Developing a High Power Electron Paramagnetic Resonance Spectrometer to Study Electron Spin Dynamics

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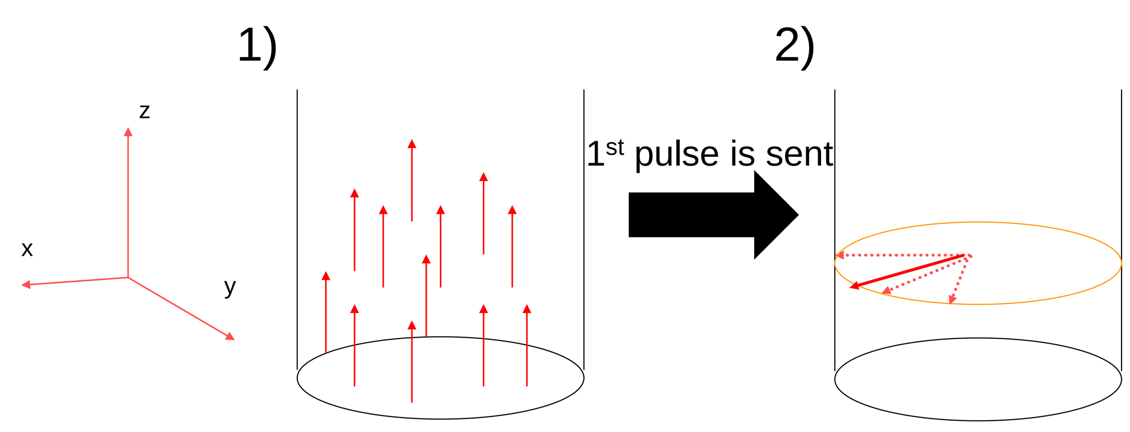
Project Overview:

- Analyze two-pulsed EPR experiment
- Use UCSB's Free Electron Laser (FEL) operating at 240 GHz and producing 1000 watt power as source of radiation
- Identify and isolate superfluous radiation entering the system
- Improve efficiency of pulse slicing process
- Study the electron spin dynamics of fast moving systems (i.e. proteins at room temperature)

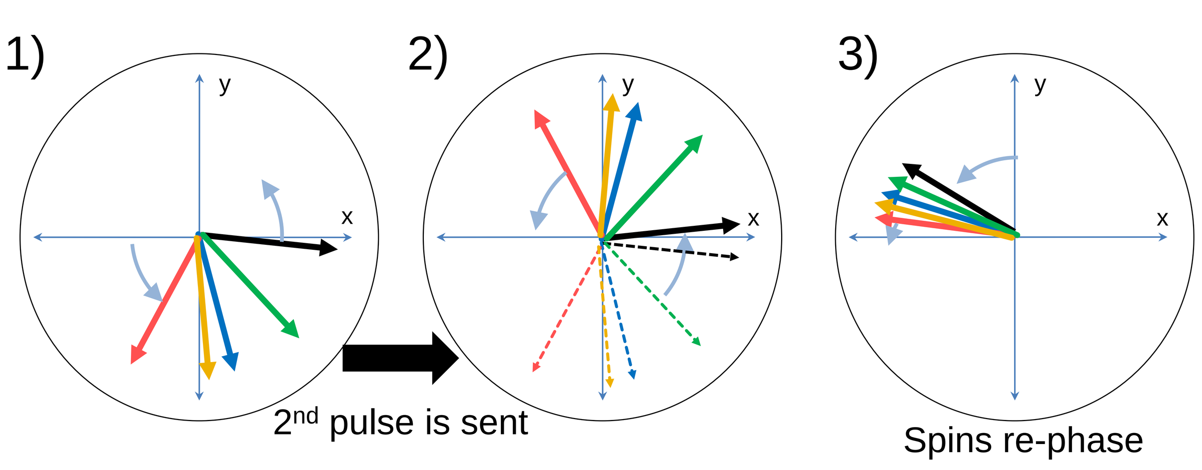
Background:

- Two-pulsed EPR is used to study electron spin dynamics of a substance that is placed in a high magnetic field in order to understand the local environments surrounding electron spins.
- We expose the sample to two separate pulses of radiation and measure its reaction.



1. We place a sample in a high magnetic field (~8.5 T) to orient the electron spins in the vertical direction
2. The first pulse of radiation knocks the spins horizontally, where they begin to process counter-clockwise

- The spins rotate with varying velocity, and the spins begin to de-phase



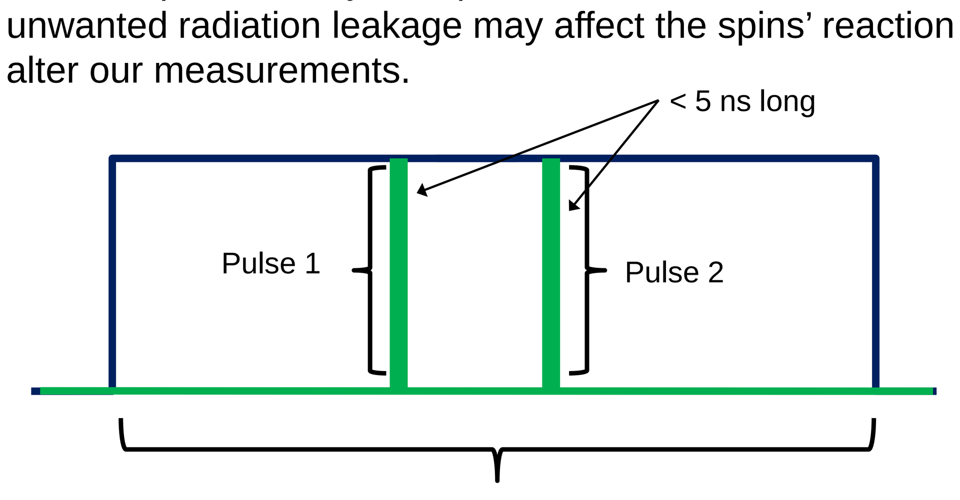
- Images of the electron spins from above. Arbitrarily color coded to illustrate individuality. The black spin rotates most rapidly, while the red spin rotates slowest.
- Two dimensional reference plane shown

1. This shows the electron spins de-phased.
2. The second pulse rotates the spins around the x-axis. The slowest spin now leads and the fastest spin trails
3. Image of electron spins re-phasing. Because the faster spins are lagging, they soon catch up to slower spins and re-phase, creating an "echo"

- We will measure the echo, which indicates how many electron spins are able to re-phase, and how many spins are affected too much by their local environments

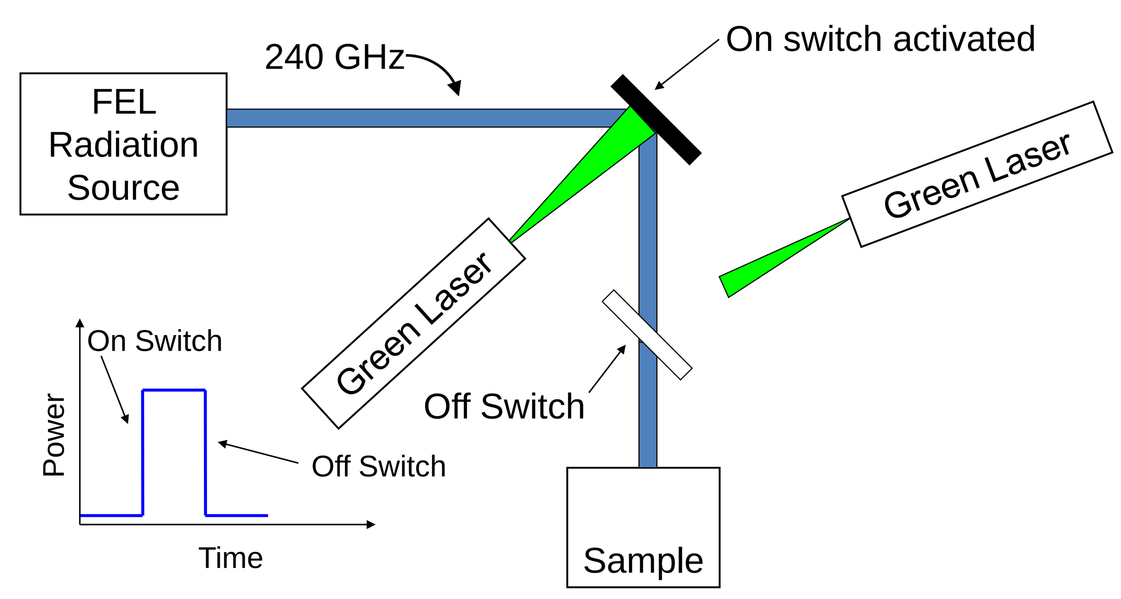
Sherwin Research Group Focus:

- Our focus is to develop and improve the two pulses of radiation being sent into the sample
- We wish to study samples with fast spin dynamics, meaning the electron spins will react very quickly to the applied radiation
- We seek to develop a two-pulsed system producing 1-5 nanosecond pulses. High power is required in order to produce such pulses.
- We will also focus on reducing the presence of background radiation leaking into the sample. We will apply kW power, but the echo produced by the spins are on the scale of nW, so unwanted radiation leakage may affect the spins' reaction and alter our measurements.



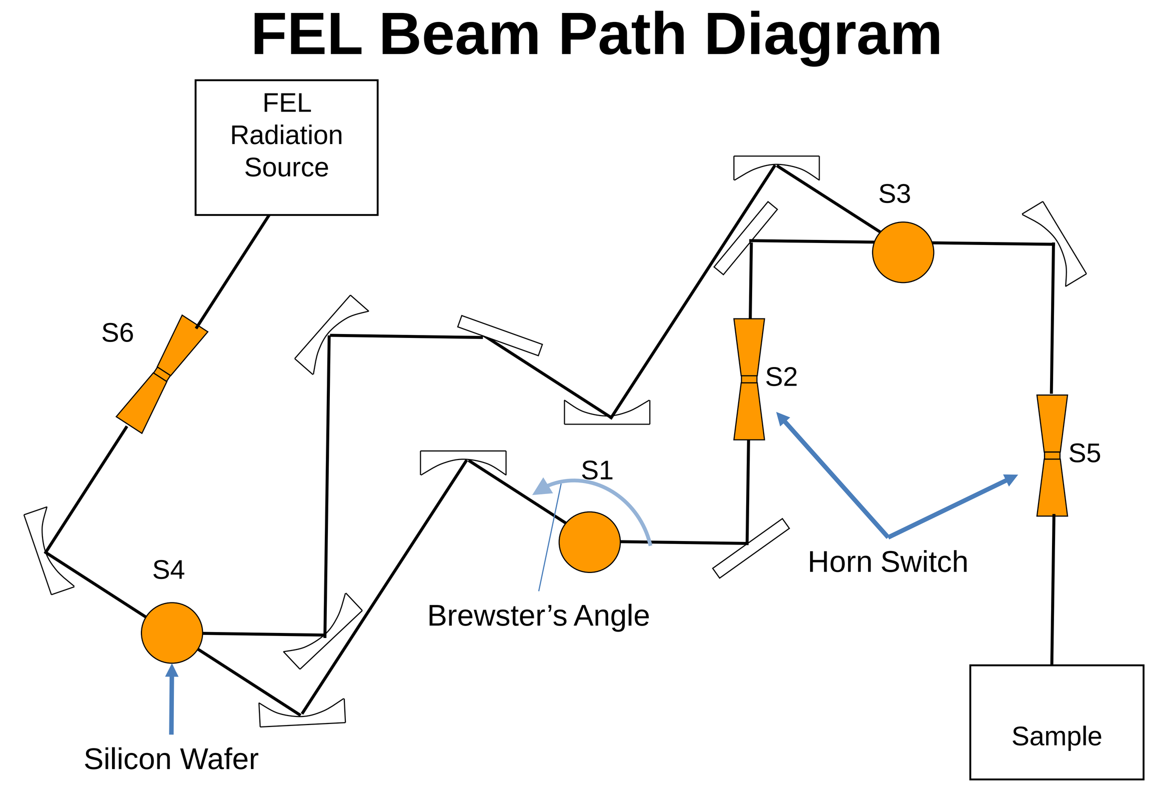
- We look to slice the 1 μs pulse of radiation produced by the FEL into two separate pulses, each less than 5 nanoseconds long.
- We create the pulses by using silicon switches activated by high-powered Yttrium Aluminum Garnet (YAG) lasers
- Since we use < 1% of the FEL pulse, a main concern is to prevent the unused radiation from entering our system

Creating a Pulse

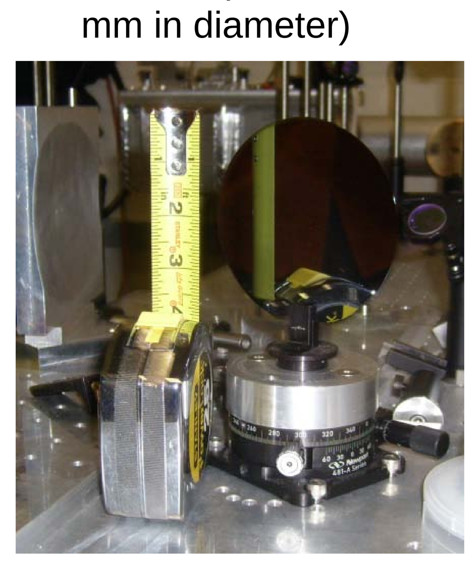


- At 240 GHz radiation, the silicon switches are transparent. When activated by the YAG lasers, electrons are excited on the surface of the silicon, creating a plasma surface resulting in the switches becoming reflective.
- We activate the "on switch" to direct the radiation into the sample, and activate the "off switch" to direct the radiation away from the sample, creating a pulse.

FEL Beam Path Diagram

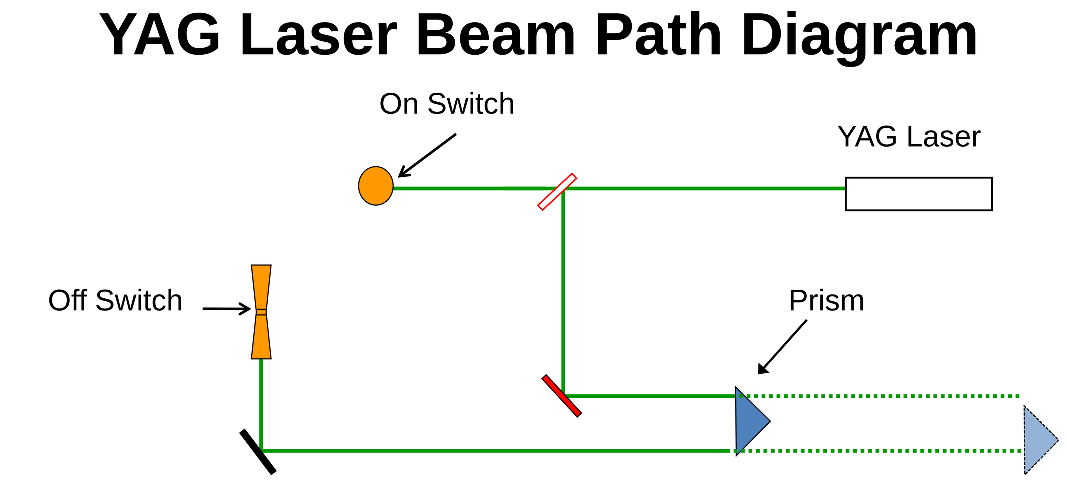


- Radiation passes through six switches, all activated by two YAG lasers at various times to create the two pulses.
- Two types of switches are: silicon wafers (round wafer ~4 in. diameter) and horn switches (two horns separated by silicon ~5 mm in diameter)




Left: image of a silicon wafer
Above: image of a horn switch

YAG Laser Beam Path Diagram



- Schematic of how one YAG laser activates multiple switches
- YAG laser beam passes through lenses, mirrors, and a prism and is directed toward each switch.
- Some beam paths are longer than others, creating a delay in their activation.
- Prism is adjustable, creating a variance in duration of the delay
- Light travel 1 ft./ns. If the beam path to the off switch is 4 feet longer than that of the on switch, there is a 4 ns delay

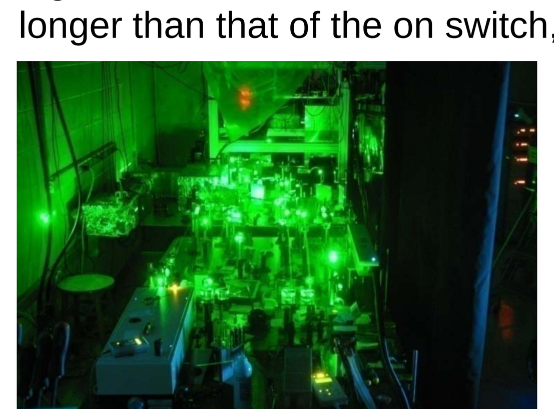


Image of high-powered YAG lasers activating the silicon switches

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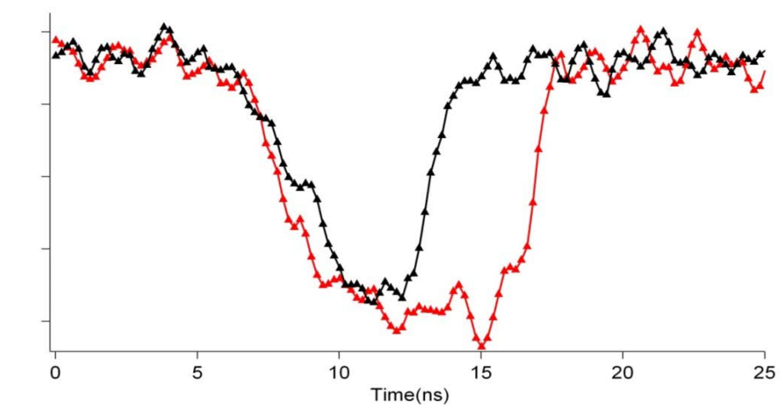
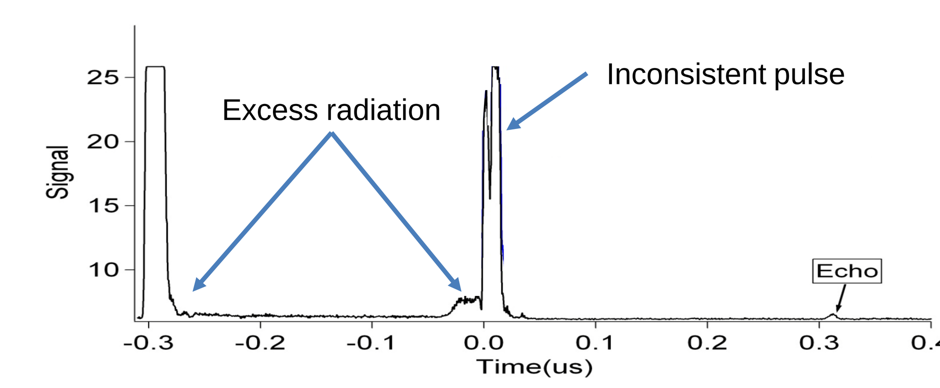
First Pulse: Changing Length



- Graph showing the effect of moving the prism
- The black pulse represents the prism location corresponding with the shortest beam path to the off switch, creating a shorter delay and a pulse ~4 ns long
- The red pulse represents the longest beam path to the off switch, creating ~8 ns delay
- We hope to implement a new track for the prism, creating greater pulse length variability



- Graph illustrating an entire two pulse measurement
- There is an abundance of excess radiation entering our system, creating background noise and inconsistent pulses

Progress

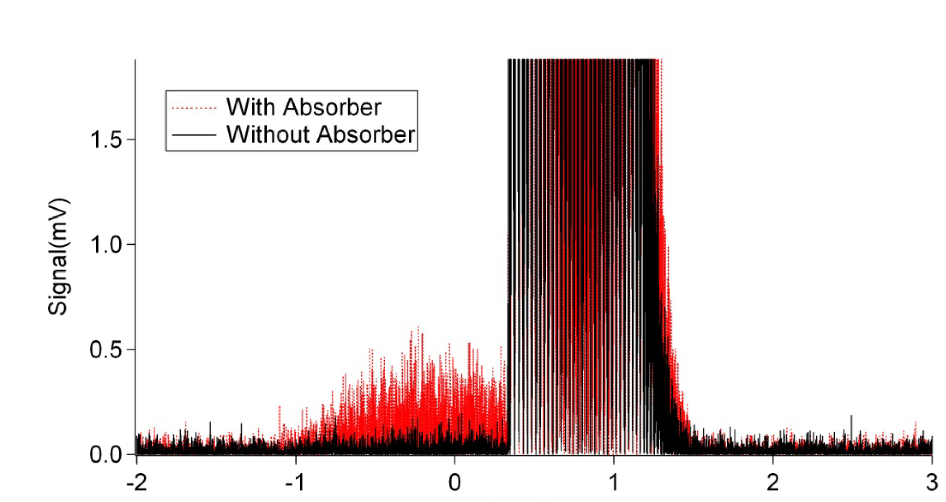
Our progress this summer included:

- Identifying the source of leaking radiation and to prevent it from entering our system.
- Creating diagrams of the YAG lasers and FEL beam paths for analysis
- Altering and aligning YAG laser beam to ensure maximum reflection from the silicon switches
- Brainstorming procedures to improve the consistency of the switch activation.

Excess Radiation Prevention


- Images of isolation boxes (left) and radiation dumping apparatus (witch's hat, right).
- We developed these devices to reduce noise due to scattered light and radiation from before switches are activated

Effect of Witch's Hat Implementation



- Above is a graph of the analysis of the first switch.
- The red graph represents the pulse before the witch's hat was implemented, and the black graph represents the pulse after the witch's hat was in place.
- The excess radiation before the pulse was significantly reduced with the witch's hat.

Further Research

- Further research includes implementing another off switch to reduce contrast to ~100 dB
- We wish to create a new path for the existing prisms in order to increase the pulse length variability.
- We will run a two-pulsed EPR experiment again shortly and compare to previous experiments to see improvements in pulse quality and reduction of background radiation, and to discover flaws for further improvements.