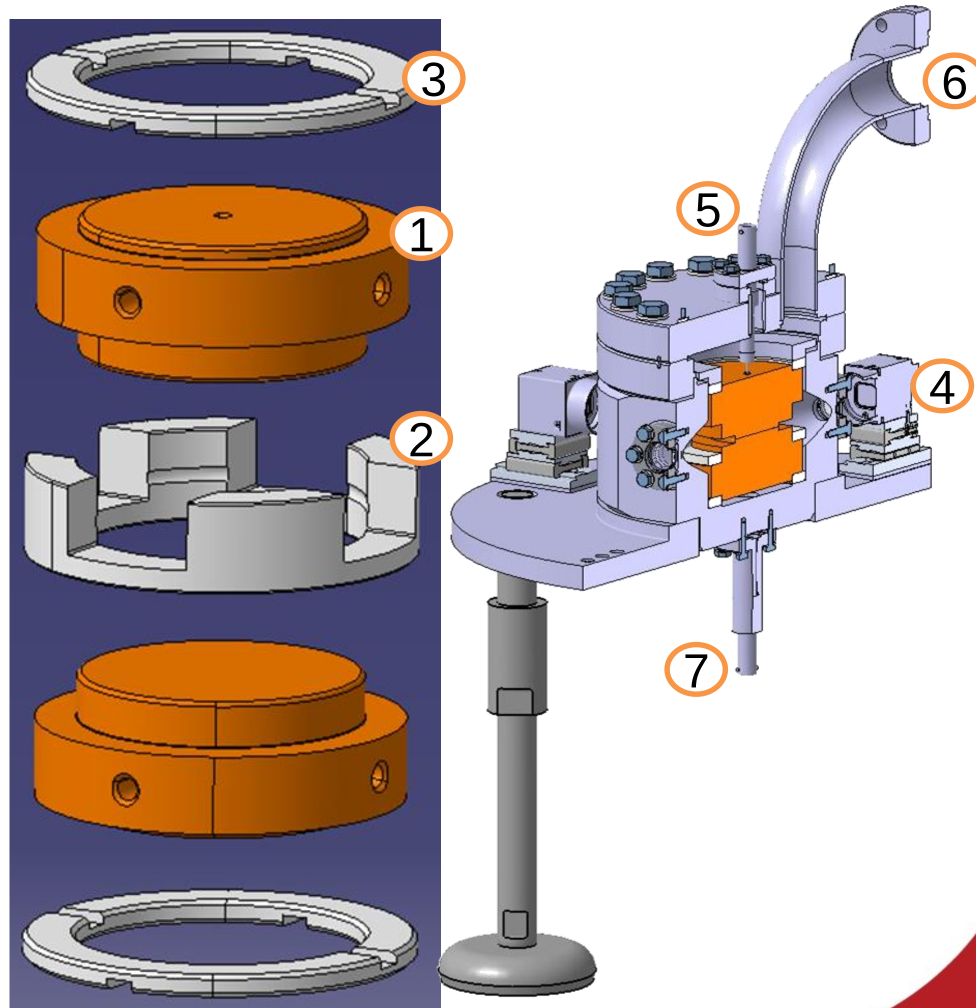
Measurement of field-emission induced optical emission spectra

14th May 2020

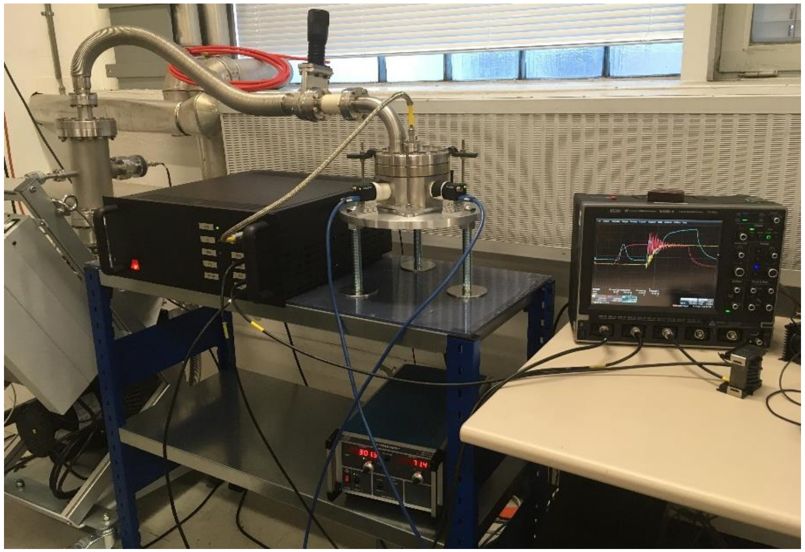
Ruth Peacock (ruth.peacock@cern.ch)

Pulsed DC Large Electrode System Chamber

- Configuration
  1. 2 high precision machined electrodes (1µm tolerances)
  2. High tolerance ceramic spacer between electrodes providing a gap of 20µm, 40µm, 60µm, or 100µm
  3. Ceramic spacers to isolate electrodes from the chamber
  4. 4 Windows and 2 perpendicular cameras
  5. High voltage feed though
  6. Vacuum pump output (5x10^-9)
  7. Connection from the bottom electrode to ground (outside of system)

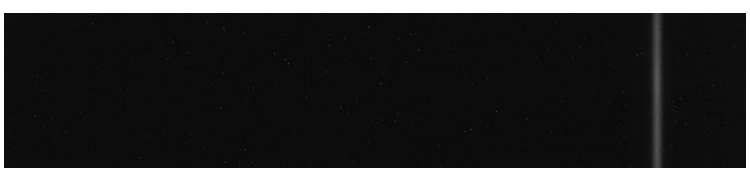


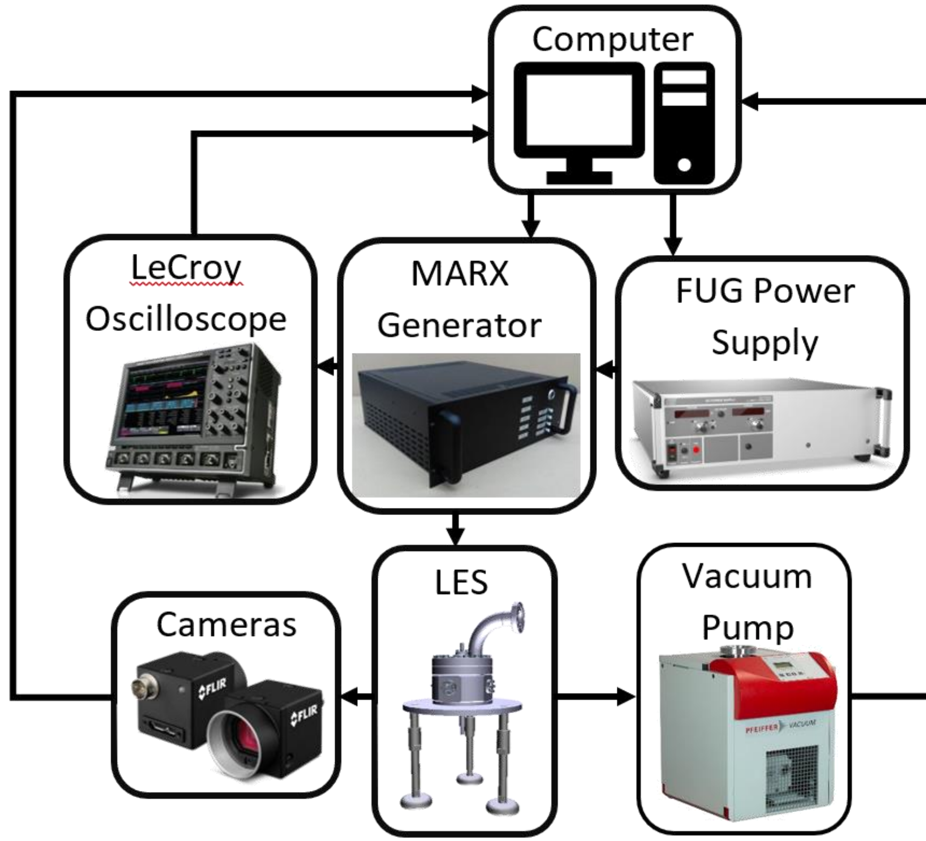
Pulsed DC Large Electrode System Setup



Camera 1

Camera 2

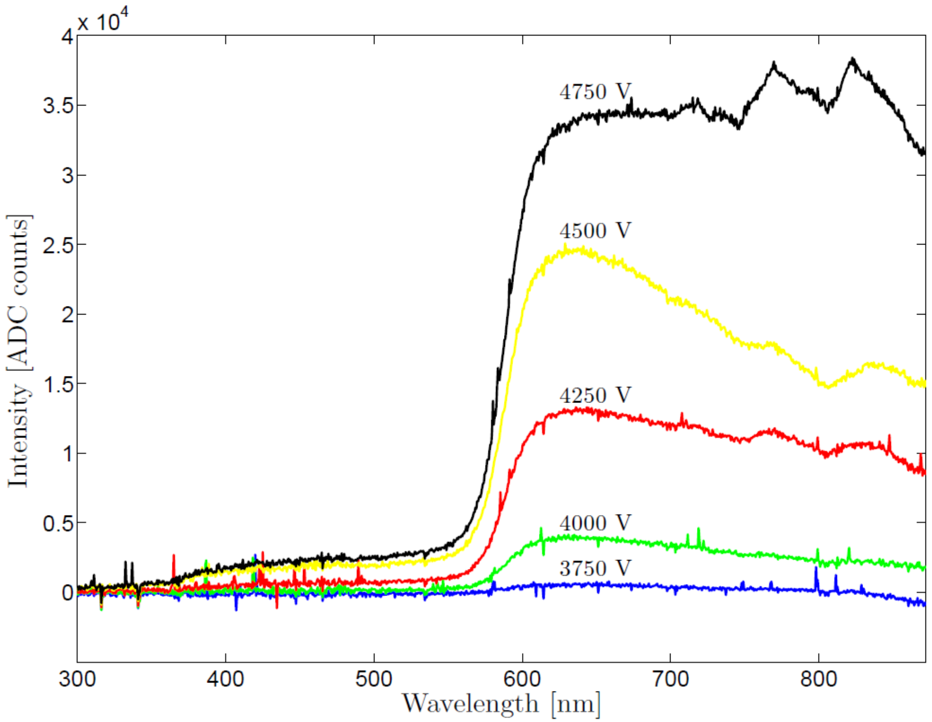




Spectrum measured during field emission Results

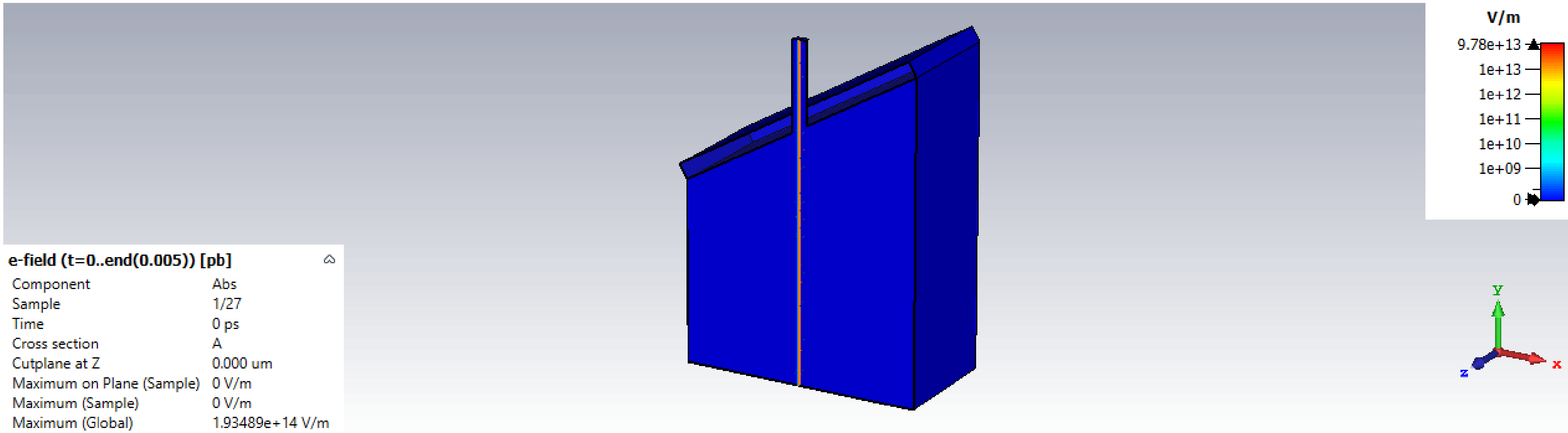
Why Light Spectrum?

- Light was seen in the original DC system by Jan Kovermann and he concluded the light was the results of Optical Transition Radiation (OTR)
- There are several possible causes of light
    - Optical Transition Radiation
    - Thermal – Black body radiation
    - Cathode-luminescence of copper
- Features that affect the light detected
    - Material acts as a filter
    - Optical restrictions due to system
    - Limited light emission
    - Plasmon oscillations

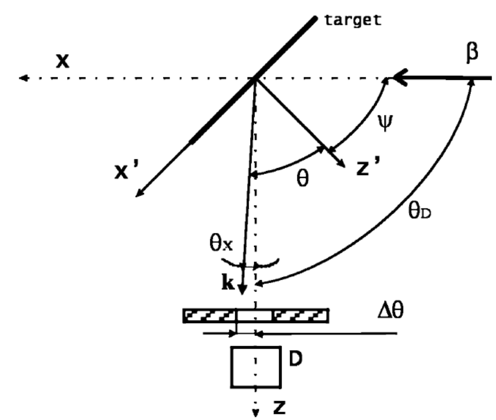


Comparative studies of high-gradient RF and DC breakdowns, Jan Kovermann

Optical Transition Radiation (OTR)



- The simulation shows a CST simulation of a beam going through a small hole using the wakefield solver… to replicate the process of OTR.
- OTR is the light generated from the field around the electron that is reflected when the electron passes through a change in permittivity.



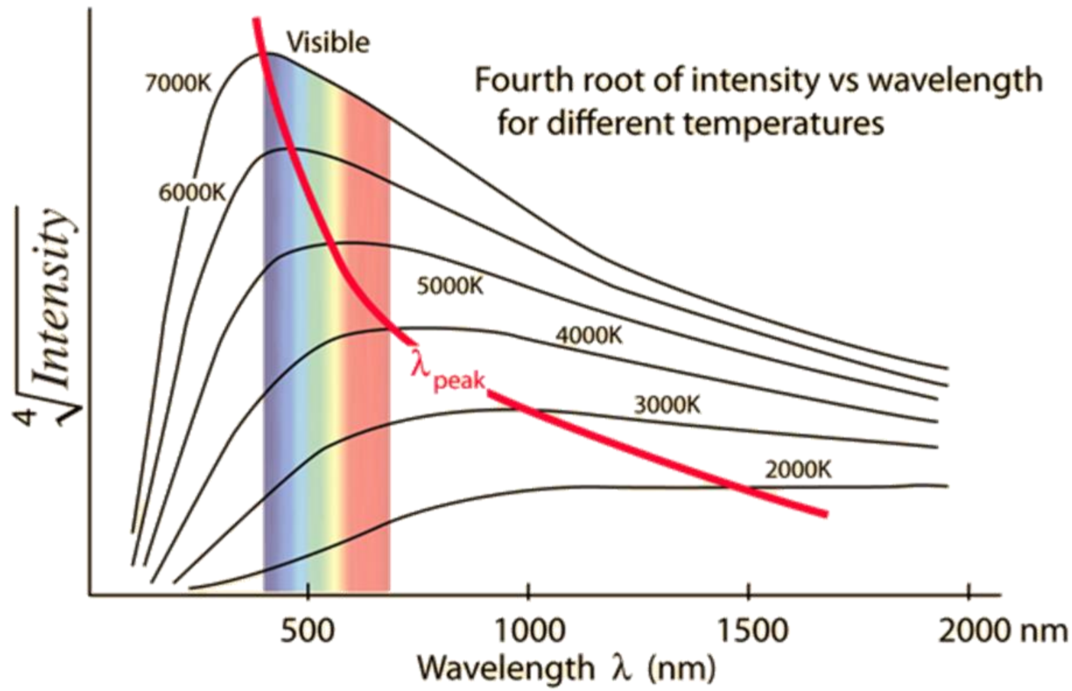
A.N. Aleinik et al. / Nucl. Instr. and Meth. in Phys. Res. B 201 (2003) 34–43

Black Body Radiation

A black body emits radiation that depends on its temperature only, meaning it does not transmit or reflect radiation from other sources.

Planck's law defines the spectral radiance as a function of wavelength and temperature:

$$B(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{\exp\left(\frac{hc}{\lambda k_B T}\right) - 1}$$



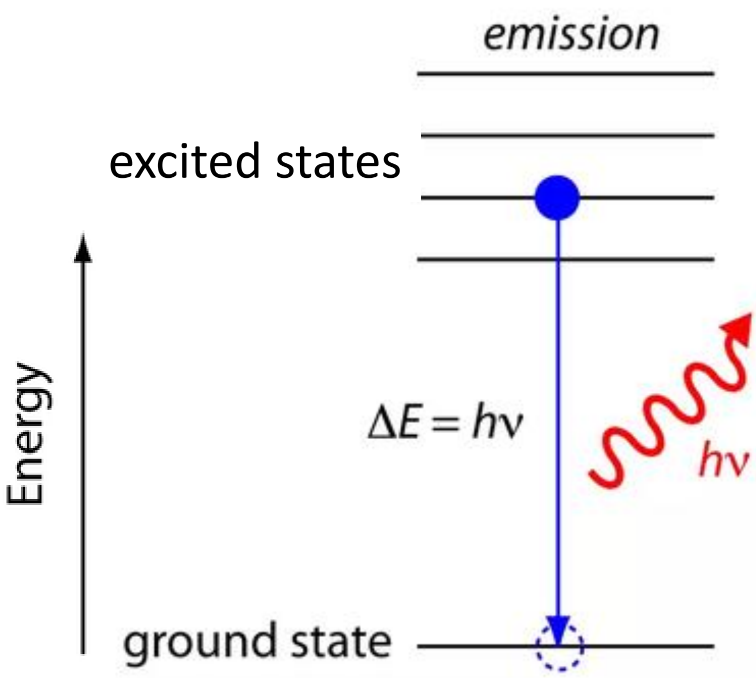
Wien's displacement law gives the wavelength of the peak of the spectrum:

$$\lambda_{peak}[m] = \frac{2.898 \times 10^{-3}}{T\ [K]}$$

This means that for the peak to be within the visible range, the temperature has to be at least 4000 K.

Cathode-luminescence of copper

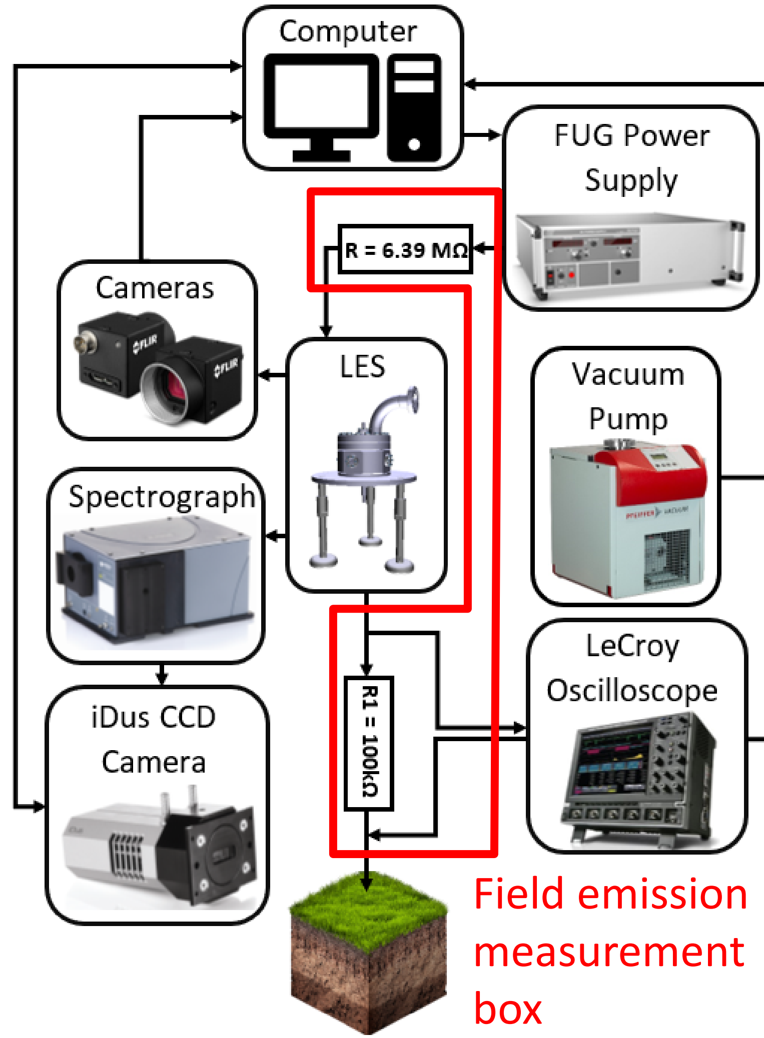
- Cathode luminescence is the emission of light caused by the decay of an excited electron
- Electrons entering the surface are captured in an excited state
- When the electron looses energy by settling to a lower energy band it emits a photon
- This process would have a time delay from the electron entering the surface and it decaying
- Using a fast spectrometer could determine if this is the source



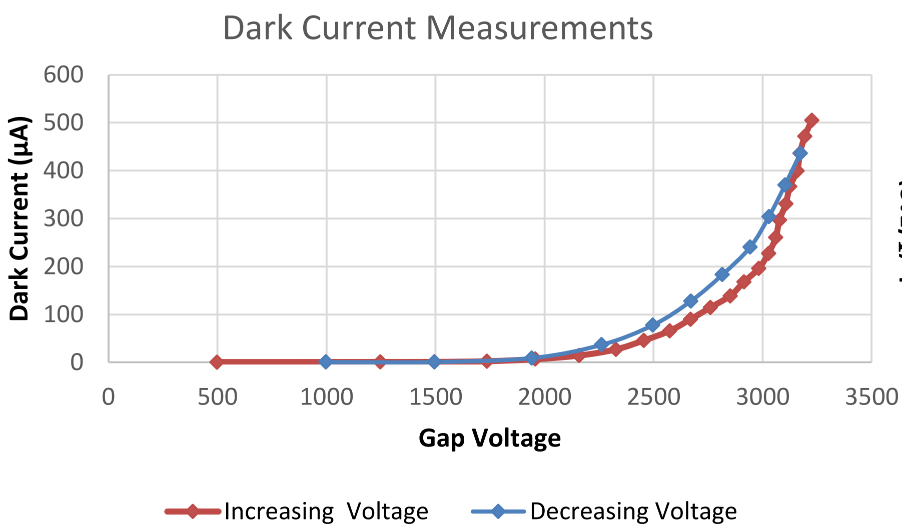
https://www.quora.com/Can-a-single-electron-emit-more-than-one-photon-If-so-is-there-a-limit

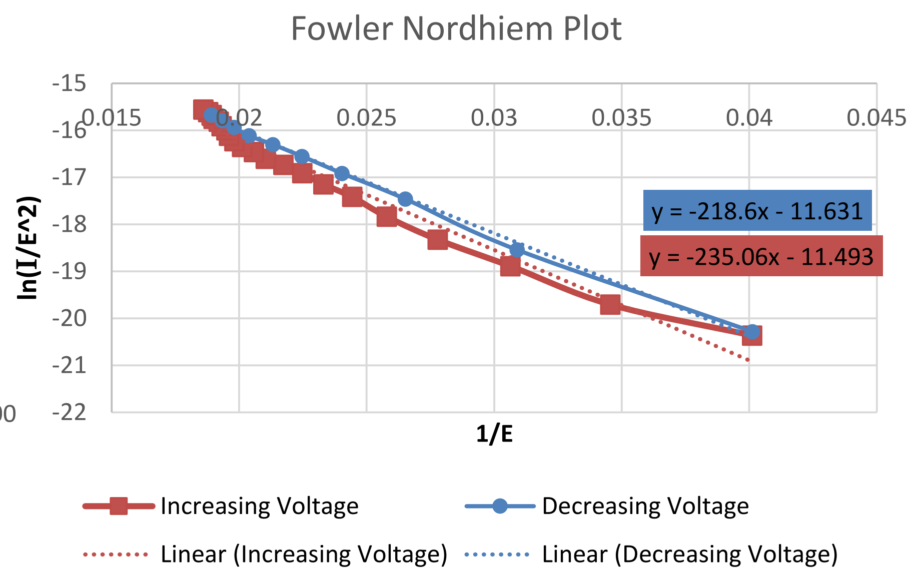
Pulsed DC Large Electrode System Chamber

The MARX generator supplies a pulsed voltage up to 10kV and frequency up to 6kHz



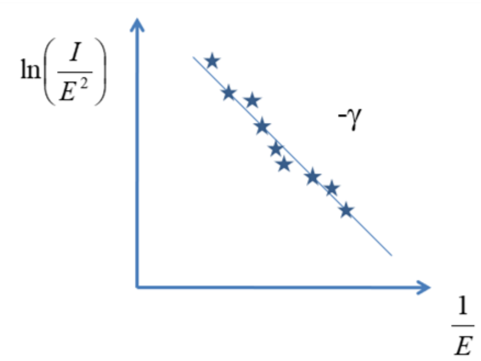
Field Emission Measurements





Fowler Nordheim Current is given as:

$$I_F = A\frac{1.54\times10^{-6}\times10^{4.52\phi^{-0.5}}\beta^2E^2}{\phi}\ \exp\left(-\frac{6.53\times10^9\phi^{1.5}}{\beta E}\right)$$



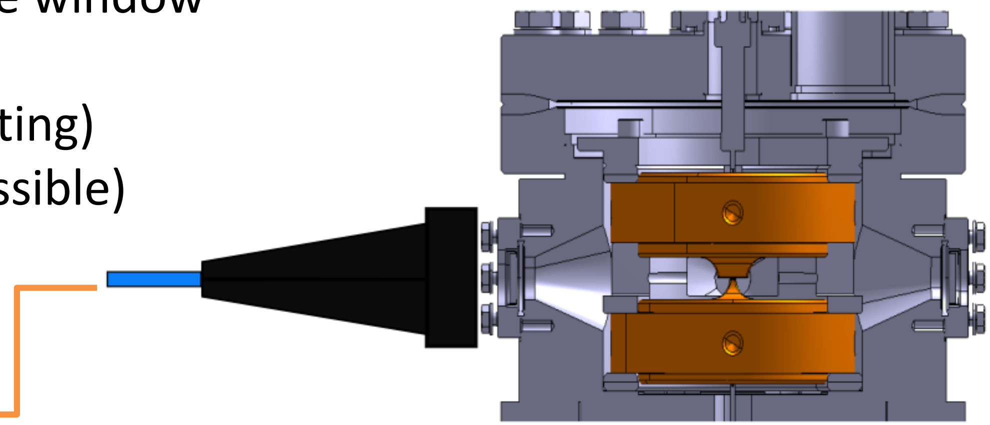
This is used to calculate beta (Field Enhancement Factor):

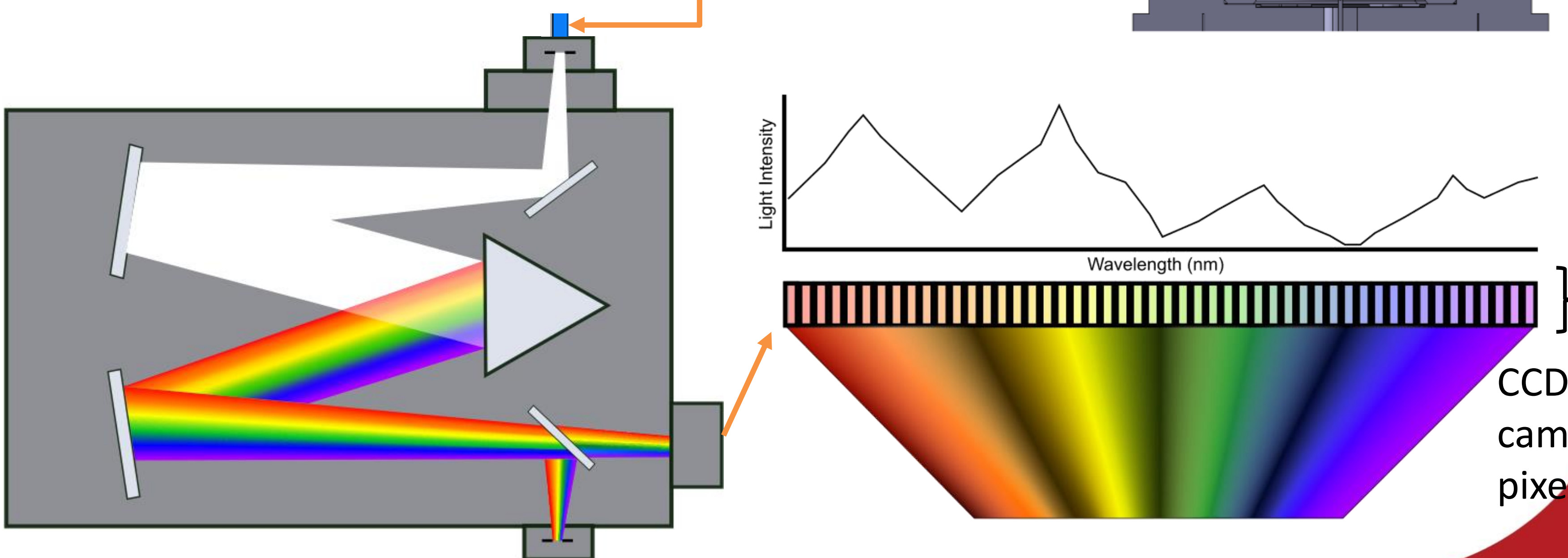
$$\beta = \frac{6.53\times10^3\varphi^{3/2}}{\gamma}$$

Where $-\gamma$ is the gradient of the line when plotted as shown (FN Plot)

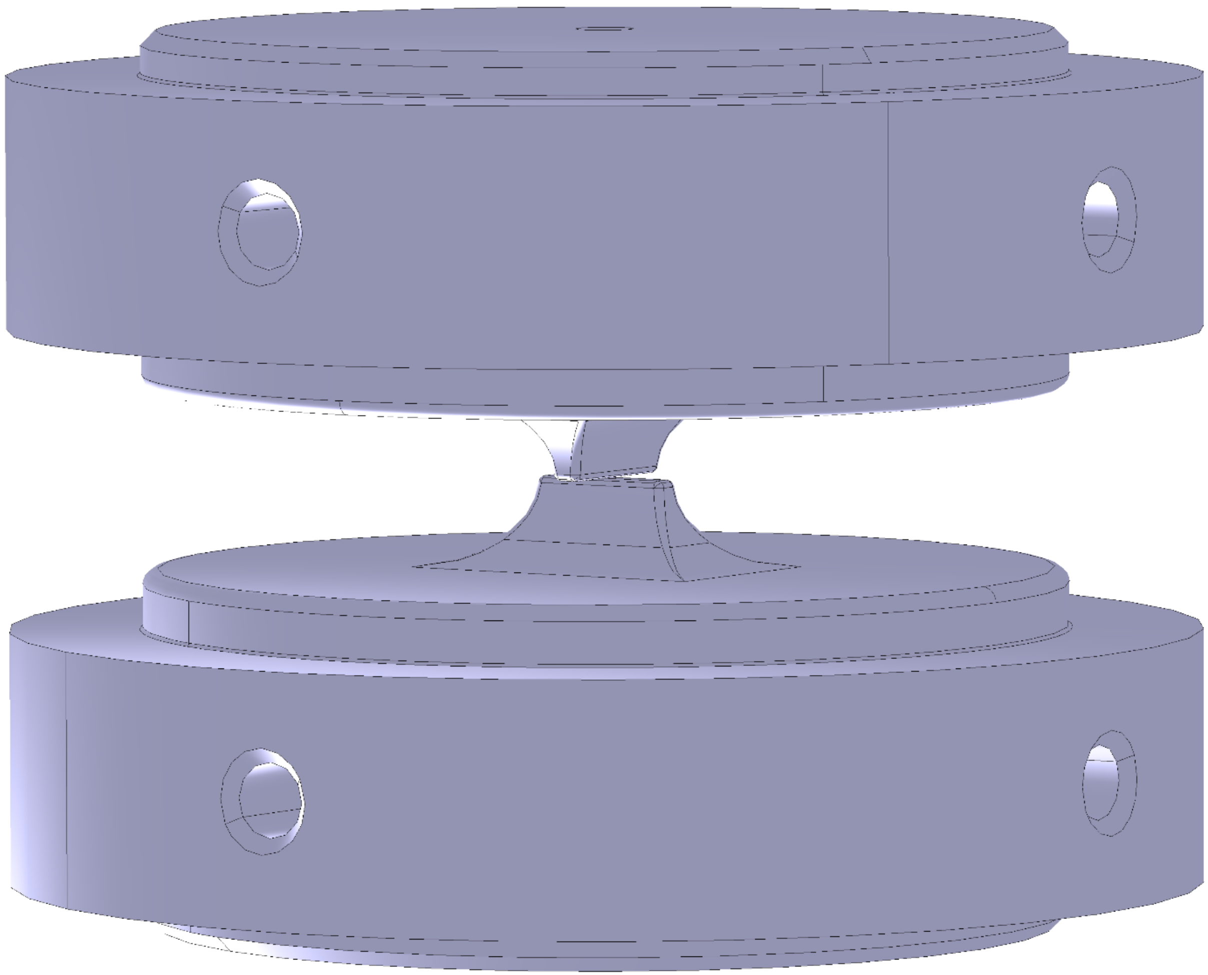
Spectrometer and Setup

- Collimator collects light from the window
- Optical Fibre (UV or NIR)
- Spectrograph (550nm range grating)
  - Slit 2500µm (as much as possible)
- IDus CCD camera
  - Exposure time of 5 seconds

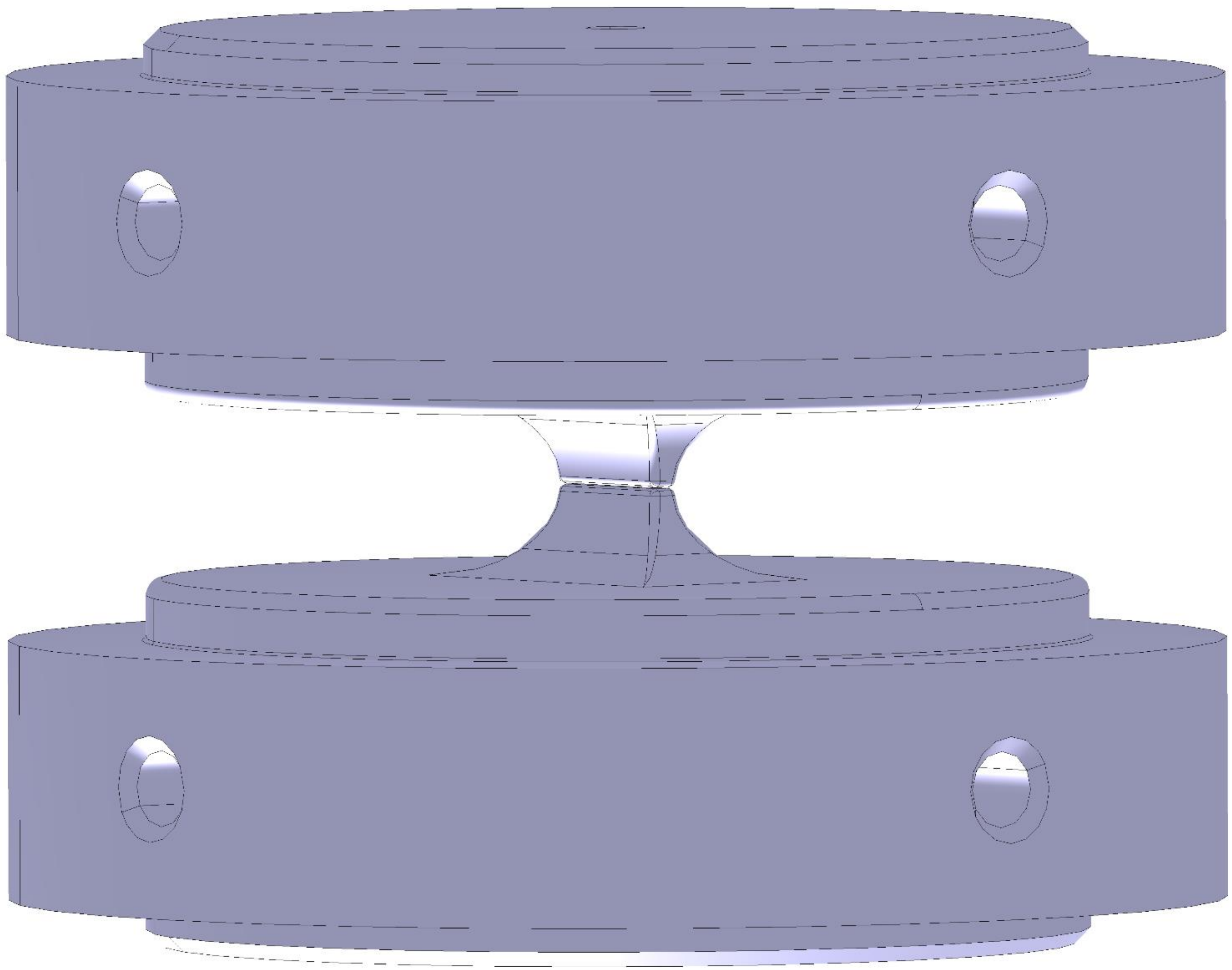




Crossed Setup



Parallel Setup



Crossed and Parallel Electrodes Spectrum – 60um Gap

CERN

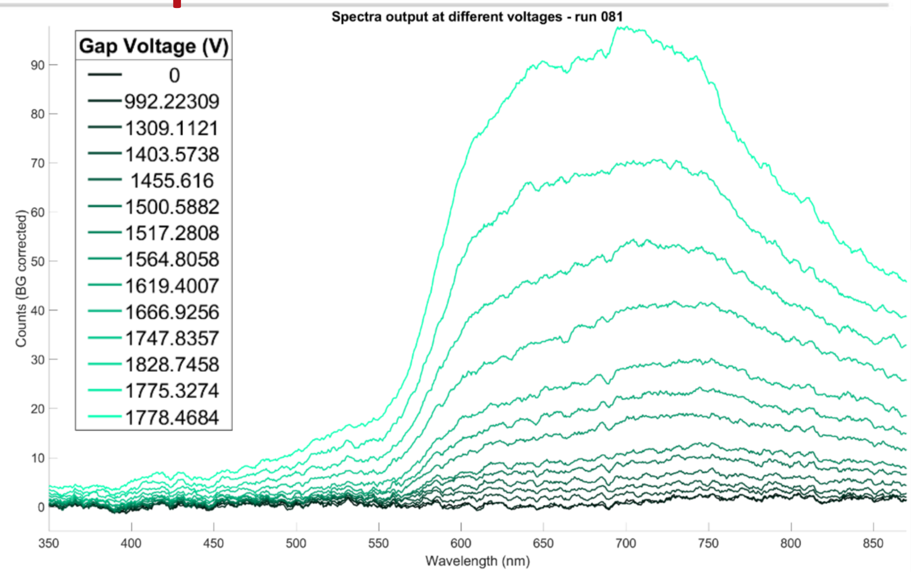
The Cockcroft Institute of Accelerator Science and Technology

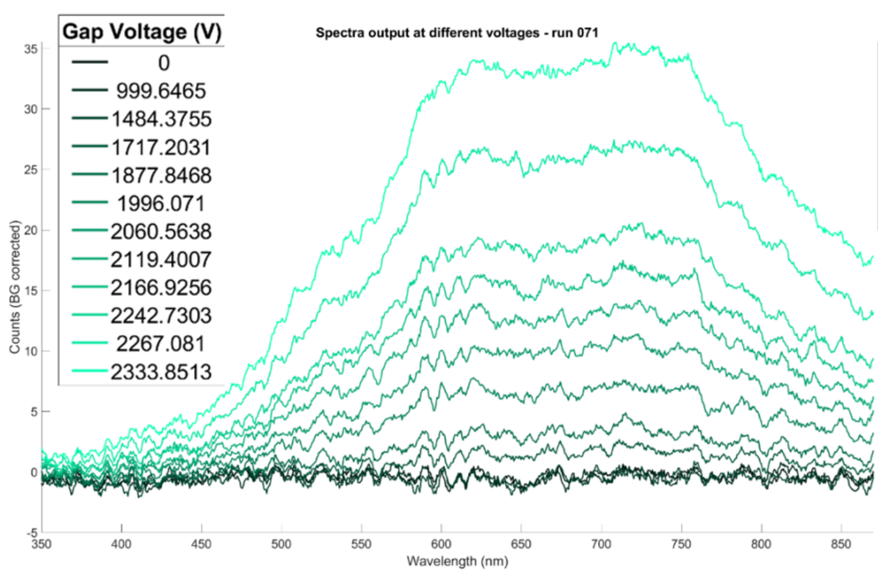
Engineering | Lancaster University

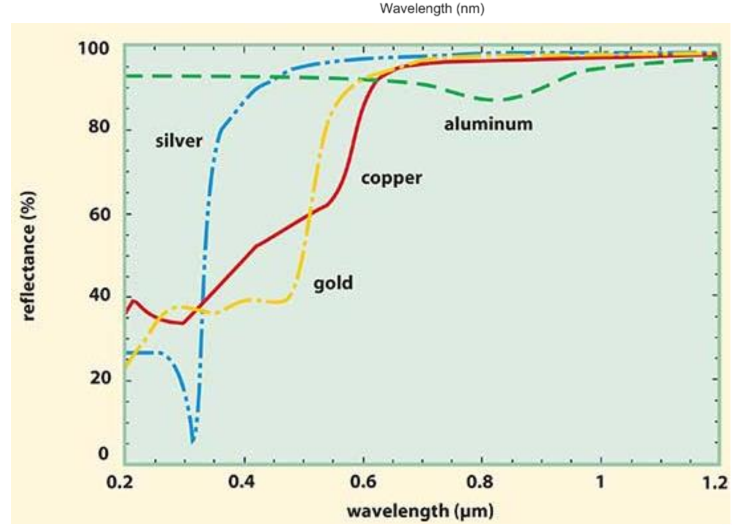
Spectra from Parallel Setup

- Broadband light from 600nm to 800nm
- Copper reflectivity suggests that the copper acts as a filter absorbing wavelengths below 600nm

- Wavelength (nm) vs Counts (BG Corrected)
- X-axis are the same in both plots



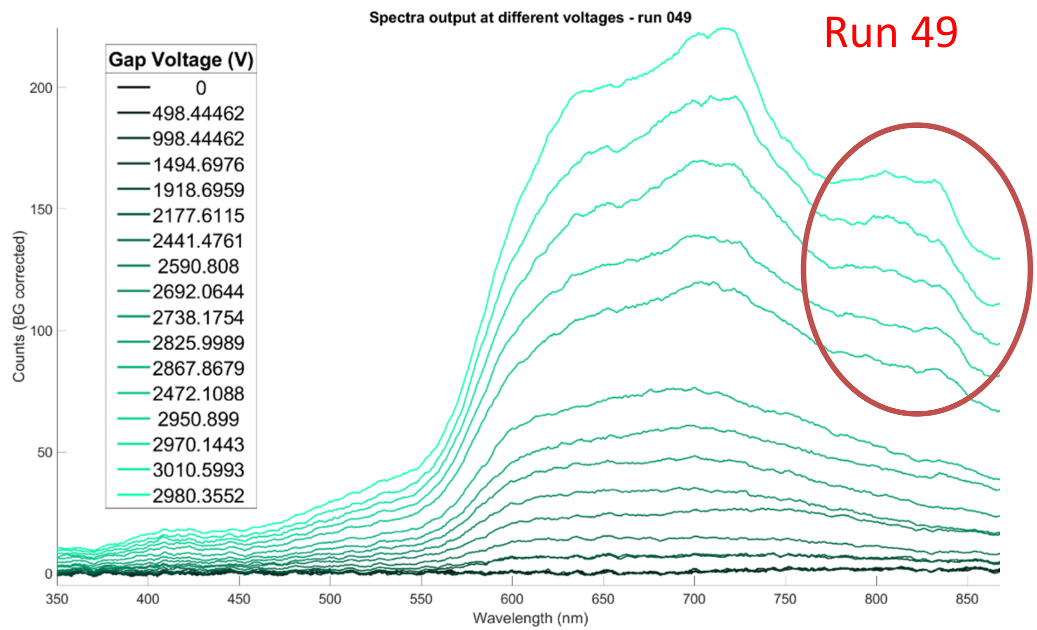




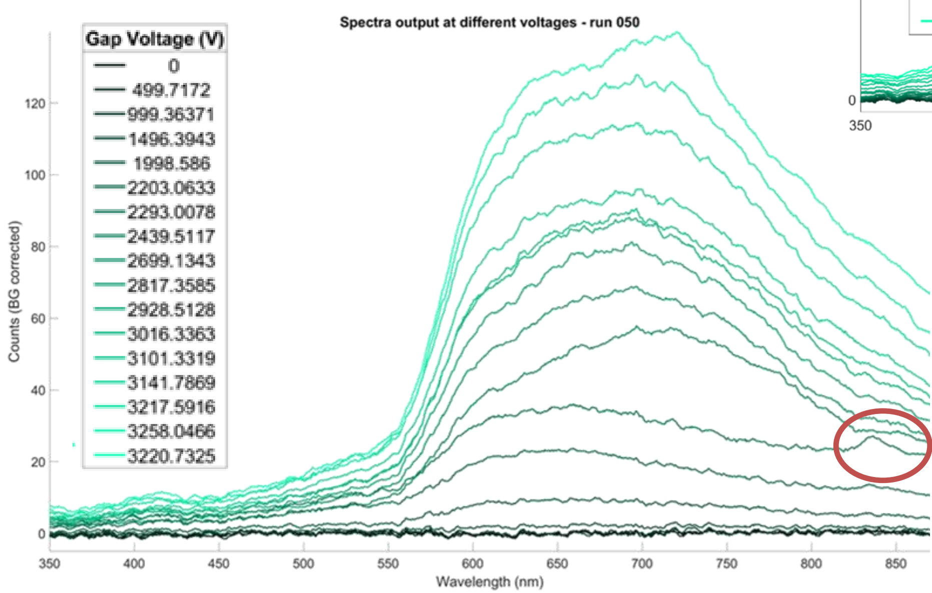
Spectra from Crossed Setup

- More light detected possibly due to alignment
- Similar shape to parallel starting around 500nm
- An additional feature that appears to change with time

Run 49



Run 50

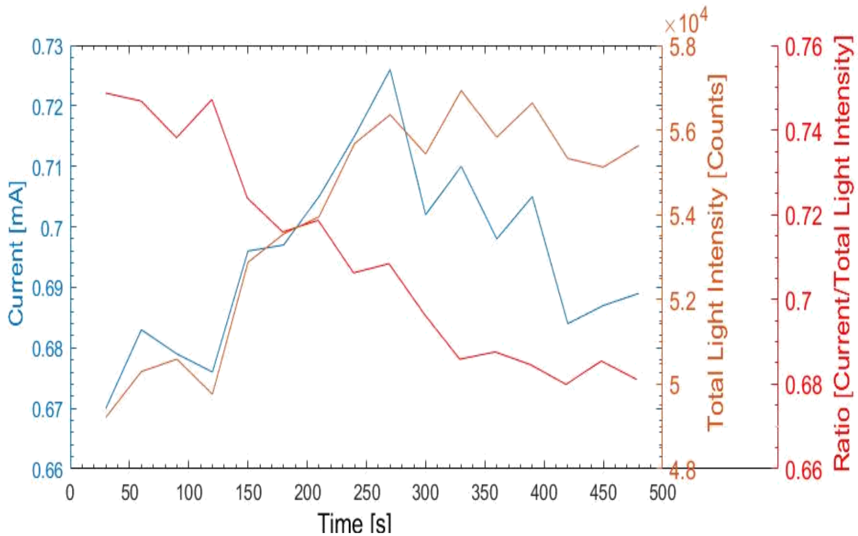


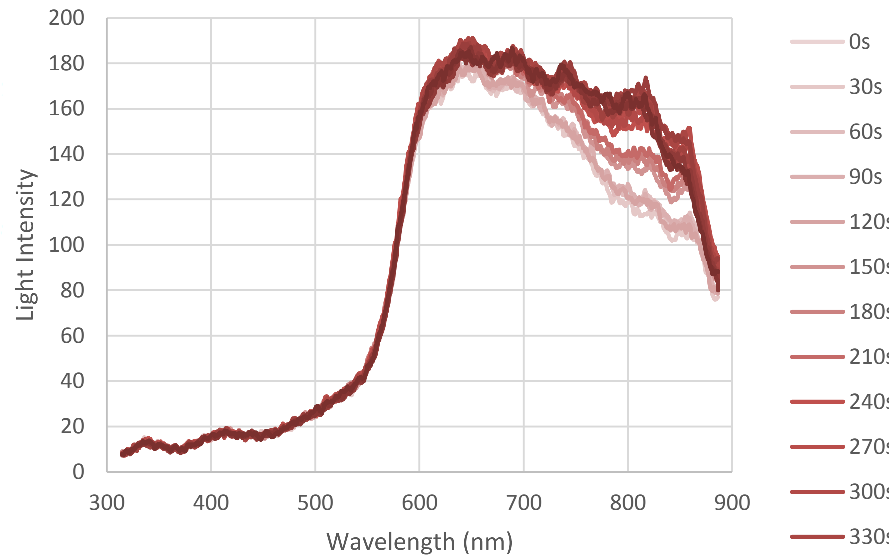
- Wavelength (nm) vs Counts (BG Corrected)
- X-axis are the same in both plots

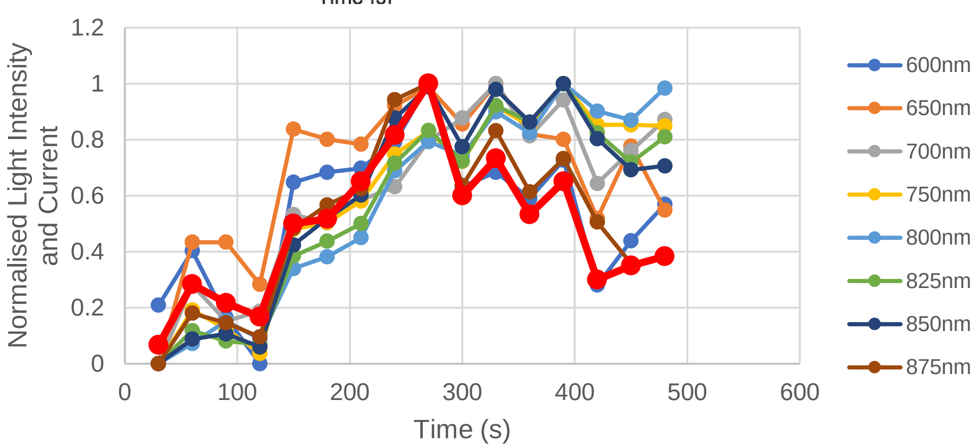
Spectrum Changes with Respect to Time

Spectrum recorded every 30s

7kV voltage throughout







Looking at the total number of counts (orange) compared to the current (blue). They also correlate and have some discrepancy when there is a spike in current.

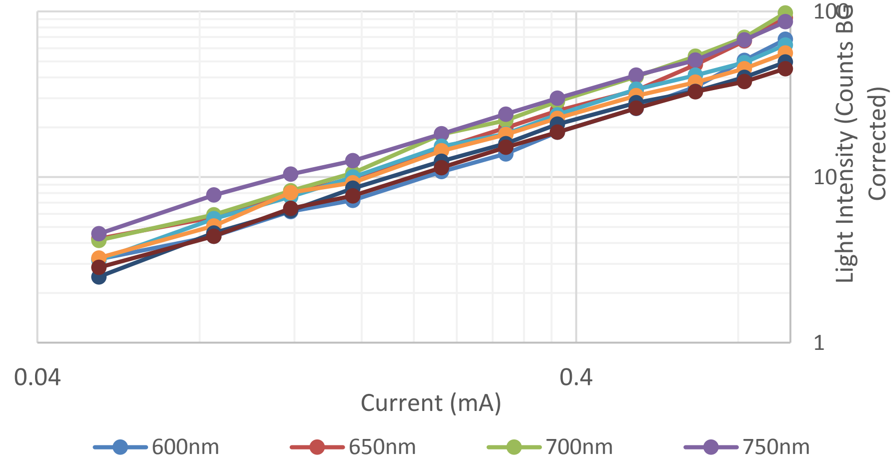
Crossed and Parallel Electrodes Correlations

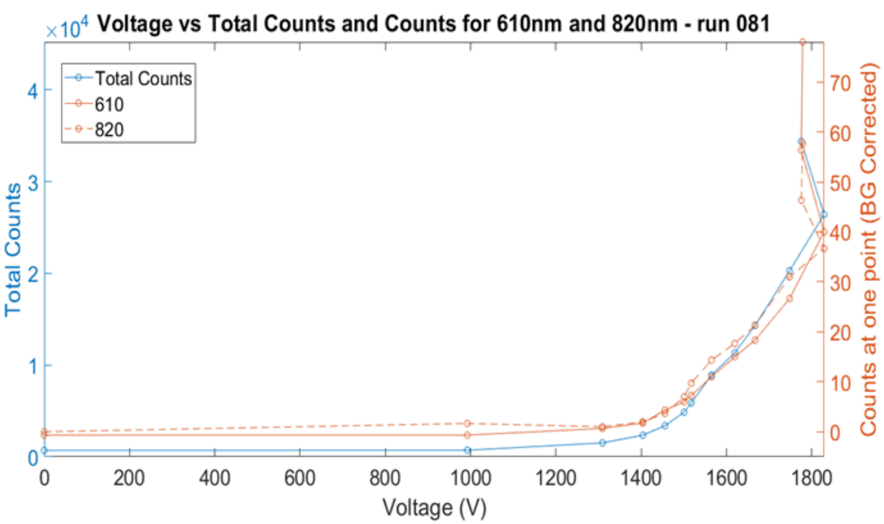
Justification

- Looking at light emission at specific wavelengths and the total light emission over the entire spectra (area under the curve)
- Possible correlation of light emission with either the current or power across the gap
- Light emission correlation with the Fowler Nordheim Theorem

Current and Voltage vs Light Intensity

The correlation between current with respect to light intensity appears to be linear, the plot for power looks the same. At this point this does not indicate which one of these the light is related to.



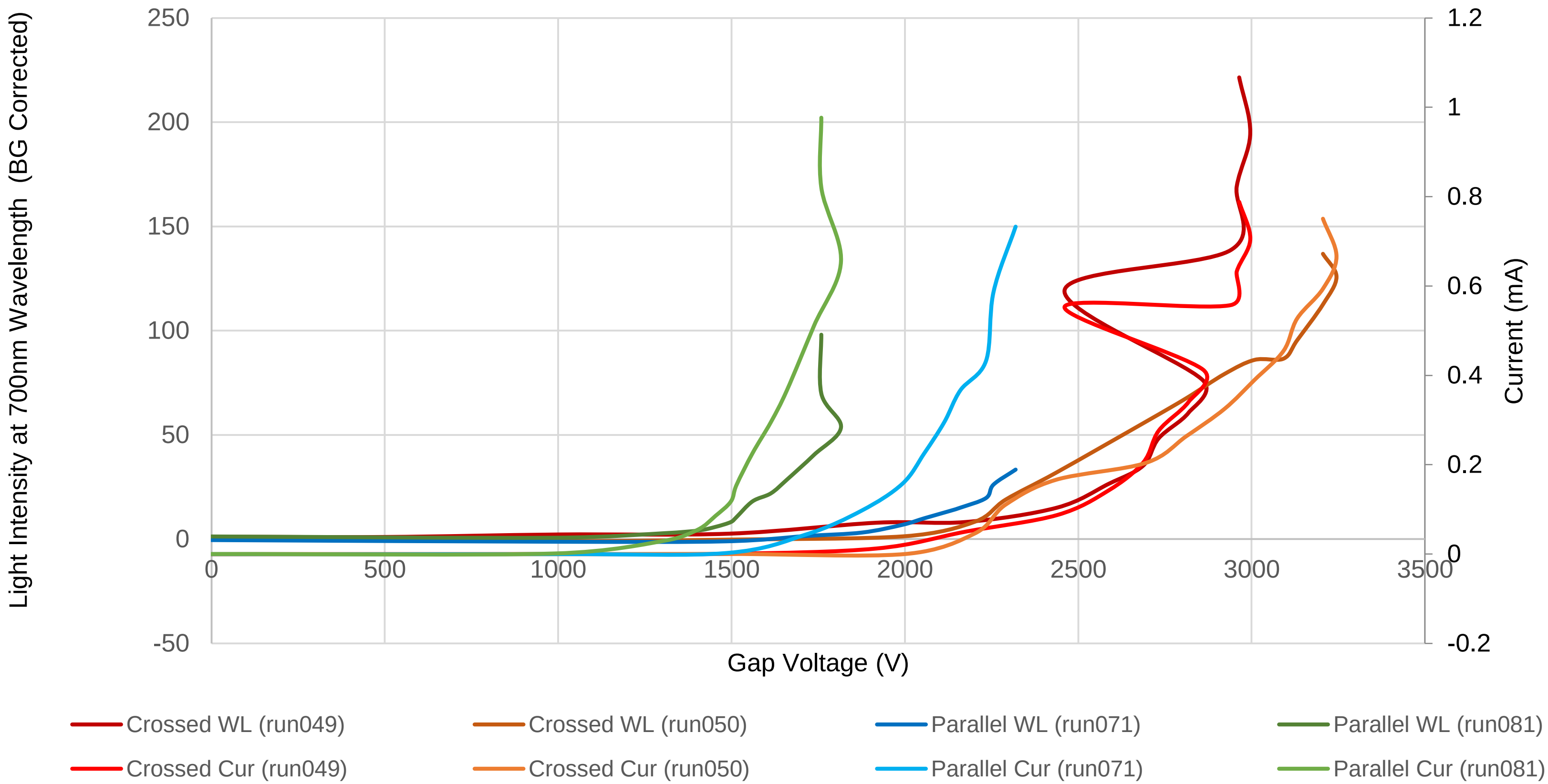


Looking for light emission correlation with the Fowler Nordheim Theorem. Light intensity when plotted with respect to voltage gives a plot that resembles the emission plot.

Crossed vs. Parallel Electrodes

Voltage vs Current and light emission for different alignments

R49 & R50 = Crossed,
R71 & R81 = Parallel

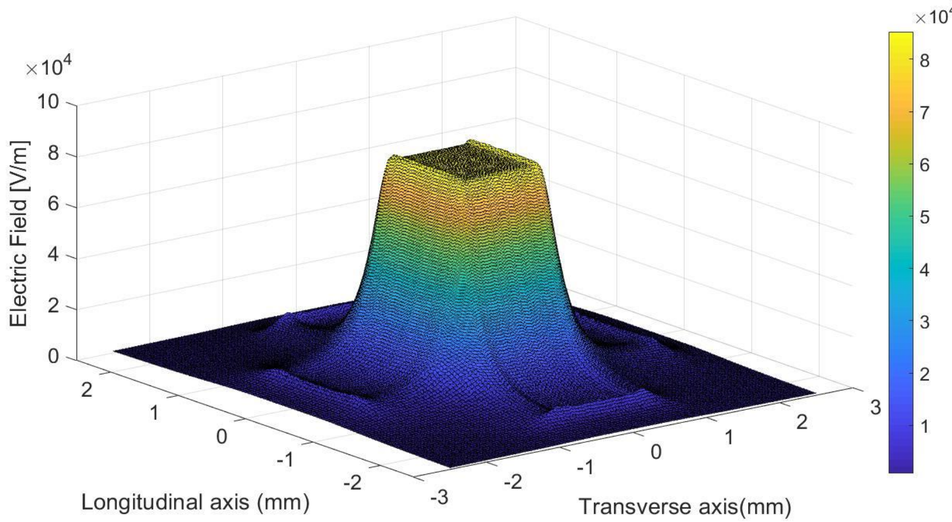


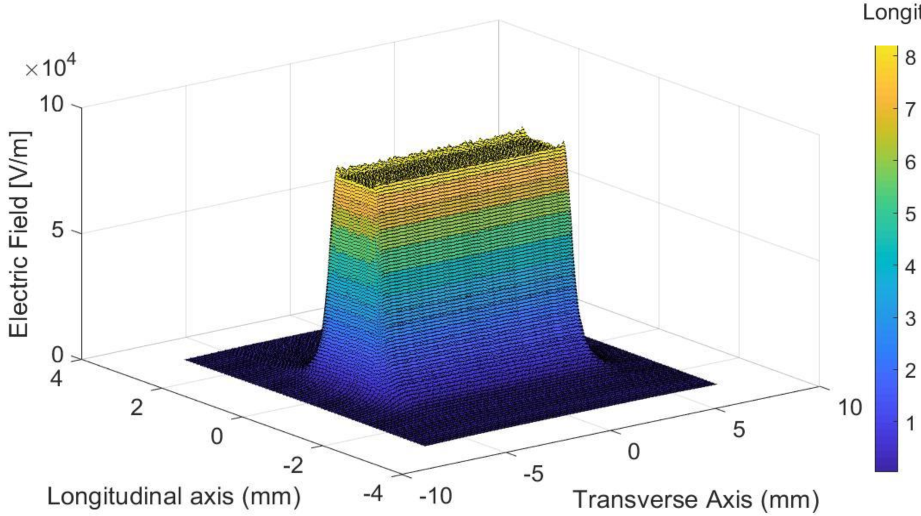
Lower light intensity from parallel electrodes with similar amounts of current compared to crossed electrodes.

3D Plot of Electric Field on the Surface

Calculating the E-Field at the edges of the crossed and parallel setups to determine if the crossed setup has a higher field.

The parallel setup has a higher field, therefore a higher field emission would be probable for a lower electric field.



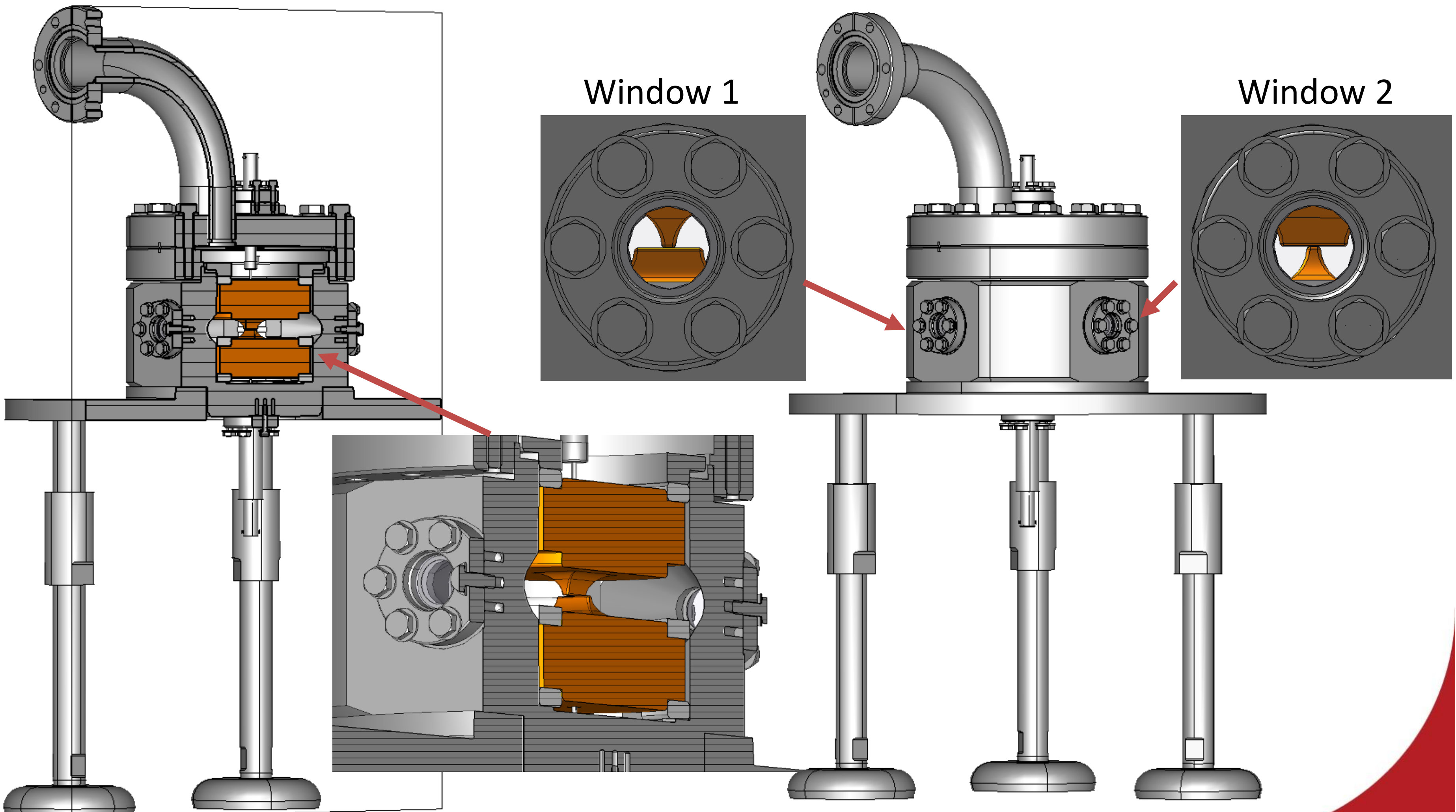


The maximum simulated electric field for a gap voltage of 5kV for the parallel alignment was 87557V/m and for the crossed alignment was 85251V/m

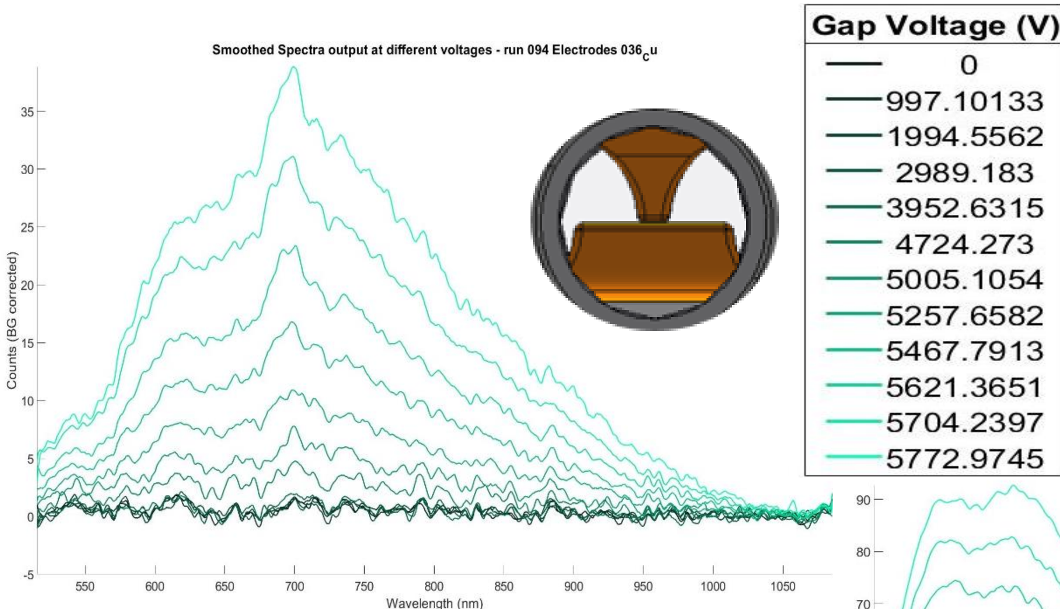
Crossed Electrodes – Gap increased from 60µm to 100µm

Hoping to see more light from the gap…

Perpendicular Windows on LES

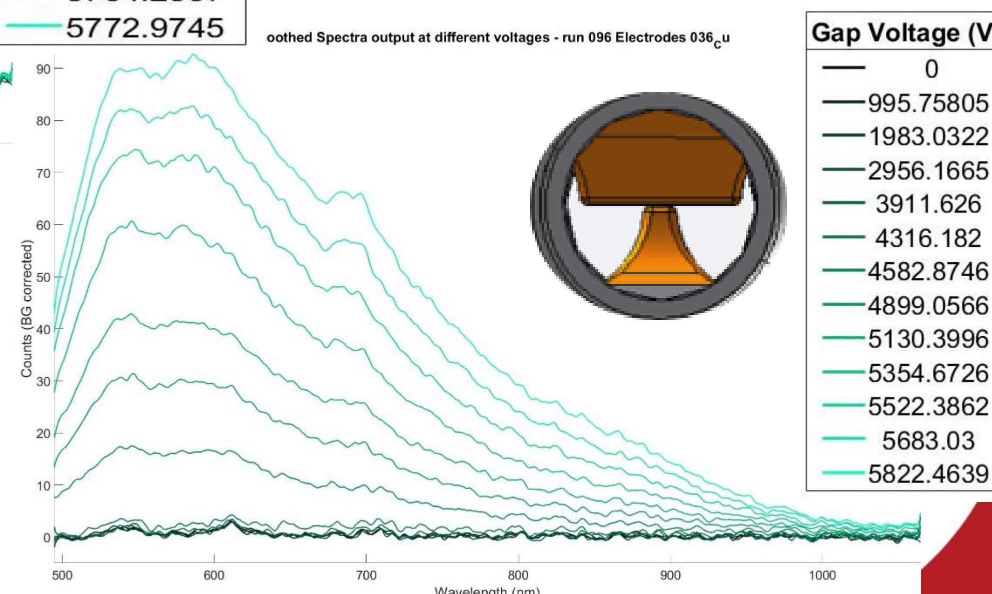


Perpendicular Window Measurements



Note the images of what the spectrometer would be looking at for each prospective…

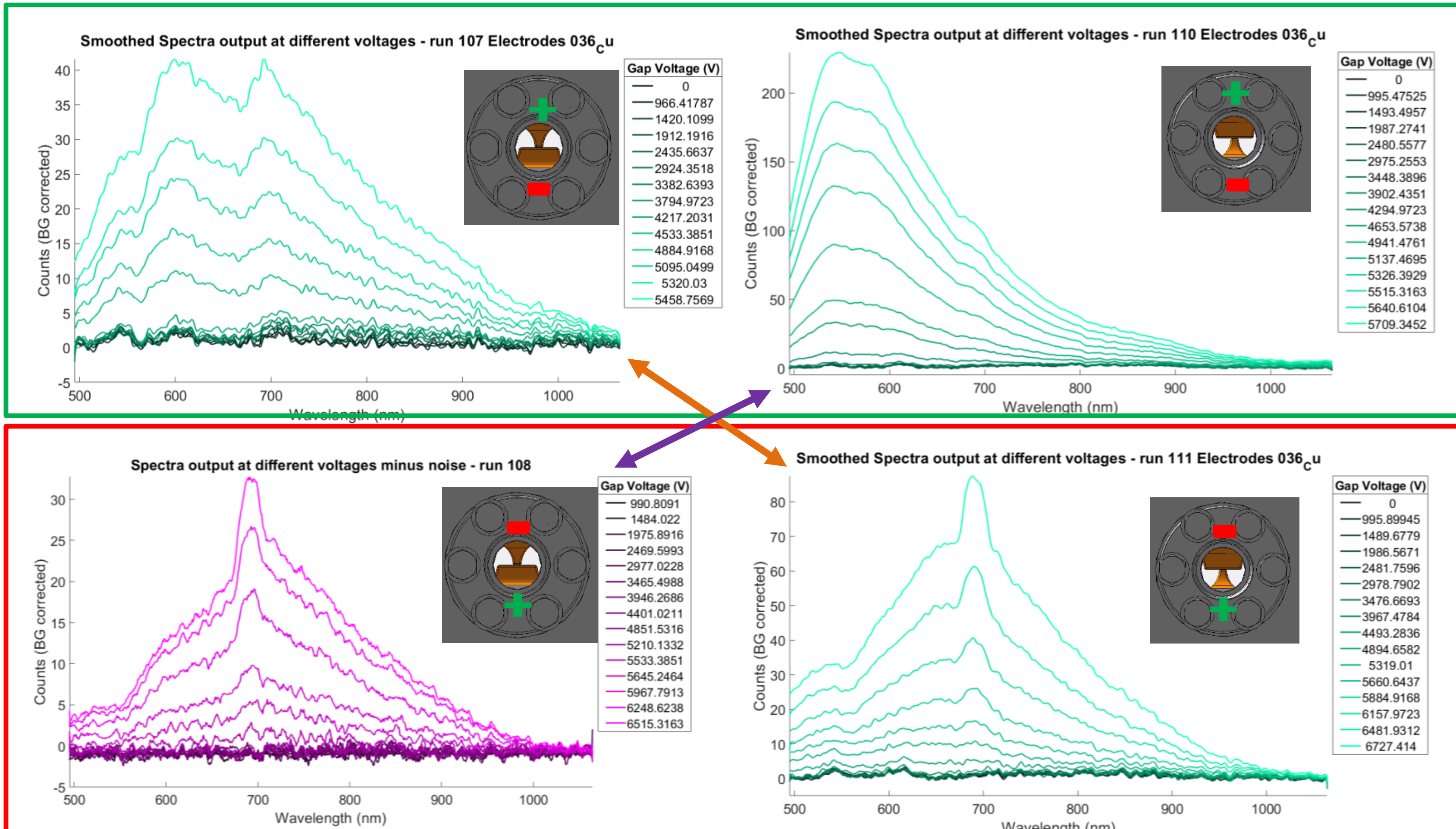
- A peak at 700nm appears in both plots
- There is additional spectra between 500 and 600 from one prospective (may also be present but less visible from the other)



Polarity test with crossed electrodes

To determine whether the difference in light from the different windows was related to the prospective of the collimator onto the emitting surface a test with different polarities was done…

Different Position and Polarity



Condition Positive Polarity

Conditioned Negative Polarity

Spectra with the negative polarity to conditioning shows a clear relatively narrow peak at 700nm

Planned Experiments

Spectroscopy

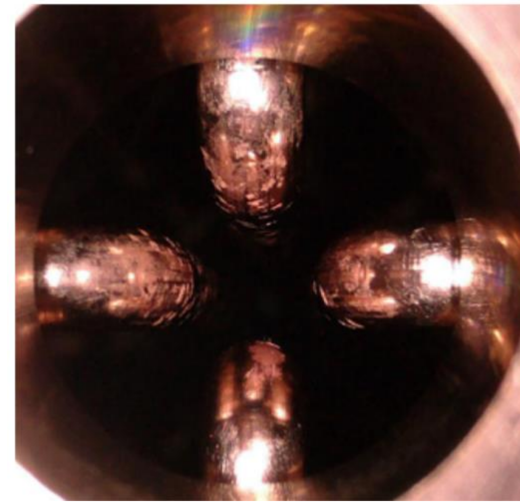
- Soon to incorporate an optical table to improve reliability of results
- Tests to observe the optical beta for different materials
- What do results say about light?
- Use of solid state spectroscopy to study the possibility of cathode luminescence
- Fast Photo Diode for cathode luminescence

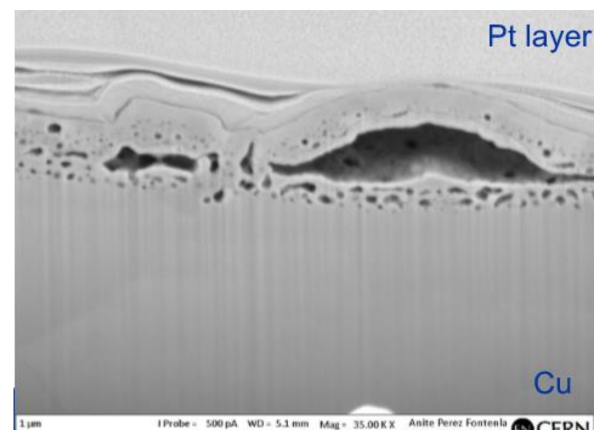
Gas Injection Experiment

- Parts for the gas injection ordered and delivered
- Installation of gas hardware onto the system
- Test with different pressures and the effect on breakdowns

LINAC4 RFQ - Irradiation of Electrodes

- Run of Brazed Electrodes as a benchmark with similar parameters to the RFQ
- Future electrodes will be irradiated to analyse breakdown locations
- New edge equation tested for machining of new electrodes
  - Electrodes made of different materials
  - Re-machining of electrodes

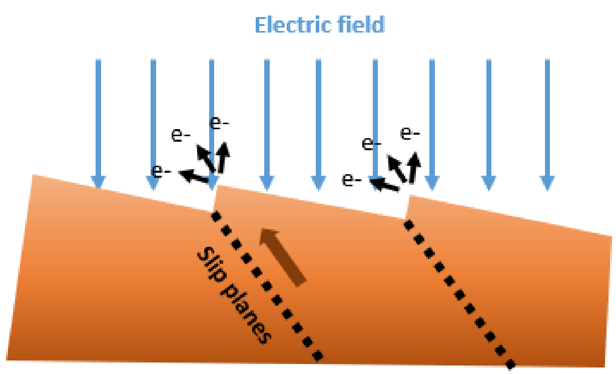




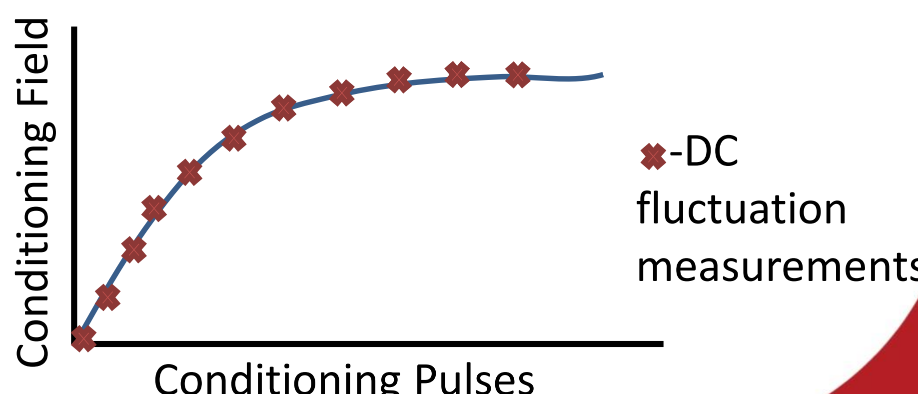
Suitbert Ramberger - https://indico.cern.ch/event/918452/

Unconditioned Large Electrode Fluctuations

- Hard and soft copper fluctuation measurements during conditioning
- Dark current measurements at intervals throughout initial conditioning
- Electronic components made and need testing



Jan Paszkiewicz - https://indico.cern.ch/event/917715/



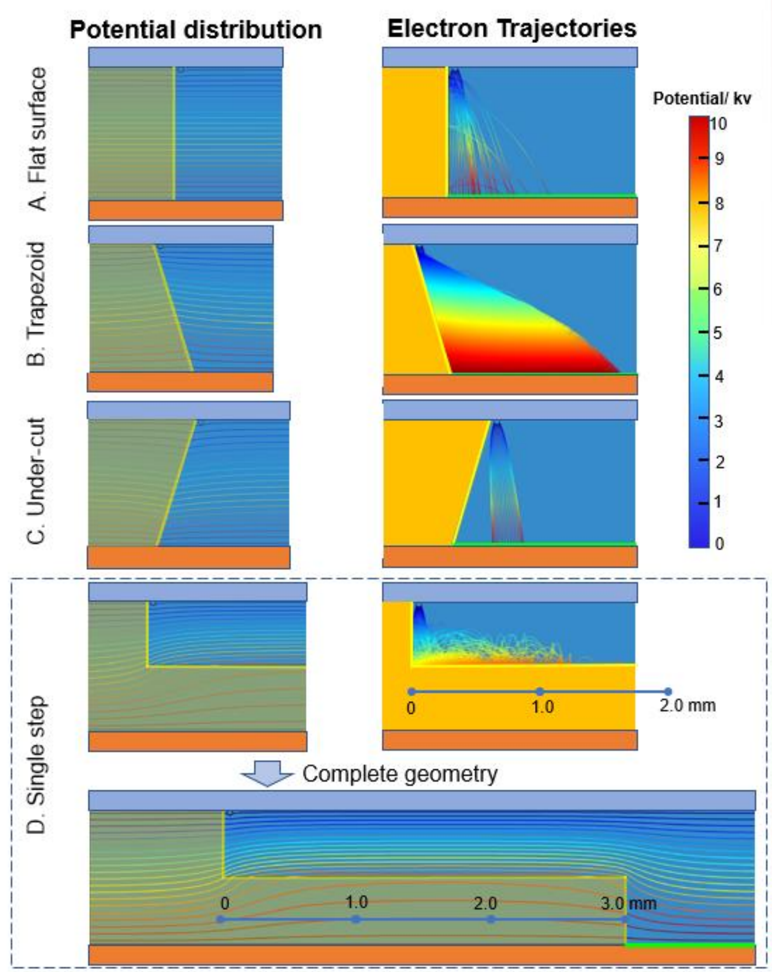
DC Cryogenic System Fluctuations

- There is a Cryo system!!
- There should not be fluctuations at cryo temperatures
- Dislocations should not be able to move
- Measurements can be done at different temperatures

https://indico.cern.ch/event/865560/

Ceramic Spacer

- Had to change the design slightly and need to test everything fits
- Theoretical analysis by Xiaoli Gou
- Plan tests when travelling is possible
- LES3 with Marx4 for dual polarity



Summary

- Field emission spectra measured
- Distinct features observed that change with time
- Indications spectra depend on surface conditions of the electrodes
- Understanding these changes should give insight into with field emitter characteristics, giving new diagnostic for high-field surfaces
- Work will continue with better optics and different material electrodes
- Lots of plans for experiments!

Thank You

15th July 2020

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