PPLN CRYSTAL NONLINEAR GAIN MEASUREMENTS FOR TABLETOP WAVEGUIDED OPTICAL PARAMETRIC AMPLIFICATION

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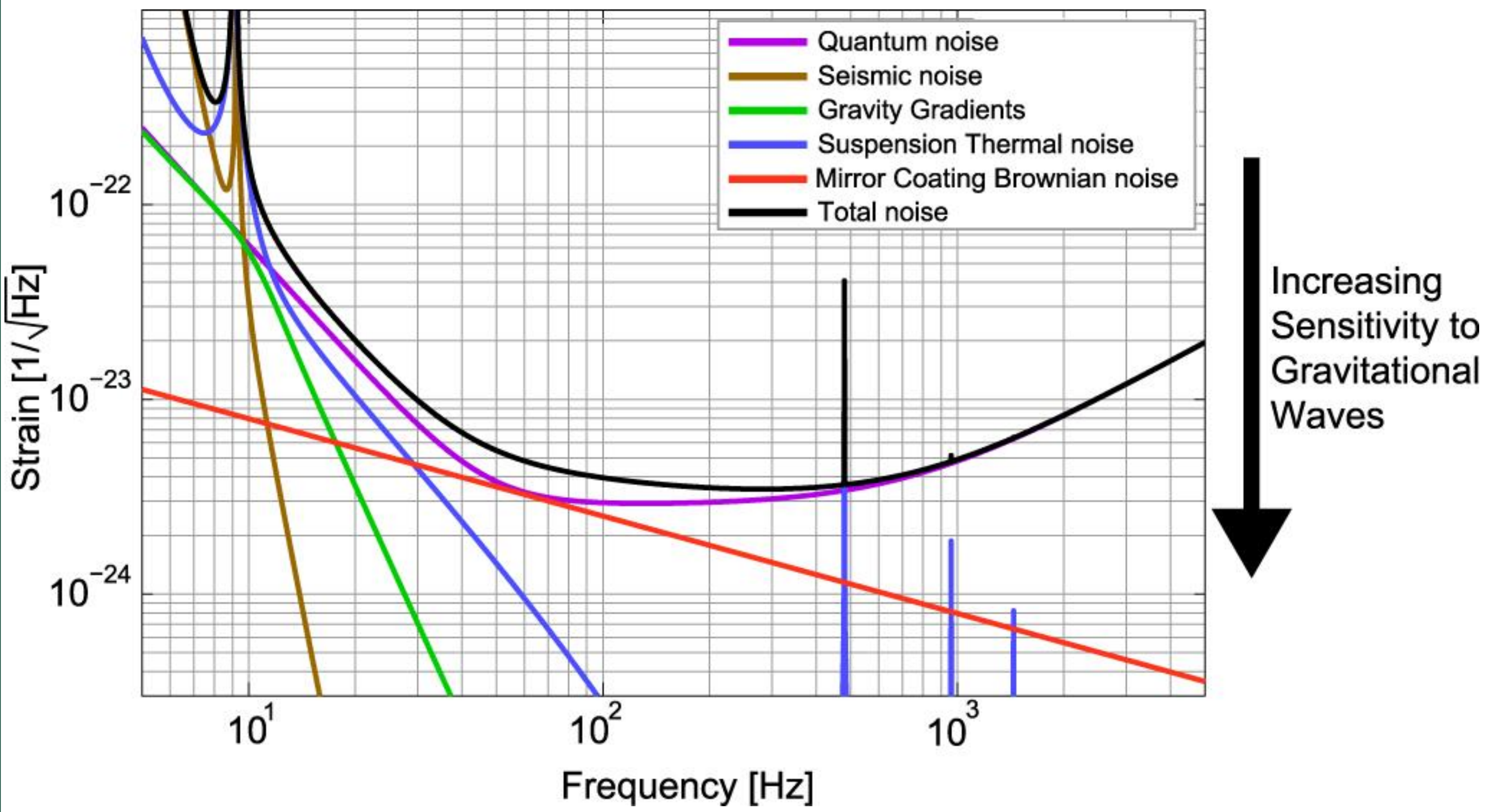
MOTIVATION FOR PROJECT

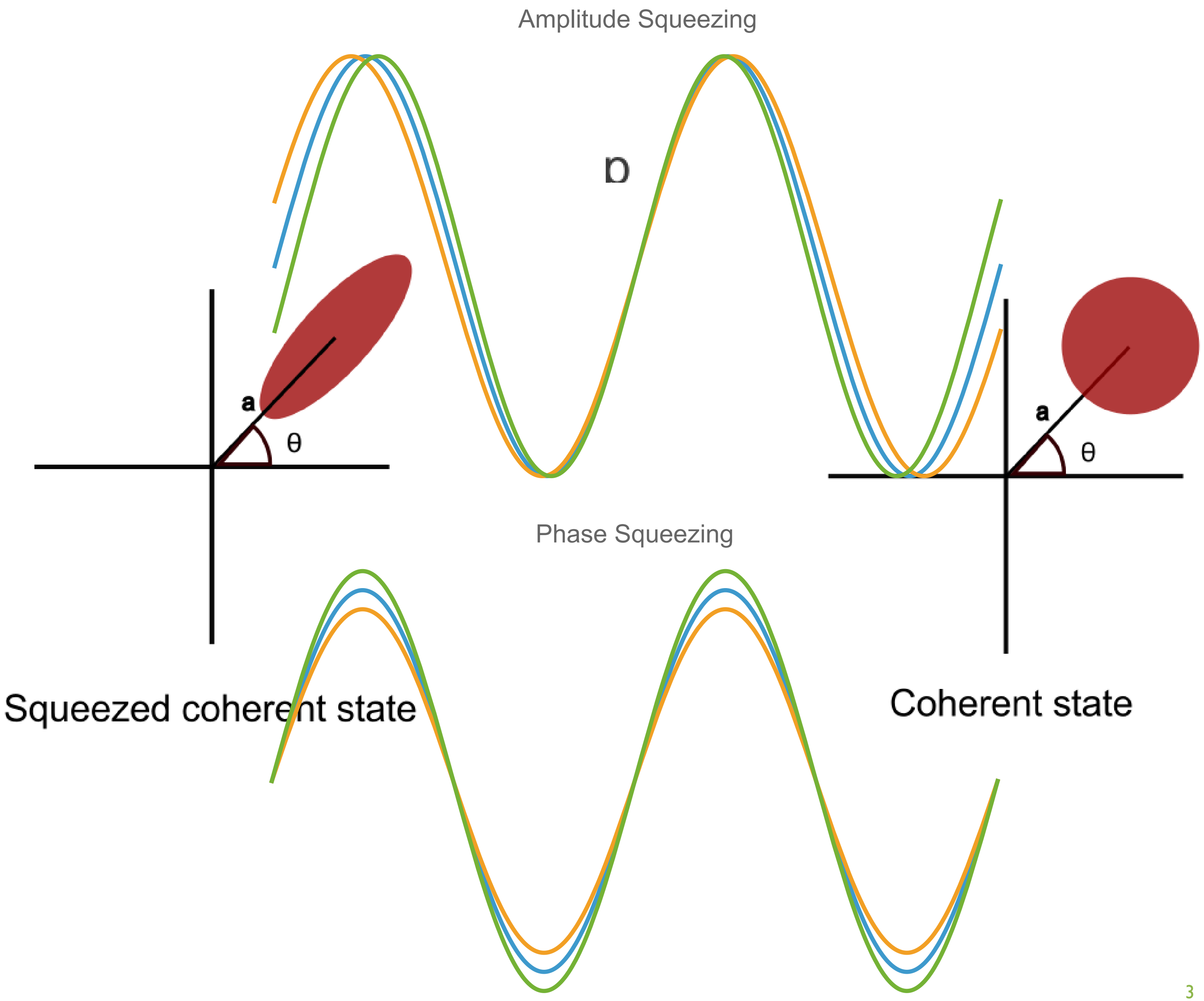
- LIGO's sensitivity to gravitational waves >500Hz is mostly limited by quantum noise
- Shot noise due to uncertainty in phase
- Quantum back action/radiation pressure noise due to uncertainty in amplitude



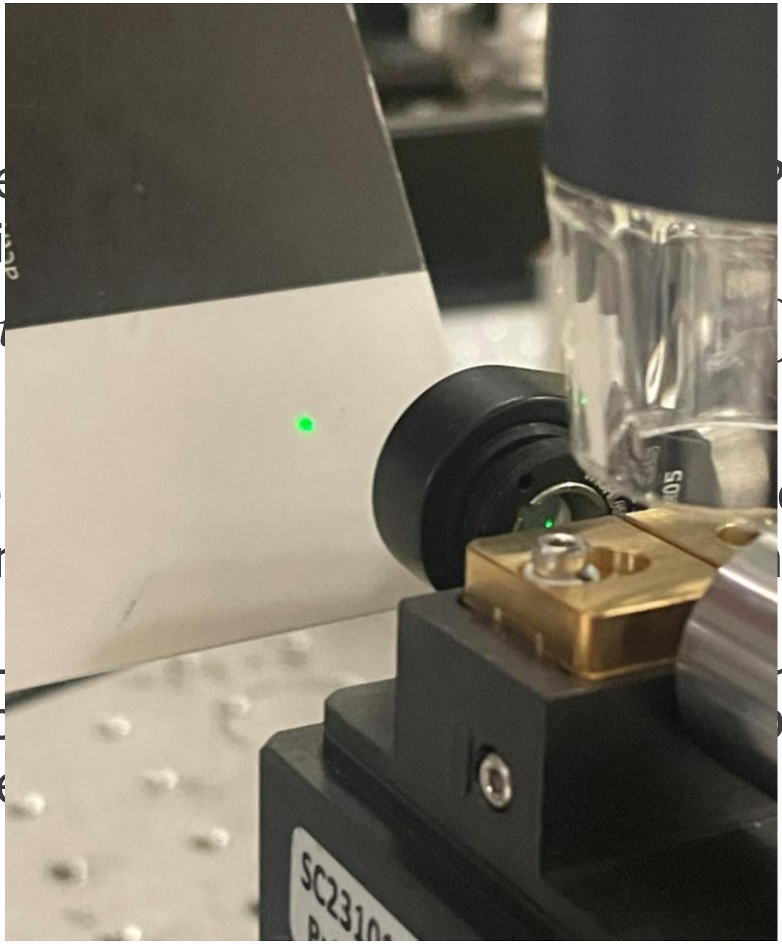
S S Y Chua *et al* 2014 *Class. Quantum Grav.* **31** 183001

BACKGROUND: QUANTUM SQUEEZING

- Quantum squeezing allows us to reduce uncertainty in one quadrature of light
- The overall uncertainty of the light must still obey the uncertainty principle, $\Delta x \Delta p \geq \hbar/2$
- The squeezing parameter, r, determines the degree of squeezing



BACKGROUND: CRASH COURSE IN NONLINEAR OPTICS



- The … $P(t)$, can be wri…

  $P(t$ … $)$

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- PPL… ugh to allo… tical inte…

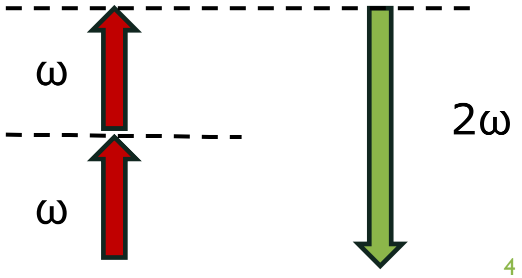
Ex. Second-harmonic generation (SHG)

Second-harmonic term

$$\tilde{P}^{(2)}(t) = 2\epsilon_0\chi^{(2)}EE^* + \left(\epsilon_0\chi^{(2)}E^2e^{-i2\omega t} + \text{c.c.}\right)$$

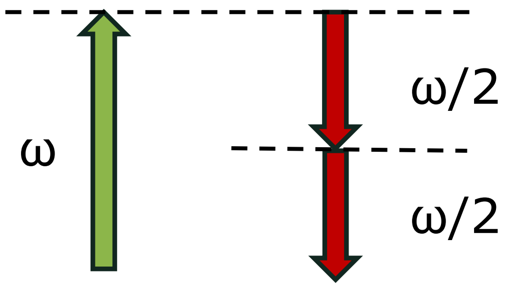
2 pump photons → 1 signal photon

Energy level diagram of SHG



BACKGROUND: GENERATION OF SQUEEZED LIGHT

Energy level diagram of SPDC

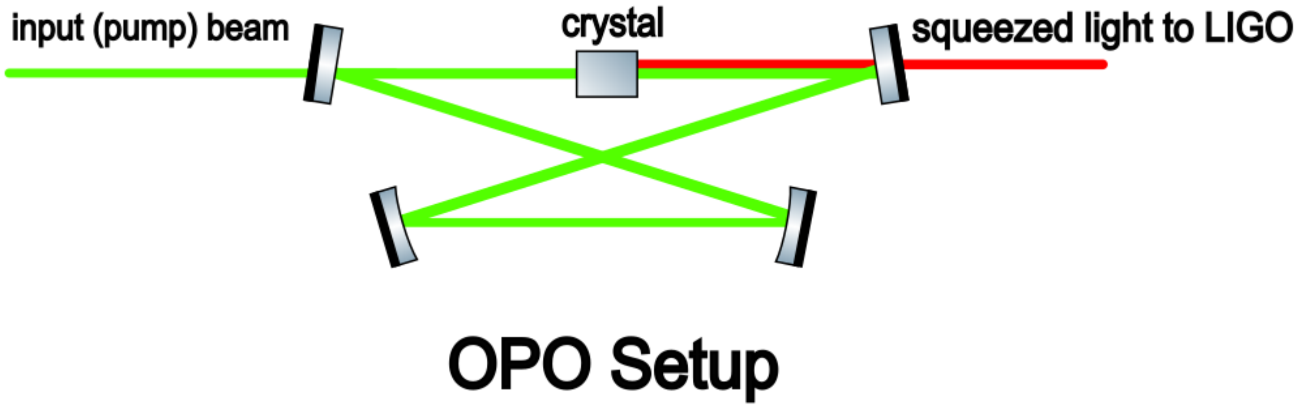


Radiation of ω/2 frequency light due to nonlinear interactions with vacuum field in crystal

- Use a nonlinear optical process called Type 0 spontaneous parametric down conversion (SPDC)
- Converts a pump photon to a pair of photons of half the original frequency such that all photons have the same polarization
- Generated pairs coupled in polarization and phase and therefore squeezed

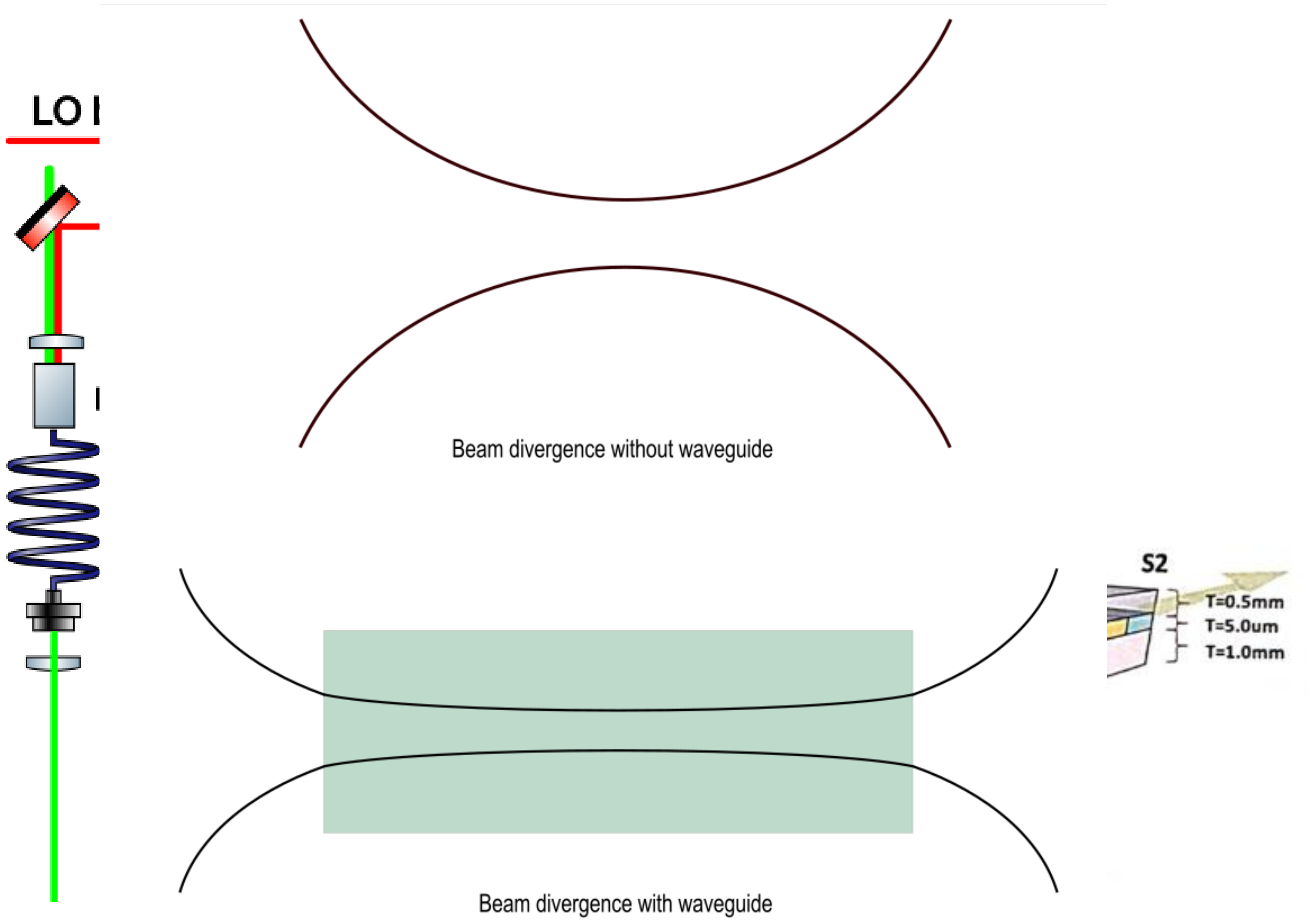
BACKGROUND: LIGO'S CURRENT SQUEEZING METHOD

- LIGO uses an optical parametric oscillator (OPO) to generate squeezed light which is mixed with the LIGO beam and squeezes it
- This consists of a KTP bulk crystal inside of a bowtie cavity



BACKGROUND: SIMPLIFYING THE SQUEEZING METHOD

- This project aims to simplify the current squeezing method and eliminate cavity loss present in OPO
- Similar process to OPO called waveguided optical parametric amplification (WOPA)
- Generate squeezed light with a single pass through a periodically poled Lithium Niobate (PPLN) waveguide



Simplified WOPA setup

LIMITS TO SQUEEZING LEVEL IN WOPA

- There exist multiple sources of potential loss in the WOPA system
  - Polarization mismatch
  - Mode mismatch
  - Fiber misalignment
  - BHD visibility
- To better identify the sources of loss affecting measured squeezing level, we calculated our expected squeezing level from the nonlinear gain of the process generating the squeezed light

SQUEEZING LEVEL AS A FUNCTION OF NONLINEAR GAIN

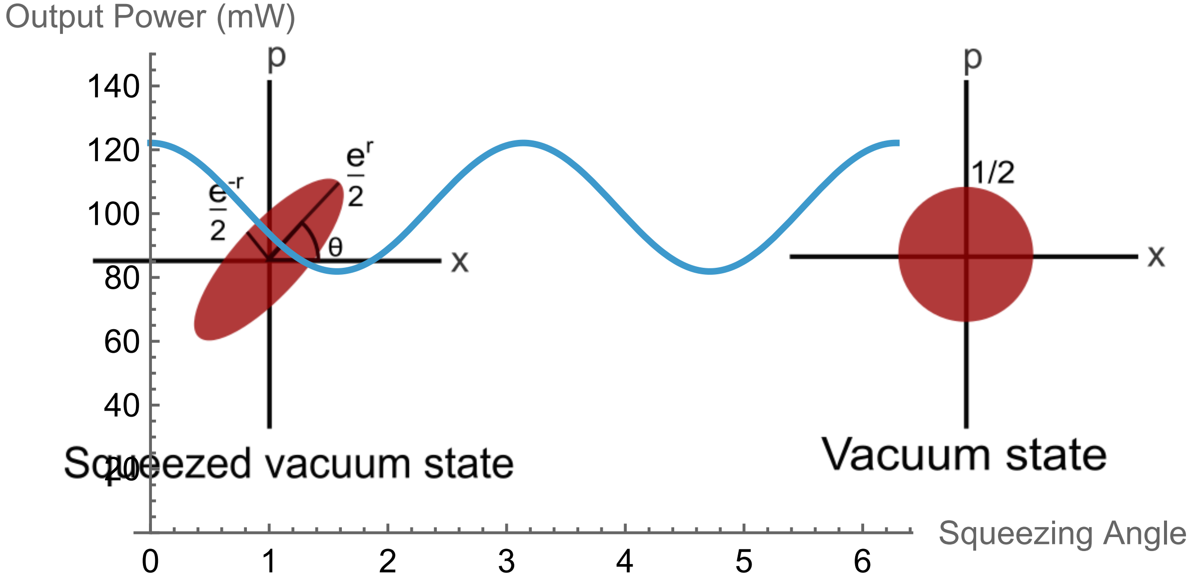
- The output power can be written as a function of the squeezing parameter and angle

$$P_s = \alpha^2(\cosh 2r + \cos 2\psi \sinh 2r)$$

- We can use this to solve for r and calculate the expected squeezing level as

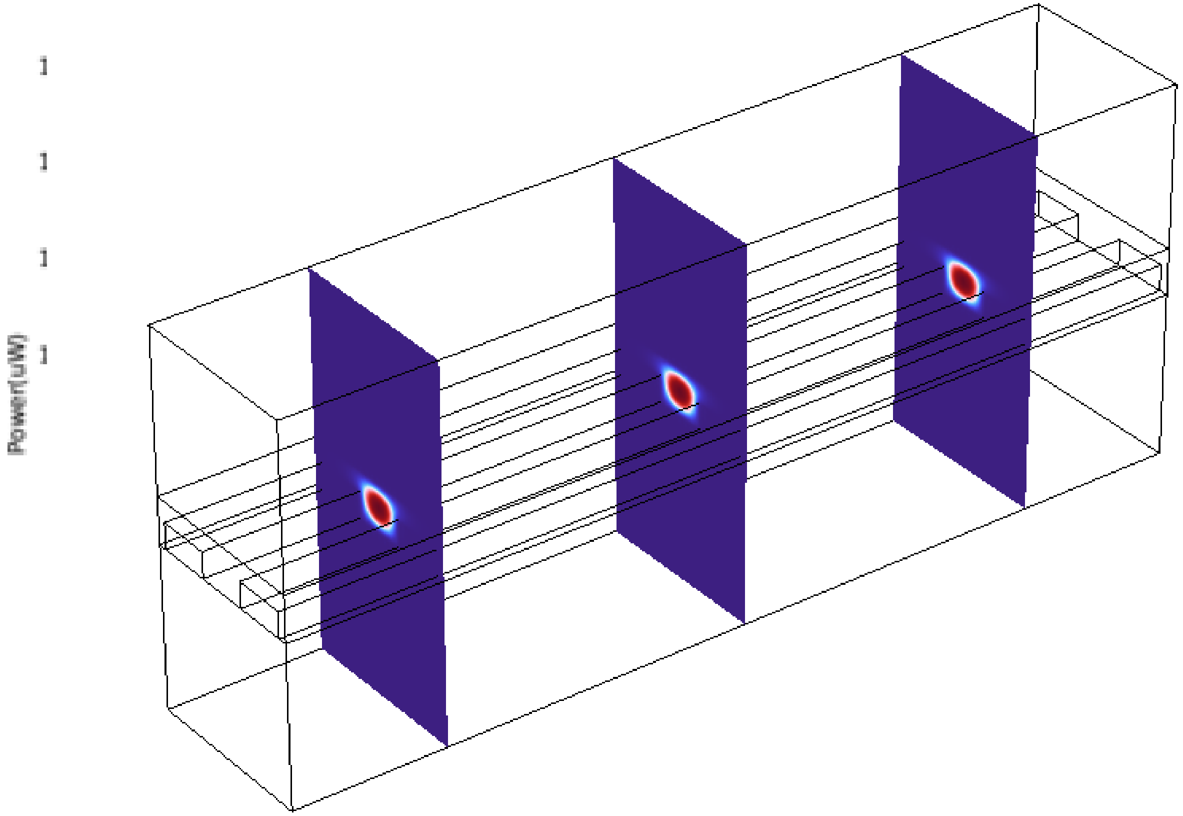
$$Sq(dB) = -10\log_{10}(e^{-2r})$$

Output Power for r=0.1 and 100mW Seed Power



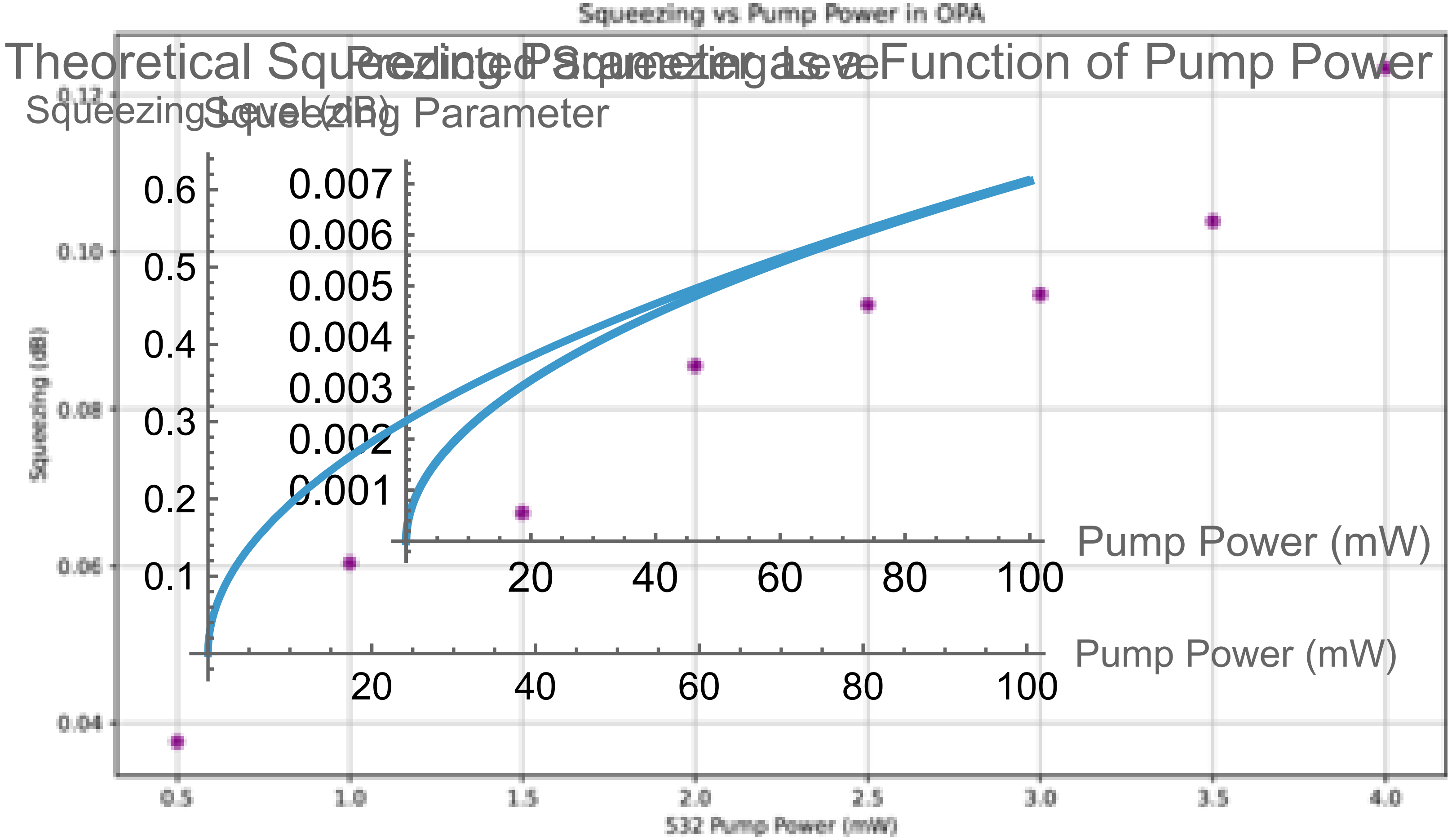
INITIAL NONLINEAR GAIN MEASUREMENT METHOD

- First align 1064nm beam to crystal axis by maximizing SHG
- Then maximize 532nm transmission through crystal while maintaining SHG
- Modulate signal beam phase and measure amplitude of peaks



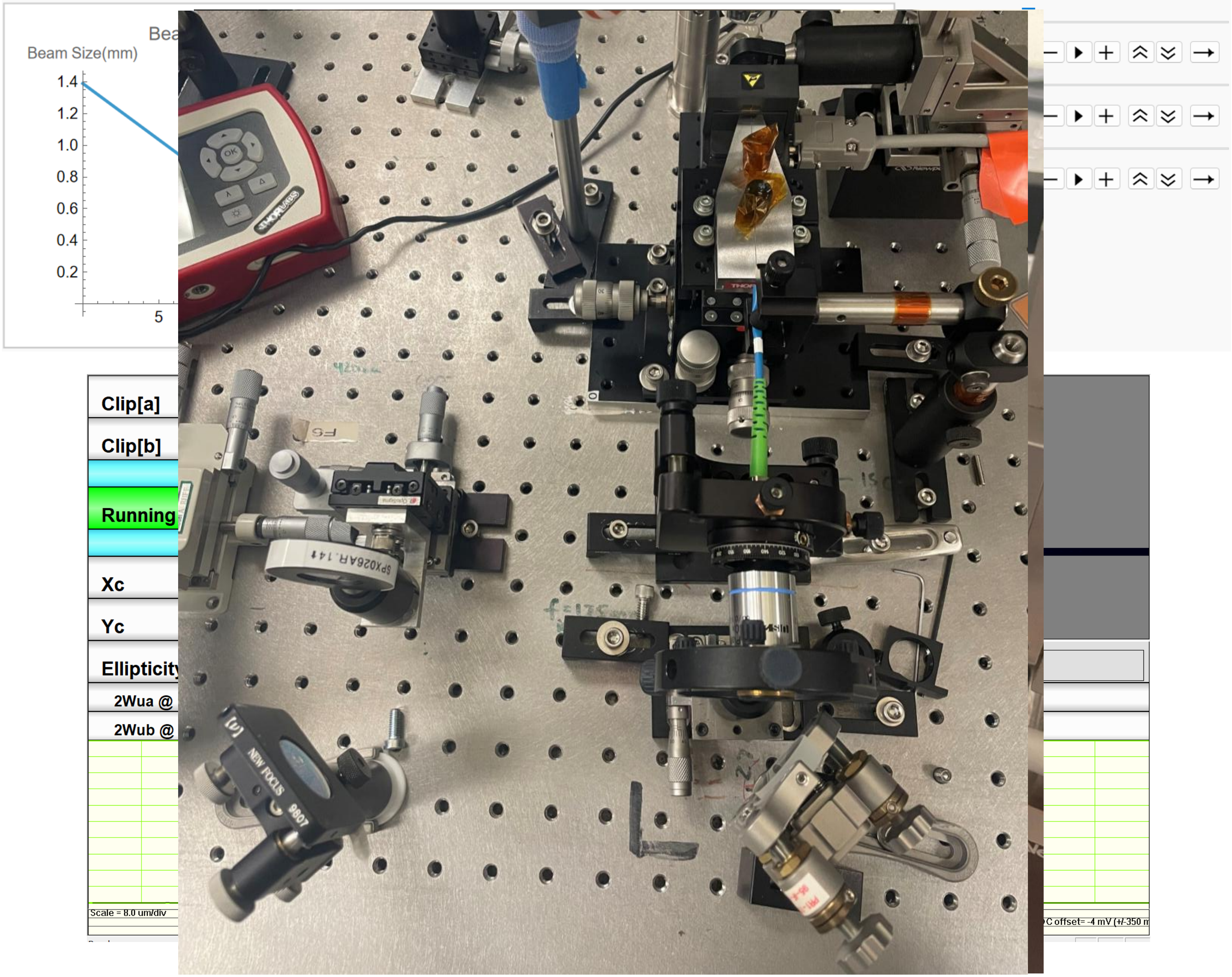
INITIAL NONLINEAR GAIN MEASUREMENT RESULTS

- We measure an initial maximum gain of 0.12dB for 4mW of pump power
- This agrees with the previously measured maximum squeezing level of 0.13dB
- Extrapolating our data predicts a squeezing level of 0.612dB for 100mW of pump power



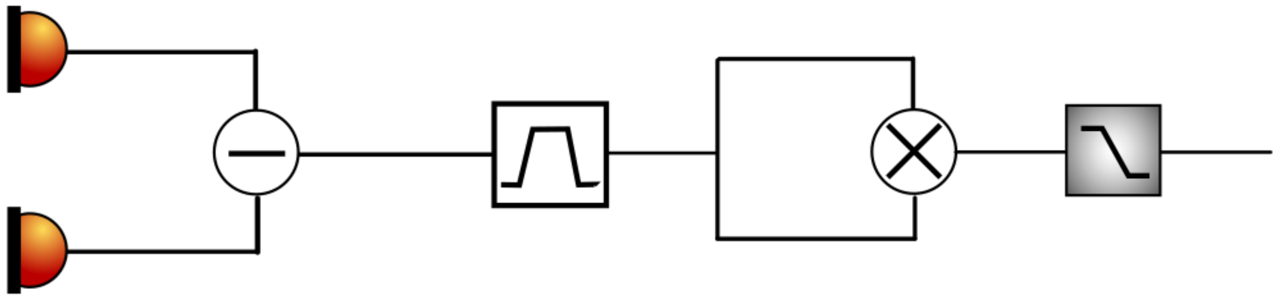
TUNING GAIN/SQUEEZING LEVEL

- Polarization measurements and tuning
  - By tuning the polarization, we were able to increase the nonlinear gain by 0.05dB or 4.25%
- Fiber and free-space coupling
  - MFD of crystal 4.83um x 4.16um
- Crystal temperature



MEASURING SQUEEZING

- To measure squeezing, we use a balanced homodyne detector (BHD) and modulate the phase of our local oscillator (LO)
- BHD visibility improved slightly from previous squeezing measurements to 62%
- The two PDs of the BHD measure fluctuations in shot noise due to squeezing and anti-squeezing



NEXT STEPS…

- Optimize pump power and crystal alignment to measure squeezing
  - Via simultaneous alignment for SHG or by measuring nonlinear gain
- Free space coupling
  - Would eliminate fiber losses in polarization, mode, and power
- Laser realignment
  - Reduce power fluctuations and loss in the system

THANK YOU!

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- My parents