Fixed-Target Signals of Multi-Component Light Hidden Sectors

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with

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hep-ph/1402.4817

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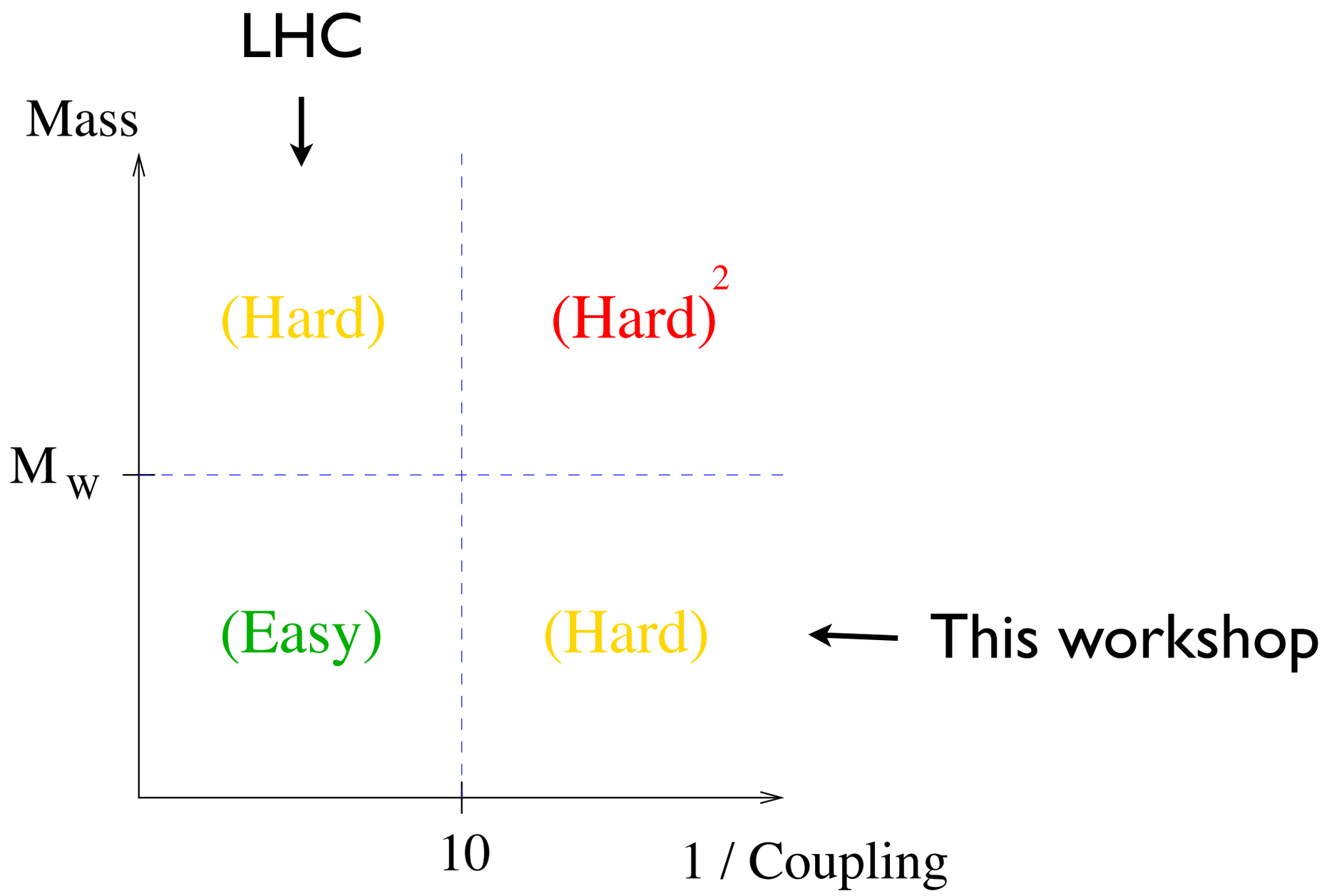
UVic DarkStuff Mini-Workshop

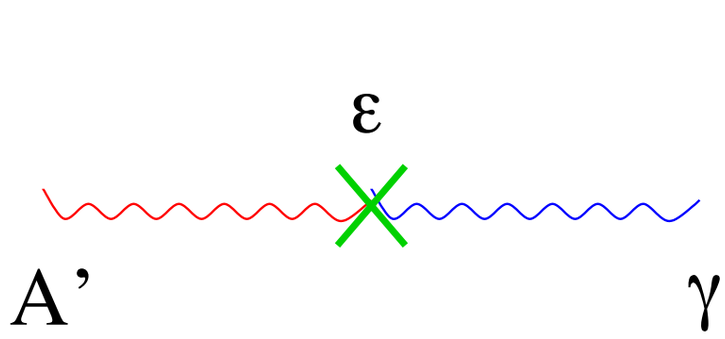
Searching for New Phenomena



Portals to Hidden Physics

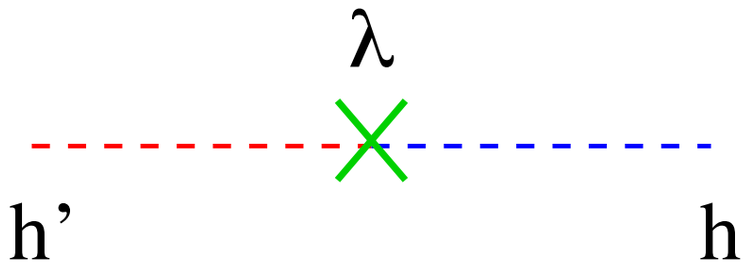
- Two nice ways for new hidden physics to couple:
  - Vector Portal:
    (A' = "hidden photon")

$$\epsilon F'_{\mu\nu} F^{\mu\nu}$$



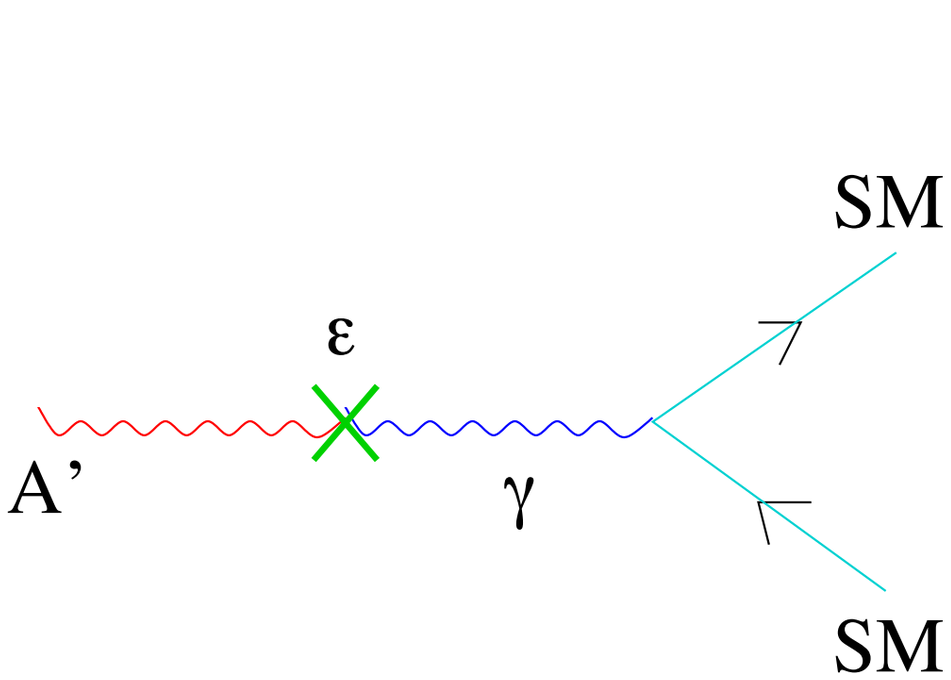
  - Higgs Portal:
    (H' = "hidden Higgs")

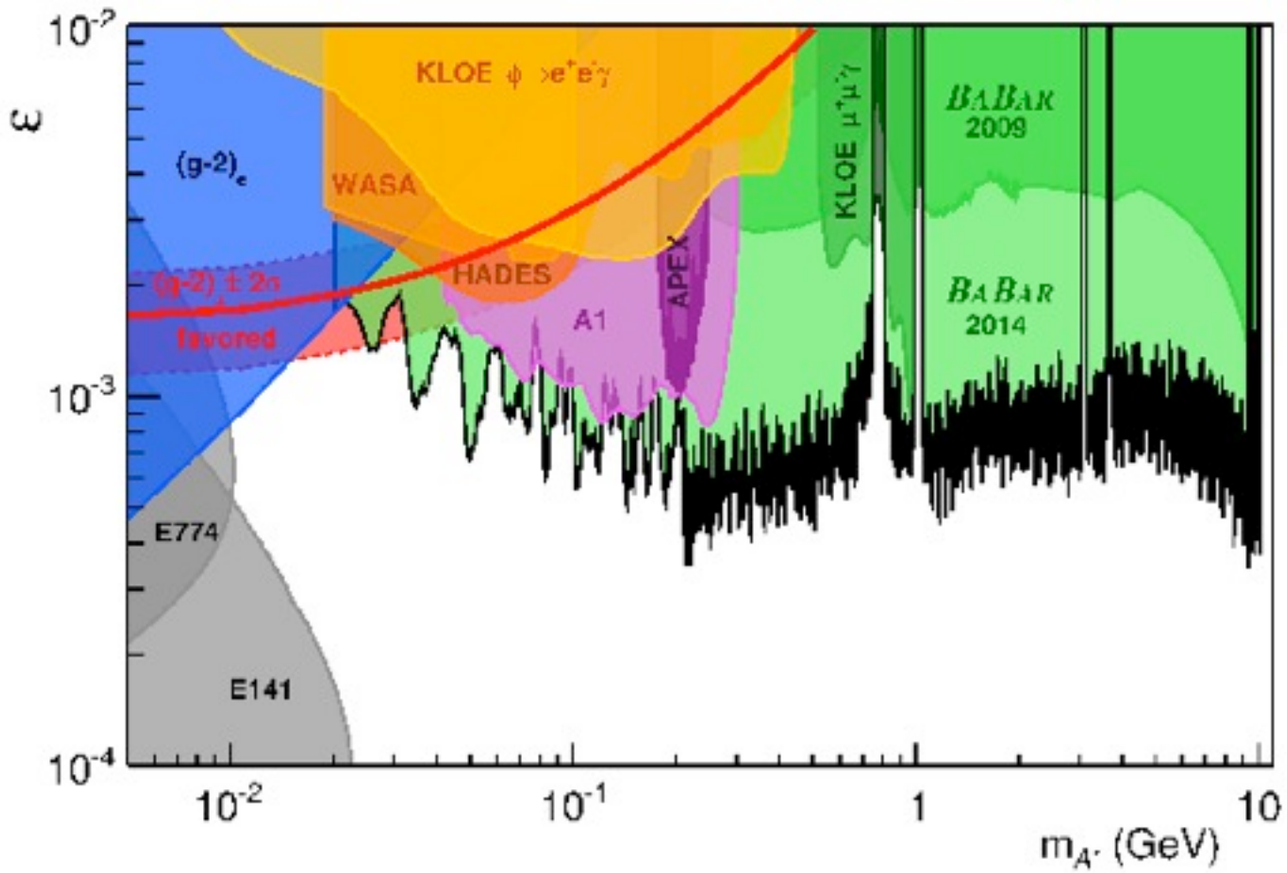
$$\lambda |H'|^2 |H|^2$$



Minimal Vector Portal

- Hidden photon A’ with mass $m_{A'}$, A’ → SM+SM:

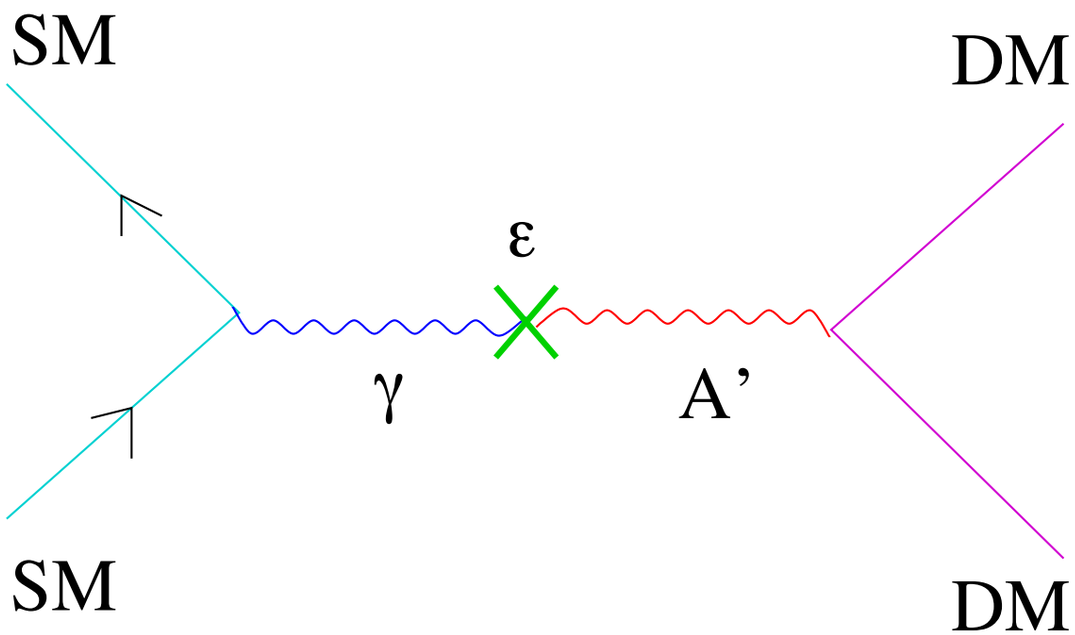


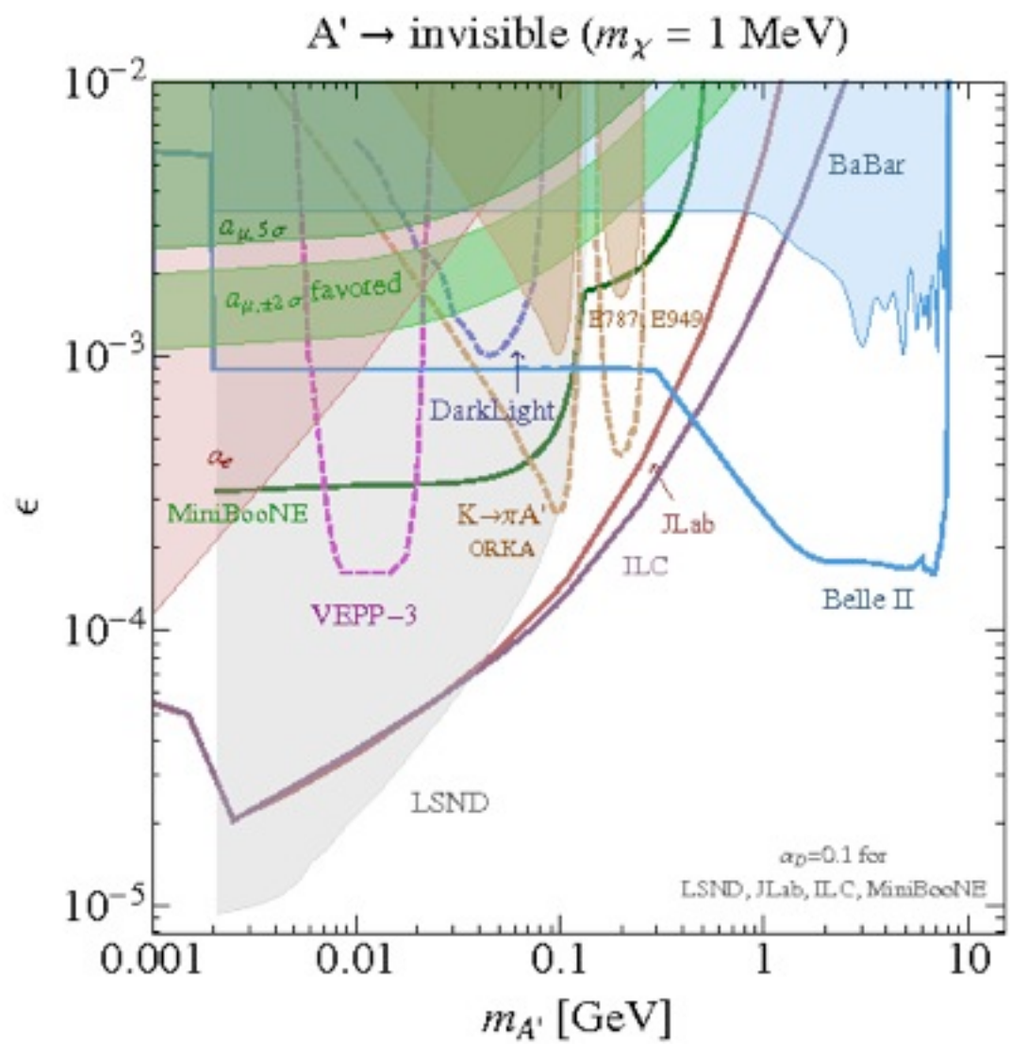


[Bjorken, Essig, Schuster, Toro 2009; ...; BaBar 2014]

Minimal Dark Vector Portal

- Hidden photon A’ with mass $m_{A'}$, A’ → DM+DM:

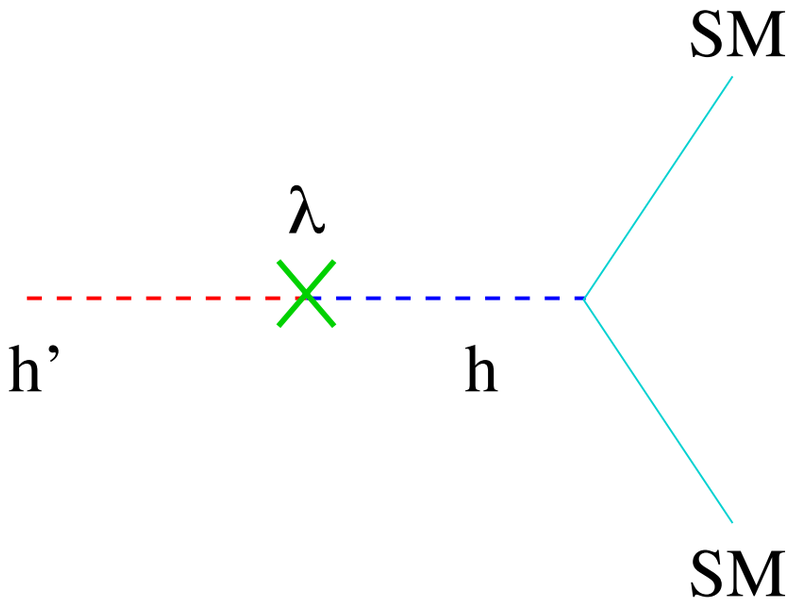




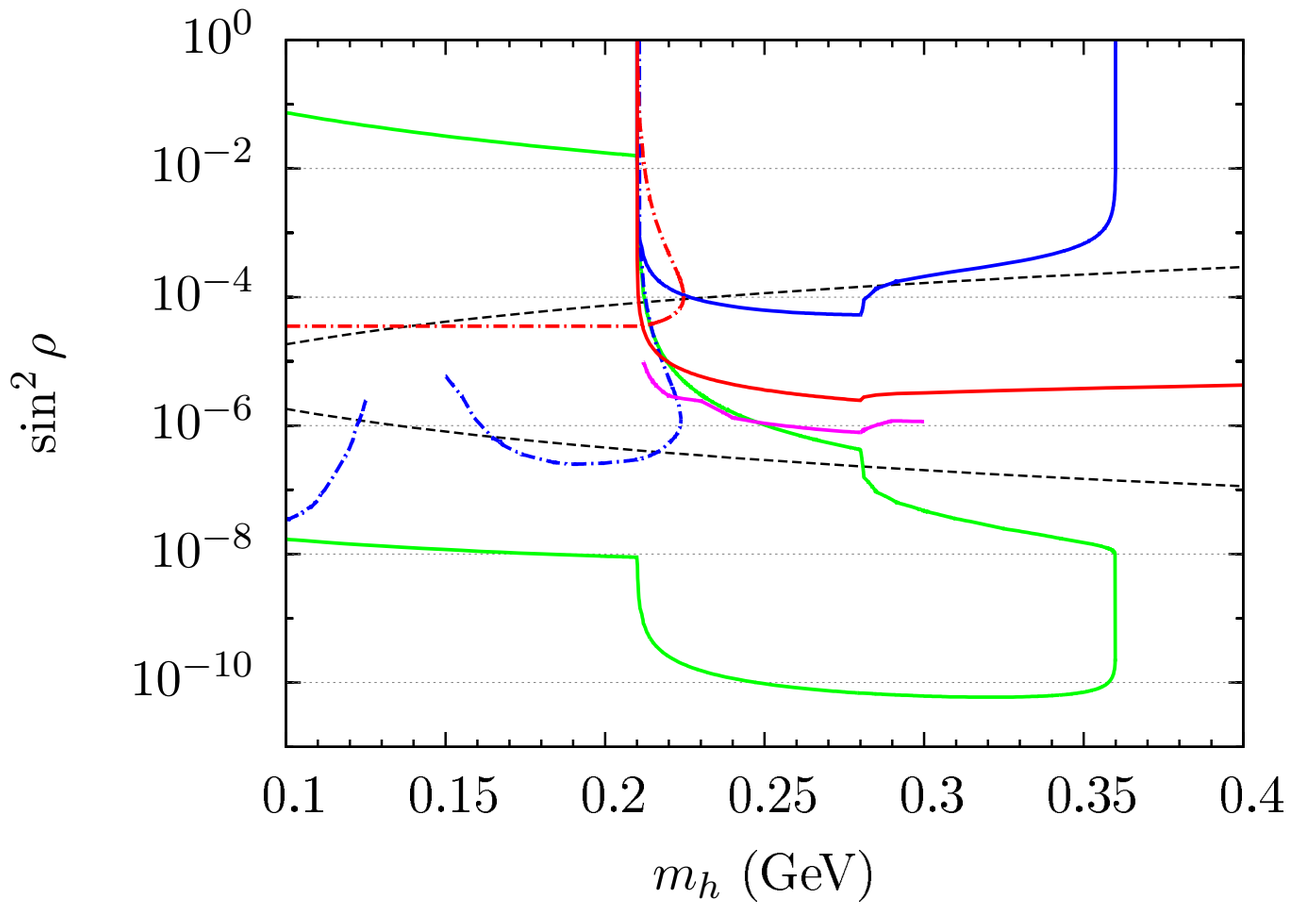
[Batell, Pospelov, Ritz 2009; ...; Essig et al. 2013]

Minimal Higgs Portal

- Hidden Higgs h' with mass $m_{h'}$, h' → SM+SM:



$$\sin^2\rho \simeq \lambda^2 \left(\frac{m_{h'}}{m_h}\right)^2$$



[...; Batell, Pospelov, Ritz 2009; Bezrukov+Gorbunov 2013; Clarke, Foot, Volkas 2013]

Beyond Minimal

- Hidden sectors can be more complicated than minimal. These can produce new and interesting signatures.
- How does the dark photon get a mass?
  → Higgsing, Strong Coupling, Stueckelberg, ...
- What keeps the hidden sector light?
  → Supersymmetry, Compositeness/Warping, ...
- Are there experimental signals we are missing?

- Can we learn about the visible sector by discovering a hidden sector?

Beyond Minimal #1: SUSY Dark Vector

- Why Supersymmetry (SUSY)?
  - Some people are quite fond of it.
  - Can explain why the hidden sector is so light.
  - Gives a concrete non-minimal vector portal theory.
  - Studying new theories can motivate new exp. searches.

SUSY Hidden Sector Setup

- Hidden U(1)' gauge symmetry kinetically mixes with $U(1)_Y$.
- Hidden Higgs fields spontaneously break the U(1)'.

$$\mathcal{L} \supset \int d^2\theta \left(\underbrace{\frac{\epsilon}{2c_w} B^\alpha X_\alpha}_{\text{vector portal}} + \underbrace{\mu' H H'}_{\text{hidden Higgs fields}} \right) + (h.c.)$$

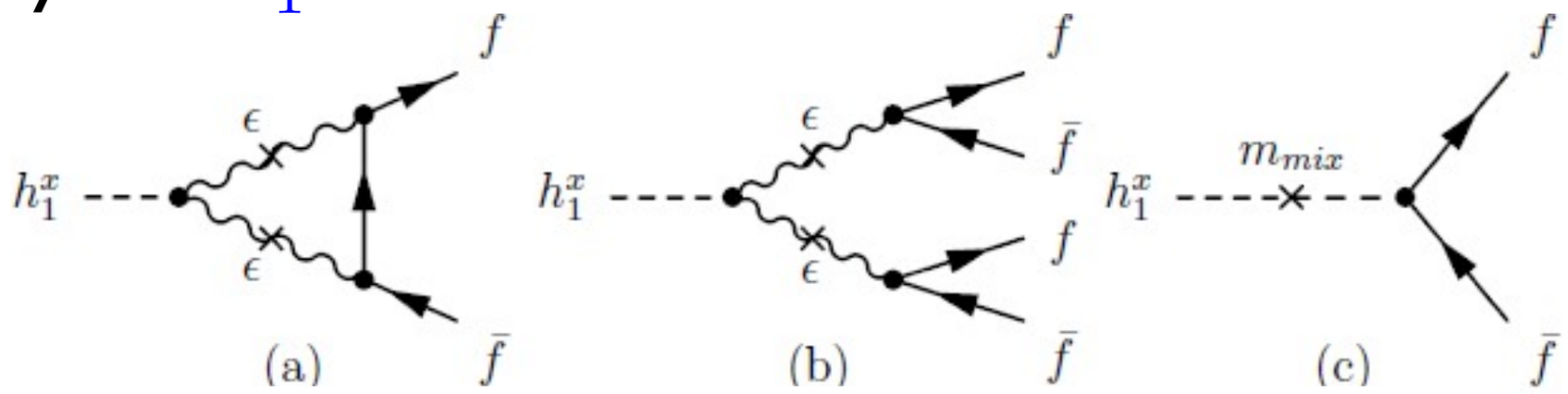
- Physical states:
  - 1 A' massive hidden photon
  - 3 $\chi^x_{1,2,3}$ hidden fermion "neutralinos" (lightest is stable)
  - 2 $h^x_{1,2}$ hidden scalar Higgs bosons
  - 1 a^x hidden pseudoscalar Higgs boson

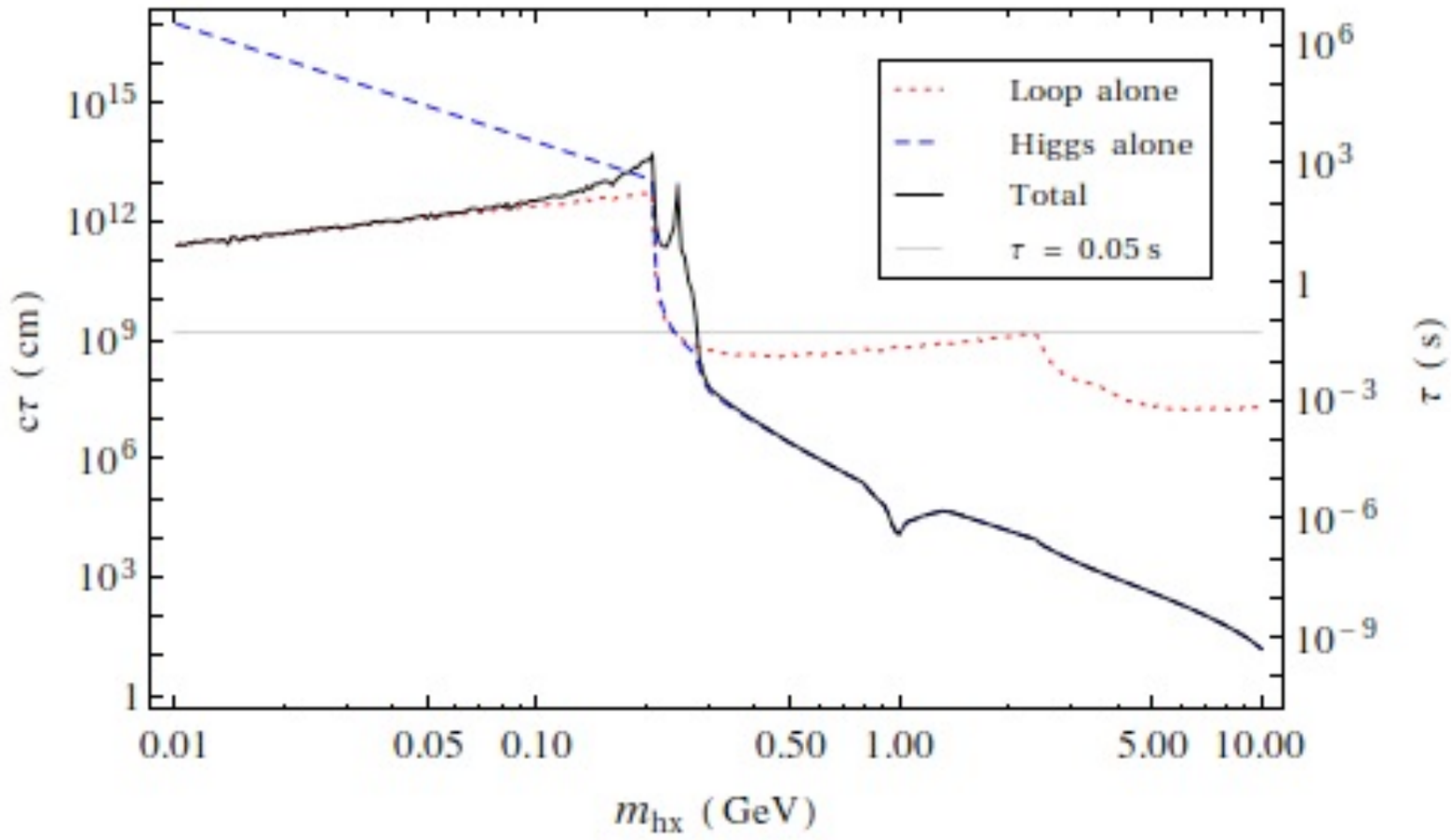
Experimental Signals of the Theory

- Depend mainly on how the hidden photon decays. This is determined mostly by the mass spectrum.
- Four main cases:
  - A: $A' \to SM + SM$, similar to minimal vector portal
  - B: $A' \to \chi_1^x + \chi_1^x$, similar to dark vector portal
  - C: $A' \to h_1^x + a^x$, not much attention [Schuster, Toro, Yavin 2009]
  - D: $A' \to \chi_1^x + \chi_2^x$, new!
- I will focus on cases C and D.

Case C: $A' \to h_1^x + a^x$

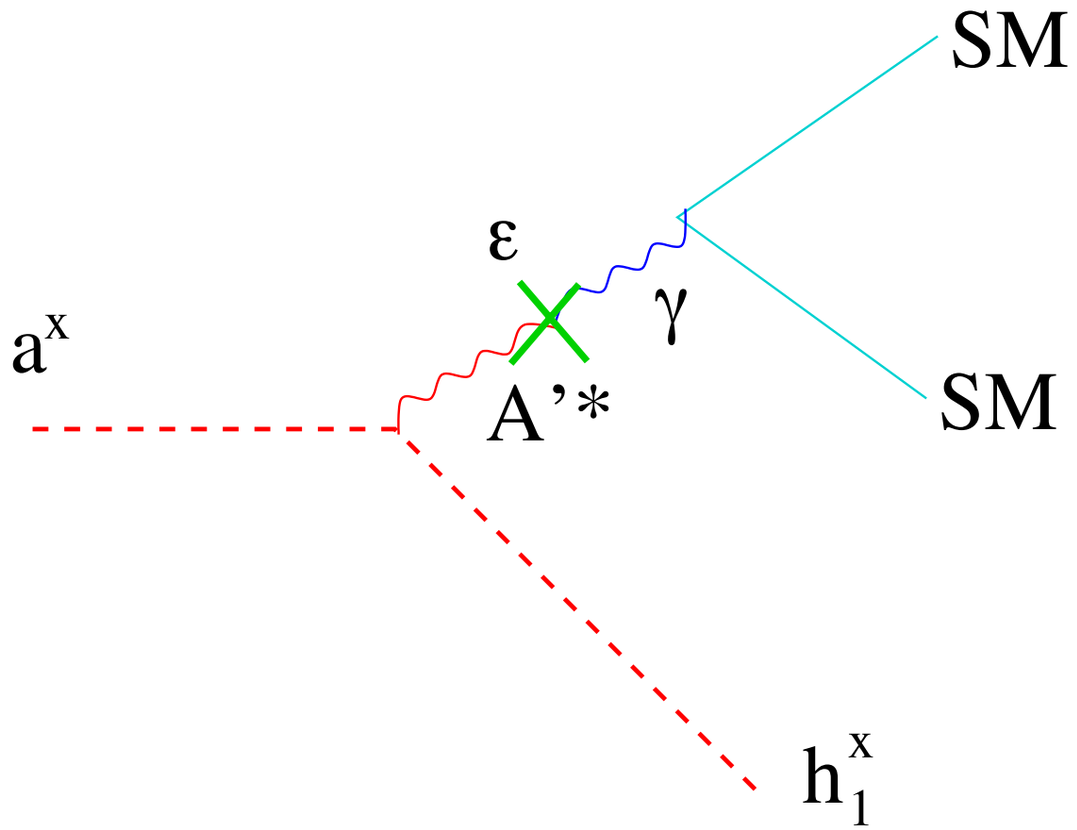
- Decays of h_1^x :





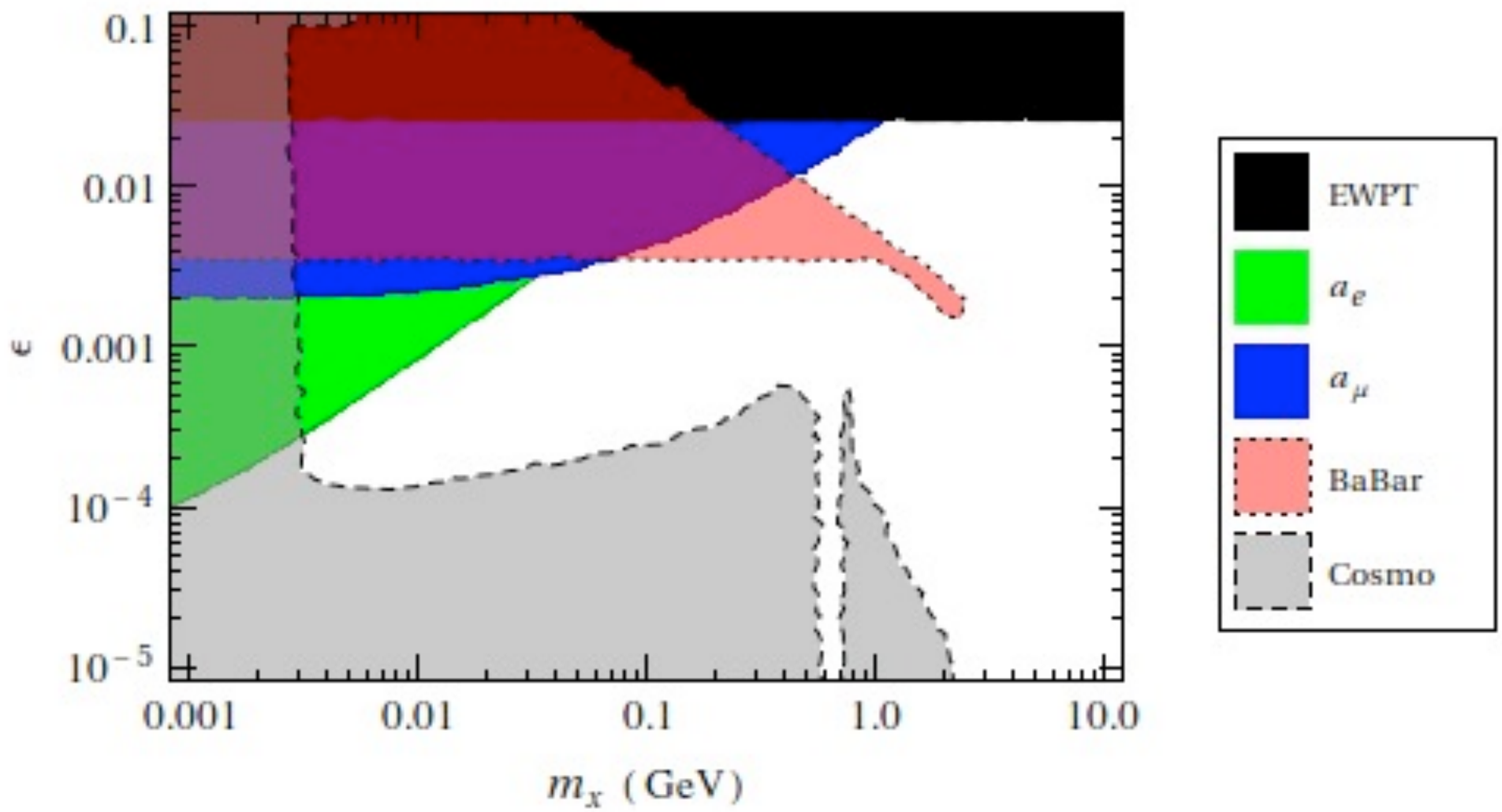
Case C: $A' \to h_1^x + a^x$

- Decays of a^x:



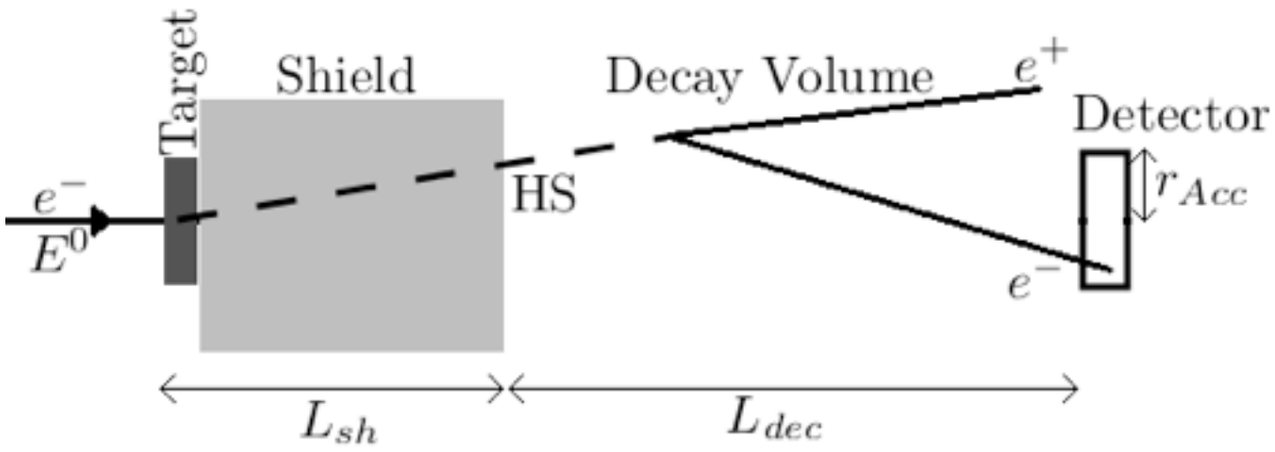
- Lifetime depends on relative a^x and A' masses.

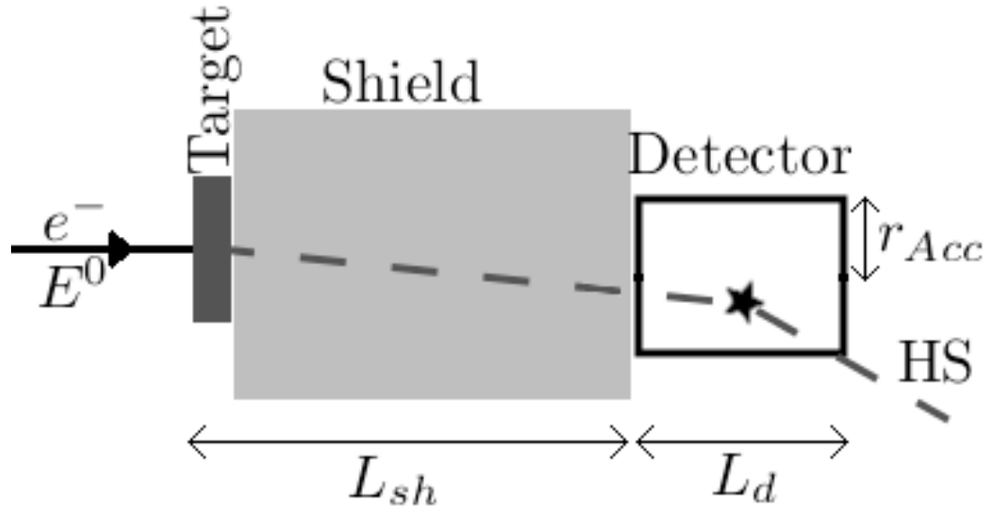
Case C: Precision and Meson Factories



Case C: Electron-Fixed-Target Signals

- Signal Sources:



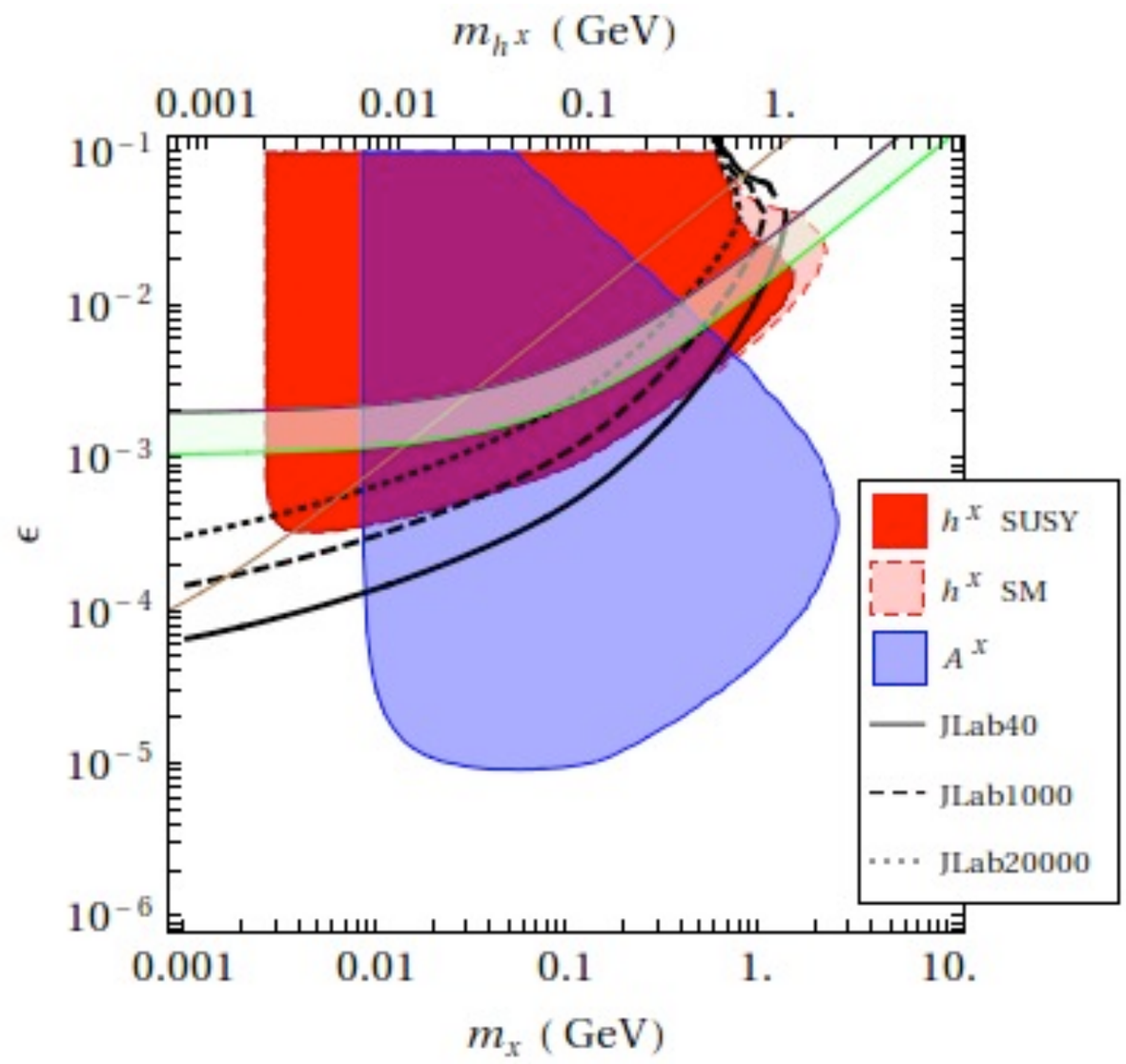


- A' is produced relatively efficiently, mostly along the beam.
- Two sources of signals:

  1. decay products of h_1^x or a^x are seen in the detector.
  2. h_1^x or a^x scatters quasi-elastically in the detector.

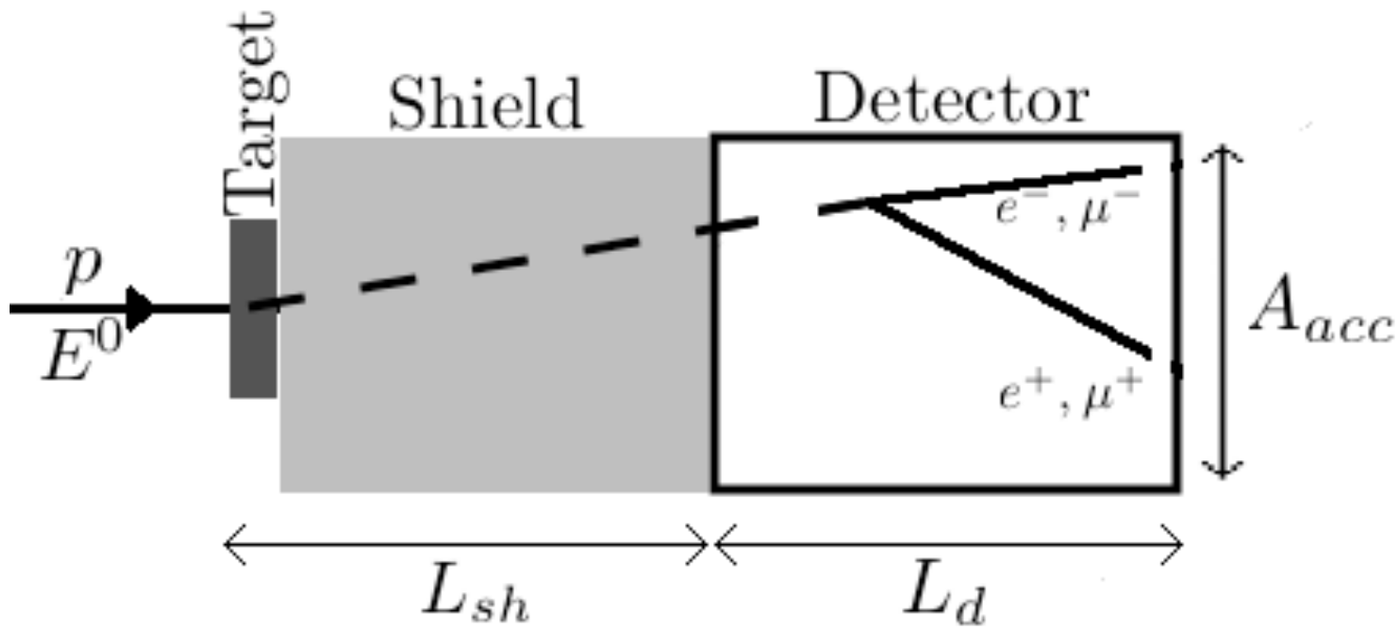
Case C: Electron Fixed Target Limits

- Set all parameters as fixed ratios of $m_{A'}$, $\alpha' = \alpha$.
- Best limits come from E137.



Case C: Hadronic Fixed Target Signals

- Signal Sources:

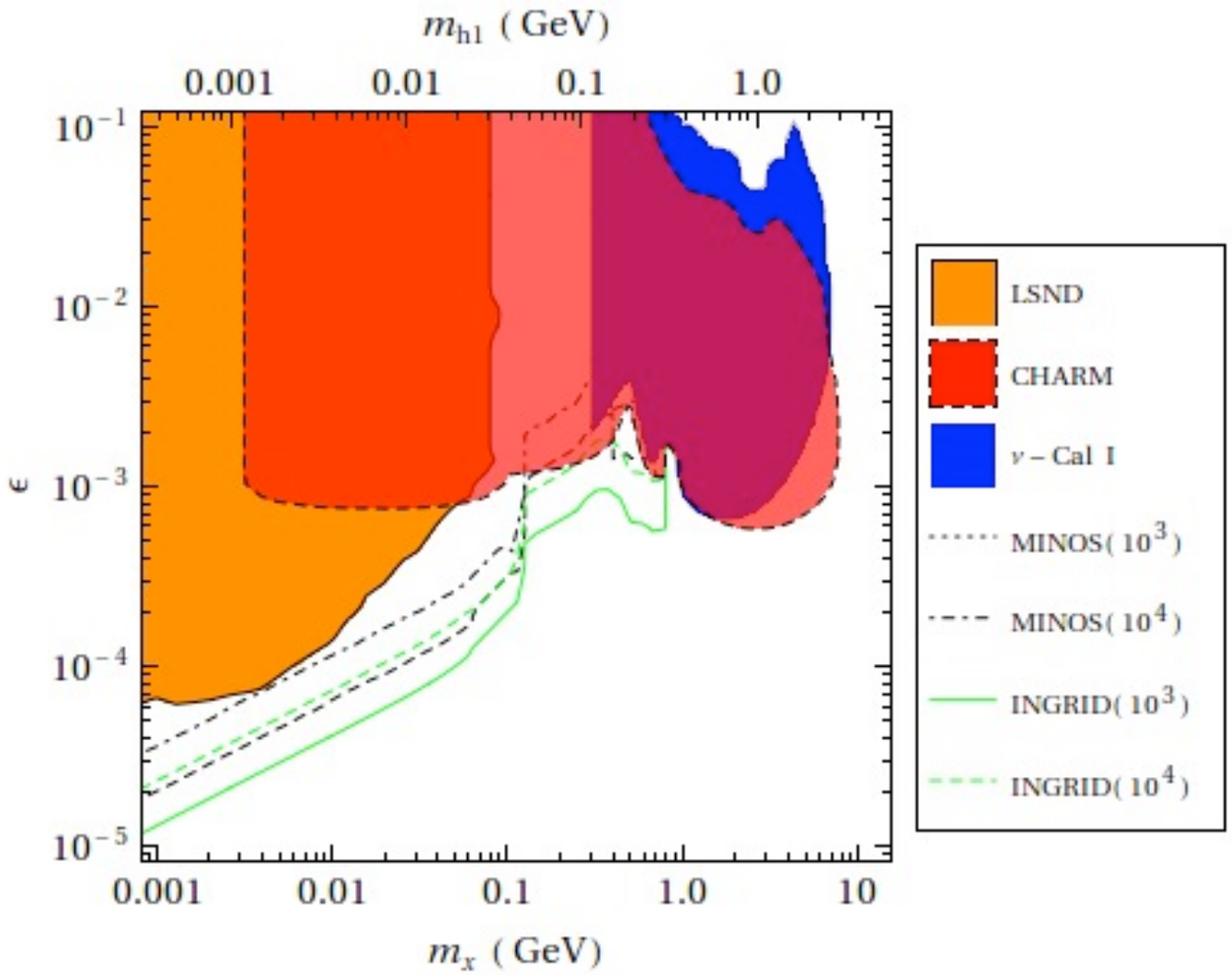


- A' production from parton collisions or meson decay.
- Two sources of signals:

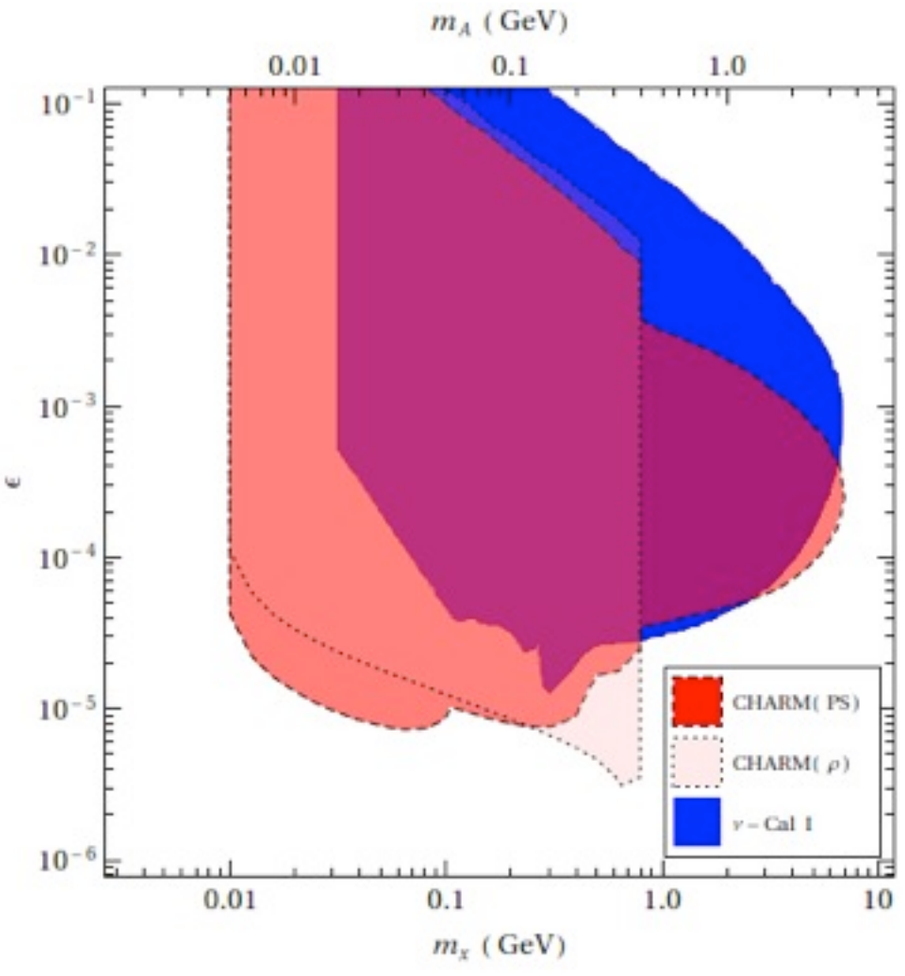
  1. decay products of h_1^x or a^x are seen in the detector.
  2. h_1^x or a^x scatters quasi-elastically in the detector.

Case C: Hadronic Fixed Target Limits

- Set all parameters as fixed ratios of $m_{A'}$, $\alpha' = \alpha$.
- Best limits come from CHARM, LSND, and ν-Cal I.



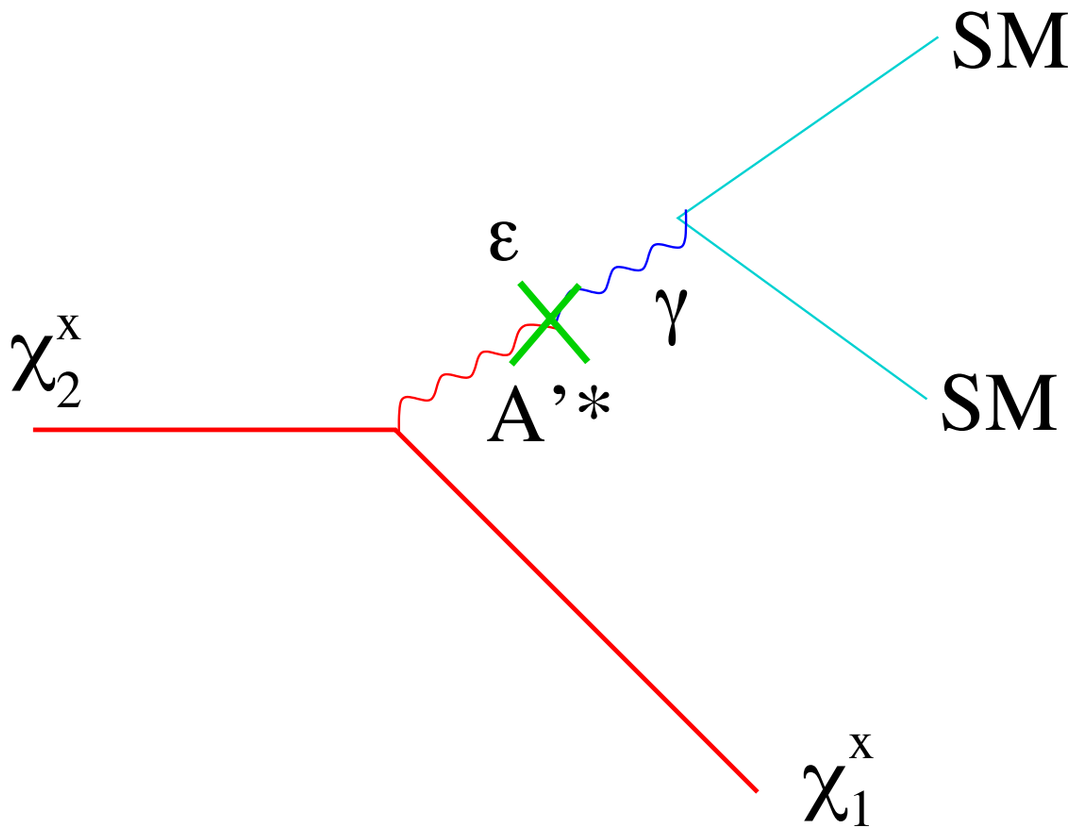
$h_1^x + invisible$



a^x

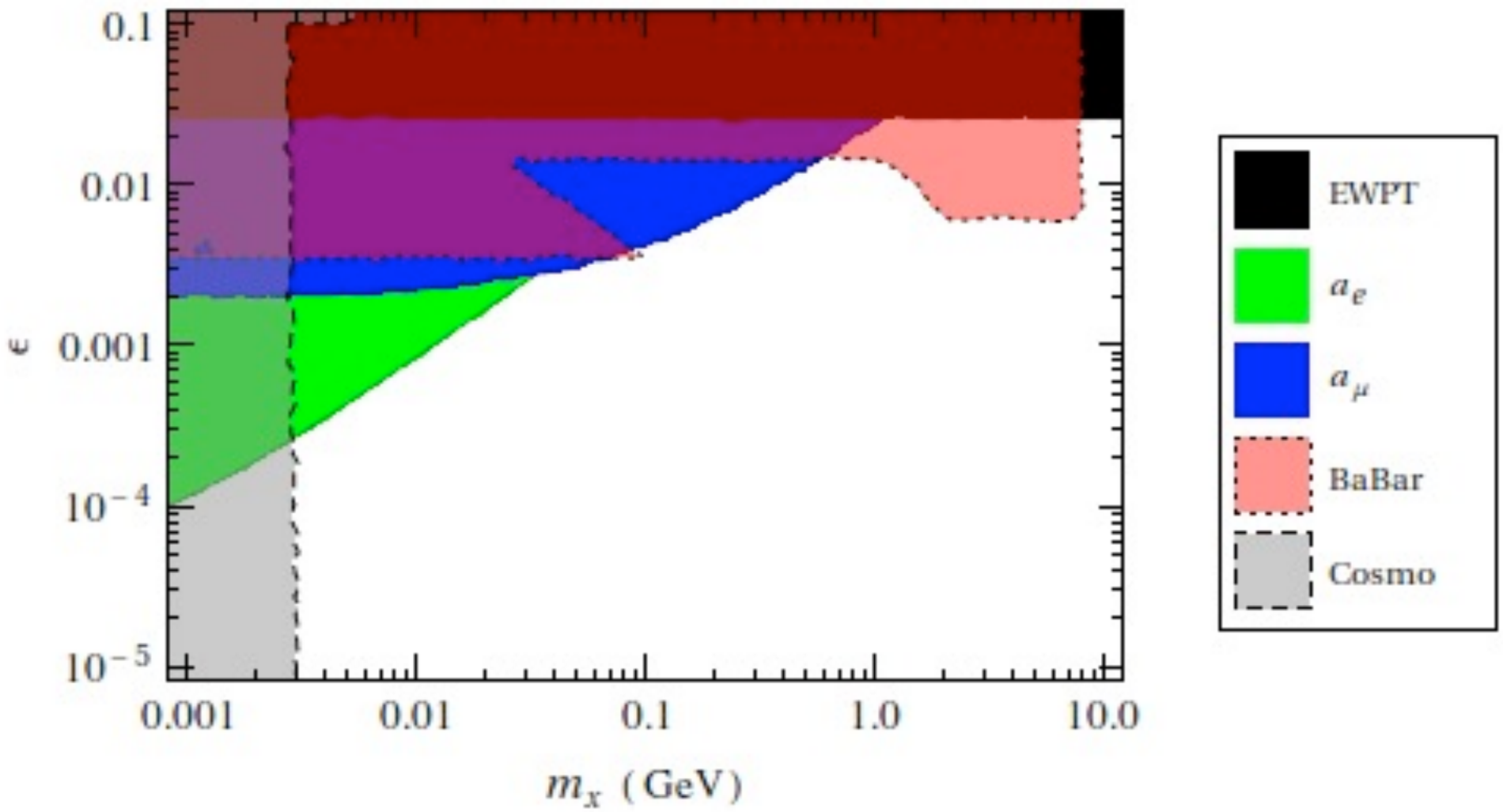
Case D: $A' \to \chi_1^x + \chi_2^x$

- Decays of χ_2^x:



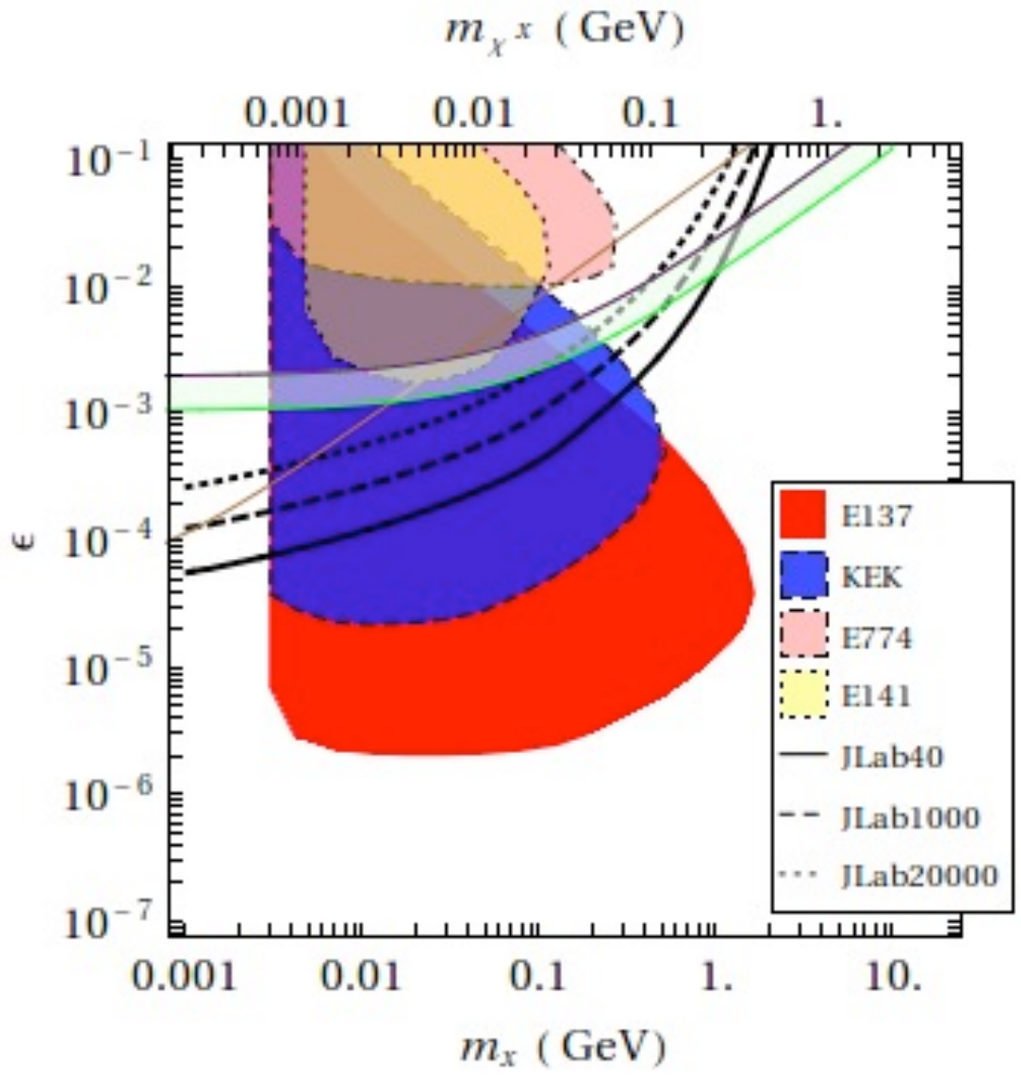
- Lifetime depends on relative χ_2^x and A' masses.

Case D: Precision and Meson Factories



Case D: Electron Fixed Target Limits

- Set all parameters as fixed ratios of $m_{A'}$, $\alpha' = \alpha$.
- Best limits come E137 and others.



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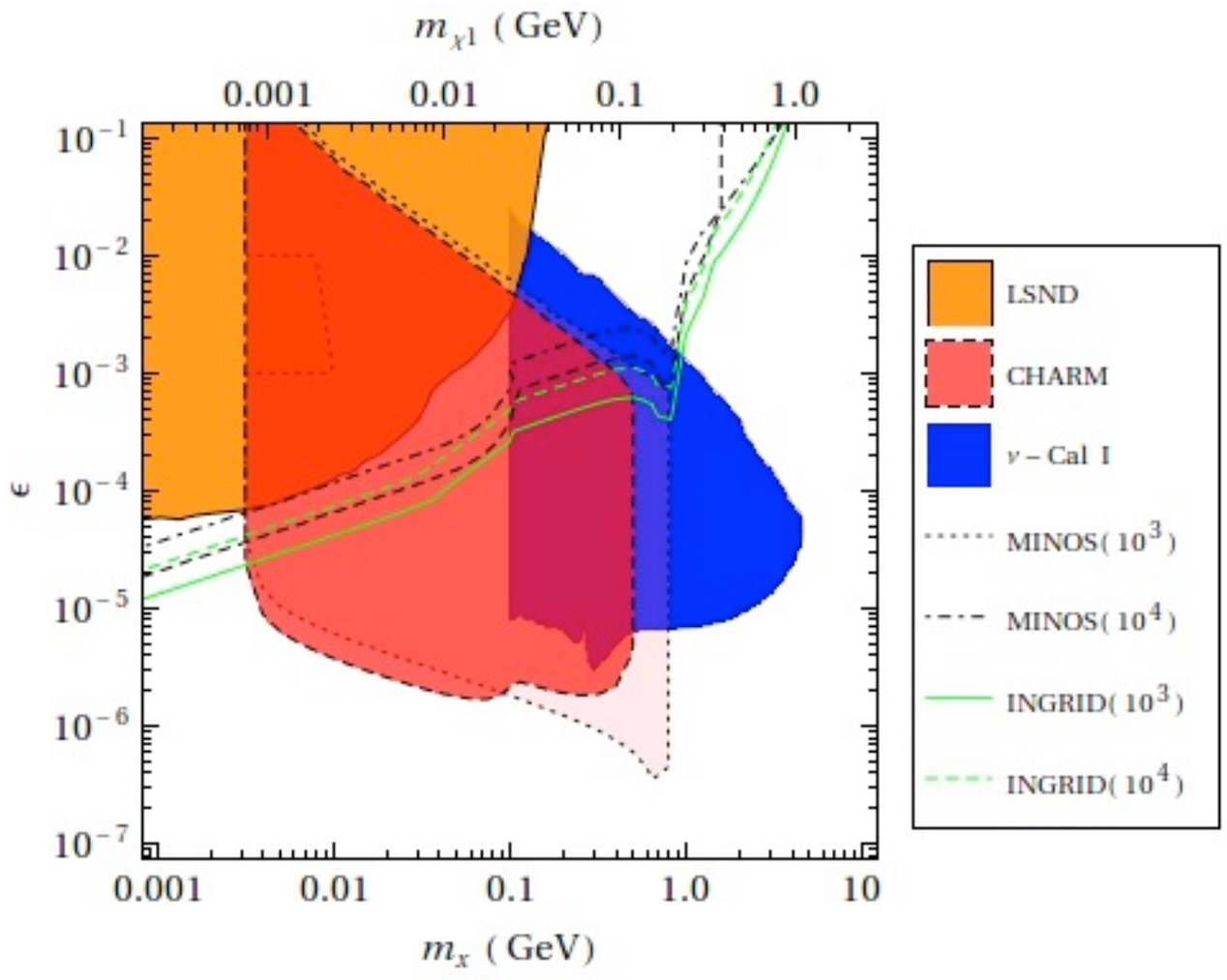


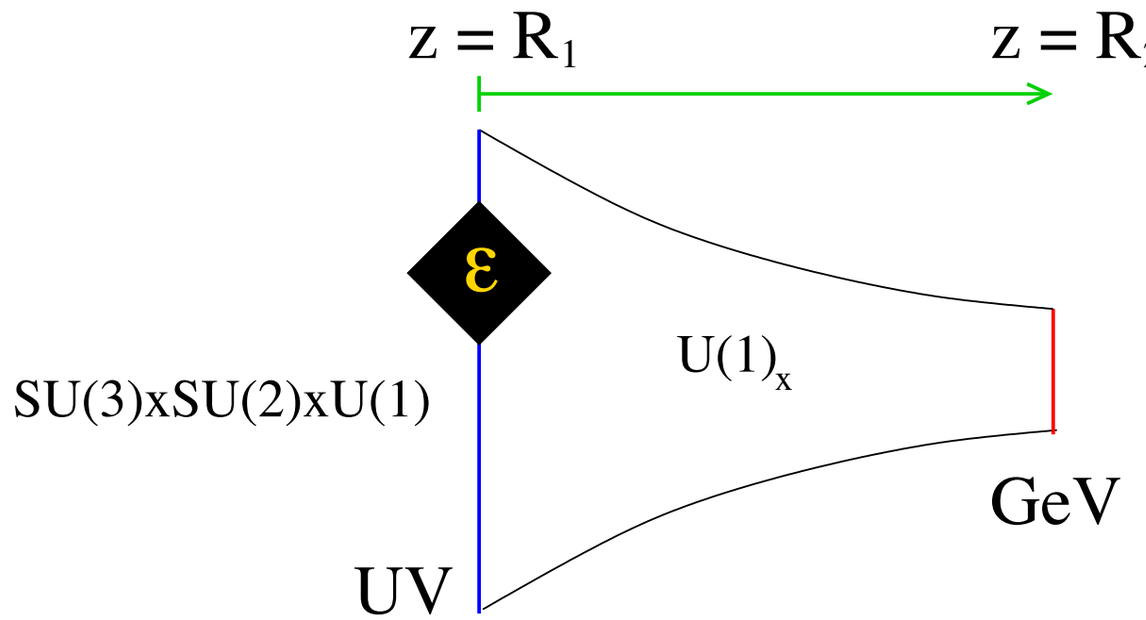
Beyond Minimal #2: Warped Dark Vector

- Why a warped extra dimension?
  - Some people are quite fond of it.
  - Can explain why the hidden sector is so light.
  - Gives a concrete non-minimal vector portal theory.
  - Studying new theories can motivate new exp. searches.

Beyond Minimal #2: Warped Dark Vector

- We live on a 4-D slice of a warped 5D spacetime.
  A dark $U(1)_x$ vector (and gravity) probes the full 5D.

[McDonald, DM '10]



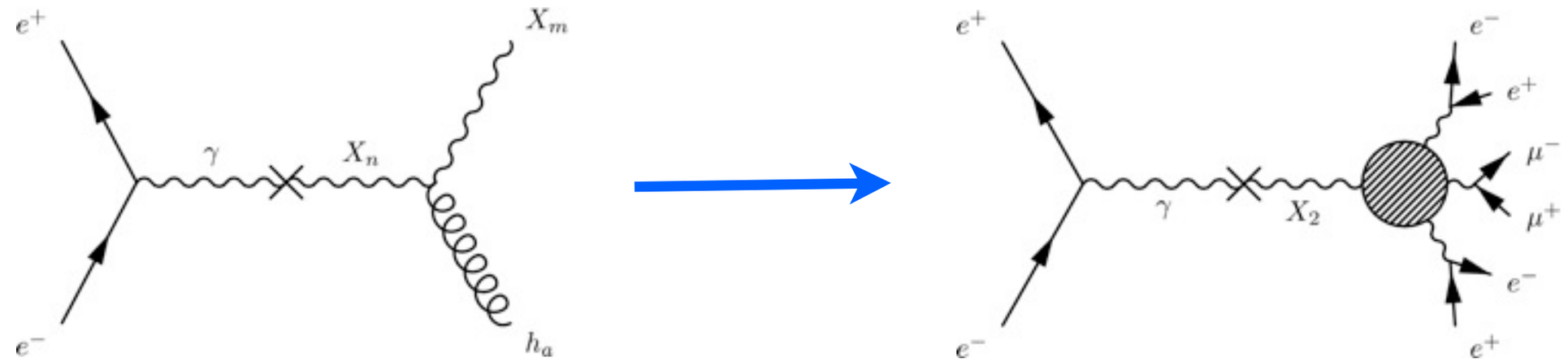
- Predicts a dark photon (n=0) and KK excitations (n > 0):

$$m_n \simeq (n\sqrt{\mathrm{Log}}) \times m_0 \qquad n = 1, 2, 3 \ldots$$

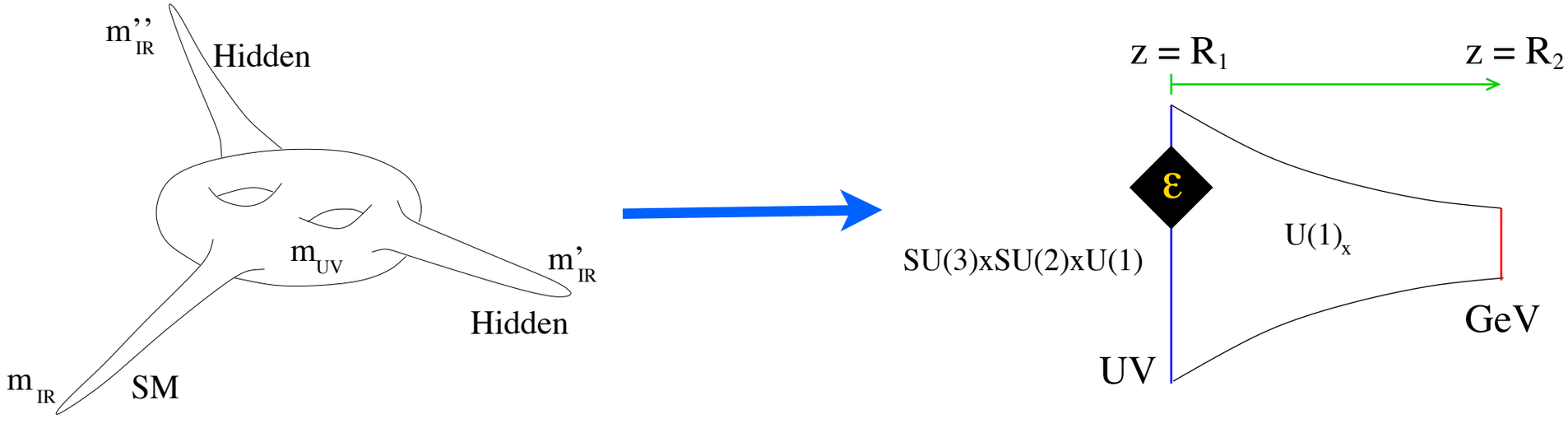
$$\epsilon_n = (1/\sqrt{n\,\mathrm{Log}}) \times \epsilon_0$$

Beyond Minimal #2: Warped Dark Vector

- Higher vector modes can decay to lower vector modes, or to KK graviton excitations.



- This is a toy model for hidden strong dynamics, or certain string theory scenarios with "warped throats".



Summary

- New hidden states can produce new signals.
- e.g. SUSY hidden sector with Cases A, B, C, D:
  - Cases A ($A' \to SM + SM$) and B ($A' \to \chi_1^x + \chi_1^x$) are similar to what has been studied previously.
    - Cases C and D have not received much attention, but are particularly well-suited to fixed target searches.
- Many other possibilities...

Extra Slides: SUSY

Electron Fixed-Target Experiments

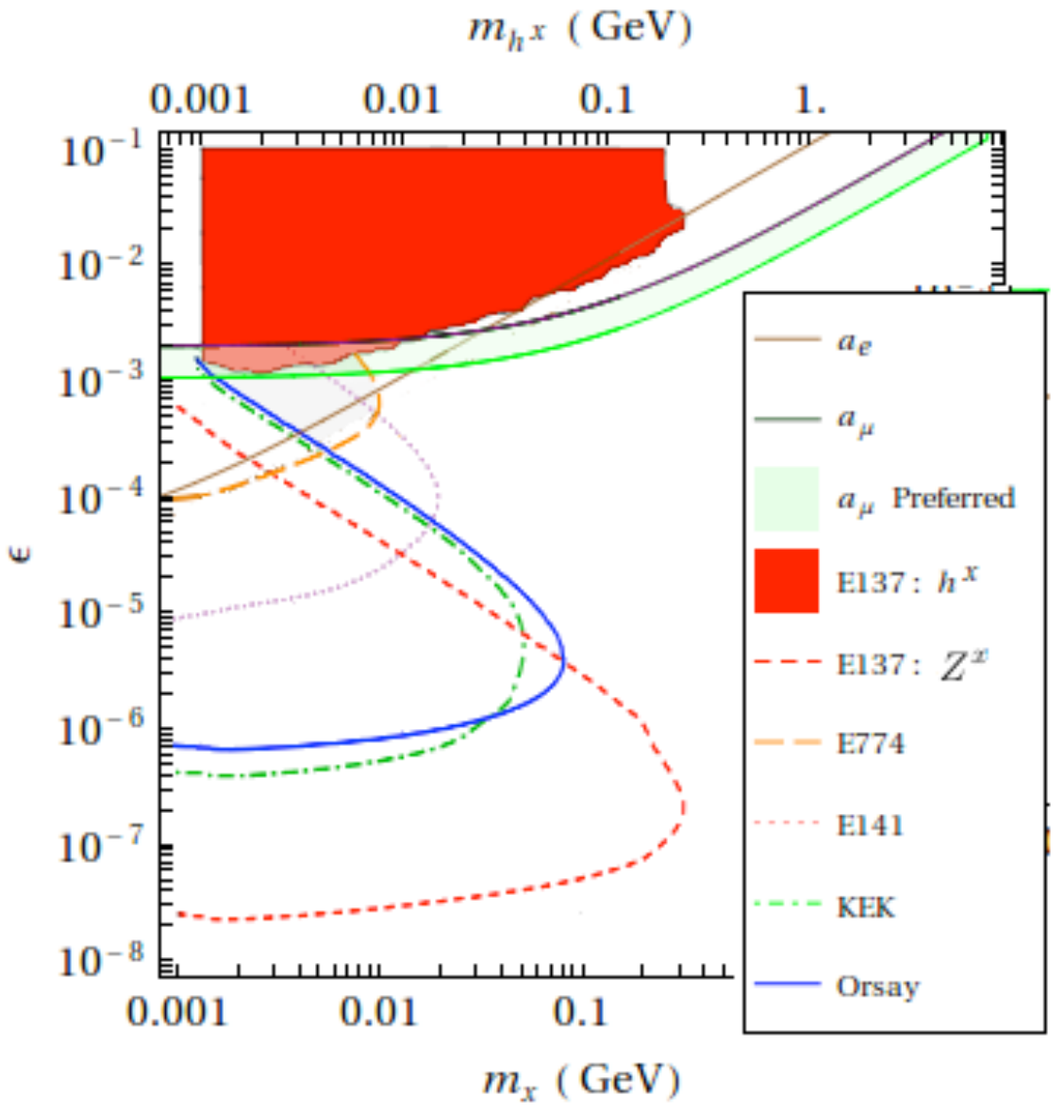
Expt	Target	E (GeV)	$Log_{10}N_e$	L_{sh}	L_{dec}
E137	Al	20	20	179	204
E141	W	9	15	0.12	35
E774	W	275	9	0.3	2
KEK	W	2.5	17	2.4	2.2
Orsay	W	1.6	16	1	2
JLab	Al	12	20	10	1

[Izaguirre, Krnjaic, Schuster, Toro 2013]

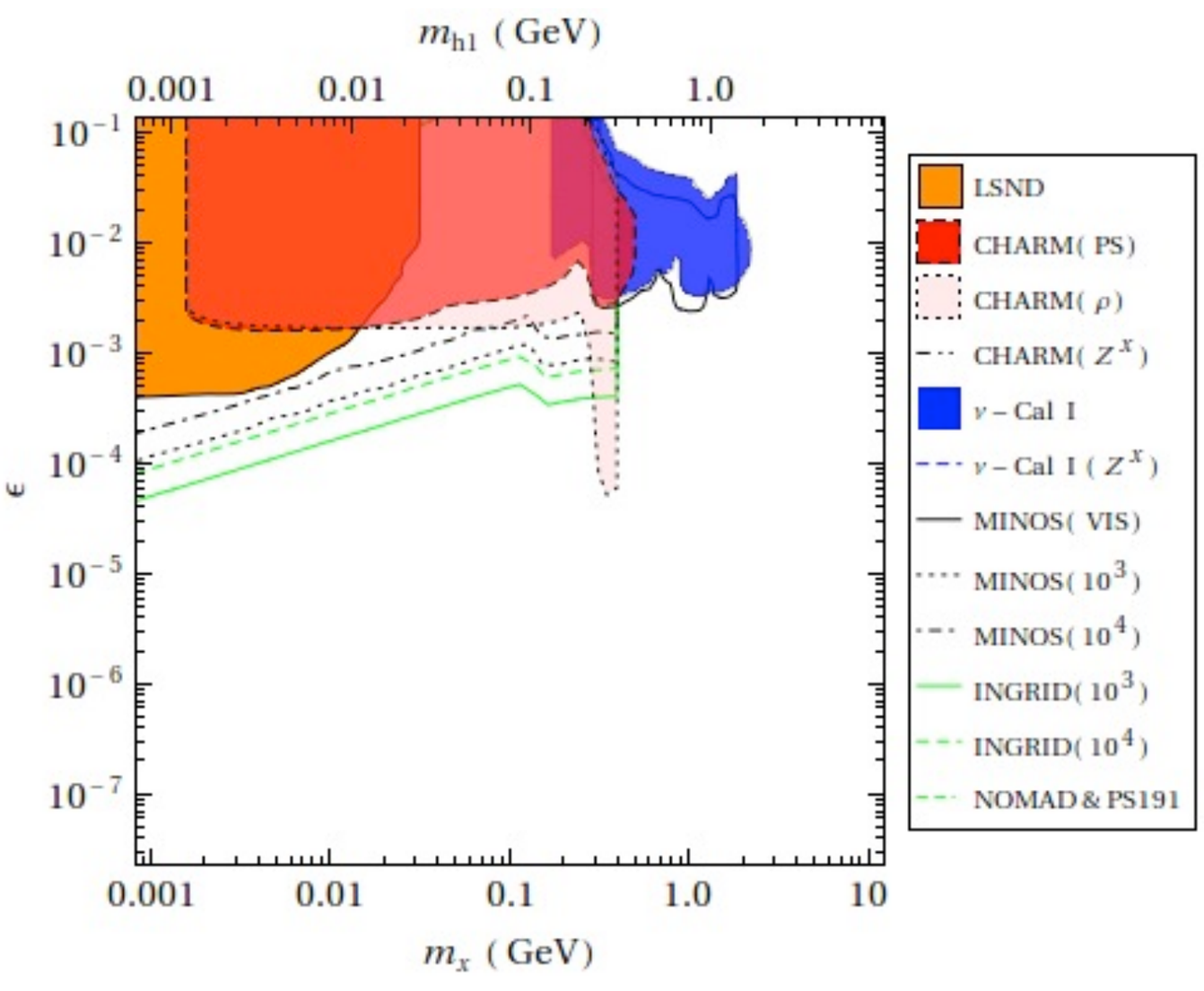
Hadronic Fixed-Target Experiments

Expt	Target	E (GeV)	$Log_{10}N_p$	L_{sh}	L_{dec}
CHARM	Cu	400	18	480	35
MINOS	C	120	21	1040	1.3
ν-Cal I	Fe	70	18	64	23
INGRID	C	30	21	280	0.585
LSND	...	0.798	...	30	8.3

Case A - Fixed Target

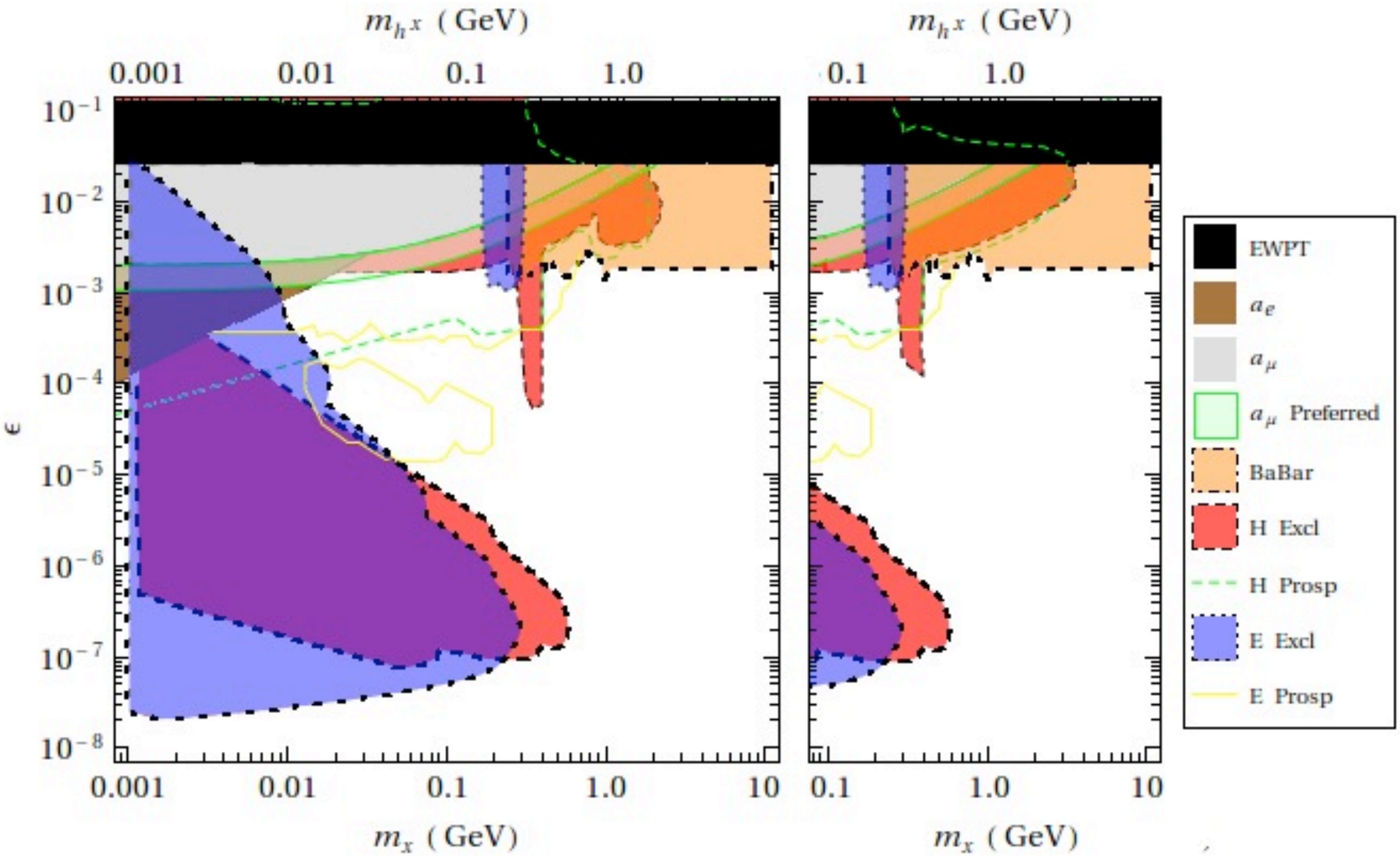


E Beam

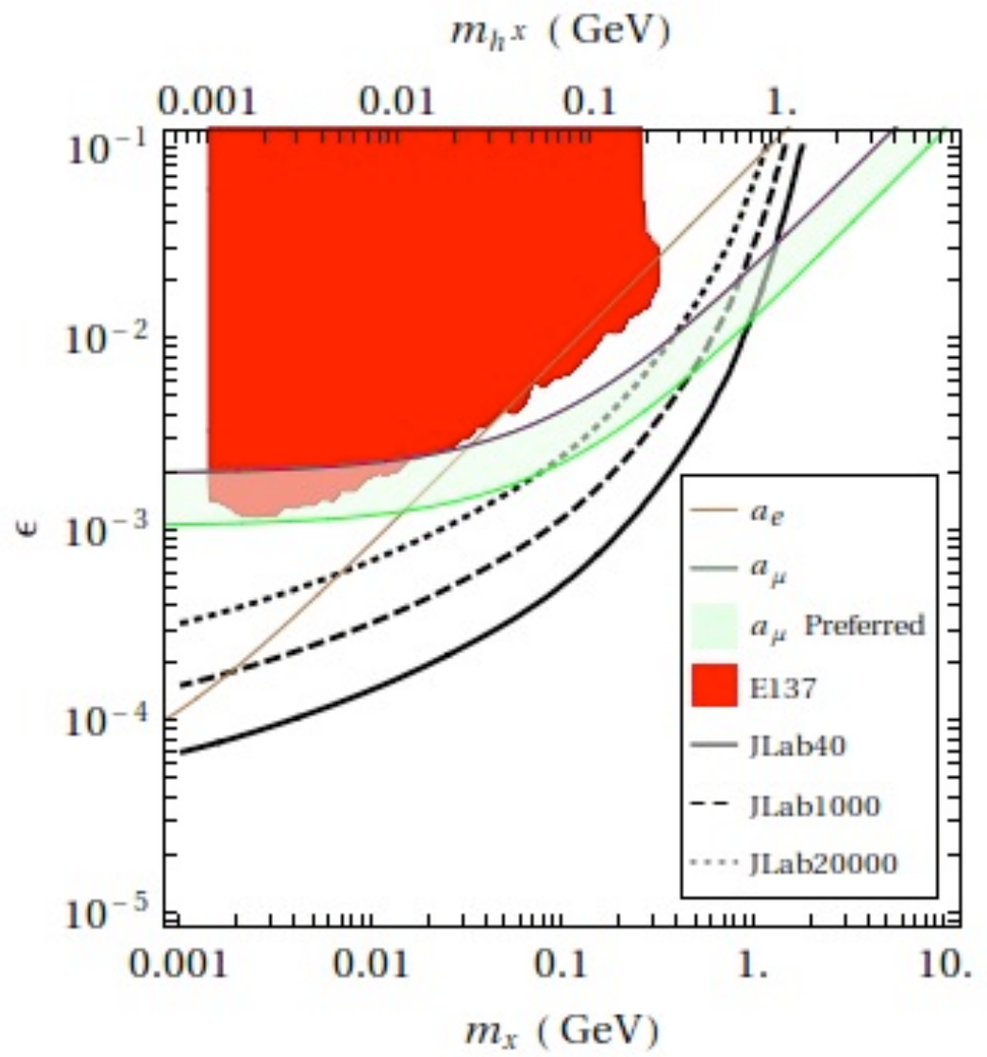


H Beam

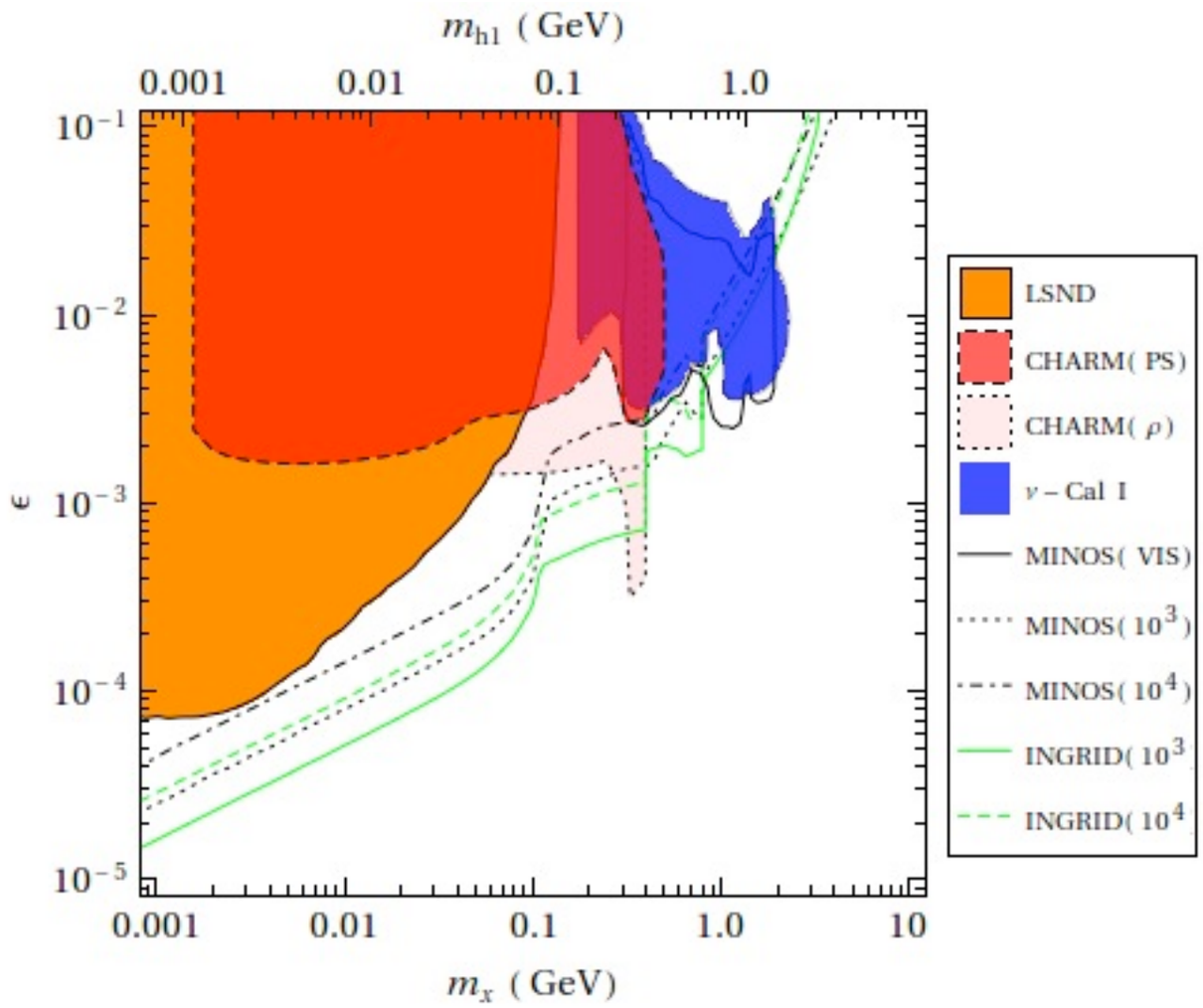
Case A - Summary



Case B - Fixed Target

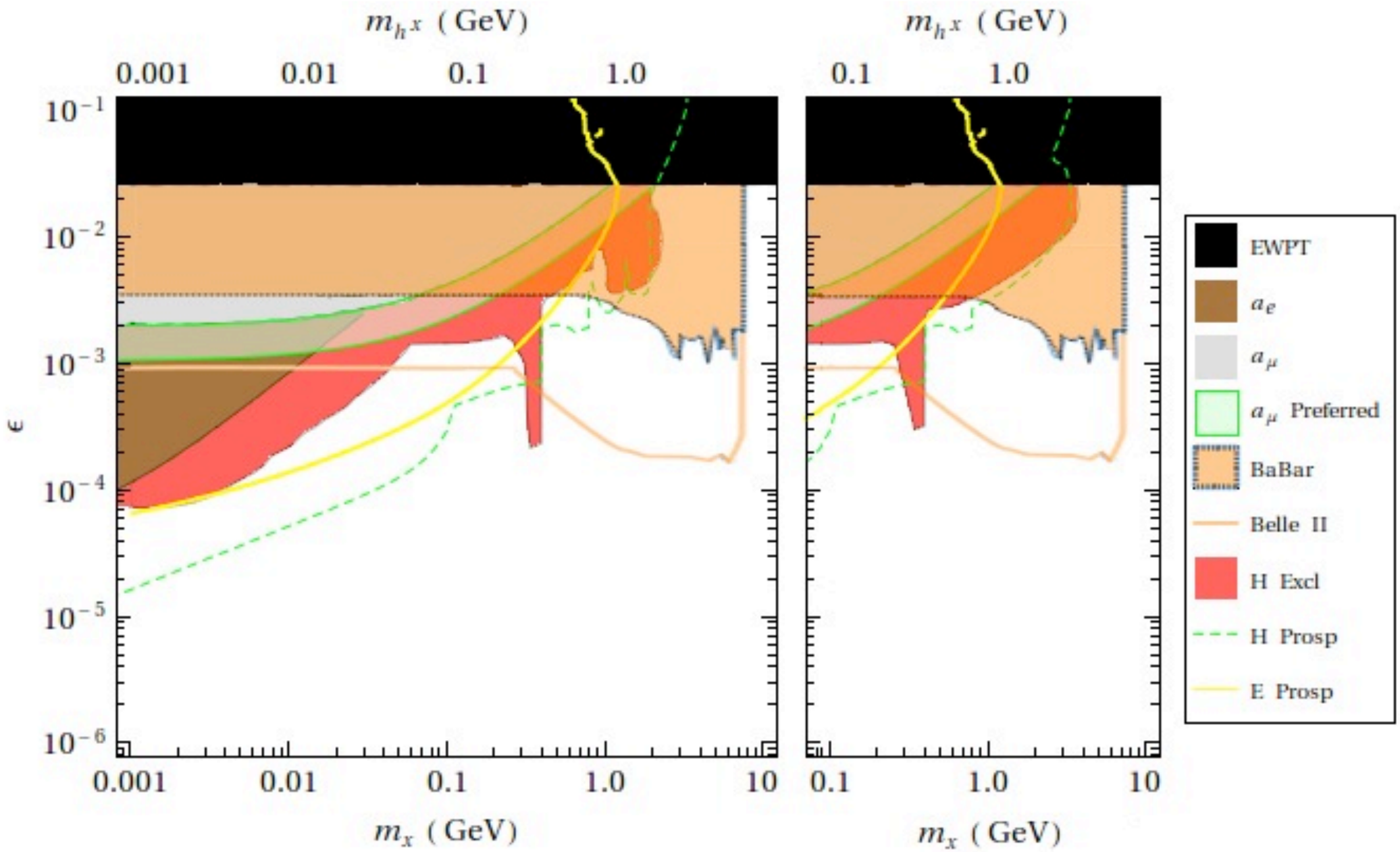


E Beam

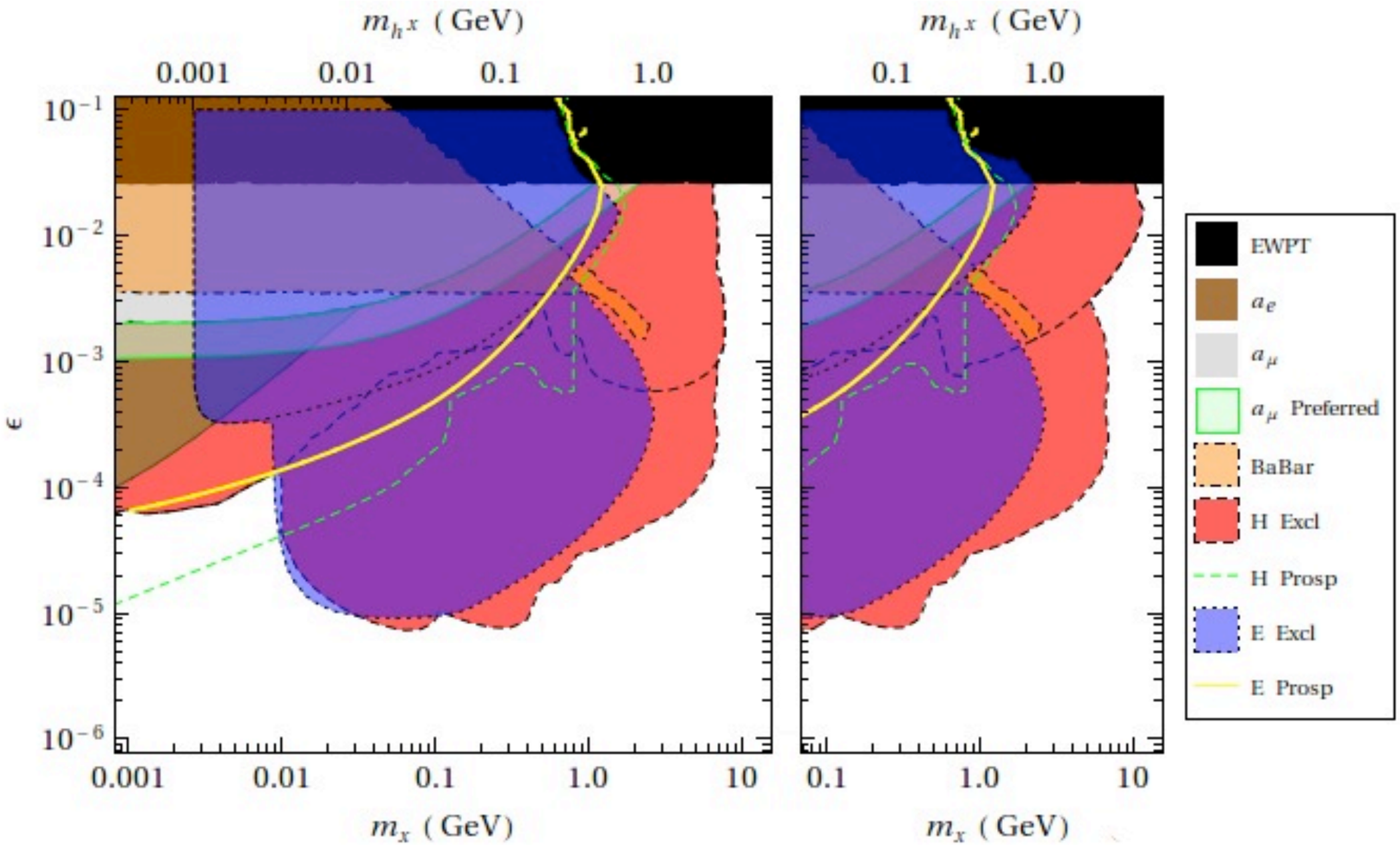


H Beam

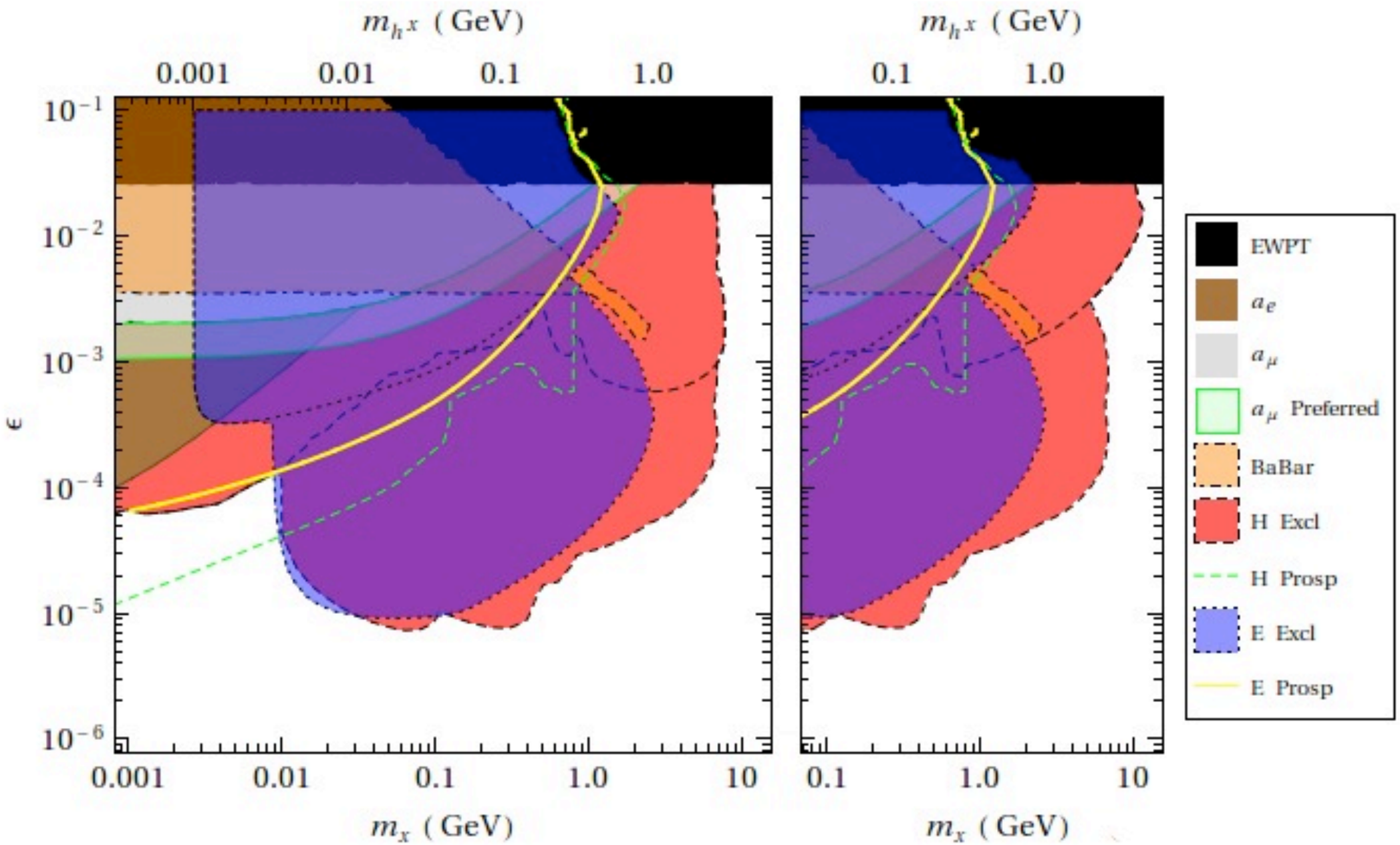
Case B - Summary



Case C - Summary



Case D - Summary



Extra Slides: Warped

Stringy Warped Throats

[Baumann,Dymarsky,Kachru,Klebanov,McAllister '10]