Fundamental Physics @ Low Energies

J. Jaeckel[†]

S. Abel[†], M. Goodsell[*], S. Gardiner[†], H. Gies[0]
V. Khoze[†], J. Redondo[x], A. Ringwald[*], S. Roy[†]

[†]Durham University, [*]DESY,
[x]MPI Munich, [0]ITP Jena

Where we want to go…

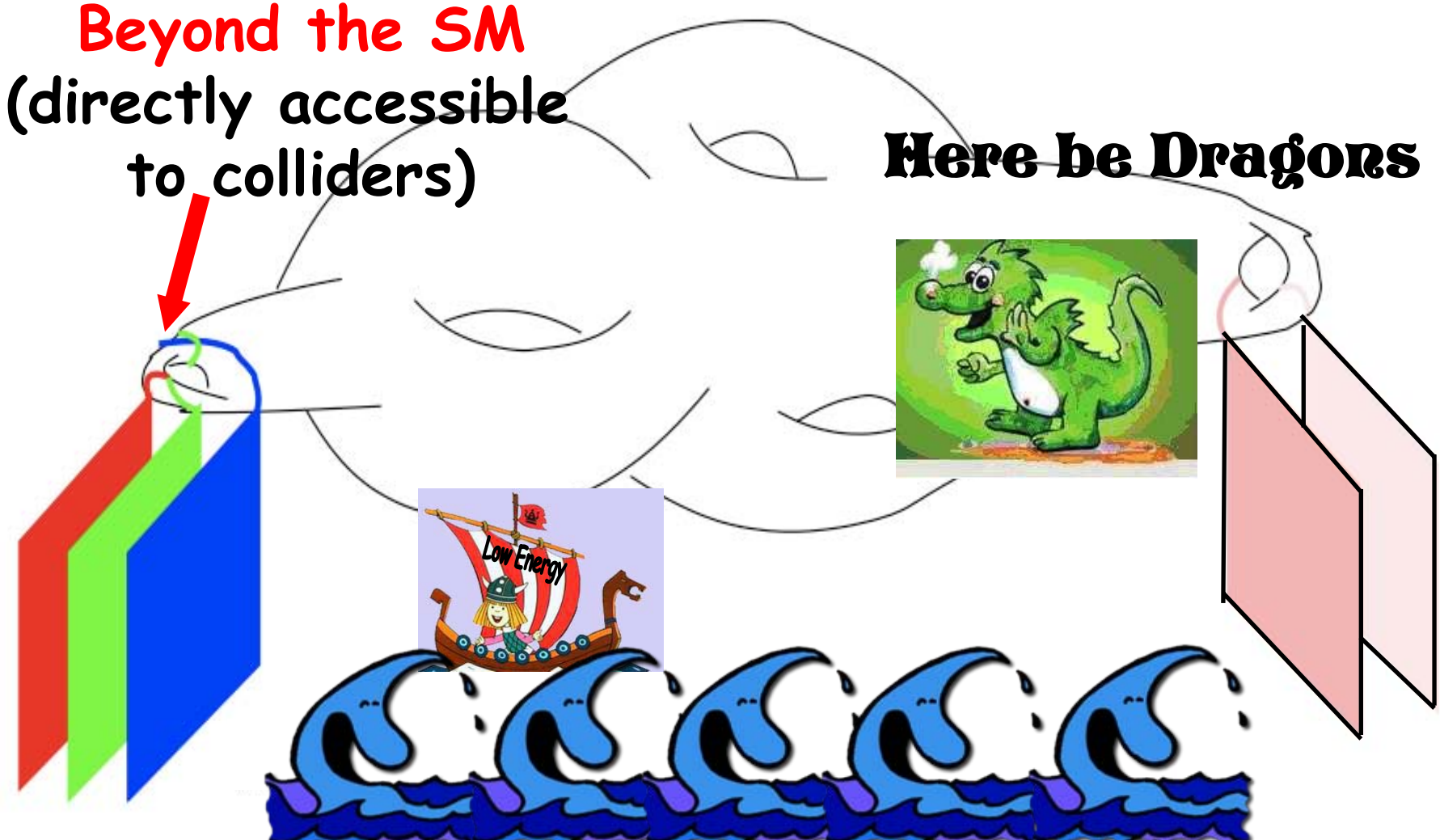
The Standard Model

+

Beyond the SM

(directly accessible to colliders)

The Hidden Sector



We need...

Physics beyond the Standard Model

The Standard Model

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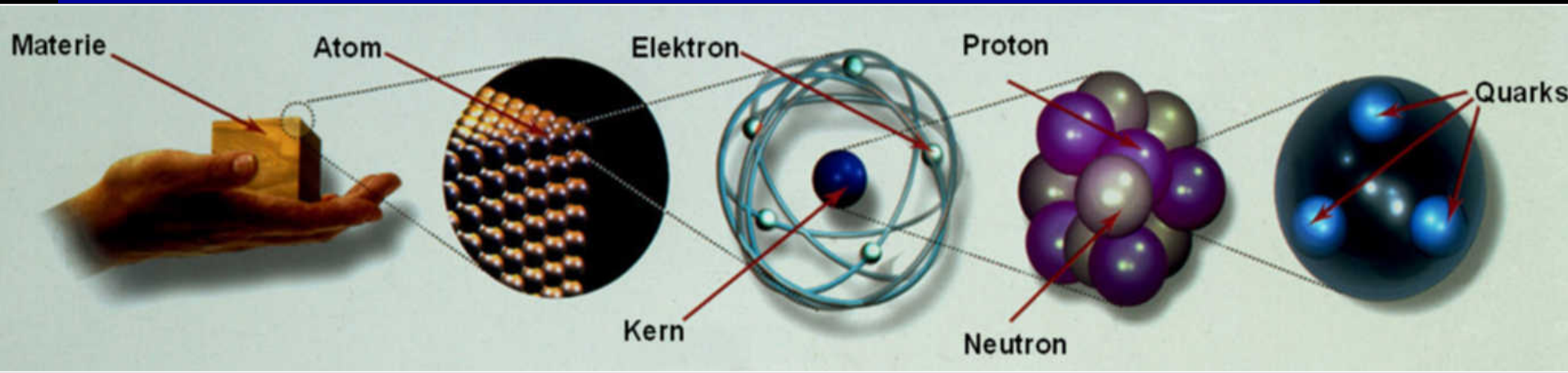


	Quarks		Leptons	
	Charge +2/3	Charge –1/3	Charge –1	Charge 0
1. Family	Up u	Down d	Electron e	e-Neutrino ν_e
2. Family	Charm c	Strange s	Myon μ	μ-Neutrino ν_μ
3. Family	Top t	Bottom b	Tau τ	τ-Neutrino ν_τ

Gravitation ➡ graviton

Weak forces ➡ W- und Z-bosons

Electromagnetism ➡ photons (γ)

Strong forces ➡ gluons

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)

A dirty little secret...

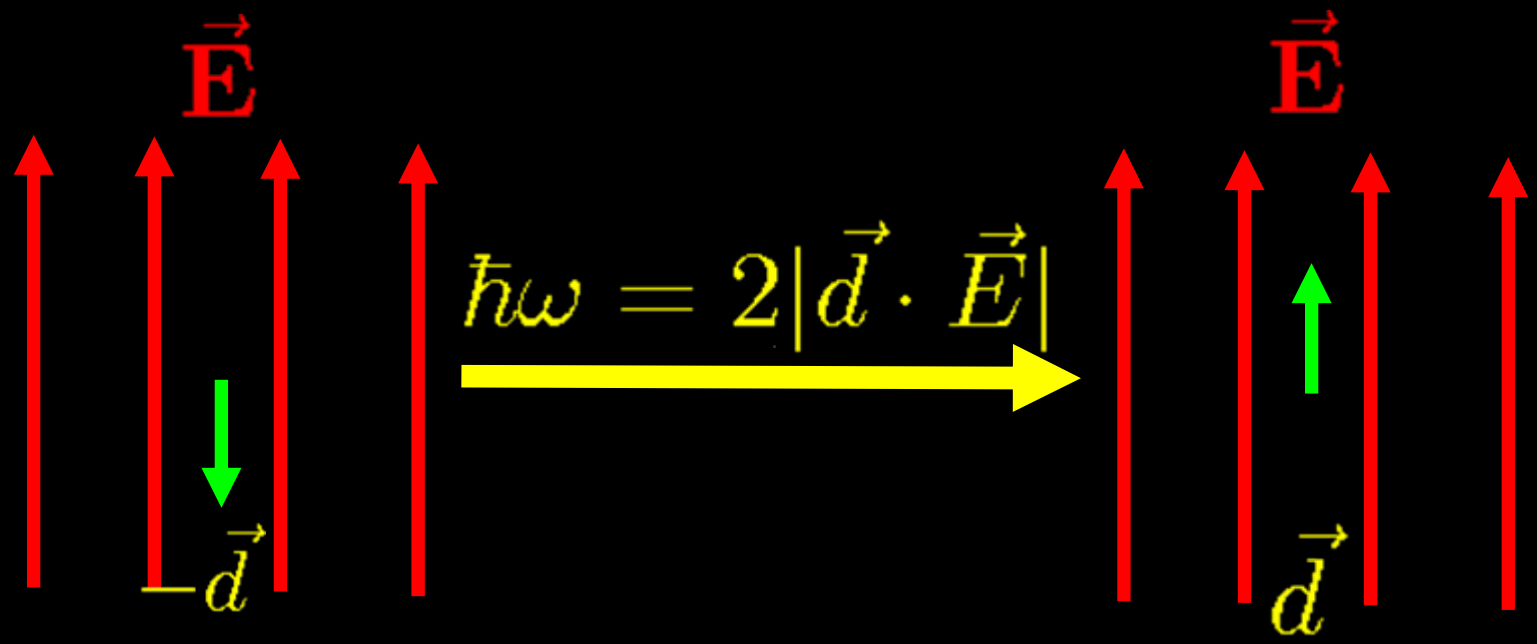
$$S = \int d^4x \left[-\frac{1}{4} G^{\mu\nu} G_{\mu\nu} - \frac{\theta}{4} G^{\mu\nu} \tilde{G}_{\mu\nu} + i\bar{\psi} D_\mu \gamma^\mu \psi + \bar{\psi} M \psi \right]$$

- The θ-term is CP violating!
- Connected to strong interactions!

➡ Measure electric dipole moment of the neutron!

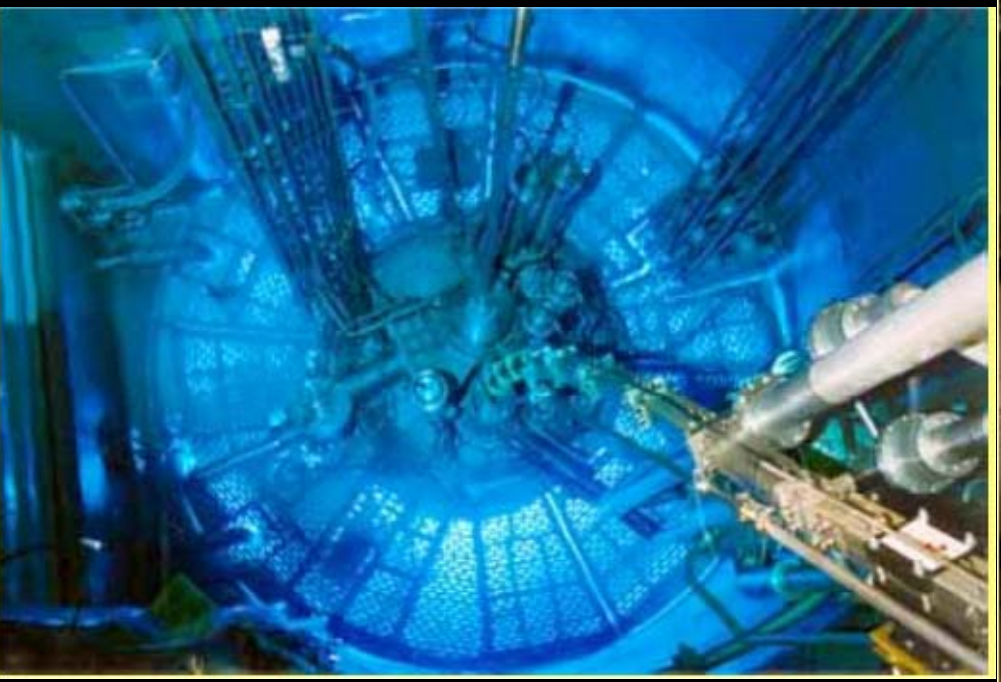
Neutron electric dipole moment

- θ would cause neutron EDM ➡ Experiment



➡ Measure transition frequency.

No neutron electric dipole moment...



$$|\vec{d}| < 3\,10^{-26} e\,cm$$
$$= 3\,10^{-13} e\,fm$$

No neutron electric dipole moment...

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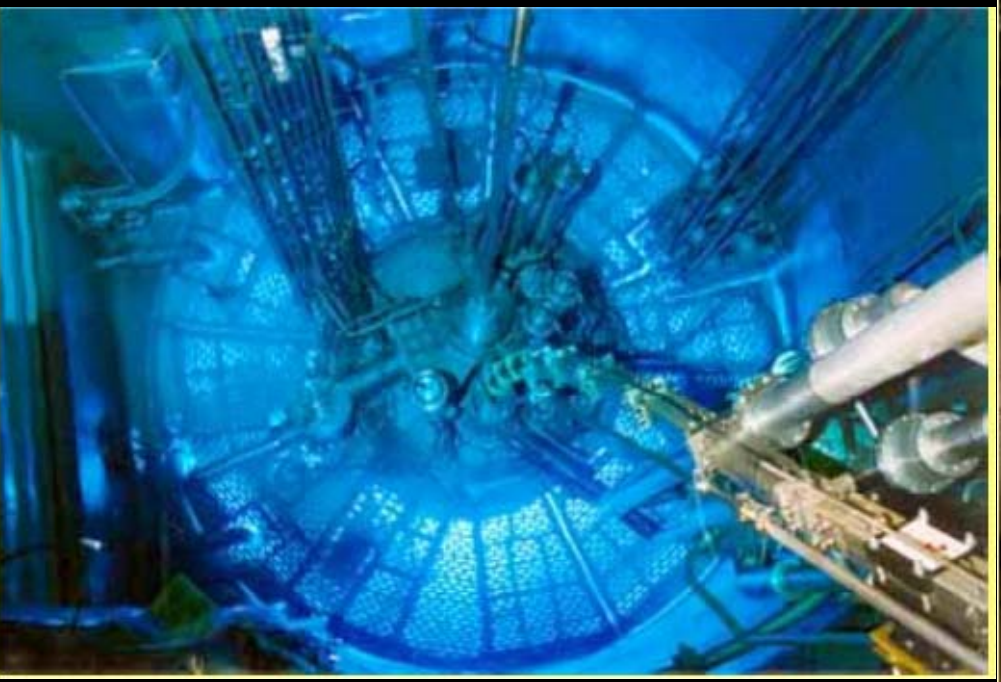


$$|\vec{d}| < 3\,10^{-26} e\,cm$$
$$= 3\,10^{-13} e\,fm \lll\lll \frac{\theta}{16\pi^2} e\,fm$$

➡ Very unnatural!

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)

BSM physics @ Work

- $(g-2)_\mu$ deviations from SM prediction

- DAMA anomaly
- CoGeNT etc.

- PAMELA+Fermi observation

- WMAP observes extra "neutrinos"

- Proton radius in muonic hydrogen

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'

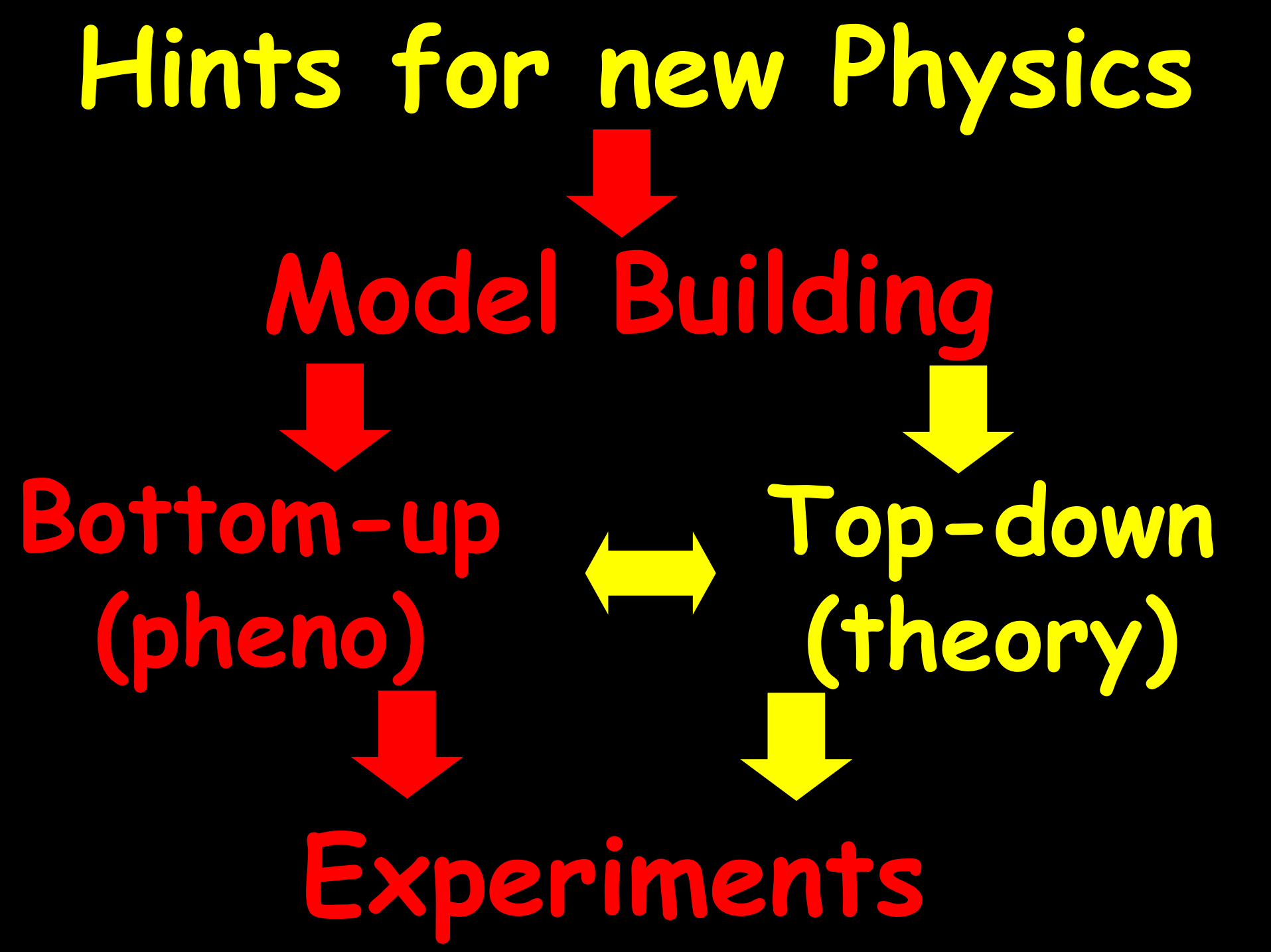
The strong CP problem: Axions

- 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

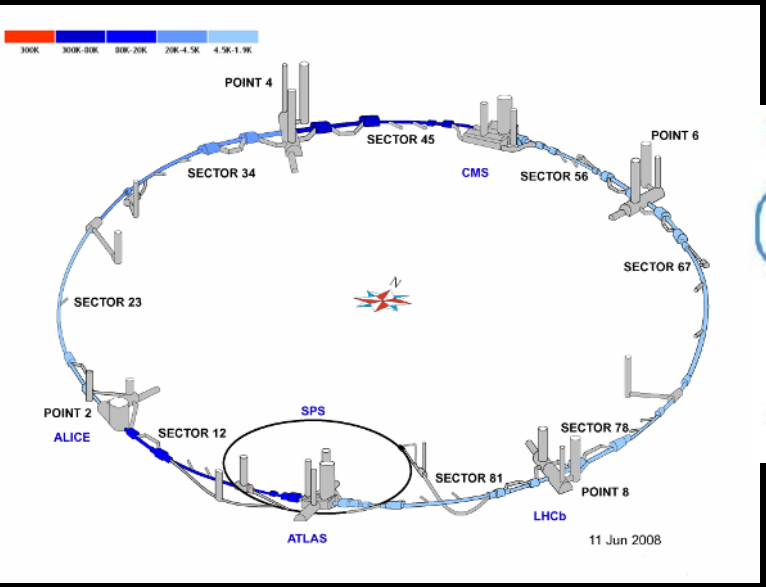
Good motivation
for axion/WISP experiments

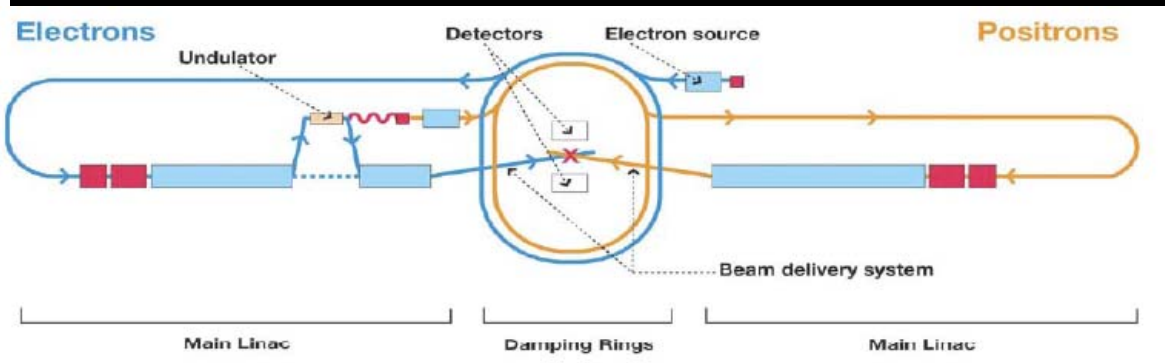

Hints for new Physics
Model Building
Bottom-up
(pheno)
Top-down
(theory)
Experiments

Exploring fundamental high energy physics…

- The direct approach: MORE POWER

LHC, Tevatron + ILC,CLIC





- Detects most things within energy range
- E.g. may find SUSY particles, WIMPs etc.

But…

- May miss very weakly interacting matter (Axions, WIMPs, WISPs…)
- Current maximal energy few TeV

- Man its DANGEROUS…

But…

- May miss very weakly interacting matter (Axions, WIMPs, WISPs…)
- Current maximal energy few TeV

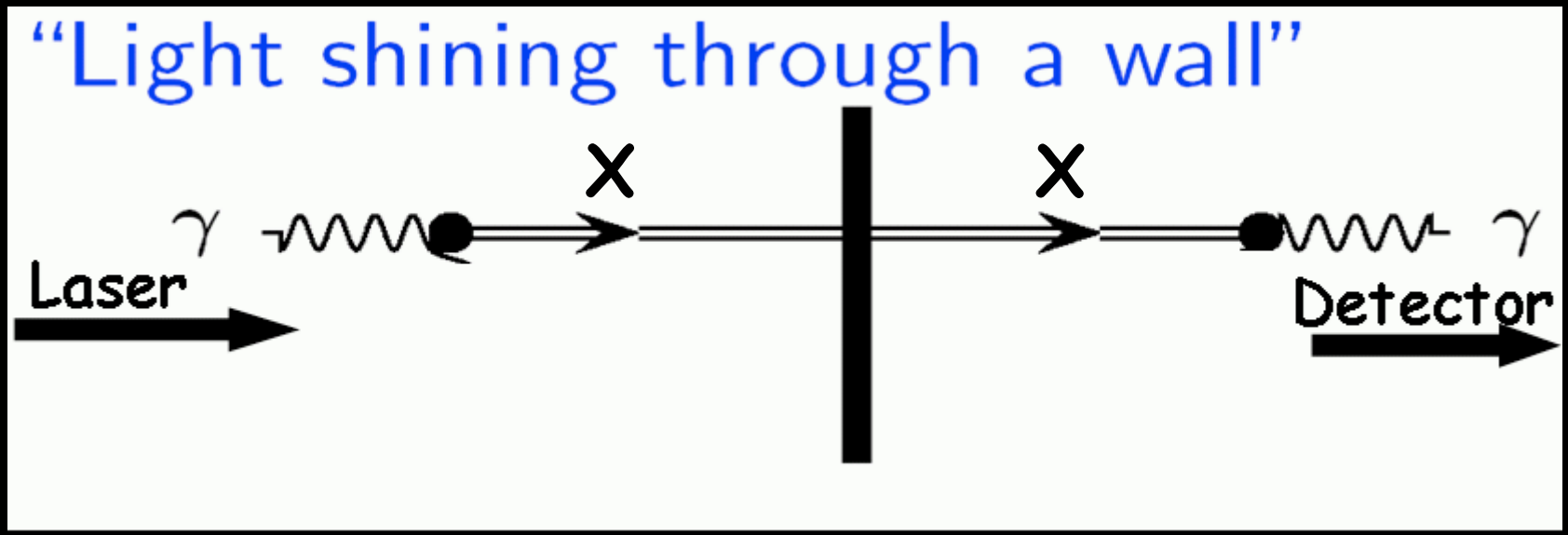
- Or much much more horryfying:

NO SIGNAL ABOVE BACKGROUND!

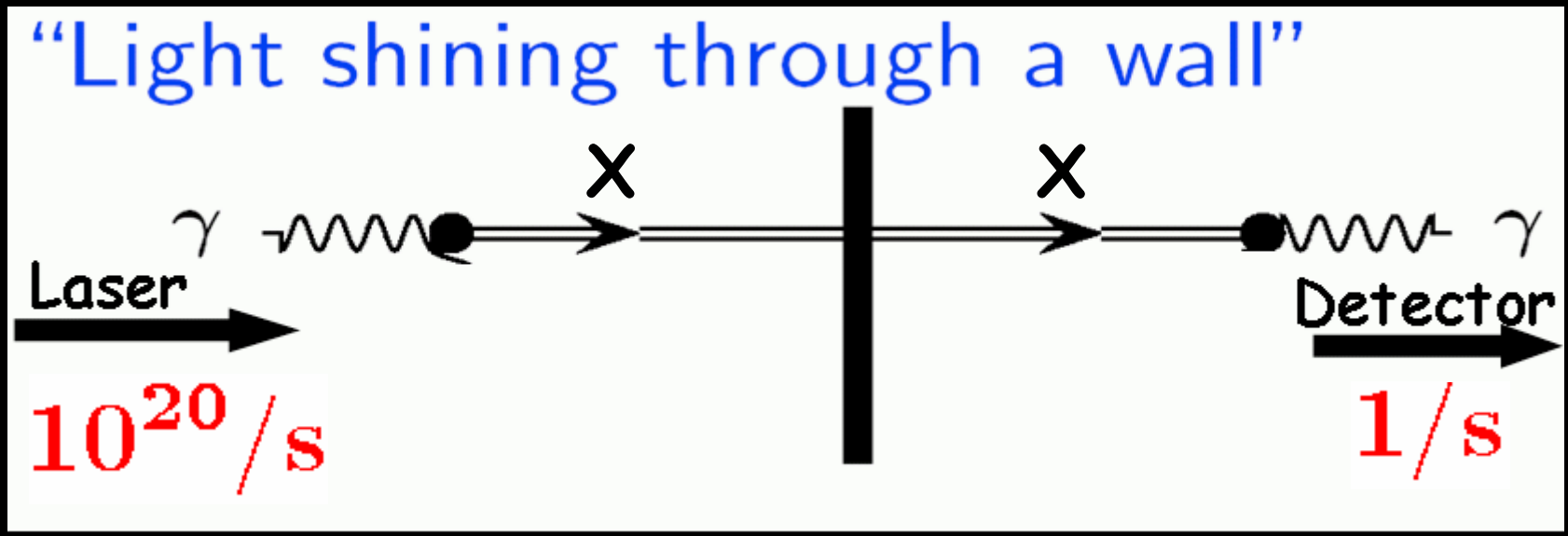
Recycling...

Complementary approaches

Light shining through walls



Light shining through walls

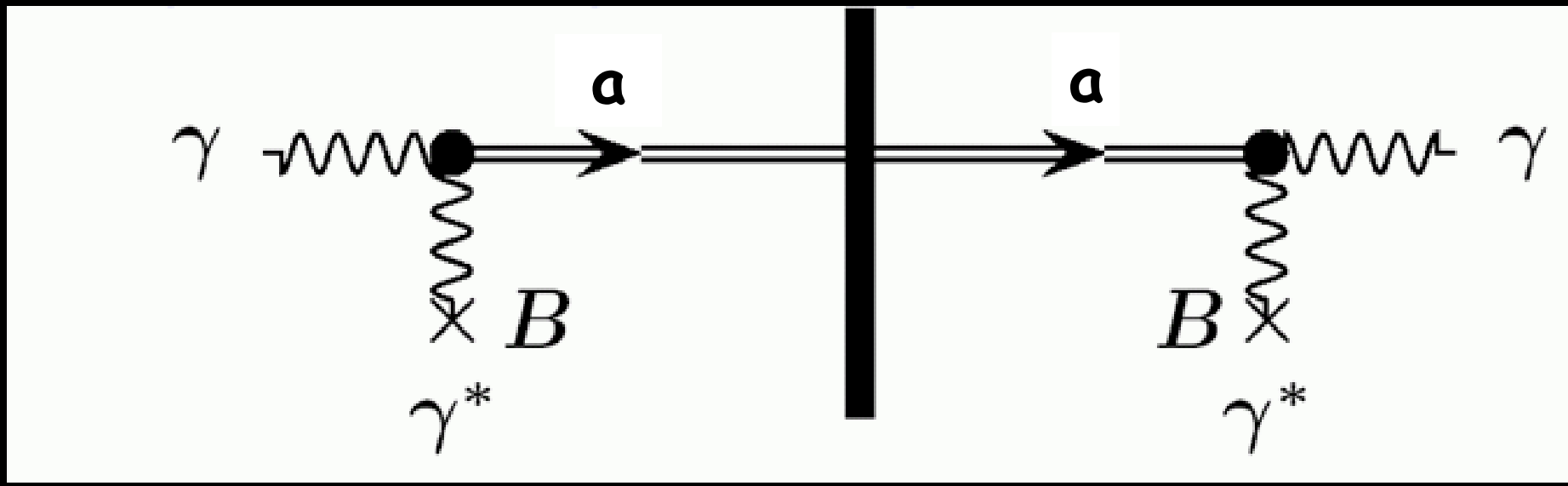


- Test $P_{\gamma \to X \to \gamma} \lesssim 10^{-20}$

- Enormous precision!
- Study extremely weak couplings!

Photons coming through the wall!

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



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

Light Shining Through Walls

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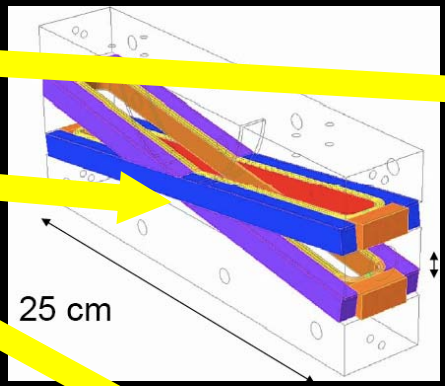
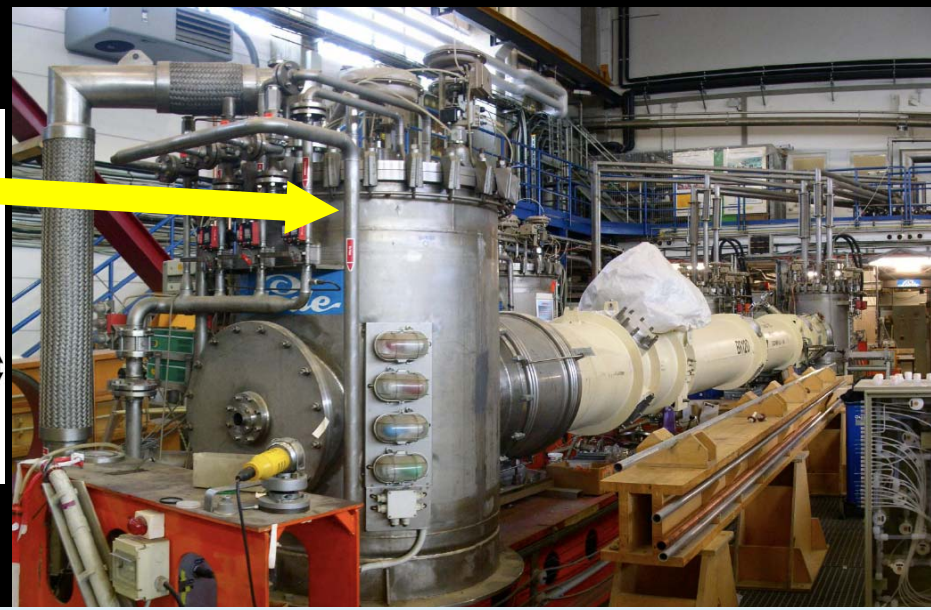
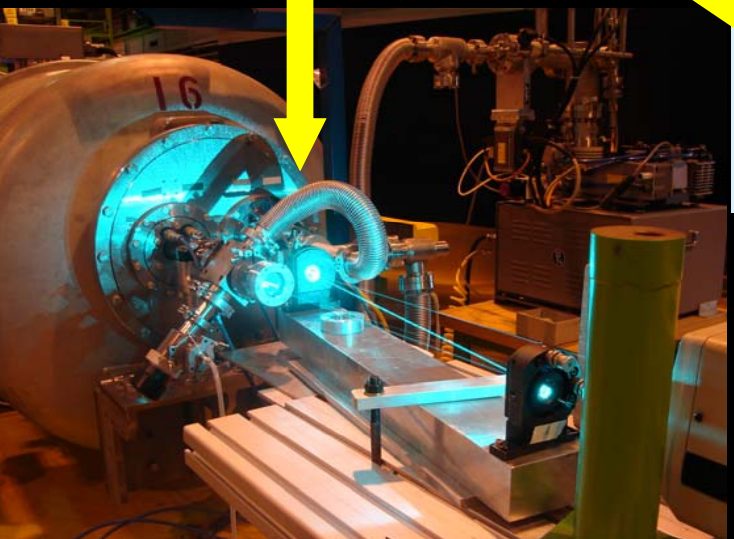
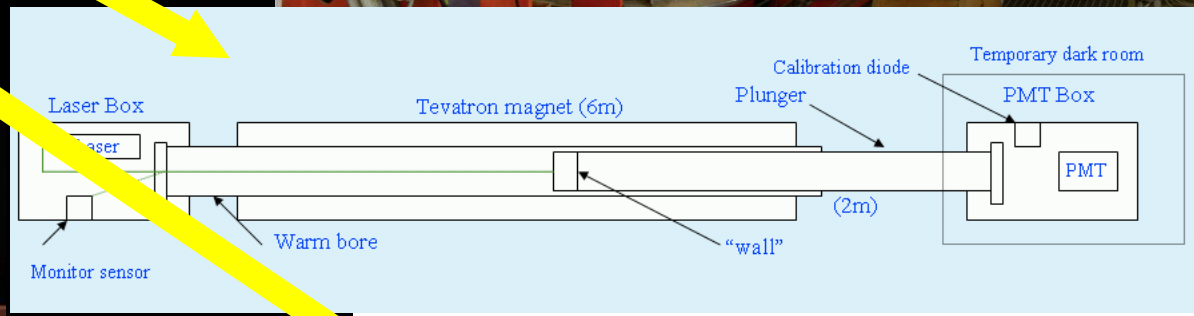
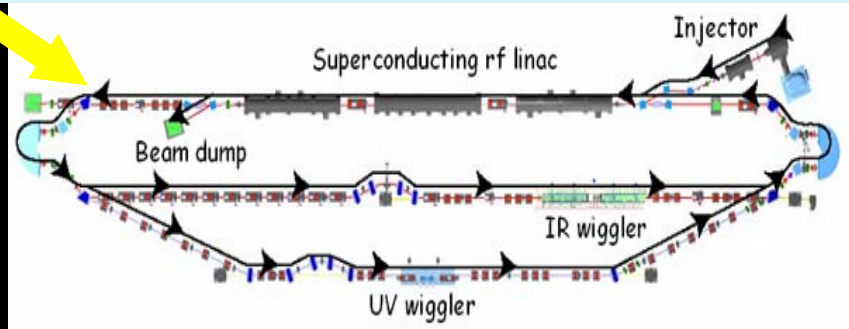
- A lot of activity
  - ALPS
  - BMV
  - GammeV
  - LIPPS
  - OSQAR



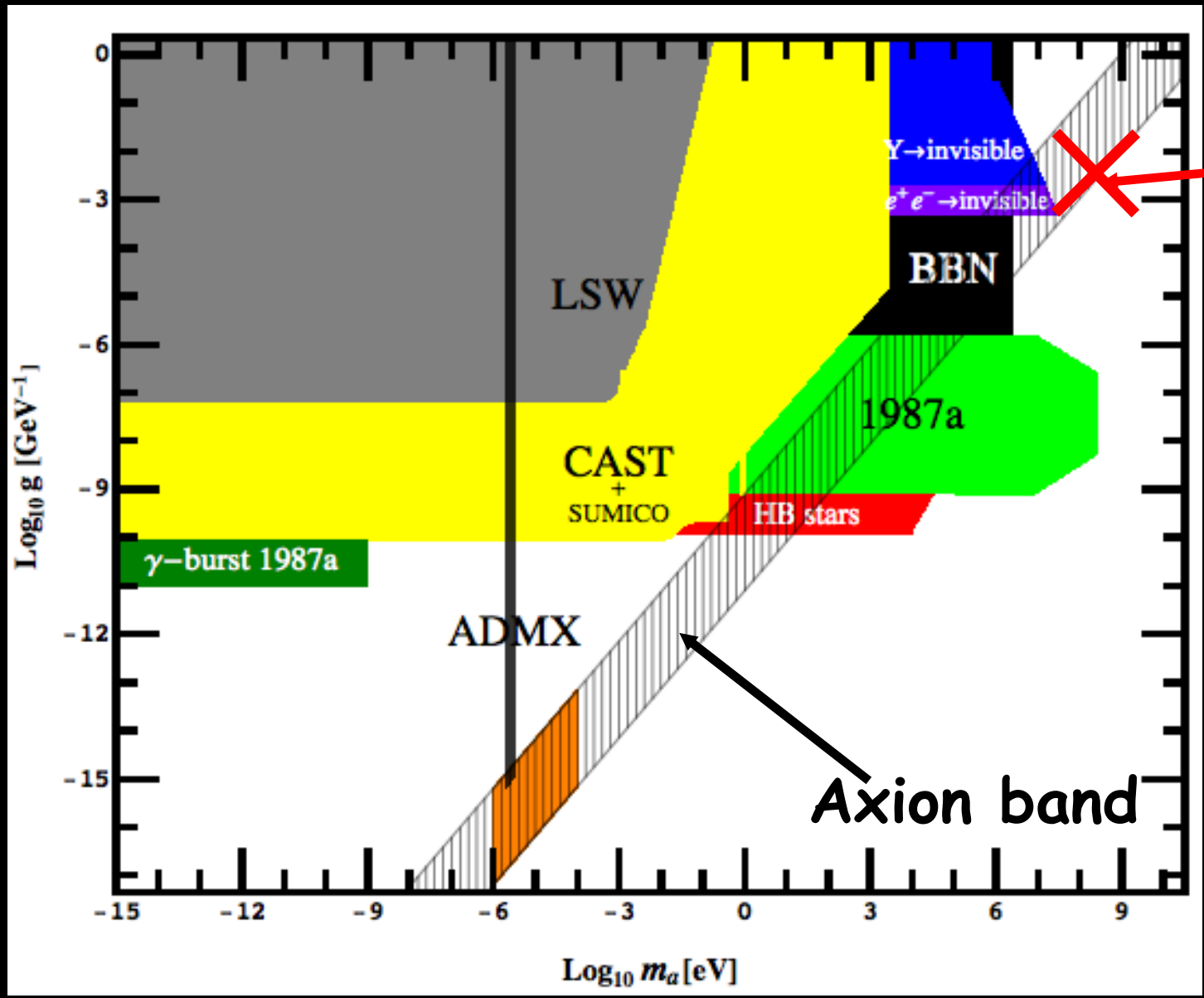








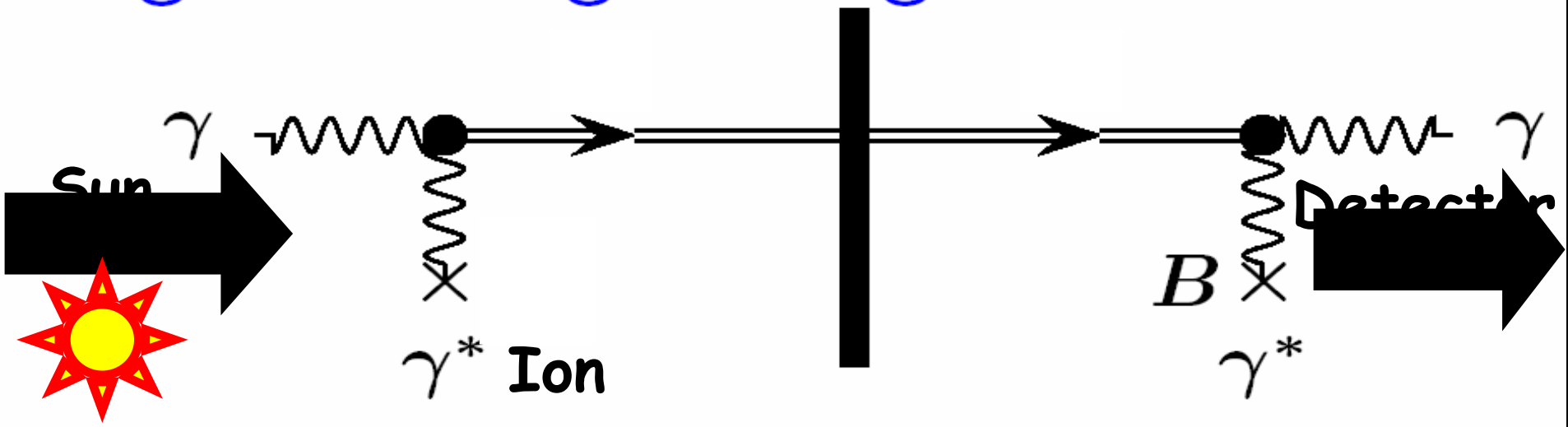
Small coupling, small mass



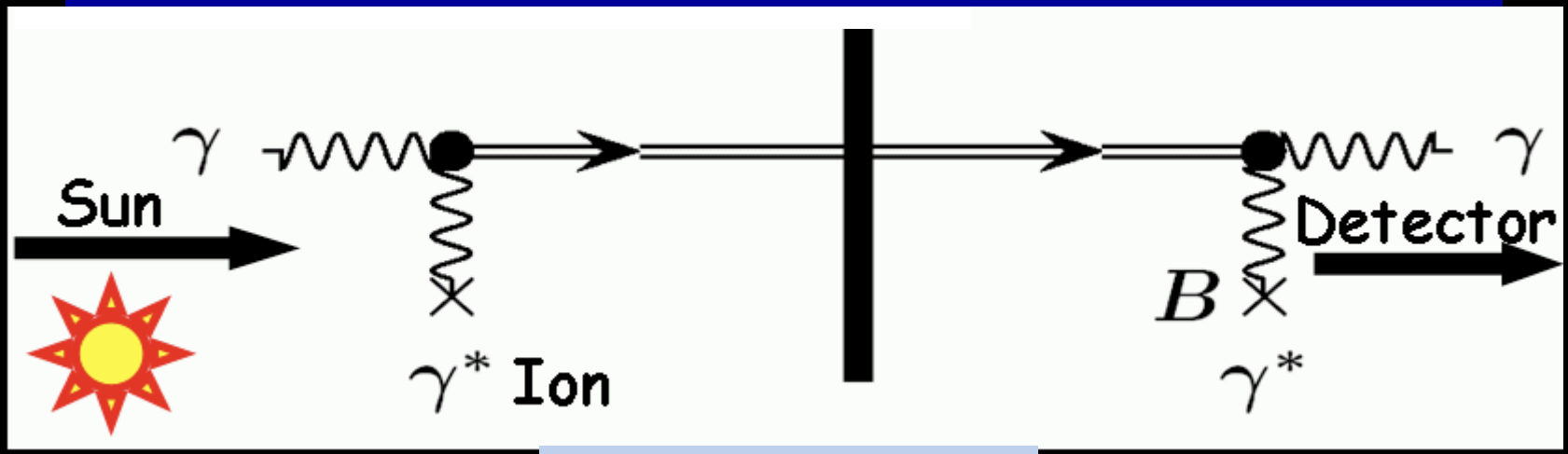
Helioscopes

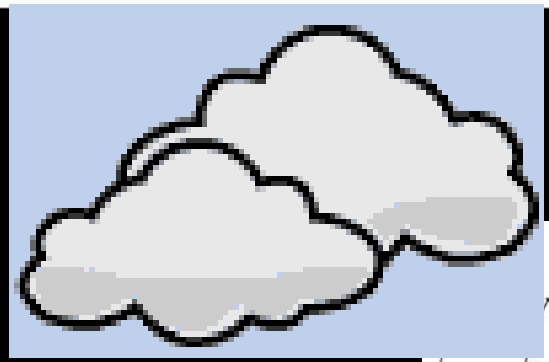
CAST@CERN
SUMICO@Tokyo
SHIPS@Hamburg

"Light shining through a wall"



Perfect for astronomy in Durham or Hamburg ;-)

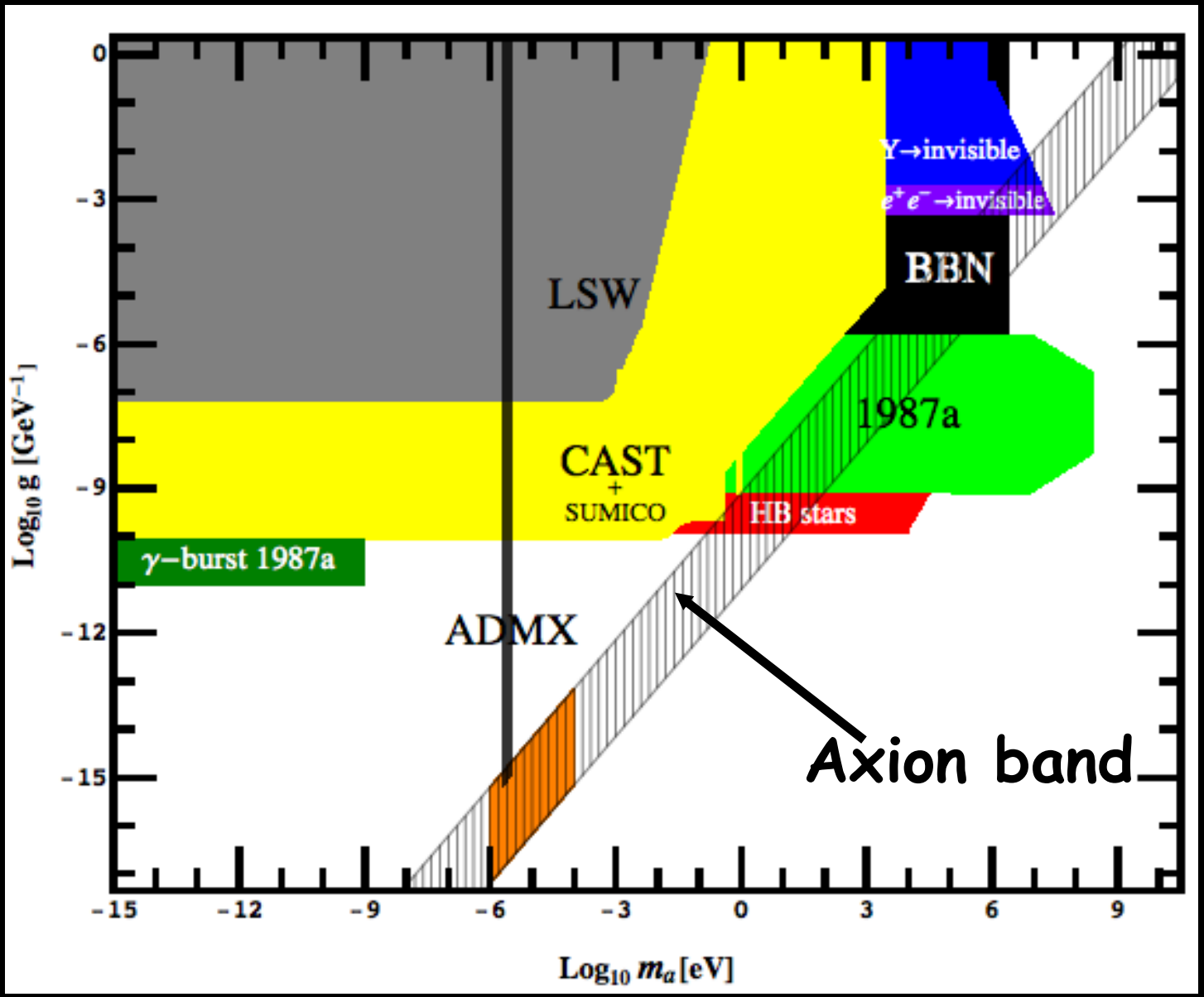




This isn't Dark matter,

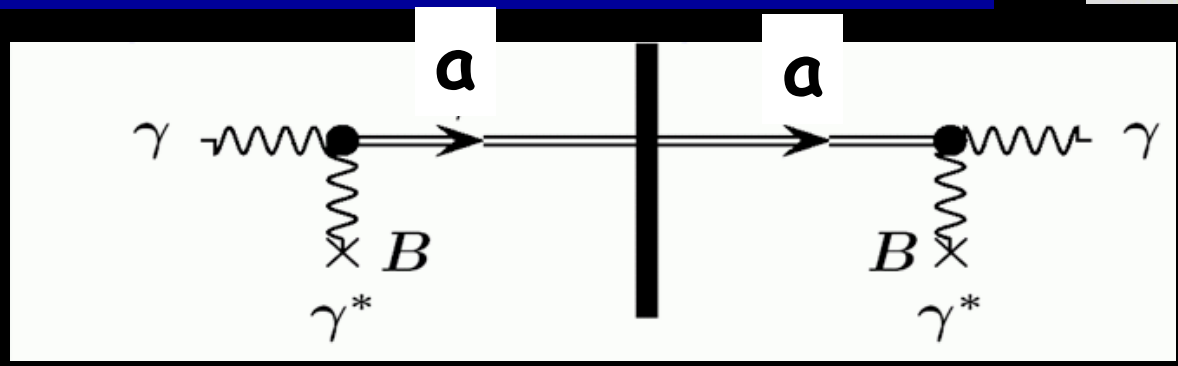
I just forgot to take off the lens cap

Sensitivity

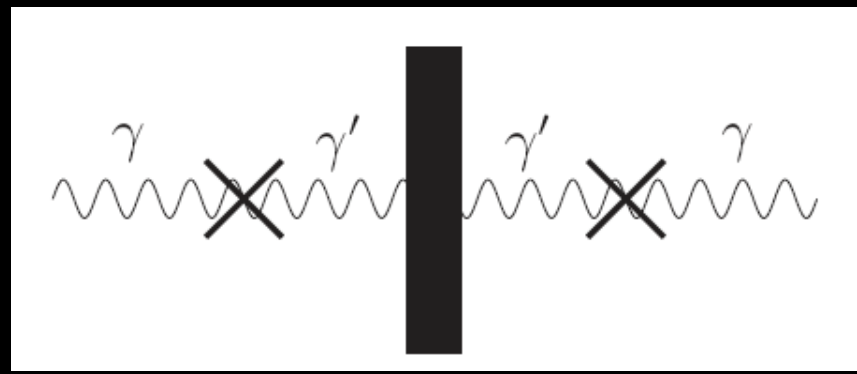


WISPS=Weakly interacting sub-eV particles

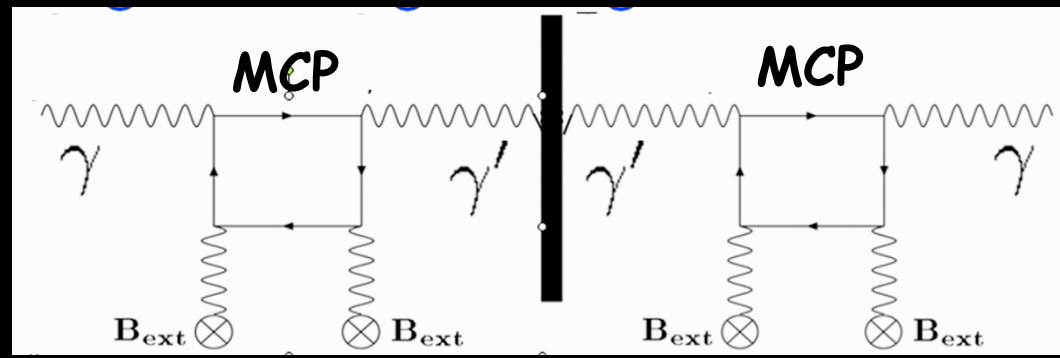
- Axions



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



- Hidden photon + minicharged particle (MCP)



Hidden Photons

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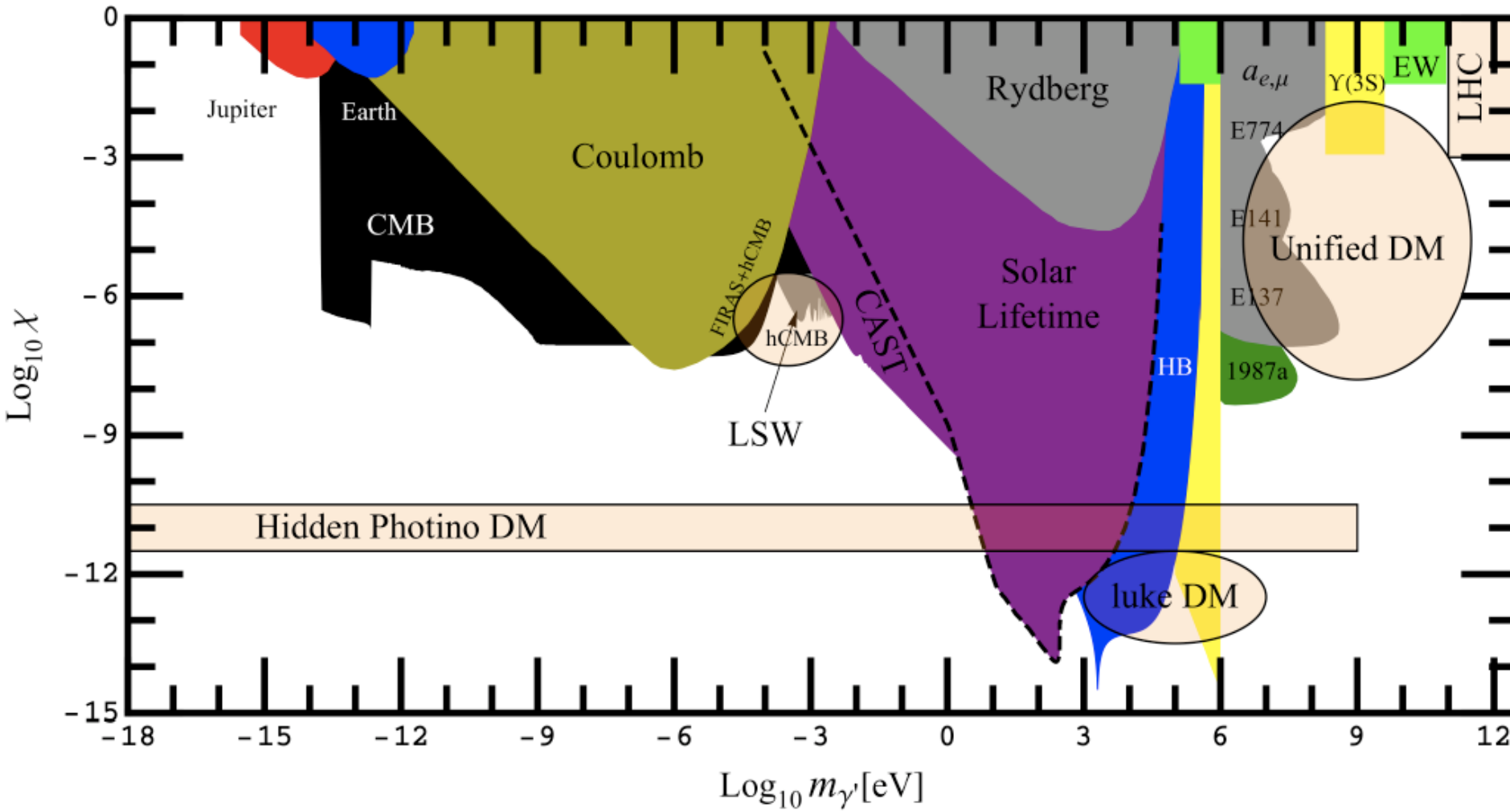
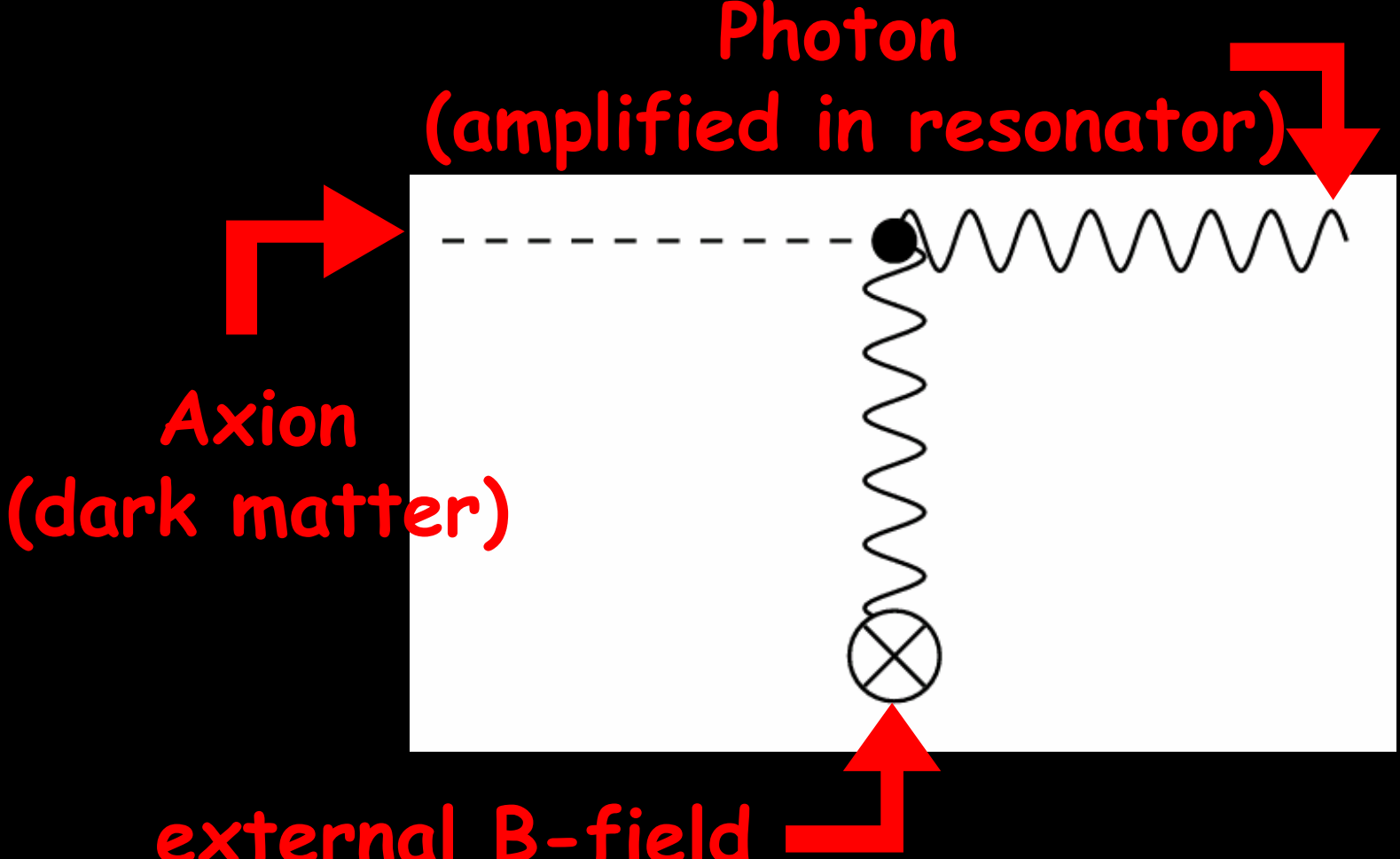
LSW already competitive + testing interesting area



Electricity from Dark Matter ;-).

- Photon Regeneration



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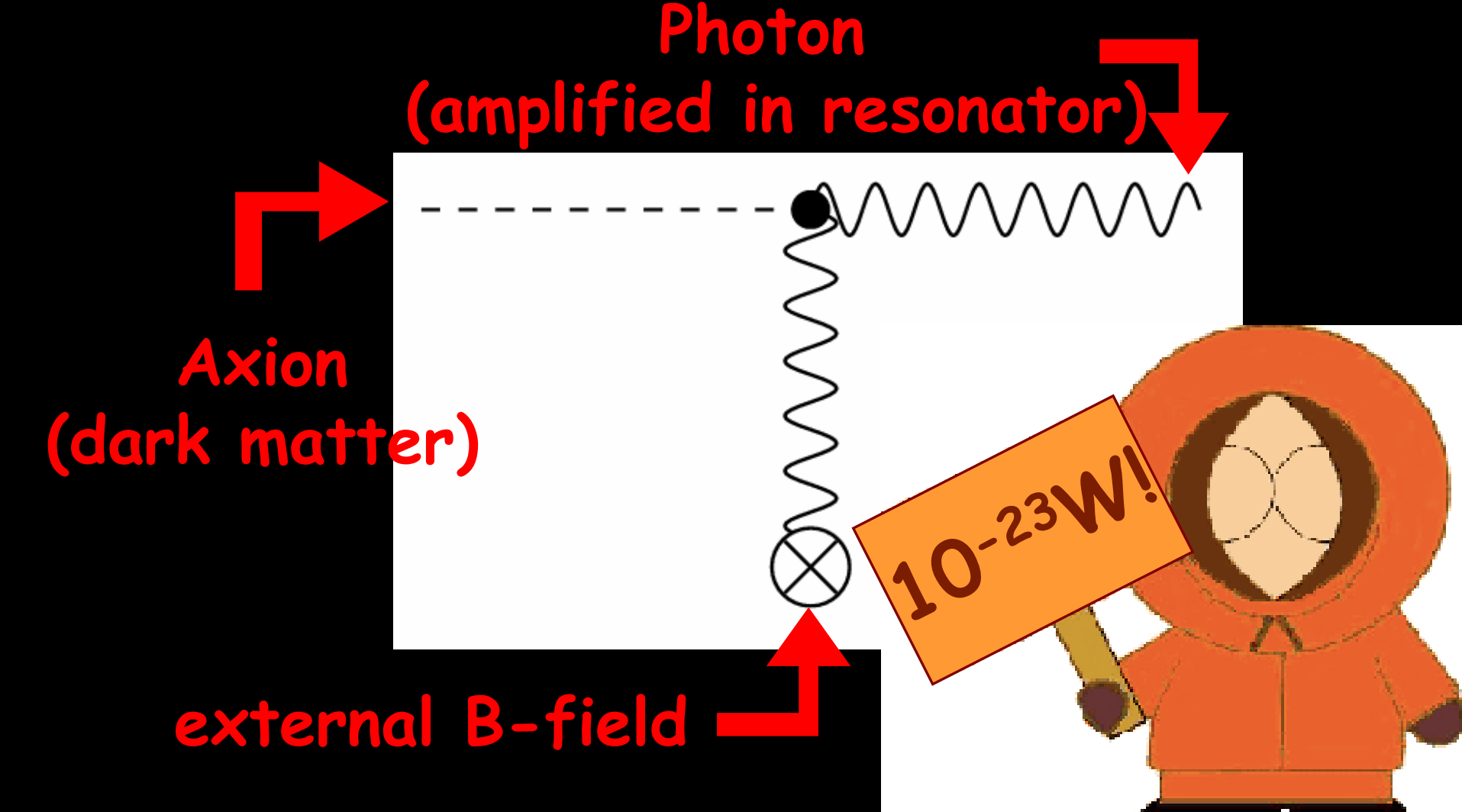
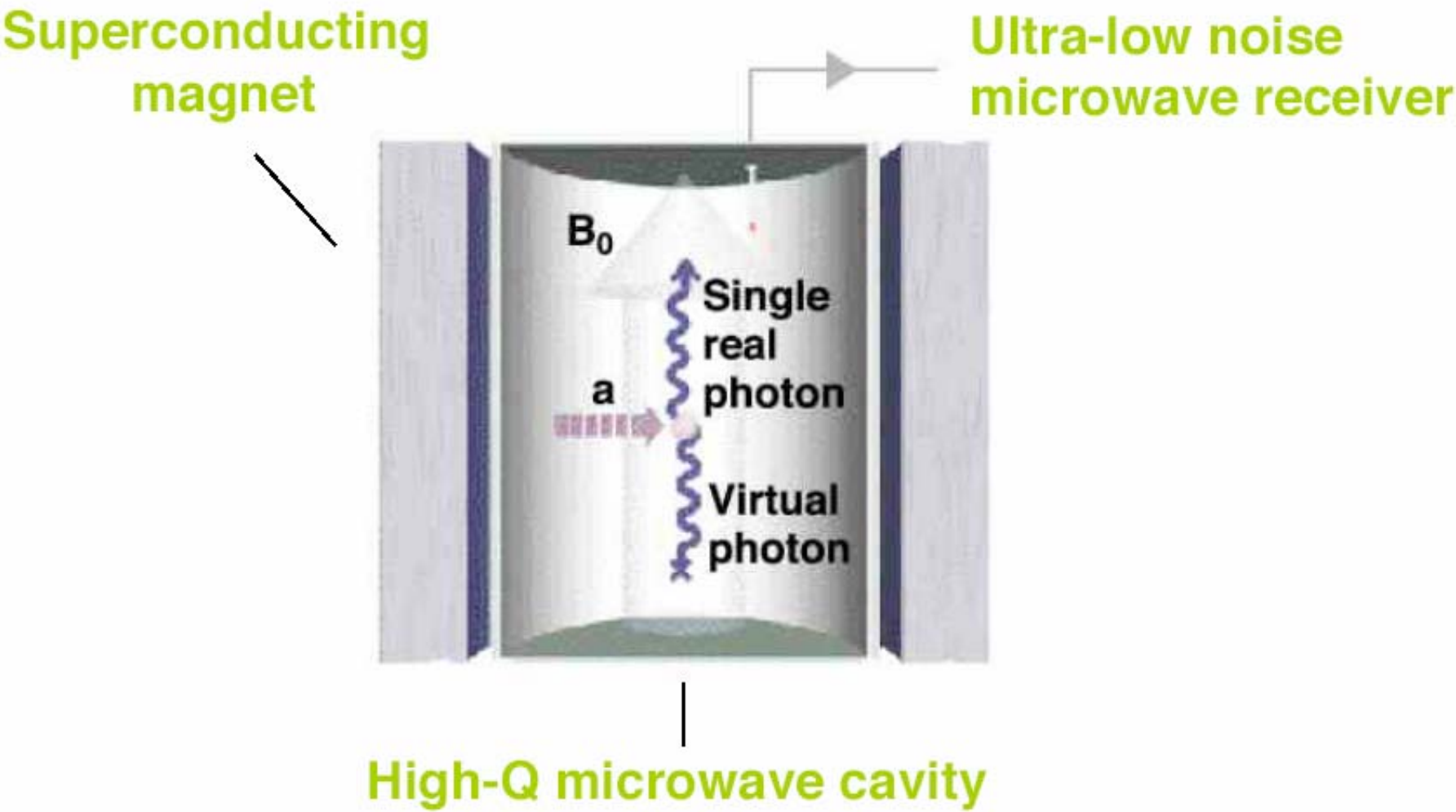
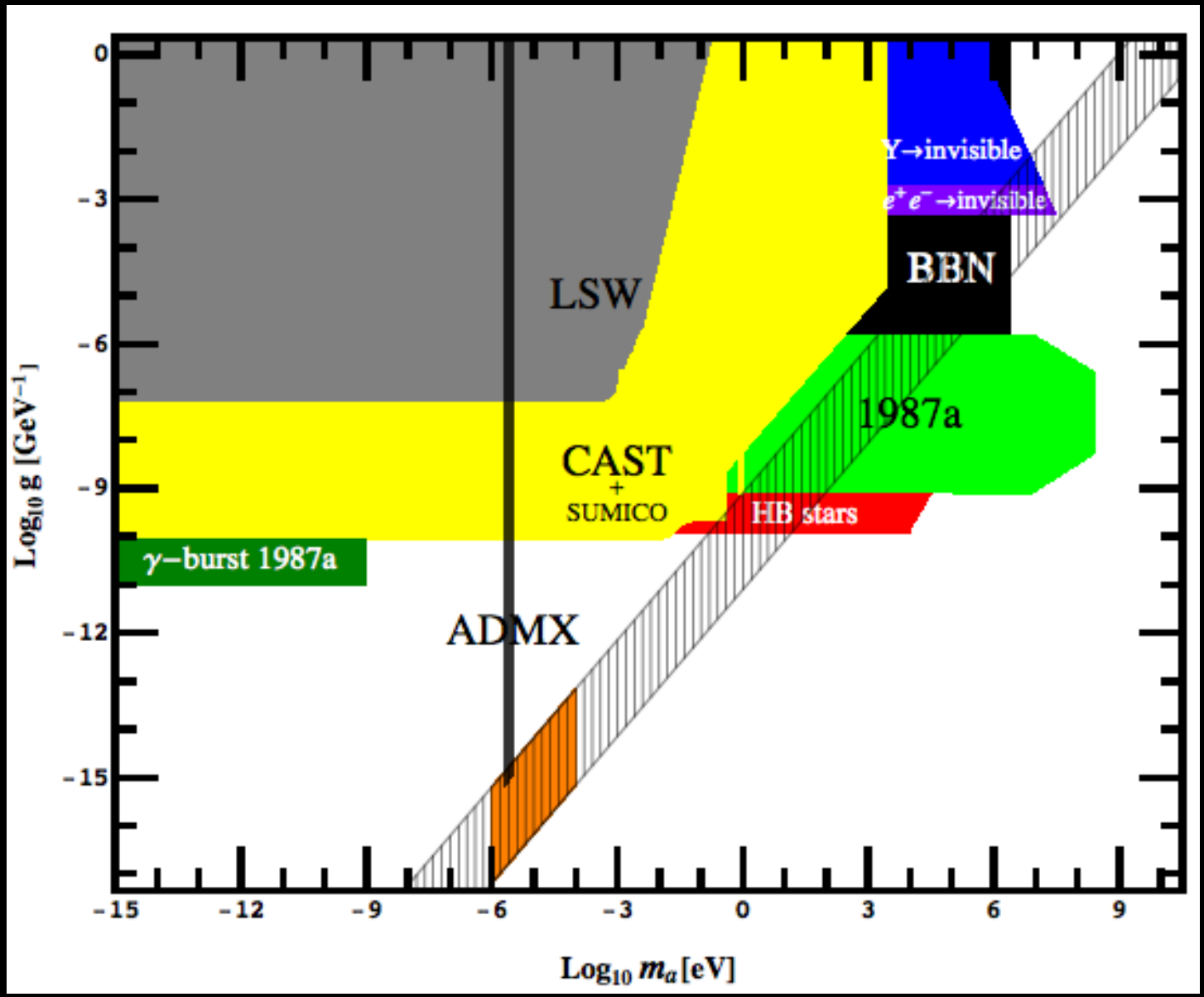


Searching axion dark matter



ADMX: Super sensitive

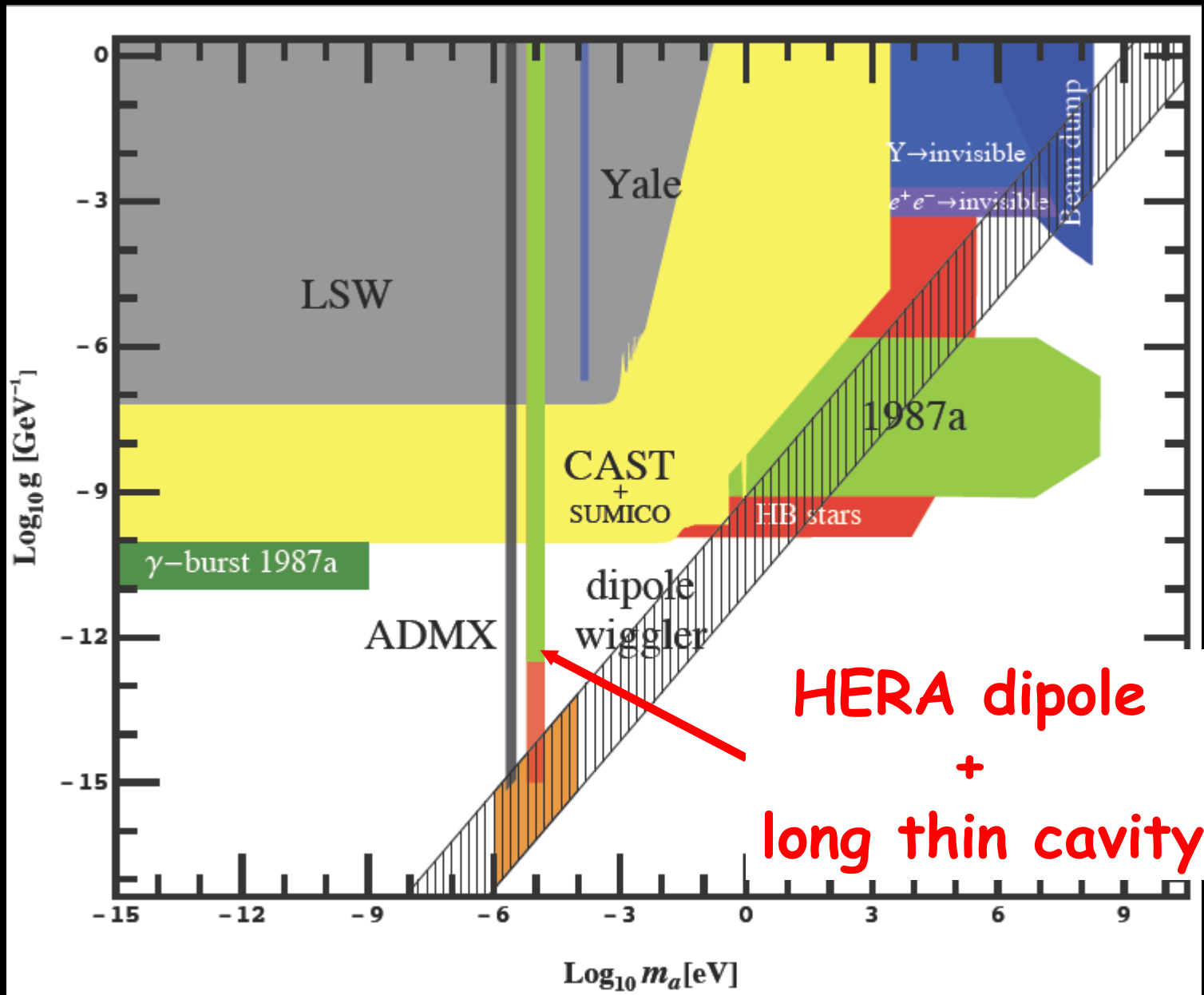


Opportunity for DESY

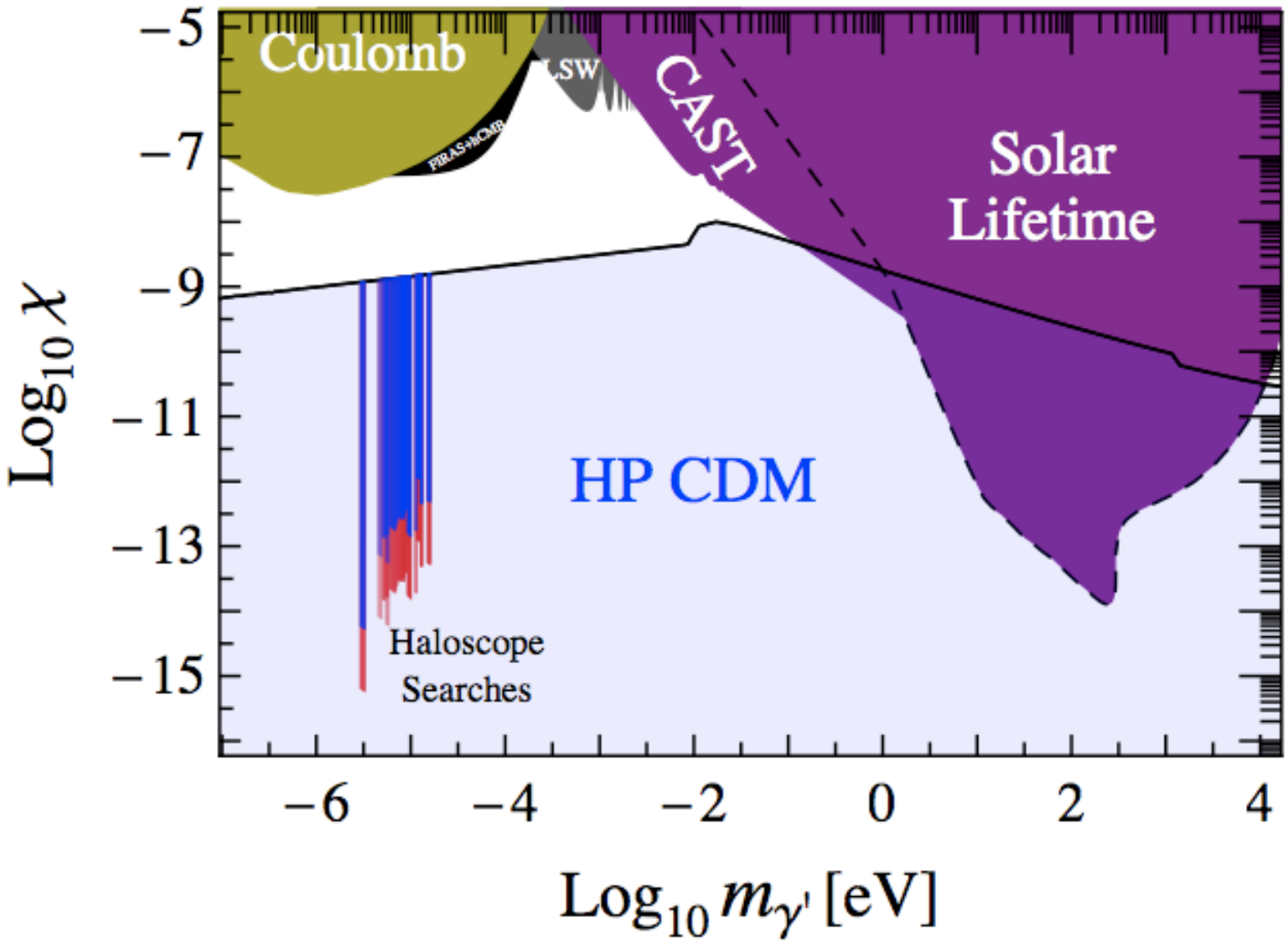
- Use Hera magnets ;-).
- Dipoles instead of solenoids

  ➔ Higher frequencies

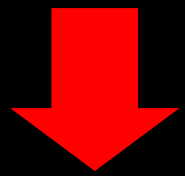
Sensitive to higher masses



Hidden photons could be Dark Matter, too



Hints for new Physics



Model Building

Hope for light particles?

YES, we can!

Coincidences?

- Neutrino masses:

$$m_\nu \sim \mathrm{meV}$$

- Scale of dark energy:

$$\rho_\Lambda \sim (\mathrm{meV})^4$$

- Energy density of the Universe:

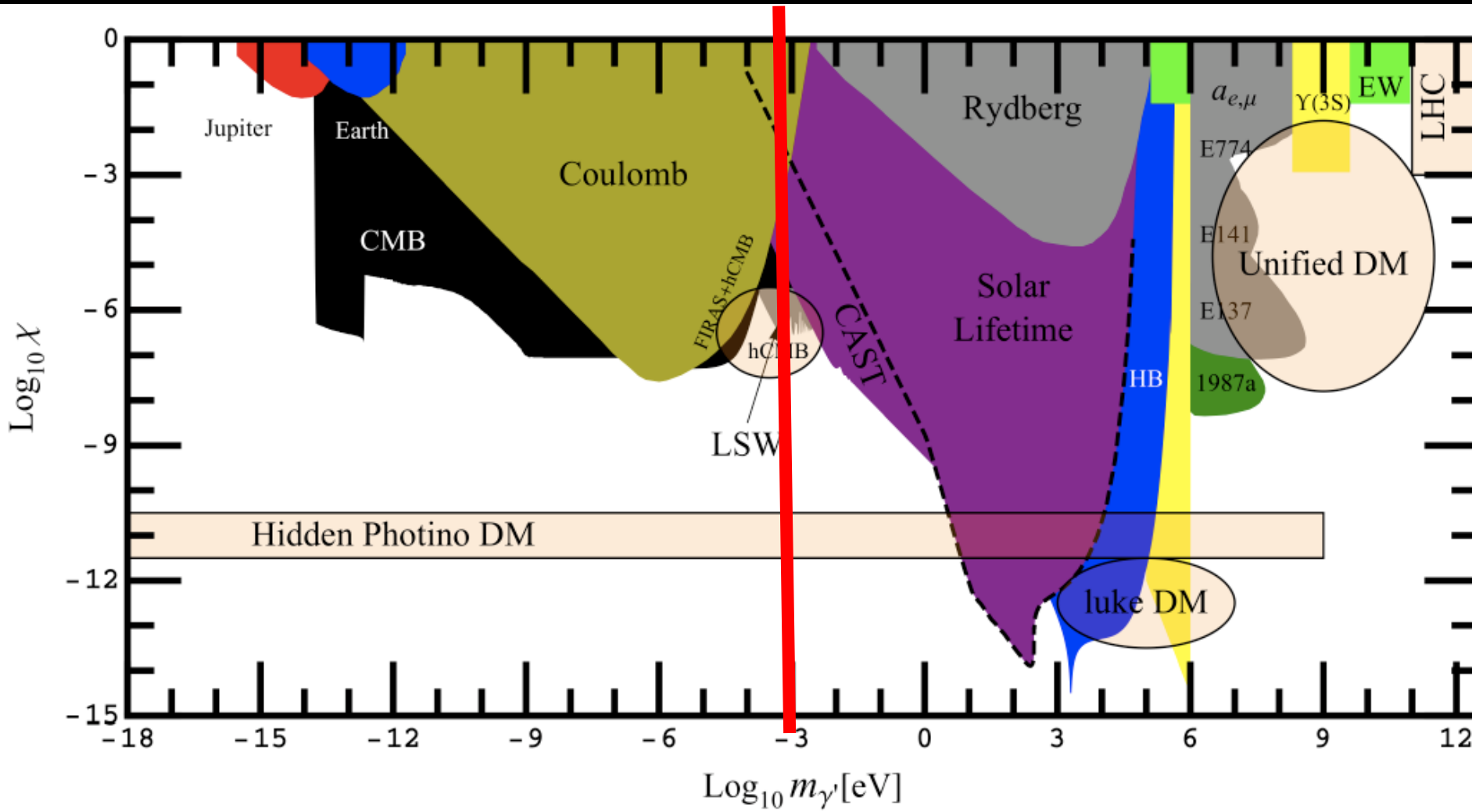
$$\rho_{\mathrm{today}} \sim (\mathrm{meV})^4$$

Hidden Photons

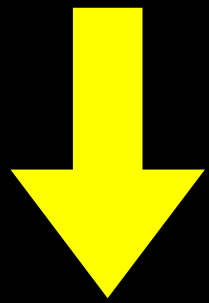
University of Durham

LSW already competitive + testing interesting area

Dark energy scale



High Scale



Small Coupling

Example: Axion coupling

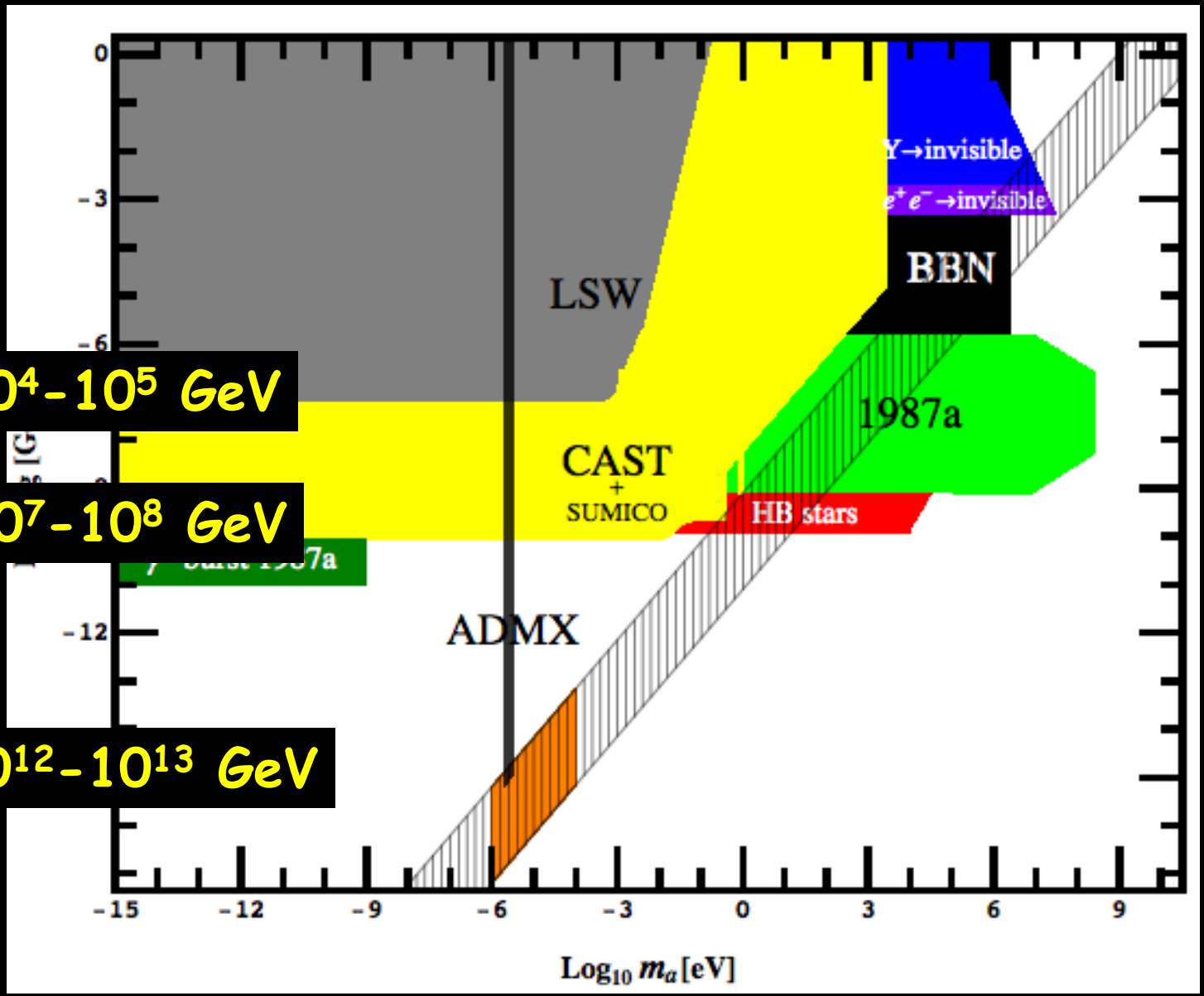
- Effective higher dimensional coupling

$$\mathcal{L}_{Int} = -\frac{1}{4} g a F^{\mu\nu} \tilde{F}_{\mu\nu} = -g a \mathbf{E} \cdot \mathbf{B}$$

- Small coupling for large axion scale:

small → $g \sim \frac{\alpha}{2\pi f_a}$ ← large

Huge Scale>> LHC Energy!

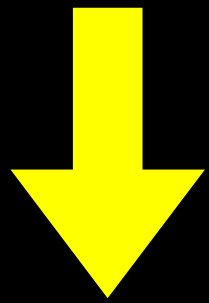


ca 10^4-10^5 GeV

ca 10^7-10^8 GeV

ca 10^{12}-10^{13} GeV

High Scale



Small Mass

Example: Axion See-Saw

- The axion mass is small, too!

Small → $m_a \sim \frac{m_\pi f_\pi}{f_a}$ ← Large

Example: Axion See-Saw

- The axion mass is small, too!

Small → $m_a \sim \frac{m_\pi f_\pi}{f_a}$ ← Large

Pseudo-Goldstone Boson!

Example: Axion See-Saw

- The axion mass is small, too!

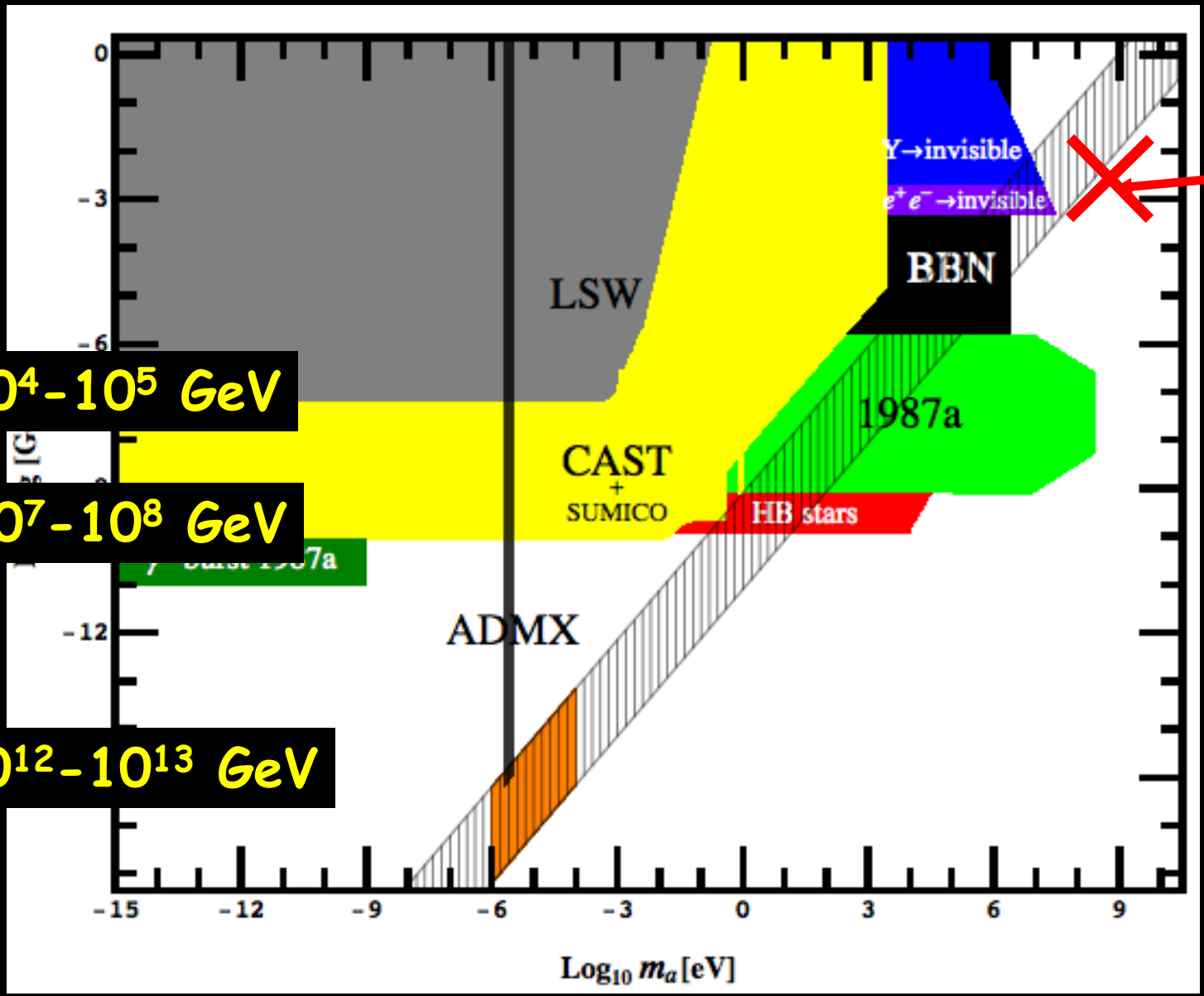
$$m_a \sim \frac{m_\pi f_\pi}{f_a}$$

$$\sim 0.6\,\mathrm{meV}\left(\frac{10^{10}\,\mathrm{GeV}}{f_a}\right)$$

Sub-eV mass

Large scale

Large Scale but light!



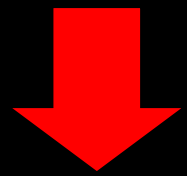
ca 10^4-10^5 GeV

ca 10^7-10^8 GeV

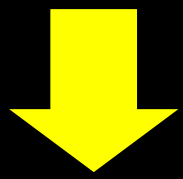
ca 10^{12}-10^{13} GeV

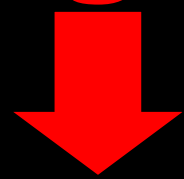
π^0

Hints for new Physics

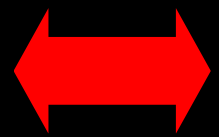


Model Building





Bottom-up (pheno)



Top-down (theory)

Go back to drawing board
`Start from scratch'

WISPs
from
String Theory

String theory

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

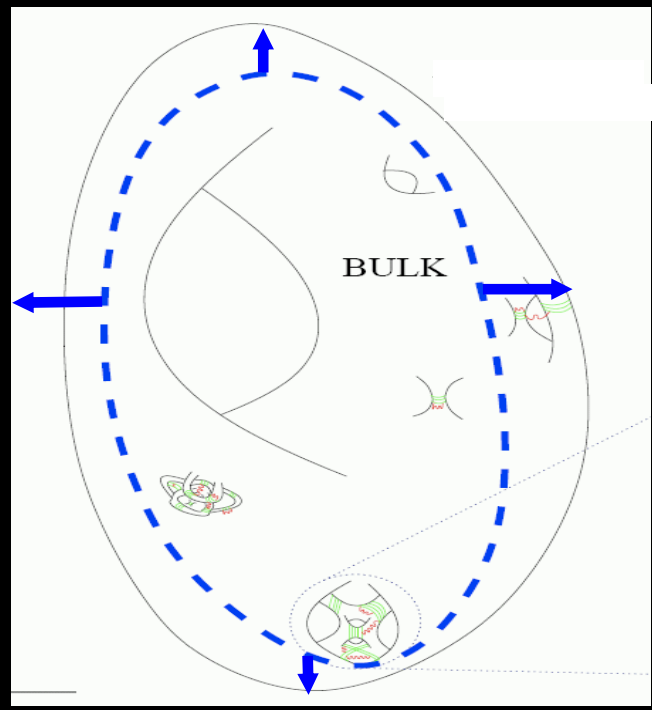
Axion(-like particles)

String theory: Moduli and Axions

- String theory needs Extra Dimensions

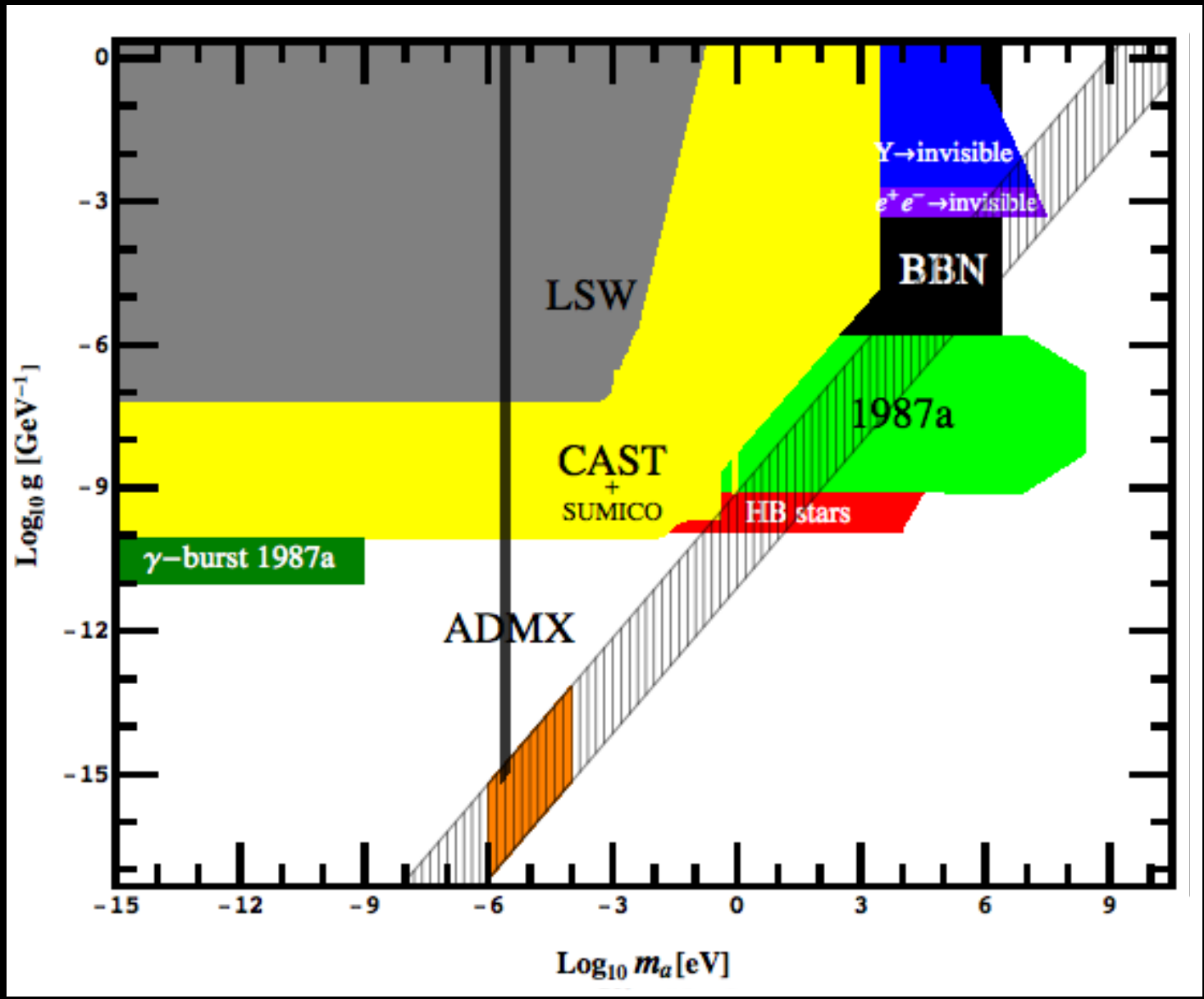
Must compactify

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

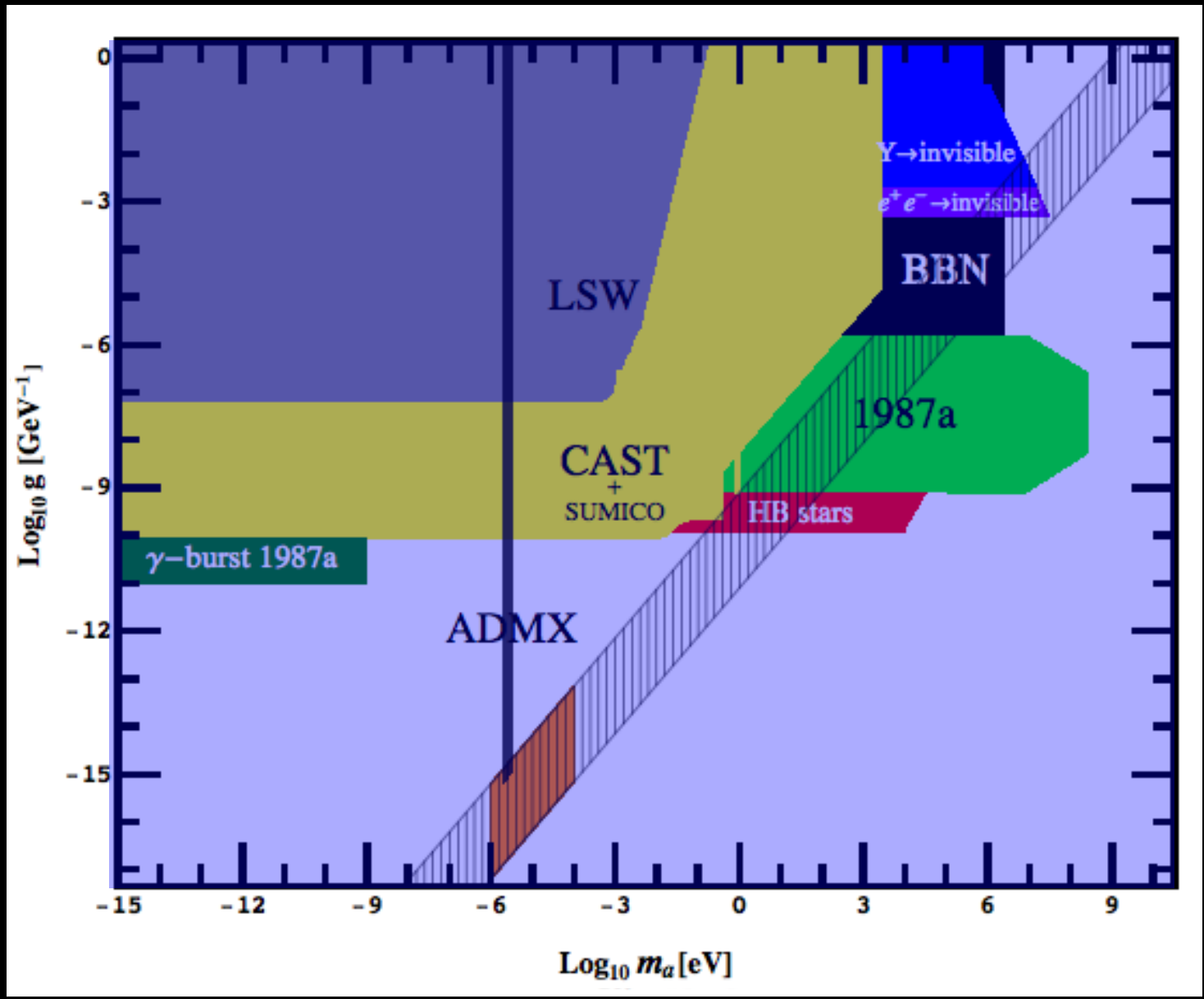


WISP candidates

Axion (like particles): Where are we?

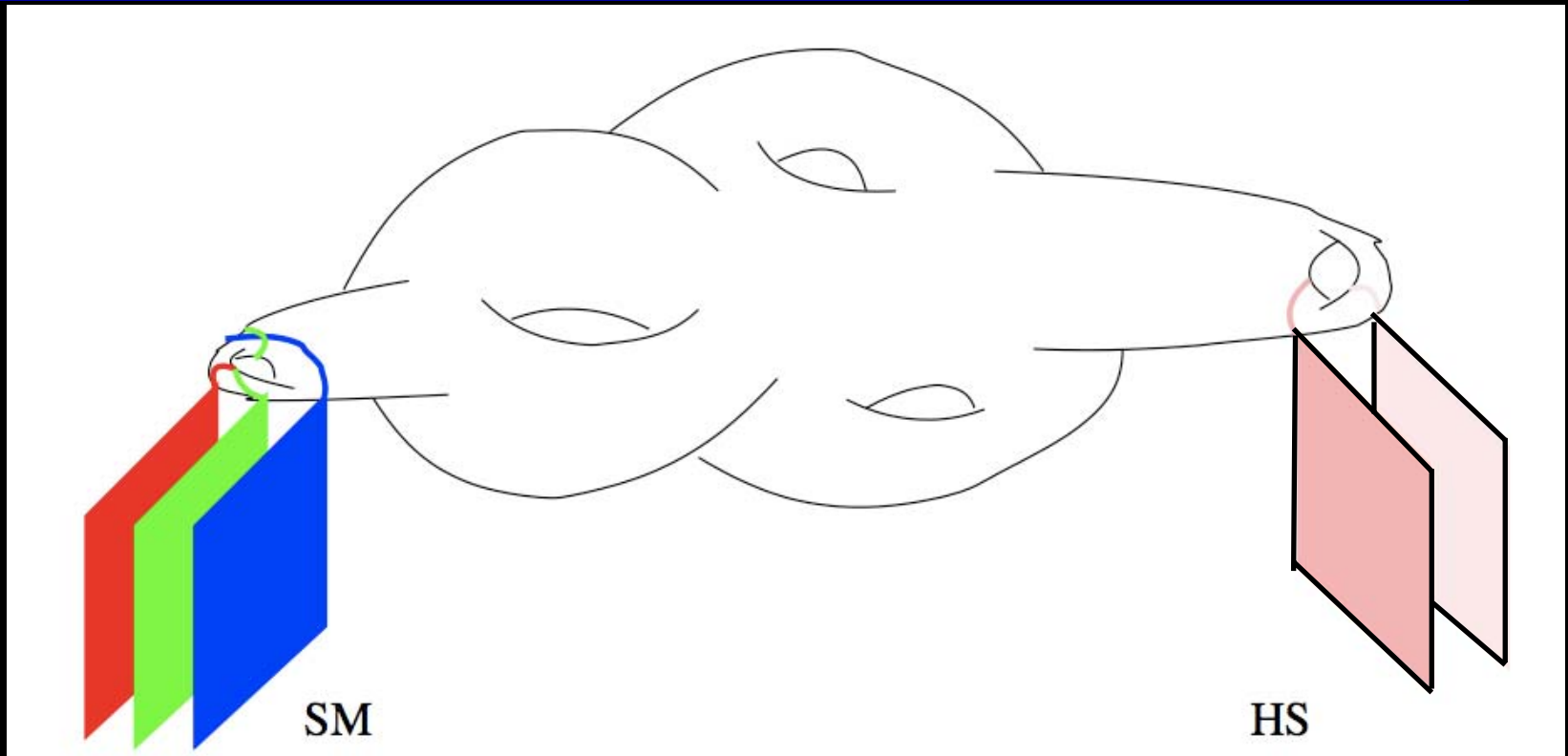


Axion (like particles): Where are we?



Hidden Photons

String theory likes extra gauge groups



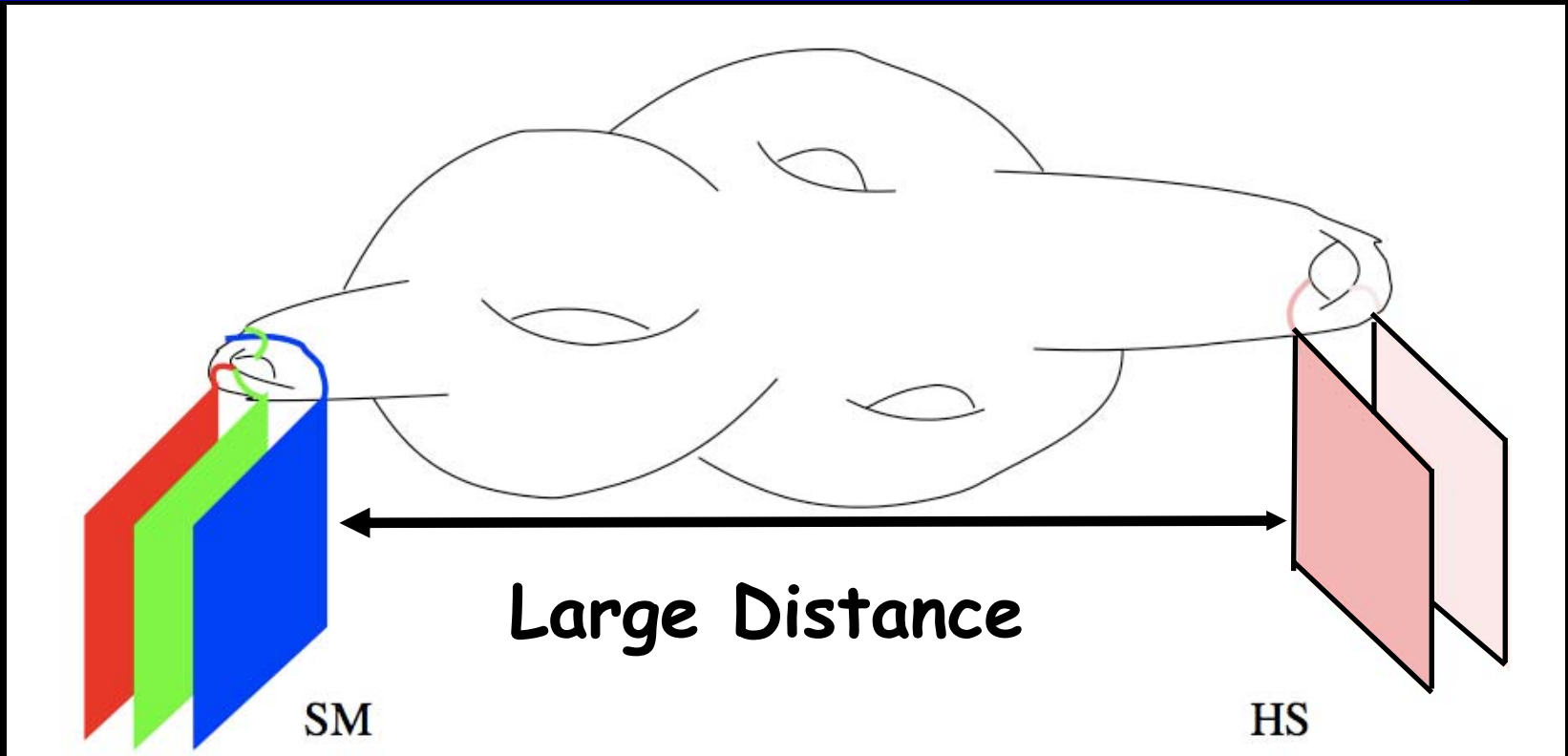
$U(A) \times U(B) \times U(C)$

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

➡ Many extra U(1)s!

➡ Candidates for WISPs

Hidden by distance



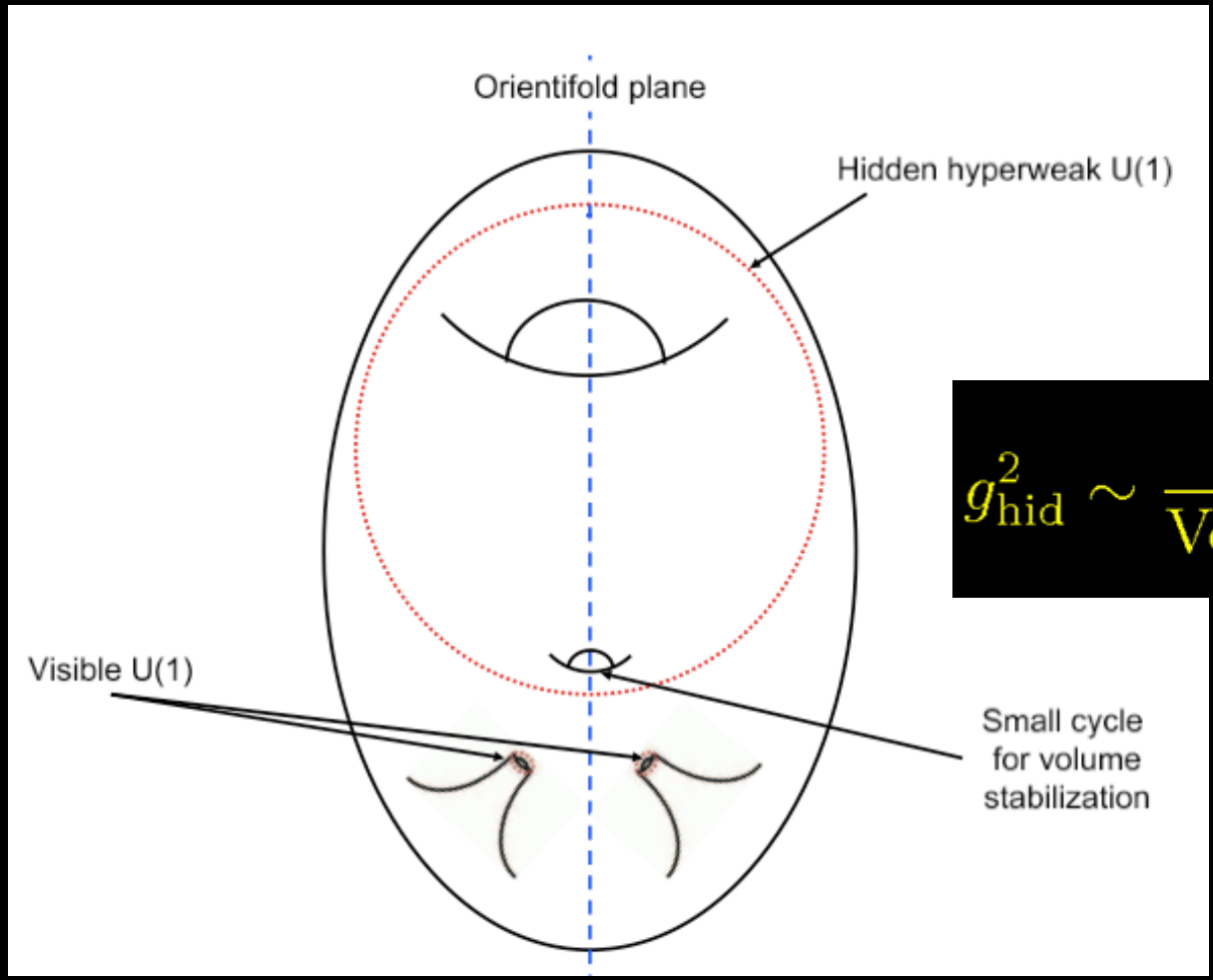
$U(A) \times U(B) \times U(C)$

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

$$\chi \sim \frac{g_s}{8\pi} \frac{1}{Volume^x}$$

$$g_{\rm hid} \sim 1$$

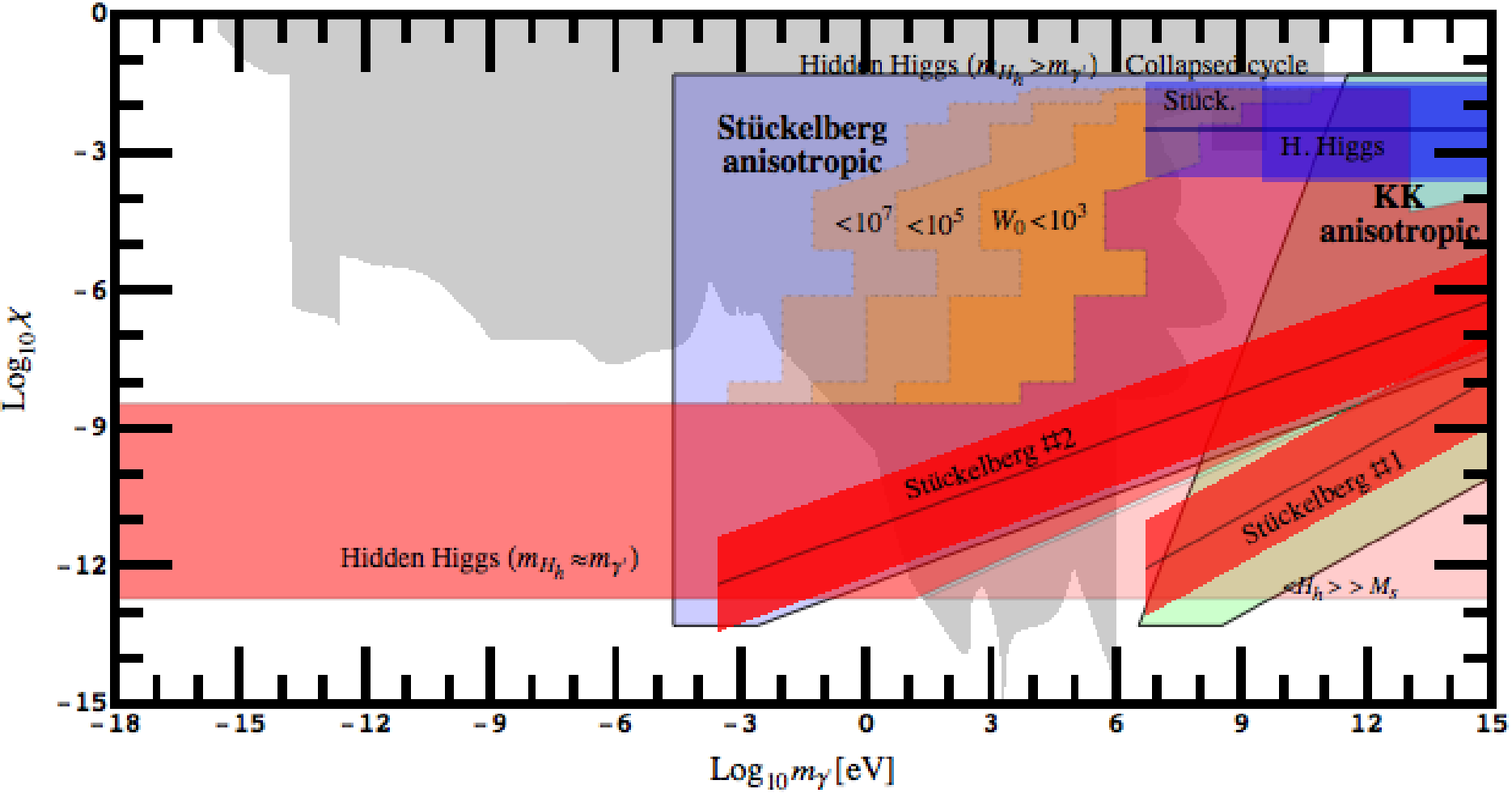
Hidden by weakness



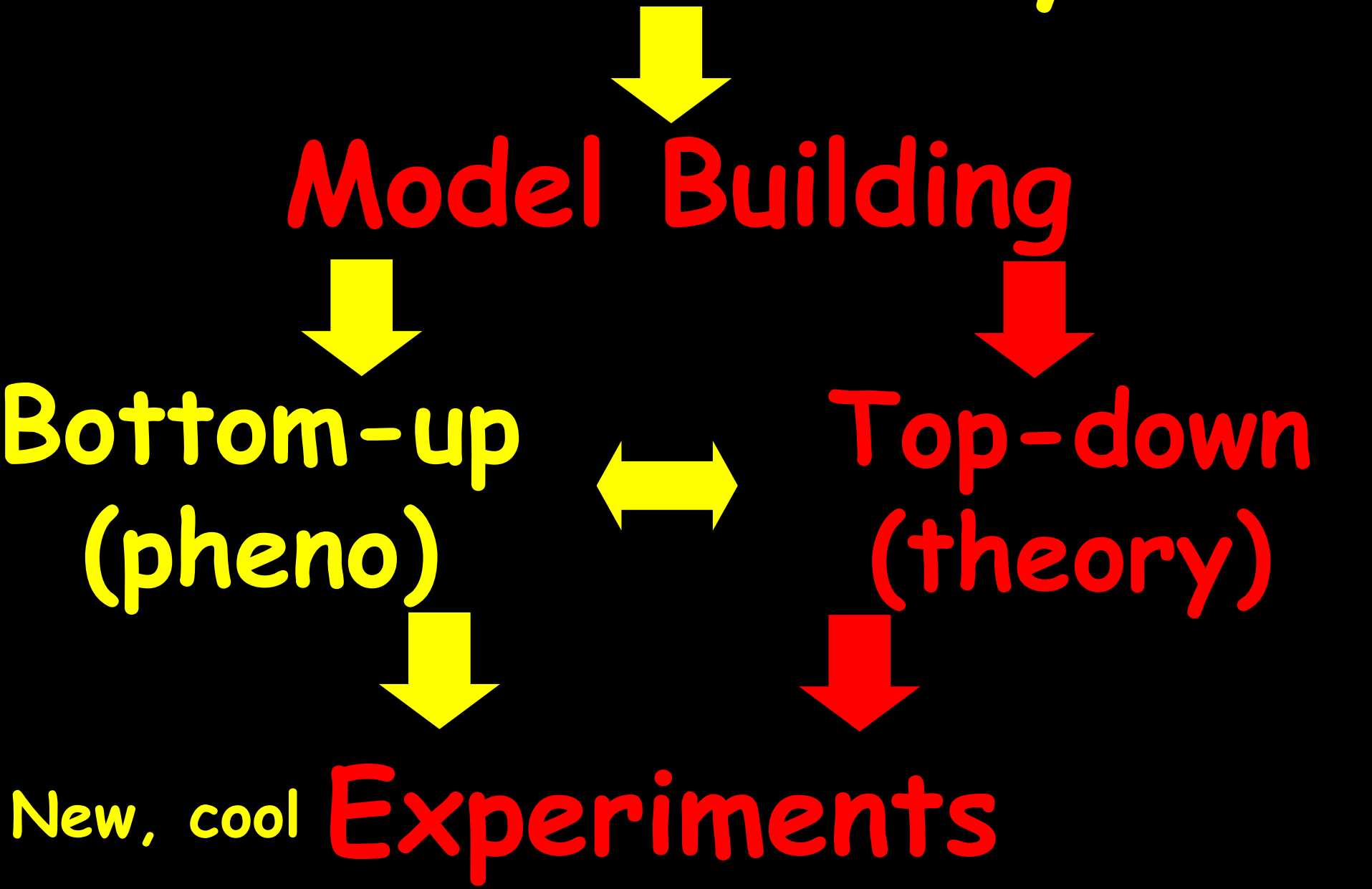
$$g^2_{\rm hid} \sim \frac{2\pi g_s}{\rm Volume^x} \sim \left(\frac{M_s^2}{M_P^2}\right)^x \ll 1$$

$$\chi \sim \frac{g_{\rm vis} g_{\rm hid}}{16\pi^2} \sim \frac{2\pi g_s}{\rm Volume^{x/2}} \sim \left(\frac{M_s^2}{M_P^2}\right)^{x/2} \ll 1$$

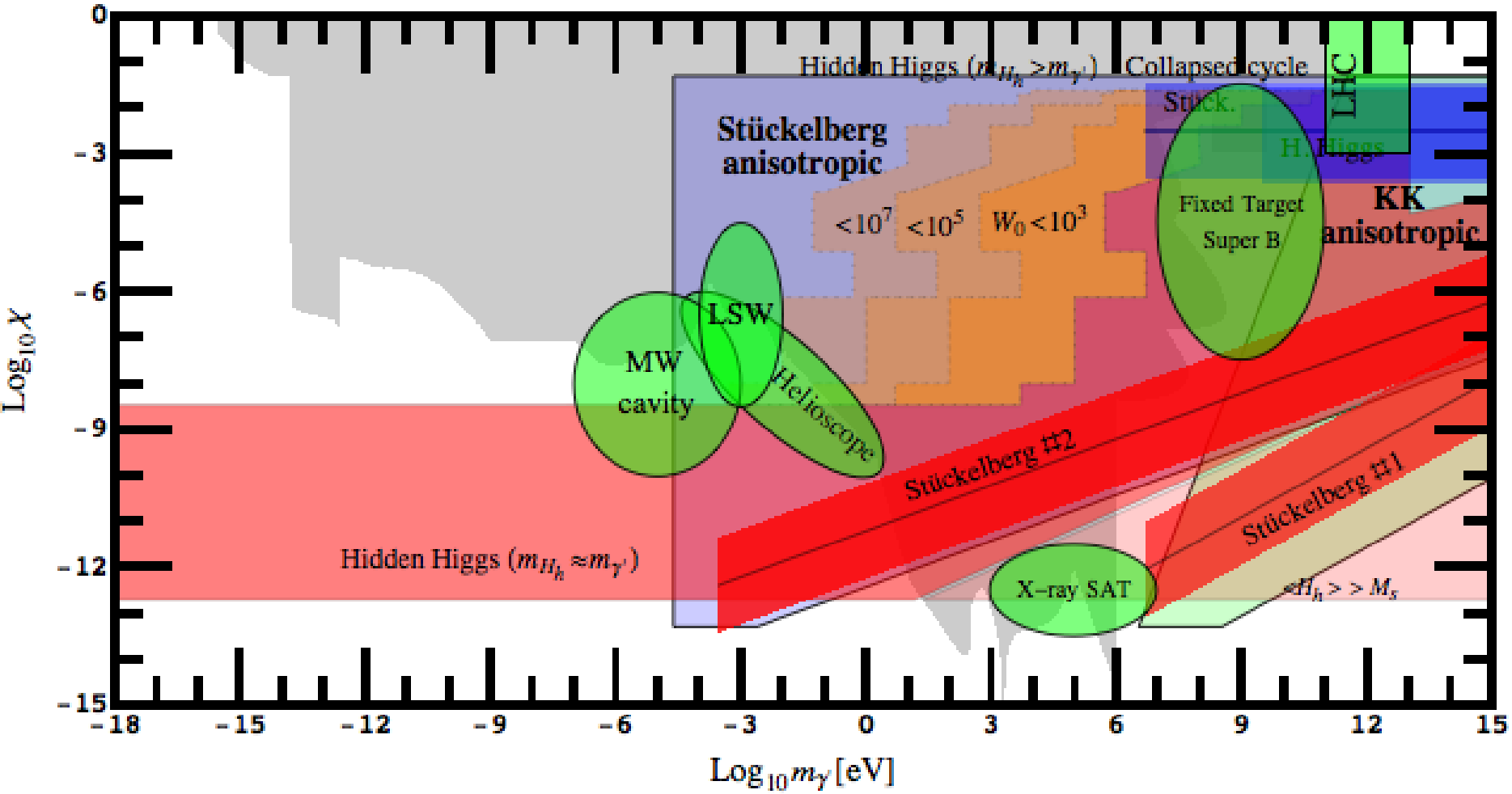
Hidden Photons, all over the place



Hints for new Physics



Hidden Photons: Back to Experiment

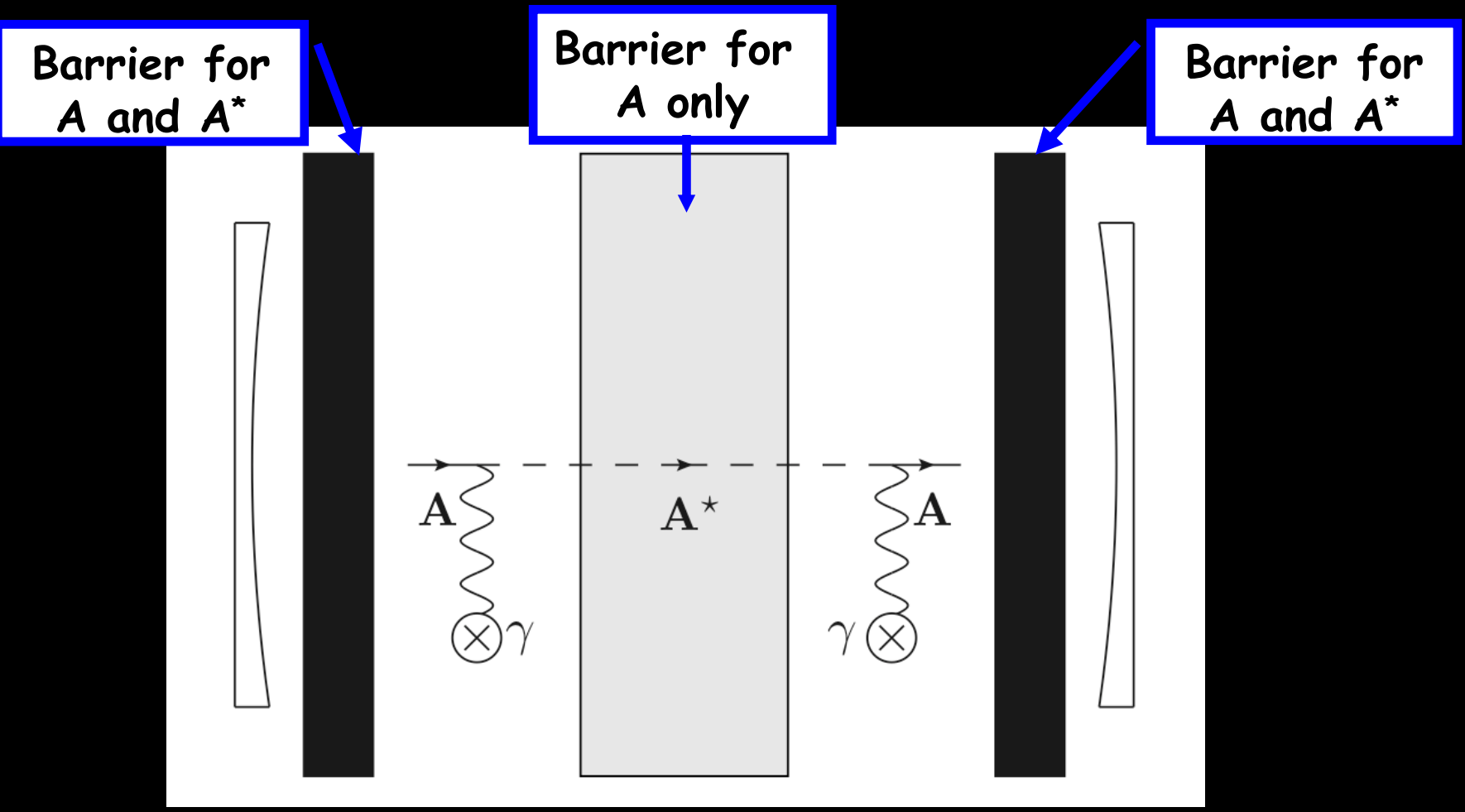


If you don't believe me...
(or in BSM physics)

Atoms

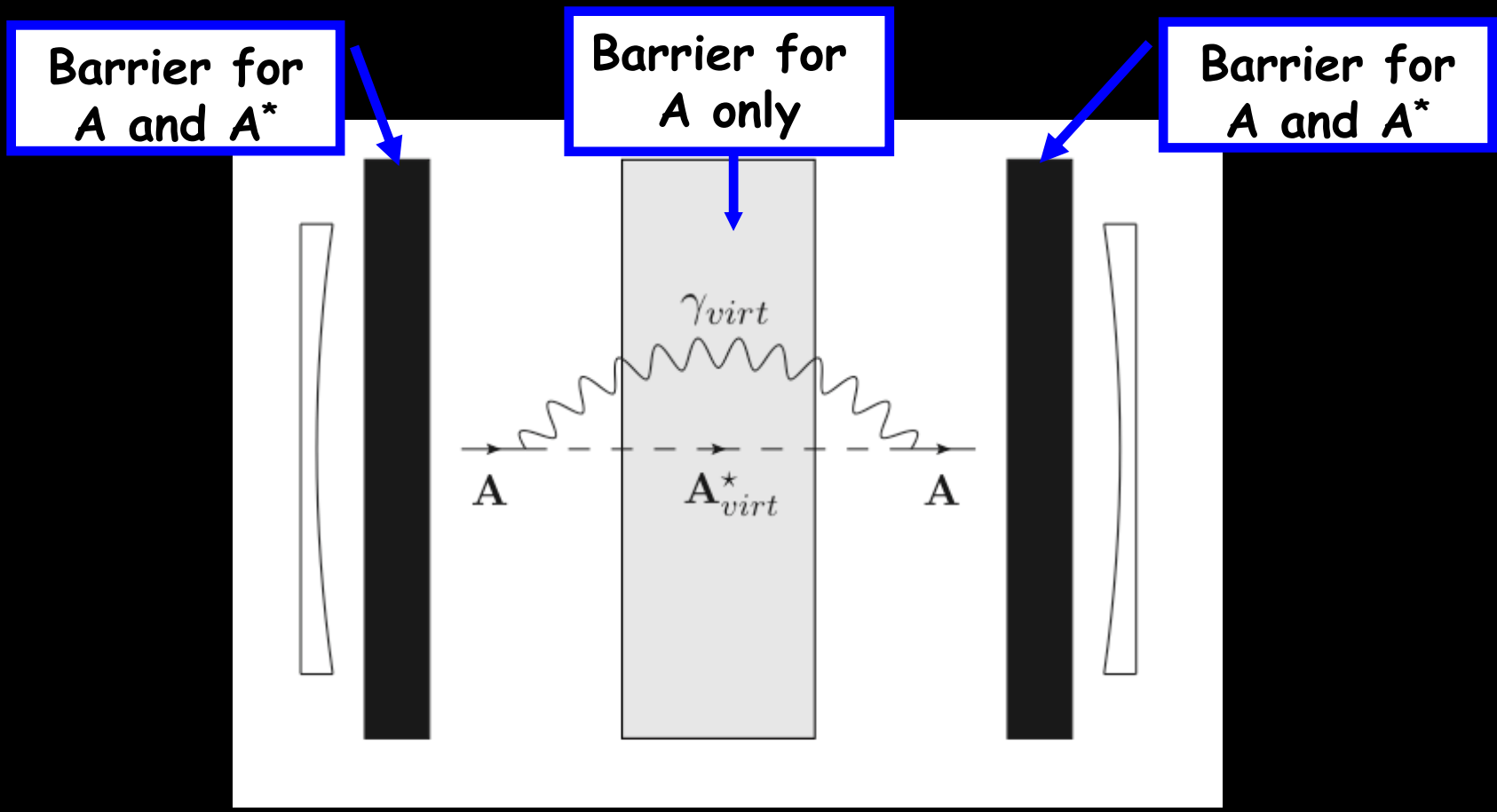
~~Light~~ shining through walls

Atoms shining through walls



Atoms could be used to simulate "LSW"

Tunneling of the 3rd kind…



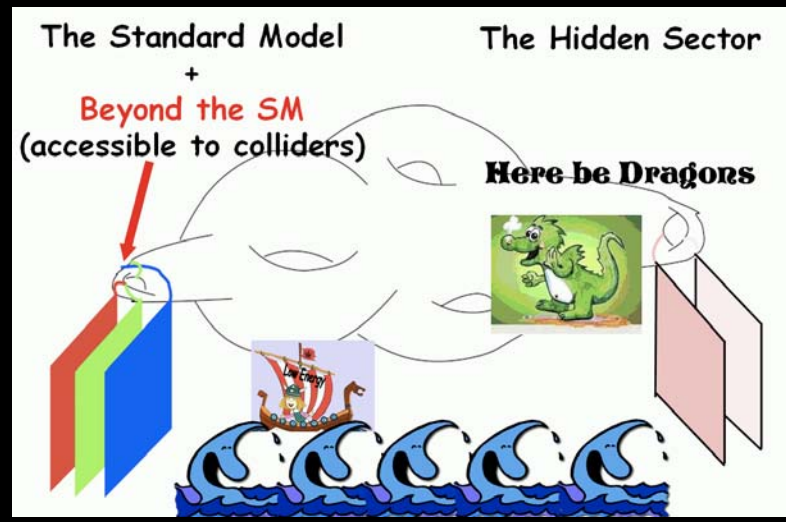
"Macroscopic" quantum loop

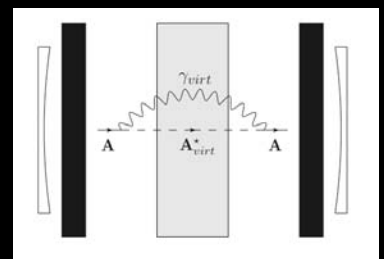
Tests effective non-locality of QFT

Conclusions

Conclusions

- Good Physics Case for Axions 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
- Atoms shining through walls demonstrate "big" quantum loops





Discover the Hidden Islands