Search for Dark Photon at Belle Experiment

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On behalf of Belle Collaboration

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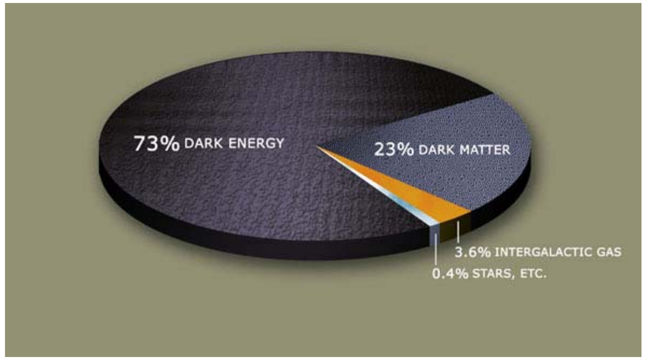
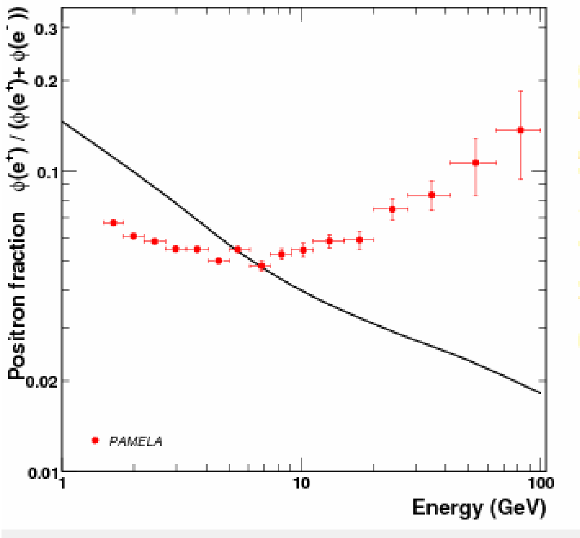
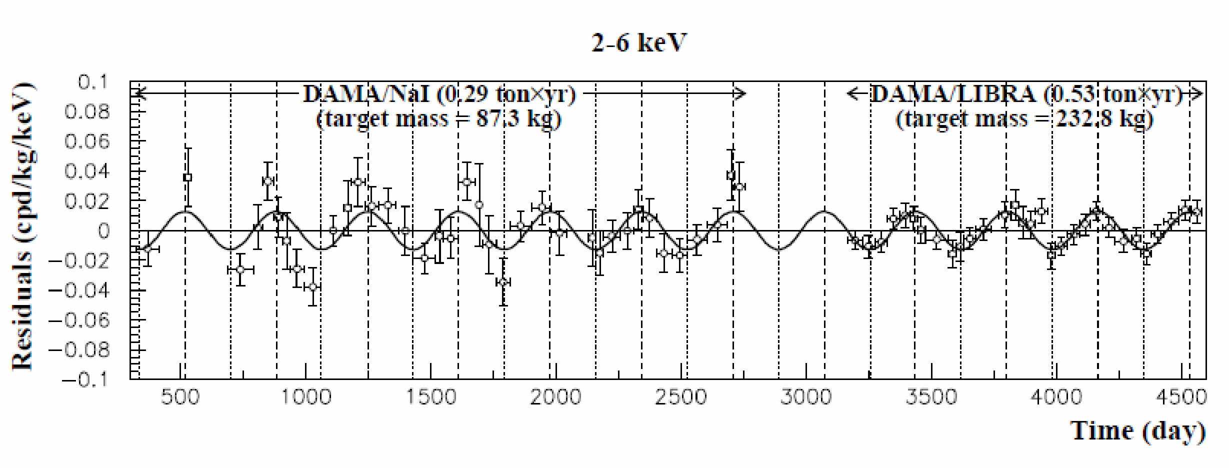
Motivation

Dark matter (DM) consists 23% of our universe.
DM search has many results recently



PAMELA: positron excess by no $\bar{p}$ excess

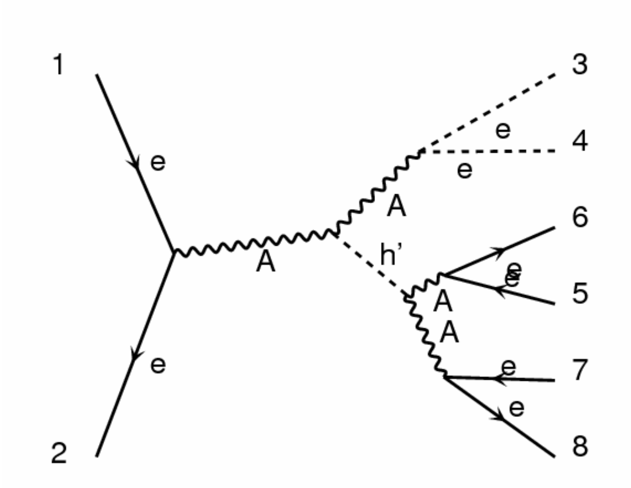




Direct detection of dark matter (DAMA/LIBRA)

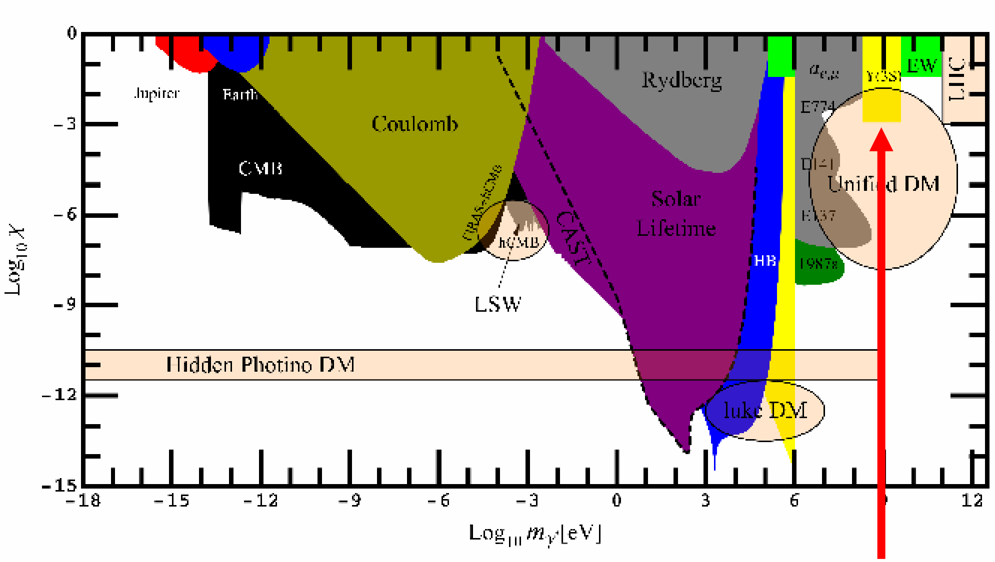
PAMELA - O. Adriani et al. Nature 458, 607-609 (2009)
DAMA/LIBRA – R. Bernbei et al. Eur. Phys. J. C (2008) 56: 333-355

Higgs Strahlung Mechanism



$e^+ e^- \rightarrow Ah'$ ($\rightarrow AA$)
With $A \rightarrow l^+l^-$ (l= e/u) or hadrons

B. Batell, M. Pospelov, and A. Ritz arXiv:0903.0363 (2009).



We searched here

J. Jaeckel and A. Ringwald – arXiv: 1002.0329

Channels presented today:

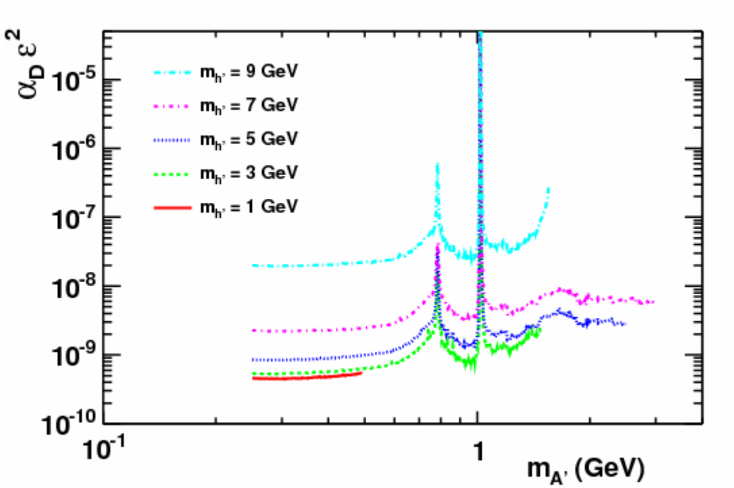
- $e^+e^- \rightarrow 3e^+3e^-$
- $e^+e^- \rightarrow 3\mu^+3\mu^-$

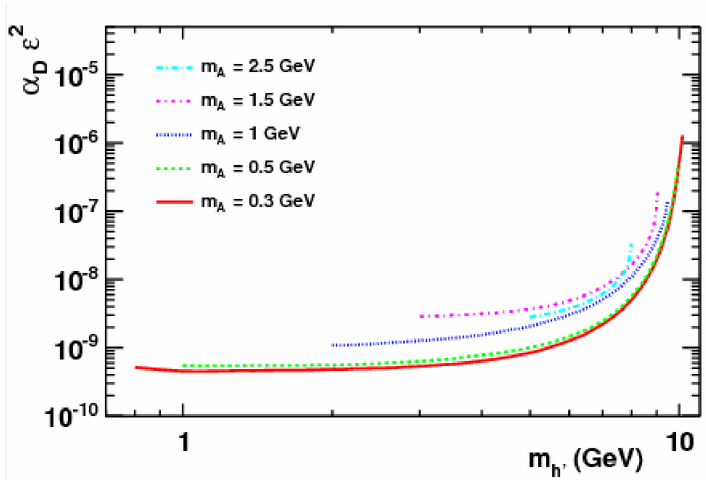
- $0.27 < m_A < 3\ \mathrm{GeV}/c^2$
- $0.54 < m_{h'} < 10.86\ \mathrm{GeV}/c^2$

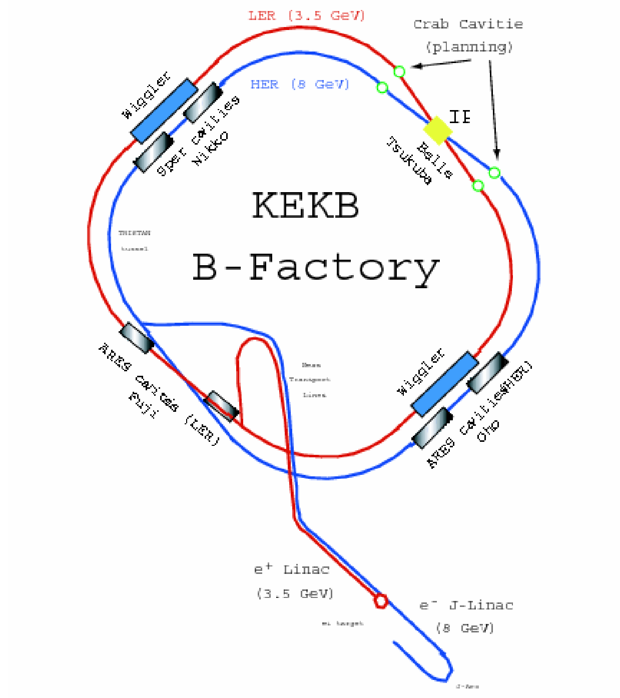
Previous Results from BaBar

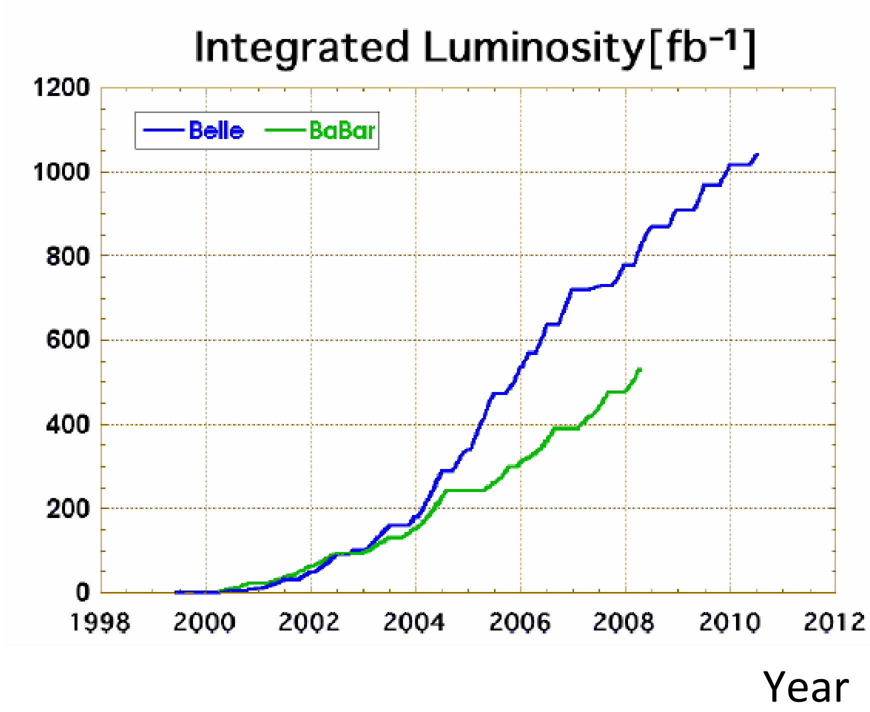
BaBar : arXiv: 1202.1313

L = 521 fb-1 date on Υ(2S, 3S, 4S) and off-resonance



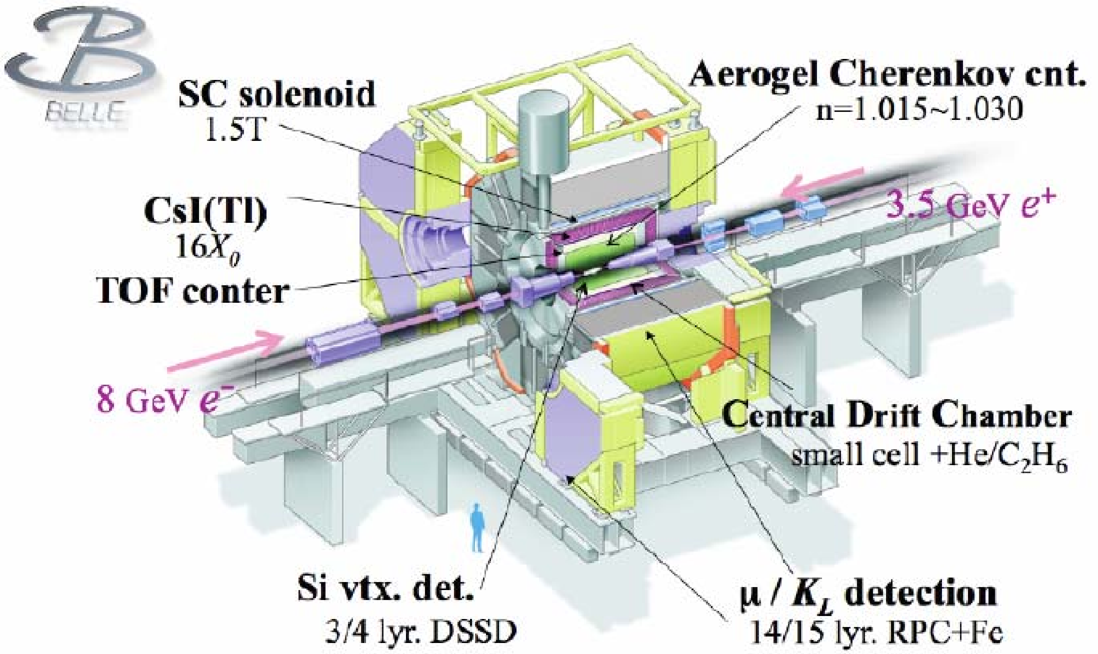






- Located in KEK, Japan
- Asymmetric Electron – Positron (8GeV + 3.5 GeV, $\beta\gamma$ = 0.425 @ Y(4S)) collider
- High luminosity (peak: 21 $nb^{-1}s^{-1}$)
- More than 1, 000 fb^{-1} data accumulated since started
- In this analysis, We used all the data

Belle Detector & PID



Electron ID: Electromagnetic Calorimeter (ECL) and Tracking System (CDC + SVD)
Shower shape & Energy/momentum
Efficiency > 90%, hadron fake rate ~ 0.5% (1GeV~3GeV)

Mu ID: Tracking System and Muon/K_L Detector
Matching of K_L/Muon hit and extrapolated track
Efficiency 89%, K/pi fake rate ~ 2% @1GeV

Analysis Strategy

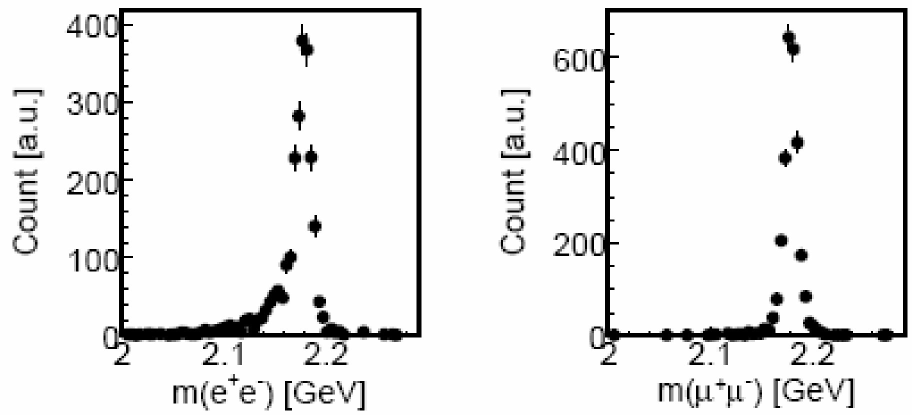
$e^+ e^- \rightarrow Ah' (\rightarrow AA),\ A \rightarrow l^+l^- \ (l = e/u)$

- $0.27 < m_A < 3\ \mathrm{GeV}/c^2$
- $0.54 < m_{h'} < 10.86\ \mathrm{GeV}/c^2$

- Only 6 tracks in final state, 3 pairs of opposite charge
- Geometry cut to constrain the tracks from IP
- 3/6 leptons to be identified, to keep a high efficiency
- Require energy and momentum conservation
- Calculate invariant mass for each combination of leptons consistent with three distinct $A \rightarrow l^+ l^-$

Analysis Strategy

Keep combinations with three masses $(m_A^1,\ m_A^2 \text{ and } m_A^3)$ "equal" and $m_{h'} > 2m_A$



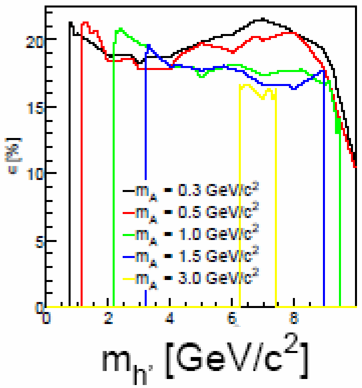
Signal Monte Carlo: Invariant mass of particle pairs

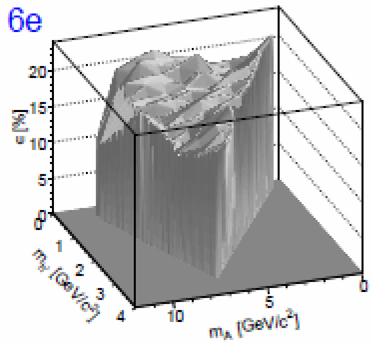
Generated for: $m_{h'} = 5$ GeV/c^2 and $m_A = 2.19$ GeV/c^2.

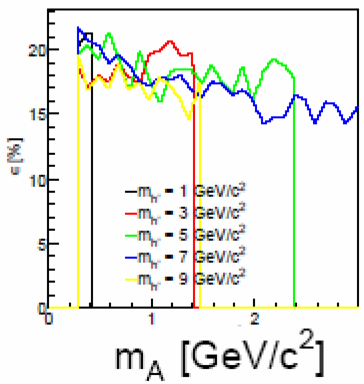
Detection Efficiency

$e^+e^- \to Ah' \to AAA$

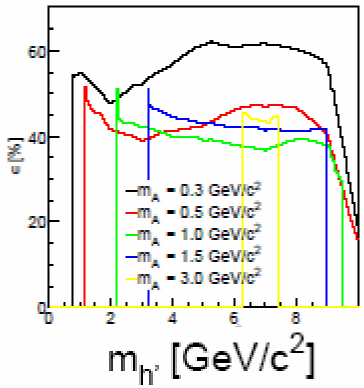
- $e^+e^- \to 3e^+3e^-$
- $e^+e^- \to 3\mu^+3\mu^-$

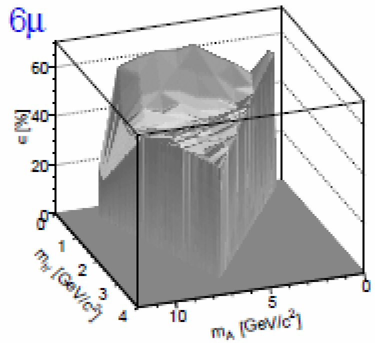


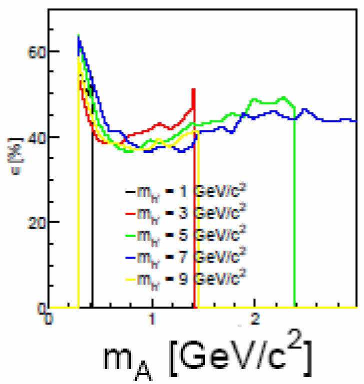




Efficiency : 18%





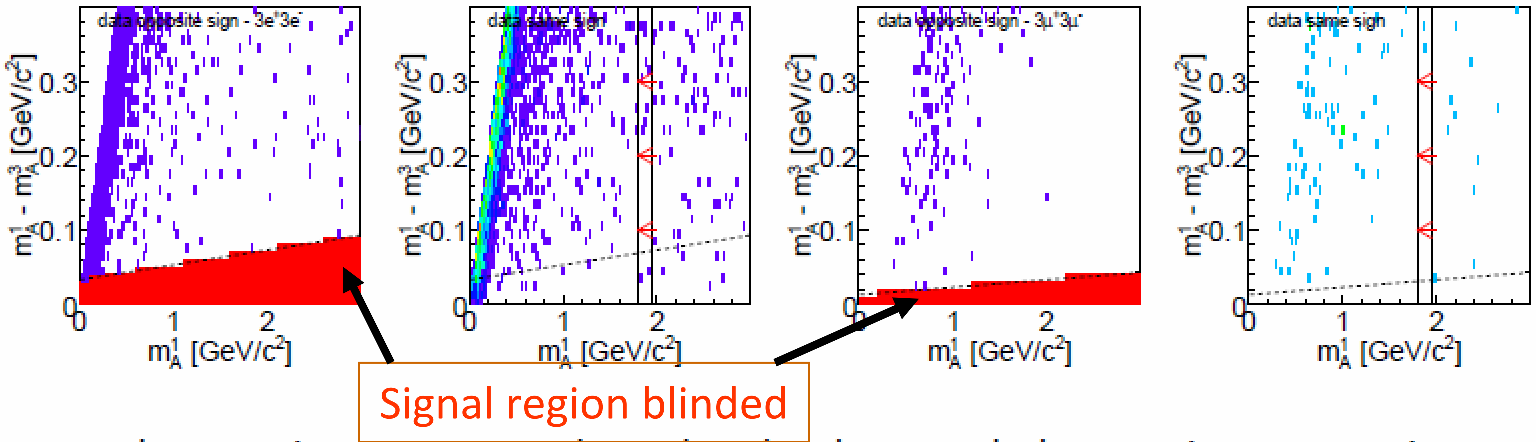


Efficiency : 40%

Background Estimation

- no realistic background model available
  => data driven background estimation
- estimate background using "same sign" events
  $e^+e^- \to Ah' \to A(l^+l^-)A(l^+l^+)A(l^-l^-)$
- order masses of lepton $m_A^1 > m_A^2 > m_A^3$ and plot m_A^1 vs. $m_A^1 - m_A^3$

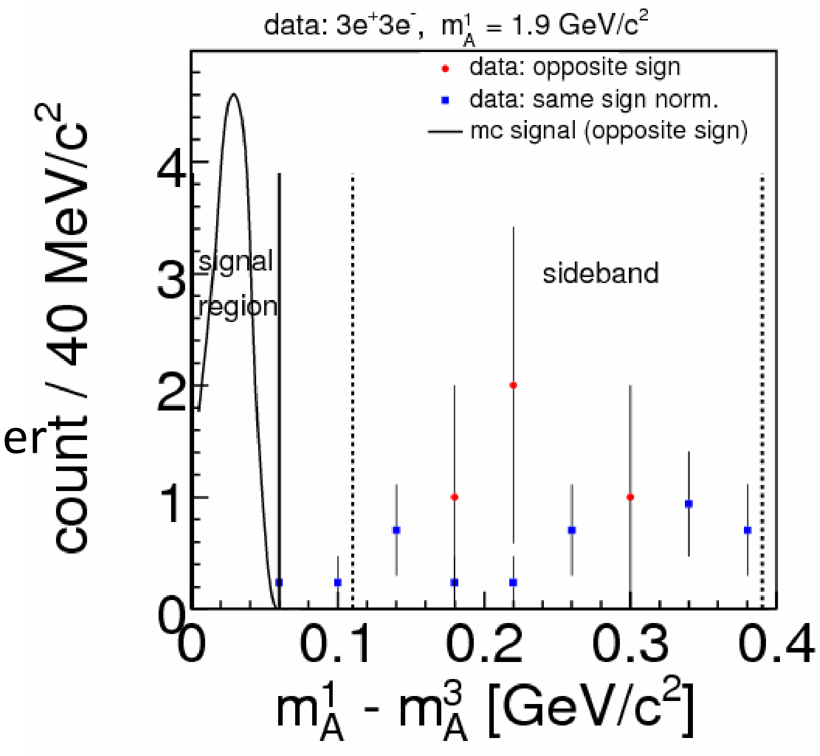
▸ $e^+e^- \to 3e^+3e^-$ ▸ $e^+e^- \to 3\mu^+3\mu^-$



- select region in m_A and predict background there using same sign

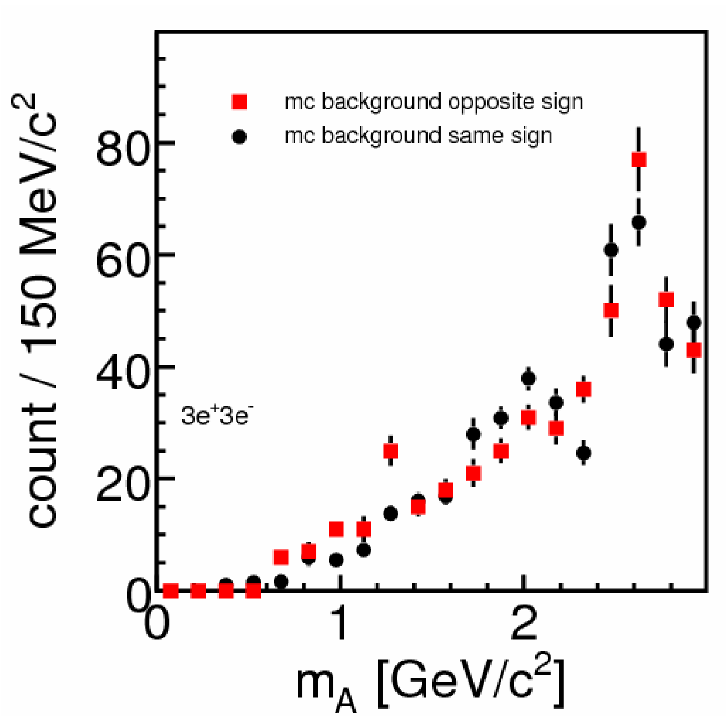
Normalization Factor

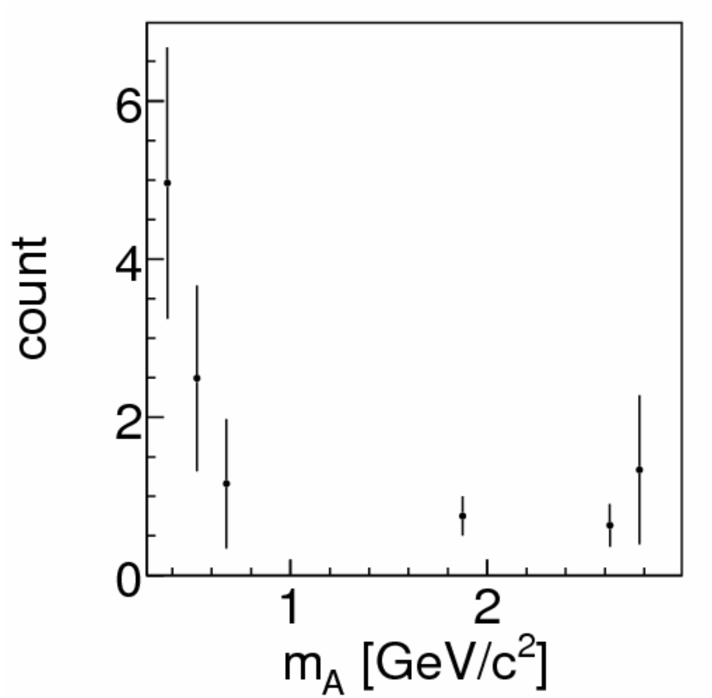
- Project to $m_A^1 - m_A^3$
  Signal region : solid line
  Sideband: dashed line
- Sideband used to normalize same sign to opposite sign
- Background estimated from the number of counts in the signal region of the same sign distributions



Right: shows projection on $m_A^1 - m_A^3$ for $m_A^1 = 1.9$ GeV/c^2

MC test & Estimated Background Level





$e^+e^- \to 3e^+3e^-$ FS uncorrelated

Background estimation method verified successfully with MC (Left plot)

For Experimental data, Predicted BG (Right plot):

> 20 events for electron final state

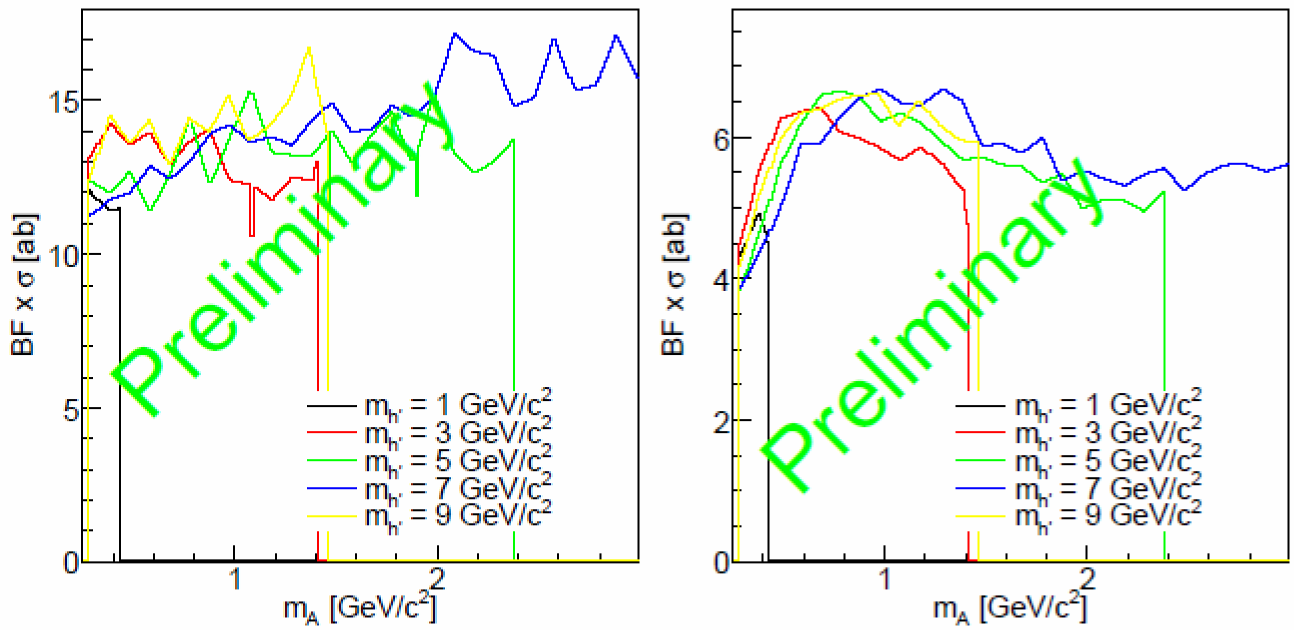
0 event for muon final state

Preliminary sensitivity

- Assume number of events observed = number of expected background
- Upper limit (90% C. L) determined by Feldman-Cousins method

$$BF.\sigma^{exp.} = \frac{N}{L.\epsilon}$$

- $e^+e^- \rightarrow 3e^+3e^-$
- $e^+e^- \rightarrow 3\mu^+3\mu^-$



Conclusion

Search for “Dark photon” and “Dark Higgs” in the mass ranges:

- $0.27 < m_A < 3 \text{ GeV/c}^2$
- $0.54 < m_{h'} < 10.86 \text{ GeV/c}^2$

From our control data sample:

- background is estimated to be small, implying
- sensitivity scales nearly linearly with integrated luminosity

  for $e^+e^- \to 3\mu^+3\mu^-$

Results will be unblinded soon

Thank you for your attention!

Backup

With $h' \to AA$ and $A \to l^+l^-$ or hadrons.

- $e^+e^- \to 3e^+3e^-$
- $e^+e^- \to 3\mu^+3\mu^-$
- $e^+e^- \to 3\pi^+3\pi^-$
- $e^+e^- \to 2e^+2e^-\mu^+\mu^-$
- $e^+e^- \to 2e^+2e^-\pi^+\pi^-$
- $e^+e^- \to 2\mu^+2\mu^-e^+e^-$
- $e^+e^- \to 2\mu^+2\mu^-\pi^+\pi^-$
- $e^+e^- \to 2\pi^+2\pi^-e^+e^-$
- $e^+e^- \to 2\pi^+2\pi^-\mu^+\mu^-$
- $e^+e^- \to e^+e^-\mu^+\mu^-\pi^+\pi^-$
- $e^+e^- \to 2e^+2e^-X$

We will only discuss the $e^+e^- \to 3e^+3e^-$ and $e^+e^- \to 3\mu^+3\mu^-$.

The theoretical cross section is defined as:

$$\sigma^{th.} = \frac{\pi \alpha \alpha_D \epsilon^2}{3s} \left(1 - \frac{m_A^2}{s}\right)^{-2} \sqrt{\lambda\left(1, \frac{m_{h'}^2}{s}, \frac{m_A^2}{s}\right)} \left[\lambda\left(1, \frac{m_{h'}^2}{s}, \frac{m_A^2}{s}\right) + \frac{12 m_A^2}{s}\right] \quad (3)$$

where:

- α is the electromagnetic coupling is equal $\sim 1/137$
- $\alpha_D = \frac{g_D^2}{4\pi}$ is the dark sector constant with g_D^2 is the dark sector gauge coupling between the dark Higgs and the dark photon
- $\epsilon^2 = \frac{\alpha'}{\alpha}$ is the kinetic mixing with α' the electromagnetic coupling of the dark photon to the Standard Model fermions
- m_A and $m_{h'}$ are respectively the dark photon and dark Higgs masses
- s is the energy squared in the center-of-mass
- $\lambda = A^2 + B^2 + C^2 - 2AB - 2AC - 2BC$

The mass "equality" is defined as following:

- $m_A^{mean} - 3.\sigma(m_A^{mean}) < m_A^1 < m_A^{mean} + 3.\sigma(m_A^{mean})$
- $m_A^{mean} - 3.\sigma(m_A^{mean}) < m_A^2 < m_A^{mean} + 3.\sigma(m_A^{mean})$
- $m_A^{mean} - 3.\sigma(m_A^{mean}) < m_A^3 < m_A^{mean} + 3.\sigma(m_A^{mean})$

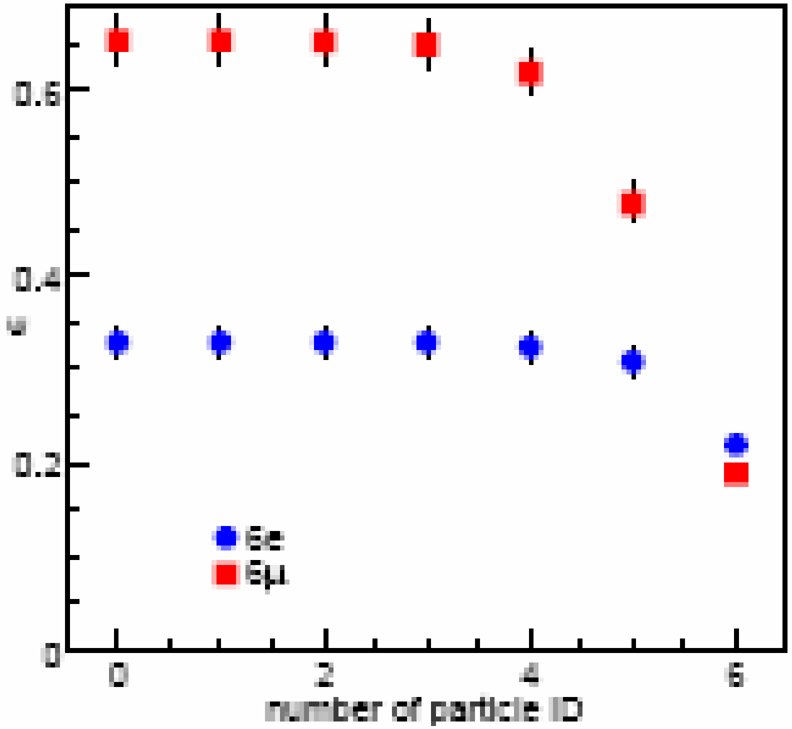
where:

$$m_A^{mean} = \frac{m_A^1 + m_A^2 + m_A^3}{3} \tag{10}$$

$$\frac{\sigma(m_A^{mean})}{m_A^{mean}} = \frac{a}{m_A^{mean1/2}} + \frac{b}{m_A^{mean1/3}} + \frac{c}{m_A^{mean1/4}} \tag{11}$$

The cut on the mass "equality" varies as function of the final states and dark photon mass.

$$m(A^1A^2) > 2m_A^{mean} || m(A^1A^3) > 2m_A^{mean} || m(A^2A^3) > 2m_A^{mean}$$



0.6
0.4
ε
0.2
0
0
2
4
6
number of particle ID
6e
6μ