Search for BSM Physics at BaBar and Belle

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Several windows on new physics at B-factories

Unfortunately for presentation, many topics are really far from each other, it's difficult to give a coherent picture without making choices

I'll focus on the search for light Higgs at B-factories and its decay to visible and invisible states

Motivation: in nMSSM many models allow the existence of a CP-odd Higgs at low mass. In the limit of $m_A < 2m_b$, it becomes accessible at B-factories

$\Upsilon(nS) \to \gamma A^0 \quad A^0 \to l^+l^-, \quad A^0 \to gg, \quad A^0 \to q\bar{q}$

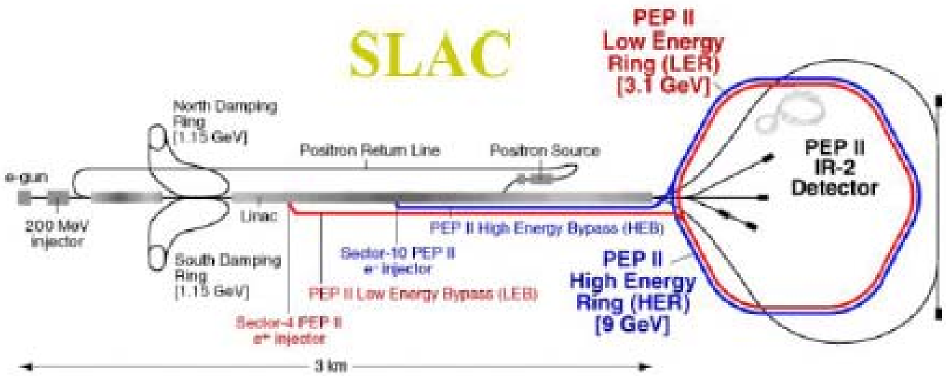
Hiller, PRD 70 (2004) 034018,
Dermisek/Gunion/McElrath, PRD 76 (2007) 051105

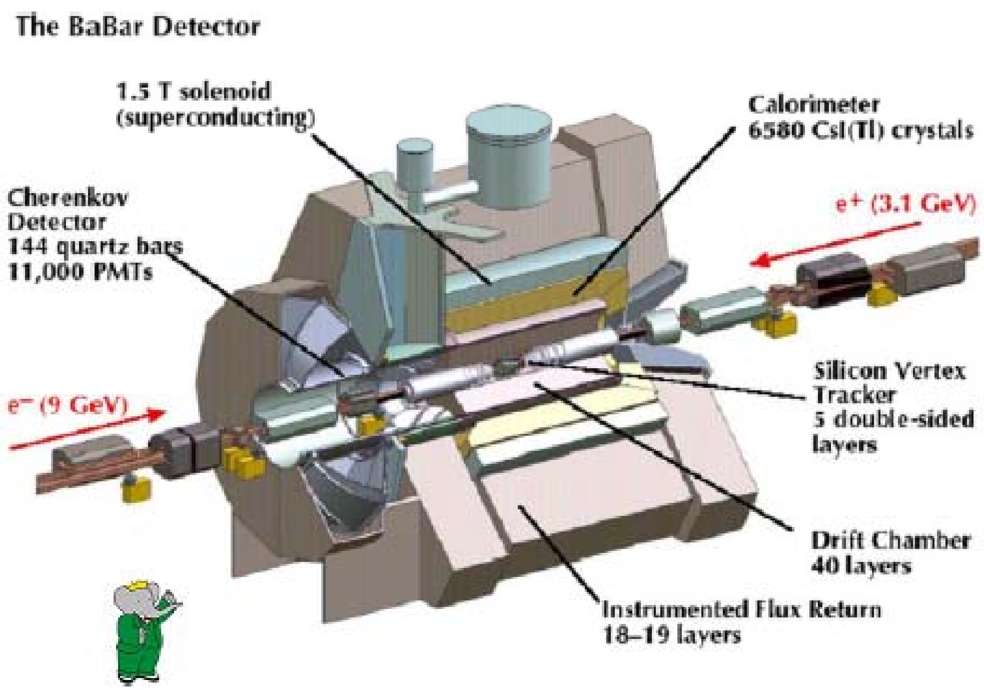
$\Upsilon(nS) \to \gamma A^0 \to \gamma\chi\bar{\chi}$ or $\Upsilon(1S) \to \chi\bar{\chi}$
(invisible neutralinos) -> consequences for Dark Matter

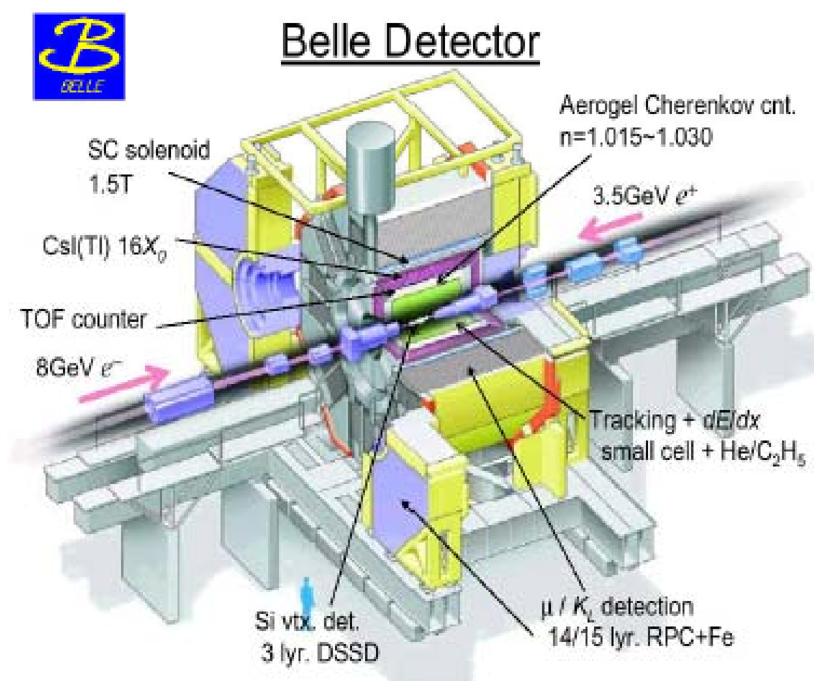
Shrock/Suzuki, PLB 110 (1982) 250, Fayet, PRD81 (2010) 054025

B invisible decays

The two experiments

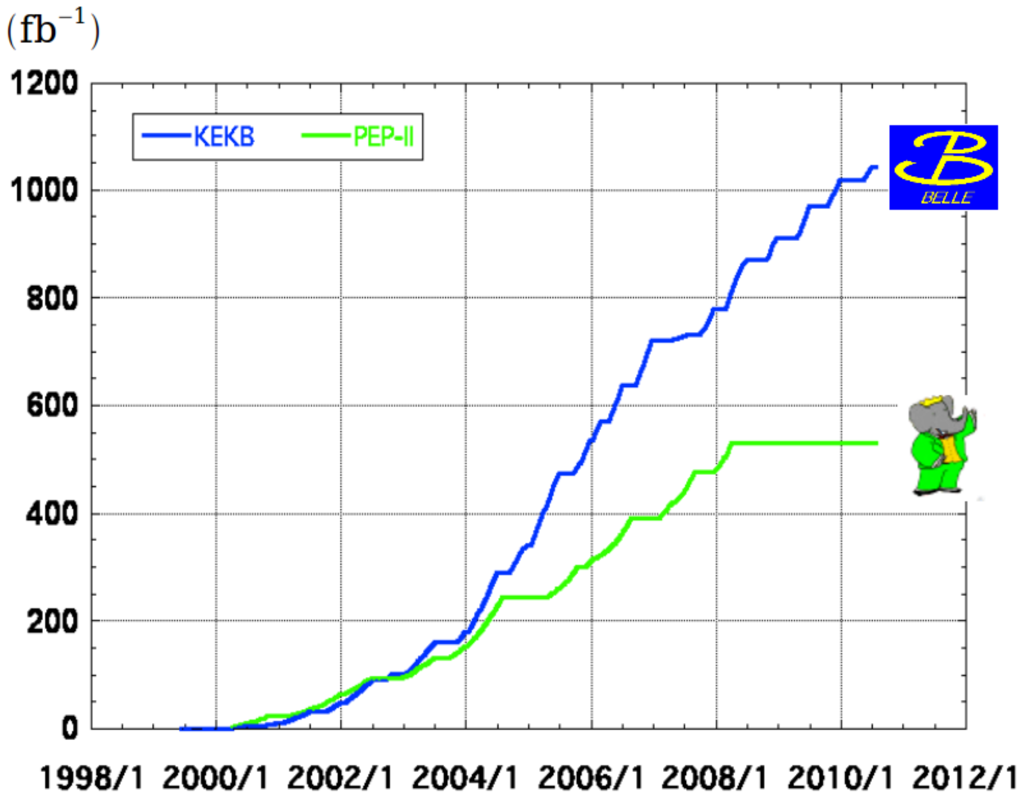






The datasets

Integrated luminosity of B factories



> 1 ab^{-1}
On resonance:
$\Upsilon(5S)$: 121 fb^{-1}
$\Upsilon(4S)$: 711 fb^{-1}
$\Upsilon(3S)$: 3 fb^{-1}
$\Upsilon(2S)$: 25 fb^{-1}
$\Upsilon(1S)$: 6 fb^{-1}
Off reson./scan:
~ 100 fb^{-1}

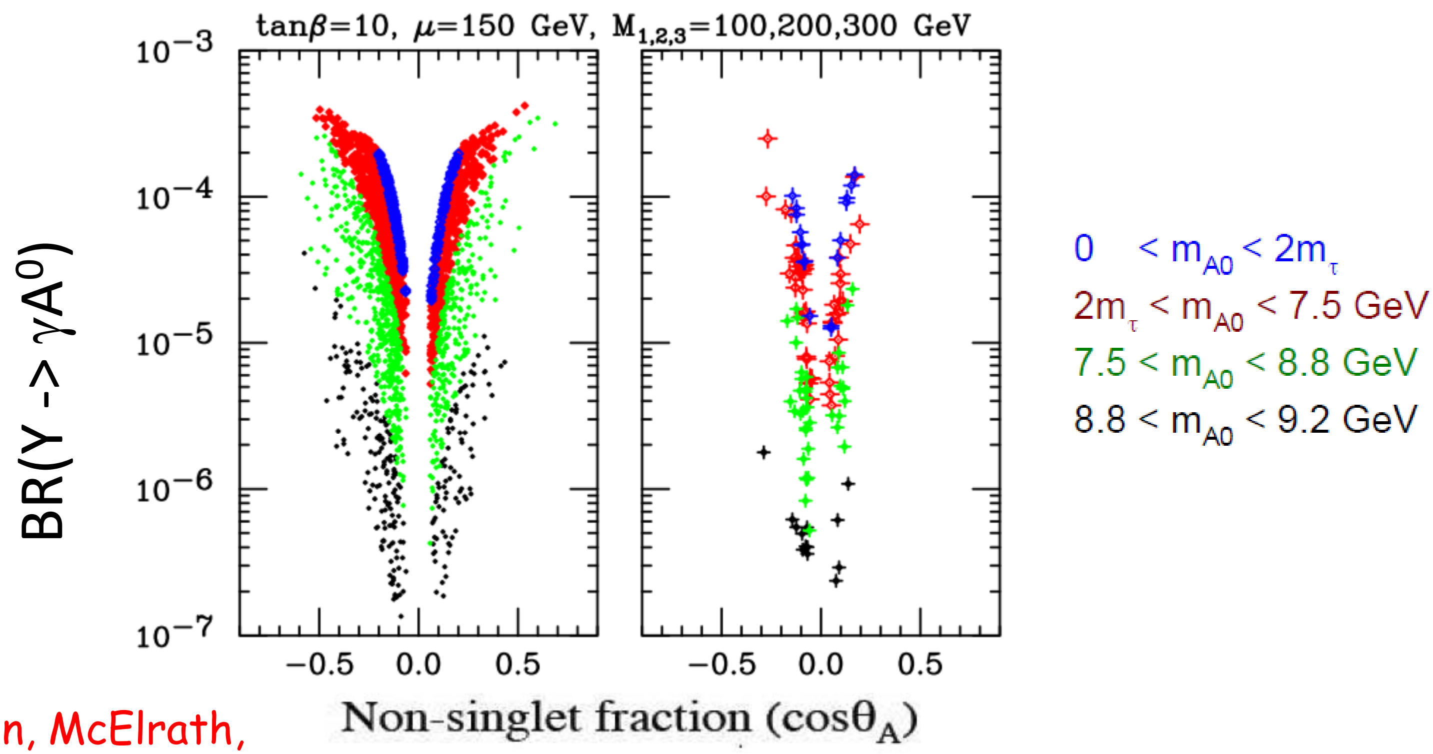
~ 550 fb^{-1}
On resonance:
$\Upsilon(4S)$: 433 fb^{-1}
$\Upsilon(3S)$: 30 fb^{-1}
$\Upsilon(2S)$: 14 fb^{-1}
Off resonance:
~ 54 fb^{-1}

Resonance	BaBar	Belle
Υ(3S)	121 M	12 M
Υ(2S)	98+(3) M	175 M
Υ(1S)	(23) M	113+(32) M

(*) from feed-down

Light Higgs

- A light Higgs (< $2M_B$) expected in extensions to the SM such as nMSSM, allowing $\Upsilon(nS) \to \gamma A^0$
- Branching fractions are predicted to be relatively large, depending on the underlying model parameters



Dermisek, Gunion, McElrath, PRD 76, 051105 (2007)

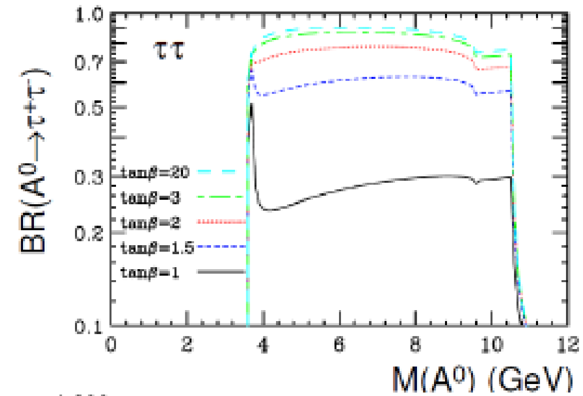
$A^0 = \cos\theta_A A_{MSSM} + \sin\theta_A A_S$

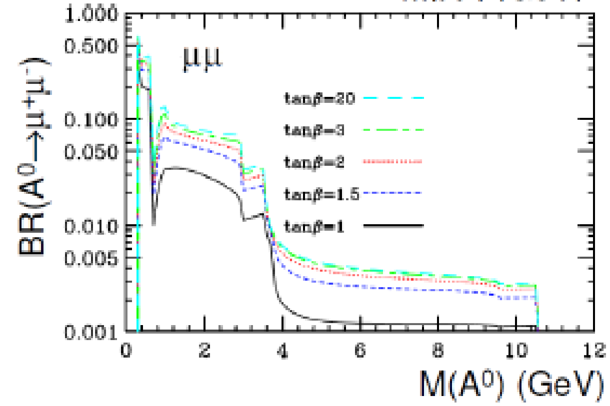
- BR(Υ(nS) -> γA^0) x (A^0 -> $f\bar{f}$) predicted to be up to 10^{-4}

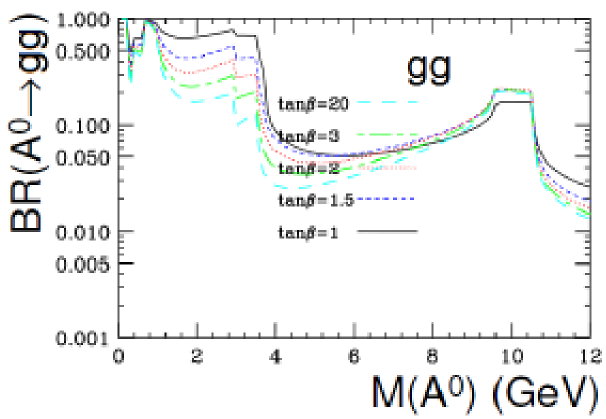
- Search for A^0 -> $f\bar{f}$ ($\mu\mu$, $\tau\tau$, gg, $s\bar{s}$, $c\bar{c}$)

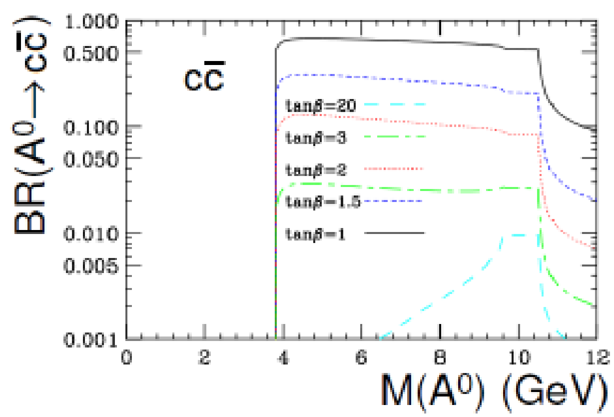
- Favoured decays depend on m(A^0) and parameters values

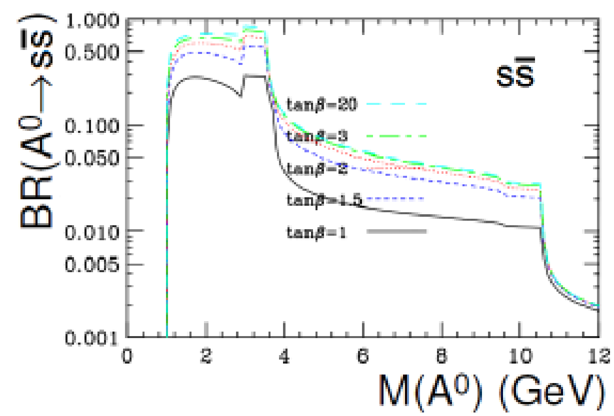
Dermisek, Gunion, PRD 81, 075003 (2010)











$\Upsilon(2,3S) \to \gamma A^0 \to \gamma\mu^+\mu^-$

PRL 103, 081803 (2009)

- Event selection

$E\gamma > 0.2$ GeV and two oppositely-charged tracks

$\mu^+\mu^-\gamma$ system compatible with the decay of $\Upsilon(2,3S)$ in luminous region

- Main backgrounds

$e^+e^- \to \mu^+\mu^-\gamma$	QED radiative di-muons
$e^+e^- \to \rho \to \pi^+\pi^-\gamma$	rho production
$e^+e^- \to \Upsilon(1S)\,\gamma$	ISR events

$e^+e^- \to \Upsilon(2,3S) \to \chi_b\,\gamma \to \Upsilon(1S)\,\gamma\,\gamma \to \mu^+\mu^-\gamma\,\gamma$

- Signal efficiency: 25-20% over the A^0 mass range (0.212-9.3 GeV)

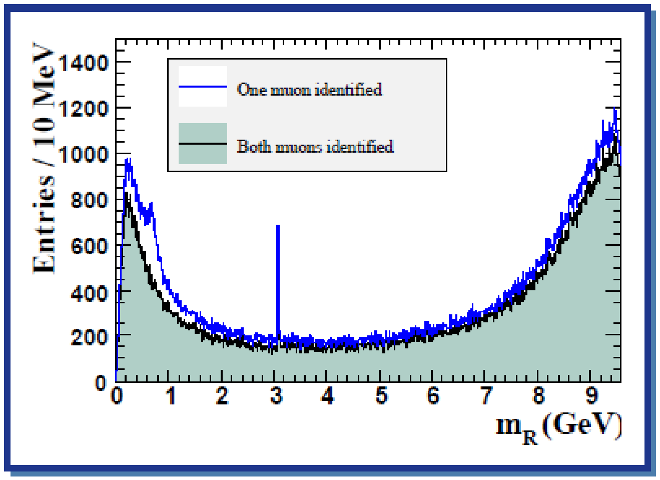
- Signal yield

Fit expected peak in the reduced mass distribution $m_R = \sqrt{m_{\mu\mu}^2 - 4m_\mu^2}$

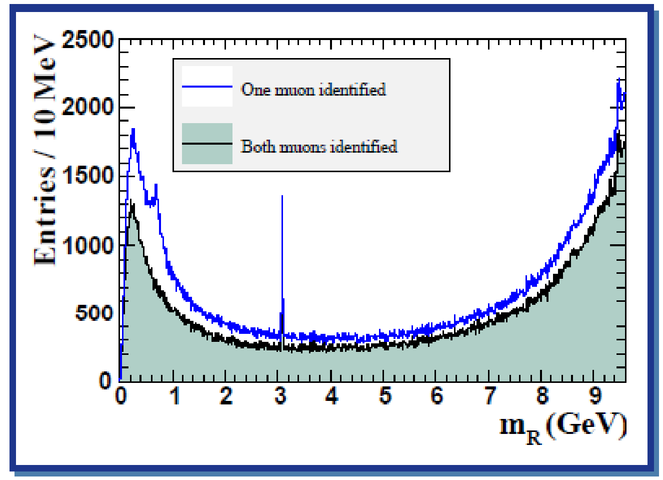
Continuum and peaking background subtraction

● Results $A^0 \to \mu^+\mu^-$ (continued)

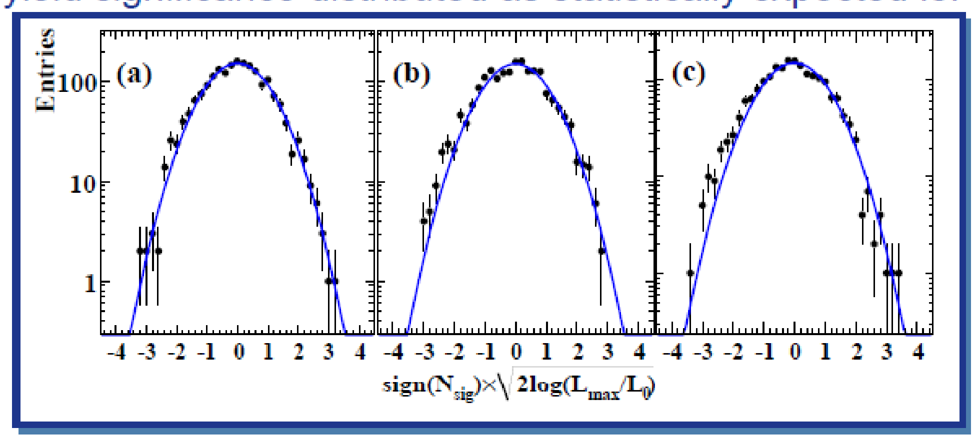
Υ(2*S*) sample A^0 candidates



Υ(3*S*) sample A^0 candidates



signal fit yield significance distributed as statistically expected for no signal

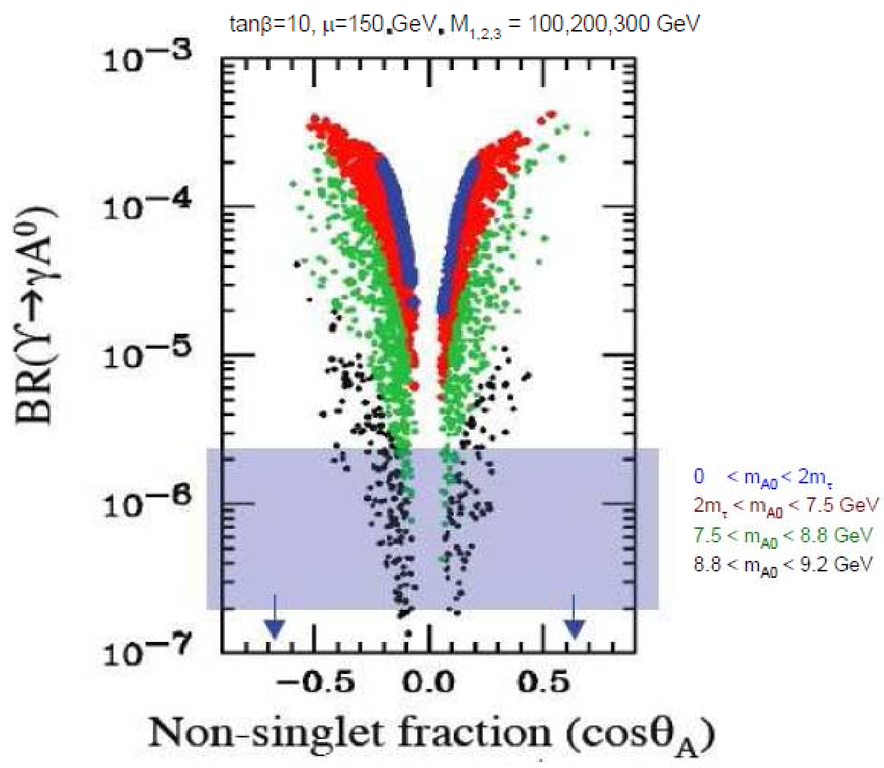


Results $A^0 \to \mu^+\mu^-$ (continued)

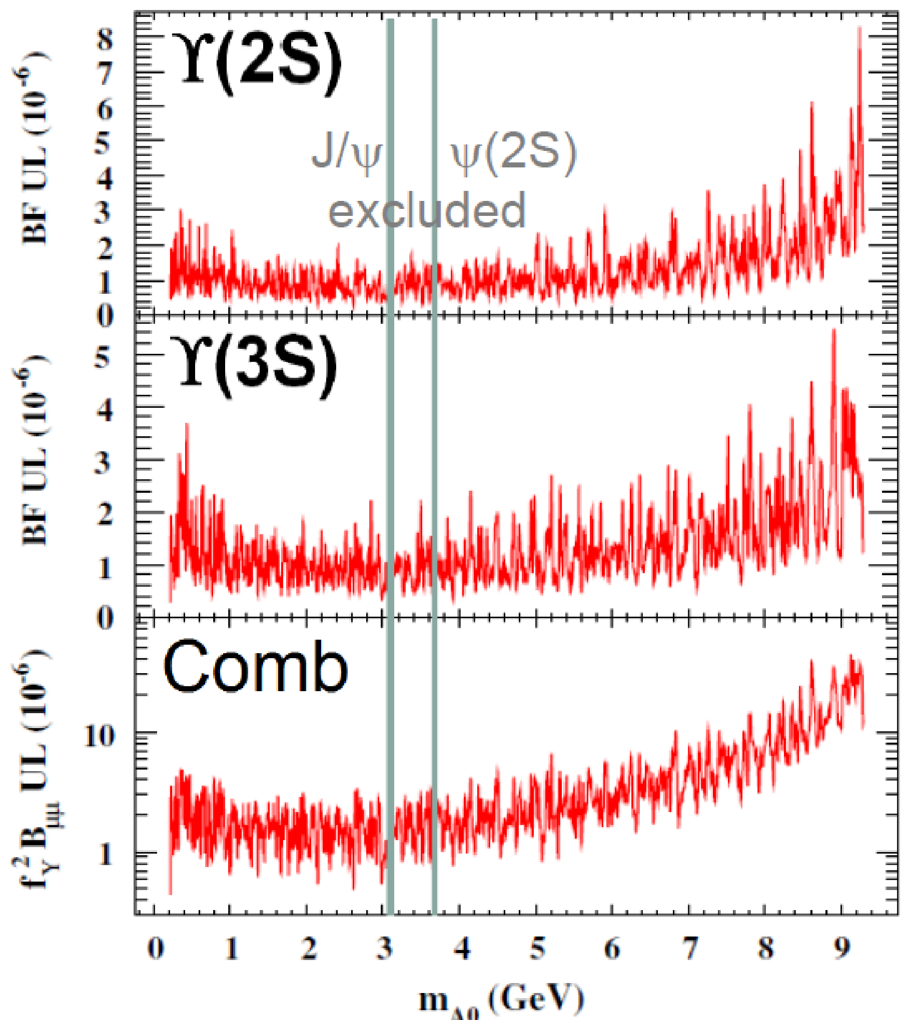
90% CL upper limits established

$B(\Upsilon(2S)\to\gamma A^0(\mu^+\mu^-) < (0.26\text{-}8.3)\times10^{-6}$

$B(\Upsilon(3S)\to\gamma A^0(\mu^+\mu^-) < (0.27\text{-}5.5)\times10^{-6}$



$A^0 = \cos\theta_A A_{MSSM} + \sin\theta_A A_S$



PRL 103, 081803 (2009)

$\Upsilon(3S) \to \gamma A^0 \to \gamma\tau^+\tau^-$

- Event selection

  $E\gamma > 0.1$ GeV and two tracks (1-prong τ pairs): ee, eμ, $\mu\mu$

  Discriminating variables: Etot, Pt, missing mass, angles

- Main backgrounds

$e^+e^- \to \tau^+\tau^-\gamma$	QED radiative tau pairs
$e^+e^- \to \rho \to \pi^+\pi^-\gamma$	rho production
$e^+e^- \to$ 4 leptons	QED process

  $e^+e^- \to \Upsilon(2,3S) \to \chi_b\,\gamma \to \Upsilon(1S)\,\gamma\,\gamma \to \tau^+\tau^-\gamma\,\gamma$

- Signal efficiency: 10-26% depending on $E\gamma$

- Signal yield

  Fit expected peak in the photon energy distribution

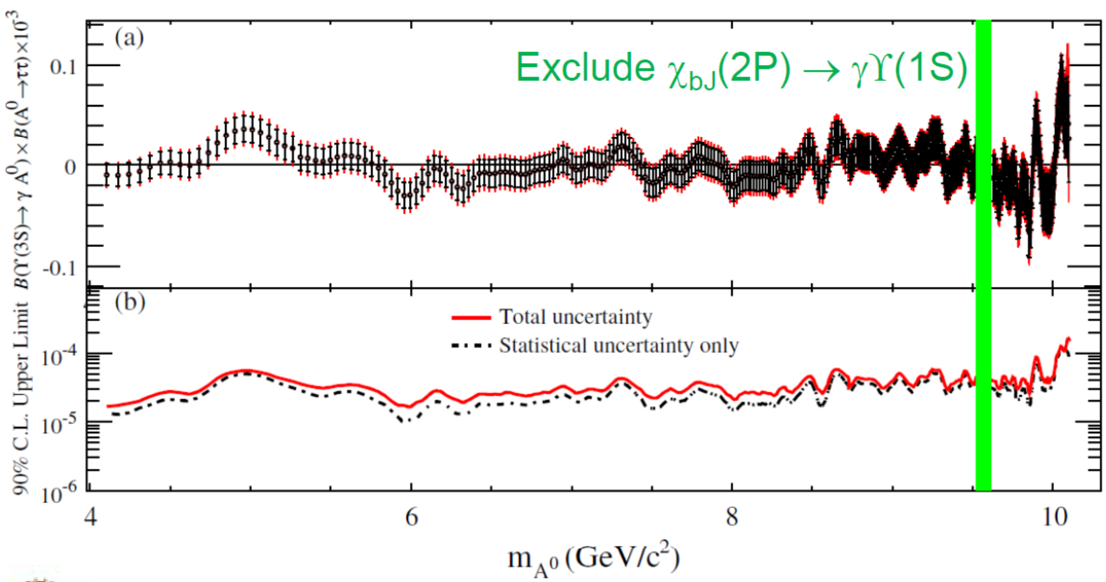
  Continuum and peaking background subtraction

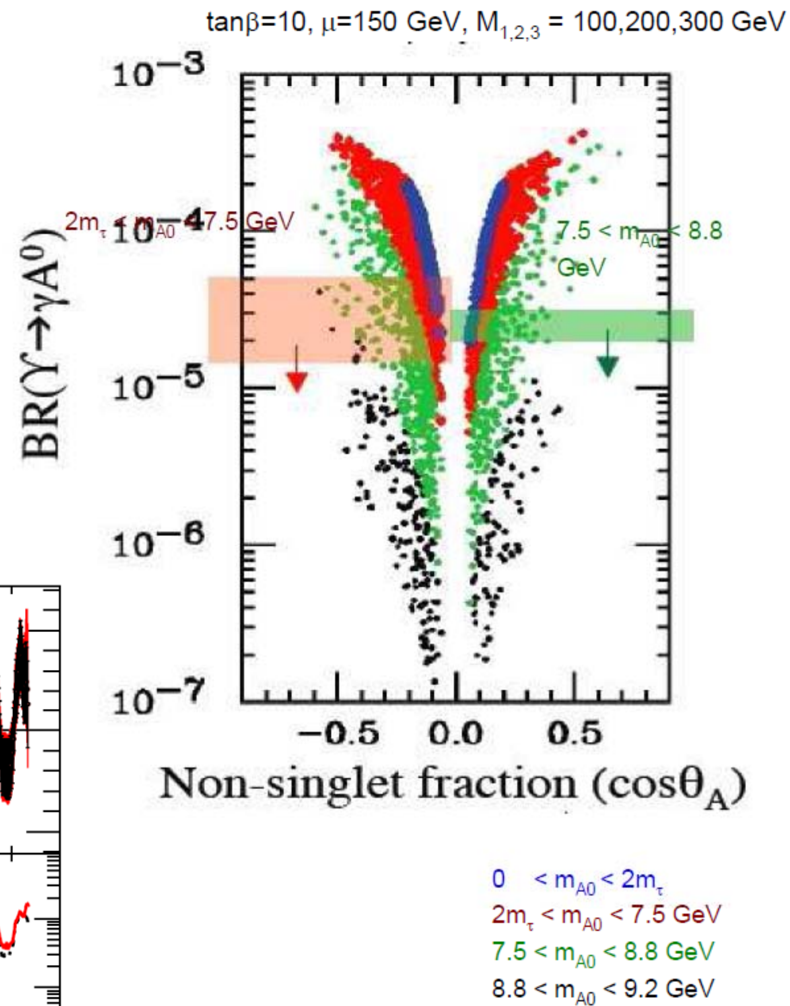
Results (BaBar)

No significant signal

90% CL upper limits established

$B(\Upsilon(3S)\to\gamma A^0(\tau^+\tau^-) < (1.5 - 16) \times 10^{-5}$





PRL 103, 181801 (2009)

$\Upsilon(2,3S)$ -> γA^0 -> hadrons

New Result!
arXiv:1108.3549

- Event selection: both CP-odd and CP-all analyses

  Fully reconstructed hadronic events

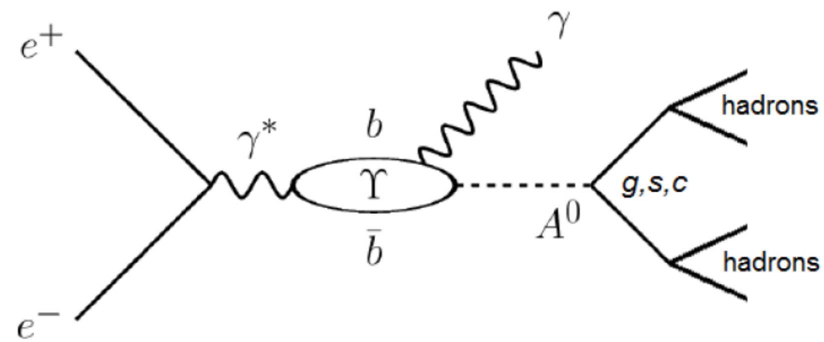
  Highest-energy photon (> 2.2 / 2.5 GeV) is radiative photon candidate

  A^0 candidate from sum of all 4-momenta of remaining objects
  (Ks, K, π, p, π^0, leftover γ)

  Constrain common vertex and energy

  π^0 and η veto for radiative photon

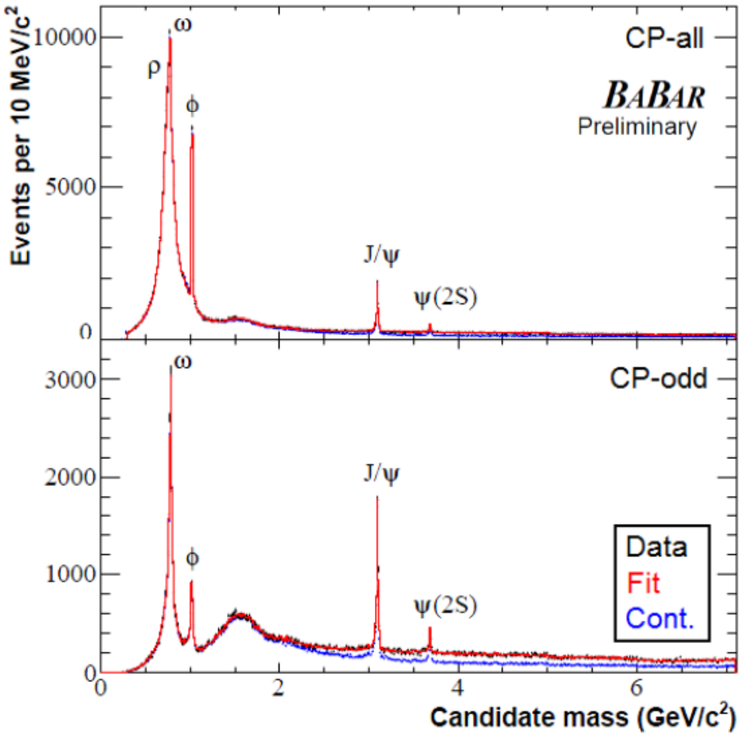
  Radiative Bhabha and muon rejection



- CP-all and CP-odd (no $\pi\pi$, KK candidates) event selection

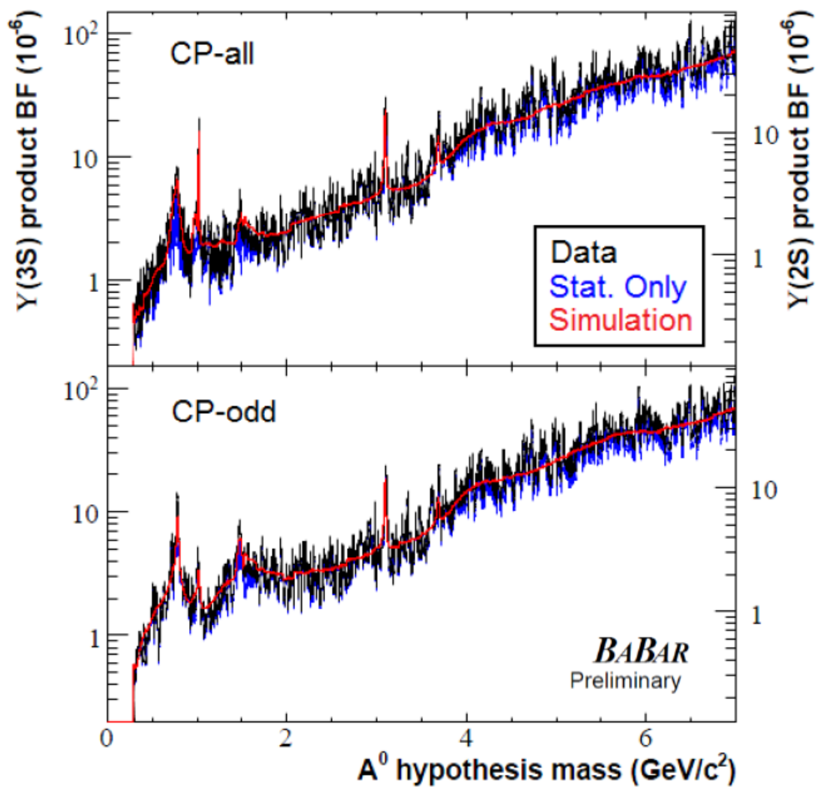
- Main backgrounds

  Continuum and $\Upsilon(4S)$ (γ ISR + meson)
  $\Upsilon(nS)$ -> γ + mesons (seen by CLEO in $\Upsilon(1S)$ decay)
  Non –resonant radiative decays, γ from π^0



Mass window scan
(0.29 – 7 GeV/c²)

Systematics due to uncertainty on efficiency, background scaling and presence of light resonances



No significant yield observed, 90% CL limits set

$$B(\Upsilon(nS) \rightarrow \gamma A^0(\text{hadrons})) < (0.1\text{-}8) \times 10^{-5}$$

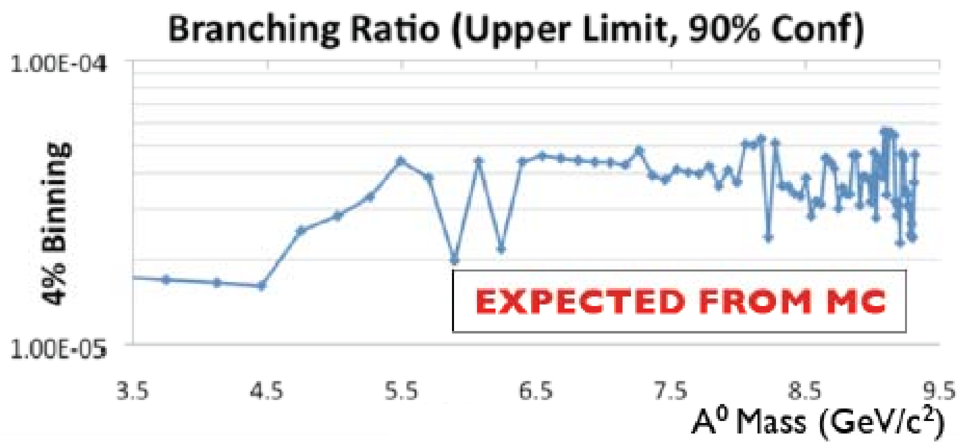
arXiv:1108.3549

Work in progress

New

- BaBar: complementary analyses with dipion tags
  - $\Upsilon(nS) \rightarrow \pi^+\pi^- \Upsilon(1S) \rightarrow \gamma A^0 \rightarrow (\mu^+\mu^-, \tau^+\tau^-)$
  - $\Upsilon(nS) \rightarrow \pi^+\pi^- \Upsilon(1S) \rightarrow \gamma A^0 \rightarrow$ (hadrons)

- Belle: $\Upsilon(1S) \rightarrow \gamma A^0 \rightarrow (\tau^+\tau^-)$
  - Scan for peaks in E_γ distribution
  - Expected sensitivity to match CLEO, improve for high mass
  - Currently includes eμ tau modes, will include ee and $\mu\mu$



J. Rorie, EPS 2011

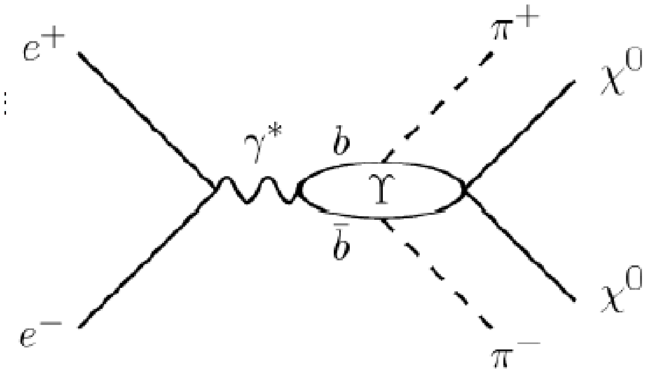
If you are interested in these results, you might also be interested in the new BESIII limit of $J/\psi \rightarrow \gamma A^0 \rightarrow \gamma\mu\mu$ arXiv:1111.2112 (Nov 2011)

Invisible Decays

In some nMSSM with light LSP χ
$A^0 \to \chi^0 \bar{\chi}^0$ is dominant mode

This mechanism could also be a component for Dark Matter.

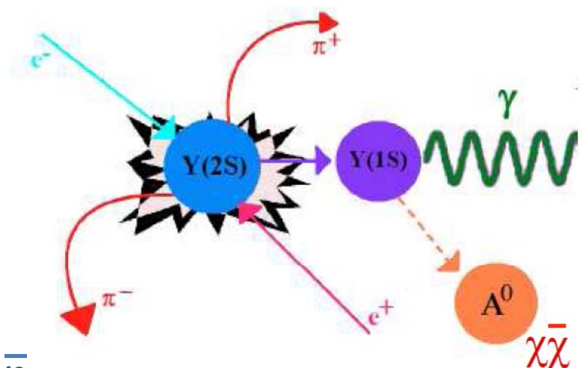
Again, this could be observed in Υ decays



Example: B($\Upsilon(1S) \to \gamma\chi\chi$) could be as large as (4-18) x 10^{-4} arXiv:0712:0016

Signature:

- Single photon recoil against invisible decay in $\Upsilon(1S) \to \gamma A(\chi\bar{\chi})$
- Tag: $\Upsilon(nS) \to \pi^+\pi^- \Upsilon(1S)$ from the $\pi^+\pi^-$ recoil mass



Main backgrounds

$e^+e^- \to \pi^+\pi^-\gamma$
Peaking backgrounds: $\Upsilon(1S) \to \gamma K_L K_L$ and $\Upsilon(1S) \to \gamma n\bar{n}$

$\Upsilon(3S) \to \gamma A^0$(invisible)

Signature:

- Monochromatic photon in conjunction with missing energy

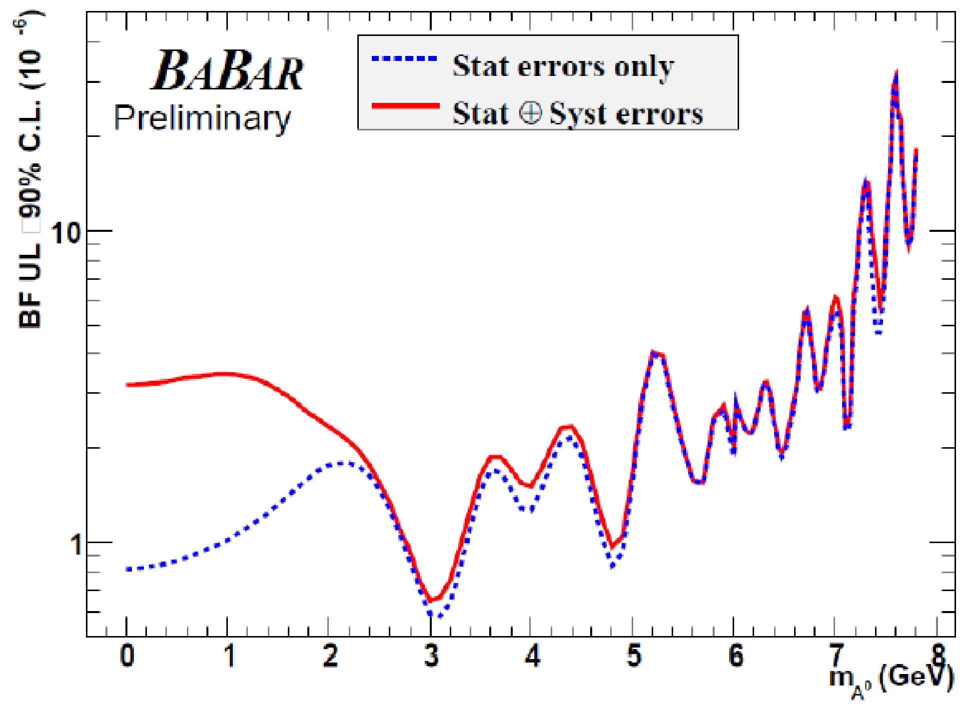
Analysis:

- Peak in $E\gamma$ distribution
- Compute mass of the recoiling system

No signal observed,
Upper limit established

$$B(\Upsilon(3S) \to \gamma\, A^0(\text{invisible})) < (0.7 - 31) \times 10^{-6}$$

arXiv:0808.0017



$\Upsilon(3S)$ -> $\pi^+ \pi^-$ $\Upsilon(1S)$ -> invisible

Event selection:

Require $\pi\pi$ pair and no additional tracks in the event

Background from $\Upsilon(3S)$ -> $\pi^+ \pi^-$ $\Upsilon(1S)$, $\Upsilon(1S)$ -> $l^+ l^-$ (leptons undetected)

Fit m_{recoil} as expected from m[$\Upsilon(1S)$]

Subtract continuum and peaking backgrounds

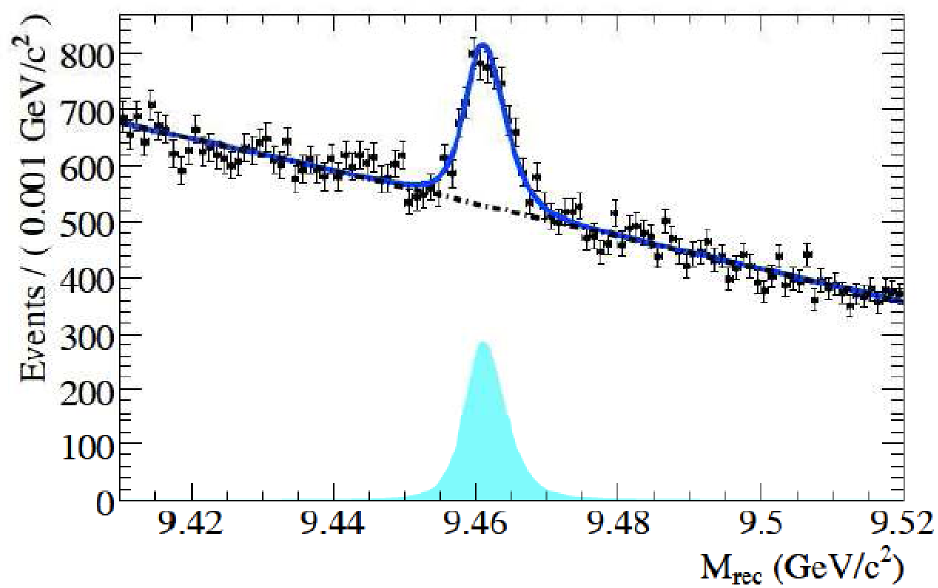
Results

- Fit: 2326 ± 105
- Bkgd: 2444 ± 123
- Signal: -118 ± 105 ± 24

$B(\Upsilon(1S) \to \text{invisible})$

$< 3.0 \times 10^{-4}$

PRL 103, 251801 (2009)



Previous measurements BF(Y(1S) → invisible)

CLEO:	BF < 3.9 x 10^{-3} @ 90% CL	PRD 75 (2007) 031104
Belle:	BF < 2.5 x 10^{-3} @ 90% CL	PRL 98 (2007) 132001

$\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S) \to \gamma$ + invisible

PRL 107, 021804 (2011)

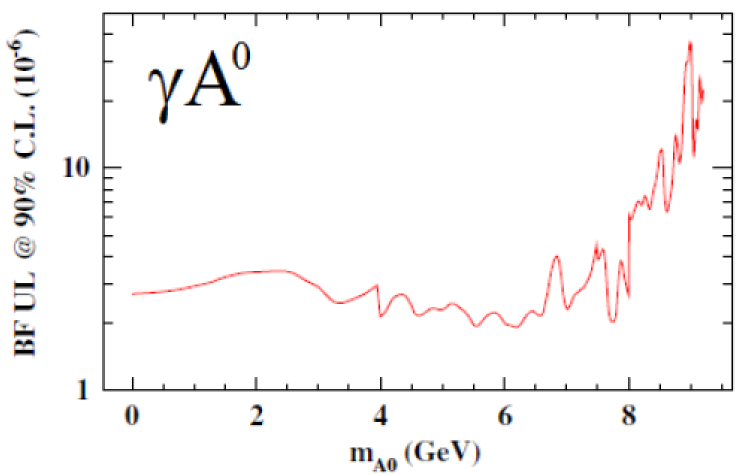
Event selection:

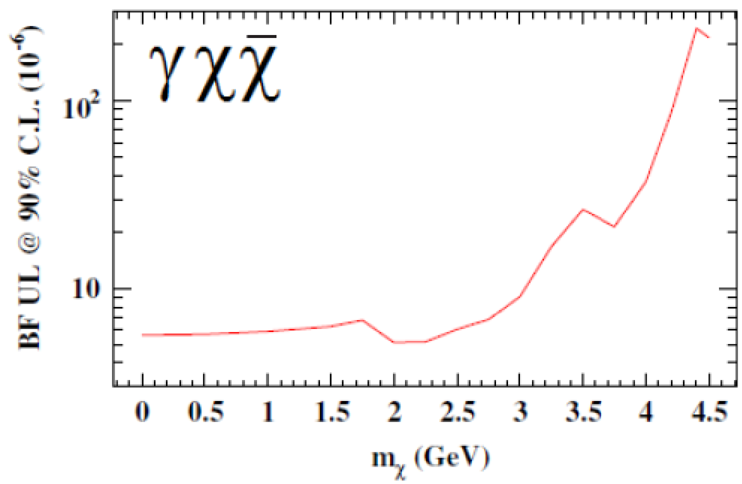
Tag $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$ using $\pi\pi$ recoiling pair

Search for $\Upsilon(1S) \to \gamma$ A^0(invisible) and non-res $\gamma\chi\bar{\chi}$

Fit m_{recoil} and missing mass $M_X^2 = (\mathcal{P}_{e^+e^-} - \mathcal{P}_{\pi\pi} - \mathcal{P}_\gamma)^2$

Main backgrounds: $\Upsilon(1S) \to \gamma K_L K_L$ and $\Upsilon(1S) \to \gamma n\bar{n}$ IFR veto





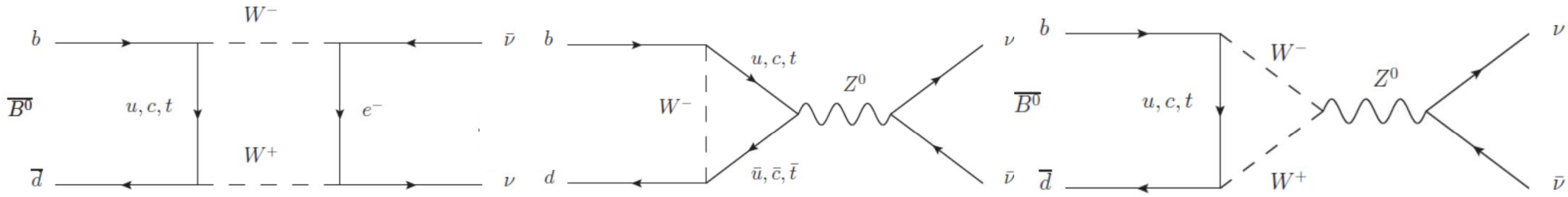
No signal observed,
Upper limit established

$B(\Upsilon(1S) \to \gamma A^0(\text{invisible})) < (1.9 - 37) \times 10^{-6}$

$B(\Upsilon(1S) \to \gamma\chi\bar{\chi}) < (0.5 - 24) \times 10^{-5}$

Other searches for NP in invisible decays

B -> invisible

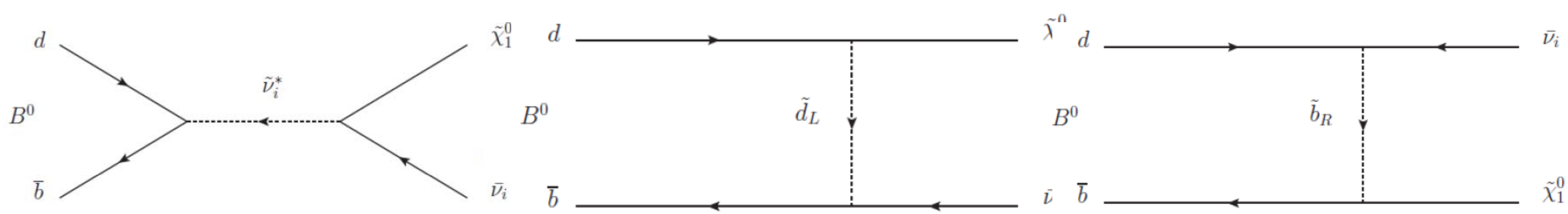


B -> $\nu\bar{\nu}$ strongly suppressed in Standard Model

Buchalla and Buras, Nucl.Phys. B 400(1-3), 225(1993)

At the same time, R-parity violating mechanisms as B -> $\bar{\nu}\tilde{\chi}_1{}^0$ could enhance the branching fractions to 10^{-7}-10^{-6}

Dedes, Dreiner and Richardson, Phys. Rev. D65, 015001 (2001)

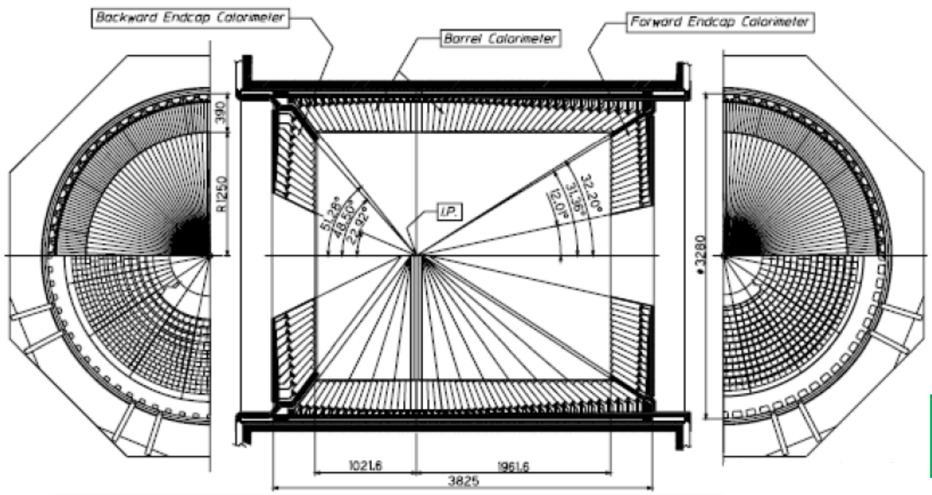


Belle analysis: hadronic tag in B -> invisible

Event selection:

Fully reconstruct one B (no leptons !)

The other B's final state should be invisible



ECL: Electromagnetic Calorimeter comprised of 8736 CsI(Tl) crystals(=cesium iodide crystal doped with thalium)

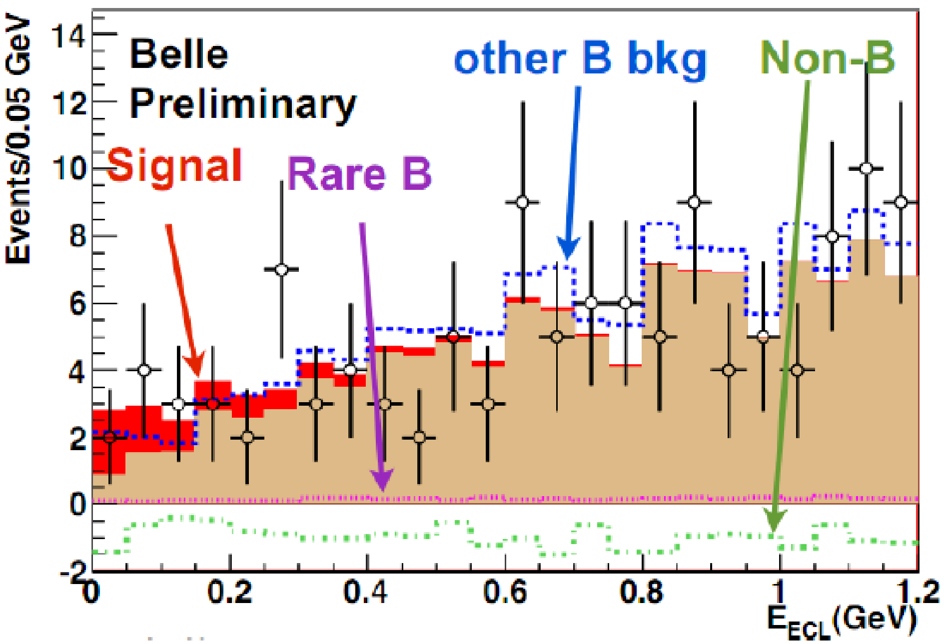
E_{ECL} = E(total deposit in ECL)-$E_{tagged\text{-}B}$

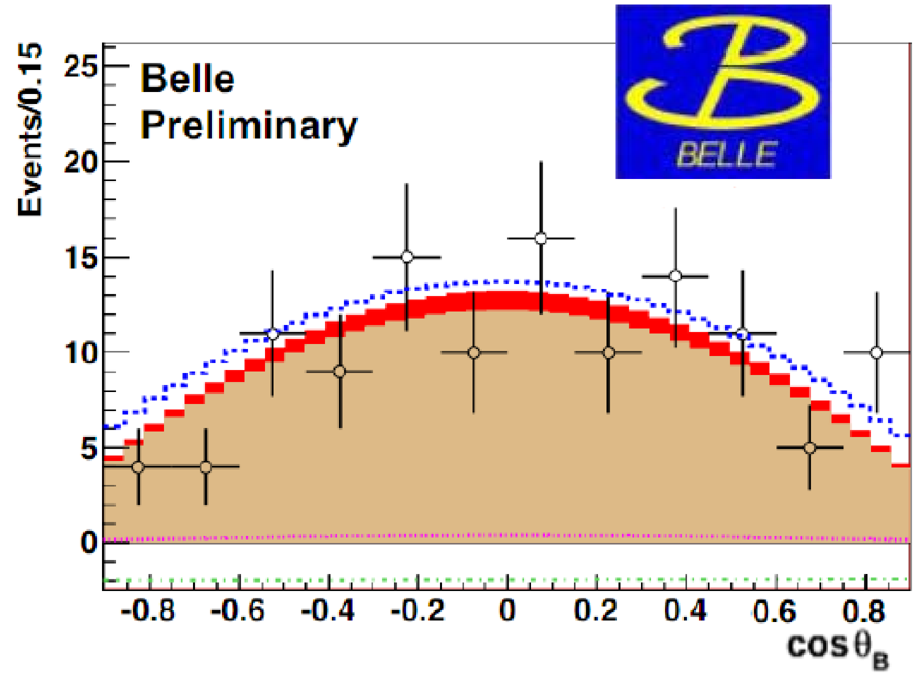
The most powerful variable to separate signal and background !

Continuum suppression ($\cos\theta_T$)

2D unbinned ML fit to (E_{ECL} , $\cos\theta_B$)

Fitting the results





No signal observation

$$N_{sig} = 8.9^{+6.3}_{-5.5}(stat)^{+2.6}_{-2.7}(syst)$$

Upper limit estabilished

BR($B^0 \to$ invisible) < 1.3 x 10^{-4} @90%CL

Belle preliminary result with 657M $B\bar{B}$

Sources	Yield
Signal	9±6
b→c BG	132^{+22}_{-23}
Non-B BG	-23^{+22}_{-17}
Rare-B BG	~4
Total	121

BaBar previous limit: BR < 2.2 x 10^{-4}
(88.5M BB) **Phys.Rev.Lett. 93 (2004) 091802**

Conclusions

No evidence for light new physics found by BaBar and Belle in e^+e^- collisions at and below the $\Upsilon(4S)$

- No evidence of light Higgs found
- No Dark Matter component provided by this mechanism

In any case, many more limits set in the sector of $\Upsilon(nS)$ decays, and existing ones (mainly CLEO) have been improved significantly

Additional analyses still ongoing on the huge BaBar and Belle datasets.