CW-Lyman-α Source for Laser Cooling of Antihydrogen in a Magnetic Trap

F. Markert, M. Scheid, D. Kolbe, A. Müllers,
T. Weber, V. Neises, R. Steinborn and J. Walz

Institut für Physik, Johannes Gutenberg-Universität Mainz

Goal: Cooling of Antihydrogen for CPT-Test

- CPT-test by comparing $\nu_{1s\text{-}2s}$ in H (2 466 061 413 187 103(46) Hz) and $\bar{\mathrm{H}}$

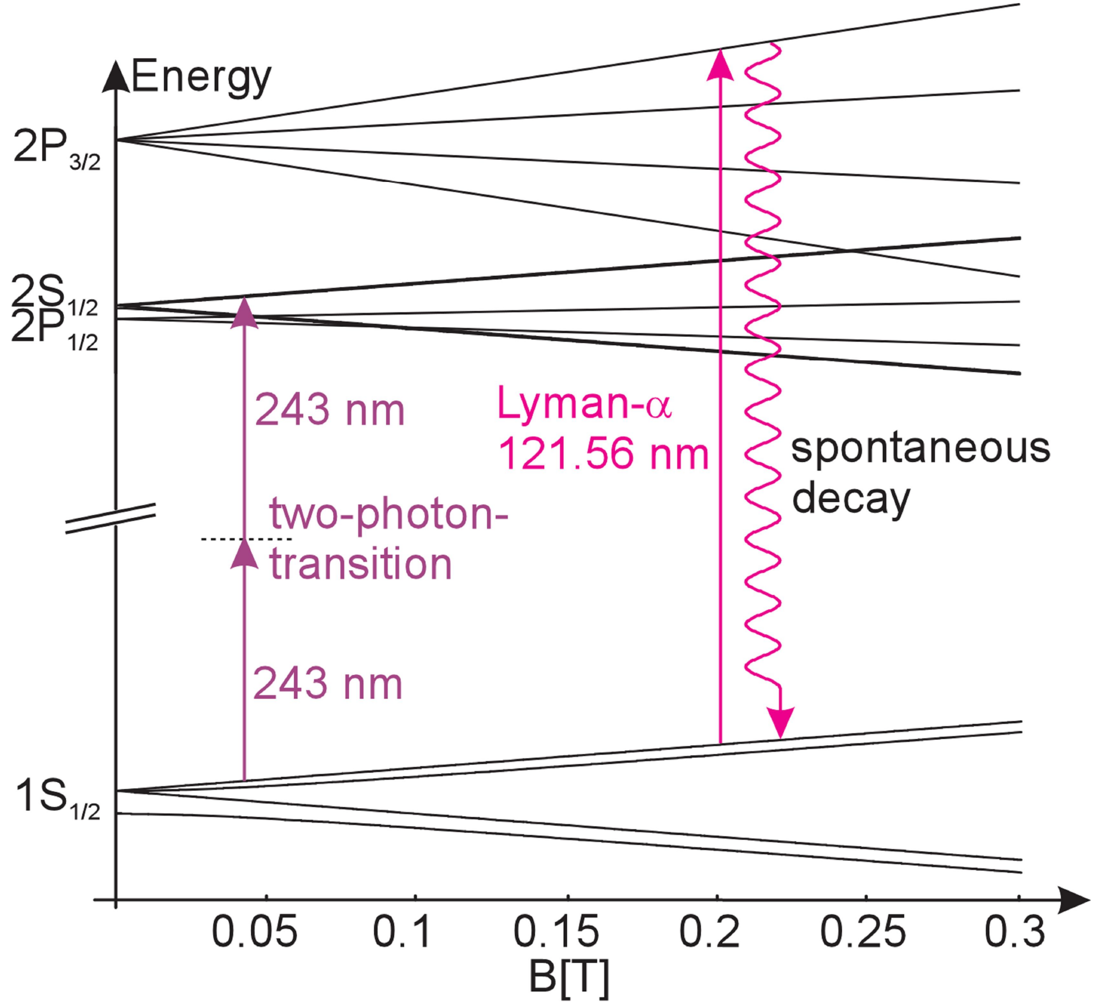
- Antihydrogen in Ioffe-Trap (0.67K/T)

  → Zeeman shift dependent on position in B-field (186kHz/T)

⟹ Cooling of the $\bar{\mathrm{H}}$ atoms for localization at the center of the trap

→ Doppler limit 2.4mK

Energy level scheme of $\bar{\mathrm{H}}$ in a B-field



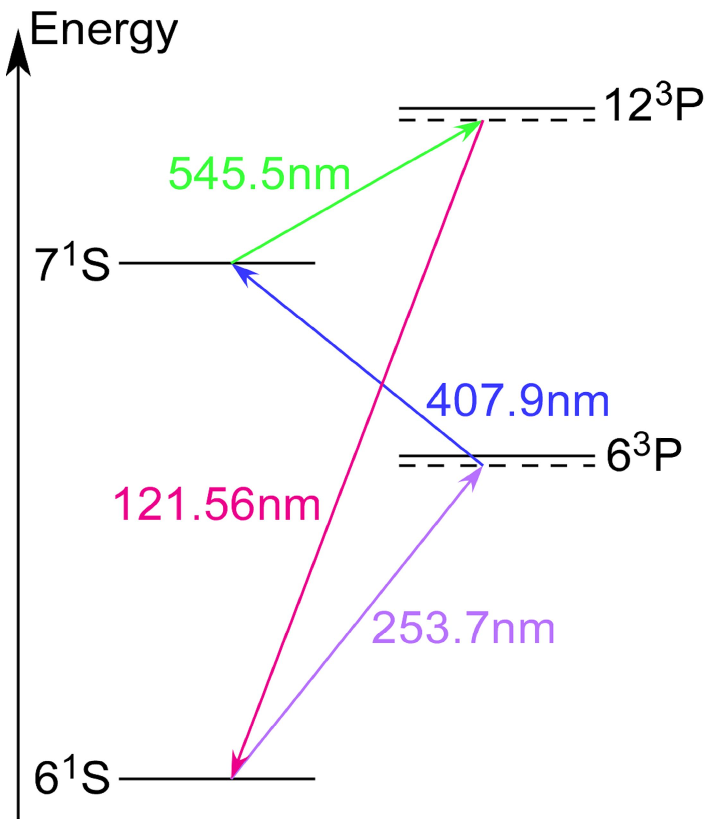
Generation of Lyman-α

Four wave mixing in mercury vapor

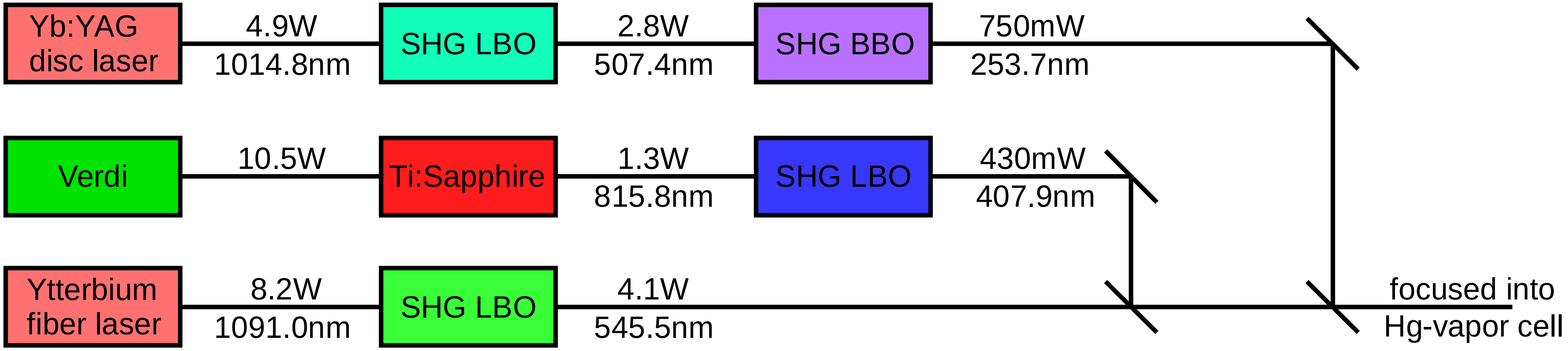
→ Enhancement of the conversion Efficiency by near resonance to the 6^3P level and resonance to the 7^1S level

→ Third fundamental wavelength determined by Lyman-α

Energy level scheme of Hg



Generation of the fundamental laser beams

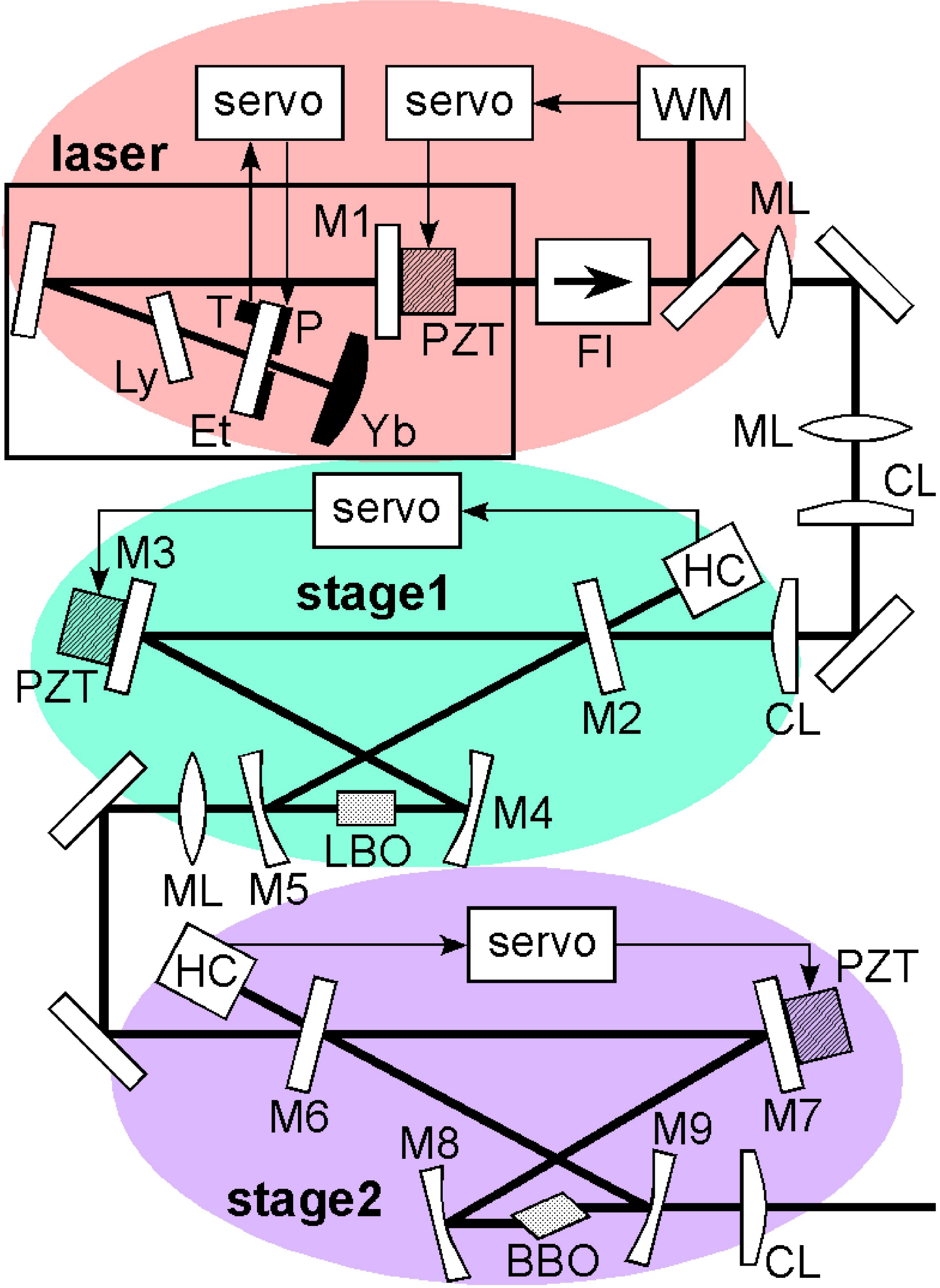


Setup of the Laser System at 253.7nm

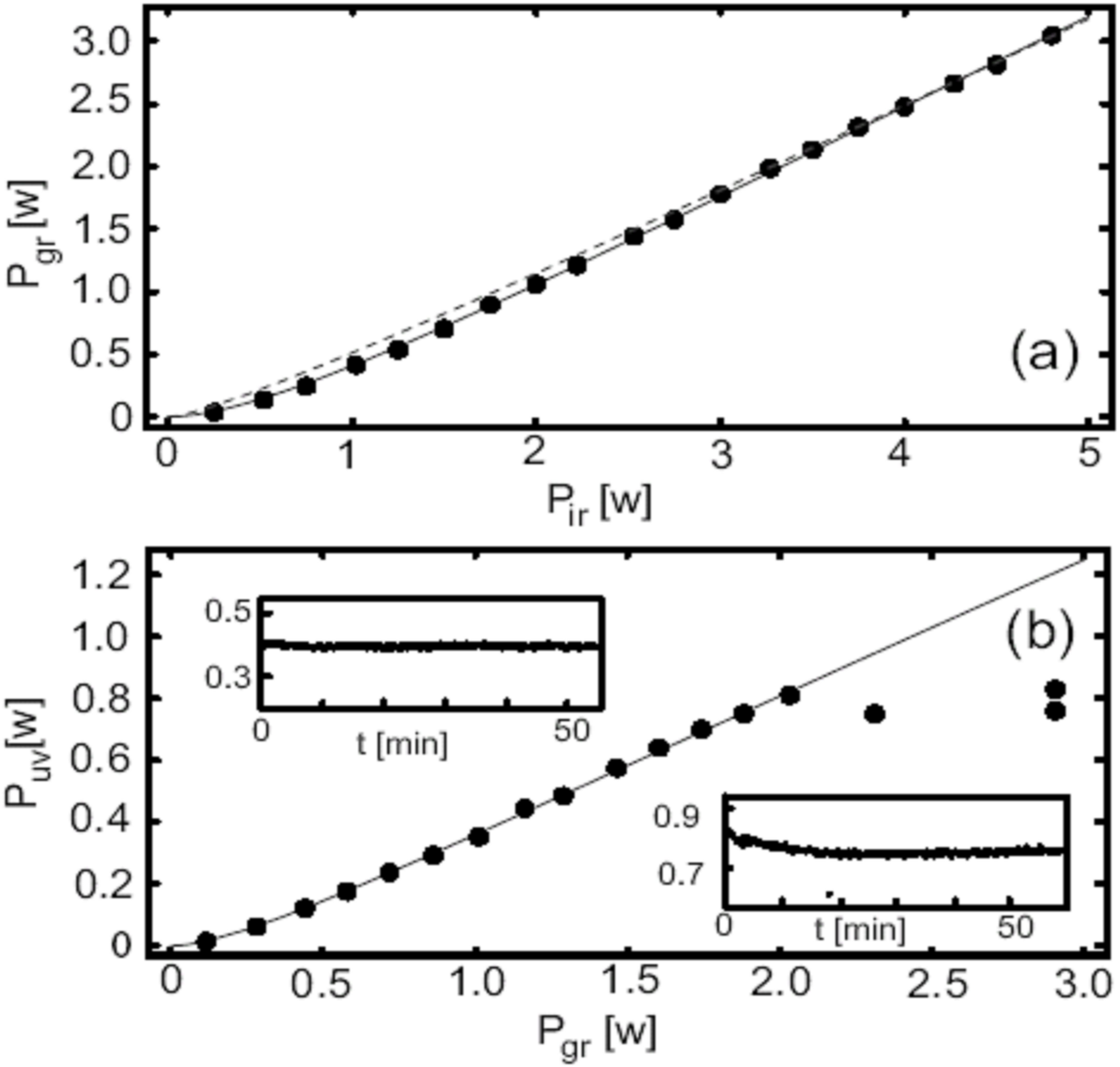
- Yb:YAG disc laser with wavelength control

- First frequency doubling stage using a 90° cut temperature phasematched LBO crystal and the Hänsch-Couillaud locking scheme

- Second frequency doubling stage using a brewster cut angle phasematched BBO crystal and the Hänsch-Couillaud locking scheme



Power Converted from 1015nm to 254nm



(a)
from 4.8W at 1014.8nm
stable 3W at 507.4nm
are generated

(b)
from 2W at 507.4nm
stable 750mW at
253.7nm are generated

for higher input powers
converted powers
degrade from up to 1W
to lower levels

Stabilizing and Scanning the Disc Laser

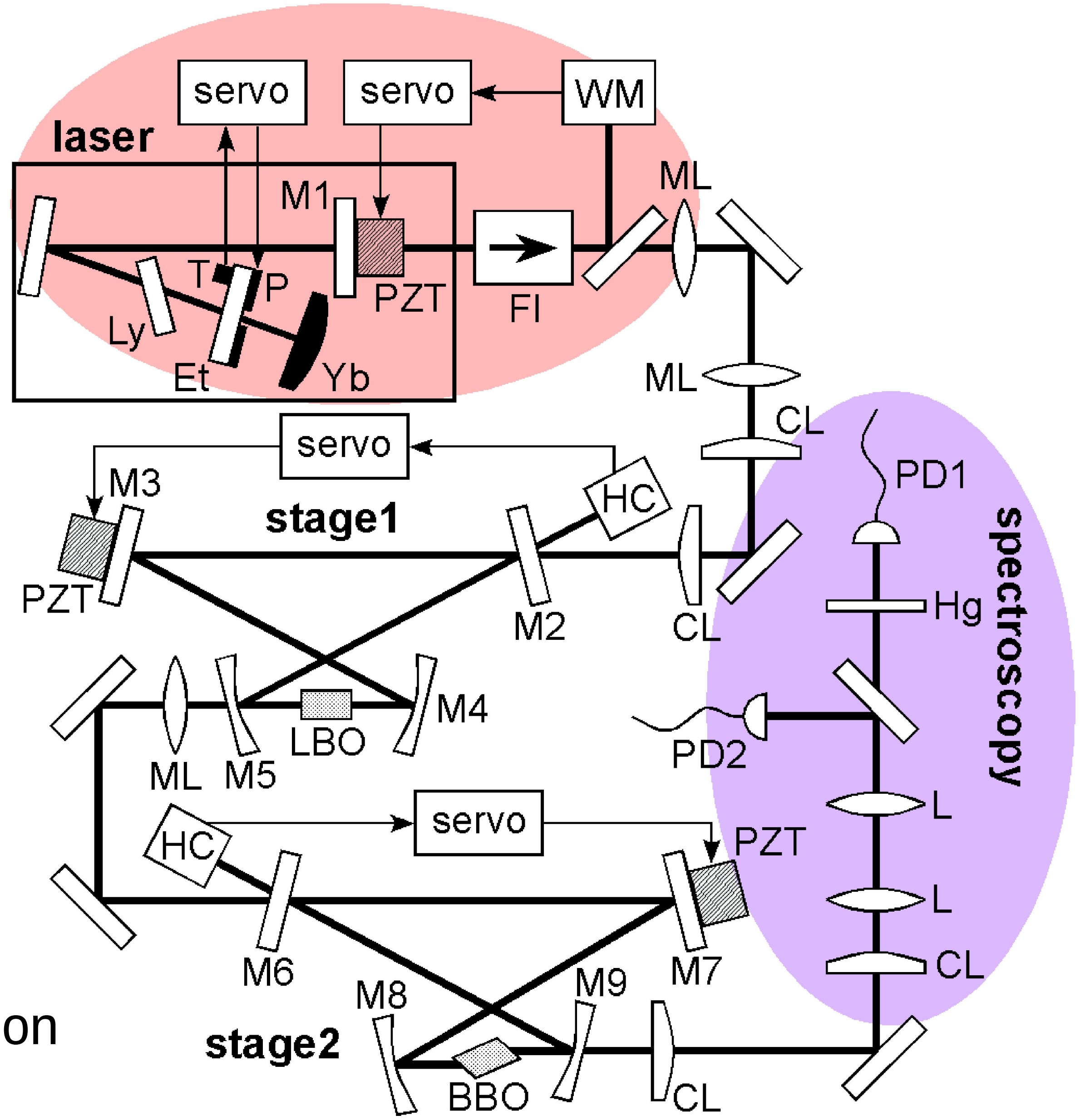
- The disc laser's frequency is stabilized to the wavemeter's short time accuracy (3MHz)

→ Stabilization of the etalon's temperature and of the length of the laser cavity

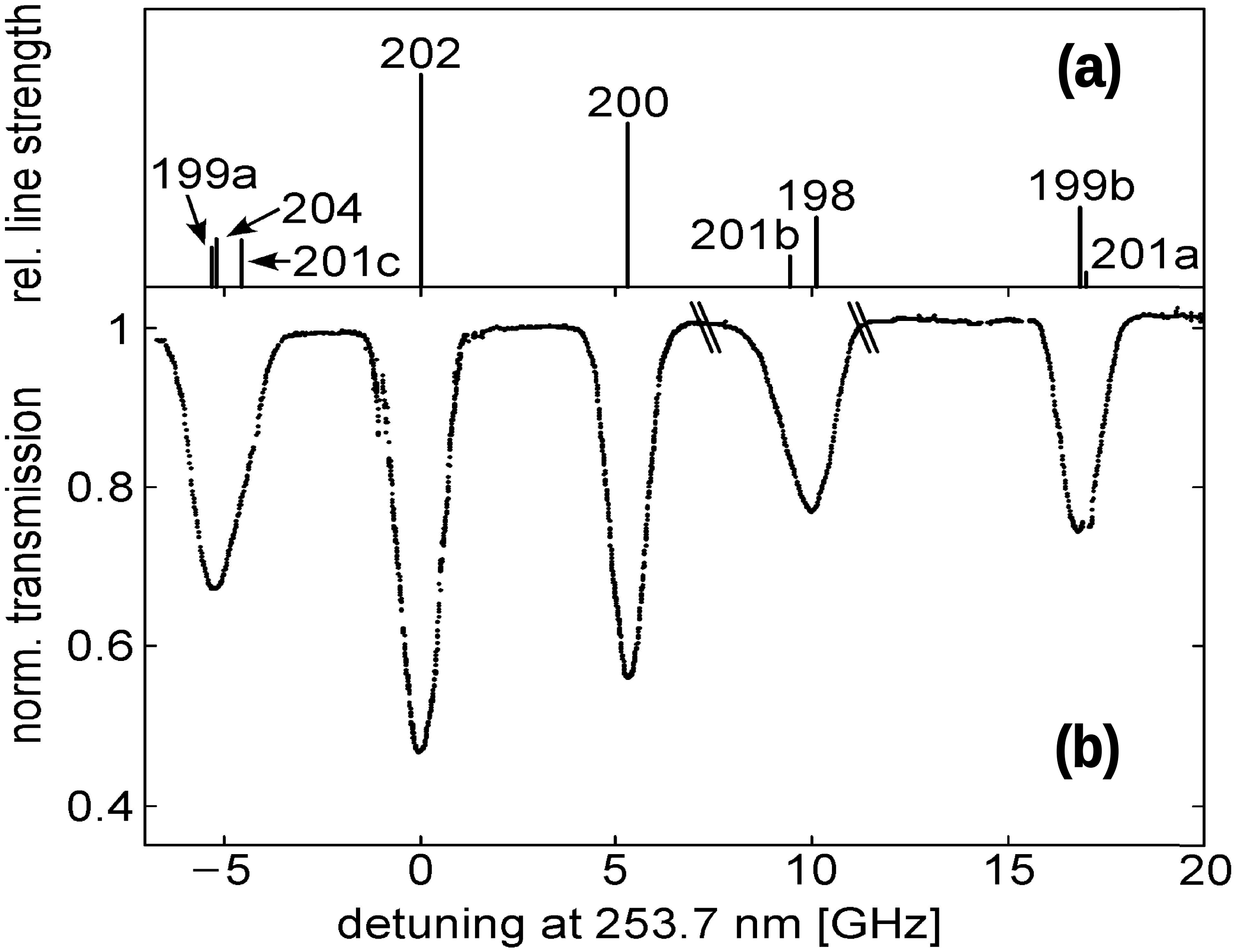
- Scanning the laser's wavelength by simultaneously ramping the temperature of the etalon and the voltage applied to the piezo at the outcoupling mirror

- Scanning ranges of up to 8GHz in the UV are realized (14MHz/s)

- To demonstrate scanning absorption spectroscopy on mercury is set up



Spectroscopy on atomic Mercury



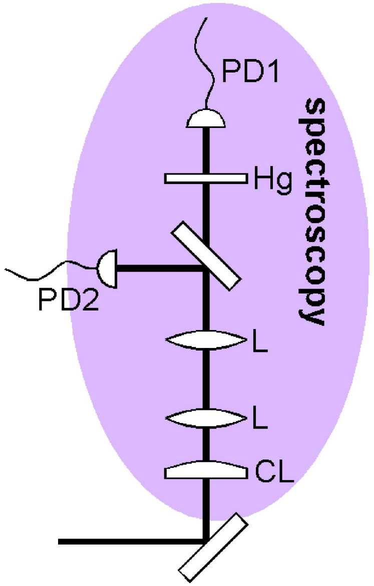
(a)

Line centers of the different mercury isotopes. Letters indicate hyperfine components of the odd isotopes.

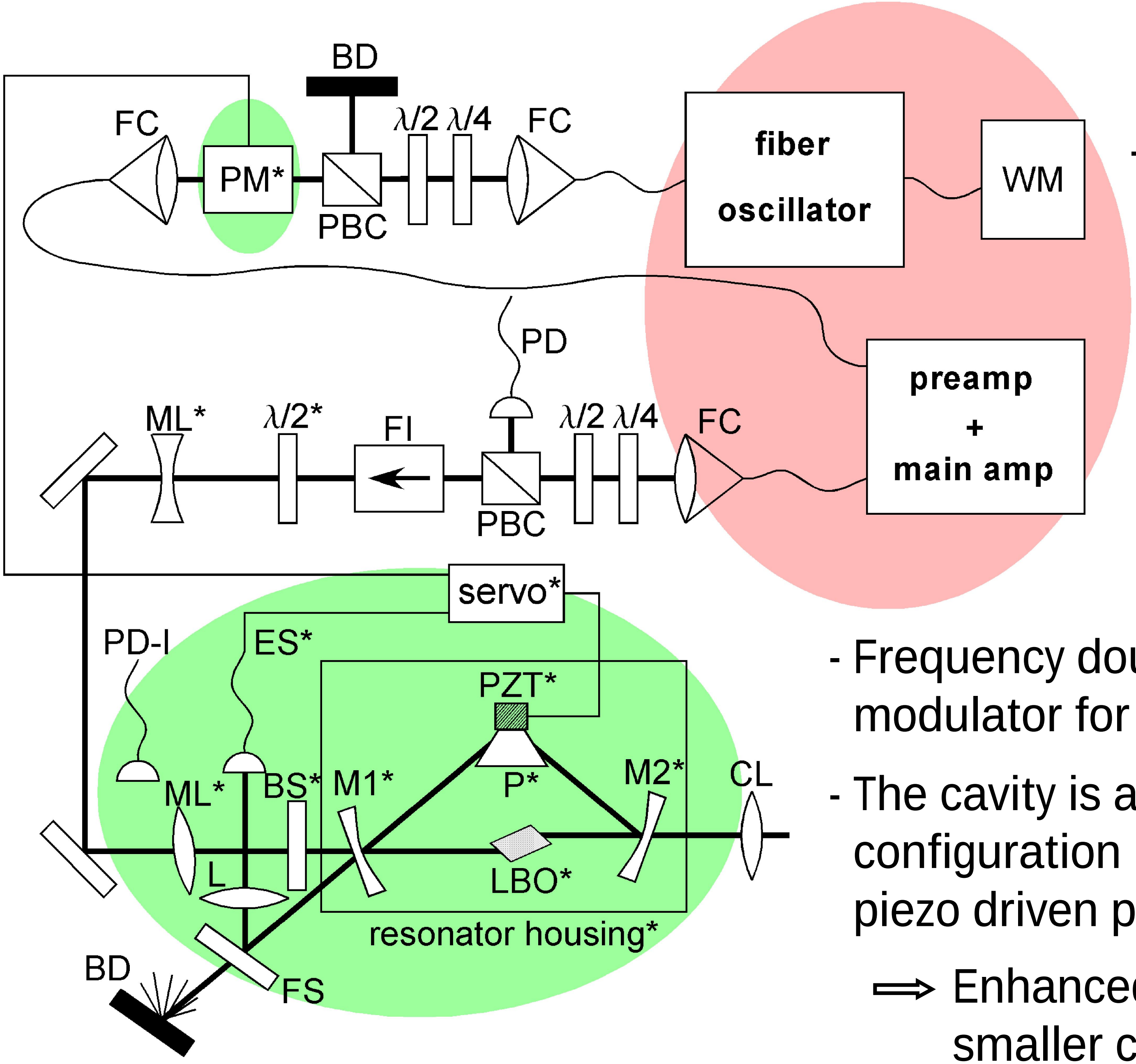
a, *F*=1/2; b, *F*=3/2; c, *F*=5/2

(b)

Absorption spectrum of the $^1S_0$–$^3P_1$ transition of atomic mercury. Double slashes indicate the ranges of three individual scans.



Setup of the Laser System at 545.5nm



- Fiber laser and amplifier with wavemeter

- Frequency doubling stage and phase modulator for Pound-Drever-Hall lock

- The cavity is arranged in a triangular configuration using two mirrors and a piezo driven prism

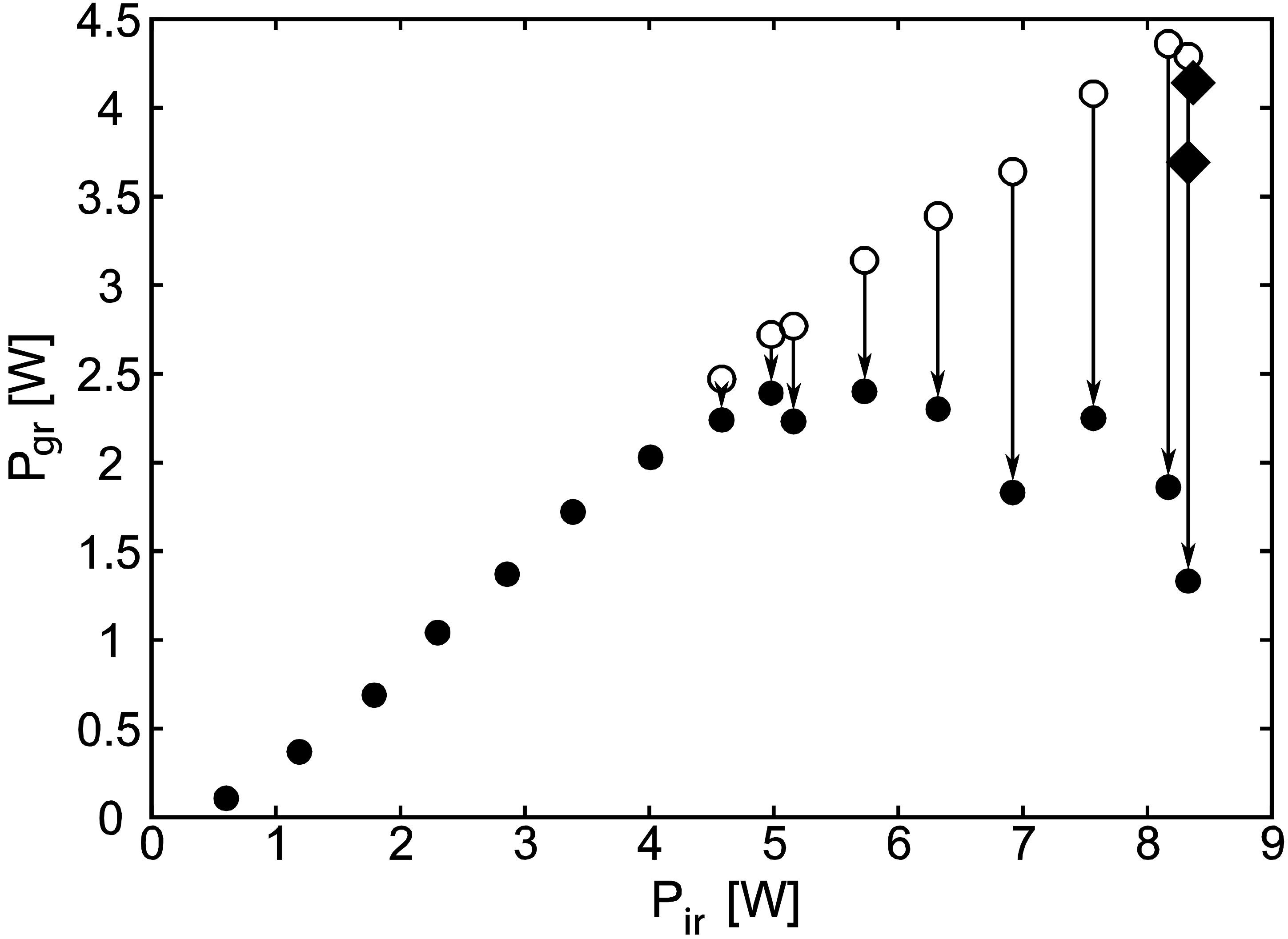
⟹ Enhanced stability due to smaller cavity

Converted Power from 1091nm to 546nm

- Stable green output powers for input powers below 4.5W

- Above 4.5W significant heating of the LBO-crystal due to linear absorption
  ⟹ Change of phase matching angle with reversible degredation of the green power

→ adjustment of the crystal‘s angle leads to stable (>45min) output powers of up to 4.1W shown as diamonds



Scanning the Fiber Laser and Spectroscopy on Iodine

Scanning the wavelength of the fiber laser:

- From 1090.89nm to 1091.19nm by changing the temperature of the lasing fiber
- For fast modulation for an additional 8.4GHz by applying a voltage to a piezo that stretches the lasing fiber

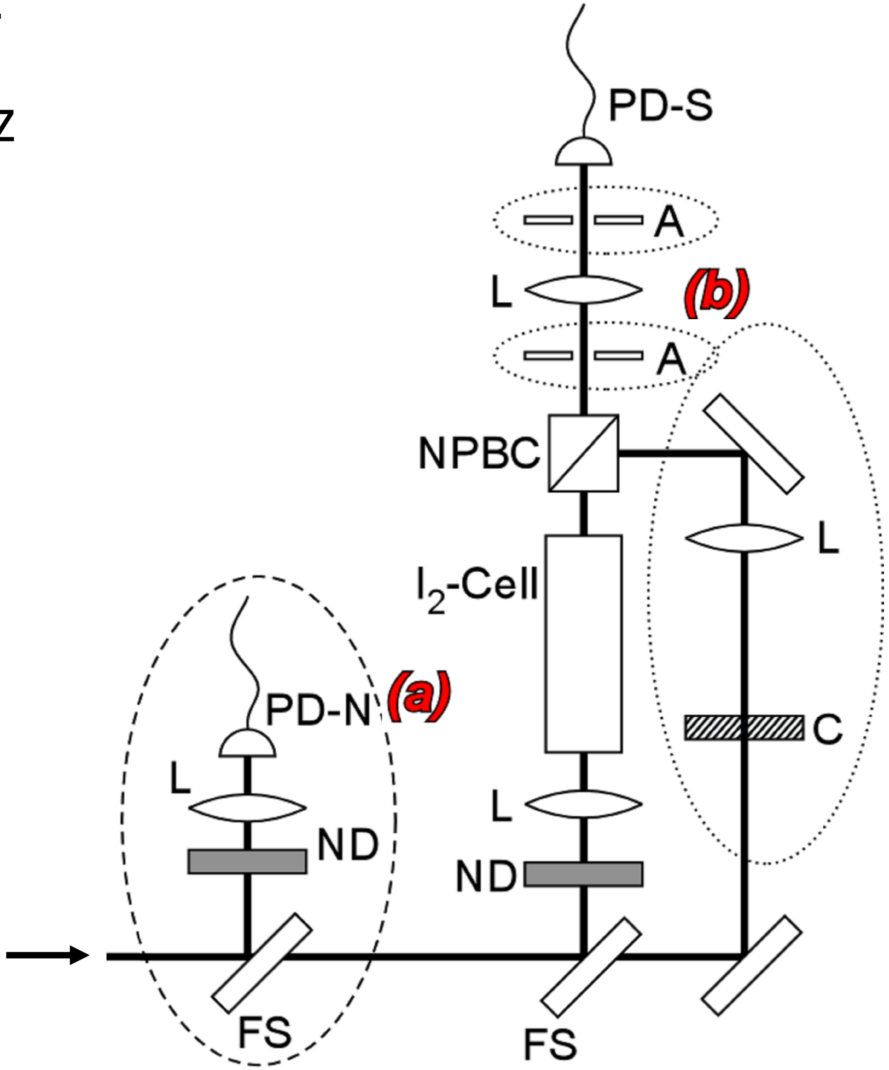
To demonstrate scanning of the green light and single frequency operation spectroscopy on Iodine is set up

- Labeled parts are used only in

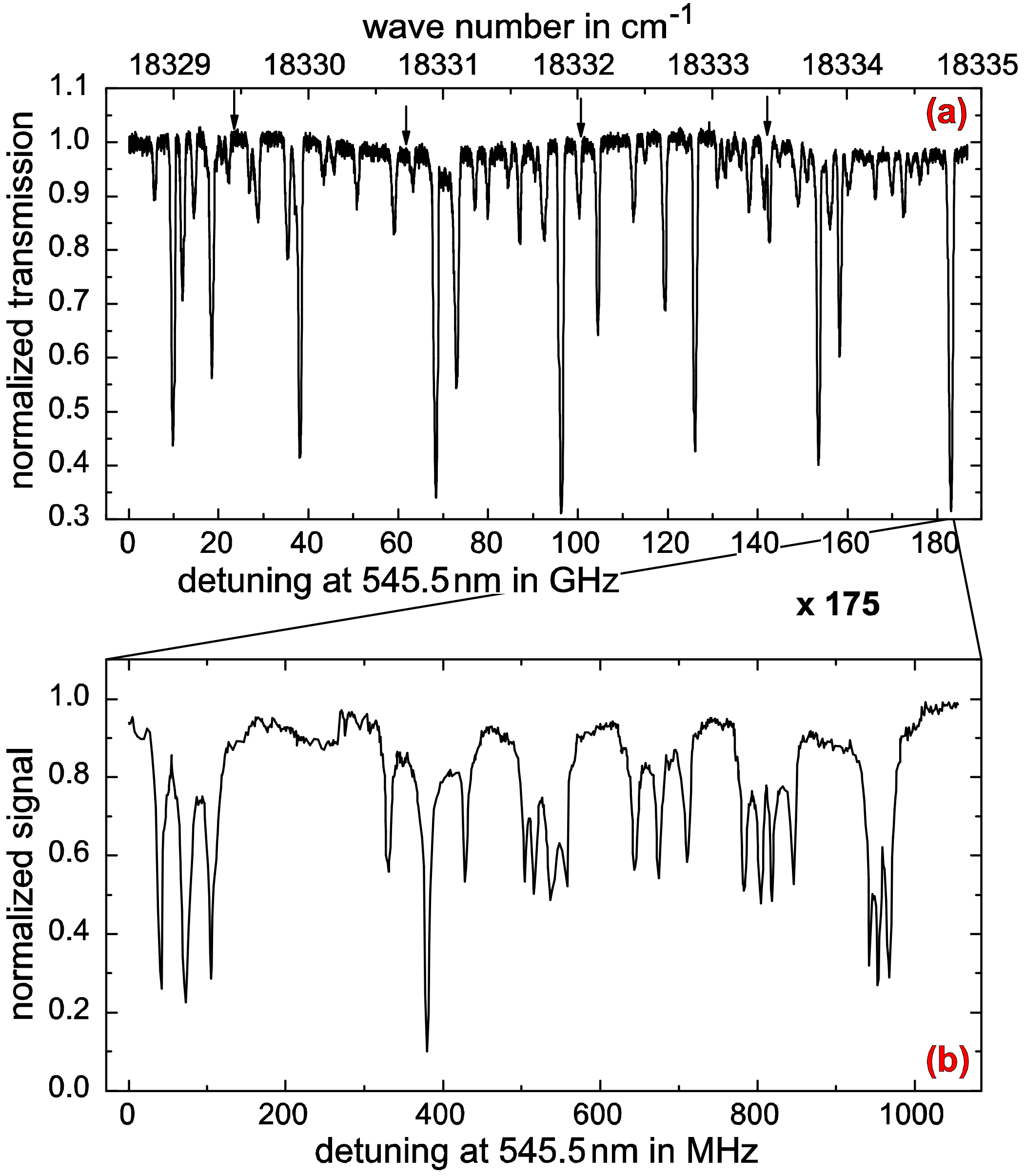
(a) Absorption spectroscopy

(b) Saturation spectroscopy

Spectroscopy on Iodine

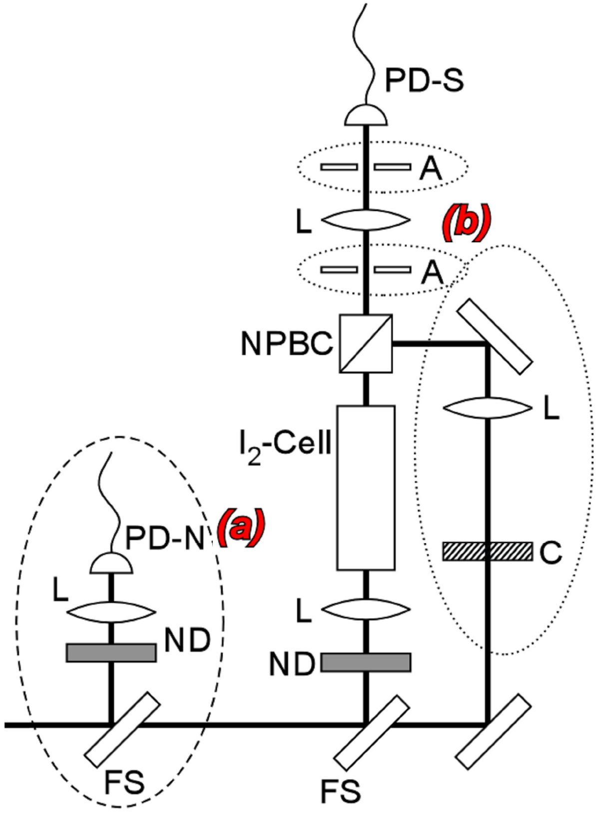


Spectroscopy on Iodine



(a) Absorption spectroscopy over the full tuning range of the fiber laser;

(b) Doppler free saturation spectroscopy on one strong Iodine line

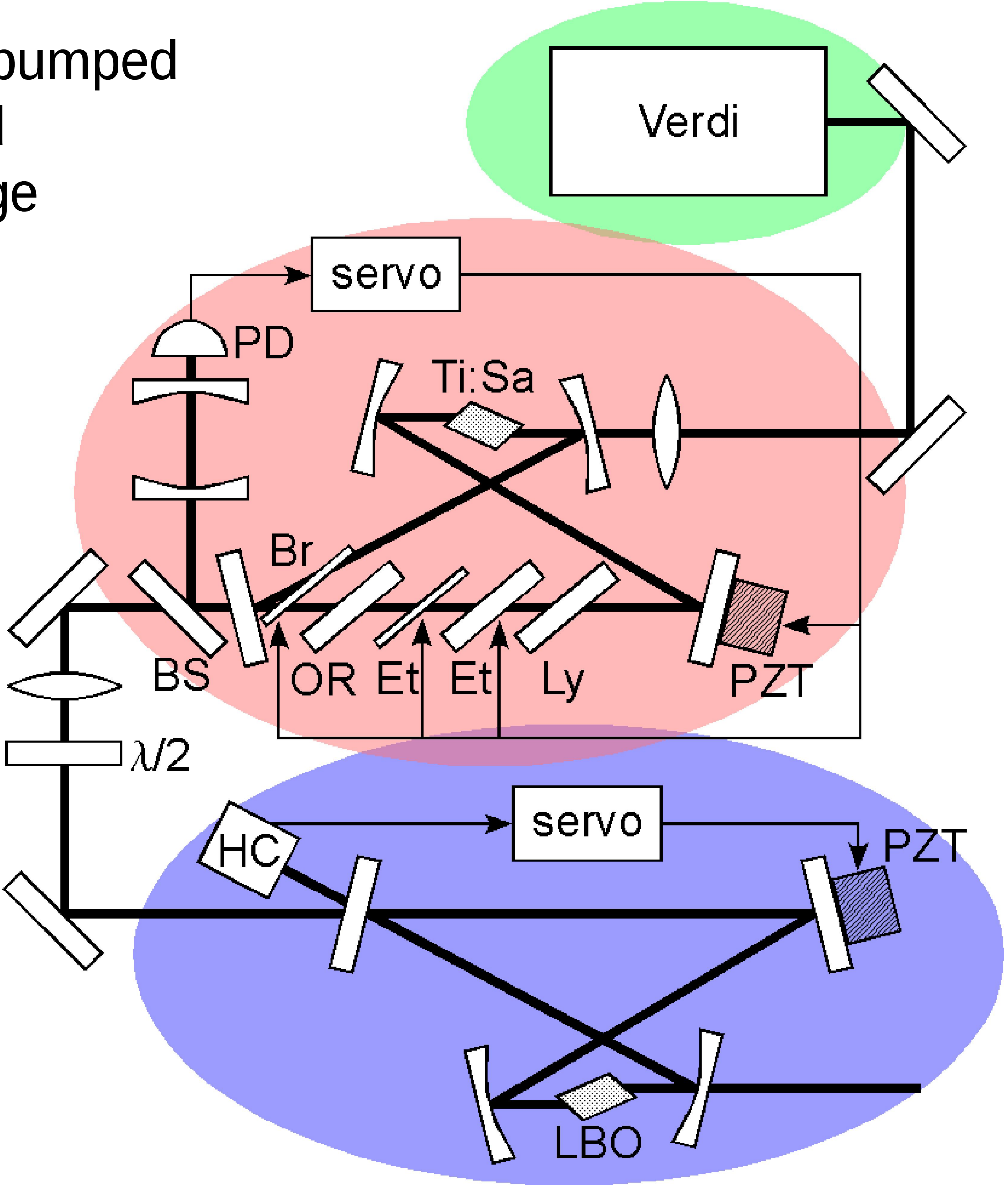


The Laser System at 407.9nm

- The laser system consists of a Verdi pumped Ti:Sapphire laser (Coherent 899) and a successive frequency doubling stage using a brewster cut LBO crystal

- 10.5W pump power deliver 1.3W infrared light which is converted to 430mW in the blue

- The Ti:Sapphire laser is frequency stabilized using a reference cavity and has a mode hop free tuning range of 30GHz



Overlapping the Fundamental Beams

The fundamental beams are shaped and overlapped on dichroitic mirrors to be focussed into the Hg cell

Beam shaping

- No astigmatism

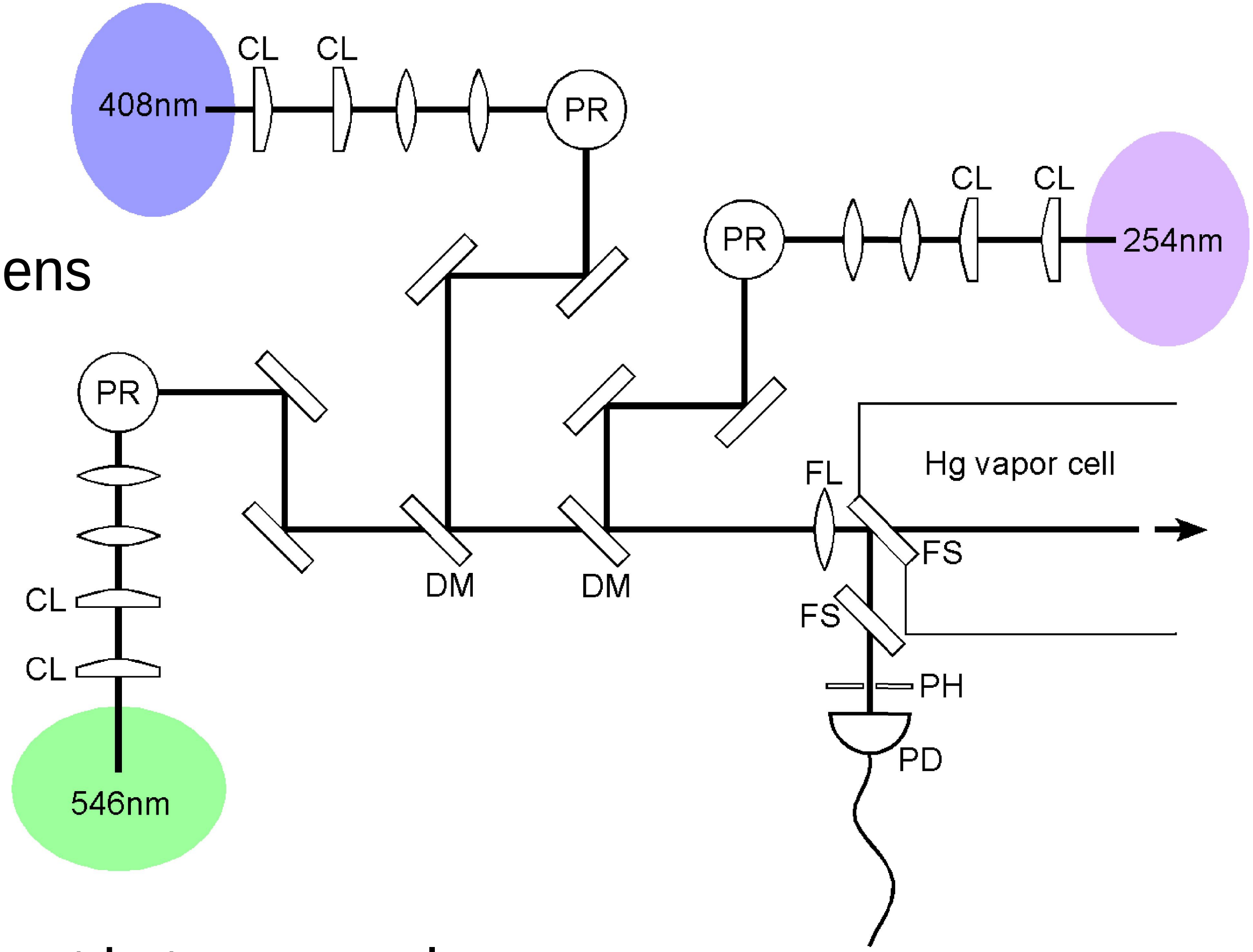
→ High intensity in the focus

- Large beams on the focussing lens

→ High intensity in the focus

- Divergence of the beams adjusted to each other

→ Foci at the same point in beam direction

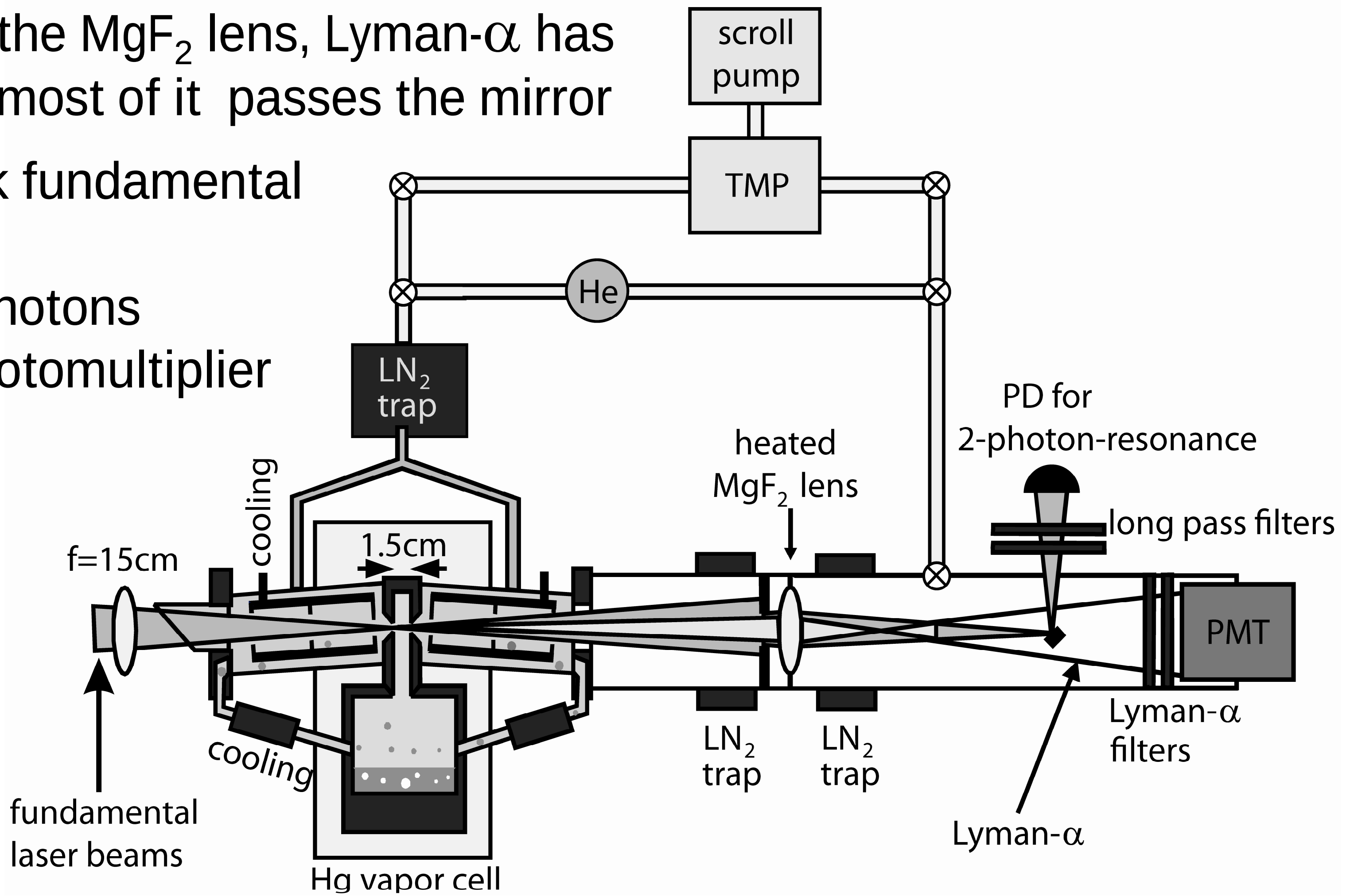


Beam positioning

- Foci are adjusted to the same spot in transversal direction using a pinhole and a photodiode

Lyman-α Generation and Detection Setup

- Fundamental beams are focussed into the Hg cell where Lyman-α is produced
- All four divergent beams are focussed by a MgF_2 lens
- The fundamental beams hit a small mirror and are guided from the apparatus where a photodiode is placed for detection of the 2-photon-resonance
- Due to dispersion in the MgF_2 lens, Lyman-α has an earlier focus and most of it passes the mirror
- Lyman-α filters block fundamental stray light before the vacuum-ultraviolet photons hit the solar blind photomultiplier



Summary

- A cw-Lyman-α source is essential for cooling of $\bar{H}$

- Cold $\bar{H}$ enables ultrahigh-resolution CPT test by 1s-2s spectroscopy

- A second generation Lyman-α source is currently being set up at Mainz:

  - Only reliable solid state lasers are used for generation of the fundamental beams

  - The fundamental laser beams are ready

  - Currently the four wave mixing is implemented

  $\Longrightarrow$ Lyman-α soon

253.7nm: M. Scheid et al, Optics Letters, 32(8):955-957, 2007

545.5nm: F. Markert et al, Optics Express, 15(22):14476-14481, 2007