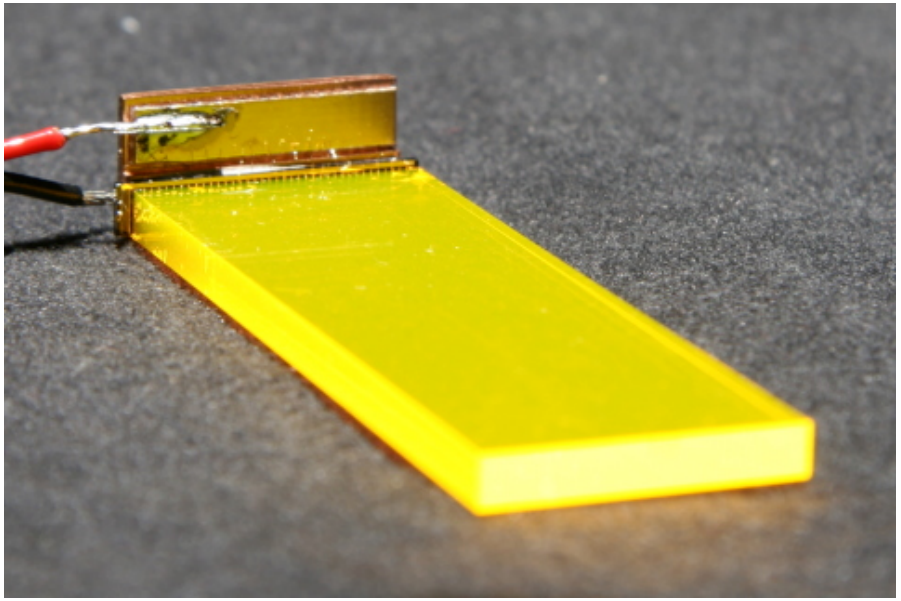
ulm university universität uulm

Simulation of Fluorescent Concentrators

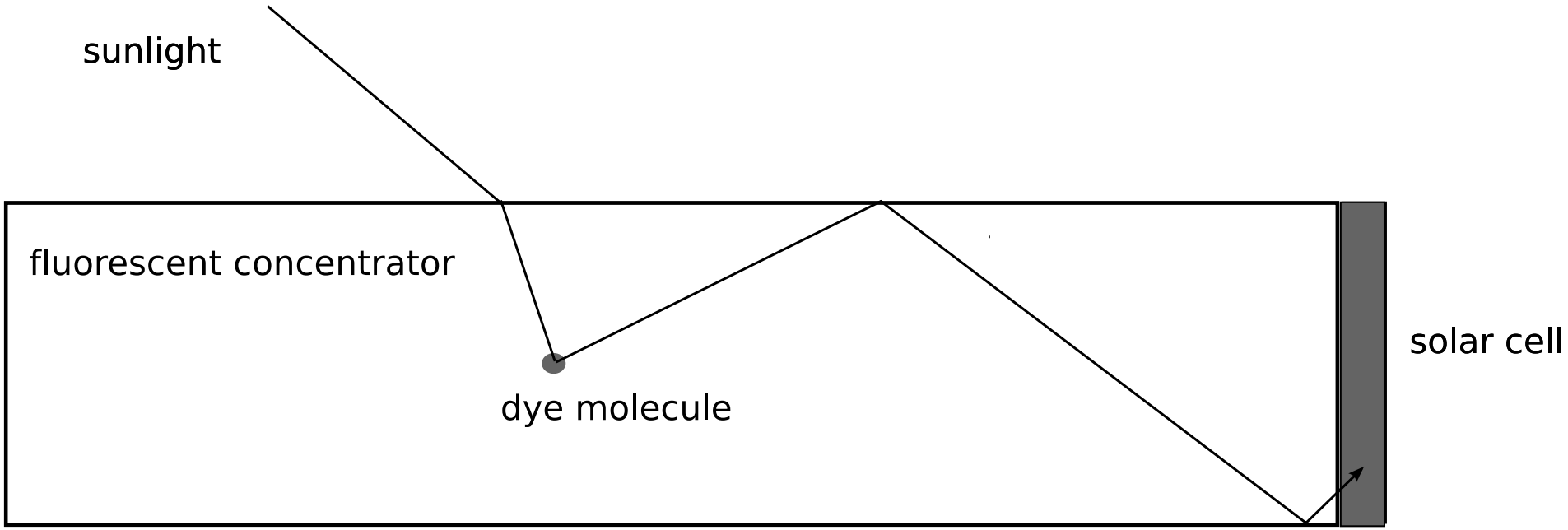
M. Bendig, J. Hanika, H. Dammertz, J. C. Goldschmidt, M. Peters, and M. Weber | August 10, 2008

Solar Energy Research

- cooperation with the Fraunhofer Institute for Solar Energy Systems in Freiburg
- raise efficiency – by concentration of light
- problem: diffuse light
- idea (around 1970): trap light inside medium
- low efficiency $\longrightarrow$ low research interest
- interest increased again in the last years due to improved dyes, solar cells and concepts

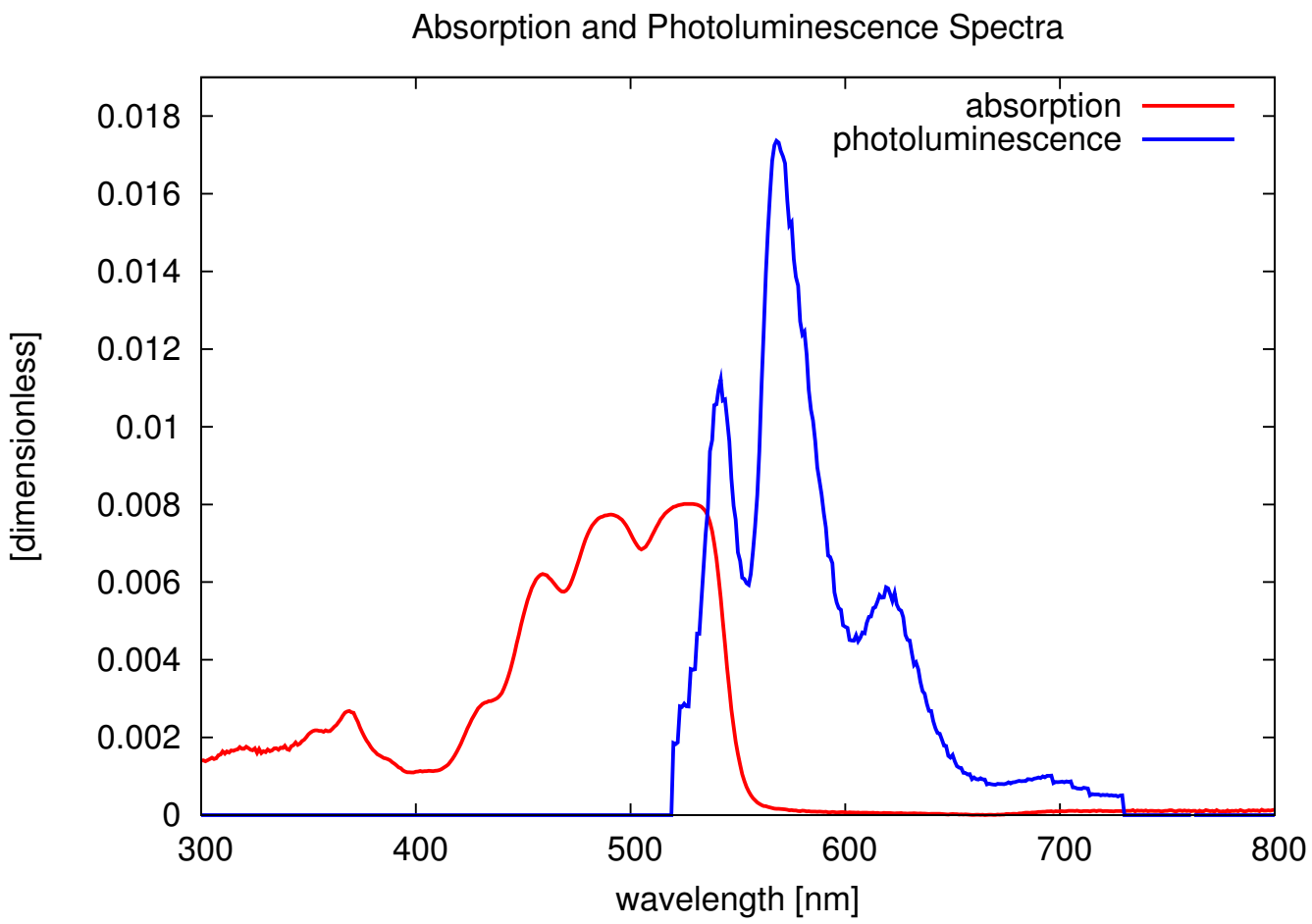


What is a Fluorescent Concentrator?



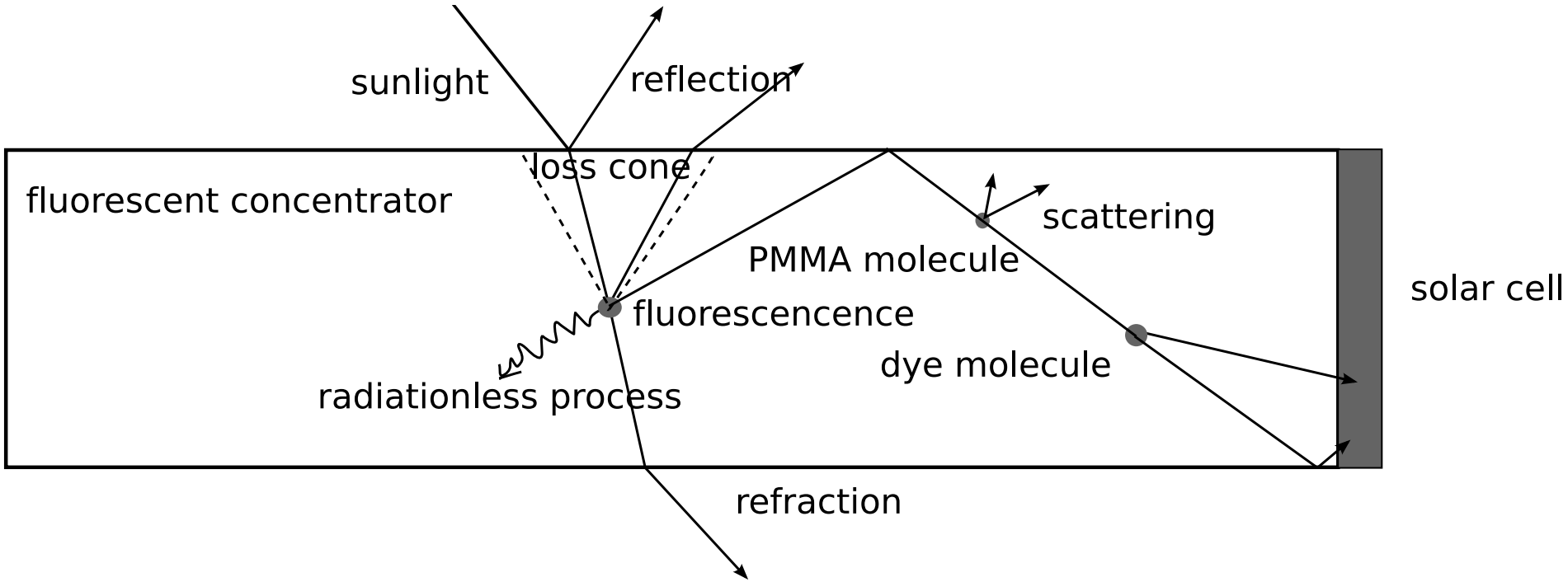
- PMMA (acrylic glass) and fluorescent dye
- concentrates direct and diffuse light on a solar cell
- principle:
  - absorption in dye
  - re-emmitance according to Stokes shift (longer wavelength)
  - total internal reflection (trap light inside medium)

Absorption and Photoluminescence Spectra



- re-absorption only possible in overlap

Energy Loss Mechanisms



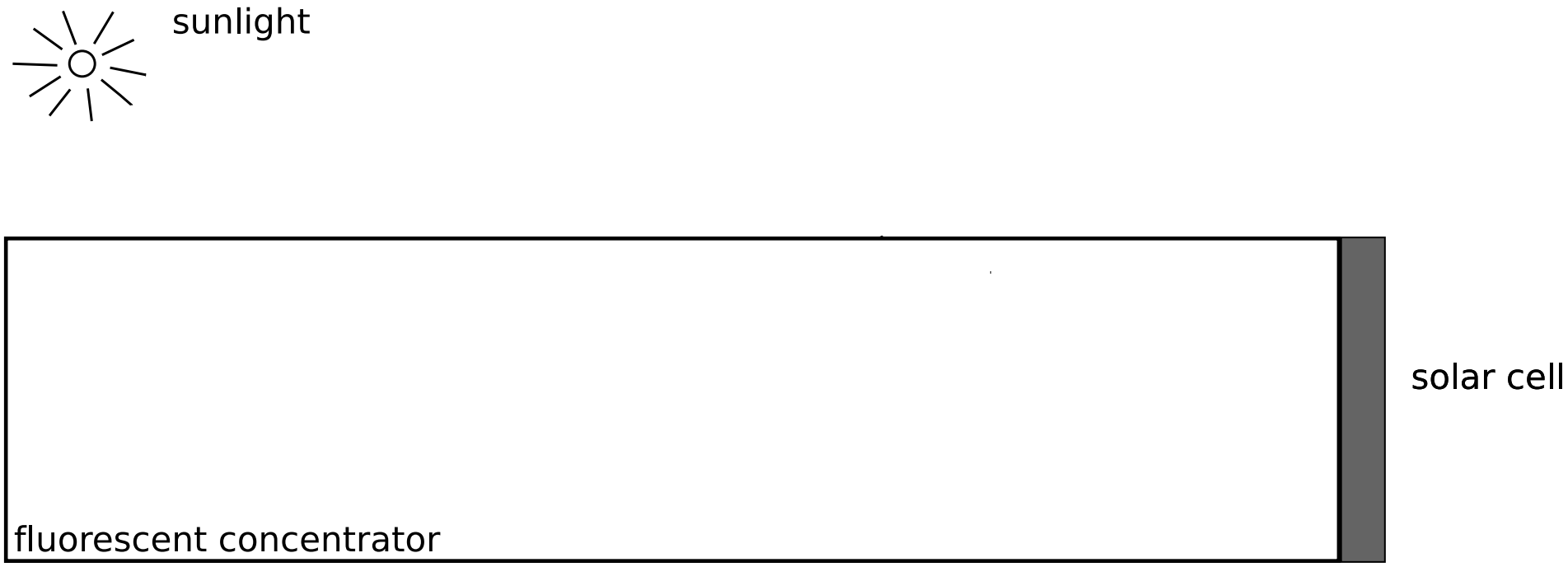
- loss mechanisms have to be analysed for improvement
- experimental testing of new concepts and analysis of physical processes difficult and expensive
- analytical calculations and simulation complex and time-consuming

Simulation Model

⇒ Monte Carlo (MC) method

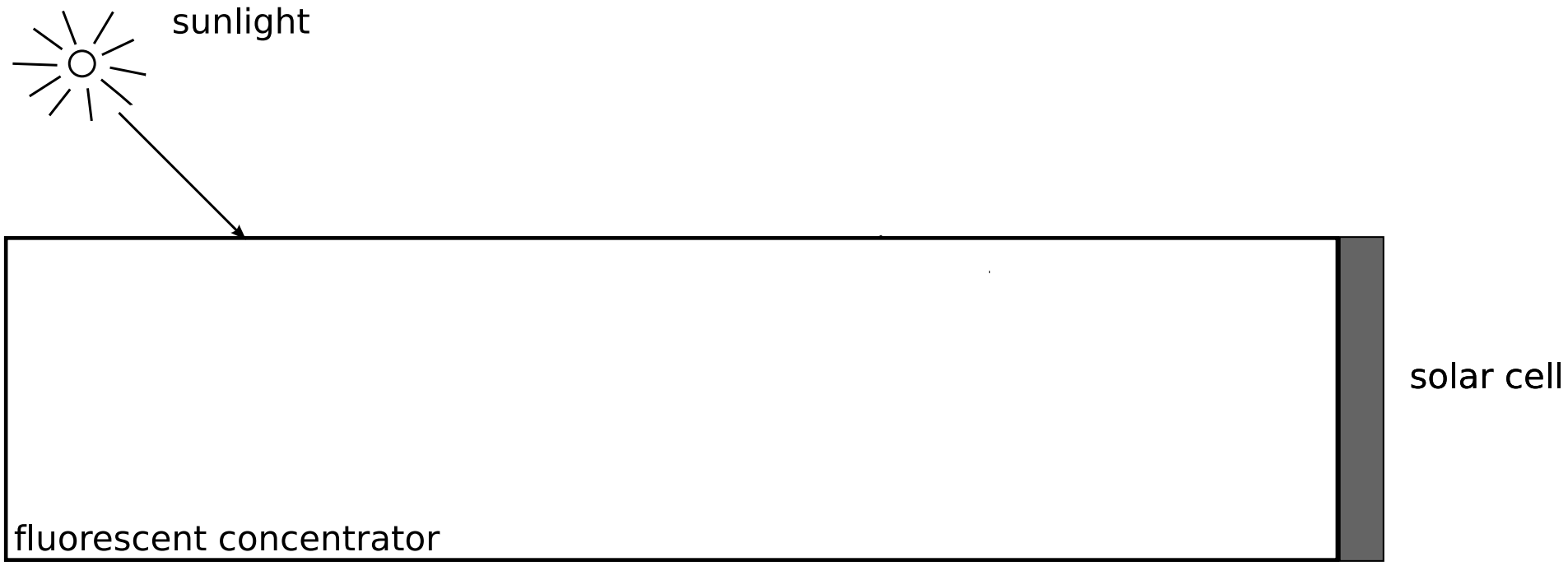
- ray tracing of single photons (simplest simulation model, least error-prone)
- uni-directional particle transport to avoid problems arising when connecting paths with different wavelengths
- allows to investigate effects isolated from global path

A Photon's Path trough the Concentrator



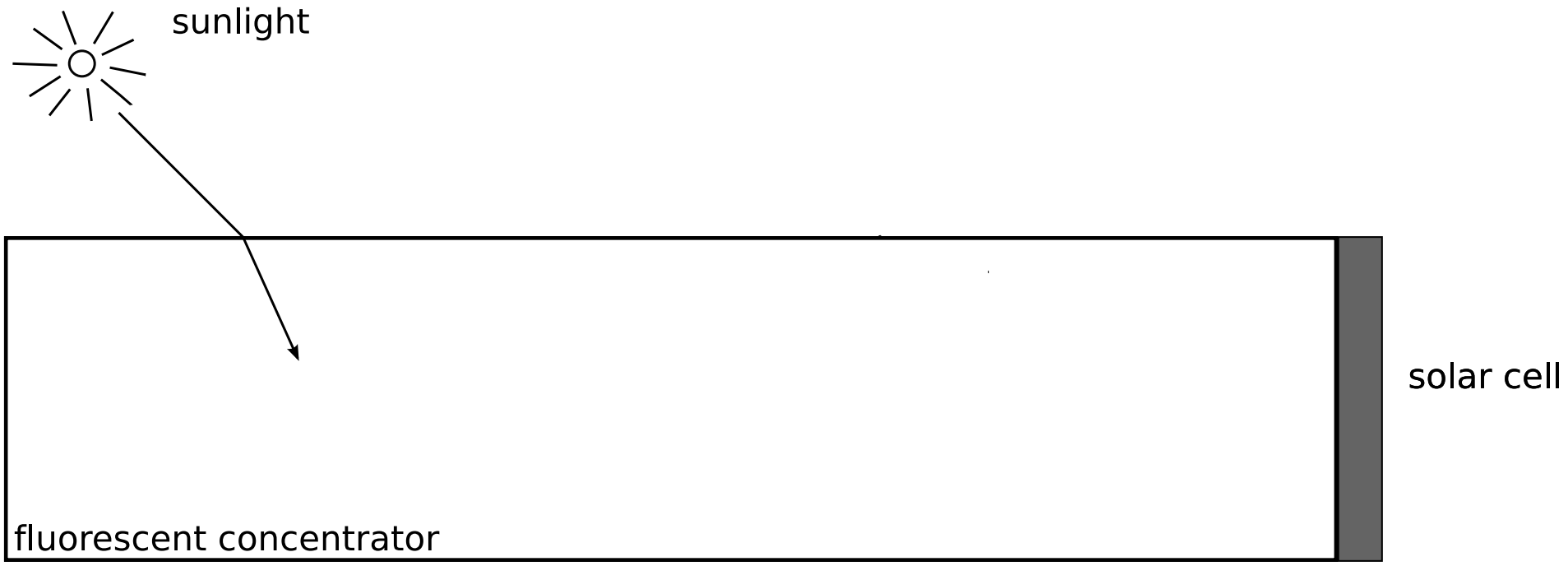
- sample spectrum AM 1.5 (*MC inversion method*)
- sample start point
- fix direction

A Photon's Path trough the Concentrator



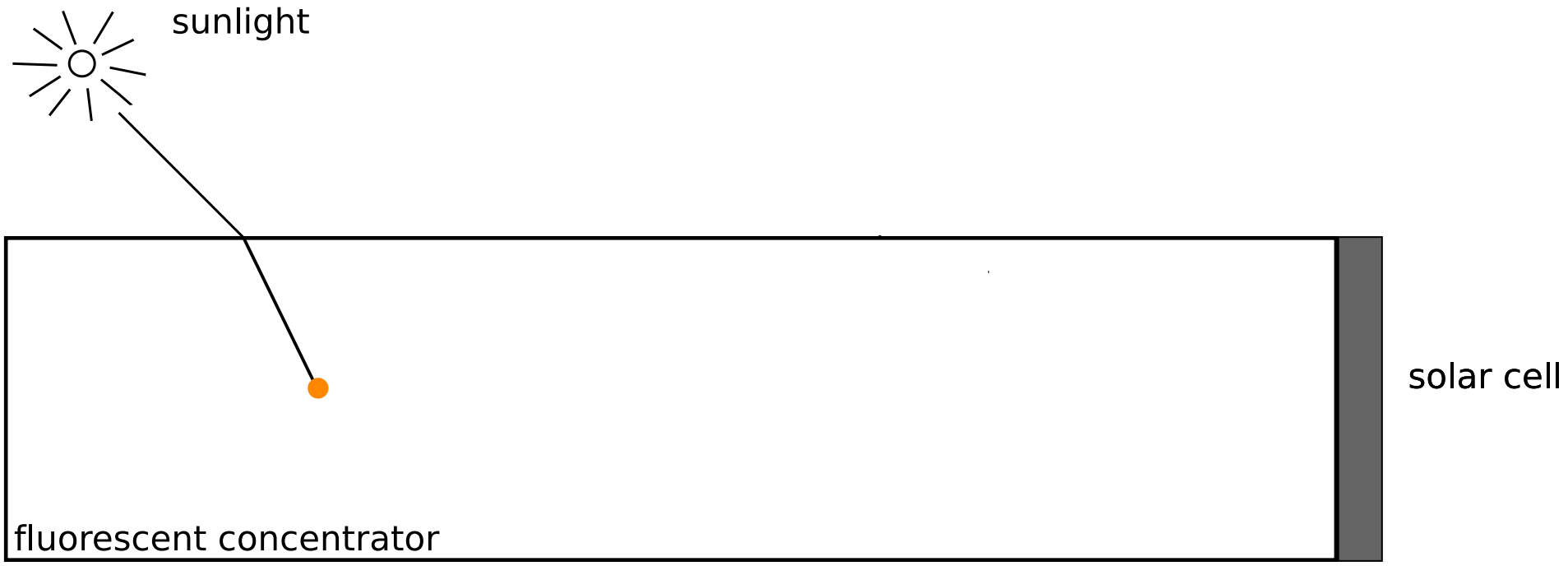
- calculate intersection with boundary
- calculate reflection coefficient (*Fresnel*, *Cauchy*)
- calculate new ray direction (*Snell*)

A Photon's Path trough the Concentrator



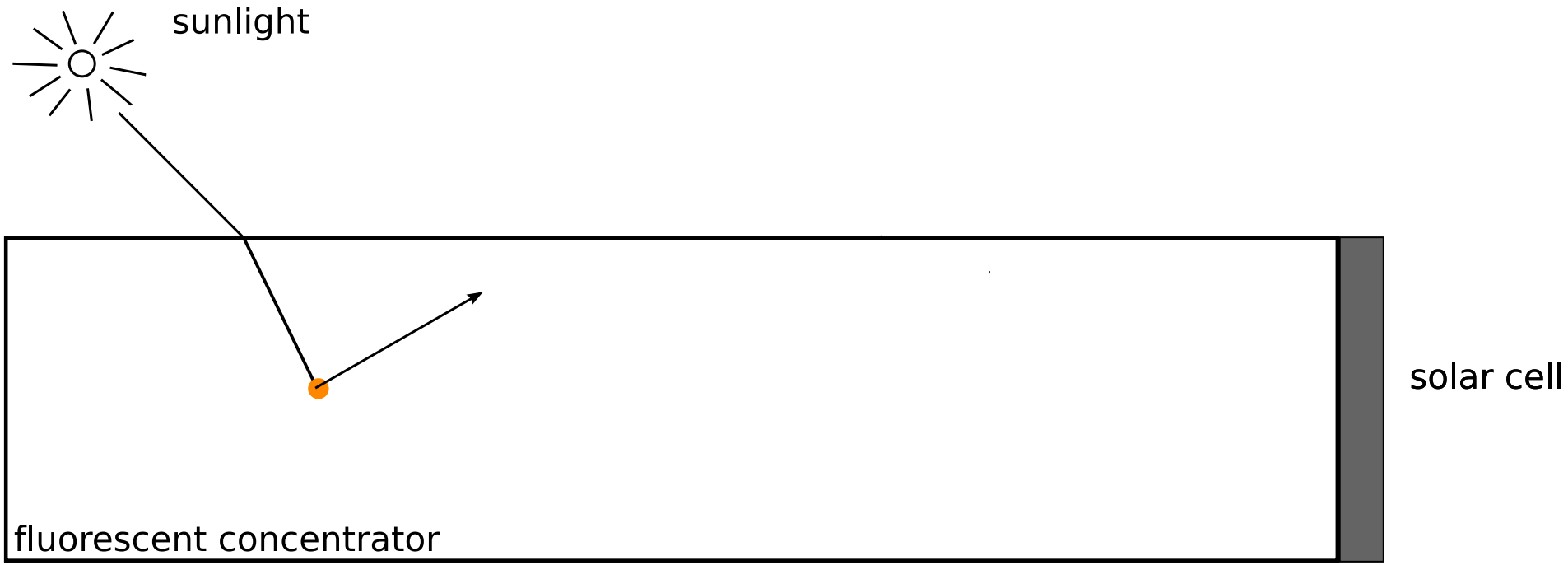
- sample pathlength (*MC inversion method, Lambert-Beer*)

A Photon's Path trough the Concentrator



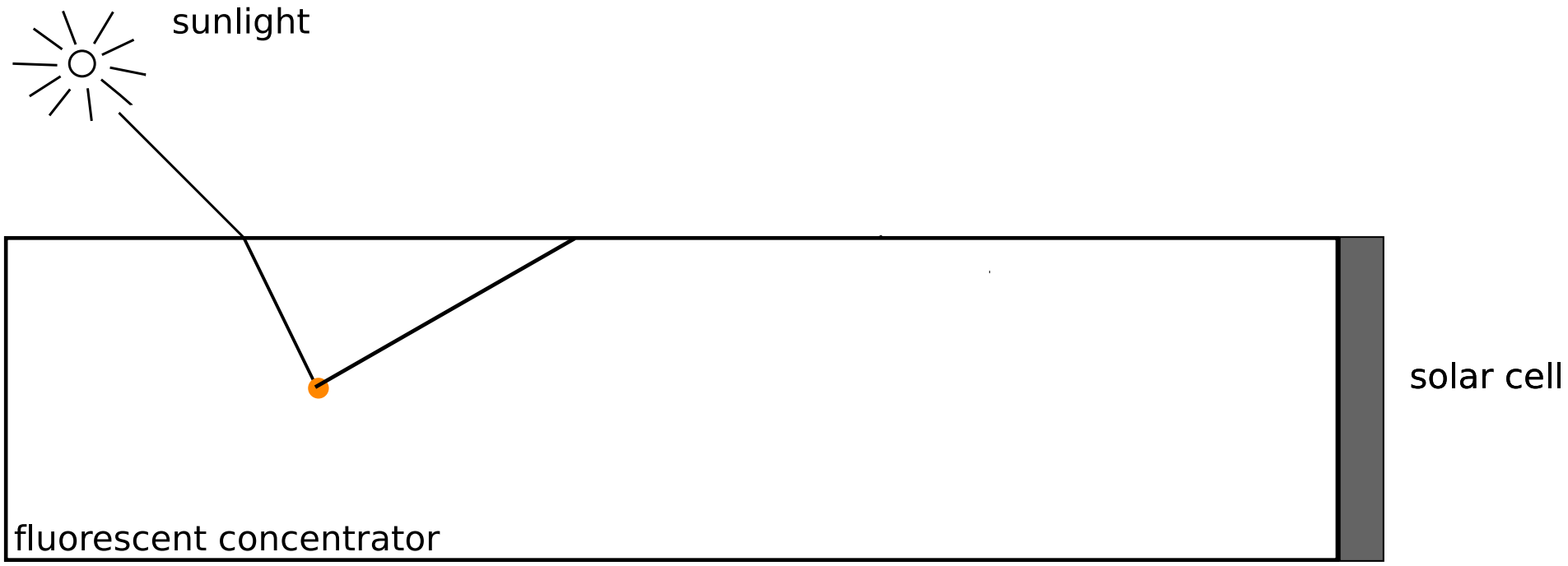
- estimate absorption event

A Photon's Path trough the Concentrator



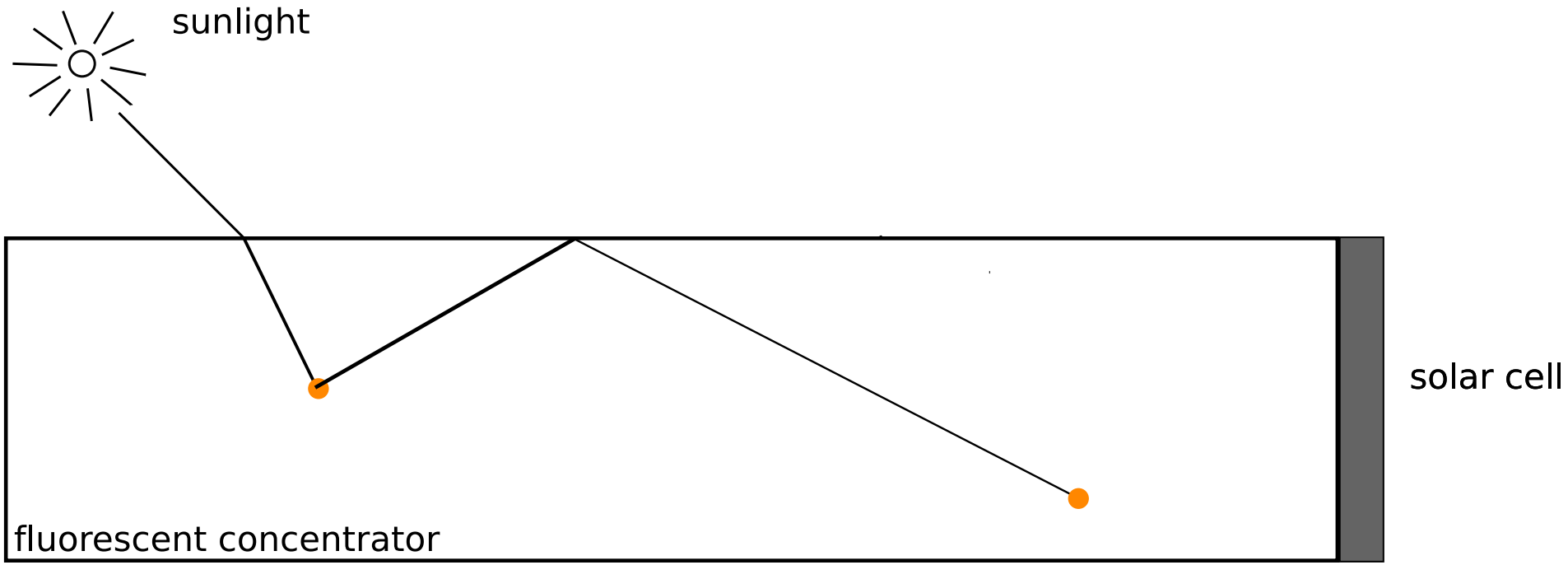
- sample PL-spectrum (*MC inversion method*)
- sample direction (*MC inversion method*)
- sample pathlength (*MC inversion method,) Lambert-Beer*

A Photon's Path trough the Concentrator



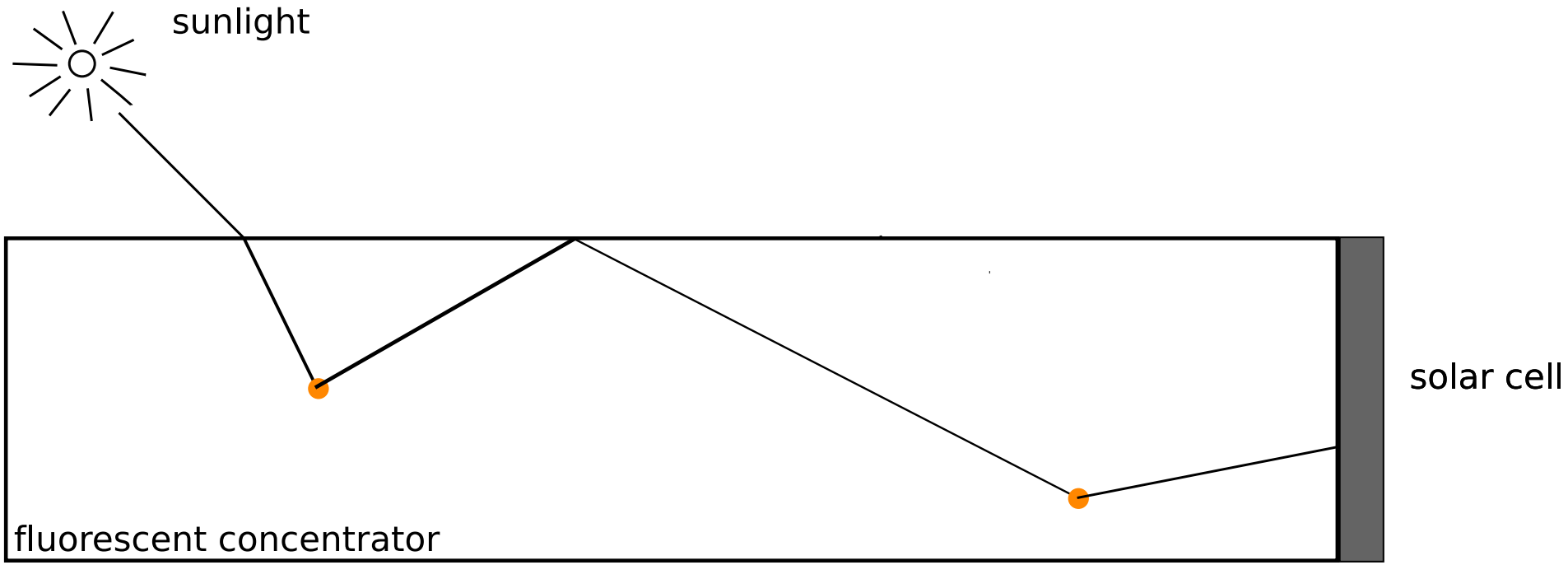
- calculate intersection with boundary
- calculate reflection coefficient (*Fresnel, Cauchy*)
- calculate new ray direction (*reflection angle equals angle of incidence*)

A Photon's Path trough the Concentrator



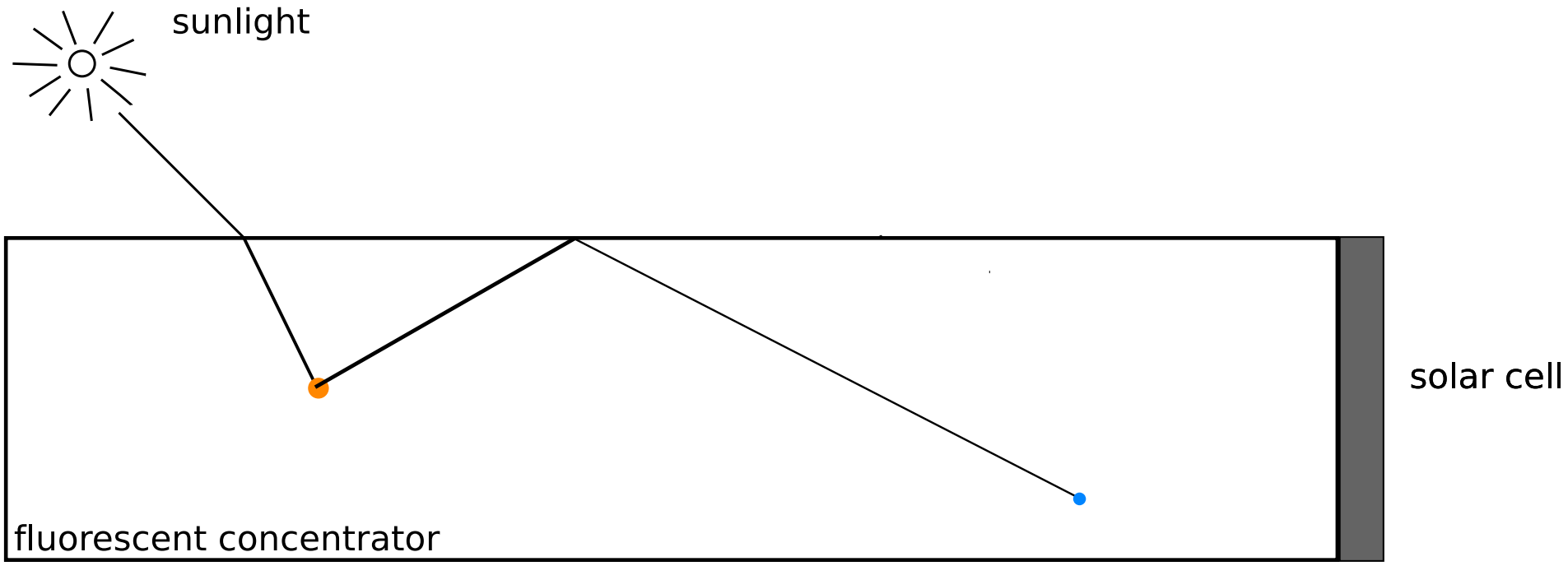
- sample pathlength (*MC inversion method, Lambert-Beer*)
- estimate absorption event

A Photon's Path trough the Concentrator



- sample PL-spectrum (*MC inversion method*)
- sample direction (*MC inversion method*)
- sample pathlength (*MC inversion method, Lambert-Beer*)
- calculate intersection with boundary

A Photon's Path trough the Concentrator

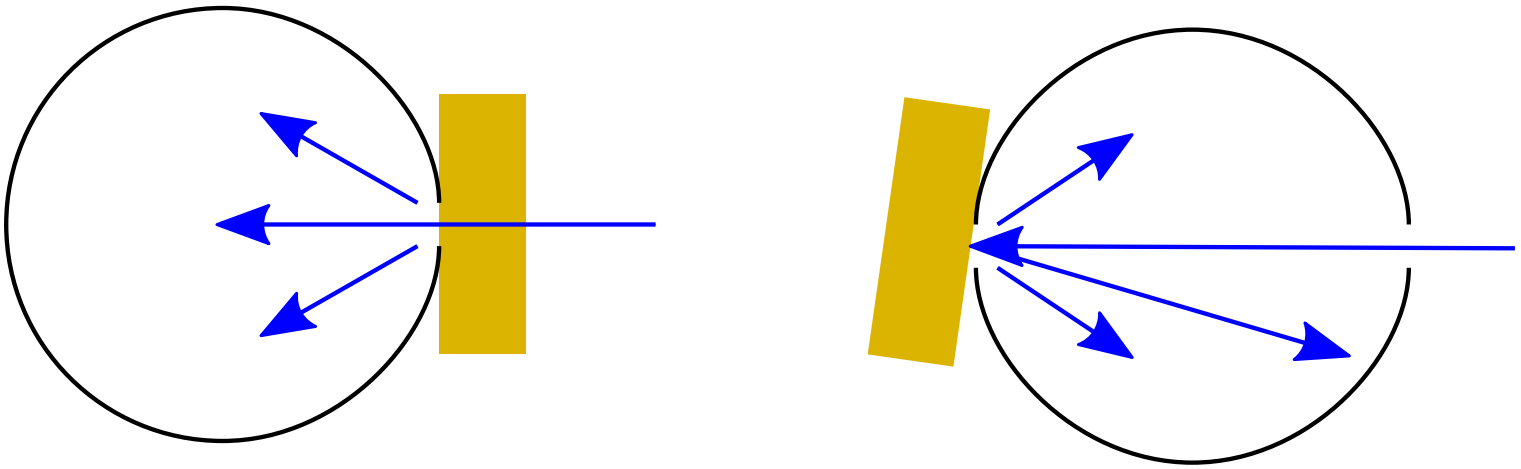


- estimate absorption event $\longrightarrow$ terminate ray

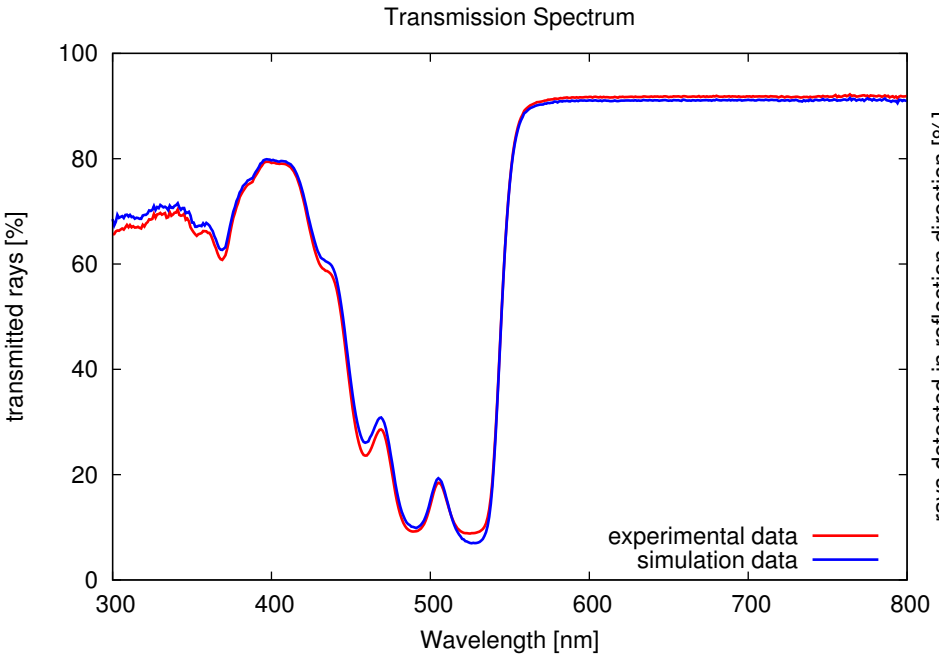
Experiments and their Simulation

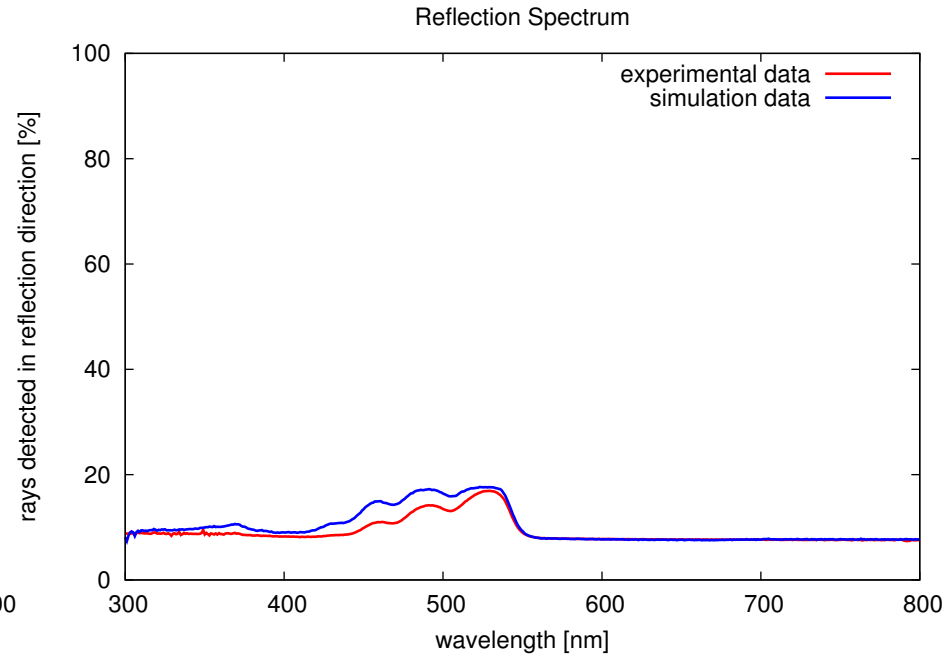
- physical measurement of input parameters: absorption spectrum, photoluminescence (PL-) spectrum, refractive indices and geometry
- several experiments for analysis of fluorescent concentrators
- first step:
  - reproduce experiments "exactly"
  - compare data to verify implementation
  - explain small differences
- second step:
  - simulate experiments without limitations of "real" setup
  - parameter variation
  - evaluate results

Reflection and Transmission Experiment



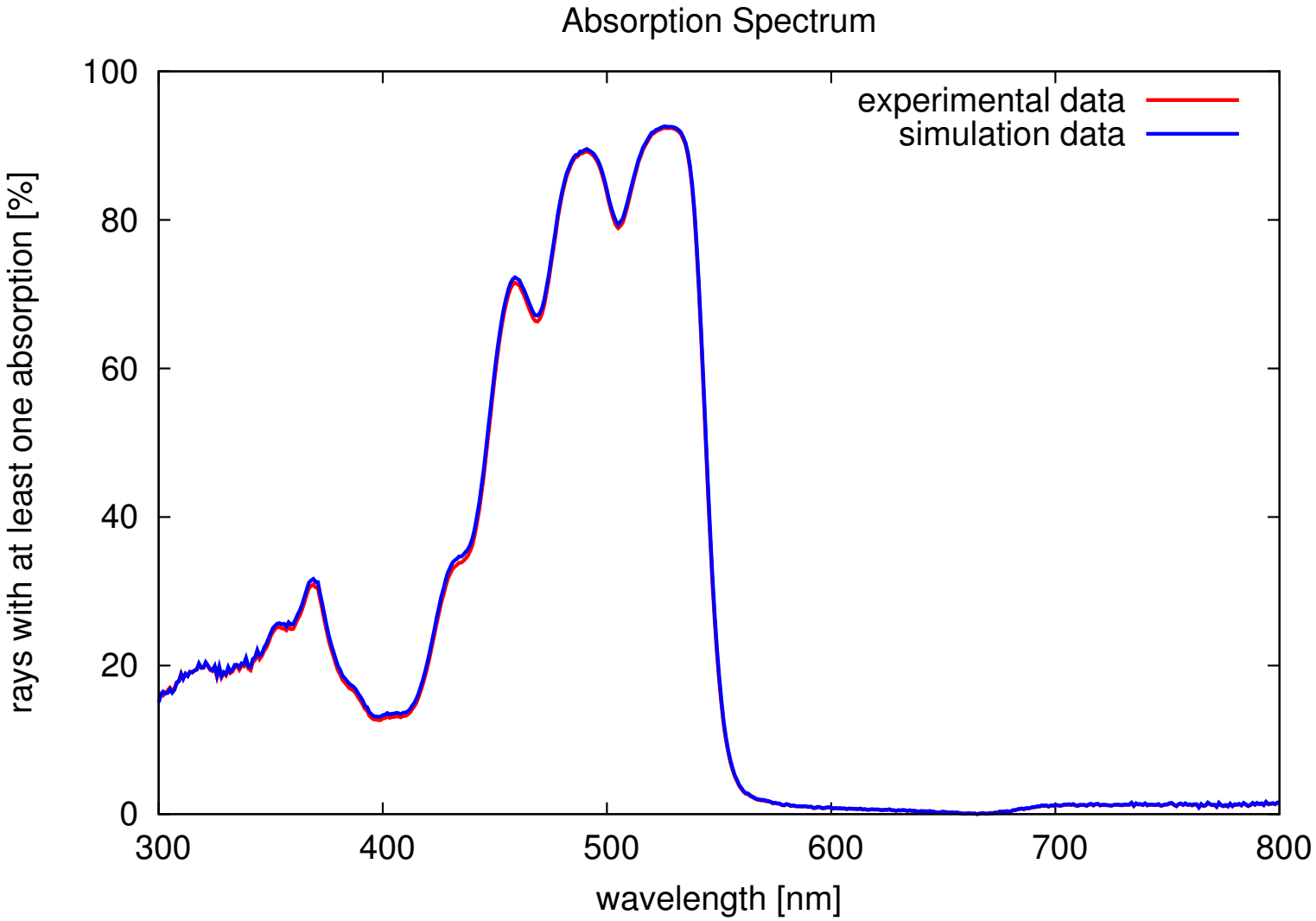
experiments with integrating sphere



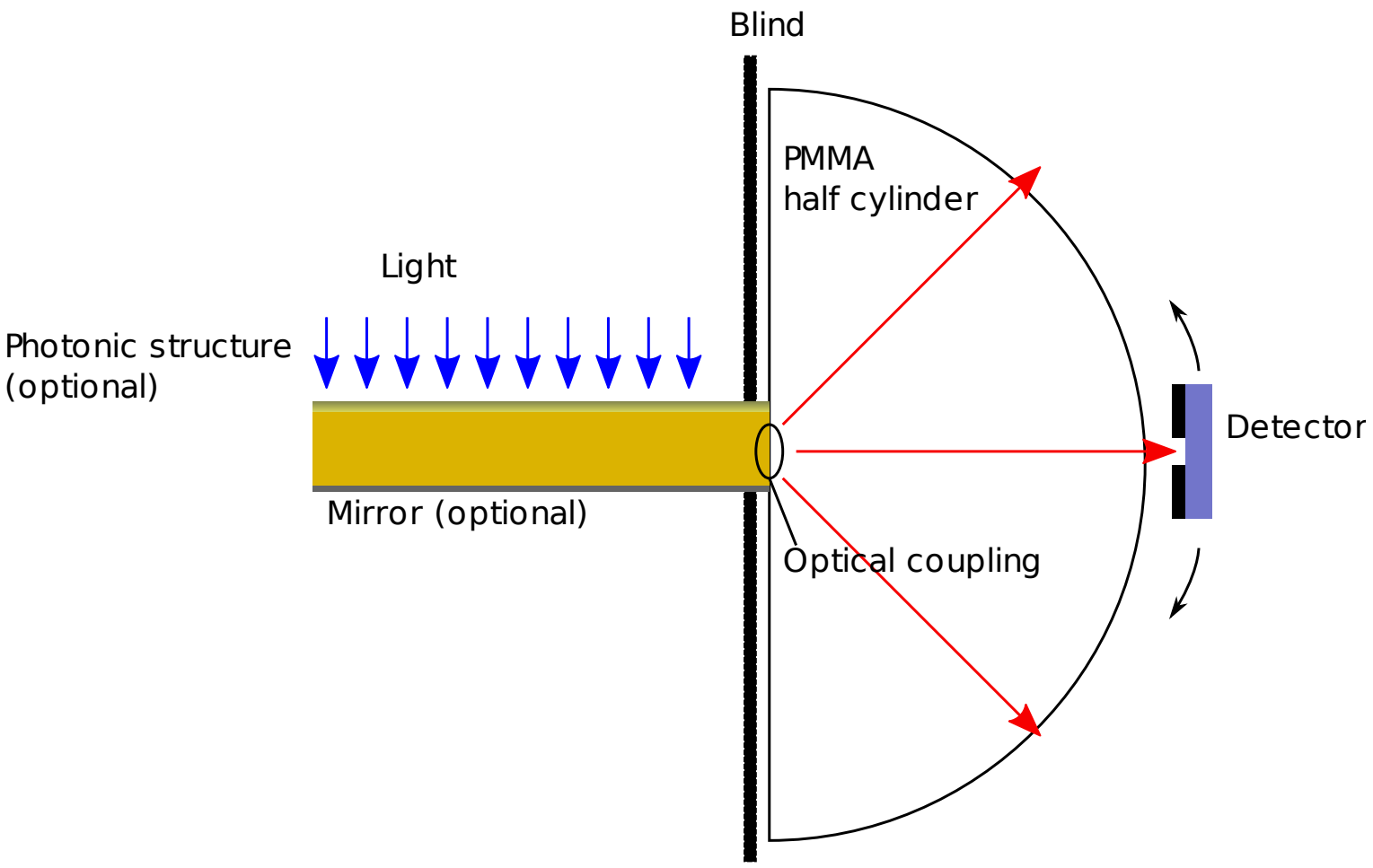


Absorption

- $Absorption \approx 1 - Reflection - Transmission$
- calculated absorption as input $\rightarrow$ verification of simulated absorption

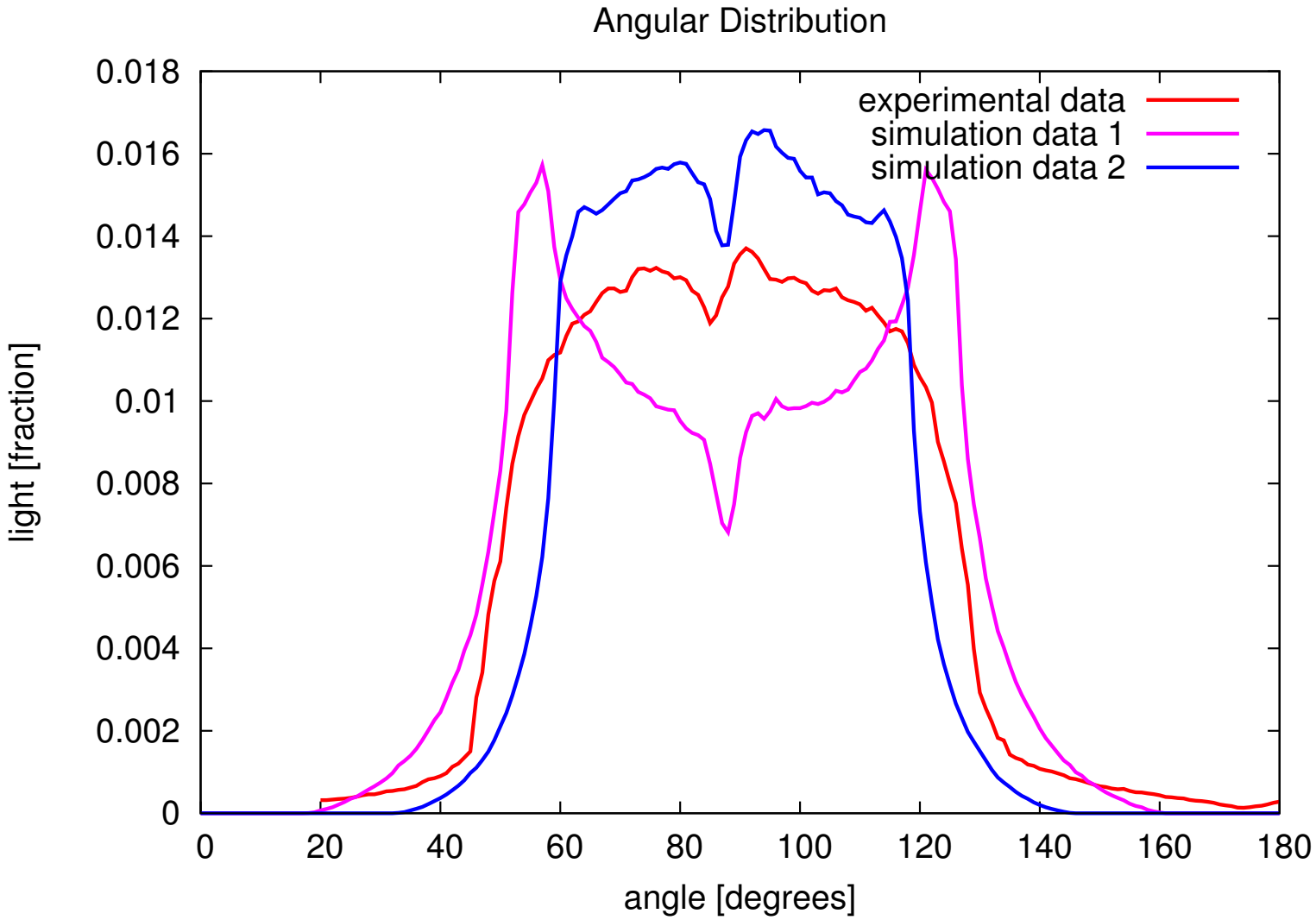


Angular Experiment

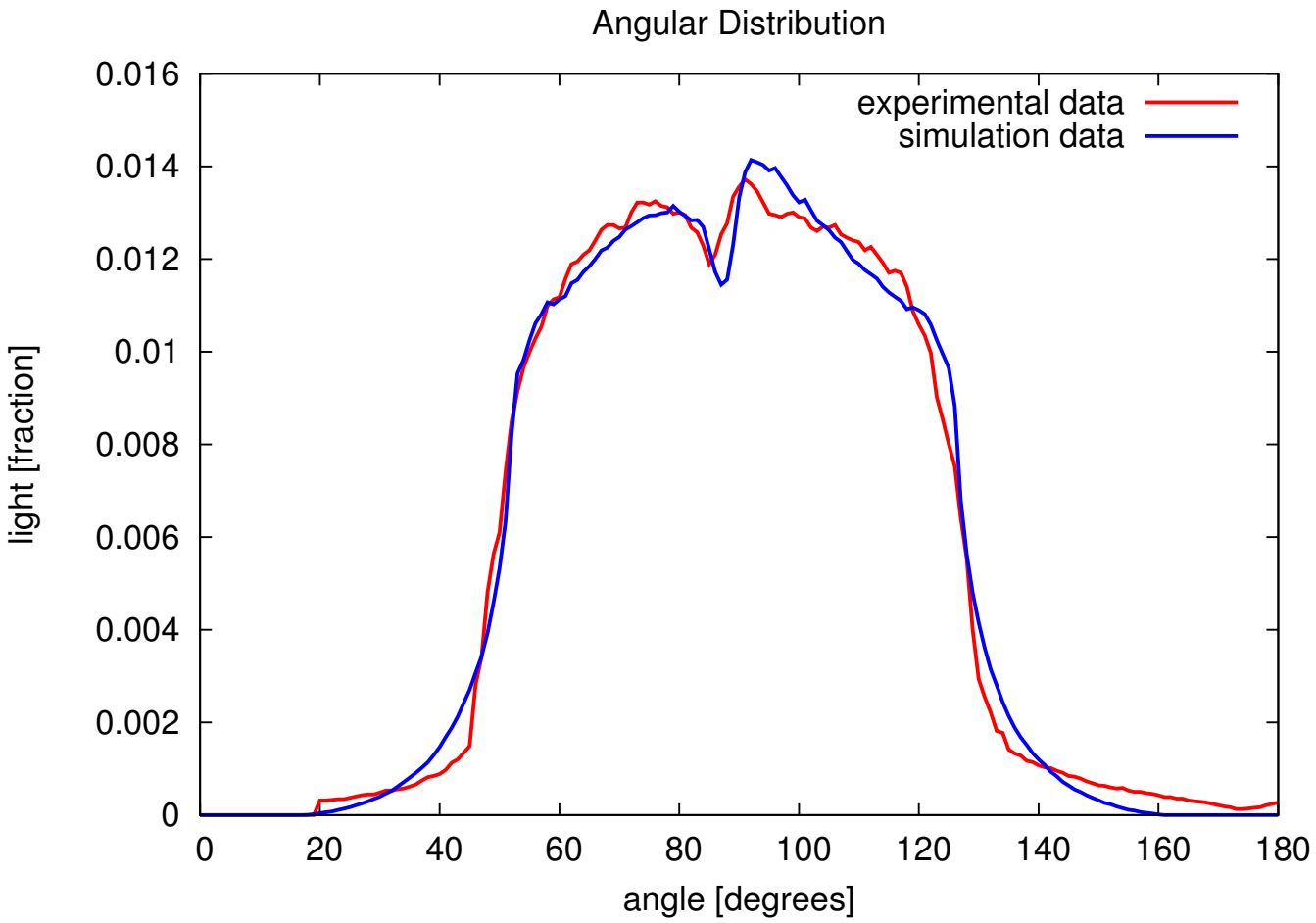


Angular Experiment

- not fully specified → parameter variation: imperfect surface, scattering, properties of the blind, properties of the coupled cylinder



Angular Experiment

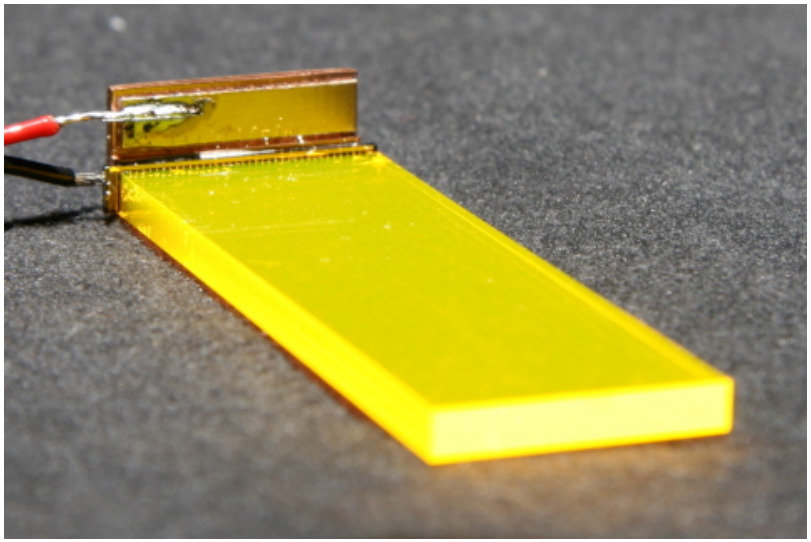


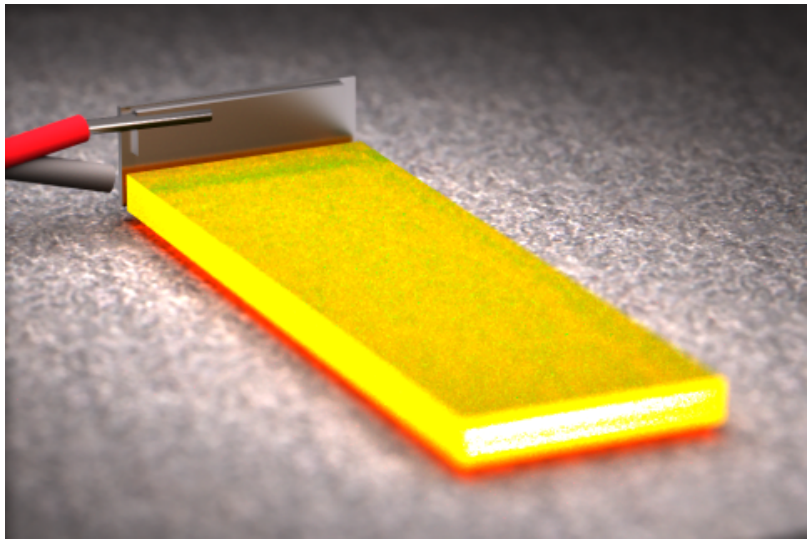
Fast Ray Tracing

- several millions of rays to be traced for one graph
- exponentially more (in the number of parameters) needed for parameter variation
- incoherent rays: ray packets/bundles not an option
- ray tracing kernel
  - triangle-based
  - 4-ary BVH
  - SAH-based construction

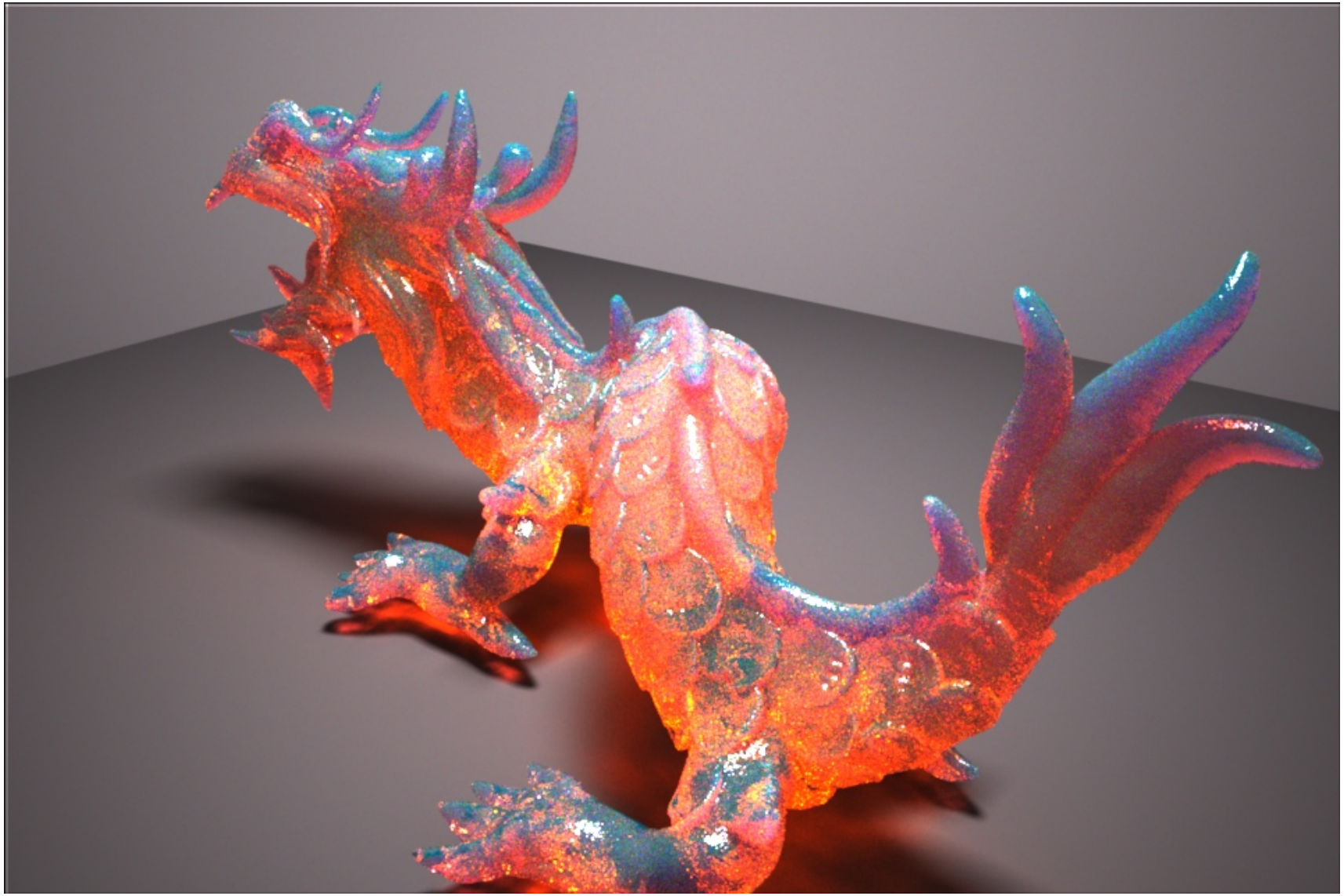
Visuals

- direct comparison photograph/render

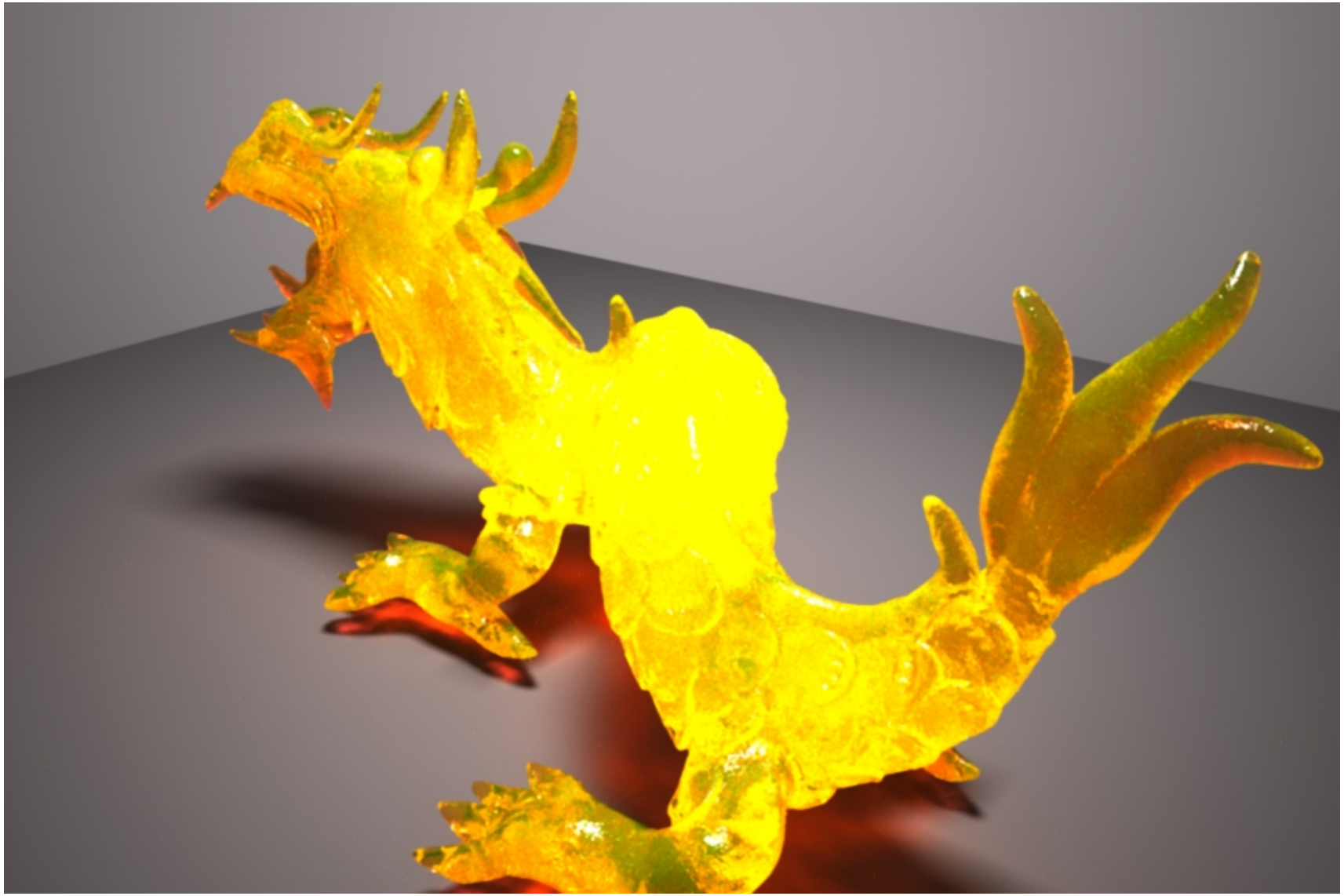




Non-Fluorescent Dragon

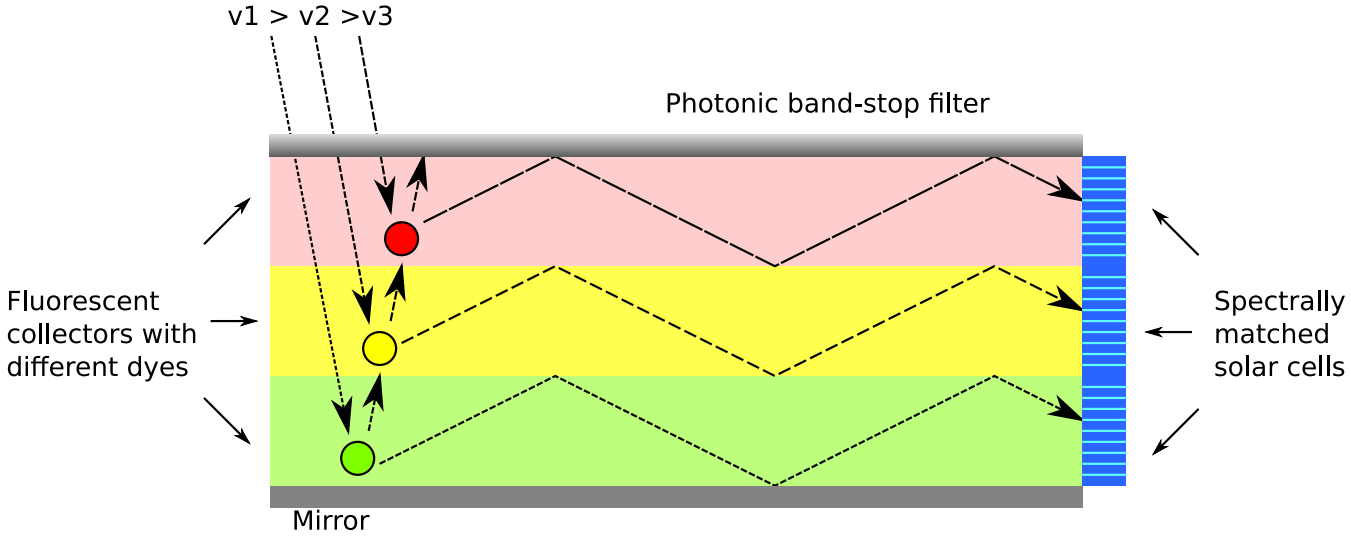


Fluorescent Dragon



Future Work

- optimisation:
  - concentrator stacks



  - photonic structures, mirrors, additional solar cells
  - geometry optimisation
  - different dyes (problem: infra-red range)

Summary

- fluorescent concentrators are made for improvement of efficiency and applicability of solar cells.
- testing by simulation possible before (expensive) experimental testing
- fast ray tracing makes automated parameter variation possible
- general Monte Carlo simulation framework for physicists to gain insights in involved processes, for parameter optimisation (dye properties, geometry, ..) and for testing of new ideas

Questions?

Experimental Setup