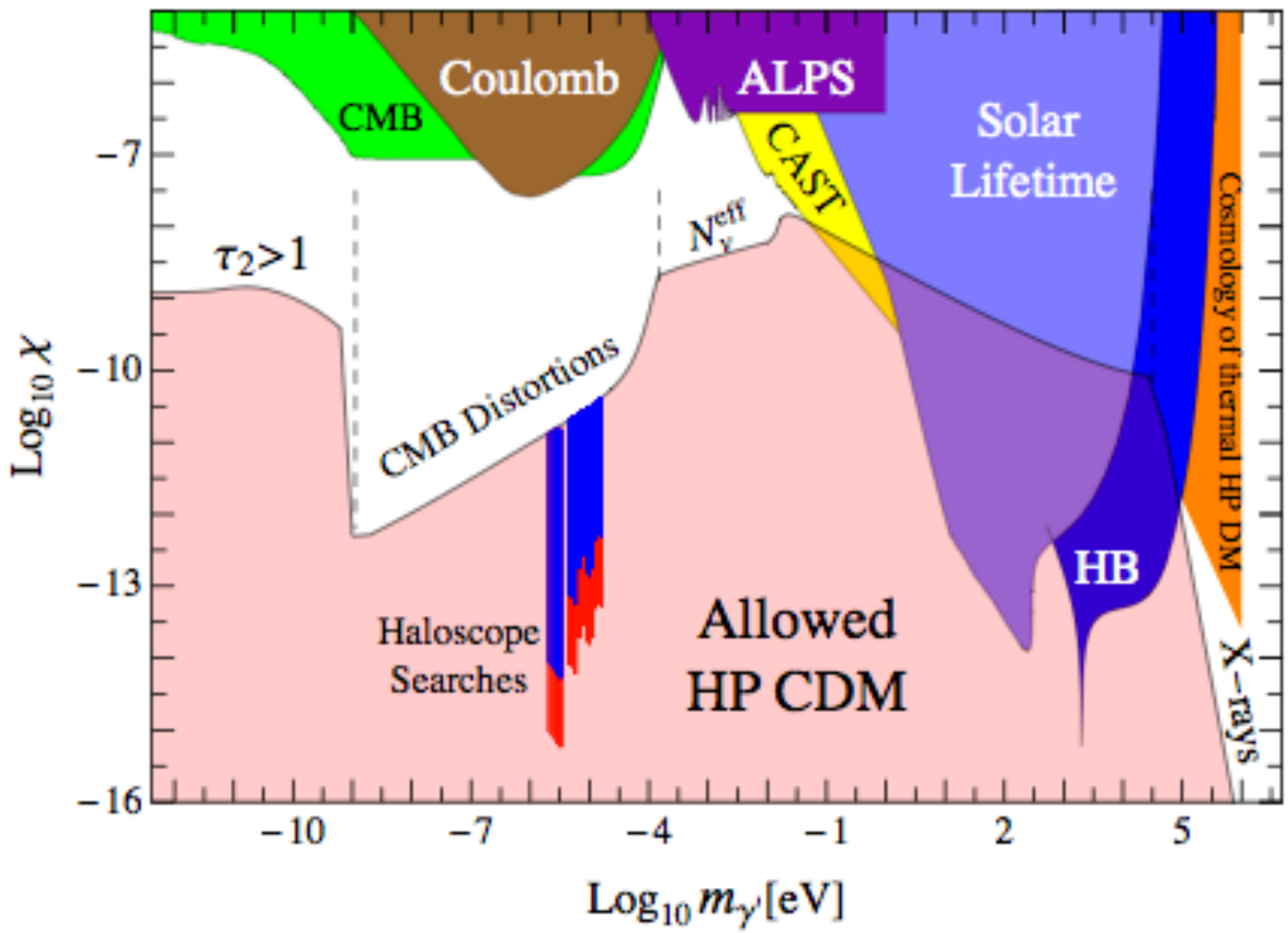
cavity searches for new particles

OK Baker - Yale University

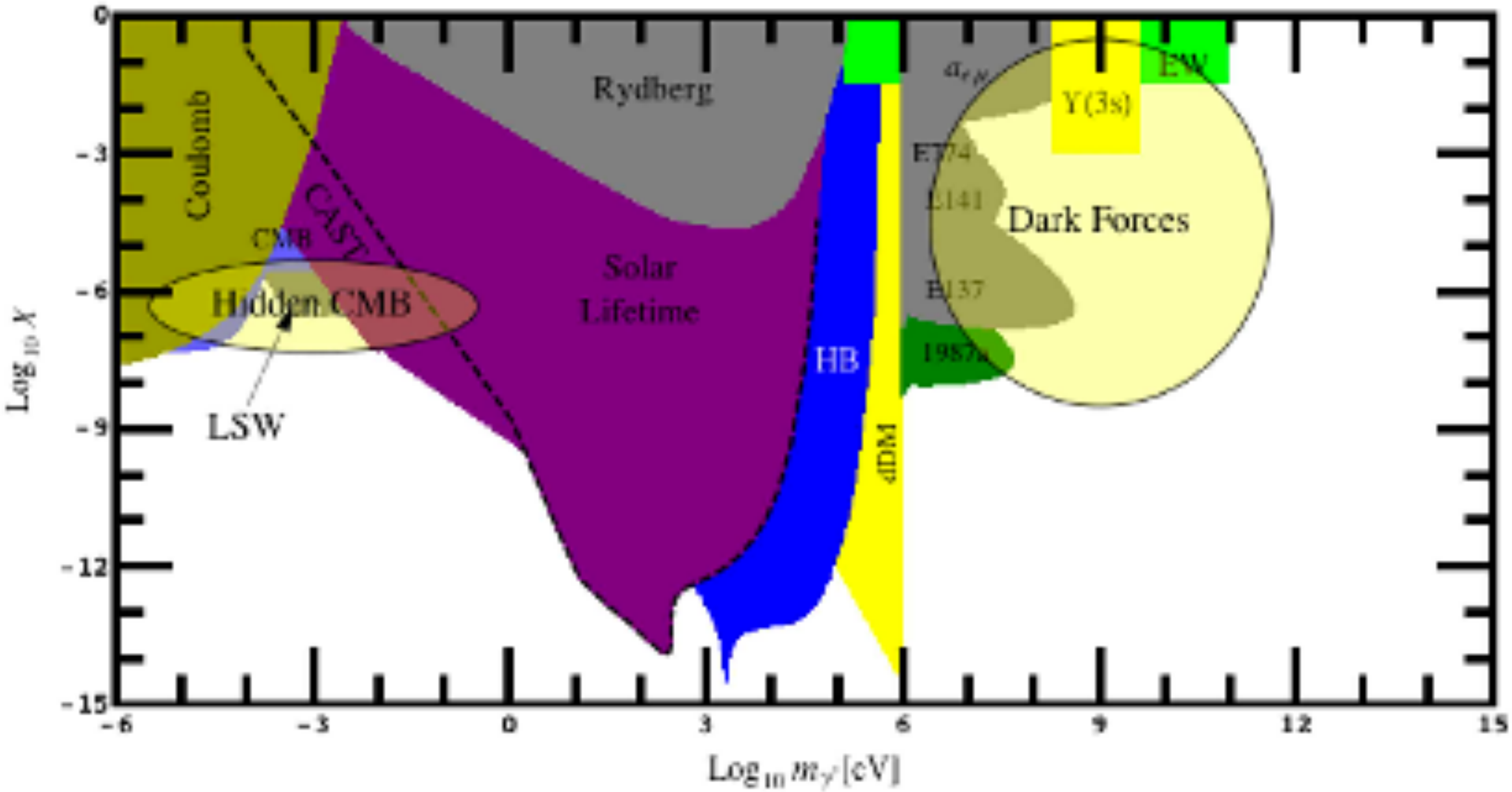
Snowmass Intensity Frontier Workshop

physics motivation

allowed parameter space for hidden sector CDM

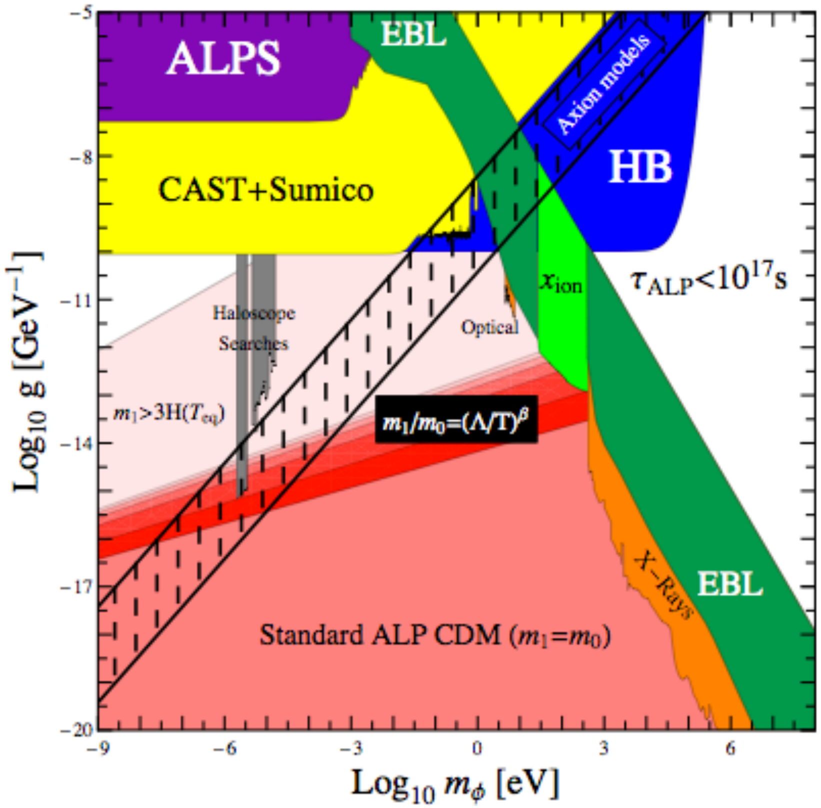


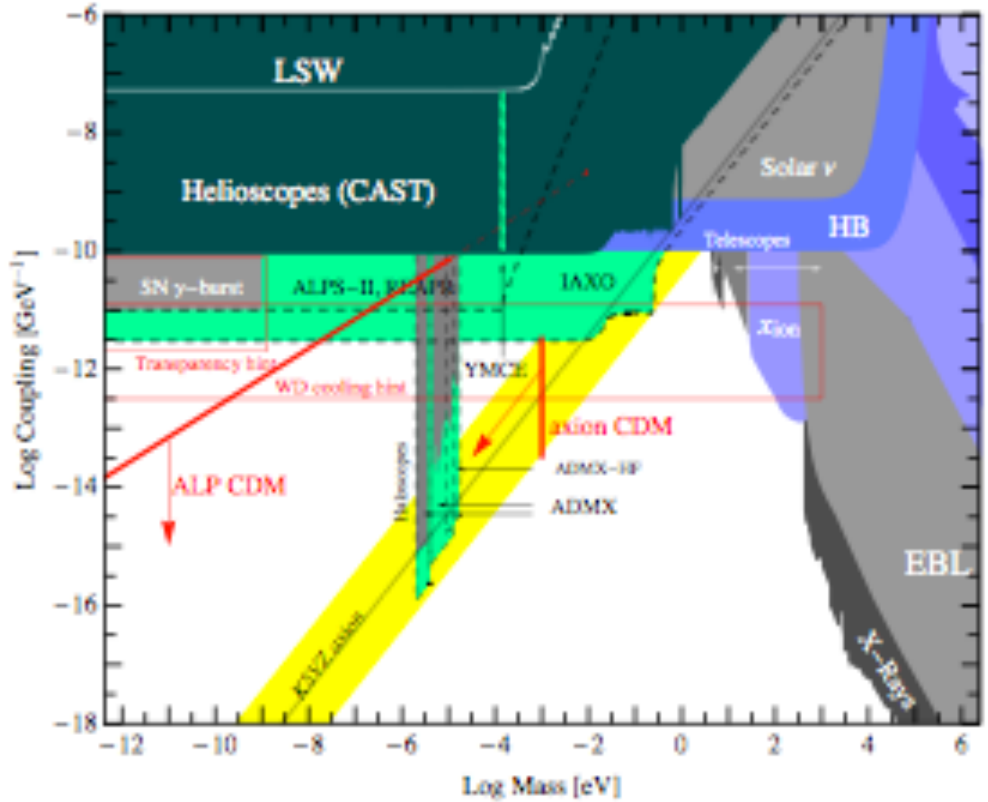
P. Arias, D. Cadamuro, M. Goodsell, J. Jaeckel, J. Redondo, A. Ringwald arXiv:1201.5902, JCAP (2012) constraints on kinetic mixing parameter from astrophysics; interesting regions in yellow



M Cicoli, M. Goodsell, J. Jaeckel, A. Ringwald; arXiv:1103.3705 (2011)

constraints on axion and ALP parameter from astrophysics and terrestrial expts

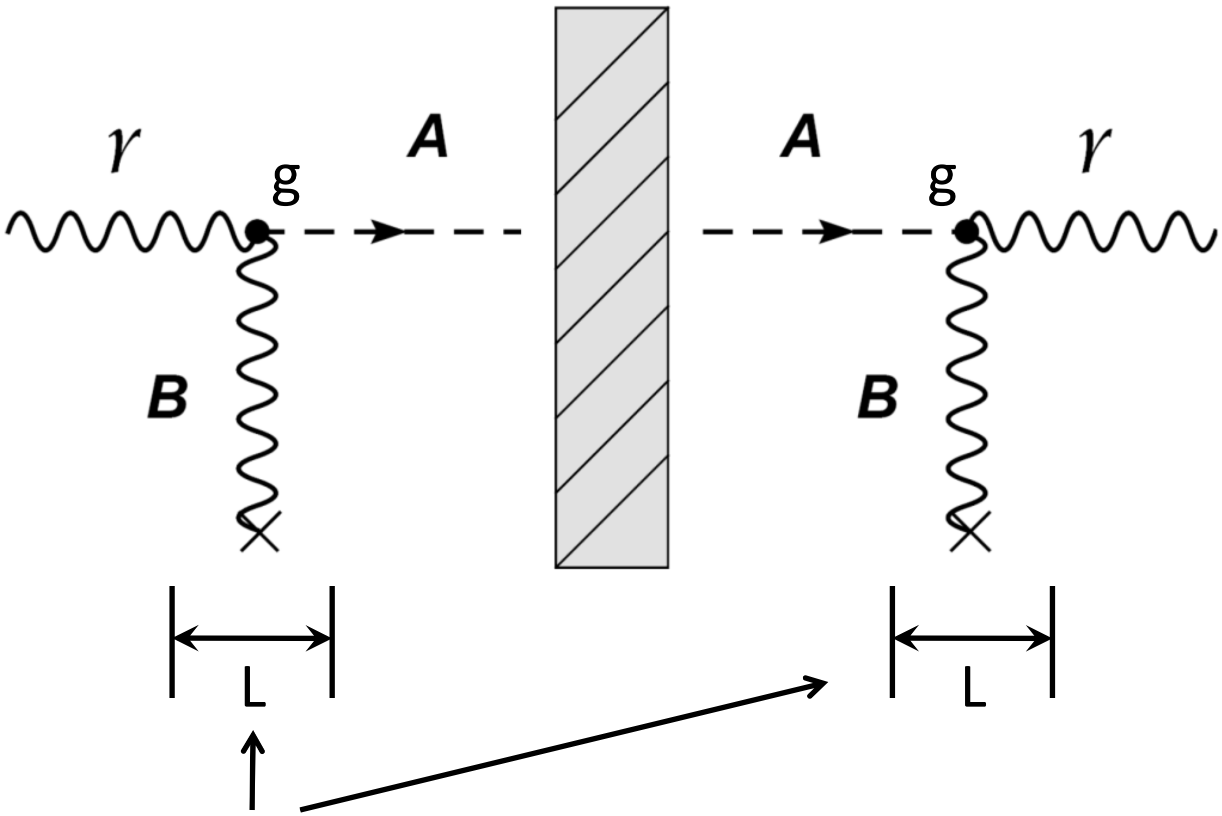




P. Arias, D. Cadamuro, M. Goodsell, J. Jaeckel, J. Redondo, A. Ringwald arXiv:1201.5902, JCAP (2012)

techniques

light shining through walls (LSW): B field



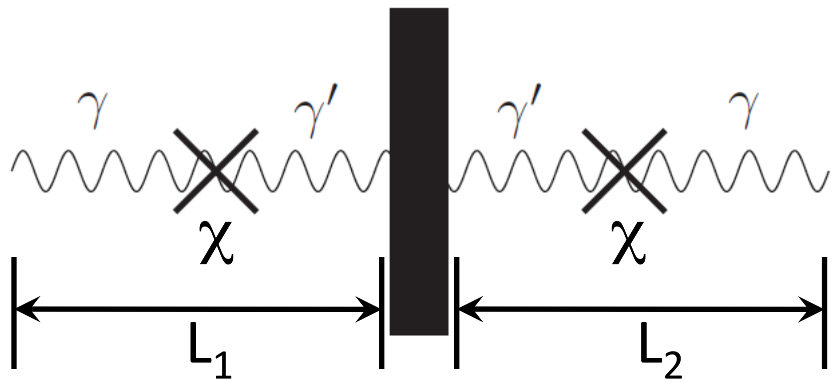
Regions of length L with strong magnetic field B

$$P_{det} \approx \left(\frac{1}{4}(gBL)^2\right)^2$$

Sov. Phys. JETP 56, 502 (1982)

light shining through walls (LSW); no B field

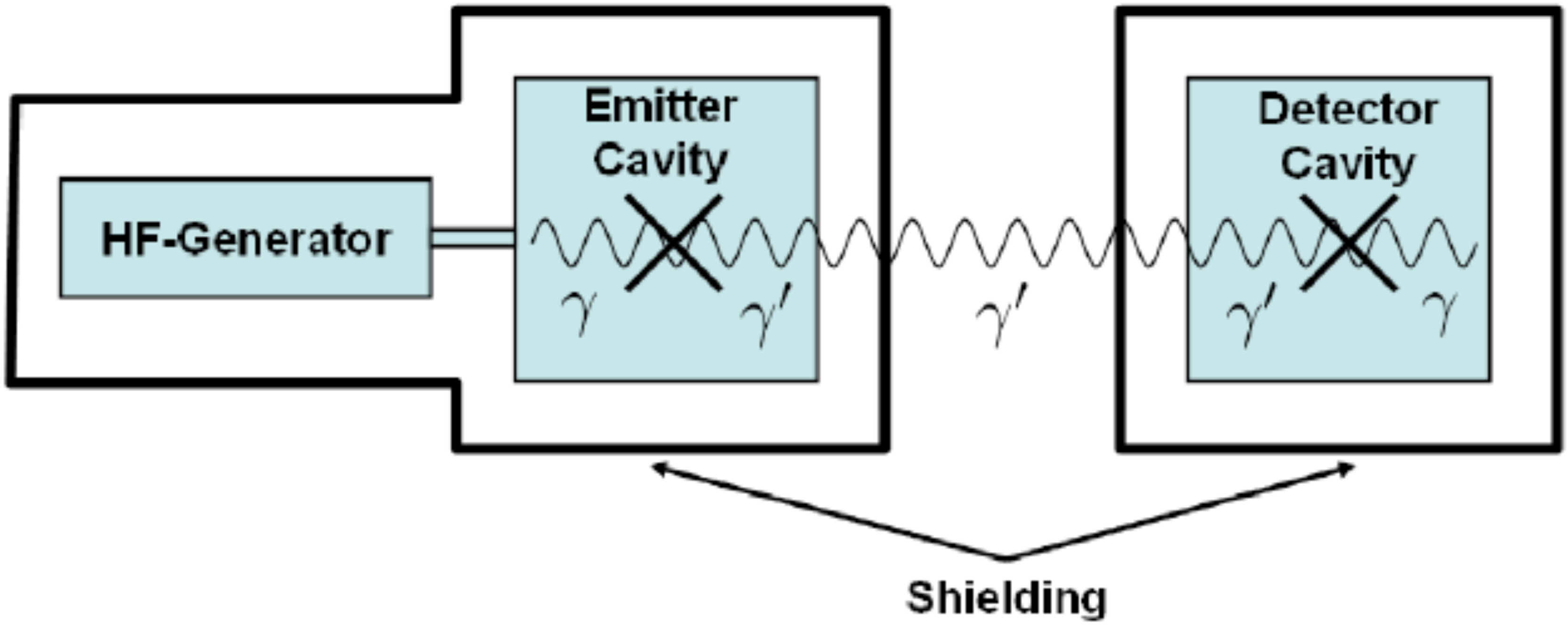
Light shining through walls by γ-γ' mixing (no B_{ext} required):



$$P_{det} = 16\chi^4 \left[sin\left(\frac{\Delta k L_1}{2}\right) sin\left(\frac{\Delta k L_2}{2}\right)\right]^2, \quad \Delta k = \omega - \sqrt{\omega^2 - m_{\gamma'}^2}$$

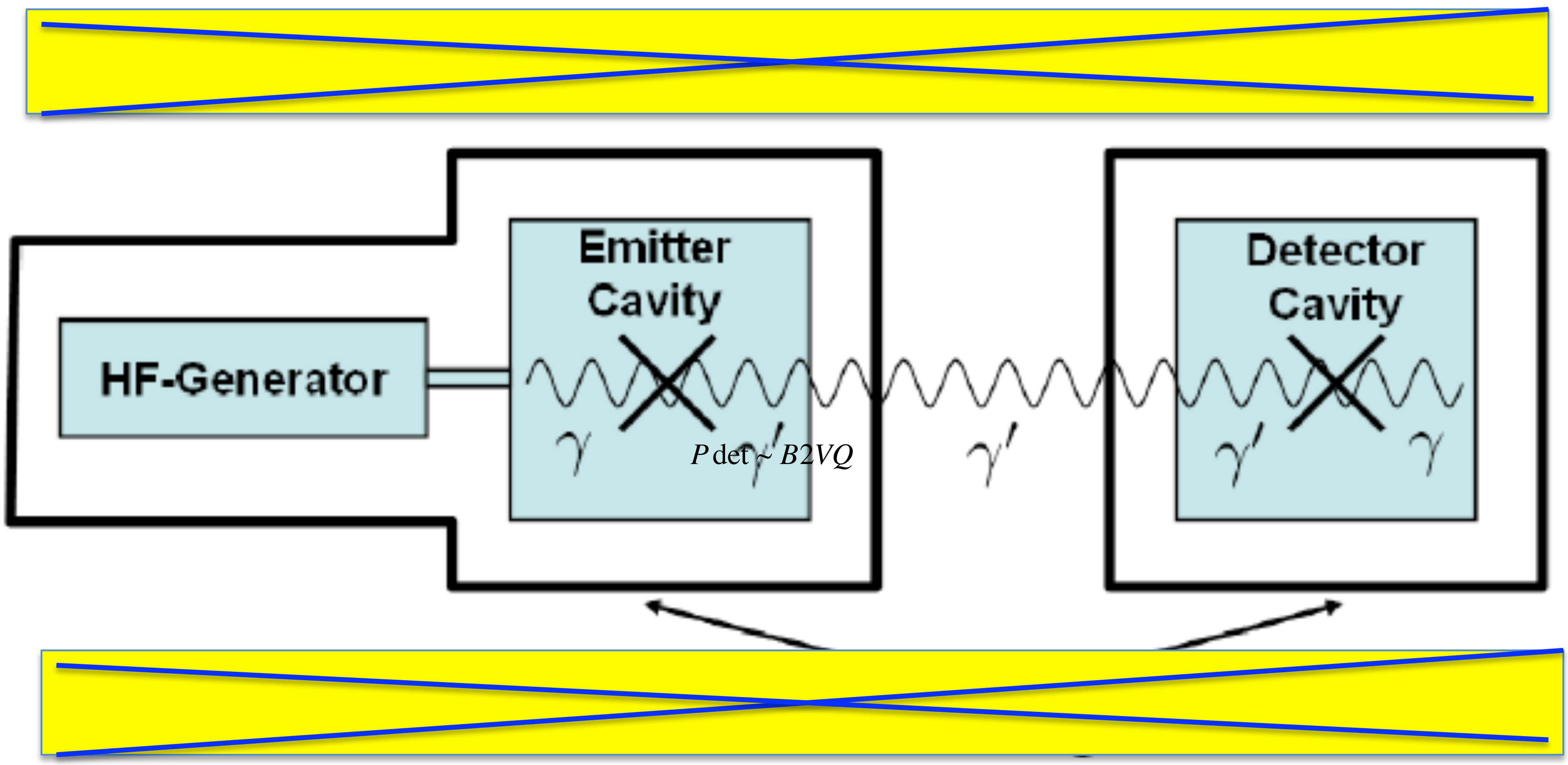
J. Redondo and A. Ringwald, arXiv:1011.3741v1

hidden sector search example



$$\mathscr{P}_{\rm det} = \chi^4 \frac{m_{\gamma'}^8}{\omega_0^8} |G|^2 QQ' \mathscr{P}_{\rm em}$$

axion search example



here γ' → a

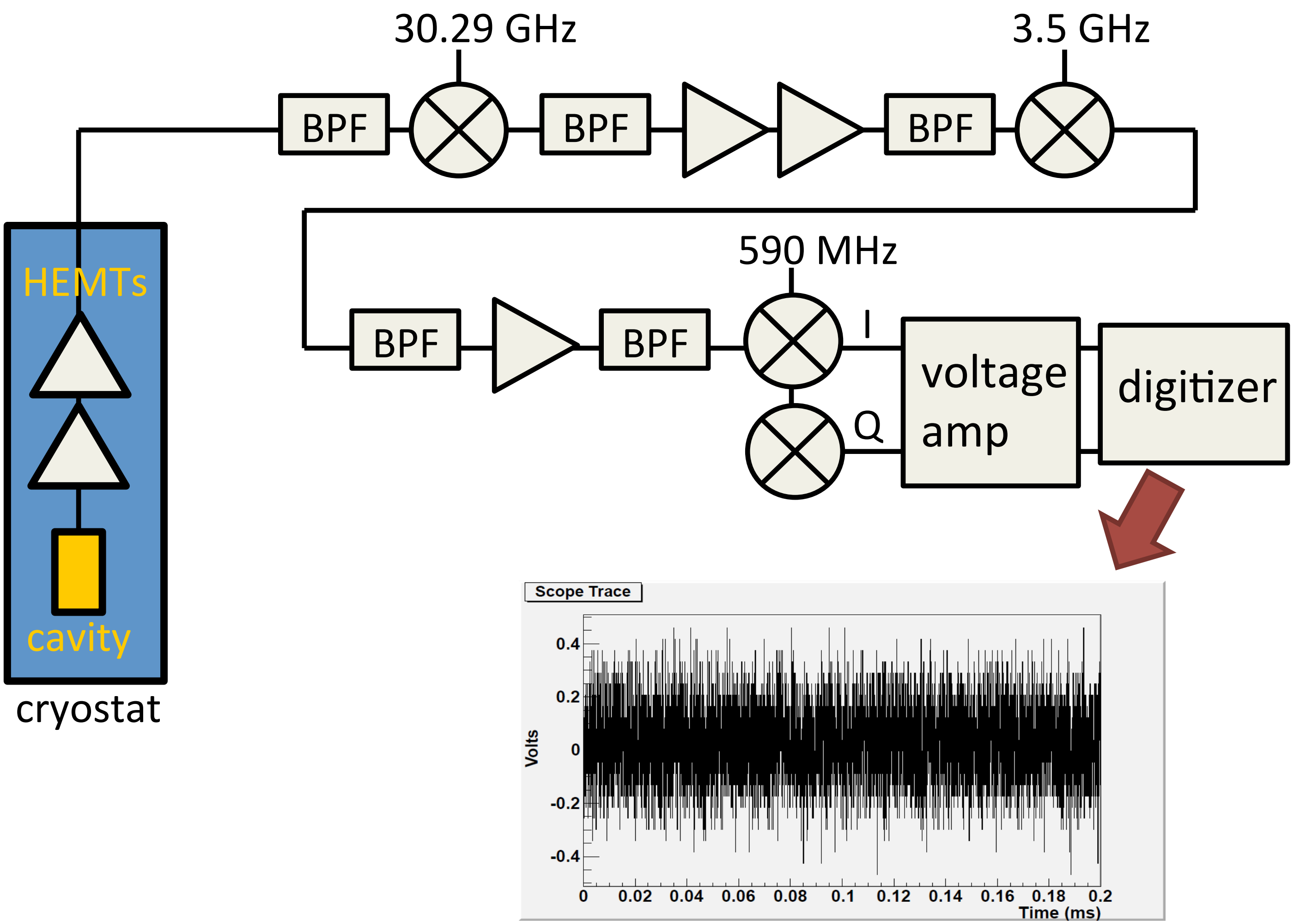
$$P_{S\gamma} = g^2_{S\gamma\gamma} V B^2_{ext} \rho_a C_{lmn} Q$$

kinetic mixing → coupling to B field

Yale microwave cavity experiment

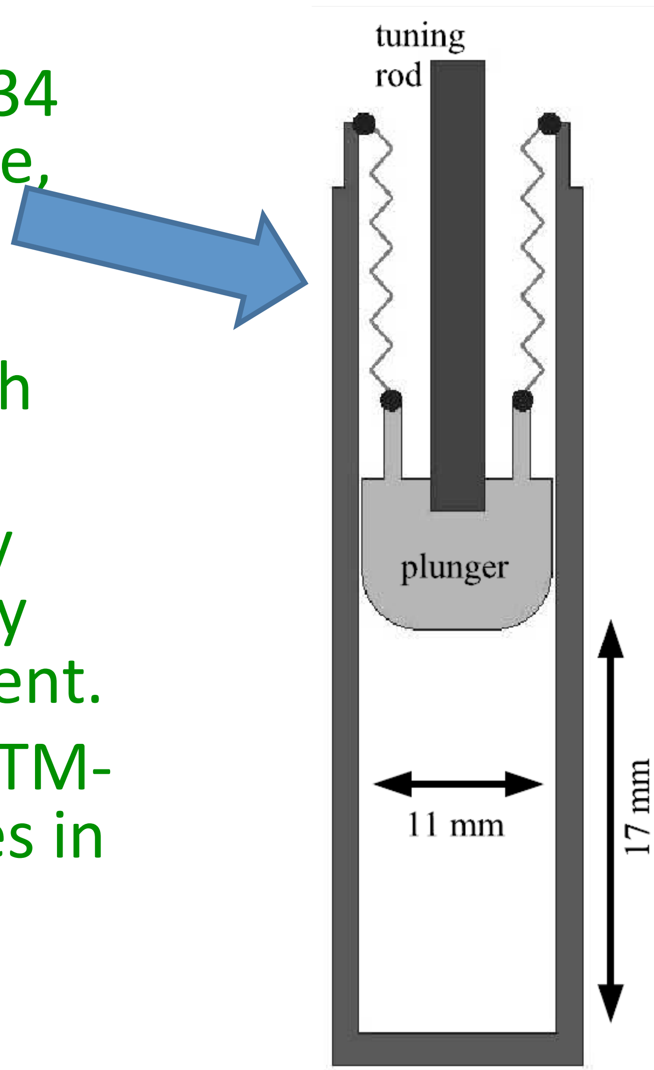
• O. K. Baker		Yale
• M. Betz		CERN
• F. Caspers		CERN
• J. L. Hirshfield		Yale
• Y. Jiang		Yale
• G. Kazakevitch		Muons, Inc
• S. Kazakov		Yale
• M. A. LaPointe		Yale
• **A. T. Malagon**	**(graduate student)**	**Yale**
• **A. J. Martin**	**(research scientist)**	**Yale**
• S. Shchelkunov		Yale
• **Penny L. Slocum**	**(research scientist)**	**Yale**
• A. Szymkowiak		Yale

microwave receiver - ymce

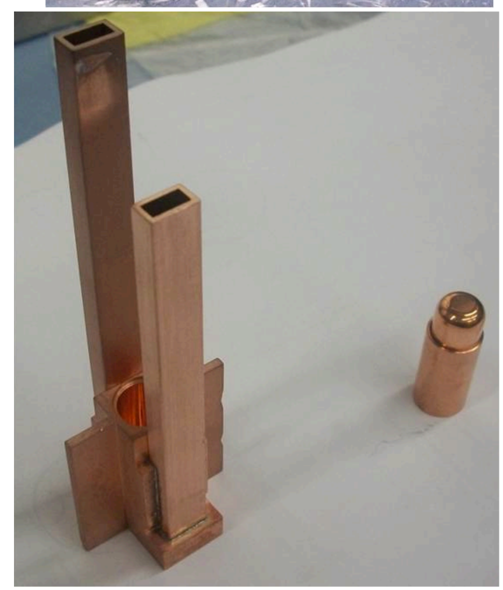


present experiment at 34 GHz

- Cu signal cavity resonant at 34 GHz, cooled to T=4 K, tunable, TE011 mode.
- second drive cavity at room temperature, coupled to high power 34 GHz magnicon.
- experiment can be a 2-cavity LSW experiment or a 1-cavity galactic halo ALP measurement.
- can use TE-mode (scalar) or TM-mode (pseudoscalar) caviities in magnetic field

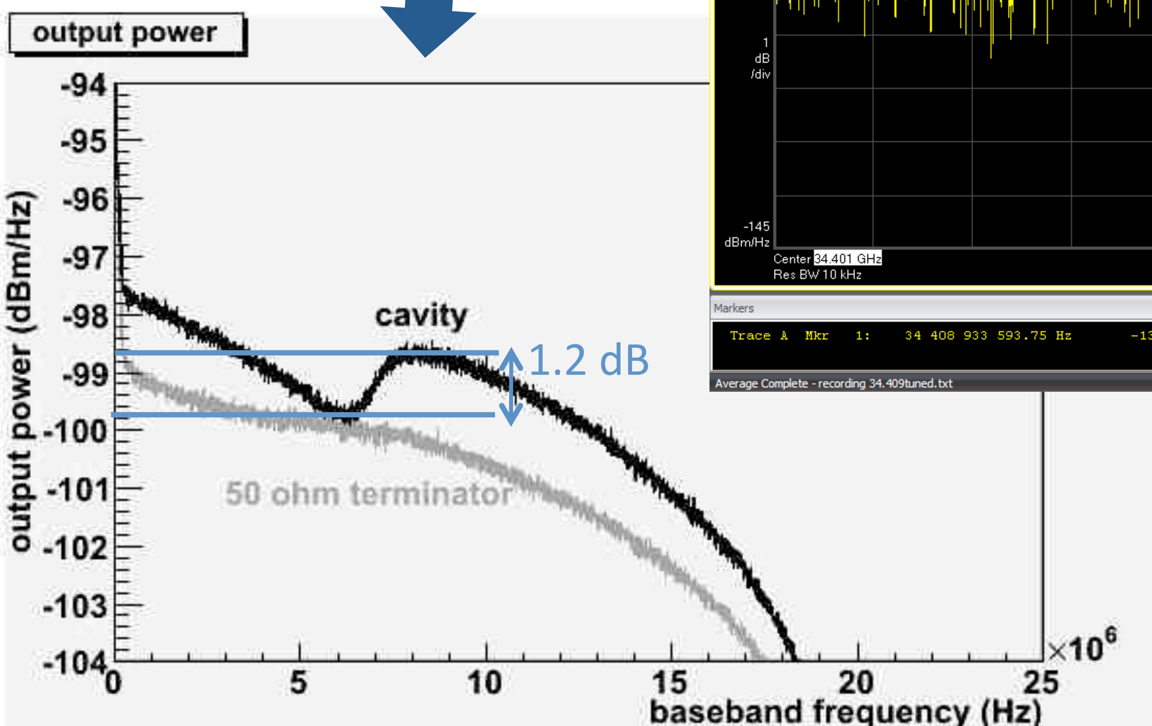


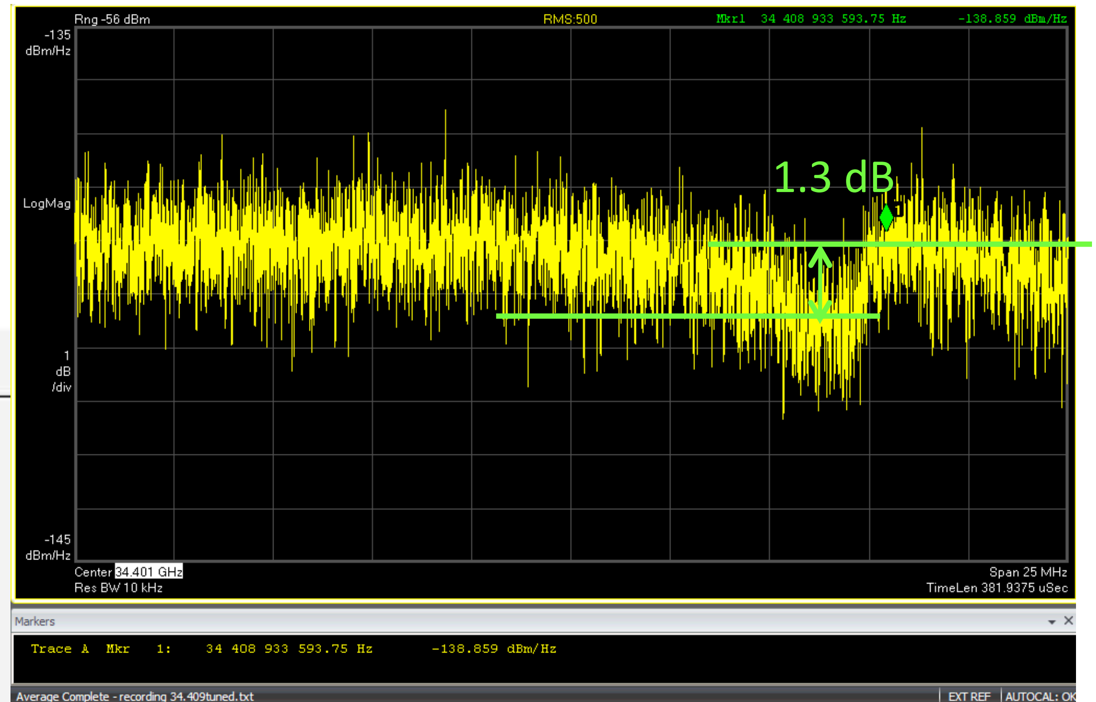
Yale microwave cavity expt (ymce)



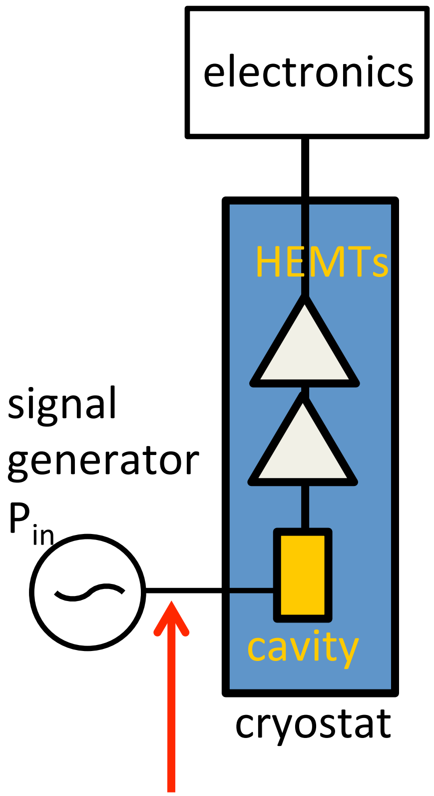
Resonant dip

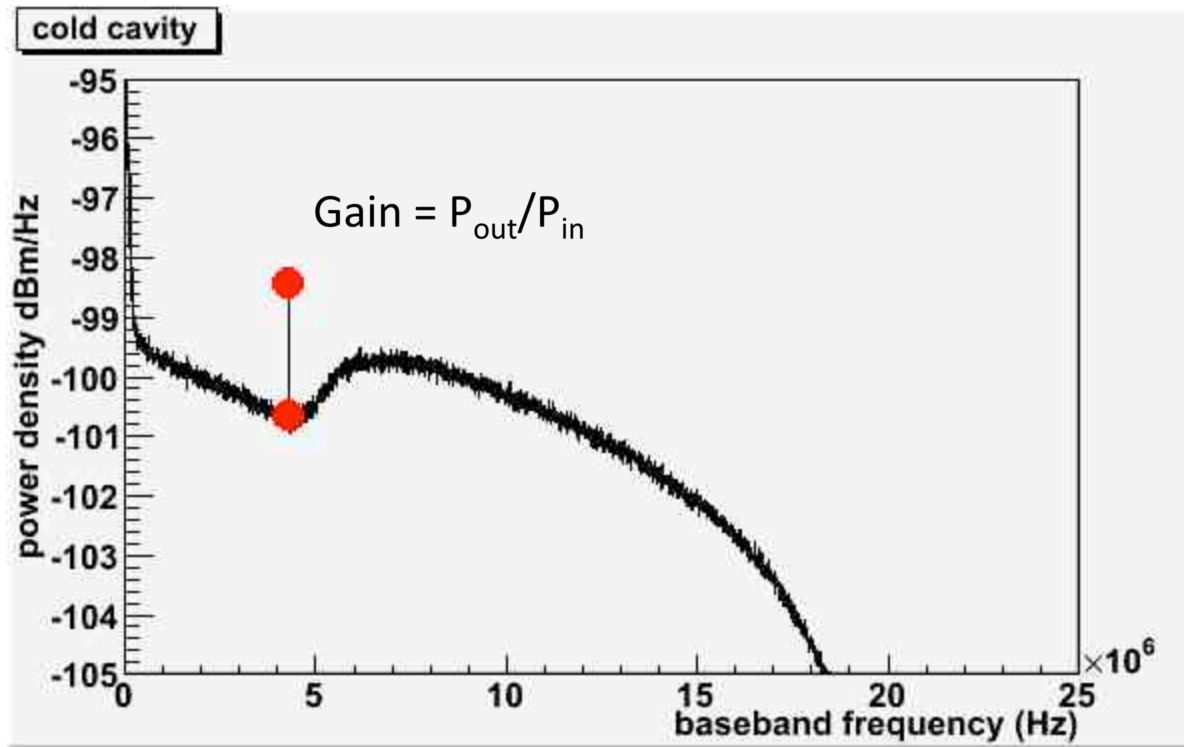
Cavity tuned to 34.409 GHz.





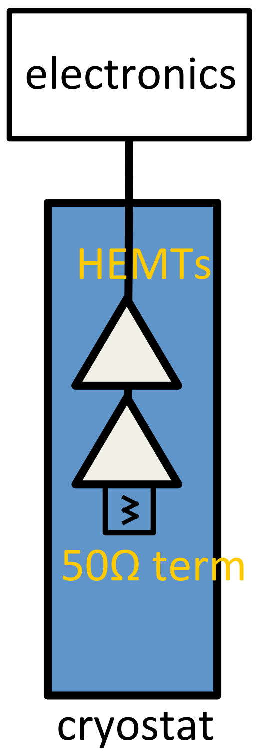
Gain Measurements

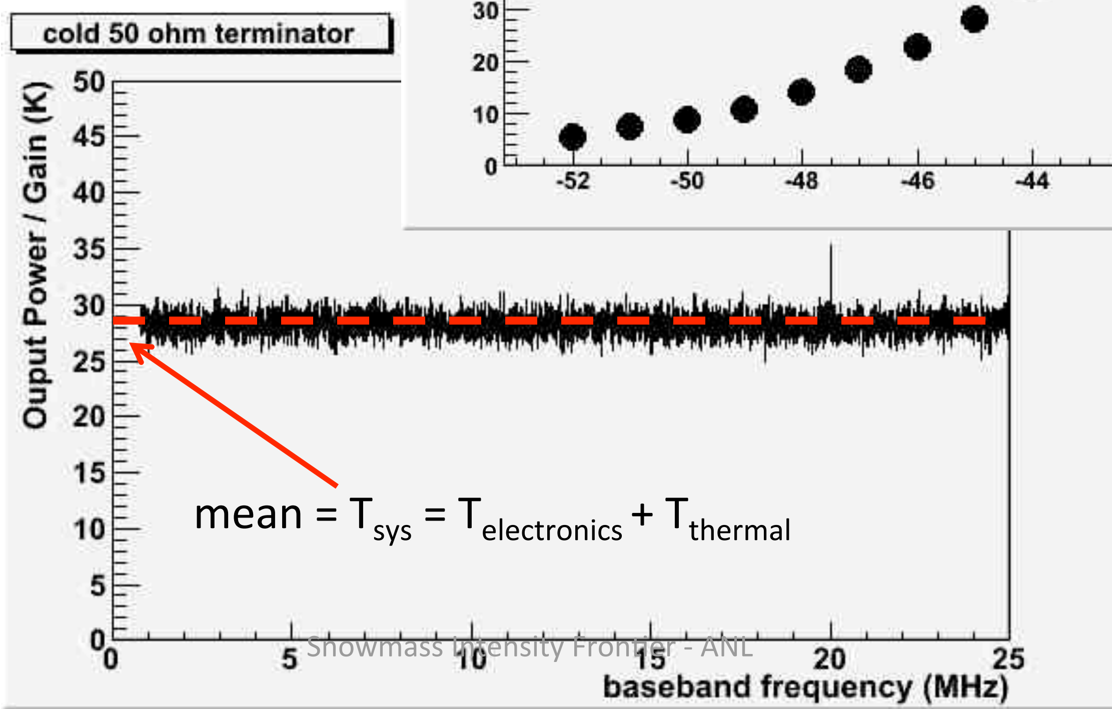


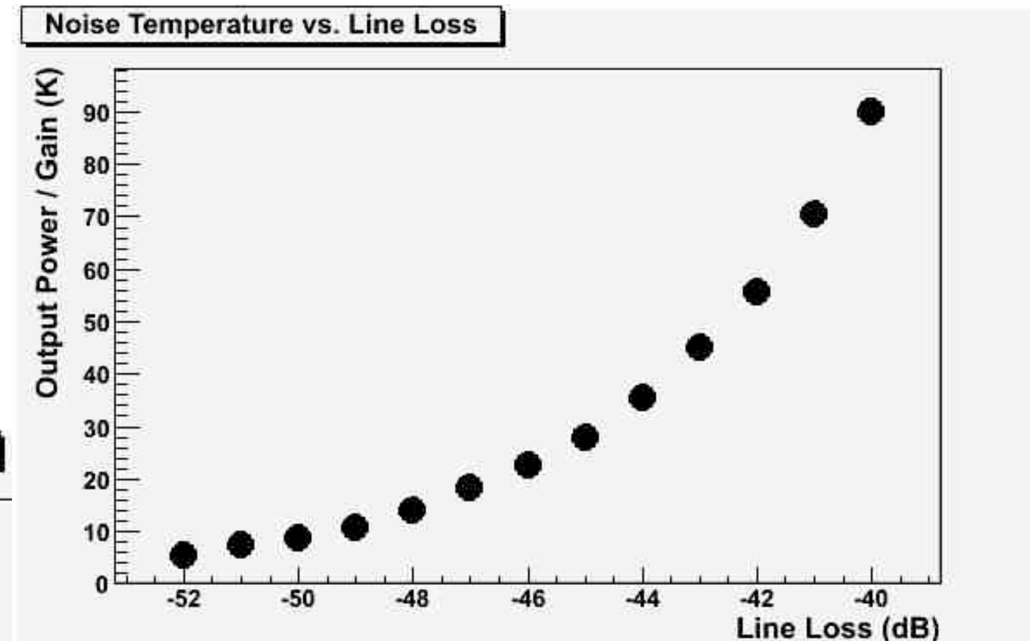


Line loss through calibration port.
Defines our knowledge of gain.

Noise temperature measured from output power density

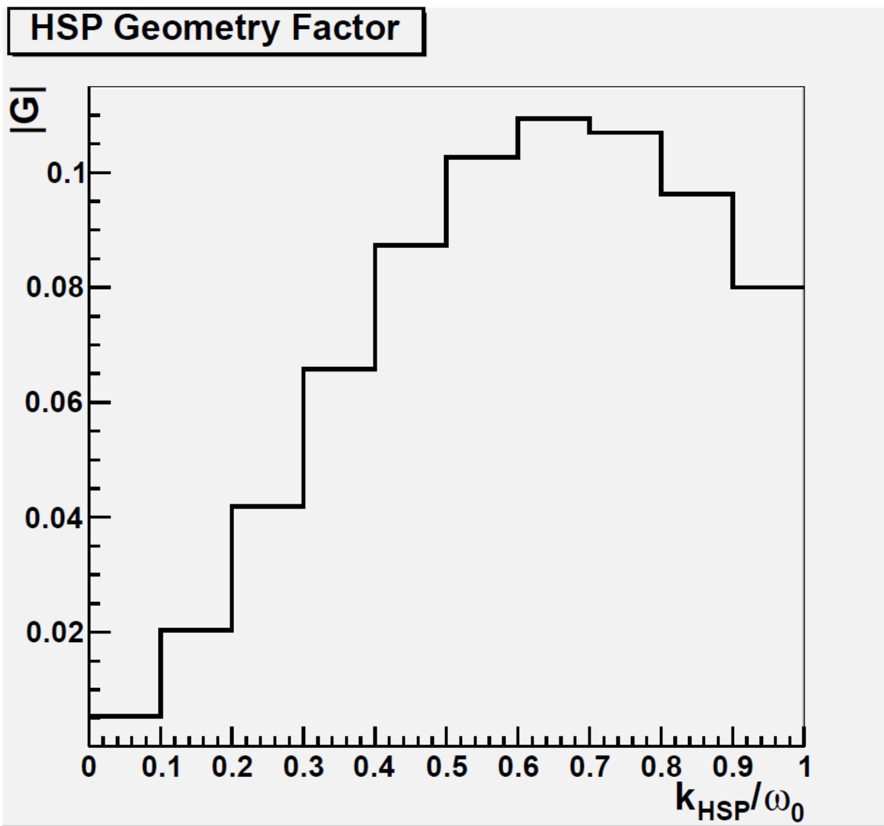






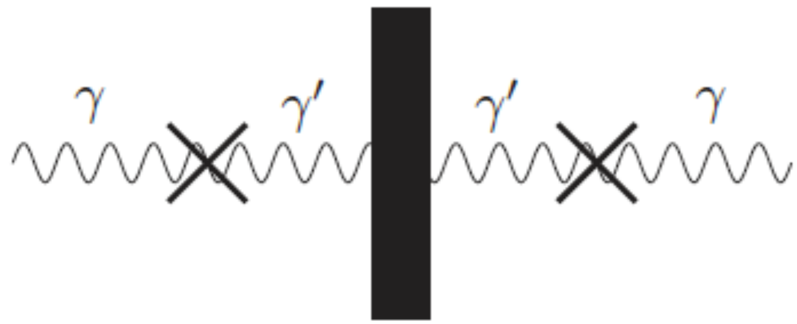
Geometry Factor* for hidden photons in microwave cavity searches

$$G_{HSP} \equiv \omega_0^2 \int_{V'} \int_V d^3\mathbf{x} d^3\mathbf{y} \frac{exp(ik|\mathbf{x}-\mathbf{y}|)A(\mathbf{y})A'(\mathbf{x})}{4\pi|\mathbf{x}-\mathbf{y}|},$$



Separates geometry information (e.g. cavity fields and their overlap) from the remainder of the calculation.

* J. Jaeckel and A. Ringwald, Phys. Lett. B 659 (3) 509, 2008.



measured transmission probability

$$P_{trans} = \chi^4 QQ' \frac{m_{\gamma'}^8}{\omega_0^8} \left| G^2 \right|$$

Q (Q'): cavity Quality factor (~10^4)

m: hidden sector photon mass

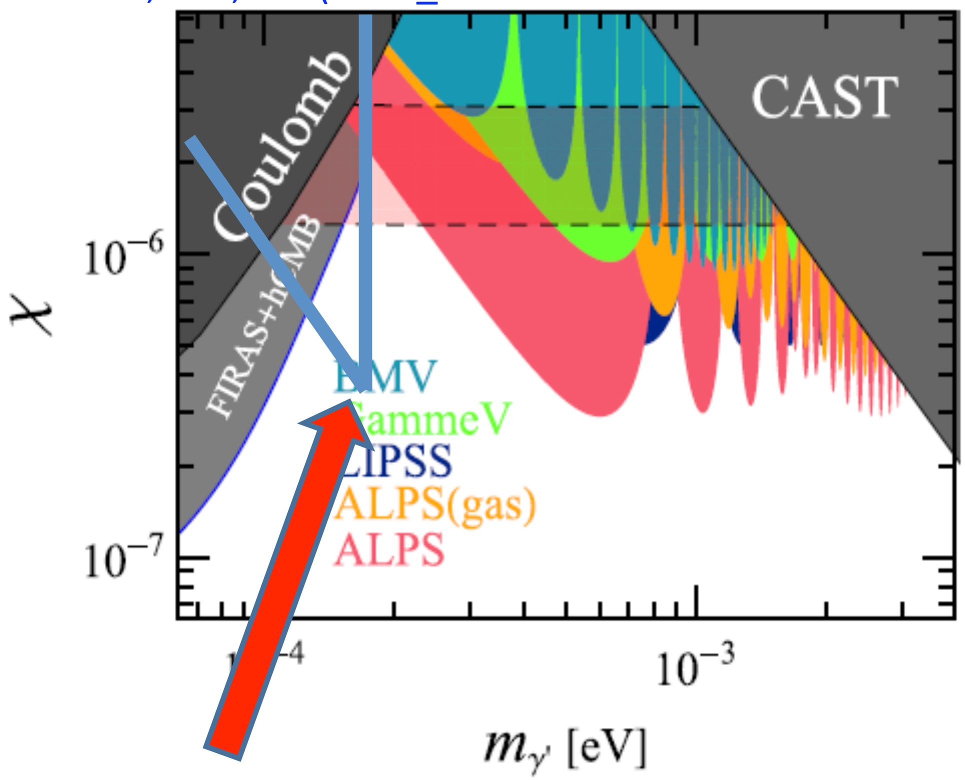
ω: photon frequency (34 GHz)

G: geometry factor

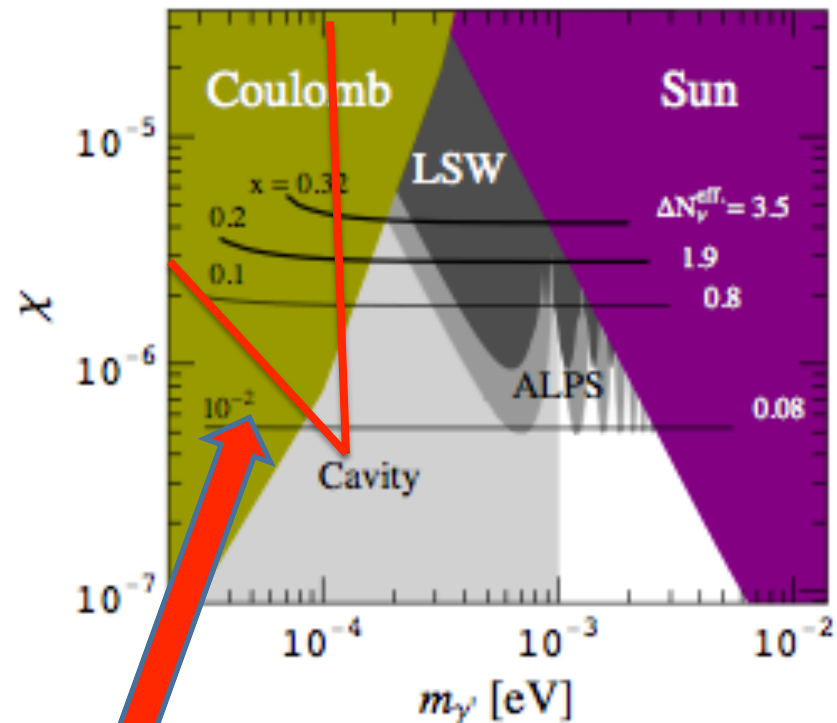
current/near future results

sensitivity to hidden photons

K. Ehret et al,
PLB, 689,149 (2008_.



J. Jaeckel, J. Redondo, A. Ringwald
Phys.Rev.Lett.101:131801,2008

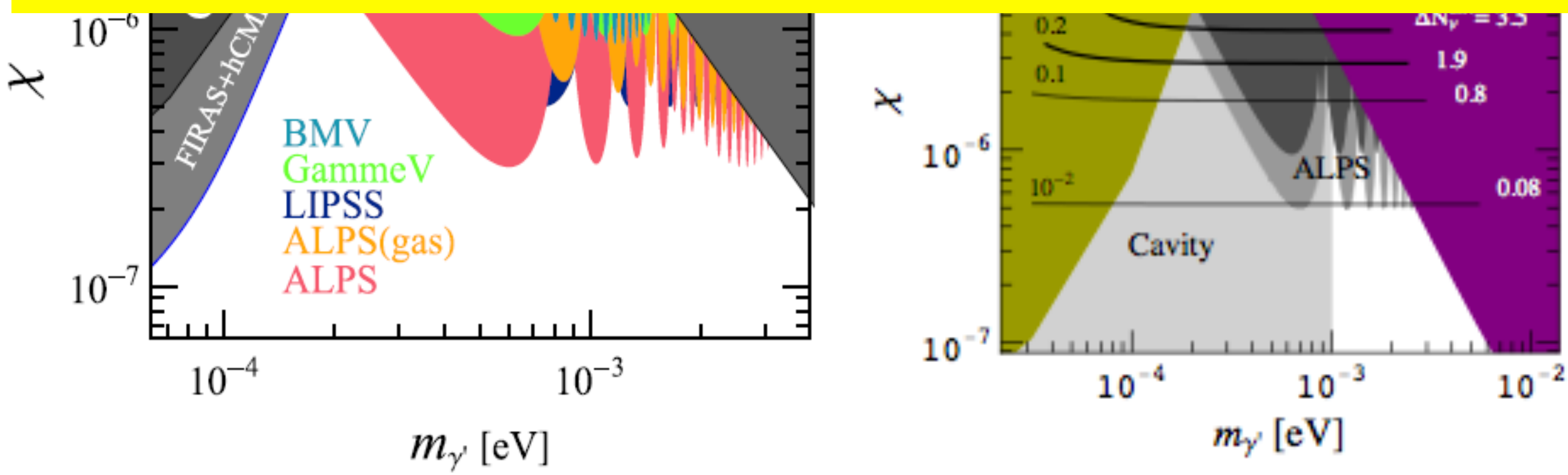


present result

present result

already constraining theory

want to make measurements at higher mass (higher frequencies: requires new techniques; improved technologies



ADMX-HF Collaboration

Steve Lamoreaux, Yulia Gurevich (PD), Ben Brubaker (GSR), Sid Cahn

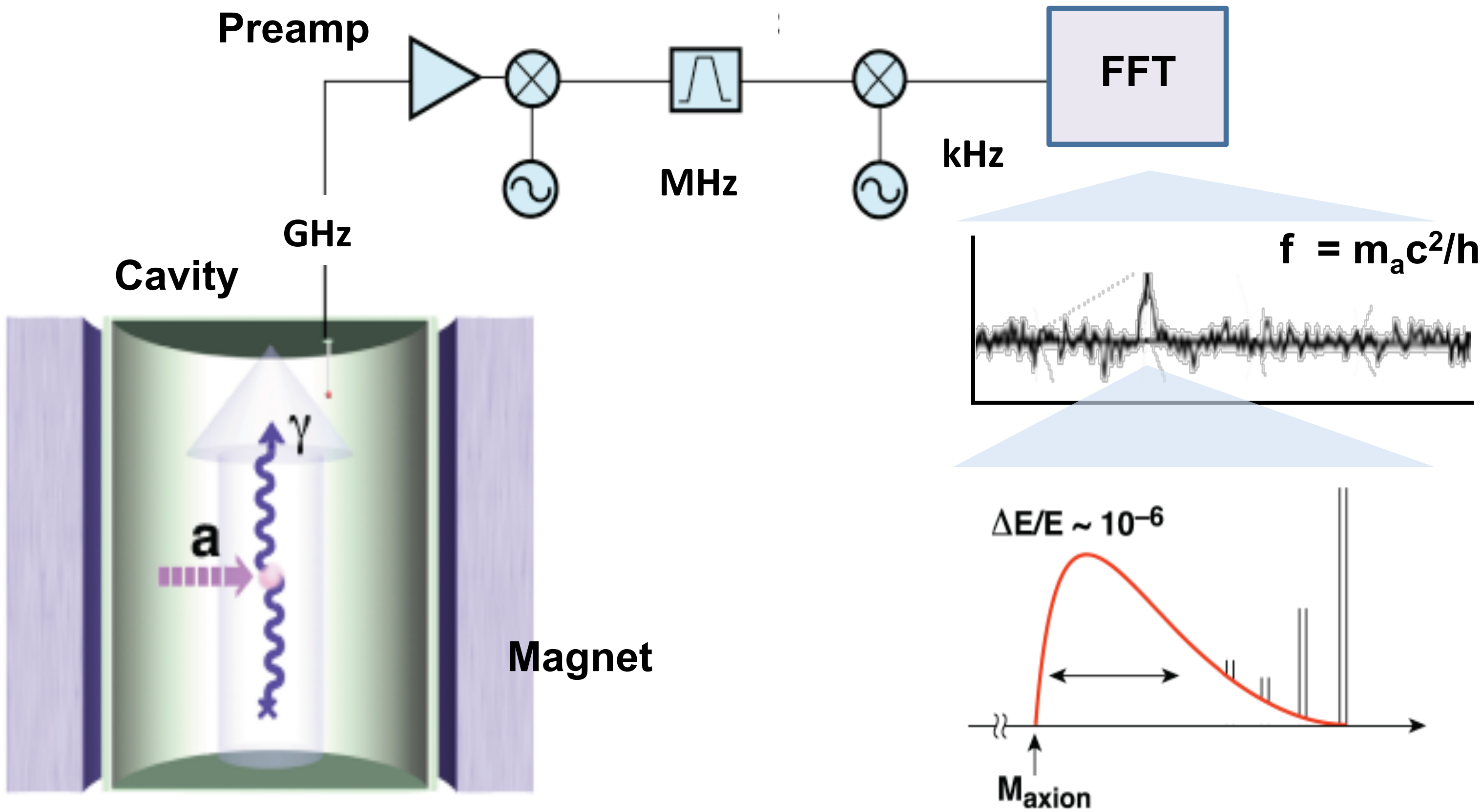
Konrad Lehnert, Mehmet Ali Anil (GSR)

Karl van Bibber, Jaben Root (UGSR)

Gianpaolo Carosi

We gratefully acknowledge support of the National Science Foundation, and the U.S. Department of Energy (GC, Early Career Award)

principle of the experiment *(Sikivie, 1983)*

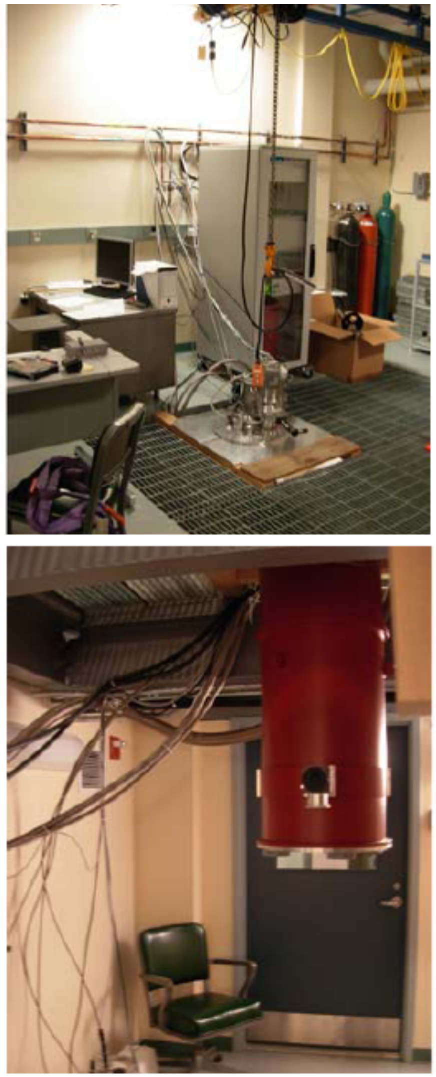


ADMX-HF example

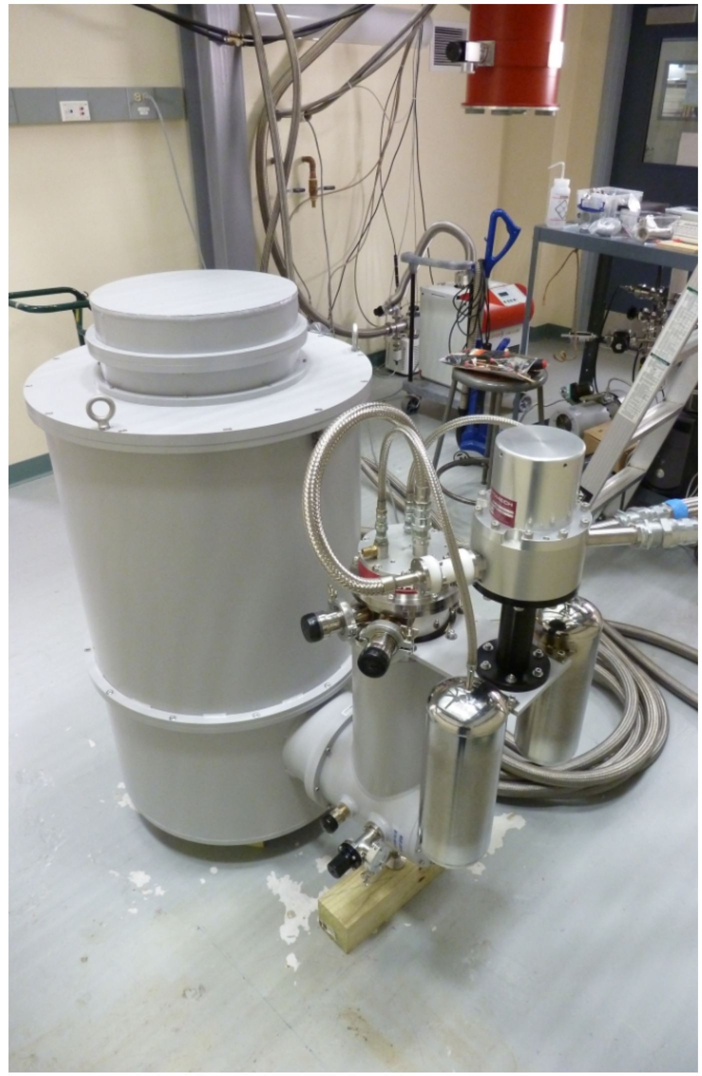
$$P_{sig} \propto (B^2 V Q_{cav})(g^2 m_a \rho_a) \qquad s/n = \frac{P_{sig}}{kT_{sys}}\sqrt{\frac{t}{\Delta\nu}}$$

ADMX-HF at Yale

Microwave Cavity



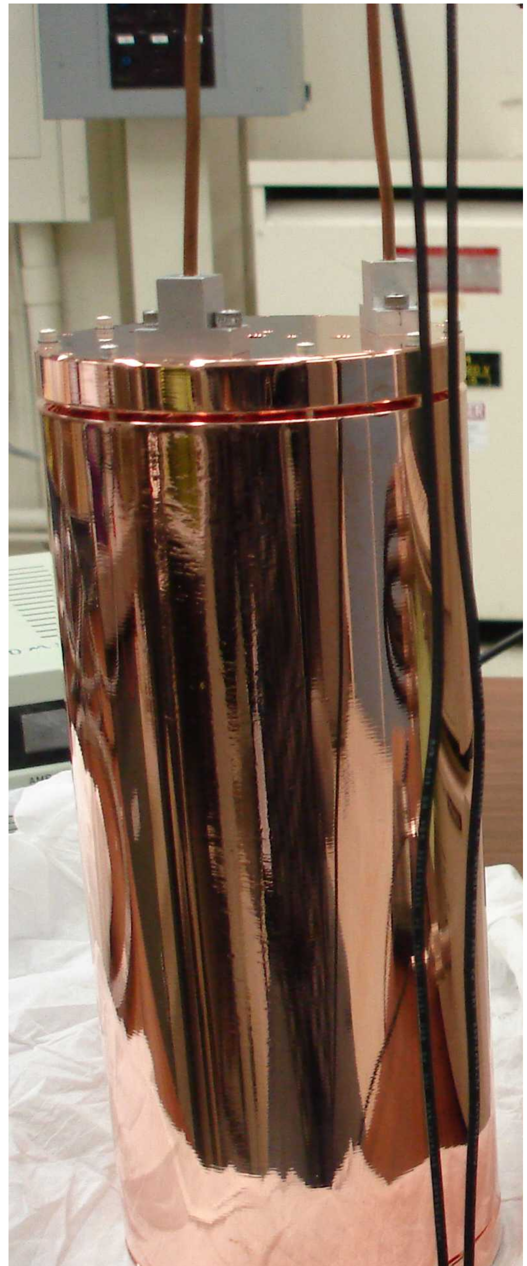
Dilution Refrigerator

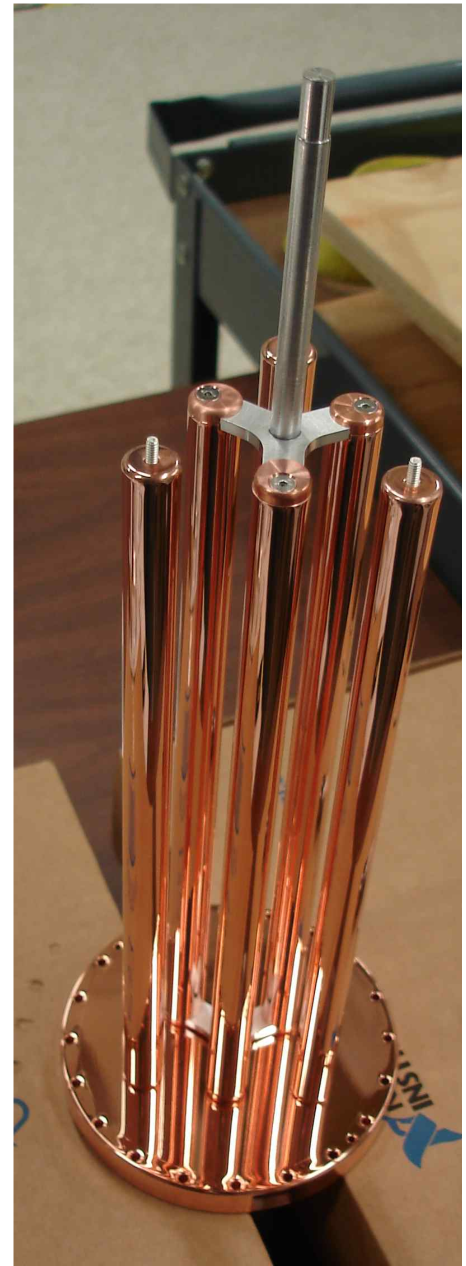


Superconducting Magnet

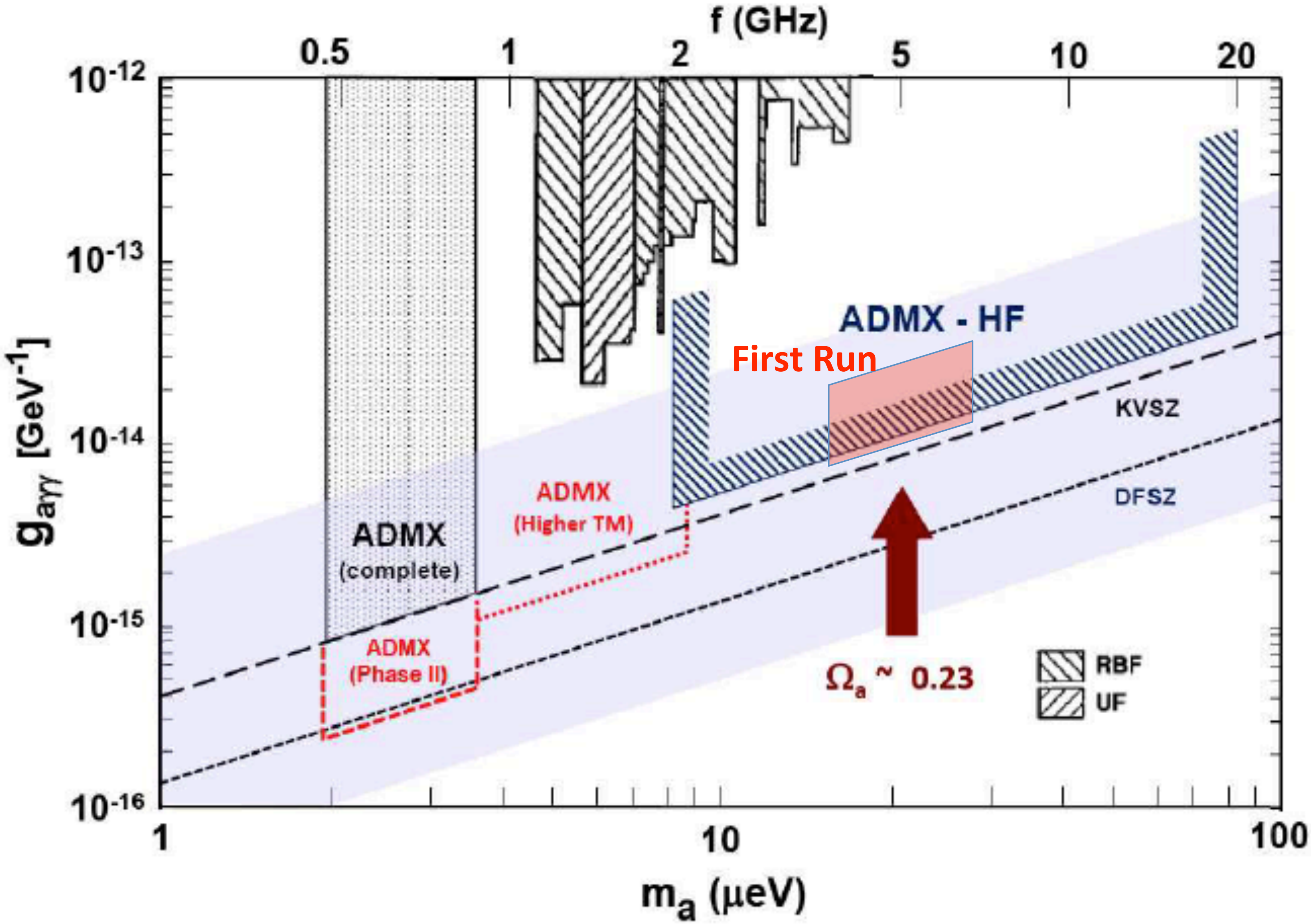
ADMX-HF cavity update

- Q = 18,800 before annealing @ 300K
- Q = 27,200 after annealing
- Should be >100,000 @ 4K (without rods)
- Integrate late-April



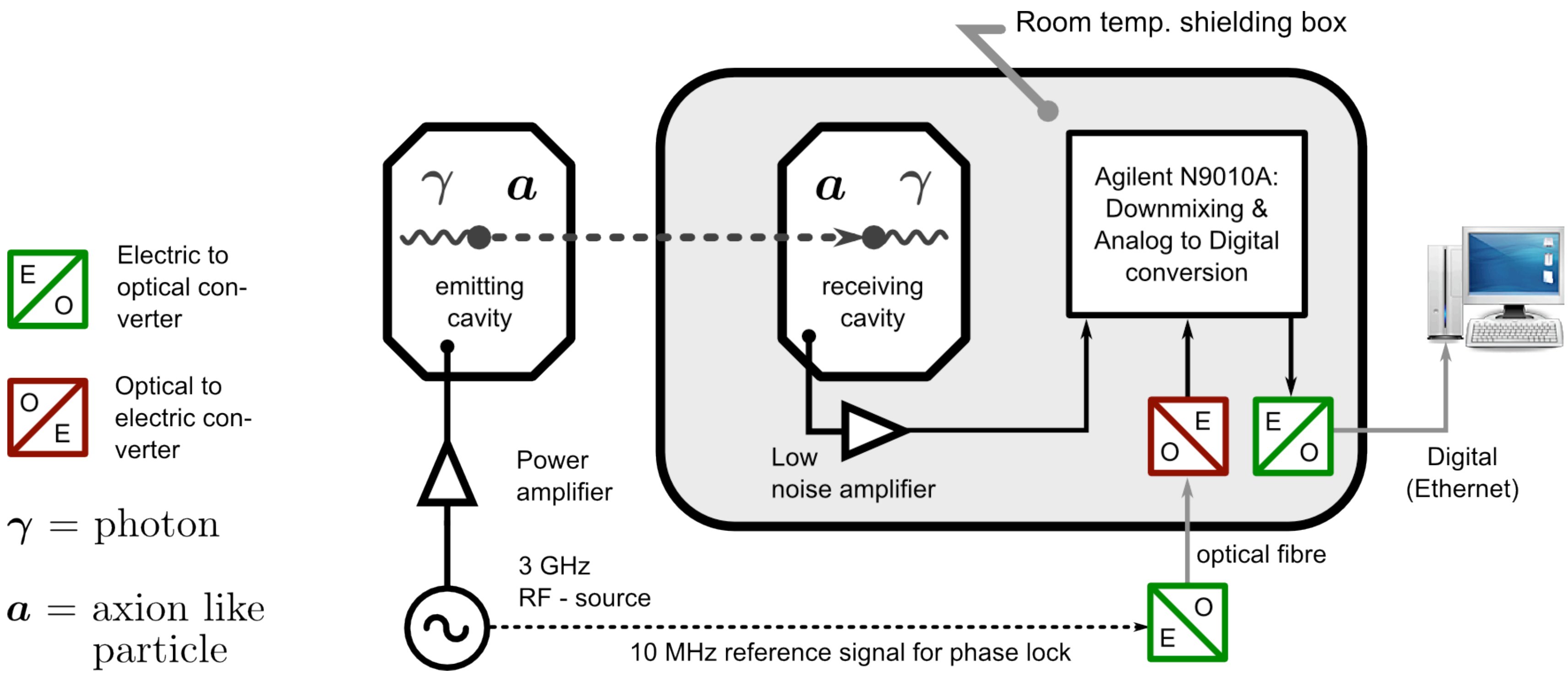


What we hope we can achieve



hidden sector search example: CERN setup

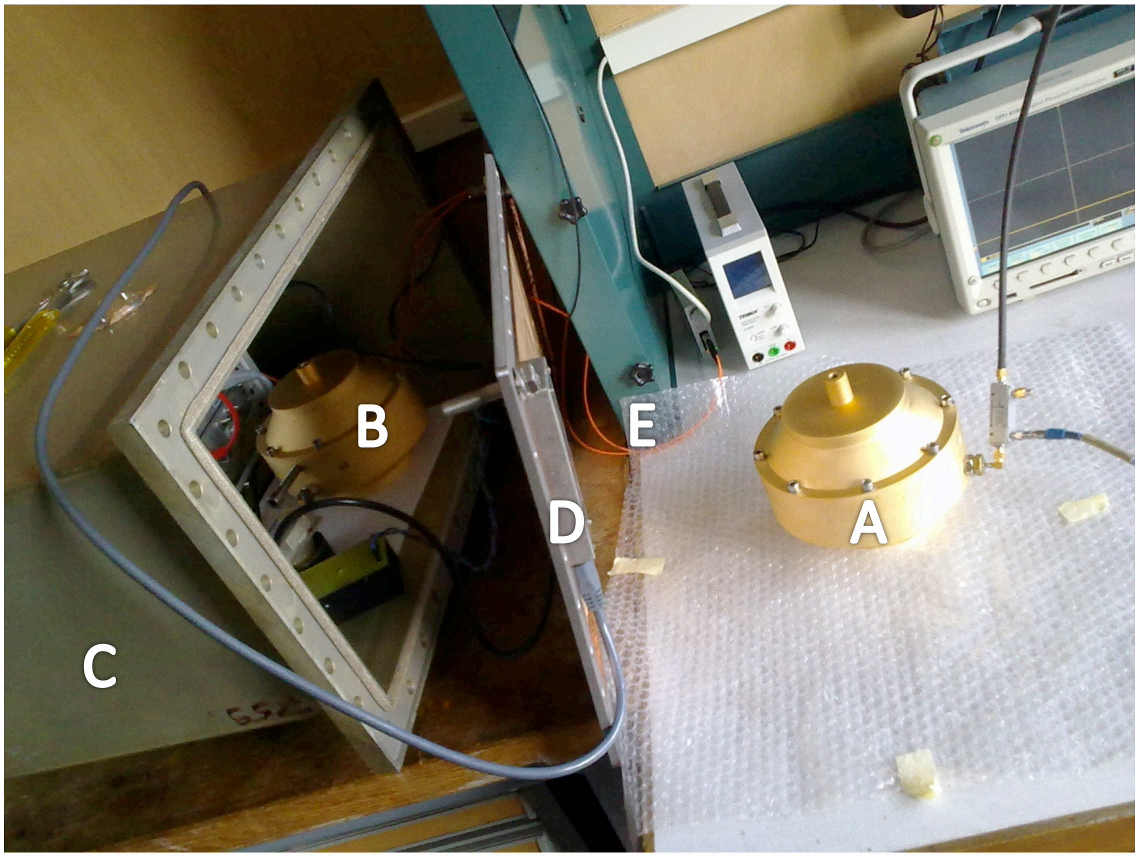
M. Betz, F. Caspers, K. Zioutas (2011)



$$\mathscr{P}_{\mathrm{det}} = \chi^4 \frac{m_{\gamma'}^8}{\omega_0^8} |G|^2 QQ' \mathscr{P}_{\mathrm{em}}$$

CERN - current lab setup

M. Betz, F. Caspers, K. Zioutas (2011)



- emitting cavity (**A**)
- detecting cavity (**B**) in microwave shielding enclosure (**C**)
- **C** provides 100 dB of additional microwave attenuation (measured) and contains a spectrum analyzer
- custom feed-trough filter for 230 V mains (**D**)
- all signals are transmitted over optical fibres (**E**)

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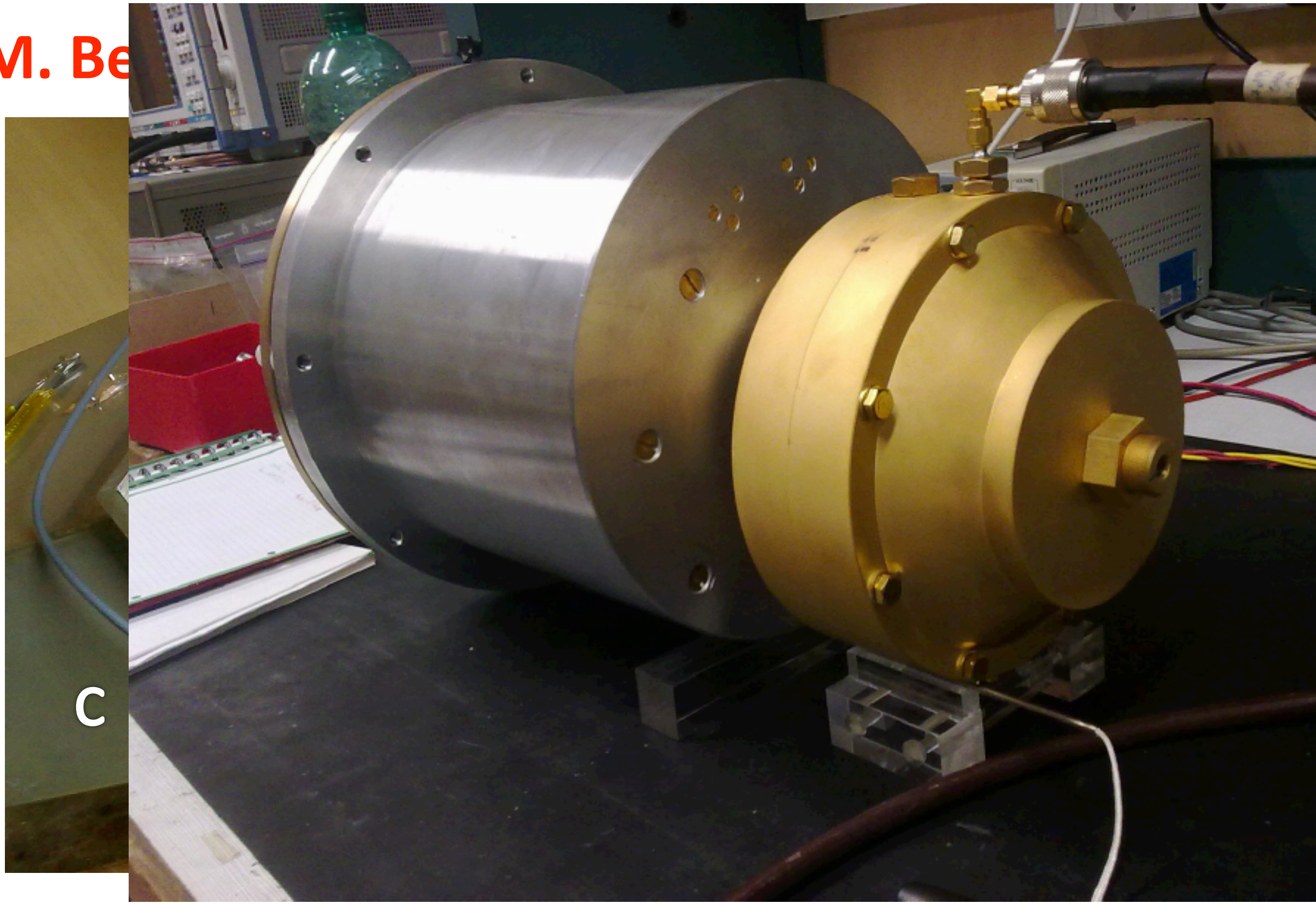
CERN - current lab setup w/ magnet

M. Be



cavity (**A**)
cavity (**B**) in
e shielding
(**C**)
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analyzer
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230 V mains
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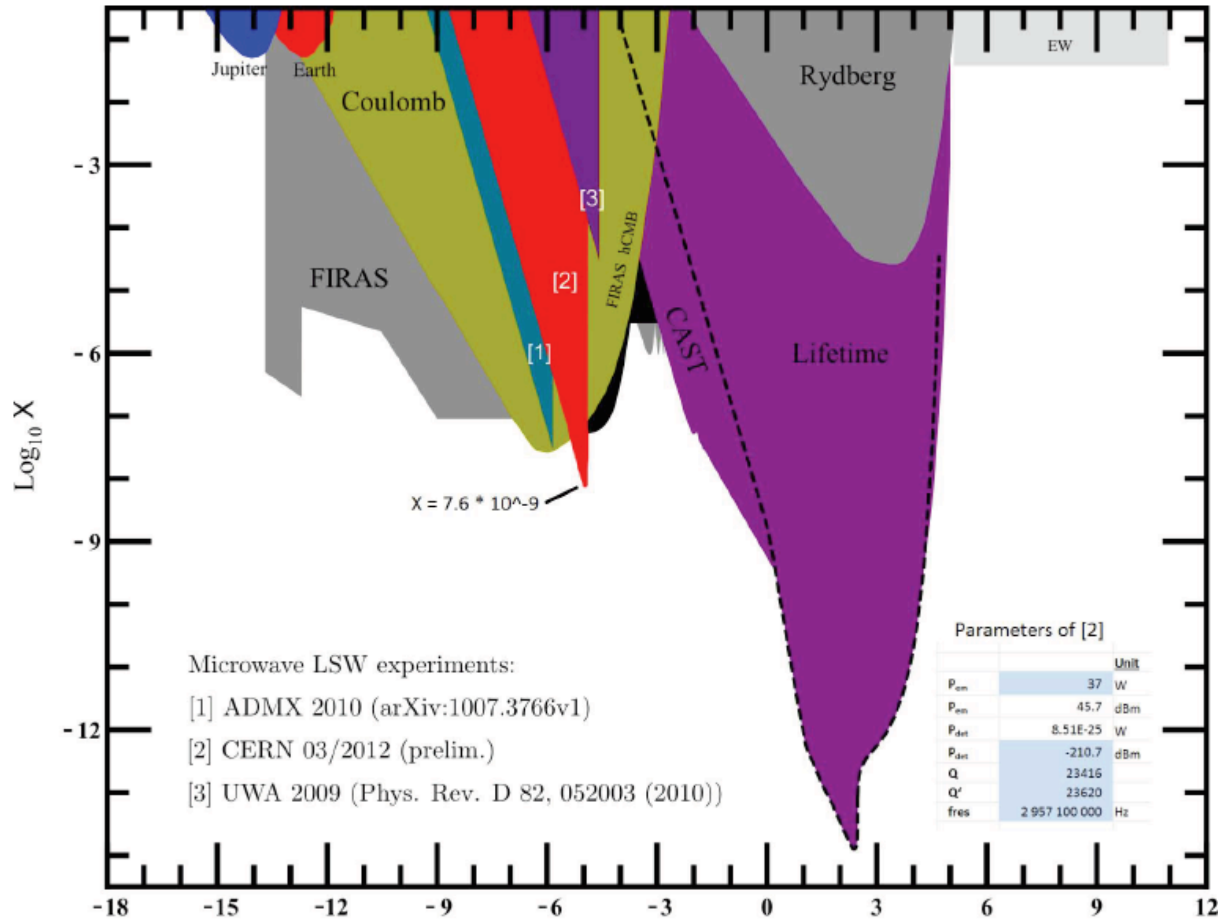
30

sensitivity to hidden photons in 2011 (CERN)



- there is also a planned experiment at CERN
  - M. Betz, F. Caspers, A microwave paraphoton and axion detection experiment with 300 dB electromagnetic shielding at 3 GHz, proceedings of IPAC 2012
- additionally 200 MHz cavities from CERN SPS

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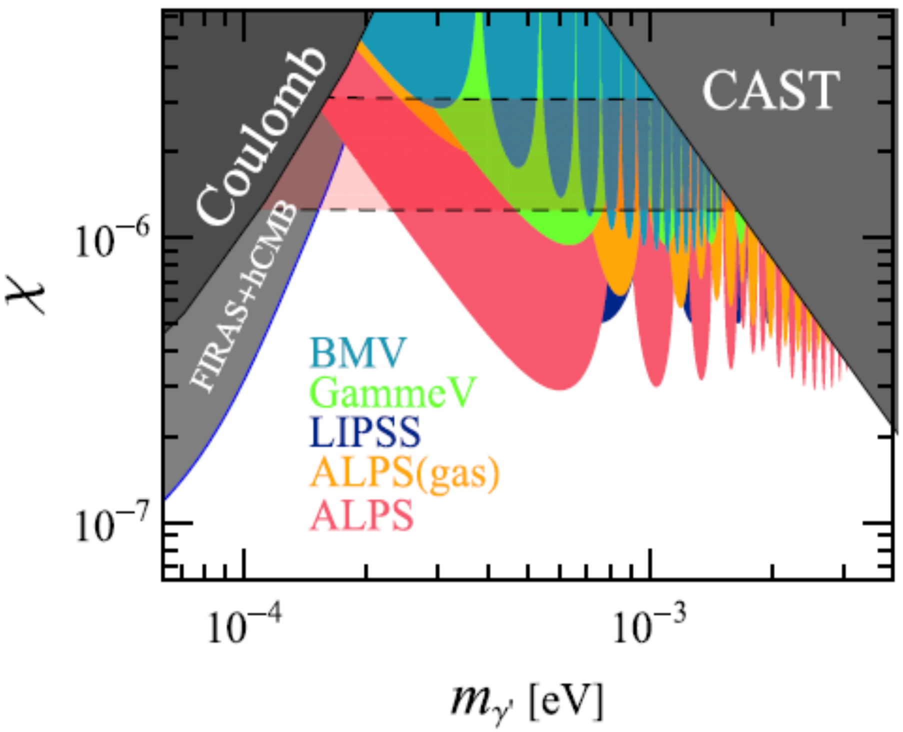
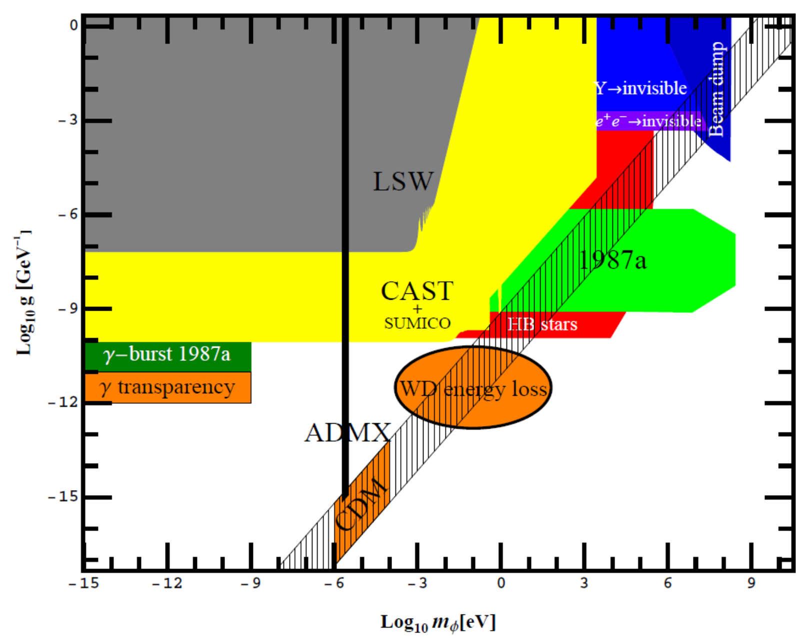
summary

microwave cavity searches
future improvements

- stronger magnetic fields (increased sensitivity)
- superconducting cavities (higher Q)?
- larger cavities (increased sensitivity at lower masses)
- smaller cavities (higher masses)
- improved amplifiers



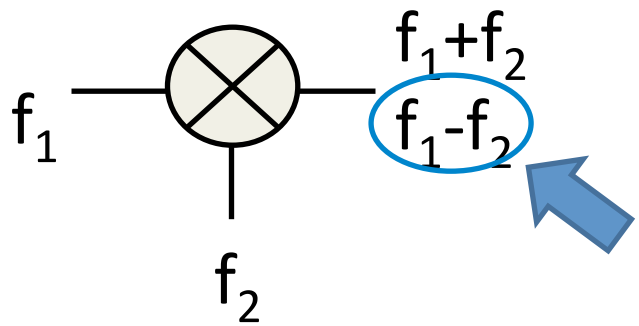


additional slides

microwave receiver - ymce

based on the trig identity:

$$\sin(\theta)\sin(\phi) = \tfrac{1}{2}(\cos(\theta-\phi) - \cos(\theta+\phi))$$

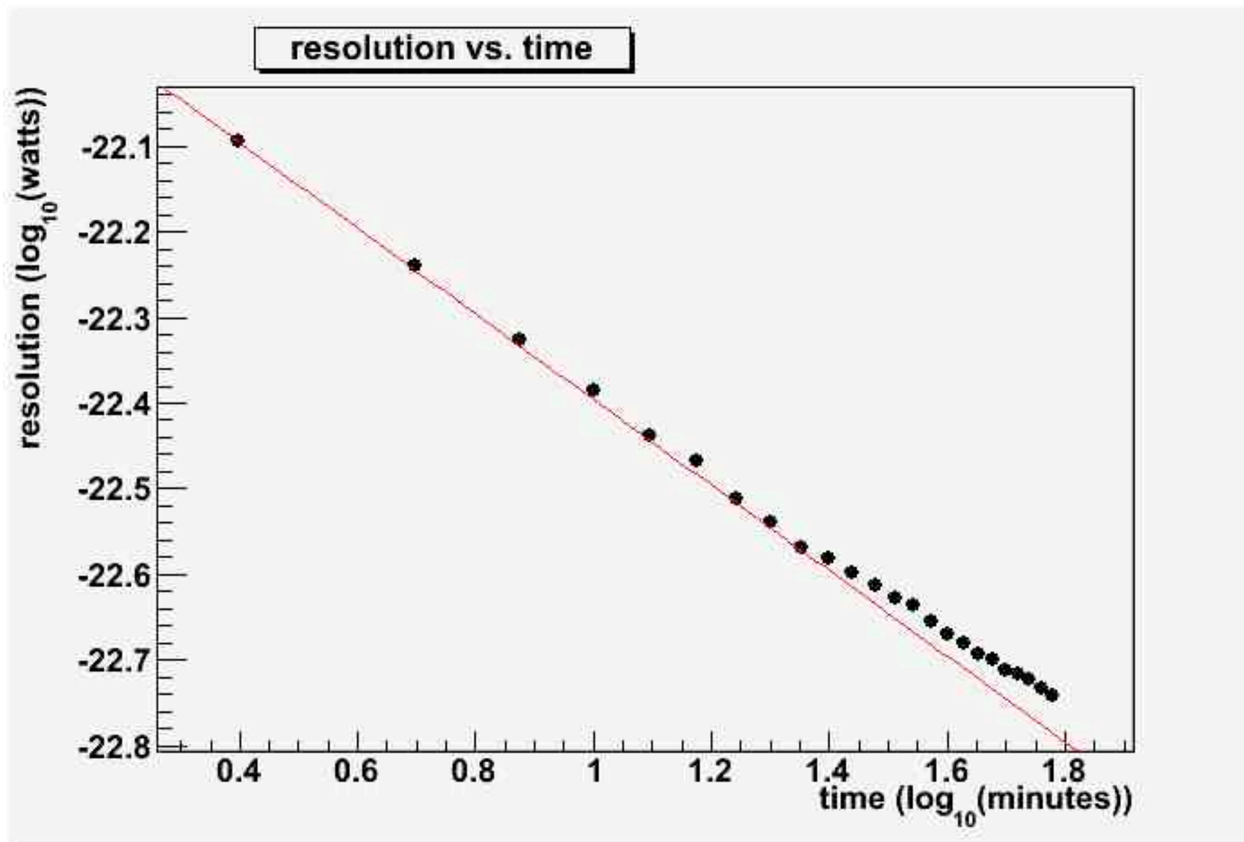


intermediate frequency

"Image frequency" $2f_2-f_1$ will also mix with f_2 to give f_1-f_2. Suppress it with a filter before the mixer.

noise resolution

- 1 Hz resolution bandwidth
- 1 hour integration time
- 2 x 10^{-23} watts



10 minutes integration time