Constraints on Dark Forces from the B Factories and Low-Energy Experiments

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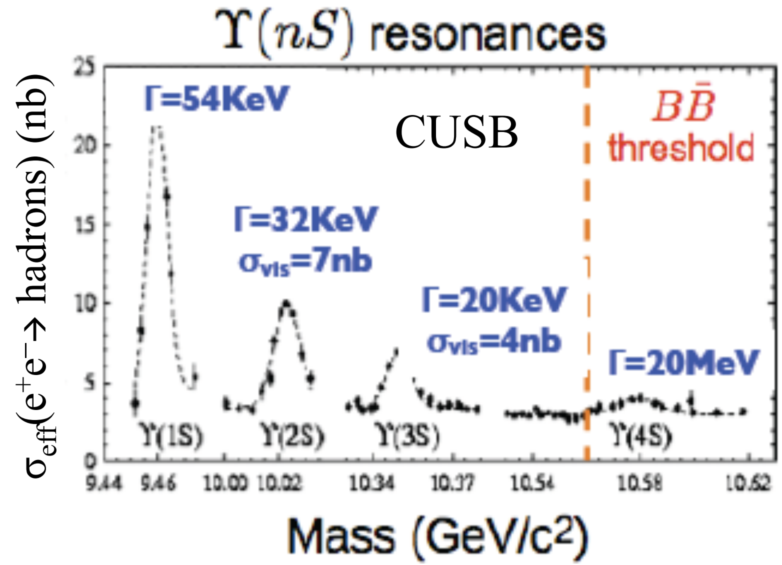
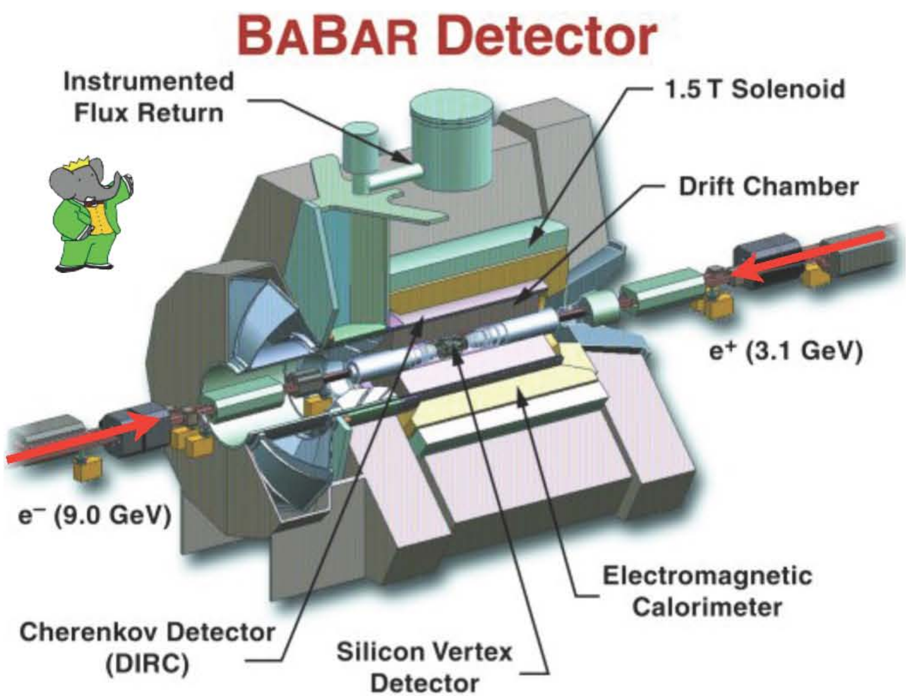
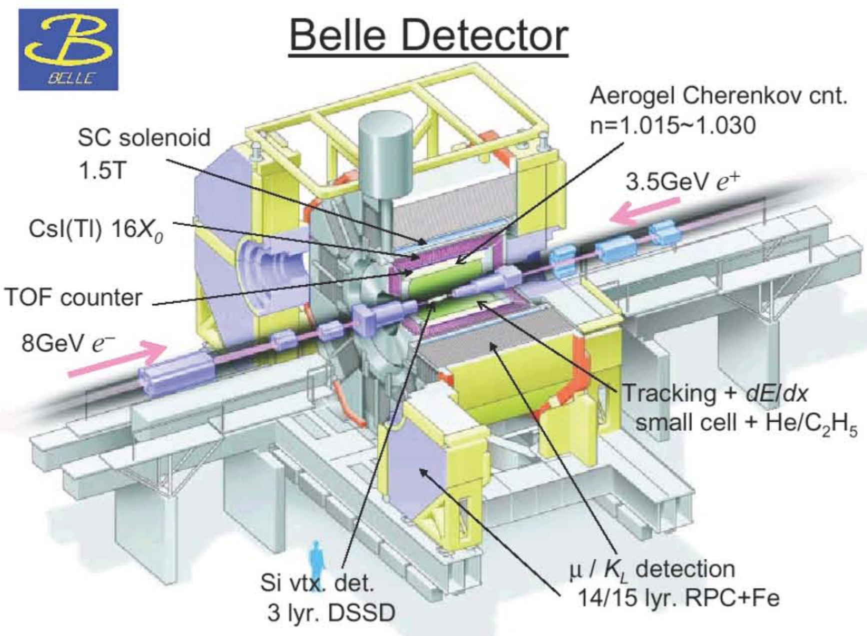
Tel Aviv University
Representing the BABAR collaboration

IPA, Queen Mary, University of London, August 2014

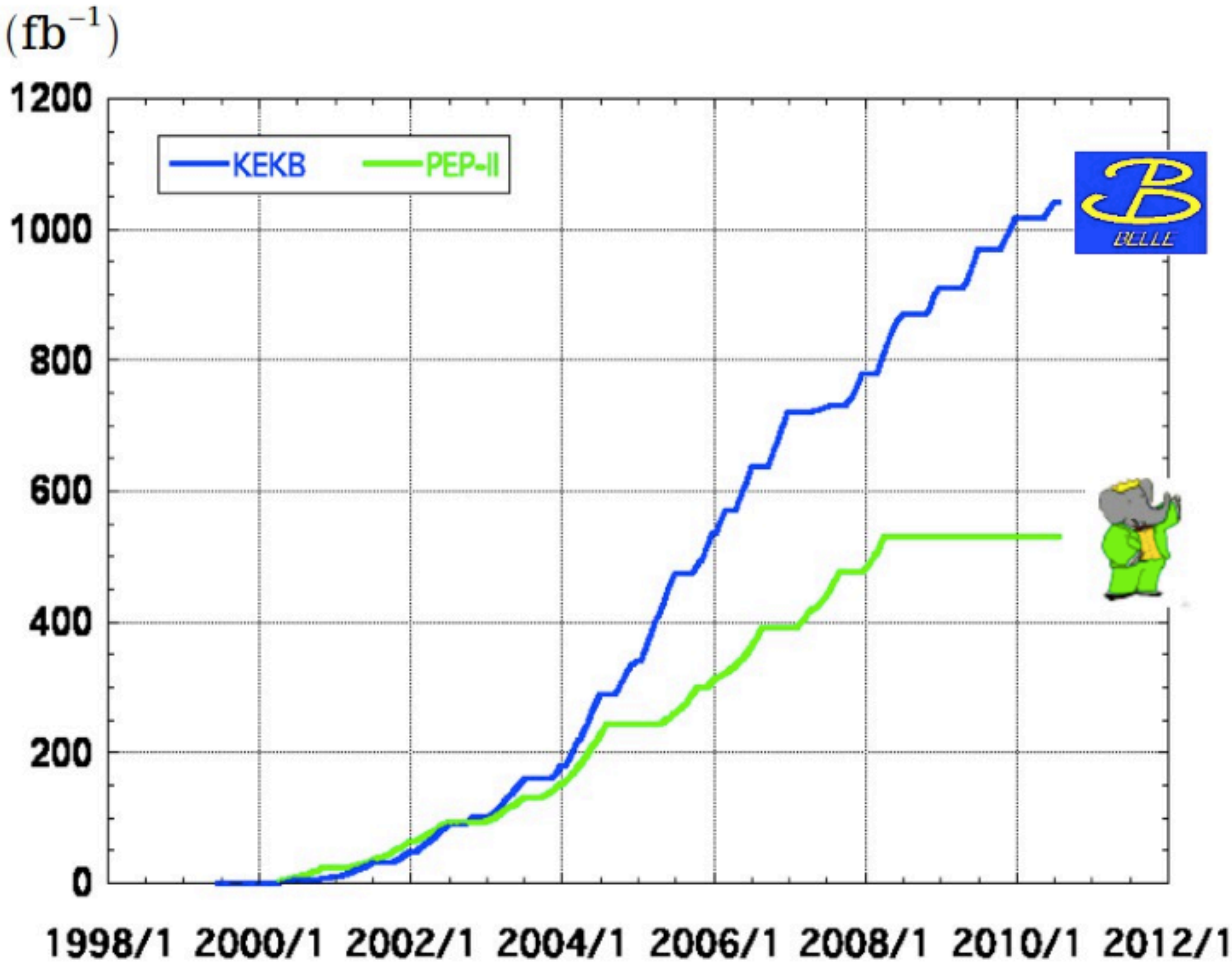
The B factories







B-factory data samples



> 1 ab^{-1}

On resonance :

$\Upsilon(5S)$: 121 fb^{-1}

$\Upsilon(4S)$: 711 fb^{-1} , 657 M

$\Upsilon(3S)$: 3 fb^{-1}

$\Upsilon(2S)$: 25 fb^{-1}

$\Upsilon(1S)$: 6 fb^{-1}

Off reson./scan :

$\sim$ 100 fb^{-1}

513.7 ± 1.8 fb^{-1}

On resonance:

$\Upsilon(4S)$: 424 fb^{-1}, 471 M

$\Upsilon(3S)$: 28 fb^{-1} , 122 M

$\Upsilon(2S)$: 14 fb^{-1} , 99 M

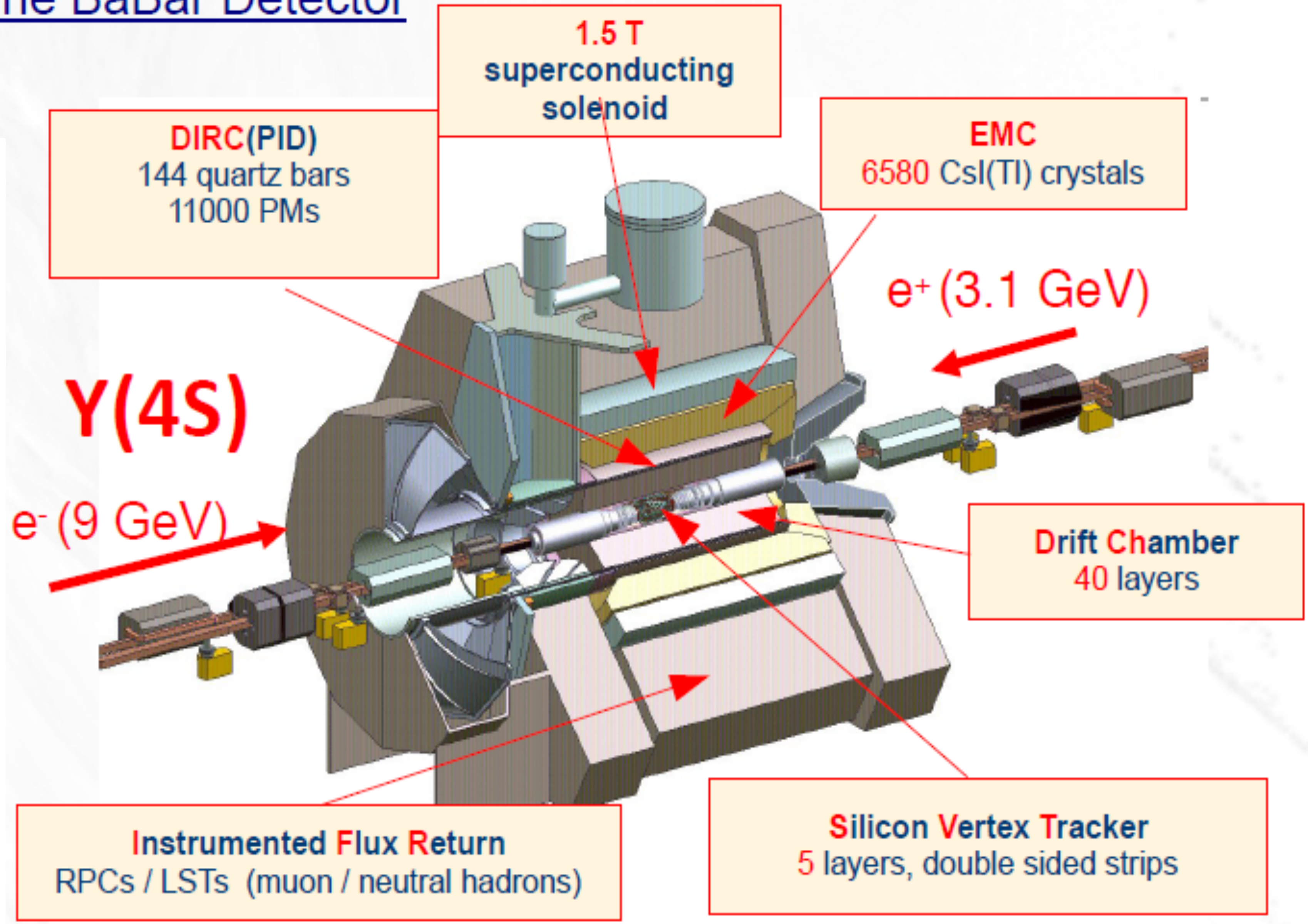
Off resonance:

48 fb^{-1}

CLEO:

$\Upsilon(1S)$: 1.1 fb^{-1}, 22 M

The BaBar Detector



Dark forces

- We often think of DM as one particle – the WIMP
  - E.g., the SUSY LSP
- But DM may involve rich phenomenology, an entire "dark sector"
  - Why should the SM particles, which account for only ~1/5 of the matter in the universe, have all the fun?
- Possible "dark forces" serve as portals between the SM sector and the dark sector → interesting measurements

The dark photon

See Mitesh's talk

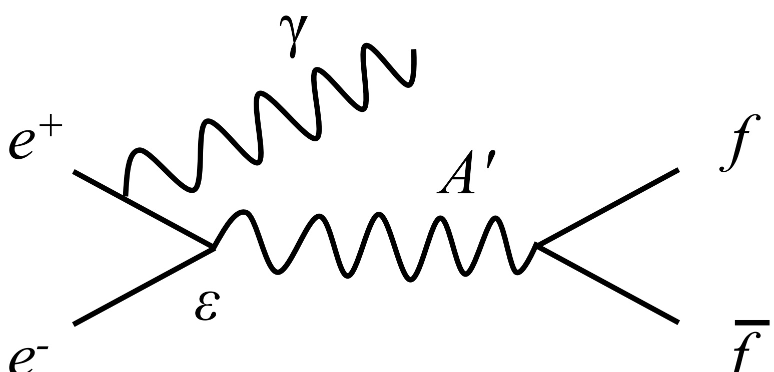
- Postulate U(1) gauge interaction in dark sector, with massive "dark photon" A'
- Effective Lagrangian mixes the dark U(1) and SM photon:

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} - \frac{1}{4} F'_{\mu\nu} F'^{\mu\nu} + \frac{m^2_{A'}}{2} A'_\mu A'^\mu - \frac{\varepsilon}{2} F'_{\mu\nu} F^{\mu\nu}$$

Mixing parameter

SM EM field

Dark U(1) field



@ 10 GeV: $\sigma(e^+e^- \rightarrow \gamma\gamma) \approx 3$ nb

Recent interest

See Martin's talk

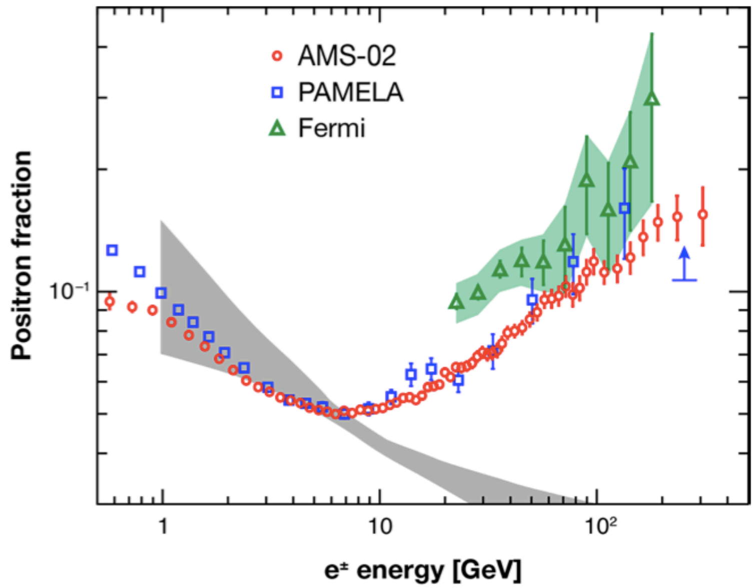
PRL 110, 141102 (2013)
Nature 458, 607 (2009)
PRL 108, 011103 (2012).

PRD 79, 015014 (2009)

- Excess of high-energy cosmic positrons interpreted as annihilations of ~TeV DM:

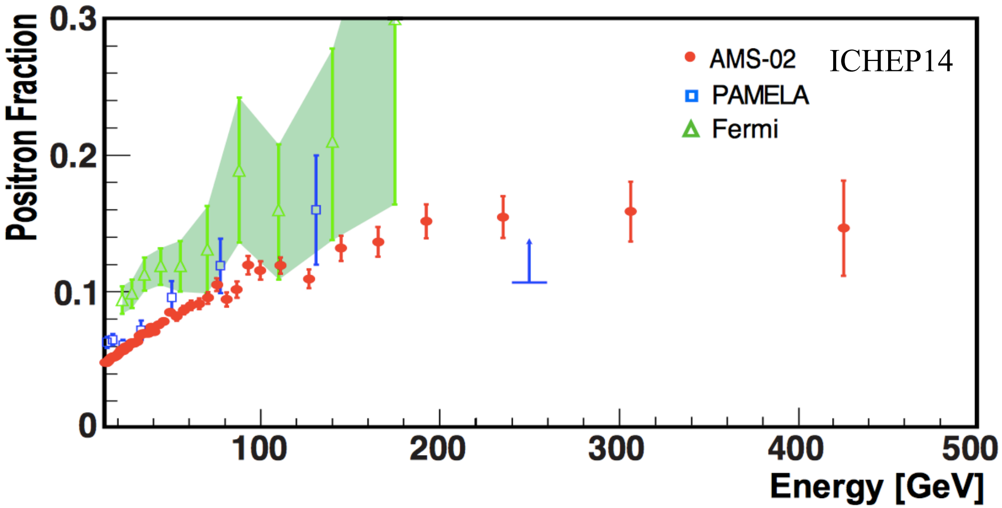
$$\chi\chi \to A'A' \to (e^+e^-)(e^+e^-)$$

- Lack of antiproton excess → $m_{A'} <$ few GeV

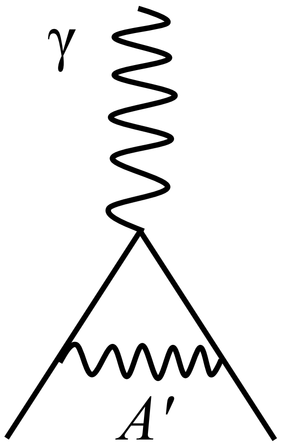


- The excess may very well have astrophysical sources

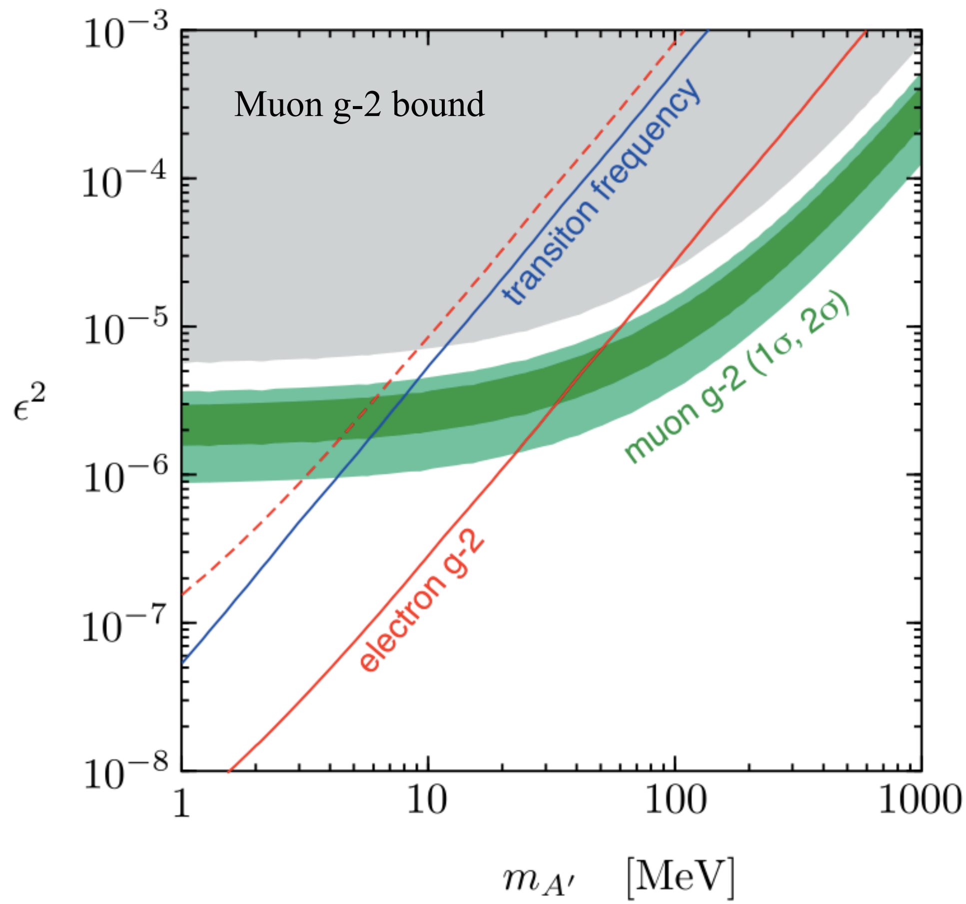
- But it has inspired research on GeV-scale new physics we hadn't thought of previously.



Constraints from *g*–2 & hydrogen transition frequency

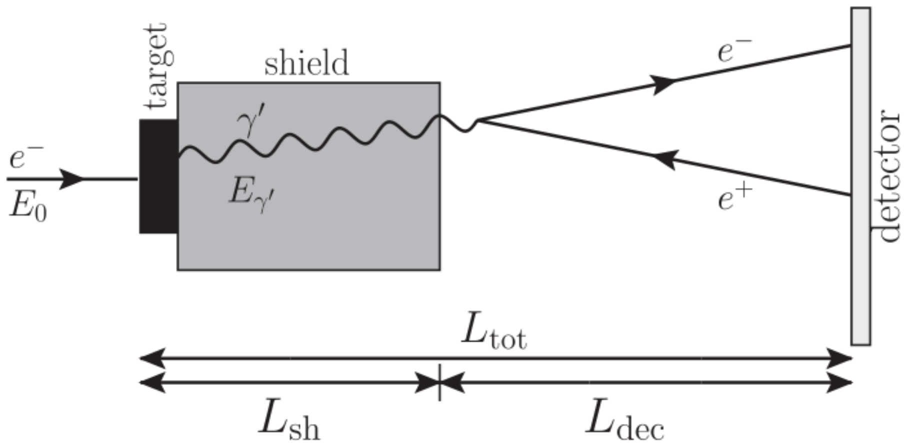


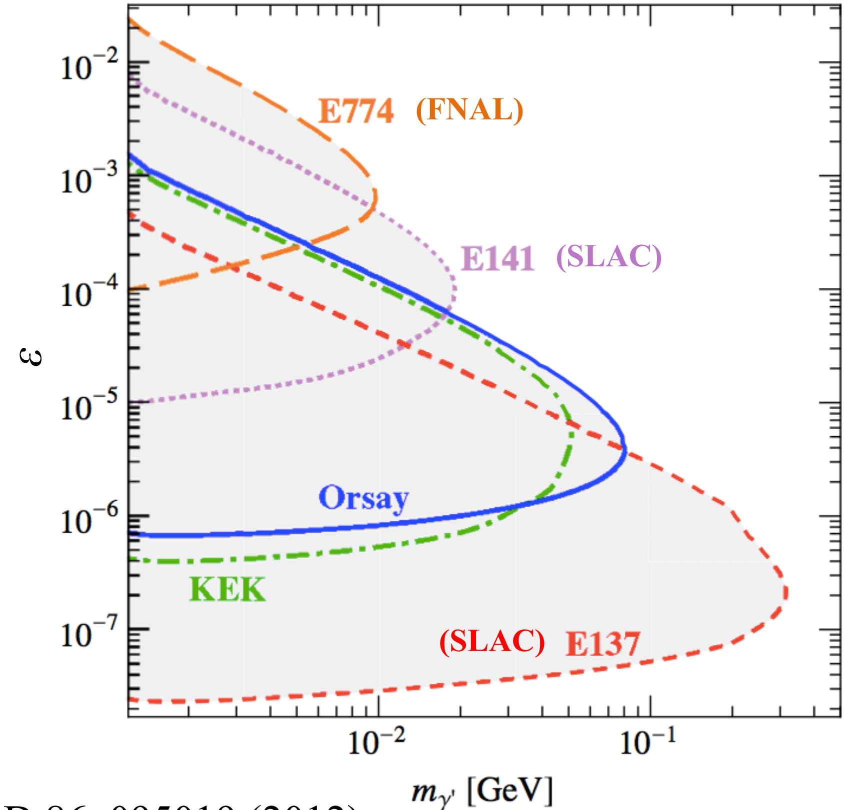
PRD 86, 095029 (2012)



μ g–2 ring en route to FNAL

Long-lived A' @ e⁻ fixed target expts.

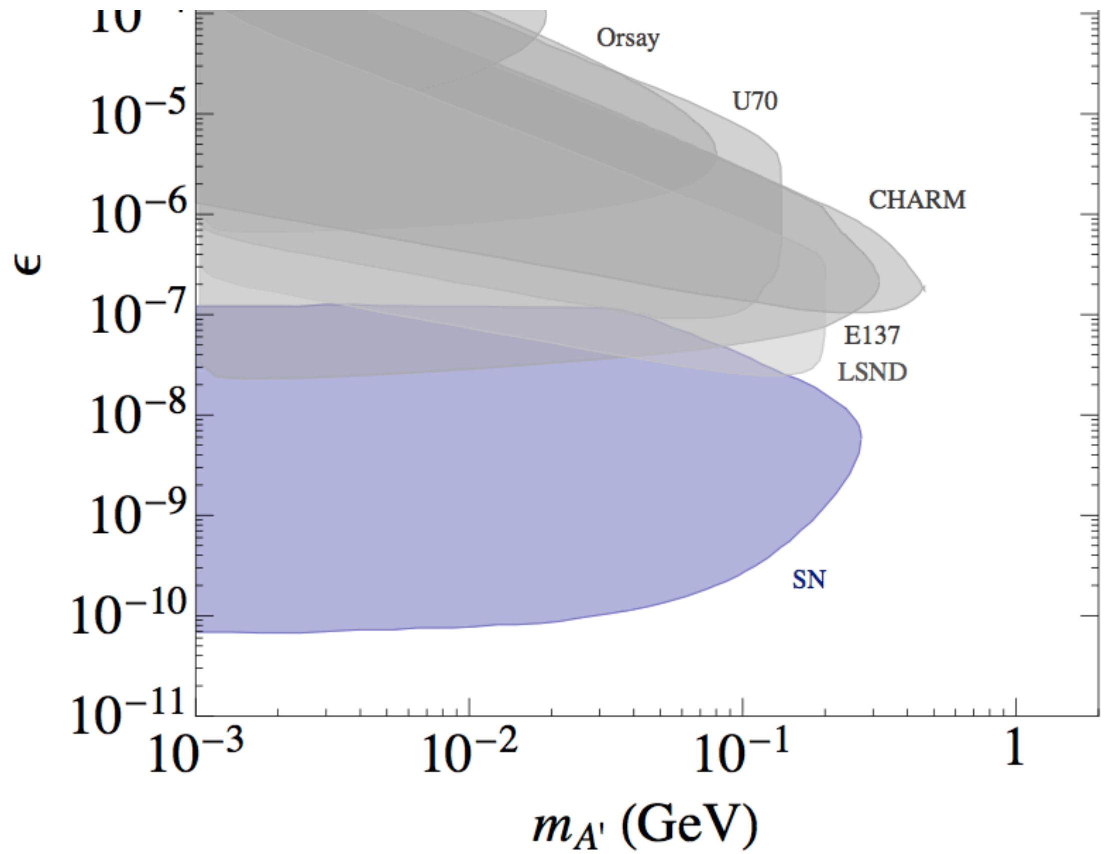




PRD 86, 095019 (2012)

Experiment	E_0 [GeV]	electrons	L_{sh} [m]	L_{dec} [m]	N_{obs}	$N_{95\%up}$	Year
E141 [47]	9	2×10^{15}	0.12	35	1126^{+1312}_{-1126}	3419	1987
E137 [48]	20	1.87×10^{20}	179	204	0	3	1988
E774 [49]	275	5.2×10^{9}	0.3	2	0^{+9}_{-0}	18	1991
KEK [39]	2.5	1.69×10^{17}	2.4	2.2	0	3	1986
Orsay [40]	1.6	2×10^{16}	1	2	0	3	1989

Proton fixed target + supernova cooling



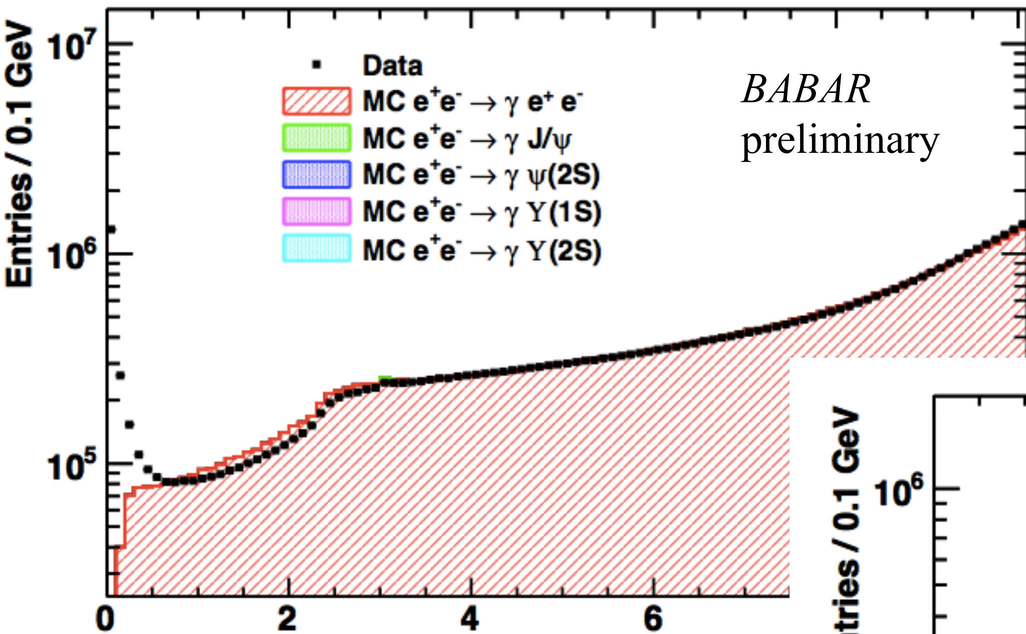
Experiment	E_0 [GeV]	Protons	Year
LSND	0.8	4.6×10^{23}	1998
CHARM	400	1.4×10^{18}	1986
U70	70	1.7×10^{18}	1991

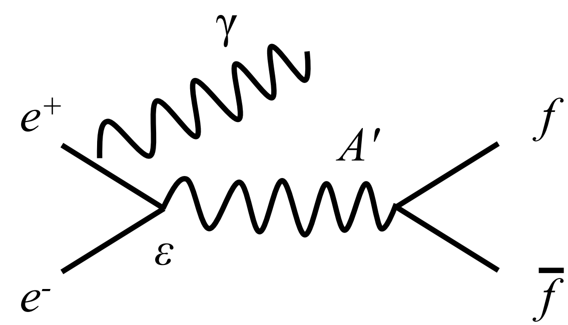
arXiv:1311.0029

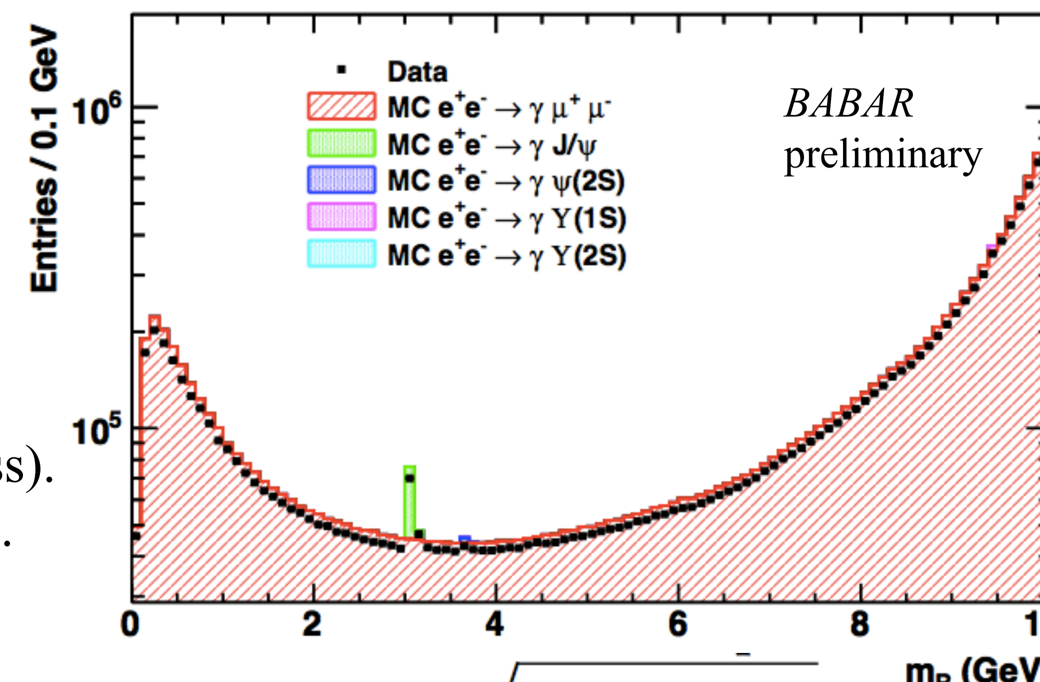
Thanks to Yoni for ref.

BABAR: Invariant mass distributions

arxiv:1406.2980





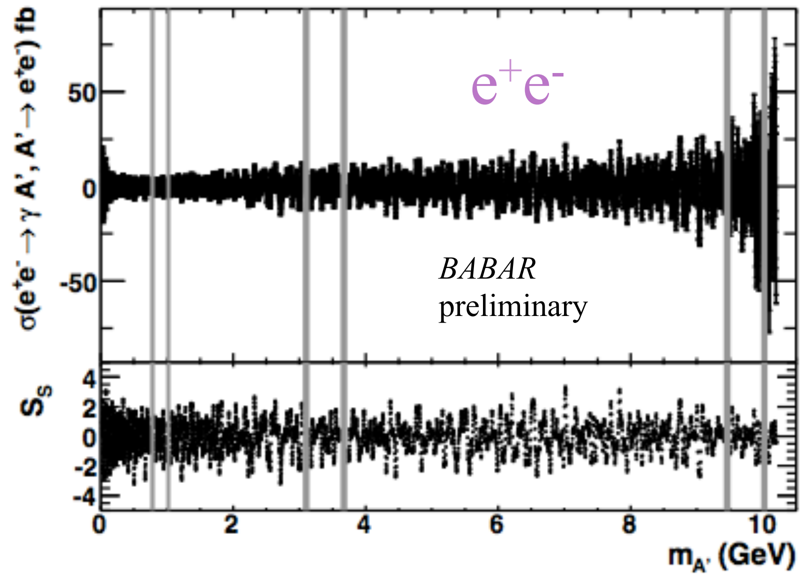


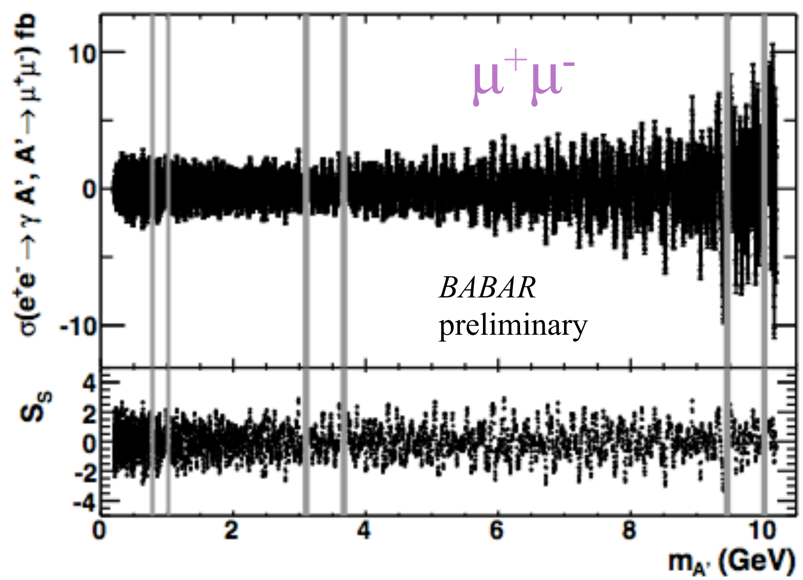
Some Data-MC discrepancy seen (generator not meant for low e^+e^- mass). MC not used for background estimate.

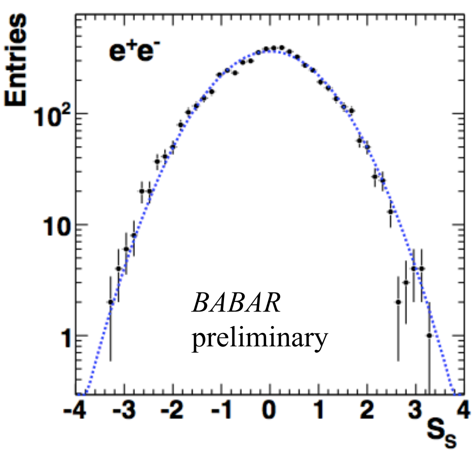
Smoother near-threshold behavior than $m_{\mu\mu}$ ⟵ $m_R = \sqrt{m_{\mu\mu}^2 - 4m_\mu^2}$

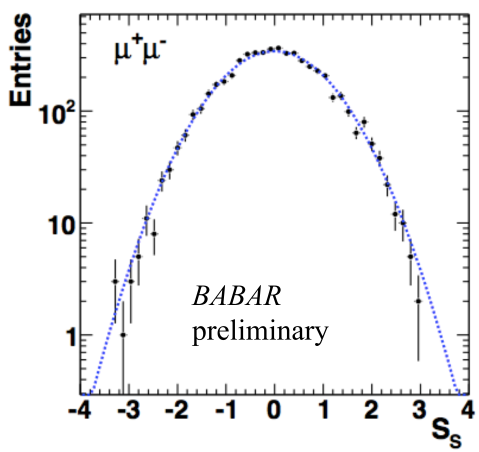
Signal search

- Fit for signal peak + background (3^{rd} or 4^{th} order polynomial) in intervals 20 × wider than signal
- Calculate cross section for each fit
- Statistical significance ~ Gaussian

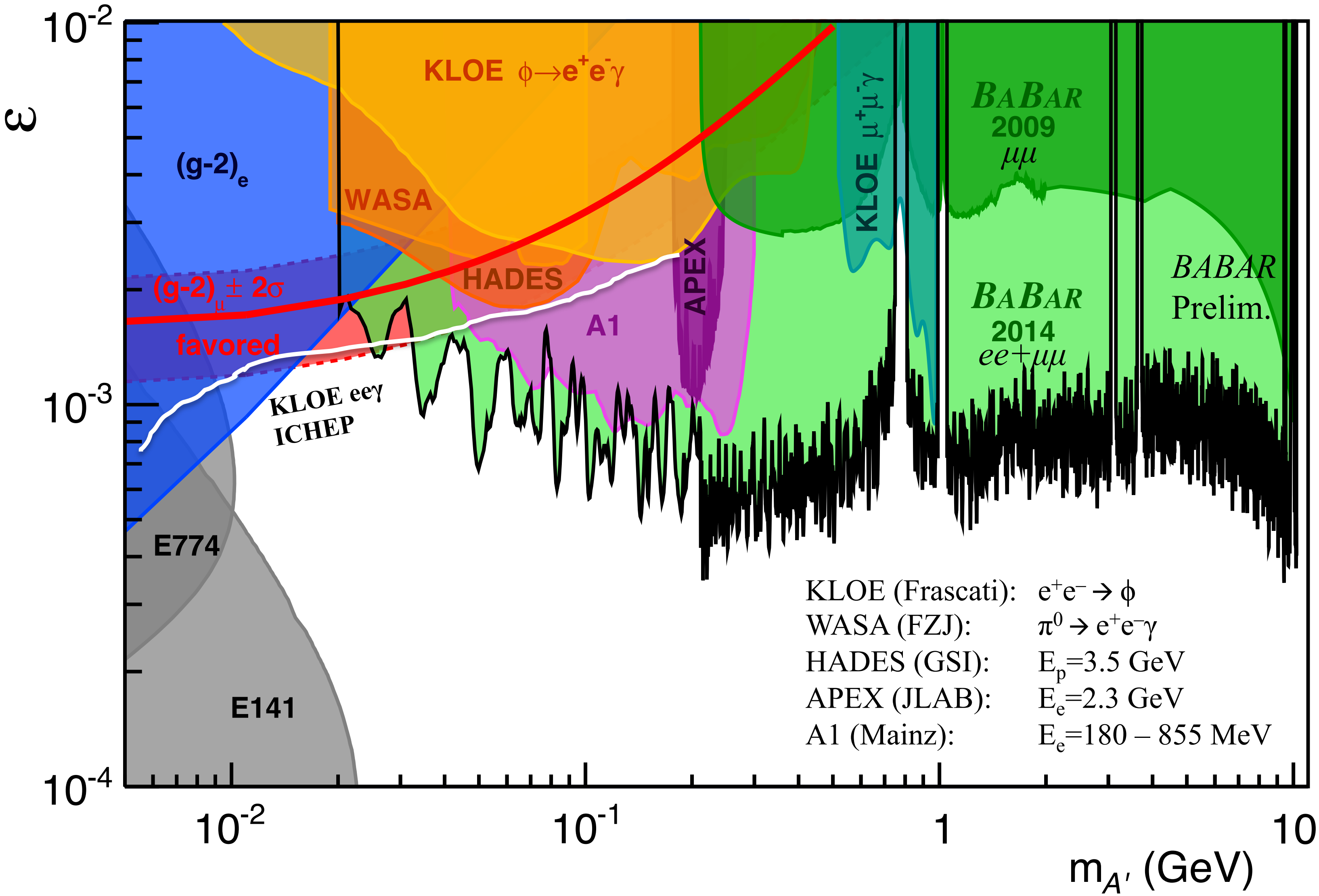




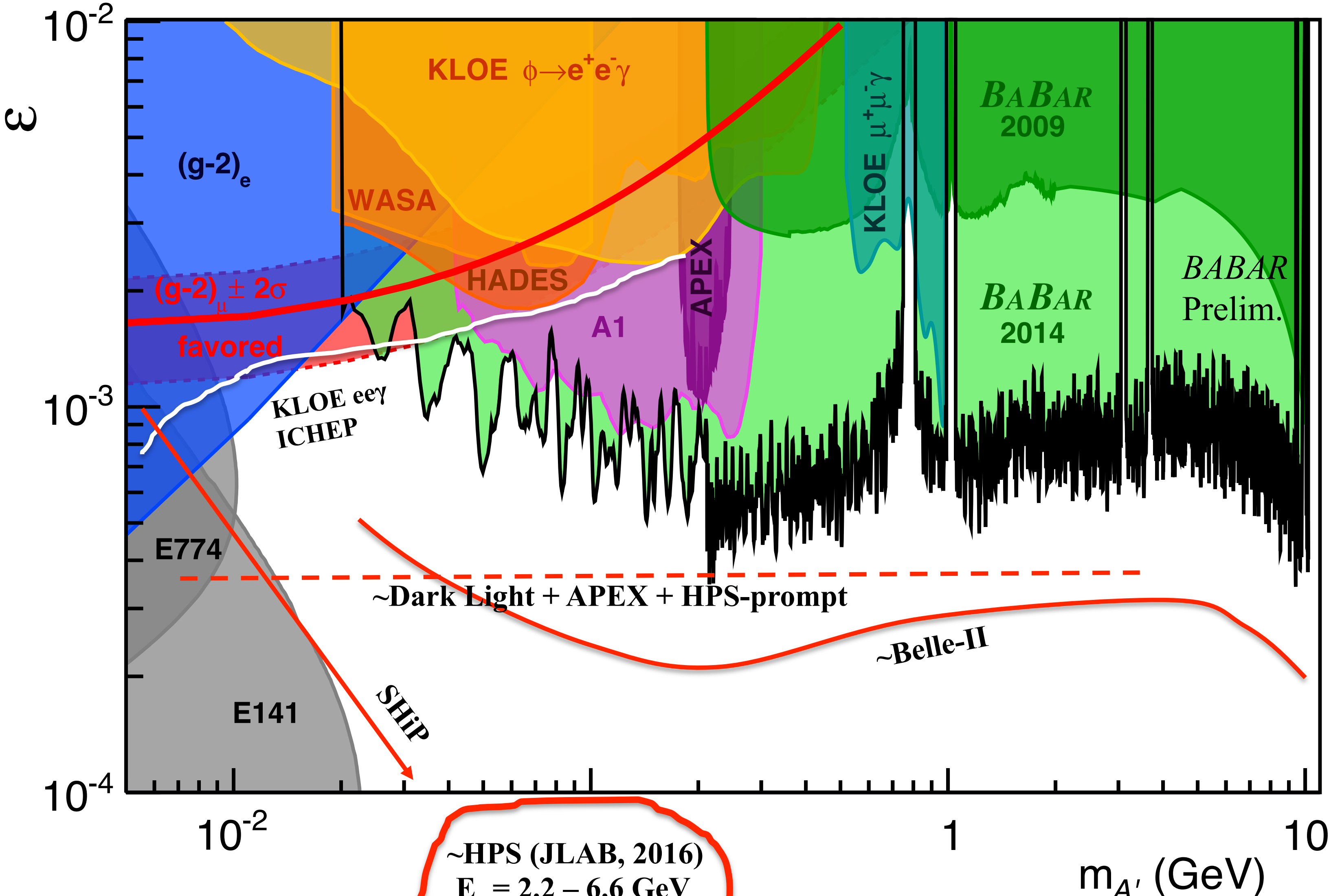




Model constraints

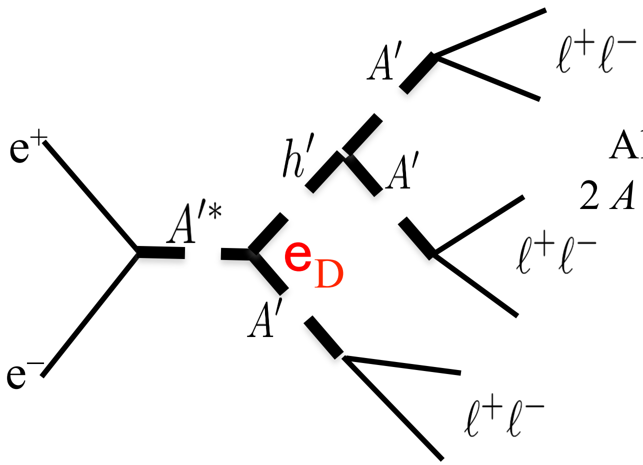


Model constraints + future outlook

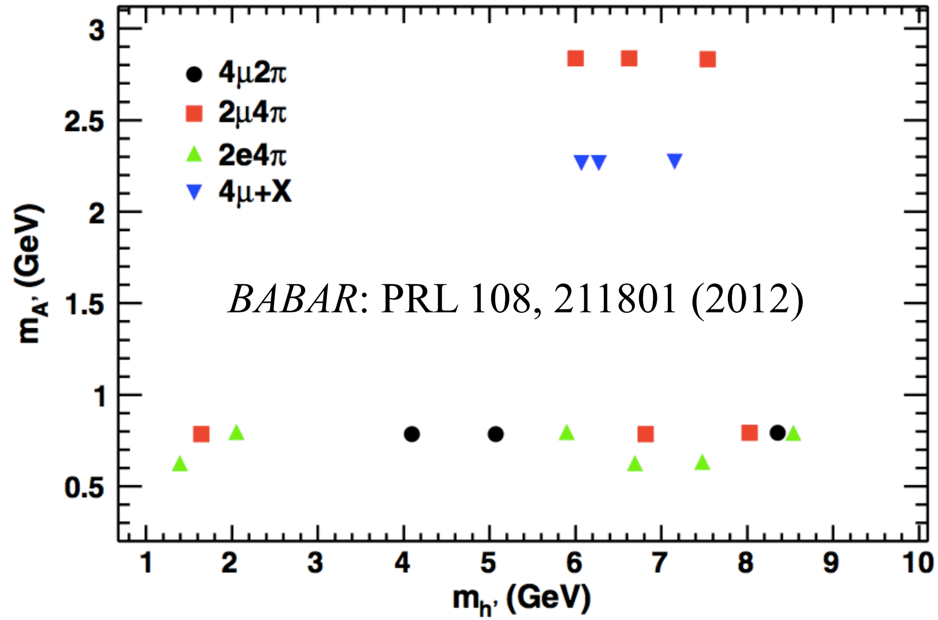


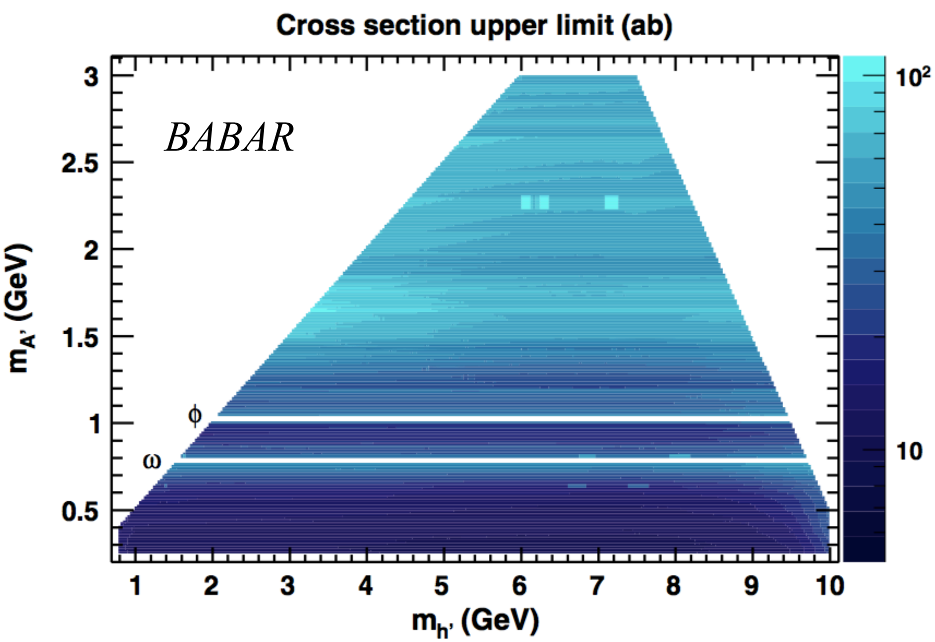
~HPS (JLAB, 2016)
$E_e = 2.2 - 6.6$ GeV
$10^{-5} < \varepsilon < 10^{-4}$

Dark Higgsstrahlung



Allow up to
2 A' → hadrons

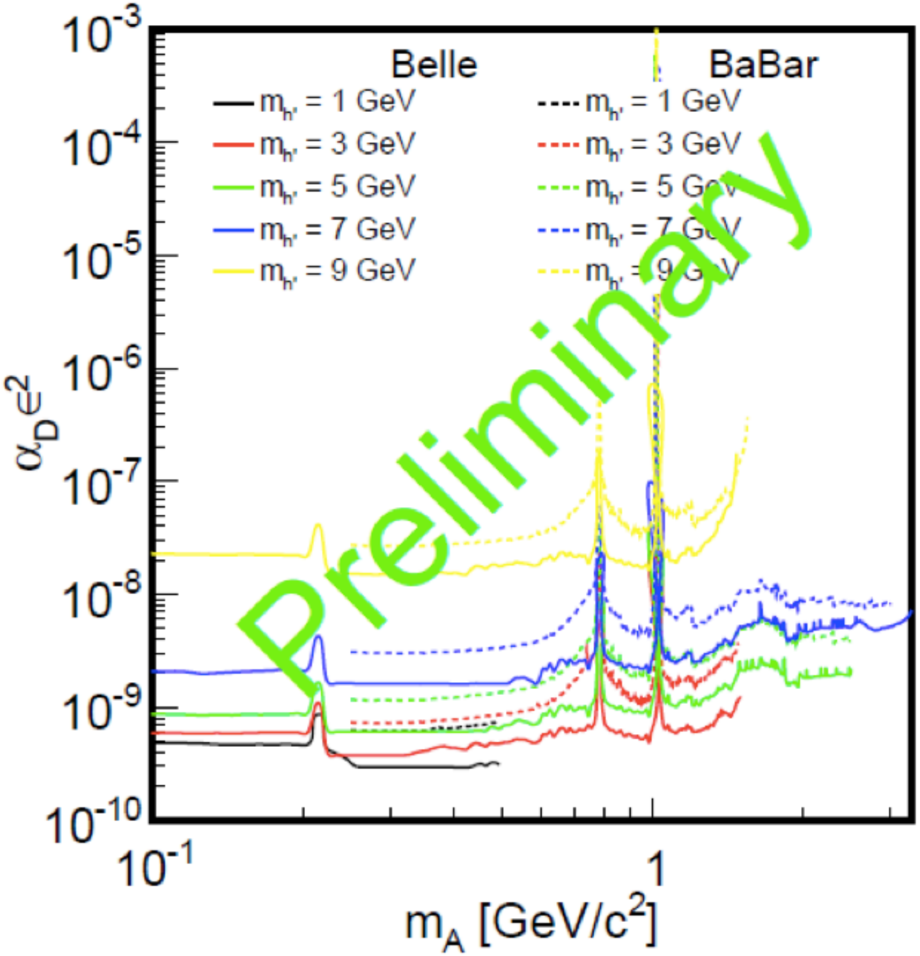


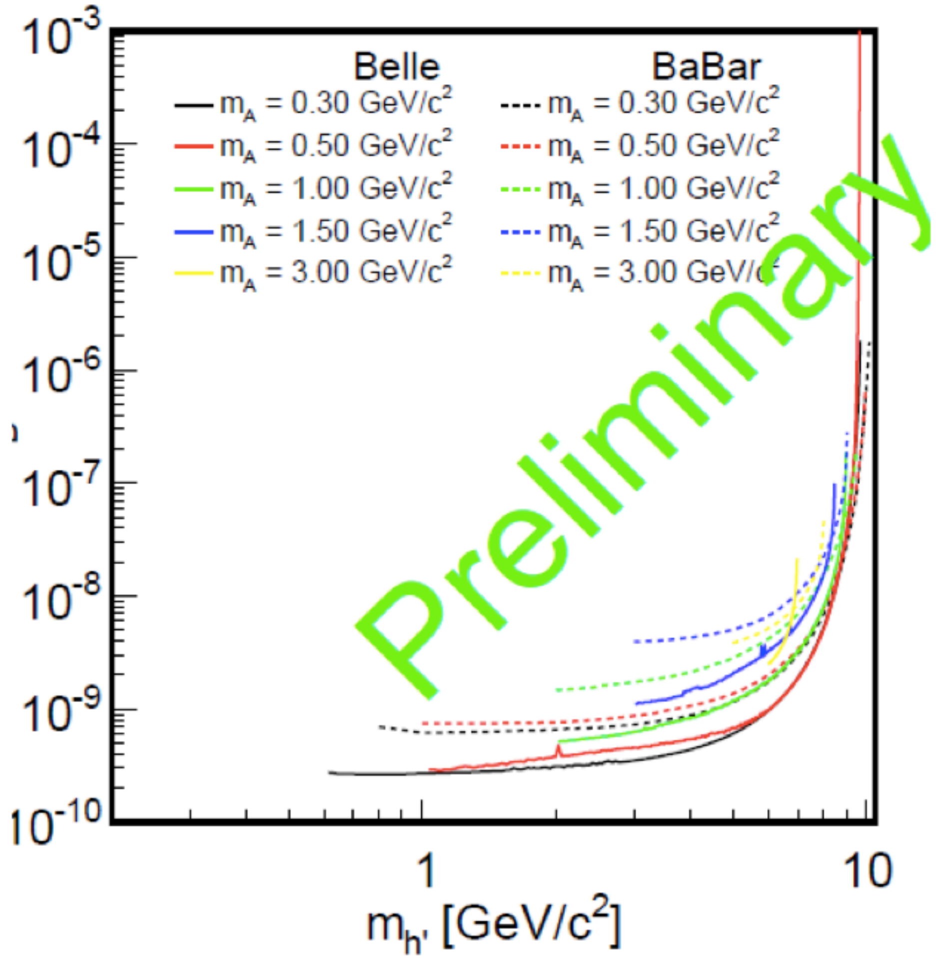


See 6 events, all with hadrons.
(Each plotted with 3 possible
h′→*A′A′* assignments)

Model-parameter limits

Belle: ICHEP14



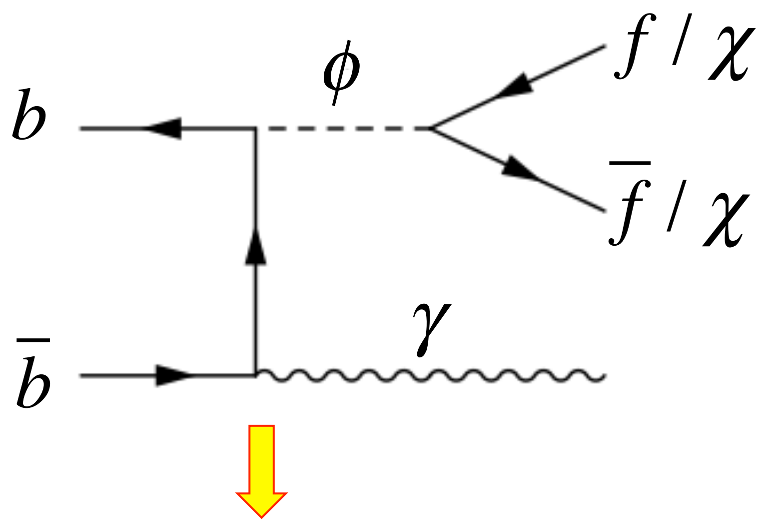


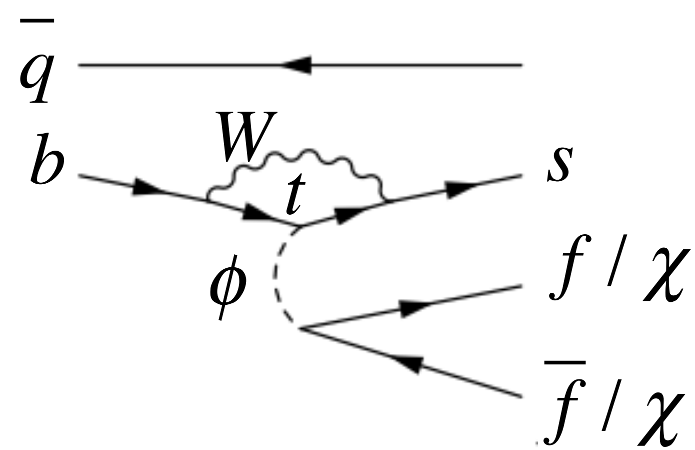
The dark Higgs portal

- A scalar that mixes with the SM Higgs, studied in various scenarios
  - e.g., JHEP 1402, 123 (2014); PLB 727, 506 (2013)

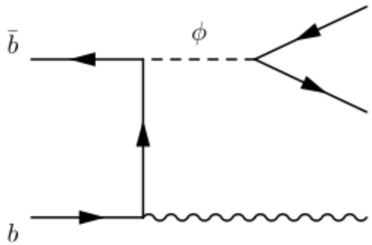
$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} - \frac{y m_f}{v} \phi \bar{f} f - \frac{1}{2} \kappa \phi \bar{\chi} \chi$$

- Scalar produced in *Υ* or *B* decays, decays to SM or dark fermions:





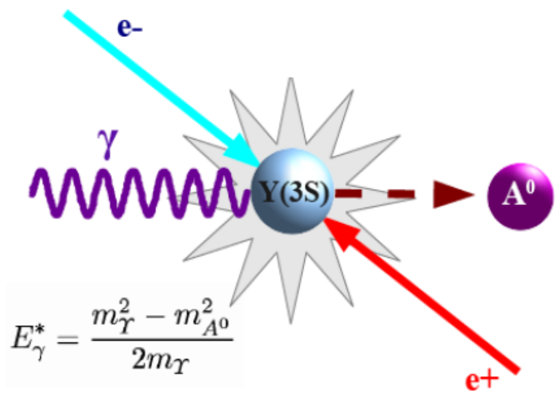
- Same topology as *BABAR*'s search for NMSSM CP-odd Higgs A^0



Searches for $\Upsilon \to \gamma A^0$

$$\frac{\mathcal{B}(\Upsilon(nS) \to \gamma A^0)}{\mathcal{B}(\Upsilon(nS) \to l^+l^-)} = \frac{g_b^2 G_F m_b^2}{\sqrt{2}\pi\alpha} \mathcal{F}_{QCD} \left(1 - \frac{m_{A^0}^2}{m_{\Upsilon(nS)}^2}\right)$$

Radiative Decays of Υ(nS)
Signature: monochromatic photon



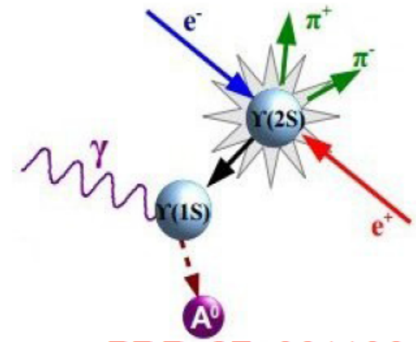
BABAR

$A^0 \to \mu^+\mu^-$, PRL **103**, 081803 (2009)
$A^0 \to \tau^+\tau^-$, PRL **103**, 181801 (2009)
$A^0 \to$ hadrons, PRL **107**, 221803 (2011)
$A^0 \to$ invisible, arXiv:0808.0017

CLEO 1S $A^0 \to \mu^+\mu^-$, $\tau^+\tau^-$, PRL 101, 151802 (2008)

BESIII J/ψ $A^0 \to \mu^+\mu^-$, PRL 101, 151802 (2008)

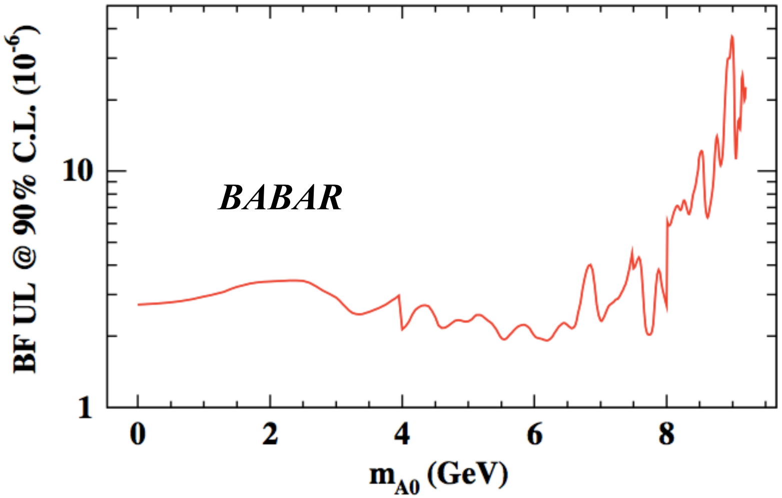
Additional constraints: Υ(1S) from $\Upsilon(2S,3S) \to \pi^+\pi^-\Upsilon(1S)$ transitions
Signature: two low-momentum pions, recoiling against Υ(1S)



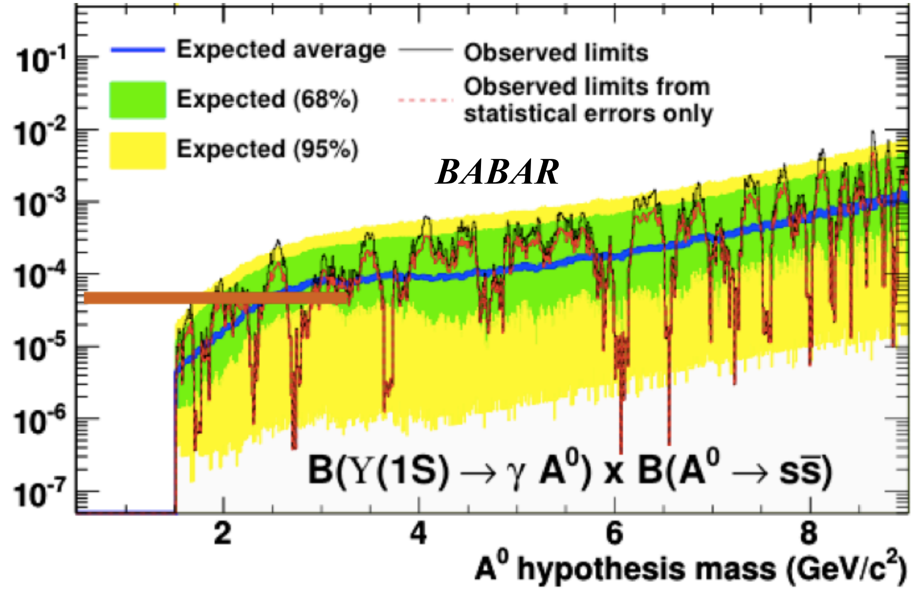
BABAR

$A^0 \to \mu^+\mu^-$, PRD **87**, 031102 (2013)
$A^0 \to \tau^+\tau^-$, PRD **88**, 071102 (2013)
$A^0 \to$ hadrons, PRD **82**, 0317019R (2013)
$A^0 \to$ invisible (light dark matter), PRL **107**, 021804 (2011)

Invisible

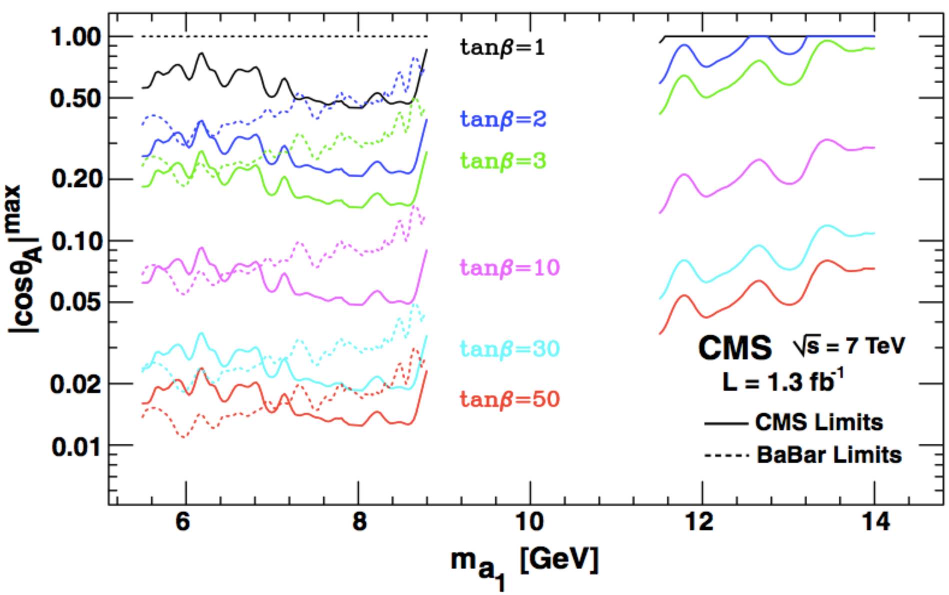


Hadrons

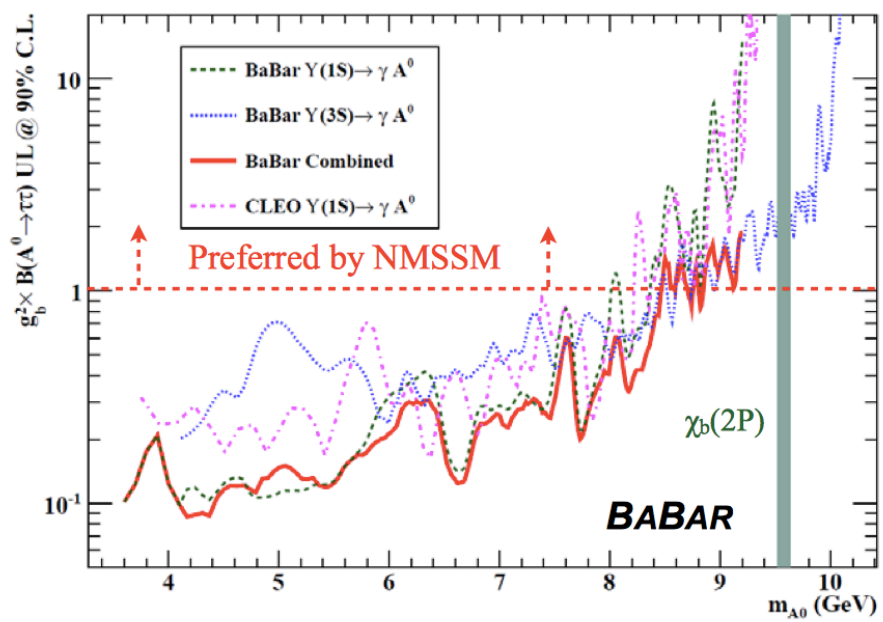


$\mu^+\mu^-$

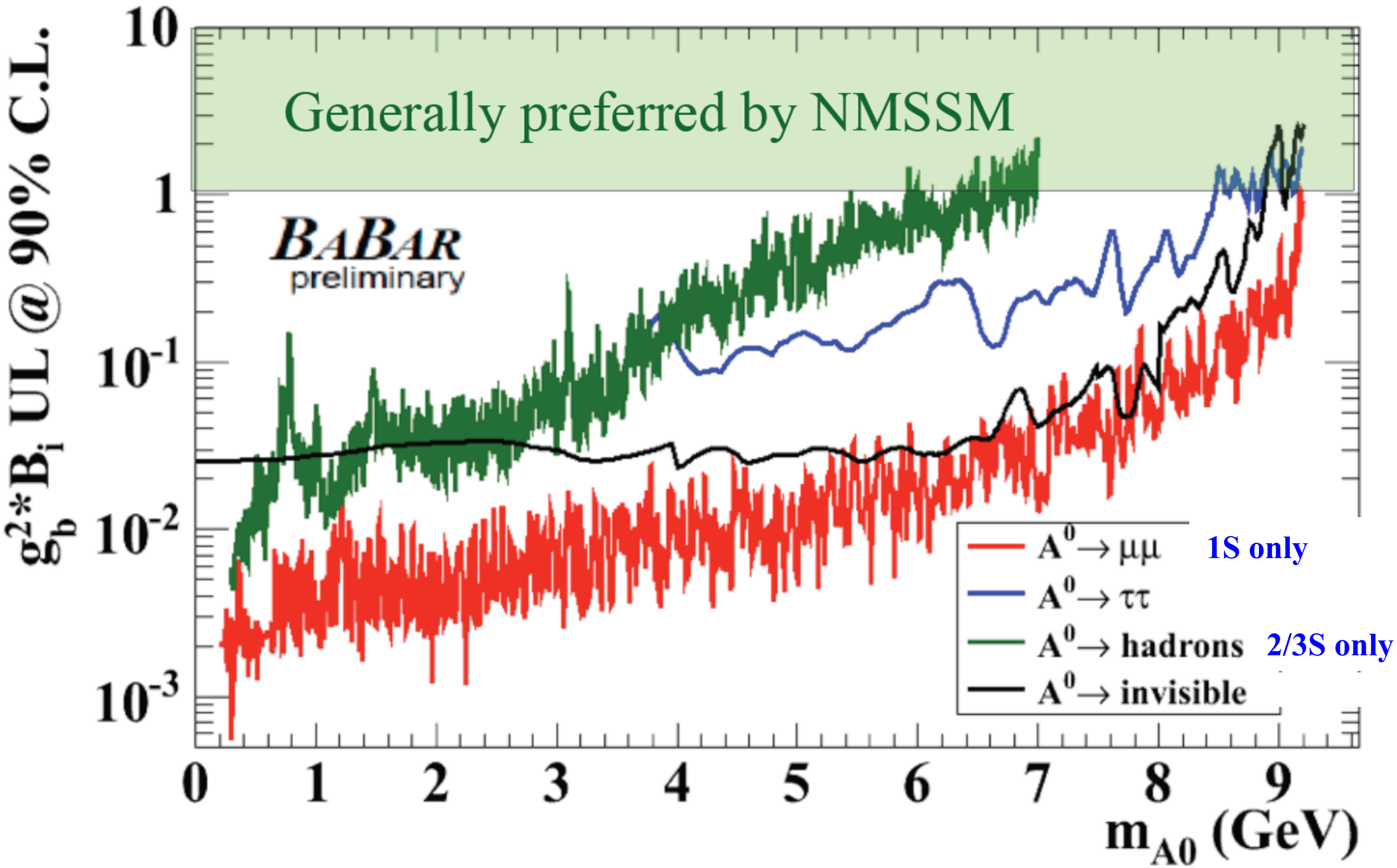
CMS: PRL 109, 121801 (2012)

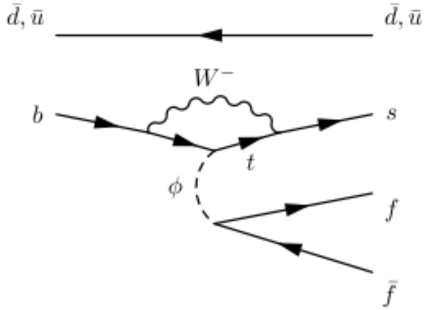


$\tau^+\tau^-$



Summary of *BABAR* $Y \rightarrow \gamma A^0$ results

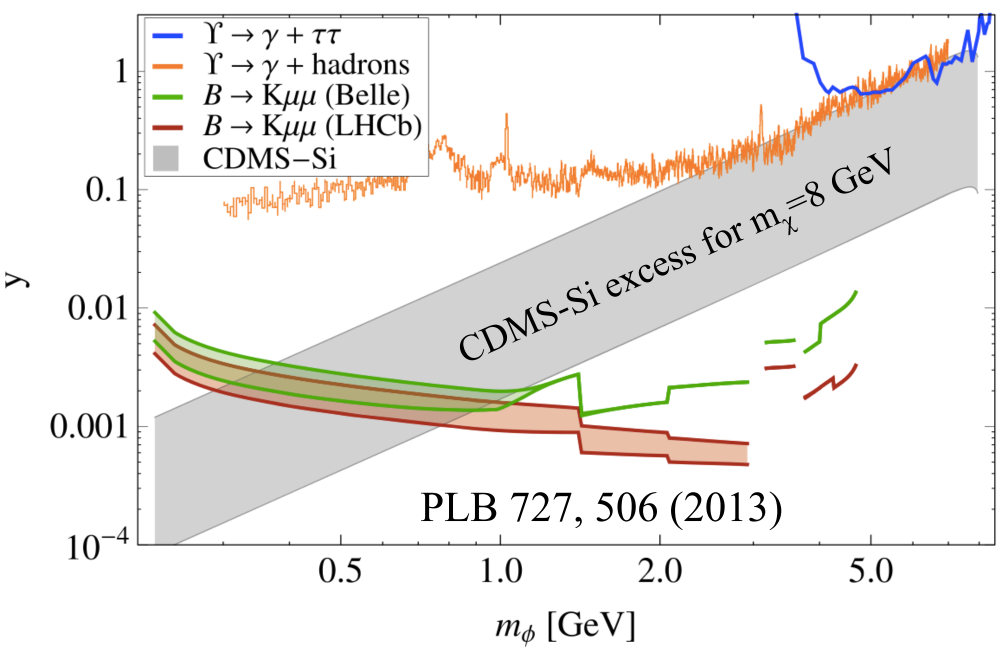


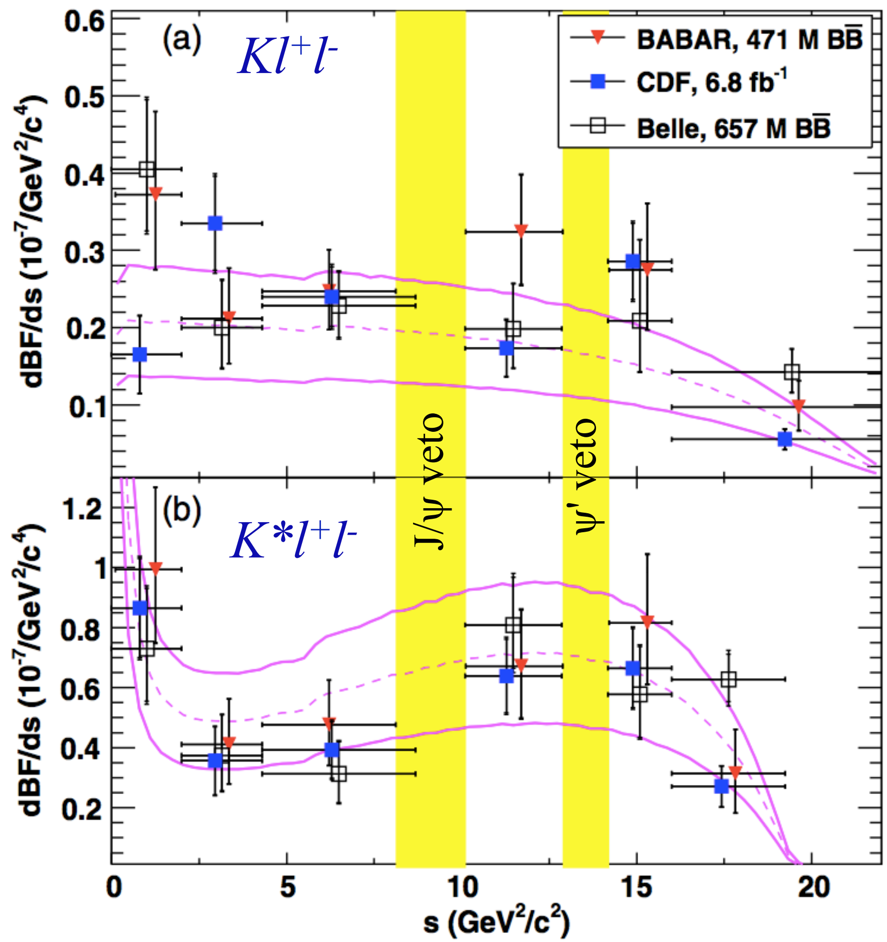


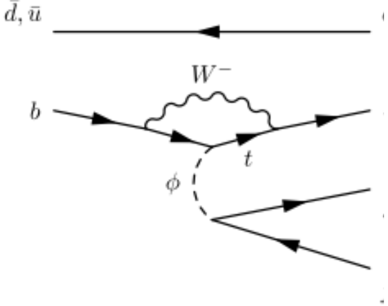
Results for $B \rightarrow K^{(*)} l^+ l^-$

Belle (l^+l^-): PRL 103, 171801 (2009)
CDF ($\mu^+\mu^-$): PRL 107, 201802 (2011)
BABAR (l^+l^-): PRD 86, 032012 (2012)

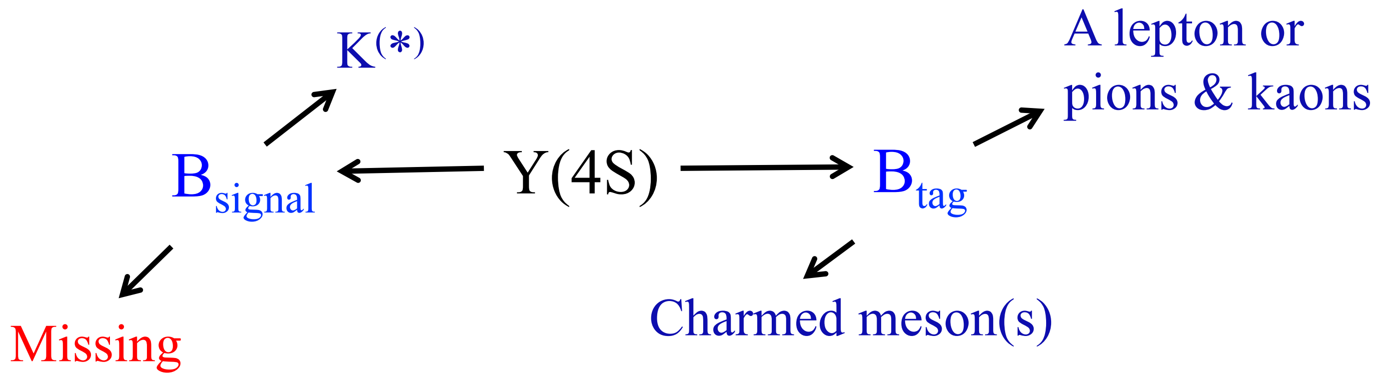
LHCb ($\mu^+\mu^-$): JHEP 1302, 105 (2013)
CDMS: PRL 111, 251301 (2013)



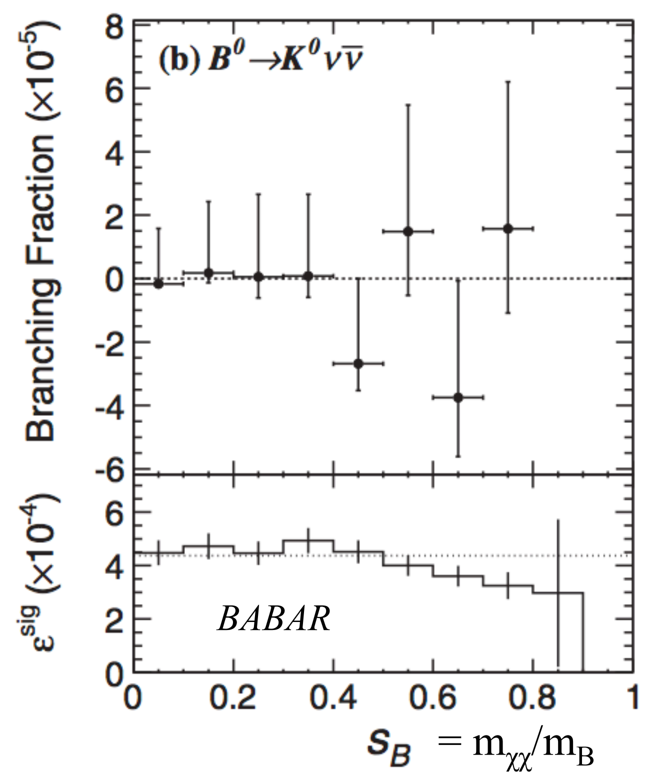




Searches for $B \to K^{(*)} \chi\bar{\chi}$



Mode	Belle	BABAR
$B^+ \to K^+ \nu\bar{\nu}$	$<5.5 \times 10^{-5}$	$<1.6 \times 10^{-5}$
$B^0 \to K_s^0 \nu\bar{\nu}$	$<9.7 \times 10^{-5}$	$<4.9 \times 10^{-5}$
$B^+ \to K^{*+} \nu\bar{\nu}$	$<4.0 \times 10^{-5}$	$<6.4 \times 10^{-5}$
$B^0 \to K^{*0} \nu\bar{\nu}$	$<5.5 \times 10^{-5}$	$<12 \times 10^{-5}$

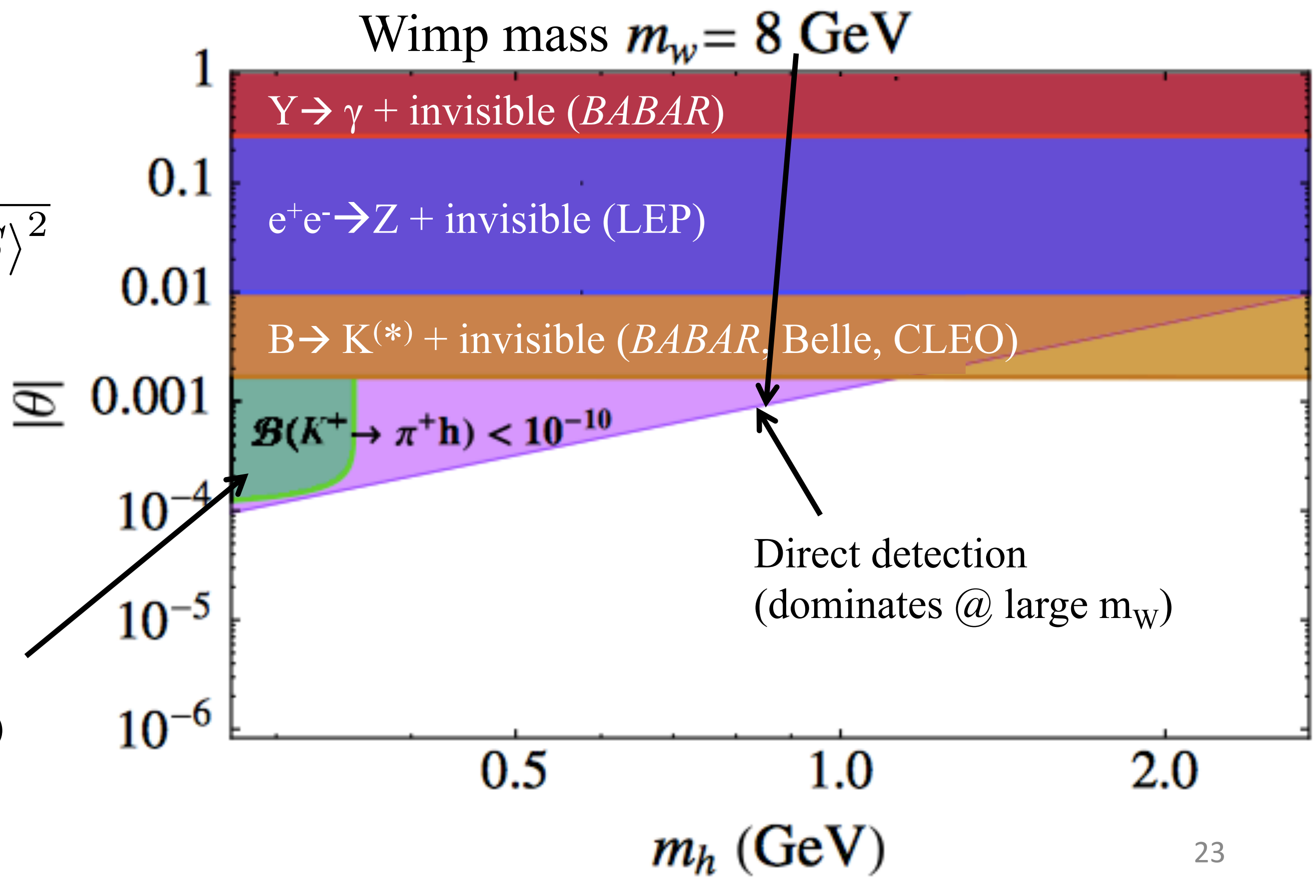


Constraints from $B \to K^{(*)}\chi\bar{\chi}$ & $Y \to \gamma\chi\bar{\chi}$

PRD 89, 083513 (2014)

$$\mathcal{L} = \partial_\mu S^\dagger \partial^\mu S + \mu^2 S^\dagger S - \lambda (S^\dagger S)^2 - g_\theta (S^\dagger S)(\Phi^\dagger \Phi) + \mathcal{L}_{SM}$$

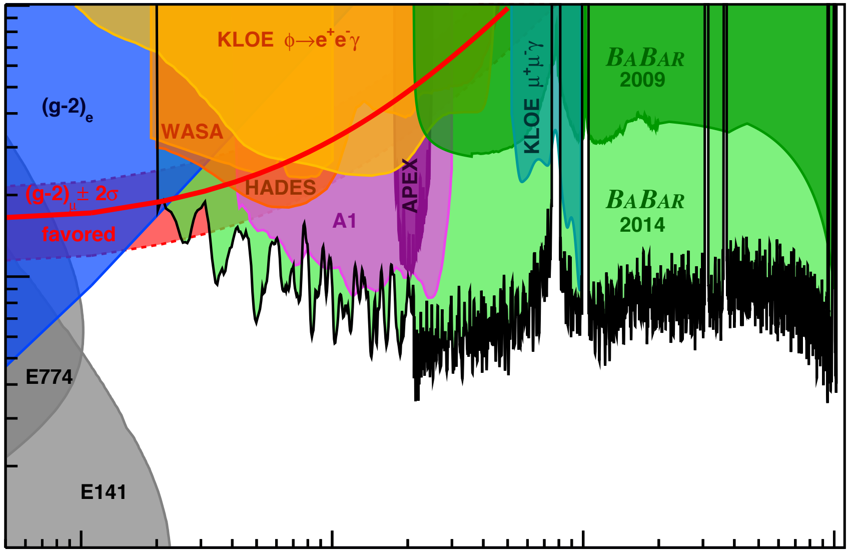
$$\tan 2\theta = \frac{g_\theta \langle S \rangle \langle \phi \rangle}{\lambda_{SM} \langle \phi \rangle^2 - \lambda \langle S \rangle^2}$$



E787: PRL 88, 041803 (2002)
E949: PRD 79, 092004 (2009)
(BML)

Conclusions

- Great interest in exploring a GeV-scale dark sector
- B factories well suited for this purpose
  - "Right" energy, high luminosity
  - Heavy flavors sensitive to mass-dependent couplings
  - Dominate many of the constraints in this mass range
- Have yet to use all channels and data
- Improved constraints from, e.g., LHCb, Belle-II, HPS, SHiP

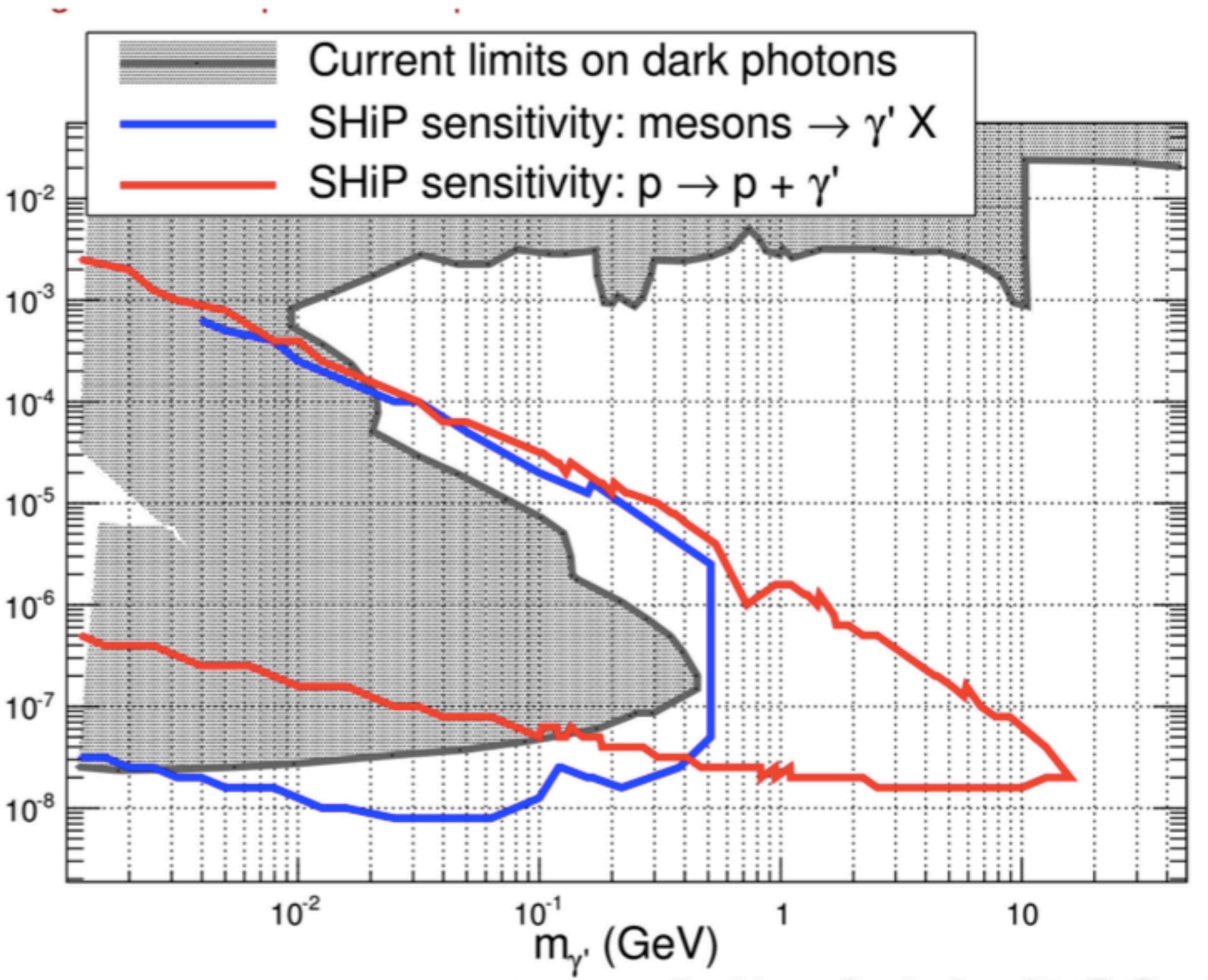



BUTLERS WHARF
BUTLERS WHARF


SUSY?
Mini black holes?
Dark forces?
…?


SUSY?
Mini black holes?
Dark forces?
…?
Queen Mary
University of London
Interplay between Particle and
Astropartical Physics 2014

Backup slides



SHiP limits (from Mitesh's talk)