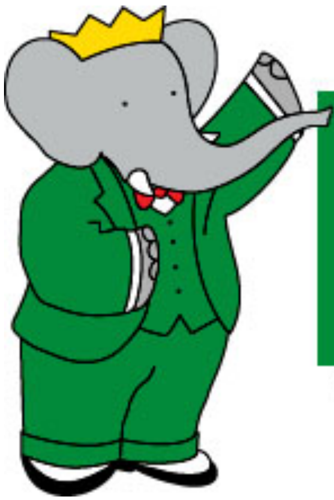
Search for low mass Higgs at *BABAR*

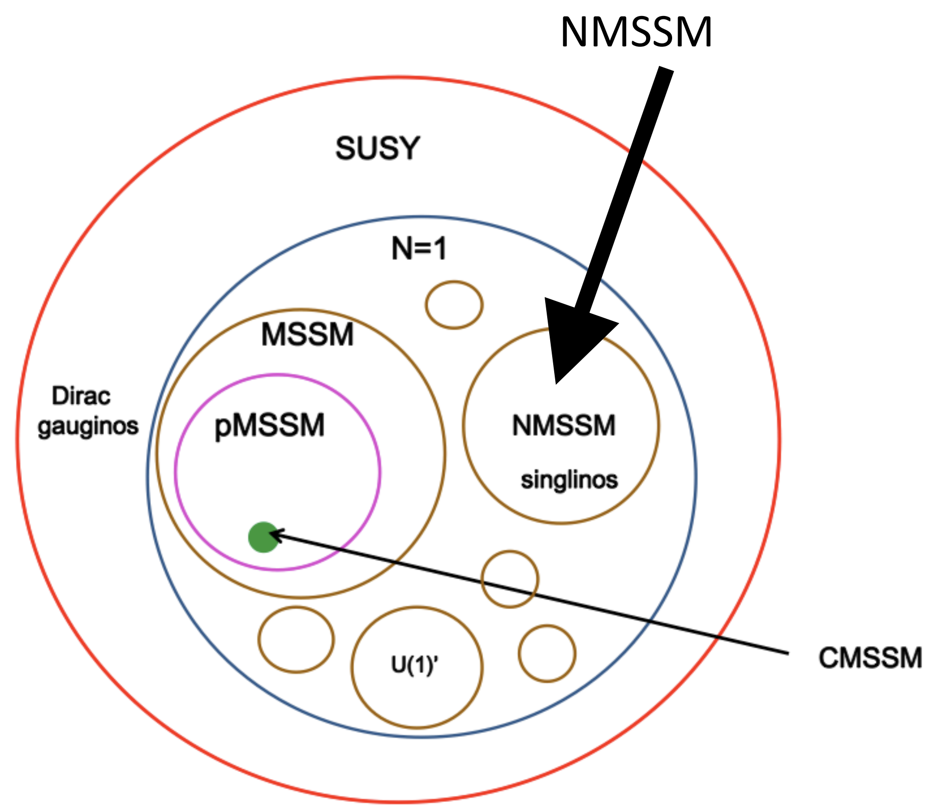


Rocky So
University of British Columbia, Canada
Representing the *BABAR* Collaboration

DPF UC Santa Cruz, Aug 15th, 2013

Possibility of a CP-odd light Higgs A^0

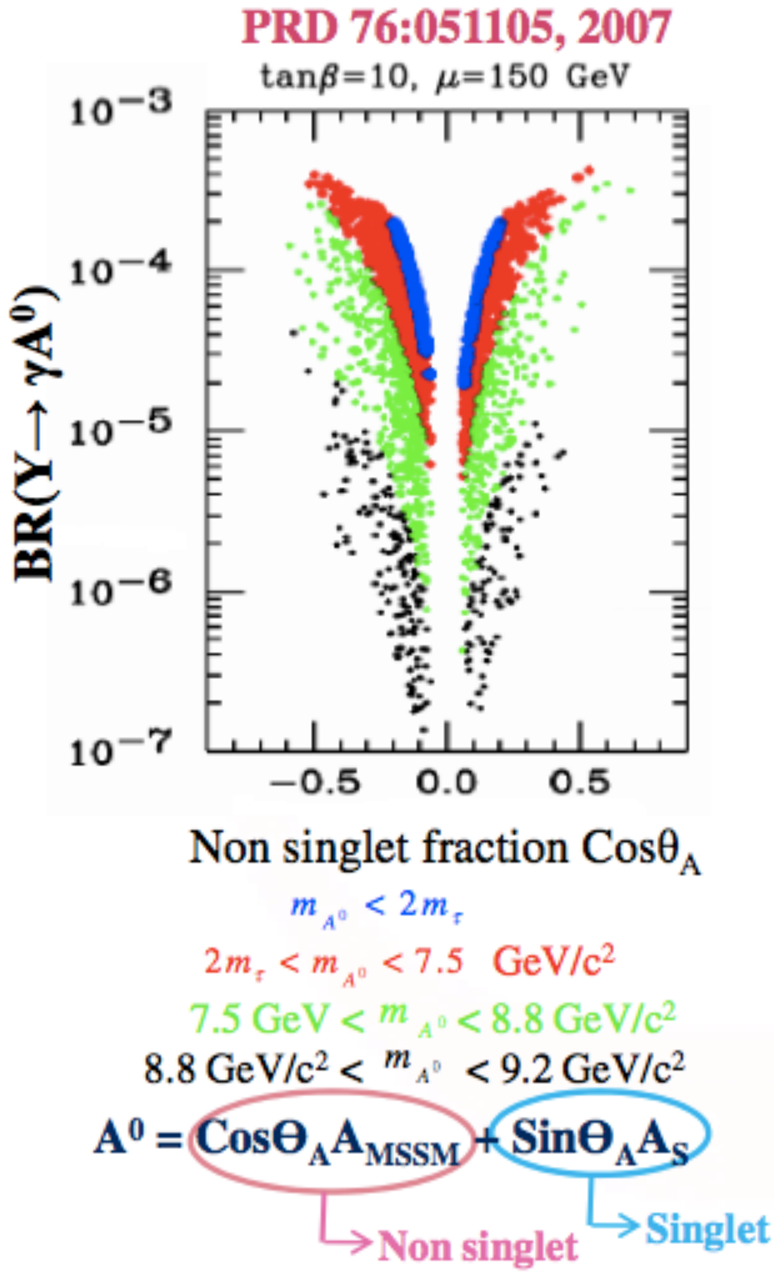
- A light Higgs boson, with quantum numbers $J^{PC}=0^{-+}$, is predicted in extensions of the Standard Model, such as the Next-to-Minimal Supersymmetric Standard Model
  - R. Dermisek and J. F. Gunion, "New constraints on a light CP−odd Higgs boson and related NMSSM ideal Higgs scenarios", Phys. Rev. D 81, 075003 (2010).
- Such a Higgs with a mass < $2m_b$ is not excluded from LEP constraints



T. Rizzo (SLAC Summer Institute 2012)

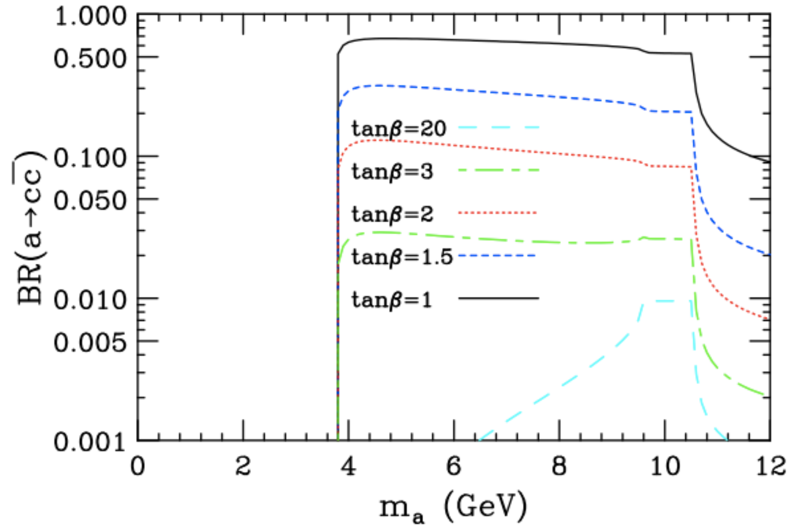
NMSSM Parameter Space

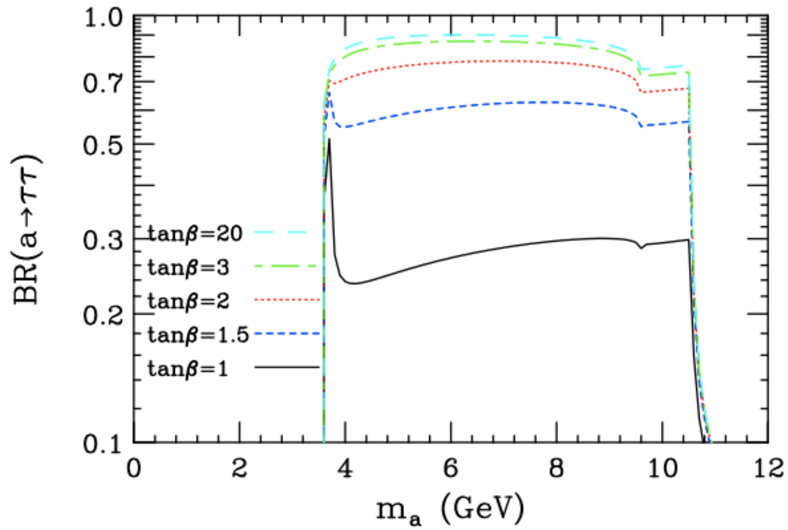
- BF($\Upsilon(1S) \rightarrow \gamma A^0$) depends on non-singlet fraction
- High mass Higgs very difficult to exclude

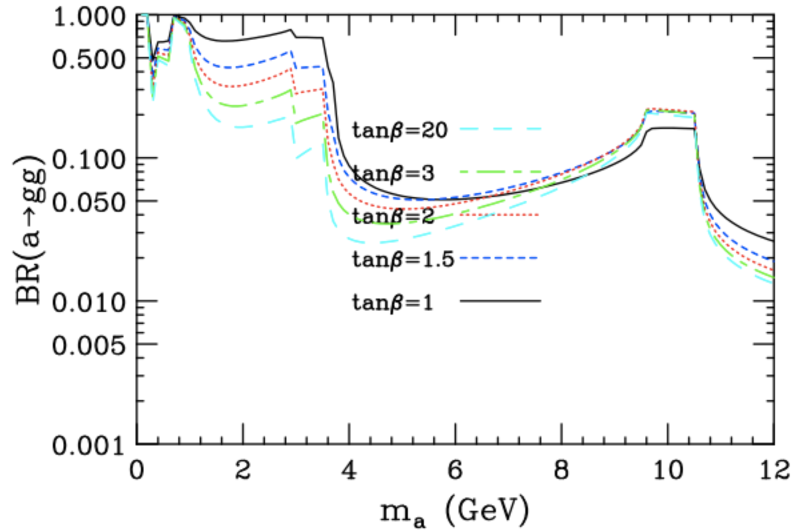


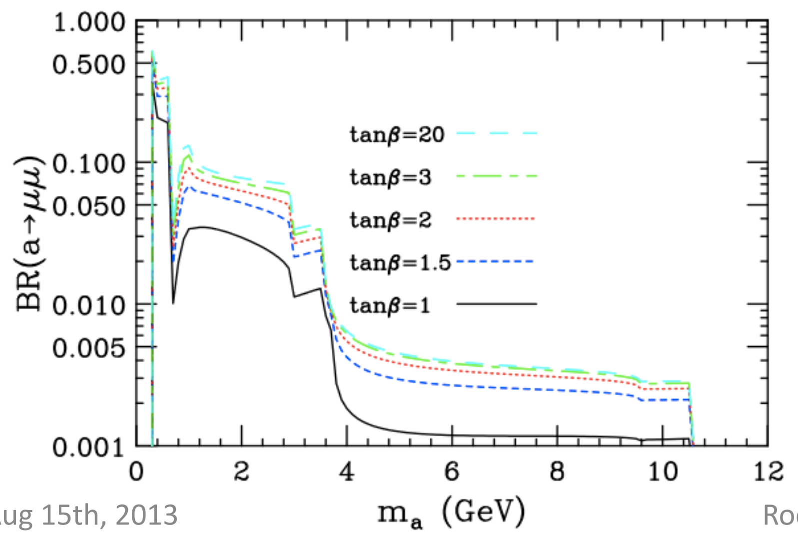
Higgs Branching Fractions

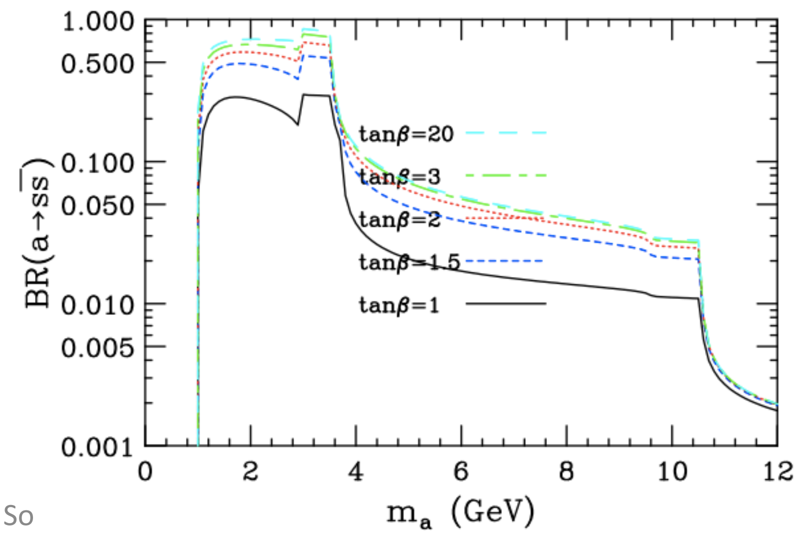
$$B\left(A^0 \to f\bar{f}\right) \propto m_f^2 / \tan^2\beta \quad \text{up-type fermions}$$
$$B\left(A^0 \to f\bar{f}\right) \propto m_f^2 \tan^2\beta \quad \text{down-type fermions}$$







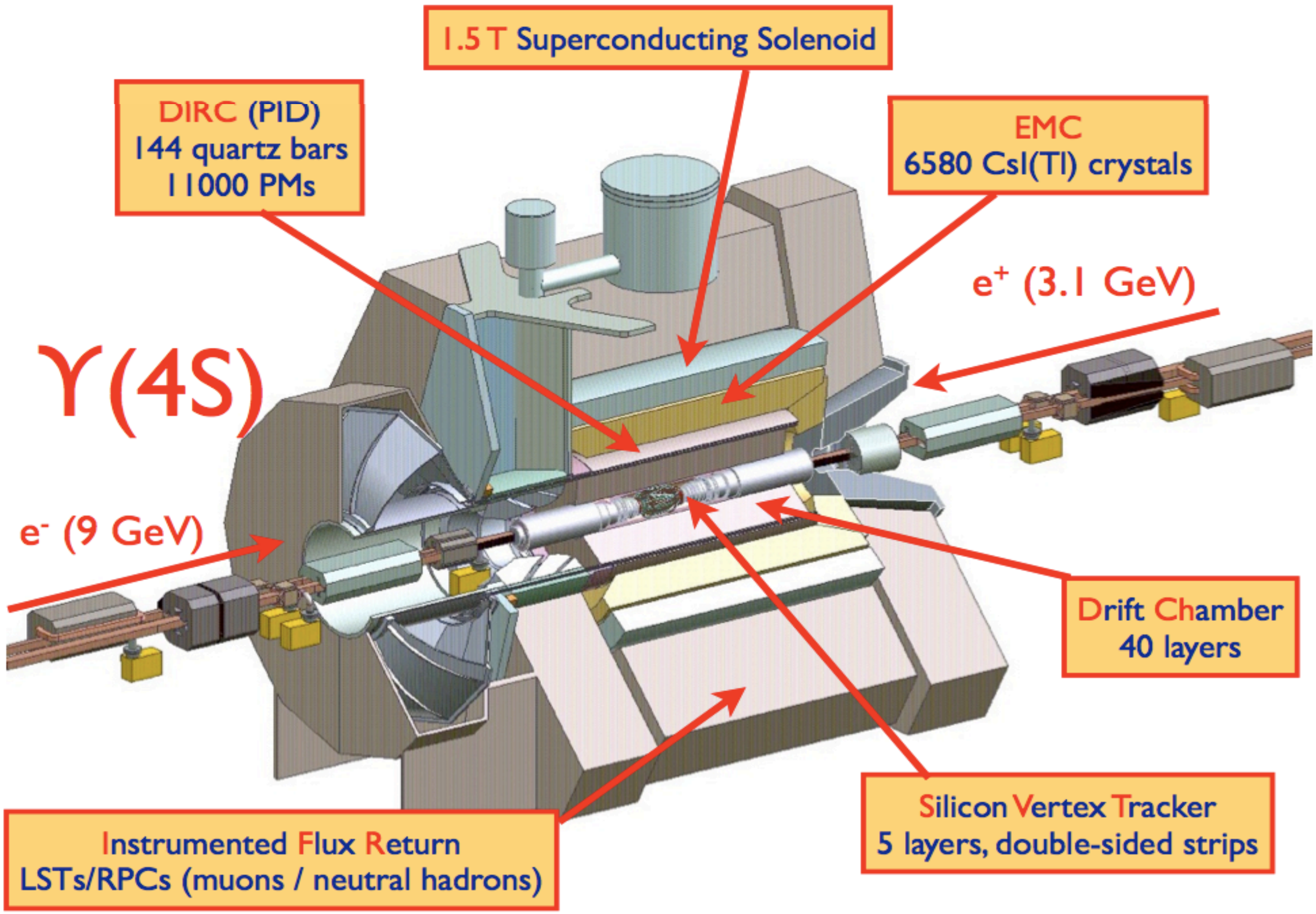




BABAR light Higgs searches

Presented in DPF 2011	
$\Upsilon(2,3S) \rightarrow \gamma\ A^0; A^0 \rightarrow \mu^+\mu^-$	PRL 103, 081803 (2009)
$\Upsilon(3S) \rightarrow \gamma\ A^0; A^0 \rightarrow \tau^+\tau^-$	PRL 103, 181801 (2009)
$\Upsilon(1S) \rightarrow \gamma\ A^0; A^0 \rightarrow$ invisible	PRL 107, 021804 (2011)
$\Upsilon(2,3S) \rightarrow \gamma\ A^0; A^0 \rightarrow$ hadrons	PRL 107, 221803 (2011)
Today's talk	
$\Upsilon(1S) \rightarrow \gamma\ A^0; A^0 \rightarrow \mu^+\mu^-$	PRD 87, 031102(R) (2013)
$\Upsilon(1S) \rightarrow \gamma\ A^0; A^0 \rightarrow \tau^+\tau^-$	arXiv:1210:5669
$\Upsilon(1S) \rightarrow \gamma\ A^0; A^0 \rightarrow gg$ or $s\bar{s}$	PRD 88, 031701(R) (2013)

The *BABAR* Experiment



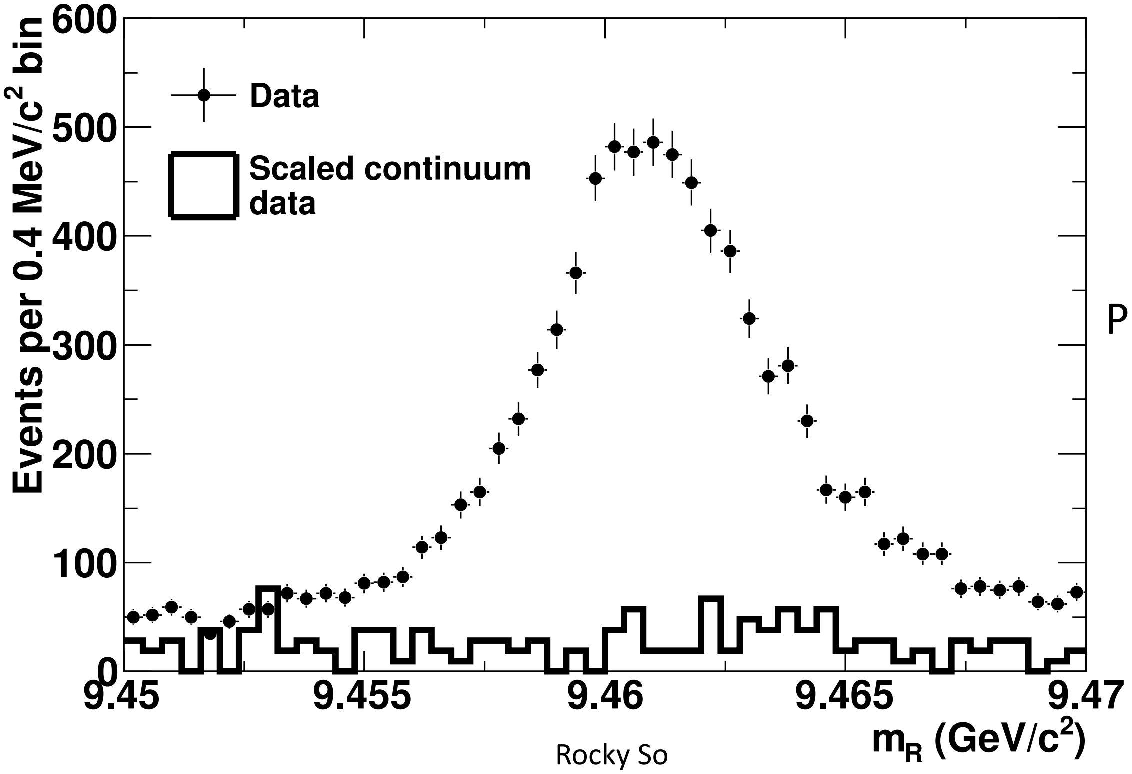
Dataset

- 122M $\Upsilon(3S)$ and 99M $\Upsilon(2S)$
  - 30/fb at 10.35GeV e^+e^- center of mass energy
    14/fb at 10.02GeV
  - 2.6/fb at 10.32GeV
    1.4/fb at 9.99GeV

- 5M $\Upsilon(1S)$ by tagging dipions $\Upsilon(3S) \to \pi^+\pi^-\Upsilon(1S)$
  18M $\Upsilon(1S)$ by tagging dipions $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$

Dipion tagging: recoil mass

- Removes continuum background and a clean Υ(1S) sample remains
- Select on recoil mass $M^2_{recoil} = M^2_{\Upsilon(2S)} + M^2_{\pi\pi} - 2M_{\Upsilon(2S)}E_{\pi\pi}$



PRD 88, 031701(R) (2013)

Gaussian with long tail on both sides

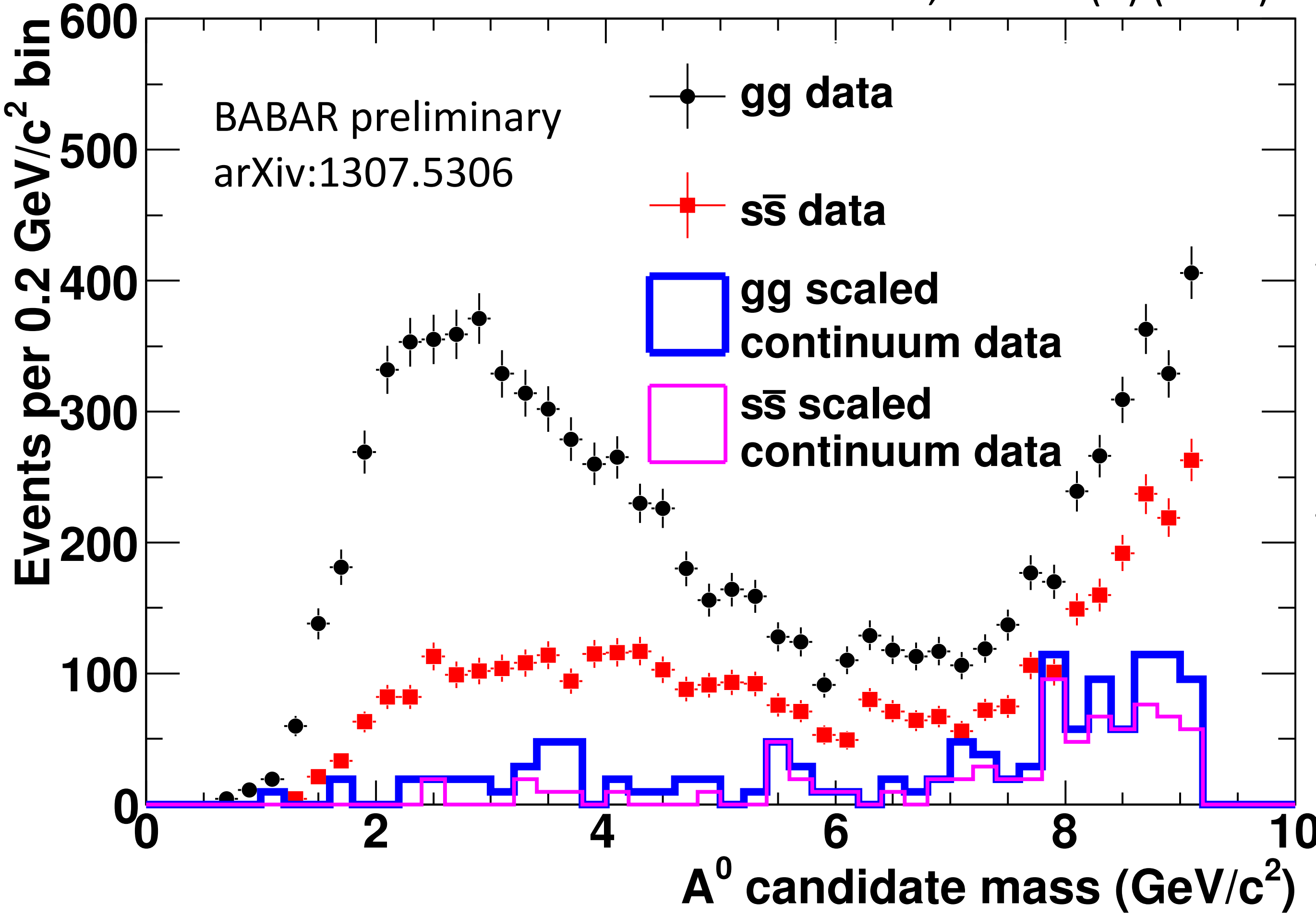
$\Upsilon(1S) \to \gamma A^0$; $A^0 \to gg$ or $s\bar{s}$

- Fully reconstruct gg using 26 channels
- Fully reconstruct $s\bar{s}$ using the subset that contains 2 or 4 kaons
- Require the hadronic system and a photon to be consistent with the mass of an $\Upsilon(1S)$

#	Channel	#	Channel
1	$\pi^+\pi^-\pi^0$	14	$K^+K^-\pi^+\pi^-$
2	$\pi^+\pi^-2\pi^0$	15	$K^+K^-\pi^+\pi^-\pi^0$
3	$2\pi^+2\pi^-$	16	$K^\pm K^0_S\pi^\mp\pi^+\pi^-$
4	$2\pi^+2\pi^-\pi^0$	17	$K^+K^-\eta$
5	$\pi^+\pi^-\eta$	18	$K^+K^-2\pi^+2\pi^-$
6	$2\pi^+2\pi^-2\pi^0$	19	$K^\pm K^0_S\pi^\mp\pi^+\pi^-2\pi^0$
7	$3\pi^+3\pi^-$	20	$K^+K^-2\pi^+2\pi^-\pi^0$
8	$2\pi^+2\pi^-\eta$	21	$K^+K^-2\pi^+2\pi^-2\pi^0$
9	$3\pi^+3\pi^-2\pi^0$	22	$K^\pm K^0_S\pi^\mp 2\pi^+2\pi^-\pi^0$
10	$4\pi^+4\pi^-$	23	$K^+K^-3\pi^+3\pi^-$
11	$K^+K^-\pi^0$	24	$2K^+2K^-$
12	$K^\pm K^0_S\pi^\mp$	25	$p\bar{p}\pi^0$
13	$K^+K^-2\pi^0$	26	$p\bar{p}\pi^+\pi^-$

$\Upsilon(1S) \rightarrow \gamma A^0$; $A^0 \rightarrow gg$ or $s\bar{s}$

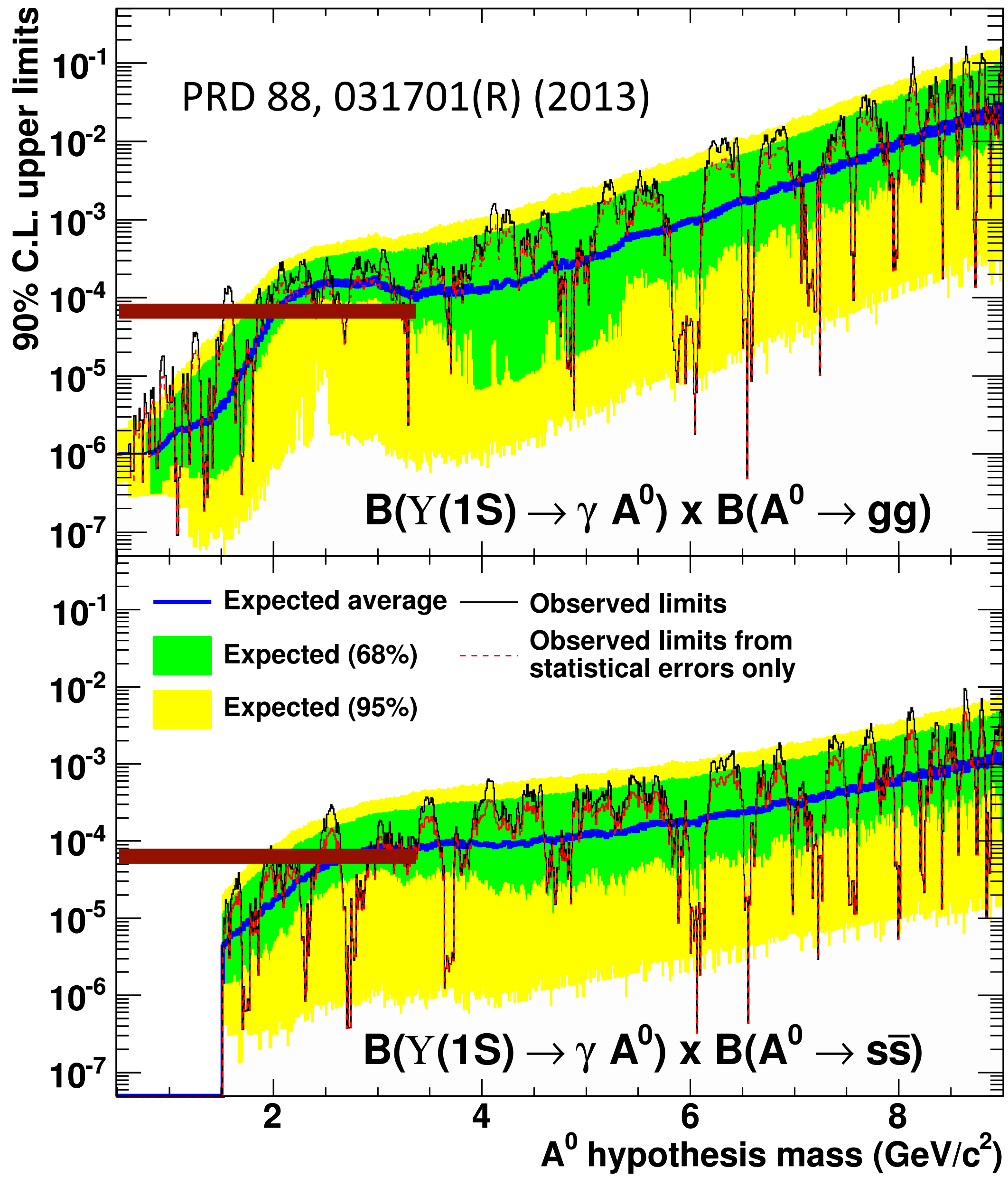
PRD 88, 031701(R) (2013)



A^0 resolution is ~100MeV/c^2

Efficiencies from a few % to 10^{-4} at masses ~9GeV/c^2

Branching Fraction Upper Limits



Our limits excludes some NMSSM parameters space for A^0 mass less than $\tau^+\tau^-$

Thick maroon line = approximate prediction

Scan in 5MeV/c^2 steps

$\Upsilon(1S) \rightarrow \gamma A^0; A^0 \rightarrow \tau^+\tau^-$

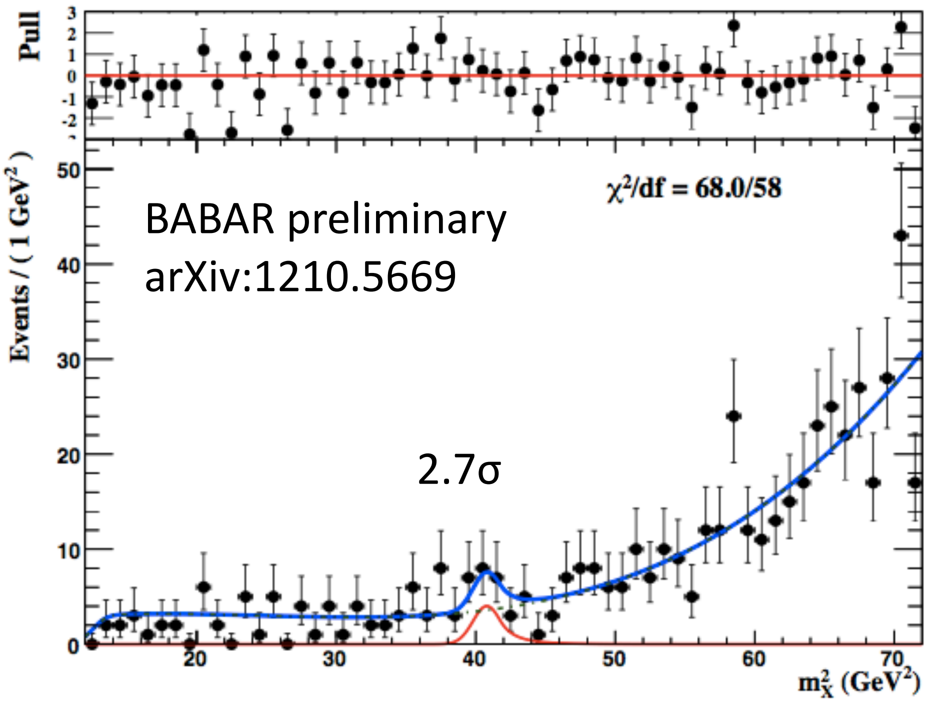
- Select tau pair events by using:
  ee, eμ, eπ, μμ, μπ
- Search for Higgs in the m_X^2 spectrum

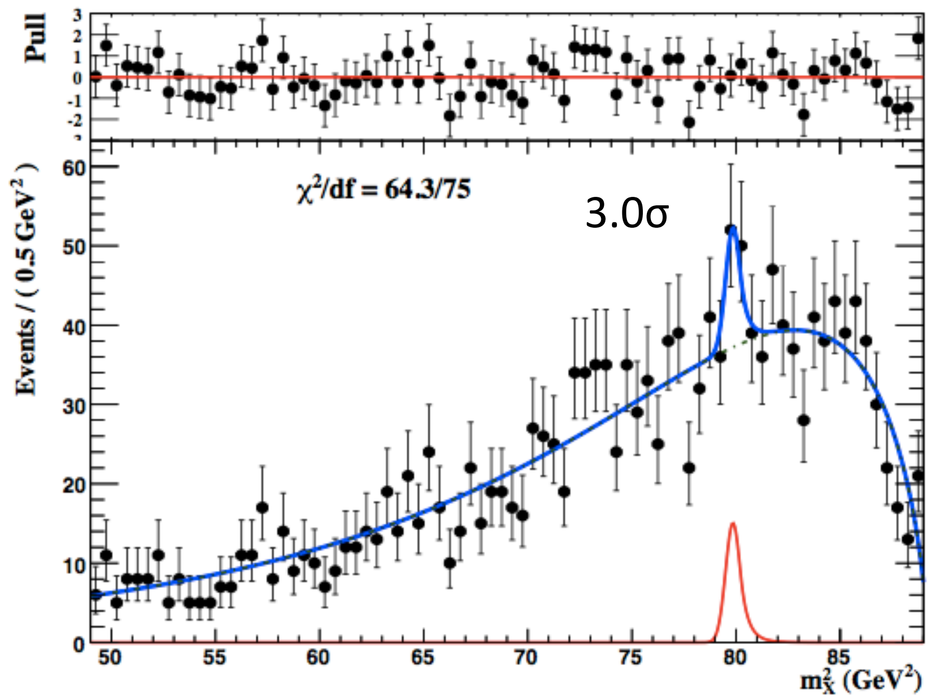
$$m_X^2 = (P_{e^+e^-} - P_{\pi\pi} - P_\gamma)^2$$

- The photon is mono-chromatic

$\Upsilon(1S) \rightarrow \gamma A^0 ; A^0 \rightarrow \tau^+\tau^-$

- Used two mass regions, so two sets of selection criteria
- Fit the largest upward fluctuation
- 7.5% of pseudo-experiments have a 3.0σ+ fluctuation of local significance





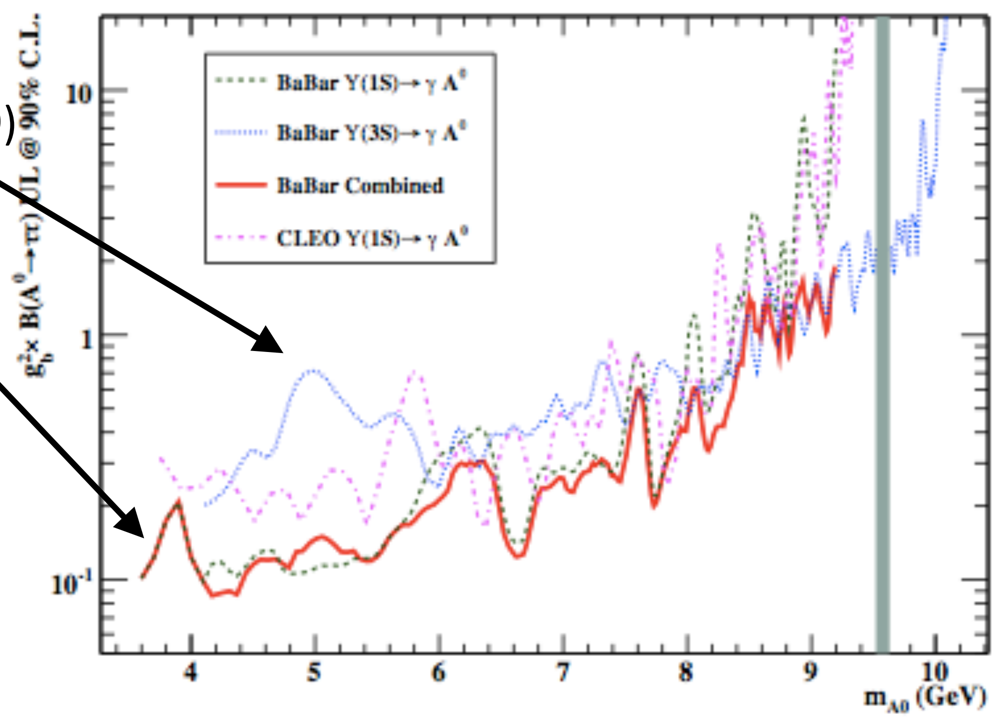
Combine with previous results on $\Upsilon(3S) \rightarrow \gamma A^0$; $A^0 \rightarrow \tau^+\tau^-$

$$\frac{\mathcal{B}(\Upsilon(nS) \rightarrow \gamma A^0)}{\mathcal{B}(\Upsilon(nS) \rightarrow l^+l^-)} = \frac{g_b^2 G_F m_b^2}{\sqrt{2}\pi\alpha} \mathcal{F}_{QCD} \left(1 - \frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right)$$

Previous result
PRL 103, 181801 (2009)

New combined result

The Υ(1S) analysis has better limits because the Υ(1S) sample has less background



g_b = Yukawa coupling

BABAR preliminary
arXiv:1210.5669

$\Upsilon(1S) \rightarrow \gamma A^0$; $A^0 \rightarrow \mu^+\mu^-$

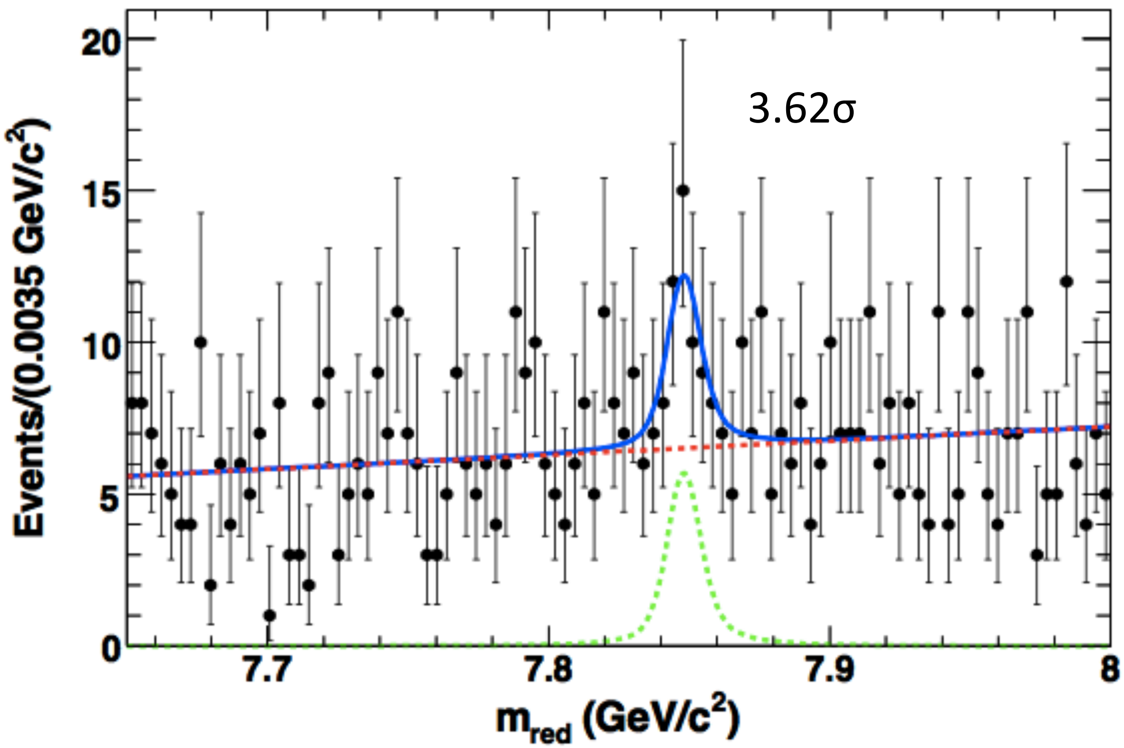
- Search for the Higgs in m_{red} spectrum

$$m_{\rm red} = \sqrt{m^2_{\mu^+\mu^-} - 4m^2_\mu}$$

- Simplifies the fitting procedure for Higgs mass close to $\mu^+\mu^-$

$\Upsilon(1S) \rightarrow \gamma A^0$; $A^0 \rightarrow \mu^+\mu^-$

- Unbinned max likelihood fit to highest upward fluctuation
- Using pseudo experiments, 18.1% probability of observing a 3.62σ+ fluctuation of local significance



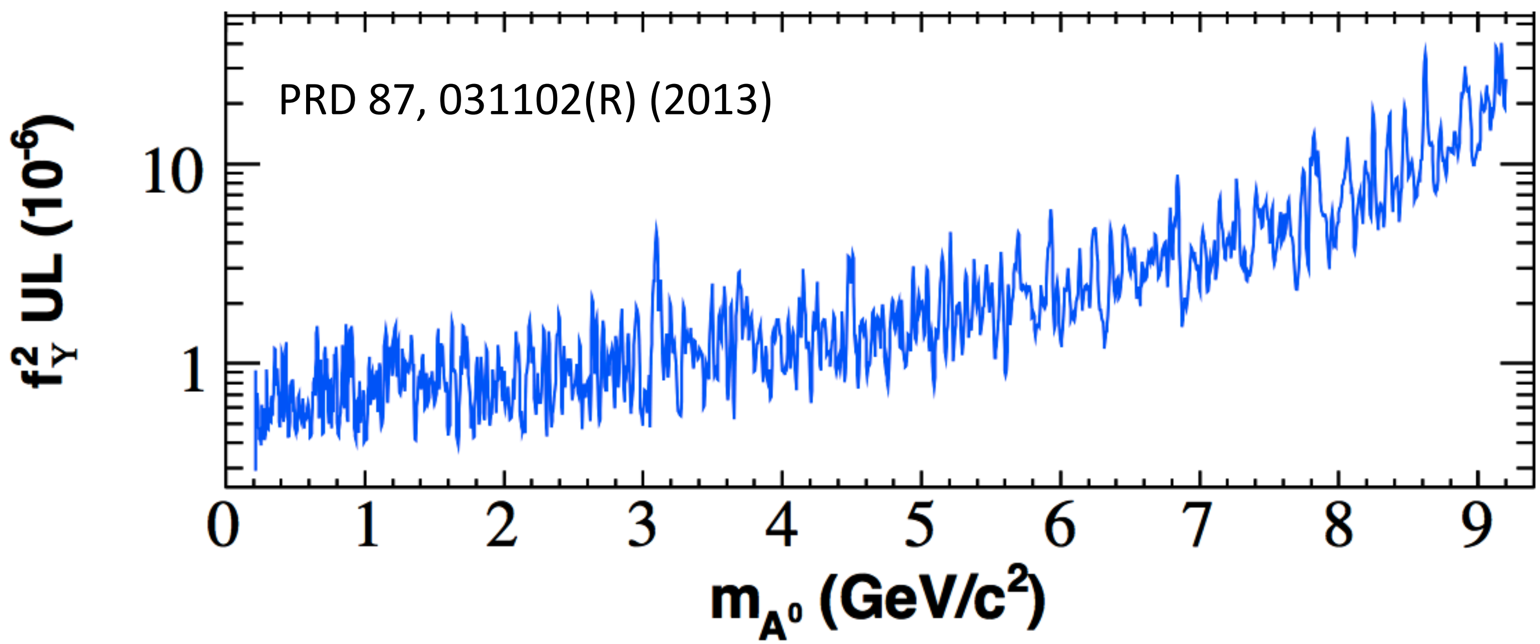
PRD 87, 031102(R) (2013)

Combine with previous results on $\Upsilon(2S,3S) \rightarrow \gamma A^0$; $A^0 \rightarrow \mu^+\mu^-$

Previous results: PRL 103, 081803 (2009)

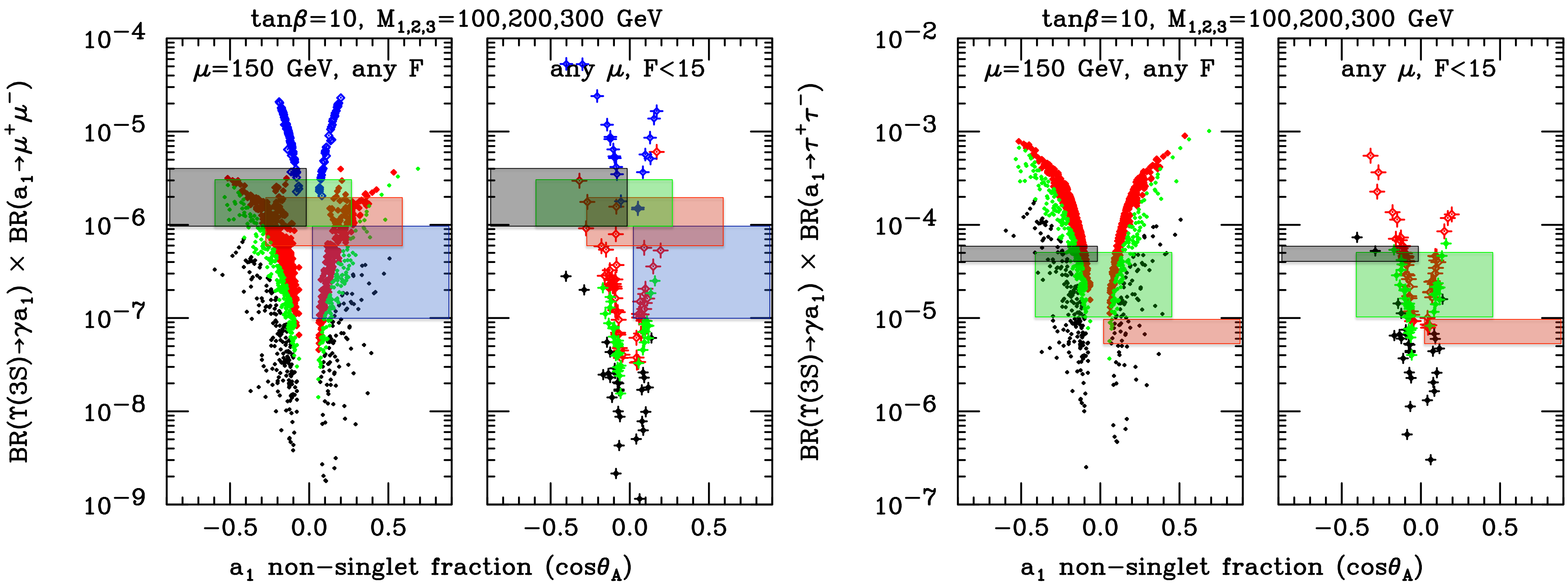
$$\frac{\mathcal{B}(\Upsilon(nS) \rightarrow \gamma A^0)}{\mathcal{B}(\Upsilon(nS) \rightarrow l^+l^-)} = \frac{f_\Upsilon^2}{2\pi\alpha}\left(1 - \frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right)$$

f_Υ = effective Yukawa coupling



Parameter space excluded by data

$\mu^+\mu^-$ PRD 81, 075003 (2010) $\tau^+\tau^-$



$$F = \max_a F_a \equiv \max_a \left| \frac{d \log m_Z}{d \log a} \right|$$

$0 < m_A < 2m_\tau$ $7.5 < m_A < 8.8\text{GeV}$

$2m_\tau < m_A < 7.5\text{GeV}$ $8.8 < m_A < 9.2\text{GeV}$

Dots = prediction at different masses

Box = range of exclusion by data at different masses

We reject the space above the boxes

(horizontal location of boxes separated for visual purposes)

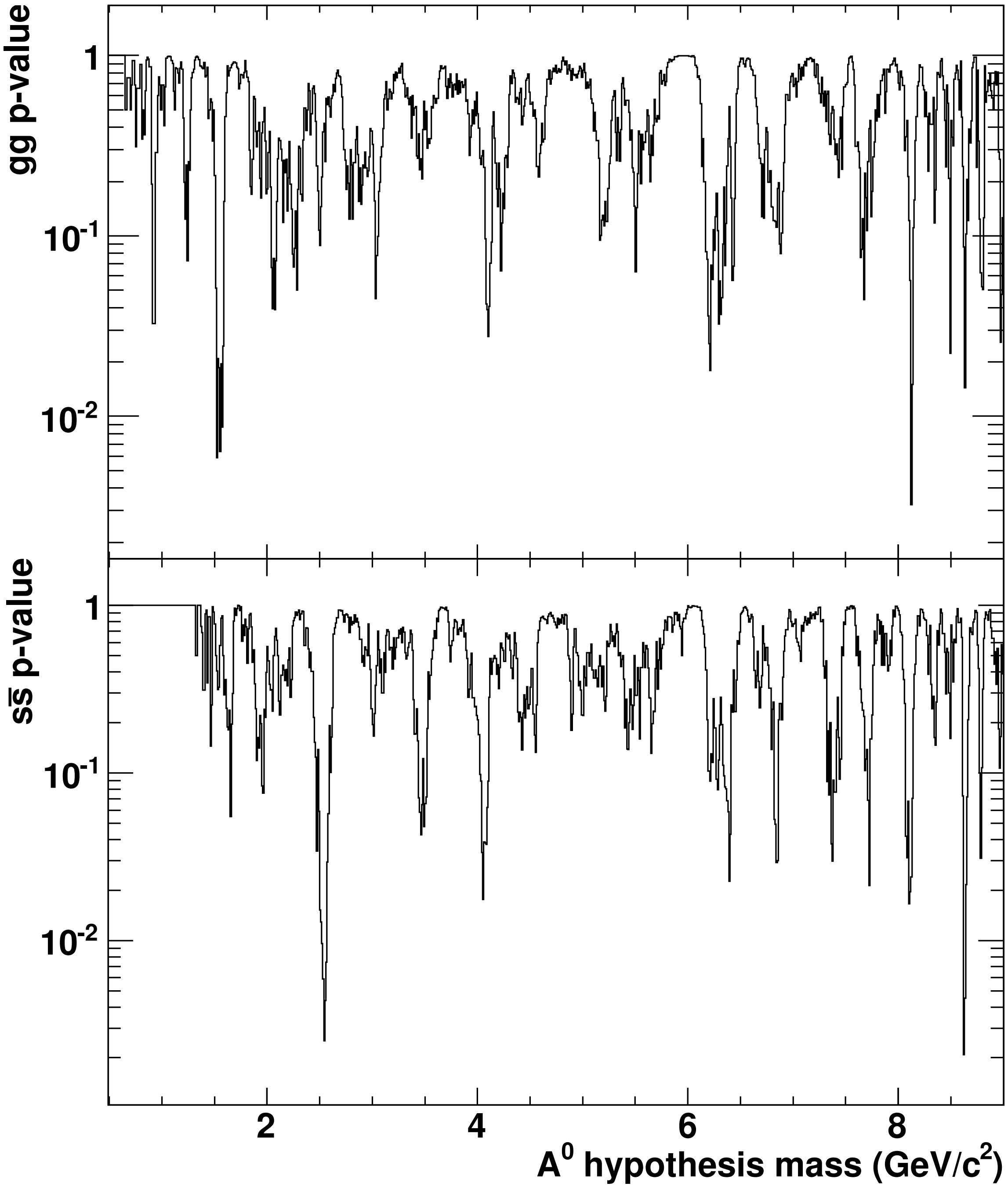
Summary and Outlook

- *BABAR* has seen no evidence for a CP-odd light Higgs boson

- We exclude some NMSSM parameter space
  - Well exclude $m_{A0} < 7.5 GeV/c^2$

- Analyses searching for A^0 decaying into $\gamma\gamma$ or $c\bar{c}$ are in progress

Extra Slide


gg p-value
1
10^{-1}
10^{-2}
s$\bar{s}$ p-value
1
10^{-1}
10^{-2}
2
4
6
8
A^0 hypothesis mass (GeV/c^2)