Search for long-lived particles at BABAR

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On behalf of the BABAR Collaboration

PRL 114, 171801 (2015)

Search History

There have been many searches for long lived particles (LLPs)

Electron Beam Dumps

Andreas, Niebuhr, Ringwald, PRD86, 095019 (2012)

Neutrino Experiments

$\pi^0 \to \gamma X$: Gninenko, PRD **85** 055027 (2012)
NuTeV: PRL **83**, 4943 (1999), **84**, 4043 (2000), **87**, 041801 (2001)

Hadron Colliders

D0: PRL **97**, 161802 (2006), **103** 071801 (2009)
CDF: PRD **58**, 051102(R) (1998)
ATLAS: PL **B 719** 280 (2013), PRL **108**, 251801 (2012)
CMS: PRL **114**, 061801 (2015), PRD **91** 052012 (2015)
LHCb: Eur. Phys. J. C **75** 152 (2015)

Most of these searches were optimized for m< GeV or m>> GeV

Experiments at B-factories well suited for particles with mass ~ few GeV

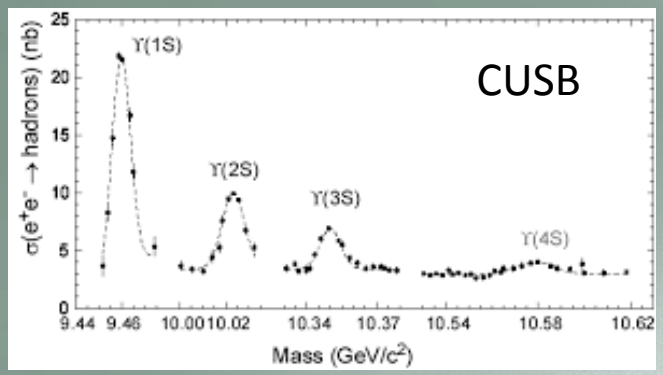
Very large data sets, open triggers, "simple" event topologies.

"Search for heavy neutrinos at Belle," PRD **87**, 071102 (2013) ($m_K < m_\nu < m_B$, model dependent)

This analysis is generic, uses long lifetime as signature

BaBar Data Set

Took data 1999-2008 at PEP-II asymmetric e^+e^- collider:
~1.3x10^9 $e^+e^- \rightarrow c\bar{c}$, ~0.9x10^9 $e^+e^- \rightarrow \tau^+\tau^-$, ~0.5x10^9 $e^+e^- \rightarrow B\bar{B}$, ~0.2x10^9 $e^+e^- \rightarrow b\bar{b}$



LLP production at B factories-I

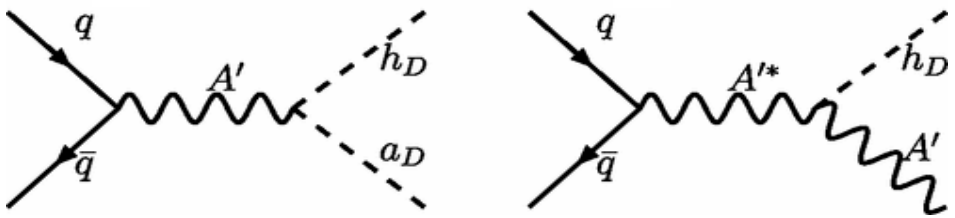
Via dark vector portal

Produce a dark-sector photon A′ via kinetic mixing with the SM photon: $\varepsilon F^{uv}F'_{uv}$

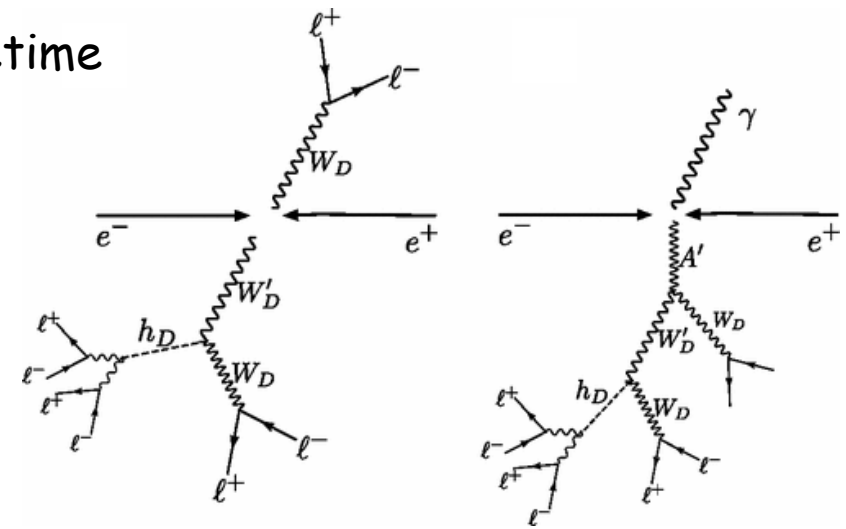
A′ decays into dark (pseudo)scalar or vectors

Some of these dark particles can be long lived & decay into SM particles

h_D, a_D=dark higgs
W_D=dark gauge boson } can have long lifetime
A′=dark photon



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



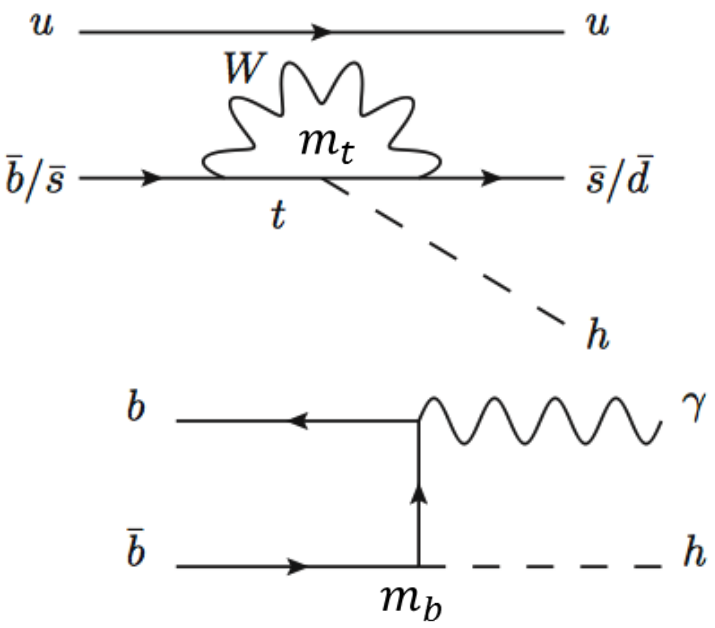
Essig, Schuster, Toro, PRD80 015003(2009)

LLP production at B factories-II

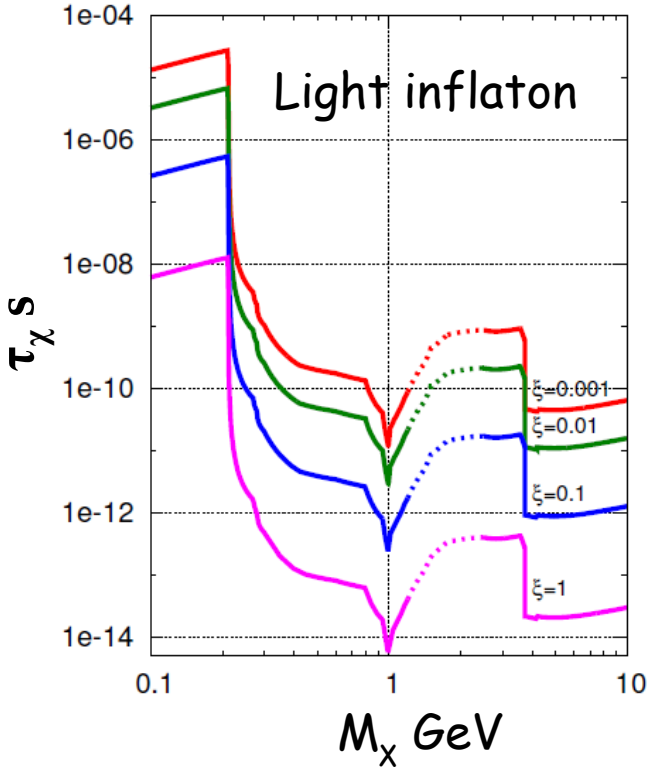
Via Higgs portal

A light scalar h/X mixes with SM Higgs

Production rate $\propto m^2_b$ or m^2_t, decay rate $\propto m^2_f$



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



B(b->χX_s) ≈O(10^{-6}) large!

Bezrukov, Gorbunov, JHEP 1307 (2013) 140

Analysis: Event Selection

Form vertex out of track pairs.

Use PID to loosely select e^+e^- , $\mu^+\mu^-$, $e^\pm\mu^\mp$, $\pi^+\pi^-$, K^+K^-, $\pi^\pm K^\mp$

Allow overlaps, i.e. more than one combo.

Require:

Track $d_0 > 3\sigma$

Vertex $\chi^2 < 10$ (1 DOF)

$1 < r < 50$ cm, $\sigma_r < 0.2$ cm

No hits before the vertex

$\alpha < 0.01$ rad

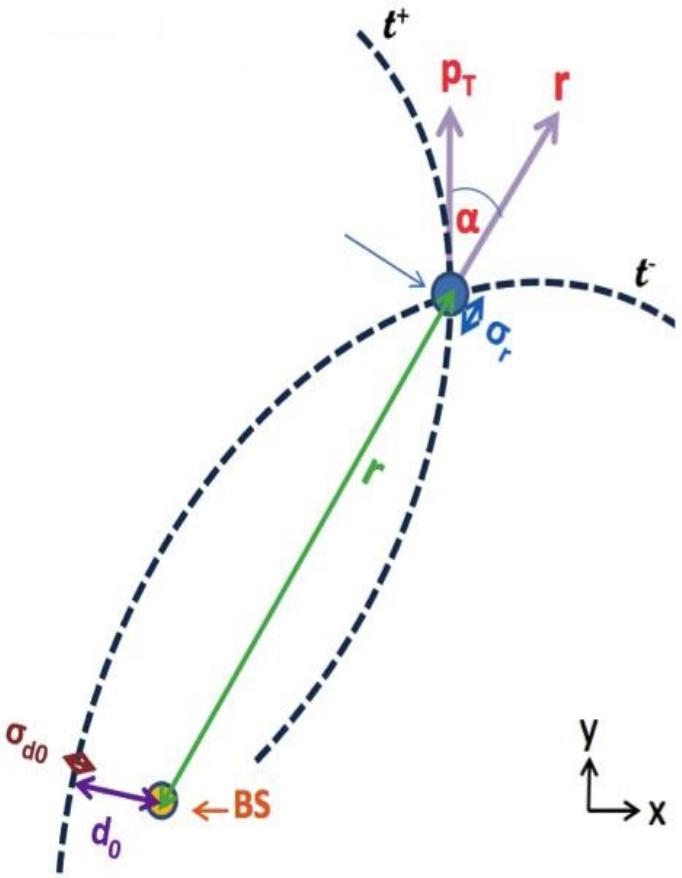
$\sigma_m < 0.2$ GeV/c^2

Eliminate:

K_s and Λ with mass cuts

$e^+e^- \to e^+e^-$ & cosmics with angle cuts

Beampipe, support tube, drift chamber wall



Analysis: Signal Extraction Overview

LLP fully reconstructed: A signal would appear as a mass peak
Fit the *m* distribution assuming background only to obtain the background shape
Perform unbinned extended maximum likelihood fit
Scan for a signal on top of background in 2 MeV steps
For each scan point (m_o) determine signal significance (S)

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

Mass @ scan point

Sign of signal yield

Maximum likelihood with background-only hypothesis

Maximum likelihood with background+signal hypothesis

Analysis: probability density functions

Signal PDF (P_s): Determine from simulation

evaluate at 12 masses for each decay mode

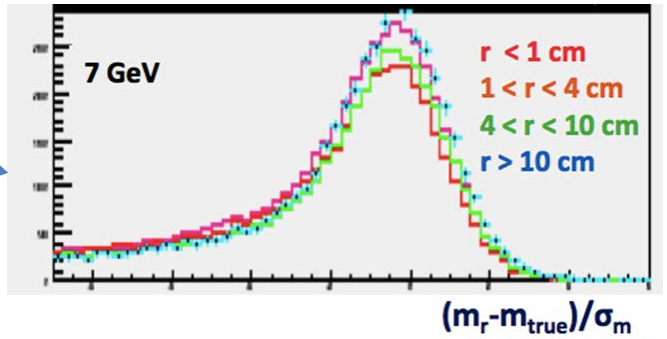
$$P_S \propto R\left[\frac{(m - m_0)}{\sigma_m}\right]$$

The event's measured mass

Scan point hypothesized mass

The event's mass uncertainty

Resolution function from signal simulation



Background PDF (P_B): Determined from data

A 2nd-order polynomial spline with knots separated by 15 times the signal mass resolution (mass-dependent)

Gives optimal balance b/w signal sensitivity and low fake-signal rate

At low mass, optimum found only in $\mu^+\mu^-$ mode.

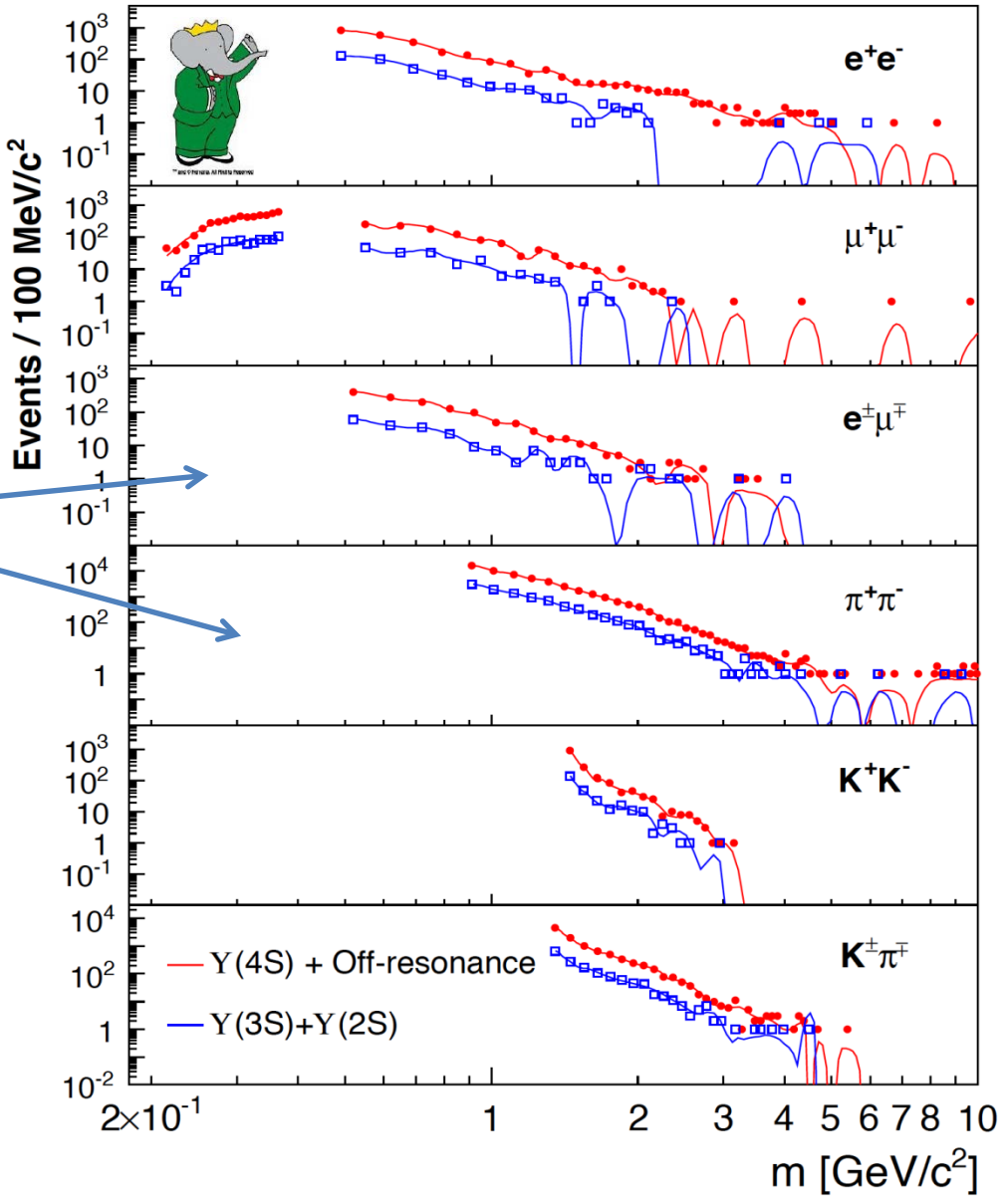
Low-mass regions discarded in other modes (too much structure in MC)

Data Mass Distributions

Curves are background PDFs

Low-mass discarded regions
too much structure in MC

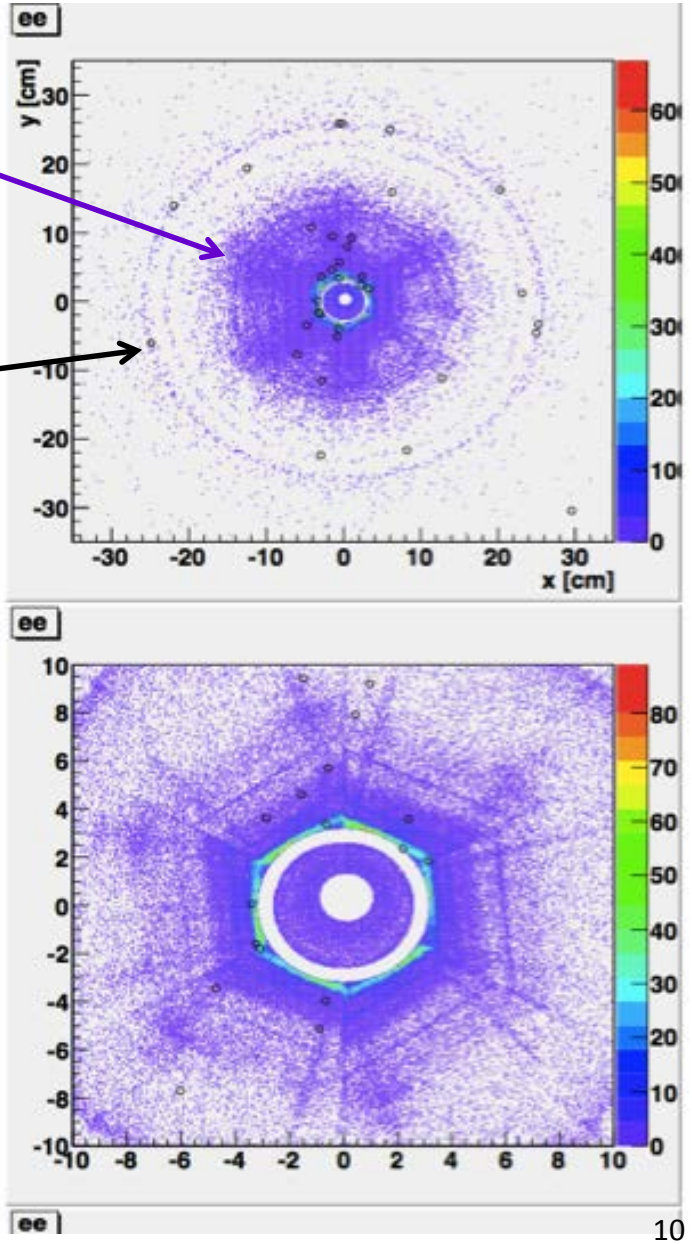
No obvious mass peaks…
$S(m_0) < 3$ everywhere but at 2 points in the μμ mode.



Highest-significance mass points

$m_{\mu\mu}$=0.212 GeV
S=4.7
13 signal events
p-value=4×10^{-4} with look-elsewhere effect in $m_{\mu\mu}$ < 0.37 GeV
More than 50% of the candidates are in or near material regions.
All have 0.2 <p < 0.3 GeV where is e-μ discrimination is poor.
Consistent with γ-conversions

γ-conversion, m_{ee} < 10 MeV



$m_{\mu\mu}$=1.24 GeV
S=4.2
10 signal events
p-value=8×10^{-3} with look-elsewhere effect in $m_{\mu\mu}$ < 0.5 GeV

Model independent Upper Limits

Calculate 90% CL upper limits on $\sigma(e^+e^- \to LX)BF(L \to f)\varepsilon(f)$

Include systematic errors on:

P_B spline binning

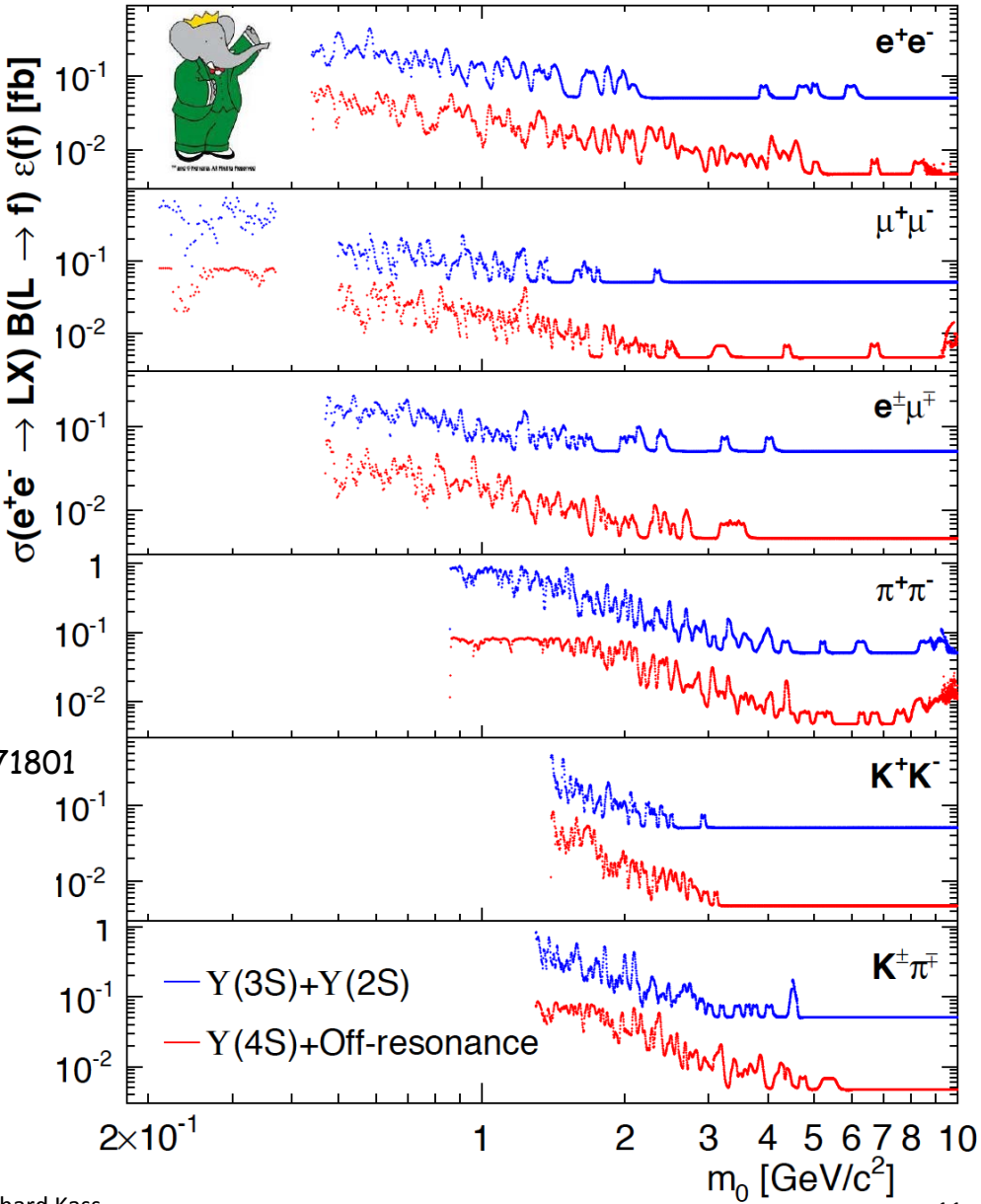
P_s dependence on r, m, p_T

Signal mass resolution

Provide an efficiency table for each channel as a function of m, $c\tau$, p_T

http://link.aps.org/supplemental/10.1103/PhysRevLett.114.171801

Limits can be re-evaluated for any model one simulates

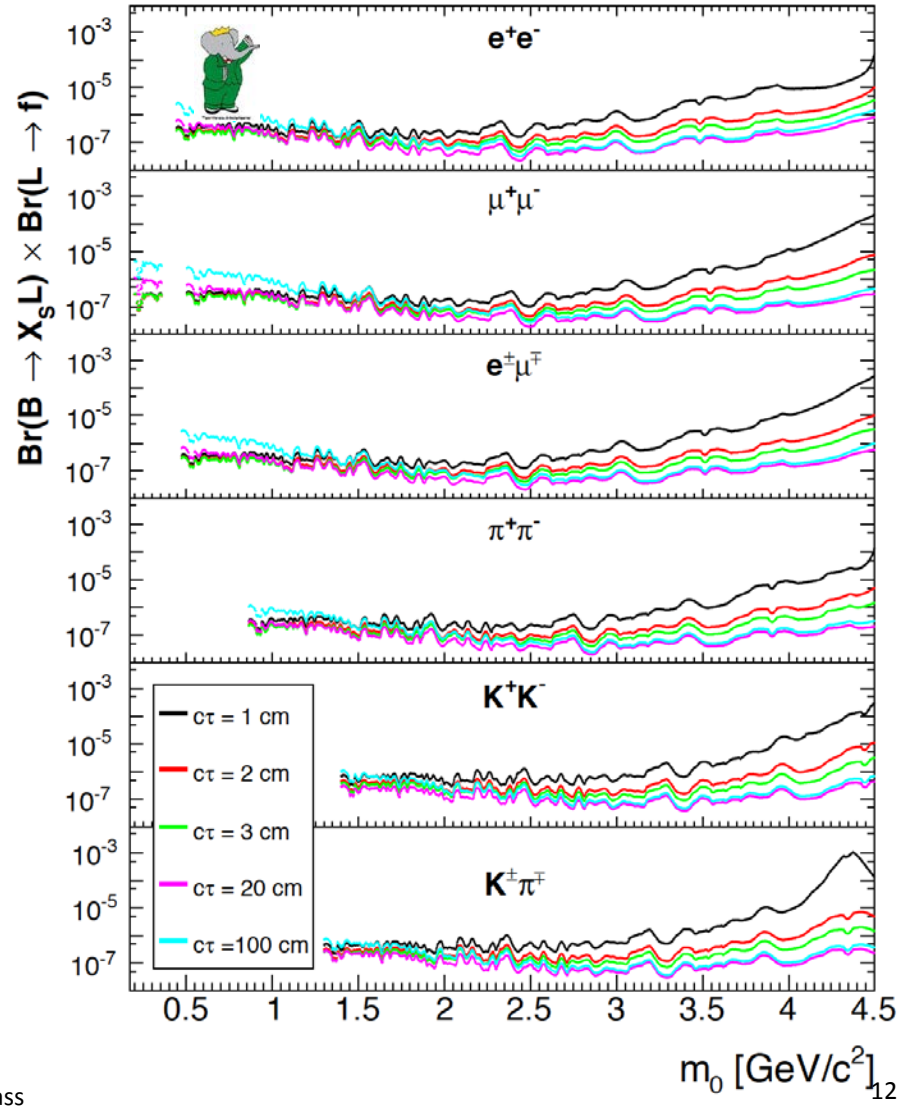


Higgs portal ULs for B->X_sL for different L lifetimes

Calculate 90% CL upper limits on BF(B→X_sL)BF(L→f)

L= spin 0
X_s hadronic system with strangness =-1

Include systematic errors:
- Luminosity
- Reconstruction efficiency
- Monte Carlo statistics



Summary

First O(GeV) mass-range search to use the long lifetime as the main signature

Model-independent limits

efficiency tables for application to any model available at:

http://link.aps.org/supplemental/10.1103/PhysRevLett.114.171801

Model-dependent limits for Higgs-portal scenario

Published: PRL 114, 171801 (2015)

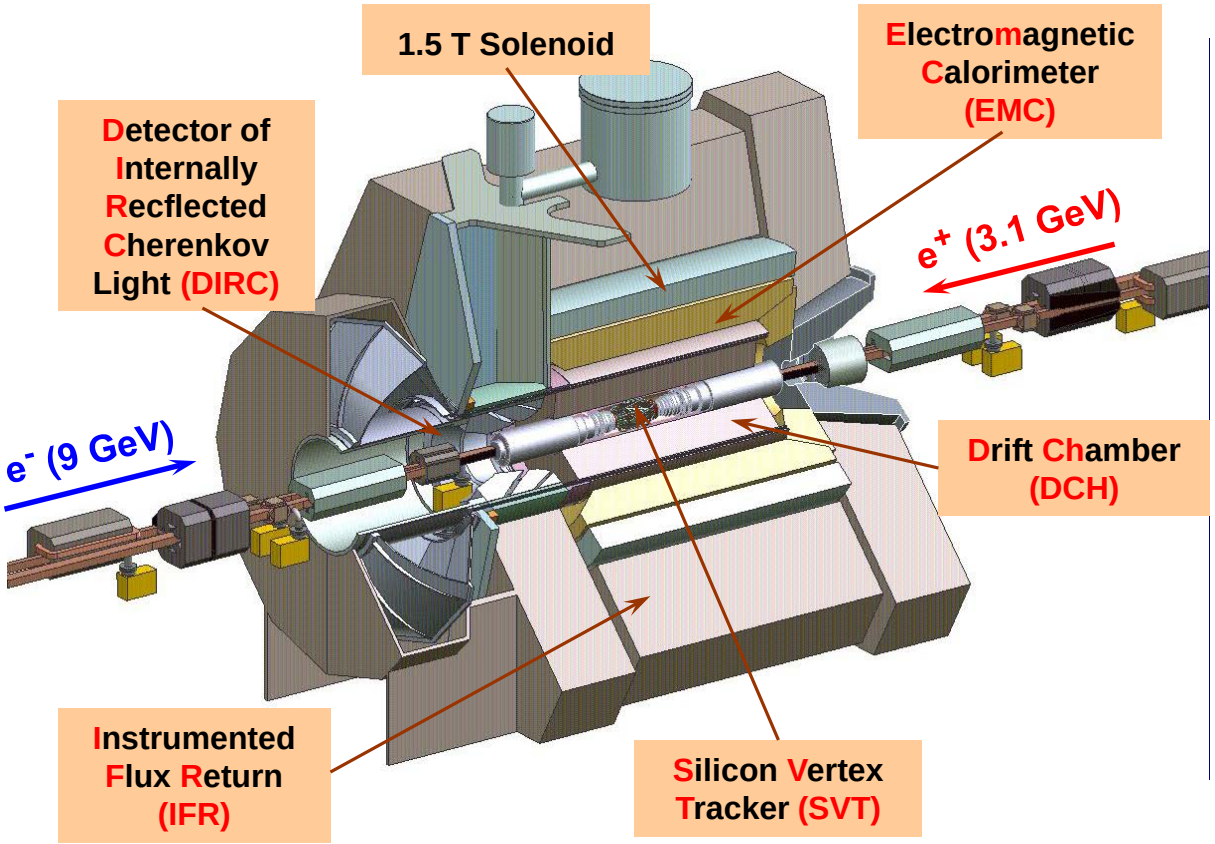
Future outlook:

Similar measurements can be done at Belle now with ~2X BaBar's data sample

Eventually Belle-II will have ~30X the BaBar+Belle data sample

Extra Slides

BaBar Detector



SVT, DCH: charged particle tracking: vertex & mom. resolution, K^0_s/Λ

EMC: electromagnetic calorimeter: $\gamma/e/\pi^0/\eta$

DIRC, IFR, DCH: charged particle ID: $\pi/\mu/K/p$

Highly efficient trigger for B mesons

NIM A479, 1 (2002)
NIM A729, 615 (2013)