- "Test of lepton universality in $\Upsilon(1S)$ decays at BaBar", Phys. Rev. Lett. **104**, 191801 (2010).
- "Search for Production of Invisible Final States in Single-Photon Decays of $\Upsilon(1S)$", Phys. Rev. Lett. **107**, 021804 (2011).
- "Search for hadronic decays of a light Higgs boson in radiative decays $\Upsilon \to \gamma\ A^0$". To be submitted to Phys. Rev. Lett.

Backup slides

Upsilon resonant component in fit

- Nominally include five light resonances in fit, $\Upsilon \rightarrow \gamma M$. Relativistic BW, fixed mass and width.
- Add and remove resonances for systematic studies.

	M (MeV/c^2)	Γ (MeV)	CLEO measurement	BF (10^{-5})
$f_0(980)$	980 ± 10	70 ± 30	$\Upsilon(1S) \rightarrow \gamma f_0 \rightarrow \pi^+\pi^-$	$1.8^{+0.8}_{-0.7} \pm 0.1$
$f_2(1270)$	1275.1 ± 1.2	$185.1^{+2.9}_{-2.1}$	$\Upsilon(1S) \rightarrow \gamma f_2$	$10.2 \pm 0.8 \pm 0.7$
$f_2'(1525)$	1525 ± 5	73^{+6}_{-5}	$\Upsilon(1S) \rightarrow \gamma f_2'$	$3.7^{+0.9}_{-0.7} \pm 0.8$
$f_0(1710)$	1720 ± 6	135 ± 6	$\Upsilon(1S) \rightarrow \gamma f_0 \rightarrow K^+K^-$	$0.38 \pm 0.16 \pm 0.04$
$f_4(2050)$	2018 ± 11	237 ± 18	$\Upsilon(1S) \rightarrow \gamma f_4 \rightarrow \pi^+\pi^-$	$0.37 \pm 0.14 \pm 0.03$

Upsilon non-resonant fit component

- Fit the non-resonant component $\Upsilon \to \gamma X$ with a 16-knot cubic spline. Amplitudes at first and last knots are fixed, others float, together with overall normalization.
- Typically 0.5 GeV/c^2 between knot locations, so the non-resonant fit cannot conform to a narrow signal resonance.
- However, large correlations between non-resonant and resonant fit components make measurements of the resonant contributions unreliable.

Systematic errors

- Primary efficiency uncertainty is in the A^0 decay modes.
  - below the cc threshold, compare 50% ss and 50% gg to 100% gg. 8% uncertainty for CP all, 4% for CP odd.
  - above the cc threshold, compare equal mixture of cc, ss, and gg to 50% cc and 25% each ss and gg. 21% uncertainty.
- Uncertainties on backgrounds by comparing fixed and floating continuum scaling factor, and by varying light resonances included in the fit.