

B-factory searches for light scalars and other new states

Presented at 2nd Topical Meeting: Higgs to Dark Matter, Geilo, Norway

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16th December 2014



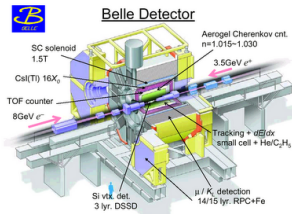
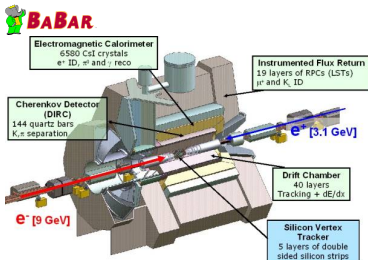
Thanks to Abi Soffer and Gianluca Inguglia for material



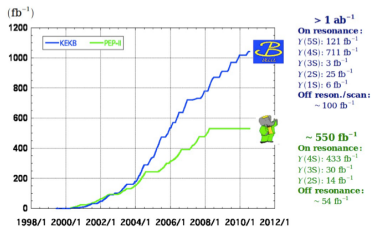
The B factories

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 π/K separation
 Asymmetric: CM frame moving in the lab
 Covers most but not all of 4π



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 ϵ 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

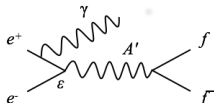
Not covered here: Indirect signals such as FCNC b decays, where virtual BSM particles can interfere with the W/Z , e.g. $B \rightarrow K\ell^+\ell^-$, $B \rightarrow \tau\nu$ etc.

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.

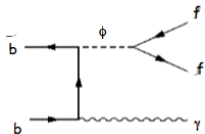
Two main production methods: First involves coupling to electrons, second method to b quarks

Initial State Radiation photon



Tag: photon

Υ decay



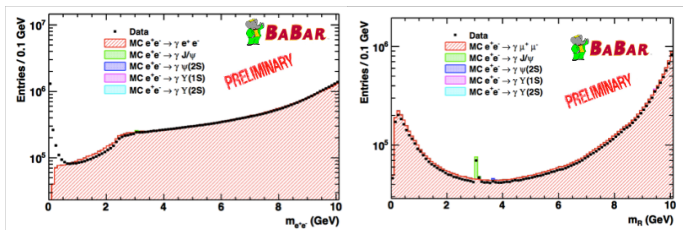
Either directly : $e^+e^- \rightarrow \Upsilon \rightarrow \gamma A'$: Tag: monochromatic photon
 or via radiative decays $e^+e^- \rightarrow \Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-$: Tag: photon and
 $\hookrightarrow \gamma A'$

two low-momentum pions . Less rate but very clean

The ISR method

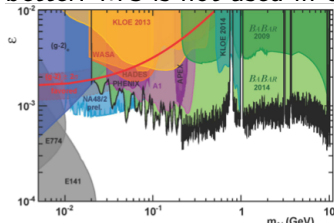
ArXiv: 1406.2980

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 l^+l^- pairs. MADGRAPH does better. MC is not used in extraction of results.



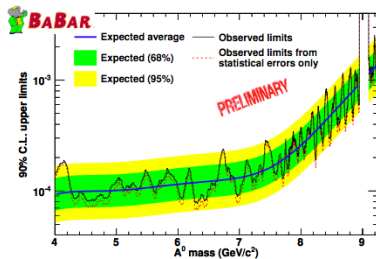
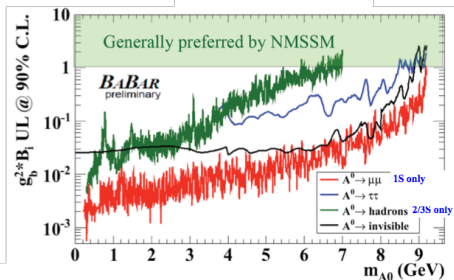
Upper limits set on ϵ at level $10^{-3} - 10^{-4}$
Nothing seen for $0.02\text{GeV} < m_{A'} < 10.2\text{GeV}$
Exclude almost all of the remaining region of parameter space favoured by $g_\mu - 2$ discrepancy.

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.

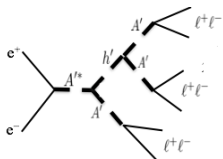
Tagged and untagged Υ decay analyses for $A^0 \rightarrow \mu^+\mu^-, \tau^+\tau^-,$ hadrons, and invisible



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

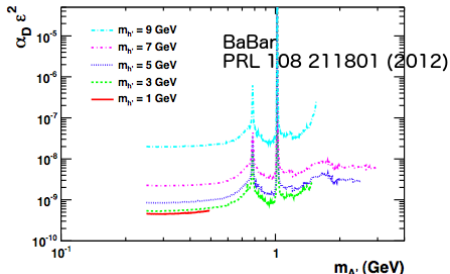
PRL 108,211801 (2012)



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

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

α_D : the dark
 coupling
 constant

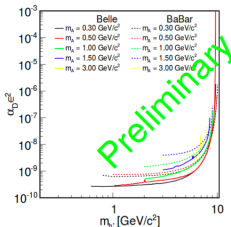
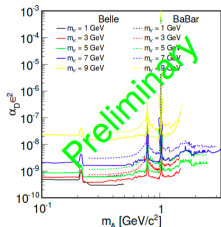
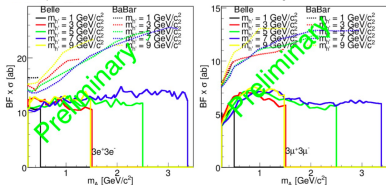




Belle results on Dark Higgsstrahlung

arXiv: 1211.1403

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



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

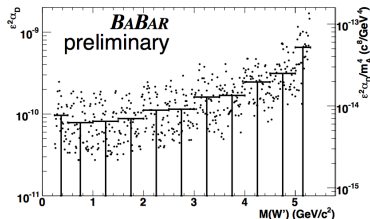
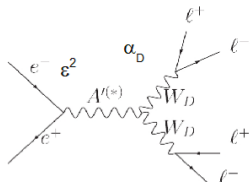
Dark Gauge Bosons

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 $c\tau$.

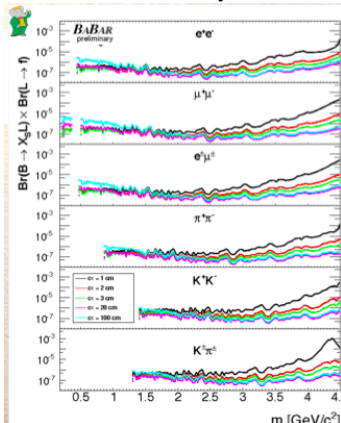
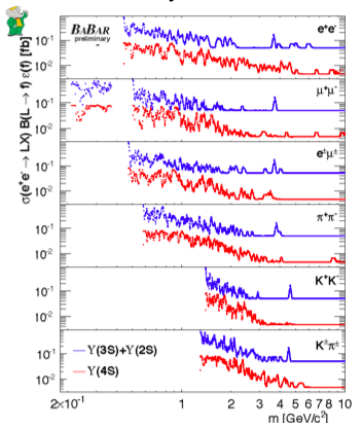
Produced in: $e^+e^- \rightarrow \gamma^* \rightarrow A'^* \rightarrow A'h$ or $\Upsilon \rightarrow h\gamma$ or $b \rightarrow sh\dots$

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

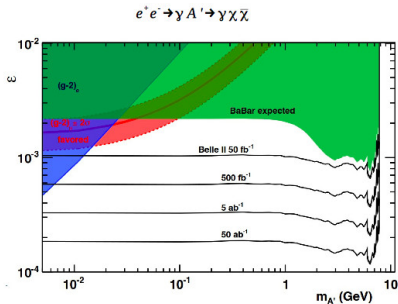
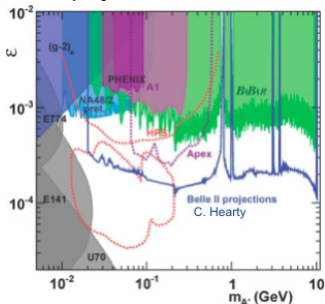


Belle2 at SuperKEKb will take 40x more statistics

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