Searches for low-mass Higgs and dark-sector particles at BaBar

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Representing the BaBar Collaboration

NMSSM: Next-to-Minimal Supersymmetric Standard Model

- The search continues for the Standard Model Higgs and for evidence for MSSM and other Beyond Standard Model physics
- NMSSM solves the "μ-problem" of MSSM
- The NMSSM sector has 3 CP-even, 2 CP-odd and 2 charged Higgs bosons, with the possibility that the lightest CP-odd state is light, with mass < $2m_{b,}$ not excluded by LEP data
- We present BaBar searches for such a light, CP-odd boson in radiative decays of Υ(3S,2S,1S)
- Complementary to searches at the LHC

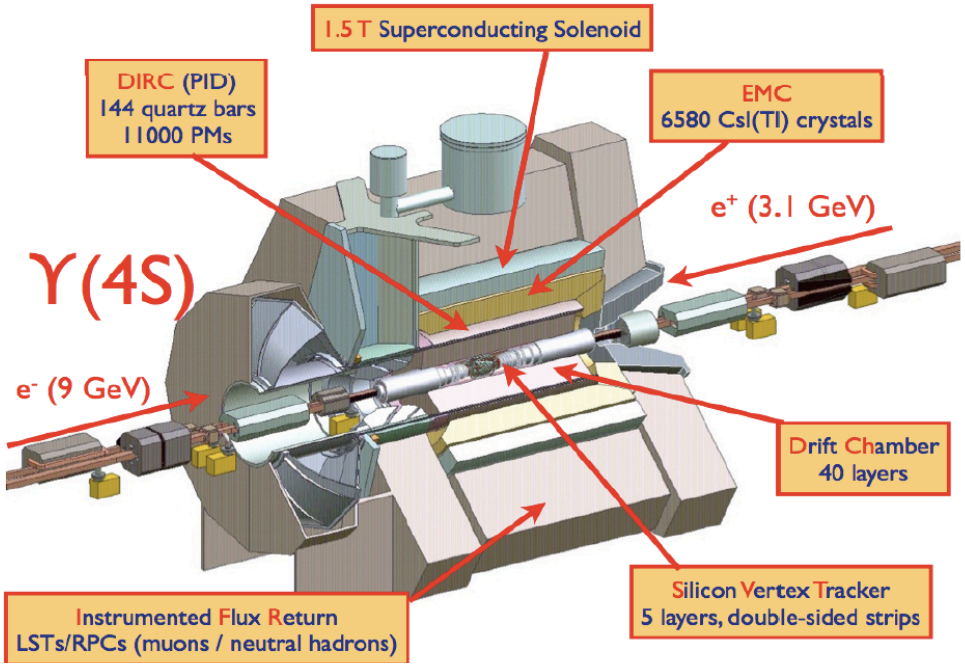
The nature of Dark Matter

- The search continues for WIMPs, as the favoured candidates for dark matter, motivated by SUSY and the proposed existence of a lightest supersymmetric particle (LSP)
- In (non-SUSY) models with hidden (dark) gauge sectors, WIMP-like dark matter particles may be charged, and can annihilate into pairs of dark photons, A', the gauge bosons of the new group. The dark photon mass is generated by a Higgs mechanism, by including a dark Higgs boson, h'
- Such models could explain observed positron excess by PAMELA, FERMI …
- Astrophysics constrains A' mass below a few GeV, and the h' mass could also be low
- The dark sector has a coupling constant α_D and mixing strength ε with SM
- We present a BaBar search for such a light, dark-sector Higgs boson and put limits on the product $\alpha_D \varepsilon^2$

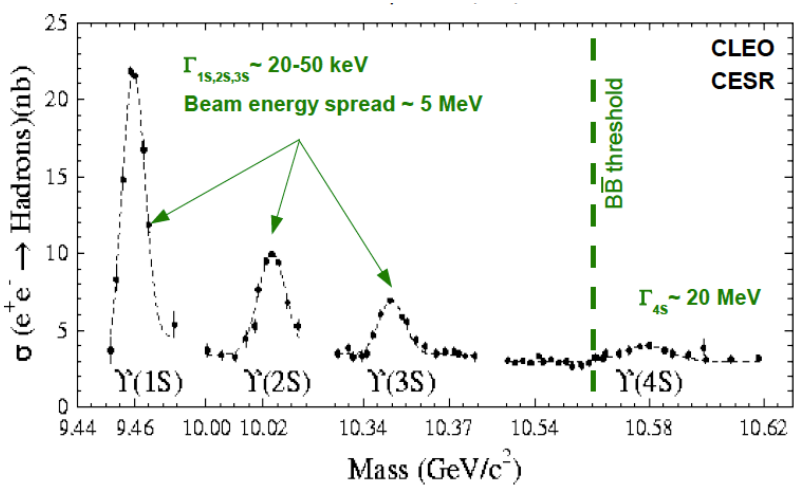
Searches by BaBar

- BaBar has made many searches for New Physics, including light Higgs bosons and dark sector particles, summarized later
- This talk covers:
  - $e^+e^- \to \Upsilon(3S,2S) \to \gamma A^0$ with $A^0 \to$ hadrons
  - $e^+e^- \to \Upsilon(3S,2S) \to \pi^+\pi^- \Upsilon(1S)$ with $\Upsilon(1S) \to \gamma A^0$ and $A^0 \to \mu^+\mu^-$
  - $e^+e^- \to A'^* \to h'A'$ with $A' \to h'h'$ and $h' \to l^+l^-$

The BaBar experiment and datasets



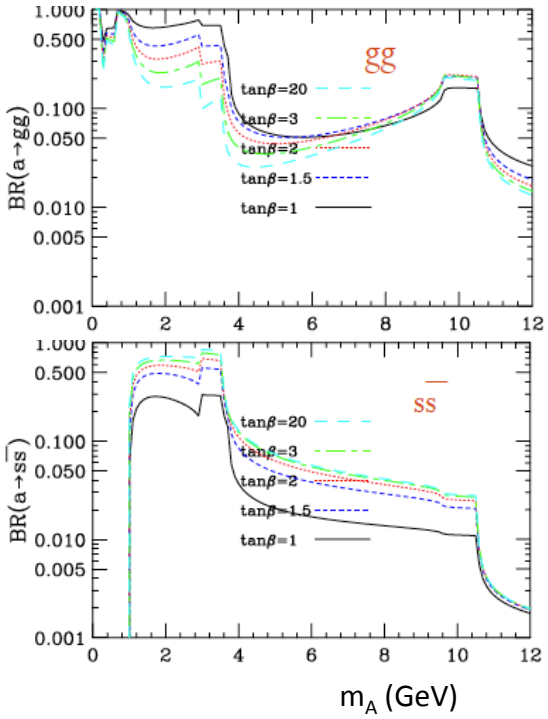
BaBar collected data at SLAC's PEPII between 1999 and 2007 at Υ(4S), and in 2008 at Υ(3S) and Υ(2S)



~470 x 10^6 Υ(4S)
~120 x 10^6 Υ(3S) (10x Belle, 25x CLEO)
~100 x 10^6 Υ(2S) (10x CLEO)
~ 23 x 10^6 Υ(1S) from Υ(3S,2S)→ $\pi^+\pi^-$ Υ(1S)

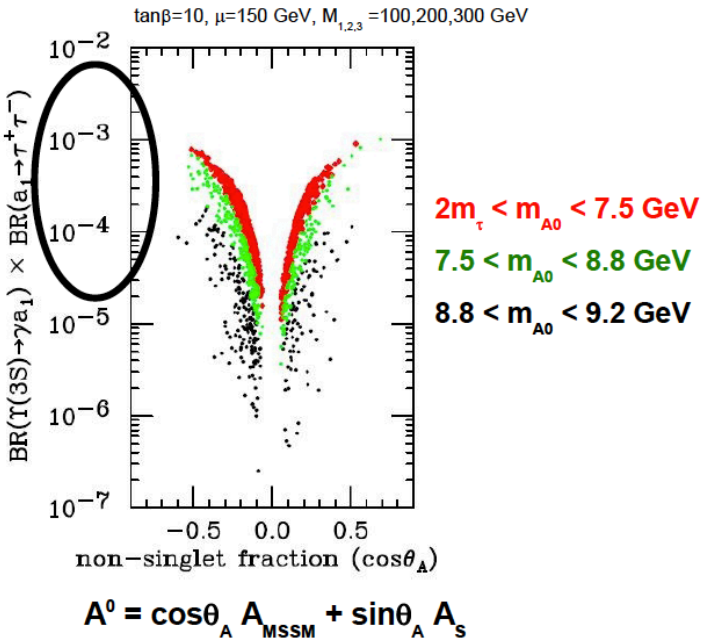
Search for a light CP-odd Higgs boson

A^0 hadronic decay BFs for various tan β



R Dermisek and J F Gunion, Phys Rev D 81, 075003 (2010)

A^0 leptonic decay product BFs



R Dermisek and J F Gunion, Phys Rev Lett 95, 041801 (2005)

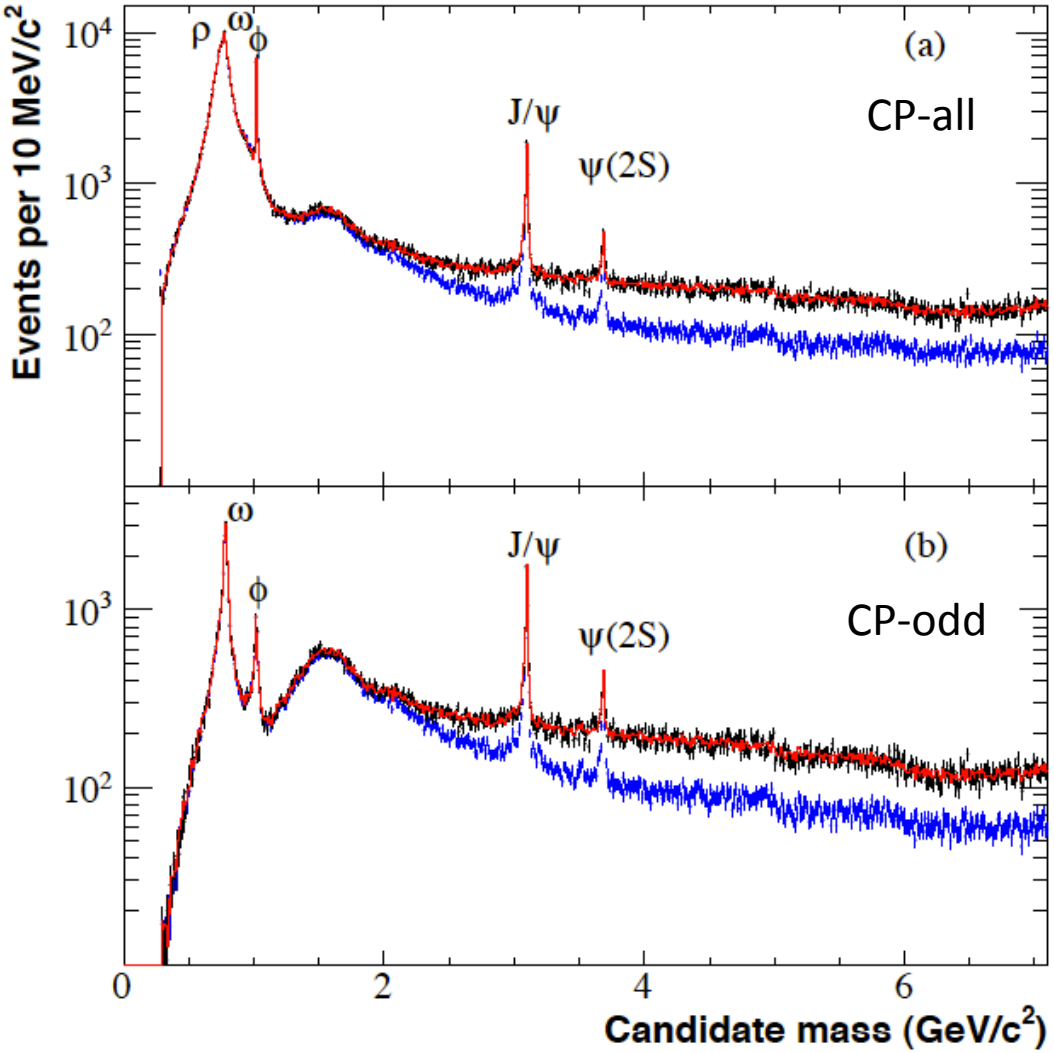
Hadronic decays of A^0 can be dominant, depending on mass and tanβ

Search for a light CP-odd Higgs boson decaying into hadrons

BaBar Collaboration, Phys Rev Lett 107, 221803 (2011)

Outline of analysis:

- Look for narrow resonances in candidate A^0 mass spectrum from fully reconstructed $\Upsilon(3S,2S) \rightarrow \gamma A^0$ candidate events
- Assume A^0 is CP-odd, or make no assumption ("CP-all" sample)
- Use particle identification and kinematics to reject $e^+e^- \rightarrow \gamma e^+e^-$ and $\gamma\mu^+\mu^-$
- Remaining backgrounds are:
  - Continuum: including resonances and non resonant $e^+e^- \rightarrow \gamma X$
  - Radiative Υ decays: including resonant and non resonant $\Upsilon \rightarrow \gamma X$
  - At high candidate A^0 mass, π^0 can fake radiated photon
- Use off-peak and on $\Upsilon(4S)$ peak data as continuum control samples
  - $\Upsilon(4S) \rightarrow B\bar{B}$ events do not pass the signal selections



Candidate mass spectra

Black points: on-peak data

Red curves: background fits

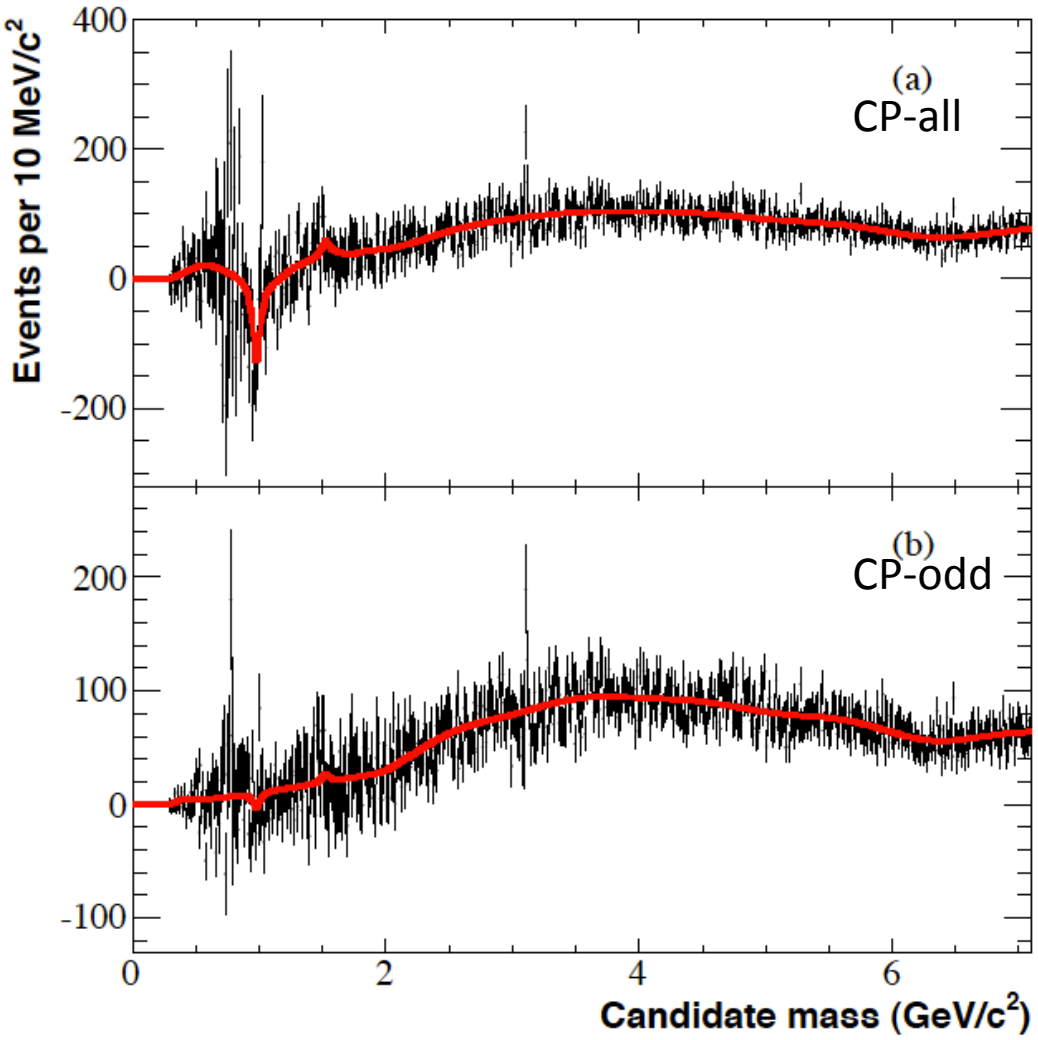
Blue points: scaled continuum data

Prominent ISR resonances seen

Higgs signal

- The Higgs "signal" at a particular mass hypothesis is the number of events in a mass window around the proposed mass minus the expected number of background events in that window

- The number of background events comes from a fit to the candidate mass distribution, with three components:
  - A continuum component with a single parameter, which is a simple scaling from the mass spectrum of the continuum data sample
  - Five light resonances seen by CLEO in $\Upsilon(1S) \rightarrow \gamma h^+h^-$
  - A smooth curve for non-resonant $\Upsilon(3S,2S) \rightarrow \gamma X$ decays



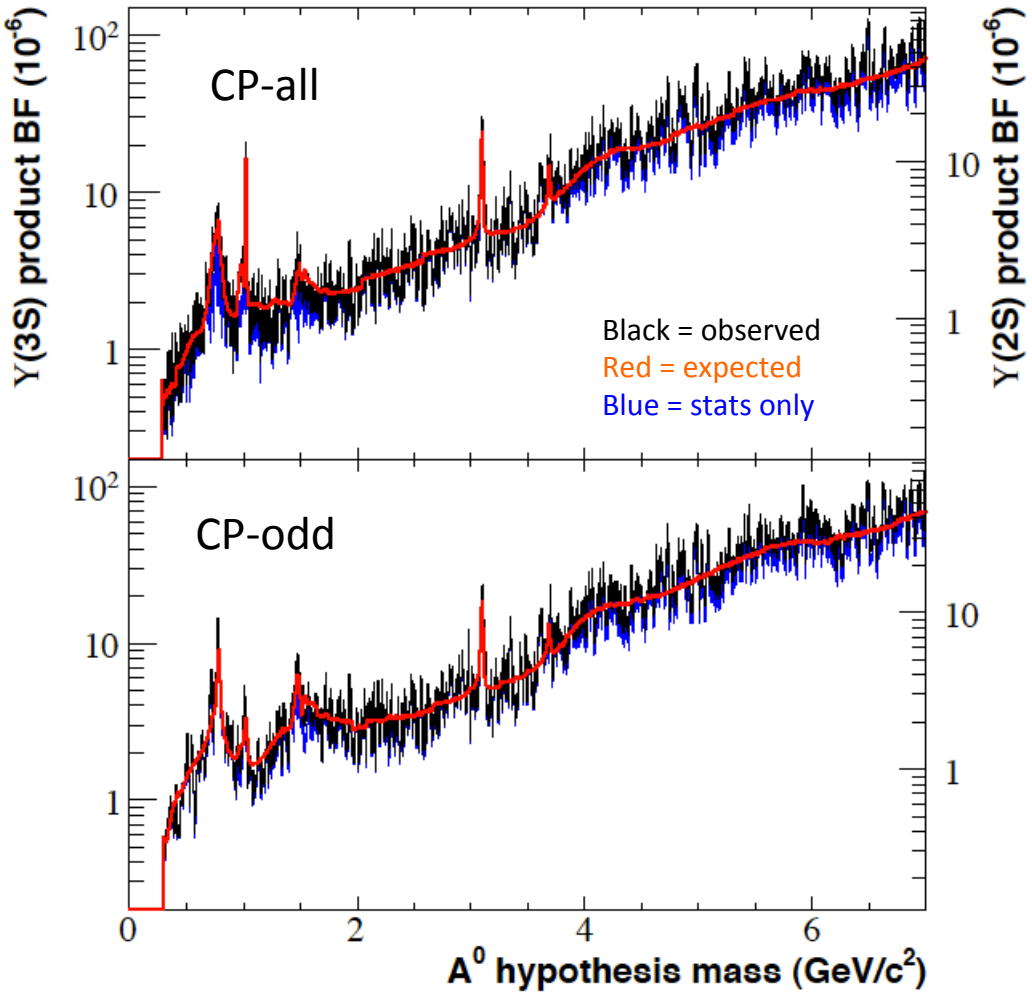
A^0 candidate mass spectra from data and fit after subtraction of normalized continuum spectrum

Systematic errors

- The main efficiency uncertainty is in the A^0 decay modes
- Uncertainties on backgrounds obtained by varying continuum scaling factor (fixed and floating) and varying the light resonances included

Most significant signals

- In CP-all, 3.5σ at mass of 3.107 GeV and 2.9σ at 1.295 GeV
  - 33% of toy Monte Carlo experiments have larger fluctuations
- In CP-odd, 3.2σ at mass of 0.772 GeV and 3.1σ at mass 4.727 GeV
  - 63% of toy Monte Carlo experiments have larger fluctuations



Upper limits at 90% CL on product branching fractions

Red curves: limits expected on basis of simulated experiments

Blue curves: limits from statistical errors only

Assume that $\Upsilon(3S)$ and $\Upsilon(2S)$ decays are described by the same matrix element

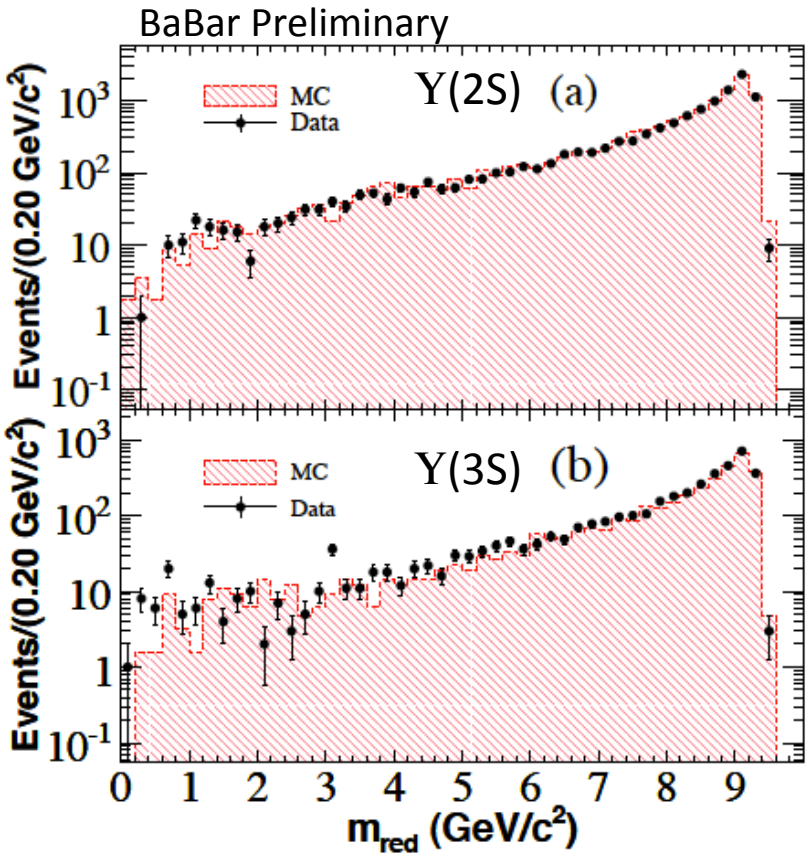
Limits on product BFs range from 10^{-6} to 8×10^{-5}

Search for a light CP-odd Higgs decaying to $\mu^+\mu^-$

BaBar Preliminary

We search for dimuon decays of A^0 via $e^+e^- \rightarrow \Upsilon(3S,2S) \rightarrow \pi^+\pi^- \Upsilon(1S)$ with $\Upsilon(1S) \rightarrow \gamma A^0$ and $A^0 \rightarrow \mu^+\mu^-$

- Analysis uses 117M Y(3S) and 93M Y(2S) events
- Reconstruct four charged tracks and a photon with at least 200 MeV in the centre-of-mass frame
- For the $A^0 \rightarrow \mu^+\mu^-$ candidate we require either track to be identified as a muon
- Entire decay chain is kinematically fitted using beam energy and particle mass constraints
- A random forest (RF) classifier is trained and optimized to suppress background, using a large number of kinematic variables
- Analysis is done blind, with 5% of the $\Upsilon(3S,2S)$ datasets used as a control sample to optimize selection criteria and check agreement between data and Monte Carlo

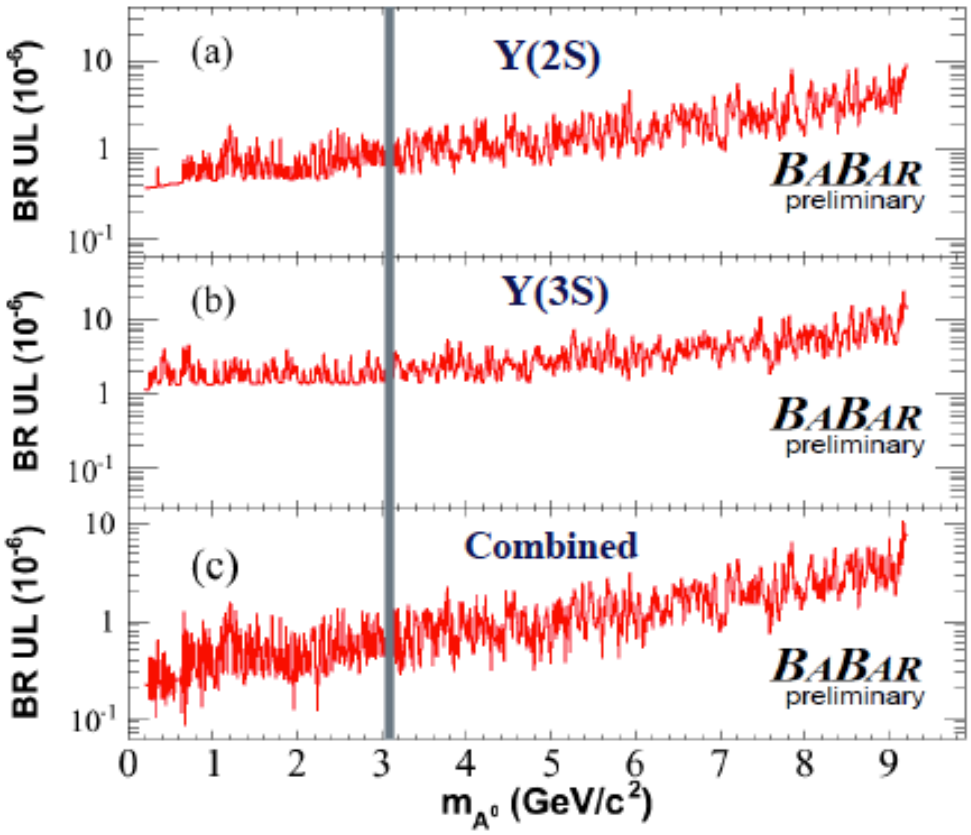


Reduced dimuon mass in the final data sample ($m_{red}^2 = m_{\mu\mu}^2 - 4m_\mu^2$)

Background is dominantly from $\Upsilon(3S,2S) \rightarrow \pi^+\pi^- \Upsilon(1S)$ with $\Upsilon(1S) \rightarrow \gamma\mu^+\mu^-$

$\Upsilon(3S)$ data has a peak at J/ψ but none in $\Upsilon(2S)$ data

Generally, no evidence for any signal, and good agreement with Monte Carlo



Upper limits set at 90% CL on product branching fractions

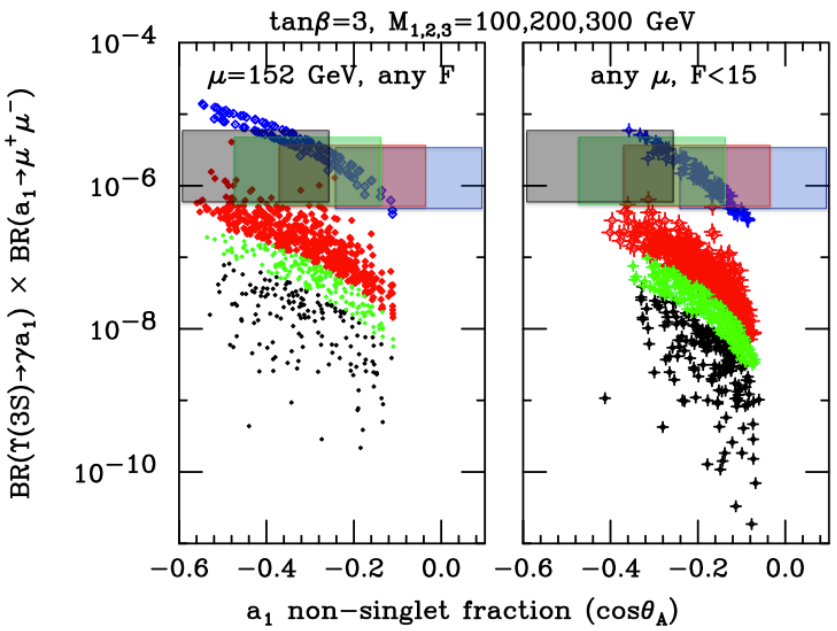
Limits on product BFs

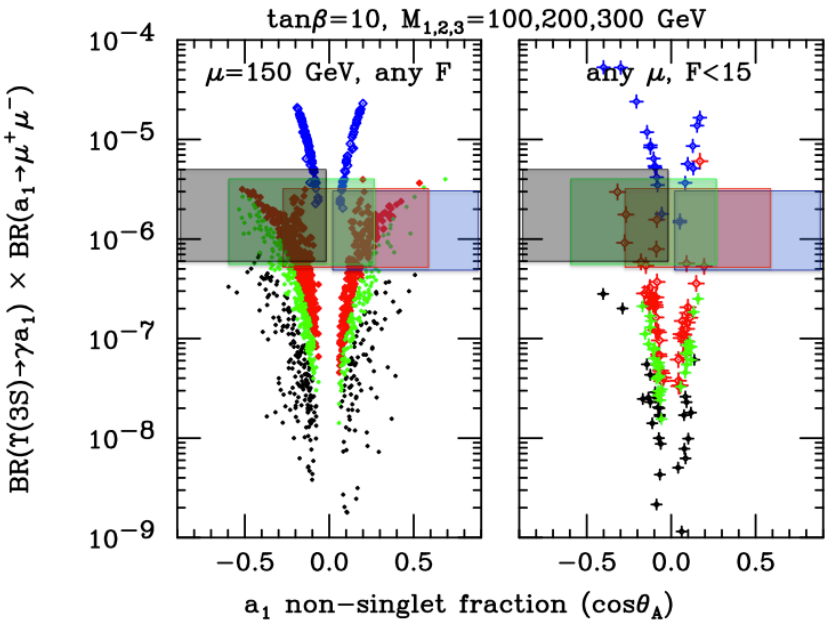
BF(Υ(1S) → γA^0) x BF(A^0 → $\mu^+\mu^-$)

in range (0.22 - 10.38) x 10^{-6}
for A^0 mass (0.2 – 9.2) GeV

Some exclusions based on the BaBar results

BF calculations (points) from R. Dermisek and J. F. Gunion, Phys. Rev. D 81, 075003 (2010)





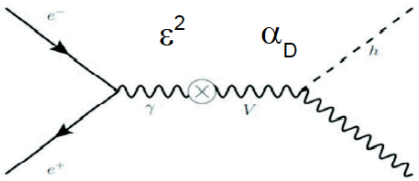
Blue: $0 < m_A < 3.6$ GeV
Red: $3.6 < m_A < 7.5$ GeV
Green: $7.5 < m_A < 8.8$ GeV
Black: $8.8 < m_A < 9.2$ GeV

Boxes: BaBar maximum to minimum exclusions (we exclude the regions above the boxes)

Search for low-mass dark-sector particles

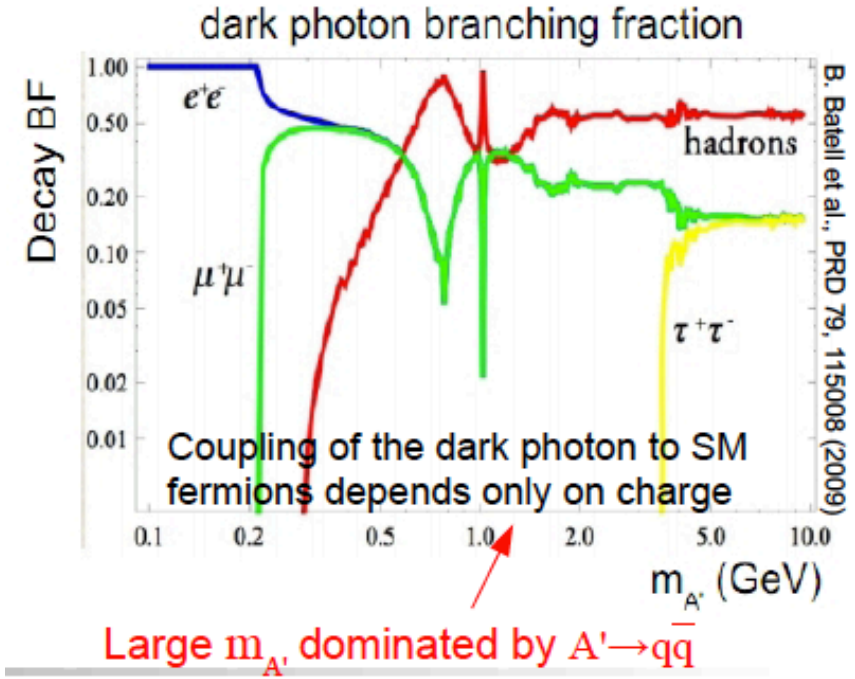
BaBar Collaboration, Phys Rev Lett 108, 211801 (2012)

We search for the "Higgs-strahlung" process
$e^+e^- \to A'^* \to h'A'$ with $h' \to A'A'$
(with $m_{h'} > 2m_{A'}$)



Event selections:

- Uses full BaBar dataset of 516fb^{-1}
- Full reconstruction of all 3 dark photons in $A' \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-$ (using PID)
  - Requires 6 tracks with mass >0.95√s
- Partial reconstruction with 2 A' decays via lepton pairs and the other reconstructed by kinematic constraints
  - Requires 4 or more tracks
- Require the 3 A' candidates to have similar masses



Results:

The search covers h′ mass from 0.8 to 10 GeV with A′ mass range 0.25 to 3 GeV

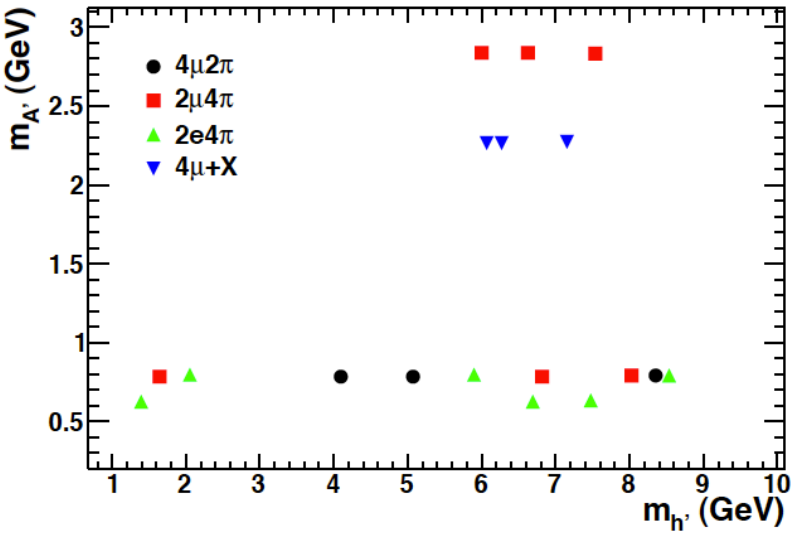
We see 6 events in the data (each candidate has 3 entries for the possible $h' \to A'A'$ assignments)

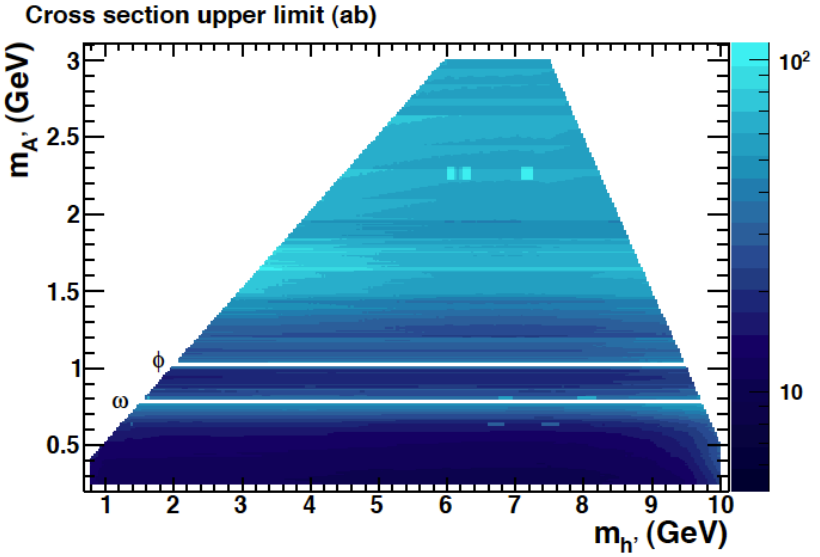
No candidates in the 6-lepton search

4 candidates consistent with $e^+e^- \to e^+e^-\rho\rho$ or 6π

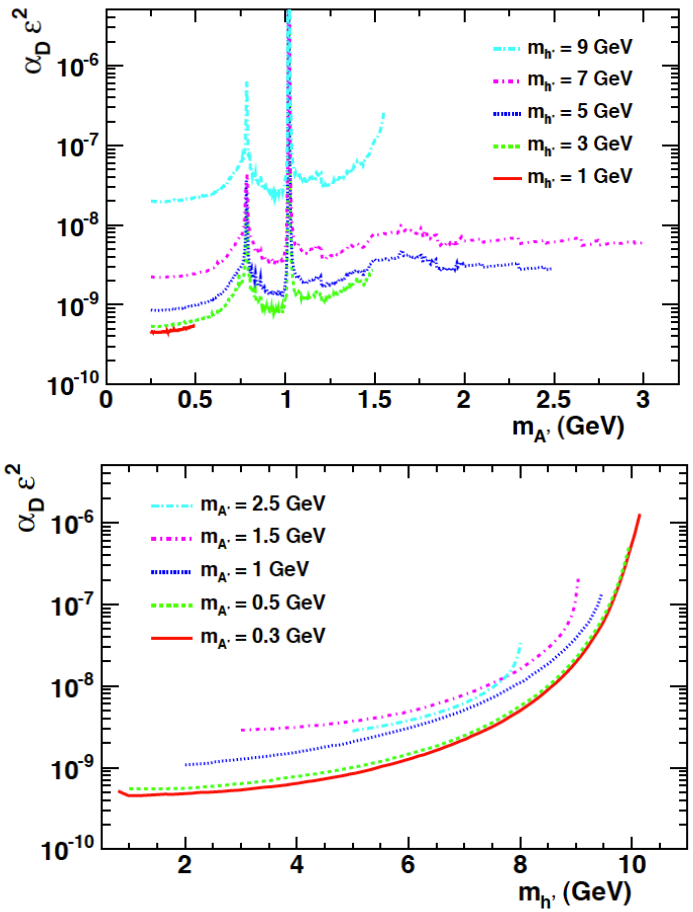
Results consistent with expectation from pure background hypothesis (using control samples)

We set limits:
$\sigma(e^+e^- \to h'A', h' \to A'A') < 10\text{-}100$ ab at 90% CL





Limits on dark sector coupling and mixing with SM based on BaBar results



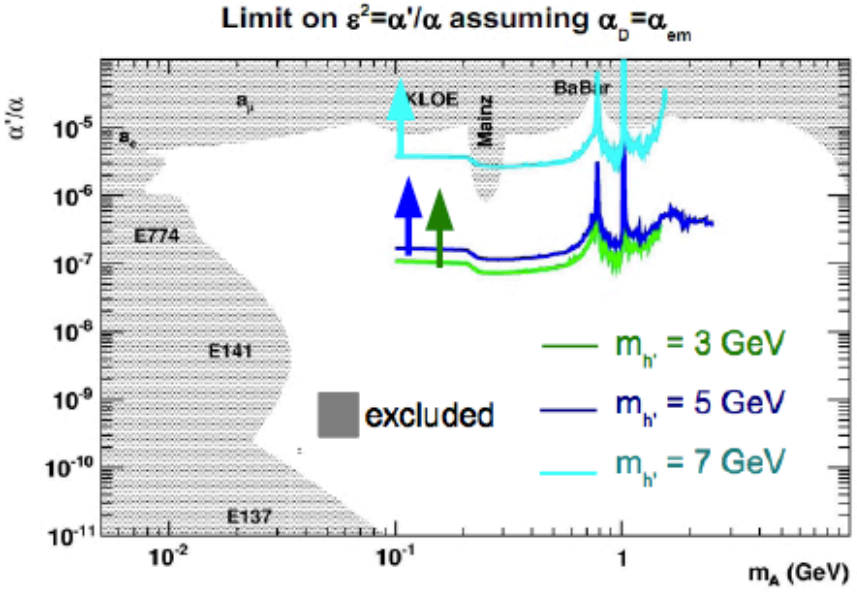
Upper limits (90% CL) as functions of A′ and h′ masses

$\alpha_D \varepsilon^2 <$ few x 10^{-10} at 90% CL

$\alpha_D \equiv g_D^2/4\pi$

g_D = dark sector coupling constant

ε = mixing strength



J. D. Bjorken, R. Essig, P. Schuster and N. Toro, Phys. Rev. D80, 075018 (2009) and references therein

S. Giovannella, J. Phys. Conf. Ser. 335, 012067 (2011)

S. Abrahamyan et al. [APEX Collab.], Phys. Rev. Lett. 107, 191804 (2011)

Conclusions on searches for low-mass Higgs and dark sector particles at BaBar

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Channel	Analysis Status
$\Upsilon(2,3S) \to \gamma A^0; A^0 \to \mu^+\mu^-$	PRL 103, 081803 (2009)
$\Upsilon(1S) \to \gamma A^0; A^0 \to \mu^+\mu^-$	In progress
$\Upsilon(3S) \to \gamma A^0; A^0 \to \tau^+\tau^-$	PRL 103, 181801 (2009)
$\Upsilon(1S) \to \gamma A^0; A^0 \to \tau^+\tau^-$	In progress
$\Upsilon(1S) \to \gamma A^0; A^0 \to$ invisible	PRL 107, 021804 (2011)
$\Upsilon(2,3S) \to \gamma A^0; A^0 \to$ hadrons	PRL 107, 221803 (2011)
$\Upsilon(1S) \to \gamma A^0; A^0 \to$ hadrons	In progress
$\Upsilon(1S) \to \gamma A^0; A^0 \to \gamma\gamma$	In progress

- More than 4 years after the end of data-taking BaBar is still able to search for new particles and probe the parameter space for BSM physics
- Searches for low-mass Higgs and dark sector particles are ongoing
- So, far no evidence for either
- But we haven't yet excluded all possibilities

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