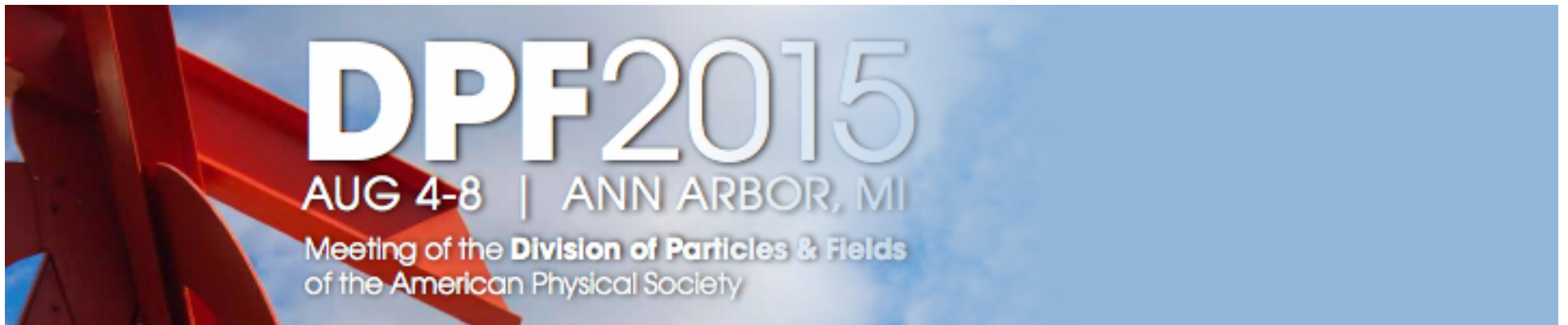# Search for a Dark Photon at *BABAR*

David N. Brown

University of Louisville

On behalf of the *BABAR* Collaboration

Search for a Dark Photon at *BABAR*

- **Motivation**

- **The *BABAR* Experiment**

- **Search for a Dark Photon, *A'***   PRL **113**, 201801 (2014)

Motivation – Search for the Dark Sector

- **Existence of dark matter is well-established from astrophysical evidence, but its nature is not known**

- **Collider experiments allow for:**
  - **Direct searches for dark matter particles through decays to Standard Model (SM) particles**

- **Electron-positron collider experiments are particularly clean environments and in many cases provide the best reach in searches for new physics**
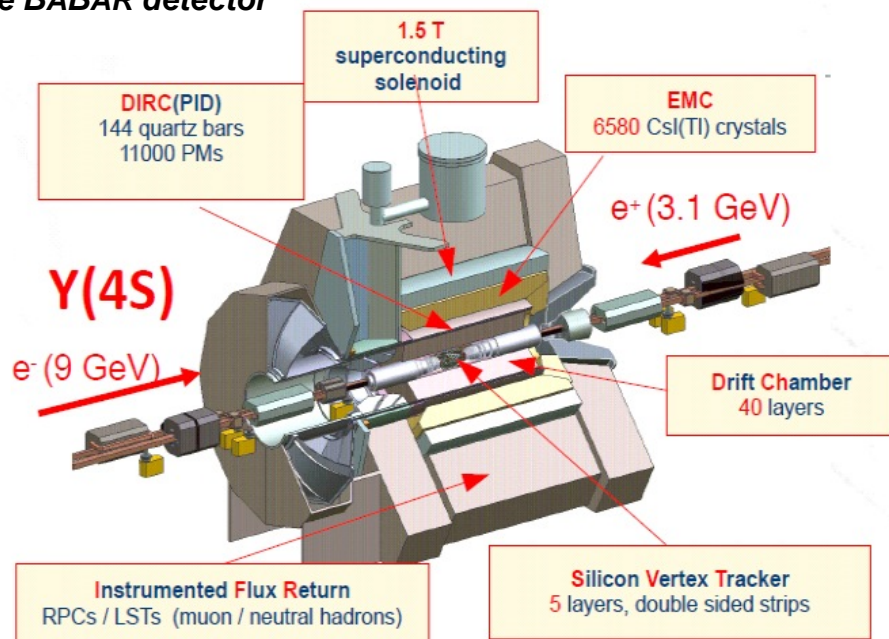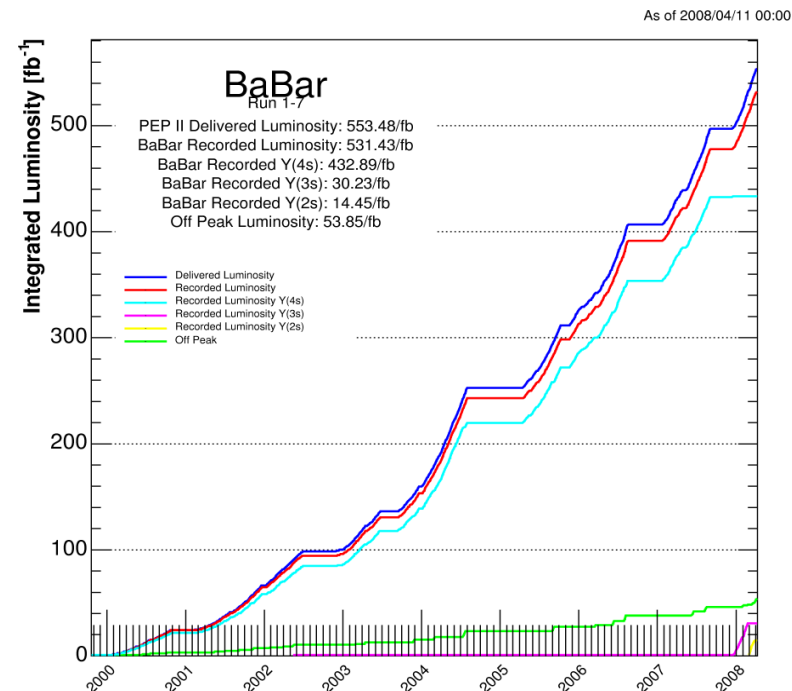
Zwicky, AcHPhys 6 (1933); et al.

The *BABAR* Experiment

The BABAR detector

- Primarily designed for study of *CP*-violation in *B* meson decays
- Quality and general-purpose design make it suitable for a large variety of studies

BABAR data sample contains

~470 x 10^6 $\Upsilon(4S)$
~120 x 10^6 $\Upsilon(3S)$ (10x Belle)
~100 x 10^6 $\Upsilon(2S)$ (10x CLEO)
~ 23 x 10^6 $\Upsilon(2S,3S) \rightarrow \Upsilon(1S)\, \pi^+\pi^-$

Dark Sector Overview

- Theory introduces idea of a new force corresponding to a new U(1)'.

  PLB 166, 196 (1986)

- Applied to the dark sector, the gauge boson, the so-called dark photon (A'), may be light (MeV – GeV mass) in these models.

  PLB 662, 53 (2008); PRD 79, 015014 (2009); arXiv:1311.0029, for example

- Dark sector particles do not couple directly to the SM content. Interaction dark sector - SM via kinetic mixing between the dark photon and photon/Z with a mixing strength ε among other "portals".

- In other words, there is a dark photon – SM fermion coupling $\alpha' = \varepsilon^2 \alpha$ Strength small, but how small?

  Currently favor $10^{-7} < \varepsilon < 10^{-2}$

Standard Model
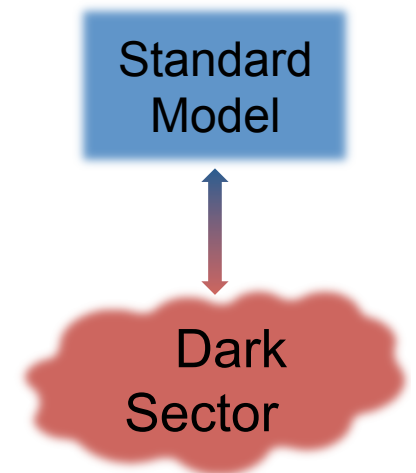
Dark Sector

[Slatyer, Schuster&Toro,…]
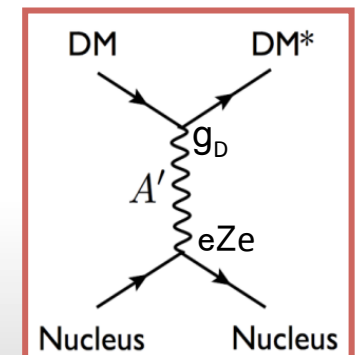
Dark Sector Overview contd.

- In this framework, wimp-like TeV-scale dark matter particles can annihilate into dark photons, which subsequently decay to SM fermions.

- If the dark photon is light → can only decay to light states. Could explain recent observations in cosmic rays (electron excess but no antiprotons) and by ground experiments.

- Other explanations of these anomalies have been proposed, but the possibility of a hidden MeV/GeV-scale sector is poorly constrained and really worth exploring.


[AMS-02]

[PAMELA]

CDMS, arXiv:1304.4279

[FERMI]

[Finkbeiner Dobler et al.,]
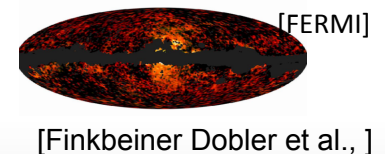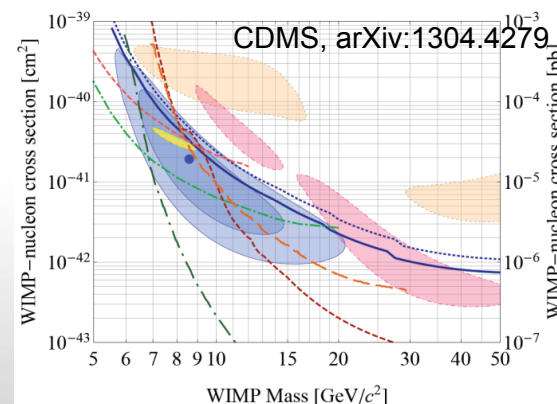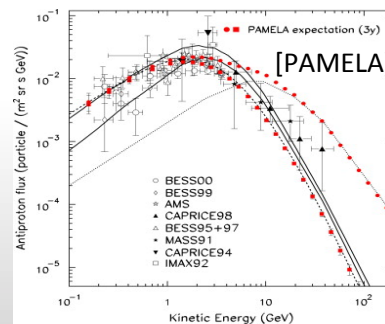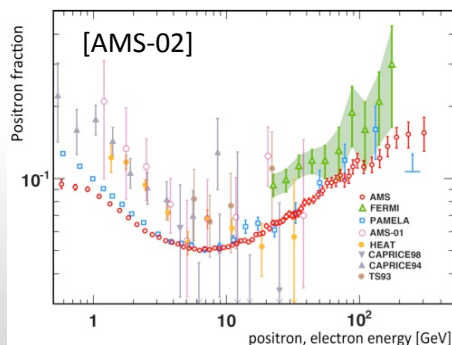
And many others…

Particle Physics Implications

- Can produce dark photons. In fact, photons in any process can be replaced by a dark photon (with an extra factor of ε).

- Decays back to lepton/quark pairs → search for resonances

- Dark photon decay can be prompt or displaced (long-lived)

- Current bounds on the mixing parameter ε are shown as a function of the dark photon mass.

- Constraints from electron/muon g-2, beam dump and fixed target experiments and e^+e^- colliders (some constraints reinterpreted from limits of other measurements by theorists, e.g. *BABAR*)
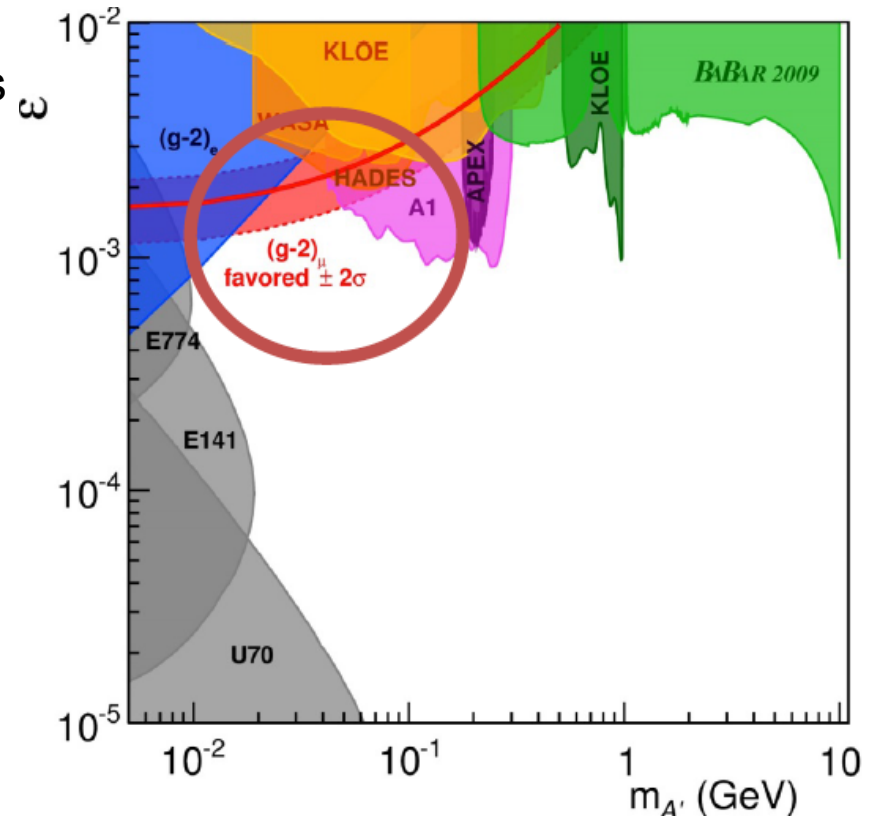
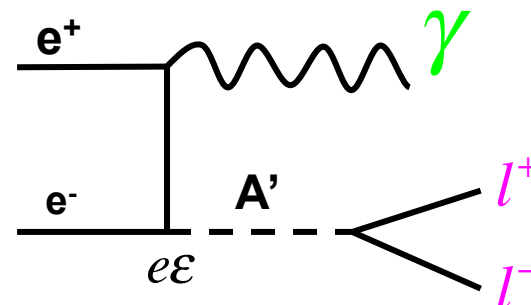
Plot courtesy B. Echenard

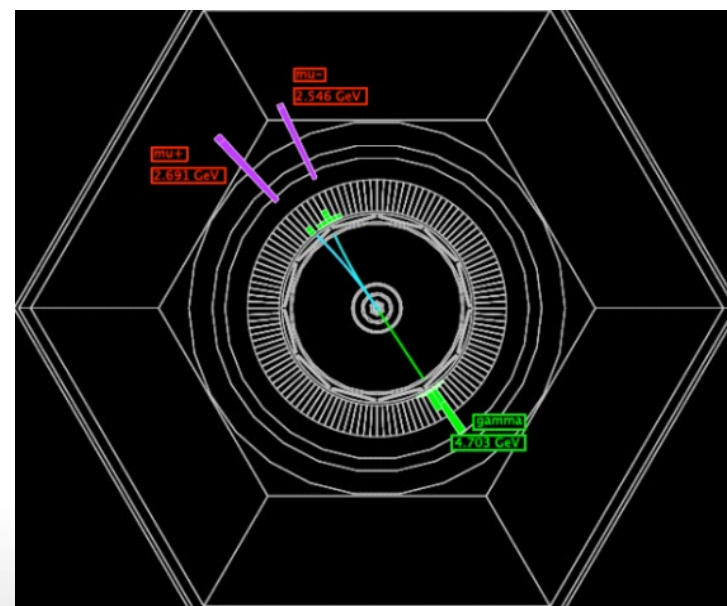# Dark Photon Production

A dark photon can be produced in

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

Select events with one photon and two oppositely charged leptons*. Look at spectrum of dilepton mass. Use reduced mass for muons.

$$m_{\text{Red}} = \sqrt{m_{\mu\mu}^2 - 4m_\mu^2}$$

Tracks
Photon
Signal in muon/hadron detector

***with further cuts to reduce radiative Bhabhas**

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Analysis Technique

Scan the dielectron and dimuon reduced mass spectra and fit a background plus signal function at each step. Background includes resonances - ρ^0, ϕ $J/\psi, \psi(2S), \Upsilon(nS)$

Mass resolution varies between 1.5 and 8 MeV
Window size 30x mass resolution
Step size approximately half the mass resolution

> Electrons: 5704 fits, 0.02 – 10.2 GeV
> Muons: 5370 fits, 0.212 – 10.2 GeV
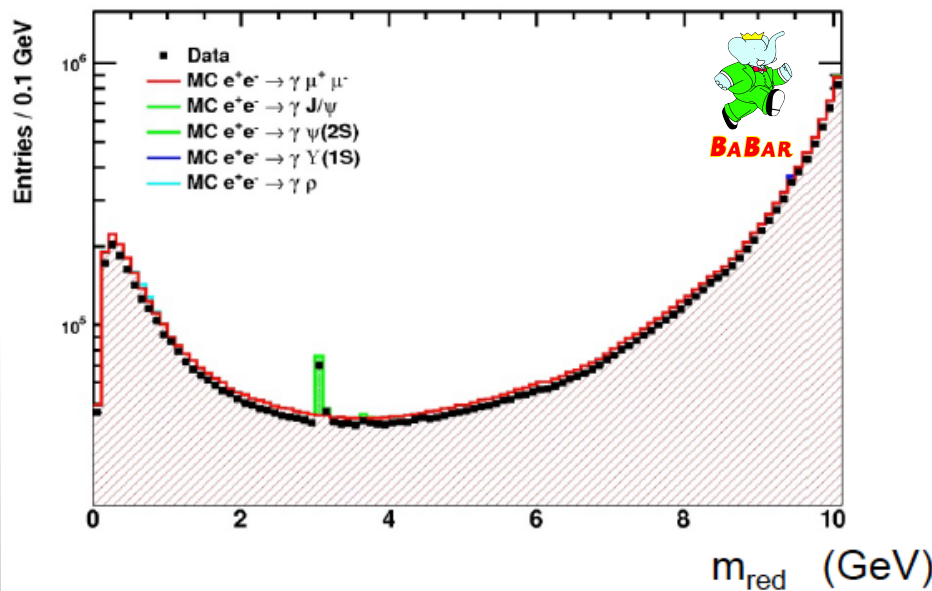
Assign a statistical significance for each fit:

$$S_S = \sqrt{2\log(L/L_0)}$$

L: likelihood w/background + signal
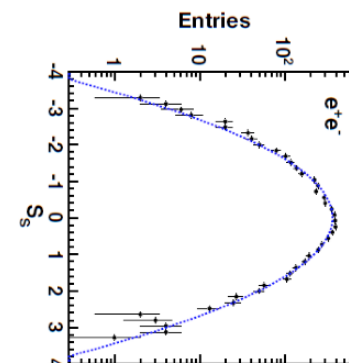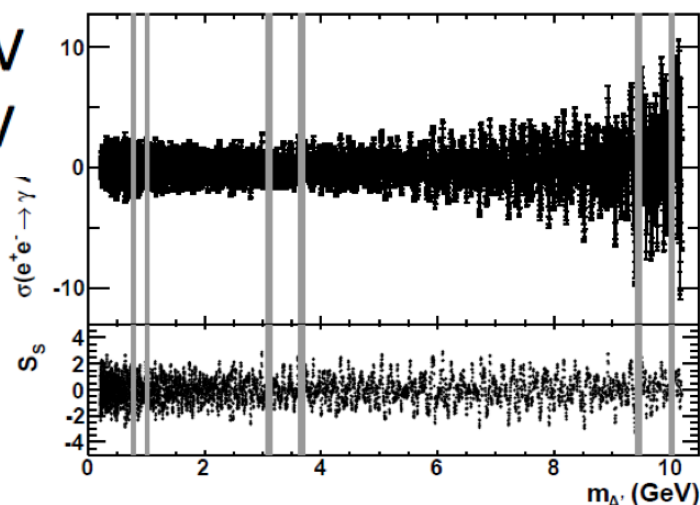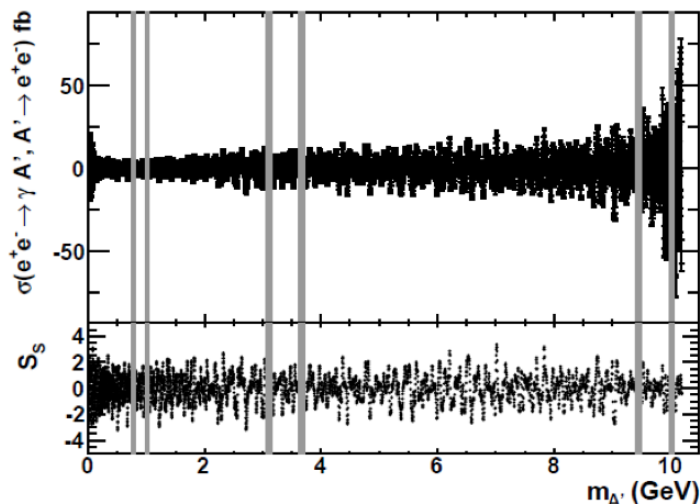L_0: likelihood w/background only

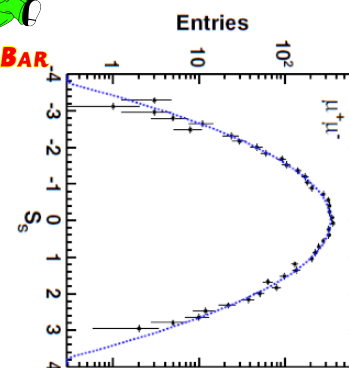# Results – both channels

- Highest fluctuations

➢ 3.4 σ (e) M=7.02 GeV
➢ 2.9 σ (μ) M=6.09 GeV

5704 trials
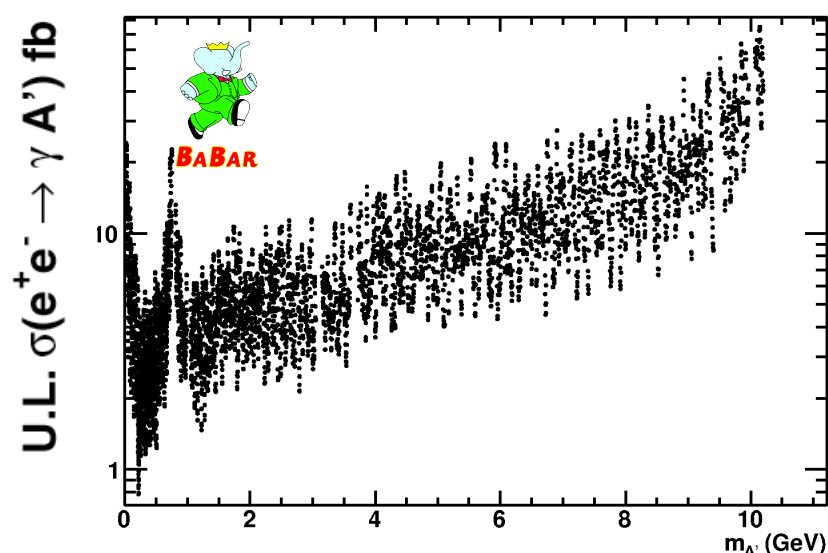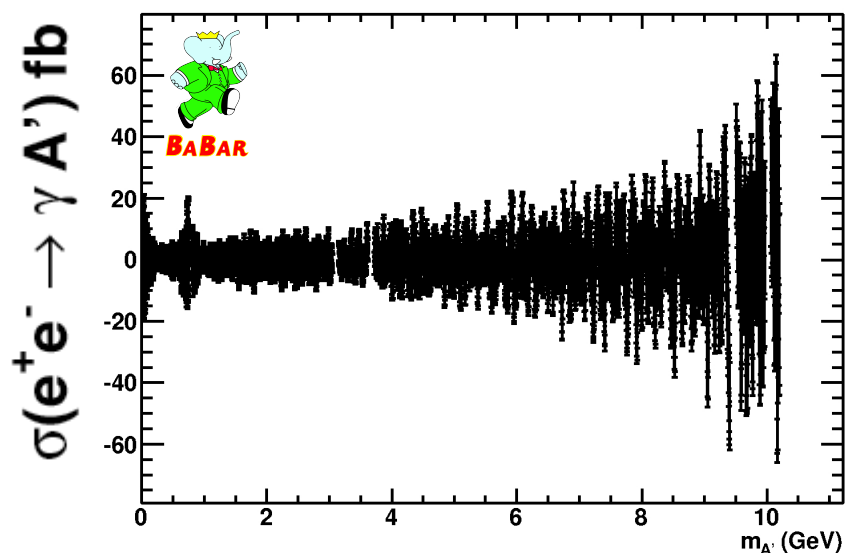
5370 trials
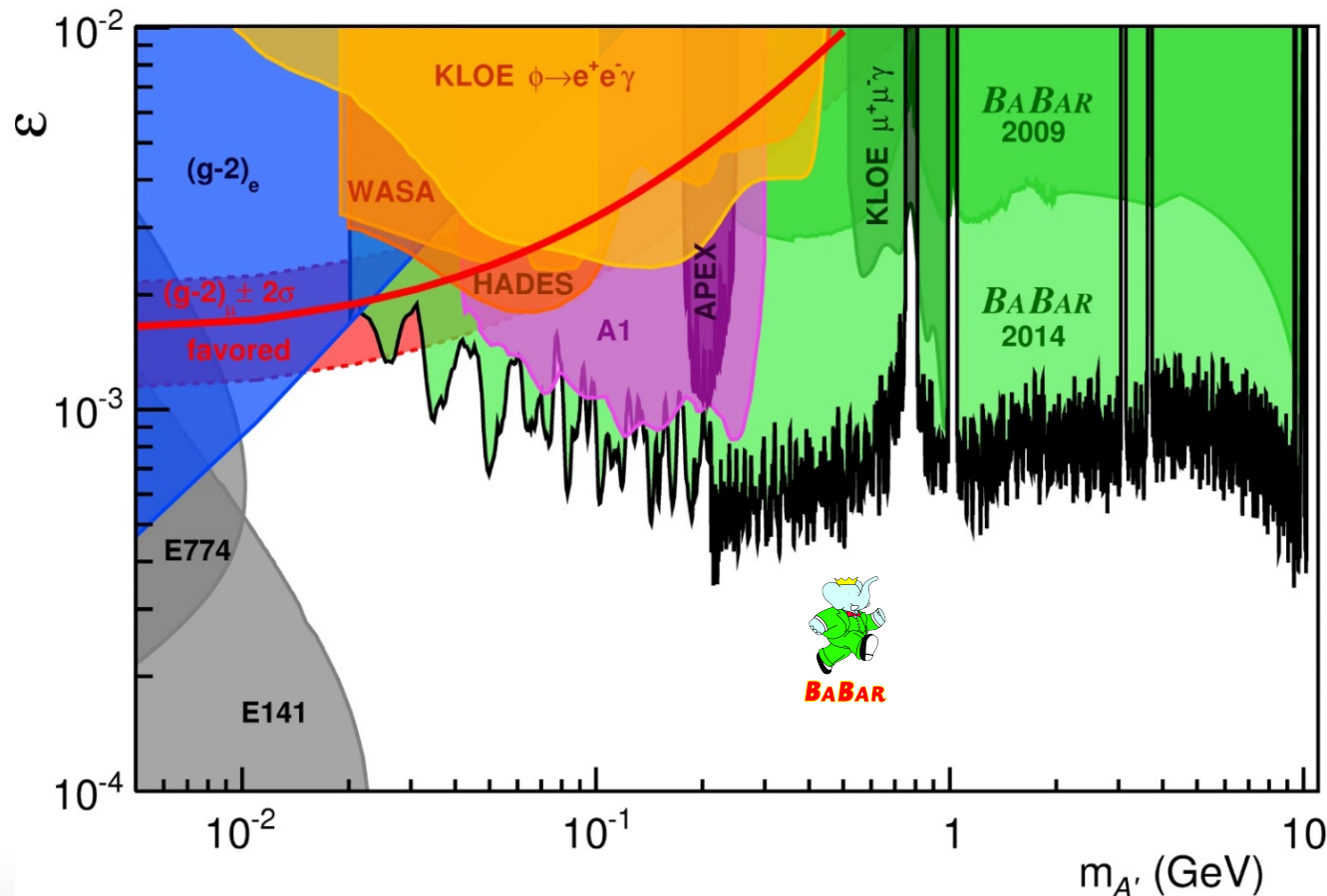
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Cross-section Results

Combined

90% Confidence Level Upper Limit

Including Trial factors,
Most significant excursion from null hypothesis for electrons: $0.6\,\sigma$
Most significant excursion from null hypothesis for muons: $0.1\,\sigma$

Dark Sector Mixing Results
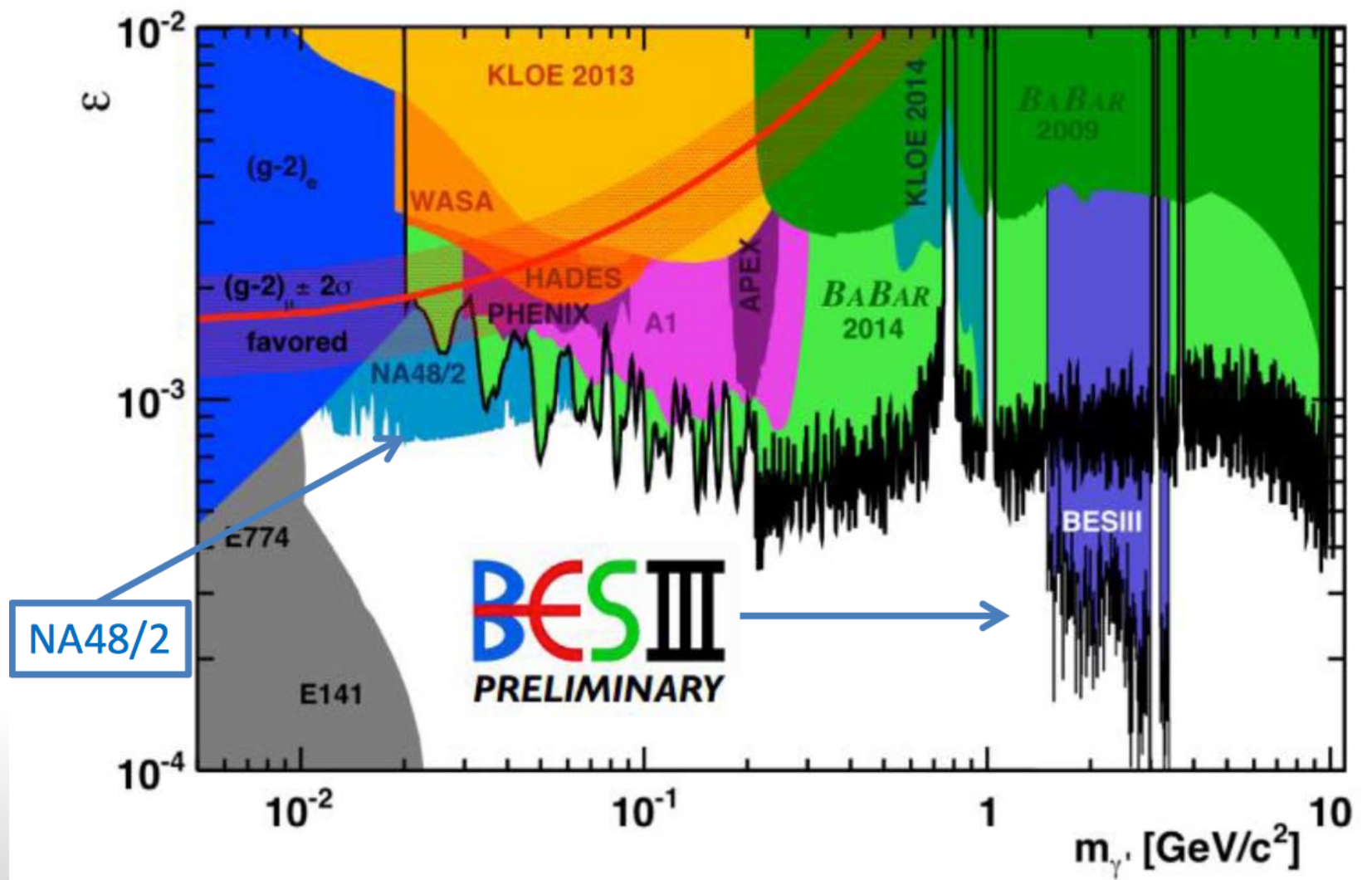
- Further exclude the region favored by the g-2 measurement and improve the existing constraints over a wide range of masses.

Recent Addition to the Story

New Search for Dark Photon

The Dark photon could decay to dark particles, which would be invisible to a SM detector.

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

Experimentally, search for single photon events, look for peak in Energy spectrum. Preliminary result based on small portion of *BABAR* data taken at $\Upsilon(3S)$ energy. Will be extended to full dataset.

$$\mathcal{B}(\Upsilon(3S) \rightarrow \gamma A^0) \times \mathcal{B}(A^0 \rightarrow \text{invisible}) < 31 \times 10^{-6}$$

At 90% CL   *BABAR* Preliminary
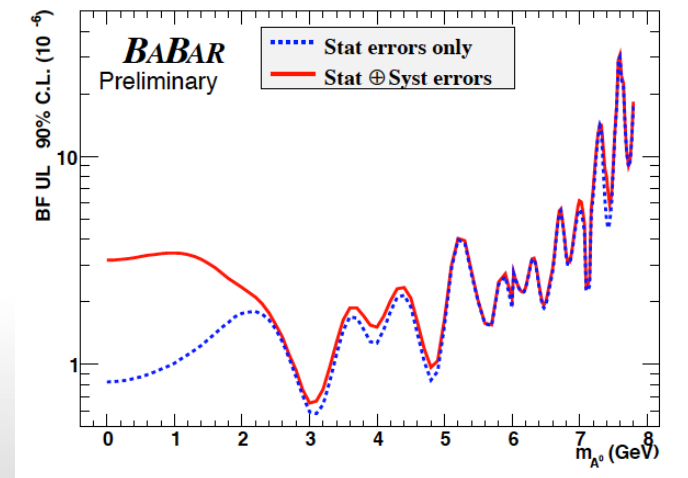

Belle II could push this limit down significantly

Summary

- **Dark matter is well-established but mysteries remain**

- ***BABAR* has completed searches for the dark photon**
    - **No evidence for it, but**
    - **Tighten constraints on dark sector models**

- **The dark sector is an exciting field, to which electron-positron collider experiments can make significant contributions**
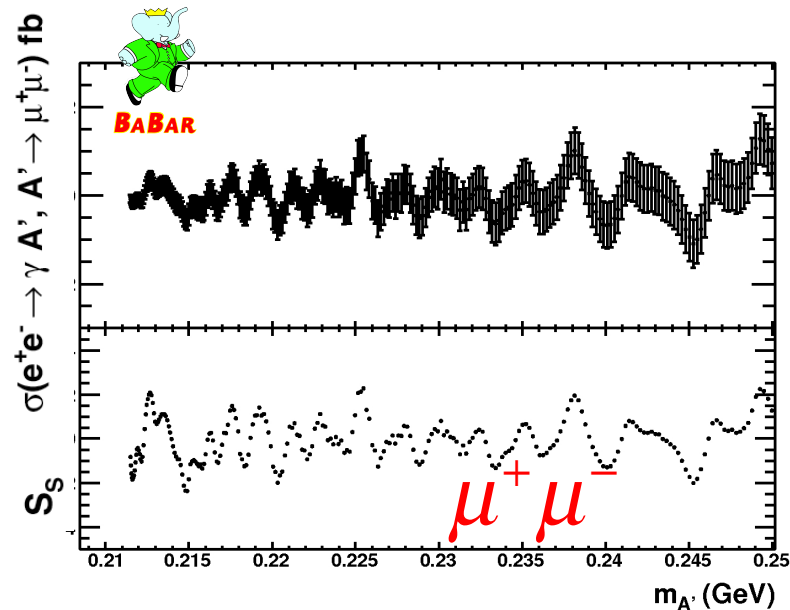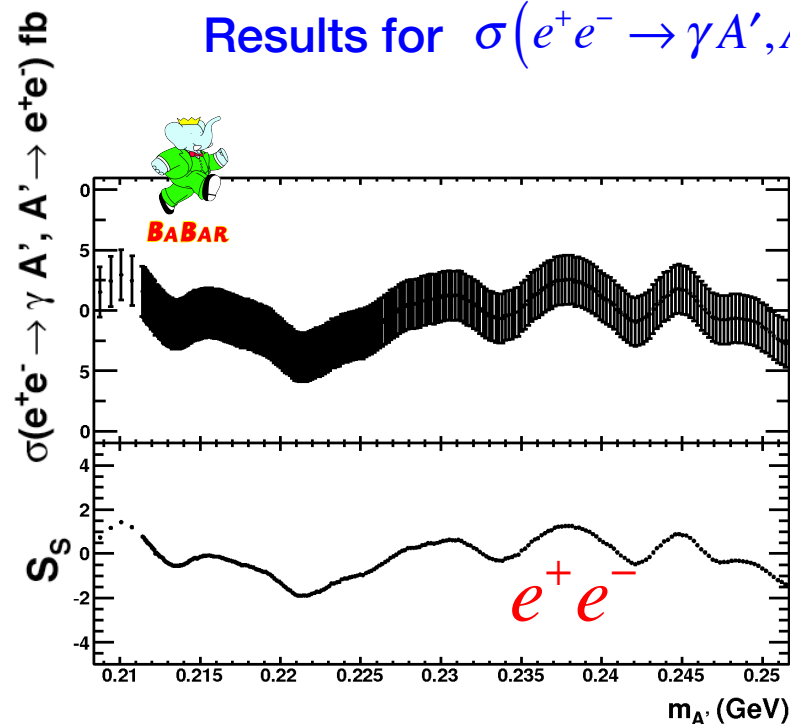
Thank you to B. Echenard for use of several slides
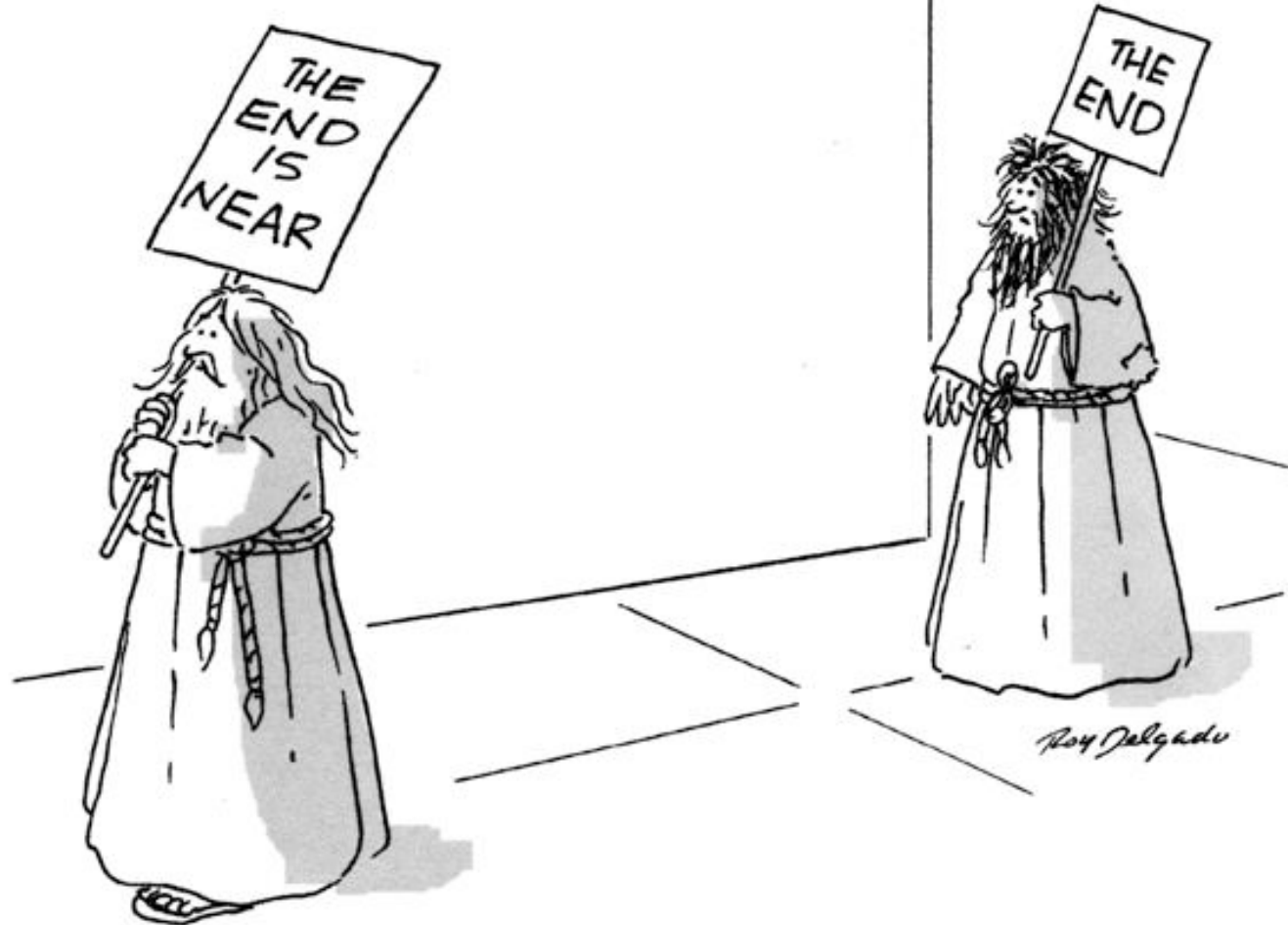
Thanks!

Back Up Slides

Dark Photon Results

Results for $\sigma\left(e^+e^- \to \gamma A', A' \to l^+l^-\right)$ for combined Y(2S,3S,4S)

$$S_S = \sqrt{2\log\left(L/L_0\right)}$$

Here, look in 200 MeV region as suggested by excess in HyperCP results

No excess observed

PRL 94, 021801 (2005)