2008 Annual Meeting Council for Optical Radiation Measurements
Session 3: Transportation Applications

Instant Retroreflection Measurements: Prepared in 1 Minute

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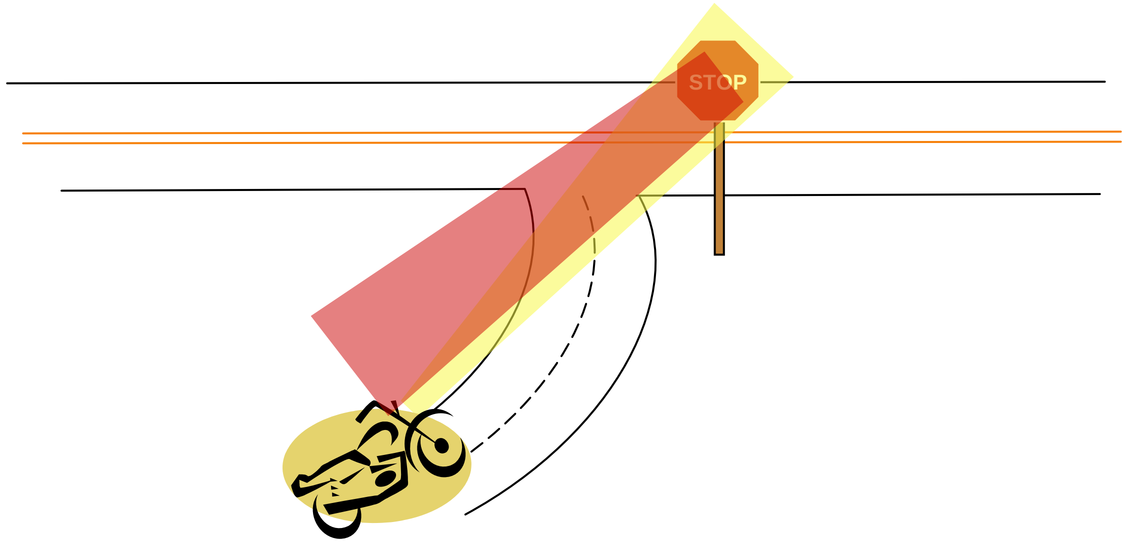
Background

1. Traffic scenario/performance based system

- CIE TC 4-40 "Performance Evaluation of Retroreflective Traffic Signs"



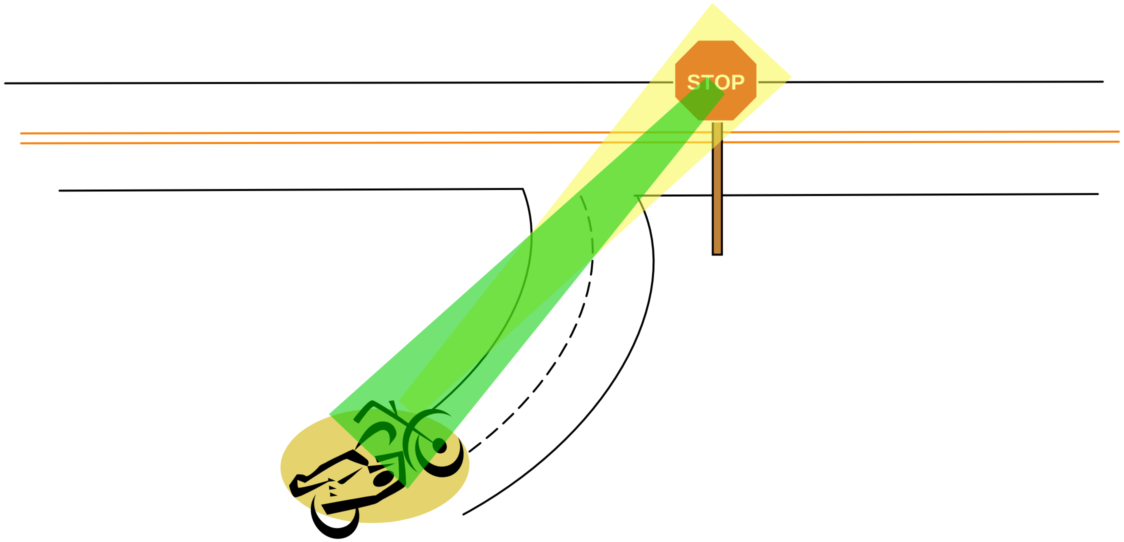
Background

1. Traffic scenario/performance based system

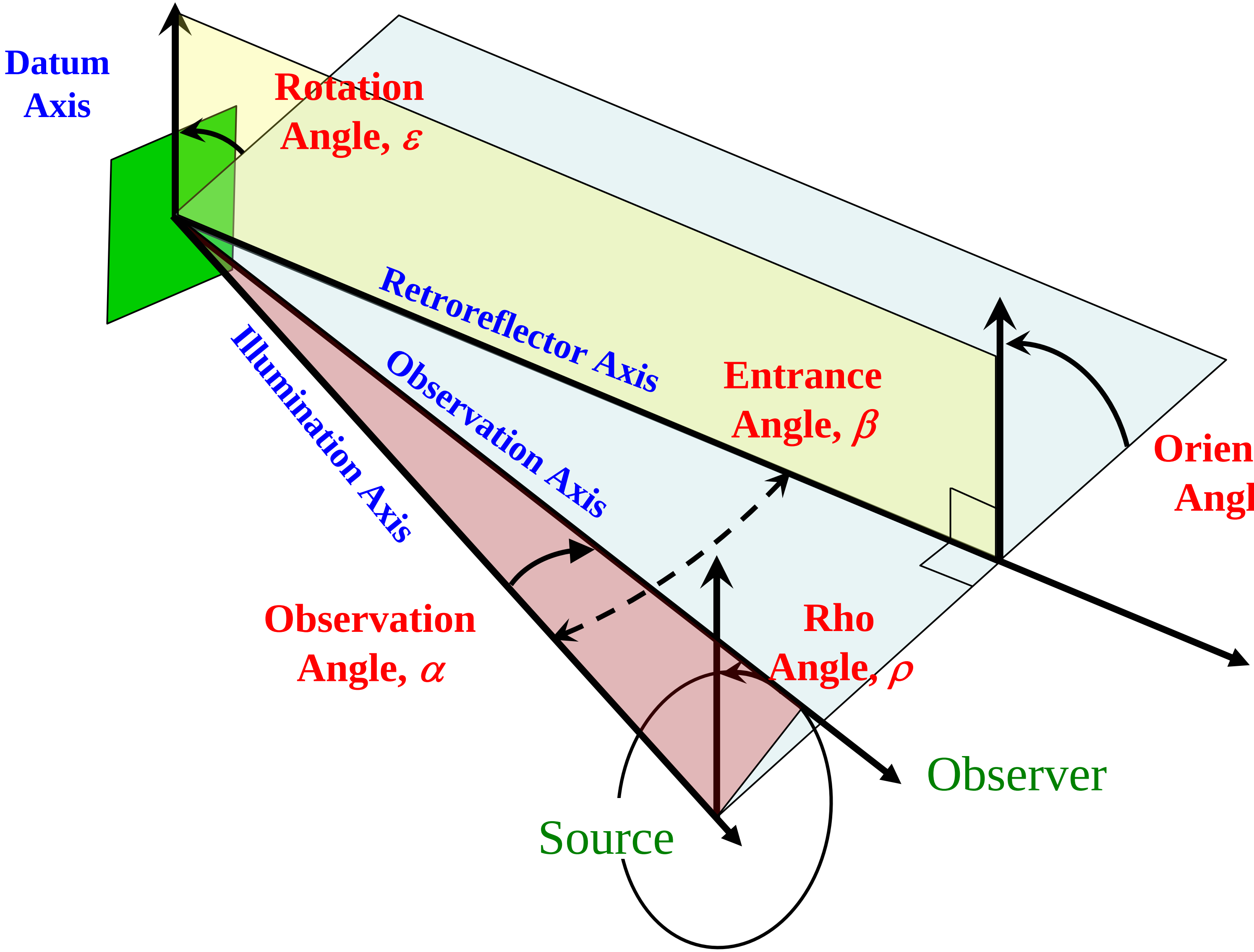
- CIE TC 4-40 “Performance Evaluation of Retroreflective Traffic Signs”

2. Fractional retroreflectance, R_T

- The fraction of unidirectional flux illuminating a retroreflector that is received at observation angles of less than a designated value.



Application System



Fractional Reflectance

$$R_{\mathrm{T}} = \int_{\alpha=0}^{\alpha_{\max}} \int_{\rho=-\pi}^{\pi} \alpha \frac{R_{\mathrm{A}}(\alpha,\rho)}{\cos\beta} \mathrm{d}\rho \mathrm{d}\alpha$$

$\dfrac{R_{\mathrm{A}}(\alpha,\rho)}{\cos\beta}$ = the coefficient of retroreflected luminance $\dfrac{cd/m^2}{lx} = \dfrac{lm/sr/m^2}{lm/m^2} = \dfrac{1}{sr}$

Angles β and ω_{S} remain fixed

Angles α and ρ are in radians

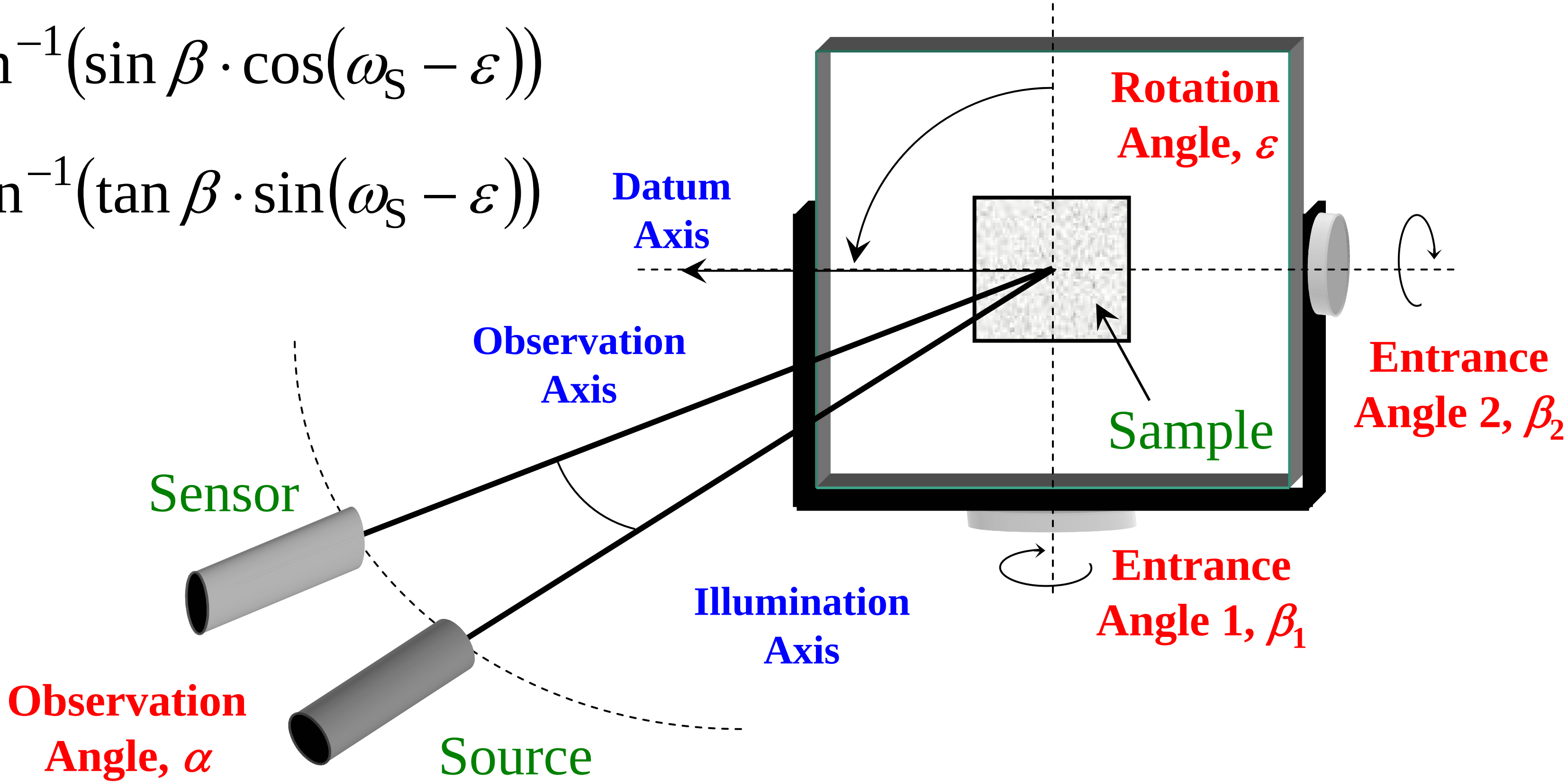
$$\int_{\rho=-\pi}^{\pi} \frac{R_{\mathrm{A}}(\alpha,\rho)}{\cos\beta} \mathrm{d}\rho = \sum_{-\pi}^{\pi} \frac{R_{\mathrm{A}}(\alpha,\rho)}{\cos\beta} \Delta\rho = 2\pi \frac{\overline{R_{\mathrm{A}}}(\alpha)}{\cos\beta}$$

$$R_{\mathrm{T}} = \int_{\alpha=0}^{\alpha_{\max}} 2\pi\alpha \frac{\overline{R_{\mathrm{A}}}(\alpha)}{\cos\beta} \mathrm{d}\alpha = \sum_{\alpha=0}^{\alpha_{\max}} 2\pi \frac{\overline{R_{\mathrm{A}}}(\alpha)}{\cos\beta} \alpha\Delta\alpha$$

CIE Goniometer System

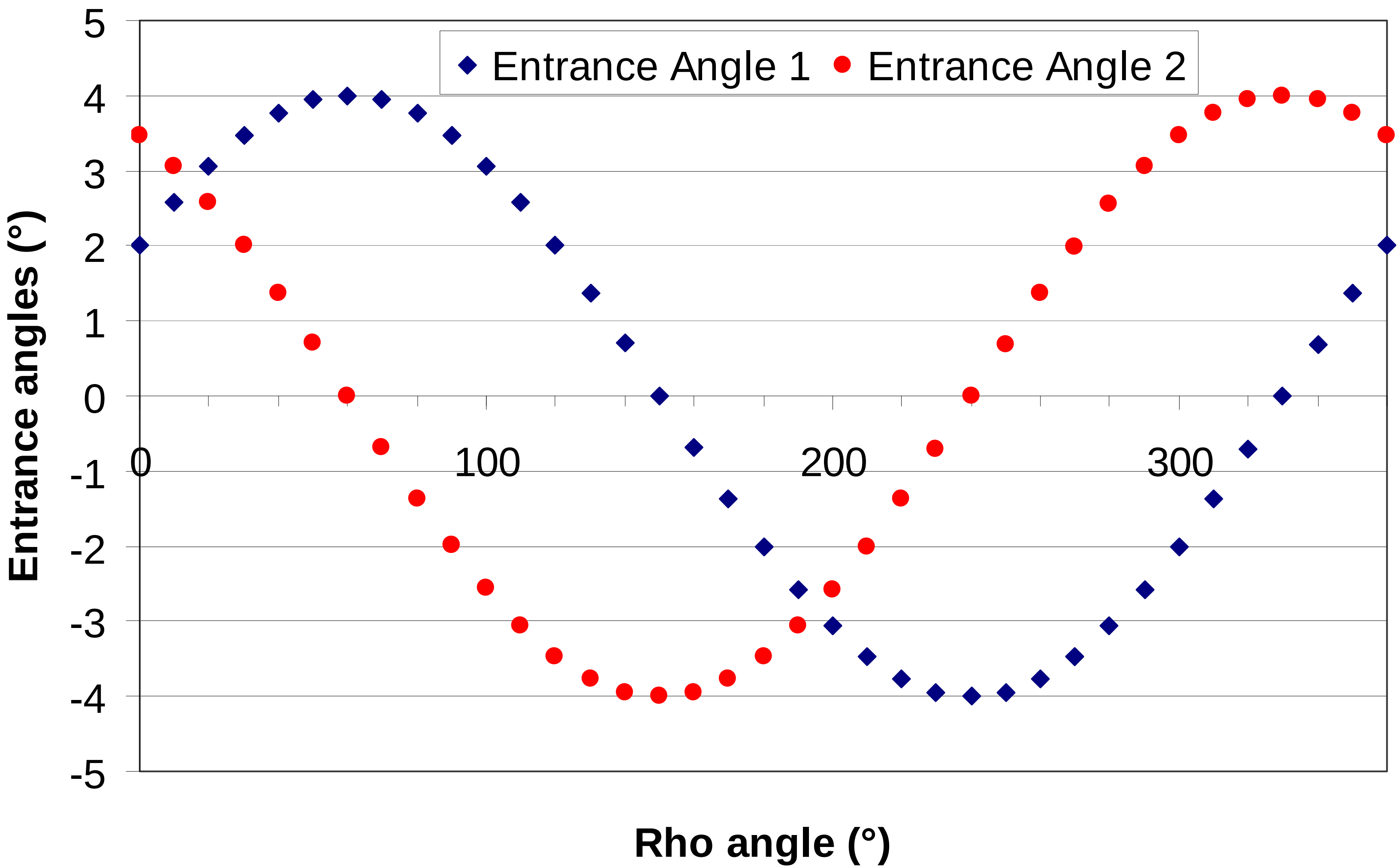
$$\beta_1 = \sin^{-1}\left(\sin\beta \cdot \cos\left(\omega_S - \varepsilon\right)\right)$$

$$\beta_2 = \tan^{-1}\left(\tan\beta \cdot \sin\left(\omega_S - \varepsilon\right)\right)$$



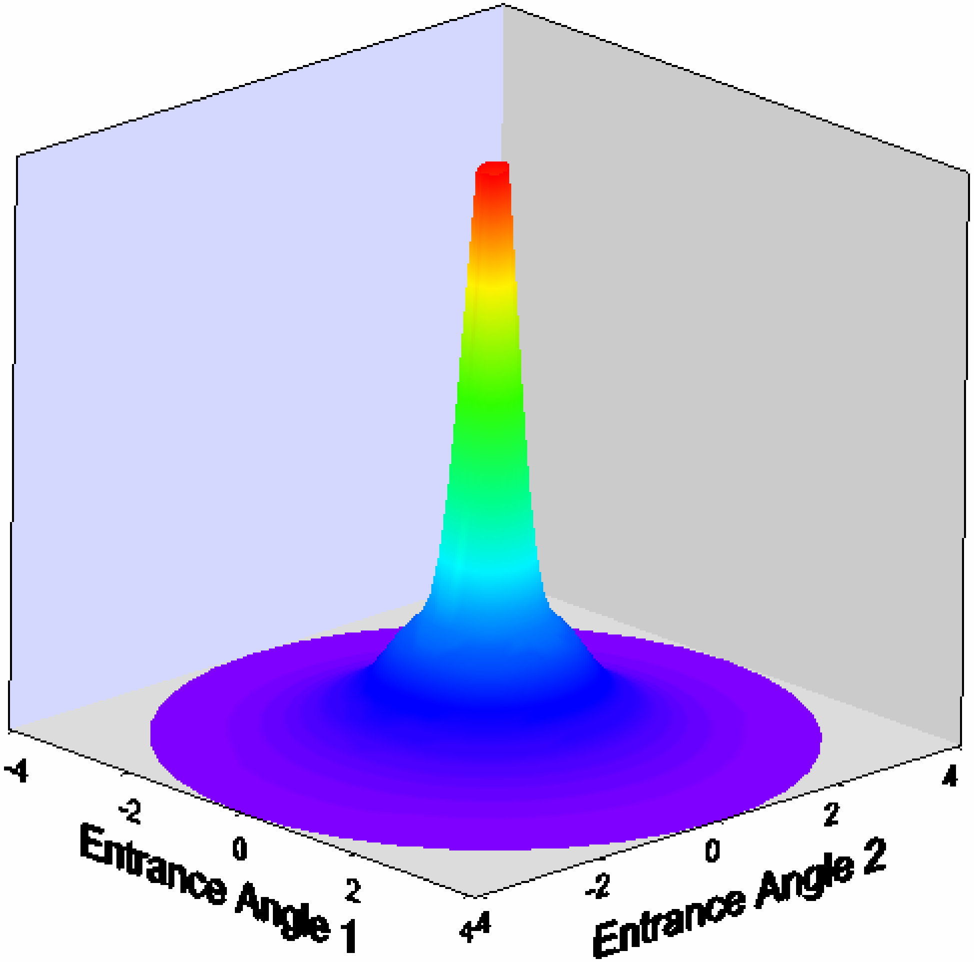
$$\varepsilon = \omega_S - \tan^{-1}\left(\frac{\tan\omega_S \cos\beta - \tan\rho\cos^2\beta}{\cos\beta + \tan\omega_S \tan\rho}\right)$$

Entrance Angle Components, β_1 and β_2



Measure every 0.10°along the observation angle for every 10° rho

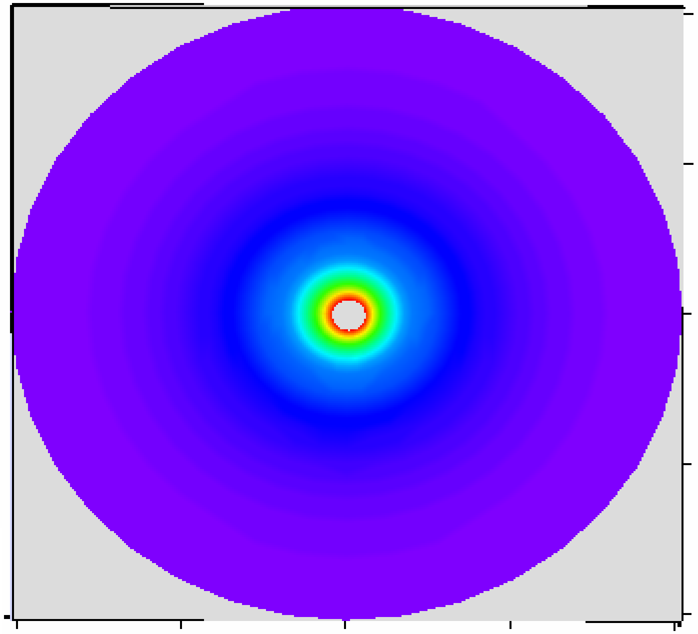
CHARRM Measurements



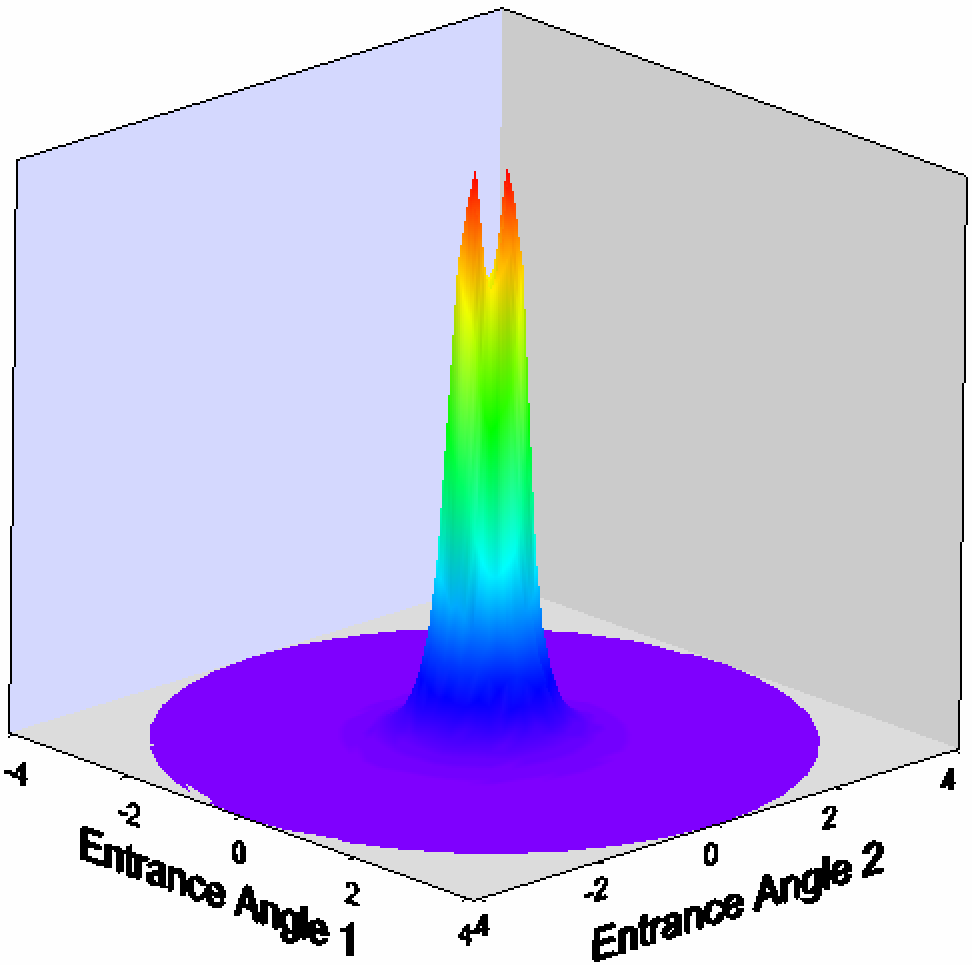
Type I Material

$\beta = 4°$
$\omega_S = 60°$

R_A=121 cd/m^2/lx



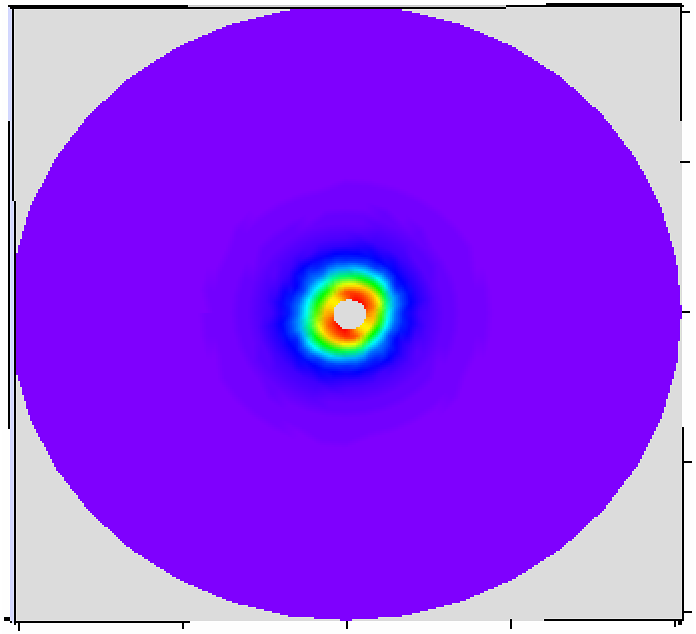
CHARRM Measurements



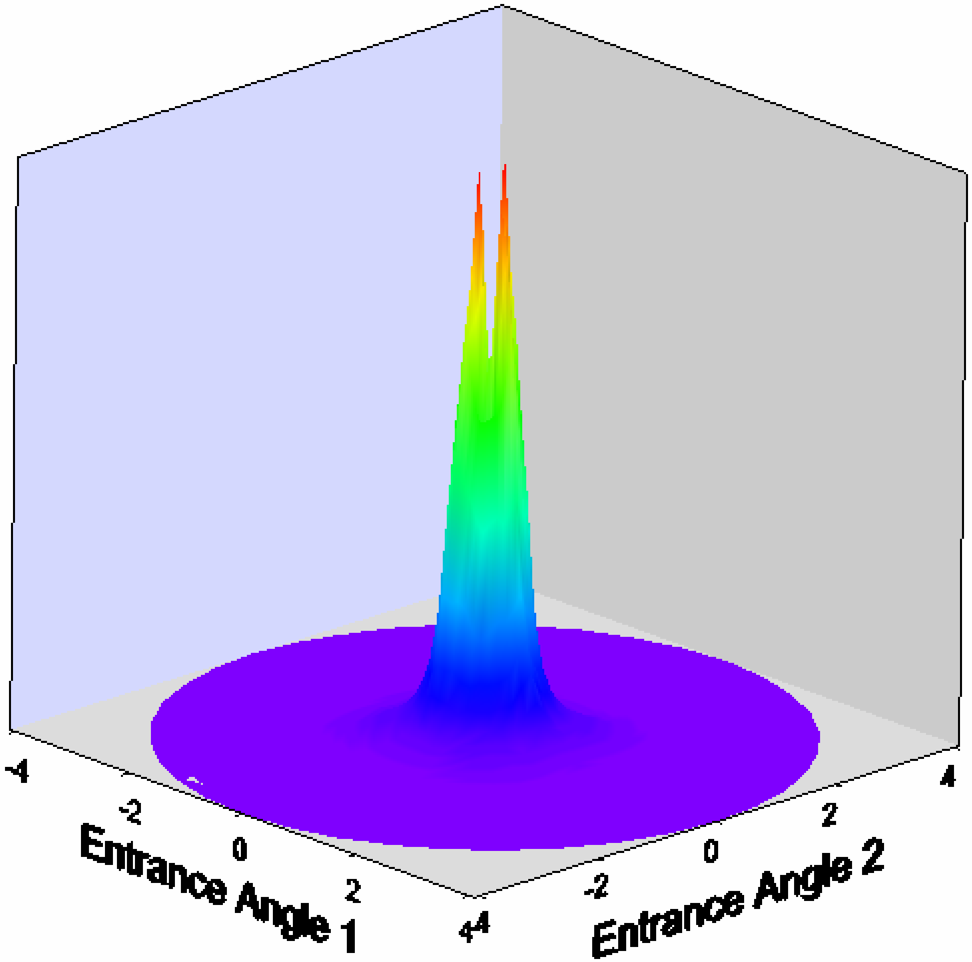
Type VIII Material

$\beta = 4°$
$\omega_S = 60°$

R_A=790 cd/m^2/lx



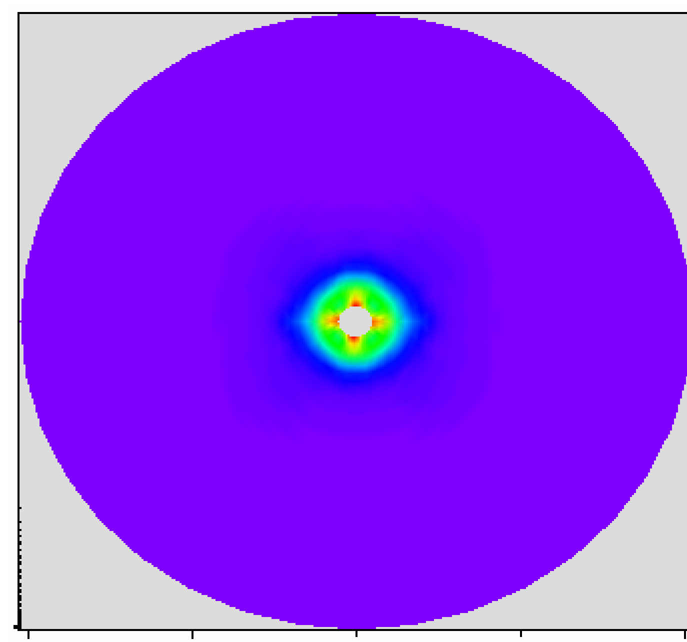
CHARRM Measurements



Type IX Material

$\beta = 4°$
$\omega_S = 60°$

R_A=690 cd/m^2/lx



0º Relative Measurements

Signal with and without pellicle
Laser signal with and without 0° system
Factor = 4.429

Type I

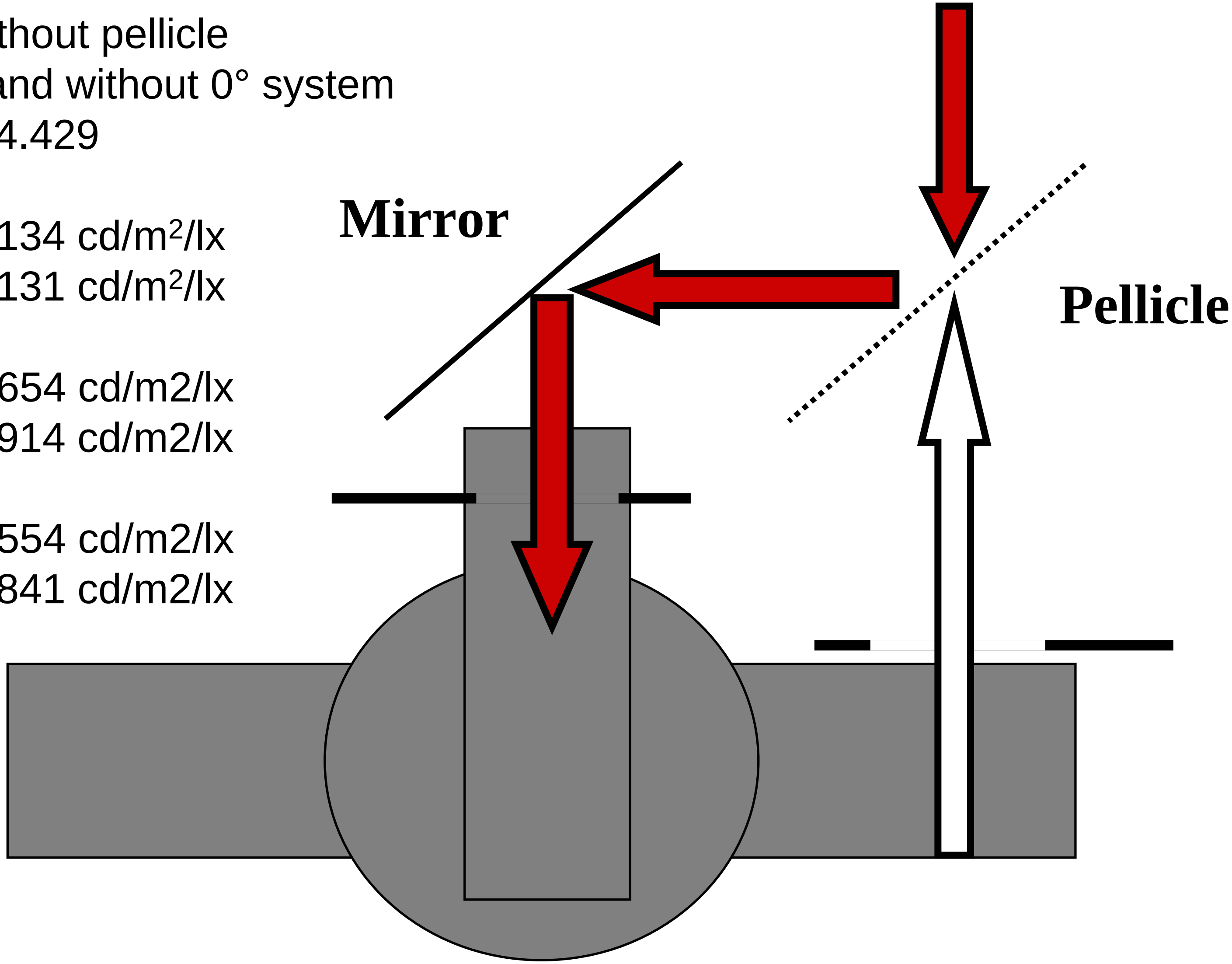
0.00°	134 cd/m²/lx
0.10°	131 cd/m²/lx

Type VIII

0.00°	1654 cd/m2/lx
0.10°	914 cd/m2/lx

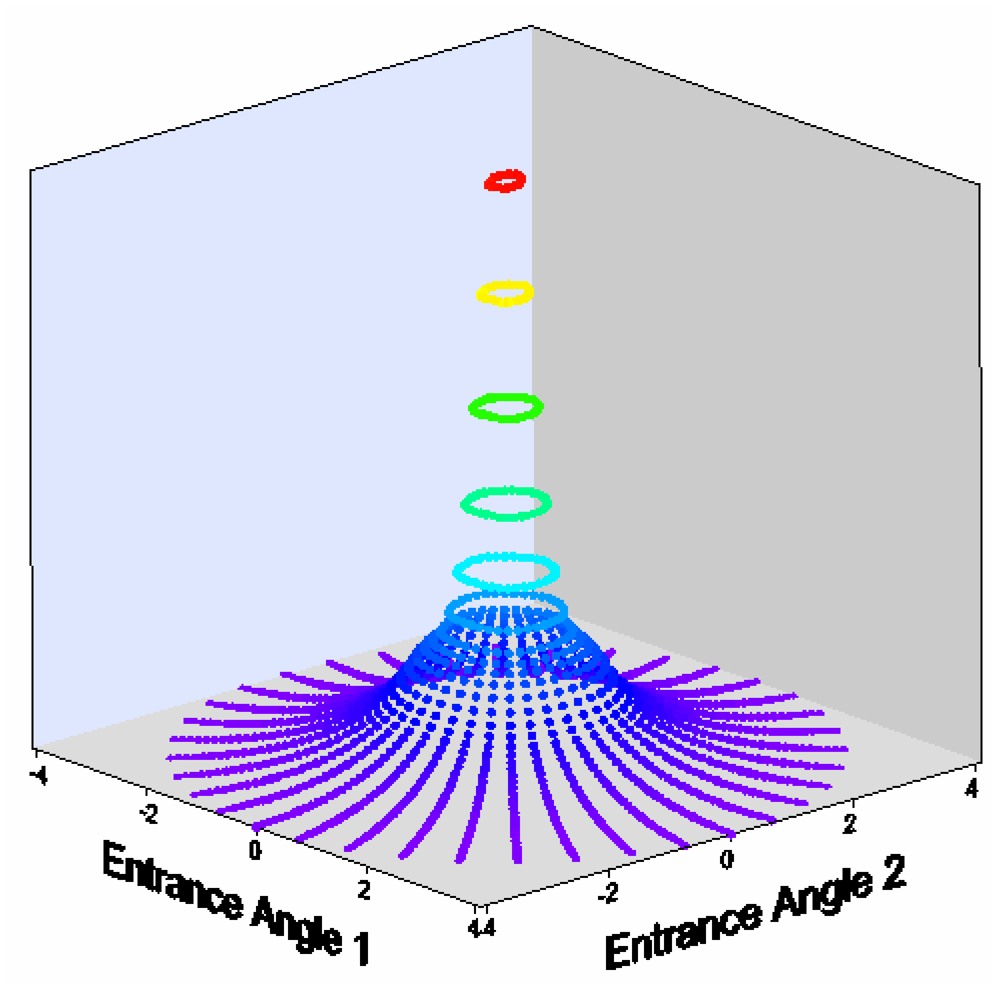
Type IX

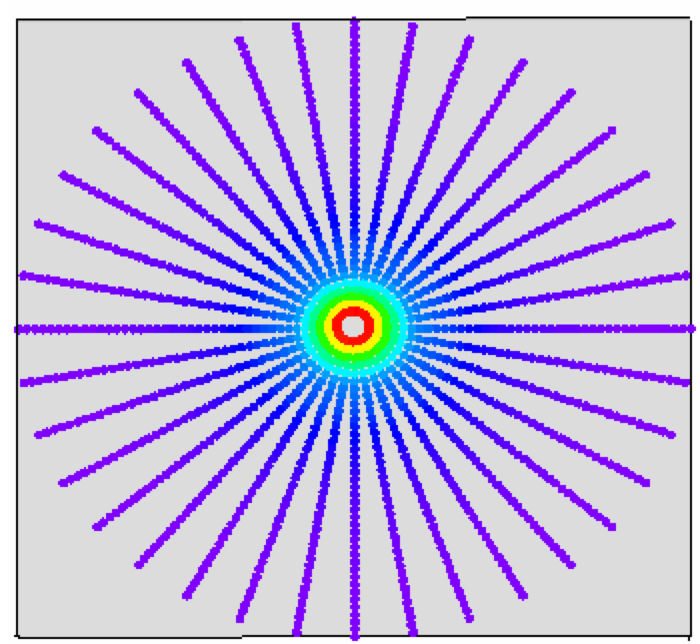
0.00°	1554 cd/m2/lx
0.10°	841 cd/m2/lx



Fractional Reflectance Calculation

$$R_{\mathrm{T}} = \sum_{\alpha=0}^{\alpha_{\max}} 2\pi \frac{\overline{R_{\mathrm{A}}}(\alpha)}{\cos\beta} \alpha \Delta\alpha$$

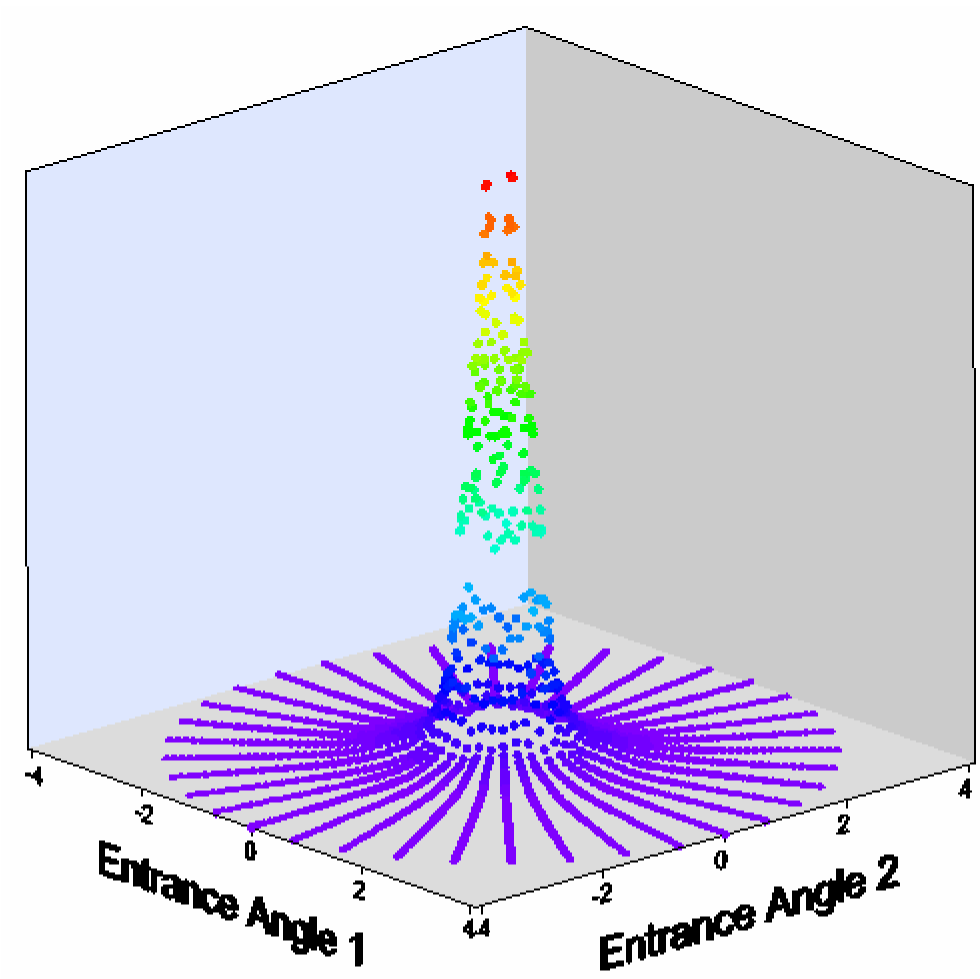


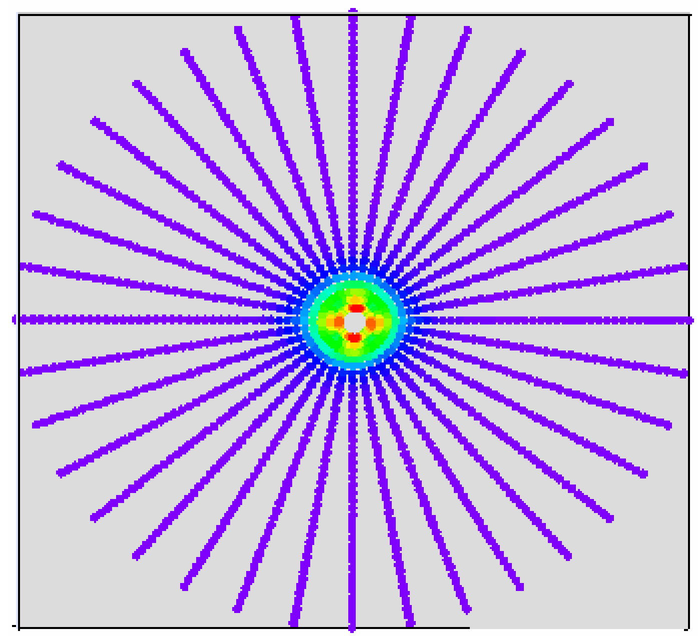


Adequate sampling to 0.60° observation angle

Fractional Reflectance Calculation

$$R_{\mathrm{T}} = \sum_{\alpha=0}^{\alpha_{\max}} 2\pi \frac{\overline{R_{\mathrm{A}}}(\alpha)}{\cos\beta} \alpha \Delta\alpha$$





Uncertainty Budget – Single Measurement

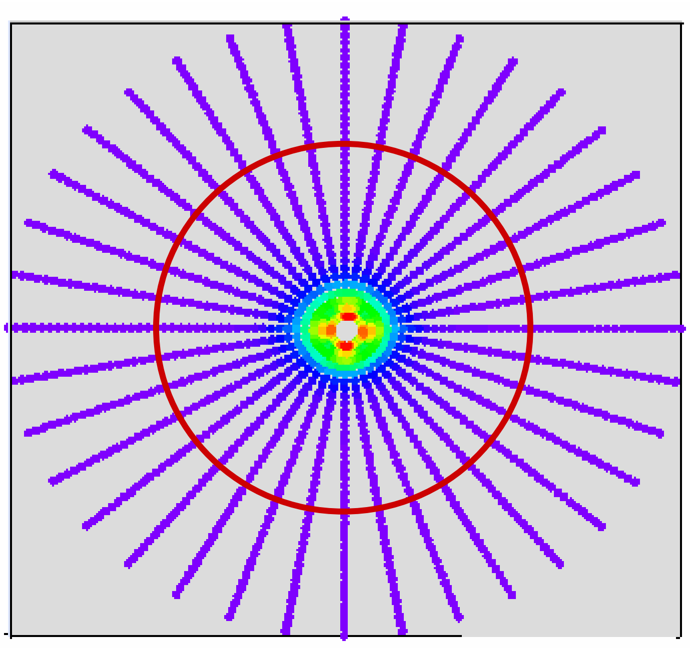
Uncertainty factor	Type	Relative standard uncertainty [%]
Source intensity stability	A	0.05
Illumination spectra difference	B	0.08
Illumination measurement	A	0.30
Illuminance uniformity and sample	B	0.15
Illumination distance	B	0.12
Amplifier linearity	B	0.10
Detector uniformity	B	0.45
Observation distance	B	0.12
Geometrical placement of sample	B	0.45
Uncertainty in mounting (flatness)	B	0.30
Drift of detector	B	0.05
Stray light	B	0.20
Sample temperature issues	B	0.20
Area measurement of the test sample	A	1.5
Viewing angle	B	0.10
Combined uncertainty		**1.7**
Expanded uncertainty for coeff. of luminous int. (*k*=2)		**3.5**

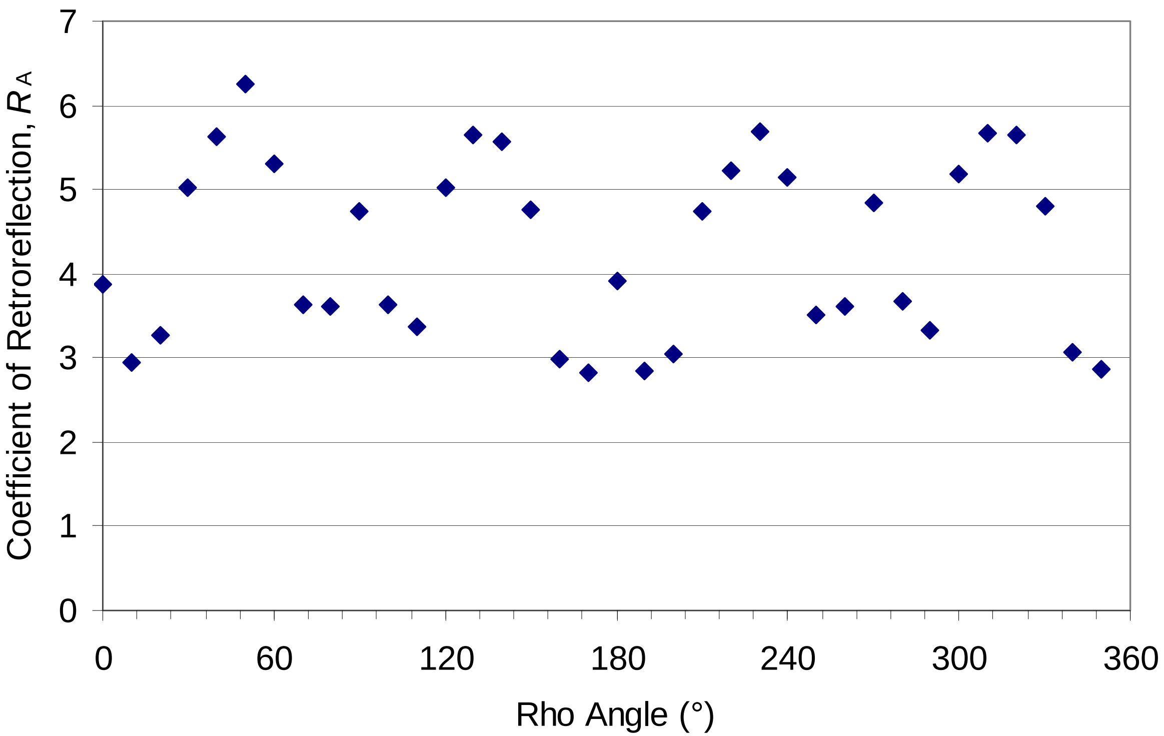
Uncertainty Budget – R_T

Uncertainty factor	Type	Relative standard uncertainty [%]
Individual points		
Source intensity stability	A	0.05
Illuminance uniformity and sample	B	0.15
Drift of detector	B	0.05
Combined uncertainty		**0.17**
All 760 points	B	4.57
Common factors	B	1.73
Combined uncertainty		**4.9**
Expanded uncertainty for fractional refl. (*k*=2)		**9.8**

For the total uncertainty of the points measured.

Uncertainty Budget – R_T

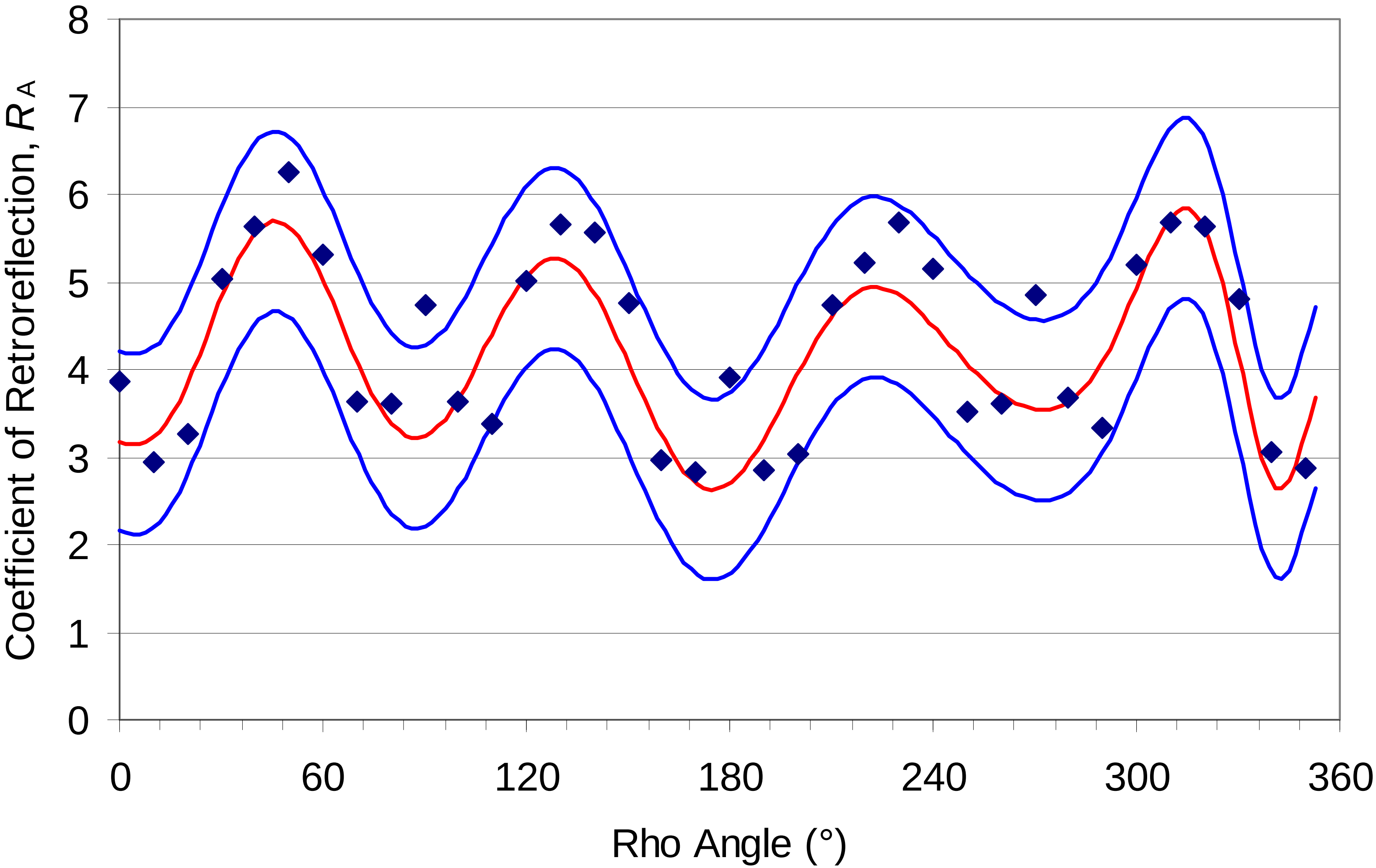




Evaluate the space between the measurements

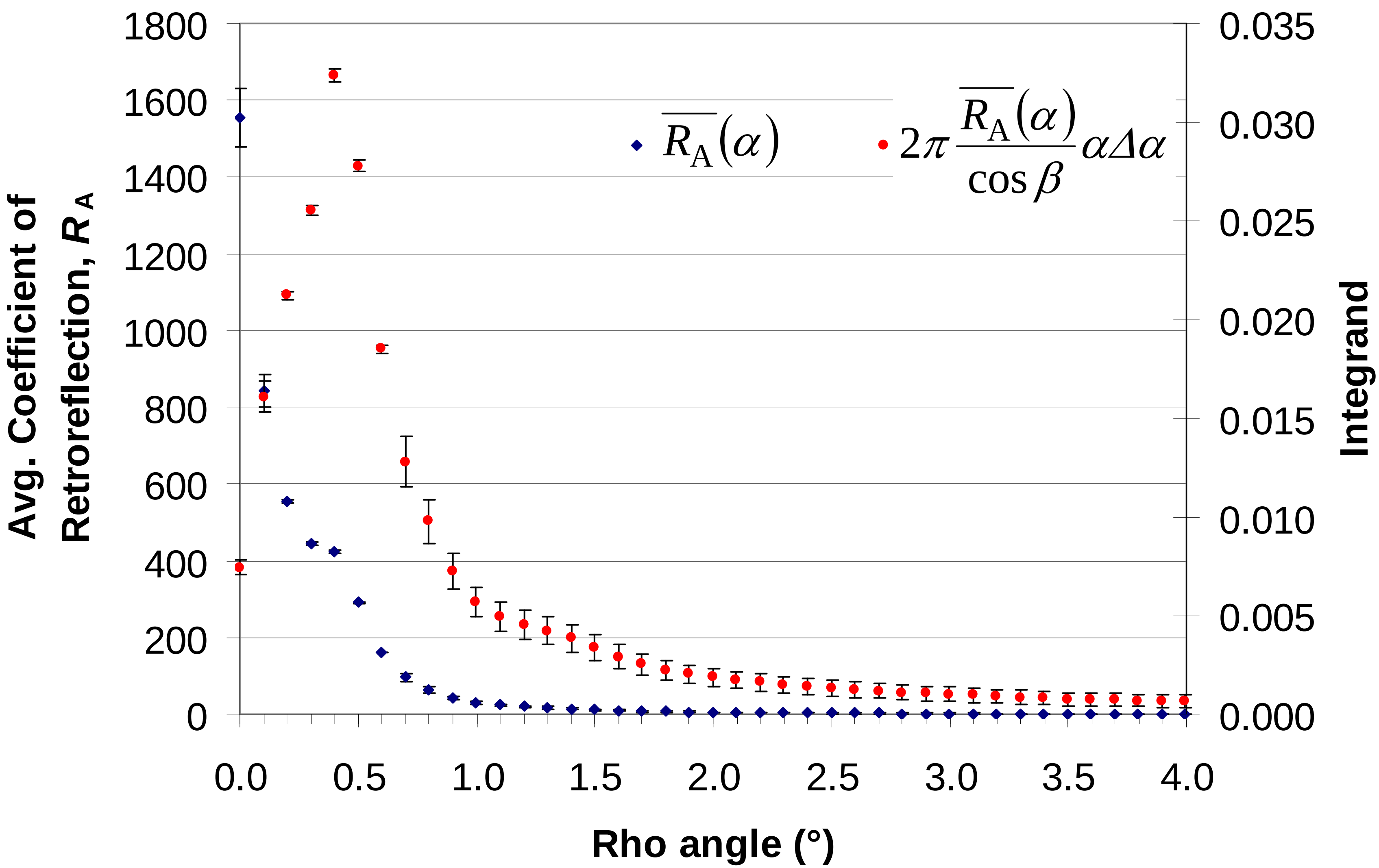
Fit a model to the measured points, 2° observation angle

Uncertainty Budget – R_T



Prediction Band Analysis – Relative Standard Uncertainty 25 %

Uncertainty Budget – R_T



Results and Uncertainty Budget – R_T

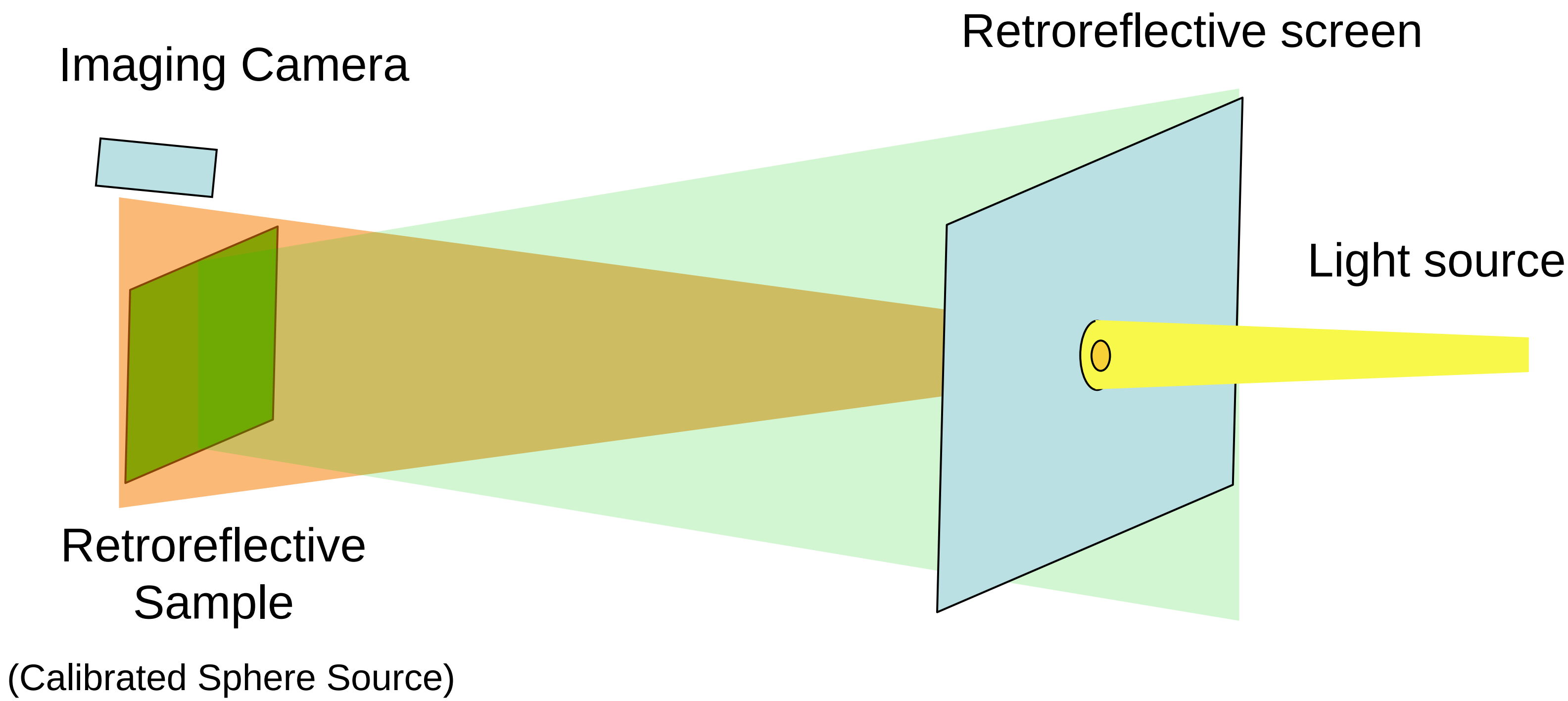
Type IX Material

$\beta = 4°$

$\omega_S = 60°$

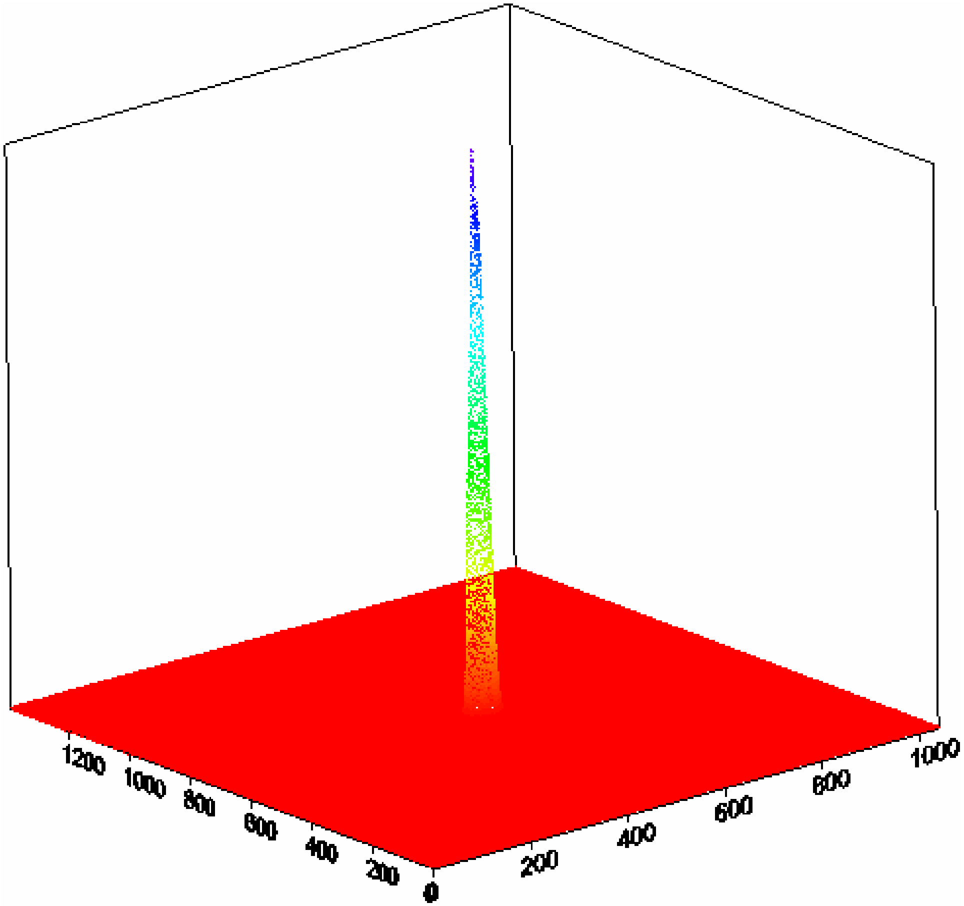
α_{max}	R_T [%]	Rel. Expanded Unc.
0.5	13.1	3 %
1.0	18.5	7 %
2.0	21.7	12 %
4.0	23.8	17 %

Imaging Measurements

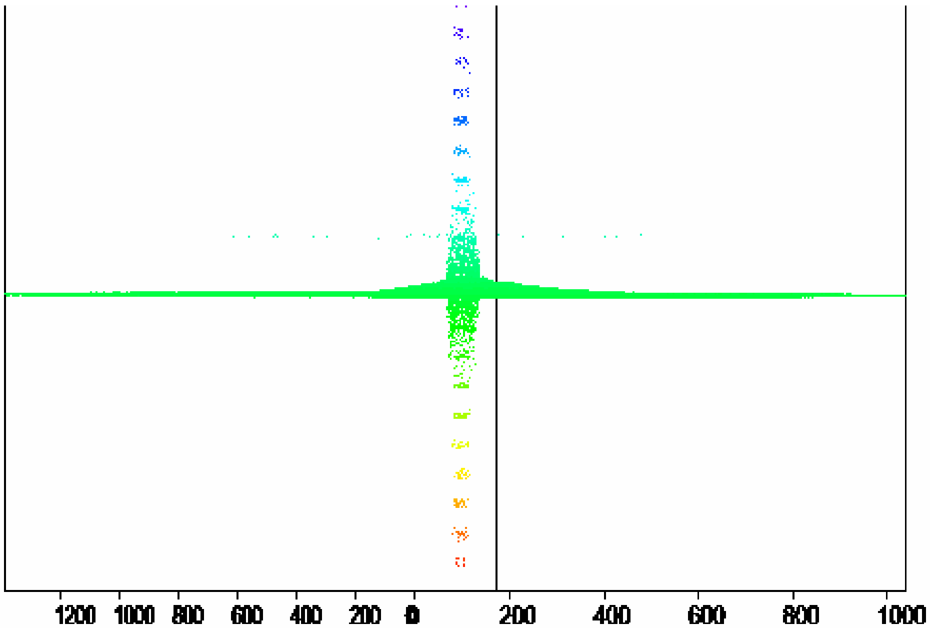


- Capture image with no sample
- Capture image with calibrated sphere source
- Capture image with retroreflective sample

Calibration Measurements

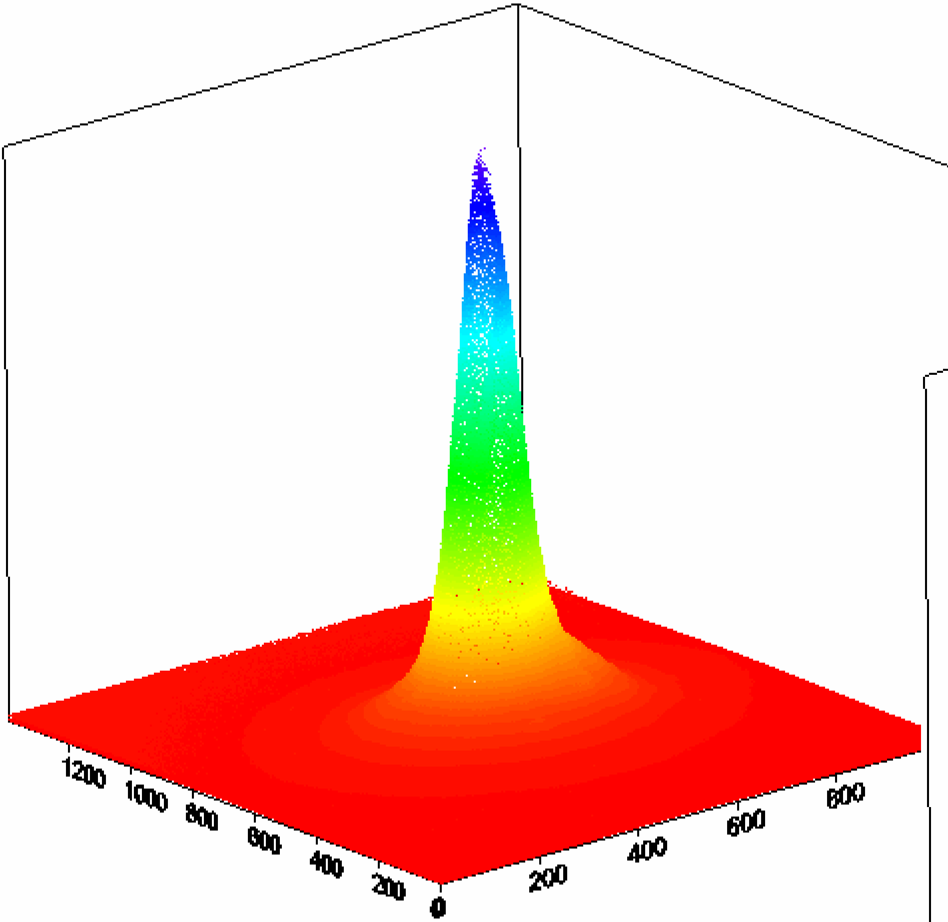


Zero Calibration – No Sample
Max 516



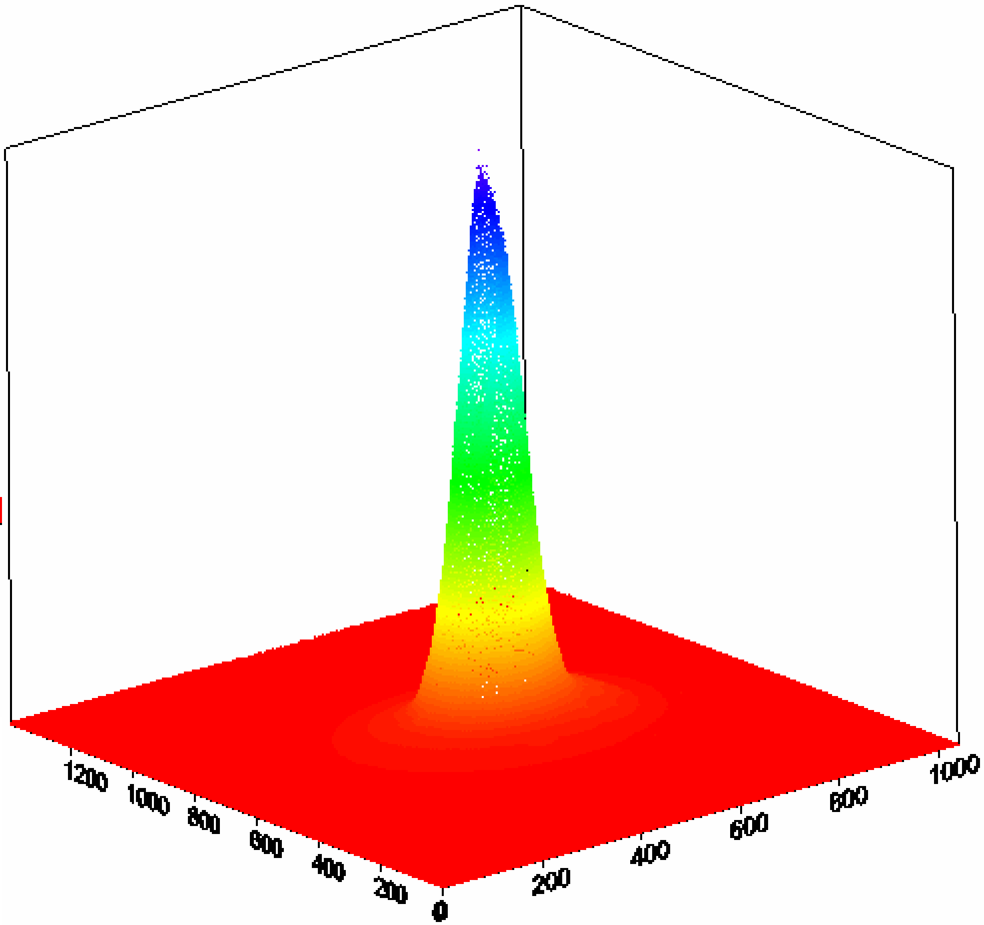
Sphere Source Calibration
Max 22

Imaging Measurements



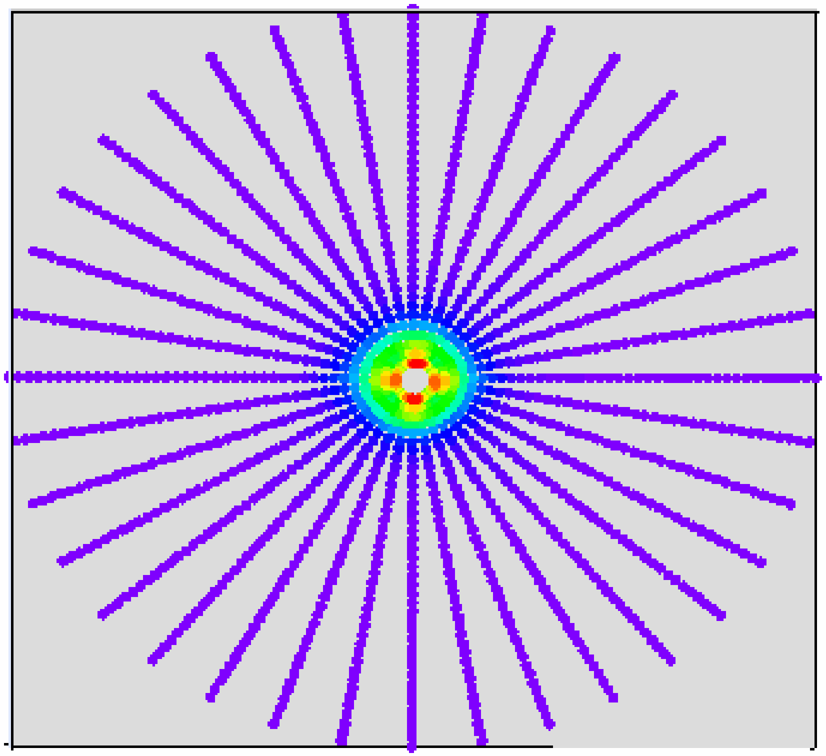
Type I Material

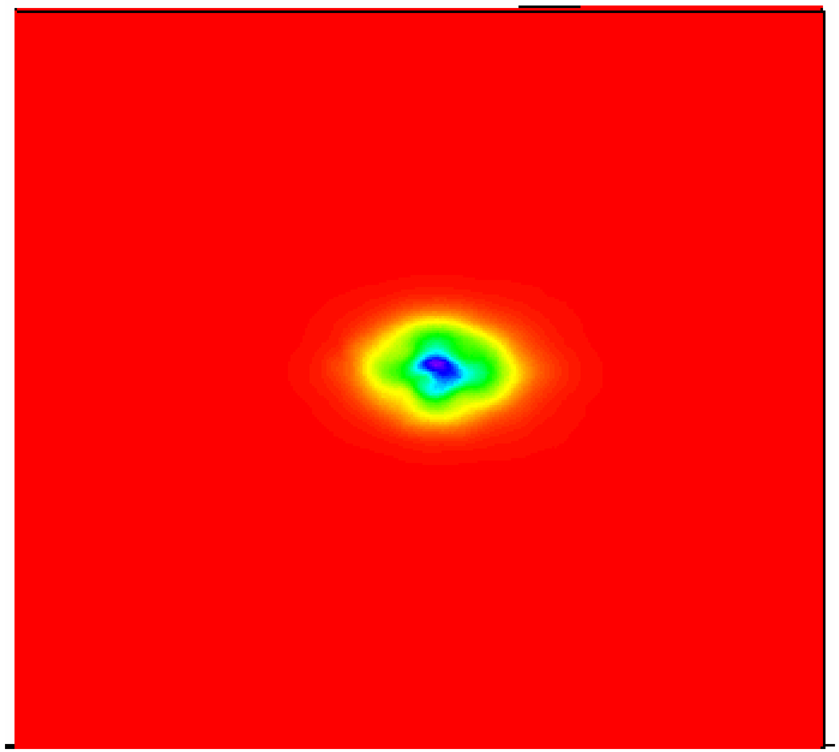
Type III Material



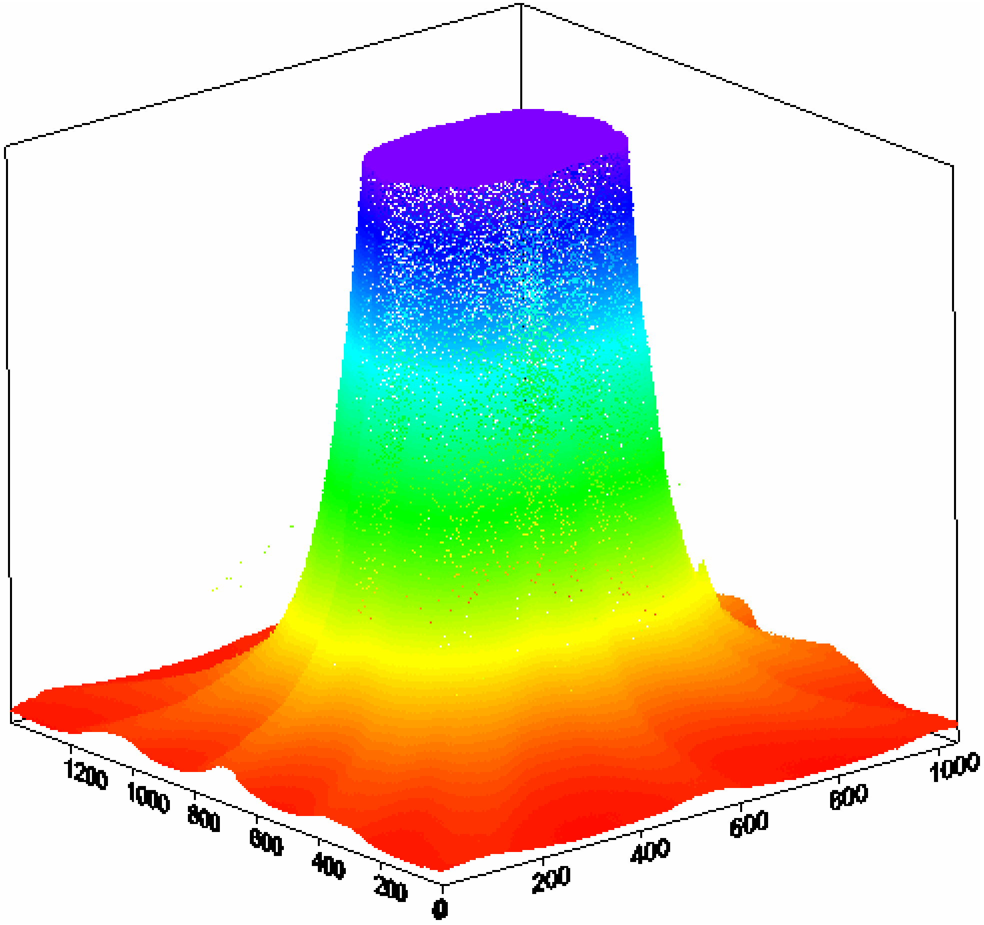
Imaging Measurements

Type IX Material

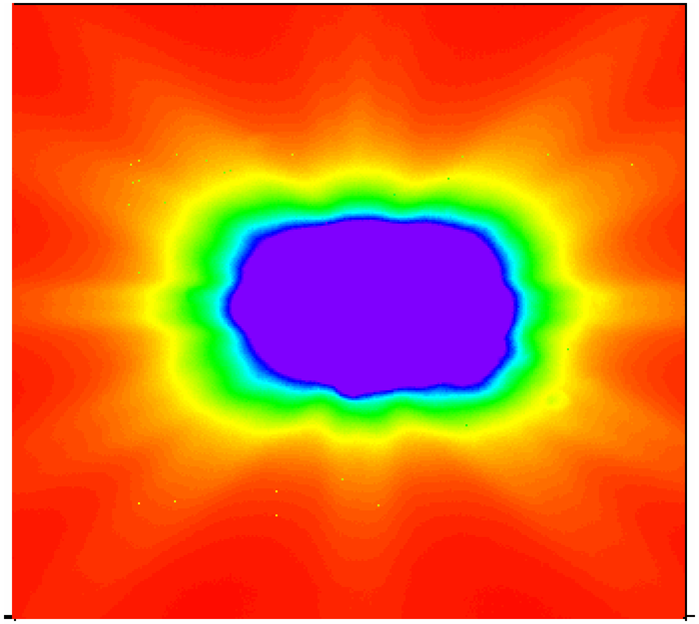




Imaging Measurements



Type IX Material



$$R_{\mathrm{T}} = \sum_{\alpha=0}^{\alpha_{\max}} \sum_{-\pi}^{\pi} \frac{R_{\mathrm{A}}(\alpha,\rho)}{\cos\beta} \alpha \Delta\rho \Delta\alpha$$

R_T Summary

R_T [%]		
Type	Points	Camera
I	12.5	12.0
III	15.3	14.6
VIII	29.9	29.0
IX	23.8	23.1

$\beta = 4°$
$\omega_S = 60°$
$\alpha_{max} = 4°$

- 2 hours versus 1 minute
- Uncertainty 17 % (k=2) → 5 % (k=2) – camera largest uncertainty component
- 2 hours to collect a complete set of data for a large set of entrance angles