Introduction to lasers

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Chapter 4: Features of laser emission

I - Laser efficiency – output power

To complete

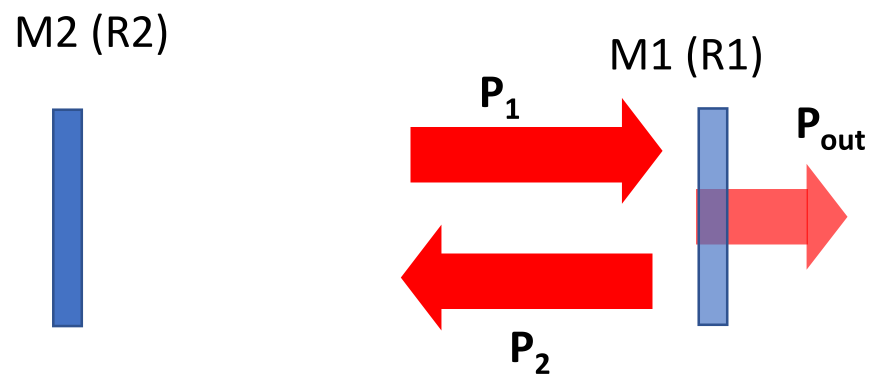
Only a small portion of the internal intensity (or power) determined by $P = Psat\left(\frac{\gamma_0}{\alpha_t} - 1\right)$ leaves the resonator in the form of the useful light (P_{out}).

The internal power (or intensity) is the sum of P1 and P2

$$\left.\begin{aligned} P &= P_1 + P_2 \\ P_{out} &= P_1 \cdot T_1 \\ P_2 &= R_1 P_1 \end{aligned}\right\} \Rightarrow P = \underbrace{\frac{P_{out}}{T_1}}_{P_1} + R_1 \cdot \underbrace{\frac{P_{out}}{T_1}}_{P_1}$$

$$P = \frac{(1 + R_1)}{(1 - R_1)} P_{out}$$

$$\boxed{P_{out} = \left(\frac{1 - R_1}{1 + R_1}\right) P}$$



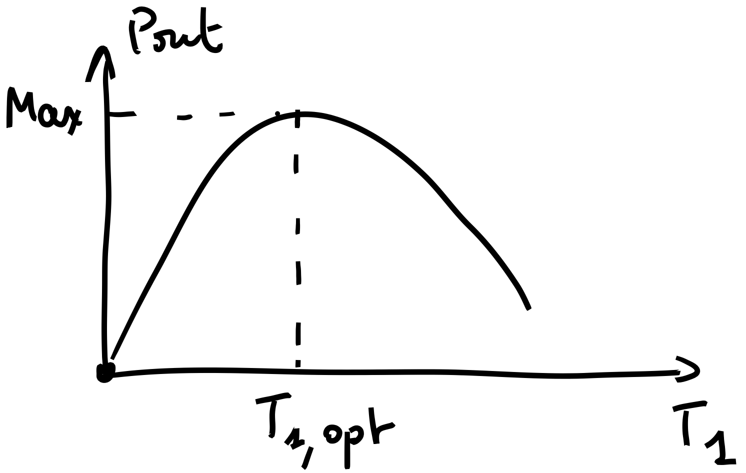
[R_1 and R_2 close to 1 = assumption $\Rightarrow$ P does not depend on z.]

Note: $R_1 \simeq 1 \Rightarrow P_{out} = \frac{T_1}{2} P \Rightarrow P_{out} \propto T_1$

Optimization of the output coupler coefficient → see exercise

To complete

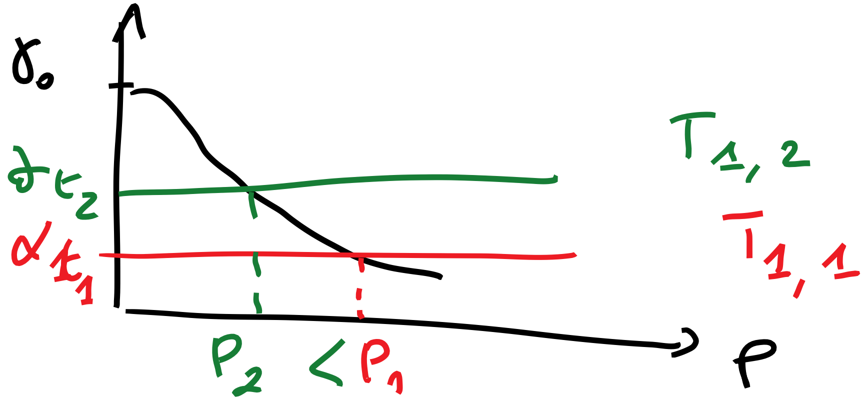
Optimization of the output coupler coefficient → see Tutorial 1



If $T_1 \simeq 0$ => All the power is confined inside the cavity => P_{out} : small

If $T_1 \nearrow$ Then the level of losses $\nearrow$ => $P \searrow$ => $P_{out} \searrow$

↳ Compromise

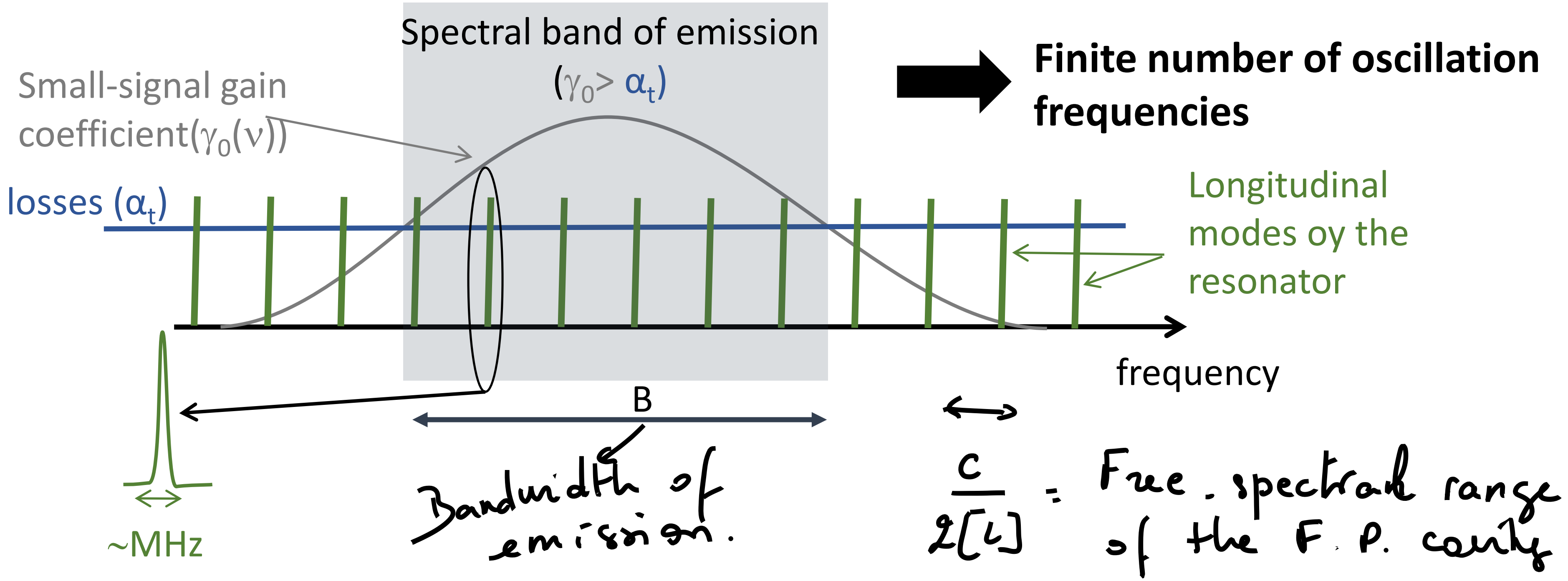


Comment: Laser efficiency → $P_{out} = f(P_{pump})$ → see Tutorial 1

$$\alpha_t = \alpha - \frac{\ln R_1 R_2}{2d}$$

II - Spectral characteristics

- Threshold condition: $\gamma_0 > \alpha_t$
- Phase condition giving the longitudinal modes: $\nu_q = q.\frac{c}{2,[L]}$



Finite number of oscillation frequencies

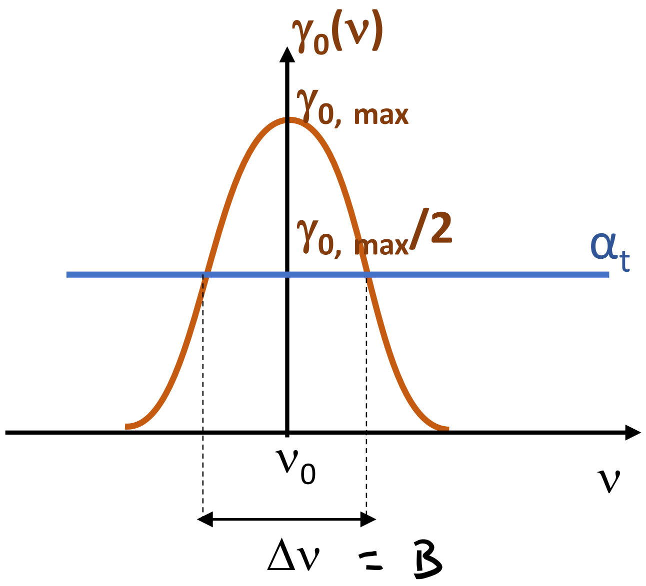
$$\nu = \frac{c}{\lambda} \rightarrow \Delta\nu = \frac{c}{\lambda_0^2}\Delta\lambda$$

Typical spectral characteristics of well-known lasers

	$\Delta\nu$ Gain bandwidth	L (cavity)	c/2[L]	Number of modes*
He-Ne (λ_0= 632 nm)	1 GHz/ 1.3 pm	0,3 m	2 GHz	2;3 modes
Nd:YAG (λ_0= 1064 nm)	150 GHz/ 0.5 nm	1 m	150 MHz	1 000 modes
Ytterbium doped fiber (λ_0= 1050 nm)	2.7 THz/ ~10 nm	10 m	15 MHz	180.10^3 modes

*

$$= \frac{\Delta\nu}{\frac{c}{2[L]}}$$



To complete

III - Spatial characteristics

1. Definition of a transverse mode

Transverse mode: electromagnetic field distributions which reproduces itself after a full cavity round trip

The laser emission starts on the spontaneous emission which is a kind of noisy signal. At each round trip this noise is filtered ~~by~~ the components of finite size of the cavity until a stable transverse profile is established

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TRANSVERSE MODE

In particular the Gaussian beam is a transverse mode of the Fabry-Perot cavity.

To complete

2. Autocollimation condition for free-space cavities

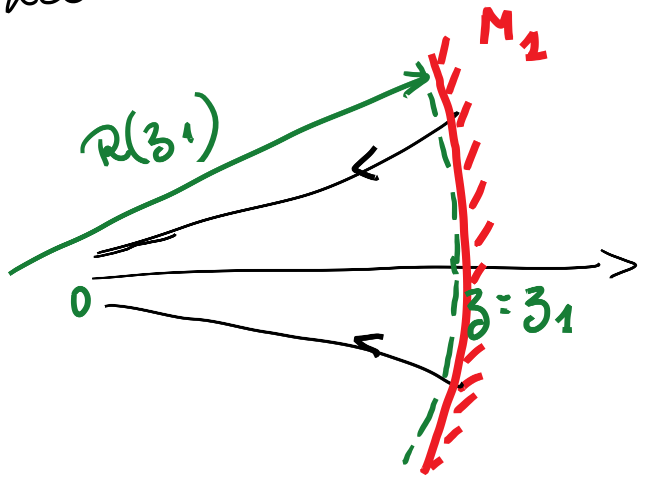
Case of the Gaussian beam

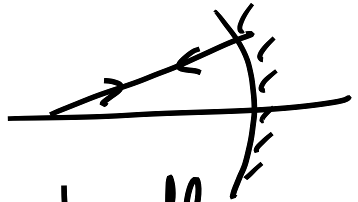
Let's consider a Gaussian beam reflected by a spherical mirror.

Autocollimation condition: $\boxed{R(z_1)} = \boxed{R_{M_1}}$

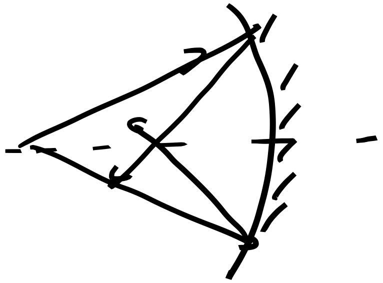
Gaussian Beam

Curvature radius of M_1





autocoll



no autocoll

The reflected be retraces the incident beam

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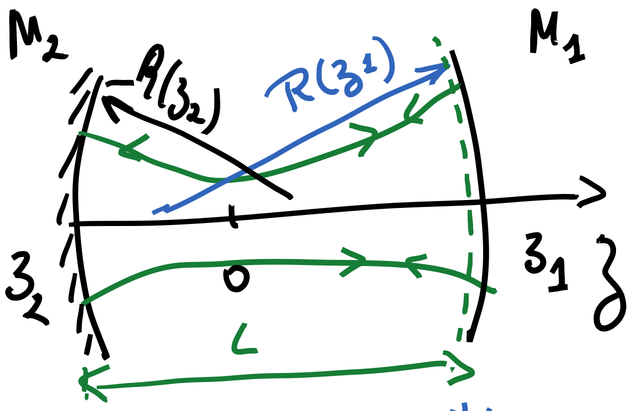
– Condition for transverse mode

$\boxed{R_{M_1}}$ = curvature radius of the spherical mirror M_1



$R(z) = z + \frac{d^2}{z} > z$

$M_1 \rightarrow R_{M_1}$ curvature > 0 concave mirrors

$M_2 \rightarrow R_{M_2}$ " > 0

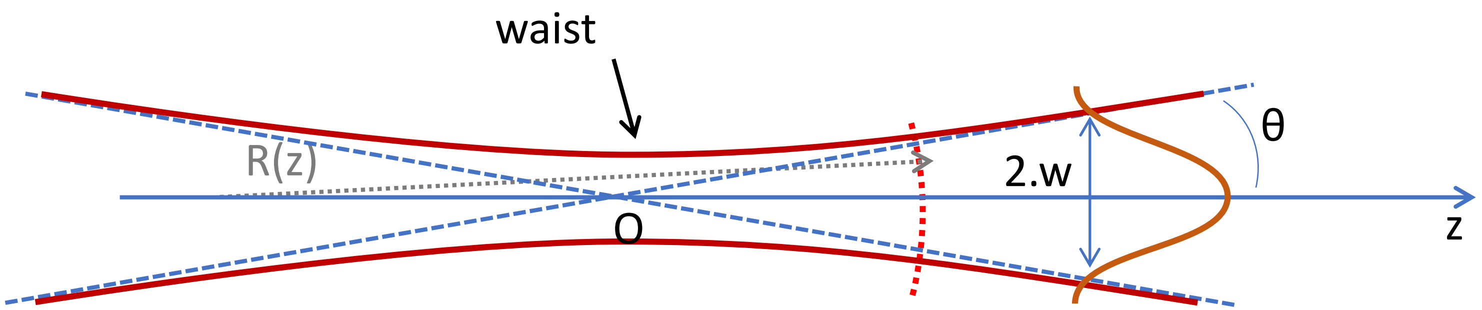
Gaussian beam ≡ Mode of the FP cavity

$$\begin{cases} R_{M_1} = R(z_1) \\ \underbrace{R_{M_2}}_{\text{mirrors}} = \underbrace{-R(z_2)}_{\text{Gaussian beam}} \\ L = z_1 - z_2 \end{cases}$$

$R(z_2) < 0$

3. Gaussian beam: TEM00 mode

- Lowest divergence beam

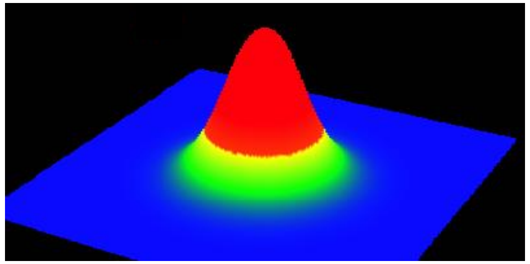


$\alpha = \pi w_0^2/\lambda$ = Rayleigh length

$w^2(z) = w_0^2[1+z^2/\alpha^2]$ = beam radius

$R(z) = z[1+ \alpha^2/z^2]$ = curvature radius

$\theta = \lambda/\pi w_0$ = half divergence

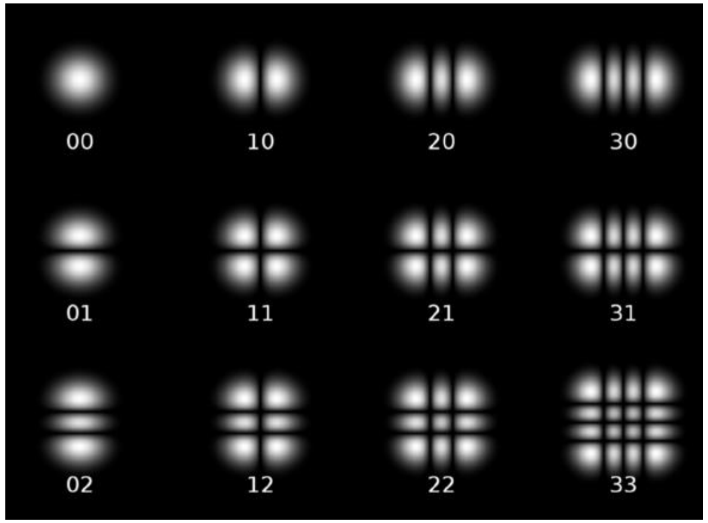


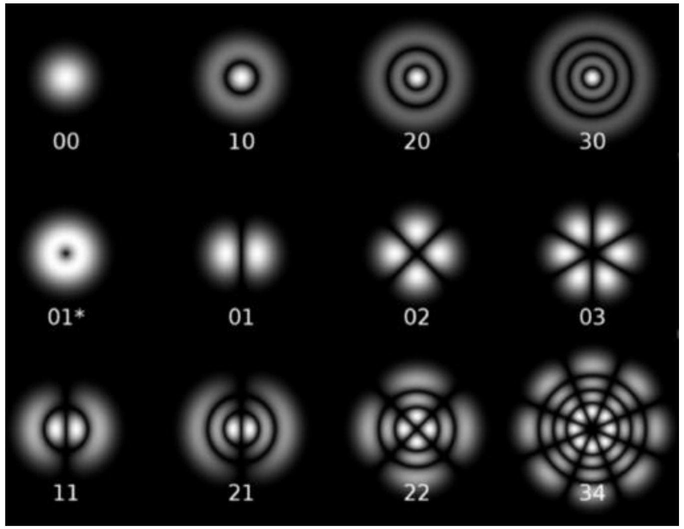
4. Other modes

Modes of free-space cavities:

Laguerre-Gauss modes : rotational symmetry
Hermite-Gauss modes: cartesian symmetry

Free-space propagation invariant





Selection by diffracting obstacles
+ cavity geometry (phase matching on mirrors)

Minimum losses

Multimode beam

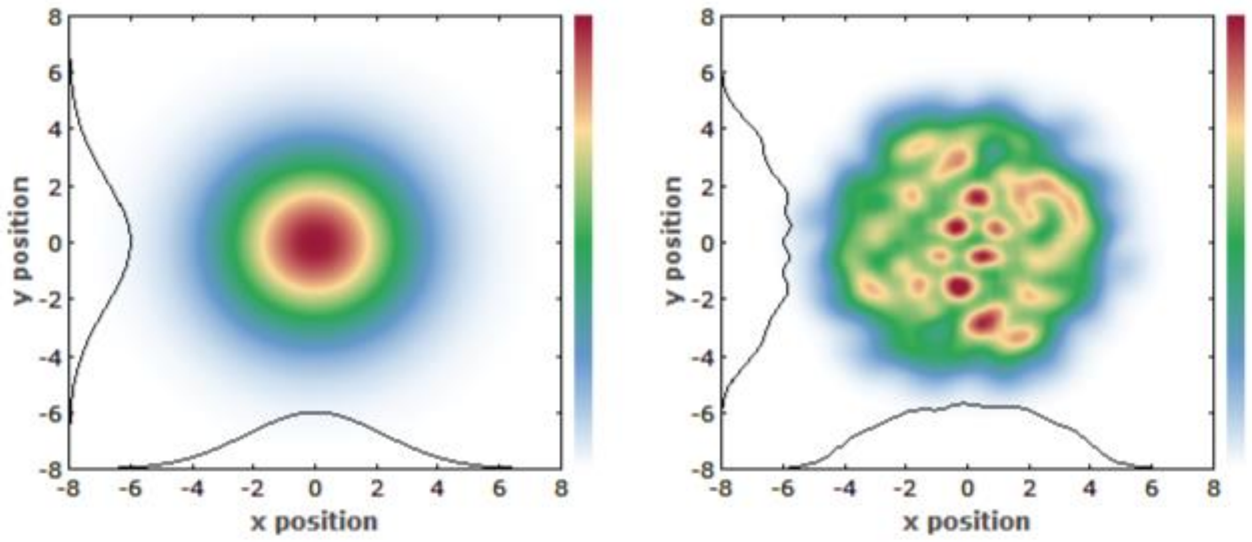
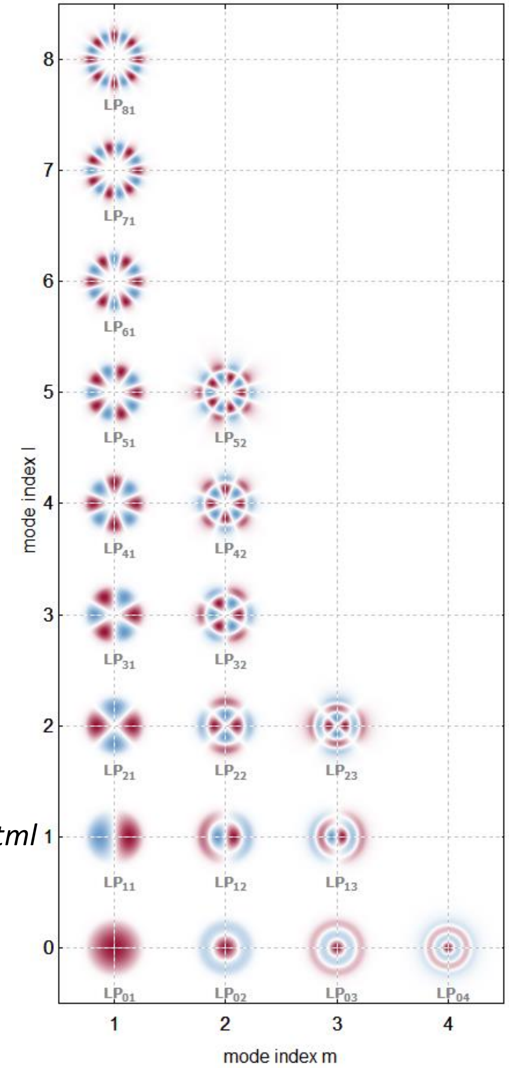


Figure 1: Intensity profiles of a Gaussian beam (left) and a multimode laser beam (right). The latter exhibits more complicated variations of the intensity. Such multimode beams can be generated in lasers where the fundamental resonator modes are substantially smaller than the pumped region in the gain medium.

https://www.rp-photonics.com/beam_profilers.html

Modes of fiber lasers: **LPmn modes**

Invariant propagation though the fiber



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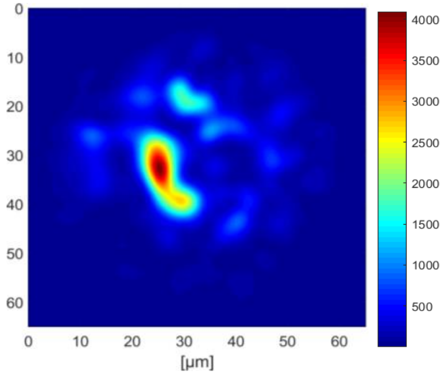

Multimode beam