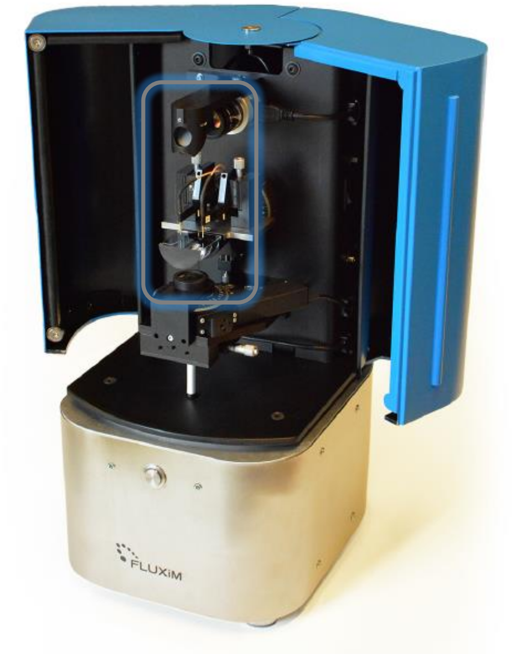
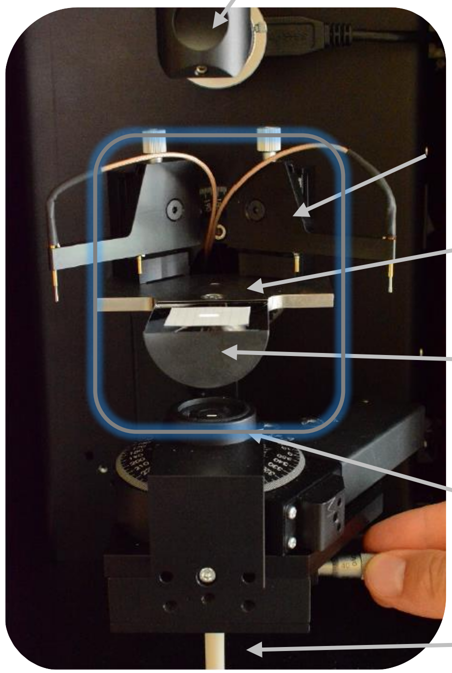
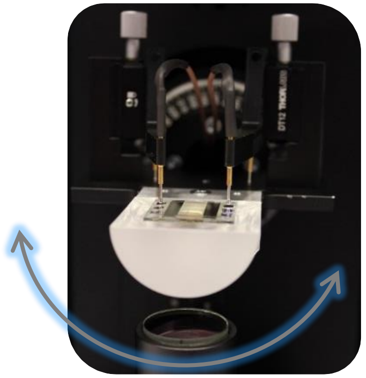
Phelos

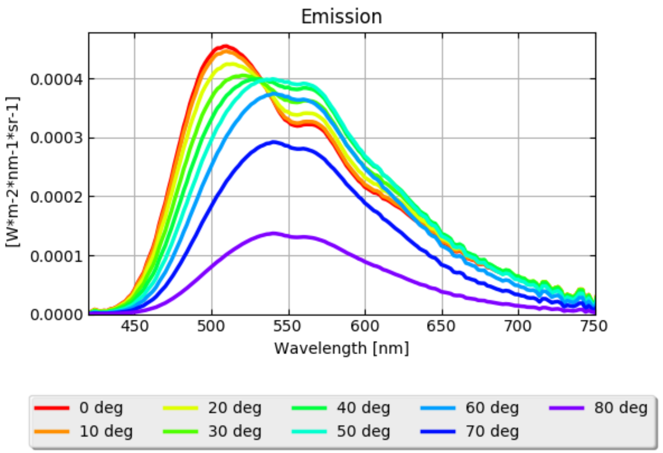
angular luminescence spectrometer

Phelos inside









Electrical (SMU):

- Voltage: +/- 20 V
- Current: +/- 120 mA
- Resolution: < 1nA
- Source current or voltage

Angular:

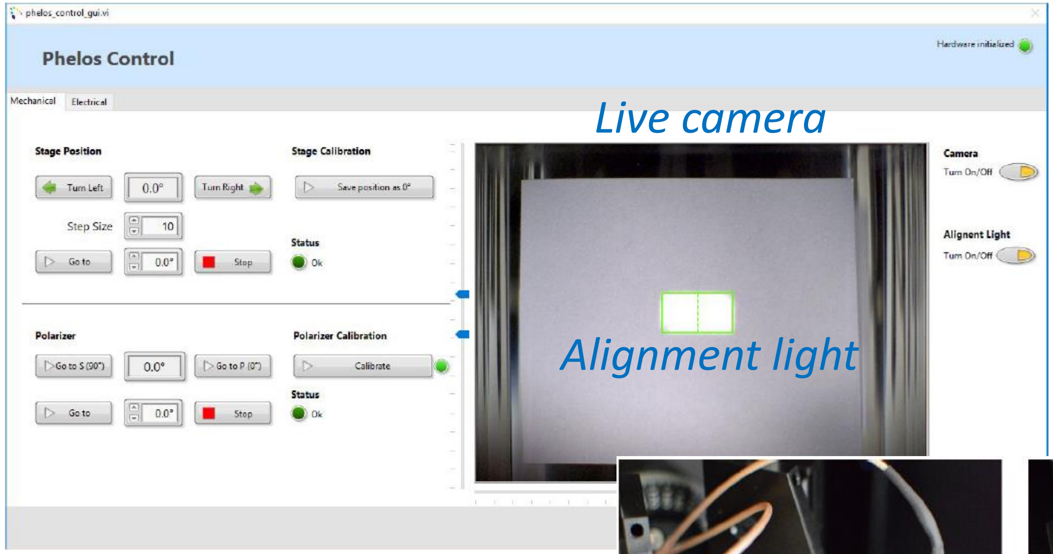
- Resolution: < 1°
- Range: +/- 85°
- Rotation: inclination angle

Spectral:

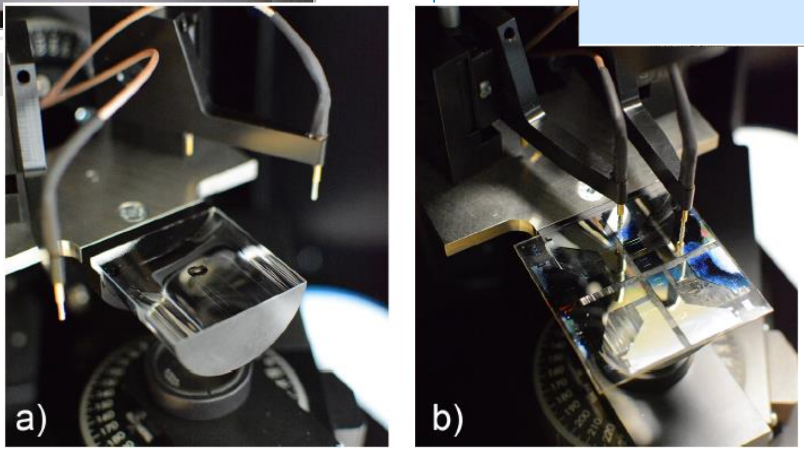
- range: 380 – 880/1100 nm
- resolution: 1.2/2.4 nm

User-friendly software

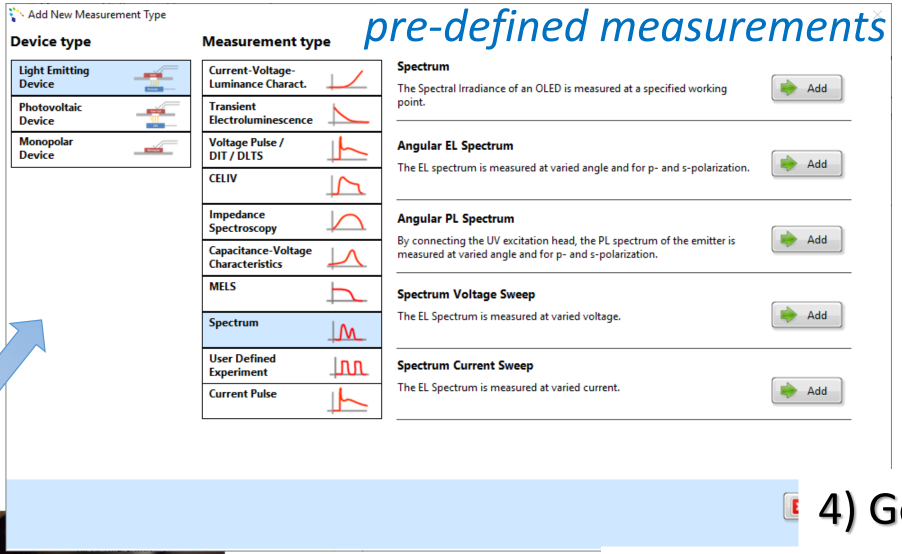
1) Mark measurement spot



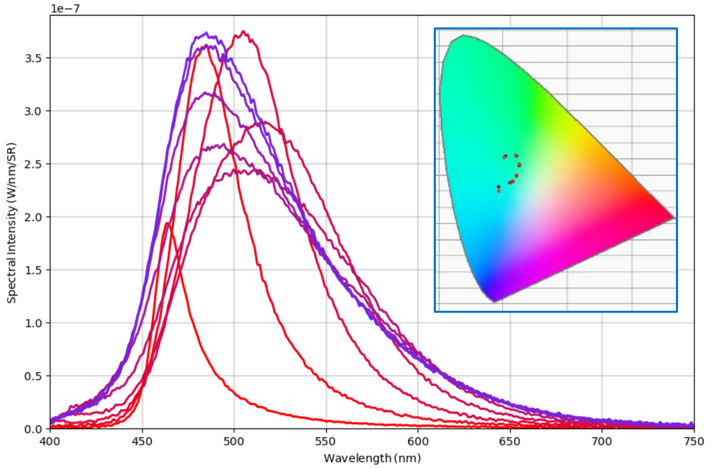
2) Place your sample



3) Choose the measurement type

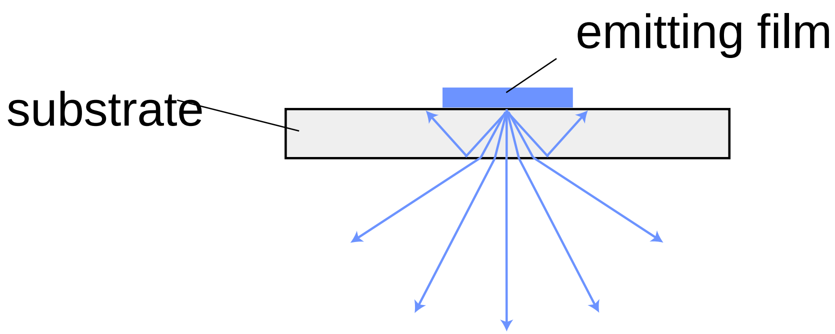


4) Get high quality data



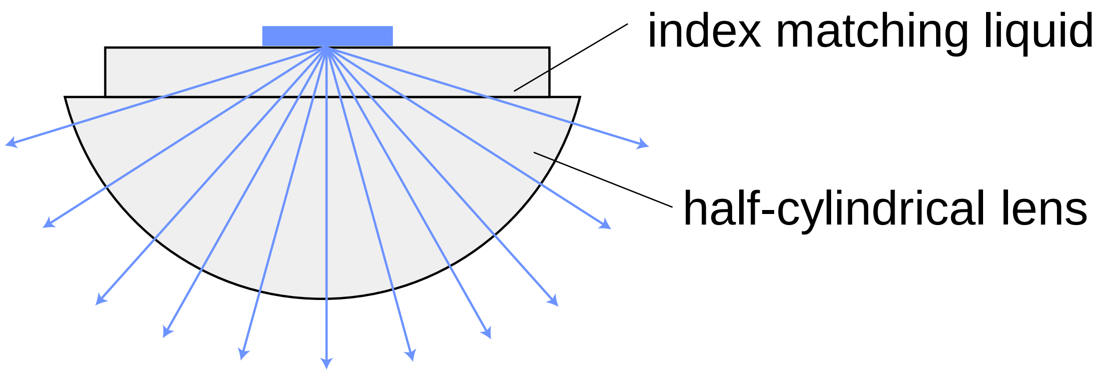
Why using a lens?

Light extraction: **bare sample**



→ total internal reflection at ~ 42°

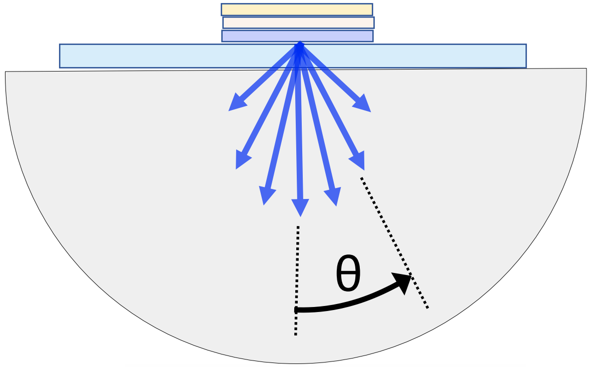
with **macro extractor lens**

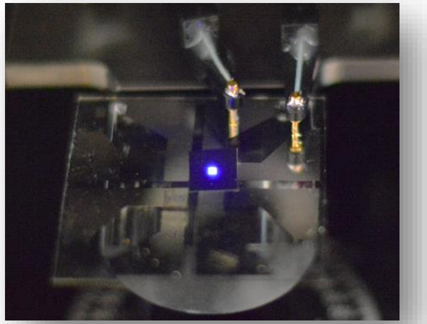


→ Outcoupling of substrate modes

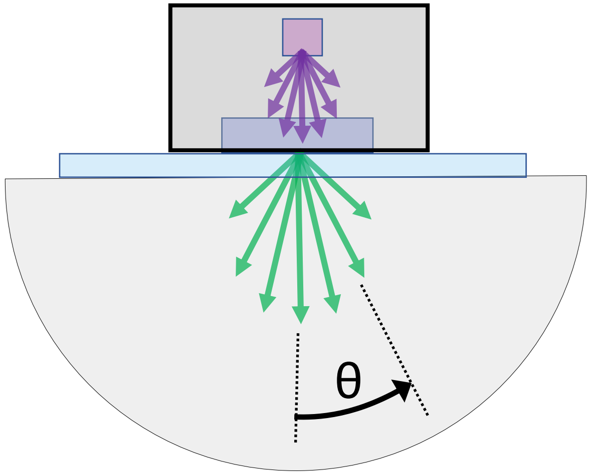
Phelos modes

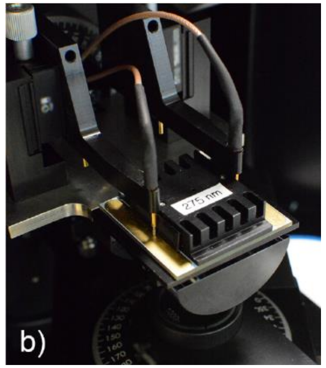
1) (O)LED
(Electroluminescence)



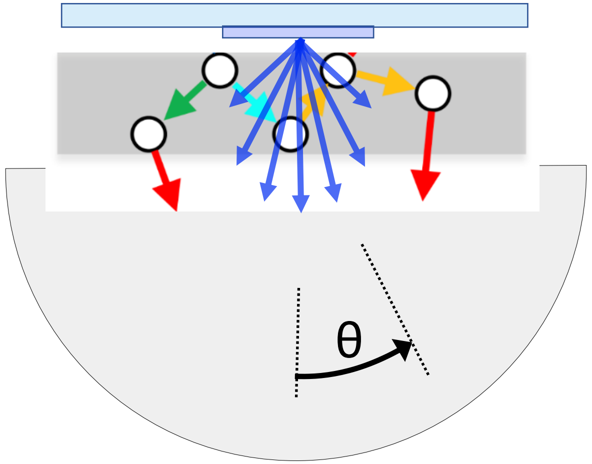


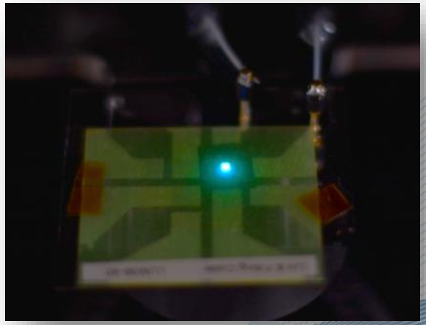
2) Emitter film
(Photoluminescence)





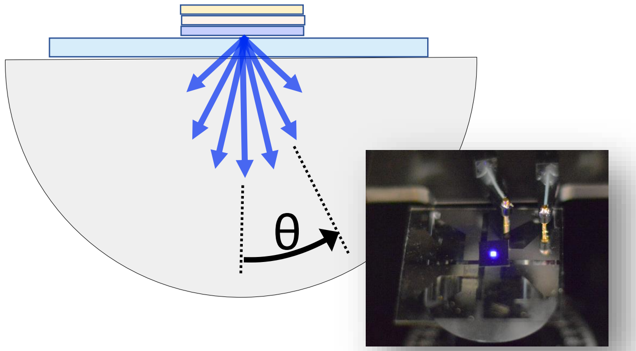
3) QD/scattering film



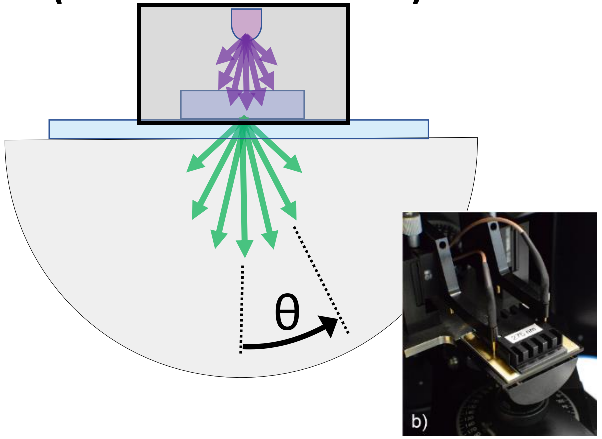


Phelos modes

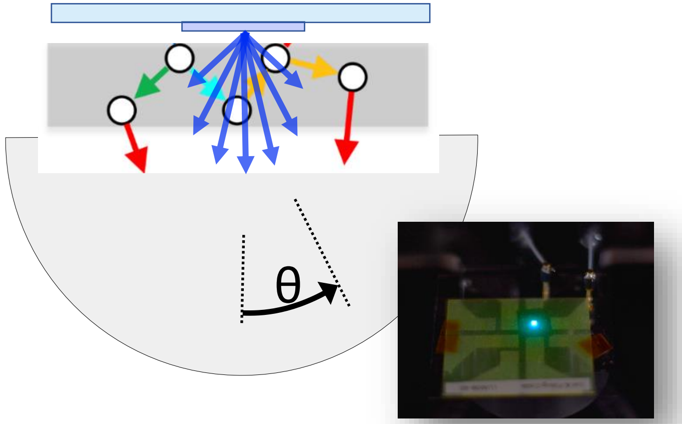
1) (O)LED (Electroluminescence)



2) Emitter film (Photoluminescence)



3) QD/scattering film

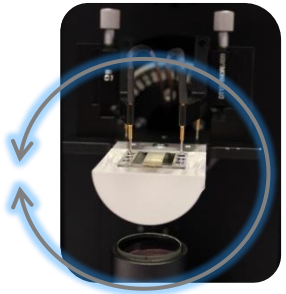


- Analysis of color
- Efficiency (EQE, lm/W, power eff.)
- Emission zone fit
- Emitter orientation

- Emitter orientation

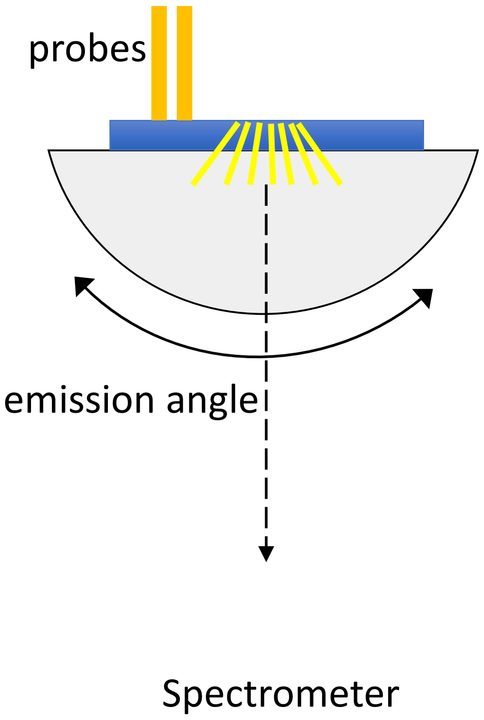
- Scattering/down-conversion film characterization
- OLED with QD characterization

Measuring BE and TE OLEDS

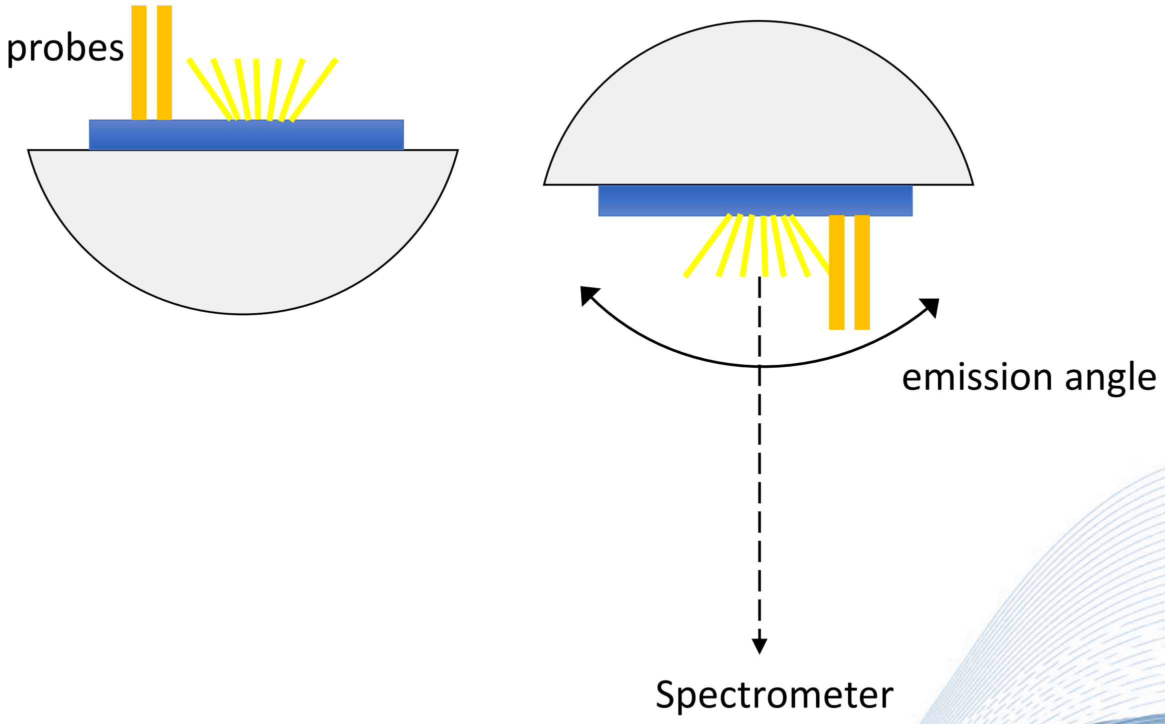


360° rotation
is possible

BE sample



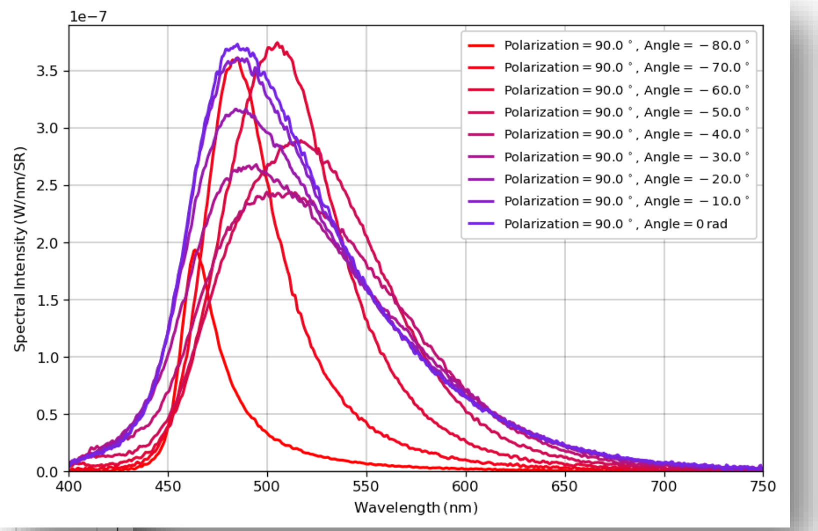
TE sample

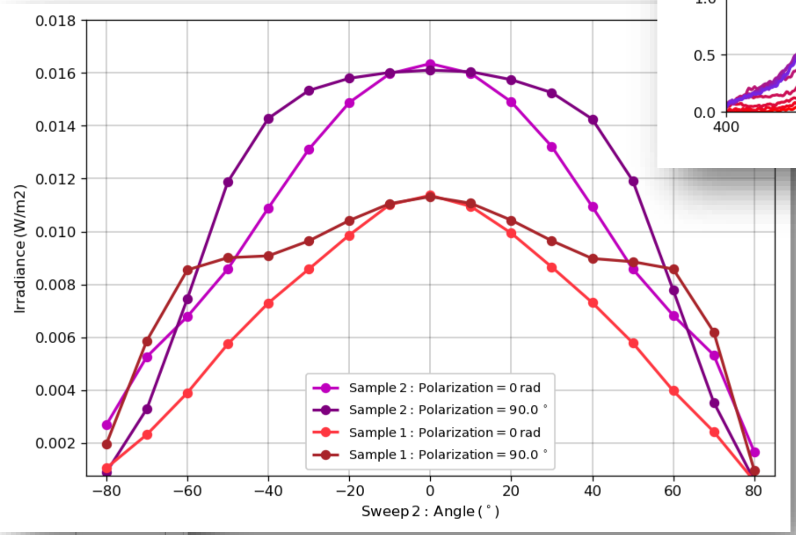


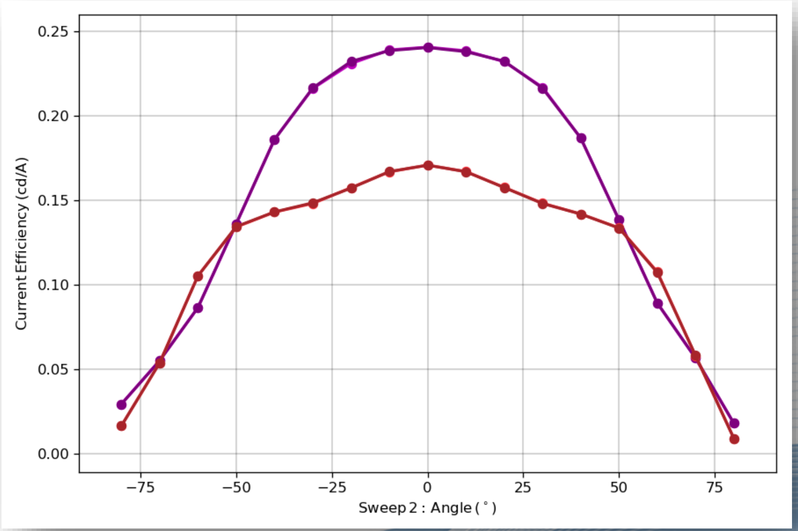
OLED example

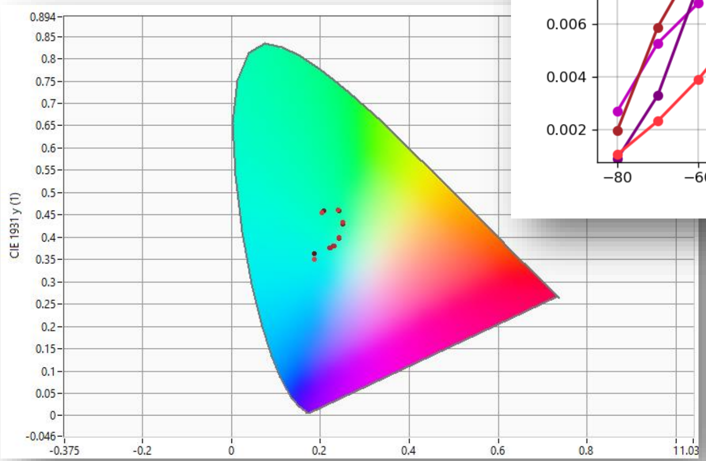
Directly processed data:

- Spectral Irradiance/Intensity
- Radiance/Radiant Intensity
- Luminous Intensity
- Working point
- Efficacy (cd/A)
- CIE coordinates
- Color temperature, CRI
- …

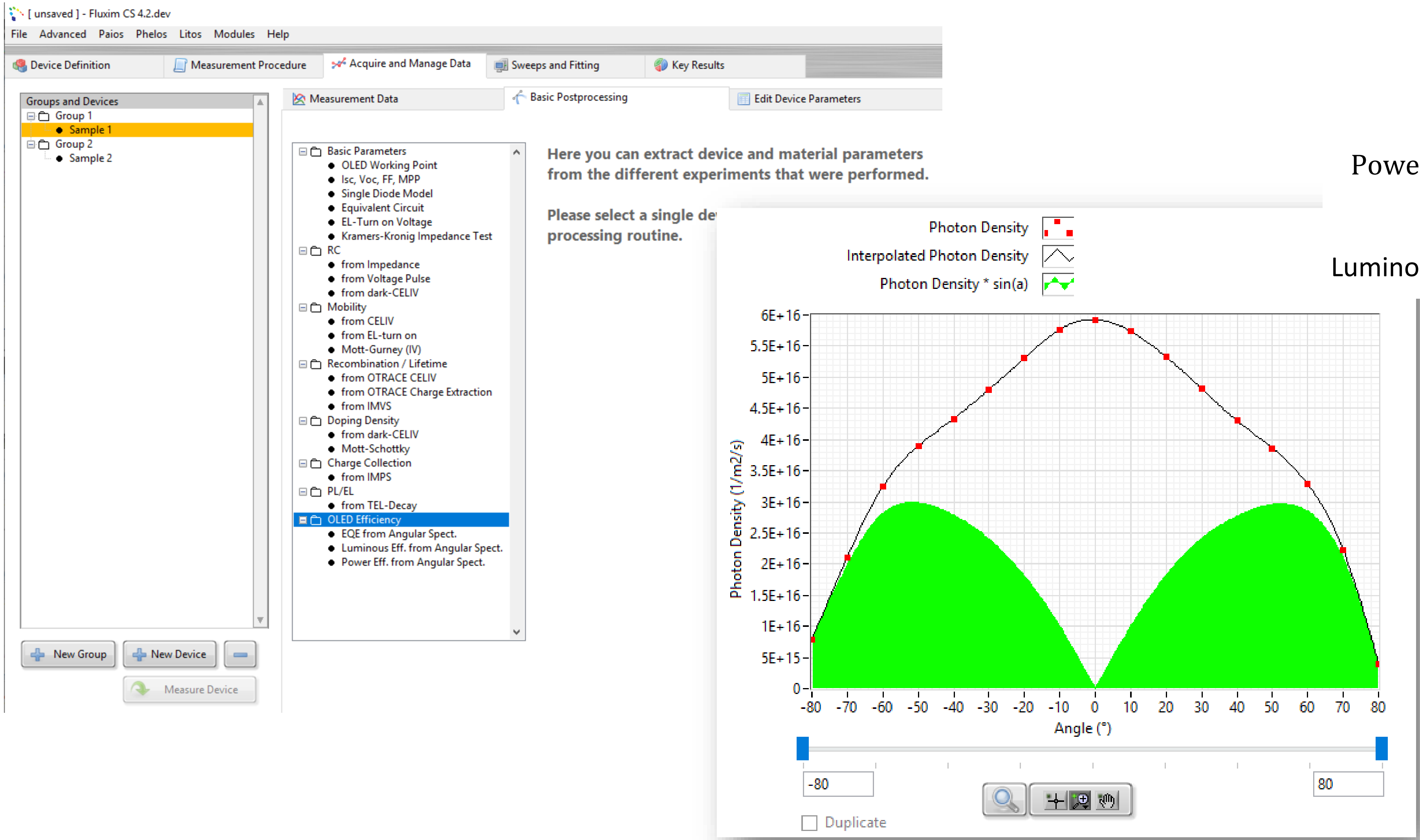








OLED efficiency post-processing



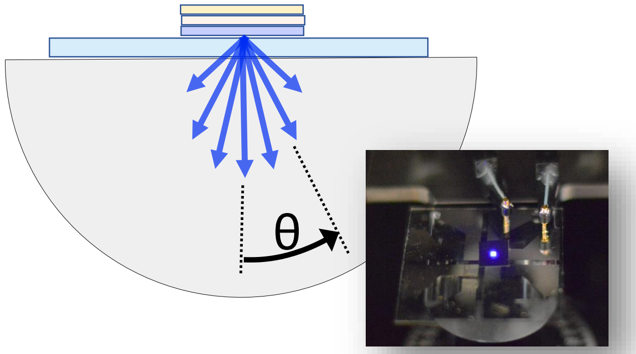
$$EQE = \frac{Photon\ Flux}{Electron\ Flux}$$

$$\text{Power efficiency} = \frac{Photon\ Power}{V \cdot I}$$

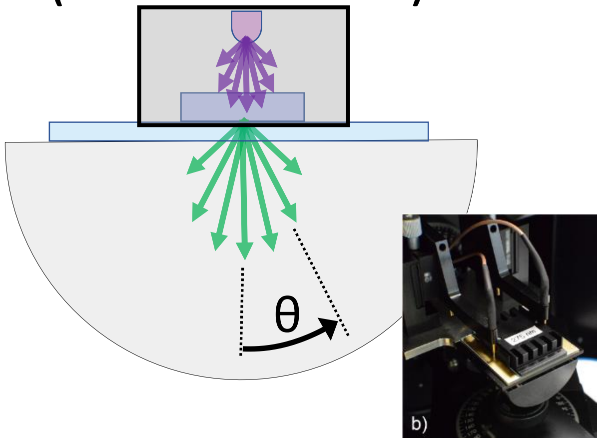
$$\text{Luminous efficiency} = \frac{Luminous\ Flux}{V \cdot I}$$

Phelos modes

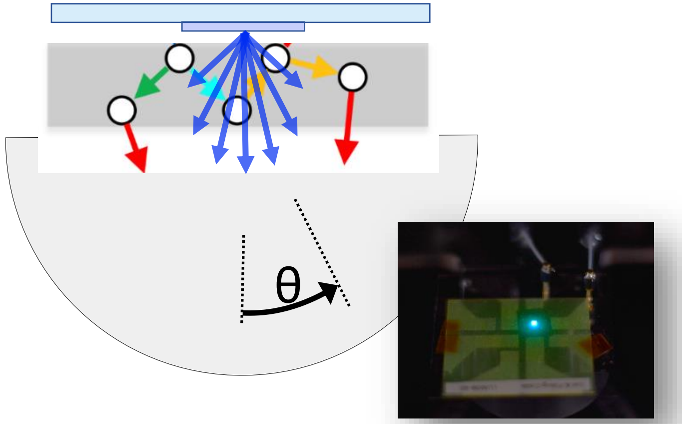
1) **(O)LED (Electroluminescence)**



2) **Emitter film (Photoluminescence)**



3) **QD/scattering film**



- Analysis of color
- Efficiency (EQE, lm/W, power eff.)
- Emission zone fit
- Emitter orientation

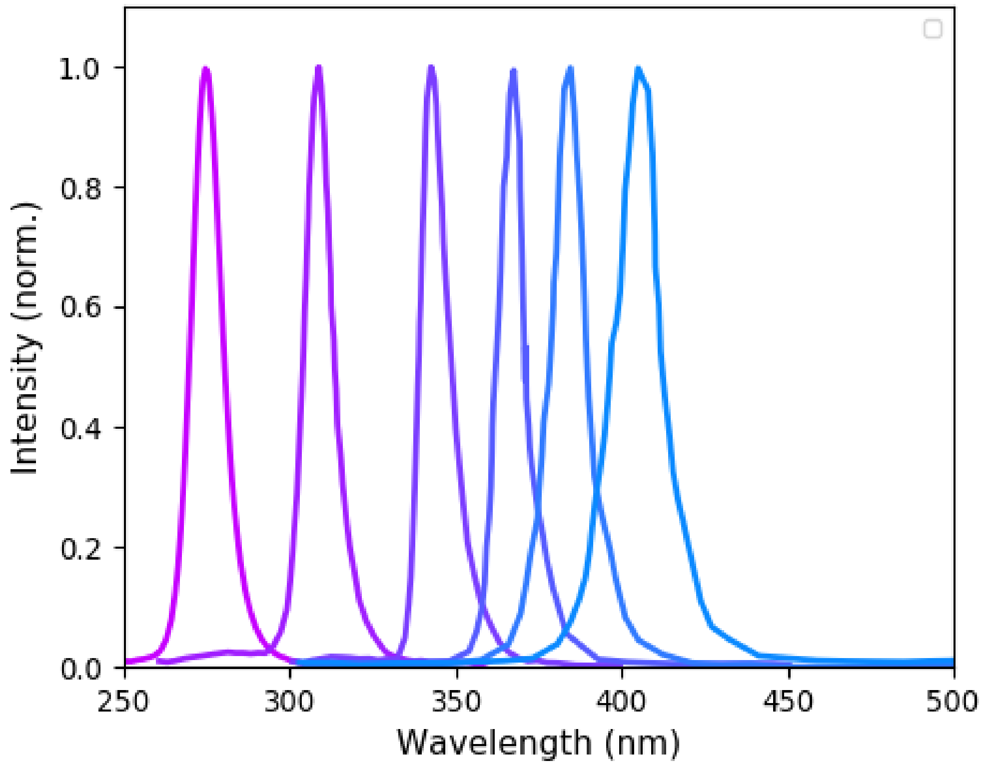
- Emitter orientation

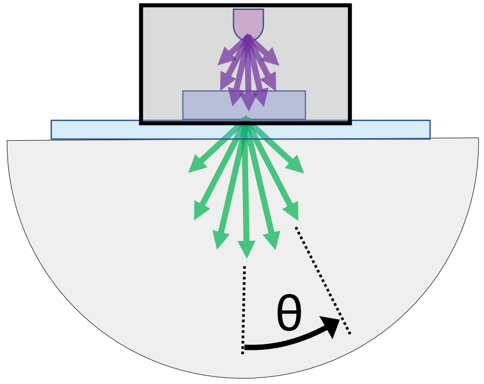
- Scattering/down-conversion film characterization
- OLED with QD characterization

Excitation sources

List of excitation sources

- 275 nm*
- 310 nm*
- 340 nm
- 365 nm
- 385 nm
- 405 nm
- others upon request

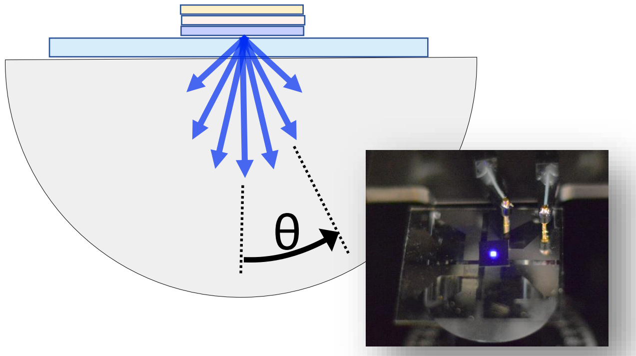




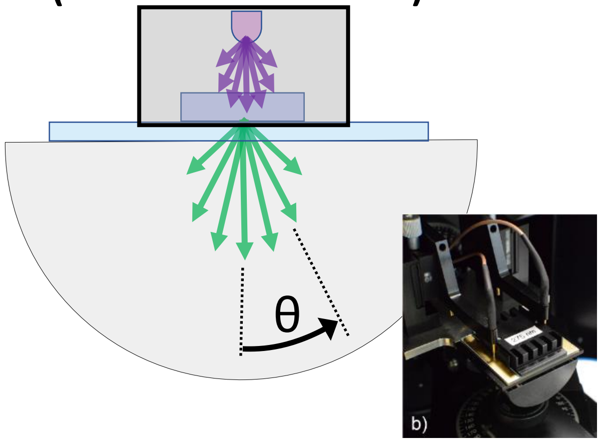
*requires quartz glass encapsulation

Phelos modes

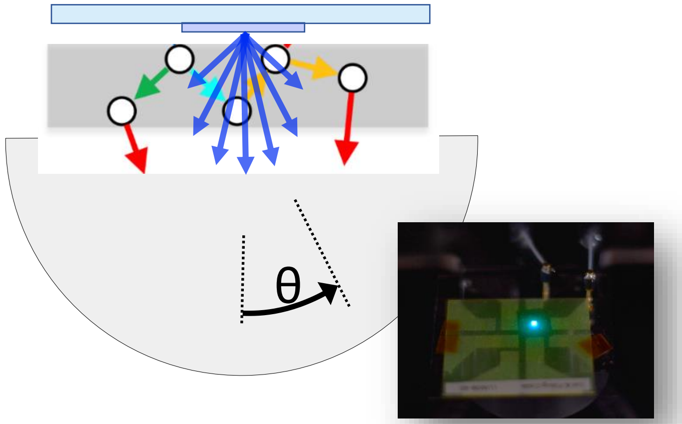
1) OLED (Electroluminescence)



2) Emitter film (Photoluminescence)



3) QD/scattering film

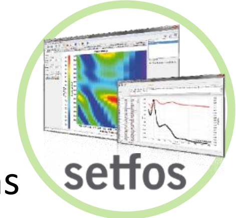


- Analysis of color
- Efficiency (EQE, lm/W, power eff.)
- Emission zone fit*
- Emitter orientation*

- Emitter orientation*

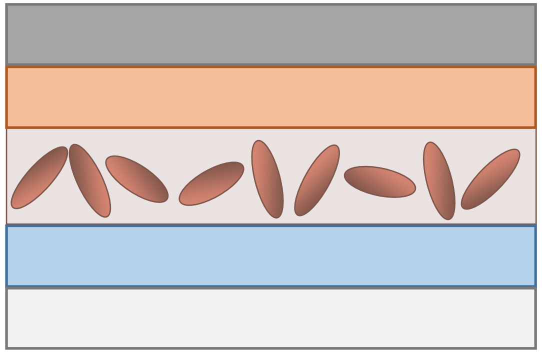
- Scattering/down-conversion film characterization
- OLED with QD characterization

*quantitative analysis requires optical simulations



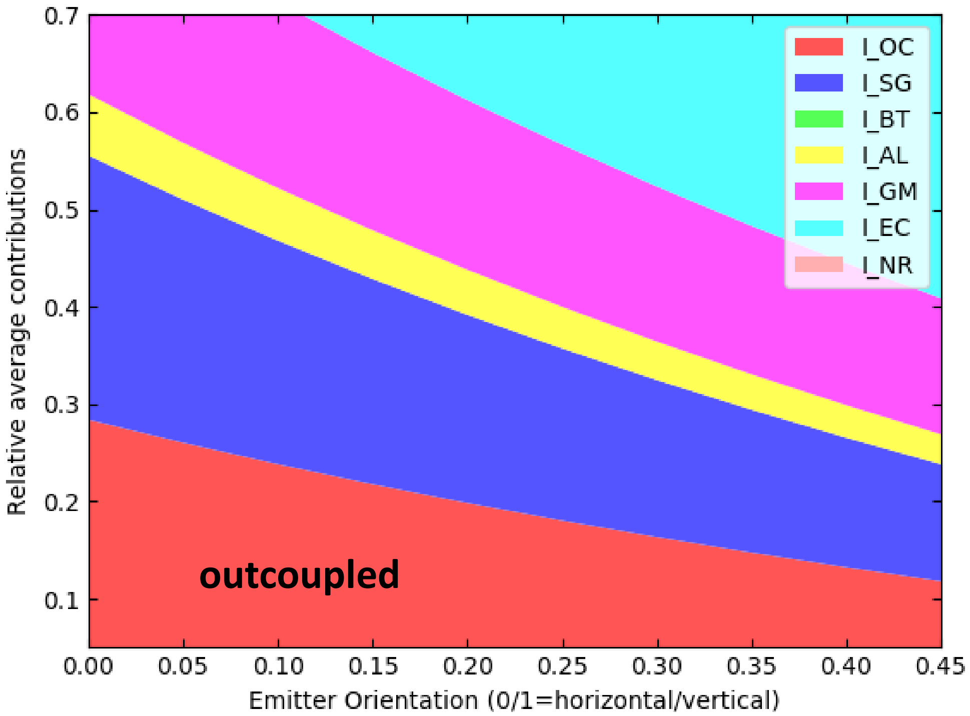
Emitter dipole orientation

Outcoupling efficiency is strongly influenced by the average emitter orientation

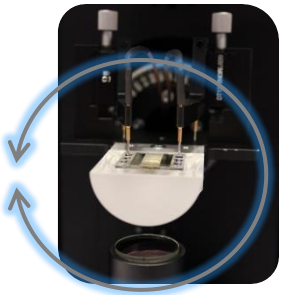


$$EQE = \gamma \cdot \eta_{s,t} \cdot q_{eff} \cdot \eta_{out}$$

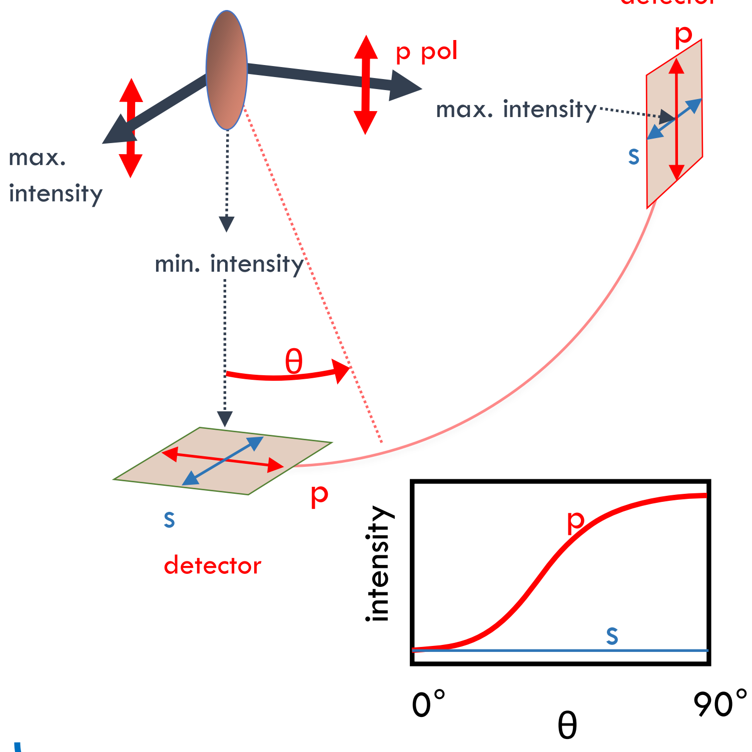
Horizontal alignment leads to higher EQE!



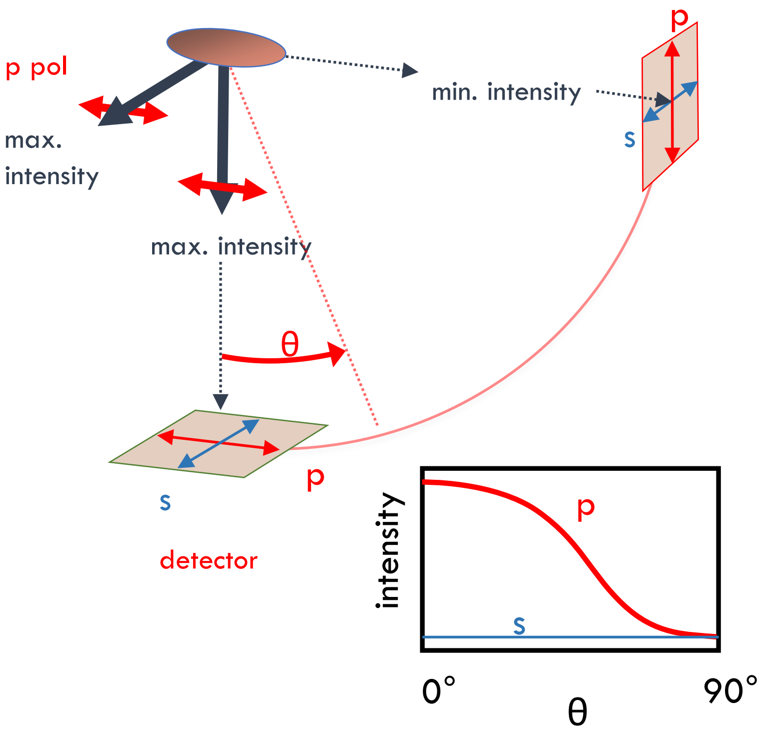
Emitter dipole orientation



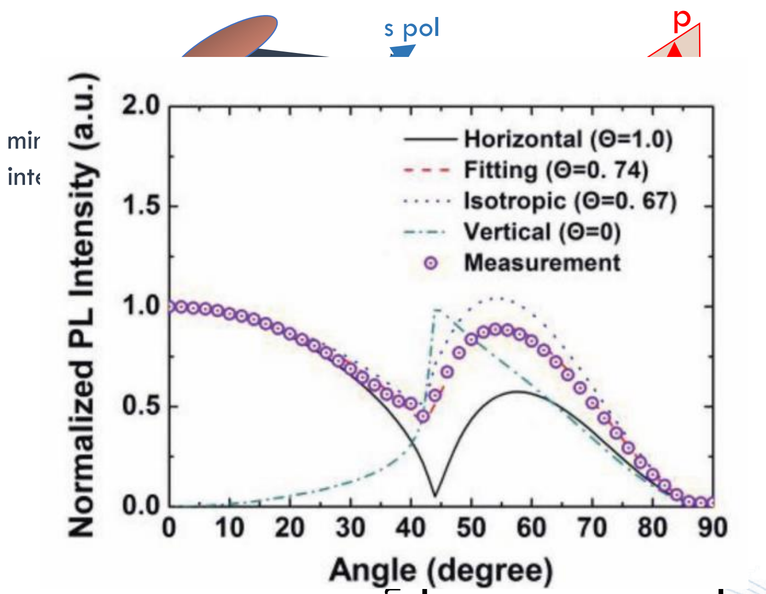
vertical dipole



horizontal dipole, x



horizontal dipole, y

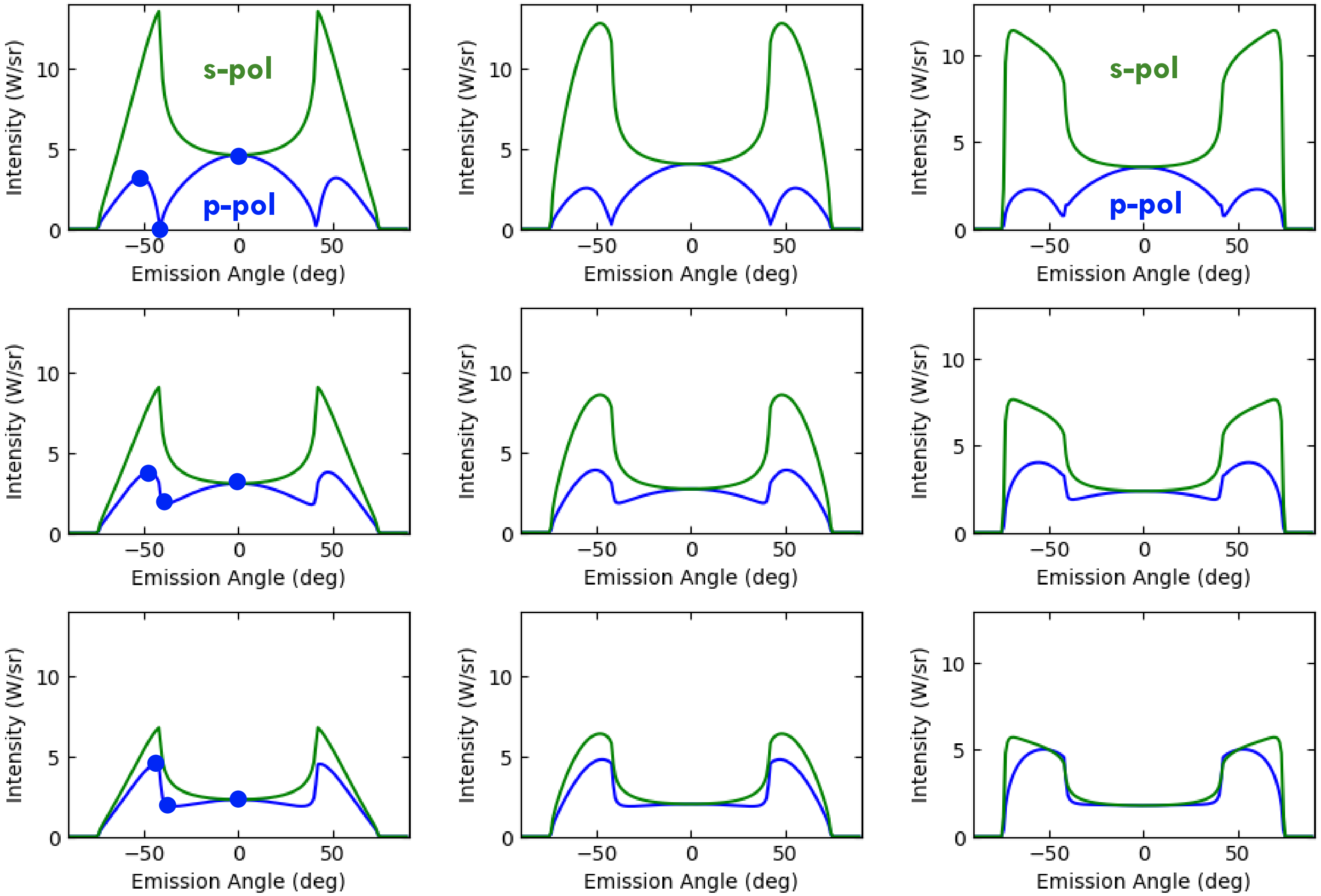


Kwon-Hyeon Kim and Jang-Joo Kim, Adv. Mater. **2018**, 1705600

-> **p**-polarized emission is sensitive to **emitter orientation**

Angular PL signal: a fingerprint of the dipole orientation

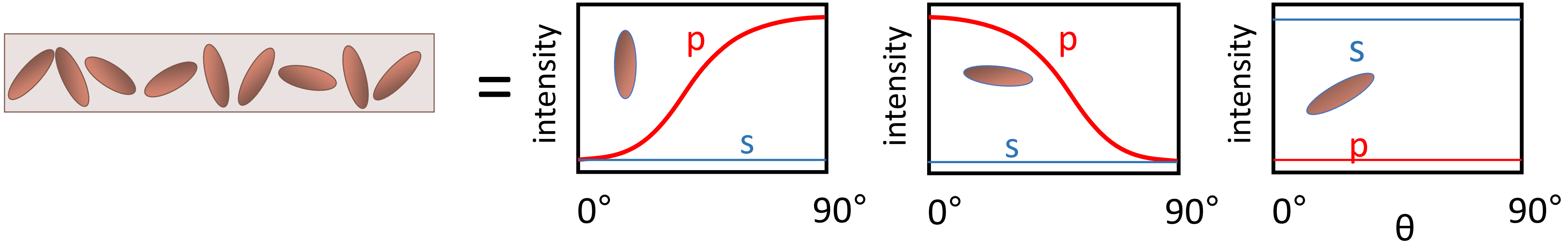
	10 nm *thin*	**50 nm**	**100 nm** *thick*
z = 0.0 *horizontal*			
z = 0.33 *isotropic*			
z = 0.5 *more vertical*			



Angular PL signal: a fingerprint of the dipole orientation

Real emitter film:

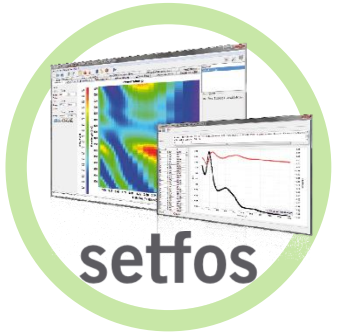
Superposition of statistically distributed dipoles



+ **Further effects:**

- back-reflection from org-air interface
- interference / cavity effects
- refraction / birefringence

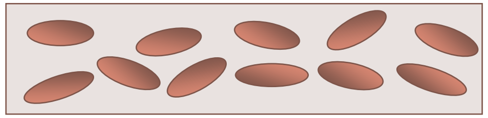
→ accurate description requires full optical modeling



Emitter orientation in host-guest system: example

real case study

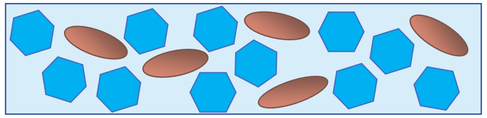
pure emitter film



- horizontal alignment shown using ***VASE*** (variable angle spectroscopic ellipsometry)

- order parameter estimated from optical constants / birefringence

emitter (9%) : host



- ellipsometry results reflect optical properties of emitter-host blend

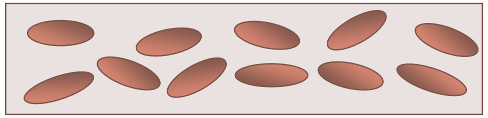
→ no information about emitter dipole orientation inside host matrix

- ***angular PL*** probes emitter orientation directly, independent of host matrix

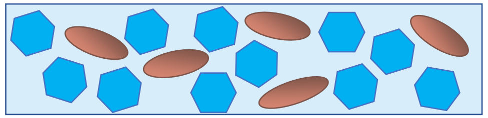
Emitter orientation in host-guest system: example

real case study

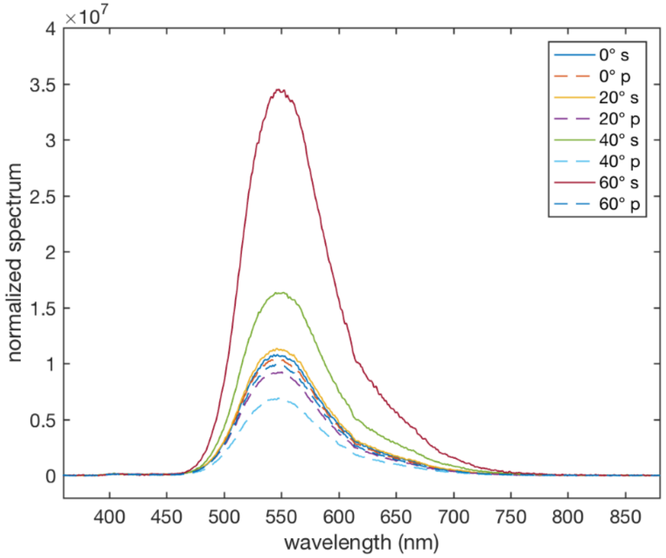
pure emitter film

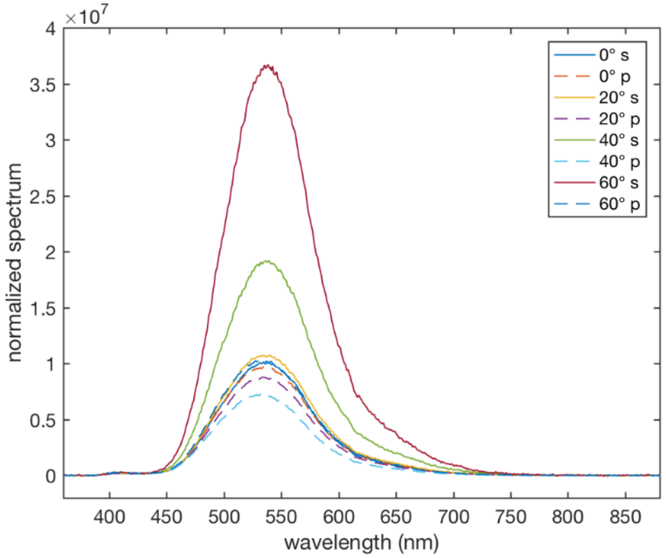


emitter (9%) : host



Angular PL, spectral:

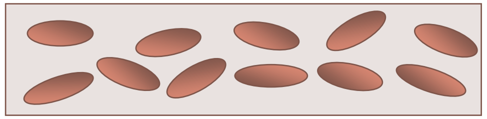




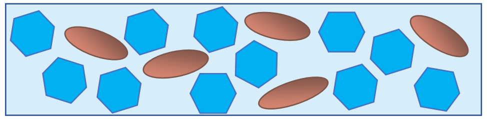
Emitter orientation in host-guest system: example

real case study

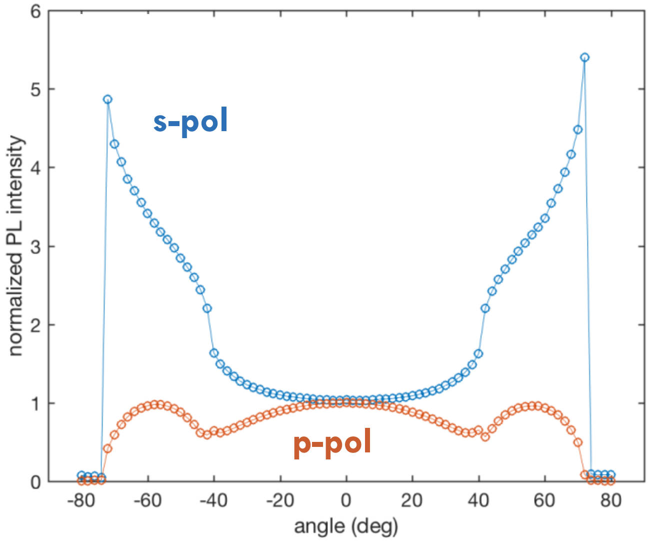
pure emitter film

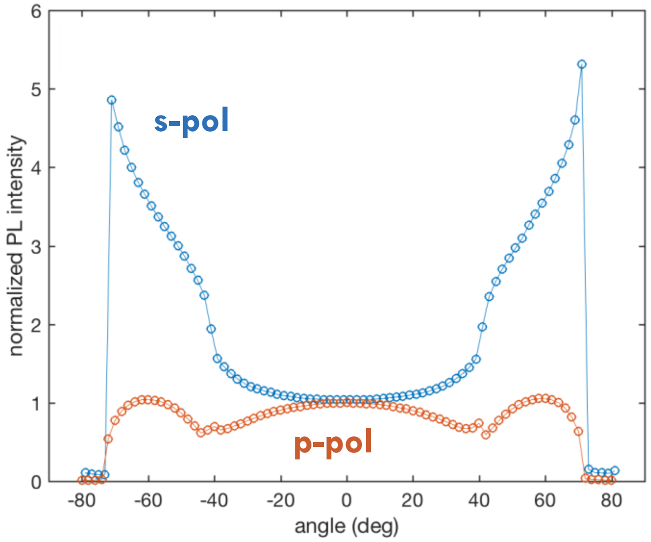


emitter (9%) : host



Angular PL, integrated:

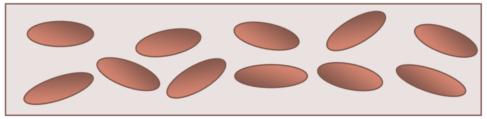




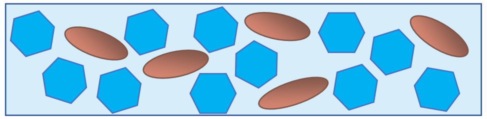
Emitter orientation in host-guest system: example

real case study

pure emitter film



emitter (9%) : host



Dipole orientation from model fit

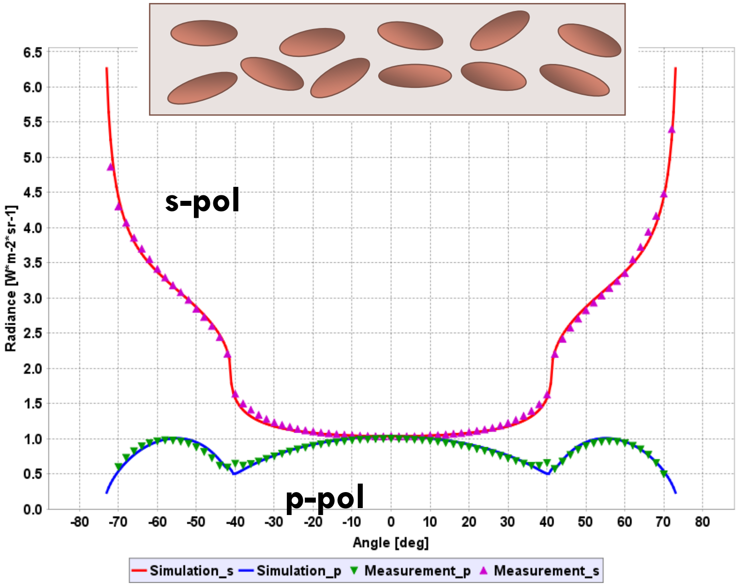
parameters:

- optical constants / birefringence of emitter layer and substrate — ellipsometry or fitting parameter
- film thickness — AFM, crystal-monitor, ellipsometry, fitting parameter
- emitter intensity — scalar fitting parameter
- emitter orientation — **fitting parameter of interest**
- emission zone — e.g. exponential decay (UV absorption)

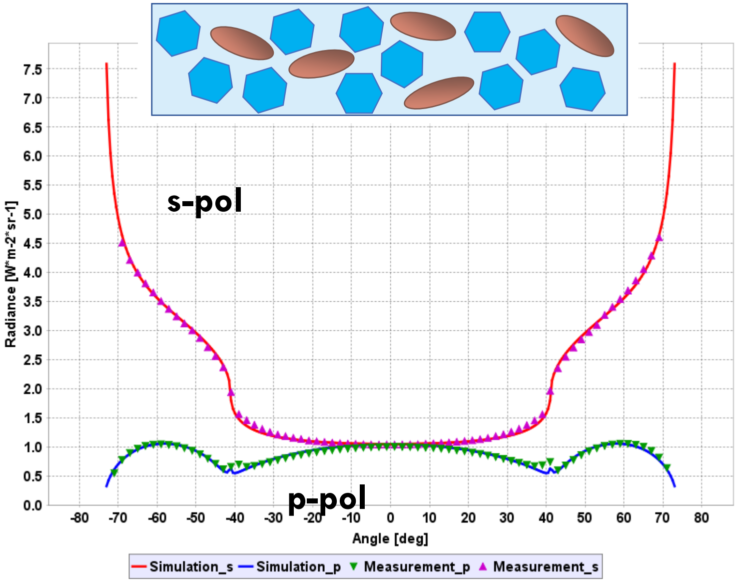
Emitter orientation in host-guest system: example

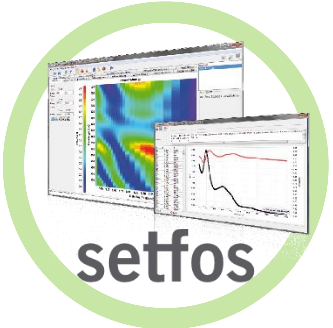
real case study

pure emitter film



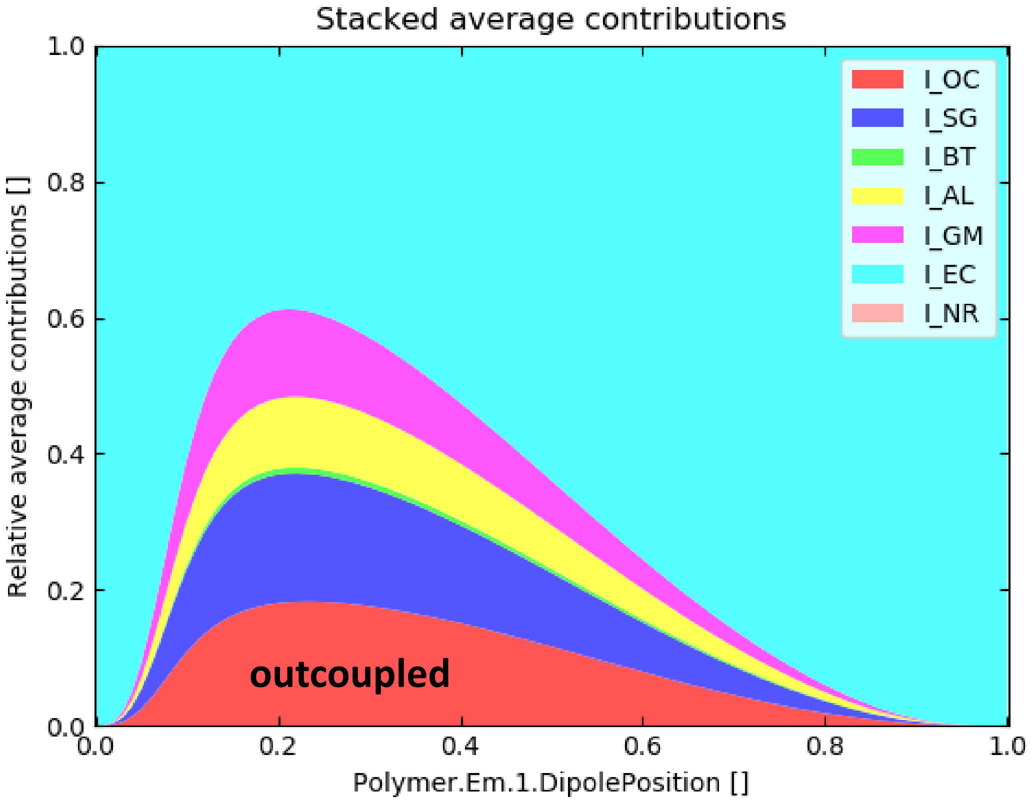
emitter (9%) : host



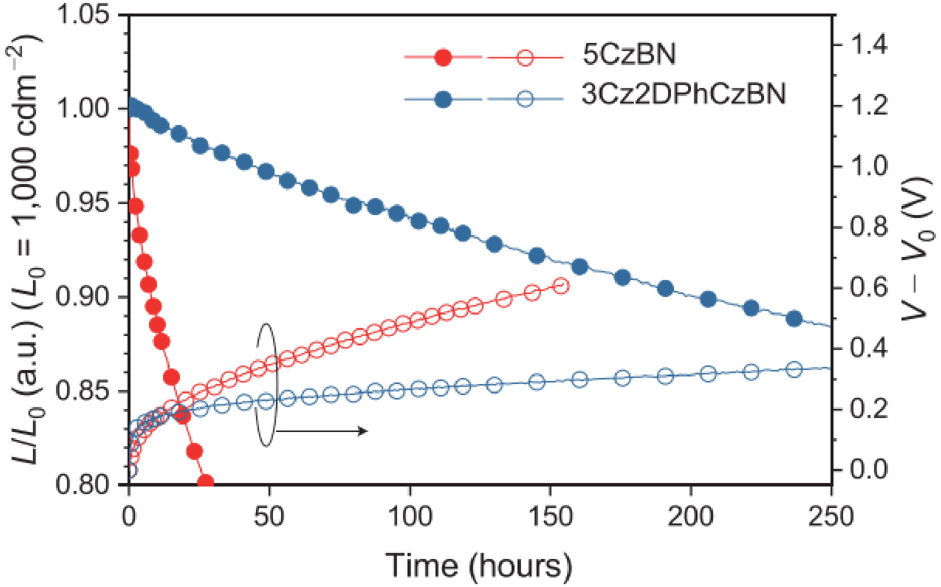


	Pure emitter	Emitter:host blend
nominal thickness (ellipsometry)	53 nm	56 nm
thickness angular PL	53 nm	58 nm
dipole orientation (% vertical)	**19.4 %**	**18.6 %**

Emitter distribution

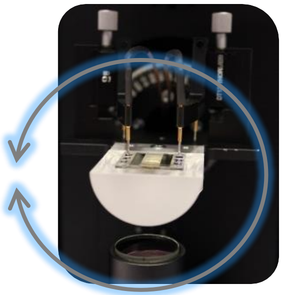


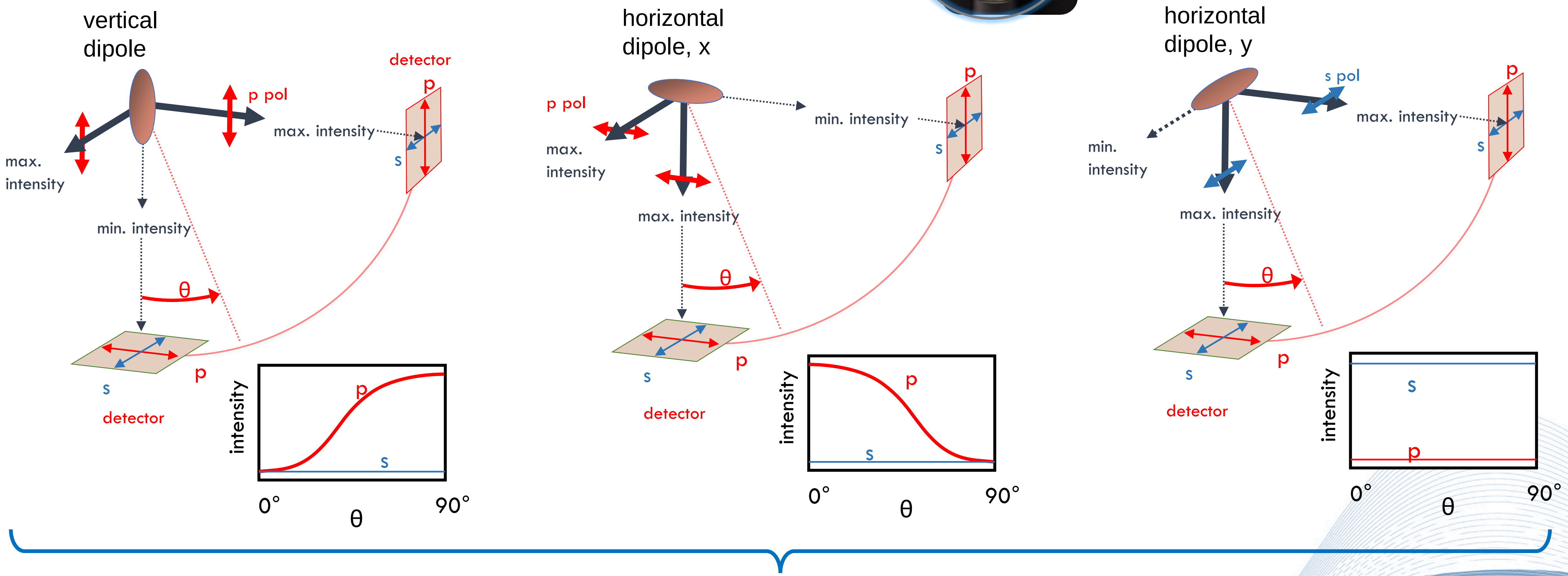
- The emitter distribution influences the outcoupling efficiency
- Analyzing the emission zone is necessary to understand degradation



M. Tanaka et al., Adv. Electron. Mater. **2019**, 1800708

Emitter position determination

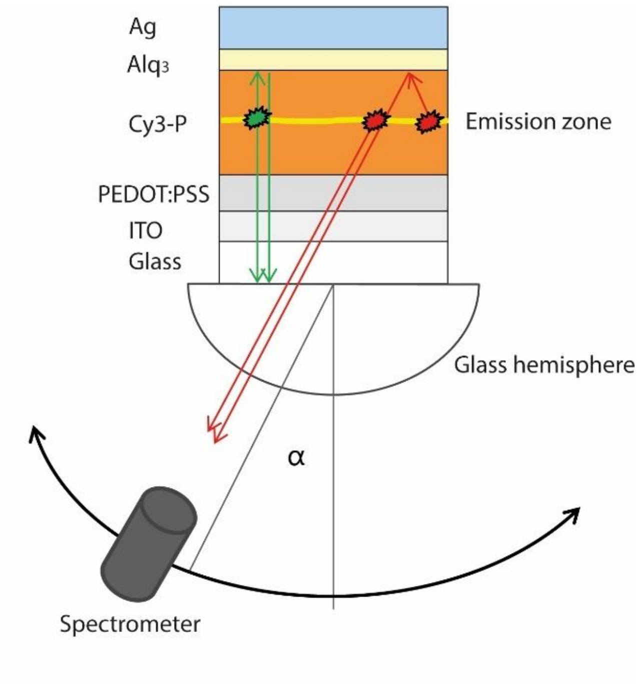




Angle-dependent **s**-polarized emission is independent from the dipole orientation
-> determination of **emitter distribution**

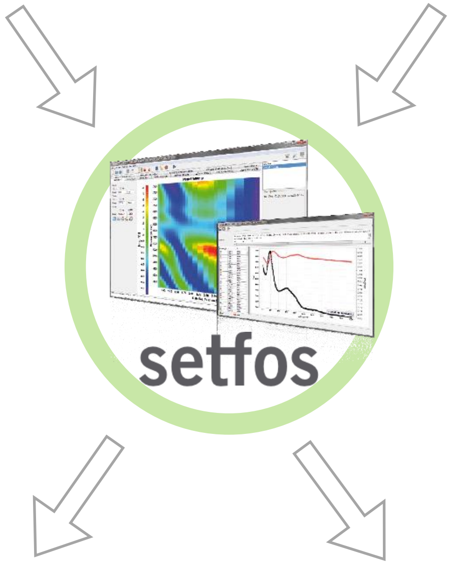
Emitter distribution

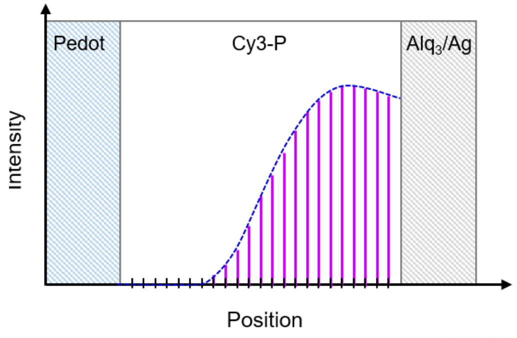
- Compare experimental and simulated spectral emission automatically -> emission zone fitting[1]
- Use angle dependent data to increase the sensitivity[1]



Structure, nk data, emitter spectrum

s- (and p-)pol EL emission spectra

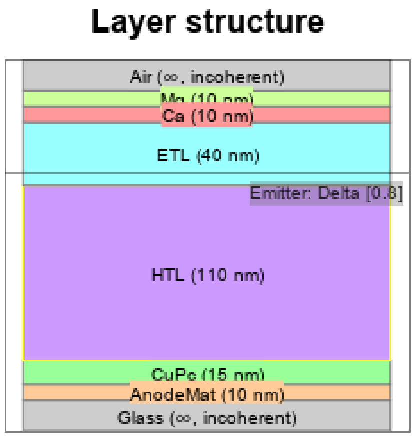


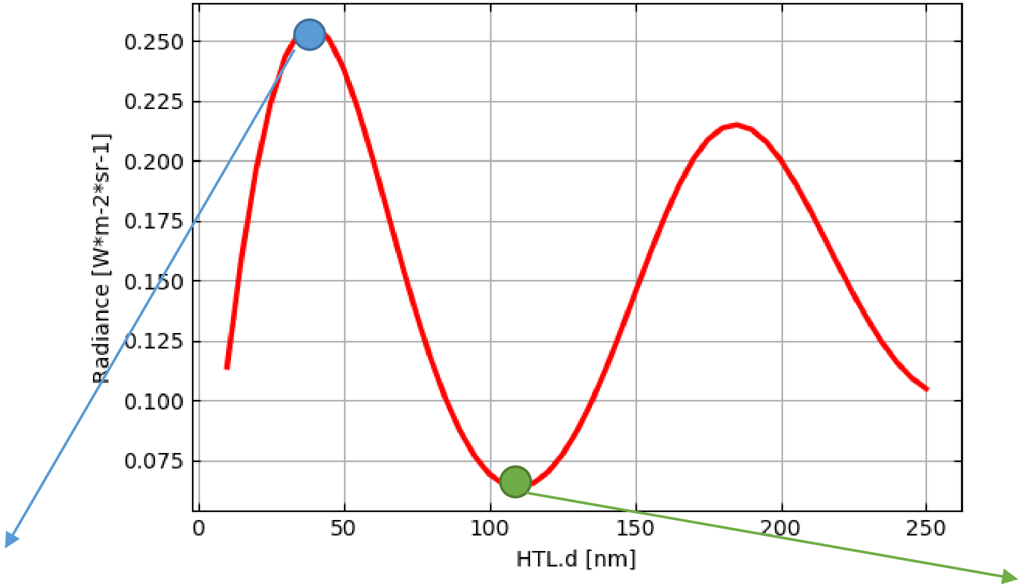


emitter spectrum

[1]B. Perucco et al., Optics Express **2010**, 18 (S2), A246

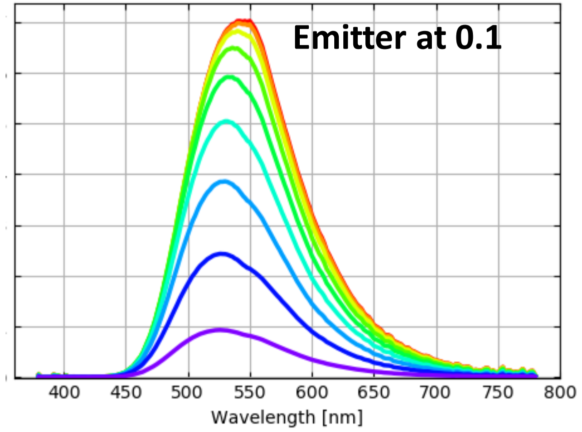
Emitter distribution

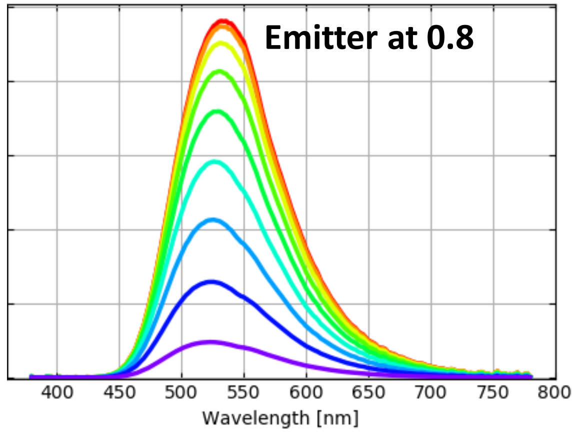


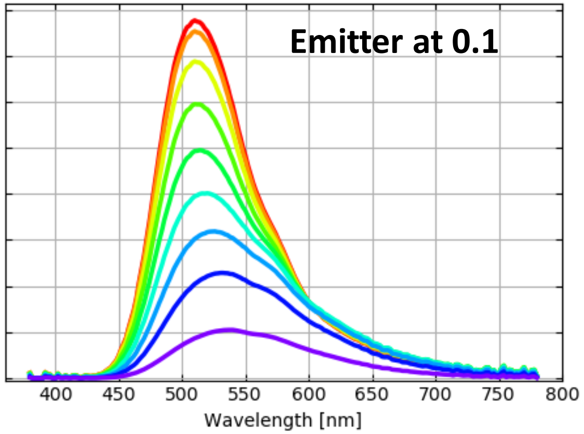


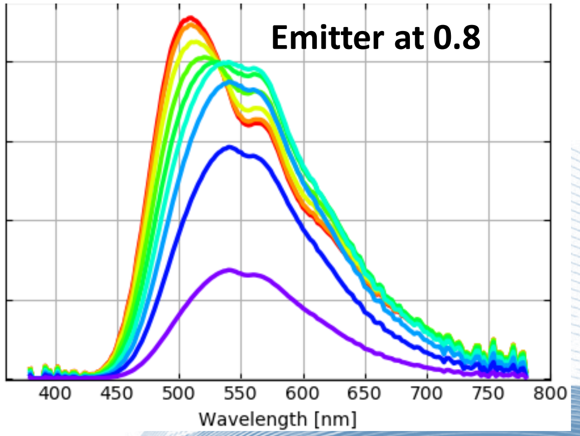
Tuned OLED does not show different spectral emission for different emitter positions

Detuned OLEDs are more suitable for emission zone determination





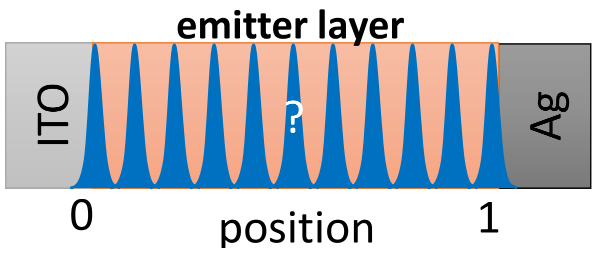


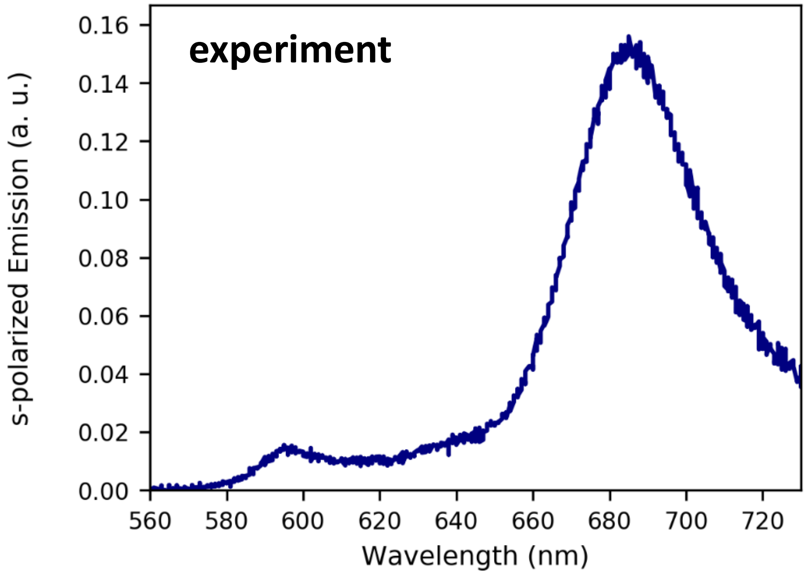


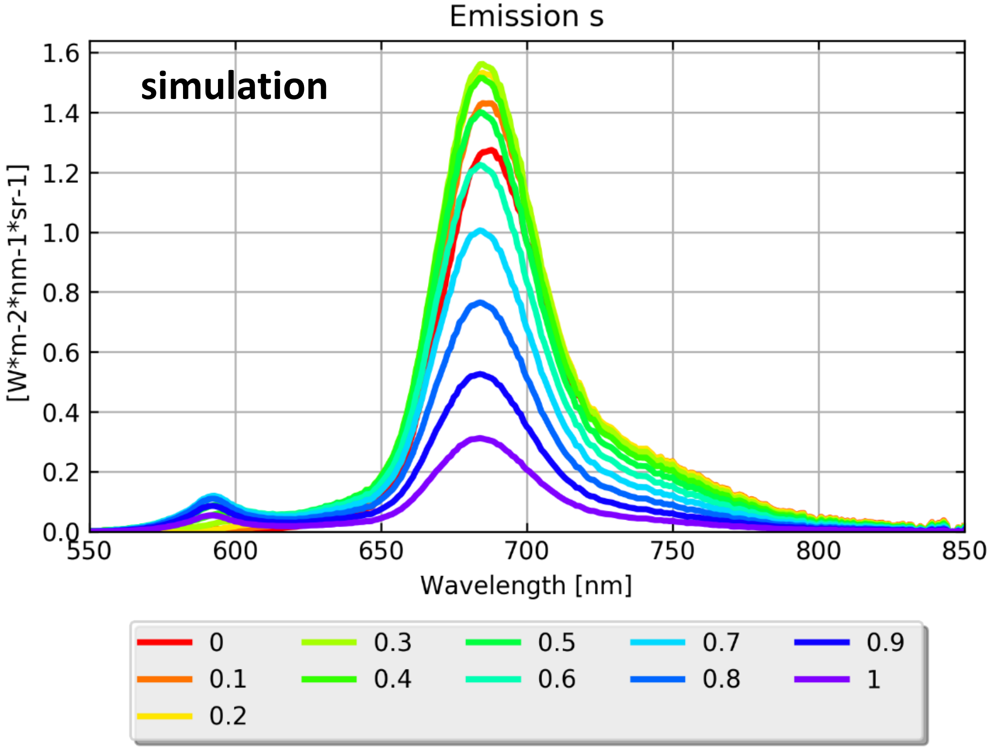
Emission zone determination: example 1

real case study

- Compare experimental and simulated spectral emission
- Use peak ratio to determine position **-> 0.67**

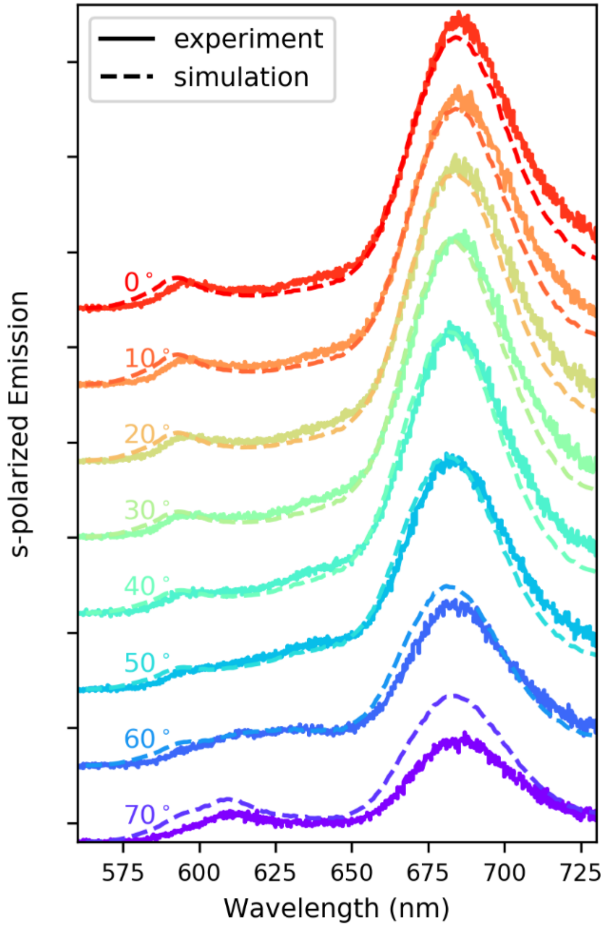




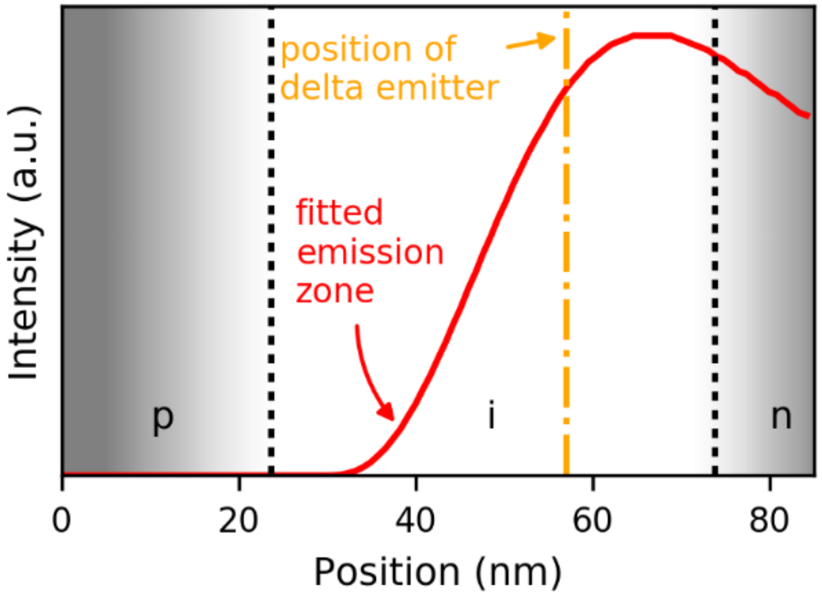


B. Perucco et al., Optics Express **2010**, 18 (S2), A246
S. Jenatsch et al., ACS Photonics, **2018**, 5 (4), 1591–1598

Emission zone determination: example 1



Use full angle dependence to determine the **emitter distribution** inside EML (red line)

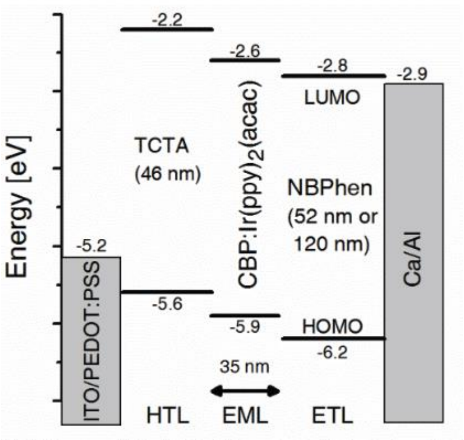


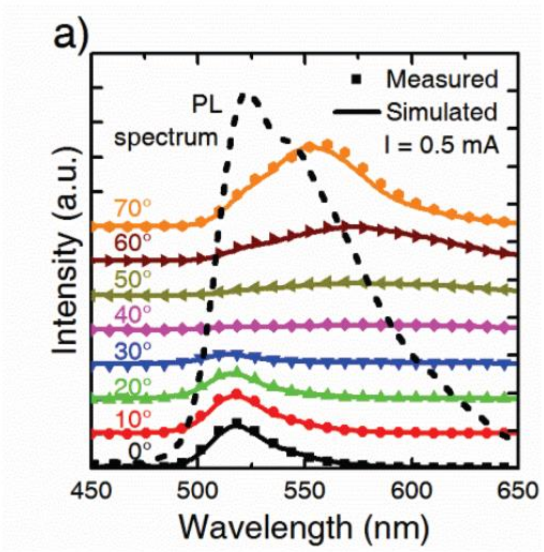
real case study

S. Jenatsch et al., ACS Photonics, **2018**, 5 (4), 1591–1598

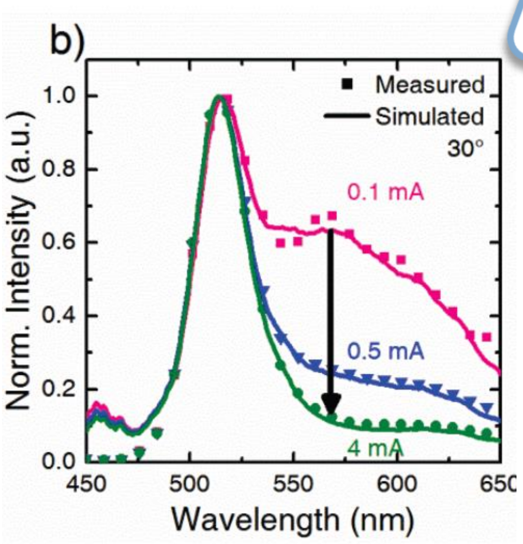
Emission zone determination: example 2

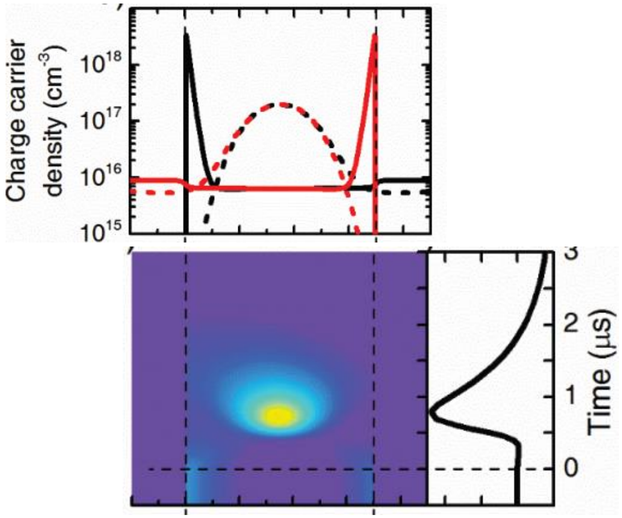
real case study

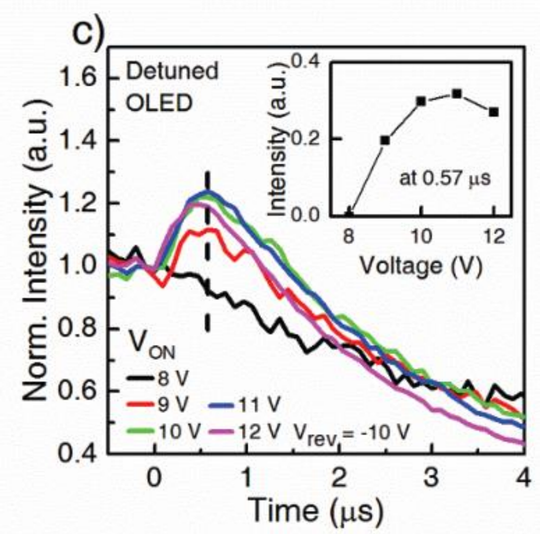




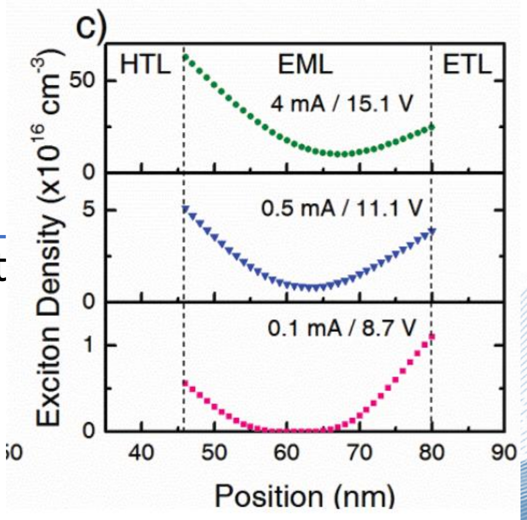
Bias dependent emission zone







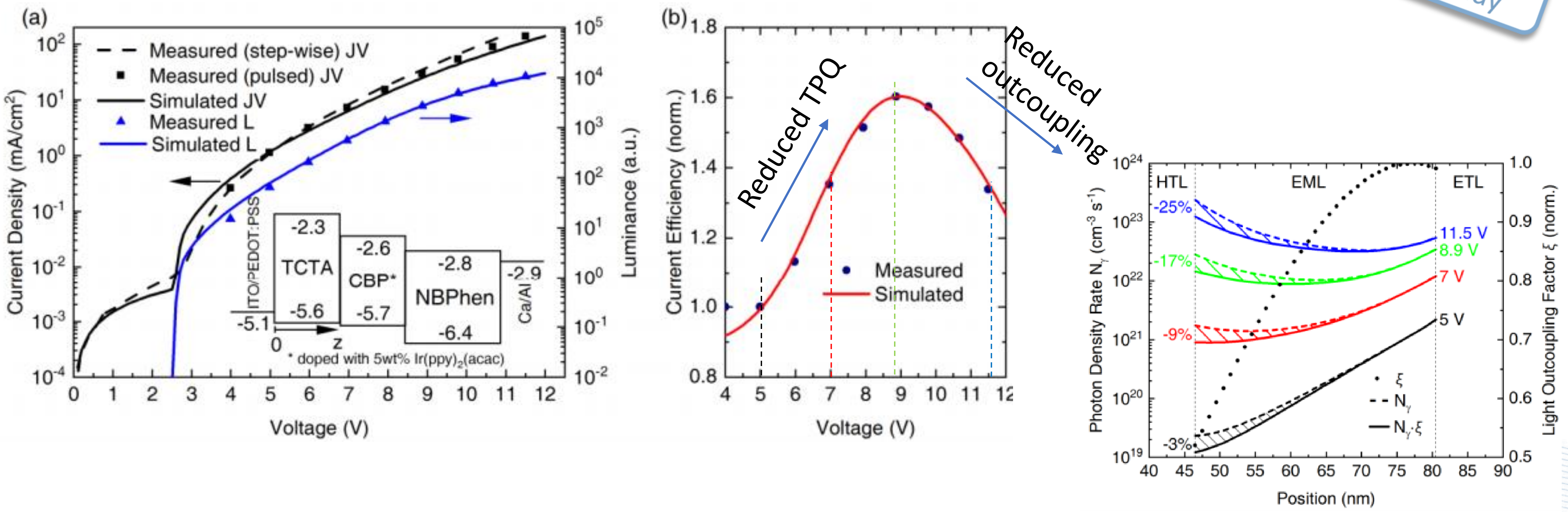
Split emission zone shows TEL overshoot



M. Regnat et al., ACS Appl. Mater. Interfaces, **2018**, 10 (37), 31552-31559

Emission zone determination: example 2

real case study

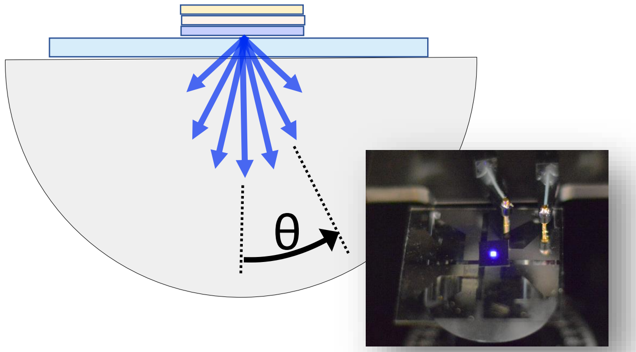


- Reduced outcoupling due to shift of the emission zone results in CE reduction
- Increased TTA contributes to the CE decrease
- Reduced TPQ due to emission zone shifts explains the CE rise

M. Regnat et al., Organic Electronics, **2018**, 70, 219–226

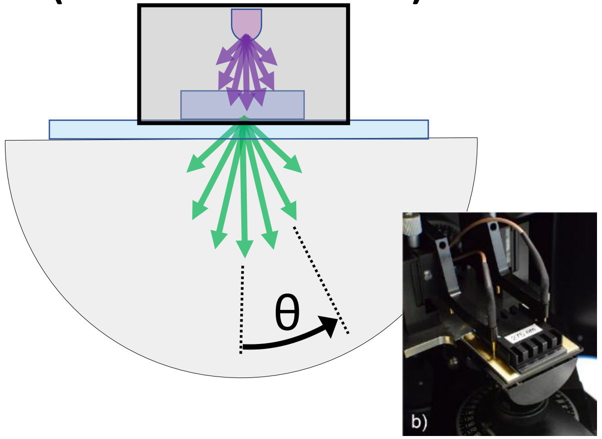
Phelos modes

1) **OLED (Electroluminescence)**



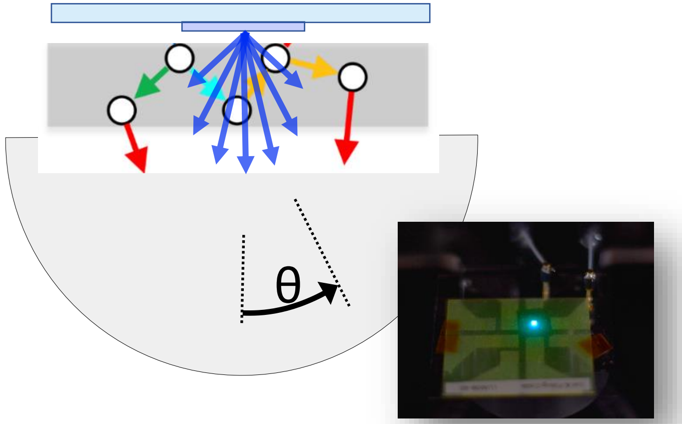
- Analysis of color
- Efficiency (EQE, lm/W, power eff.)
- Emission zone fit
- Emitter orientation

2) **Emitter film (Photoluminescence)**



- Emitter orientation

3) **QD/scattering film**

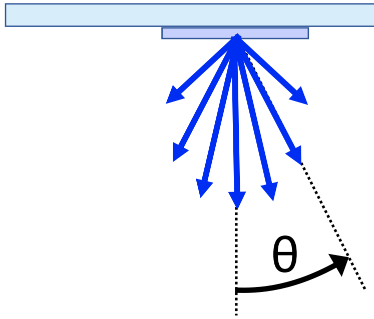


- Scattering/down-conversion film characterization
- OLED with QD characterization

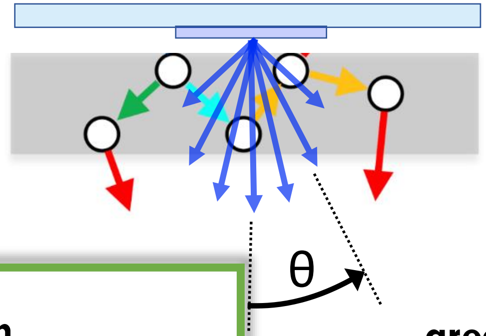
Angular Characterization of QD films

real case study

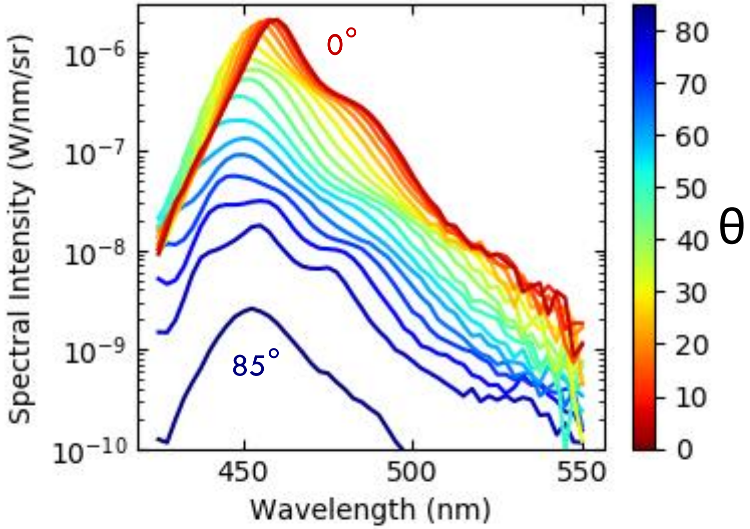
blue TE OLED



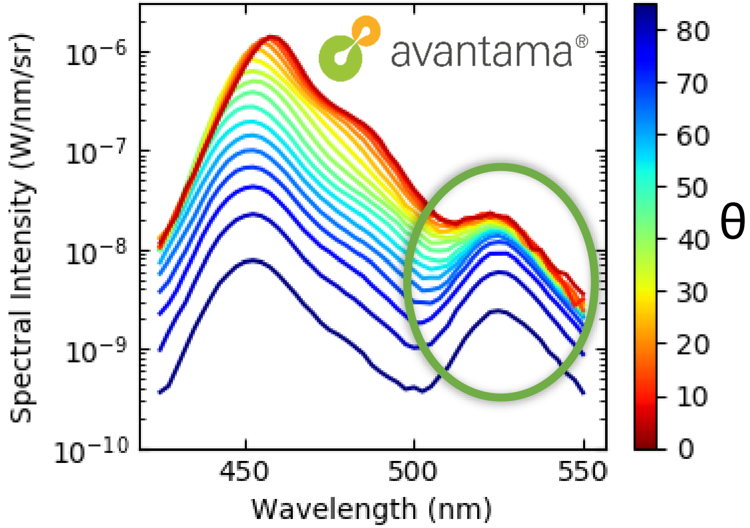
blue OLED + QD film



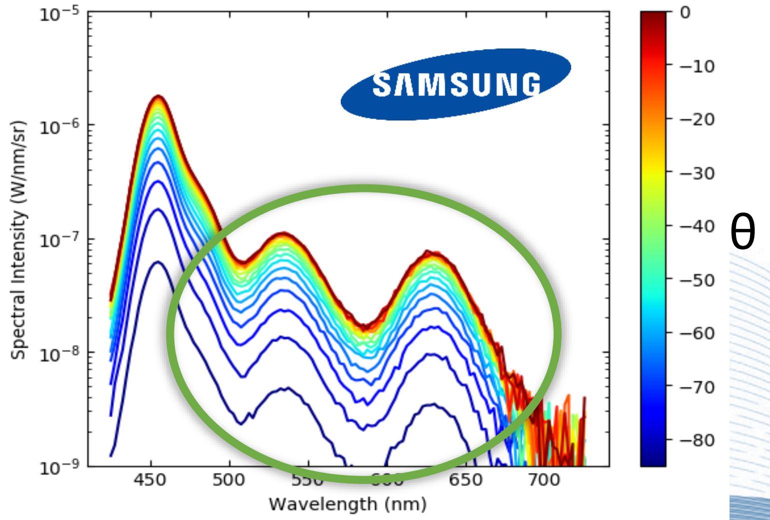
blue OLED



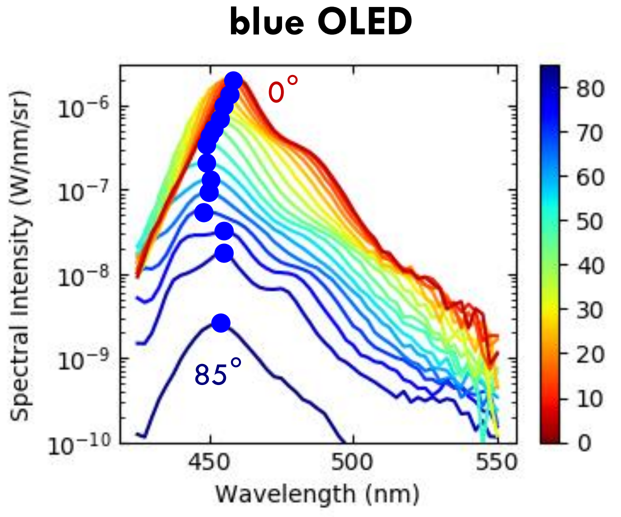
green QD conversion film from Avantama, Switzerland

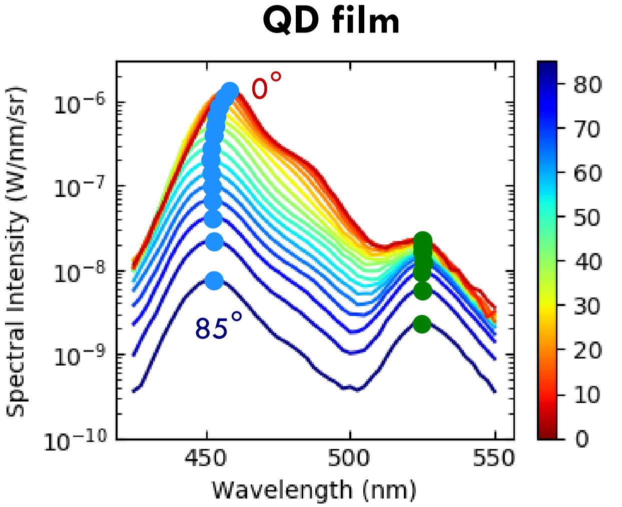


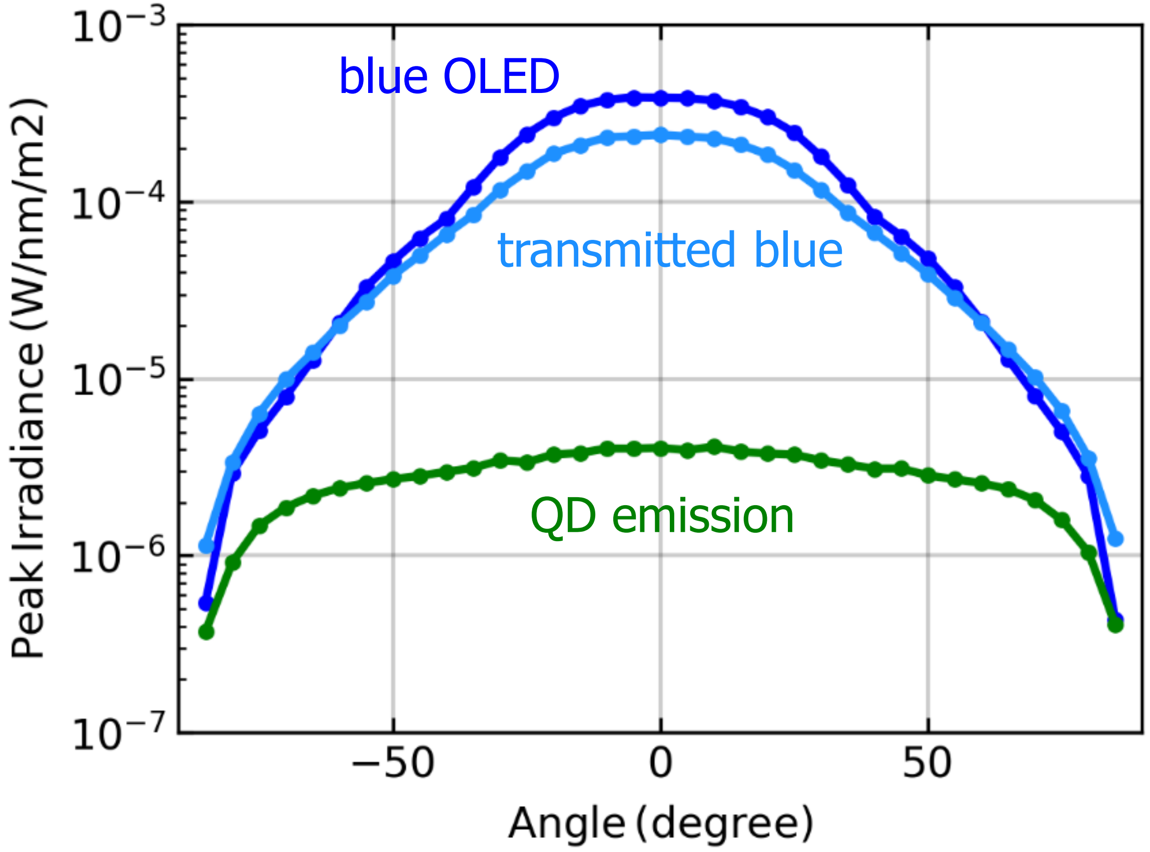
green+red QD conversion film from Samsung QD TV



Green emitting perovskite down conversion film

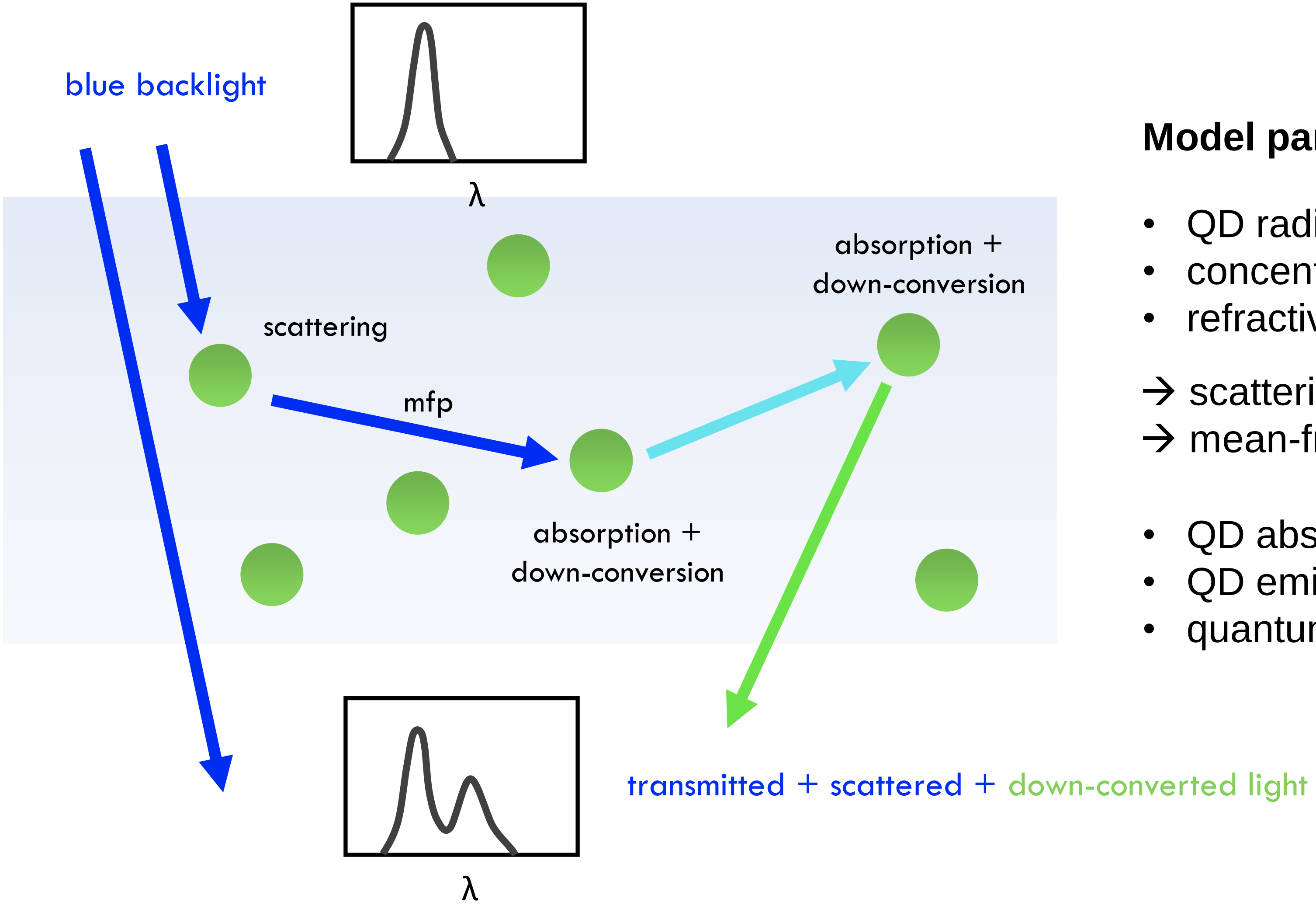






real case study

Modeling the QD downconversion: Setfos 4.6



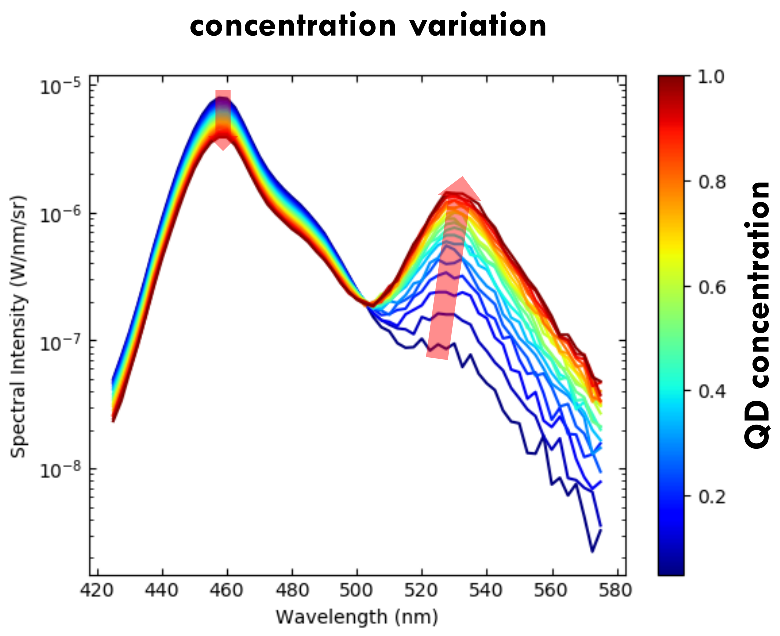
Model parameters:

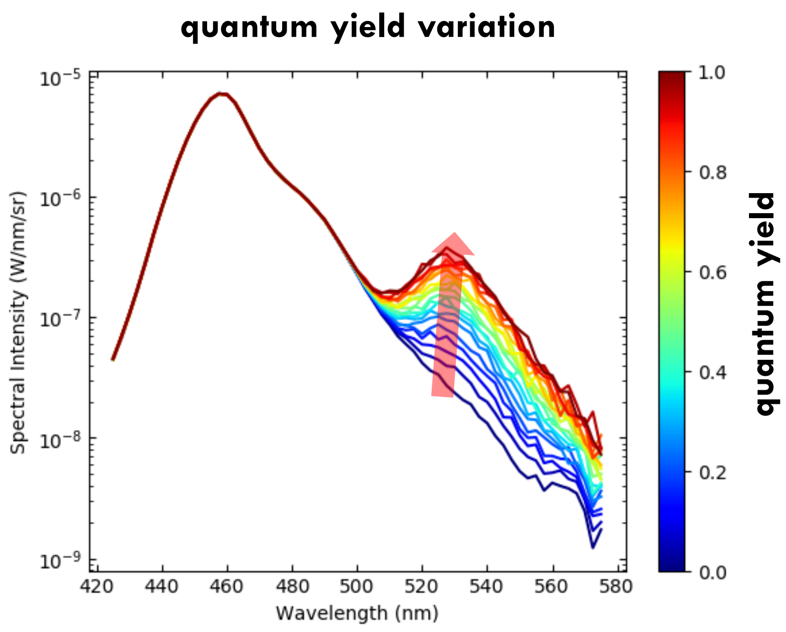
- QD radius
- concentration
- refractive index

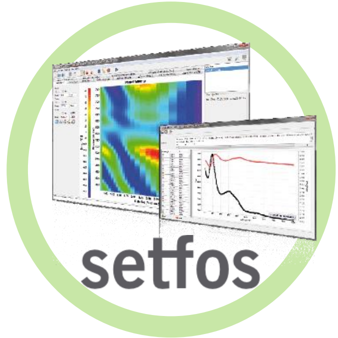
→ scattering cross section
→ mean-free-path

- QD absorption spectrum
- QD emission spectrum
- quantum yield

QD downconversion simulation: examples



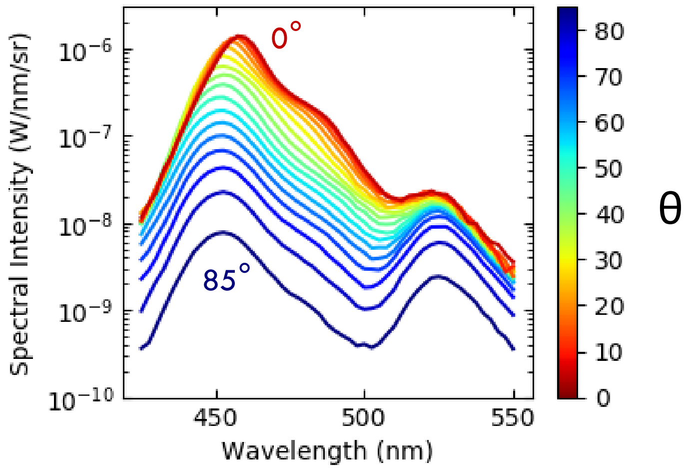


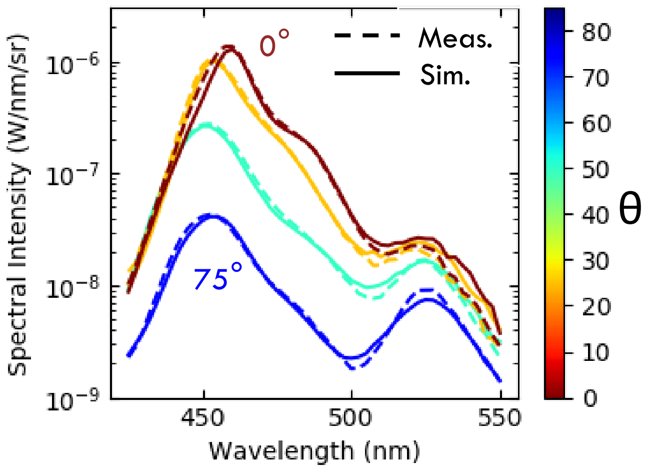


Fitting results

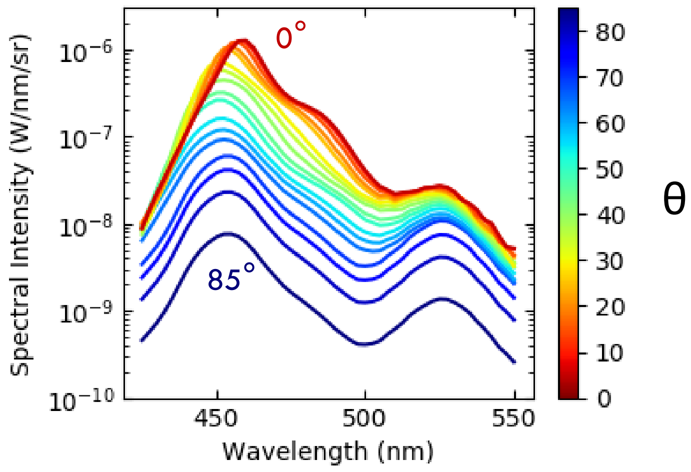
real case study

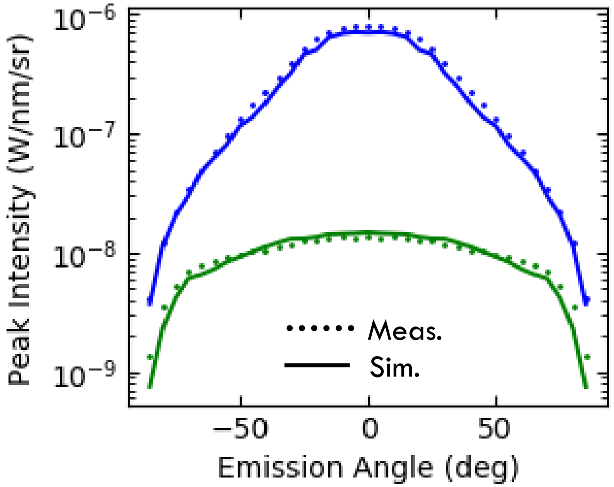
Measurement





Simulation





Model parameters:

- Mean-free path:
  $mfp = 0.02 \times mfp_{solution}(\lambda)$
  ⇔ concentration: 0.6 wt%
- Quantum yield:
  QY = 99%
- QD absorption probability
  α = 6% @450nm
  → 94% of the blue light is scattered
  α < 1% @525nm
  → green light not re-absorbed