INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

Searching WISPs
-
From theory to detection

J. Jaeckel[**]

S. Abel[†], J. Berges[**], M. Goodsell[xx], S. Gardiner[†], H. Gies[0]
V. Khoze[†], A. Lobanov[y], J. Redondo[x], A. Ringwald[*], C.Wallace[†]

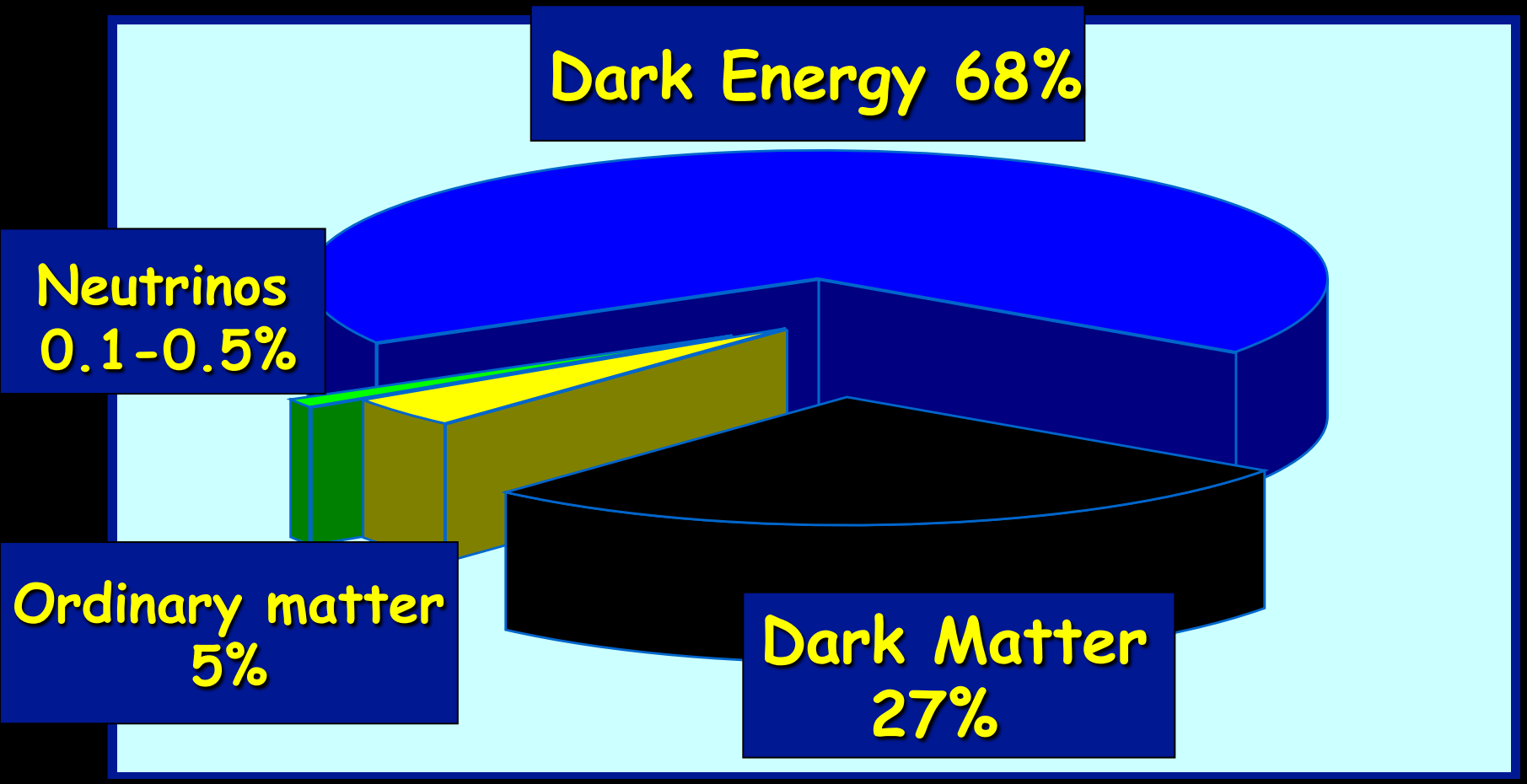
[**]ITP Heidelberg, [†]IPPP Durham, [*]DESY,
[y]MPIfR Bonn, [x]MPI Munich, [xx]Cern, [0]ITP Jena

We know...

...nothing

Inventory of the Universe

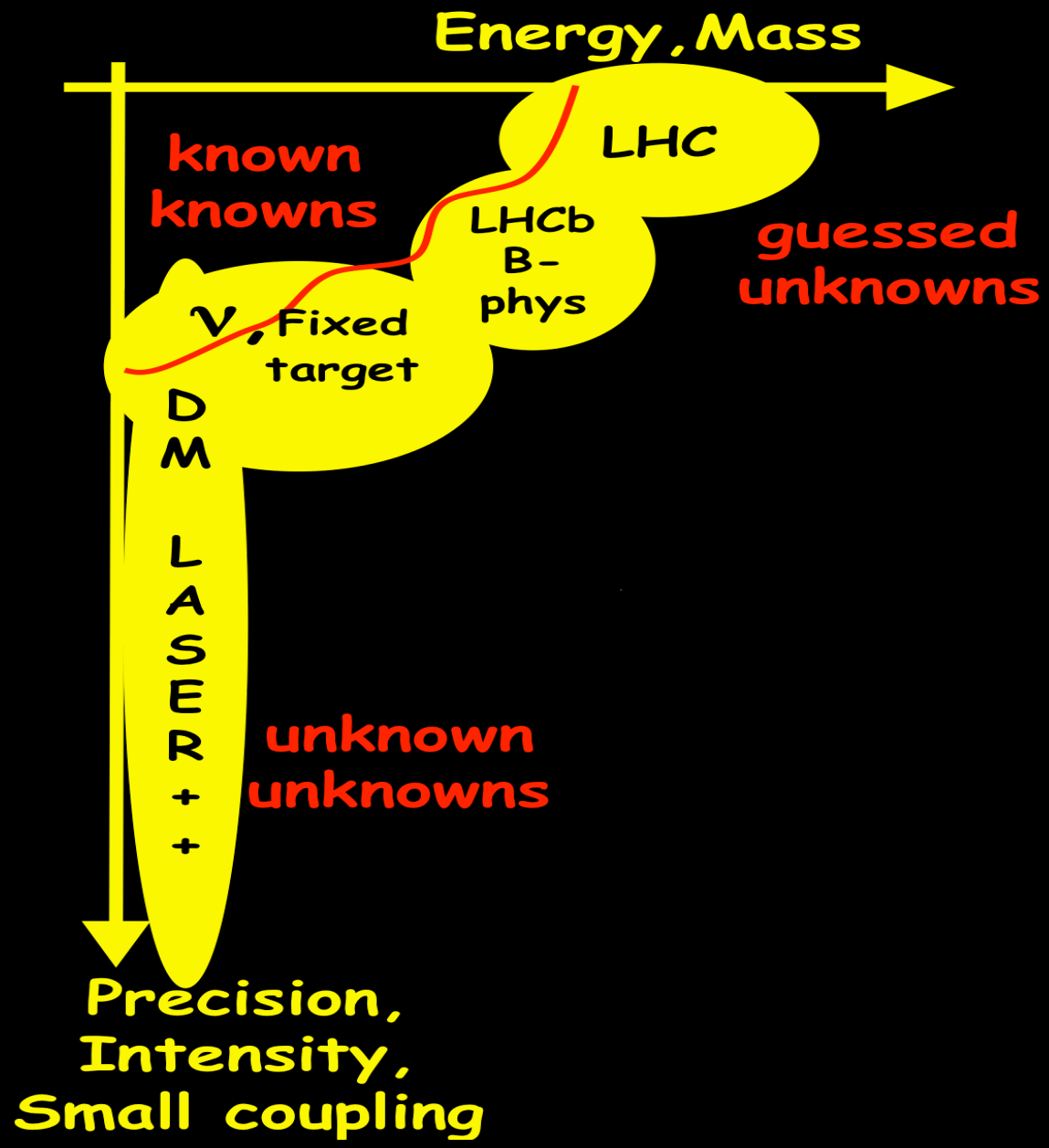
INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



Where does physics beyond the SM hide?

Exploring is (at least) 2 dimensional

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



Example WISP:

(Weakly Interacting Sub-eV Particle)

Axions in a nutshell

A dirty little secret...

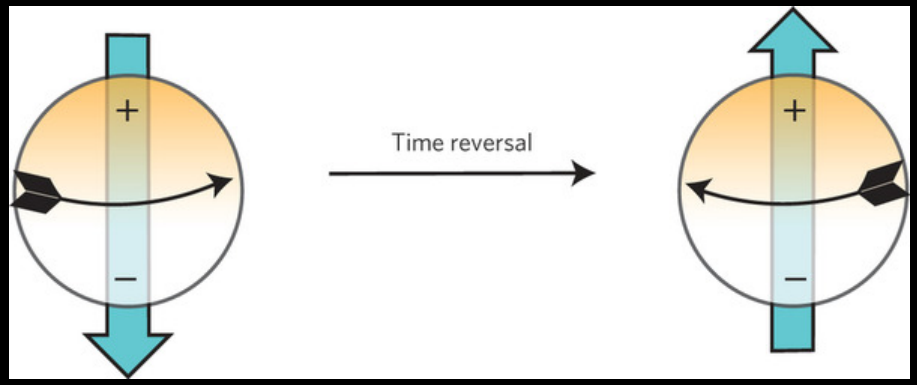
INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

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

$$\text{"} \sim \theta \vec{E} \cdot \vec{B} \text{"}$$

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

➡ Electric dipole moment of the neutron!



Not found
➔ θ~0!!!

A dirty little secret...

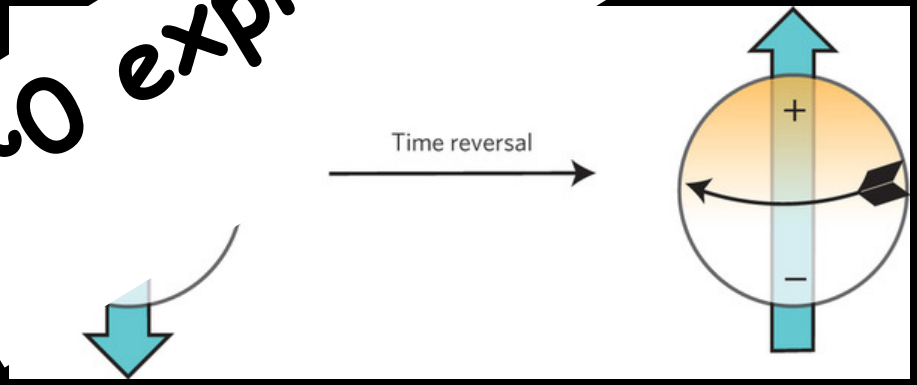
$$S = \int d^4x \left[-\frac{1}{4} G^{\mu\nu} G_{\mu\nu} - \frac{\theta}{4} G^{\mu\nu} \tilde{G}_{\mu\nu} + \ldots \right]$$

$$\text{"} \sim \theta \vec{E} \cdot \vec{B} \ldots$$

- The θ-term violates ti… =CP)!
- Connected to stro… s!

Electri… ment
…tron!

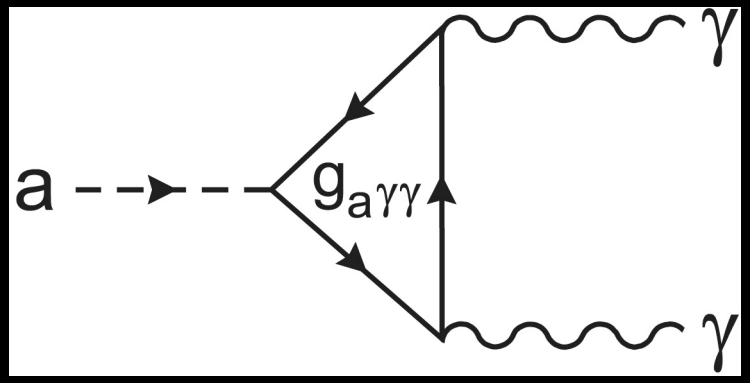
θ~0 explained by Peccei-Quinn mechanism
➔ Axion!



Not found
➔ θ~0!!!

Axion is light + couples to two photons

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



small < eV

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}\partial_\mu a \partial^\mu a - m^2 a^2 - \frac{1}{4}g_{a\gamma\gamma} a F^{\mu\nu}\tilde{F}_{\mu\nu} + \ldots$$

Coupling to two photons

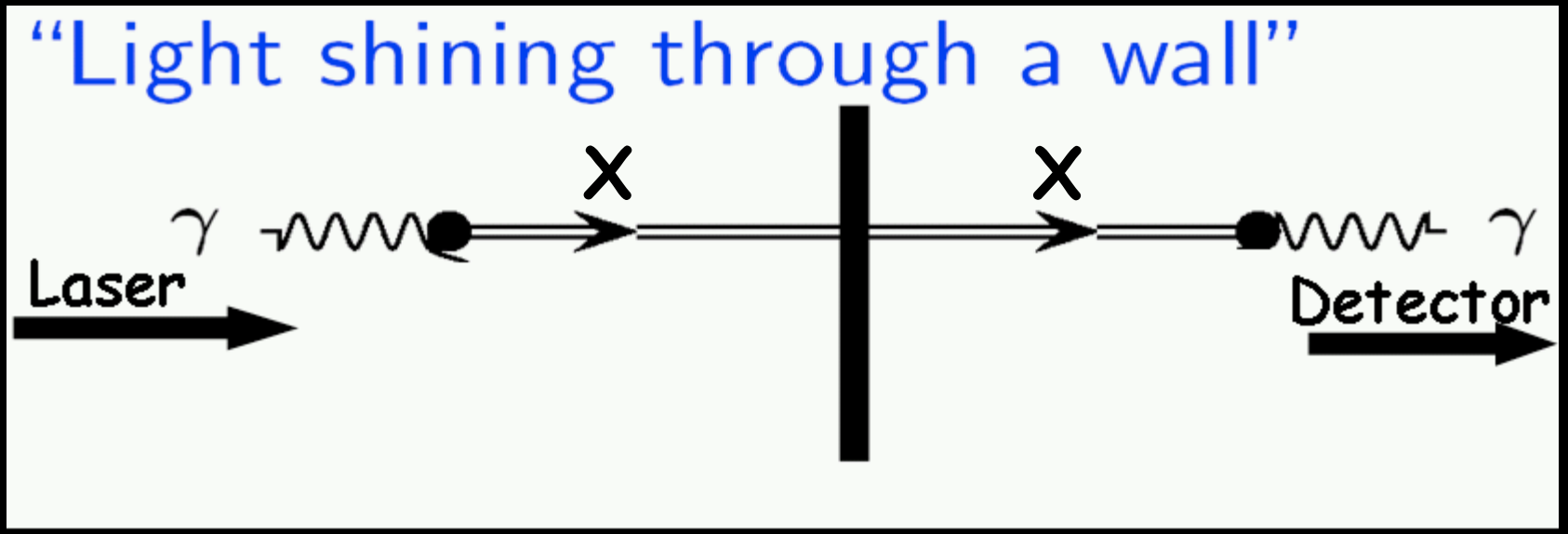
Very very weak $g_{a\gamma\gamma} \sim \dfrac{\alpha}{2\pi\, f_a}$

Because: Very large

Searching Axions in the lab

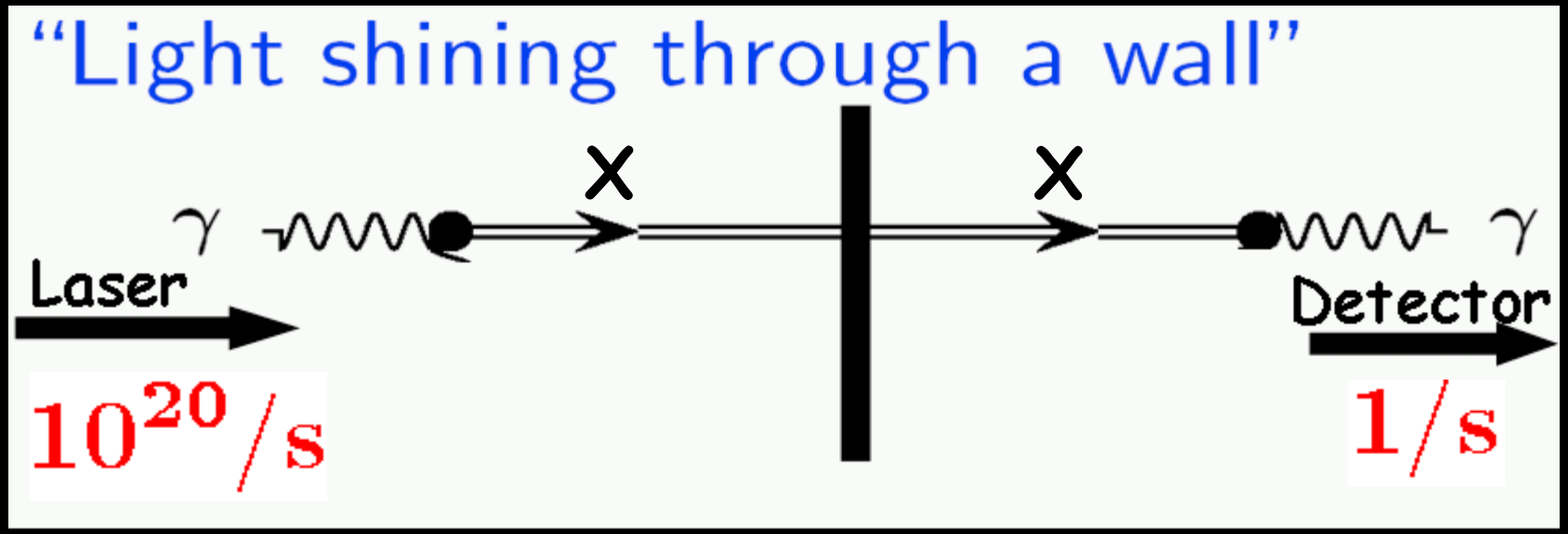
Light shining through walls

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



Light shining through walls

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



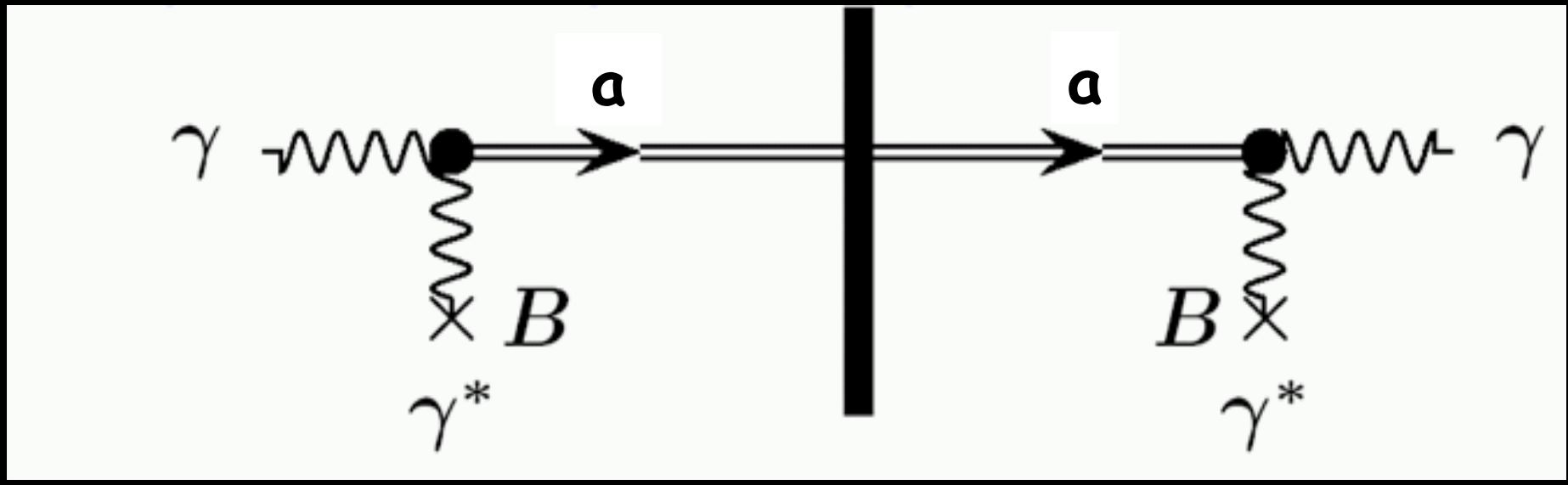
- Test $P_{\gamma \to X \to \gamma} \lesssim 10^{-20}$

- Enormous precision!
- Study extremely weak couplings!

Photons coming through the wall!

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

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

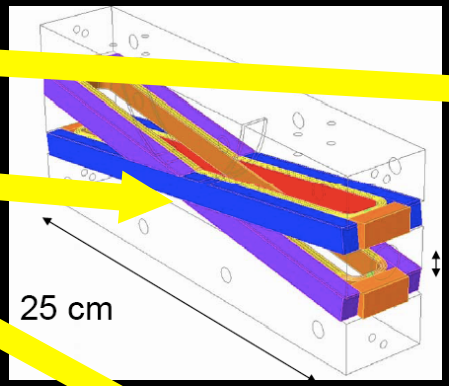


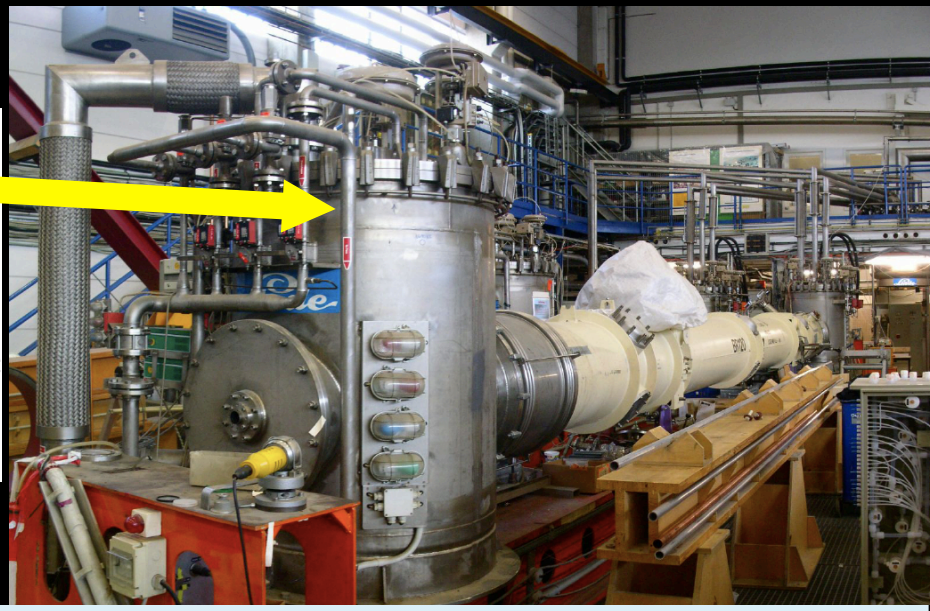
$$P_{\gamma \to a \to \gamma} \sim N_{\text{pass}} \left(\frac{BL}{M} \right)^4$$

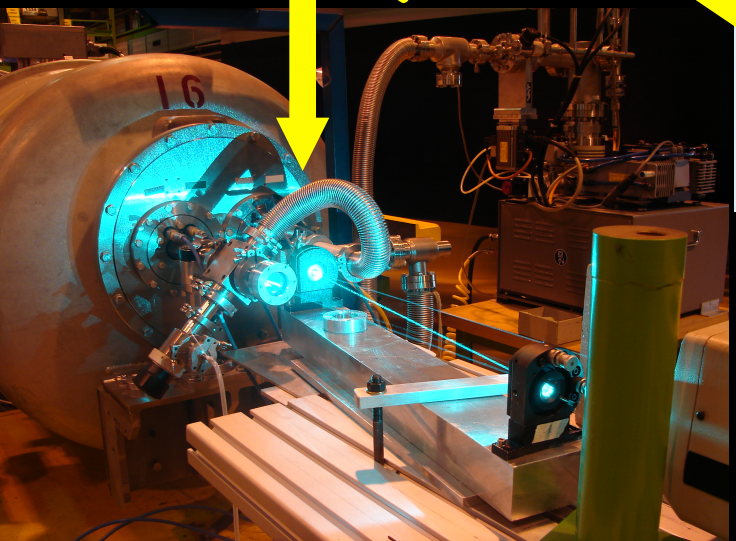
Light Shining Through Walls

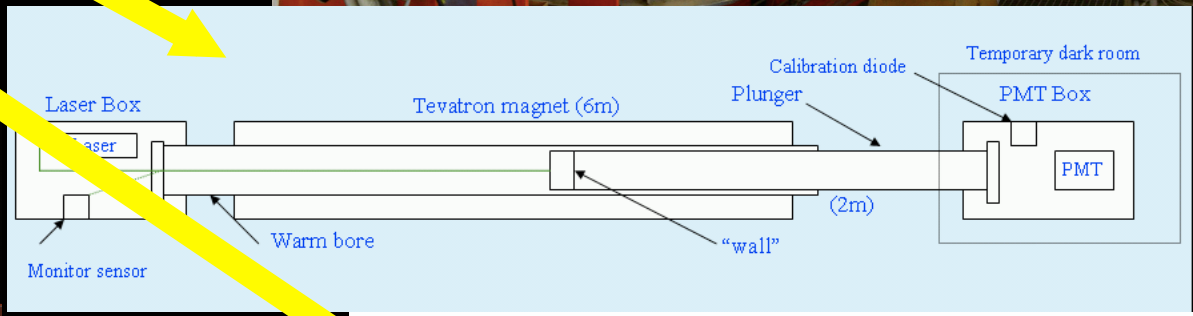
INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

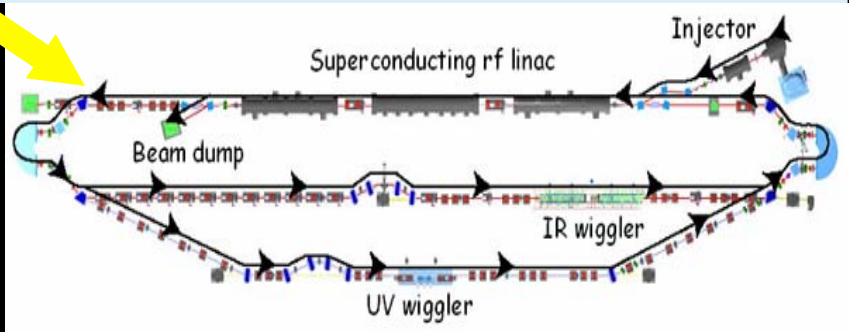
- A lot of activity
  - ALPS
  - BMV
  - GammeV
  - LIPPS
  - OSQAR









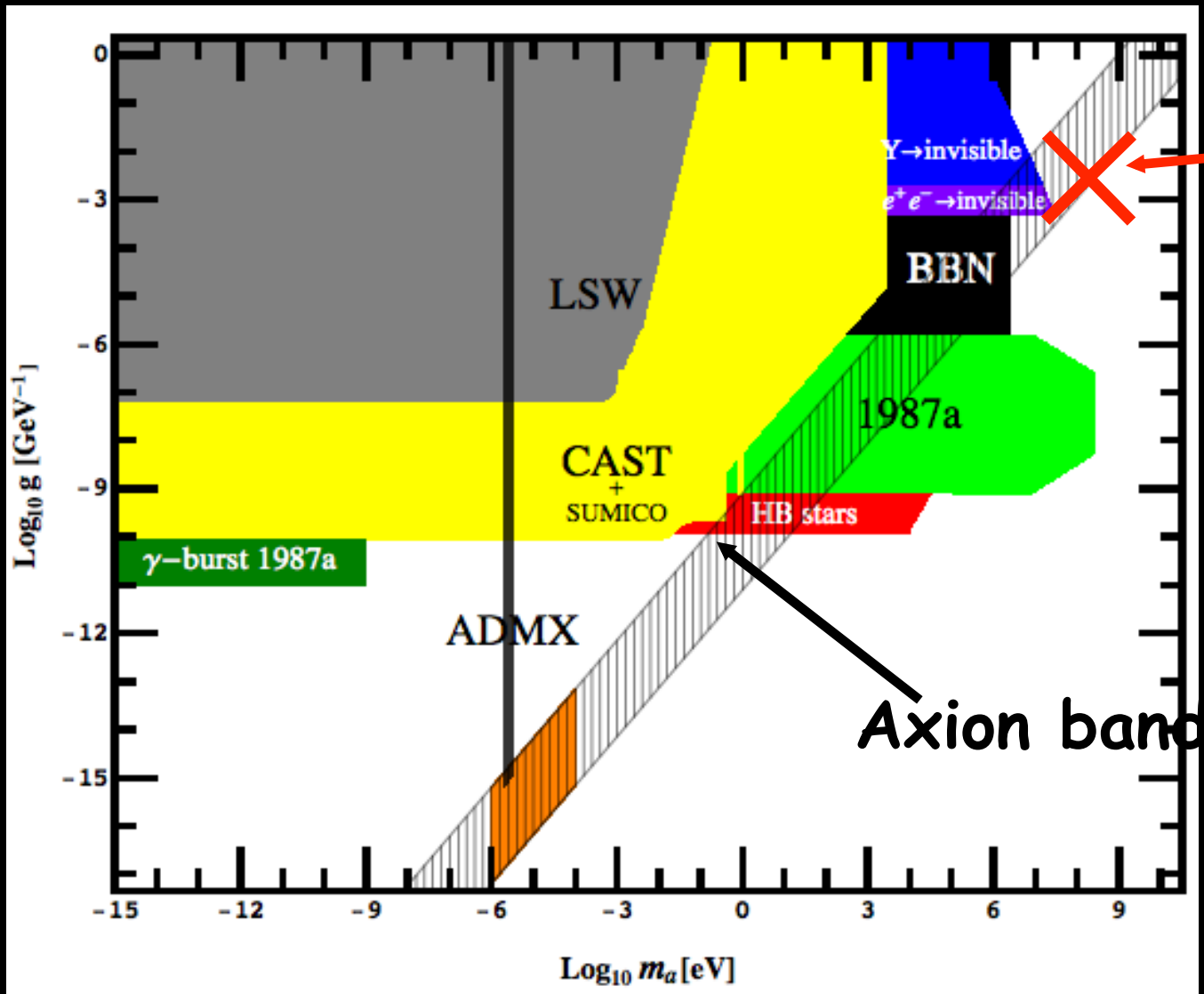


Small coupling, small mass

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

mass/energy

Weaker interaction

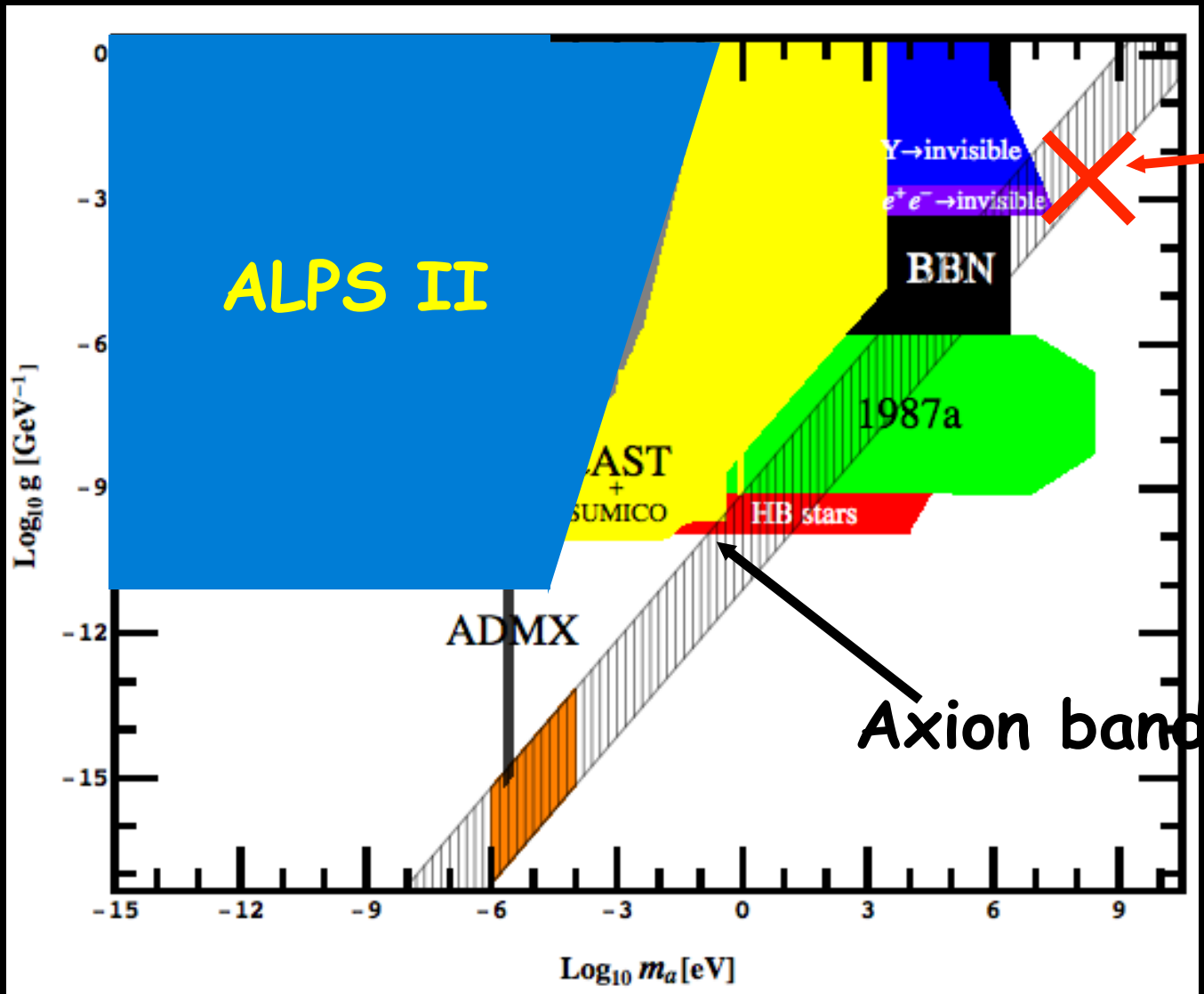


Small coupling, small mass

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

mass/energy

Weaker interaction



Dark Matter(s)

Can Dark Matter be WISPy?

(Weakly Interacting Sub-eV Particley)

Slim

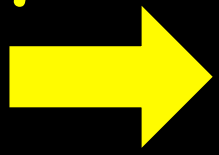
Properties of Dark Matter

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

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

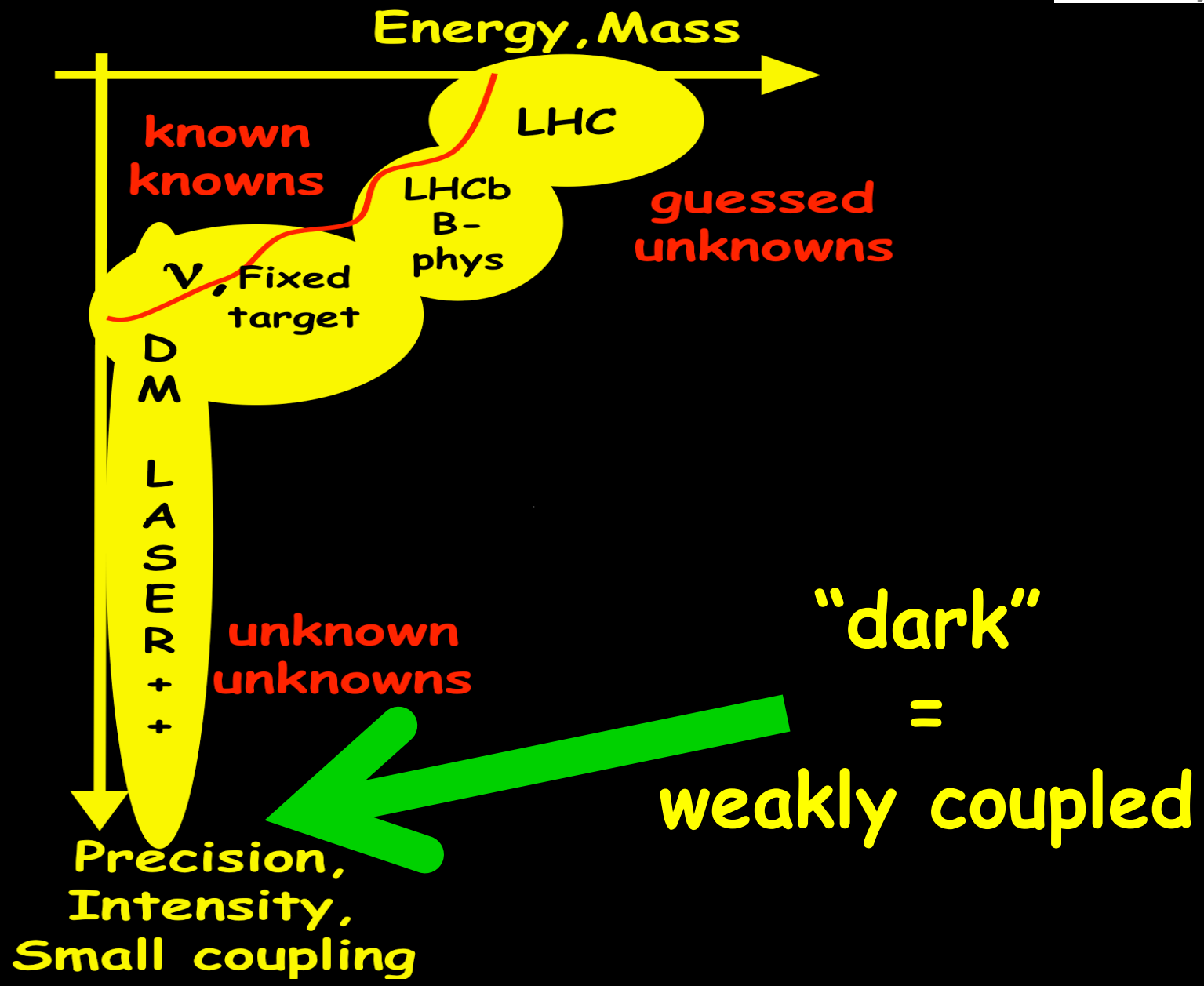
➔ very, very weak interactions with light and with ordinary matter

➔ Exactly the property of WISPs



Exploring is (at least) 2 dimensional

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



A common prejudice

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- Dark Matter has to be heavy: $m_{\rm DM} \gtrsim {\rm keV}$.

- Prejudice based on thermal production!
  and/or fermionic DM!

Both assumptions give minimal velocity (thermal/Fermi)

➔ galaxy, i.e. structure, formation inhibited!

Weakly interacting sub-eV DM

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- Has to be non-thermally (cold!!!) produced

  ➡ See misalignment mechanism

- Bosonic!

  ➡ Axion(-like particles)
  Hidden Photons

Dark matter has to be heavy…

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

Dark matter has to be heavy $m_{\rm DM} \gtrsim {\rm keV}$?

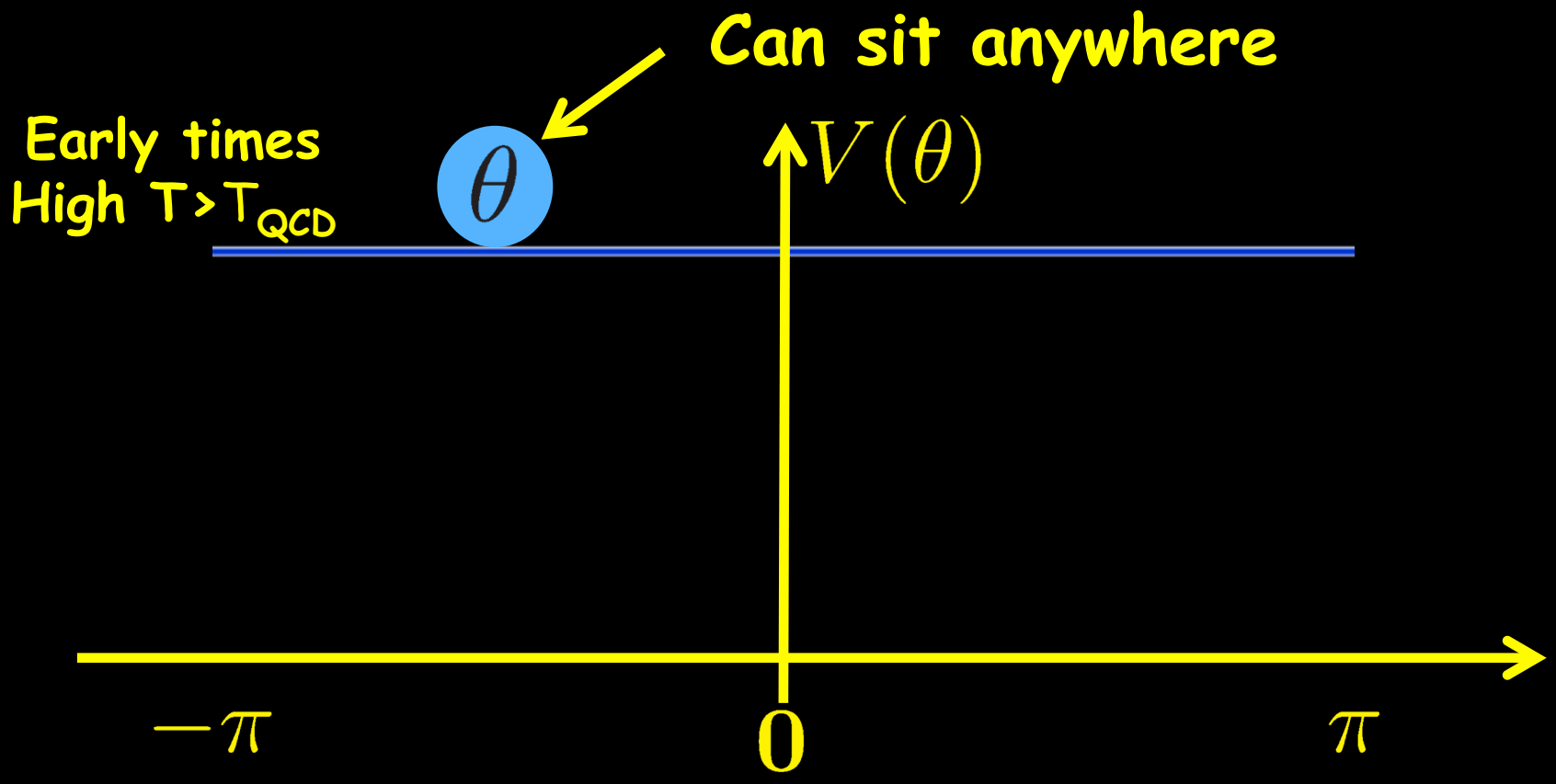
Dark matter has to be heavy…

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

Axion Dark Matter

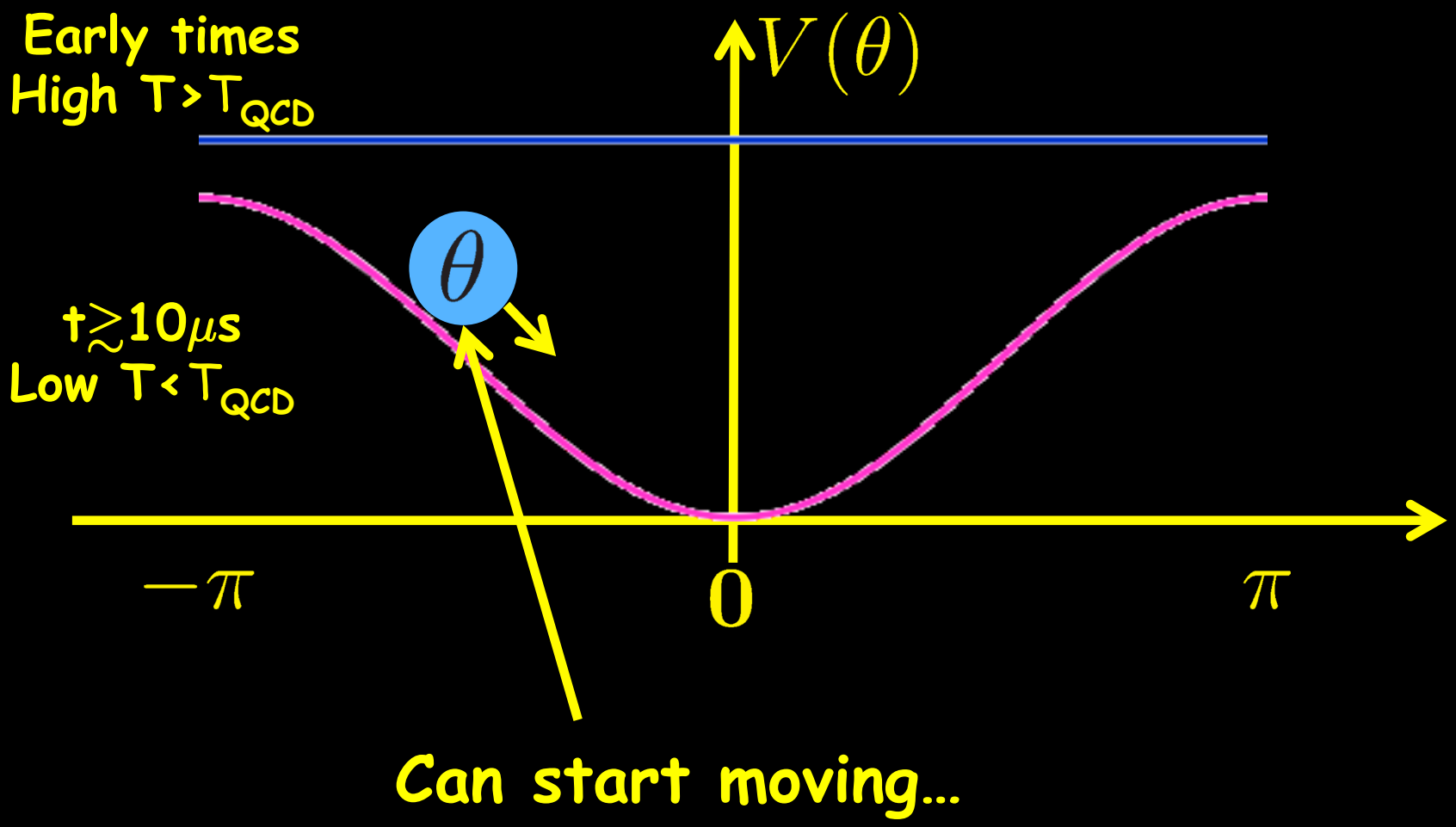
The axion has no clue where to start

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



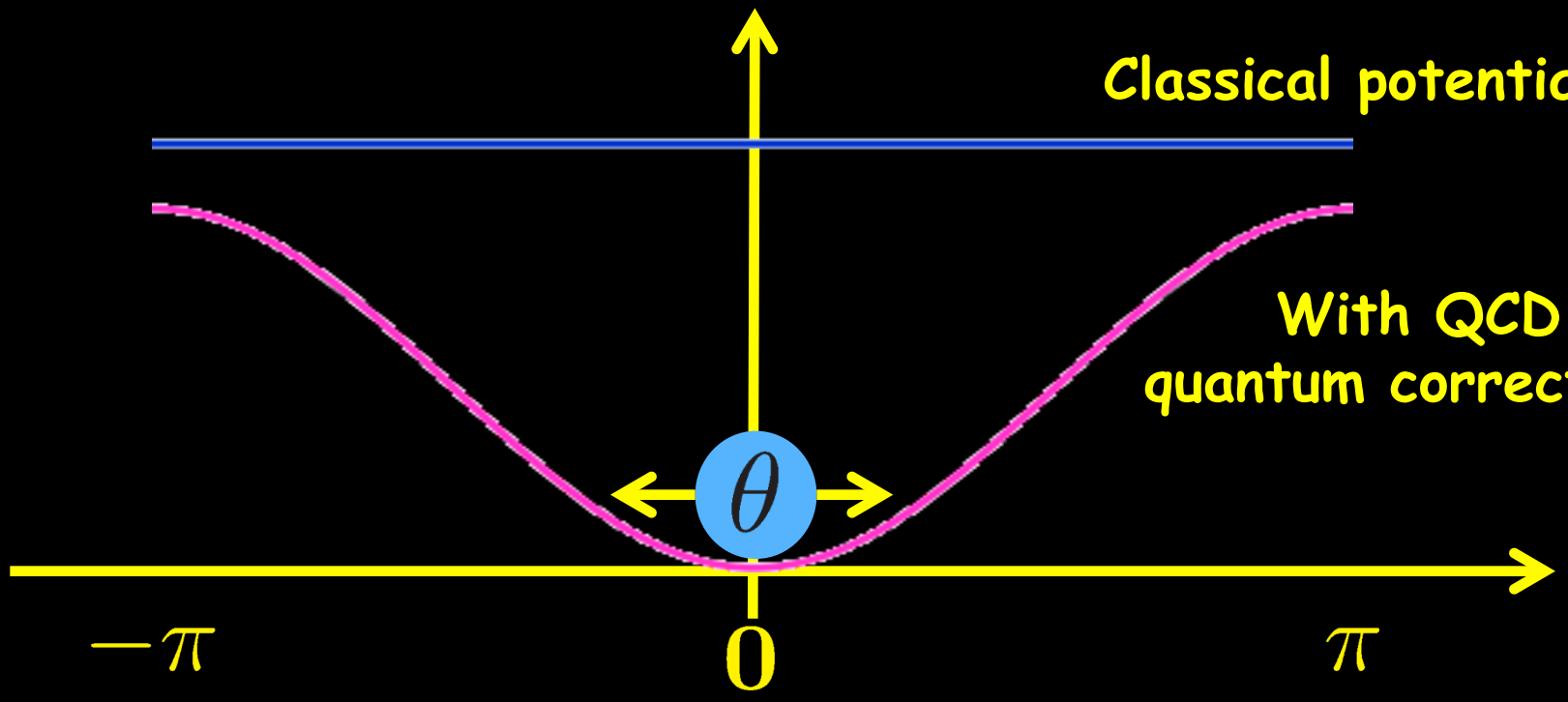
The axion has no clue where to start

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



The axion solution to the strong CP problem

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



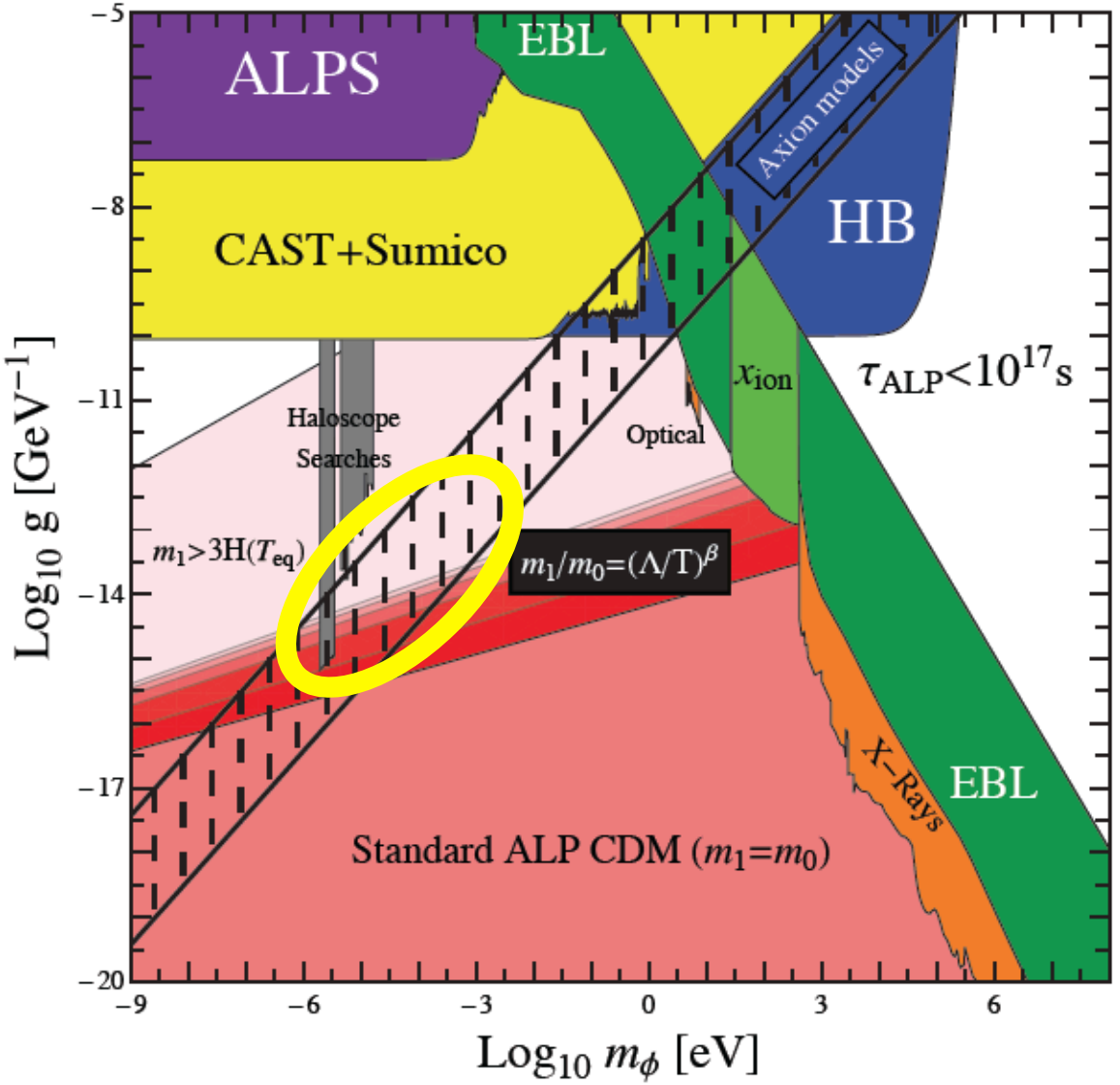
➔ Oscillations contain energy
➔ behave like non-relativistic particles (T=0)

Axion(-like particle) Dark Matter

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

~10^8 GeV

~10^{12} GeV



Detecting WISPy DM

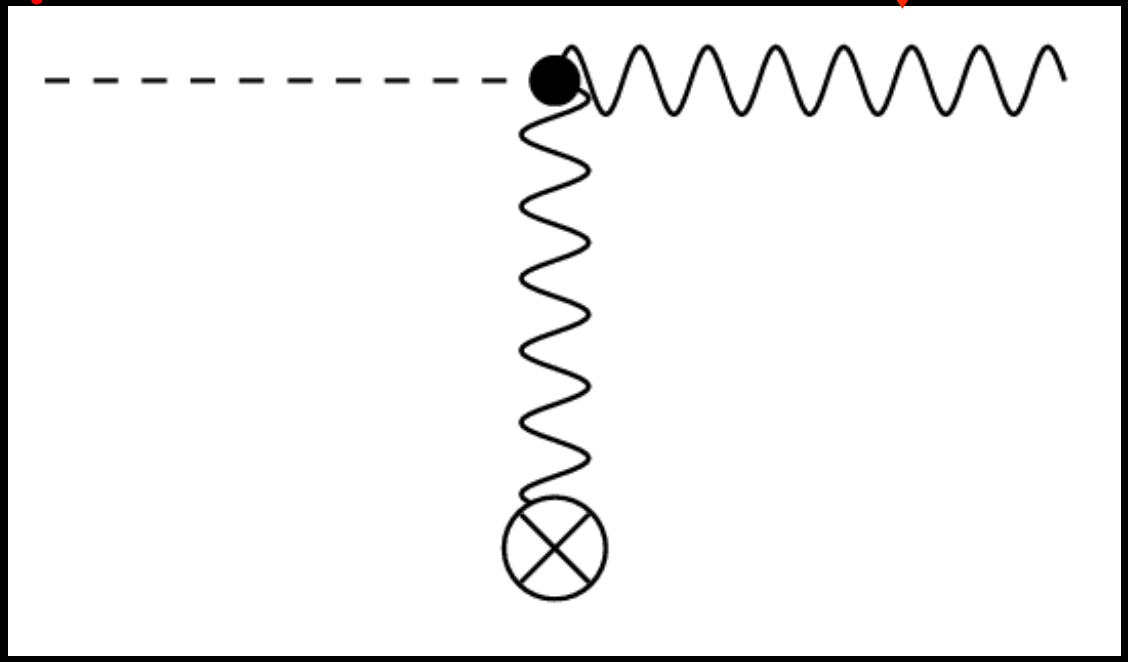
Use a plentiful source of axions

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- Photon Regeneration

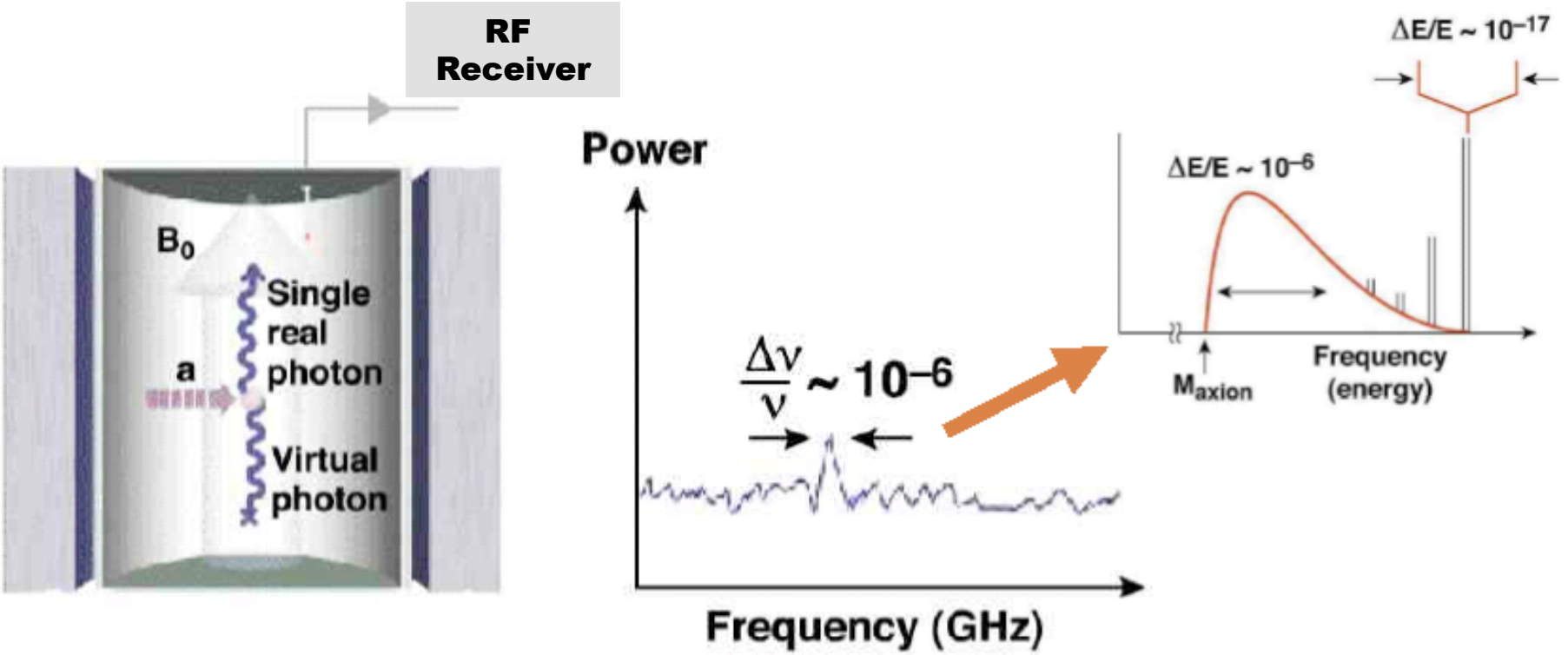
Photon
(amplified in resonator)

axion
(dark matter)



Signal: Total energy of axion

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

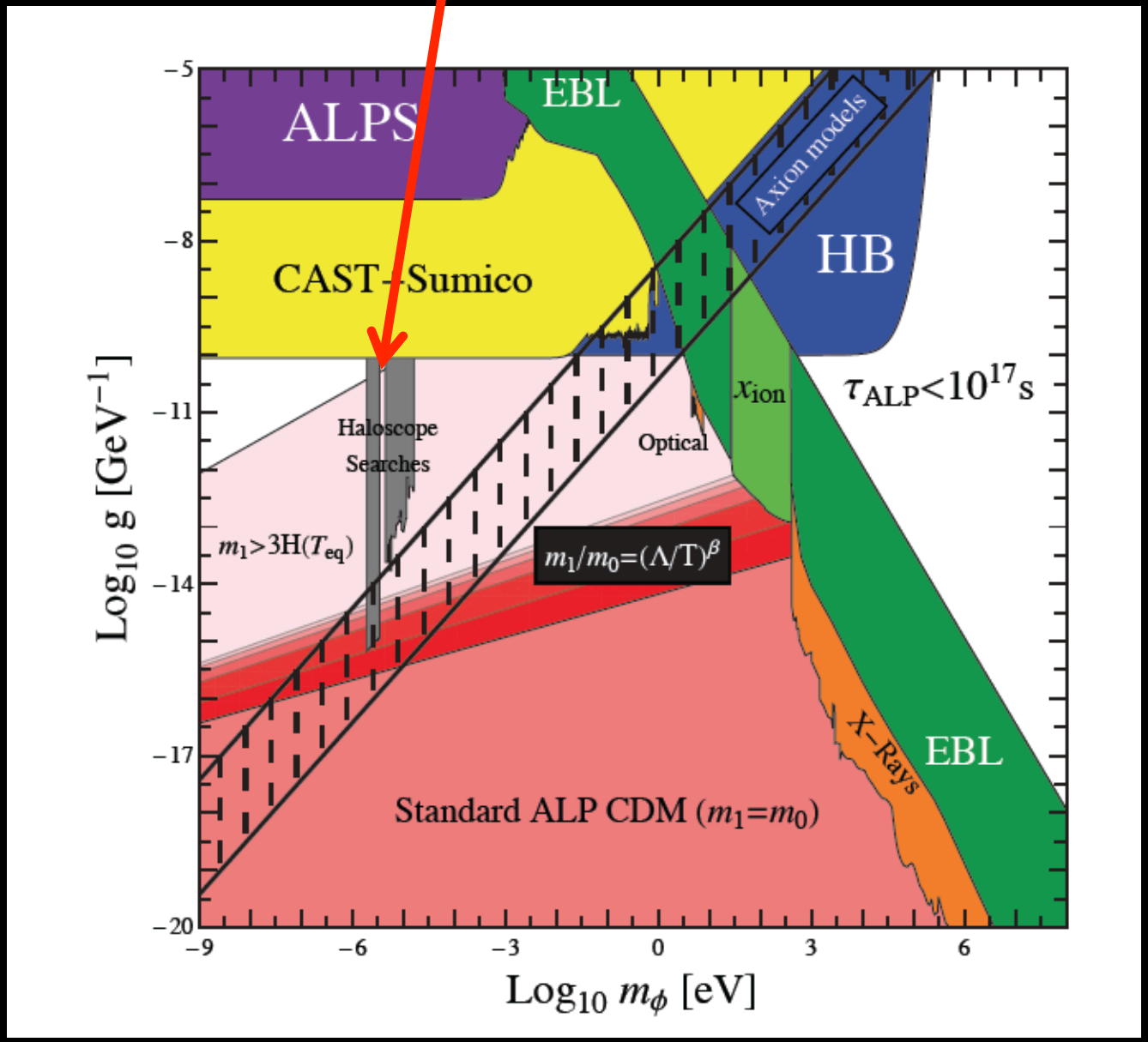


$$h\nu = m_a c^2 [1 + \mathcal{O}(\beta^2 \sim 10^{-6})]$$

Virial velocity in galaxy halo!

An extremely sensitive probe!!!

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



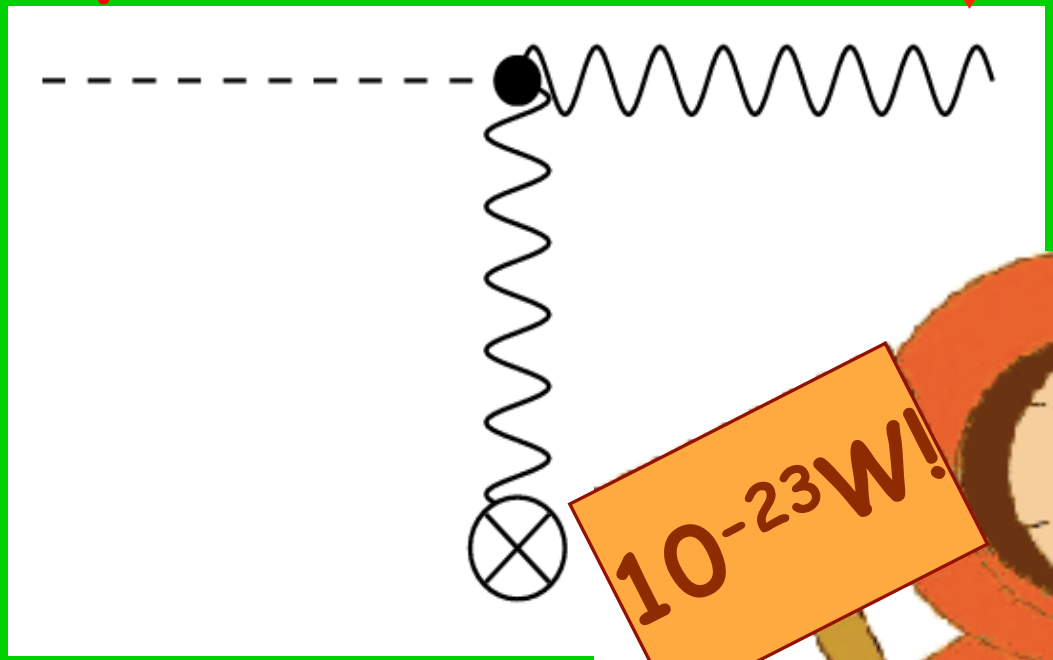
Electricity from Dark Matter ;-).

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- Photon Regeneration

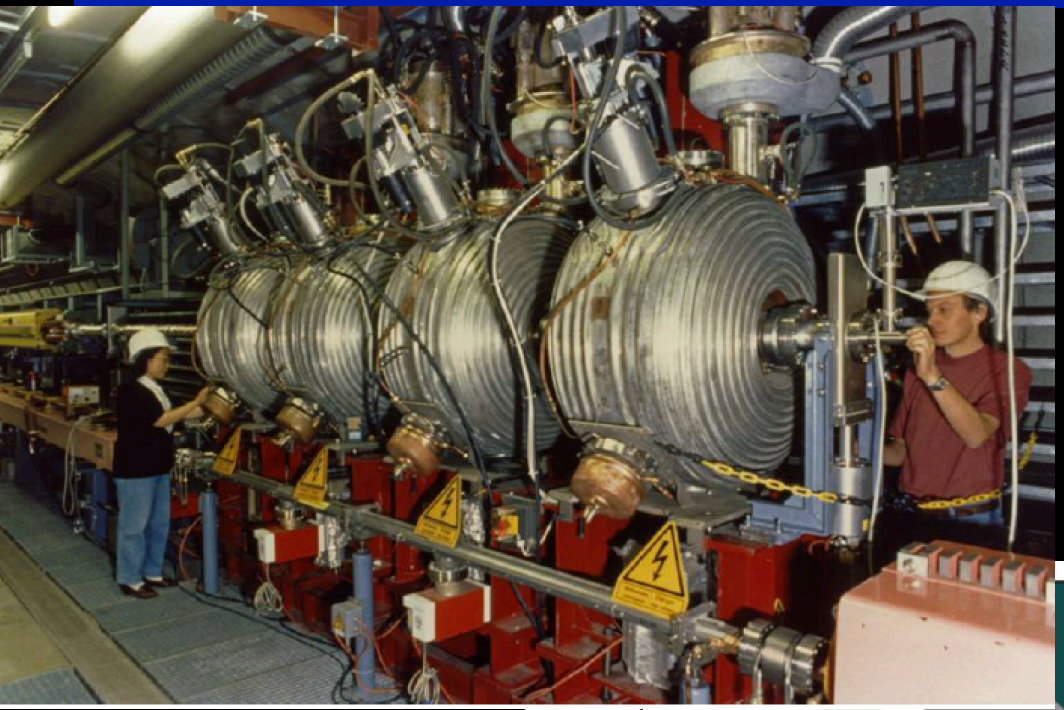
Photon
(amplified in resonator)

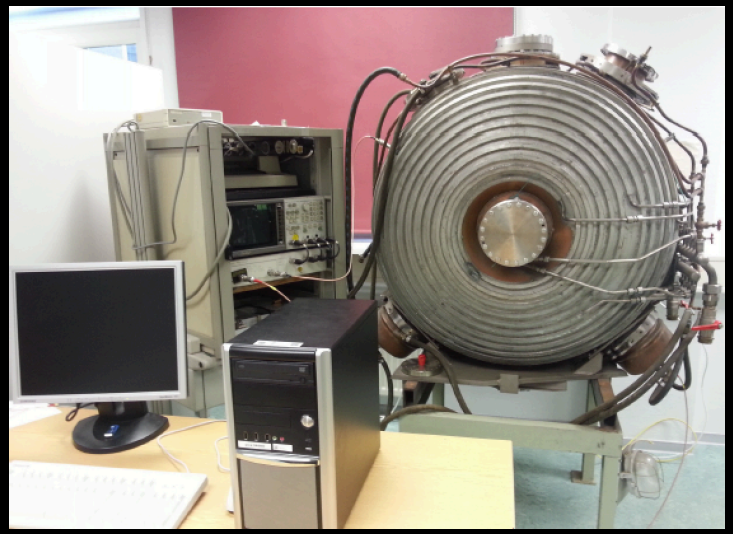
axion
(dark matter)

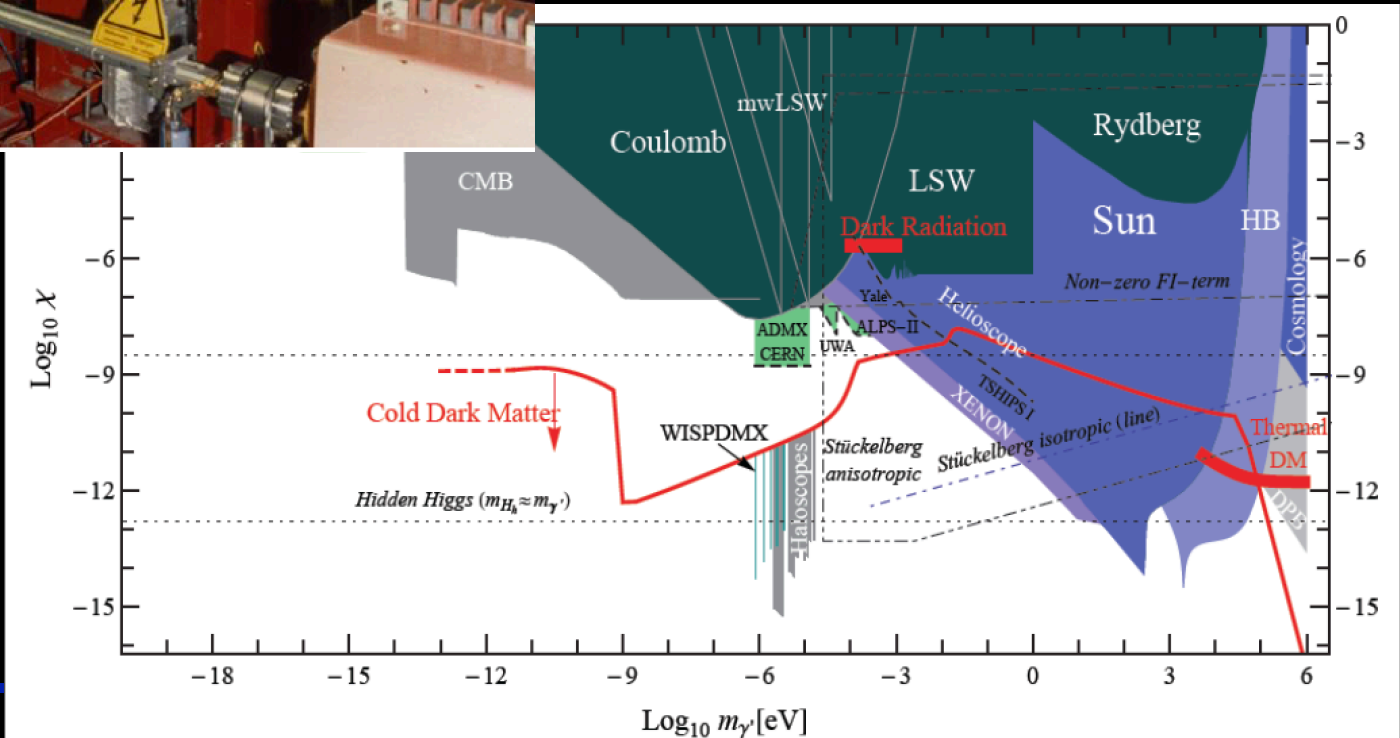


@ DESY + Bonn: WISPDMX

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



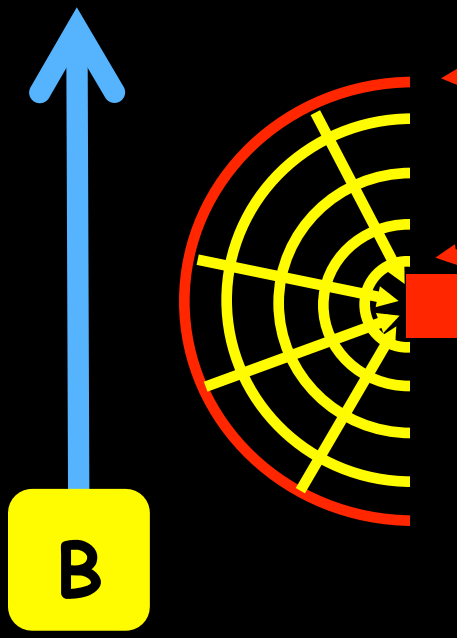




Broadband Search Strategy

Dark Matter Antenna

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

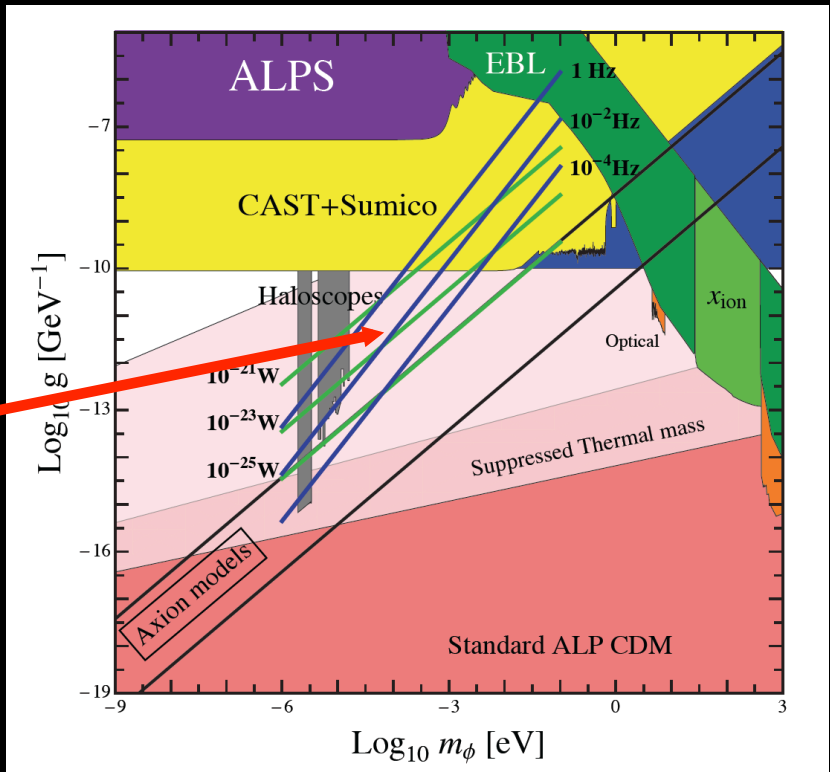


Antenna converts axion->photon

Radiation concentrated in center

Detector

Probes here;
very sensitive!!



@ DESY + Karlsruhe

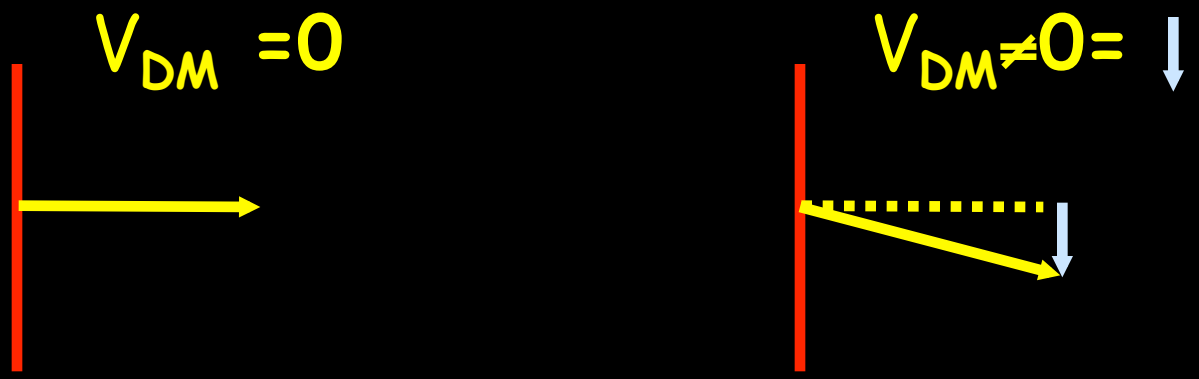
INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

Recycle Auger mirror

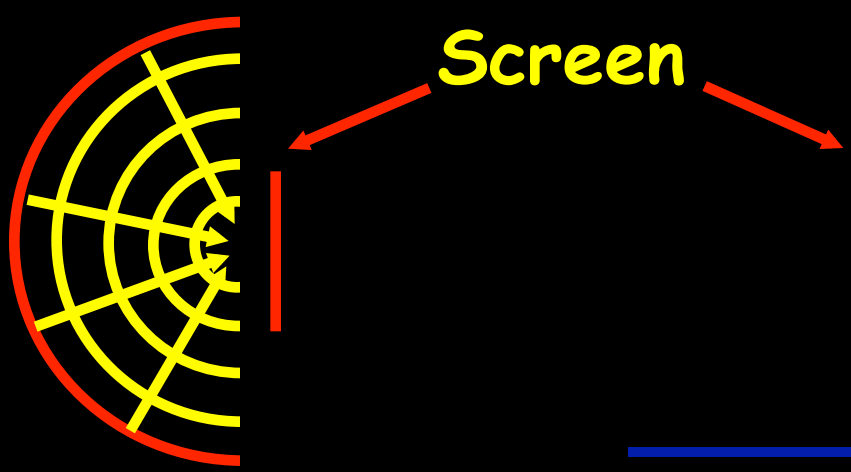
A Dream for ~~Astrology~~ ehhm Astronomy

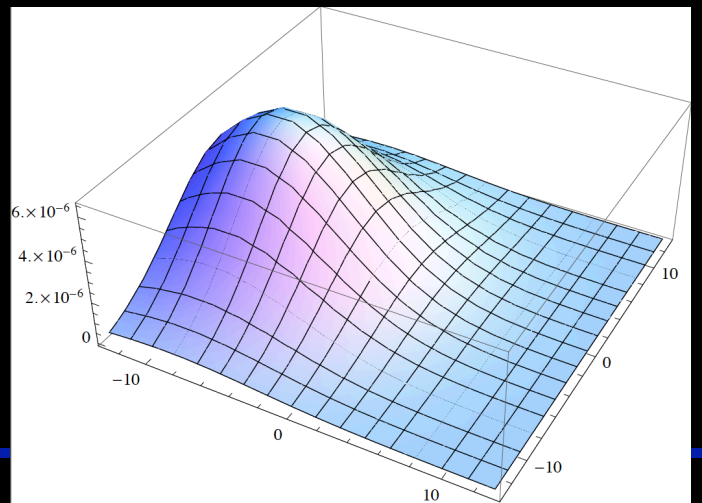
INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- Emission from moving dark matter



- A picture of the DM-velocity distribution





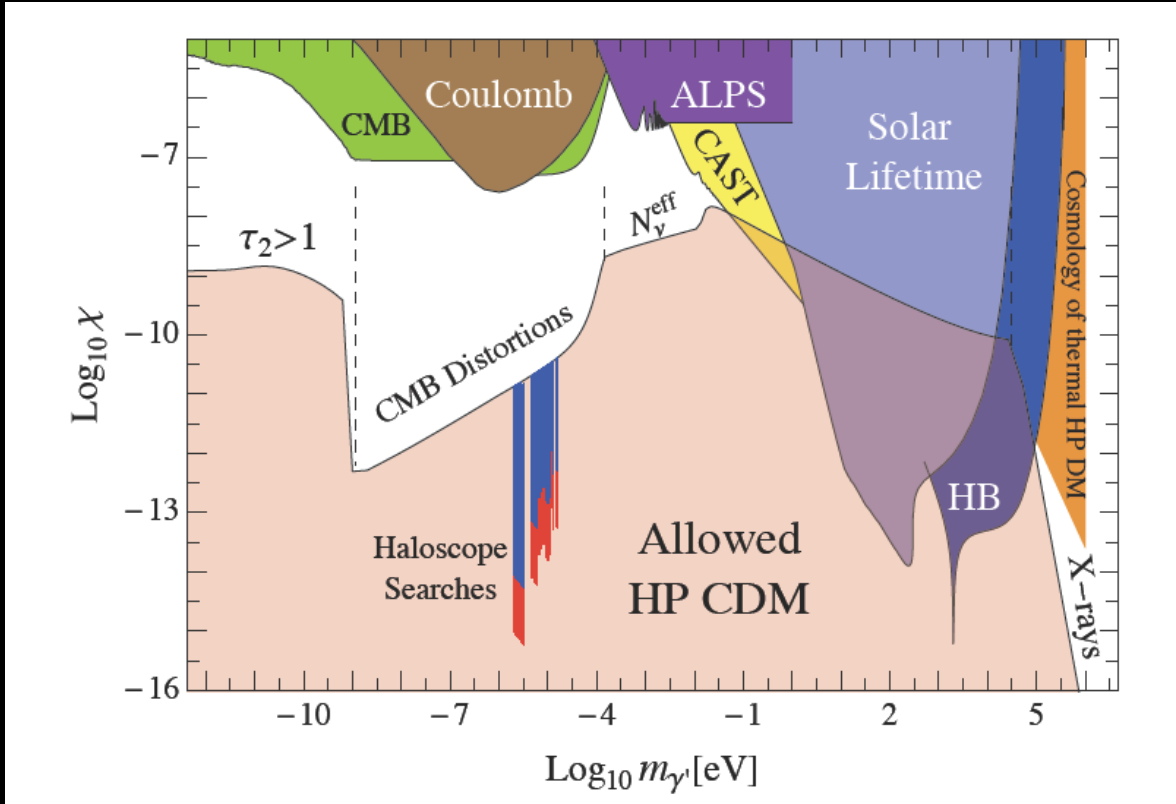
Pre-Final words

Also for hidden photons!!!

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- Most things also work for other well motivated light particles.
- E.g

extra (hidden) U(1) bosons=hidden photons!!!



Conclusions

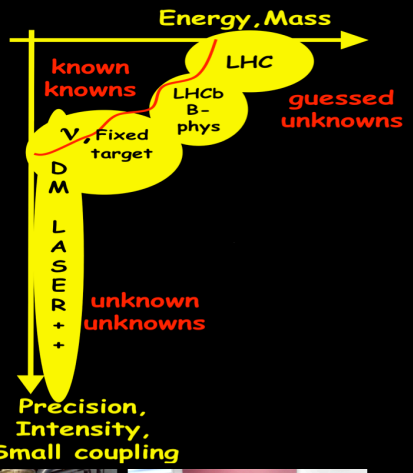
Conclusions

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

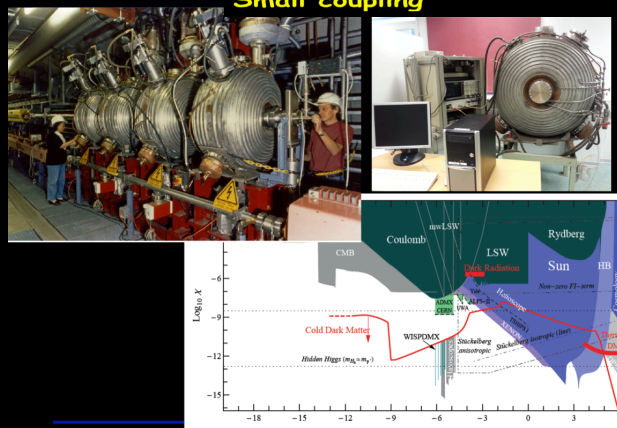
- Good Physics Case for Axions and WISPs

➡ explore `The Low Energy Frontier'

- Low energy experiments complementary to accelerators!



- Dark Matter may be WISPy ☺
  - ➔ New Search opportunities!
  - ➔ Searches ongoing!



Hidden sector

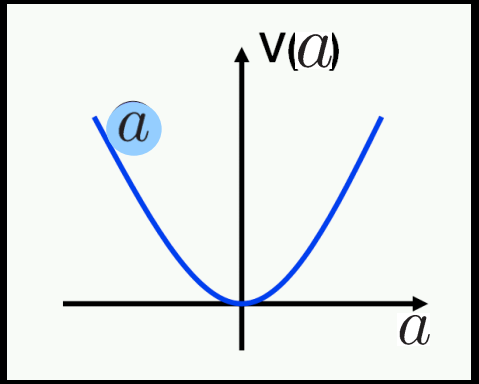
Axion Dark Matter

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

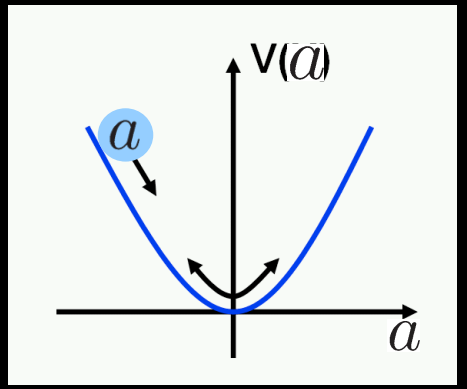
$$\ddot{a} + 3H\dot{a} + m_a^2 a = 0$$

$$H = \frac{\dot{R}(t)}{R(t)}$$

- $H \gg m_a$ ➔ overdamped oscillator



- $H \ll m_a$ ➔ damped oscillator



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

➔ Dark Matter

Beyond Photon Couplings

Light bosons can couple to fermions

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- Goldstone bosons naturally couple to fermions (charged under the symmetry)

- E.g. Family symmetry changing e into μ

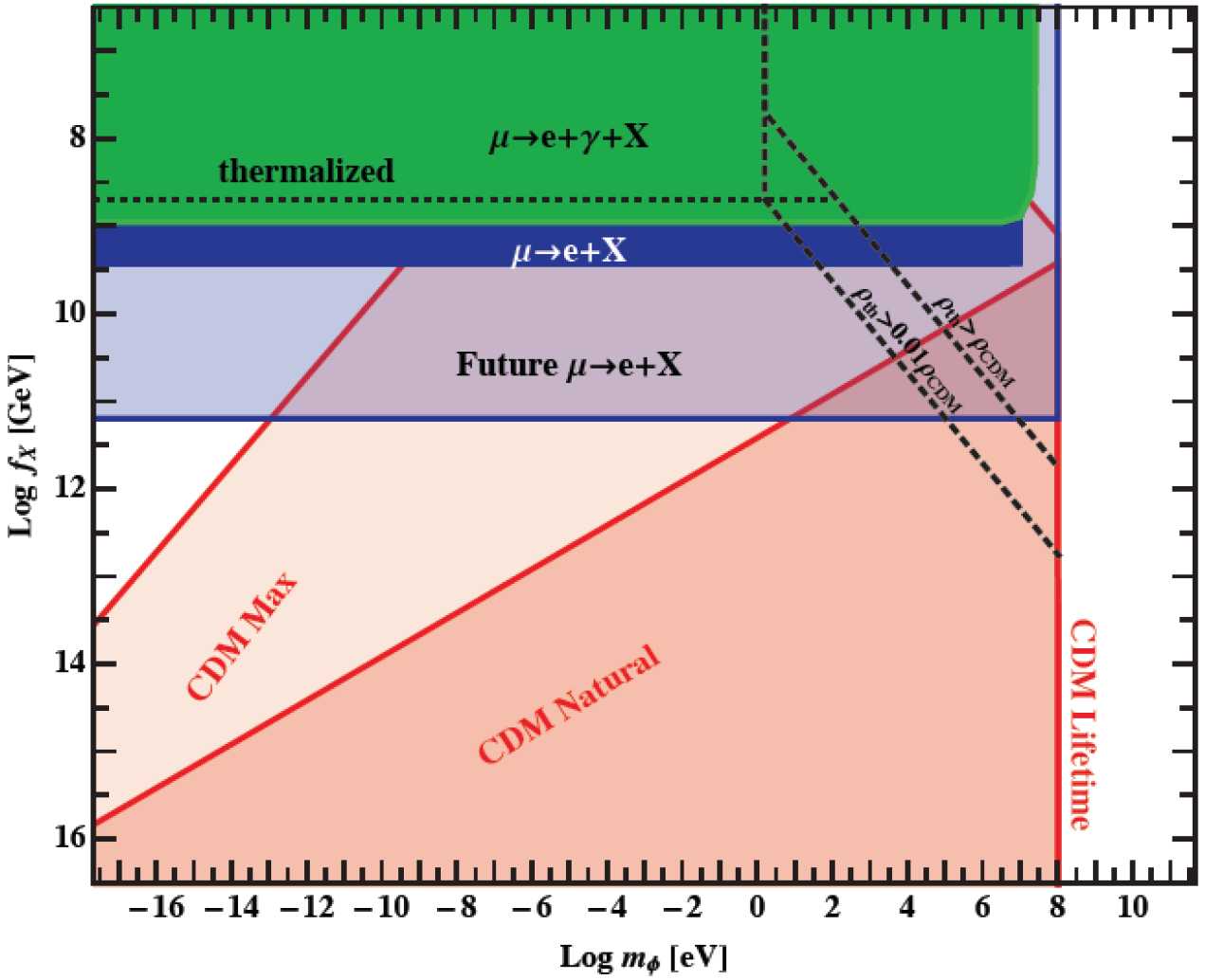
$$(\partial_\mu \phi)\bar{\mu}\gamma^\mu e + h.c.$$

Interestingly these couplings are not very constrained from astrophysics!

(not enough energy to make μ s

Plenty of room for dark matter

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



INSTITUT FÜR
THEORETISCHE PHYSIK
Heidelberg
University

Flexing BICEP 2

Axion/ALP DM: Two Scenarios

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

1) Phase Transition before inflation

Inflation ensures:

same initial field value everywhere

➔ Can choose this value

➔ Tune to right DM density (always poss.)

But quantum fluctuations from inflation

➔ Isocurvature fluctuations ~H_I

2) Phase Transition after inflation

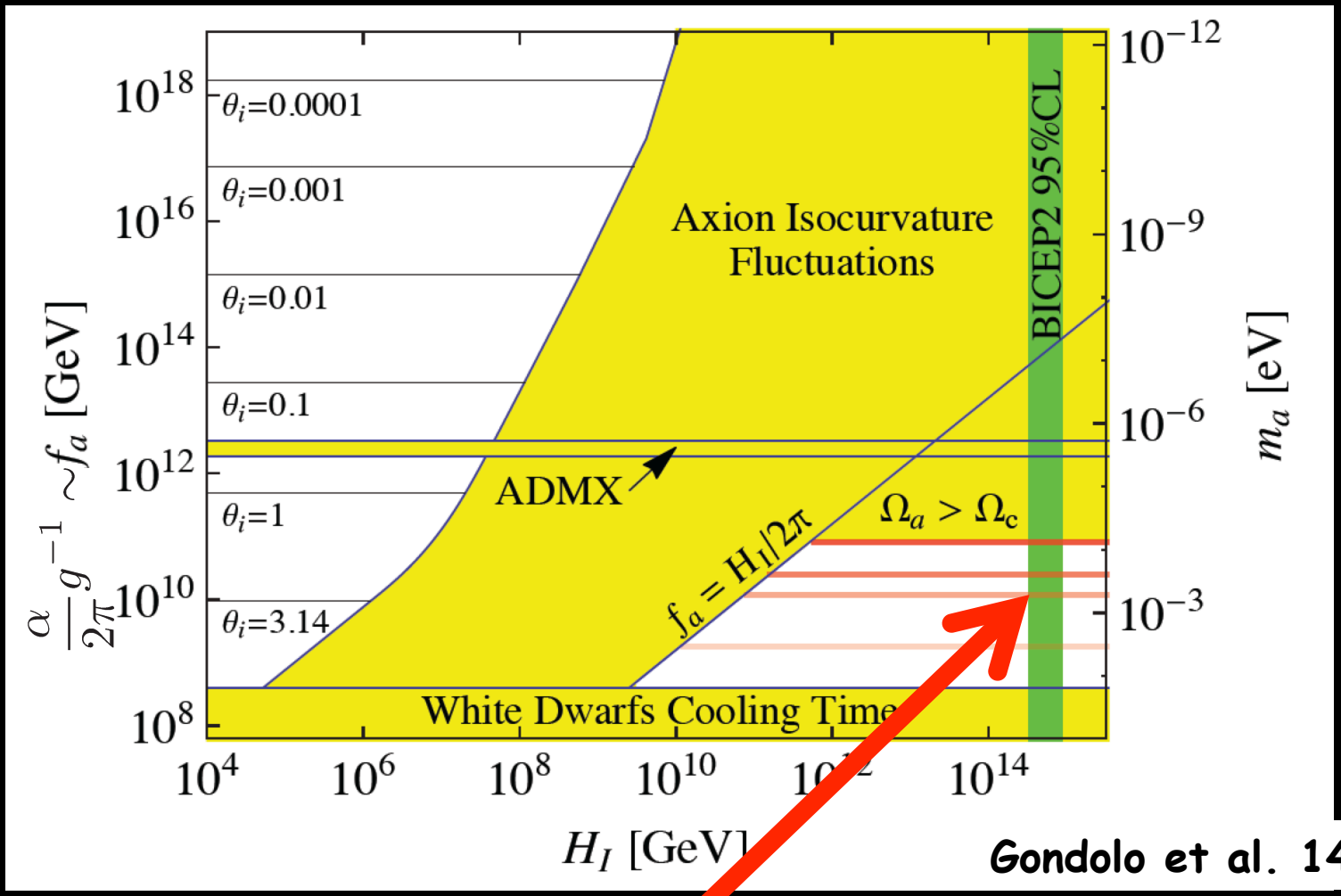
average over initial field values

➔ Predict DM density (correct only for specific mass/coup.)

➔ No isocurvature fluctuations

What is allowed?

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University



Gondolo et al. 1403.4594

Preferred range!

Two.5 comments

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

1) Similar behavior for other ALPs/WISPs

2) Can be circumvented by non-trivial couplings to gravity.

2.5) Needs to be confirmed

Properties of Dark Matter

INSTITUT FÜR THEORETISCHE PHYSIK
Heidelberg University

- 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