

# Dual-comb modelocked lasers

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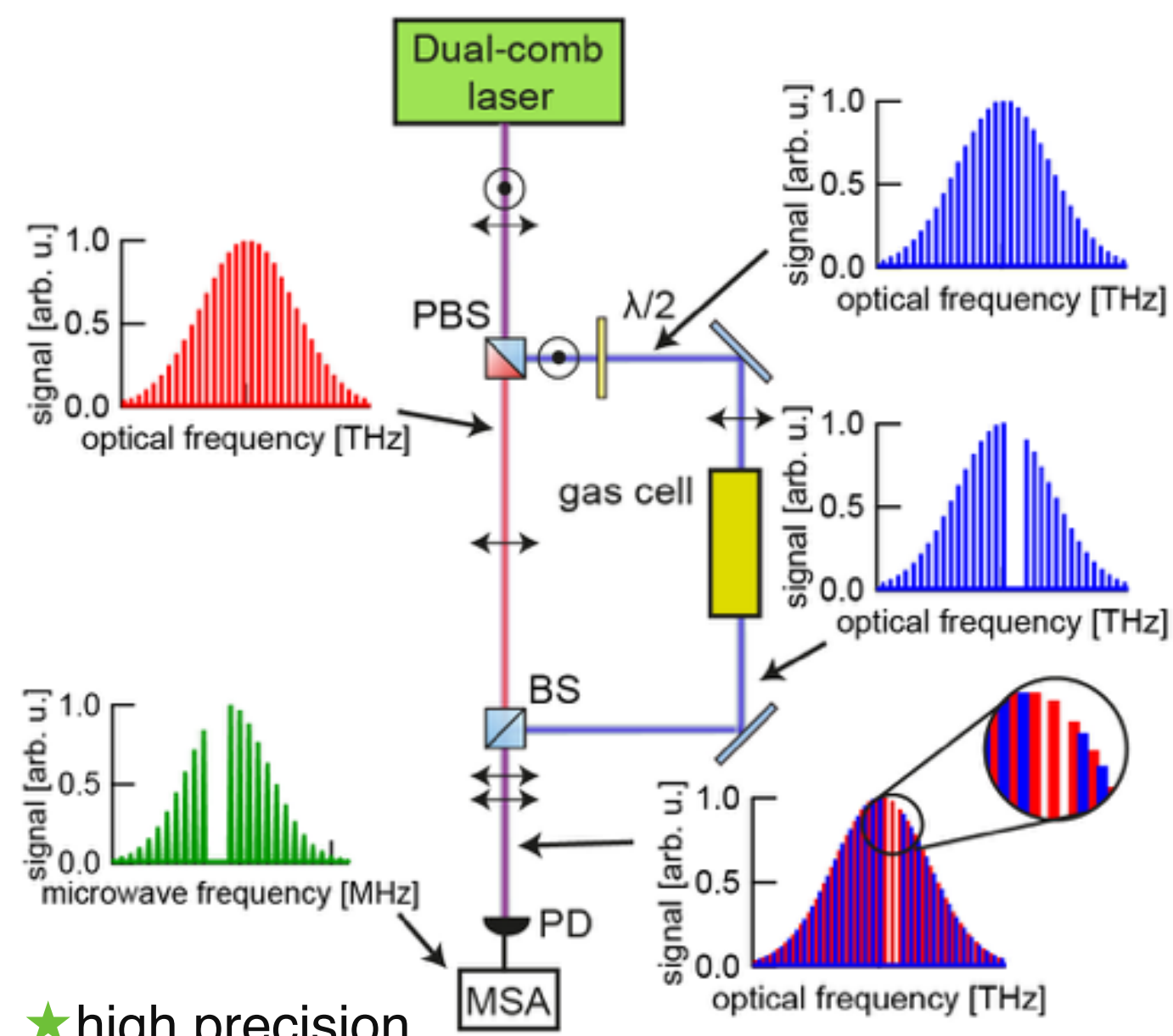
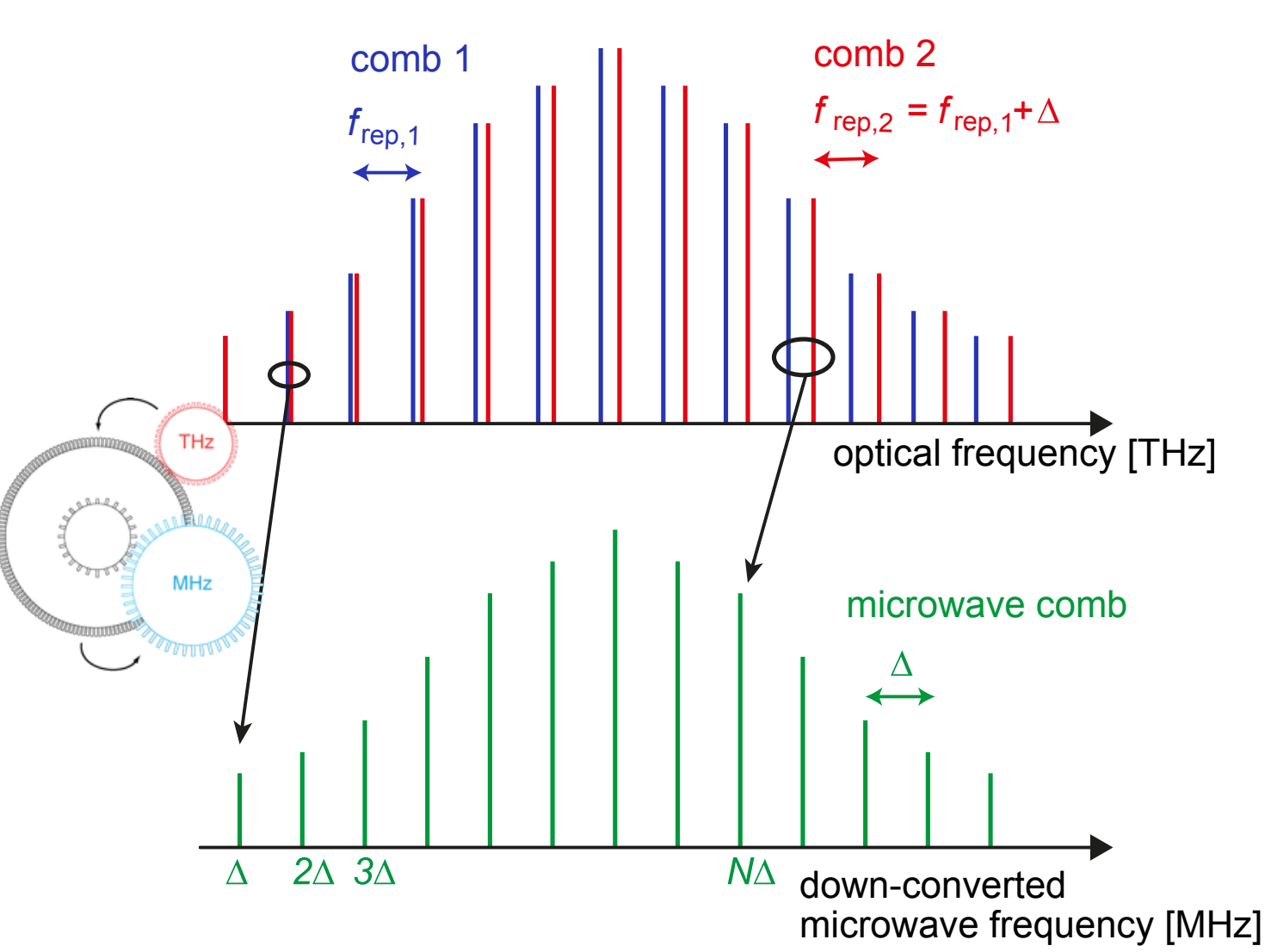
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ETH

Eidgenössische Technische Hochschule Zürich  
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## Motivation

### dual-comb spectroscopy [1]



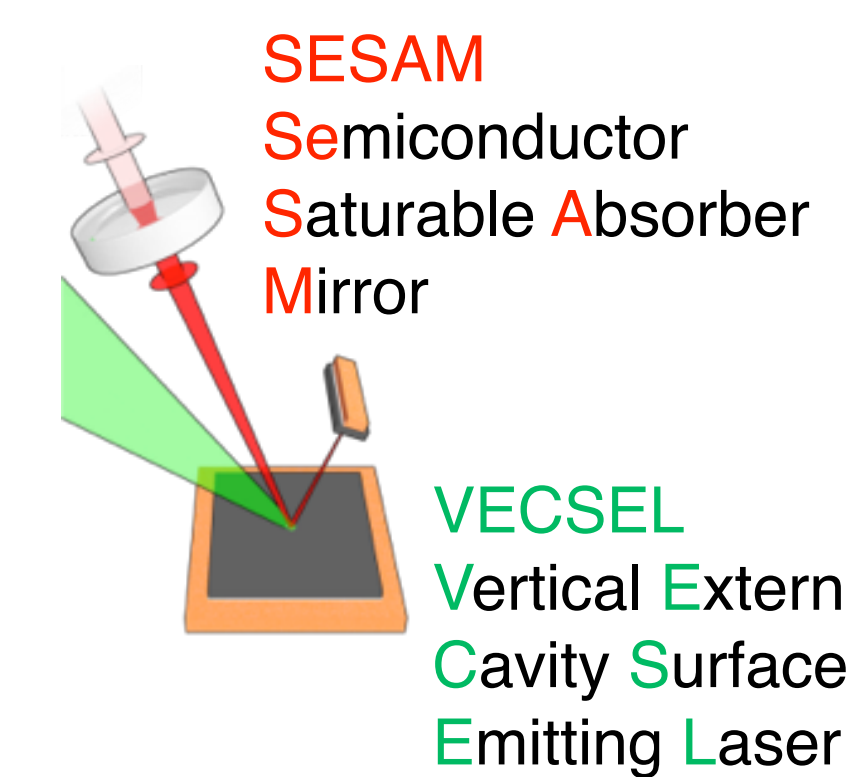
- ★ high precision
- ★ very fast data acquisition
- ★ two modelocked lasers (complex and expensive)

need for compact, cost-efficient, dual-comb source

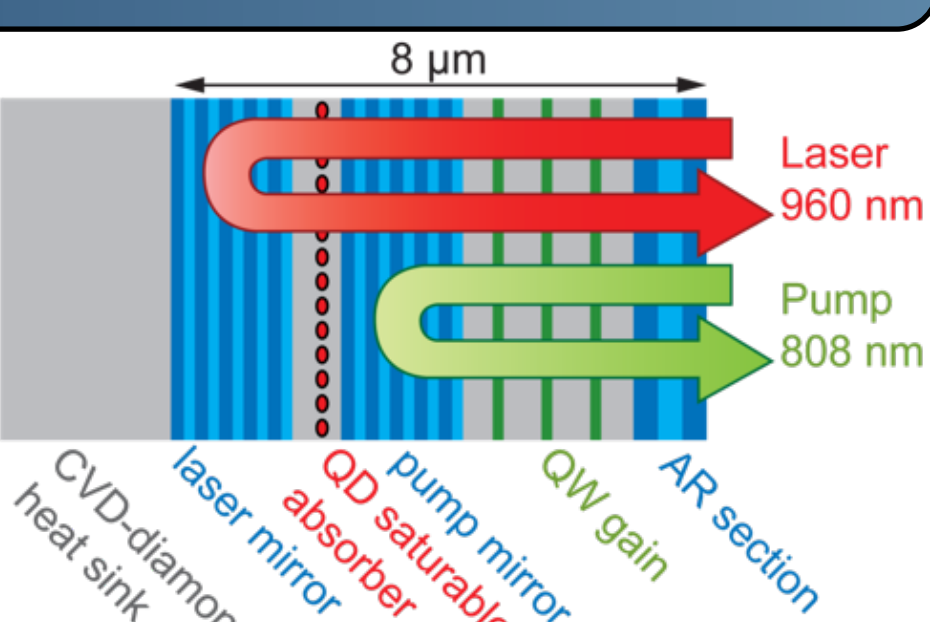
[1] S. Schiller, Opt. Lett. 27 (9), 766-768 (2002)

## MIXSEL concept

### integration concept



MIXSEL<sup>[1]</sup>  
Modelocked Integrated  
eXternal-cavity Surface  
Emitting Laser

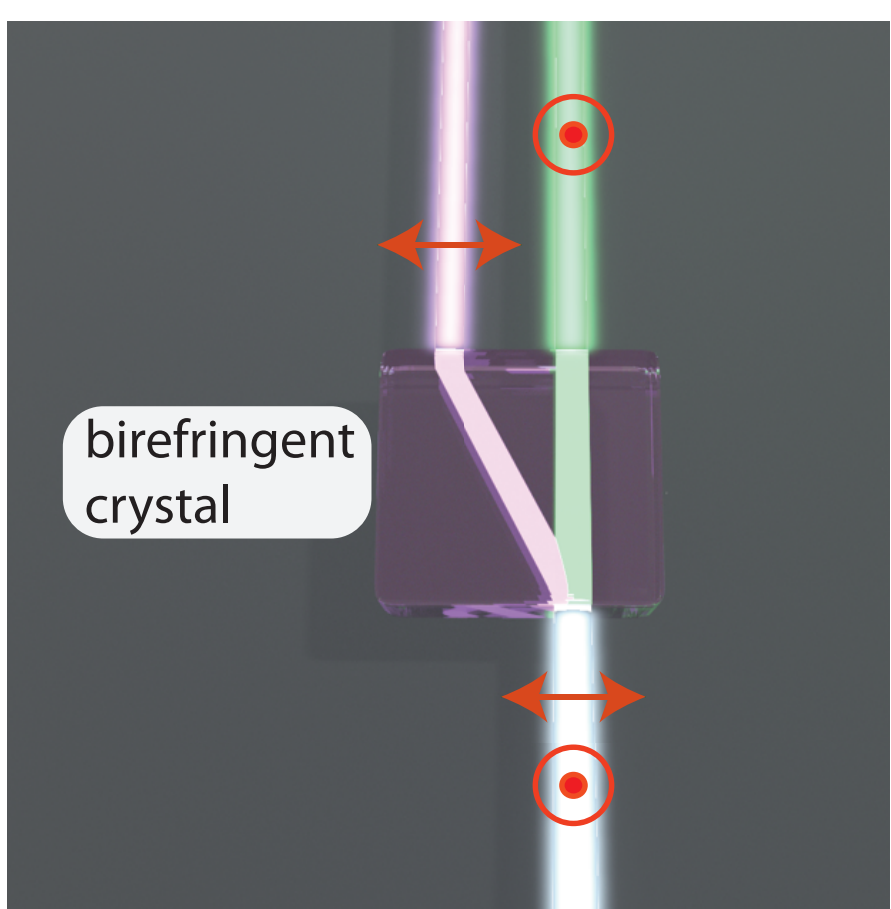


- ★ very compact cavity
- ★ simple pulse repetition rate scaling possible (5-100 GHz with single chip [2])
- ★ very low noise performance [3]

[1] D. J. H. C. Maas, A.-R. Bellancourt, B. Rudin, M. Golling, H. J. Unold, T. Südmeyer, and U. Keller, Appl. Phys. B 88, pp 493, 2007  
[2] M. Mangold, C. A. Zaugg, S. M. Link, M. Golling, B. W. Tilma, and U. Keller, Optics Express 22, No. 5, pp. 6099-6107, 2014  
[3] M. Mangold, S. M. Link, A. Klenner, C. A. Zaugg, M. Golling, B. W. Tilma, and U. Keller, Photonics Journal, IEEE 6, 1-9 (2014)

## Laser setups

### concept

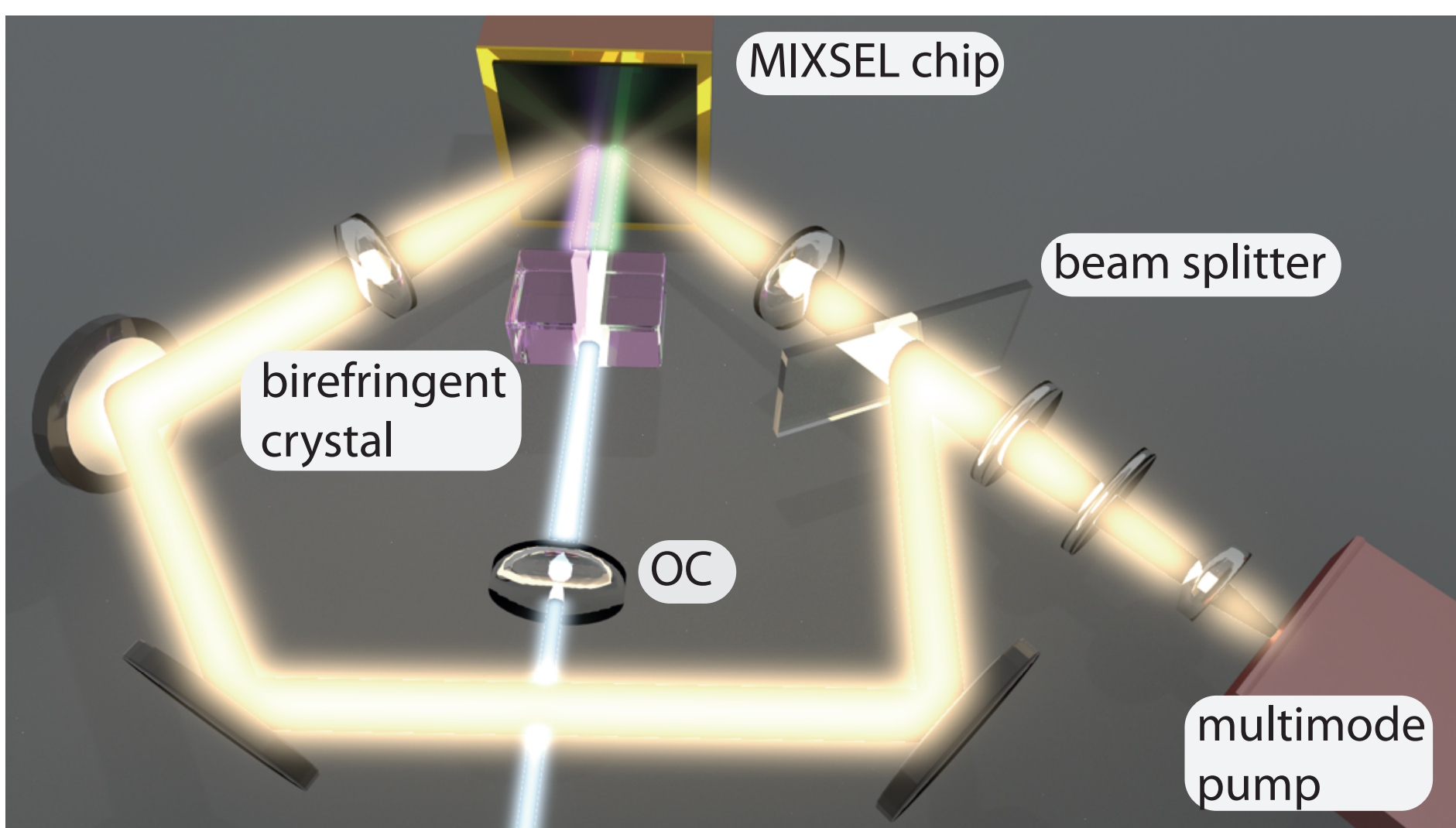


birefringent crystal splits one cavity beam into two collinear but spatially separated beams with orthogonal polarizations

two fundamentally modelocked pulse trains with slightly different pulse repetition rates from a single gain medium

- ★ applied to two different laser systems, a MIXSEL and a SESAM-modelocked Nd:YAG solid state laser

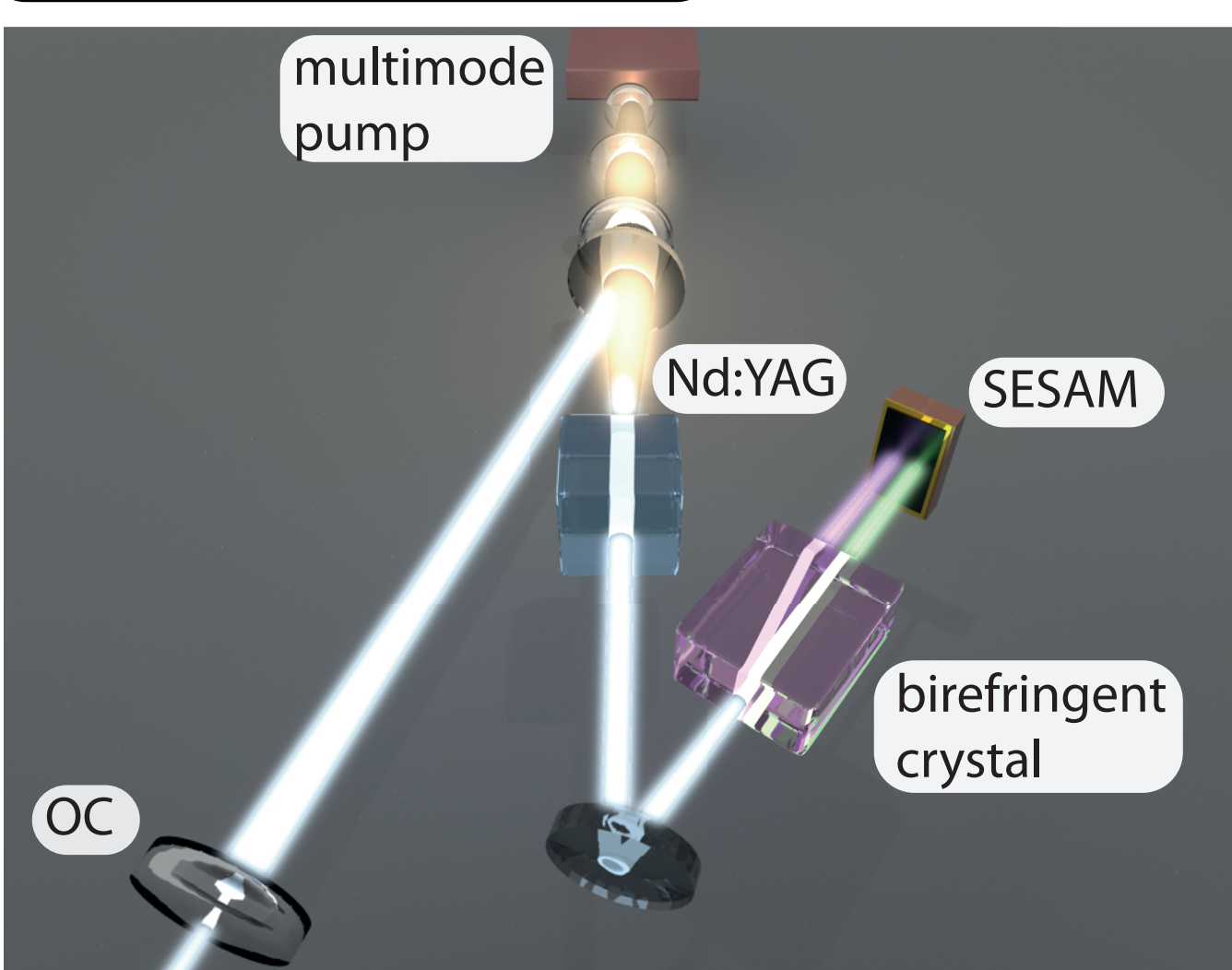
### dual-comb MIXSEL



### straight linear cavity

- MIXSEL chip
  - gain: 7 InGaAs QW
  - absorber: 1 InAs QD layer
- fused silica etalon
- output coupler (OC) (T=0.5 %)
- birefringent crystal (CaCO<sub>3</sub>, 2 mm)

### dual-comb Nd:YAG



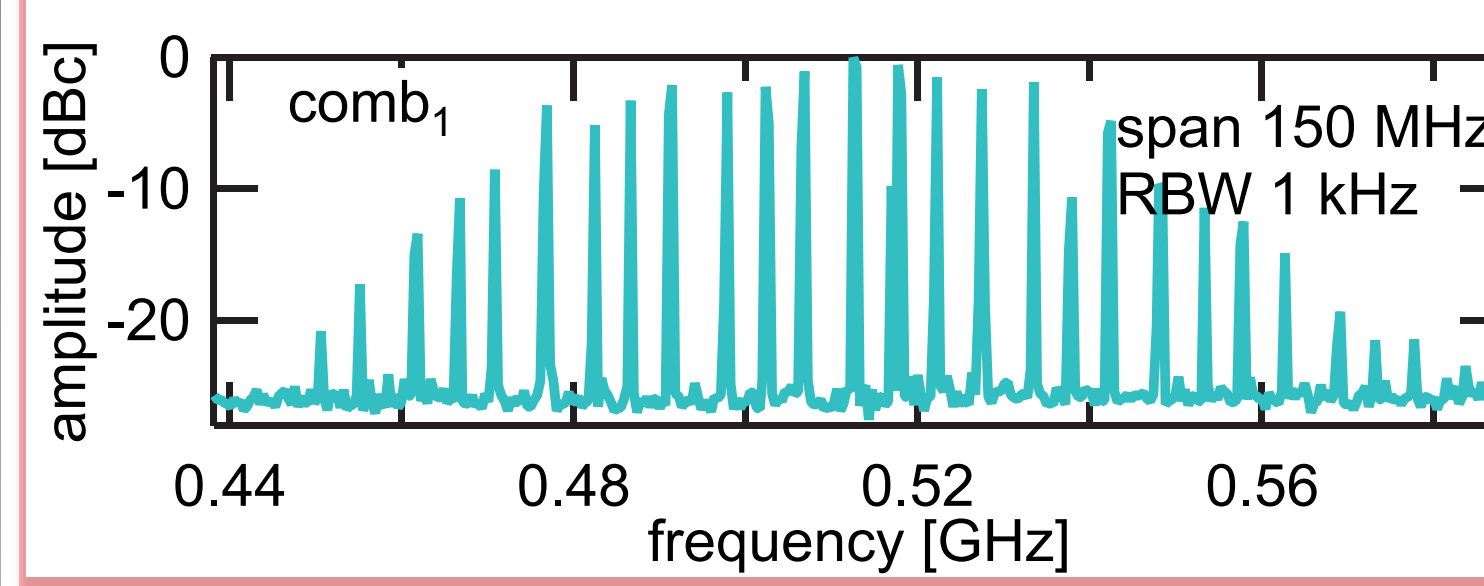
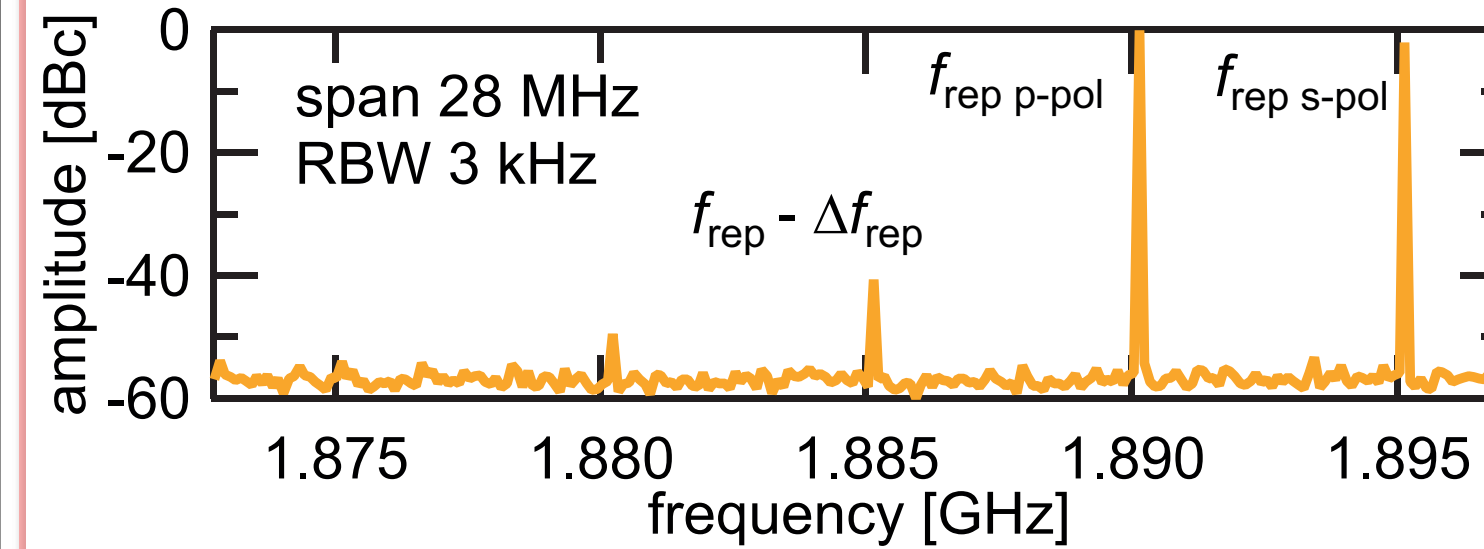
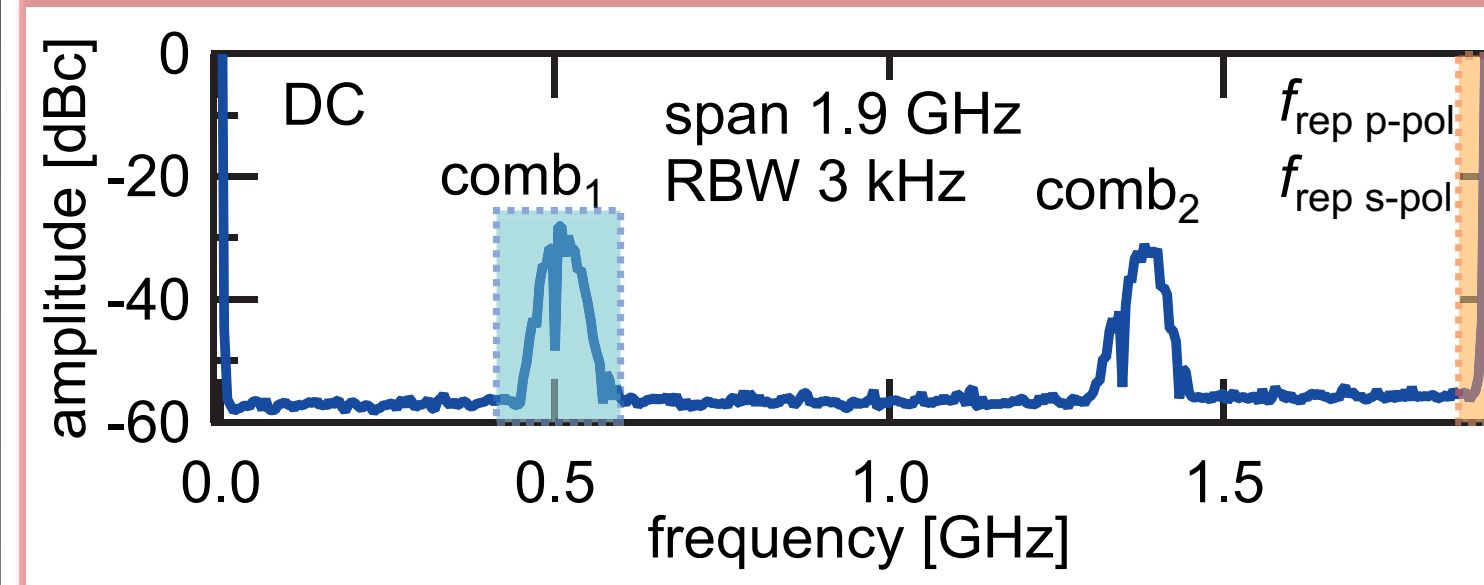
### z-shaped cavity

- Nd:YAG as gain crystal
- output coupler (OC) (T=0.5 %)
- two folding mirrors, one with R<sub>OC</sub> = 50 mm, one flat and dichroic
- birefringent crystal (CaCO<sub>3</sub>, 3 mm)

## Dual-comb results

### dual-comb MIXSEL

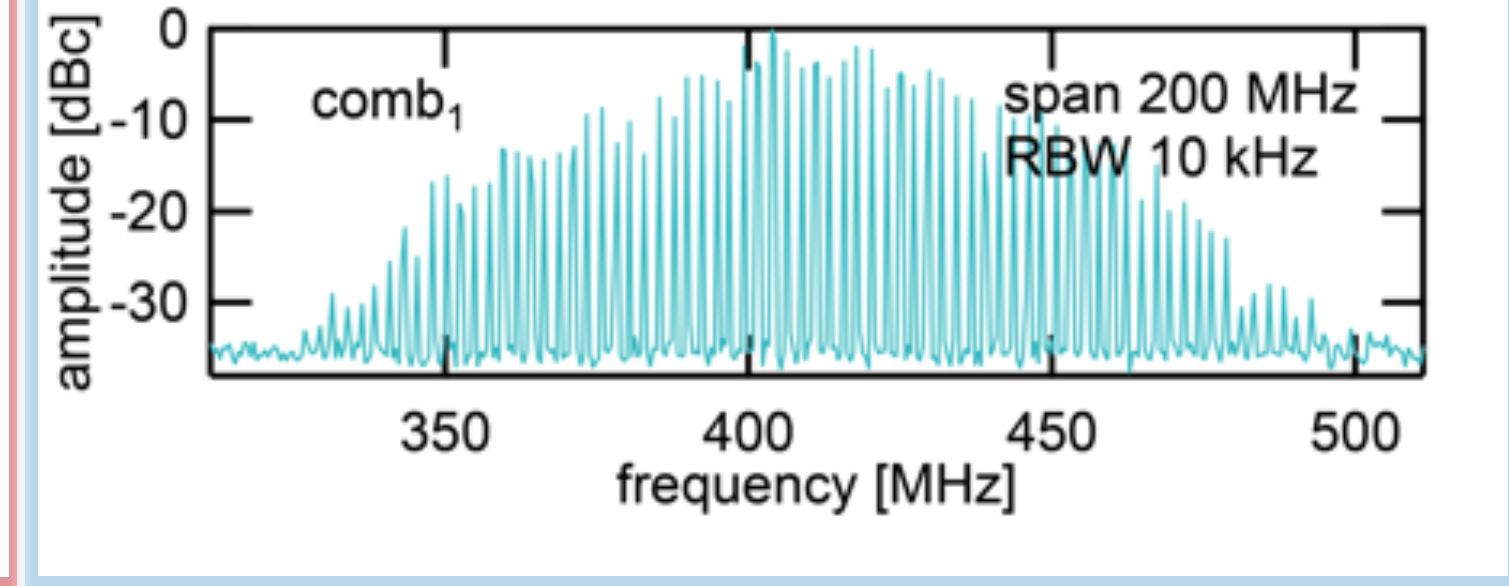
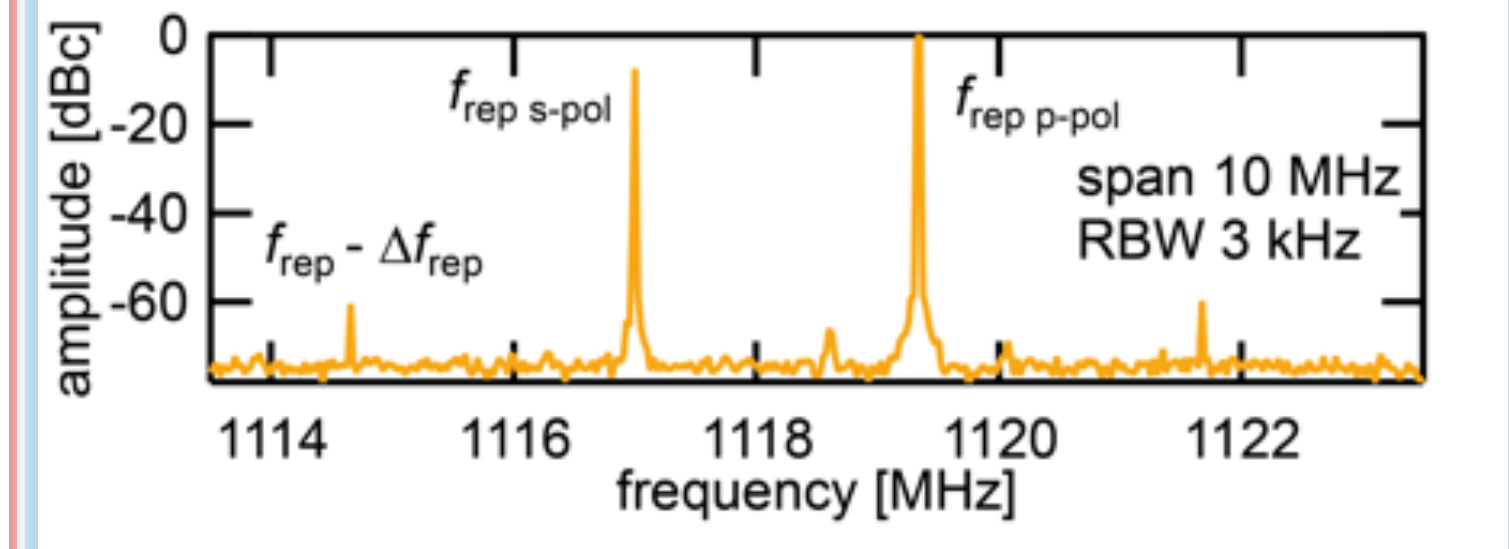
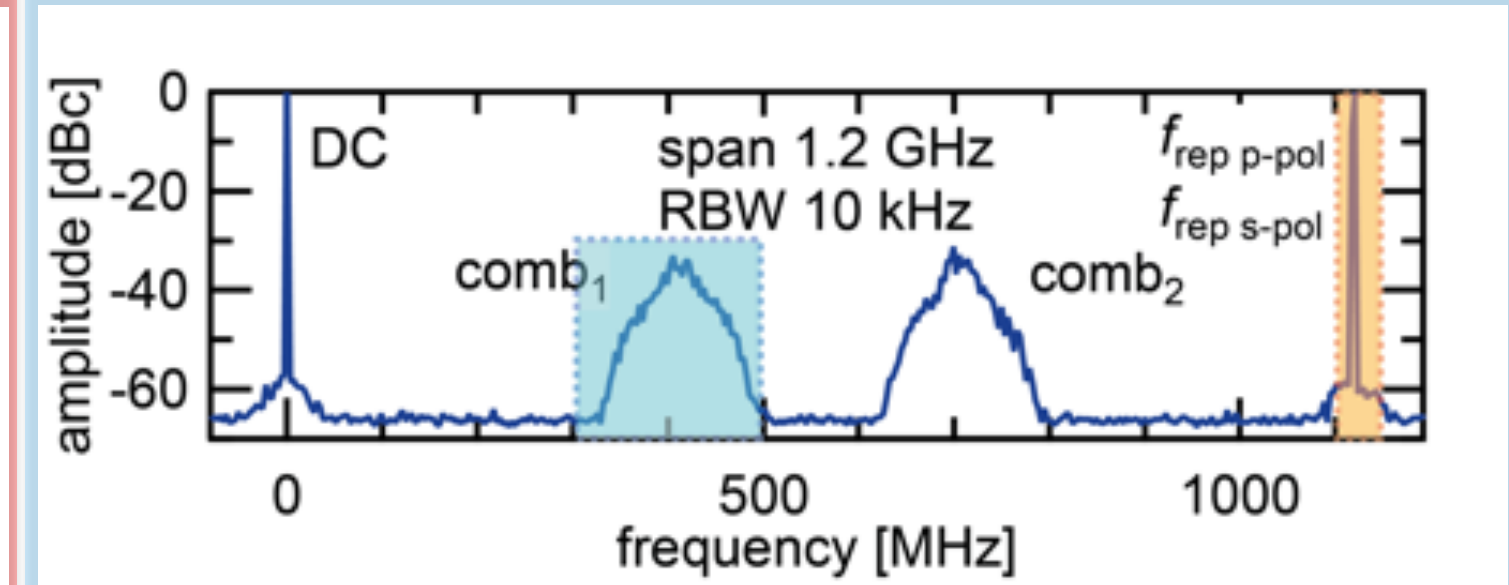
	pulse duration	output power	center wavelength
s-pol:	13.5 ps	78 mW	966.11 nm
p-pol:	19.1 ps	70 mW	966.01 nm



$f_{rep\ p-pol} = 1.890\ GHz, f_{rep\ s-pol} = 1.895\ GHz, \Delta f_{rep} = 5\ MHz$

### dual-comb Nd:YAG

	pulse duration	output power	center wavelength
s-pol:	13.2 ps	400 mW	1064.2 nm
p-pol:	13.3 ps	530 mW	1064.2 nm

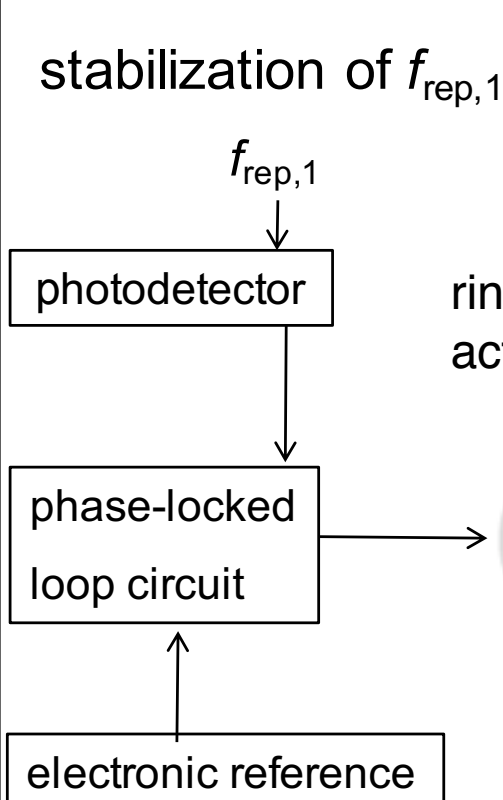


$f_{rep\ p-pol} = 1.117\ GHz, f_{rep\ s-pol} = 1.119\ GHz, \Delta f_{rep} = 2.3\ MHz$

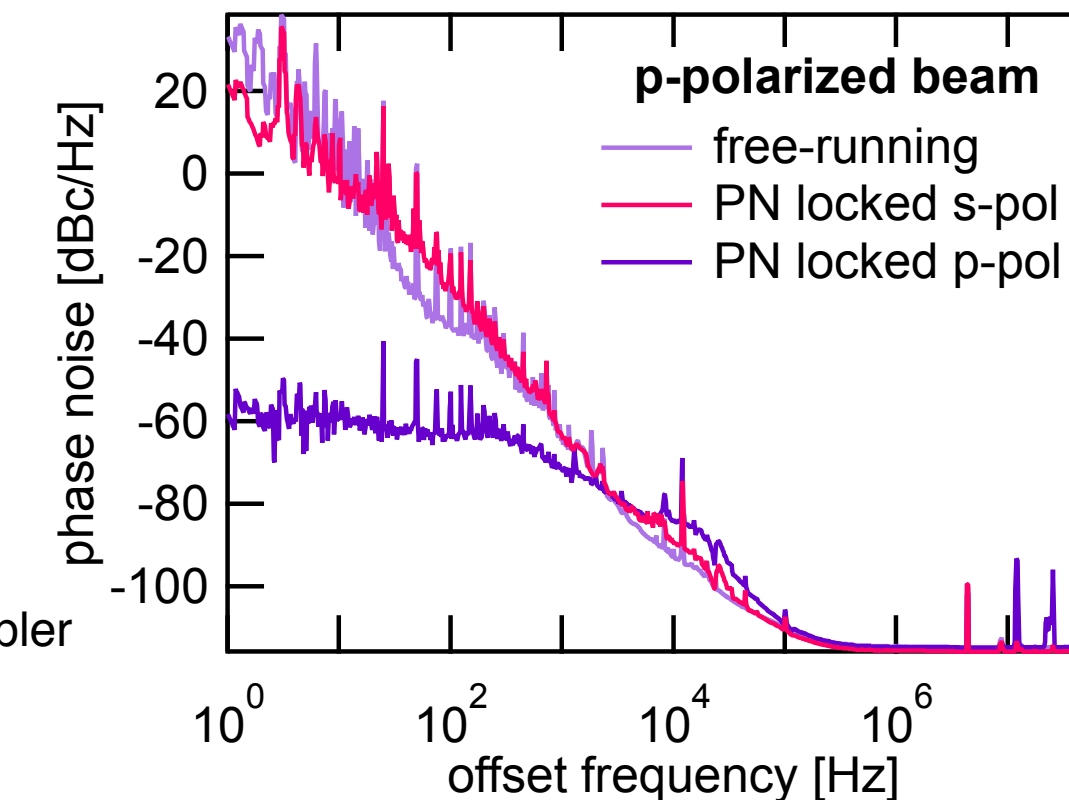
microwave comb resulting from interference between the two optical combs, providing a direct link between the terahertz optical frequencies and the electronically accessible microwave regime

## Noise analysis and stabilization

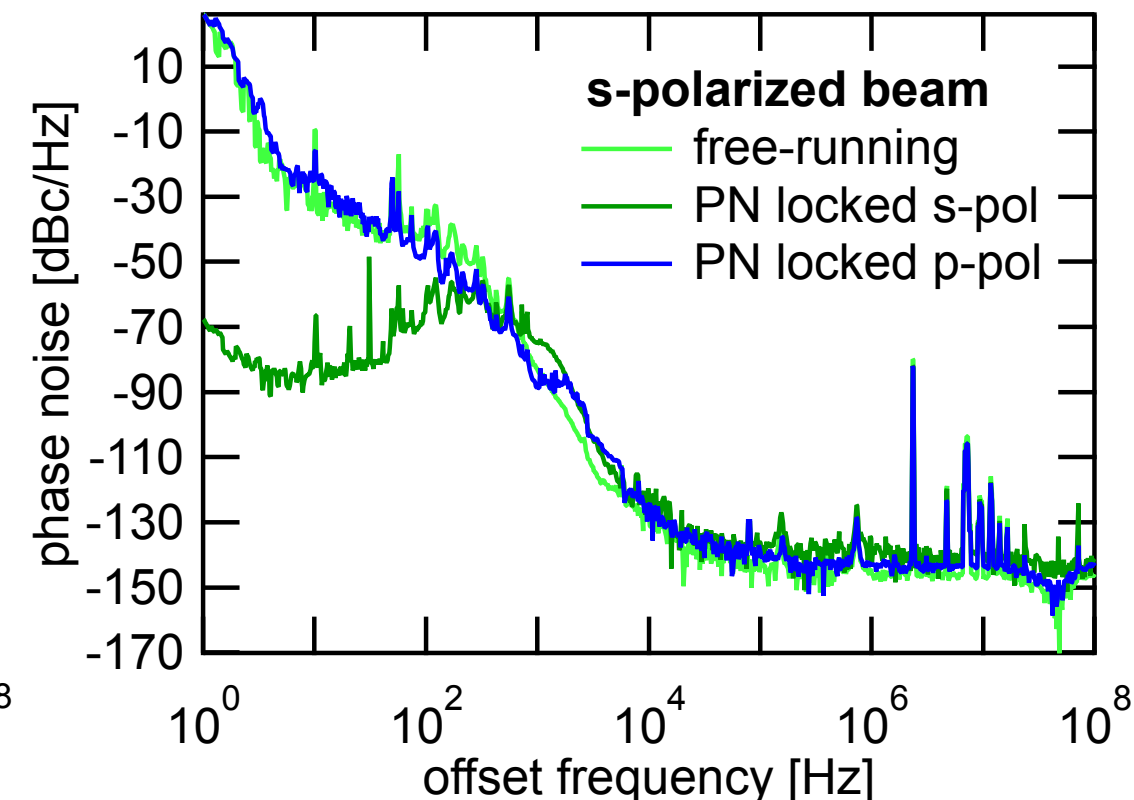
### stabilization of the pulse repetition rate



### dual-comb MIXSEL

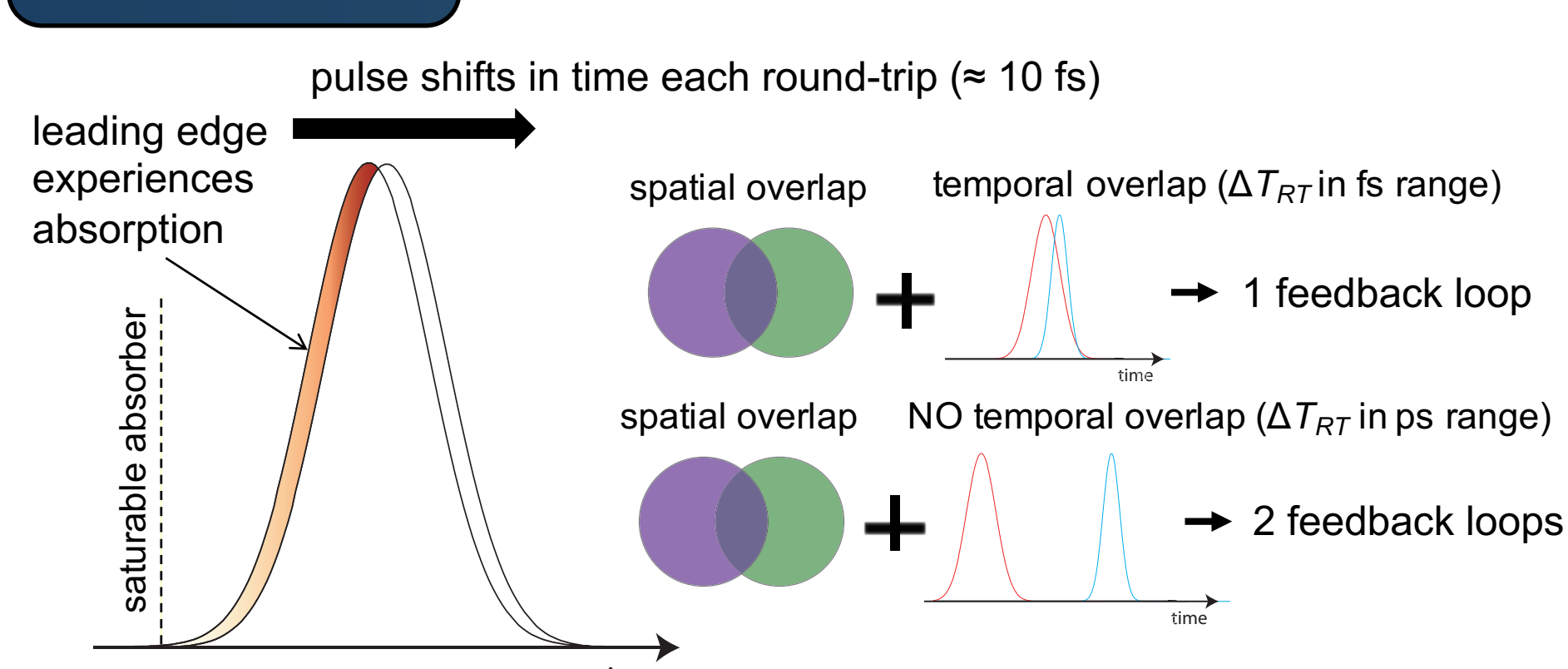


### dual-comb Nd:YAG



- ★ mechanical feedback has no effect on other beam
- ★ phase noise of two beams sharing the same cavity is uncorrelated

### explanation

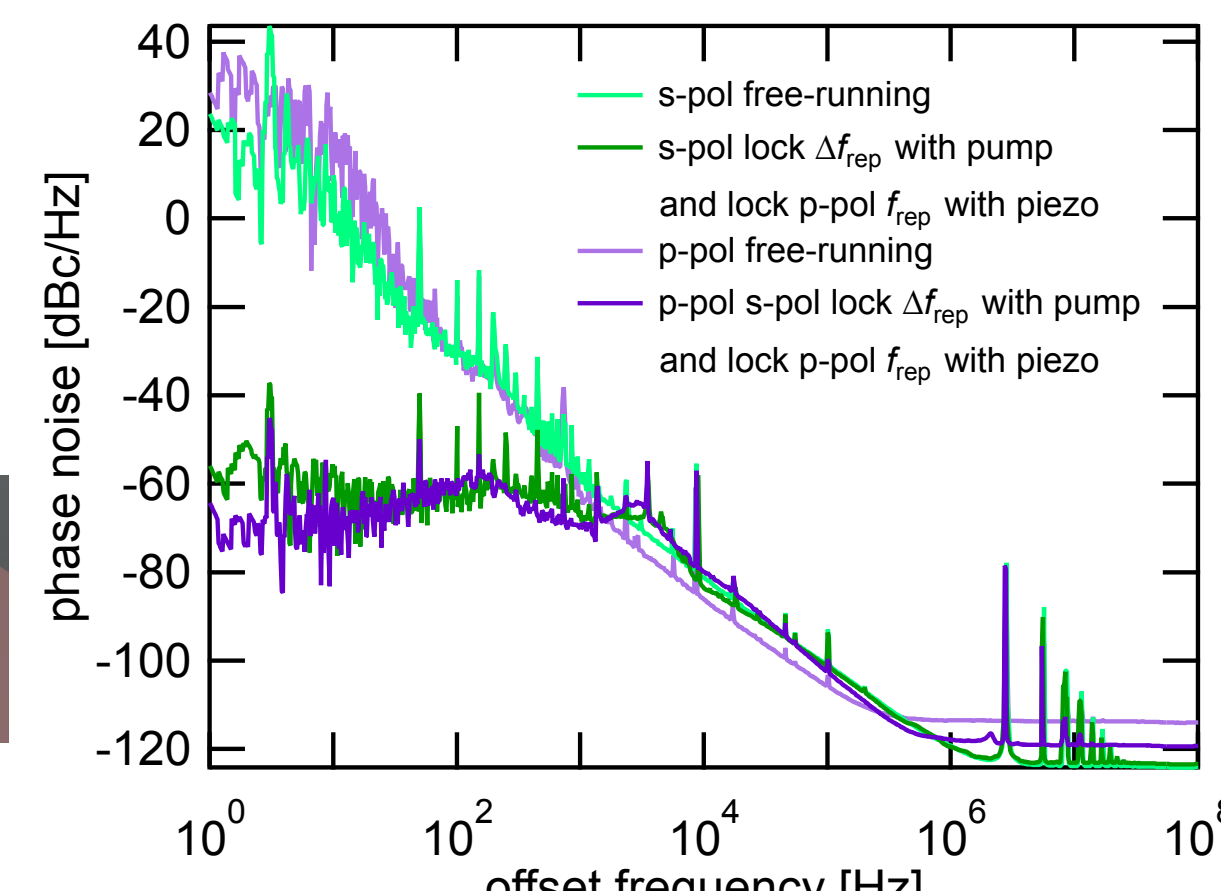
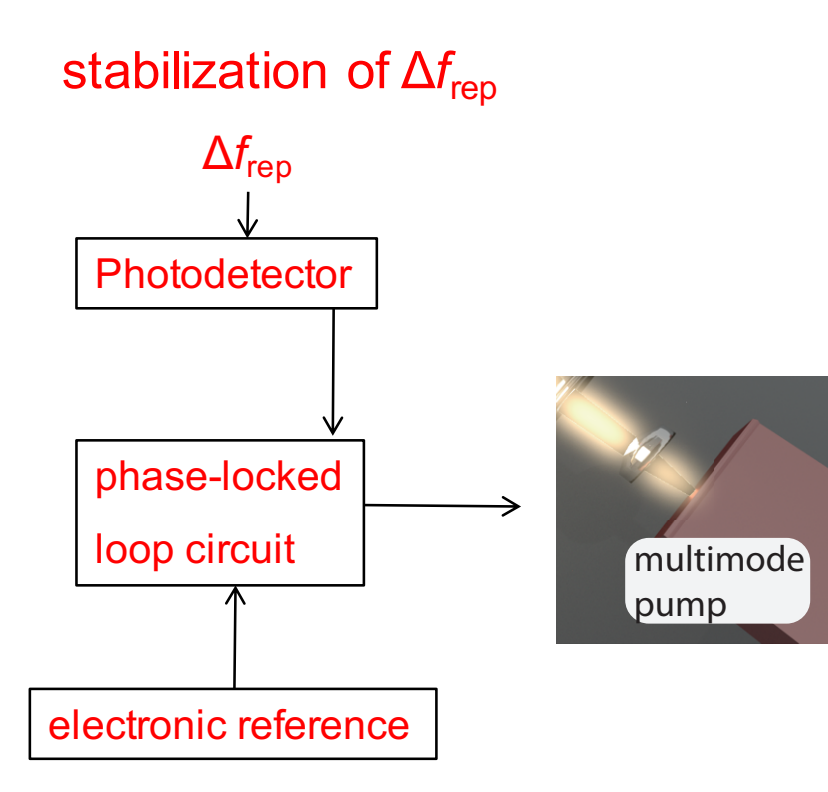


pulse shift on saturable absorber decouples noise

additional feed-back loop to stabilize the difference in pulse repetition rate

both pulse repetition rates simultaneously stabilized

### solution



## Conclusion and outlook

### conclusion

- ★ compact way of generating two modelocked beams
- ★ simple link between terahertz optical frequencies and microwave regime
- ★ saturable absorber decouples noise, but with additional feedback loop both beams can be stabilized simultaneously

### outlook

- ★ stabilization of the microwave comb
- ★ femtosecond dual-comb from MIXSEL operating around 1030 nm

More details on the results of this poster can be found in the paper:  
S. M. Link, A. Klenner, U. Keller, Optics Express 24, No. 3, pp. 1889-1902, 2016