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The Issues of Measurement of Optical Hazard Using Photometers

EMRP JRP ENG05

Metrology for Solid State Lighting

Simon Hall ,Paul Miller, Neil Haigh, Ben Thornton, Neil Haigh (Lux TSI)

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Metrology for Solid State Lighting

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Background

- Increasing demand for optical radiation safety related testing

  Lamps (UV),

  LEDs (UV,VIS,NIR)

- Increasing concern with light safety

  European Union 'AORD' safety requirement

  LED product safety

    e.g. LED signalling

  Safety of LED lighting (Blue Light Hazard);

  Photobiological 'manipulation' using light

safety studies

- ANSES – France 25/10/201

  LED Lighting health issues

- SCENIHR – EU 19/3/2012

  EU Scientific Committee on Emerging and Newly Identified Health Risks

- CELMA – EU 09/2011

  European Lamp Companies Federation

  ‘Biological Efficient Illumination’

Adverse and beneficial impact of LED lighting is an important and newly emerging field

Underpinning Issues

- Two 'core' measurement parameters

  Spectral irradiance

  Spectral radiance

  …spectral irradiance using a defined 'Field of View'

  Note: 'field of view' ≅ 'acceptance angle'

Exposure Hazard Value (EHV)

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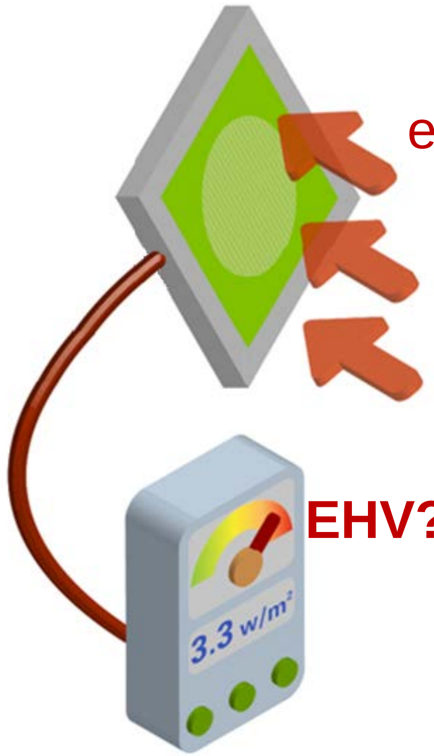

Need to compare the exposure to the beam against defined permissible limits i.e. Quantify the Exposure Hazard Value (EHV)

Keynote Concern: EHV ± U?

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- Optical safety testing requires:

  Effective EHV < 1.0 where:

  Effective EHV = EHV(meas) – EHV(Uncertainty)

EHV?

- What is the uncertainty in the reported EHV?
- How does EHV uncertainty depend on test parameters?
- How much conservatism should be adopted?

{Note: This paper does not include systematic reproducibility of testing setup.}

Optical Safety Hazard bands

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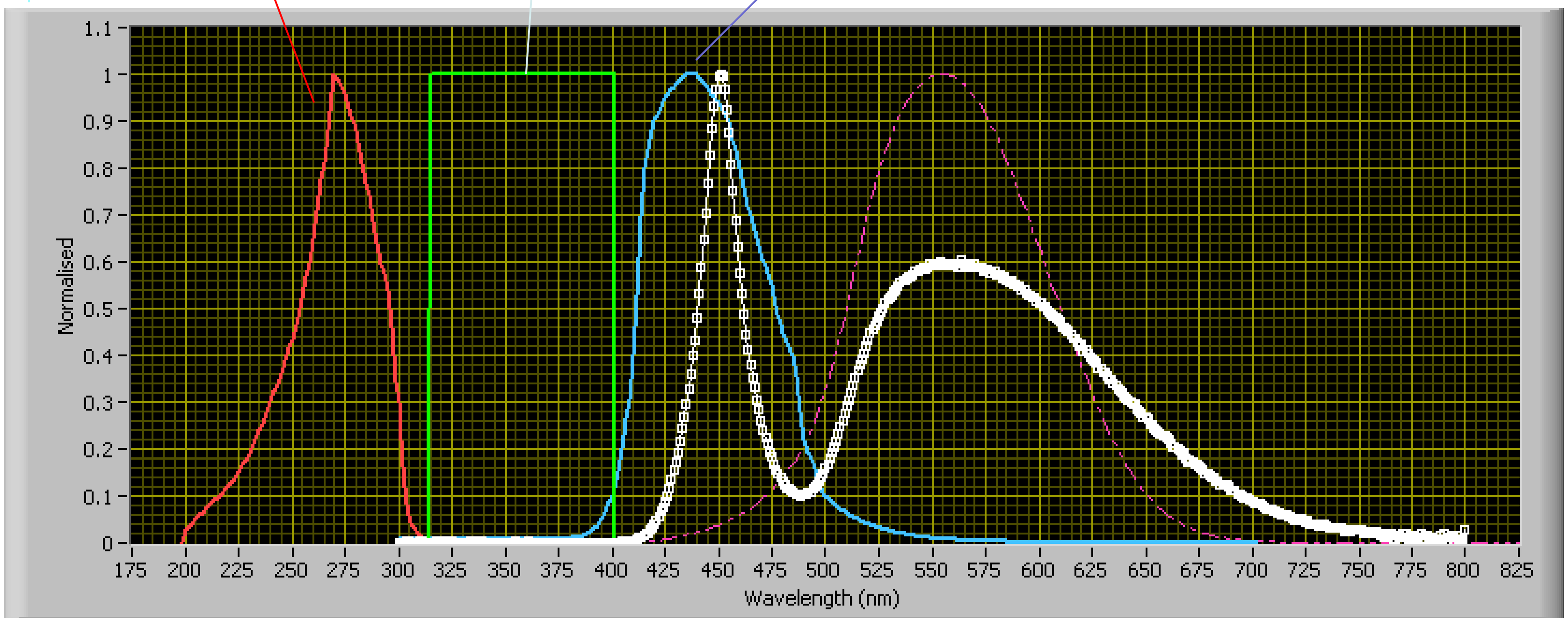
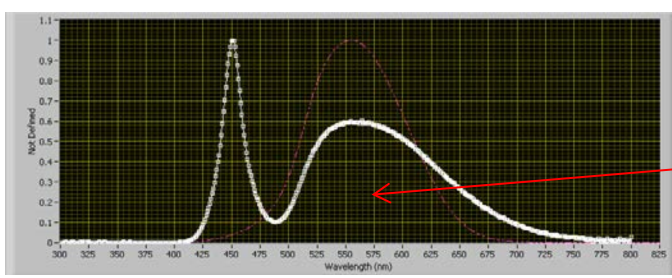
Actinic UV **Near UV** **Blue Light Hazard**





Cool White LED spectrum

Spectral Band & Measurement Type

IEC 62471 Hazard Band	Wavelength Range (nm)	Measurement Type
Actinic UV Skin & Eye	200 to 400	Irradiance
Eye UV-A	315 to 400	Irradiance
Blue Light ‘small’ source	300 to 700	Irradiance
Blue Light ‘extended’ source	300 to 700	Radiance
Retinal Thermal	380 to 1400	Radiance
Retinal thermal (weak stimulus)	780 to 1400	Radiance
Infrared hazard to eye	780 to 3000	Irradiance
Skin thermal hazard	380 to 3000	Irradiance

Retinal hazards based on a radiance assessment

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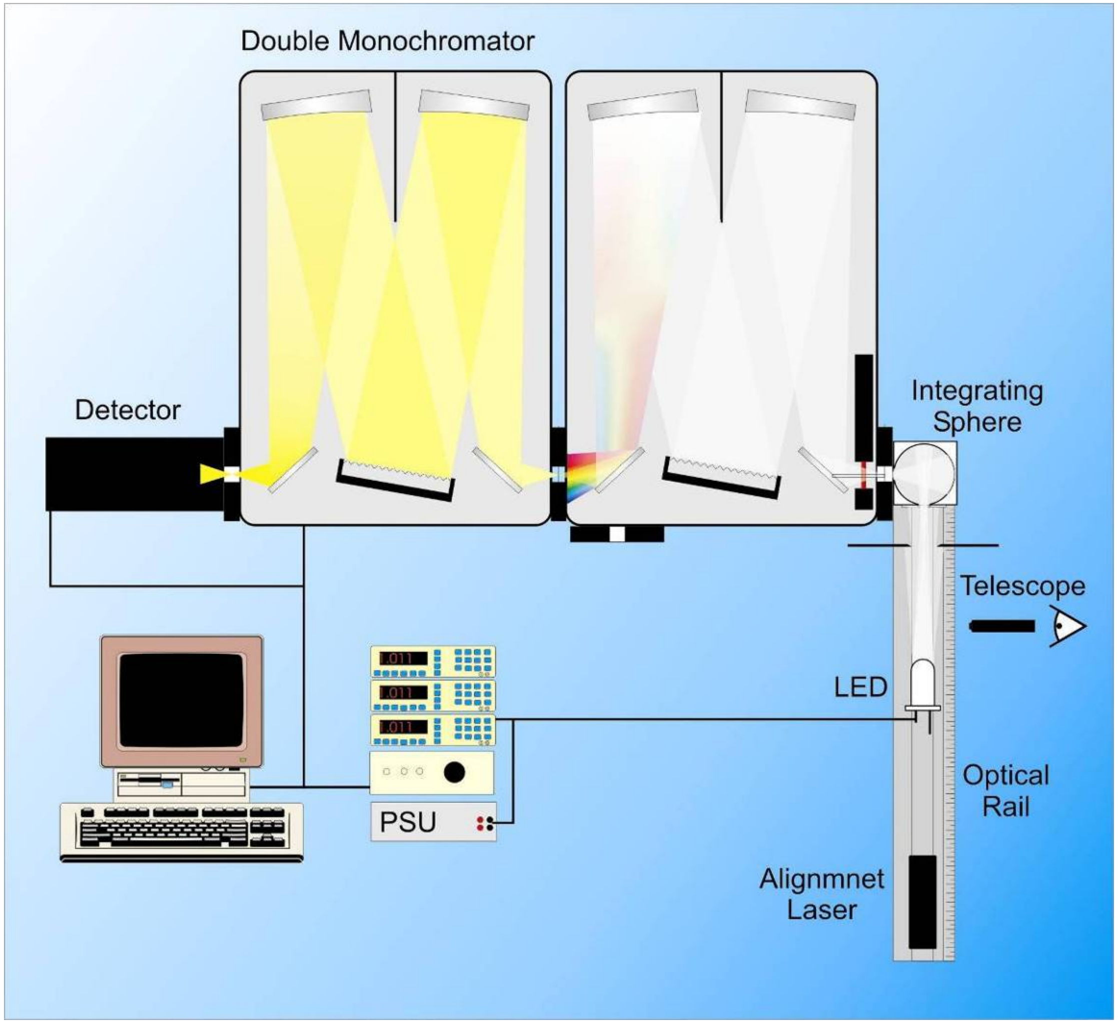
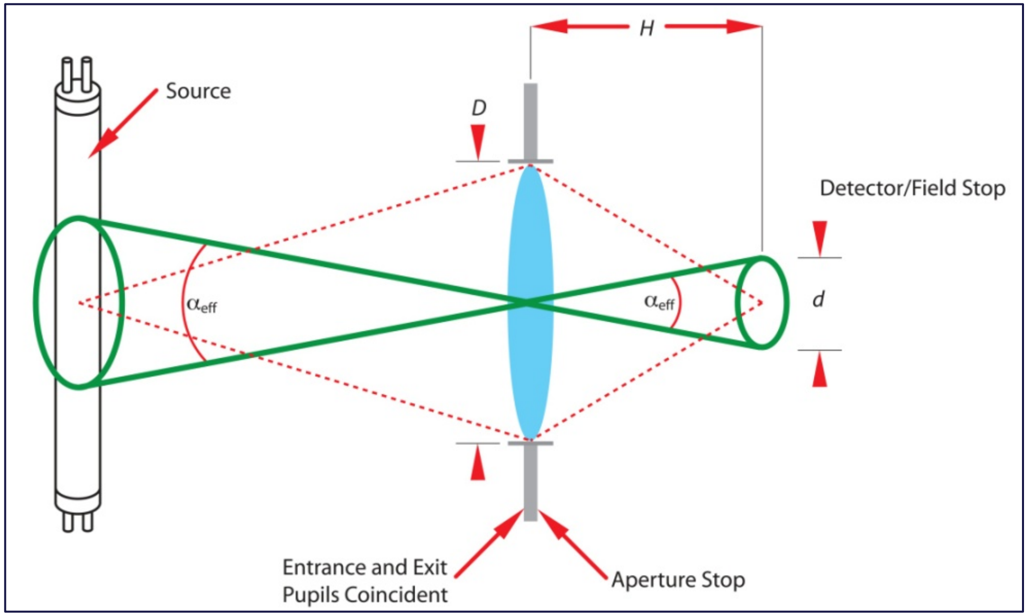
Spectral Radiometry

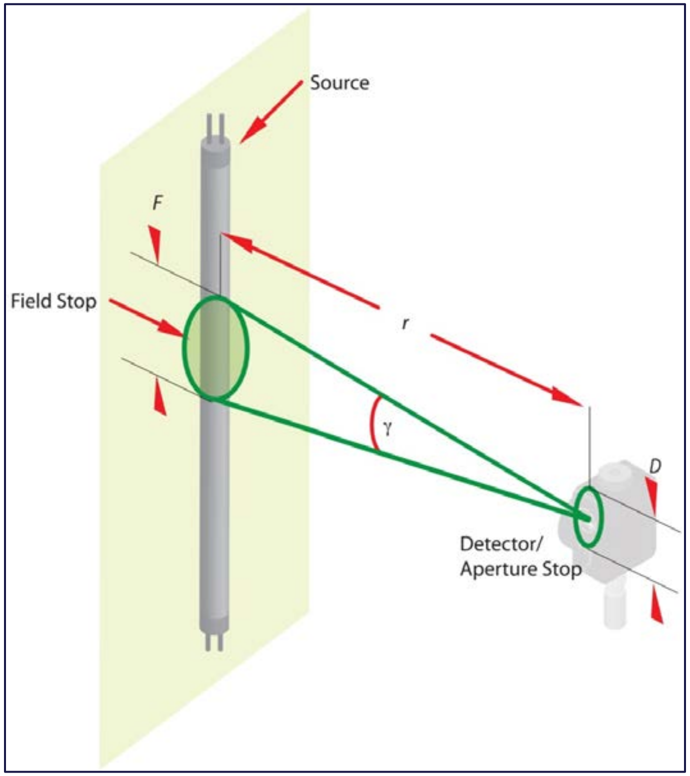


Double monochromator method

Test methodologies

- Radiance & Irradiance testing regimes





Radiance Testing Basics

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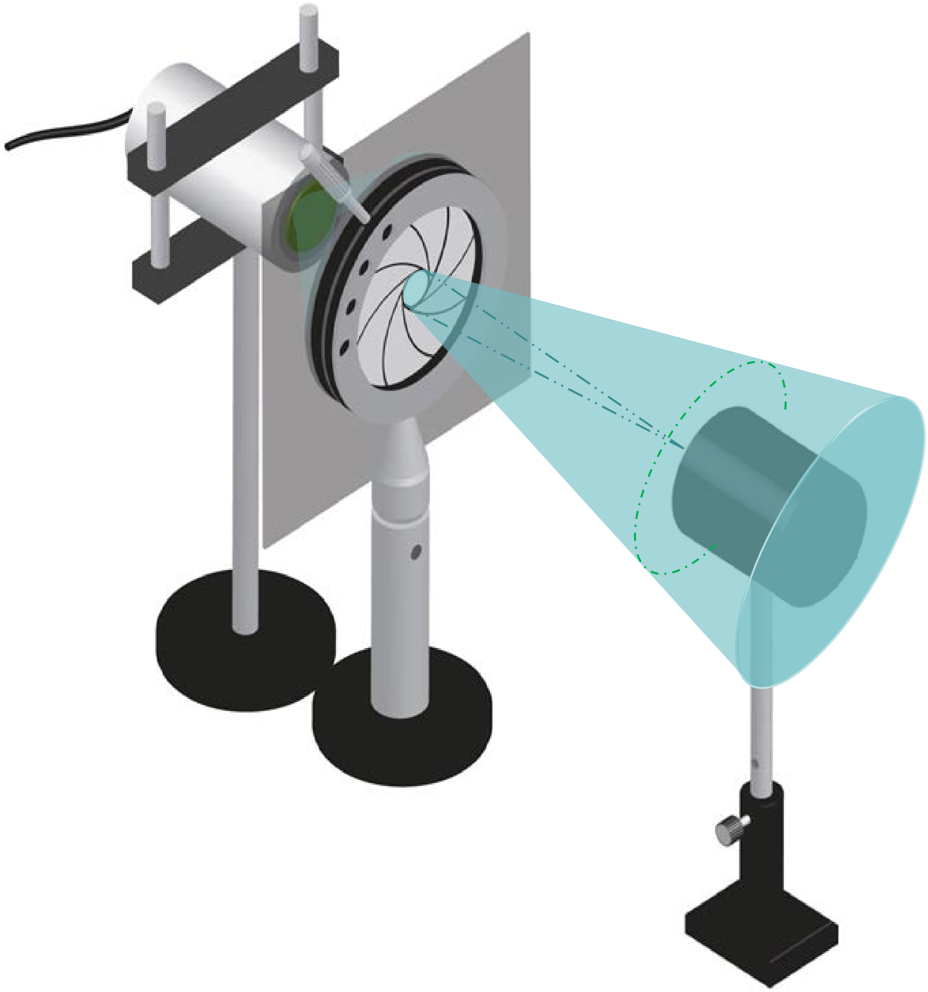
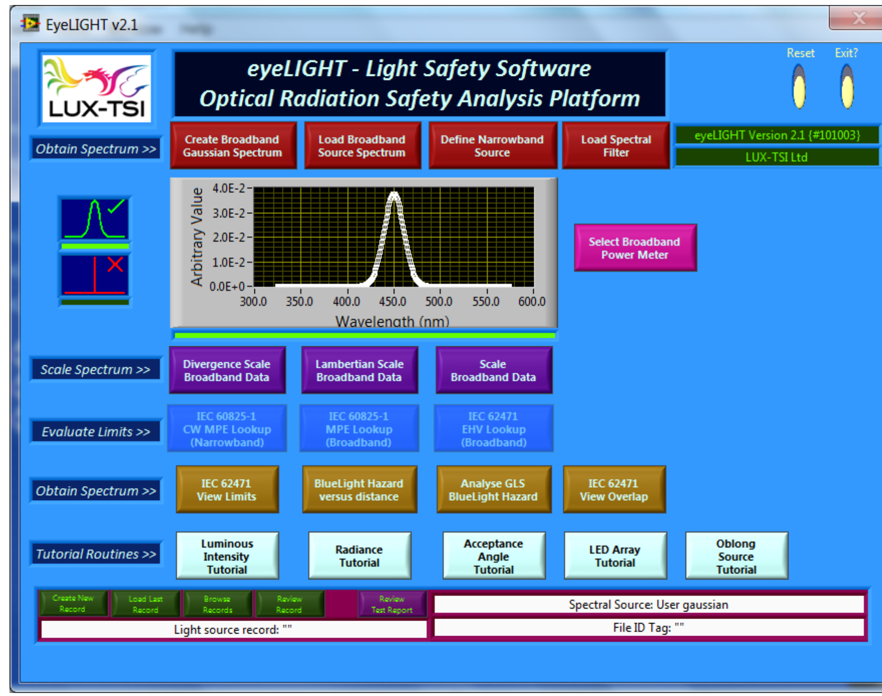


EyeLIGHT Software Platform



IEC 62471:
- Practical Testing

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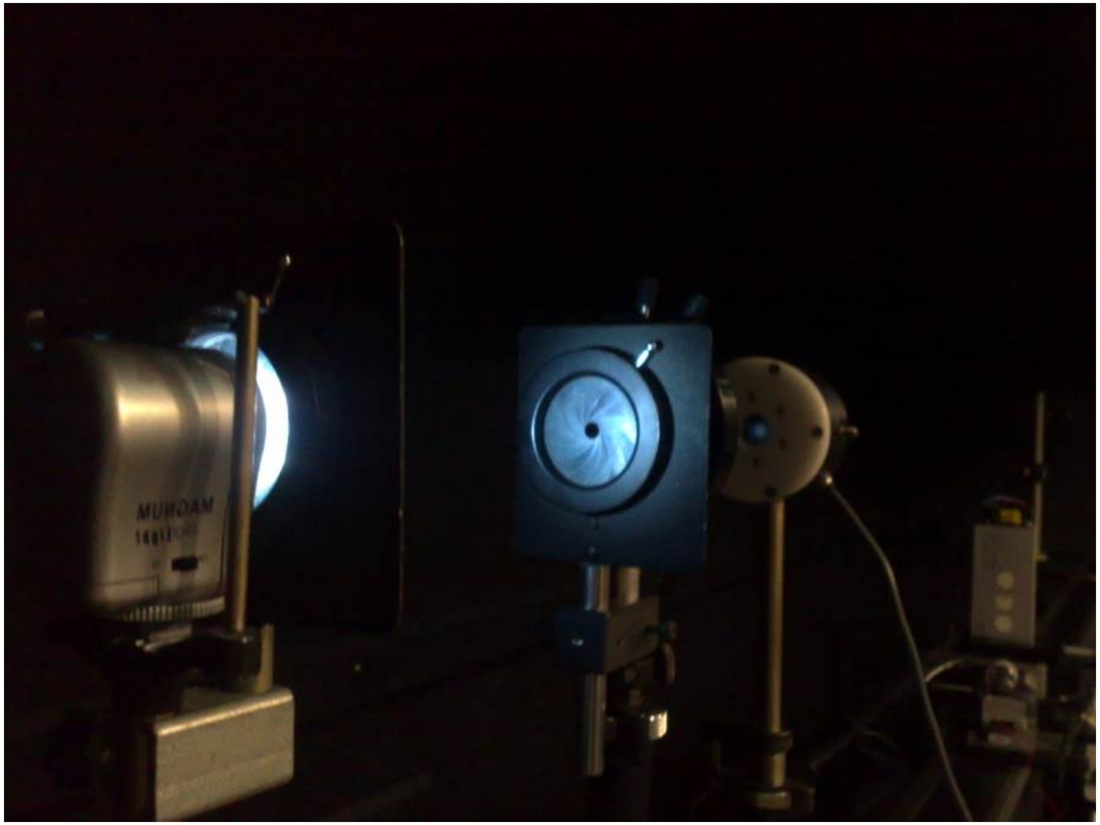
LED lamps and luminaires



Practical LED Safety Testing

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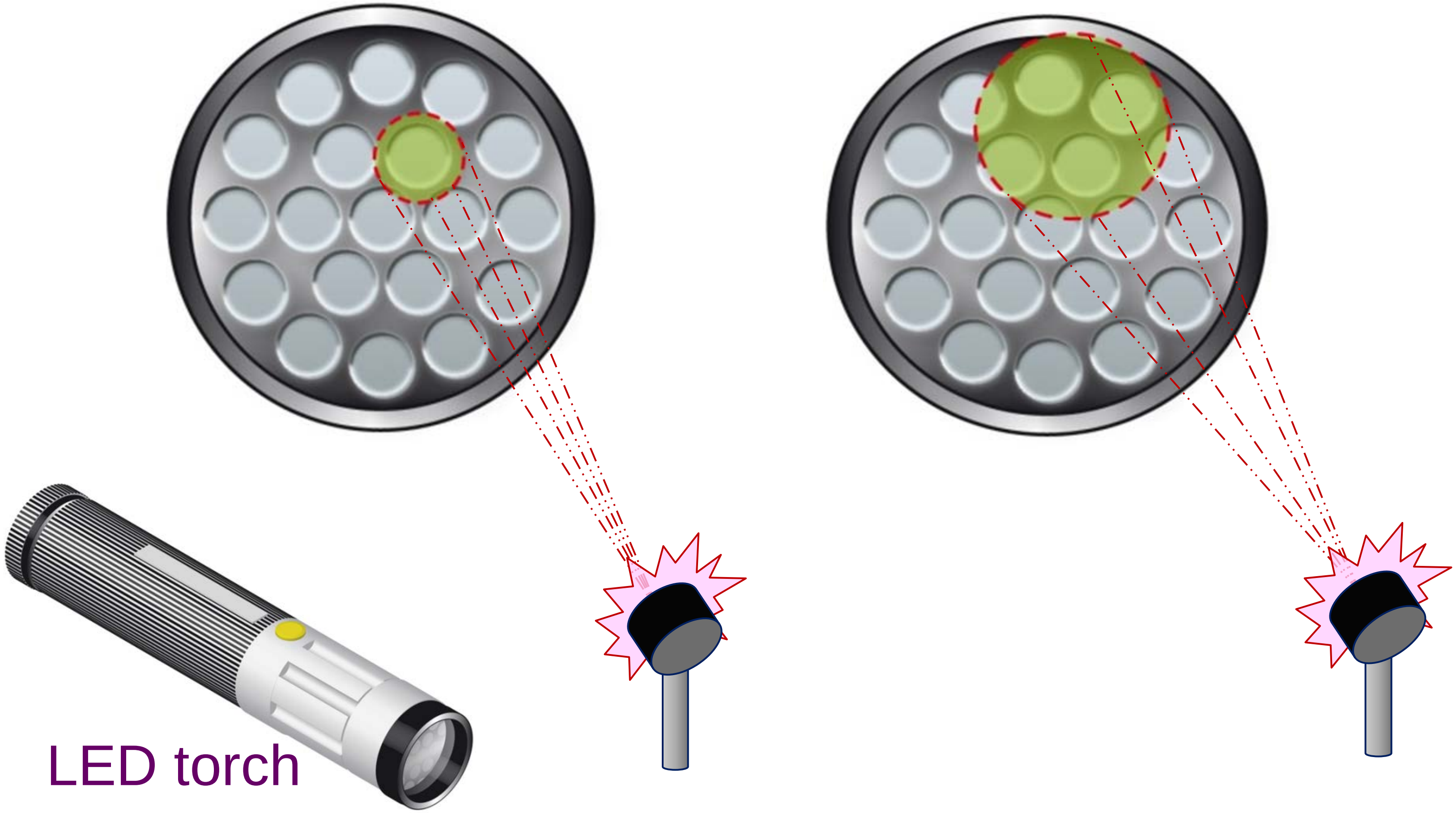
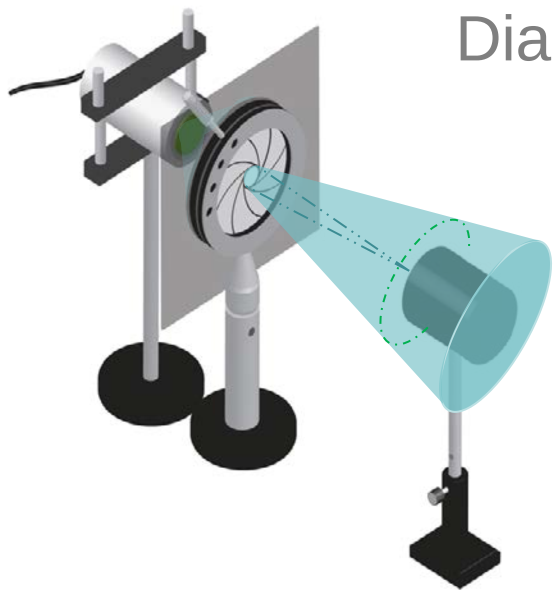
Radiance Problem (LED Array Sources)



Radiance Dependencies

Field Stop Diameter

Aperture Stop Diameter



Spectral Radiant Power

Apparent Source Location (distance)

Acceptance Angle

Wavelength

Field of View

Solid Angle

Software Evaluation Method

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- Select representative source spectrum

  eg 440 nm indigo blue LED,

  High brightness cool white LED,

  Ultraviolet LED
- Adjust the source metrics to yield EHV = 1.0

  (see next page)
- Vary the source metrics
- Explore influence upon EHV Value
- Relate to uncertainty level

‘Scaling the Metrics’

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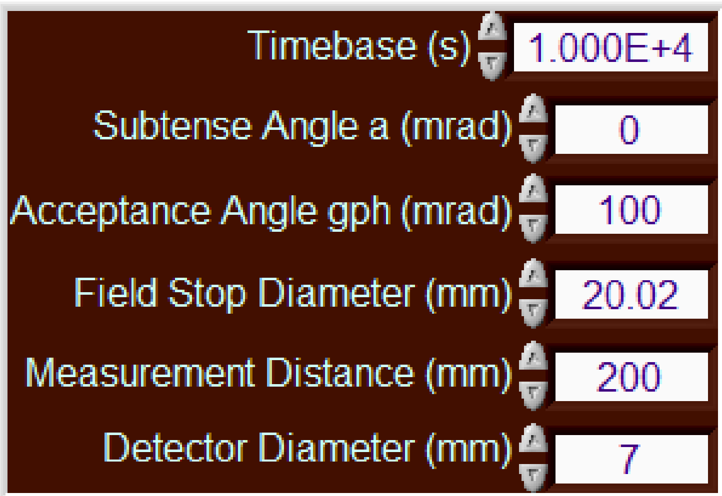

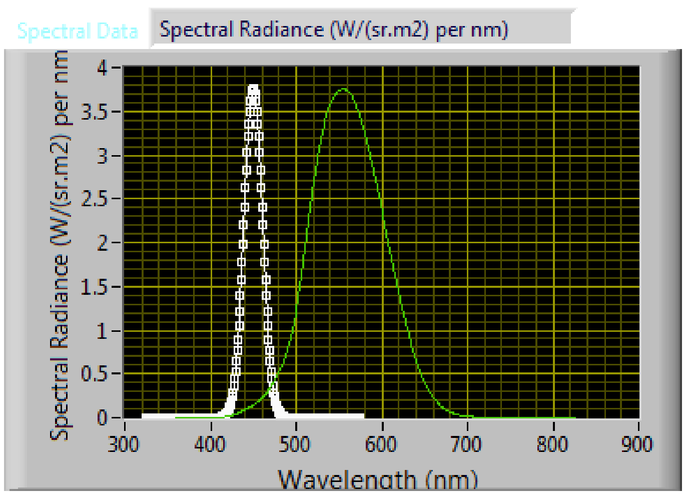

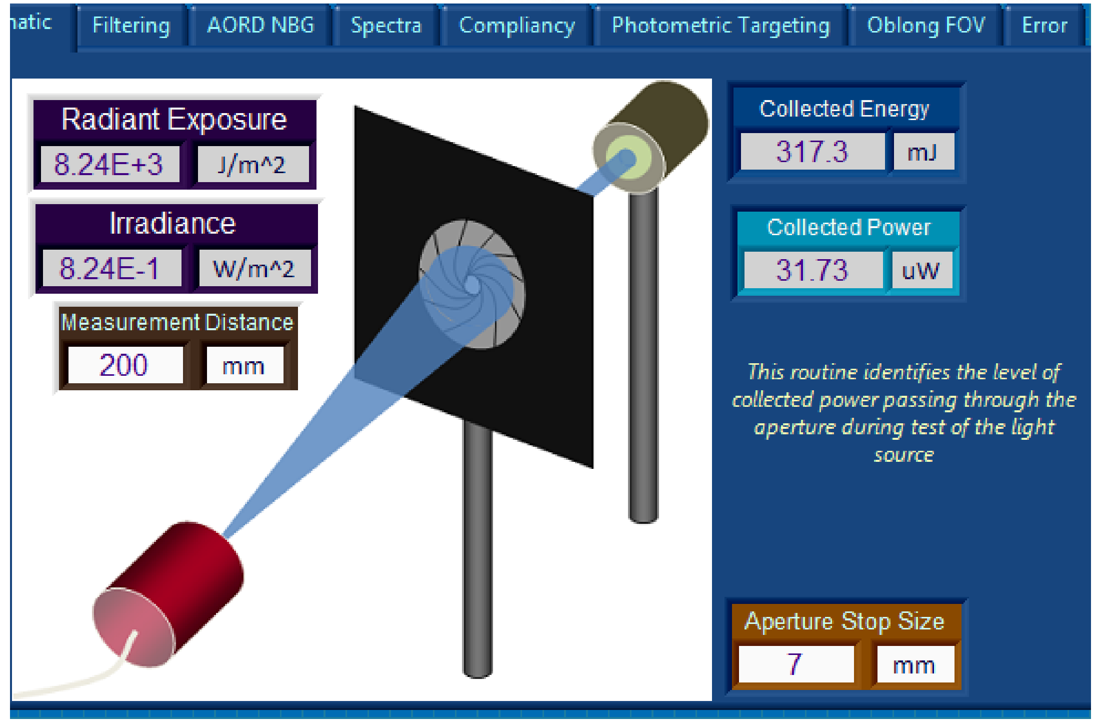

Indigo blue LED (440 nm)

Total spectral radiance L = 105 $W.m^{-2}.sr^{-1}$

Blue Light Hazard EHV = 1.0

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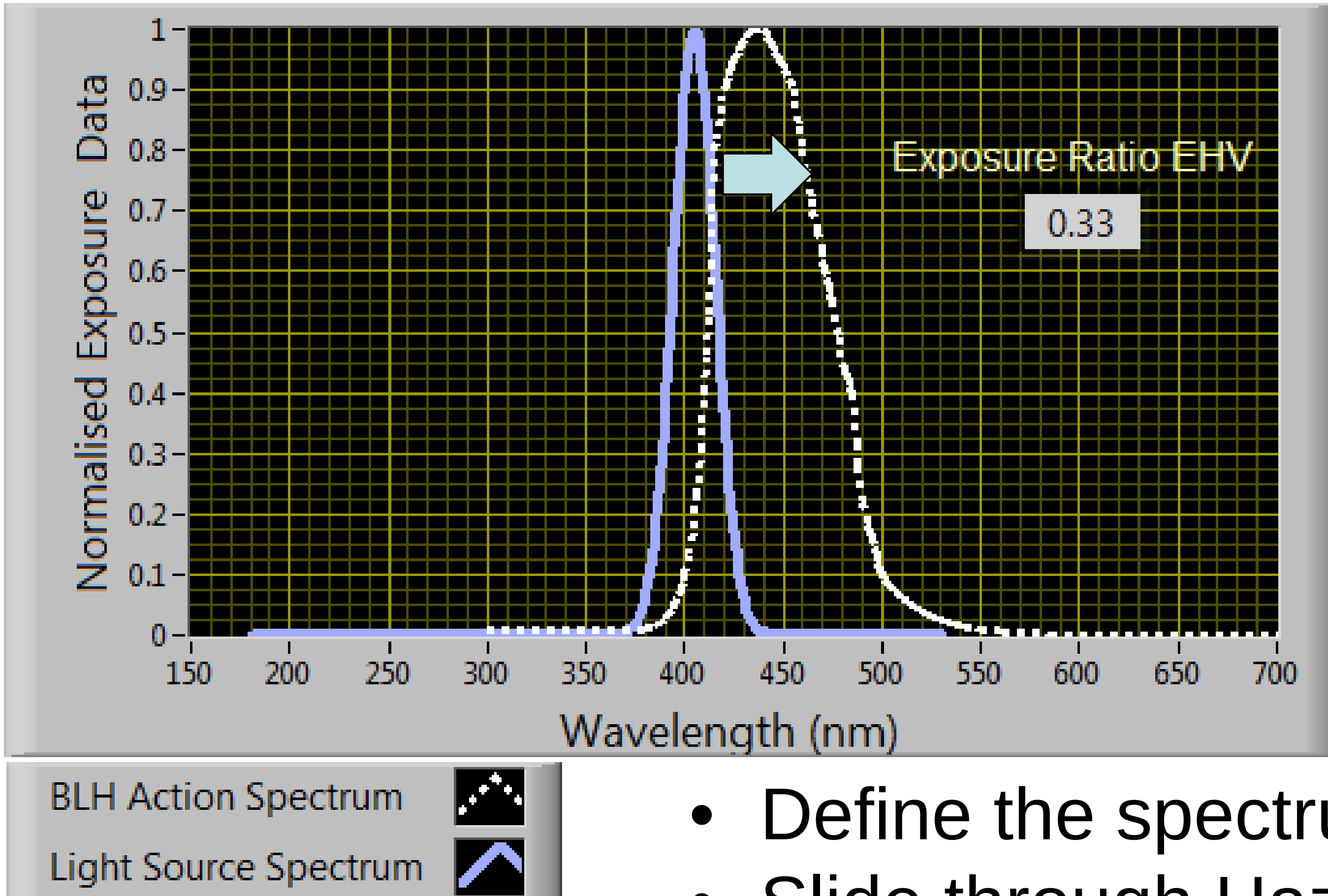
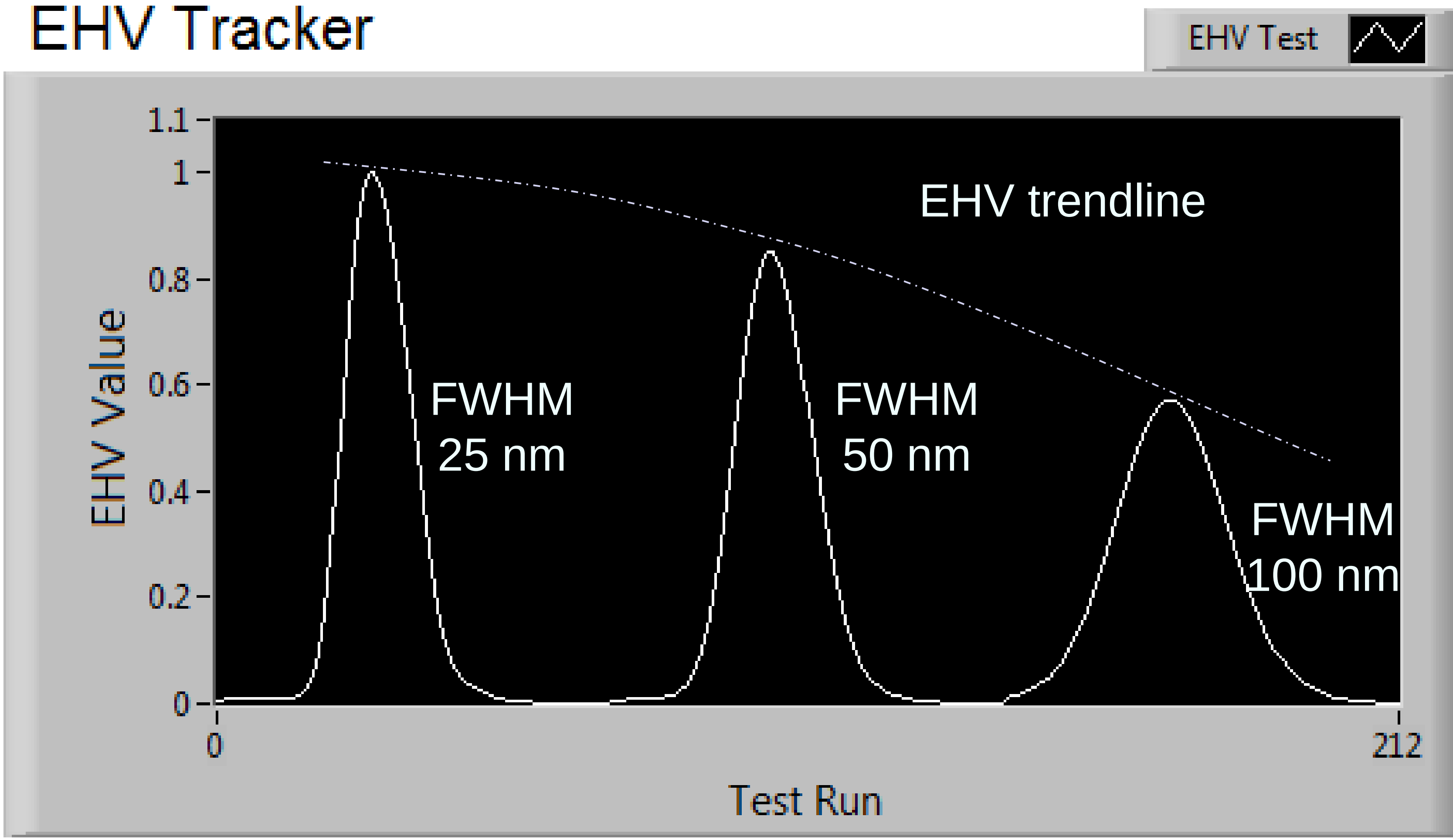
Influence of Spectral Properties



- Define the spectrum
- Slide through Hazard Band
- Plot EHV

Dynamic EHV Tracking



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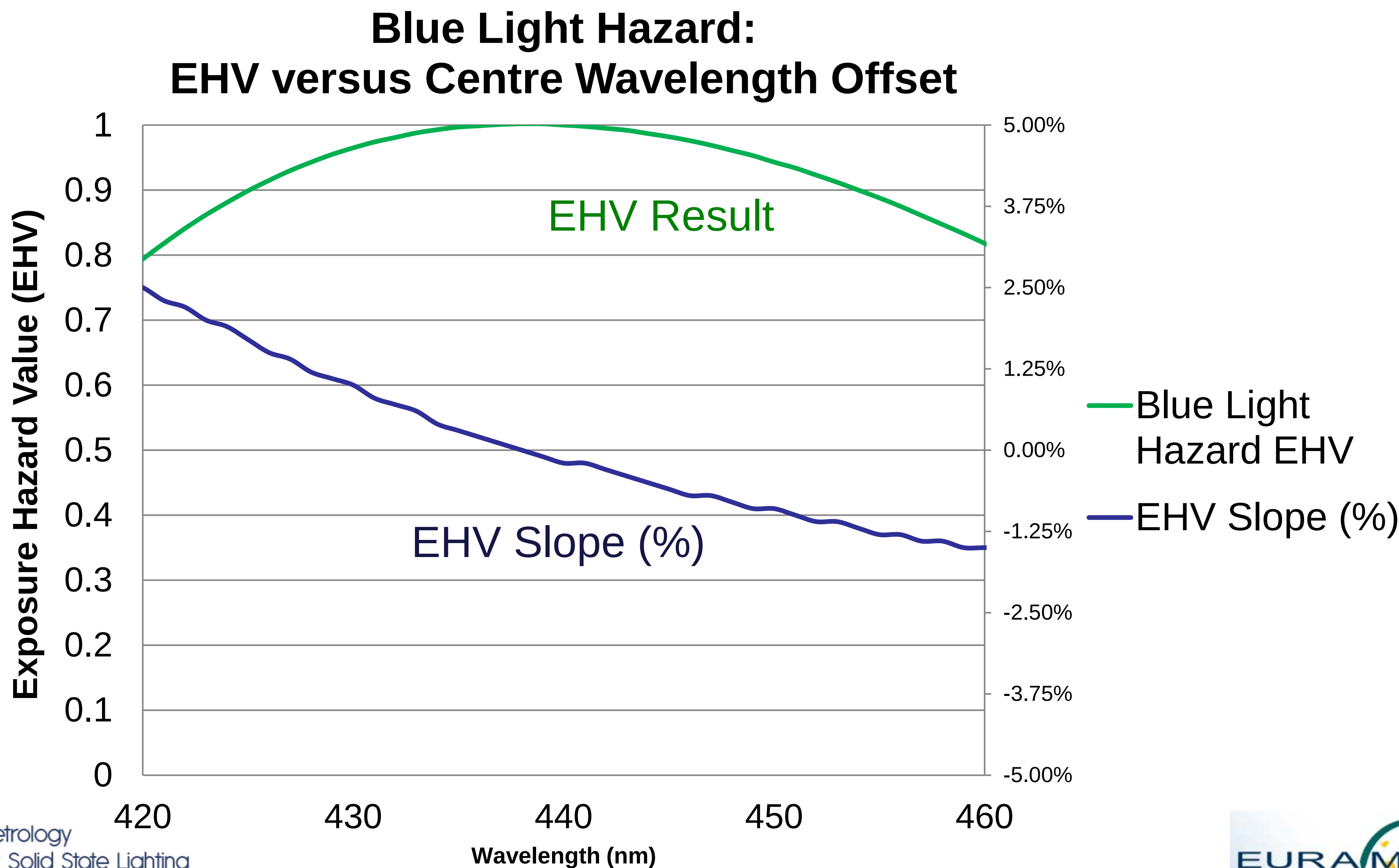
EHV – Spectral Analysis



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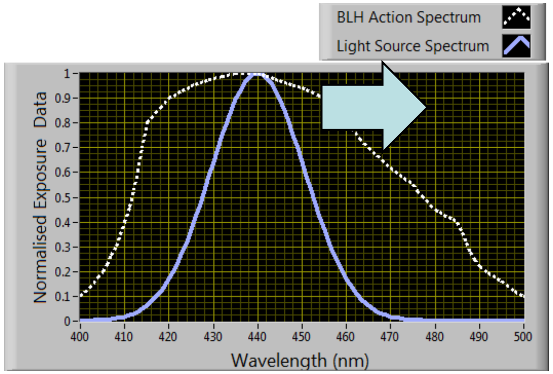
EHV & Spectral Analysis - Outcome

- Wavelength offset modifies EHV value

  1% for every 10 nm shift

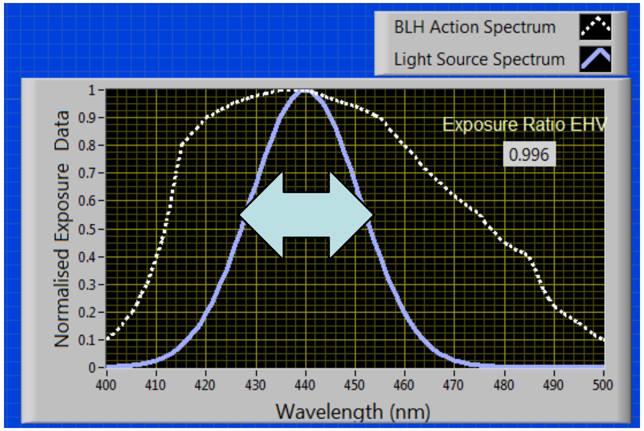
  Surprisingly low effect



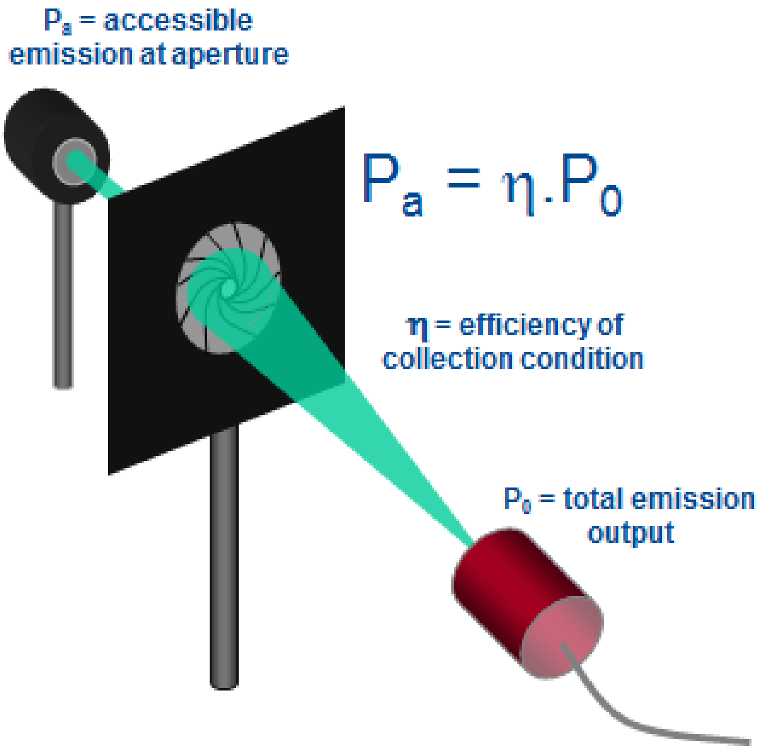
- Spectral linewidth

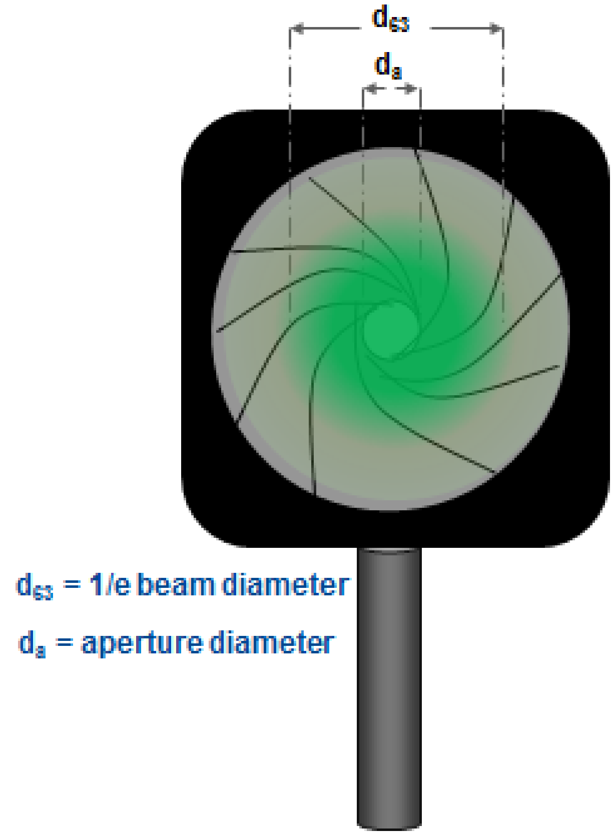
  Increasing FWHM reduces EHV 'finesse'

  2% EHV reduction per 5 nm broadening



Spectral Irradiance Measurement





Irradiance = Power per unit detector area

Irradiance Coupling

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- Uniform Irradiance at Aperture Stop
  - Coupled power increases quadratically with stop diameter
  - Calculated Irradiance is constant with stop size
- Gaussian Profile Irradiance at Aperture Stop
  - Coupled power decreases exponentially with increasing stop diameter
  - Irradiance falls with increasing stop size
- IEC 62471-1 Recommendation
  - Use 7 mm diameter unless irradiance at detector has good uniformity profile

EHV versus Detector Aperture Stop

Beam Divergence		d_{63} at 200 mm	Practical Stop Diameter	Gaussian Coupling Efficiency	Accessible Emission	EHV	Aperture Stop Irradiance
mrad	deg	mm	mm	%	uW		$W.m^{-2}$
100	6	20	6.9	11.2	30.8	0.97	0.80
		20	7	11.5	31.7	1.00	0.82
		20	7.1	11.8	32.5	1.02	0.84
500	29	102	6.9	0.457	30.8	0.97	0.80
		102	7	0.470	31.7	1.00	0.82
		102	7.1	0.483	32.6	1.03	0.84

Typically 2-3% EHV change per 100 micron diameter uncertainty

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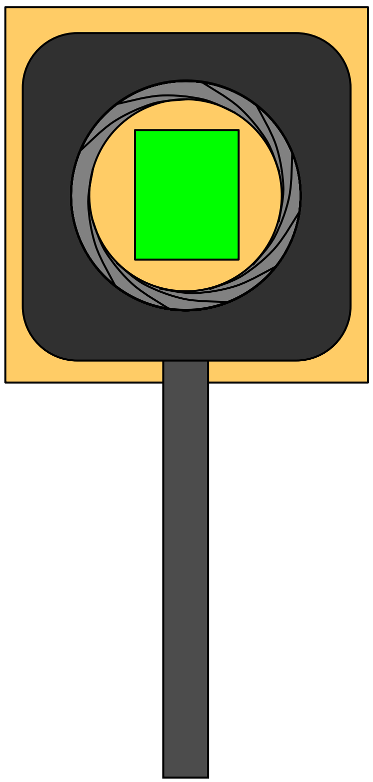
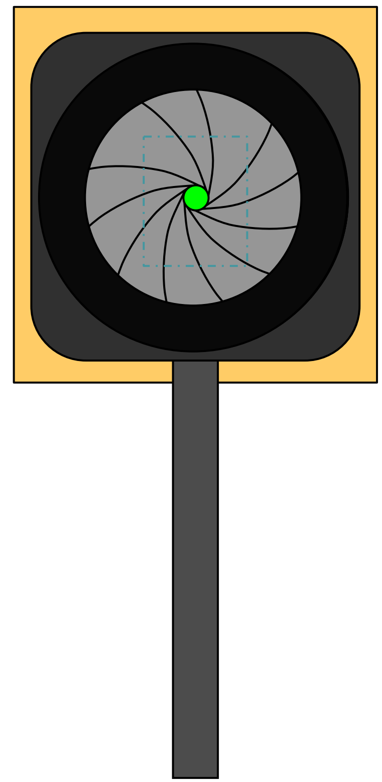
EHV versus Aperture Stop

- As aperture stop is increased
  - Detected radiant power should increase
- EHV assessment calculation
  - Assumes defined stop diameter
    - e.g. 7.0 mm aperture stop at 200 mm distance
- Use of slightly large aperture stop setting
  - Will overestimate EHV result
  - Typically 2-3 % EHV increase for gaussian profile beam at stop set incorrectly by + 100 μm
  - Yields a conservative EHV outcome

Spatially Averaged Radiance



Source size smaller than FOV (under-filled)



Source size larger than FOV (overfilled)

Radiance = Detected Irradiance per unit source solid angle

Exempt & Low Risk BLH

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- Blue Light Hazard Testing – Exempt Condition

  Exposure Time = 10000 s

  Acceptance Angle γ = 100 mrad ('field of view')

  Implies a 20 mm diameter field stop located over the source

- Blue Light Hazard Testing – Low Risk Condition

  Exposure Time = 100 s

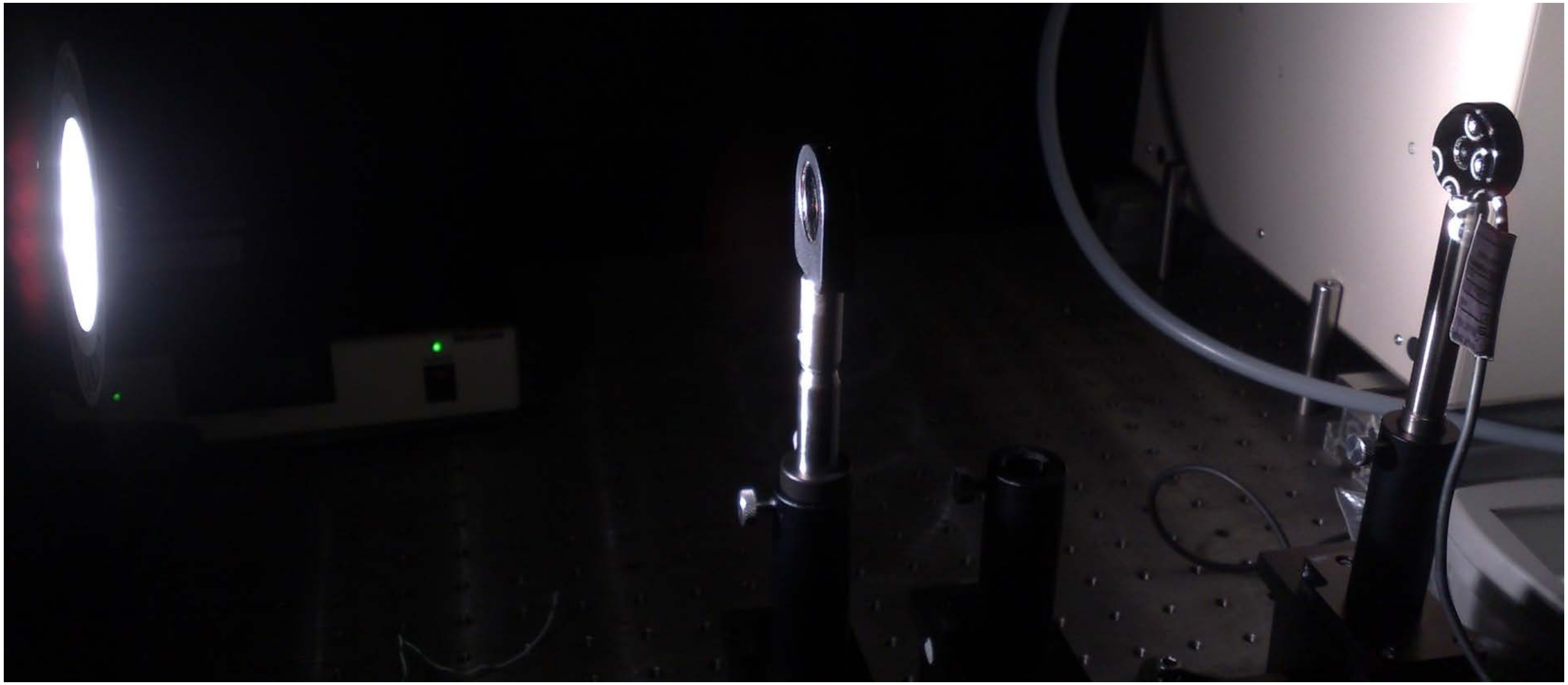
  Acceptance Angle γ = 11mrad

  Implies a 2.2 mm diameter field stop located over the source

Field stop setting precision will influence radiance result

Reference Test Method recommends 'imaging' setup

Low Risk BLH Imaging Method



Source 1:1 imaging lens Field of View

Low Risk BLH Imaging Method

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1:1 images of HB-LED sources

Field stop and LED chip size are both of the order of 2 mm for Low Risk Testing at 11 mrad

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Low Risk BLH
LED EHV Analysis

- Assume for LED chip evaluated at 200 mm:

  LED Chip diameter ≈ 2.0 mm

  Assume gaussian 'exitance' profile

  Field Stop at 200 mm ≈ 2.2 mm

- Assess EHV due to power coupled through the field stop

  11 mrad field stop can substantially vignette certain source types

Field stop may 'vignette' source emission

11 mrad FOV – Gaussian_Coupling

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Simulation of Gaussian Profile Stop Coupling

Required Field of View (mrad)	Test Distance (mm)	Assumed Field Stop Diameter (mm)	Nominal LED Chip Diameter (mm)	Gaussian Coupling Efficiency (%)	Gaussian Coupled Power (uW)	EHV
11	200	2.1	2	70.18	36.5	0.95
11	200	2.2	2	66.8	38.4	1.00
11	200	2.3	2	73.33	40.1	1.04

Assuming gaussian source exitance profile on field stop…

….Typically 5% EHV change per 100 μm field stop uncertainty

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11 mrad FOV – Uniform Coupling

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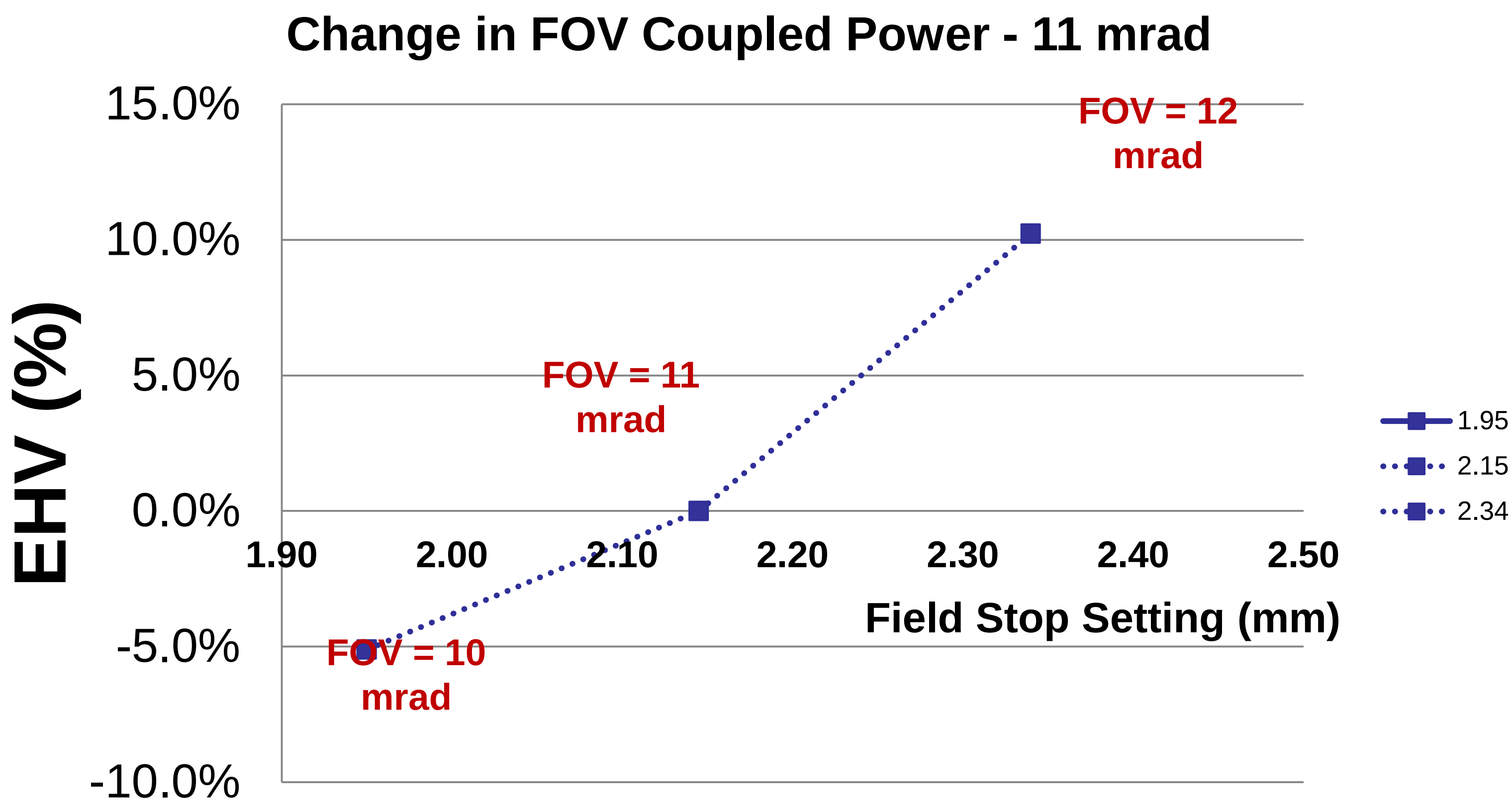
Simulation of Uniform Exitance Profile Field Stop Coupling

Required Field of View (mrad)	Test Distance (mm)	Assumed Field Stop Diameter (mm)	Nominal LED Chip Diameter (mm)	Uniform Irradiance Coupled Power (uW)	Relative EHV
11	200	2.1	2	35	0.91
11	200	2.2	2	38.4	1.00
11	200	2.3	2	42	1.09

Assuming uniform exitance profile on field stop…

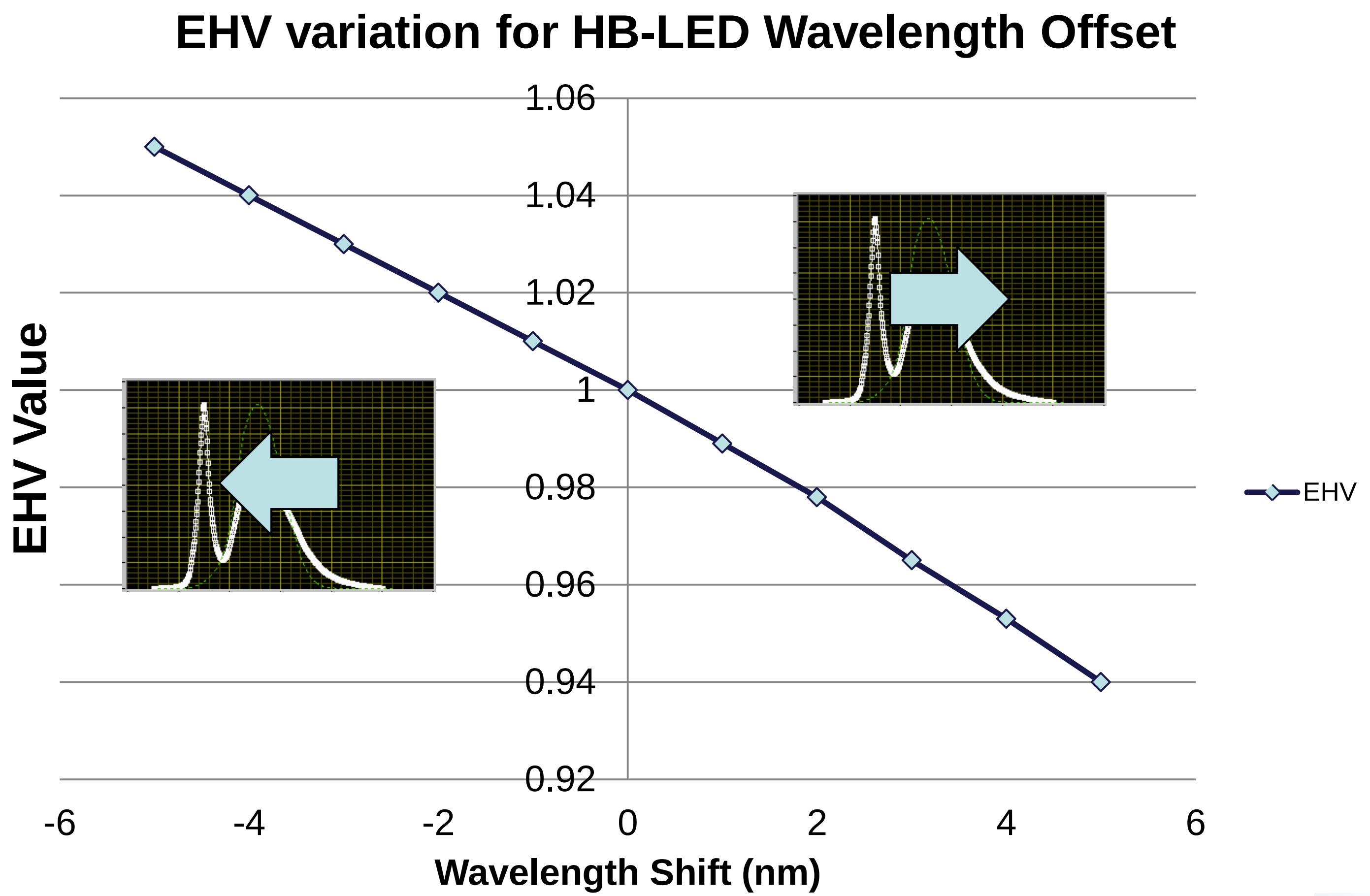
….Typically 10% EHV change per 100 μm field stop uncertainty

Practical Data (FOV = 11 mrad)

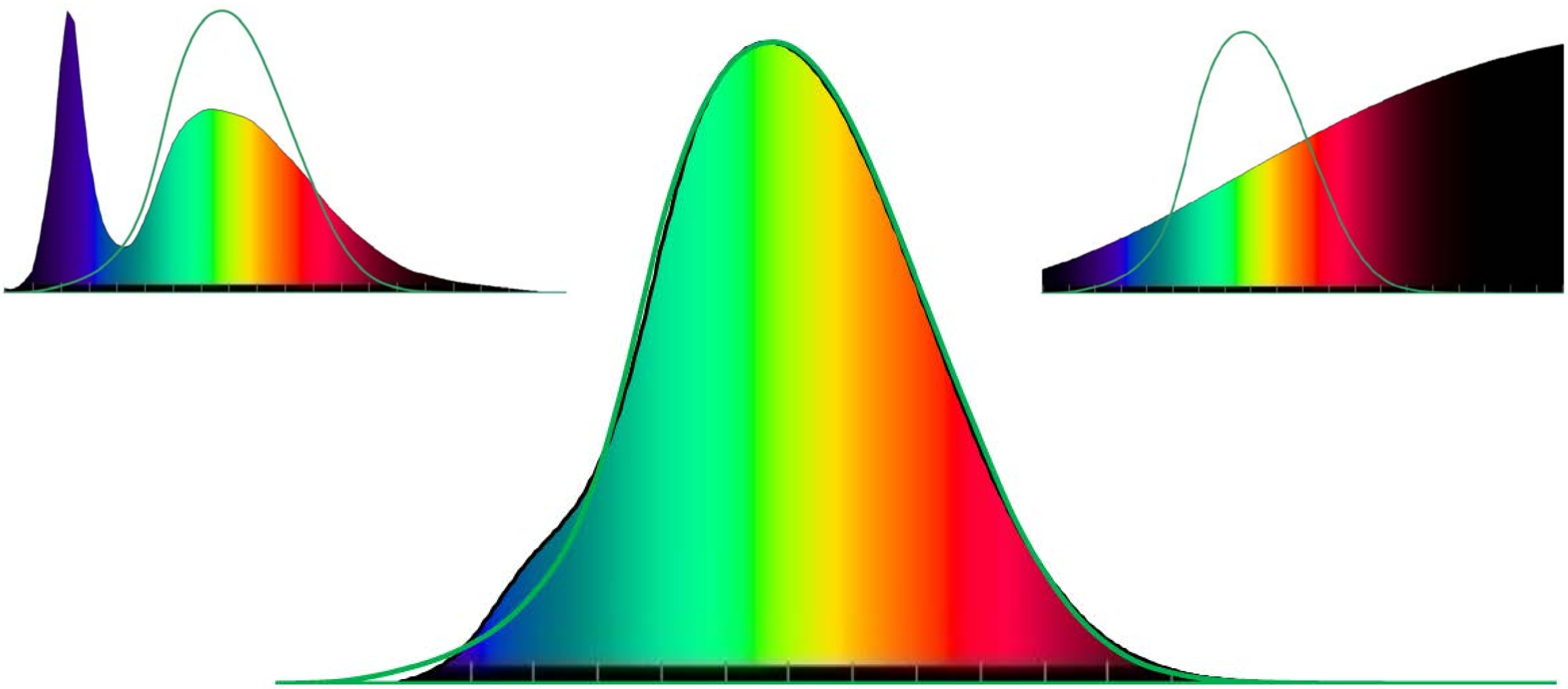


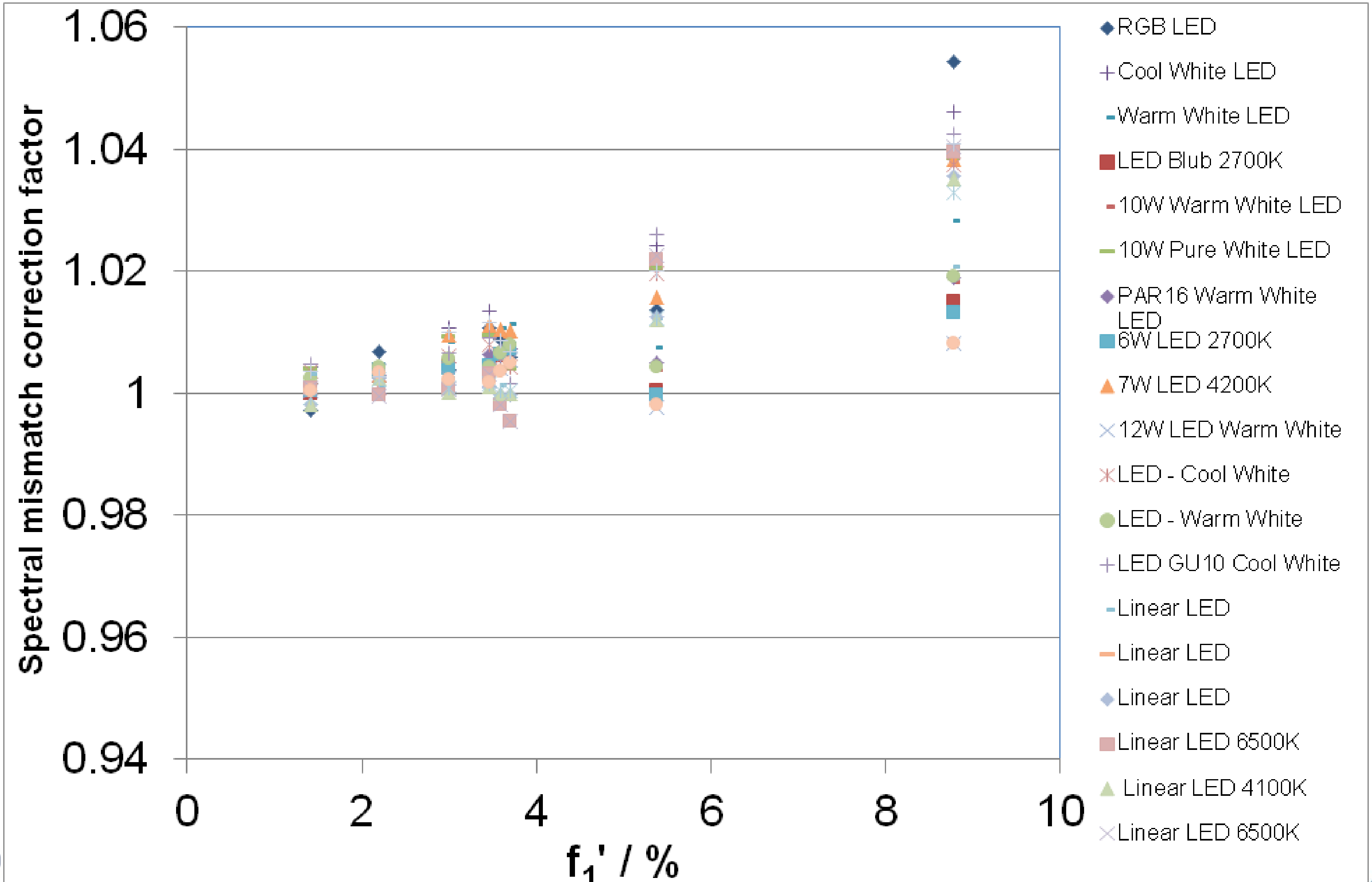
Typically 5% EHV change per 100 μm field stop diameter increment

EHV Variation for a Cool White LED

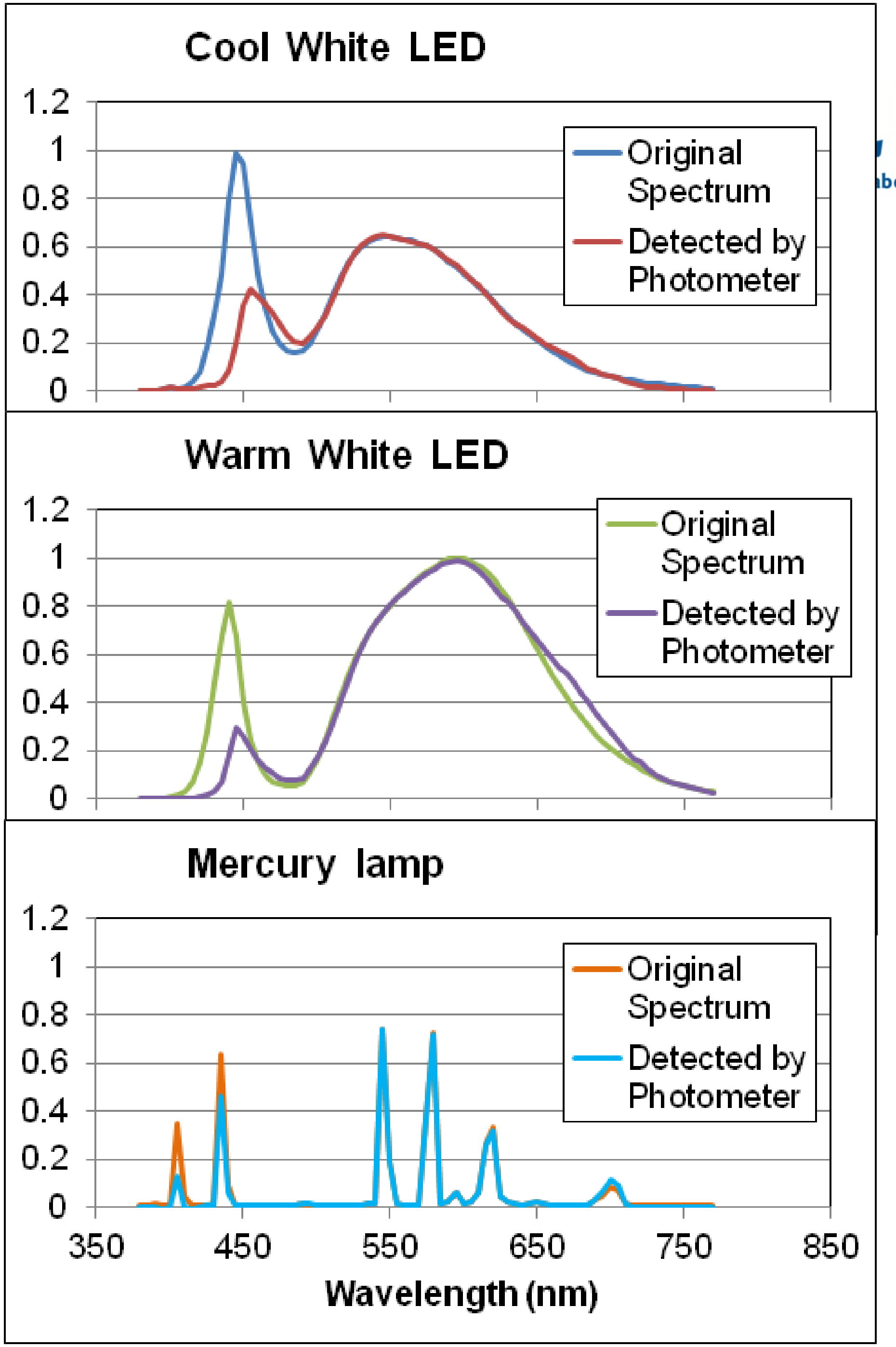


Spectral





1.06
1.04
1.02
1
0.98
0.96
0.94
Spectral mismatch correction factor
0
2
4
6
8
10
f1' / %
RGB LED
Cool White LED
Warm White LED
LED Blub 2700K
10W Warm White LED
10W Pure White LED
PAR16 Warm White LED
6W LED 2700K
7W LED 4200K
12W LED Warm White
LED - Cool White
LED - Warm White
LED GU10 Cool White
Linear LED
Linear LED
Linear LED
Linear LED 6500K
Linear LED 4100K
Linear LED 6500K


Cool White LED
1.2
1
0.8
0.6
0.4
0.2
0
Original Spectrum
Detected by Photometer
Warm White LED
Mercury lamp
350
450
550
650
750
850
Wavelength (nm)

EHV & Field Stop Coupling

- The smaller the required acceptance angle γ
  - The more stringent the precision on the field stop diameter setting (and location within field of view)
- Stop uncertainty implies uncertainty of power coupled through field stop
  - Implies increased uncertainty in radiance and EHV value
- 5% to 10% EHV uncertainty at γ = 11 mrad
  - For 100 μm change in field stop diameter
- Conservative approach
  - Use slightly larger field stop setting than specified

Summary of 62471 Uncertainties

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- Optical radiation safety ‘EHV’ value

  Requires uncertainty value to be reported

  Adoption of conservative approach recommended

    i.e. ensure collection of (slightly) more radiant power

- Advance software simulation process

  Spectral ‘sliding’ & Stop size ‘dithering’

  Uncertainty of influencing parameters can be gauged and analyzed dynamically

Typical 62471 EHV Uncertainties

Parameter	Influence on Blue Light Hazard Exposure Hazard Value
Centre wavelength	≈ 1% per every 10 nm offset
Spectral Linewidth	≈ 2% per every 5 nm FWHM spread
Spectral radiant power	≈ 2 to 5% depending on detector type
Irradiance (Area of detector)	≈ 2 to 3% per 100µm @ 7 mm detector diameter
Radiance (area of field stop)	≈ 5 to 10% per 100µm @ 2.2 mm diameter (Low Risk Testing at 11 mrad FOV)

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Thank you for your attention

With acknowledgement to EMRP

And thanks to LUX-TSI Ltd