Looking for hidden-sector U(1) bosons kinetically mixing with the photon

Javier Redondo

Deutsches Elektronen Synchrotron (DESY)

SFB meeting at DESY Zeuthen (2008/02/14)

In collaboration with A. Ringwald, H. Gies, A. Ibarra, J. Jaeckel, M. Ahlers and C. Weniger

Outline:

- Very brief theoretical motivation
- Phenomenology of novel low mass U(1) bosons
- The meV "valley"
- The massless case
- Conclusions

A (brief) theoretical motivation...

Hidden photons, shadow photons, paraphotons, Z primes ...

Additional U(1) gauge symmetries are ubiquitous in PBSM
- Unification
- String Theory

If SM particles uncharged $\longrightarrow$ Hidden sector
- window to high energy content through ren. operator:
- Kinetic mixing -

New particles charged under new U(1)
- unquantized small electric charge
- Dark Matter?

A (brief) unmotivation...

for low mass U(1) bosons...

determined in terms of the mass matrix and the charges, that are known.

One of the anomalous $U(1)$ gauge bosons comes from a brane that wraps the two large dimensions [16]. This implies that its UV mass term as well as the mixing terms with the other $U(1)$ gauge bosons should be anywhere between M_s and $\sim 10^{-3}$ eV. We will assume in this paper, for simplicity that its mass comes from an $N = 2$ sector and therefore its physical mass is of the order of the string scale. In any case, its mass must be larger than around 50 MeV to avoid standard supernova cooling constraints [17].

In the neutrino sector that is not discussed in this paper, there are further parameters that enter. If there is a single bulk right handed neutrino then there are three parameters associated

Corianò et al.

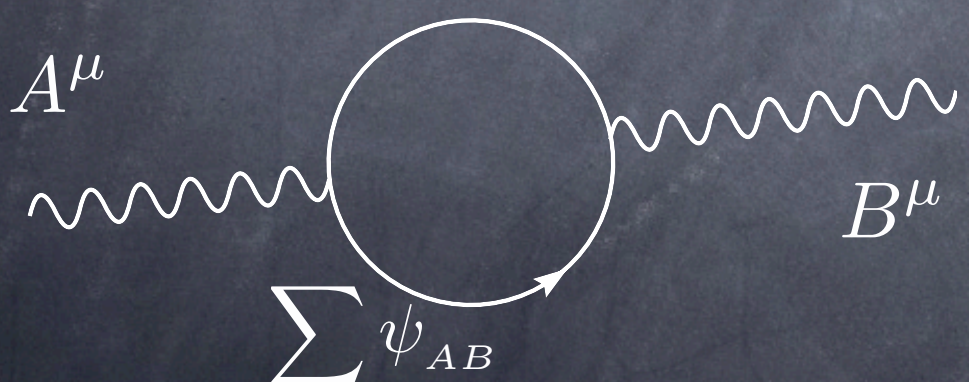
...simplicity?

relevant operators at low energies ...

$$\mathcal{L}_H = \underbrace{-\frac{\sin\chi}{2} A_\mu B^\mu}_{} - \frac{1}{4} B_{\mu\nu} B^{\mu\nu} + \frac{1}{2} m_{\gamma'}^2 B_\mu B^\mu$$

kinetic mixing with photon (or hypercharge)

- In principle can have any value between 0 and 1...
- If B belongs to a broken non abelian group, $\sin\chi = 0$ at high E, but it can develop a nonzero value below the SSB scale



$$= \frac{e g_B}{6\pi^2} \sum_{\psi_{AB}} Q_A Q_B \,\mathrm{Log}\frac{m_{\psi_{AB}}}{\mu}$$

SUSY, String theory ...

$$\sin\chi = 10^{-4,-16}$$

mass degeneracy

K. R. Dienes, C. F. Kolda, and J. March-Russell. Nucl. Phys., B492:104–118, 1997.

photon "Flavor" oscillations & kinetic mixing

L. B. Okun. Sov. Phys. JETP, 56:502, 1982.

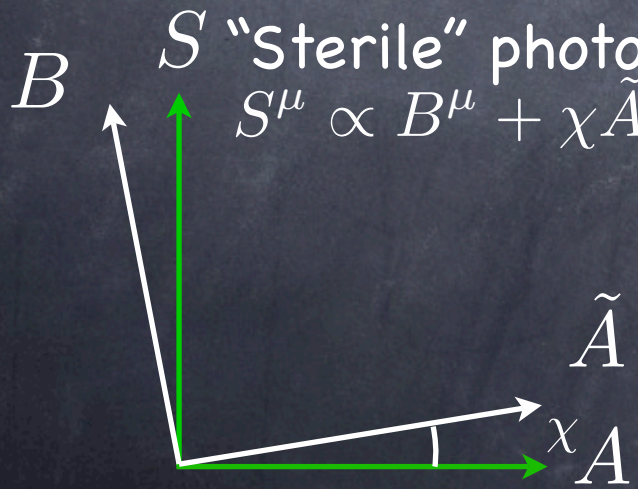
$$-\frac{1}{4}A_{\mu\nu}A^{\mu\nu} + ej_\mu A^\mu \qquad -\frac{\sin\chi}{2}A_{\mu\nu}B^{\mu\nu} \qquad -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{\gamma'}B_\mu B^\mu$$

$$A^\mu \to \tilde{A}^\mu - \sin\chi B^\mu \sim \tilde{A}^\mu - \chi B^\mu$$

$$-\frac{1}{4}\tilde{A}_{\mu\nu}\tilde{A}^{\mu\nu} \qquad ej_\mu(\tilde{A}^\mu - \chi B^\mu) \qquad -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m^2_{\gamma'}B_\mu B^\mu$$

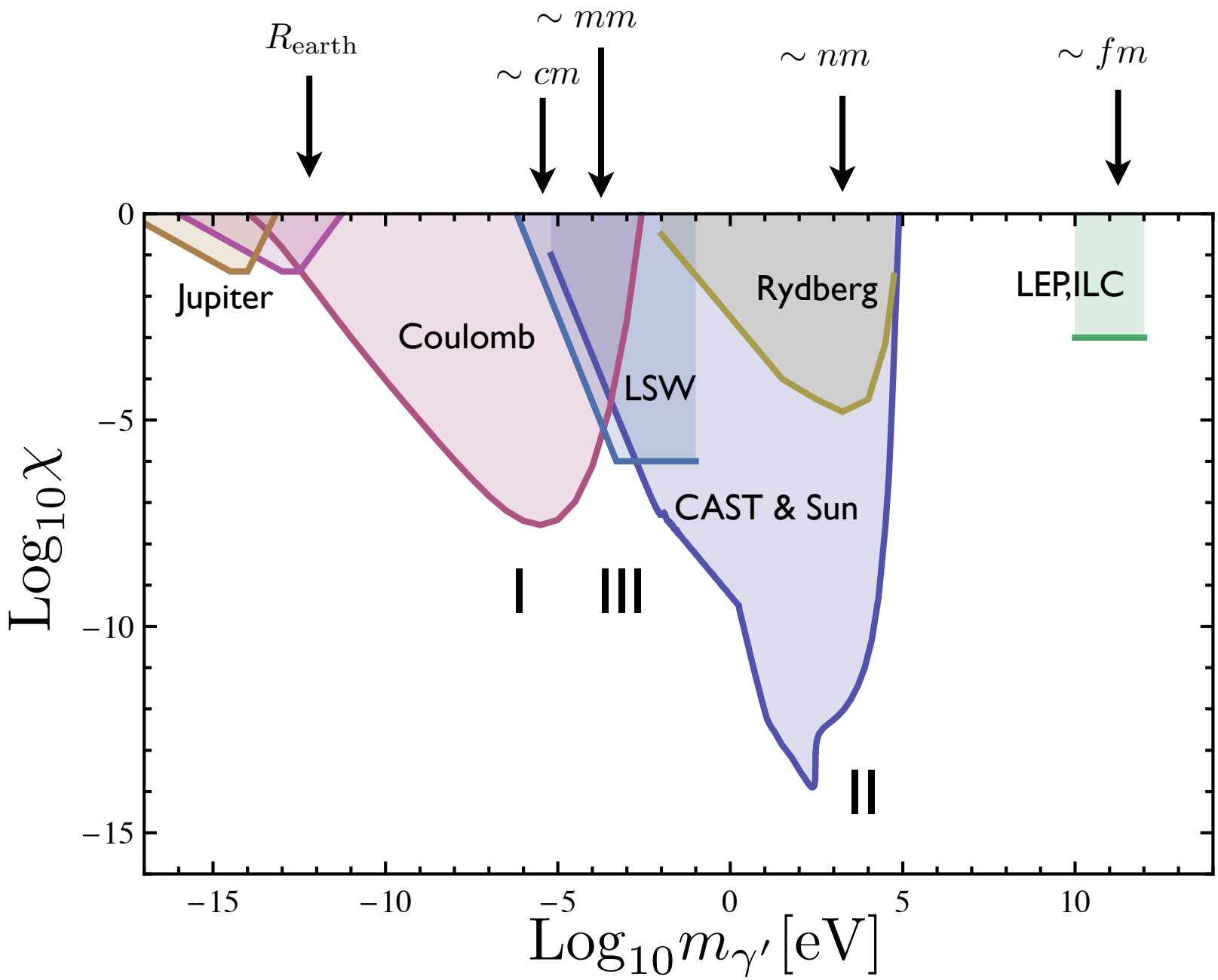
"Flavor" eigenstate

"mass" eigenstates

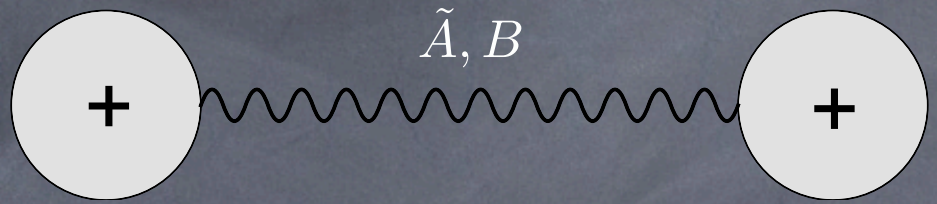


photon-sterile oscillation prob.

$$P_{A-S} = \sin^2 2\chi \times \sin^2 \frac{m^2_{\gamma'}L}{4\omega}$$

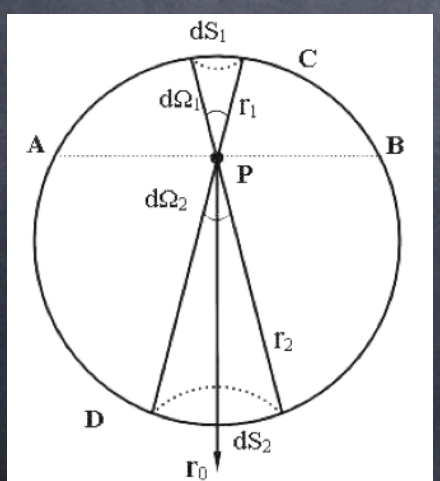

$R_{\rm earth}$
$\sim cm$
$\sim mm$
$\sim nm$
$\sim fm$
Jupiter
Coulomb
LSW
CAST & Sun
Rydberg
LEP,ILC
I
III
II
$\mathrm{Log}_{10}\chi$
$\mathrm{Log}_{10}m_{\gamma'}\,[\mathrm{eV}]$
0
−5
−10
−15
−15
−10
−5
0
5
10

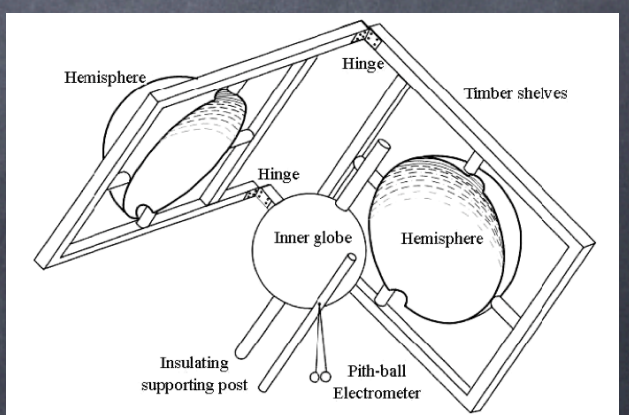
I - Test of Coulomb's Law (Henry Cavendish 1773)



$$i\mathcal{A} = e^2 \left(\frac{1}{q^2} + \frac{\chi^2}{q^2 - m_{\gamma'}^2} \right)$$

$$V(r) = \mathcal{FT}\{i\mathcal{A}(\bar{q}^2)\} = e^2 \left(\frac{\alpha}{r} + \frac{\alpha\chi^2}{r} e^{-m_{\gamma'} r} \right)$$





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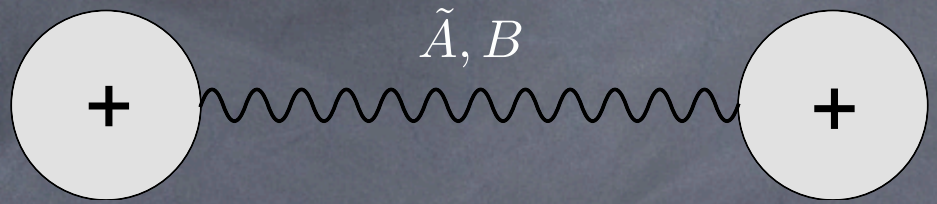

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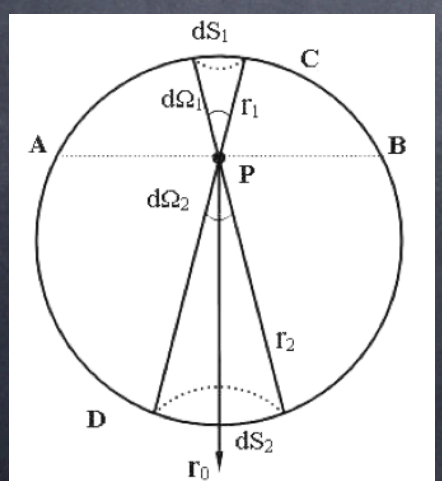
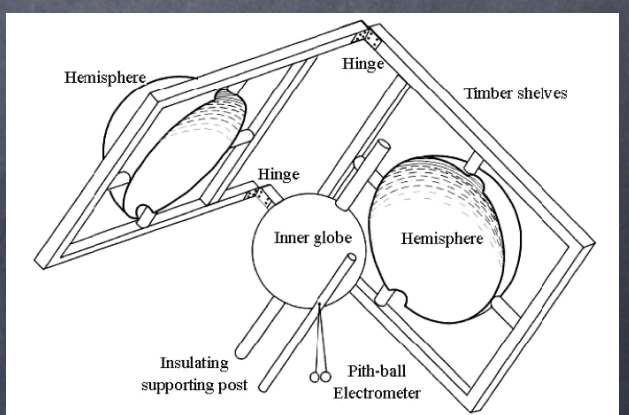
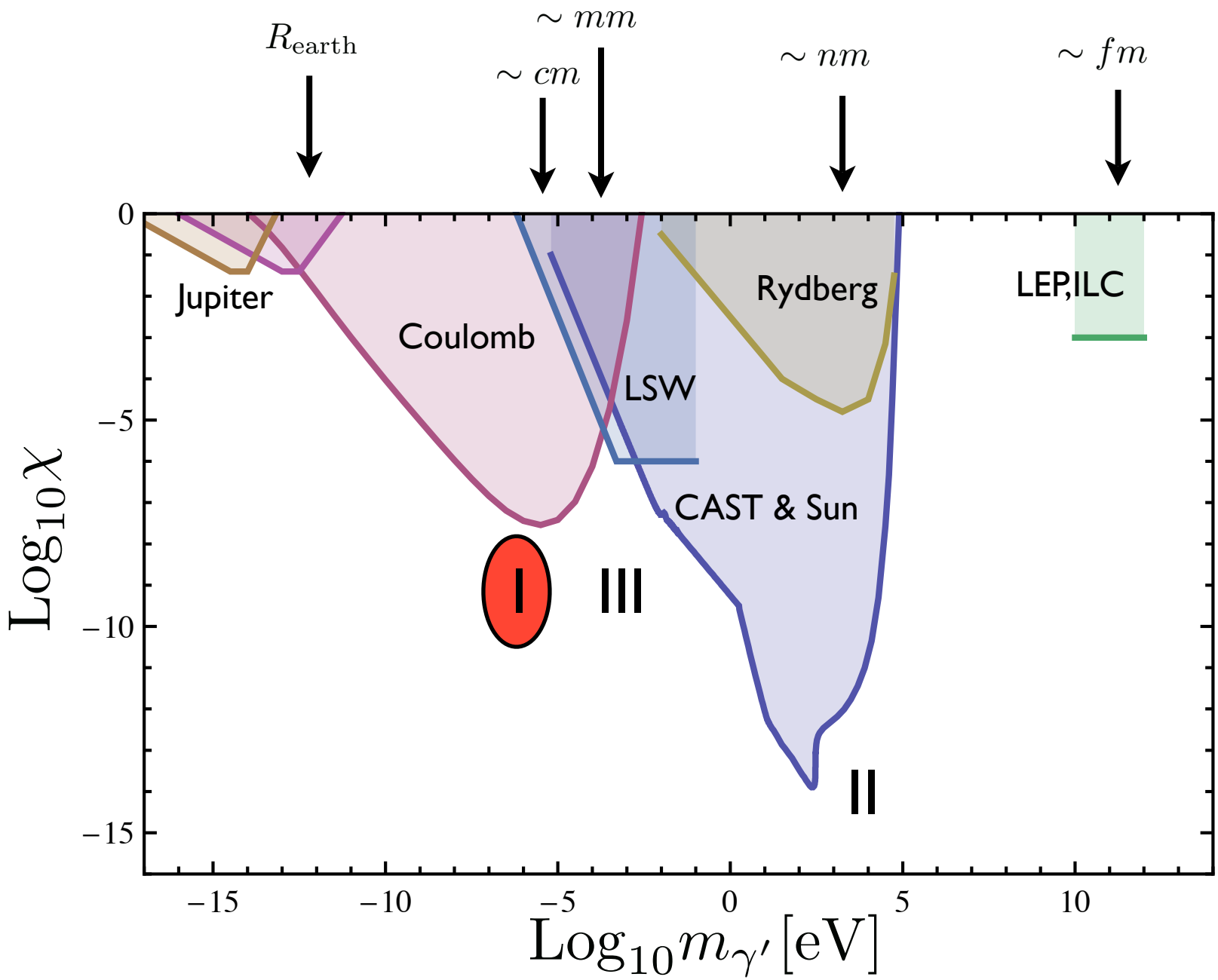




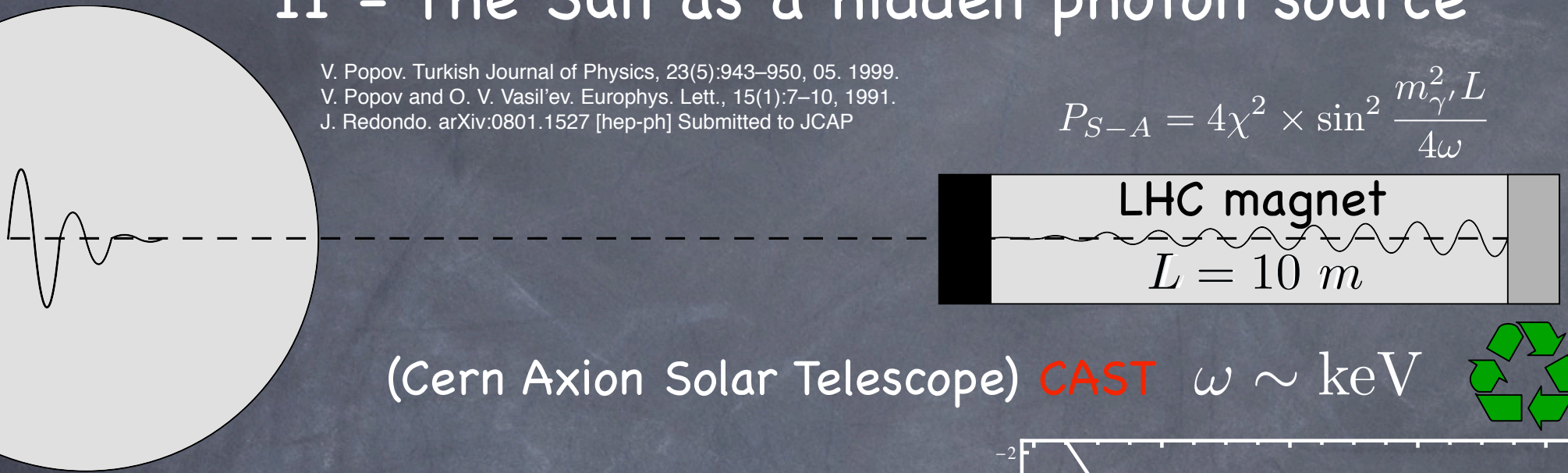


E. R. Williams, J. E. Faller, and H. A. Hill. Phys. Rev. Lett., 26:721–724, 1971.
D. F. Bartlett and S. Loegl. Phys. Rev. Lett., 61:2285–2287, 1988.

II - The Sun as a hidden photon source

V. Popov. Turkish Journal of Physics, 23(5):943–950, 05. 1999.
V. Popov and O. V. Vasil'ev. Europhys. Lett., 15(1):7–10, 1991.
J. Redondo. arXiv:0801.1527 [hep-ph] Submitted to JCAP

$$P_{S-A} = 4\chi^2 \times \sin^2 \frac{m_{\gamma'}^2 L}{4\omega}$$



(Cern Axion Solar Telescope) CAST $\omega \sim \mathrm{keV}$

- photons behave as massive particles in a plasma with $m \simeq \omega_{\mathrm{P}}$ (plasma freq.) $\omega_P^2 \sim 1 - 300\mathrm{eV}$

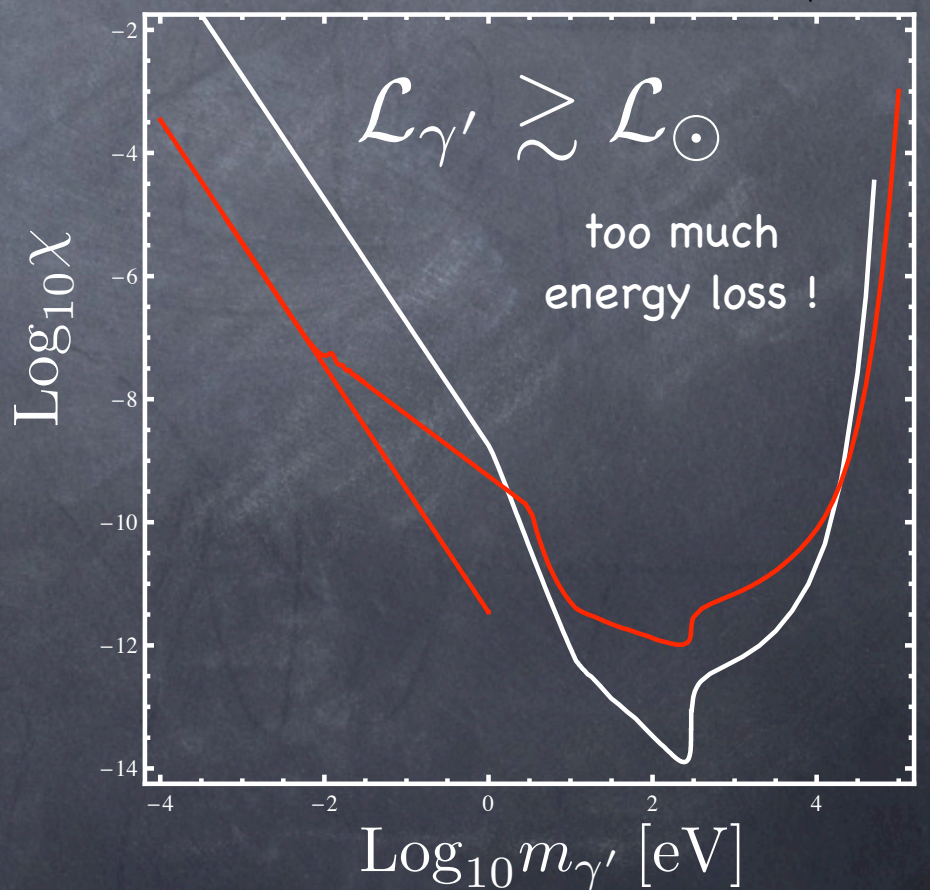
$$\chi_{eff} = \chi \frac{m_{\gamma'}^2}{\omega_P^2 - m_{\gamma'}^2 - i\omega\Gamma}$$

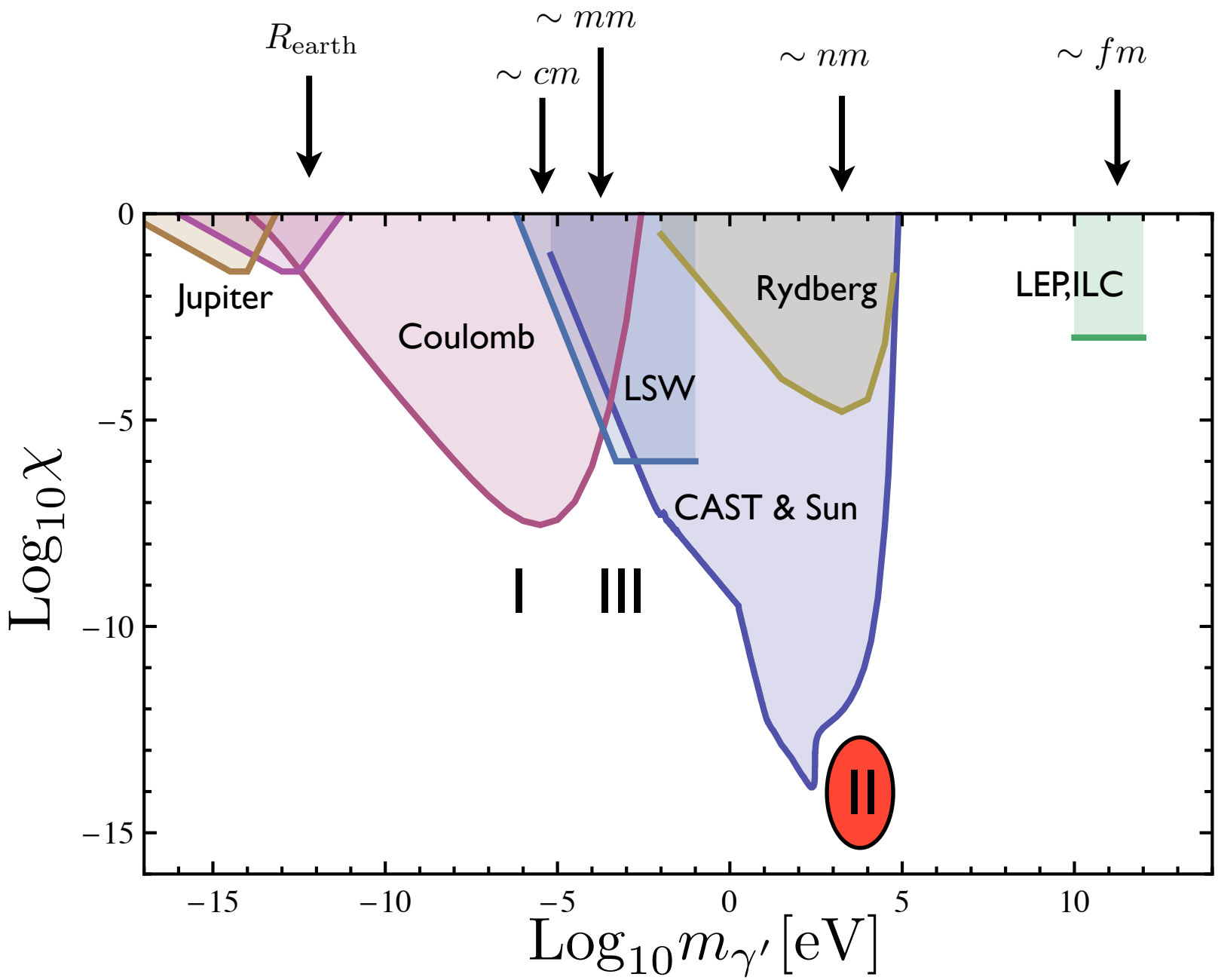
- Three cases:

1 - Suppressed production $m_{\gamma'} \ll \omega_P$

2 - Resonance $m_{\gamma'} = \omega_P \ (\omega\Gamma \ll \omega_P)$

3 - Normal regime $m_{\gamma'} \gg \omega_P \ (\chi_{eff} = \chi)$

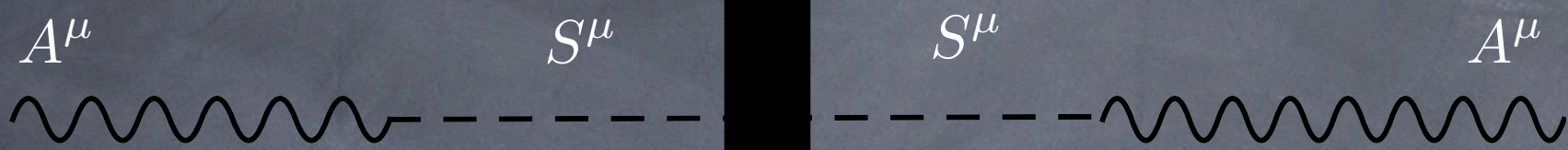




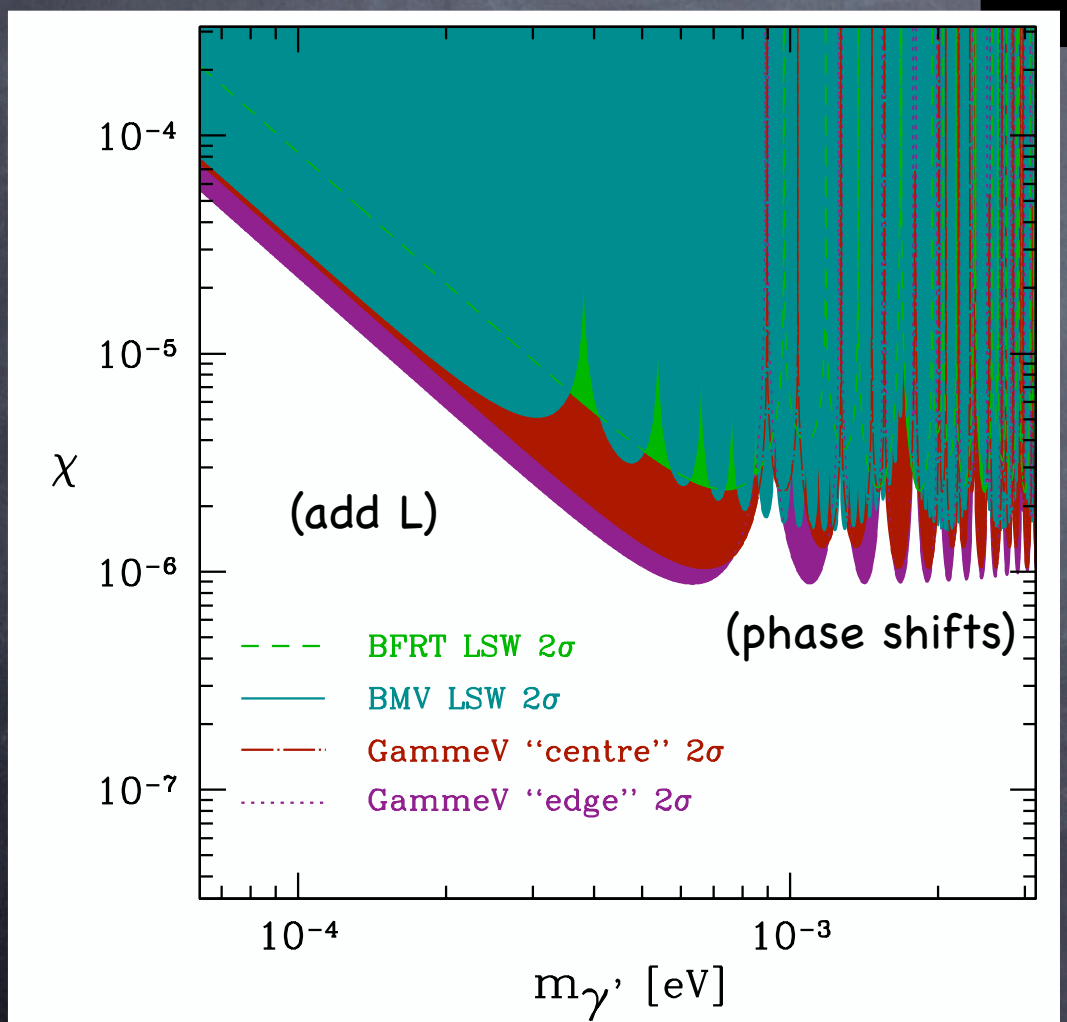
J. Redondo. arXiv:0801.1527 [hep-ph] Submitted to JCAP

III- "Light shinning through walls"

meV valley



Laser as intense/controlled source: BFRT (BNL), BMV (LNCMP), GammeV (FL), ALPS (DESY)



... looking for axion-like particles

M. Ahlers, H. Gies, J. Jaeckel, J. Redondo, and A. Ringwald. Laser experiments explore the hidden sector. 2007.

regeneration probability

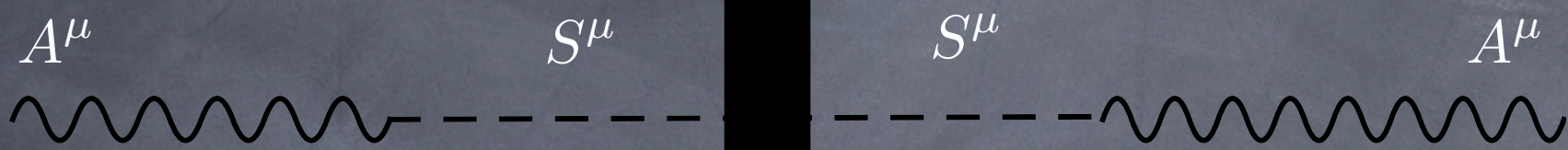
$$P = 16\chi^4 \sin^2 \frac{m_{\gamma'}^2 L_1}{4\omega} \sin^2 \frac{m_{\gamma'}^2 L_2}{4\omega}$$

typical configurations

$$L \sim m, \ \omega \sim \text{eV}$$

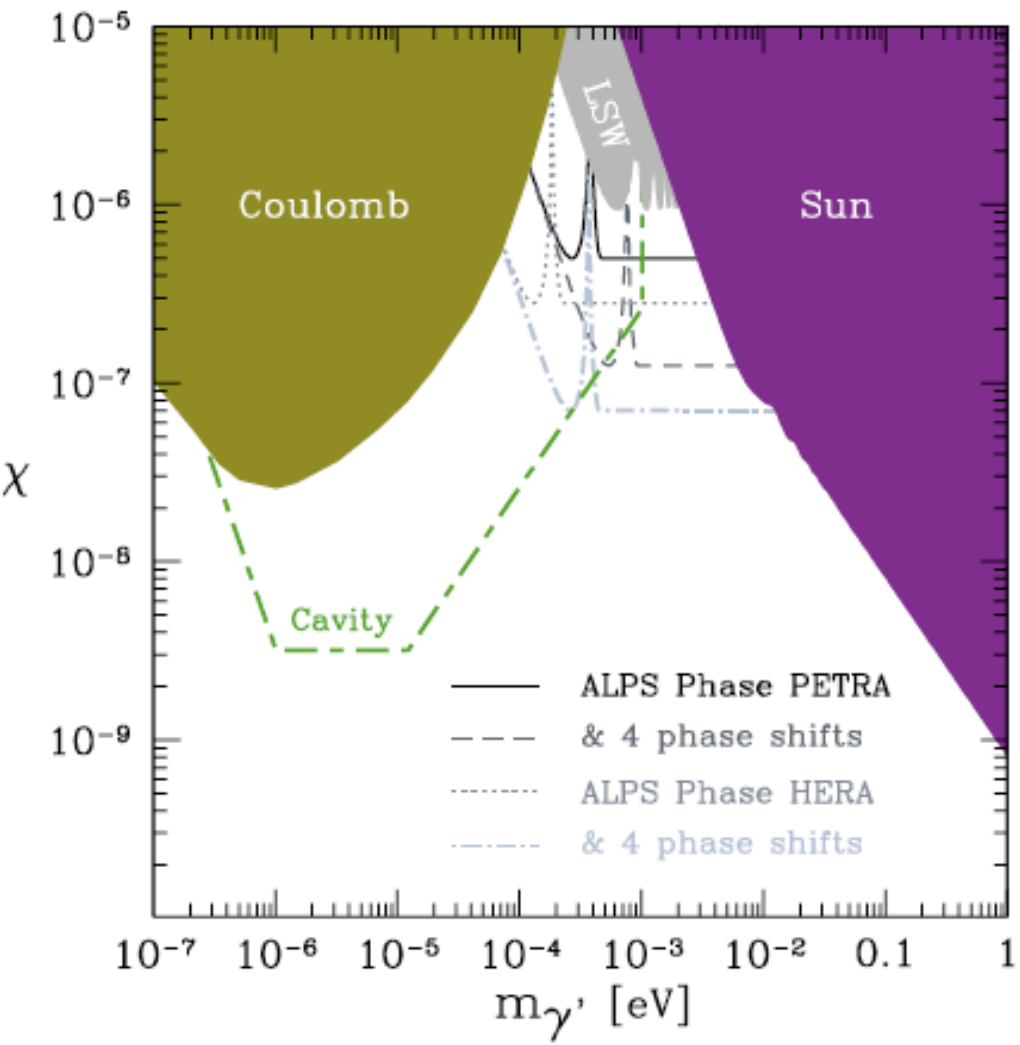
"Light shinning through walls"

meV valley



Laser as intense/controlled source: BFRT (BNL), BMV (LNCMP), GammeV (FL), ALPS (DESY)

(axion recycling)



regeneration probability

$$P = 16\chi^4 \sin^2 \frac{m_{\gamma'}^2 L_1}{4\omega} \sin^2 \frac{m_{\gamma'}^2 L_2}{4\omega}$$

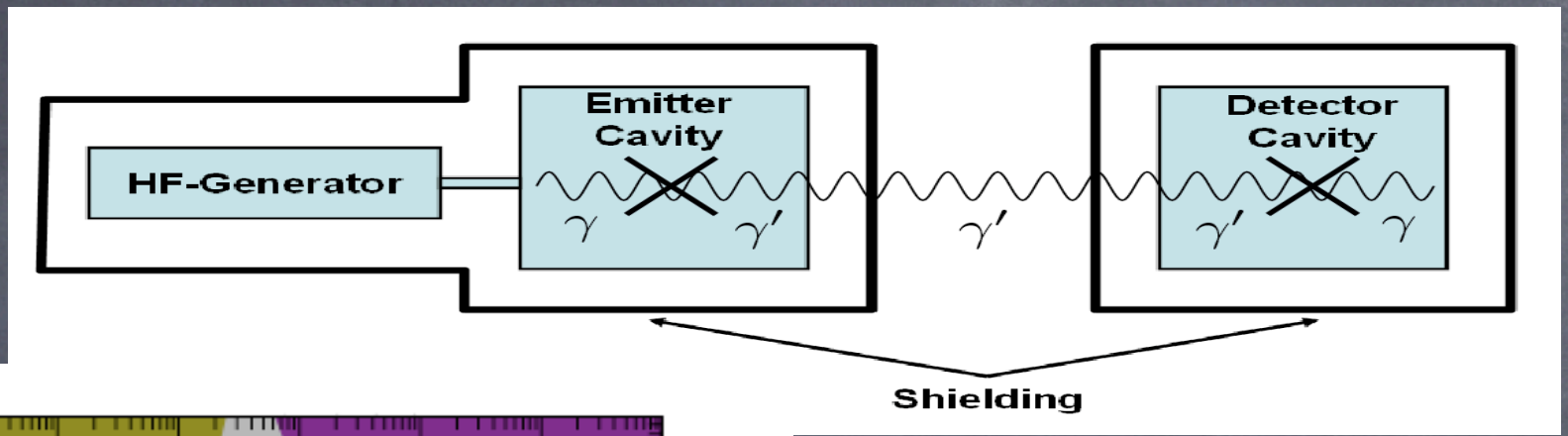
longer config.

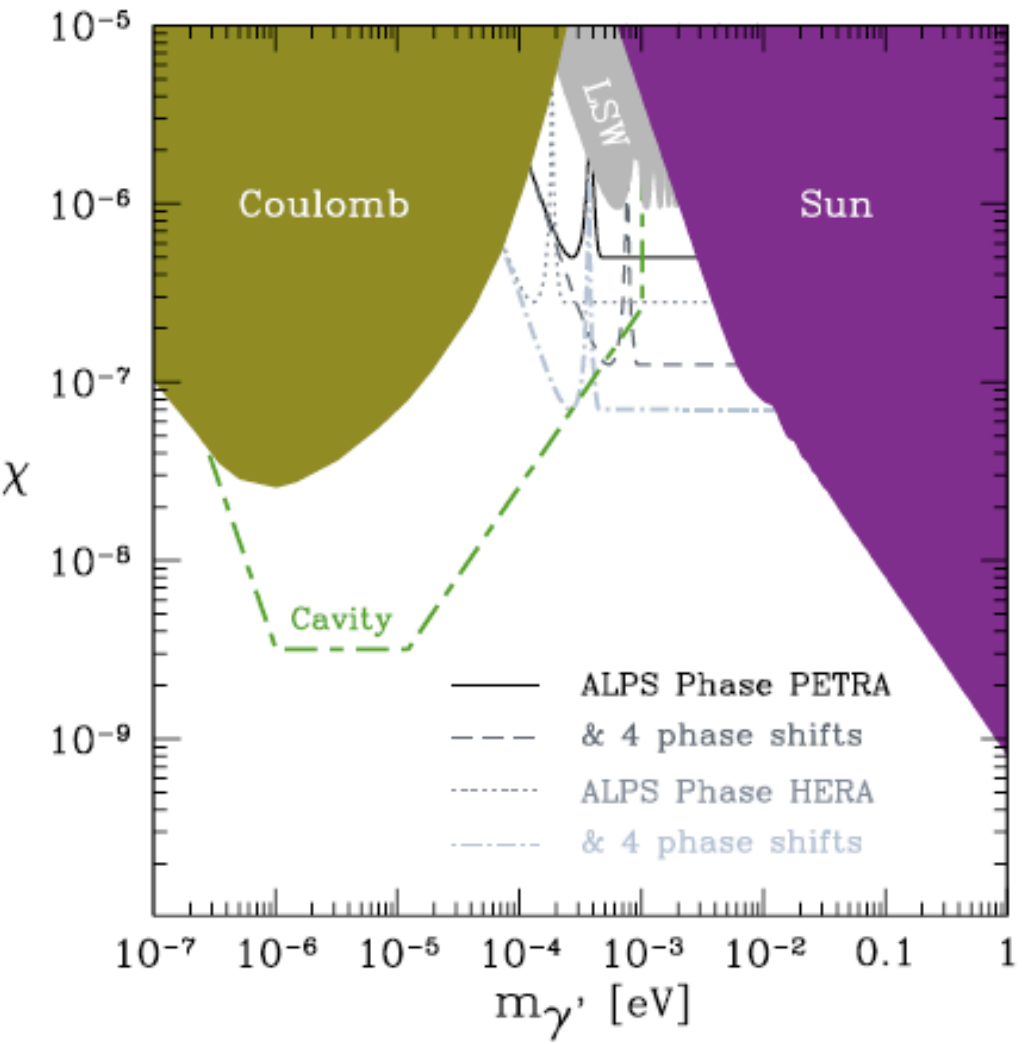
$$L \sim 40 - 100\ m$$

... phase shift plates?

J. Jaeckel and A. Ringwald. Phys. Lett., B653:167–172, 2007.

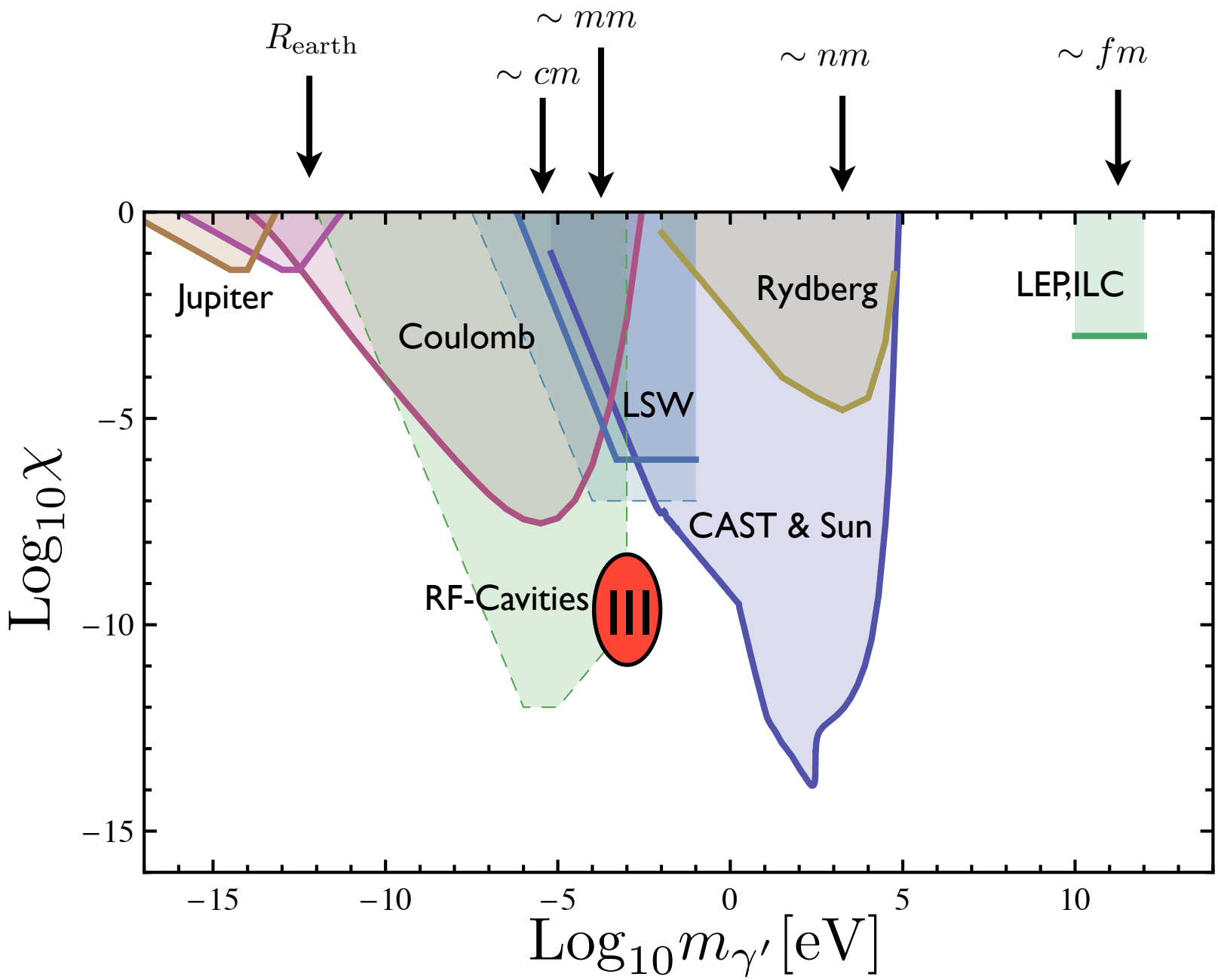
"Light shinning through walls" RF cavities





dedicated experiment!

J. Jaeckel and A. Ringwald. arXiv:0707.2063 [hep-ph]


$R_{\rm earth}$
$\sim cm$
$\sim mm$
$\sim nm$
$\sim fm$
Jupiter
Coulomb
LSW
Rydberg
LEP,ILC
CAST & Sun
RF-Cavities
0
−5
−10
−15
$\mathrm{Log}_{10}\chi$
−15
−10
−5
0
5
10
$\mathrm{Log}_{10} m_{\gamma'}\,[\mathrm{eV}]$

The m=0 case

$$-\frac{1}{4}A_{\mu\nu}A^{\mu\nu} + ej_\mu A^\mu \qquad -\frac{\sin\chi}{2}A_{\mu\nu}B^{\mu\nu} \qquad -\frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

$$B^\mu \to \tilde{B}^\mu - \sin\chi A^\mu$$

$$-\frac{1-\sin^2\chi}{4}A_{\mu\nu}A^{\mu\nu} + ej_\mu A^\mu \qquad -\frac{1}{4}\tilde{B}_{\mu\nu}\tilde{B}^{\mu\nu}$$

$\sin\chi \longrightarrow$ harmless renormalization of electric charge

$$-\frac{1}{4}A_{\mu\nu}A^{\mu\nu} + \frac{e}{\cos\chi}j_\mu A^\mu$$

The m=0 case... harmless?

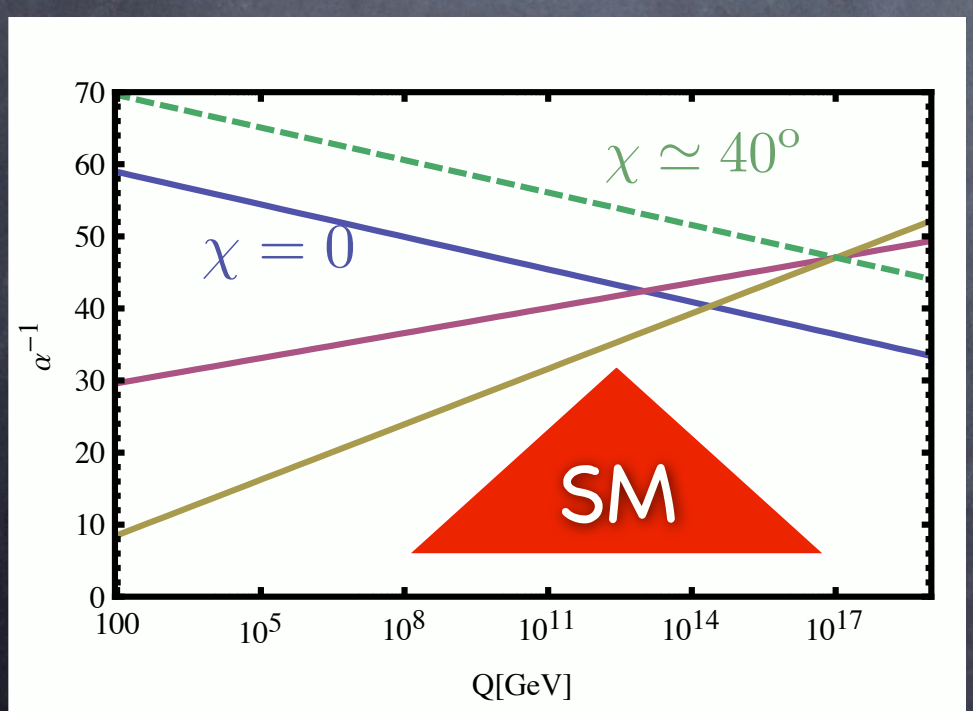
In progress... with A. Ibarra, A. Ringwald and C. Weniger

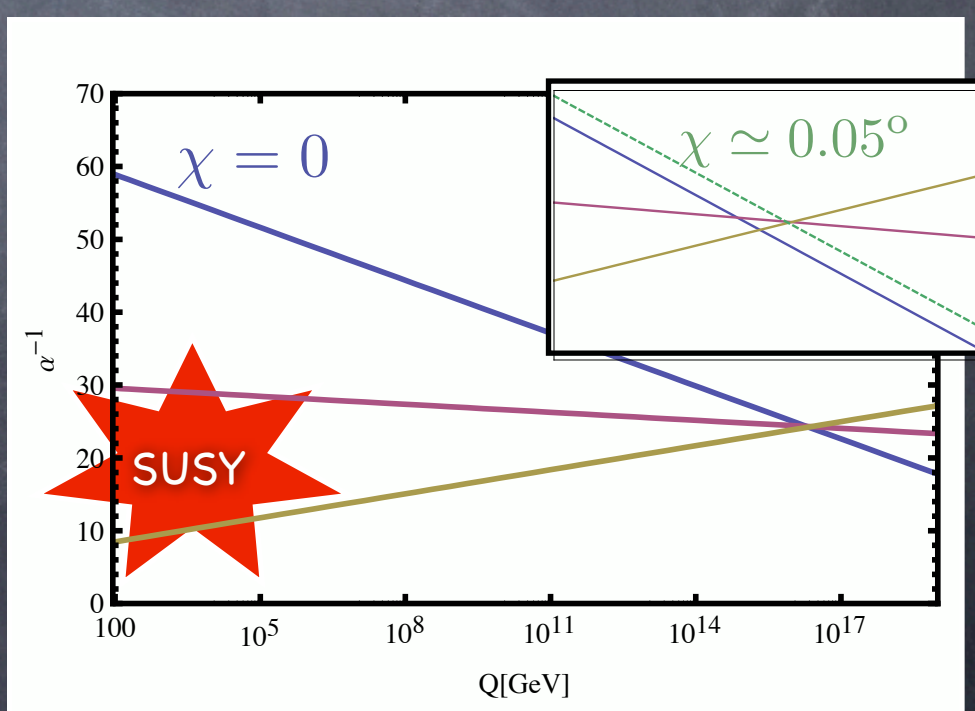
In a general framework (SM), B^μ, mixes with hypercharge Y^μ

In bare SM, g' is a free parameter ... so kinetic mixing is completely invisible!

But!! this is not the case in GUT models !

$$-\frac{1}{4}Y_{\mu\nu}Y^{\mu\nu} + \frac{g'}{\cos\chi} j^Y_\mu Y^\mu \qquad \frac{g'}{\cos\chi} \equiv g'_{\rm mes} \qquad g' < g'_{\rm mes}$$





Conclusions

- Additional U(1) symmetries ubiquitous in PBSM
- Lab. (LSW) opportunities  from axion searches
- Powerful new experiments proposed (RF cavities)
- can "mask" gauge coupling unification?