SEARCHES FOR LIGHT NEW PHYSICS WITH BABAR

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on behalf of the BABAR Collaboration

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SUSY 2011, Fermilab

Light exotic particles could be discovered at BABAR or New Physics probed at TeV scale!

Discovery potential for light Higgs boson, dark matter, dark forces, LFV,...

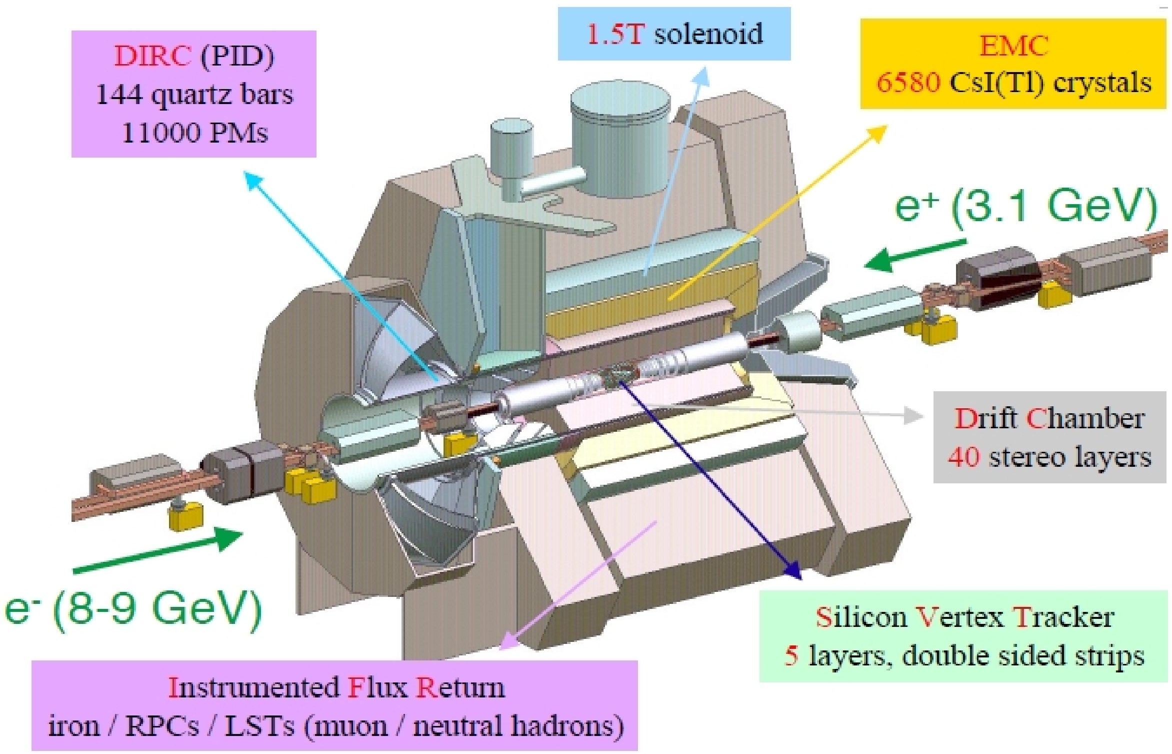
A hunt for

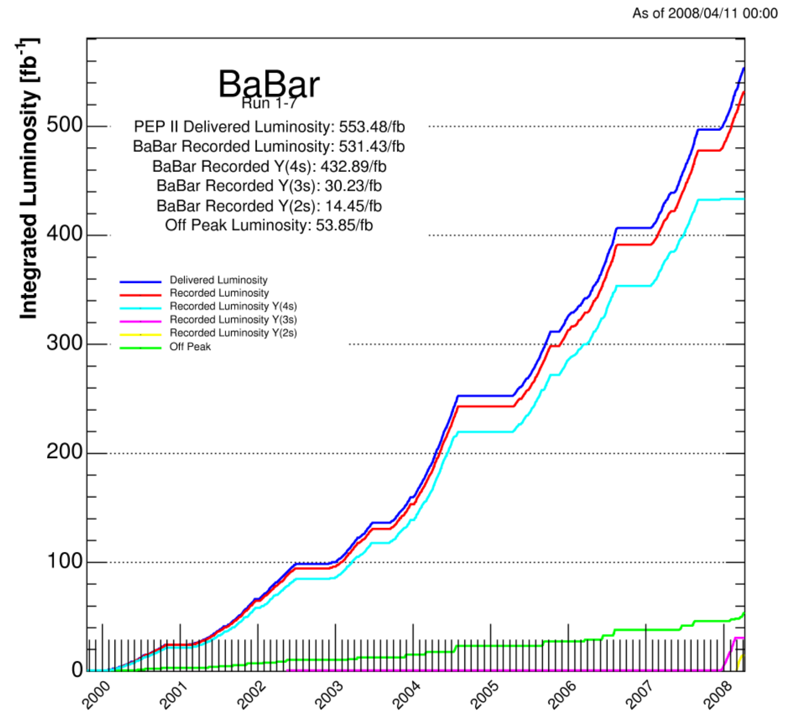
Light Higgs boson in Υ(3S,2S) decays

Dark Matter in Υ(1S,2S,3S) decays

Dark forces in e^+e^- interactions

B*ABAR* collected around 513 fb^{-1} of e^+e^- collisions around the $\Upsilon(4S)$





B*ABAR* data sample contains

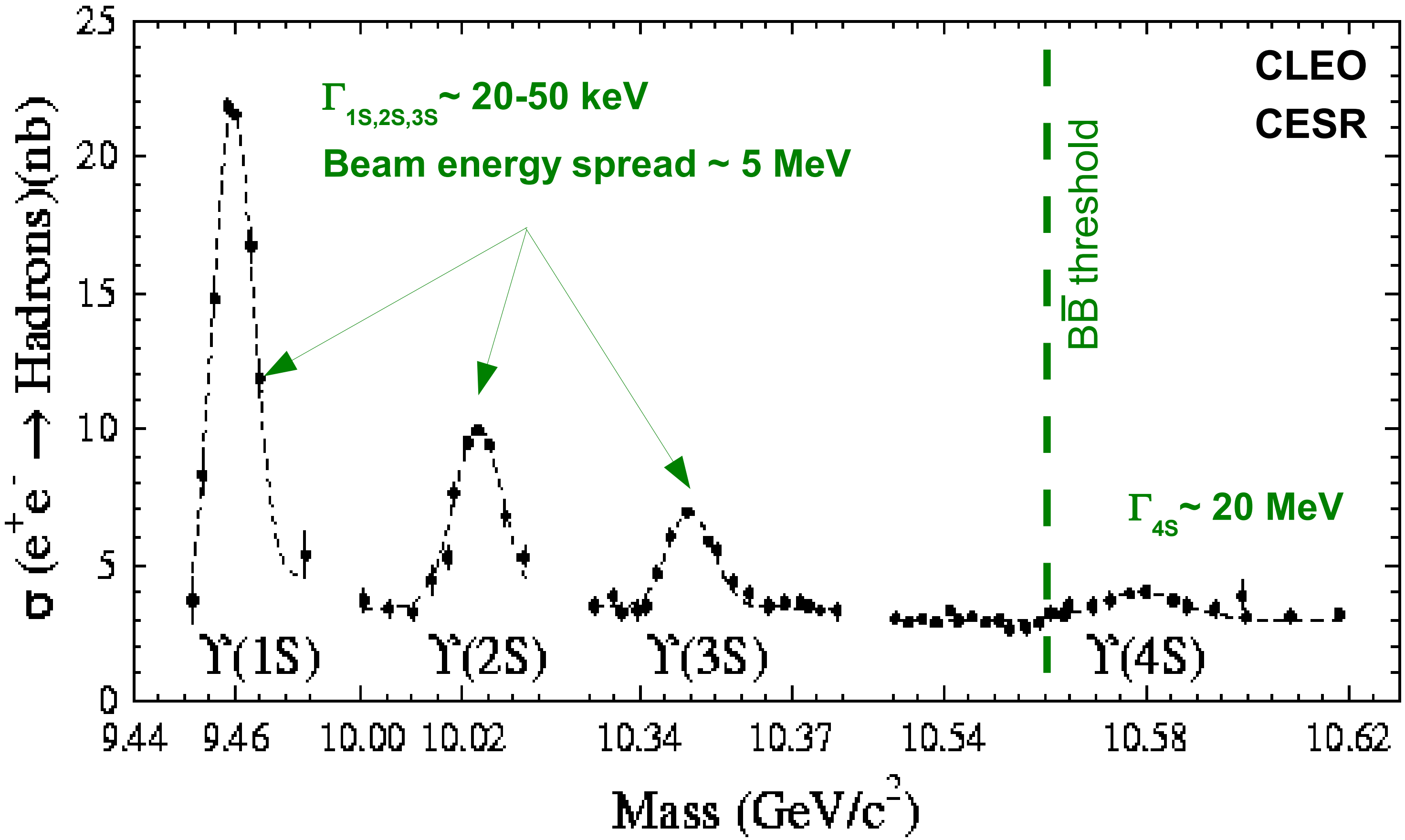
~470 x 10^6 $\Upsilon(4S)$

~120 x 10^6 $\Upsilon(3S)$ (10x Belle, 25x CLEO)

~100 x 10^6 $\Upsilon(2S)$ (10x CLEO)

~ 18 x 10^6 $\Upsilon(1S)$ from $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$

$e^+e^- \rightarrow \gamma^* \rightarrow \Upsilon(nS)$



$BF(\Upsilon(nS) \rightarrow X) / BF(\Upsilon(4S) \rightarrow X) = \Gamma_{4S,total} / \Gamma_{nS,total}$ (n=1,2,3)

Significantly better sensitivity to direct production of light degrees of freedom at narrow resonances

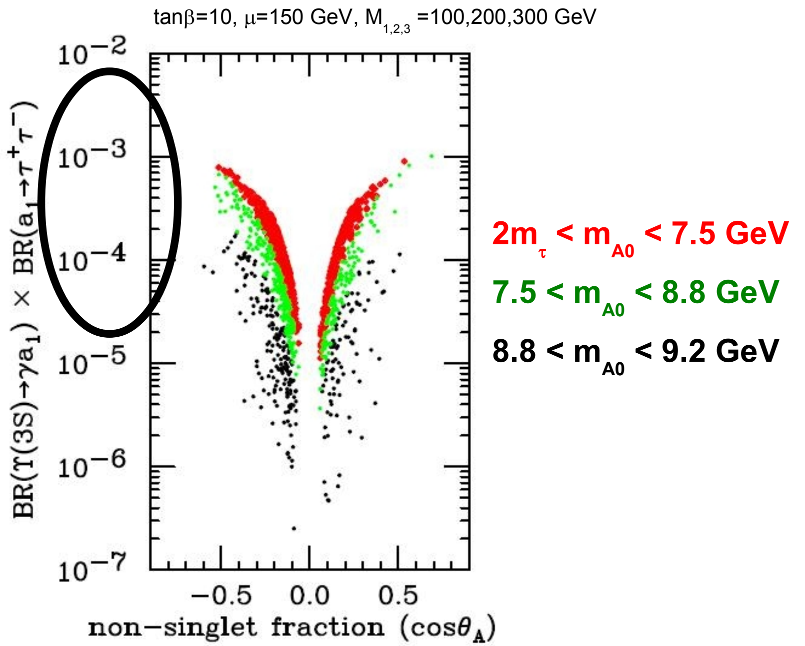
LIGHT HIGGS BOSON

- Many SM extensions include the **possibility of a light Higgs**
- NMSSM proposed to solve the "μ problem", adding one CP-odd Higgs, one CP-even Higgs and one neutralino to MSSM content
- A light CP-odd Higgs A^0 with mass lower than $2m_b$ is **not excluded** by LEP constraints and could explain the excess observed in $e^+e^- \to Zb\bar{b}$ events at M_{bb} ~ 100 GeV
- Radiative $\Upsilon(nS)$ decays (n=1,2,3) offer an ideal environment to search for light Higgs

Radiative $\Upsilon(nS) \to \gamma A^0$ decays

- Fully reconstructed in $A^0 \to \mu^+\mu^-$
- Partially reconstructed in $A^0 \to \tau^+\tau^-, q\bar{q}$
- Invisible decay $A^0 \to \chi_1 \chi_1$ if $m_{A0} > 2m_\chi$

Can have a very large branching fraction



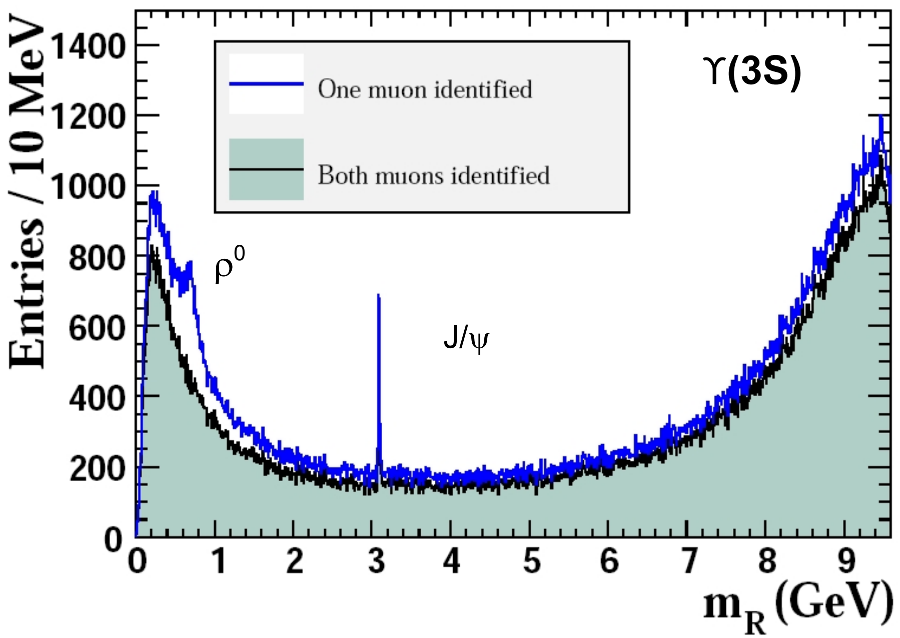
$A^0 = \cos\theta_A\, A_{MSSM} + \sin\theta_A\, A_S$

Shrok,Suzuki, PLB 110, 250 (1982)
Hiller, PRD 70, 034018 (2004)
Dermisek,Guinon,McElrath., PRD 76, 051105 (2007)
Dermisek and Guinon, PRD 81, 075003 (2010)

PRL103, 081803 (2009)

Event selection

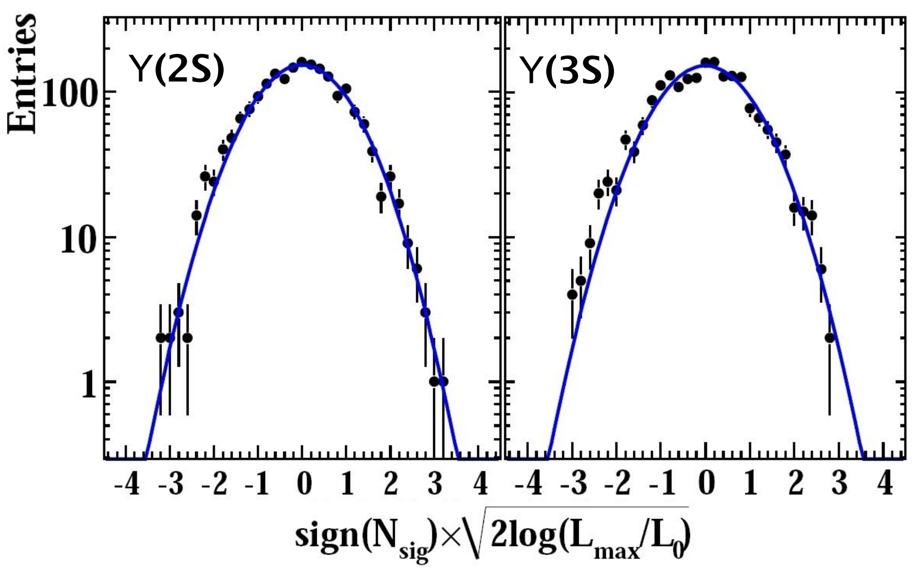
- Two tracks and a photon with $E_\gamma^* > 0.2$ GeV
- One or two tracks identified as muon(s)
- Energy and beam constraints for $\Upsilon(2,3S)$ candidate
- Muon pair and photon back-to-back in the CM frame



Signal extraction

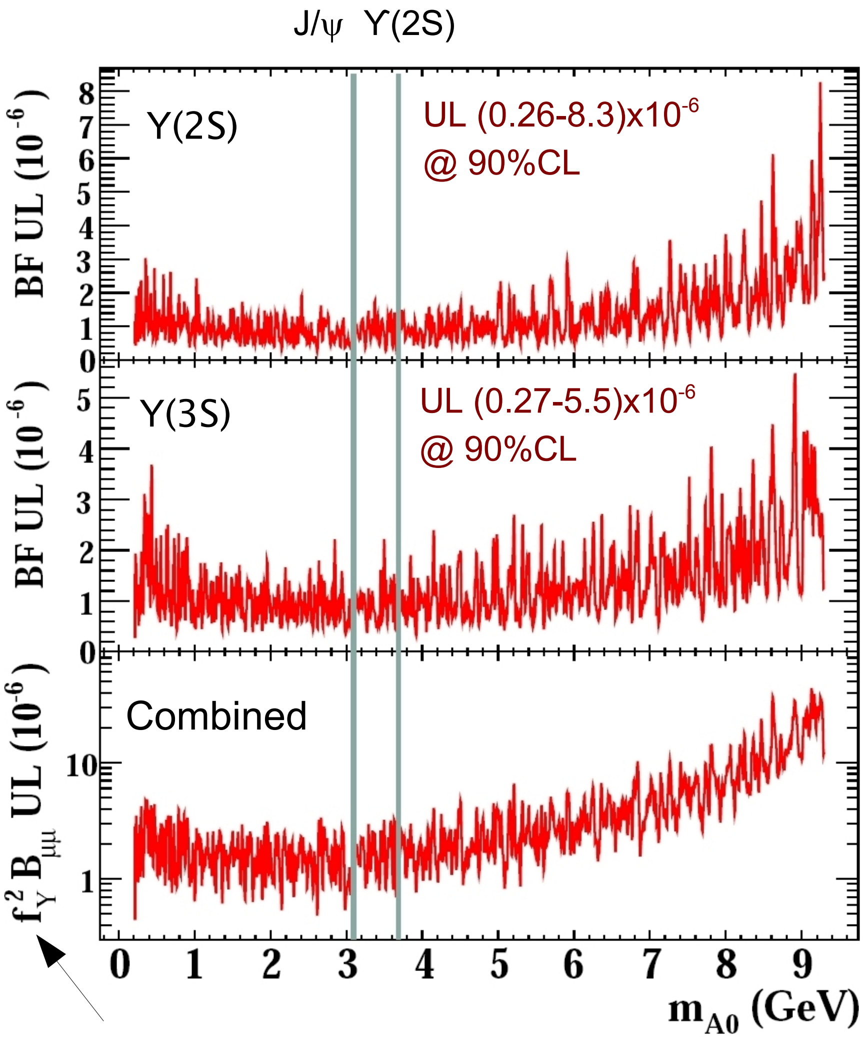
- Fit the reduced mass $m_r = (m^2_{A0} - 4^2 m_\mu)^{1/2}$
- Scan A^0 mass between 0.212 – 9.3 GeV in steps of 2-5 MeV

sign(Nsig) x (2 log(L_{max}/L_0))$^{1/2}$

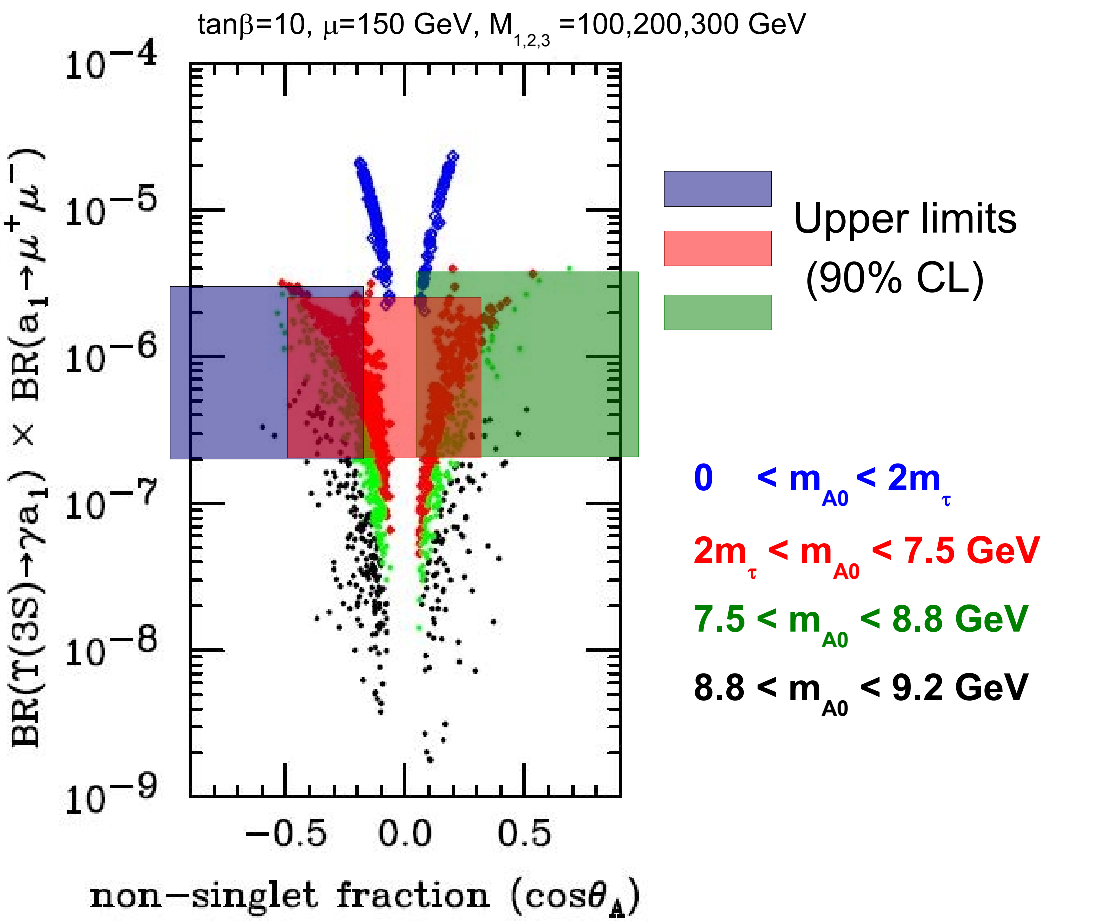


Agree with null hypothesis

PRL103, 081803 (2009)



f_Y: effective Yukawa coupling of bound b-quark to A^0



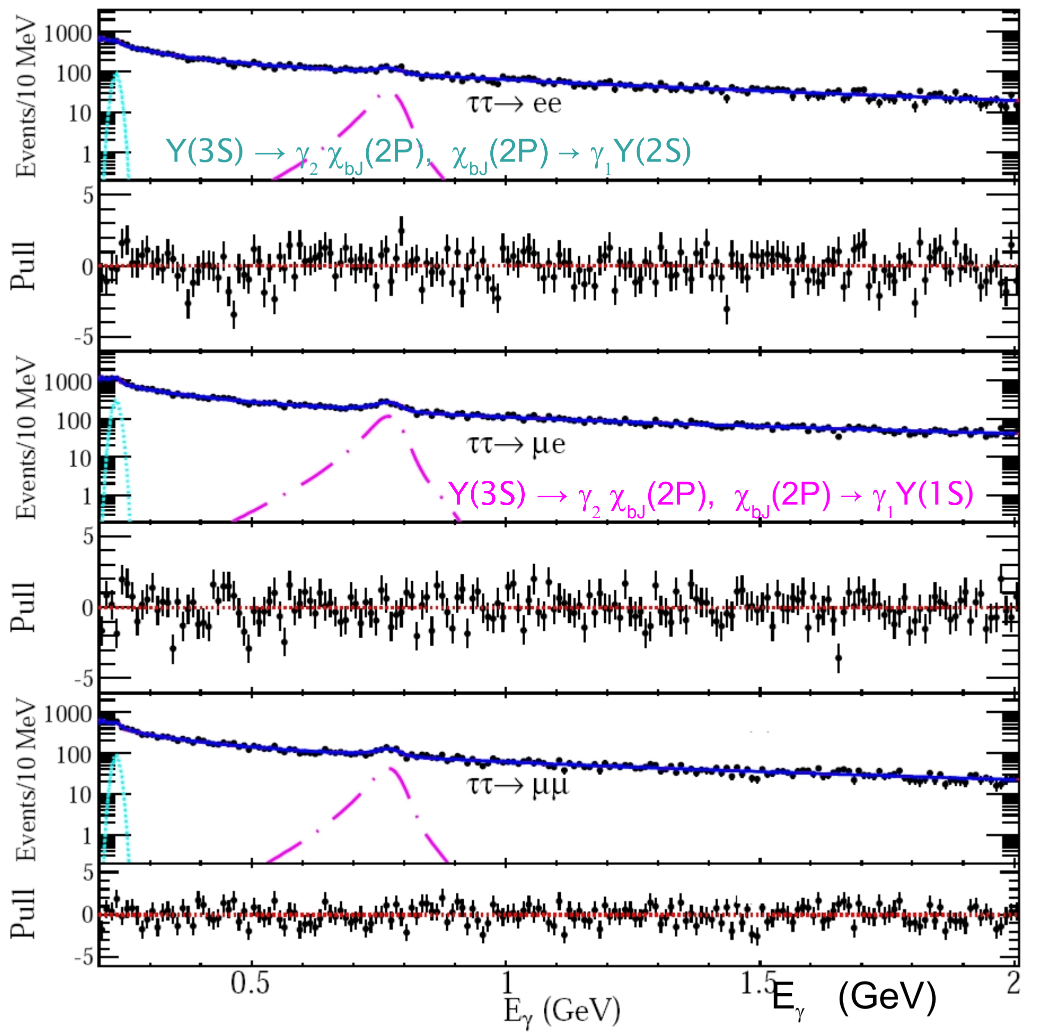
Significant constraints on other theories (axion-like particles, dark photons,...)

PRL103, 181801 (2009)

Event selection

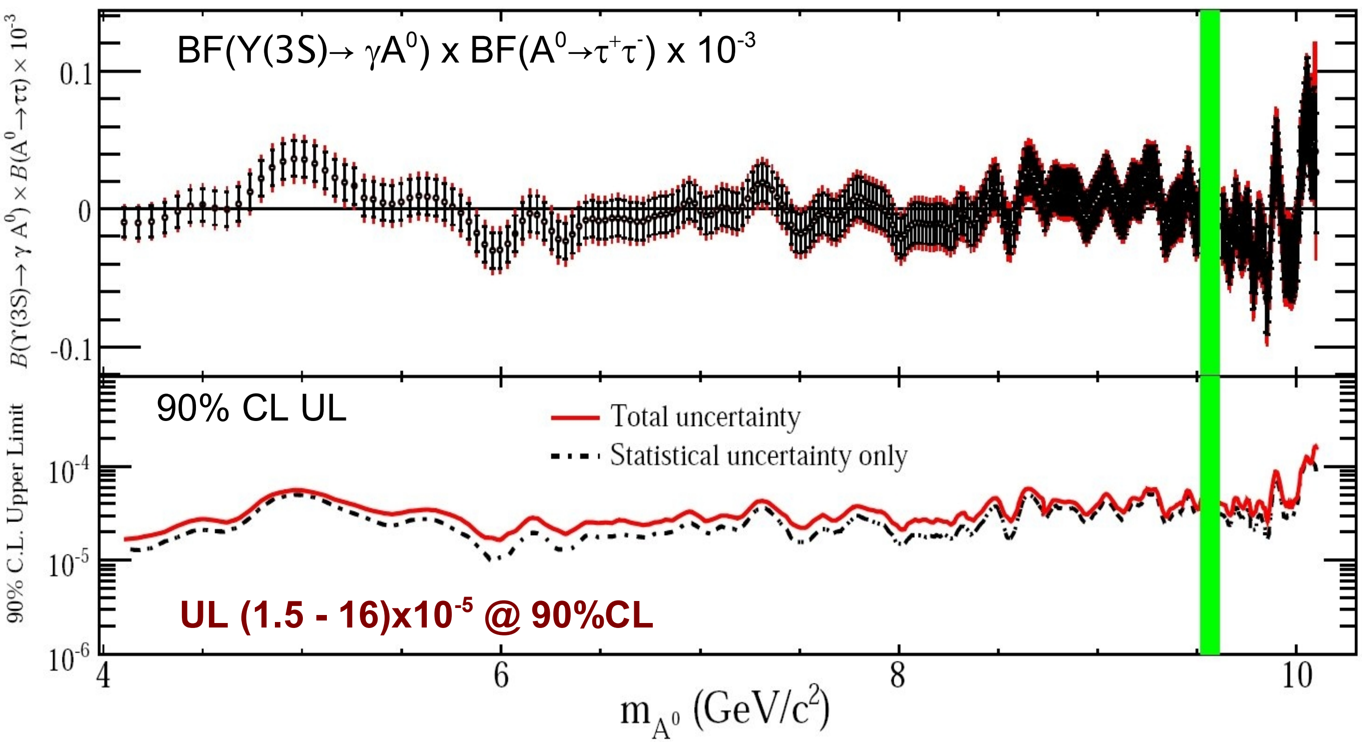
- Leptonic decays for both τ: ee, eμ and $\mu\mu$ modes
- Two tracks and a photon with $E_\gamma > 0.1$ GeV
- Cuts on additional discriminating variables to improve purity

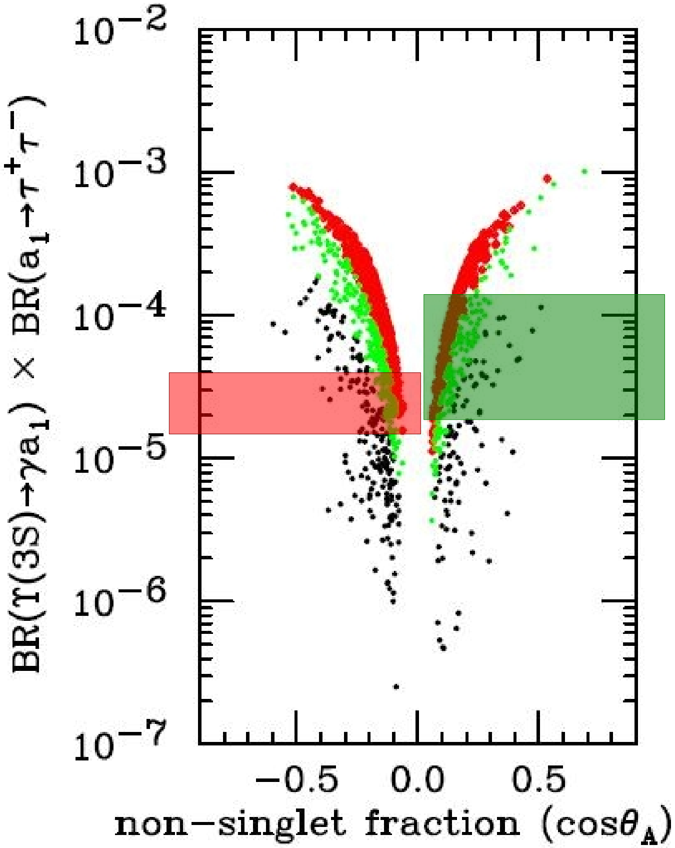
$\Upsilon(3S,2S) \to \gamma A^0$, $A^0 \to \tau^+\tau^-$



Signal extraction

- Fit the photon energy spectrum for peak, include continuum and peaking backgrounds
- Scan A^0 mass between 4.03 - 10.10 GeV in steps of 4-23 MeV





Upper limits (90% CL)

$2m_{\tau} < m_{A0} < 7.5$ GeV

$7.5 < m_{A0} < 8.8$ GeV

No evidence of light CP-odd Higgs

BABAR preliminary

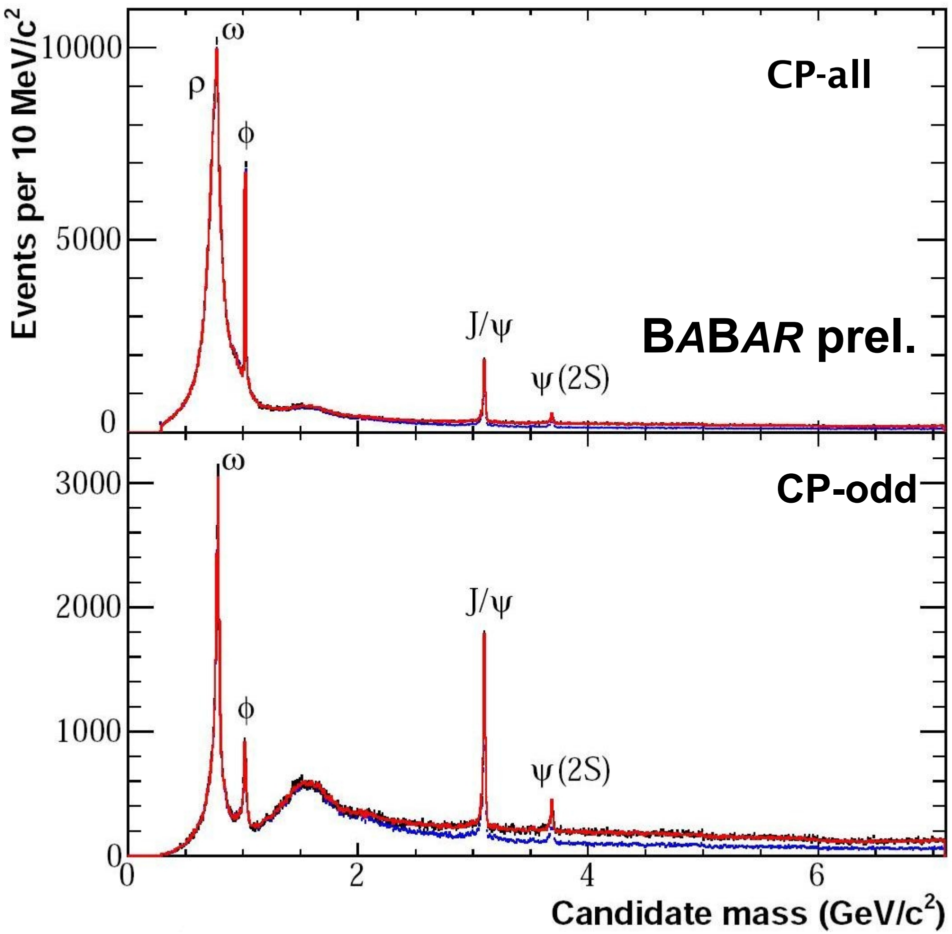
Event selection

- At least two tracks and one photon with $E_\gamma^* > 0.2$ GeV
- Reconstructed the full candidate
- Energy and beam constraints to improve resolution
- Consider both CP-all and CP-odd (no $\pi\pi$/KK) hypotheses

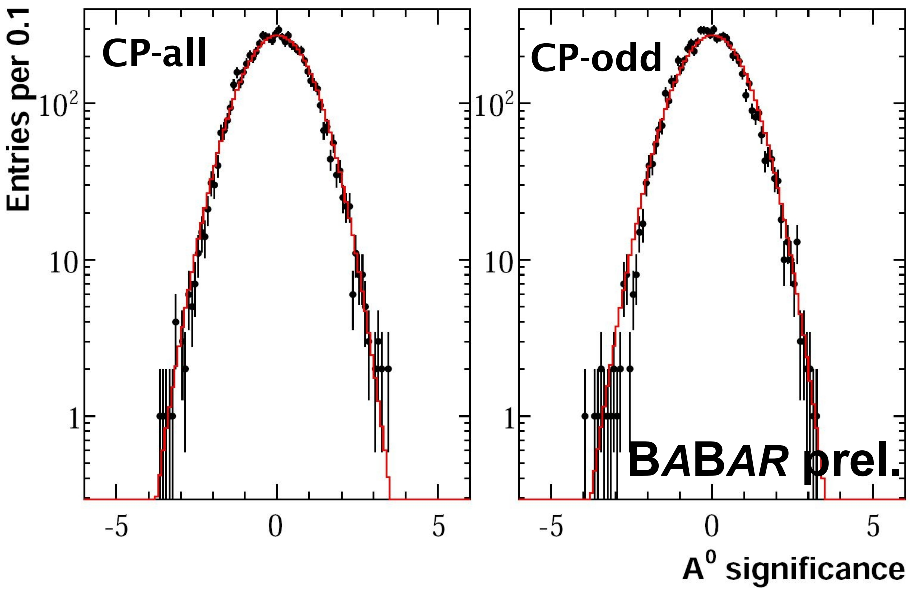
Signal extraction

- Fit the hadronic mass distribution
- Include $e^+e^- \to q\bar{q}$ (q=u,d,s,c) continuum, Y(nS) decays and additional resonances (f_0, f_2, f_4)
- Scan A^0 mass between 0.29 – 7.1 GeV in steps of 1 MeV

Higgs candidate mass distribution

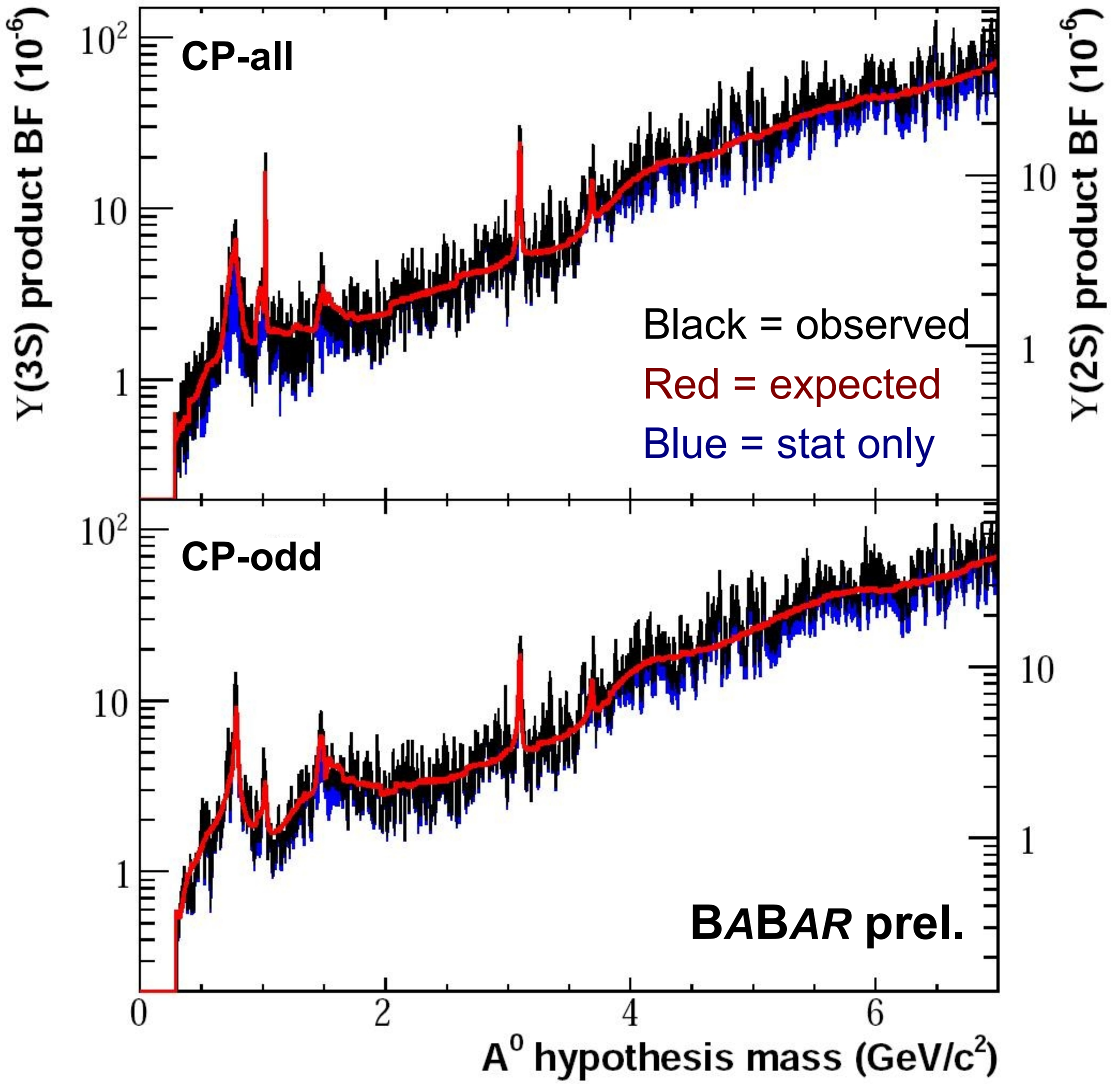


Fit significance distribution



Agree with null hypothesis

90% CL upper limits

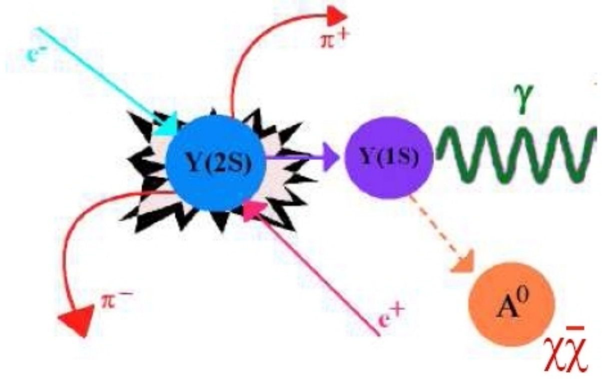


No evidence of light Higgs

PRL107, 021804 (2011)

Event selection

- Tag the dipion transition $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$ using MVA classifier
- Two tracks of opposite charge and a photon with $E_\gamma > 0.15$ GeV
- No additional activity
- Missing energy and momentum



Major backgrounds

- Continuum: $e^+e^- \to \gamma\, \pi^+\pi^-$, $\Upsilon(1S) \to \gamma\, l^+l^-$
- Peaking: $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$, $\Upsilon(1S) \to \gamma\, n\bar{n}$, $\gamma\, K_L K_L$

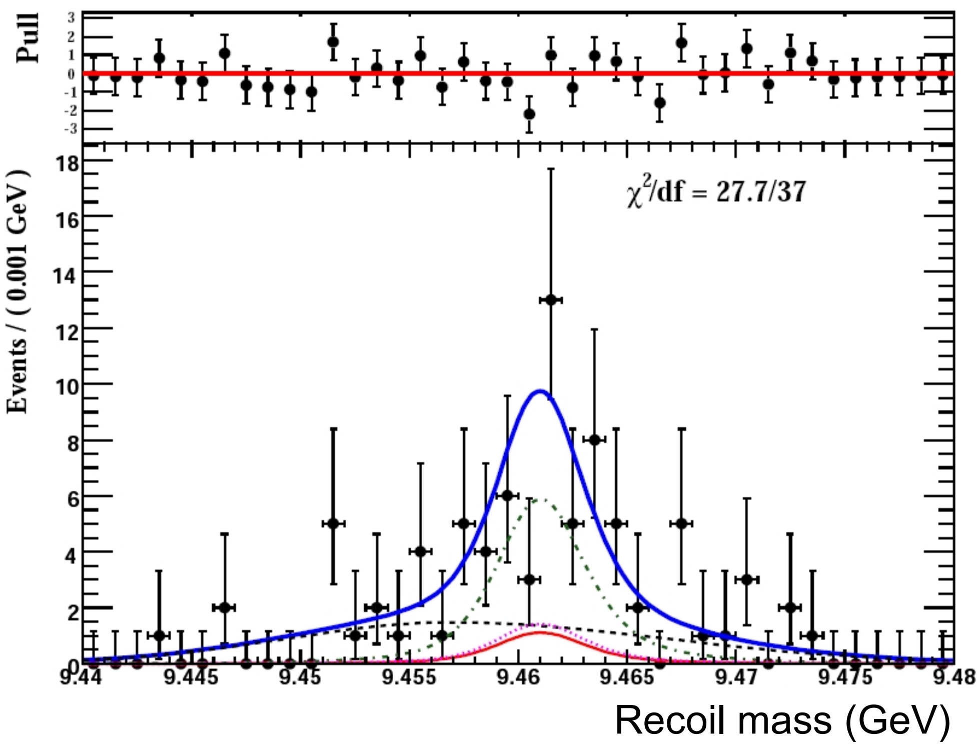
Signal extraction

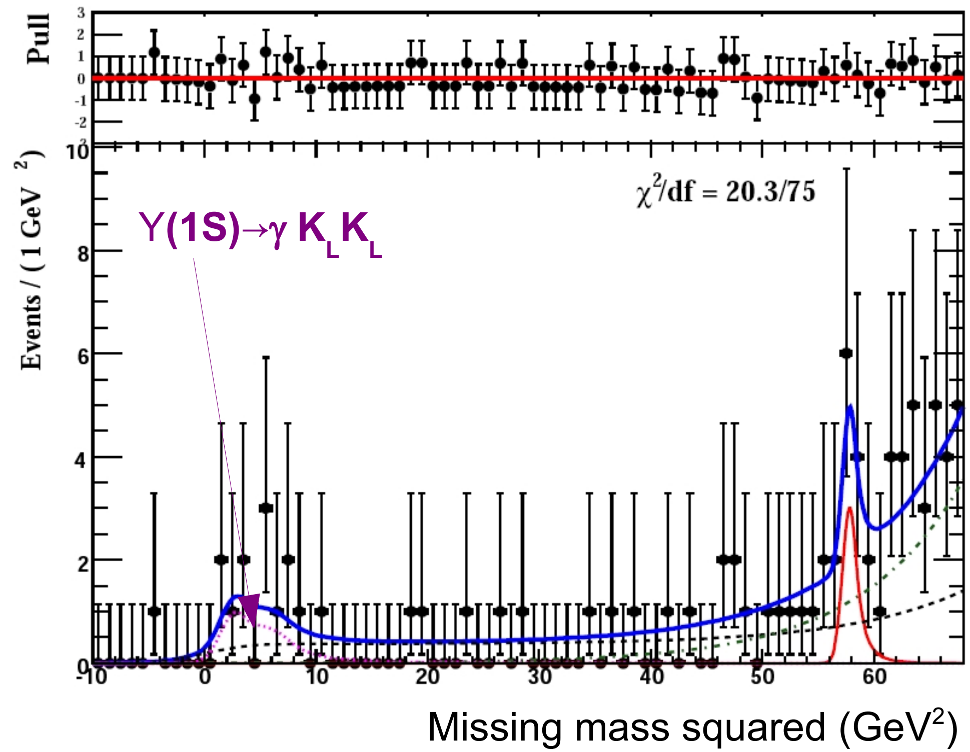
- Consider **both $\Upsilon(1S) \to \gamma A^0$ (two-body) and $\Upsilon(1S) \to \gamma\chi\chi$ (multi-body) decays**
- 2D fit the the recoil mass squared (M^2_{recoil}) and missing mass (M^2_x) squared

$$M^2_{\rm recoil} = M^2_{\Upsilon(2S)} + m^2_{\pi\pi} - 2M_{\Upsilon(2S)}E^*_{\pi\pi}$$
$$M^2_X = (\mathcal{P}_{e^+e^-} - \mathcal{P}_{\pi\pi} - \mathcal{P}_\gamma)^2$$

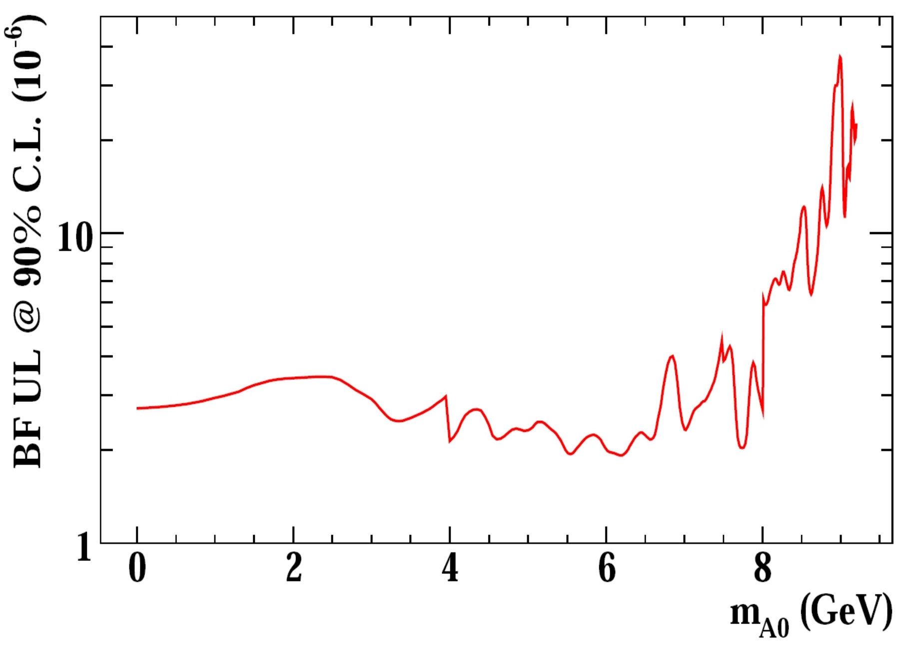
- Scan A^0 mass 0 – 9.2 GeV and χ mass 0 – 4.5 GeV

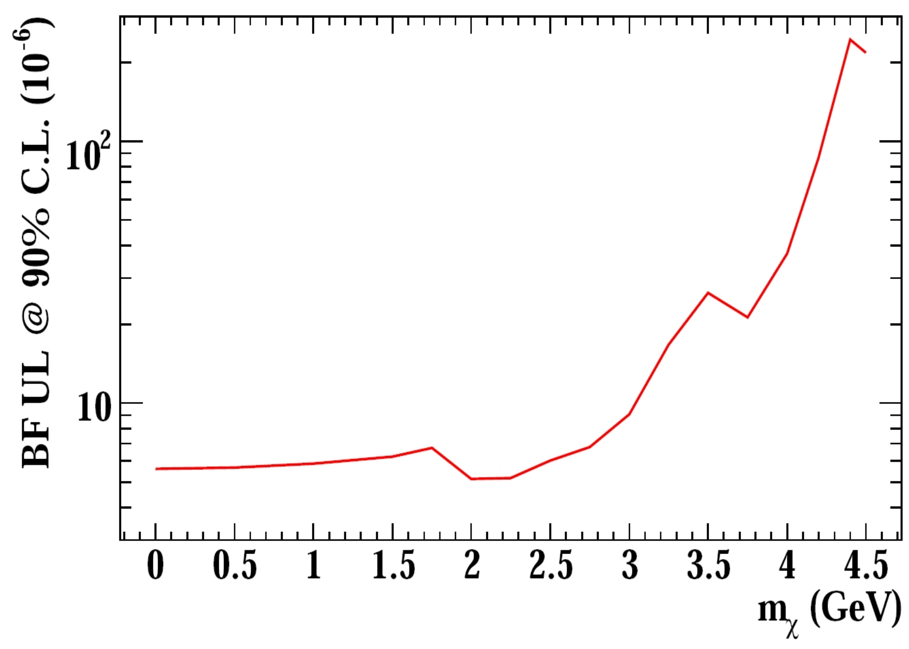
Most significant peak at m_A = 7.58 GeV with significance 2.0σ.





Probability >30% to observe a peak of this significance *anywhere*





Upper limits (90% CL)

$BF(\Upsilon(1S) \to \gamma A^0, A^0 \to invisible) < (1.9 - 37) \times 10^{-6}$

$BF(\Upsilon(1S) \to \gamma\chi\chi) < (0.5 - 25) \times 10^{-5}$

Previous limit (CLEO[3])

$BF(\Upsilon(1S) \to \gamma\chi\chi) \sim 10^{-3}$

Predictions[1,2]

$BF(\Upsilon(1S) \to \gamma A^0, A^0 \to invisible) \sim 10^{-4}$

$BF(\Upsilon(1S) \to \gamma\chi\chi)$ $10^{-5} - 10^{-4}$

Significant constraints on these models

1) PRD 76 ,051105 (2007) 2) PRD 80,115019 (2009), arXiv:0712.0016 3) CLEO, PRD 51, 2053 (1995)

DARK MATTER
AND
DARK FORCES

McElrath, PRD 72, 103508 (2005)

Generic Dark Matter model

- Minimal model introducing a dark matter particle χ and a new scalar or gauge boson A' to serve as a s-channel annihilation mediator ($m_A > 2m_\chi$)
- Scalar/boson A' couples to SM via Higgs mixing (scalar) or kinetic mixing with SM hypercharge (vector)
- Could explain 511 keV gamma rays excess from the galactic center reported by INTEGRAL and electon/positron excess by PAMELA/FERMI
- Could increase the invisible decay width of the Y(1S) predicted by SM[1)] by orders of magnitude. Rate estimates are fairly model independent, based on cosmological observations and assuming time-reversal symmetry

Rate predictions

$BF(\Upsilon(1S)\to\chi\chi) \sim 4.2 \times 10^{-4}$ (s-wave) (*PRD 72, 103508 (2005)*)

$BF(\Upsilon(1S)\to\chi\chi) \sim 1.8 \times 10^{-3}$ (p-wave) (*PRD 72, 103508 (2005)*)

$BF(\Upsilon(1S)\to\nu\nu) \sim 9.9 \times 10^{-6}$ (*PLB 441, 419 (1998)*)

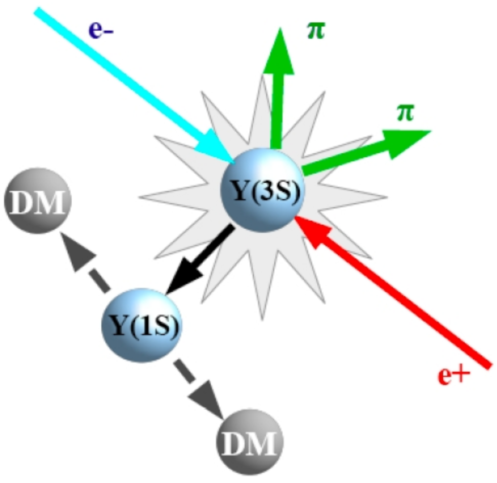
Large increase from SM predictions

1) PLB 441, 419 (1998).

PRL 103, 251801 (2009)

Analysis strategy

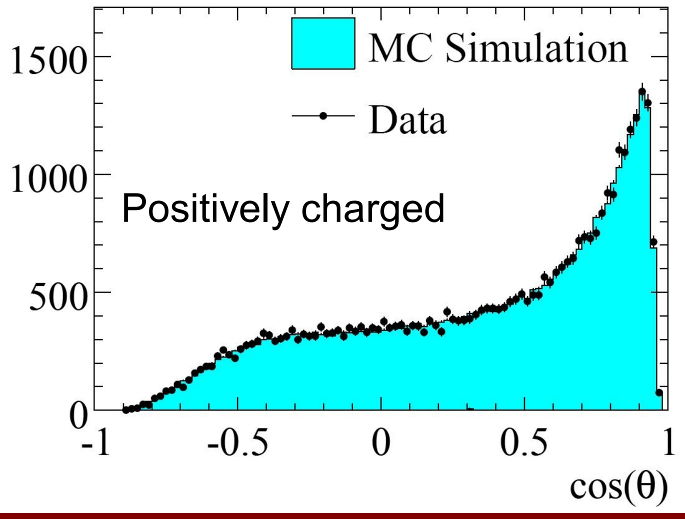
- Tag $\Upsilon(1S)$ mesons in $\Upsilon(3S) \rightarrow \pi^+\pi^- \Upsilon(1S)$ transition
- Select event containing two oppositely-charged tracks only (no extra activity)



Data sample contains

- Non-peaking background from random $\pi^+\pi^-$ combinations
- Peaking background (indistinguishable from signal) $\Upsilon(3S) \rightarrow \pi^+\pi^- \Upsilon(1S)$, $\Upsilon(1S) \rightarrow X$ (X undetected)
- Signal: $\Upsilon(3S) \rightarrow \pi^+\pi^- \Upsilon(1S)$, $\Upsilon(1S) \rightarrow$ invisible

Lepton polar angle ($\pi^+\pi^-\ l^+l^-$ sample)



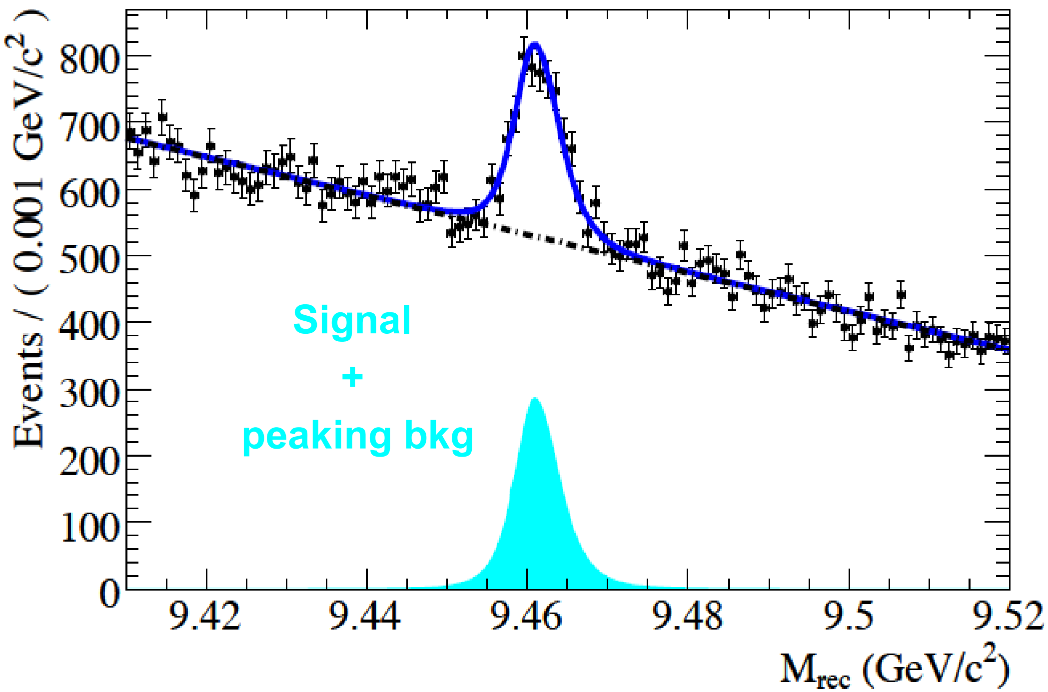
Signal extraction

- Fit recoil mass $M_{rec} = (s + M^2_{\pi\pi} - 2sE^*_{\pi\pi})^{1/2}$, should peak at $\Upsilon(1S)$
- Subtract peaking background estimated from MC. Use $\Upsilon(1S,2S) \rightarrow l^+l^-$ with one or two reconstructed leptons to check and correct simulations

PRL 103, 251801 (2009)

Fit

- Extended unbinned maximum likelihood fit of recoil mass M_{rec}
- Sum of signal + peaking background (Nsum)
  - Crystal-Ball (Gaussian with power-law tail)
- Non-peaking background
  - 1^{st} order polynomial



Results

Fit yield (Nsum)	2326 ± 105
Peaking bkg (MC)	2444 ± 123
Signal only	**-118 ± 105 ± 124**

Upper limit (90% CL)

BF(ϒ(1S) → invisible) < 3.0×10^{-4}

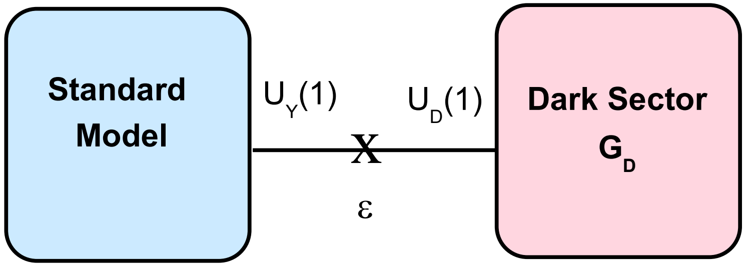
Previous measurements BF(ϒ(1S) → invisible)

CLEO:	BF < 3.9×10^{-3} @ 90% CL	PRD 75 (2007) 031104
Belle:	BF < 2.5×10^{-3} @ 90% CL	PRL 98 (2007) 132001

No evidence of dark matter contribution to invisible ϒ(1S) decays

Dark forces

- Models of dark matter introduce a new dark sector with a $U(1)_D$ gauge group (and corresponding charge). The corresponding gauge boson has a mass O(GeV) and is usually called a dark photon.



$$\Delta\mathcal{L}_{mix} = \varepsilon\, F^{\mu\nu} B_{\mu\nu}$$

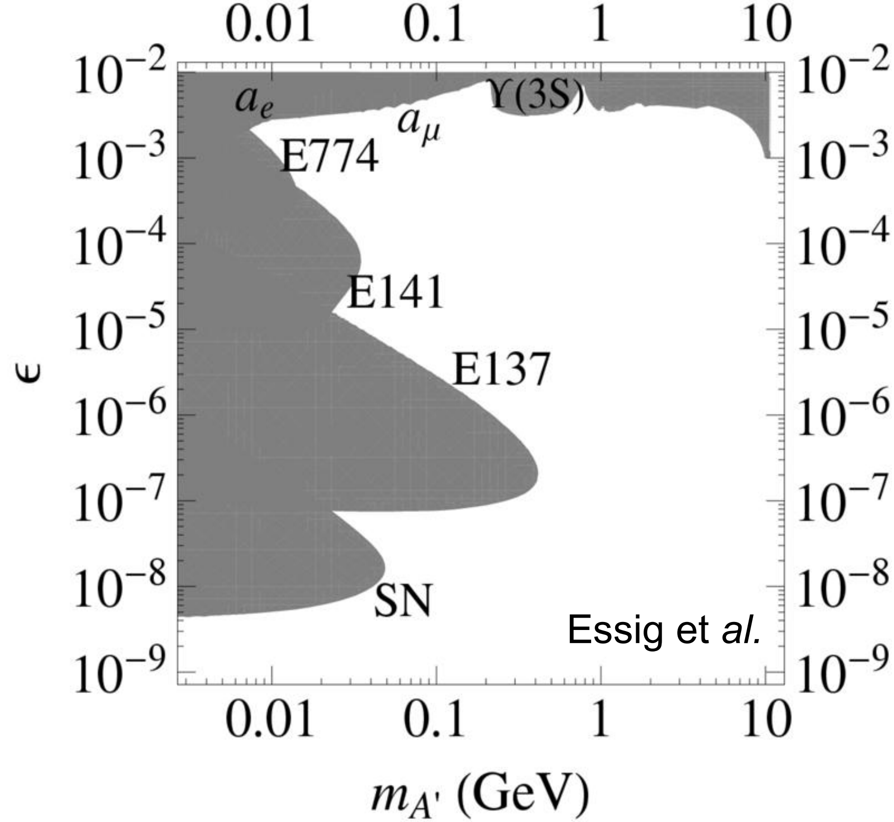
- Interaction with the SM is via kinetic mixing

$$\varepsilon\, F^{\mu\nu} B_{\mu\nu}$$

For a low mass dark photon, the mixing is essentially with the photon with a mixing strength ε.

- Non-Abelian group allows non-elastic scattering that could explain the modulation observed by DAMA and the absence of signal reported by Xenon and CDMS.

- **Parameter space is largely unexplored**

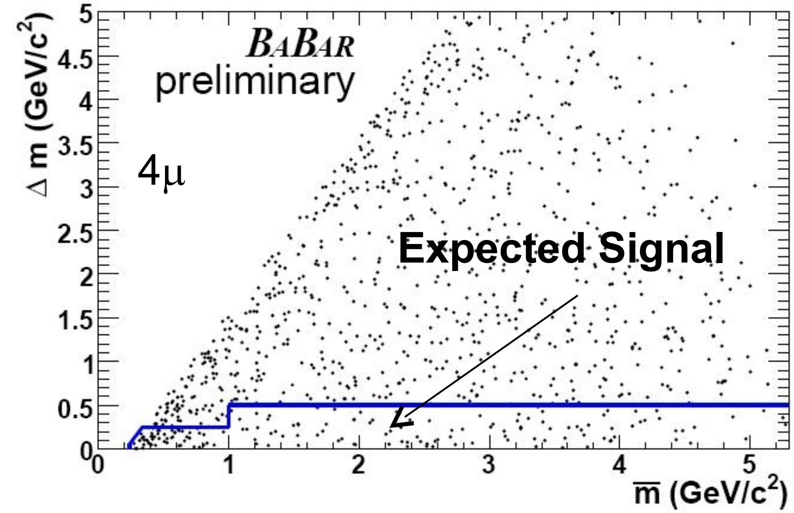


See for example:
N. Arkani-Hamed et al., PRD 79, 015014 (2009)
M. Pospelov et al., PLB 662 (2008) 53, PLB 671, 391 (2009).
B. Batellet al., PRD 79, 115008 (2009)
R. Essig et al., PRD 80, 015003 (2009)

arXiv:0908.2821

Search for $e^+e^- \rightarrow A'^* \rightarrow W_D\, W_D \rightarrow (l^+l^-)\,(l^+l^-)$ $l=e,\mu$

- Two dilepton resonances with full beam energy and momentum
- Resonances have similar masses
- Signal extracted using a cut-and-count analysis, background estimated from sidebands

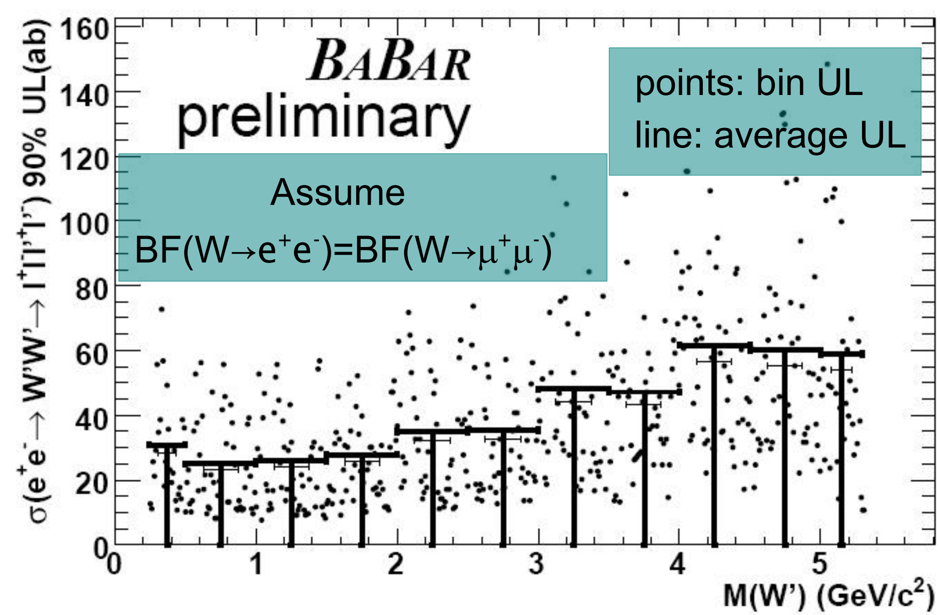


No evidence of dark boson found yet!

Upper limits (90% CL)

$\sigma(e^+e^- \rightarrow W_D\, W_D \rightarrow (l^+l^-)\,(l^+l^-)) < 25\text{-}60$ ab

$g_D\varepsilon^2 < 10^{-9} - 10^{-7}$



g_D - dark sector coupling constant

On our way back from the hunt...

No significant evidence for light new Physics has been found and upper limits have been set with a sizable improvement over previous measurements

Excluded a large fraction of parameters space for some New Physics models.

A Super-B factory can significantly improve these searches, exploring regions difficult to access at the LHC, and help elucidate the structure of New Physics.

Still many on-going analyses, the quest continues...