Recent results on search for new physics at BaBar

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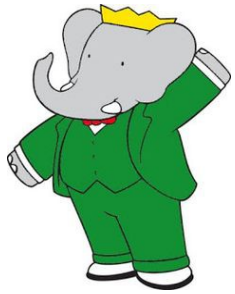
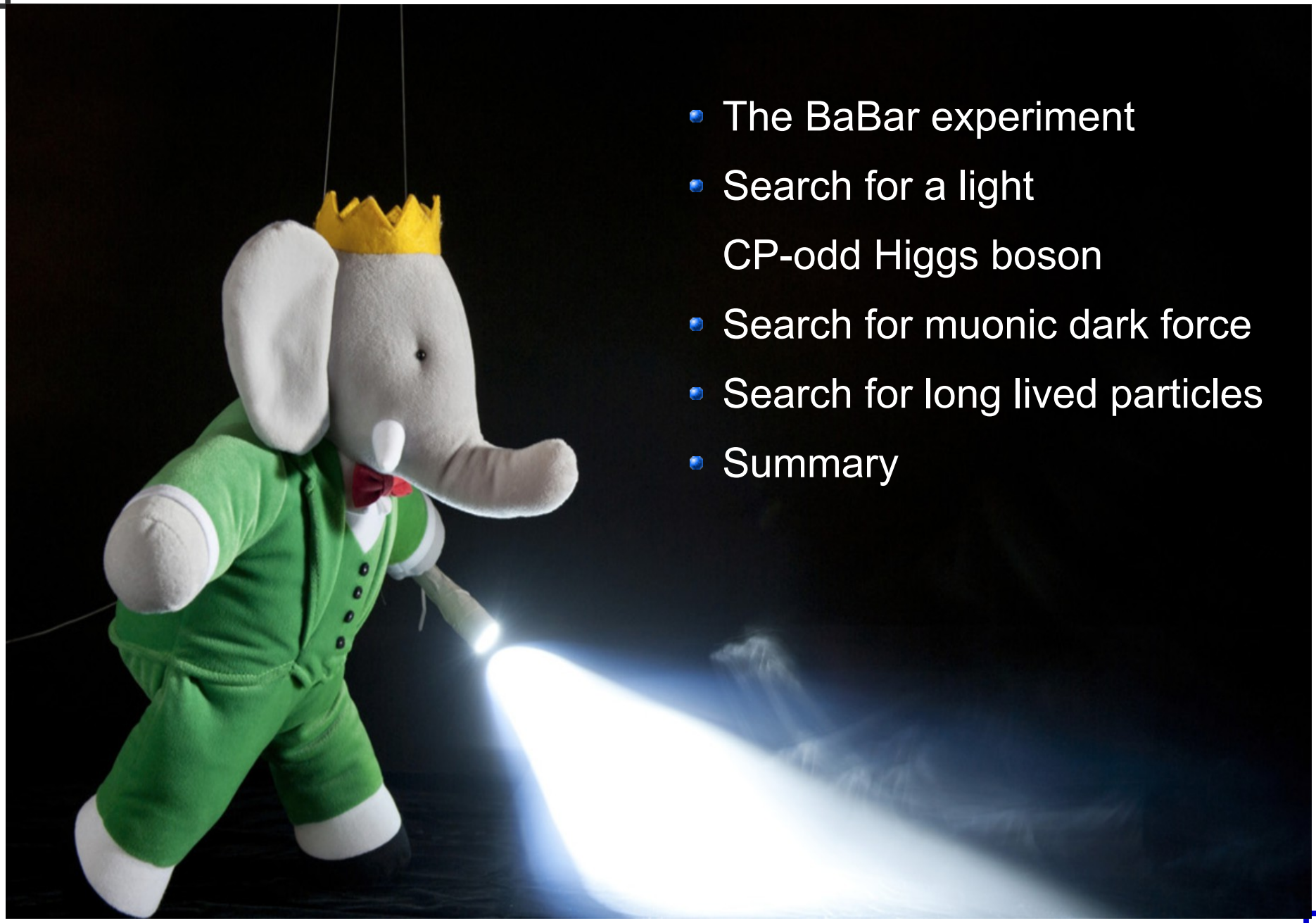
International Symposium
Advances in Dark Matter and Particle Physics
Messina, Italy
25th October 2016

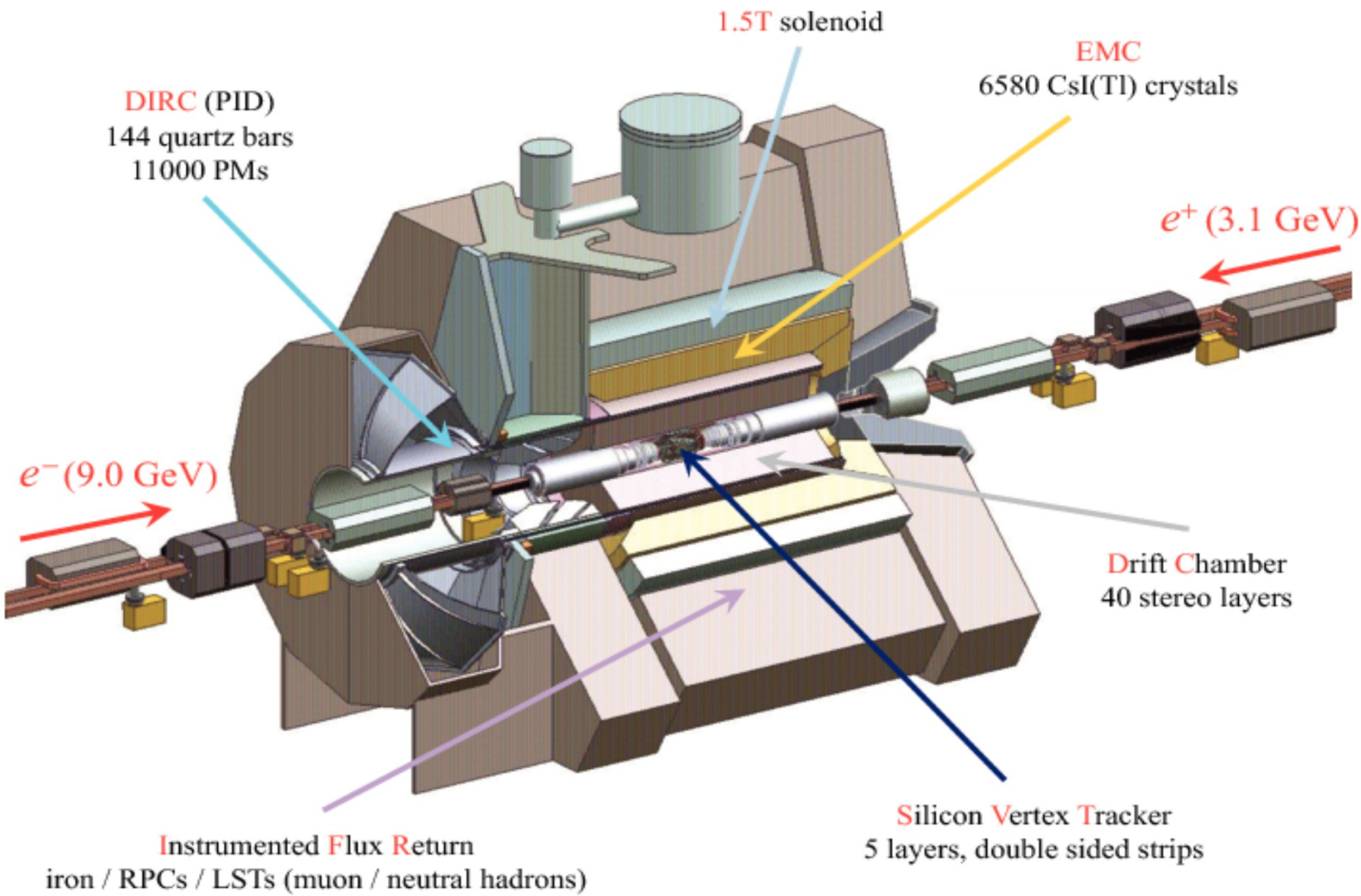


Outline



- The BaBar experiment
- Search for a light CP-odd Higgs boson
- Search for muonic dark force
- Search for long lived particles
- Summary

The BaBar experiment

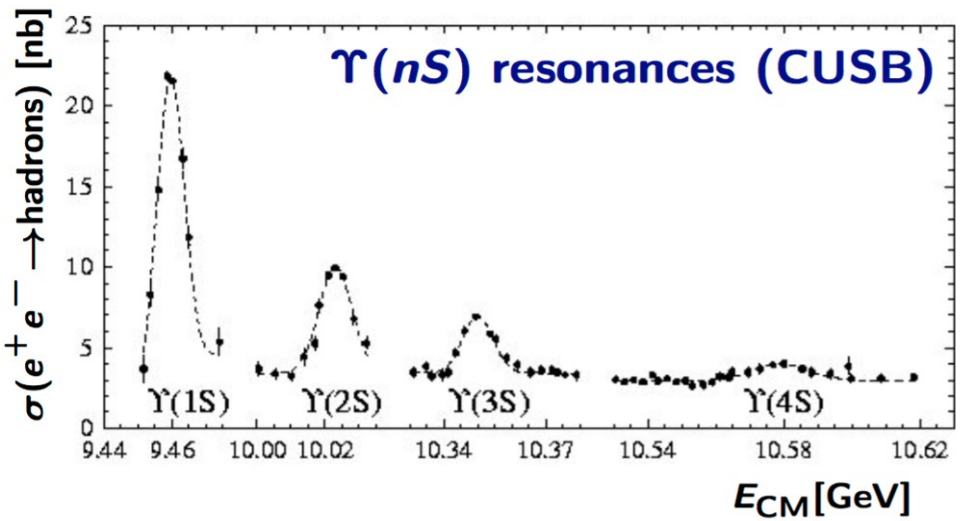


- Data taking from 1999 to 2008 at PEP-II asymmetric B-factory at SLAC

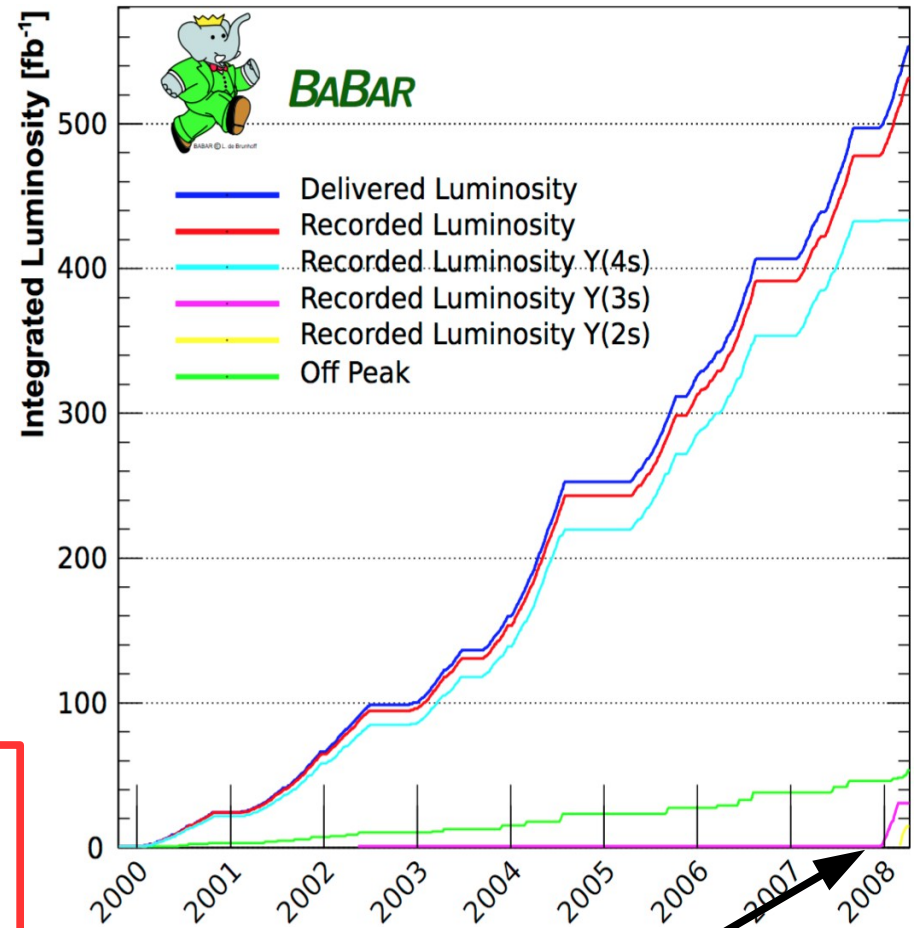
Nucl.Instrum.Meth. A 479, 1 (2002)
Nucl.Instrum.Meth.A 729, 615 (2013)

The BaBar data sample

Center of Mass Energy



Integrated luminosity



Y(2S), Y(3S) data

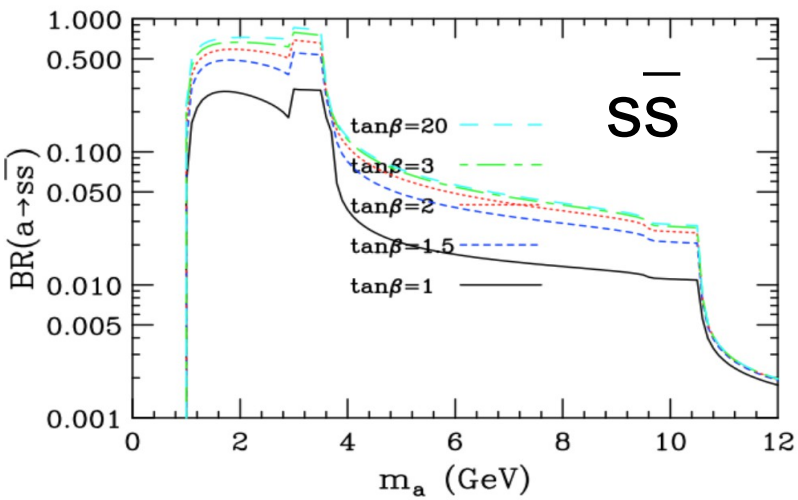
BaBar data samples

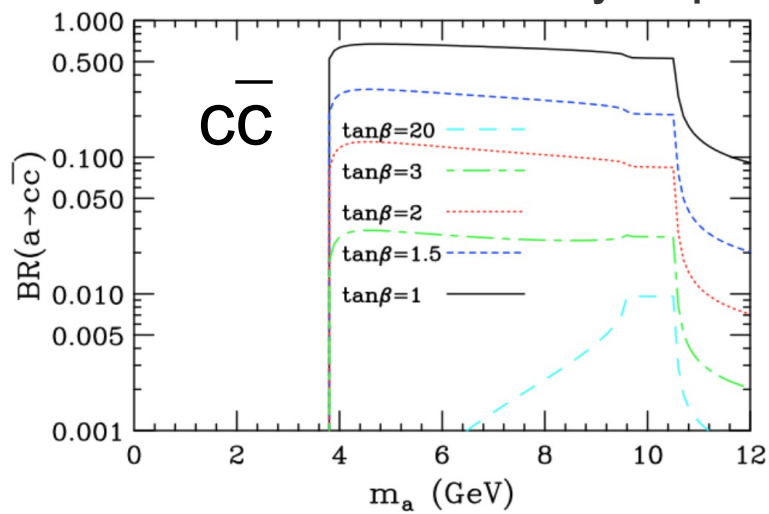
$(98.3 \pm 0.9) \times 10^6$	Y(2S)	(13.6 fb^{-1})
$(121.3 \pm 1.2) \times 10^6$	Y(3S)	(27.9 fb^{-1})
$(471.0 \pm 2.8) \times 10^6$	Y(4S)	(424.2 fb^{-1})

Light CP-odd Higgs A^0

- Various New Physics models, e.g. nMSSM, predict a light CP-odd Higgs boson A^0
- Below $2m_b$ CP-odd Higgs is not constrained by LEP measurements
- Favored decay modes depend on model parameters: may couple preferentially to up or down type quarks and leptons

Phys.Rep. 496, 1 (2010)





Former searches at BaBar

$\Upsilon(2S,3S) \to \gamma A^0$		$\Upsilon(1S) \to \gamma A^0$	
$A^0 \to$ invisible	arXiv:0808.0017 (2008)	$A^0 \to$ invisible	PRL 107, 021804 (2011)
$A^0 \to \mu^+\mu^-$	PRL 103, 081803 (2009)	$A^0 \to \mu^+\mu^-$	PRD 87, 031102 (2013)
$A^0 \to \tau^+\tau^-$	PRL 103, 18181 (2009)	$A^0 \to \tau^+\tau^-$	PRD 88, 071102 (2013)
$A^0 \to$ hadrons	PRL 107, 221801 (2011)	$A^0 \to gg, s\bar{s}$	PRD 88, 031701 (2013)

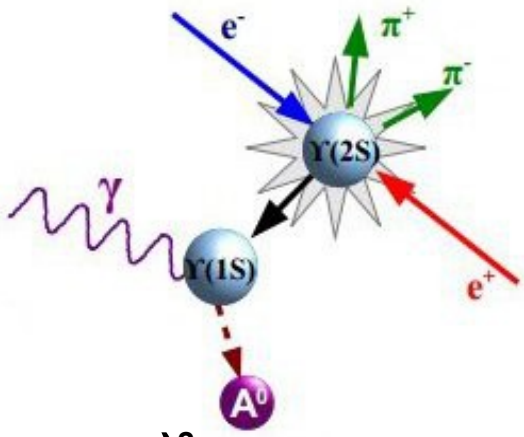
This search: $\Upsilon(1S) \to \gamma A^0$, $A^0 \to c\bar{c}$

CP-odd Higgs with charm tag

- We look for: $e^+e^- \to \Upsilon(2S)$, $\Upsilon(2S) \to \pi^+\pi^-\Upsilon(1S)$, $\Upsilon(1S) \to \gamma A^0$, $A^0 \to c\bar{c}$
- Tagged $\Upsilon(1S)$: smaller statistics but cleaner sample:

  13.6 fb^{-1} at $\Upsilon(2S)$ peak □ $(98.3 \pm 0.9) \times 10^6$ $\Upsilon(2S)$

  $(17.5 \pm 0.3) \times 10^6$ $\Upsilon(1S)$ via $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$



- Signal: 2 pions, 1 photon, 1 charm tag
- The mass m_R of the recoil against the di-pion within 10 MeV/c^2 of $\Upsilon(1S)$ mass

$$m_R^2 = (p_{e+e-} - p_{\pi+\pi-})^2$$

- Semi-inclusive analysis: D(*) + X
- We reconstruct 5 D decay chains:

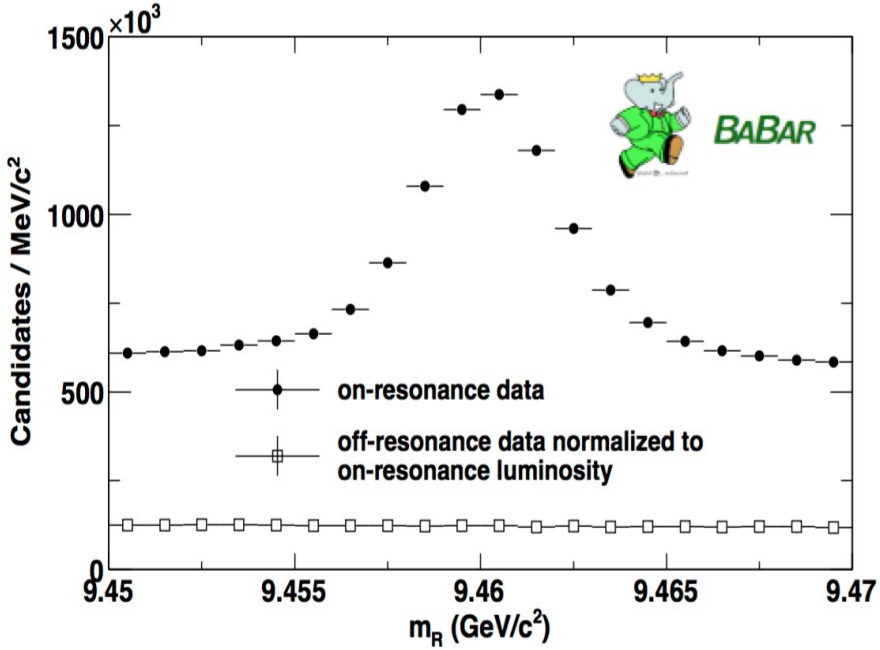
  $D^0 \to K^-\pi^+$

  $D^+ \to K^-\pi^+\pi^+$

  $D^0 \to K^-\pi^+\pi^+\pi^-$

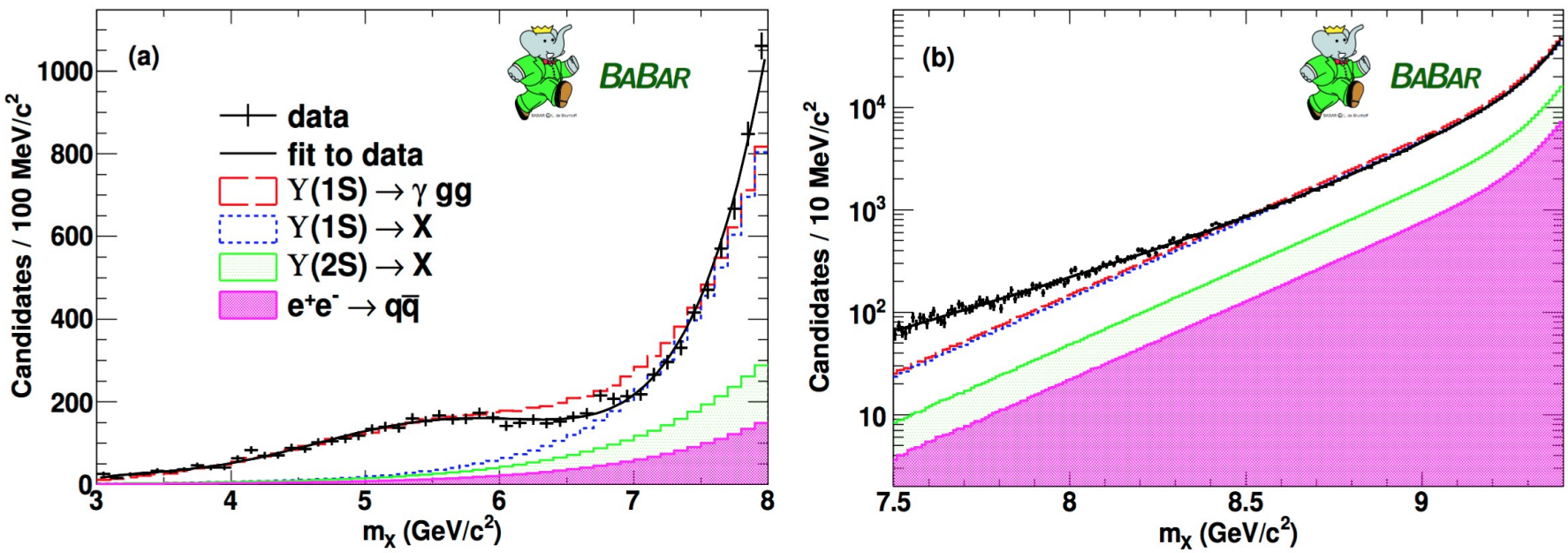
  $D^0 \to K_S^0\pi^+\pi^-$

  $D^*(2010)^+ \to \pi^+D^0$ with $D^0 \to K^-\pi^+$



CP-odd Higgs: signal selection

- We consider 2 mass regions:
  - Low Higgs mass region (< 8.0 GeV/c^2) → hard photon → low background
  - High Higgs mass region (> 7.5 GeV/c^2) → soft photon → high background
- Use BDT (Boosted Decision Tree) classifiers to select signal over background: 10 BDTs, one for each of the 5 D decay modes for the 2 Higgs mass regions



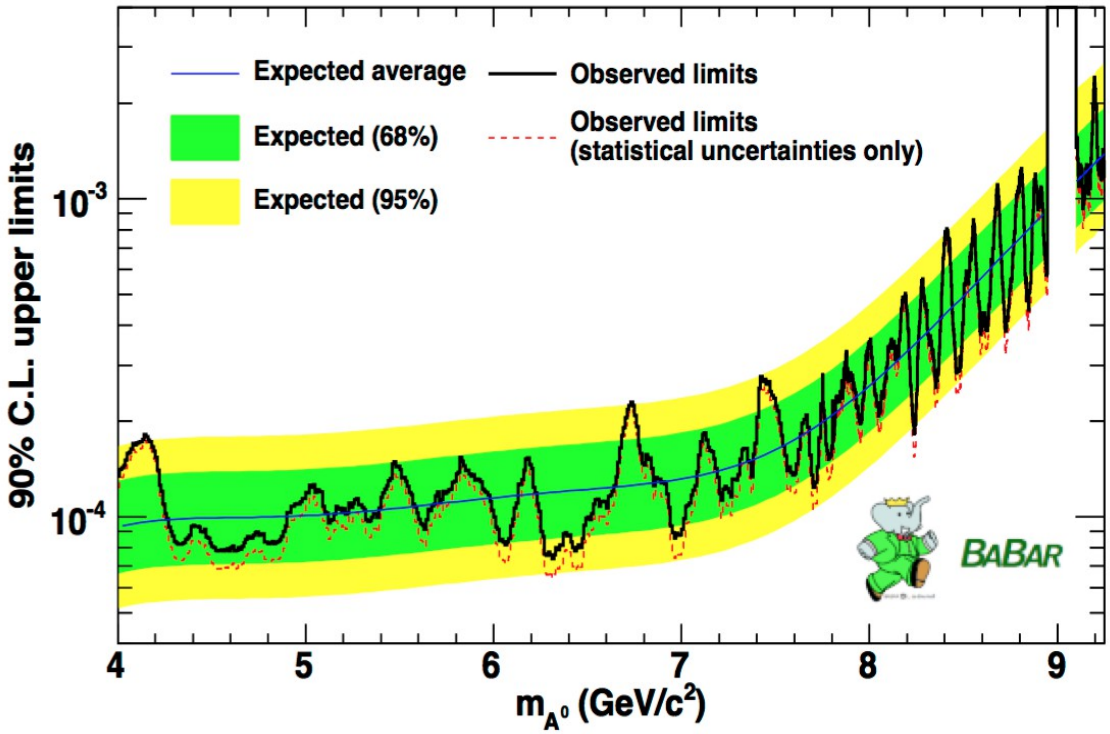
CP-odd Higgs: results

- Scan for mass peak with maximum likelihood fit in 10 MeV/c^2 (low mass), 2 MeV (high mass) steps
- Exclude $8.95 < m_A < 9.10$ GeV/c^2 where $\Upsilon(2S) \to \gamma\chi_{bJ}(1P)$, $\chi_{bJ}(1P) \to \gamma\Upsilon(1S)$
- No significant signal is observed
- 90% CL Bayesian limits are computed including systematic uncertainties

Upper limits at 90% CL on $B(\Upsilon(1S) \to \gamma A^0) \times B(A^0 \to c\bar{c})$

limits range: $7.4 \cdot 10^{-5} - 2.4 \cdot 10^{-3}$

Phys. Rev. D 91, 071102 (2015)

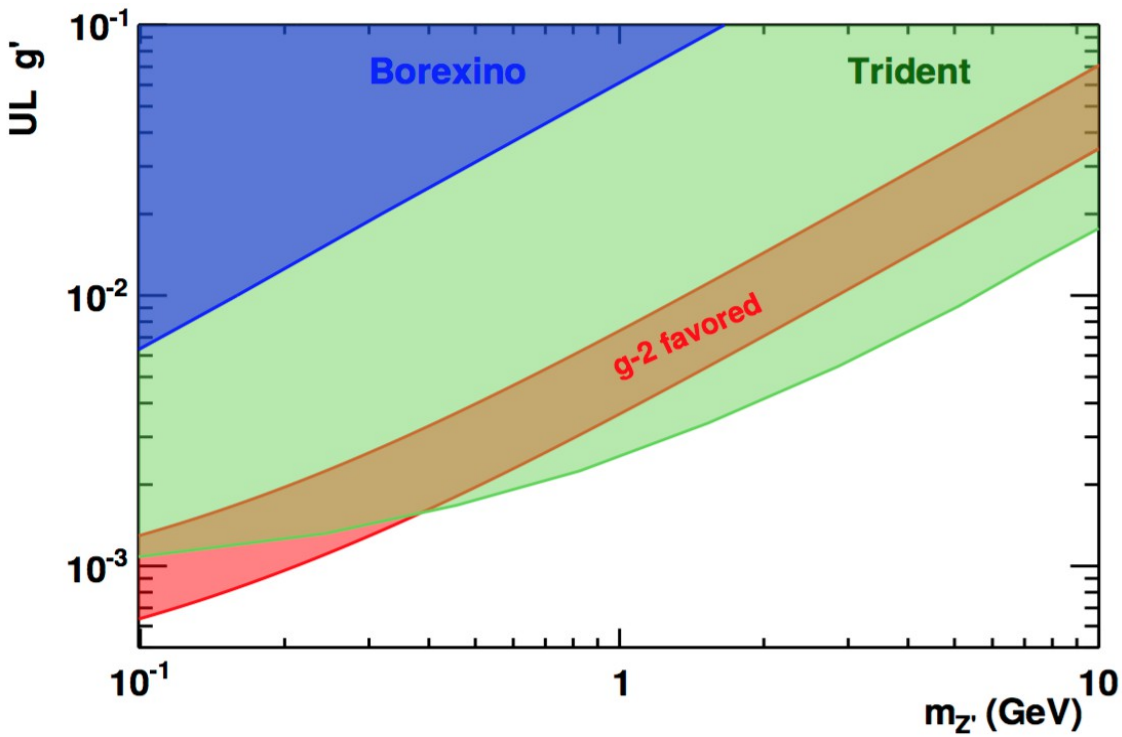


Muonic dark force

- Some dark matter models postulate $L_\mu - L_\tau$ gauge interaction: new gauge boson, Z′ may be produced from radiation of the heavy-flavor leptons
- Could account for $(g\text{-}2)_\mu$ discrepancy

X. G. He *et al.*, Phys. Rev. D 43, 22 (1991).
X. G. He *et al.*, Phys. Rev. D 44, 2118 (1991).

- Can be parametrized by the mass of Z′ ($M_{Z'}$) and the gauge coupling (g')
- Simplified model: SM plus new gauge Z′



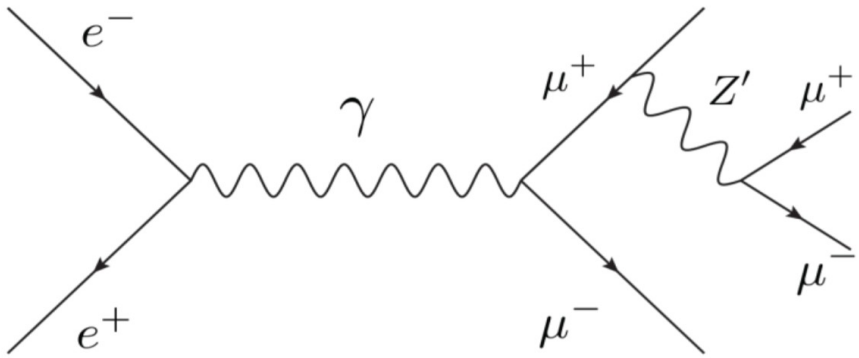
Trident: W. Altmannshofer *et al.*, Phys. Rev. Lett. 113, 091801 (2014).

A. Kamada and H. B. Yu, Phys. Rev. D 92, 113004 (2015).

Current limits rely on Z′−neutrinos coupling, absent in some models

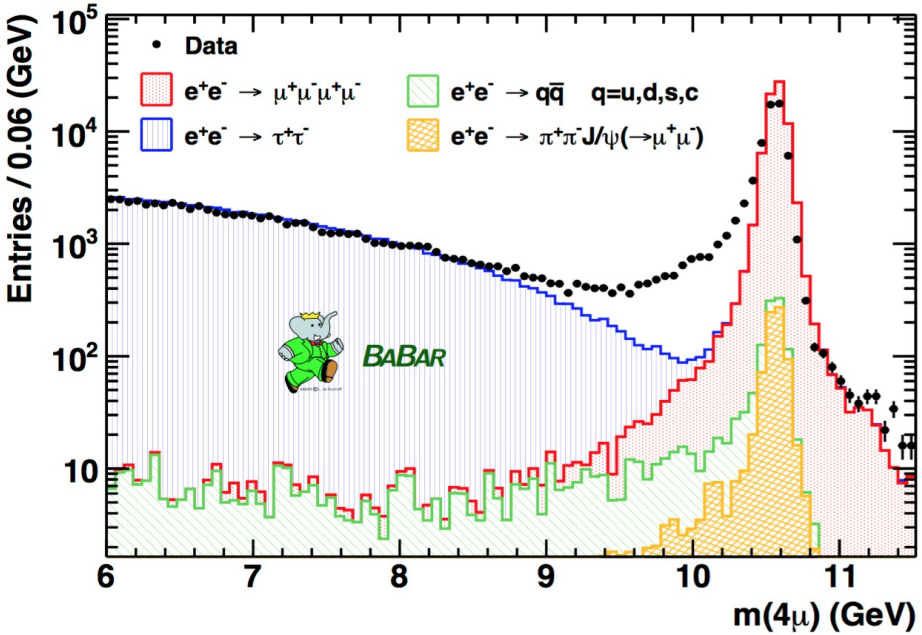
Muonic dark force at BaBar

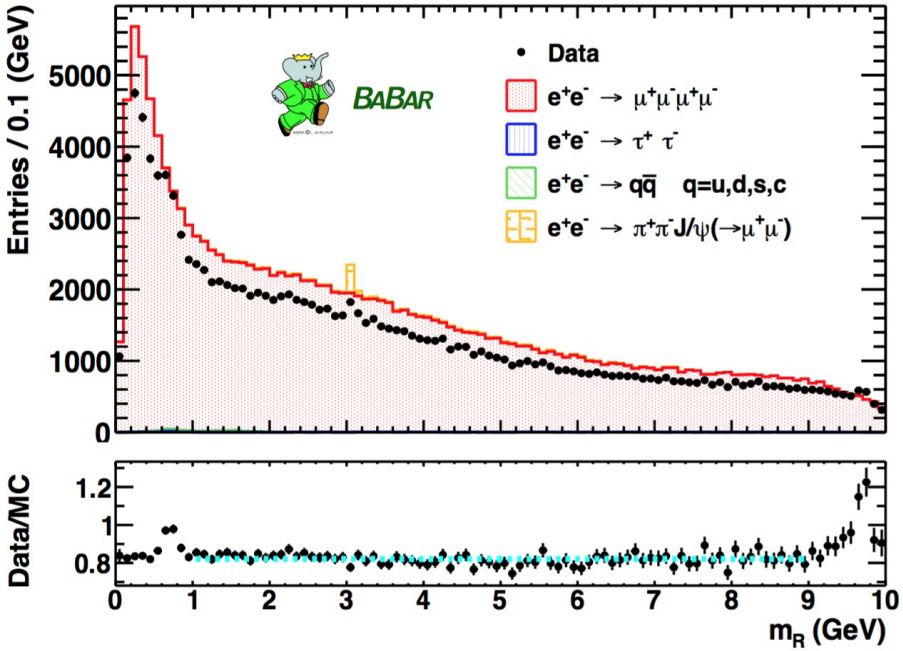
- Cleanest channel at BaBar: $e^+e^- \rightarrow \mu^+\mu^- Z', Z' \rightarrow \mu^+\mu^-$



- Use full dataset of 514 fb^{-1}: Y(4S), Y(3S) and Y(2S)
- Select exactly 4 tracks in two oppositely charged pairs t_1^+, t_2^+, t_1^-, t_2^-
- Excess neutral energy less than 200 MeV
- Muon ID on either same-sign track pair ($t_1^+t_2^+$ or $t_1^- t_2^-$)
- Invariant mass within 500 MeV of event center-of-mass energy
- To suppress events with Y(2S, 3S) $\rightarrow \pi^+\pi^-$Y(1S), Y(1S) $\rightarrow \mu^+\mu^-$ we reject candidates with any $t^+ t^-$ invariant mass within 10MeV of Y(1S) mass

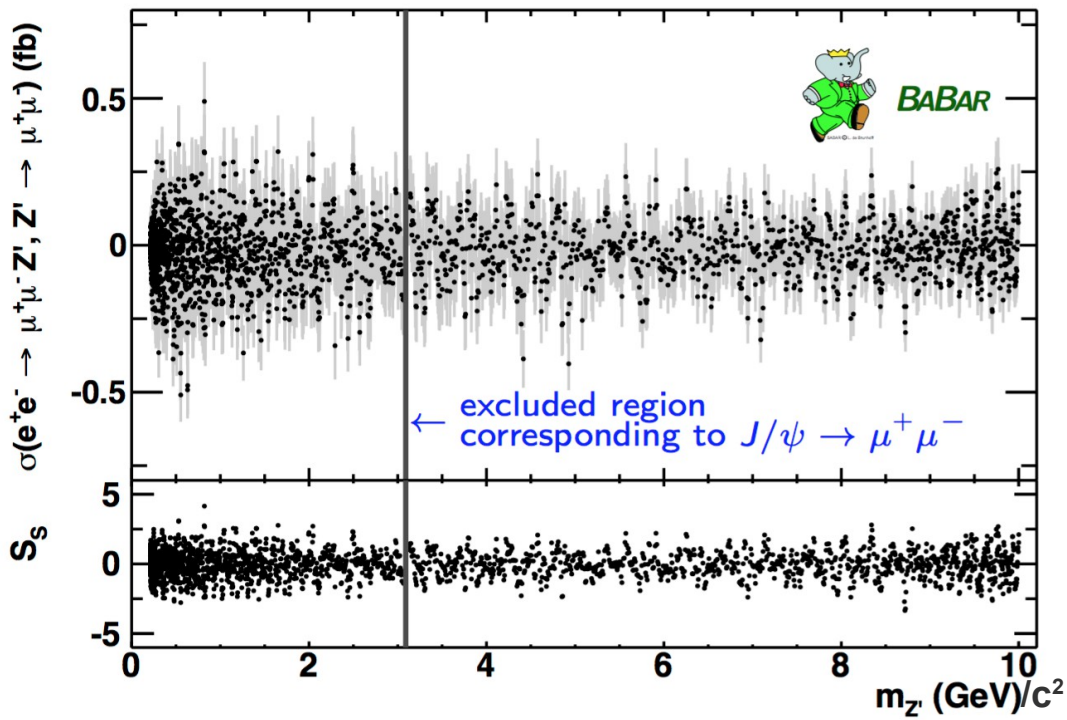
Muonic dark force: event selection





- Background dominated by $e^+e^- \to \mu^+\mu^-\mu^+\mu^-$, contribution from $e^+e^- \to \pi^+\pi^- J/\psi$, $J/\psi \to \mu^+\mu^-$
- MC generator used to produce $e^+e^- \to \mu^+\mu^-\mu^+\mu^-$ (Diag36) does not have ISR simulation → data have 30% lower peak and ISR radiation tail → does not affect this search, as background is fit on m(Z′) data sidebands
- Get MC/data correction in [0, 9] GeV/c^2 invariant mass interval

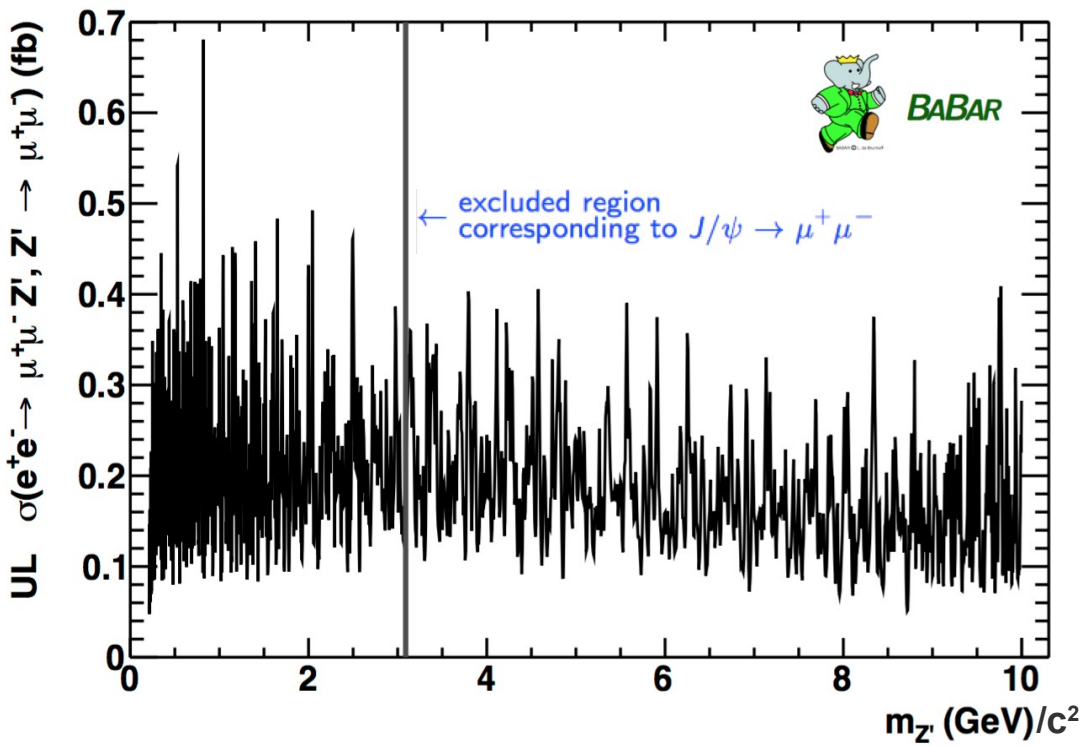
Muonic dark force: signal extraction



- 2219 unbinned maximum likelihood fits for $0 < m_{Z'} < 10$ GeV/c^2 on $m_{Z'}$ intervals ~50 × $\sigma(m_{Z'})$
- exclude $m_{Z'}$ region corresponding to $J/\psi \to \mu^+\mu^-$
- signal MC: MadGraph 5 + Pythia 6, simulated for several masses and interpolated

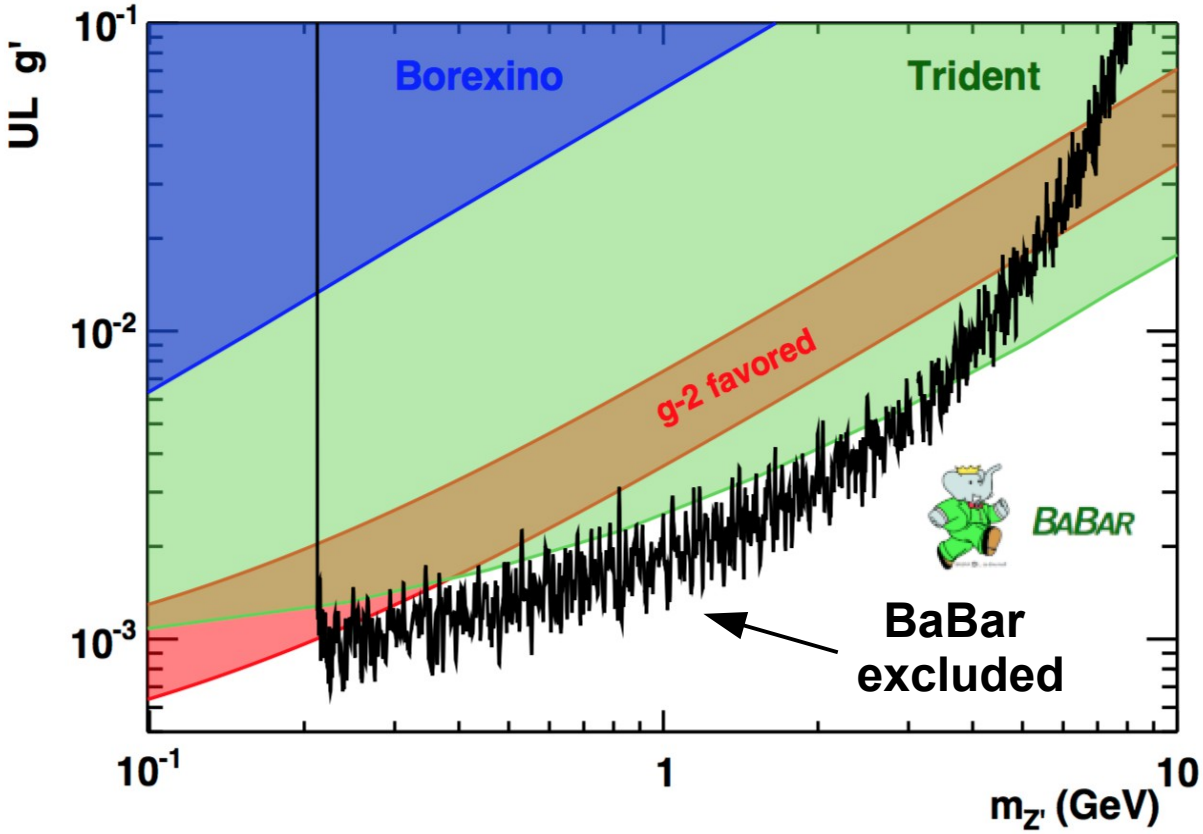
Muonic dark force: results

- Maximum local significance 4.3 σ at $m_{Z'}$ = 0.82 GeV/c^2 corresponding to a global significance of 1.6 (null hypothesis)
- Derive 90% confidence level Bayesian upper limit (UL) on cross section assuming uniform prior
- Use combined likelihood for the 3 samples, Υ(4S), Υ(3S) and Υ(2S)



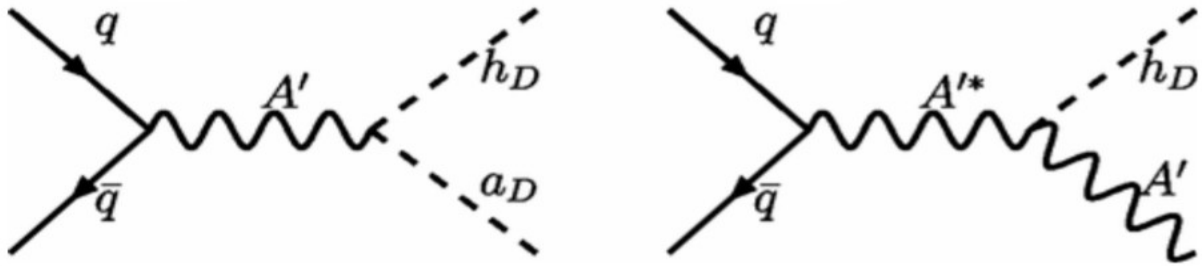
Muonic dark force: results

- No significant signal is observed for Z′ mass in range 0.212 - 10 GeV
- Can set limits on new gauge coupling g′ as a function of Z′ mass
- Upper limits down to 7×10^{-4} near di-muon threshold are set
- Published in Phys. Rev. D. 94, 011102 (2016)



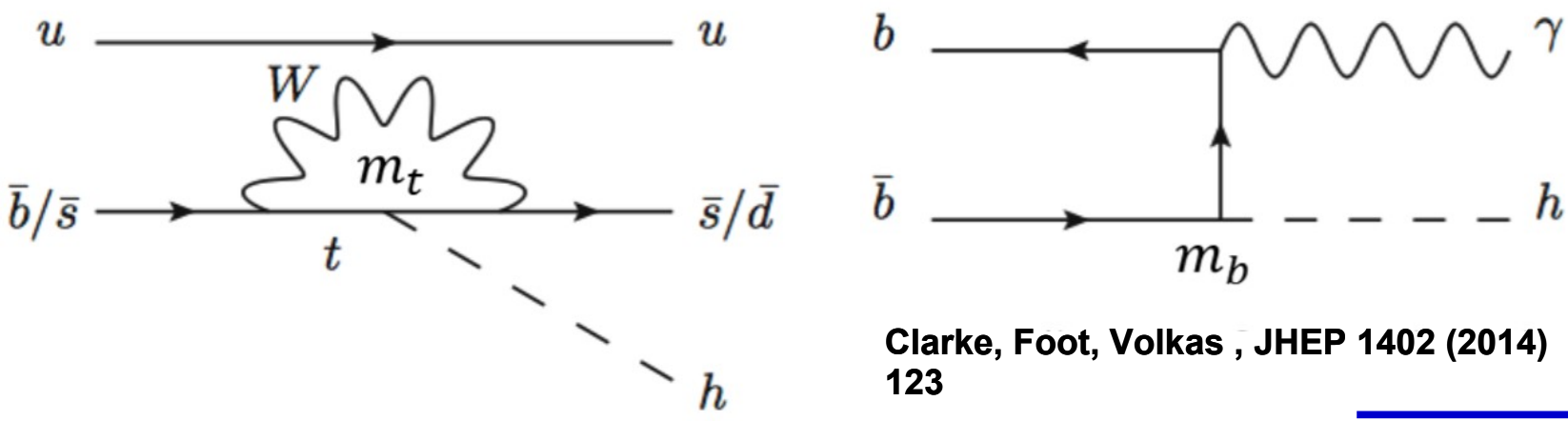
Search for long lived particles

- Long lived particles (LLP) may be produced by dark "portals"
- Vector portal: produce a dark sector photon via kinetic mixing with SM photon $\varepsilon F_{\mu\nu} F'_{\mu\nu}$



Schuster, Toro,Yavin,PRD81, 016002 (2010)

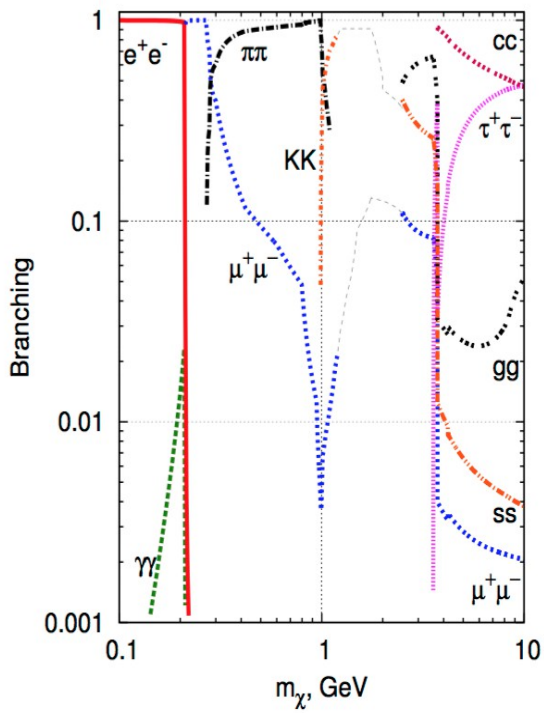
- Higgs portal: produce a dark scalar through kinetic mixing with SM Higgs, production rate ~m_t^2, m_b^2 respectively

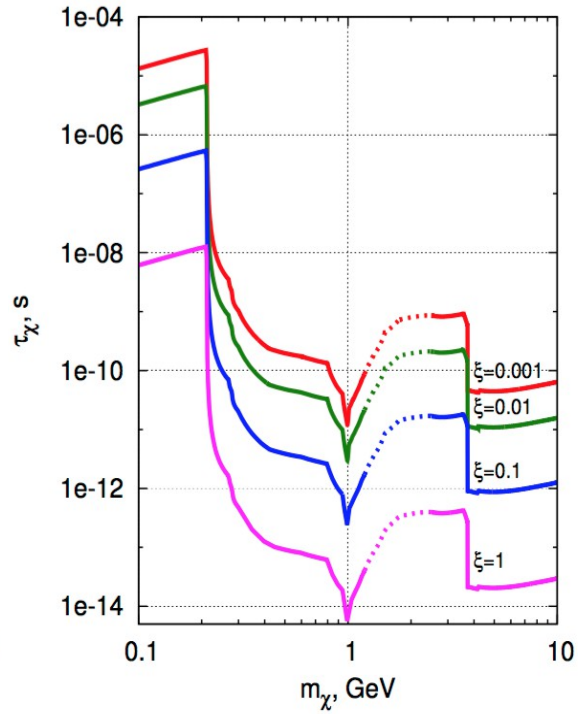


Clarke, Foot, Volkas , JHEP 1402 (2014) 123

Search for long lived particles

- If they can decay only to SM particles they can be long lived ($\sim m_f^2$)





Bezrukov, Gorbunov, 1303.4395, 0912.0390

Light inflaton with Higgs-like couplings decaying to SM fermions

- Searches at << GeV scale..:

  Andreas, Niebuhr, Ringwald, 1209.6083, Gninenko, 1112.5438, NuTeV, hep-ex/0104037

- ..and >> GeV scale:

  D0: hep-ex/0607028, 0906.1787, CDF: hep-ex/9805017

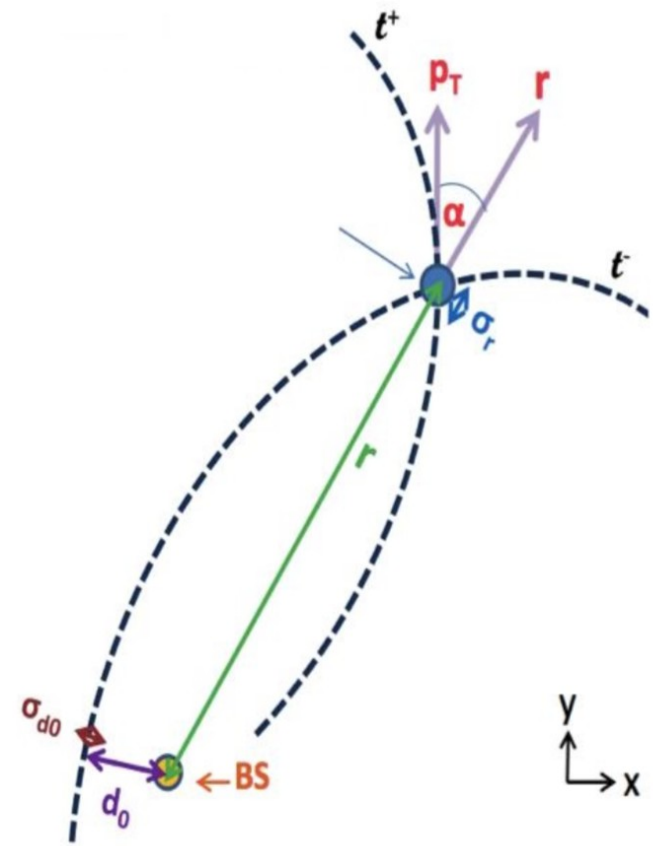
  ATLAS: 1210.7451, 1203.1303, CMS: 1409.4789, 1411.6977, LHCb: 1412.3021

- So far few searches at B-factories: **Belle: long-lived heavy neutrino 1301.1105**

Selection strategy

- Full BaBar data-sample: Υ(2S), Υ(3S), Υ(4S)
- Look for $e^+e^- \rightarrow LX$, $L \rightarrow f$, $f = e^+e^-, \mu^+\mu^-, e^\pm\mu^\pm, \pi^+\pi^-, K^+K^-, \pi^\pm K^\pm$

- Require:
  - Impact parameter significance $d_0/\sigma_{d0} > 3$
  - Vertex fit χ^2/d.o.f. < 10
  - Transverse decay length $1 < r < 50$ cm
  - $\sigma_r < 0.2$ cm
  - $\sigma_m < 0.2$ GeV/c^2 where m is L mass
  - Reject K_S^0- and Λ-like decays
  - Reject events with vertices on beam-pipe, supports and drift chamber walls



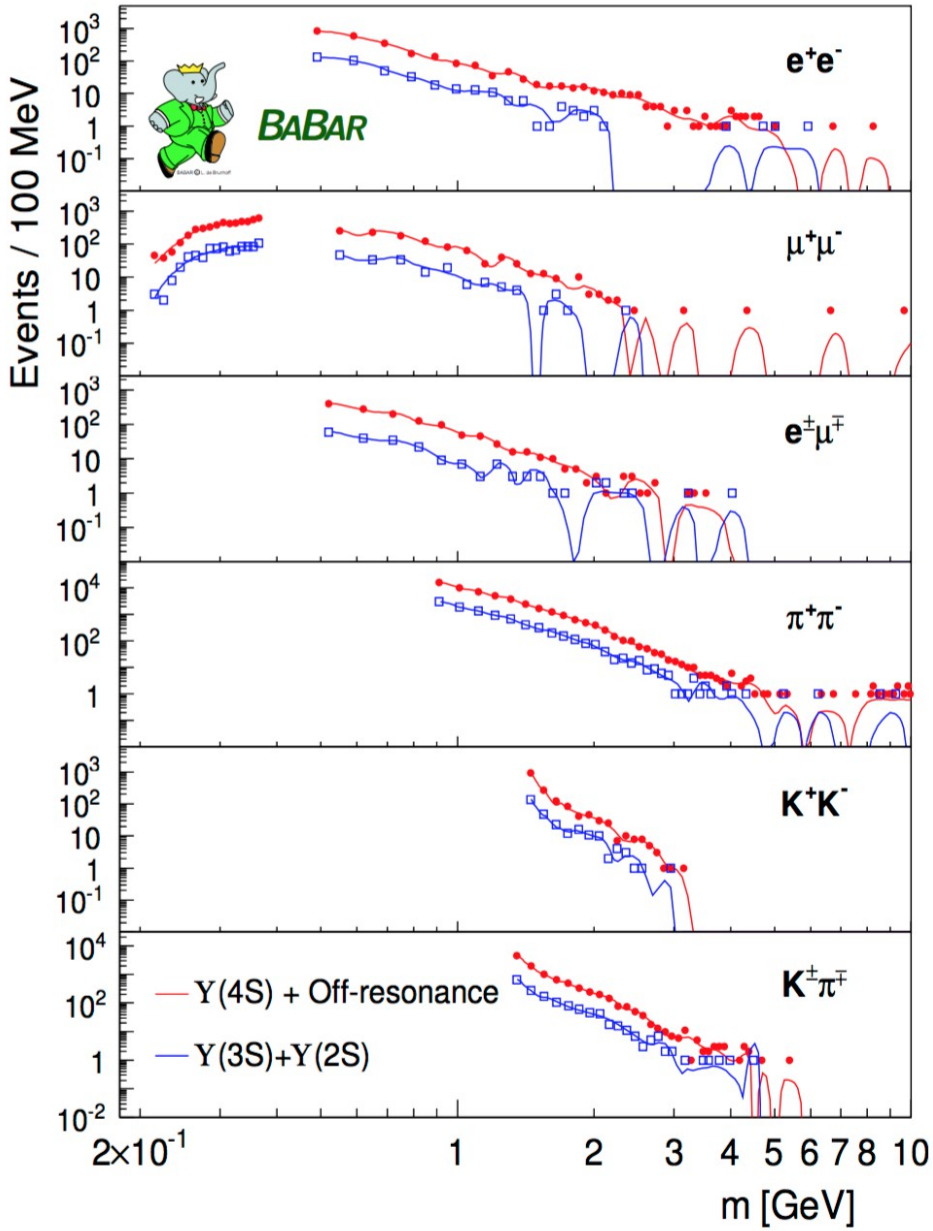
Signal yield

- Background from random track crossing and detector interactions
- Background shape from 2nd order spline fit to data

  Y(4S): —— bkg • data

  Y(2S)+Y(3S): —— bkg • data

- We include only regions in which background is a smooth function:
  - $m_{ee} > 0.44$ GeV/c^2
  - $m_{\mu\mu} < 0.37$ and $m_{\mu\mu} > 0.50$ GeV/c^2
  - $m_{e\mu} > 0.48$ GeV/c^2
  - $m_{\pi\pi} > 0.86$ GeV/c^2
  - $m_{K\pi} > 1.35$ GeV/c^2
  - $m_{KK} > 1.05$ GeV/c^2



Signal extraction

- Signal extraction by fit to mass peak
- Signal shape determined by Monte Carlo simulation
- 12 masses for each final state, then interpolation from closest masses
- Perform un-binned maximum likelihood fit in 2 MeV steps
- Compute (signed) significance:

$$S(m_0) = \pm\sqrt{-2\log\frac{L_0}{L_1}}$$

Mass at scan point

Sign of signal yield

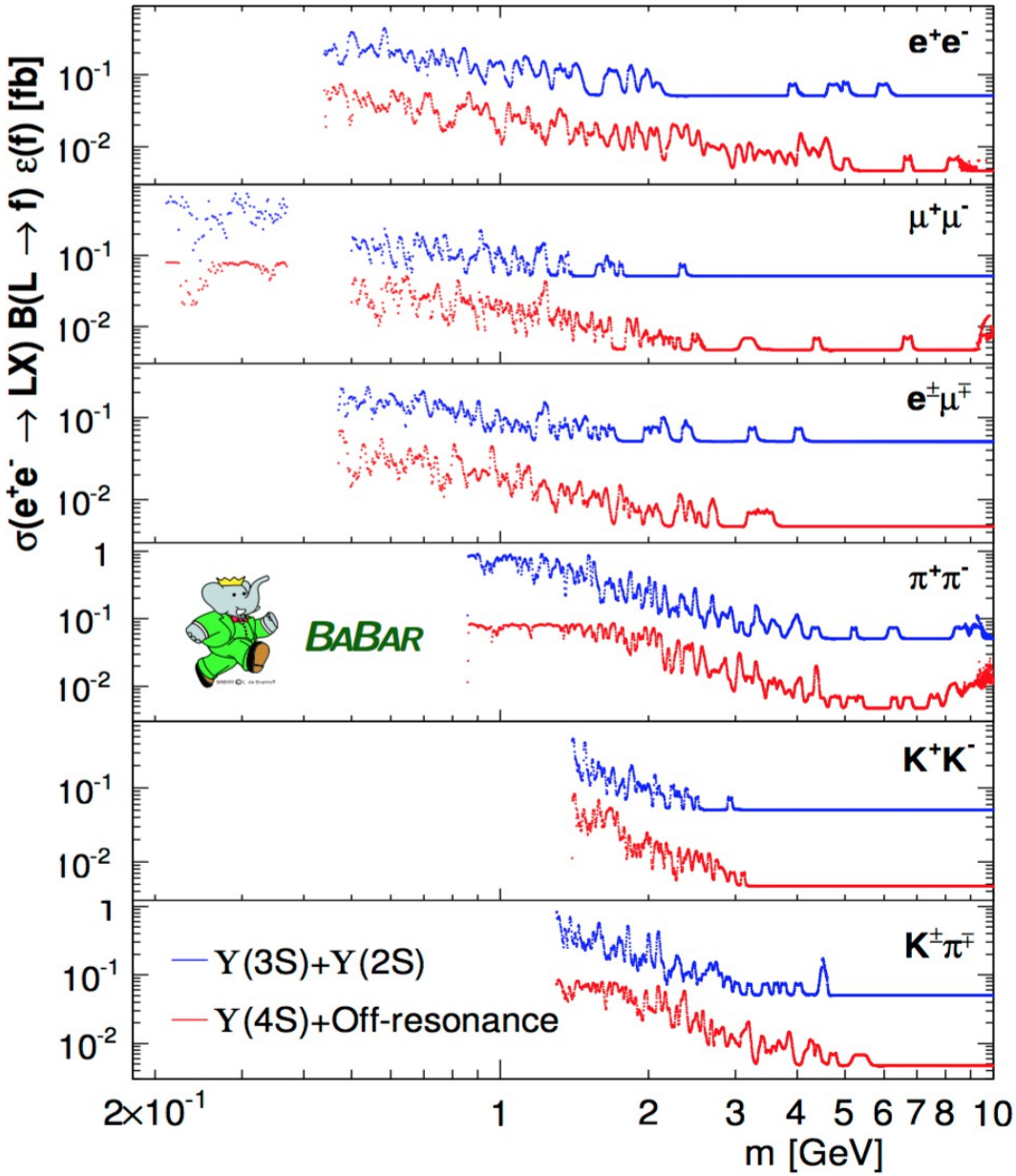
Maximum likelihood with background-only hypothesis

Maximum likelihood with background+signal hypothesis

- compute global significance of maximum local significance of each channel scan → compute global significance for each channel
- no evidence for signal in any channel → compute upper limits

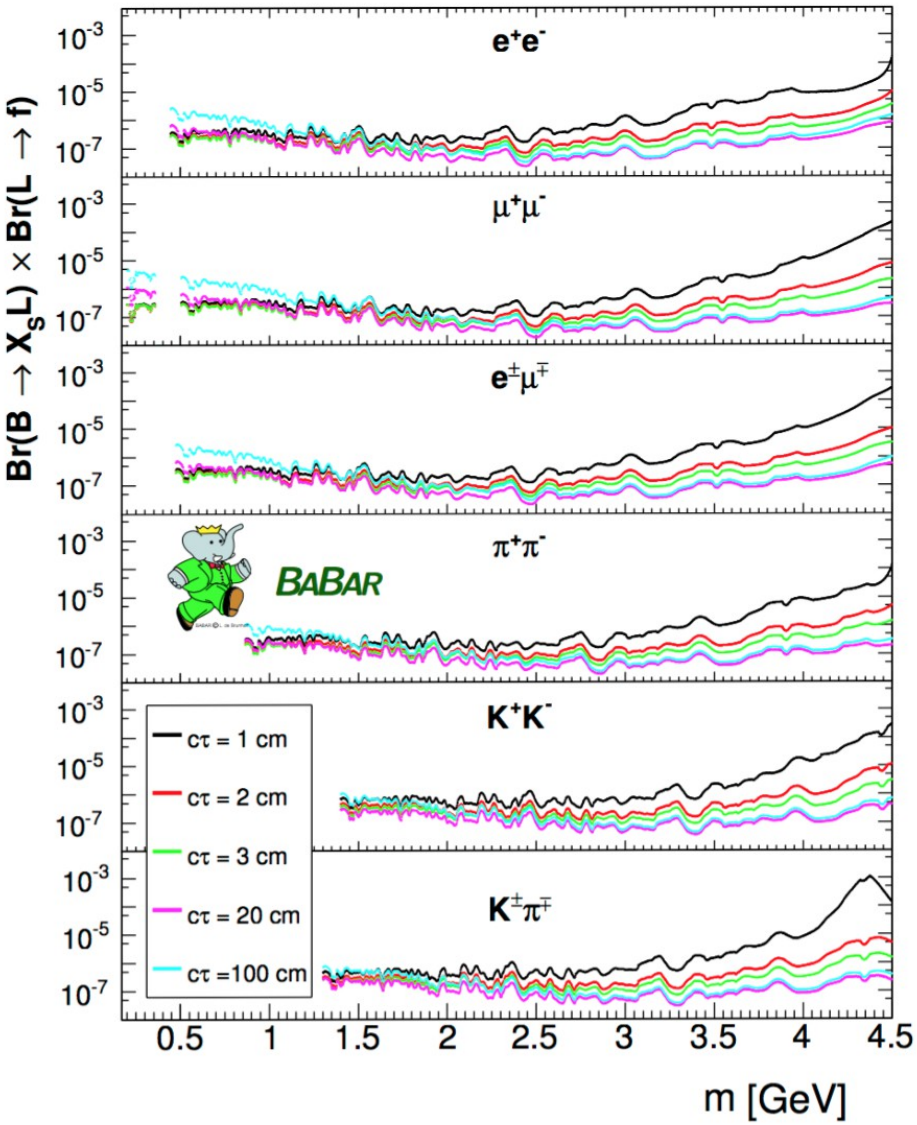
Results

- We extract 90% CL flat-prior Bayesian limits on signal yield including syst. uncertainties
- We get 90%CL UP limits on $\sigma(e^+e^- \to LX)\cdot B(L \to f)\cdot \varepsilon(f)$ $\varepsilon(f)$ = selection efficiency for $e^+e^- \to LX$, $L \to f$ from MC simulation down to 6×10^{-3} fb
- Model independent limits
- Detailed $\varepsilon(f)$ tables provided
- PRL 114, 171801 (2015)



Limits on dark light inflaton

- Following:
  Bezrukov and Gorbunov, "Light inflaton after LHC8 and WMAP9 results" JHEP 10-5 1307, 140 (2013)
- We can also set 90% CL upper limits on the predicted decay $BF(B \to X_s L) BF(L \to f)$ where L= spin 0, X_s hadronic system with strangeness = -1
- Monte Carlo simulation to estimate the selection efficiency of the decay chain $e^+e^- \to B\overline{B}$, $B \to X_s L$, $L \to f$ we get limits on $B(B \to X_s L) \times B(L \to f)$



Summary

- B-factories can provide significant constraints on new physics models
- We searched for a light CP-odd Higgs boson with a charm tag in the energy intervals 4.00 - 8.95 GeV/c^2 and 9.10 - 9.25 GeV/c^2. We found no significant signal and we set UL at 90% CL for the process $B(\Upsilon(1S) \rightarrow \gamma A^0) \times B(A^0 \rightarrow c\bar{c})$ down to 7.4×10^{-5}
- We performed a search for a new gauge boson, Z′ coupling primarily to heavy flavor leptons, and we found no significant signal setting limits on the new gauge coupling constant down to 7×10^{-4} and excluded most of the (kinematically accessible) $(g\text{-}2)_\mu$ preferred parameter space.
- We searched for long lived particles decaying to fermion pairs and we set model independent 90% CL UL for $(e^+e^- \rightarrow LX)\cdot B(L \rightarrow f)$ and for the production of a dark scalar trough the “Higgs portal” in B decays
- New searches are being performed on BaBar data, more results to come

Thanks!

Backups

Backup

- .....