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| **Title:** | Direct Measurement of Light Scattering and Quantum State Preservation from Non-Specular Materials |
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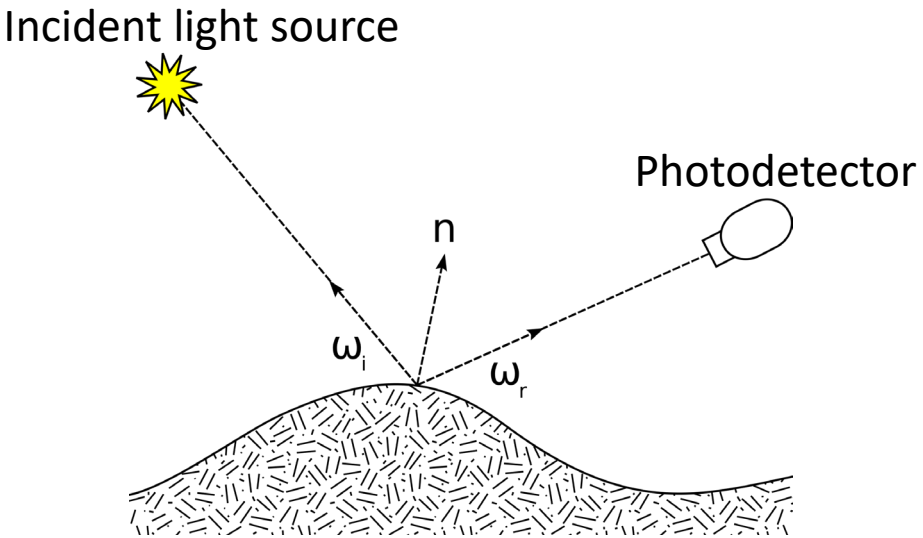
Los Alamos NATIONAL LABORATORY

# Direct Measurement of Light Scattering and Quantum State Preservation from Non-Specular Materials

Kristina Meier, ISR-2

October 11th, 2023

# Bidirectional Reflectance Distribution Function

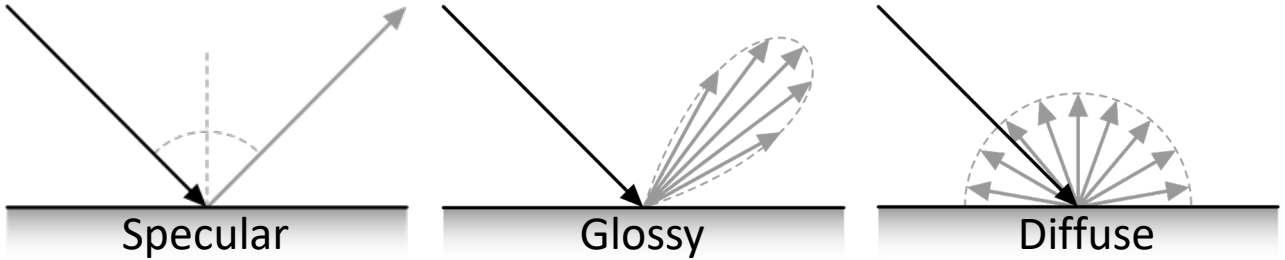



$$BRDF = \frac{L_0}{E_i}$$

$L_0 =$ Amount of reflected light in direction of $\omega_r$

$E_i =$ Amount of incident light along path of $\omega_i$

C. Wynn, *A Basic Introduction to BRDF-Based Lighting*, NVIDIA

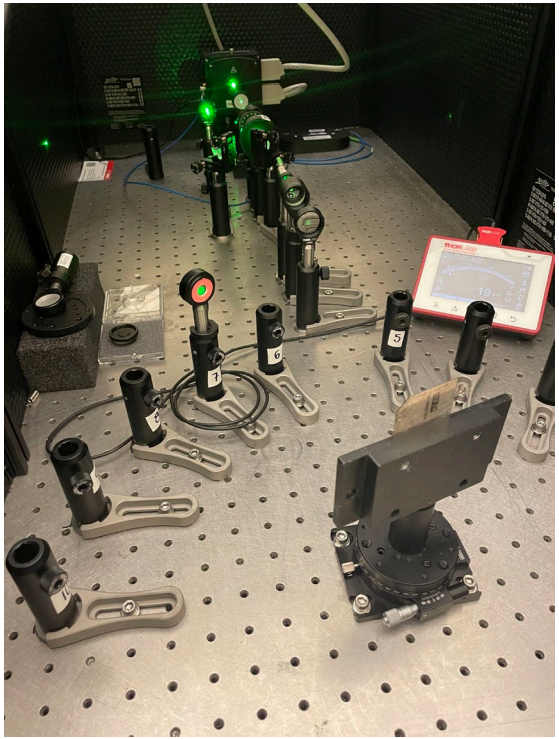


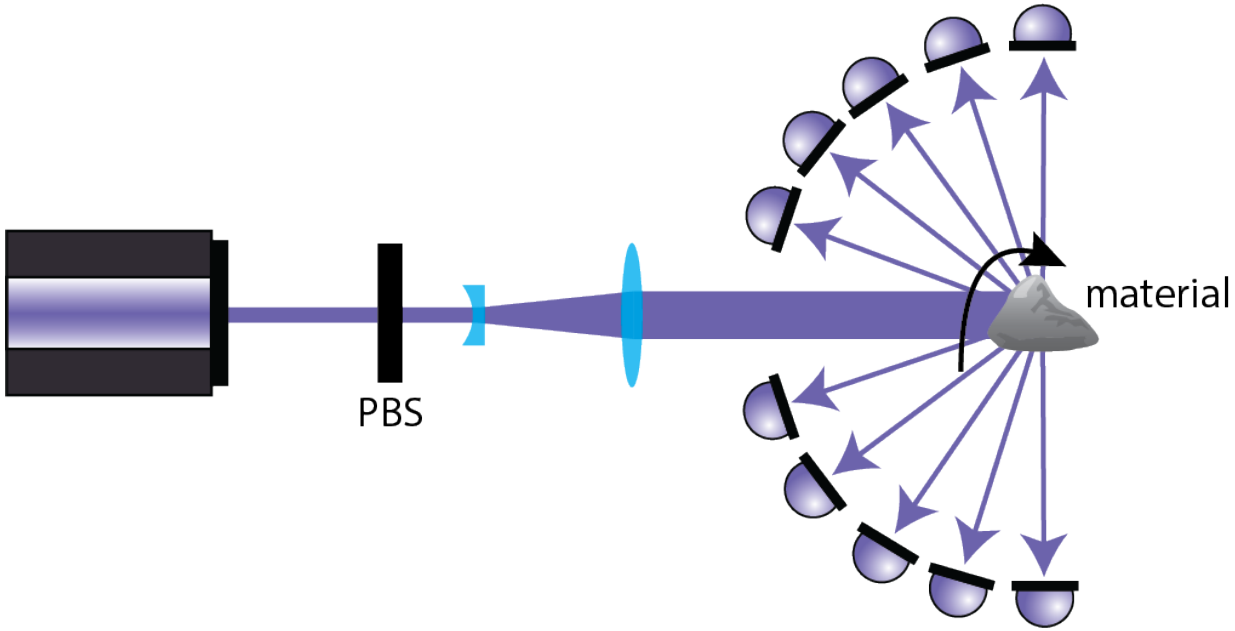

https://en.wikipedia.org/wiki/Bidirectional_reflectance_distribution_function

# Motivation for Satellite Materials: (Quantum) Radar? (Quantum) Remote Sensing?

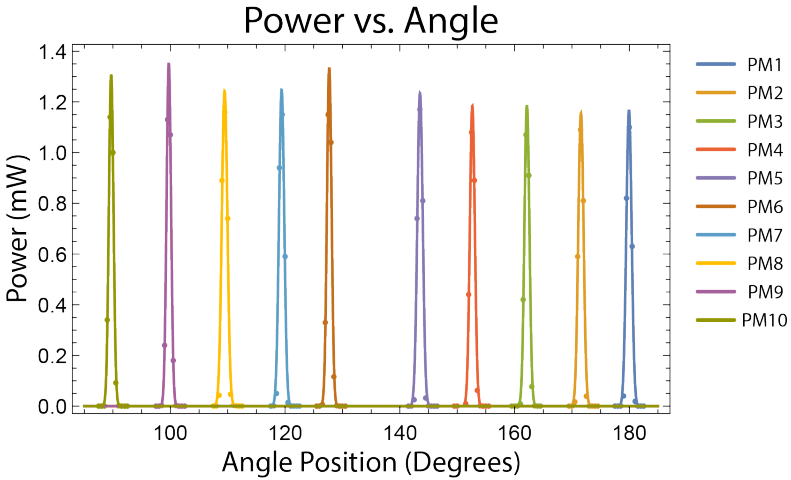
NASA.gov

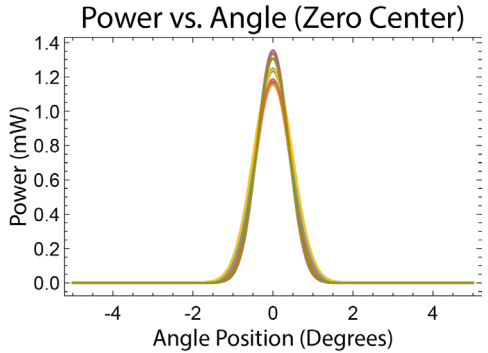
# Measuring BRDF in the lab

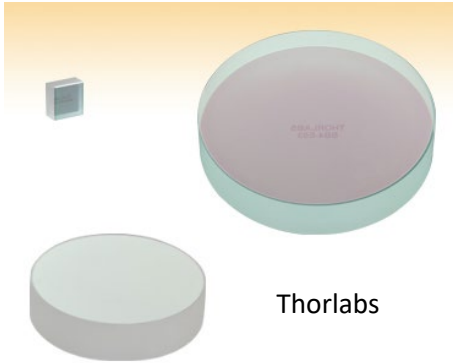


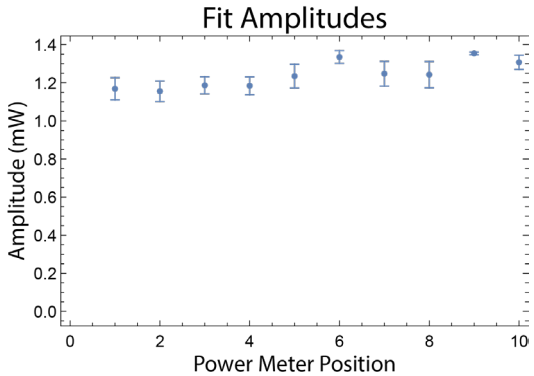


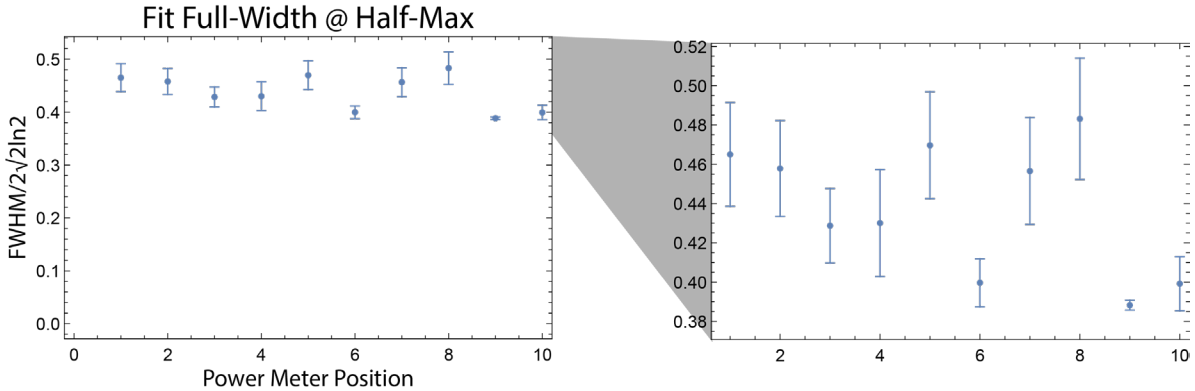
# Mirror (Thorlabs BB1-E02 – Coated for 400-750 nm)



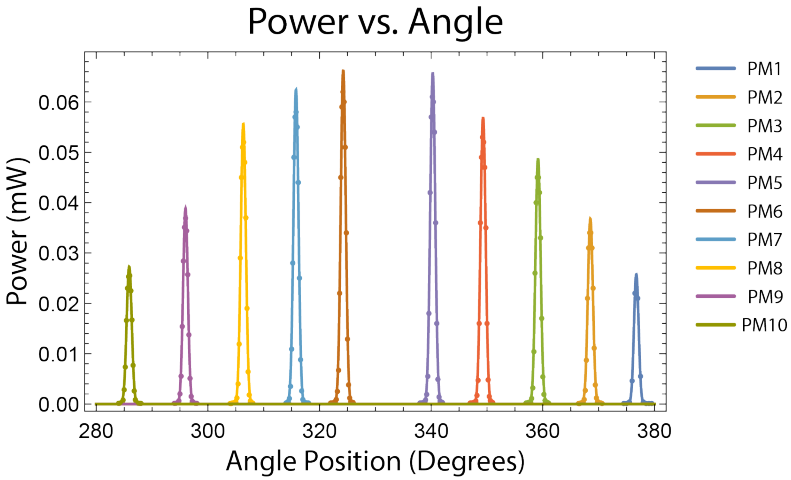



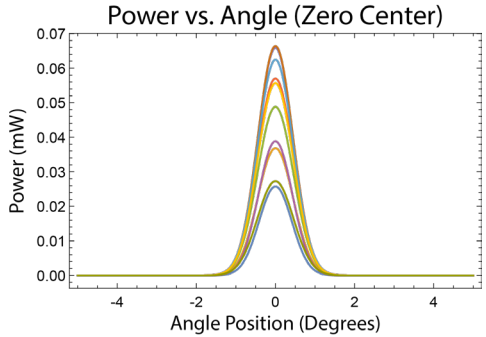



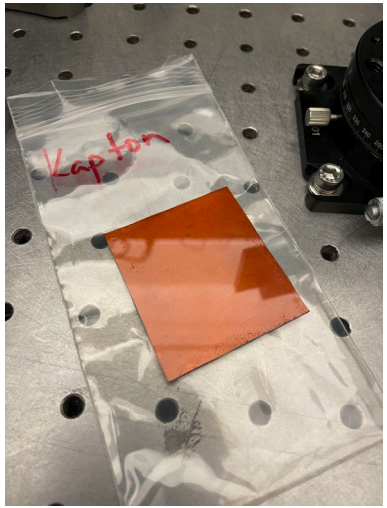



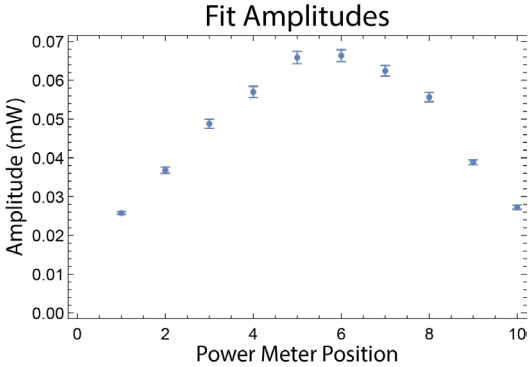



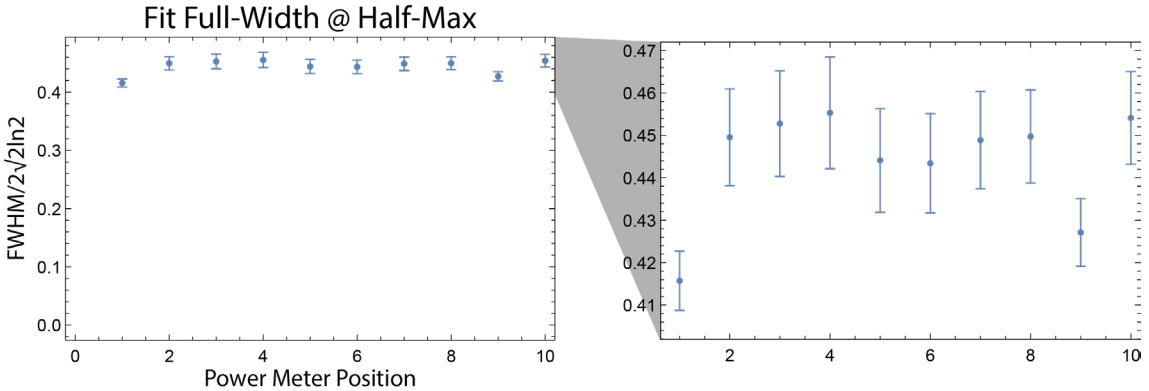
# Kapton


Power vs. Angle
Power (mW)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
280
300
320
340
360
380
Angle Position (Degrees)
PM1
PM2
PM3
PM4
PM5
PM6
PM7
PM8
PM9
PM10

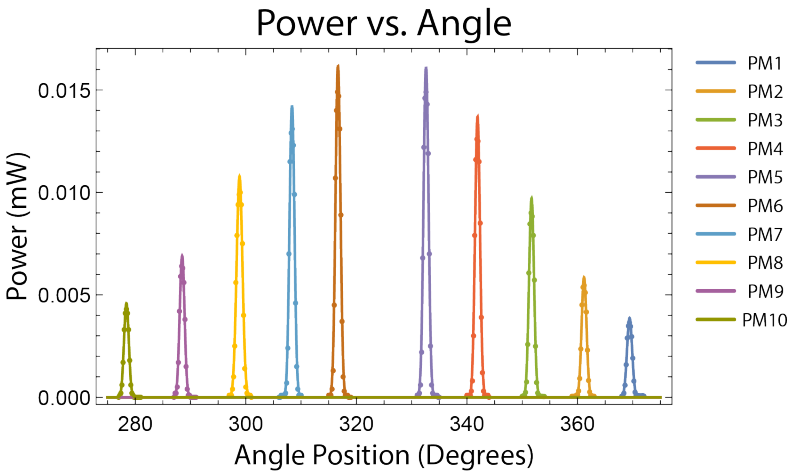

Power vs. Angle (Zero Center)
Power (mW)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
-4
-2
0
2
4
Angle Position (Degrees)

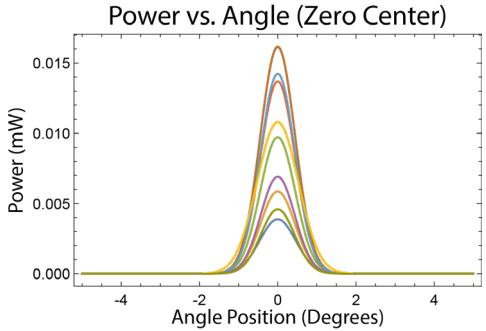

Kapton

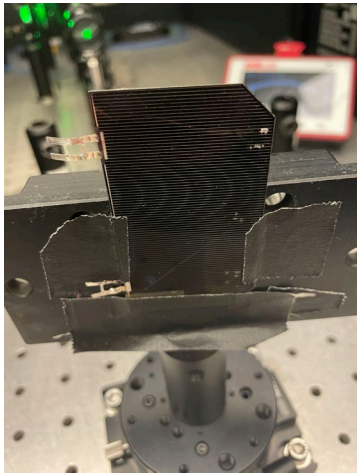

Fit Amplitudes
Amplitude (mW)
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0
2
4
6
8
10
Power Meter Position

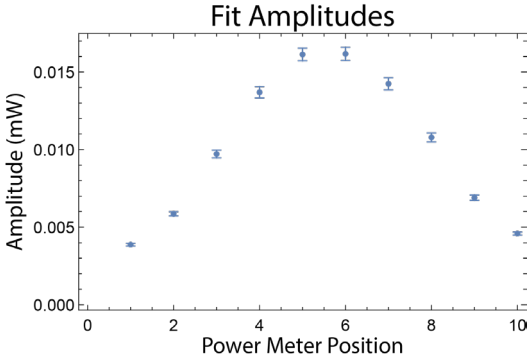

Fit Full-Width @ Half-Max
FWHM/2√2ln2
0.0
0.1
0.2
0.3
0.4
0
2
4
6
8
10
Power Meter Position
0.41
0.42
0.43
0.44
0.45
0.46
0.47
2
4
6
8
10

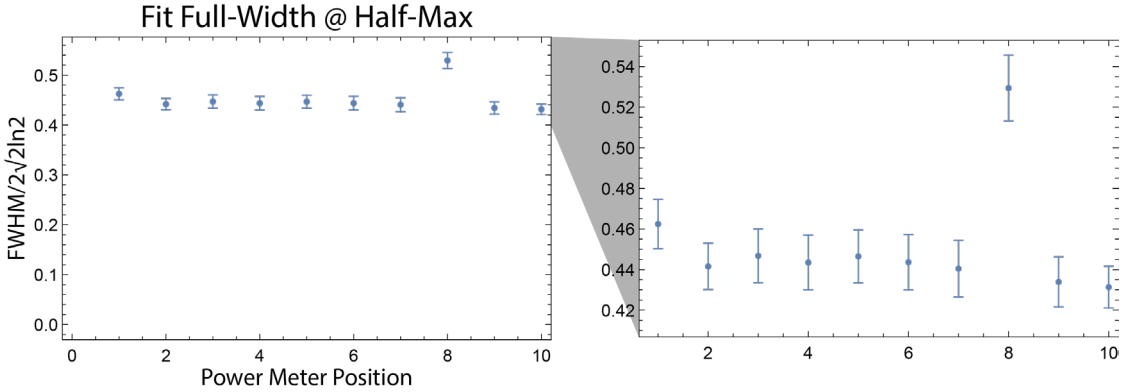
# Solar Cells


Power vs. Angle
Power (mW)
0.015
0.010
0.005
0.000
280
300
320
340
360
Angle Position (Degrees)
PM1
PM2
PM3
PM4
PM5
PM6
PM7
PM8
PM9
PM10

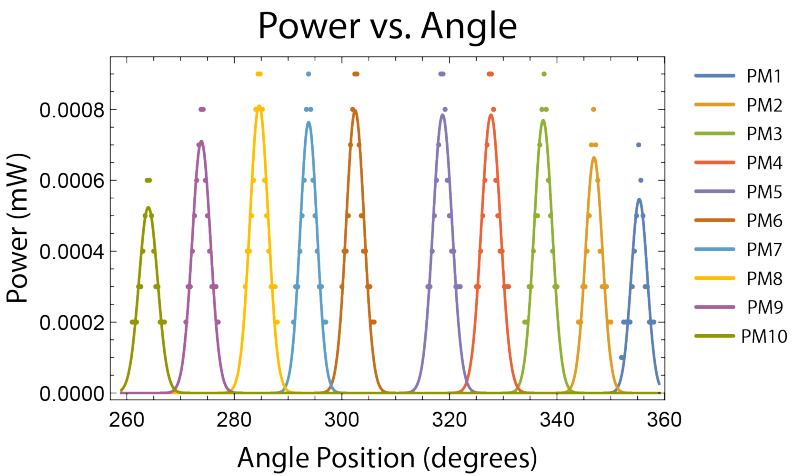

Power vs. Angle (Zero Center)
Power (mW)
0.015
0.010
0.005
0.000
-4
-2
0
2
4
Angle Position (Degrees)

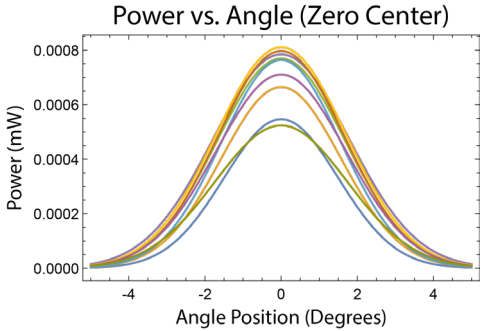


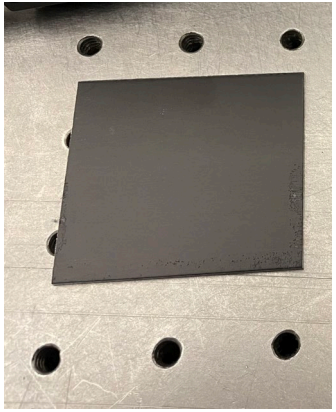

Fit Amplitudes
Amplitude (mW)
0.015
0.010
0.005
0.000
0
2
4
6
8
10
Power Meter Position

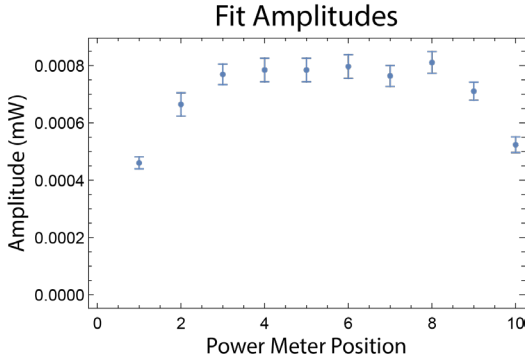

Fit Full-Width @ Half-Max
FWHM/2√2ln2
0.5
0.4
0.3
0.2
0.1
0.0
0
2
4
6
8
10
Power Meter Position
0.54
0.52
0.50
0.48
0.46
0.44
0.42

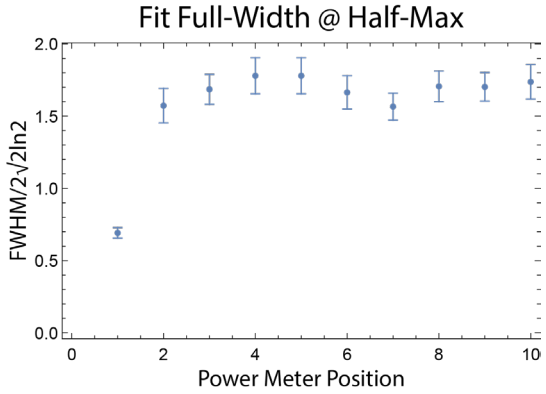
# Anodized Aluminum

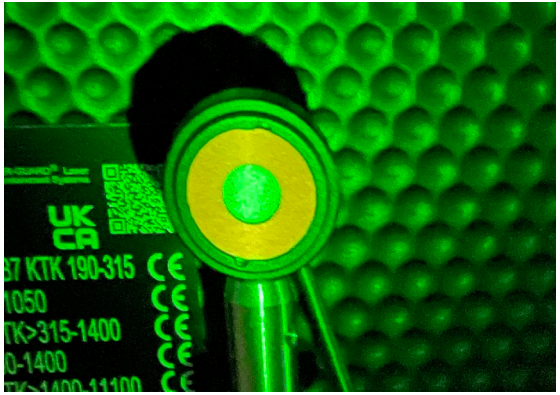


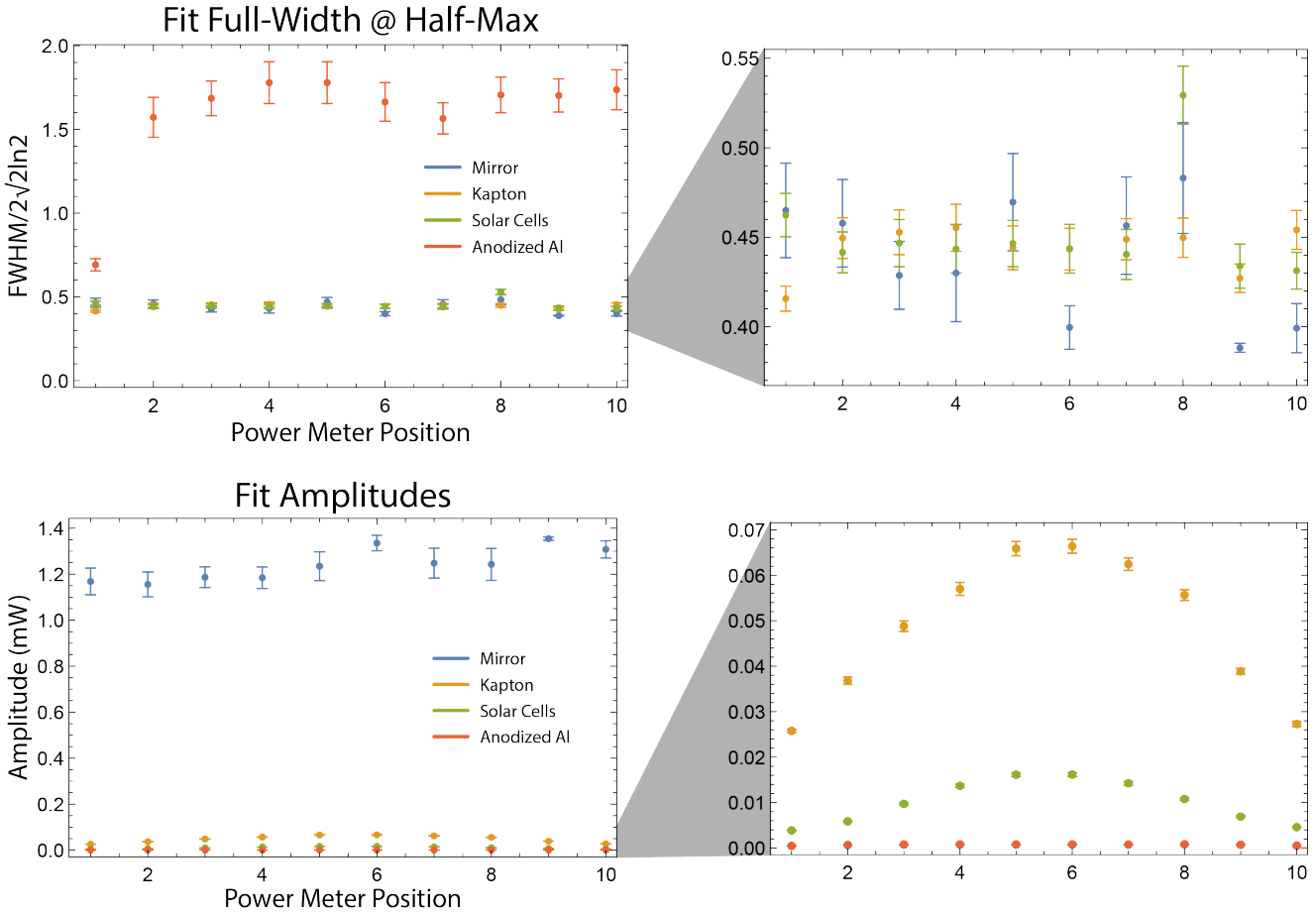





# Comparison between Materials



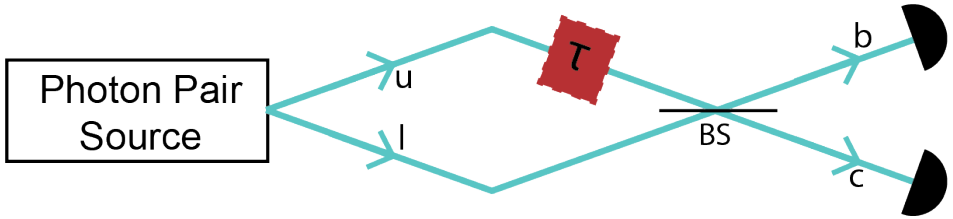
# Conclusions from BRDF Measurements

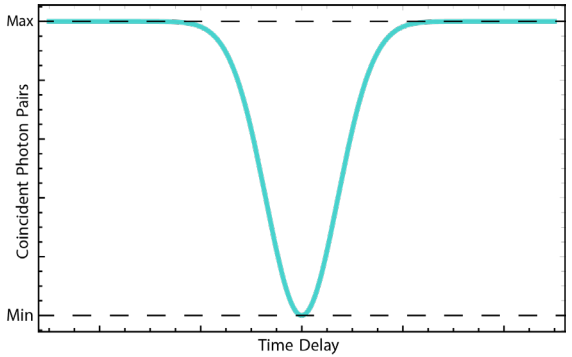
- Mirrors are specular and have consistent reflectance over a range of angles. The measured power of the reflected light was consistent for all power meter positions
- Kapton had a similar specular response as the mirror (FWHM), but displayed varying power levels for the different power meter positions (much like the Anodized Al and the Solar Cells)
- The Solar Cells had very high loss consistent with a material that is supposed to absorb light, but still exhibited specular behavior for FWHM
- The Anodized Al had the most diffuse (highest FWHM) reflectance and low BRDF amplitude.
- Also tried to measure the BRDF Aeroglaze (a common satellite coating) but the power meter was not sensitive enough. To the eye, this material seemed very absorbent and any reflection would be very diffuse

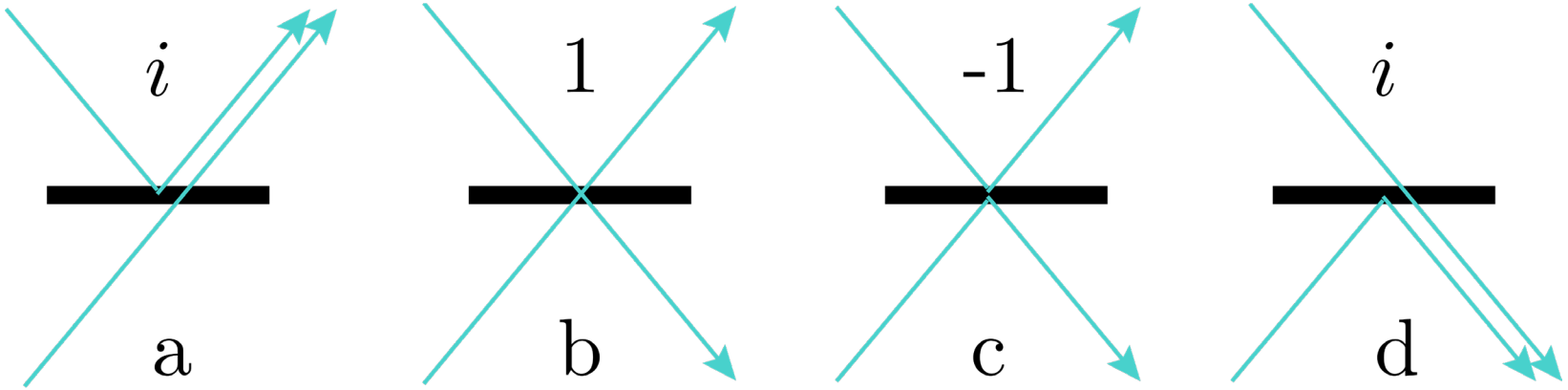
# And now for some Quantum…

# And now for some Quantum…what if we instead probed a satellite with an entangled photon/quantum state?

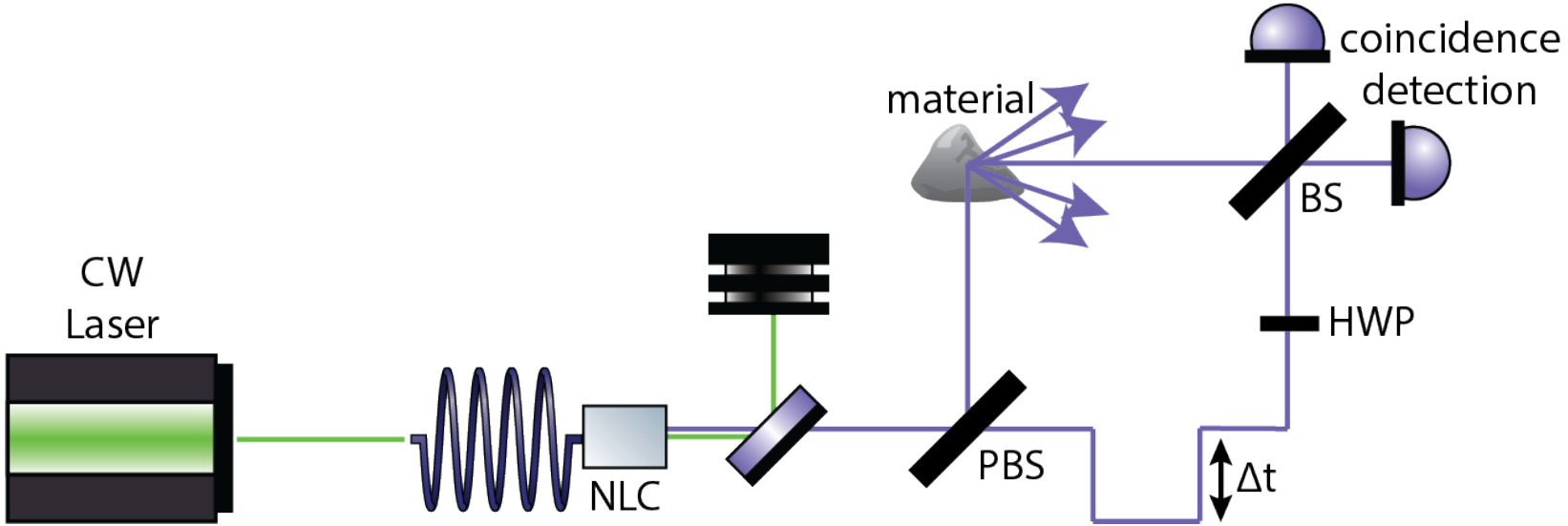
# And now for some Quantum…Hong-Ou-Mandel Interference



# And now for some Quantum…Hong-Ou-Mandel Interference with satellite materials




My thought after diving deeper into this project is that the main effect of the satellite material (vs. a mirror), will be loss in one arm of the interferometer. Loss should not affect the HOM dip depth (visibility) since it's based on coincidence detection.

# Accomplishments (for Part 2)

- Designed and ordered custom nonlinear crystal source for creating entangled photon pairs through AdvR, Inc. (532 nm → 1064 nm + 1064 nm)
- Designed optical layout and ordered parts
- Borrowed NIR single photon detectors, but was unable to get the control/driver electronics ready in time for end of FY.
- Spoke with experts in the field about potential outcome of this experiment.

# Moving Forward

- More time and perhaps some funding for off-the-shelf NIR detectors
- More time and funding to further explore BRDF measurements – how does wavelength, polarization, orientation of material, type of material affect BRDF?
- What sort of automation can be done to increase measurement efficiency and accuracy?
- More sensitive photodetectors? Use single photon detectors for very diffuse materials?

**Questions?**

**Project Team:**
Raymond Newell, MPA-Q
Nick Dallmann, MPA-Q
Tyler Volkoff, T-4
Charlotte Duda, MPA-Q

Special thanks to JP Martinez, ISR-5, for providing material samples