Search for dark-sector Higgs and gauge bosons at *BABAR*

Adrian Bevan

Outline

- Motivation

- The *BaBar* experiment and PEP-II

- What are we looking for?

- Searches for $e^+e^- \to A'h' \, (h' \to A'A')$

- Summary

Motivation

- Overwhelming astrophysical evidence for dark matter with several possibly related anomalies:

  - Rotational velocity of spiral galaxies,

  - Integral's 511 keV γ excess,

  - PAMELA rising e^+ fraction, FERMI, DAMA/LIBRA results,

  - WMAP data ...

M31 Rotational Velocity

INTEGRAL, Astron. Astrophys. **441** 513-532 (2005)
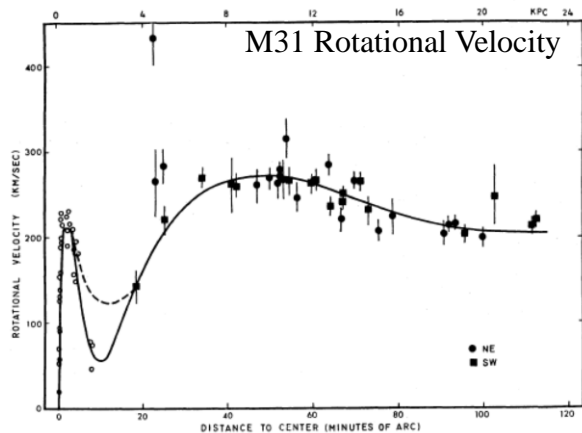
Rubin & Ford, APJ **159** 379-403 (1970)
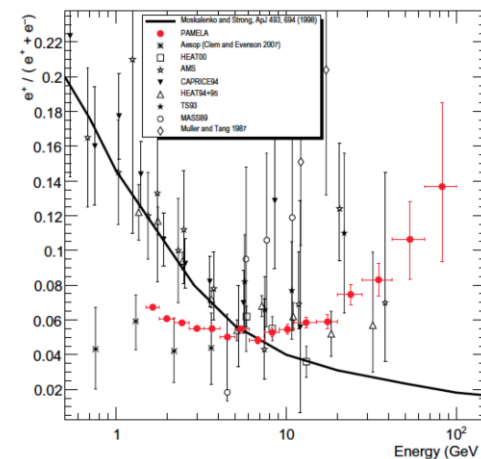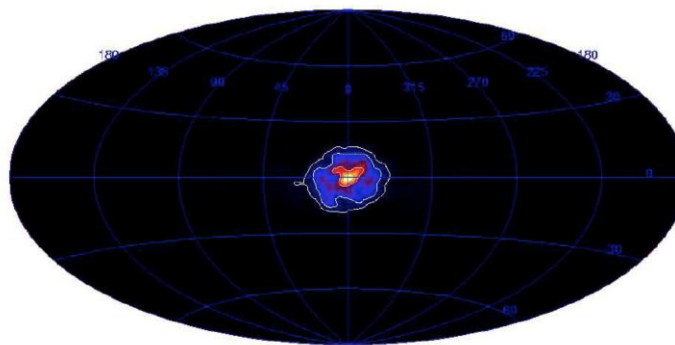
PAMELA, New J. Phys. 11 105023 (2009)

- This motivates ongoing searches for SUSY at the LHC and light scalars and dark sector particles at B Factories.
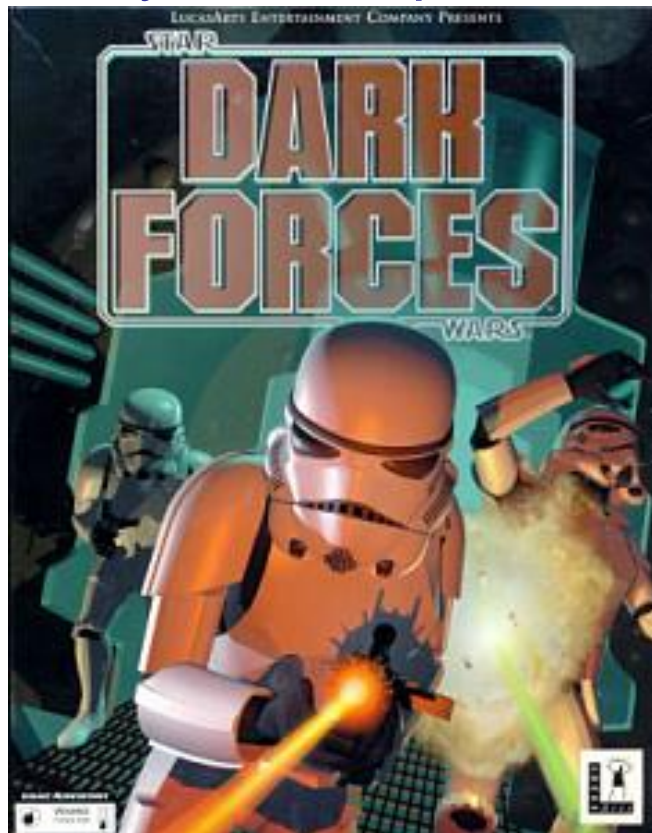
Motivation

- The need for dark matter is well understood – but this is part of the solution. Many models postulate

Motivation

- The need for dark matter is well understood – but this is part of the solution. Many models postulate

For example see the following Refs:

N. Arkani-Hamed et al.
[PRD **79** 015014 (2009)]

B. Batell et al.
[PRD **79** 115008 (2009)]
[PRD **80** 095024 (2009)]

Bjorken et al.
[PRD **80** 075018 (2009)]
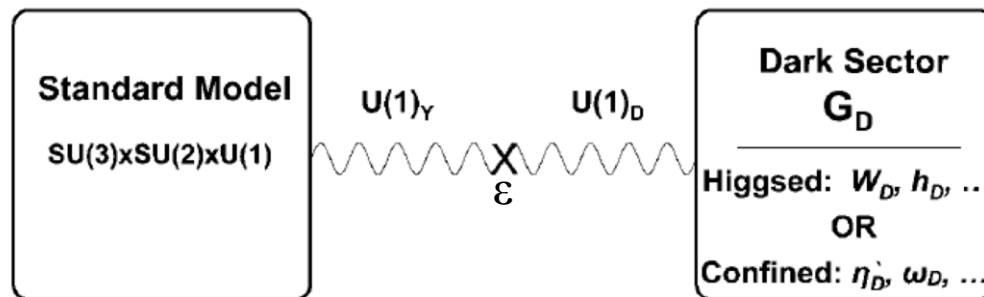
R. Essig et al.
[PRD **80** 015003 (2009)]

- ~ TeV DM self interaction can be mediated by dark forces with a light hidden sector & dark gauge boson at ~GeV.

Motivation

- The need for dark matter is well understood – but this is part of the solution.

e.g. R. Essig et al.
[PRD **80** 015003 (2009)]

MeV – 10 GeV low energy dark sector:

- MeV scale dictated by interpretation of INTEGRAL data:

$$\chi\chi \to e^+e^- \qquad \text{vs.} \qquad \chi\chi \to \chi\chi^* \to \chi\chi e^+e^-$$

- Natural dark sector mass scale of O(GeV) for ~TeV scale DM.

Interaction with SM matter through kinetic mixing ε, and we want to constrain the coupling g_D and/or ε.

- B factories are a good place to look for dark forces.

- Asymmetric energy e^+e^- collider operating primarily at the $\Upsilon(4S)$.

At the SLAC National Laboratory

SLAC@50
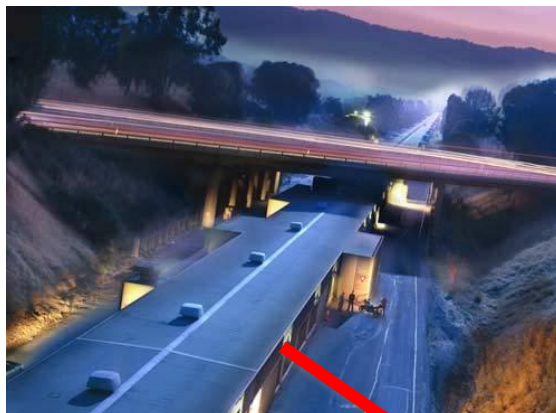
- Asymmetric design.
- Central tracking system
- Particle Identification System
- Electromagnetic Calorimeter
- Solenoid Magnet
- Muon/K^0_L Detection System
- High operation efficiency

IFR

SOLENOID

EMC

e^+

e^-

SVT

DCH

DIRC
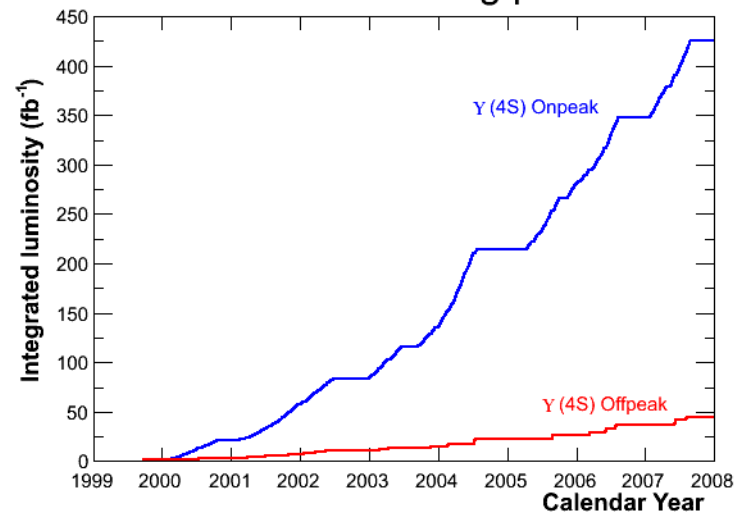
BaBar

PEP-II
ASYMMETRIC B FACTORY
SLAC/LBL/LLNL
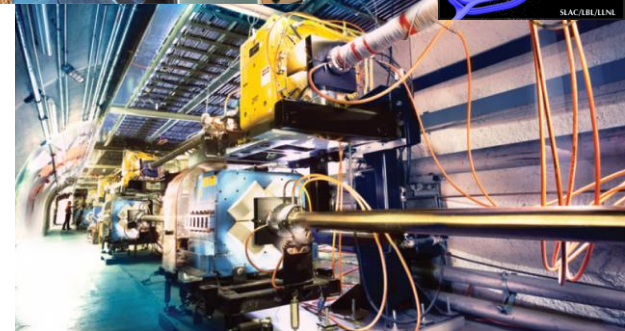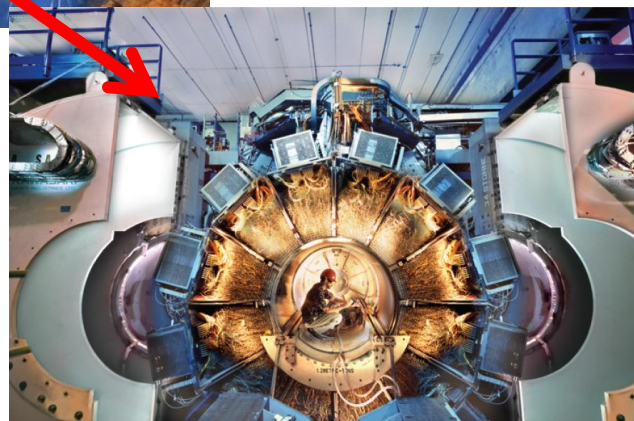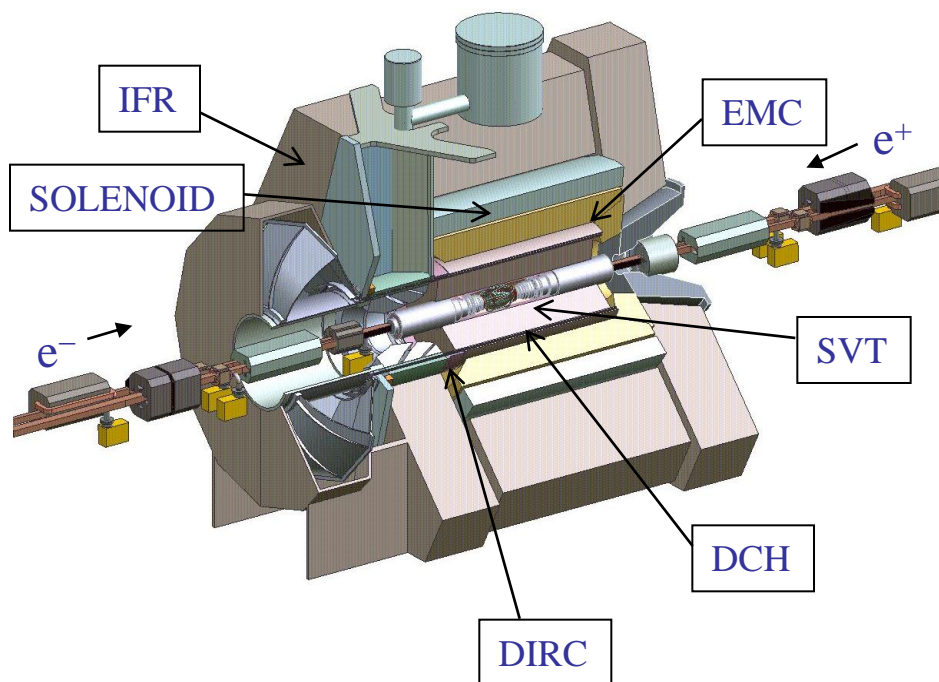
BaBar & PEP-II

- Data was taken from 1999 through 2008

  - Mostly at the *Y(4S),*
  - Some "offpeak" just below the *Y(4S),*
  - also at the *Y(2S) & Y(3S),*
  - and a high energy scan above the *Y(4S).*

  - 524fb^{-1} recorded in total.

  - Use data from all energies in this analysis.
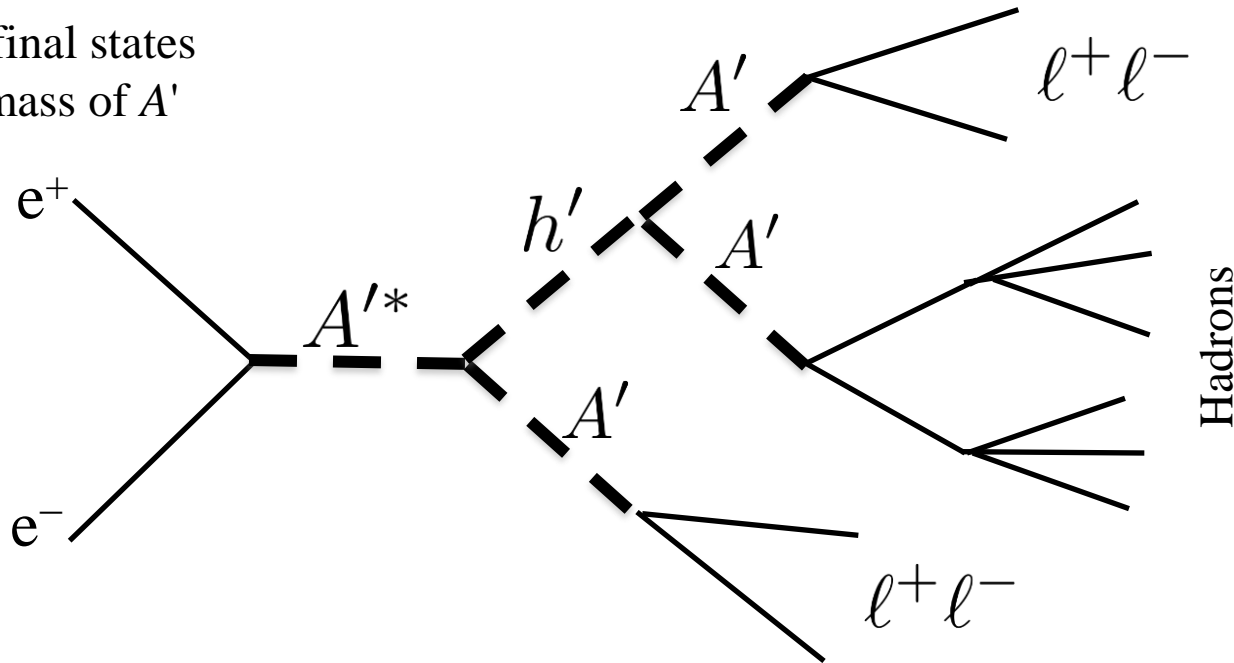

BABAR data taking periods
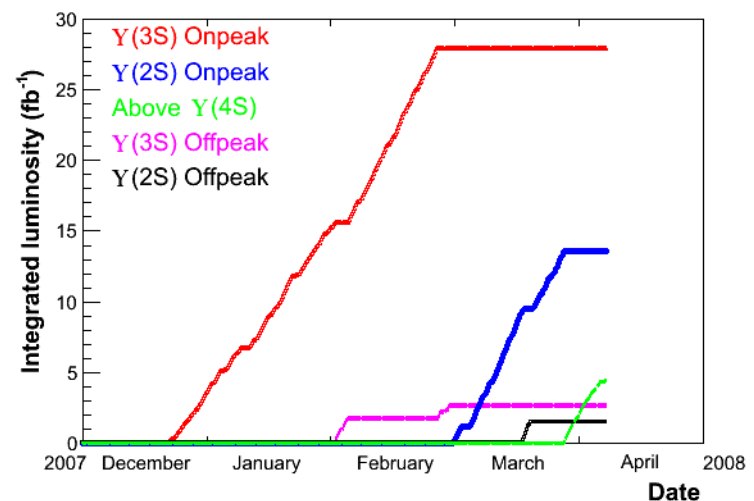
What are we looking for?

- We can look for Higgsstrahlung $e^+e^- \rightarrow A'h' \ (h' \rightarrow A'A')$

Accessible final states
depend on mass of A'

- Has the advantage of being suppressed only by ε^2.
- Search for $A' \rightarrow e^+e^-, \mu^+\mu^-, \pi^+\pi^-$ combinations.
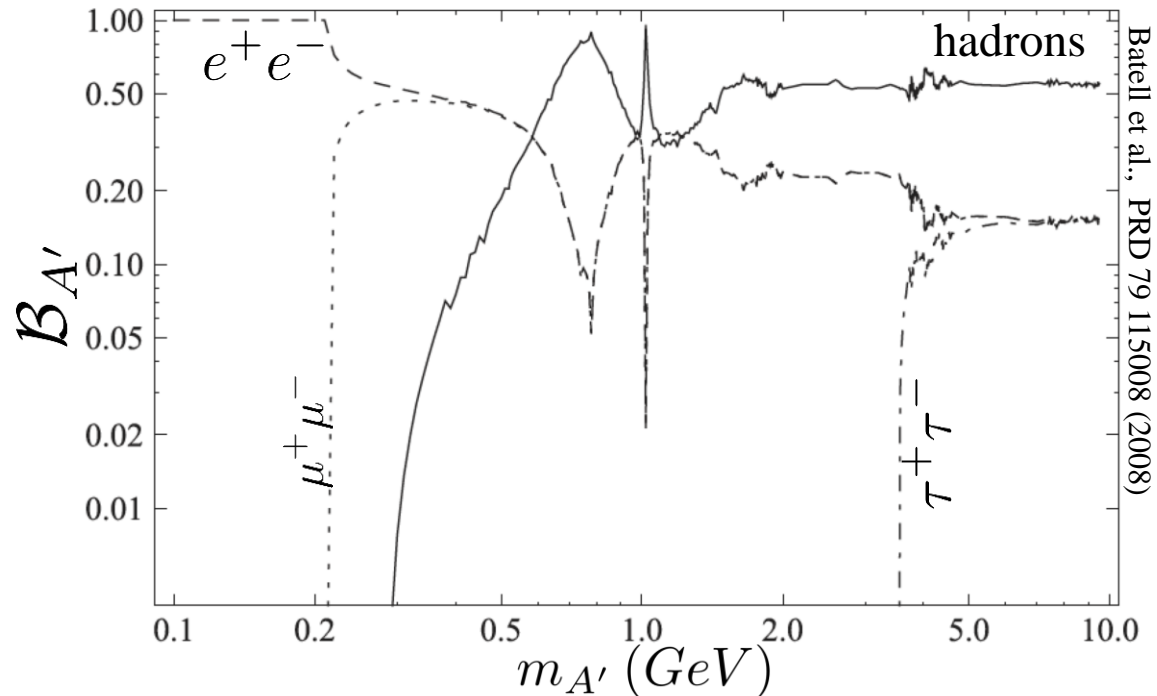
A' = dark photon, h' = dark Higgs

Related Dark Mater Searches: see talk by Y. Kolomensky

What are we looking for?

- We can look for Higgsstrahlung $e^+ e^- \to A' h' \, (h' \to A' A')$

Accessible final states depend on mass of A'

Batell et al., PRD 79 115008 (2008)

- Has the advantage of being suppressed only by ε^2.
- Search for $A' \to e^+ e^-, \mu^+ \mu^-, \pi^+ \pi^-$ combinations.

A' = dark photon, h' = dark Higgs

Related Dark Mater Searches: see talk by Y. Kolomensky

$$e^+ e^- \rightarrow A'h' \left(h' \rightarrow A'A'\right)$$

- Higgs-strahlung search strategy: inclusive and exclusive searches:
    - Reconstruct $A' \rightarrow e^+ e^-, \mu^+ \mu^-, \pi^+ \pi^-$
    - Exclusive final states:
        - Search for 6 tracks with at least a pair of oppositely charged leptons.
        - *3A'* candidate events must contain 95% of CM energy.
        - *A'* masses must be within 10-140 MeV/c^2 of each other.
        - *A'* vertices all point back to the IP.

    - Inclusive: $e^+ e^- \rightarrow 4\ell + X \left(X \neq \pi^+ \pi^-\right)$
        - Search for *4µ+X* or *2µ2e+X* states with mass above 1.2GeV/c^2.
        - di-lepton final state decays must point to IP.
        - Recoil mass of the system must have similar mass as the di-lepton *A'* candidates.

$$e^+e^- \rightarrow A'h' \; (h' \rightarrow A'A')$$

- Veto's are applied to remove ϕ and ω from the search.
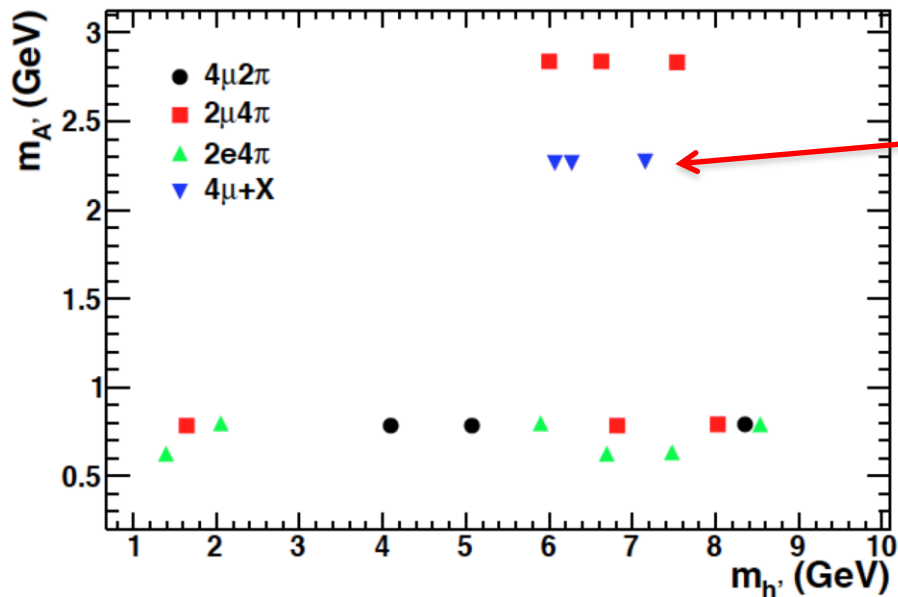- The final event sample contains the following candidates:

$$1 \times 4\mu 2\pi$$
$$2 \times 2\mu 4\pi$$
$$2 \times 2e4\pi$$
$$1 \times 4\mu X$$

Data passing selection (by final state assignment)

- Plot shows 3 entries per event to cover possible combinations for the Higgs decay assignment.

- Observed events are consistent with a background only hypothesis.

$$e^+e^- \rightarrow A'h' \, (h' \rightarrow A'A')$$

- Veto's are applied to remove ϕ and ω from the search.
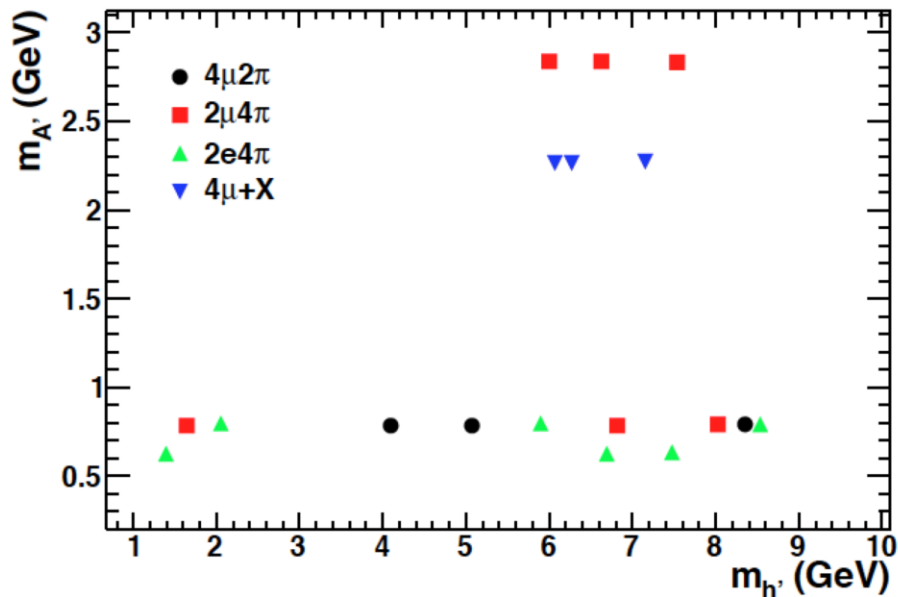- The final event sample contains the following candidates:

$$1 \times 4\mu 2\pi$$
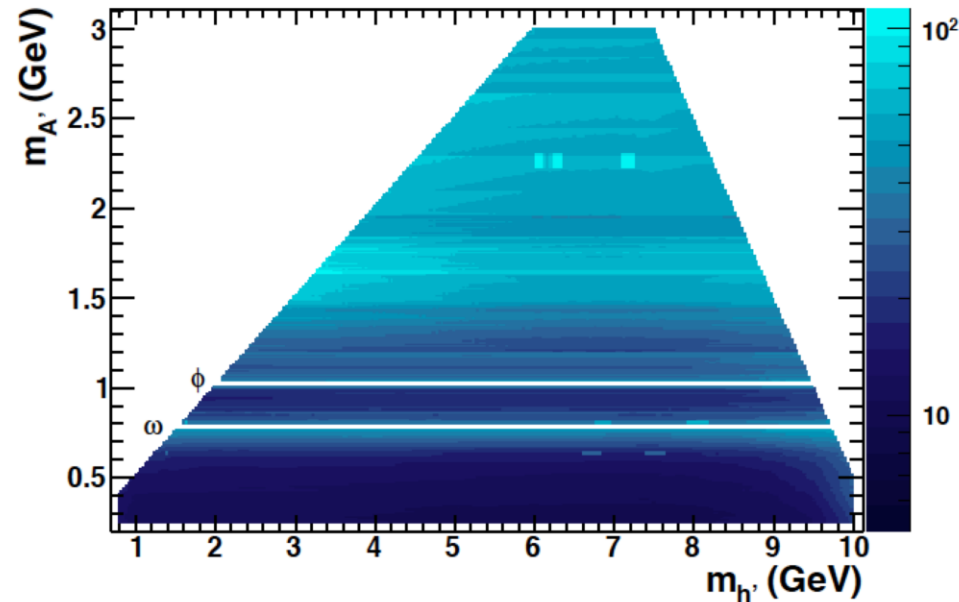
$$2 \times 2\mu 4\pi$$

$$2 \times 2e4\pi$$

$$1 \times 4\mu X$$

- Bayesian upper limit computed using a uniform prior.
- 90 % confidence level reported.

Data passing selection (by final state assignment)
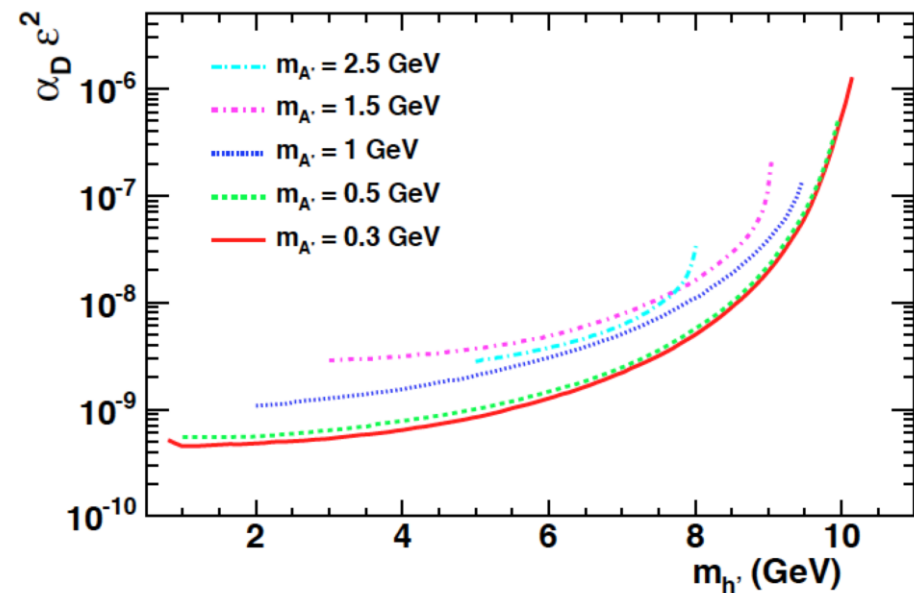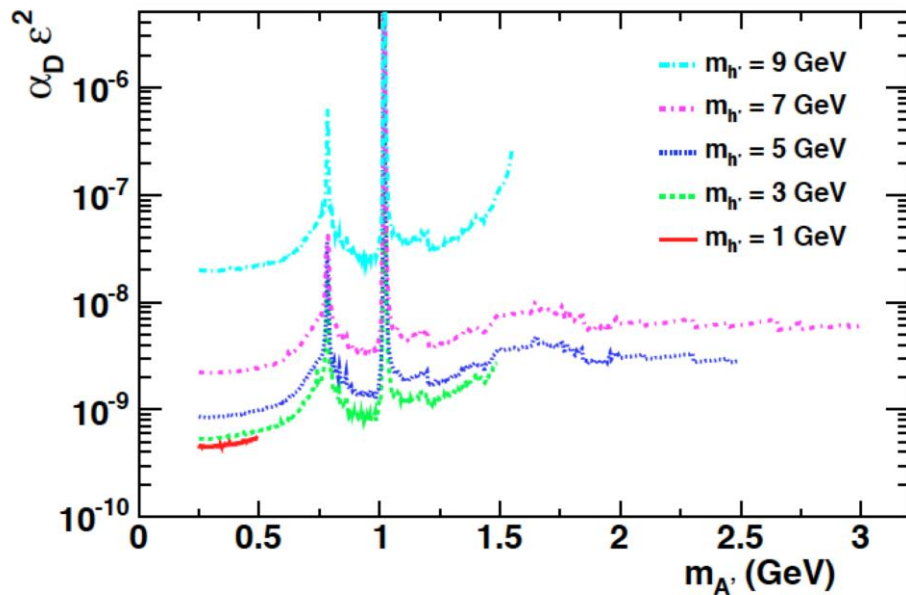
Cross section upper limit (ab)

Limits on $\alpha_D \varepsilon^2$

- The dark photon width is proportional to $\alpha_D \varepsilon^2$; so we can place limits on this combination of coupling and mixing.

- Reminder: ϵ (dark sector - SM mixing strength)
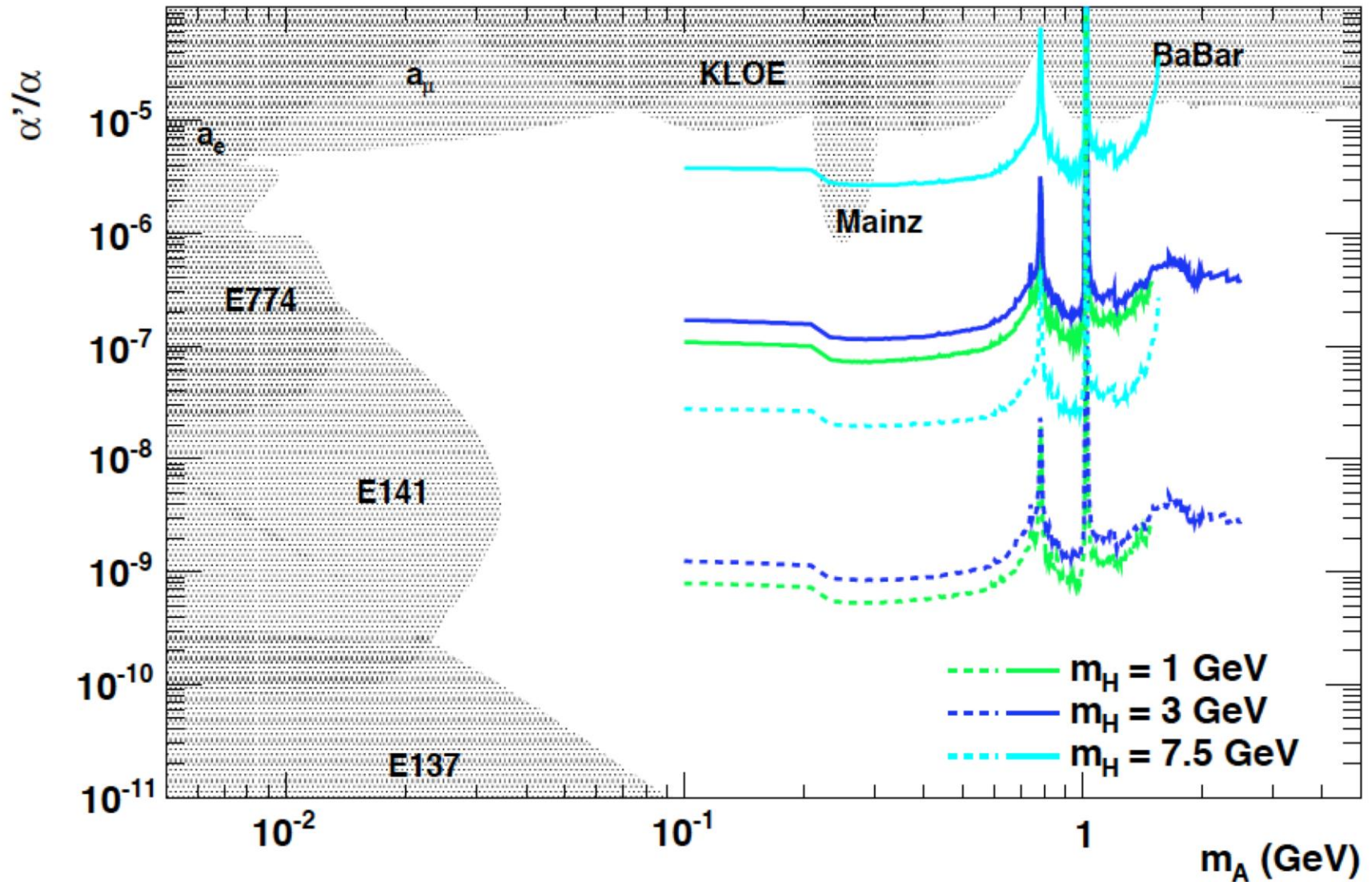
$$\alpha_D = g_D/4\pi \text{(dark sector gauge coupling)}$$

- Assuming $\alpha_D \sim \alpha$, limits on ε are $[10^{-3}, 10^{-4}]$, about 10 × better than previous bounds.

Limits on α_D/α

Solid: $\alpha_D = 1/137$
Dashed: $\alpha_D = 1$

Summary

- BaBar has searched for h' and A' particles.
  - Able to place limits on $e^+e^- \rightarrow A'h'\,(h' \rightarrow A'A')$

    for $0.25 < \quad m_{A'} \quad < 3\,GeV/c^2,$

    $\quad\quad 0.8 < \quad m_{h'} \quad < 10\,GeV/c^2,$

    $\quad\quad$ for $\quad m_{h'} \quad > 2m_{A'}$

  - Improved the constraints on the dark-sector SM coupling ε.

- Also searched for light gauge bosons via *Υ* decays.
  - Placed improved limits on the cross section of light scalar DM/Higgs candidates.
  - **See talk by Yury Kolomensky for details.**

- The next generation will continue this work: **SuperB** & *B* Belle II