Probing a Secluded U(1) at B-Factories*

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*with Maxim Pospelov and Adam Ritz
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Dark Forces - 9/24/09

Plan

- Phenomenology of GeV-scale secluded U(1) at low energy e^+e^- colliders

- New states - V_μ, h'

- Predictions are simple, testable, and striking

Related e^+e^- collider studies

Context of MeV-dark matter:

Borodatchenkova, Choudhury, Drees '05
Fayet and others - numerous works
Zhu '07

Context of PAMELA, etc.

Essig, Schuster, Toro '09
Reece, Wang '09
Bossi '09
Yin, Liu, Zhu '09
BaBar ($4l$ final states) '09

Dark Forces Thesaurus:

Secluded U(1) $\sim$ Dark photon $\sim$ U-Boson

Secluded Dark Matter

Pospelov, Ritz, Voloshin '07

$$\chi \text{ - - - - - } V_{\mu\nu}B^{\mu\nu} \text{ - - - - - } \mathrm{SM}$$

Holdom '86

Secluded Dark Matter

Pospelov, Ritz, Voloshin '07

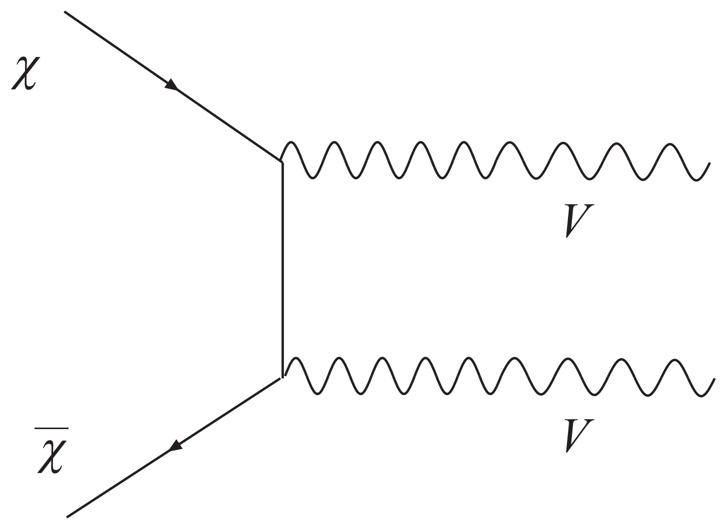
$$\chi \text{ - - - - - } V_{\mu\nu}B^{\mu\nu} \text{ - - - - - } \mathrm{SM}$$

Holdom '86

A new entry to the dark forces thesaurus: Holdom boson

Secluded regime: $m_\chi > m_V$

- Annihilation via $\overline{\chi}\chi \to VV$
- Relic abundance independent of WIMP-SM coupling
- Thermal WIMP with potentially no direct detection, collider signatures



Astrophysical signatures

Arkani-Hamed, Finkbeiner, Slatyer, Weiner '08

Pospelov, Ritz '08

If the U(1) is light ($m_V \leq$ GeV):

- Long range force can lead to an enhanced galactic annihilation cross section (e.g. Sommerfeld enhancement, WIMPonium bound state)
- Mediator cannot decay to (anti-)protons by kinematics

Connection with cosmic ray anomalies?

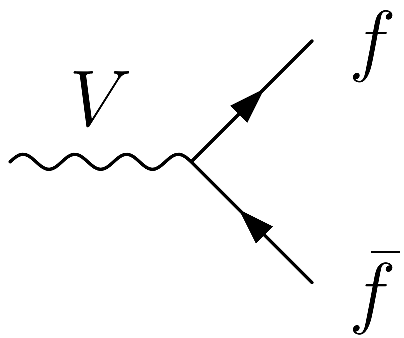
“Minimal” secluded U(1)

$$\mathcal{L} = -\frac{1}{4}V_{\mu\nu}^2 + \frac{1}{2}m_V^2 V_\mu^2 + \frac{1}{2}(\partial_\mu h')^2 - \frac{1}{2}m_{h'}^2 h'^2 + \mathcal{L}_{int}$$

$$\begin{aligned} \mathcal{L}_{int} &= -\frac{\kappa}{2}V_{\mu\nu}F^{\mu\nu} + \frac{m_V^2}{v'}h'V_\mu^2 + \dots \\ &\to -\kappa e V_\mu J^\mu_{EM} + \frac{m_V^2}{v'}h'V_\mu^2 + \dots \end{aligned}$$

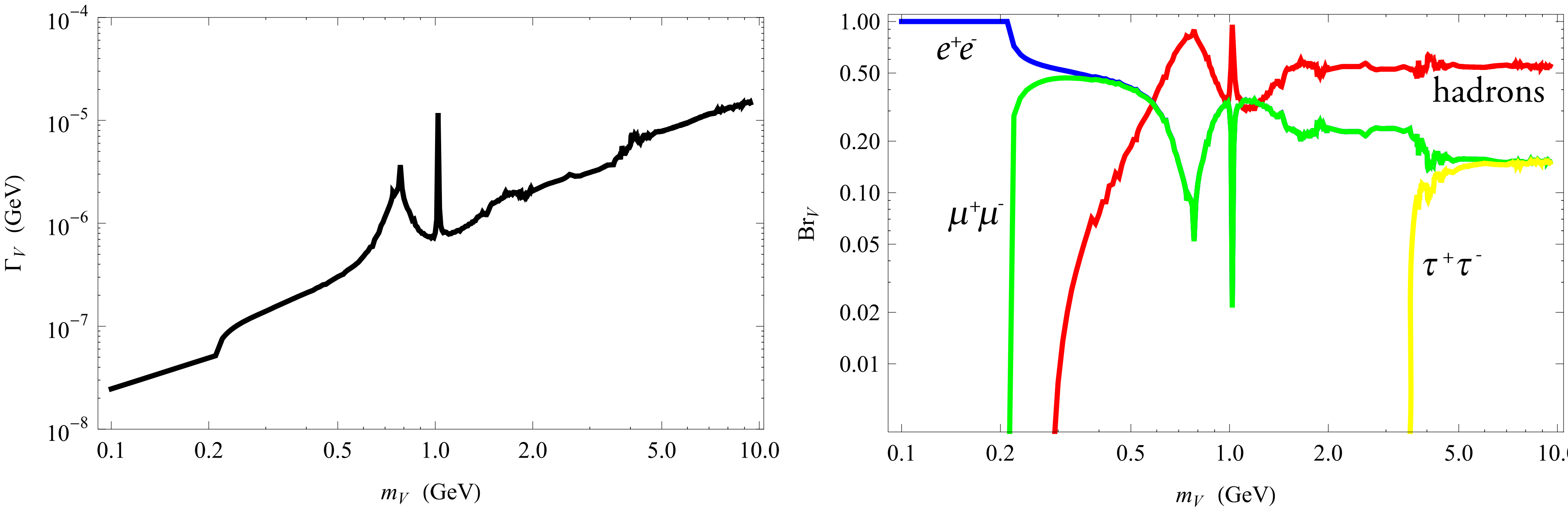
- Assume all other particles in hidden sector are heavy (e.g. WIMP)
- $V - Z$ mixing negligible for low-energy processes

V_μ decays:



- $\Gamma_V \approx \mathcal{O}(\text{keV}) \times \left(\frac{\kappa^2}{10^{-5}}\right)\left(\frac{m_V}{\text{GeV}}\right)[N_l + R(s = m_V)]$
- $R = \frac{\sigma_{e^+e^- \to hadrons}}{\sigma_{e^+e^- \to \mu^+\mu^-}}$

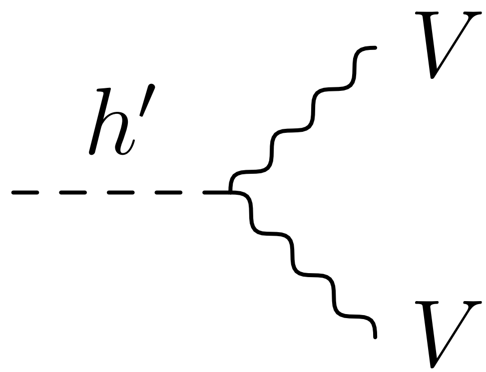
V_μ decays:



- V_μ always has a significant branching to leptons
- Very narrow resonance $\sim$ keV in l^+l^-

h' decays:

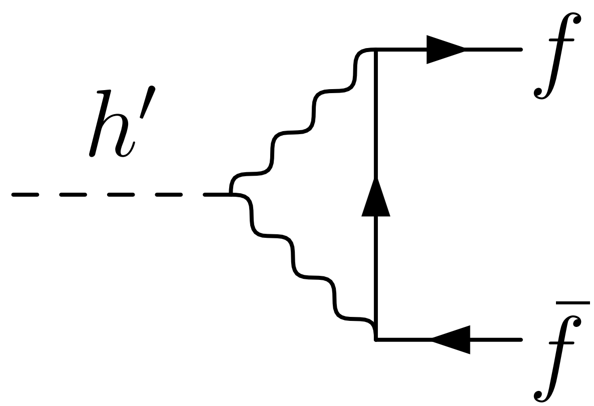
$m_{h'} > m_V$:



- $\Gamma_{h'} \sim 100\text{MeV} \times \left(\frac{\alpha'}{\alpha}\right) \left(\frac{m_{h'}}{\text{GeV}}\right)^3 \left(\frac{100\,\text{MeV}}{m_V}\right)^2$

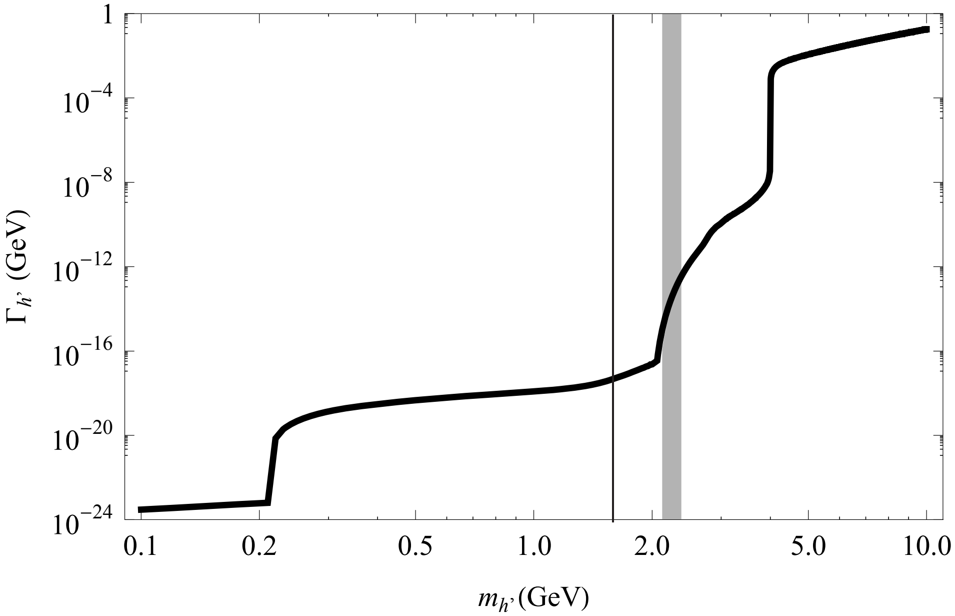
h' decays:

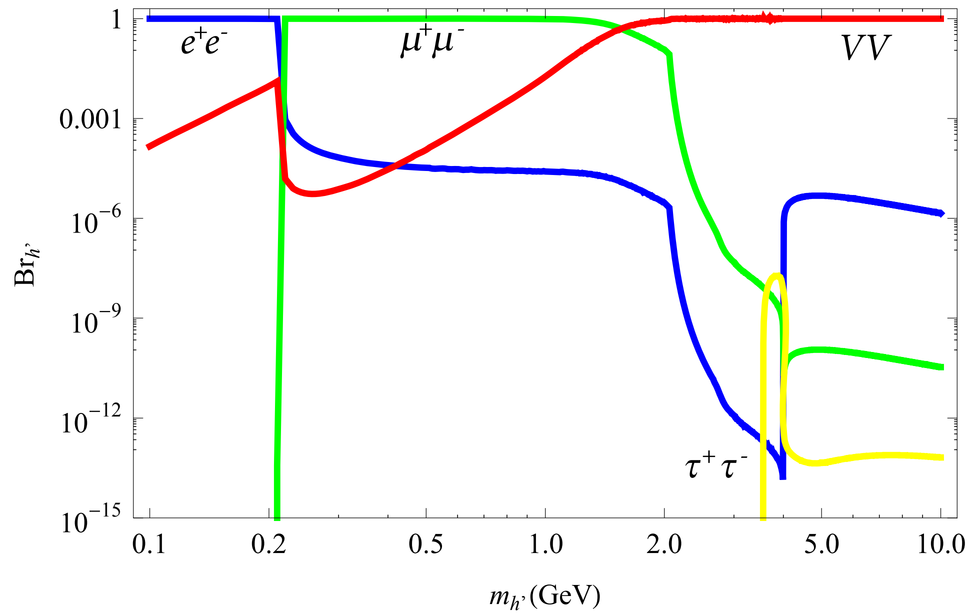
$m_{h'} < m_V$:



- $c\tau_{h'} \sim 100\,\mathrm{m} \times \left(\frac{\alpha'}{\alpha}\right)\left(\frac{\kappa^2}{10^{-5}}\right)^{-2}\left(\frac{m_{h'}}{\mathrm{GeV}}\right)^{-1}\left(\frac{m_V}{2m_f}\right)^2$

h' decays:





- Heavy Higgs': $h' \to 2V \to 4l$
- Light Higgs': missing energy at colliders
- $m_h \sim m_V$: possible displaced vertices

B-factories

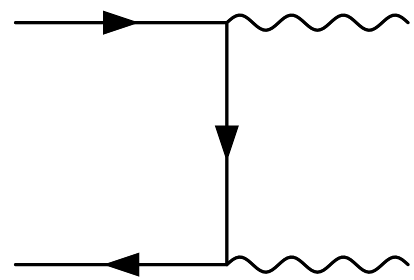
B-factories BaBar and Belle have the following advantages in probing a GeV scale hidden sector:

- Large data sets > 1 ab^{-1}
- Low COM energy $\sqrt{s} \simeq 10$ GeV, close to masses of V, h'

Note: signal goes as $\dfrac{\mathcal{L}}{s}$, so lower energy experiments such as KLOE, BESIII, can be competitive for lighter secluded states

See talks by Fabio Bossi, Hai-Bo Li, Yangheng Zheng

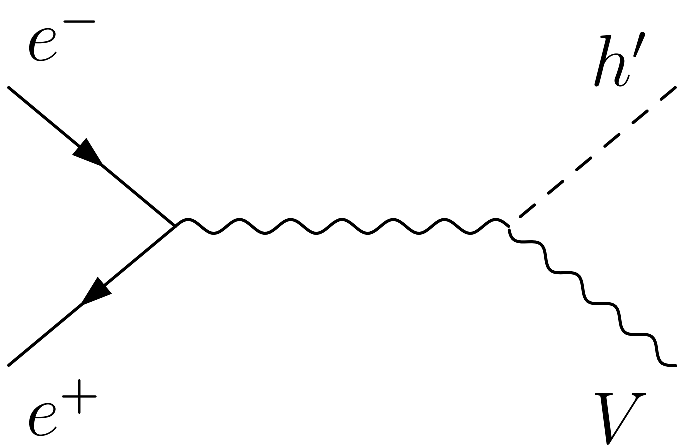
Pair annihilation to $V\gamma$



- $\sigma \approx 60\,\mathrm{fb} \times \left(\frac{\kappa^2}{10^{-5}}\right) \frac{(10\,\mathrm{GeV})^2}{s}$
- $\gamma l^+ l^-$ signature

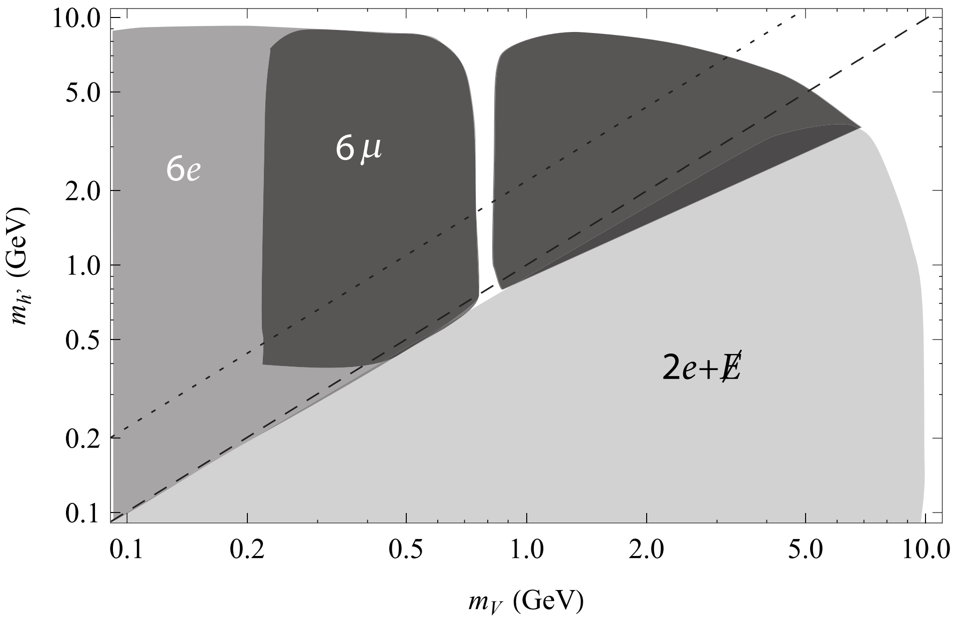
Talk by Lian-Tao Wang

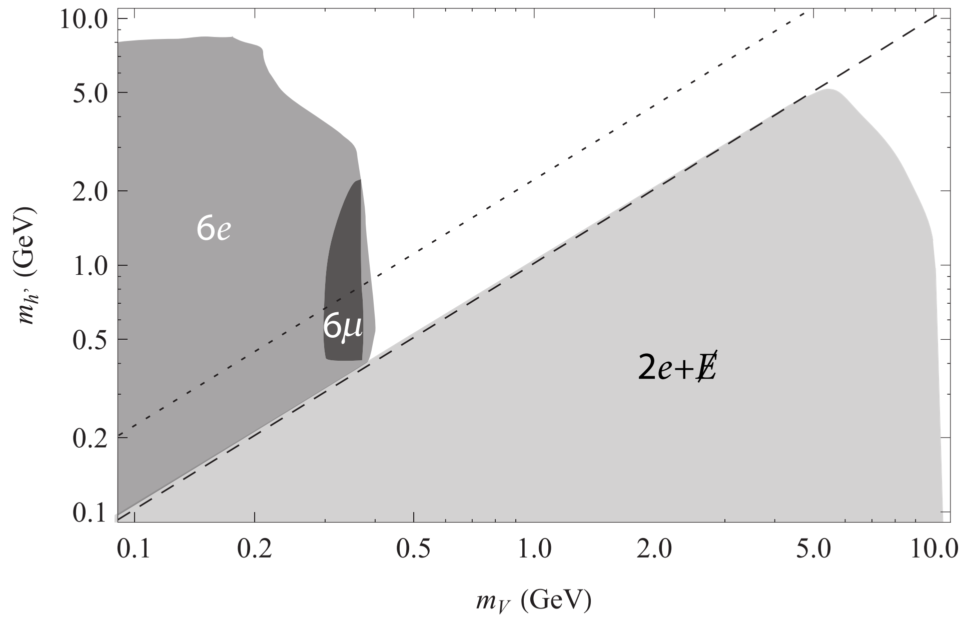
Higgs′-strahlung



- $\sigma \approx 2\,\mathrm{fb} \times \left(\frac{\alpha'}{\alpha}\right)\left(\frac{\kappa^2}{10^{-5}}\right)\frac{(10\,\mathrm{GeV})^2}{s}$
- $6l$ or $2l + \not{E}$ signature

Higgs′-strahlung signal





- Backgrounds, cuts not taken into account
- Could be 1000s of events on tape!

Comments on backgrounds

- Potentially very large QED backgrounds events with e^+e^- in final state
- e.g. $e^+e^- \to e^+e^-\mu^+\mu^-$

$$\sigma_{e^+e^-\to e^+e^-\mu^+\mu^-} \approx \frac{\alpha^4}{\pi m_\mu^2}\left(\log\frac{s}{m^2}\right)^2 \log\frac{s}{m_\mu^2} \approx 100\,\mathrm{nb}.$$

- But ...
  - background electrons are forward
  - reconstruct V,h' invariant masses in lepton pairs
  - if cascade decay (e.g. Higgs′-strahlung), reconstruct parent mass
    see talk by Mathew Graham

Model dependence

- Minimal secluded U(1) model:
  - Explains positron excess
  - Phenomenology simple but striking (e.g. 6 lepton states)
  - Distinctive (no 4 lepton final states) - see talk by Mathew Graham
- More structure in dark sector:
  - Mass splittings, origin of GeV scale - Nonabelian dark force, SUSY
  - Easily can get higher multiplicity lepton final states

Conclusions

- Minimal secluded U(1): new states V_μ, h'
- Survey of e^+e^- collider phenomenology
  - Pair annihilation, Higgs′strahlung
  - Signatures: $\gamma + 2l, 6l, 2l + \not{E}$
  - Events could be sitting in data!
- Predictions are simple, testable, and striking!