Limits on the Dark Sector from BaBar

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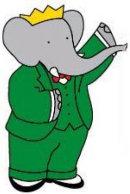
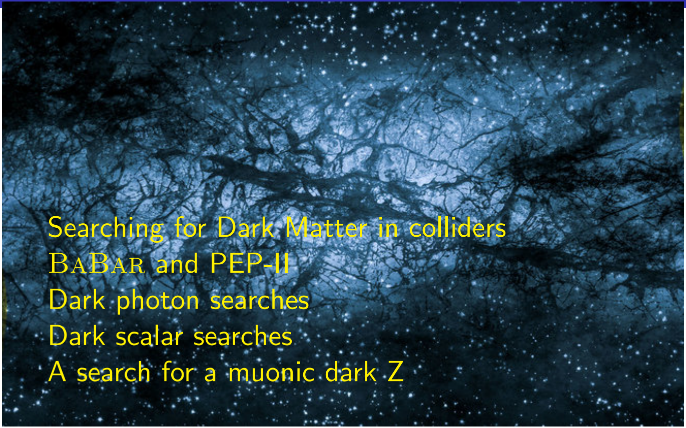


Dark Matter searches with BaBar



- Searching for Dark Matter in colliders
- BaBar and PEP-II
- Dark photon searches
- Dark scalar searches
- A search for a muonic dark Z

Why searching for Dark Matter in colliders?

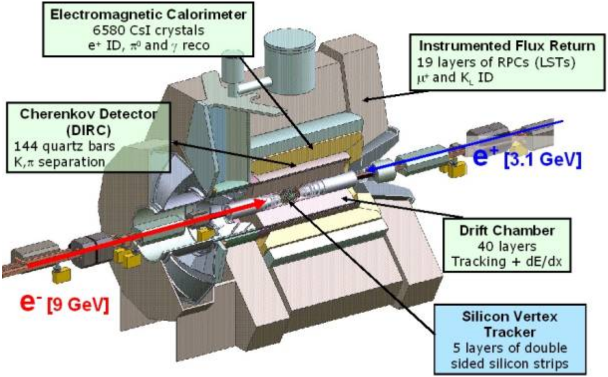
1. We know it's there, because of Galaxy motion and CMB
2. It interacts gravitationally, so it has mass
3. It presumably gets its mass from a Higgs field
4. So it has some sort of gauge structure
5. Hence gauge bosons
6. Although these are dark they connect with our gauge bosons through kinetic mixing: small (ballpark estimate $\epsilon \sim 10^{-4}$) but inescapable.
7. Search in particle collisions – events have very small cross sections and subtle but distinctive signatures.
8. So need large amounts of data, clean environment, hermetic detector and high quality energy/ momentum measurements and particle identification

The BaBar Detector at PEP-II

e^+e^- collider
Asymmetric beams
$E_{cms} \sim 10$ GeV

Highly hermetic detector
Superb π/K separation
Excellent γ detection

Ran from 1999-2008
Collected 0.5 ab^{-1}
(over 1 billion Bs)

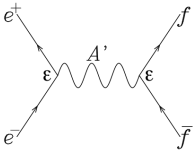


Established CP violation in the B sector, plus many other physics results...

Dark photon searches using ISR

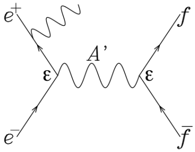
"Search for a dark photon in e^+e^- collisions at BaBar", *Phys. Rev. Lett.* **113**, 201801 (2014)

Dark Photon A'
Kinetic mixing ϵ with standard photon A (or γ).



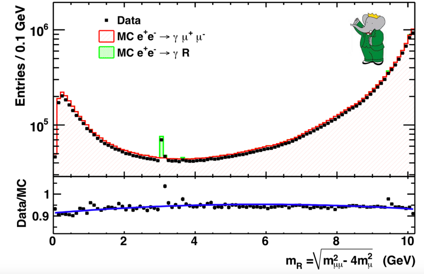
Scan for narrow A' peak in $e^+e^- \to A'$ difficult as the beam energy has to be exactly right.

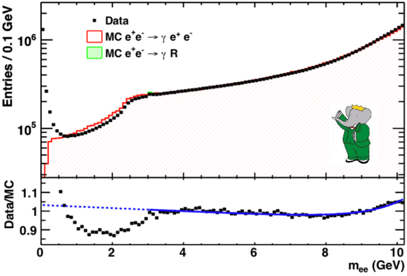
Instead use ISR process, measuring photon.



Measure $\mu^+\mu^-$ (and e^+e^-) pairs and look for narrow peak in invariant mass.

Dark photon searches using ISR





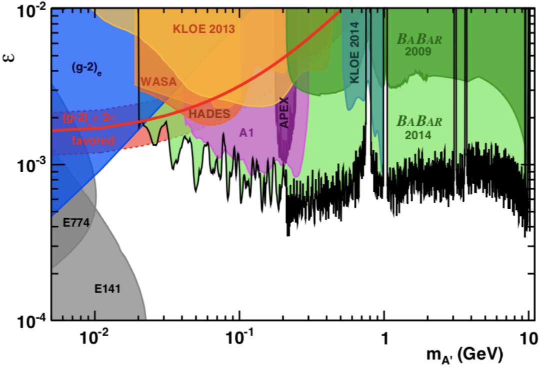
Trigger on two oppositely charged tracks + photon(s)

Handy to work with $m_R = \sqrt{M^2_{\mu^+\mu^-} - 4m^2_\mu}$

Electron channel harder due to high background. Also MC does not describe low mass region.

No sign of any signal in electron or muon channel. ψ and Υ resonances show up, but nothing new

Dark photon searches using ISR



Convert non-observation of signal into limits of $M_{A'}$ and ϵ using cross section given by R. Essig, P. Schuster, and N. Toro, Phys. Rev. D 80, 015003 (2009).

Search for invisible dark photon

J P Lees *et al*, "Search for invisible decays of a dark photon produced in e^+e^- collisions at BABAR", Phys. Rev. Lett. **119** 1031804 (2017)

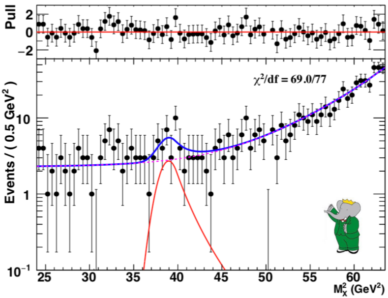
Search for a dark photon decaying invisibly to dark matter objects

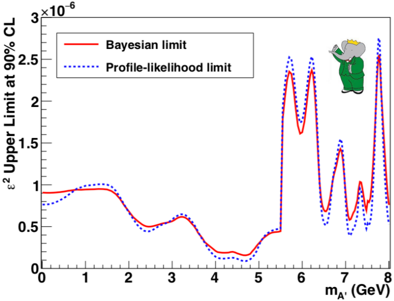
Not whole dataset - only 53 fb^{-1} out of full 514 fb^{-1} - due to need for specific trigger: a 2 GeV (later 1 GeV) photon and no tracks from intersection point found in the drift chamber.

Main background from $e^+e^- \to \gamma\gamma$ with badly measured photons. Separation using BDT with 12 inputs from clusters in electromagnetic and hadron calorimeters.

Search for invisible dark photon

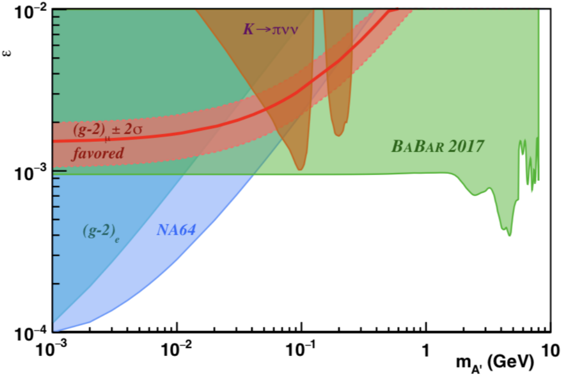
Missing mass from $M_X^2 = s - 2E_\gamma^* \sqrt{s}$.
No significant signal: best (at $M_X = 6.21$ GeV) is 2.6 σ





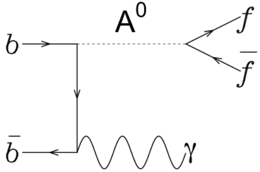
Search for invisible dark photon

Exclusion region (90% confidence upper limit)



Dark scalar searches

Search for a dark scalar A^0 in $\Upsilon(1S)$ decays.



Good place to look as higgs-like A^0 may couple to high mass b quark.
Obvious strategy would be to run at $\sqrt{s} = M_{\Upsilon(1S)} = 9.46 GeV$. But background from $e^+e^- \rightarrow q\overline{q}$ continuum still very high.
To get pure sample of $\Upsilon(1S)$, run on $\Upsilon(2S)$ and tag the 2 pions in $\Upsilon(2S) \rightarrow \Upsilon(1S)\pi^+\pi^-$ decays
$\Upsilon(3S)$ can also be used.....

Dark scalar searches

Limit on product branching ratio
$Br(\Upsilon(1S) \to \gamma A^0) \times Br(A^0 \to \text{final state})$
Require $\pi^+\pi^-$ giving Υ tag, fairly energetic photon + specific signature(s)

Final state	90% CL Limit for small m_A	BaBar Reference
invisible	3×10^{-6}	*Phys. Rev. Lett.* **107**, 021804 (2011)
hadrons	10^{-6}	*Phys. Rev. Lett.* **107**, 221803 (2011)
$\mu^+\mu^-$	3×10^{-7}	*Phys. Rev.* **D 87**, 031102 (2013)
$\tau^+\tau^-$	10^{-5}	*Phys. Rev.* **D 88**, 071102 (2013)
gg	10^{-6}	*Phys. Rev.* **D 88**, 031701 (2013)
$s\bar{s}$	10^{-5}	*Phys. Rev.* **D 88**, 031701 (2013)
$c\bar{c}$	10^{-4}	*Phys. Rev.* **D 91**, 071102 (2015)

Analyses can be interpreted in framework on NMSSM 2-Higgs models, which gives predictions for branching ratios depending on $\tan\beta$. But results stand on their own.

Dark scalar search decaying to $c\overline{c}$

"Search for a light Higgs resonance in radiative decays of the $\Upsilon(1S)$ with a charm tag"
Phys. Rev. **D 91**, 071102 (2015)

Select on

- Energetic photon
- $\pi^+\pi^-$ with $m_R = \sqrt{M^2_{\Upsilon'} + m^2_{\pi\pi} - 2M_{\Upsilon'}E_{\pi\pi}}$ within $9.45 - 9.47 GeV/c^2$
- A least one charm meson from (inc charge conjugates) $D^0 \to K^-\pi^+, D^0 \to K^0_s\pi^+\pi^-, D^0 \to K^-\pi^+\pi^+\pi^-,$ $D^+ \to K^-\pi^+\pi^+, D^*(2010) \to \pi^+ D^0(\to K^-\pi^+\pi^0)$

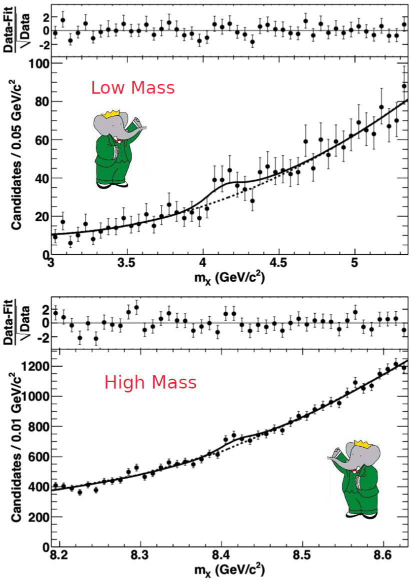
Separate high and low A^0 mass regions 4-8 and 7.5-9.25 GeV due to high background from low energy photons at large $M_{A'}$
Then select using 10 BDTs (2 regions, 5 channels) with 24 variables

Dark scalar search decaying to $c\bar{c}$

Reconstruct missing mass from well-measured quantities

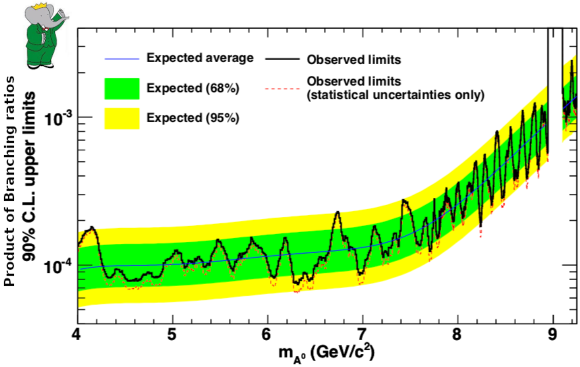
$$M_X^2 = (P_{e^+e^-} - P_{\pi\pi} - P_\gamma)^2$$

No sign of any a significant excess over background (2.3 σ at best)



Dark scalar search decaying to $c\bar{c}$

Non-observation translates to 90% upper limits

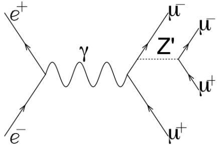


A search for a dark Z

Search for a muonic dark force at BABAR *Phys. Rev.* **D 94**, 011102 (2016)

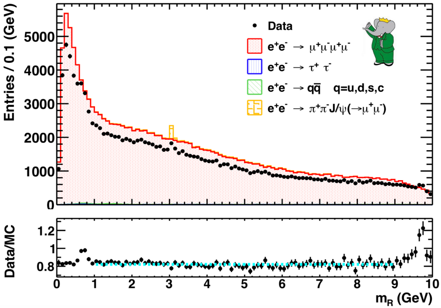
Possible dark Z' boson coupling to 2nd and 3rd generation but not 1st.

X G He, G C Joshi, H Lew & R R Volkas, *Phys. Rev.* **D 44**, 2118 (1991).



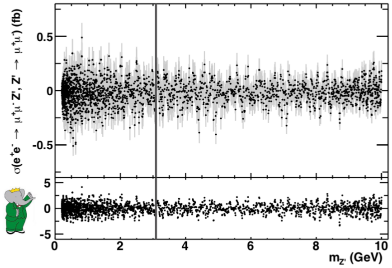
4 tracks, with muon ID and no missing energy/momentum

No signal seen
Simulation does not include full radiative corrections hence different shape.
But can still extract limits



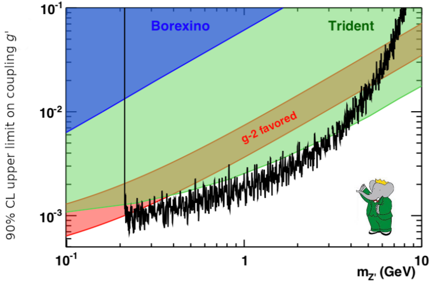
A search for a dark Z

Measurement of cross section as function of $m_{Z'}$

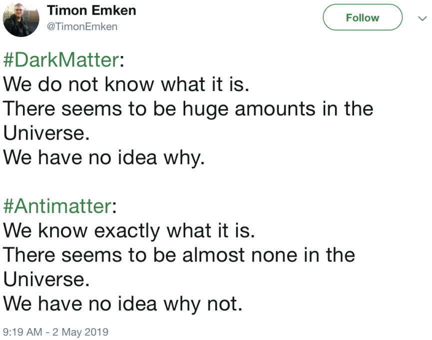


Extract 90% CL limits on coupling as a function of mass

Rule out wide range



Conclusions


Timon Emken
@TimonEmken
Follow

#DarkMatter:
We do not know what it is.
There seems to be huge amounts in the Universe.
We have no idea why.

#Antimatter:
We know exactly what it is.
There seems to be almost none in the Universe.
We have no idea why not.

9:19 AM - 2 May 2019

BaBar has contributed not only to our knowledge of #Antimatter but also to our puzzlement over #DarkMatter

Good luck to Belle II !