

10 orders of magnitude lighter

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Fundamental Physics @ Really Low Energies

J. Jaeckel**

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In the year 1 AH^* ...



...we think we understand EW symmetry breaking

* After Higgs discovery

Understanding the origin of mass

We are still trying to understand most of the mass in the Universe: **The Dark Matter Mass**

SUSY WIMPs

$$m_{WIMP} \sim M_{SUSY} - \text{const.} \frac{m_Z^2}{M_{SUSY}}$$







0% - ε%
understood

Understanding the origin of mass

We are still trying to understand most of the mass in the Universe: **The Dark Matter Mass**

SUSY WIMPs





$$m_{WIMP} \sim M_{SUSY} - \text{const.} \frac{m_Z^2}{M_{SUSY}}$$

0% - ε%
understood

Axions

$$m_{axion} \sim \frac{\sqrt{m_{quark} \Lambda_{QCD} \Lambda_{QCD}}}{M_{PQ}}$$

>75%
understood



Where we want to go... a mythical story

The Standard Model

+

The Hidden Sector

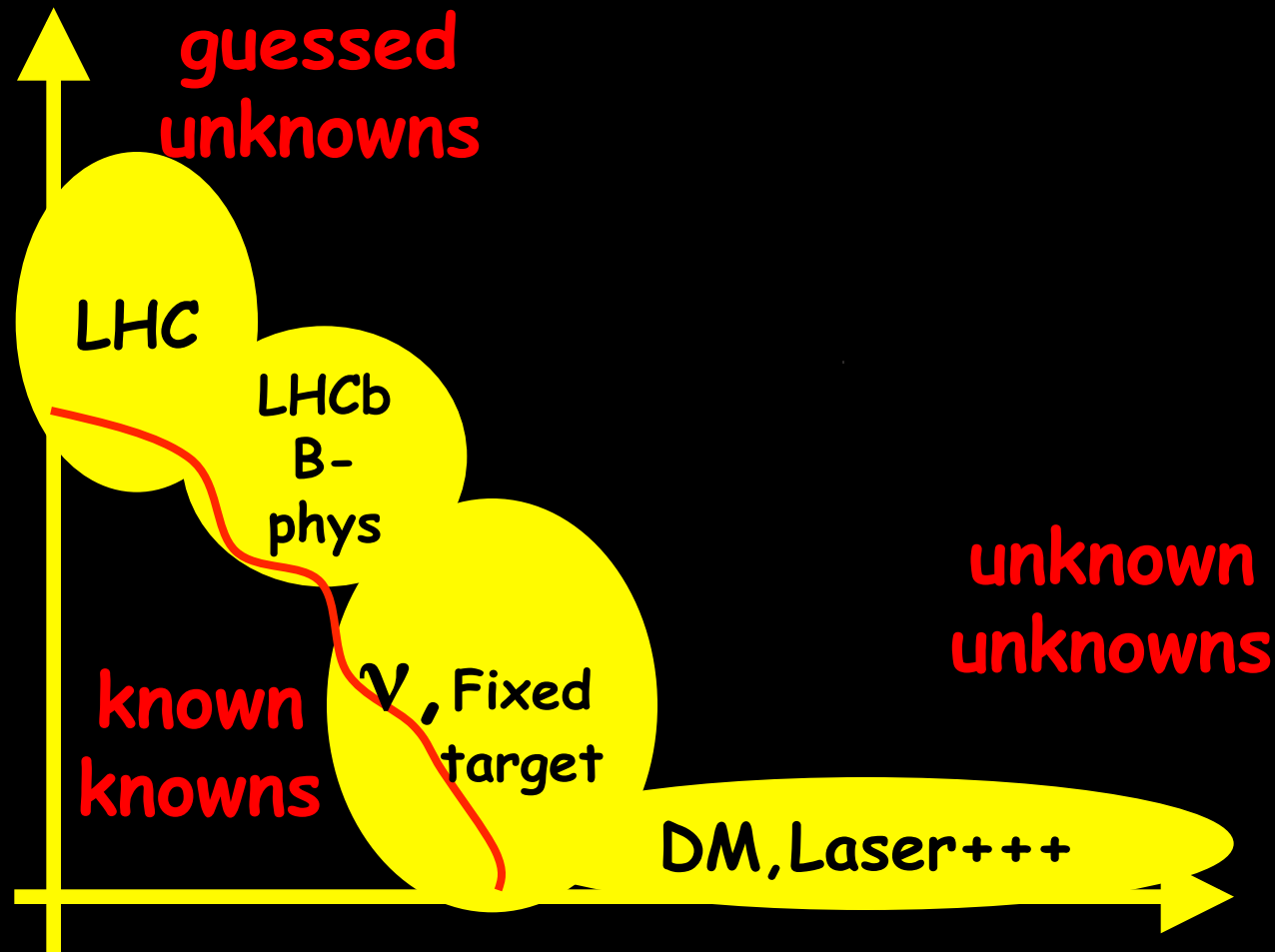
Beyond the SM
(directly accessible
to colliders)

Here be Dragons



Exploring is (at least) 2 dimensional

Energy, Mass



Precision,
Intensity,
Small coupling

Today's question:

Are the extra
(gauge) Forces?

$SU(3) \times SU(2) \times U(1) \times ???$

The simplest case

Hidden Photons:

$$??? = U(1)_{\text{hid}}$$

The simplest case

Hidden Photons:

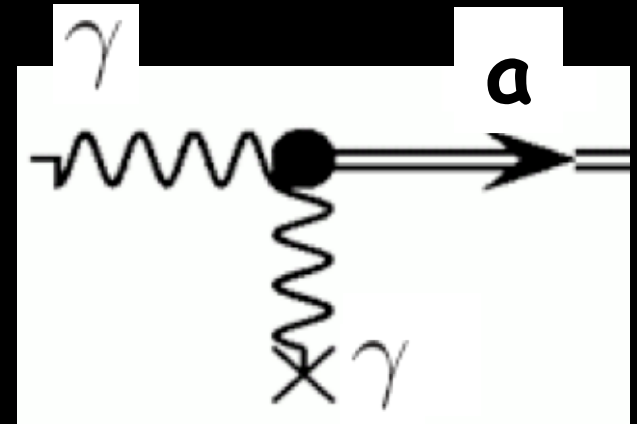
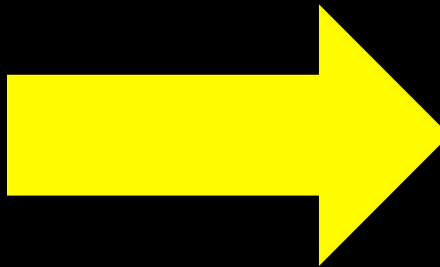
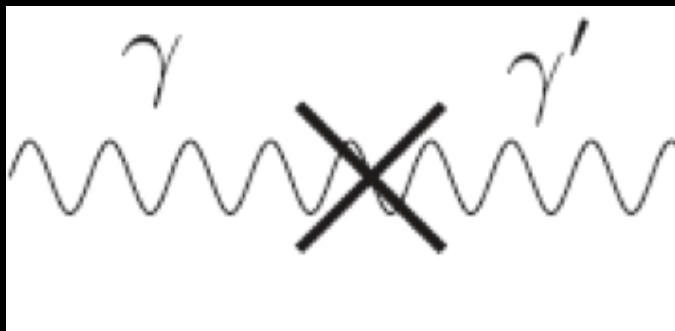
$$??? = U(1)_{\text{hid}}$$



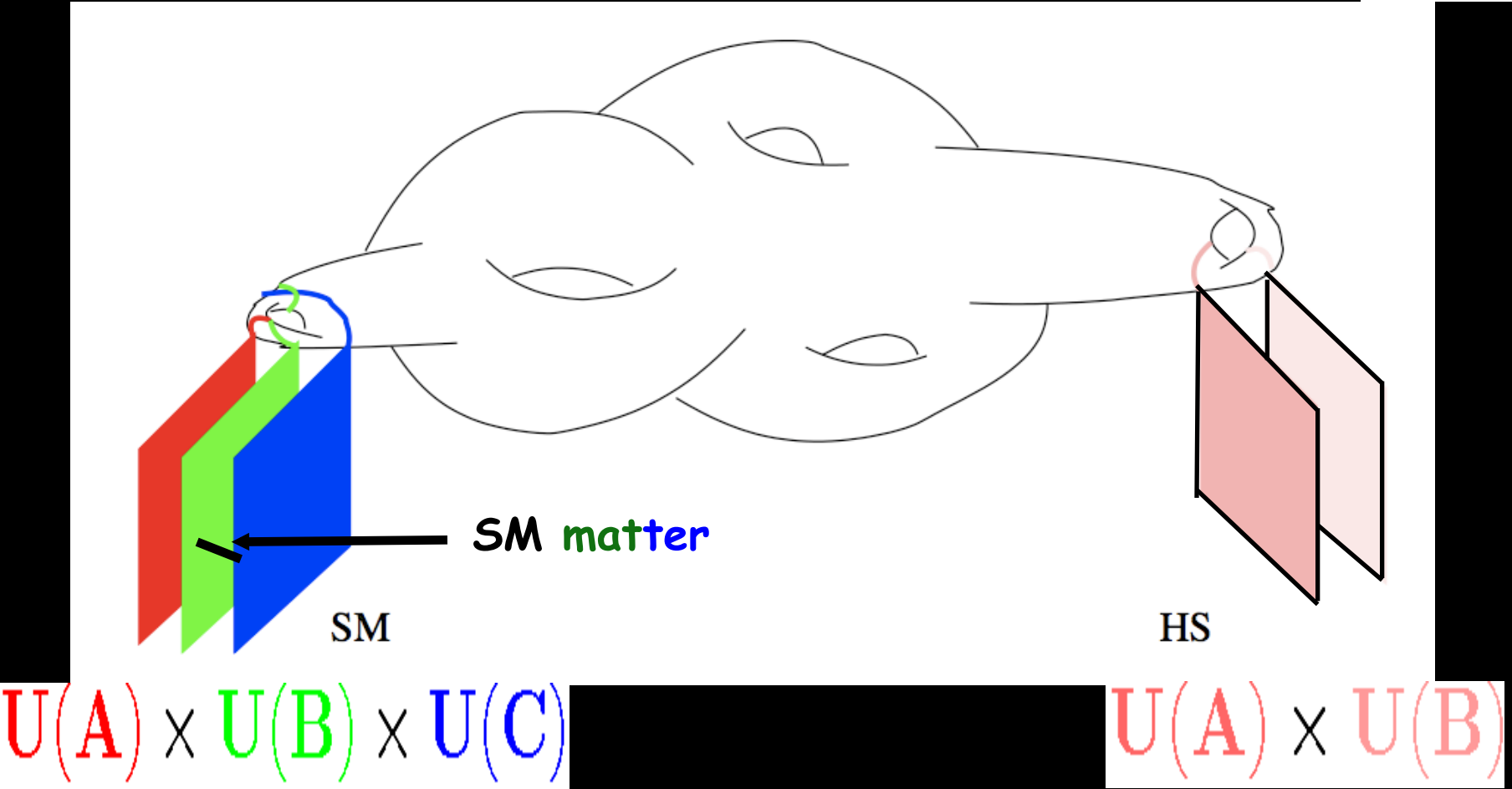
Will be light + very weakly coupled

→ Weakly Interacting Slim Particle = WISP

General WISPs, e.g. axions

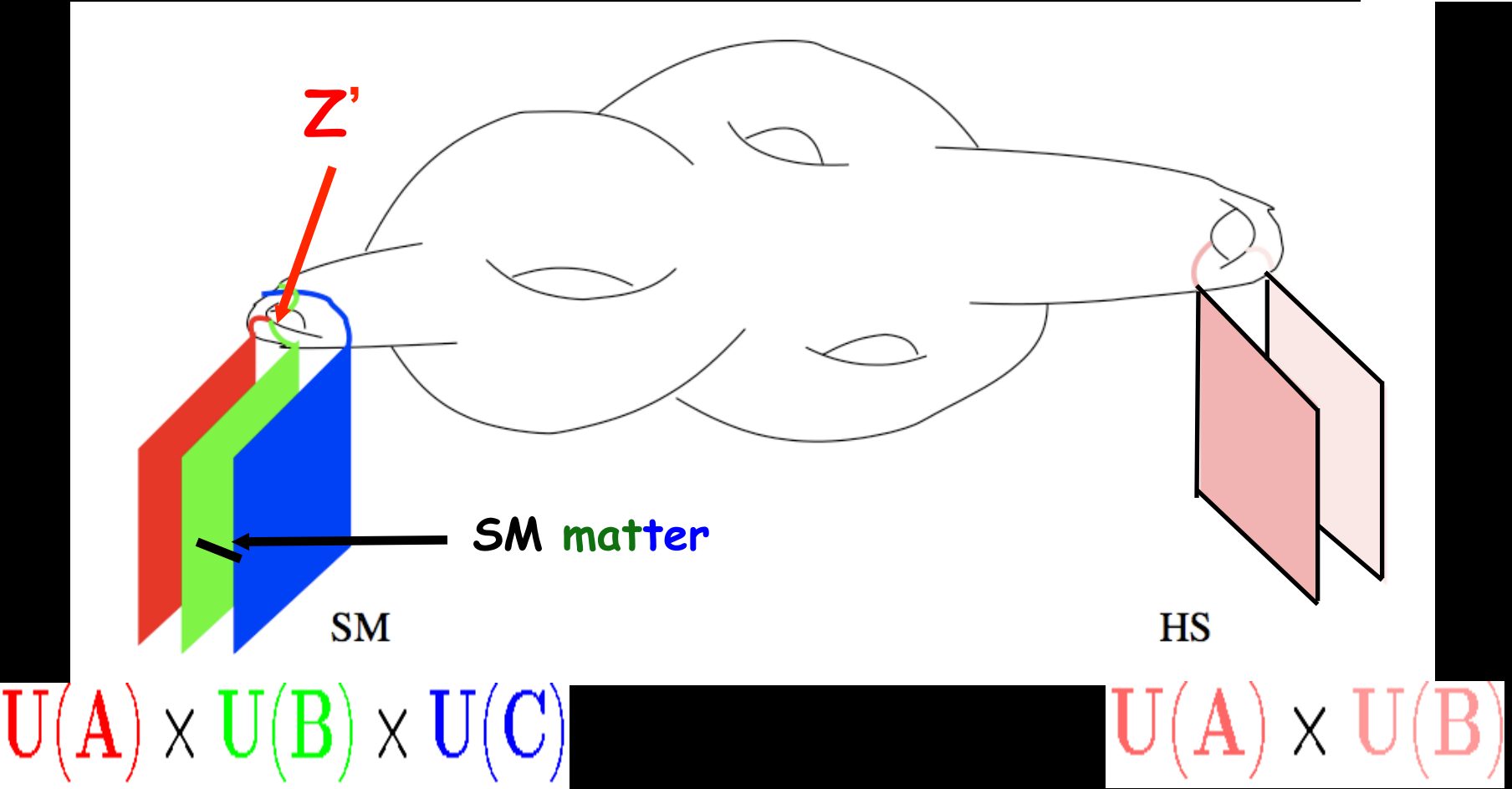


String theory likes extra gauge groups



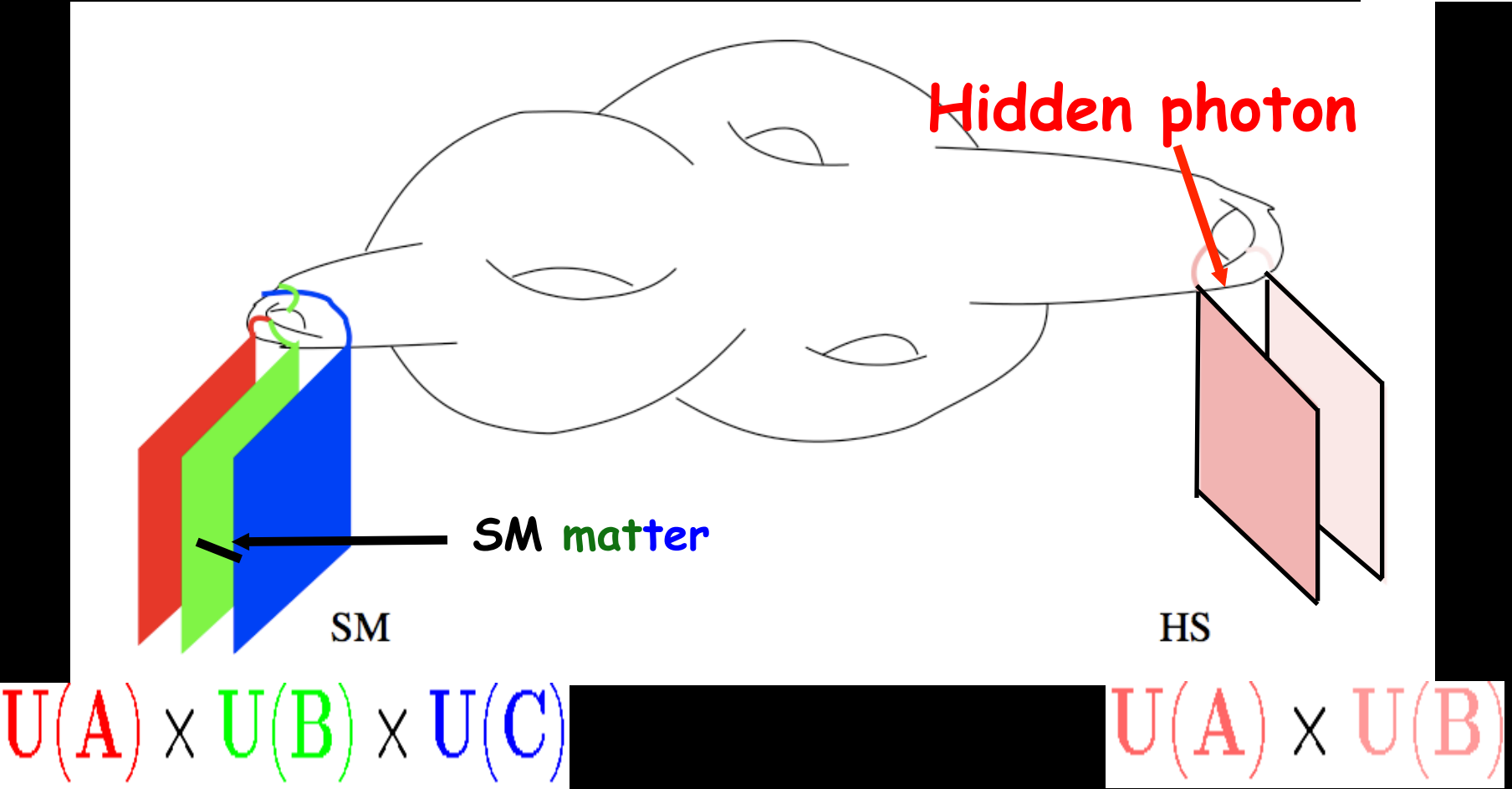
➔ Many extra $U(1)$ s!

String theory likes extra gauge groups



➔ Many extra $U(1)$ s!

String theory likes extra gauge groups



➔ Many extra $U(1)$ s!

Hidden Photon interactions

- Kinetic mixing

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

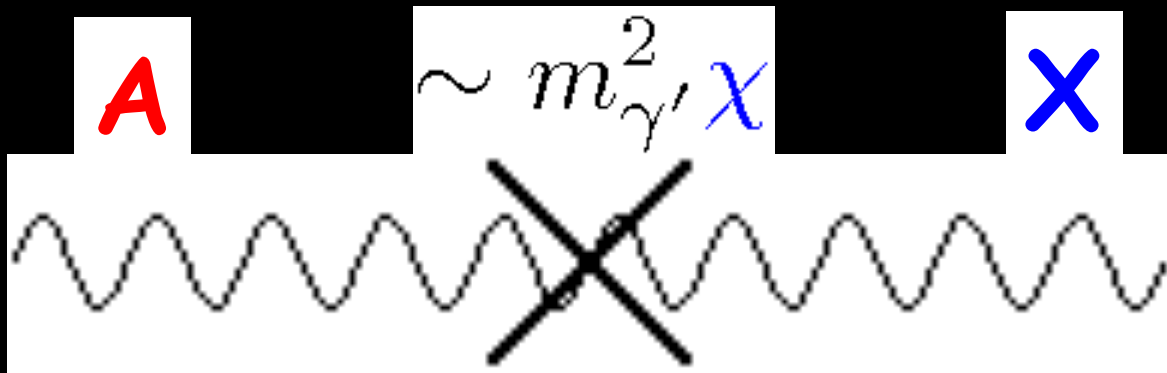
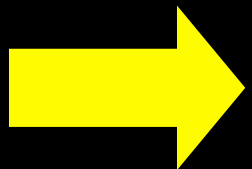
„Our“ U(1)

„Hidden“ U(1)

Mixing

+ Mass

$$\mathcal{L}_{\text{mass}} = \frac{1}{2}m_{\gamma'}^2 X^\mu X_\mu$$



Modified Coulomb's Law → Extra force!

- Kinetic mixing

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

„Our“ U(1)

„Hidden“ U(1)

Mixing

+ Mass $\mathcal{L}_{\text{mass}} = \frac{1}{2}m_{\gamma'}^2 X^\mu X_\mu$

$$\delta V \sim \alpha q^2 \chi^2 \frac{\exp(-m_{\gamma'} r)}{r}$$

Hidden by
small coupling

Hidden by
large mass

Hidden Photon interactions

- Kinetic mixing

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

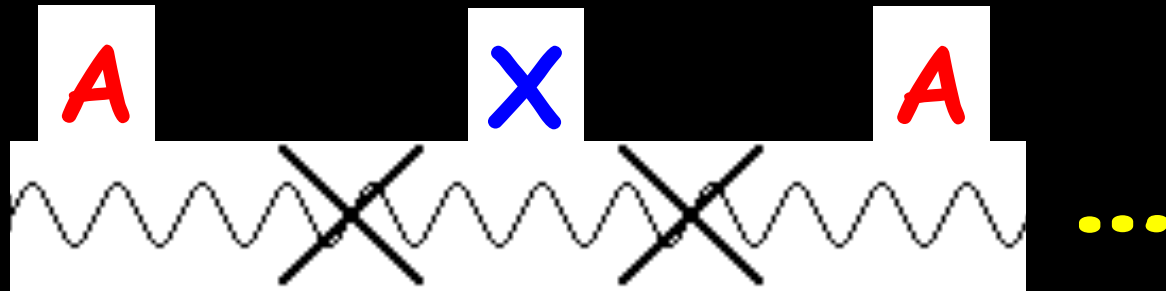
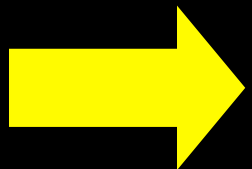
„Our“ U(1)

„Hidden“ U(1)

Mixing

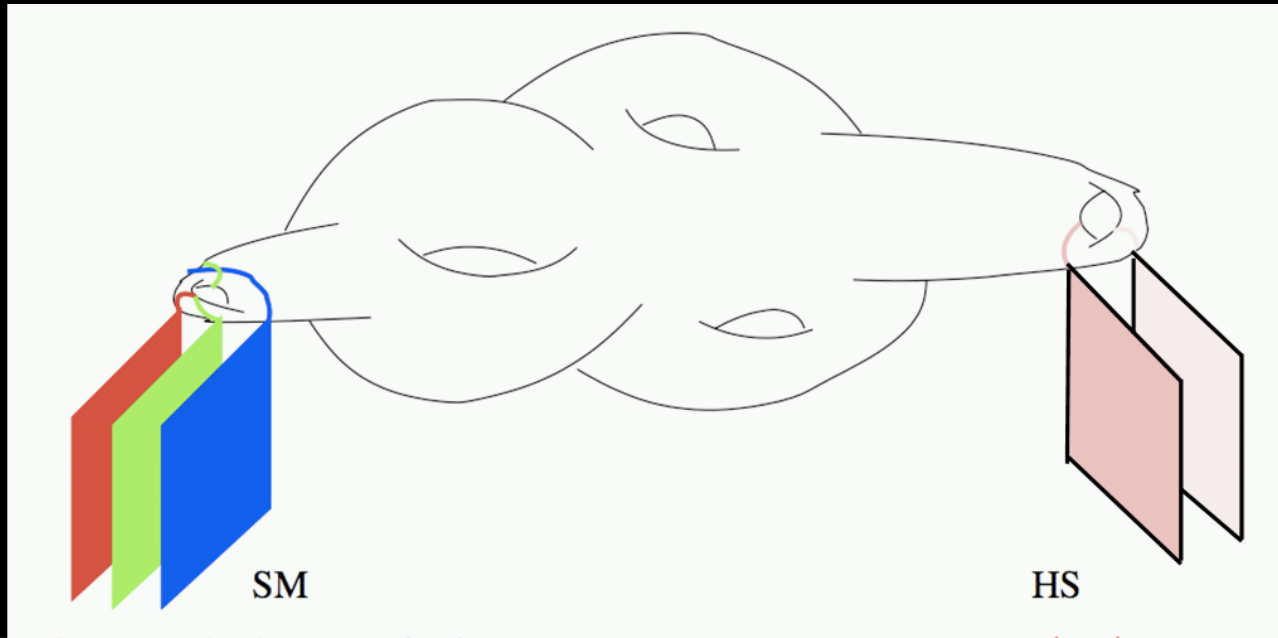
+ Mass

$$\mathcal{L}_{\text{mass}} = \frac{1}{2}m_{\gamma'}^2 X^\mu X_\mu$$



=analog ν -oscillations

Explore fundamental properties.



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

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

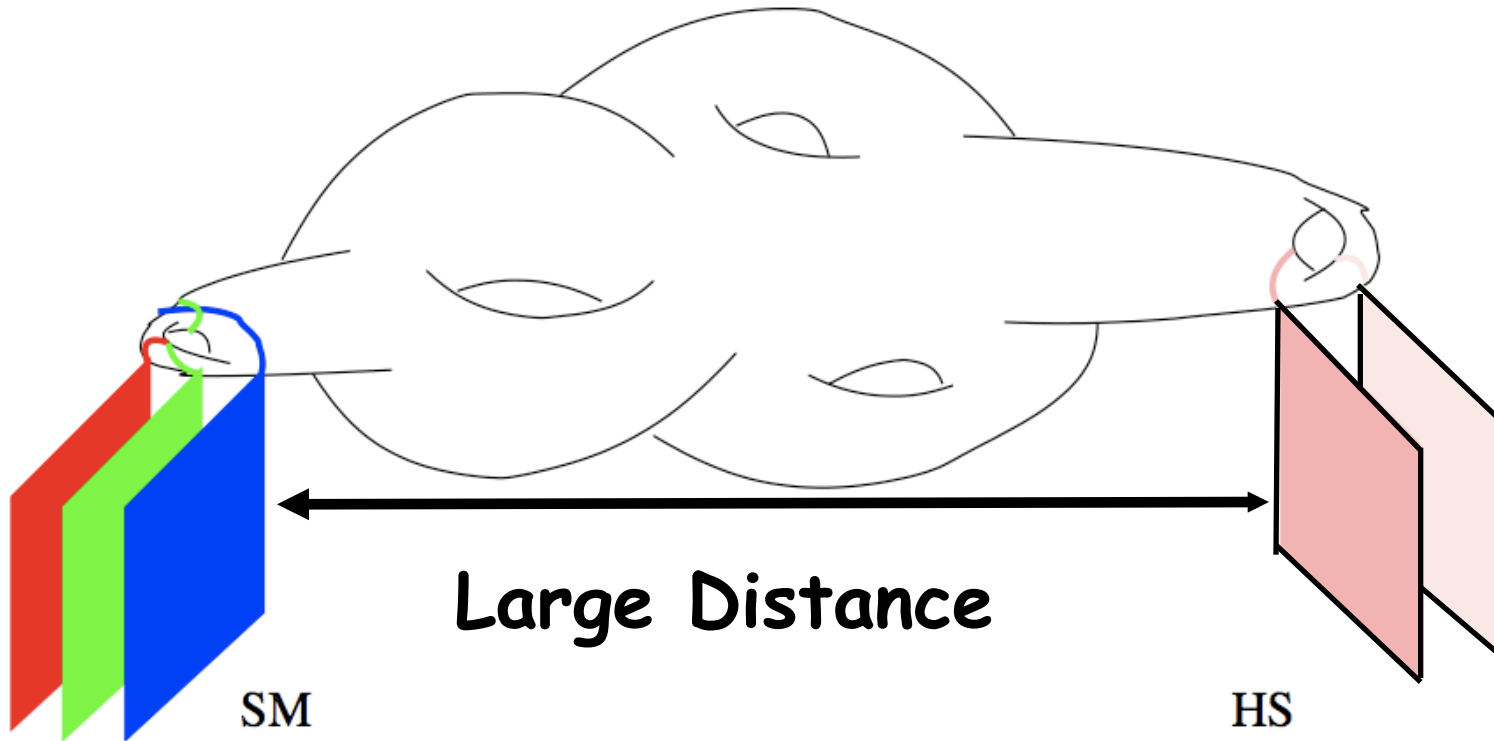
$$\chi \sim \frac{g_s}{8\pi} \frac{1}{Volume^x}$$

$$m_{\gamma'}^2 \sim \frac{M_s}{Volume^y}$$

Global feature

Fundamental high energy scale!

Hidden by distance



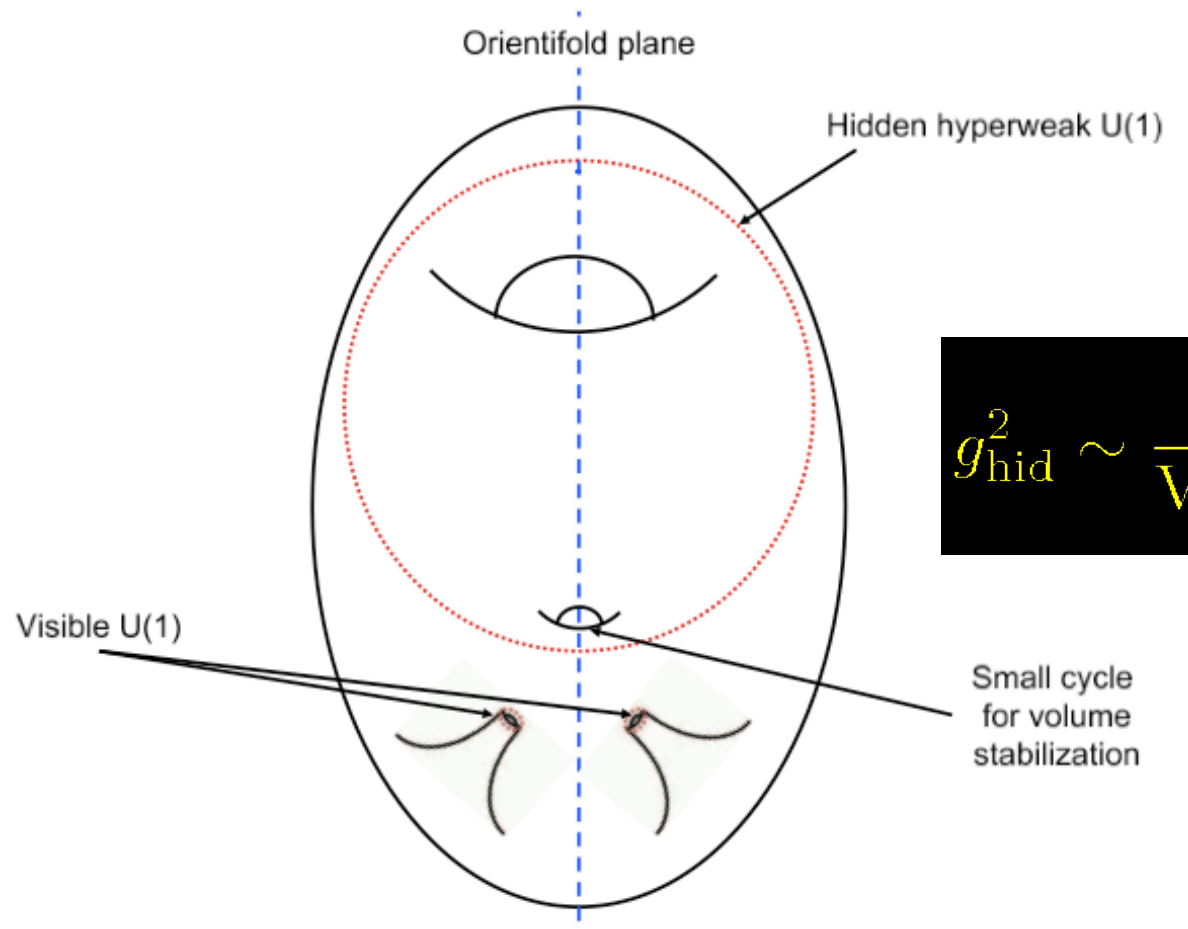
$$U(A) \times U(B) \times U(C)$$

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

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

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

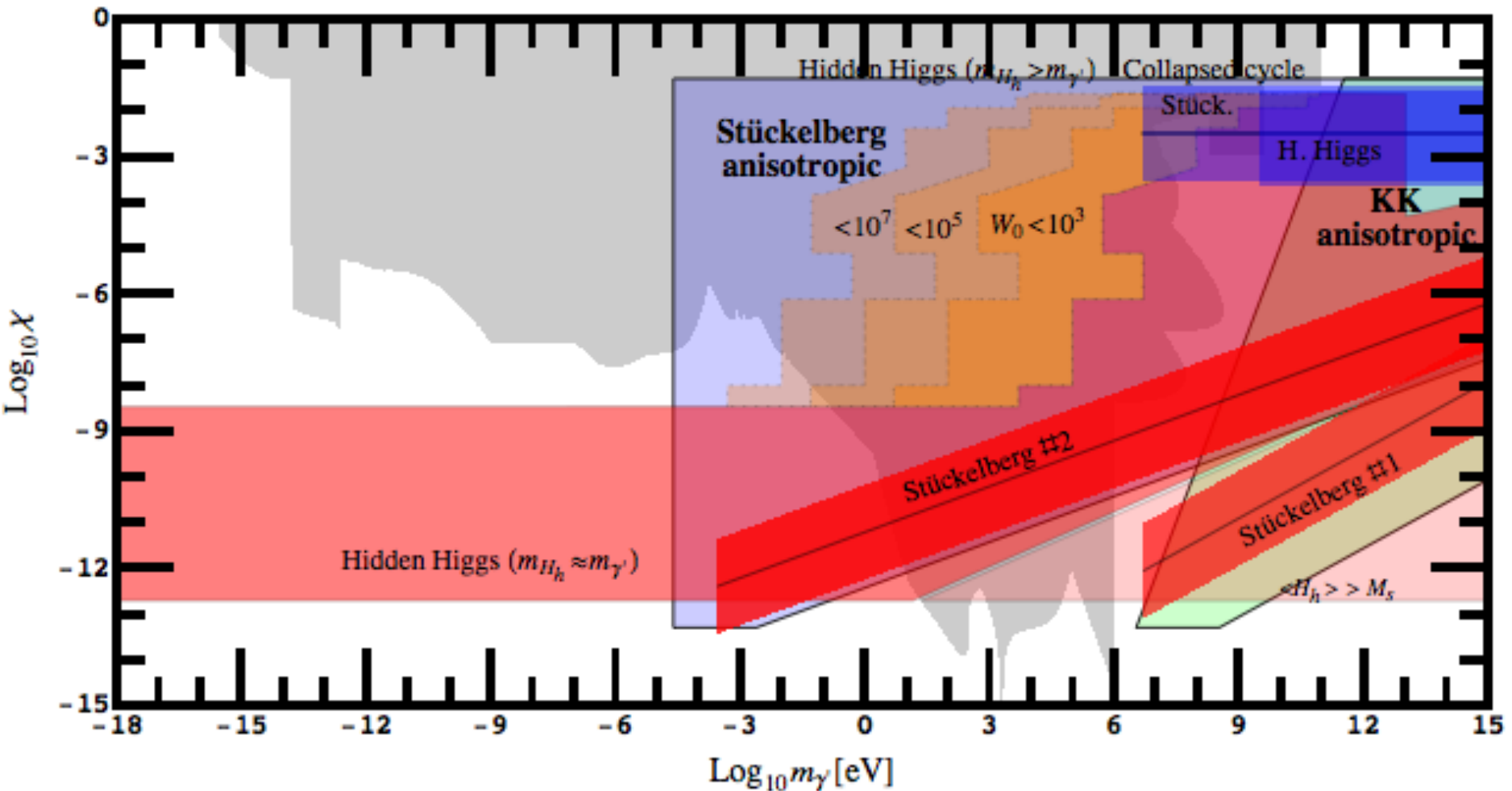
Hidden by weakness



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

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

Hidden Photons, all over the place

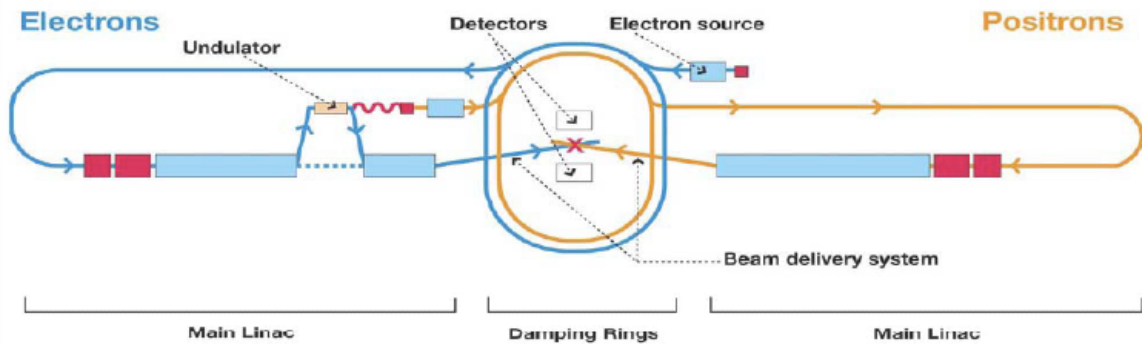
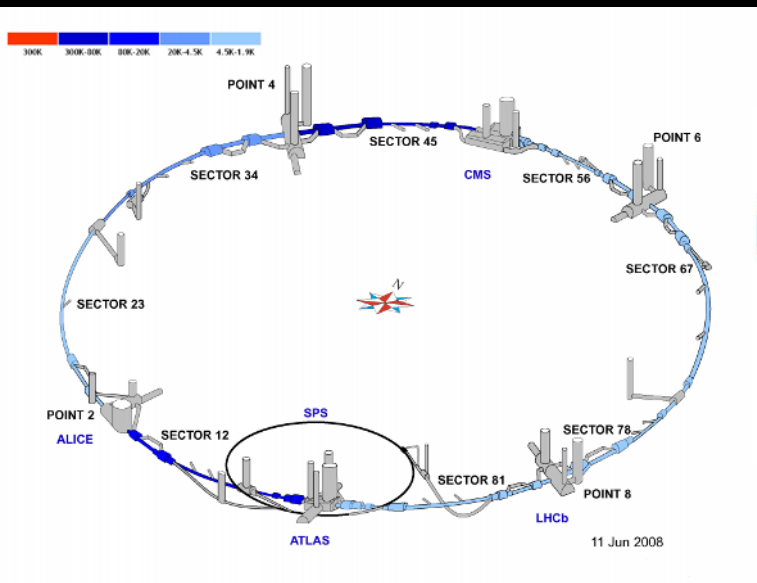


Low energy Experiments

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, Z' etc.

But...

- May miss very weakly interacting matter:
Hidden photons, (Axions, WIMPs, WISPs...)
- Current maximal energy few TeV
- Man its DANGEROUS...



But...

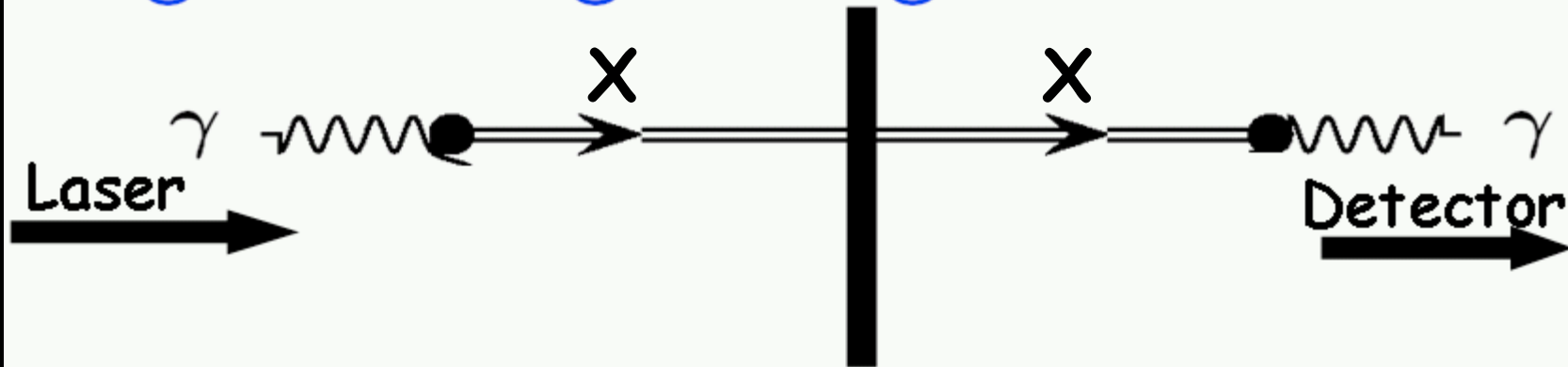
- May miss very weakly interacting matter:
Hidden photons, (Axions, WIMPs, WISPs...)
- Current maximal energy few TeV
- Or much much more horrifying:

NO SIGNAL ABOVE BACKGROUND!

Complementary approaches

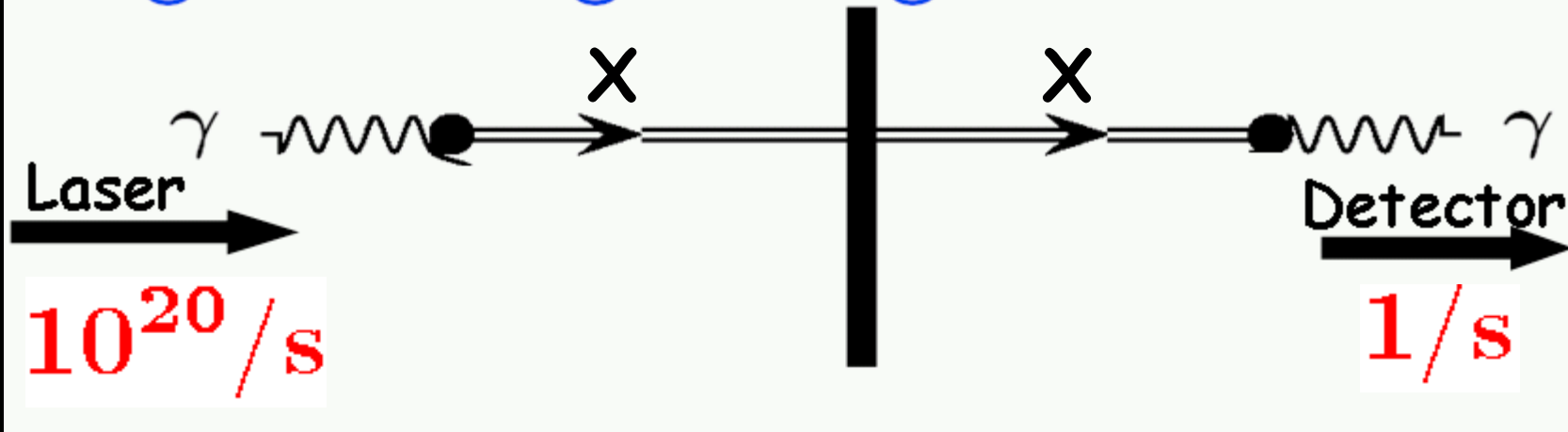
Light shining through walls

“Light shining through a wall”



Light shining through walls

“Light shining through a wall”



- **Test** $P_{\gamma \rightarrow X \rightarrow \gamma} \lesssim 10^{-20}$
- Enormous precision!
- Study extremely weak couplings!

Light Shining Through Walls

- A lot of activity

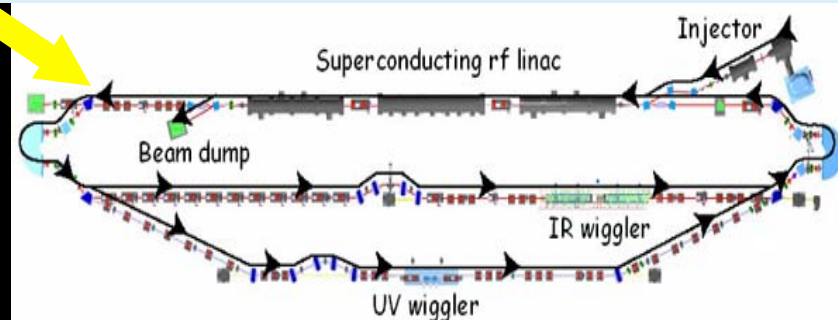
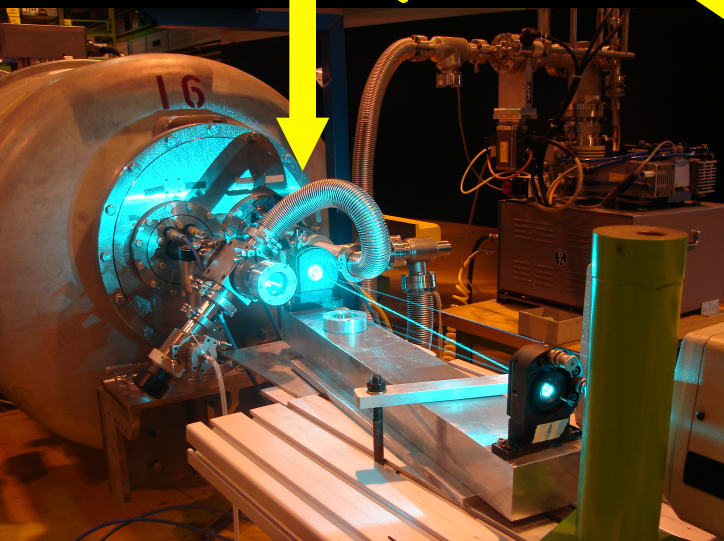
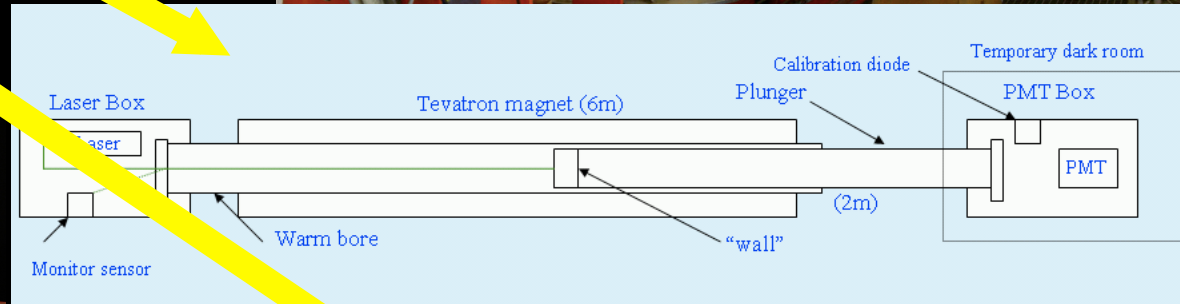
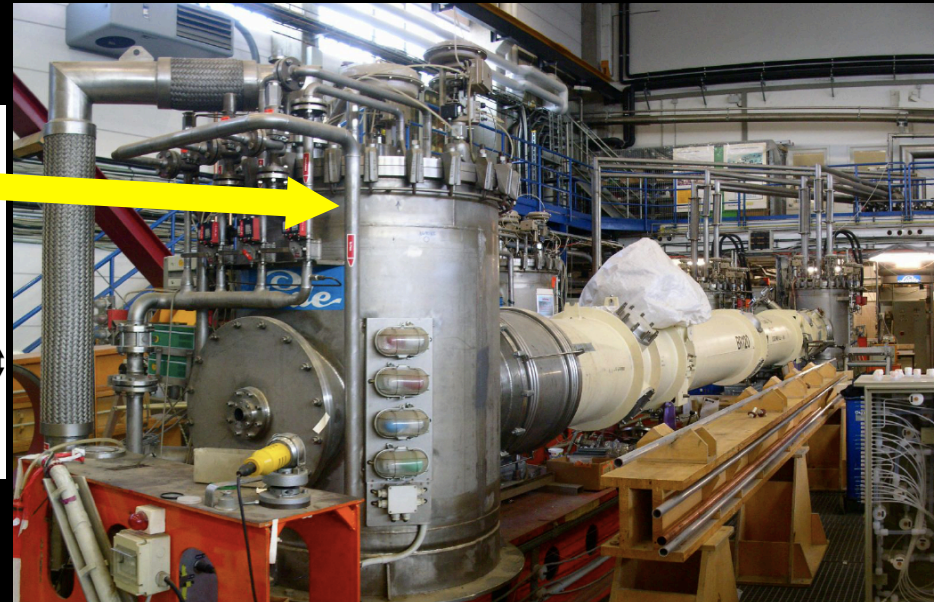
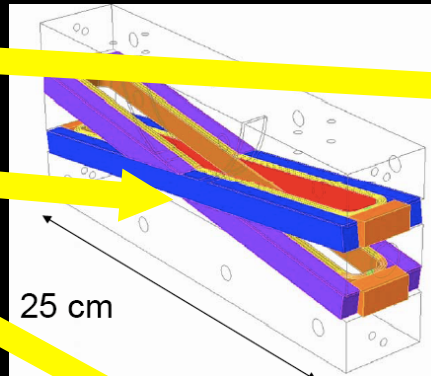
- ALPS

- BMV

- GammeV

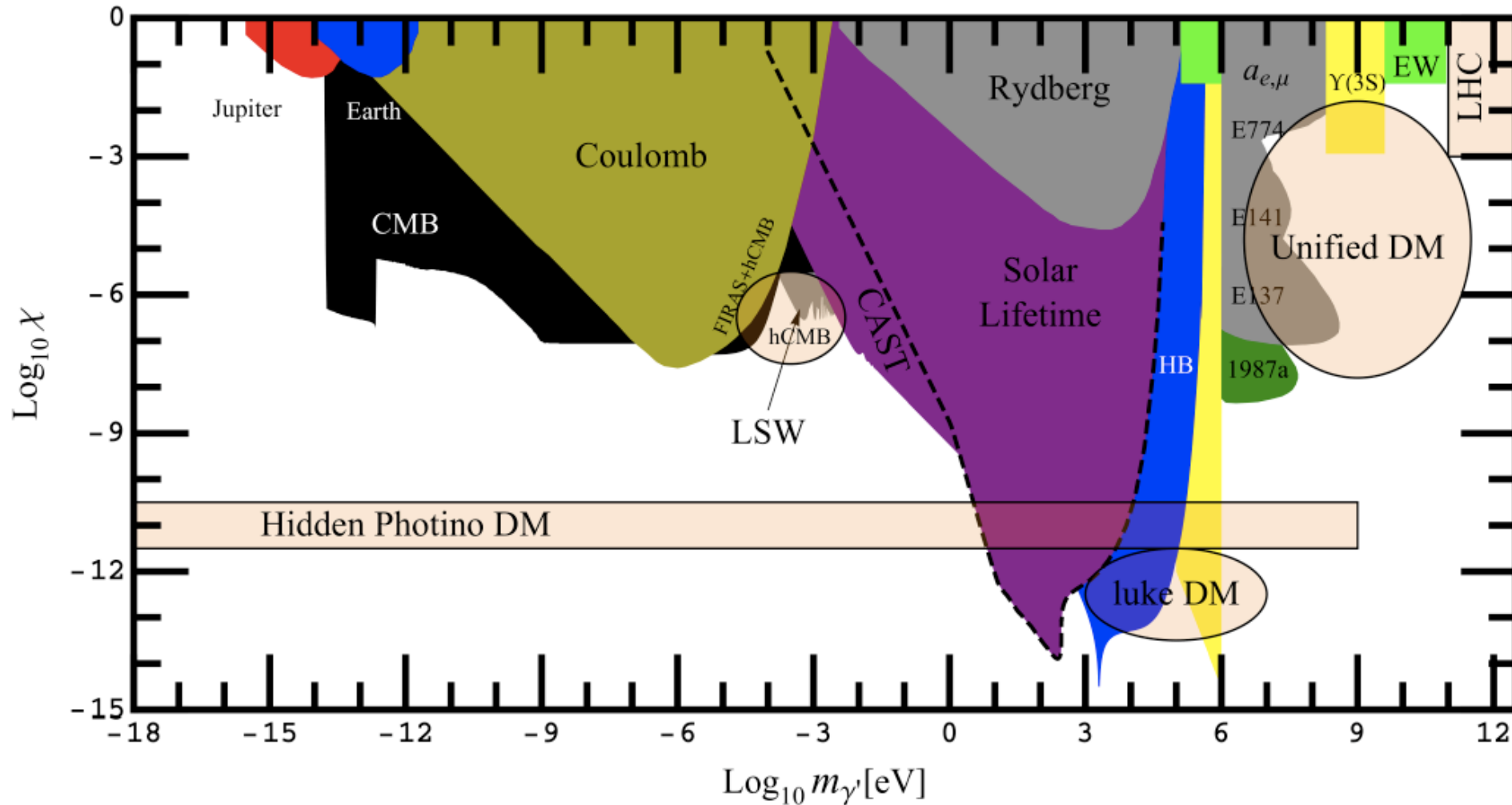
- LIPPS

- OSQAR



Hidden Photons

LSW already competitive + testing interesting area



Coincidences?

- Neutrino masses:

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

- Scale of dark energy:

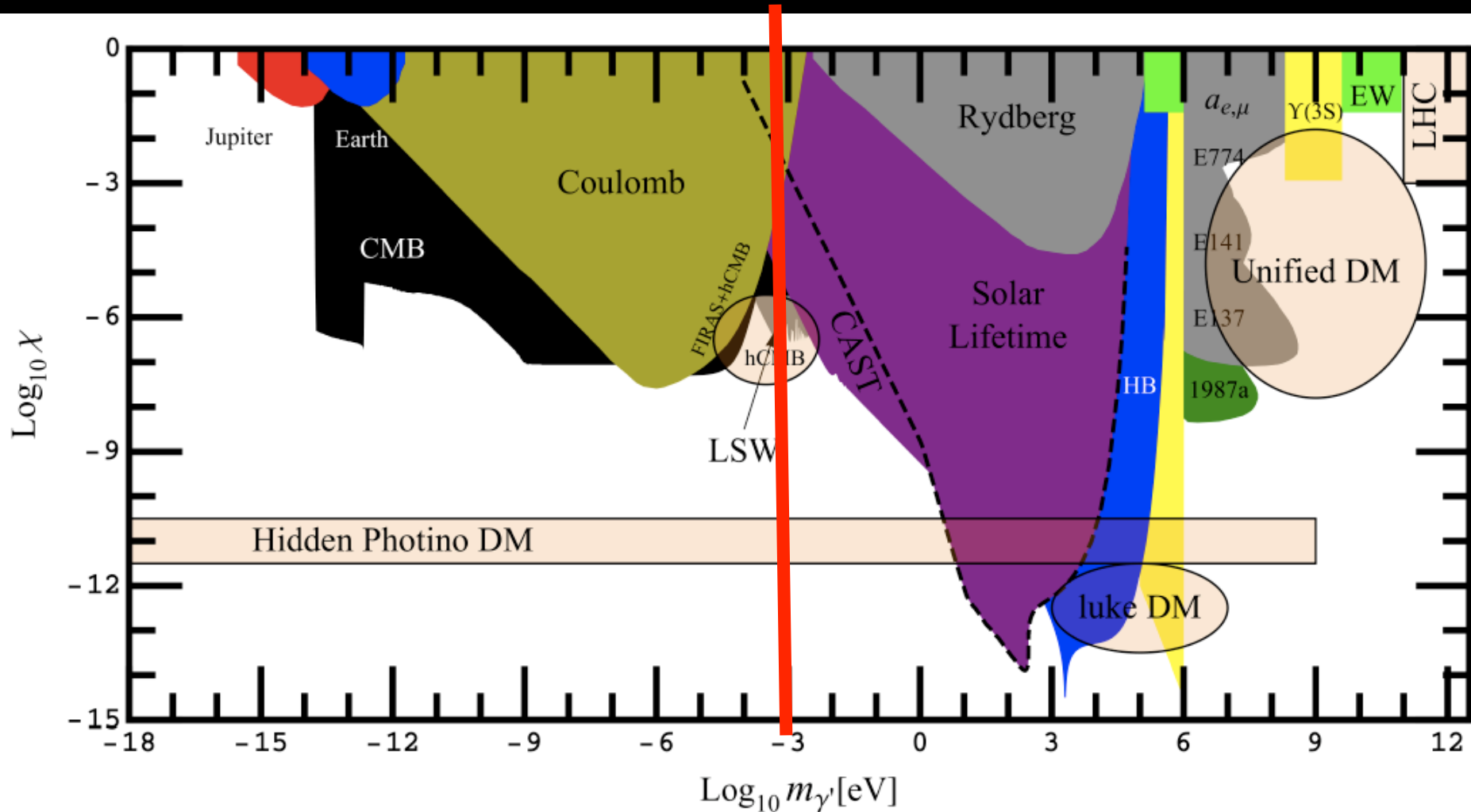
$$\rho_\Lambda \sim (\text{meV})^4$$

- Energy density of the Universe:

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

Hidden Photons

LSW already competitive + testing interesting area
Dark energy scale



Helioscopes

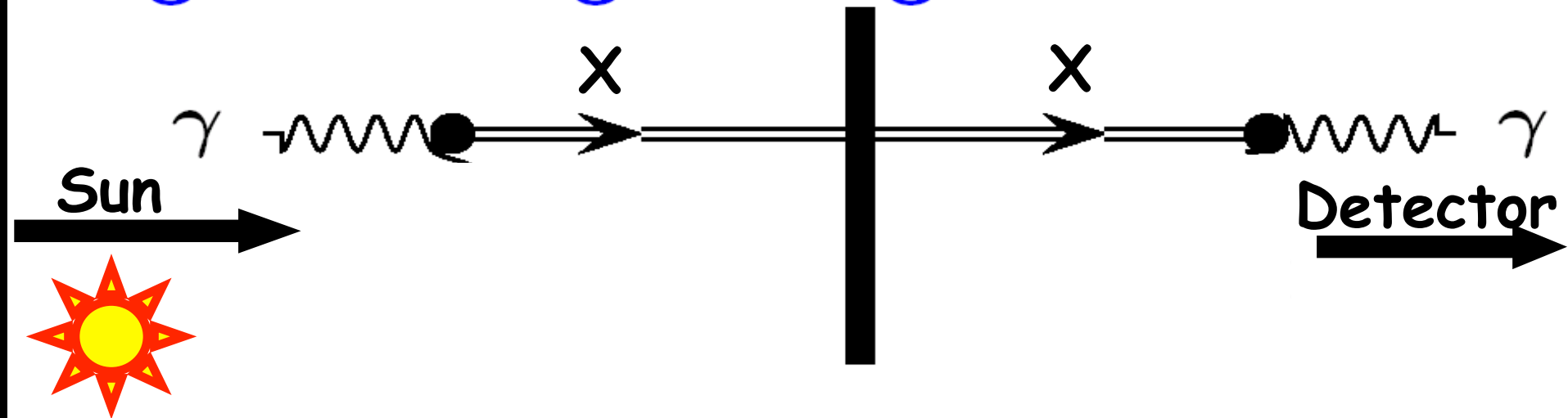
CAST@CERN

SUMICO@Tokyo

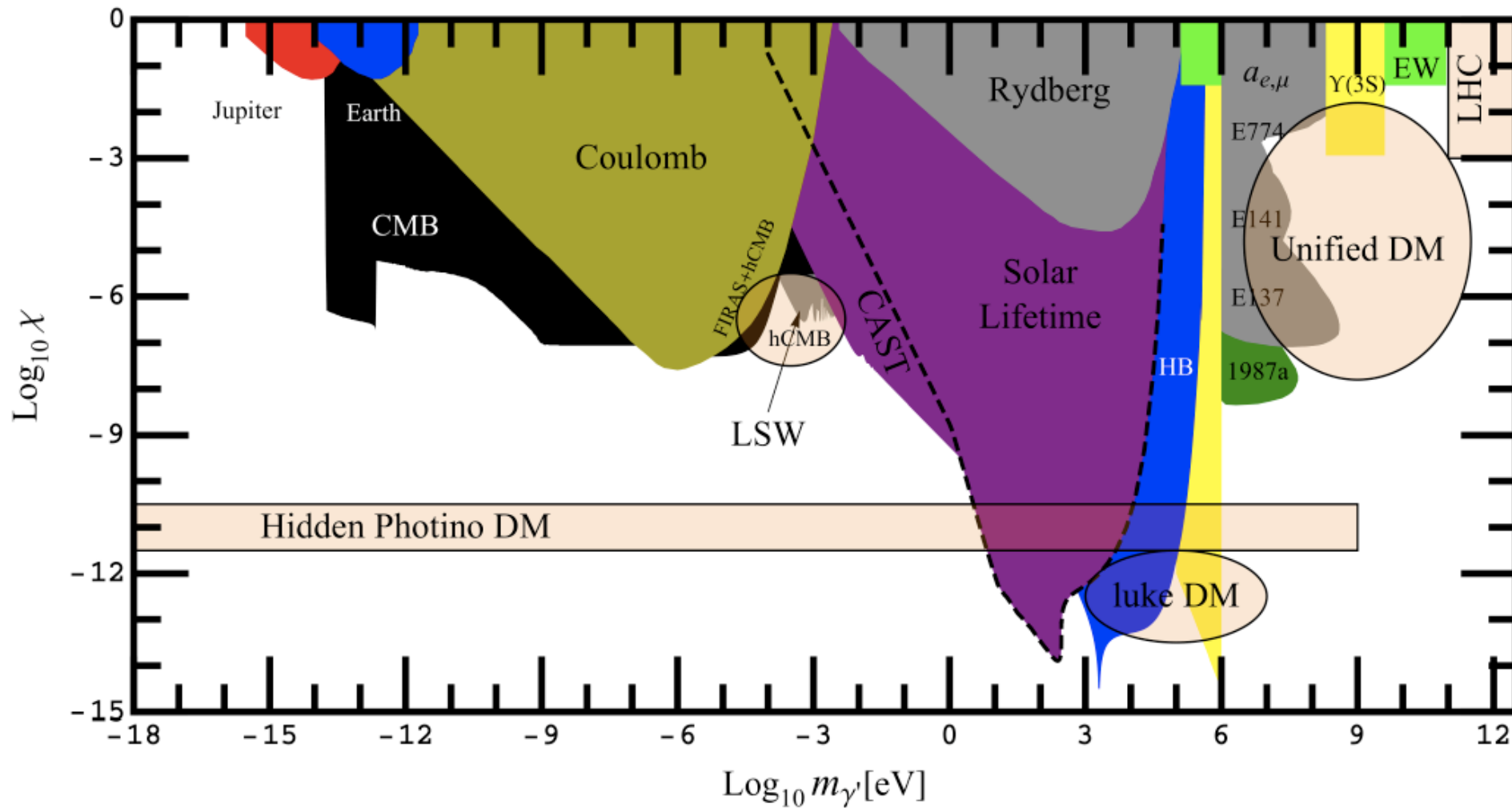
SHIPS@Hamburg



“Light shining through a wall”

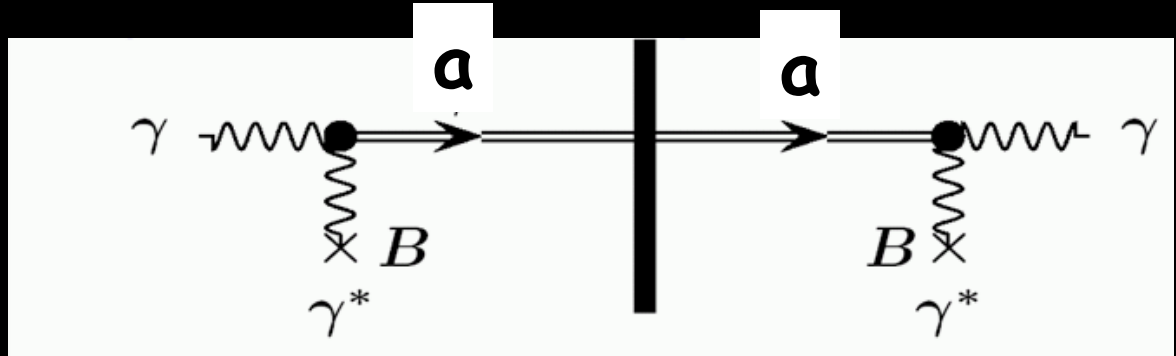


Helioscopes sensitivity

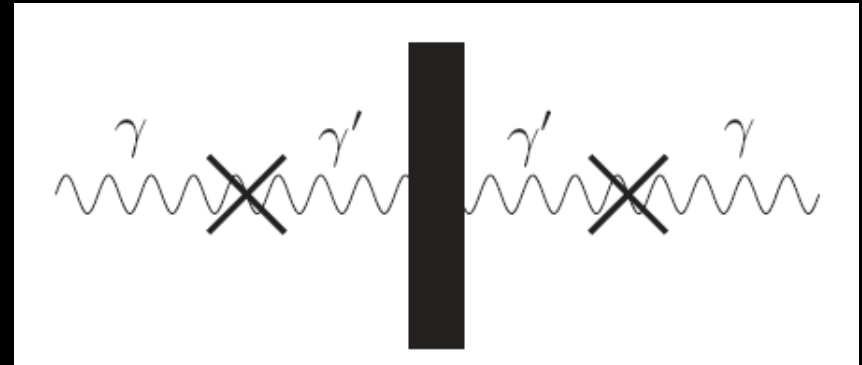


WISPS=Weakly interacting sub-eV particles

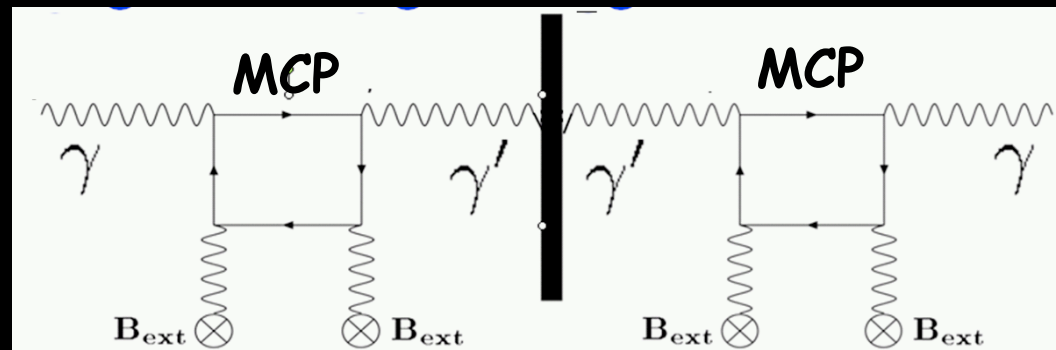
- Axions



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



- Hidden photon + minicharged particle (MCP)



Dark Matter(s)

Hidden = Dark photon matter

$$\ddot{\bar{X}}_i + 3H\dot{\bar{X}}_i + m_{\gamma'}^2 \bar{X}_i = 0$$

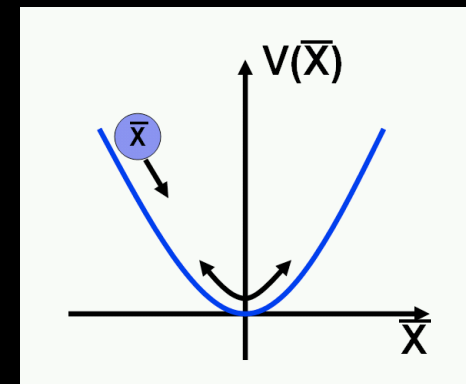
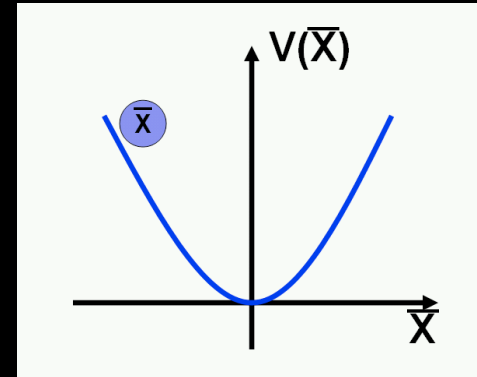
(includes non-minimal coupling to gravity $(R/12)X^\mu X_\mu$)

• $H \gg m_{\gamma'} \rightarrow$ overdamped oscillator

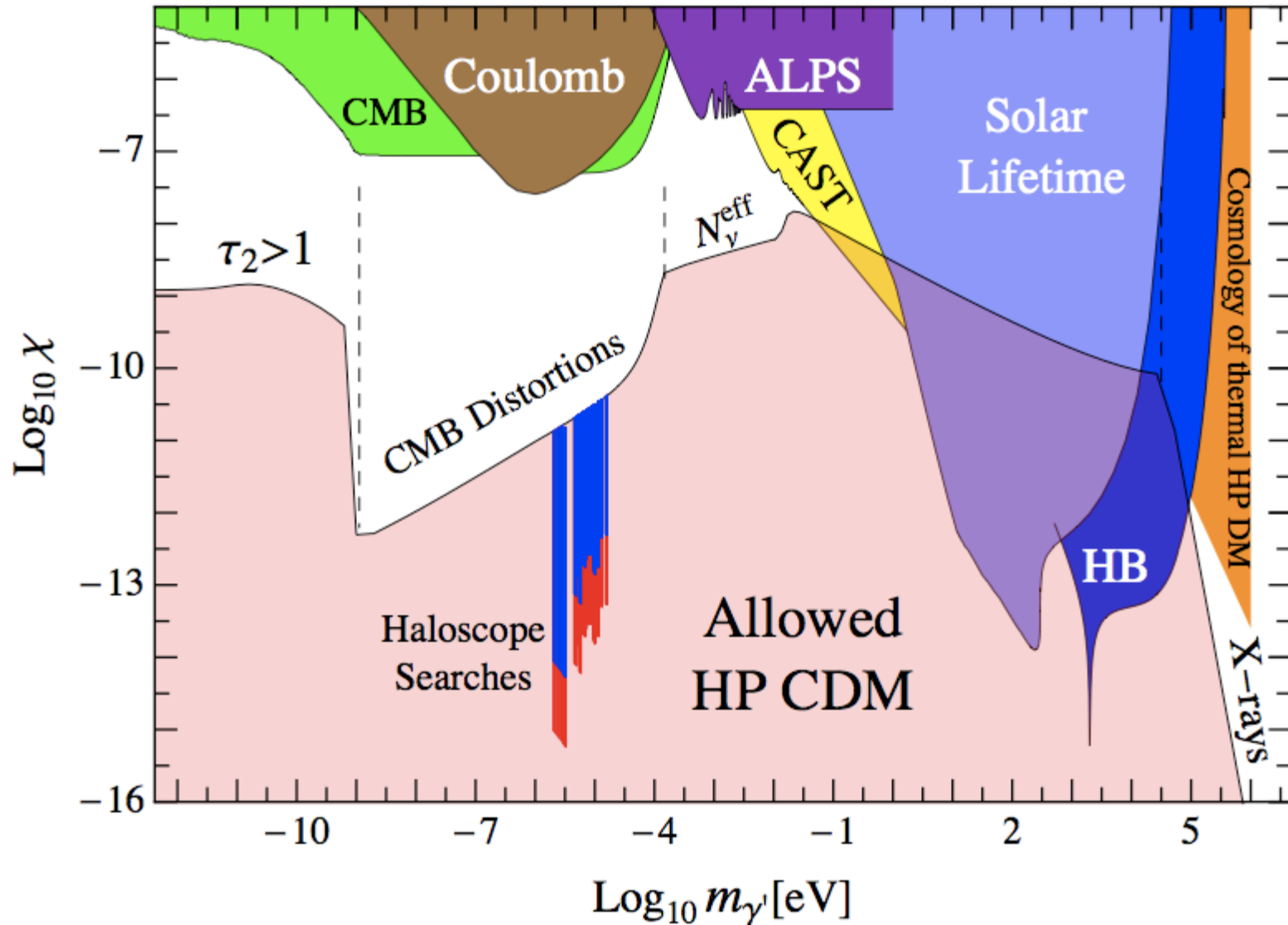
• $H \ll m_{\gamma'} \rightarrow$ damped oscillator

$$\rho_X(t) = \frac{\rho_{ini}}{a^3(t)} \rightarrow \text{Dark Matter}$$

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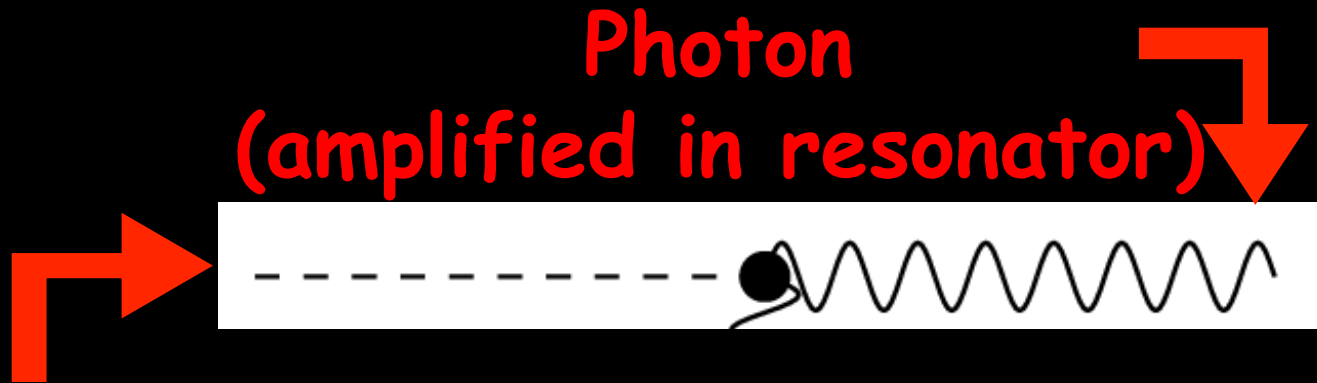


Hidden Photon Dark Matter



Use a plentiful source of HPs

- Photon Regeneration

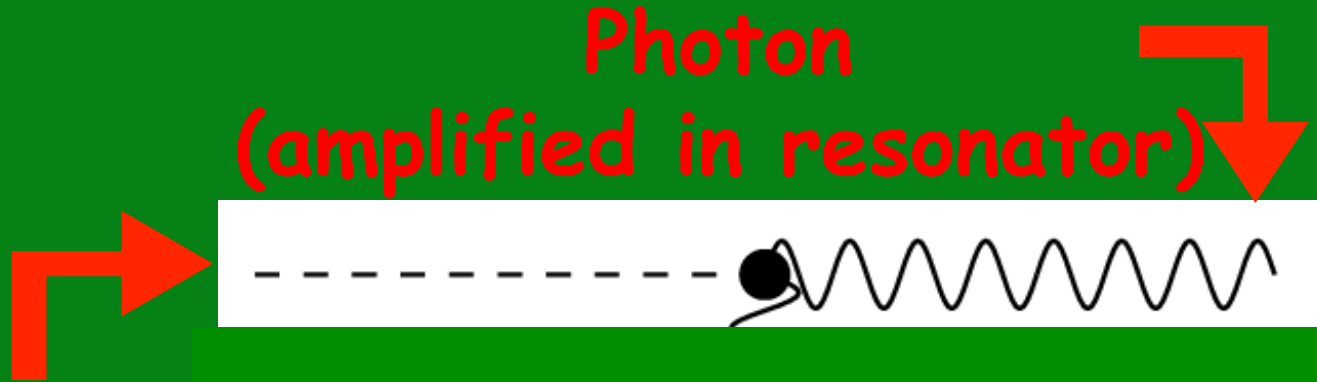


Hidden photon
(dark matter)

→ See ADMX talk

Electricity from Dark Matter :-).

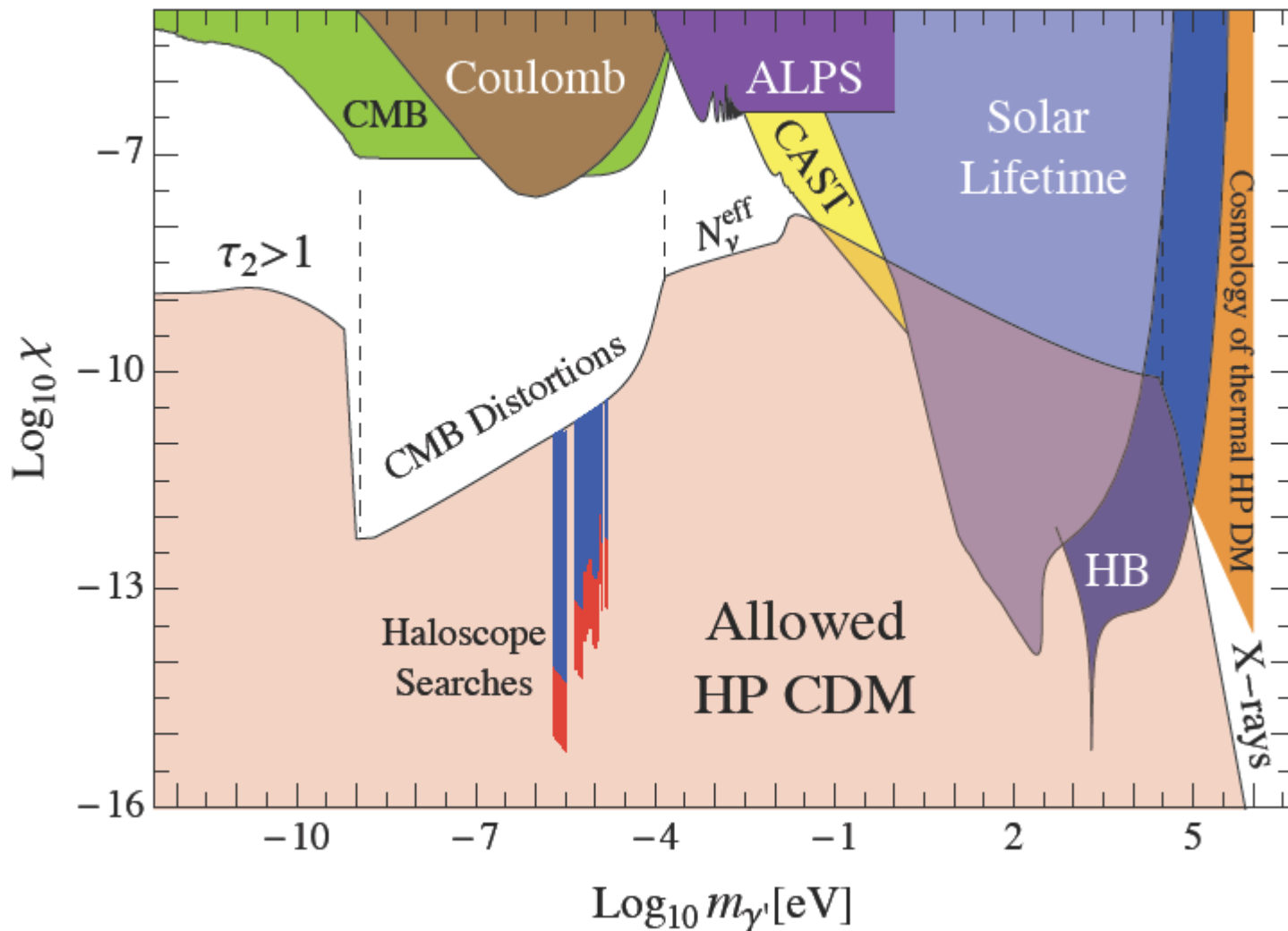
- Photon Regeneration



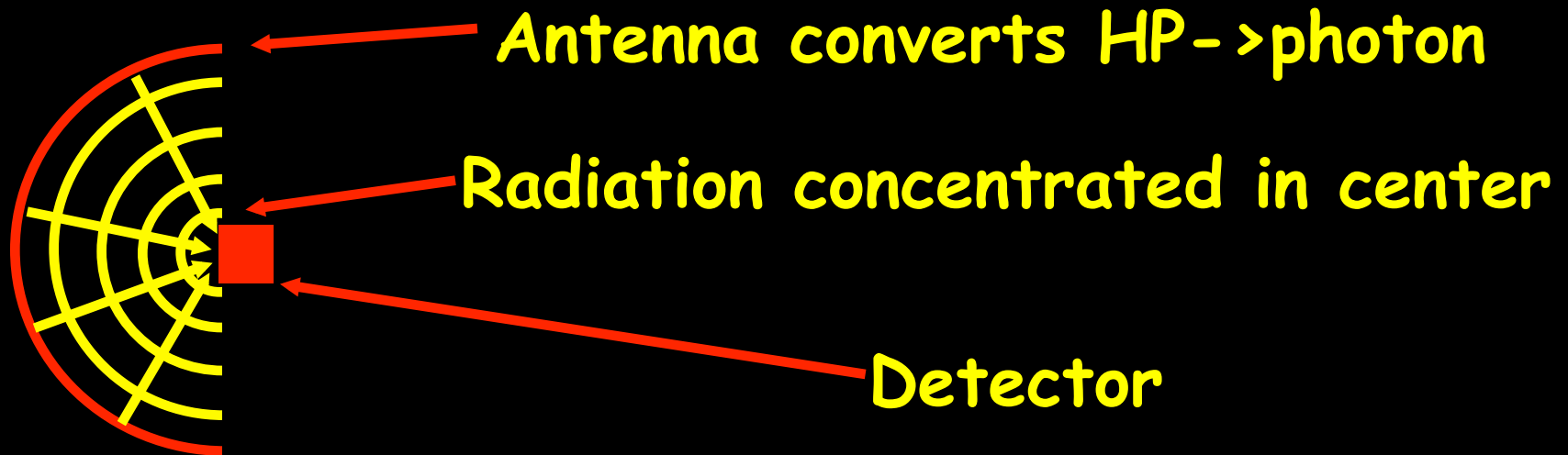
Hidden photon
(dark matter)



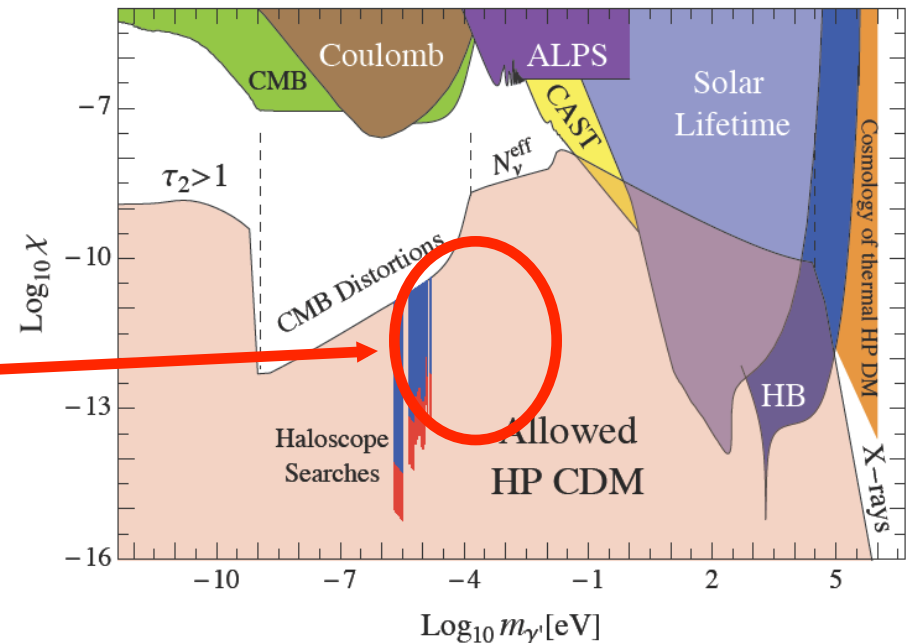
An extremely sensitive probe!!!



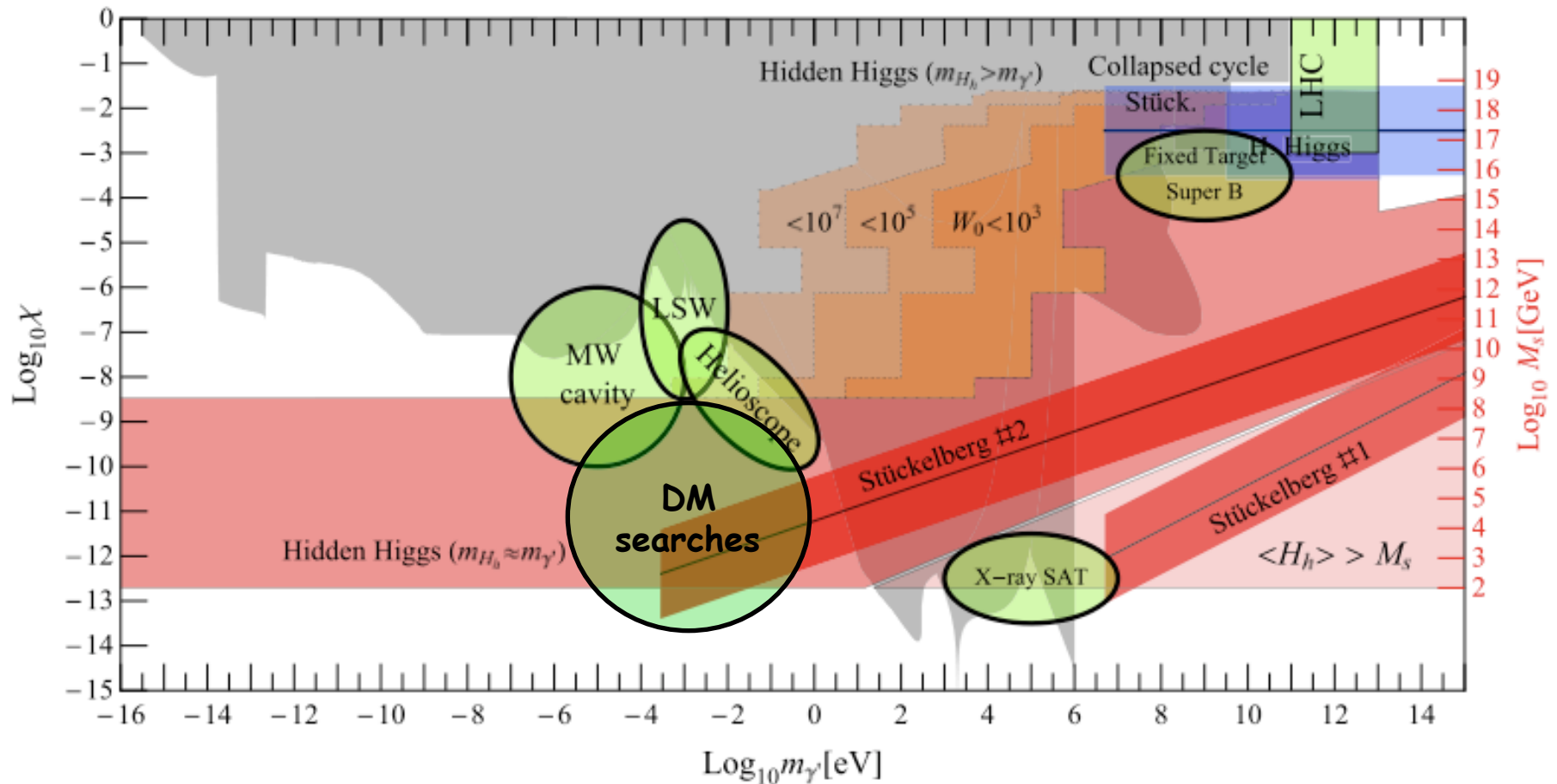
Dark Matter Antenna



Probes here;
very sensitive!!



Many more tests...

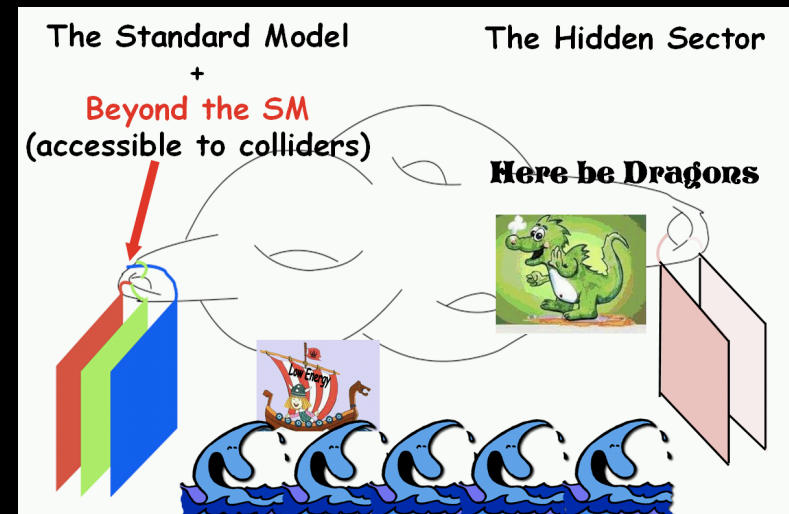


Exciting things go on NOW!!!

Conclusions

Conclusions

- Good Physics Case for HPs + other light stuff
➡ explore 'The Low Energy Frontier'
- Ongoing: Low energy experiments test directions not tested in accelerators
➡ Complementary!
- May provide information on hidden sectors and thereby on the underlying fundamental theory





Discover the Hidden Islands