Recent Measurements from the Yale Microwave Cavity Experiment (YMCE)

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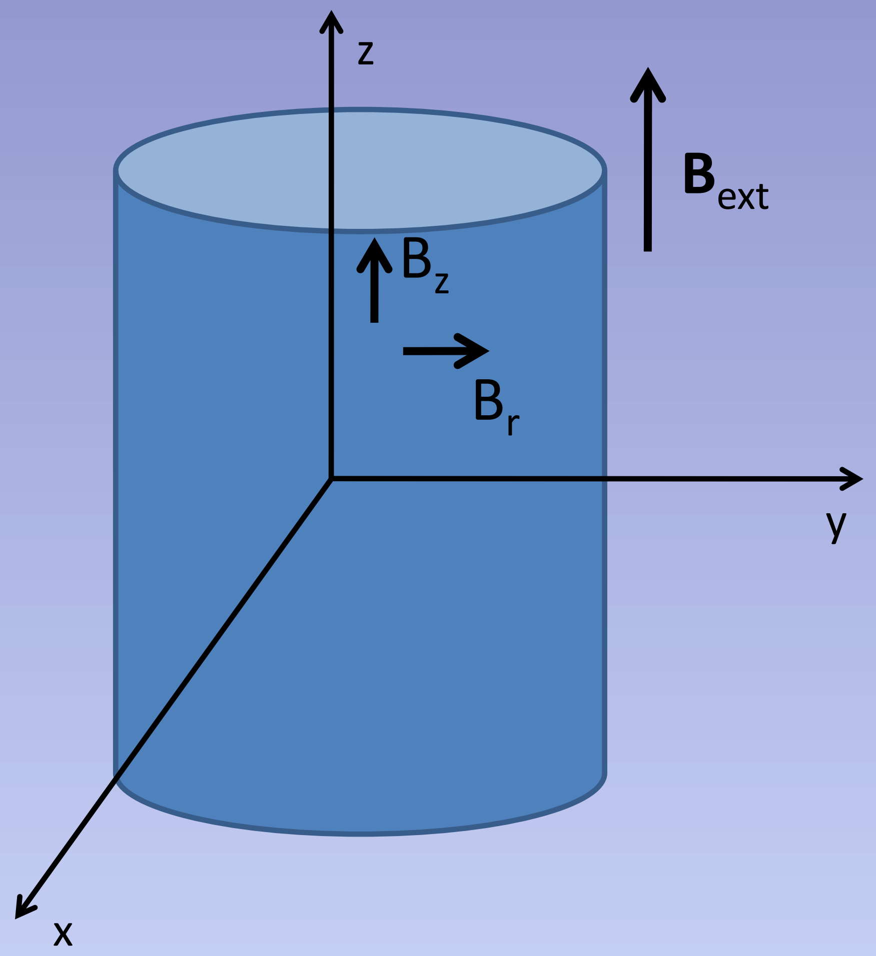
YMCE Measurements at 34 GHz

- Scalar ALPs
- Scalar Chameleons
- Hidden Sector Photons
- Pseudoscalar ALPs with TM cavity

Resonant cavity searches

- Pioneered by Pierre Sikivie and ADMX collaborators in 1980s.
- ADMX: Single low-mode cavity in B-field to look for $\gamma\gamma$ coupling with local galactic halo axions (μeV).
- $\mathcal{L} = -g\phi \mathbf{B}_\gamma \cdot \mathbf{B}_{ext}$ (scalar ALP)
- $\mathcal{L} = -g\phi \mathbf{E}_\gamma \cdot \mathbf{B}_{ext}$ (pseudoscalar ALP)

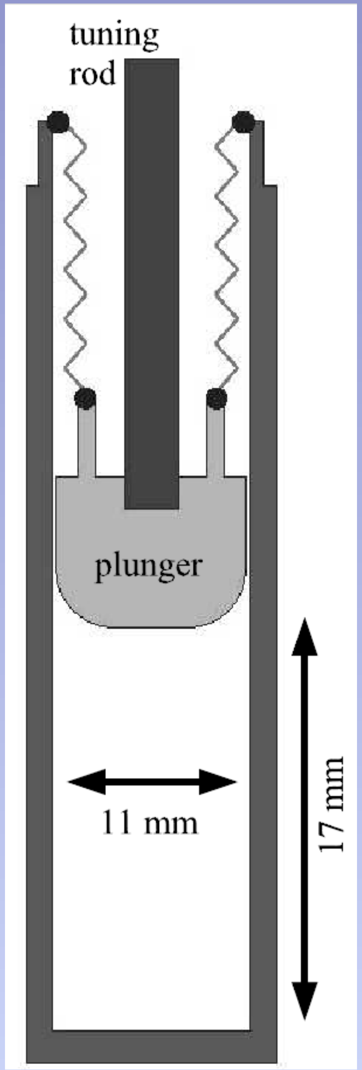


YMCE experiment at 34 GHz

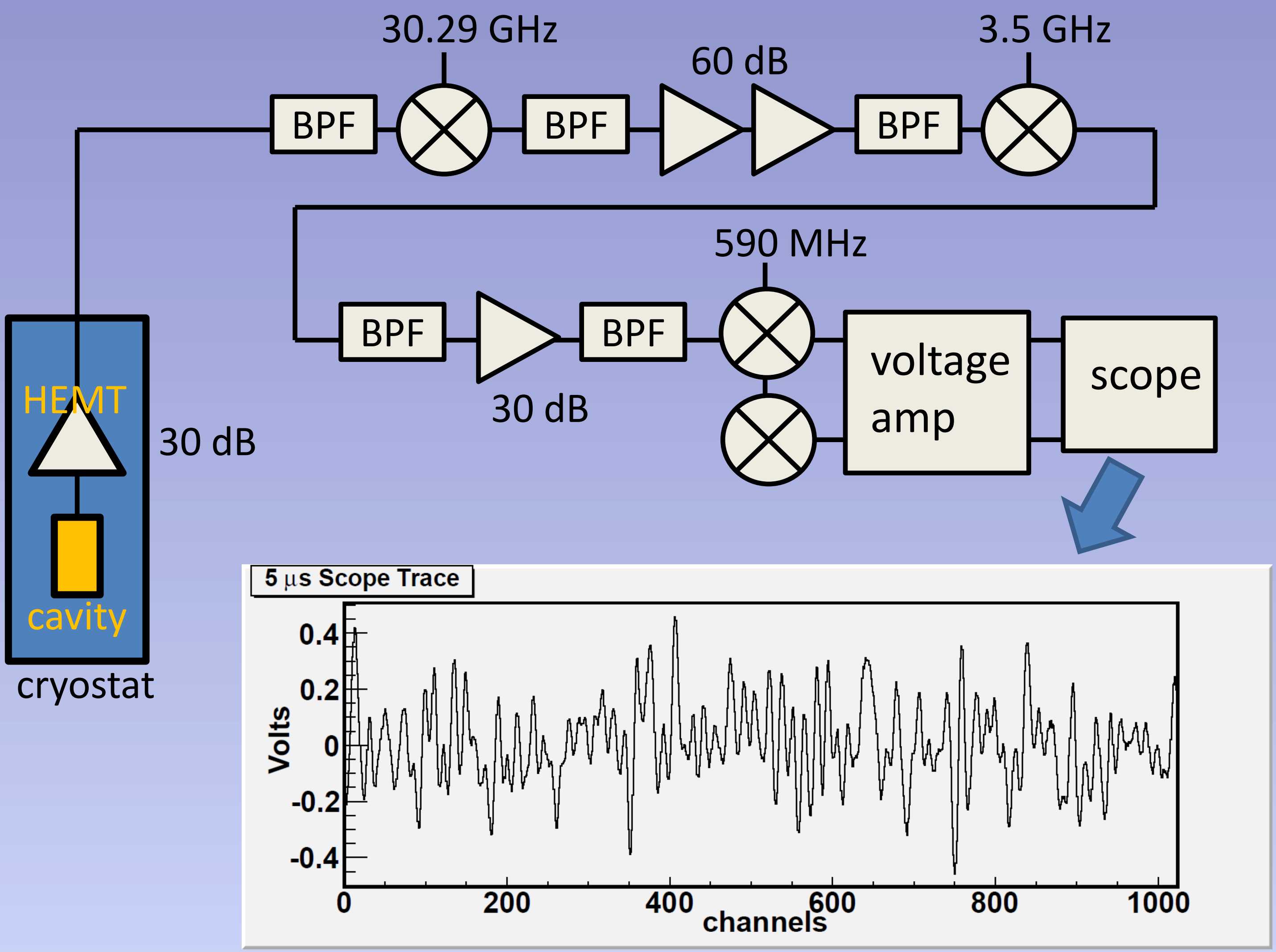
- Cu resonant cavity at 34 GHz, cooled to T~4 K, tunable, TE011 mode.
- From the Lagrangian,

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

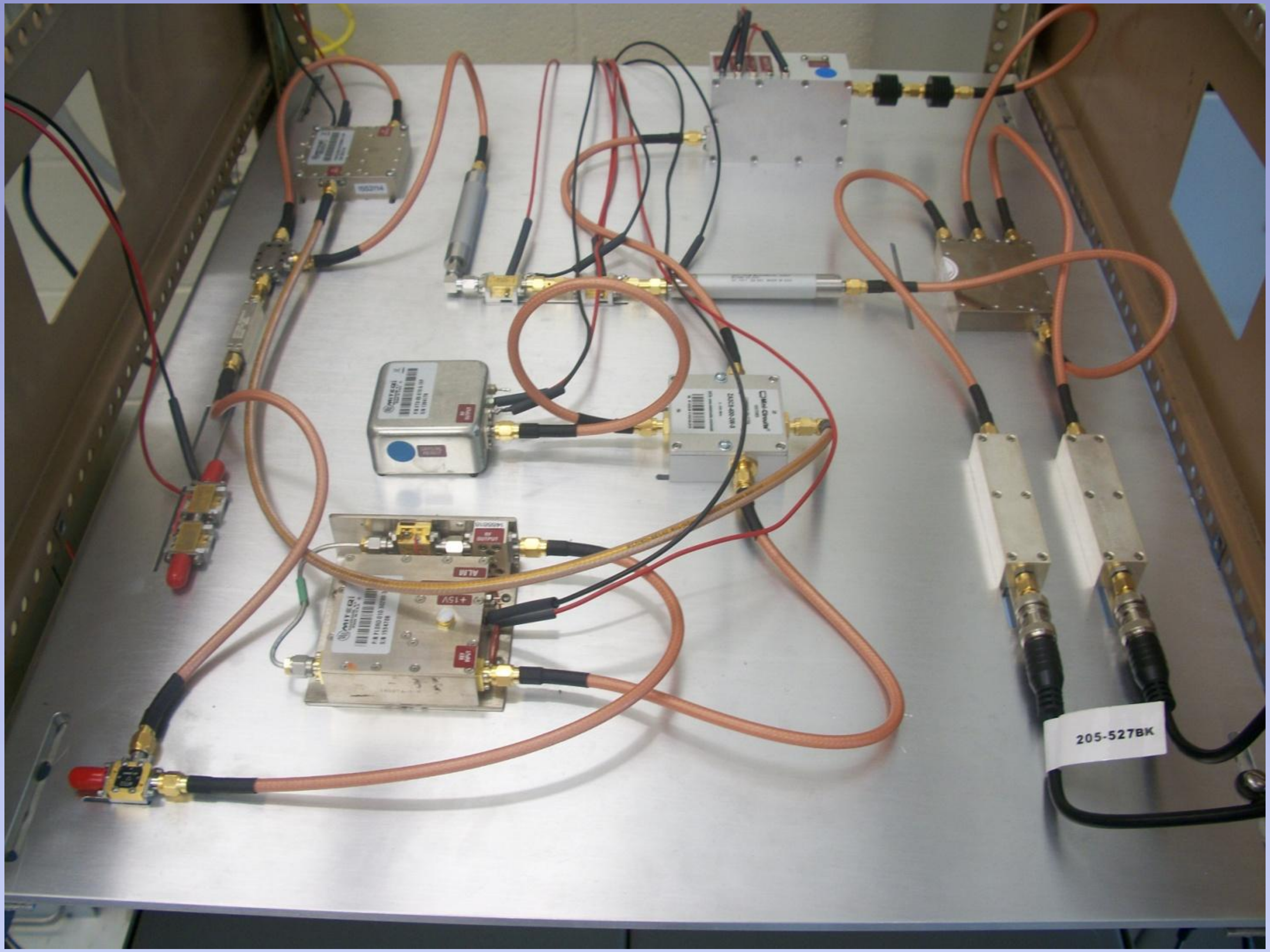
$$C_{lmn} \equiv \frac{\left| \int_V d^3x \mathbf{B} \cdot \hat{\mathbf{B}}_{\text{ext}} \right|^2}{V \int_V d^3x \frac{1}{\mu} \left| \mathbf{B} \right|^2}$$



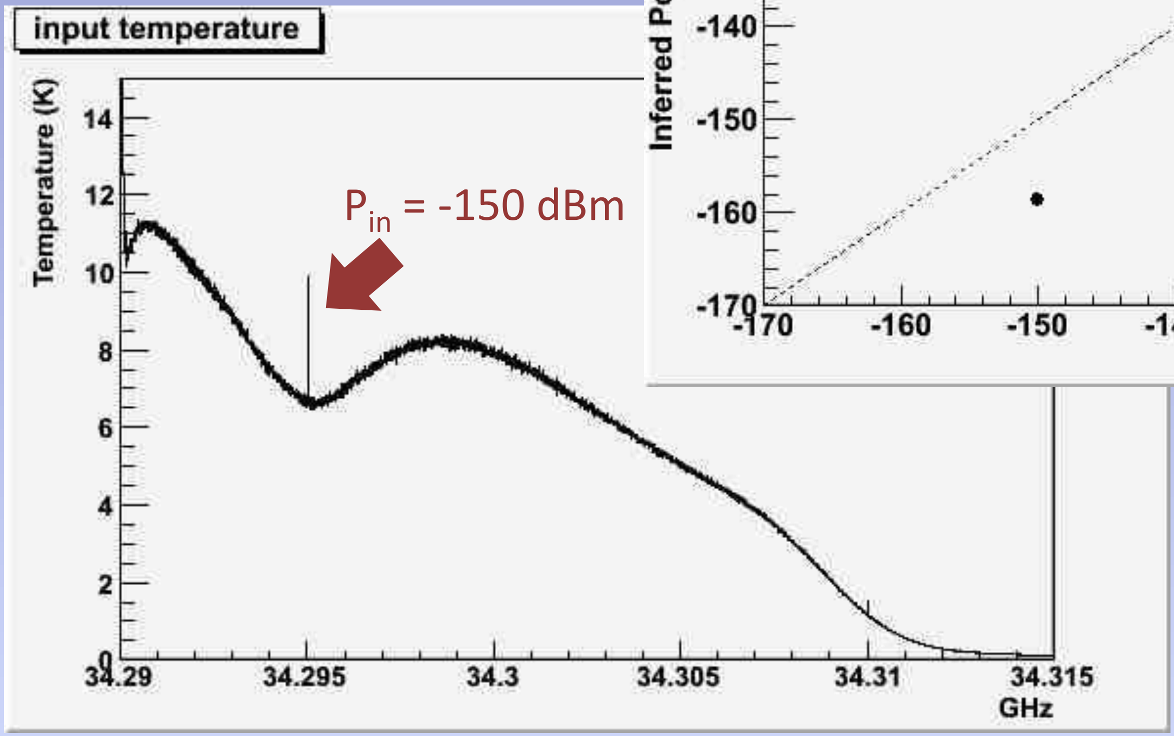
Microwave receiver

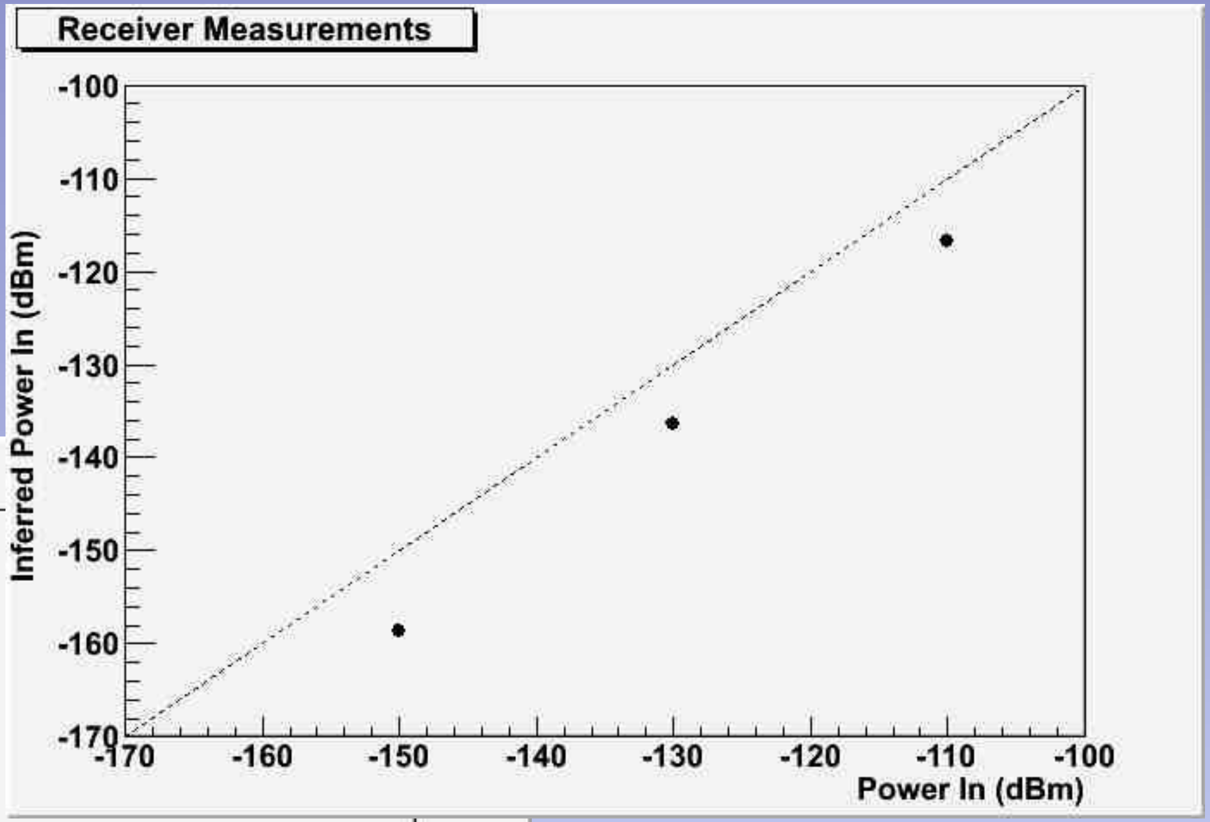


Receiver layout



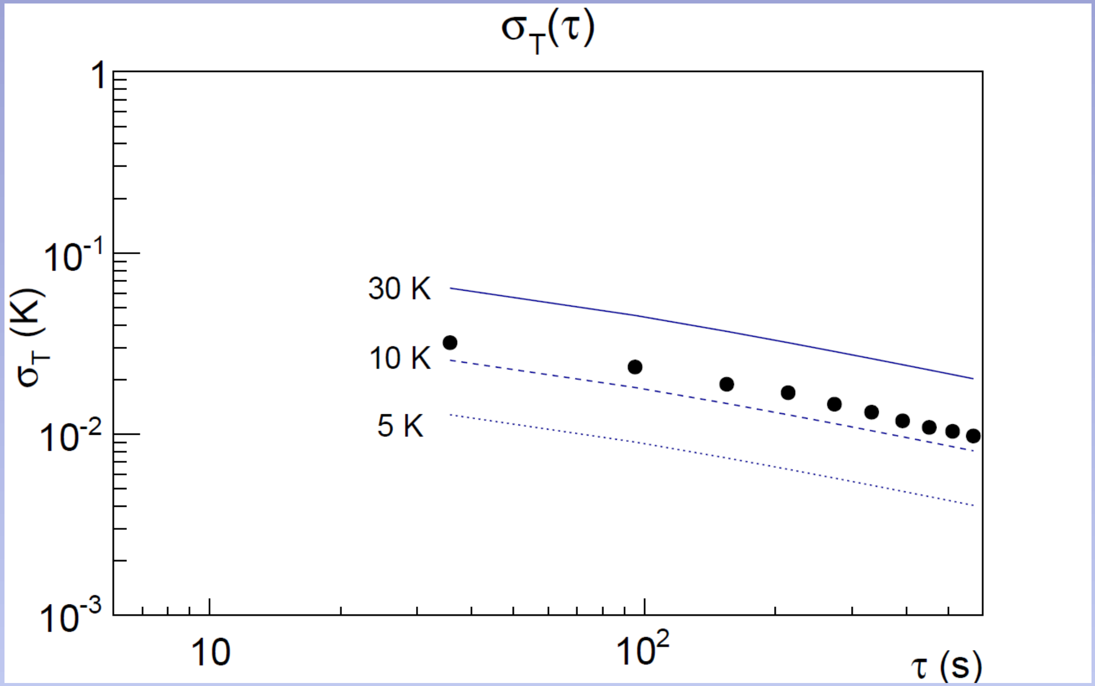
Receiver Tests



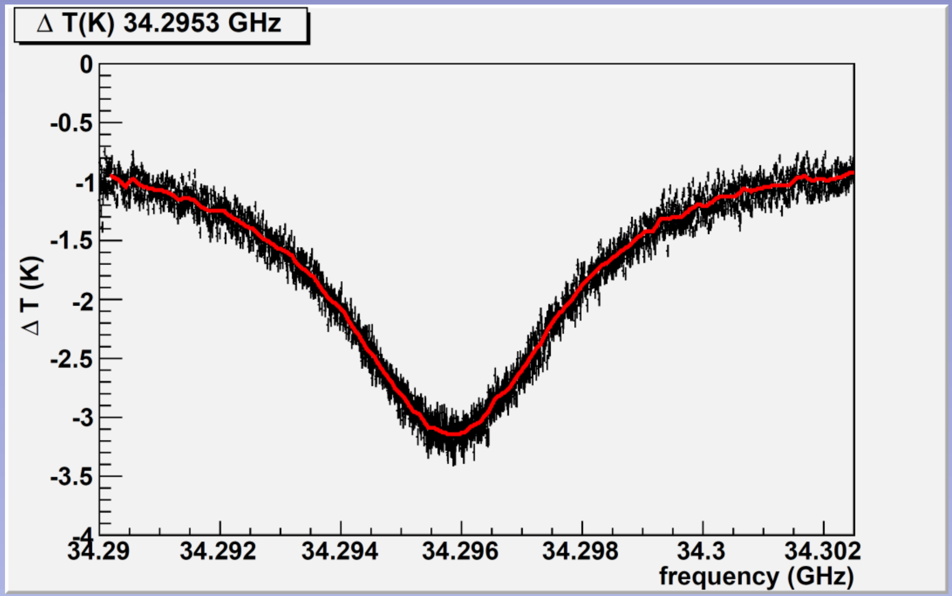


Noise floor of system

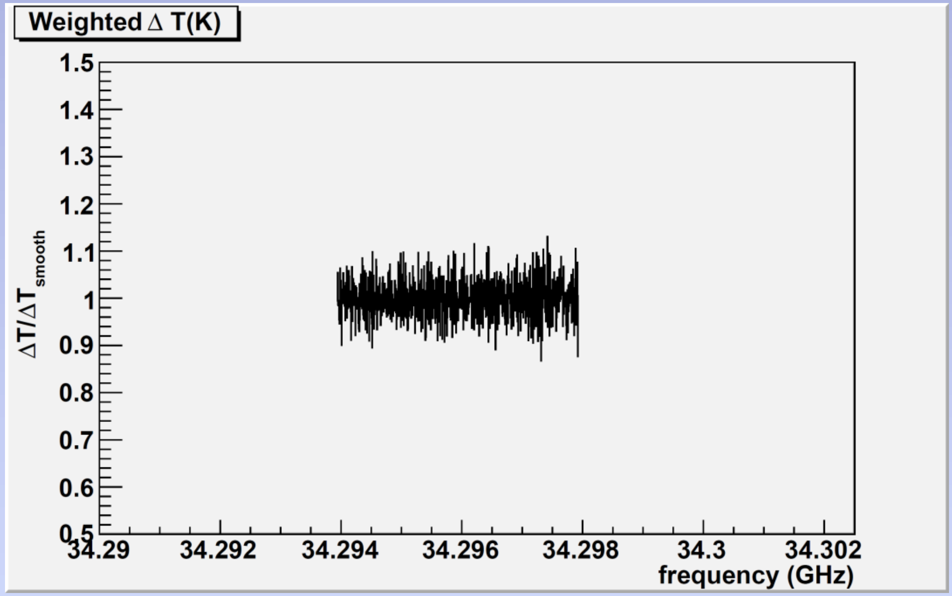
- $T_{sys} = T_{cavity} + T_{HEMT}$ ~ 15 K.
- σ_T ~ 10 mK for $\Delta\nu$=5 kHz.
- $P_{min} = k_B \Delta\nu T$ = 10^{-21} W.



One scan, cavity tuned to 34.295 GHz

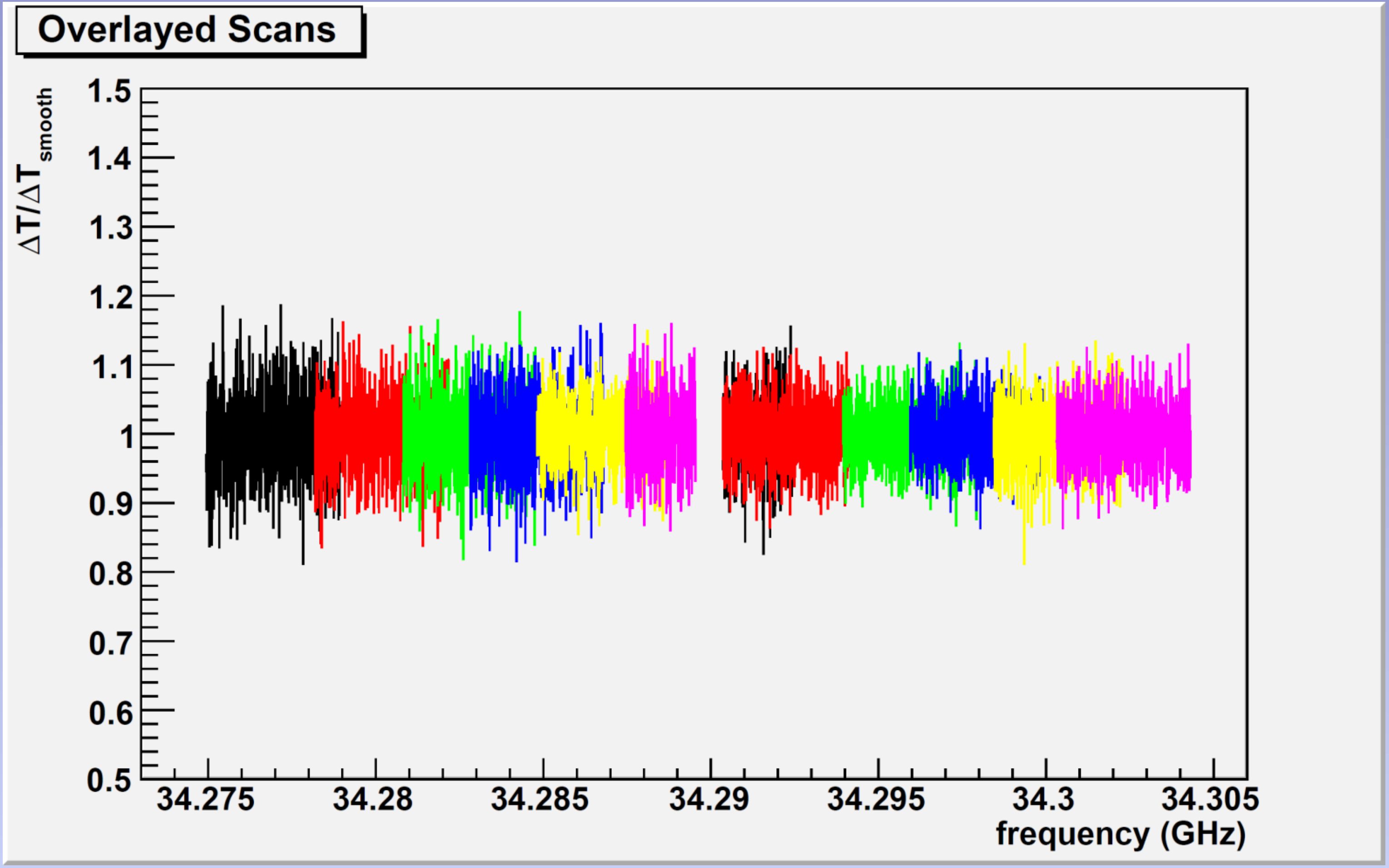


After baseline subtraction.

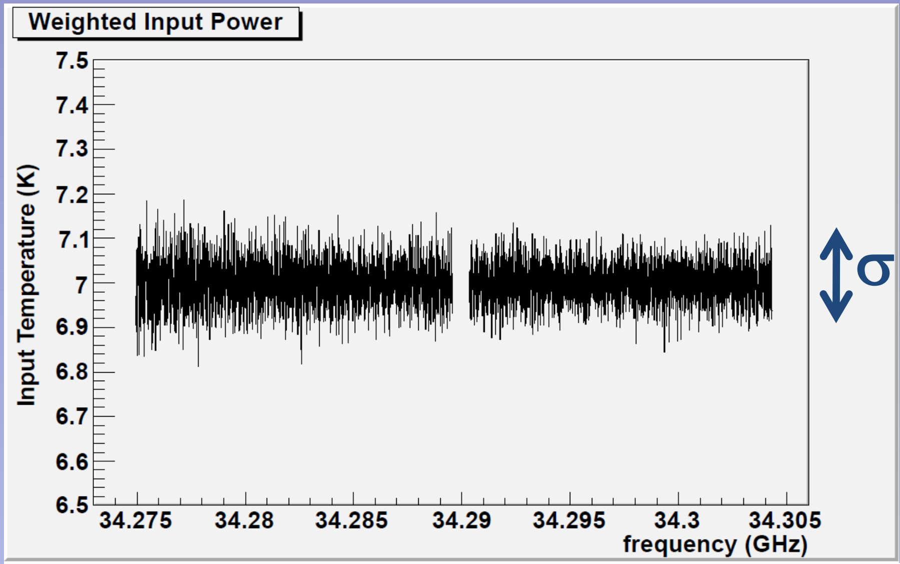


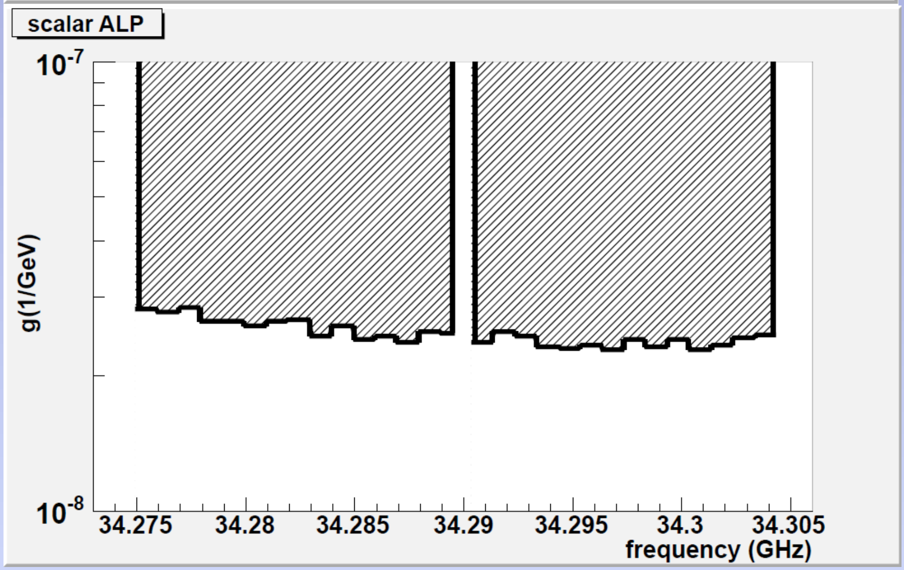
After baseline subtraction and weighting,
cut on cavity.

Overlayed scans



Averaged scans and results



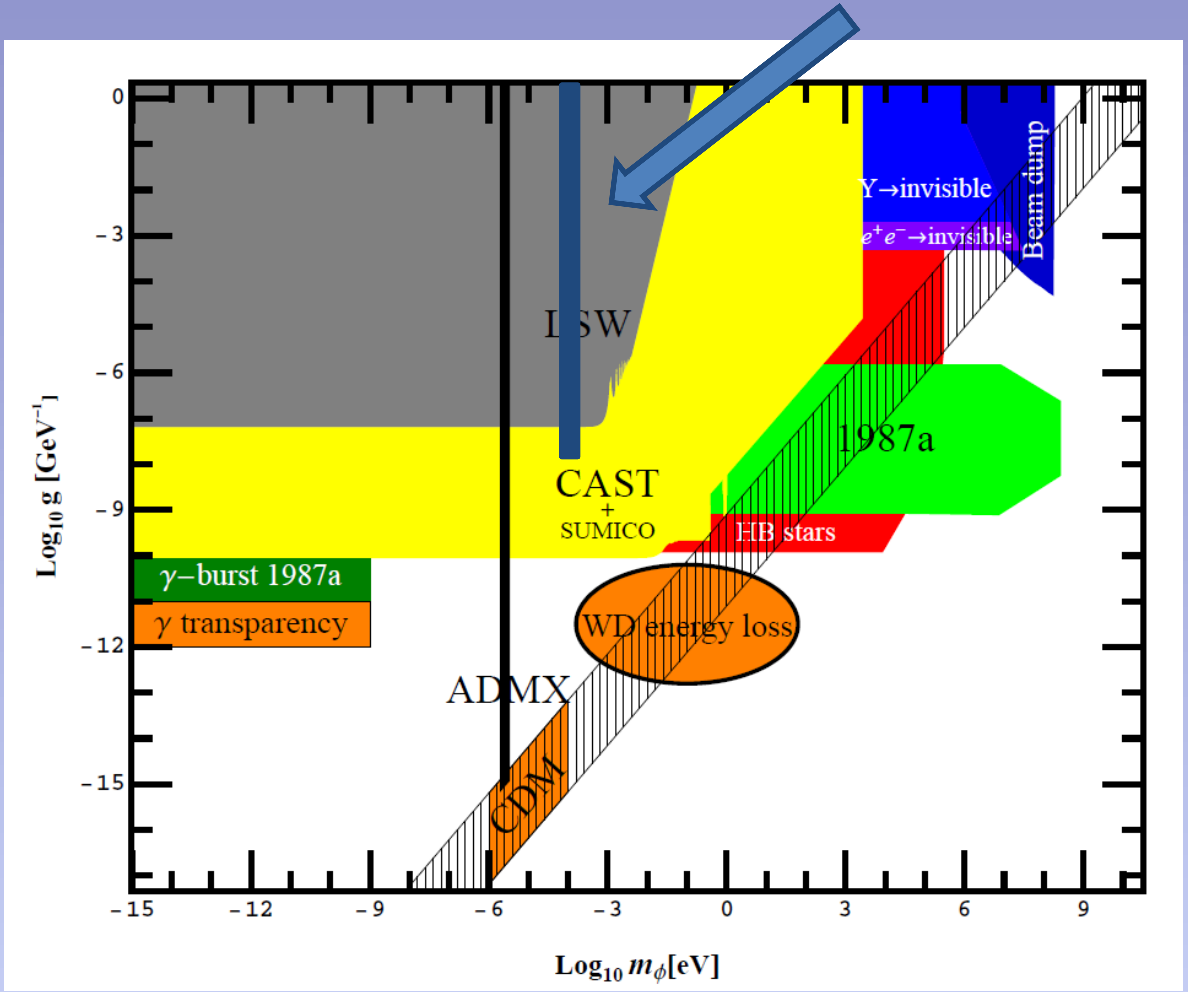


$$P_{S\gamma} = g_{S\gamma\gamma}^2 V B_{ext}^2 \rho_a C_{lmn} Q$$

$$C_{lmn} \equiv \frac{\left|\int_V d^3x \mathbf{B}\cdot\hat{\mathbf{B}}_{\rm ext}\right|^2}{V\int_V d^3x \frac{1}{\mu}\left|\mathbf{B}\right|^2}$$

submitted for publication.

Status of axions and ALPs



J. Jaeckel and A. Ringwald, Ann. Rev. of Nuc. and Particle Sci., 60, 405, 2010.

Scalar chameleons

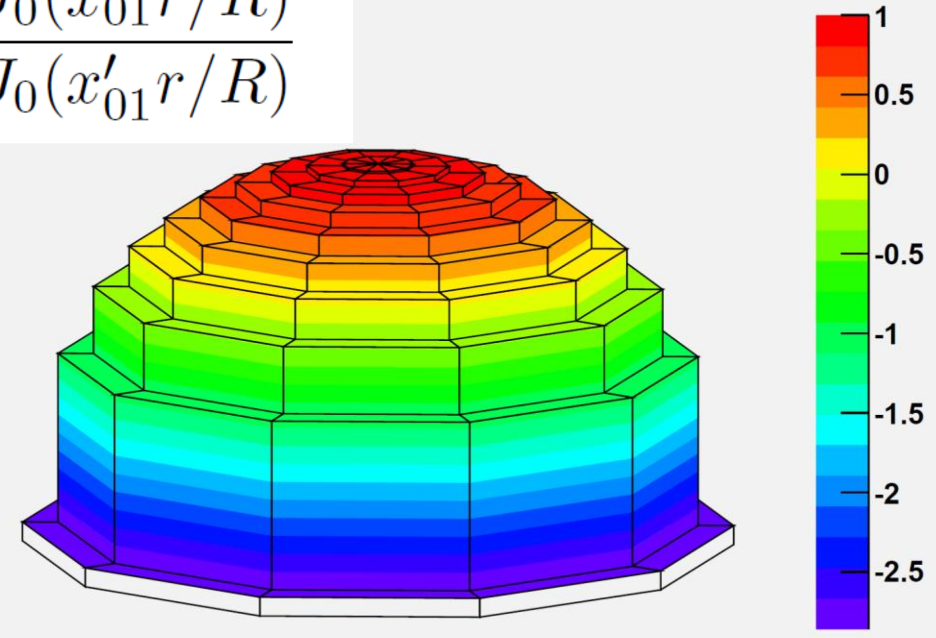
- Dark energy candidate.
- m_{eff} depends on local energy densities $\rho_m(\mathbf{x})$ and $\rho_\gamma(\mathbf{x})$ with coupling strengths β and β_γ. (*)
- After excitation chameleons could be trapped inside resonant cavity according to $\rho_m(\mathbf{x})$.
- Significant overlap between TE_{011} and 011 chameleon cavity modes.

(*) P. Brax, C. van de Bruck, A.-C. Davis, J. Khoury, and A. Weltman, Phys. Rev. D 70, 123518 (2004).

Overlap between TE_{mnp} mode and ϕ_{mnp} mode

- Apply TE_{mnp} and ϕ_{mnp} mode solutions to modified wave equations. (*)
- Overlap is *f*.
- Average of *f* over cavity volume is ~0.6 .

$$f \equiv \frac{J_0(x_{01}r/R)}{J_0(x'_{01}r/R)}$$



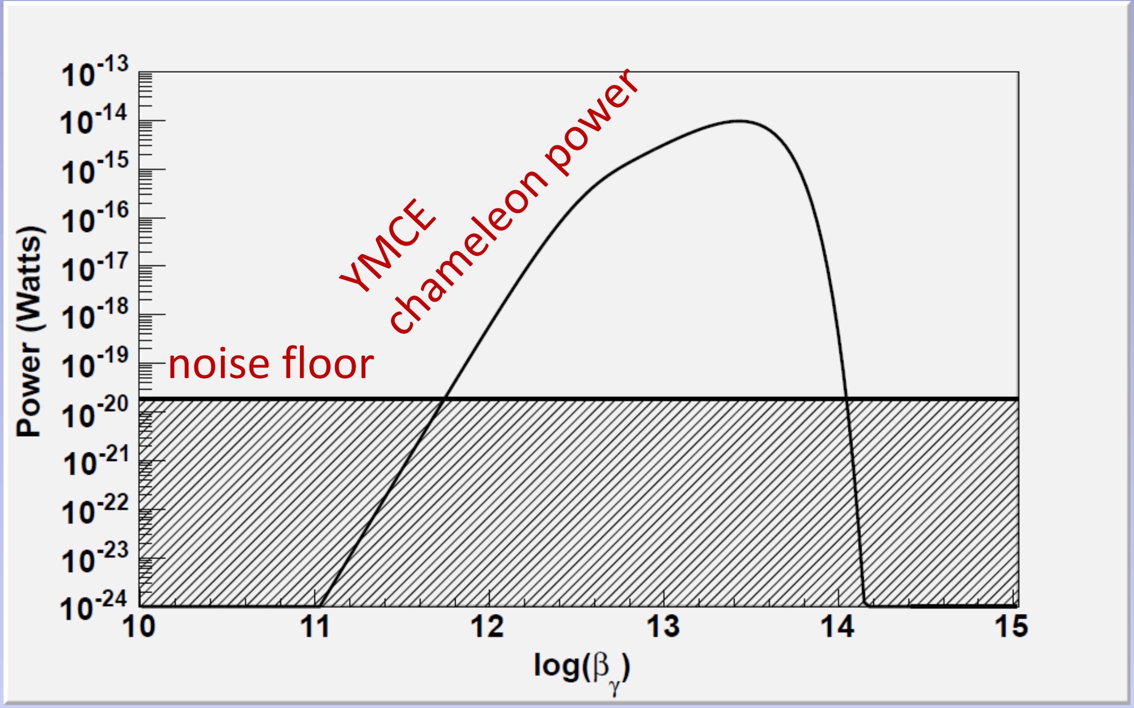
(*) G. Rybka, ADMX internal note: Scalar chameleon search, 2009.

Chameleon power in YMCE apparatus

$$P_{\text{out}} = P_{\text{in}} \frac{\pi\Gamma}{2b}(1 - e^{-\Gamma/2t_0})^2 e^{-\Gamma t}$$ (*)

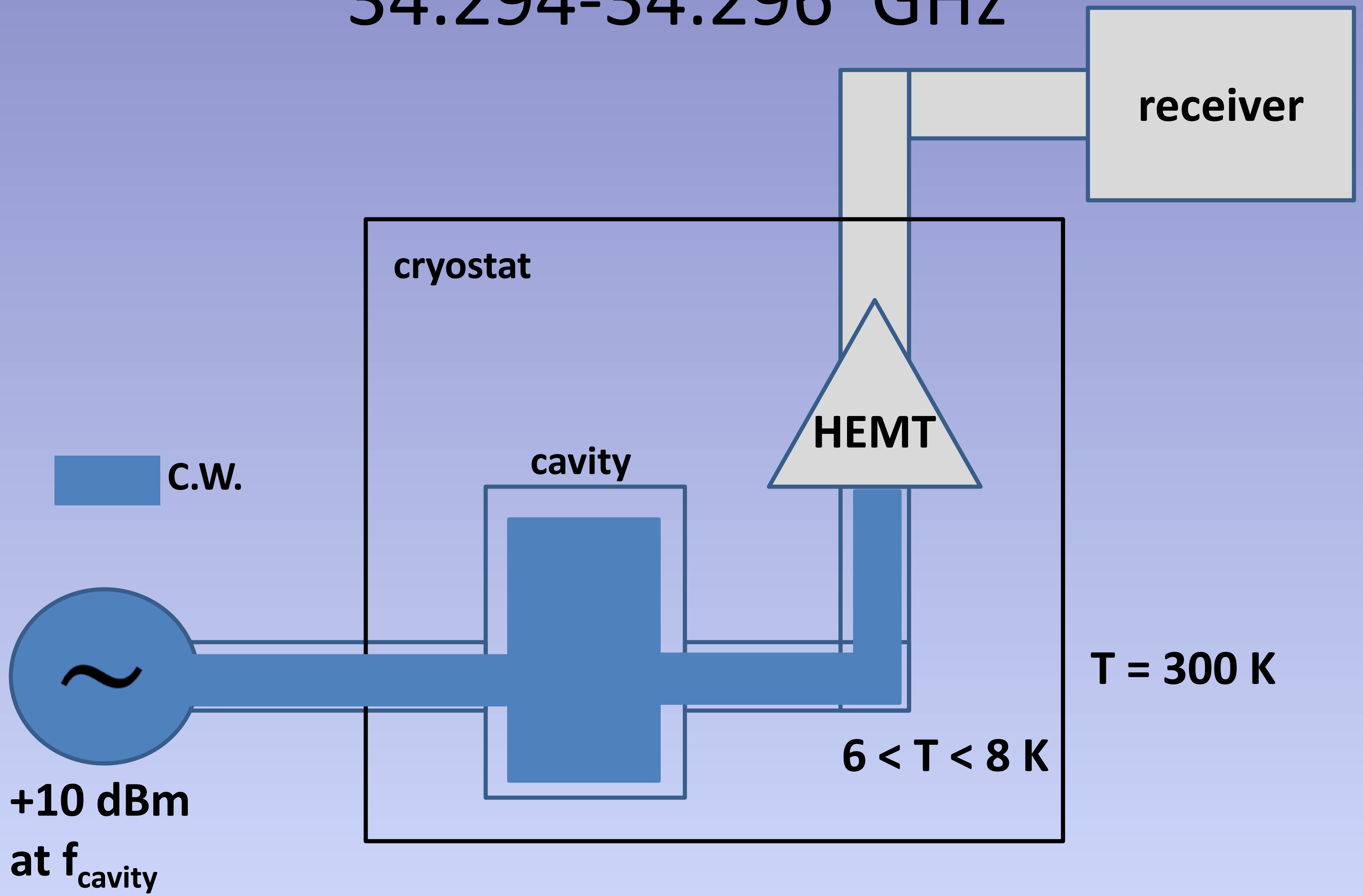
$$\Gamma = \frac{\beta_\gamma^2 f^2 B^2 Q k_{\text{tr}}^2}{M_{\text{pl}}^2 \omega^3}$$ (*)

<< $\Delta\nu_{RF}$ in experiment.

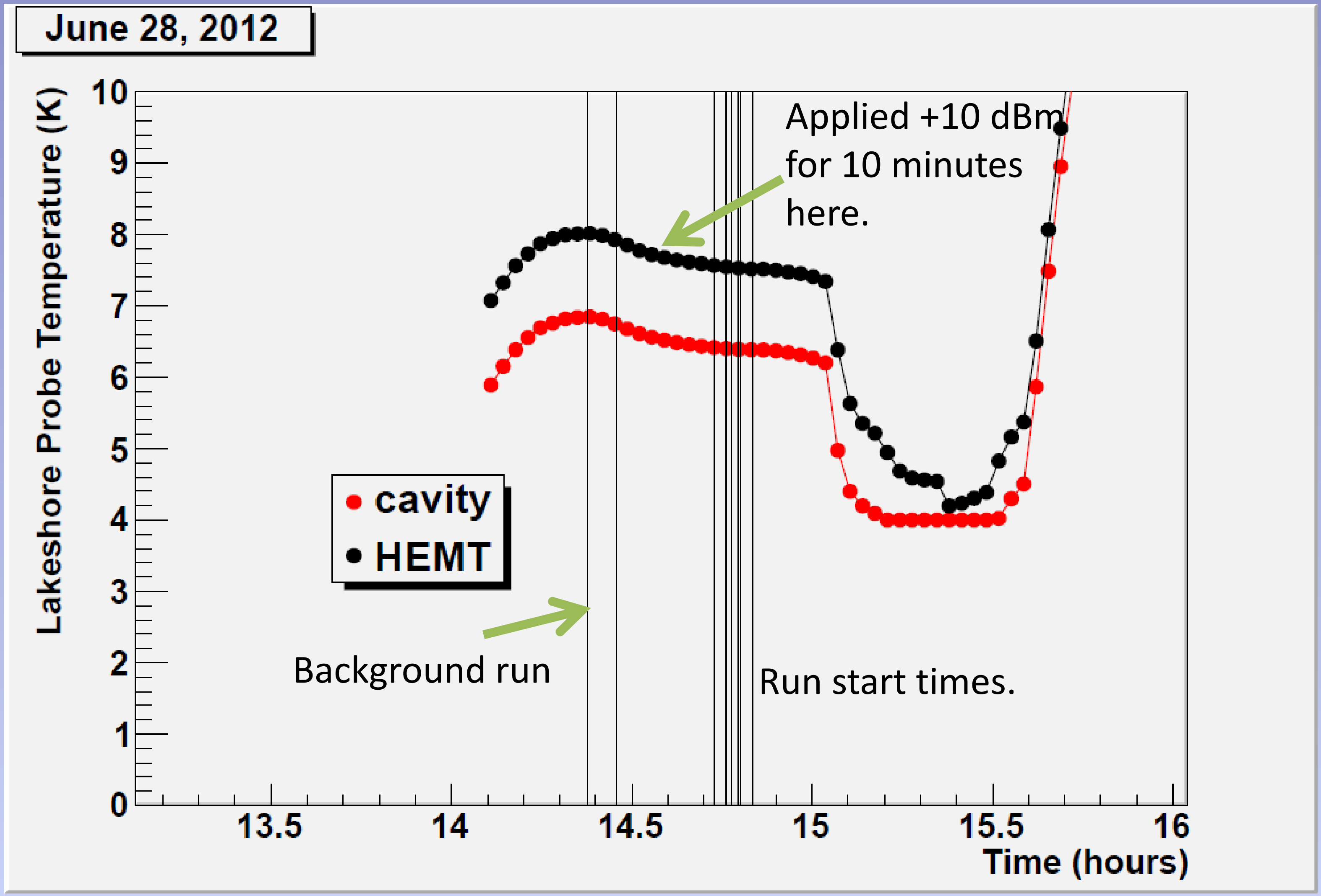


(*) G. Rybka et al., PRL **105**, 051801 (2010)
P. Sikivie Phys. Rev. D **32**, 2988 (1985)

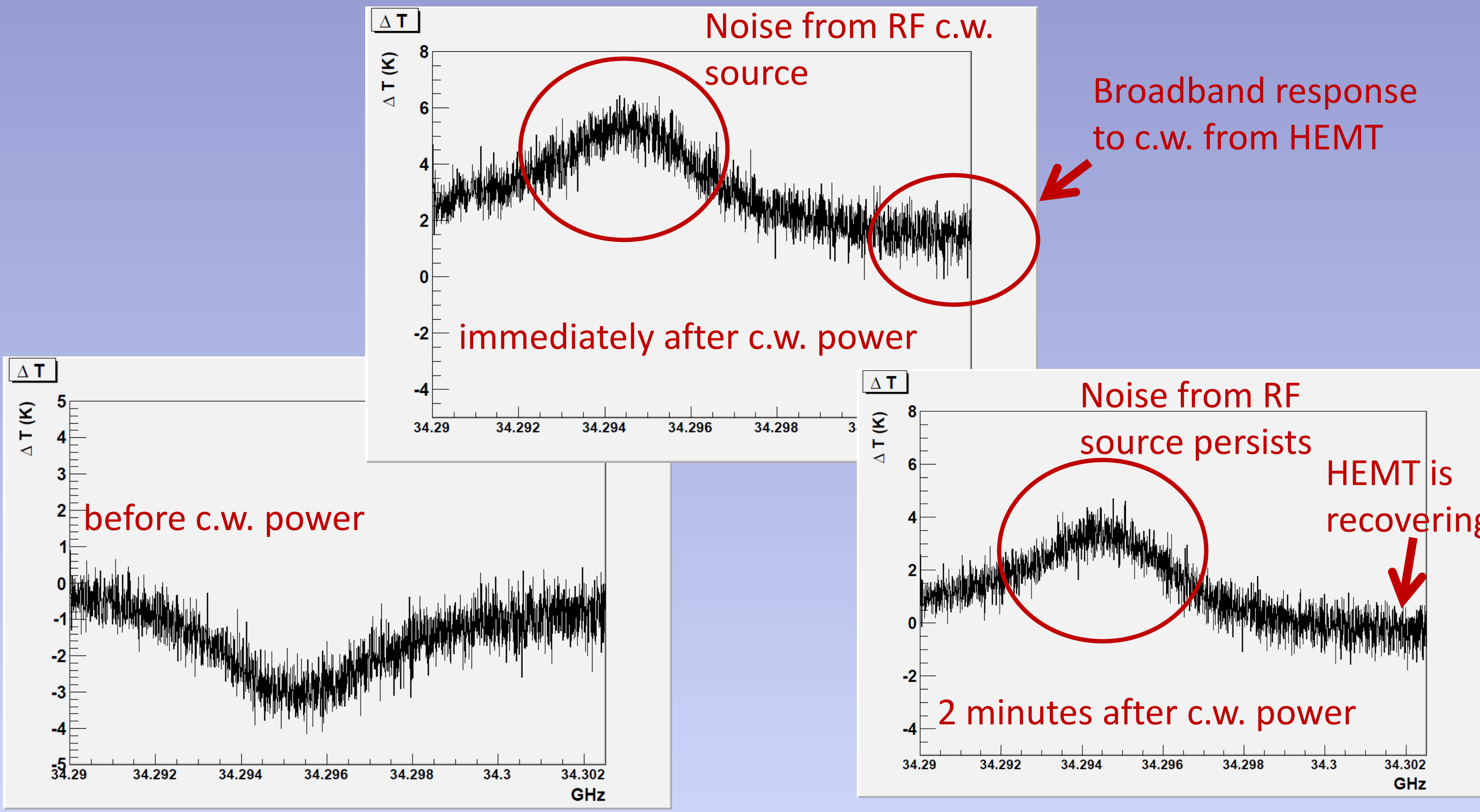
+10 dBm for 10 min. at 34.294-34.296 GHz



Temperatures inside cryostat



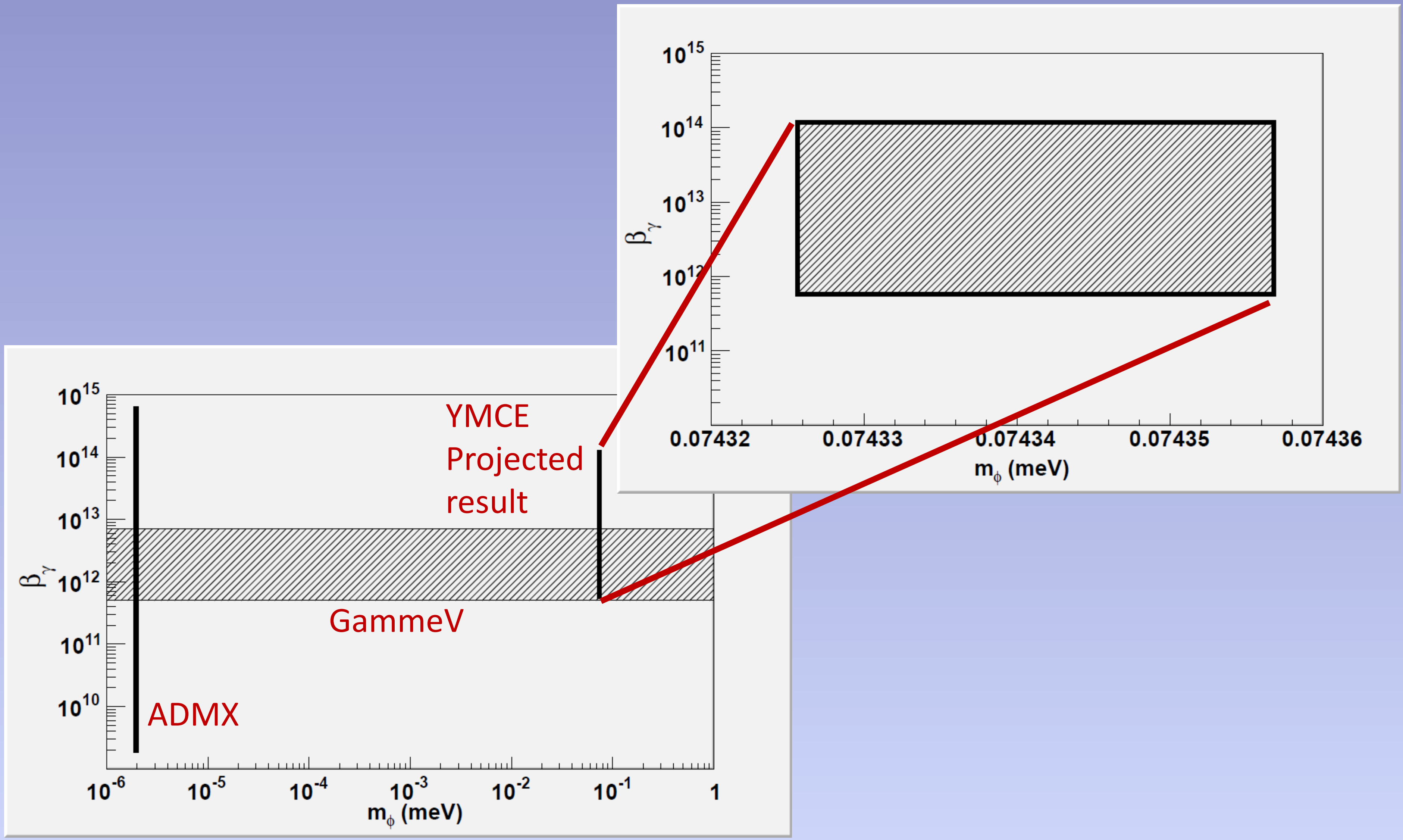
System shake-out for chameleon search



Status of chameleon search

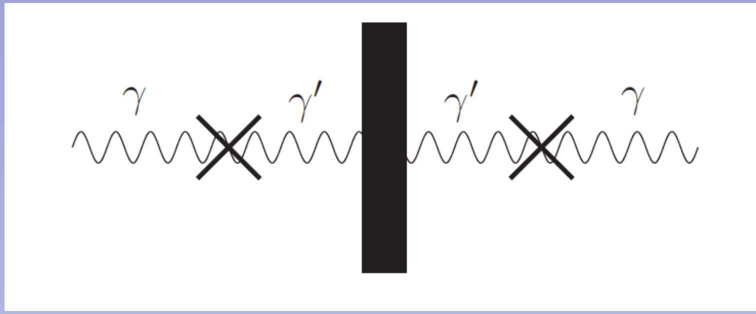
- HEMT behavior can be explained by traps in transistor semiconductor. Charge carriers are knocked out of traps by strong c.w. power. Time constant can be minutes.
- This effect should be reduced with lower c.w.
- RF leak can be eliminated with improved switching.

Chameleon searches



Hidden photons

For LSW-type experiment, 2 cavities are needed.



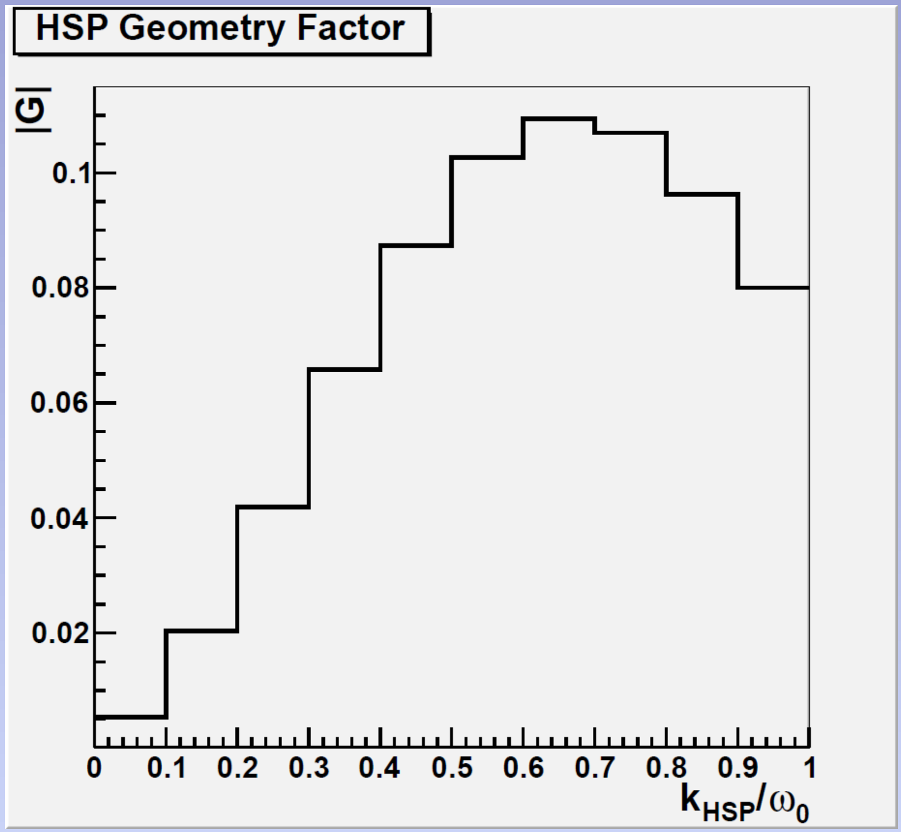
$\mathcal{L} = \chi m_{\gamma'}^{2} A_{\mu} X^{\mu}$

$$P_{trans} = \chi^4 Q Q' \frac{m_{\gamma'}^8}{\omega_0^8} |G_{HSP}|^2.$$

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

Geometry Factor* – hidden photons

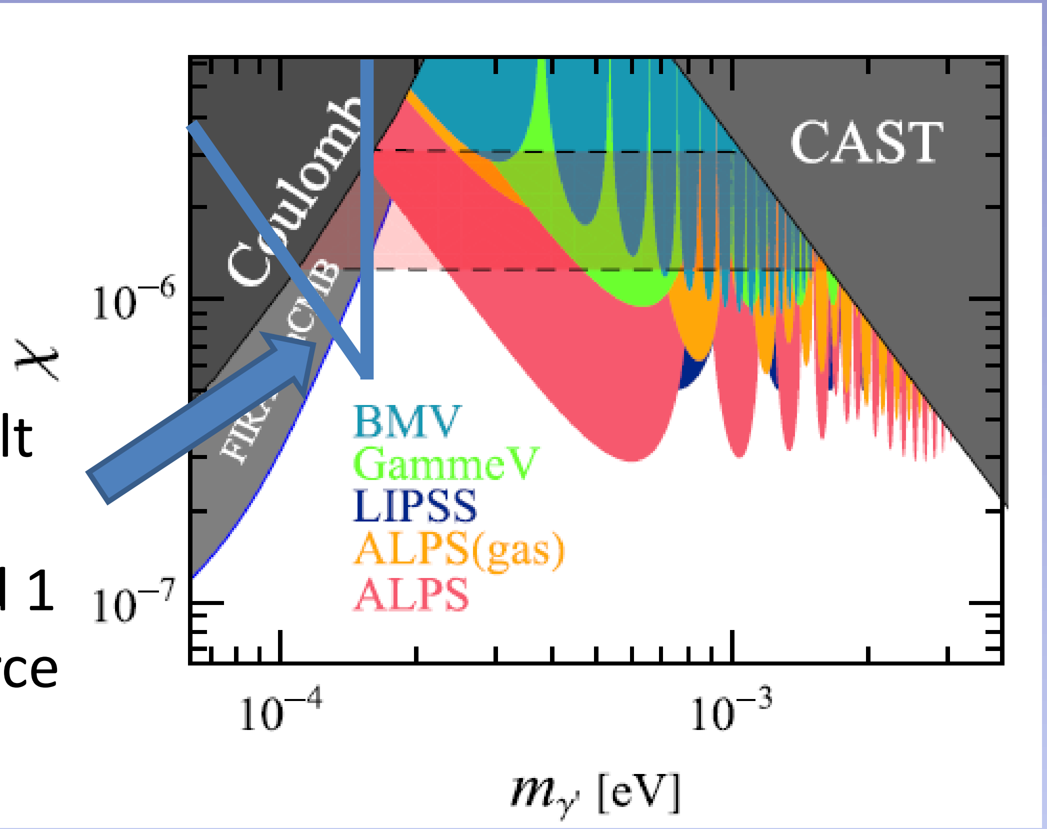
$$G_{HSP} \equiv \omega_0^2 \int_{V'} \int_V d^3\mathbf{x} d^3\mathbf{y} \frac{exp(ik|\mathbf{x}-\mathbf{y}|)A(\mathbf{y})A'(\mathbf{x})}{4\pi|\mathbf{x}-\mathbf{y}|},$$



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.

Sensitivity to hidden photons



(*)

Expected result with 10 mK resolution and 1 Watt c.w. source

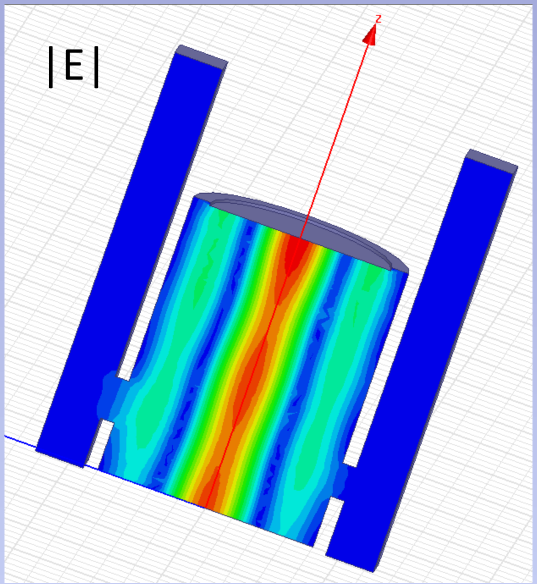
* K. Ehret et al, Physics Letters B, Volume 689, Issue 4-5, p. 149-155.

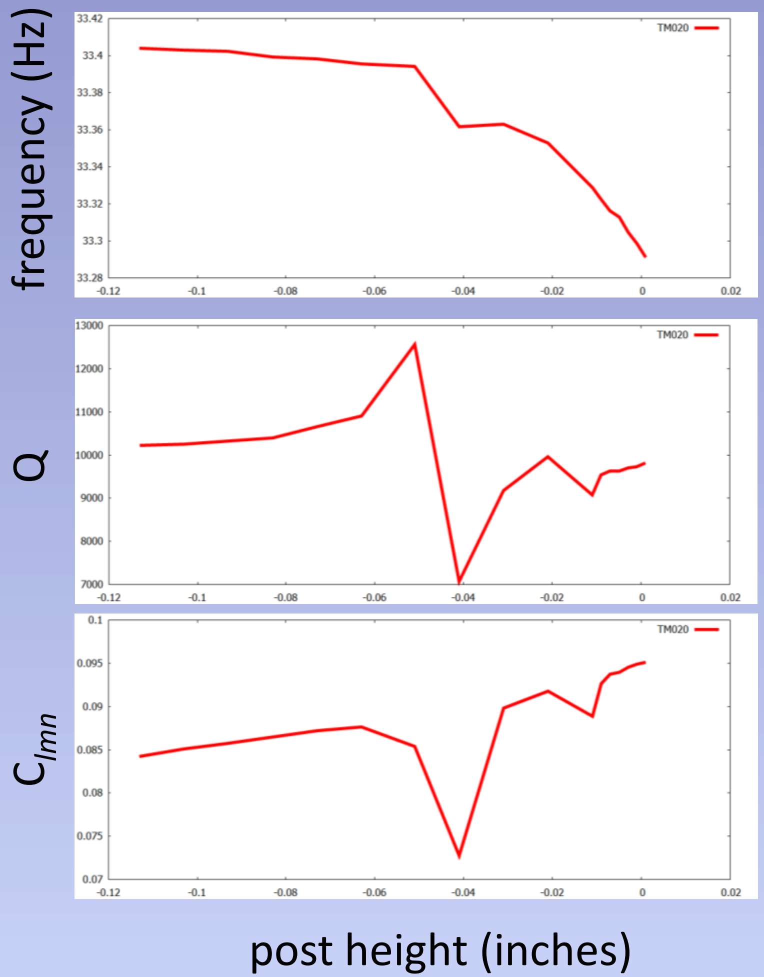
Working prototype of TM_{020} cavity

- Sensitive to pseudoscalar $a\gamma\gamma$.
- Bench tests underway.
- Limited tunability with dielectric post and spring-loaded contacts.
- Cavity performance is modeled in HFSS software.

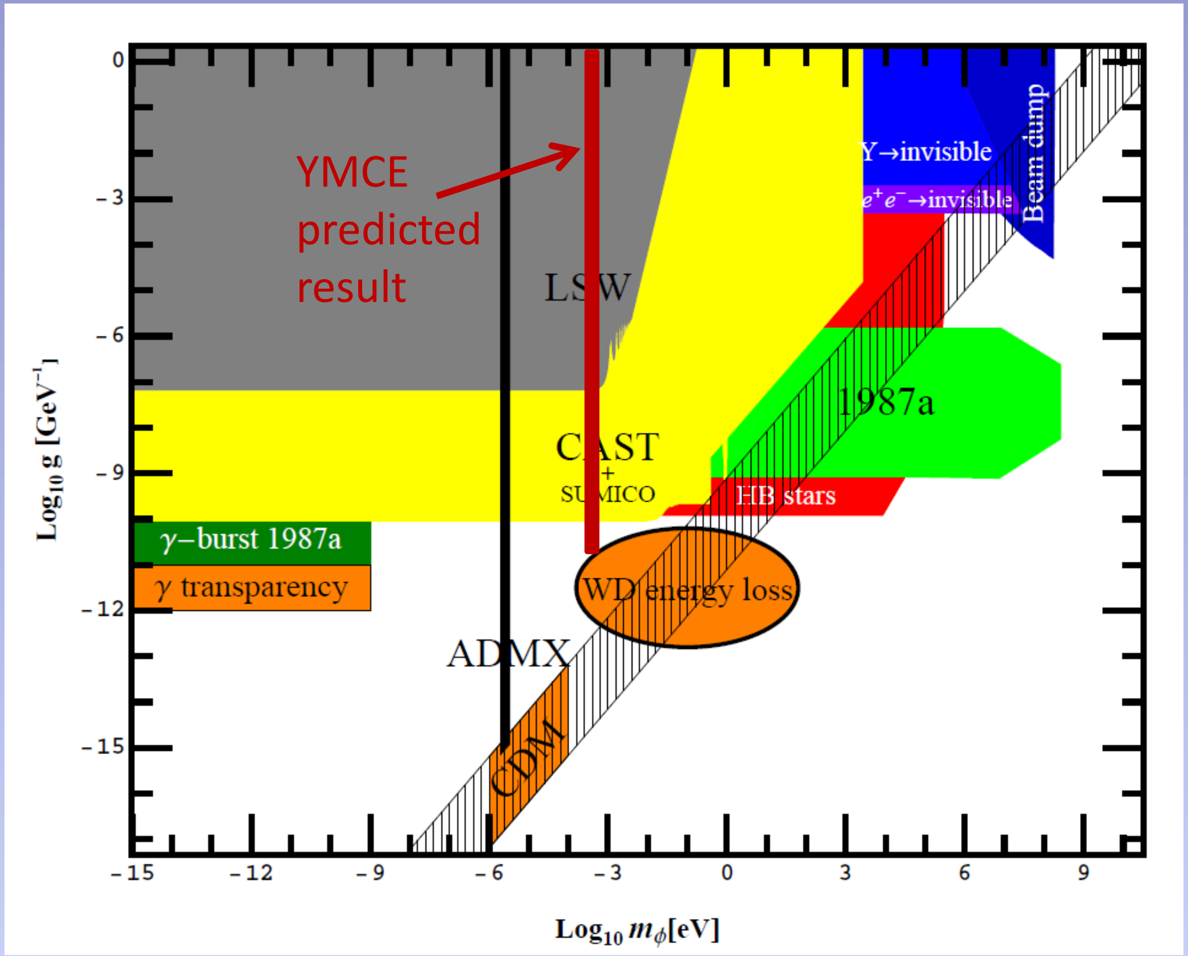
HFSS simulations for TM_{020} cavity

- Tuning range of 100 MHz.
- C_{lmn} is 0.1 .





1 cm TM_{020} cavity with HEMT, $\Delta\nu_{RF}$ = 5 kHz and σ_T=10 mK



J. Jaeckel and A. Ringwald, Ann. Rev. of Nuc. and Particle Sci., 60, 405, 2010.

Summary

- Scalar ALP measurement is the first narrow band exclusion of $S^0\gamma\gamma$ at 0.1 meV .
- Chameleon search at 0.1 meV is underway.
- Drive cavity for HSP search is now complete and ready to be installed into the experiment.
- Bench tests with early TM cavity have begun.

Auxiliary slides

TE modes in cylindrical cavity with chameleons

$$\nabla^2 B_z - \frac{\partial^2}{\partial t^2} B_z = \frac{\beta_\gamma}{M_P} \mathbf{B} \left(\frac{\partial^2}{\partial z^2}\phi - \frac{\partial^2}{\partial t^2}\phi \right)$$

$$\nabla^2 \phi - \frac{\partial^2}{\partial t^2}\phi - m_\phi^2 \phi = \frac{\beta_\gamma}{M_P} B_z \mathbf{B}$$

Wave equations in vacuum with scalar chameleons ϕ, in cylindrical cavity with longitudinal **B** field. (*)

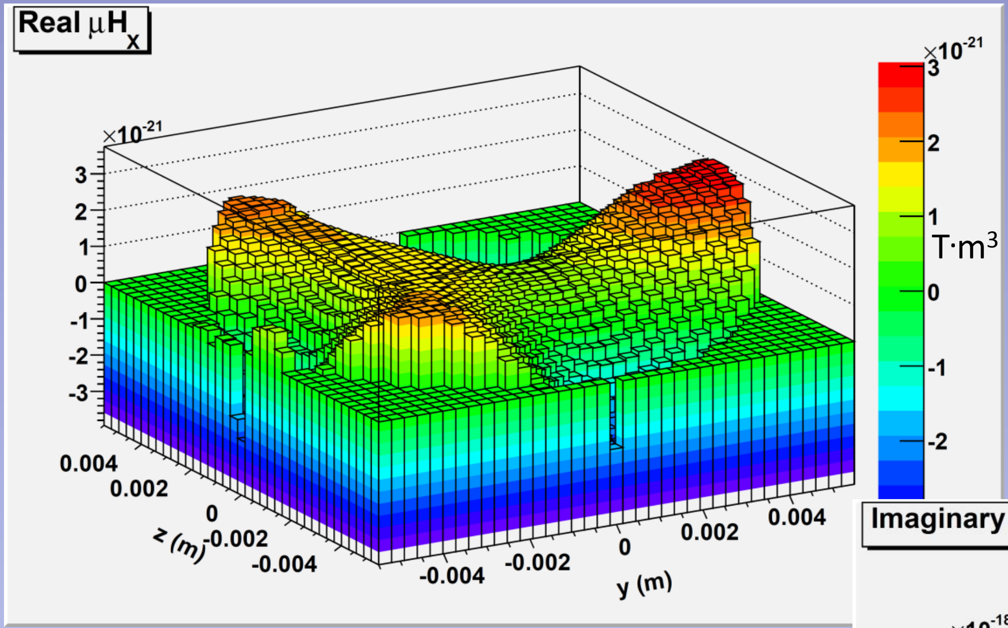
Wave function shapes of TE and ϕ *mnp* modes in cavity of radius R and height d. (*)

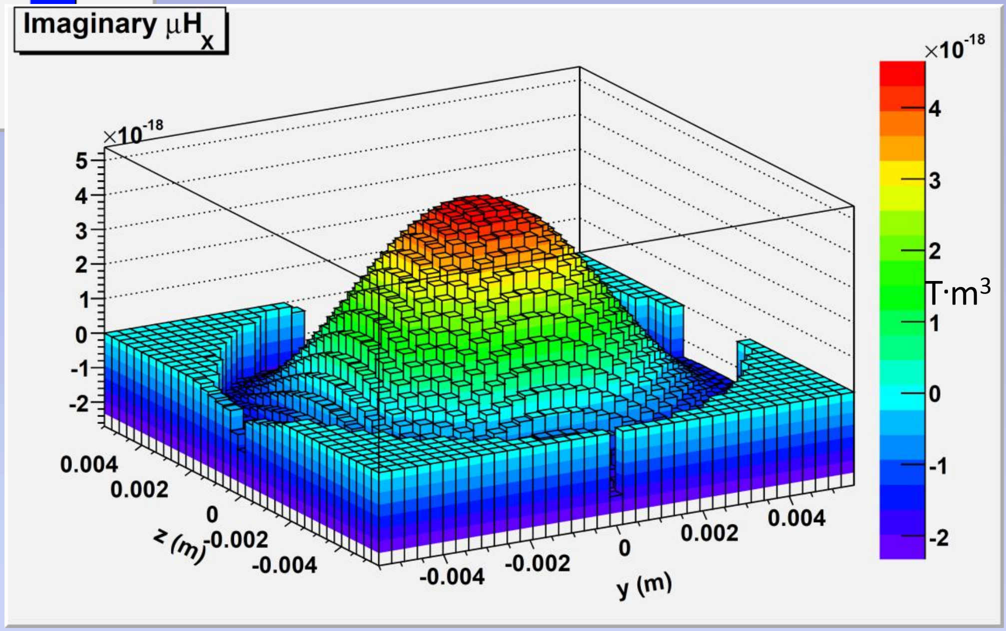
$$B_z = B_0 J_m \left(\frac{x'_{mn} r}{R} \right) sin \left(\frac{p\pi z}{d} \right) e^{\pm i m \phi}$$

$$\phi = \phi_0 J_m \left(\frac{x_{mn} r}{R} \right) sin \left(\frac{p\pi z}{d} \right) e^{\pm i m \phi}$$

(*) G. Rybka, ADMX internal note: Scalar chameleon search, 2009.
P. Sikivie, Phys. Rev. Lett. 48 (1982), 1156

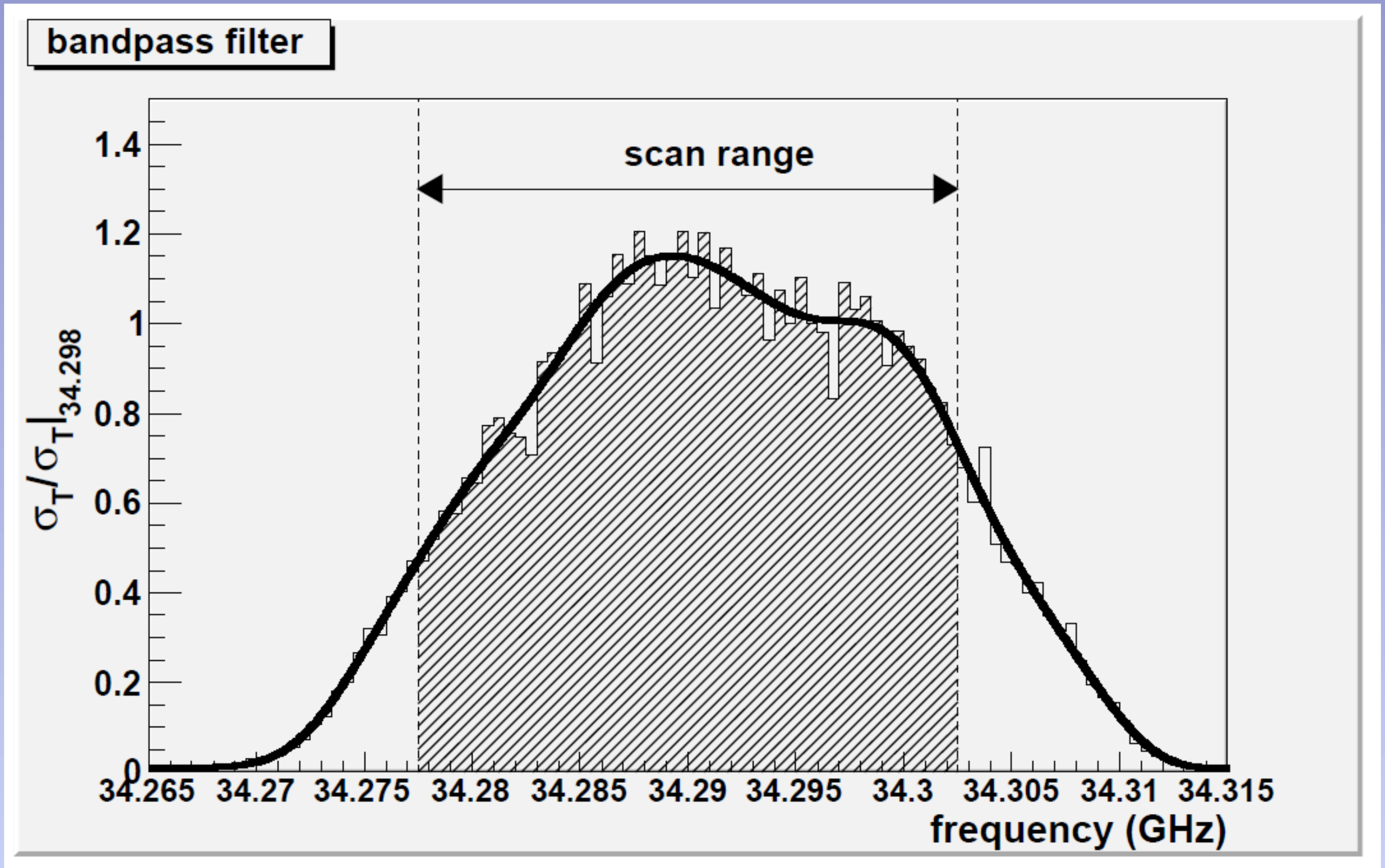
Simulated axial B fields





$\Rightarrow$ $C_{lmn}=O(10^{-6})$

Receiver passband



Ideal signal to noise ratio