Search for New Physics @ Low Energies

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The participants of the Brainstorming&Calculationshop + The 5th Patras Workshop

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Hints for new Physics

Uglyness of old models

- The Standard Model has many free parameters: O(30)

- Naturalness problems. Finetuning.
  Examples:
  Higgs mass, θ-angle (strong CP-problem)

- Gravity separate, i.e. not unified.

- (Probably) Breaks down at a finite energy scale
  Landau poles etc.

Unexplained Stuff

- Dark Matter (25%)
  (astrophysical + cosmological observations)

- Dark Energy (70%)
  (astrophysical + cosmological observations)

- Mass Hierarchies
  (colliders, neutrino exp, etc)

- Small parameters (θ-angle, again)
  (neutron electric dipole measurements)

Contradictions (not proven)

- (g-2) deviations from SM prediction
- DAMA anomaly
- PAMELA observation

Hints for new Physics

Model Building

Bottom-up (pheno)

Fix problem
`here and now'

Top-down (theory)

Go back to drawing board
`Start from scratch'

No neutron electric dipole moment...

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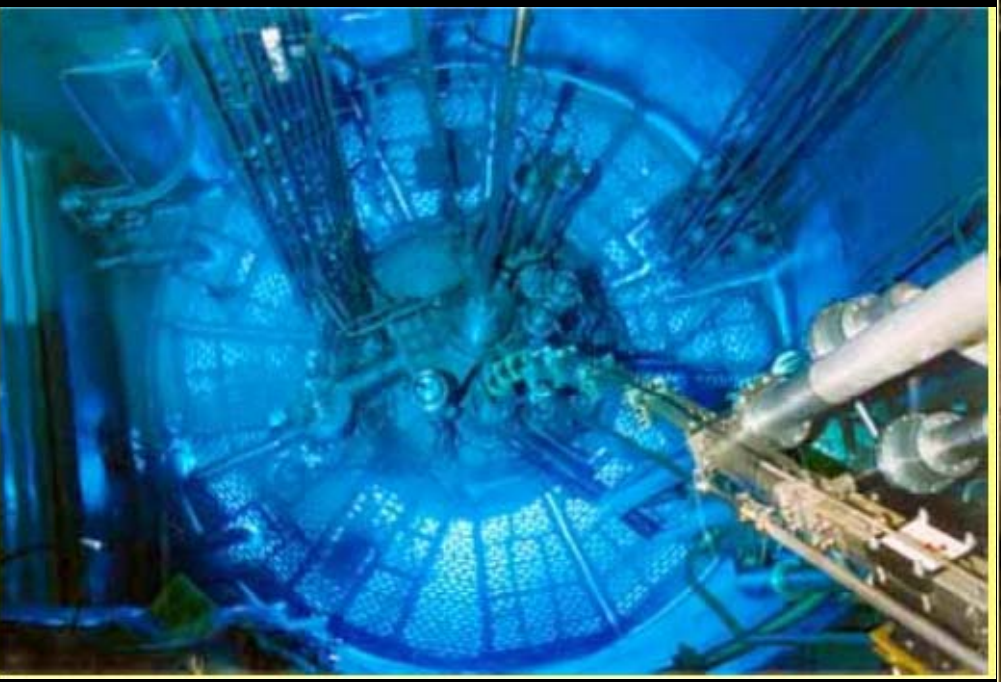


$$|\vec{d}| < 3\,10^{-26} e\,cm$$

$$= 3\,10^{-13} e\,fm \lll \frac{1}{16\pi^2} e\,fm$$

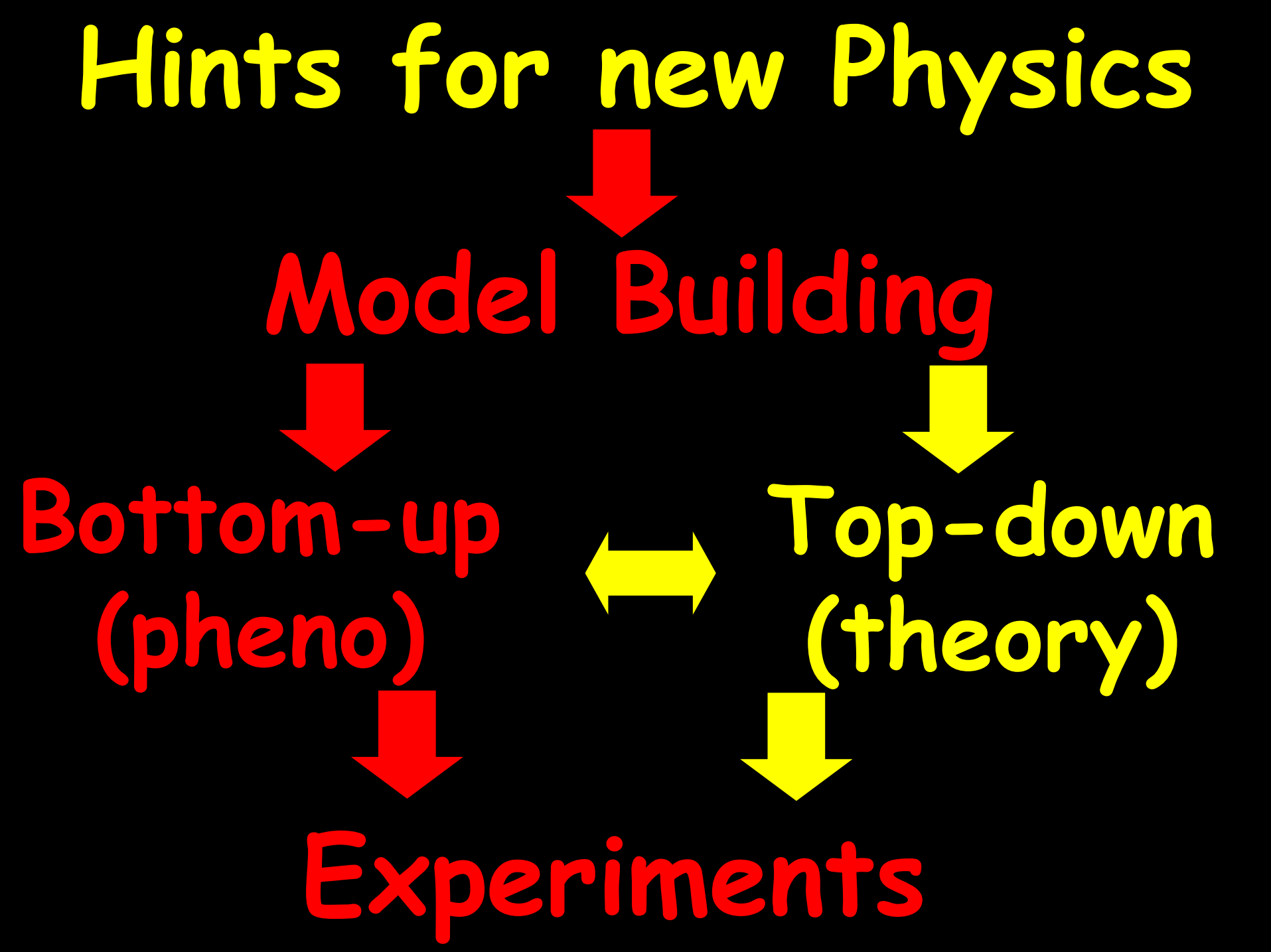
The strong CP problem: Axions

- Introduce new Peccei-Quinn symmetry to solve naturalness problem

- Predict as a consequence a new particle: The Axion
  (it's a Weakly Interacting Sub-eV Particle)

Dark matter candidate

Good `physics case' for WISP experiments


Hints for new Physics
Model Building
Bottom-up
(pheno)
Top-down
(theory)
Experiments

Exploring fundamental high energy physics…

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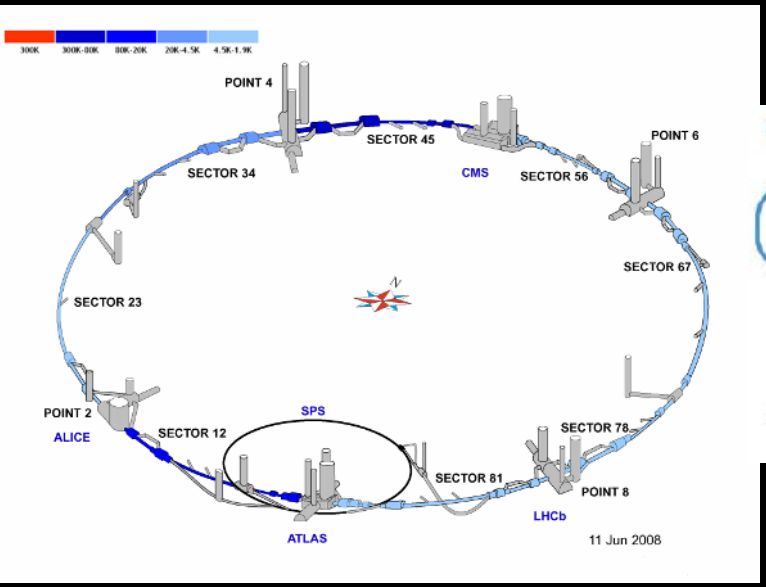
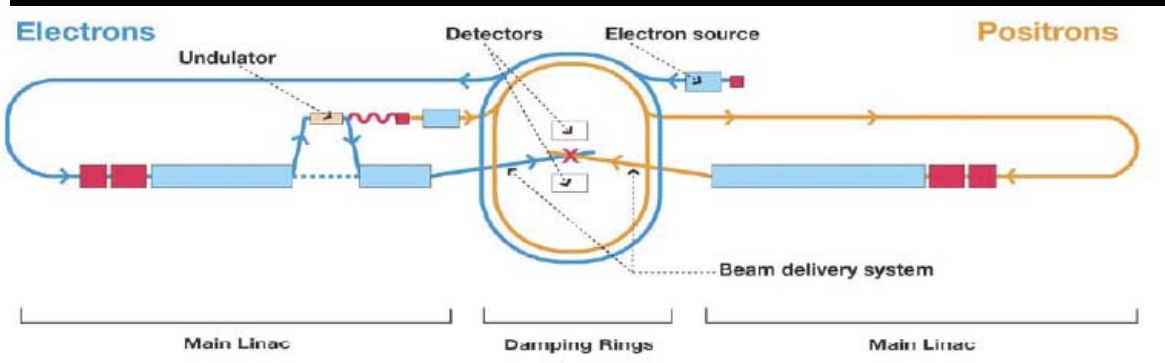
- The direct approach: MORE POWER

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

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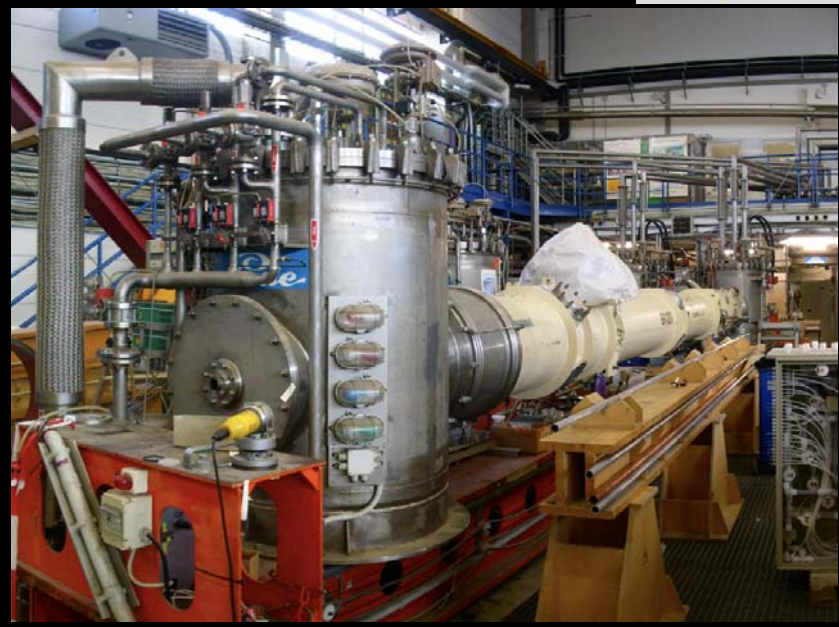
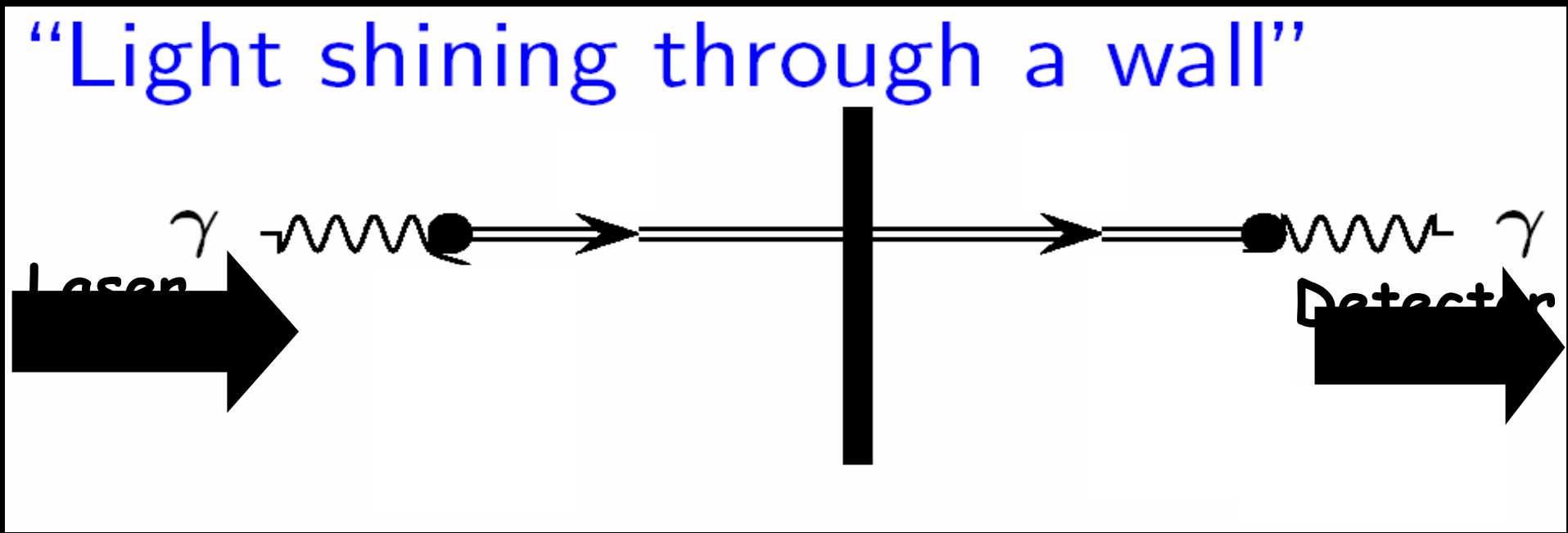
Example:
ALPS@DESY=
Axion-like particle search
Any-light particle search





Light Shining through a wall

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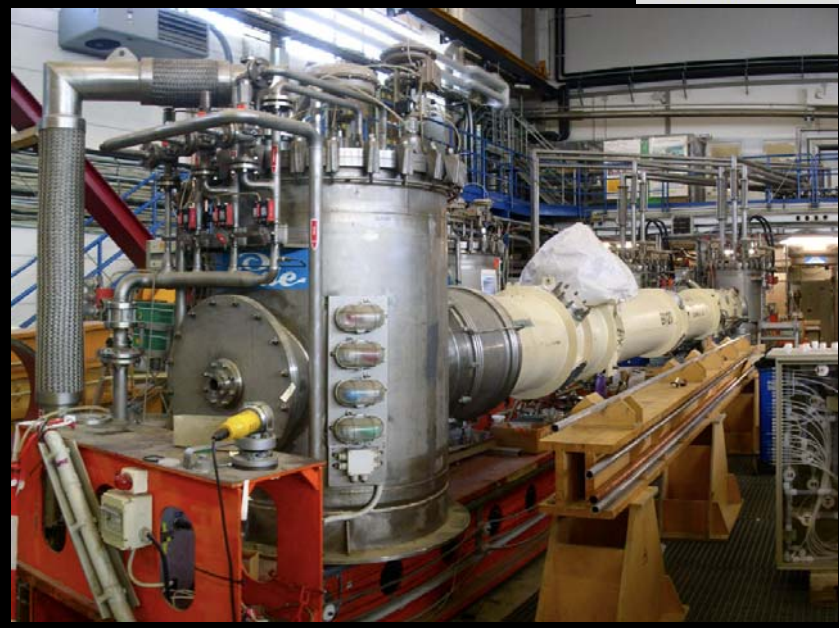
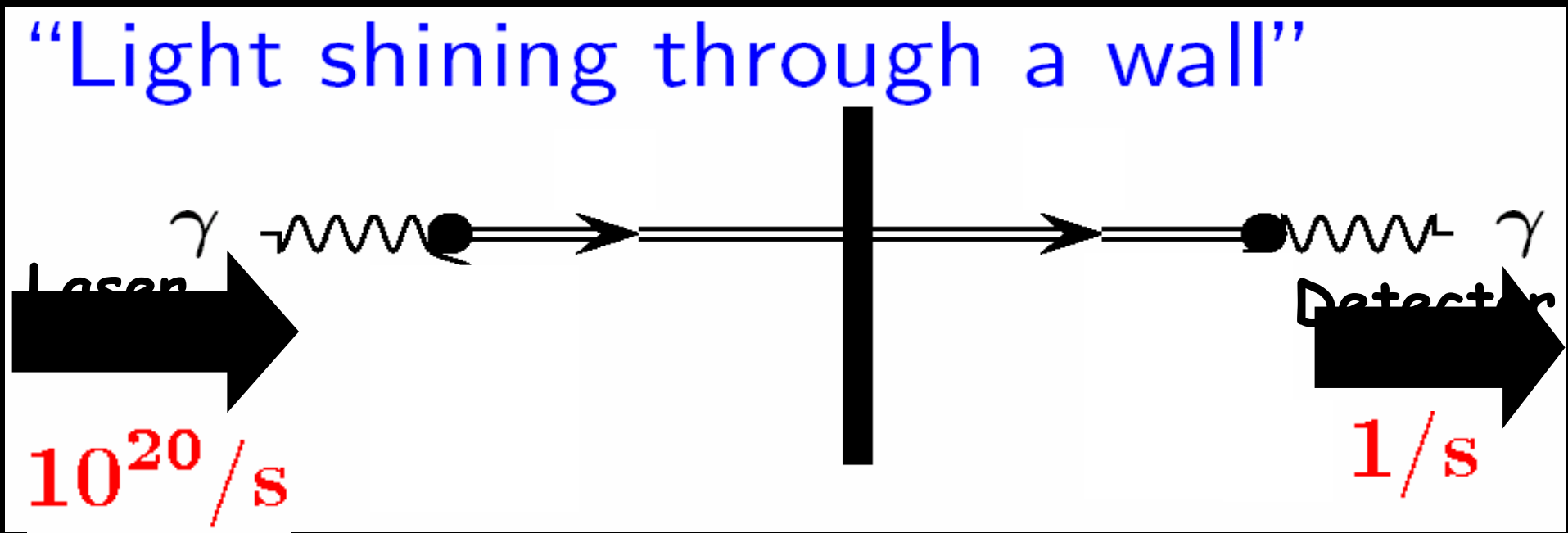
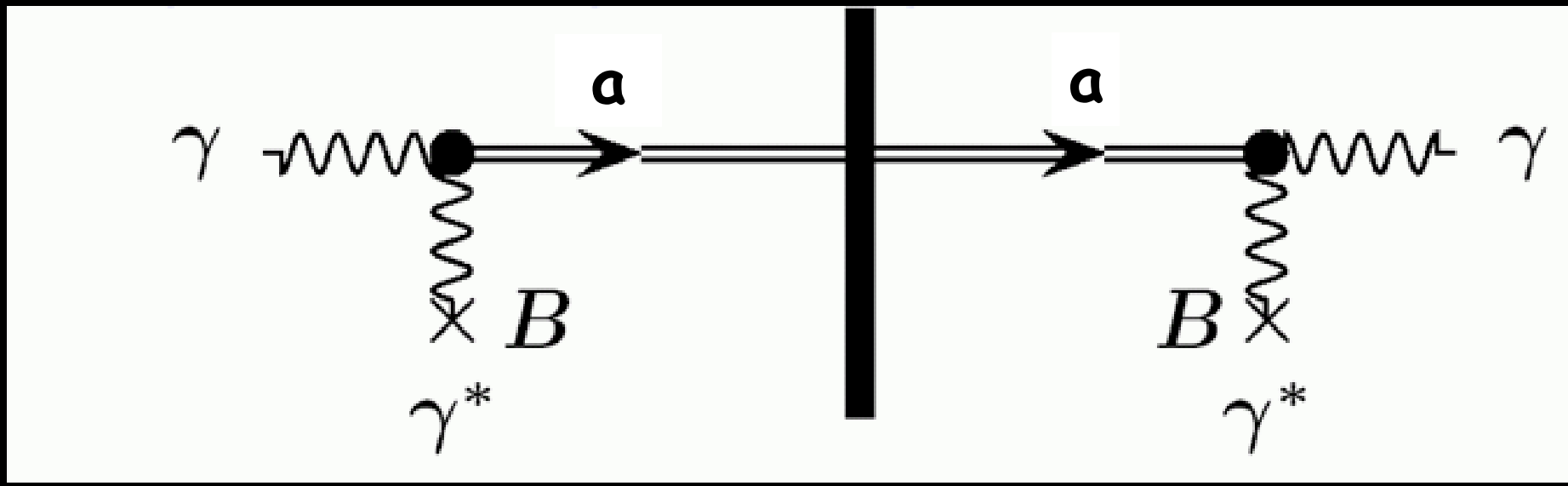




Photons coming through the wall!

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



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

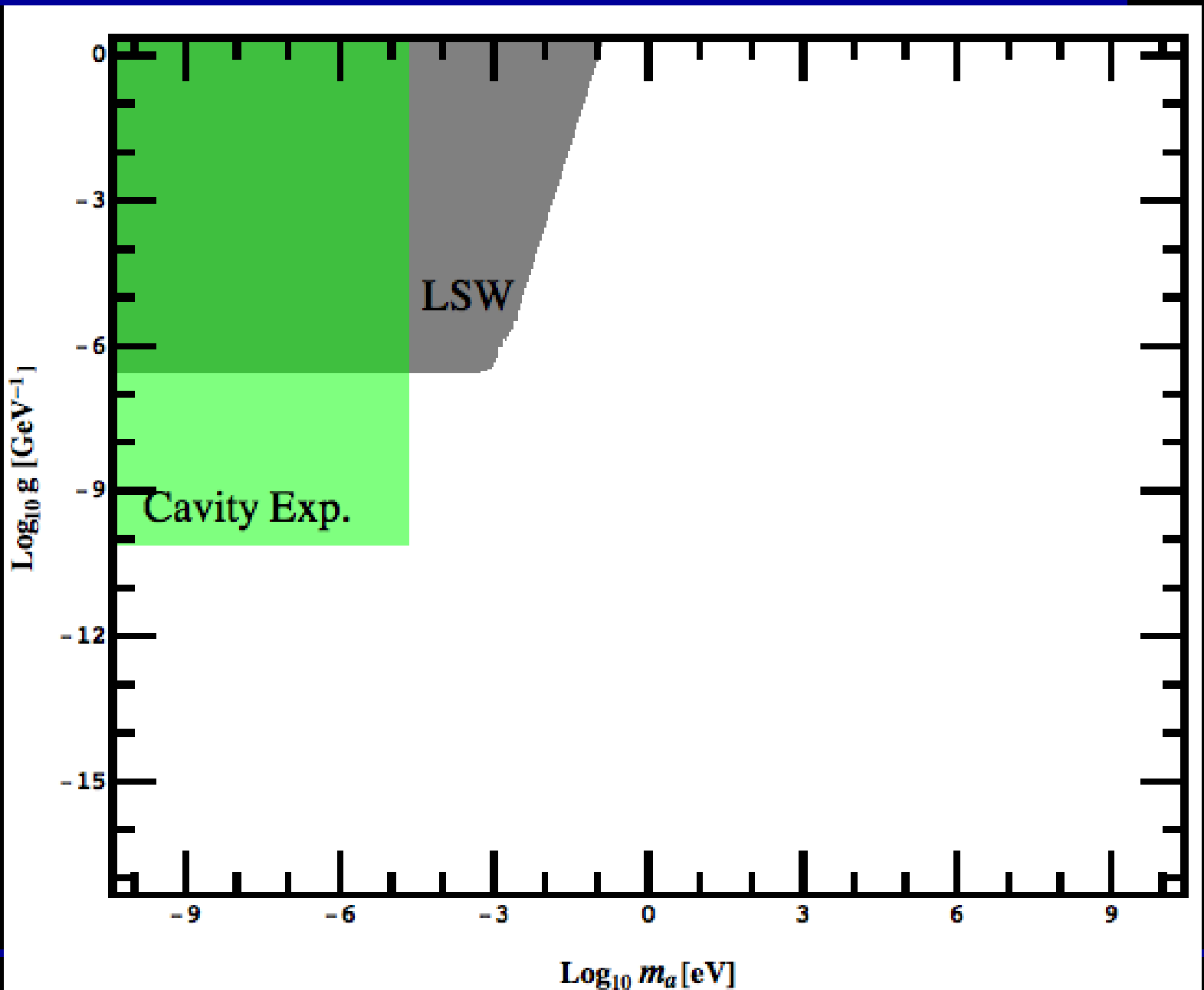
Many experiments

- ALPS@DESY
- BMV@Toulouse + polarization
- GammeV@Fermilab
- LIPSS@Jefferson
- OSQAR@CERN + polarization

In preparation
- Yale Cavity

Planned
- Australien Cavity
- Daresbury Cavity
- PVLAS II resonant regeneration + polarization
- REAPR@xxx

Probing very high energies…



Helioscopes

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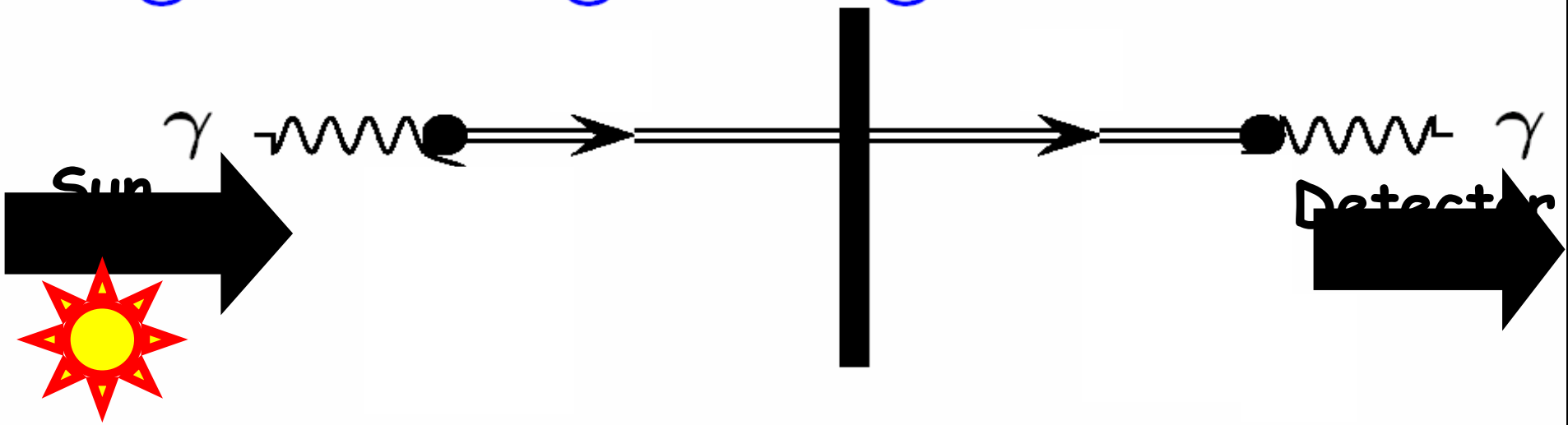
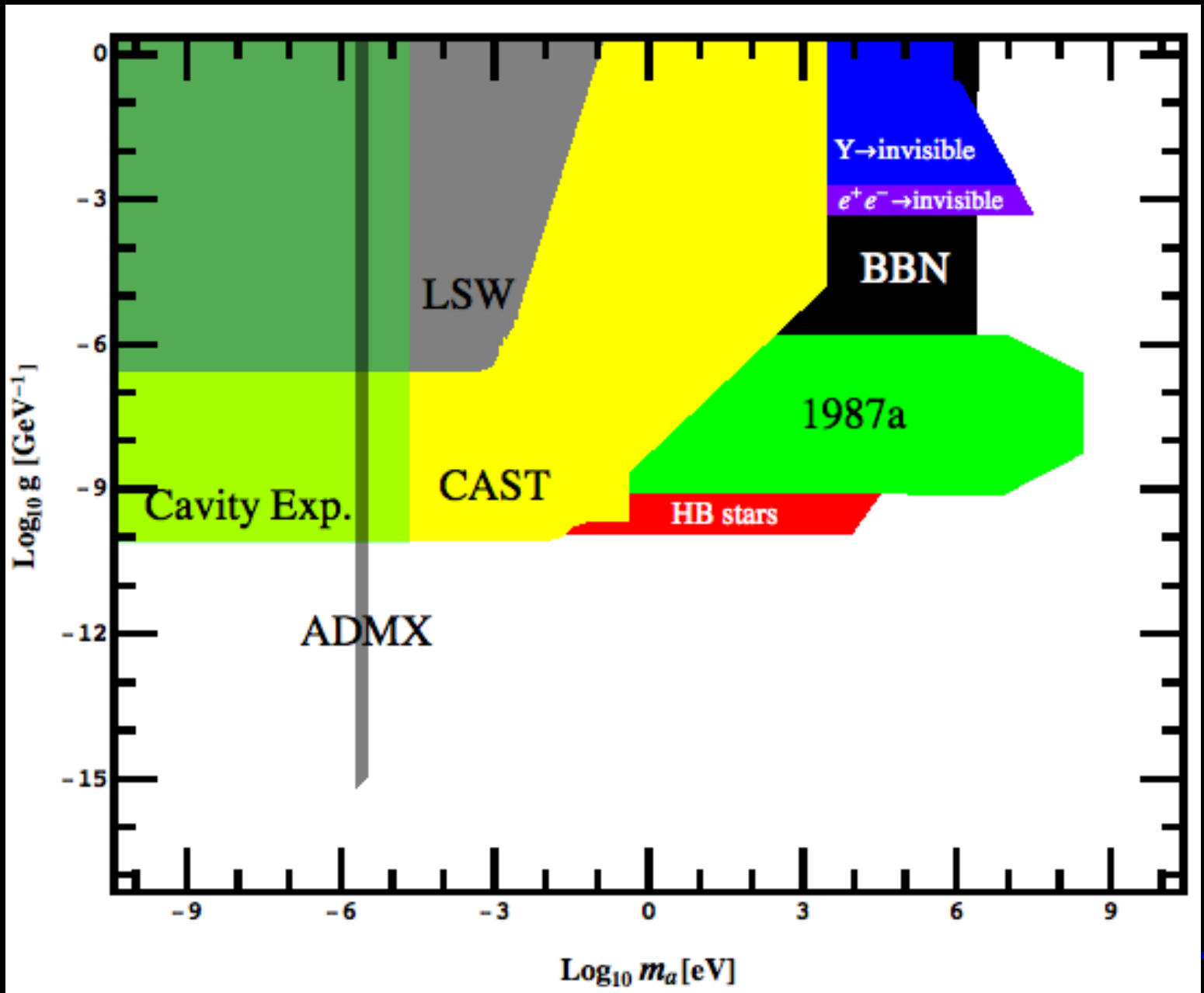
CAST@CERN
SUMICO@Tokyo

"Light shining through a wall"



Axion (like particles): Where are we?



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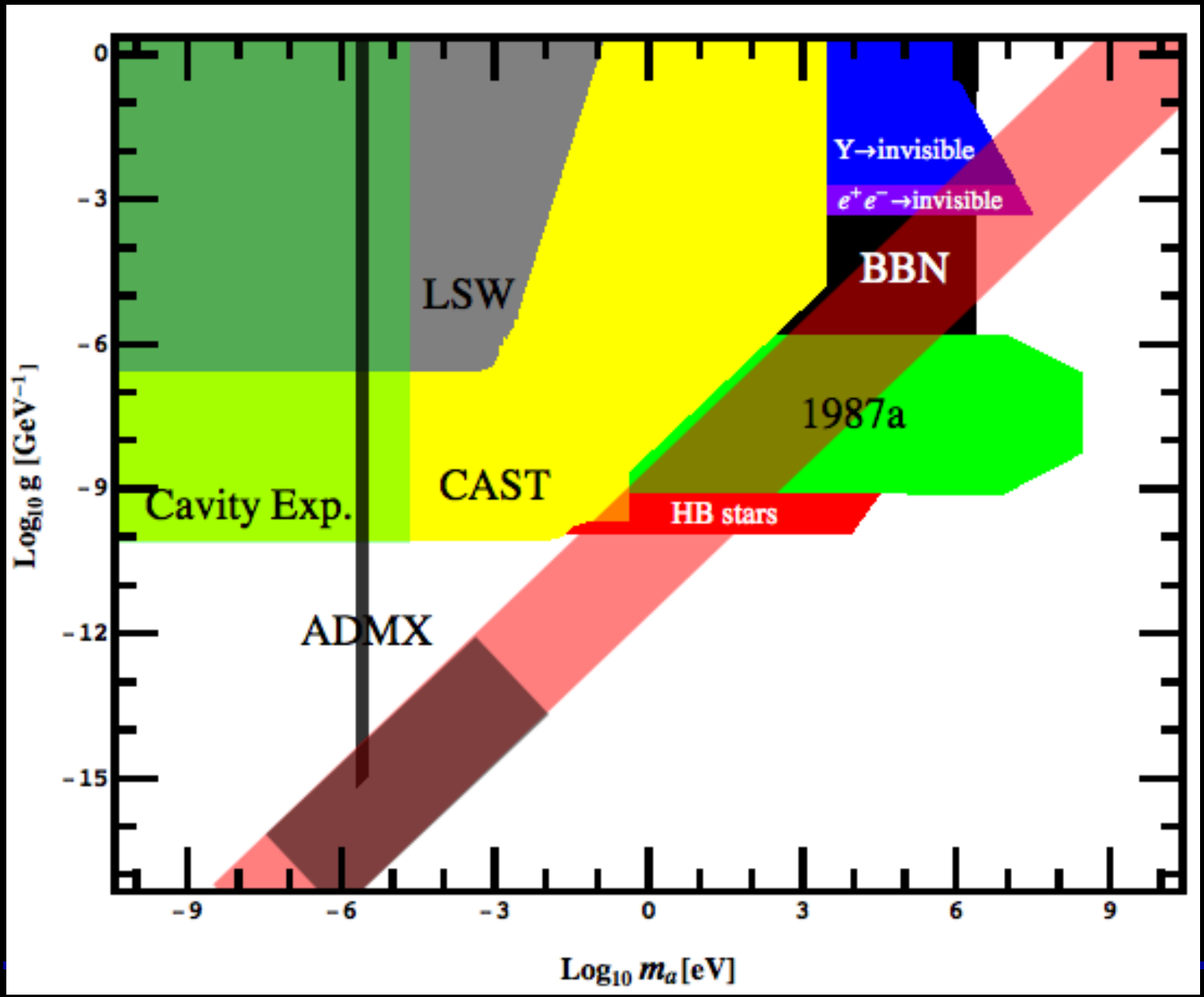
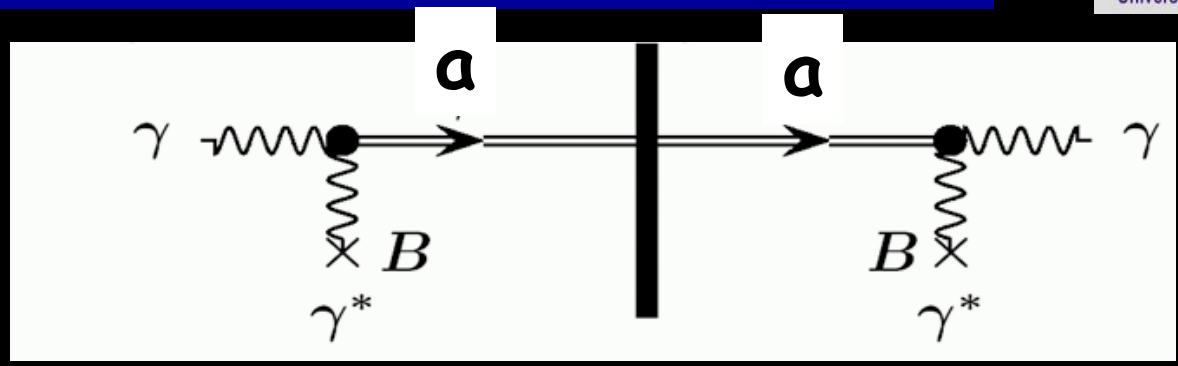
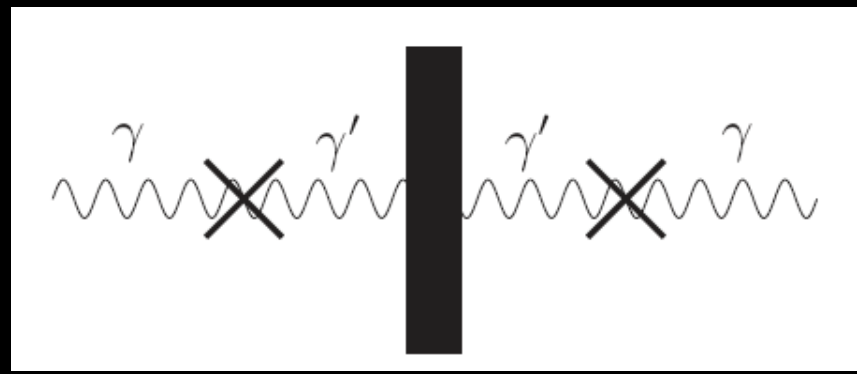


WISPS=Weakly interacting sub-eV particles

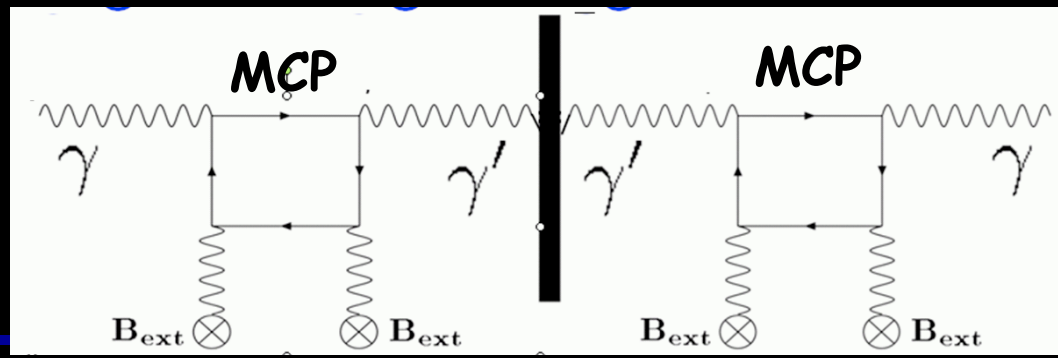
- Axions



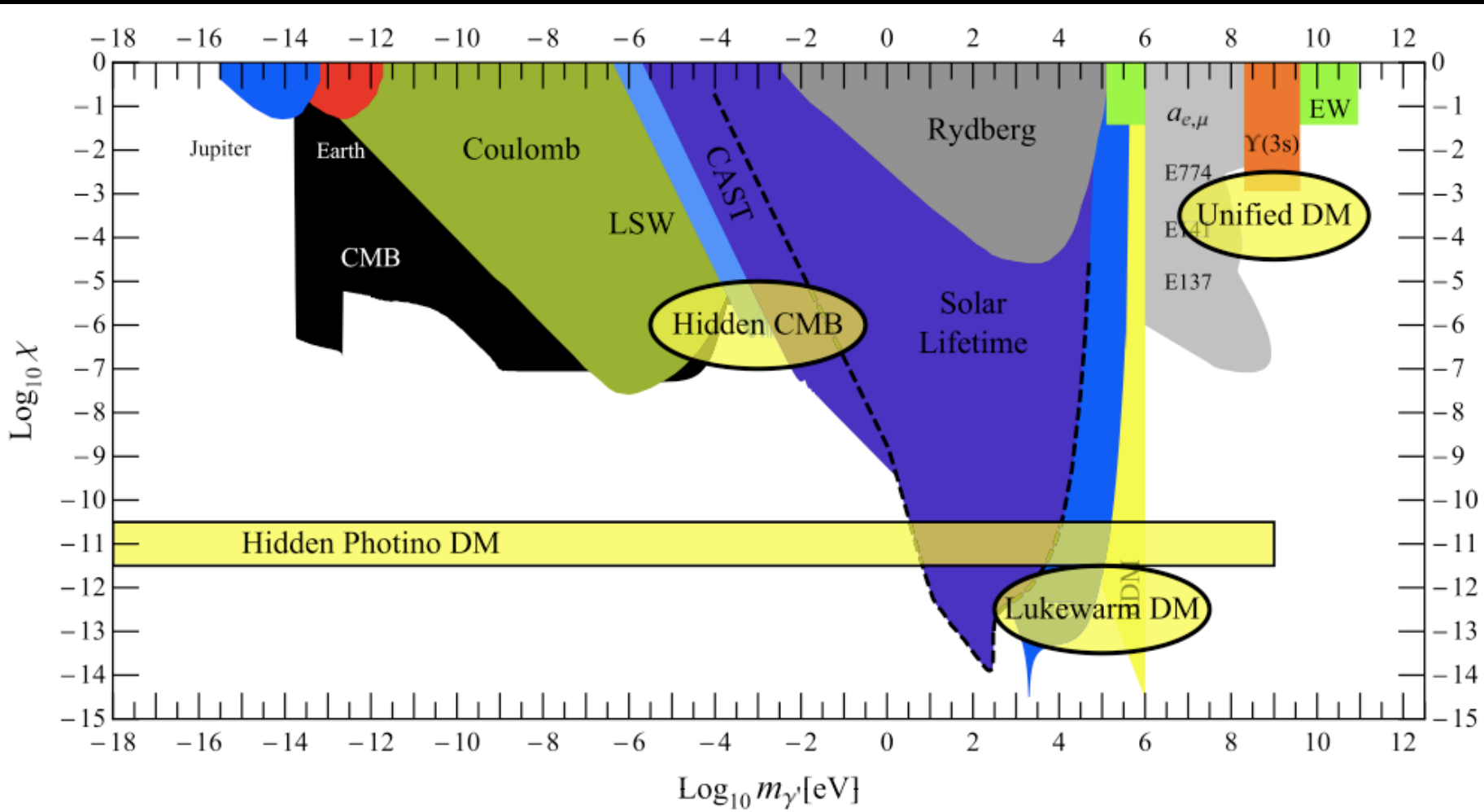
- Massive hidden photons (without B-field) =analog ν-oscillations



- Hidden photon + minicharged particle (MCP)



Hidden Photons: An impressive range



Something to hide?

Something to hide?

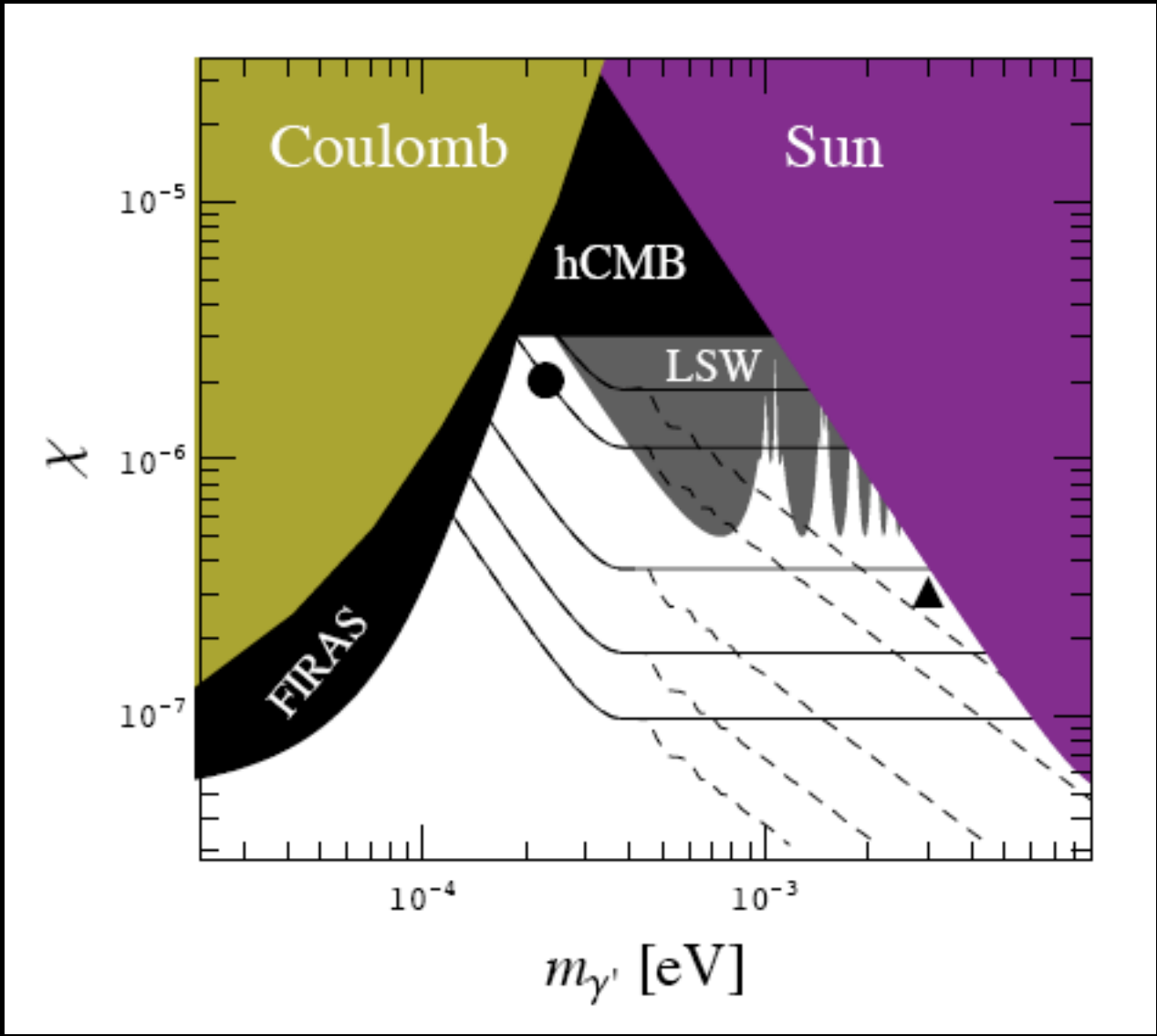
Use Hidden Photons©

to communicate!

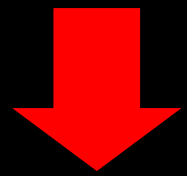
Practical applications ;-)

- Communicating through the Earth

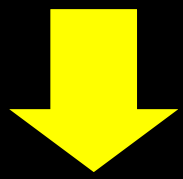
Practical applications ;-)

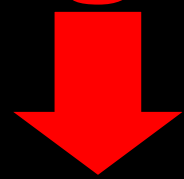


Hints for new Physics

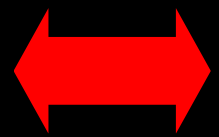


Model Building





Bottom-up (pheno)



Top-down (theory)

Go back to drawing board
`Start from scratch'

String theory

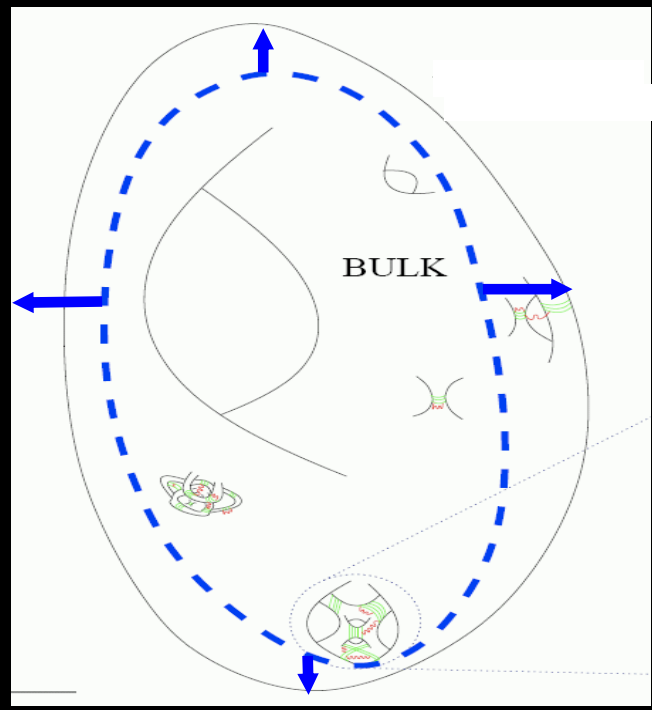
- Attempt to unify SM with gravity
- New concept: strings instead of point particles

String theory: Moduli, Axions, etc.

- String theory needs Extra Dimensions

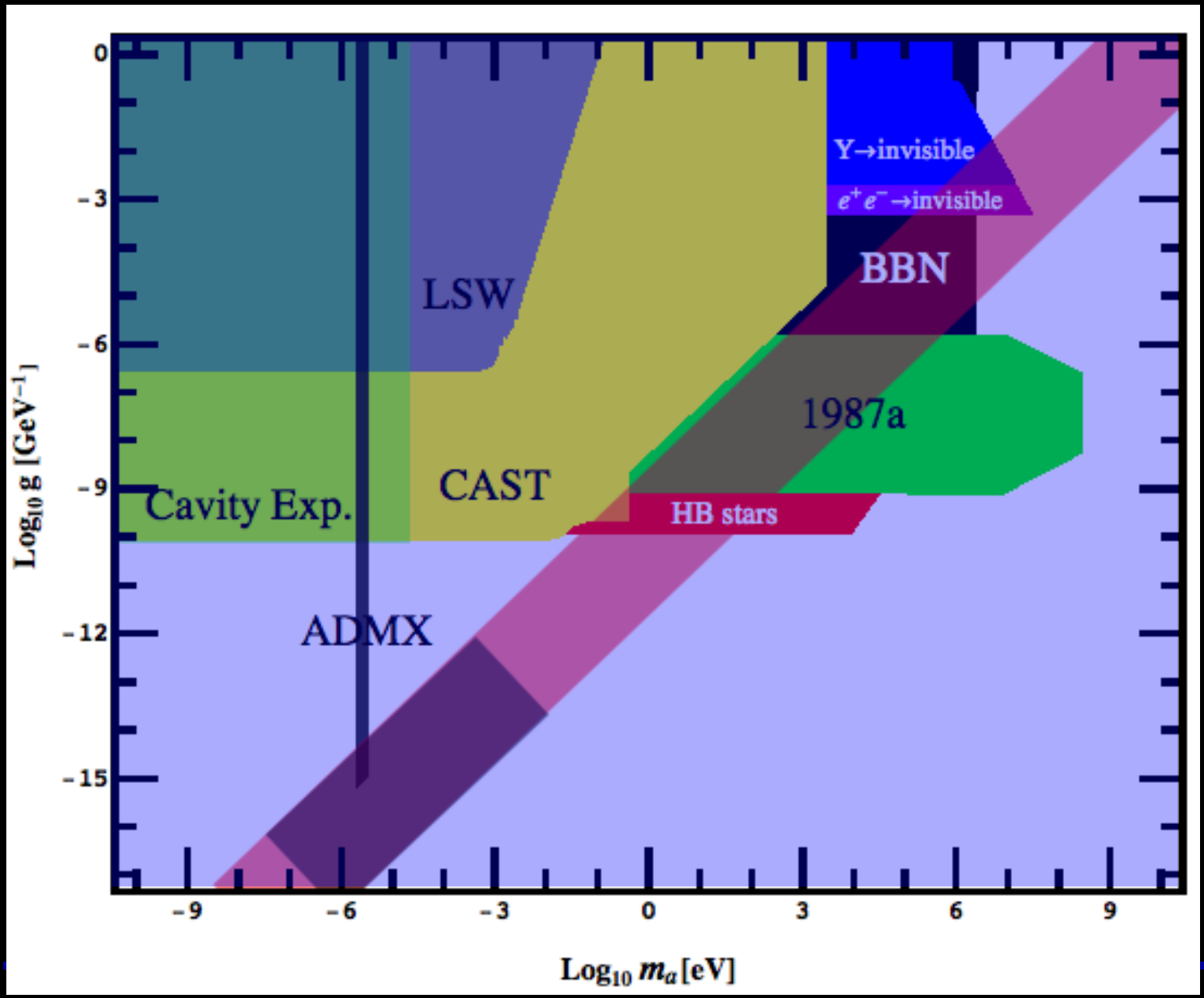
Must compactify

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

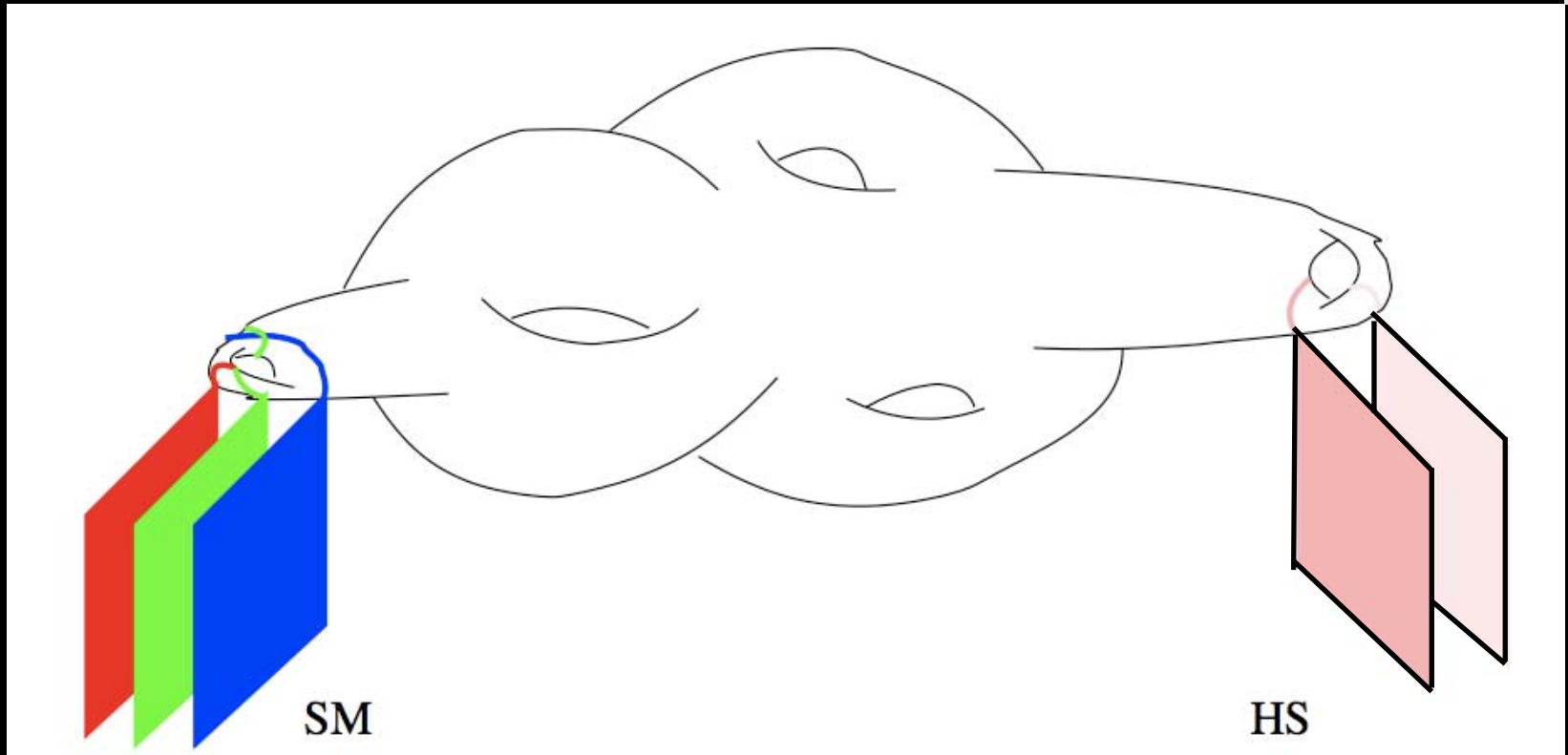


`Physics case' for WISPs strengthened

Axion (like particles): Where are we II?



String theory likes extra gauge groups



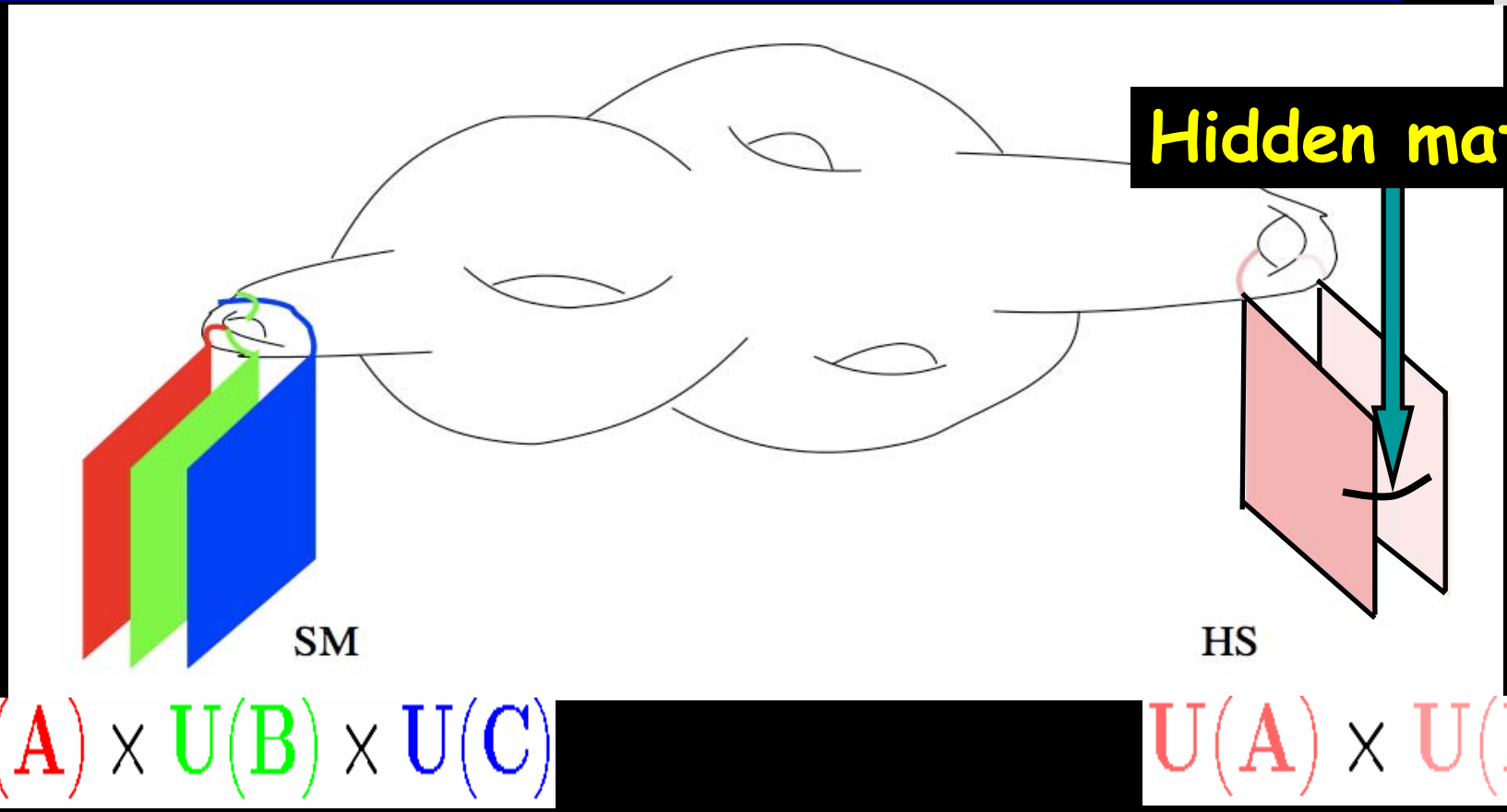
$U(A) \times U(B) \times U(C)$

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

➡ Many extra U(1)s!

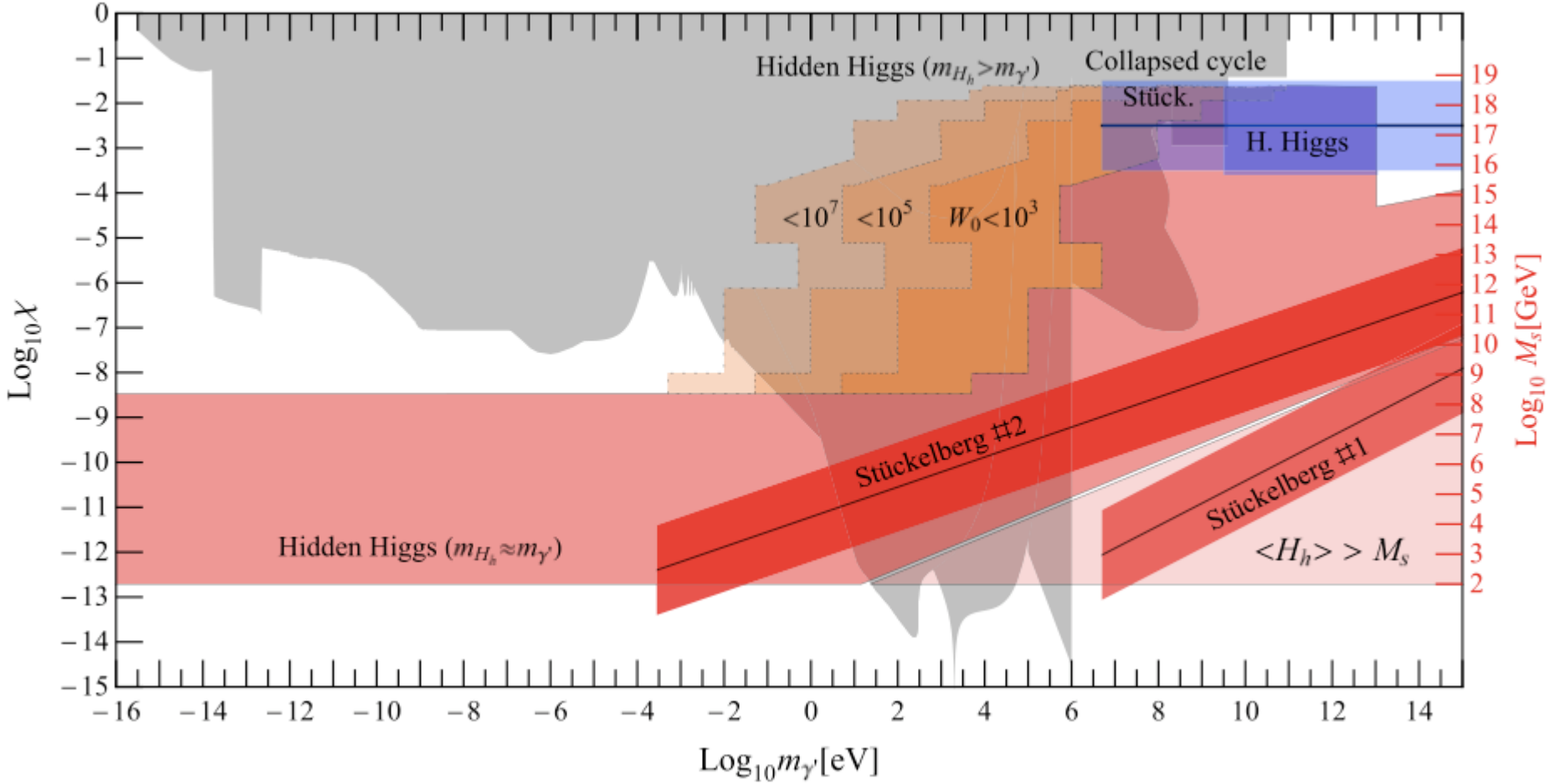
➡ Candidates for WISPs

String theory likes extra matter

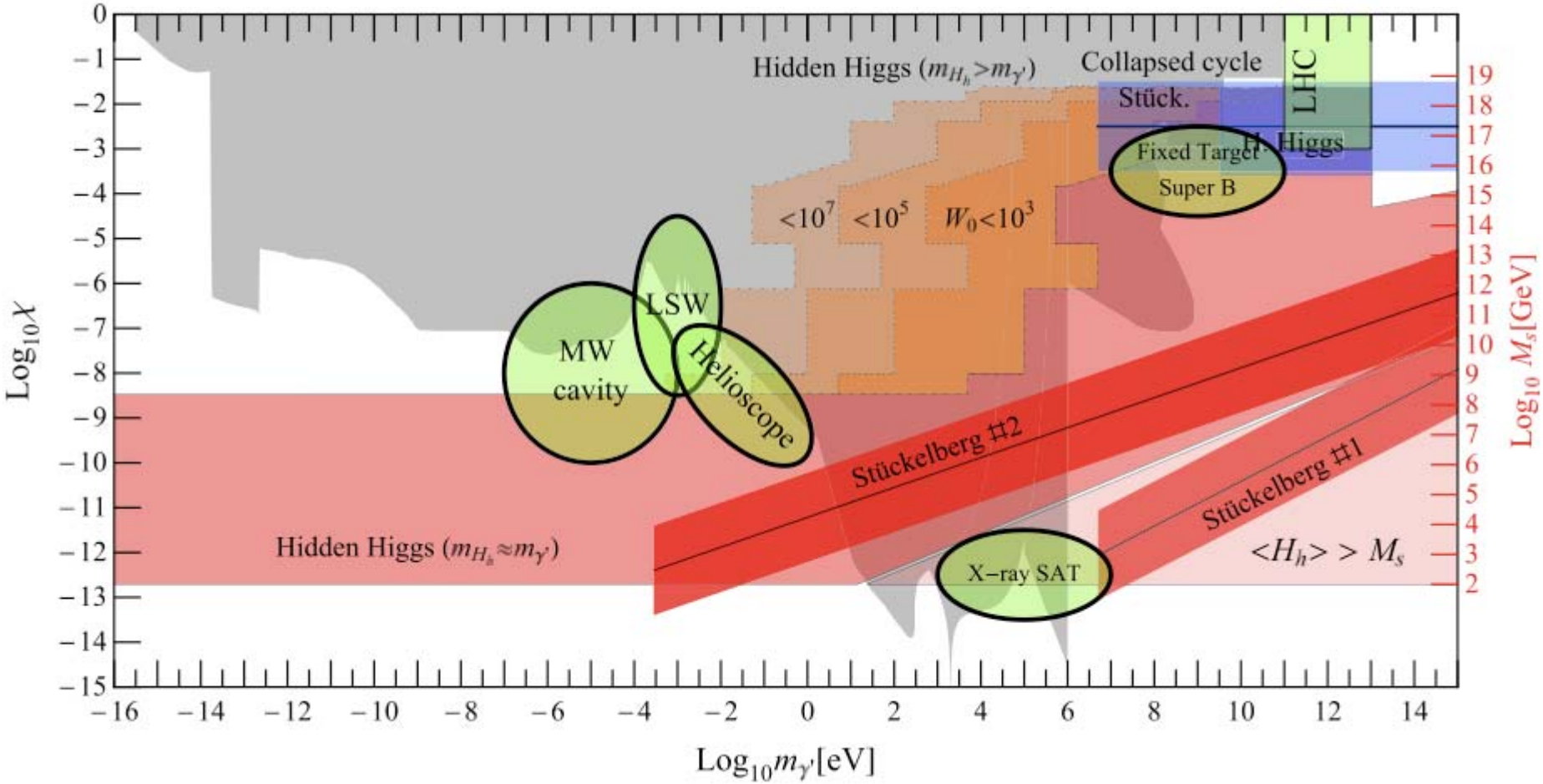


- Hidden sector matter
- May be light and WISPy
  Or WIMPy and dark matter

Hidden Photons, All over the place

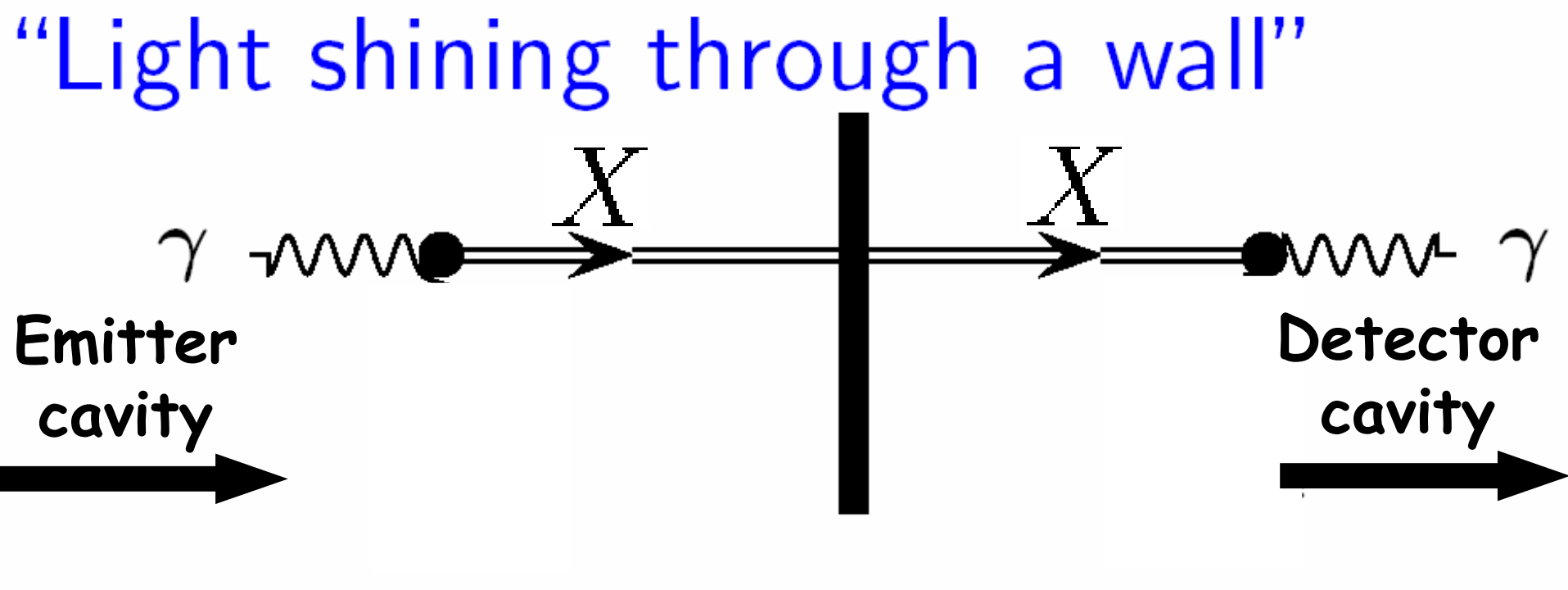


Hidden Photons: Back to Experiment



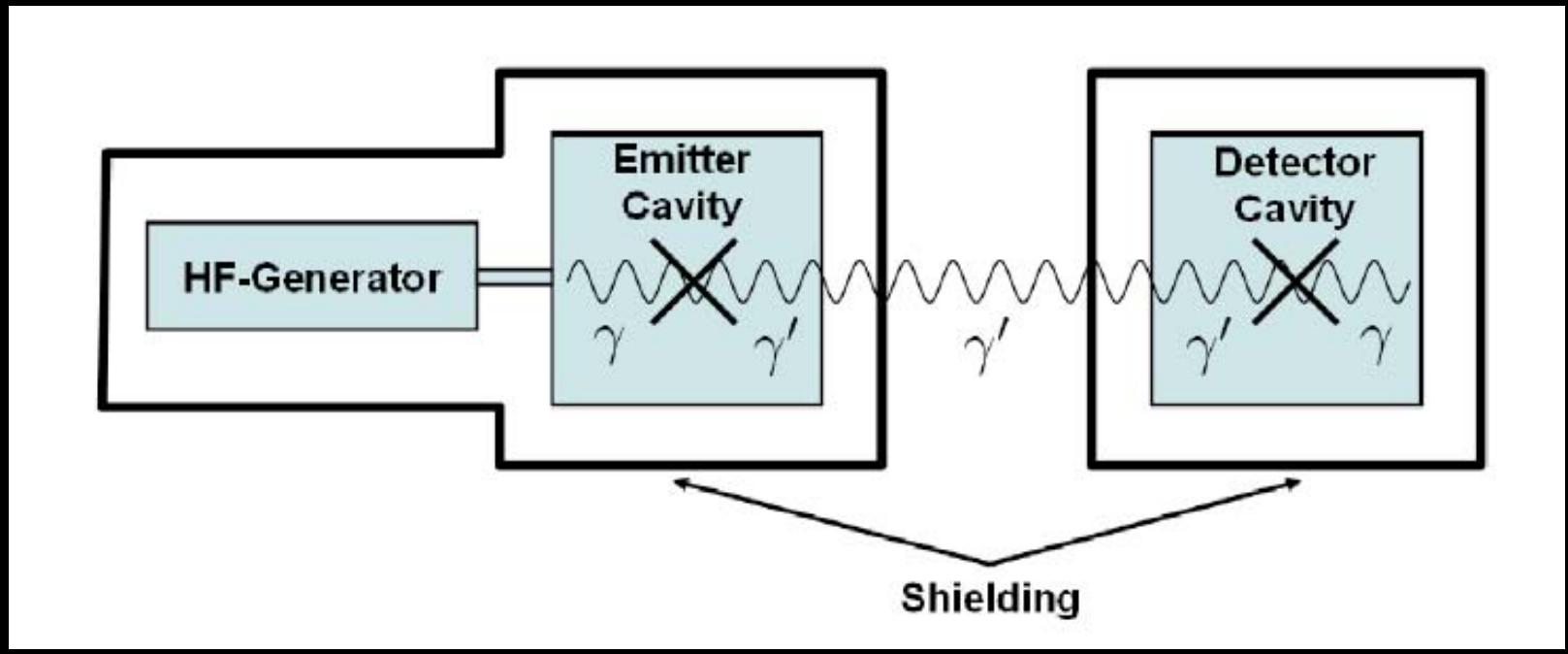
A cavity experiment

It's a Light shining through walls clone

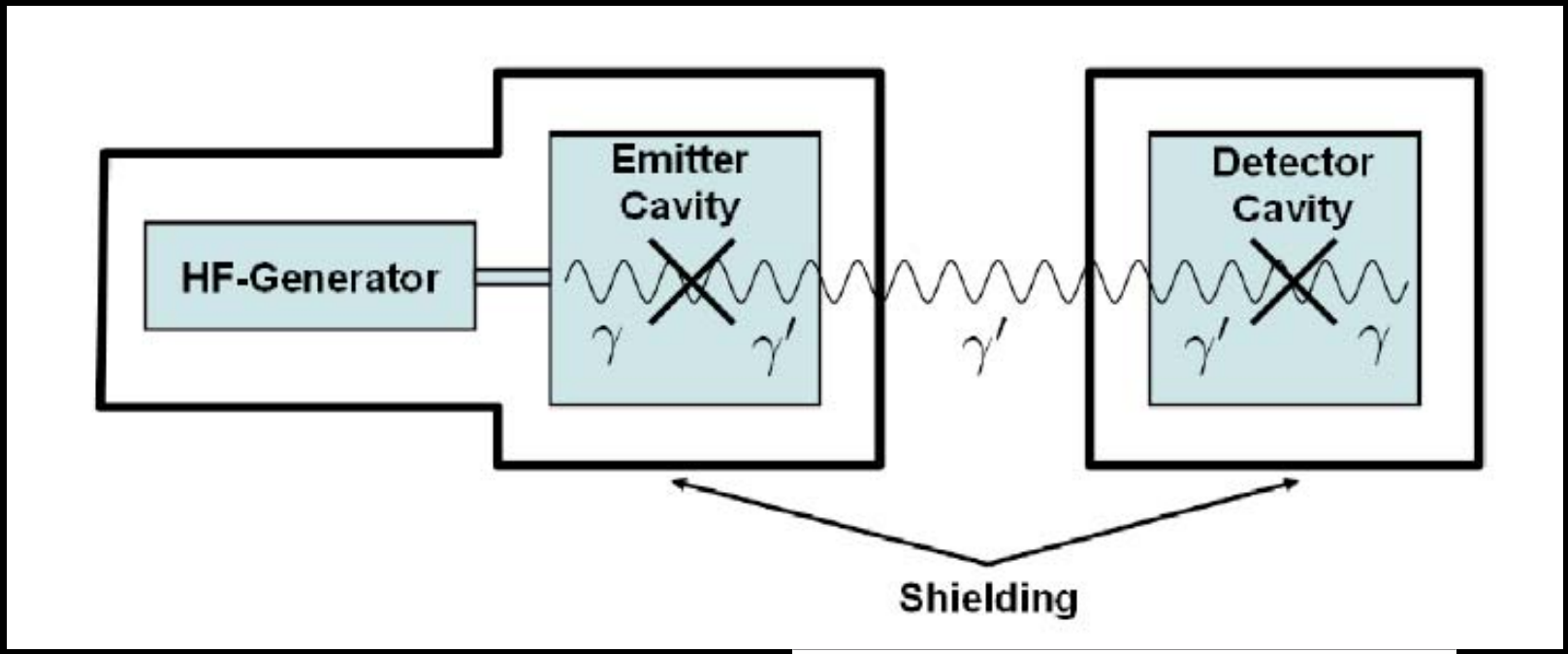


- Microwaves instead of laser

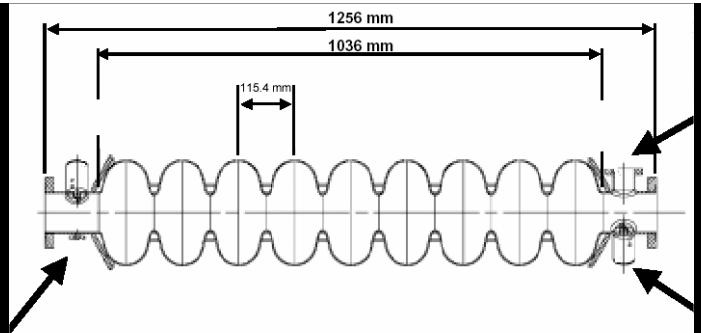
Setup

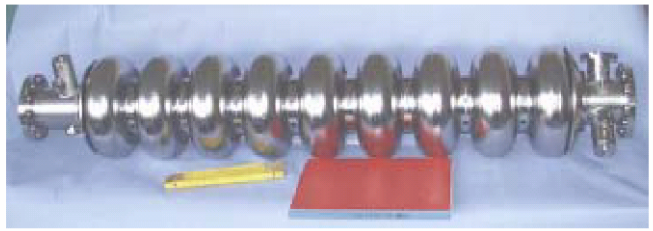

Emitter
Cavity
HF-Generator
Detector
Cavity
γ
γ'
γ'
γ'
γ
Shielding

Setup



More recycling:





Advantages

- Resonant cavity setup: Cavity in production and regeneration region

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

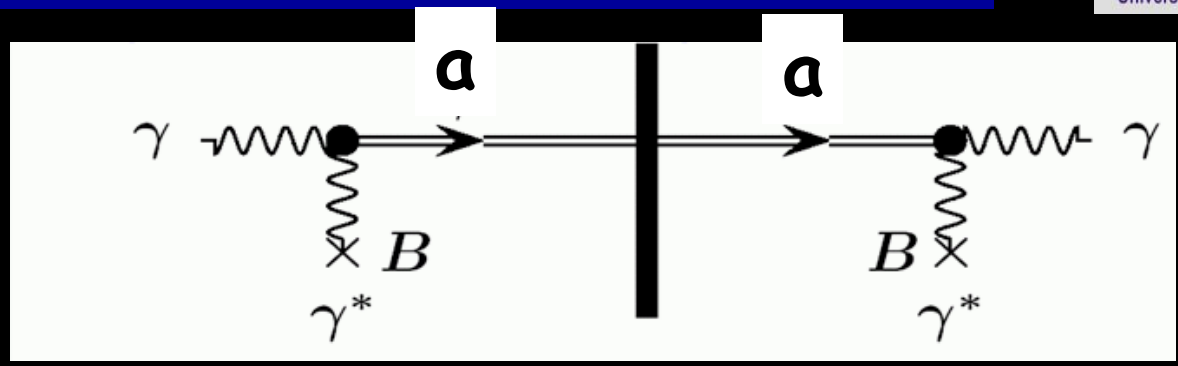
- Microwave cavities can have very high Q-factors~10^{11}!

- 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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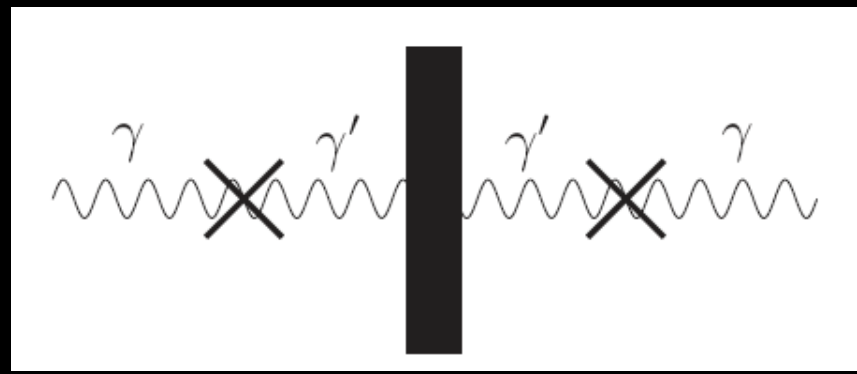

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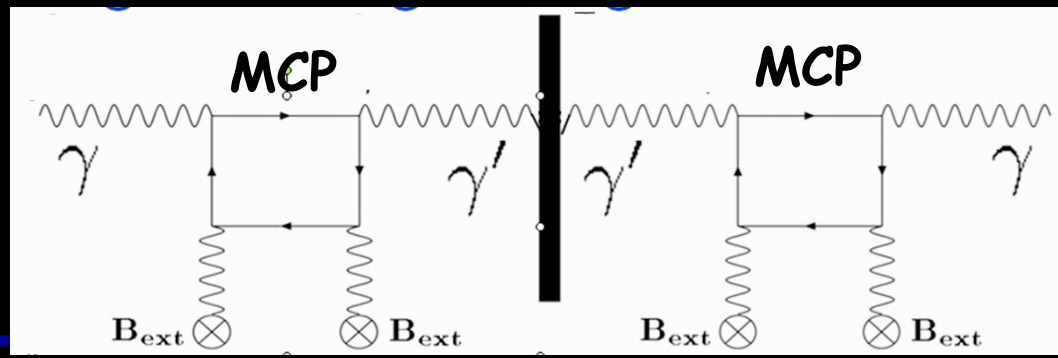
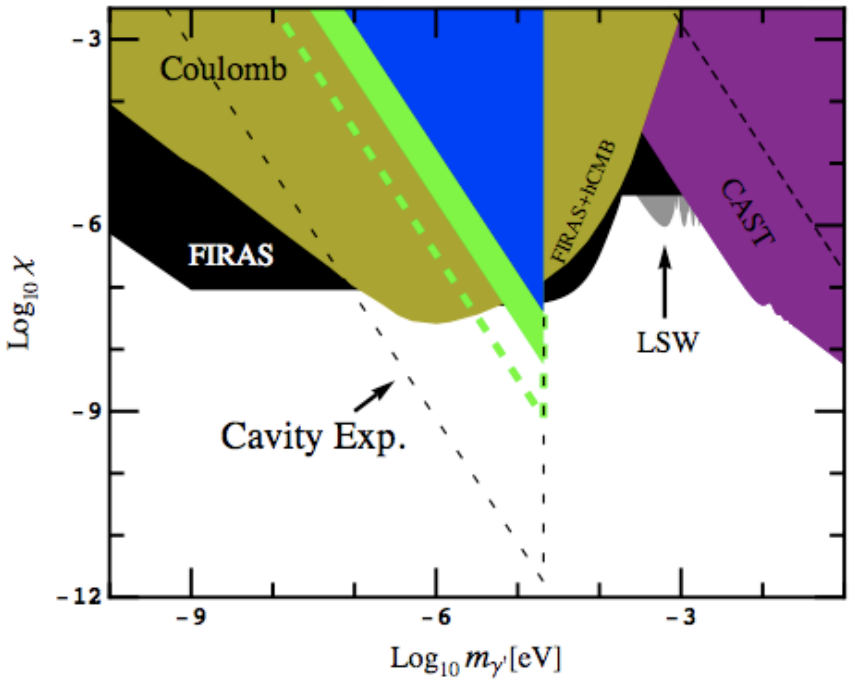
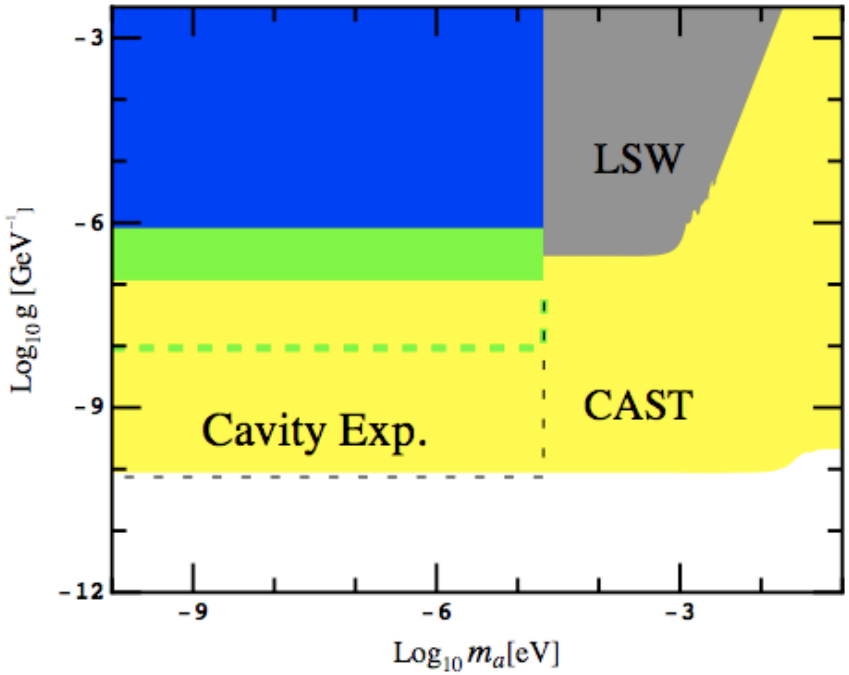
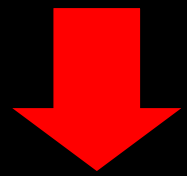


With currently available technology…

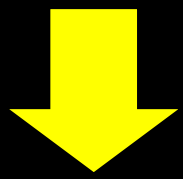


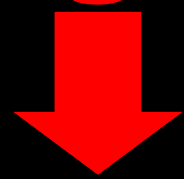


Hints for new Physics

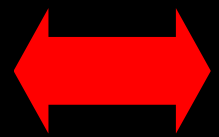


Model Building





Bottom-up (pheno)

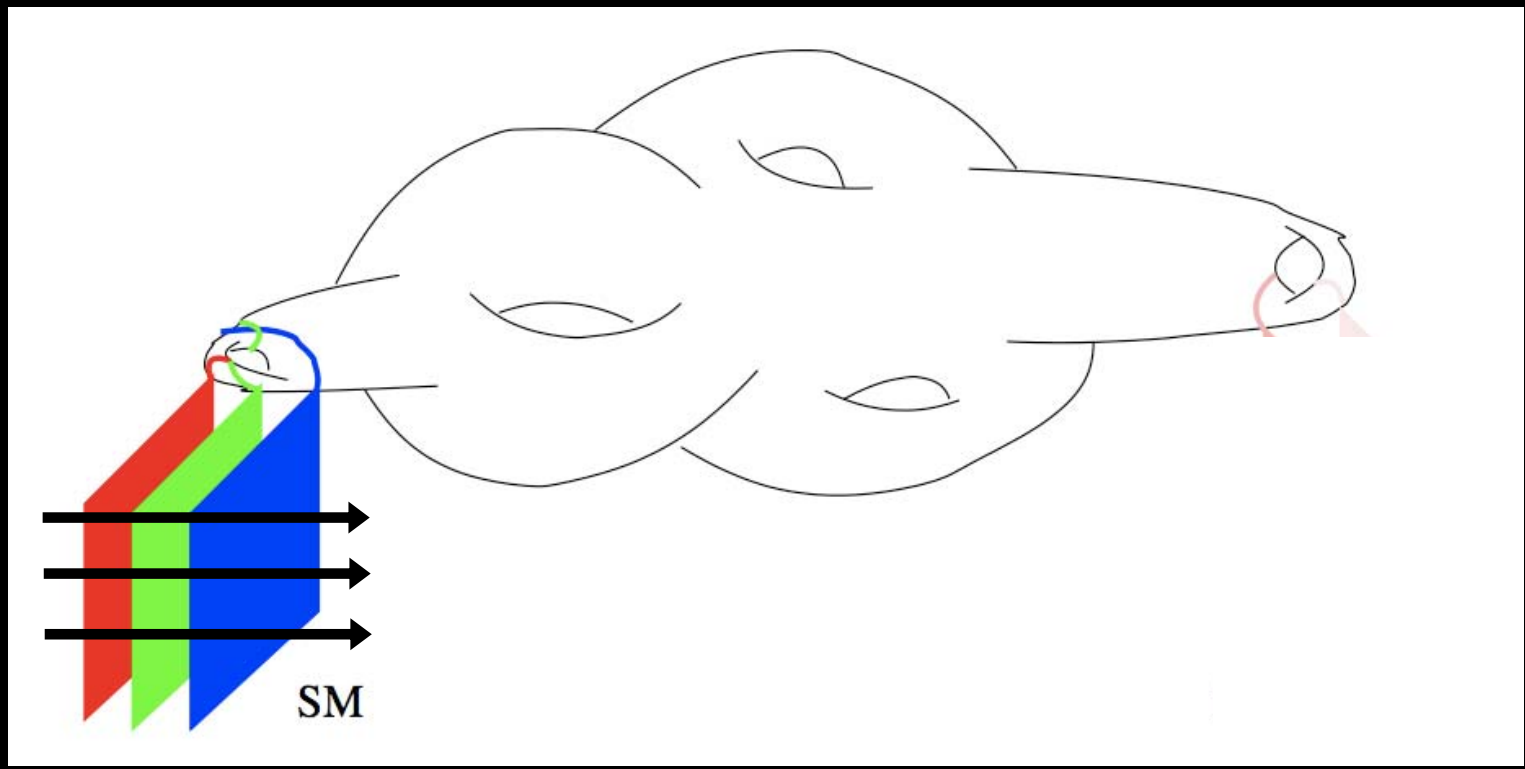


Top-down (theory)

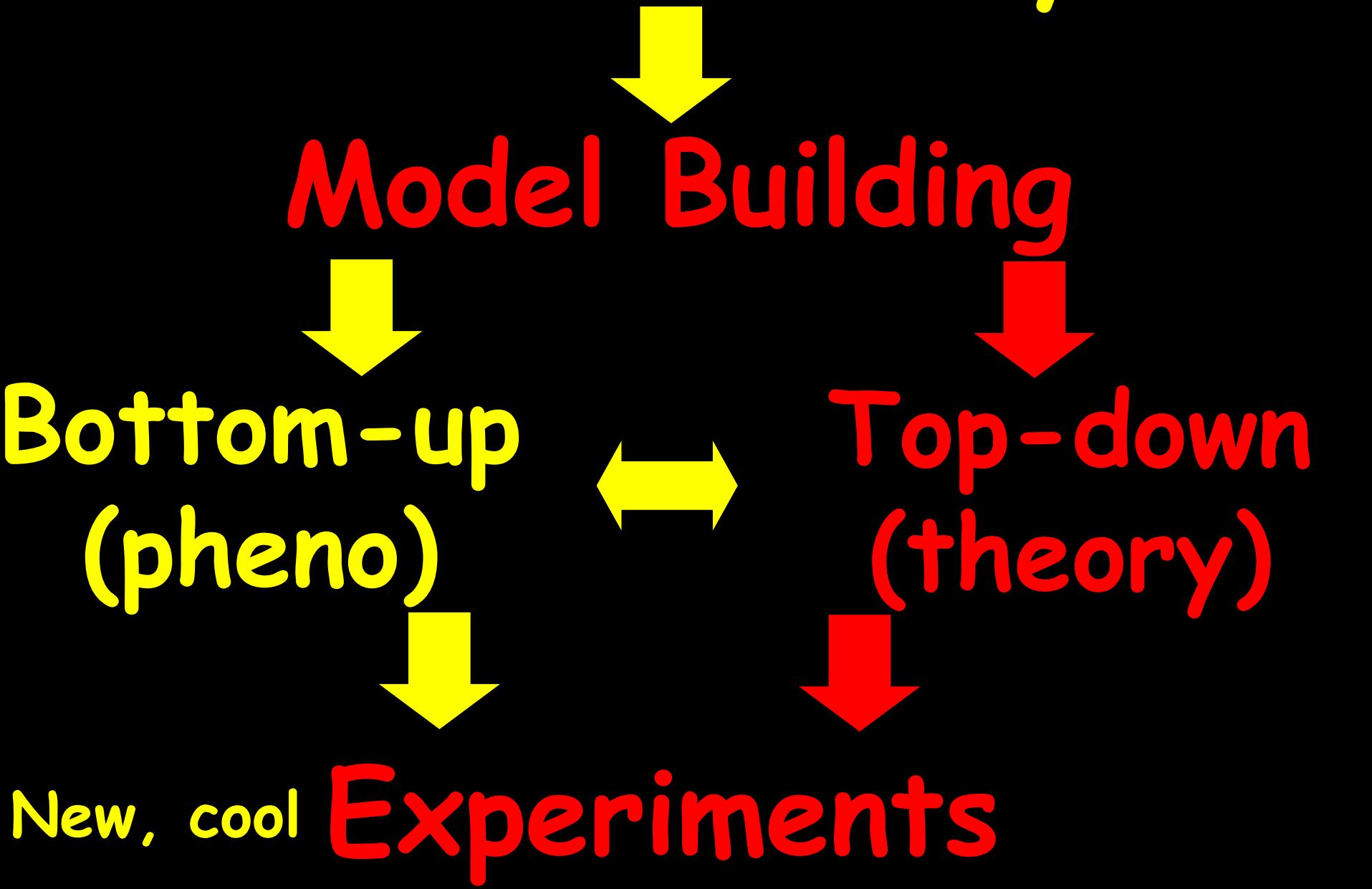
Go back to drawing board
`Start from scratch'

String theory inspires weird stuff

- Some string theory models predict noncommutativity and other forms of Lorentz symmetry violation



Hints for new Physics



Test Lorentz symmetry

- Lorentz symmetry breaking can leads to vacuum birefringence

➡ Ultra high Precision

➡ Test (nearly) Planck scale physics

Enormous precision

- Laboratory: $\frac{\Delta c}{c} \sim 10^{-14}$
- Astro: $\frac{\Delta c}{c} \sim 10^{-16}$
- Cosmo: $\frac{\Delta c}{c} \sim 10^{-32}$
- Example: $\frac{\Delta c}{c} \sim 10^{-34} \left(\frac{M_{\rm Planck}}{M_{\rm NC}} \right)^2$

➡ Ultra high Precision

➡ Test (nearly) Planck scale physics

Conclusions

Conclusions

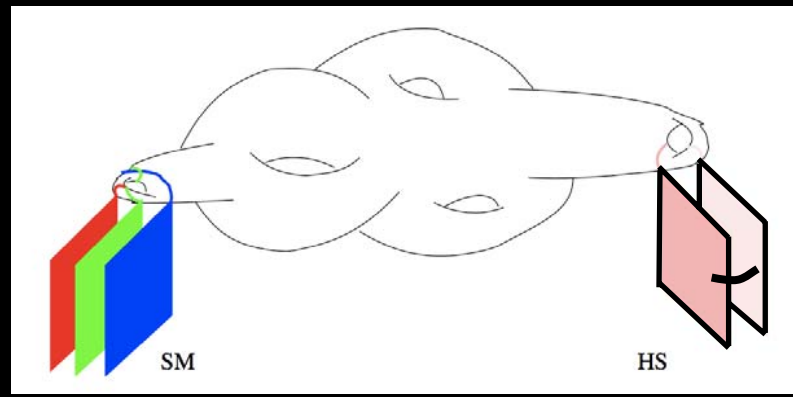
- Good Physics Case for Axions, WIMPs and WISPs

  ➡ explore `The Low Energy Frontier'

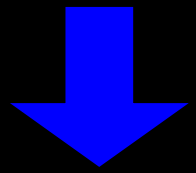
- Low energy experiments test energy scales much higher than accelerators

  ➡ Complementary!

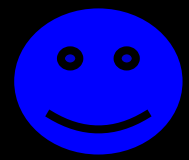
- May provide information on hidden sectors and thereby into the underlying fundamental theory

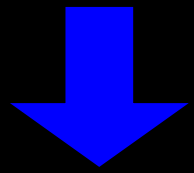


- Surprises like Lorentz symmetry violation possible!

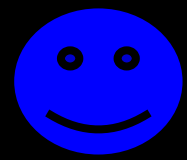


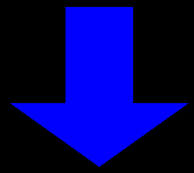
Photons are a good probe of
Fundamental physics
complementary to
accelerator experiments





Low energy tests are a good probe of Fundamental physics complementary to accelerator experiments





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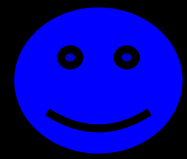

More fun with cavities

Schwinger Pair Production

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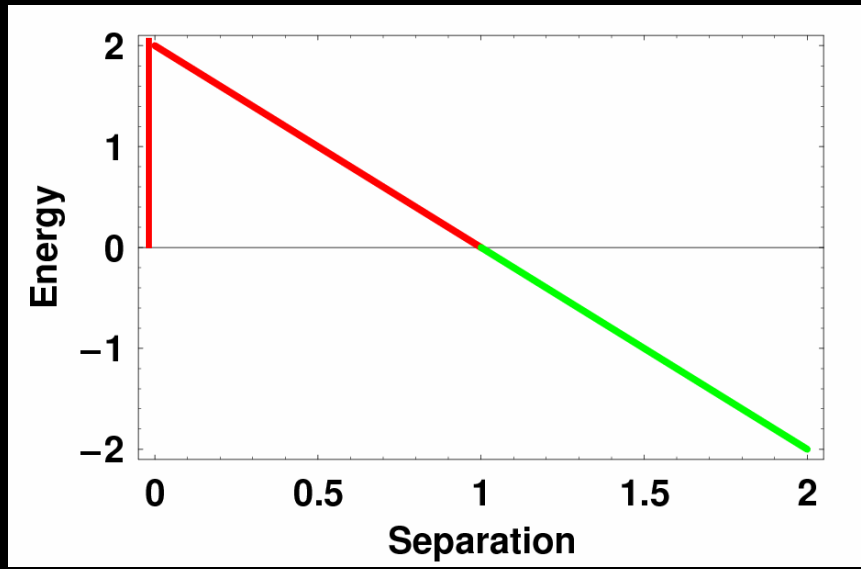
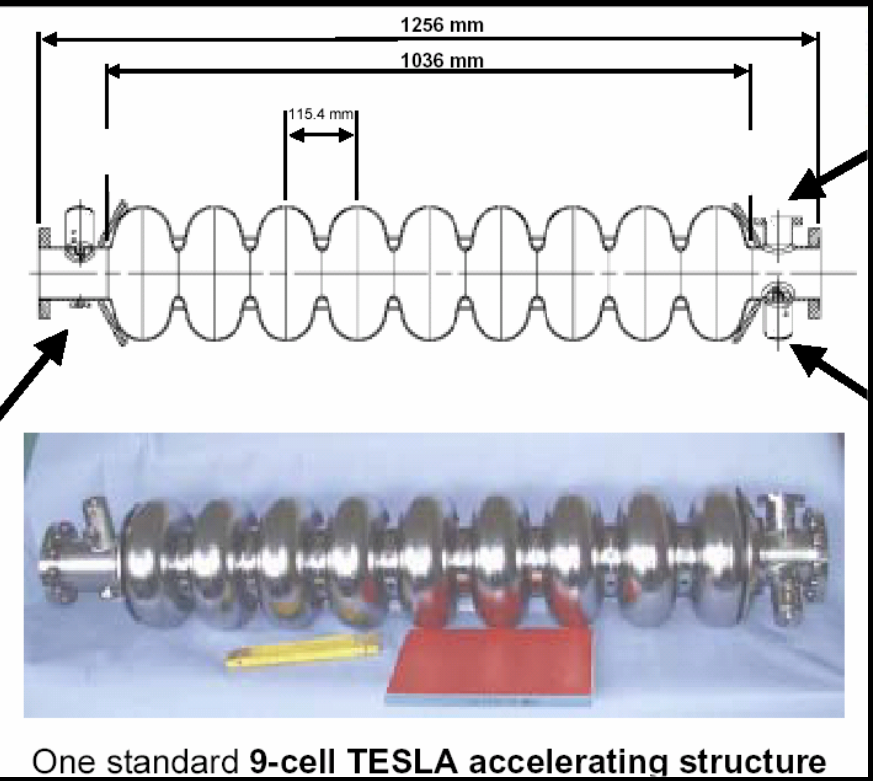
- Pair Production in a strong electric Field (without Laser)!
- Similar to tunneling:

Energy of
`vacuum pair'



- An $\mathbf{f}, \bar{\mathbf{f}}$ -pair separated by a distance $d > \frac{2m_e}{ceE}$ 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 $\gtrsim$

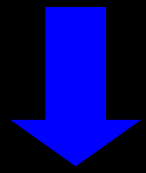
$$\mathbf{E}_{crit} = \frac{m_\epsilon^2}{\epsilon e}$$

➡ Sensitive to

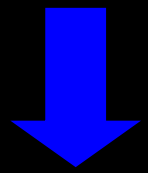
$$\epsilon < 2 \times 10^{-6} \quad \text{for} \quad m_\epsilon < 0.01\,\mathrm{eV}$$

Finding the produced MCPs

- Effects of millicharged particles decreases with smaller ϵ



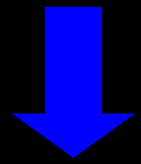
Direct detection is difficult



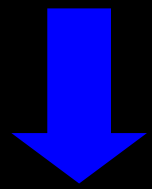
Look for macroscopic effects

Energy loss

- If many particles are produced we get a

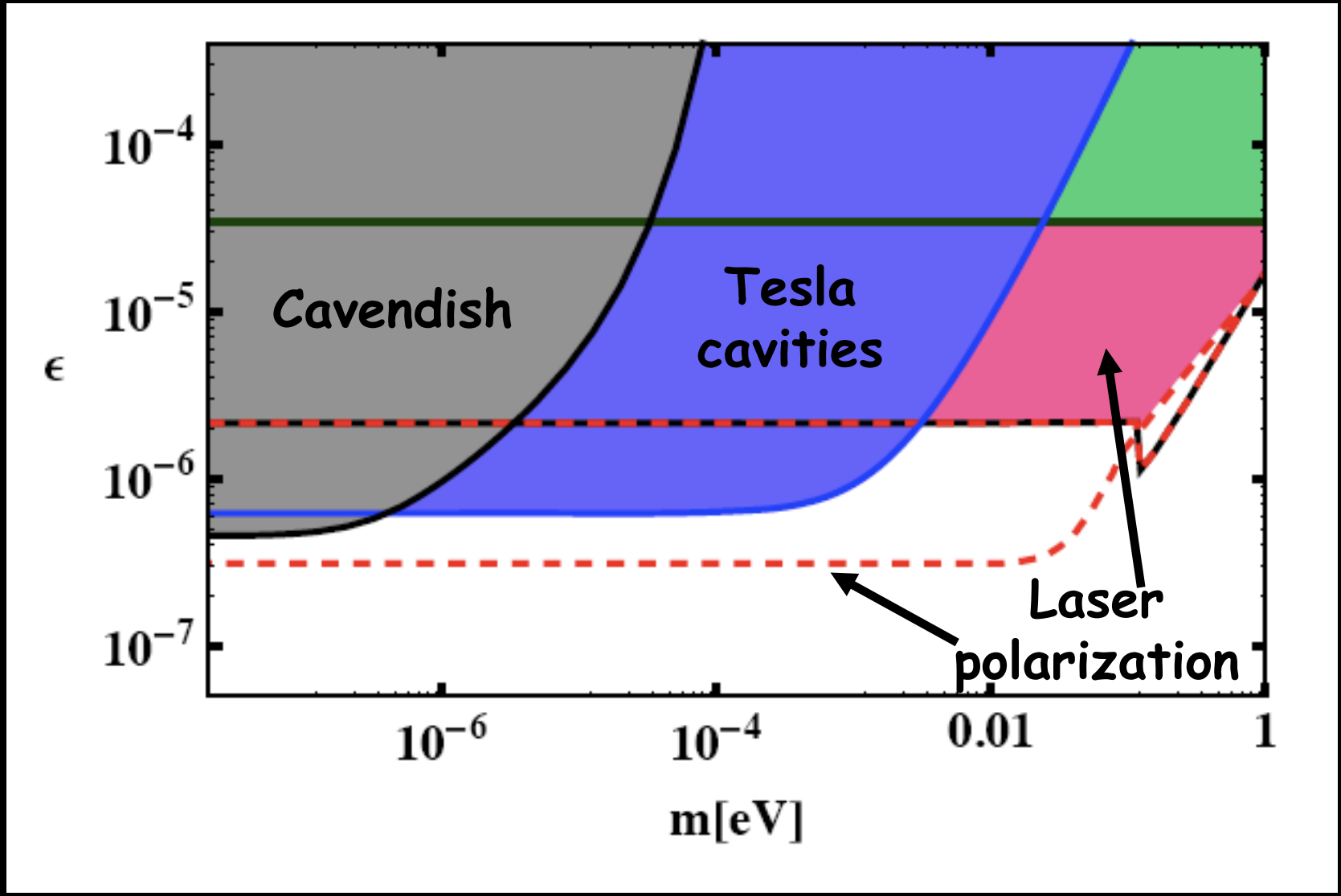


Macroscopic energy loss!



Can be measured

Quite strong bounds!



Not quite competitive with astrophysical bounds..

Nearly-direct detection...

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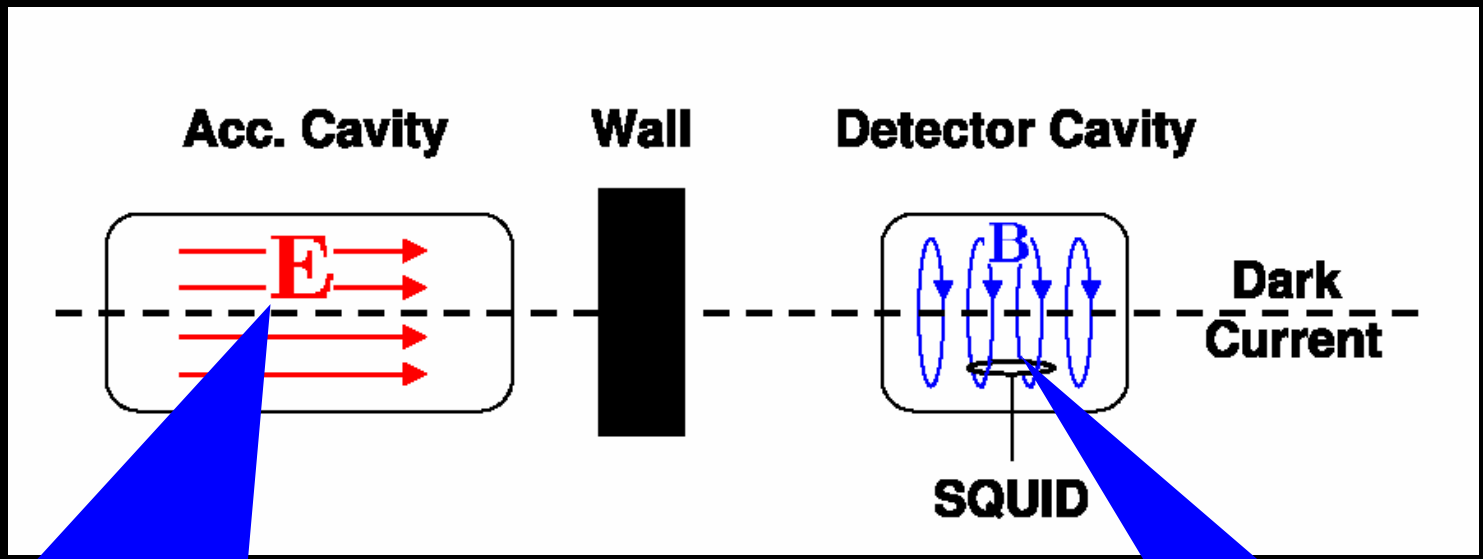
Dark Current Shining through a Wall!



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!

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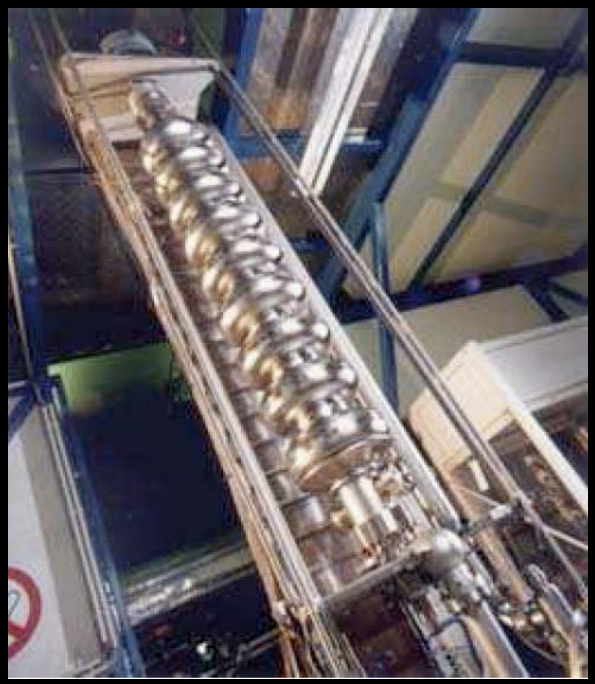
Cavity



Cryogenic Current Comparator

Highway To Hell
The Ultimate AC/DC Tribute