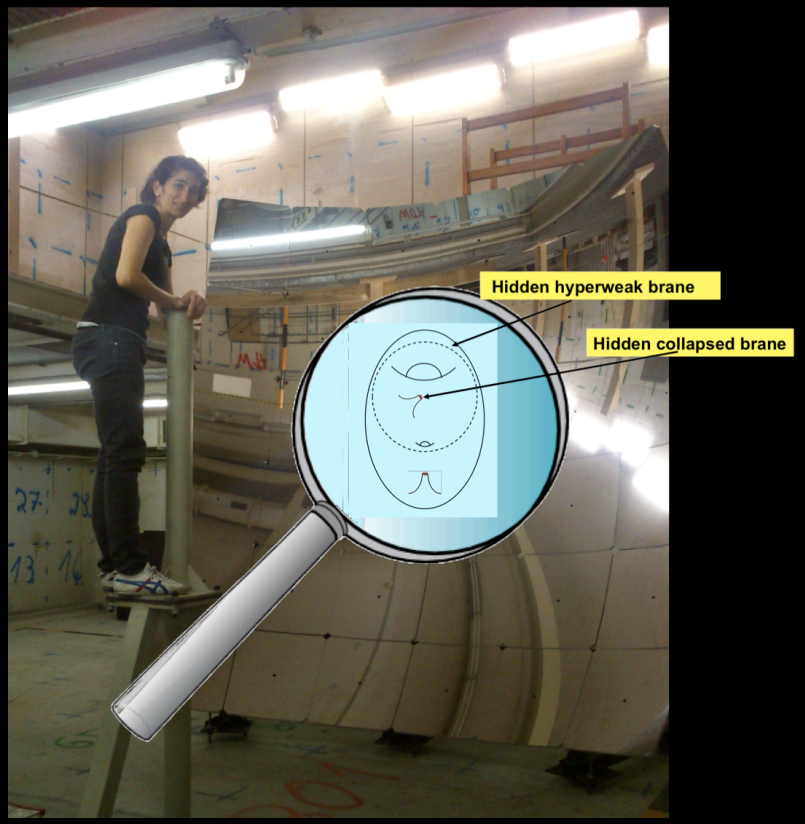
Shining Light into and out of the Hidden Sector

J. Jaeckel
ITP Heidelberg



S. Abel, M. Cicoli, B. Doebrich, R. Engel, D. Horns,
M. Goodsell, H. Gies, V. Khoze, A. Lindner, A. Lobanov,
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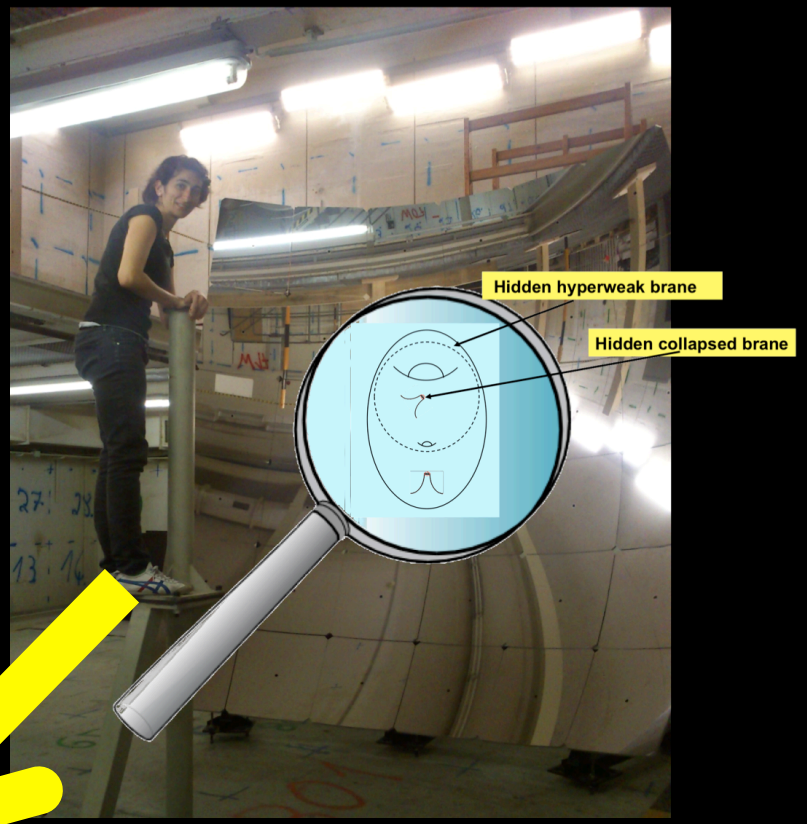

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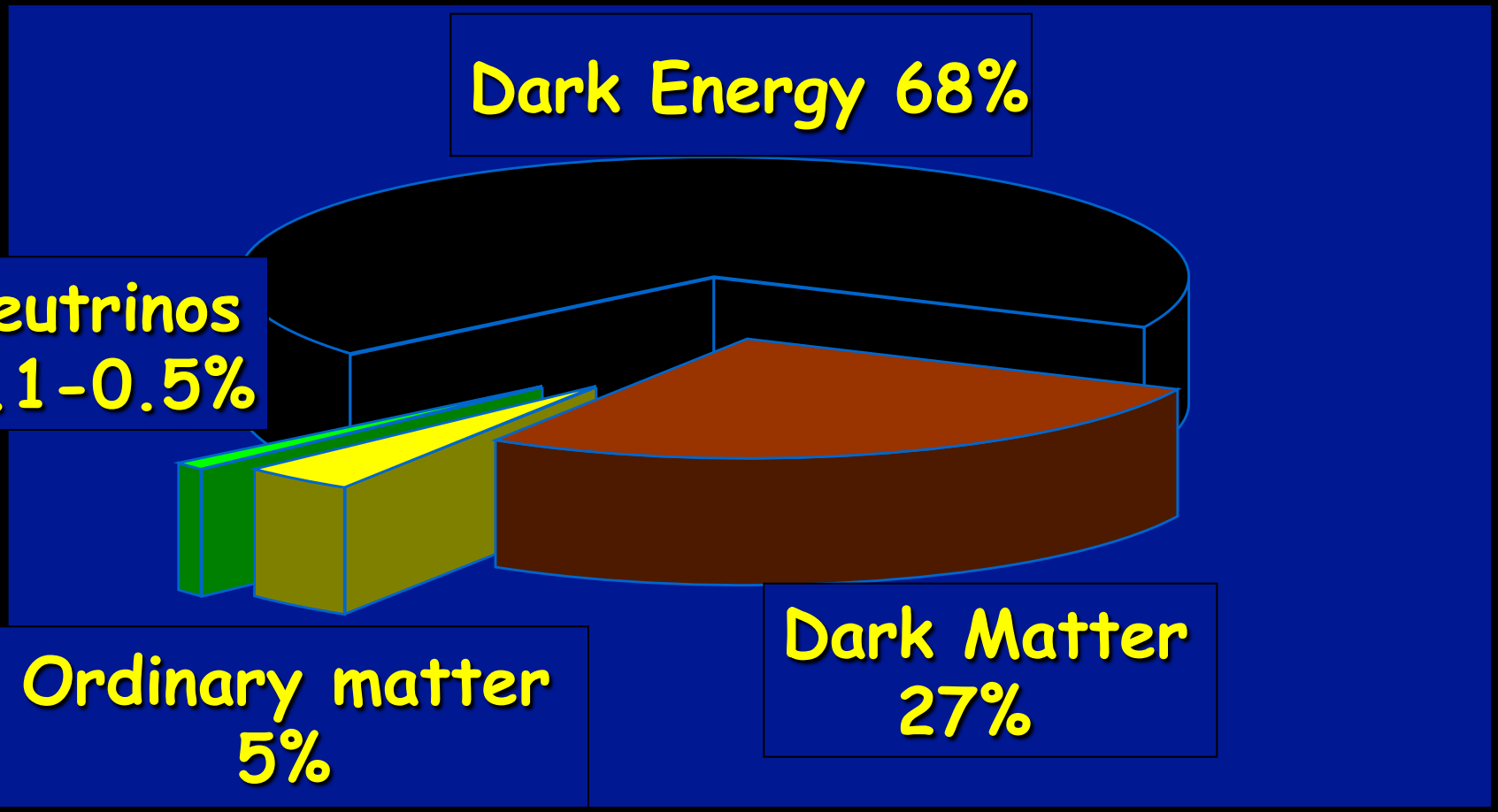
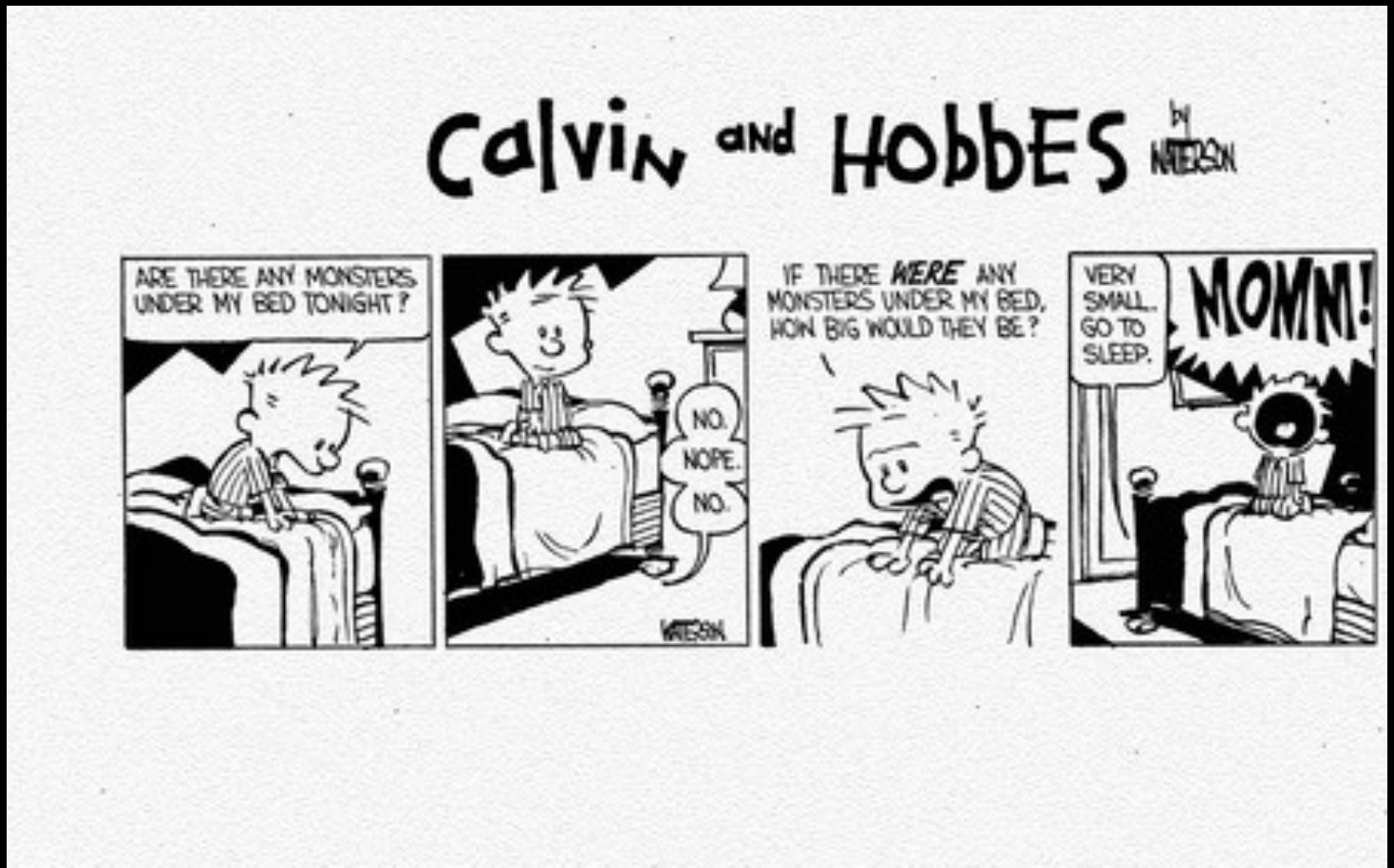
We need...

Physics beyond the Standard Model

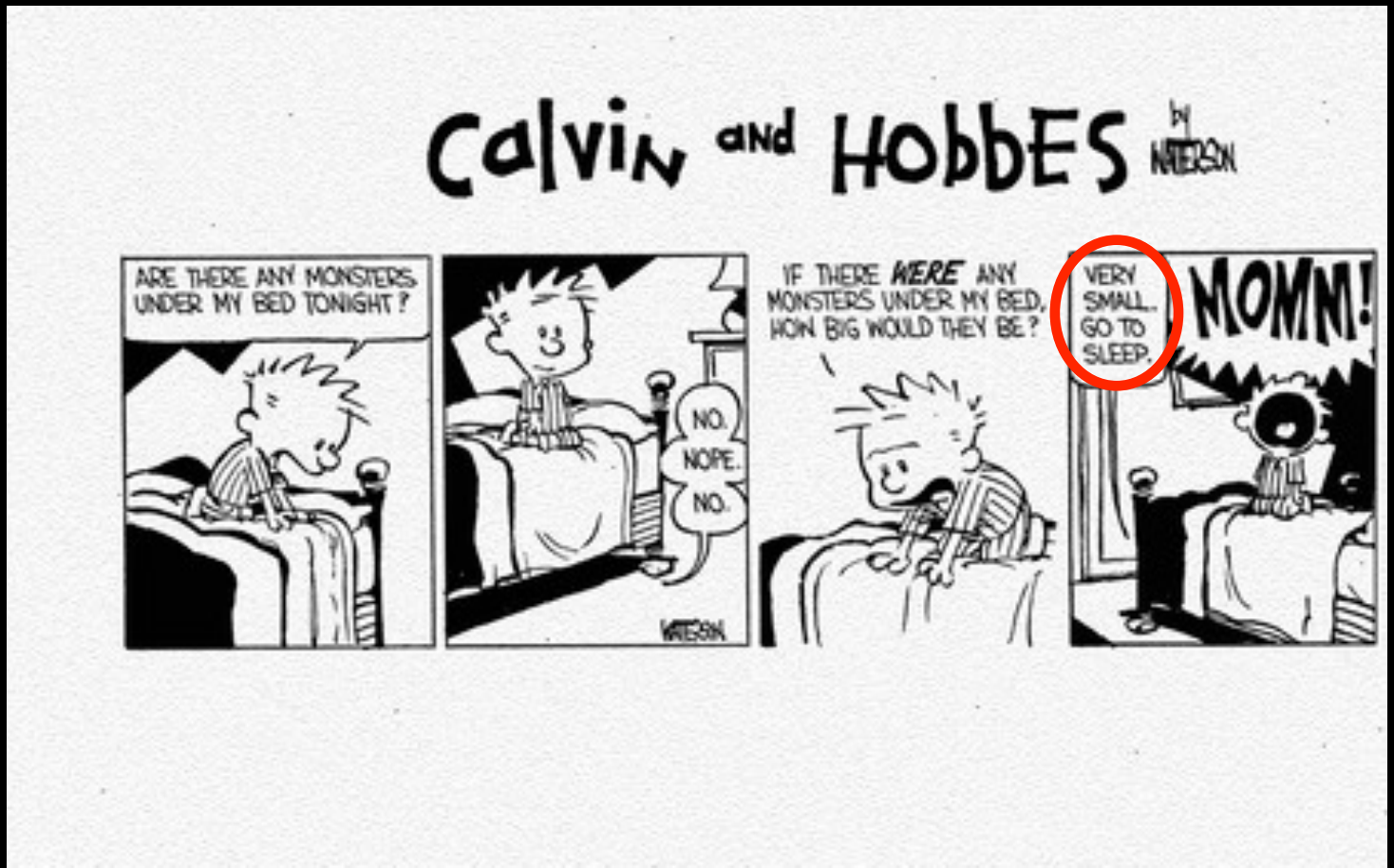
Inventory of the Universe



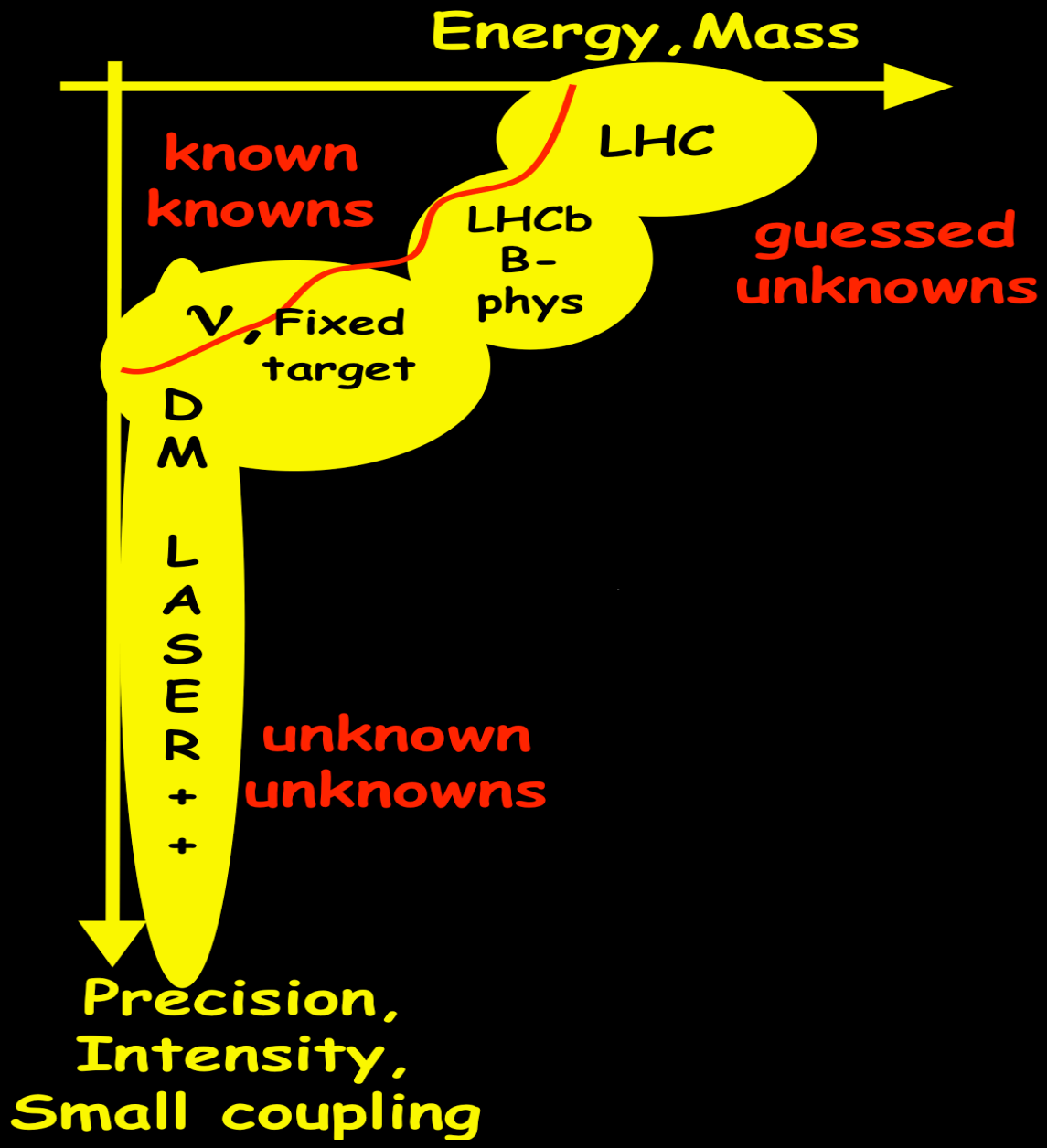
Where does it hide?



Where does it hide?



Exploring is (at least) 2 dimensional



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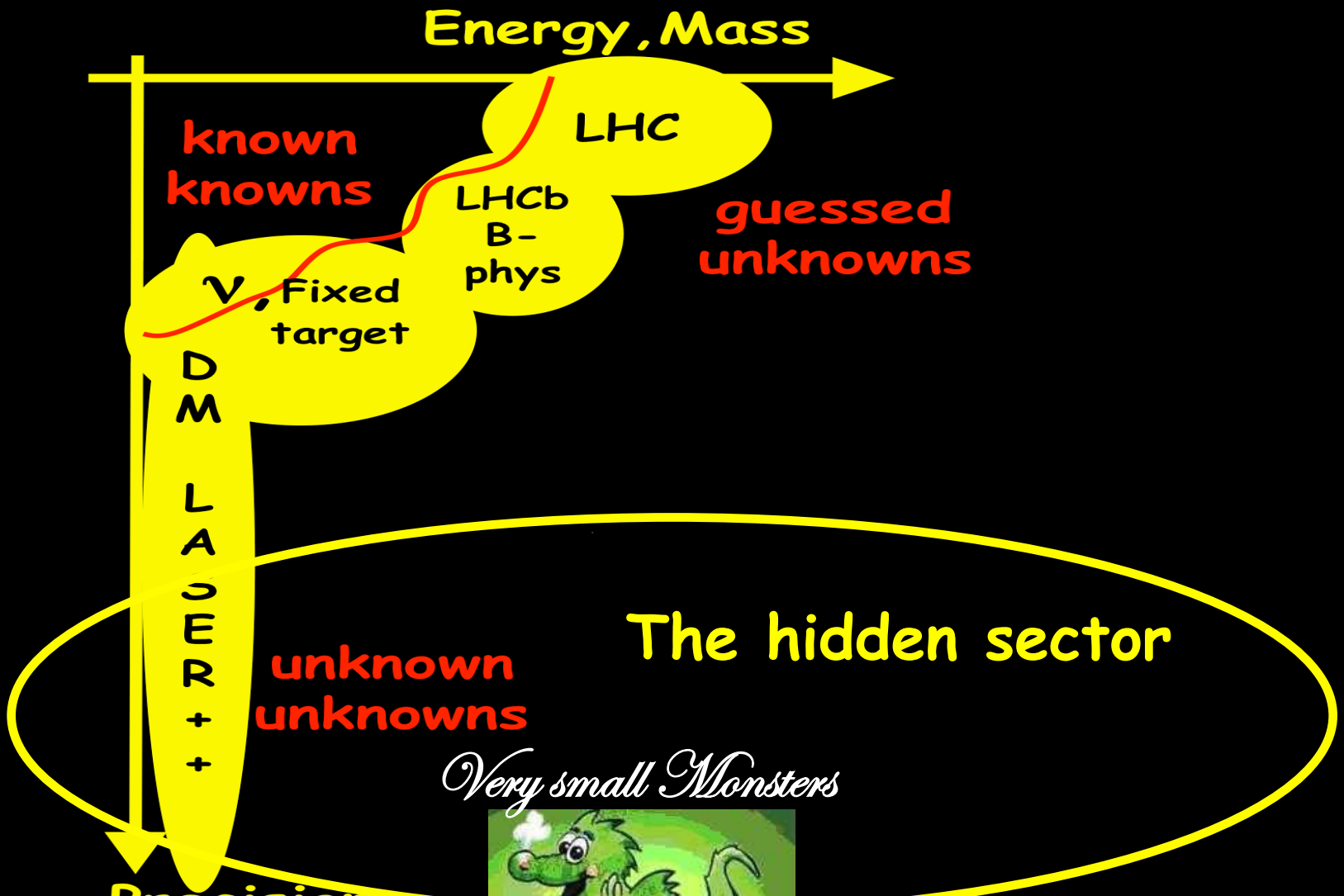

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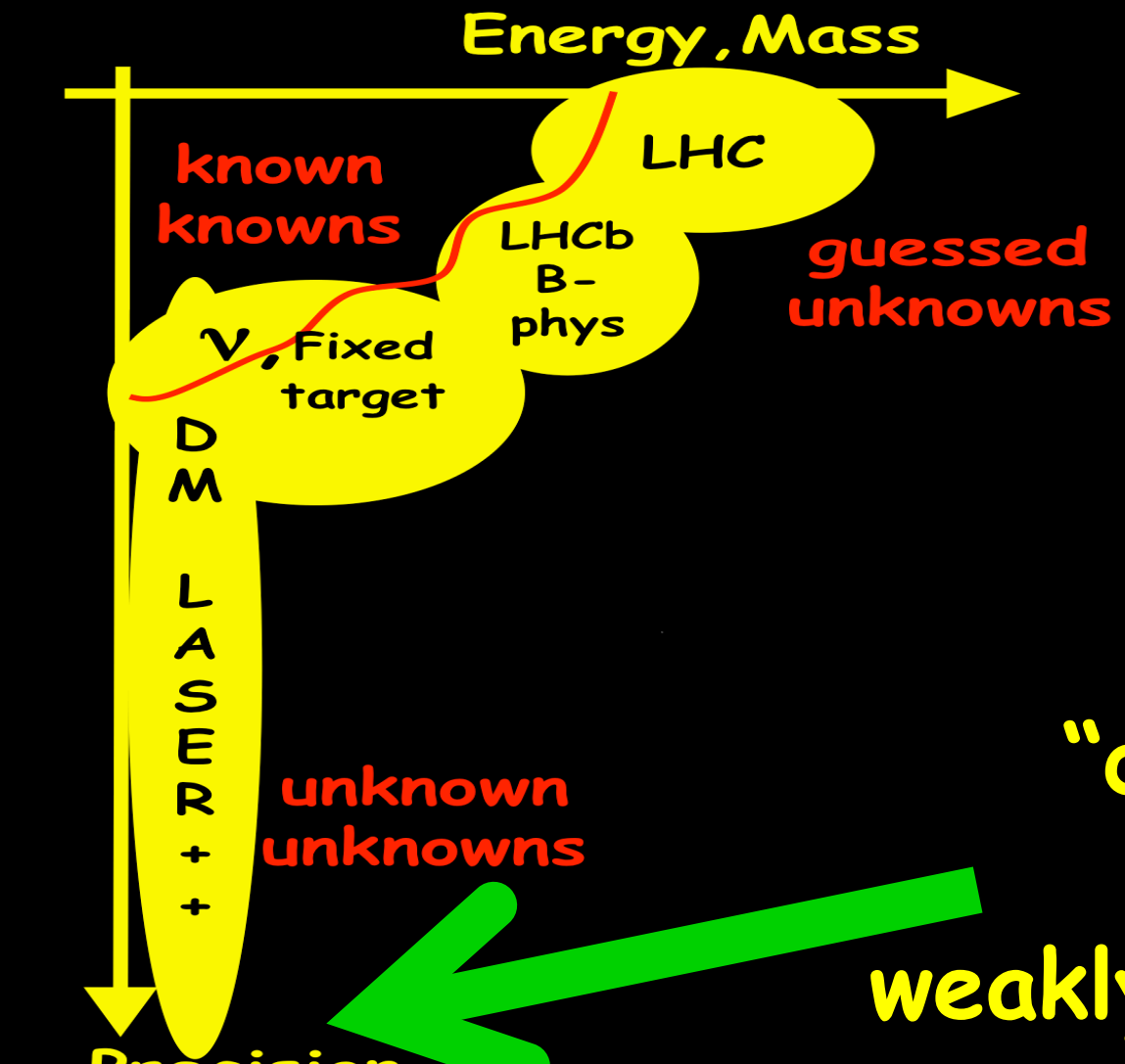


"dark"
=
weakly coupled

A „visible“ Hint for new Physics

The strong CP Problem

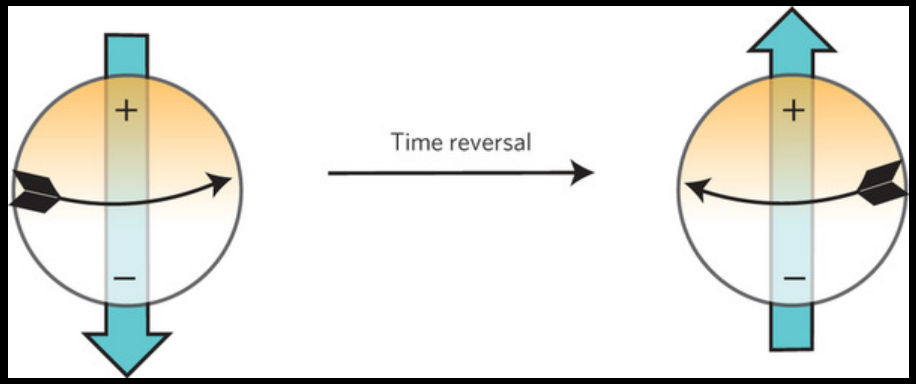
A dirty little secret...

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

$$\text{“} \sim \theta \vec{E} \cdot \vec{B} \text{”}$$

- The θ-term violates time reversal (T=CP)!
- Connected to strong interactions!

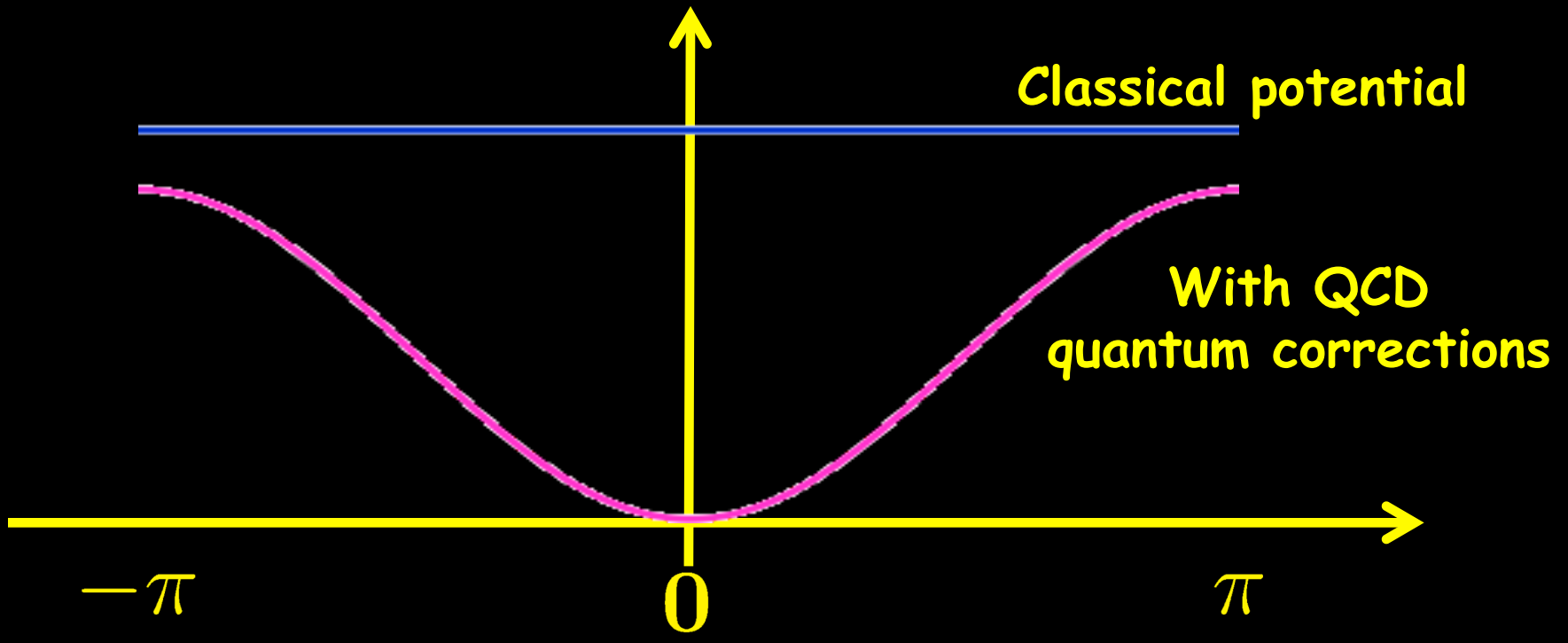
➡ **Electric dipole moment of the neutron!**



Not found ➔ θ~0!!!

The axion solution to the strong CP problem

- Make θ dynamical ➔ it can change its value



The axion solution to the strong CP problem

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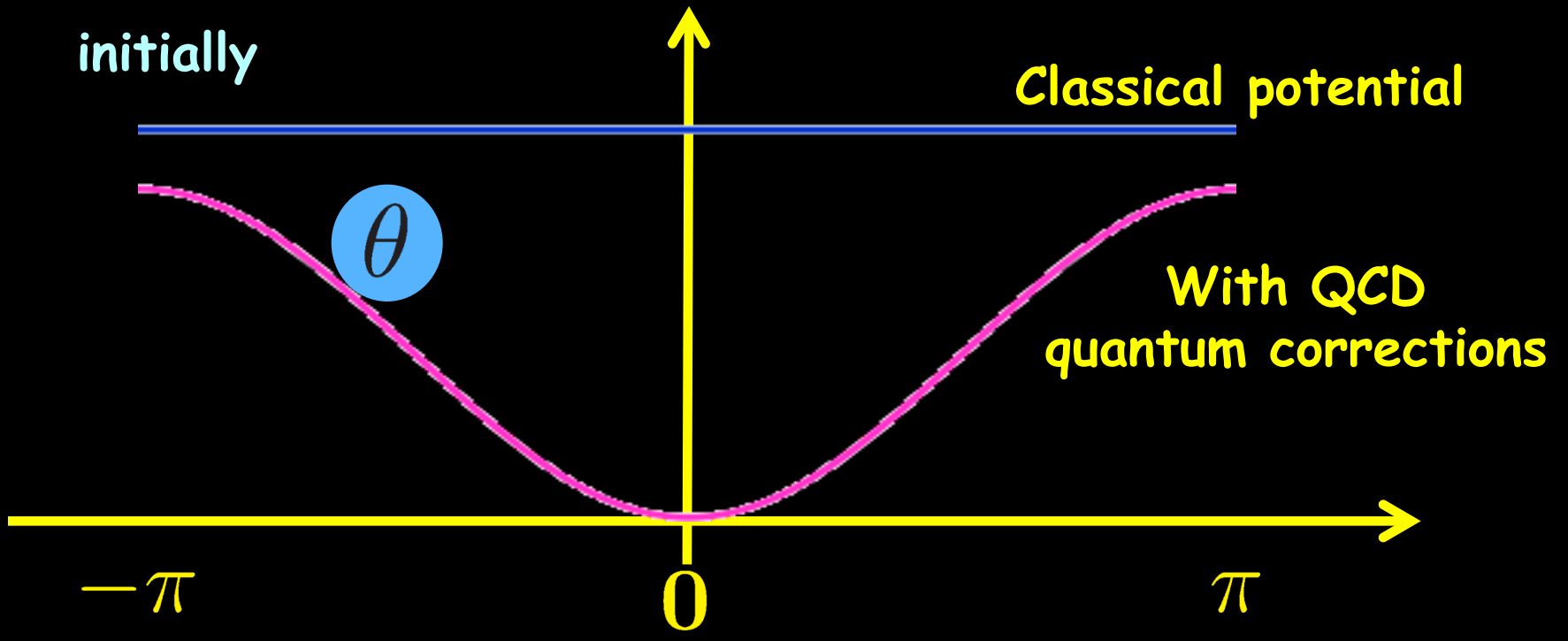

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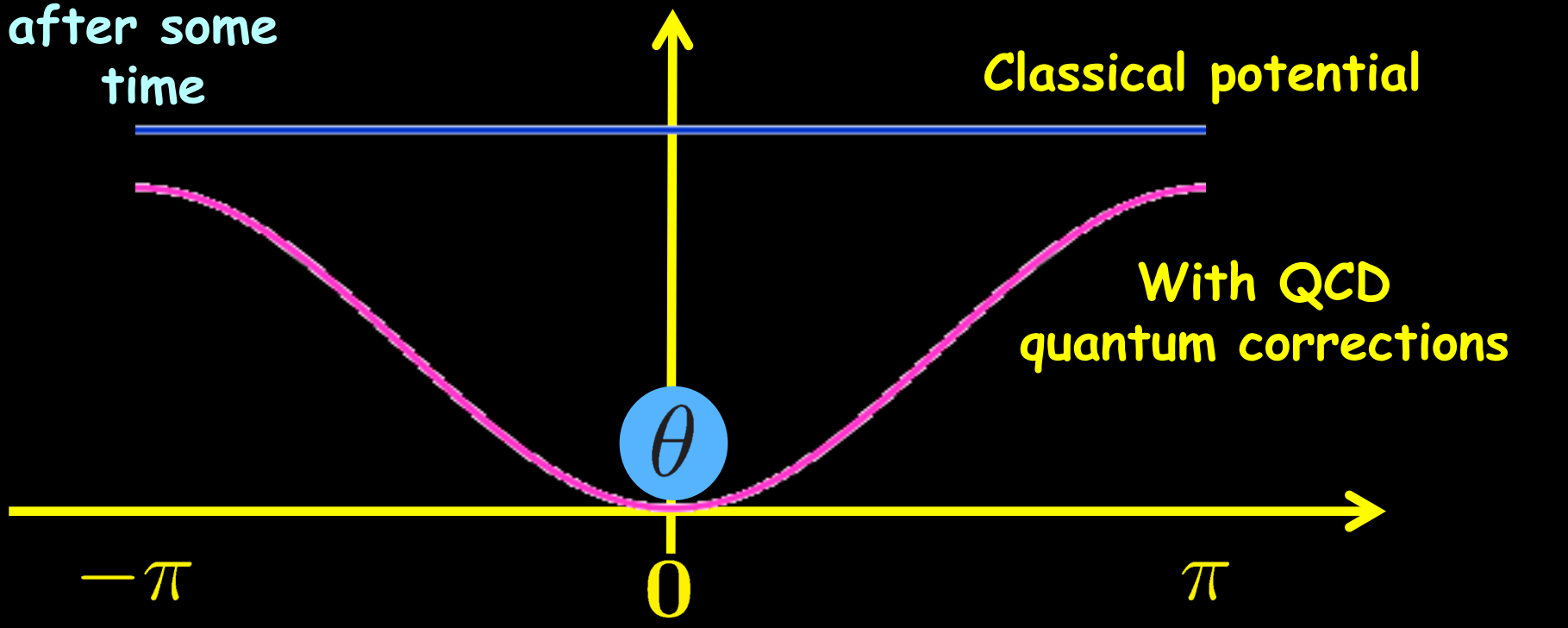
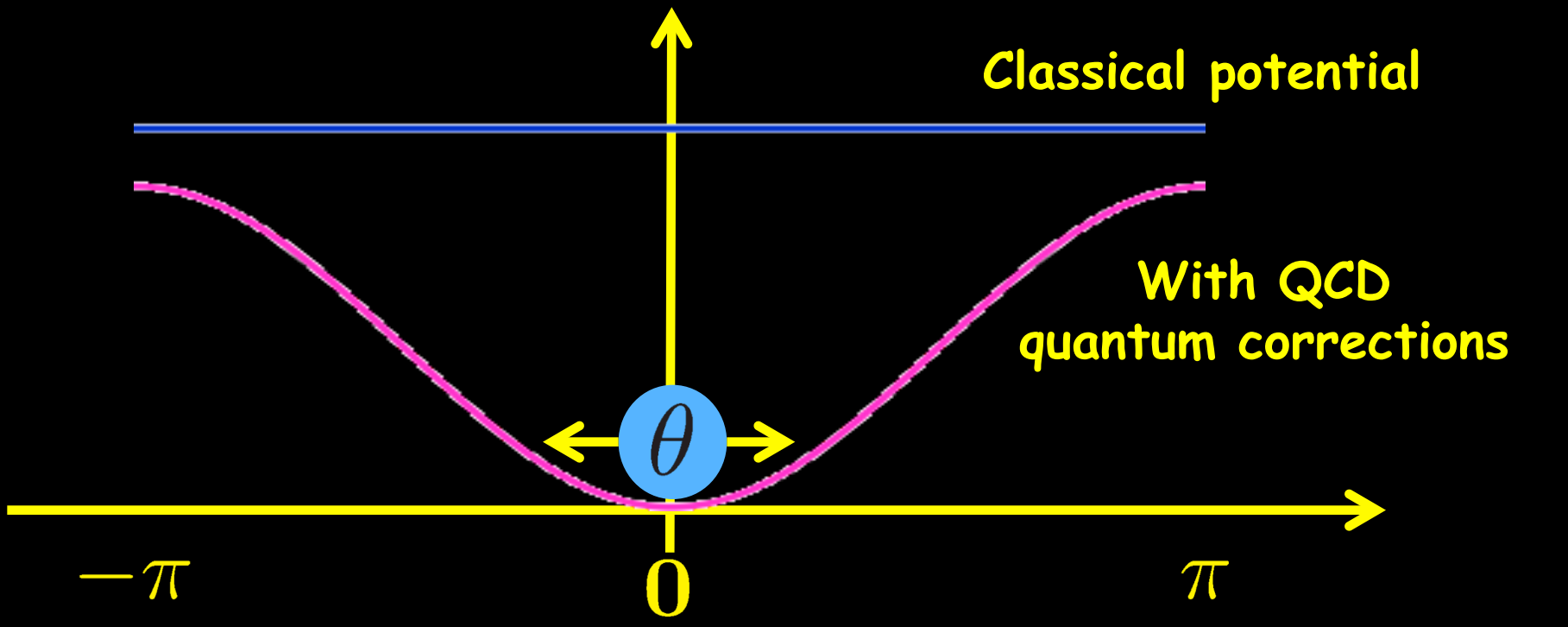


➔ QCD likes to be CP conserving (if we allow it)

The axion solution to the strong CP problem

- Make θ dynamical ➔ it can change its value

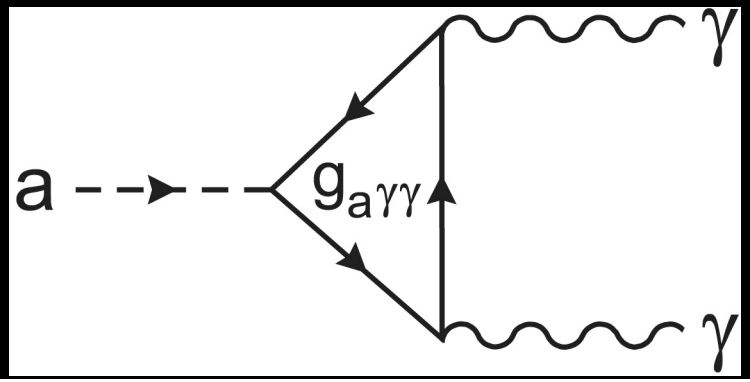


➔ Can still move

➔ new particle = axion

Phenoslides

Axion couples to two photons

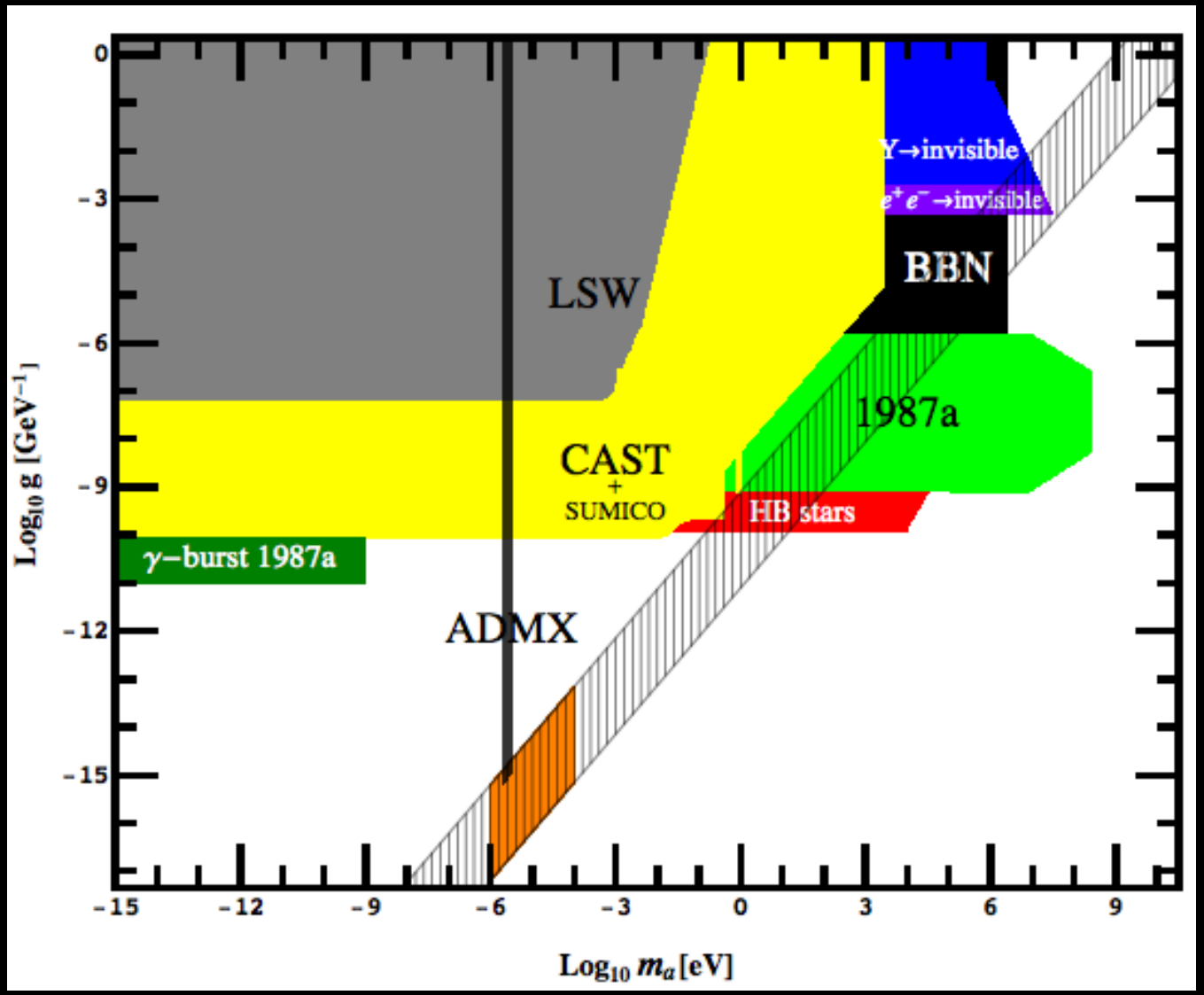


$$\mathcal{L}_{\rm int} - \frac{1}{4} g a F^{\mu\nu} \tilde{F}_{\mu\nu} + \ldots$$

small ⟶ $g \sim \dfrac{\alpha}{2\pi f_a}$ ⟵ large

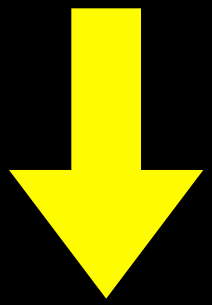
➔ Look for very weak interactions!

Axions and ALPs=Axion-like Particles



„Proper“ Top-down Theory ;-).

High Scale



Small Coupling

Example: Axion coupling

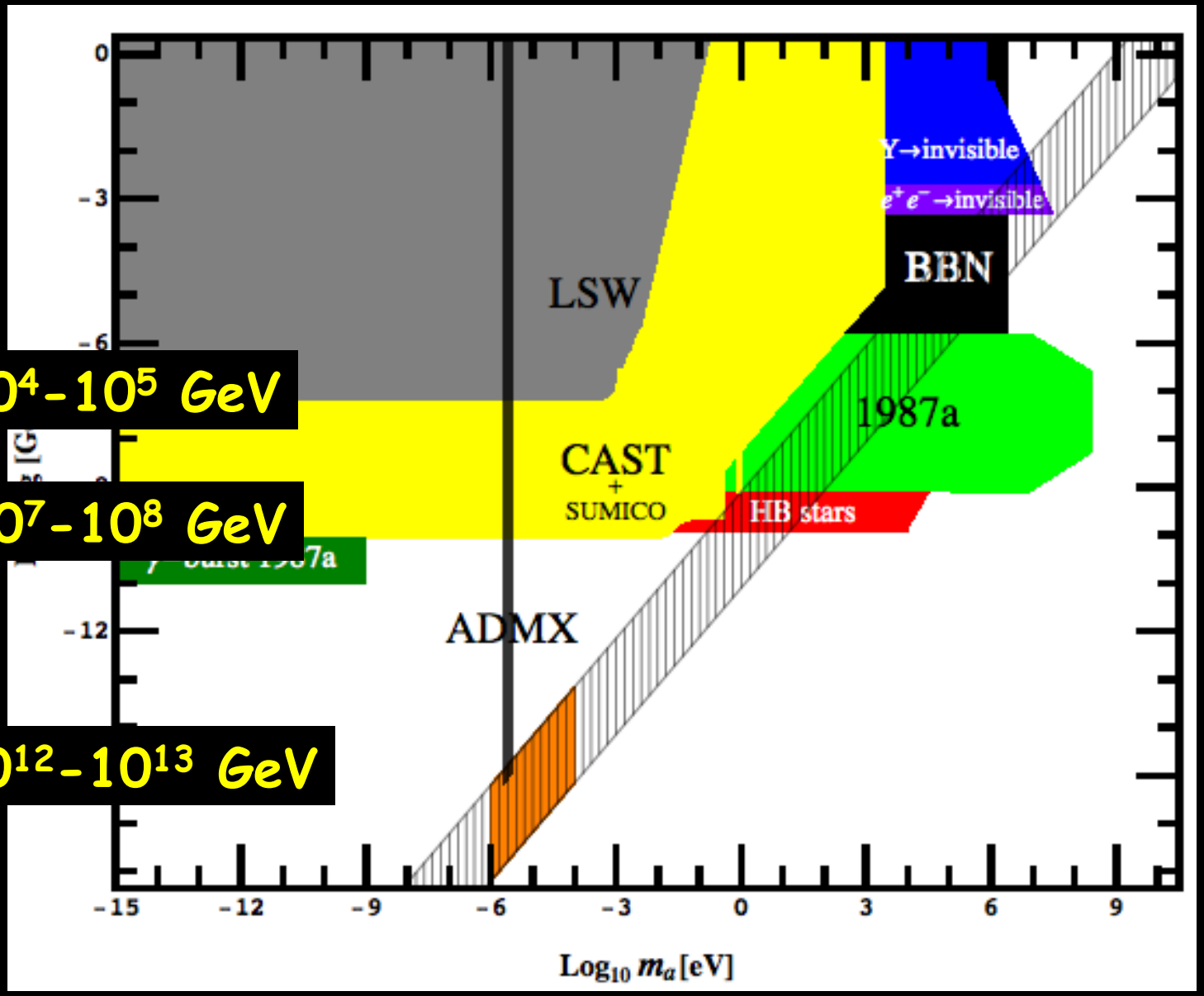
- Effective higher dimensional coupling

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

- Small coupling for large axion scale:

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

Huge Scale>> LHC Energy!

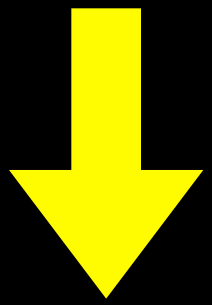


ca 10^4-10^5 GeV

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!

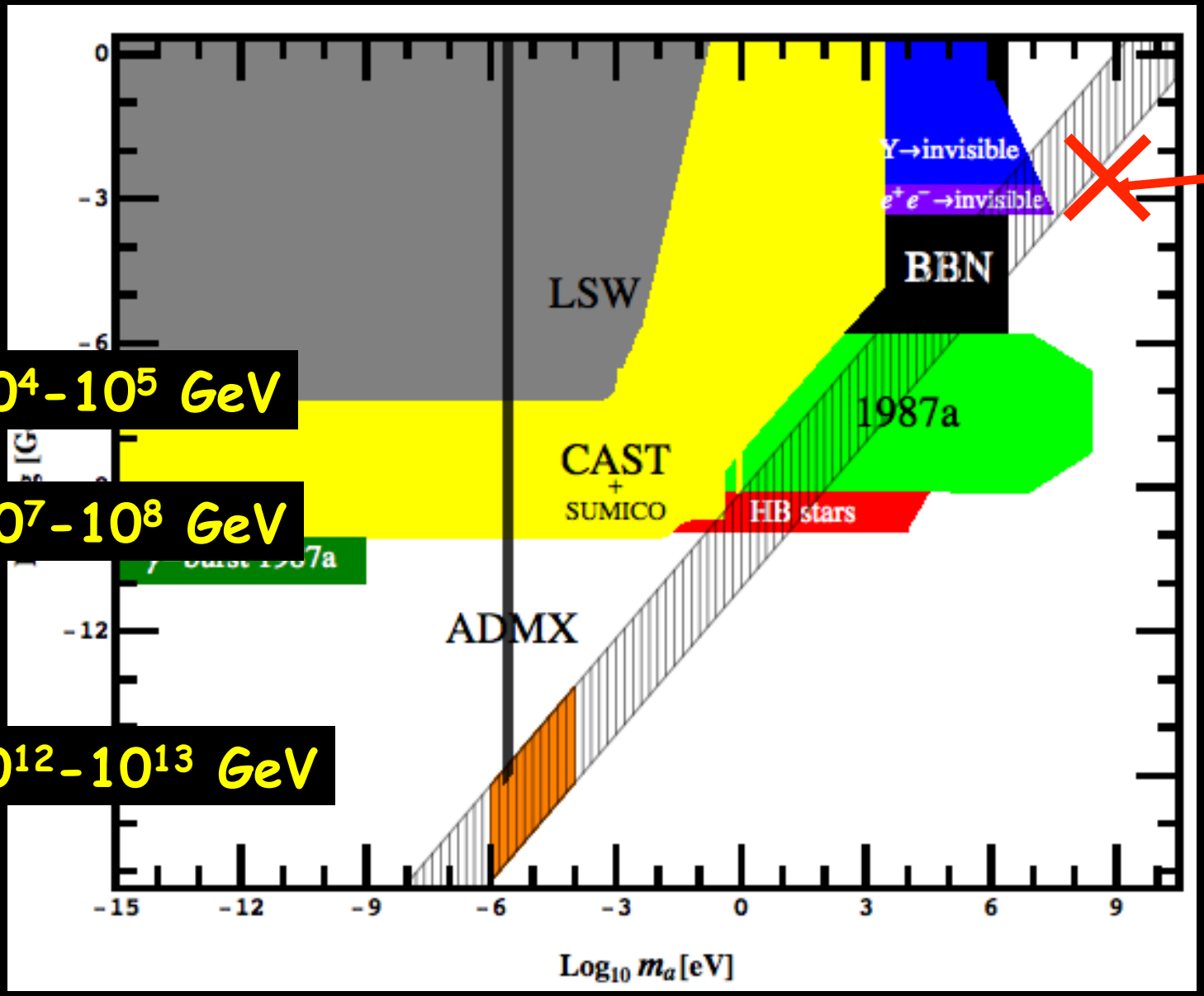
$$m_a \sim \frac{m_\pi f_\pi}{f_a}$$

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

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

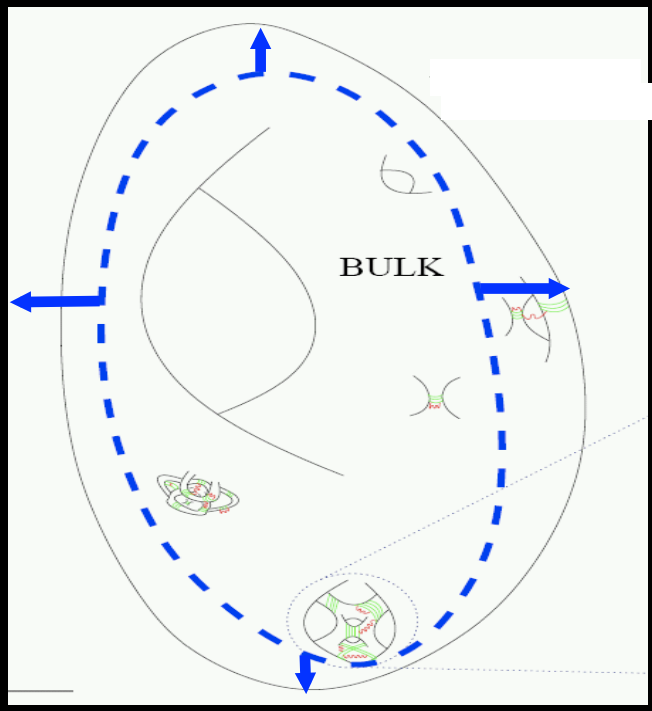
ALPs
from
String Theory

String theory: Moduli and Axions

- String theory needs Extra Dimensions

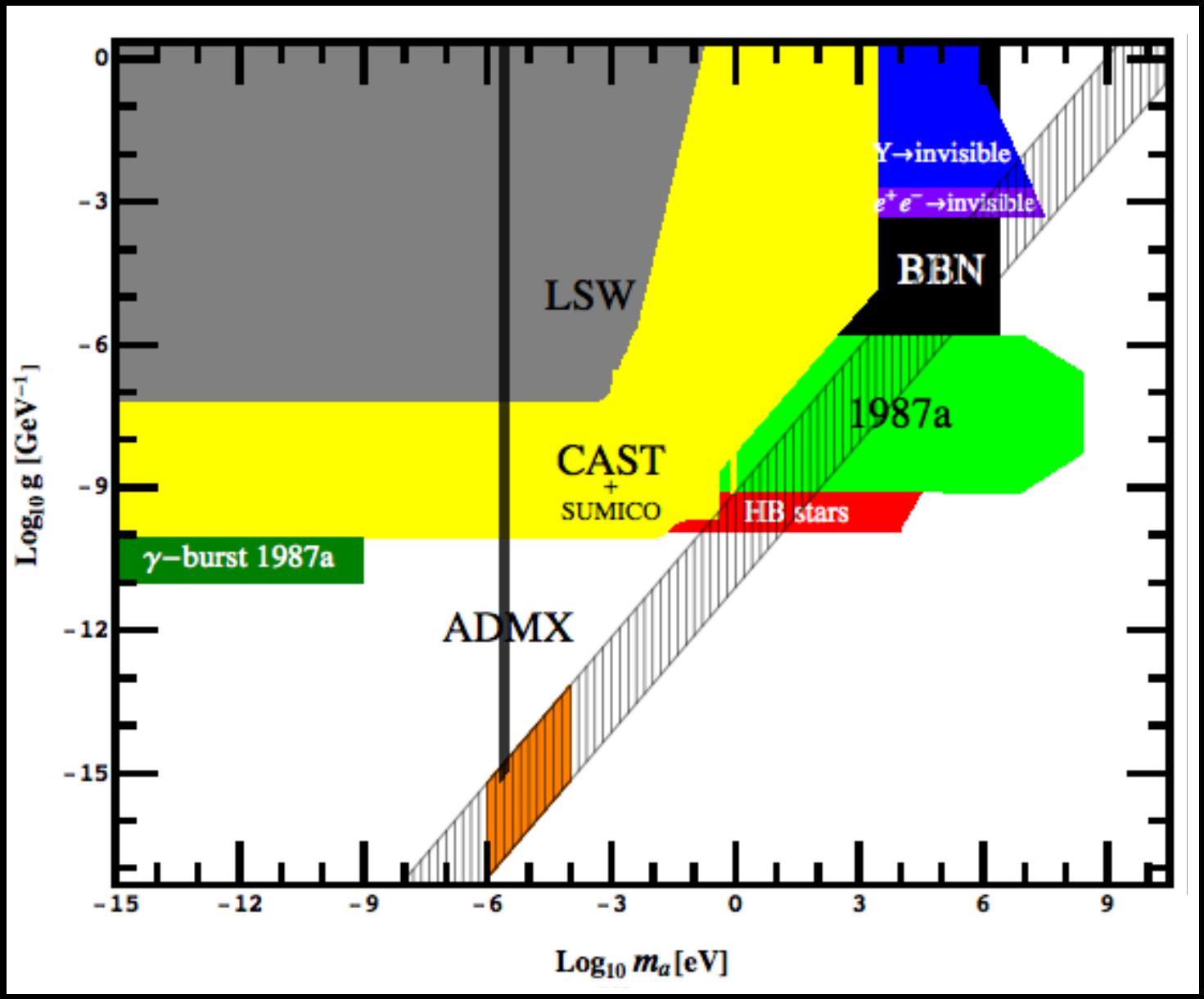
Must compactify

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

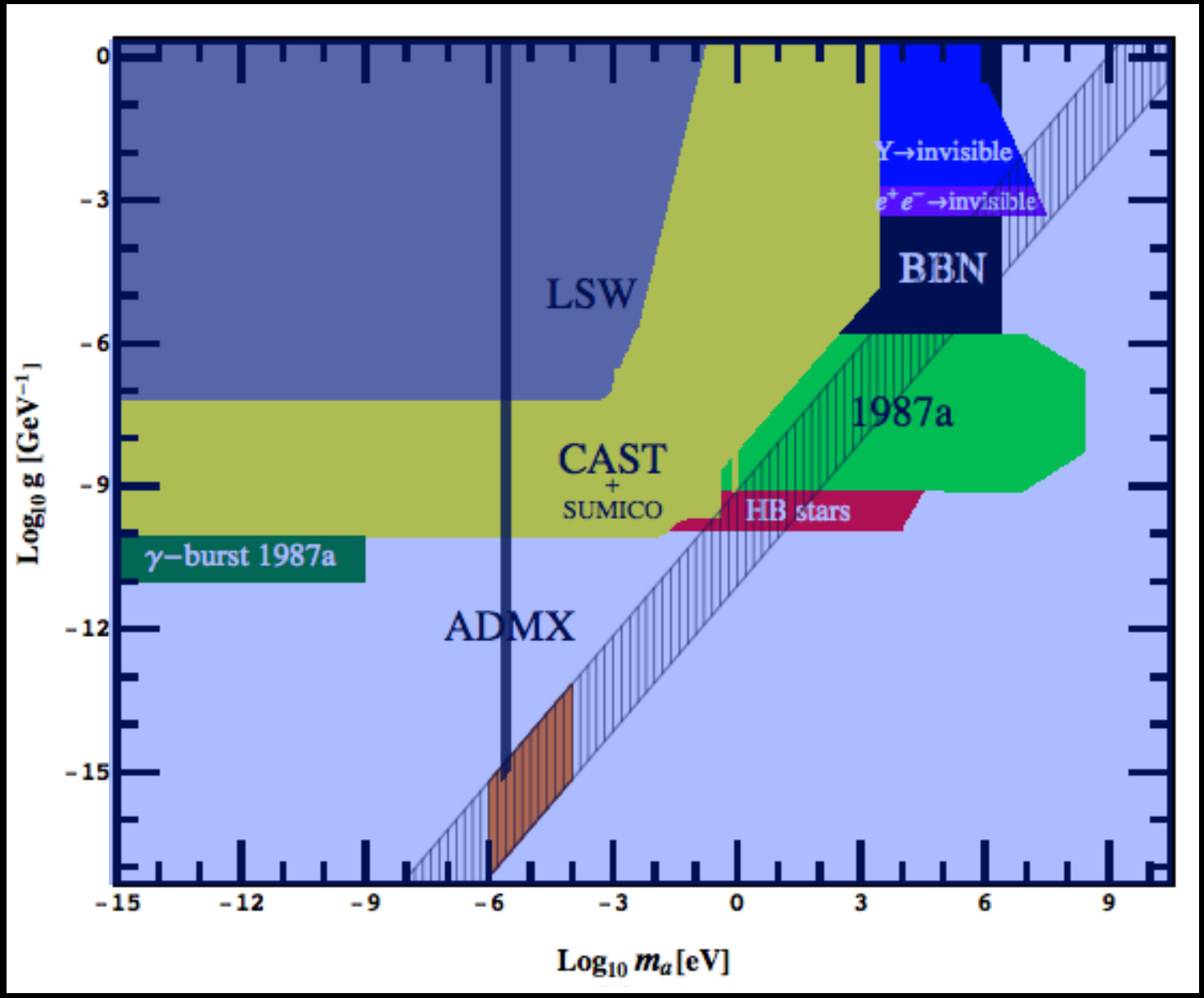


WISP candidates

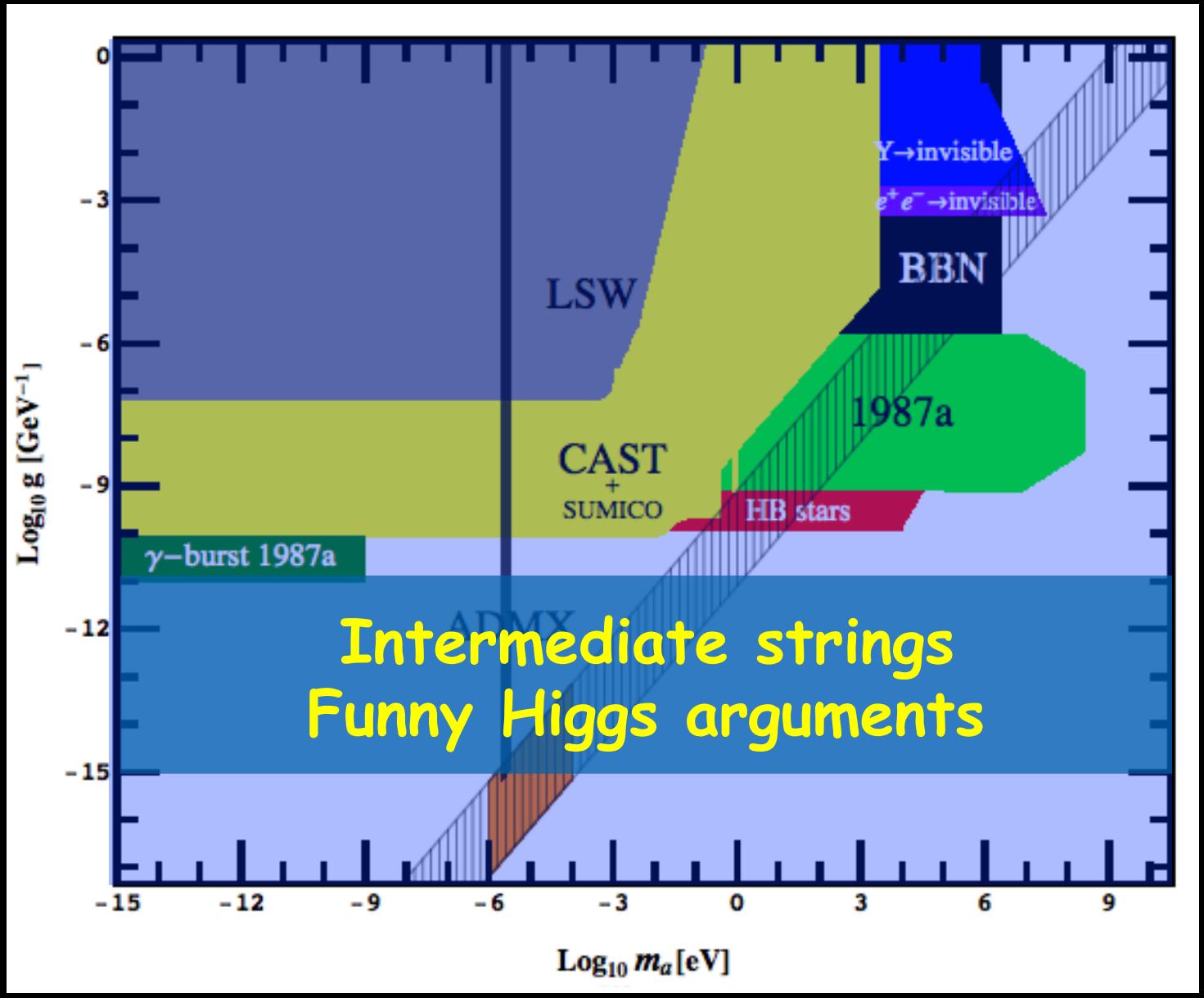
Axion (like particles): Where are we?



Axion (like particles): Where are we?

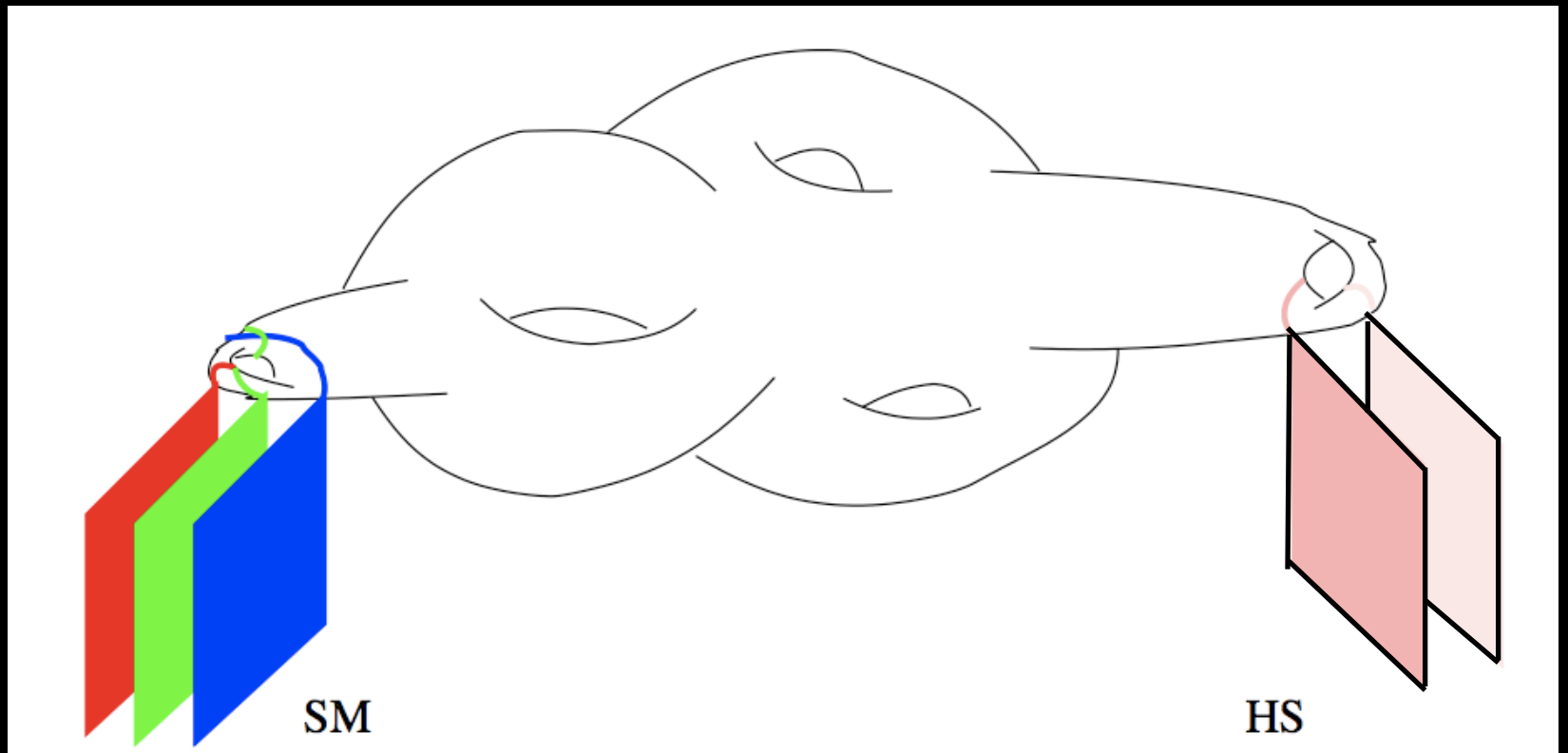


Axion (like particles): Where are we?



Hidden Photons

String theory likes extra gauge groups



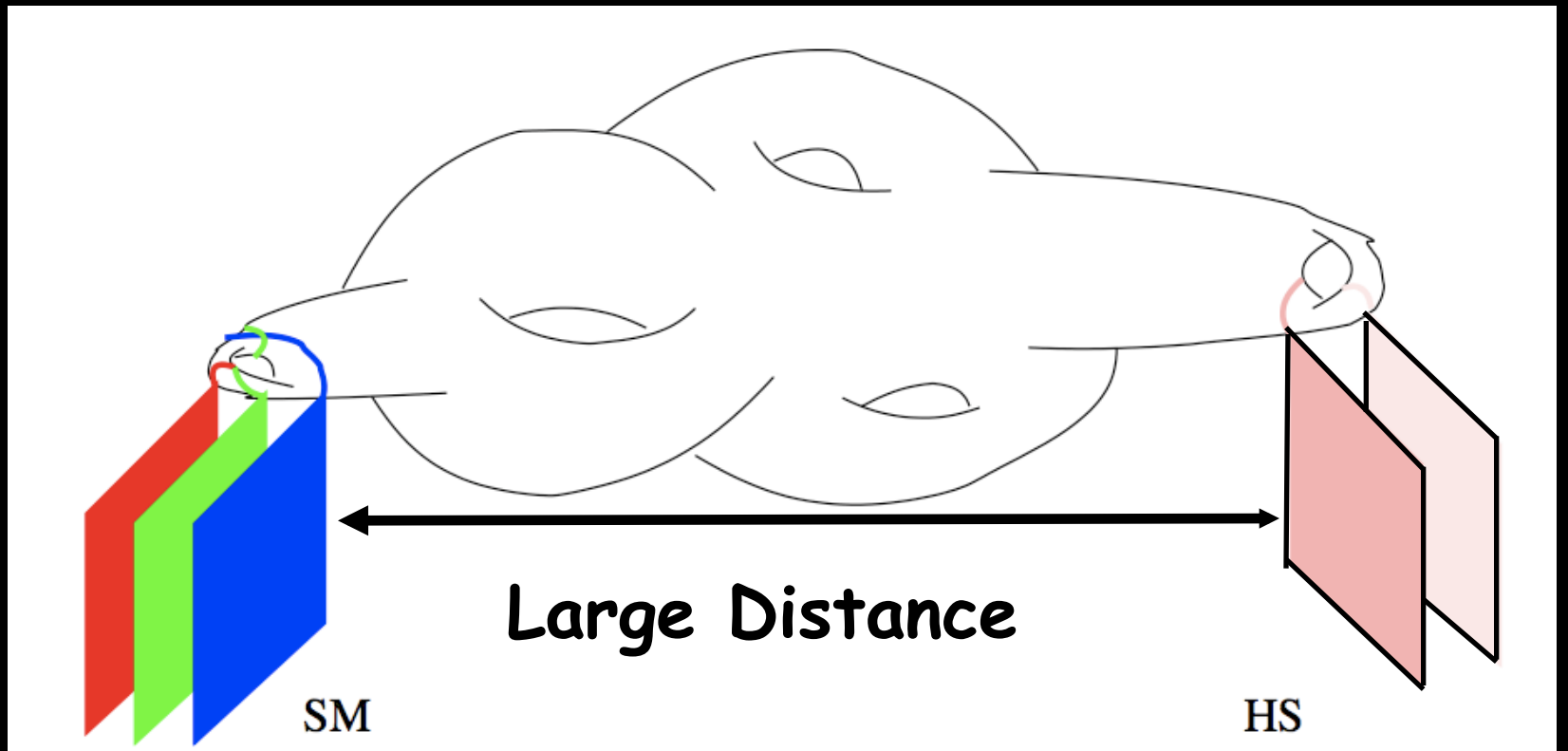
$U(A) \times U(B) \times U(C)$

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

➡ Many extra U(1)s!

➡ Candidates for WISPs

Hidden by distance



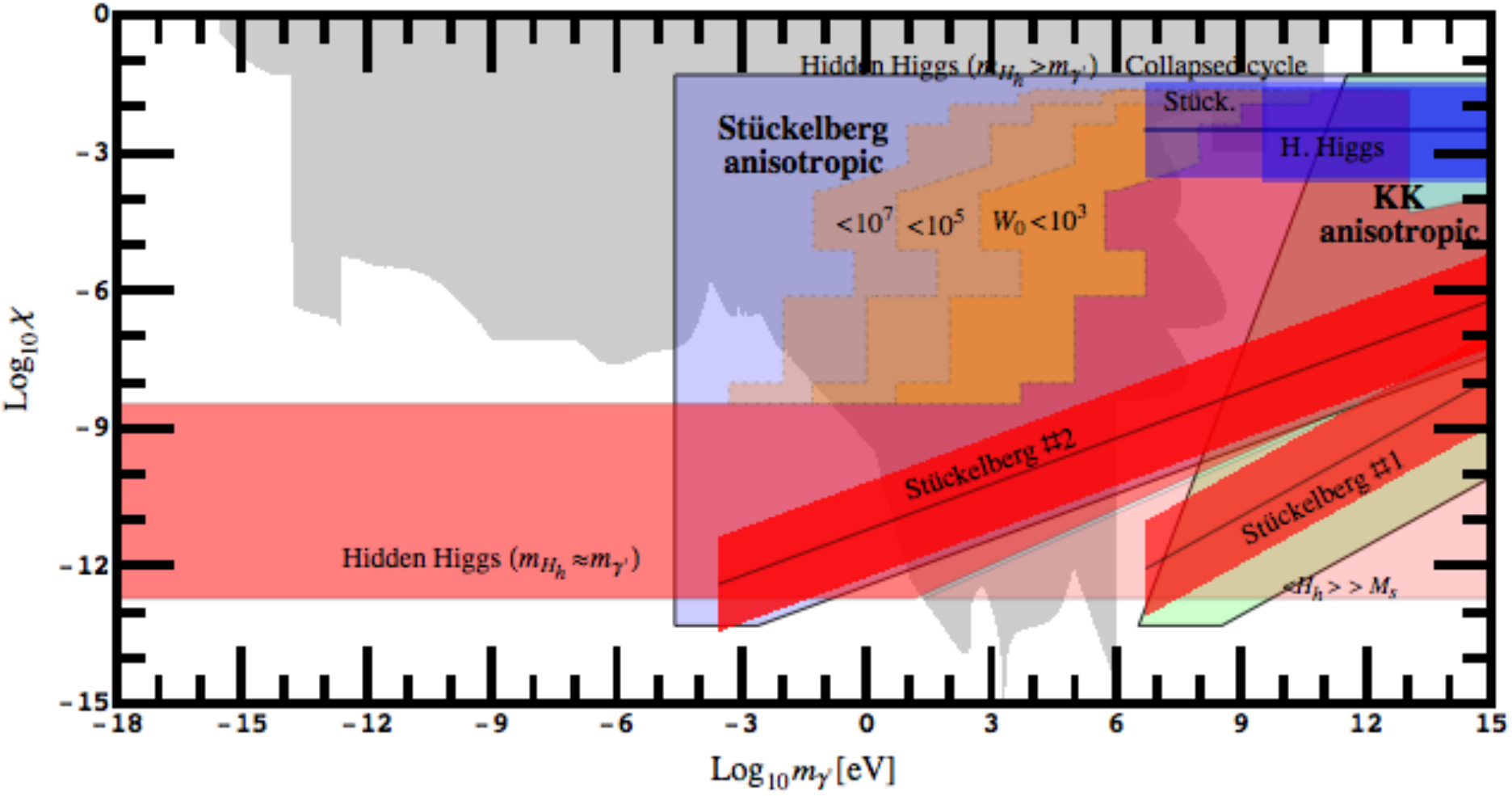
$U(A) \times U(B) \times U(C)$

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

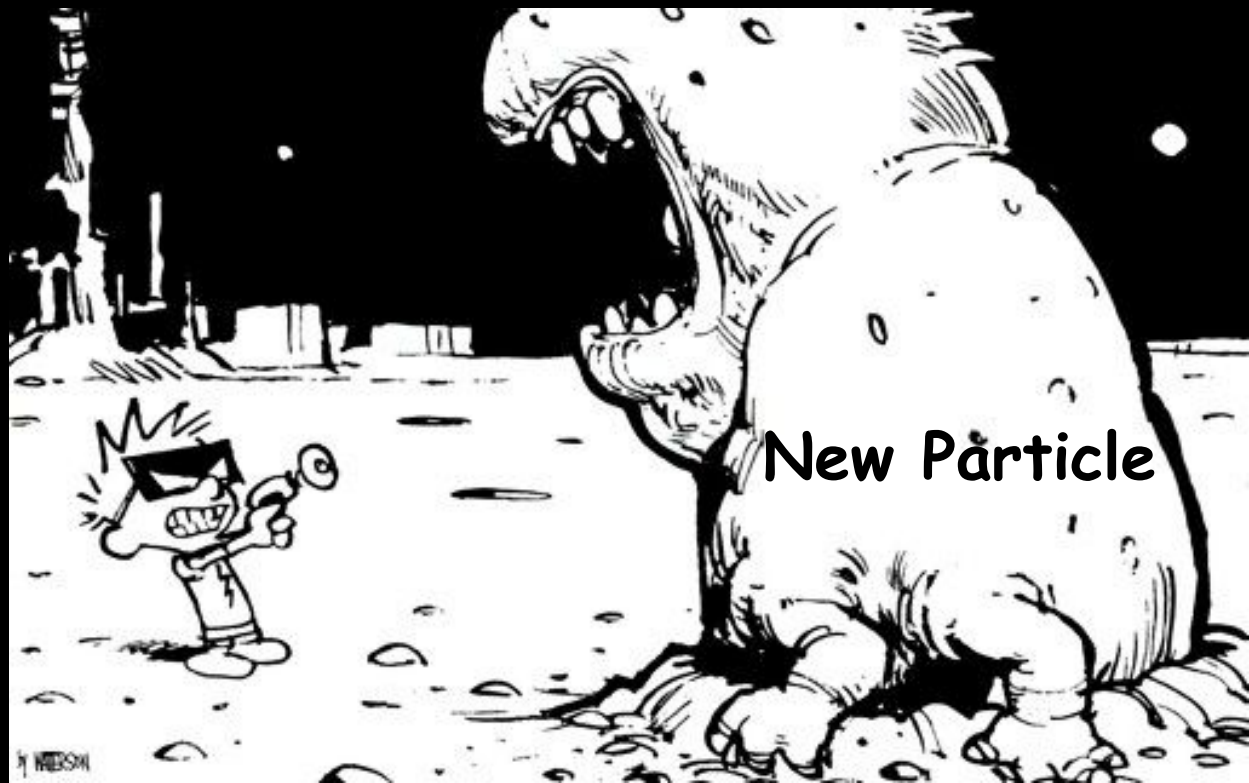
$$\chi \sim \frac{g_s}{8\pi} \frac{1}{Volume^x}$$

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

Hidden Photons, all over the place



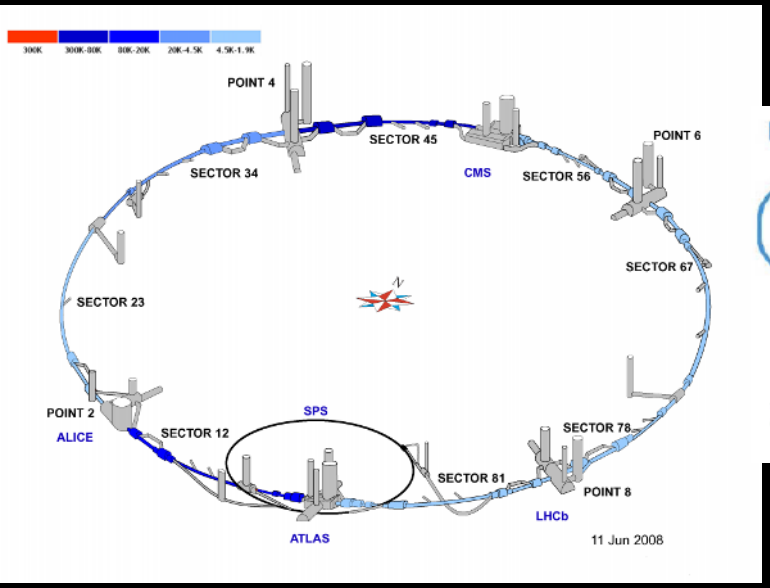
Experimental Tests

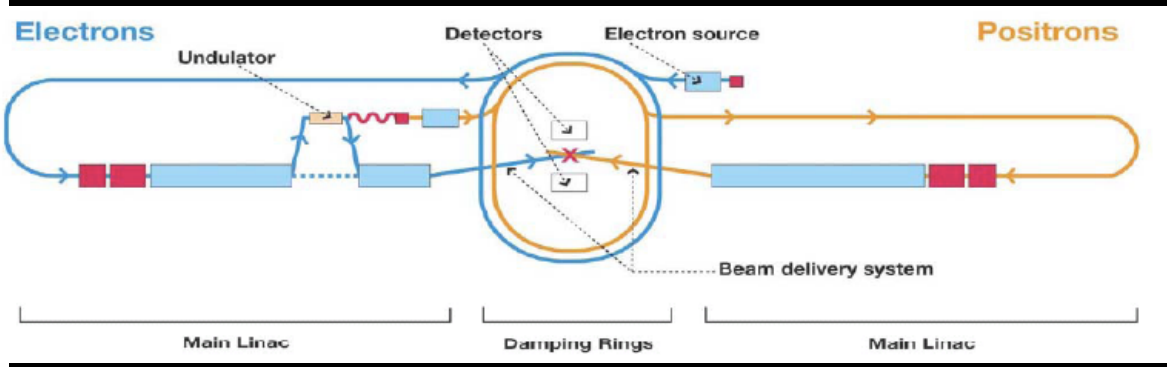


Exploring fundamental high energy physics…

- 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, Hidden Photons, WIMPs, WISPs…)
- Current maximal energy few TeV

But…

- May miss very weakly interacting matter
  Hidden photons, Axions, ALPs, WIMPs, WISPs…
- Current maximal energy few TeV

- Man its DANGEROUS…

But…

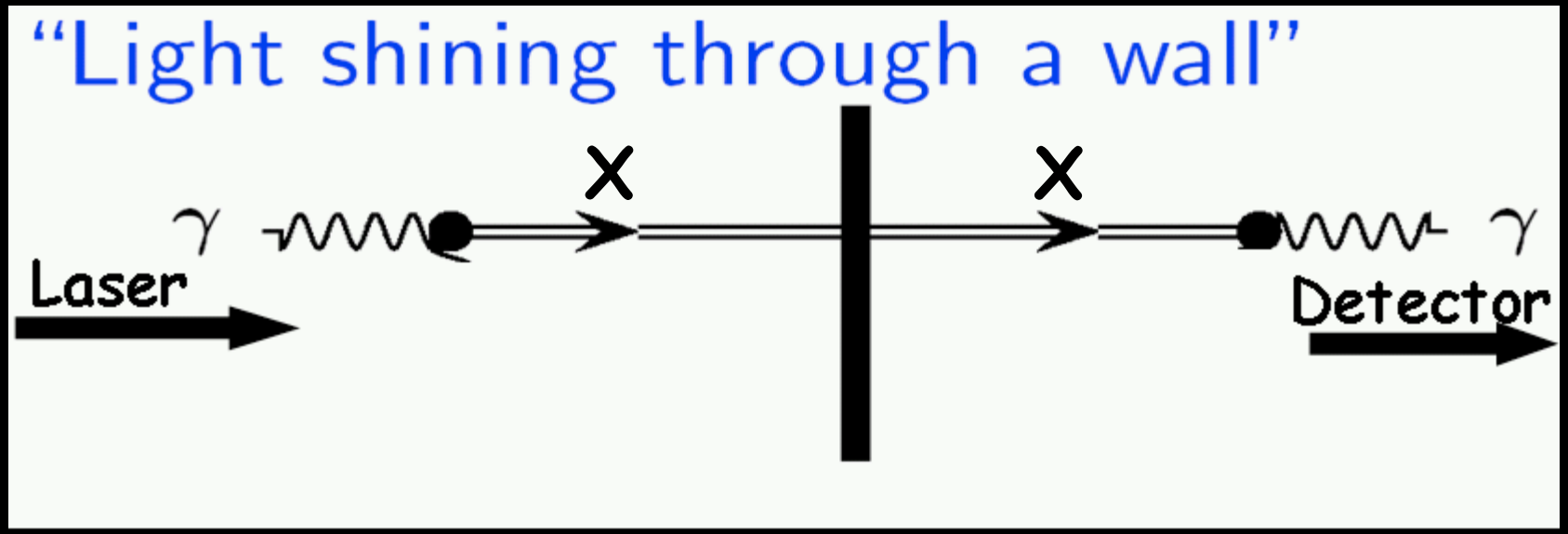
- May miss very weakly interacting matter: Hidden photons, Axions, ALPs, WIMPs, WISPs…
- Current maximal energy few TeV

- Or much much more horrifying:

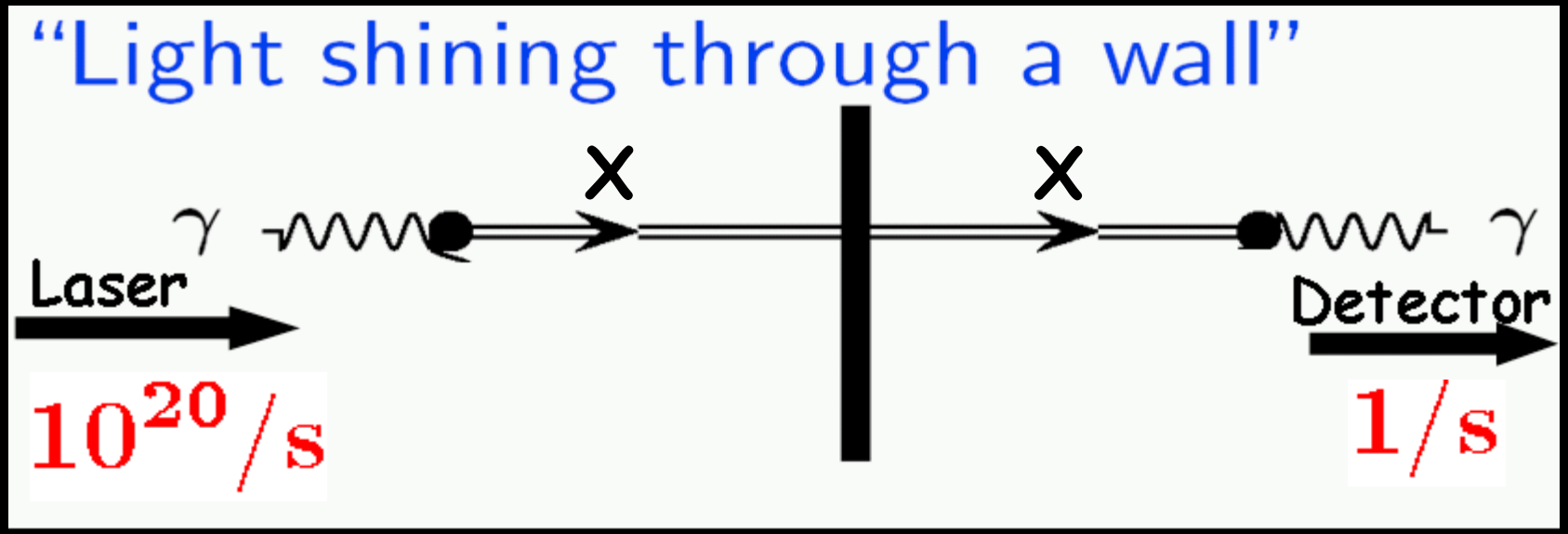
NO SIGNAL ABOVE BACKGROUND!

Complementary approaches

Light shining through walls



Light shining through walls

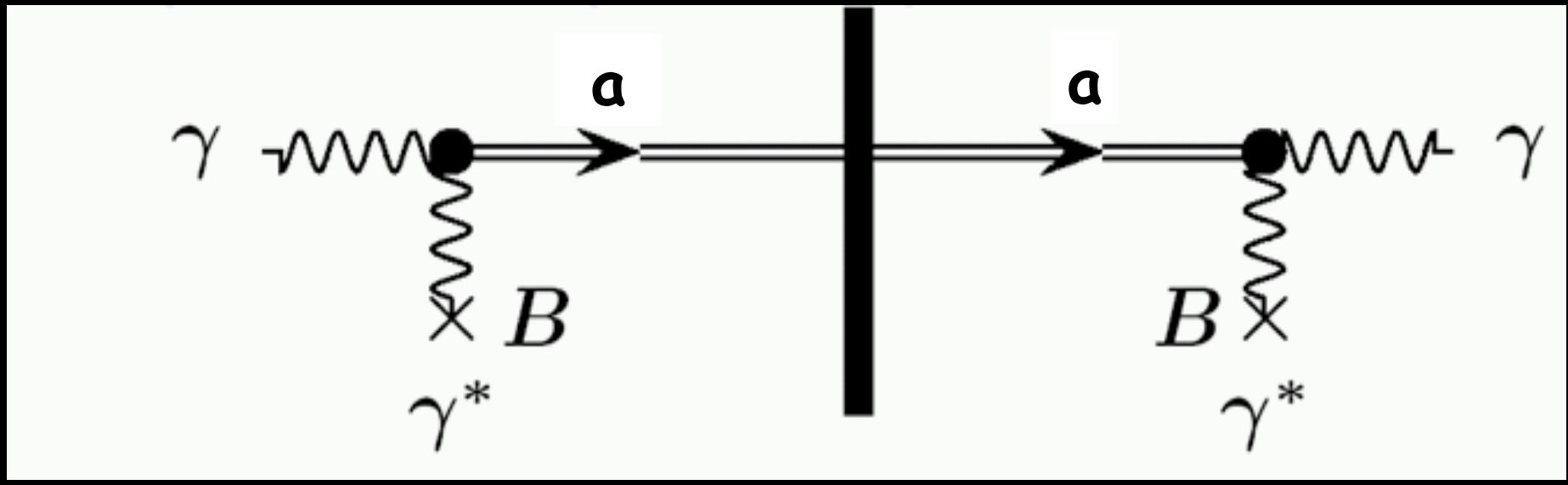


- Test $P_{\gamma \to X \to \gamma} \lesssim 10^{-20}$

- Enormous precision!
- Study extremely weak couplings!

Photons coming through the wall!

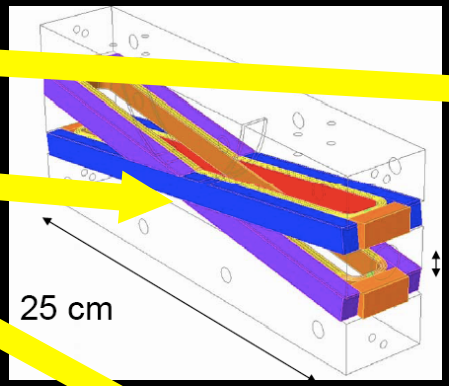
- It could be Axion(-like particle)s!
- Coupling to two photons: $\frac{1}{M} a \tilde{F} F \sim \frac{1}{M} a \vec{\mathbf{E}} \cdot \vec{\mathbf{B}}$

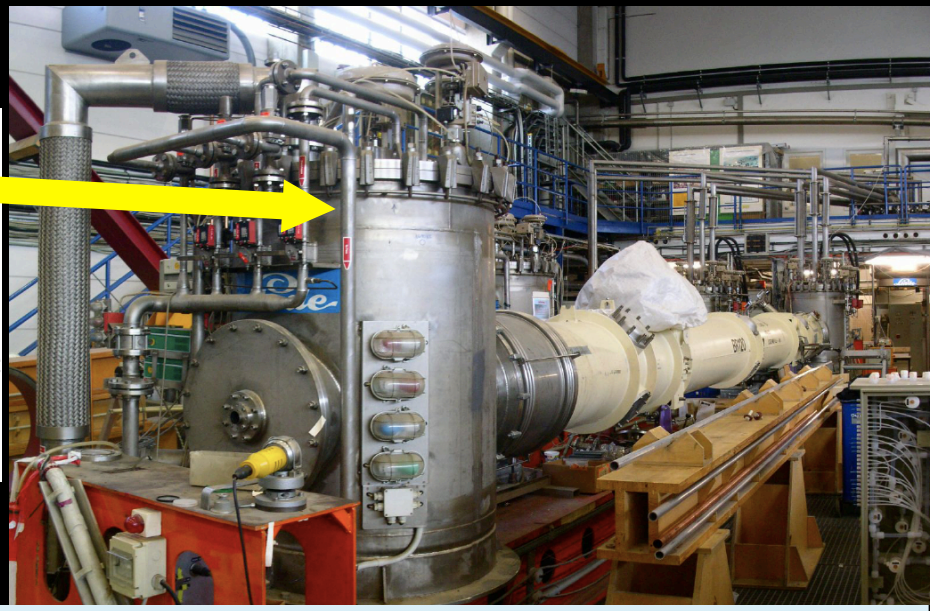


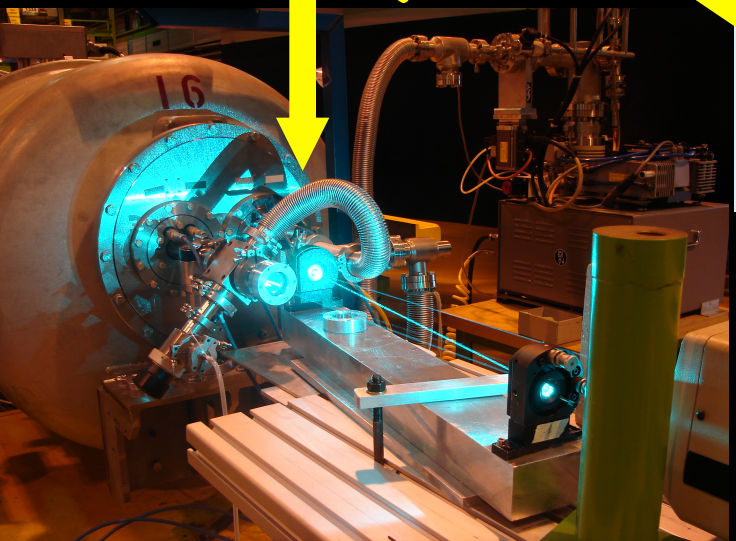
$$P_{\gamma \to a \to \gamma} \sim N_{\mathrm{pass}} \left(\frac{BL}{M} \right)^4$$

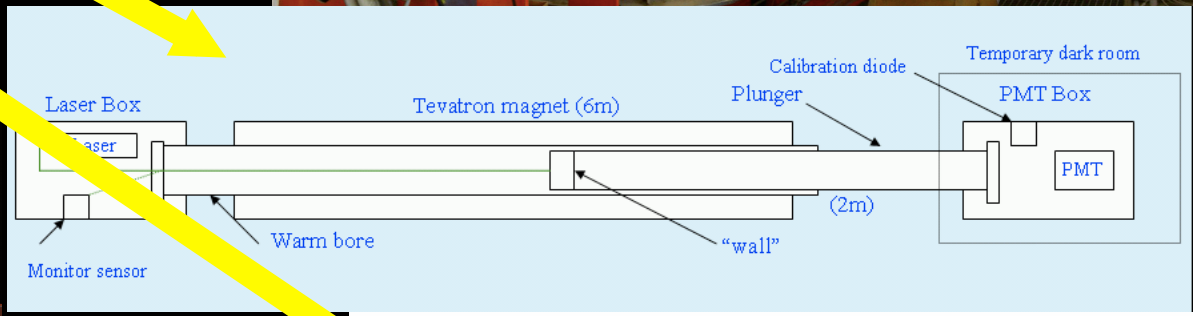
Light Shining Through Walls

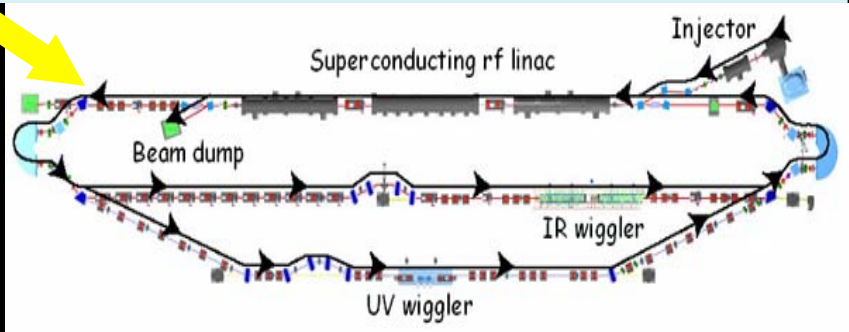
- A lot of activity
  - ALPS
  - BMV
  - GammeV
  - LIPPS
  - OSQAR







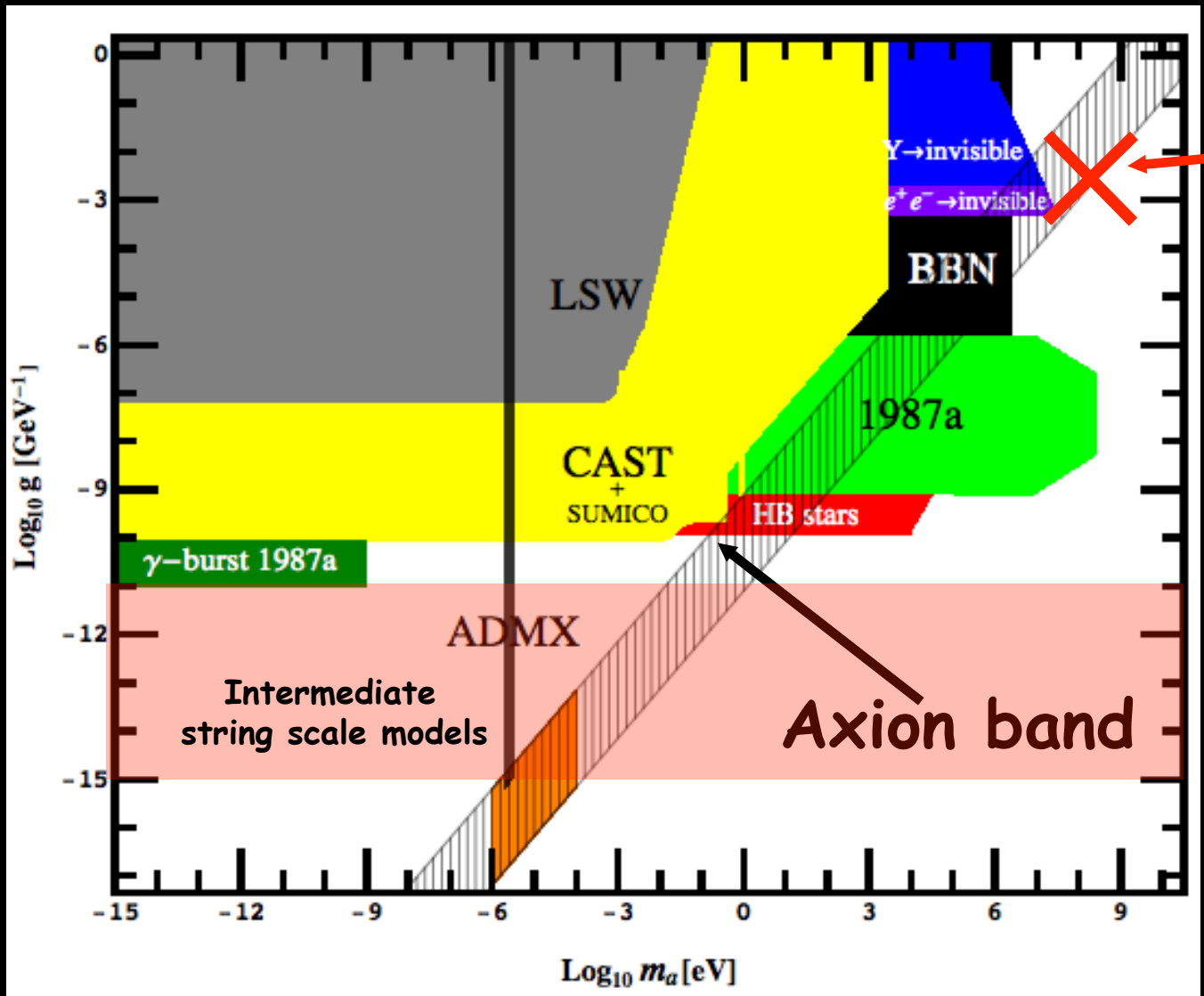




Small coupling, small mass

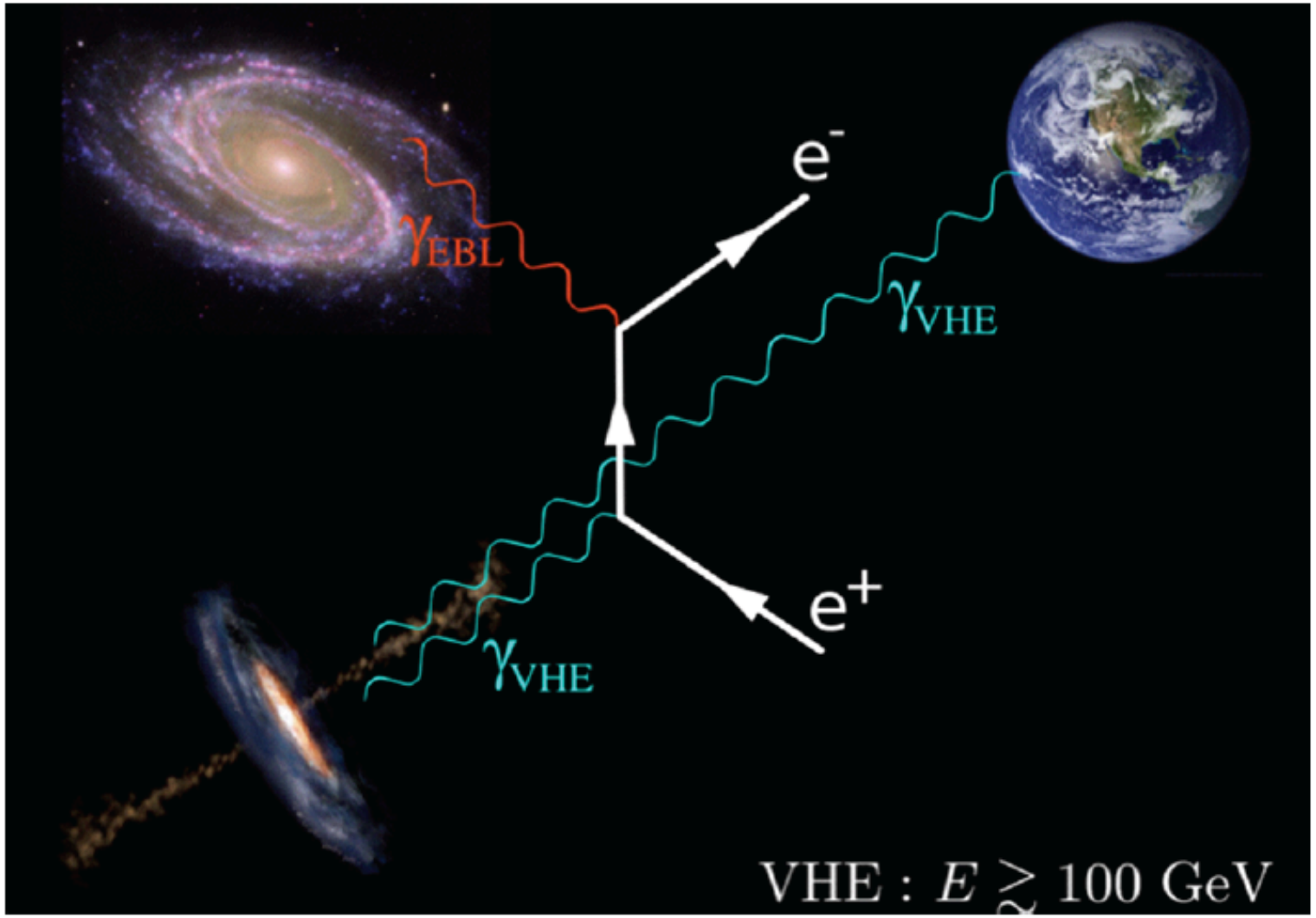
mass/energy

Weaker interaction



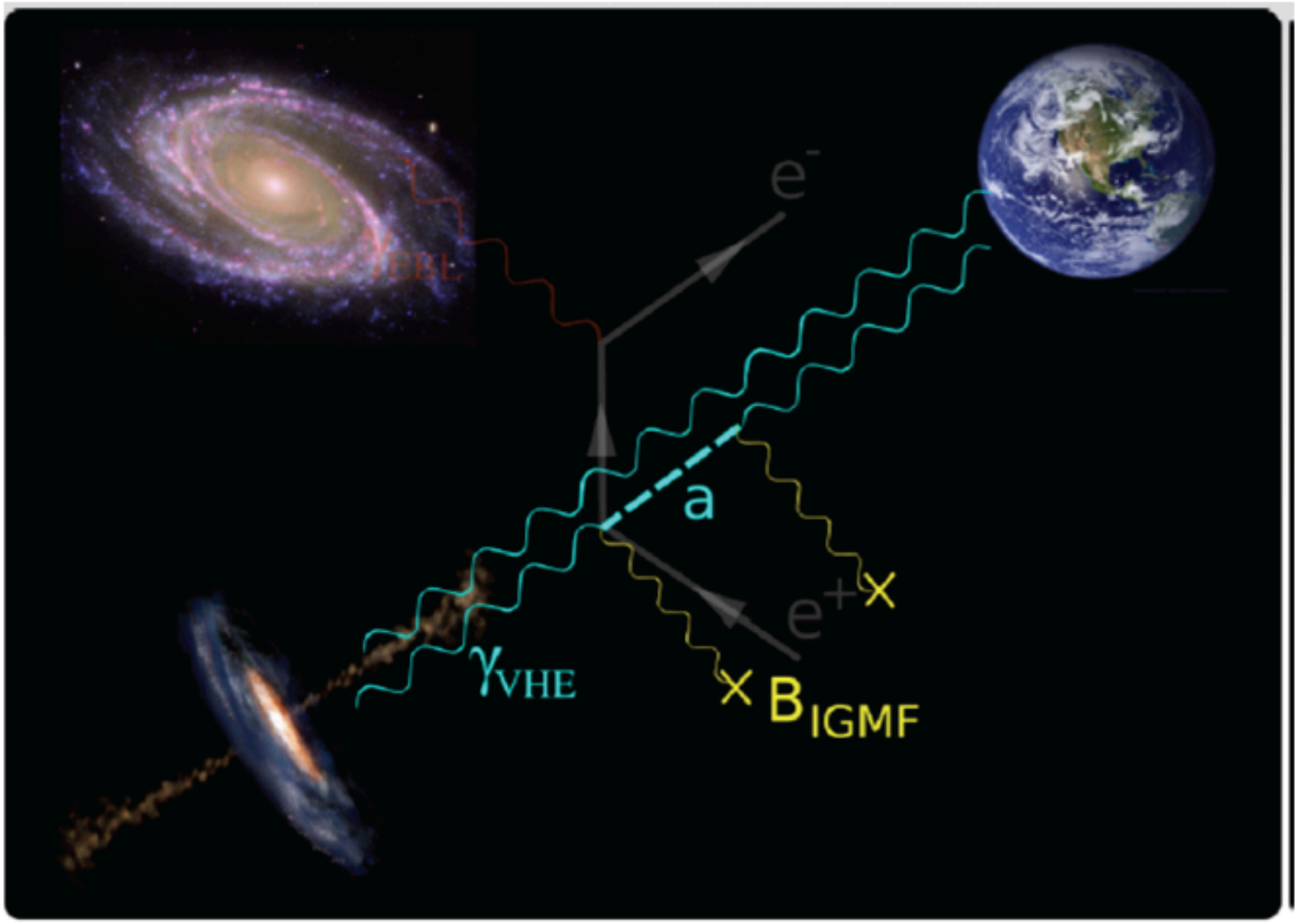
A cosmic hint for ALPs

High energy cosmic rays get absorbed



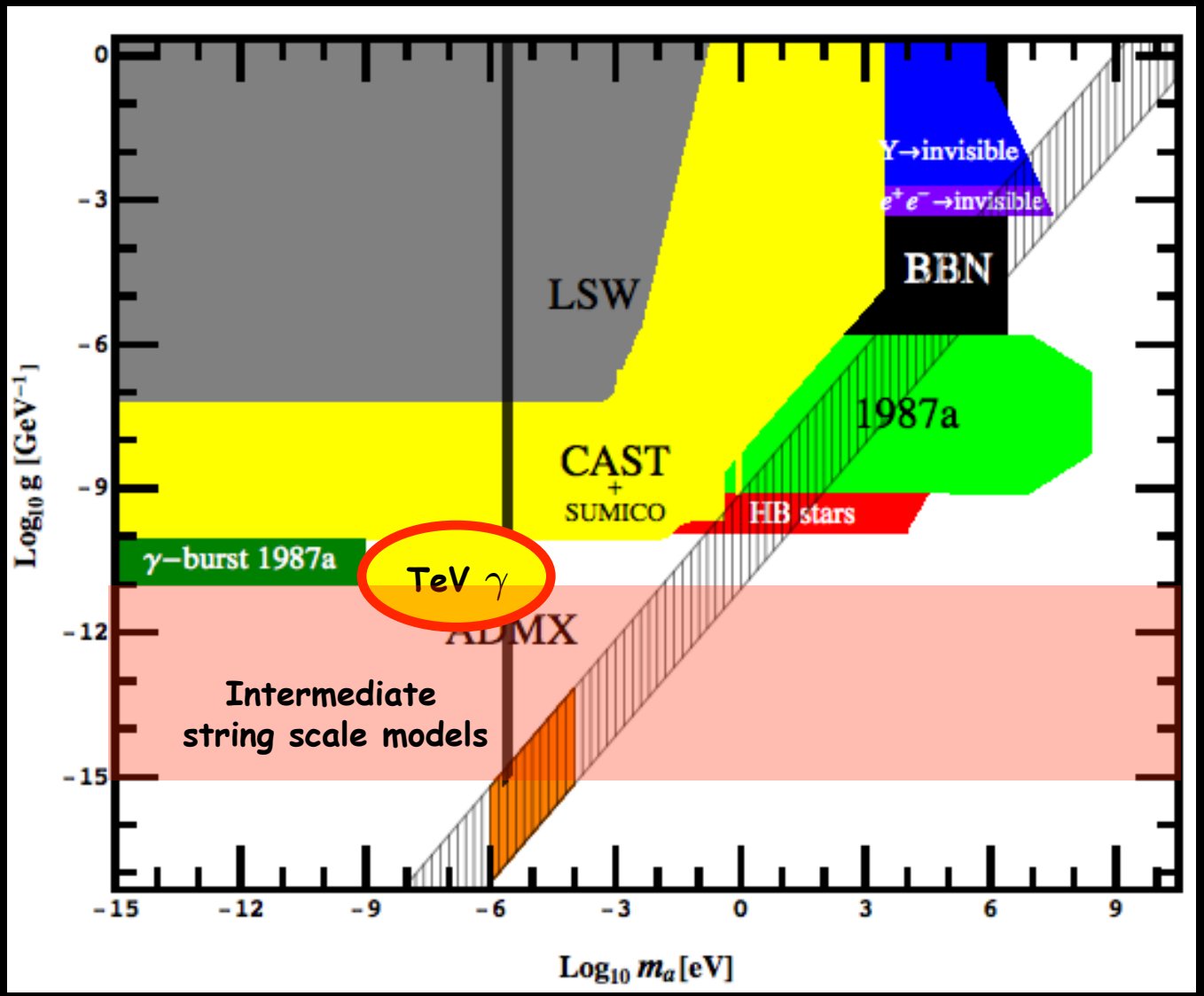
[Manuel Meyer 12]

Cosmic Light-shining-through-walls

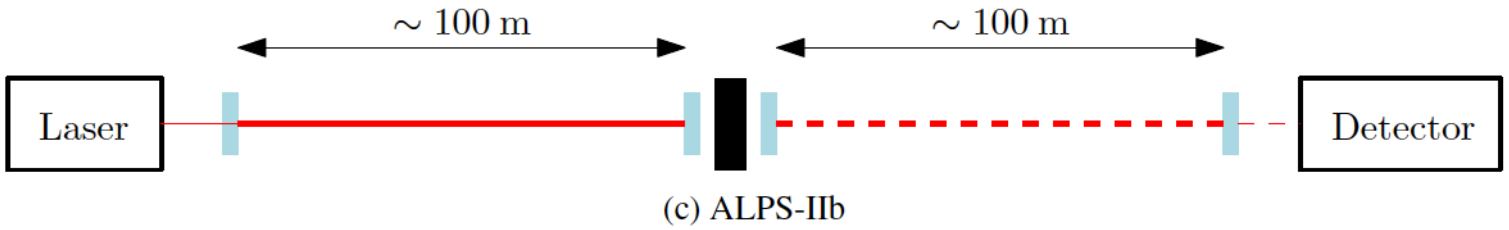


[Manuel Meyer 12]

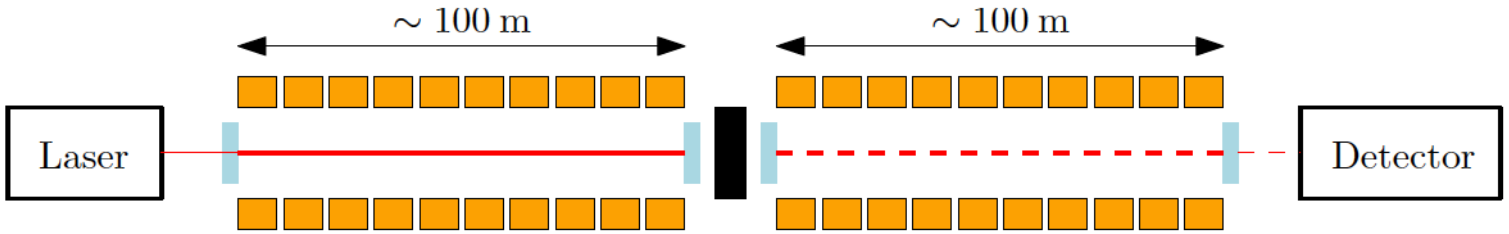
An interesting area…



The future ALPS-II @ DESY

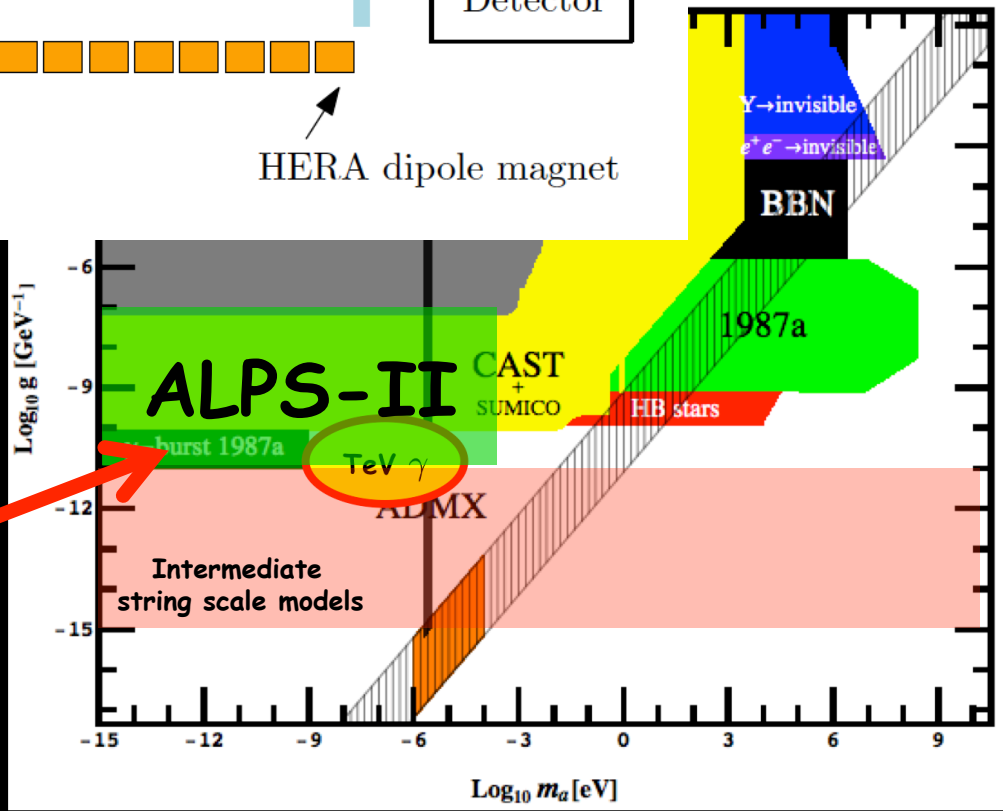


(c) ALPS-IIb



(d) ALPS-IIc

Test of
TeV transparency

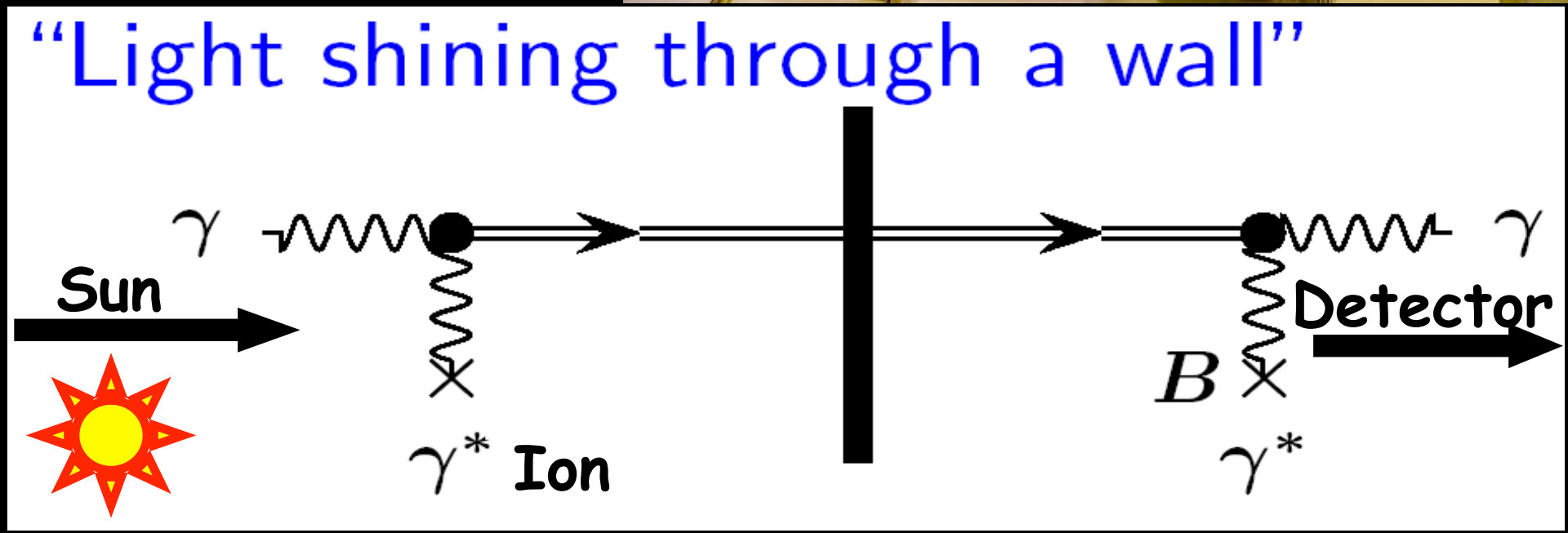


Going deeper

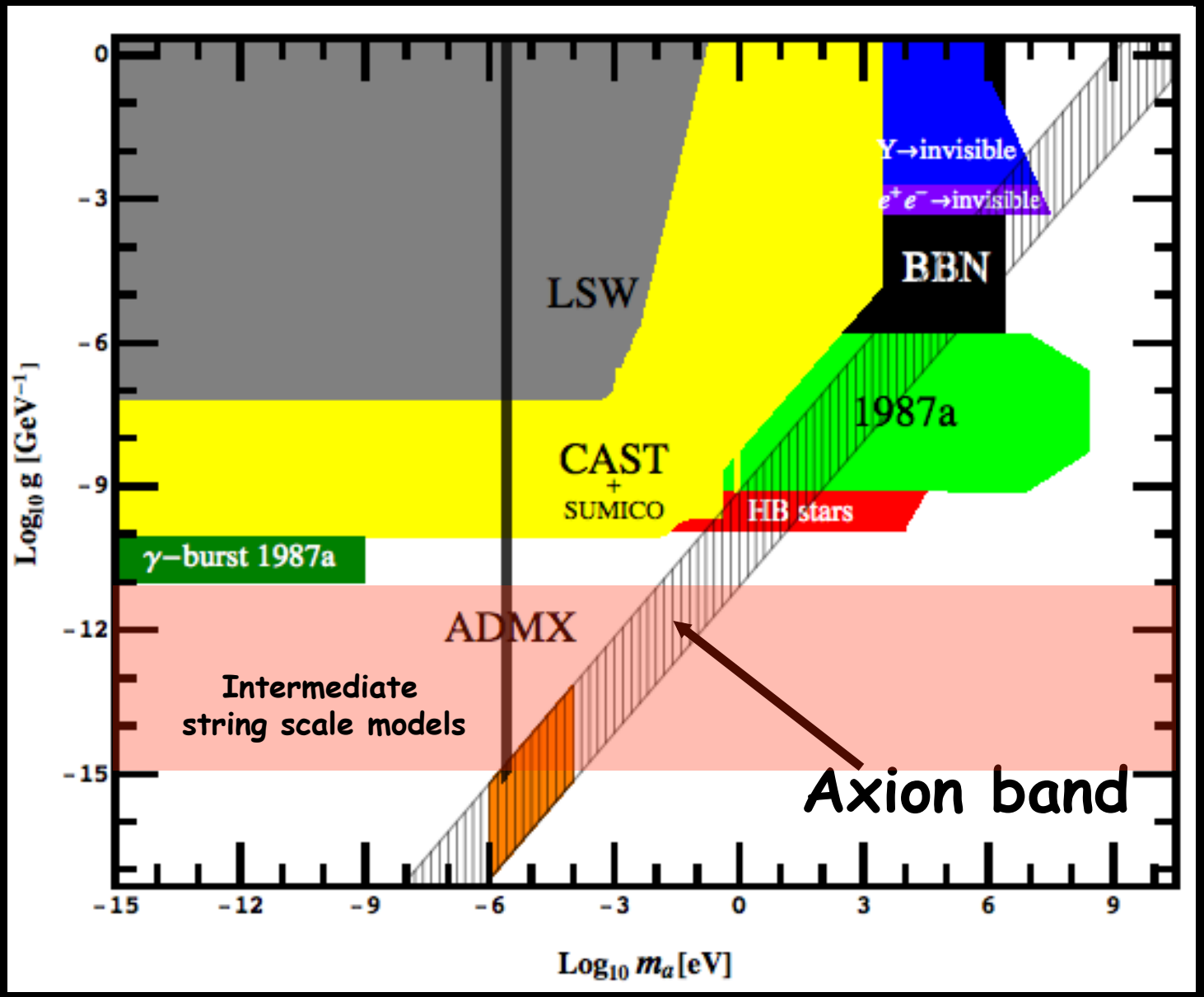
Helioscopes

CAST@CERN
SUMICO@Tokyo

SHIPS@Hamburg

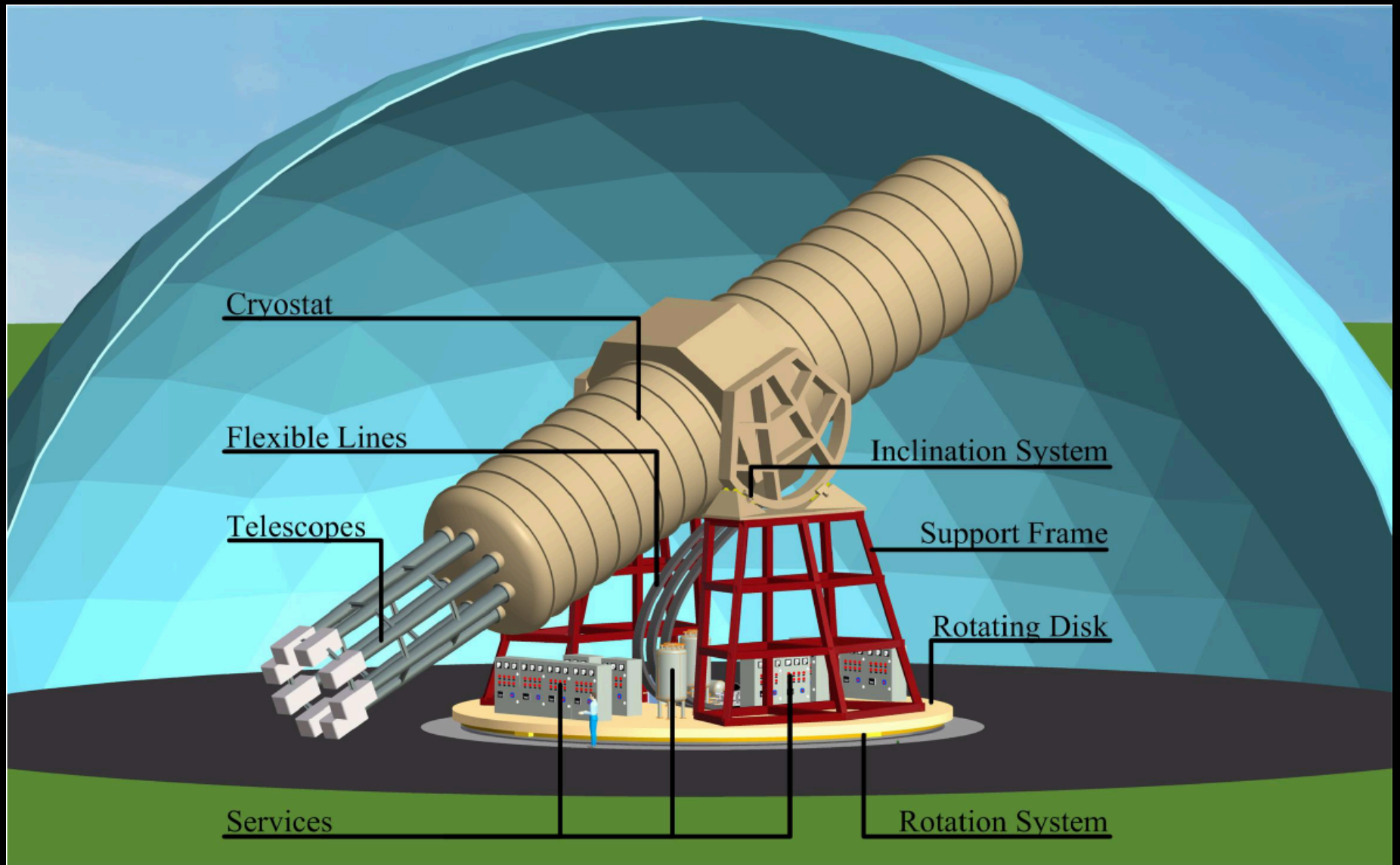


Sensitivity

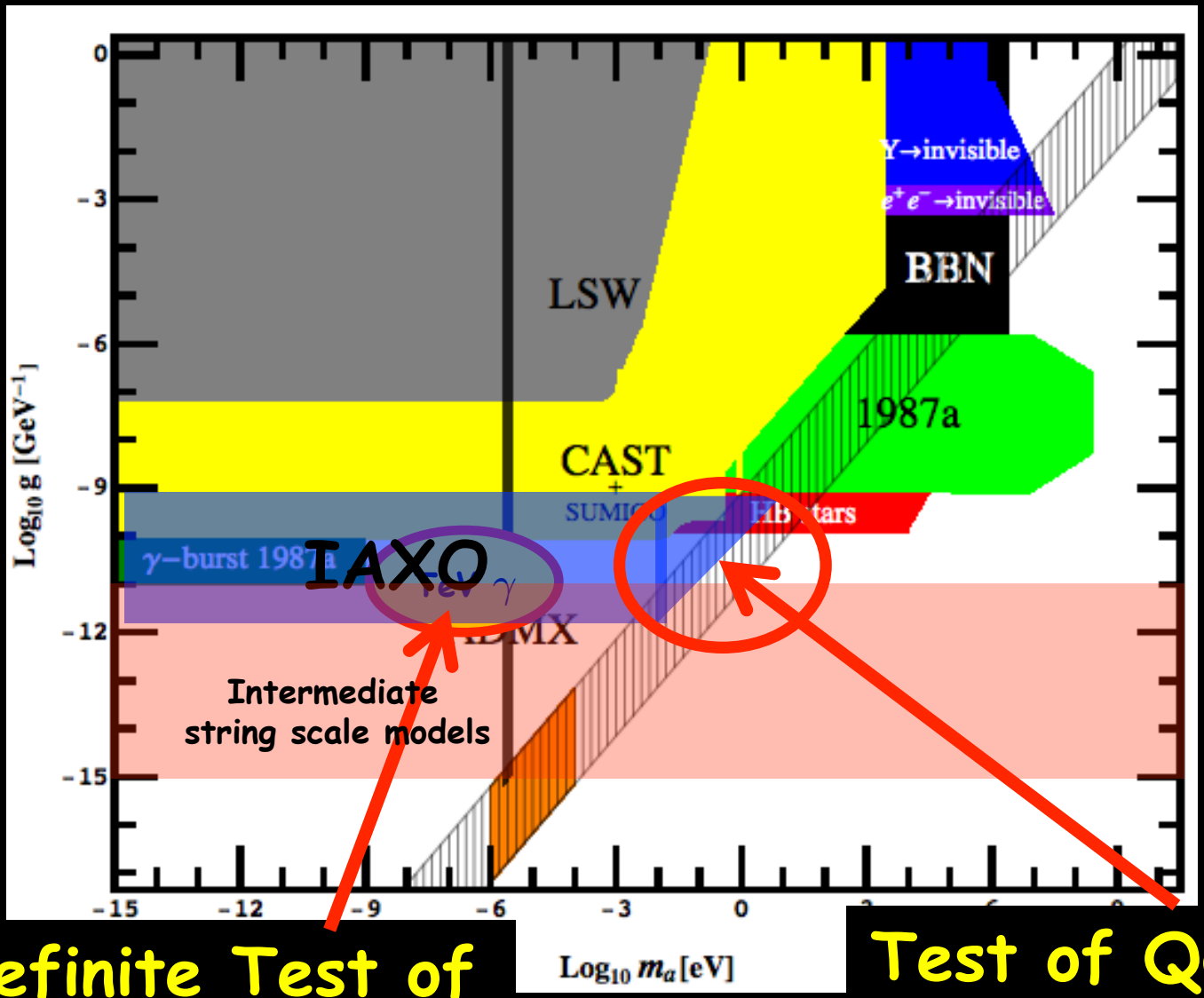


Going to the future: IAXO

The International Axion Observatory



An interesting area…



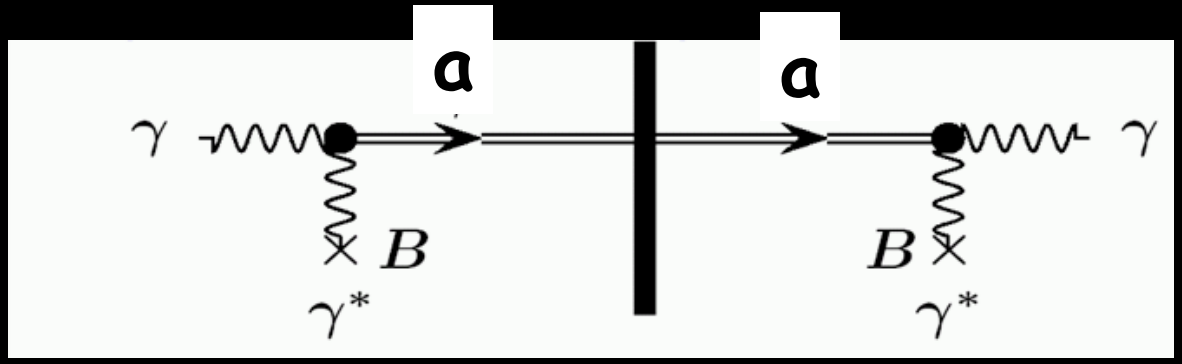
Definite Test of TeV transparency

Test of QCD axion
+ white dwarf anomaly

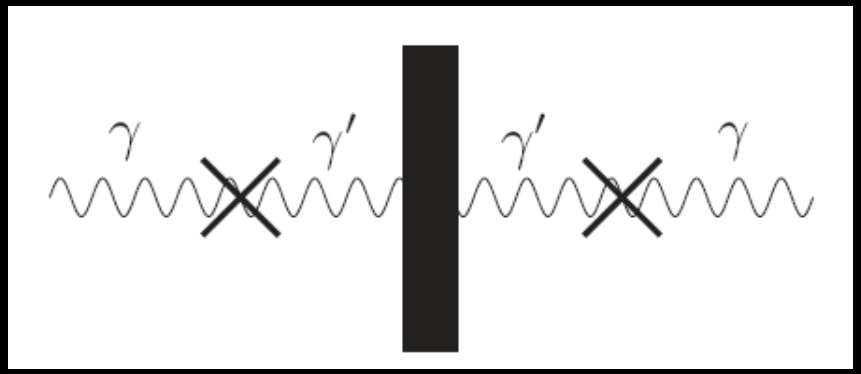
Works not only for ALPs

WISPS=Weakly interacting sub-eV particles

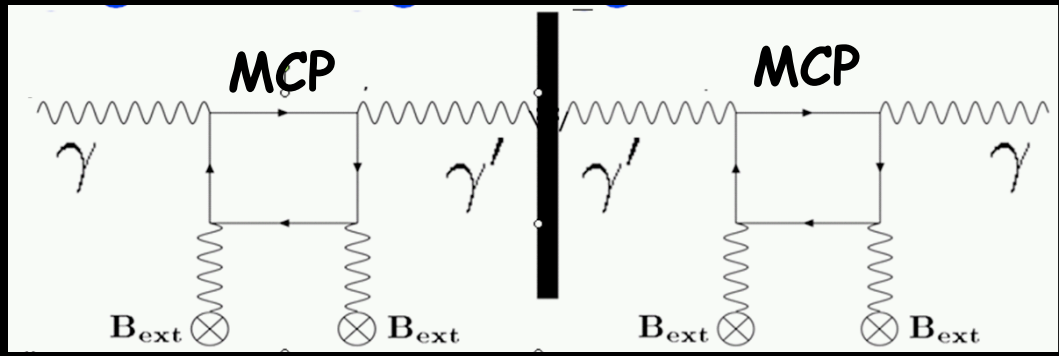
- Axions



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



- Hidden photon + minicharged particle (MCP)



Dark Matter(s)

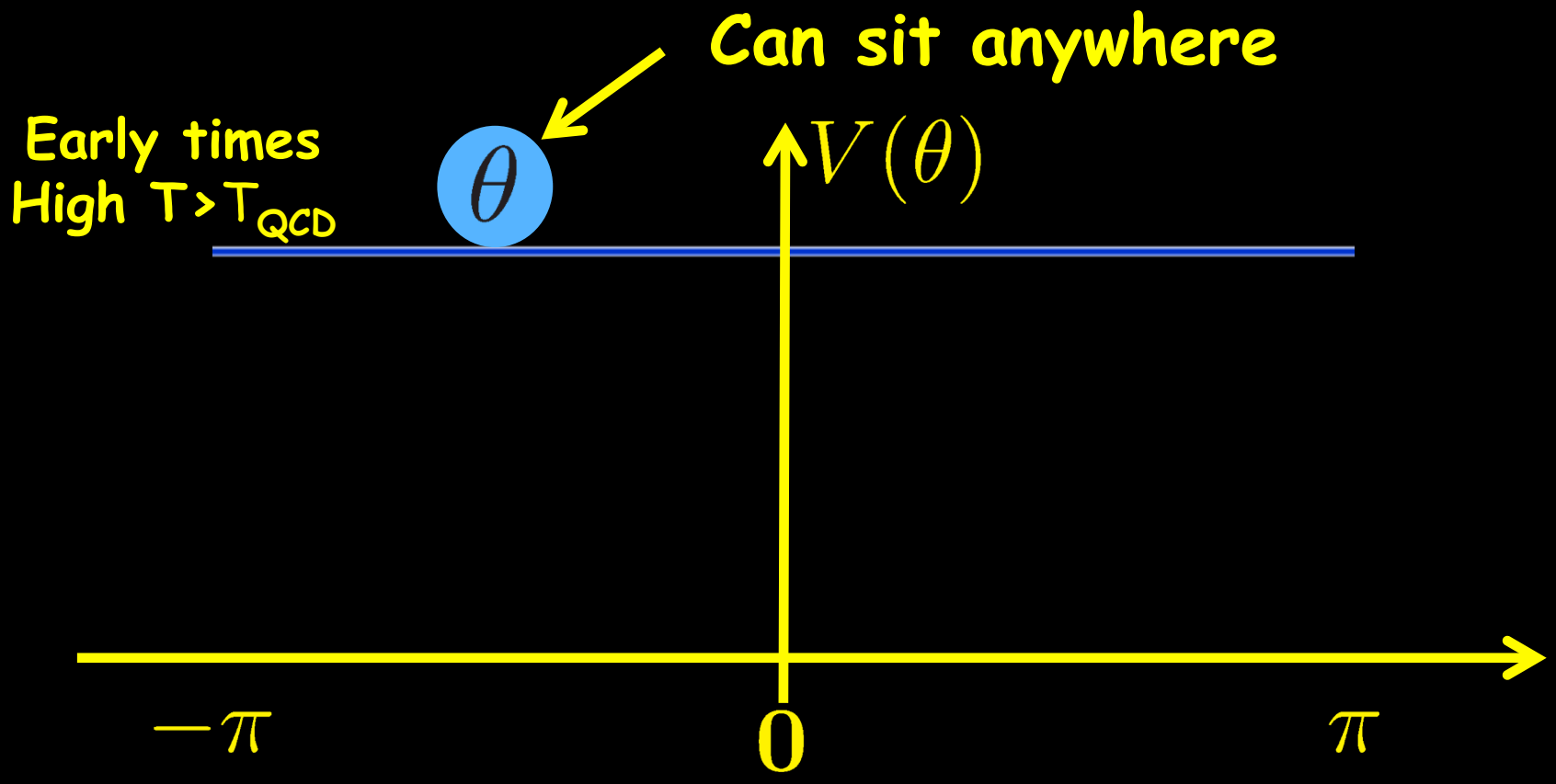
Properties of Dark Matter

- Dark matter is dark, i.e.
  it doesn't radiate!
  (and also doesn't absorb)

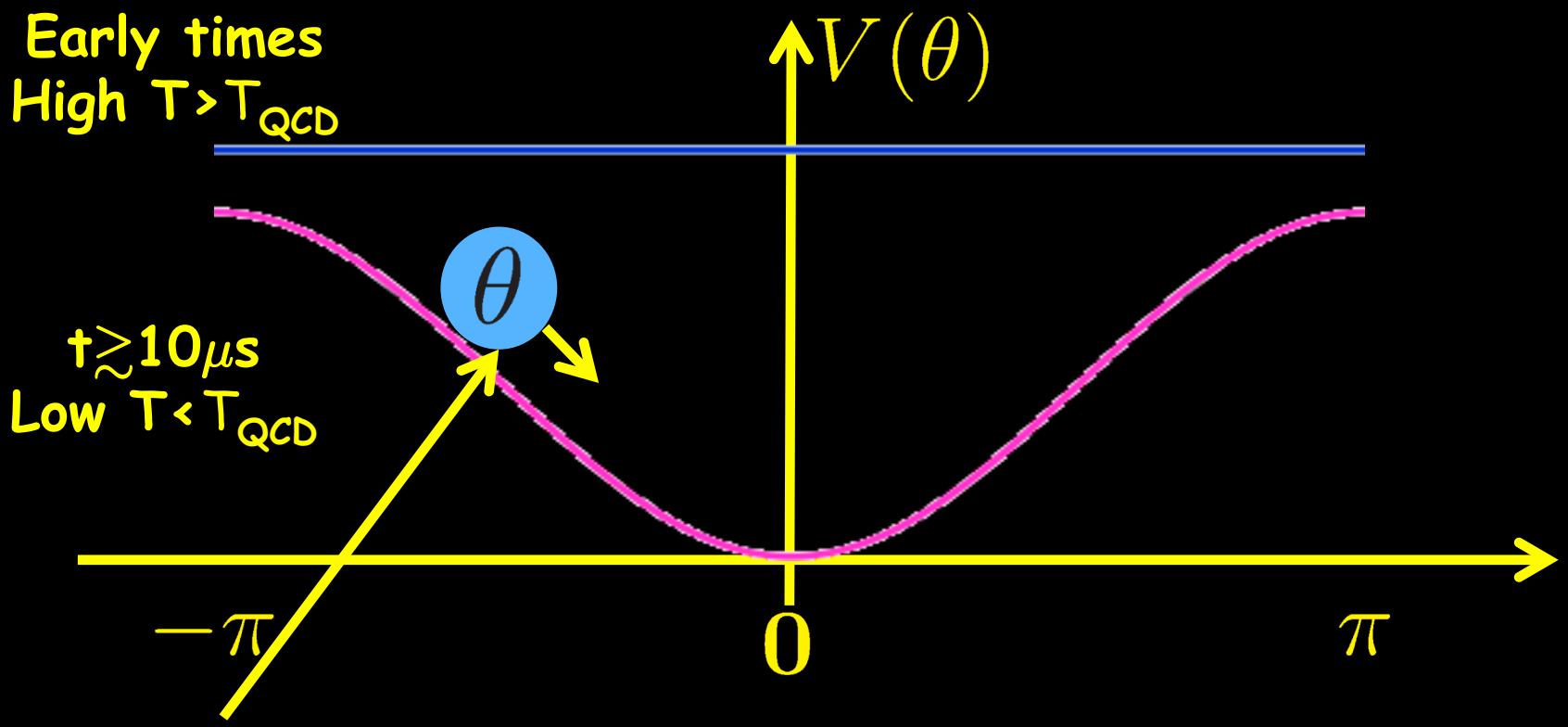
➔ very, very weak interactions with light
and with ordinary matter

➔ Exactly the properties of
axions(-like particles)

The axion has no clue where to start



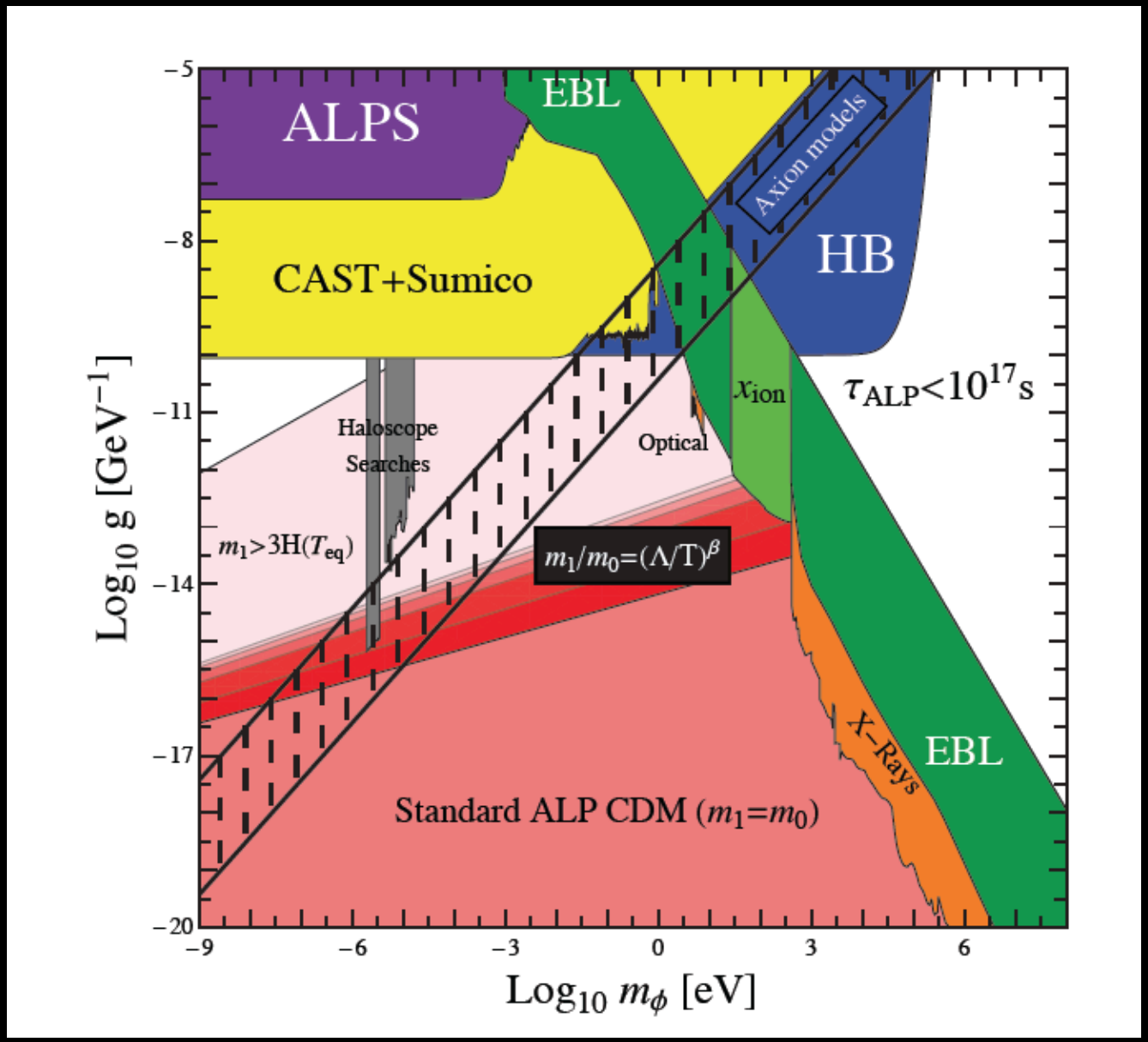
The axion has no clue where to start



$$\rho_a(t) = \frac{\rho_{ini}}{R^3(t)}$$

➔ Dark Matter

Axion(-like particle) Dark Matter

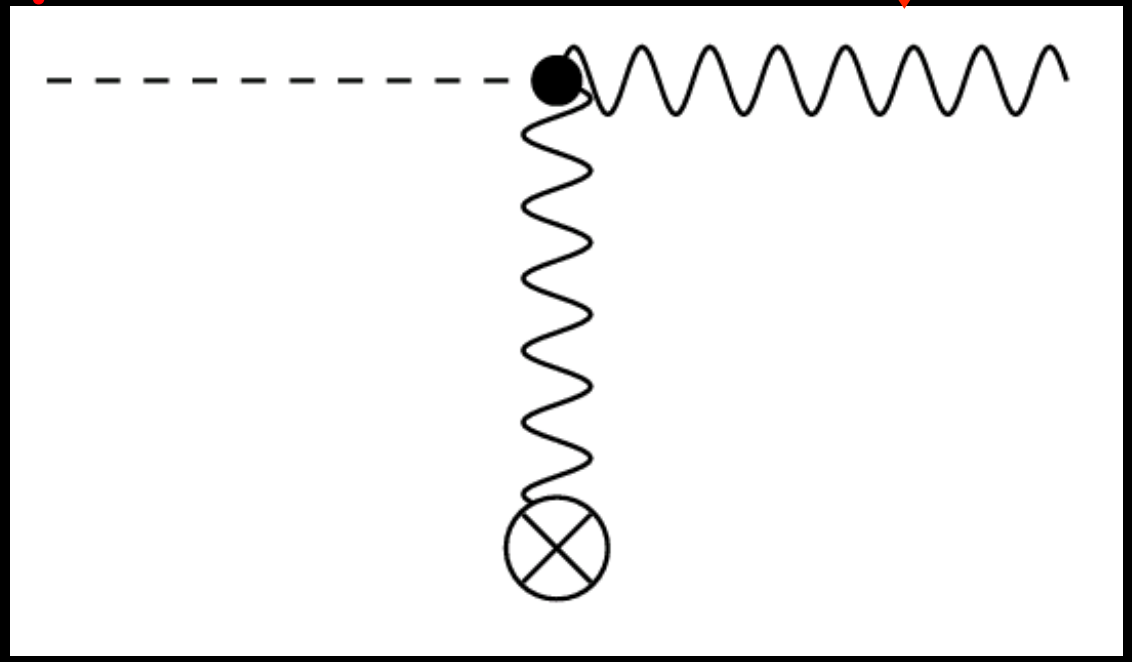


Detecting ALP/WISP Dark Matter

Use a plentiful source of axions

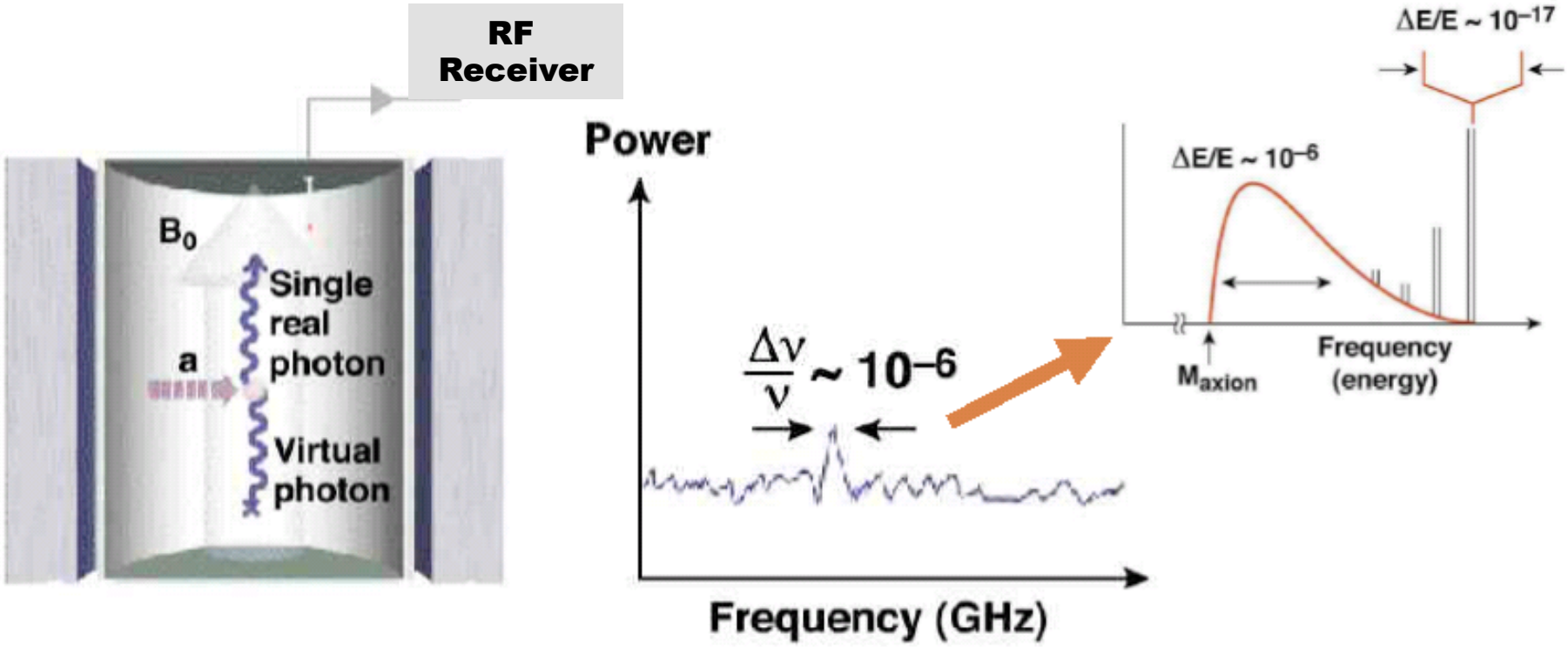
- Photon Regeneration

Photon
(amplified in resonator)



axion
(dark matter)

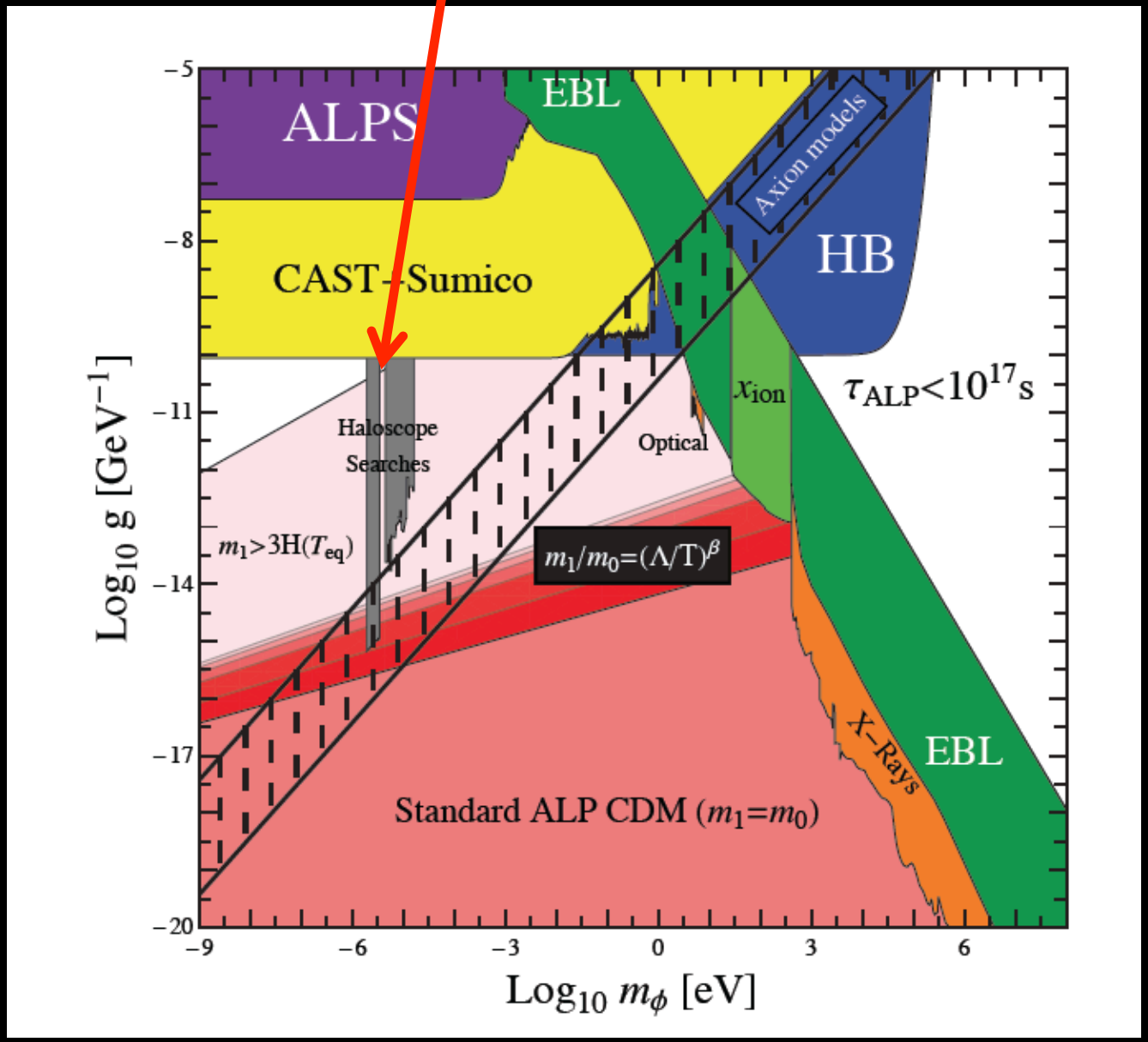
Signal: Radiofrequency peak (see talk by Leslie Rosenberg next week)



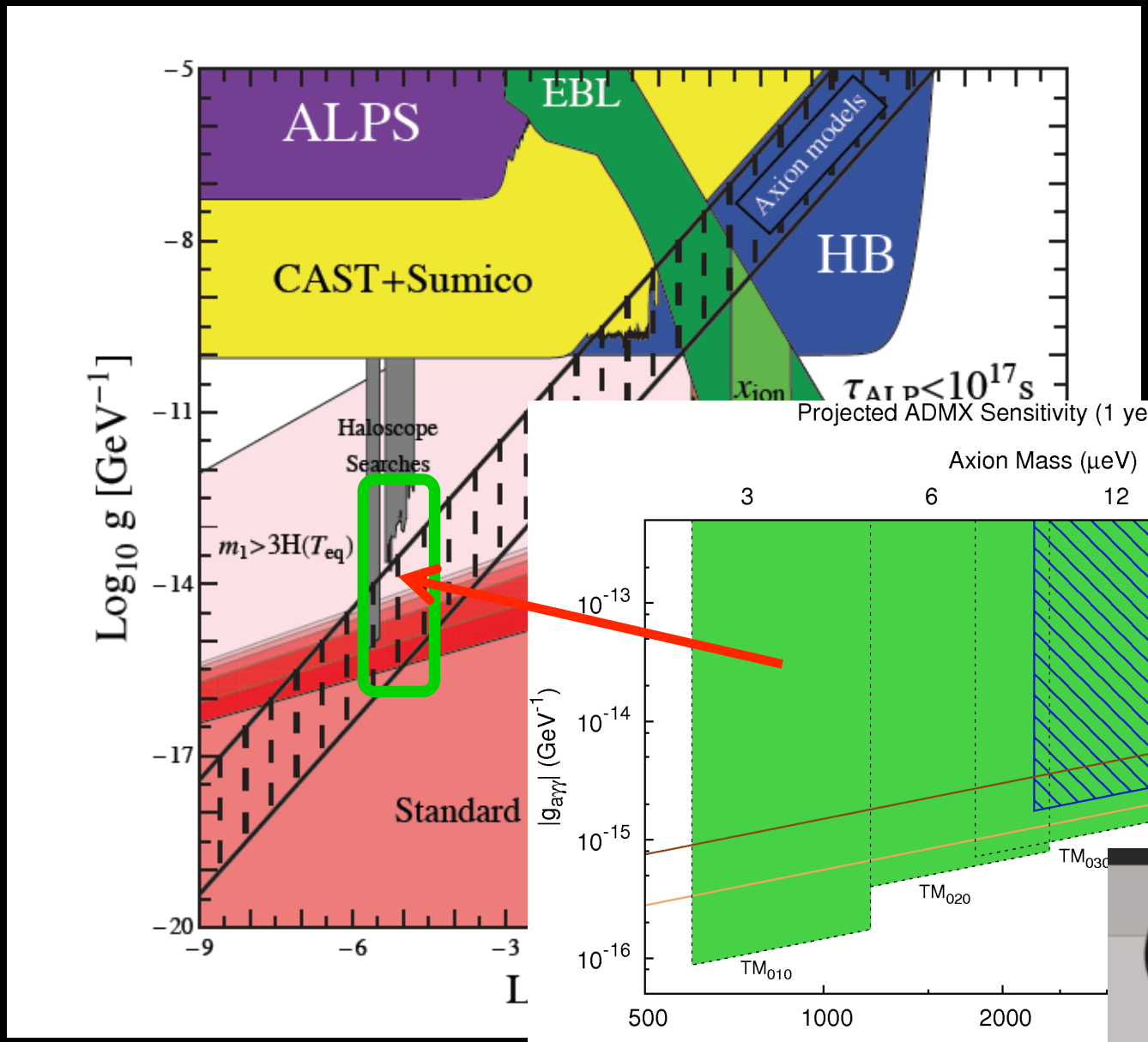
$$h\nu = m_a c^2[1 + \mathcal{O}(\beta^2 \sim 10^{-6})]$$

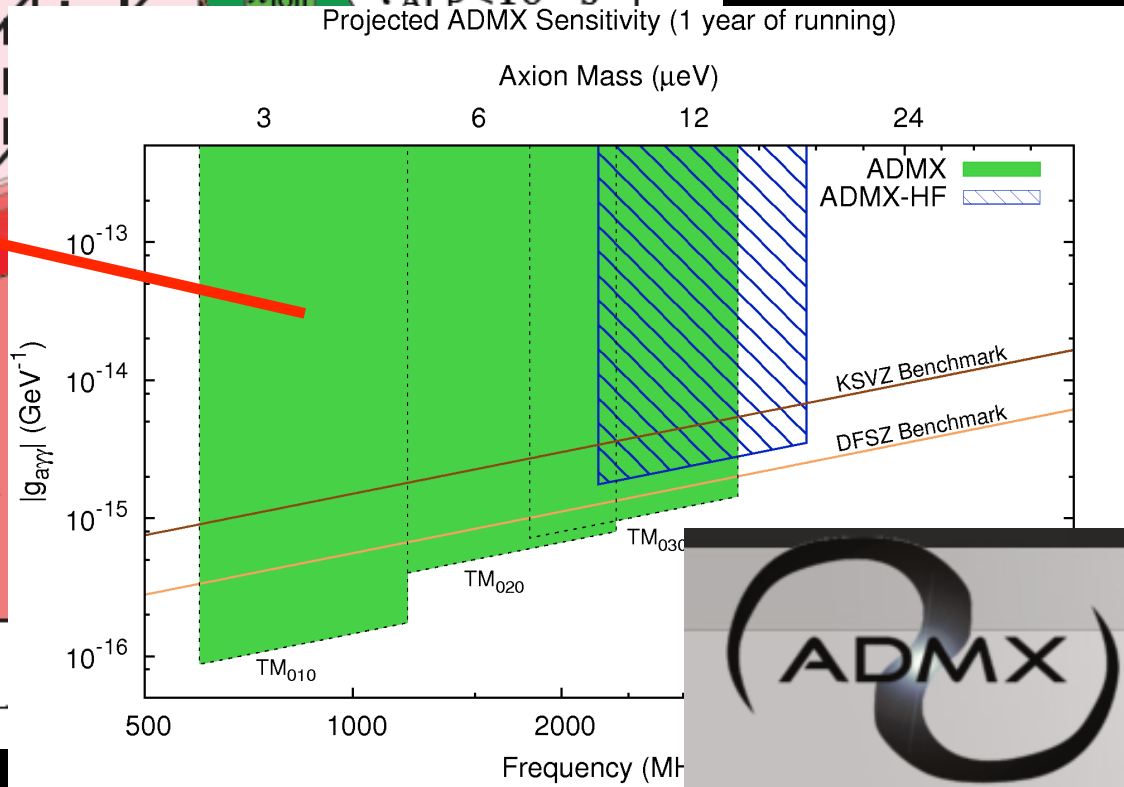
Virial velocity in galaxy halo!

An extremely sensitive probe!!!

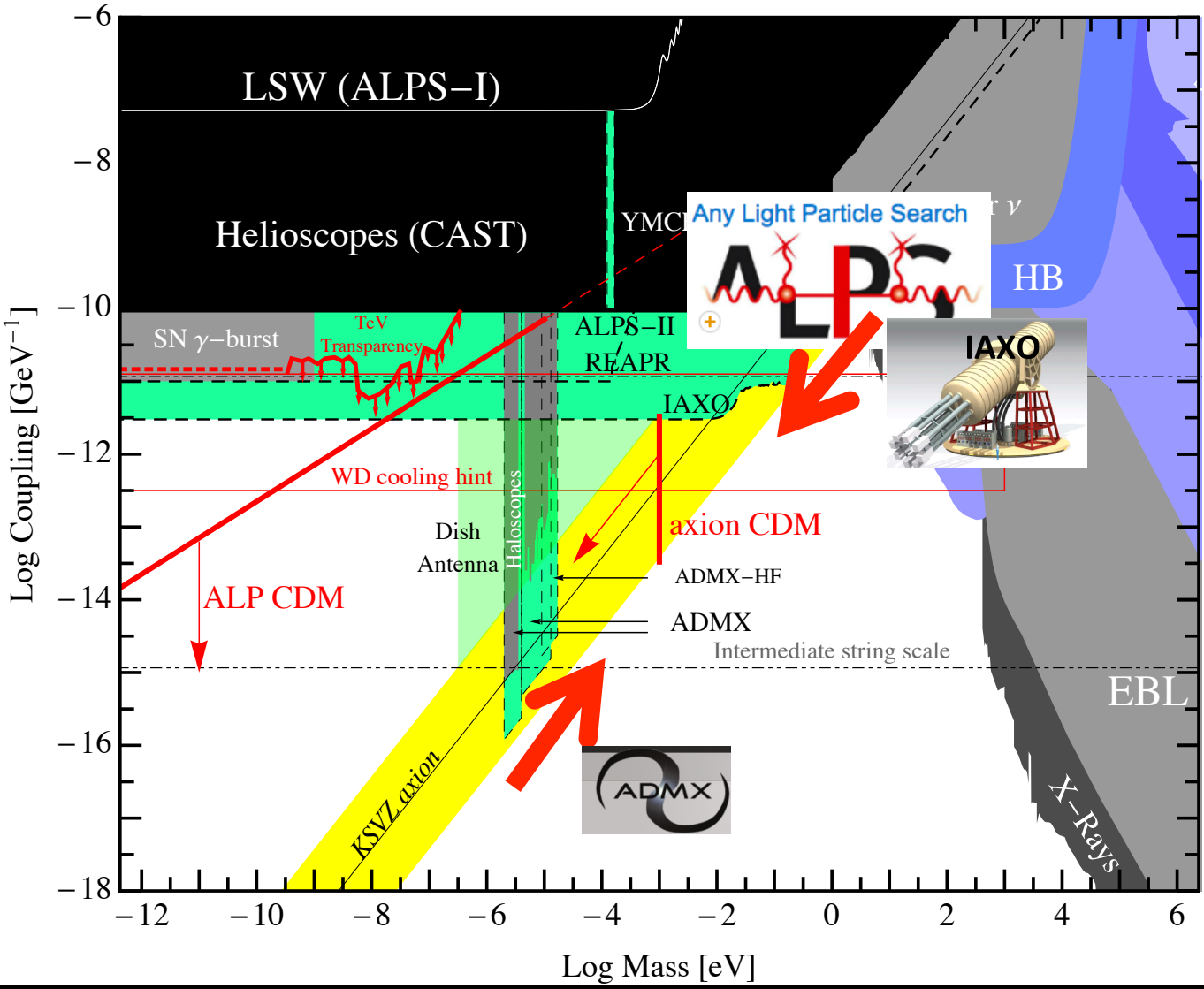


An extremely sensitive probe!!!

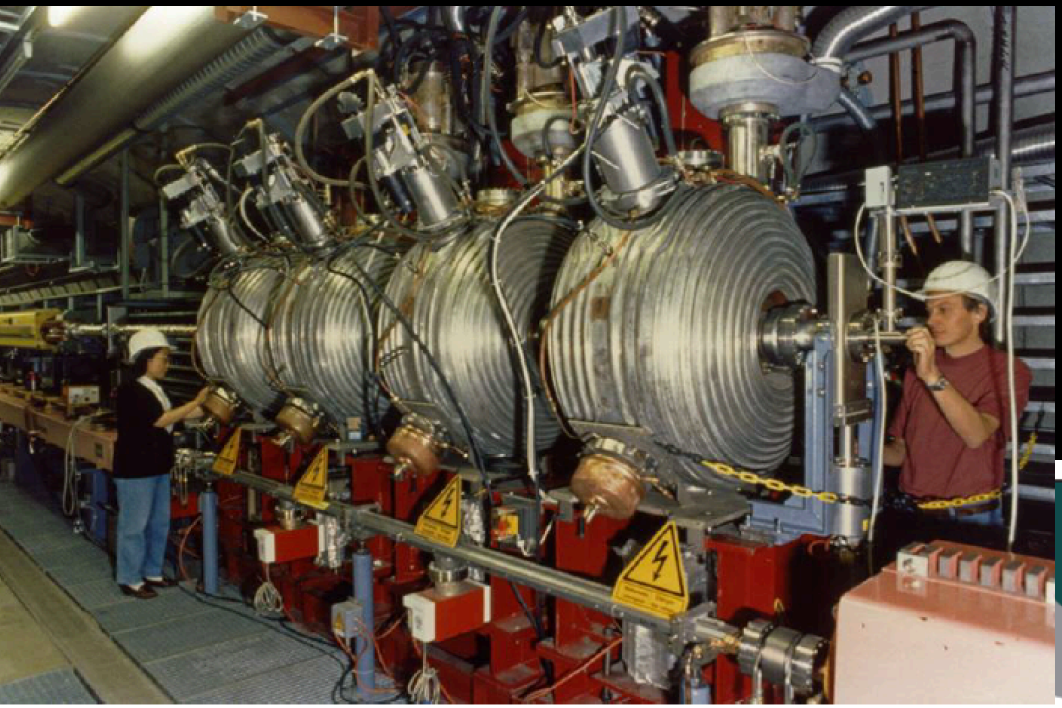


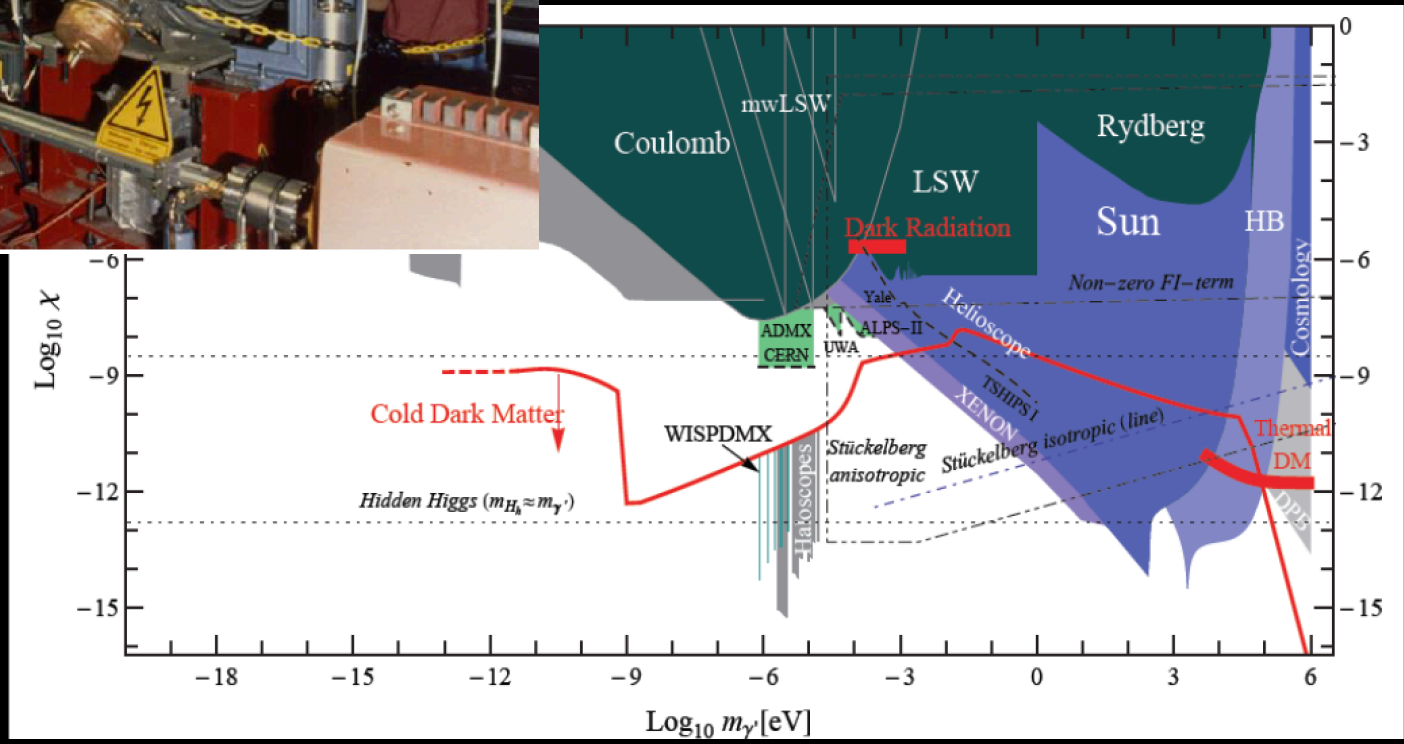


Encircling the axion...



@ DESY + Bonn: WISPDMX

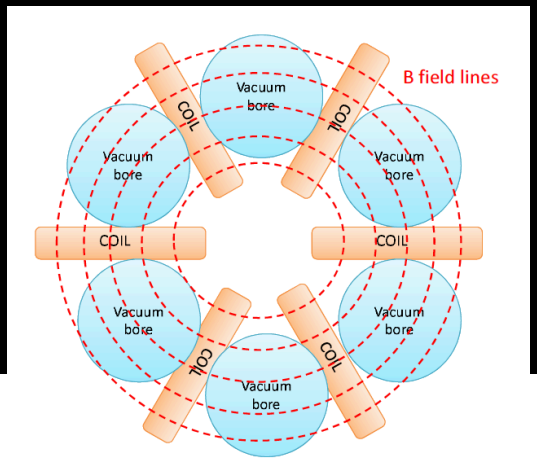


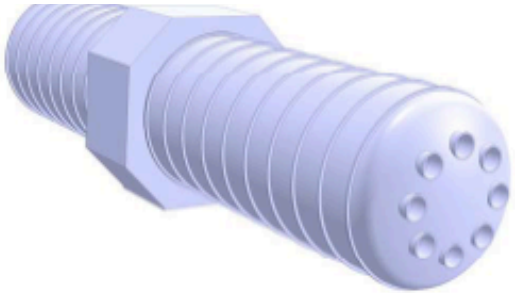


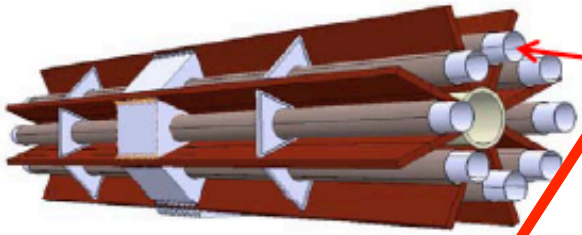
IAXO as facility

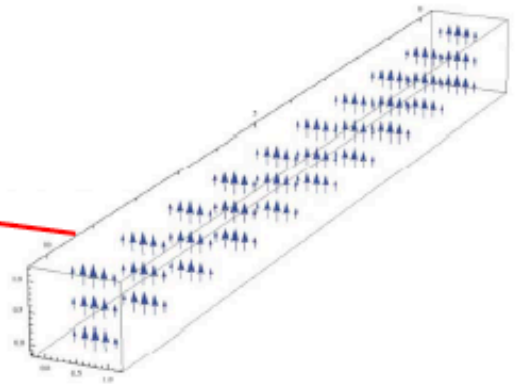
IAXO facility

- IAXO provides large magnetized volume
  ➔ useful for ALP DM search









Igor G. Irastorza / Universidad de Zaragoza

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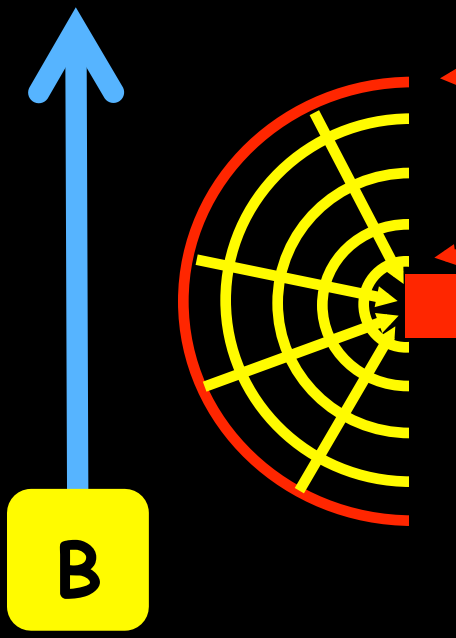
Insert long thin cavities

Broadband Search Strategy

Dark Matter Antenna

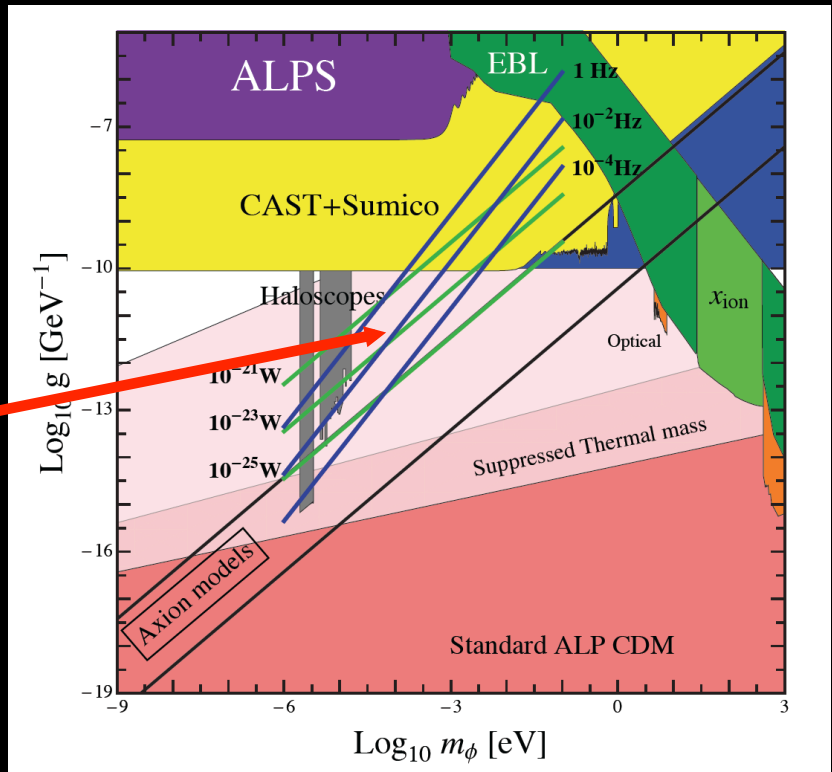


Antenna converts axion->photon

Light concentrated in center

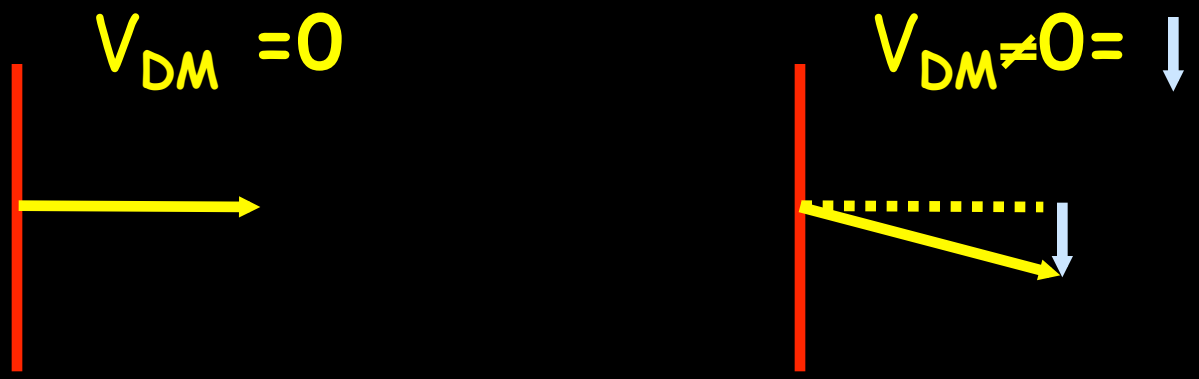
Detector

Probes here;
very sensitive!!

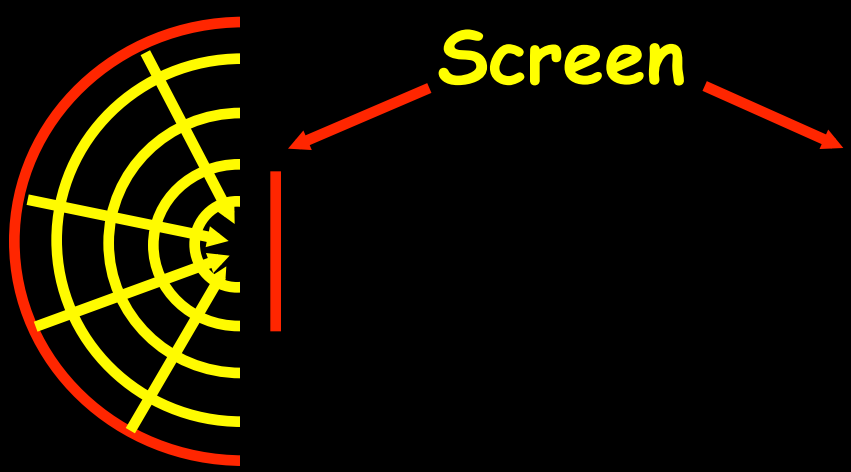


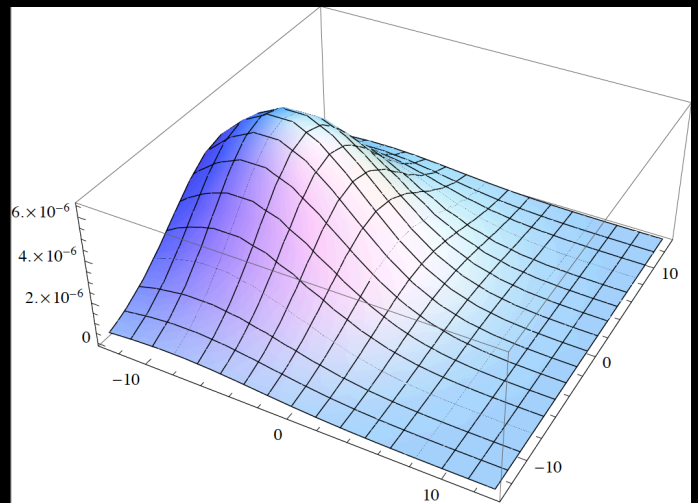
A Dream for ~~Astrology~~ ehhm Astronomy

- Emission from moving dark matter



- A picture of the DM-velocity distribution





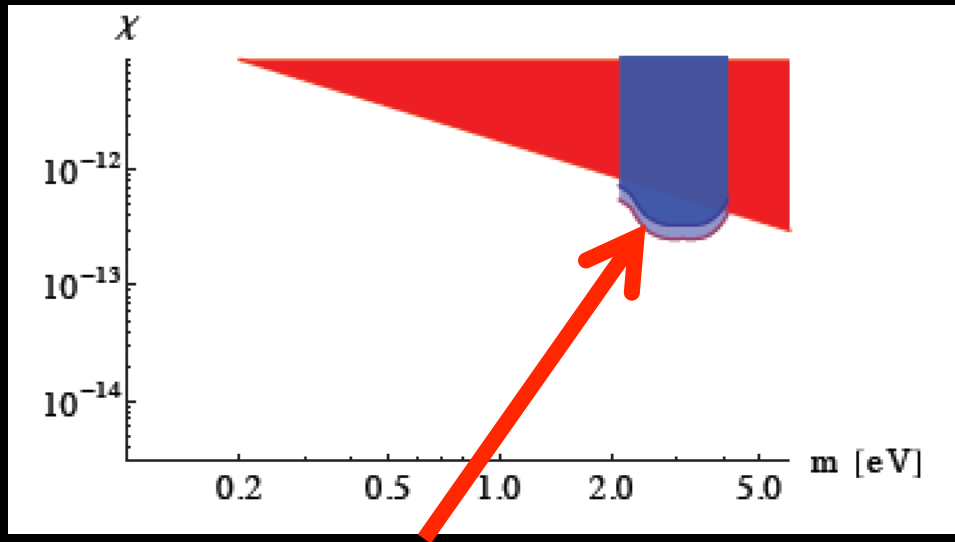
The FUNK experiment

Recycle Auger mirror

FUNK 98.4

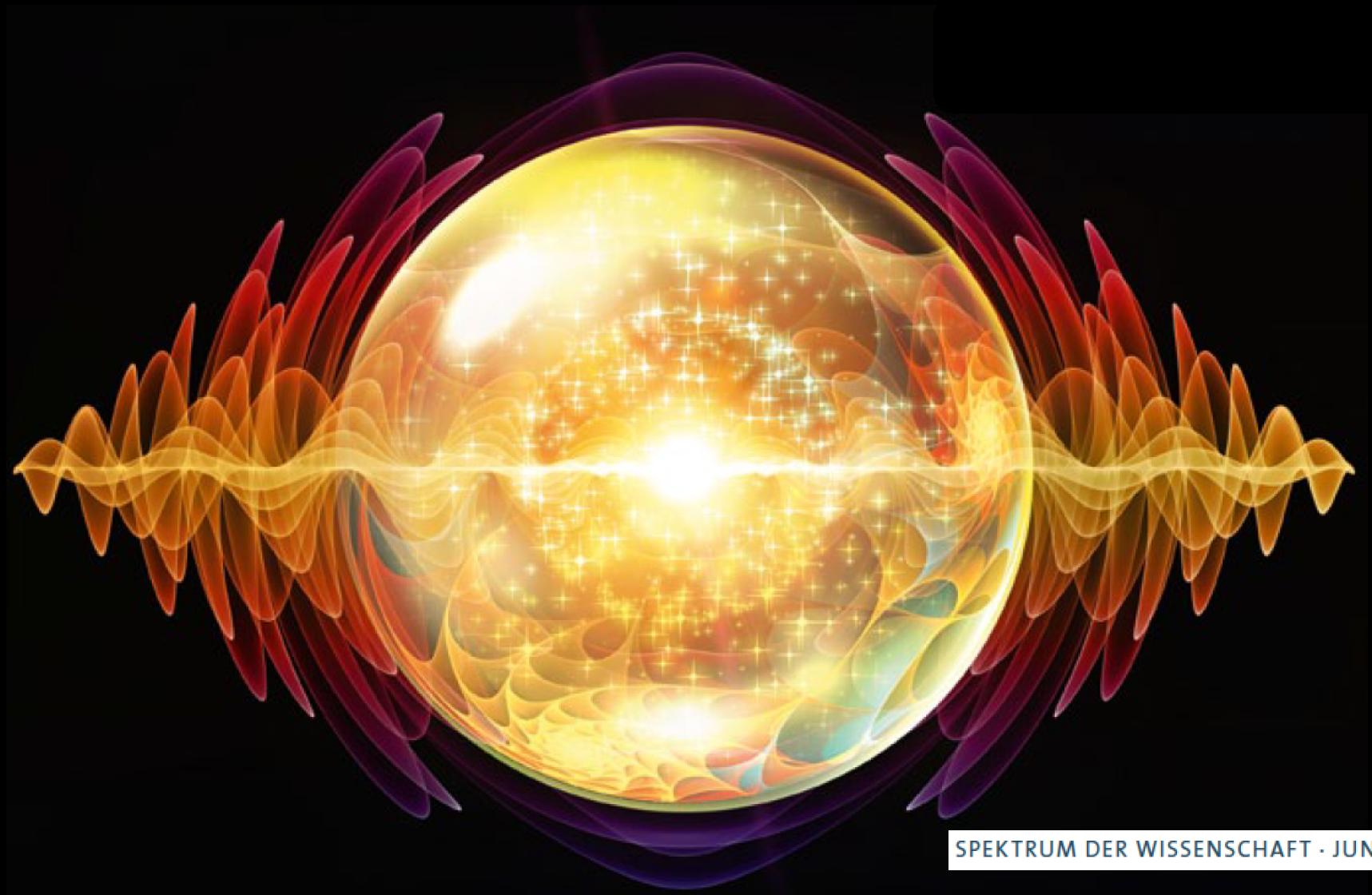
the experiment ...

First measurements in the next few months



Could detect hidden photon DM!!!

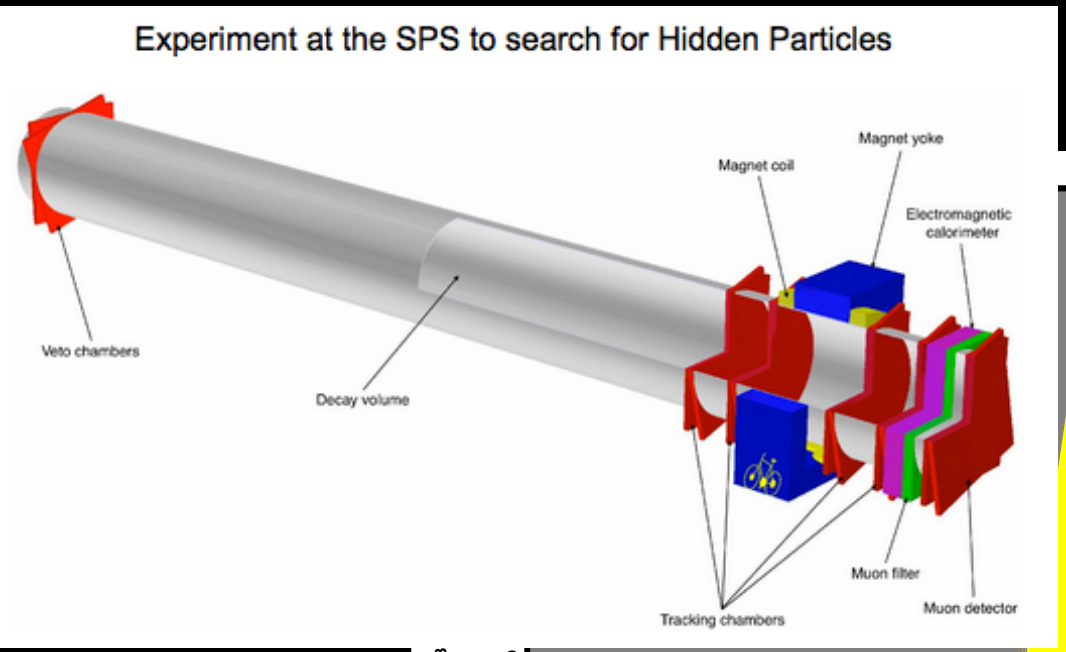
We are cleaning the world of dark matter…

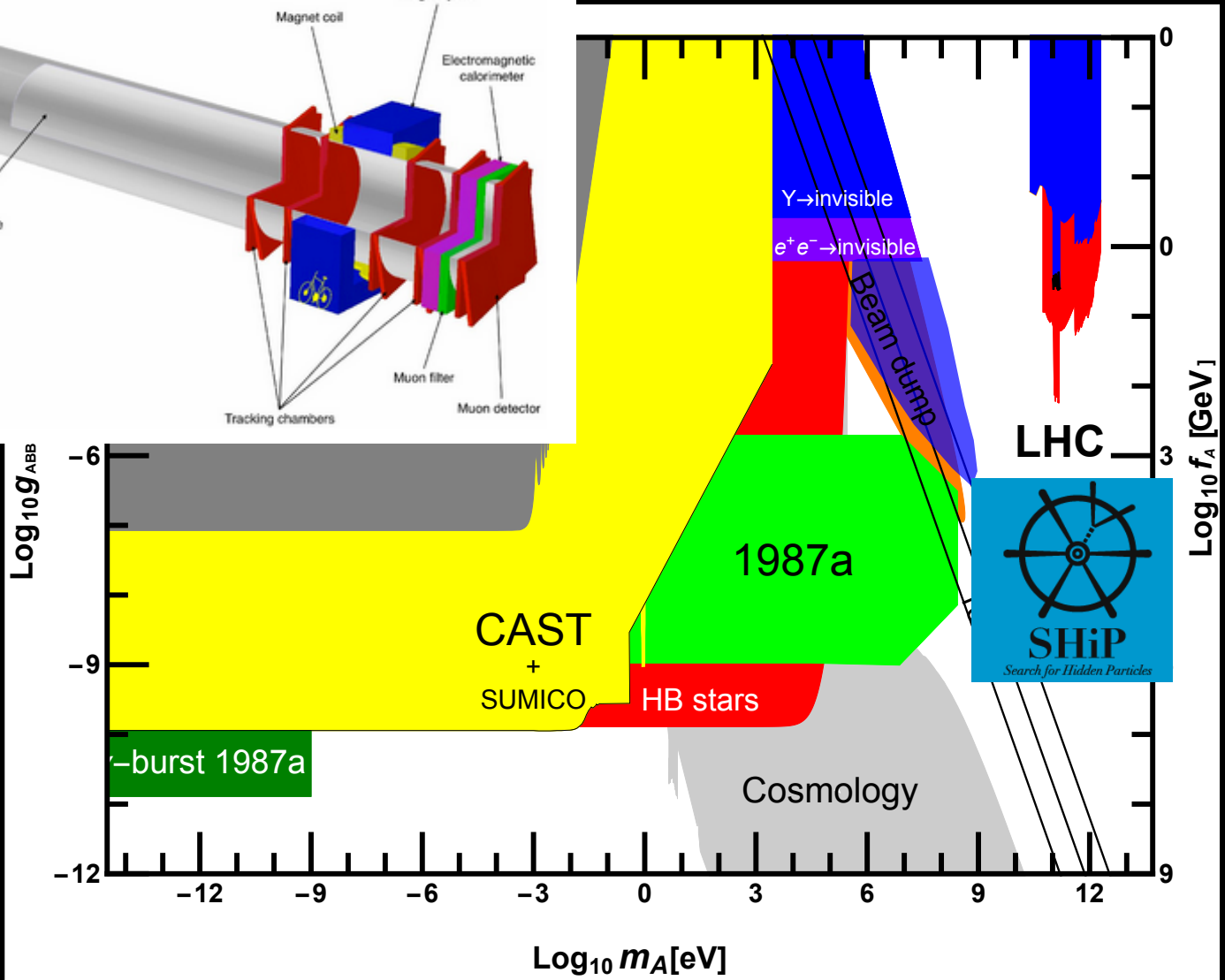


Fuer besseres Raumklima und mehr positives Licht

Pre-final remark

Looking for heavier ~GeV ALPs





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!
- Exciting experiments in the next few years!!!
- Dark Matter may be ALPy/WISPy ☺

Hidden sector

Status of IAXO

- Conceptual Design Report
- Letter of intent well received

- Gathering support for technical design report
- Support for prototype magnet and detector likely

- Collaboration growing
- Memorandum of understanding in preparation