Yale Microwave Cavity Experiment

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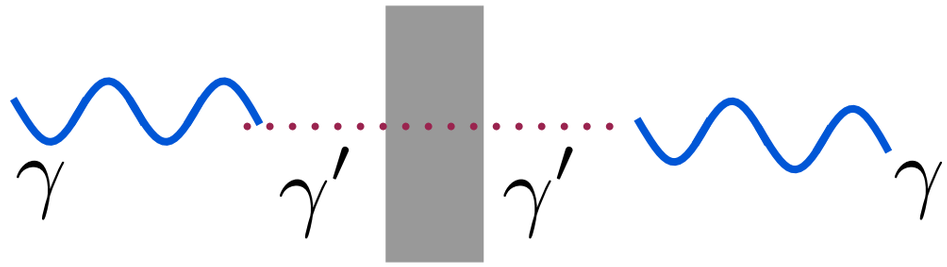
Hidden Photons

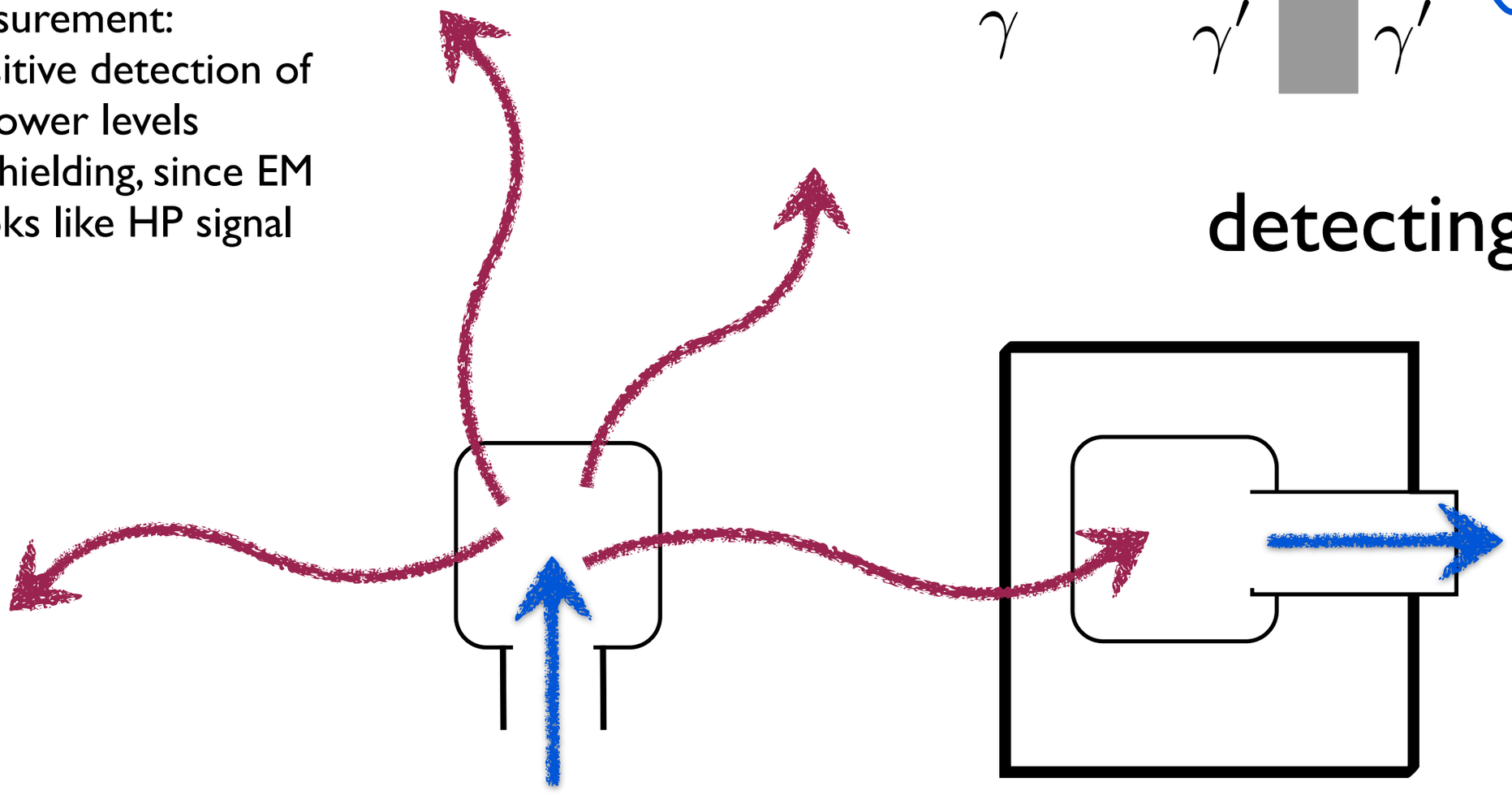
- Many Beyond the Standard Model Theories predict a neutral U(1) gauge boson with mass.
- The Lagrangian for hidden photons is renormalizable and gauge invariant.
- Dominant coupling to SM via hidden photon-photon oscillations.

Light Shining Through Wall

LSW is a power measurement:
>needs sensitive detection of low power levels
>excellent shielding, since EM leakage looks like HP signal



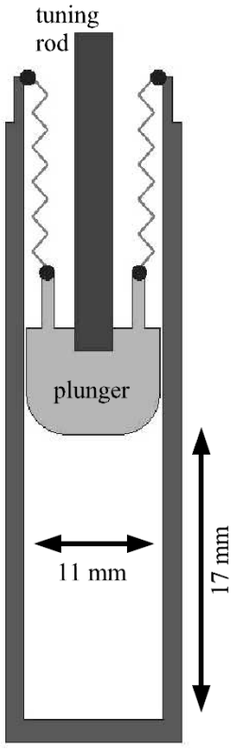
detecting cavity



emitting cavity

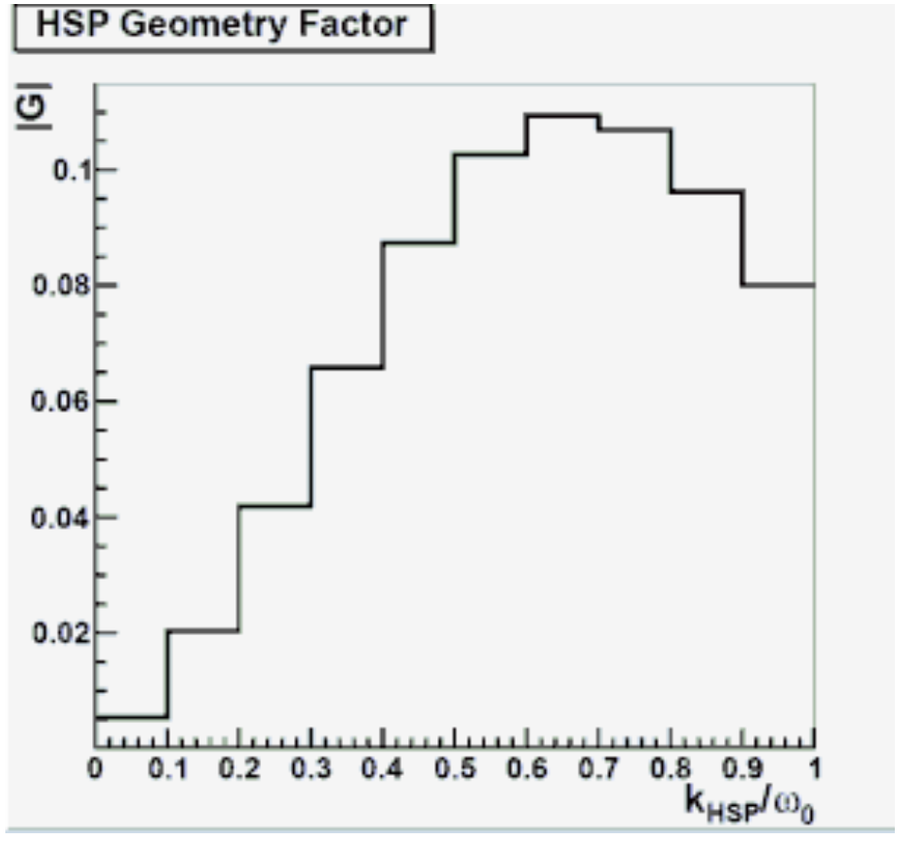
J. Jaeckel and A. Ringwald, Physics Letters B 659, 509 (2008)

Sensitivity



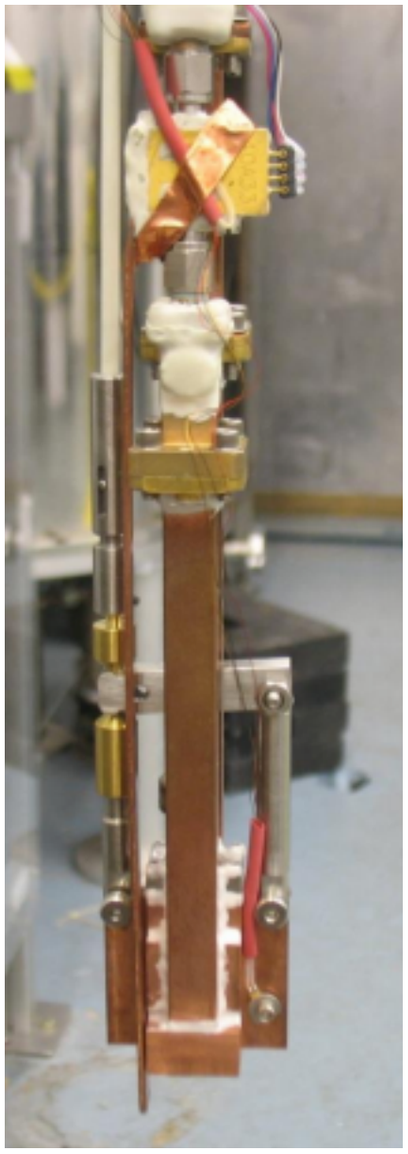
$$P_{\rm sig} = P_{\rm in}\chi^4|G|^2 Q_{\rm em} Q_{\rm det} (m_{\gamma'}/\omega_0)^8$$

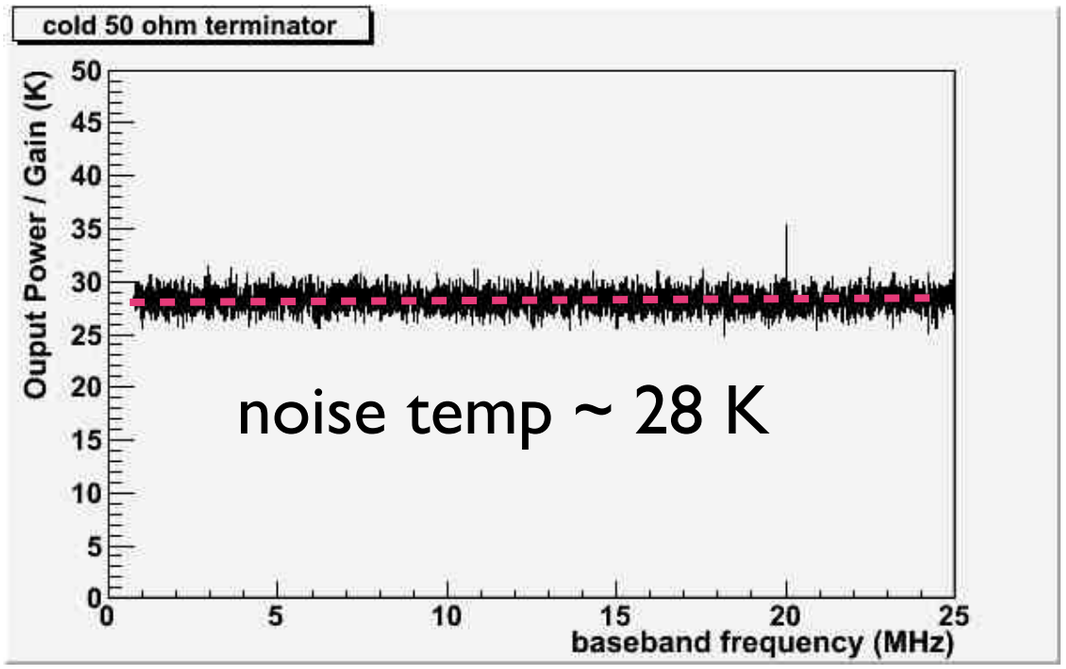
G ~ 0.1
for TE_{011} cavities 2 cm apart.



$$Q_{\rm em} \approx 7000$$
$$Q_{\rm det} \approx 9000$$
$$P_{\rm in} = 158 \text{ mW}$$
$$\omega_0 = 2\pi \times 34.3 \text{ GHz}$$

Noise Temperature



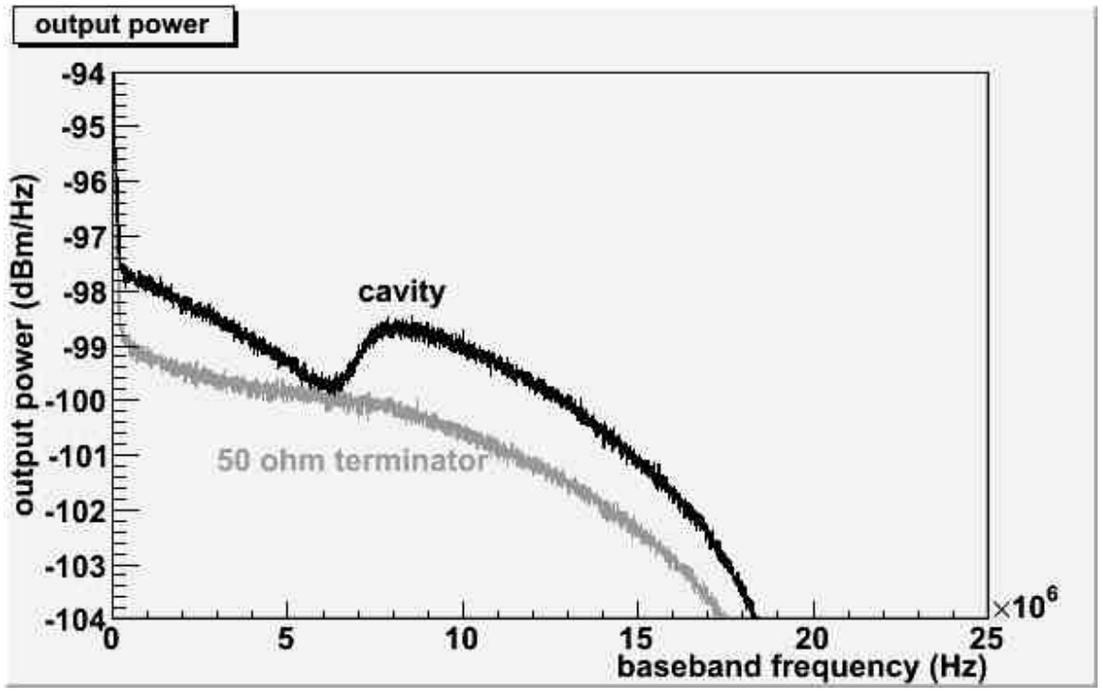


Since expected signal is at one frequency, we improve our SNR by doing a narrowband measurement

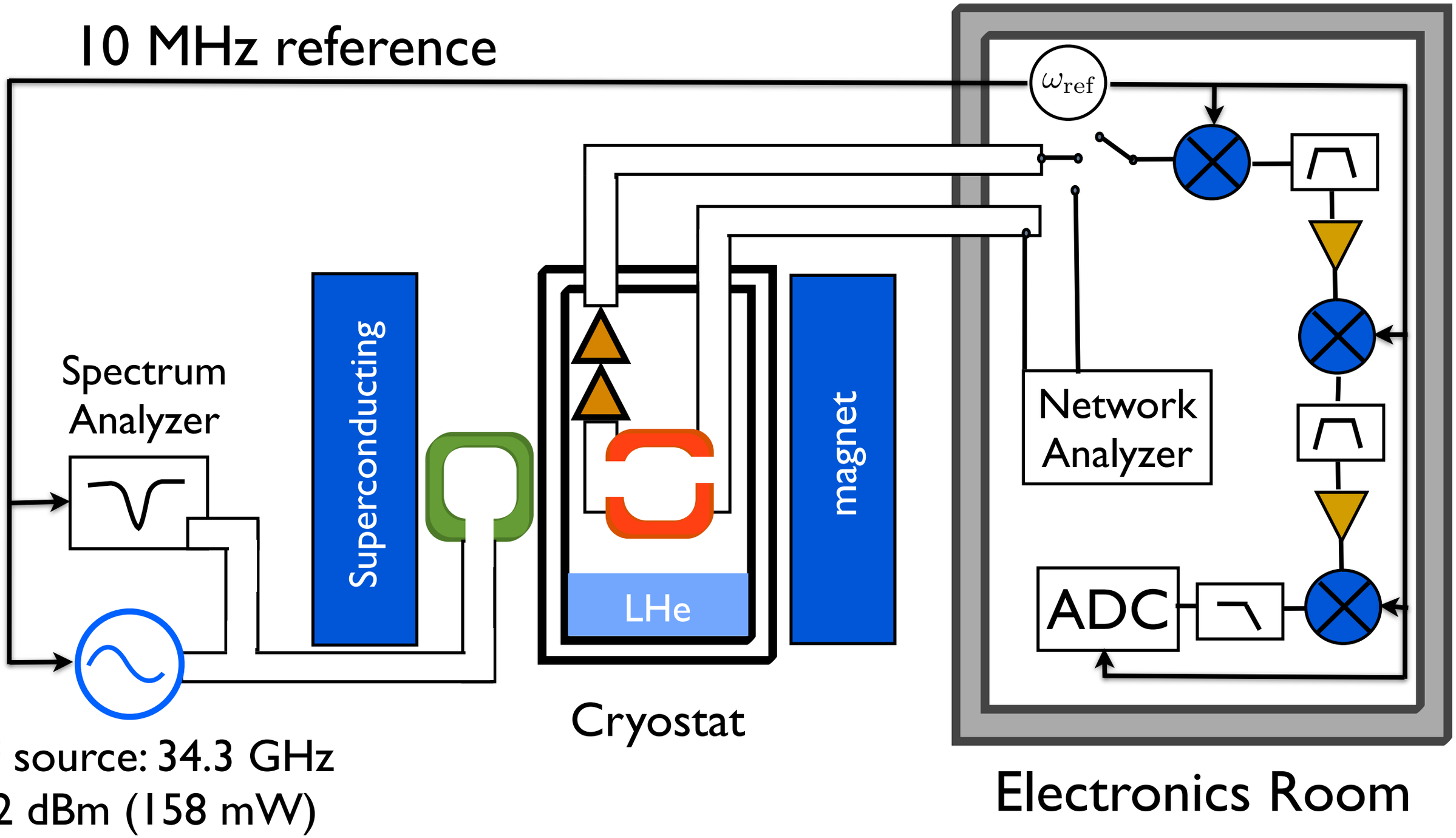
$P_n = k_B T_{\rm sys} B$ average noise power

$T_{\rm sys} = T_{\rm cav} + T_{\rm HEMT} + T_{\rm elec}$

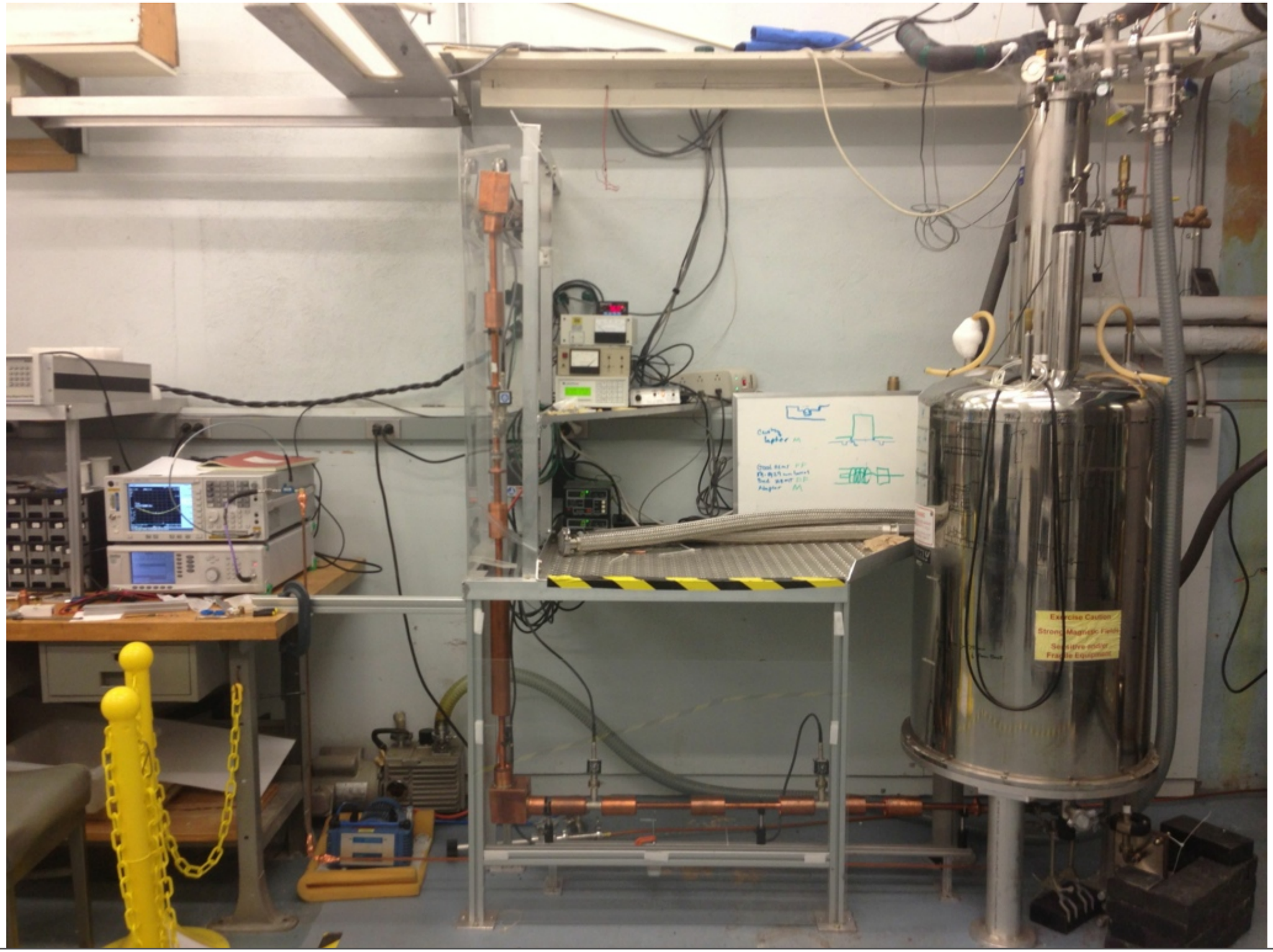
effective noise temperature



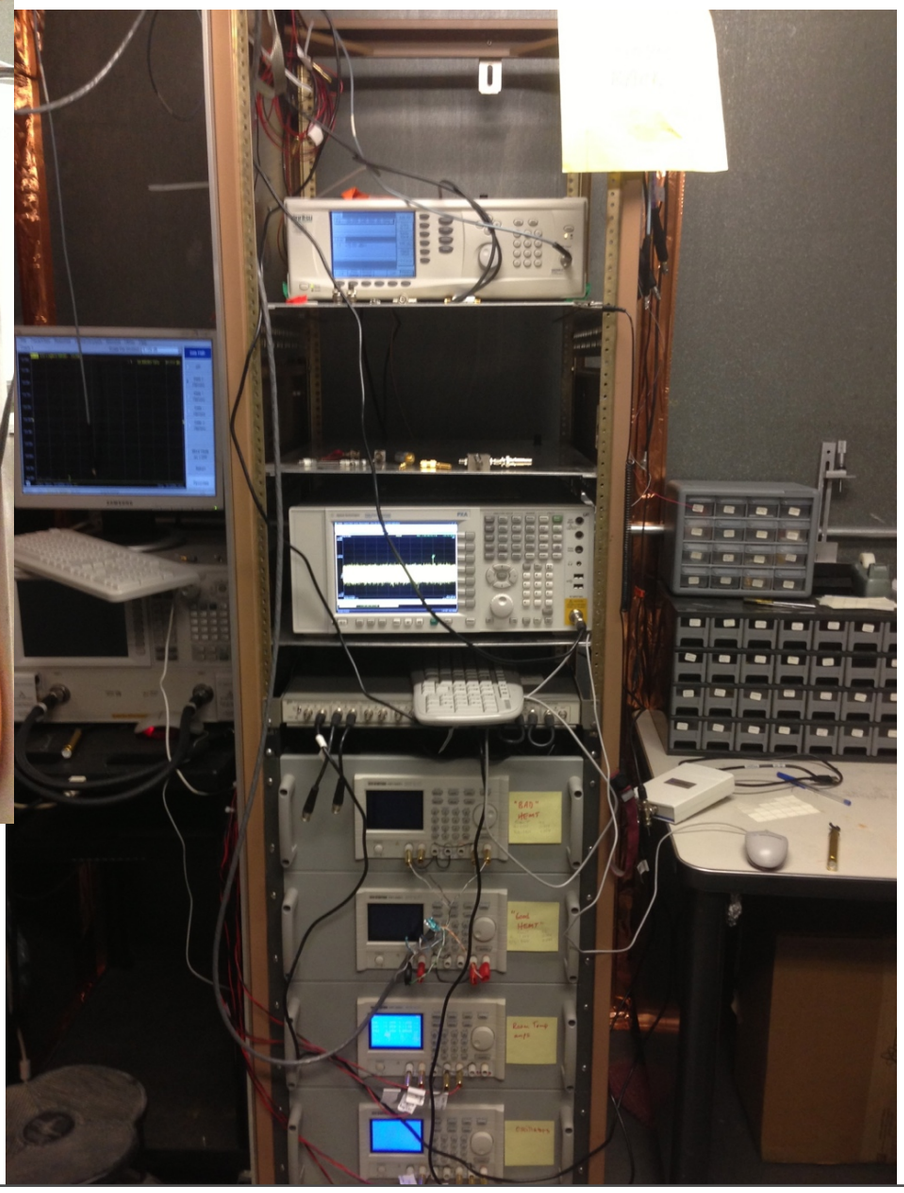
Experimental Setup

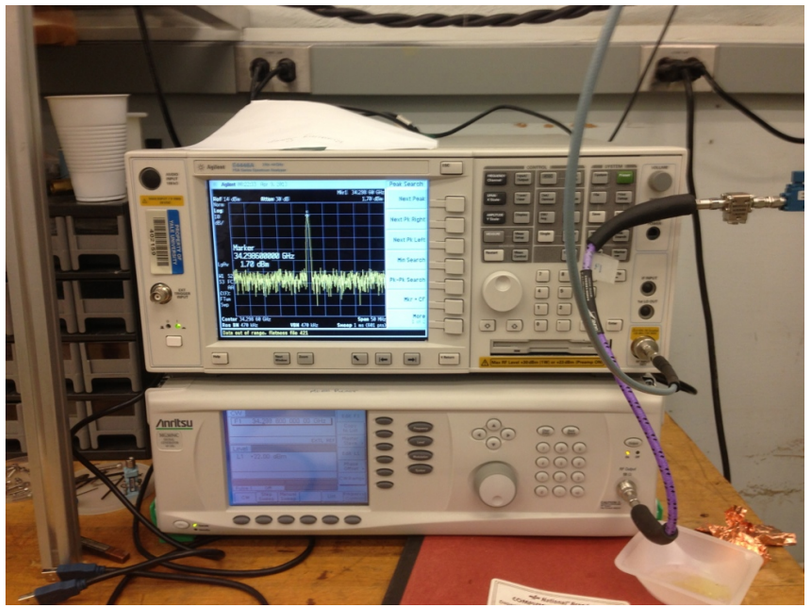


In the Lab


Exercise Caution
Strong Magnetic Fields
Sensitive electronic
Fragile Equipment

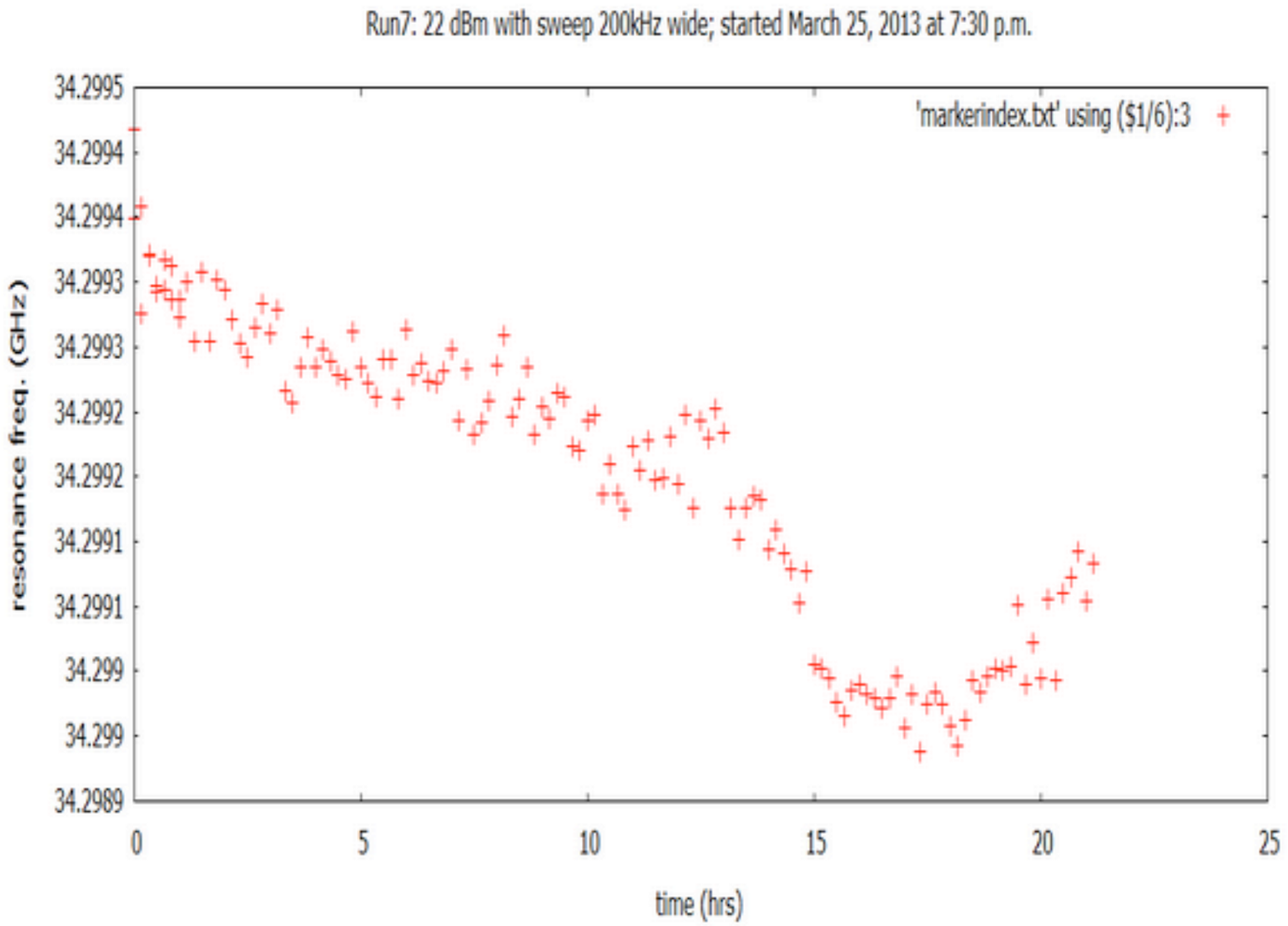
Electronics

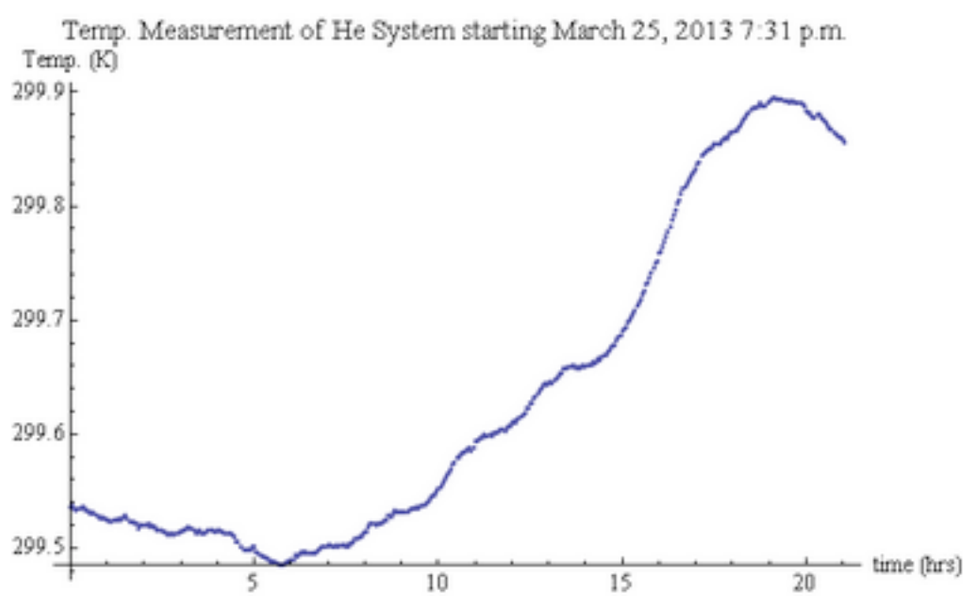




Frequency Drift

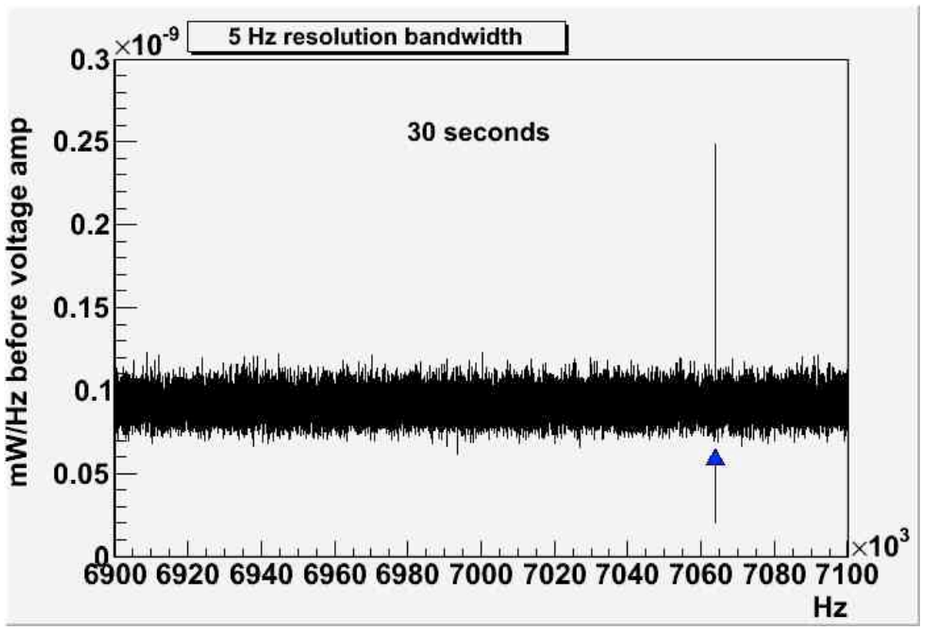
Drive Cavity drifts slightly due to room temperature variations. Time scale seems to be < 600 kHz drift in 15 hrs.



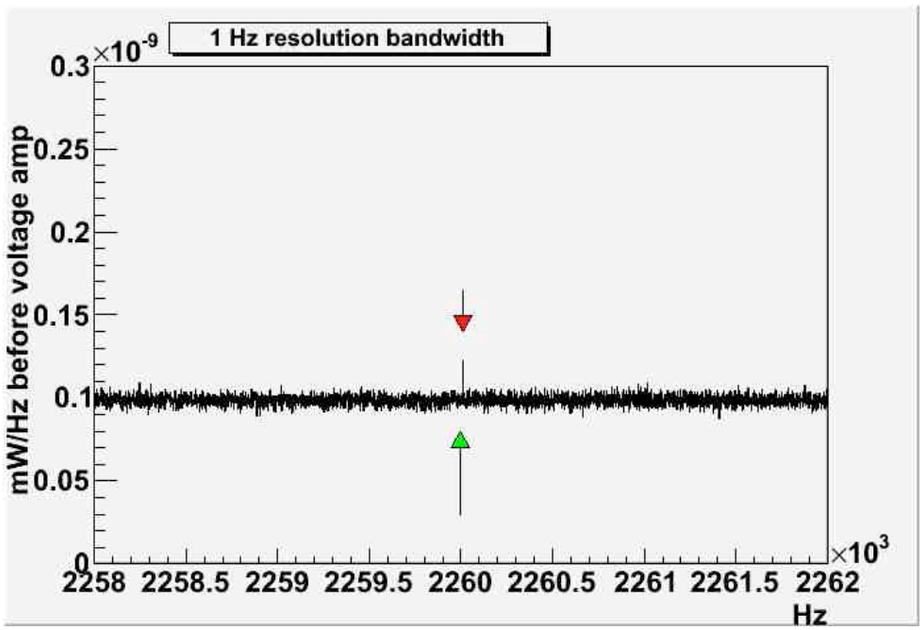


Data Taking

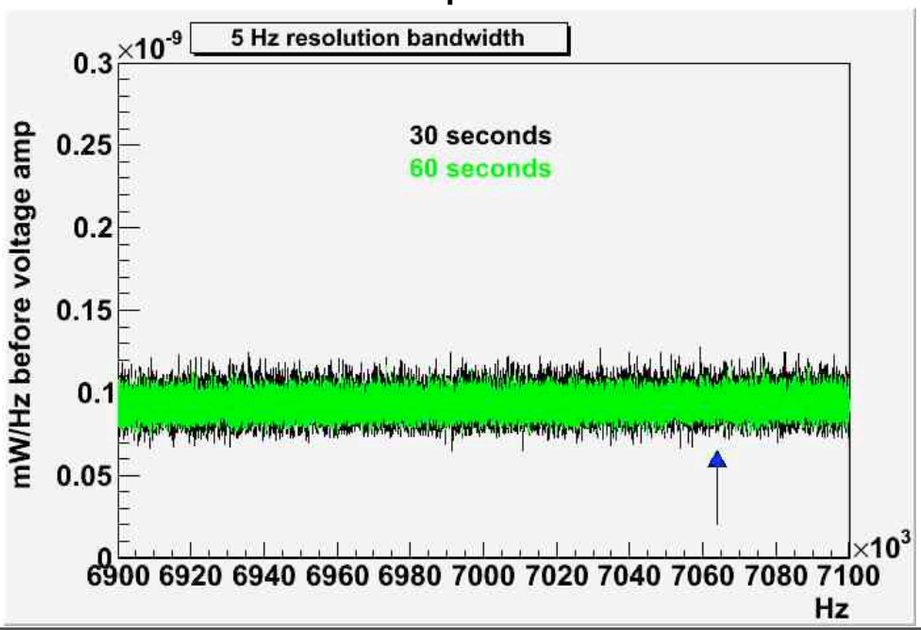
Run 1: shielding room open, expected a leak



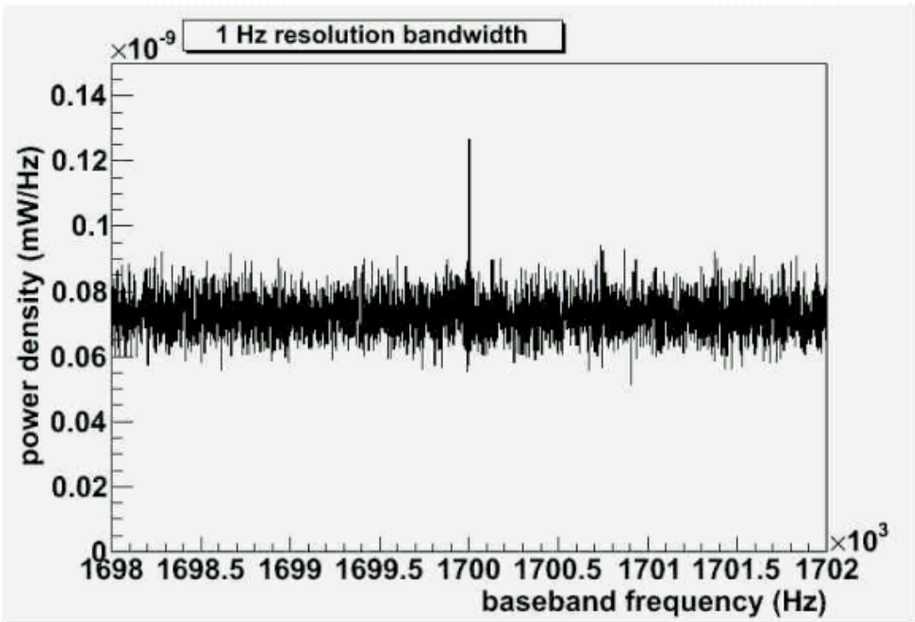
Run 3: same shielding as Run 2 but reduced bandwidth and took 20 mins of data. Realized signal was drifting12 Hz -> locked ADC. Drive cavity was detuned from RF source and signal cavity in this run.



Run 2: shielding room open but all joints covered with Cu tape. Al wool, terminated cable.

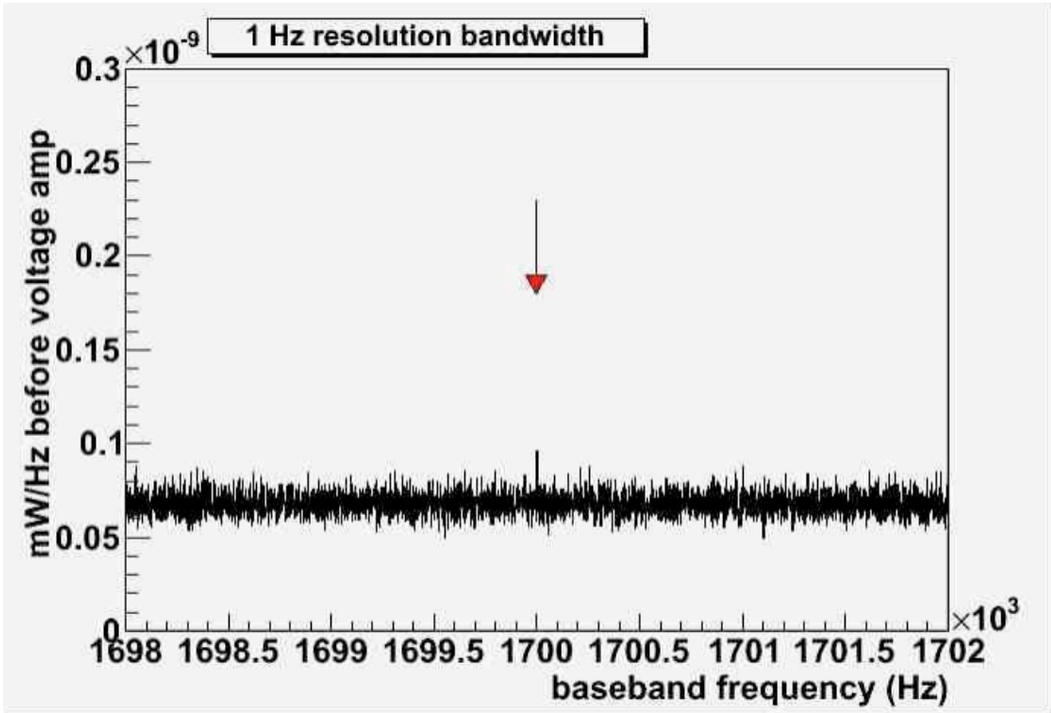


Run 4: shielding room closed. HEMT power supplies shielded. Everything locked to 10 MHz reference. Leak still appears.

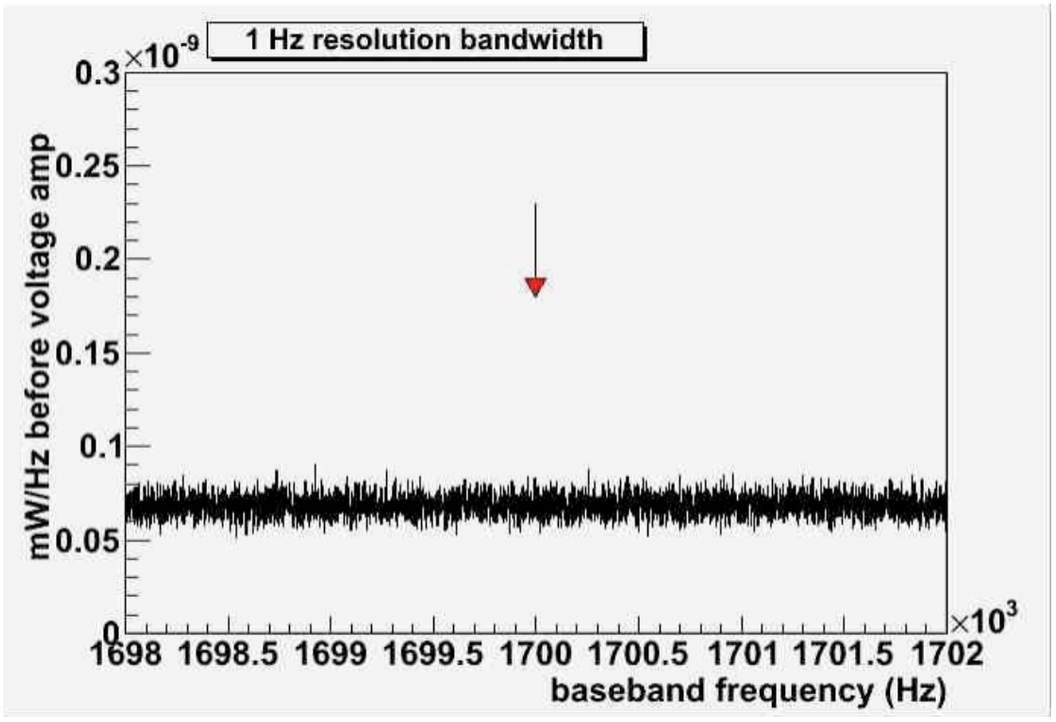


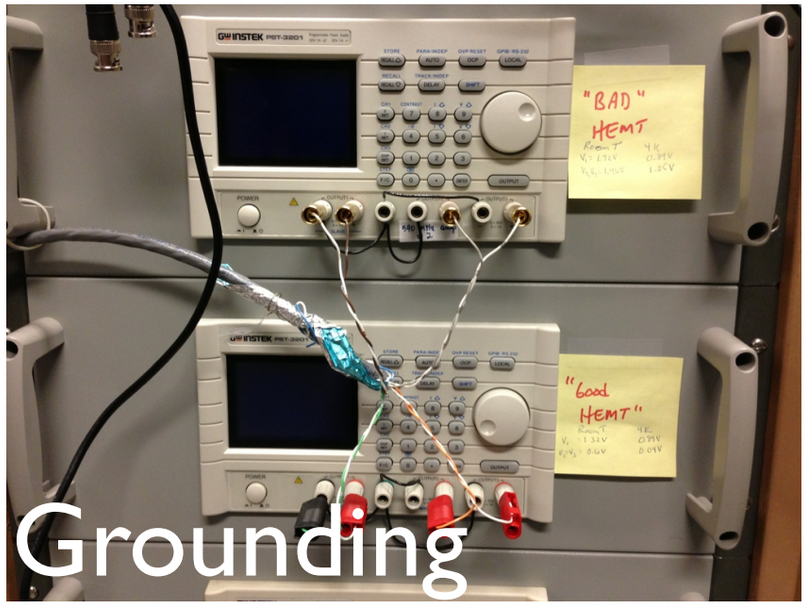
Data

Run 5: Eccosorb foam on 10 MHz feedthrough

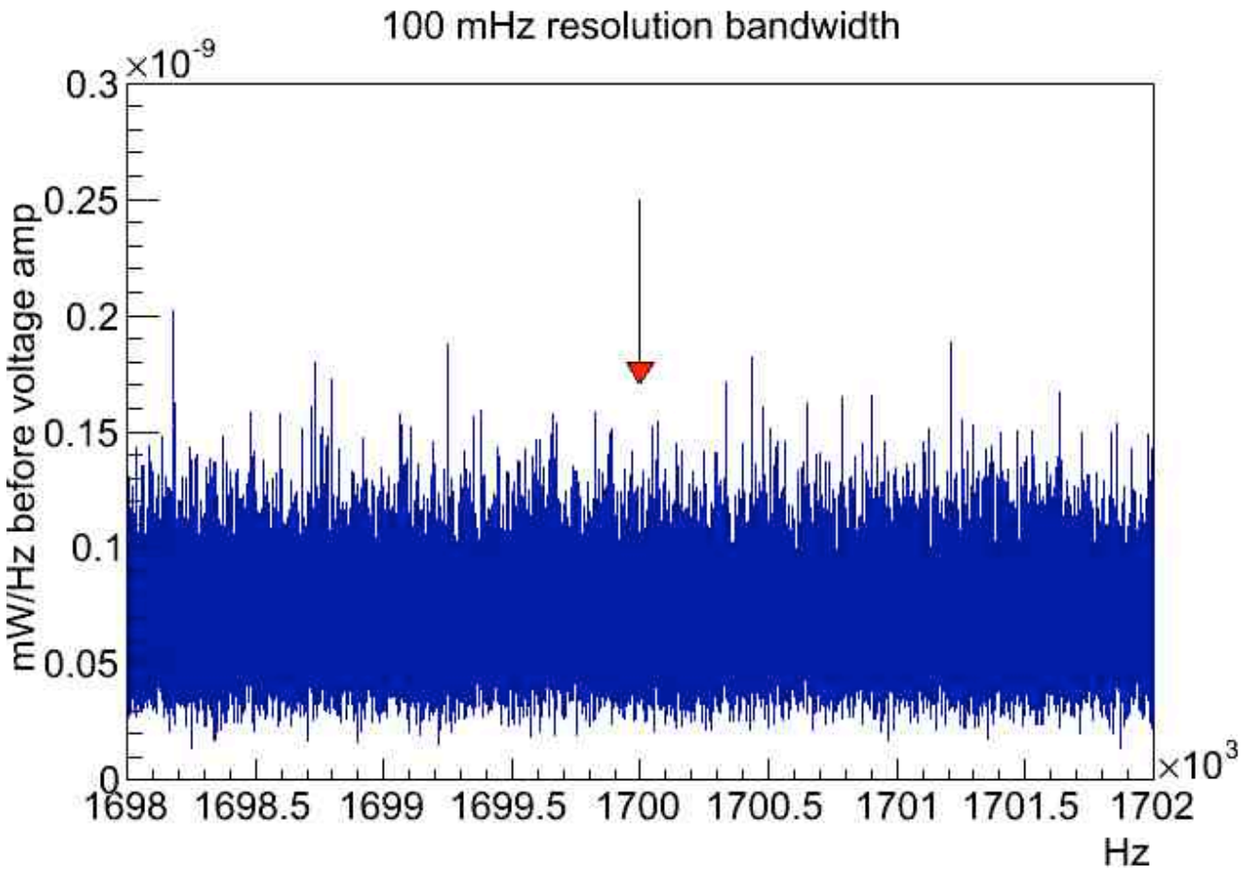


Run 6: Changed grounding configuration



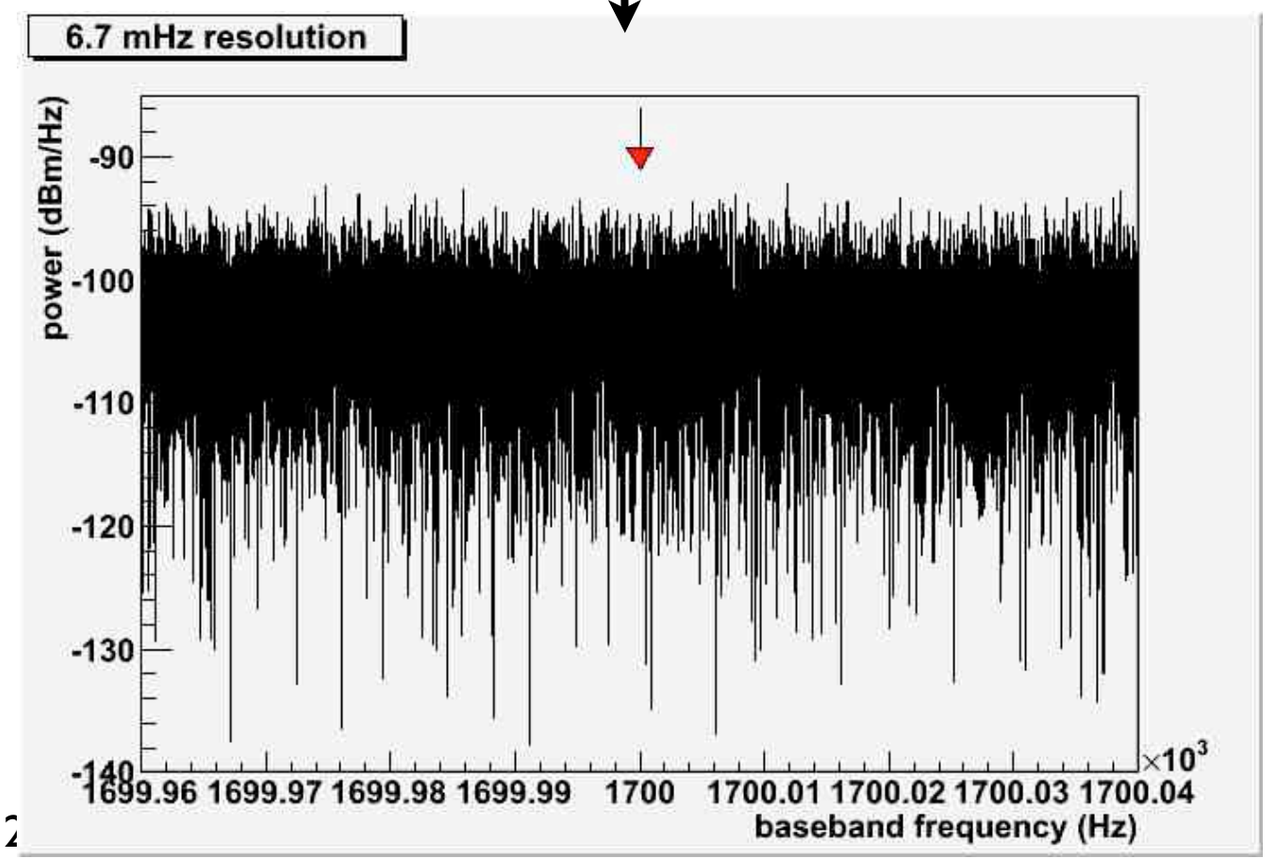


Run 6



$$\chi < 1.7 \times 10^{-7}$$

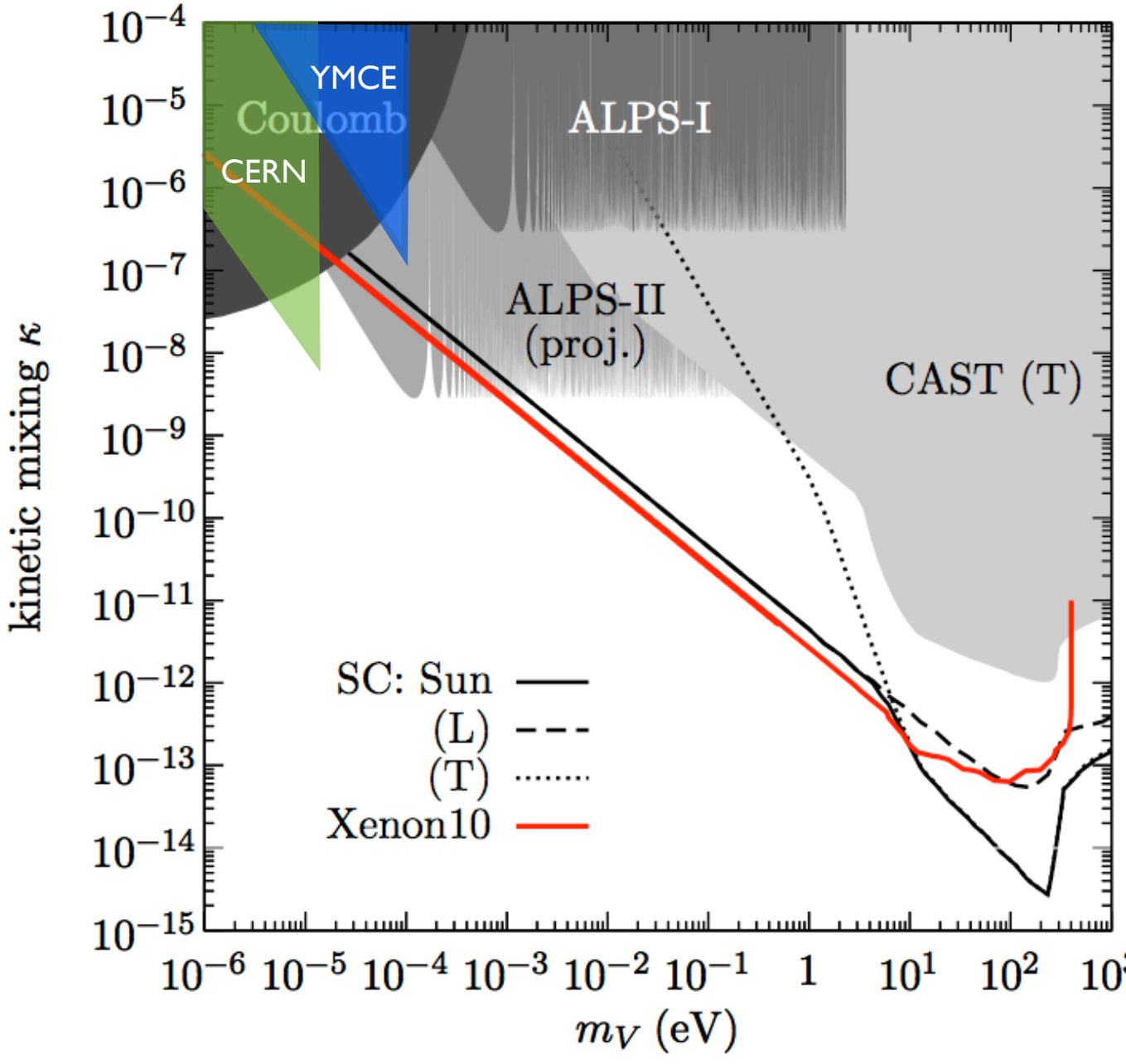
$$m_{\gamma'} = 0.14 \text{ meV}$$



>210 dB shielding

2.5 min
1.5e9 points

Preliminary Limit



$$\chi < (\omega_0/m_{\gamma'})^2 \left(\frac{P_{\rm sig}}{P_{\rm drive}}\right)^{1/4} F(\dots)$$

$$\frac{P_{\rm sig}}{P_{\rm drive}} = \frac{k_B T_{\rm sys} B}{158\ {\rm mW}}$$

To get to SC Sun limit, need 12 hrs of data (B = 20 microHz)

To get to XENON10 limit, need 42 hrs of data (B = 6 microHz)

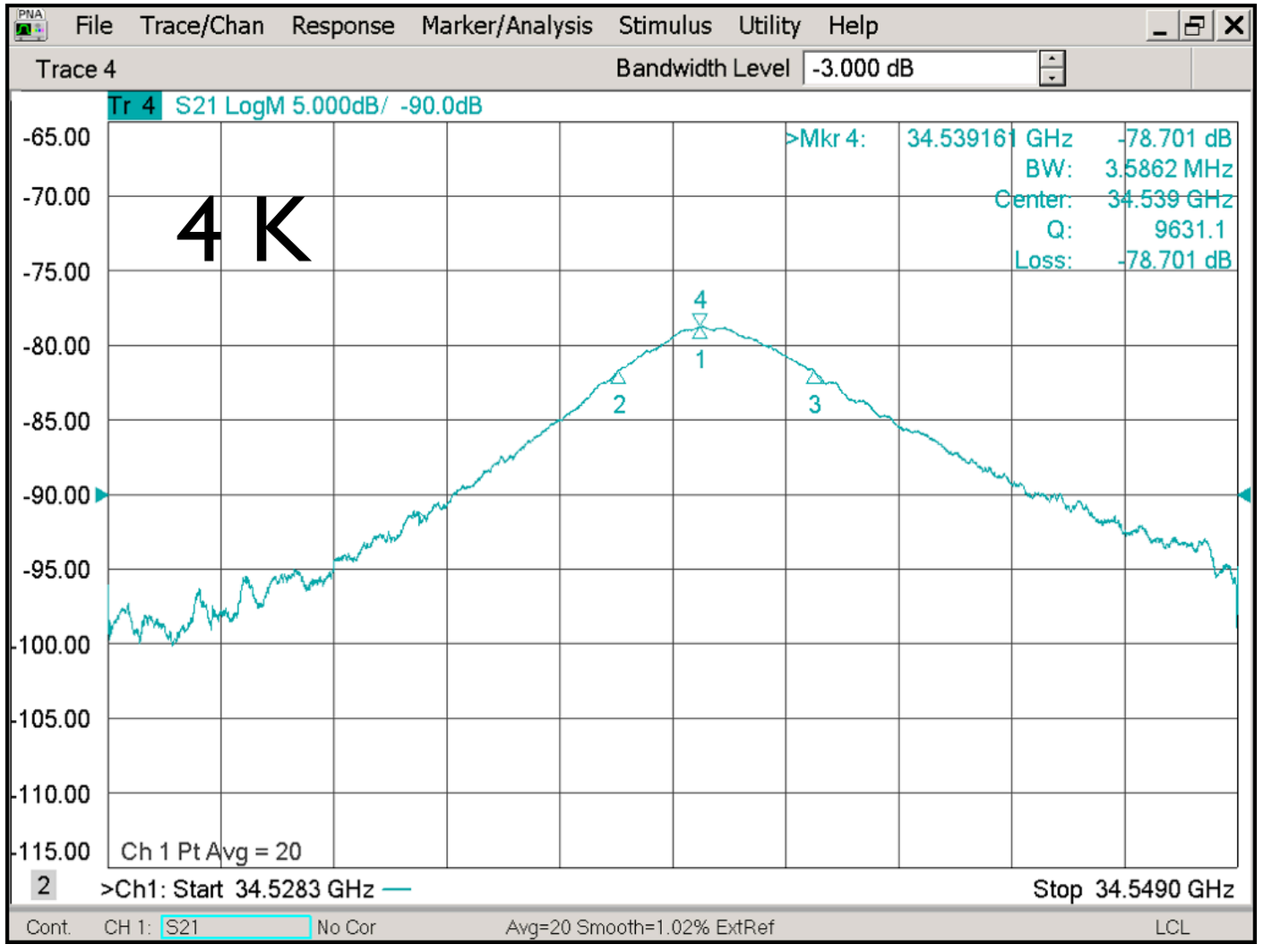
superconducting cavities?

Redondo, Raffelt arXiv:1305.2920v1

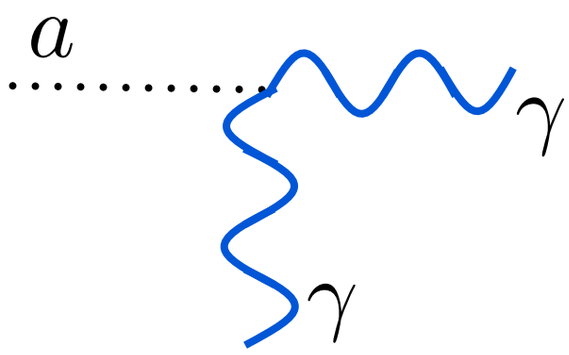
An, Pospelov, Pradler arXiv:1304.3461

TM_{020} Cavity

Tunable with alumina dielectric over 1.5 GHz



Dark Matter ALPs



$$P_{\rm sig} = g_\gamma^2 B^2 C_{020} V Q \rho_a / m_a$$

integration time
50 minutes

$B = 7$ T

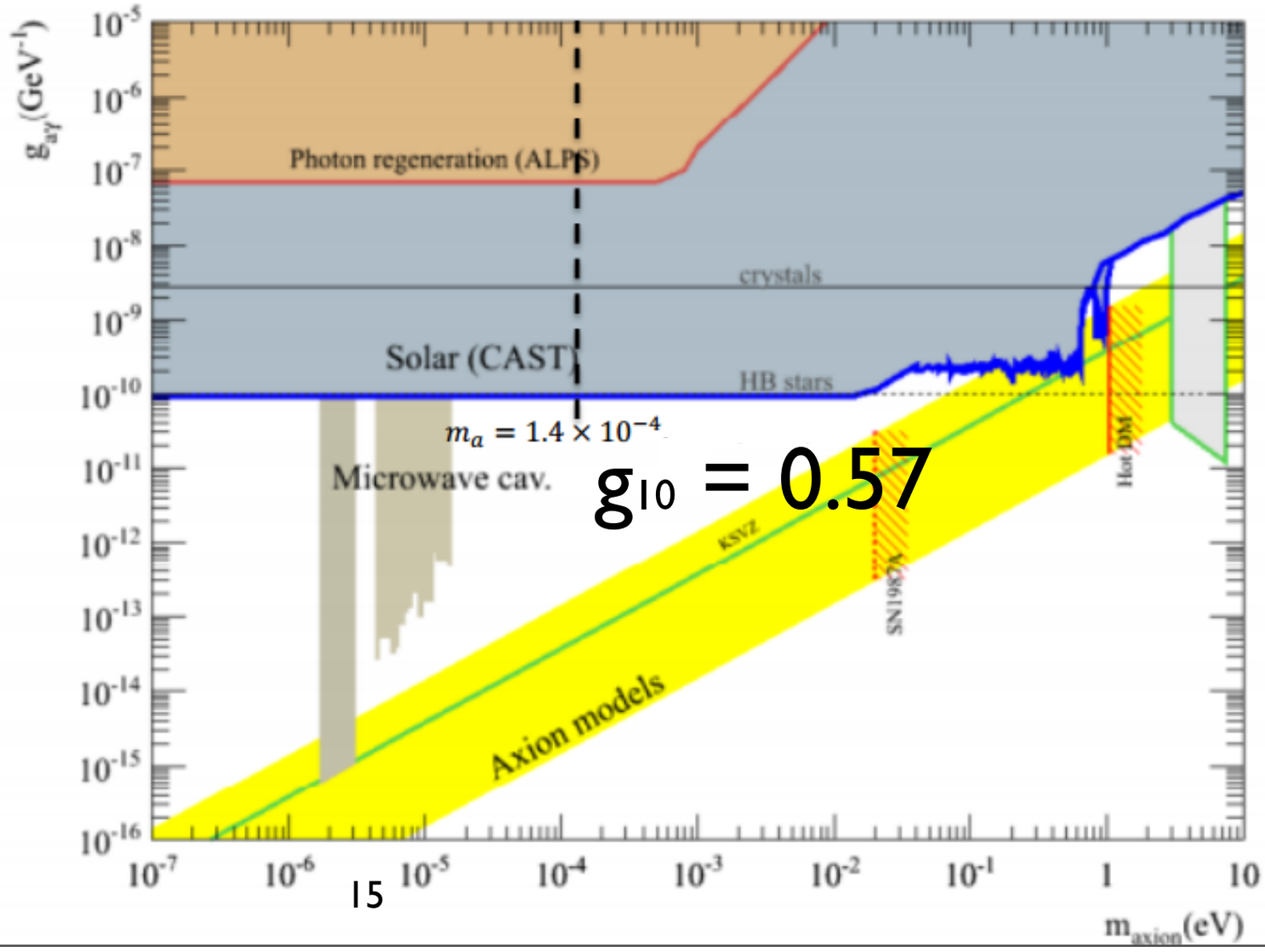
$C_{020} = 0.12$

$V = 1.6$ cm^3

$Q \approx 10,000$

$m_a = .14$ meV

$\rho_a = .3$ GeV/cm^3



Cold Dark Matter Hidden Photons

$$P_{\rm sig} = \chi^2 G_{020} V Q \rho m_{\gamma'}$$

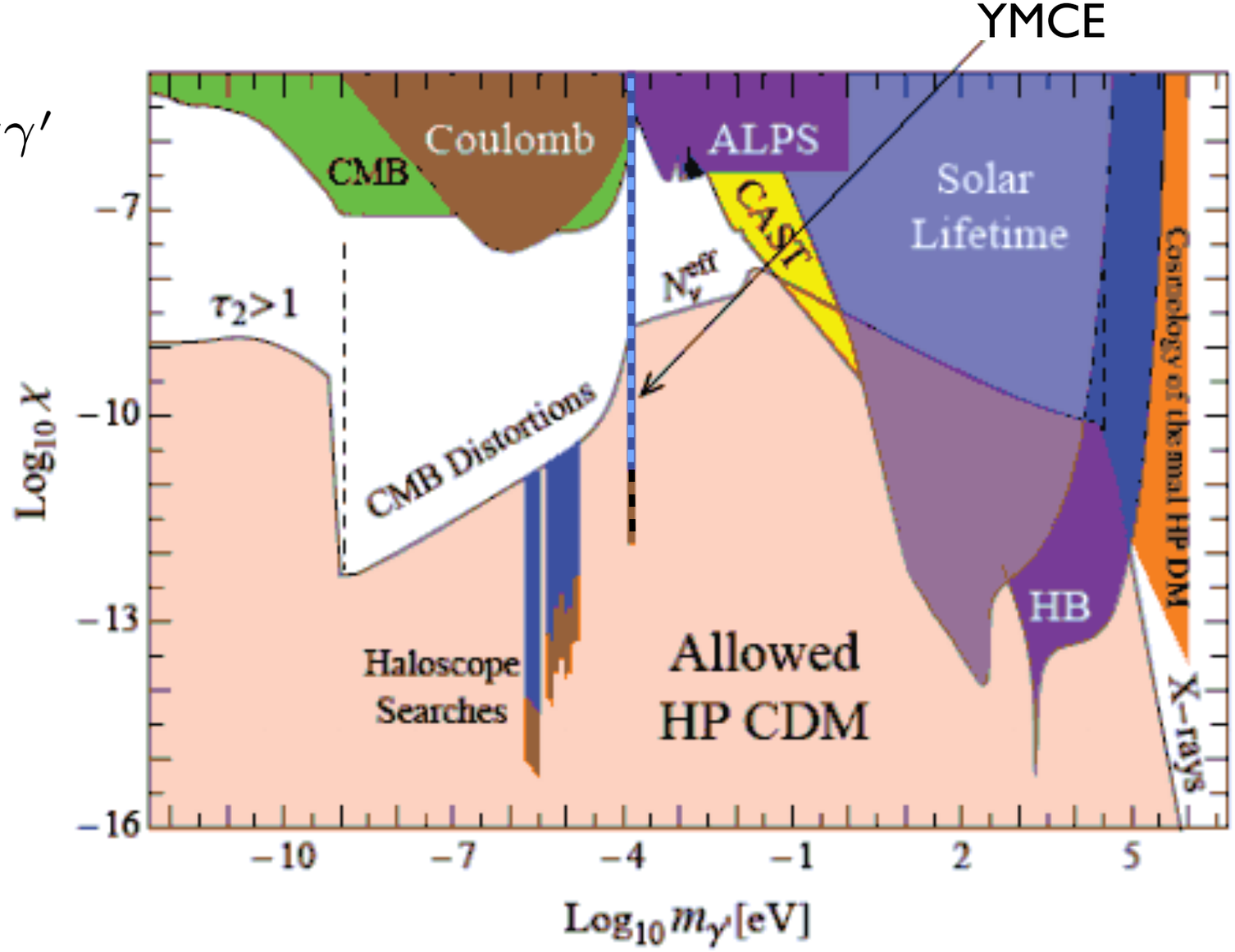
$$G_{020} = C_{020} \cos(\theta)^2$$

$$\cos(\theta)^2 = 0.0025$$

homogenous

random direction

$$\cos(\theta)^2 = 1/3$$



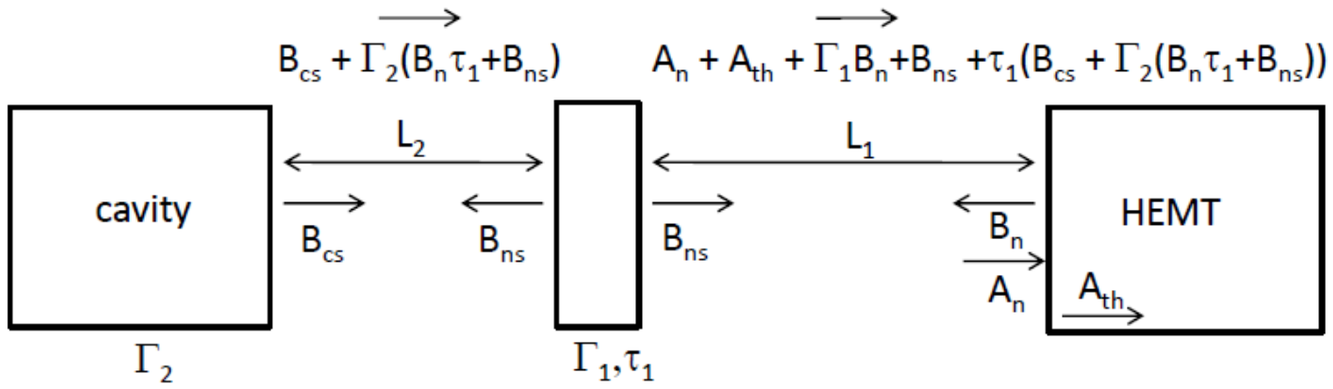
Arias et al. arXiv 1201.5902

Next Steps

- HEMT amplifiers currently under repair
- Noise Temperature Measurement
- TM cavity run
- Superconducting Cavities?

Backup Slides

Noise Calibration I

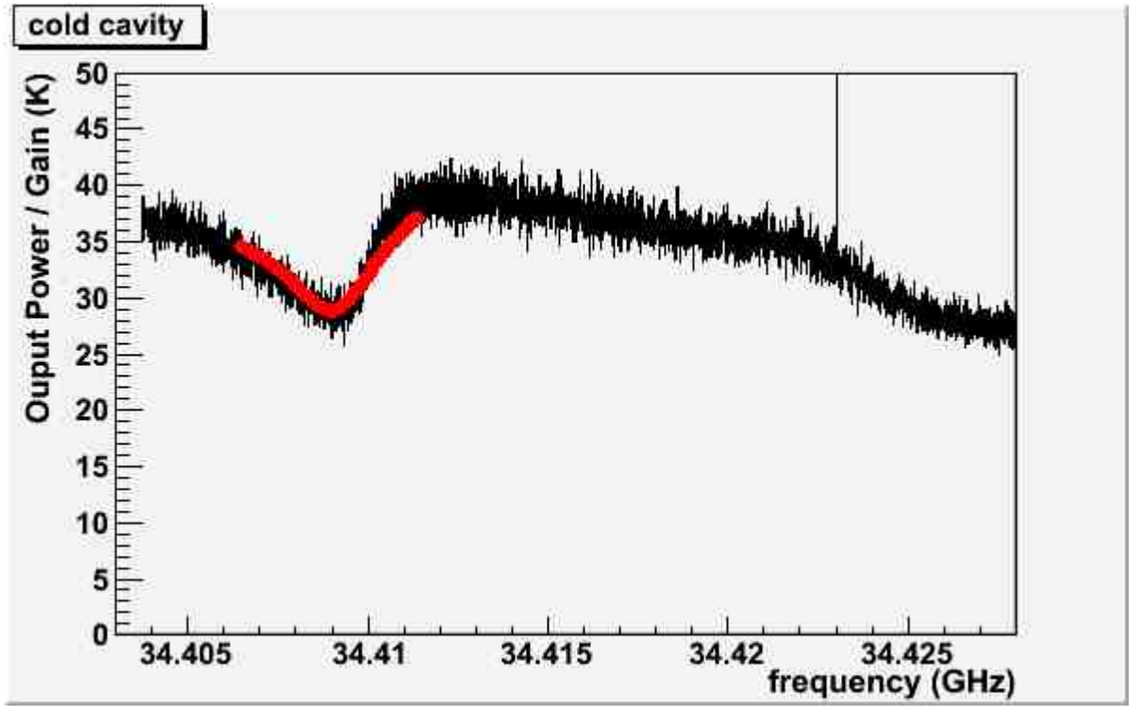


Waveguide-to-coax

$$A_{ns} = A_n + A_{th} + \Gamma_1 B_n + \Gamma_2 B_n \tau_1^2$$

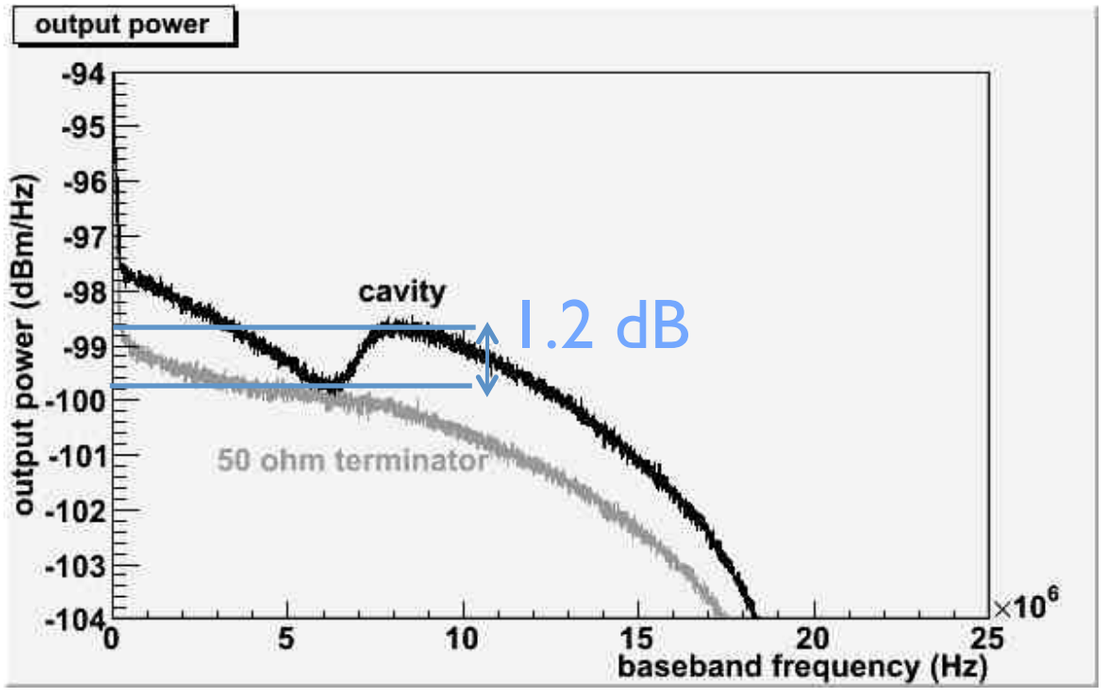
$$\begin{aligned}
\overline{|A_{ns}|^2} &\equiv k_B T_{ns} \Delta f \\
\overline{|A_n|^2} &\equiv k_B T_a \Delta f \\
\overline{|B_n|^2} &\equiv k_B T_b \Delta f \\
\overline{|A_{th}|^2} &\equiv k_B T_{th} \Delta f \\
\overline{A_n^* B_n} &\equiv k_B T_c \Delta f \cdot e^{i\phi_c} \\
\Gamma &= |\Gamma| e^{i\phi_s} \text{ with } \phi_{s1} = 2L_1/\lambda \text{ and } \phi_{s12} = 2(L_1 + L_2)/\lambda.
\end{aligned}$$

Noise Model

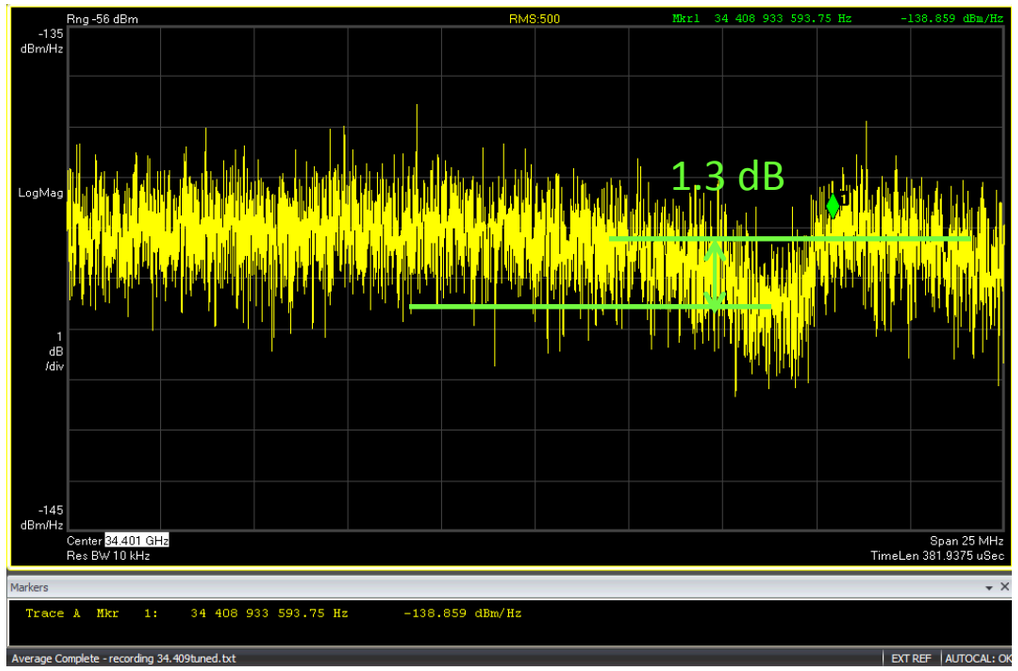

cold cavity
Ouput Power / Gain (K)
50
45
40
35
30
25
20
15
10
5
0
34.405
34.41
34.415
34.42
34.425
frequency (GHz)

Comparing Receiver to VSA

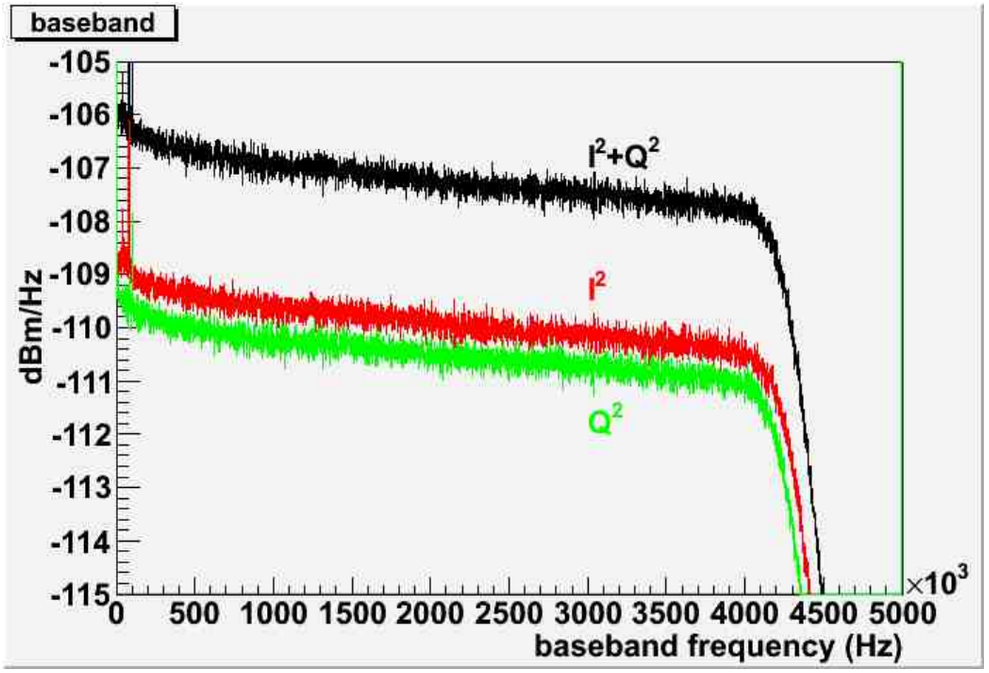
Spectra from Receiver



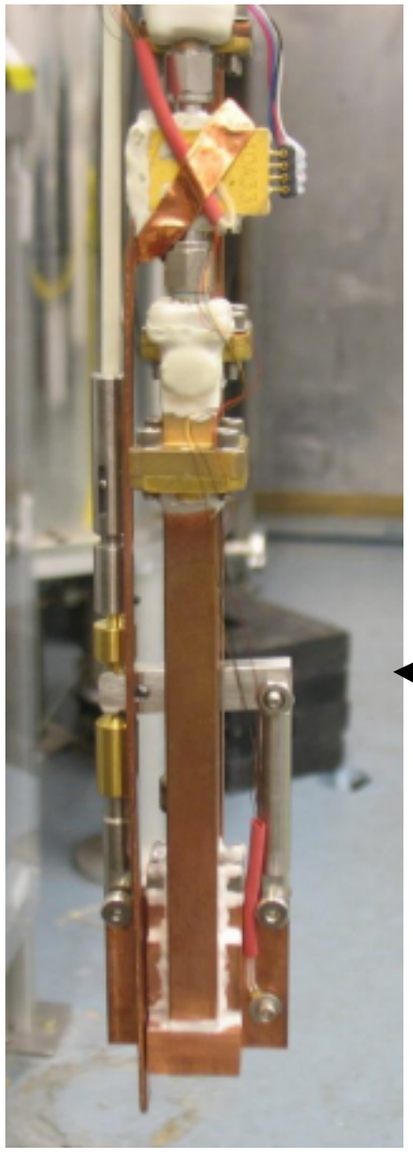
Spectra from VSA



I/Q Channels


baseband
-105
-106
-107
-108
-109
-110
-111
-112
-113
-114
-115
dBm/Hz
I²+Q²
I²
Q²
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
×10³
baseband frequency (Hz)

Cavities



TE011 mode
cavities ~4 cm apart

diameter = 1.1 cm
height = 1.7 cm
←tunable