

Analysis of a laser induced plasma in high pressure SF₆ gas

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M.S.O.S.E Candidate**



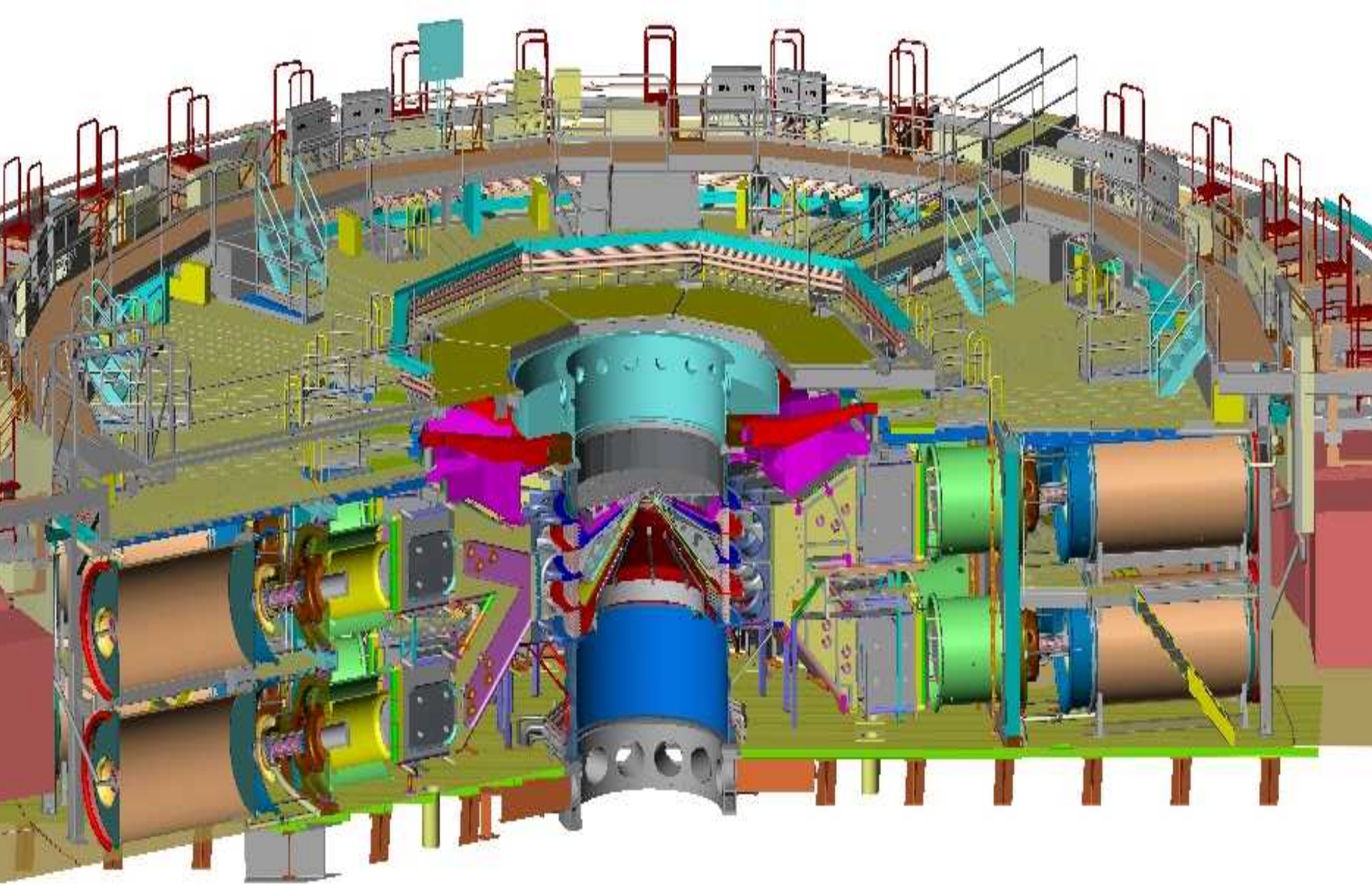
Acknowledgements

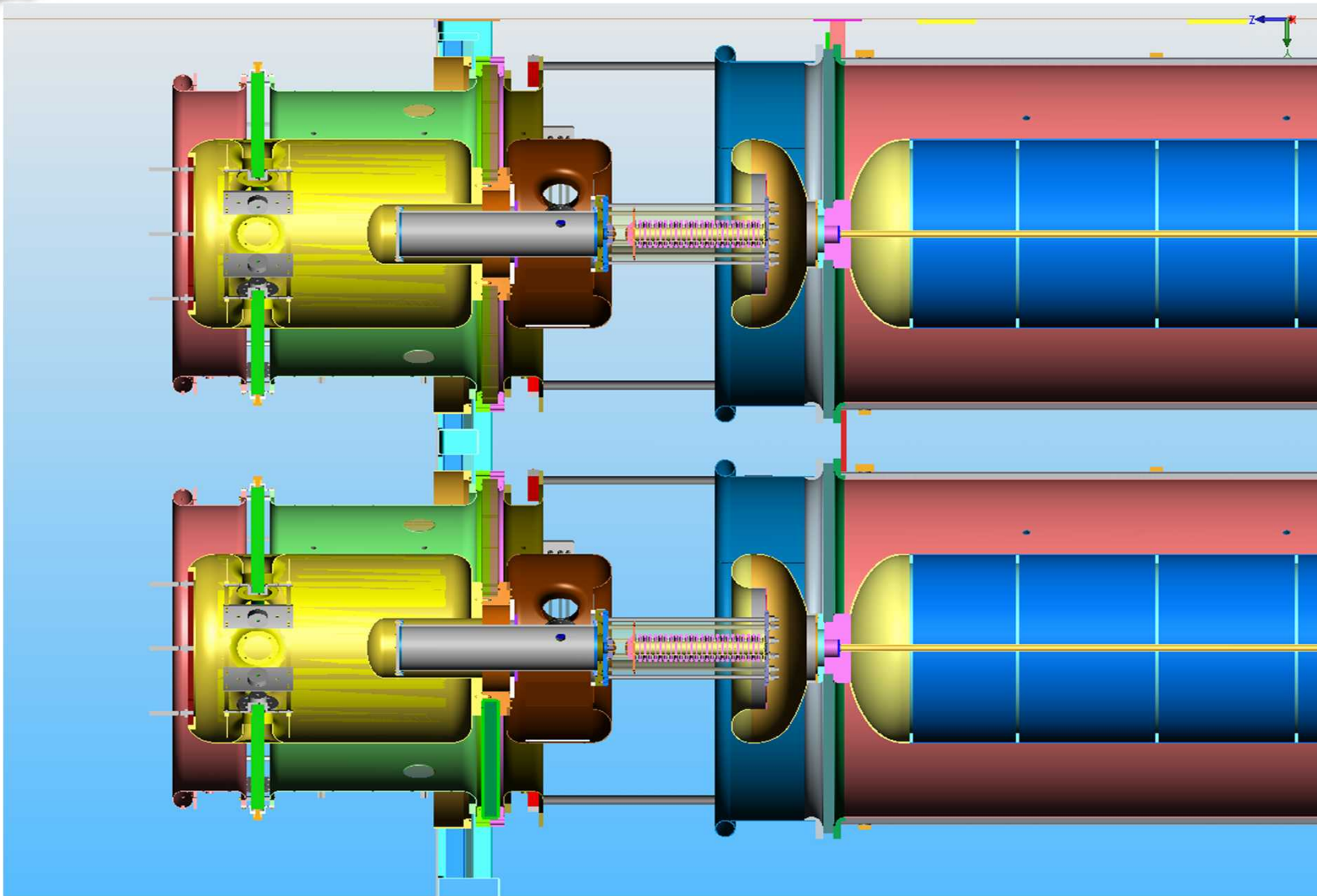
- **Committee Members**
 - **Mark Gilmore**
 - **Mark Savage**
 - **Alan Lynn**
- **Sandia Personnel**
 - **Ken Struve**
 - **John Maenchen**
 - **Brian Stoltzfus**
 - **Joe Woodworth**
 - **Dave Bliss**
- **Others**
 - **Jeremy Martin**
 - **Alim Haji**



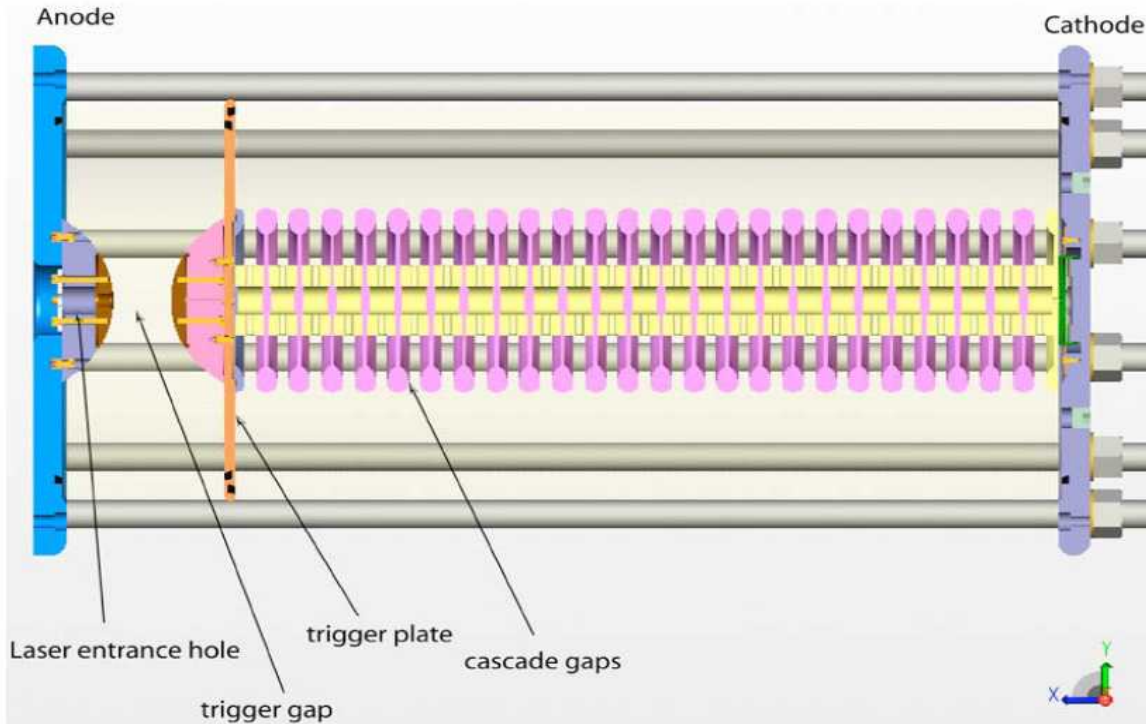
Outline

- **Intro/Project Motivation**
- **Laboratory Setup**
 - **Diagnostics**
 - **Visible**
 - **Schlieren**
 - **Electrical**
 - **Spectroscopy**
- **Results**
- **Future Work**





Full ZR Switch



- Laser triggered high voltage spark gap-pressurized with SF6 gas
- SF6 gas is extremely electronegative-holds off high voltage

Laser

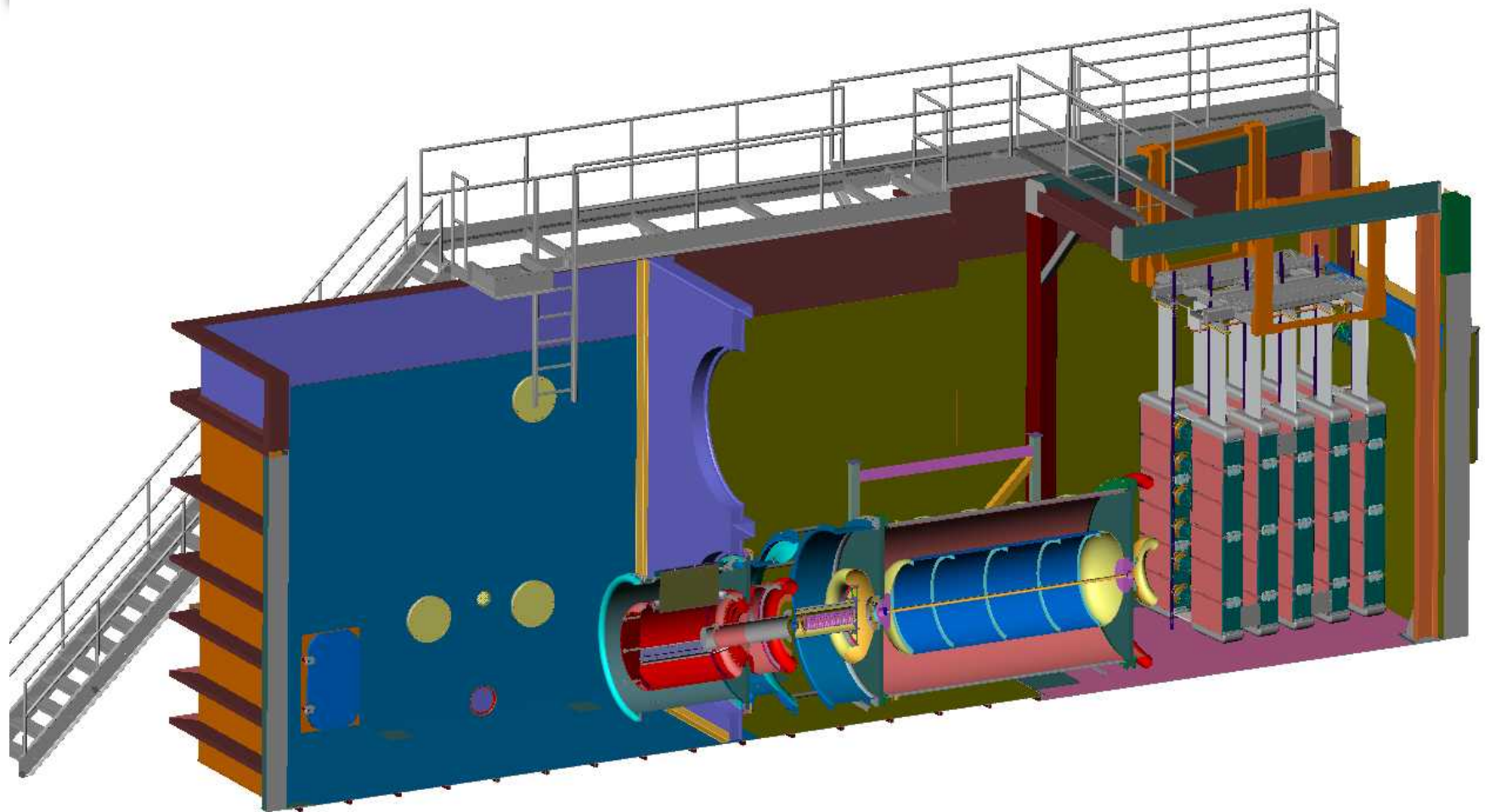


- **New Wave Research Tempest-10 laser operating in 4th harmonic at 266nm (UV)**
 - **Fundamental harmonic is 1064nm**
 - **KTP crystals used to generate laser harmonics of 532nm (2nd) and 266nm (4th)**
 - **Beam diameter ~12mm**



Z-Refurbishment

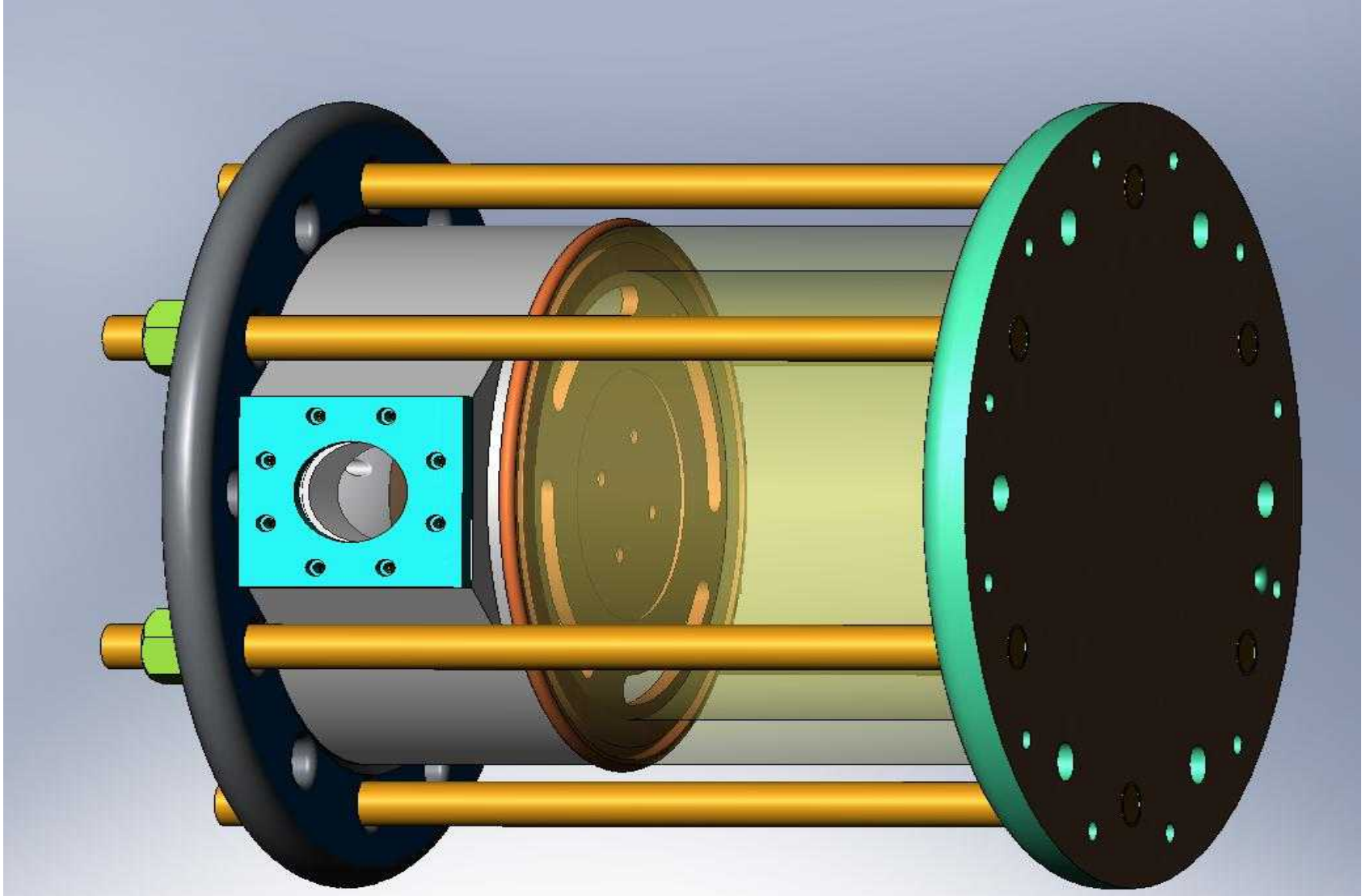
- **Sandia's Z-refurbishment project**
 - Upgrade Z machine
 - Upgrade to the SF6 gas switch
 - Last command triggered switch in power flow system
 - Reliable operation is critical-36 switches used to synchronize energy delivery to load
 - Initial tests on a switch test bed (STB) looked promising
 - Z-20 switch test bed (1 full ZR module) comes online 2003

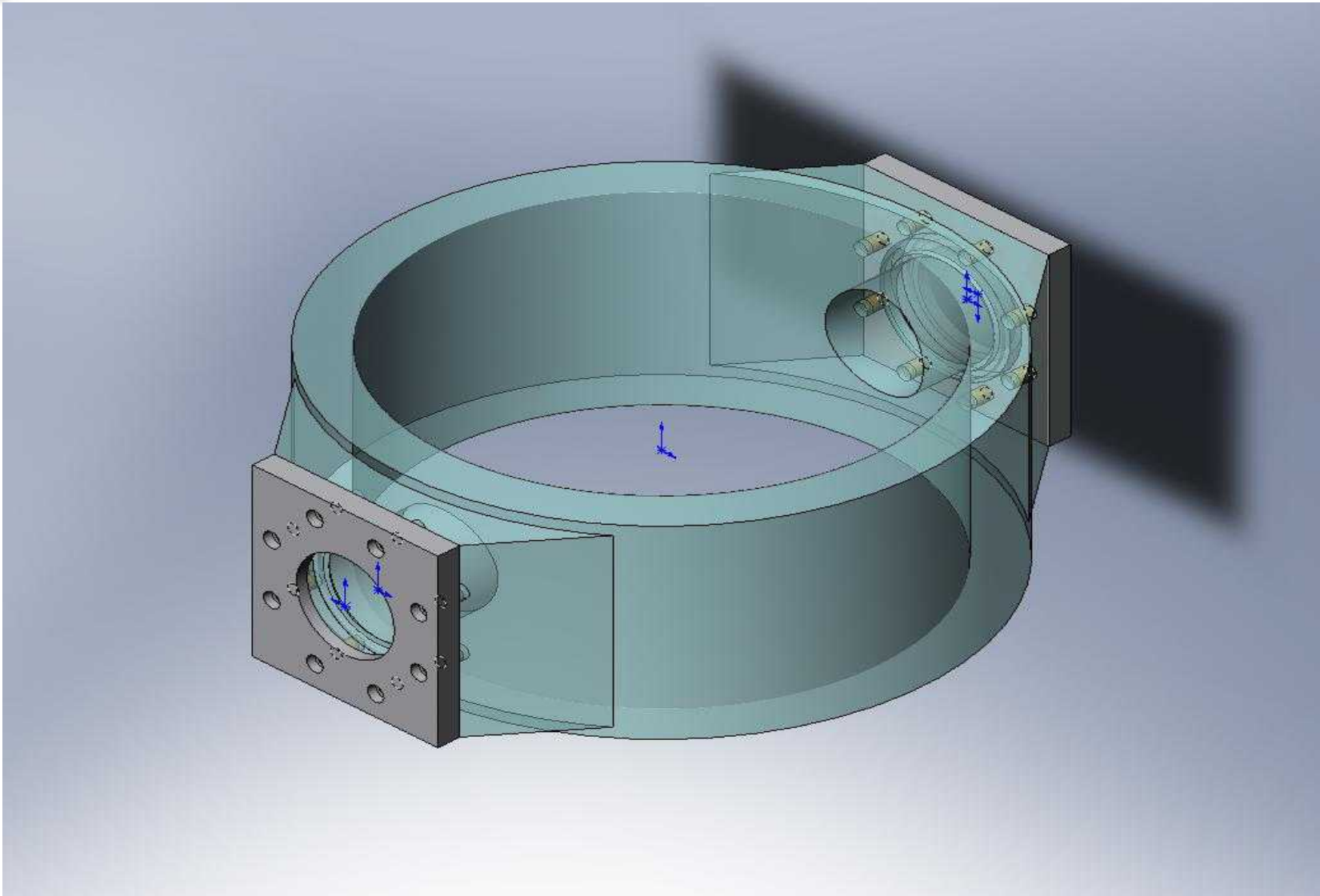


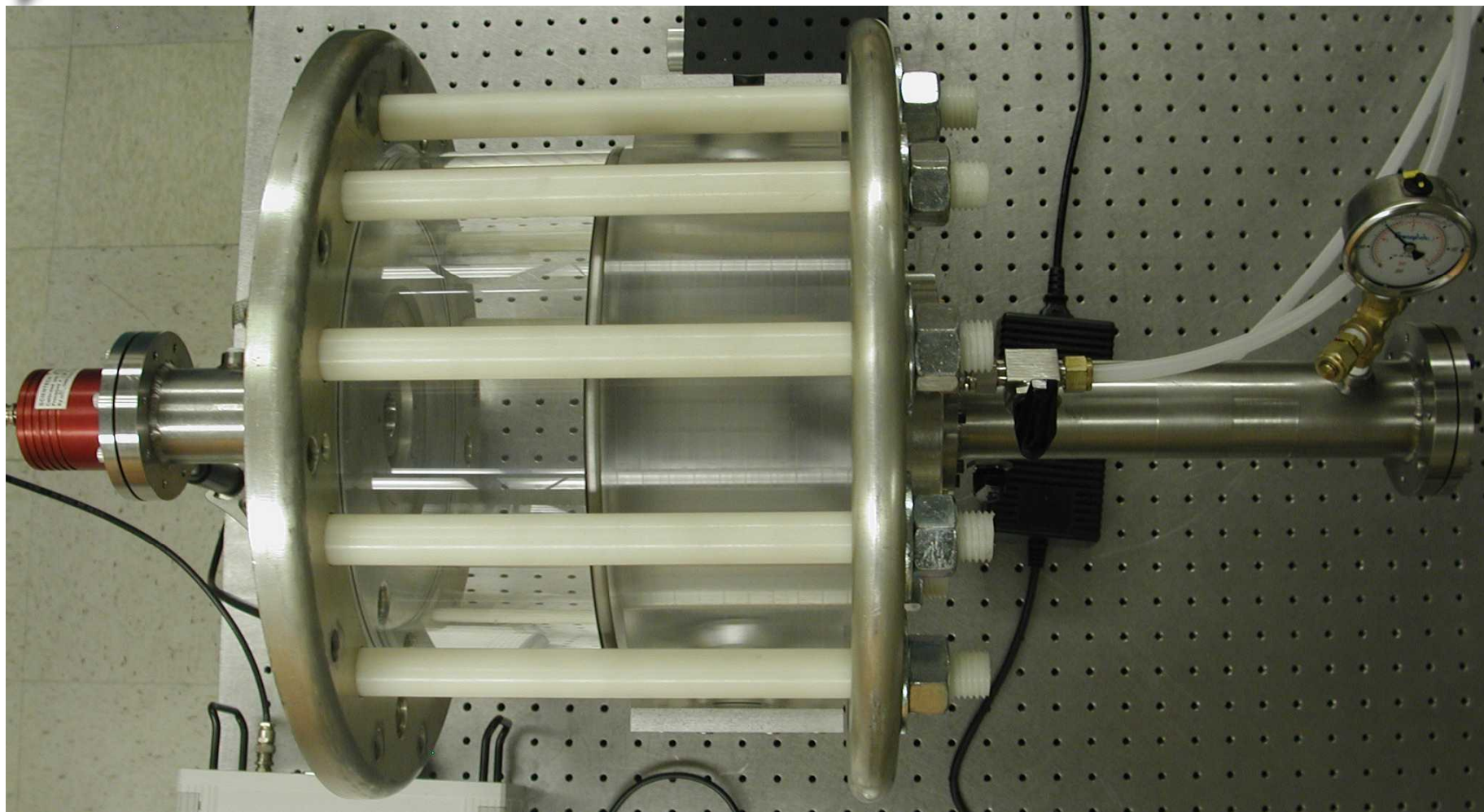


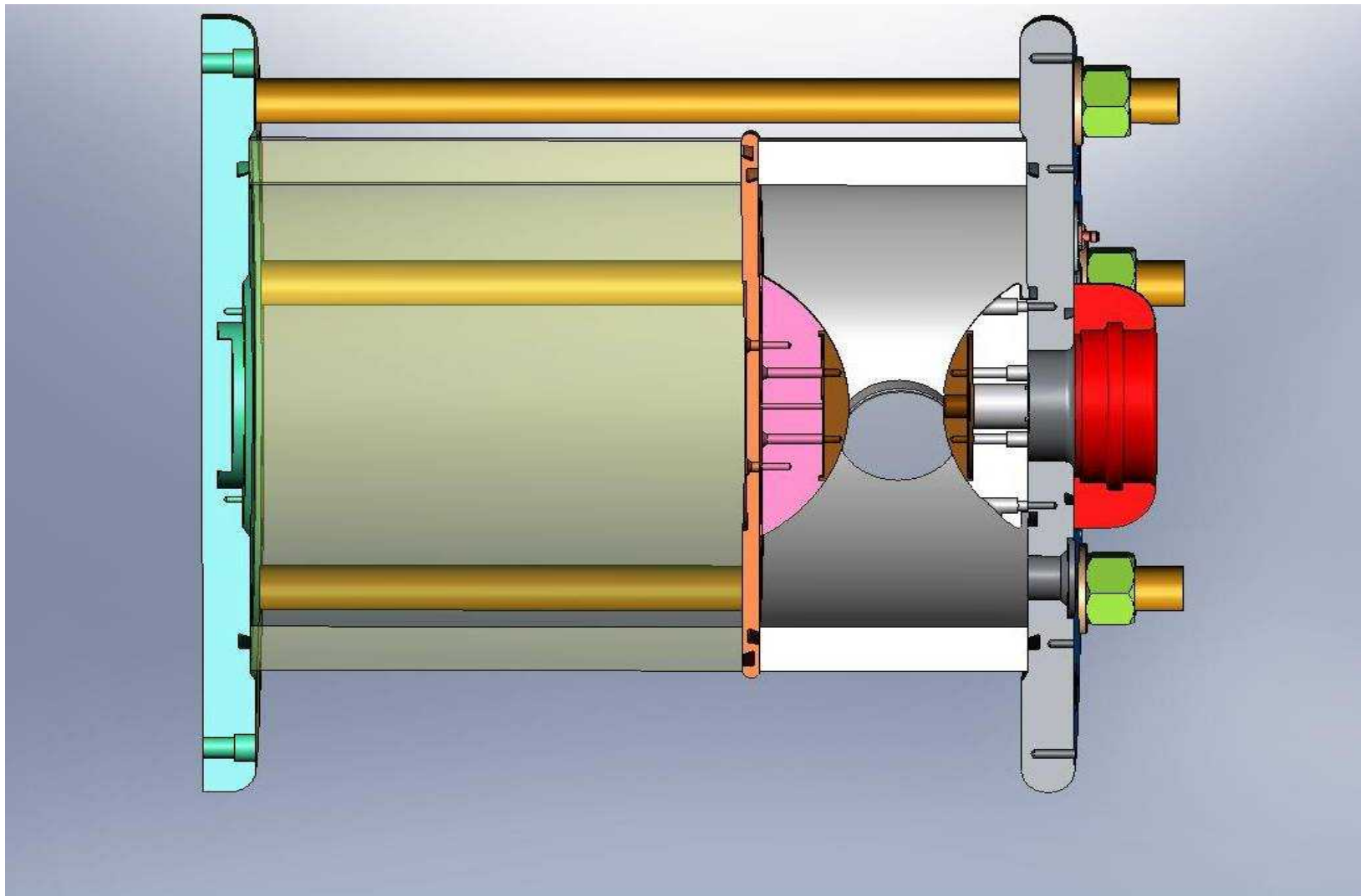
Project Motivation

- **ZR test bed (Z-20) indicate switching problems**
 - Increasing run-times
 - Laser spark intensity decreasing
- **Desire to know what is happening in switch trigger section involving:**
 - Laser plasma spark
 - SF6 gas pressure
 - Optical components











Diagnostics

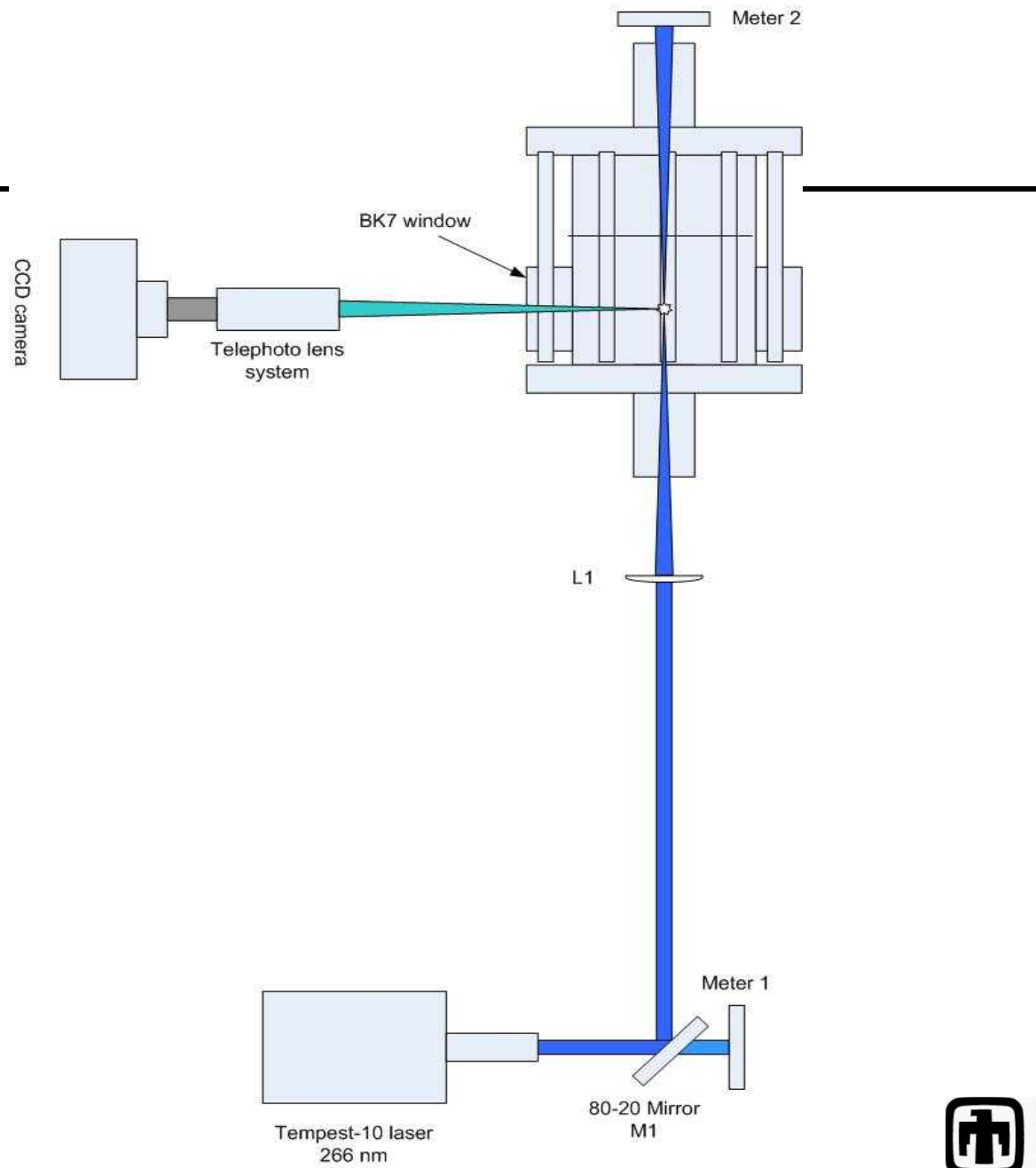
- **First three diagnostics are for spark length measurements**
 - **Visible**
 - **Schlieren**
 - **Electrical**
- **Fourth diagnostic is for spark temperature measurement**
 - **Spectroscopy**

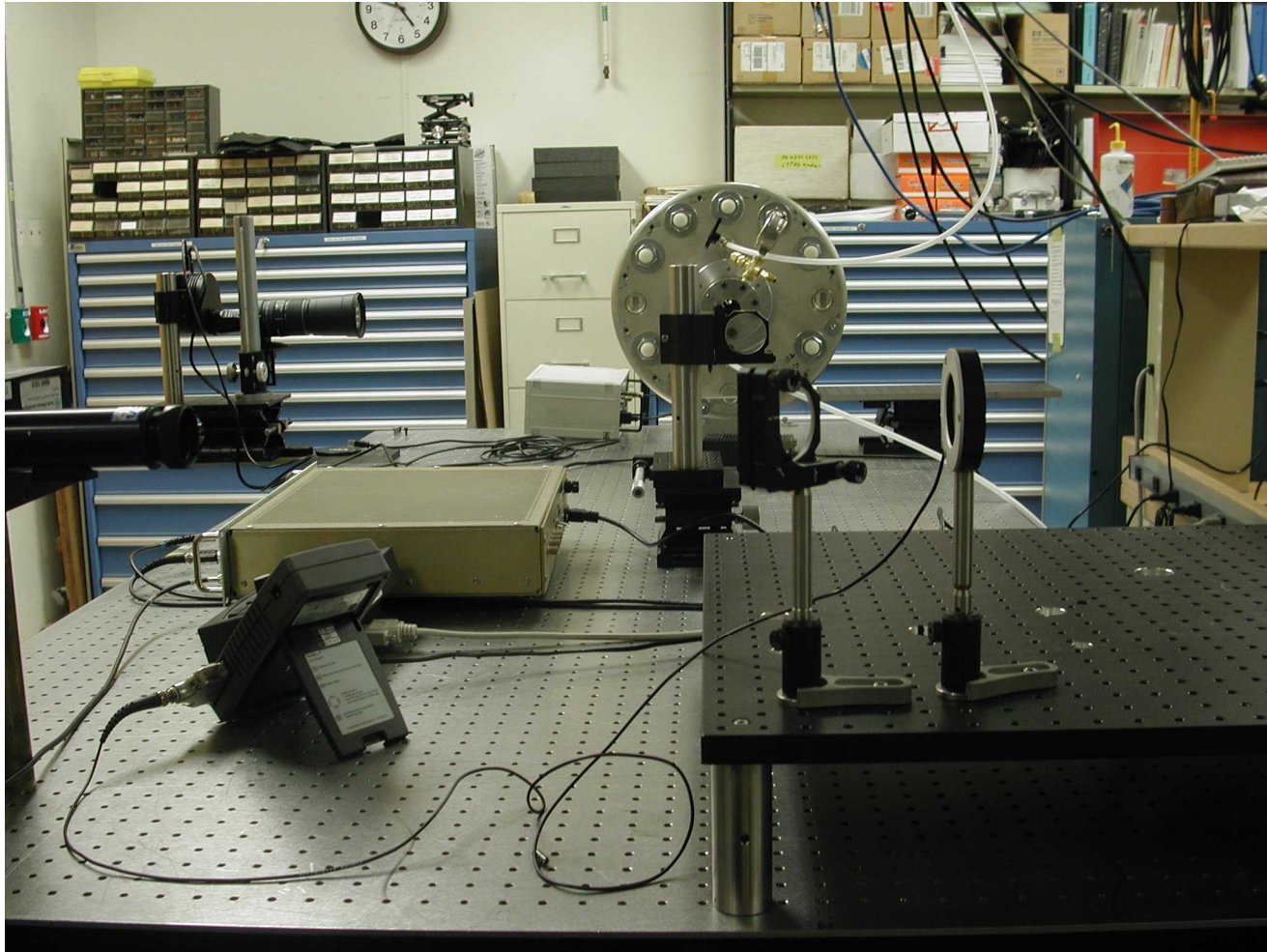


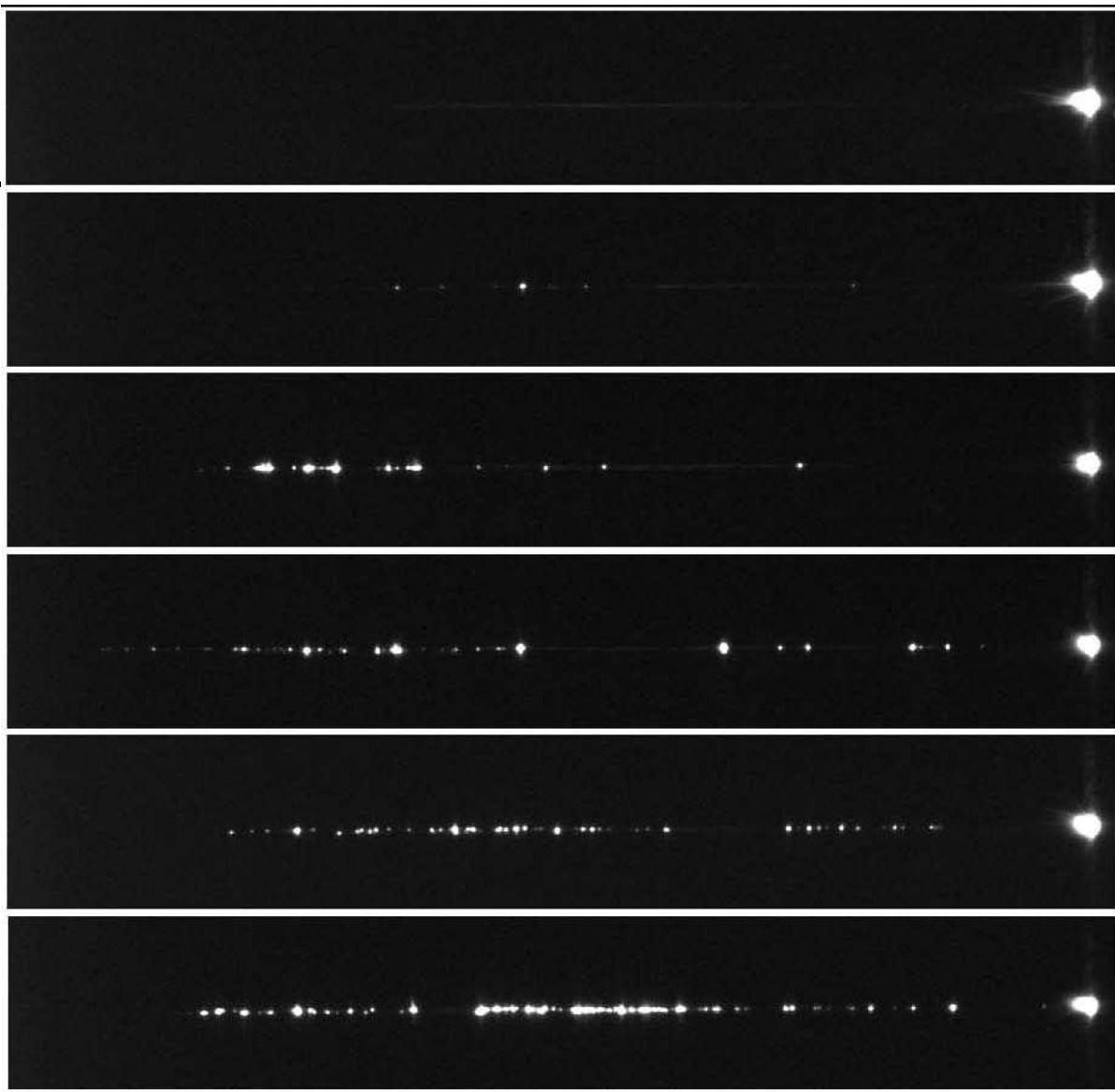
Diagnostics

Visible Imaging

- Spark imaged with CCD camera through optical windows
- Spark images obtained with varying focal length lens (500mm, 750mm, 1m)
- Gas pressure varied from 10psig – 60psig SF6
- Laser energy varied from maximum output (30mJ) to below minimum energy to create spark (this varied per focal length lens)



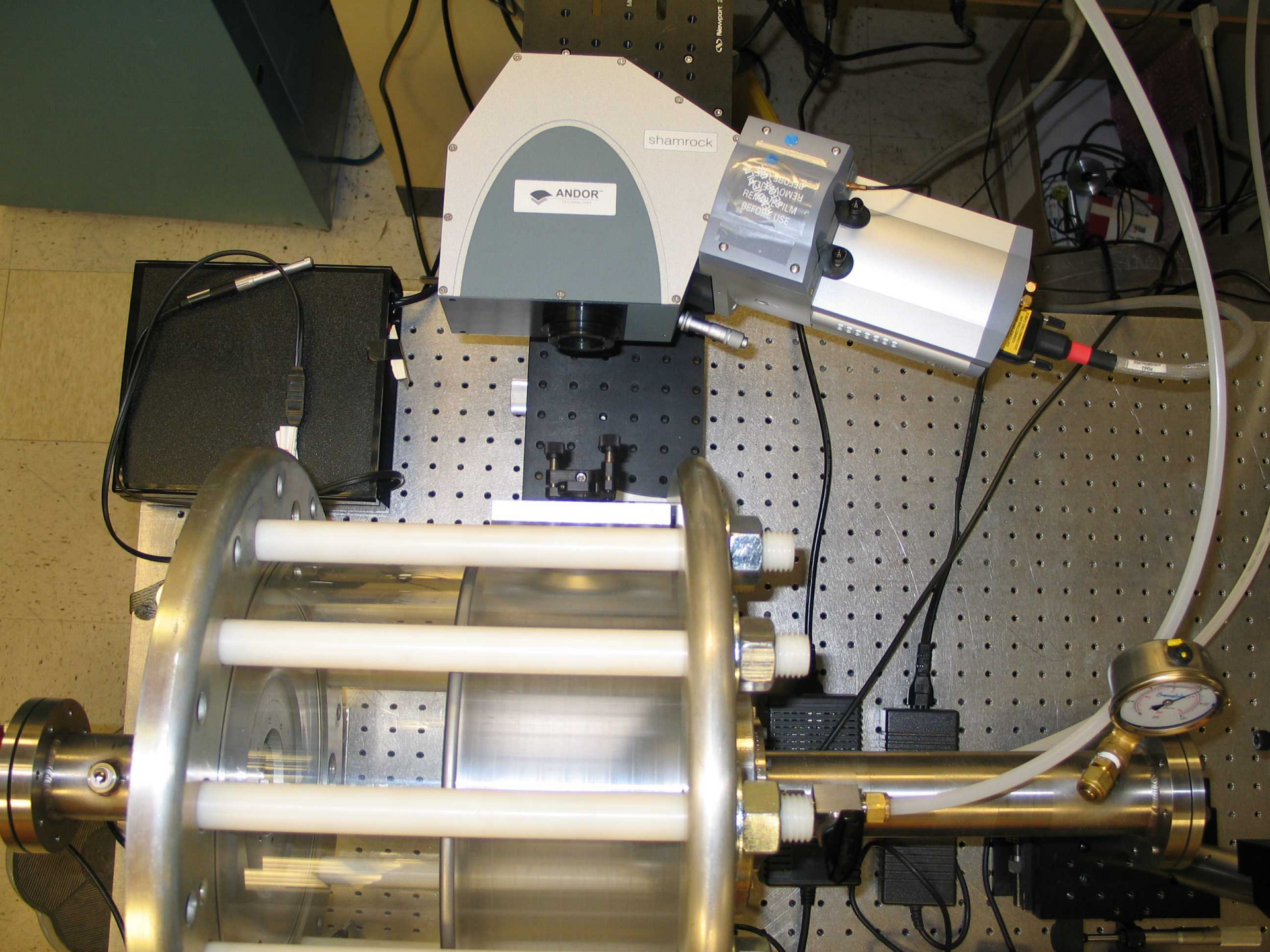






Diagnostics Spectroscopy

- **Andor Inc. Shamrock spectrometer with attached CCD camera**
 - **Positioned to view spark through UV grade fused silica window on one port**
 - **Used lens to focus image of spark onto spectrometer slit**
 - **Obtained spectra for 500mm lens at 50psig SF6**



shamrock

ANDOR
TECHNOLOGIES INC.

REMOVE FILM
BEFORE USE

Pressure Gauge

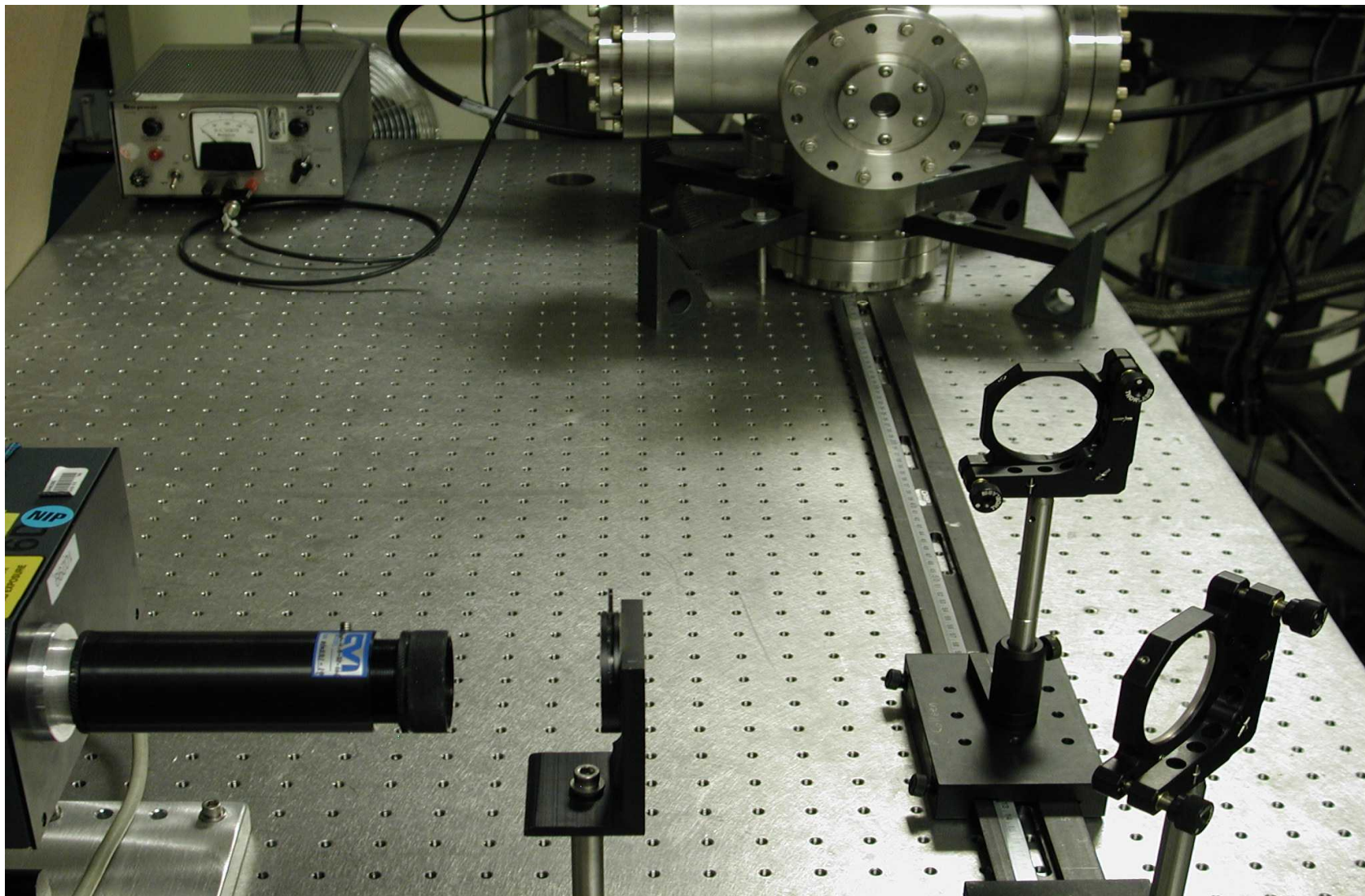


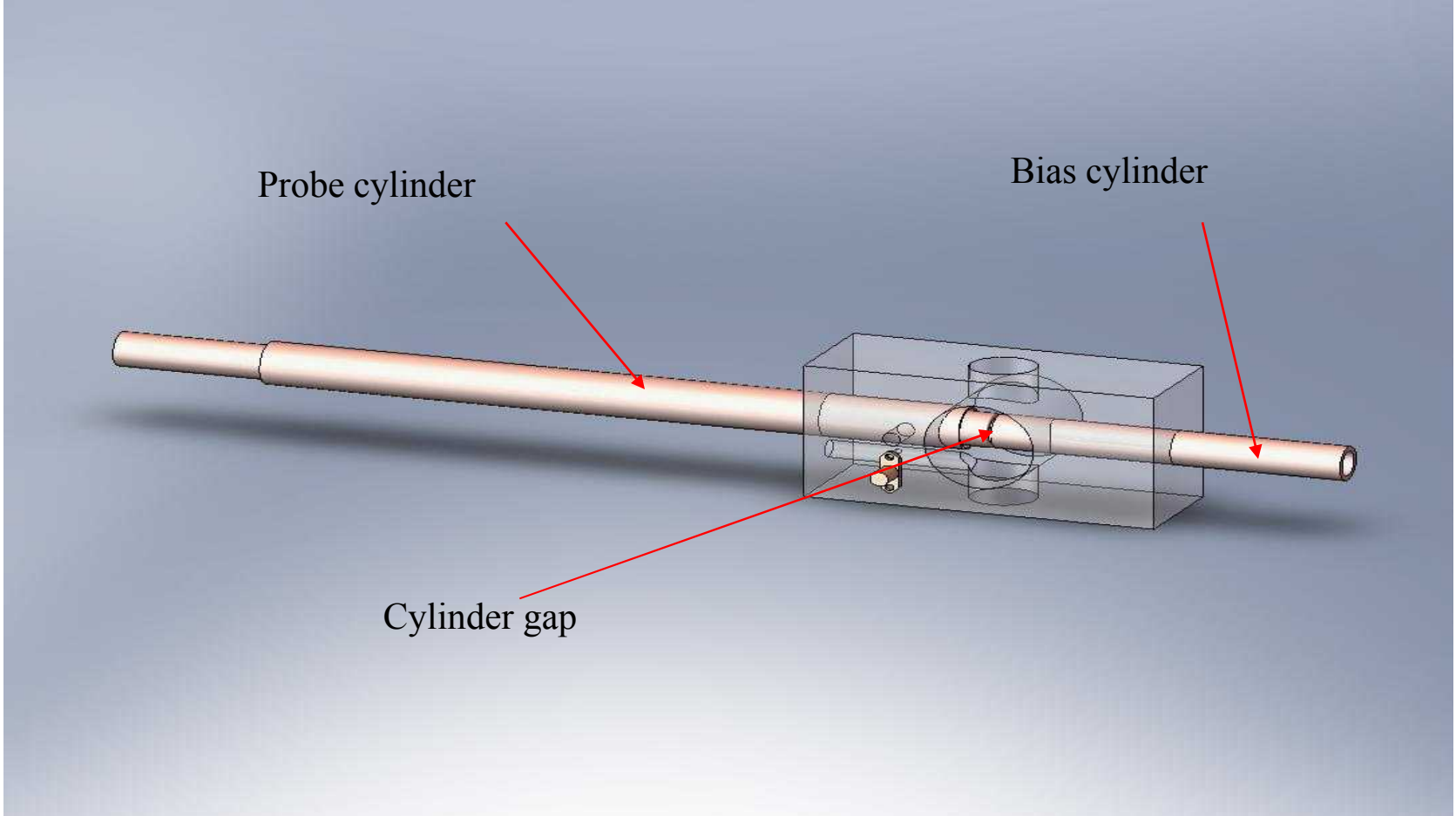
Diagnostics

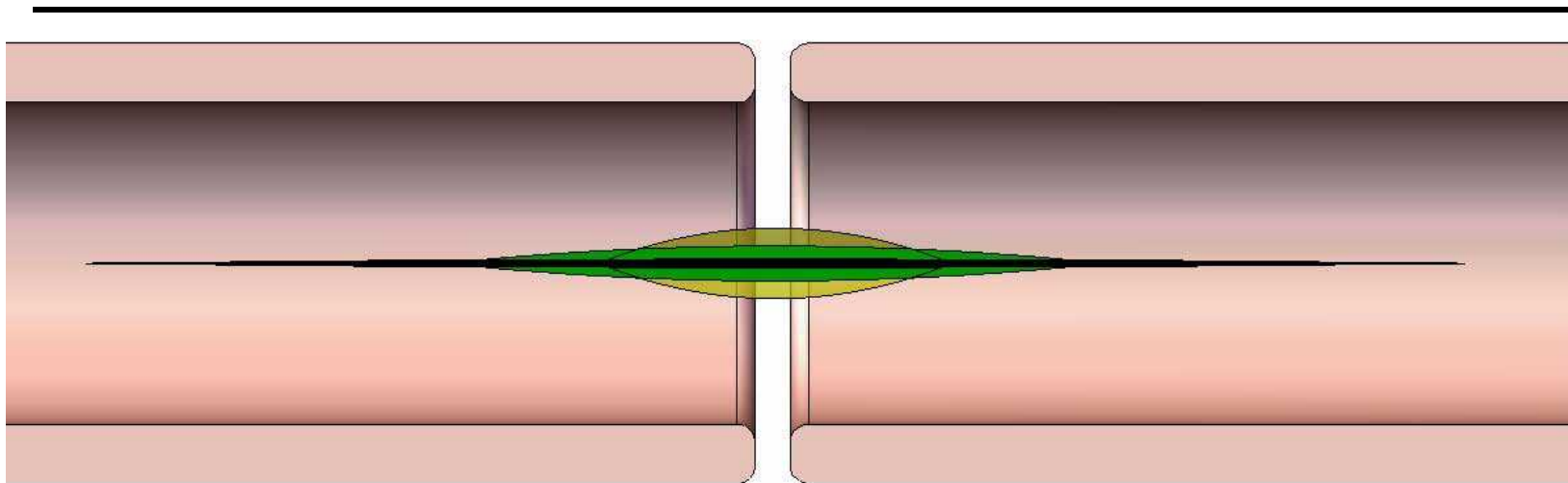
Electrical Length

- Measured change capacitance due to spark length and diameter
- Coaxial capacitance equation holds information about spark length and diameter
- Used in conjunction with electric field solving software (Electro)

$$C = \frac{2\pi\epsilon_0 l}{\ln \frac{b}{a}}$$



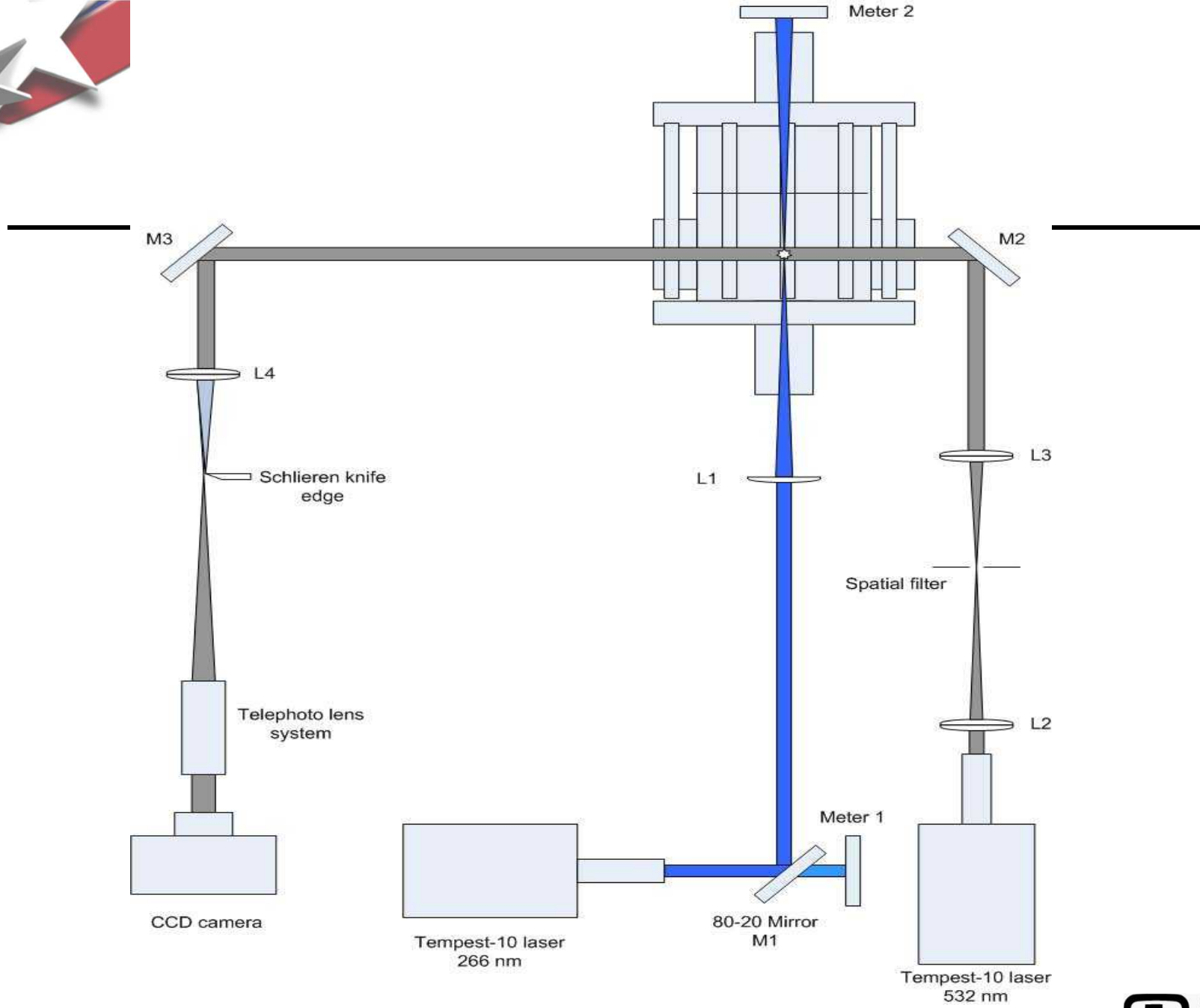
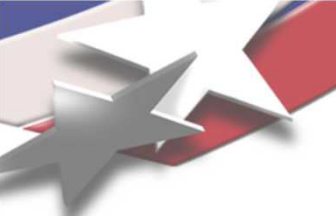


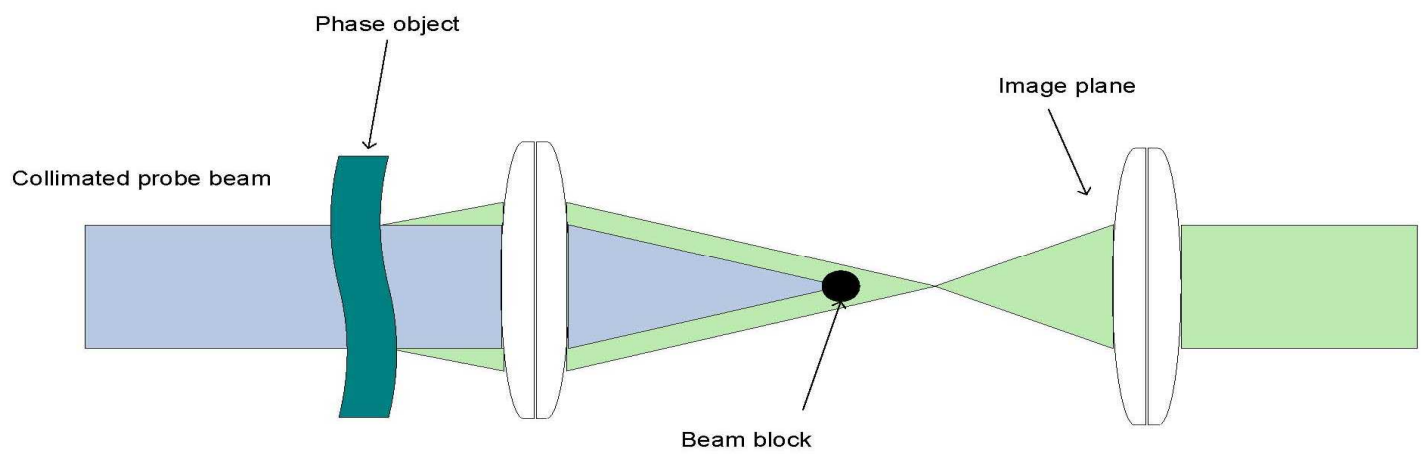




Diagnosics Schlieren Imaging

- **Schlieren method provides information on refractive index changes produced by laser plasma**
- **Schlieren images show gradient (first spatial derivative) changes in the medium (SF6)**







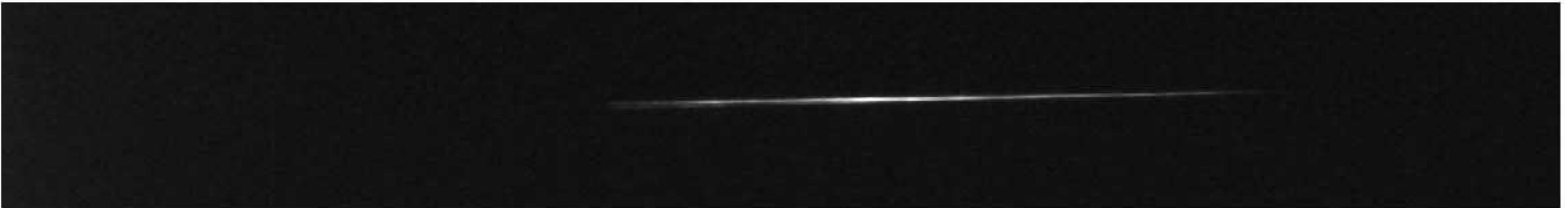
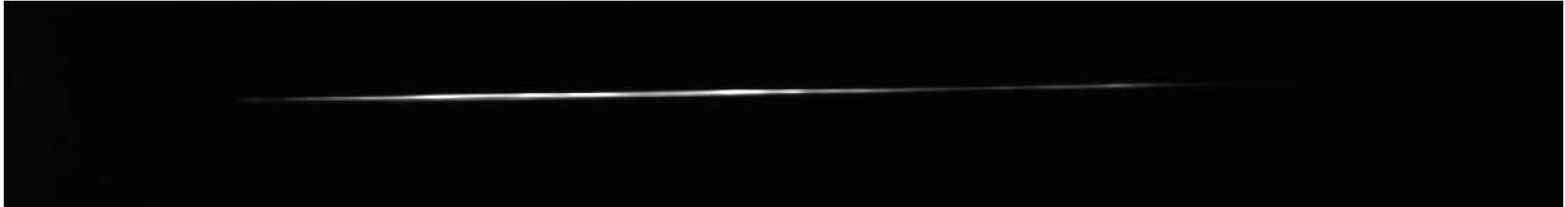
Results

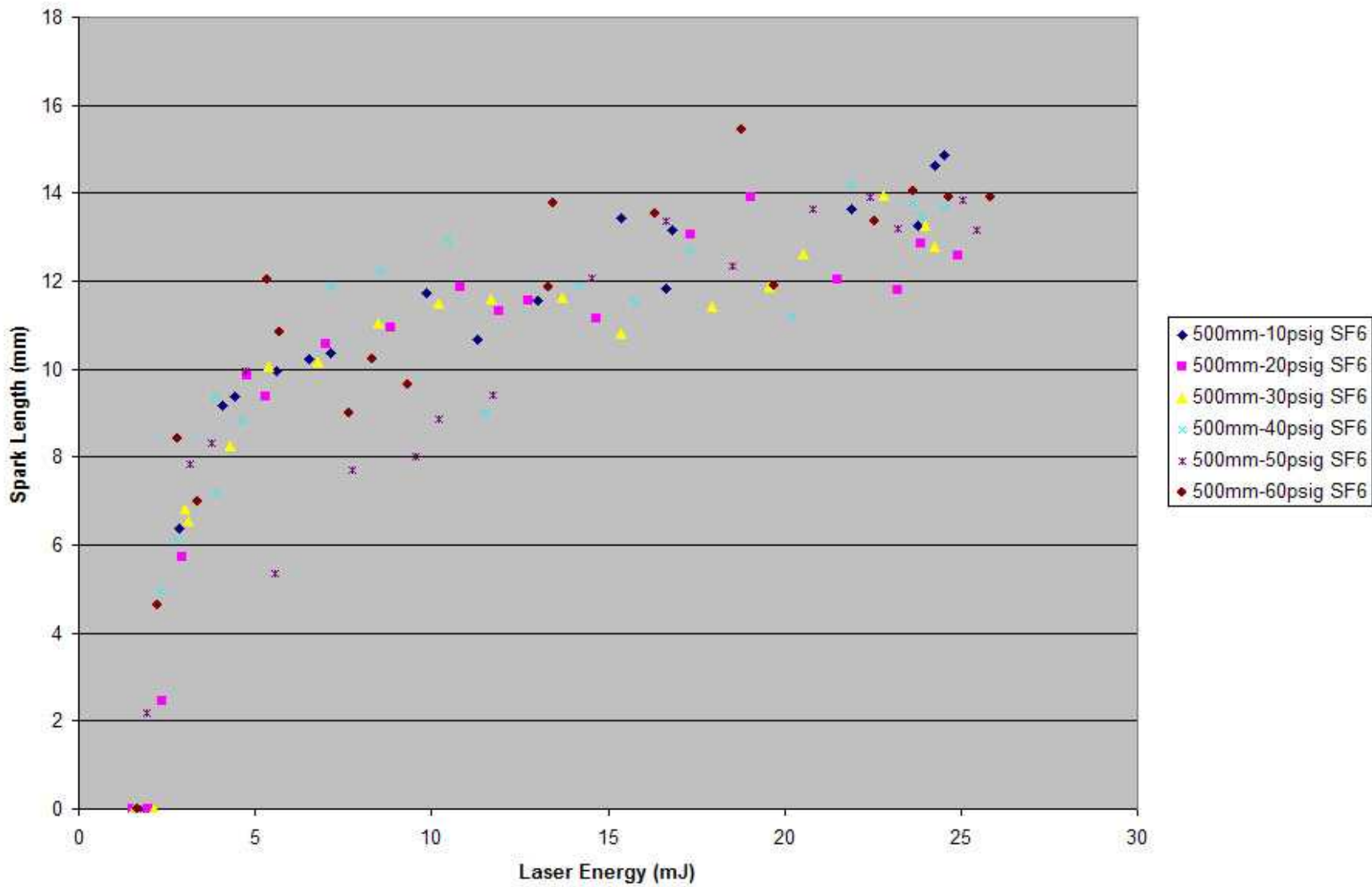
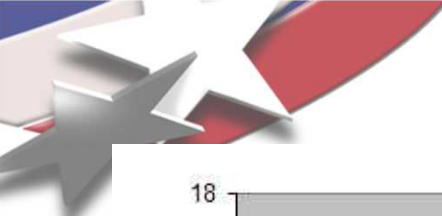
- **Spark lengths were obtained from visible imaging, schlieren imaging and electrical probe diagnostics at varying SF6 gas pressures, focal length lenses and laser energy.**
- **Spark temperature and conductivity were obtained through spectroscopy.**

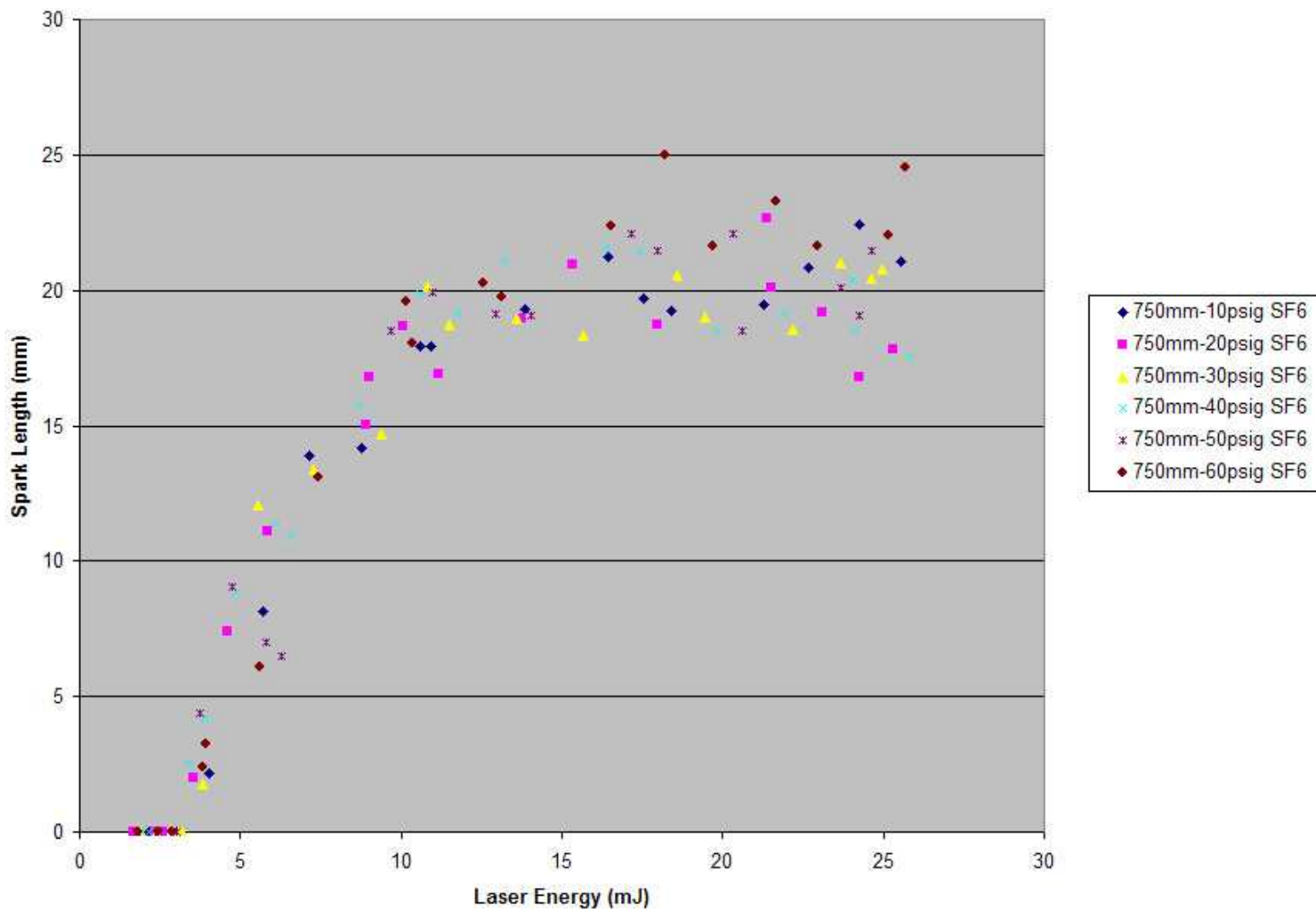


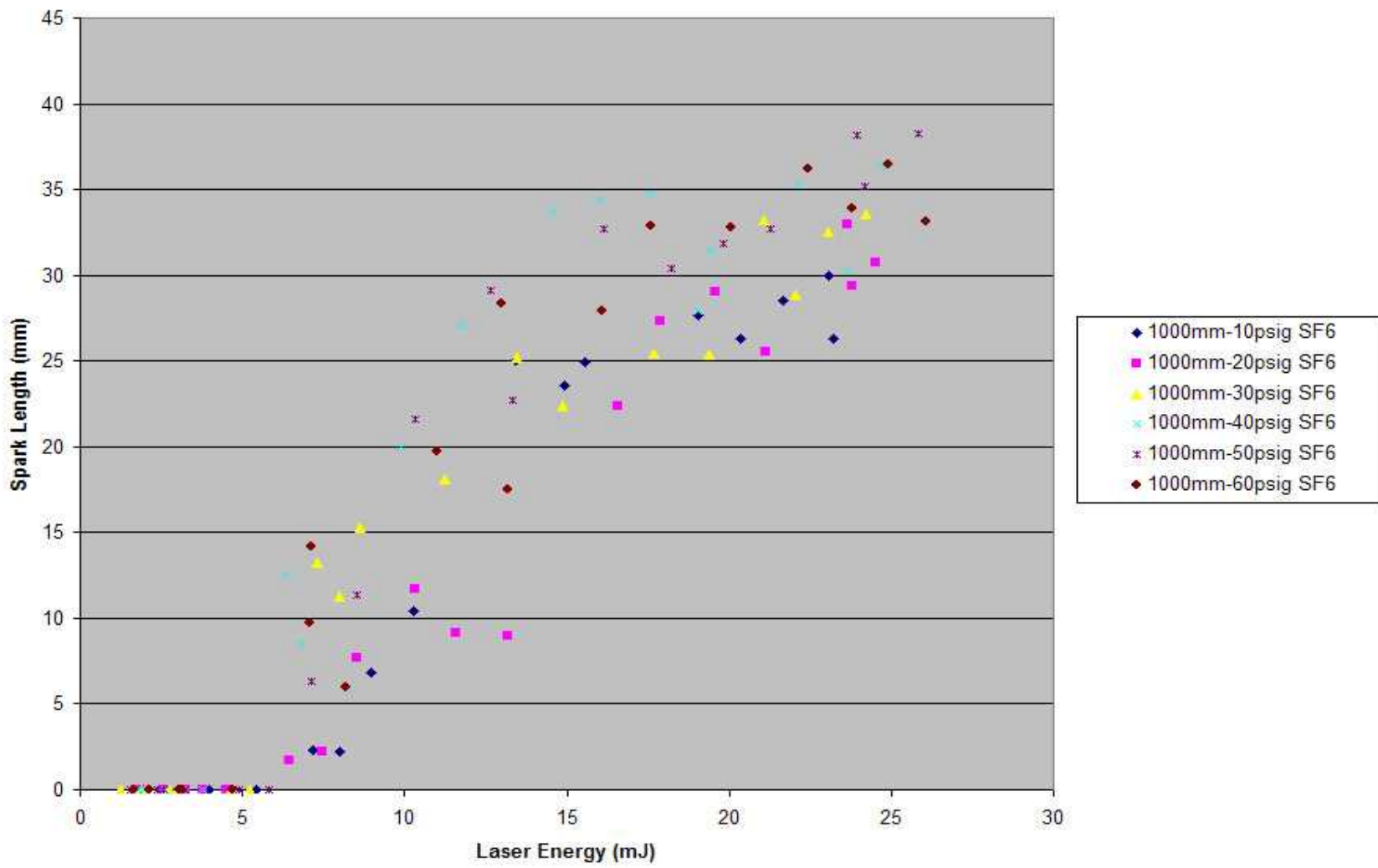
Visible imaging

- **250+ images obtained and analyzed.**
 - Images evaluated by Matlab code written to read in image and return spark length
- **Information showing spark length for varying focal length lenses and laser energy developed**



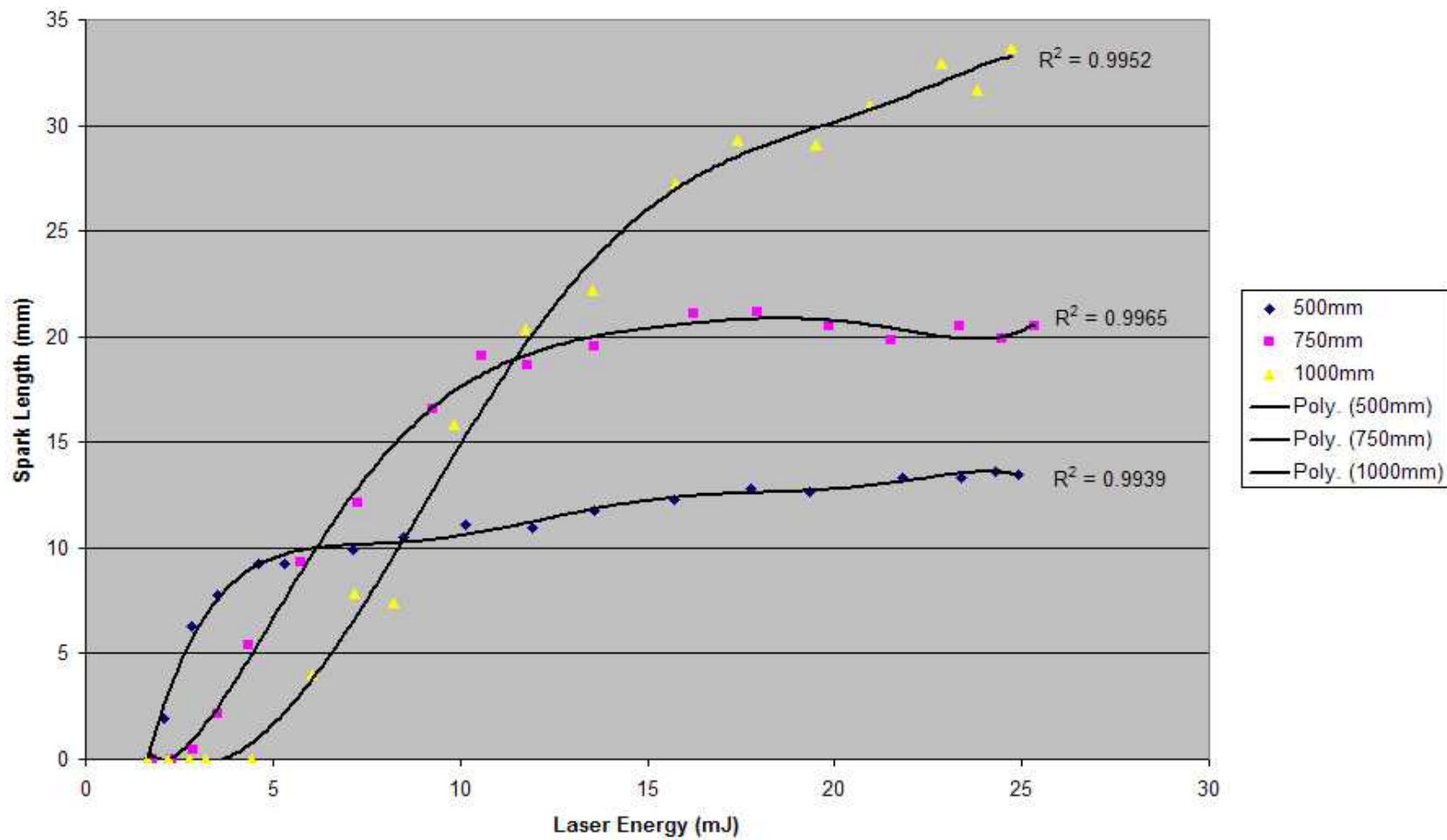








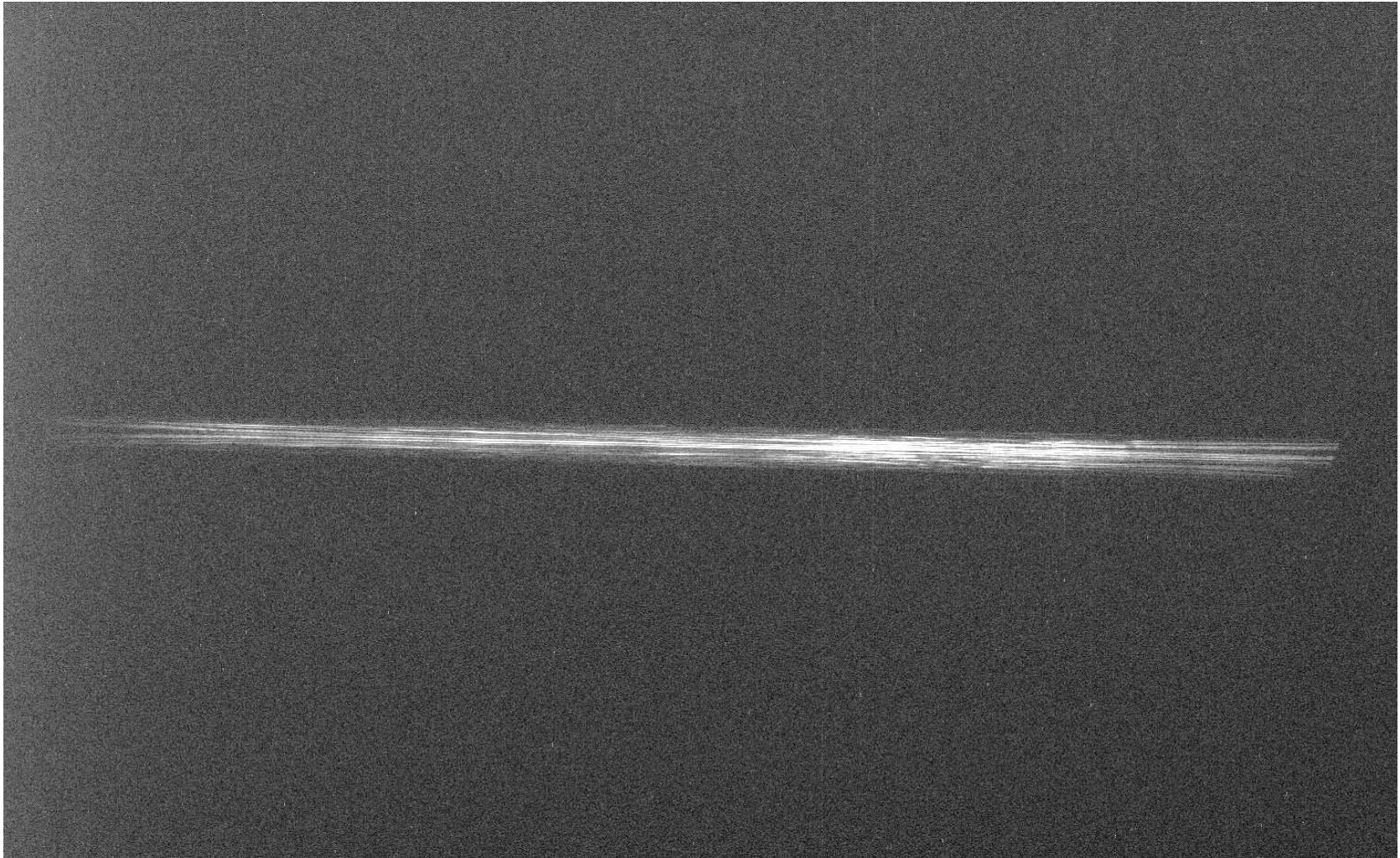
Average

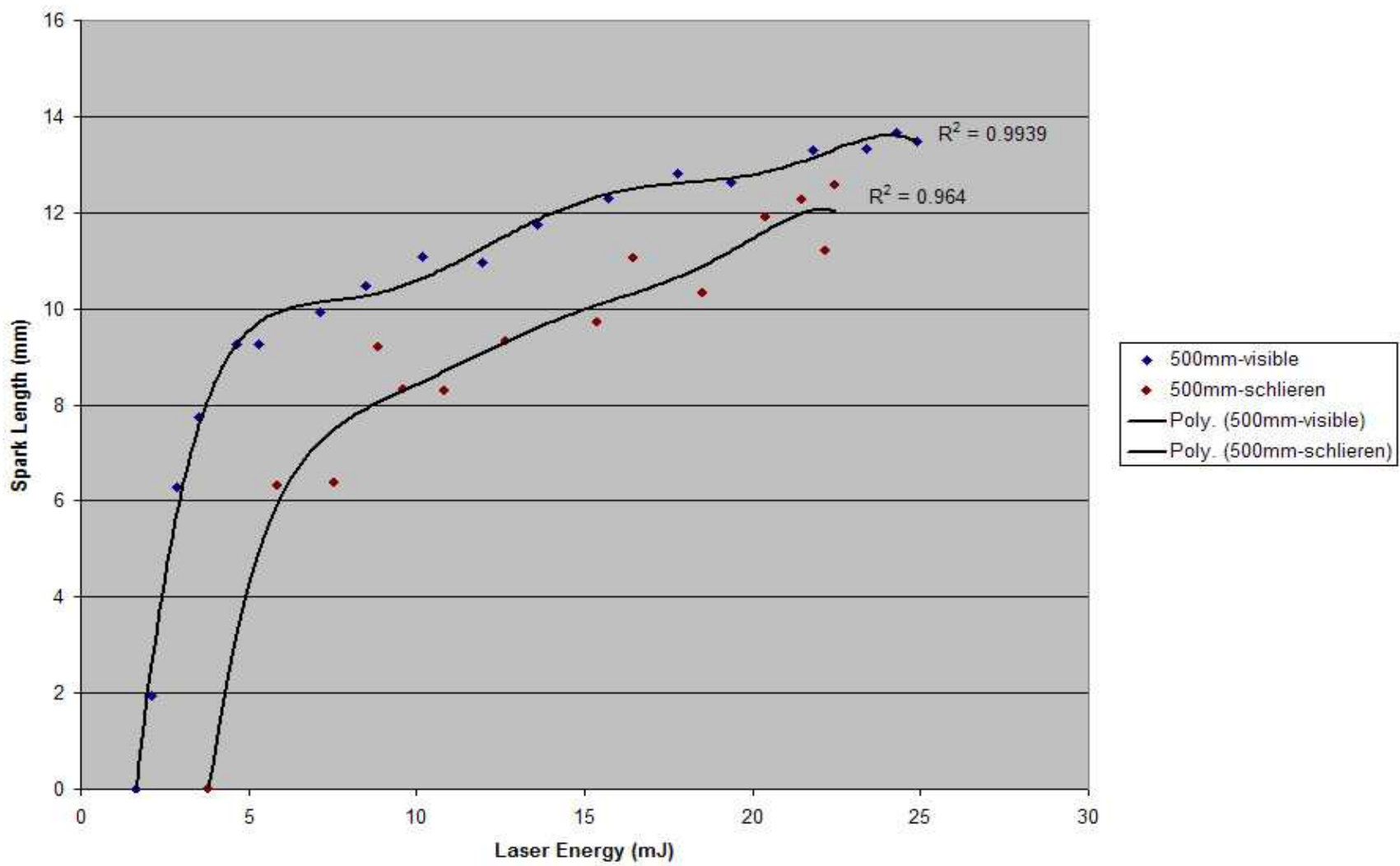




Schlieren

- **Change in refractive index along the spark propagation direction enabled a length to be calculated similar to visible imaging.**
- **Schlieren images obtained for 500mm focal length lens at 30psig SF6**





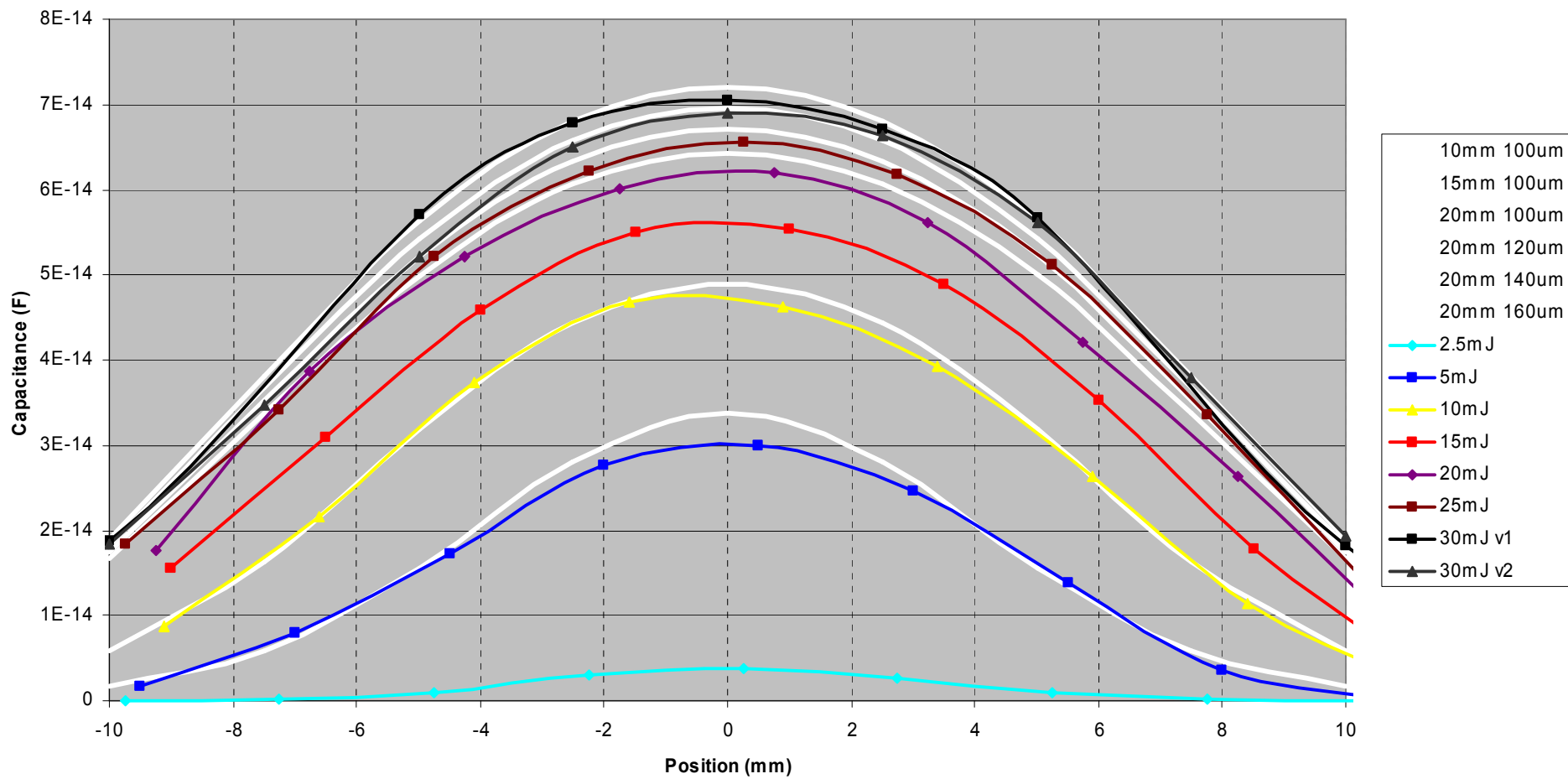


Electrical Length

- **Comparison spark length measurements obtained for 500mm and 750mm focal length lens**

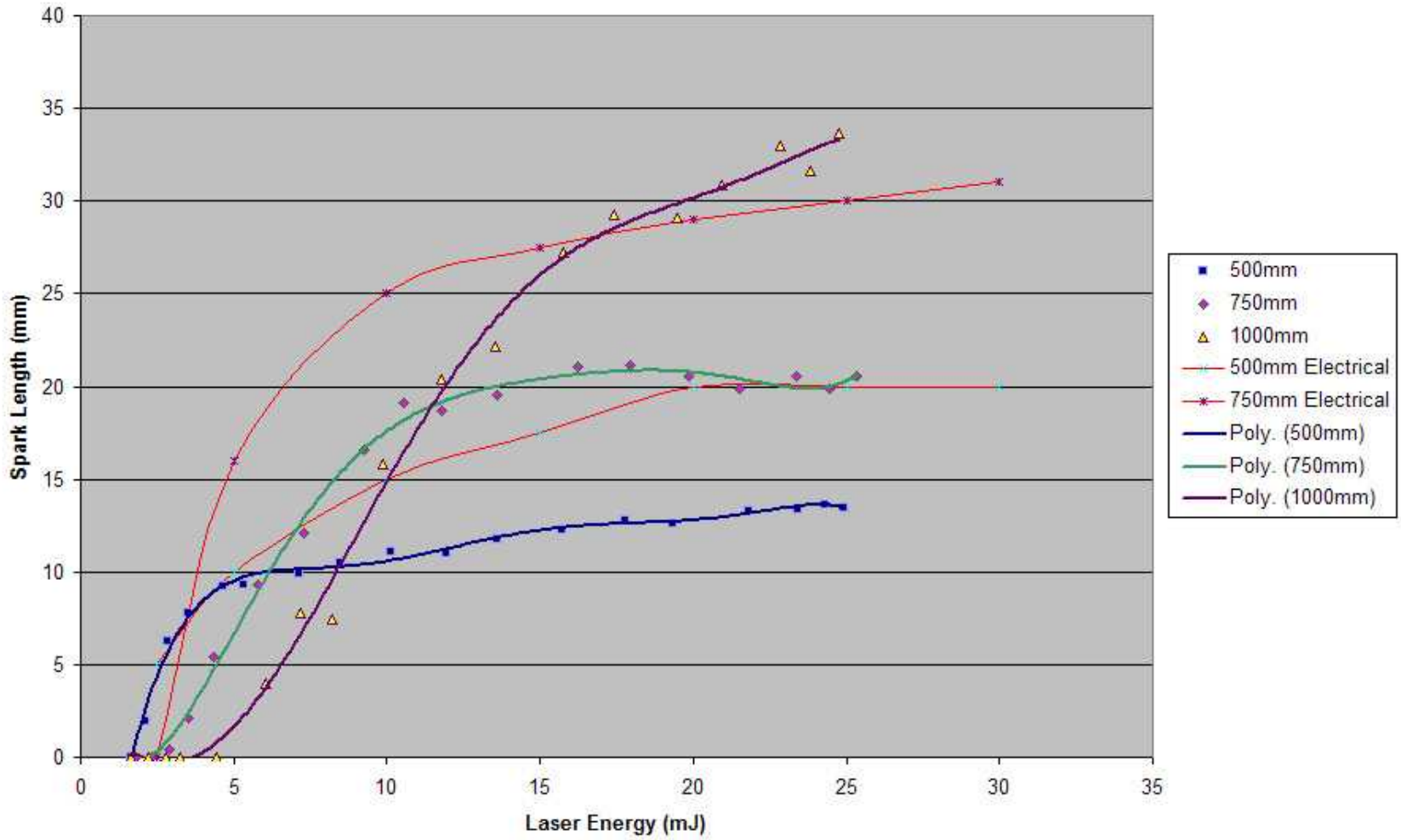


Capacitance vs. Position 500mm lens





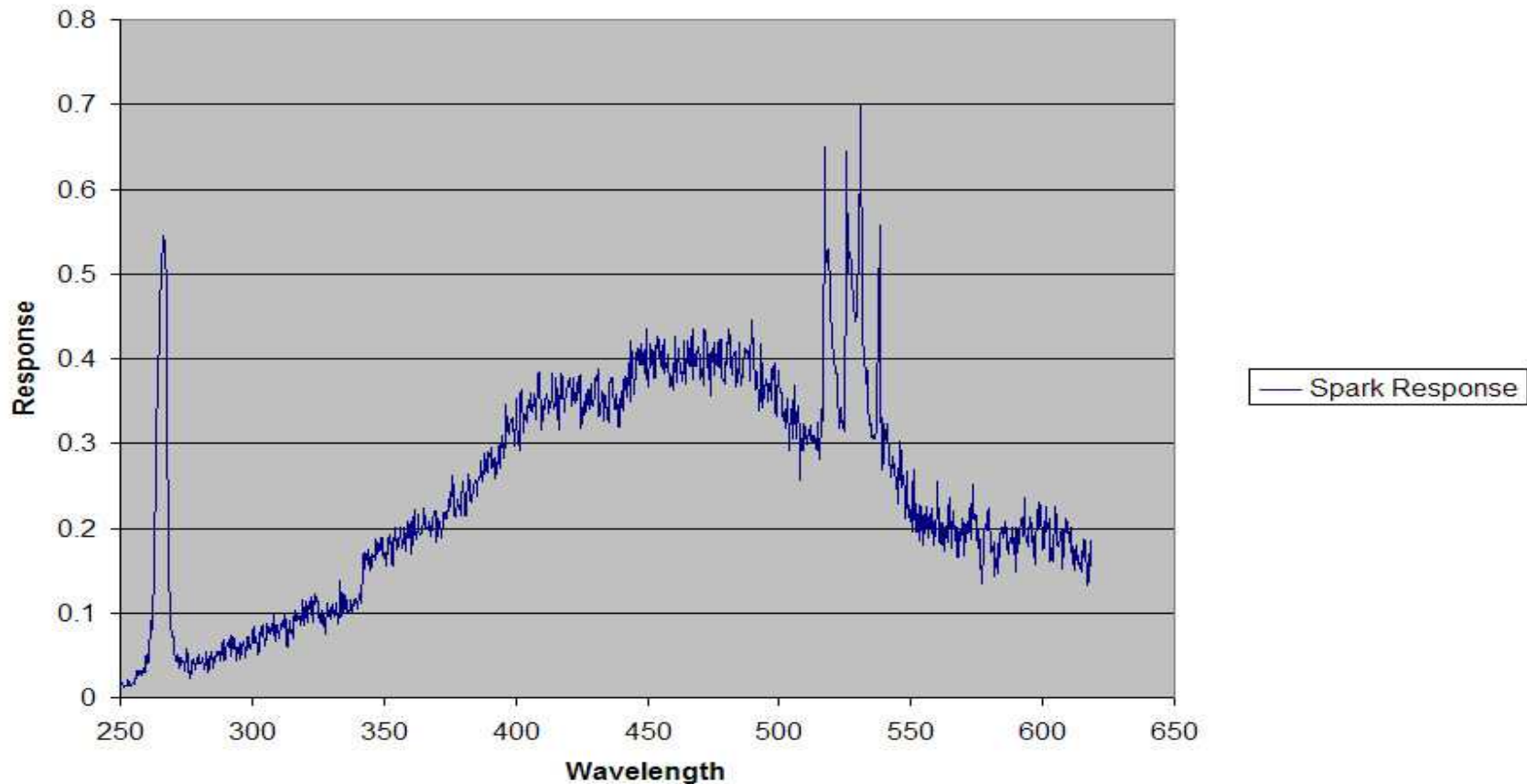
Average Spark Length (10-60psig SF6)

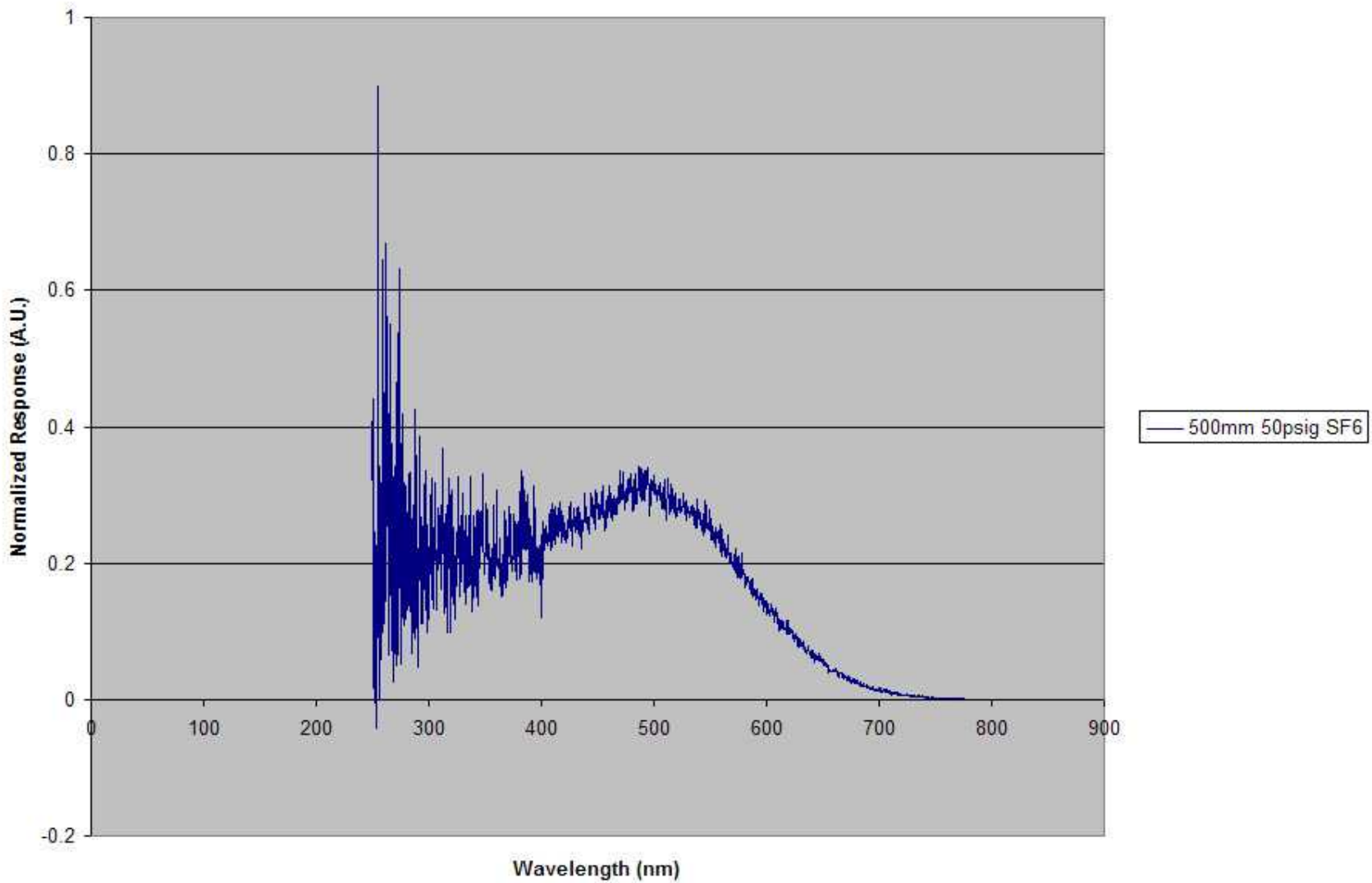




Spectroscopy

- **No predominant emission lines or absorption is found in the SF6 spectra**
- **A broad continuum from the VUV into the near infrared is observed.**
- **This continuum is assumed to be blackbody radiation and is used to calculate spark temperature**
- **From this temperature, conductivity of the spark is found.**







Plancks blackbody formula

$$S_{\lambda} = \left(\frac{2hc^2}{\lambda^5}\right) \left(\frac{1}{\exp\left(\frac{hc}{\lambda KT}\right) - 1}\right)$$

Spark plasma temperature found by using wavelength peak
of calibrated spark response

Temperature (°K) $\approx 4600 \approx .39\text{eV}$



Conductivity

Spitzer resistivity calculated from spectroscopic temperature

$$\eta = \frac{\pi e^2 \sqrt{m}}{(4\pi\epsilon_0)(KT)^{3/2}}$$

Conductivity=1/ η =259.8 S m⁻¹

- This conductivity correlates well with previous SF6 arc plasma study with temp. 4000°K spark gives 200-300 S m⁻¹.
- Braginsky conductivity in a study by T.H. Humphries shows a much greater conductivity for arc plasma in SF6.



Conclusions

- **Spark length measurements of four different diagnostics were obtained for a laser induced plasma spark in SF6 gas for varying pressures, laser energy and focal length lenses.**
 - **Comparison of methods allows for measurement sensitivity determination**
 - **Baseline spark length at given laser energy**
- **Spectroscopy obtained plasma temperature, resulting in a spark conductivity, investigated for a representative laser spark.**



Future Work

- **Schlieren imaging setup to measure propagation speed of laser plasma**

