

# B-factory searches for light scalars and other new states

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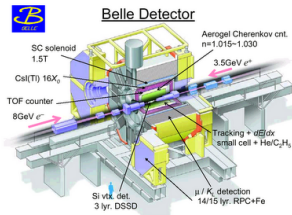
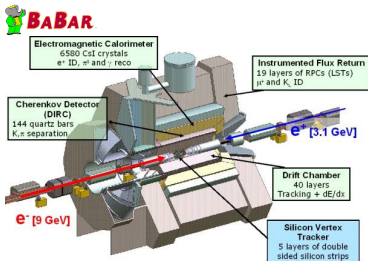
Thanks to Abi Soffer and Gianluca Inguglia for material



# The B factories

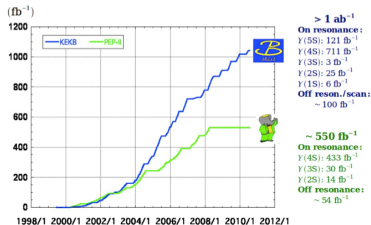
BaBar and Belle

Low energy  $e^+e^-$  collisions 10 GeV, on or near the  $\Upsilon(4S)$



Precision physics:

Huge currents, lumi, rates, samples  
Goals exceeded by accelerator and detector  
No spectators, no multiple collisions  
Excellent vertexing and  $\pi/K$  separation  
Asymmetric: CM frame moving in the lab  
Covers most but not all of  $4\pi$



# Dark Matter Particles

## Dark Fermions

Heavy particles - such as SUSY LSP - need energy frontier machine

## Dark photon

- New U(1) gives  $A'$  (Fayet PLB 95, 285(1980))
- Small coupling  $\epsilon$  to conventional photon, from kinetic mixing
- One explanation for AMS positron excess
- Must be light, or would give cosmic  $\bar{p}$  excess. Mass  $\lesssim$  GeV

Dark Higgs -  $h$  or  $A^0$ . Similar signature to dark photon

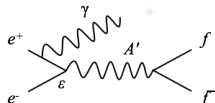
Not covered here: Indirect signals such as FCNC  $b$  decays, where virtual BSM particles can interfere with the  $W/Z$ , e.g.  $B \rightarrow K\ell^+\ell^-$ ,  $B \rightarrow \tau\nu$  etc.

# Searches for Dark photon / Dark Higgs / BSM Higgs

Signatures similar: peak in mass distribution. Insensitive to difference in spin. Interpretation of [limits on] signal in framework of model.

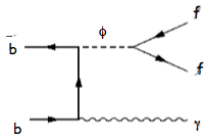
Two main production methods: First involves coupling to electrons, second method to  $b$  quarks

Initial State Radiation photon



Tag: photon

$\Upsilon$  decay



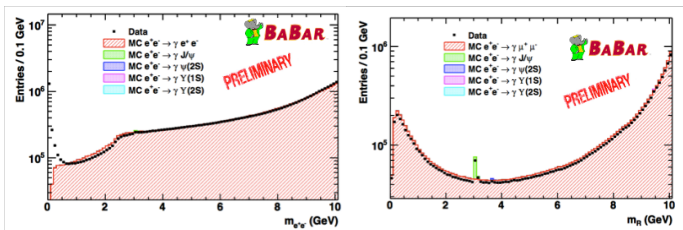
Either directly :  $e^+e^- \rightarrow \Upsilon \rightarrow \gamma A'$ : Tag: monochromatic photon  
 or via radiative decays  $e^+e^- \rightarrow \Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ : Tag: photon and  
 $\hookrightarrow \gamma A'$

two low-momentum pions . Less rate but very clean

# The ISR method

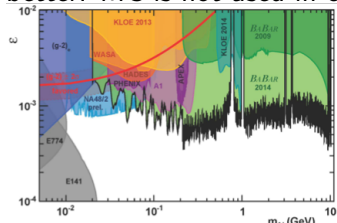
ArXiv: 1406.2980

ISR photon  
enables scan  
of  $A'$  mass



Data and SM prediction for  $e^+e^-$  and  $\mu^+\mu^-$  pairs.

Note: this MC not tuned for low mass  $\ell^+\ell^-$  pairs. MADGRAPH does better. MC is not used in extraction of results.



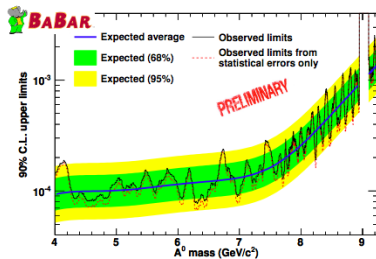
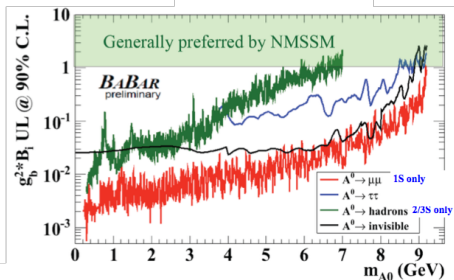
Upper limits set on  $\epsilon$  at level  $10^{-3} - 10^{-4}$   
Nothing seen for  $0.02\text{GeV} < m_{A'} < 10.2\text{GeV}$   
Exclude almost all of the remaining region of parameter space favoured by  $g_\mu - 2$  discrepancy.

# Results: $e^+e^- \rightarrow \Upsilon \rightarrow \gamma A^0$

PRL103,081803(2009),PLR 103,181801 (2009),RPRL 107,221803(2011),PRD 87,031102 (2013), PRD 88, 071102 (2013), PRD 82, 0317019R (2013), PRL 107, 021808 (2011)

$A^0$  is good match to NMSSM CP-odd Higgs.

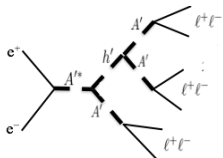
Tagged and untagged  $\Upsilon$  decay analyses for  $A^0 \rightarrow \mu^+\mu^-, \tau^+\tau^-,$  hadrons, and invisible



Tagged  $A^0 \rightarrow D\bar{D}$  recently completed.  
 Shows limit on  $BR(\Upsilon \rightarrow A^0\gamma) \times BR(A^0 \rightarrow D\bar{D})$

# Dark Higgsstrahlung

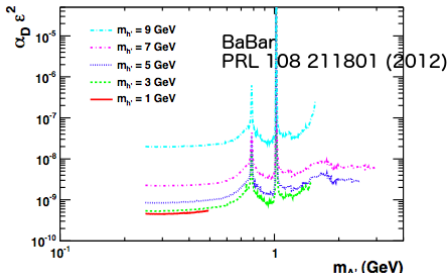
PRL 108,211801 (2012)



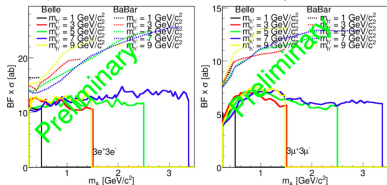
$$e^+e^- \rightarrow A'^* \rightarrow \begin{matrix} A' & h \\ \hookrightarrow l^+l^- & \hookrightarrow A' \\ & \hookrightarrow l^+l^- \end{matrix} \hookrightarrow l^+l^- \hookrightarrow l^+l^-$$

Reconstruct all 3 pairs - or 2 pairs + compatible missing mass  
 Look for  $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$  (but not  $6\pi$  mode)

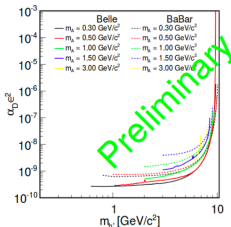
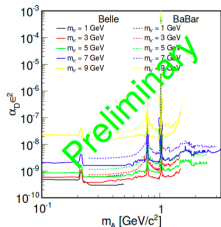
$\alpha_D$  : the dark  
 coupling  
 constant



Belle also considers cases where the  $A'$  has a long lifetime, travelling mm/cm before decay. (Possible for small coupling).



show  $6\mu$   
and  $6e$   
samples



Rule out more  
parameter space  
for various  $M_{A'}$ ,  $M_h$



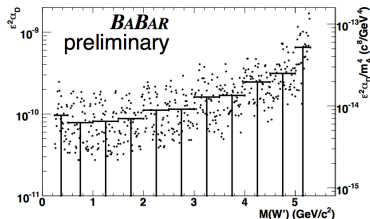
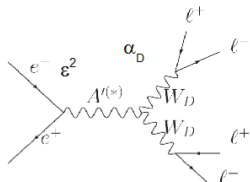
# Dark Gauge Bosons

arXiv:0908.2821

More non-Abelian symmetries  $\rightarrow$  more gauge bosons:  $W', W'' \dots$

Search for  $e^+e^- \rightarrow A'^* \rightarrow W'W'' \rightarrow \ell^+\ell^-\ell^+\ell^-$ ,  $\ell = e, \mu$

No signal...



Limits shown on  $\epsilon^2 \alpha_D$ . Left scale is for small  $m_{A'}$ , right for large  $m_{A'}$

# The longlived dark Higgs

Suppose low mass  $h$  decays to  $f\bar{f}$  as no dark channels open.

Coupling weak so long lifetime i.e. flight path  $c\tau$ .

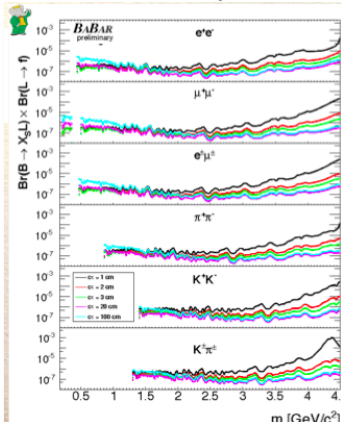
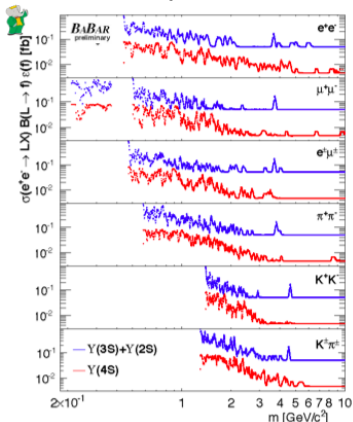
Produced in:  $e^+e^- \rightarrow \gamma^* \rightarrow A'^* \rightarrow A'h$  or  $\Upsilon \rightarrow h\gamma$  or  $b \rightarrow sh\dots$

Inclusive search for 'V' decays to  $e^+e^-$ ,  $\mu^+\mu^-$ ,  $e^\pm\mu^\mp$ ,  $\pi^+\pi^-$ ,  $K^+K^-$ ,  $K^\pm\pi^\mp$

Evaluate background, fold in systematic uncertainties. Set 90% Bayesian limits.

Left: Model independent limits on  $\sigma \times BR \times \text{effcy.}$   
Plug in tables for any particular model

Right: Model dependent limits, with strange hadron in other decay products

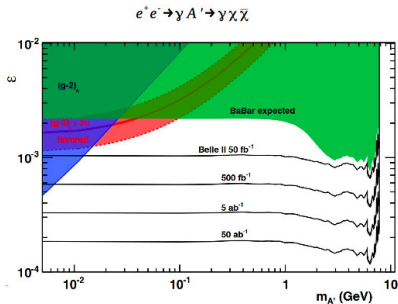
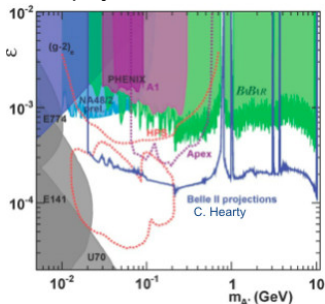


Belle2 at SuperKEKb will take 40x more statistics

Shut down for upgrade 2010.

Belle-II due to roll in mid 2015, followed by commissioning.

First physics data due 2017.



DM searches, including Higgsstrahlung analysis, will continue

# Conclusions



Many ways to search for Dark Matter and non-minimal Higgs particles.  
B factories still have a lot to contribute