Introduction
The final goal of this experiment is to produce and control laser-induced sub-femtosecond electron pulses from a field emission tip. Such electron pulses would be the fastest pulses on record and would push the Heisenberg uncertainty principle to its limits. Ultrafast electron pulses also have practical applications such as ultrafast electron microscopy.

How Short Is a Femtosecond?
A femtosecond is defined as 10⁻¹⁵s. Most modern computer processors operate at speeds of a few GHz, meaning they send a few billion electrical signals every second. Femtoseconds are so short that one million of them pass in the time it takes for a computer processor to send one signal!

Frequency Doubling and Tripling
We need to use our 800nm (red) laser to produce 400nm (violet) light. This is accomplished using a doubling crystal, which absorbs two red photons (each with energy ℏω) and emits one violet photon with twice as much energy and hence twice the frequency. Similarly, a tripling crystal combines a red pulse and a violet pulse to produce 266nm (ultraviolet) light.

Phase Dependence of a Fast Response
The tip’s response depends on the temporal alignment of the light pulses as well as the phase of the oscillations within each pulse (see diagram). We are interested in sub-cycle emission—emission due to individual oscillations—which can only take place if the tip’s response is faster than the red pulse’s 2.7fs cycle. We have shown mathematically that any observed phase dependence for red and violet light must be due to the individual oscillations within the pulses. Therefore, such a phase dependence would suggest a sub-cycle response!

Experimental Setup
• Our laser’s 800nm pulses are focused on the doubling crystal, which outputs 800nm and 400nm light.
• The beams enter the interferometer:
  – The red and violet beams are separated.
  – The path length of the violet beam is adjustable on the micron scale using a translation stage.
  – The beams are recombined and aligned spatially and temporally.
• A flip mirror directs the beams to the tripling crystal, which produces 266nm light only if the interferometer is properly aligned.
• Once aligned, the pulses are sent past the flip mirror to the field emission tip.

How Difficult Is This?
For our experiment to work, the two pulses of light have to simultaneously hit a target only a few microns wide over a path of a few meters. This is roughly equivalent to simultaneously hitting the period at the end of this sentence with two bullets fired from a kilometer away.

Results and Conclusions
• We assembled a working interferometer from scratch and precisely aligned it to observe interference between two 800nm pulses.
• We formulated a mathematical argument describing the response of the tip.
• We were not able to align our interferometer precisely enough to achieve tripling. Thus, we have not yet sent our beam to the tip.
• We have undergone extensive troubleshooting and significantly improved our optical setup and methodology. With more time, we believe we could achieve tripling and deliver temporally aligned light to the tip.

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References

What Is a Field Emission Tip?
A field emission tip is a small metal tip (usually made of tungsten) which emits electrons when a high voltage is applied to it. Similarly, the strong electric field of a pulsed laser can also induce electron emission. Our experiment studies what happens when two light pulses of different frequencies (red and violet) hit the tip at the same time.