24th Rencontres de Blois
Particle Physics and Cosmology

Searches for New Physics at BaBar

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On behalf of the BaBar Collaboration

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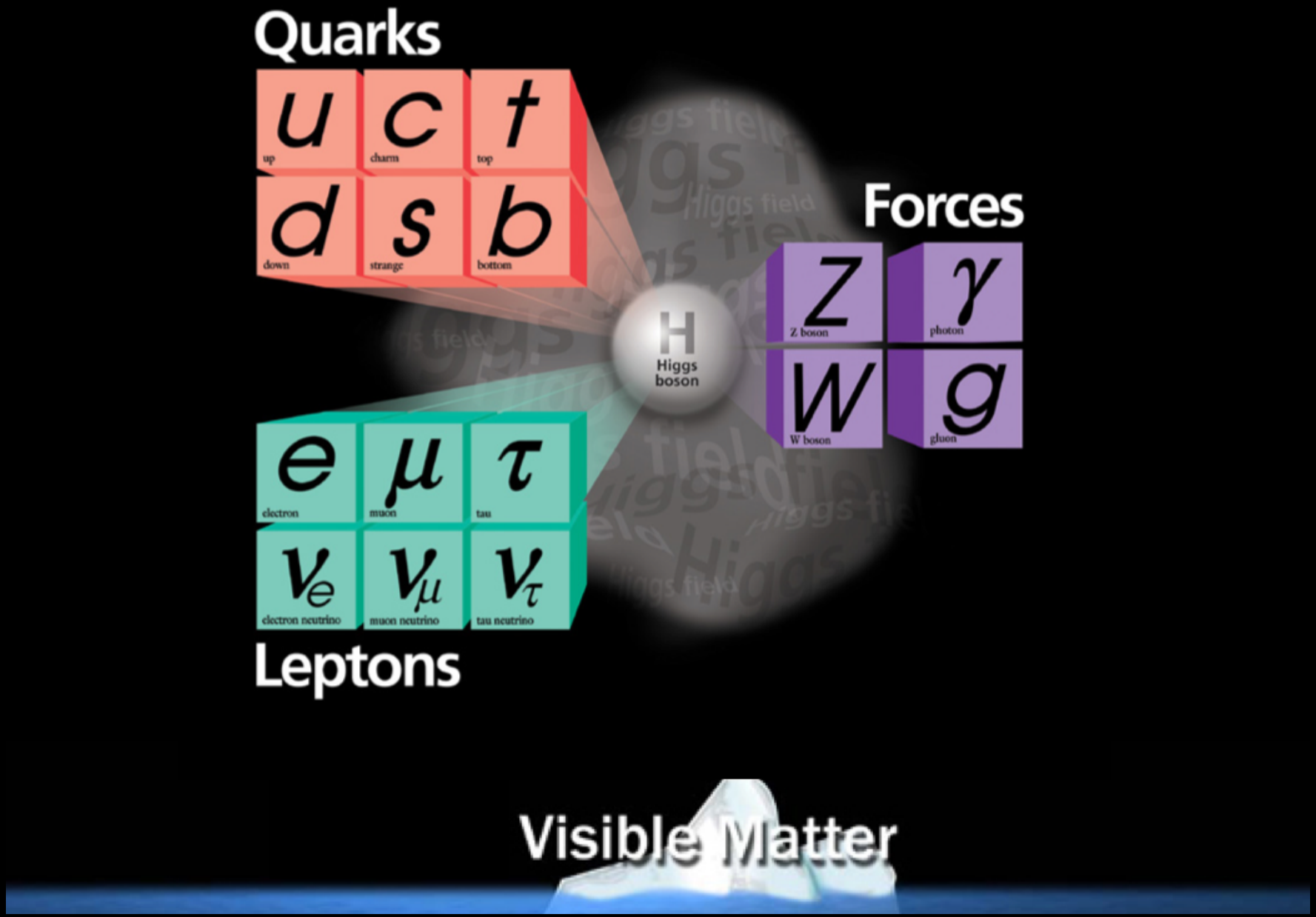
(now at Brandeis University (US))

Blois, May 30th, 2012


Quarks
u
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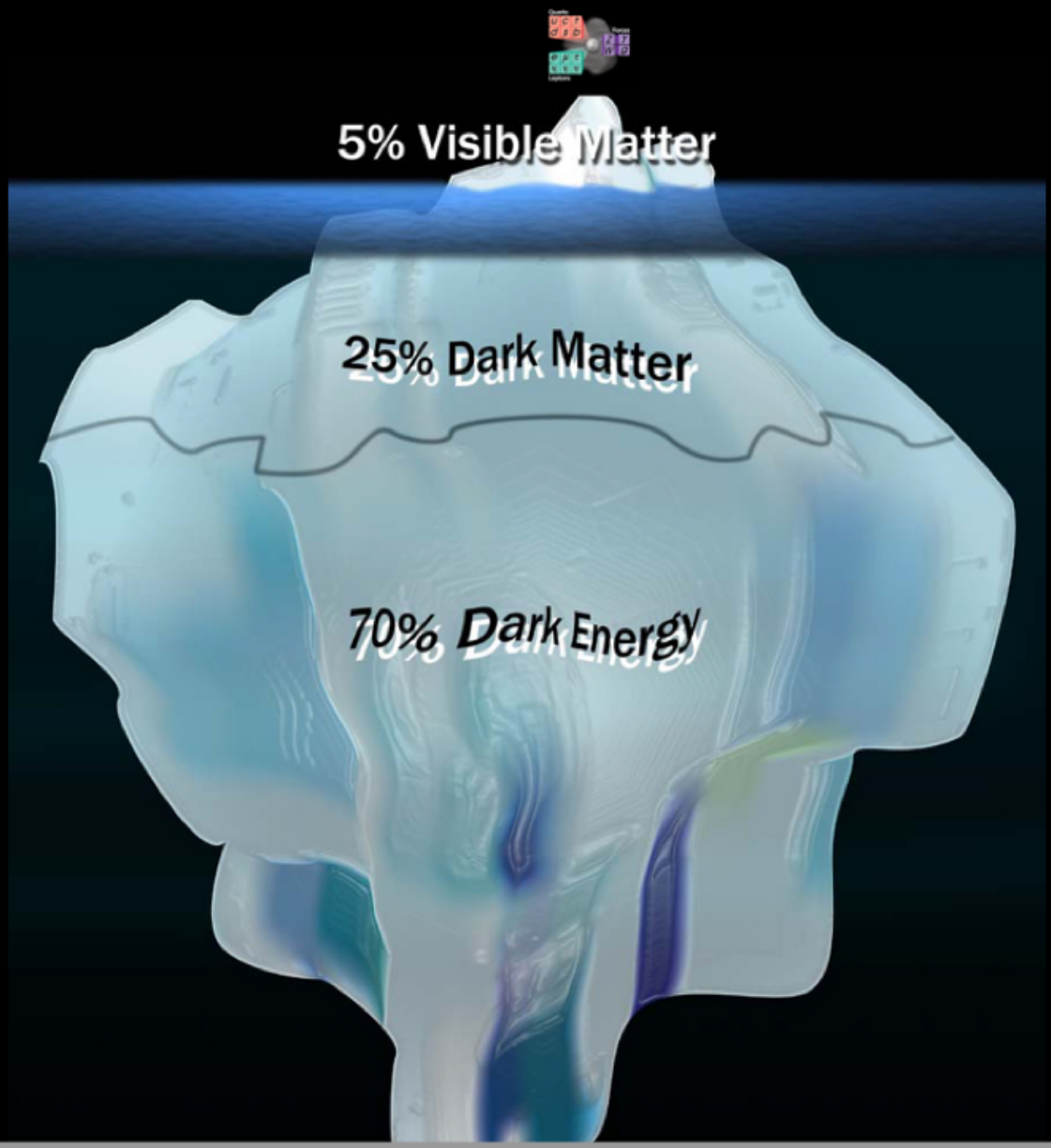
ντ
tau neutrino
Leptons
Visible Matter



Can we solve the dark matter puzzle and illuminate the Higgs sector at the same time?

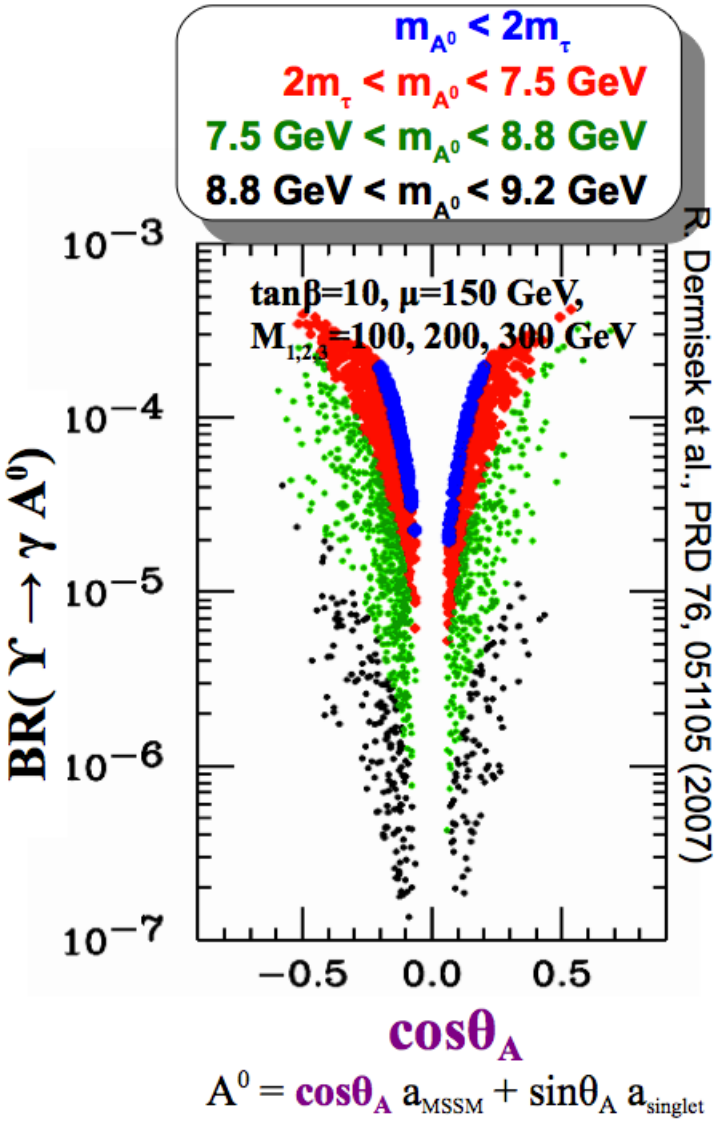
An Intriguing Perspective: NMSSM

Next to Minimal Supersimmetric Standard Model adds a Higgs singlet

- Mixes with the 2 MSSM higgs doublets: new state, A^0
- CP-odd, can be light
- If $m_{A^0} < 2m_b$, can evade LEP constraints
- Can be produced in heavy-quarkonium decays (e.g. $\Upsilon \to \gamma A^0$)

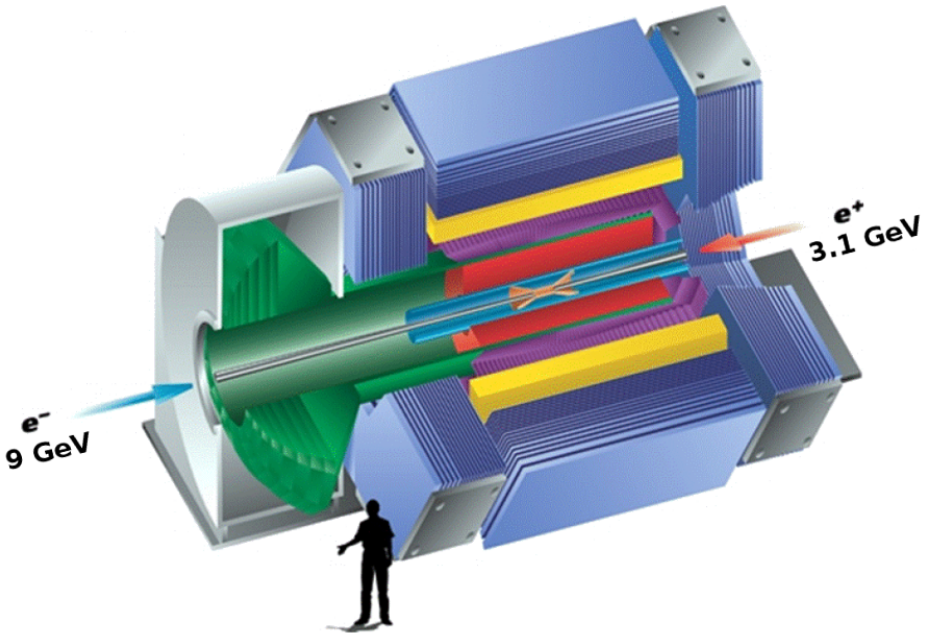
NMSSM also adds a neutralino, χ^0

- $A^0 \to \chi^0\chi^0$ might be dominant



The BABAR Experiment

PEP-II Asymmetric-energy B factory at SLAC running primarily at the $\Upsilon(4S)$ (10.58 GeV) with a center-of-mass boost $\beta\gamma = 0.55$



Magnet Coil

IFR identifies muons and neutral hadrons

EMC measures energy of electrons and photons

DIRC identifies particles by Cherenkov radiation

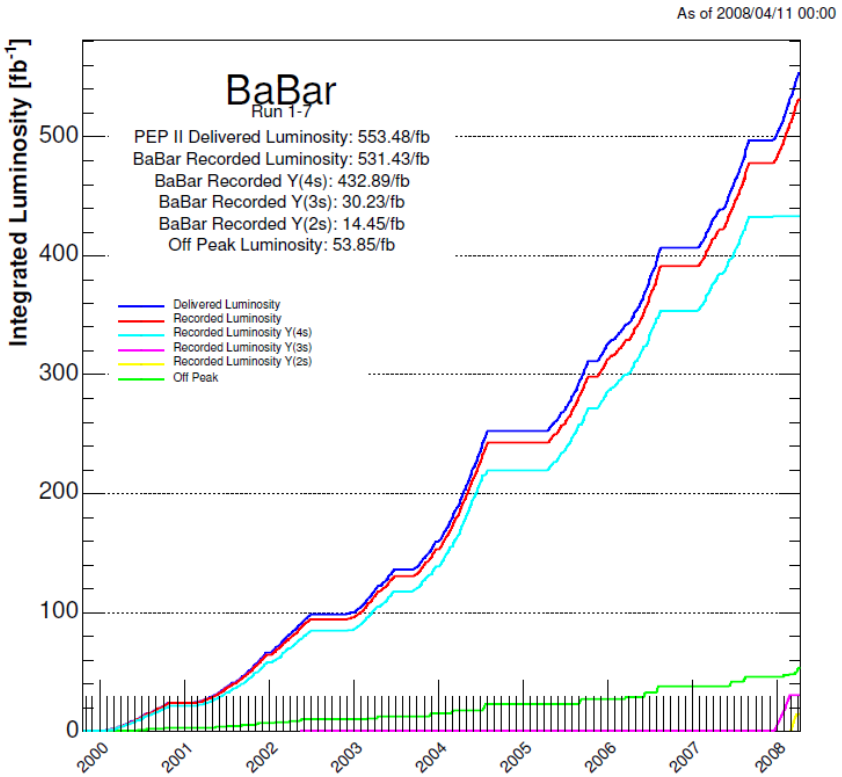
DCH measures momentum of charged particles

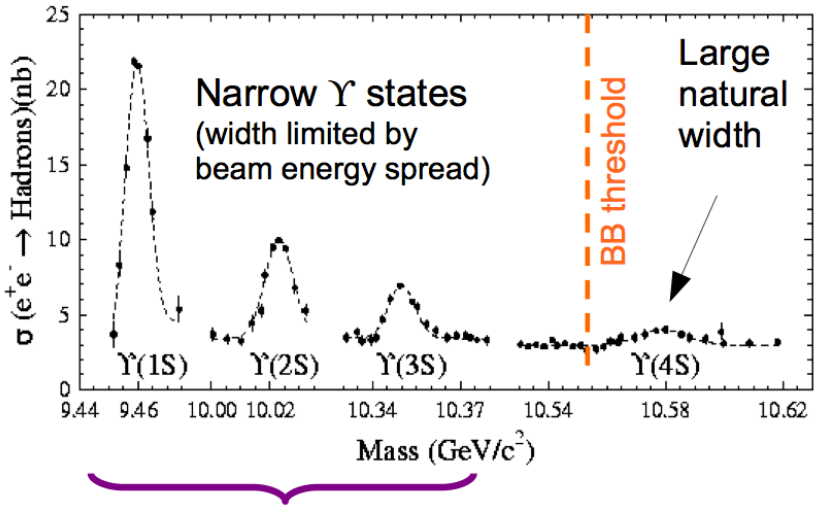
SVT measures origin of charged particle trajectories

Support Tube

SVT: 5 double-sided layers. 97% efficiency, 15μm z-hit resolution (inner layers, $\perp$ tracks).
SVT+DCH (momentum resolution): $\sigma(p_T)/p_T = 0.13\% \times p_T + 0.45\%$.
DIRC: 144 fused silica bars, provides $K - \pi$ separation $\rightarrow 4.2(2.5)\sigma$ @ 2.4(4.0) GeV/c.
EMC: 6580 $CsI(Tl)$ crystals. Energy resolution: $\sigma_E/E = 2.3\% \times E^{-1/4} + 1.91\%$.

BABAR Data Sample





No $B\bar{B}$ decays:
Clean environment for New Physics searches

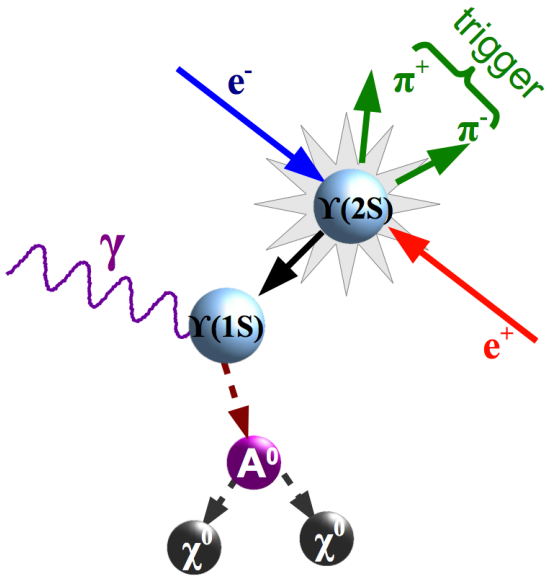
Narrow States: Ehnanced Sensitivity!

$BF(\Upsilon(nS) \to X)/BF(\Upsilon(4S) \to X) = \Gamma_{4S,total}/\Gamma_{nS,total}$

(assuming $\Gamma_{4S \to X} = \Gamma_{nS \to X}$)

- $\approx 470M\ \Upsilon(4S)$
- $\approx 120M\ \Upsilon(3S)$ [10x Belle, 25x CLEO]
- $\approx 100M\ \Upsilon(2S)$ [0.5x Belle, 10x CLEO]

A^0 Light Higgs: Analysis Technique



$A^0 \to$ *invisible*

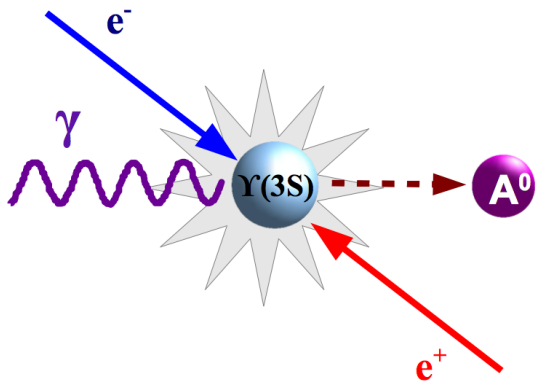
$\Upsilon(3S,2S) \to \pi\pi\Upsilon(1S), \Upsilon(1S) \to$ invisible $(+\gamma)$

- Key experimental signature: exactly 2 identified pions forming a vertex, and $M^{REC}_{\pi\pi} \simeq M_{\Upsilon(1S)}$
  - PRL 103, 251801 (2009) :: $\Upsilon(1S) \to$ *invisible*
  - PRL 107, 021804 (2011) :: $\Upsilon(1S) \to$ *inv.* $+\gamma$
- Also sensitive to $\Upsilon(1S) \to \chi\chi$ (dark matter)

$A^0 \to$ *leptons/hadrons*

2-body radiative decays $\Upsilon(3S,2S) \to \gamma A^0$

- Key experimental signature: monochromatic photon in the CM frame, $E^*_\gamma = \frac{m^2_\Upsilon - m^2_{A^0}}{2m_\Upsilon}$
  - PRL 103, 081803 (2009) :: $A^0 \to \mu^+\mu^-$
  - PRL 103, 181801 (2009) :: $A^0 \to \tau^+\tau^-$
  - PRL 107, 221803 (2011) :: $A^0 \to$ *hadrons*



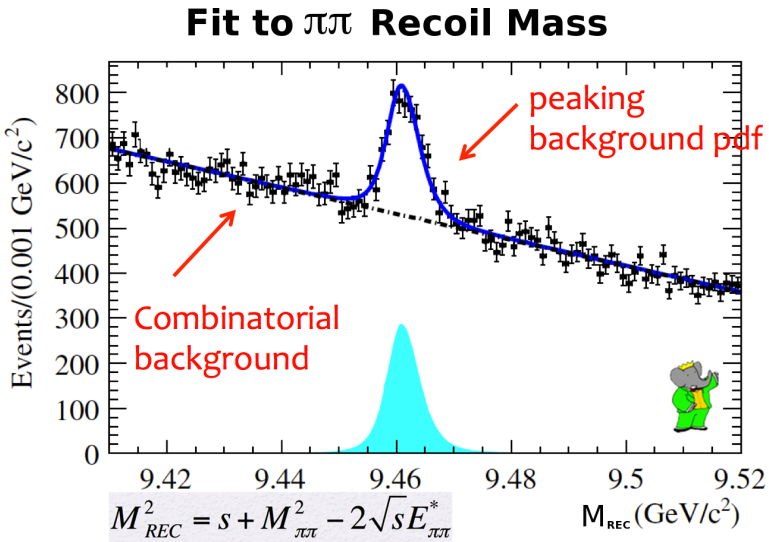
$\Upsilon(3S,2S) \to \pi\pi\Upsilon(1S), \Upsilon(1S) \to (A^0) \to$ invisible

Event selection, features:

- Exactly 2 tracks forming a vertex
- Pions satisfy PID requirements
- No additional reconstructed objects

Residual backgrounds:

- *Combinatorial*: random $\pi\pi$ (sidebands)
- *Peaking*: $\Upsilon(1S) \to$ *undetected* (MC)



NO SIGNIFICANT SIGNAL OBSERVED

No evidence for dark matter contribution

Previous measurements BF(Υ(1S)→invisible)

CLEO: BF < 3.9 x 10^{-3} @ 90% CL PRD 75 031104 (2007)

Belle: BF < 2.5 x 10^{-3} @ 90% CL PRL 98 132001 (2007)

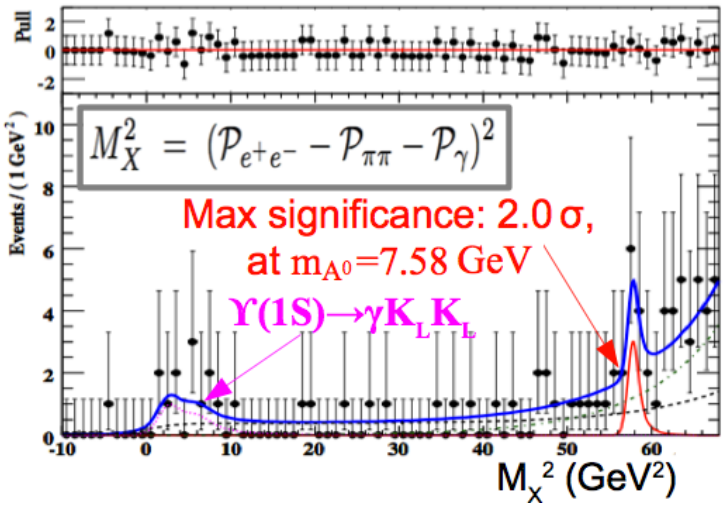
✦ **Upper Limit 90%CL**

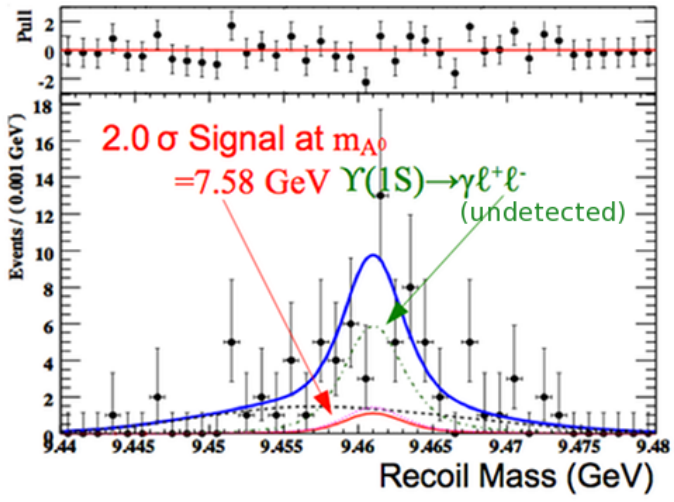
➡ **BF(Y(1S)→Invisible) < 3.0 x 10^{-4}**

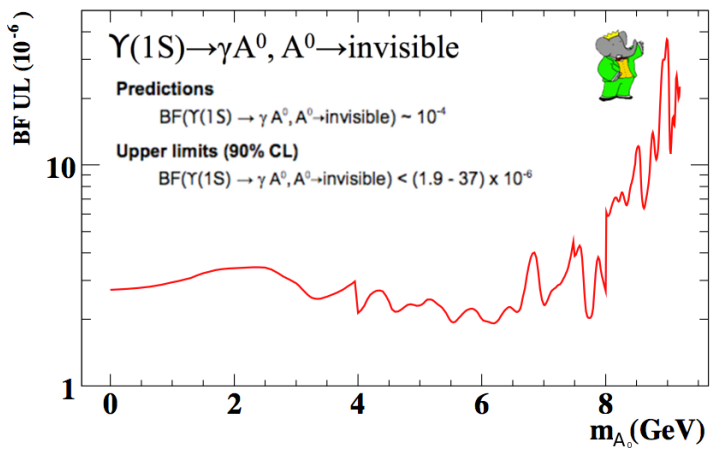
$\Upsilon(3S,2S) \to \pi\pi\Upsilon(1S), \Upsilon(1S) \to (A^0) \to$ invisible $(+\gamma)$

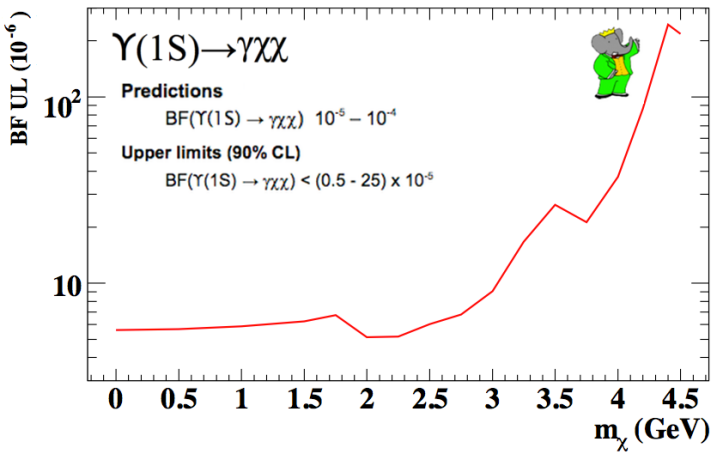
- Add 1 photon with $E_\gamma > 0.15$ GeV
- 2D fit to $\pi\pi$ Recoil Mass & Missing Mass^2

NO SIGNIFICANT SIGNAL OBSERVED









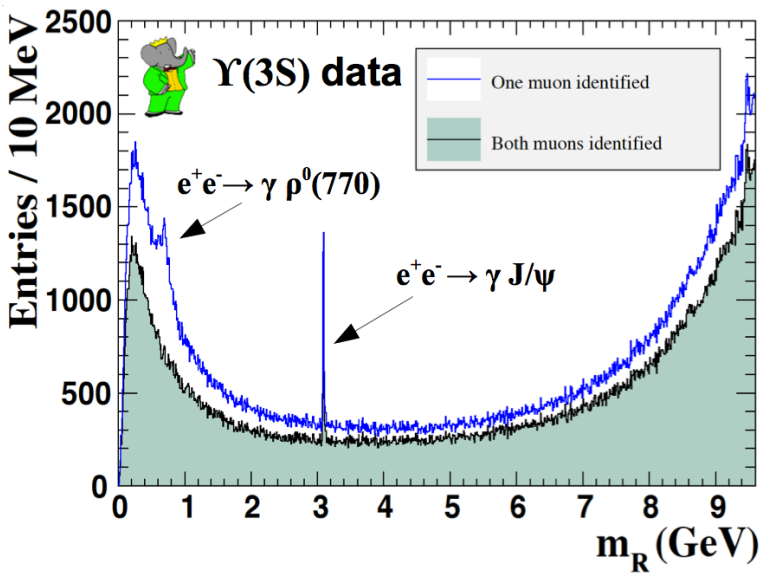
$\Upsilon(3S, 2S) \to \gamma A^0$, $A^0 \to \mu^+\mu^-$

Event selection, features:

- 2 tracks, forming vertex & μ PID
- 1 photon with E_γ >200 MeV
- Υ CM energy constrained to $\sqrt{s}$

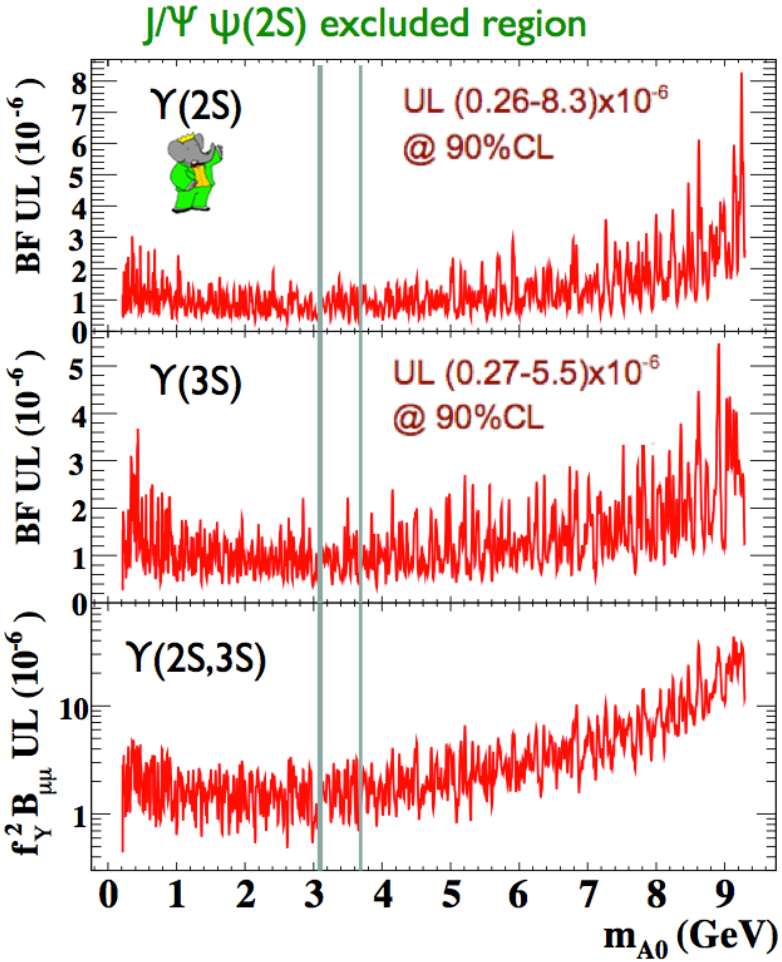
Residual backgrounds:

- *Continuum*: $\Upsilon \to \gamma\mu\mu$
- *Peaking*: ϕ, J/ψ, $\psi(2S)$, $\Upsilon(1S)$



Fit & scan $M_{reduced} = \sqrt{m^2_{\mu\mu} - 4m^2_\mu}$

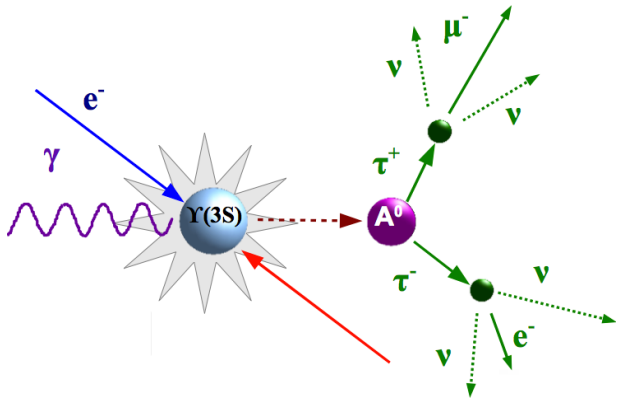
NO SIGNIFICANT SIGNAL OBSERVED



$\Upsilon(3S, 2S) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$

Event selection, features:

- Search for leptonic decays of τ's: $\mu\mu$, ee, μe
- 2 identified tracks & 1 γ with E_γ >100 MeV
- Cuts on discriminating variables against $e^+e^- \to \gamma\tau\tau$ (p_{miss}, p_T^*, angles, etc...)



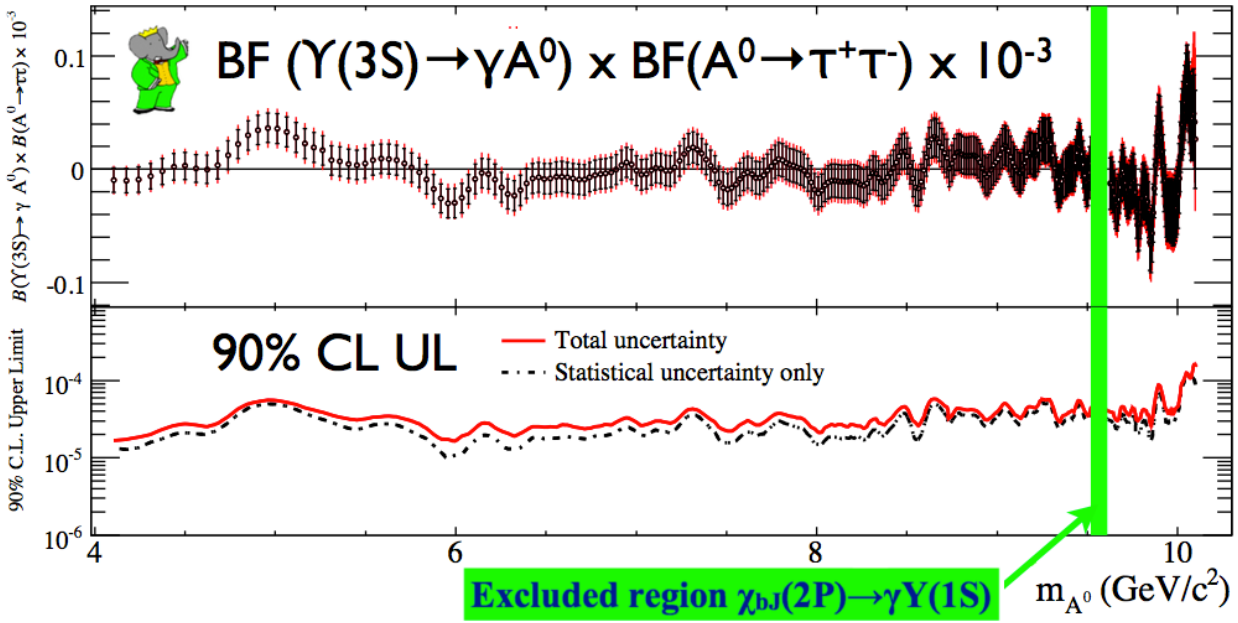
MC & data-driven background estimation

Fit & Scan

$$E_\gamma^* = \frac{m_\Upsilon^2 - m_{A^0}^2}{2m_\Upsilon}$$

simultaneously for the 3 decay modes

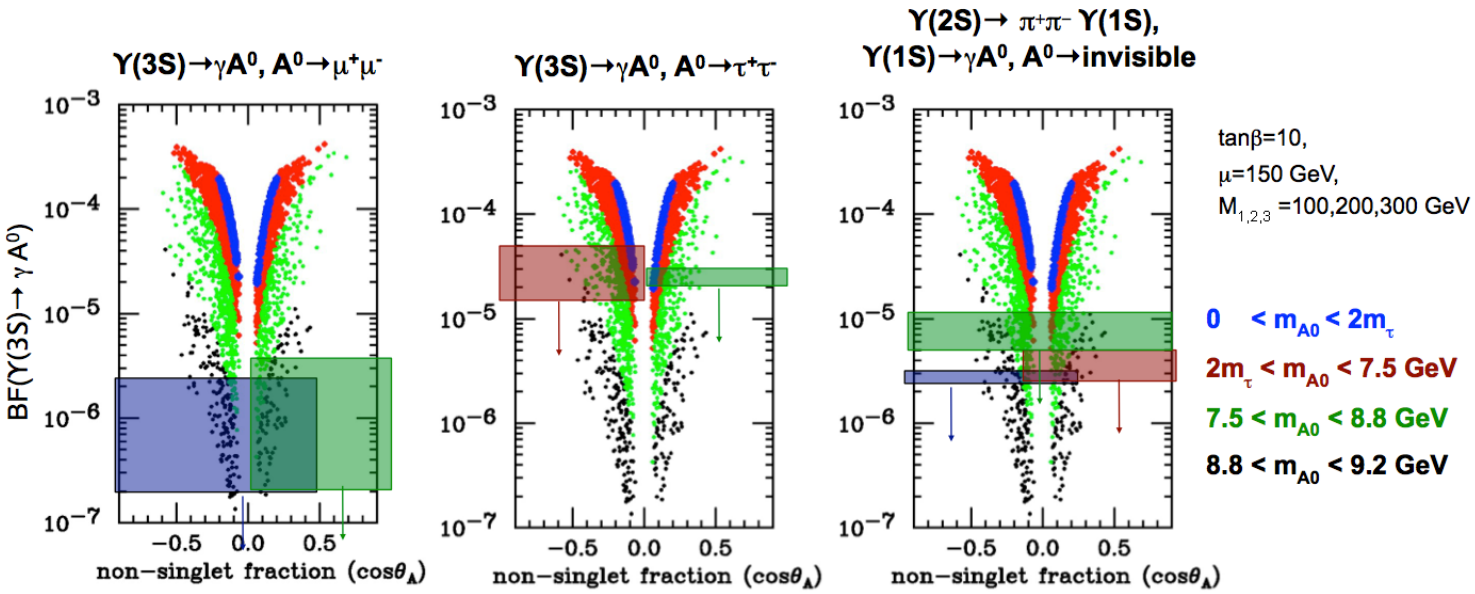
NO SIGNIFICANT SIGNAL OBSERVED



A^0 Searches at BABAR

$$A^0 = \cos\theta_A \, a_{MSSM} + \sin\theta_A \, a_{singlet}$$

R. Dermisek et al., PRD 76, 051105 (2007)



A light CP-odd Higgs is clearly disfavoured!
But $A^0 \rightarrow$ hadrons can still play a role...

R. Dermisek and J. Gunion, PRD 81, 075003 (2010):
Hadronic decays of A^0 can be dominant, depending on its mass and $\tan\beta$

$\Upsilon(3S,2S) \to \gamma A^0$, $A^0 \to$ hadrons

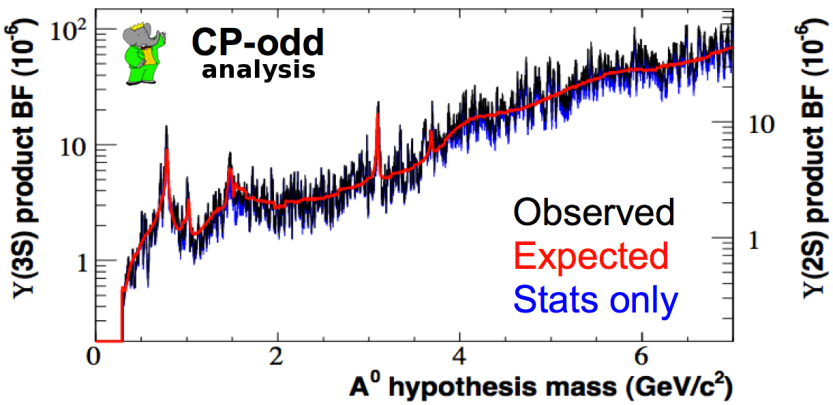
Event selection, features:

- $\geq$ 2 tracks, PID
- 1 photon with E_γ >200 MeV
- Full event energy reconstructed
- Energy and beam constraints

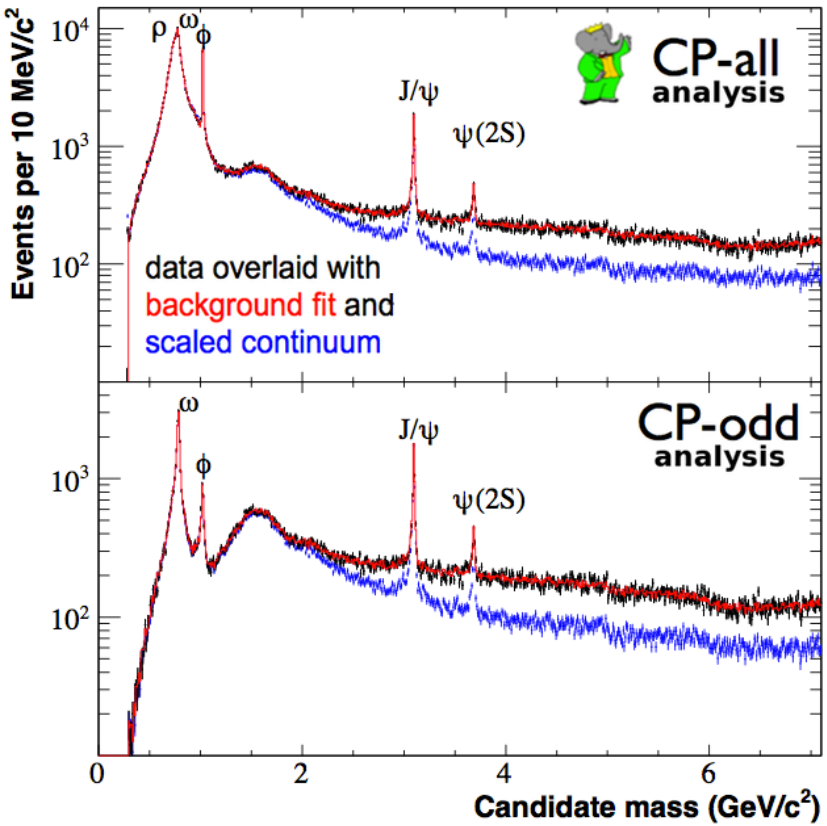
Residual backgrounds:

- *ISR Continuum*: $e^+e^- \to \gamma X, M$
- *Υ Radiative decay*: $\Upsilon \to \gamma X, M$

X=non-resonant, M=resonant



Fit & scan m(A^0)
NO SIGNIFICANT SIGNAL OBSERVED



BF $< (0.1 - 8) \times 10^{-5}$ at 90% CL

Search for Dark Sector Candidates at BABAR

Dark Forces, Theoretical Framework

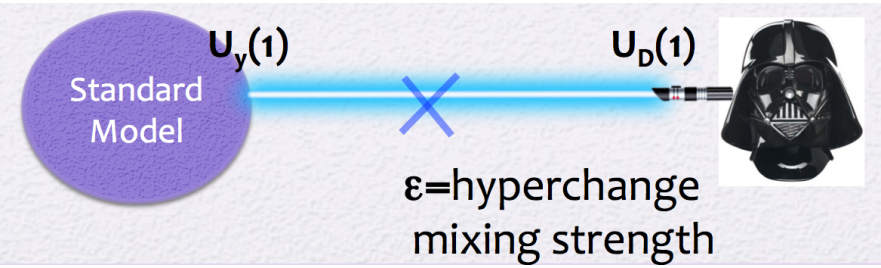
PRD 79, 115008 (2009): Models introducing a new dark force with a $G_D \supset U_D(1)$ gauge group have been proposed to explain the observations of PAMELA, FERMI, DAMA/LIBRA, ATIC...

1) $U_D(1)$ mediated by a new gauge boson ("photon") with a GeV-scale mass

- DM particles can *annihilate* into pairs of dark bosons
  $\rightsquigarrow$ SM lepton pairs (p kinematically forbidden).

2) How can SM particles couple to dark bosons?

$\rightsquigarrow$ Kinetic mixing: $\epsilon F^{\mu\nu} B_{\mu\nu}$



3) Very minimal scenario: 1 dark photon A', 1 dark higgs h'

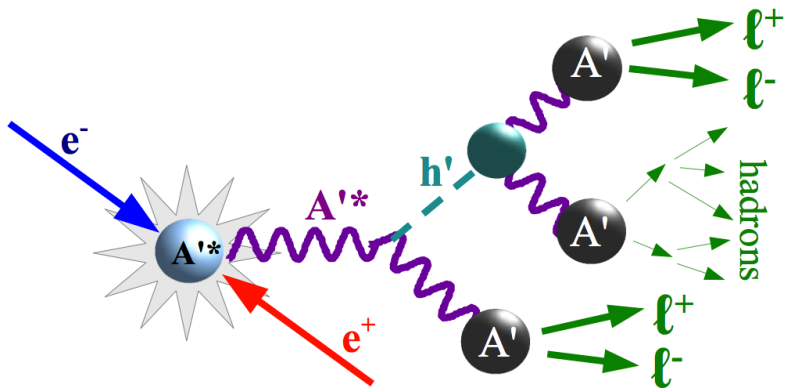
$\rightsquigarrow$ Narrow resonances, prompt decays

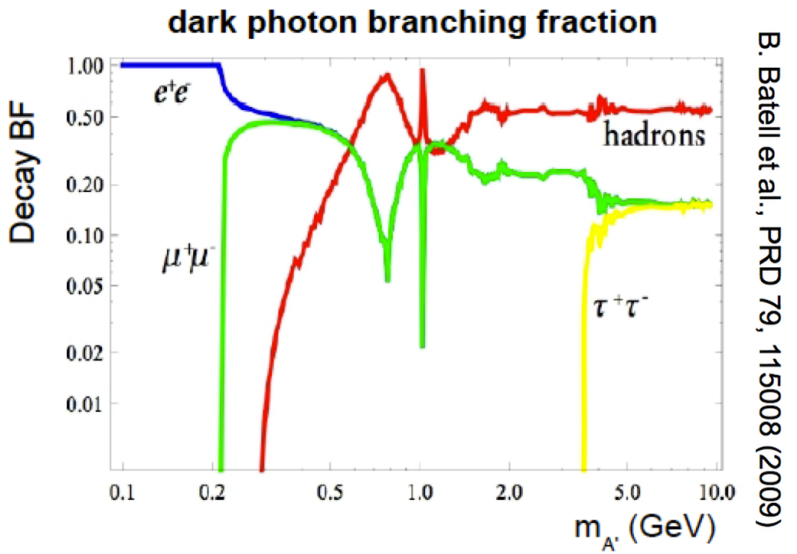
Search for a Dark Higgs h', Dark Photon A'

Event Selection, Features:

- **Full, "exclusive" reconstruction**
  - 3 A', in $\mu\mu$, ee, $\pi\pi$
  - 6 charged tracks with $m_{tot} > 0.95\sqrt{s}$
- **Partial, "inclusive" reconstruction**
  - 2 $A' \to$ leptons and 1 $A' \to q\bar{q}$
  - $A'_1 \to ee, \mu\mu$; $A'_2 \to \mu\mu$; $A'_3 \to X \neq \pi^+\pi^-$ or l^+l^-
  - At least 4 charged tracks
  - Reconstructed 4-momentum, $p_3 = p_{ee} - p_1 - p_2$
- **In both cases:**
  - 3 A' reconstructed masses equal within errors
  - PID requirement on l and π
  - cos(helicity) of $A' \to e^+e^- < 0.9$

Higgs-strahlung $\propto \epsilon^2$





Dark Forces at BABAR: Results (I) [arXiv:1202.1313]

Background estimation:

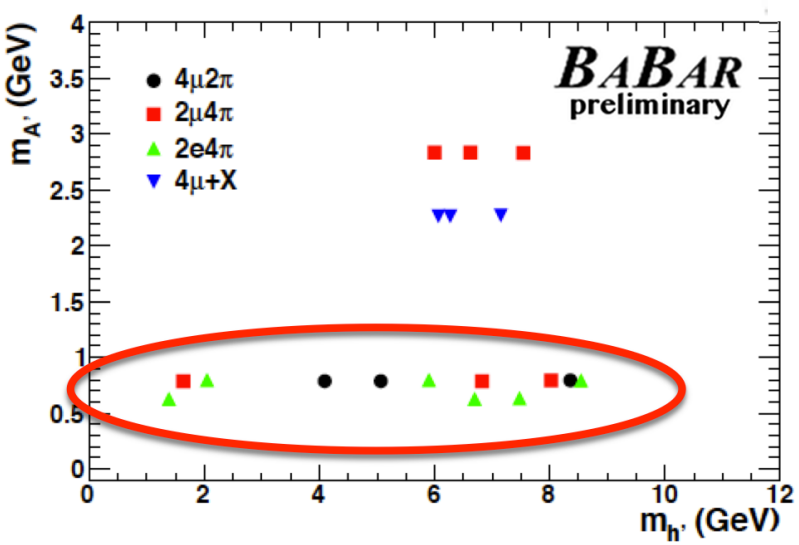
- Data driven tecnique: same-sign lepton pairs, like $e^+e^+\mu^-\mu^-\pi\pi$

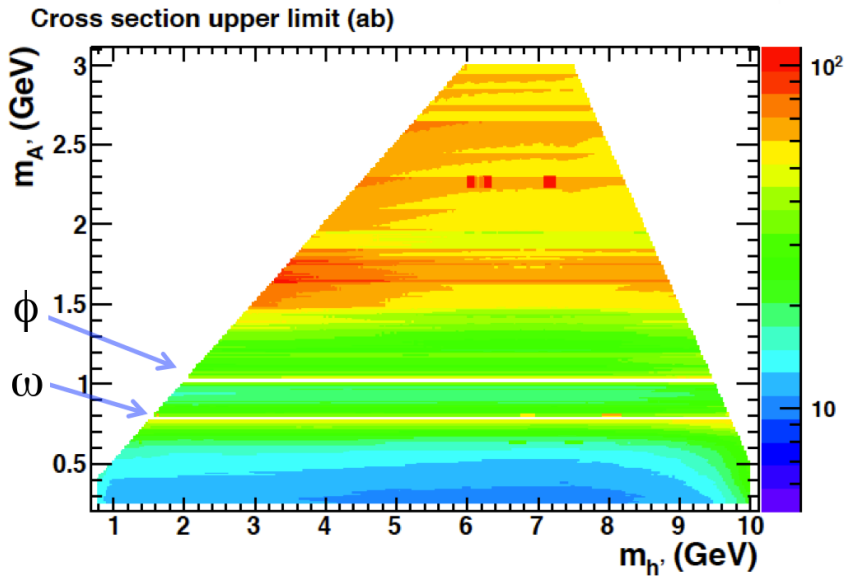
6 events surviving selection:

- 3 entries each, i.e. all possible assignments of $h' \to A'A'$
- Most likely $e^+e^- \to e^+e^-\rho\rho$, $e^+e^- \to e^+e^-\omega\omega$
- Consistent with pure background hypothesis from control sample

NO SIGNIFICANT SIGNAL OBSERVED

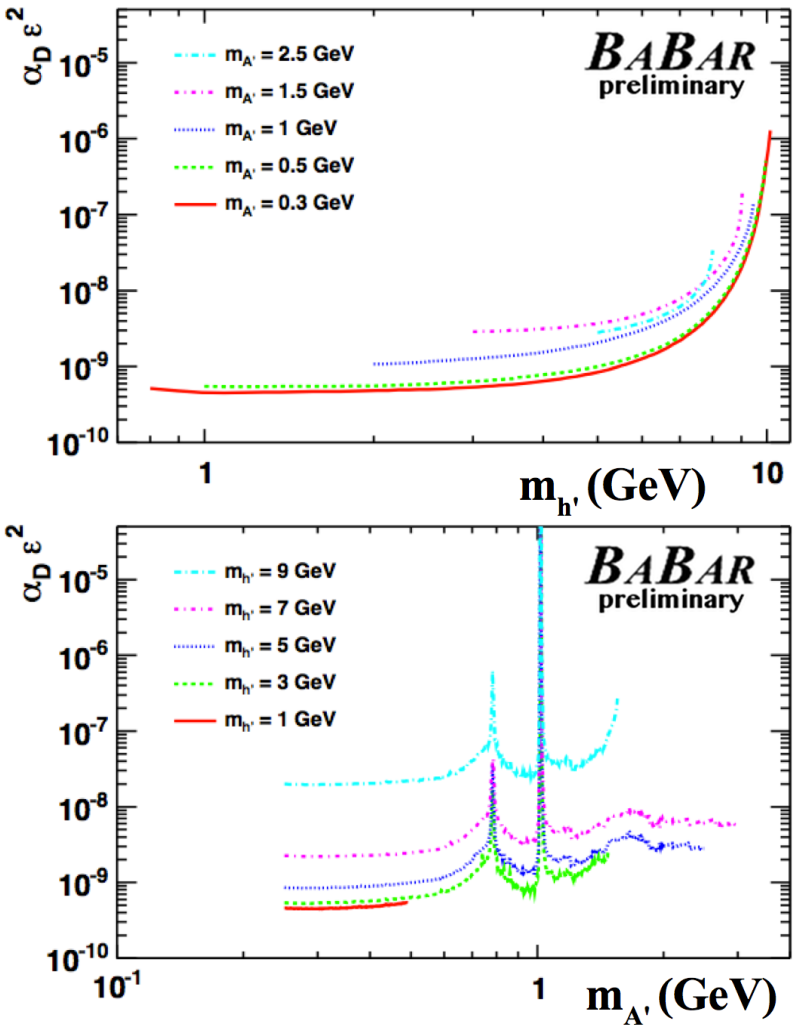
$$\sigma(e^+e^- \to A'^* \to A'h', h' \to A'A') < 10 - 100 \text{ ab, at 90\% CL}$$





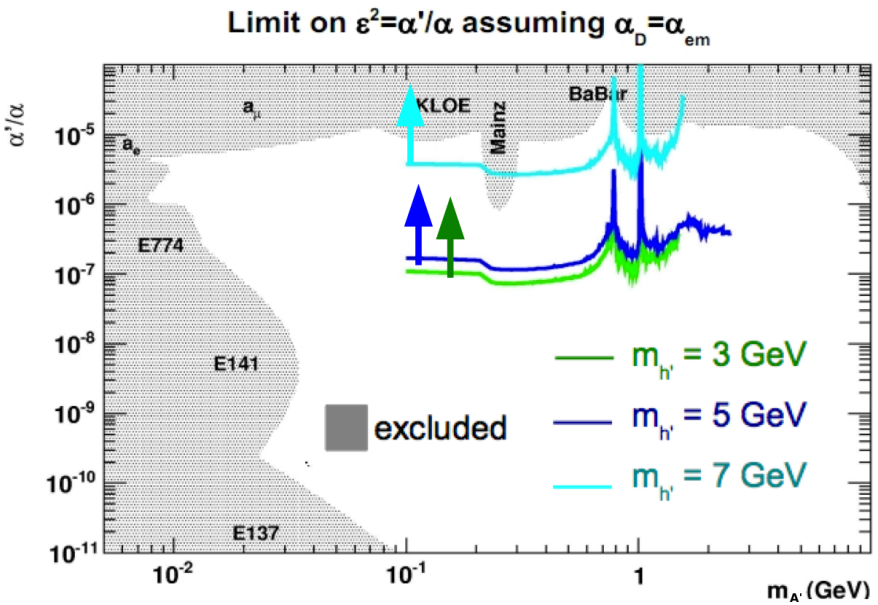
Dark Forces at BABAR: Results (II) [arXiv:1202.1313]

The limits on the cross section are translated into 90% UL on $\alpha_D \epsilon$



- $\alpha_D = g_D^2/4\pi$
- g_D = dark sector coupling constant
- ϵ = mixing strength

ACCEPTED FOR PUBLICATION



Summary & Conclusions

- In BABAR, we have searched for evidences of CP-odd light Higgs and of dark sector candidates in the $\Upsilon(2S)$ and $\Upsilon(3S)$ data
- No significant signal observed
- More stringent limits set on space parameters of NP models
- Several low energy NP searches are still ongoing...
- New results are expected in the near future!

Thanks for Your Attention!

$\Upsilon(3S, 2S) \to \gamma A^0,\ A^0 \to$ hadrons

R. Dermisek and J. Gunion, PRD 81, 075003 (2010):

Hadronic decays of A^0 can be dominant, depending on its mass and $\tan\beta$