19 Jun 2018
Max Planck Institute for Gravitational Physics Hannover

GW-DE Meeting 2018

Stabilized High-Power Lasers for 3rd Generation Gravitational Wave Detectors

Benno Willke

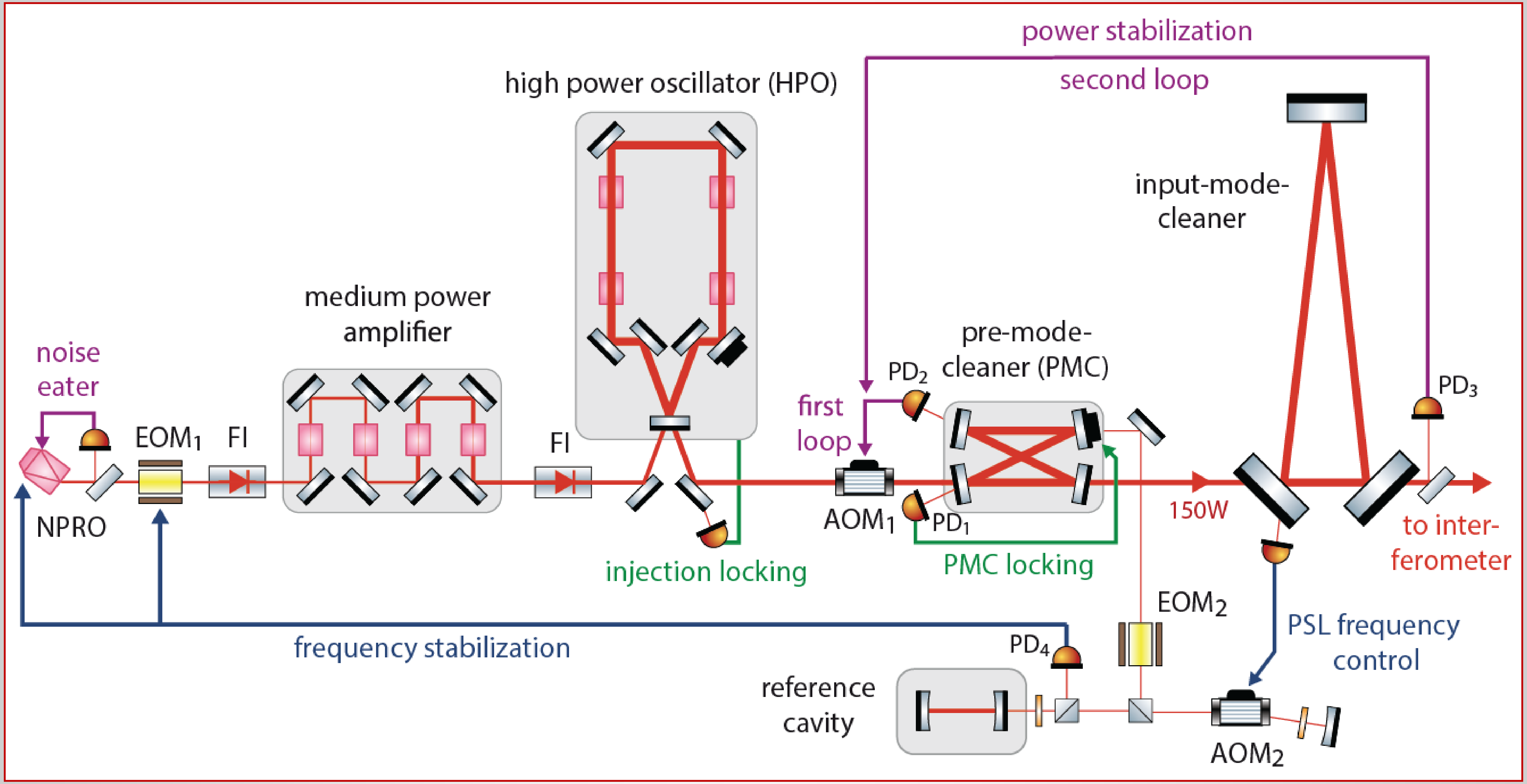
19 June 2018 (Hannover)

git: bewill/talks/18GW_DE_meeting

General Requirements

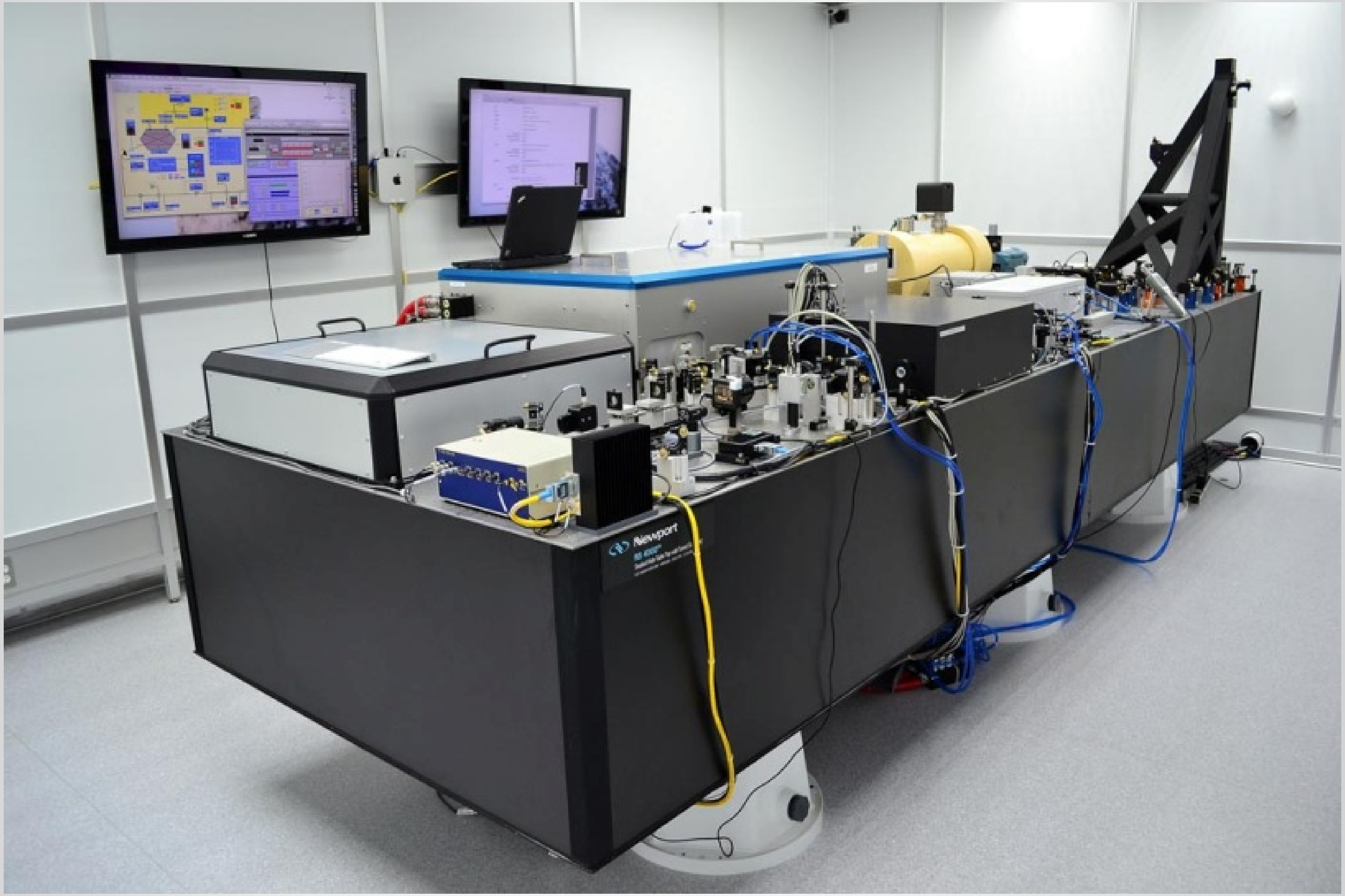
- Several hundred Watt power (cw, single-frequency, linearly-polarized)
  - To enable high circulating power in interferometer arms
- High spatial purity and low beam jitter
  - Good coupling to input-modecleaner
  - Low shot noise on sensors for laser and input-modecleaner stabilization
- Low free running noise (in laser power and frequency
  - Acceptable stabilization effort (loop gain and cross-couplings)
- Low-noise sensors (for laser power and frequency)
  - To achieve required stability for light entering the input modecleaner
- Fast actuators (for laser power and frequency) with large range
  - To allow for required loop gain in stabilization control loops
- High robustness and reliability with low maintenance requirements

Advanced LIGO Pre-Stabilized High-Power Laser



Kwee et al. Opt. Lett. (2009), Kwee et al. Opt. Express (2012)

Advanced LIGO Pre-Stabilized High-Power Laser



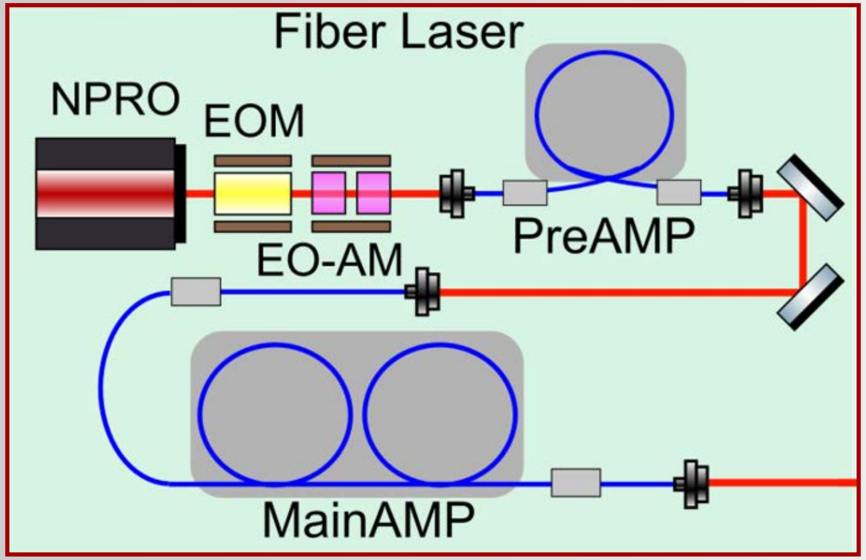
Requirements For Next Generation GWDs

Project	Wavelength	Power	Spatial mode
Einstein Telescope low f	1550 nm	3 W	HG_{00}
Einstein Telescope high f	1064 nm	500 W	LG_{33} (?)
Voyager	$\geq$ 1550 nm	200W	HG_{00}
Cosmic Explorer	$\geq$ 1550 nm	1kW	HG_{00}
Asia- Australia GWD	1064 nm	200 W	HG_{00}

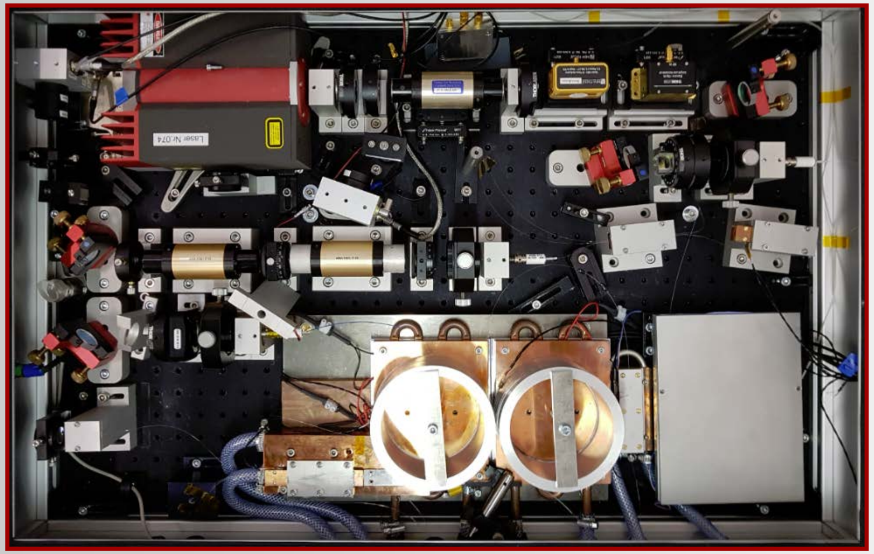
- Single-mode, single-frequency, linearly polarized, low free running noise
- Stabilization: factor 10 better than second generation GWDs
- Fast actuators with large range and low cross coupling
- High reliability
- Low maintenance downtime and costs

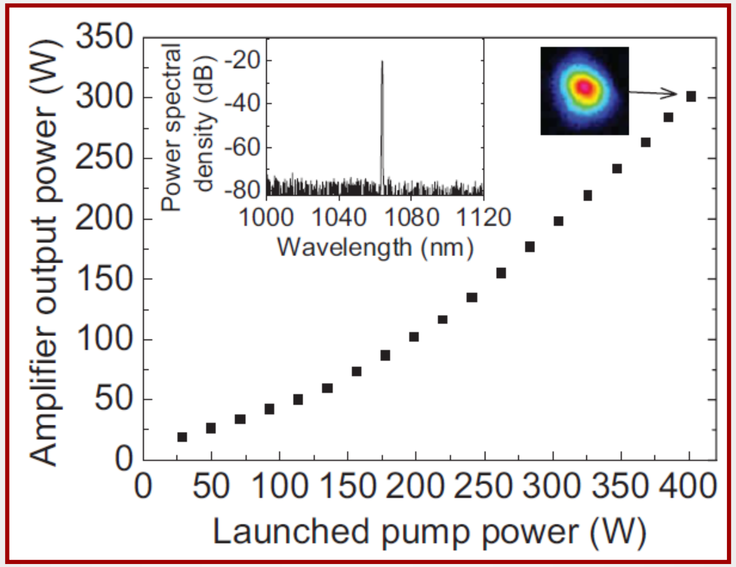
All numbers are still subject to change !

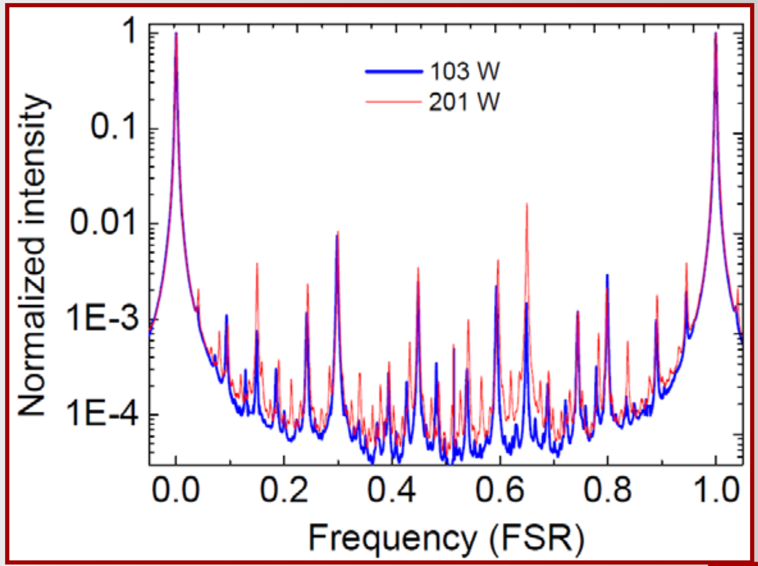
LZH / AEI Fiber Amplifier at 1064nm



- two stage fiber amplifier with NPRO seed
- good spatial profile
- output power up to 300W
- so far no long-term reliable operation

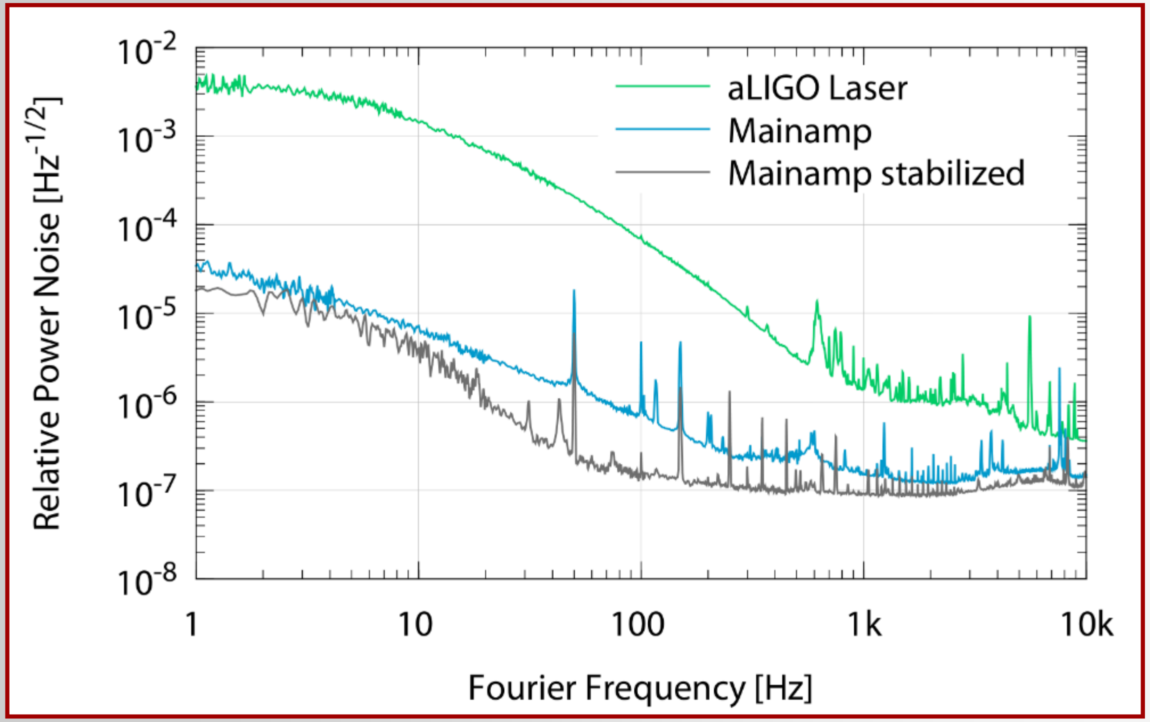


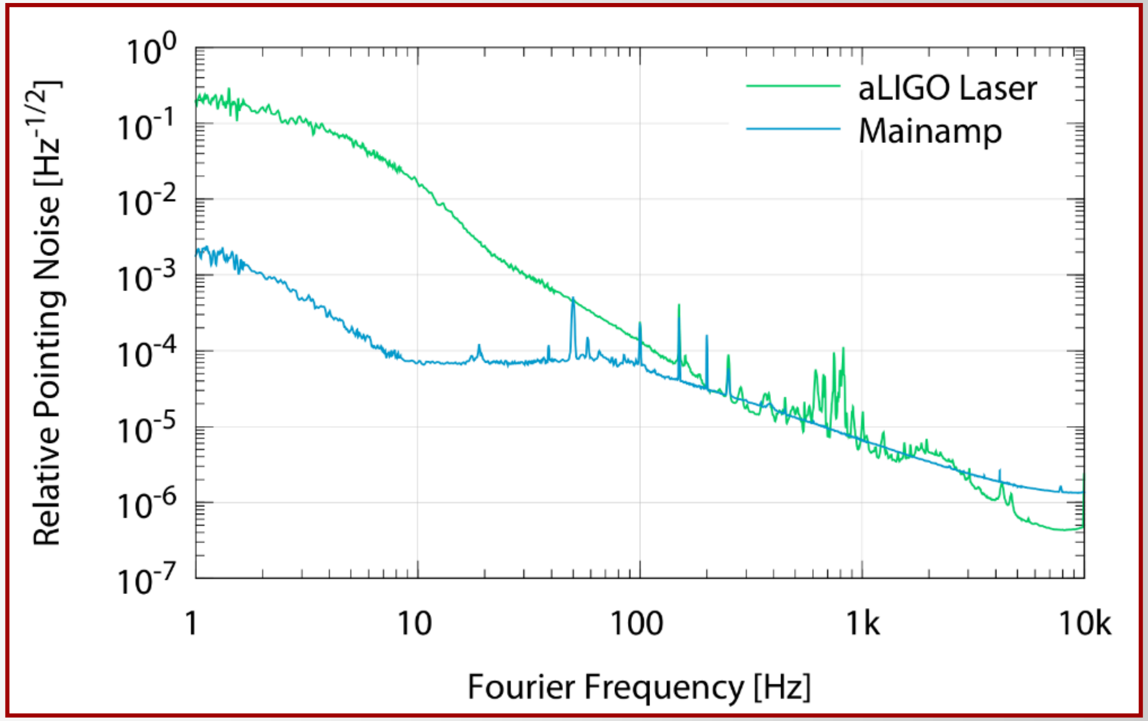




T. Theeg et al. IEEE Photon. Tech. Lett. (2012); T. Theeg et al. Opt. Express (2012)

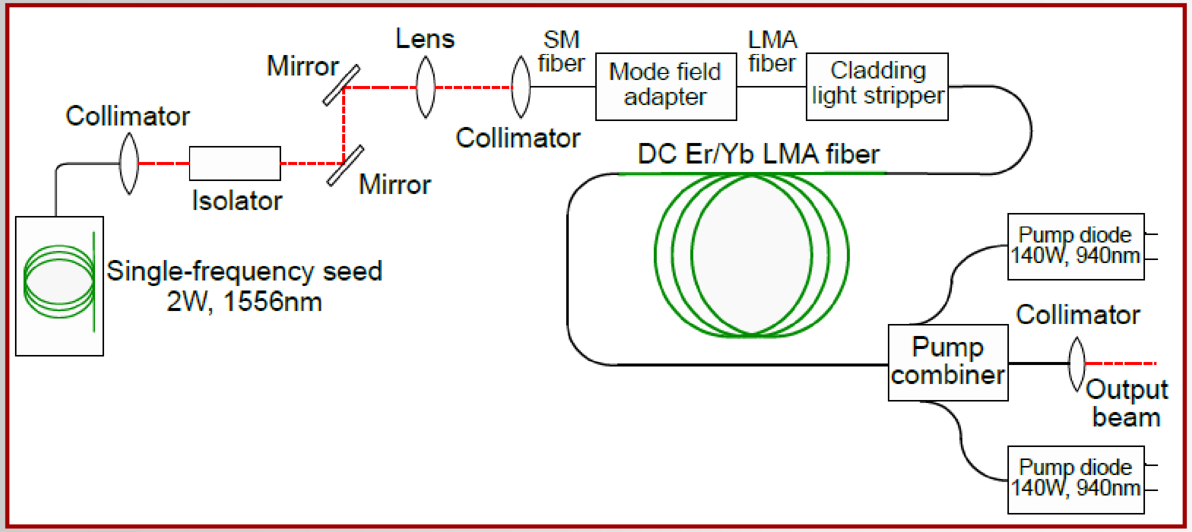
1064nm Fiber Amplifier - Performance



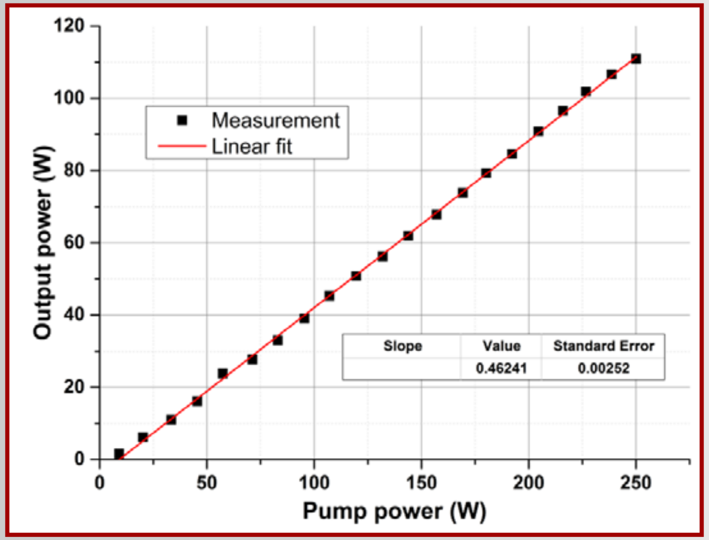


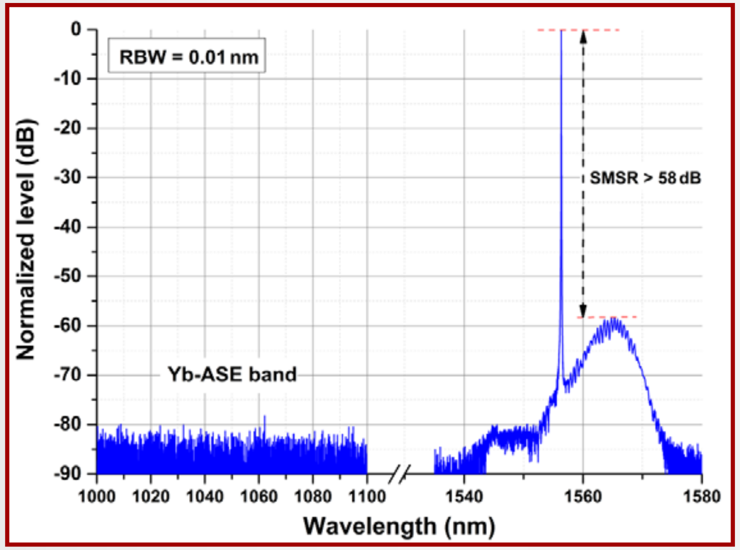
relative pointing: $\epsilon = \sqrt{\left(\frac{\Delta x}{w}\right)^2 + \left(\frac{\Delta \Phi}{\theta_{div}}\right)^2}$

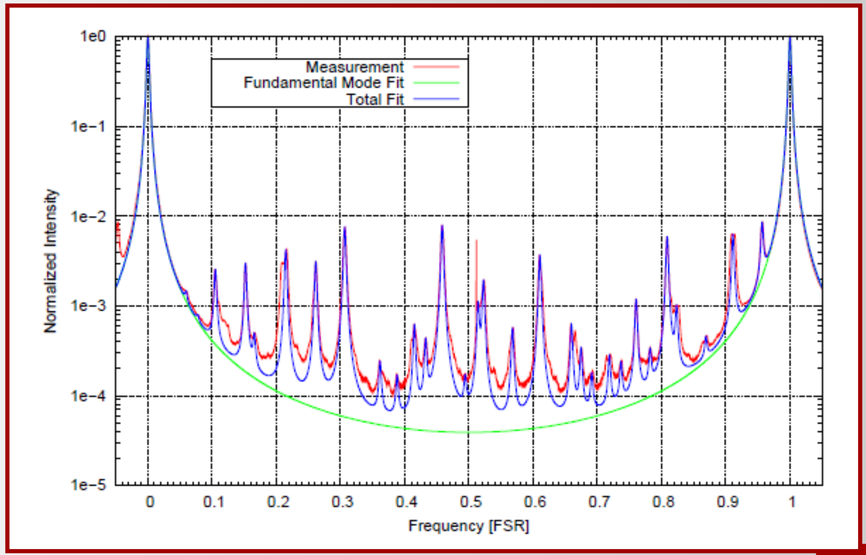
1550nm LZH Fiber Amplifier



- Off-peak pumping at 940nm
- Linear slope up to 110W
- At 110W no SBS (no excess power noise in MHz region)
- No Yb-band ASE and good suppression of Er-band ASE (~60dB)
- Output power limited by available pump power







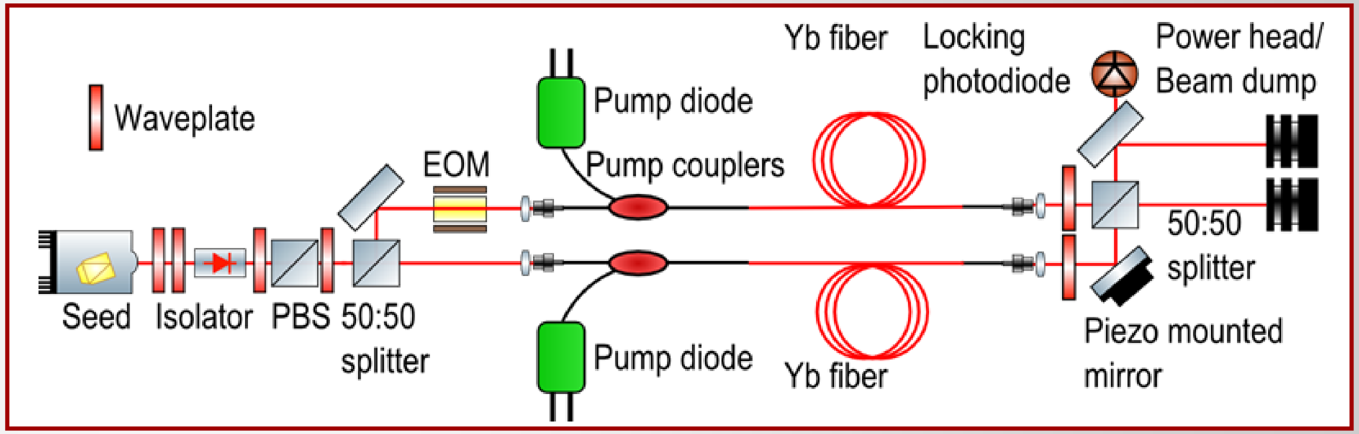
de Varona et al. Opt. Express (2017)

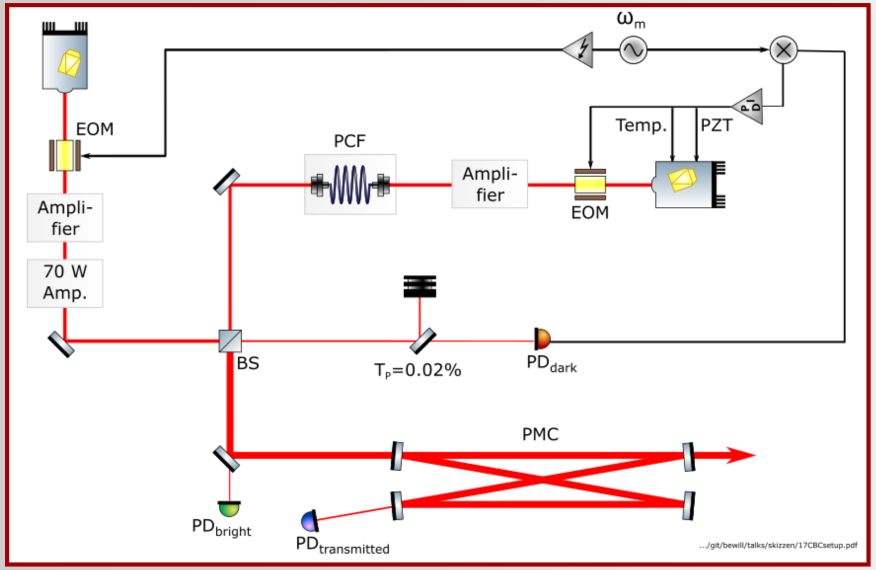
LASER ZENTRUM HANNOVER e.V.

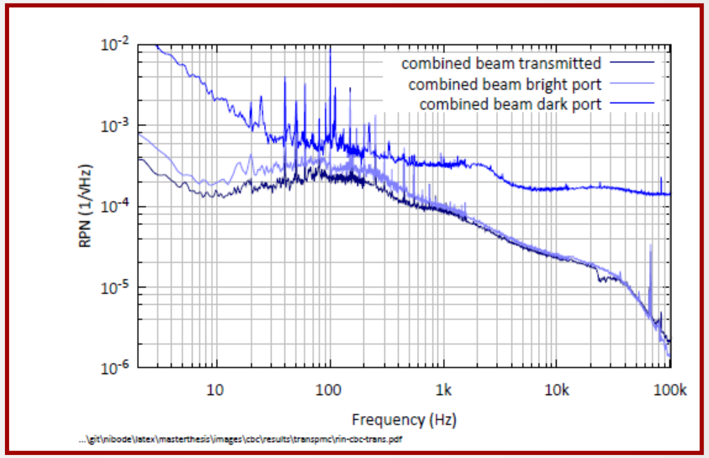
Coherent Beam Combination at AEI / LZH

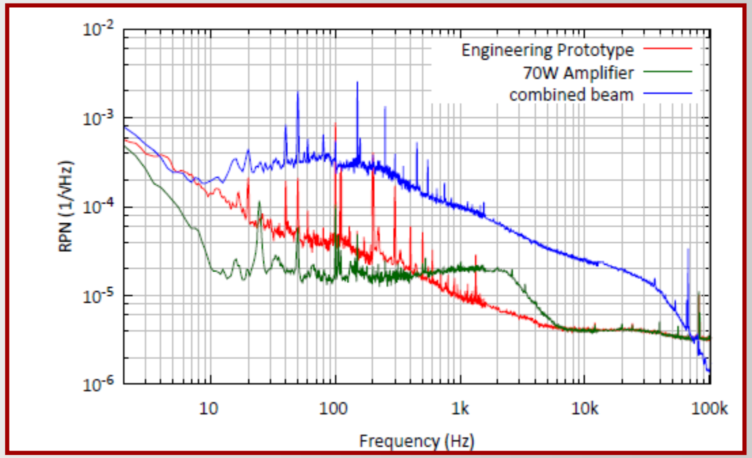
proof of principle experiments with

- two independent 5W beams taken from 70W and 35W laser
- two identically seeded 10W fiber amplifiers
- next step: two 150W lasers
- final goal: 2x250W



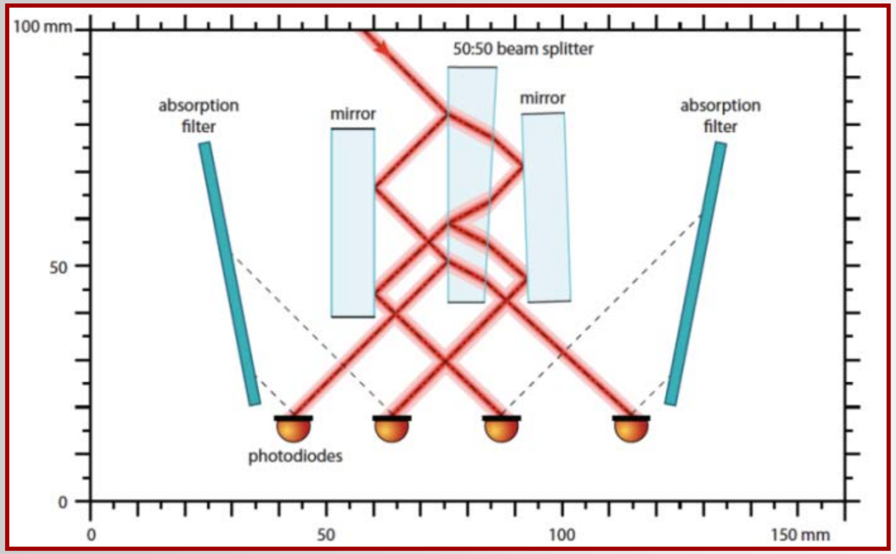




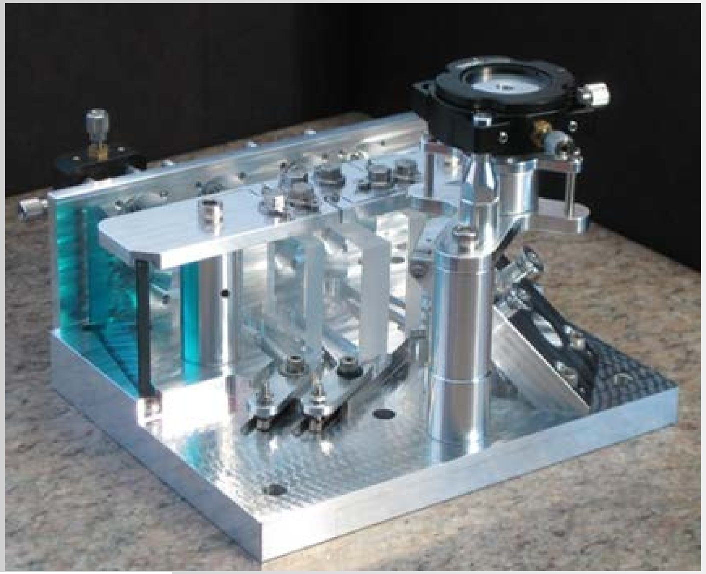


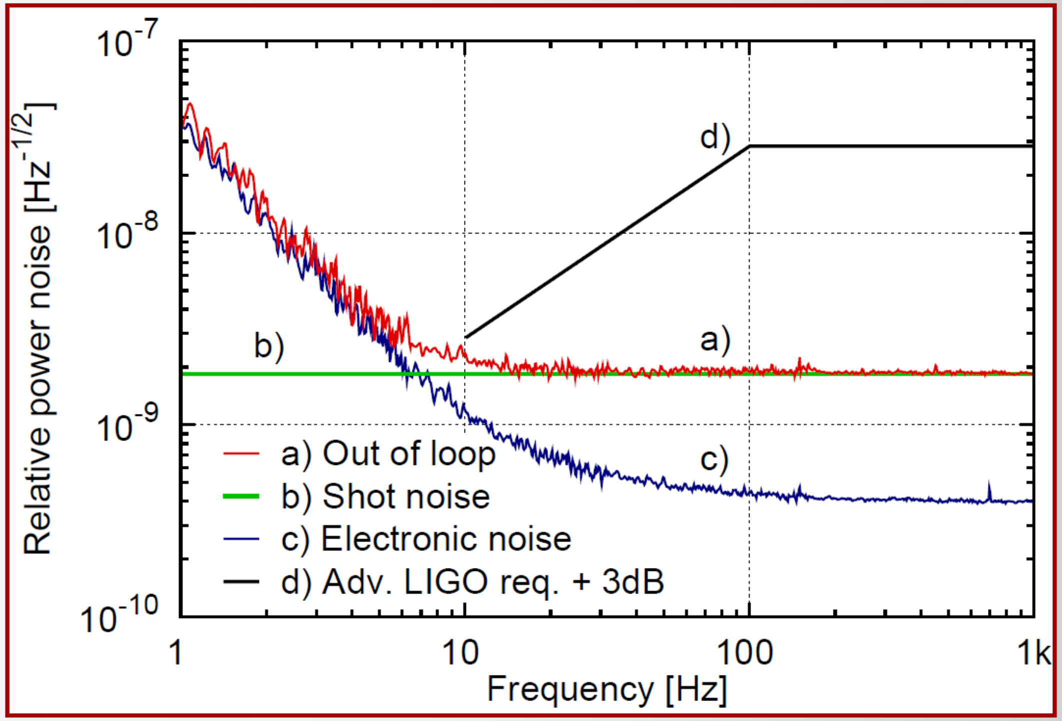
H. Tuennermann et al., Opt. Express (2011)

Power Stabilization



- beam is split onto two sets of four photodiodes (in-loop, out-of-loop)
- all stray beams are steered to absorption filters
- signal conditioning filters to reduce electronic noise coupling
- achieved $2 \times 10^{-9}\ 1/\sqrt{Hz}$ stability





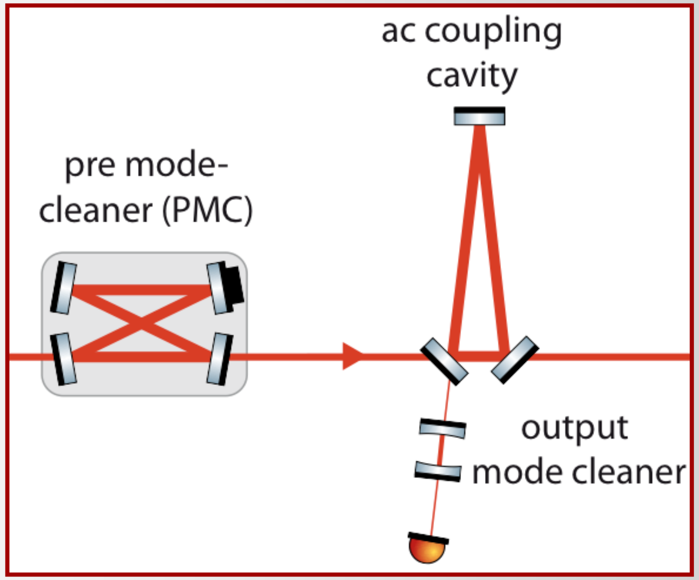
Kwee et al., Opt. Lett. 34 p 2912 (2009)

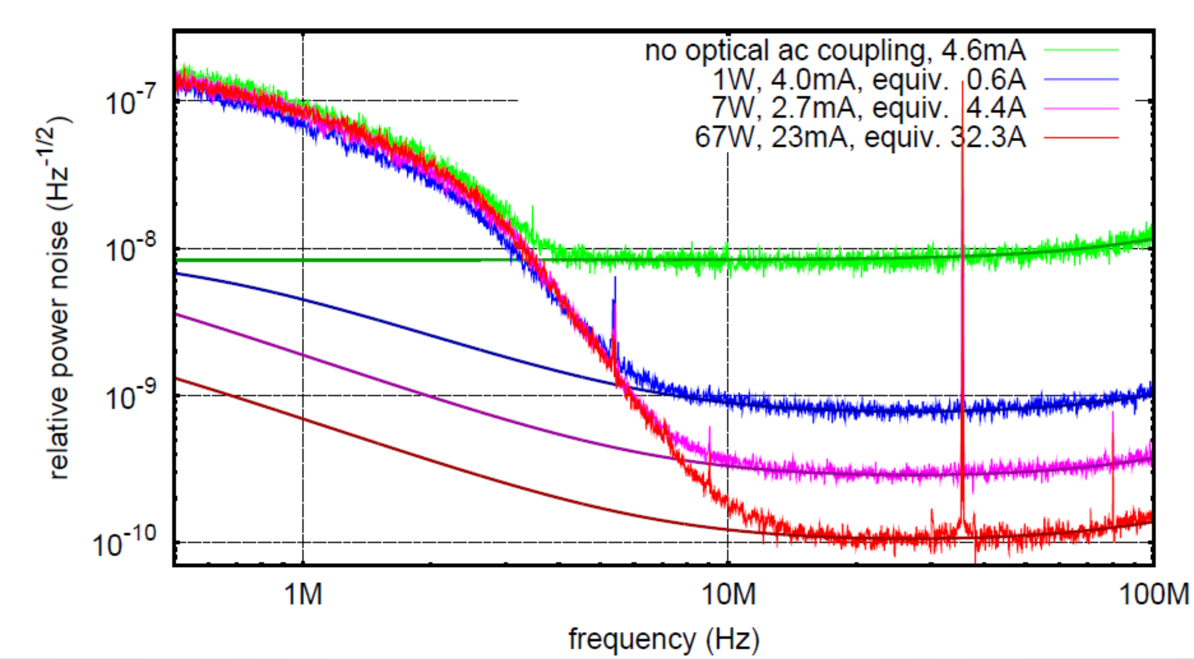
OAC with 32.2A Equivalent Photocurrent

- Power noise of 150W beam in an optical AC coupling scheme with output modecleaner
- Achieved sensing sensitivity

$$RPN = 1 \times 10^{-10}\ 1/\sqrt{Hz}$$

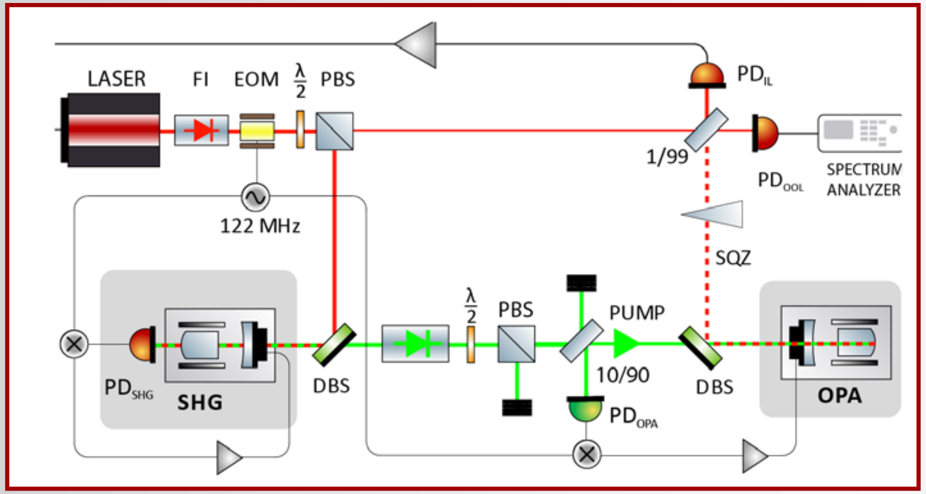
- This corresponds to shot noise of 32.2A photocurrent





Kwee et al., Opt. Lett. (2011)

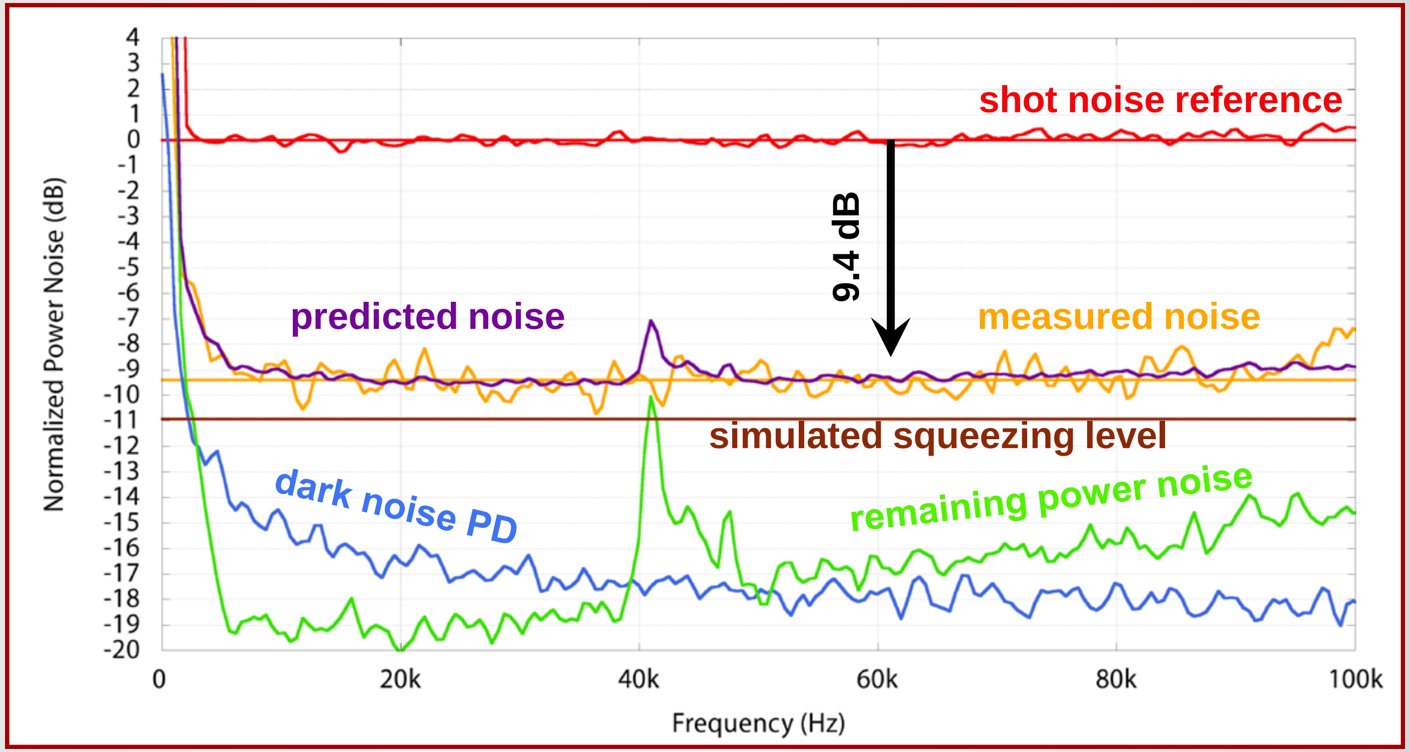
Squeezing Enhanced Power Stabilization



Simulation:
9.5 mW pump, 5.07 % losses, 10.9 dB

Prediction:
10.9 dB, +PDIL DN, +Stab IL noise

Limitations:
Losses, PD_{IL} DN, Loop Gain



Dennis Schröter, Master thesis AEI Hannover, submitted to PRL

Challenges

- Design and fabricate robust and reliable 250-300 W (fiber) amplifier for $1064\ \mathrm{nm}, 1.5\mu\mathrm{m}$ and $2\mu\mathrm{m}$
- Low-noise coherent combination of such laser with pure spatial beam profile and low beam jitter
- Power stabilization at the $RPN = 10^{-10}\ 1/\sqrt{Hz}$ level
- Transfer laser stability to suspended reference frame of GWD