Search for dark forces at *BABAR*

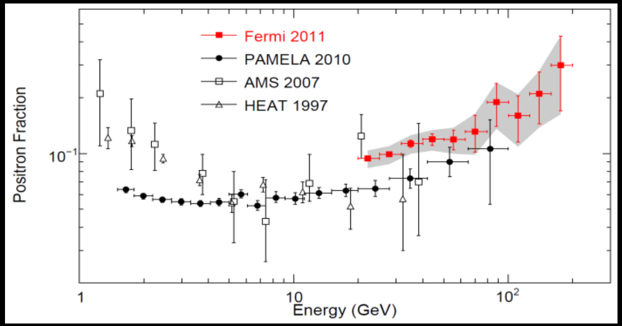
Bertrand Echenard
Caltech
On behalf of the *BABAR* COllaboration

DPF Annual Meeting
Santa Cruz – August 2013

Dark sector

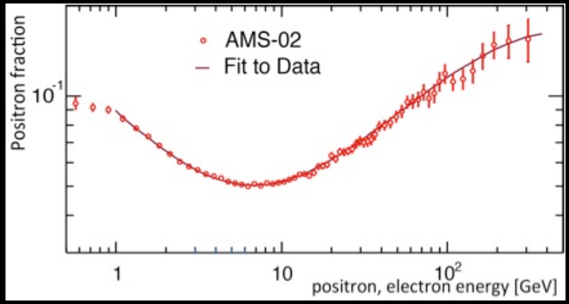
- Dark matter models introducing a new sector with a 'dark' force mediated by a light gauge boson (MeV-GeV scale) have been proposed to explain the observations of PAMELA, FERMI, AMS02, DAMA, CREST,...
- Wimp-like TeV-scale dark matter particles can annihilate into pairs of light dark bosons, which subsequently decay to lepton pairs (protons are kinematically forbidden), or can scatter on nucleons via dark boson exchange.
- More generally, the possibility of light hidden sector is poorly constrained and worth exploring. Many theories beyond the SM include dark sectors.

FERMI

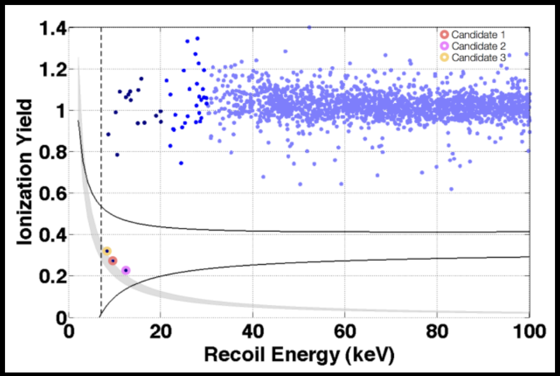


FERMI Collab., PRL 108, 011103 (2012), arXiv:1109.0521

AMS02



CDMS



arXiv:1304.4279

- New dark sector with a $U(1)_D$ gauge group
- New gauge boson: dark photon A' with O(MeV - GeV) mass

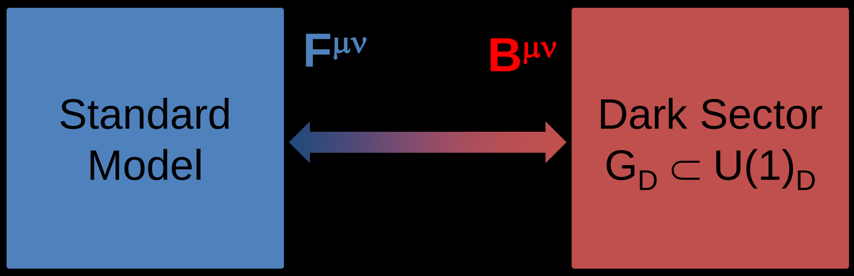
Standard Model

Dark Sector
$G_D \subset U(1)_D$

- New dark sector with a $U(1)_D$ gauge group
- New gauge boson: dark photon A' with O(MeV - GeV) mass
- Interaction with the SM via kinetic mixing

$$\varepsilon F^{\mu\nu} B_{\mu\nu}$$

with a mixing strength ε



$$\Delta\mathcal{L}_{mix} \sim \varepsilon F^{\mu\nu} B_{\mu\nu}$$

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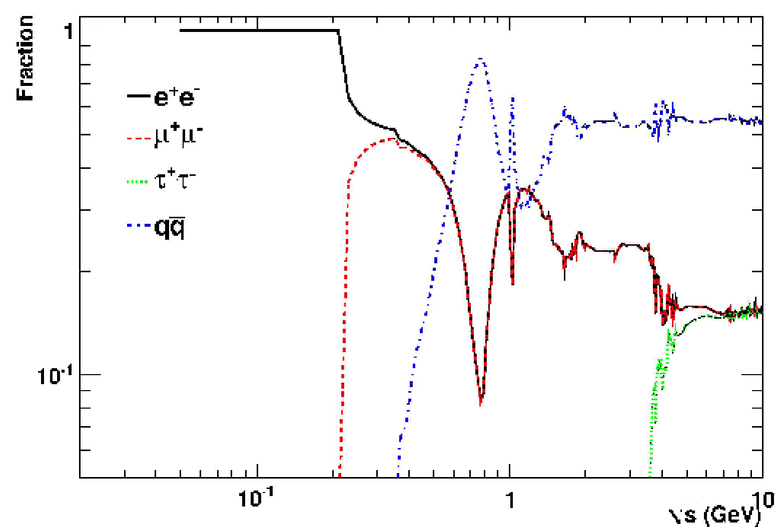
  with a mixing strength ε
- The dark photon couples to SM fermions with a charge εe

Dark photon branching fraction



The e^+e^- and $\mu^+\mu^-$ channels still make 30-40% if the total branching fraction at high masses

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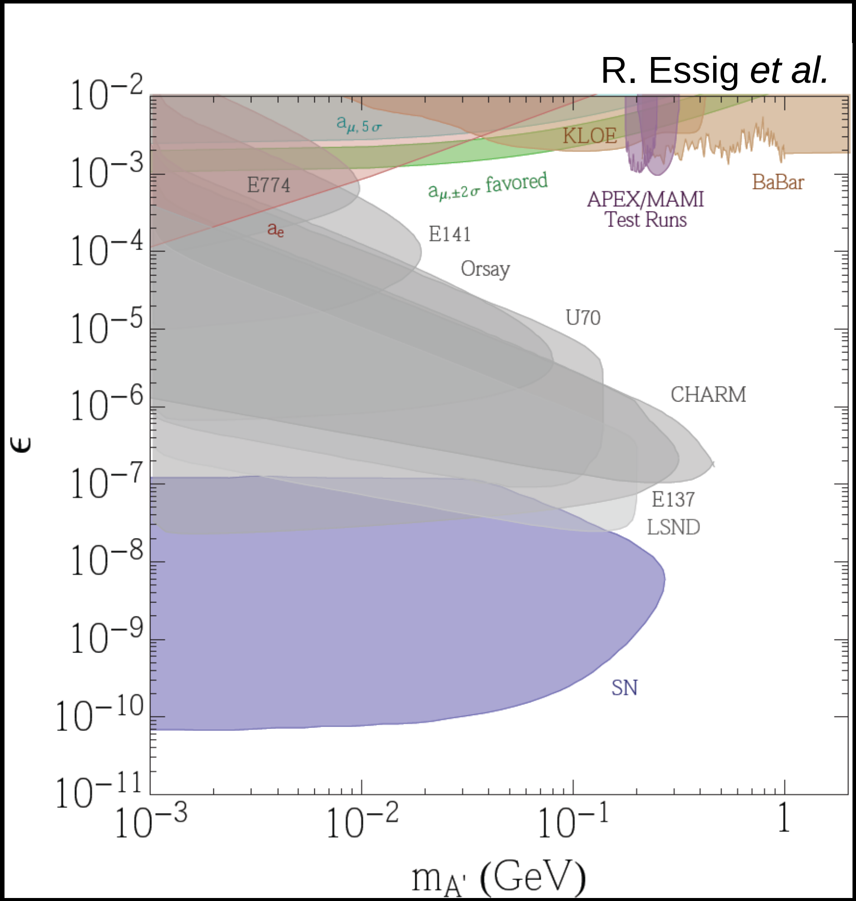
with a mixing strength ε

- The dark photon couples to SM fermions with a charge εe
- Theory favors $\varepsilon \sim 10^{-5} - 10^{-3}$, though models can accommodate lower values of ε

Current limits on ε



More on dark sectors: NLWCP subgroup of Intensity frontier
http://www.snowmass2013.org/tiki-index.php?page=New+Light%2C+Weakly+Coupled+particles

Dark sector

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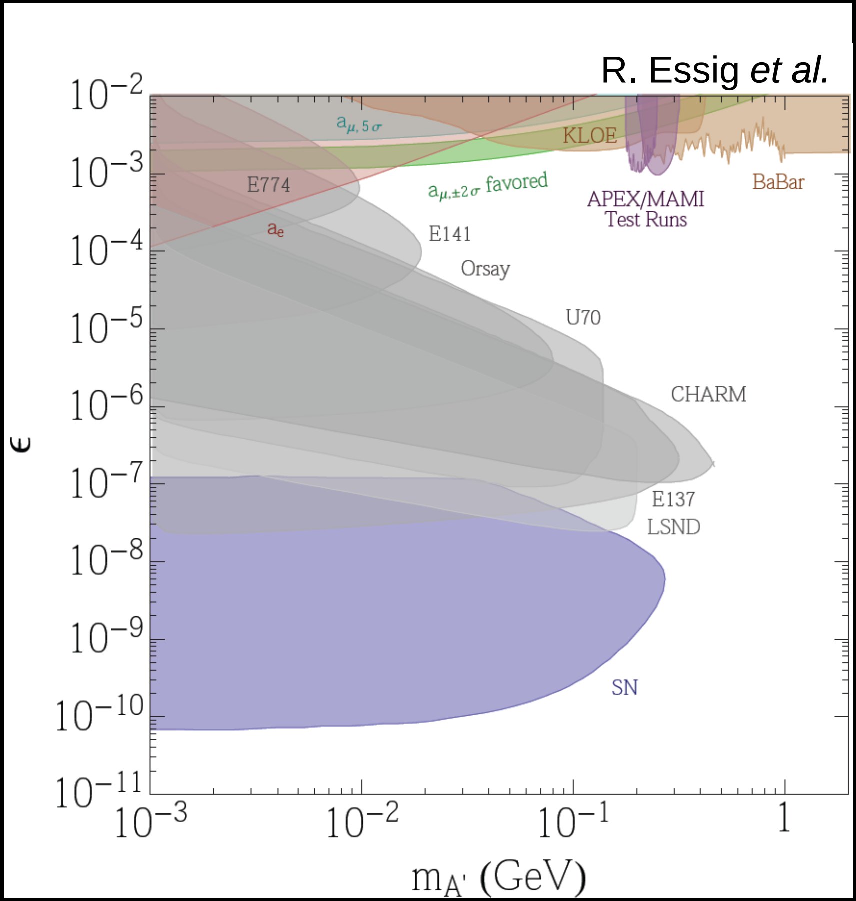
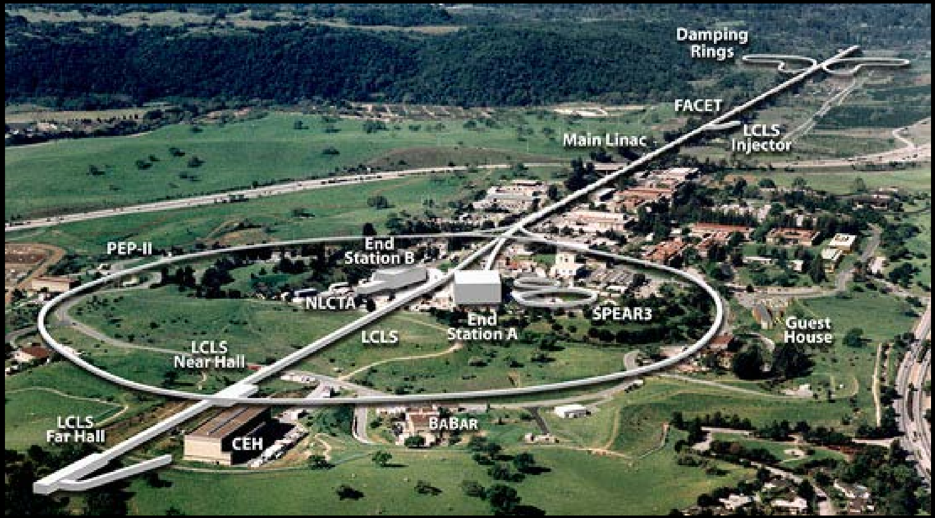
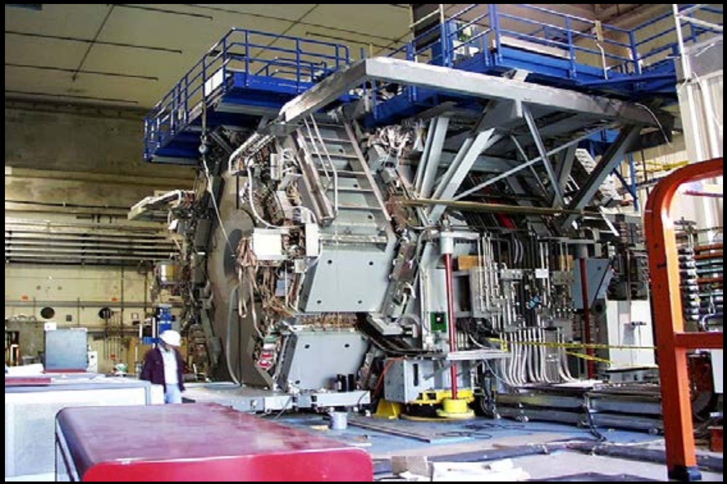
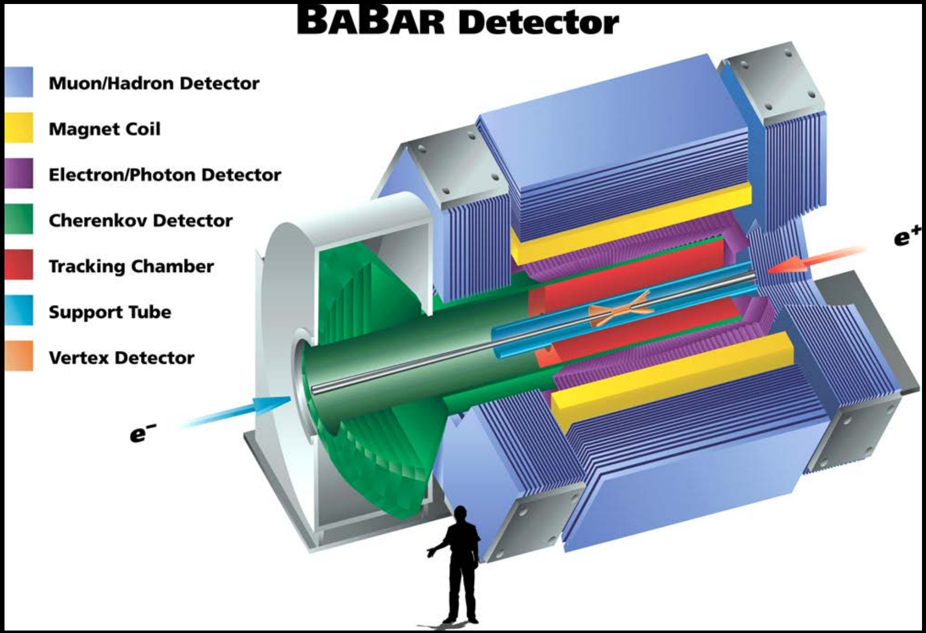


Low-energy high-luminosity e^+e^- colliders offer a ideal environment to search for MeV/GeV-scale hidden sector and explore their structure

The BABAR experiment at SLAC







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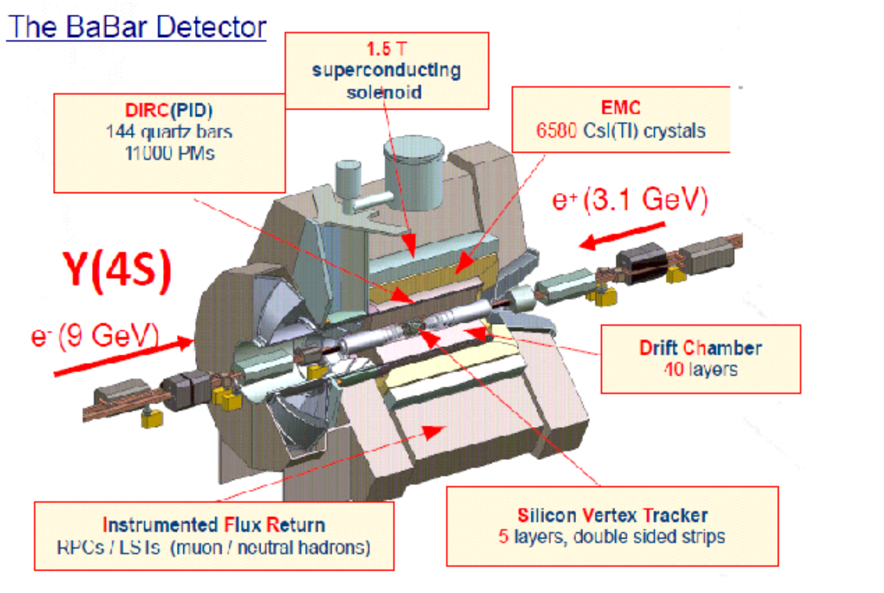

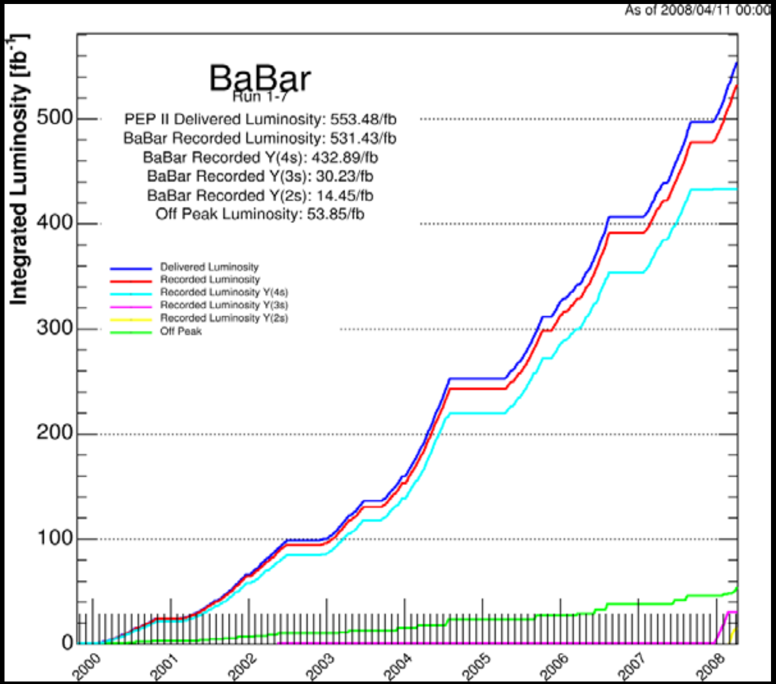

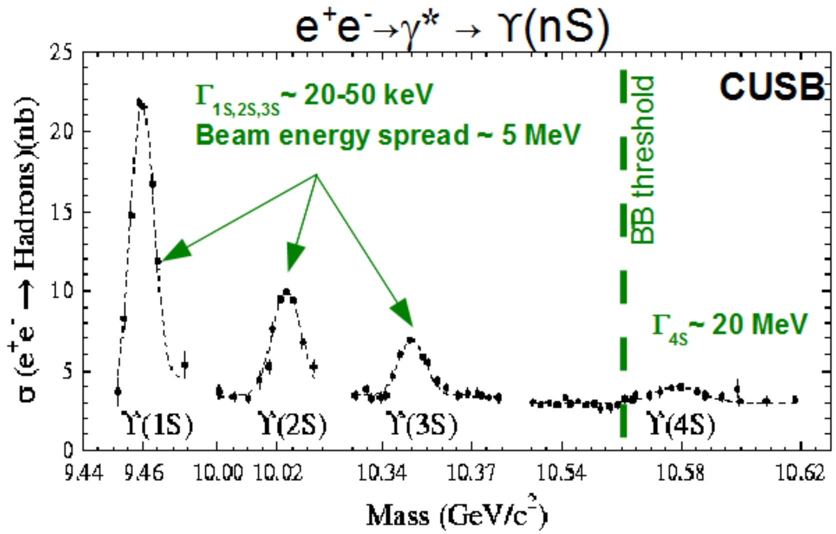

***BABAR* collected about 531 fb^{-1} of data**

$\sim 470 \times 10^6$ $\Upsilon(4S)$

$\sim 120 \times 10^6$ $\Upsilon(3S)$ (10x Belle)

$\sim 100 \times 10^6$ $\Upsilon(2S)$ (10x CLEO)

$\sim$ 18×10^6 $\Upsilon(1S)$ from $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$

Search for dark photon

$e^+e^- \to \gamma A'$, $A' \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-$
$e^+e^- \to \gamma A'$, $A' \to$ invisible

Search for dark boson(s)

$e^+e^- \to A'^* \to W' W'$,
$e^+e^- \to \gamma A' \to W' W''$

Search for dark Higgs boson

$e^+e^- \to h' A'$, $h' \to A' A'$
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Search for dark hadrons

$e^+e^- \to \pi_D + X$, $\pi_D \to e^+e^-, \mu^+\mu^-$

Search for dark photon in meson decay

$\pi^0 \to \gamma\, l^+l^-$, $\eta \to \gamma\, l^+l^-$, $\phi \to \eta\, l^+l^-$,...

Search for dark scalar (s) / pseudoscalar (a)

$B \to K^{(*)}s \to K^{(*)}\, l^+l^-$
$B \to K^{(*)}a \to K^{(*)}\, l^+l^-$
$B \to ss \to 2(l^+l^-)$
$B \to K\, 2(l^+l^-)$
$B \to 4(l^+l^-)$

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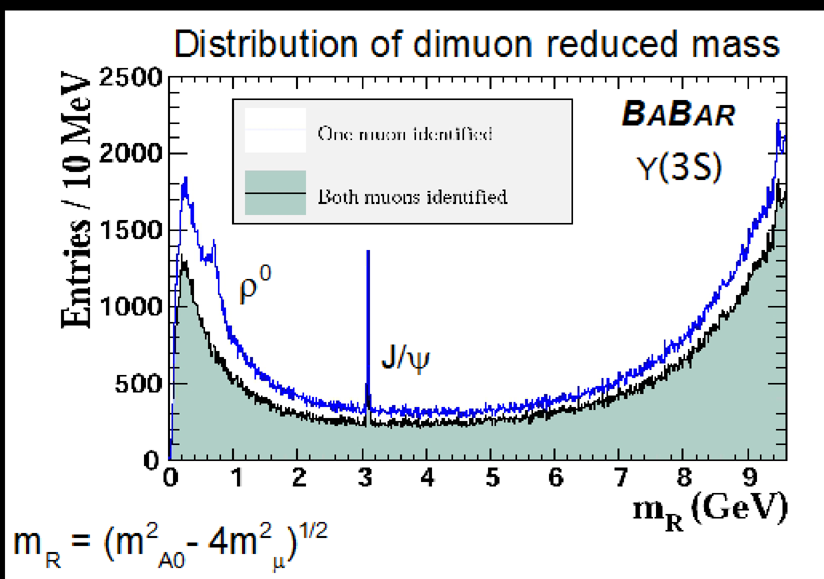
PRL 103 (2009) 081803

A dark photon can be readily produced in

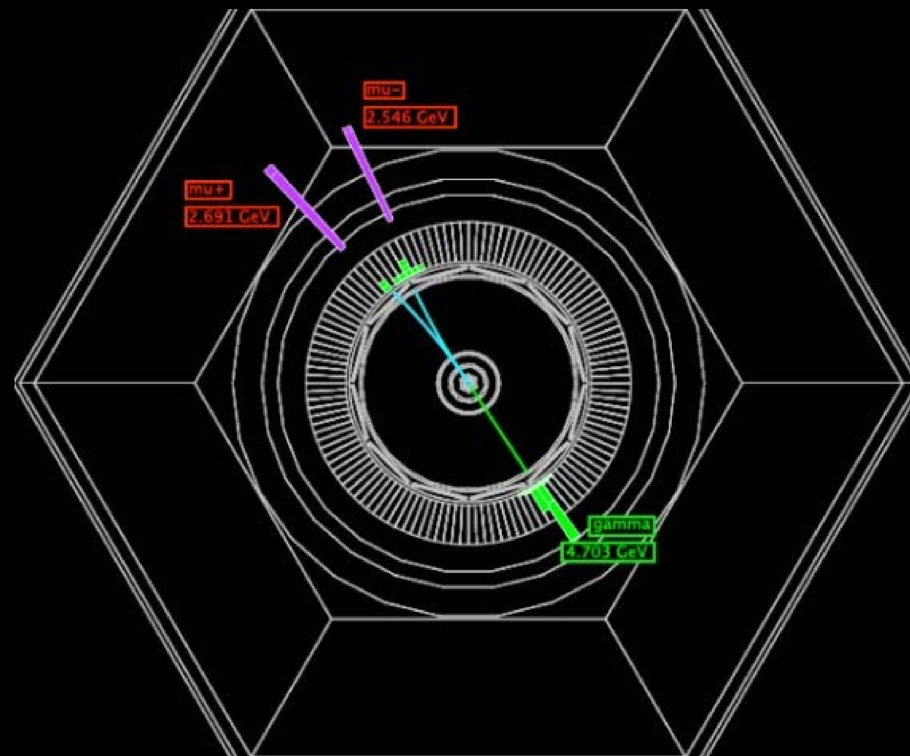
$$e^+e^- \rightarrow \gamma\, A' \rightarrow \gamma\, l^+l^-,\ \gamma\, q\bar{q}$$

So far, only one measurement of this final state at *BABAR* from light CP-odd Higgs search in Υ(2S,3S) decays based on ~45 fb^{-1} of data:

$$e^+e^- \rightarrow \gamma\, A^0,\ A^0 \rightarrow \mu^+\mu^-$$



Candidate event



Tracks
Photon
Signal in muon/hadron detector

PRL 103 (2009) 081803

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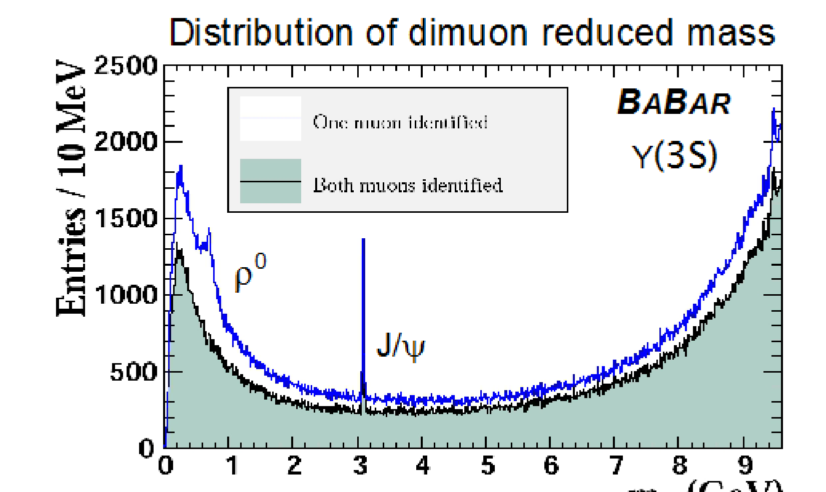
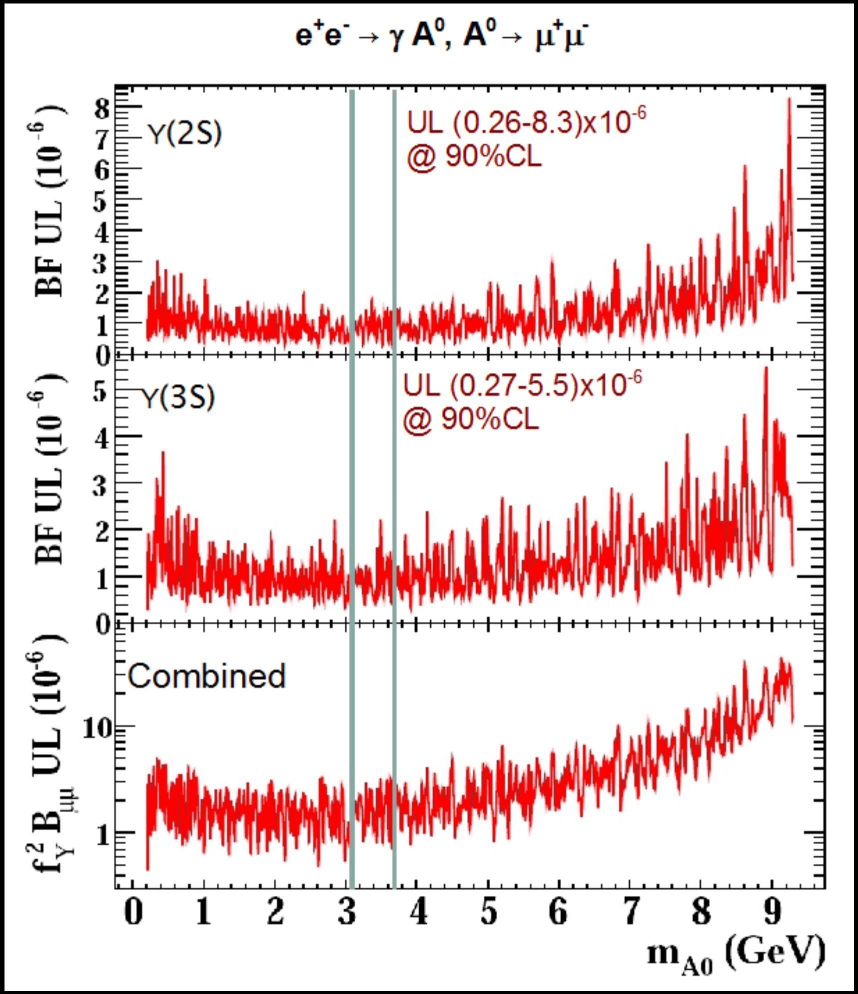


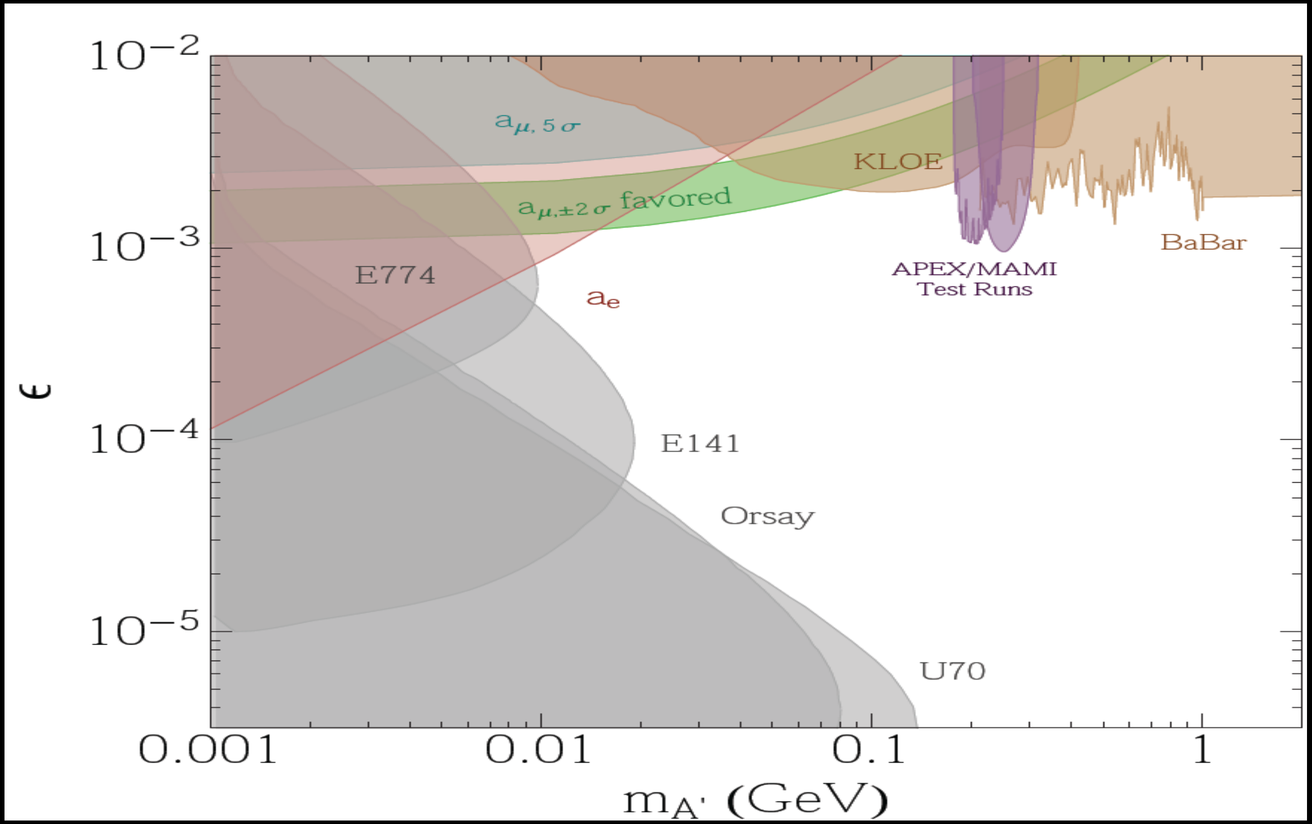
$m_R = (m^2_{A0} - 4m^2_{\mu})^{1/2}$



No sign of narrow resonance

R. Essig *et al.*

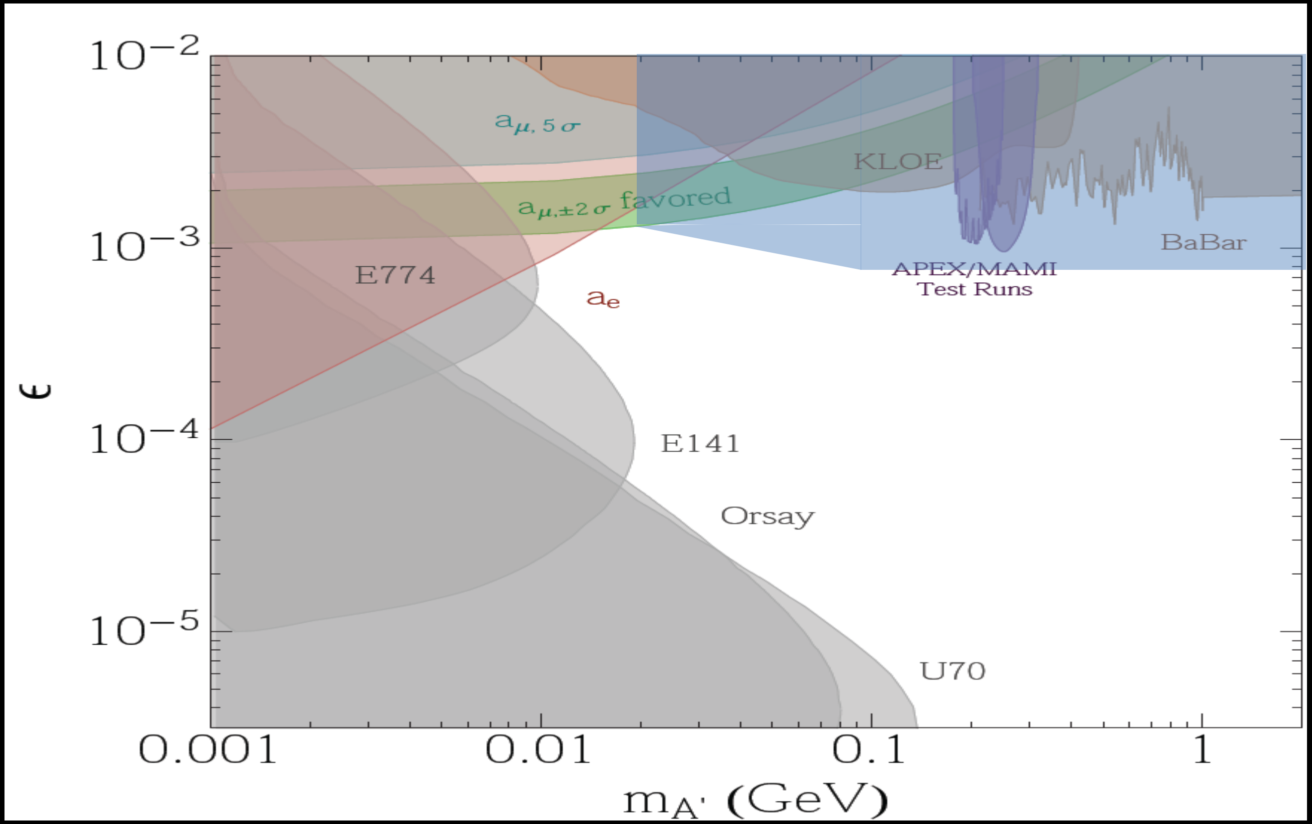
Theorists reinterpreted the previous limits as bounds on ε



Search for dark photon

R. Essig *et al.*

Projected limits with full *BABAR* dataset for $e^+e^- \to \gamma A'$, $A' \to e^+e^-, \mu^+\mu^-, \pi^+\pi^-$

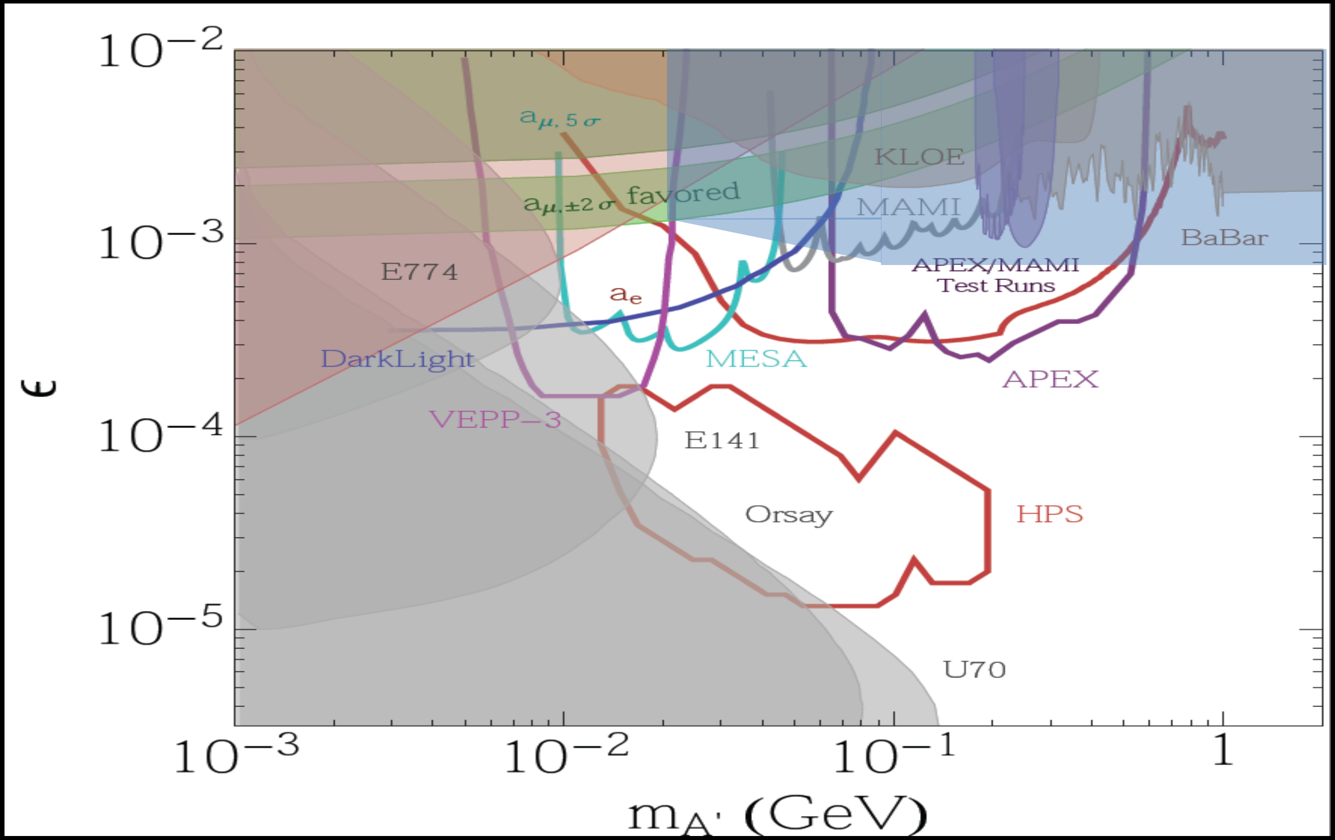


Expect significant improvement, exclude almost all the "g-2" preferred region

Search for dark photon

R. Essig *et al.*

Comparison with expected sensitivity of dedicated experiments



BABAR will already probe a substantial fraction of parameter space accessible to future experiments

Search for invisible dark photon decay

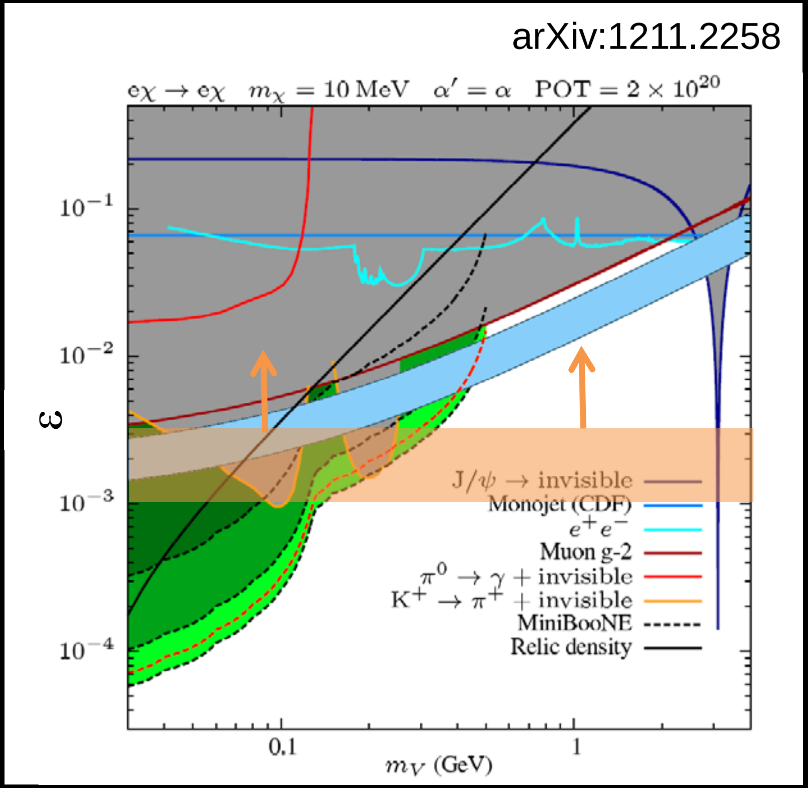
- Several scenarios where dark photon decays to invisible final states (lighter dark sector particles) or might be long lived:

$$e^+e^- \rightarrow \gamma A' \;,\;\; A' \rightarrow \text{invisible}$$

- Can tag the invisible decay by analyzing the recoiling mass against the photon

- Current measurement of this final state in progress, expect limits on ε^2 should be at the level of 10^{-5} - 10^{-6}.

- Bounds on the mixing parameters are shown on the right plot for current experiments (grey) and expected sensitivity from neutrino experiments (green). The "g-2" preferred region is also shown (light blue band).

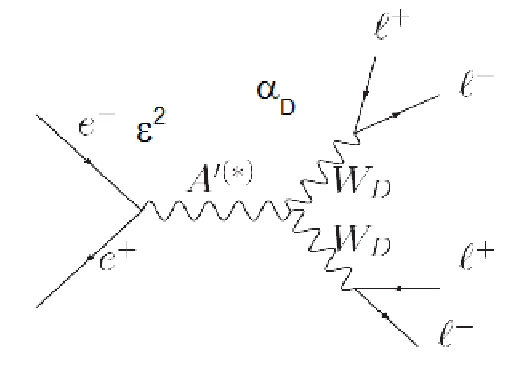


BABAR will explore a significant fraction of the allowed parameter space

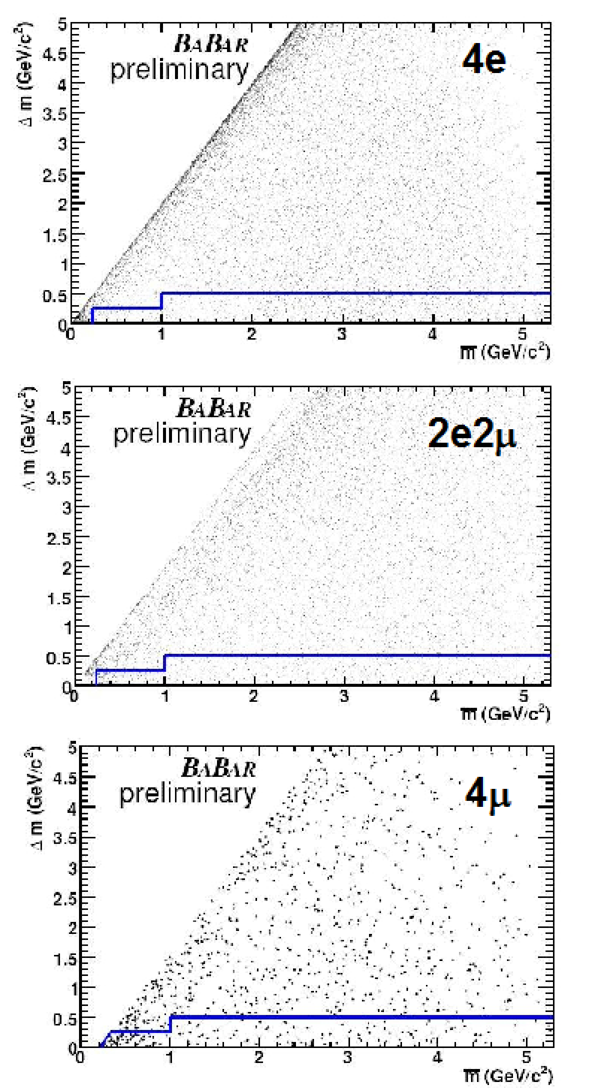
Search for dark boson

arXiv:0908.2821

$e^+e^- \to A'^* \to W_D\, W_D',$
$W_D^{(')} \to e^+e^-, \mu^+\mu^-$



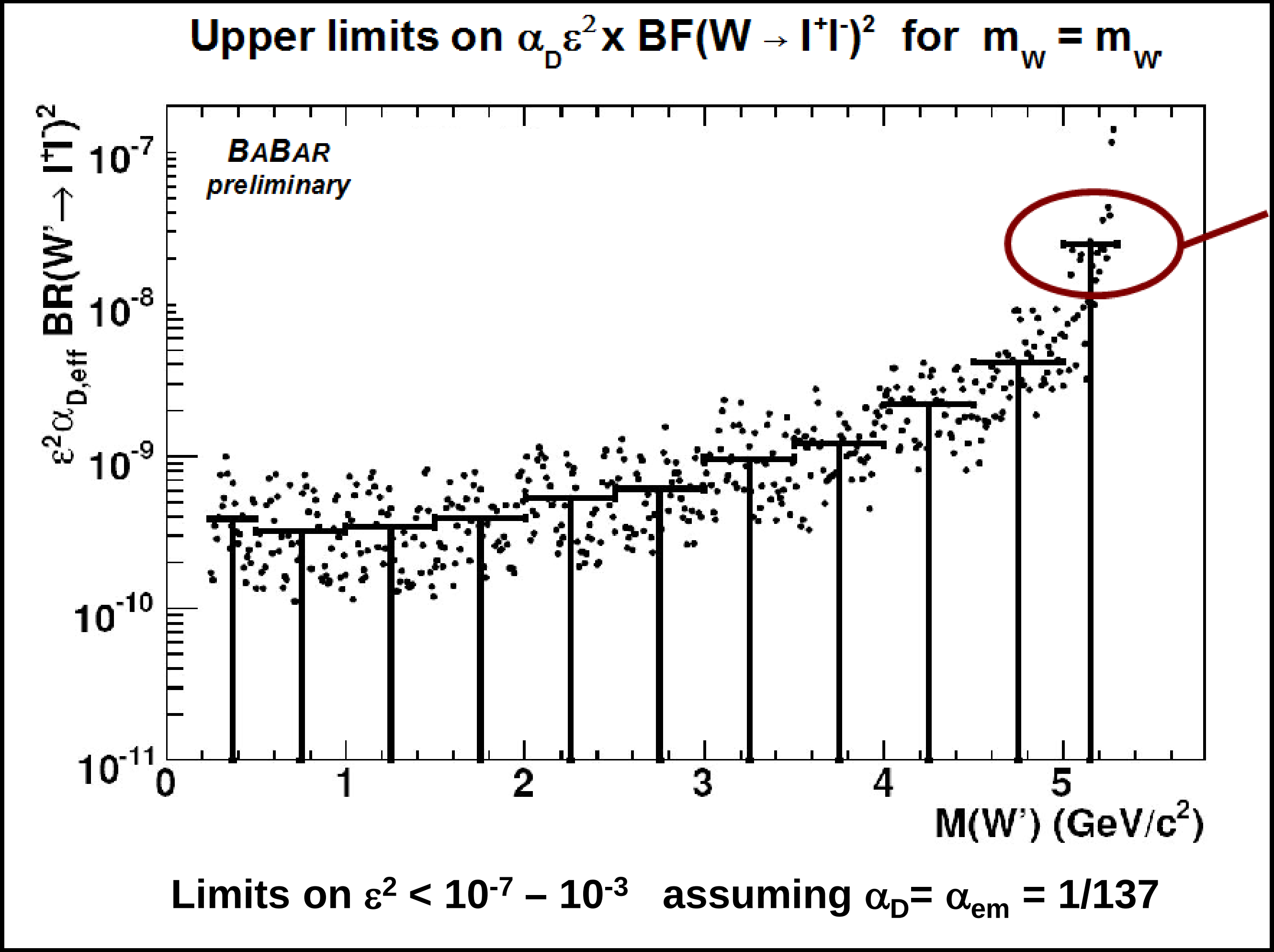
$\alpha_D = g_D^2 / 4\pi$
g_D dark sector gauge coupling



$\overline{m} = (m_{min} + m_{max})/2$
$\Delta m = (m_{max} - m_{min})/2$

- The simplest extension to a non-Abelian case is SU(2)xU(1), which has 4 bosons: A', W_D, W_D' and W_D''
- Can produce a pair of dark bosons though an off-shell A'.
- Sensitive to the dark sector gauge coupling g_D ($\alpha_D = g_D^2 / 4\pi$)
- Search for two dileptonic resonances with similar mass

arXiv:0908.2821



Average limit over many bins

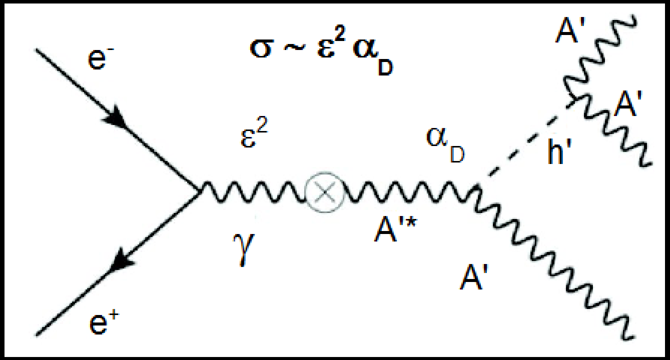
Expect similar limits for $m_W - m_{W'} >> 0$

Search for dark Higgs boson

- Dark photon mass is generated via the Higgs mechanism, adding a dark Higgs boson (h')
- A minimal scenario has a single dark photon and a single dark Higgs boson.
- In many generic models, the dark Higgs mass is also at the MeV/GeV scale
- The Higgsstrahlung process

$$e^+e^- \rightarrow A'^* \rightarrow h' A' ,\ h' \rightarrow A' A'$$

is very interesting, as it is only suppressed by ε^2 and is expected to have a very small background.



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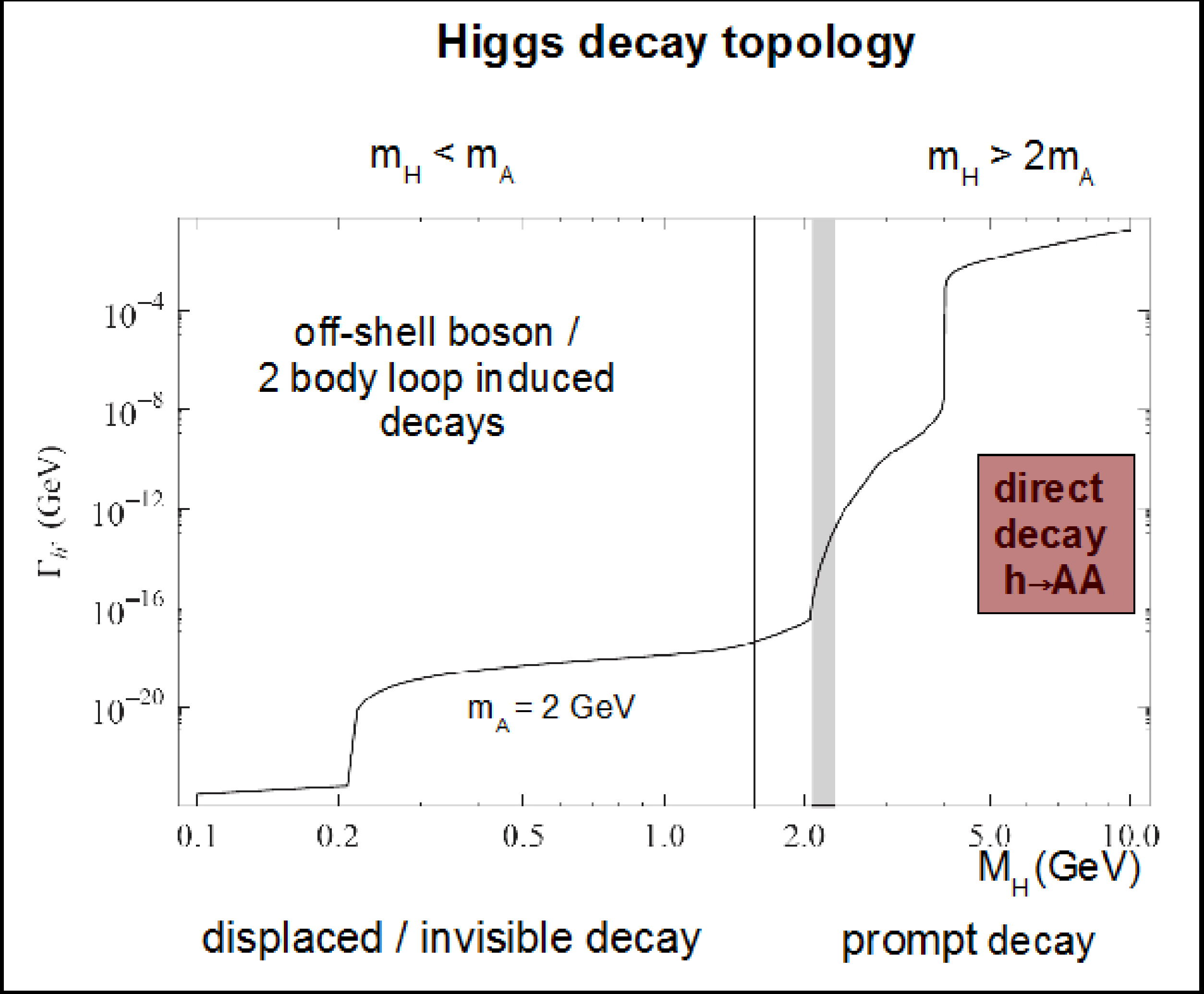
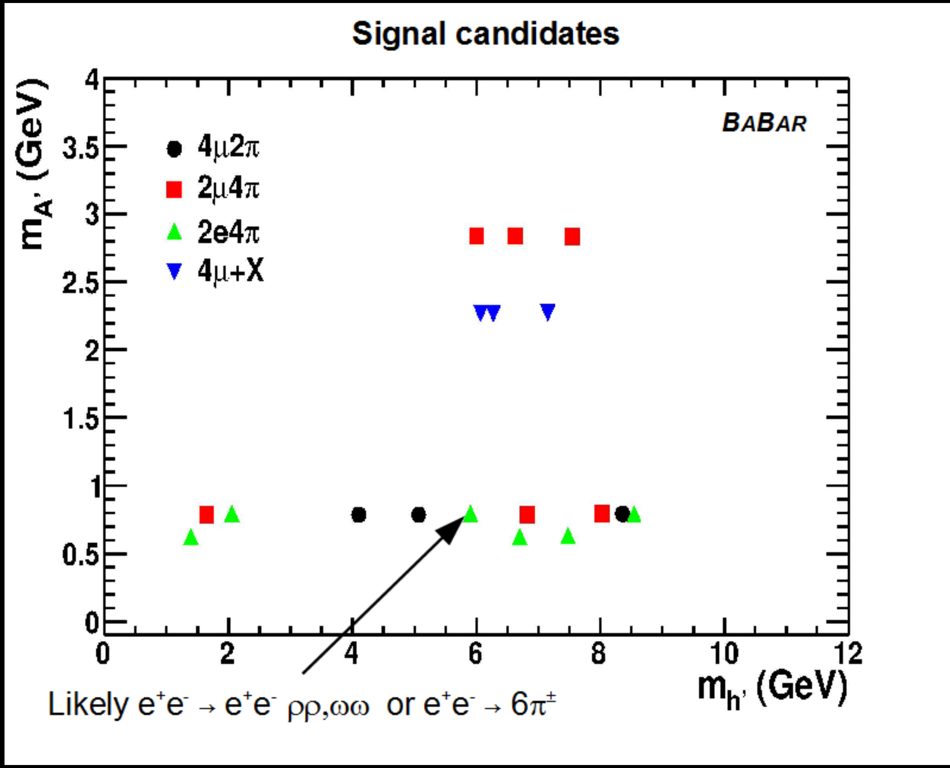


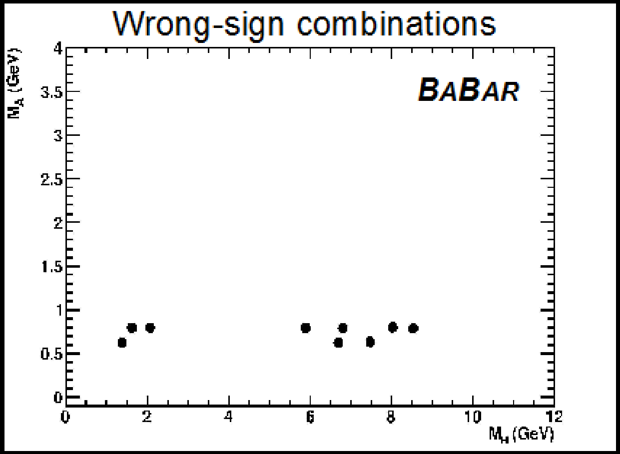
Search for prompt decays, i.e. three resonances with similar masses

Search for dark Higgs boson

PRL 108 (2012) 211801

- Six candidates are selected from the full *BABAR* dataset (~500 fb^{-1})
- Three entries for each event, corresponding to the three possible assignments of the $h' \rightarrow A'A'$ decay
- Estimate background from
  - wrong-sign combinations, e.g. $e^+e^- \rightarrow (e^+e^+)(e^-e^-)(\mu^+\mu^-)$
  - sidebands from final sample
  - rate for 6 leptons ~ 100x rate for $4\pi+2l$ above 1.5 GeV

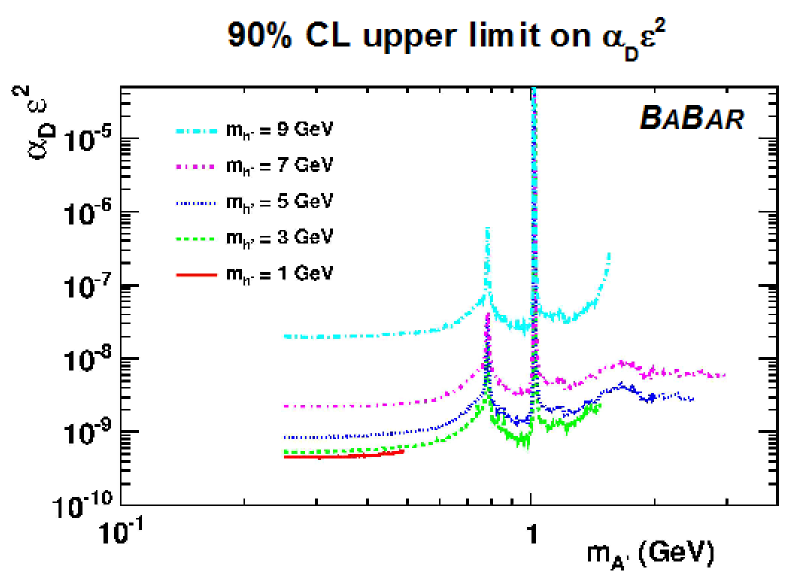


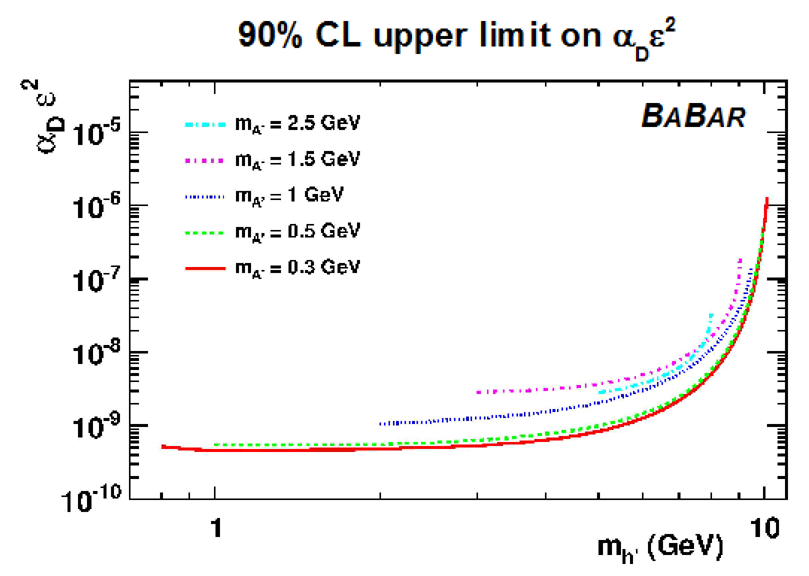


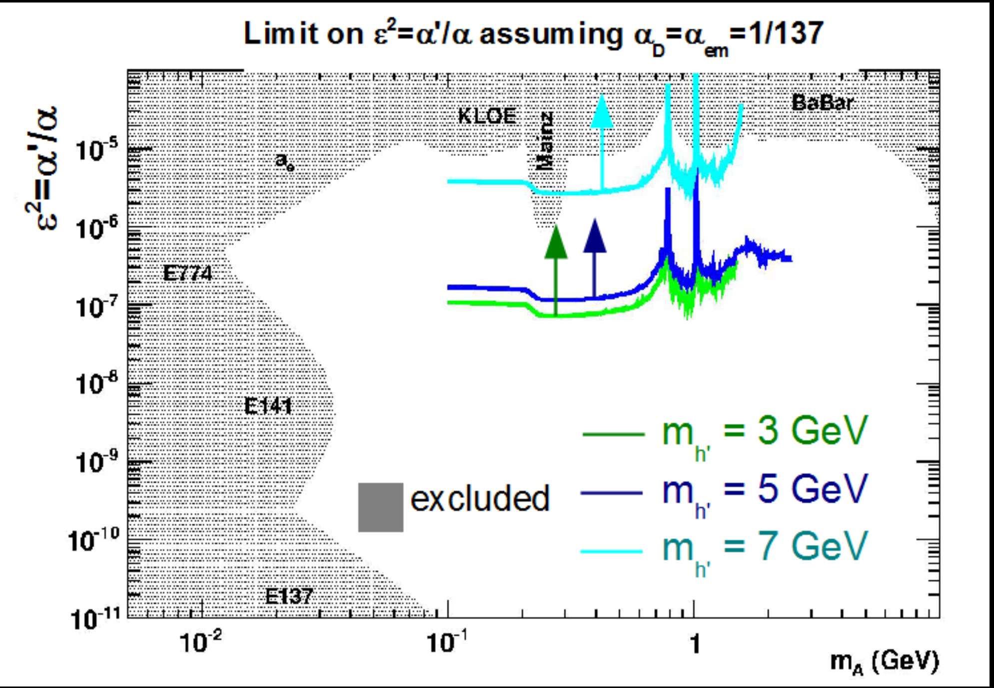
No events with 6 leptons, consistent with the pure background hypothesis

Search for dark Higgs boson

PRL 108 (2012) 211801







Substantial improvement over existing limits for $m_{h'}$ < 5 - 7 GeV if a light dark Higgs boson exists

Conclusion

- Low-energy e^+e^- colliders provide a unique opportunity to directly explore their structure: dark photon, dark Higgs boson, non-Abelian structure, scalar and pseudoscalar content,…

- Constraints on dark Higgs / dark photon production have already been set, and will be further improved in the near future. The next generation of flavor factory (SuperKEKB) can even be competitive with dedicated experiments.

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- Constraints on dark Higgs / dark photon production have already been set, and will be further improved in the near future. The next generation of flavor factory (SuperKEKB) can even be competitive with dedicated experiments.
- But light hidden sector will still be largely unconstrained are really worth exploring