Searches for Light Higgs Bosons in Radiative Υ Decays at BABAR

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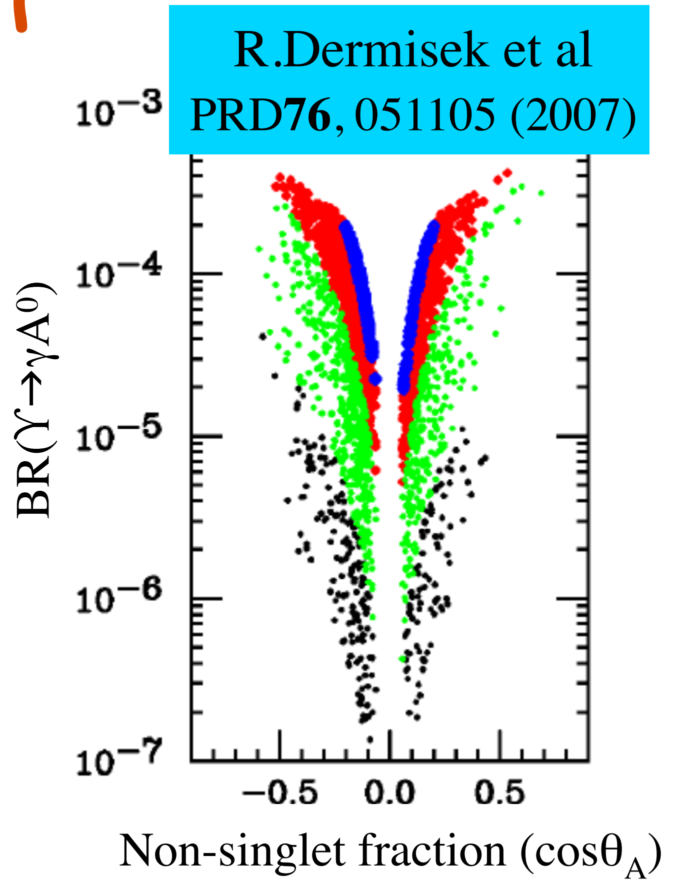
Motivation

- Higgs seems to be at hand -- but the fun is just beginning…
  - Is this a Higgs ? Or THE Higgs ?
    - ☞ Need guidance from both low and high energies
- E.g. NMSSM models with light CP-odd Higgs
  - Solve fine-tuning problems in MSSM
  - CP-odd Higgs, A^0, below $2m_b$ is not constrained by LEP
    - ☞ Observable BF for $\Upsilon\to\gamma A^0$ possible in 10^{-7}–10^{-4} range
- Accessible at B-Factories in e^+e^- annihilation or bottomonium decays



$m_{A0}<2m_\tau$

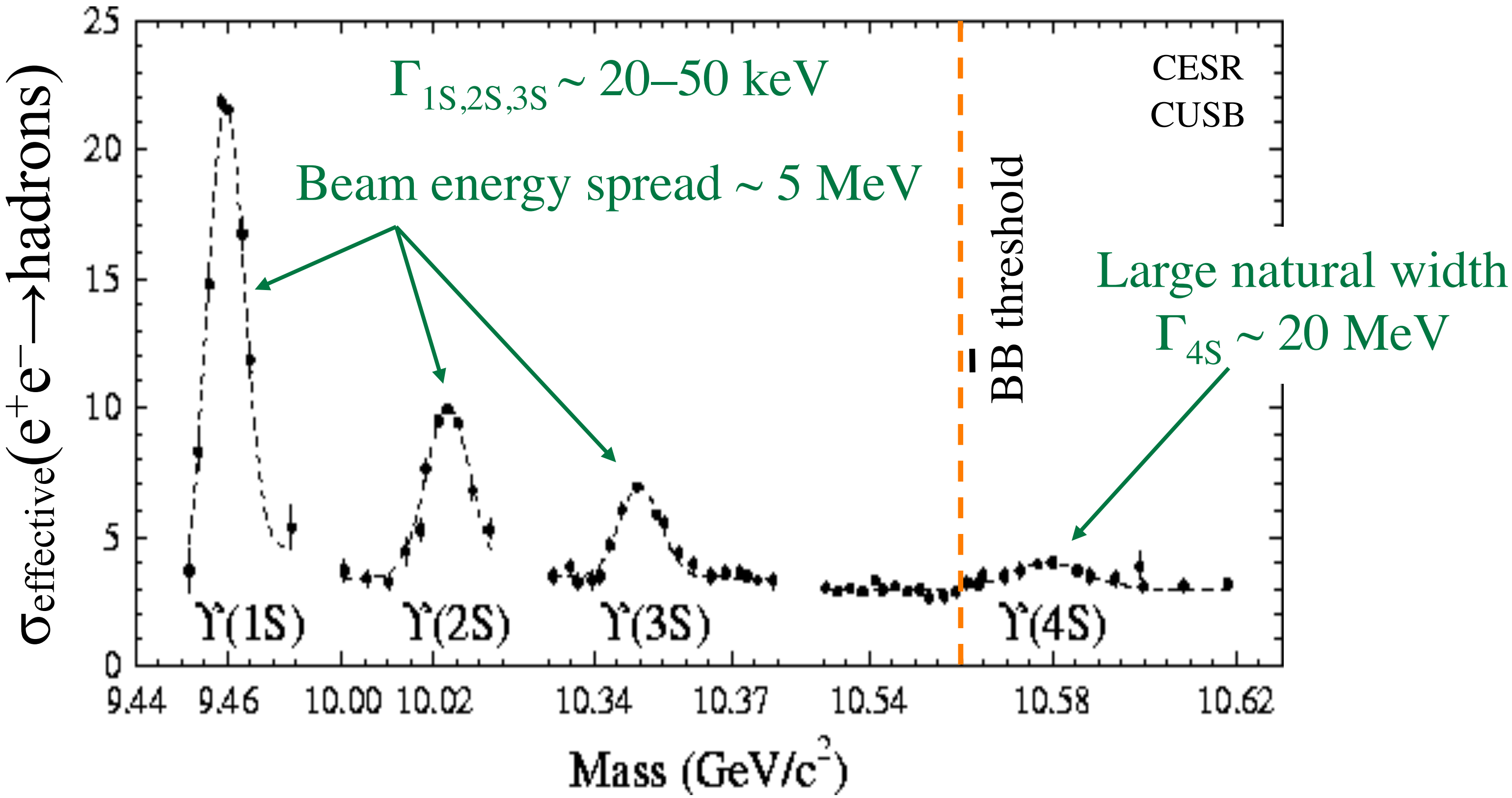
$2m_\tau<m_{A0}<7.5$ GeV

7.5 GeV$<m_{A0}<8.8$ GeV

8.8 GeV$<m_{A0}<9.2$ GeV

Upsilon Resonances

- Electron-Positron collider: $e^+e^- \to \gamma^* \to \Upsilon(nS)$

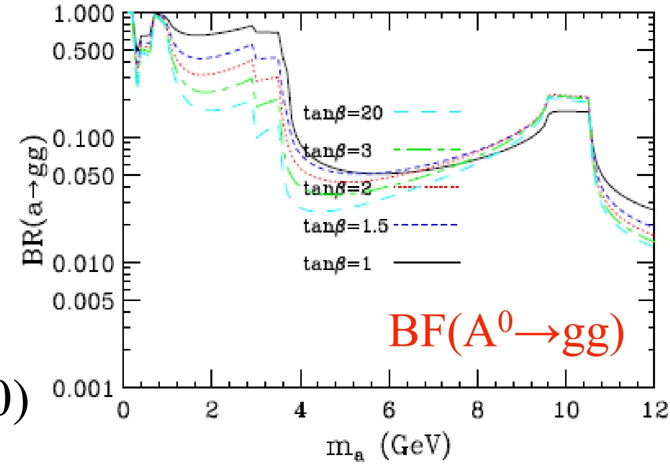


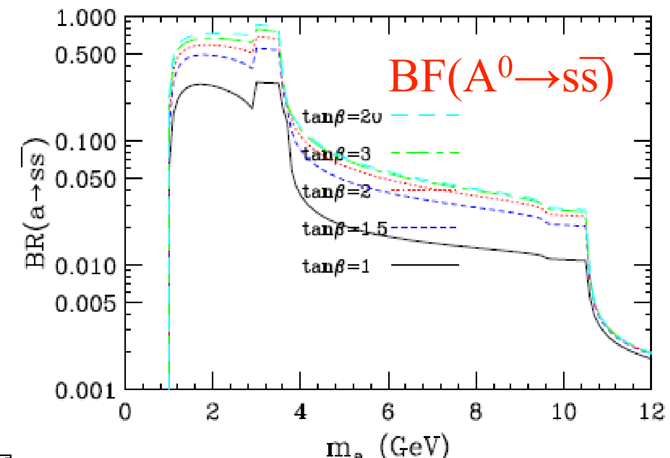
For any bottomonium process $BF_{nS}=\Gamma_{nS}/\Gamma_{tot} >> BF_{4S}$, n=1,2,3

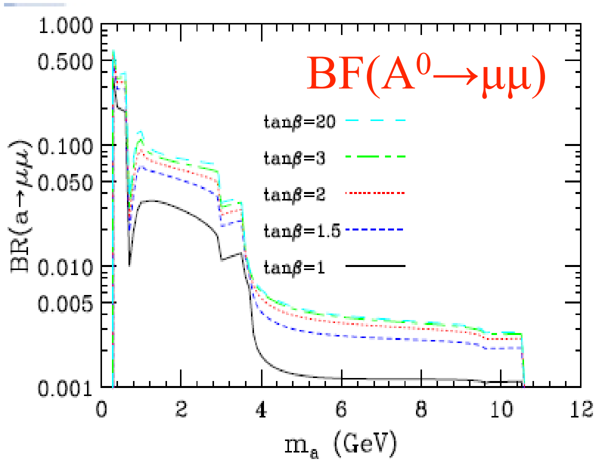
Significantly better sensitivity to direct production of light degrees of freedom @ narrow resonances

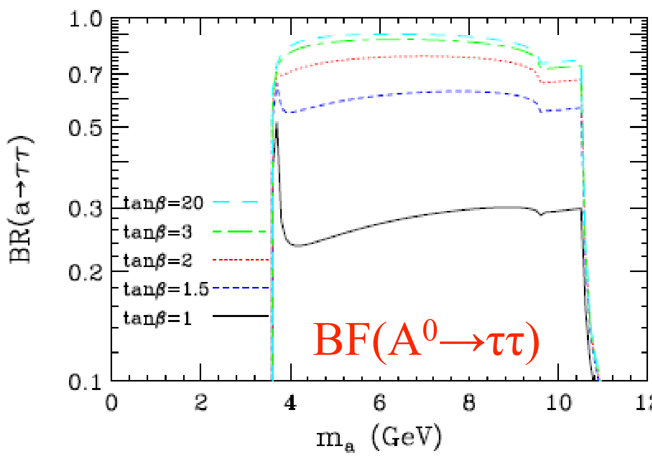
Low-Mass Higgs Decays

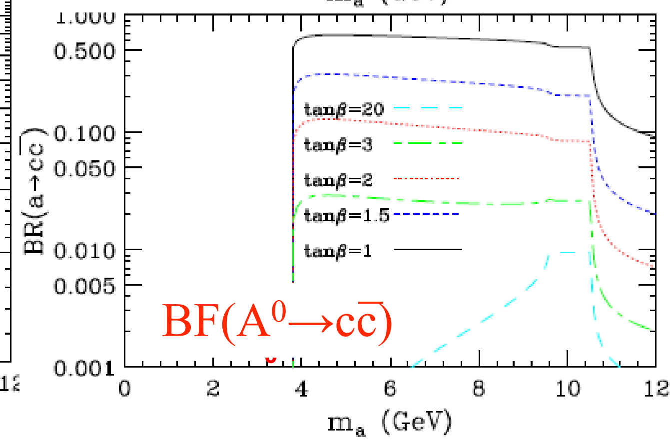
- Pattern of decays depends on A^0 mass and couplings (tanβ)
  - ☞ Dermisek & Gunion, PRD 81, 075003 (2010)
- Comprehensive search in a variety of final states
  - ❑ Leptonic and hadronic







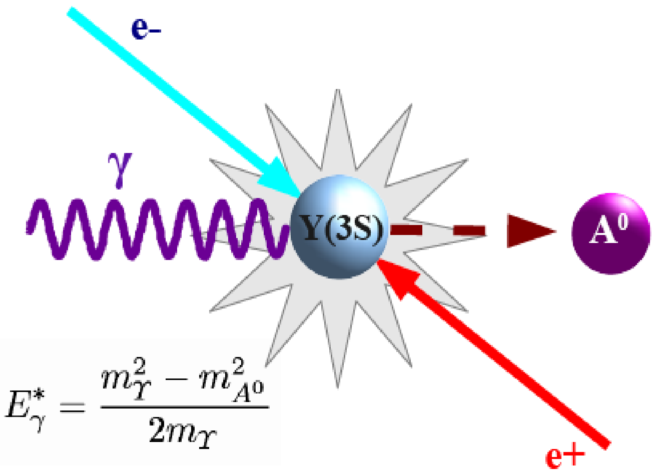




Searches for a Light Higgs in BaBar

Radiative Decays of $\Upsilon(nS)$

Signature: monochromatic photon

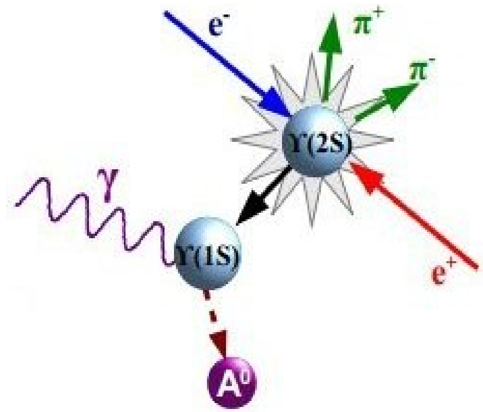


$$E^*_\gamma = \frac{m^2_\Upsilon - m^2_{A^0}}{2m_\Upsilon}$$

- ✔ $A^0 \to \mu^+\mu^-$, PRL**103**, 081803 (2009)
- ✔ $A^0 \to \tau^+\tau^-$, PRL**103**, 181801 (2009)
- ✔ $A^0 \to$ hadrons, PRL**107**, 221803 (2011) (this talk)

Additional constraints: $\Upsilon(1S)$ from $\Upsilon(2S,3S) \to \pi^+\pi^-\Upsilon(1S)$ transitions

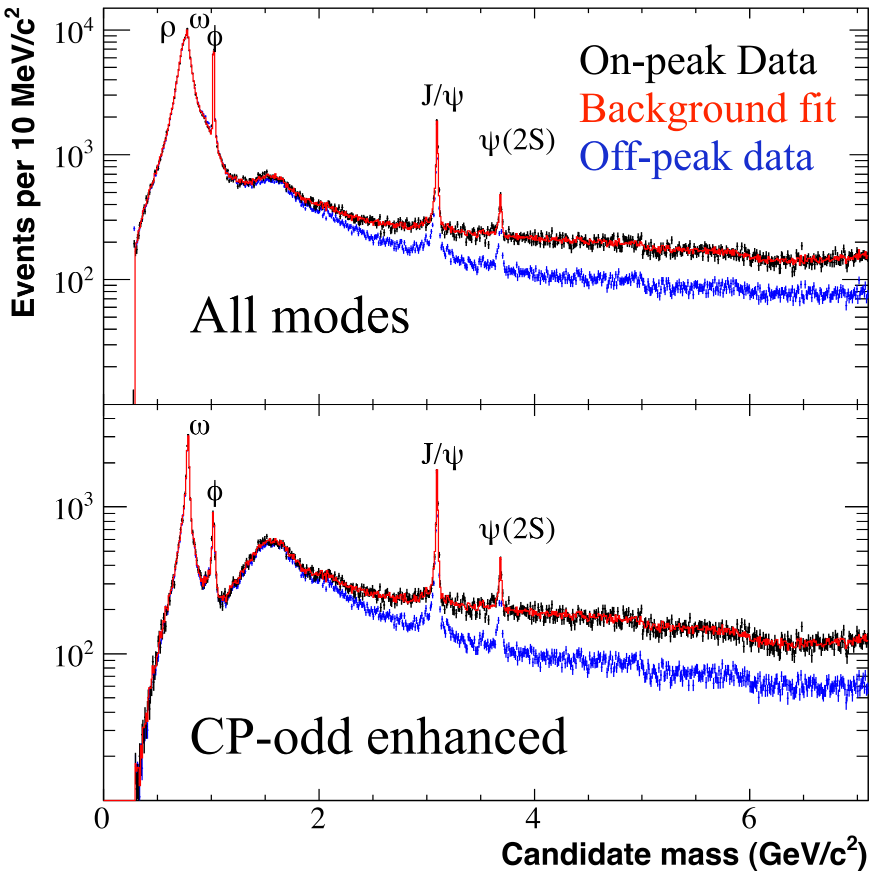
Signature: two low-momentum pions, recoiling against $\Upsilon(1S)$



- ✔ $A^0 \to \mu^+\mu^-$, NEW ! this talk
- ✔ $A^0 \to \tau^+\tau^-$, NEW ! this talk
- ✔ $A^0 \to$ invisible (light dark matter), PRL**107**, 021804 (2011)

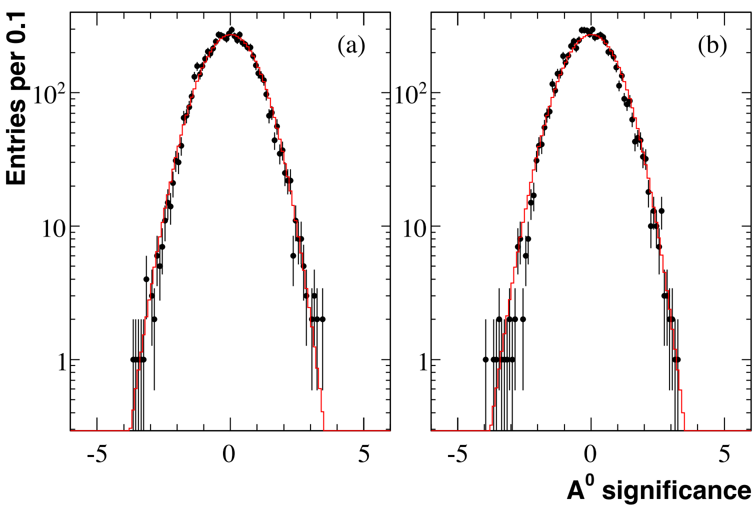
$\Upsilon(2S,3S) \to \gamma A^0$, $A^0 \to$ hadrons

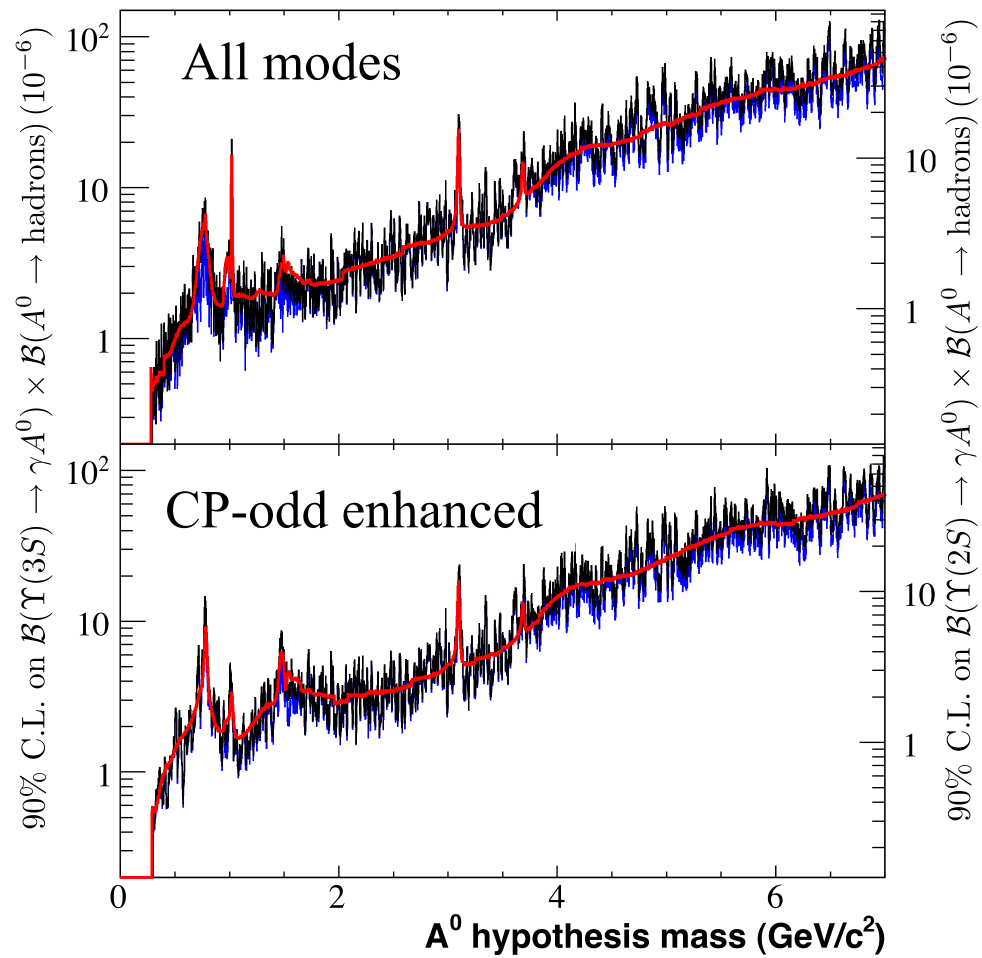
- 45 fb^{-1} collected on Υ(2S, 3S) resonances in 2008
- Fully contained final state (no missing energy)
- Beam energy constraint improves resolution
- Select: at least two hadrons and photon with $E_\gamma > 0.2$ GeV
- Fully inclusive (CP-all) and final state enhanced in CP-odd (>2 mesons)
- Look for peaks in spectrum away from known resonances



No significant peaks found: set upper limits on branching fraction as a function of A^0 mass

$\Upsilon(2S,3S)\to\gamma A^0$, $A^0\to$hadrons





Distribution of local significance consistent with null hypothesis (approximately Gaussian for 6701 points)

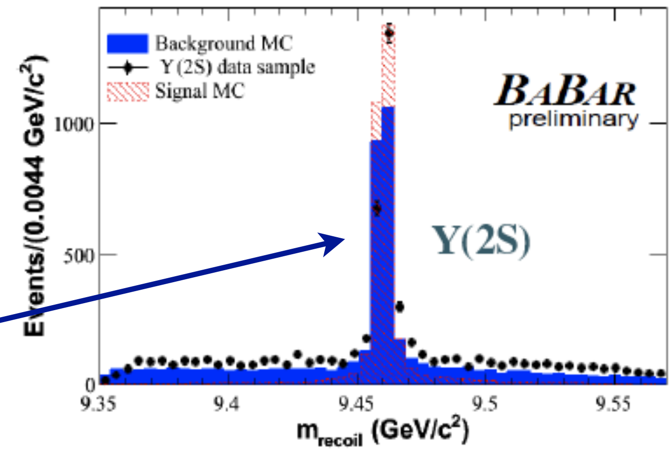
Υ(2S) and Υ(3S) data combined assuming equal couplings to A^0.

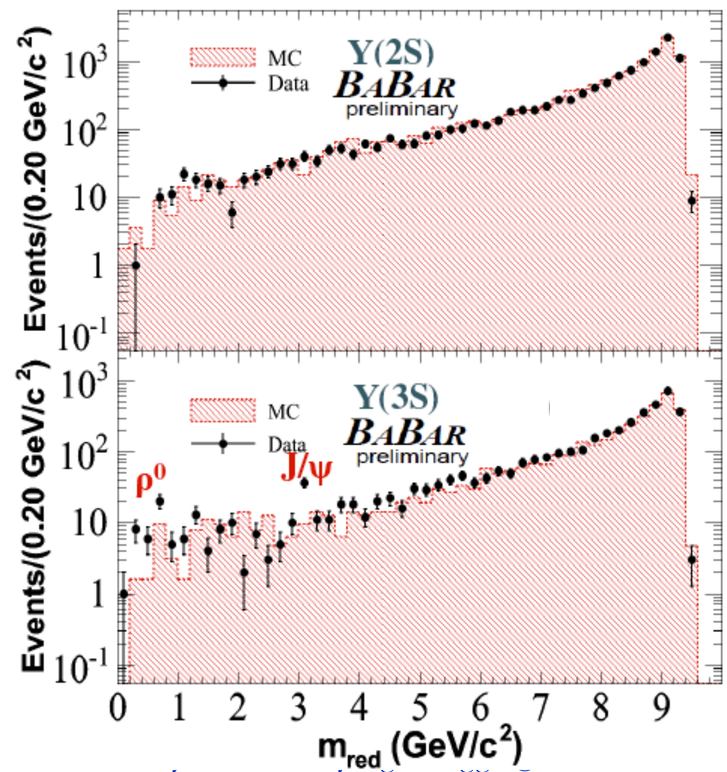
First broad-band search of this kind ! PRL **107**, 221803 (2011)

NEW!

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

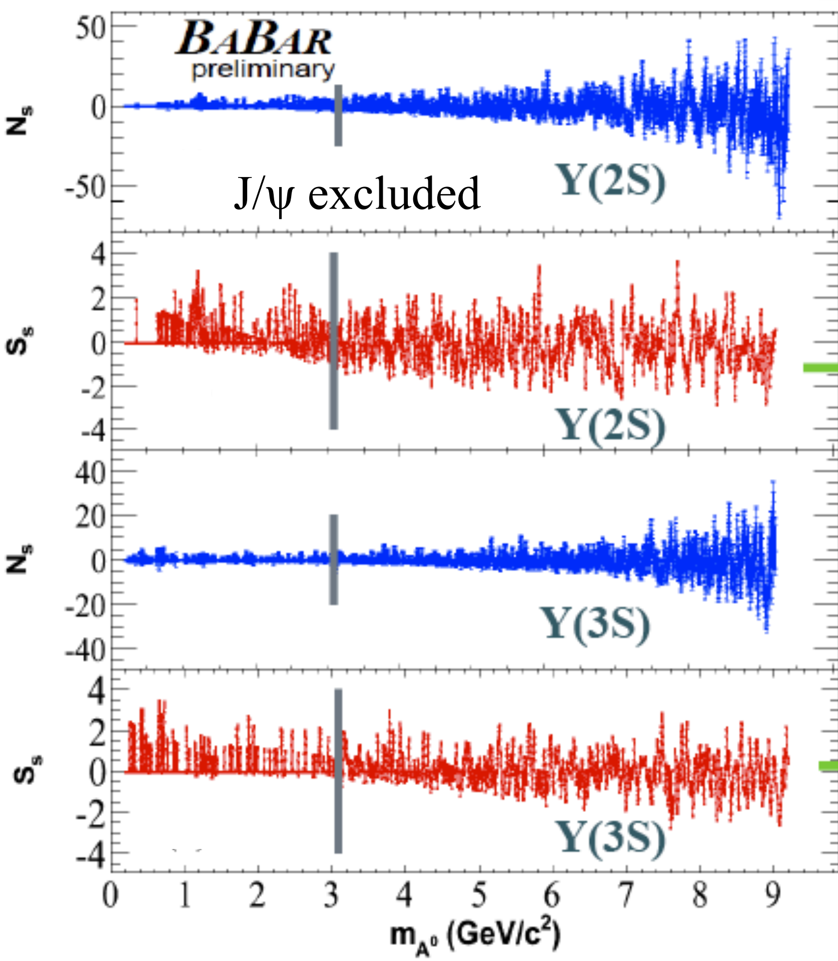
- Clean data sample with $\Upsilon(2,3S)\rightarrow\pi^+\pi^-\Upsilon(1S)$ transitions
  - ☞ 100M $\Upsilon(2S)$ and 120M $\Upsilon(3S)$ decays
- Tag $\Upsilon(1S)$ production by reconstructing mass recoiling against 2 pions
- Select events with 2 muons and photon with $E_\gamma>0.2$ GeV
- Beam energy constraint improves resolution
- Look for peaks in reduced mass spectrum $m_{\rm red} = \sqrt{m_{A^0}^2 - 4m_\mu^2}$

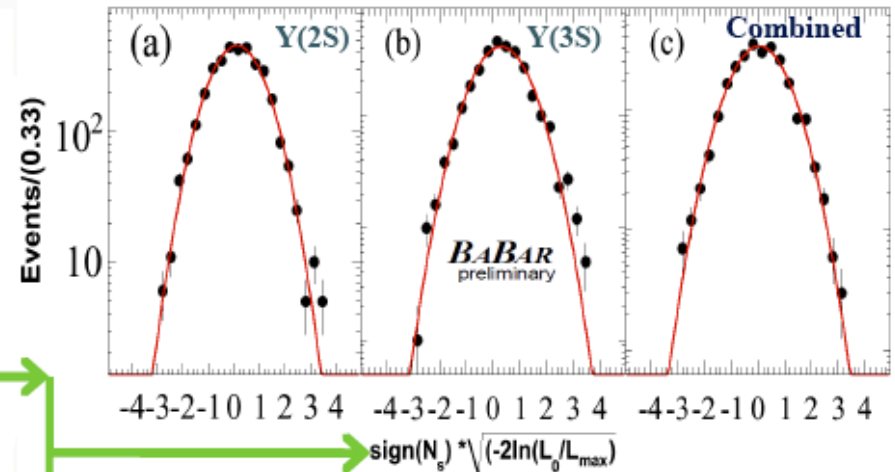




$\Upsilon(1S) \to \gamma A^0$, $A^0 \to \mu^+\mu^-$: Results

4885 ML fits in small steps of assumed A0 mass
All observed deviations consistent with background fluctuations





Significance distribution: consistent with unit-width Gaussian for 4885 trials

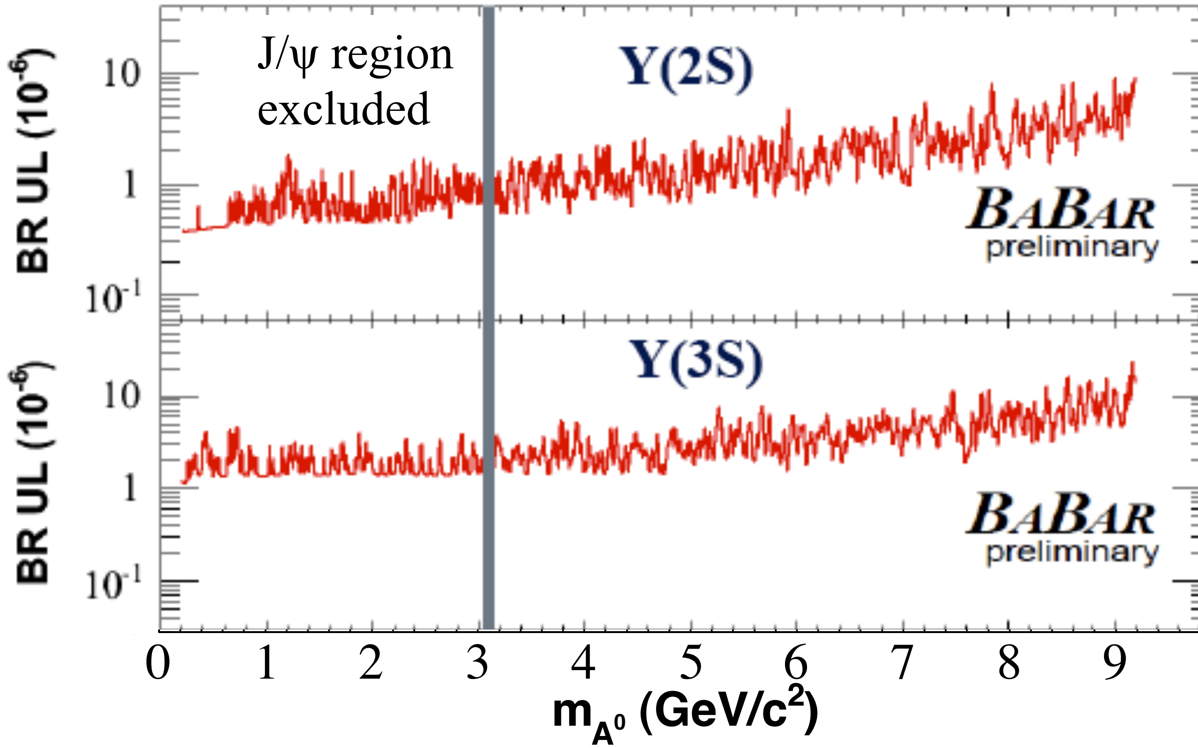
$$S = \frac{w_{\Upsilon(2S)} S_{\Upsilon(2S)} + w_{\Upsilon(3S)} S_{\Upsilon(3S)}}{\sqrt{w^2_{\Upsilon(2S)} + w^2_{\Upsilon(3S)}}}$$

$w_{\Upsilon(2S,3S)}$ is the statistical weight of Υ(2S,3S) datasets.

$\Upsilon(1S)\to\gamma A^0$, $A^0\to\mu^+\mu^-$: Results

Set 90% C.L. ULs on product $\mathcal{B}(\Upsilon(nS)\to\gamma A^0)\times\mathcal{B}(A^0\to\mu^+\mu^-)$

Some of the most sensitive constraints on CP-odd Higgs to date at low A^0 mass



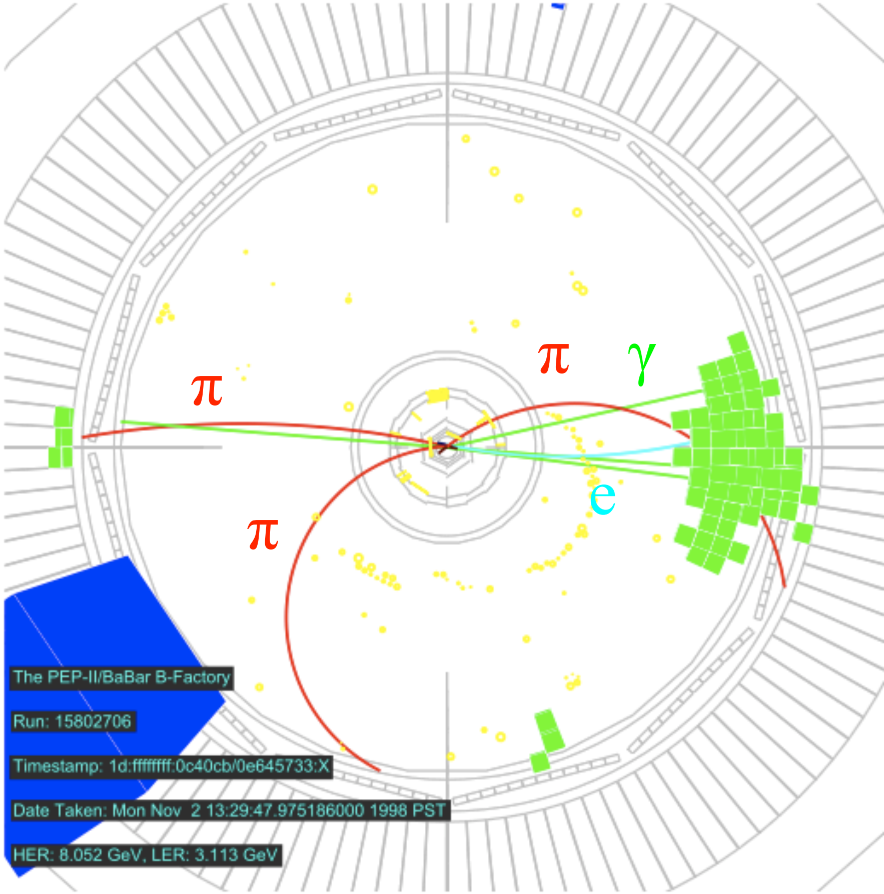
$BF(\Upsilon(1S)\to\gamma A^0)*BF(A^0\to\mu\mu) < (0.3\text{–}10)*10^{-6}$ for $0.2<m_{A0}<9.2$ GeV

Preliminary: to be submitted to PRD-RC

NEW!

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

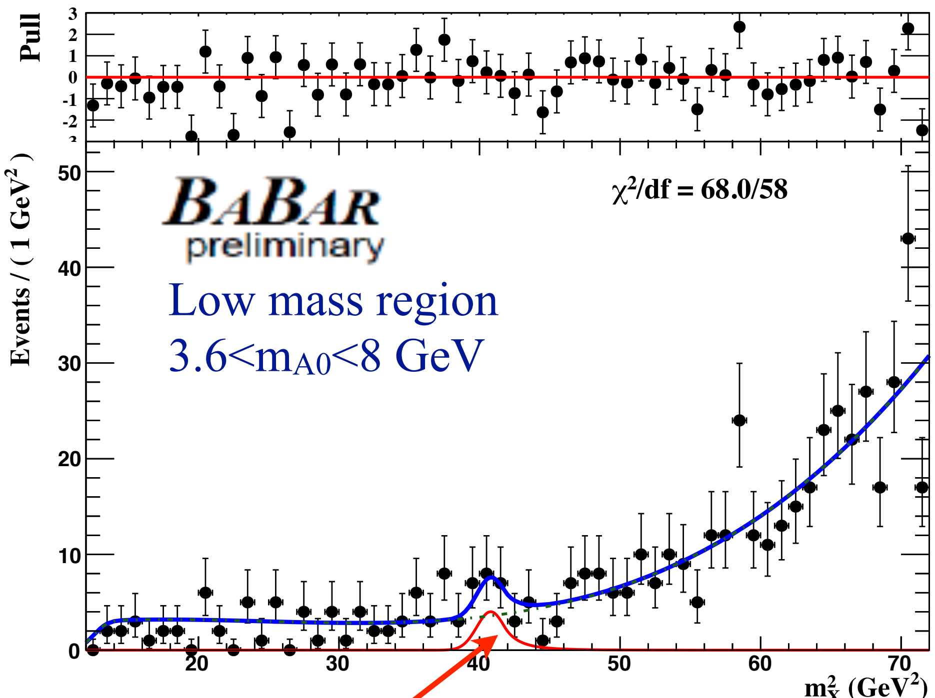
- Select clean data sample with $\Upsilon(2S)\to\pi^+\pi^-\Upsilon(1S)$ transitions
  - ☞ 100M $\Upsilon(2S)$ decays
- Look for one-prong τ decays; identify $\tau^+\tau^-$ with at least one lepton in the final state
  - ❑ 5 decay channels in total: (ee, $\mu\mu$, $e\mu$, $e\pi$, $\mu\pi$)
- Two neural net discriminants: dipion transitions and $A^0\to\tau\tau$ decays
  - ☞ Signal efficiency 1-4.5%
- Look for peaks in photon energy spectrum (mass recoiling against photon)

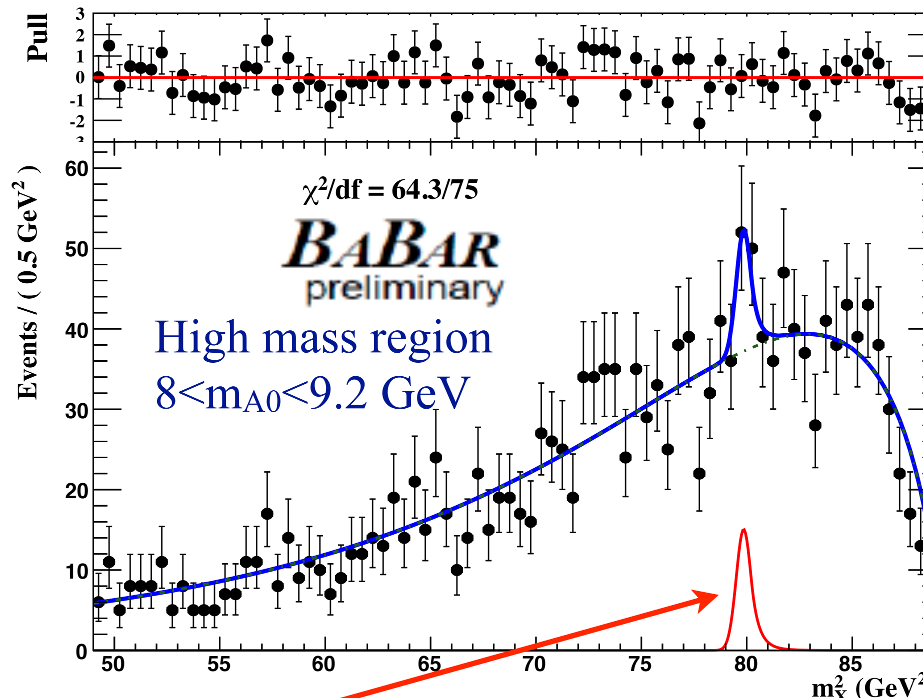


Simulated event $\Upsilon(2S)\to\pi\pi\Upsilon(1S)$, $\Upsilon(1S)\to\gamma A^0$, $A^0\to\tau\tau$, $\tau\tau\to\pi e(+3\nu)$

$\Upsilon(1S) \to \gamma A^0, A^0 \to \tau^+\tau^-$: ML Fits

ML fits to data distributions: signal peak + smooth background
Look for significant excess of signal events over background as a function of assumed A^0 mass





m_{A0}=6.36 GeV, Local significance=2.7σ

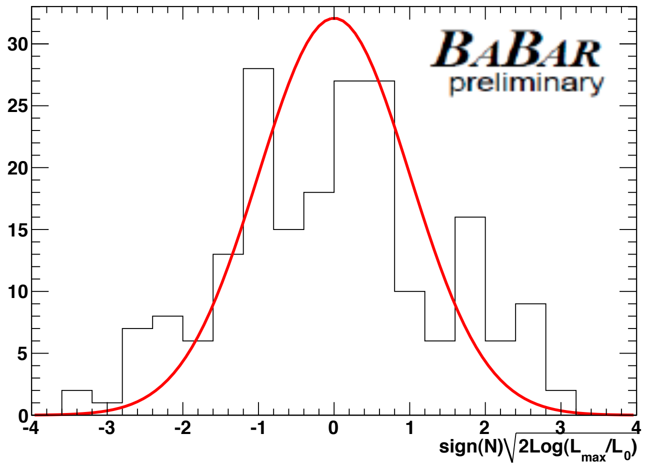
m_{A0}=8.93 GeV, Local significance=3.0σ
Global significance = 1.4σ

$\Upsilon(1S)\rightarrow\gamma A^0$, $A^0\rightarrow\tau^+\tau^-$: Results

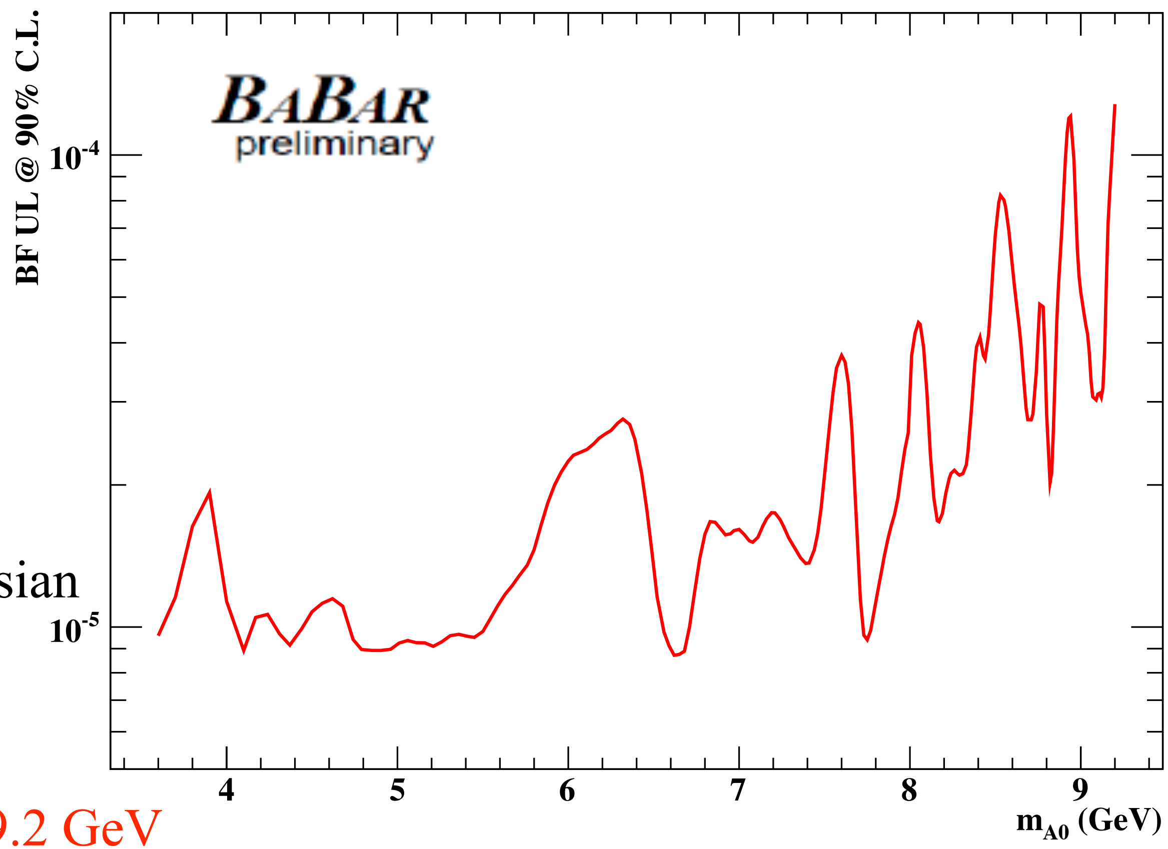
201 trials in steps of A^0 mass

All observed deviations consistent with background fluctuations

Set 90% C.L. upper limits on $\mathcal{B}(\Upsilon(1S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \tau^+\tau^-)$

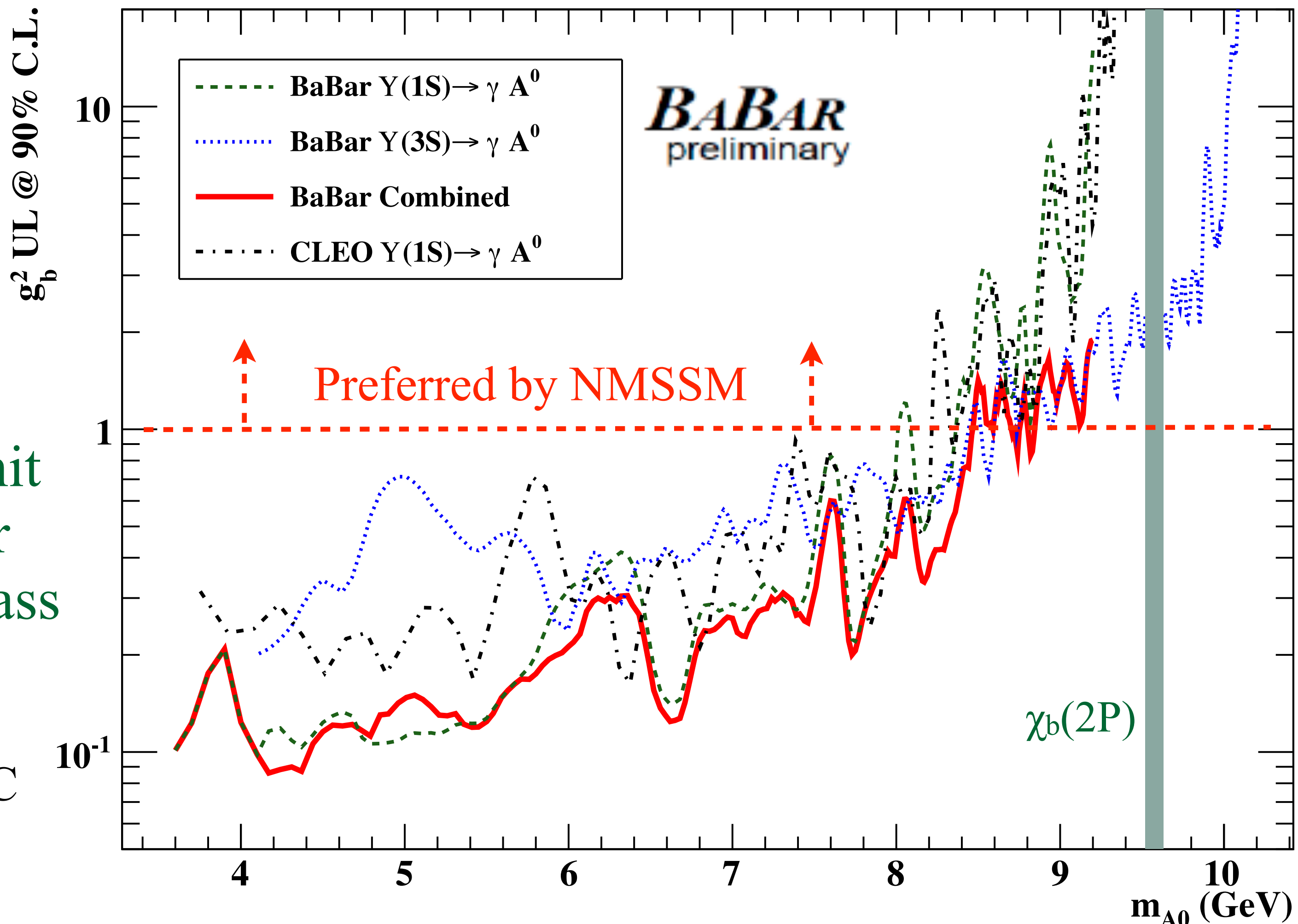


Distribution of significance consistent with unit-width Gaussian



$BF(\Upsilon(1S)\rightarrow\gamma A^0)*BF(A^0\rightarrow\tau\tau)$
$< (0.9\text{–}13)*10^{-5}$ for $3.6<m_{A0}<9.2$ GeV

$\Upsilon(nS)\to\gamma A^0$, $A^0\to\tau^+\tau^-$: Summary

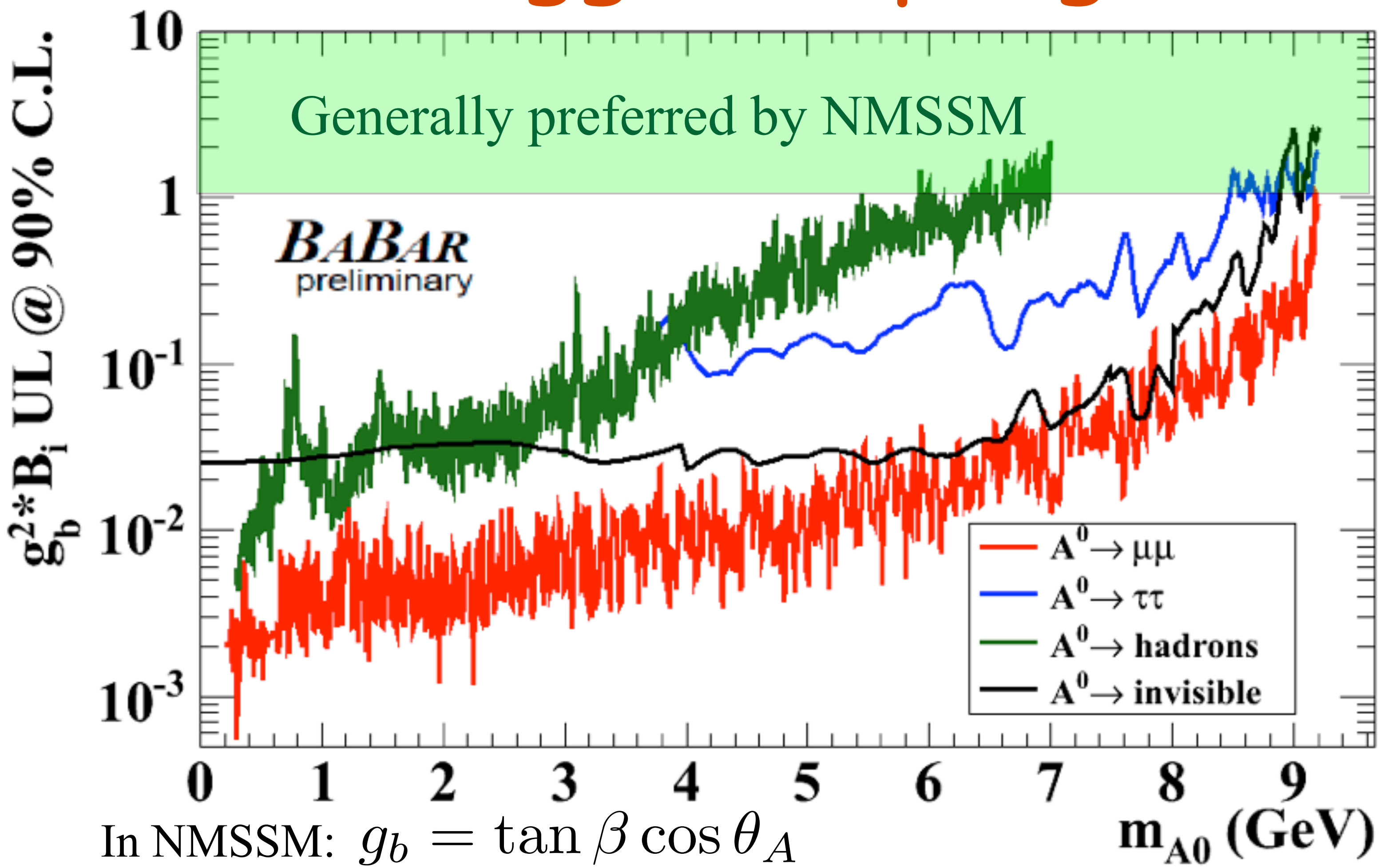


Combine results with previous BaBar search, limit A^0 couplings over broad range of mass

Preliminary: to be submitted to PRD-RC

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

BABAR Higgs Coupling Limits



In NMSSM: $g_b = \tan\beta \cos\theta_A$

Comprehensive limits on low-mass (NMSSM etc.) Higgs

Also place significant constraints on other models, e.g. axion-like states, dark photons

Summary

- B Factories continue to provide significant constraints on new physics models
  - Direct searches: unique sensitivity to low-mass new physics in high-statistics datasets
- New results on low-mass CP-odd Higgs
  - ☞ m_{A0}<9.2 GeV range
- Super B Factories will increase statistics by ~100
  - Combined with LHC discoveries, these measurements provide unique information on the dynamics and flavor structure of new physics

Backup

$\Upsilon(1S)\to\gamma A^0$, $A^0\to\mu^+\mu^-$: ML Fits

ML fits to data distributions: signal peak + smooth background
Look for significant excess of signal events over background as a function of assumed A^0 mass