Laser diagnostics and development tools

Oliver Puncken

Outline

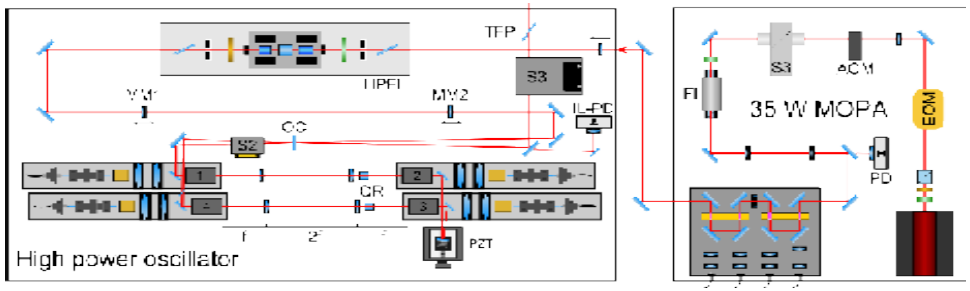
- Diagnostics inside the PSL
- Useful tools
  - Diagnostic breadboard (DBB)
  - Pump light characterization
  - Crystal characterization

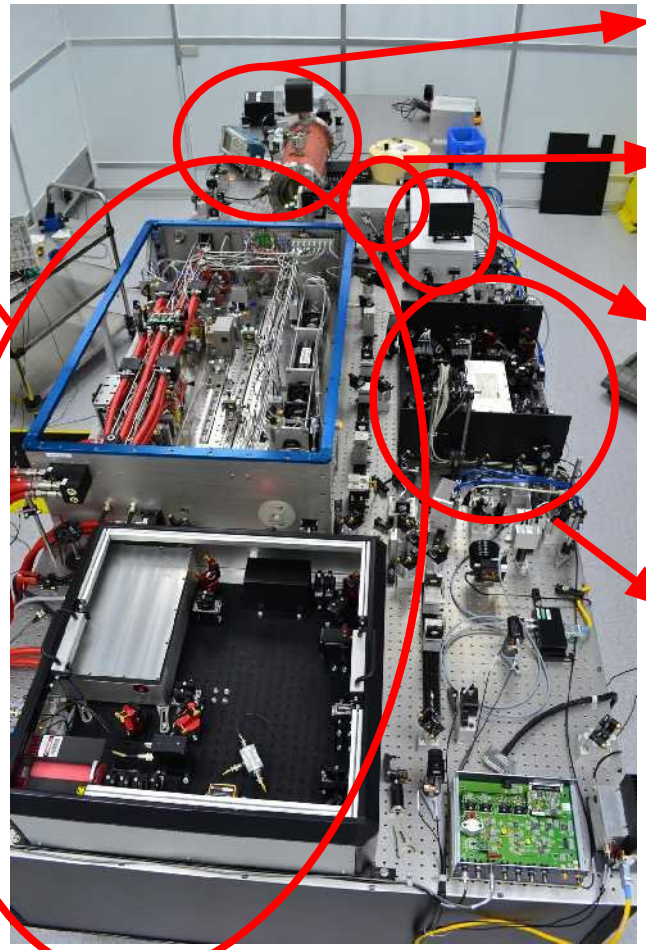
Outline

- **Diagnostics inside the PSL**
- Useful tools
  - Diagnostic breadboard (DBB)
  - Pump light characterization
  - Crystal characterization

The advanced LIGO PSL

MOPA + oscillator, ***last lecture***





Reference cavity (FSS) ***stabilization***

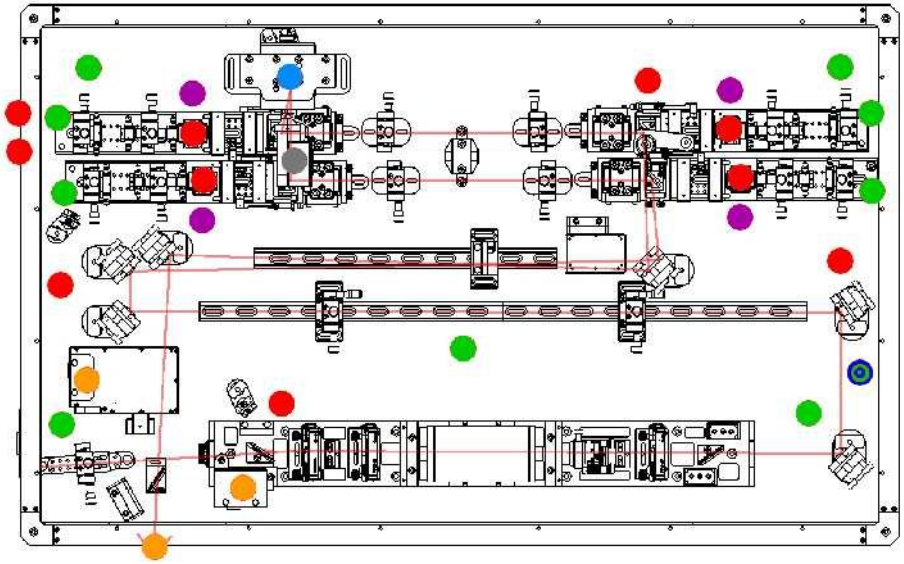
Intensity stab. (ISS) ***stabilization***

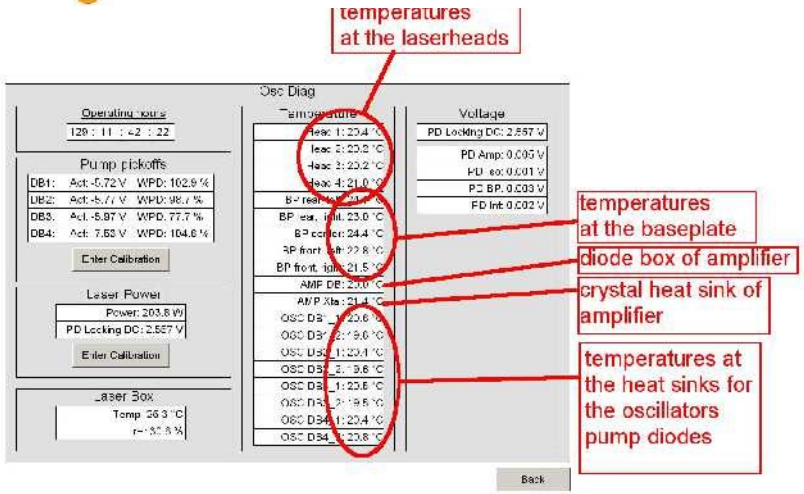
Pre-mode-cleaner (PMC) ***stabilization***

Diagnostic Breadboard (DBB) ***this lecture***

Diagnostics inside the PSL

Engineering prototype: big brother is watching you !





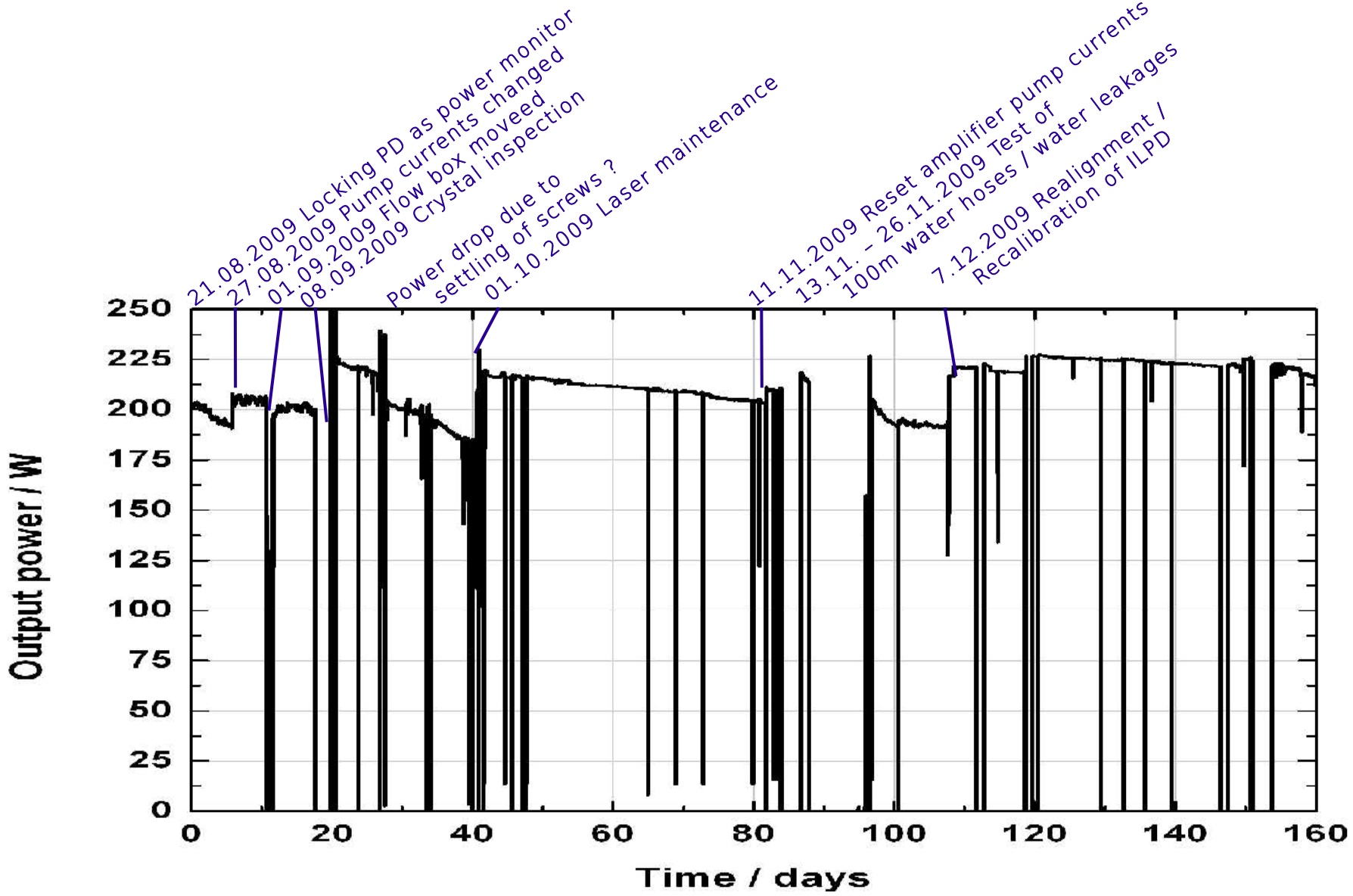
Photodiodes:
- Pump diode internal
- Pump light monitors
- Brewster plate reflected
- Injection locking / power
- Backreflected (Faraday)
- Amplifier

Temperatures:
- 5 x baseplate
- 1 x Each Laserhead
- Pump diode heatsinks
- Temp./Hum. Sensor inside the box

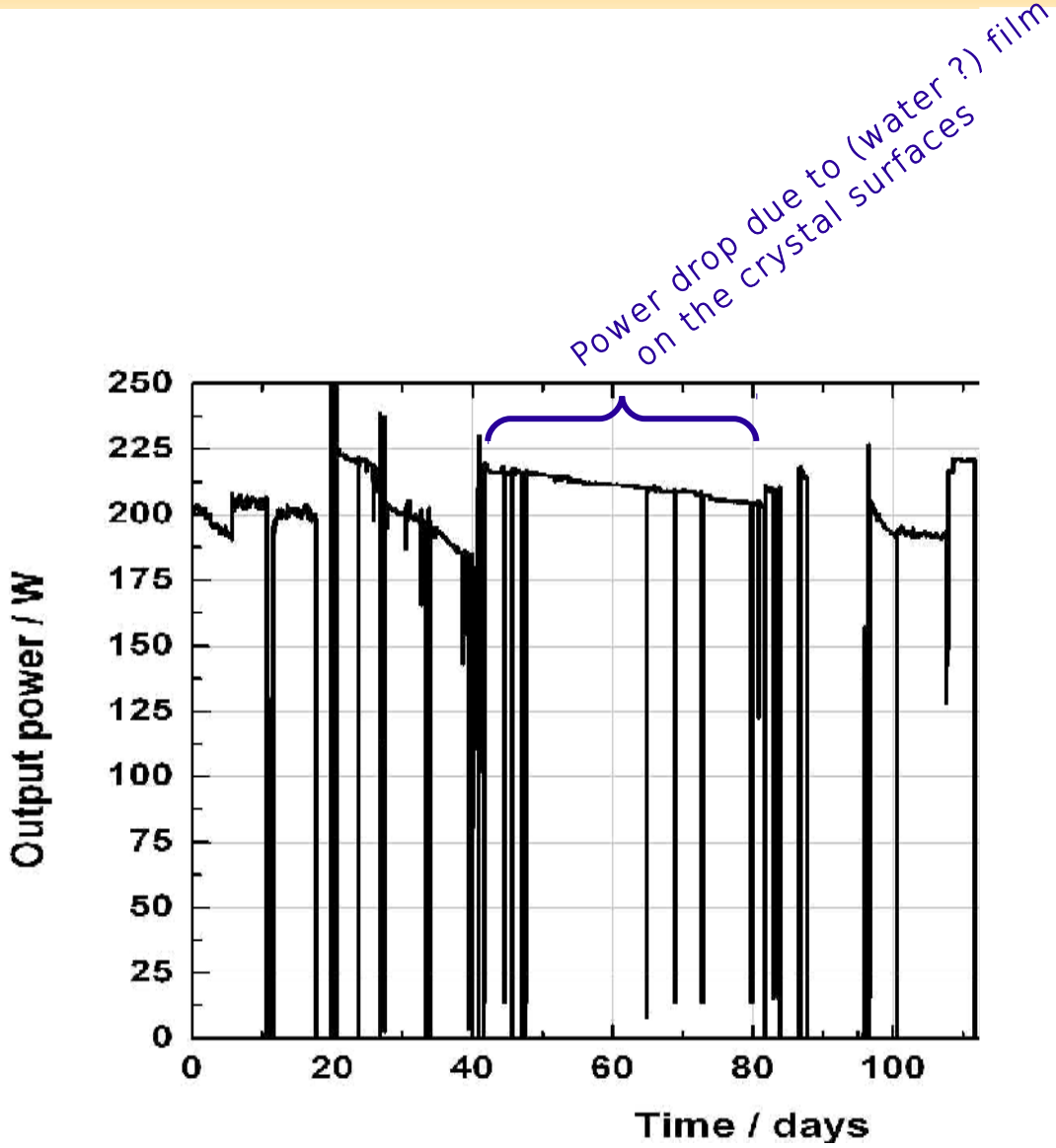
Powermeters:
- Inside high power shutter
- Behind Faraday rotator
- Outside

Others:
- PZT voltage
- LRA position
- Optical pump light spectrum
- Cooling water pressure (total)
- Cooling water flow (total, from chiller)
- Diode temperatures / currents
- …

First long term experiences (EPT)



First long term experiences (EPT)

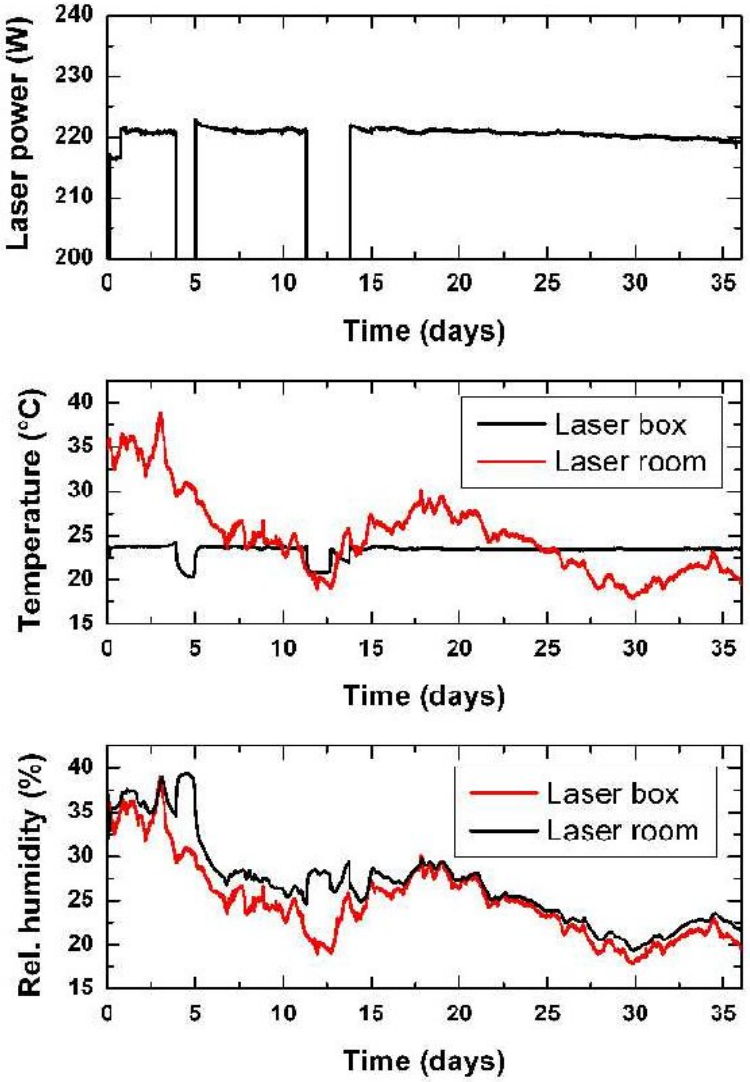


Consequences:

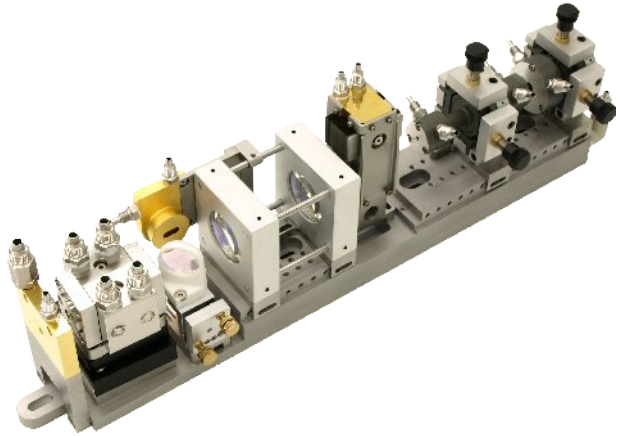
- Changed Pump chamber design
- Better sealing
- → Less power drop

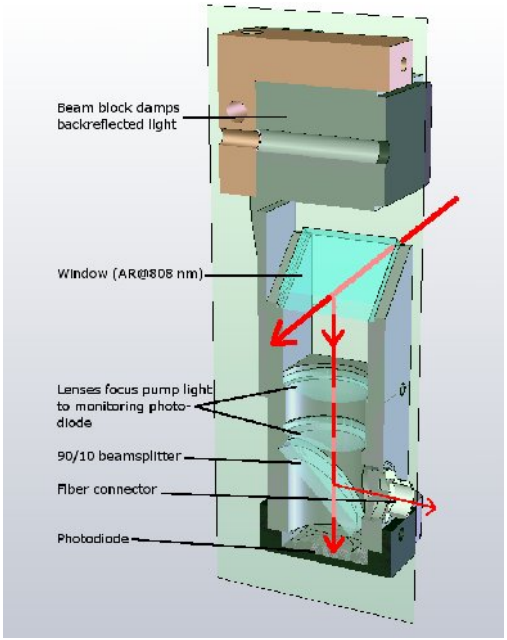
Environmental monitor

- Laser box damps temperature fluctuations
- Laser heats the box by about 4 °C
- Humidity fluctuations are not damped



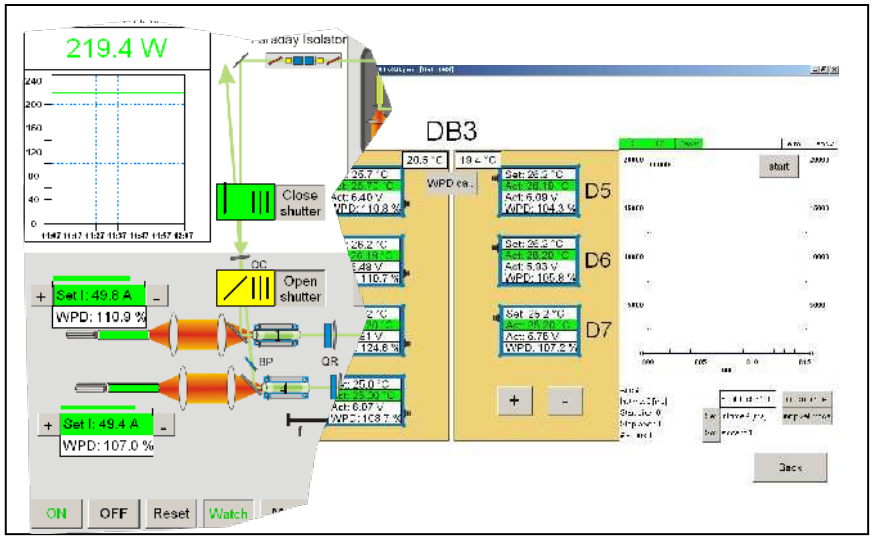
Pump-light monitoring



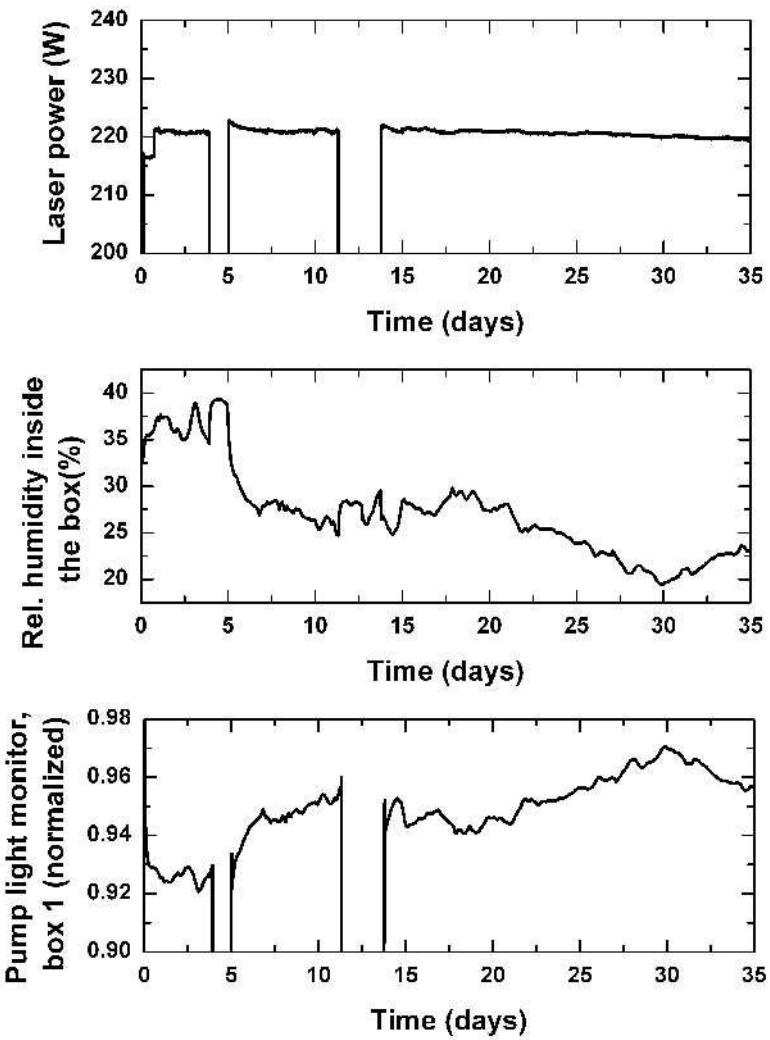


Pump-light monitors

- Measure pump power per head
- Control of pump diode degradation
- Measure pump-light spectrum of overall diode box



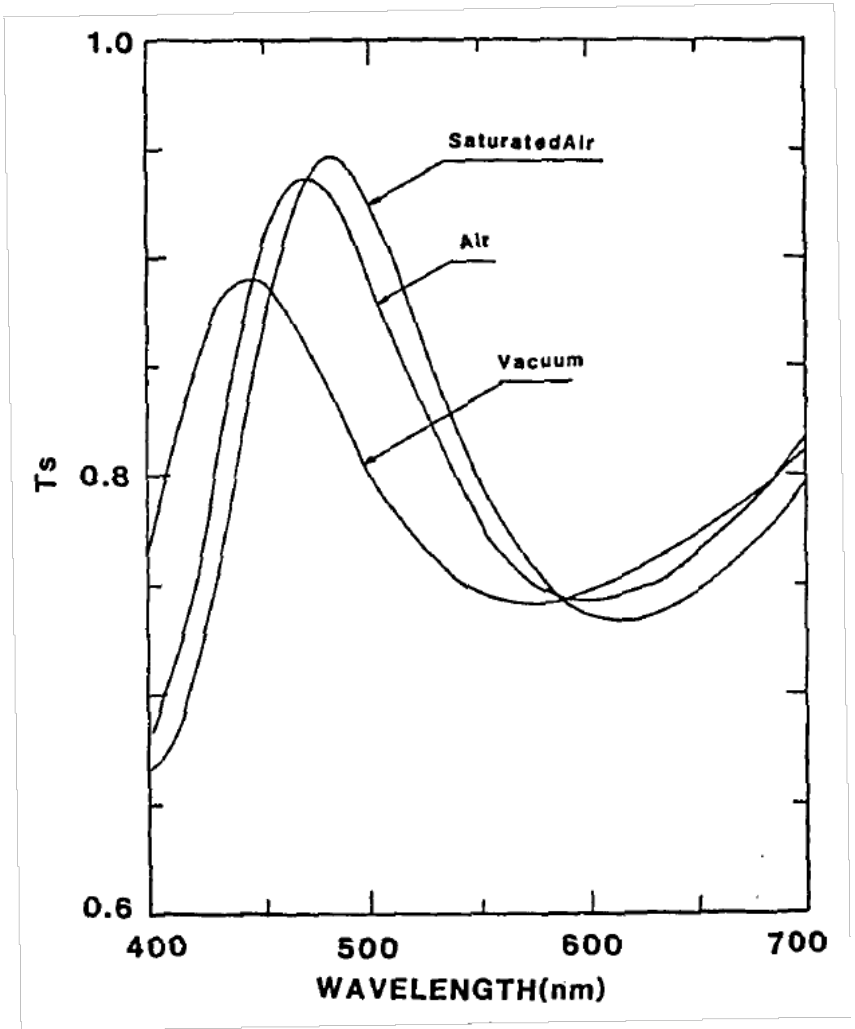
Pump-light monitoring



- Pump-light monitors of the EPT are good humidity sensors, but bad light sensors
- Problems are cause by e-beam coatings
- Lesson learned: ***use IBS coated substrates only !***

Excurs: Coating technologies

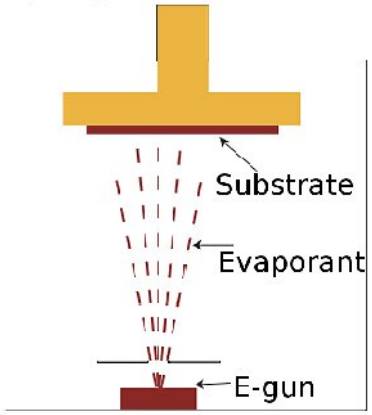
- Properties of thin films are dependent on the relative humidity
- Effect due to microstructure, which consists of nm-size cylindrical columns with voids between them
- The internal surface absorb a monolayer of water
  → refractive index changes
  → transmission changes
- Higher packing densities → increased stability



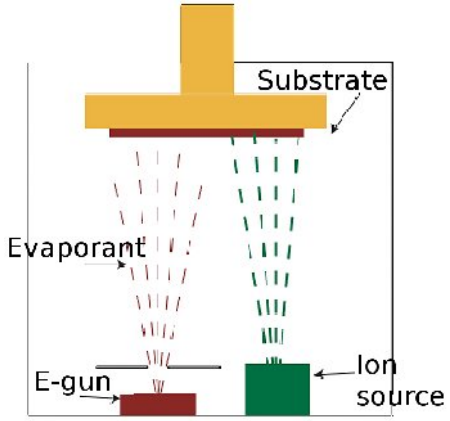
Example: transmittance vs wavelength for TiO_2 films
(taken from: P. J. Martin et. al., APPLIED OPTICS 22 (1), pp. 178-184 (1983))

Excurs: Coating technologies

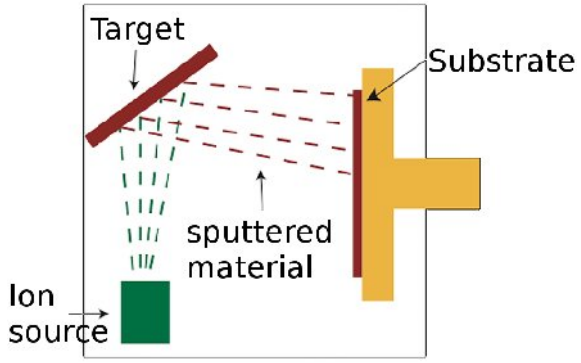
- Electron-beam
  - Source material in „electron gun“
  - Gun creates stream of electrons, which is directed to the coating material
  - Coating material evaporates and moves to the top of the coating chamber
  - Deposition on rotating substrates



- Ion assisted deposition
  - Variant of e-beam: high energy ion beam is added
  - This beam is directed to the substrate
  - These ions act like a hammer, producing higher film denisty
  - Ion beam as pre-cleaning → improved film adhesion



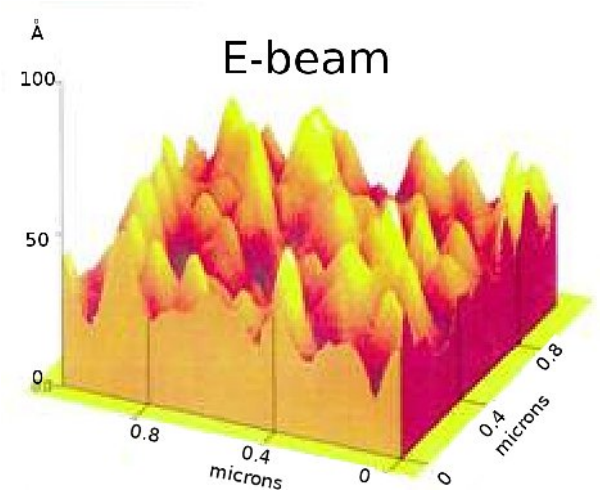
- Ion Beam Sputtering
  - Target of coating material
  - Beam of ions sputters material from this target (atoms are knocked off)
  - Sputtered material deposits on rotating substrates

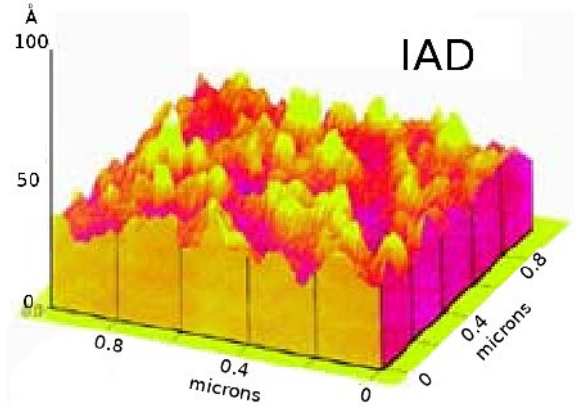


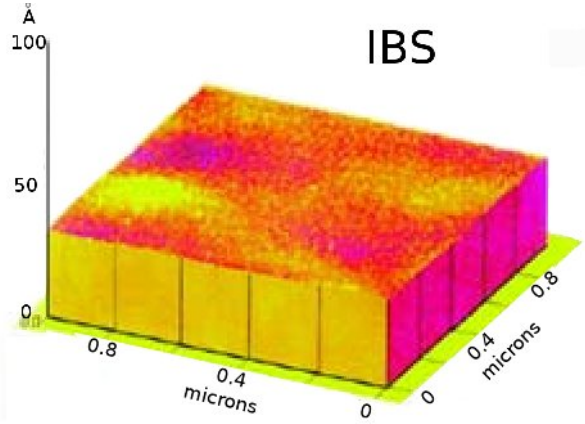
Pictures from: precisionphotonics

Excurs: Coating technologies

- Electron-beam
  - Porous
  - Columnar structure
  - High scatter
  - Poor environmental stability
- Ion assisted deposition
  - Increased density
  - Redused porosity
  - High stress
  - Improved environmental stability
- Ion Beam Sputtering
  - Dense
  - Minimal structure
  - Low scatter
  - High stability







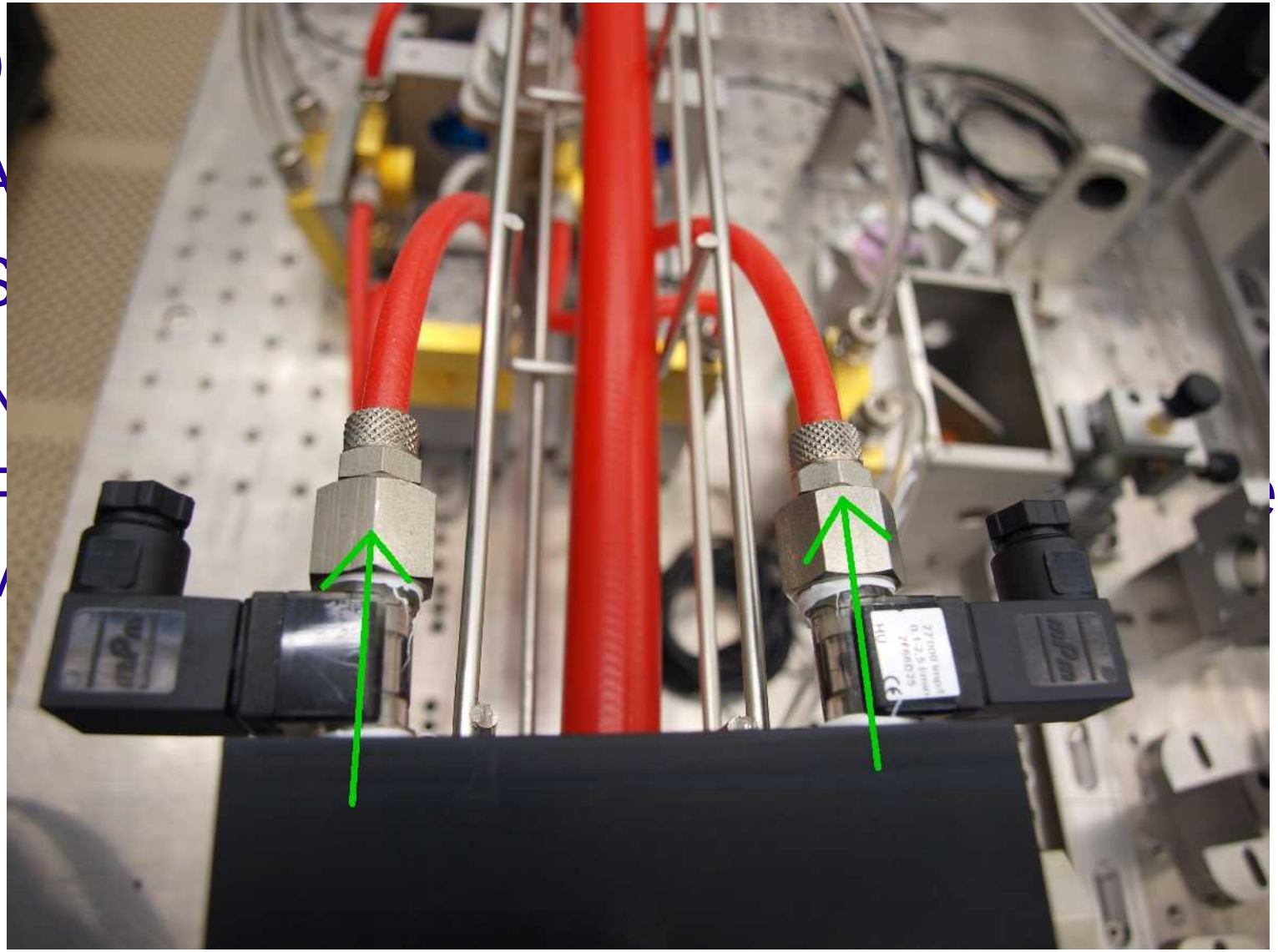
Pictures from: ATFilms

Engineering PT → Reference System

- Most important changes:
  - All optings with IBS coating
  - Simplified cooling water distribution
  - No water cooled baseplate
  - Flow sensors for each laser head and the MOPA

Engineering PT → Reference System

- Mo
  - A
  - S
  - N
  - F
    M

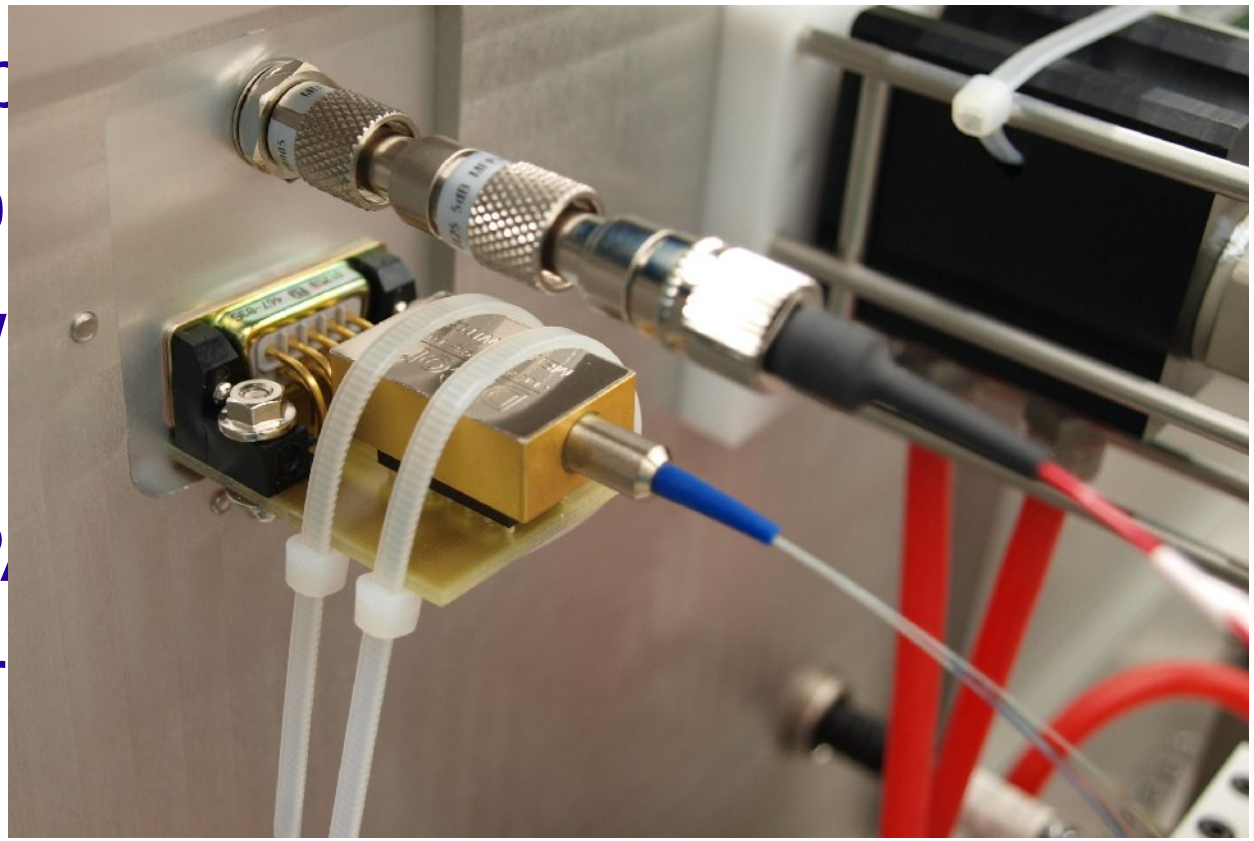


Engineering PT → Reference System

- Most important changes:
  - All optings with IBS coating
  - Simplified cooling water distribution
  - No water cooled baseplate
  - Flow sensors for each laser head and the MOPA
  - Fiber switch

Engineering PT → Reference System

- Most important changes:
  - All op
  - Simp
  - No w
  - Flow
    MOP
  - Fiber



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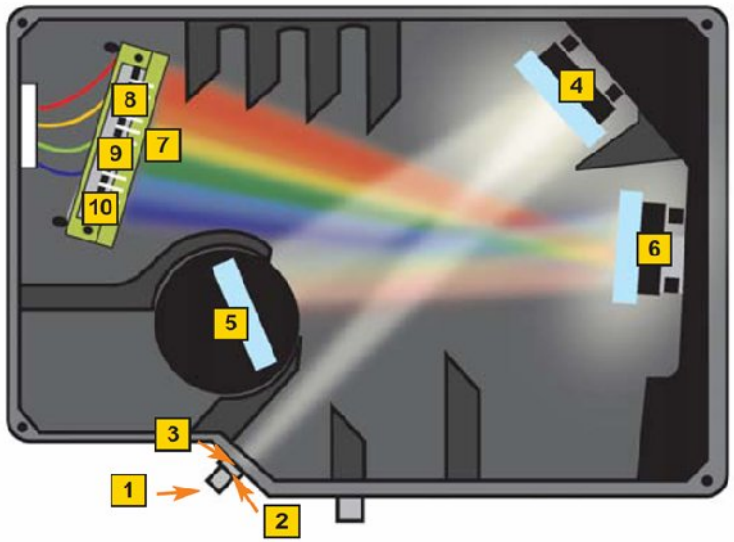
Internal optical spectrum analyzer



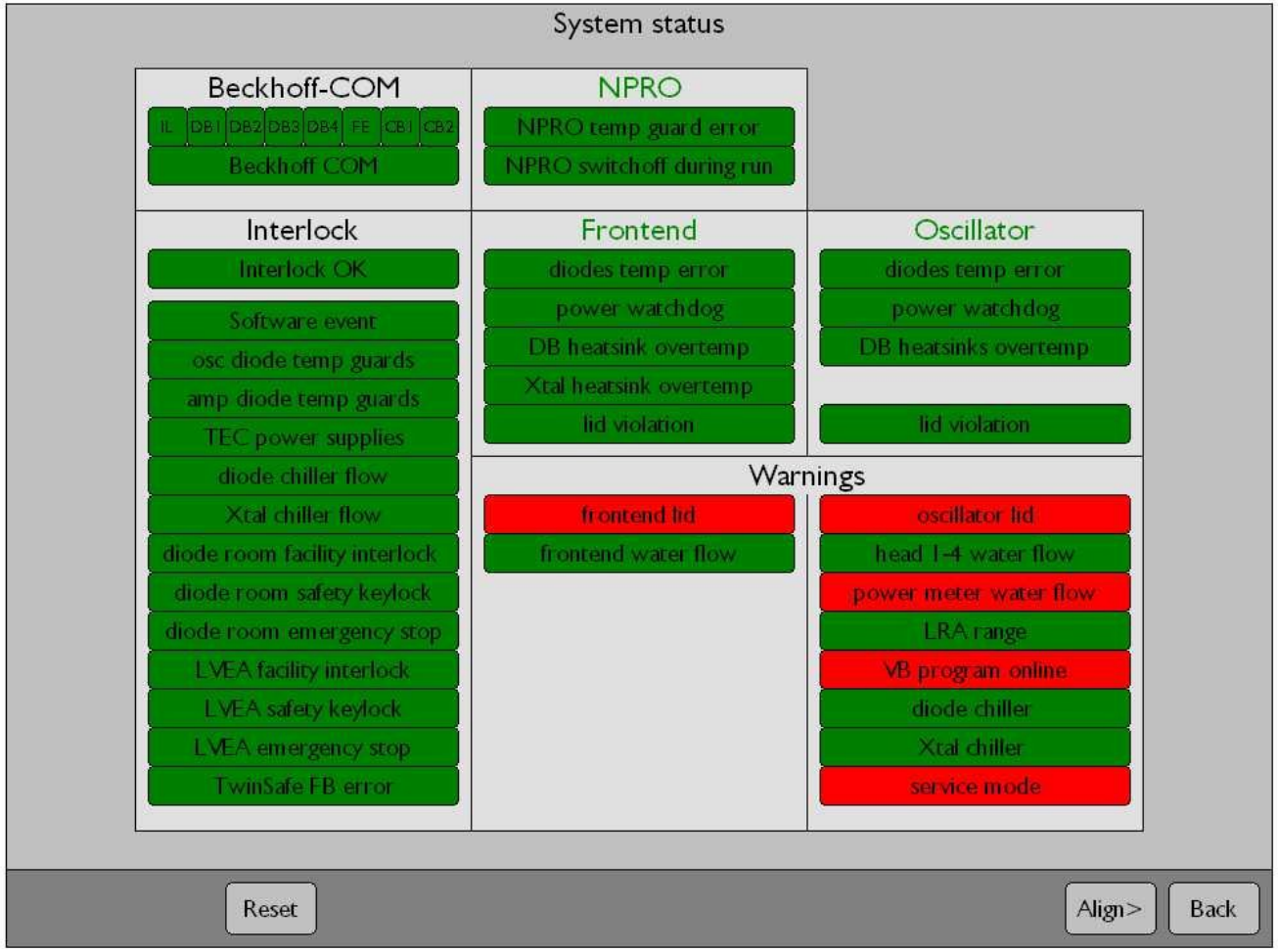
- Commercial *Ocean Optics* grating spectrometer
- Wavelength 750-930 nm
- Optical resolution @ 810 nm: < 0.1 nm
- Connection to Beckhoff via
  - "Spectra Suite"
  - Self-written program for spectra monitoring

Engineering PT → Reference System

- Most important changes:
  - All optings with IBS coating
  - Simplified cooling water distribution
  - No water cooled baseplate
  - Flow sensors for each laser head and the MOPA
  - Fiber switch
  - (new) status-screen

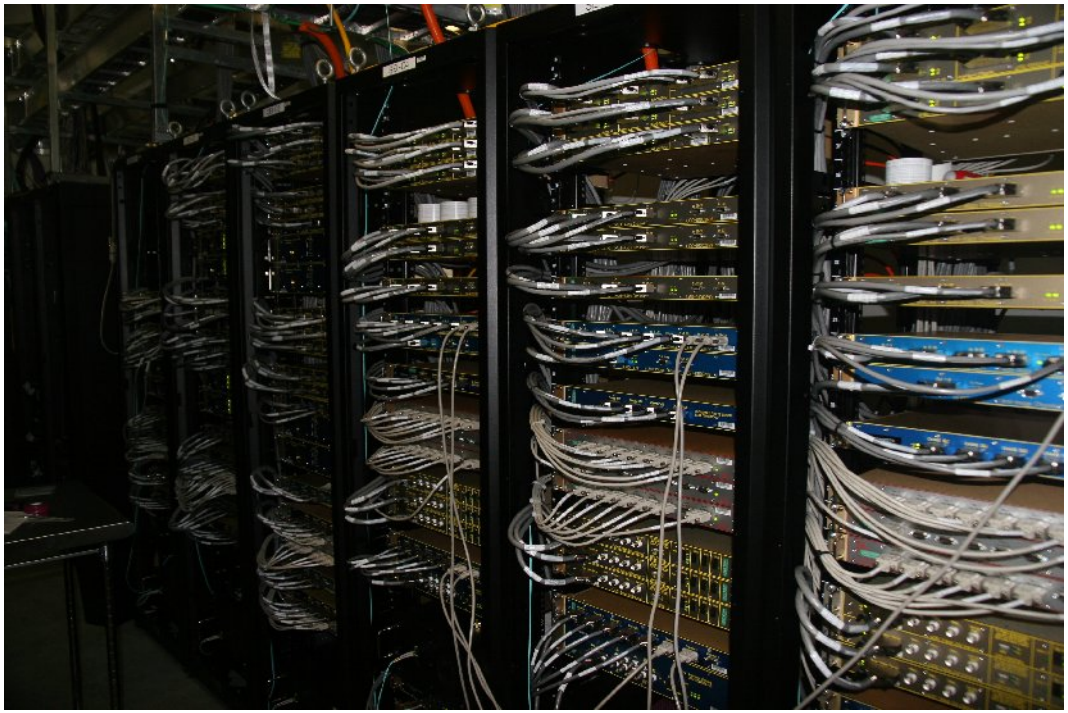
Engineering PT → Reference System

- Mos
  - Al
  - Si
  - N(
  - Fl
    M
  - Fi
  - (n



Observatory laser: data aquesition

- Access the LIGO EPICS[1] network
- Open MEDM[2] control screens to start measurement
- Time signals will be saved by some frame builder in the CDS[3] network
- Access data using a NDS[4] client, like e.g. ligoDV



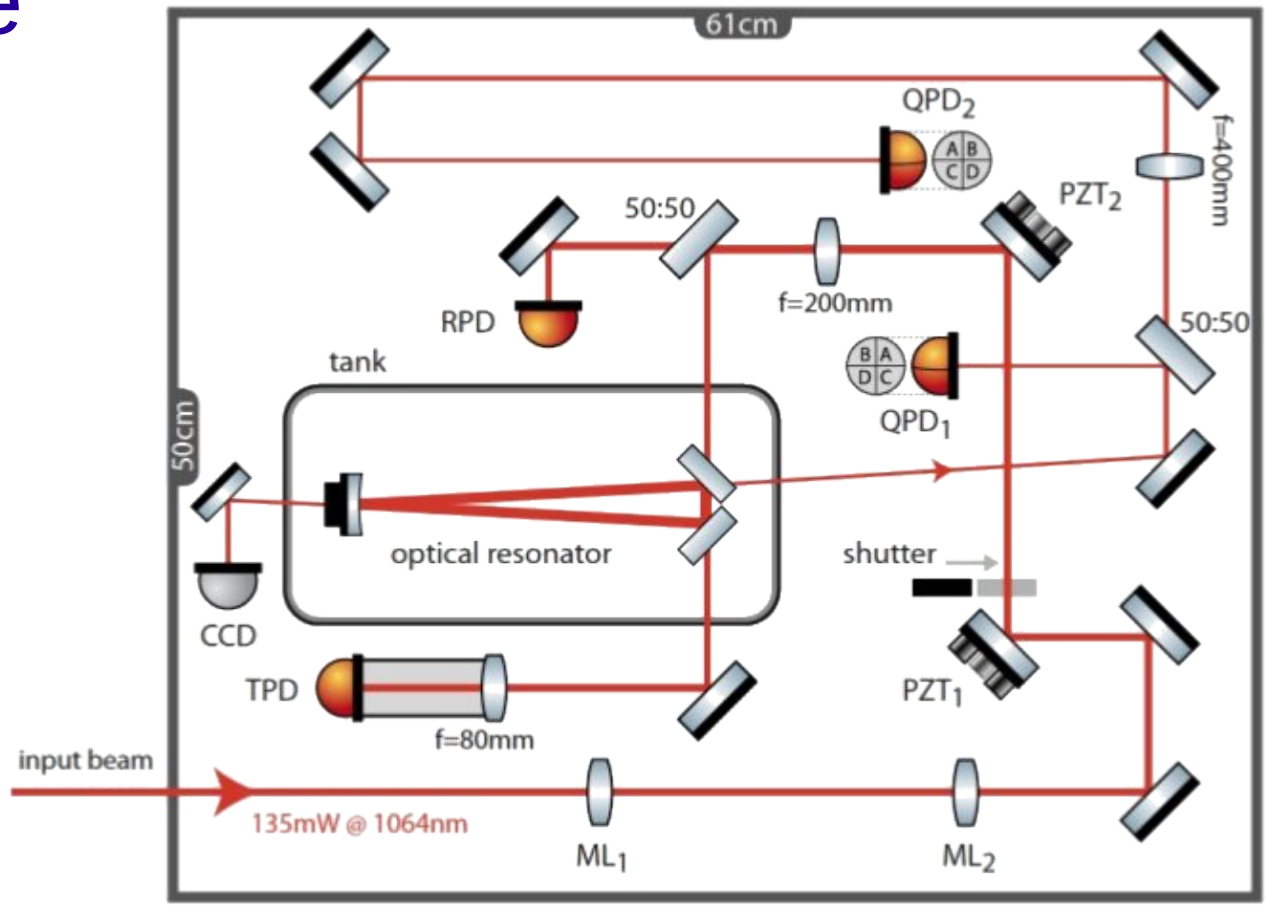
[1] **E**xperimental **P**hysics and **I**ndustrial **C**ontrol **S**ystem (a set of software tools, libraries and applications used to create distributed soft real-time control systems for scientific instruments)
[2] **M**otif **E**ditor and **D**isplay **M**anager (graphical user interface for designing and implementing control screens, to display and/or change the values of EPICS process variables)
[3] **C**ontrol and **D**ata **S**ystem (interface electronics, computing and networking systems, and software packages)
[4] **N**etwork **D**ata **S**erver

Outline

- Diagnostics inside the PSL
- **Useful tools**
  - **Diagnostic breadboard (DBB)**
  - Pump light characterization
  - Crystal characterization

Diagnostic breadboard

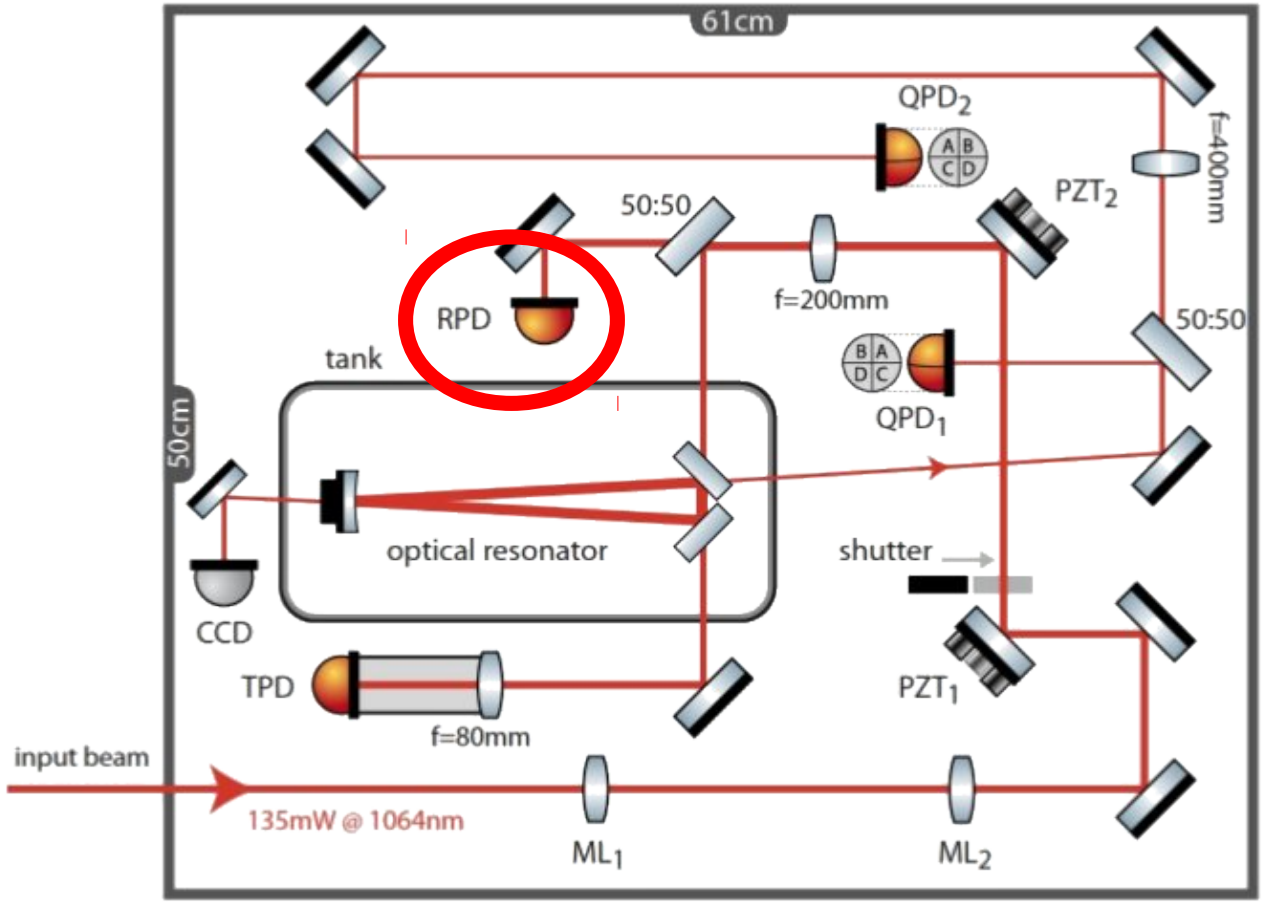
- Relative power noise (RPN)
- Frequency noise
- Beam pointing
- Beam quality
- Auto-alignment



P. Kwee et al.: Rev. Sci. Instrum., 78, 073103 (2007)

Diagnostic breadboard

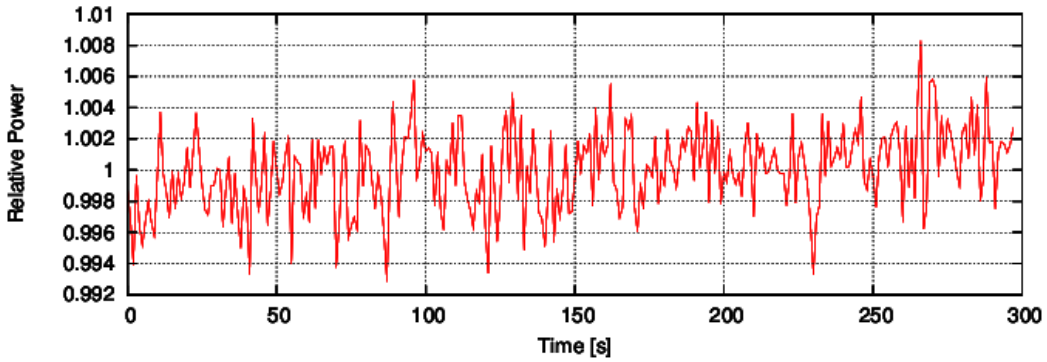
- Relative power noise (RPN)
  - $\delta P(t)=P(t)-\overline{P(t)}$

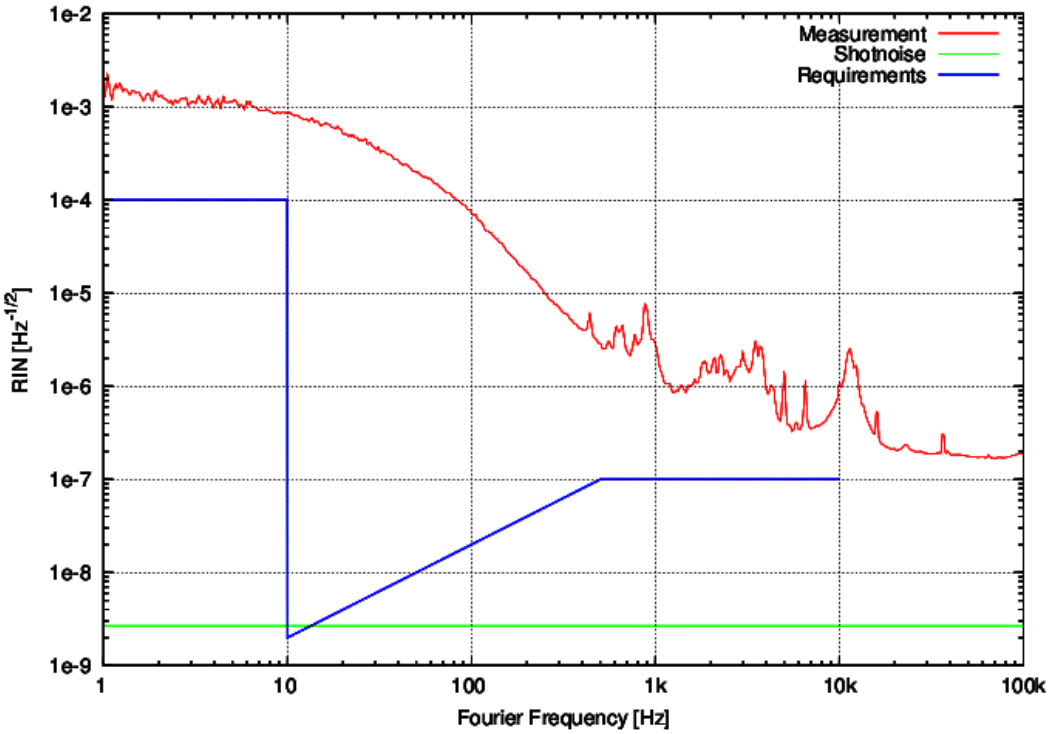


P. Kwee et al.: Rev. Sci. Instrum., 78, 073103 (2007)

Diagnostic breadboard

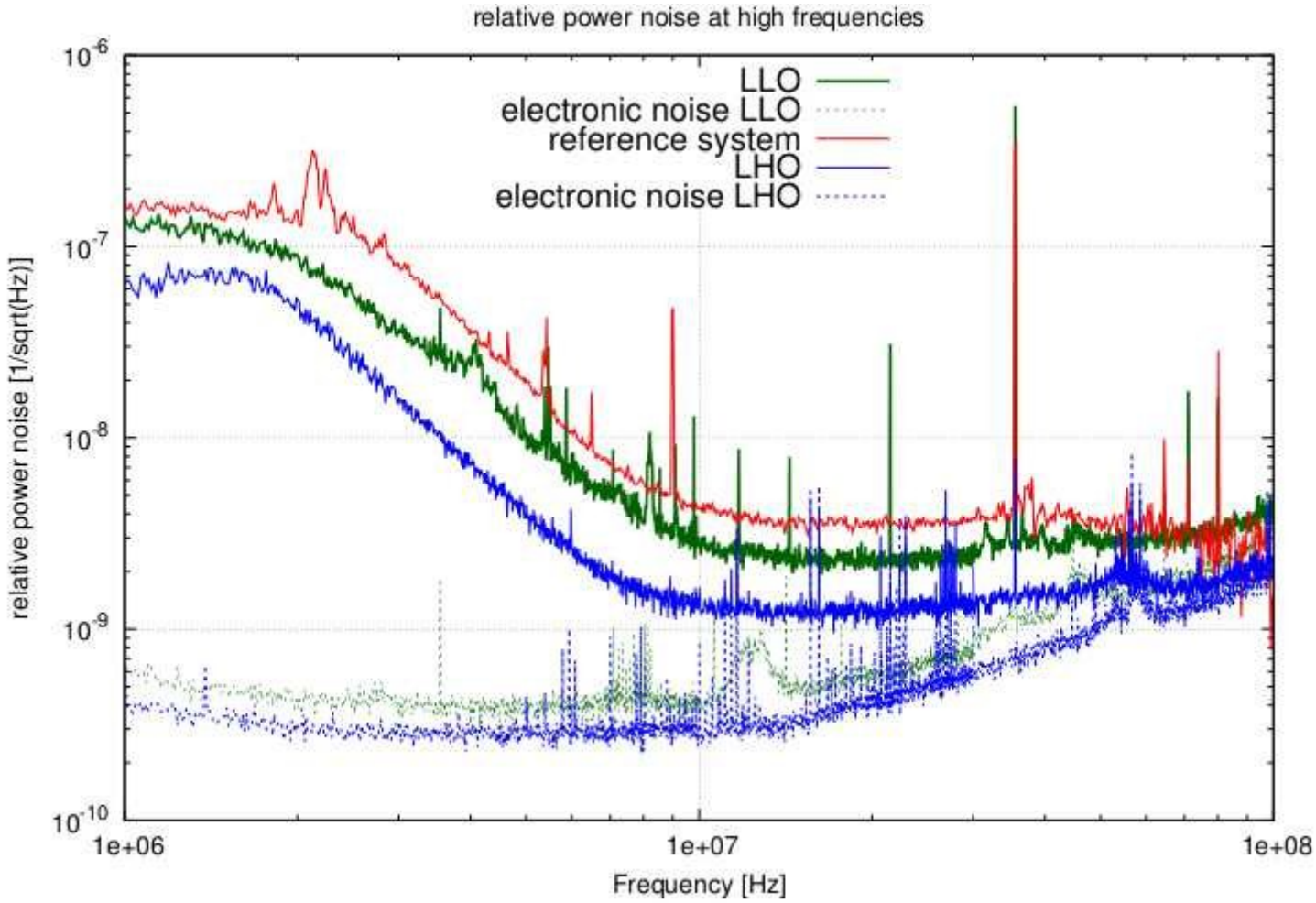
- Peak-to-peak fluctuations
- RPN





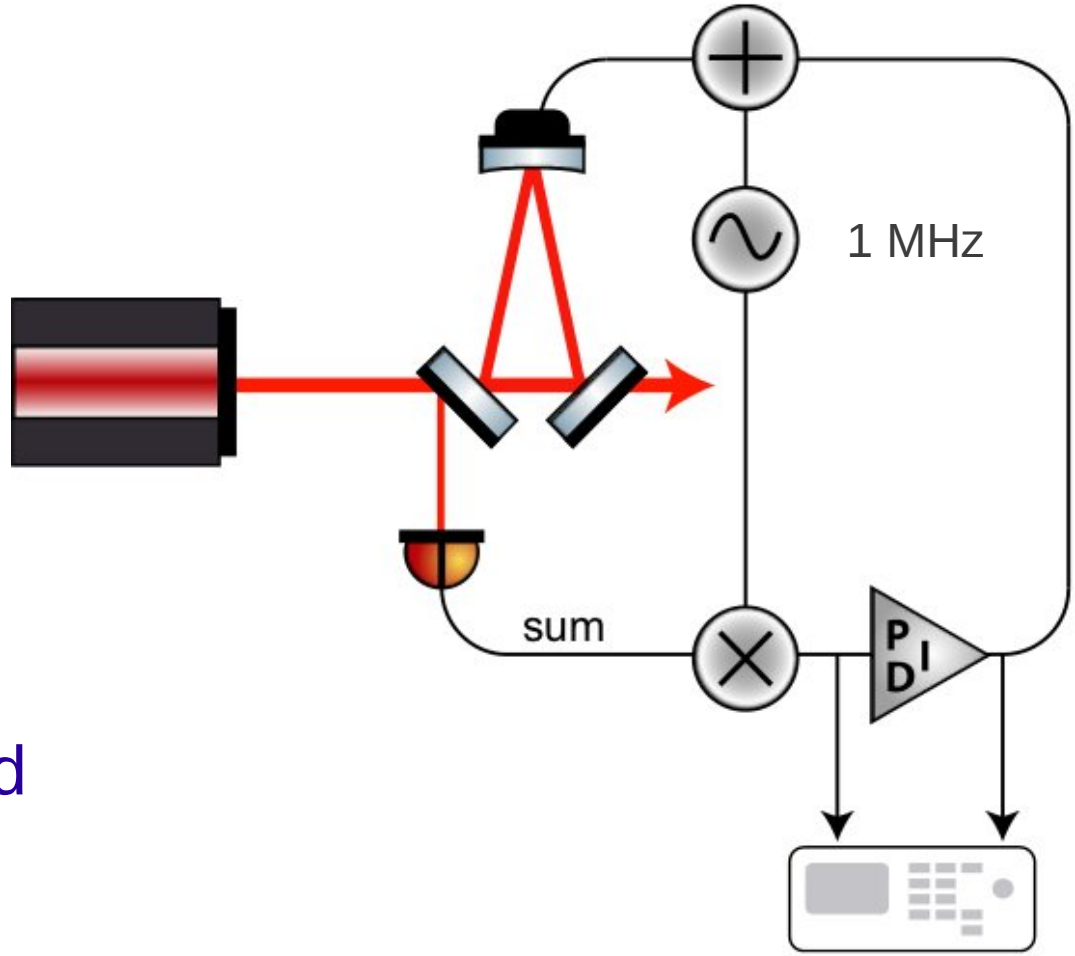
Diagnostic breadboard

- RPN at high frequencies



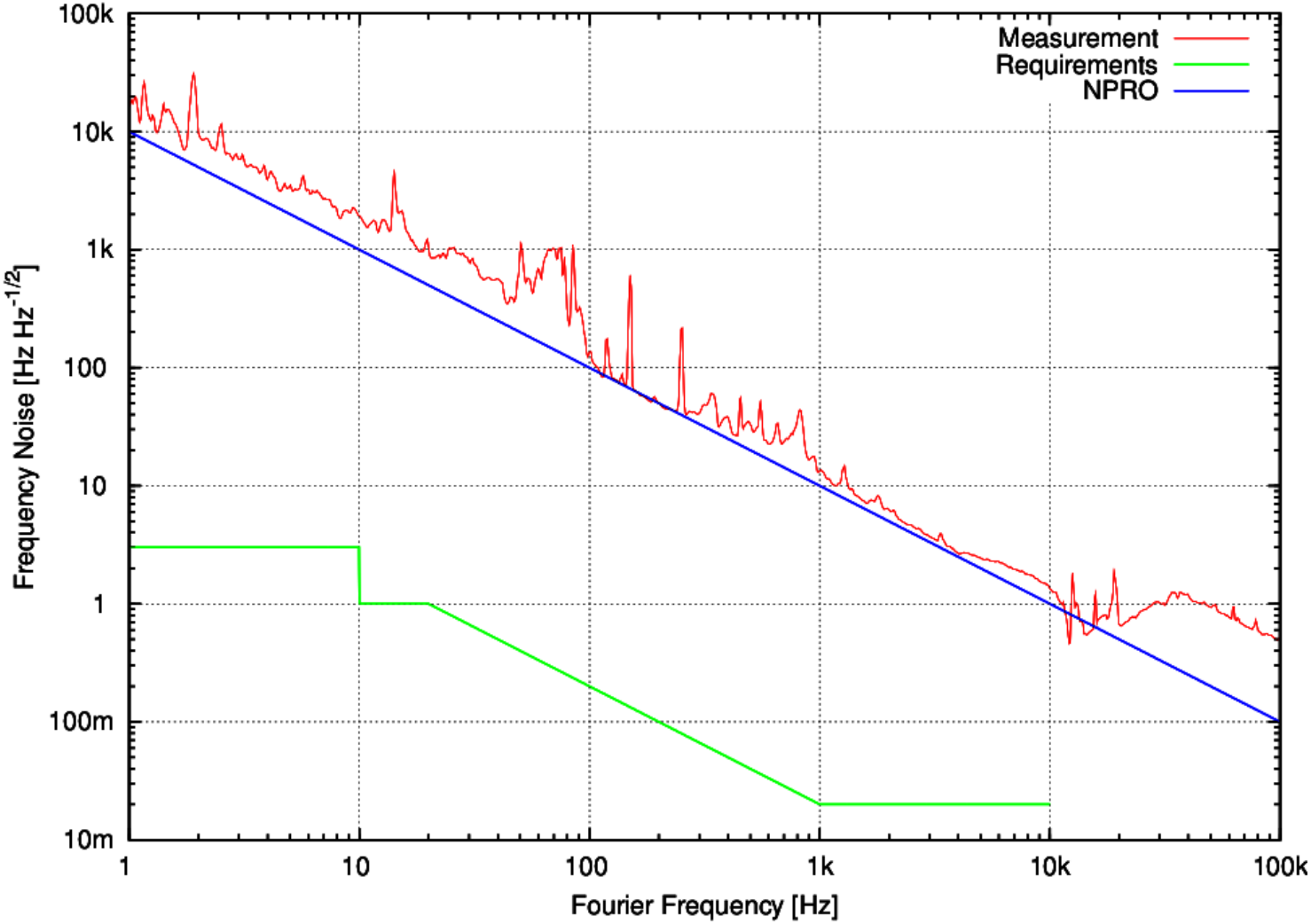
Diagnostic breadboard

- Frequency noise
  - Locked PMC as frequency reference
  - Keep path length of the PMC more stable than the laser frequency
  - Dither lock at 1 MHz
  - Measure deviation between resonance and the laser



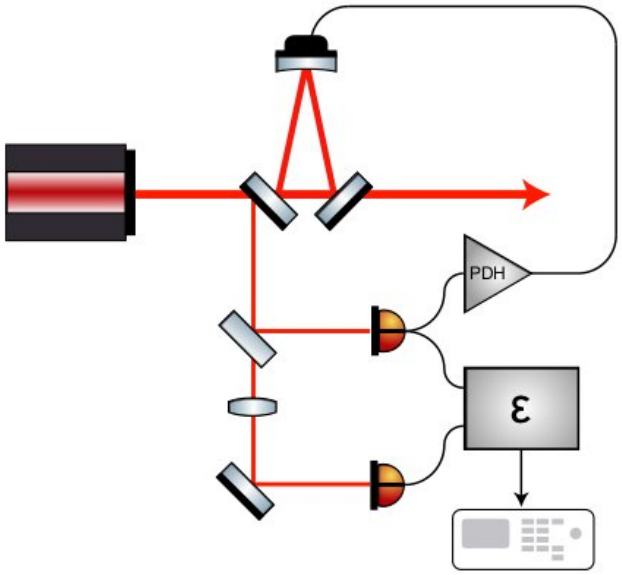
Diagnostic breadboard

- Freerunning frequency noise of the PSL

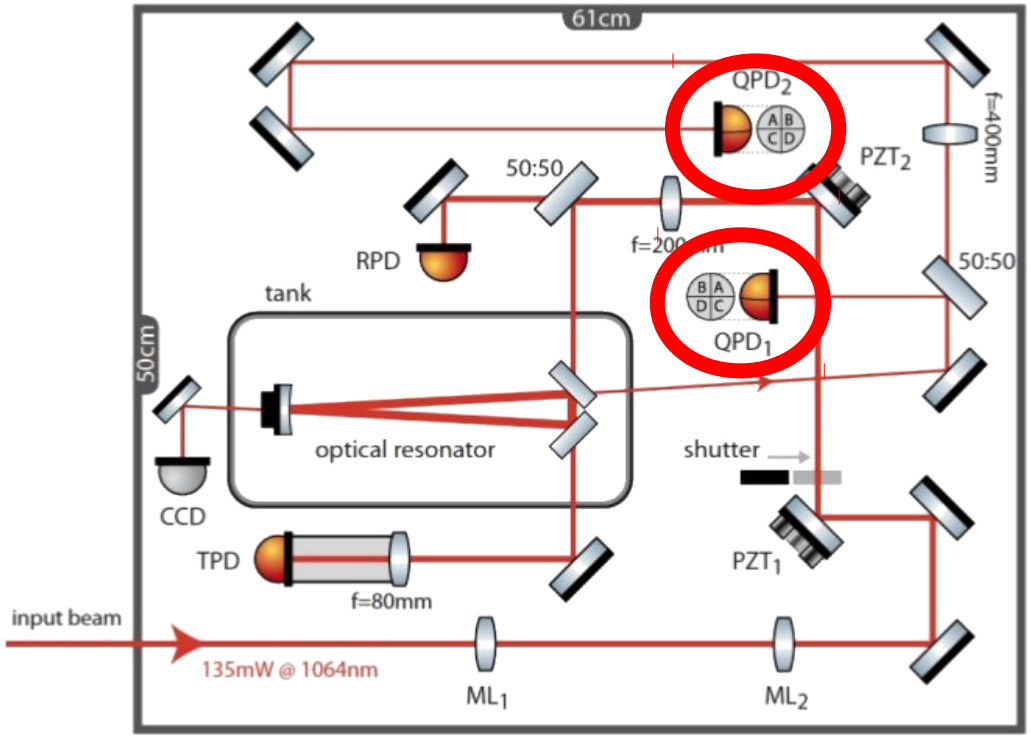


Diagnostic breadboard

- Pointing (with respect to the fundamental mode of the PMC)
- Differential wavefront sensing
- Time series acquired with A/D board

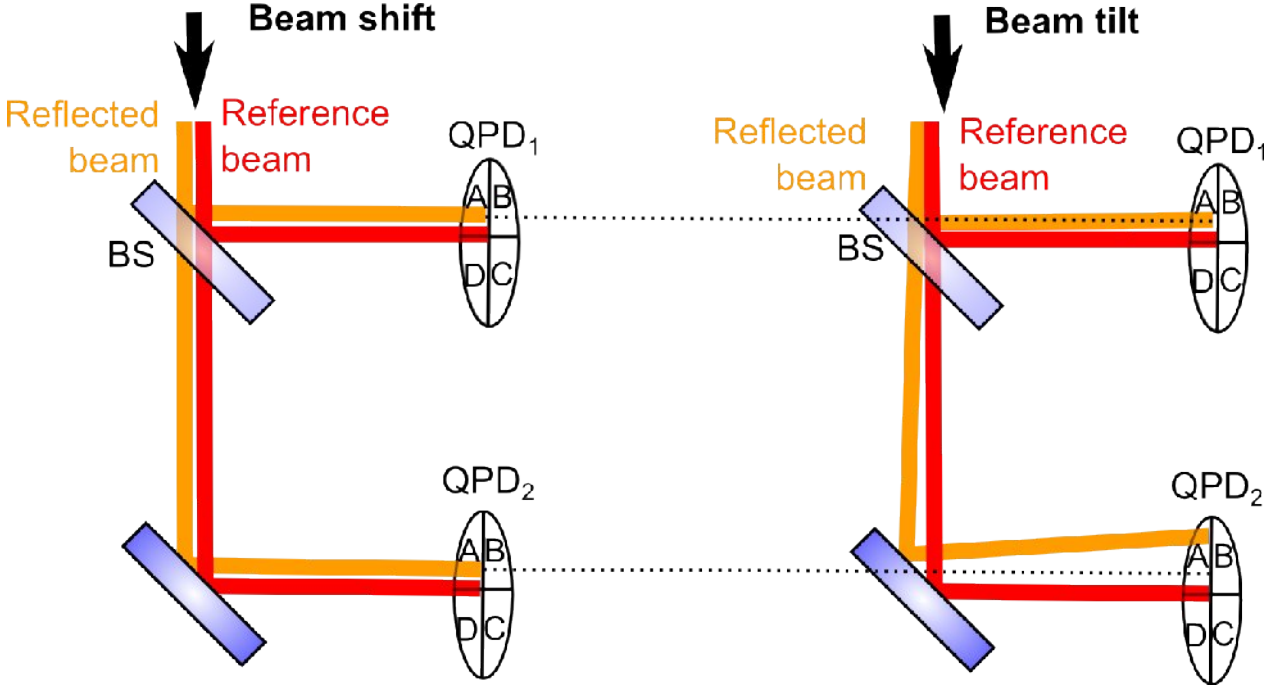


$$\varepsilon_1 = \sqrt{(\delta x / w_0)^2 + (\delta\alpha / \Theta_d)^2}$$



Differential wavefront sensing

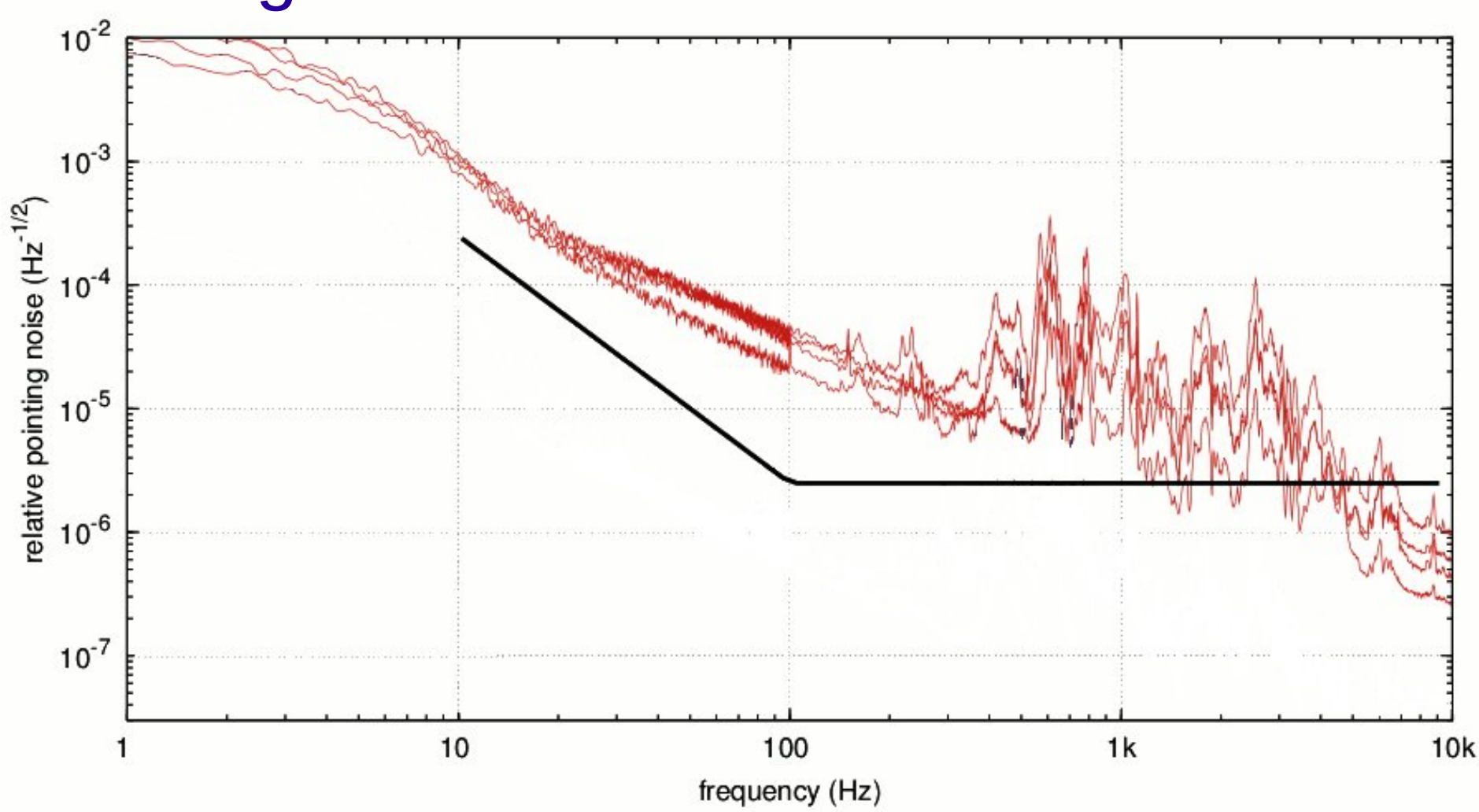
- Two quadrant photodiodes to distinguish tilt and shift



- For high precision tip/tilt: interference measurement of phase difference in reflected and reference beam
- "Tilt" causes a non-uniform interference pattern → compare the phase at two positions across the beam

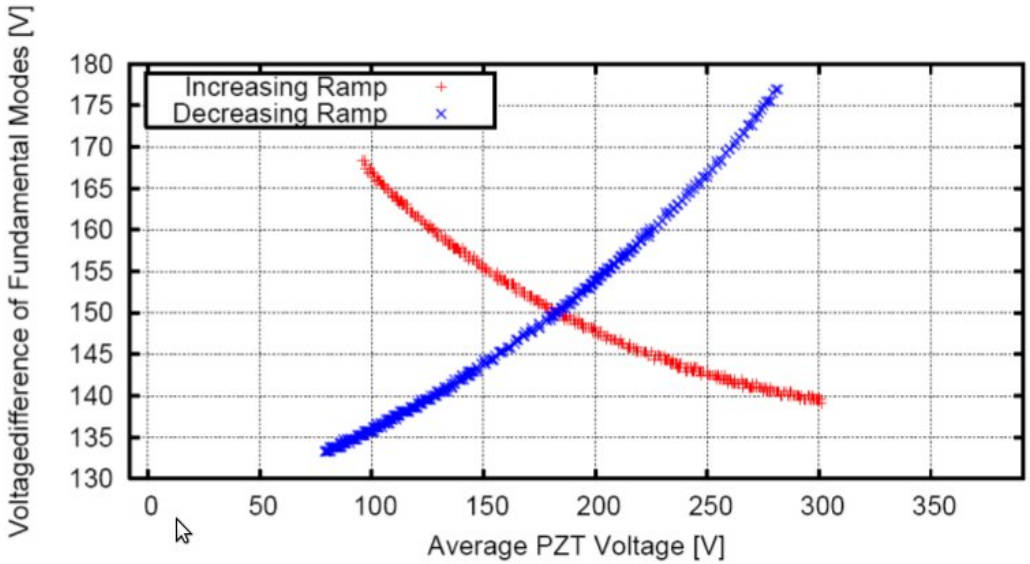
Diagnostic breadboard

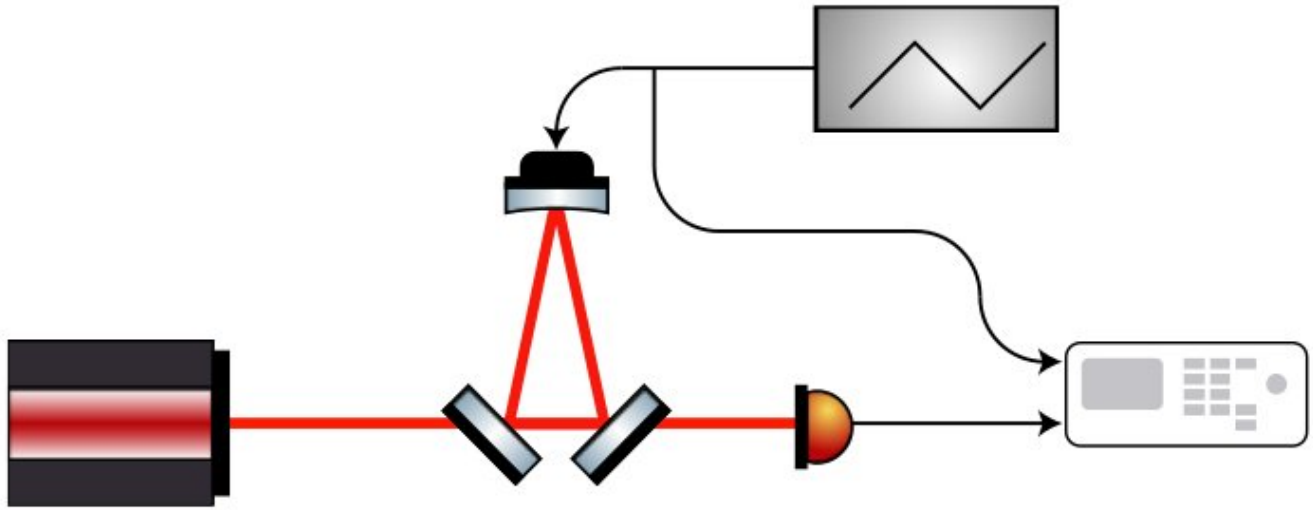
- Pointing of the PSL



Diagnostic breadboard

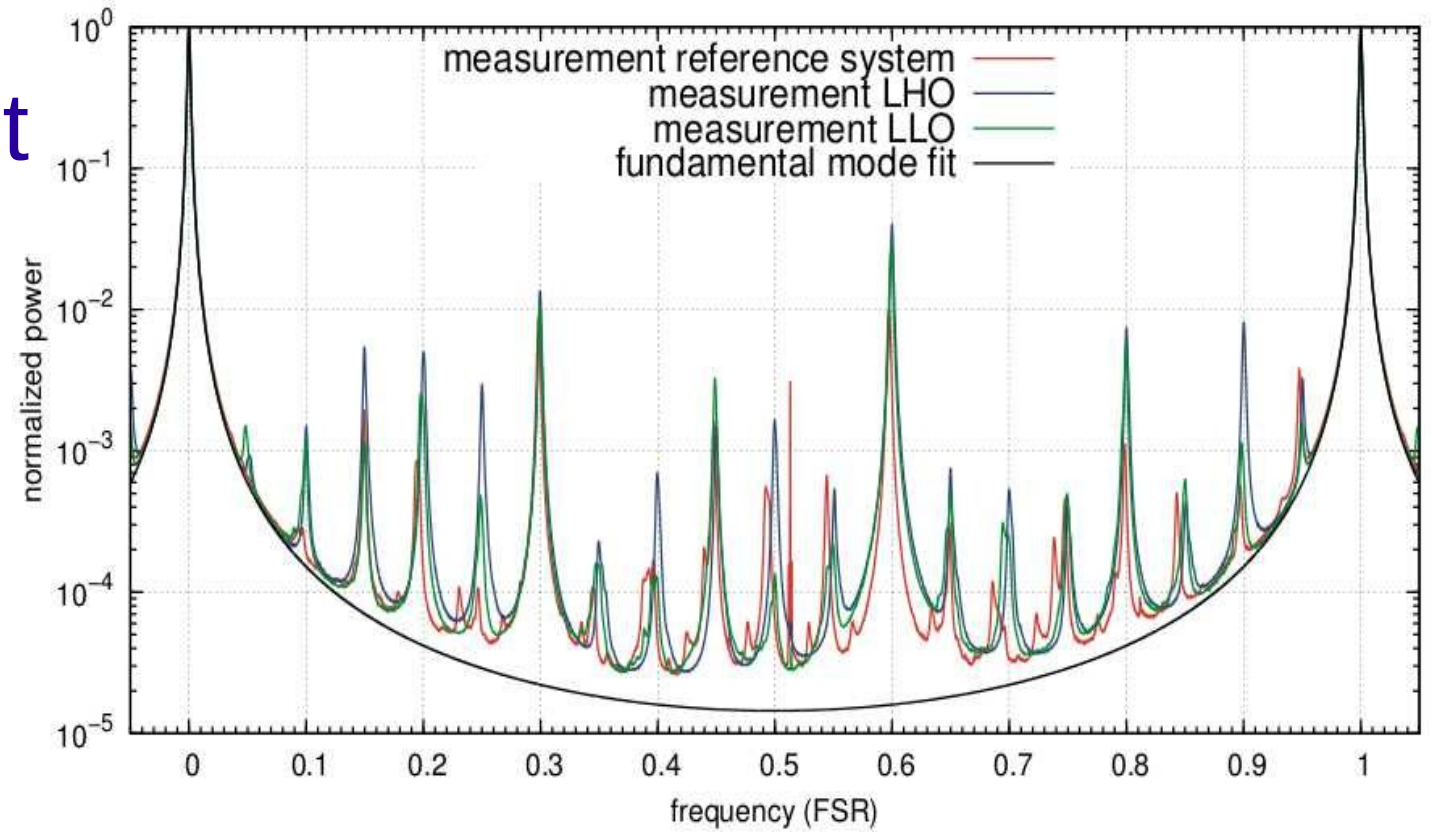
- Beam quality
- Modescan: transmission through PMC





Diagnostic breadboard

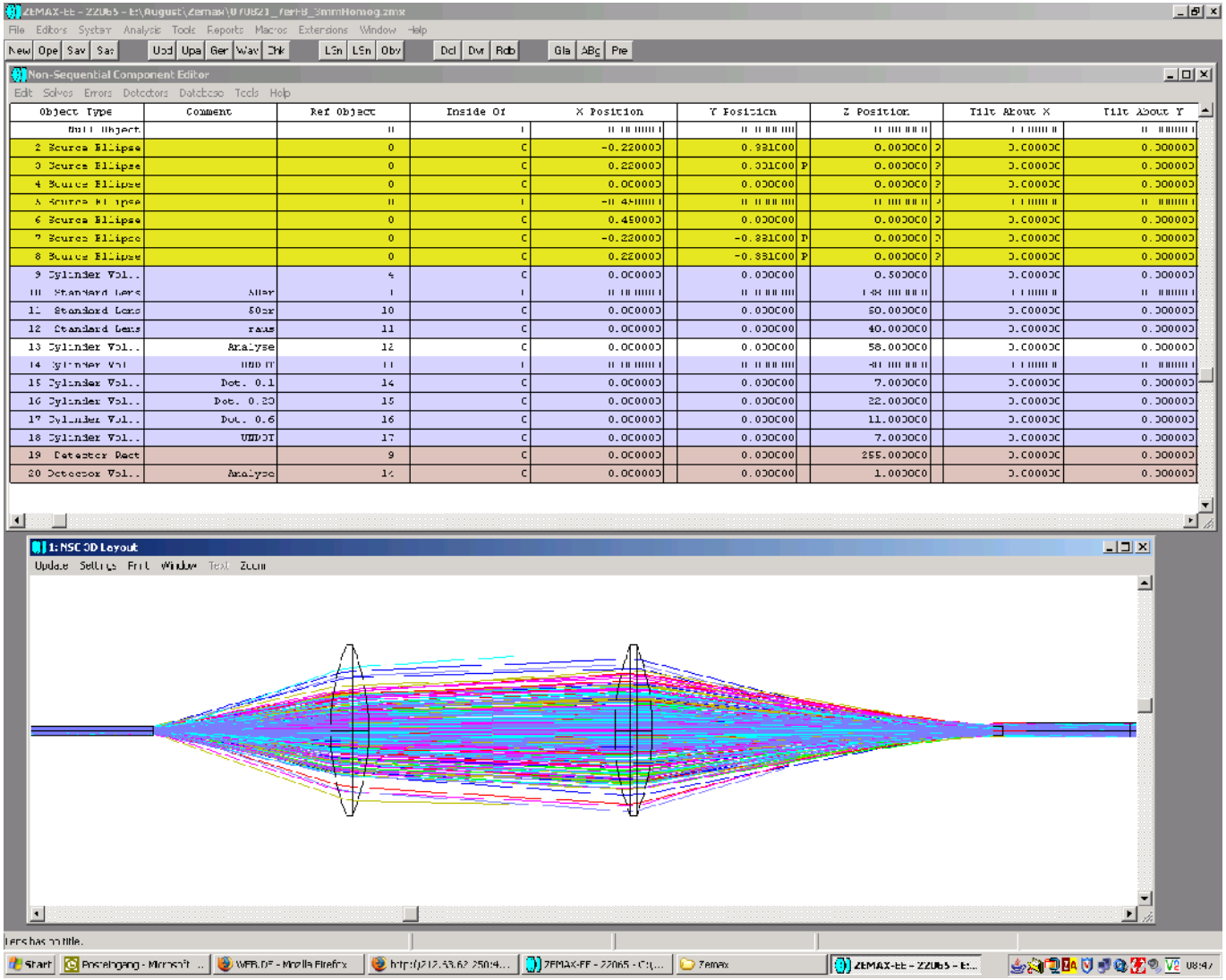
- Beam quality of the PSL (upstream high-power PMC)
- Higher order mode content
  - LLO: 5.3 %
  - LHO: 8.5 %
  - RefSys: 3.1 %



Outline

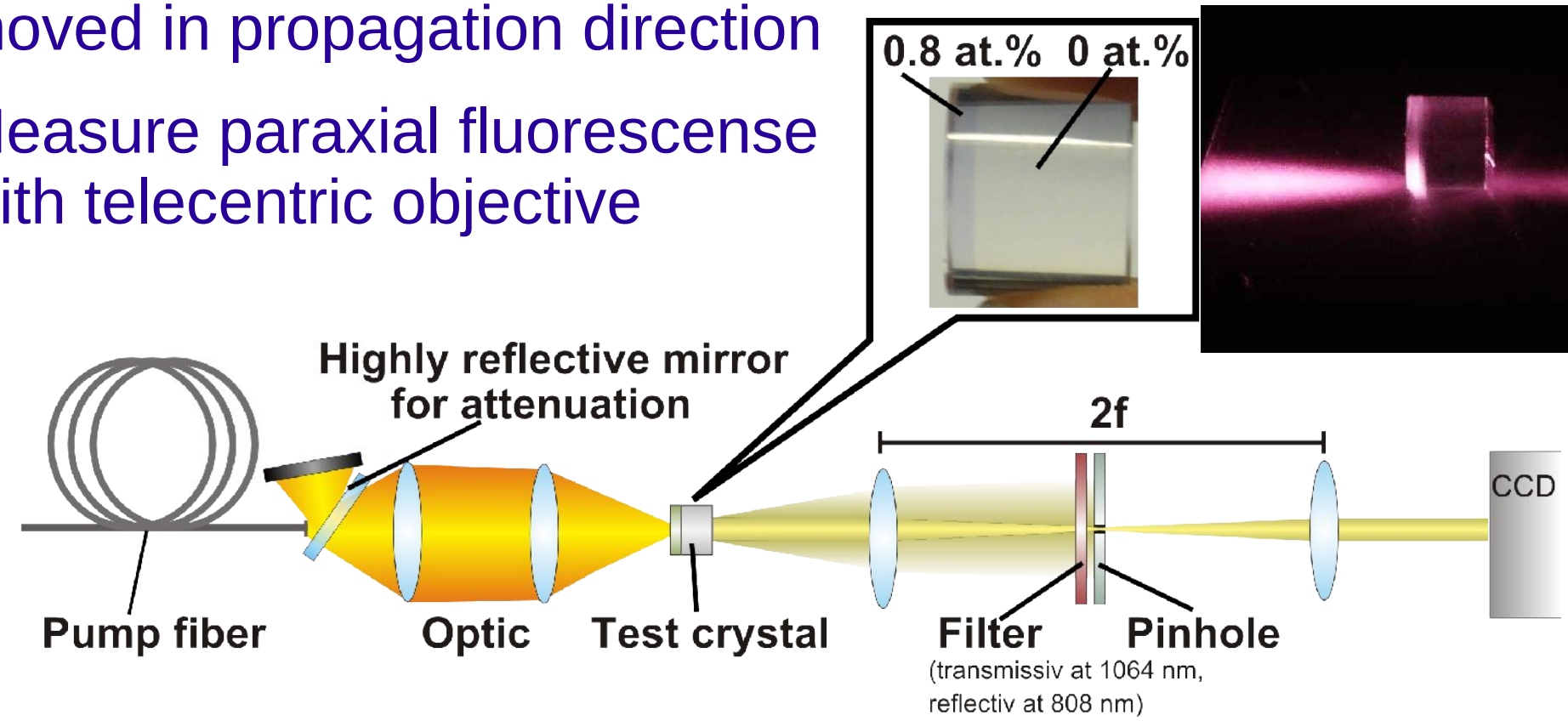
- Diagnostics inside the PSL
- **Useful tools**
  - Diagnostic breadboard (DBB)
  - **Pump light characterization**
  - Crystal characterization

Pump light simulation

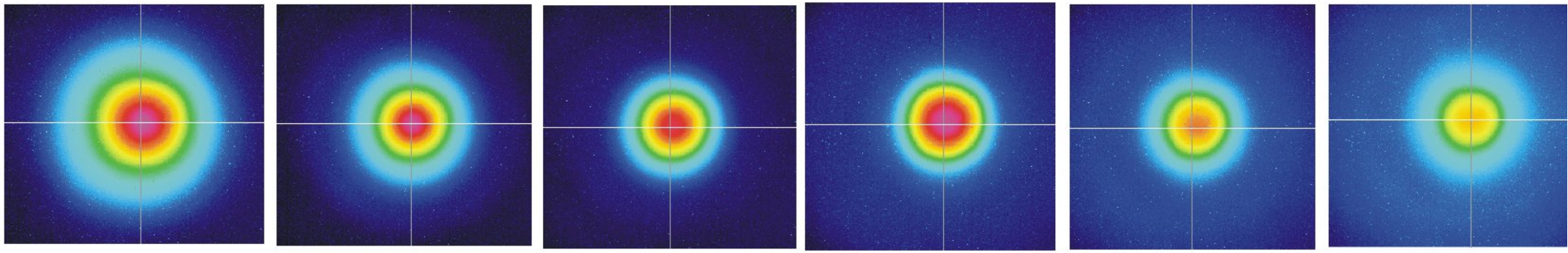


Pump light characterization

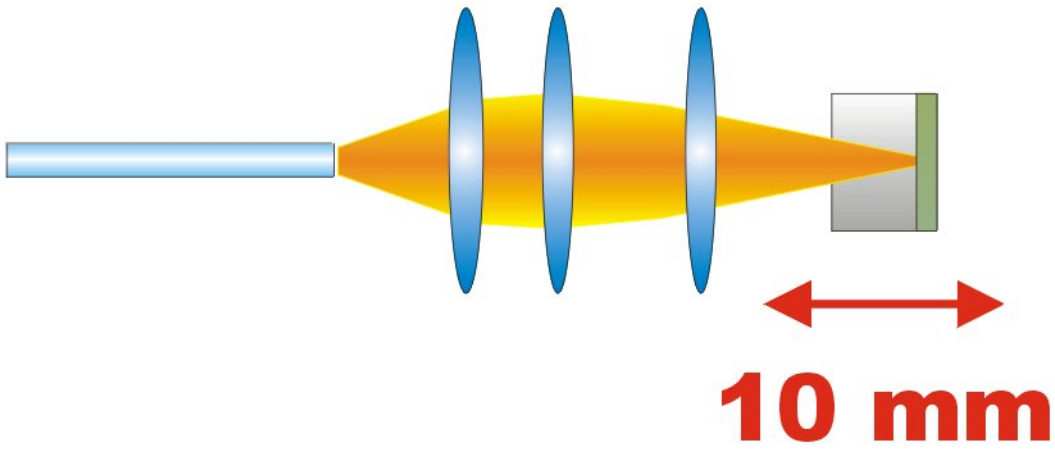
- Indirect method, shows the pump light as it appears inside the Nd:YAG crystals
- Test crystal 1 mm long, 0.8 at% doped moved in propagation direction
- Measure paraxial fluorescense with telecentric objective

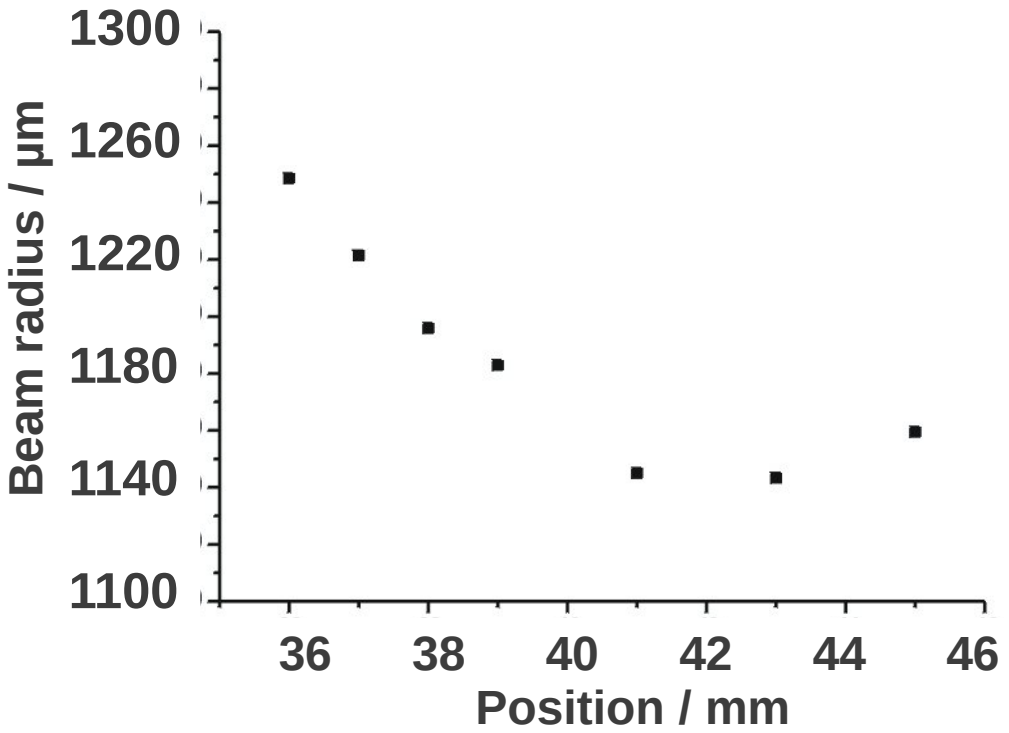


Pump light characterization



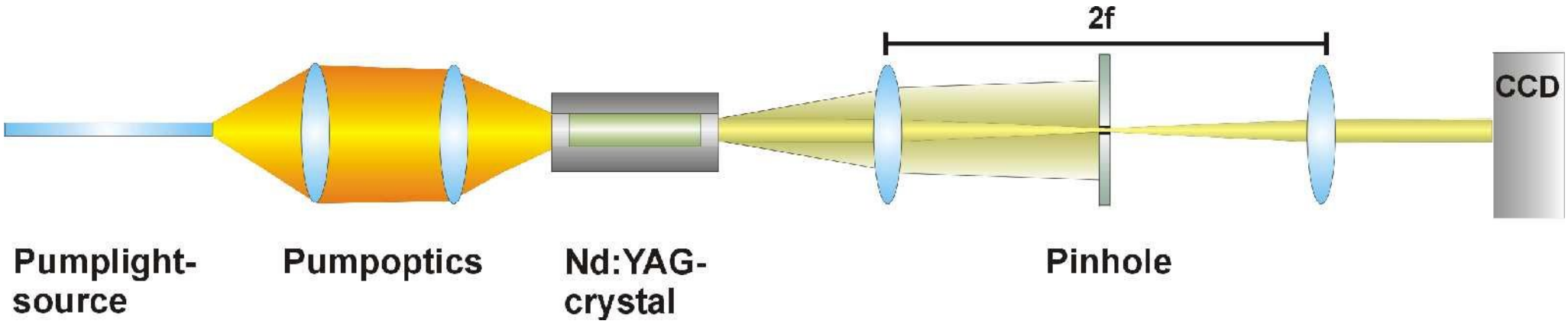
1mm





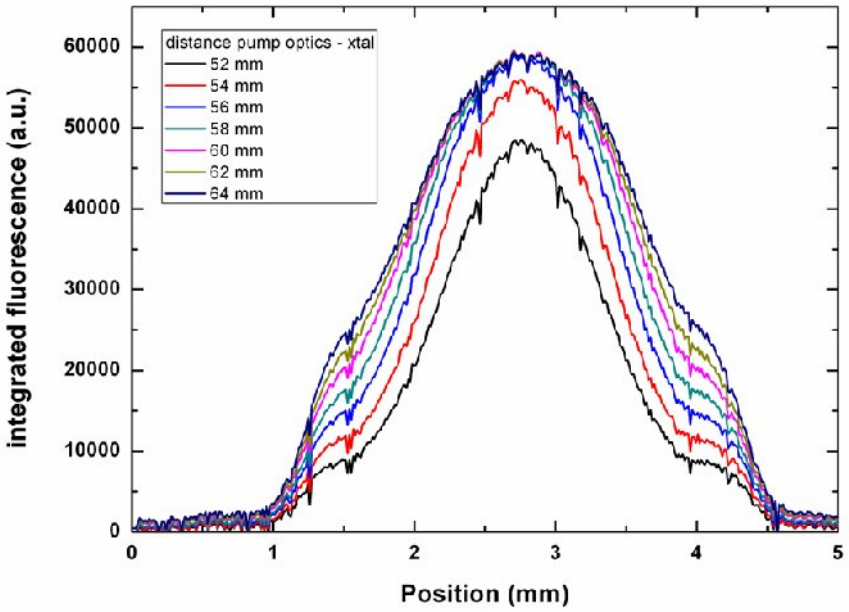
Integrated fluorescense

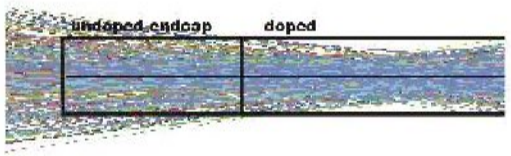
- Provides pump light distribution without knowning the caustic / intensity distribution per section
- Absorption length big compared to rod radius → divergence of pump light is not neglectable
- Internal reflections at crystal's barrel
- Fluorescense proportional to pump light



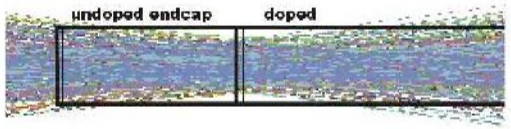
Integrated fluorescense

- Depends on
  - Size of the geometric pump spot
  - Absorption length of the crystal
  - Doping concentration
  - Spectral distribution



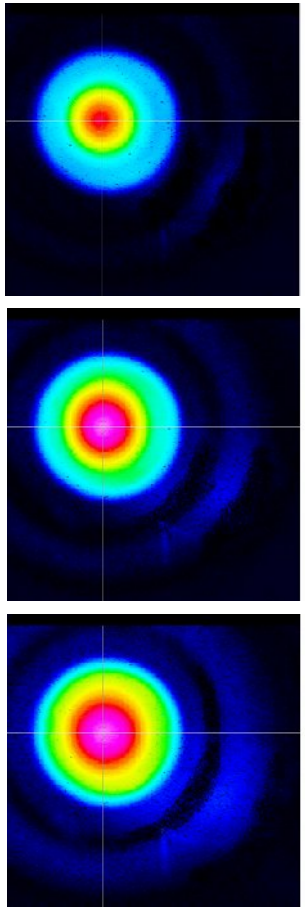


52 mm



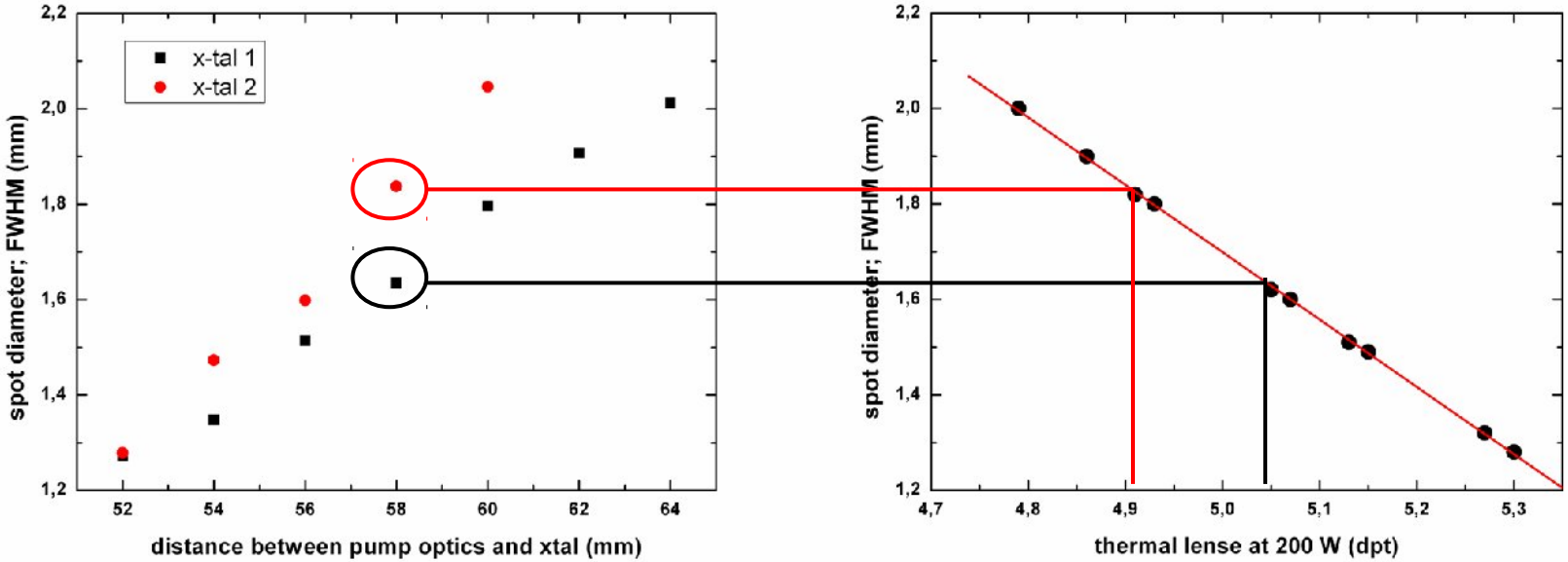
58 mm

64 mm



Integrated fluorescense

- Spot diameters from integrated fluorescense
  → incoming inspection of crystals

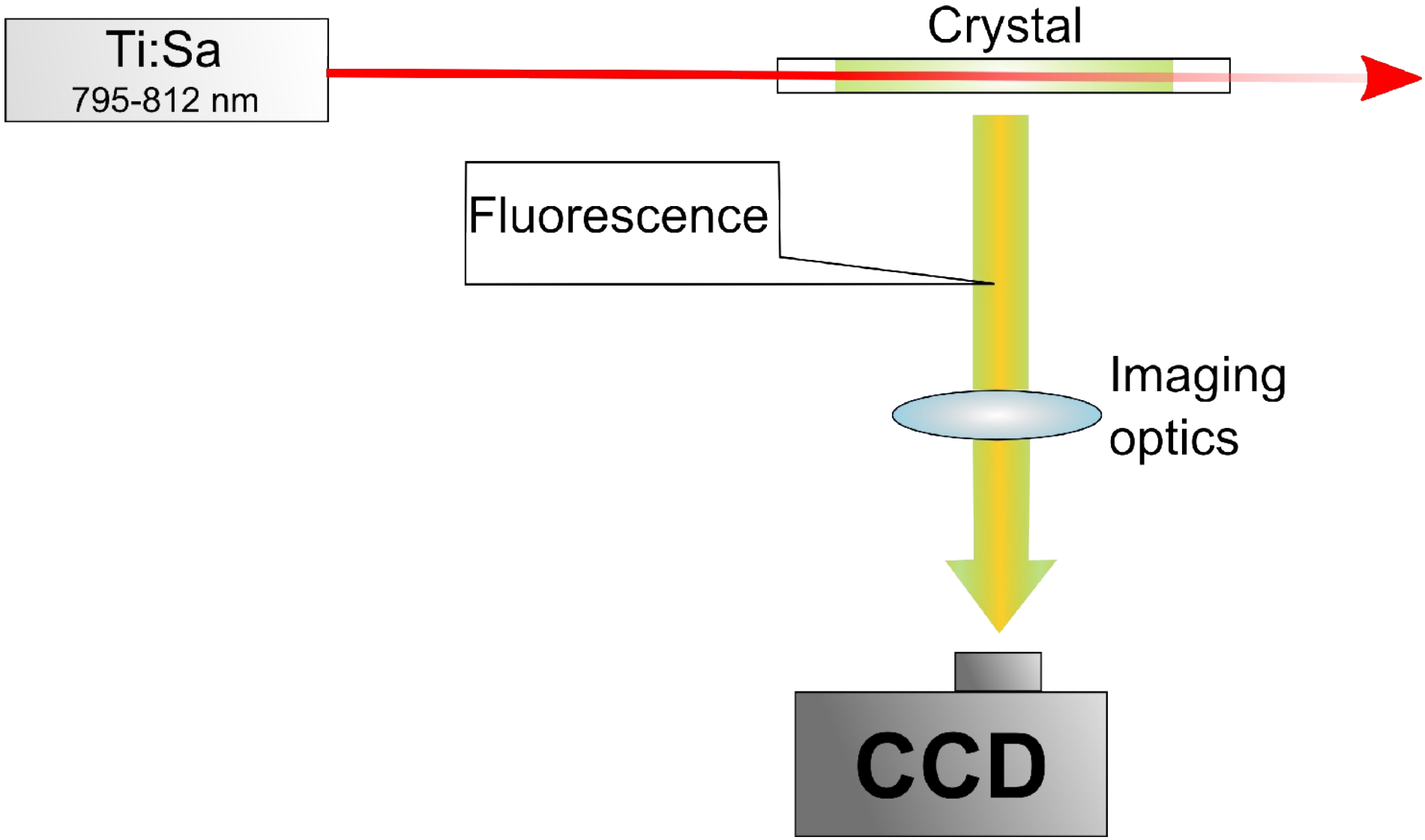


→ these crystals are slightly different doped
→ crystal characterization required

Outline

- Diagnostics inside the PSL
- **Useful tools**
  - Diagnostic breadboard (DBB)
  - Pump light characterization
  - **Crystal characterization**

Ti:Sa characterization

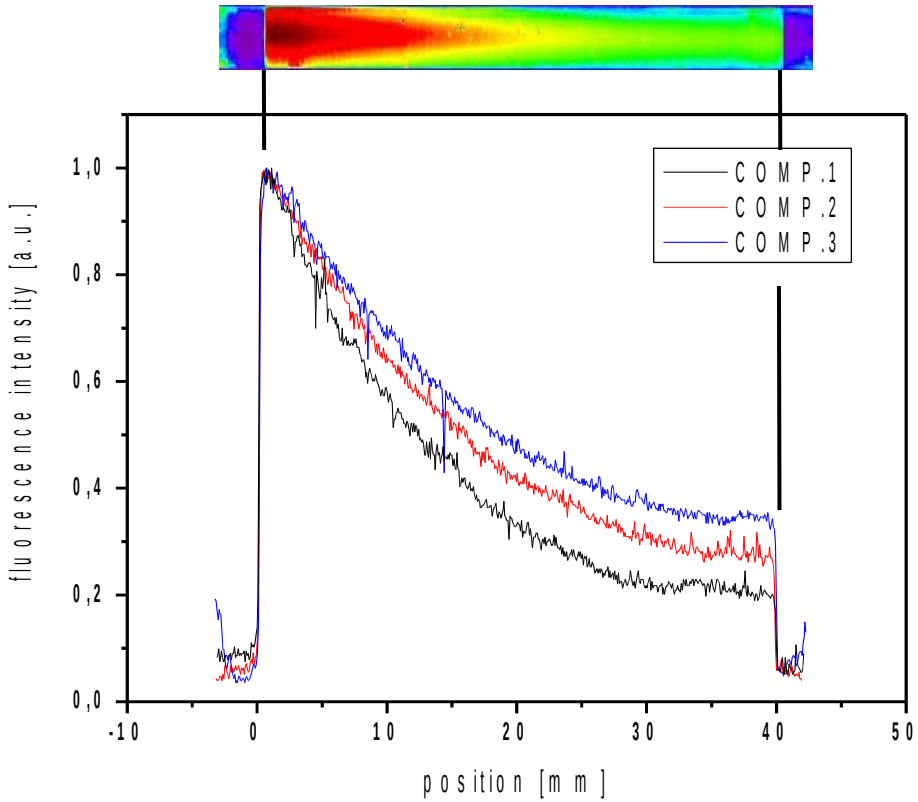


Ti:Sa characterization

- Fit Lambert-Beers law to find absorption coefficient α_{abs}
- Doped region 40 mm, pump light double pass

$$F(z) = F(0)(\exp(-\alpha_{abs} \cdot z) + \exp(-2 \cdot 40mm \cdot \alpha_{abs} + \alpha_{abs} \cdot z))$$

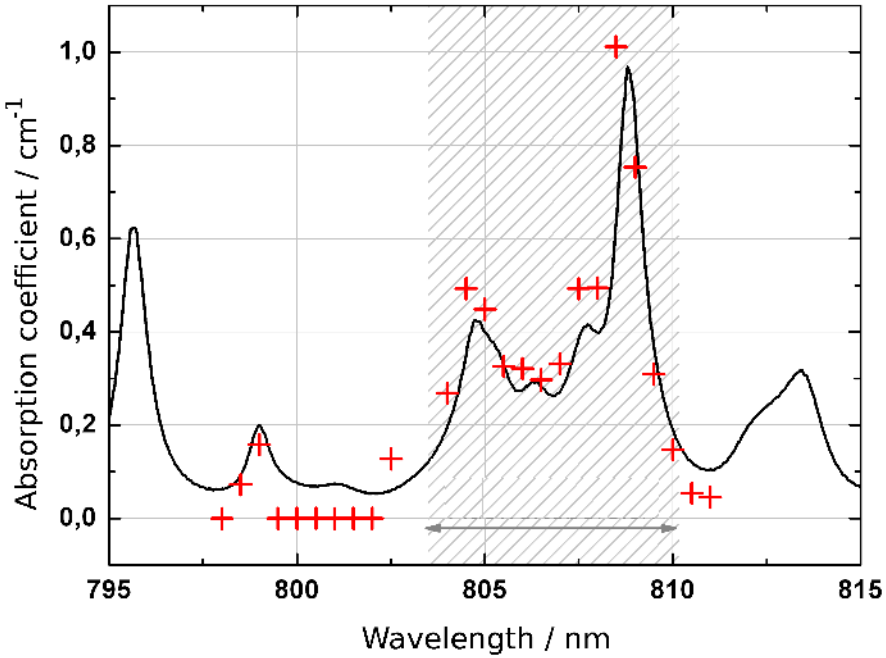
- Compare α_{abs} with an absorption coefficient for a known doping concentration

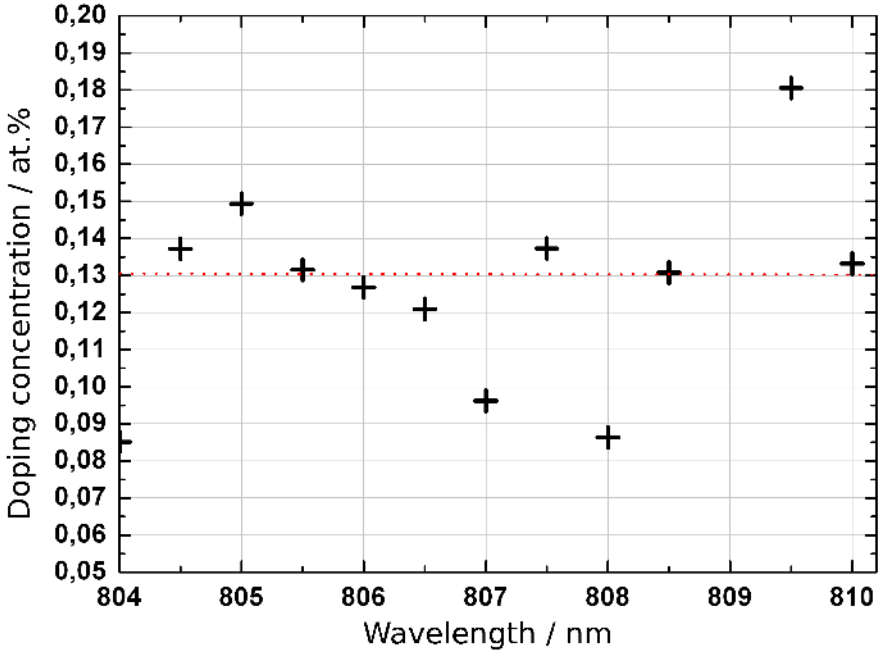


Variation of up to +/-10% in doping concentration for rods from different vendors

Ti:Sa characterization

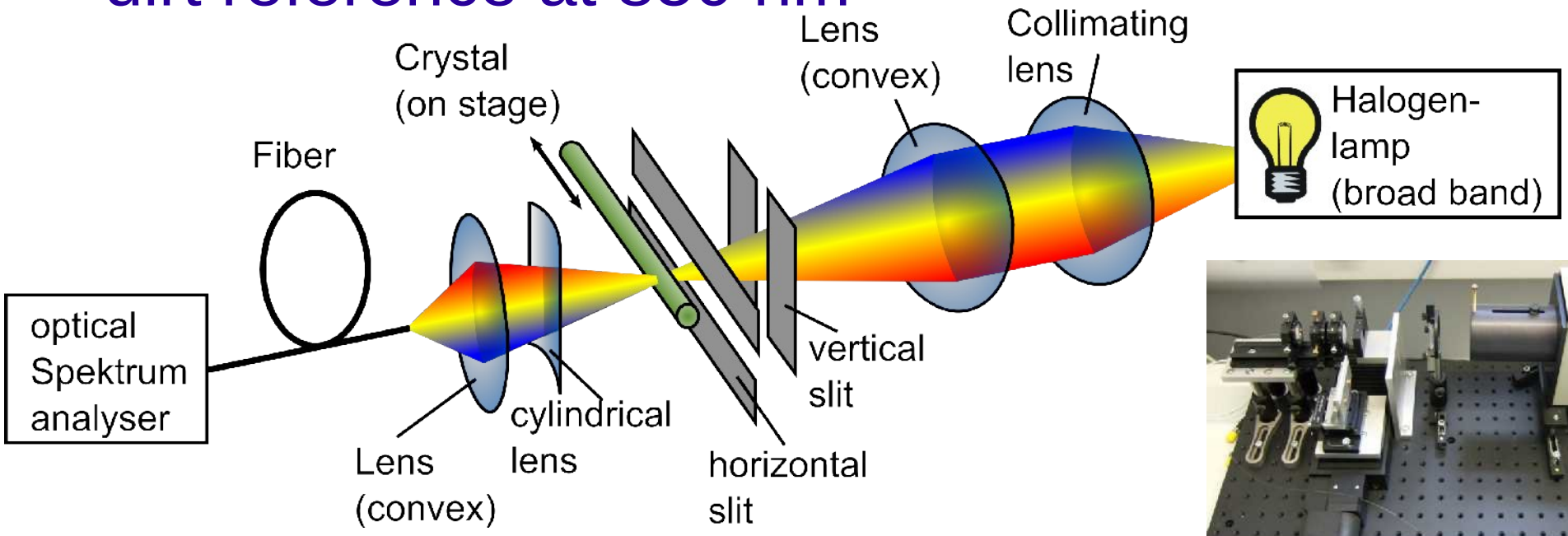
- Example measurement



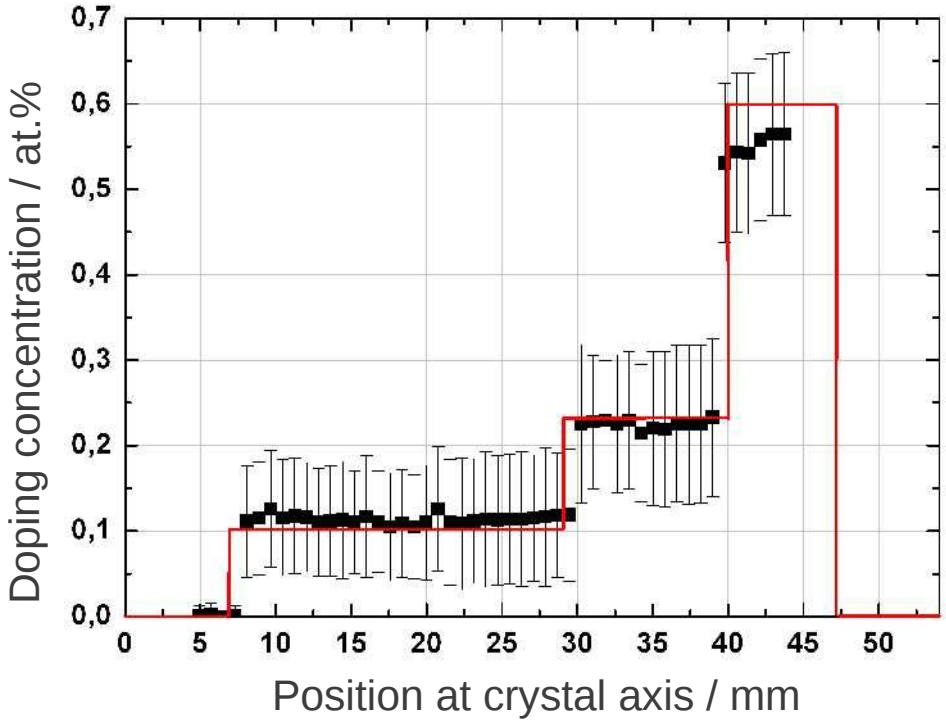


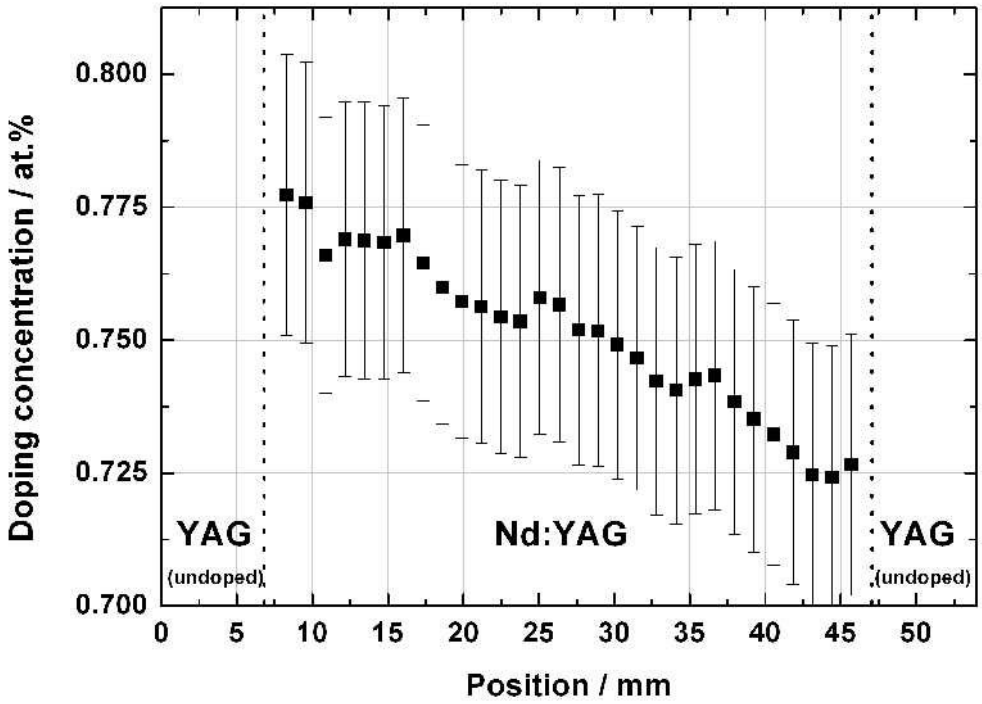
White light characterization

- Absorption measurement provides information on longitudinal doping gradients
- Reference: undoped endcap and known crystal
- dirt reference at 850 nm



White light characterization





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Thanks!