Axions and WISPs
or
Fundamental Physics @ Low Energies

J. Jaeckel[†]

S. Abel[†], M. Goodsell*, S. Gardiner[†], H. Gies[0]
V. Khoze[†], J. Redondo[×], A. Ringwald*, S. Roy[†]
[†]Durham University, *DESY,
[×]MPI Munich, [0]ITP Jena

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

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

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

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

0% - ε% understood

Axions

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

>75% understood

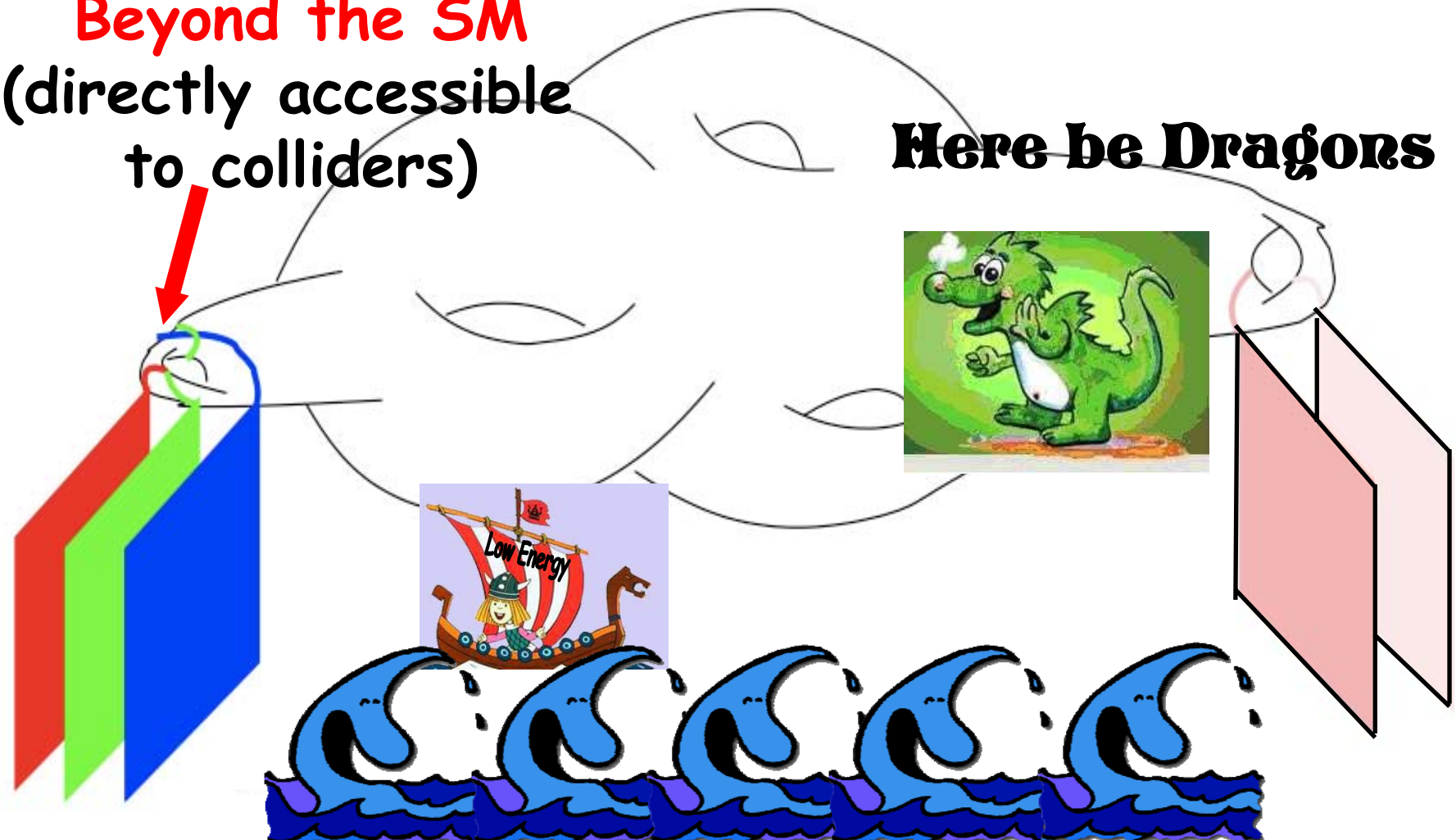
Where we want to go… a mythical story

The Standard Model

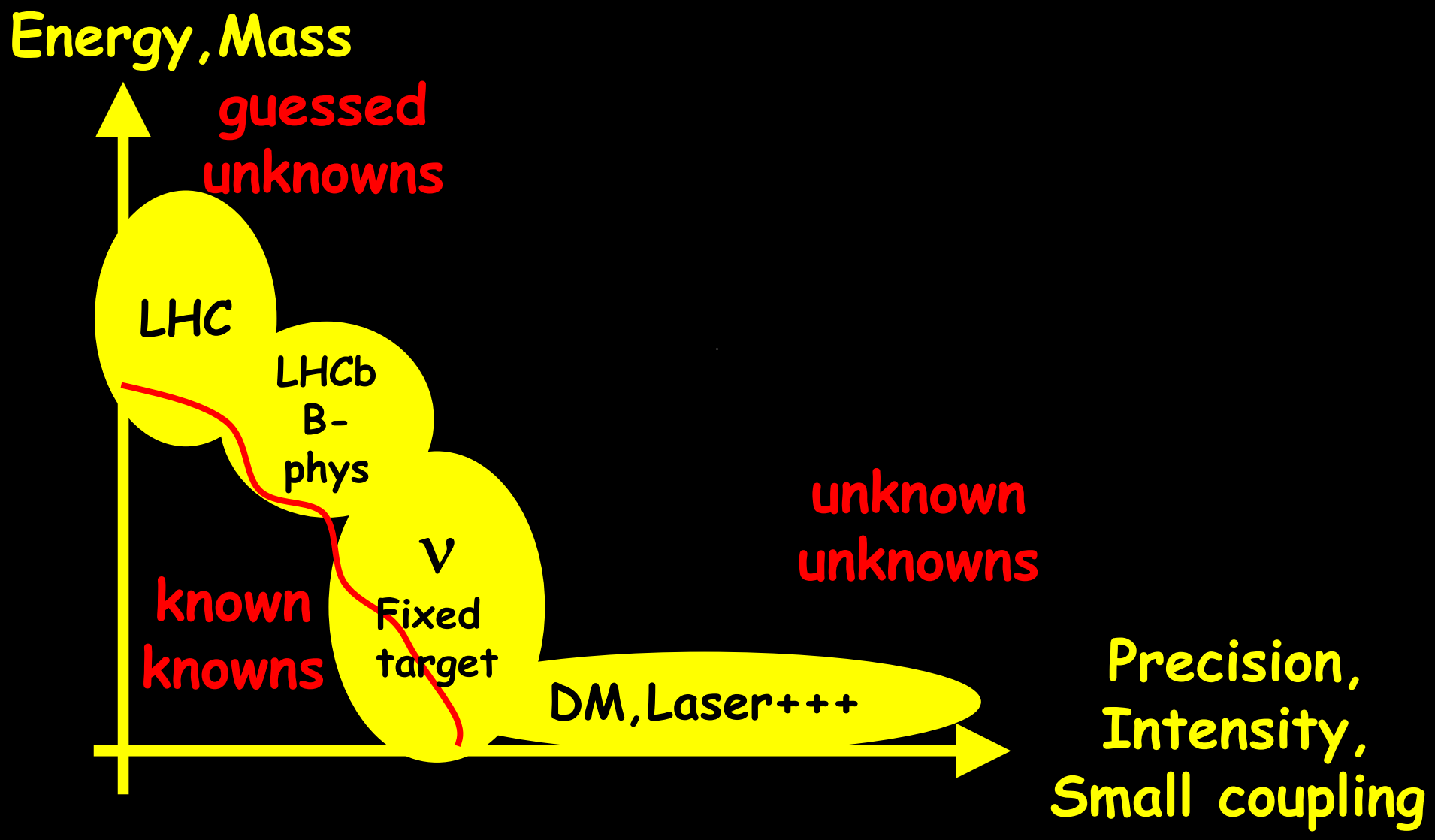
+

Beyond the SM
(directly accessible to colliders)

The Hidden Sector



Exploring is (at least) 2 dimensional



Today's question:

Are the extra (gauge) Forces?

SU(3)xSU(2)xU(1)x???

The simplest case

Hidden Photons:

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

The simplest case

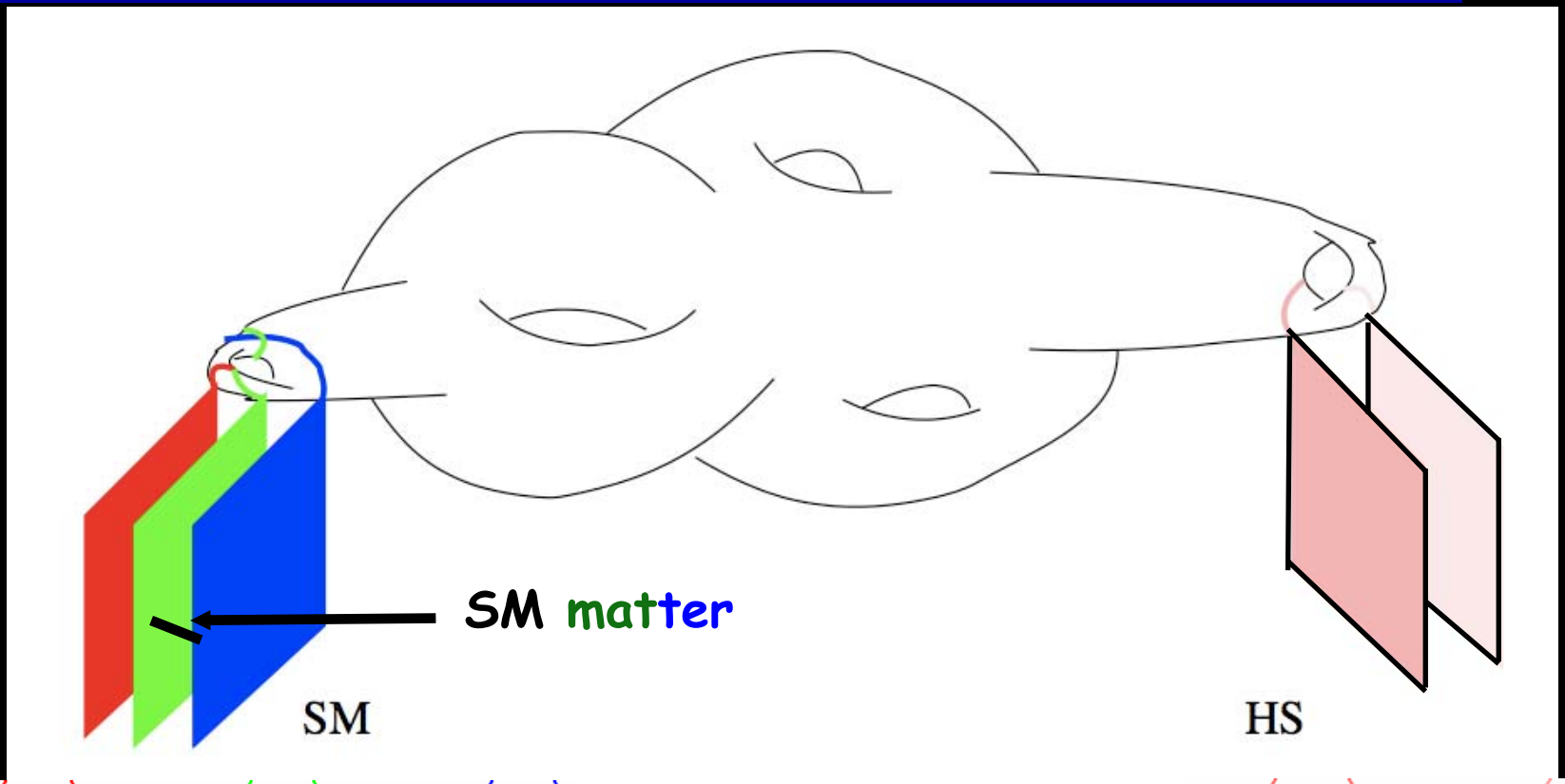
Hidden Photons:

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

Will be light + very weakly coupled

➔ Weakly Interacting Slim Particle = WISP

String theory likes extra gauge groups

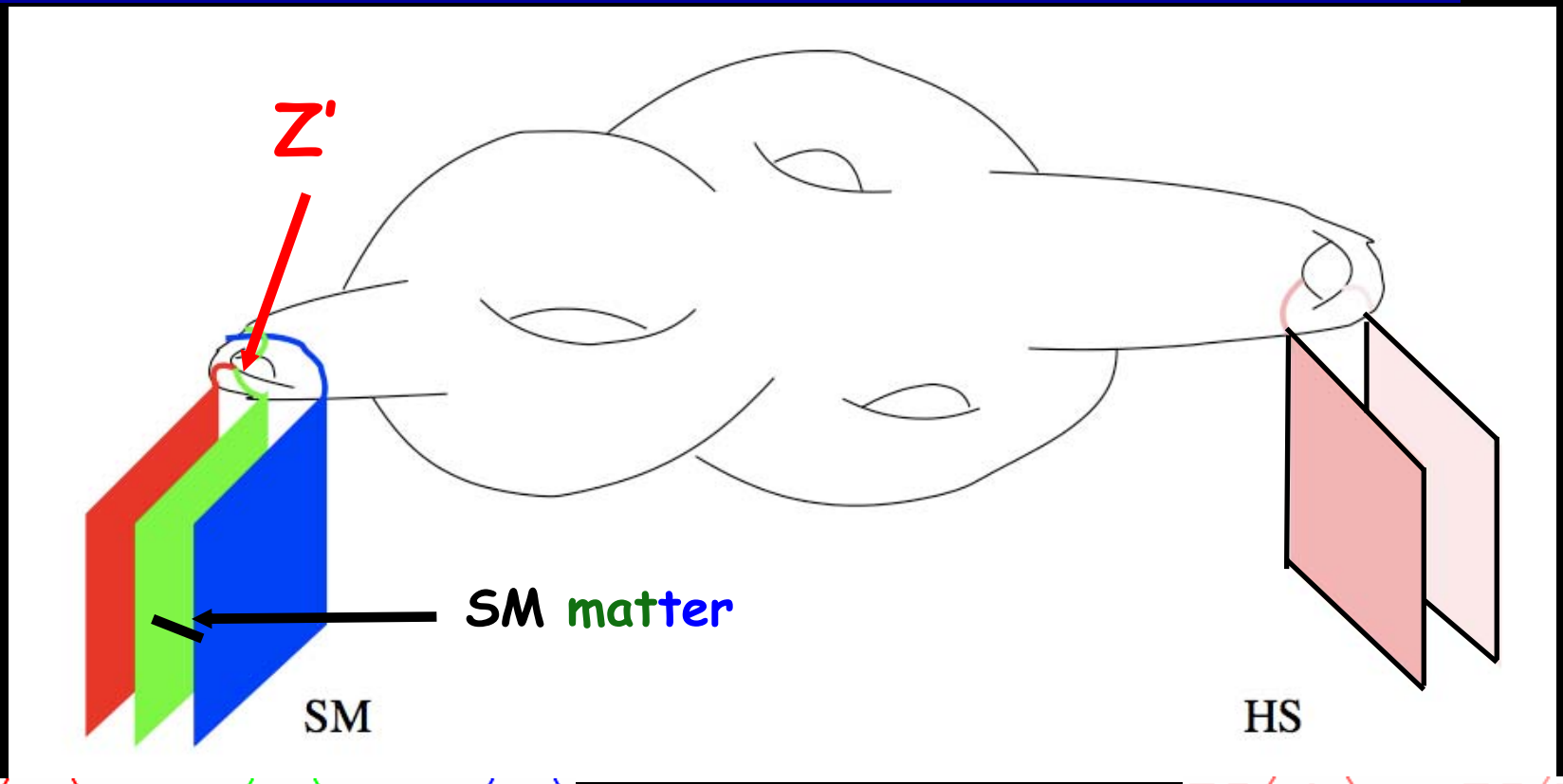


$U(A) \times U(B) \times U(C)$

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

Many extra U(1)s!

String theory likes extra gauge groups

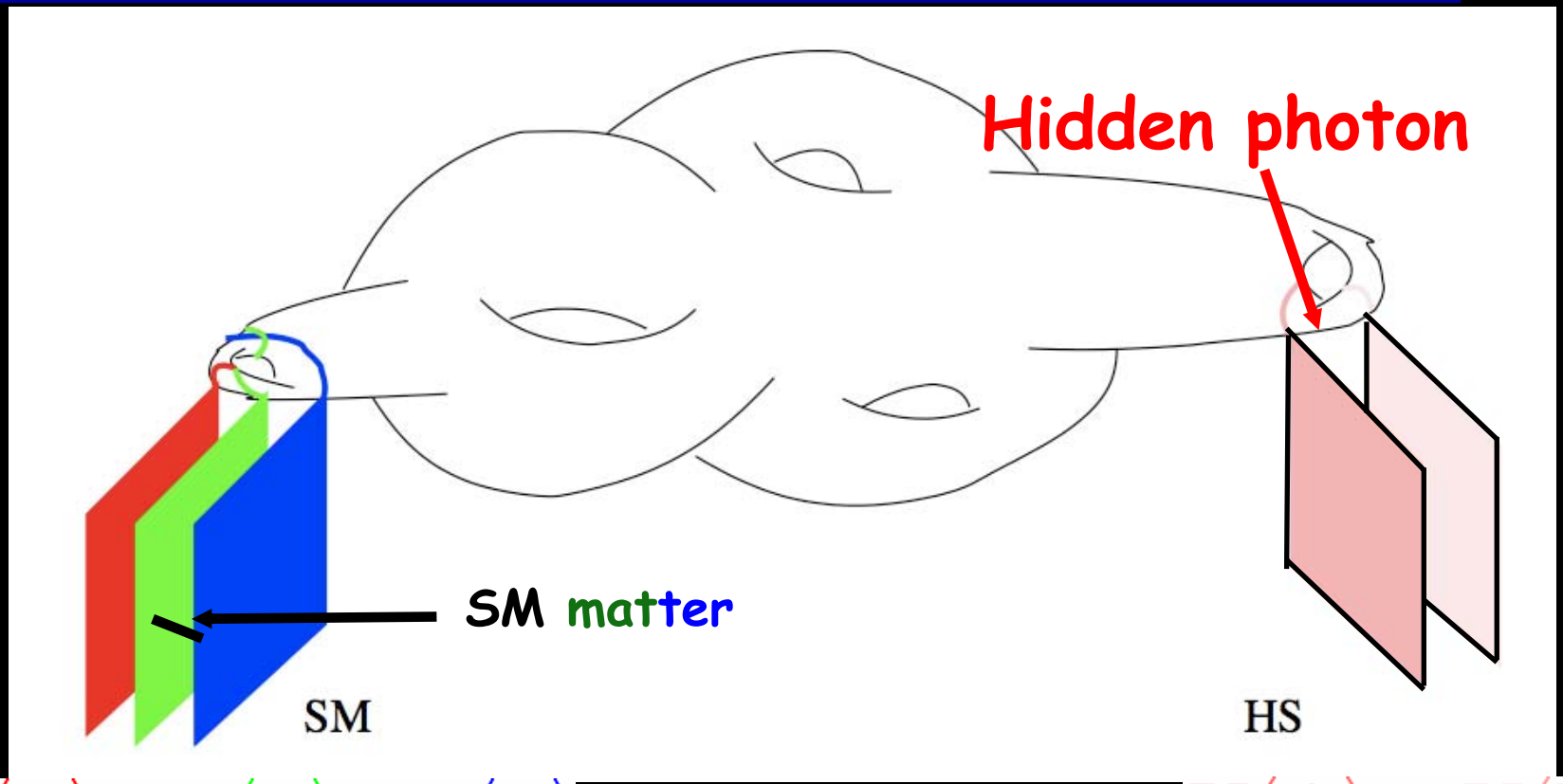


$U(A) \times U(B) \times U(C)$

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

Many extra U(1)s!

String theory likes extra gauge groups



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

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

Many extra U(1)s!

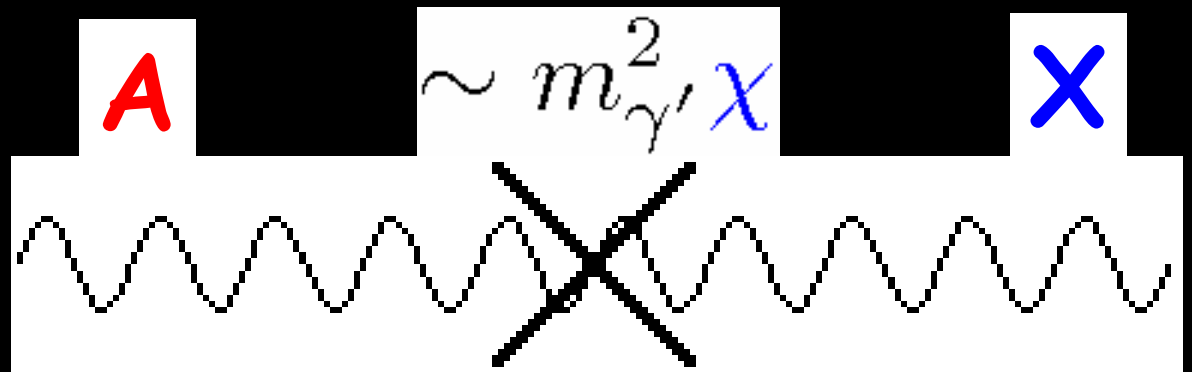
Hidden Photon interactions

- Kinetic mixing

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

„Our" U(1) „Hidden" U(1) Mixing

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



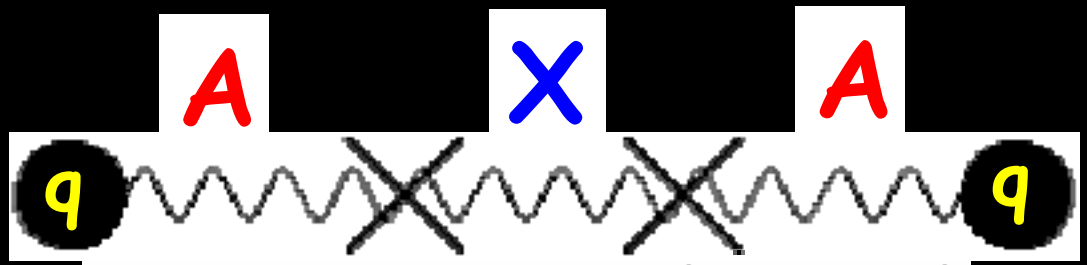
Modified Coulomb's Law → Extra force!

- Kinetic mixing

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

„Our" U(1) „Hidden" U(1) Mixing

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



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

Hidden by small coupling

Hidden by large mass

Hidden Photon interactions

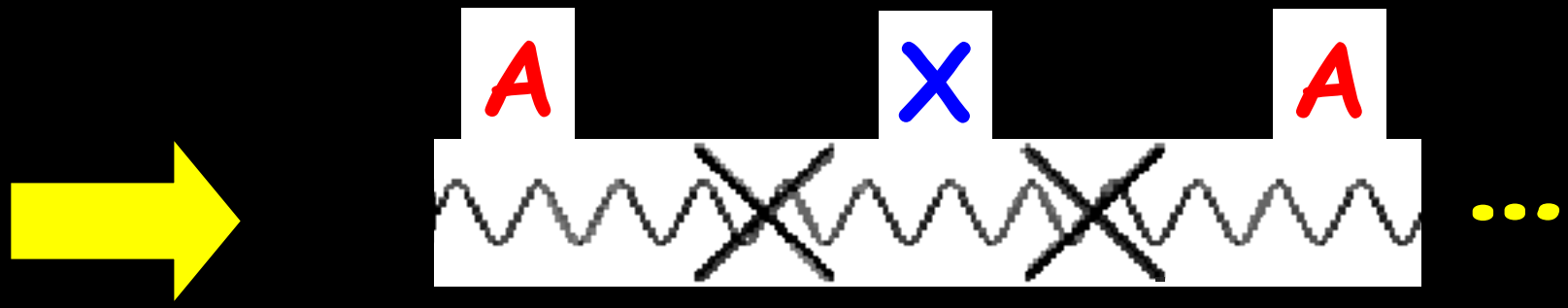
- Kinetic mixing

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

„Our" U(1) „Hidden" U(1) Mixing

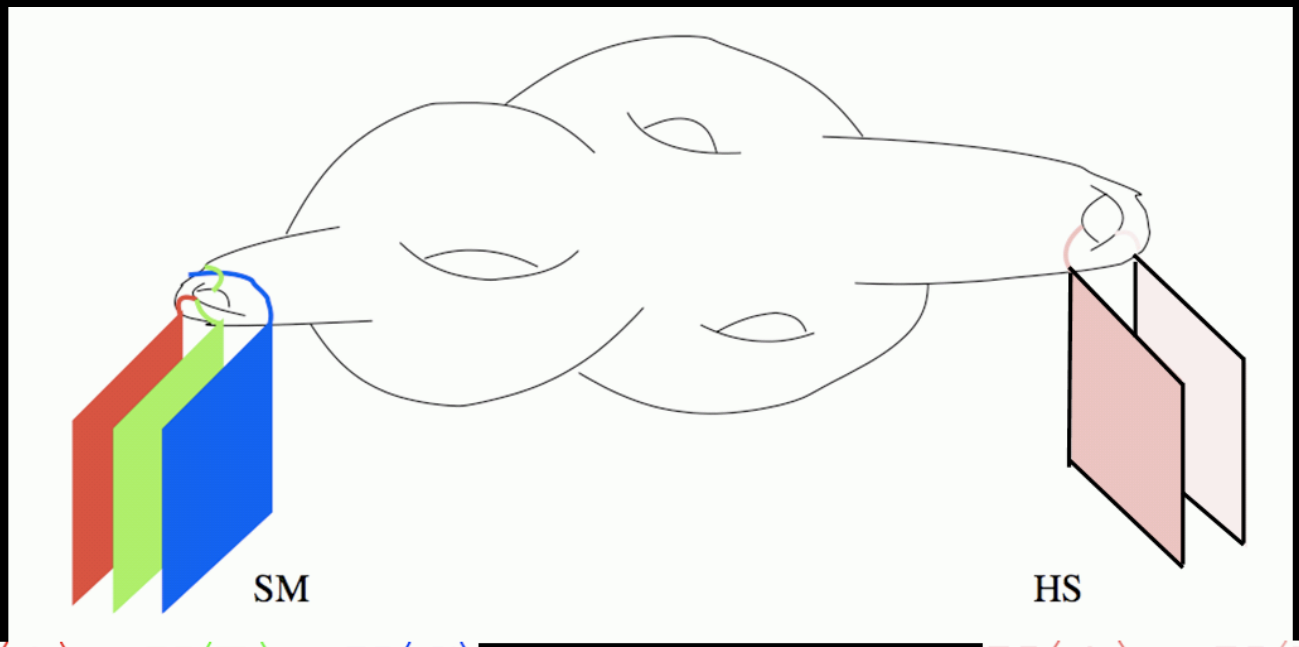
+ Mass

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



=analog ν-oscillations

Explore fundamental properties.



U(A) x U(B) x U(C)

U(A) x U(B)

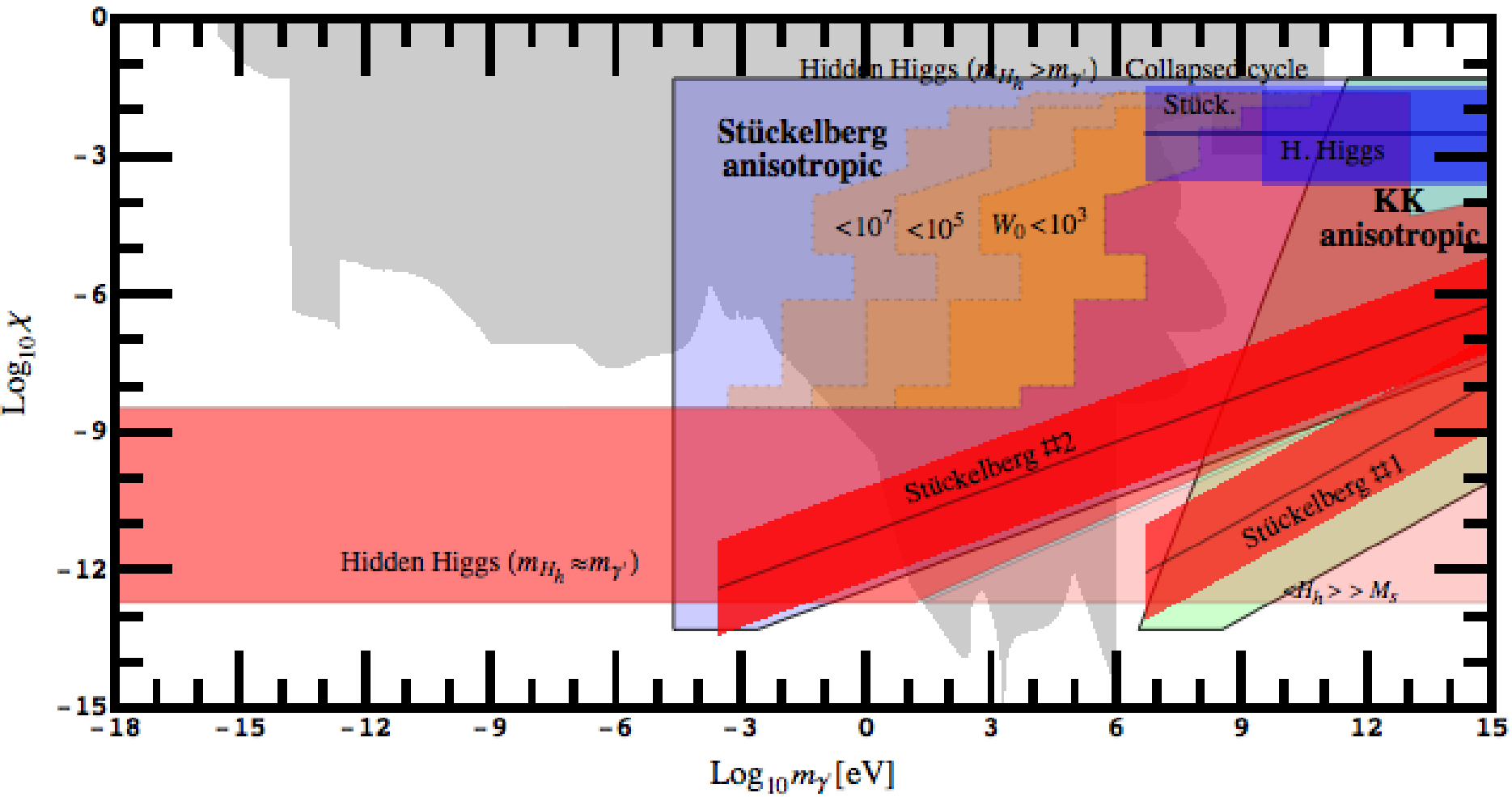
$$\chi \sim \frac{g_s}{8\pi} \frac{1}{Volume^x}$$

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

Global feature

Fundamental high energy scale!

Hidden Photons, all over the place

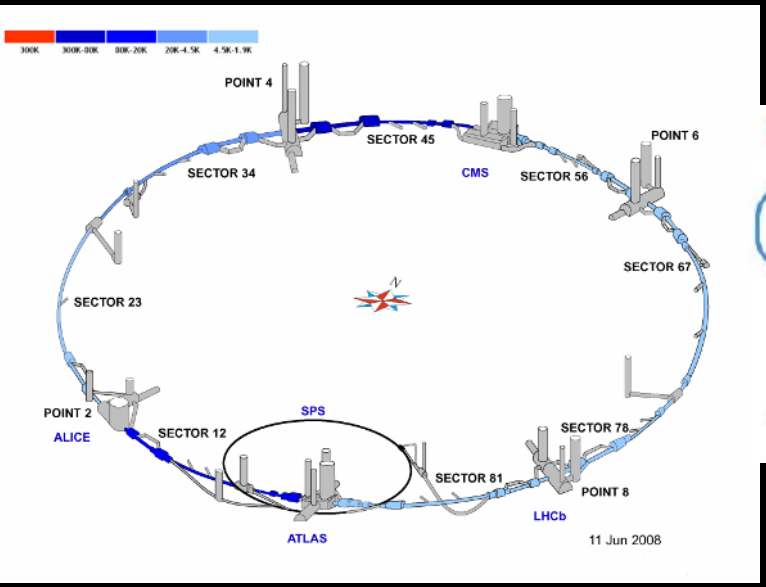


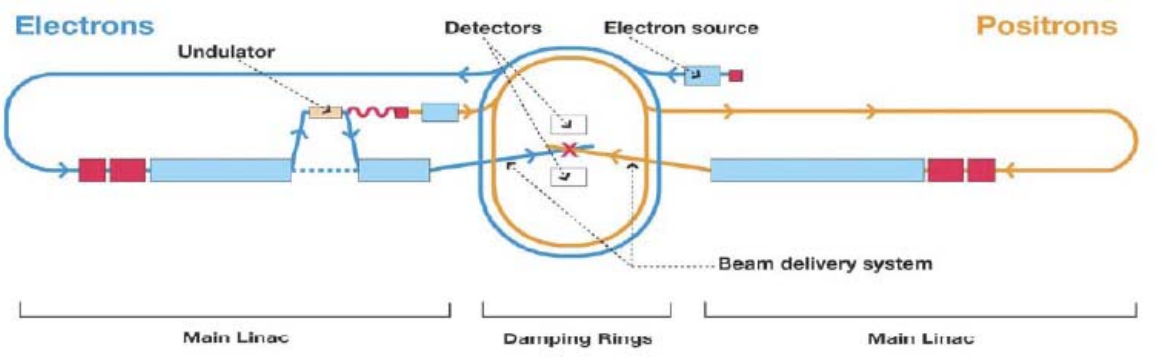
Low energy
Experiments

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…

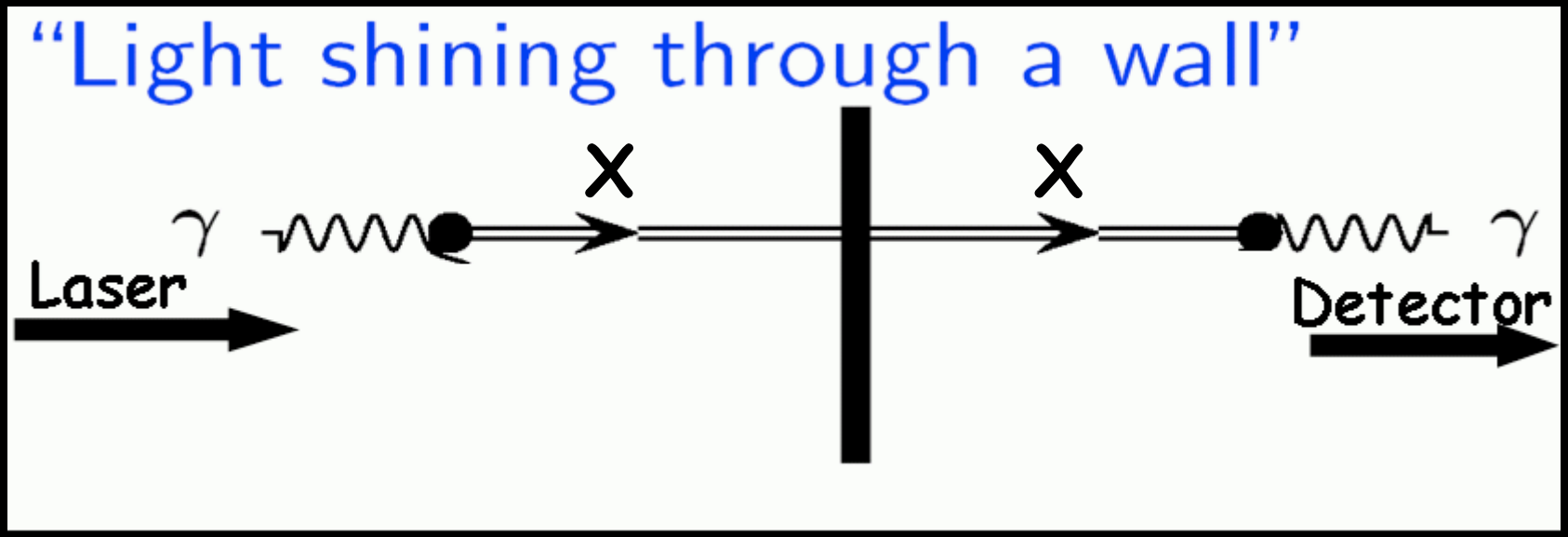
- May miss very weakly interacting matter: Hidden photons, (Axions, WIMPs, WISPs…)
- Current maximal energy few TeV

- Or much much more horrifying:

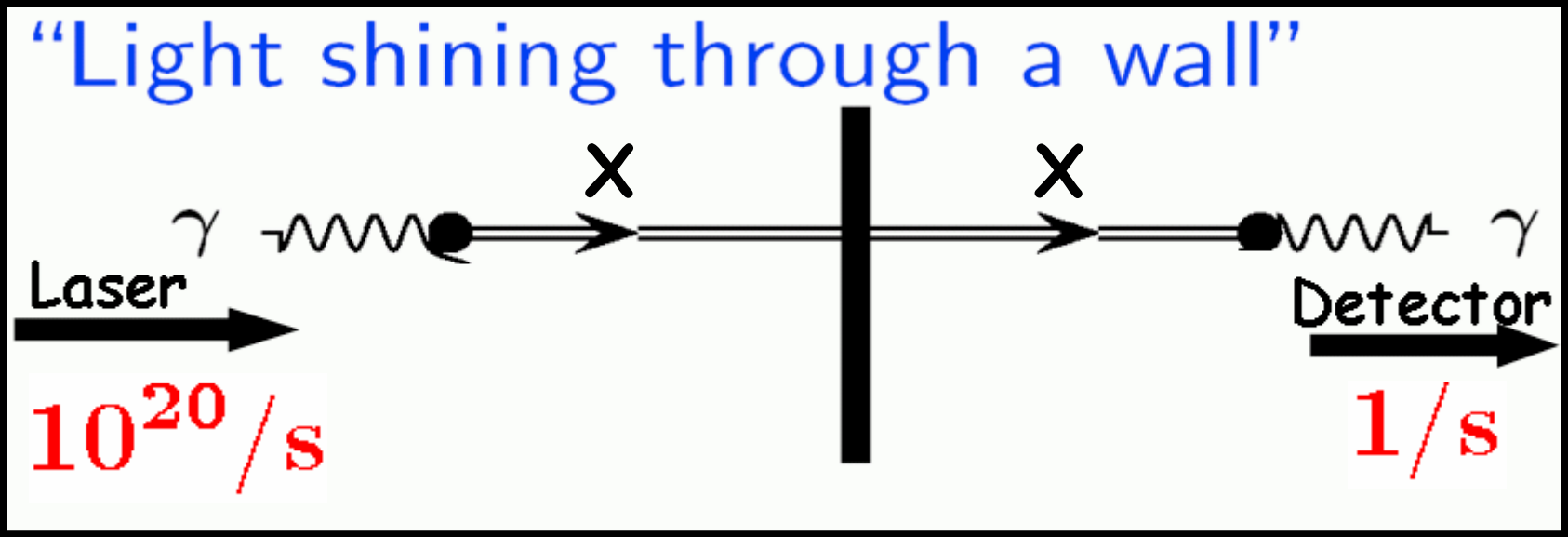
NO SIGNAL ABOVE BACKGROUND!

Complementary approaches

Light shining through walls



Light shining through walls

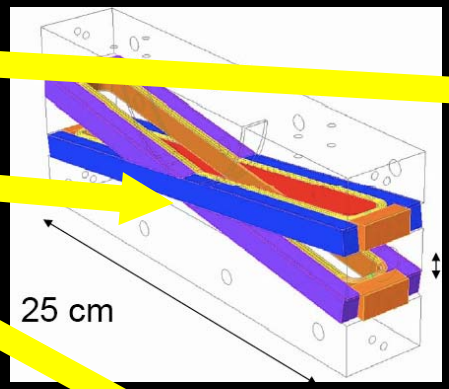


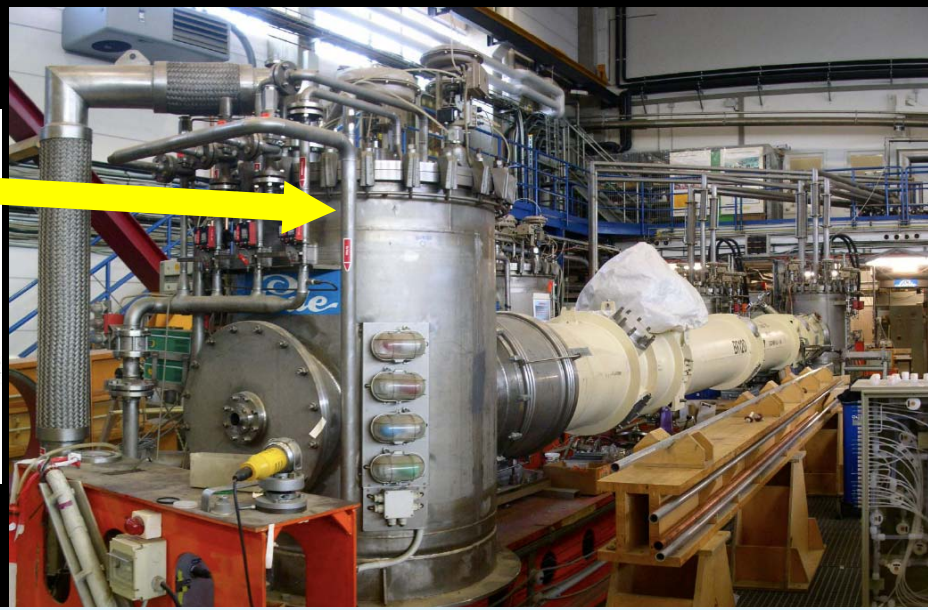
- Test $P_{\gamma \to X \to \gamma} \lesssim 10^{-20}$

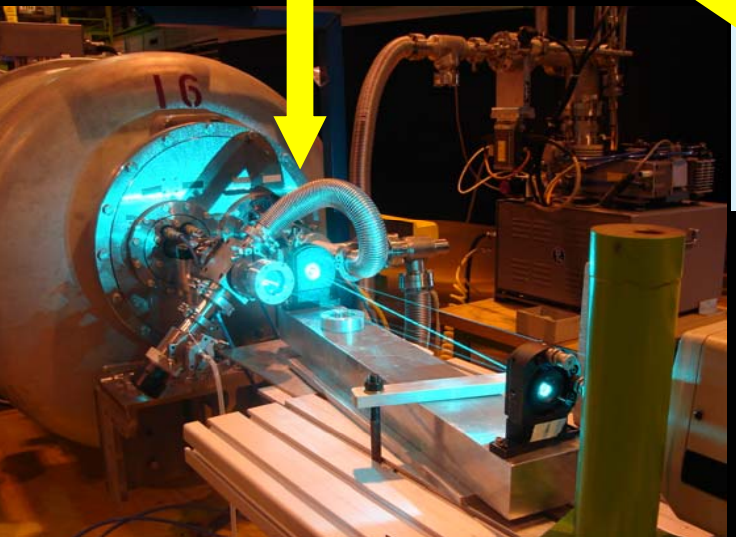
- Enormous precision!
- Study extremely weak couplings!

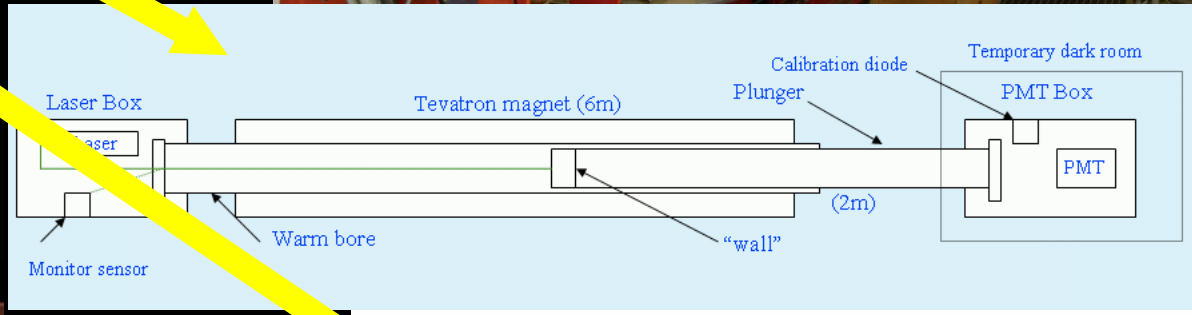
Light Shining Through Walls

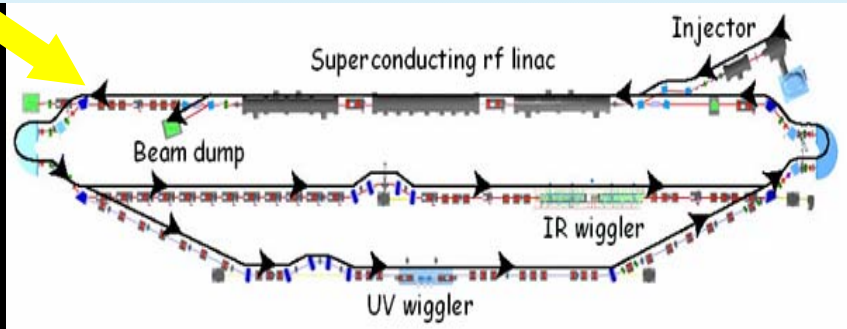
- A lot of activity
  - ALPS
  - BMV
  - GammeV
  - LIPPS
  - OSQAR





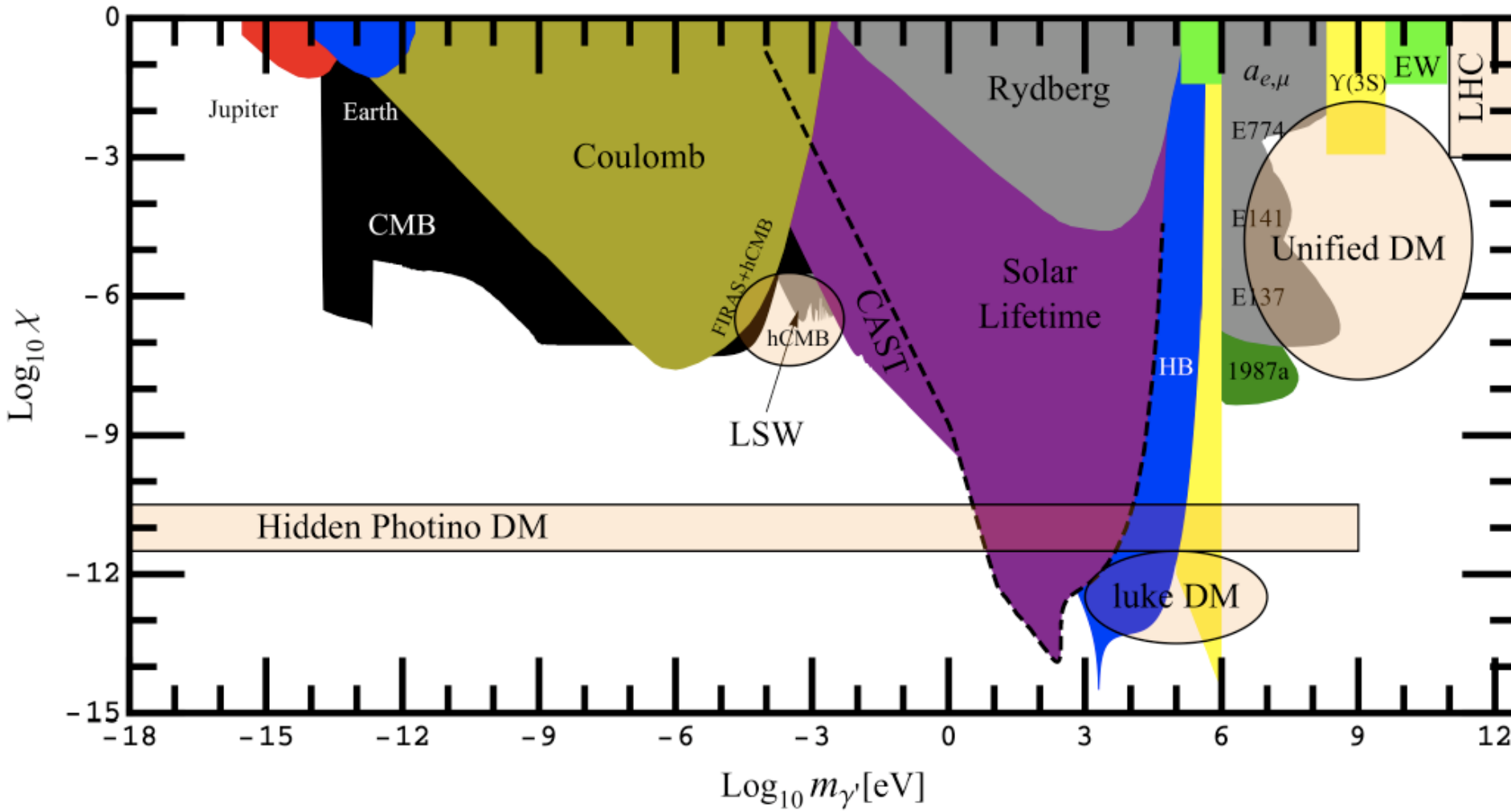






Hidden Photons

LSW already competitive + testing interesting area



Coincidences?

- Neutrino masses:

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

- Scale of dark energy:

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

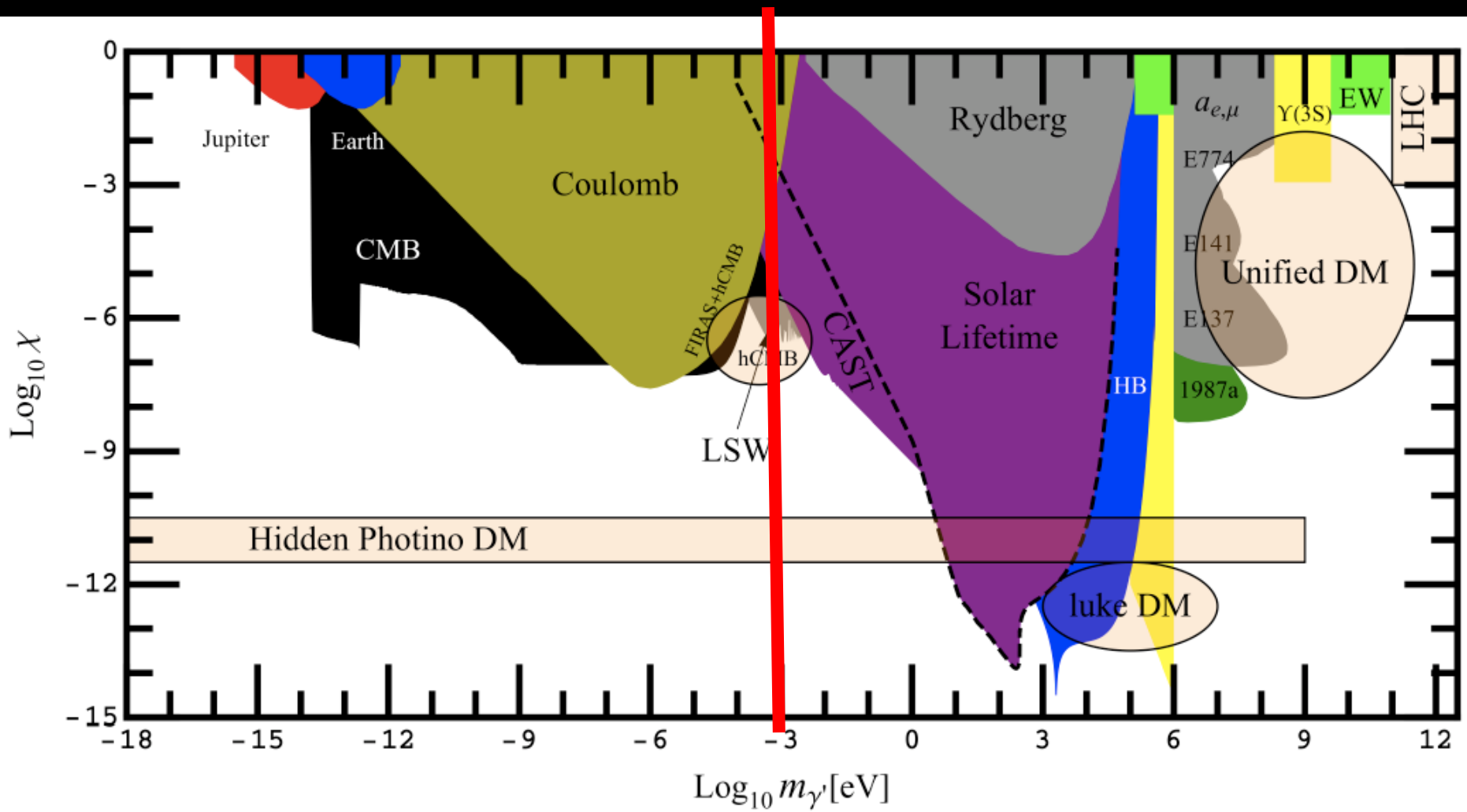
- Energy density of the Universe:

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

Hidden Photons

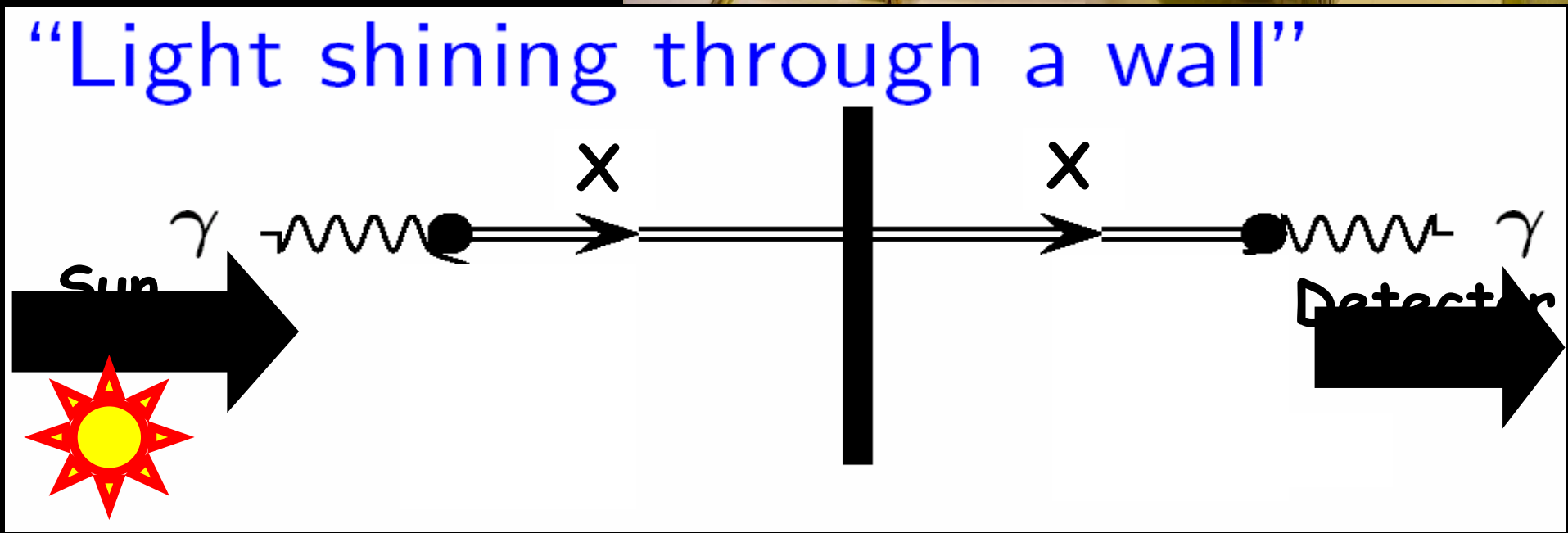
LSW already competitive + testing interesting area

Dark energy scale

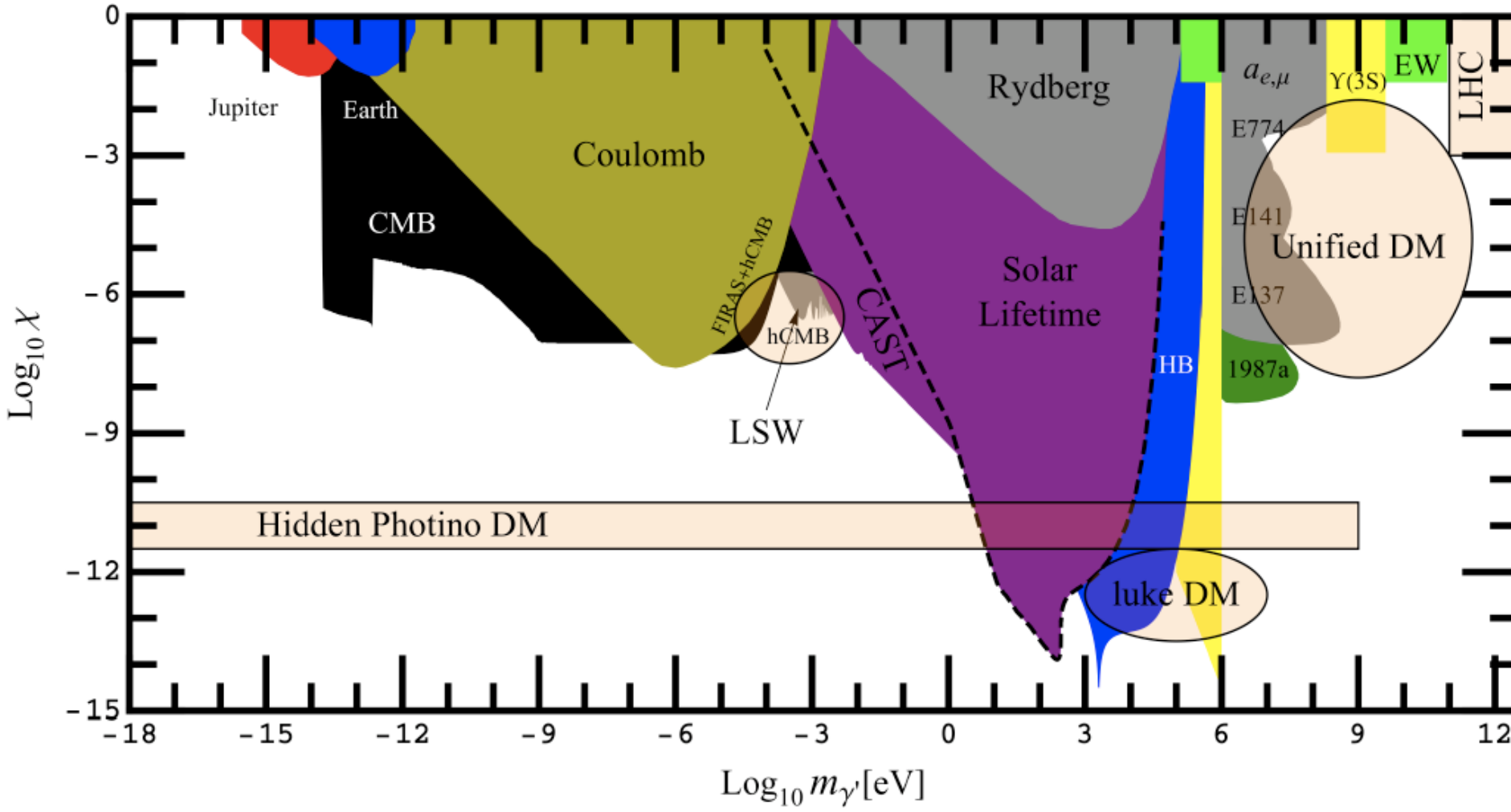


Helioscopes

CAST@CERN
SUMICO@Tokyo
SHIPS@Hamburg

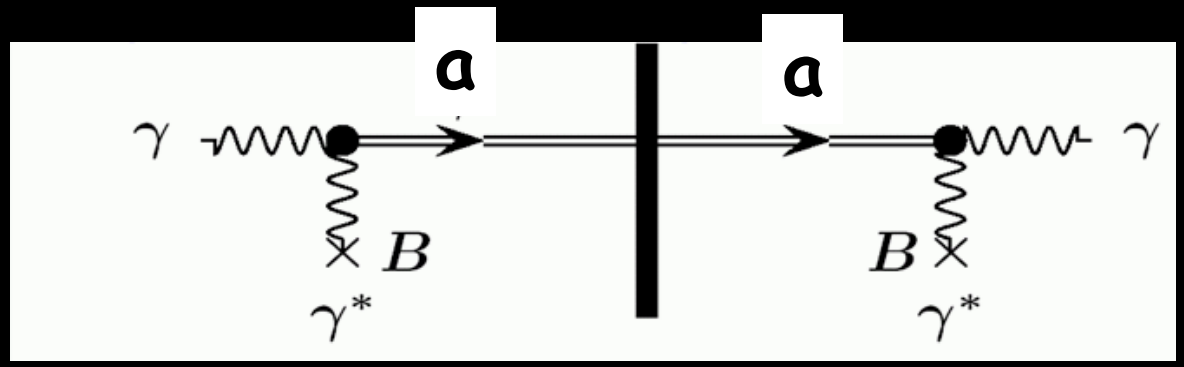


Helioscopes sensitivity

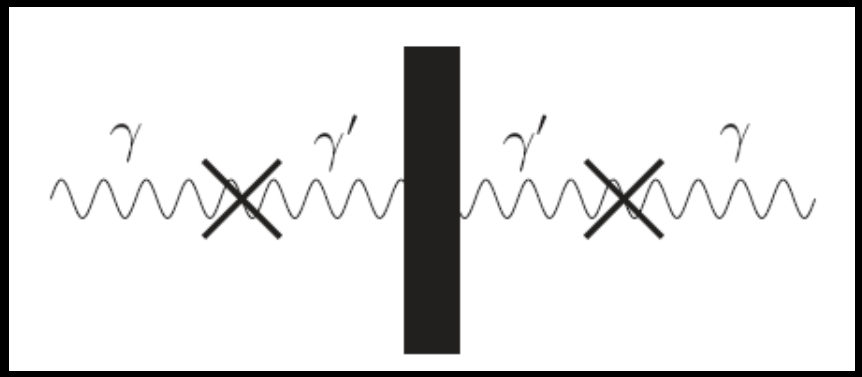


WISPS=Weakly interacting sub-eV particles

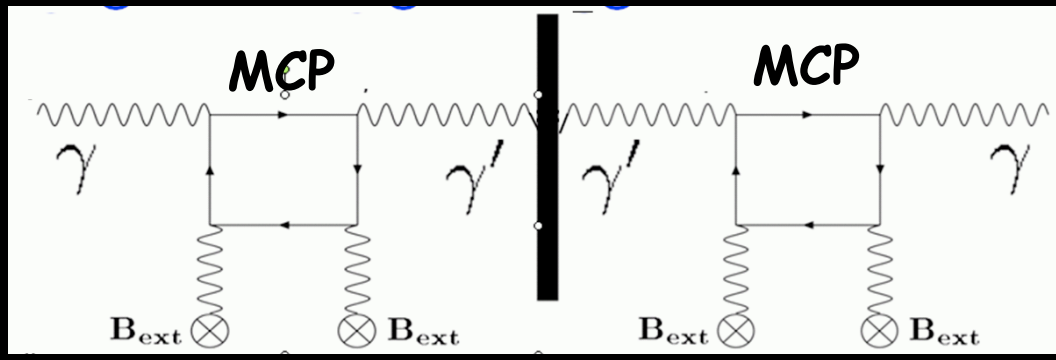
- Axions



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



- Hidden photon + minicharged particle (MCP)



Dark Matter(s)

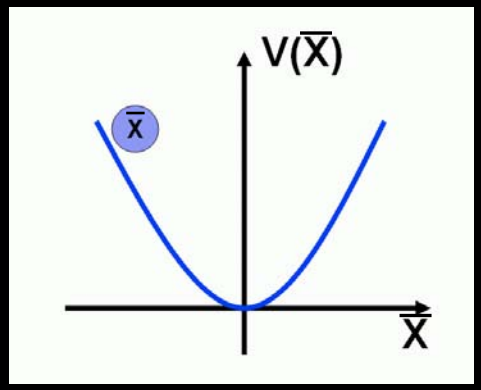
Hidden = Dark photon matter

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

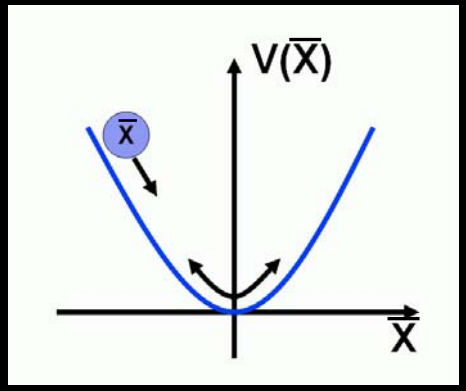
$$\bar{X}_i = X_i / a(t)$$

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

- $H \gg m_{\gamma'}$ → overdamped oscillator

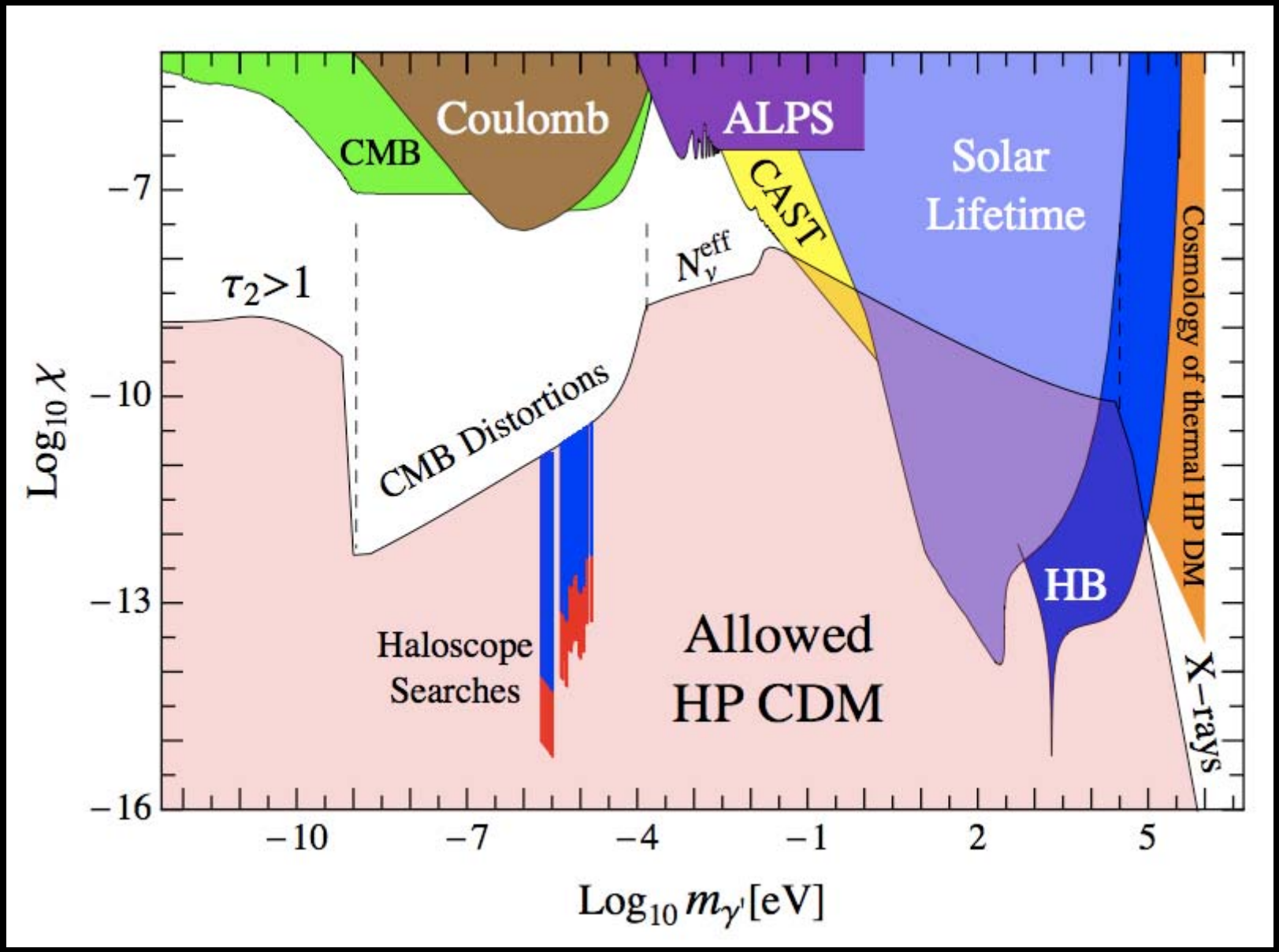


- $H \ll m_{\gamma'}$ → damped oscillator



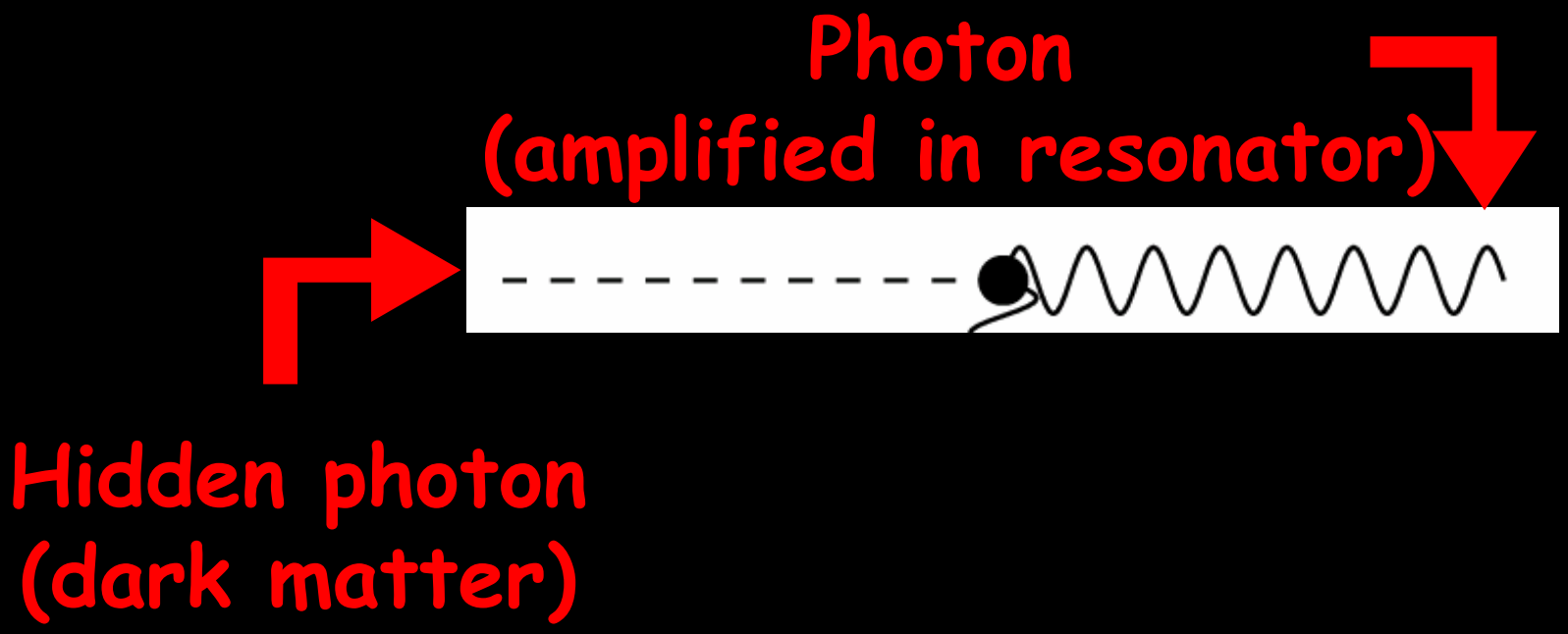
$$\rho_X(t) = \frac{\rho_{ini}}{a^3(t)}$$ → Dark Matter

Hidden Photon Dark Matter



Use a plentiful source of HPs

- Photon Regeneration

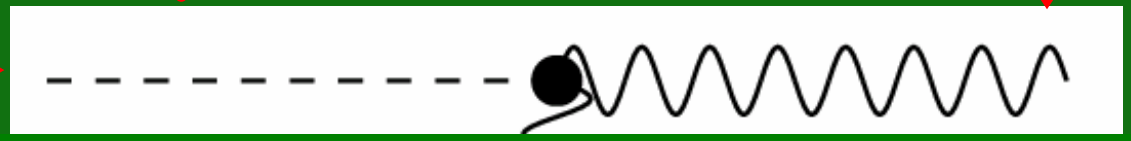


➔ See ADMX talk

Electricity from Dark Matter ;-).

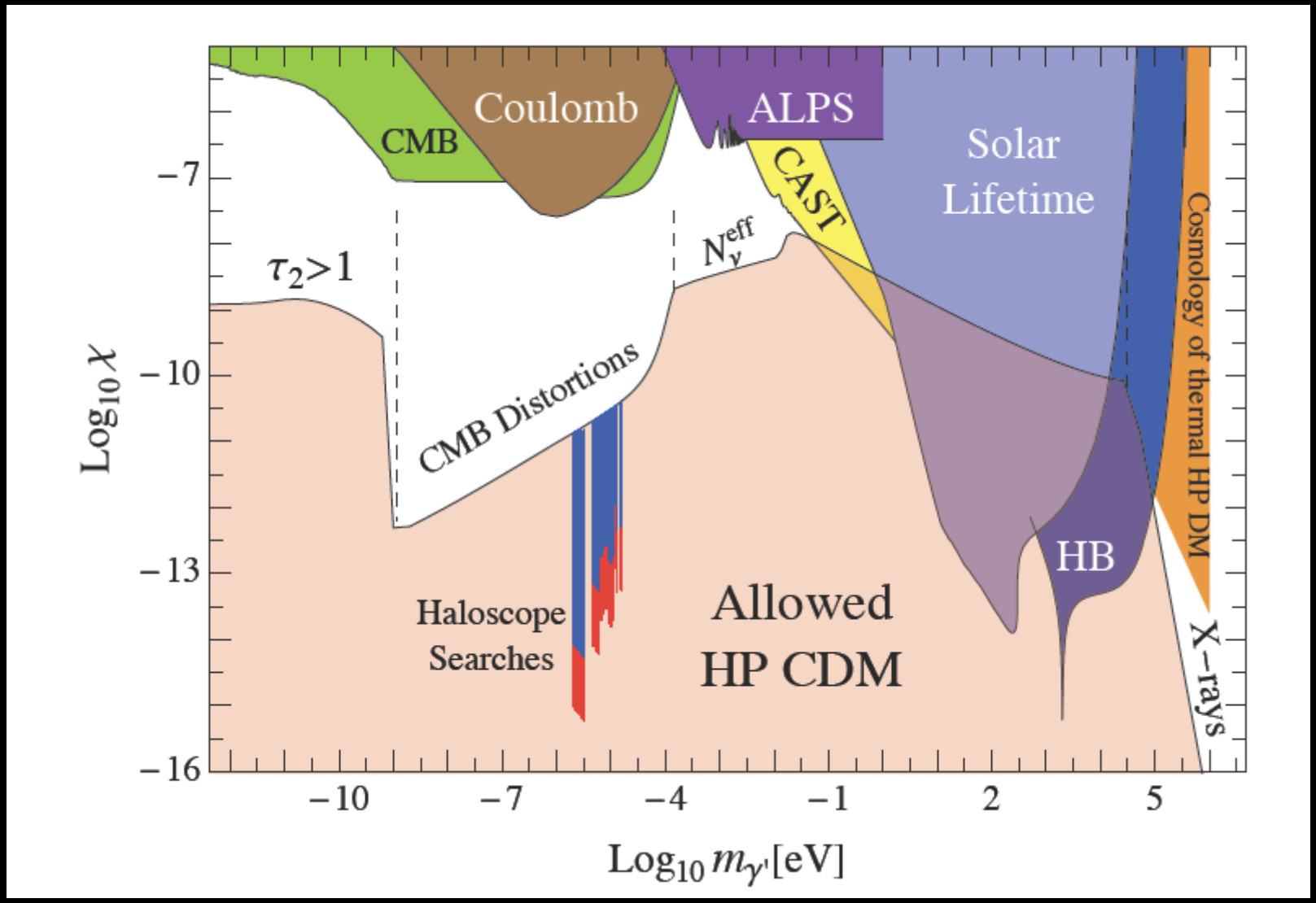
- Photon Regeneration

Photon
(amplified in resonator)



Hidden photon
(dark matter)

An extremely sensitive probe!!!



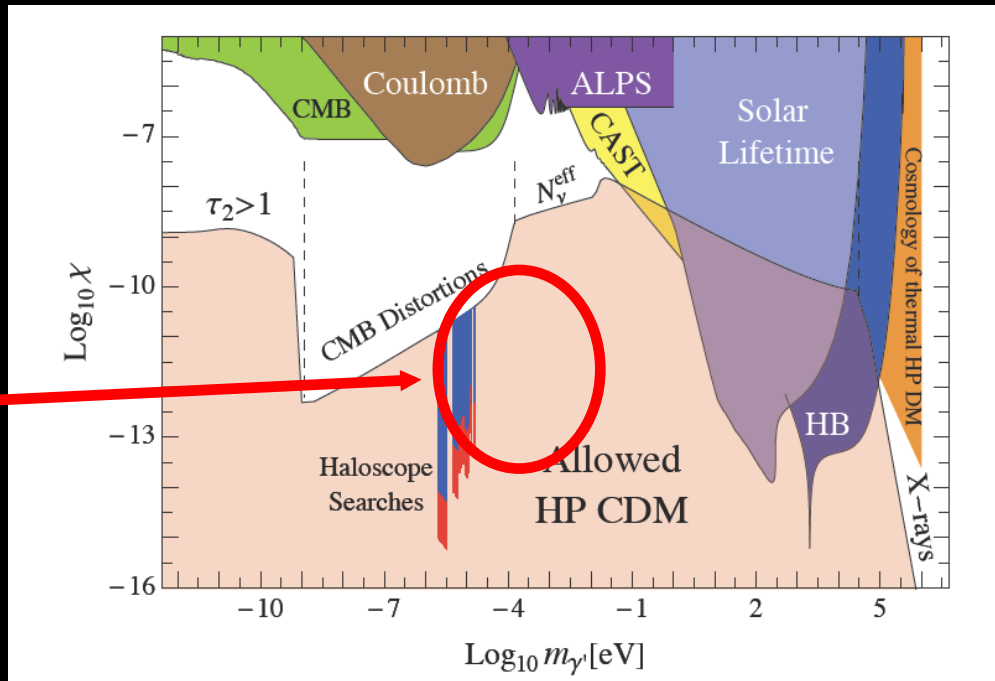
Dark Matter Antenna

Antenna converts HP->photon

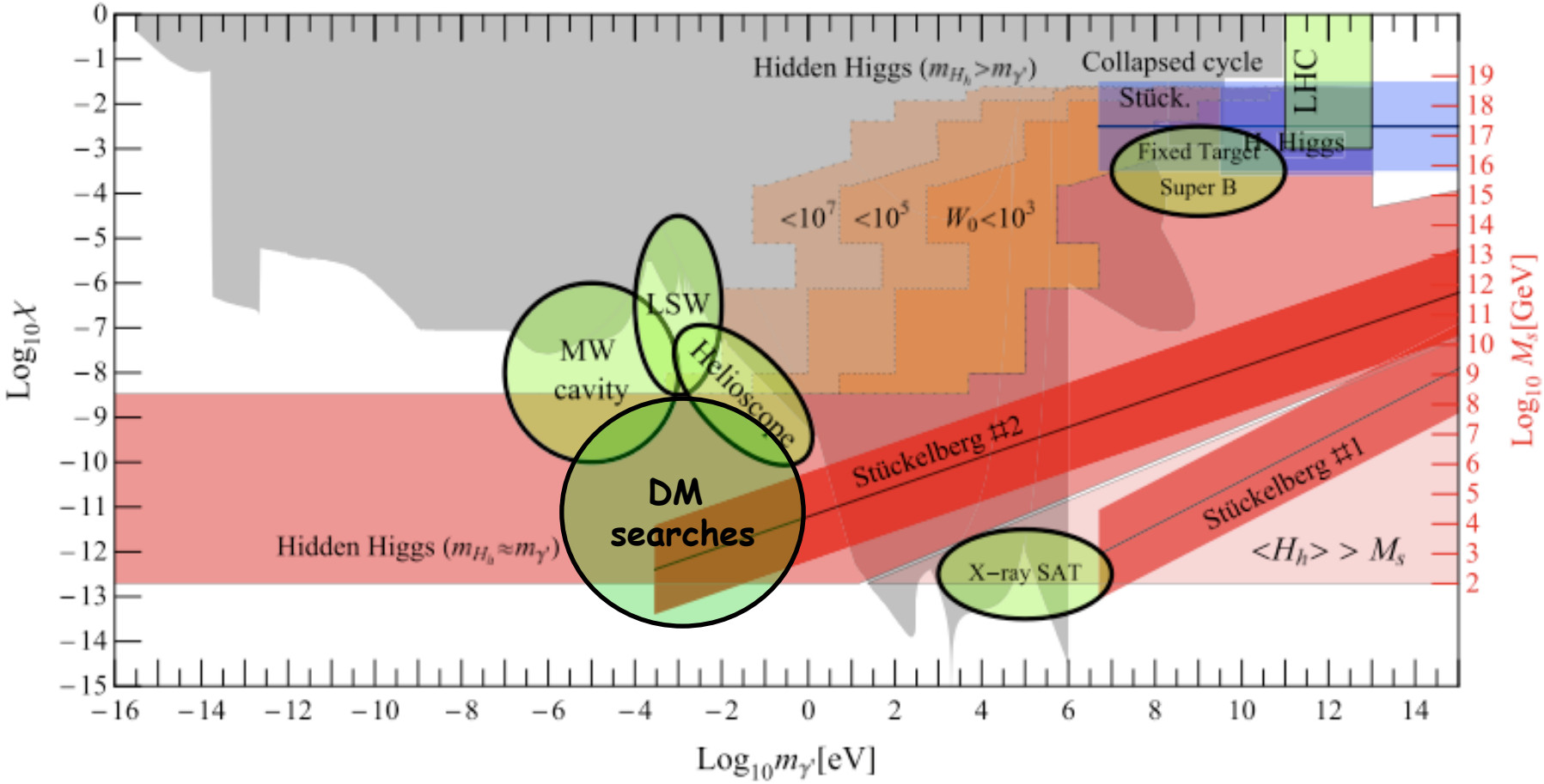
Radiation concentrated in center

Detector

Probes here; very sensitive!!



Many more tests…



Exciting things go on NOW!!!

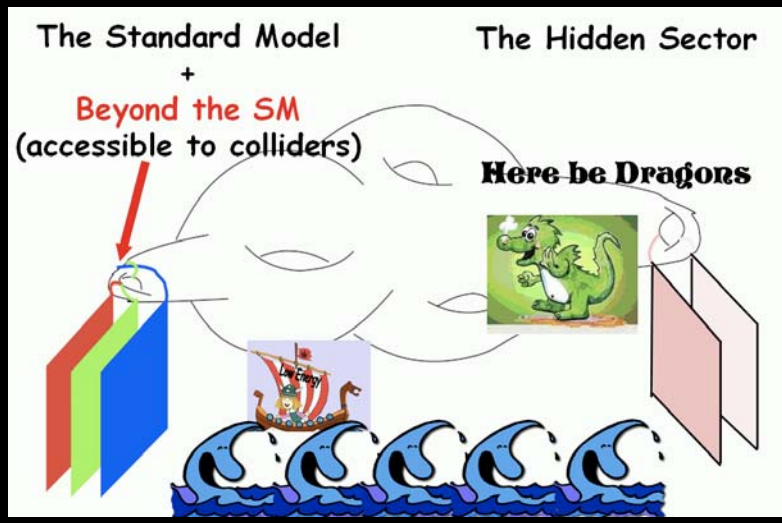
Conclusions

Conclusions

- Good Physics Case for HPs + other light stuff
  ➡ explore `The Low Energy Frontier'

- Ongoing: Low energy experiments test directions not tested in accelarators
  ➡ Complementary!

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



Discover the Hidden Islands