Current Status of sub-GeV Hidden Particle Searches

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DESY

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6th Patras Workshop on Axions, WIMPs and WISPs

in collaboration with:
O. Lebedev, S. Ramos-Sánchez, and A. Ringwald

Outline

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Bottom-Up Motivation

Dark Matter

Several astrophysical and terrestrial observations that might originate from Dark Matter

- PAMELA: rise of positron-fraction with energy [talk Sparvoli]
- FERMI: deviation from power-law in $e^+ + e^-$ spectrum [talk Strigari]

- DAMA: annual modulation in nuclear recoil event rate [talk Cerulli]
- CoGeNT: excess of events in low energy nuclear recoils

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but: PAMELA: no excess in anti-protons

- DAMA: annual modulation in nuclear recoil event rate [talk Cerulli]
- CoGeNT: excess of events in low energy nuclear recoils

but: CDMS & XENON: no signal observed [talk Balakishiyeva, Oberlack]

DM Observations

Difficulties for standard WIMPs

PAMELA & FERMI

DAMA & GoGeNT vs. CDMS & XENON

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- larger annihilation cross section required than needed for correct relic abundance: $\sigma v_{ann} \gg \sigma v_{ann}^{\Omega h^2}$
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$\Rightarrow$ non-standard WIMP?

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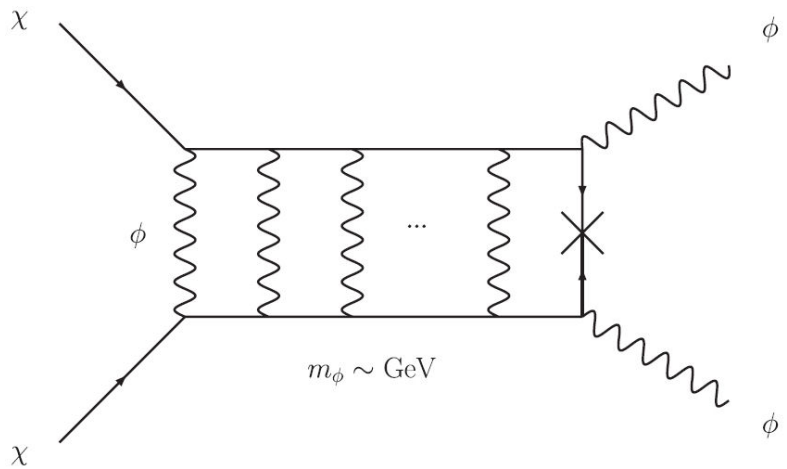

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- Axion-like Particle
  - NMSSM CP-odd Higgs[Hooper & Tait 2009]

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- Axion-like Particle
  - NMSSM CP-odd Higgs[Hooper & Tait 2009]
- hidden U(1) Photon
  - Hidden Sector[Arkani−Hamed *et al.* 2009]
  - Asymmetric Mirror World[An *et al.* 2010]

Top-Down Motivation

String compactifications

Hidden Sectors (HS)

appear naturally in various supersymmetric models descending from string theory

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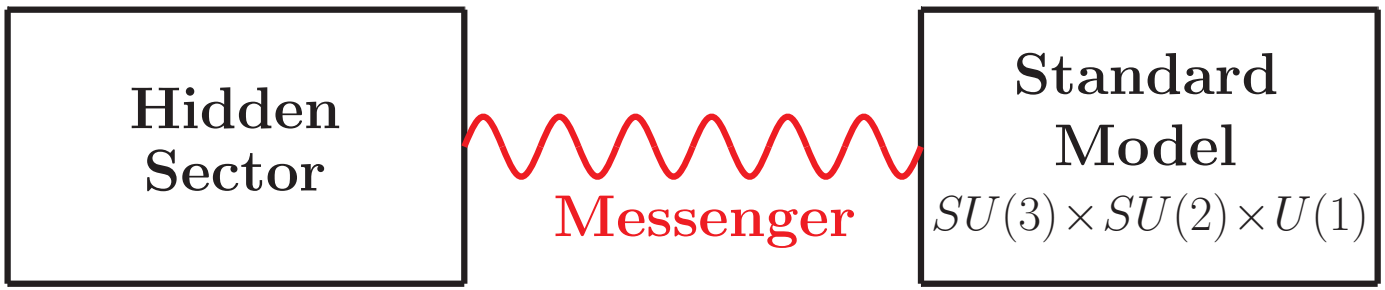
appear naturally in various supersymmetric models descending from string theory

- mediators are weakly coupled to visible sector
- mediators can be light



String compactifications

- heterotic string can reproduce the NMSSM [Lebedev&Ramos−Sanchez]
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- heterotic string can reproduce the NMSSM [Lebedev&Ramos−Sanchez]
  - in a Peccei-Quinn limit
  - with a light Pseudo-Goldstone boson, an axion-like particle (ALP)
- breaking of larger groups down to the SM gauge group can yield hidden U(1) symmetries
  - may remain unbroken down to small energy scales
  - hidden Photon may be light
  - weak coupling to visible sector via kinetic mixing

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  solution: additional decay $h \rightarrow 2A^0$ for light A^0 reduces LEP limit

The Z_3-symmetric NMSSM

- Higgs potential with approximate Peccei-Quinn symmetry in limit $\kappa \to 0$
- naturally light pseudoscalar A^0 with $m^2_{A^0} \simeq -3\kappa A_\kappa s$
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$$\Delta\mathcal{L} = -i\frac{g}{2m_W}\, C_{Aff} \left(m_d\ \bar{d}\gamma_5 d + \frac{1}{\tan^2\beta} m_u\ \bar{u}\gamma_5 u + m_l\ \bar{l}\gamma_5 l \right) A^0$$

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- avoid violation of perturbativity and/or finetuning
  $\Rightarrow 10^{-2} \lesssim C_{Aff} \lesssim 10^2$

Constraints

- $2m_\mu < m_{A^0} < 3m_\pi$: $C_{Aff} < \mathcal{O}(10^{-2})$ from K- and B-decays
- $m_{A^0} \sim 3m_\pi - m_\Upsilon$: $C_{Aff} < \mathcal{O}(10^{-1} - 1)$ from Υ-decays
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- $m_{A^0} < 2m_\mu$: not well studied

$$\Gamma_{\text{tot}} = \Gamma(A^0 \to \gamma\gamma) + \Gamma(A^0 \to e^+e^-)$$

- Meson-decays (visible & invisible)
- Pion-decay
- Muon $g-2$
- Beam dump experiments
- Reactor experiments

Meson-decays

invisible

$X \to Y + A^0 \to Y +$ inv.

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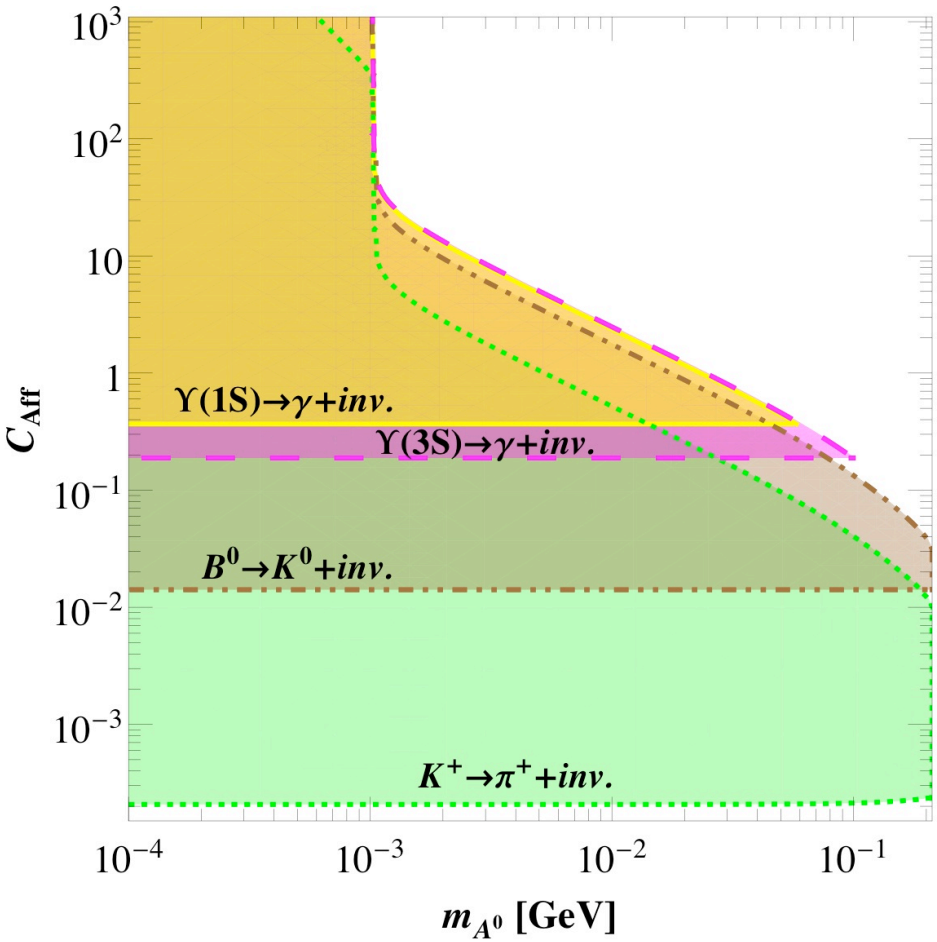

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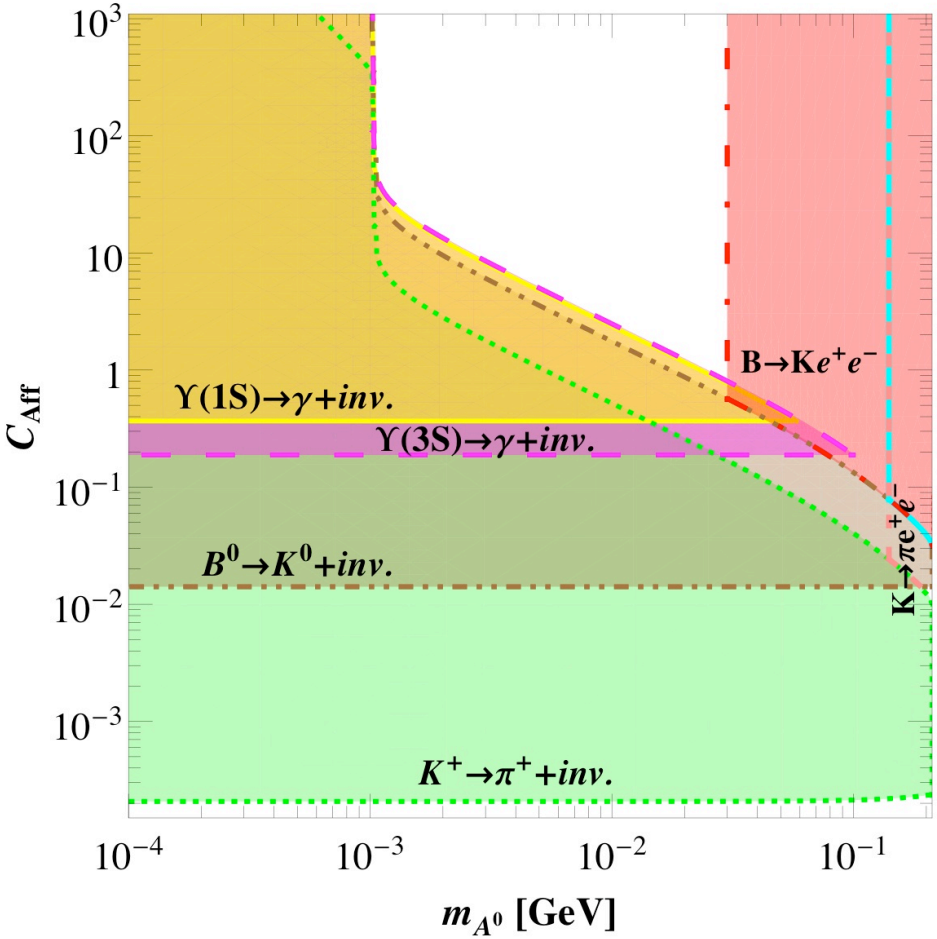

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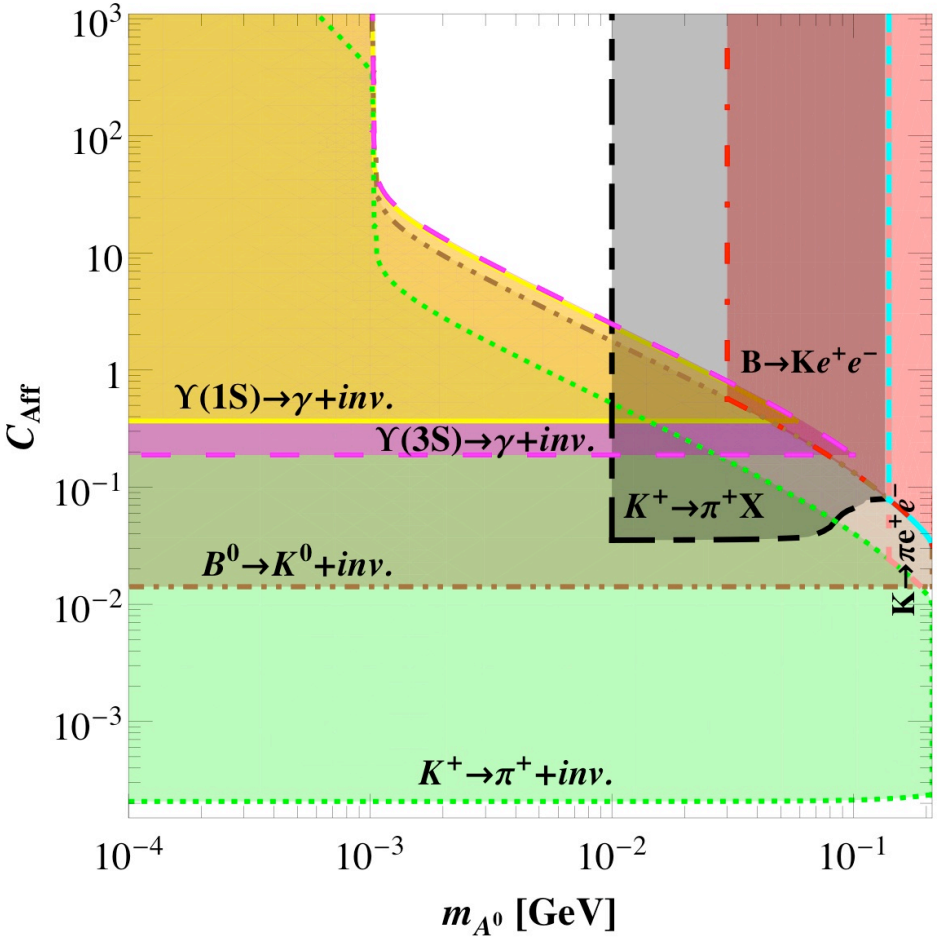
$K^+ \to \pi^+ + X$

peak in π^+ momentum spectrum



Pion-decay & Muon $g-2$

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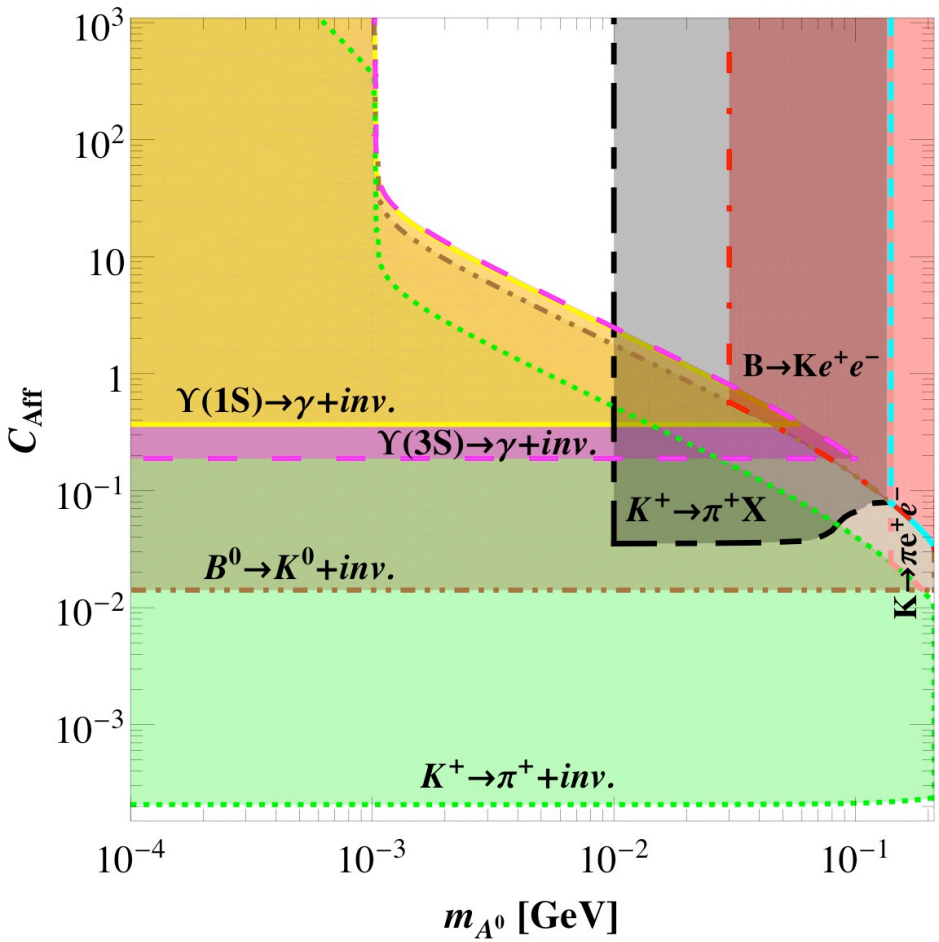

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tree level channel through A^0

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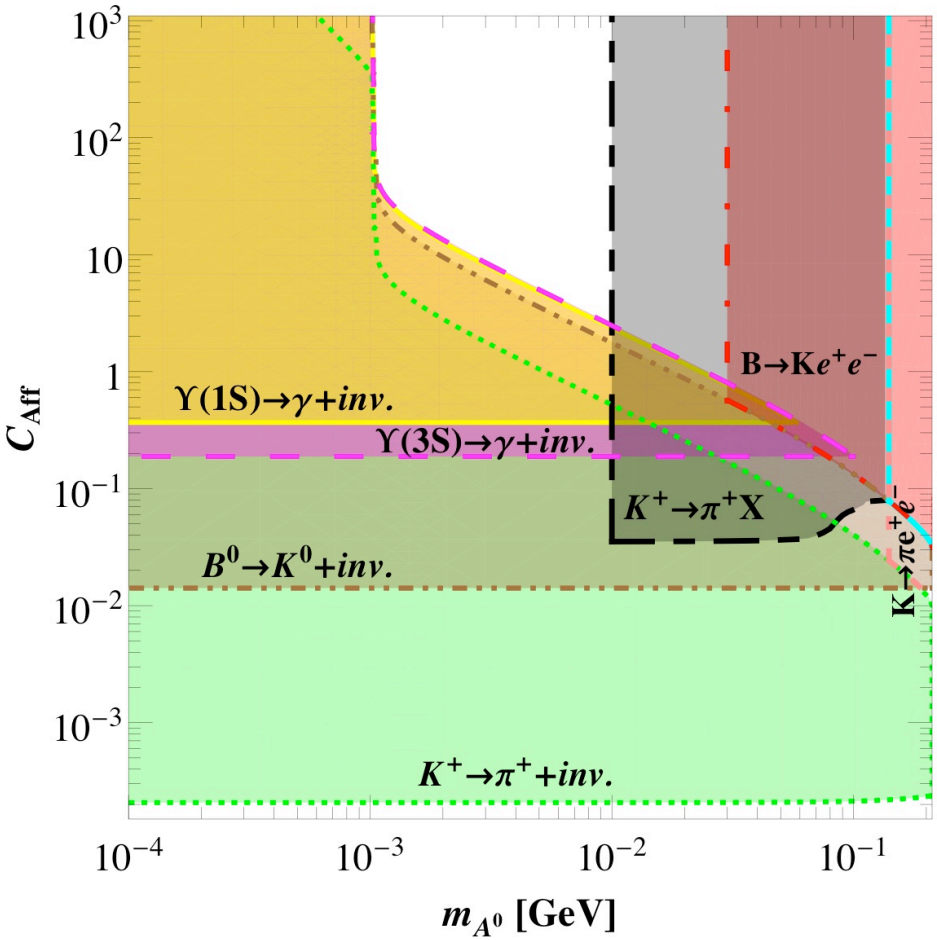

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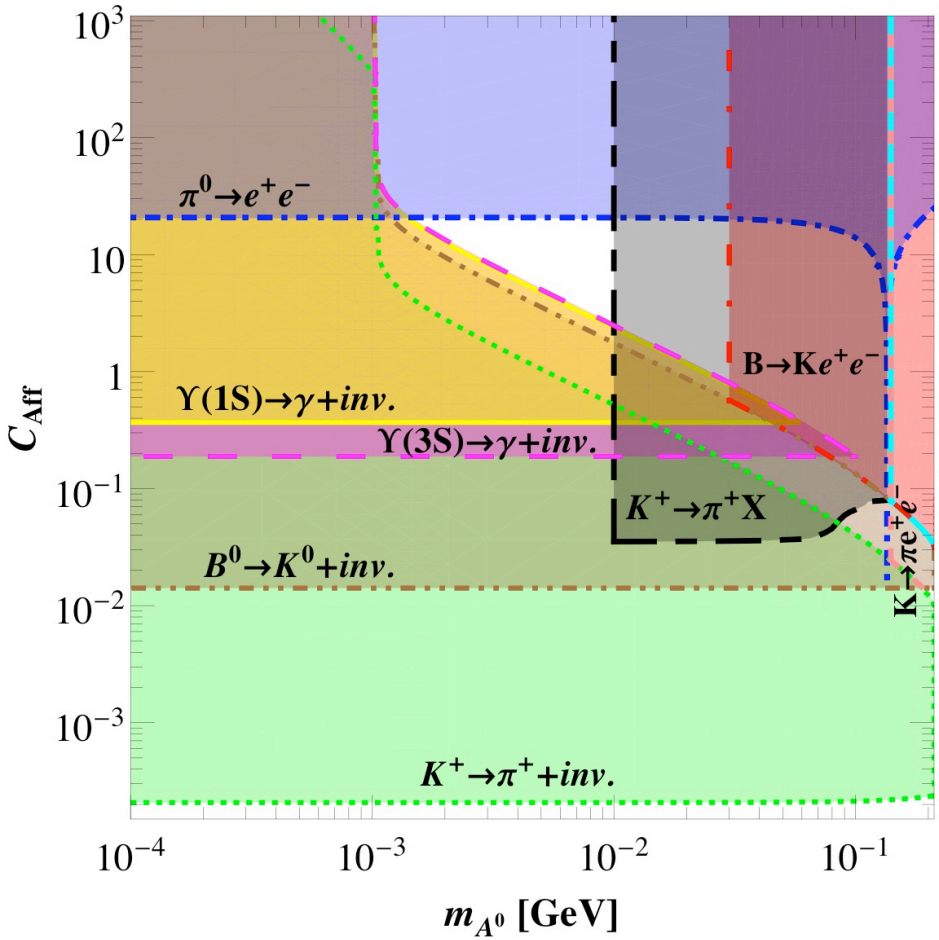

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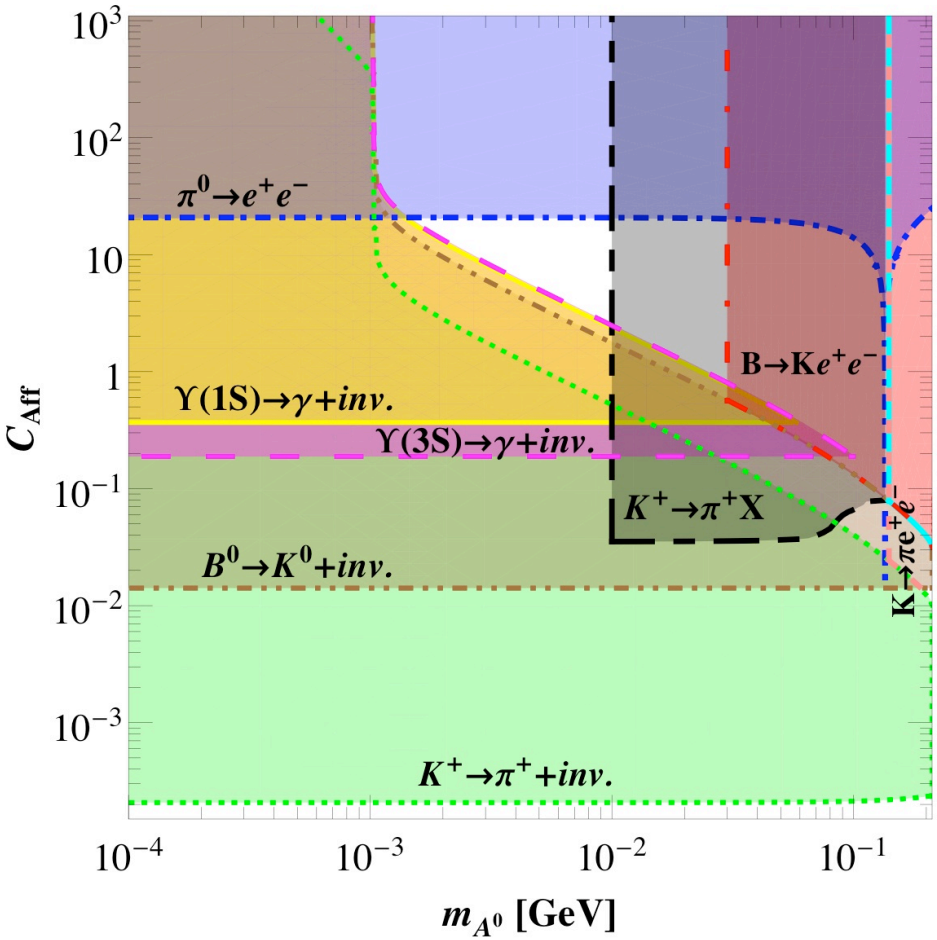
negative A^0 loop contribution



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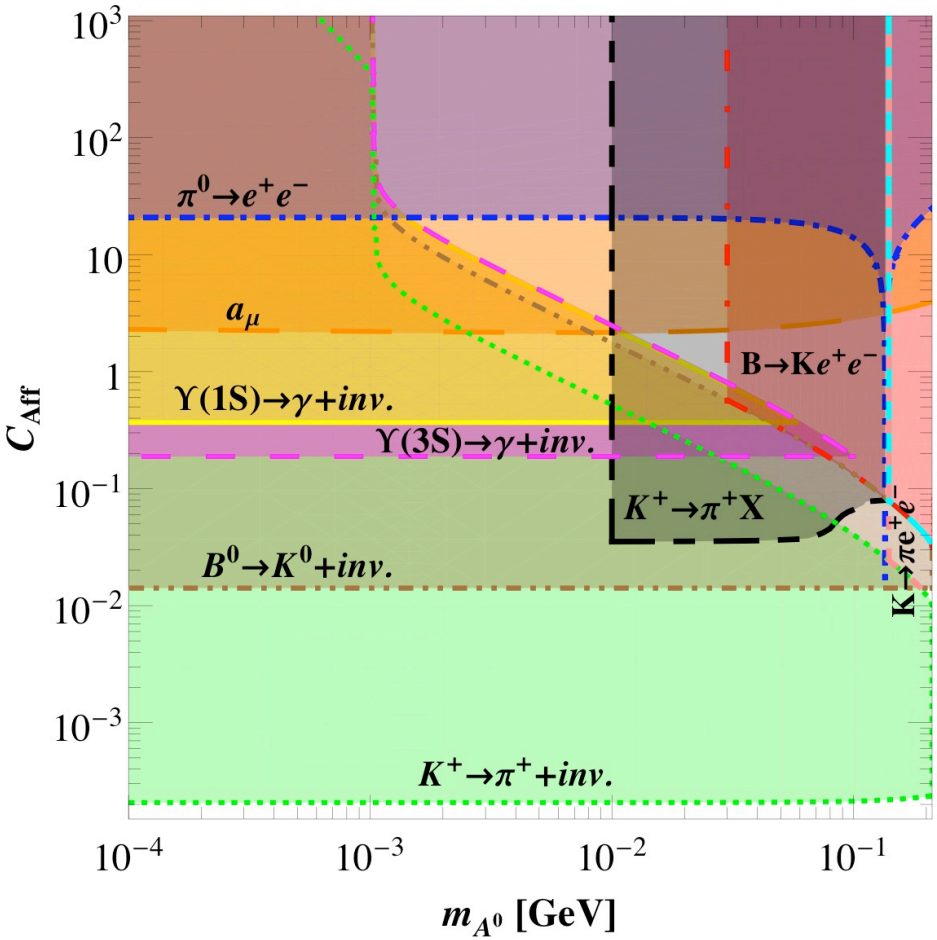
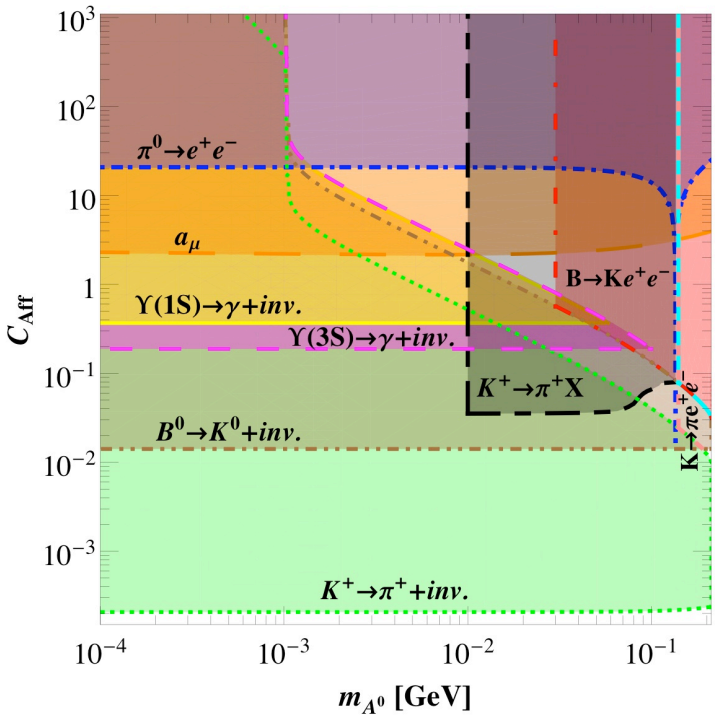
not worsen discrepancy beyond 5σ



Beam-dump & Reactor Experiments



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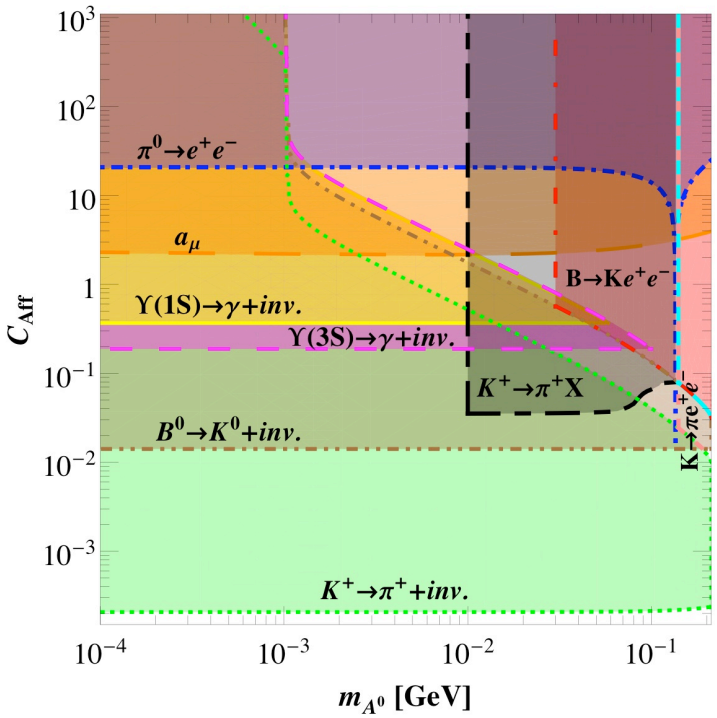

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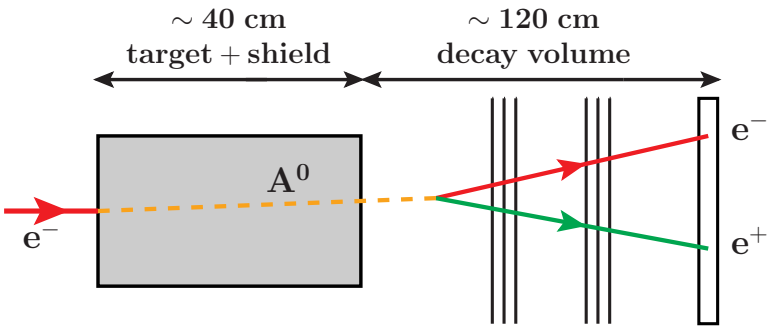
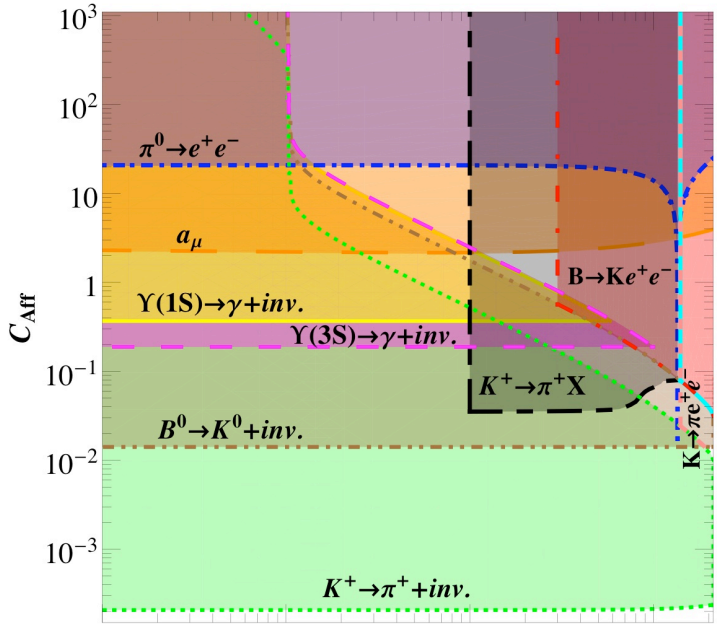
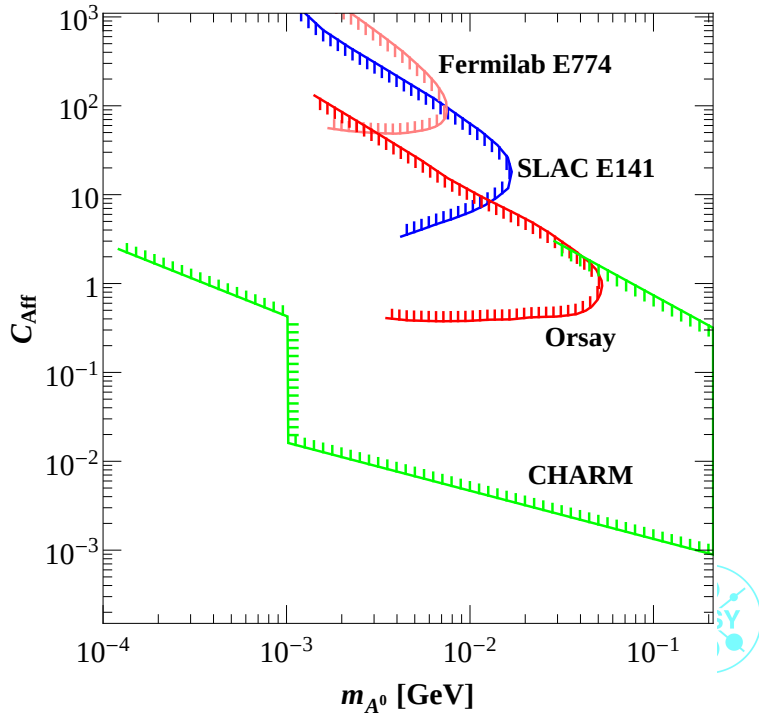
ALP emitted via bremsstrahlung from *e*- or *p*-beam







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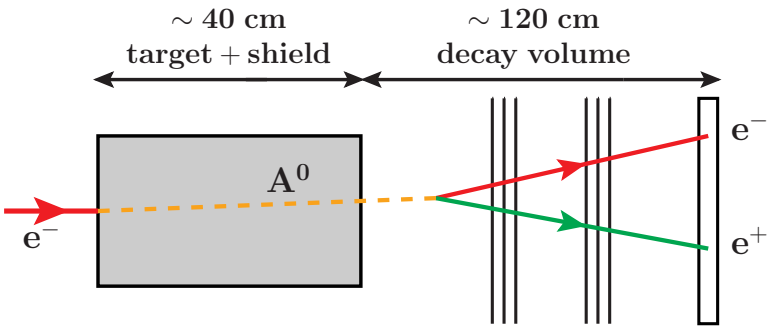
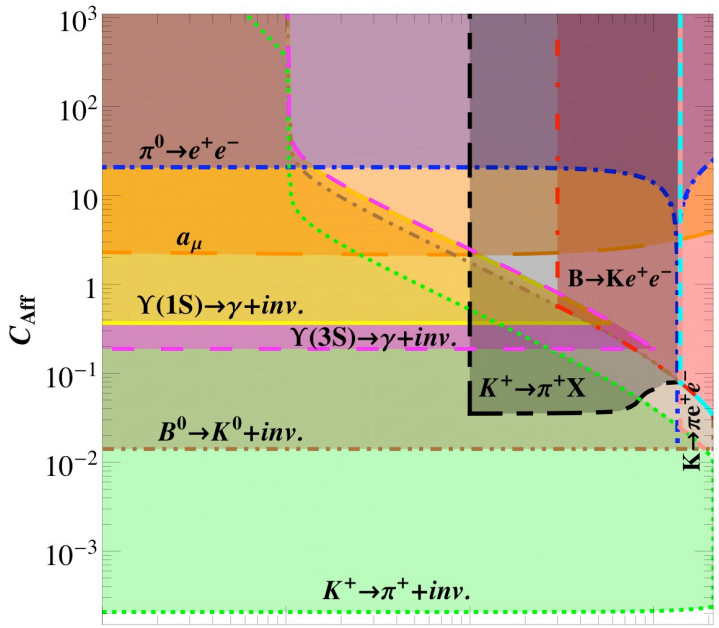
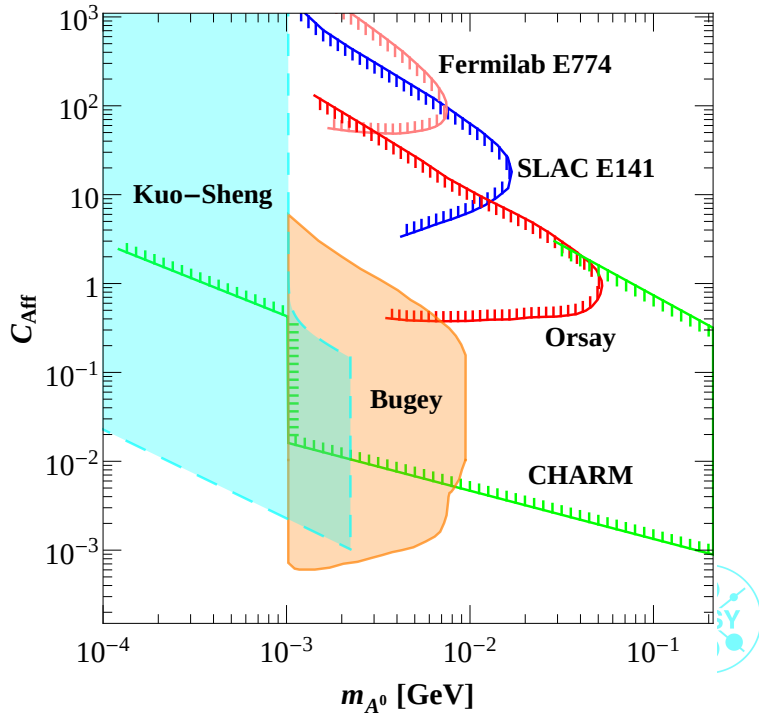


reactor experiments

ALP emitted in place of photons from excited nuclear levels





NMSSM results published in: S.A., O. Lebedev, S. Ramos-Sánchez, and A. Ringwald, *arXiv:1005.3978*

Outline

Hidden Photon and Kinetic Mixing [talk Redondo]

- additional $U(1)_h$-symmetry in HS
  $\Rightarrow$ hidden photon γ'
- SM not charged under HS and vice versa

dominant interaction: kinetic mixing of γ' and γ

- most general Lagrangian

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} - \frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{\chi}{2}B_{\mu\nu}F^{\mu\nu} + \frac{m^2_{\gamma'}}{2}B_\mu B^\mu$$

- $\chi \sim \frac{\alpha}{4\pi} \sim \mathcal{O}(10^{-4} - 10^{-3})$
  generated by loops of heavy particles charged under both $U(1)$ groups
- γ' couples and can decay to SM fermions through kinetic mixing

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Muon & Electron $g-2$

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one-loop contribution from hidden photon[Pospelov 2009]

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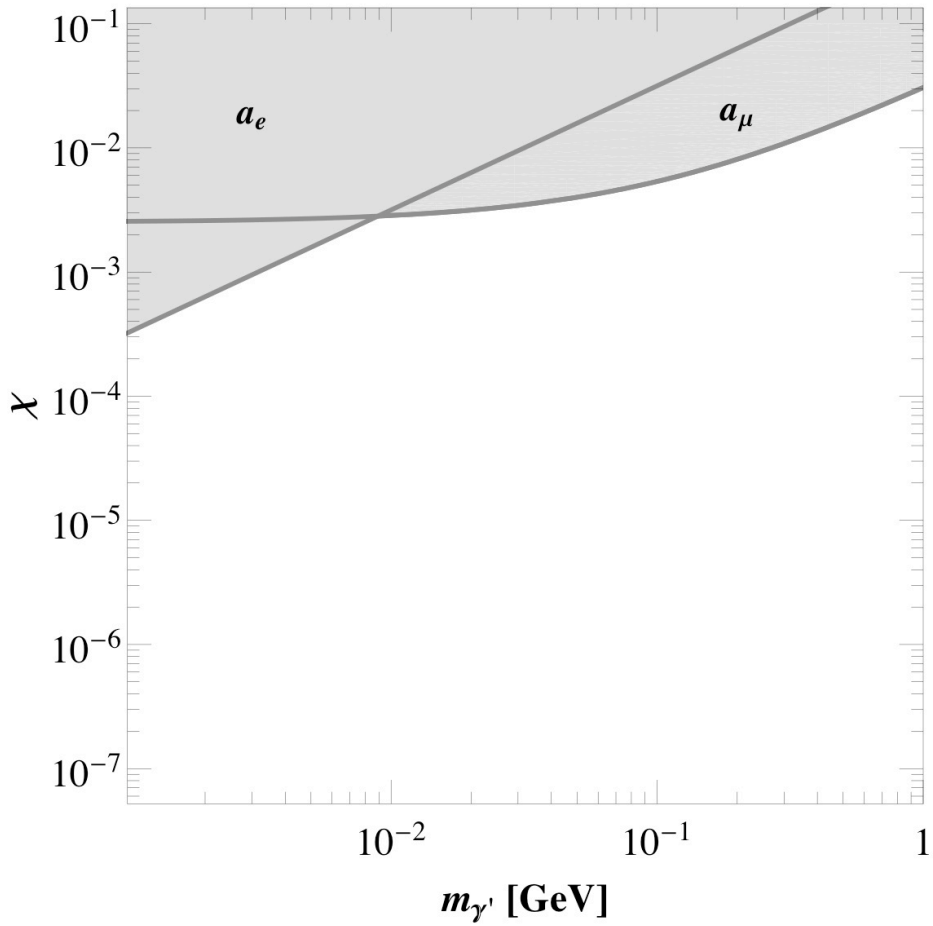

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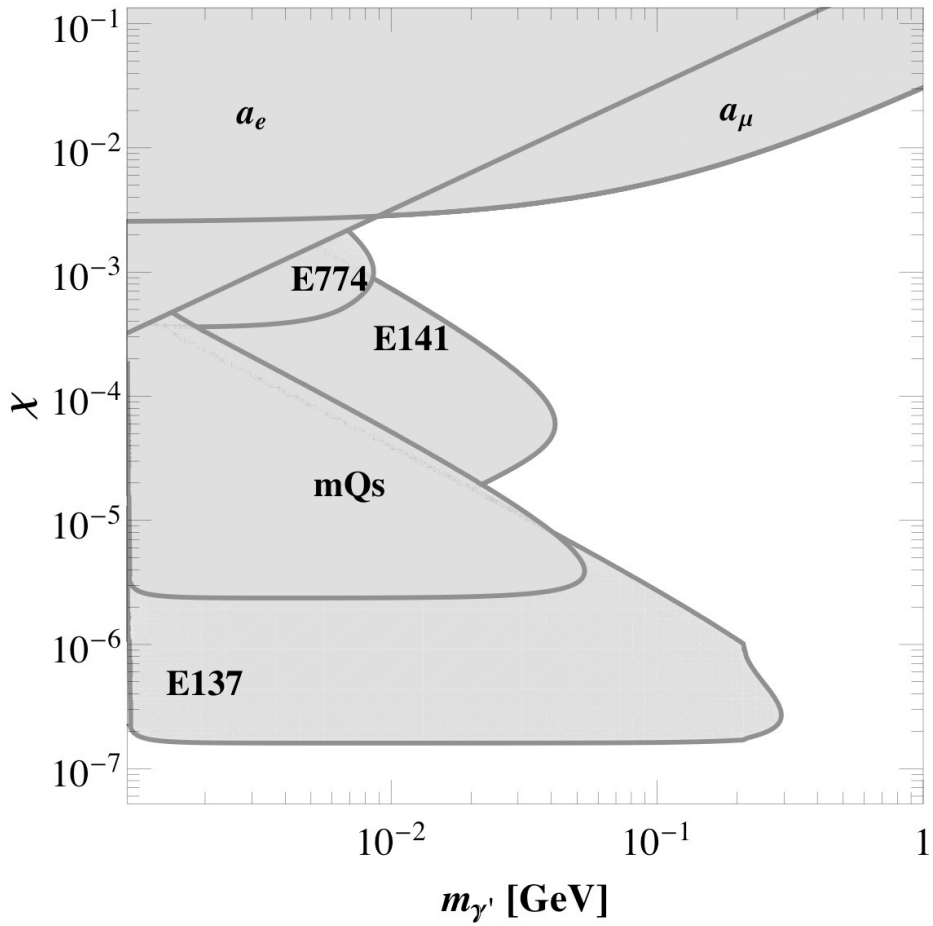

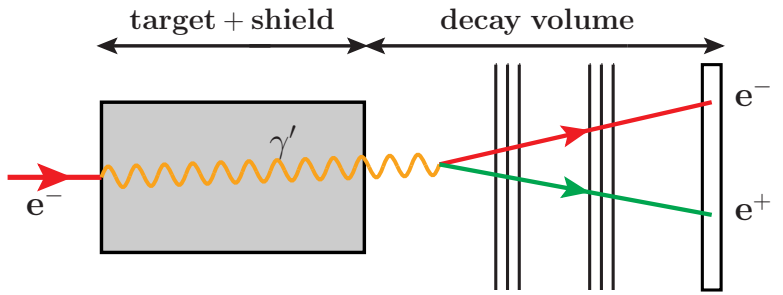

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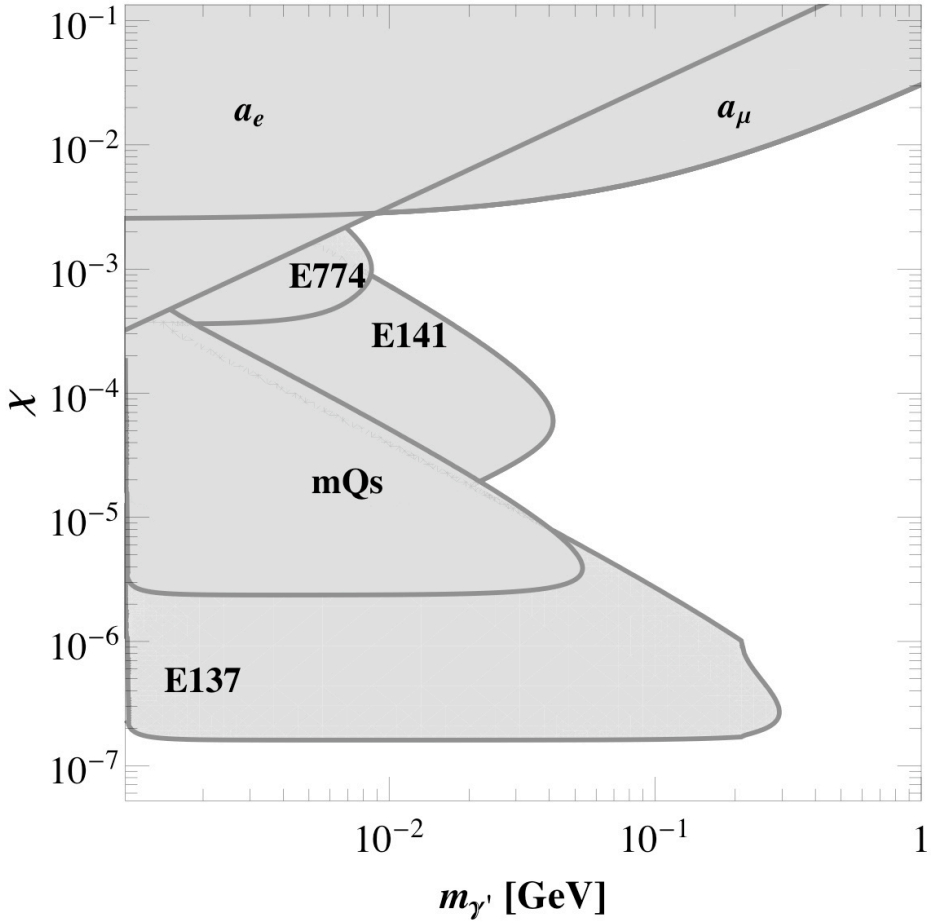

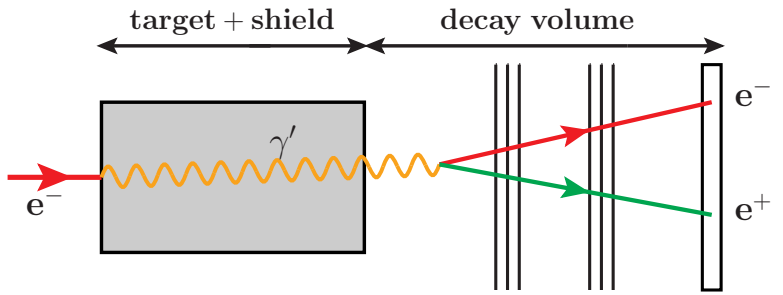

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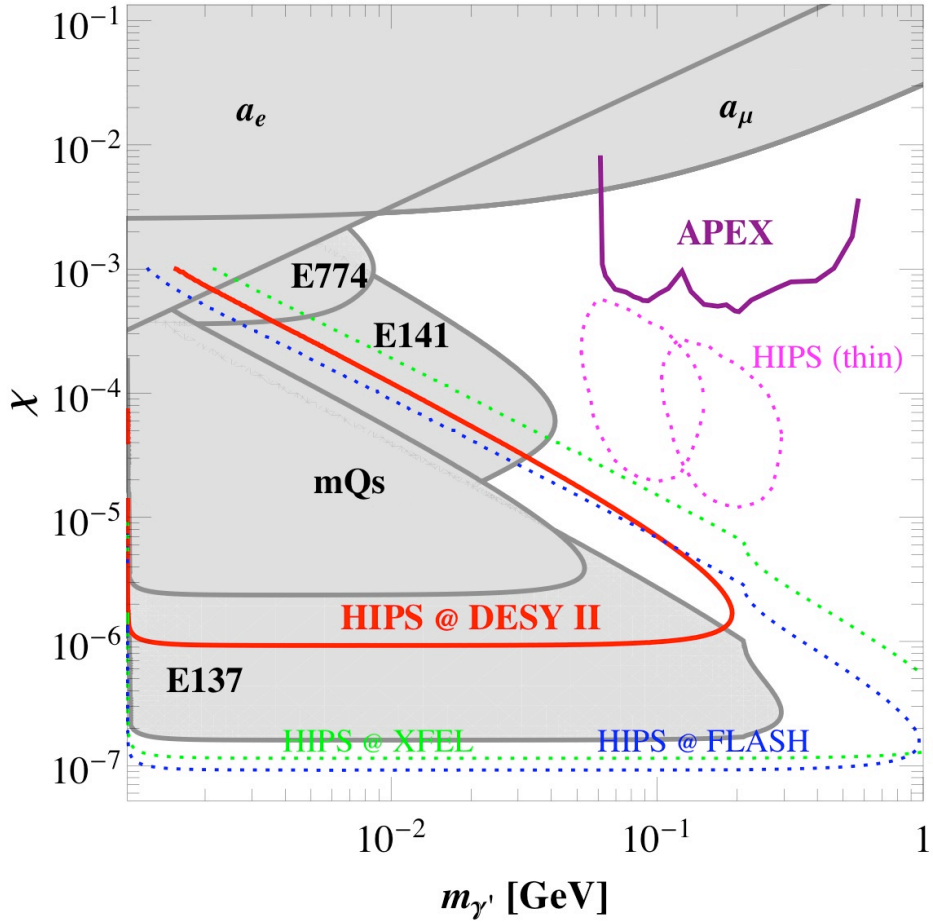
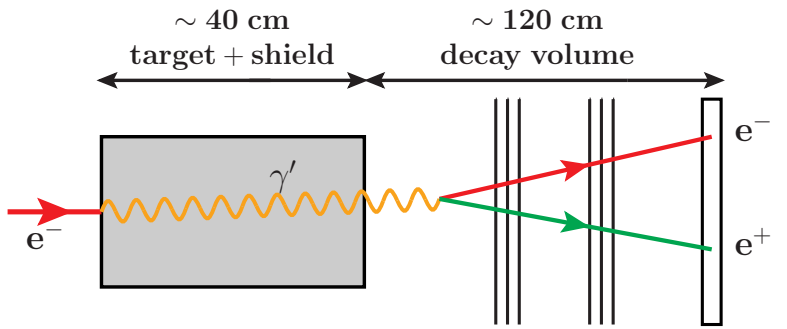
- JLab experiments e.g. APEX
- thick target at DESY: HIPS





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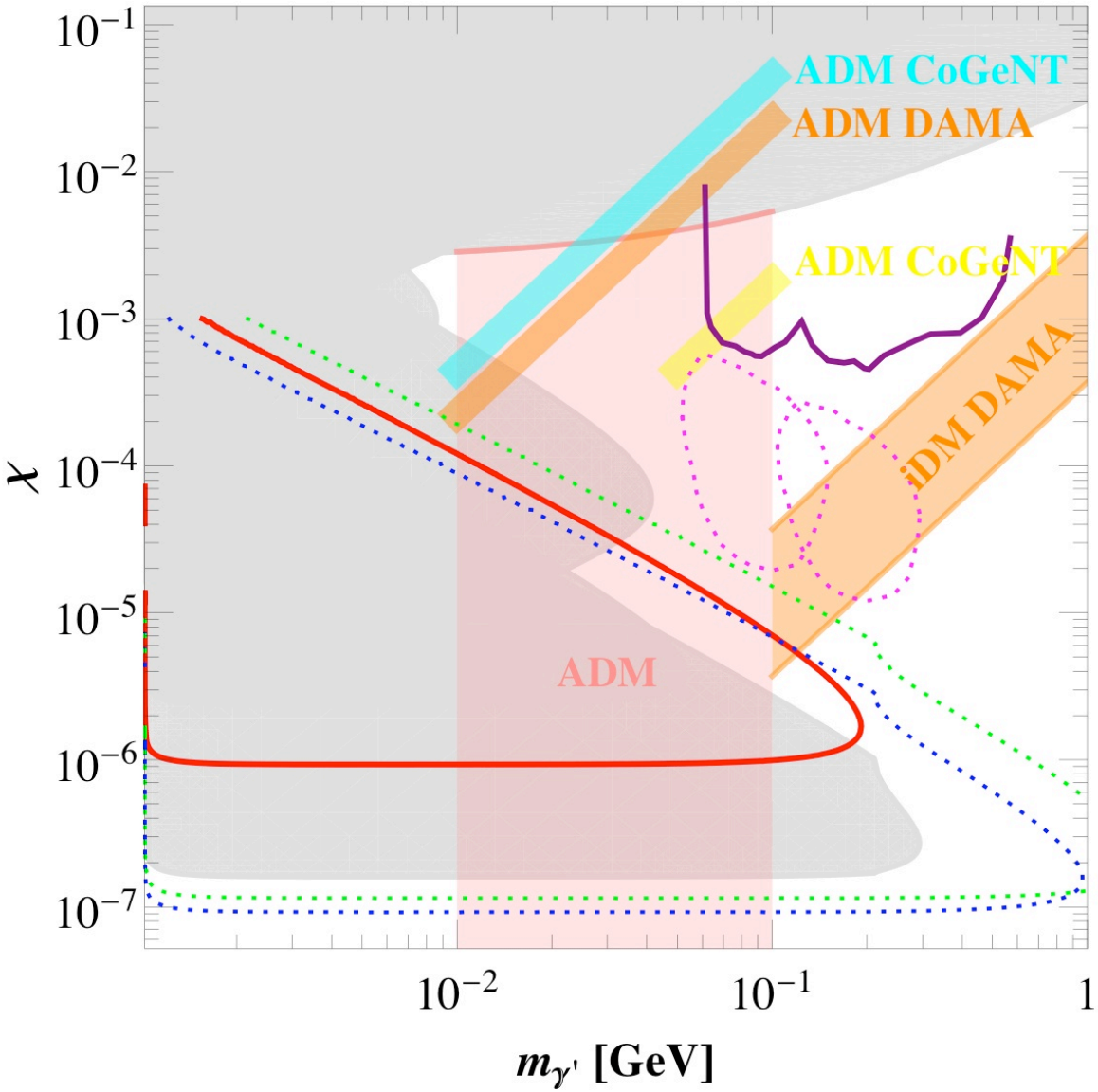
Summary

- HS well motivated: DM, SM extensions, string theory
- possibly light particles in HS with very weak couplings to SM
- constraints from various experiments
- NMSSM: A^0 heavier than 210 MeV or with 10 000 times weaker couplings to fermion than SM Higgs
- Hidden $U(1)$: γ' can be searched for at future beam dump experiments
  complementary searches at
  - JLab ⇒ see next talk by A. Afanasev
  - DESY HIPS ⇒ talk tomorrow by J. Mnich

- Asymmetric Mirror DM with hidden photon[An et al. 2010]
- Hidden Sector with hidden photon[Bjorken et al. 2009]



- NMSSM and PAMELA [Hooper & Tait 2009]
- $\chi^0\chi^0 \to A^0 h$ followed by $h \to A^0 A^0$ and $A^0 \to e^+e^-$ (top) or $\mu^+\mu^-$ (bottom)
- normalized to PAMELA, boost from Sommerfeld enhancement