# Measuring AlGaAs Electro-optic / Piezoelectric effects (initial results)

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# E-field injection concept (basic construction)

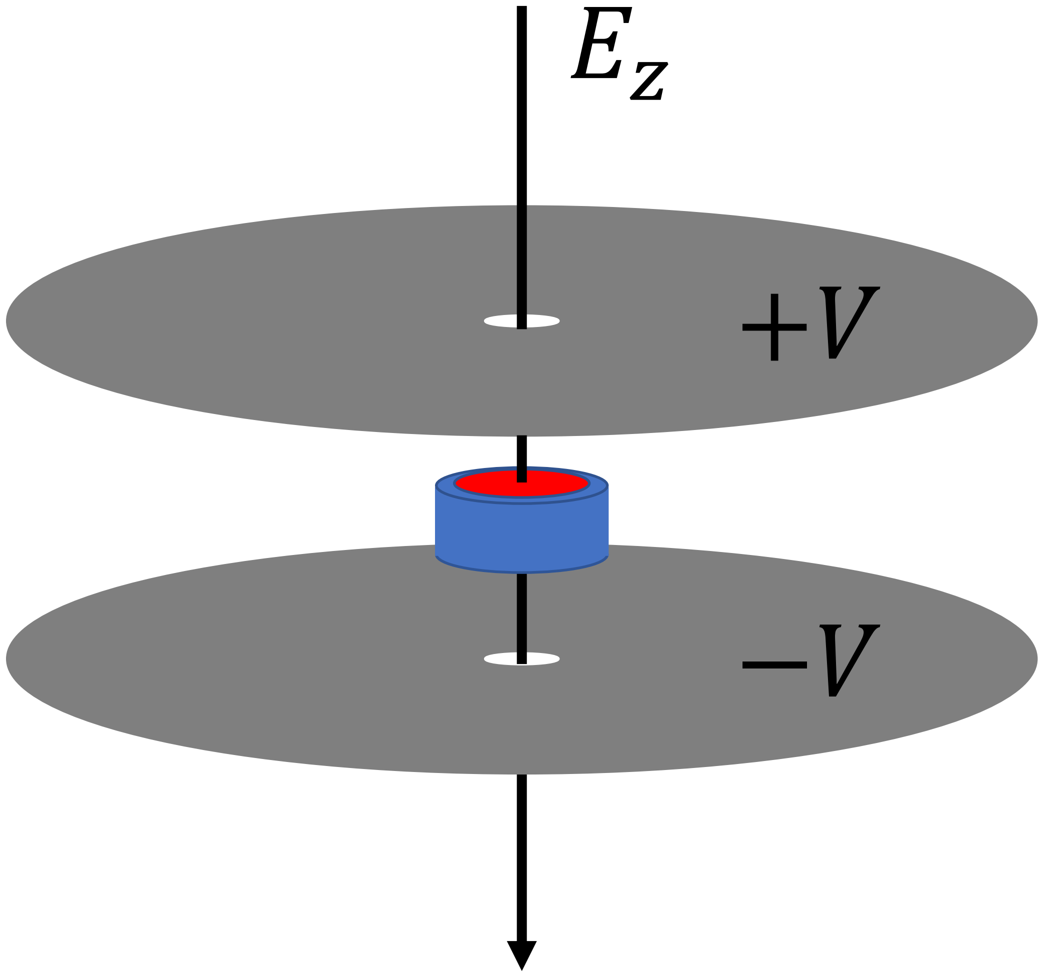
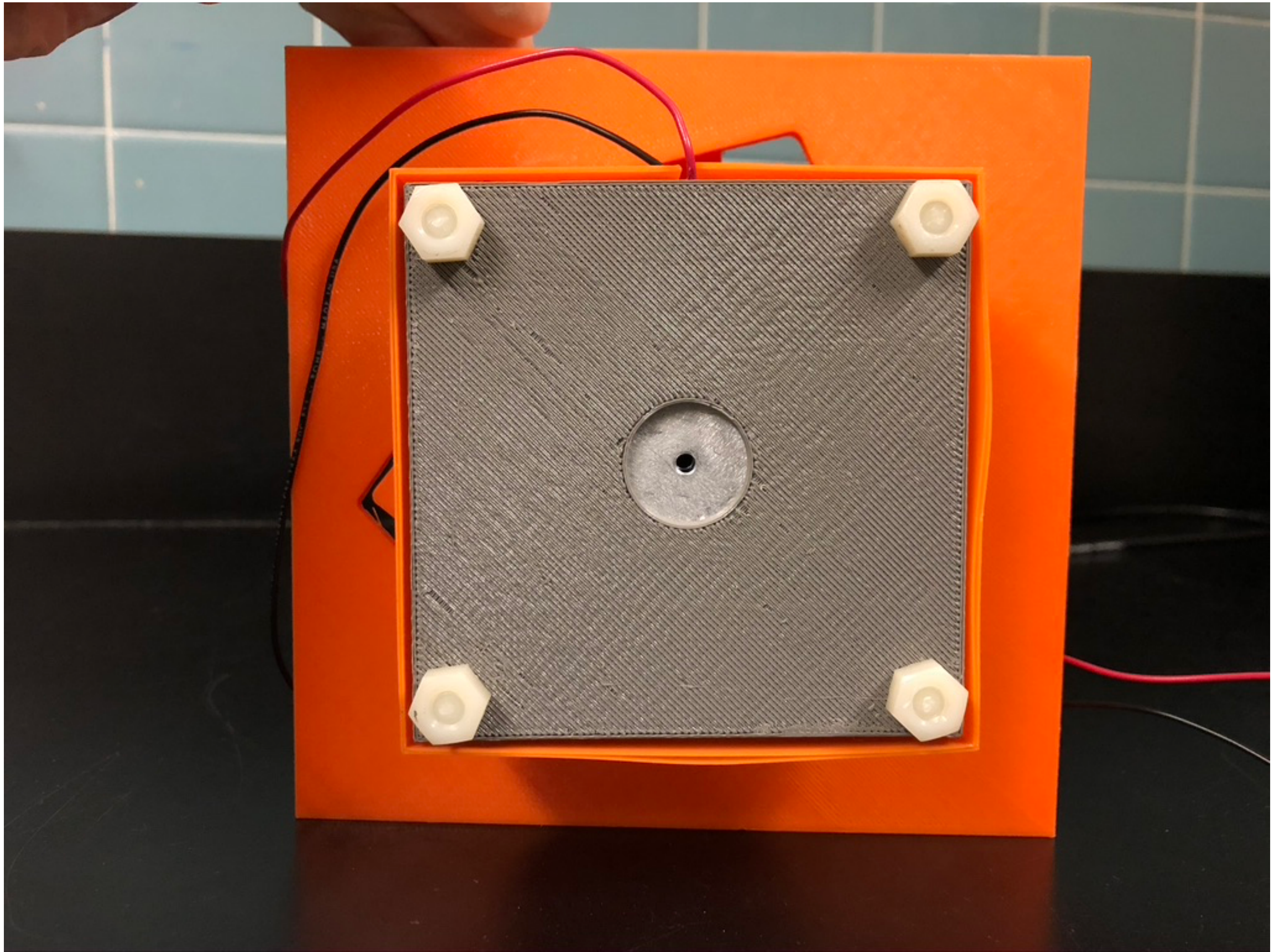



Figure elements do not reflect realistic scaling

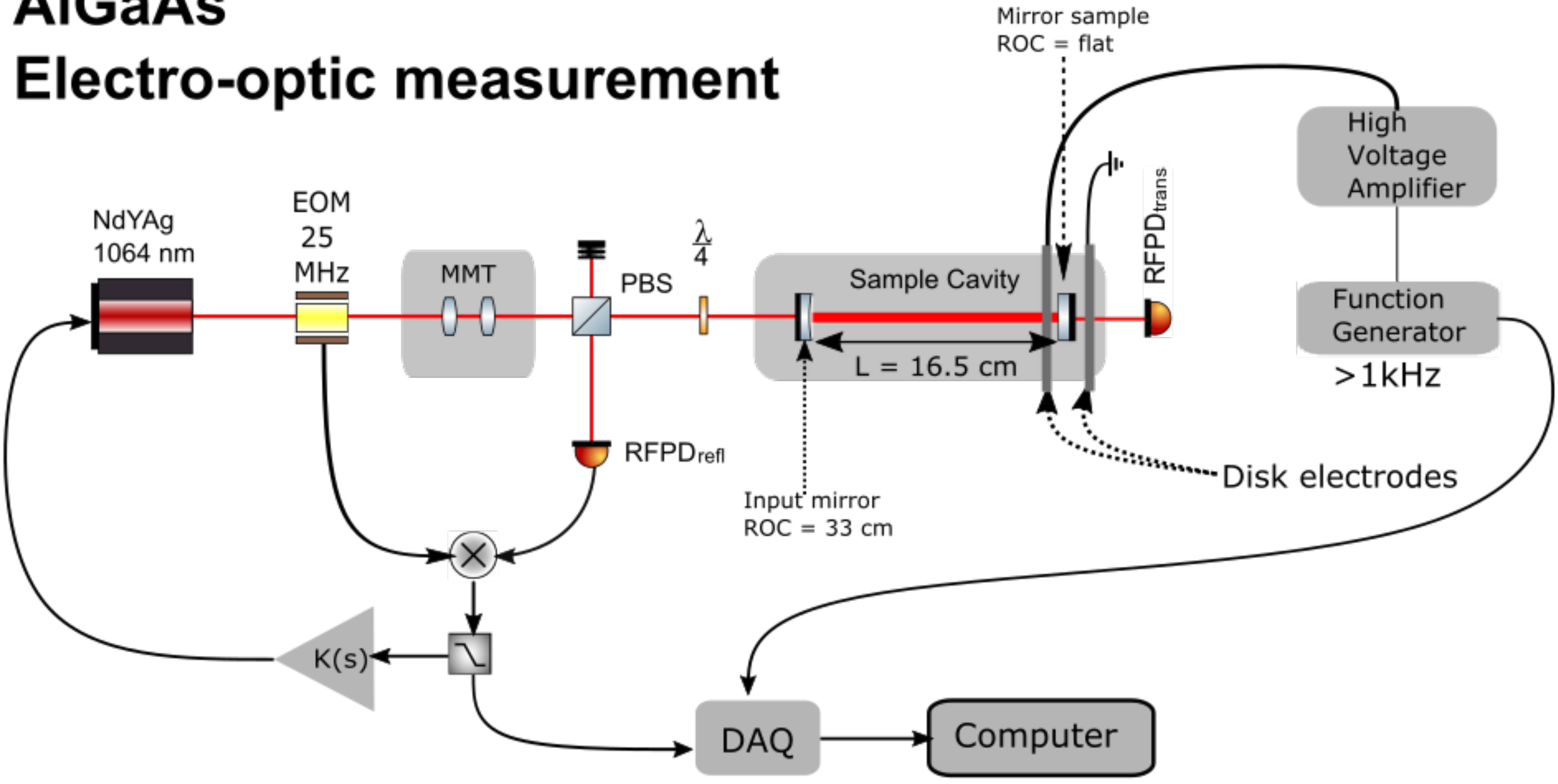
# Electrode system parameters

- Electrode plates:
  - Aperture diameter : 3 mm
  - Plates diameter : 76.2 mm
  - Plate separation : 9 mm
  - Voltage across electrodes : 300 V
- Optic:
  - Optic diameter : 25.4 mm
  - Optic thickness : 7 mm
  - Material : Fused silica
    - Amorphous coating mirror
      - $SiO_2$ /$Ta_2O_5$
    - AlGaAs mirror

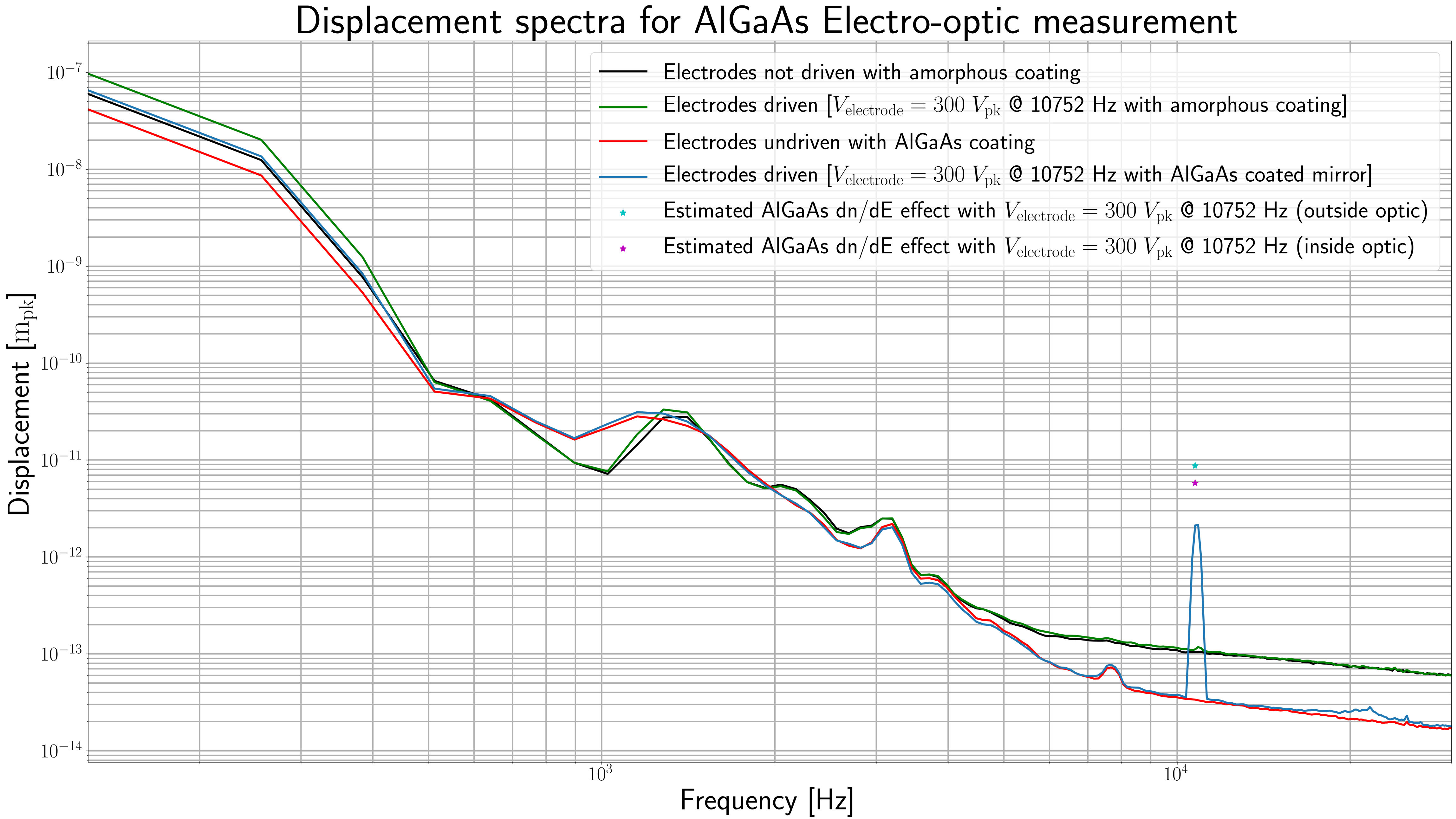
# 3D printed enclosure / optic mount



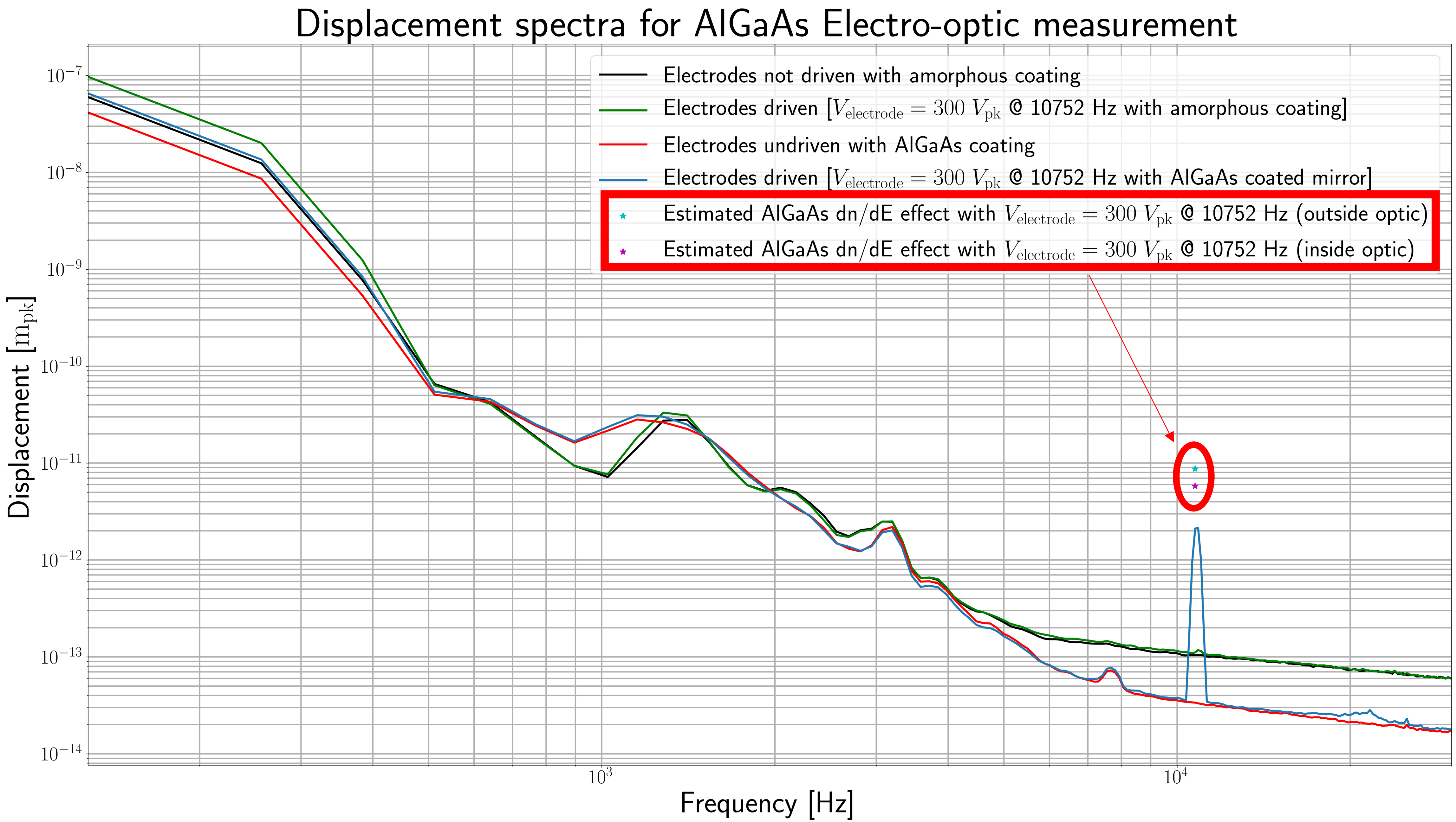
# AlGaAs
# Electro-optic measurement



# Initial results (04-26-2020)



# The Model


Displacement spectra for AlGaAs Electro-optic measurement
Electrodes not driven with amorphous coating
Electrodes driven [$V_{\mathrm{electrode}} = 300\ V_{\mathrm{pk}}$ @ 10752 Hz with amorphous coating]
Electrodes undriven with AlGaAs coating
Electrodes driven [$V_{\mathrm{electrode}} = 300\ V_{\mathrm{pk}}$ @ 10752 Hz with AlGaAs coated mirror]
Estimated AlGaAs dn/dE effect with $V_{\mathrm{electrode}} = 300\ V_{\mathrm{pk}}$ @ 10752 Hz (outside optic)
Estimated AlGaAs dn/dE effect with $V_{\mathrm{electrode}} = 300\ V_{\mathrm{pk}}$ @ 10752 Hz (inside optic)
Displacement [$\mathrm{m_{pk}}$]
Frequency [Hz]
$10^{-7}$
$10^{-8}$
$10^{-9}$
$10^{-10}$
$10^{-11}$
$10^{-12}$
$10^{-13}$
$10^{-14}$
$10^{3}$
$10^{4}$

# Where does this model estimate come from?

- Calculating $\left|\frac{\partial\phi}{\partial E_z}\right|$ ($\phi=$ reflection phase) for coating
- Numerical Poisson computation used to estimate field strength normal to surface of optic ($E_z$)

# Electro-optic effect estimate

- Treatment analogous to thermo-optic effect
  - Temperature coefficient ➔ electro-optic coefficient
- Assume incident light is polarized along the [110] crystallographic direction

$$\left|\frac{\partial \phi}{\partial E_z}\right| = \pi \frac{r_{41}}{2}\left(n_2 {n_3}^2 + n_3 {n_2}^2\right) + \frac{n_2/n_3}{1 - \left(\frac{n_2}{n_3}\right)^2}$$

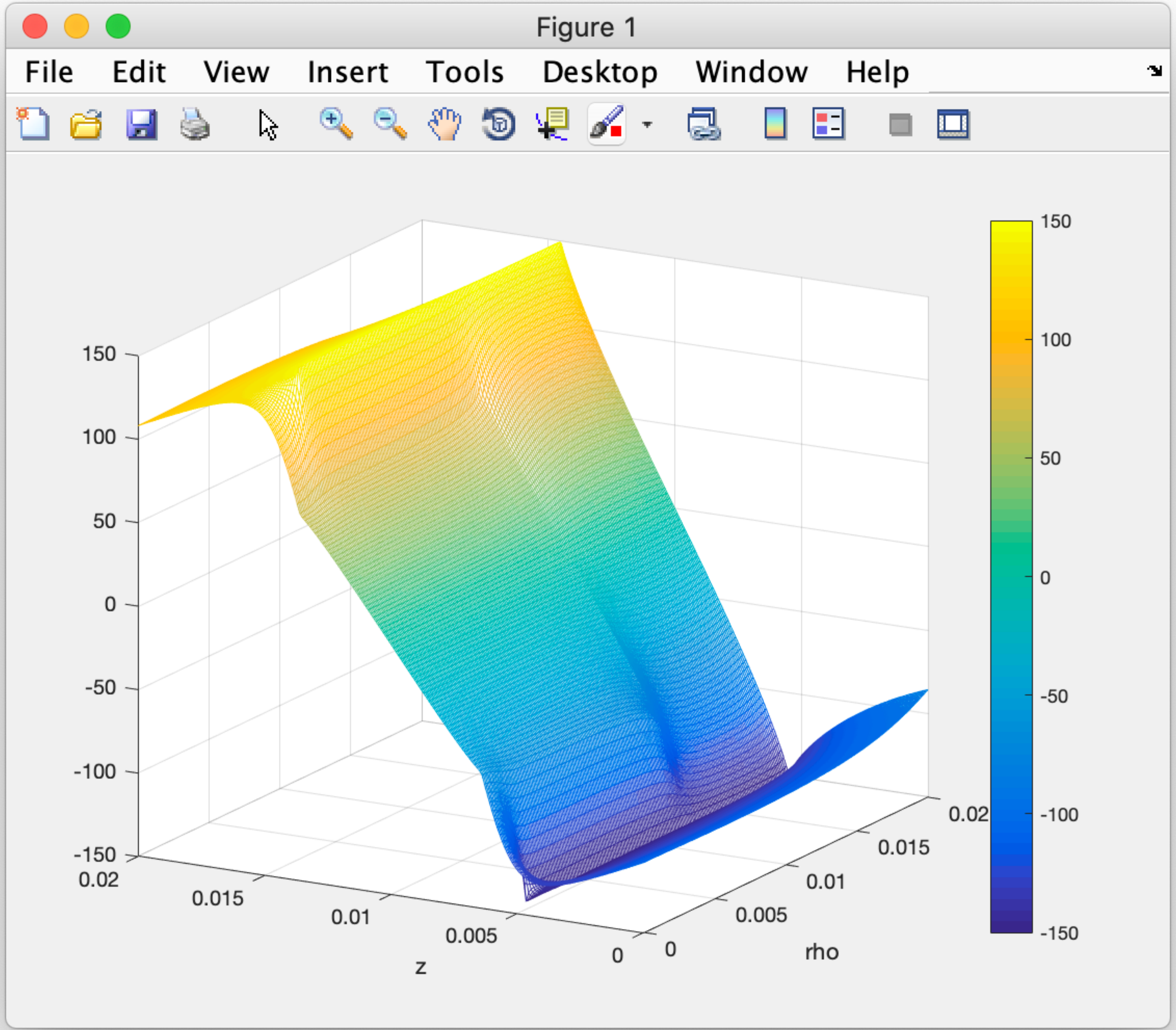
- $n_2$ and $n_3$ are the high and low index layers respectively
- $r_{41}$ is the electro-optic coefficient for GaAs (and is assumed the same here for AlGaAs)

$\left|\frac{\partial \phi}{\partial E_z}\right|$ estimate for HR AlGaAs coating

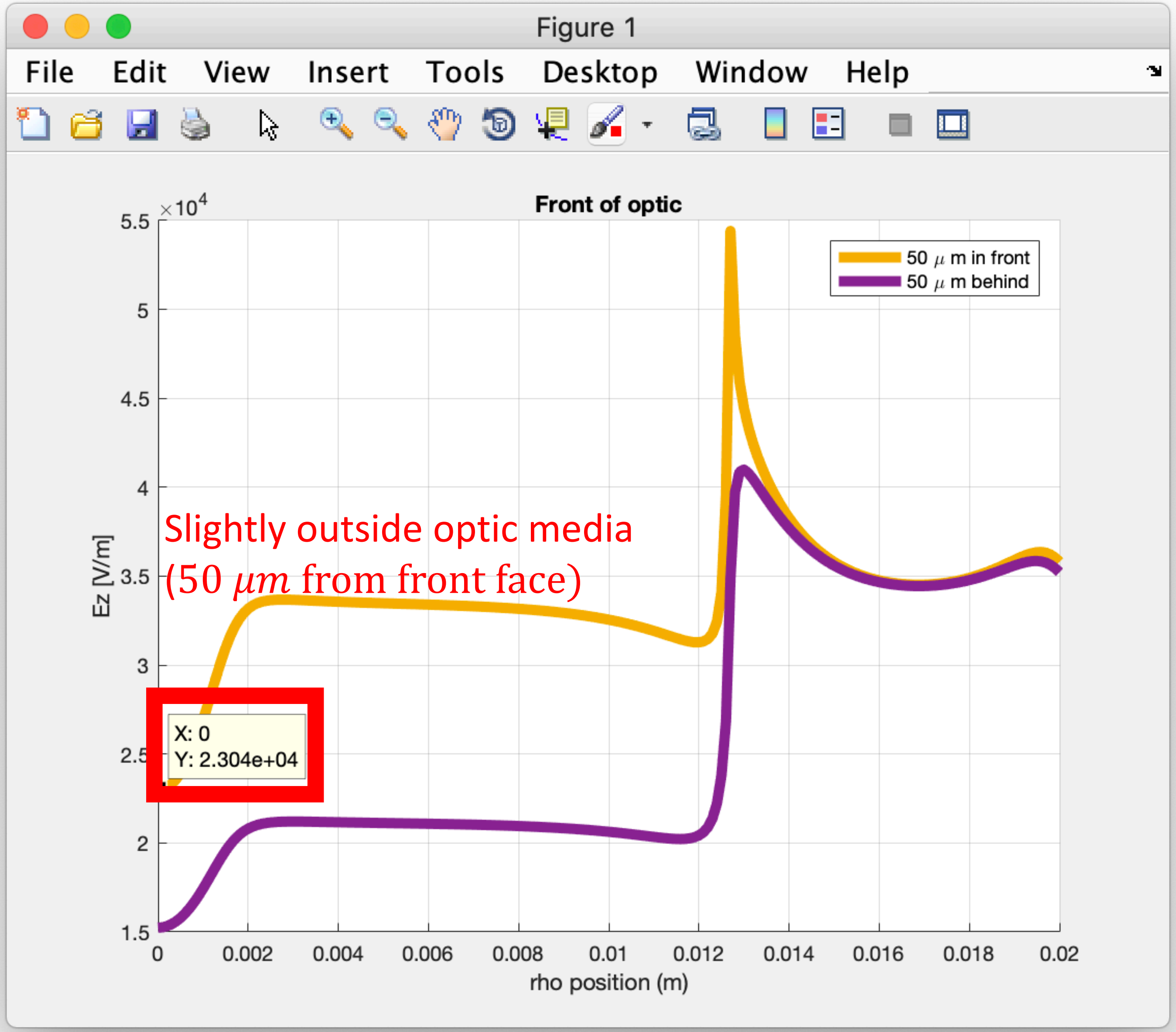
$$\left|\frac{\partial \phi}{\partial E_z}\right| = 4.5*10^{-10}\ [\text{rad}]/[\text{V/m}]$$

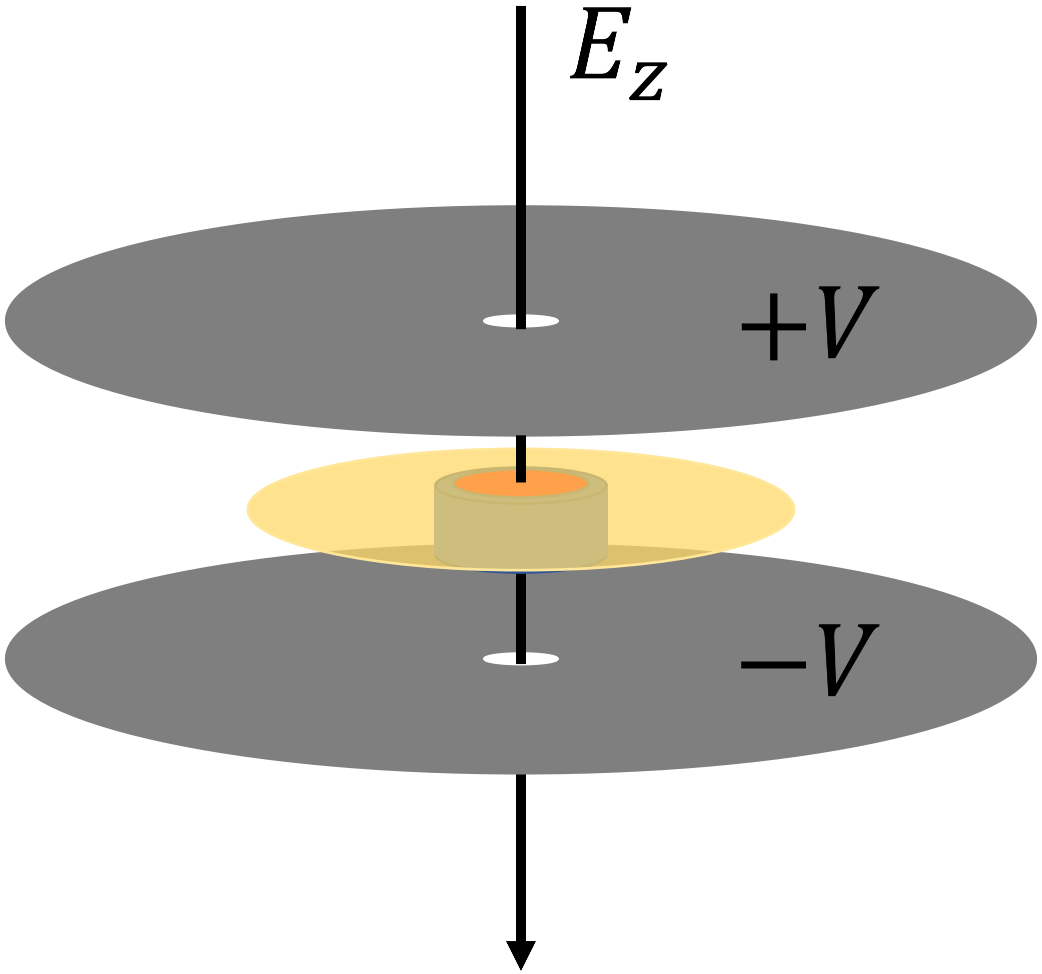
$$\left|\frac{\partial x}{\partial E_z}\right| = \frac{1064*10^{-9}}{4\pi} * \left|\frac{\partial \phi}{\partial E_z}\right| = 3.8*10^{-17}\ [\text{m/V/m}]$$

# Numerical Poisson calculator results (potential map)

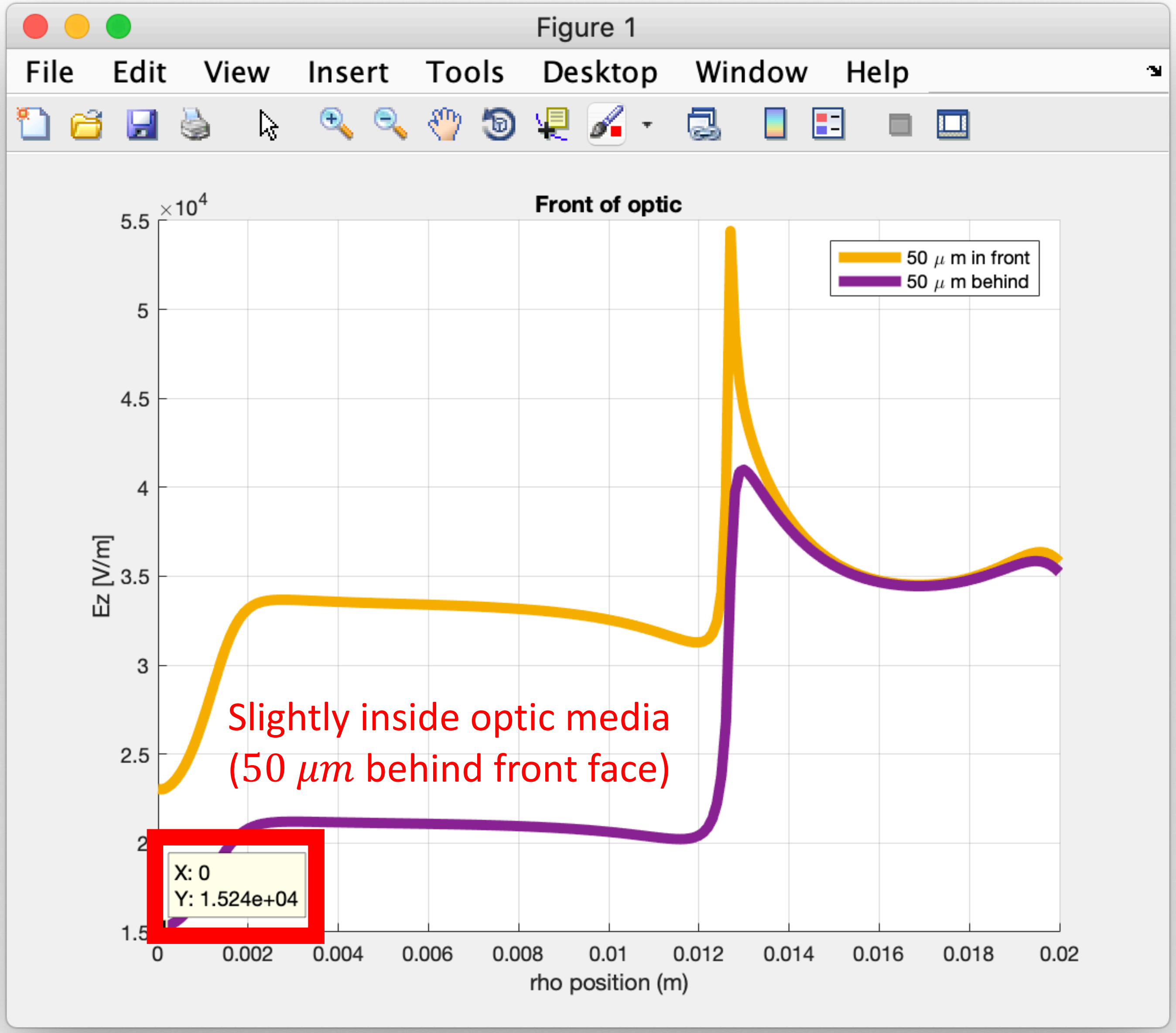


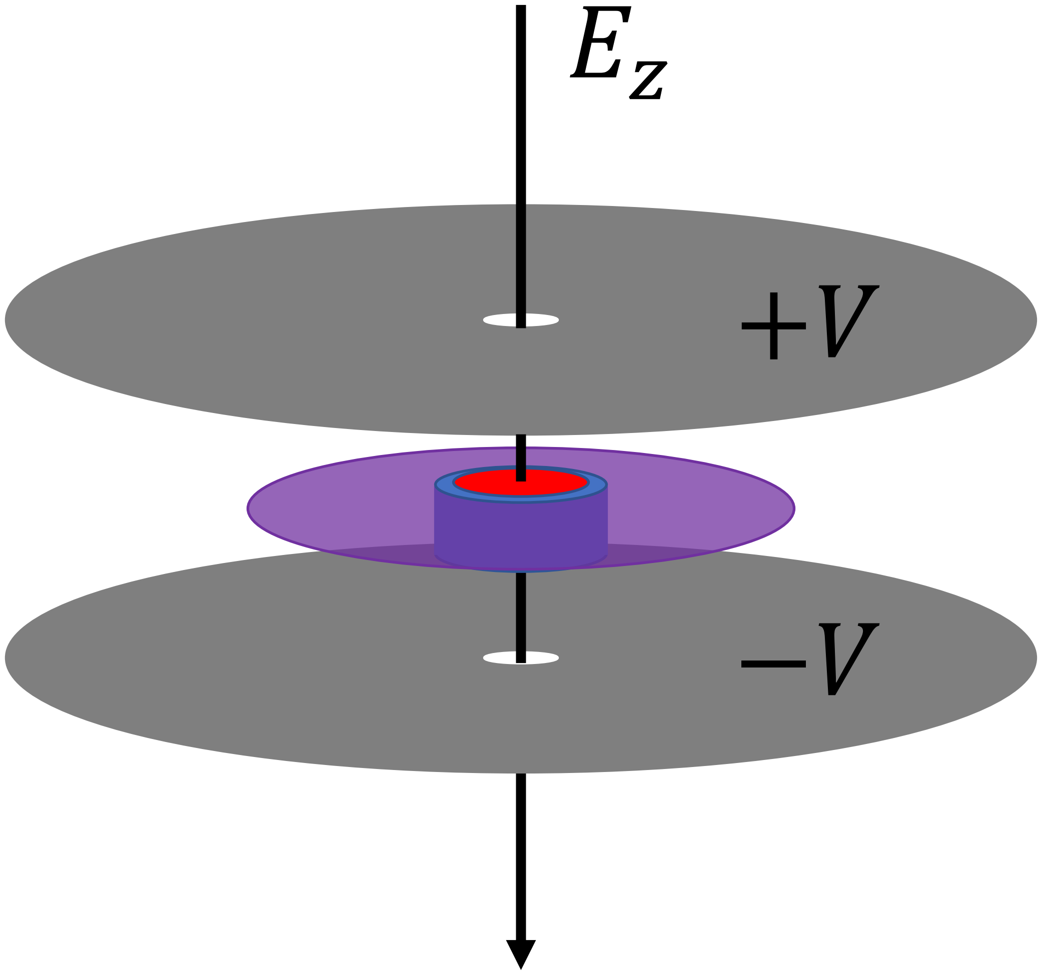
# Numerical Poisson calculator results (Ez outside)



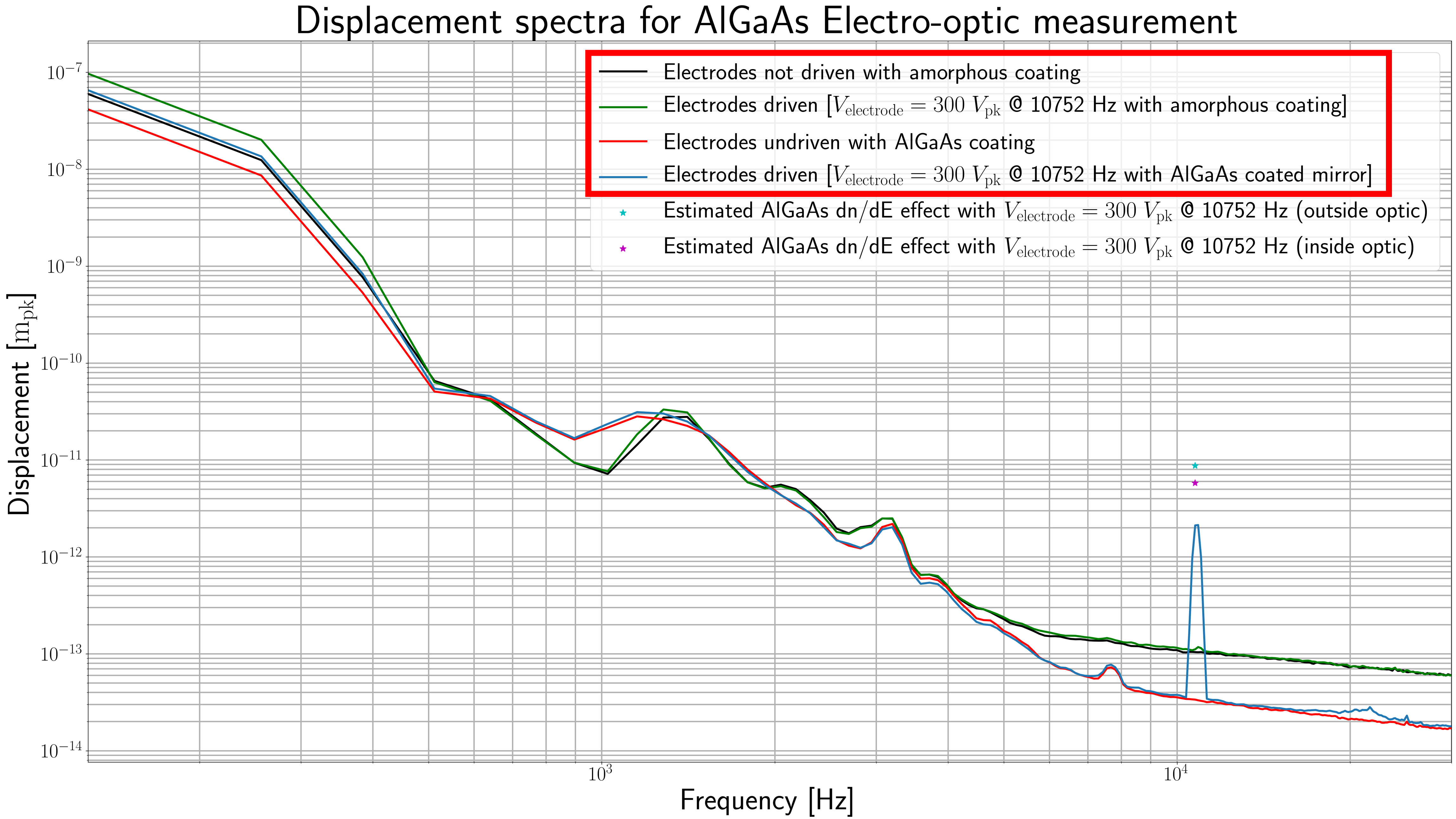



# Numerical Poisson calculator results (Ez inside)

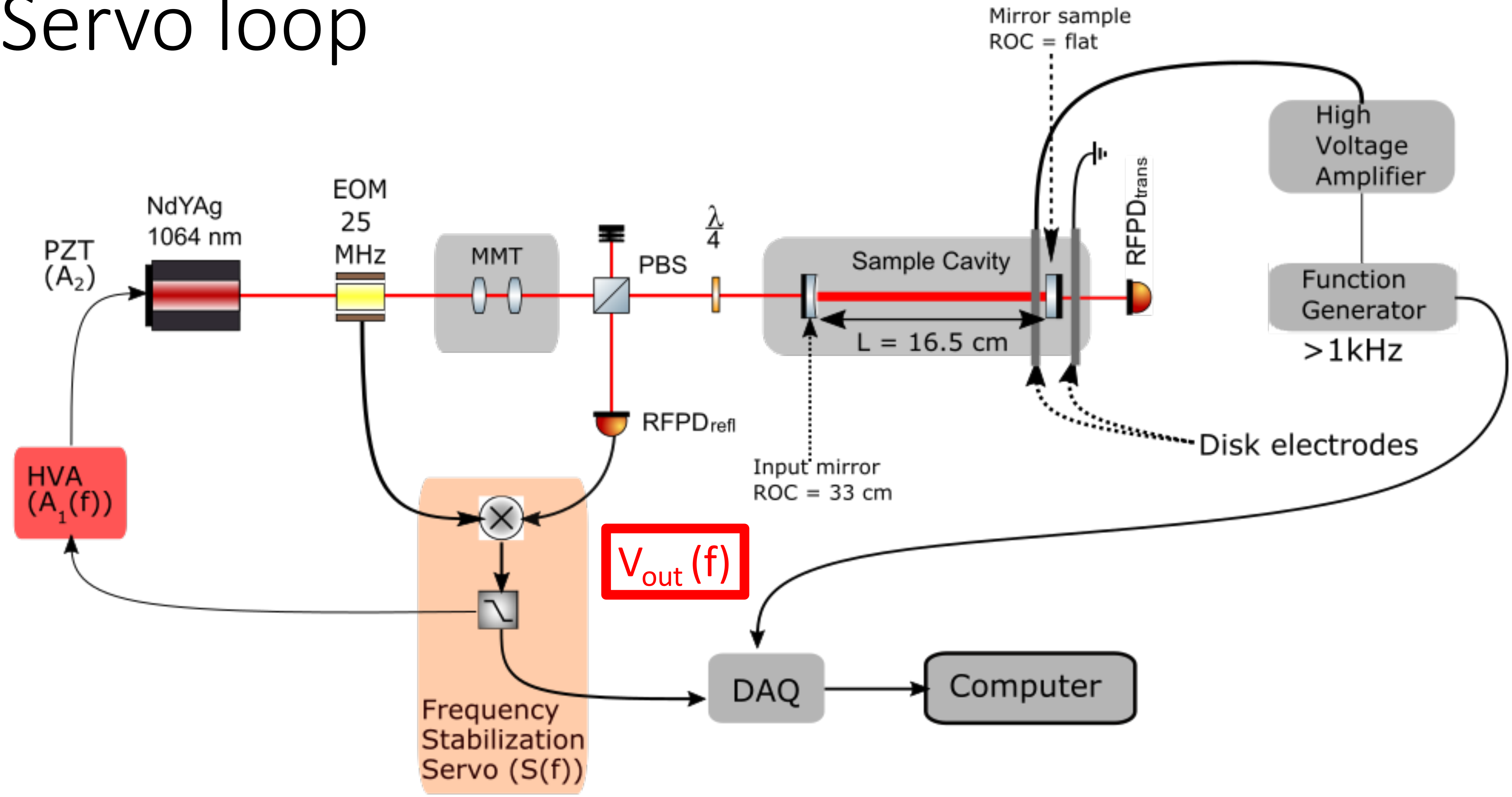


# The Measurements



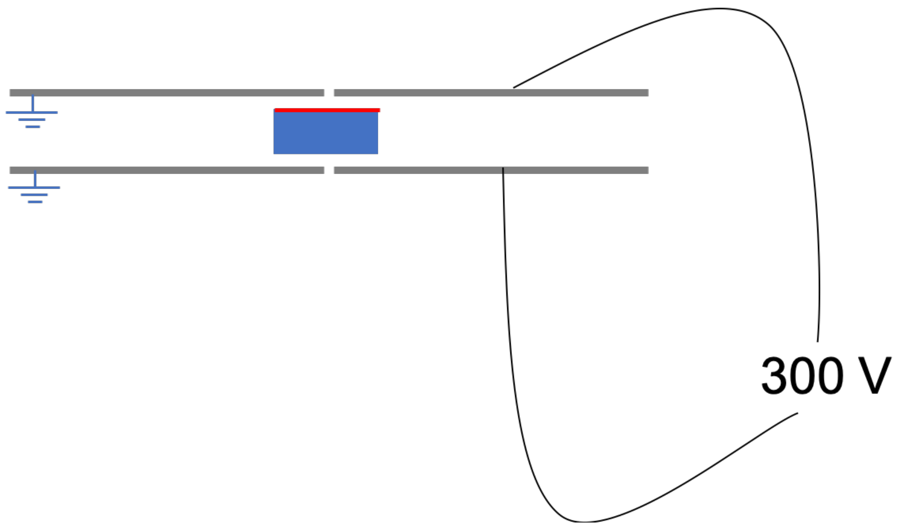
# Servo loop



Mirror sample
ROC = flat
High
Voltage
Amplifier
NdYAg
1064 nm
EOM
25
MHz
PZT
($A_2$)
MMT
PBS
λ/4
Sample Cavity
$RFPD_{trans}$
Function
Generator
>1kHz
L = 16.5 cm
$RFPD_{refl}$
Disk electrodes
Input mirror
ROC = 33 cm
HVA
($A_1$(f))
$V_{out}$ (f)
DAQ
Computer
Frequency
Stabilization
Servo (S(f))

# Next measurements

- *Frequency sweep measurement from 300 Hz to  5 kHz*
- *Harmonics measurement*
- *Sample different mirror end mirror rotations to sample different polarizations*
- Measure dn/dE + dL/dE effects for controlled non-normal fields
    - Alternative split electrode design



# Questions?

# References


- Fejer, M.M. , *Electro-optic Effects in AlGaAs mirrors* , (2018)
- Cahillane, C., *Initial Electric Field Meter Results For Advanced LIGO and Beyond*, (2018)

# *Extra Slides*

# (Some transfer function measurements and sanity checks)

# What the DAQ sees at V$_{out}$

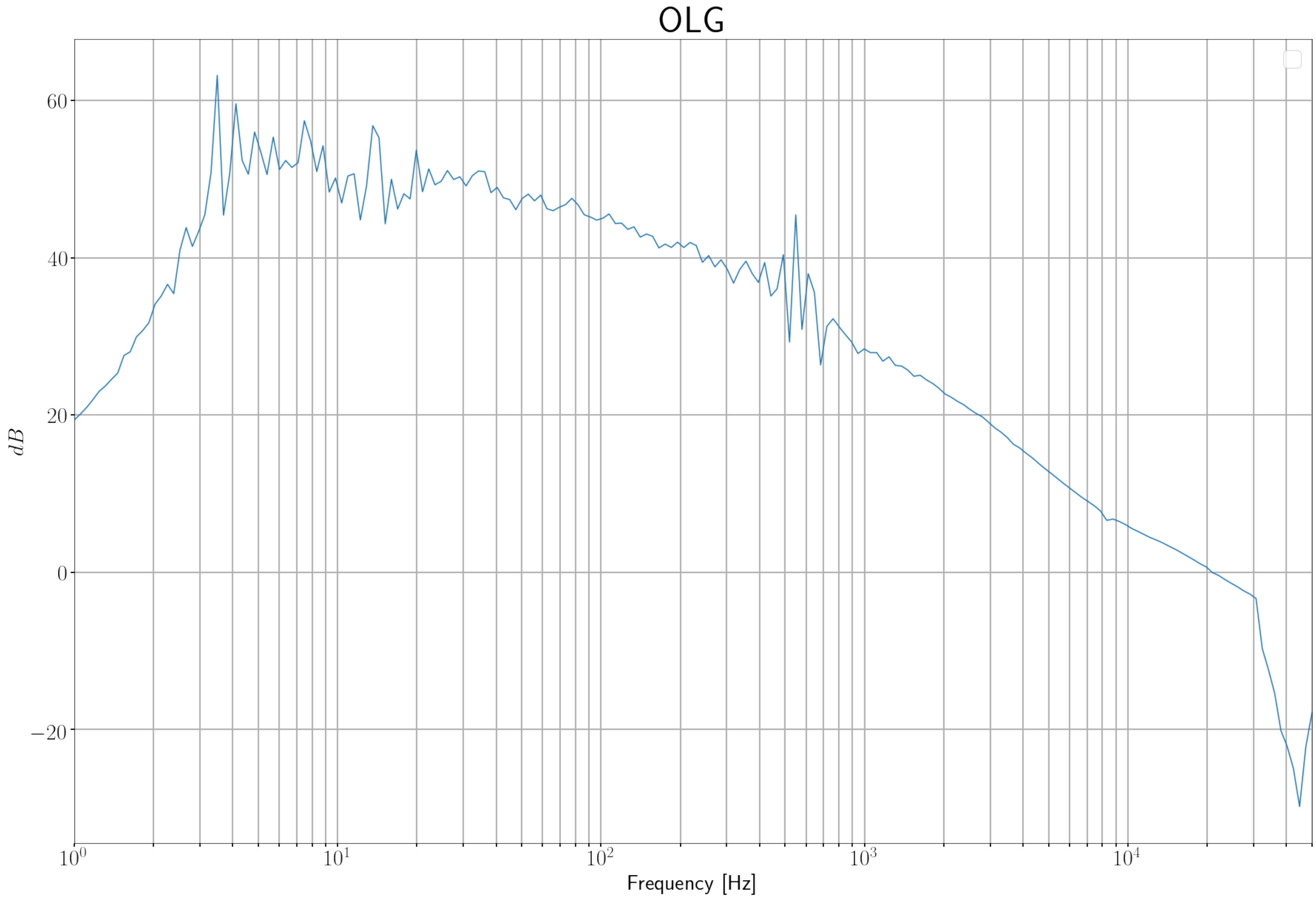
$$V_{out}(f) = S(f) * \frac{(signal)}{1 - OLG(f)}$$

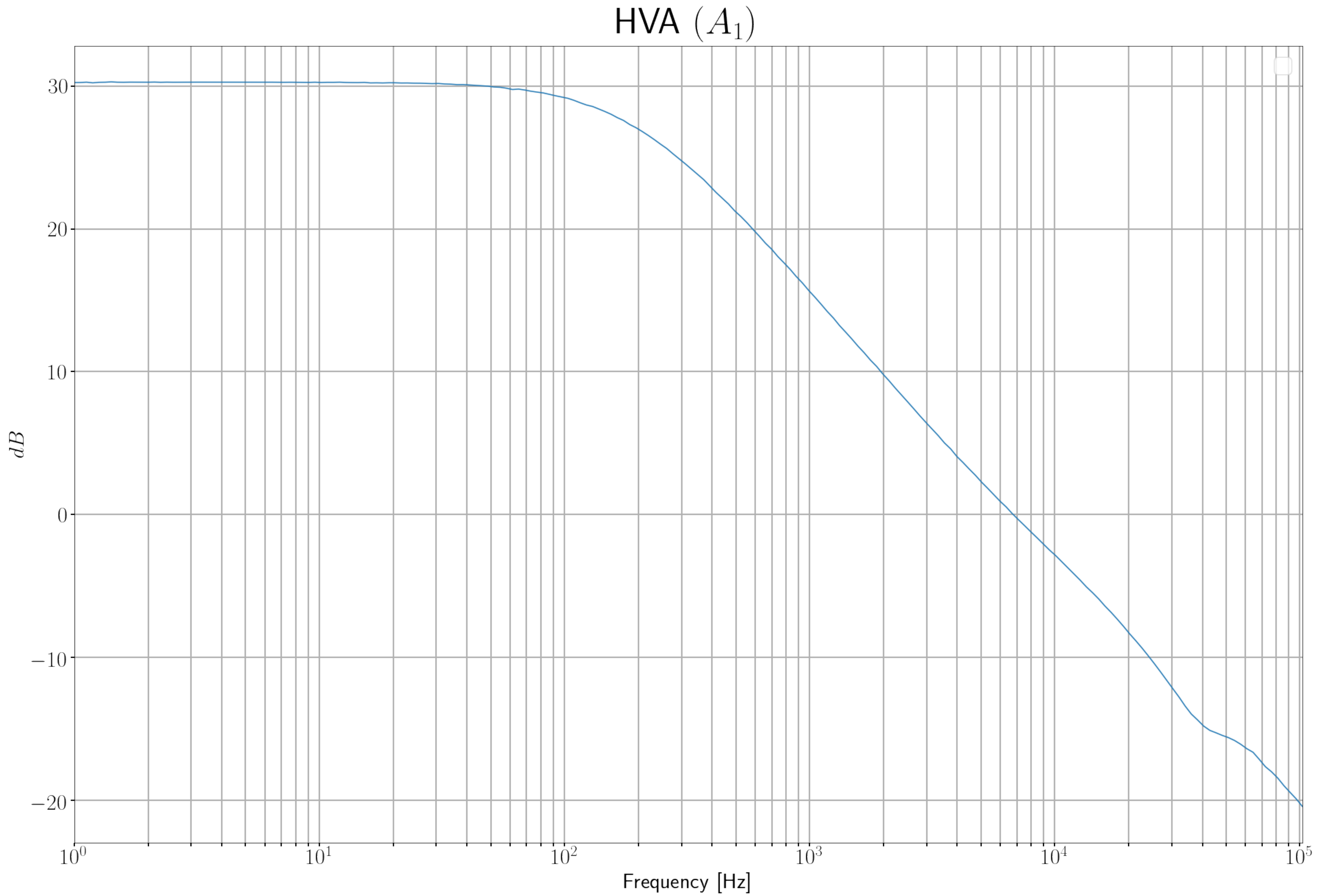
And we can say $OLG(f) = \ S(f) * A_1(f) * \ A_2$ so :

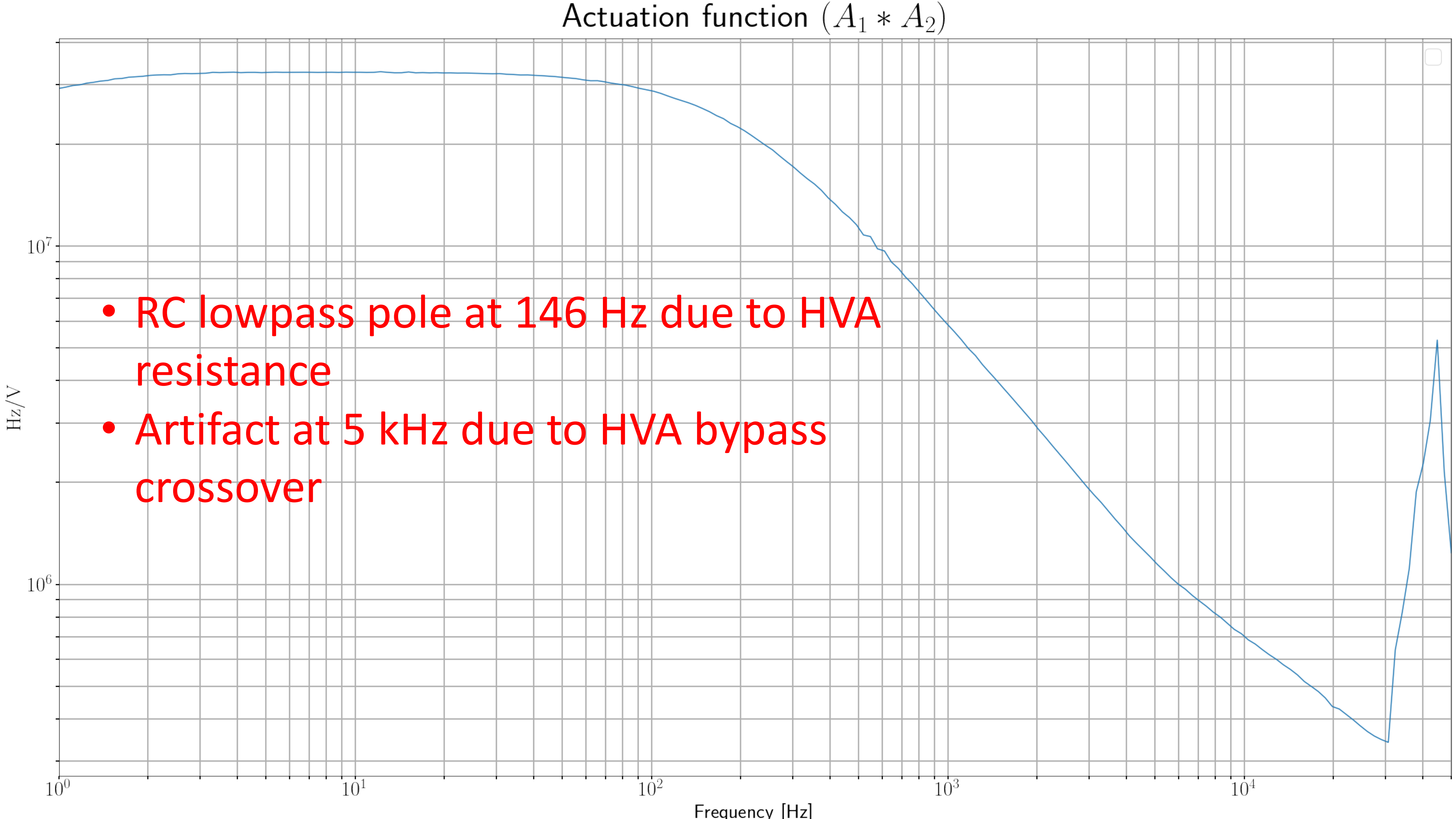
$$(signal) = \ V_{out}\ (f) * A_1\ (f) * \ A_2 * \frac{1 - OLG(f)}{OLG(f)}$$

Measured : $OLG(f), A_1(f)$ and $Vout$

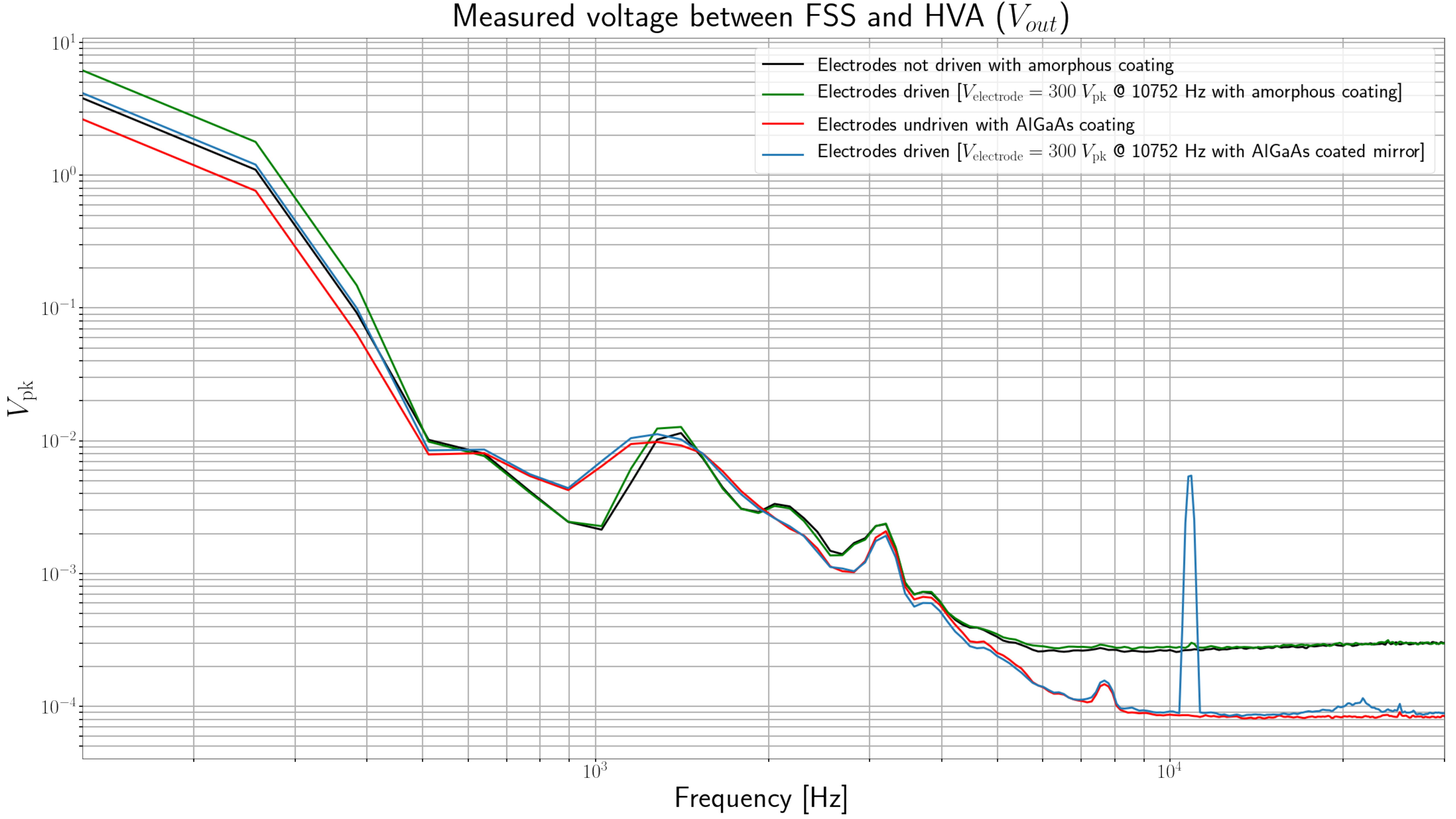
$A_2$ is laser PZT gain, currently from spec sheet, will measure with cavity sweep


OLG
60
40
20
0
−20
dB
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
Frequency [Hz]

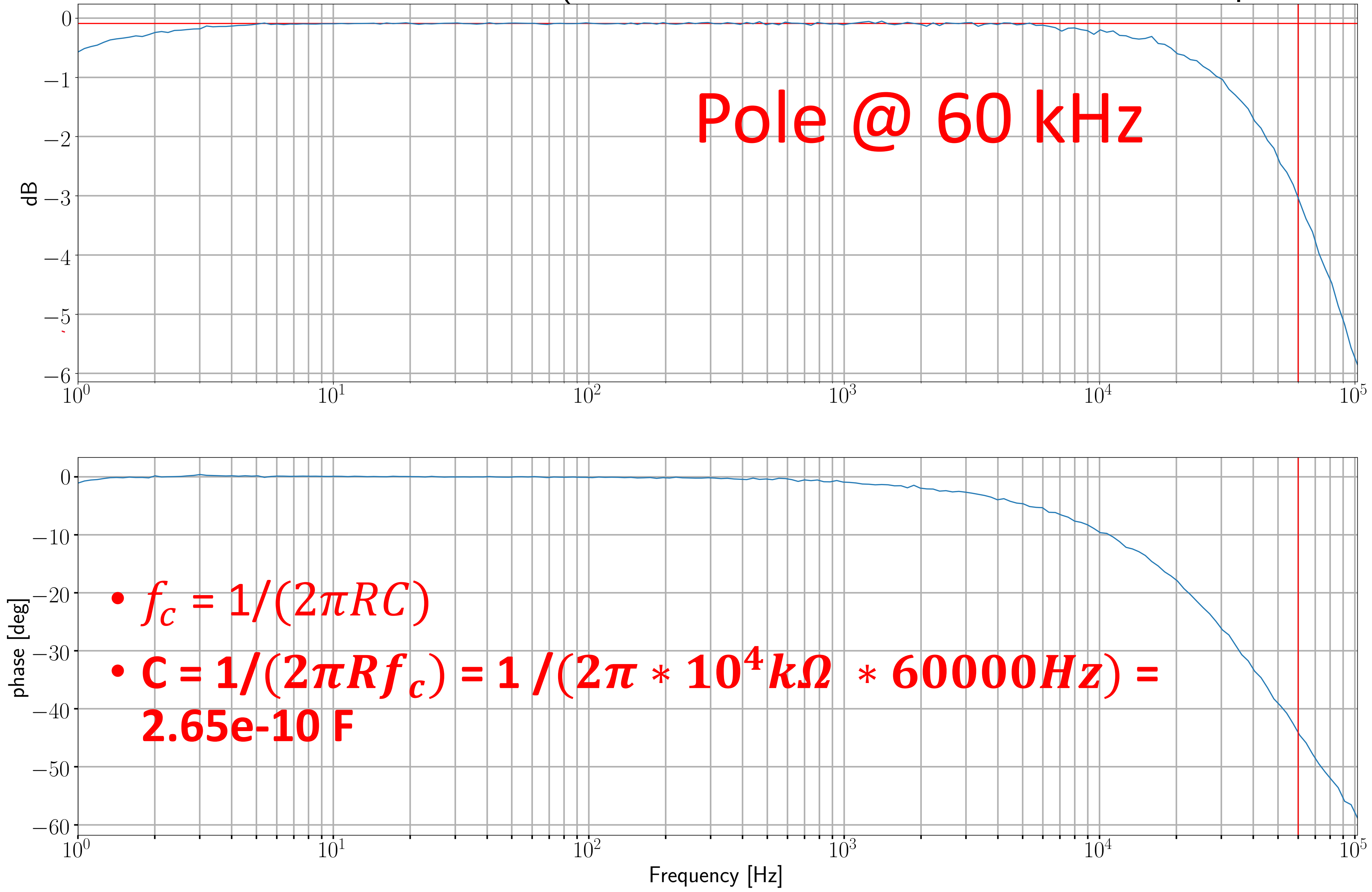

HVA $(A_1)$
30
20
10
0
−10
−20
dB
$10^0$
$10^1$
$10^2$
$10^3$
$10^4$
$10^5$
Frequency [Hz]




- RC lowpass pole at 146 Hz due to HVA resistance
- Artifact at 5 kHz due to HVA bypass crossover


Measured voltage between FSS and HVA ($V_{out}$)
Electrodes not driven with amorphous coating
Electrodes driven [$V_{\mathrm{electrode}} = 300\ V_{\mathrm{pk}}$ @ 10752 Hz with amorphous coating]
Electrodes undriven with AlGaAs coating
Electrodes driven [$V_{\mathrm{electrode}} = 300\ V_{\mathrm{pk}}$ @ 10752 Hz with AlGaAs coated mirror]
$V_{\mathrm{pk}}$
$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$10^{-4}$
$10^{3}$
$10^{4}$
Frequency [Hz]

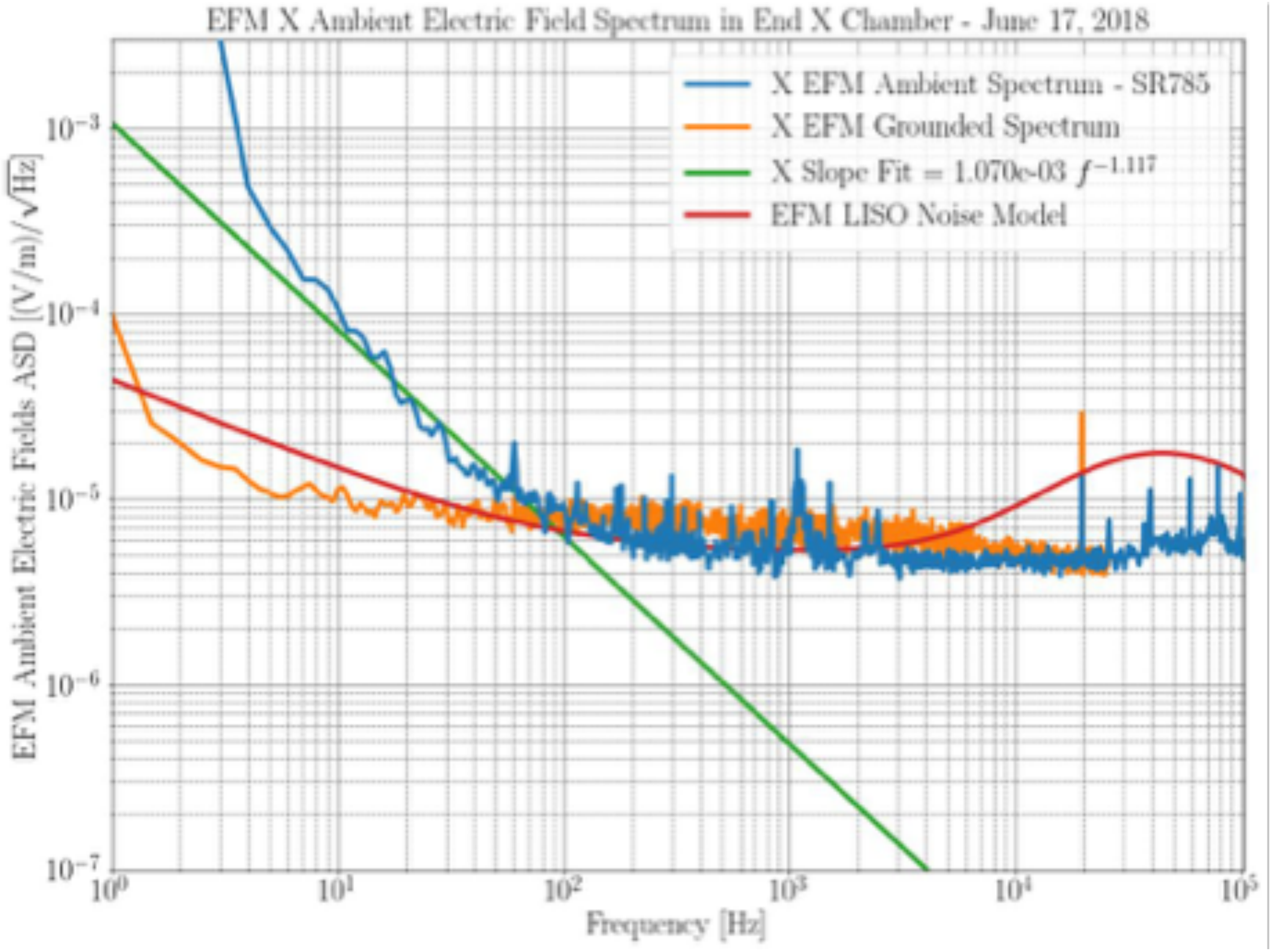
# LPF with 10kΩ resistor and electrodes (with 1in fused silica dielectric with HR amorphous coating)




- $f_c = 1/(2\pi RC)$
- **C = $1/(2\pi R f_c) = 1/(2\pi * 10^4 k\Omega * 60000 Hz)$ = 2.65e-10 F**

# LHO X-end Electric Field meter noise ASD

- Say ambient fields $\cong 10^{-5}[V/m/\sqrt{Hz}]$
- And assuming and order of magnitude estimate (based on model and measurement) of $\frac{6*10^{-12}}{300}\ [m/V/m]$
- Strain:
  - A+ : $5*10^{-23}$
  - CE : $5*10^{-24}$




Credit : Craig Cahillane