Thick-Core Fibers: Properties, possibilities and new applications

Karl-Friedrich Klein

FH/University of Applied Sciences
Giessen-Friedberg (Germany)

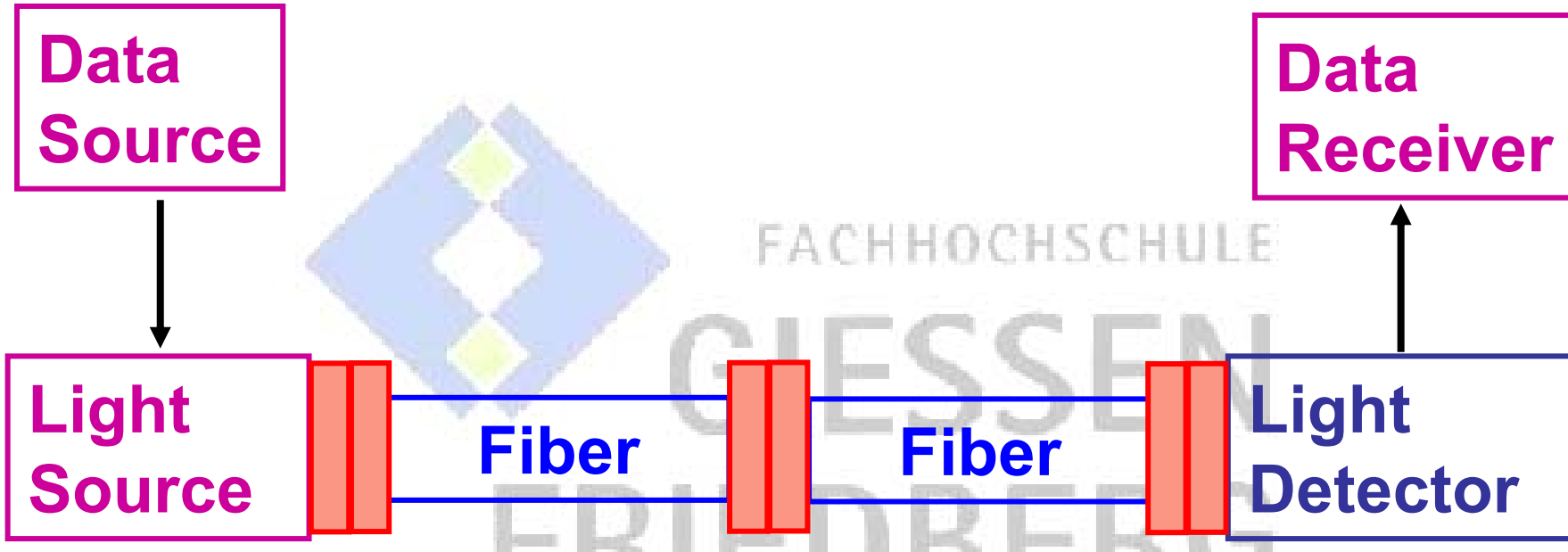
100 JAHRE
Ingenieur-Ausbildung in Friedberg
FACHHOCHSCHULE GIESSEN FRIEDBERG

PRESENTATION AT FIBERCOMM
16.Meeting of ITG „Polymer Optical Fibers“
Messe Munich, 25th June 2003

Content

- Introduction
- Fiber-types (overview)
- Selected properties for new applications
  - All-Silica fibers: UV and IR
  - HCS-fibers: detector fibers
  - POF: UV-transmission
  - FPOF: scintillating fibers
- Outlook

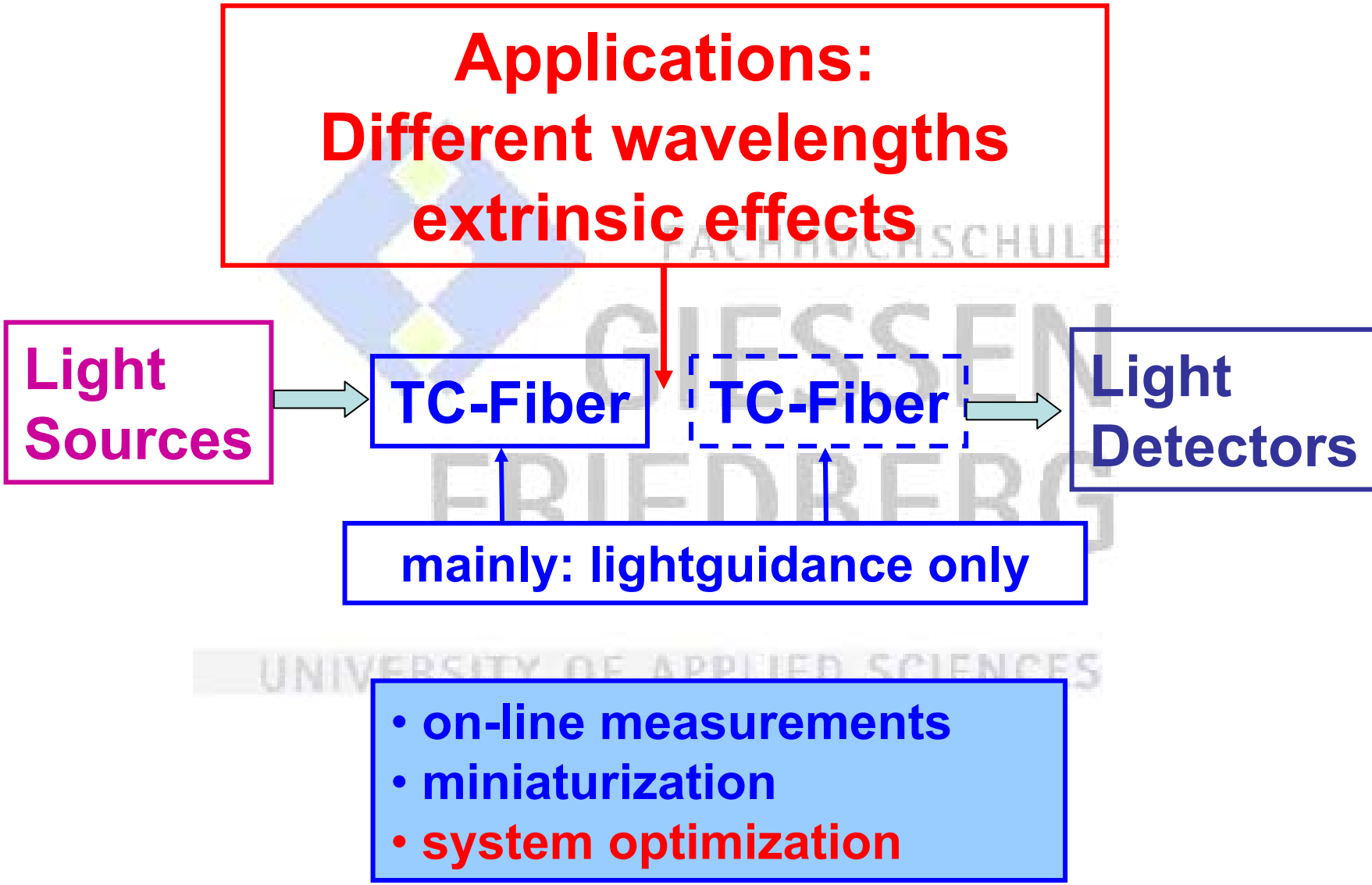
Optical systems for data transmission



- attenuation
- bandwidth
- life-time, reliability
- others

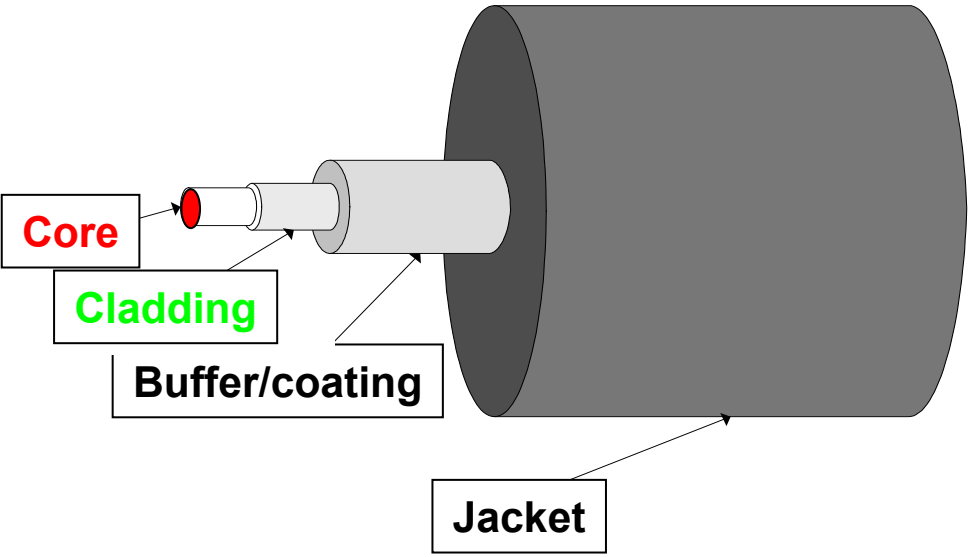
- requirements
- determination of critical points
- optimization of the whole system

Fiber-optic systems: general overview



Fiber-types with big core diameter

- (Single-) Step-Index Fibers
- Multiple-Step-Index Fibers
- Graded-Index Fibers
- Fiber Bundles



Different materials:

- Core
- Cladding
- Coating/Buffer
- Jacket

Fiber-types with big core diameter

- (Single-) Step-Index Fibers
- Multiple-Step-Index Fibers
- Graded-Index Fibers
- Fiber Bundles

Different functions and requirements (depending on the applications)

Determine the critical ones for the application in mind

Different materials:
- Core
- Cladding
- Coating/Buffer
- Jacket

Main types of Step-Index Fibers

- **All-Silica Fibers**
  - Undoped silica: high-/low OH
  - (Ge-doped silica)
  - F-doped silica (undoped silica)
- **Polymer-Clad Silica-Fibers (including HCS)**
  - Undoped silica: high-/low OH
  - Hard-Clad, silicone, Teflon, others
- **Polymer Optical Fibers (POF)**
  - PMMA (PS, PC, silicone, others)
  - Different materials possible / available
- **Fluorescent Polymer Optical Fibers (FPOF)**
  - Doped polymers (see POF)
  - Different materials possible / available

Basics for selection

- Attenuation
  - Wavelength
  - excitation-dependence (DMA)
- Pulse-spreading
  - Refractive-index difference
  - excitation-dependence (DMD)
- Bending-performance on …
- Strength
- Temperature-resistance
- Radiation-resistance
- Chemical resistance
- Connectorization, handling
- Others

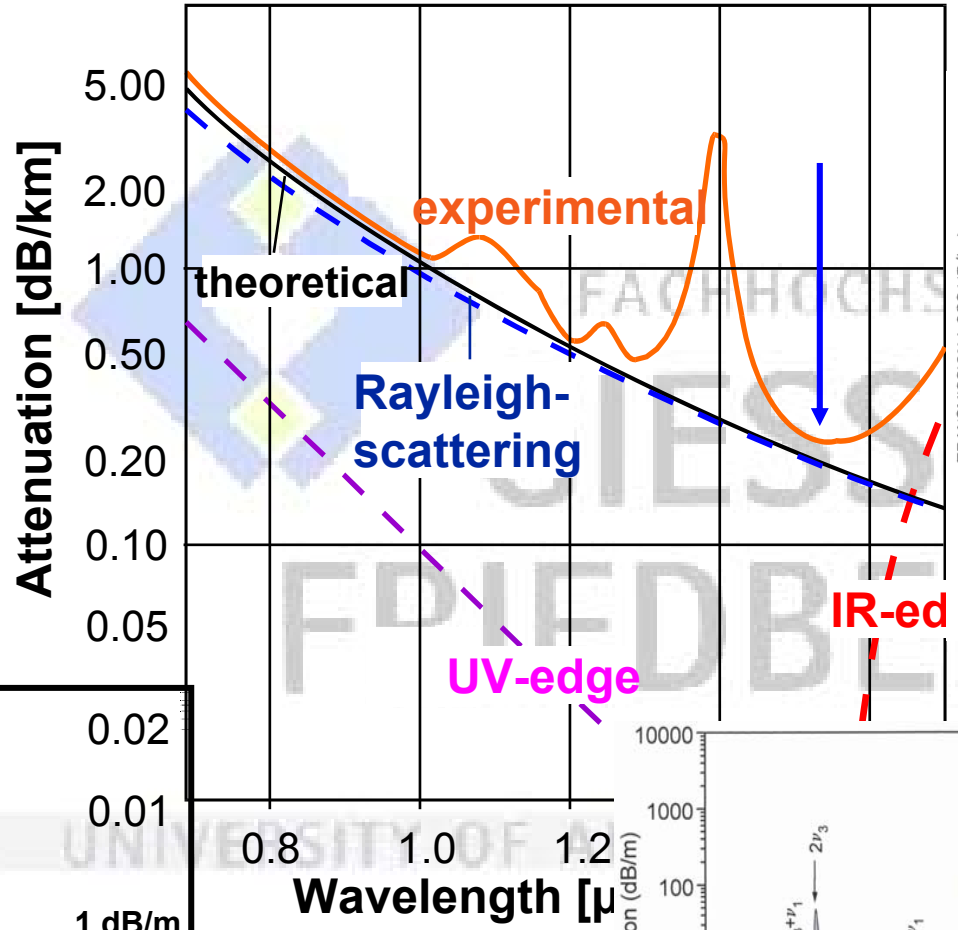
other components for the whole system

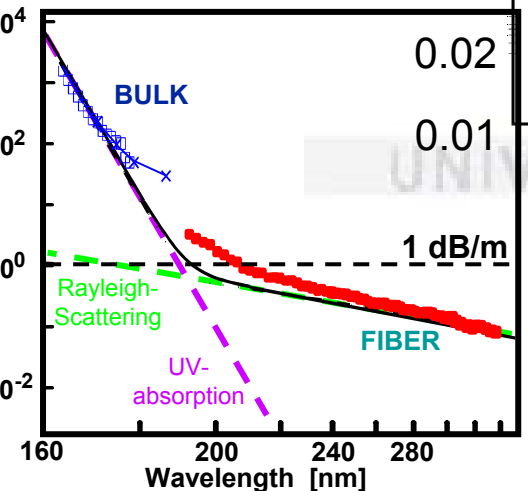
Properties of AS-Fibers

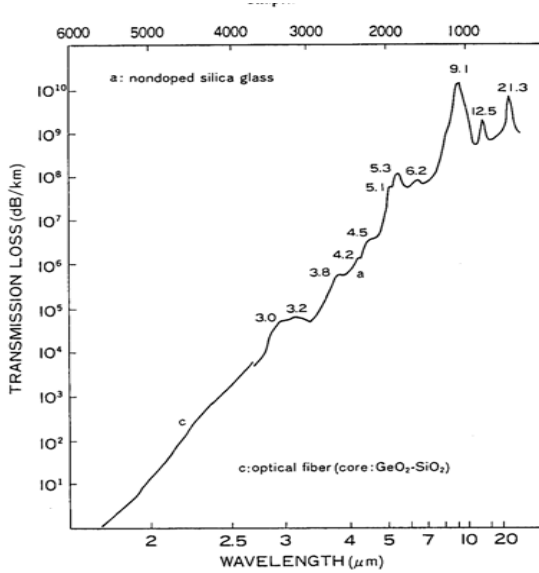
- Core diameter: 100 .. 1500 µm
- Cladding-Core-Ratio: 1.05 .. 2.5
- Numerical aperture: 0.10 to 0.28
  (with Ge-doped core: 0.32 possible)
- Coating: UV-acrylate
  Polyimide
  Silicone
  Hard-Clad possible
- Attenuation: < 1.0 dB/km at 1.55 µm
- Bandwidth: approx. 20 MHz*km

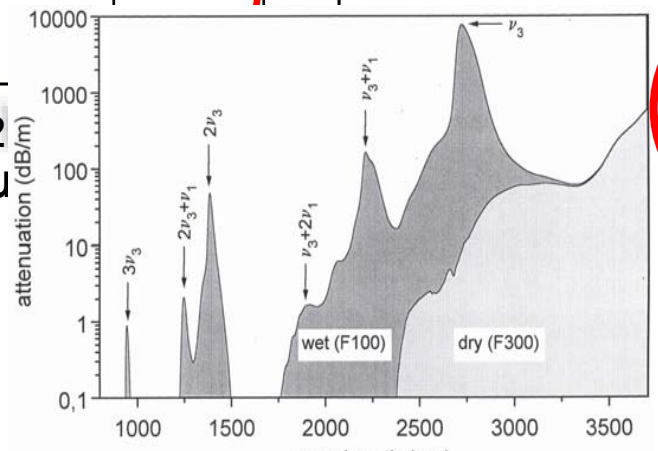
Attenuation of AS-fibers

UV





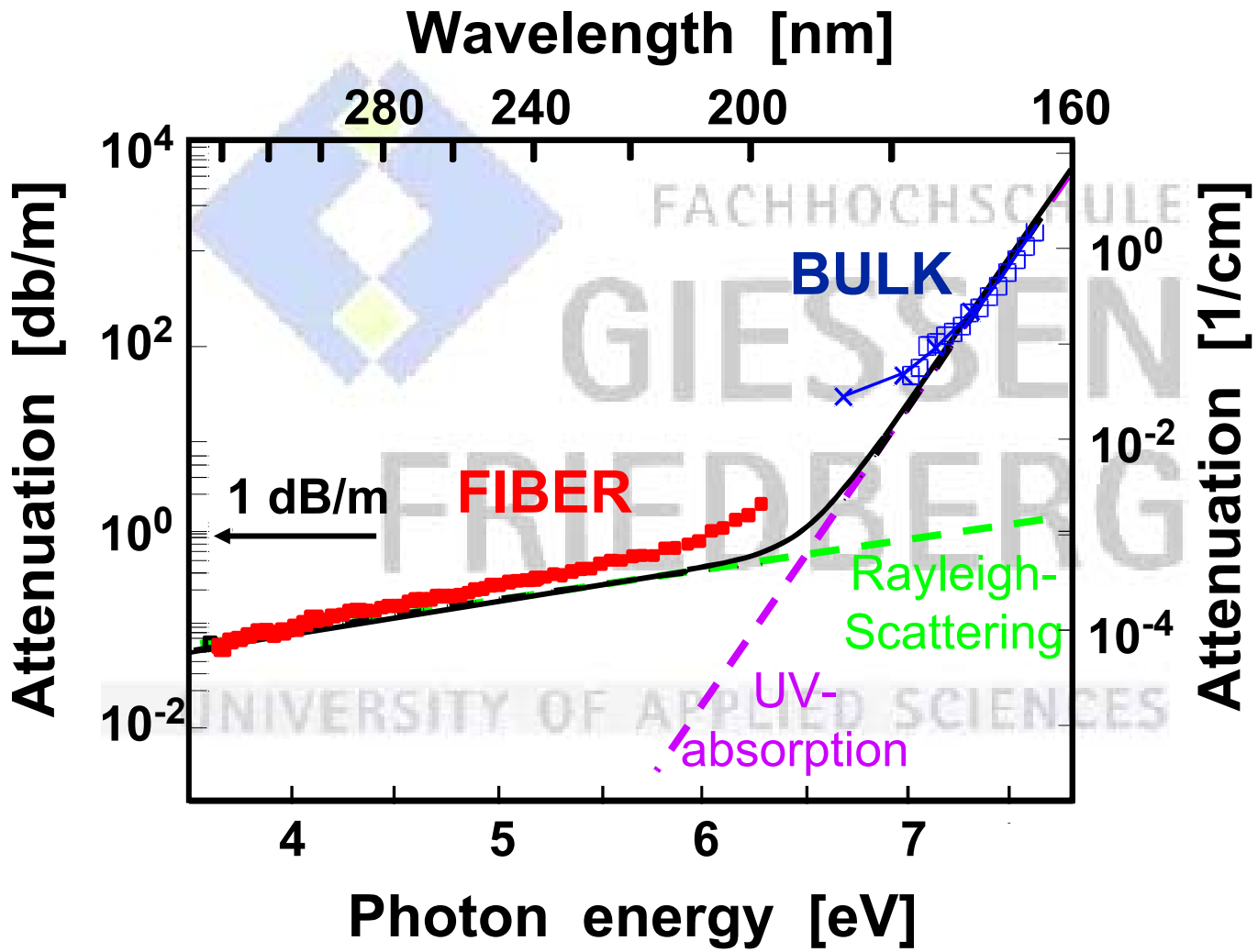




IR

UV-attenuation in silica

Source: Heraeus Quarzglas



Transmission properties

$$-\frac{dI}{dz} = \alpha_0 + \Delta\alpha(z) \cdot I + \beta \cdot I^2$$

Basic attenuation **Two-photon absorption**

UV-induced attenuation

Absorption coefficient

λ [nm]	α_0 [10^{-4} cm^{-1}]	[dB/m]	β[cm/MW]
193	40	1.7	2×10^{-3}
248	10	0.5	5×10^{-5}
266	5.0	0.25	3.6×10^{-5}
308	2.7	0.13	3.6×10^{-7}

Defects

214 nm: E_α'-center $\equiv Si^\bullet$

229 nm: E_β'-center $\equiv Si^\bullet$

243 nm: ODC 1 $-O-\dot{Si}-O-$

254 nm: ODC 2 $\equiv Si-Si\equiv$

266 nm: NBOHC $\equiv Si-O^\bullet$

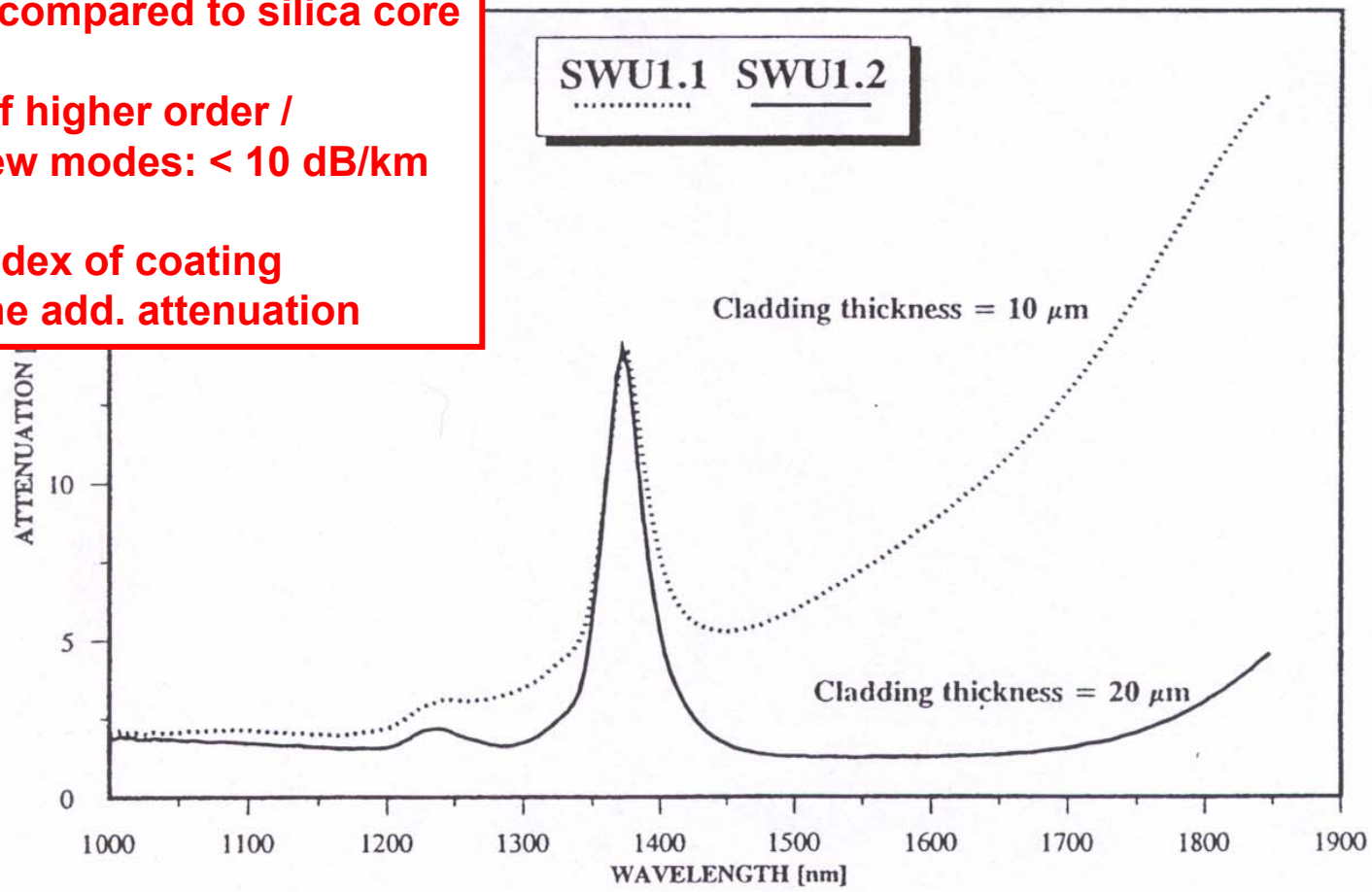
AS-fibers in IR-region: Influence of cladding thickness

Remark:
Silica cladding has (nearly) same attenuation, compared to silica core

Addit. loss of higher order / skew modes: < 10 dB/km

Refractive-Index of coating influences the add. attenuation

Source: Heraeus Quarzglas



Hard Clad Fibers: properties

Gerhard Schötz, Heraeus Tenevo AG
Jeffrey Miller, OFS Specialty Photonics Group:
„Quarzglas-Dickkernfasern“
(Presentation in Offenburg, 26.03.03)

Jim Clarkin, Polymicro Technologies:
„*Hard Clad Fibers for Automotive Applications*“

Polymer Clad: technical comments

- Higher attenuation with absorption bands, especially above 900 nm
- Numerical aperture from 0.30 to 0.65 wavelength-dependent, especially above 900 nm
- UV- and blue absorption strongly influenced by composition: to be adjusted to applications
- Chemical resistance and strength: given by composition
- Adhesion to core: given by the composition
- Connectorization: to be adjusted

CERN-detector for high-energy particles

With special
600 µm HCS-fibers

Next project: Detector for Tesla-Linearcollider with 500 GeV total energy

Polymer/Hard Clad Fibers: applications

Automotive applications

Illumination and lighting, over long lengths

Adverse enviroments: detection of radiation or high-energy particles (CERN-project)

Sensor-applications using ATR (hard-clad subsituted by sensitive cladding material)

Polymer Optical Fibers: properties

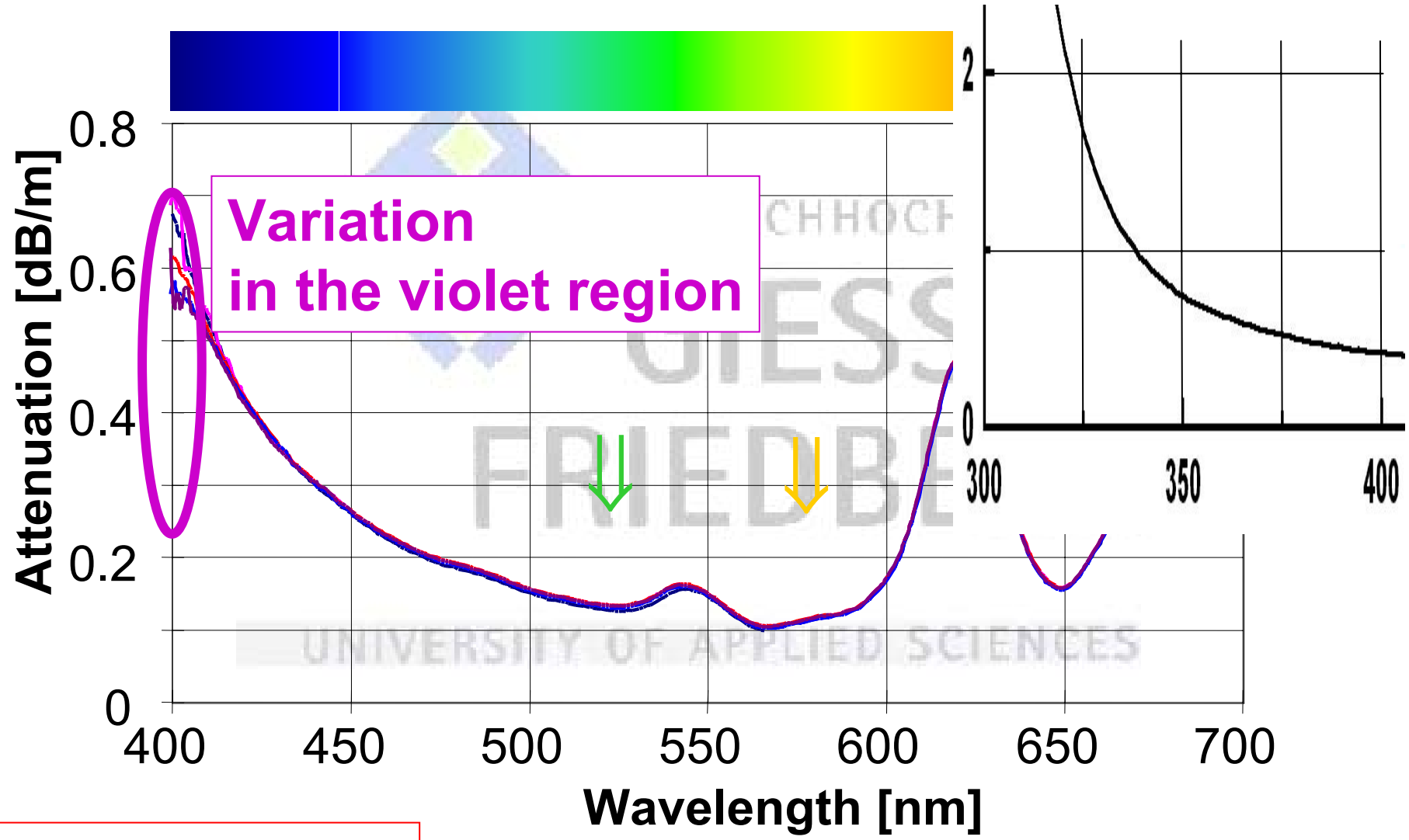
Details see, e.g.
Ziemann et.al.: “Polymer Optical Fibers”

In this presentation:

Performance in UV-region:
basic attenuation
UV-induced loss

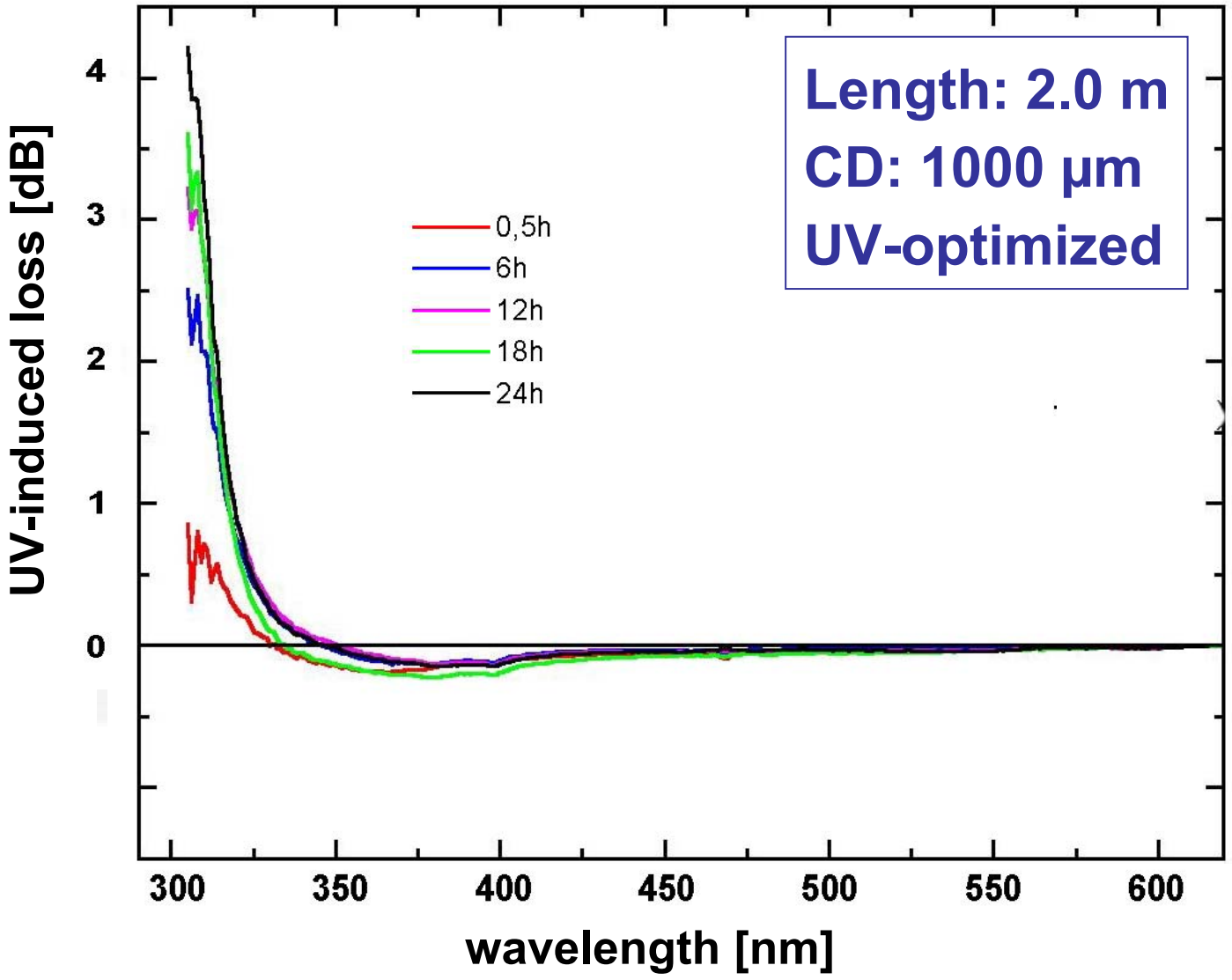
Excitation-dependent attenuation

Attenuation of Standard PMMA-POF (1mm

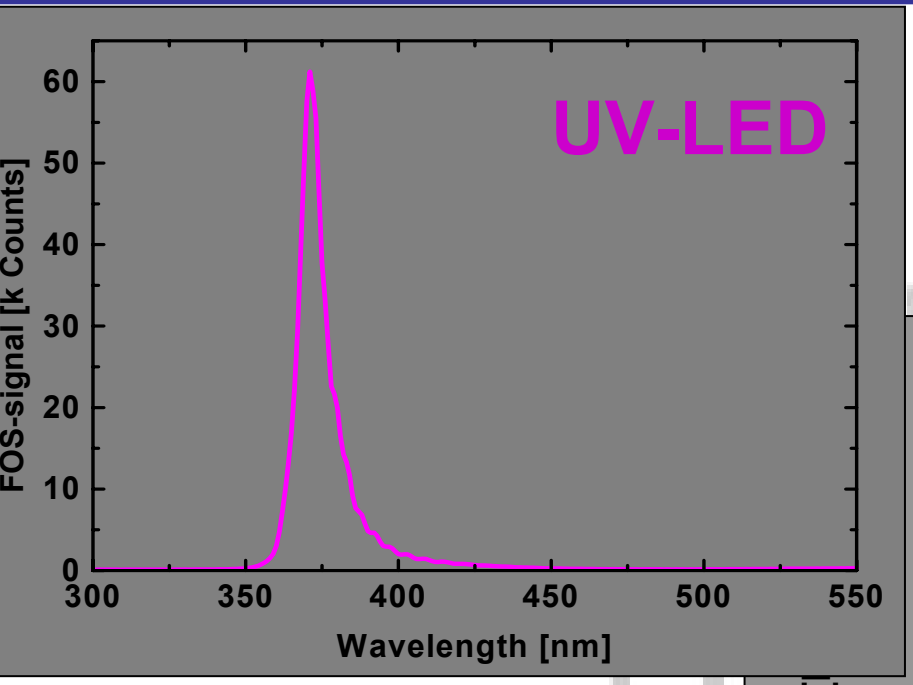


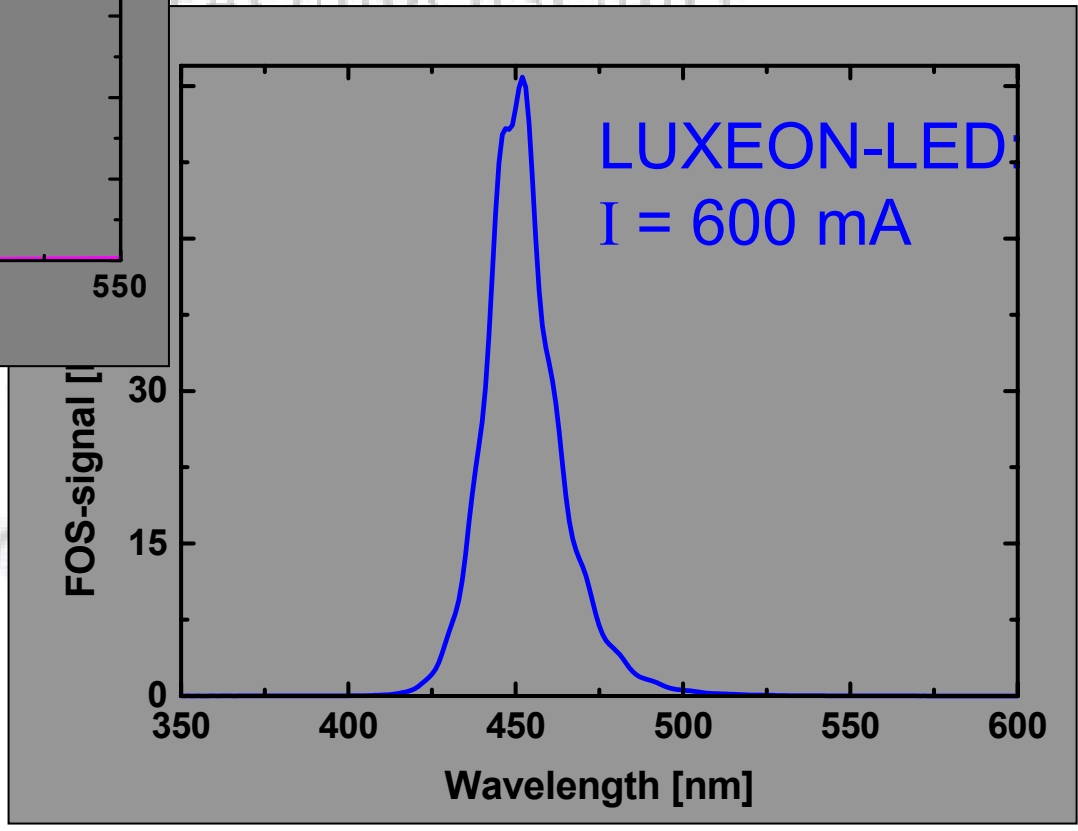
dB/m, not dB/km

Induced loss during Xe-lamp irradiation



Spectra of UV- and Blue-LEDs





UV-A spectroscopy including fluorescence

Polymer Clad of POF

Attenuation

higher attenuation of cladding

additional source: scattering at core-cladding interface

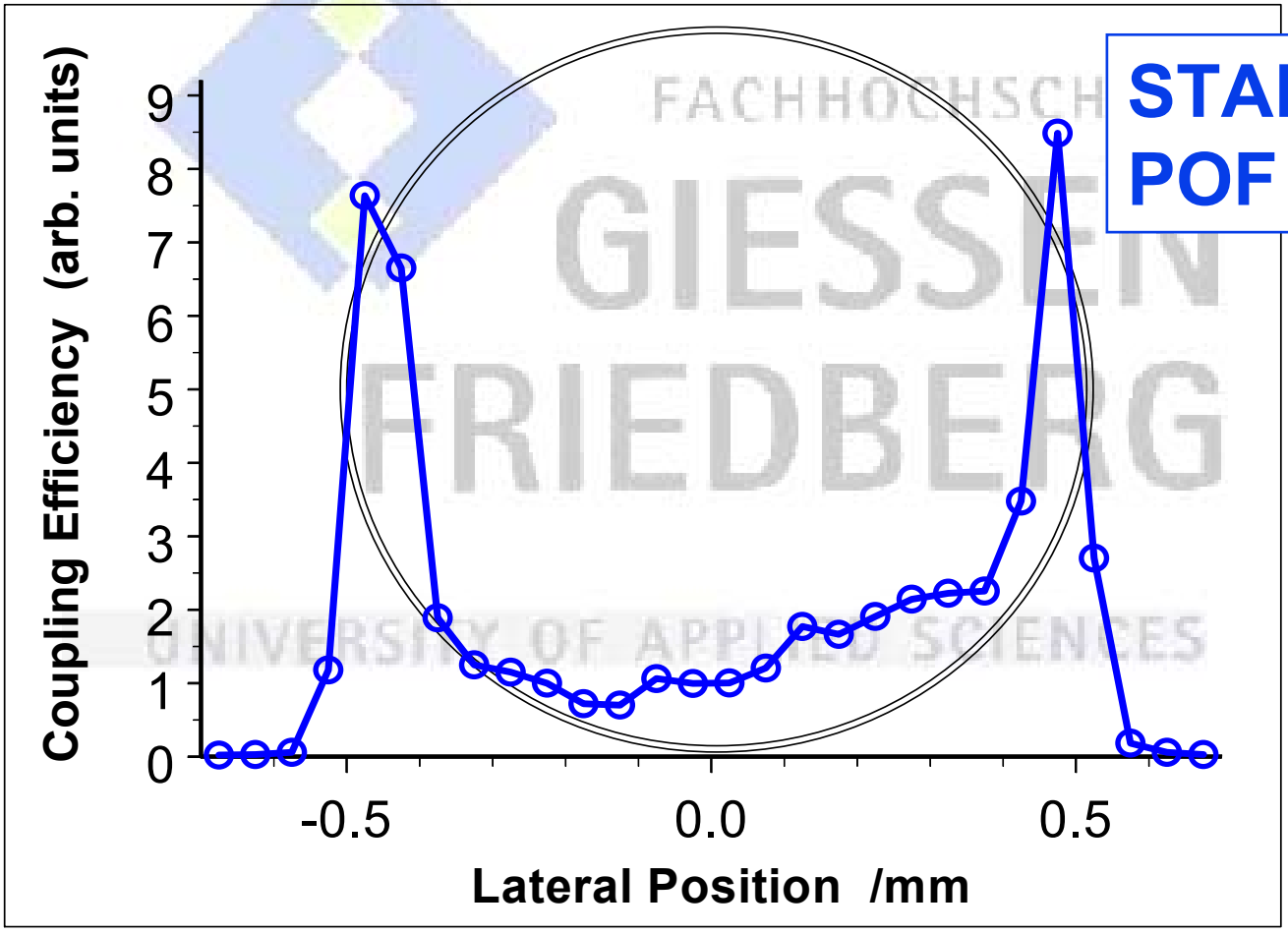
strongly dependent on excitation

Numerical aperture: 0.15 .. 0.65

UV- and blue absorption strongly influenced by composition: to be adjusted to applications

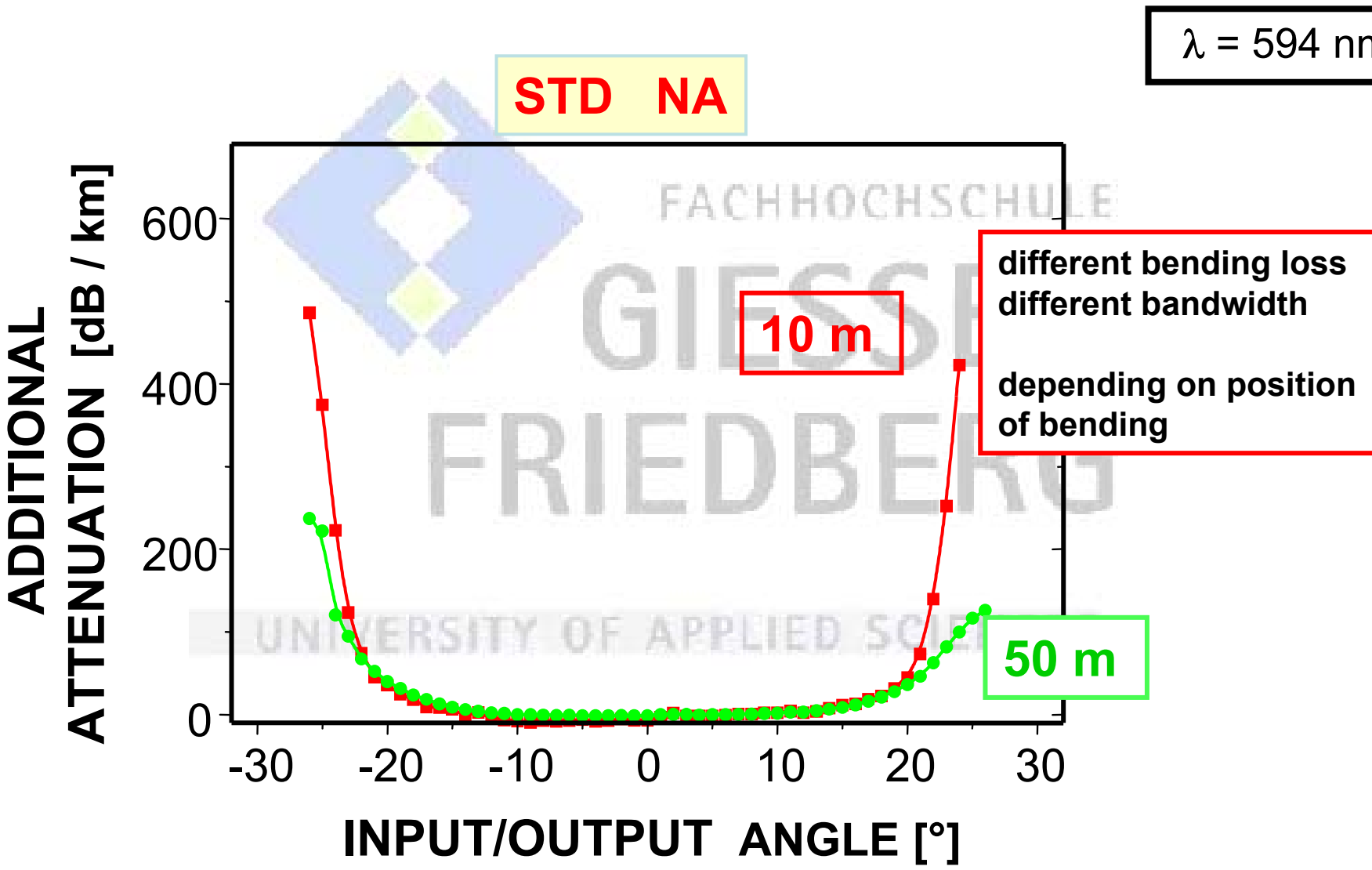
Scattering: light detection due to radial excitation

Source: Poisel, POFAC



STANDARD POF

Excitation-dependent losses



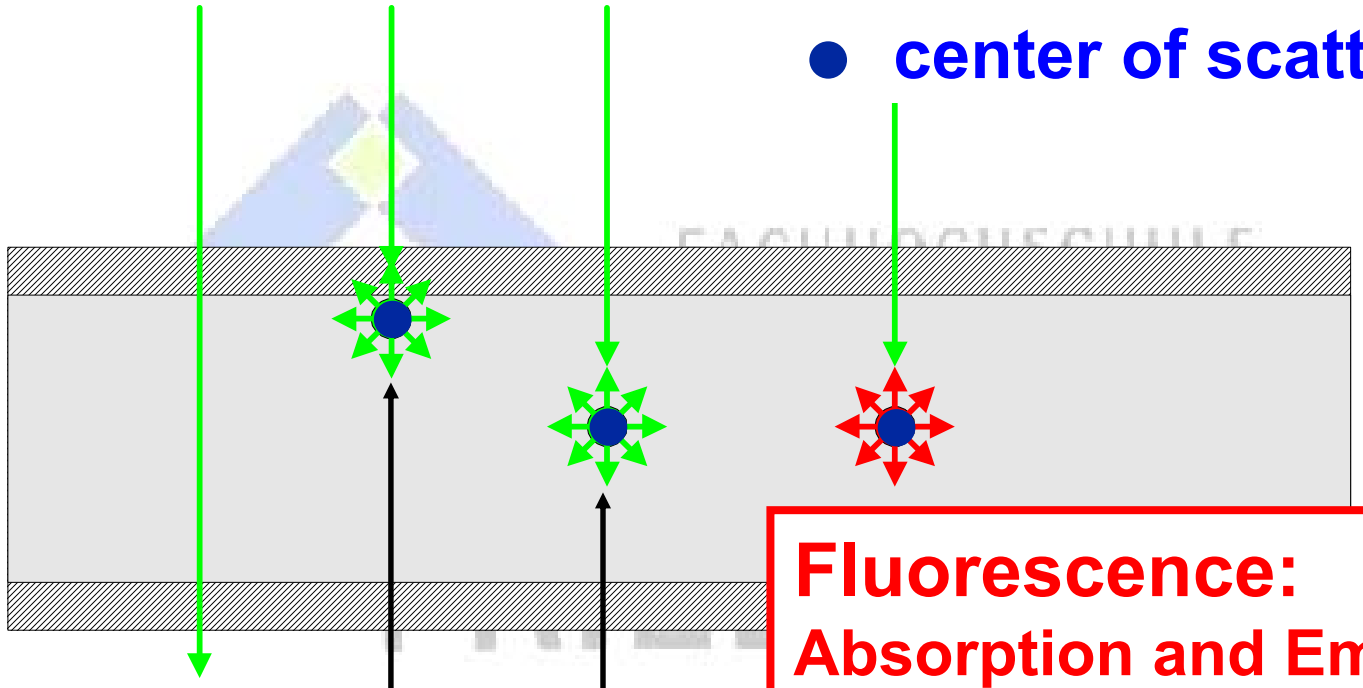
Fluorescence POF (FPOF)

With doping

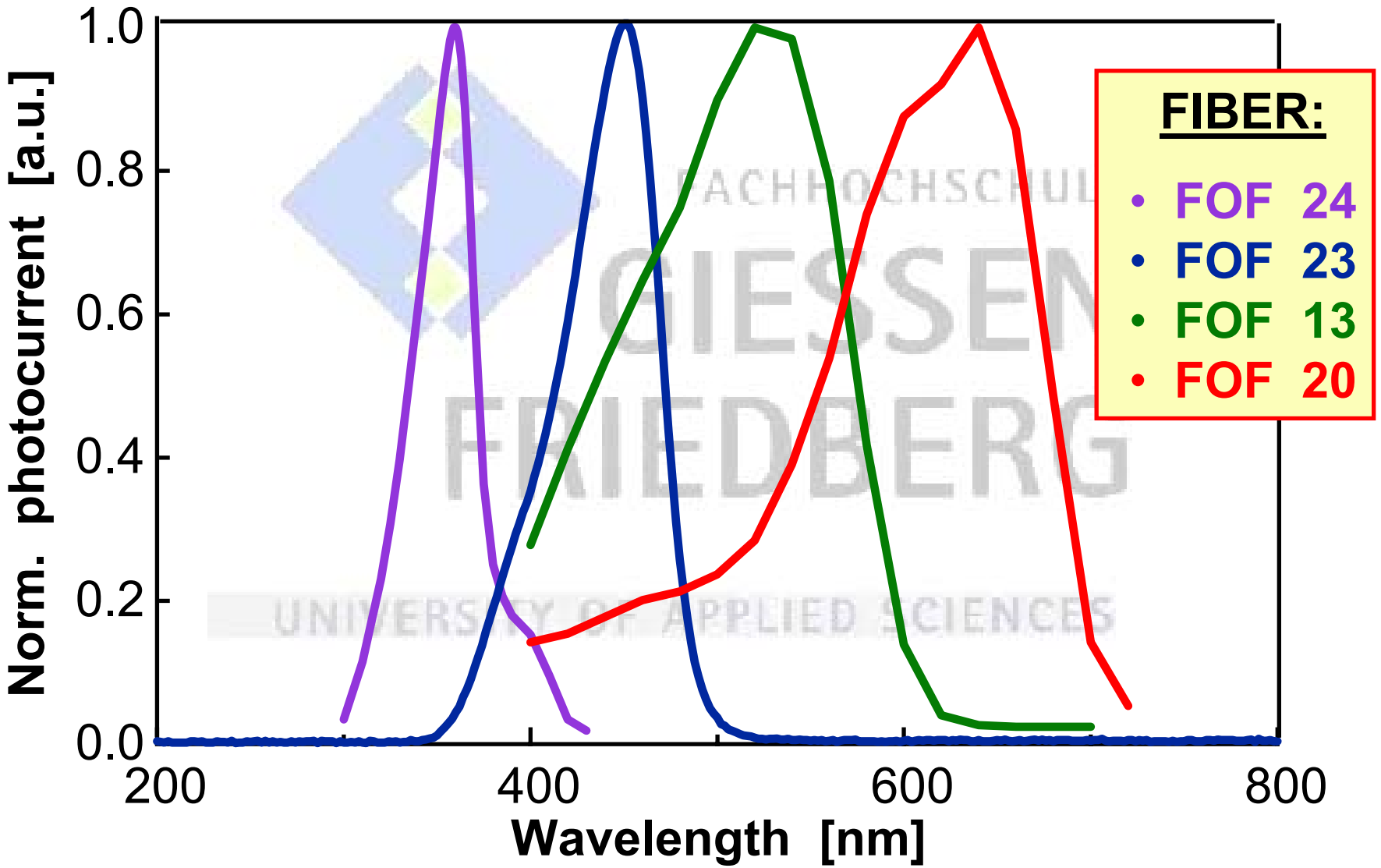
- **different materials with different fluorescence spectra**
- **in the core**
- **in the cladding**

- **Scintillating fiber**
- **Wavelength-shifting**

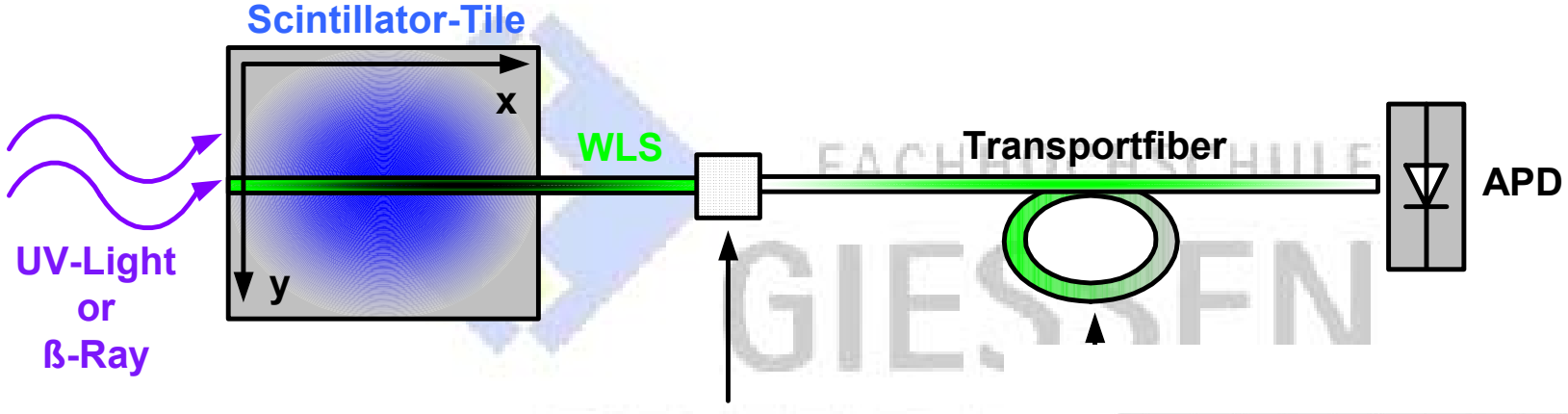
Basics of FPOFs: lateral excitation



Absorption spectra of different FOFs

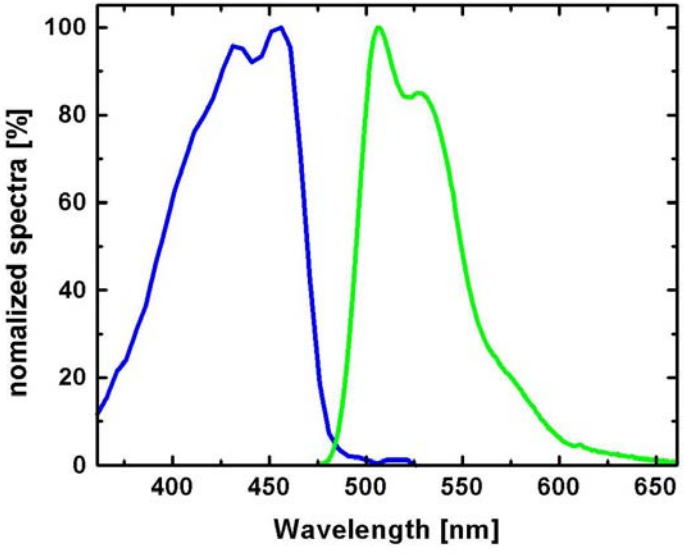


Recommendation for TESLA-detector



Simulation of high-energy particle:

- UV – Light
- ß - Ray



Outlook for TC-fibers

Thick-core Step-Index Fibers can be used in many (new or well-known) applications
many possibilities are feasible

Starting with the detailed description of the require-ments (for the whole system) within the application, the fiber has to be selected from existing ones or adjusted (many solutions possible!)

Parallel,
- **critical parameters have to be studied**
- **test-procedures (and standards) have to be established in a cooperation of end-users and suppliers**

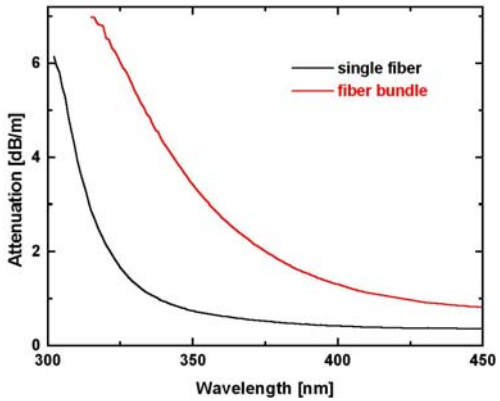
POLYMER OPTICAL FIBERS: NEW APPLICATIONS

100 JAHRE Ingenieur-Ausbildung in Friedberg

FACHHOCHSCHULE GIESSEN FRIEDBERG

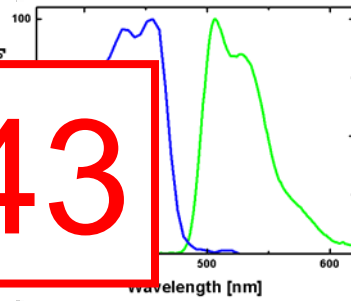
POF for UV-applications

- Good transmission in UV-A
- Flexible waveguide
- POF-bundle possible
- New UV-LEDs



Fluorescent POF

- Absor… adjust…
- Colour…
- Detect… energy particles and radiation
- Optical slipring



Booth C1. 644, 543

Illumination and advertisement

- End- or side-illumination
- Fiber-bundles vs. thick-core fibers
- Efficient light coupling
- New blue and white LEDs