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Novel tuning scheme for fiber lasers using a theta cavity design for constant repetition rates

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Member of the Leibniz Association

Jena and Optics

Ernst Karl Abbe
** 23.01.1840 - † 14.01.1905) Physiker, Statistiker, Optiker*

Carl Zeiss
** 11. 09.1816 - † 3.12.1888*
Techniker und Firmengründer

Dr. Otto Schott
**17.12.1851 - † 27.08.1935*
Begründer moderner Glastechnologie

Jena and Optics

Thuringia has 175 photonic companies with 13900 employees (>50% in Jena)

Leibniz Institute of Photonic Technology Jena (Germany)

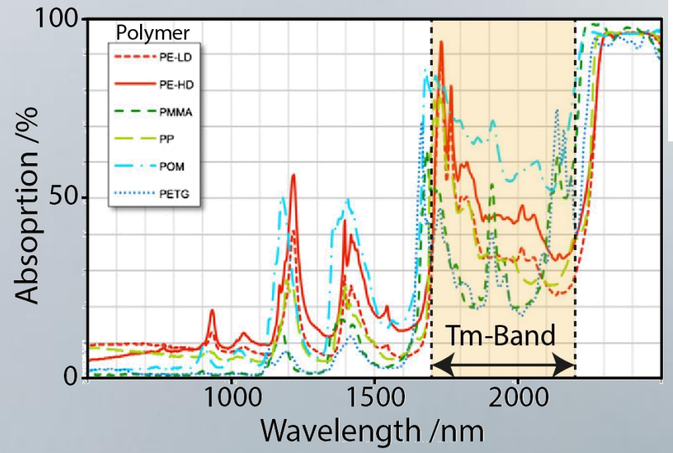
- 330 employees, including 120 scientists and 60 PhD students
- Cooperation with more than 100 academic and industrial partners
- 21 million € budget with 11 million € third body funding per year (2.5 million € from industry)
- 4 spin-off companies with about 120 jobs since 1998

Outline

- Introduction
- Modified Resonator Layout ⇨ Theta Cavity
- First Experimental Results
- Summary

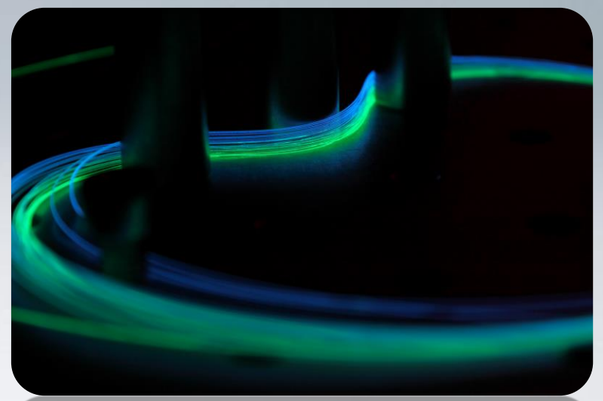
Tunable Lasers

- **Applications**
  - Spectroscopy
  - Biophotonics and medical technology
  - Material processing (e.g. Polymer)

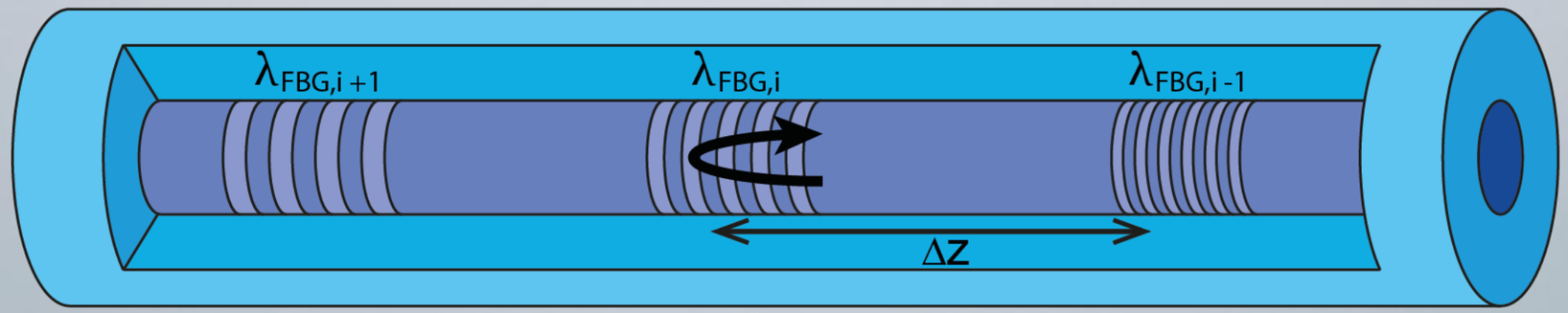


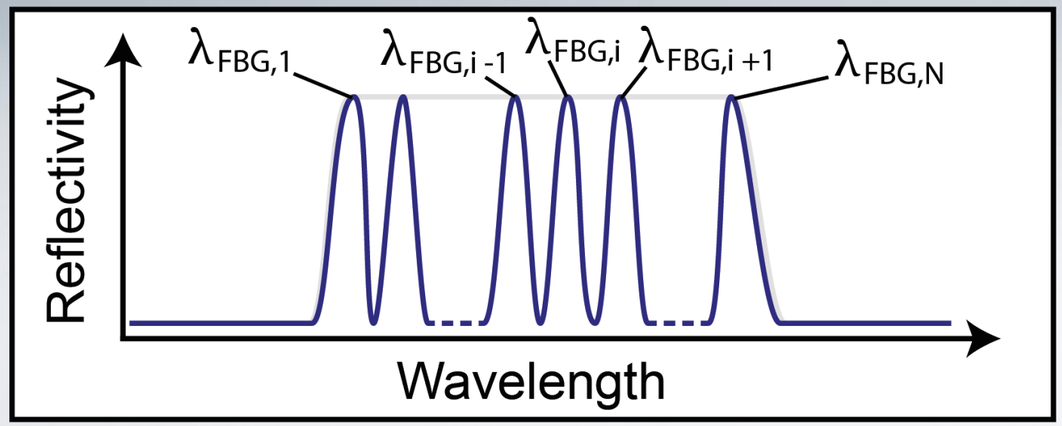
[Mingareev et al., Opt. Laser Technol. 44 (2012)]

- **Fiber lasers as perfect framework**
  - Excellent beam quality and efficiency
  - Broad gain regions
  - In fiber-integrated layout: compact, robust, user-friendly
  - Suitable tuning concepts?



Discrete tuning with FBG Arrays





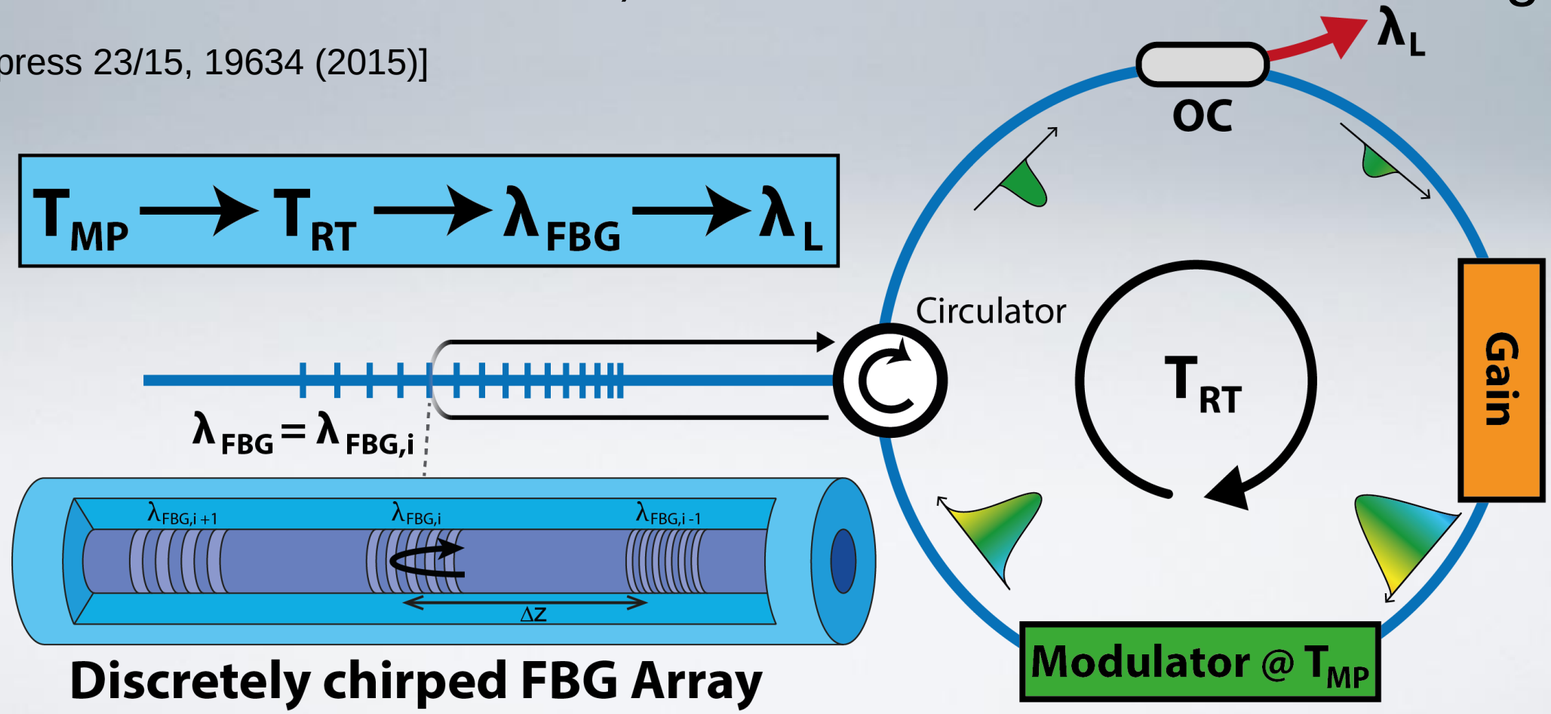
- Unique spectral freedom for tailored tuning ranges
- monolithic design
- Drawing tower inscription enables scalable filter sizes

Discrete tuning with FBG Arrays

- First realization of a pulsed tunable fiber laser with FBG arrays in a **Sigma (σ) ring resonator**
- **Control mechanism**: variable pulse repetition rate due to distributed filter feedback

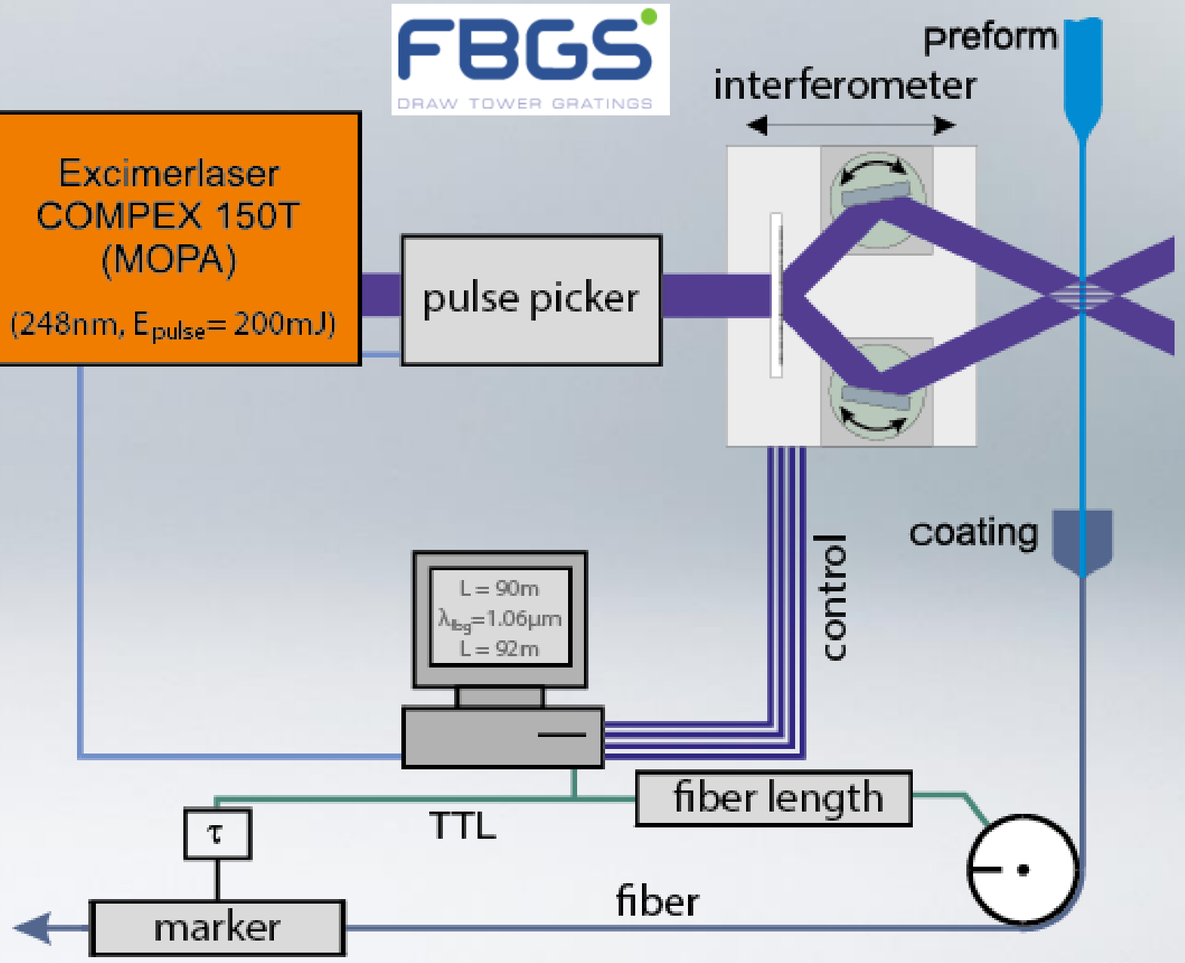
  ⇨ Excellent emission characteristics, bandwidth record for fiber-integrated Yb lasers

[Tiess, T., et al., Optics Express 23/15, 19634 (2015)]



Fabrication of FBG arrays

- Highly productive inscription during fiber drawing process
- Single-shot illumination!
  ⇨Reflectivity ≤ 40%
- Feedback wavelength tunable during inscription via interferometric setup
- Commercialized through FBGS Technologies GmbH

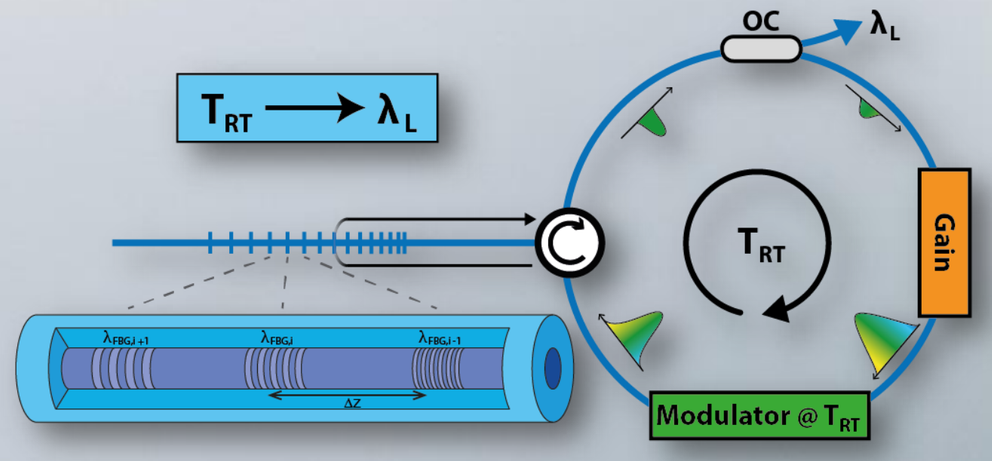


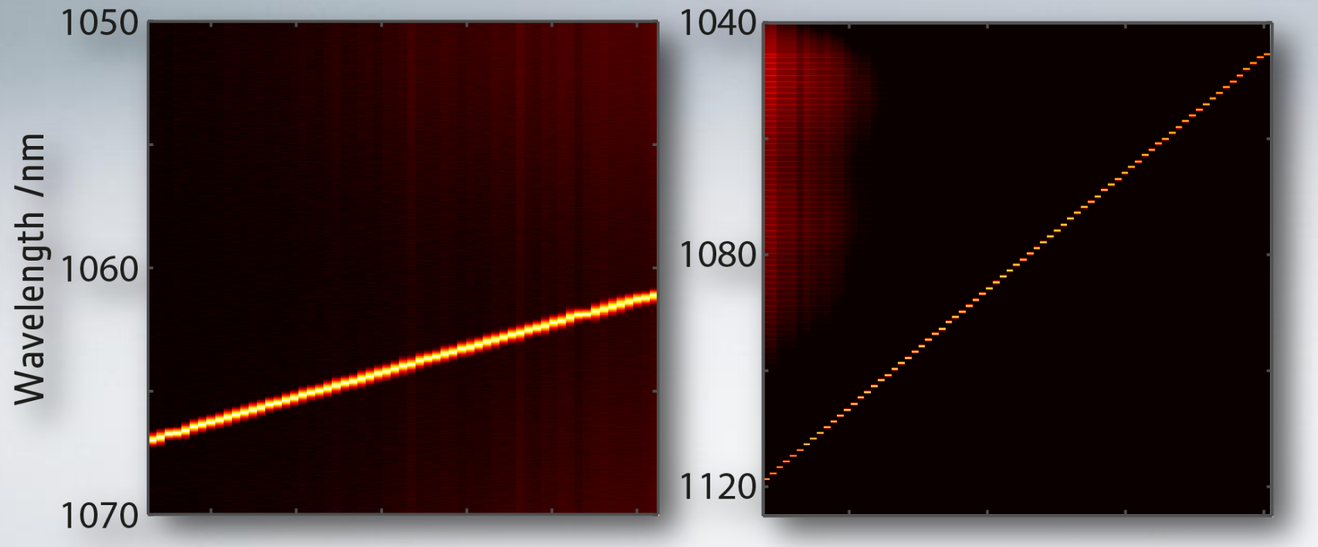
[V. Hagemann, *Dissertation*, FSU Jena (2000)]

Previous results: Sigma cavity

Discrete tuning concept for pulsed fiber-integrated lasers

- Filter: Step-chirped FBG arrays
- Electronic control mechanism



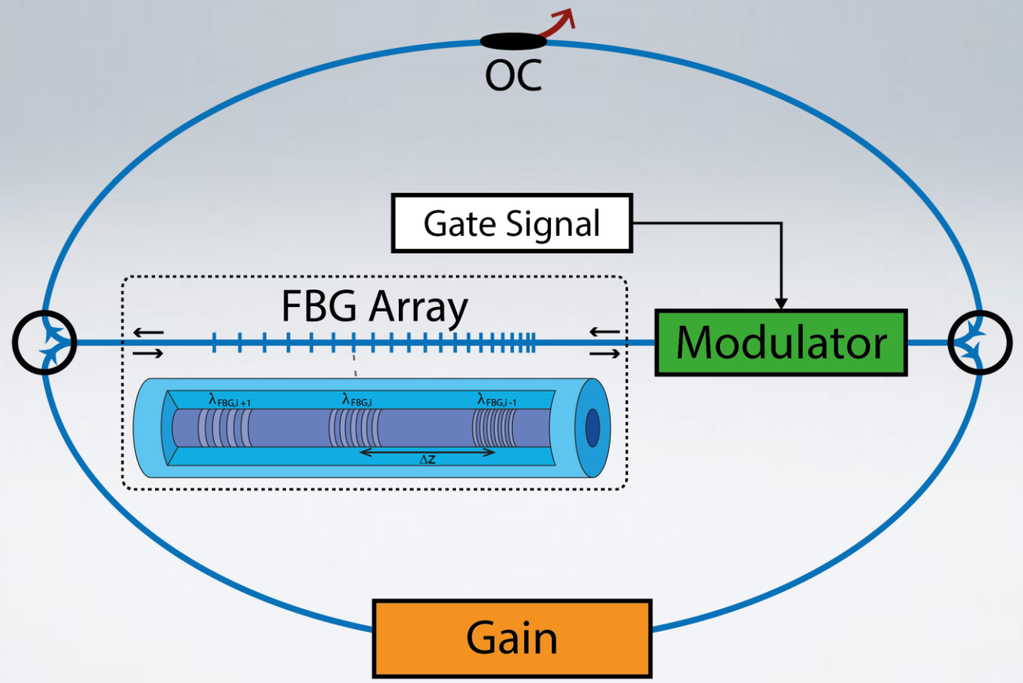


Achieved specifications

- Tuning range: **74 nm**
- Resolution: **100 pm**
- Line width: **~60 pm**
- Spectral signal contrast: **>40dB**
- Peak power: **~100 W**

Limitations of Sigma Laser Design

- **Problem**: repetition rate varies with emission wavelength
  ⇨ Changing pulse characteristics
  ⇨ No applications with synchronized processes
- New resonator layout with constant repetition rate: **Theta (θ) Cavity**



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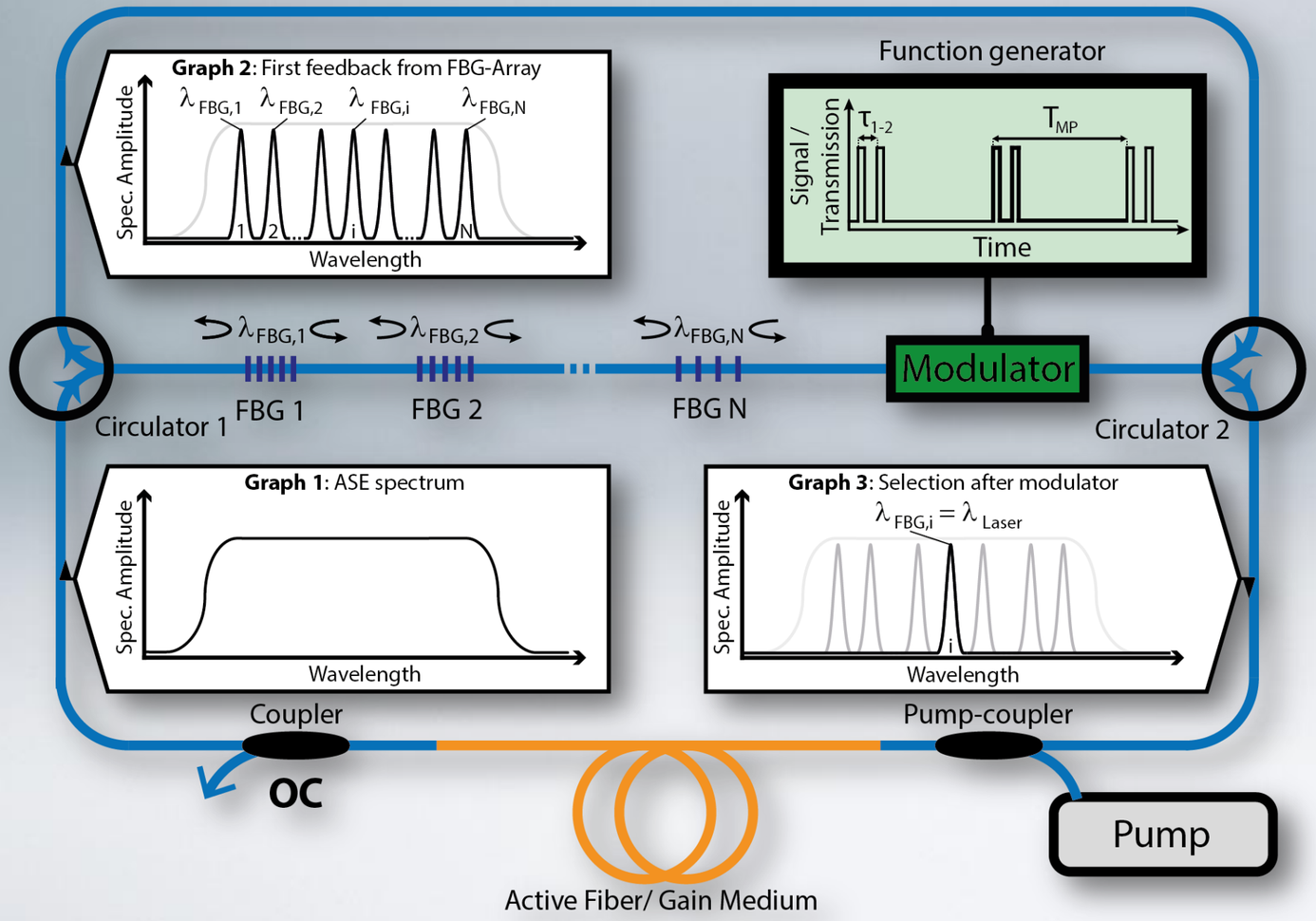
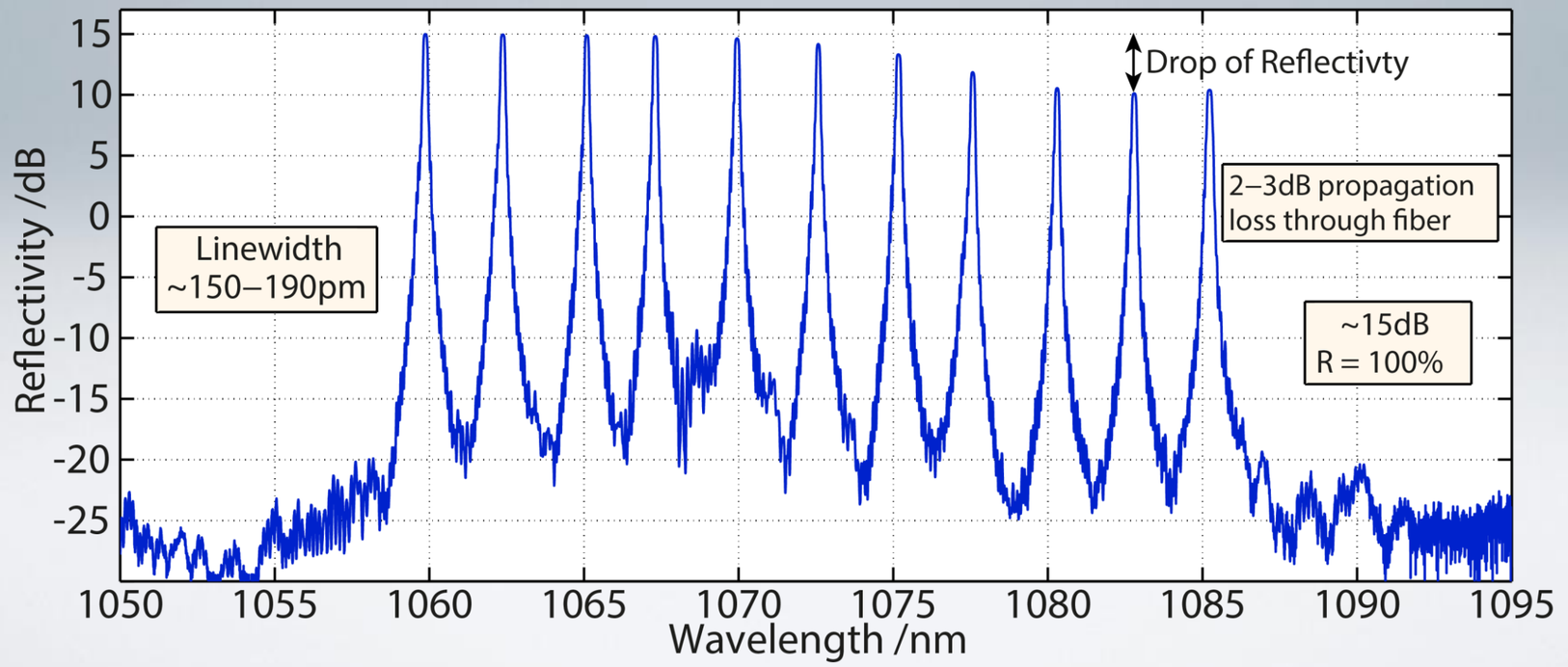
Tuning Principle with Theta Cavity



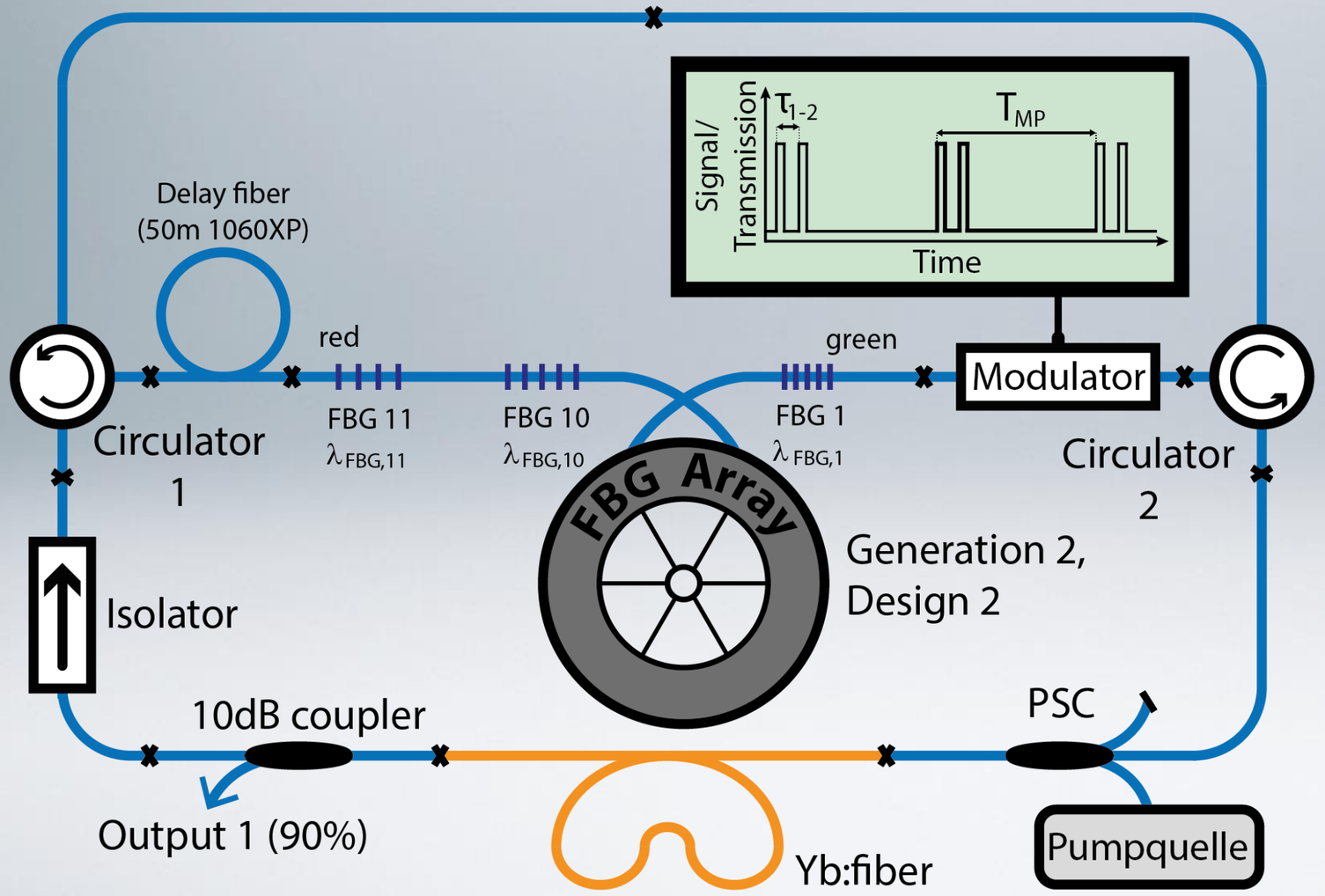
- Constant repetition rate
  ⇨ two filter passes per round trip reverse distributed feedback of FBG array
- Wavelength tuning based on gating with double pulse signal
- **Tuning parameter:** delay $\tau_{1\text{-}2}$
- Patent application pending

FBG Array

- Inscription of FBG in H_2-loaded 1060XP fiber using Excimer laser
- 11 FBGs covering a bandwidth of 25nm
- Spatial separation of FBGs: ~2.5m



Experimental Setup



- Signal paths adjusted for unambigious tuning behavior
- AOM rise time 25ns
- HR FBG array to minimize losses
- FBG Array with 11 gratings covering 25nm (1060nm:2.5nm:1085nm)

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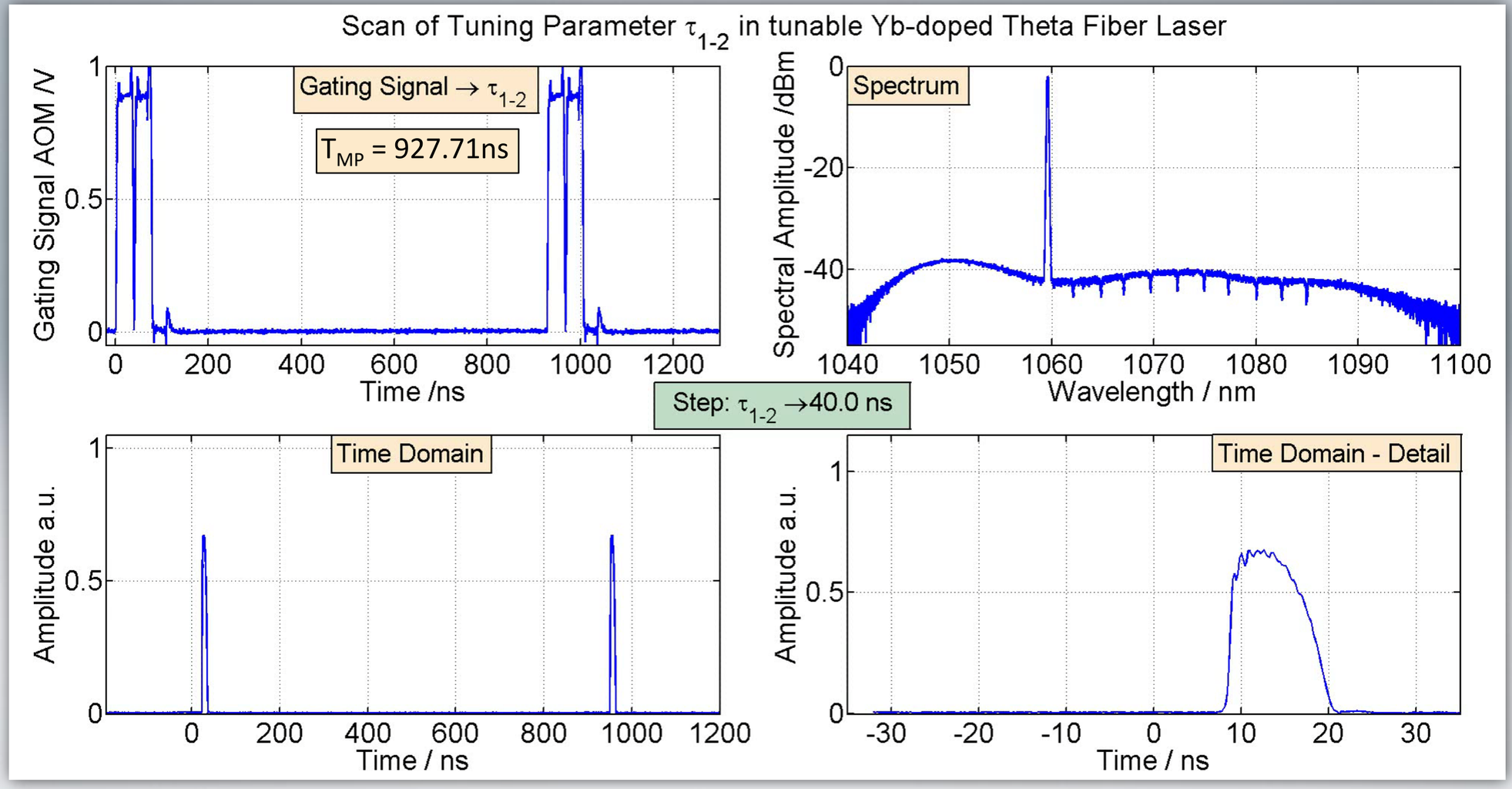
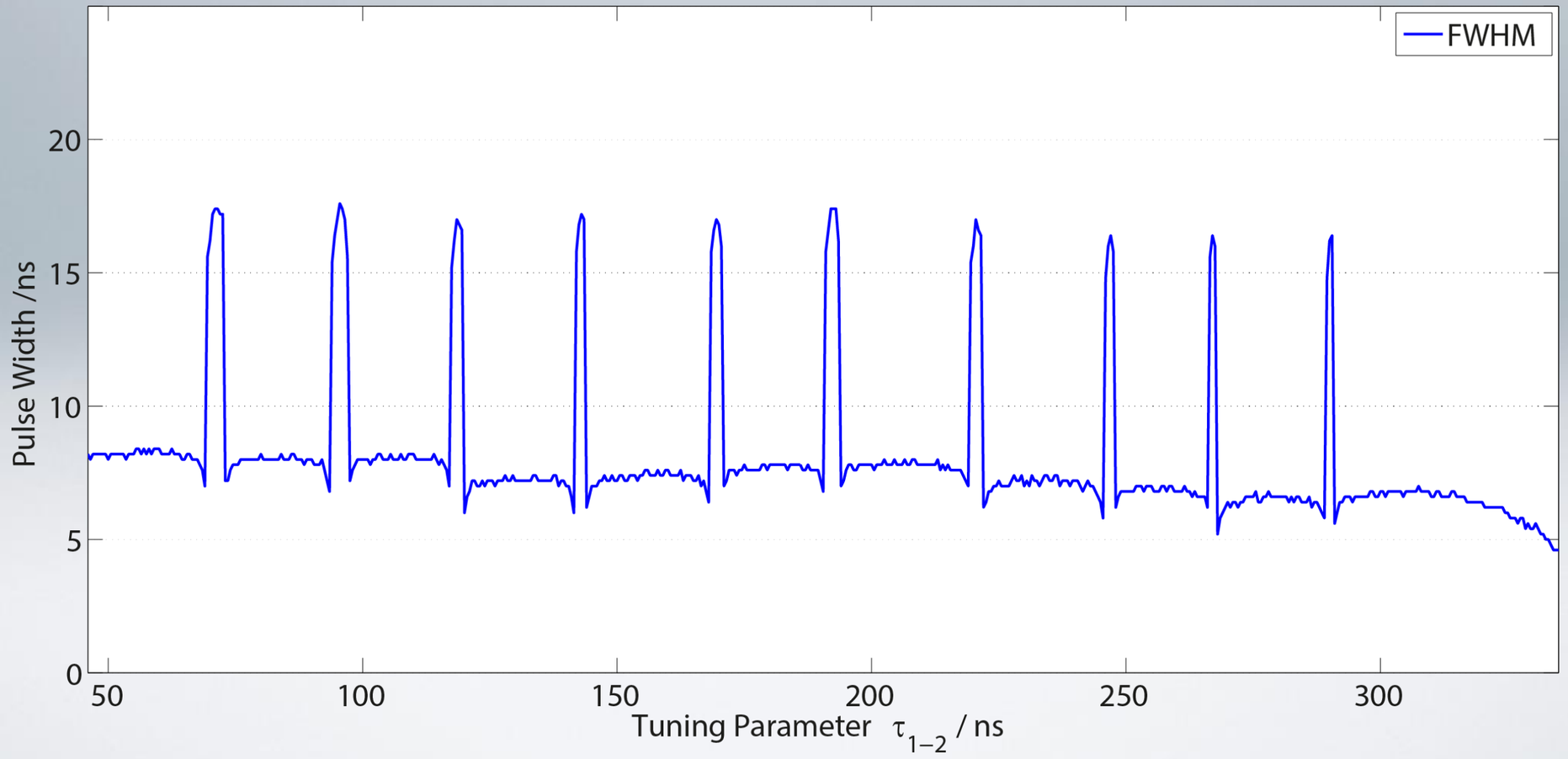
Tuning Behavior

Tuning concept works!



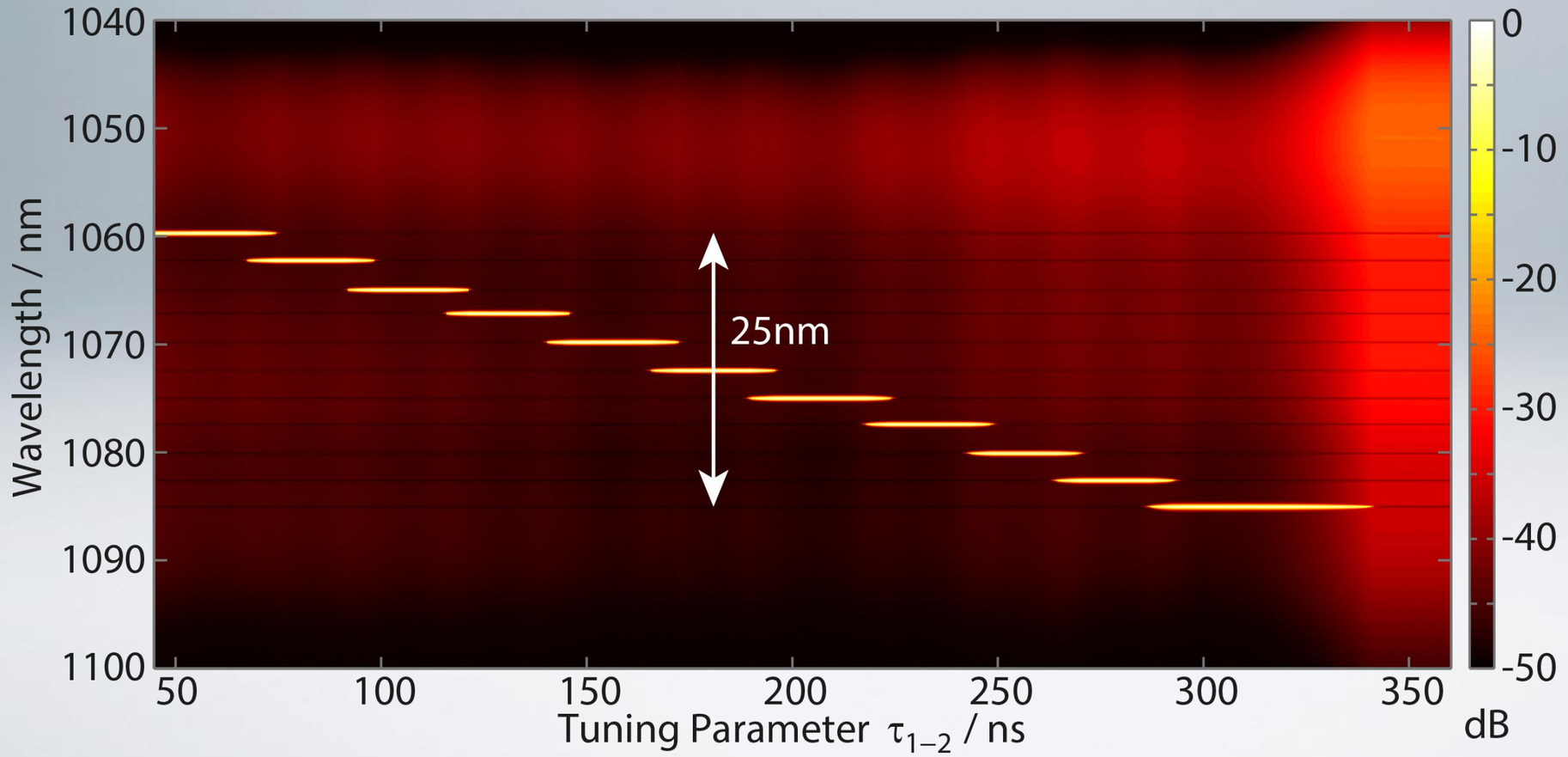
Temporal Width (Pulse duration)

- GW = 35ns → Pulse duration **6.8ns – 8.4ns**
  - ➢ Pulses much shorter than gate
- Pretty steady but slightly decreasing over tuning range



Spectral Characteristics

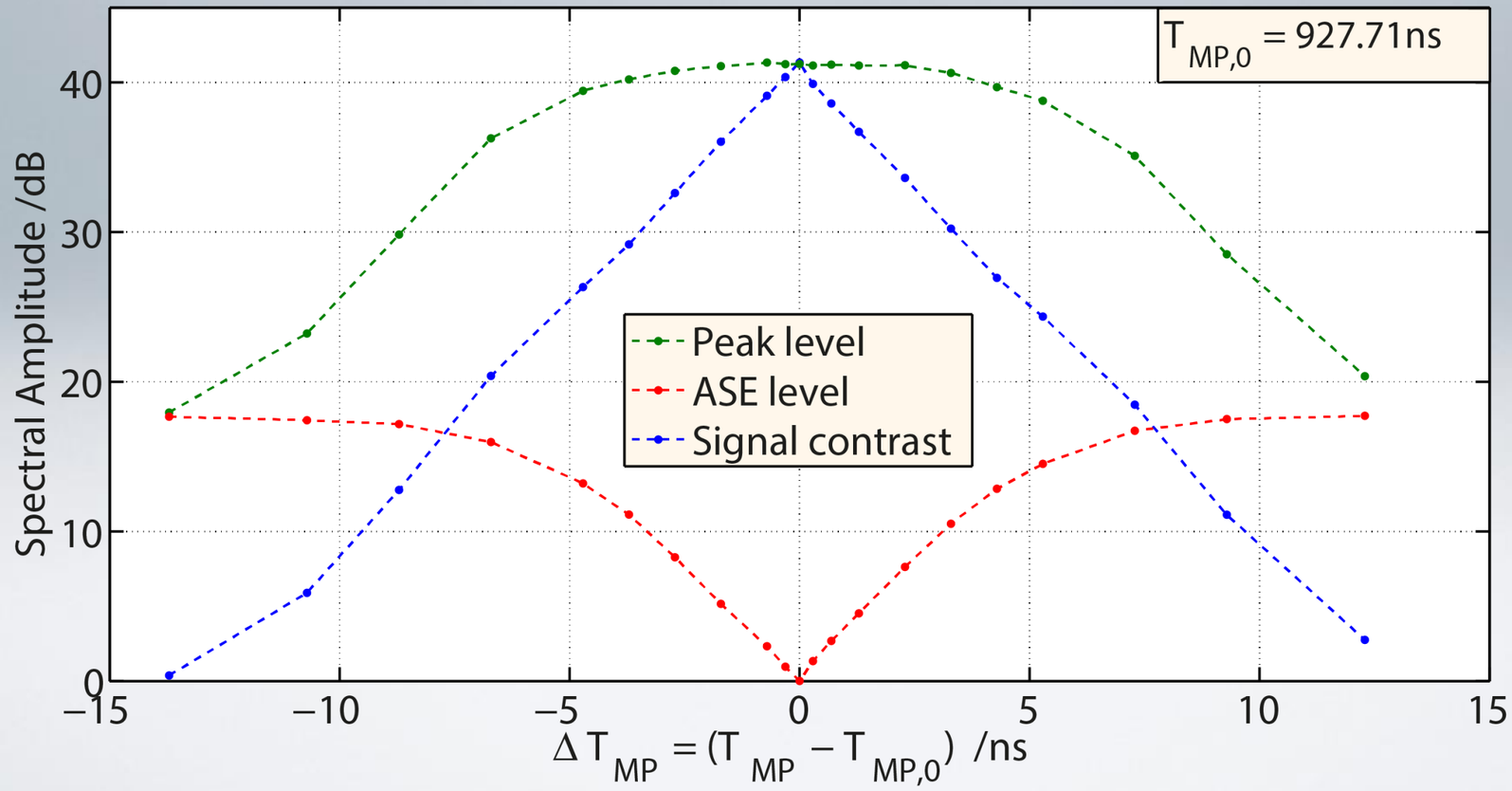
- Discrete tuning range 25nm with excellent signal contrast (>40dB)



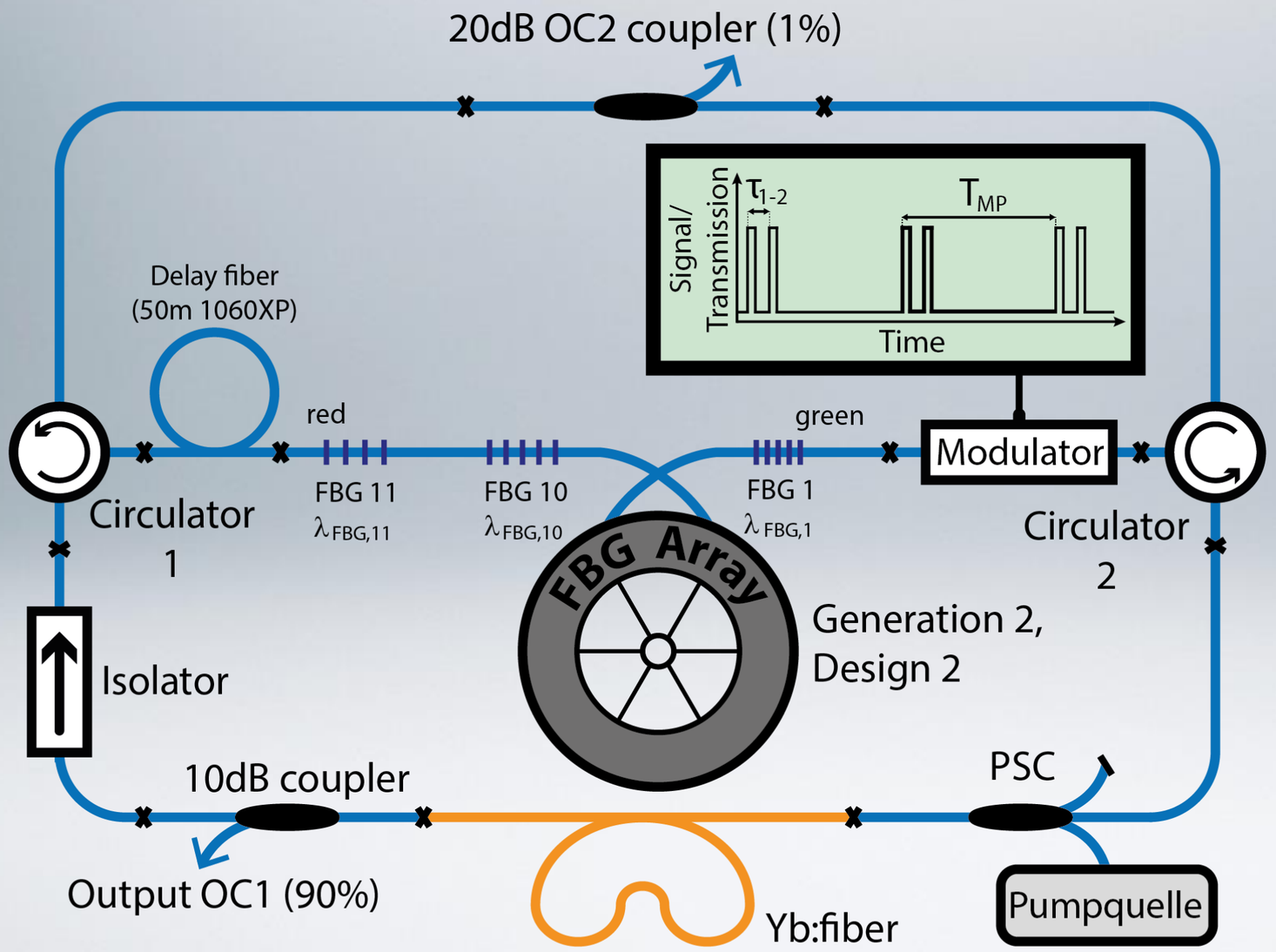
FBG linewidth
≈
Laser linewidth
≈
150pm

Sensitivity on Modulation Period T_{MP}

- Signal contrast depends on matching of T_{MP} to resonator length
- Operation window for T_{MP} ~ +/- 1%



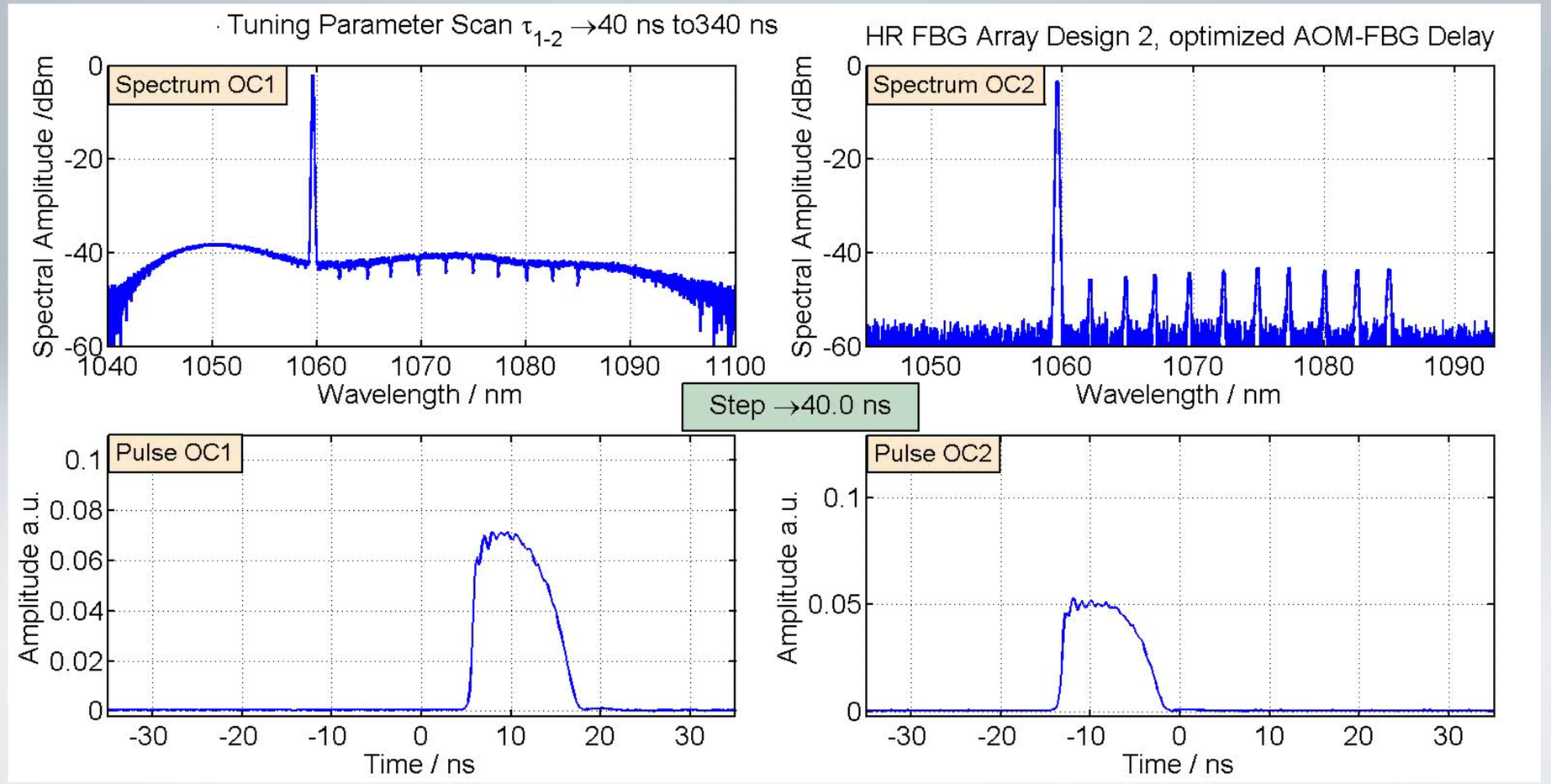
Experimental Setup 2



- 2 OC Couplers at different positions in the cavity
- **Target:** understand pulse evolution along one round trip
- AOM 25ns rise time

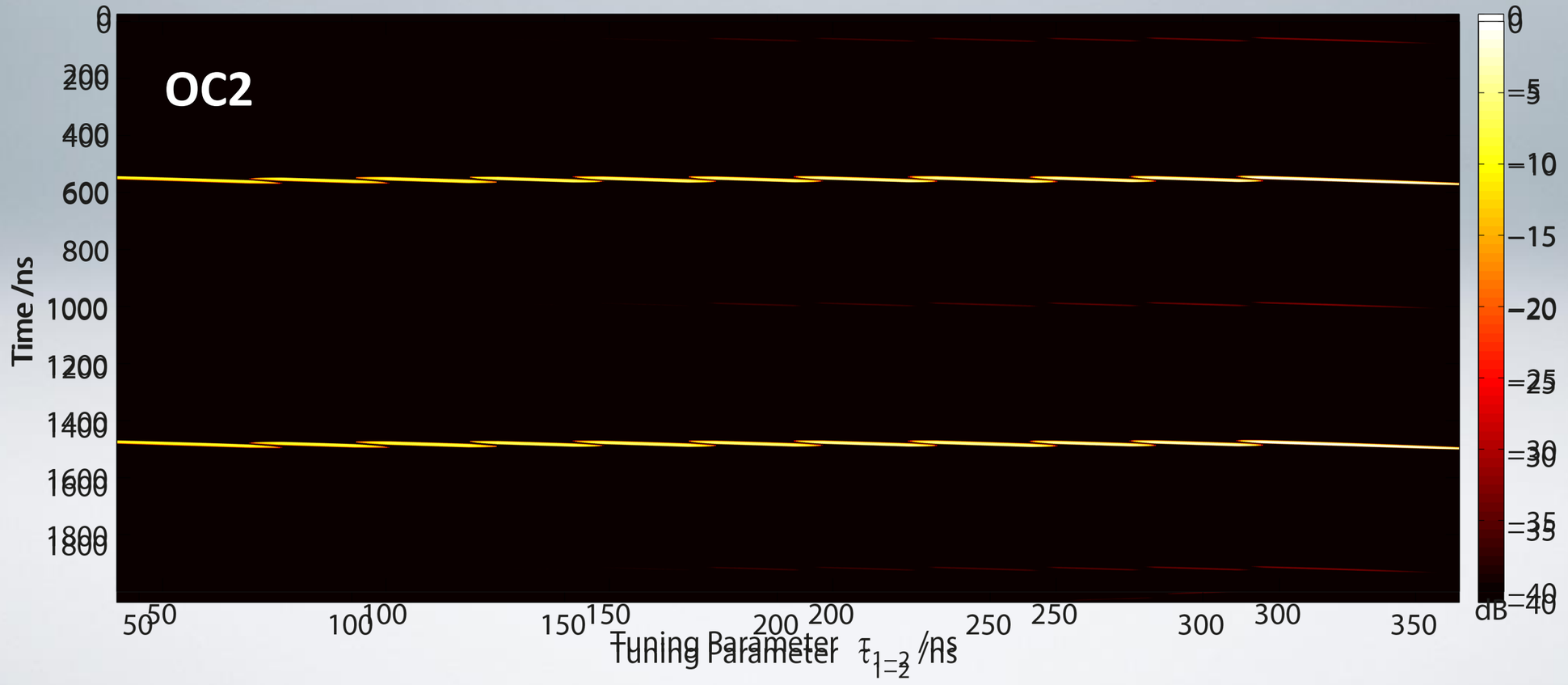
Pulse Evolution in Resonator

OC1: high output power - OC2: high spectral purity



Temporal Tuningspectrogram @ OC2

- System was not triggered on second gate for **OC2** → temporal shift
- Decaying amplitude over tuning range due to propag. Losses in filter
- Constant repetition rate obvious with right triggering



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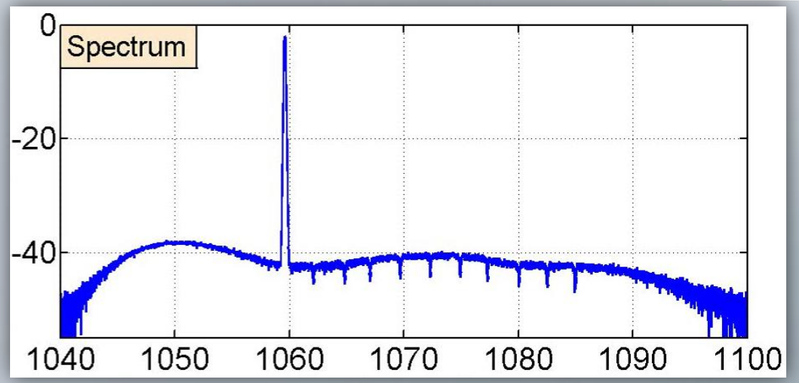
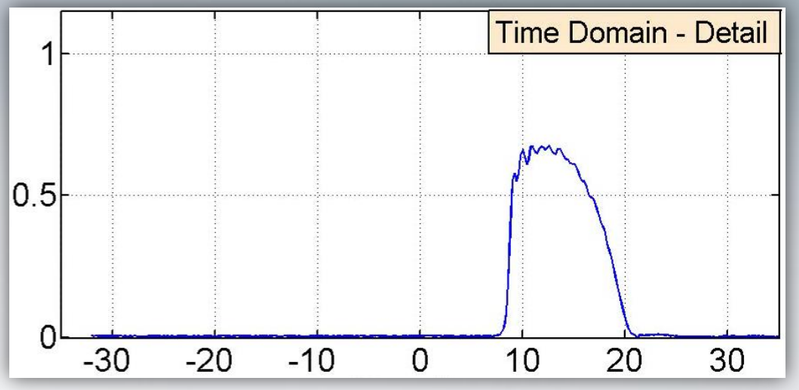
Summary

- **Tuning in Theta cavity fiber laser and constant repetition rate works!**
  - Tuning range of 25nm @ 1µm
  - High signal contrast (>40dB) and narrow emission linewidth (~150pm)
  - Stable pulse properties and tunable pulse duration
- **Outlook**
  - Detailed investigation of emission characteristics
  - Optimize and enlarge tuning range
  - Investigate mode for **tunable synchronous multi-wavelength emission**





Financial support from the Federal Ministry of Education and Research (BMBF) within the project *"FlexTune"* is gratefully acknowledged!

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Thanks a lot for your attention

Questions???

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