High power optimization of the ThomX's Fabry-Perot cavity

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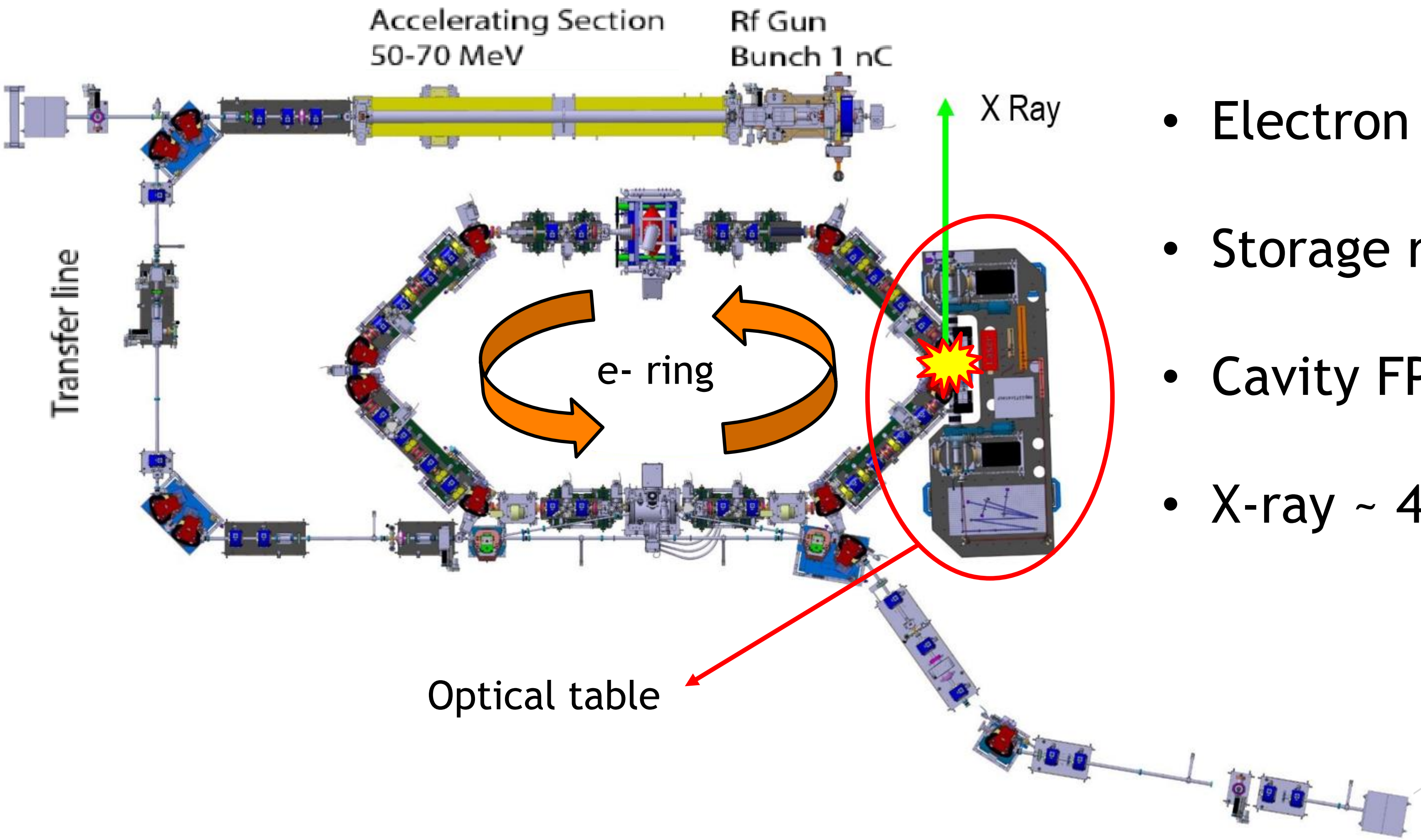
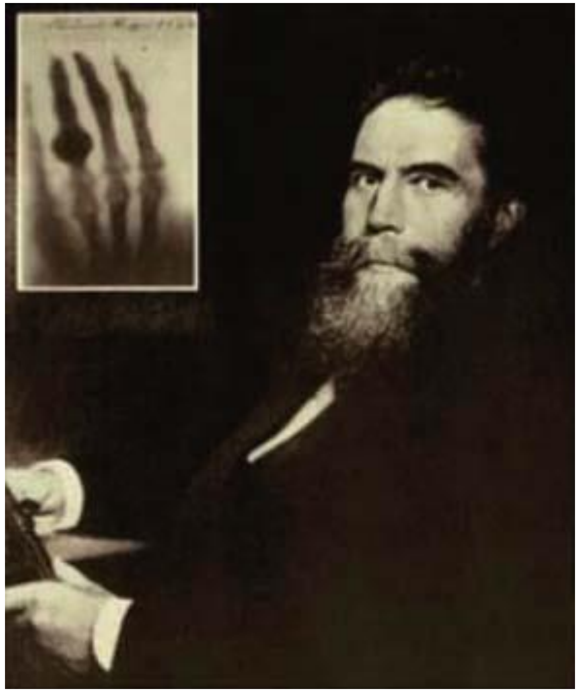
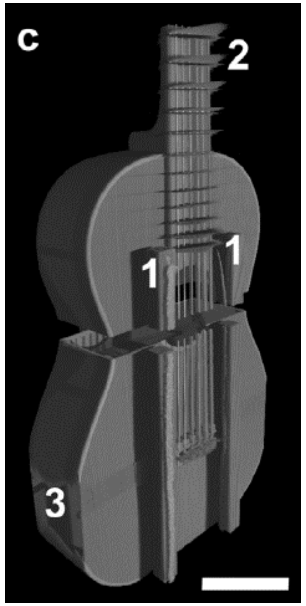
ThomX: An X-ray demonstrator

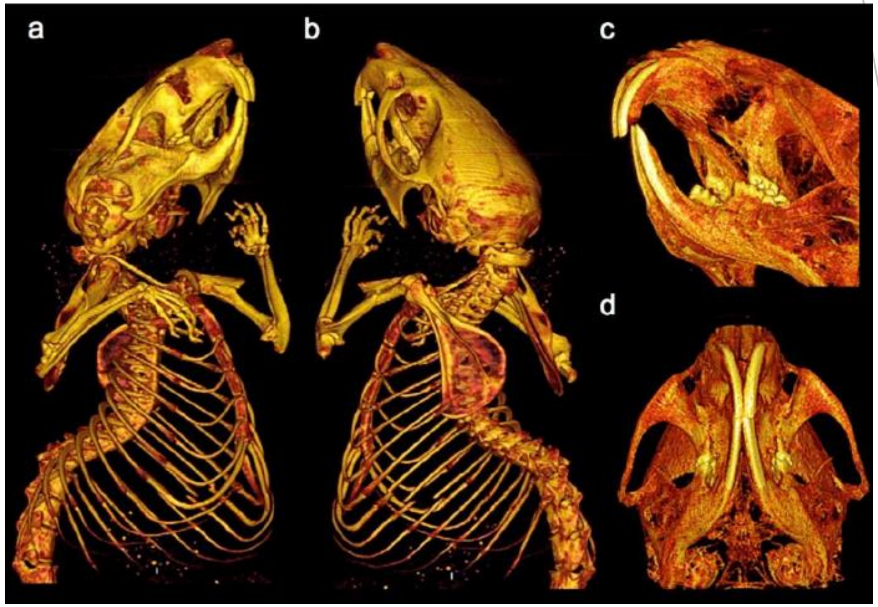


- Electron bunch ~ 50 MeV
- Storage ring ~ 16,67 MHz
- Cavity FP > 100 kW
- X-ray ~ 45 keV

Applications with high flux





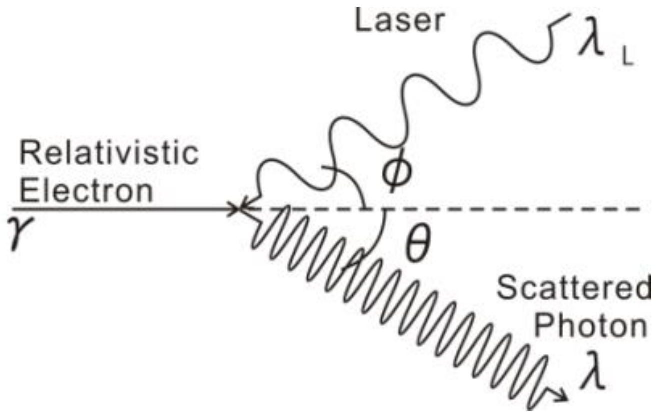


K. Achterhold et al. "Monochromatic computed tomography with a compact laser-driven X-ray source". Scientific Reports 3 (Feb. 21, 2013) Jan Van den Bulcke, et al. " Nondestructive research on wooden musical instruments: From macro- to microscale imaging with lab-based X-ray CT systems ", Journal of Cultural Heritage, 27,(2017)

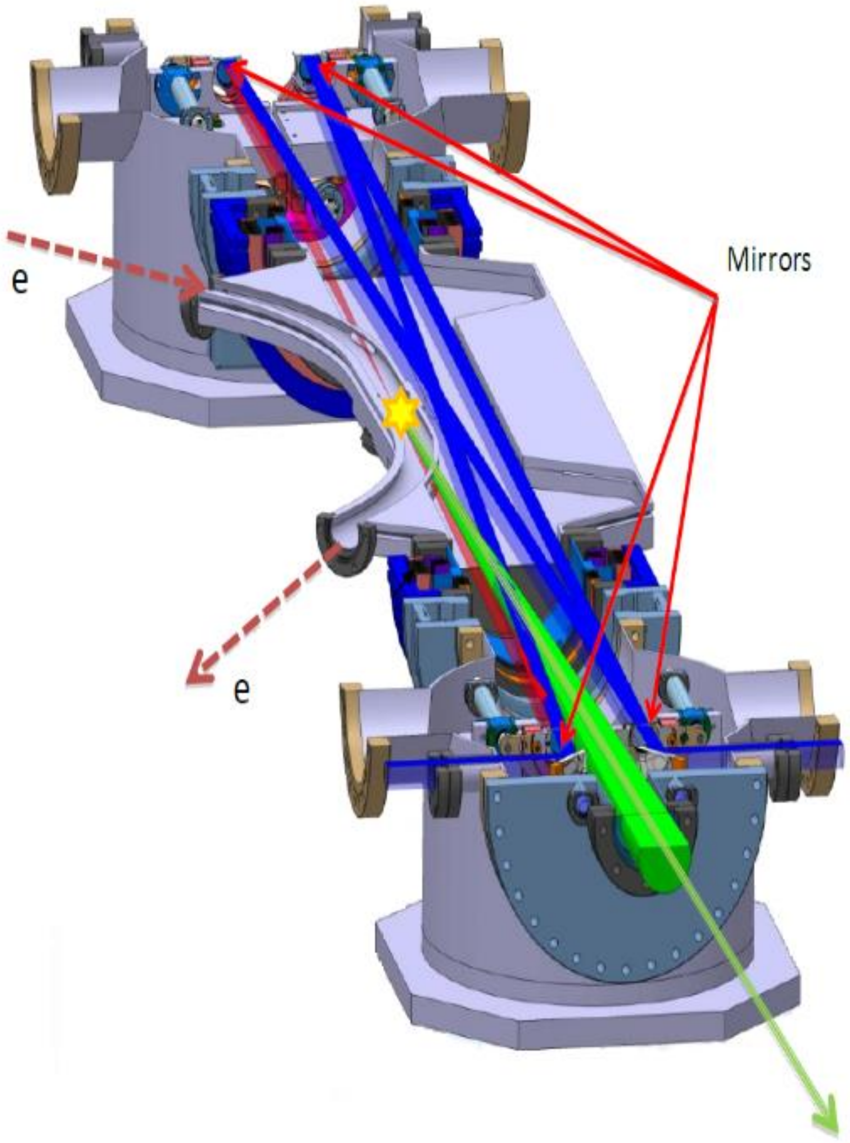
J. Dik et al. "Visualization of a Lost Painting by Vincent van Gogh Using Synchrotron Radiation Based X-ray Fluorescence Elemental Mapping". Analytical Chemistry 80.16 (2008).

Principle

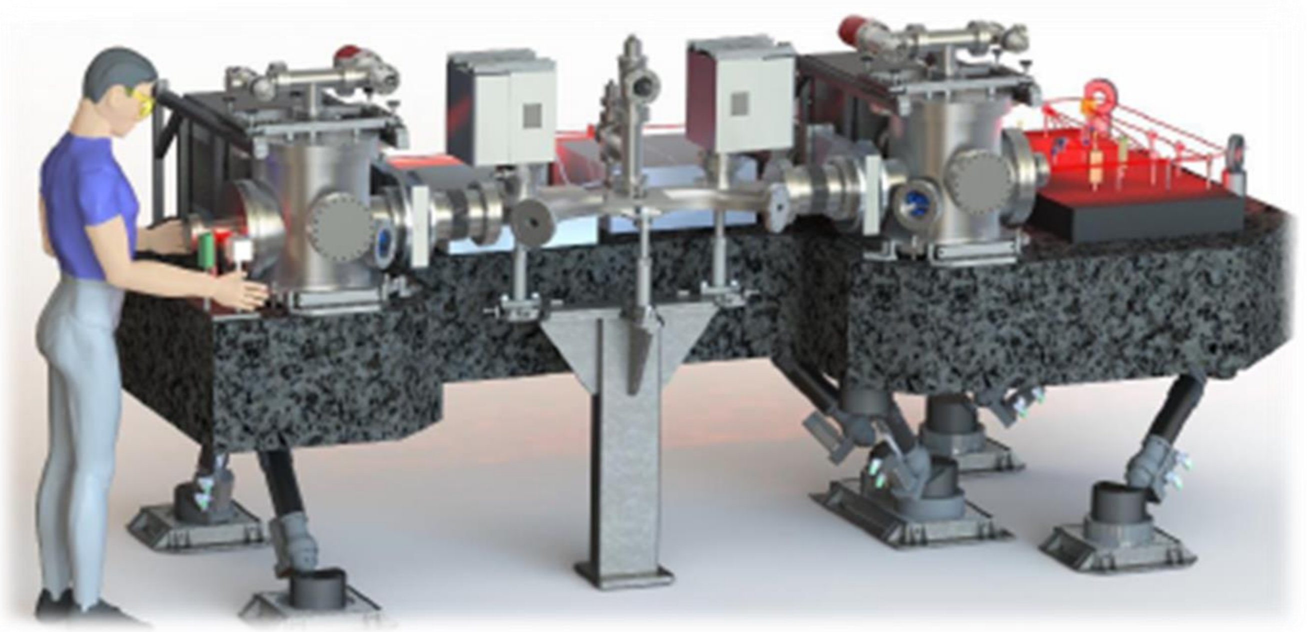
Inverse Compton Scattering:

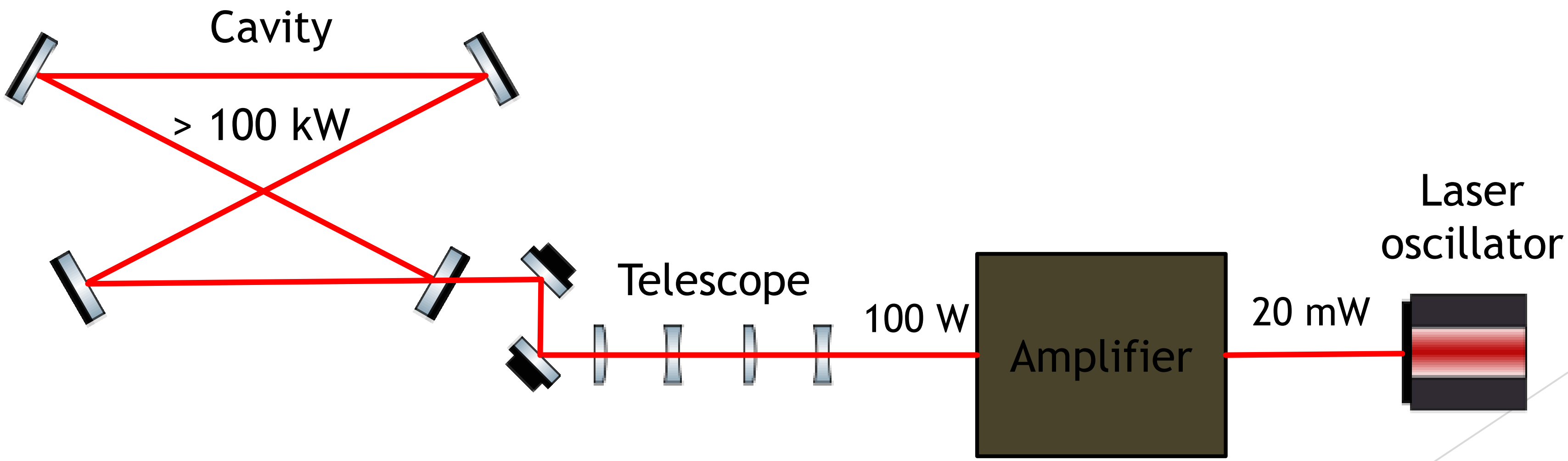


- 10^{17} photons @ λ=1µm
- > 100 kW @ 33MHz 10ps



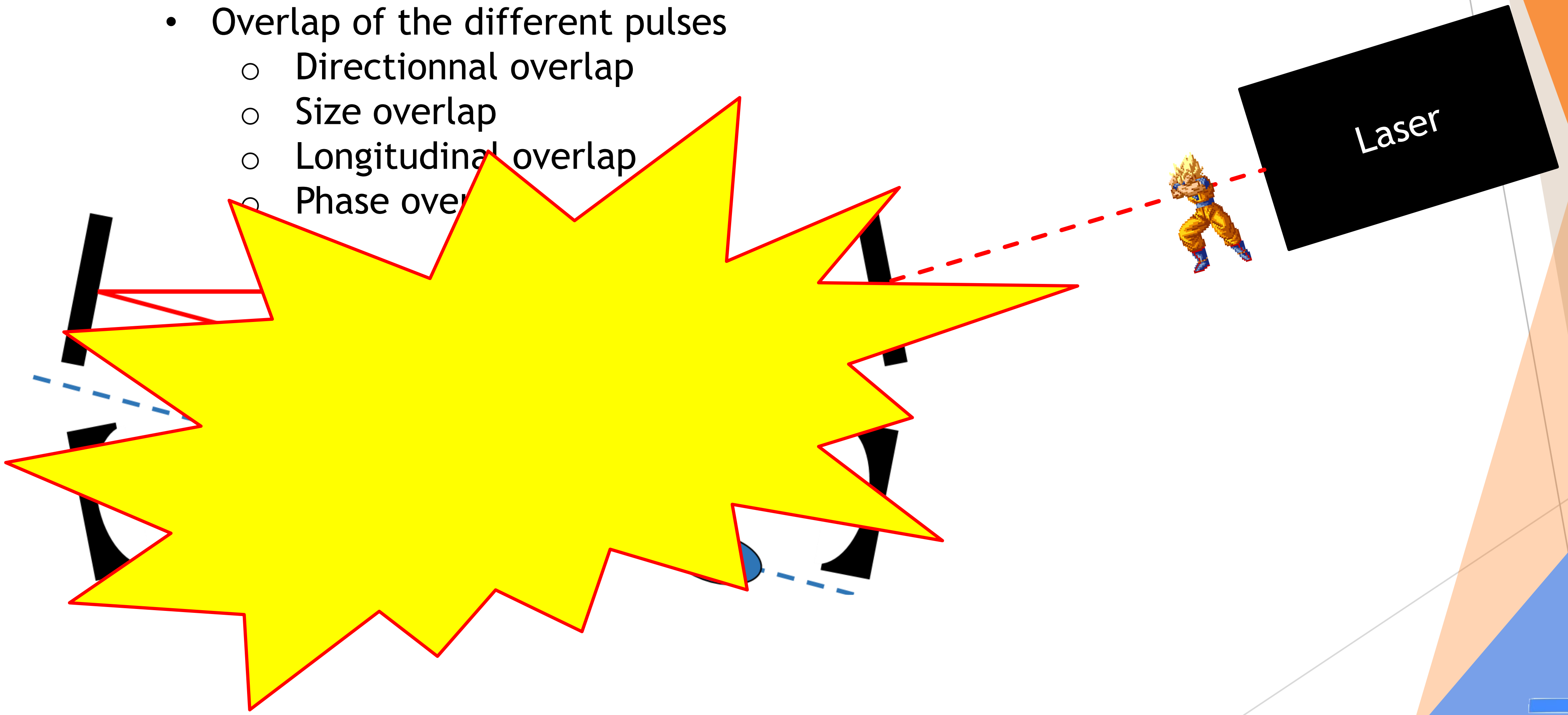
Simplified optical scheme





The Fabry-Perot Cavity

- Pulsed laser sent resonating into the cavity
- Overlap of the different pulses
  - Directionnal overlap
  - Size overlap
  - Longitudinal overlap
  - Phase ove



Challenges faced

Intra-cavity power brings important thermal effects:

- Directly heat the mirrors
- Heat the mounts by conduction
- Heat the mounts diffusion

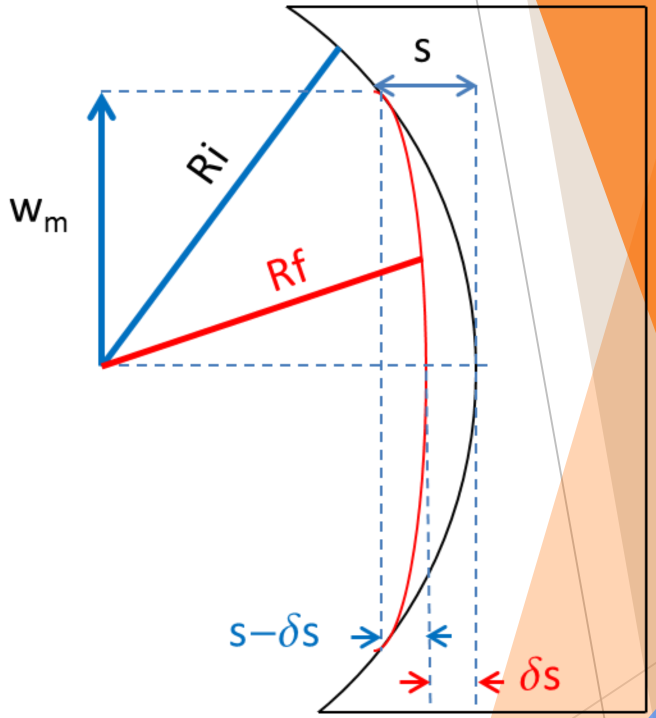
Heating and deformation of the mirror’s surface: Winkler model

- Physical charateristics of the mirrors (thermal dilatation coefficient, thermal conductivity and absorption)

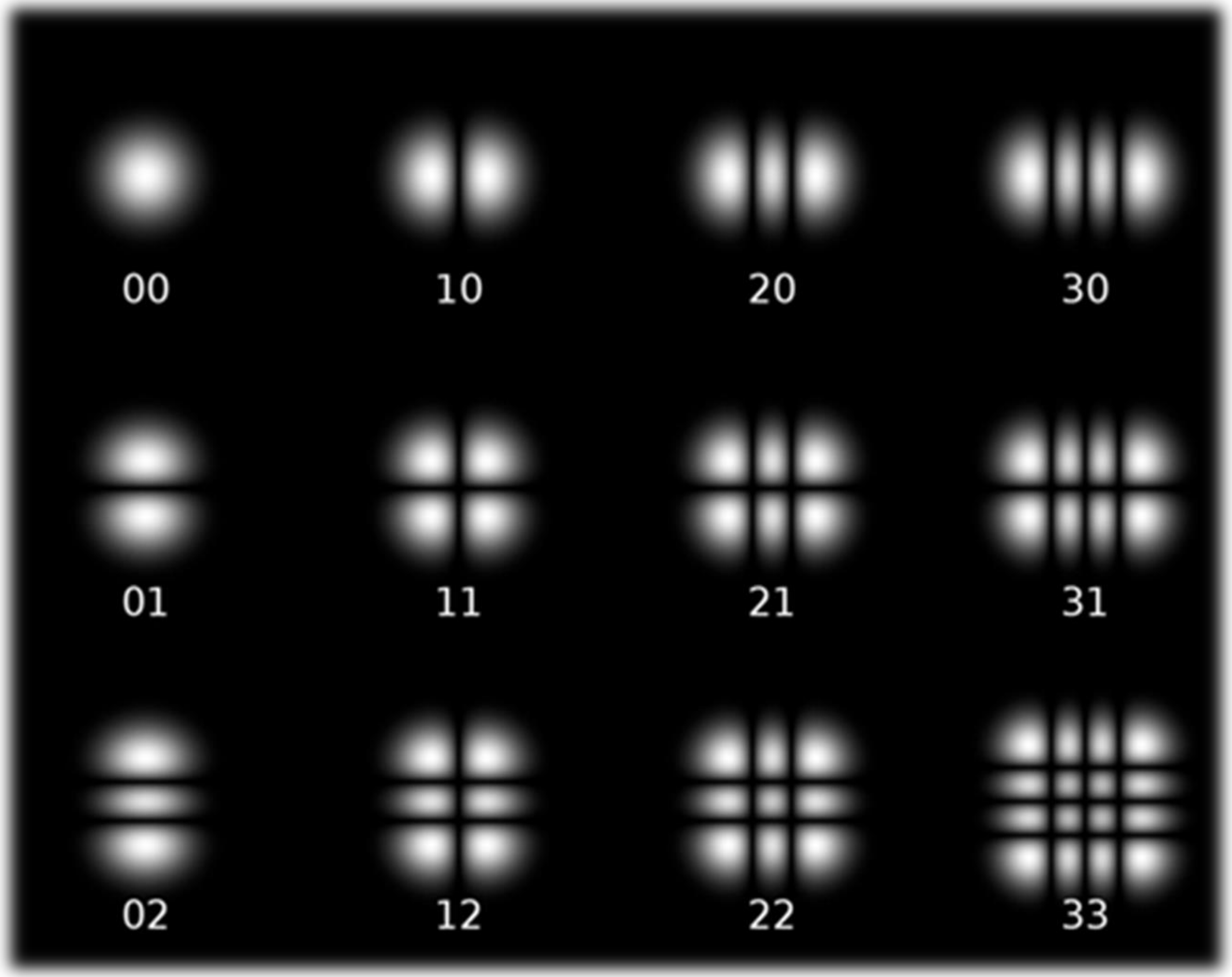
$$\delta s_e = \frac{\alpha}{4\pi} A P_s$$

- Calculation of δs thickness variation due to stored power P_s
- Deduction of local modified radius of curvature depending on laser beam waist ω_m

$$R = \frac{-{\omega_m}^2}{2 * \delta s_e}$$



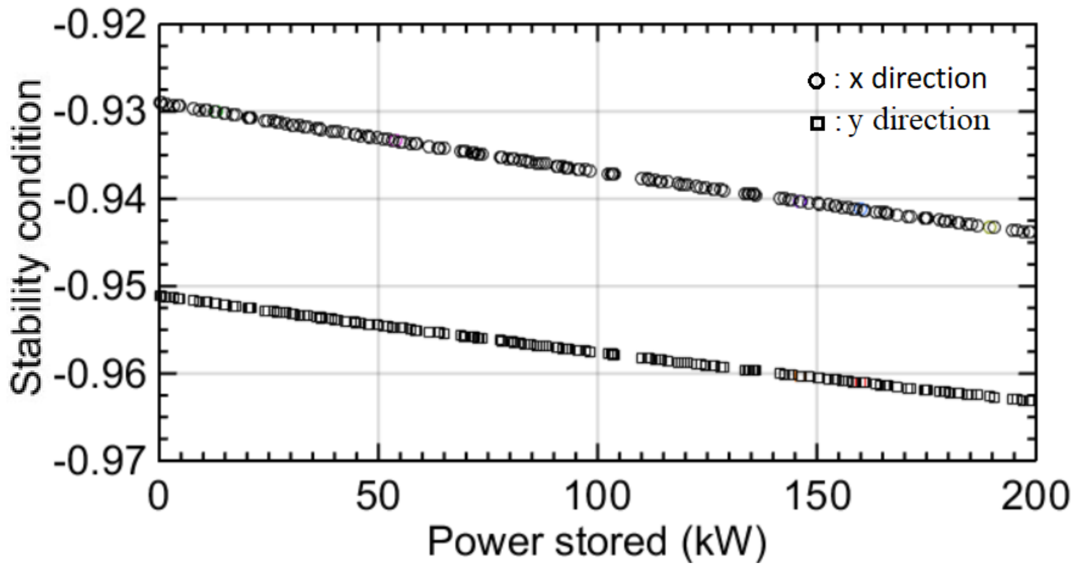
Hermite Gauss modes

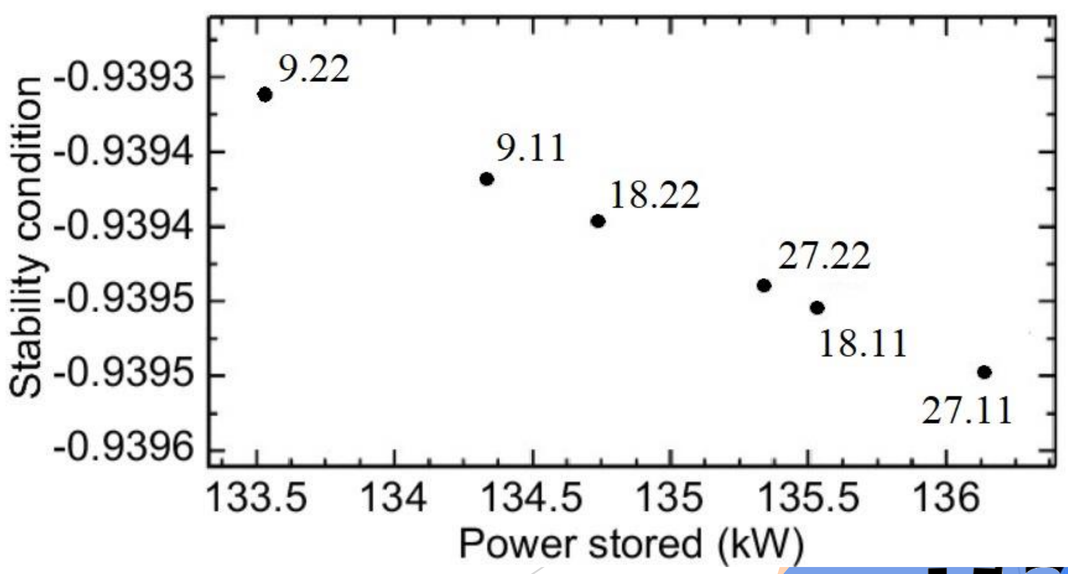


Simulation of modal resonances

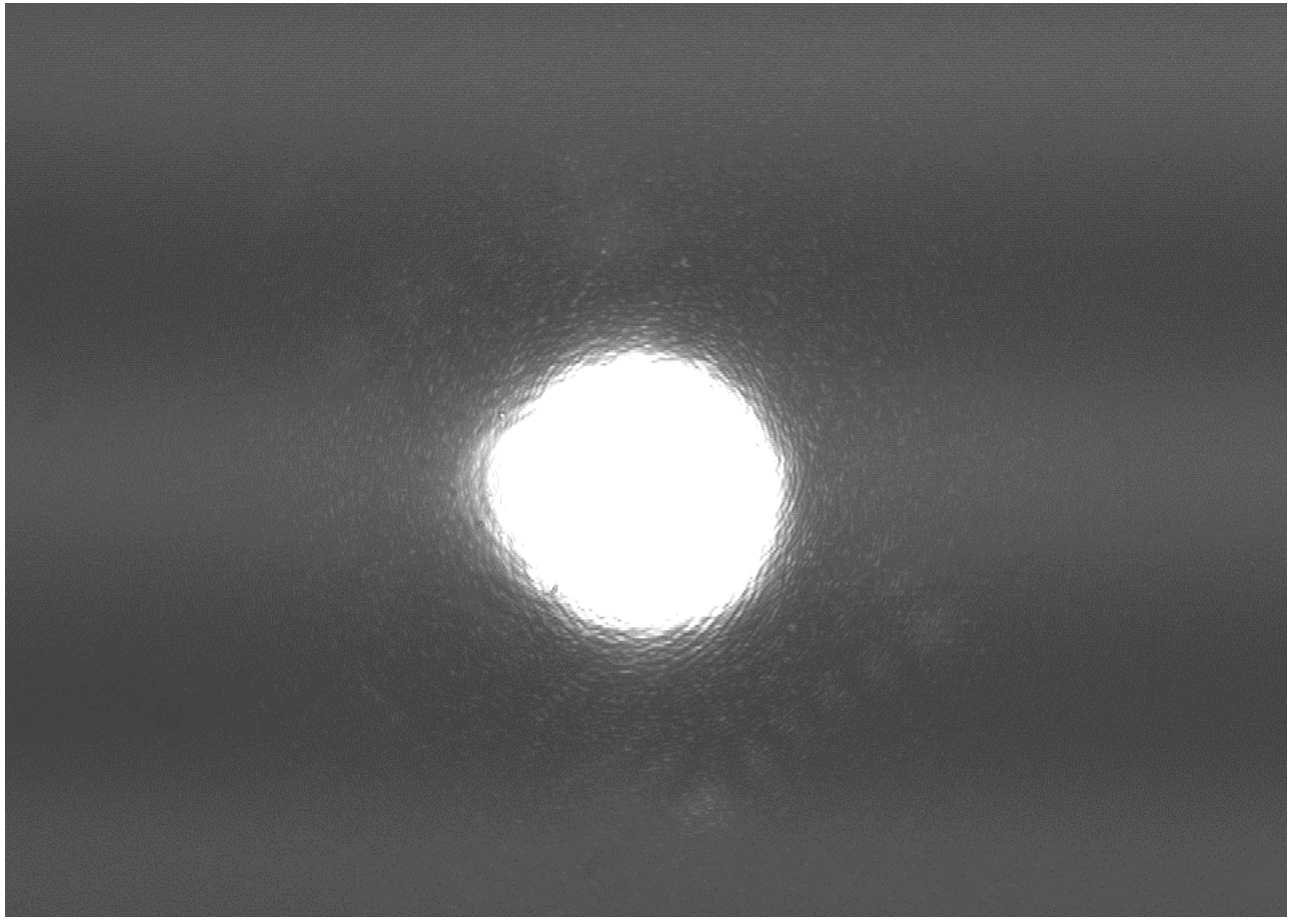
Calculation of the high order mode frequency for Gaussian Hermite (n,m) mode for a given longitudinal mode q resonant with 0,0 mode

$$F_{qnm} = \frac{c}{L}\left[q + \frac{acos\left(\frac{A_x + D_x}{2}\right)(n + \frac{1}{2})}{2\pi} + \frac{acos\left(\frac{A_y + D_y}{2}\right)(m + \frac{1}{2})}{2\pi}\right]$$



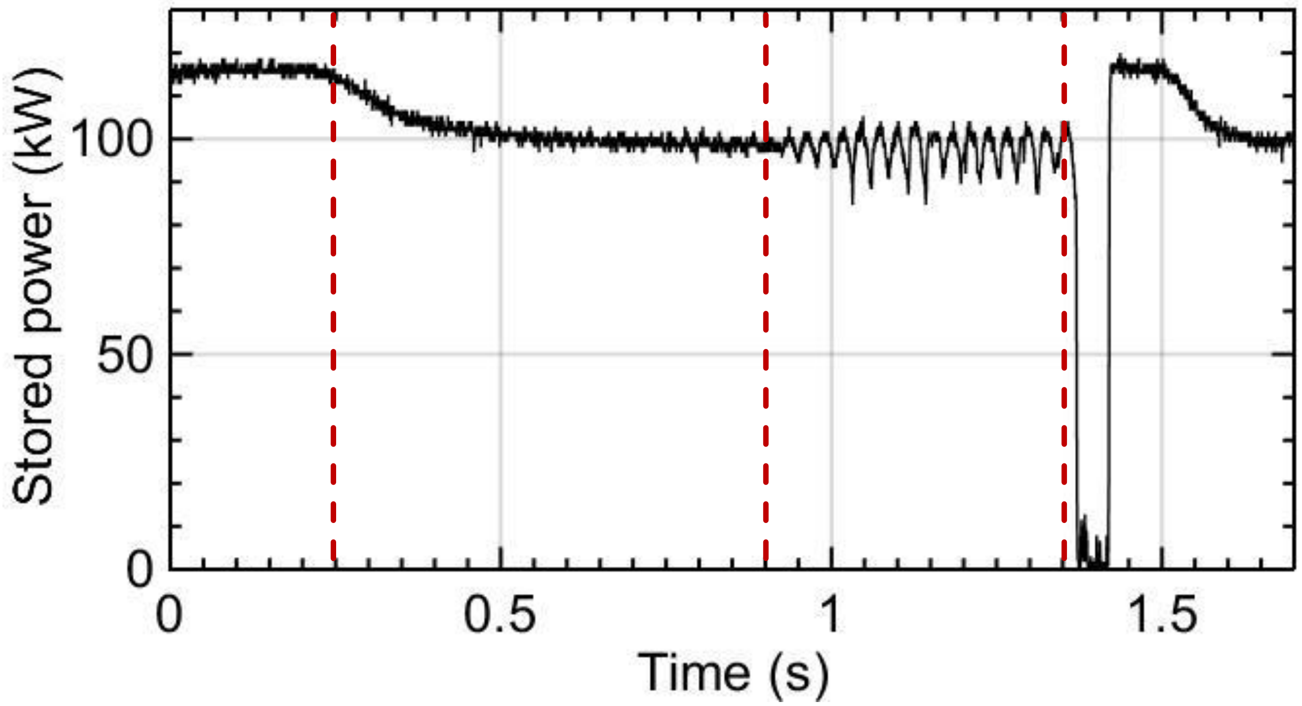


Dynamics of high order modes



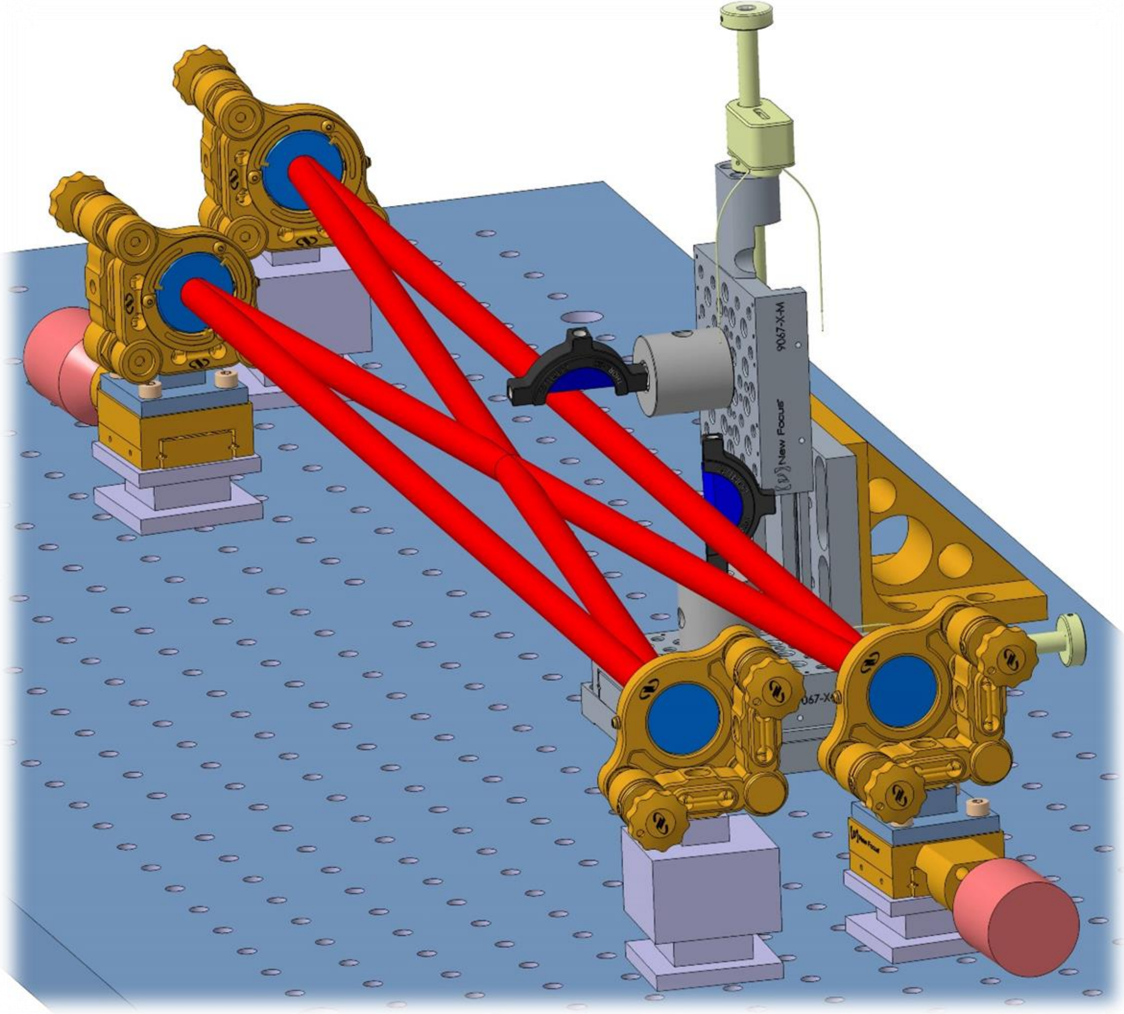
- Limits coupling
- Limits feedback system
- Limits stacked power
- Losses lock

Degeneracies effects



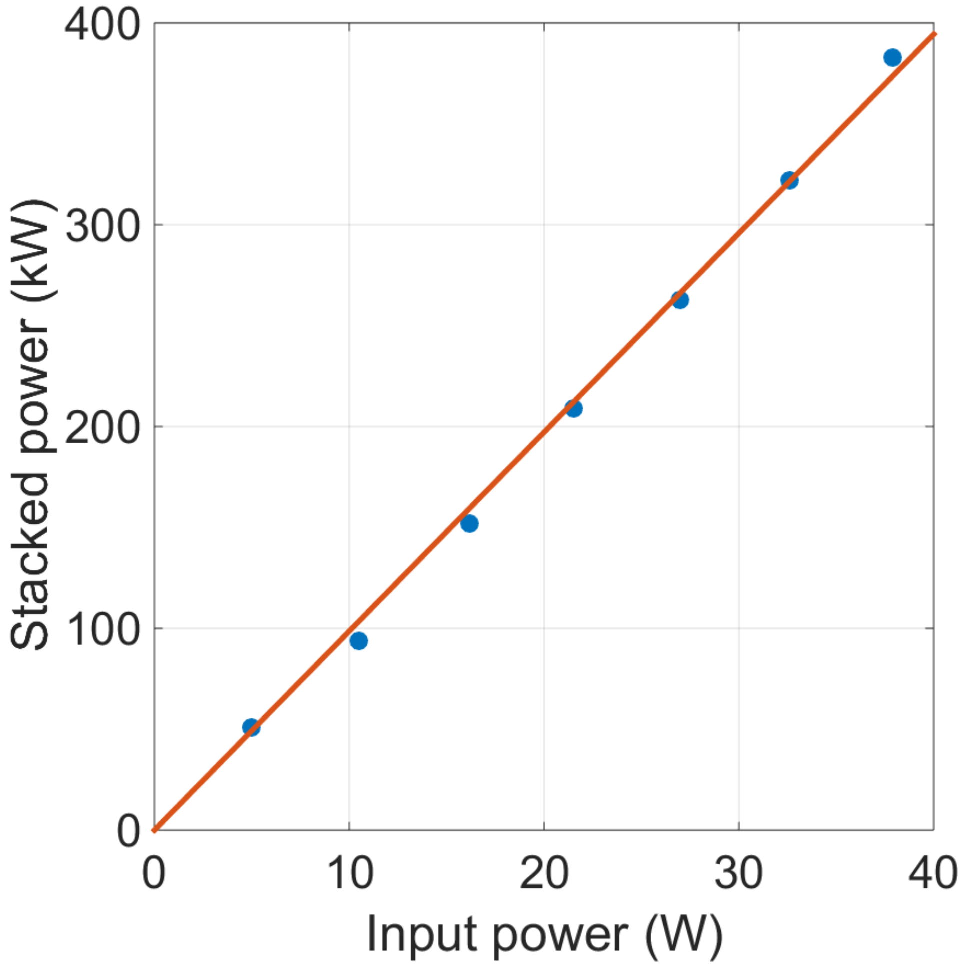
- t = 0 sec, lock on 0.0 mode
- t = 0.25 sec, degeneracy occurs with a higher order mode (2.2)
- t = 0.9 sec, beginning of oscillations between modes
- t = 1,35 sec, lost of the lock due to oscillations

Solutions



- D-shaped pickoff mirrors
- Low deformation mirror's mounts
- Stainless steel support
- Anti-diffusion panels ?

Maximum stored power

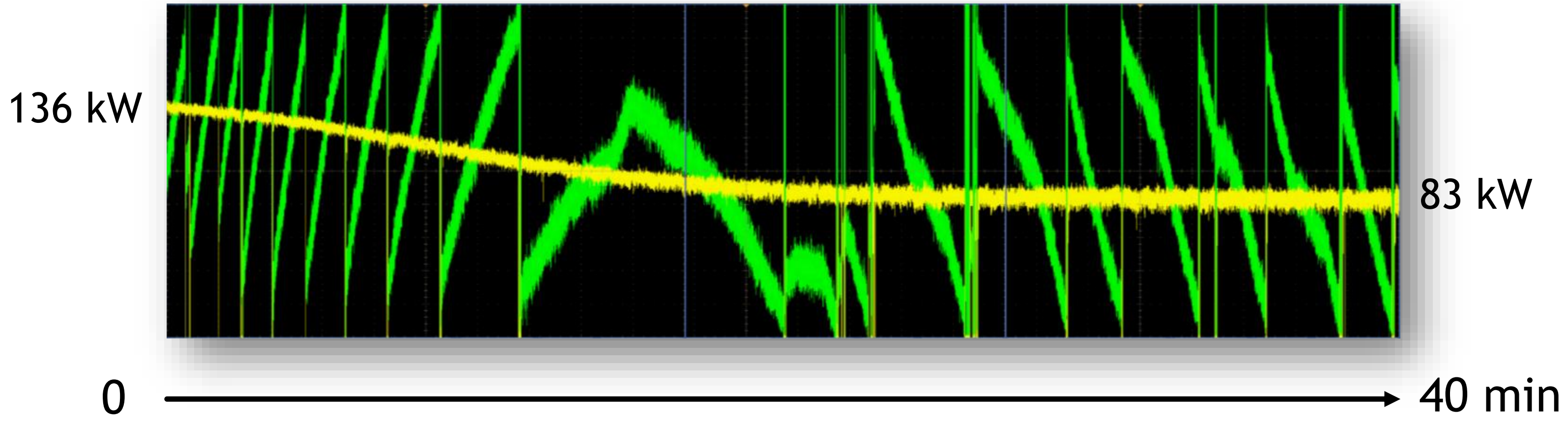


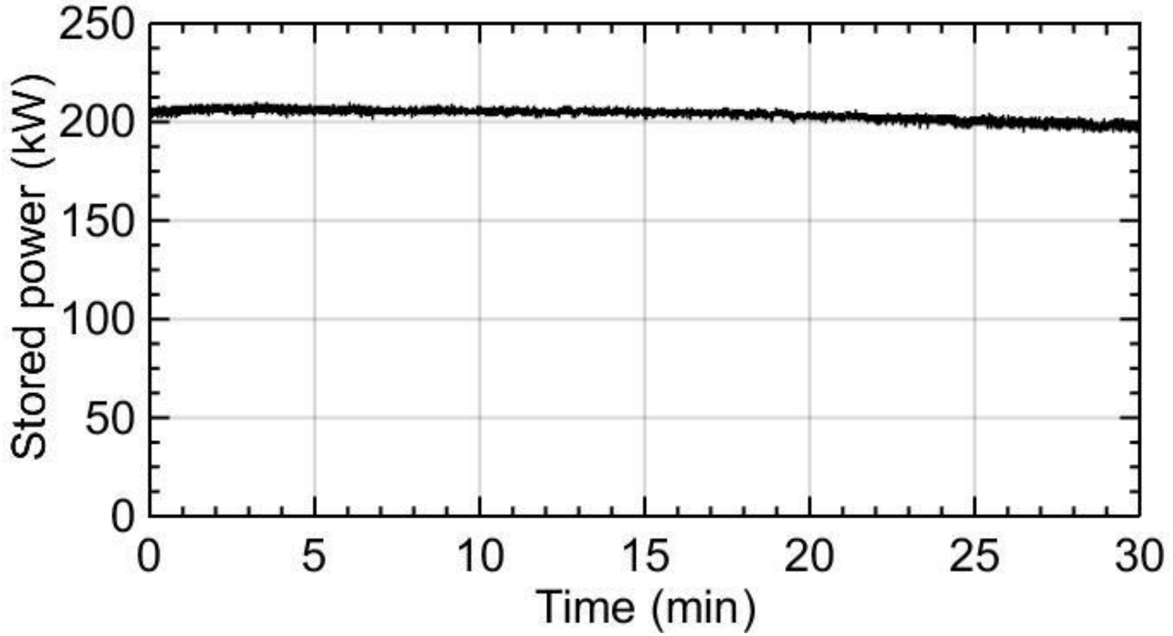
- Max stacked power ~ ***400 kW***
- Highest stored power for high finesse cavity

- Effective enhancement factor ~ ***10 000***
- Spatial coupling ~ ***90 %***

- Thorough re-alignement at every step, experiment still limited by thermal effects in the mounts

Stability performance





- 30 min run without any lock lost
- Power goes from 204 kW to 197 kW (< 4% power losses)
- Modal instabilities deleted

Thank you