The low energy frontier :
probes with photons

Javier Redondo

Deutsches Elektronen Synchrotron (DESY)

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Electroweak and unified theories

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

Motivation

in the days of exploring the TeV frontier ...

are we leaving something behind us?

are they new particles at sub eV scale?

have they any relevance?

- Understanding HE symmetries ?
- Cosmology ?
- Unification ?

5 "clear" messages :

- candidate WISPs (weakly interacting subeV particles)

  ALPs, hidden photons and MCPs

- WISPs could evade HE bounds (astrophysics and cosmology)
- Light degrees of freedom required for late Cosmology
- The ALPS experiment at DESY & meV valley
- Massless U(1)'s

WISPs #2 & #3

hidden photons & MCPs

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

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

- Kinetic mixing -

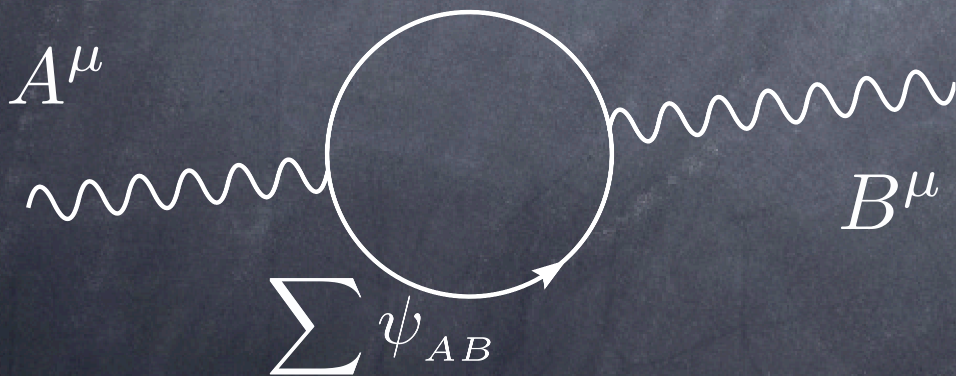
New particles charged under new U(1)
- unquantized small electric charge $\longrightarrow$ MCPs
- Chiral symmetries $\longrightarrow$ light fermions

kinetic mixing

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

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.

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

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

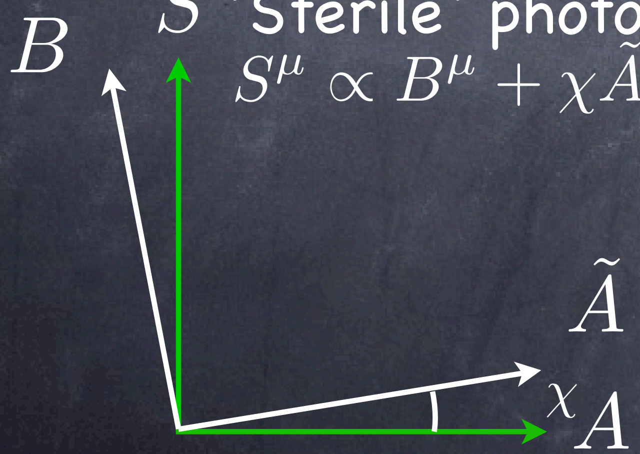
$$-\frac{1}{4}\tilde{A}_{\mu\nu}\tilde{A}^{\mu\nu} \quad ej_\mu(\tilde{A}^\mu - \chi B^\mu) \quad -\frac{1}{4}B_{\mu\nu}B^{\mu\nu} + \frac{1}{2}m_{\gamma'}^2 B_\mu B^\mu$$

"Flavor" eigenstate

"mass" eigenstates

S "Sterile" photon

$$S^\mu \propto B^\mu + \chi\tilde{A}^\mu$$



photon-sterile oscillation prob.

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

& Minicharged particles ...

Particles charged under new U(1) acquire electric charge

when $m_{\gamma'} = 0$

$$B^\mu \to B^\mu - \chi A^\mu \leftrightarrow A^\mu \to A^\mu - \chi B^\mu$$

$$\tilde{j}_\mu B^\mu \to ... - \chi \tilde{j}_\mu A^\mu$$

Fermions, scalars... charged under $U(1)_{\mathrm{h}}$

$$\epsilon \equiv Q_A = -\chi Q_B$$

(Other possibilities for MCPs... SM or extra dimensions)

Impact of WISPs

- New Long Range Forces
- Stellar cooling
- Missing energy at colliders ...
- CMB distortion
- extra neutrinos at BBN

but ...

Cosmological Constraint on the Effective Number of Neutrino Species *K. Ichikawa arXiv:0706.3465v1 [astro-ph]*

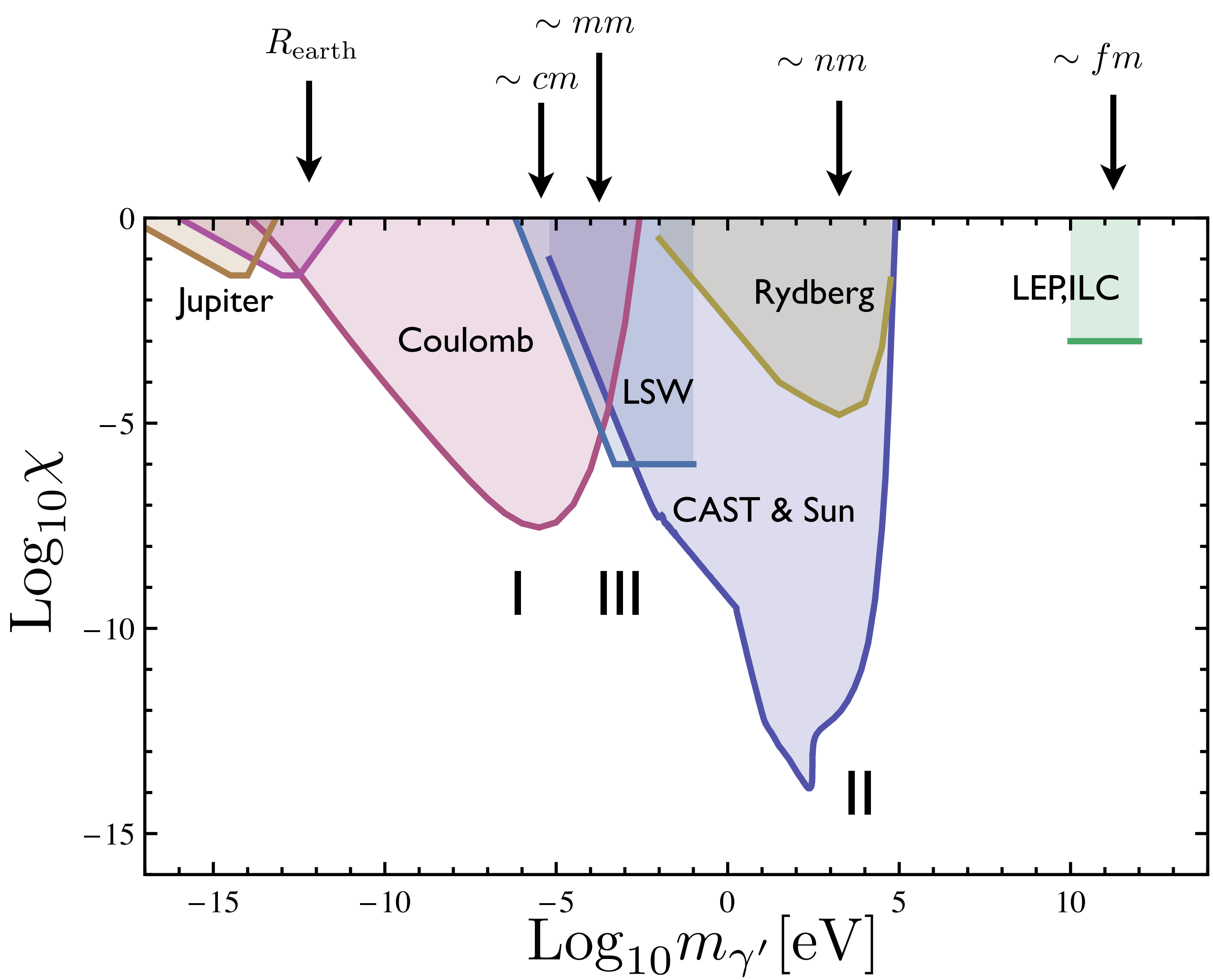
	95% limit	Data set
Seljak, Slosar, McDonald [4]	$N_\nu = 5.3^{+2.1}_{-1.7}$	All
	$N_\nu = 4.8^{+1.6}_{-1.4}$	All + HST
	$N_\nu = 6.0^{+2.9}_{-2.4}$	All − BAO
	$N_\nu = 3.9^{+2.1}_{-1.7}$	All − Lyα
	$N_\nu = 7.8^{+2.3}_{-3.2}$	WMAP3+SN+SDSS(main)
	$N_\nu = 3.2^{+3.6}_{-2.3}$	WMAP3+SN+2dF
	$N_\nu = 5.2^{+2.1}_{-1.8}$	All-2dF-SDSS(main)
Ichikawa, Kawasaki, Takahashi [11]	$N_\nu = 3.1^{+5.1}_{-2.2}$	WMAP3+SDSS(LRG)

Table 1: Comparison of N_ν constraints using various data set combinations. "All" refers to WMAP3 + other CMB + Lyα + galaxy power spectrum (SDSS main sample + 2dF) + SDSS baryon acoustic oscillation (BAO) + Supernovae Ia (SN). See Ref. [4] for details. SDSS (main) and Lyα favor $N_\nu > 3$.

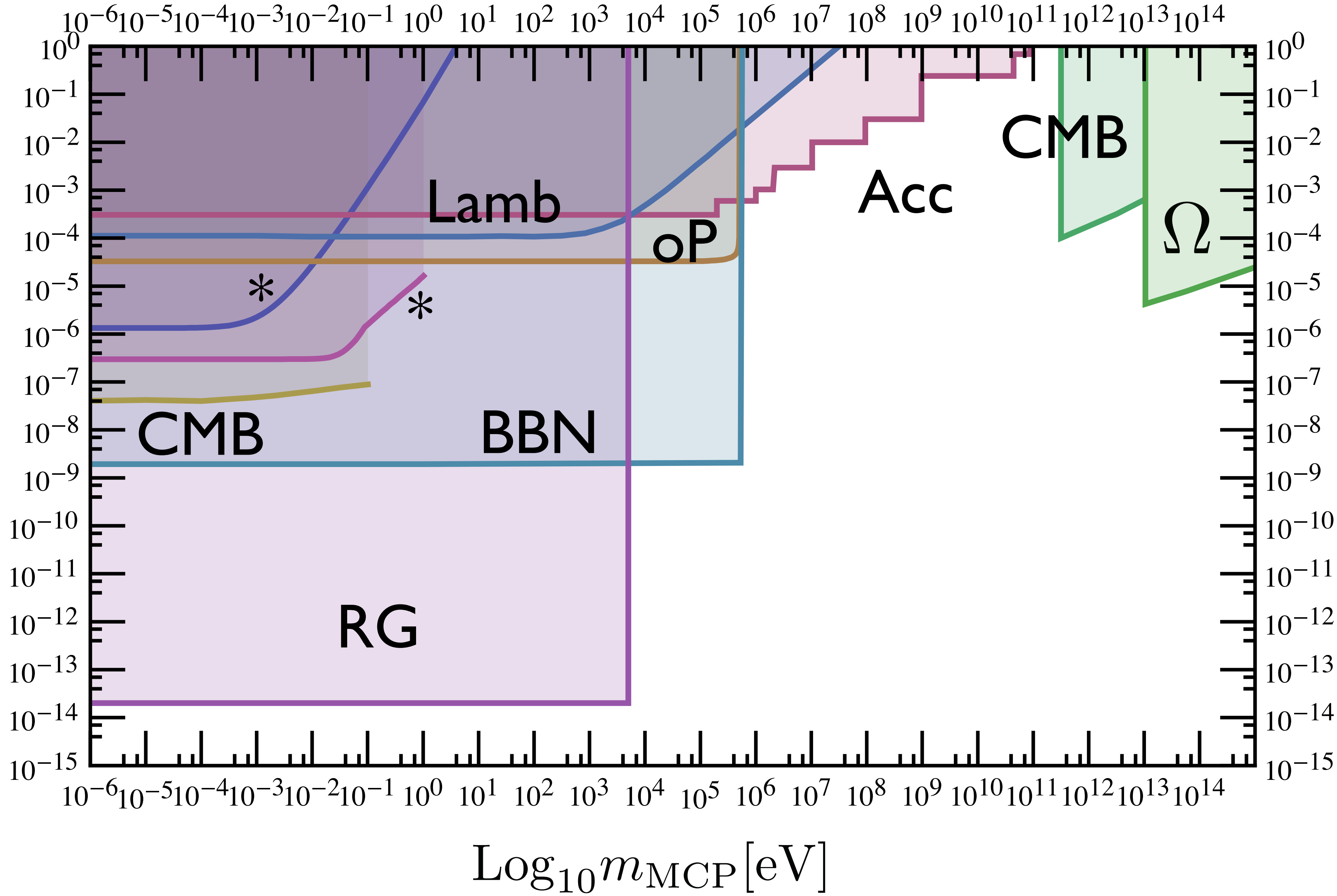
	Y_p (1σ)	N_ν (95% limit)
Olive, Skillman [21]	0.249 ± 0.009	$3.1^{+1.4}_{-1.2}$
Fukugita, Kawasaki [22]	0.250 ± 0.004	$3.20^{+0.76}_{-0.68}$
Peimbert, Luridiana, Peimbert [23]	0.2427 ± 0.0028	$3.01^{+0.52}_{-0.48}$
Izotov, Thuan, Stasinska [24]	0.2516 ± 0.0011	$3.32^{+0.23}_{-0.24}$

Table 2: Comparison of N_ν constraints from recent Y_p measurements. We also used the observed deuterium abundance D/H $= (2.82 \pm 0.27) \times 10^{-5}$ [25] and the BBN fitting formula in Ref. [26]. $N_\nu > 4$ is not favored by the three recent measurements.

Constraints on Hidden photons



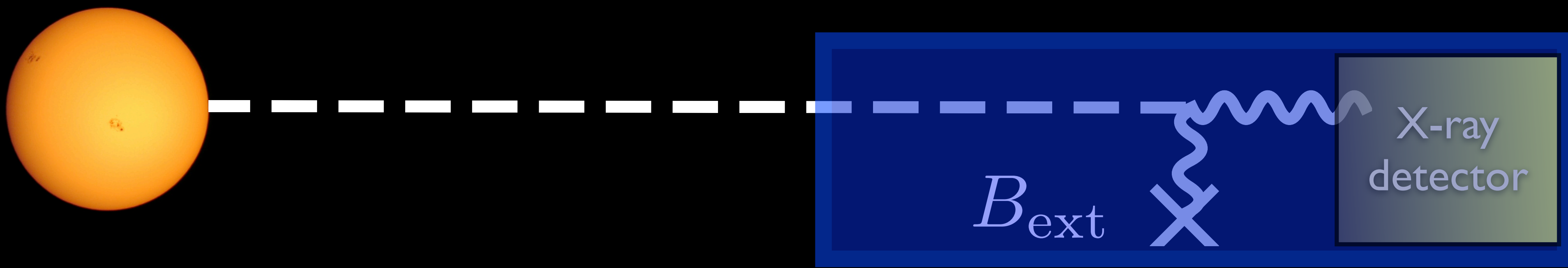
Constraints on MCPs (massless HP)



Helioscopes

P. Sikivie, Phys. Rev. Lett. 51, 1415 (1983)

Detect Solar ALPs at earth by means of inverse Primakoff conversion in a strong magnetic field



Three Helioscopes built (with no trace of ALPs)

Brookhaven (S. Moriyama et al., Phys. Lett. B434, 147 (1998), hep-ex/9805026)
Tokio (D. M. Lazarus et al., Phys. Rev. Lett. 69, 2333 (1992))
CERN (CAST, K. Zioutas et al., Phys. Rev. Lett. 94, 121301 (2005), hep-ex/0411033.)

Helioscopes

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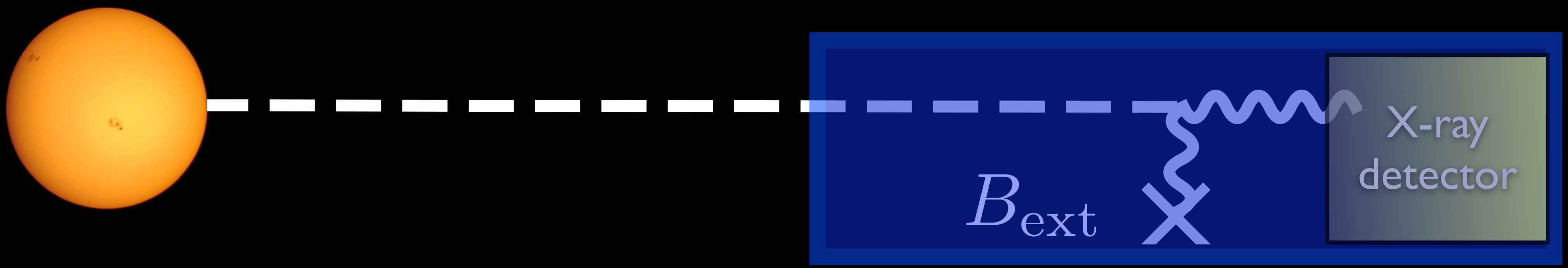


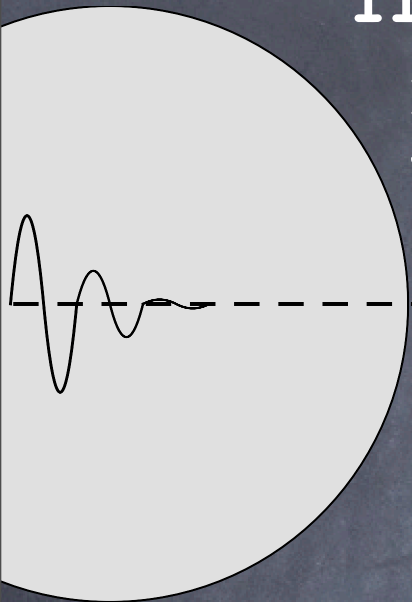
CAST Helioscope

LHC decommissioned magnet

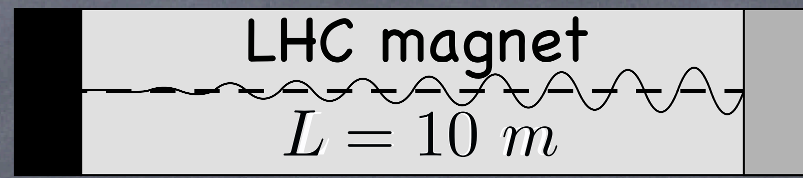
$L \sim 9.3\ \mathrm{m}\quad B_{ext} \sim 9\ \mathrm{T}$

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 $m \simeq \omega_{\rm P}$ (plasma freq.) $\omega_P^2 \sim 1 - 300\mathrm{eV}$

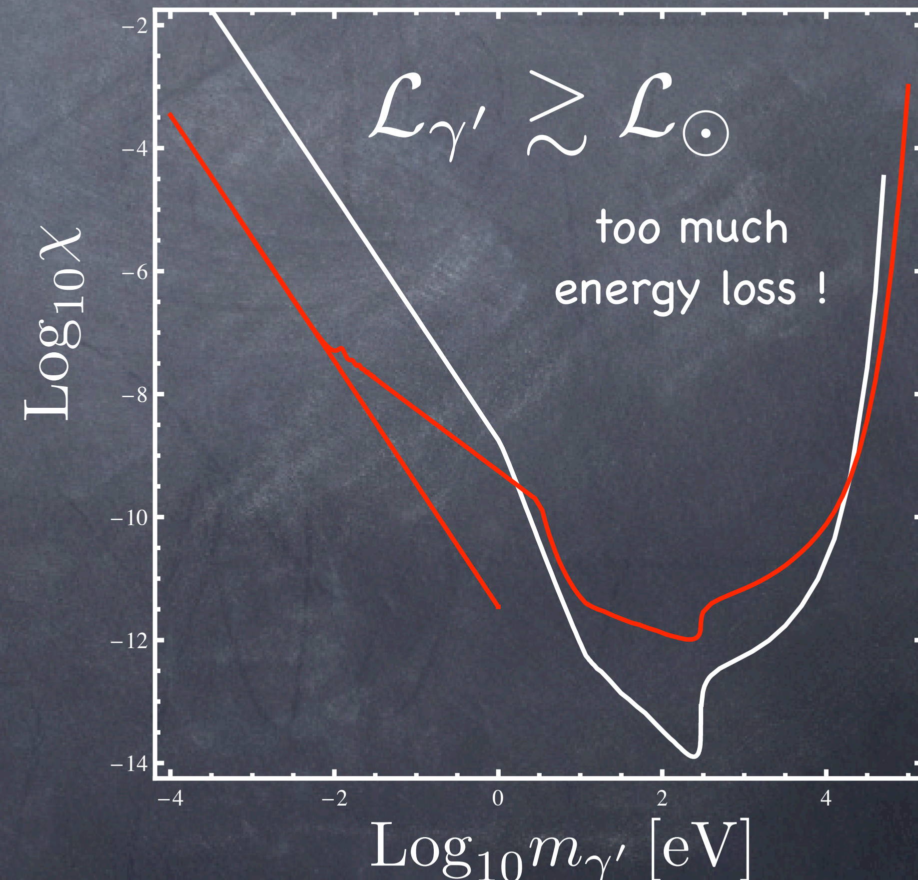
$$\chi_{eff} = \chi \frac{m_{\gamma'}^2}{\omega_P^2 - m_{\gamma'}^2 - i\omega\Gamma}$$

- Three cases:

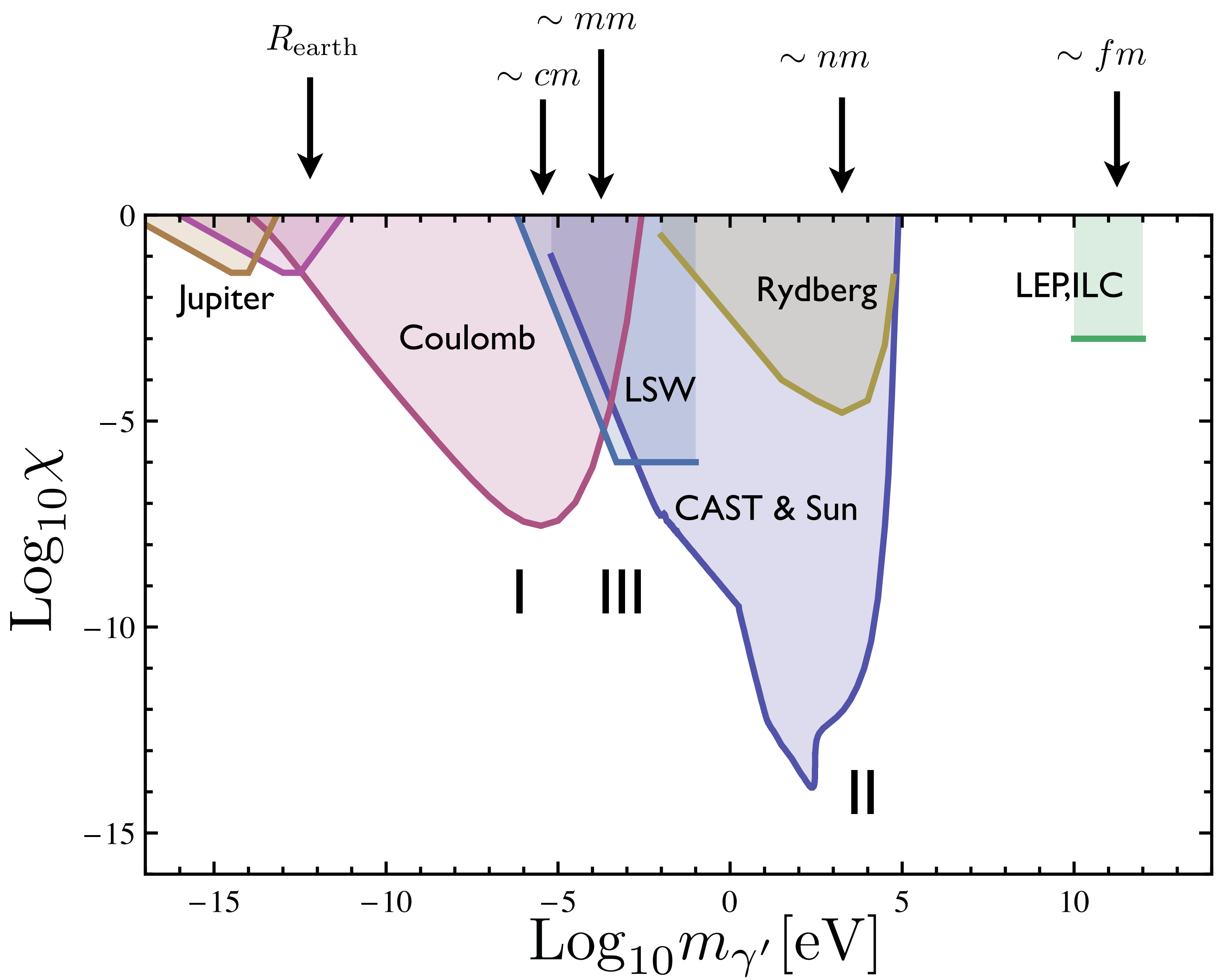
1 - Suppressed production $m_{\gamma'} \ll \omega_P$

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

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

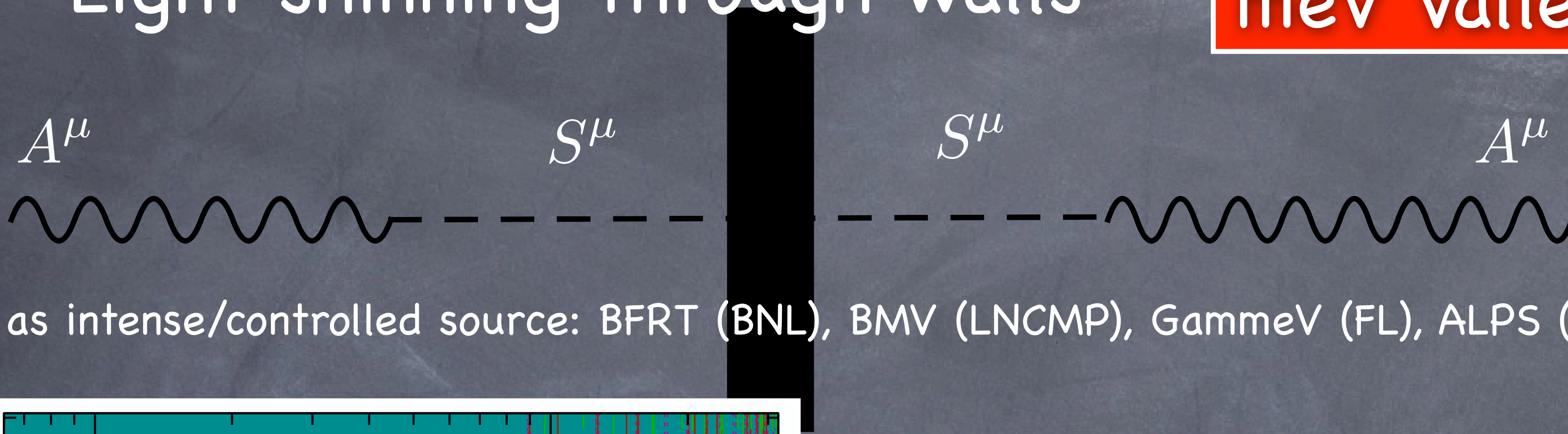


Constraints on Hidden photons

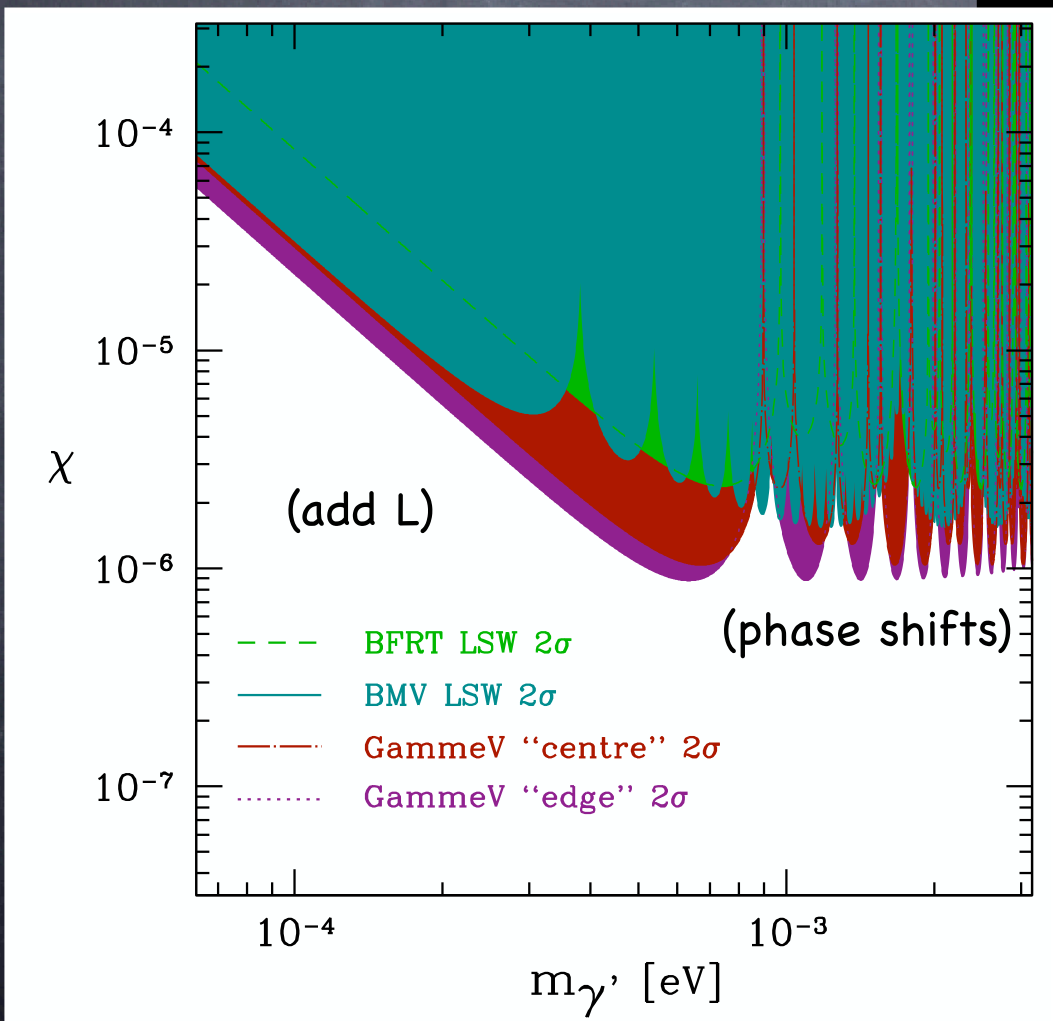


III- "Light shinning through walls"

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

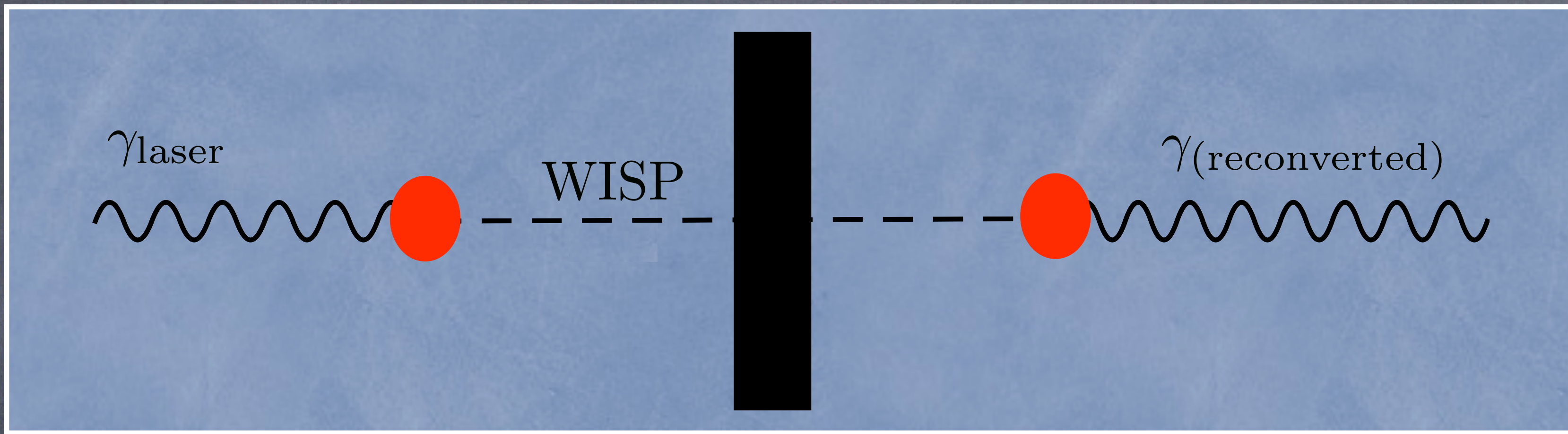
$$P = 16\chi^4 \sin^2 \frac{m_{\gamma'}^2 L_1}{4\omega} \sin^2 \frac{m_{\gamma'}^2 L_2}{4\omega}$$

typical configurations

$$L \sim m, \;\; \omega \sim \mathrm{eV}$$

“Light shinning through walls”

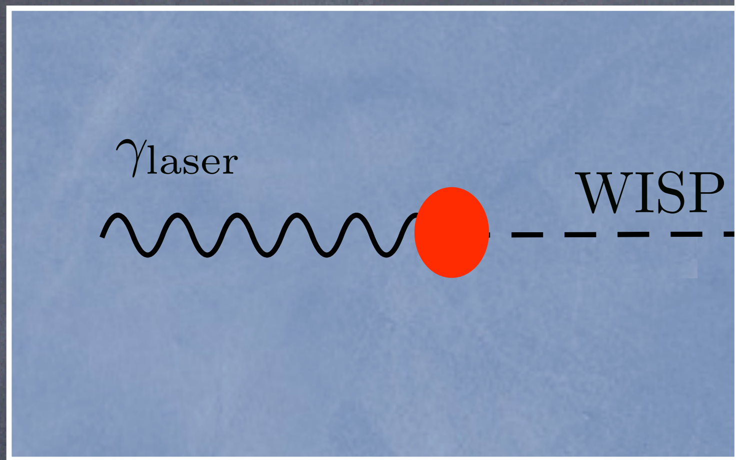
“Axion Like Particle Search”

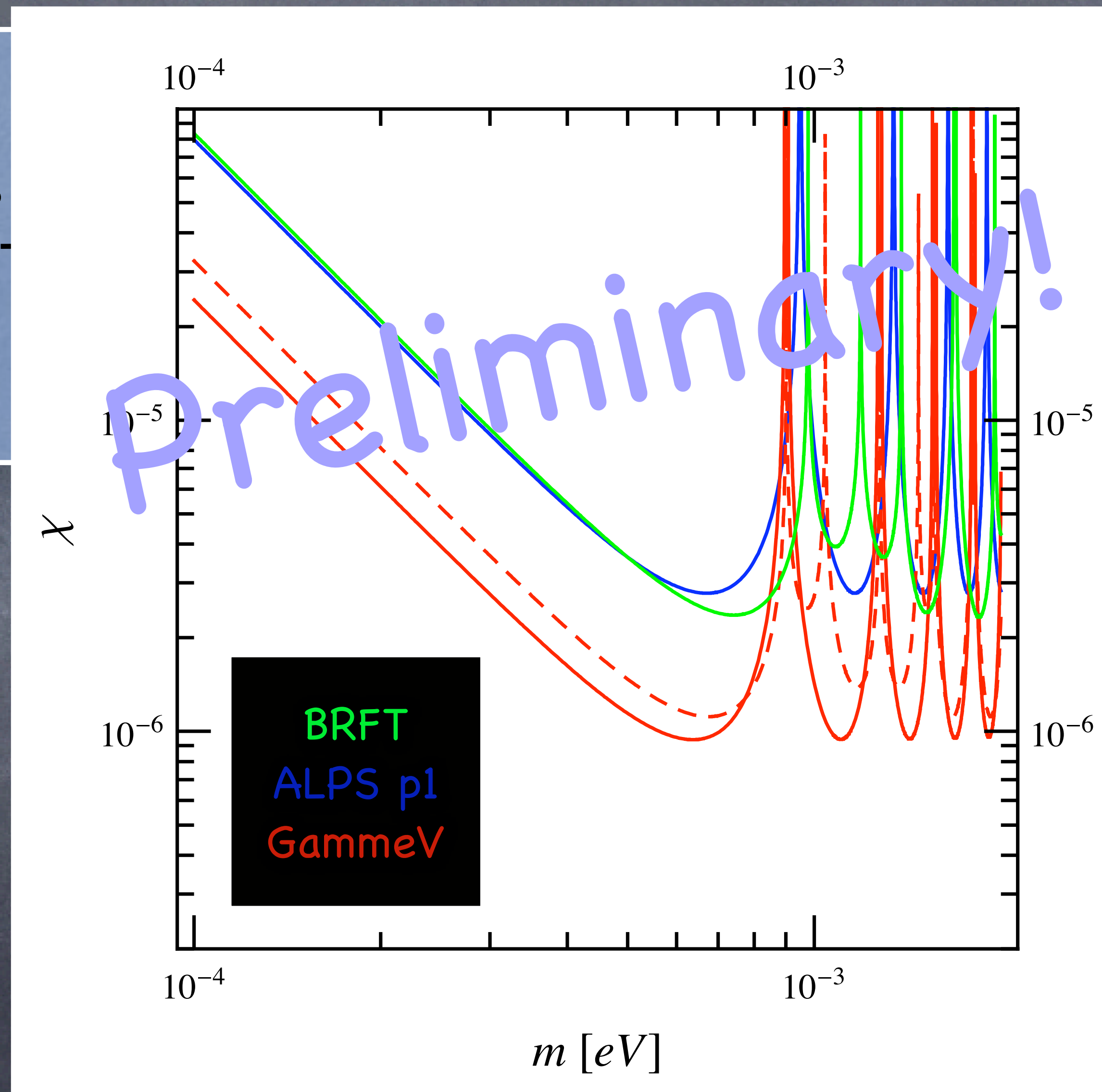


Other experiments: BFRT (BNL), BMV (LNCMP), GammeV (FL), OSQAR (CERN)

"Light shinning through walls"

"Axion Like Particle Search"





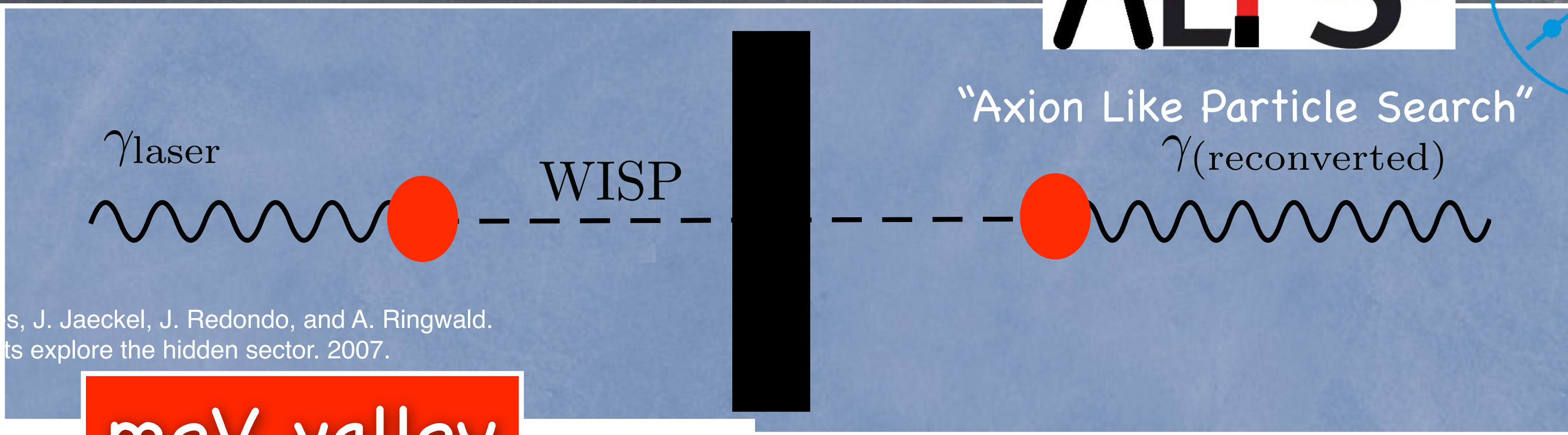
ALPS phase-1

$13\ \text{Watt},\ \omega = 2.33\ \text{eV (greeen)},$

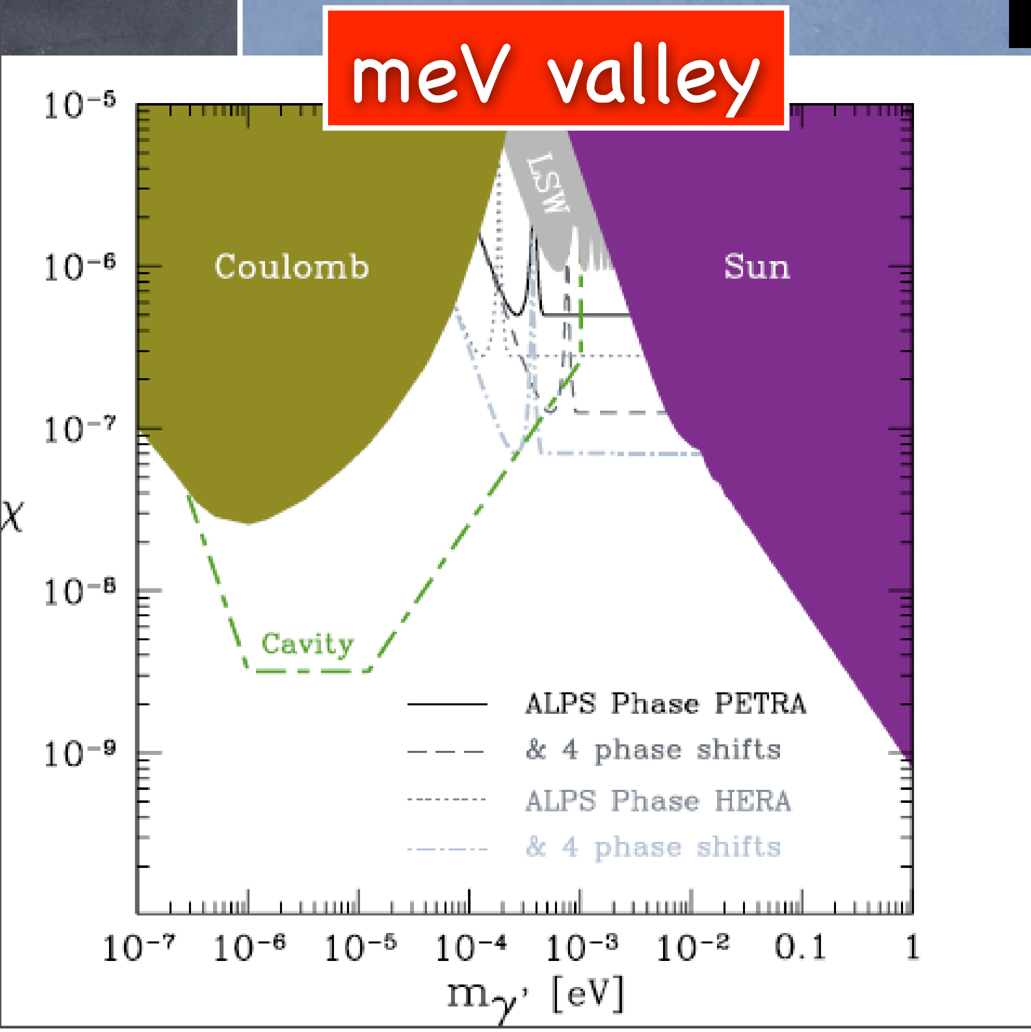
$L_1 = L_2 = 4.3\ m,\ \ B \simeq 5.2\text{T}$

"Light shinning through walls"

"Axion Like Particle Search"



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



Future Improvements :

1- longer config.

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

2- phase shift plates?

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

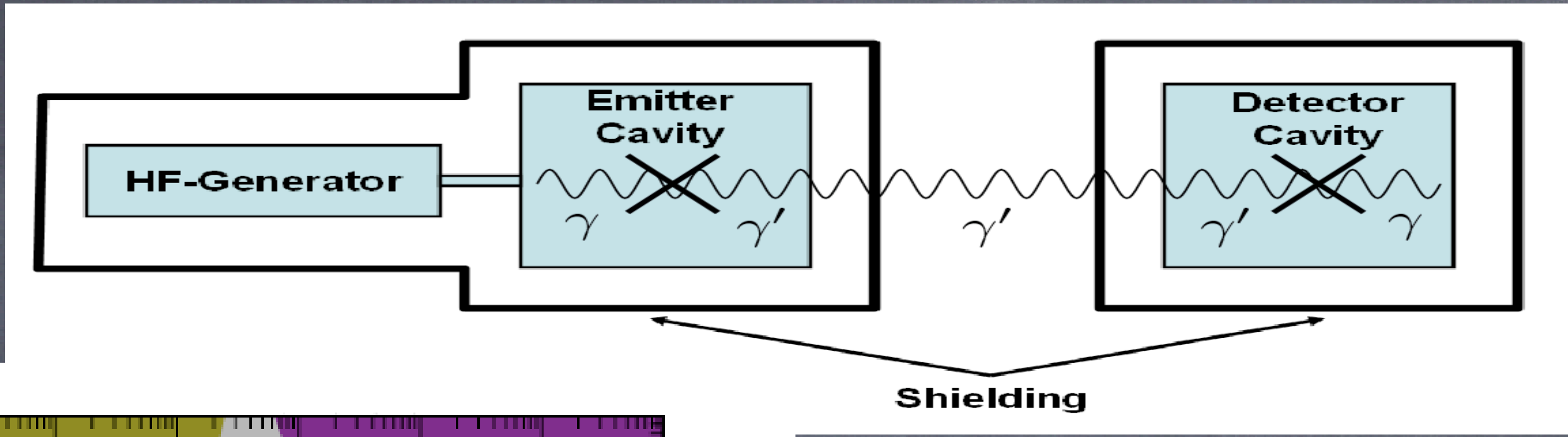
3- Increase sensitivity

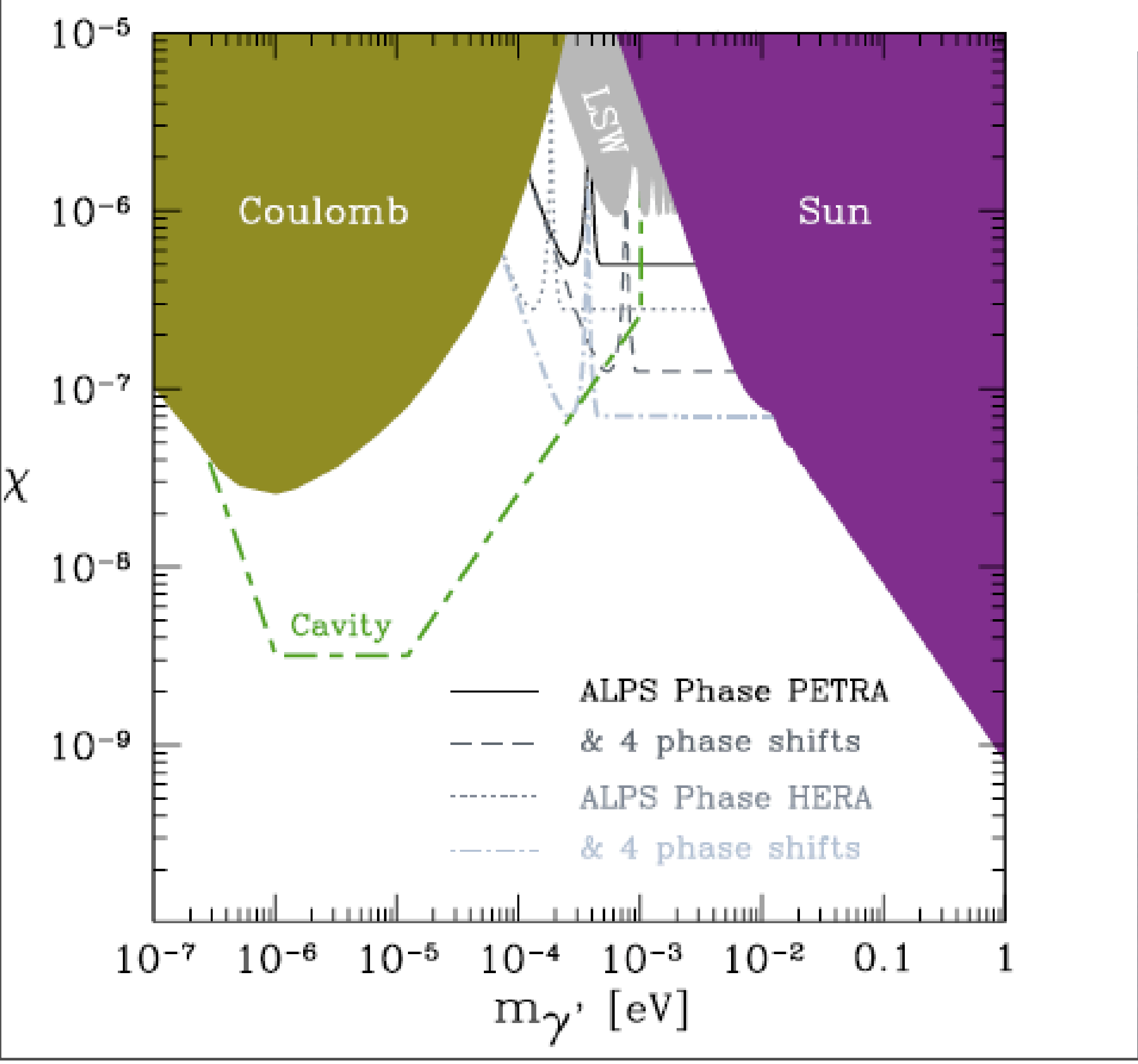
Optical cavities (orders of magnitude!)

P. Sikivie, D.B. Tanner, van Bibber, K. hep-ph/0701198

Better detector?

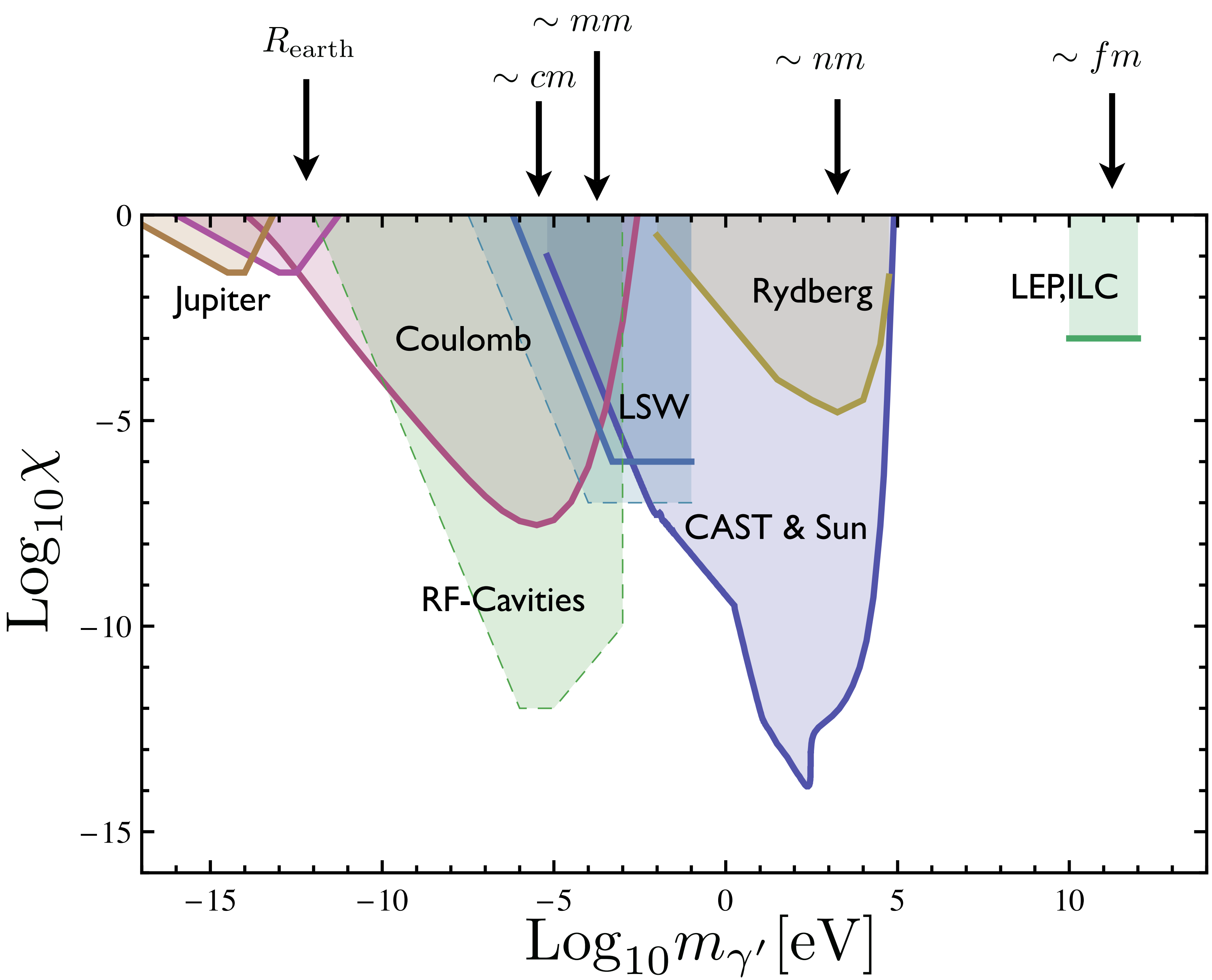
"Light shinning through walls" RF cavities





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
RF-Cavities
LSW
CAST & Sun
Rydberg
LEP,ILC
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 (no light MCP)

$$-\frac{1}{4}A_{\mu\nu}A^{\mu\nu}+ej_\mu A^\mu$$

$$-\frac{\sin\chi}{2}A_{\mu\nu}B^{\mu\nu}$$

$$-\frac{1}{4}B_{\mu\nu}B^{\mu\nu}$$

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

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

$$-\frac{1}{4}\tilde{B}_{\mu\nu}\tilde{B}^{\mu\nu}$$

$\sin\chi \longrightarrow$ 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

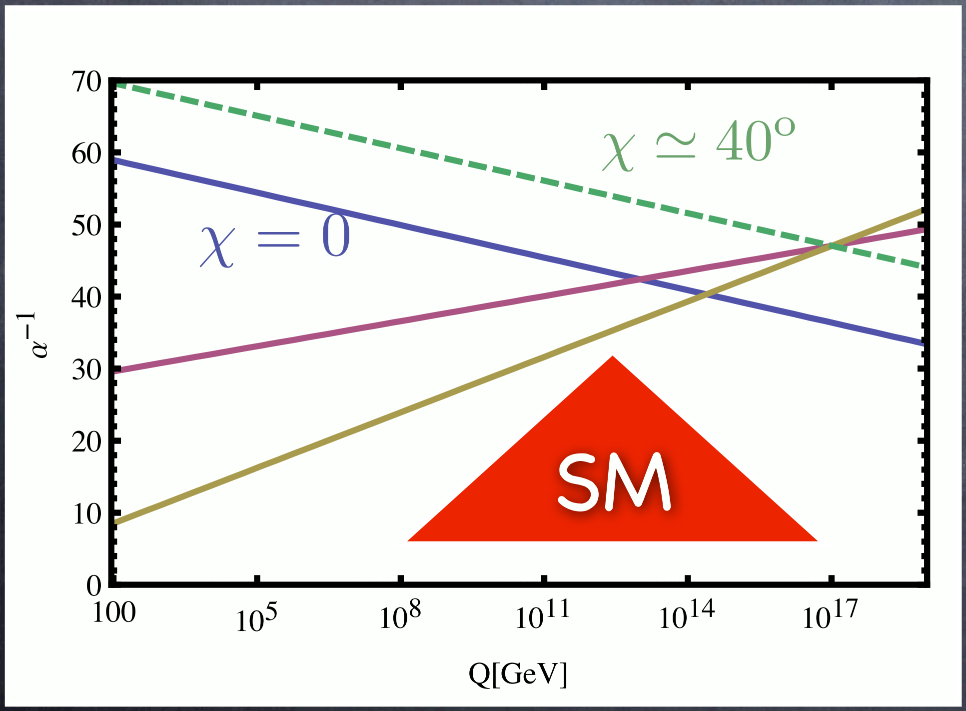
In a general framework (SM), B^μ, mixes with hypercharge Y^μ

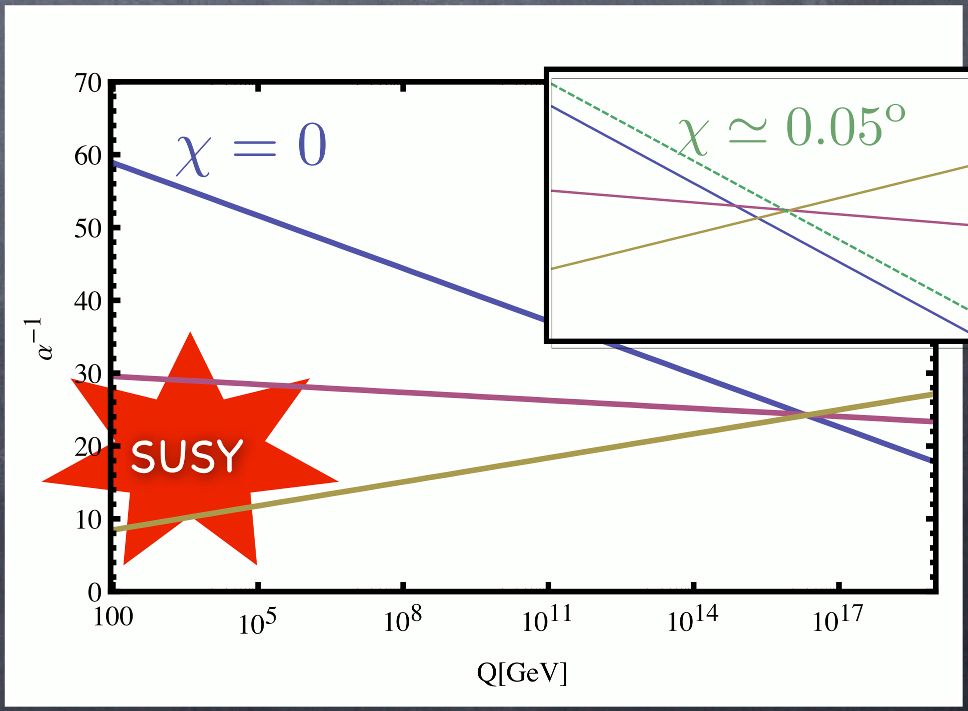
In bare SM, g' is a free parameter ... so kinetic mixing is completely invisible!

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

$$-\frac{1}{4}Y_{\mu\nu}Y^{\mu\nu} + \frac{g'}{\cos\chi}j^Y_\mu Y^\mu$$

$$\frac{g'}{\cos\chi} \equiv g'_{\rm mes} \qquad g' < g'_{\rm mes}$$





Conclusions

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