Strong fields and recycled accelerator parts as a laboratory for fundamental physics

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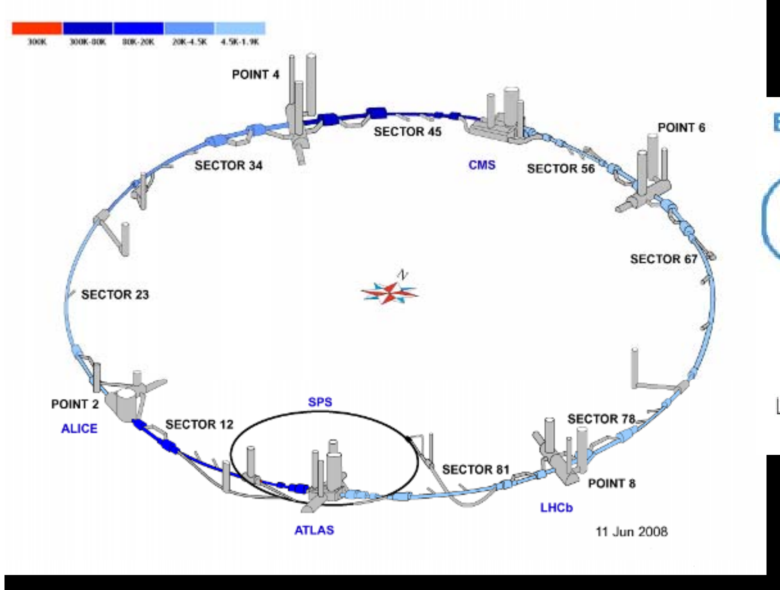
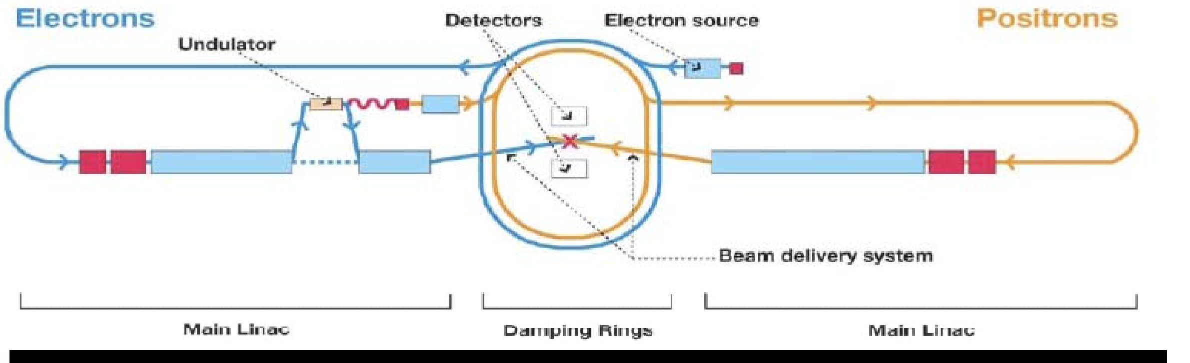
**DESY

Exploring fundamental high energy physics…

- The direct approach: MORE POWER

LHC + ILC,CLIC





- Detects most things within energy range
- E.g. may find WIMPs

But…

- Current maximal energy few TeV
- May miss very weakly interacting matter (Axions, WIMPs, WISPs…)
- Only indirect evidence for dark matter

- Man its DANGEROUS…

Recycling...

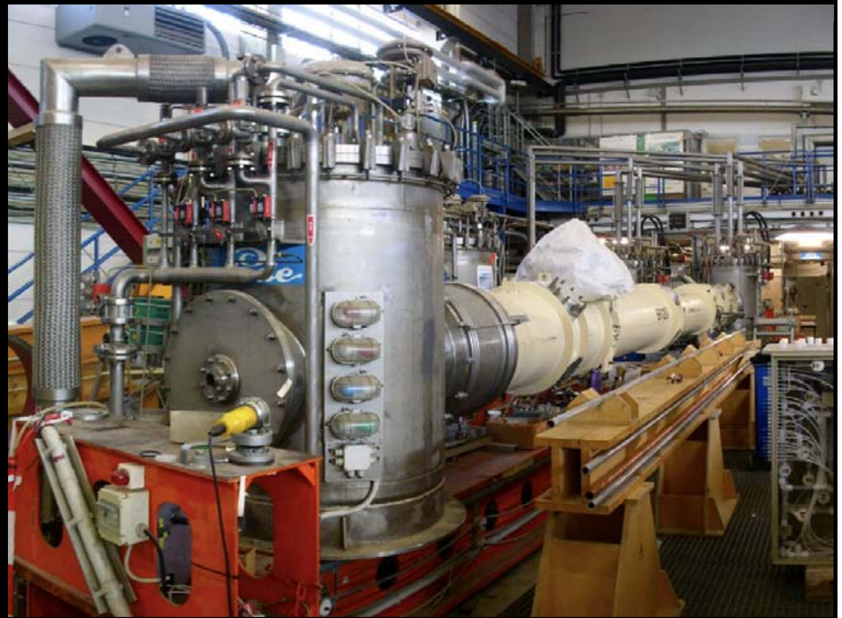
Complementary approaches

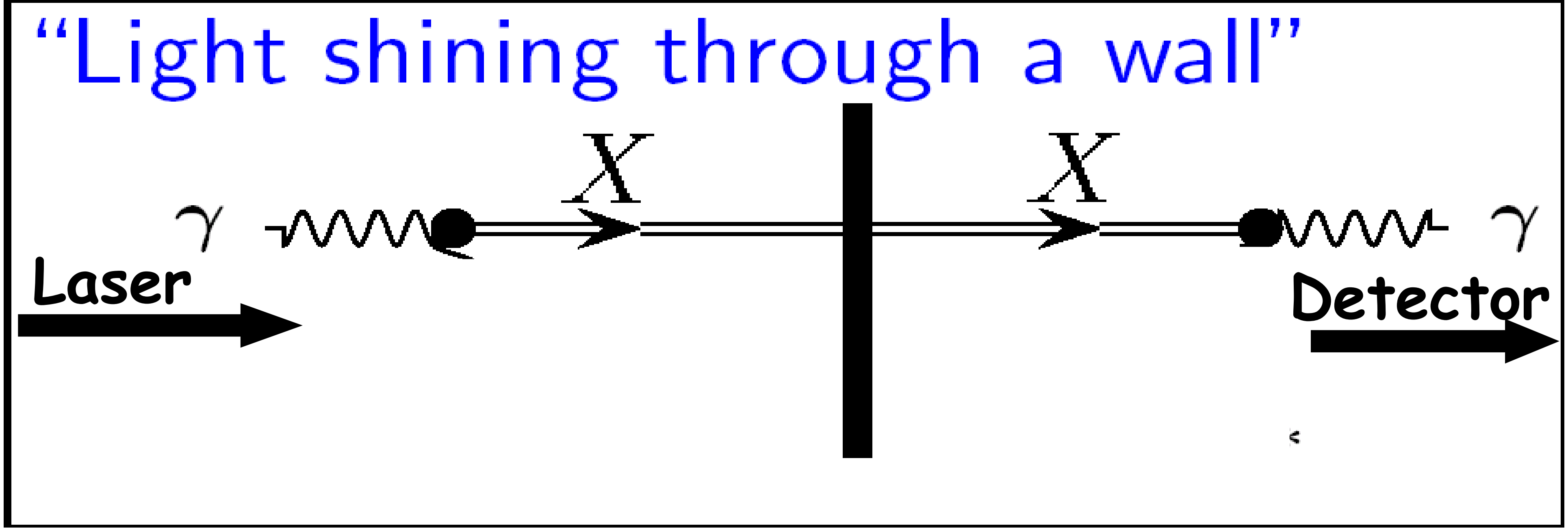
Light Shining through a wall

ALPS@DESY=

Axion-like particle search

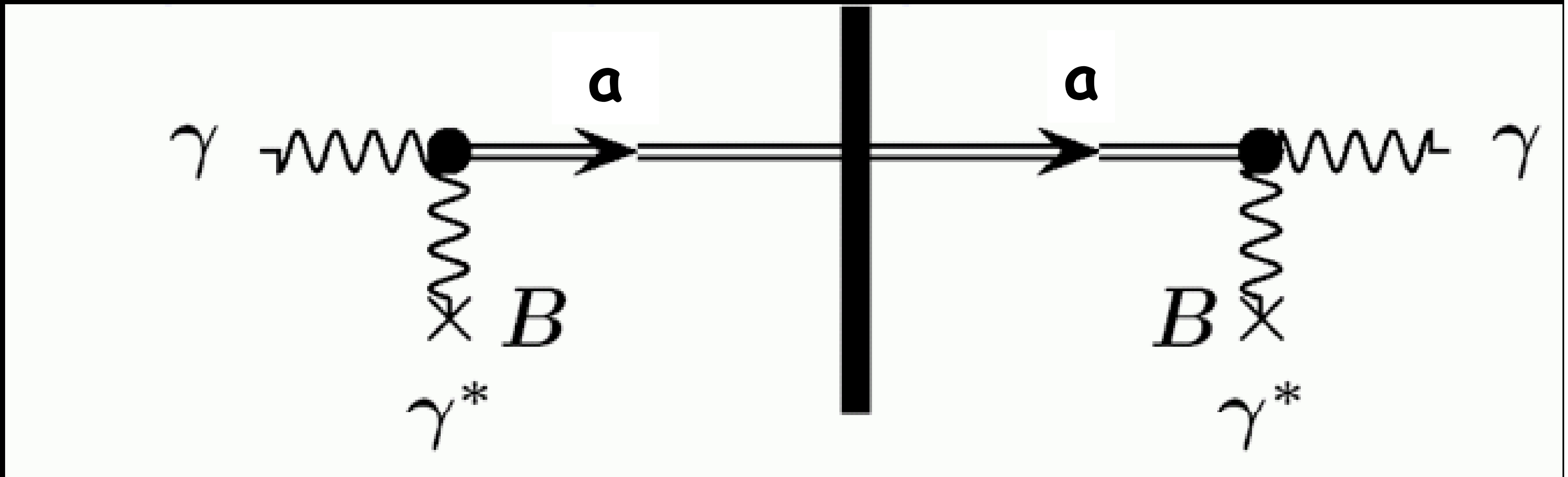
Any-light particle search





Photons coming through the wall!

- It could be Axion(-like particle)s!
- Coupling to two photons: $\frac{1}{M} a\tilde{F}F \sim \frac{1}{M} a\vec{\mathbf{E}}\cdot\vec{\mathbf{B}}$



$$P_{\gamma\to a\to\gamma} \sim N_{\rm pass}\left(\frac{BL}{M}\right)^4$$

How many photons arrive?

$$B \sim 5T \sim 1000 eV^2$$

$$L \sim 1m \sim 10^7 eV^{-1}$$

$$M \sim 10^6 GeV$$

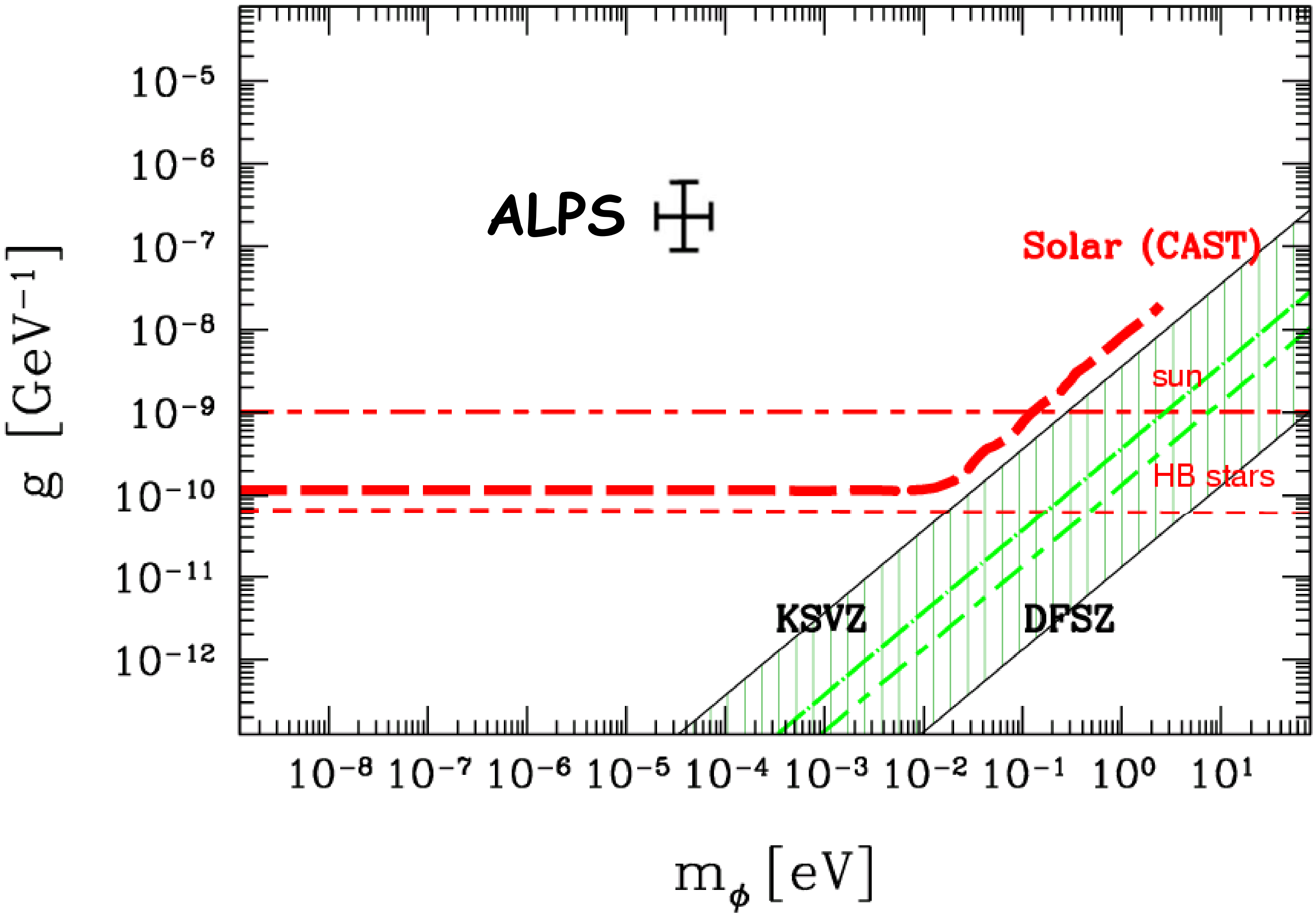
$$P_{\gamma \to a \to \gamma} \sim 10^{-20}$$

+

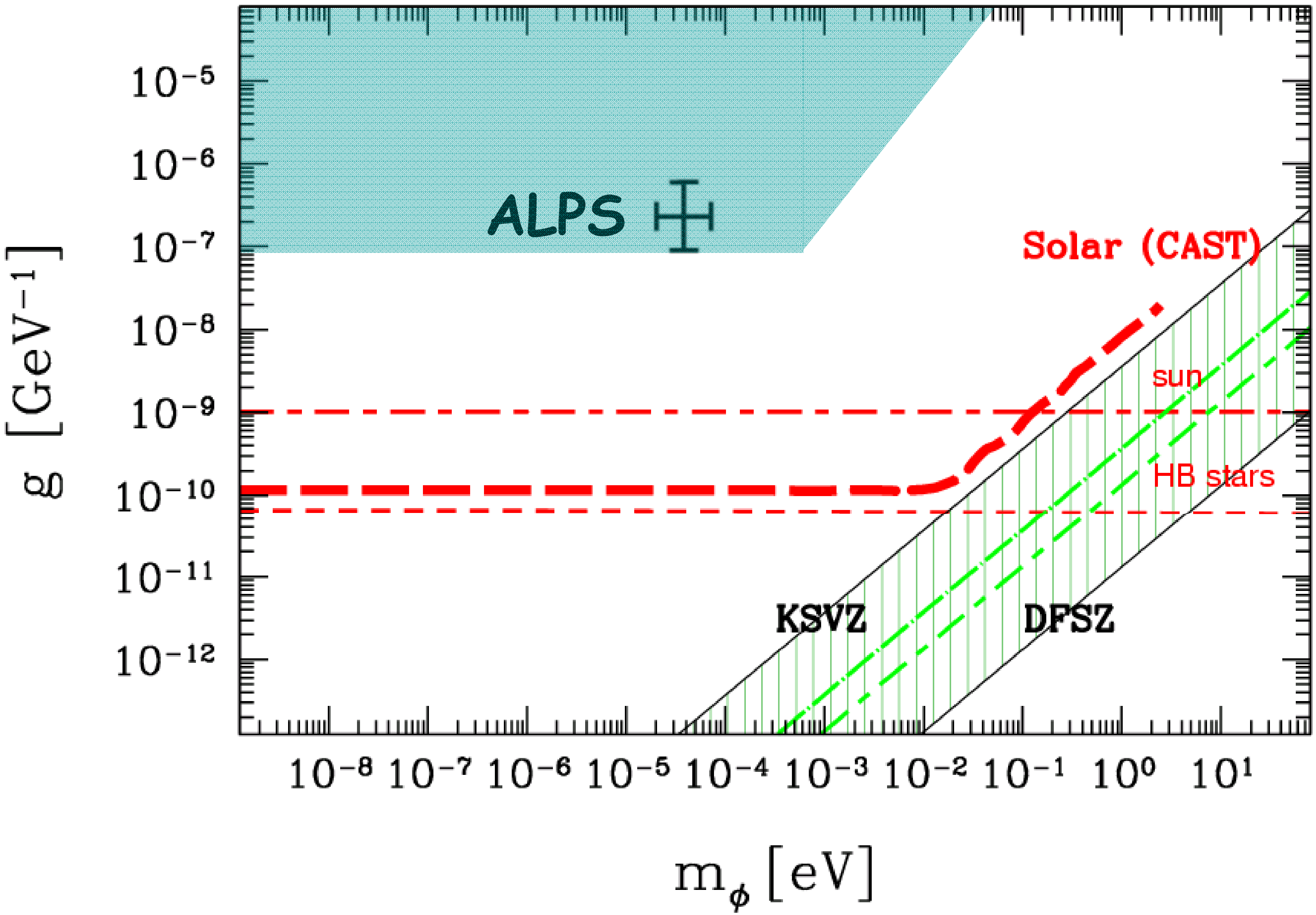
$$laser\ Power \sim 10\,W \sim 10^{20} \frac{\gamma}{s}$$

1 photon per second at detector

Tiny coupling, small mass

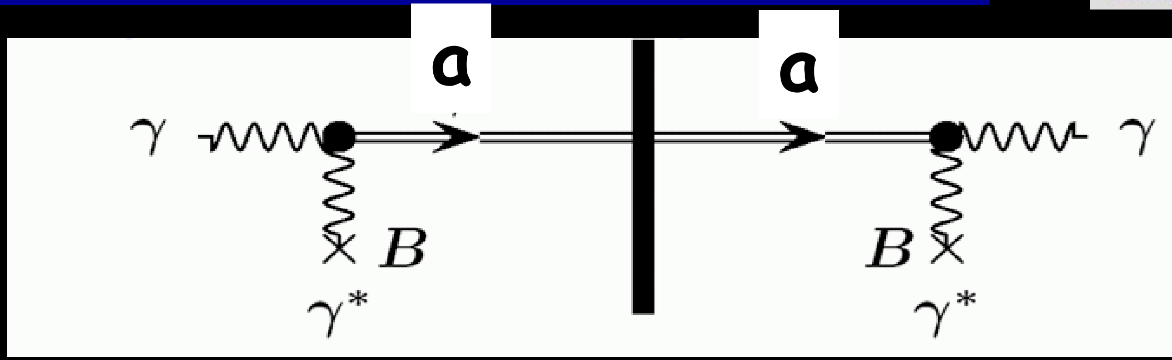


If no detection, good bound!

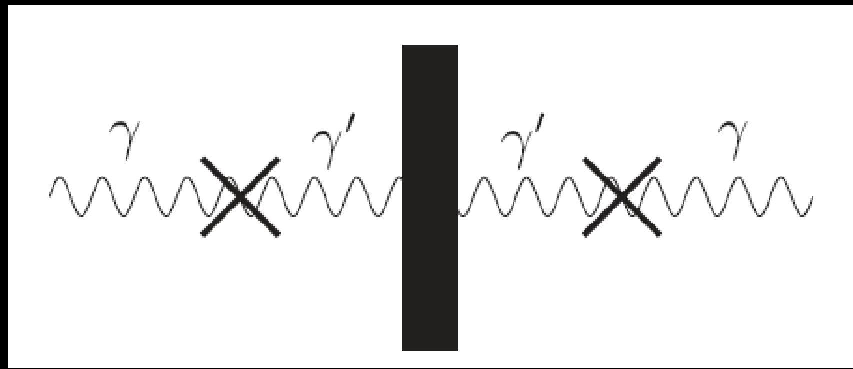


WISPS^X=Weakly interacting sub-eV particles

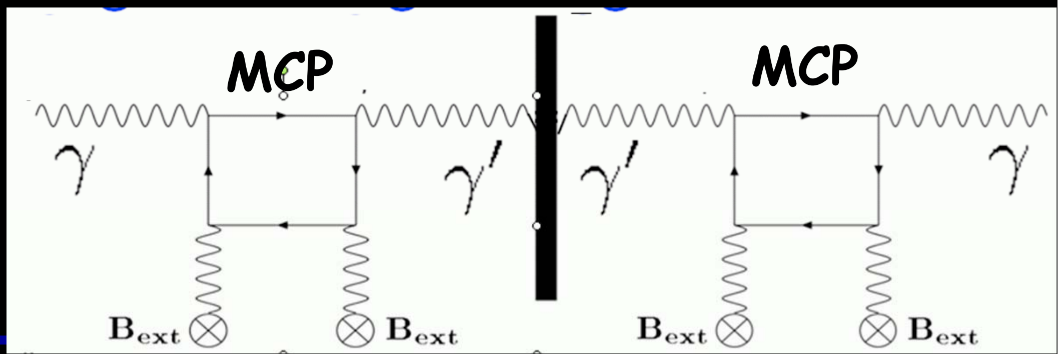
- Axions



- Massive hidden photons (without B-field) =analog ν-oscillations



- Hidden photon + minicharged particle (MCP)

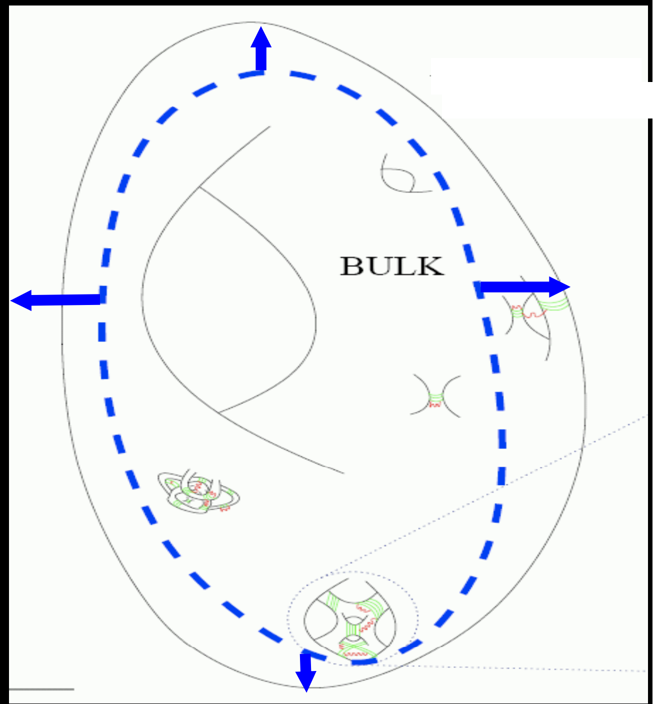


String theory: Moduli, Axions, etc.

- String theory needs Extra Dimensions

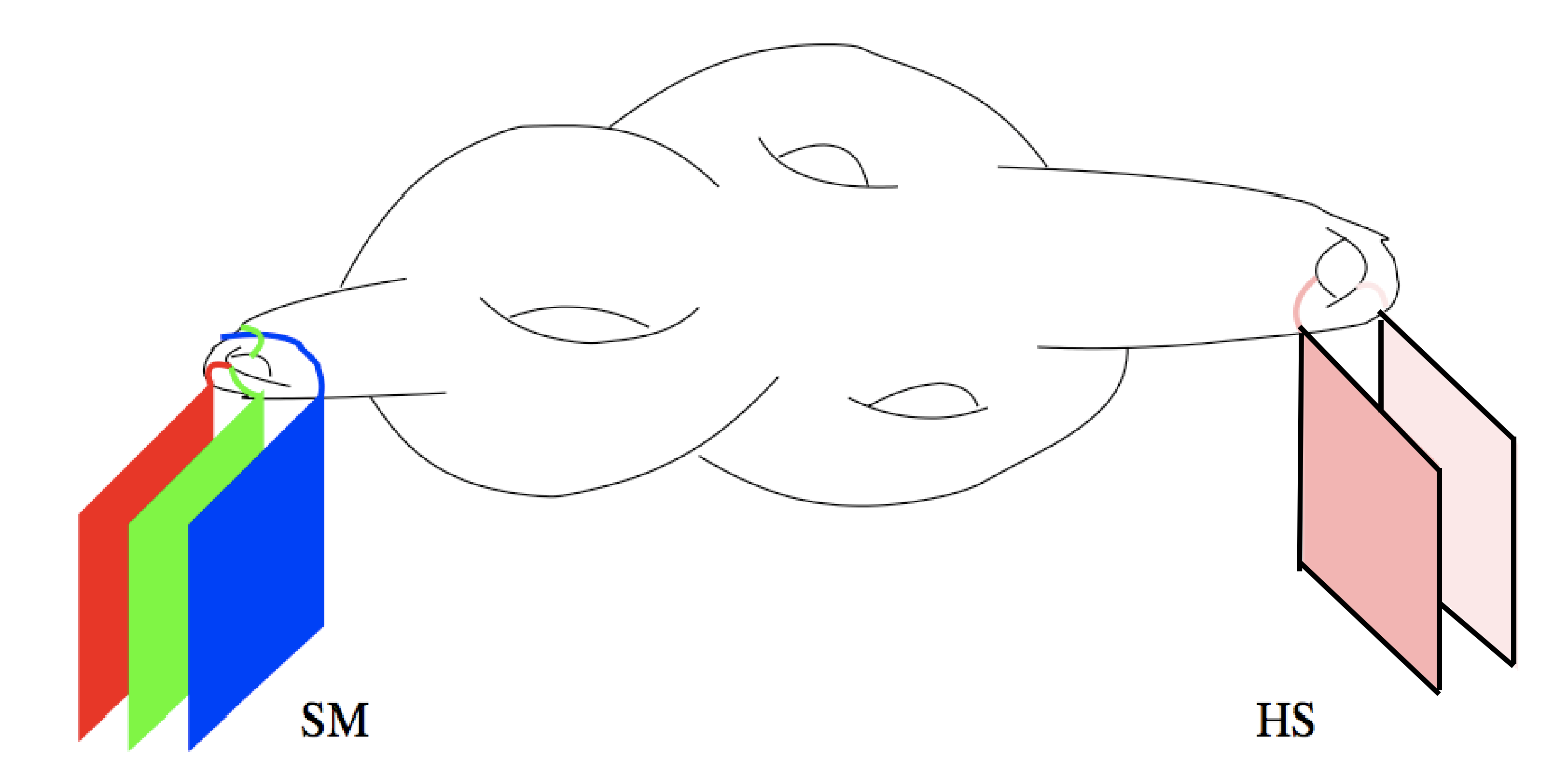
Must compactify

- Shape and size deformations correspond to fields: Moduli (WISPs) and Axions Connected to the fundamental scale, here string scale



`Physics case' for WISPs strengthened

String theory likes extra gauge groups

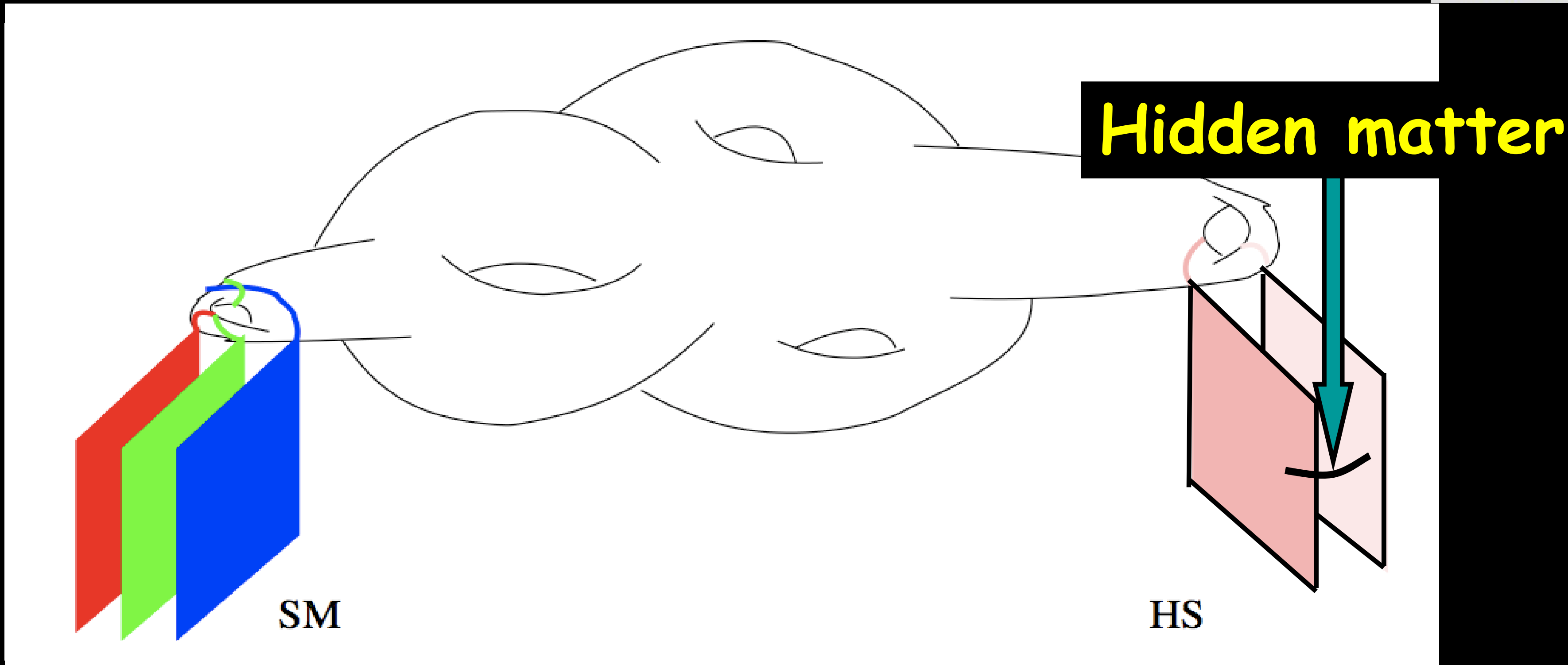


U(A) x U(B) x U(C) U(A) x U(B)

➡ **Many extra U(1)s!**

➡ **Candidates for WISPs**

String theory likes extra matter



$U(A) \times U(B) \times U(C)$ $U(A) \times U(B)$

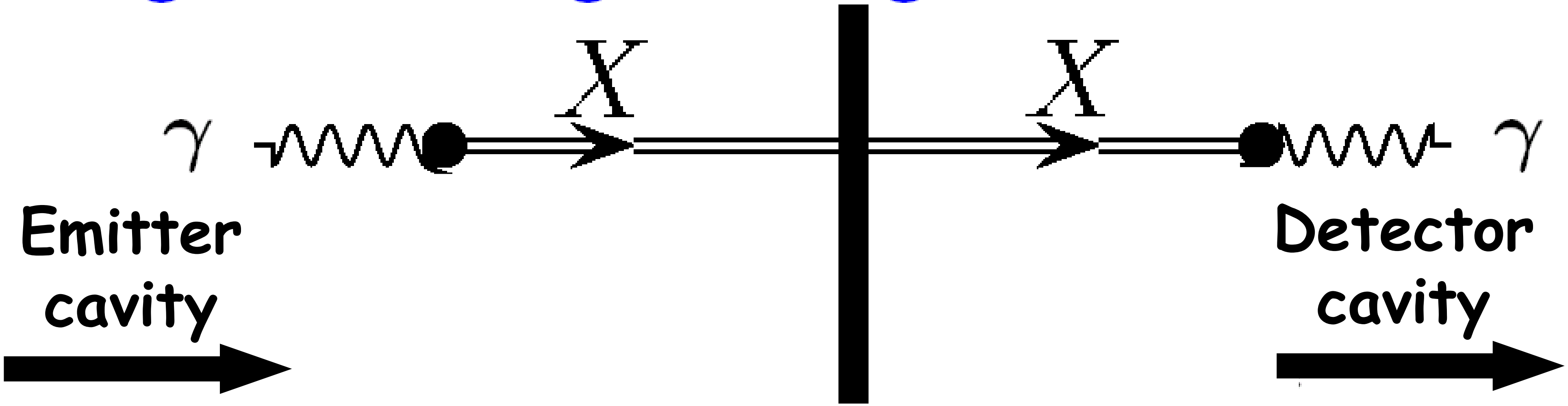
➡ Hidden sector matter

➡ May be light and WISPy
Or WIMPy and dark matter

A cavity experiment

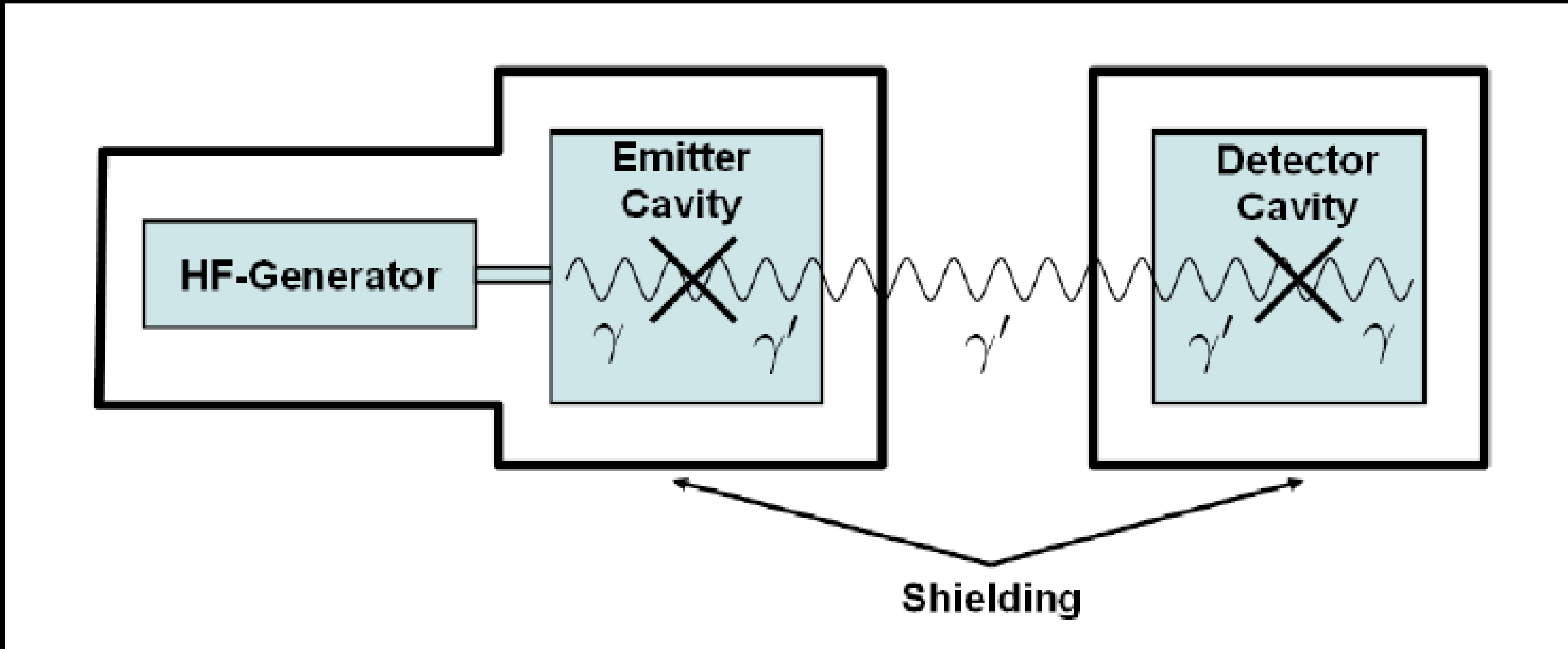
It's a Light shining through walls clone

“Light shining through a wall”



- Microwaves instead of laser

Setup



HF-Generator
Emitter Cavity
Detector Cavity
γ
γ'
γ'
γ'
γ
Shielding

Advantages

- Resonant cavity setup: Cavity in production and regeneration region

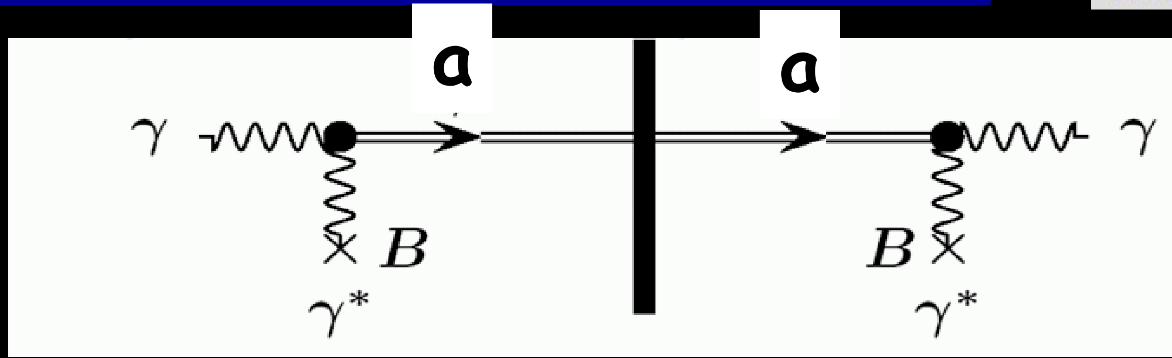
$$\mathrm{signal} \sim Q_1 \times Q_2$$

- Microwave cavities can have very high Q-factors $\sim 10^{11}$!
- Sensitive to masses in the interesting μeV-meV range

Sensitive to variety of WISPs

- Axions

$$\frac{1}{M} a \tilde{F} F$$



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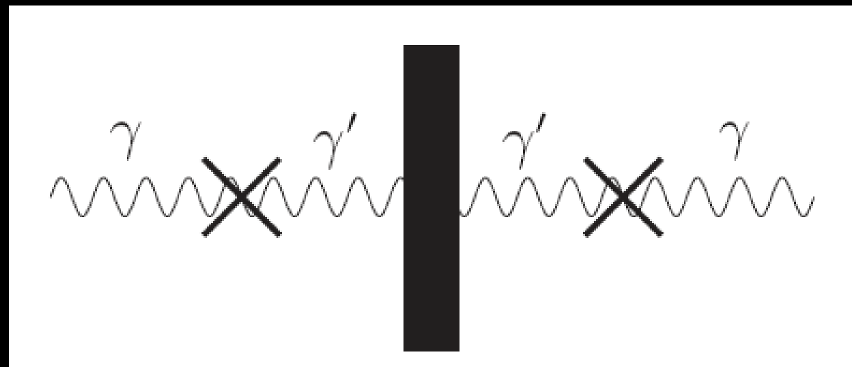
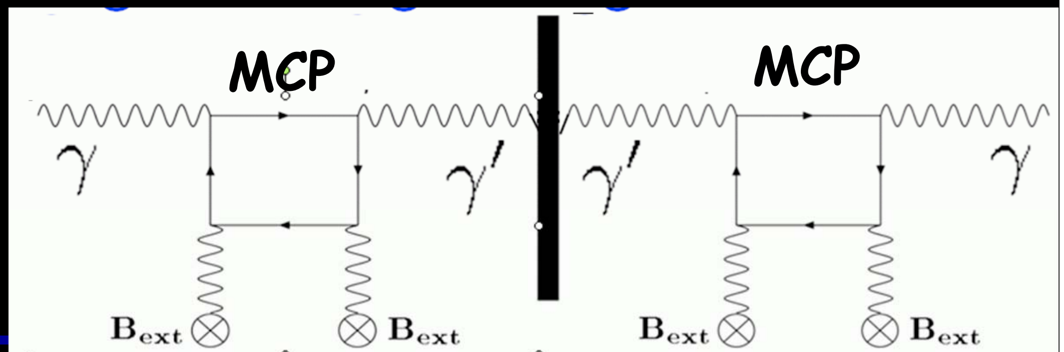
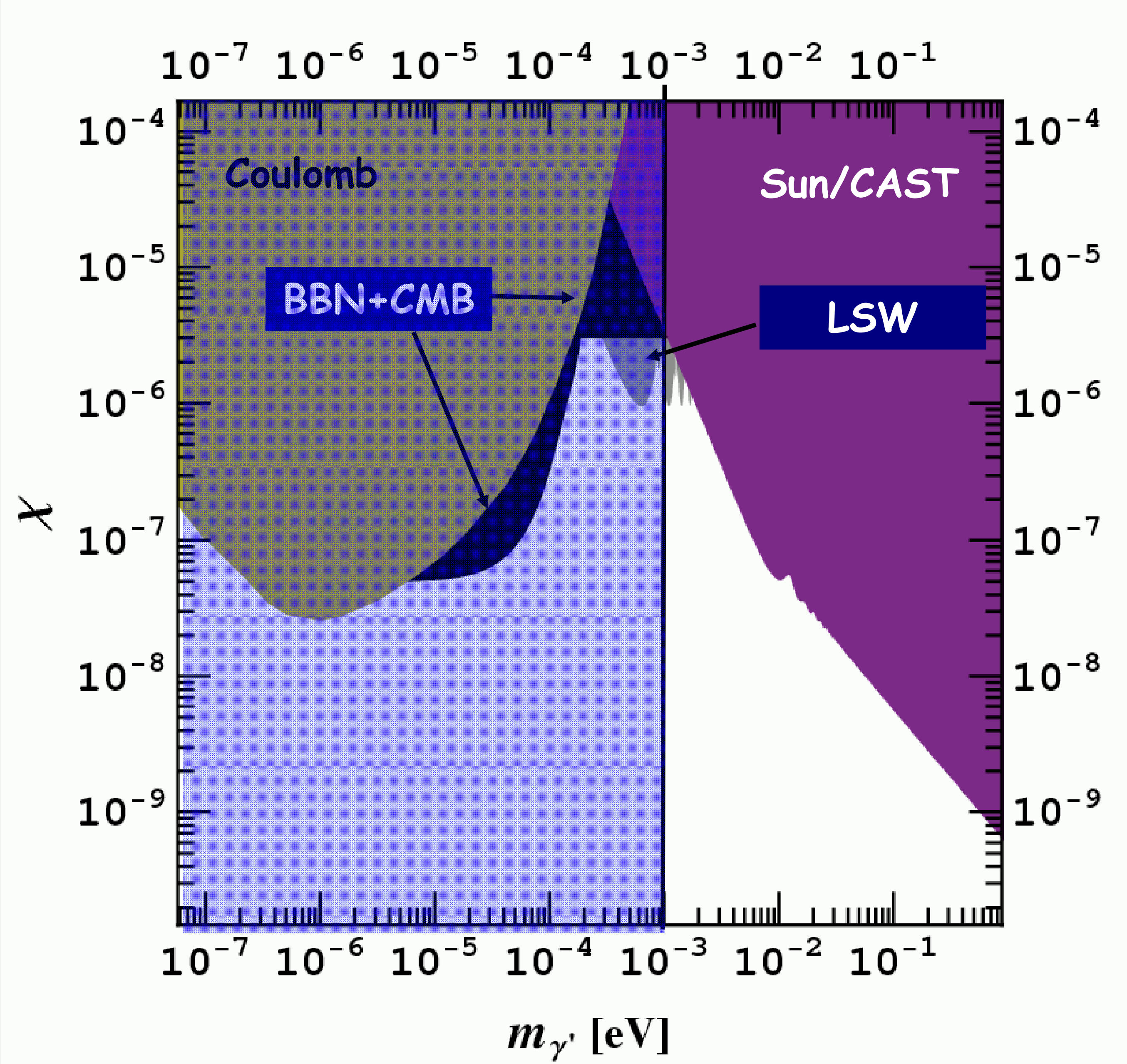


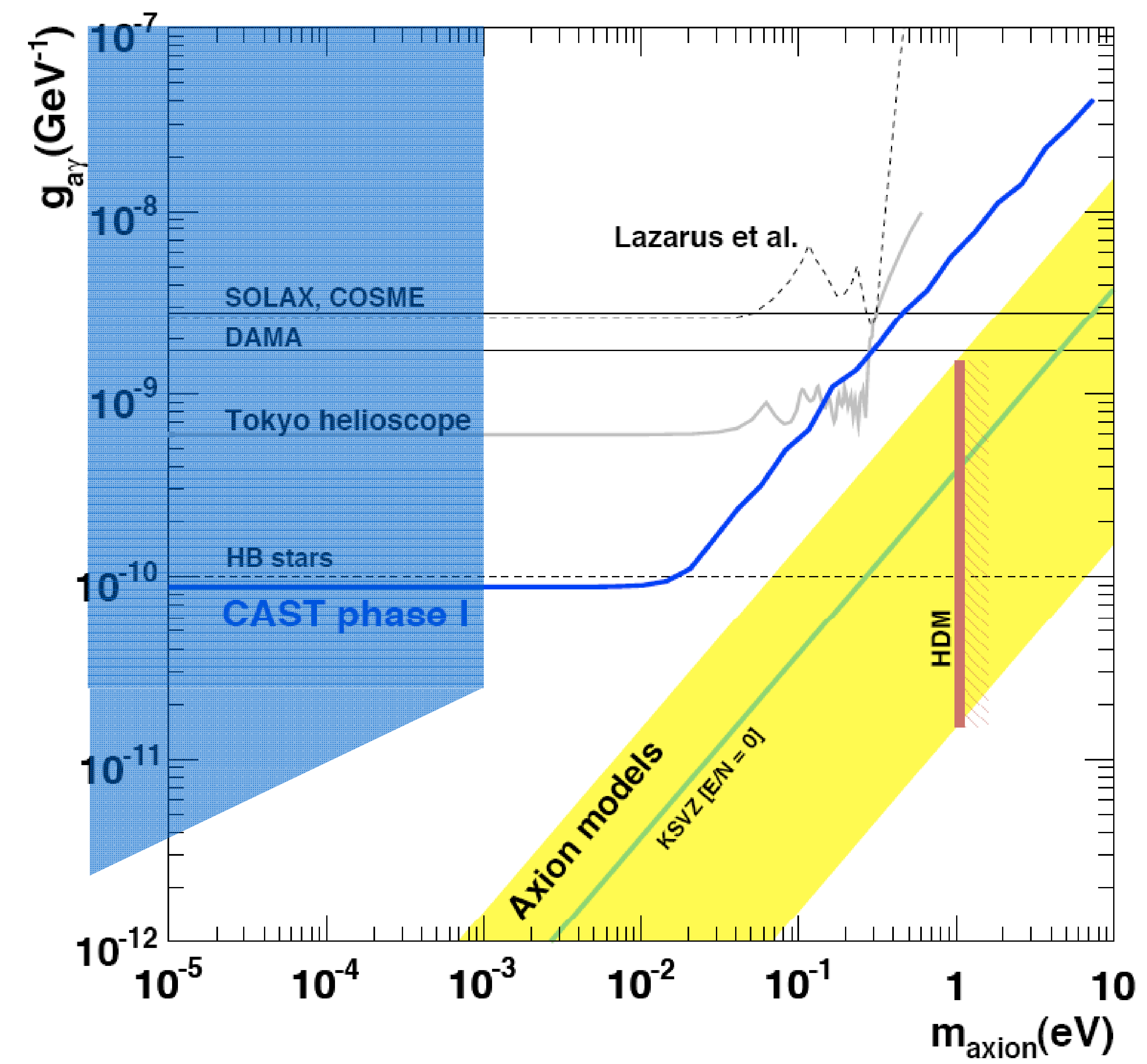
- Hidden photon + minicharged particle (MCP)



(theoretical) Sensitivity, e.g. hidden photons



Wildly optimistic proposal



AC/DC

Highway to minicharged particles

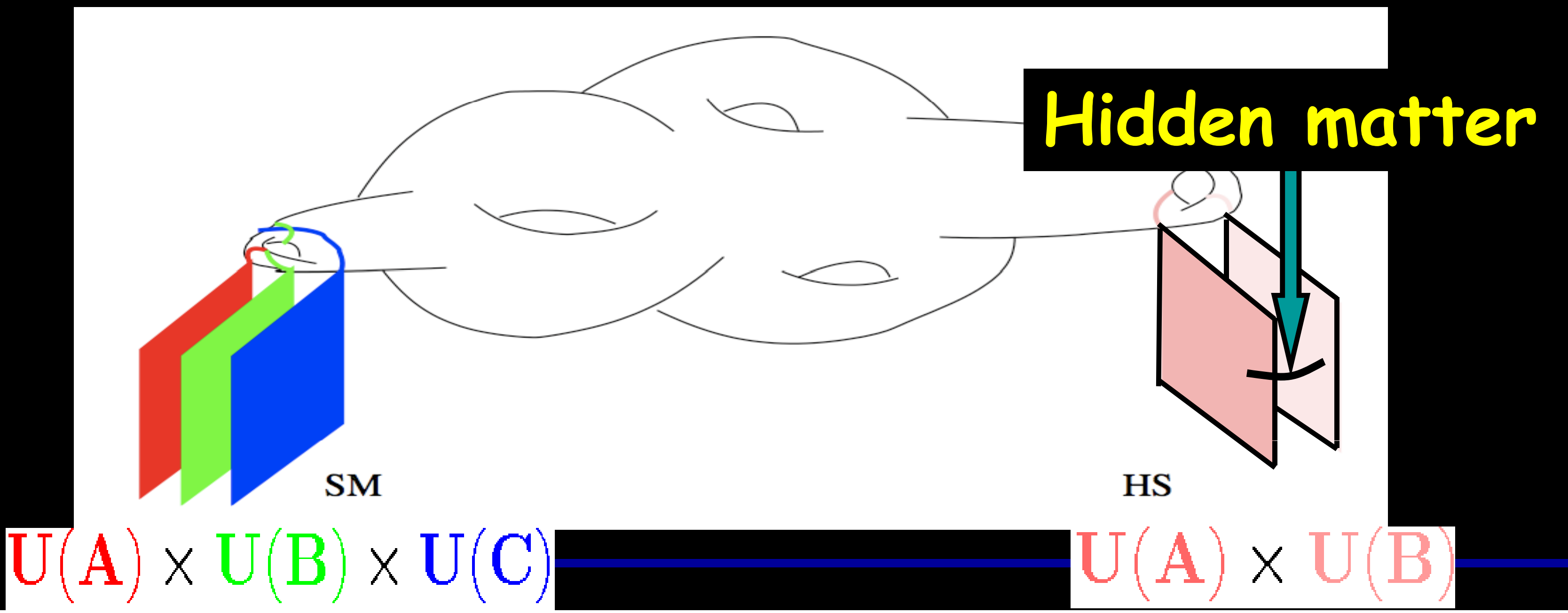
AC/DC

(accelerator cavity/dark current)

Highway to minicharged particles

Minicharged particles

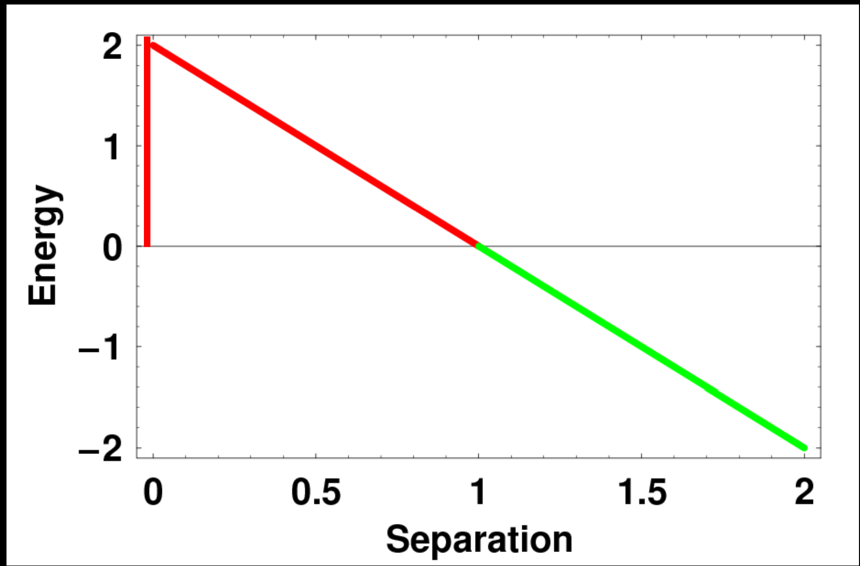
- Minicharged particles are particles which have a small fraction of the electron electric charge
- Searching them tests fundamental ideas such as charge quantization
- May give insight into fundamental physics



Schwinger Pair Production

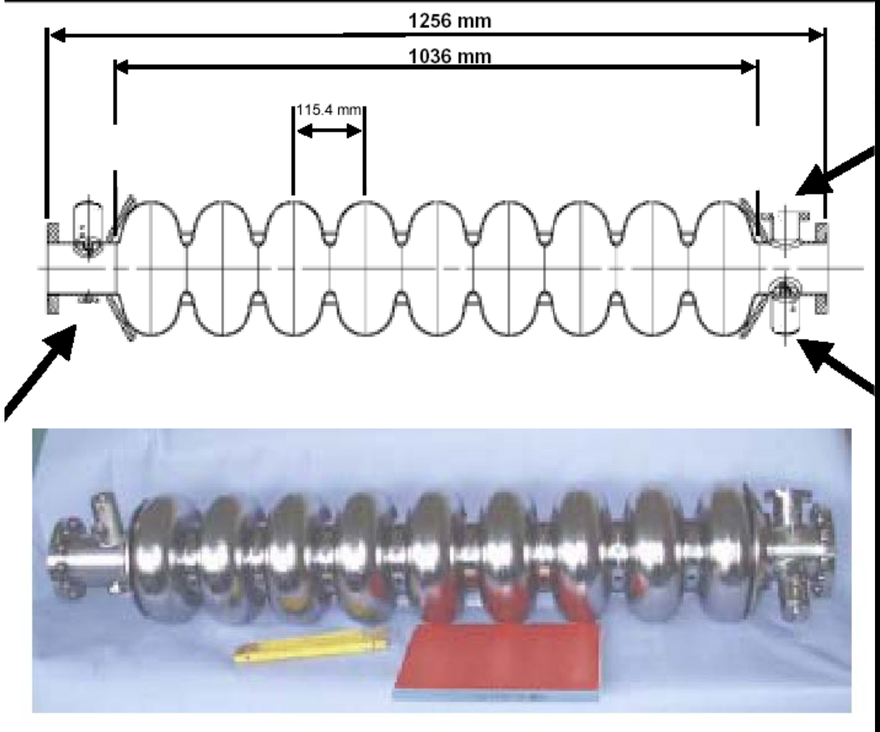
- Pair Production in a strong electric Field (without Laser)!
- Similar to tunneling:

Energy of `vacuum pair'



- An $\mathbf{f}, \bar{\mathbf{f}}$ -pair separated by a distance $d > \frac{2m_e}{\epsilon e \mathbf{E}}$ has less energy than no particles!

Acceleator cavities



One standard **9-cell TESLA accelerating structure**

$$\mathbf{E} \gtrsim 25\,\mathrm{MV/m} \approx 16\,\mathrm{eV}^2$$

must be &

$$\mathbf{E}_{crit} = \frac{m_\epsilon^2}{\epsilon e}$$

➡ Sensitive to

$$\epsilon < 2 \times 10^{-6} \quad \text{for} \quad m_\epsilon < 0.01\,\mathrm{eV}$$

Finding the produced MCPs

- Effects of millicharged particles decreases with smaller ϵ

↓

Direct detection is difficult

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Look for macroscopic effects

Energy loss

- If many particles are produced we get a

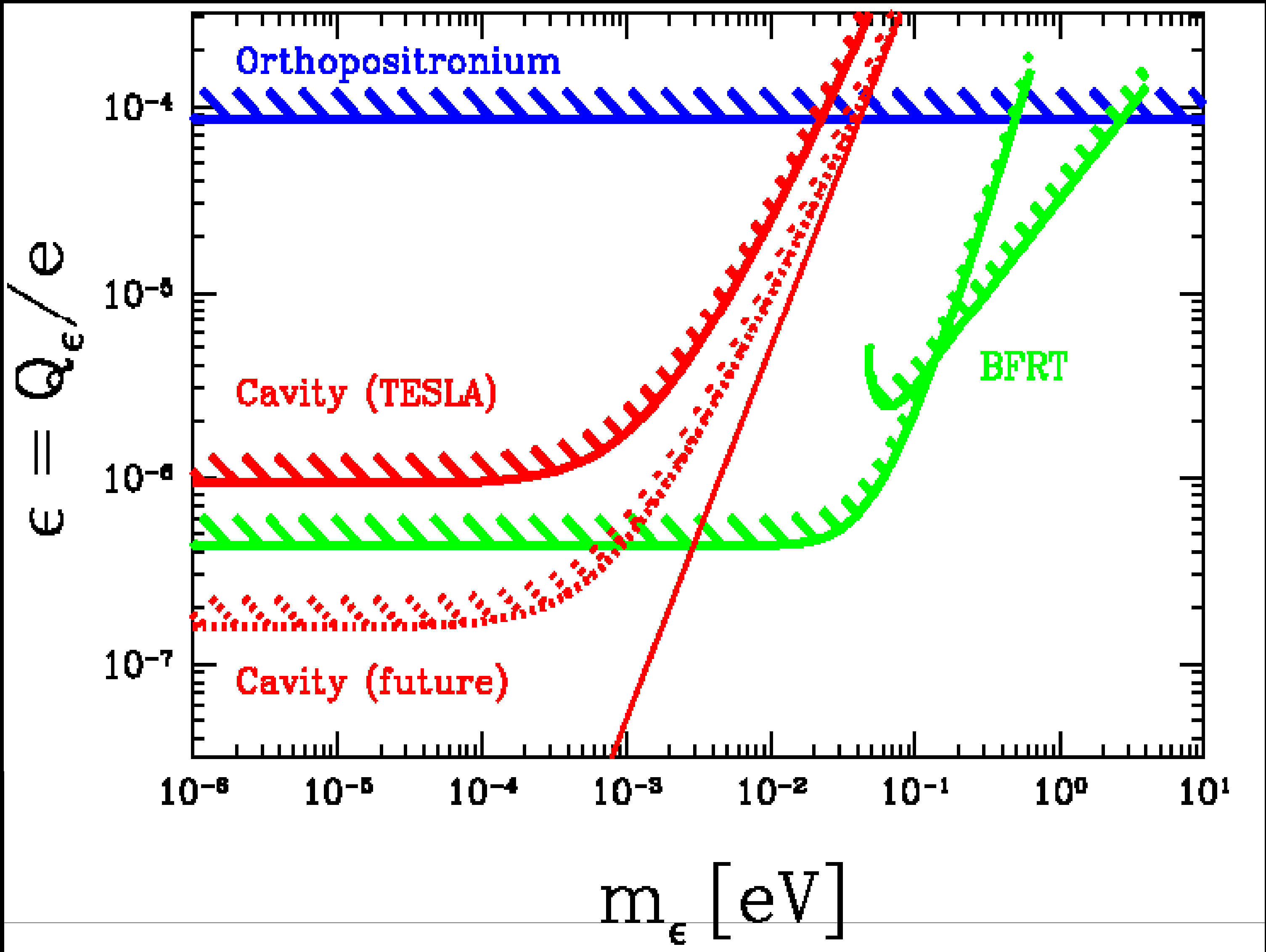
↓

Macroscopic energy loss!

↓

Can be measured

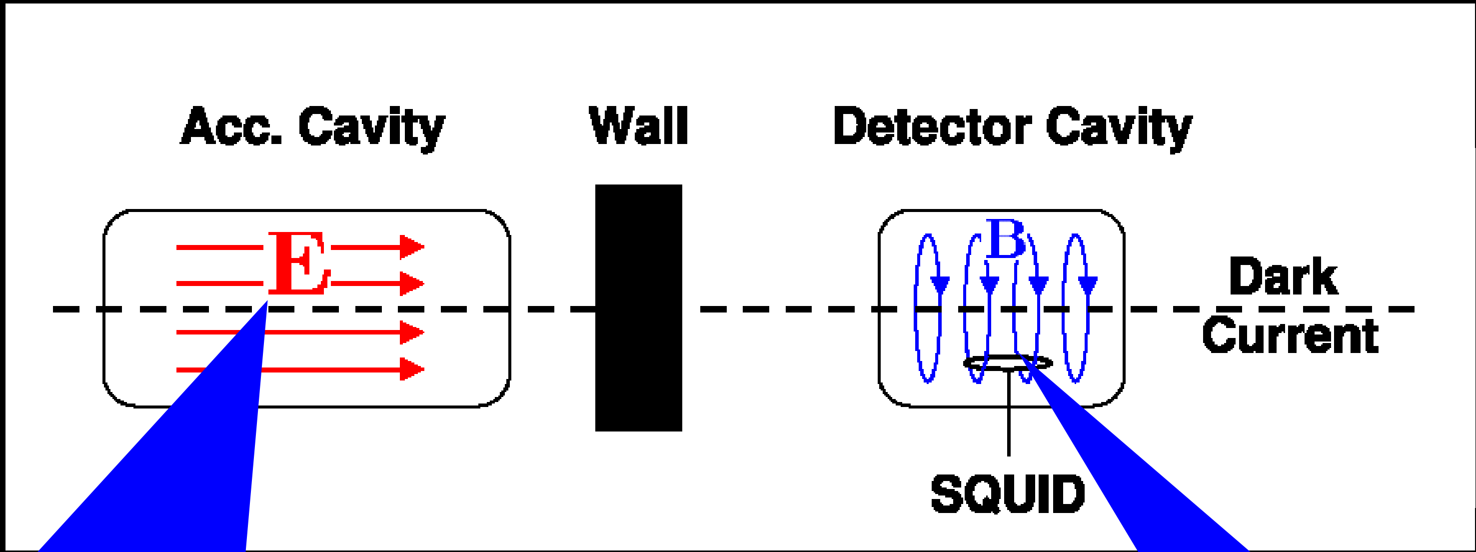
Quite strong bounds!



Not quite competitive with astrophysical bounds…

Nearly-direct detection...

Dark Current Shining through a Wall!



Minicharged particles produced in the cavity lead to a Dark Current

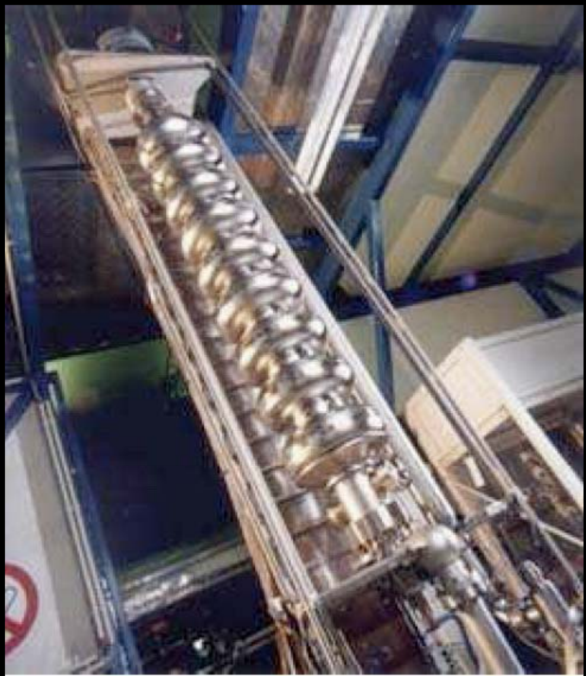
Dark Current detection

Advantages

- It's a (nearly) direct detection
- It detects minicharged particles without making use of the hidden photons

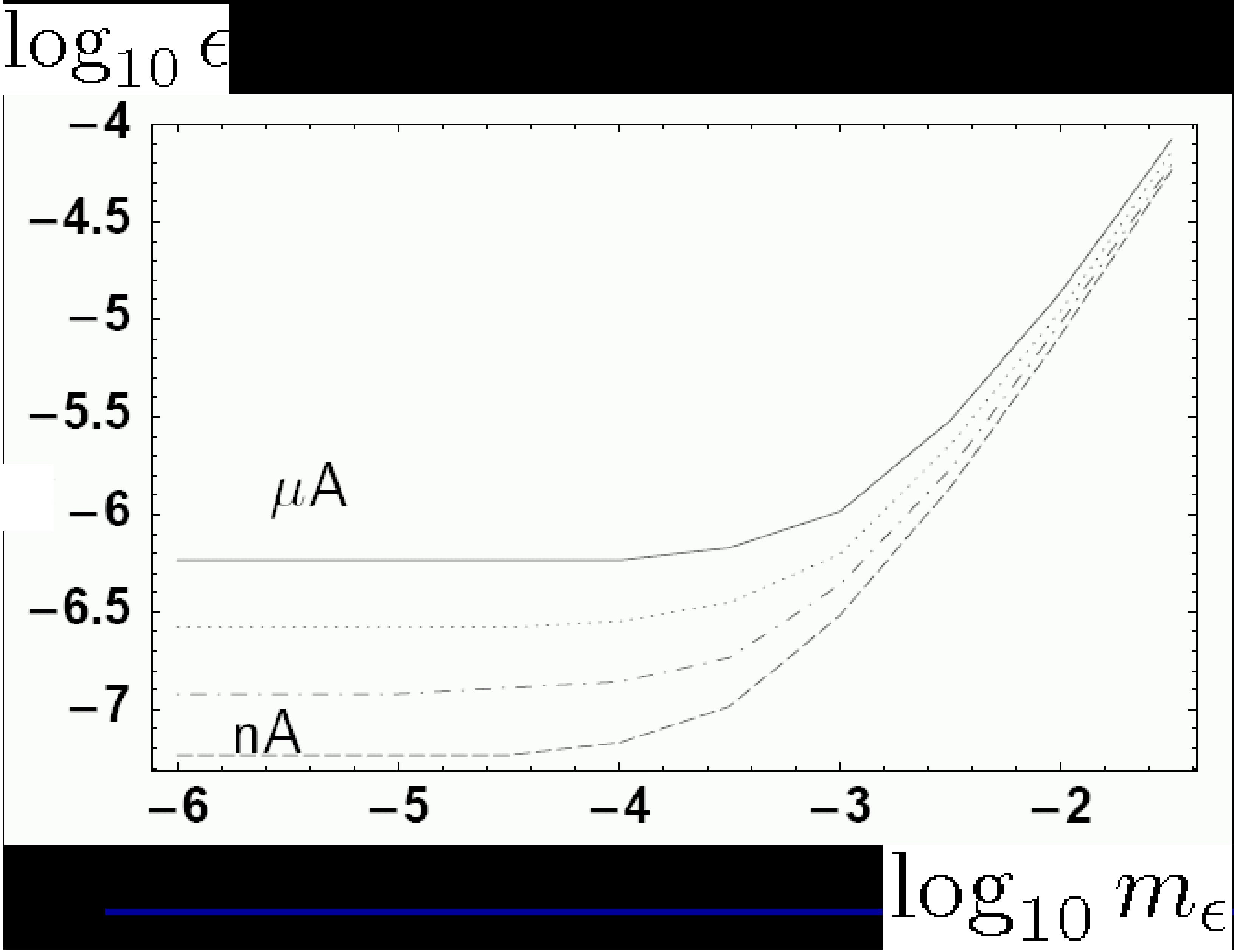
All parts exist!

Cavity



Cryogenic Current Comparator

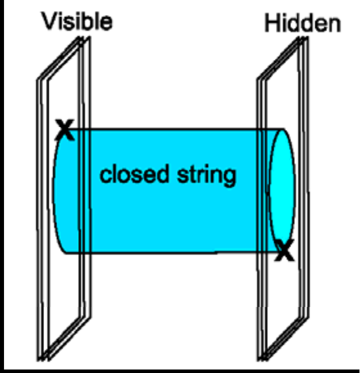
Sensitivity



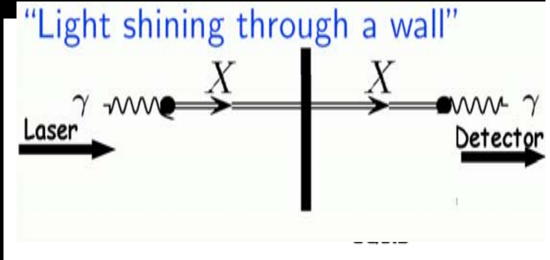
Conclusions

Searching new particles with recycled tools

- Light particles coupled to photons are "expected" in Extensions of the Standard Model, e.g. string theory



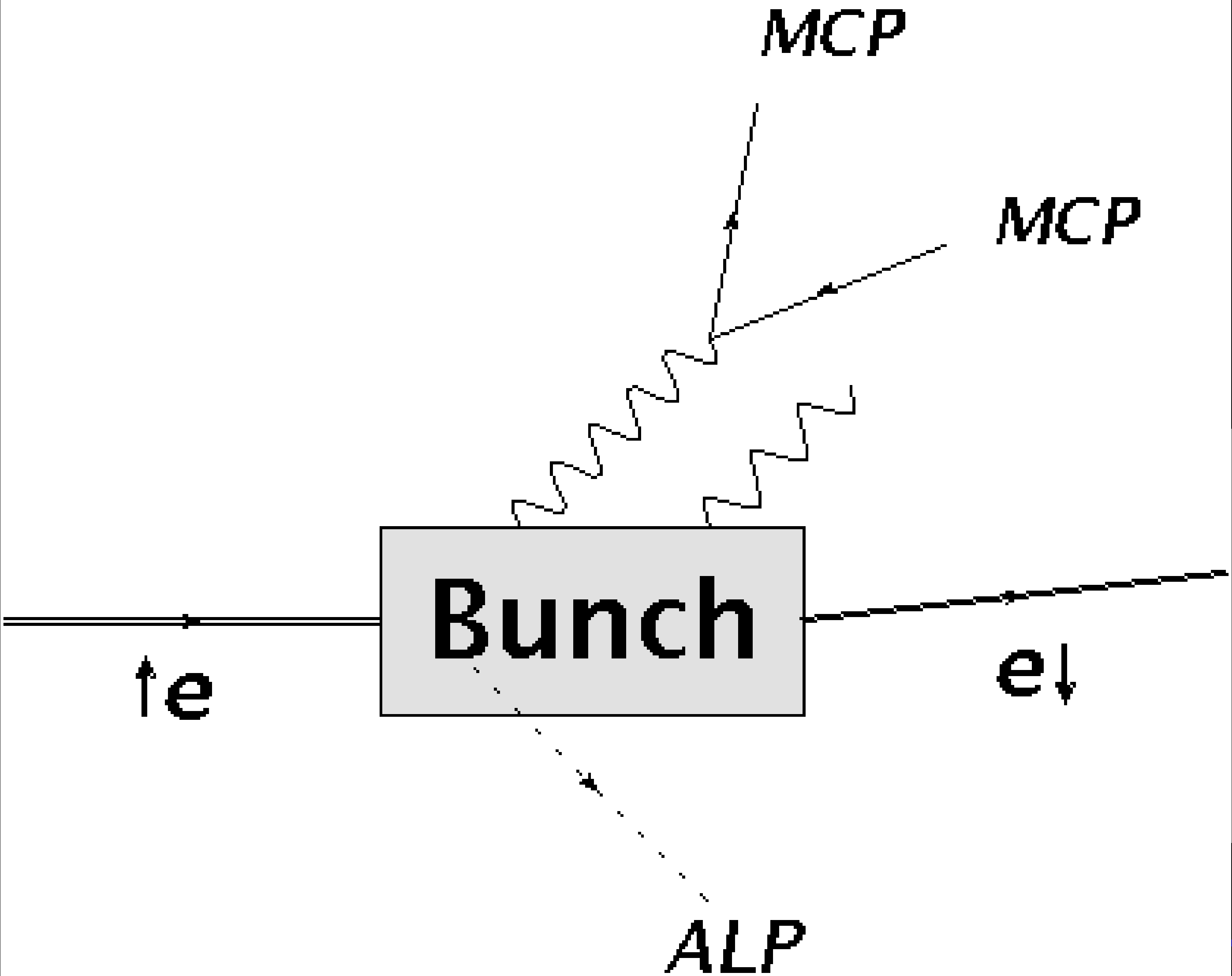
- We can search for them using low energy experiments with photons!! Using recycled accelerator parts!



- These experiments are complementary to the collisions! Test ultrasmall couplings!

- Many more cool experiments possible!

Crazy ideas…




5th Patras Workshop on
Axions, WIMPs and WISPs
13-17 July 2009
University of Durham (UK)
http://axion-wimp.desy.de
Programme:
* The physics case for WIMPs, Axions, WISPs
* Review of collider experiments
* Signals from astrophysical sources
* Direct searches for Dark Matter
* Indirect laboratory searches for Axions, WISPs
* Direct laboratory searches for Axions, WISPs
* New theoretical developments
Organizing committee:
Laura Baudis (University of Zurich)
Joerg Jaeckel (IPPP/Durham University)
Axel Lindner (DESY)
Andreas Ringwald (DESY)
Konstantin Zioutas (University of Patras)

Conclusions

University of Durham

- Low energy experiments with photons can provide for a
- AC/DC can provide (nearly) direct detection of minicharged particles
- A `Superconducting Box' experiment could explore the meV valley for `hidden photons'
- LSW with microwave cavities can provide a highly sensitive exploration of axions, and hidden photons

Conclusions

- All these experiments are small scale!
- They explore physics at ultra high energies and could detect hidden sectors

⬇

Complementary to accelerators!

Conclusions

- All these experiments are small scale!

\+

- They explore physics at ultra high energies and could detect hidden sectors

↓

Complementary to accelerators!

↓

Please build them 🙂 !

Theorists and "easy" experiments…

…lets go WISP hunting

Kinetic Mixing - How to get Minicharges

University of Durham

- Two U(1)'s

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}F^{\mu\nu}_{\rm (A)}F_{{\rm (A)}\mu\nu} - \frac{1}{4}F^{\mu\nu}_{\rm (B)}F_{{\rm (B)}\mu\nu} + \frac{\epsilon}{2}F^{\mu\nu}_{\rm (A)}F_{{\rm (B)}\mu\nu},$$

„Our“ U(1) — „Hidden“ U(1) — Mixing

$$\text{"} \quad = \text{"}\, A^2 + B^2 - 2\epsilon AB,$$

$$= A^2 + (B + \epsilon A)^2 + \mathcal{O}(\epsilon^2)$$

⇒ Diagonalization: $B^\mu \rightarrow B^\mu + \epsilon A^\mu$

Kinetic Mixing - How to get Minicharges

University of Durham

- Two U(1)'s

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}F^{\mu\nu}_{(A)}F_{(A)\mu\nu} - \frac{1}{4}F^{\mu\nu}_{(B)}F_{(B)\mu\nu} + \frac{\epsilon}{2}F^{\mu\nu}_{(A)}F_{(B)\mu\nu},$$

„Our" U(1) „Hidden" U(1) Mixing

→ Diagonalization: $B^\mu \to B^\mu + \epsilon A^\mu$

→ $\bar{\rm f} B^\mu {\rm f} \to \bar{\rm f} B^\mu {\rm f} + \epsilon \bar{\rm f} A^\mu {\rm f}$

→ ${\rm f}$ carries ϵ electric charge!

Hidden Photons

- Two U(1)'s

$$\mathcal{L}_{\mathrm{gauge}} = -\frac{1}{4}F^{\mu\nu}_{(\mathrm{A})}F_{(\mathrm{A})\mu\nu} - \frac{1}{4}F^{\mu\nu}_{(\mathrm{B})}F_{(\mathrm{B})\mu\nu} + \frac{\chi}{2}F^{\mu\nu}_{(\mathrm{A})}F_{(\mathrm{B})\mu\nu},$$

„Our" U(1)

„Hidden" U(1)

Mixing

$$\begin{aligned} \text{"} &= \text{"} A^2 + B^2 - 2\chi AB, \\ &= A^2 + (B + \chi A)^2 + \mathcal{O}(\chi^2) \end{aligned}$$

⇒ **Diagonalization:** $B^\mu \rightarrow B^\mu + \chi A^\mu$

Massive hidden photons oscillate

- Two U(1)'s

$$\mathcal{L}_{\rm gauge} = -\frac{1}{4}F^{\mu\nu}_{\rm (A)}F_{{\rm (A)}\mu\nu} - \frac{1}{4}F^{\mu\nu}_{\rm (B)}F_{{\rm (B)}\mu\nu} + \frac{\chi}{2}F^{\mu\nu}_{\rm (A)}F_{{\rm (B)}\mu\nu},$$

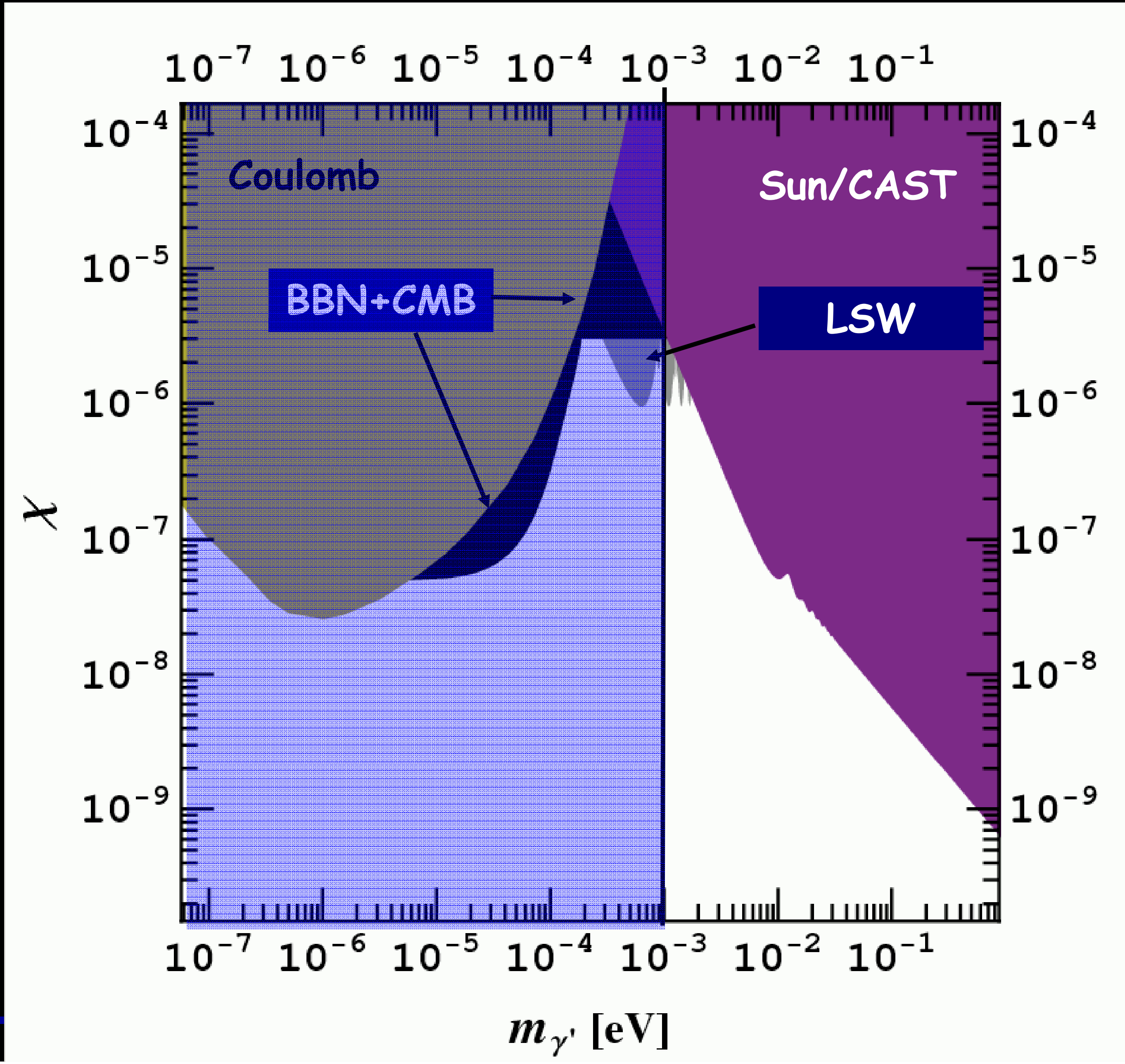
„Our" U(1) — „Hidden" U(1) — Mixing

➡ Diagonalization: $B^\mu \rightarrow B^\mu + \chi A^\mu$

➡ $$m^2_{\gamma'}B^\mu B_\mu \rightarrow m^2_{\gamma'}(B^2 + 2\chi AB + \chi^2 A^2)$$

➡ **photon – hidden photon oscillations analog neutrino oscillations**

(theoretical) Sensitivity, e.g. hidden photons



Q-factor

- Energy loss will be reflected in the Cavity's Q-factor:

$$Q = 2\pi \frac{E_{cav}}{\Delta E}$$

- We can get bounds from

$$Q_{max} \leq 2\pi \frac{E_{cav}}{\Delta E_{MCP}}$$

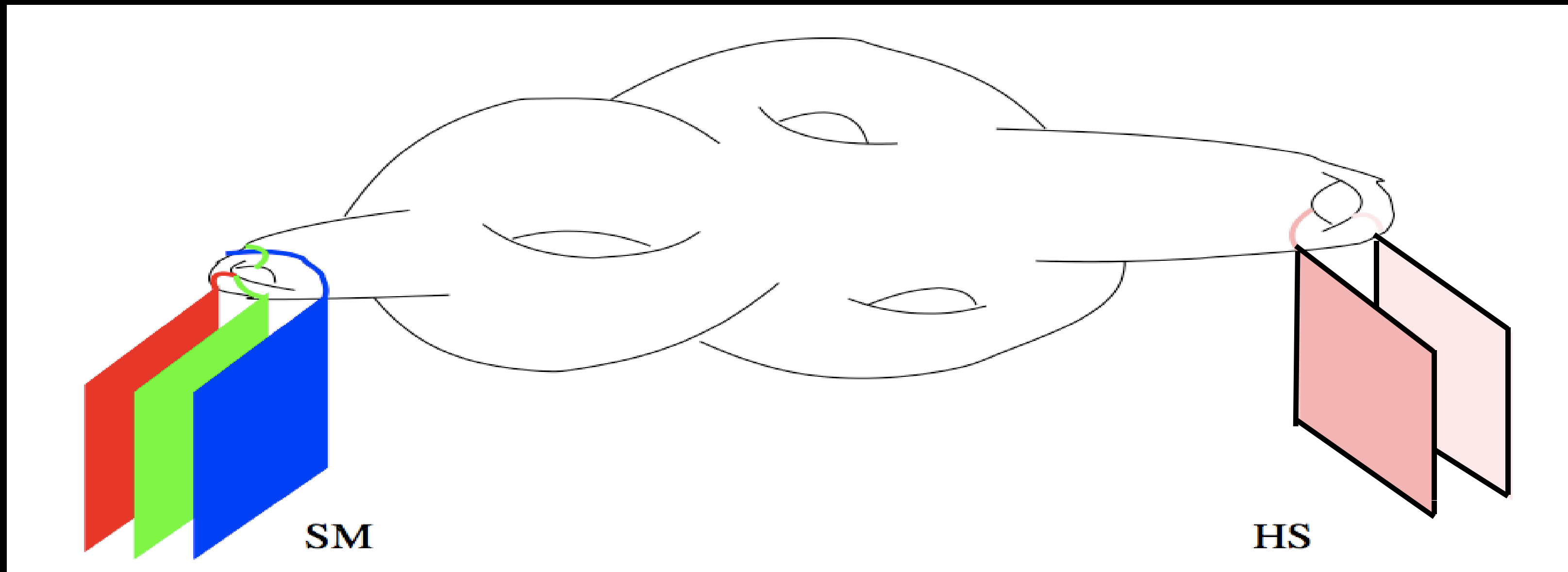
- Superconducting Cavities reach

$$Q_{max} > 10^{10}$$

Searching hidden photons inside a superconducting box

Hidden Photons

- Extra (light) U(1) gauge bosons
- Standard model particles carry no (tree-level) charge under them ➡ hidden!
- Tests hidden sectors of standard model extensions



$U(A) \times U(B) \times U(C)$ $U(A) \times U(B)$

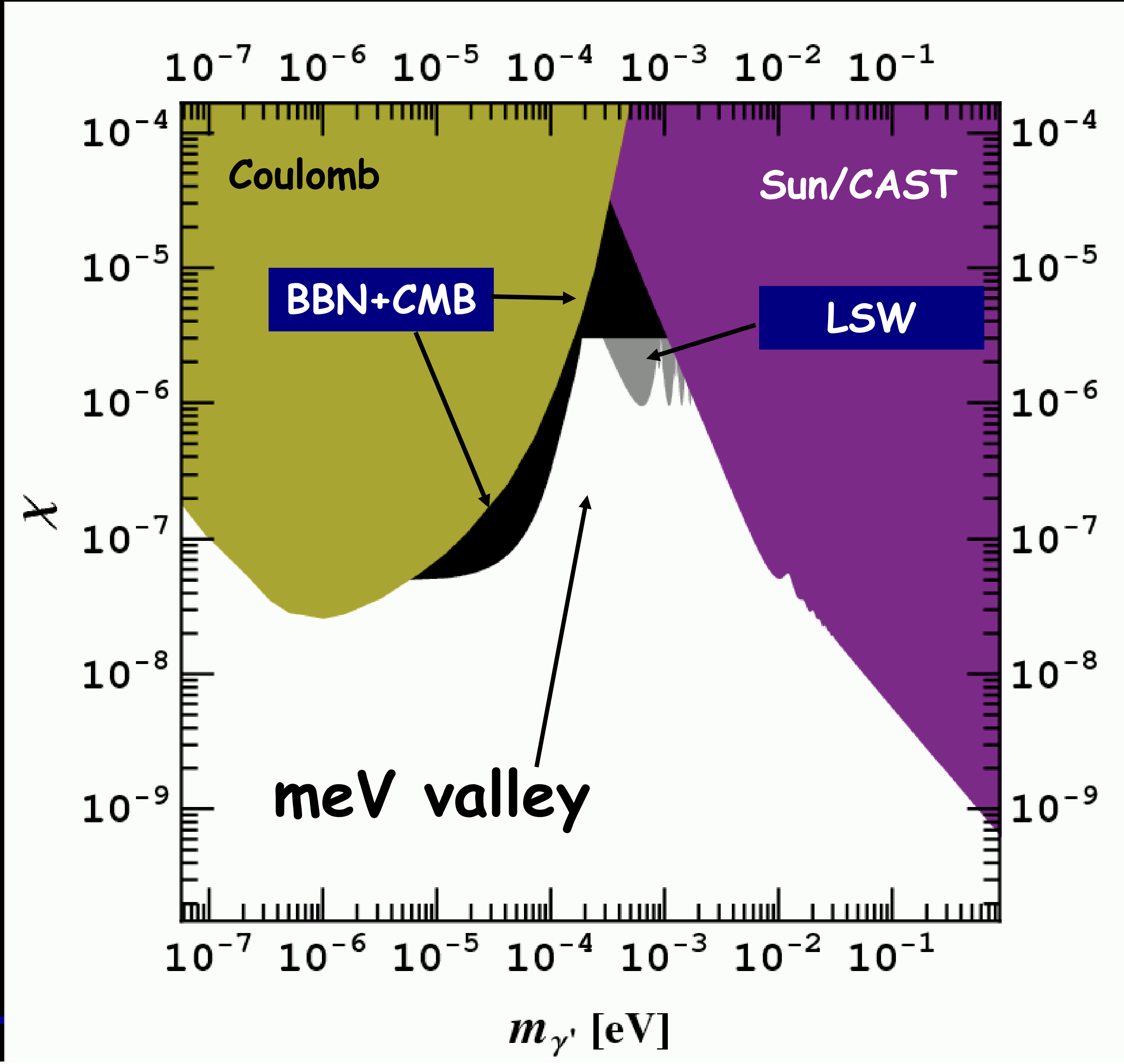
Massive hidden photons

- Hidden Photons can mix with the ordinary photon
- Propagation eigenstates are not identical with interaction eigenstates

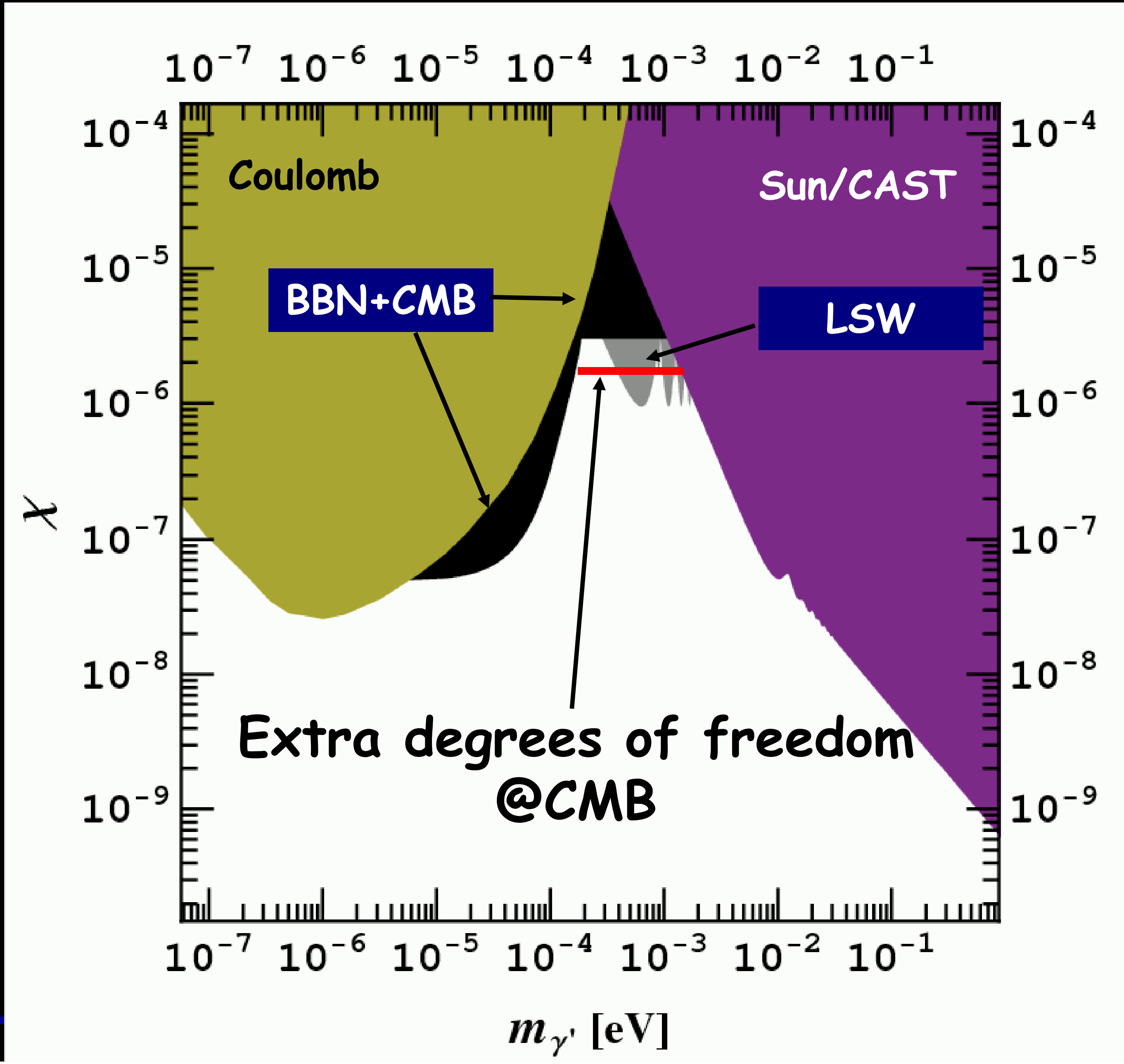
↓

- Photon – Hidden photon oscillations
- Completely analogous to neutrino oscillations

Current bounds ➡ opportunities

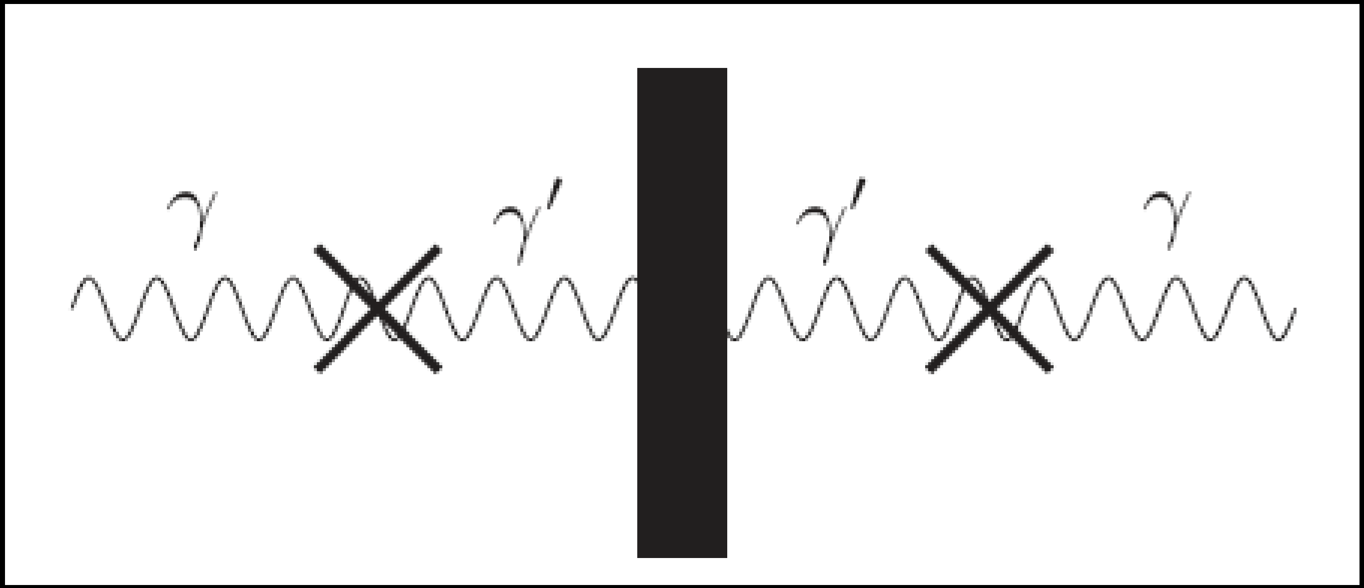


Current bounds ➡ opportunities



Basic idea

- Similar to `Light shining through walls':



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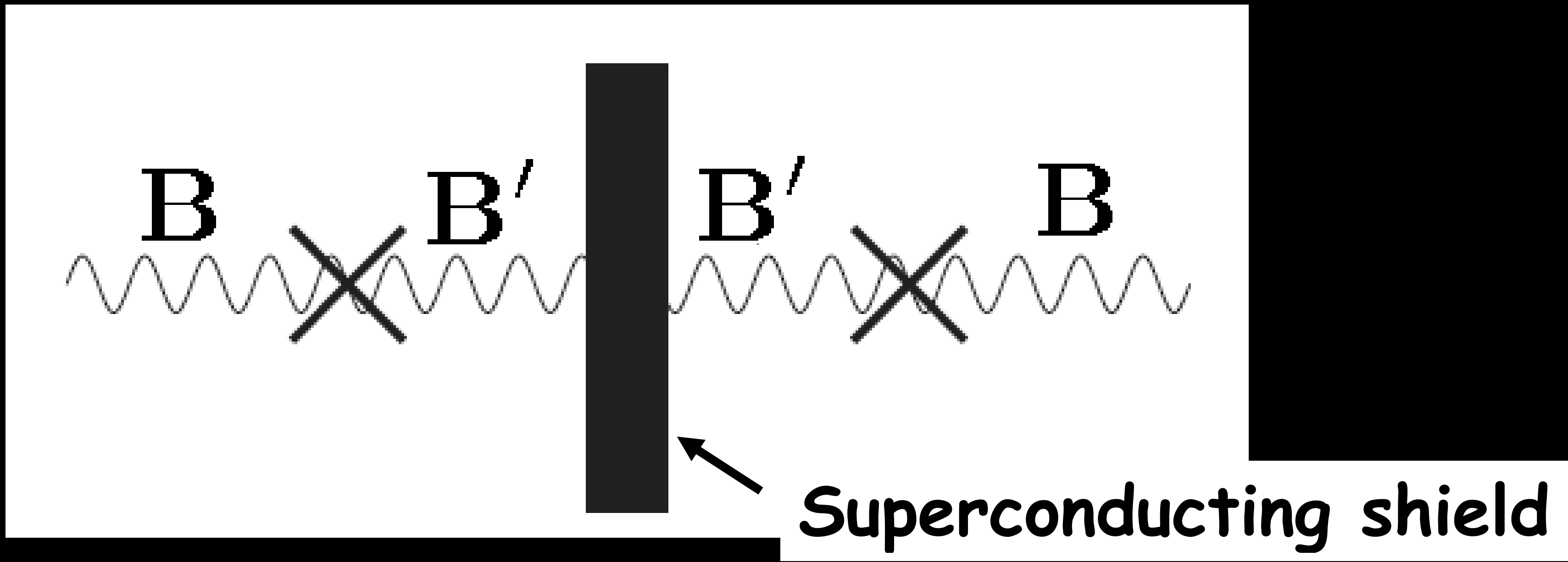
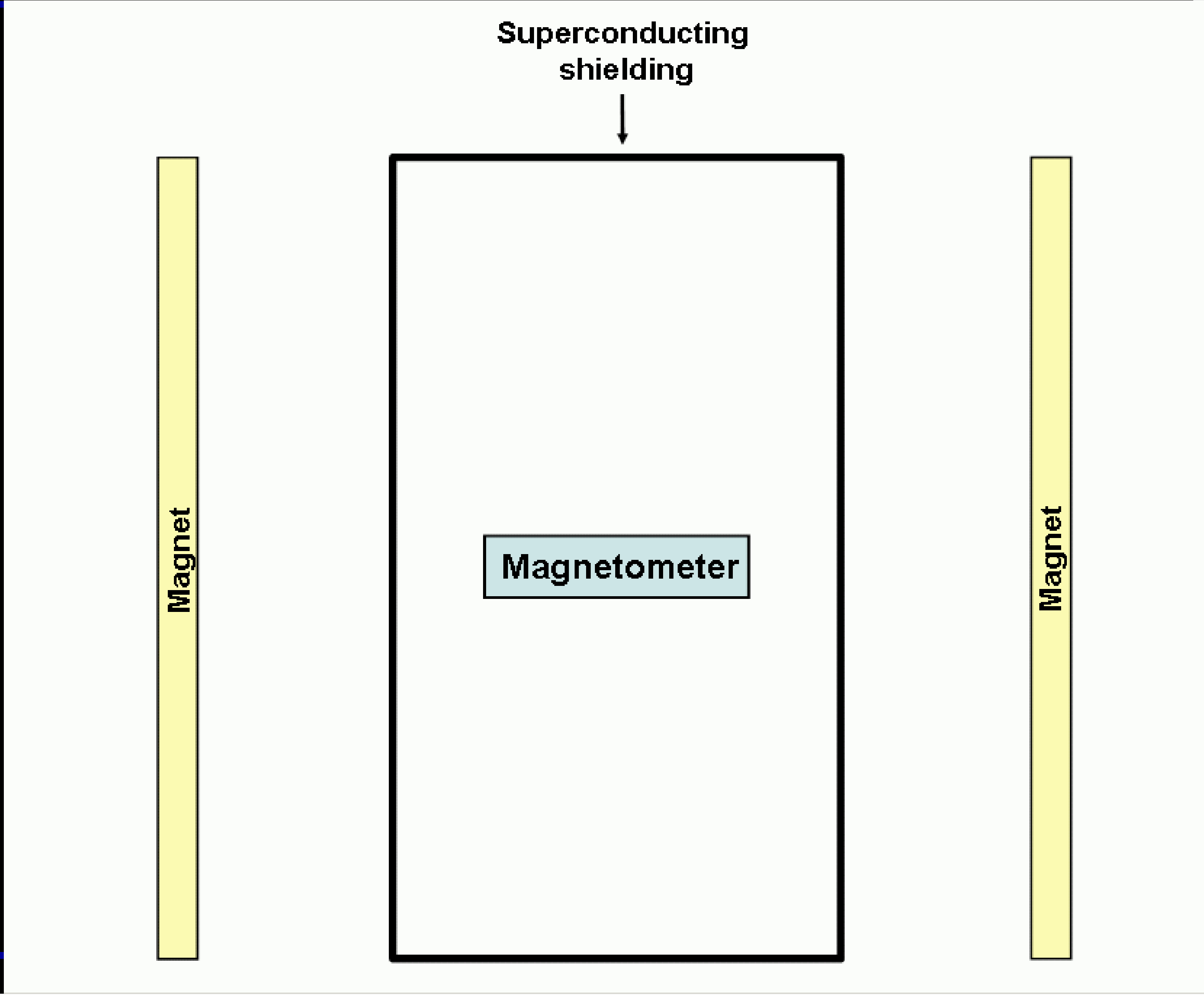
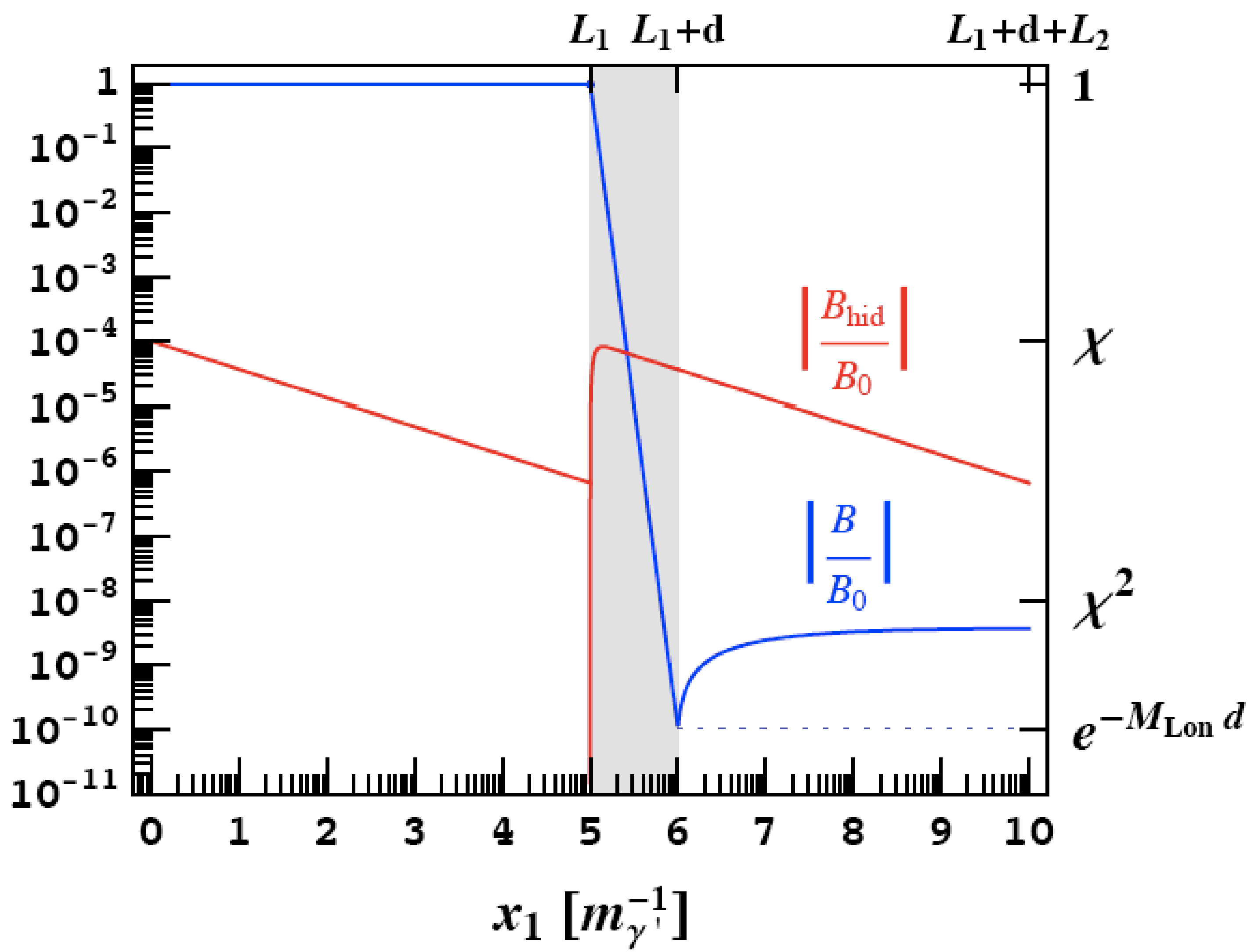


- But virtual instead of real photons,
- Magnetic field instead of Laser
- Superconductor is `wall'

Setup: The box



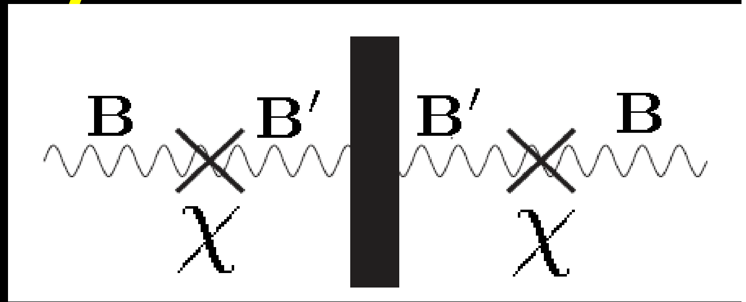
Magnetic fields from source to detector



Advantages

- Measures directly the field, i.e. amplitude instead of probability

$$\Rightarrow \quad \text{signal} \sim \chi^2$$



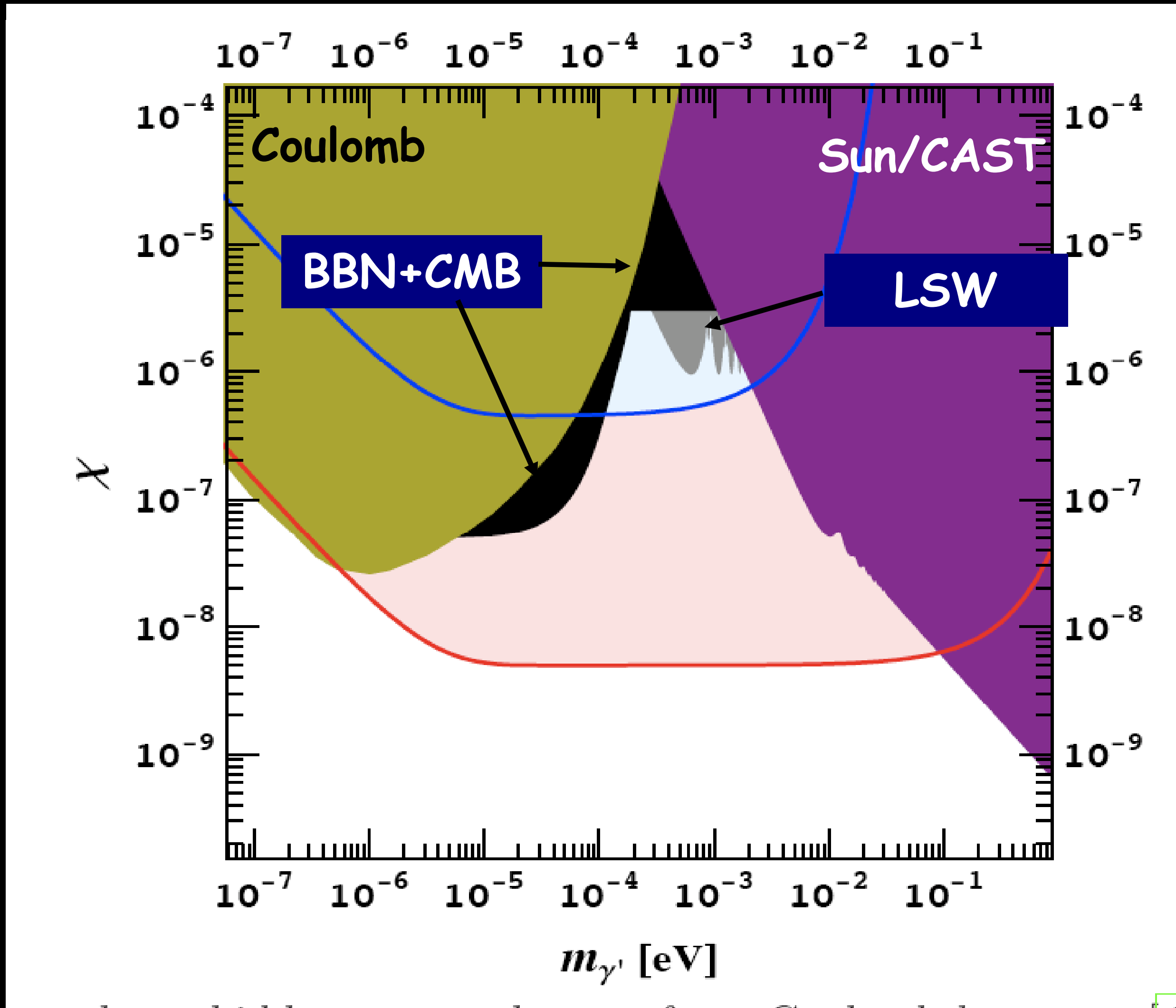
- Can use fields as high as 0.1 T (higher fields not shielded by most superconductors)

- Can detect B as low as a few 10^{-18} T

⇒ **Expect sensitivity up to χ» few 10^{-9}!**

(possible disadvatage: may not work for axions!)

Sensitivity: Exactly where we want it ☺



Could do better than astrophysics!!!