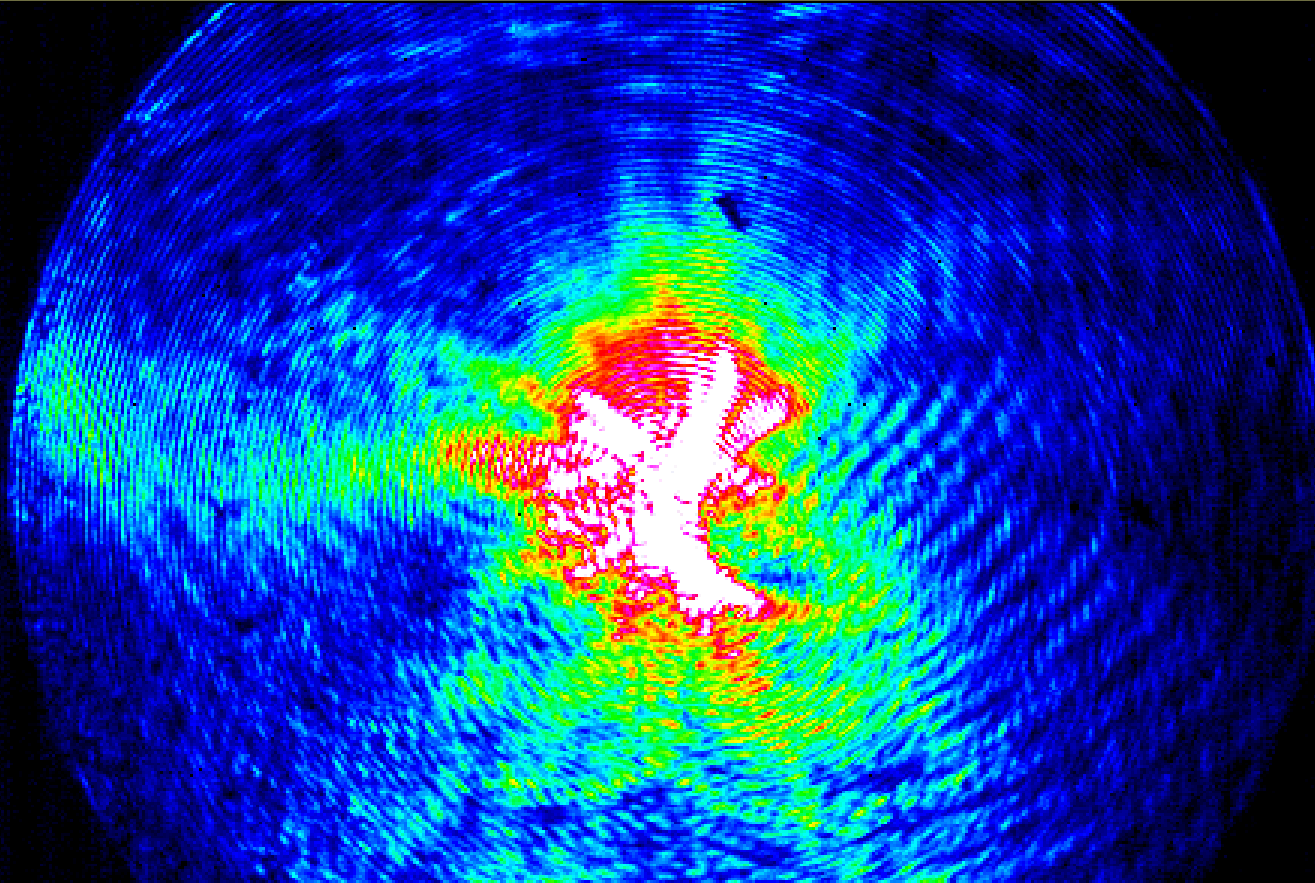


Mode excitation and bandwidth of standard large core PMMA fibers



T. Schaal, S. Seiffert, S. Poferl, E. Zeeb
DaimlerChrysler Research and Technology

Outline

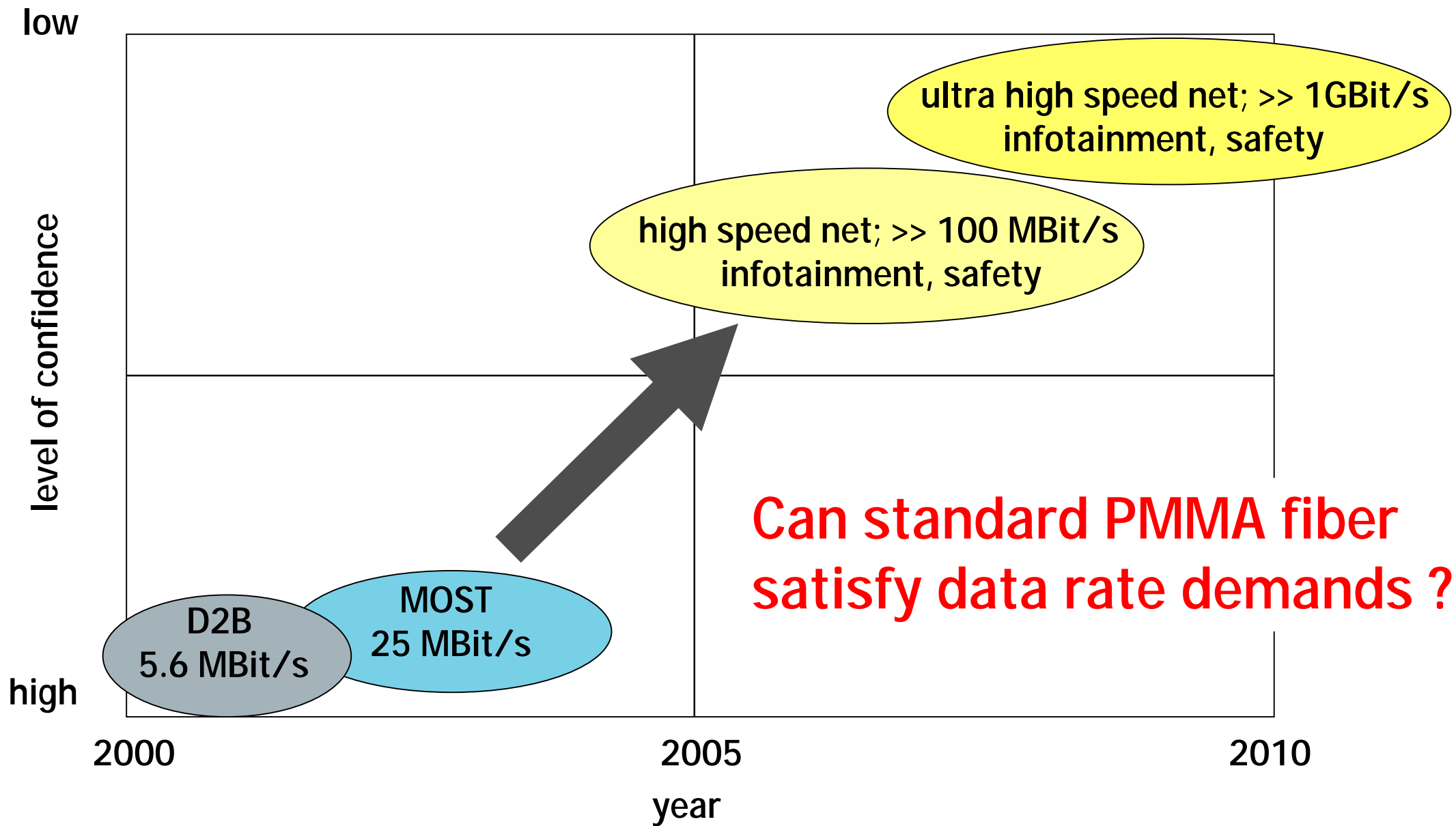
- motivation
- theoretical bandwidth estimations
- fiber bandwidth measurements
- near- and far-field measurements
- red VCSEL driven data link system
- conclusion

Optical data buses in cars: state-of-the-art

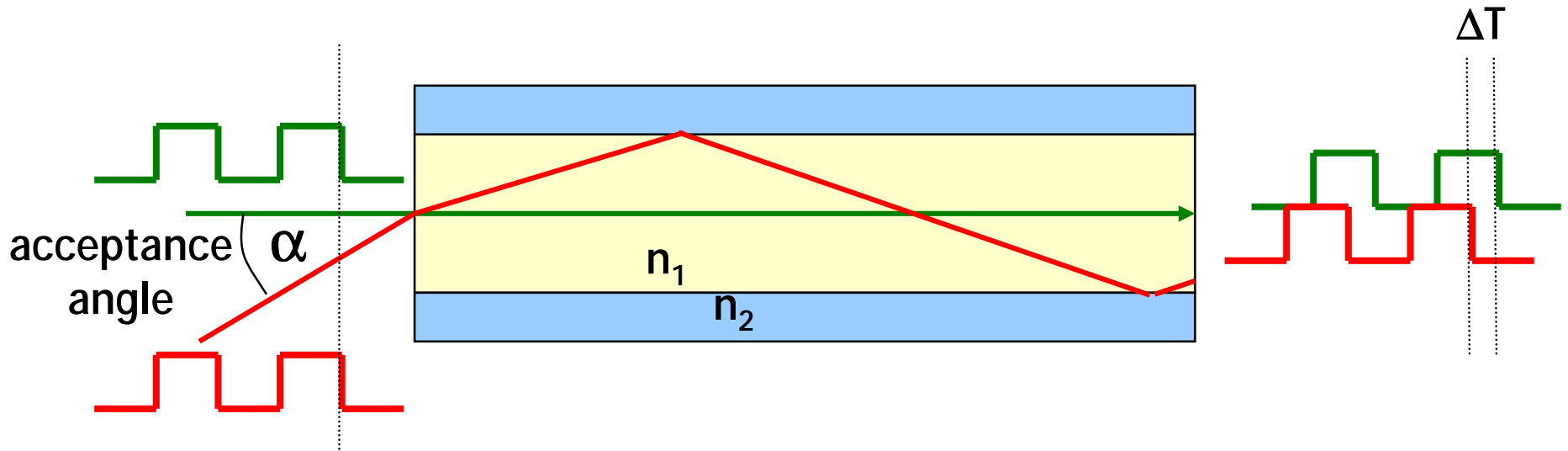
- 1 mm PMMA - fiber
- red LEDs
- telematics/infotainment applications
- ring topology
- 10 - 20 m link length
- 5.6 / 22.4 MBit/s



Expected data rates for automotive data buses



Theoretical bandwidth estimations: ray model



Time delay:
 $\Delta T \approx L(NA)^2 / (2n_1c)$

$NA = 0.5$

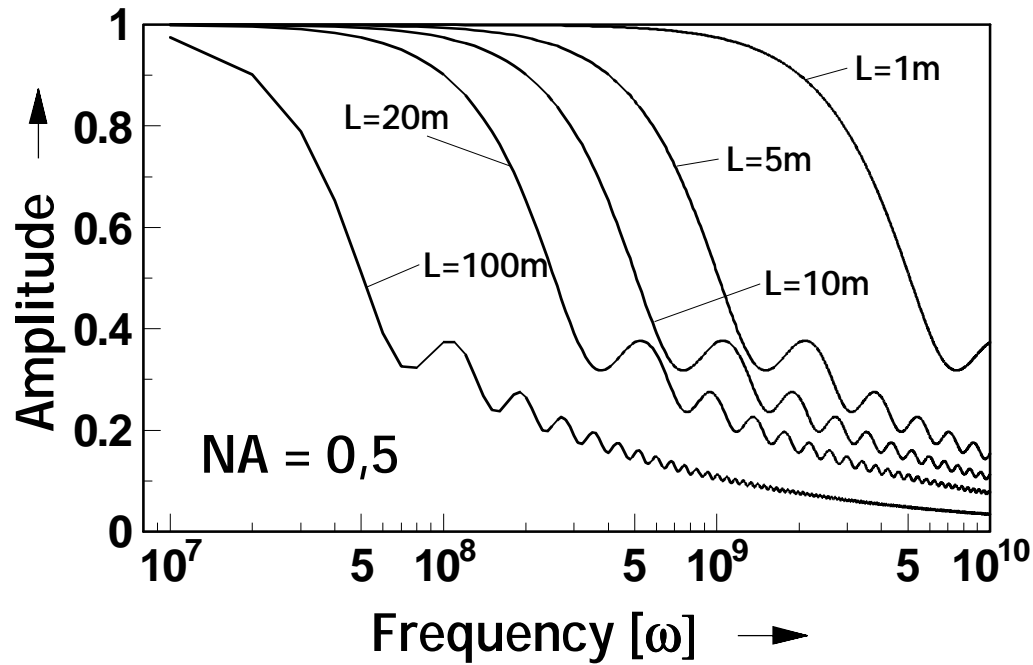
$\Delta T / L \approx 0.3 \text{ ns/m}$
 $L = 20 \text{ m} \rightarrow \Delta T \approx 6 \text{ ns}$

Bandwidth length product:
 $B \cdot L \approx (n_1c) / (NA)^2$

$n_1 = 1.5$

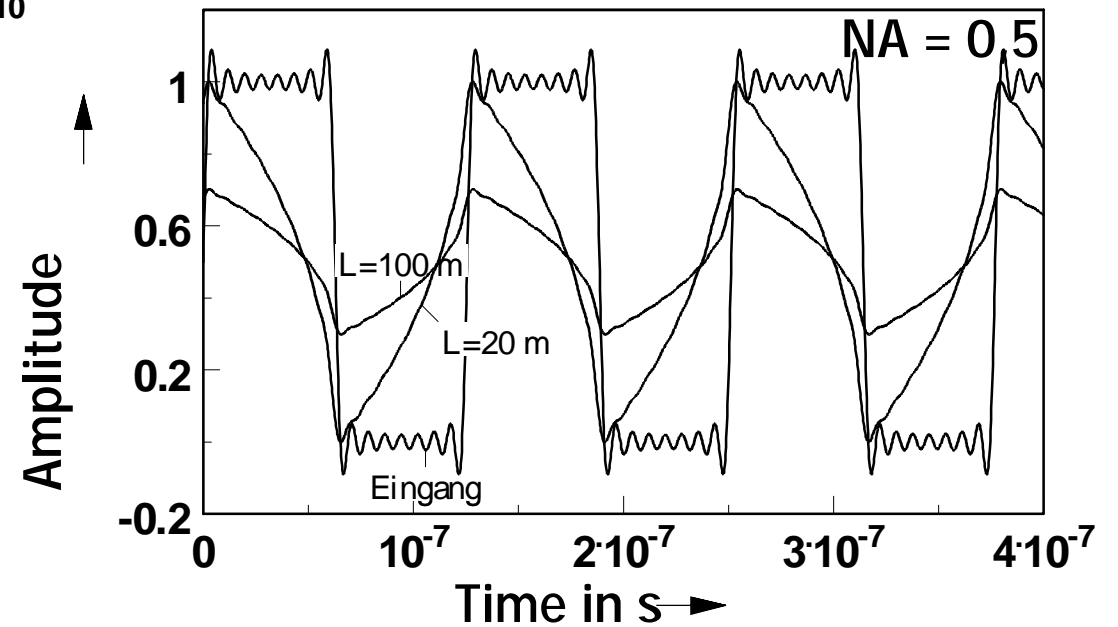
$B \cdot L \approx 3.5 \text{ GBit/s} \cdot \text{m}$
 $L = 20 \text{ m} \rightarrow B \approx 170 \text{ MBit/s}$

Transfer function:

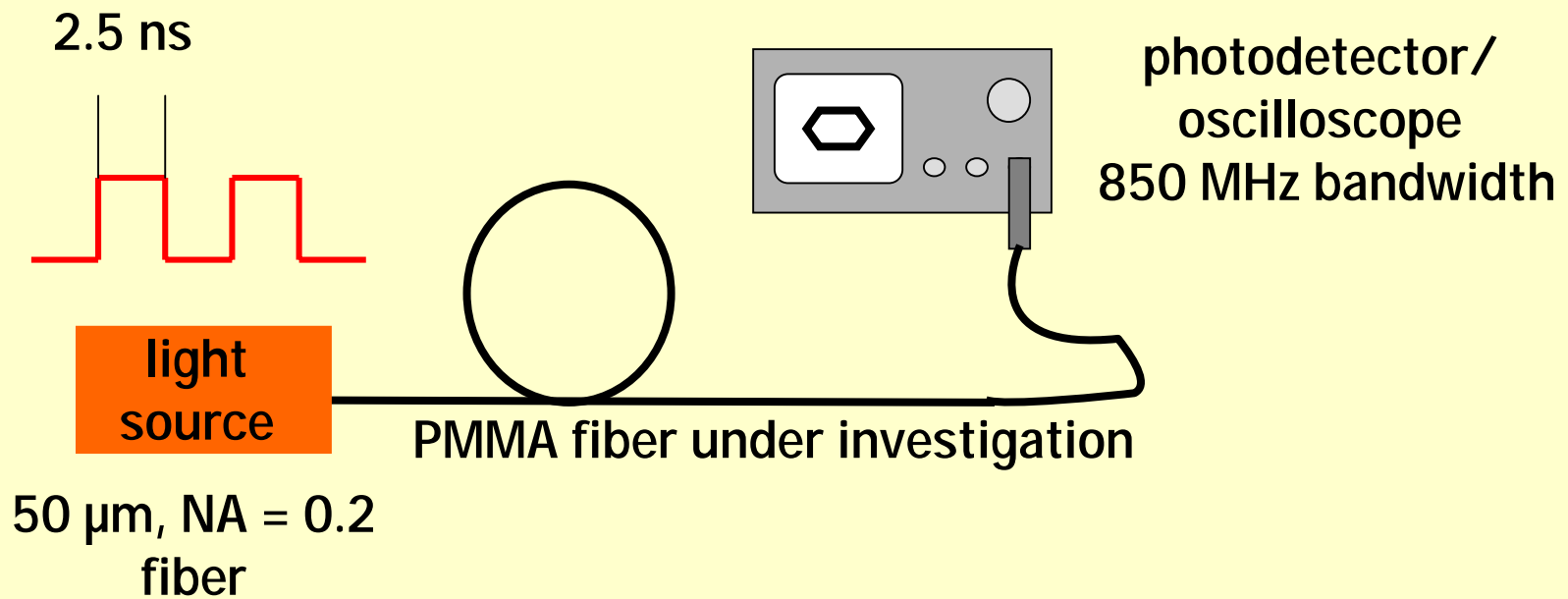


← several length

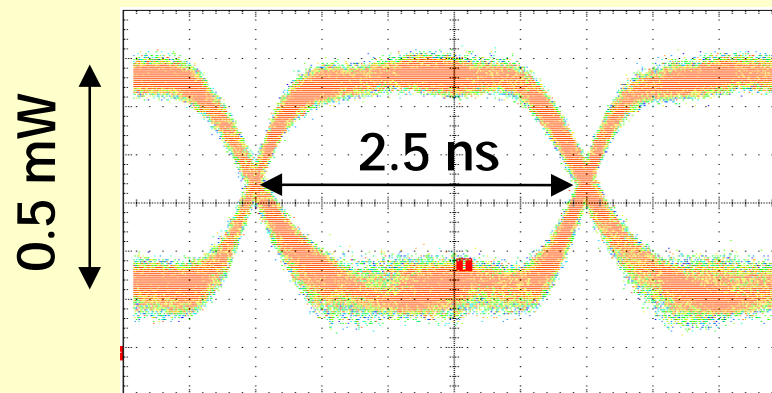
simulation with square pulses



Bandwidth measurement:

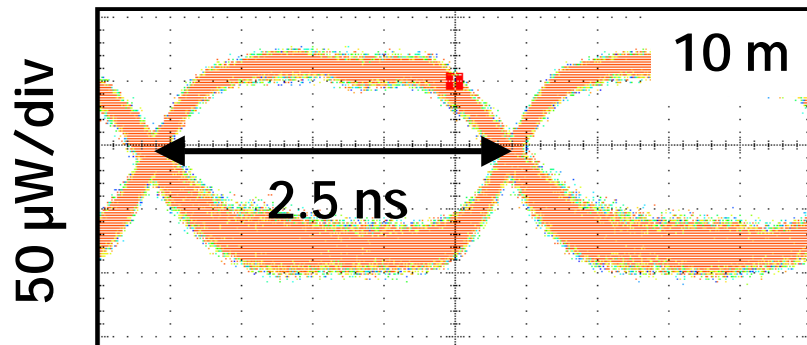
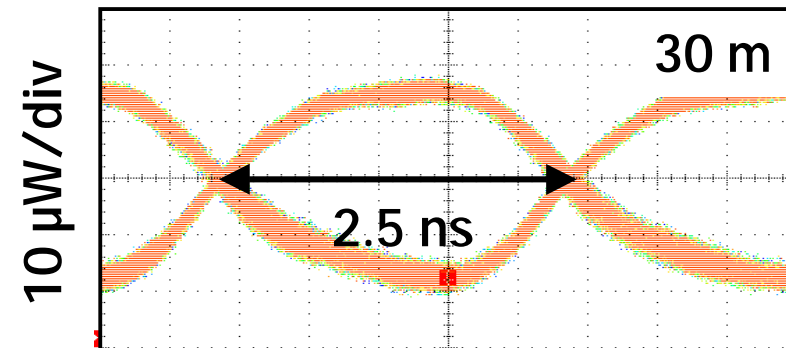
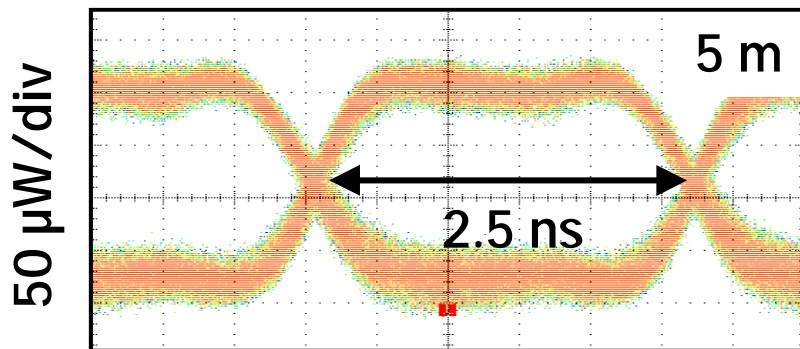
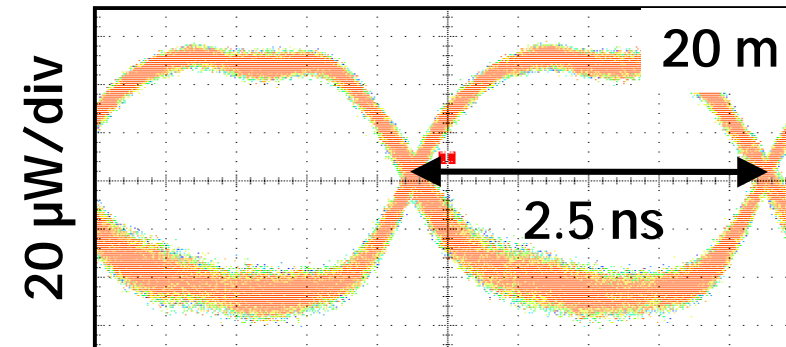
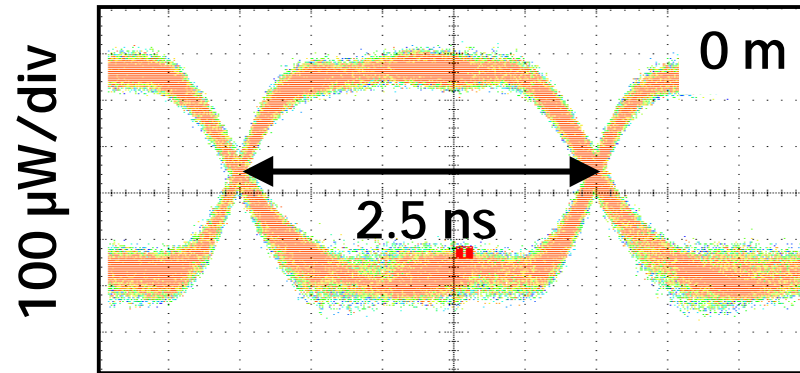


reference measurement without PMMA fiber



rise/fall time: < 1 ns

Bandwidth measurement: MOST cable

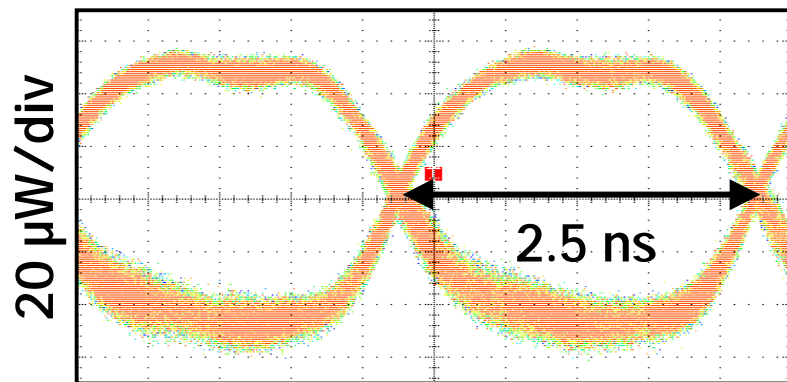


- increase of rise/fall time: $\approx 0.5 \text{ ns} / 10 \text{ m}$
- eye-closing due to fiber attenuation
- increase in PWD: not observed

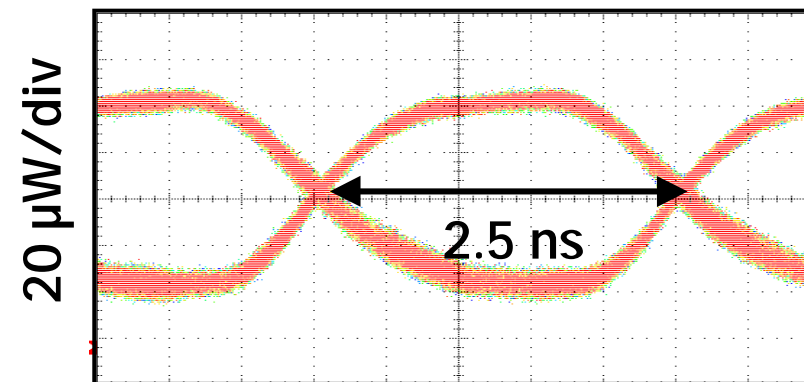
Bandwidth measurement: comparison of fibers

Eye-pattern after 20 m fiber length

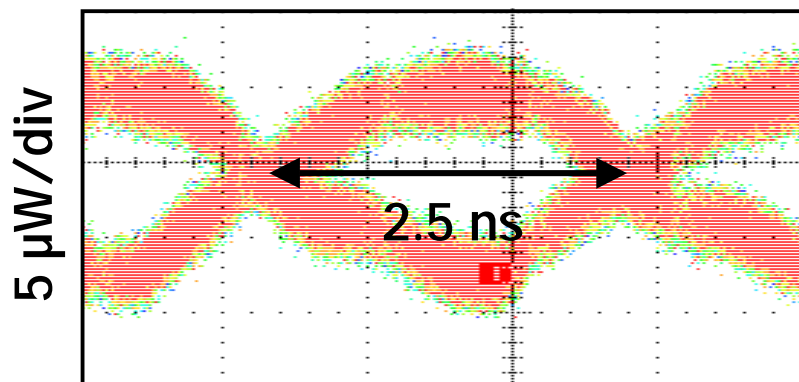
MOST: $\alpha \approx 0.15$ dB/m @ 650 nm



Toray: $\alpha \approx 0.15$ dB/m @ 650 nm



Hoechst: $\alpha \approx 0.3$ dB/m @ 650 nm

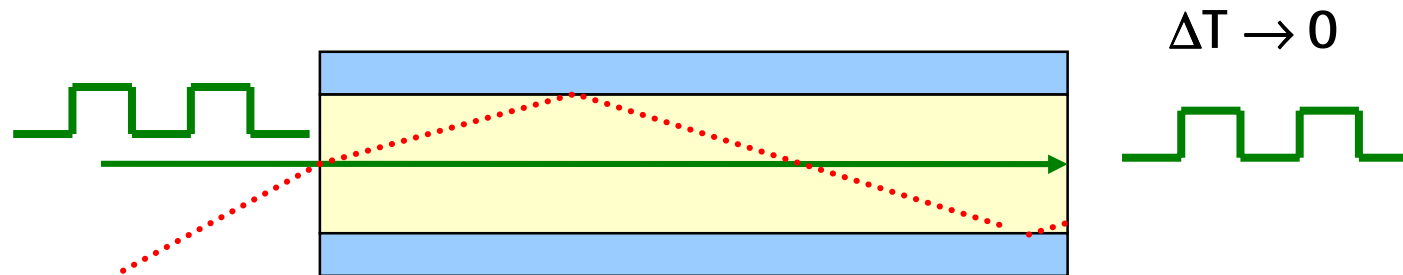


independent of individual fiber:

- increase of rise/fall time: ≈ 0.5 ns / 10 m
- eye-closing due to fiber attenuation
- increase in PWD: not observed

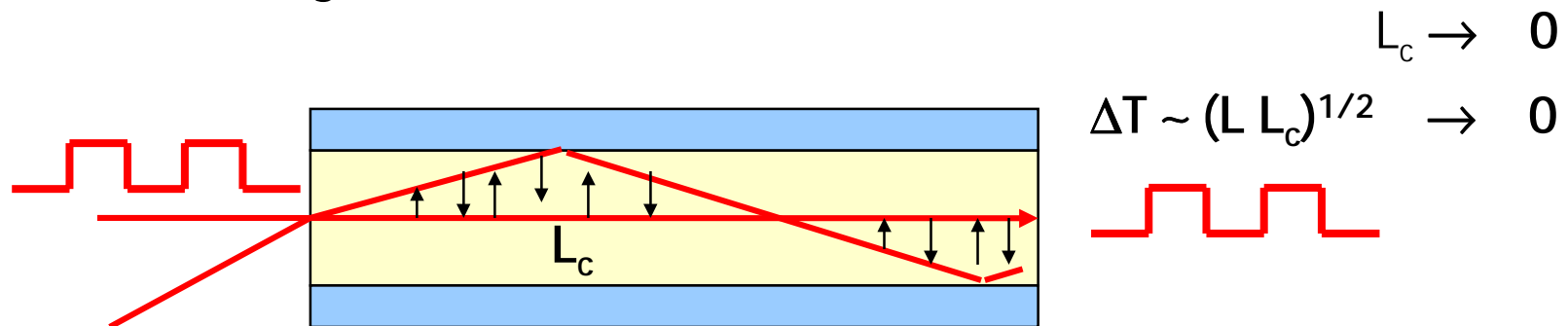
Expansion of fiber bandwidth

1.) excitation of selected mode groups



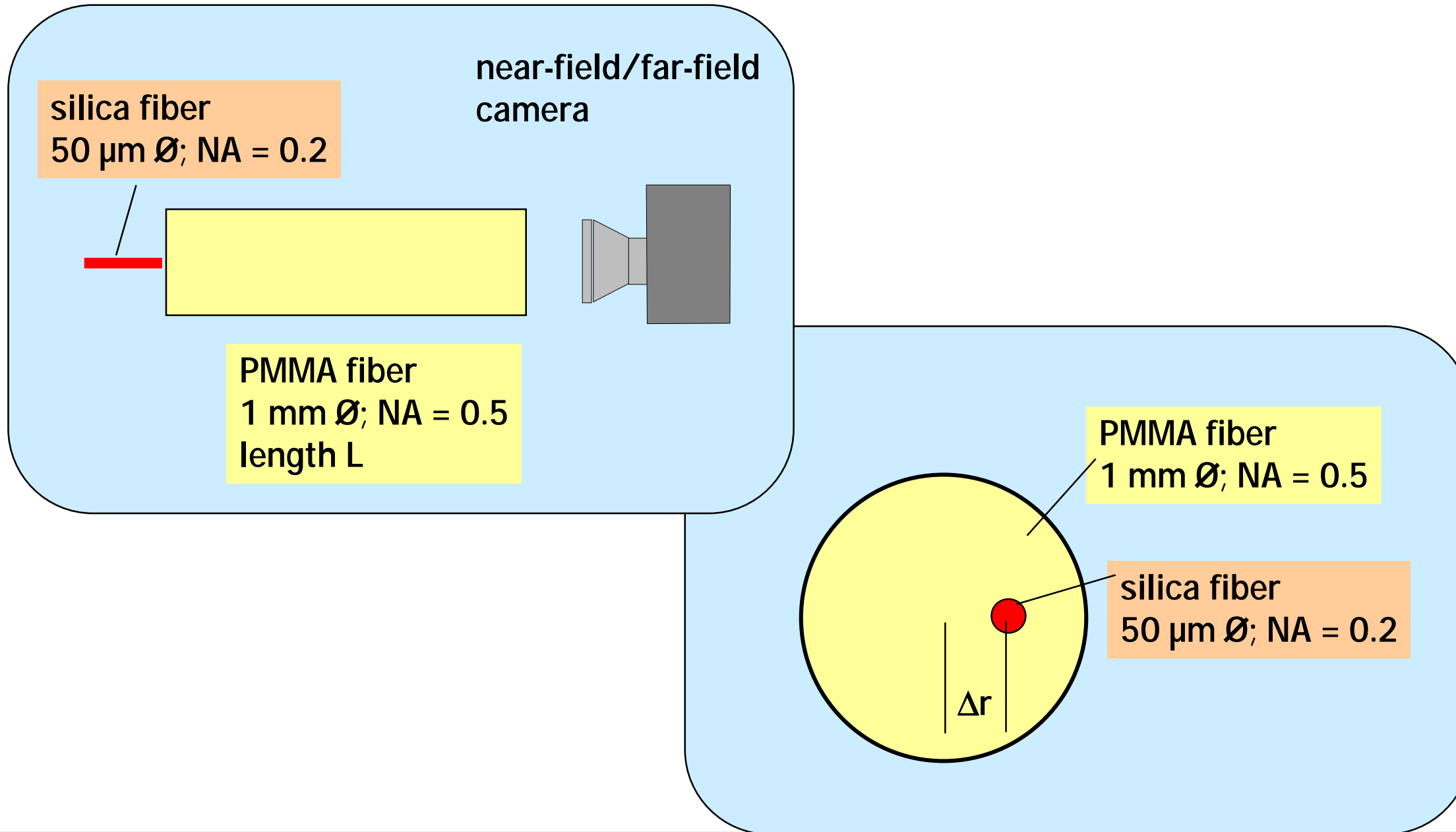
not useable if mode mixing (bending, micro bending) can not be avoided

2.) strong mode mixing in the fiber



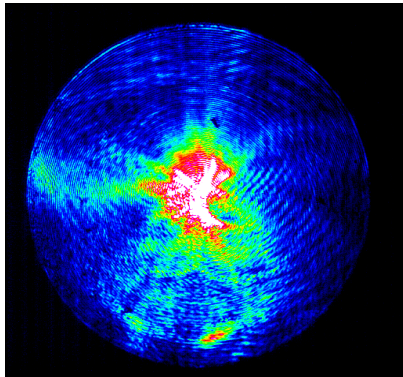
no effects expected which suppress mode mixing

Mode excitation: experimental setup

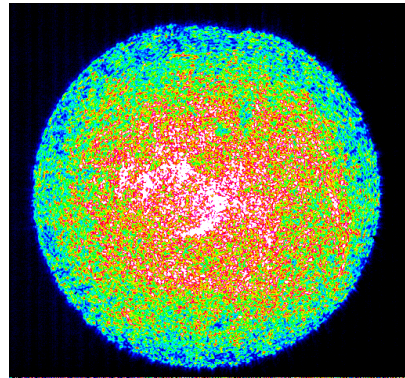


Fiber near-field pattern: central coupling, $\Delta x = 0$

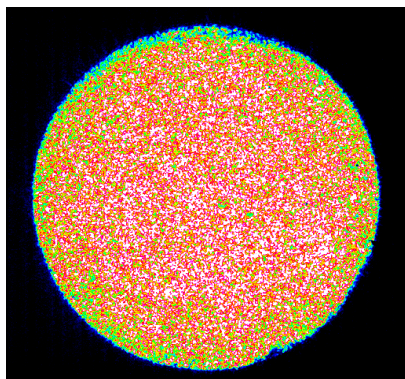
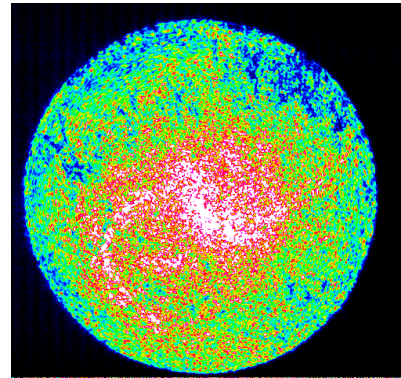
L = 6 cm



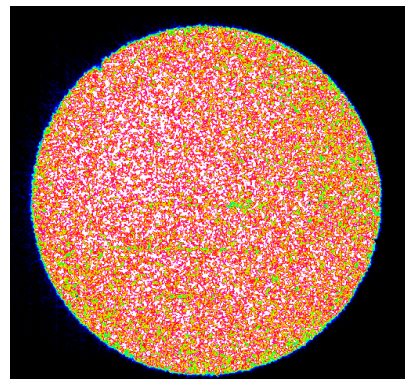
L = 20 cm



L = 30 cm



L = 40 cm



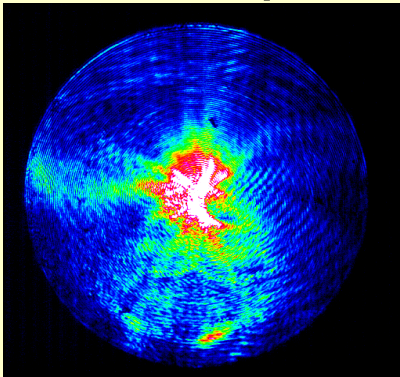
L = 60 cm

after 60 cm PMMA fiber
homogeneous near-field
distribution

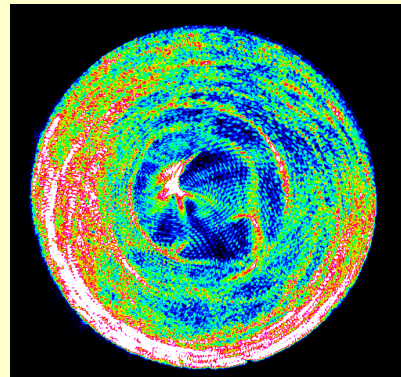
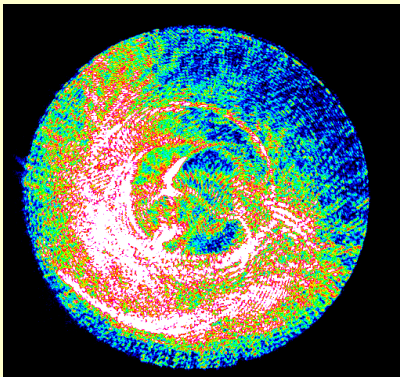
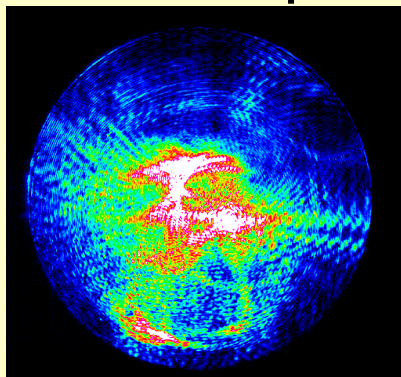
Fiber near-field pattern: off-axis coupling, $\Delta x \neq 0$

L = 6 cm

$\Delta x = 0 \mu\text{m}$



$\Delta x = 100 \mu\text{m}$

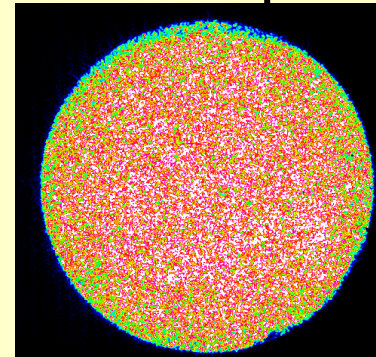


$\Delta x = 300 \mu\text{m}$

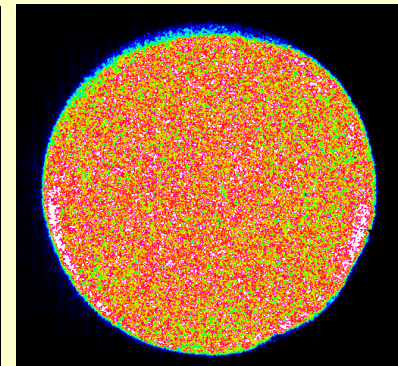
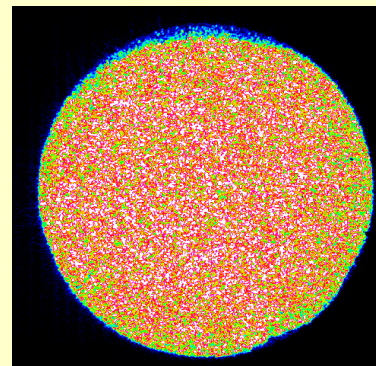
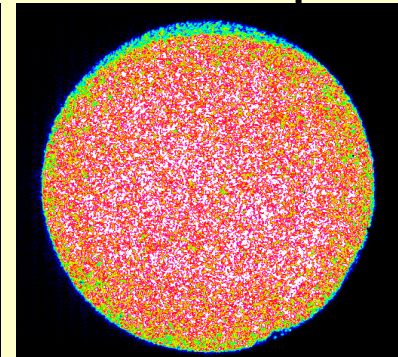
$\Delta x = 400 \mu\text{m}$

L = 40 cm

$\Delta x = 0 \mu\text{m}$



$\Delta x = 100 \mu\text{m}$

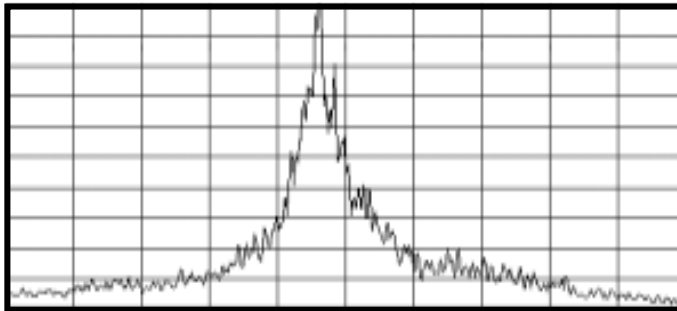


$\Delta x = 300 \mu\text{m}$

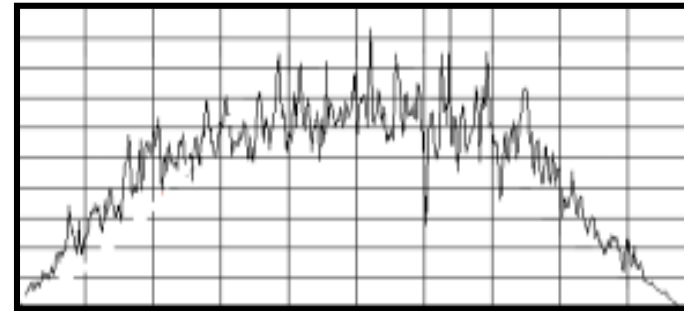
$\Delta x = 400 \mu\text{m}$

Fiber far-field pattern: on-axis coupling

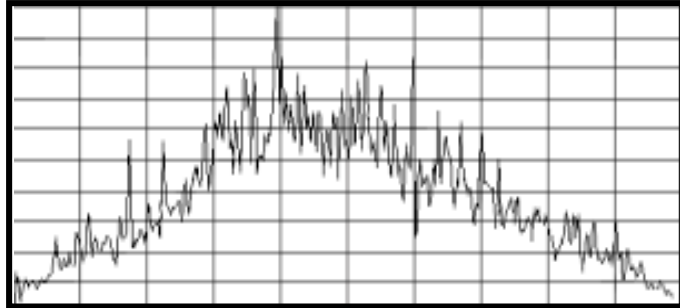
6.5 °/div. L = 6 cm



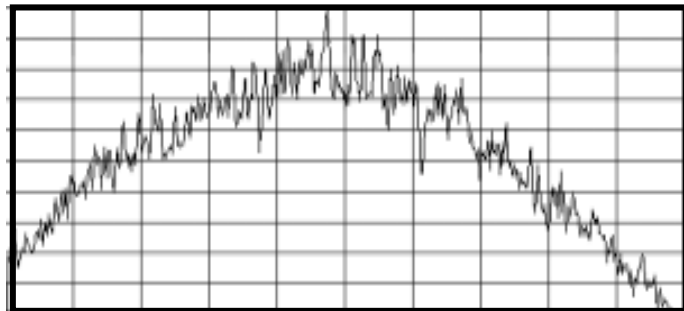
6.5 °/div. L = 60 cm



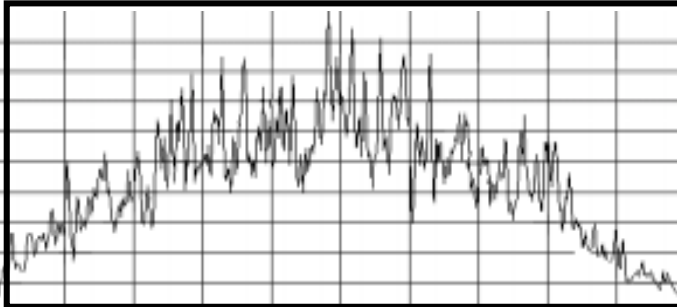
6.5 °/div. L = 20 cm



6.5 °/div. L = 10 m



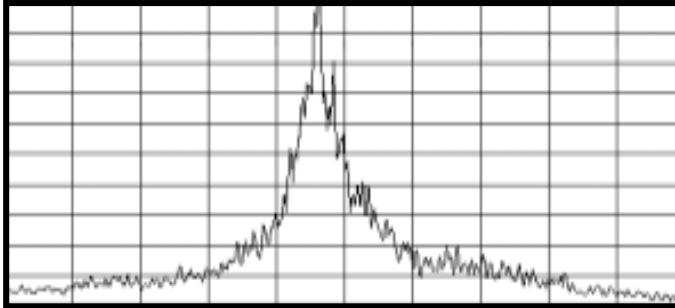
6.5 °/div. L = 30 cm



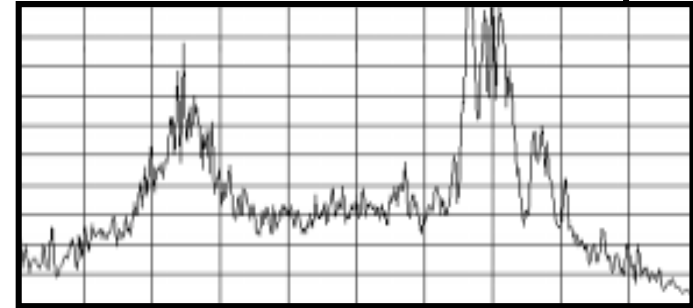
after 60 cm PMMA fiber
nearly equilibrium mode
distribution

Fiber far-field pattern: 6 cm fiber length

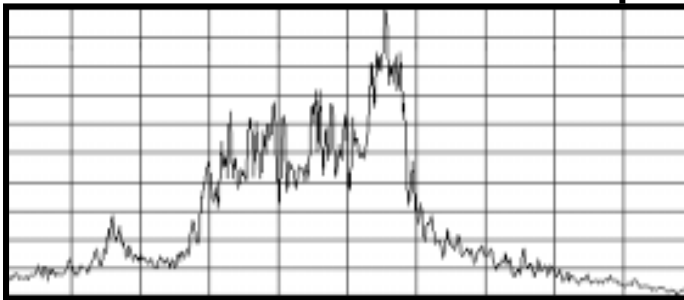
6.5 °/div. on-axis



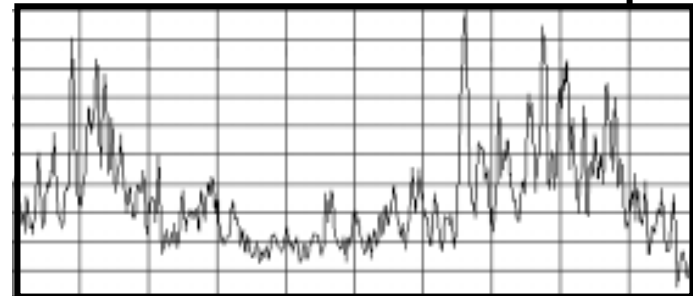
6.5 °/div. $\Delta x = 300 \mu\text{m}$



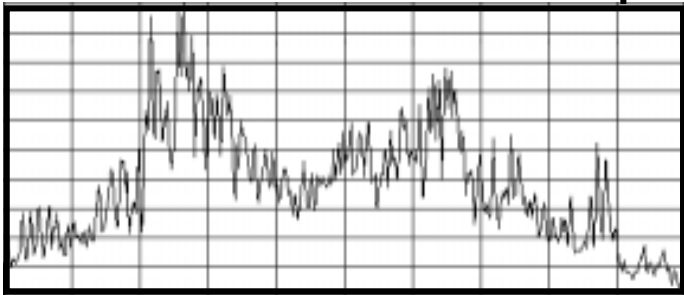
6.5 °/div. $\Delta x = 100 \mu\text{m}$



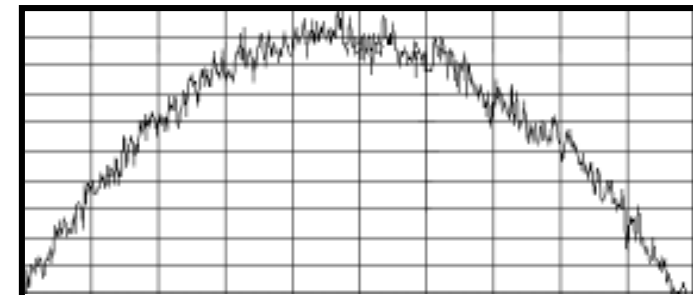
6.5 °/div. $\Delta x = 400 \mu\text{m}$



6.5 °/div. $\Delta x = 200 \mu\text{m}$

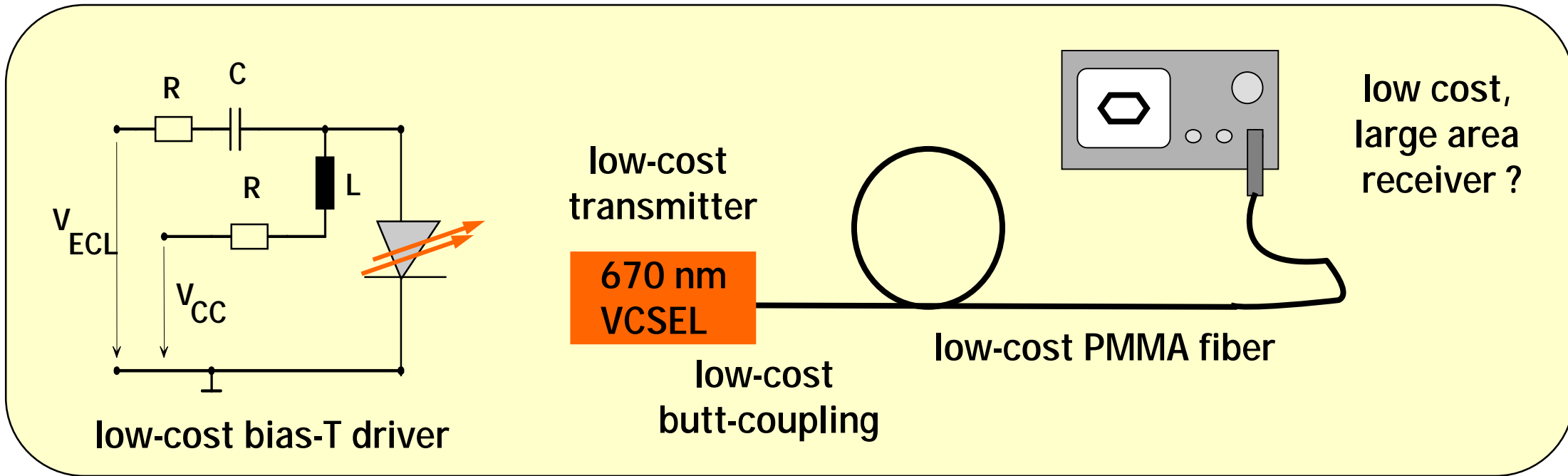


6.5 °/div. LED source

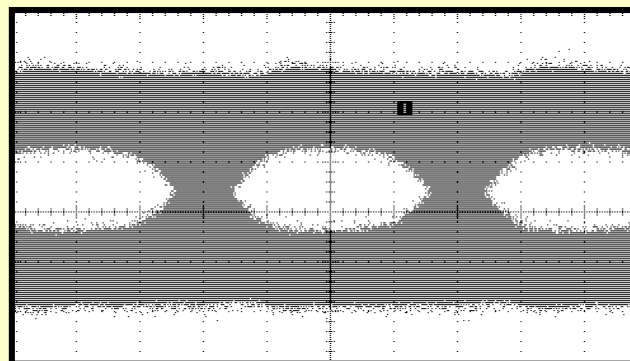
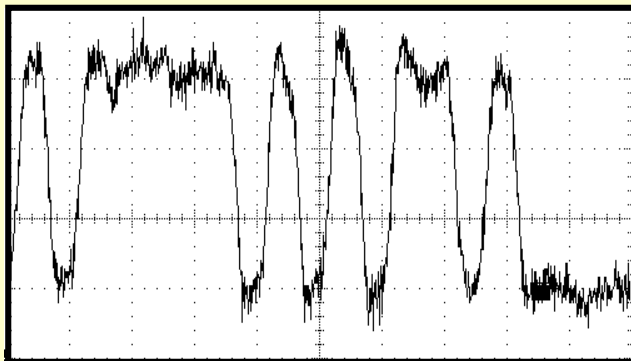


strong dependence of far-field for short fiber length

Potential low cost system: PMMA fiber and red VCSELs



500 MBit/s; PRBS $2^7 - 1$; 10 m PMMA fiber



- Open questions:
- availability of
 - 650 nm VCSELs with stable temperature characteristics
 - large area receivers

Summary

standard 1mm SI PMMA POFs:

- mode coupling length < 50 cm
- fiber bandwidth > 500 MBit/s • 20 m
- data rate of automotive data buses not limited by bandwidth but by fiber attenuation

Potential high bit rate, low-cost data bus system:

- standard 1 mm POF together with 650 nm VCSELs
- Problem: large area photodetectors