Direct Searches for New Physics Particles with BABAR

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On behalf of the BABAR Collaboration

6th SHiP Collaboration Meeting

7-9 October 2015
CERN

Scope

- Hidden sector searches emerged as a strong topic in the late years of the BABAR experiment.

- Among the particles sought by SHiP, BABAR looked for

  - Dark photon A'   PRL113, 201801 (2014)

  - Dark Higgs h'   PRL108, 211801 (2012)

  - Long lived neutral particles LLP or L   PRL114, 171801 (2015)

- Other paths to dark sectors were explored (preliminary results), some are still studied

  - Spinoff of A^0 -> invisible(s)   arXiv:0808.0017 [hep-ex]

                                                      PRL107, 021804 (2011)

  - 4 leptons events from W'   arXiv:0908.2821 [hep-ex]
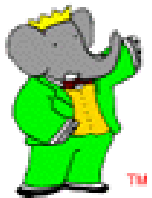
The *BABAR* Experiment

Datasets

(CUSB)
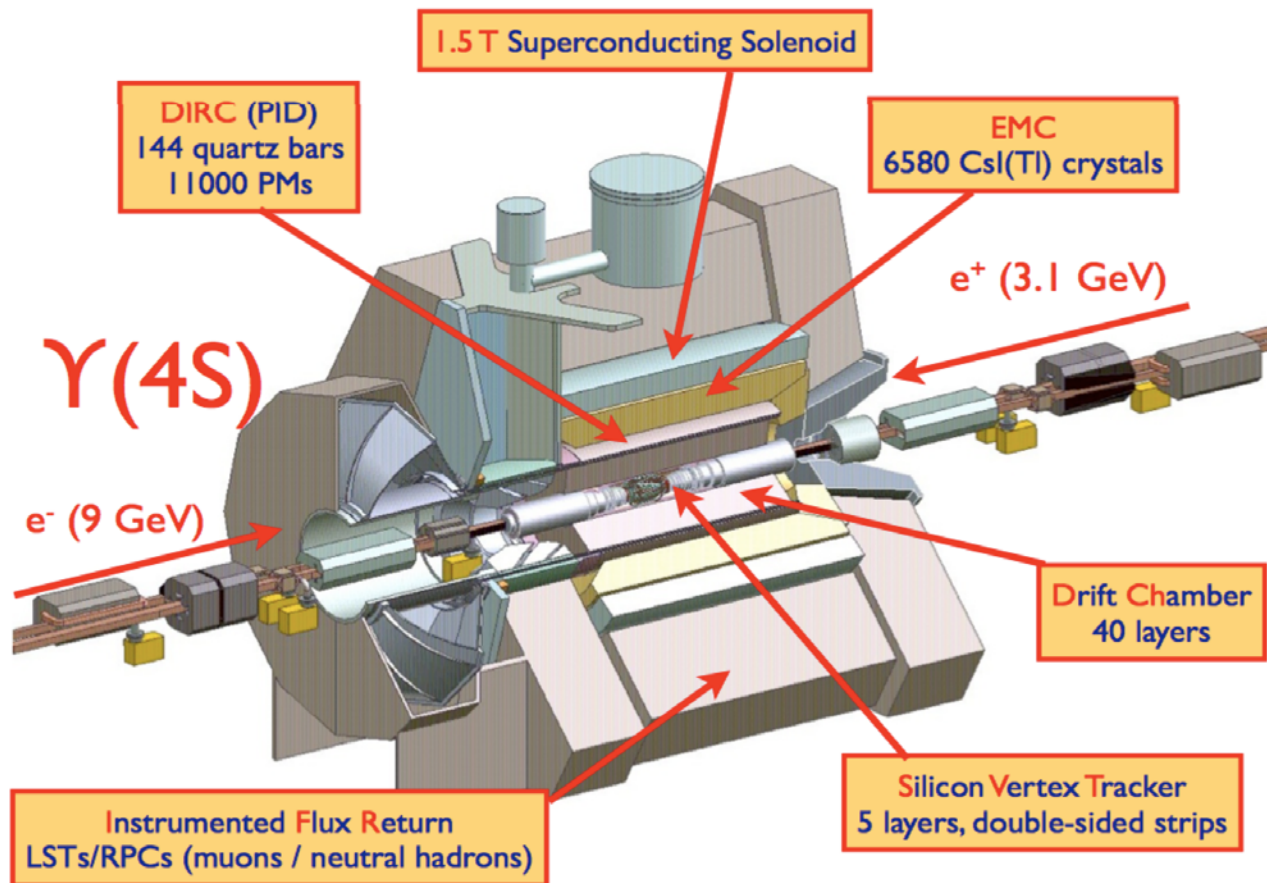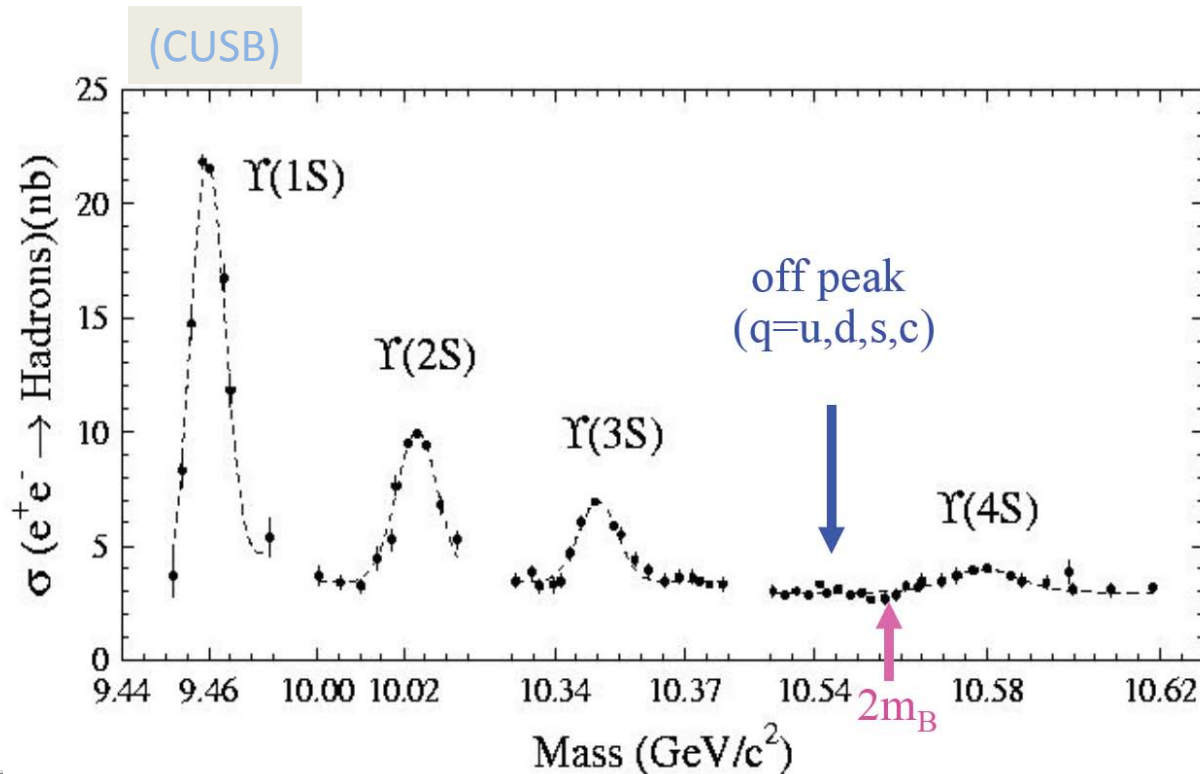
- A' and L searches on full data sample
514 fb^{-1} (of 531.34 fb^{-1})
- A^0 search on the narrow resonances
  - inclusive
  - tagged

18 M ⟵ 99 M ⟶ 122 M   471 M events
+ 5 M ⟵

$\pi\pi$ transitions

Dark photon A' (or U boson)
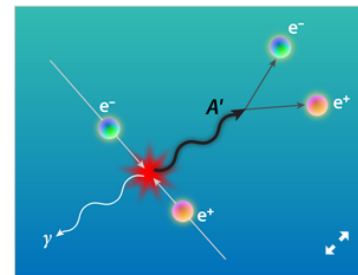
PRL113, 201801 (2014)

Viewpoint: New Light Shed on Dark Photons

Douglas Bryman, University of British Columbia, Vancouver, British Columbia V6T2A3, Canada
November 10, 2014 • Physics 7, 115

A search for a photonlike particle that could be related to dark matter has come up empty, putting new constraints on models that imagine a dark form of electromagnetism.
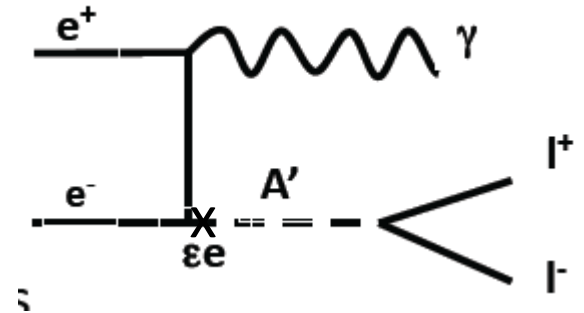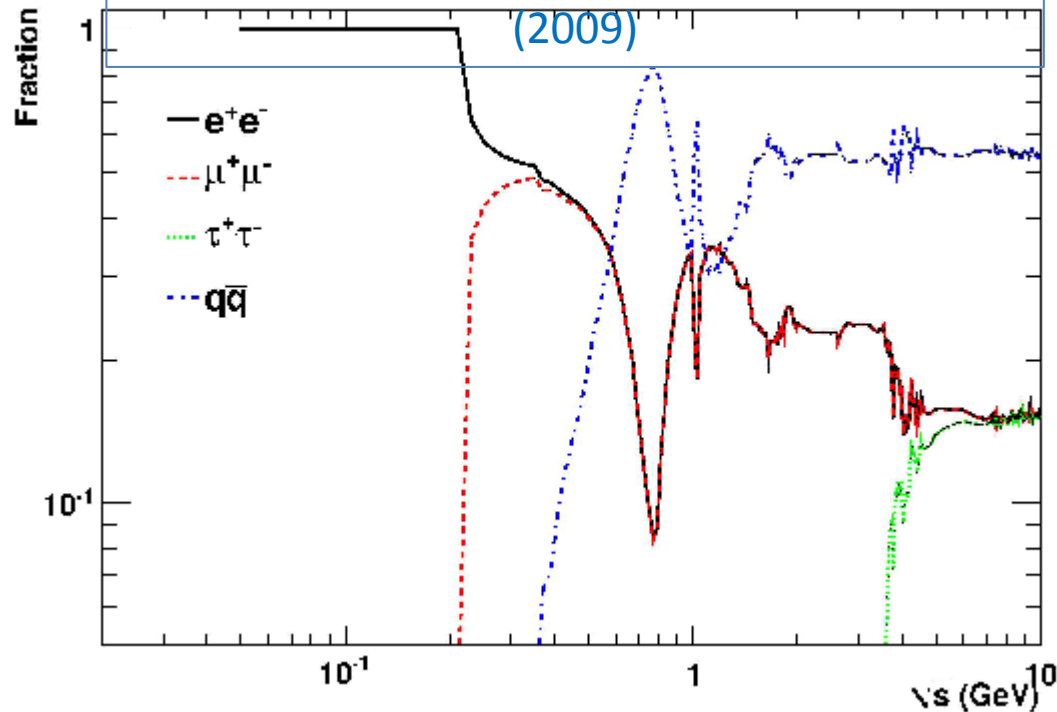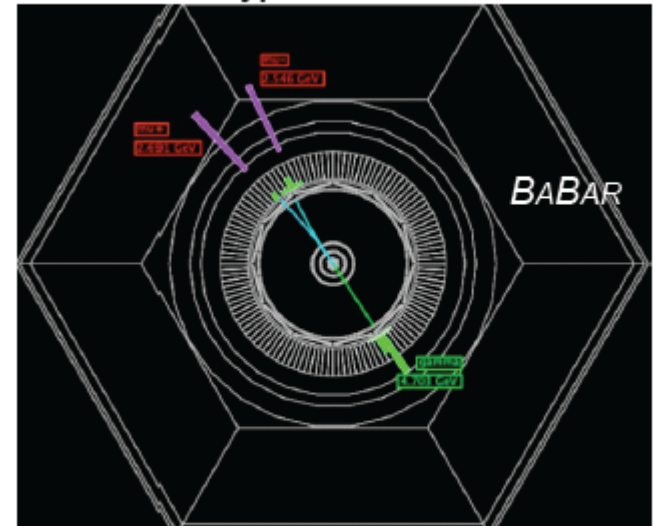
L=514 fb^{-1}

Dark photon

- photon $\rightarrow$ A'; $\alpha \rightarrow \varepsilon^2\alpha$. A' narrow
- look for narrow resonance produced in e^+e^-,
  decaying to 2 leptons   A' $\rightarrow e^+e^-, \mu^+\mu^-$

R. Batell, M. Pospelov, A. Ritz, PRD 79 115008 (2009)

Typical event

BABAR

— Tracks
— Photon
— Signal in muon/hadron detector

$A' \rightarrow e^+e^-, \mu^+\mu^-$

PRL113, 201801 (2014)

Event selection

- 2 tracks + 1 photon with E_{cm} >200 MeV

- 1 (e) or 2 (e,μ) track(s) positively identified

- Kinematic+ geometric fit

- MVA to remove conversions (e)

Measurement (blind analysis)

- Final sample with radiative Bhabha's + $\mu\mu\gamma$ + narrow resonances
  - Correction to model the remaining conversions

- Extract cross section with fits over sliding windows covering

0.02 (e), 0.212 (μ) < $m_{A'}$ < 10.2 GeV
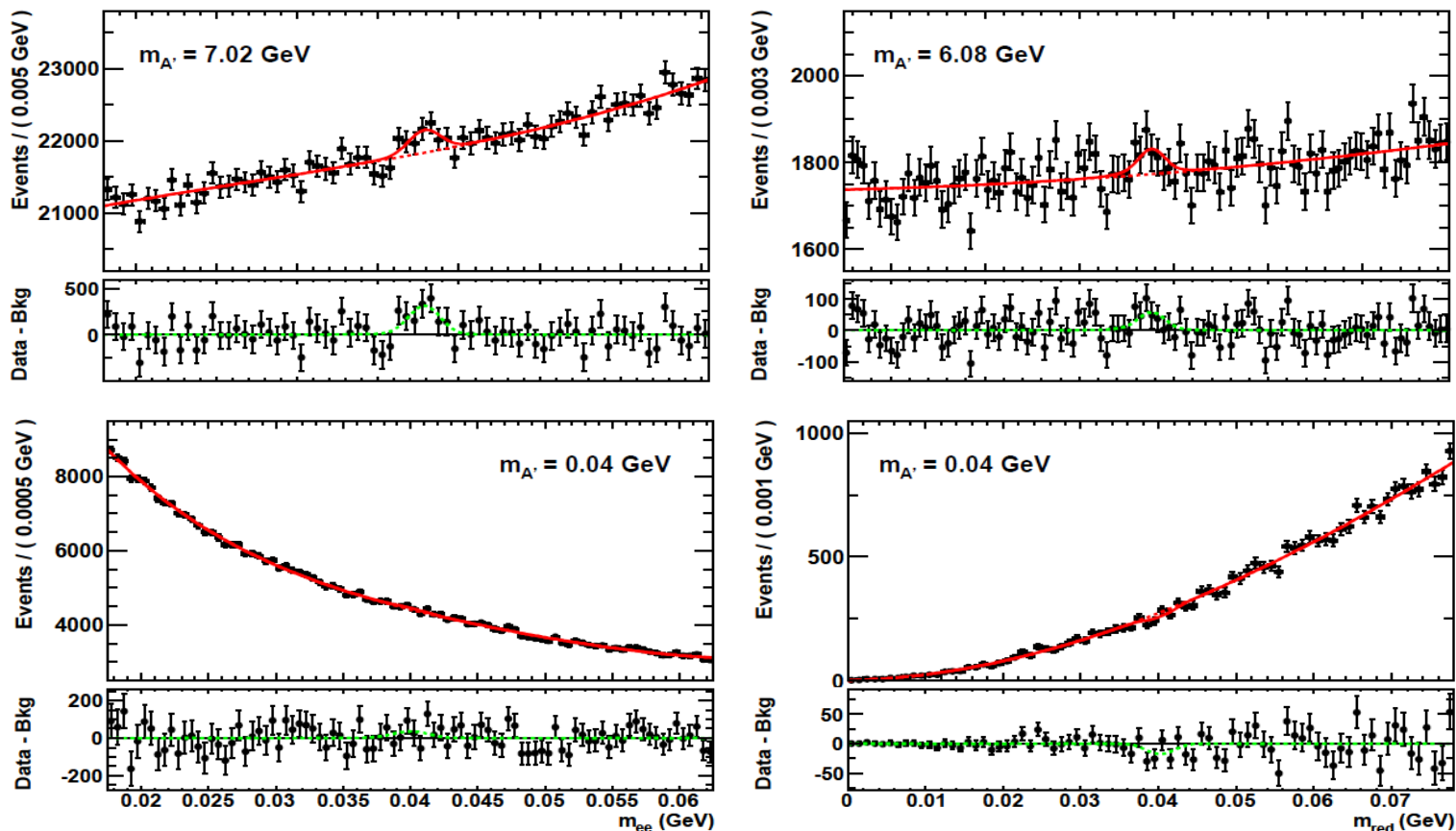
A′ → e⁺e⁻, μ⁺μ⁻

$$A' \rightarrow e^+e^-, \mu^+\mu^-$$
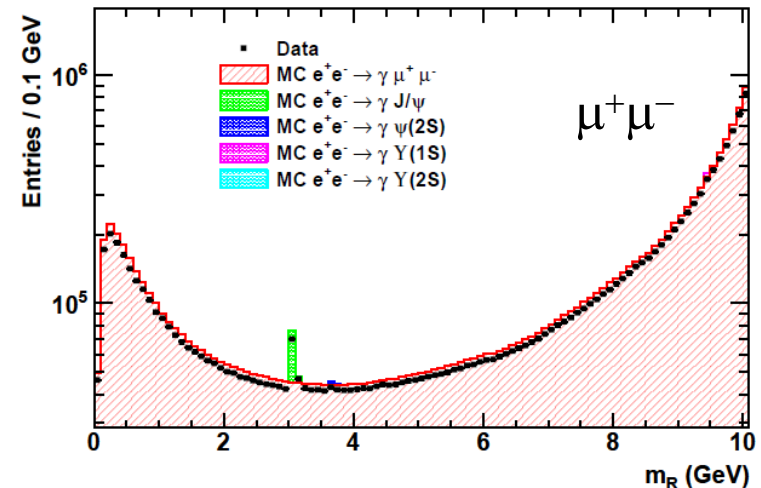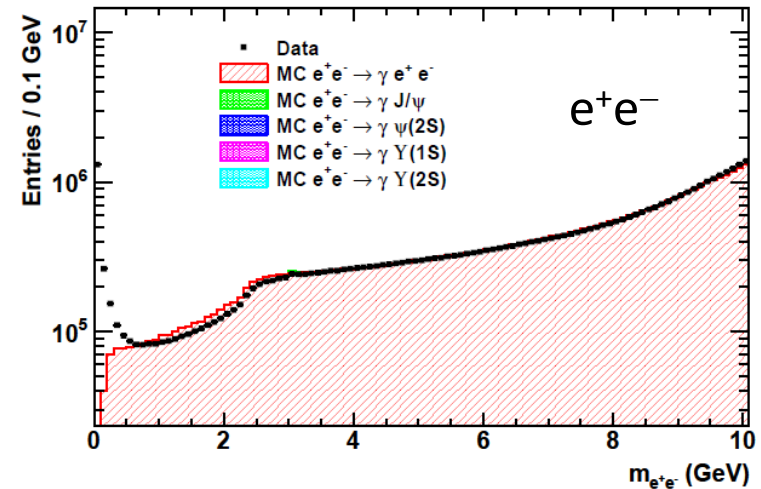
PRL113, 201801 (2014)

Fit window size >> signal width, << total mass range. Hence, we can use a polynomial background shape to obtain an optimal signal to background ratio.

A few scan points:

A′ → e⁺e⁻, μ⁺μ⁻

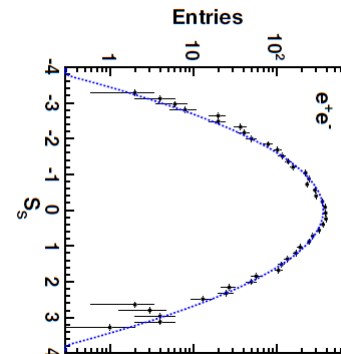$A' \rightarrow e^+e^-, \mu^+\mu^-$

PRL113, 201801 (2014)
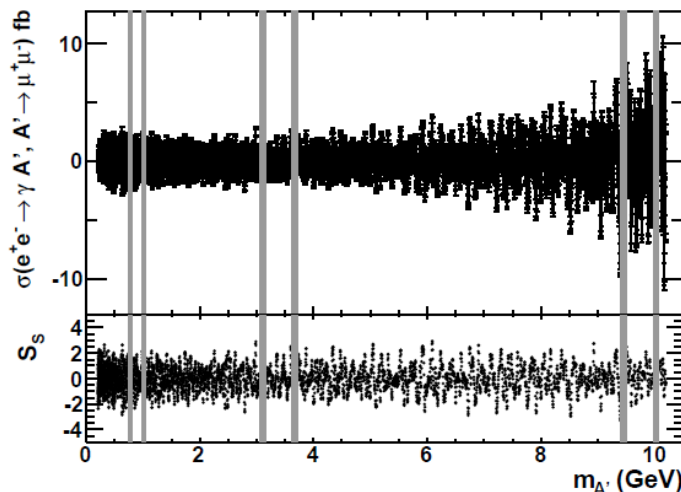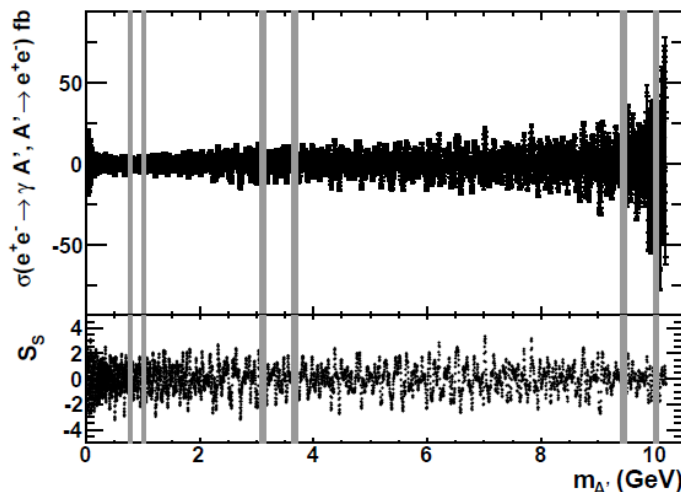
- Highest fluctuations

- ➤ 3.4 σ (e) M=7.02 GeV
- ➤ 2.9 σ (μ) M=6.09 GeV
  p-values=0.57, 0.94
  including trial factors.

5704 trials

- Bayesian 90% C.L. upper limits ~ 1 to 10 fb

5370 trials

- used to derive 90% u.l. on ε.
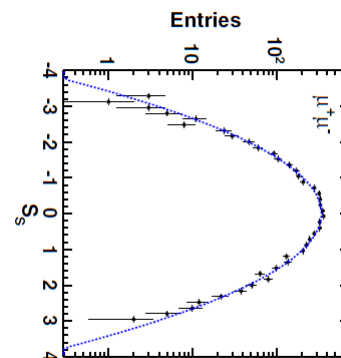
Dark photon Impact

- BABAR all inclusive search in $e^+e^- \rightarrow \gamma A'$ has improved the constraints by an order of magnitude in the relevant mass range $0.2 < m_{A'} < 10$ GeV/c^2.
- Parameter space for A' causing g-2 effect is now restricted to $15 < m_{A'} < 35$ MeV

Dark photon Impact:
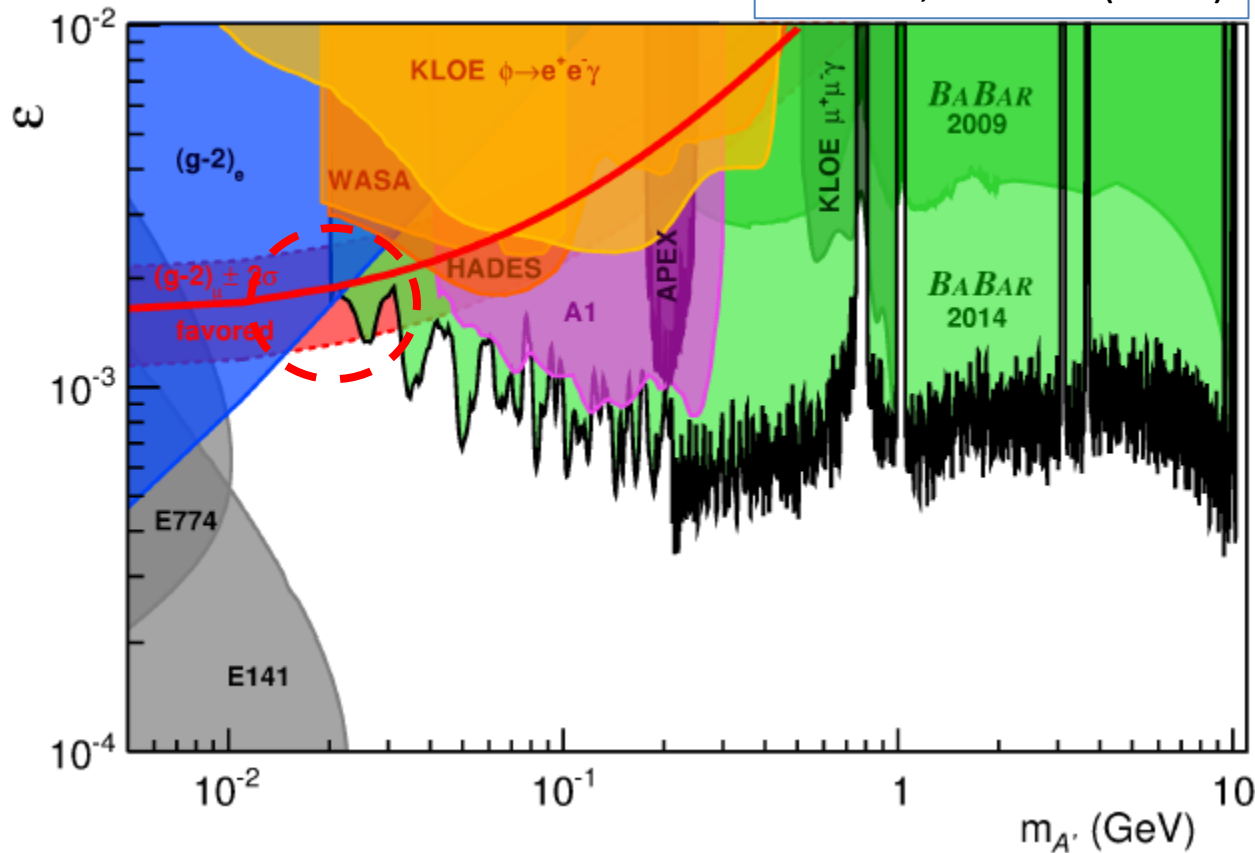## update at Phi Psi 2015/FPCP (A. Denig)
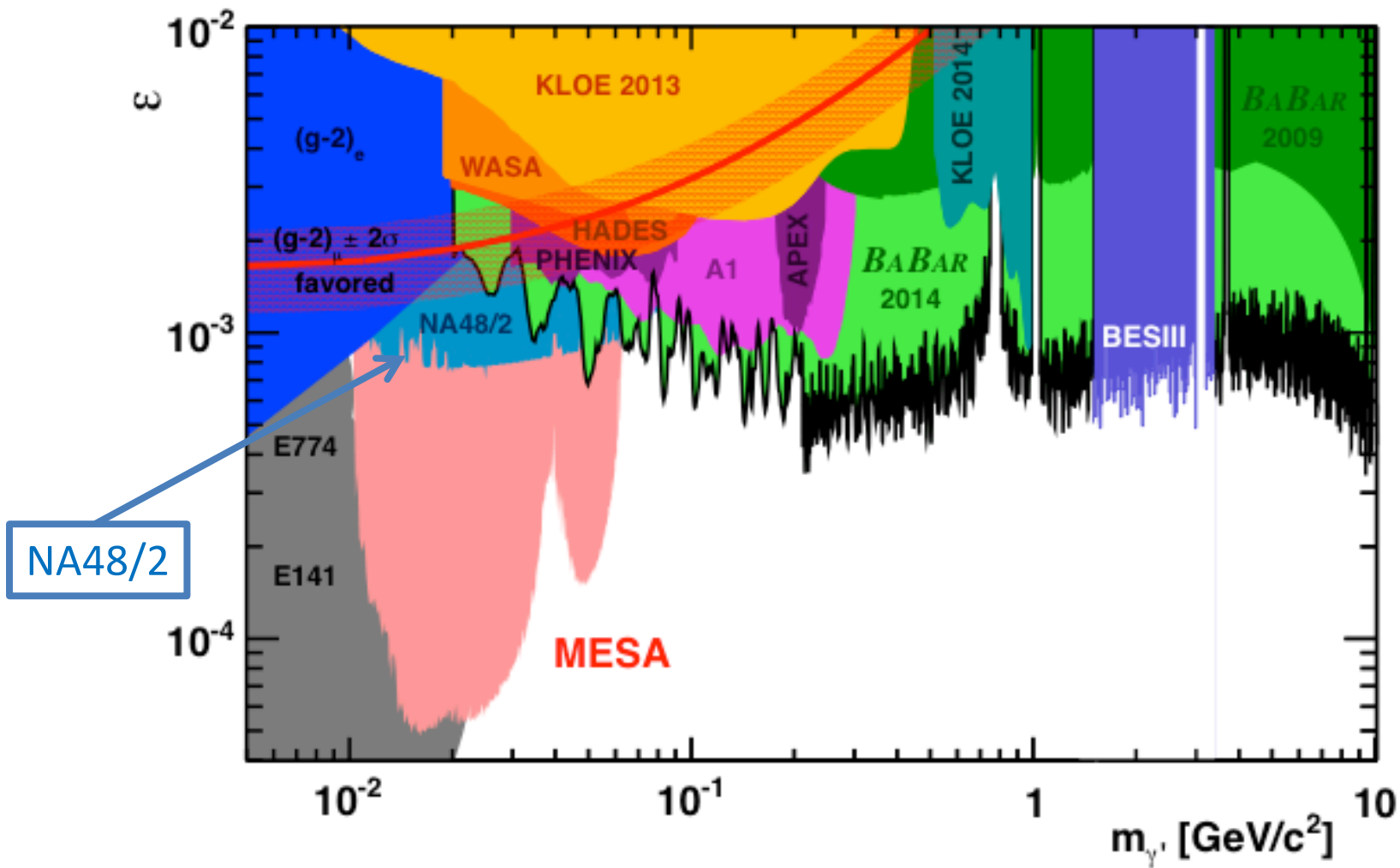
Search for long lived particles

PRL114, 171801 (2015)

L(4S) = 404 fb^{-1} N(4S) = 448 $\times 10^6$ events
(below)   44 fb^{-1}
[+ (4S)   20 fb^{-1} validation]

L(3S) =   28 fb^{-1} N(3S) = 121 $\times 10^6$
L(2S) =   14 fb^{-1} N(2S) =   98 $\times 10^6$

Motivation

At the B factories LLP could come via

- **Vector portal**

  Dark photon couples
  to light dark sector
  (pseudo) scalar/vector
  which could be long lived
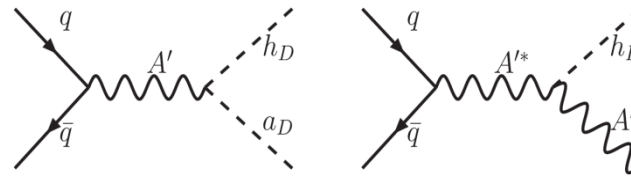
P. Schuster, N. Toro, I. Yavin, PRD 81, 016002 (2010)

R. Essig, P. Schuster, N. Toro, PRD 80, 015003 (2009)

- **Scalar portal**

  $h_{(D)}$ mixing with H

  Inflaton

J.D. Clarke, R. Foot, R. Volkas, PRD 80, 015003 (2009)
F. Bezrukov, D. Gorbunov JHEP 1307 (2013) 140

Method

- Search in e+e- collisions for **L**
  - Long lived
  - Neutral
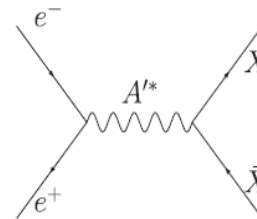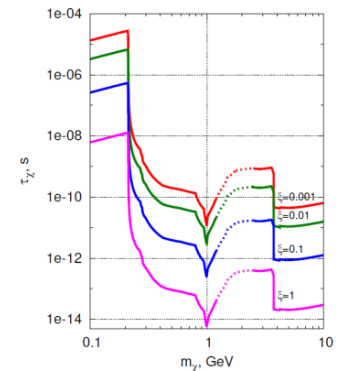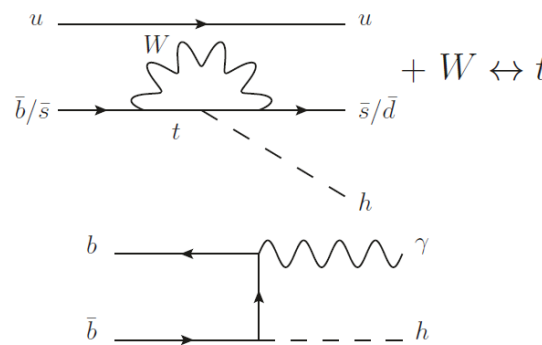 - with 2-body charged decays $\mathbf{L} \rightarrow f$, f=

    $e^+e^-,\ \mu^+\mu^-,\ e^{\pm}\mu^{\mp},\ \pi^+\pi^-,\ K^+K^-,\ \pi^{\pm}K^{\mp}$

- Presented in 2 ways
  - (MI) Model independent

  - (MD) $B \rightarrow X_s\ \mathbf{L}$

➤ Displaced vertex

➤ Peaks in V invariant mass

Upper limits vs m of

➤ $\sigma(e+e \rightarrow \mathbf{L}) \times BF(\mathbf{L} \rightarrow f) \times \varepsilon(f)$
  at or near Y(4S), at Y(2S,3S)
  giving tables of $\varepsilon(m, p_t, c\tau)$

➤ $BF(B \rightarrow X_s\ \mathbf{L}) \times BF(\mathbf{L} \rightarrow f)$

Supplement to PRL114, 171801 (2015)

Selection

- Select x⁺x⁻ pair
  - *Loose* particle identification, allowing reuse

- $d_0 > 3\,\sigma(d_0)$

- Vertex at *r* from beamspot
  - $\chi^2 < 10$
  - $1 < r < 50$ cm, $\sigma_r < 0.2$ cm
  - away from material
  - $\alpha < 0.01$ rad
  - $\sigma_m < 0.2$ GeV/c^2

- No upstream hit on tracks

- Remove Λ, K$_S$ candidates (mass)

- $\varepsilon_{max} = 52\%$ for f=$\pi\pi$ with m=2GeV/c^2, cτ=6cm and p_t>4GeV/c
- main background: random pairs of high d_0 tracks from Λ, K$_S$ and K/π decays in flight

Signal extraction

For each mode & each data sample, perform unbinned likelihood fits, scanning the mass range in 2 MeV/c² steps.

- Fit background on data assuming no peak.
- Signal PDF has the MC mass resolution shape, scaled to the measured rms.
- σ_m from 6 to 180 MeV/c² across the range.

- Significance: $S = \mathrm{sgn}(n_s)\sqrt{2Ln\dfrac{L(s+b)}{L(b)}}$

  <3 except for 2 scan points in Y(4S) sample
  - One consistent with γ conversion,
  - The other is not significant, when accounting for the *look elsewhere effect*.
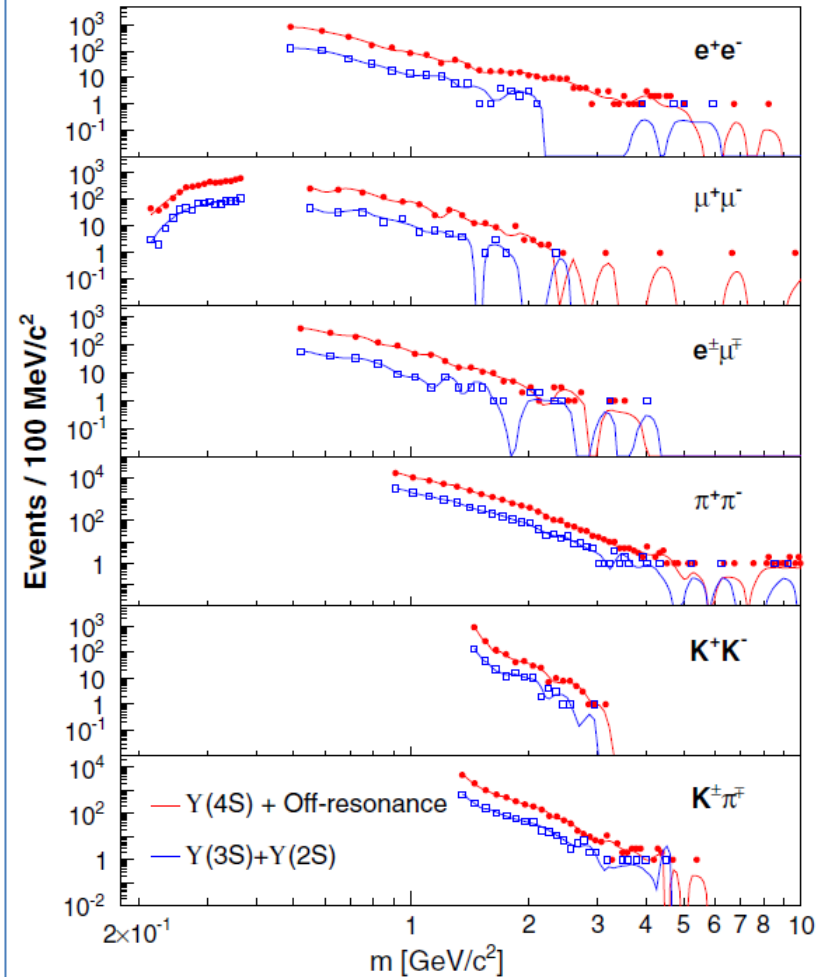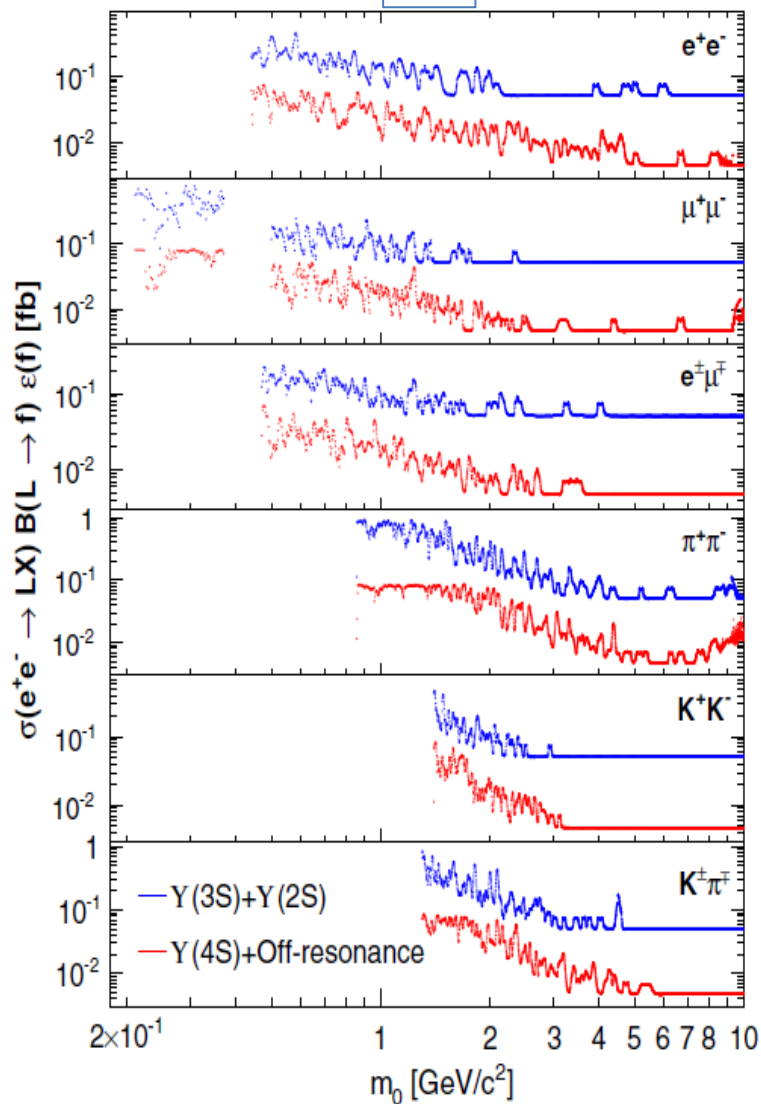
Results

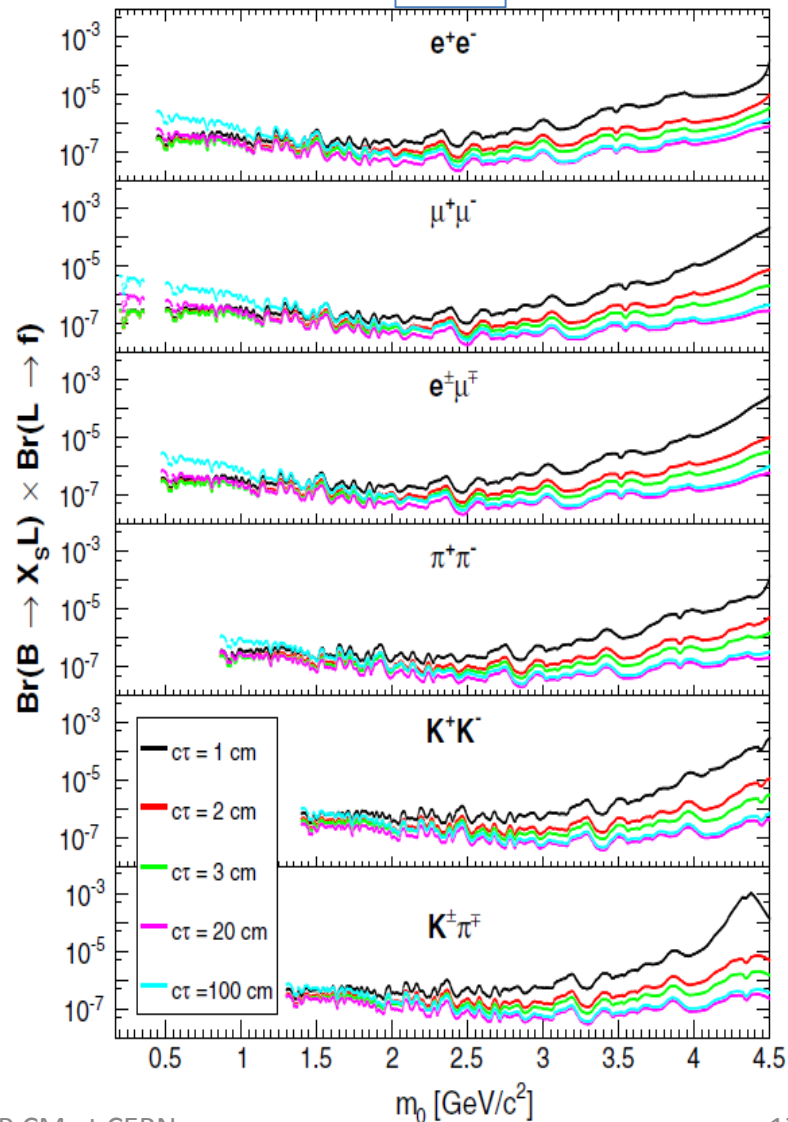90% c.l. Bayesian U.L.
including systematics
(mainly background PDF)

MI

MD

Radiative Y([1,3]S) decays to invisibles

L(2S)   = 14 fb^{-1} N(2S)   =98 $\times$ 10^6 events,

N(2S$\rightarrow\pi^+\pi^-$1S)   =18 $\times$ 10^6 events.

L(below) = 1.4 fb^{-1}.

Searches at BABAR

$\Upsilon(3S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow$ **invisible**	arXiv:0808.0017 [hep-ex]
$\Upsilon(3S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow \tau^+\tau^-$	PRL 103, 181801 (2009)
$\Upsilon(2S, 3S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow \mu^+\mu^-$	PRL 103, 081801 (2009)
$\Upsilon(2S, 3S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow$ hadrons	PRL 107, 221801 (2011)
$\Upsilon(1S) \rightarrow \gamma$ + **invisible**	PRL 107, 021804 (2011)
$\Upsilon(1S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow \mu^+\mu^-$	PRD 87, 031102 (2013)
$\Upsilon(1S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow \tau^+\tau^-$	PRD 88, 031102 (2013)
$\Upsilon(1S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow$ gg,ss	PRD 88, 031701 (2013)
$\Upsilon(1S) \rightarrow \gamma\, A^0$, $A^0 \rightarrow$ cc	PRD 91, 071102 (2015)

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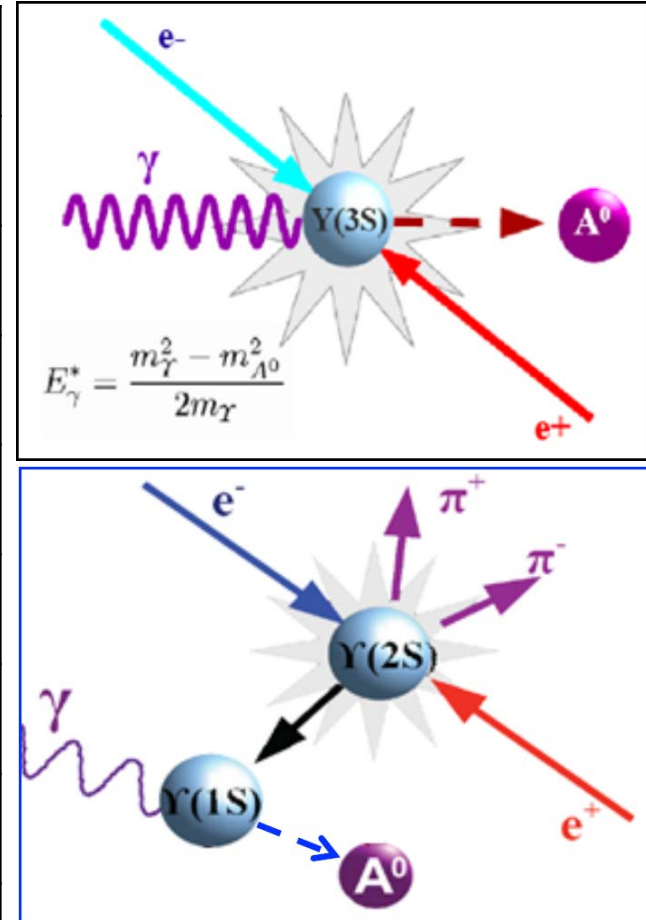
A'→ invisibles

PRL 107, 021804 (2011)

Y(1S)

90% C.L. upper limits on
$\mathcal{B}(Y(1S)\to\gamma A^0)\times\mathcal{B}$ $(A^0\to$invisible)
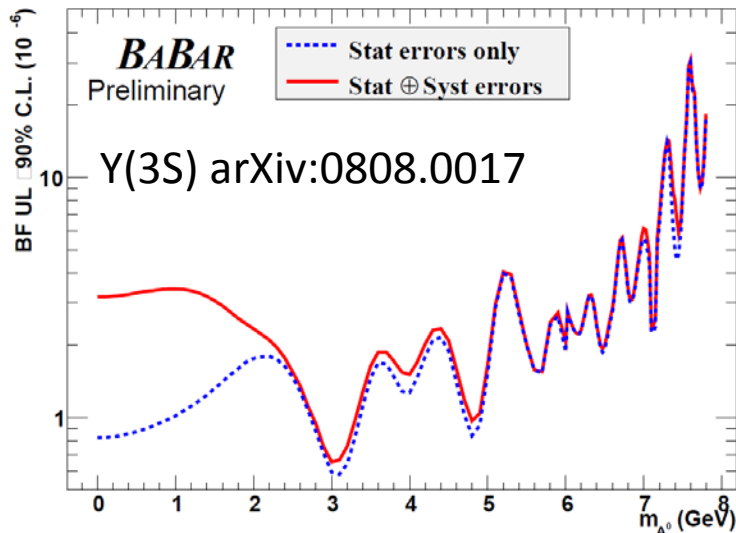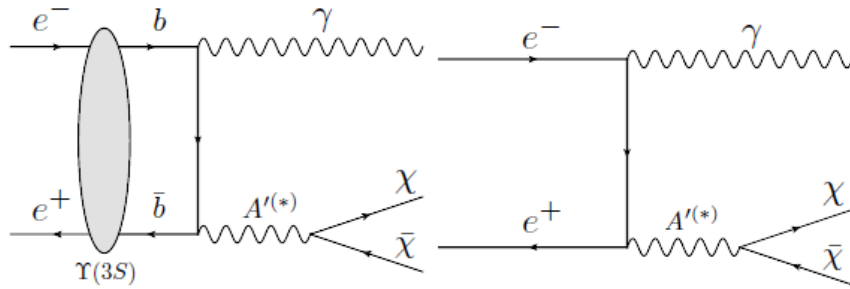
Y(3S) arXiv:0808.0017

90% C.L. upper limits on
$\mathcal{B}(Y(3S)\to\gamma A^0)\times\mathcal{B}$ $(A^0\to$invisible)
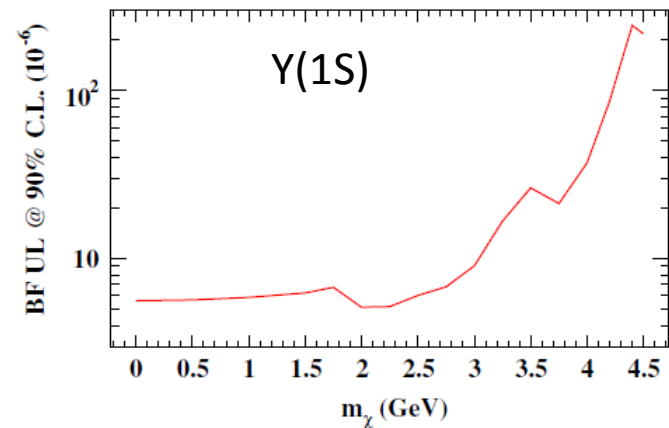
90% C.L. upper limits for $\mathcal{B}(Y(1S)\to\gamma\chi\overline{\chi})$

A'→ invisibles

- Though unpublished, BABAR Y(3S) paper arXiv:0808.0017 (2008) has 74 citations,
- e.g. a reinterpretation by theoreticians including continuum events under the 3S peak.
- This analysis is currently upgraded in BABAR.
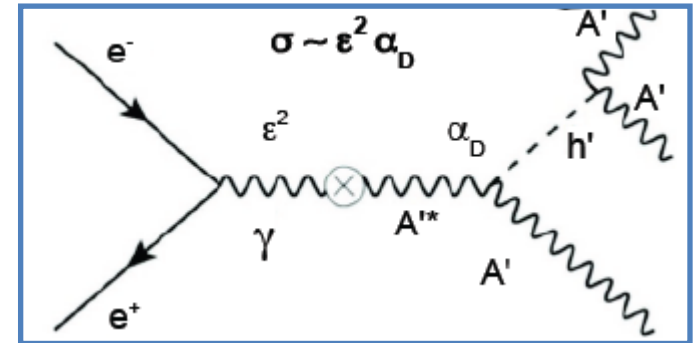- Interesting propects for Belle II.
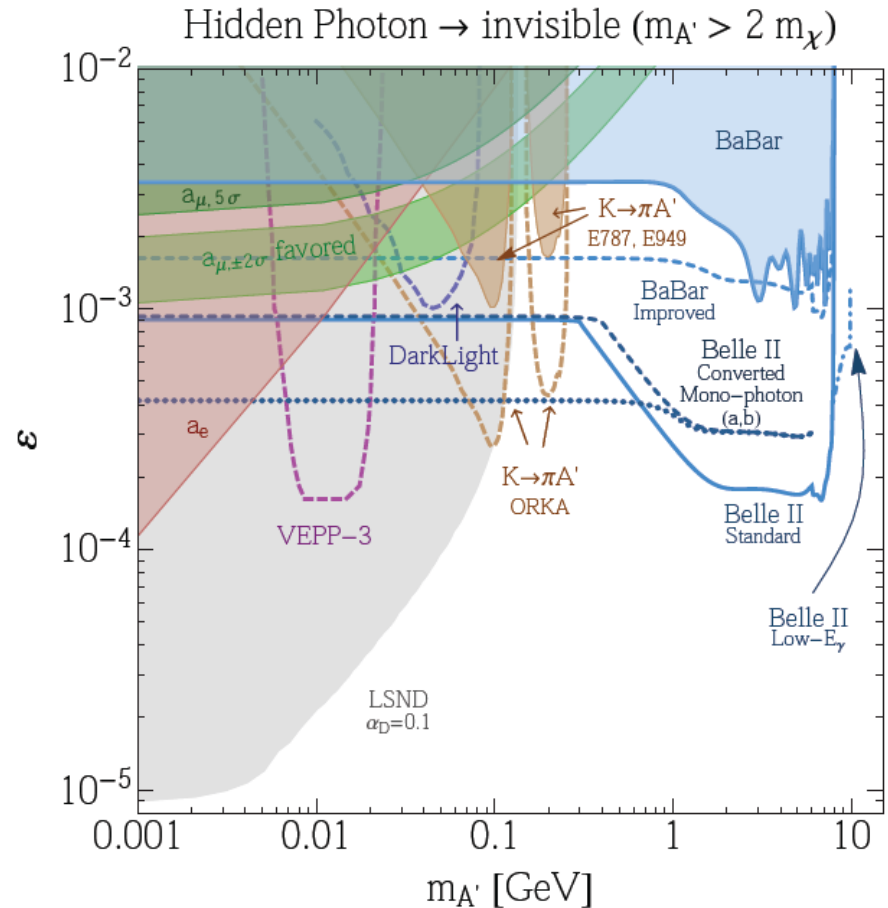
R. Essig et al., JHEP 1311 (2013) 167

Dark Higgs h'
PRL108, 211801 (2012)

- Mass generation in the dark sector
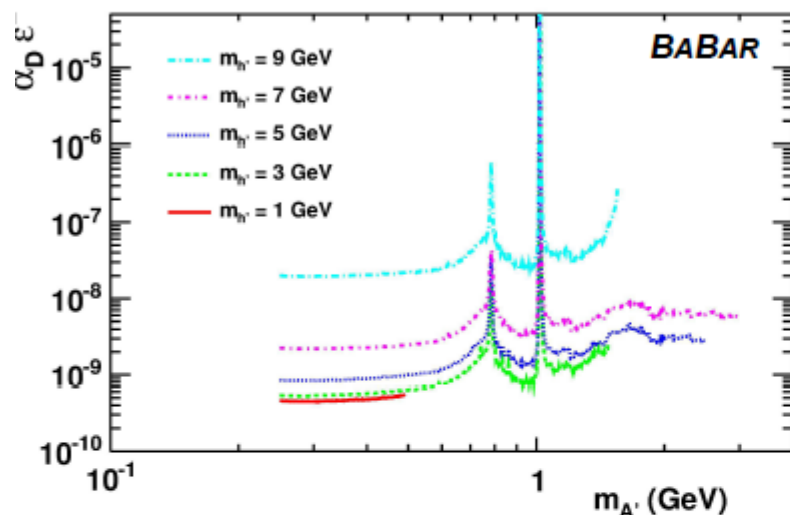- Higgs-strahlung allows a low background search in the kinematic region

  - $M_{h'} > 2\, M_{A'}$ (prompt decays)
  - $M_{h'}$ in 0.8 − 10 GeV/c2
  - $M_{A'}$ in 0.25 − 3.0 GeV/c2

- Look in full data sample (521 fb^{-1}) for 3 A' in

  3(ll), 2(ll)$\pi\pi$, ll 2($\pi\pi$), 2($\mu\mu$)X, $\mu\mu$eeX

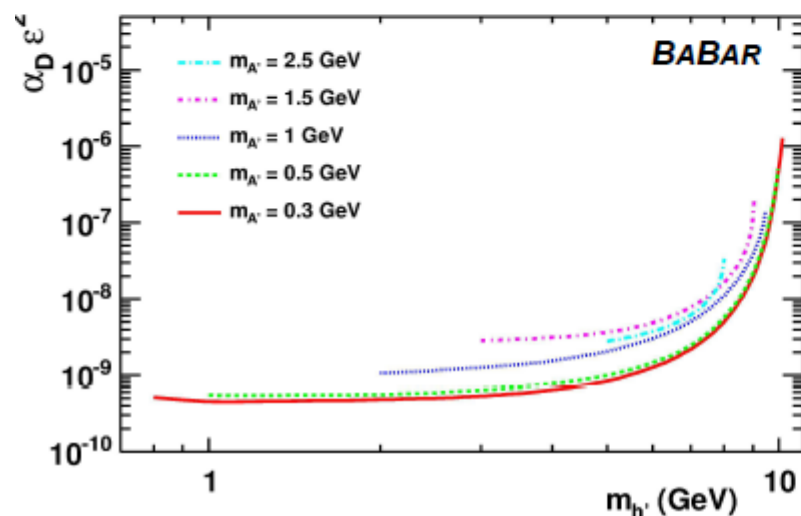- Translate 90% c.l. UL on cross sections to UL on $\varepsilon^2 \alpha_D$

Dark Higgs Limits

90% CL upper limit on $\alpha_D \epsilon^2$

Limit on $\epsilon^2 = \alpha'/\alpha$ assuming $\alpha_D = \alpha_{em} = 1/137$

BABAR

KLOE   Mainz   BaBar

a_μ

E774

E141

excluded

E137

$m_{h'} = 3$ GeV
$m_{h'} = 5$ GeV
$m_{h'} = 7$ GeV

PRL **108**, 211801 (2012)

90% CL upper limit on $\alpha_D \epsilon^2$

BABAR

$m_{A'} = 2.5$ GeV
$m_{A'} = 1.5$ GeV
$m_{A'} = 1$ GeV
$m_{A'} = 0.5$ GeV
$m_{A'} = 0.3$ GeV
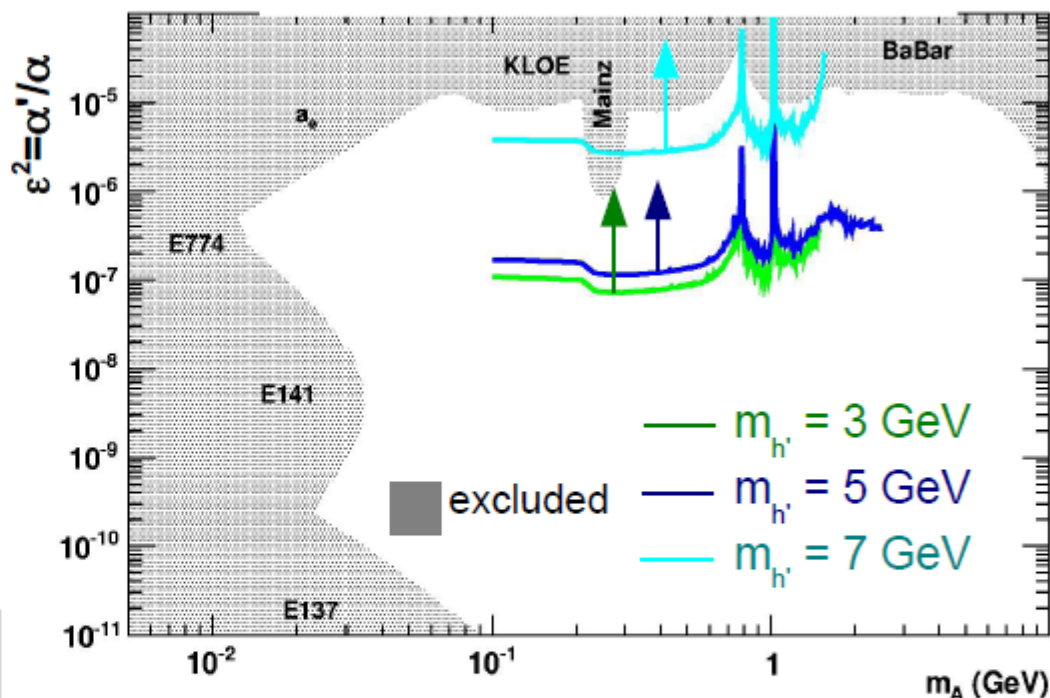
Substantial improvement over previous limits. Constrain model space

Non Abelian Dark Sector, W'

arXiv:0908.2821 [hep-ex]

- Test h-scenario with at least A', h' and **W'**.
- Search in full data sample (536 fb^{-1}) for
  4-lepton final states with 2 equal-mass
  lepton neutral pairs
  $\quad\quad$ (ee)(ee), (ee)($\mu\mu$), ($\mu\mu$)($\mu\mu$).
- Assume lepton universality.
- Upper Limits on cross sections ~ 20 – 60 ab(!)
  translate into
  $\varepsilon^2\alpha_D$ (or $\varepsilon^2\alpha_D / m^4_{A'}$) for $m_{A'}$ > (or <) Ecm.
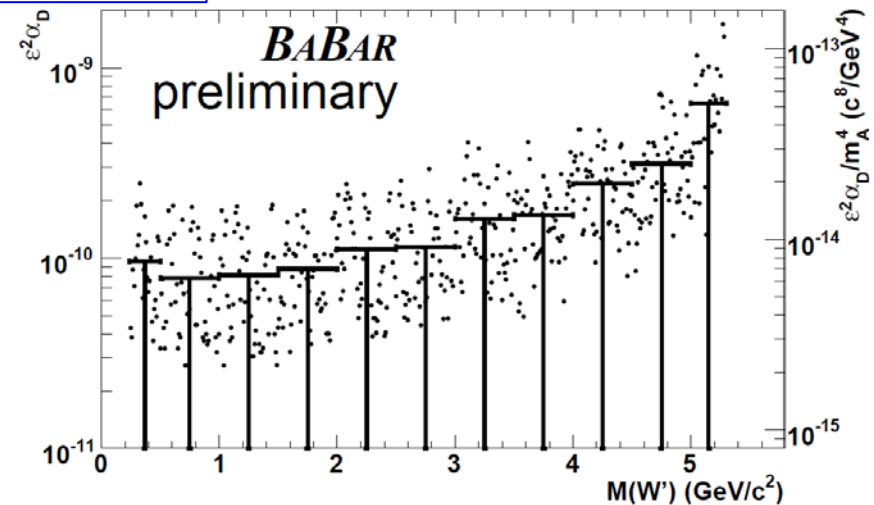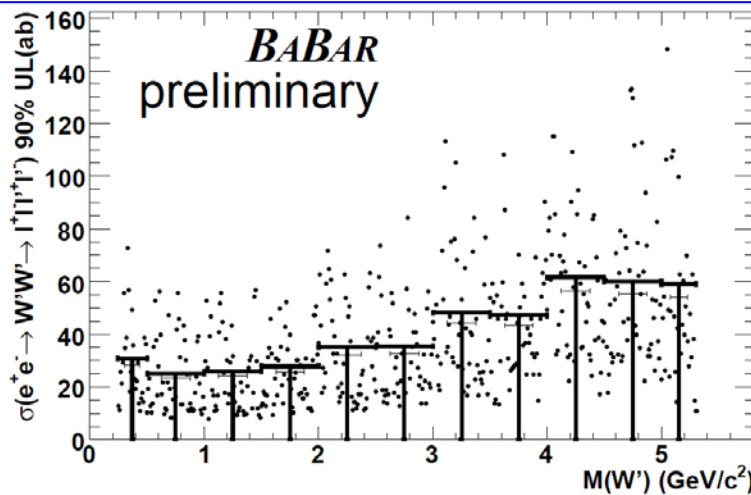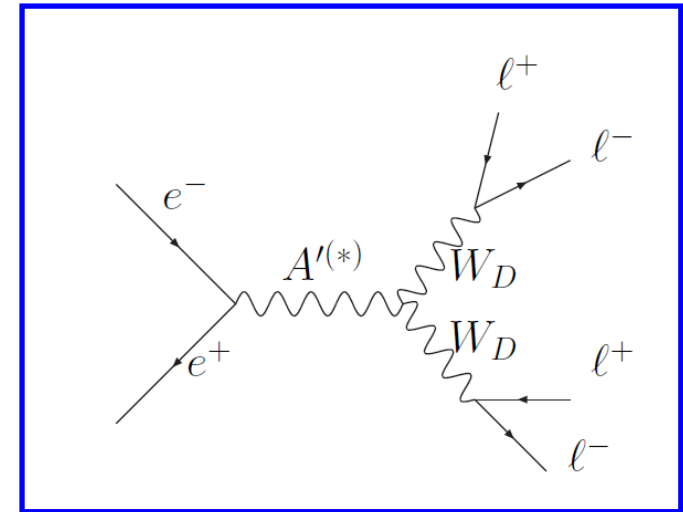
Summary and outlook

- **BABAR has made significant contributions to the emerging research on light hidden sector particles**
 - Pushing down limits on A' with ISR technique.
  - Exploring generically the production of long lived neutral particles in e^+e^- collisions and B decays.
  - *Ruling out a wide parameter space region for an NMSSM-like A^0 boson, exploring all accessible final states (most recently the*

    A^0->c$\bar{c}$ *channel)* with dark sector decays to invisible particles as spinoff.
  - Conducting h' and W' searches.
- **Further progress is expected from Intensity Frontier experiments**
  - e^+e^- machines: recently BES III, especially Belle-II.
  - Beam dump experiments: at electron (e.g. HPS) and proton (**SHiP project**).

Backup

BABAR's Scientific Productivity
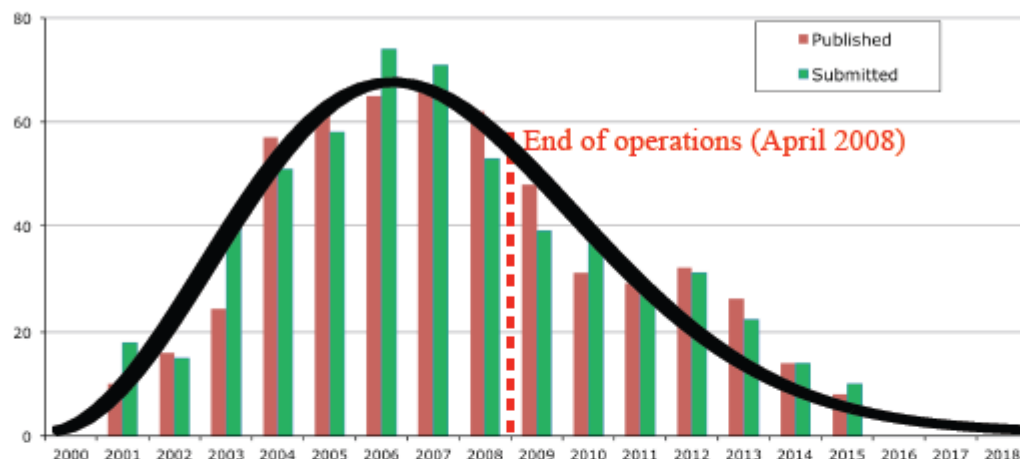
Continue harvesting scientific results from the BABAR dataset

551 papers published (as of 1-Aug-2015)

Significant number still in the pipeline

Recent highlights:

- Indirect searches for new physics (precision measurements):
  - Measurement of $\sin2\beta$ in $B^0 \to D^{(*)0}h^0$ (joint with Belle): arXiv:1505.04147, accepted to PRL
  - CPV in B mixing with dilepton events: PRL **114**, 081801 (2015), arXiv:1411.1842
  - Measurement of radiative tau decays: PRD**91**, 051103 (2015), arXiv:1502.01784
  - See also: K. Flood, "Measurement of Angular Observables in the rare decay $B \to K^* l^+ l^-$ at BABAR", Monday Session H

- Direct searches for new physics (this talk)
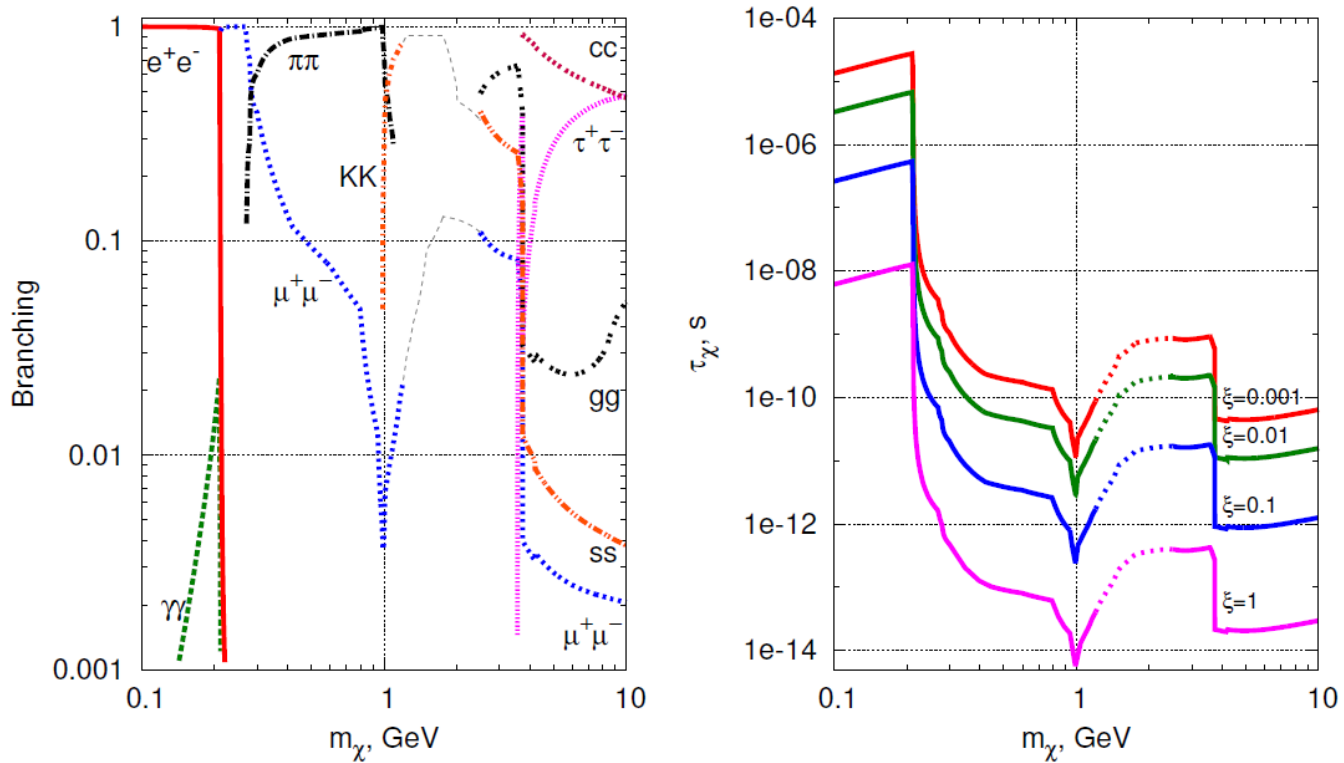
Inflaton

F. Bezrukov, D. Gorbunov JHEP 1307 (2013) 140

Figure 3: Inflaton decay branching ratios (*left plot*) and inflaton lifetime (*right plot*); theoretical predictions for $m_\chi \simeq 1 - 2\,\text{GeV}$ (thin dashed lines on the *left plot* and dotted lines on the *right plot*) suffer from significant QCD-uncertainties.

Signal PDF

- Mass uncertainty σ_m changes greatly with vertex m, r, boost

- But mass resolution function is quite stable wrt. the candidate's estimated σ_m

7 GeV

r < 1 cm
1 < r < 4 cm
4 < r < 10 cm
r > 10 cm

$(m_r - m_{true})/\sigma_m$

- So construct each event's PDF from its σ_m and the signal-MC resolution function histogram (obtained @ 12 mass points)
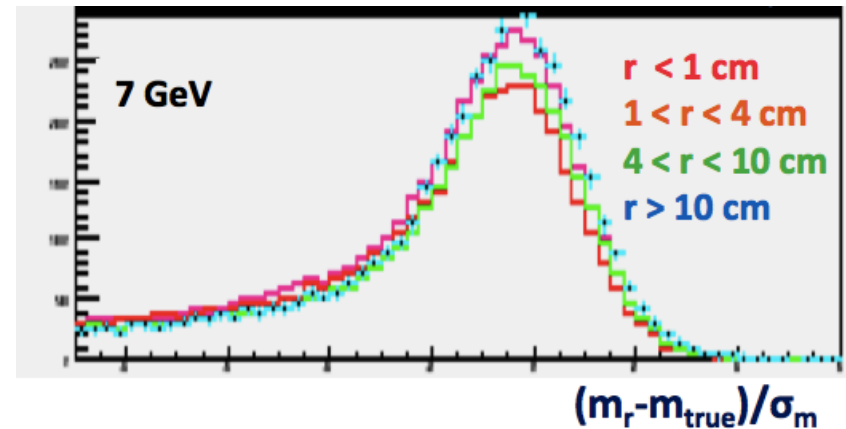
Highest-significance points

- $m_{\mu\mu} = 0.212$ GeV:
  - $S = 4.7$
  - 13 signal events
  - P-value $= 4 \times 10^{-4}$ 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 $e - \mu$ discrimination is small.
  - Look like γ conversions

- $m_{\mu\mu} = 1.24$ GeV:
  - $S = 4.2$
  - 10 signal events
  - P-value $= 8 \times 10^{-3}$ with look-elsewhere effect in $m_{\mu\mu} > 0.5$ GeV

γ conversion, $m_{ee} < 10$ MeV
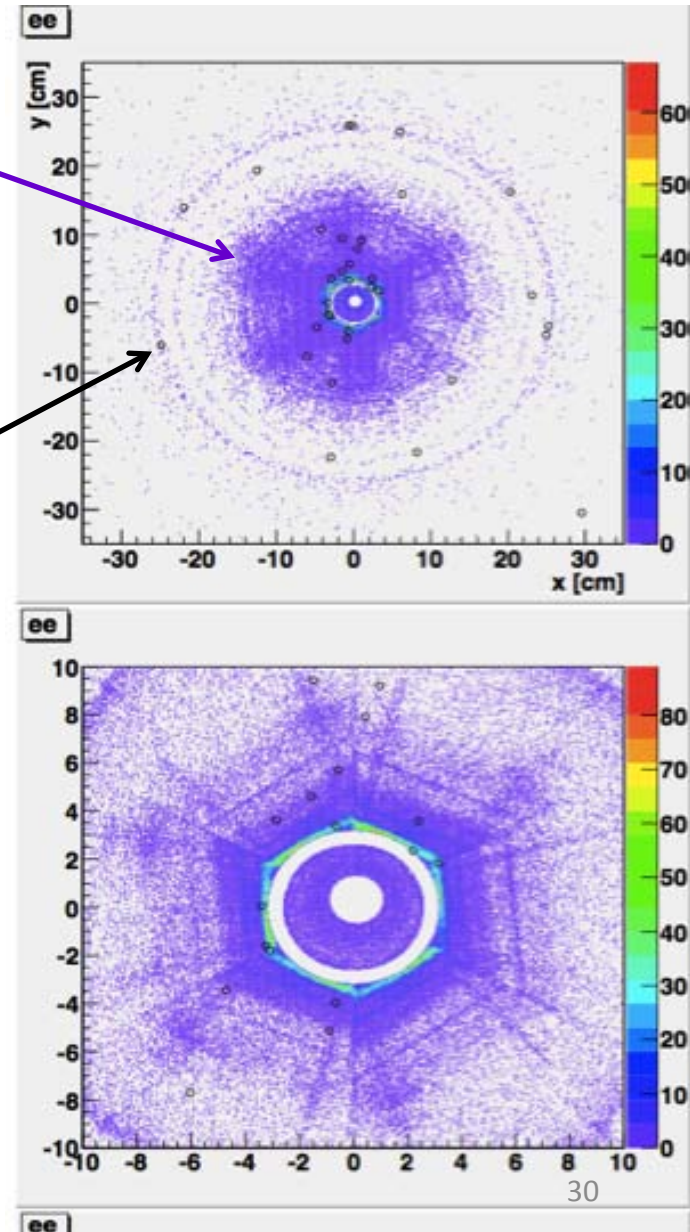
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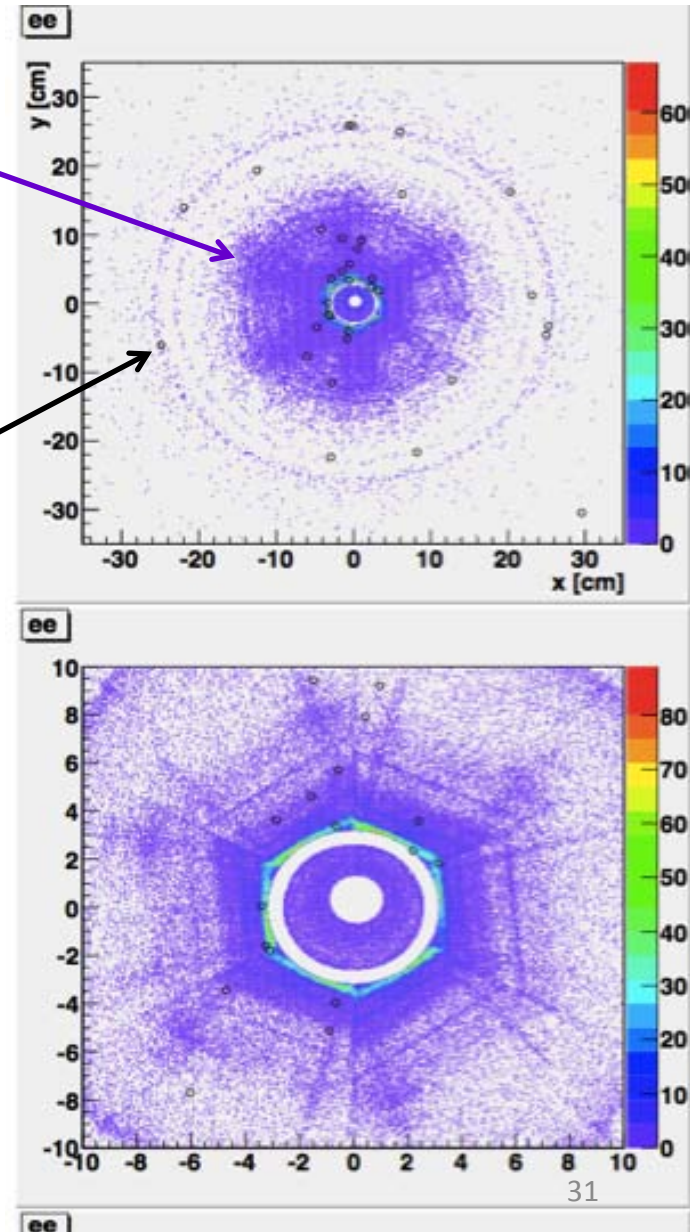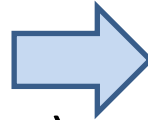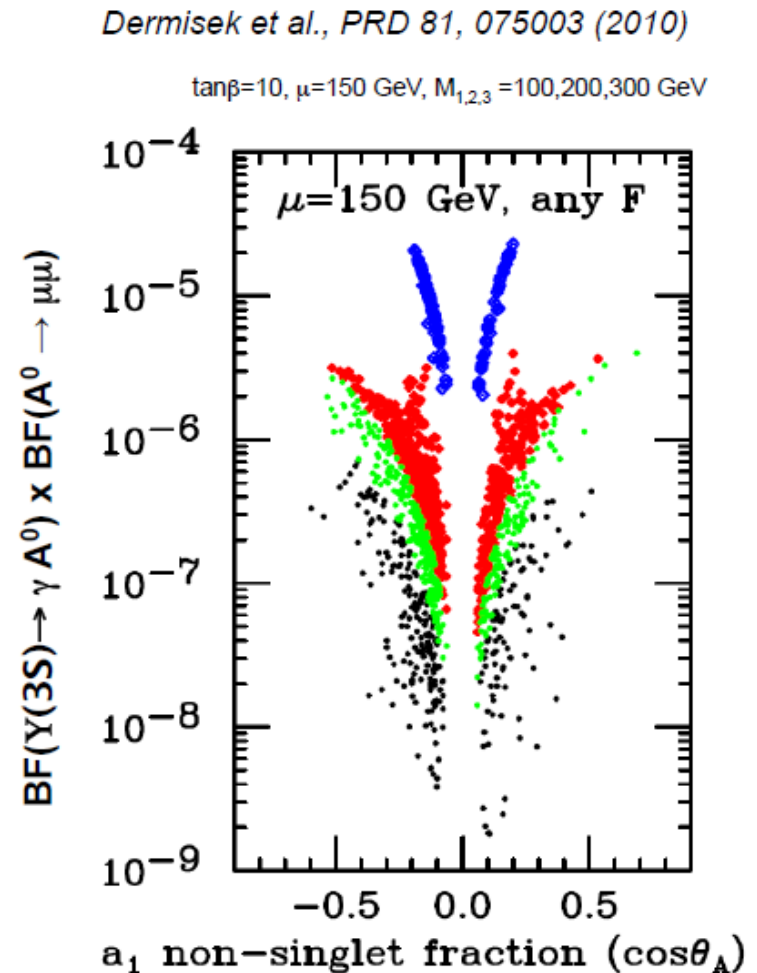
γ conversion, $m_{ee} < 10$ MeV

CP-odd Higgs in NMSSM

- $Y \rightarrow \gamma A^0$, $A^0 \rightarrow f\bar{f}$, gg

- $A^0 = \cos\theta_A A_{MSSM} + \sin\theta_A A_{singlet}$

- Predicted BF depend on
  $\cos\theta_A$, $\tan\beta$, m_{A0}
  - Scans of e.g.
    BF($Y \rightarrow A^0$) BF($A^0 \rightarrow \mu^+\mu^-$)
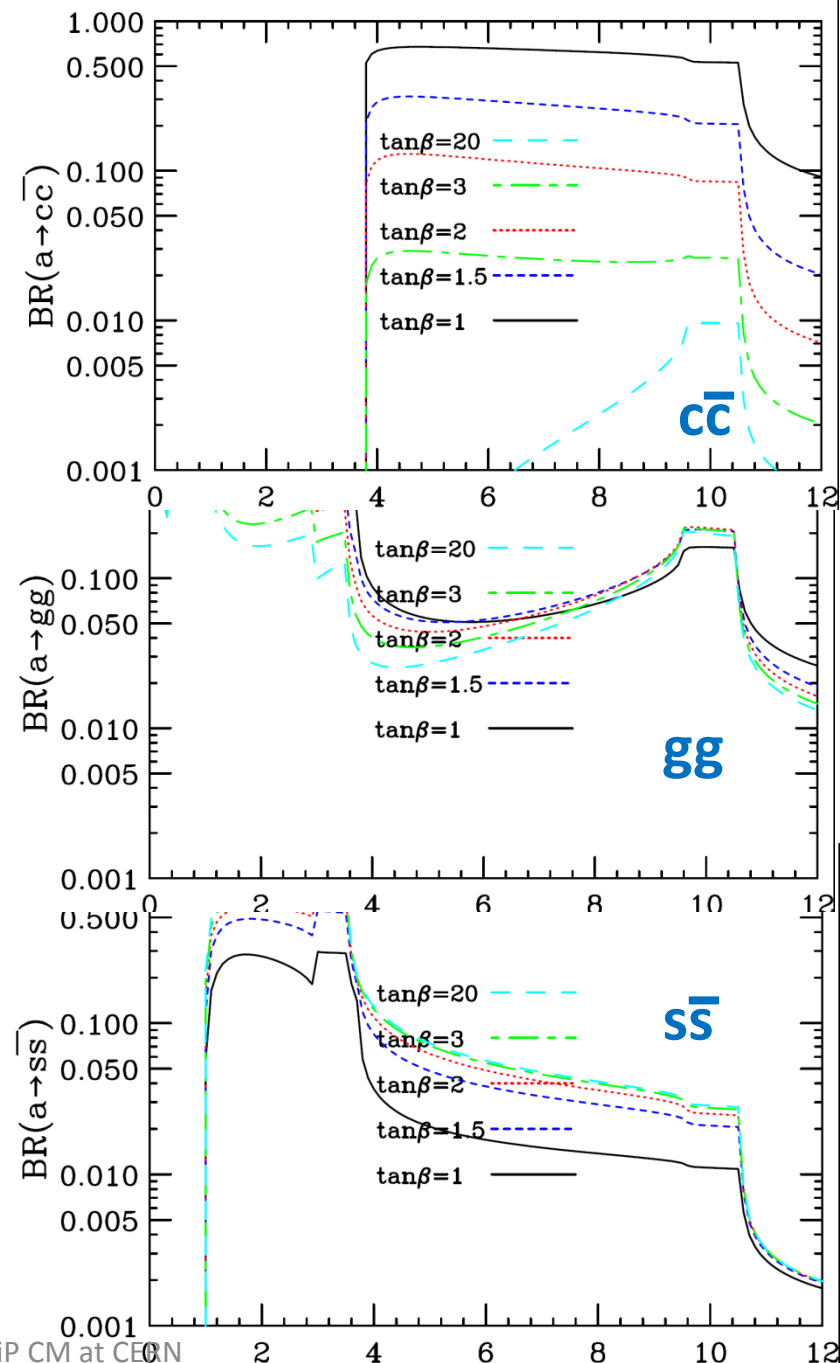
- Rate accessible to BABAR
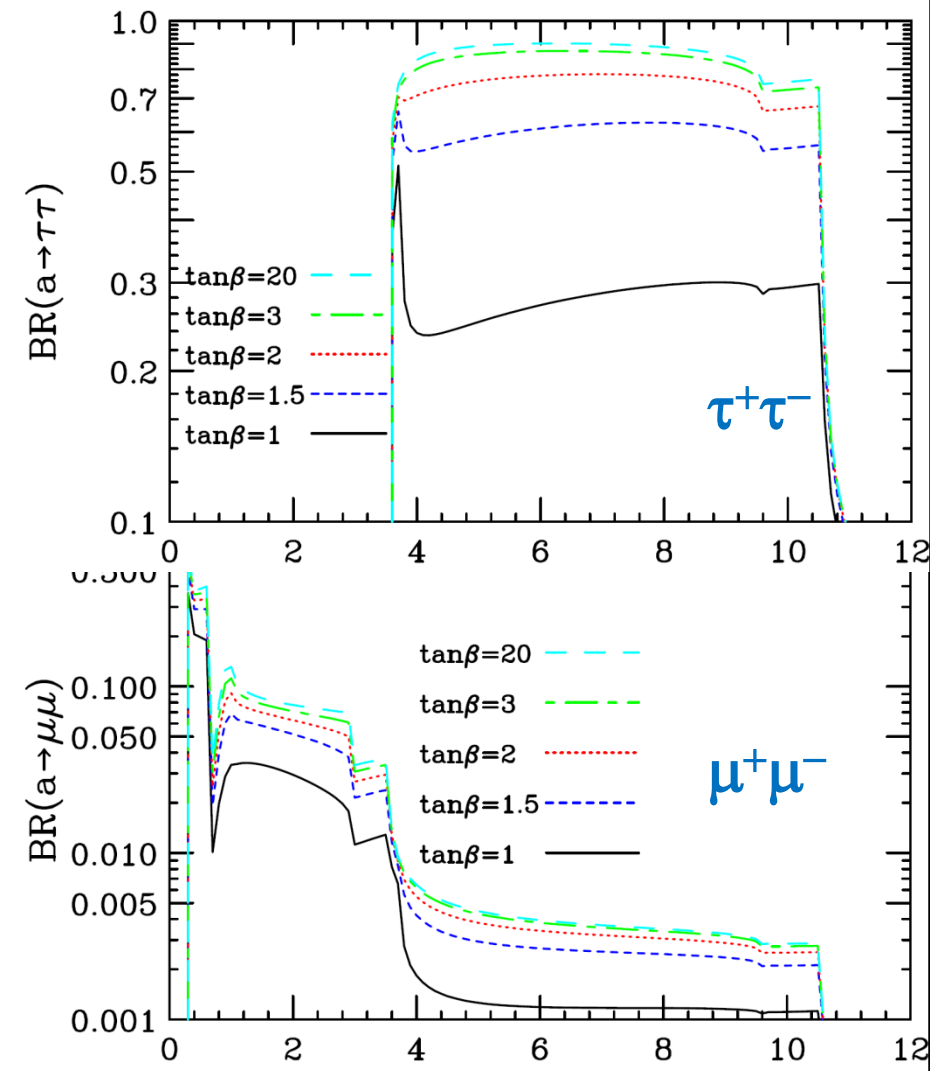
$0 < m_{A0} < 2m_\tau$
$2m_\tau < m_{A0} < 7.5$ GeV
$7.5 < m_{A0} < 8.8$ GeV
$8.8 < m_{A0} < 9.2$ GeV

Dermisek et al., PRD 81, 075003 (2010)

$\tan\beta=10$, $\mu=150$ GeV, $M_{1,2,3} =100,200,300$ GeV

$\mu=150$ GeV, any F

A⁰ branching fractions

sensitive to m_A, $\tan\beta$, fermion masses

Dermisek et al., PRD81, 075003 (2010) $\Gamma_{inv}=0$ assumed

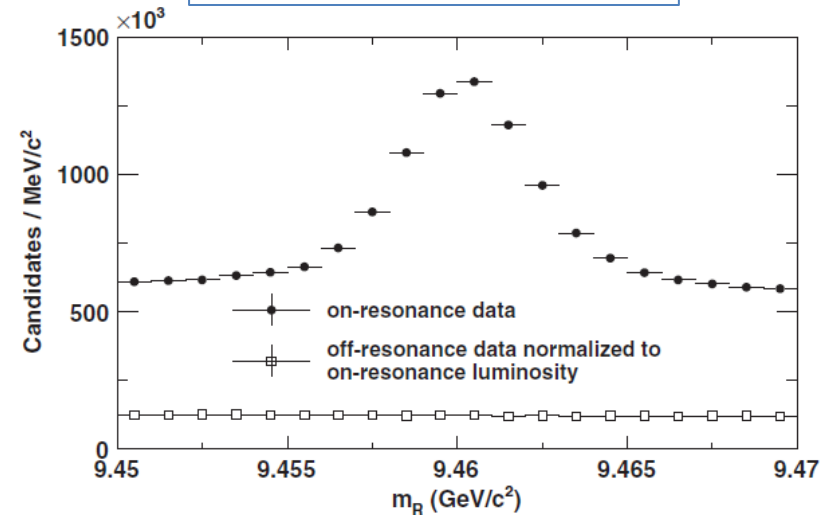# $Y(2S) \to \pi^+\pi^- Y(1S) \to \gamma A^0$, $A^0 \to c\bar{c}$

- ## Event selection

- 2 tracks (dipion), 1 photon, hadronic system (cc->D+X)

- Missing mass consistent with Y(1S)

- 5 (charm) × 2 (m) BDT to discriminate signal from background

Charm tag:
1. $D^0 \to K^- \pi^+$
2. $D^0 \to K^- \pi^+\pi^+\pi^-$
3. $D^0 \to K_S \pi^+\pi^-$

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

5. $D^{*+} \to \pi^+ D^0$,
   $D^0 \to K^- \pi^+ \pi^0$

Backgrounds:
- 1S $\to \gamma gg$
- 1S $\to$ X
- 2S $\to$ X
- qq continuum

- photon with $E_{cm} > 30$ MeV

- **Scan m_X**

$$m_X^2 = (P_{e^+e^-} - P_{\pi^+\pi^-} - P_\gamma)^2$$

➤ High mass [7.50 – 9.25] GeV/c2
➤ Low mass [4.99 – 8.00]
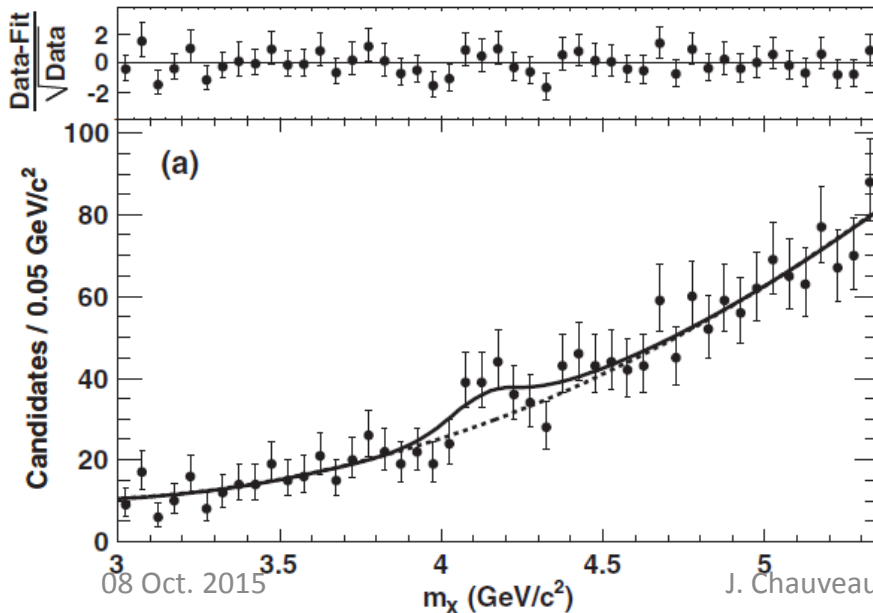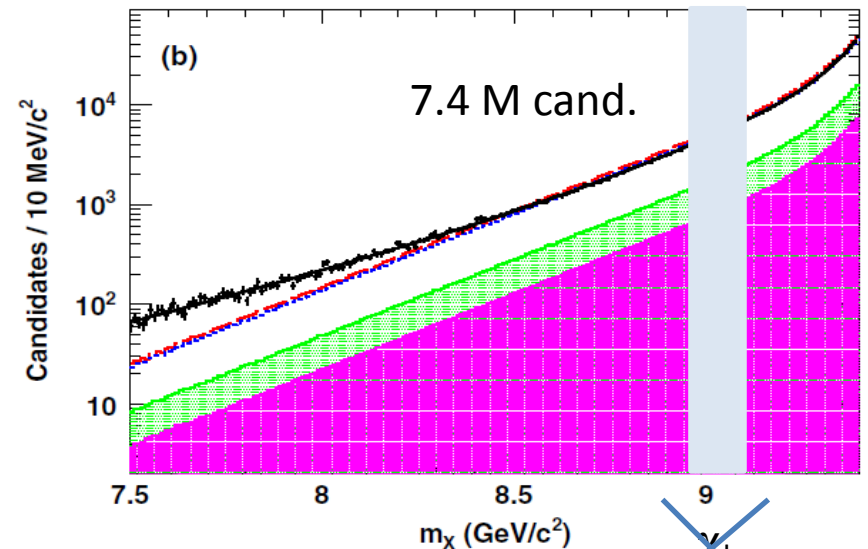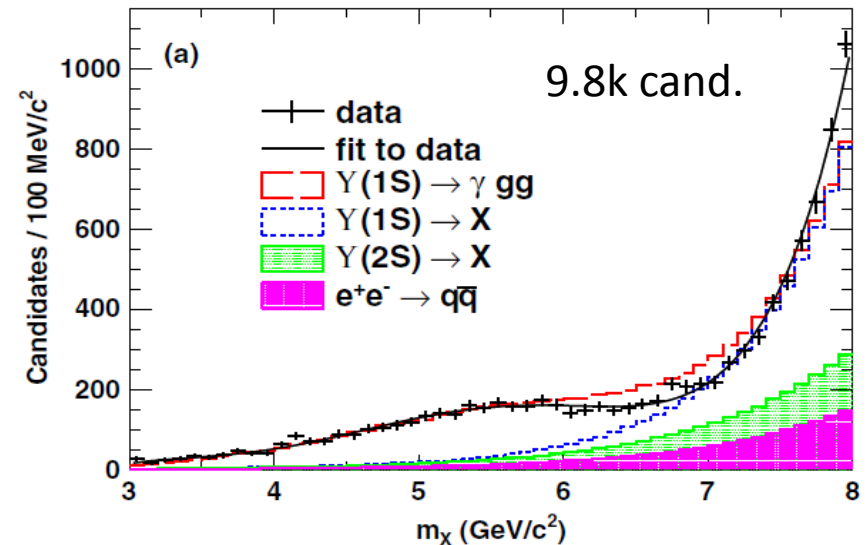- Exclude [8.95 – 9.10] to avoid
   $(2S \to \chi_b \to 1S)$ cascade

$\Upsilon(2S) \rightarrow \pi^+\pi^- \Upsilon(1S) \rightarrow \gamma A^0, A^0 \rightarrow c\bar{c}$

Measurements

- background from global fits
- efficiency from 0.04 to 0.026 with ~10% systematics ($c\bar{c}$ hadronization dominant)
- resolution from 120 MeV to 8 MeV
- Local fits in ± 10 resolution ranges
- steps < 0.3 resolution
  - signal PDF with fixed local parameters
  - background PDF 2nd order polynomial

9.8k cand.

7.4 M cand.

$Y(2S) \rightarrow \pi^+\pi^- \, Y(1S) \rightarrow \gamma \, A^0, \, A^0 \rightarrow c\bar{c}$

Biggest peaks are not significant . Derive 90% Upper Limits on BF($Y(1S) \rightarrow \gamma \, A^0$) $\times$ BF($A^0 \rightarrow c\bar{c}$)
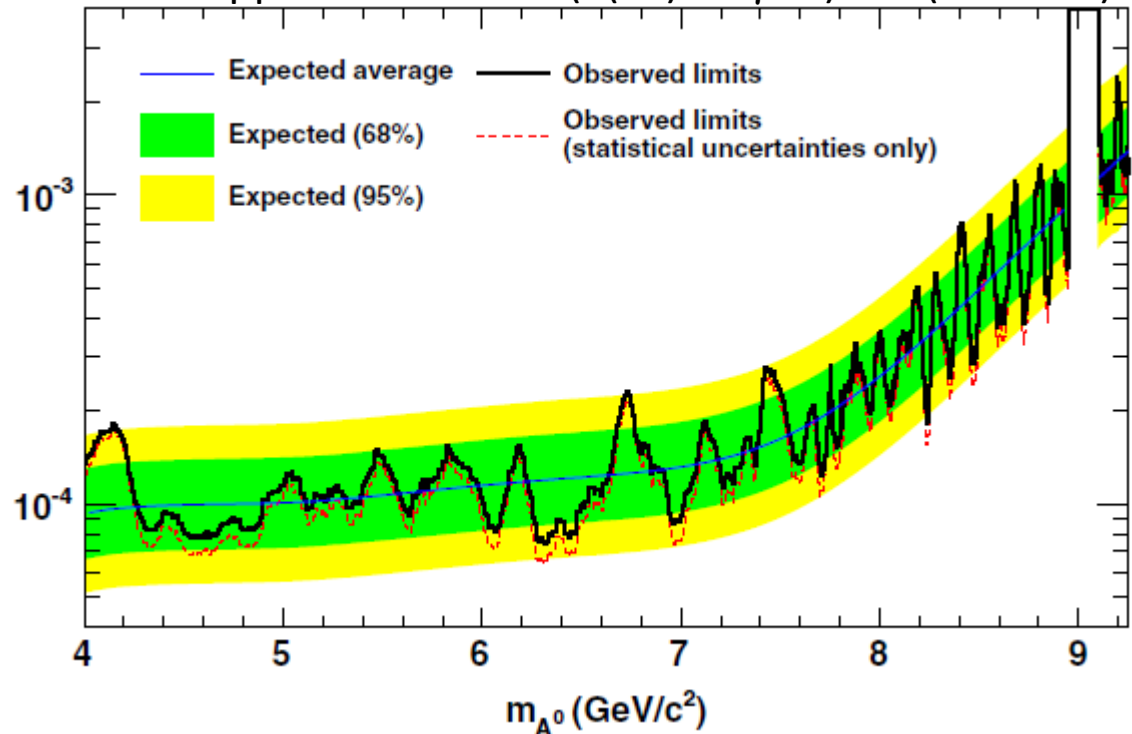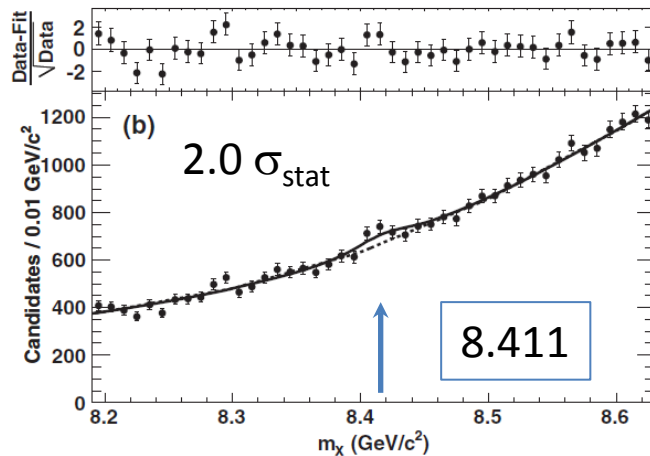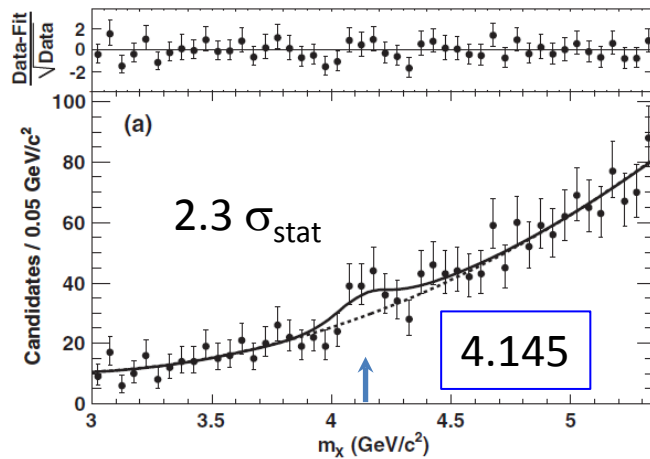
$$\text{BF}(Y(1S) \rightarrow \gamma \, A^0) \times \text{BF}(A^0 \rightarrow c\bar{c}) < [7.4 \times 10^{-5} - 2.4 \times 10^{-3}]$$
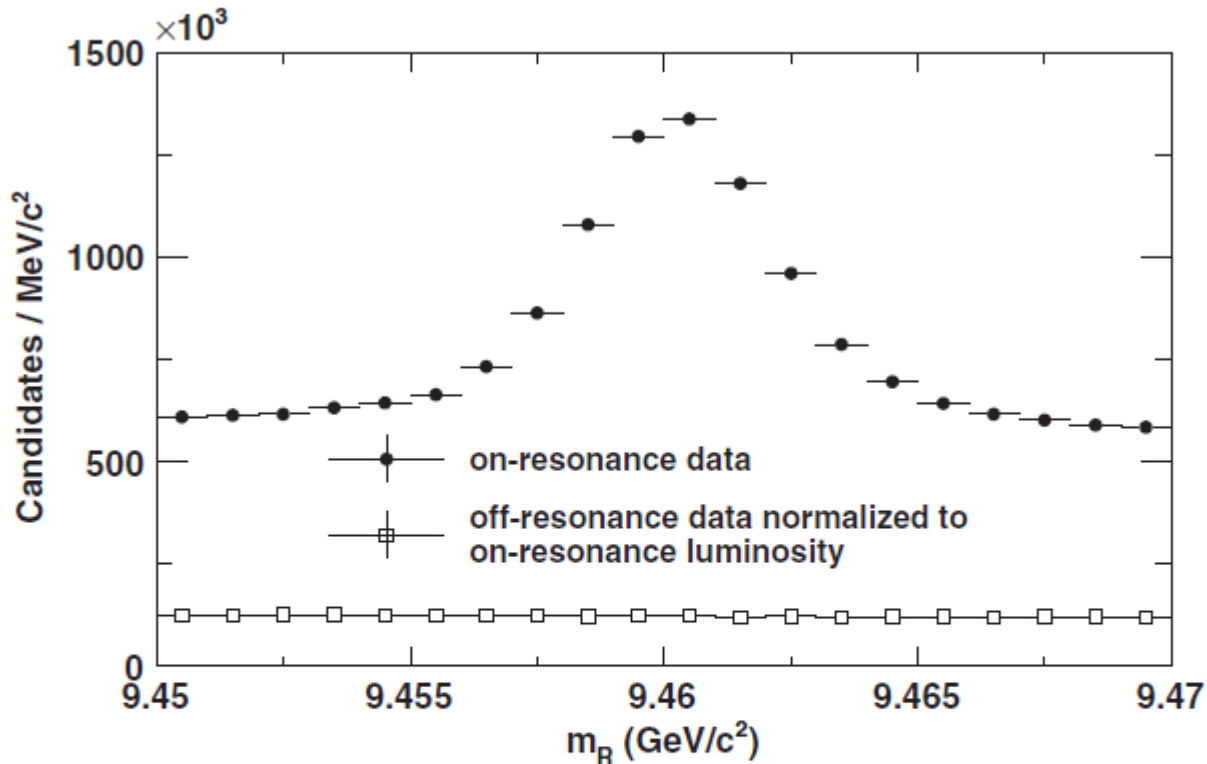$$\text{at 90\% c.l.}$$

FIG. 1. The m_R distribution of events with a dipion, charm, and photon tag before application of selection criteria based on the BDT output (see text). The solid circles indicate the on-resonance data. The open squares indicate the off-resonance data normalized to the on-resonance luminosity.

Y(2S)→ $\pi^+\pi^-$ Y(1S) → γ A^0, A^0 → ss, gg

Event selection

- 2 tracks (dipion), 1 photon, hadronic system (not 2-body, gg and/or ss)
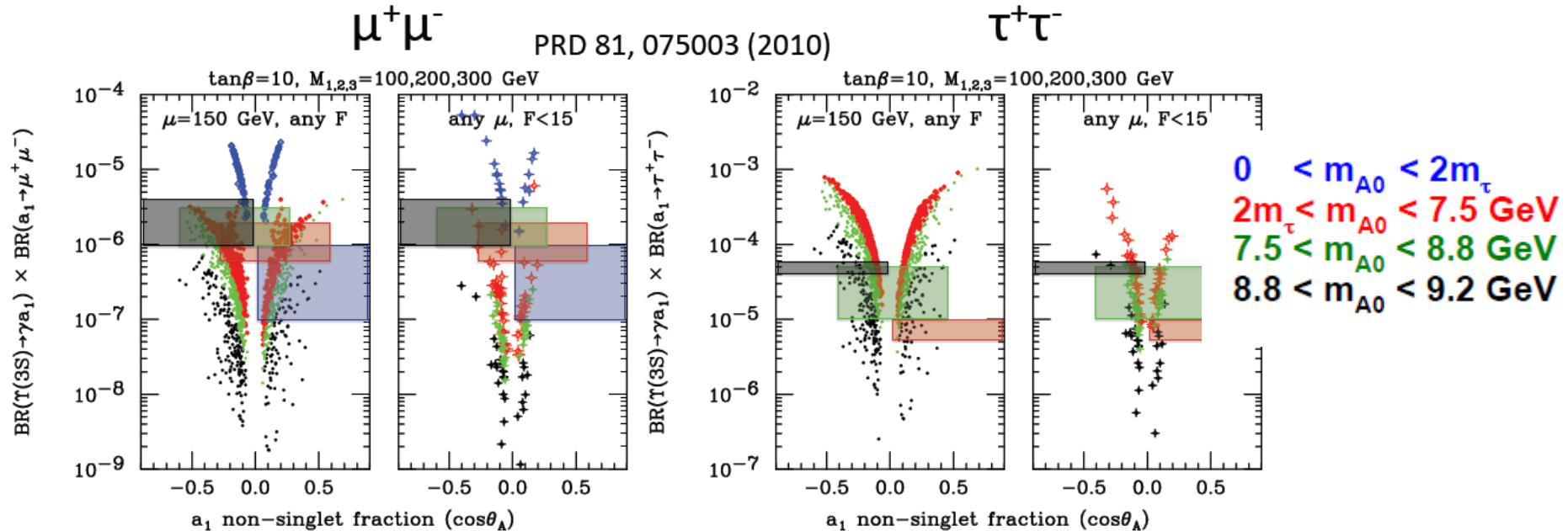- Missing mass consistent with Y(1S)
- MLP against Y hadronic background

TABLE I. Decay modes for candidate $A^0 \rightarrow gg$ and $s\bar{s}$ decays, sorted by the total mass of the decay products.

Number	Channel	Number	Channel
1	$\pi^+\pi^-\pi^0$	14	$K^+K^-\pi^+\pi^-$
2	$\pi^+\pi^-2\pi^0$	15	$K^+K^-\pi^+\pi^-\pi^0$
3	$2\pi^+2\pi^-$	16	$K^\pm K^0_S\pi^\mp\pi^+\pi^-$
4	$2\pi^+2\pi^-\pi^0$	17	$K^+K^-\eta$
5	$\pi^+\pi^-\eta$	18	$K^+K^-2\pi^+2\pi^-$
6	$2\pi^+2\pi^-2\pi^0$	19	$K^\pm K^0_S\pi^\mp\pi^+\pi^-2\pi^0$
7	$3\pi^+3\pi^-$	20	$K^+K^-2\pi^+2\pi^-\pi^0$
8	$2\pi^+2\pi^-\eta$	21	$K^+K^-2\pi^+2\pi^-2\pi^0$
9	$3\pi^+3\pi^-2\pi^0$	22	$K^\pm K^0_S\pi^\mp2\pi^+2\pi^-\pi^0$
10	$4\pi^+4\pi^-$	23	$K^+K^-3\pi^+3\pi^-$
11	$K^+K^-\pi^0$	24	$2K^+2K^-$
12	$K^\pm K^0_S\pi^\mp$	25	$p\bar{p}\pi^0$
13	$K^+K^-2\pi^0$	26	$p\bar{p}\pi^+\pi^-$
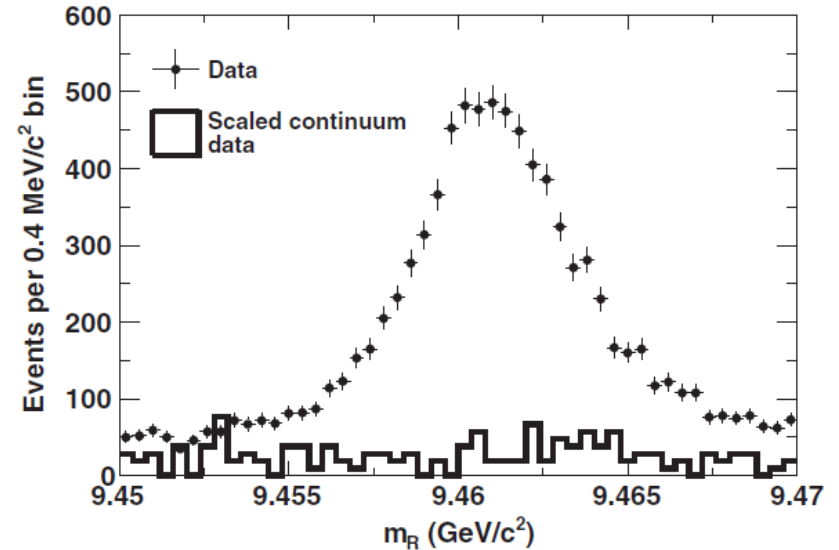
- photon with $E_{cm}>200$ MeV
- Fit constraining A^0 and γ candidates to Y(1S) mass and beam spot. Hence $\sigma(m_A)\sim100$MeV/c².
- π^0 vetos
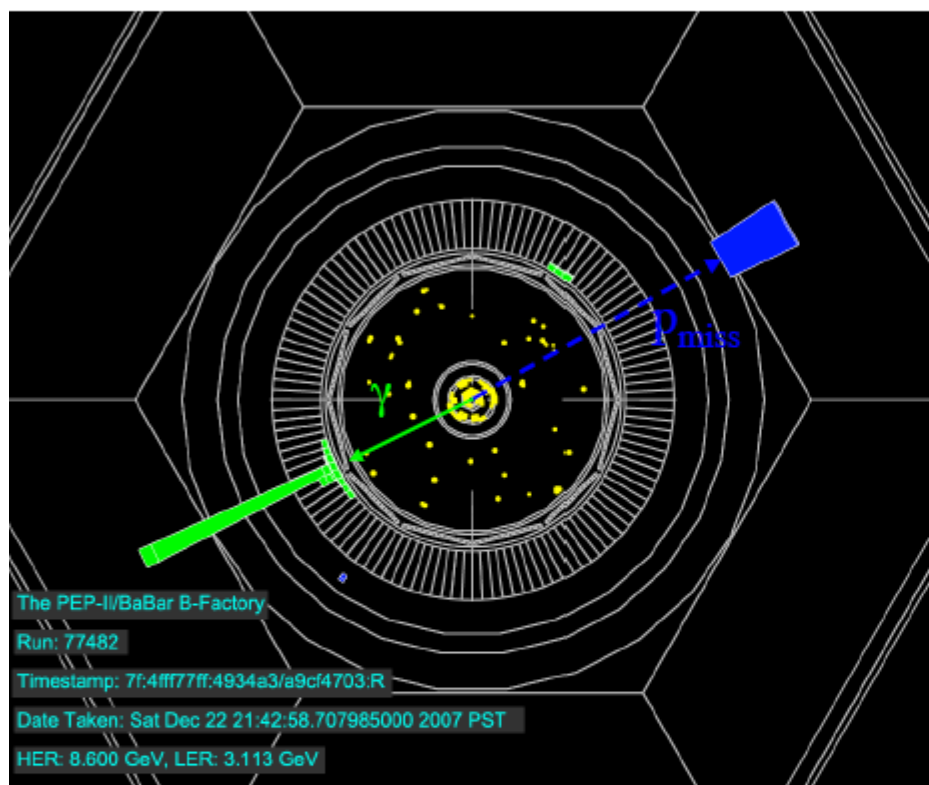
CP-odd Higgs (older results)

$\mu^+\mu^-$ PRD 81, 075003 (2010) $\tau^+\tau^-$

$0 < m_{A0} < 2m_\tau$
$2m_\tau < m_{A0} < 7.5$ GeV
$7.5 < m_{A0} < 8.8$ GeV
$8.8 < m_{A0} < 9.2$ GeV

Mode	Mass range (GeV)	BF upper limit (90% CL)
$\Upsilon(2S,3S) \to \gamma A^0, A^0 \to \mu^+\mu^-$	$0.21 < m_A < 9.3$	$(0.3 - 8.3) \times 10^{-6}$
$\Upsilon(3S) \to \gamma A^0, A^0 \to \tau^+\tau^-$	$4.0 < m_A < 10.1$	$(1.5 - 16) \times 10^{-5}$
$\Upsilon(2S,3S) \to \gamma A^0, A^0 \to$ hadrons	$0.3 < m_A < 7.0$	$(0.1 - 8) \times 10^{-5}$
$\Upsilon(1S) \to \gamma A^0, A^0 \to \chi\bar{\chi}$	$m_\chi < 4.5$ GeV	$(0.5 - 24) \times 10^{-5}$
$\Upsilon(1S) \to \gamma A^0, A^0 \to$ invisible	$m_A < 9.2$ GeV	$(1.9 - 37) \times 10^{-6}$
$\Upsilon(3S) \to \gamma A^0, A^0 \to$ invisible	$m_A < 9.2$ GeV	$(0.7 - 31) \times 10^{-6}$

arXiv: 1209.1143 (B. Echenard)

Invisible Dark Photon: $e^+e^- \rightarrow \gamma + \text{invisible}$

The PEP-II/BaBar B-Factory
Run: 77482
Timestamp: 7f:4fff77ff:4934a3/a9cf4703:R
Date Taken: Sat Dec 22 21:42:58.707985000 2007 PST
HER: 8.600 GeV, LER: 3.113 GeV

Peaking background from $e^+e^- \rightarrow \gamma\gamma$, with one of the photons missing the EM calorimeter. Veto such events by detecting activity in the muon detector (IFR).

- $\Upsilon(3S) \rightarrow \gamma + \text{invisible}$ (arXiv:0808.0017)

- Require a single photon with $E^*_\gamma > 2.2$ GeV

- No charged tracks

- No additional energy in EMC above 100 MeV

- Missing momentum points to EMC

- No activity in IFR aligning with missing momentum

- No signal found: limits on ε of order $O(10^{-3}\text{-}10^{-2})$

- Updated analysis in progress

Invisible Dark Photon: $e^+e^- \rightarrow \gamma + $invisible

Hidden Photon → invisible ($m_{A'} > 2\, m_\chi$)
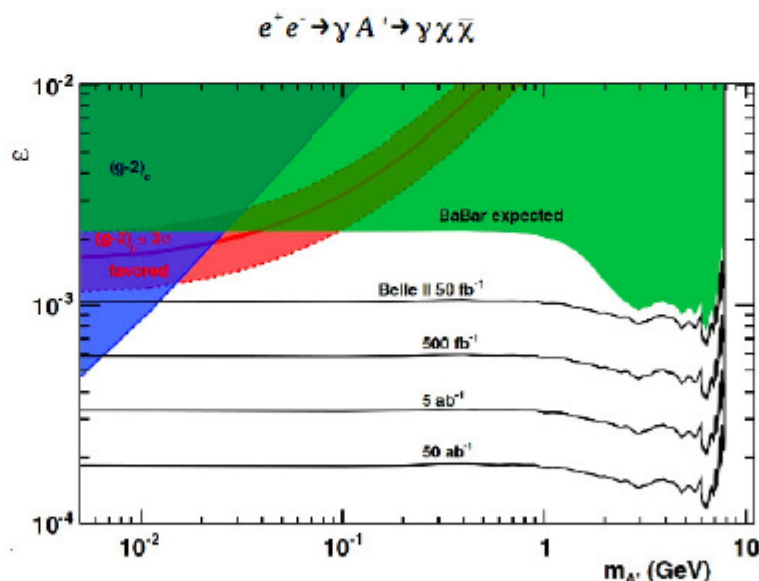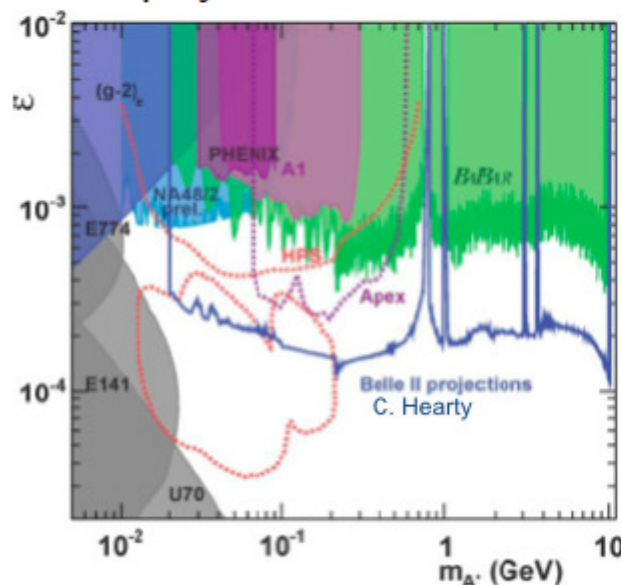
Essig *et al.*, arXiv:1309.5084

Outlook
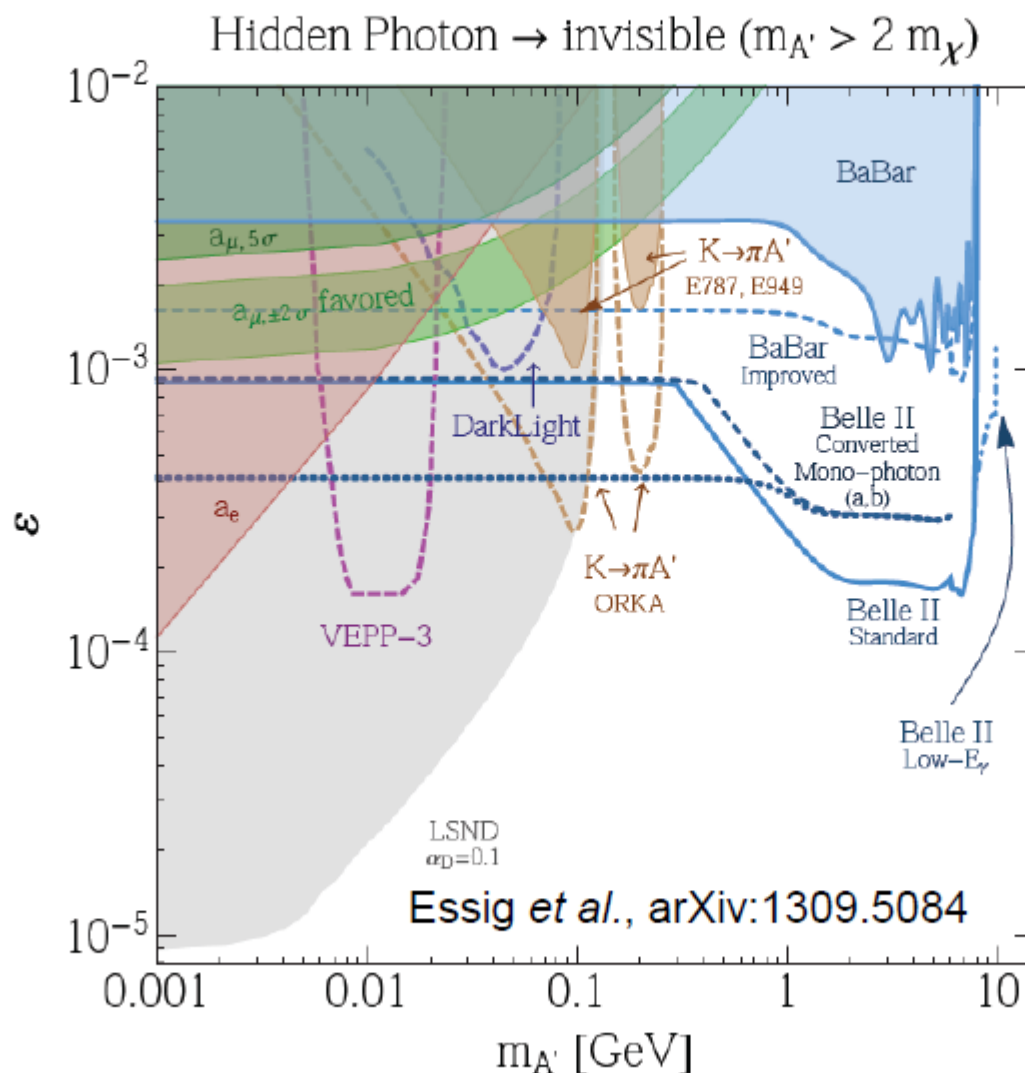
Belle2 at SuperKEKb will take 40x more statistics
Shut down for upgrade 2010.
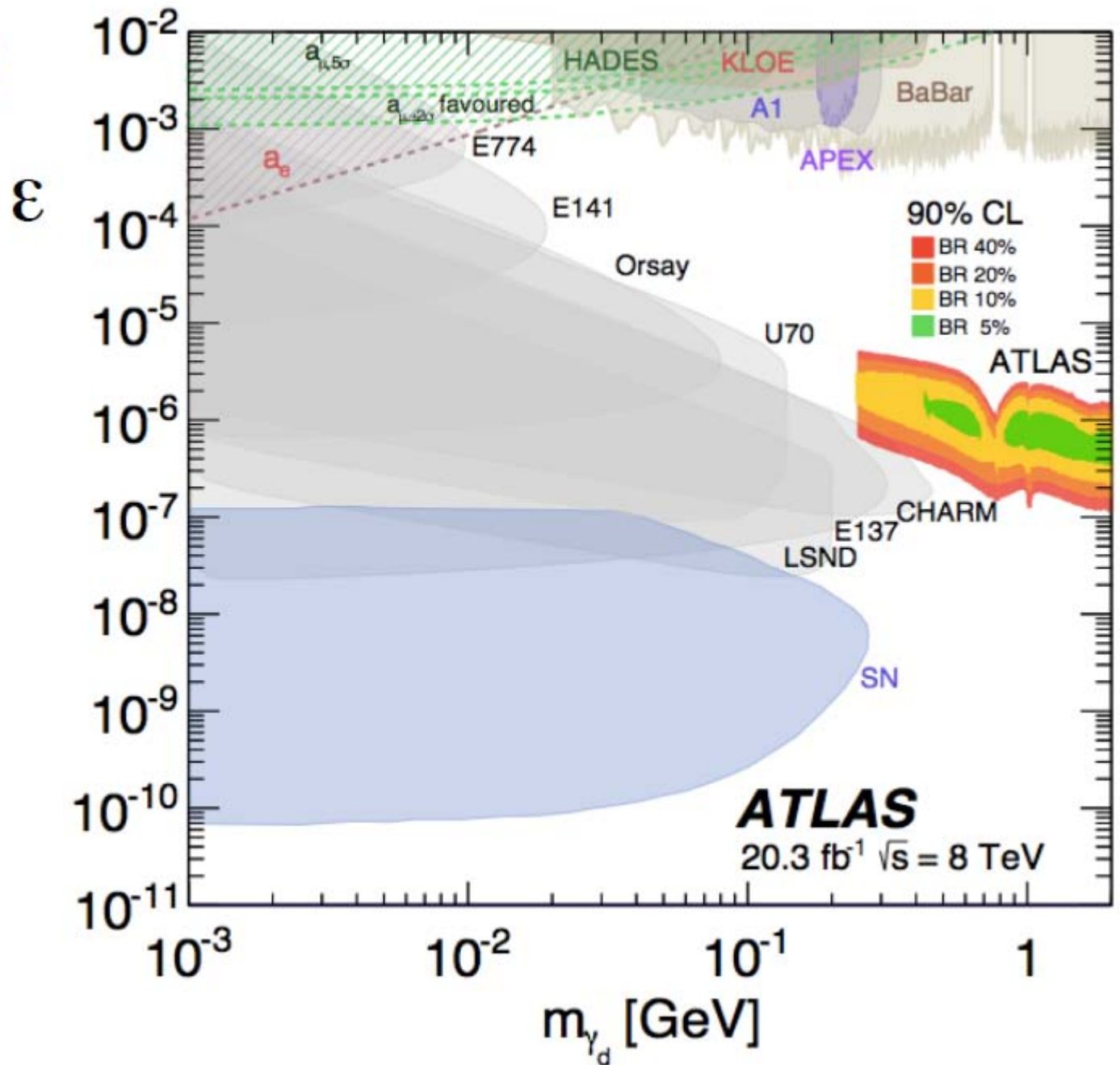Belle-II due to roll in mid 2015, followed by commissioning.
First physics data due 2017.

$e^+e^- \to \gamma A' \to \gamma \chi \bar{\chi}$

DM searches, including Higgsstrahlung analysis, will continue

08 Oct. 2015
Roger Barlow (Huddersfield University)
J. Chauveau 6th SHiP CM at CERN
B-factory searches
16th December 2014
42
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ε Limits

A. Soffer
At FPCP2015

Dark Sector

- Gauge boson of new U(1)' the A', with MeV-GeV mass

  P. Fayet PLB 95, 285(1980)

- Kinetic mixing with γ, A' couples to electric charge with strength εe

- A' couples to **dark sector particles** with α_D

- *Unexplained cosmic ray observations*

- *Impacts g-2 puzzle*

- Dark higgs h' expected ...

Recent review with references: R. Essig et al. arXiv: 1311.0029 [hep-ph]

Search for Dark Higgs

- Extension of the dark sector models: dark Higgs

  ❑ Mass generation in dark sector

  ❑ Mass can be low

  ❑ Detect by Higgs-strahlung process $e^+e^- \rightarrow A'h'$

  ❑ Decays to A' pairs

  ☞ Multi-particle (multi-lepton) final state
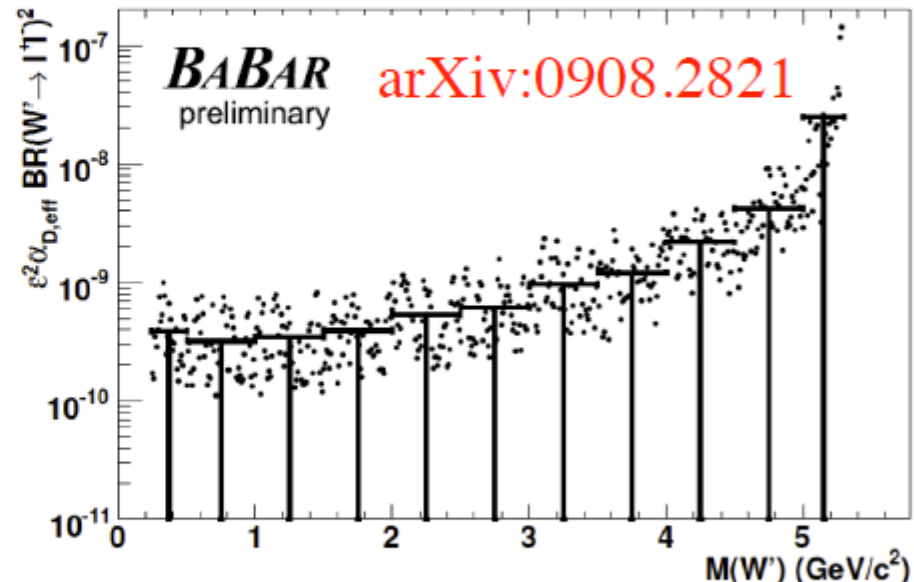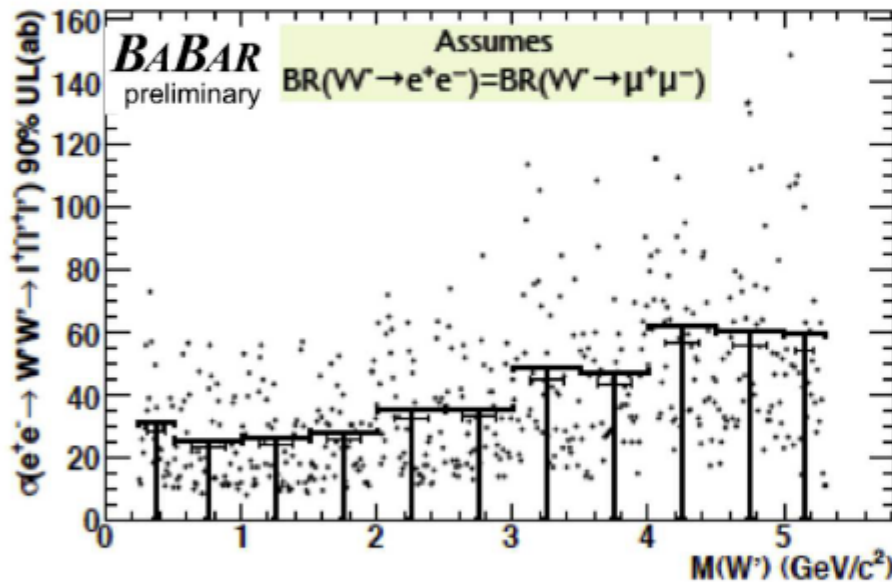
  ☞ Clean detection, virtually no QED background

$$\sigma \sim \varepsilon^2 \alpha_D$$

Higgs decay topology
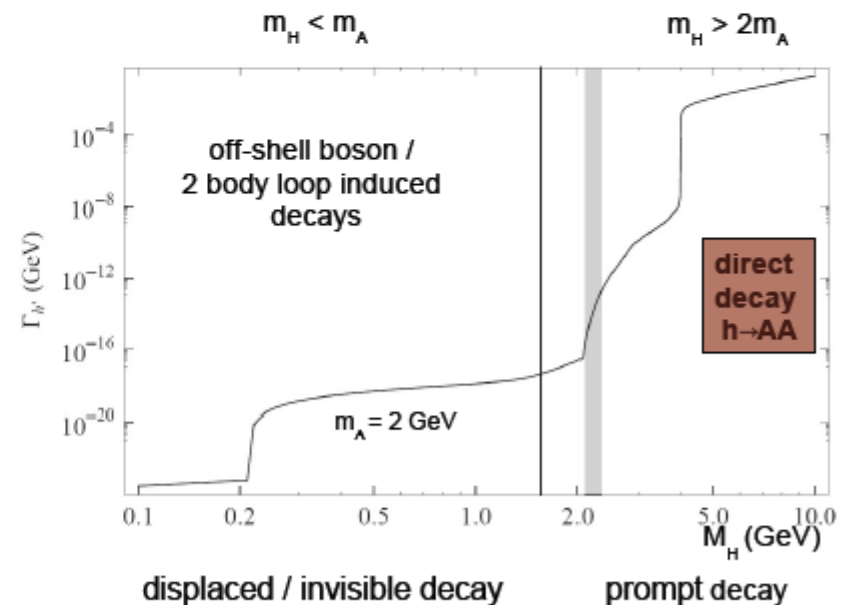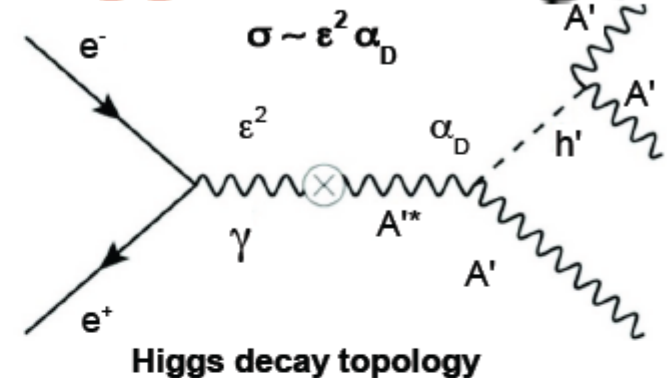
Direct Search for Dark Sector

Look for $e^+e^- \rightarrow l^+l^-l^+l^-$ final states (4e, 2e2μ, 4μ) as a function of two-lepton mass

Full BaBar dataset (~540 fb^{-1})

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

Some of the smallest cross section ULs measured @ B-Factories

Y. Kolomensky at Lomonosov Conference, Aug. 2015