

Independently tunable dual-wavelength fiber laser based on a discrete fiber Bragg grating array

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Outline

- Introduction
- Concept of Tunable Theta Cavity Fiber Laser (TCFL)
- Experimental Results
 - Independently tunable dual-wavelength emission
 - Analysis of pulse synchronicity with a Time-Delay Spectrometer (TDS)
- Conclusion

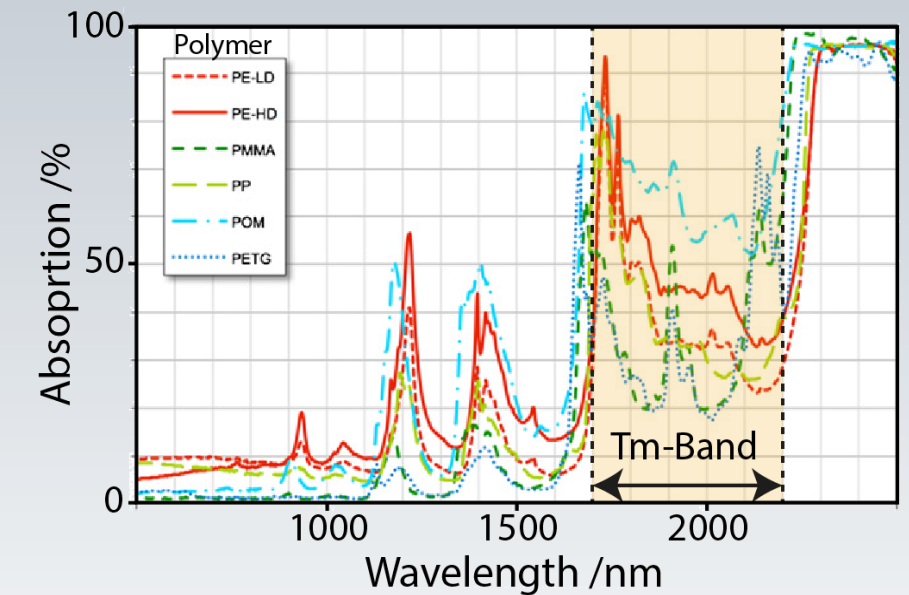
Tunable Lasers

- **Applications**

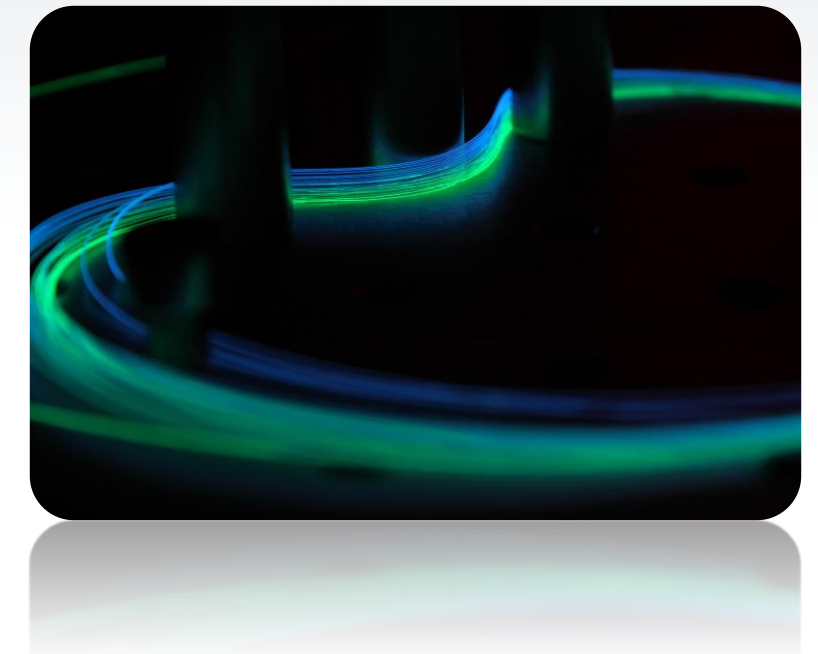
- Spectroscopy
- Biophotonics and medical technology
- Material processing (e.g. Polymer)

- **Fiber lasers as perfect framework**

- Excellent beam quality and efficiency
- Broad gain and absorption regions
- With fiber-integrated layout:
compact, robust, user-friendly, low maintenance
- Suitable tuning concepts?



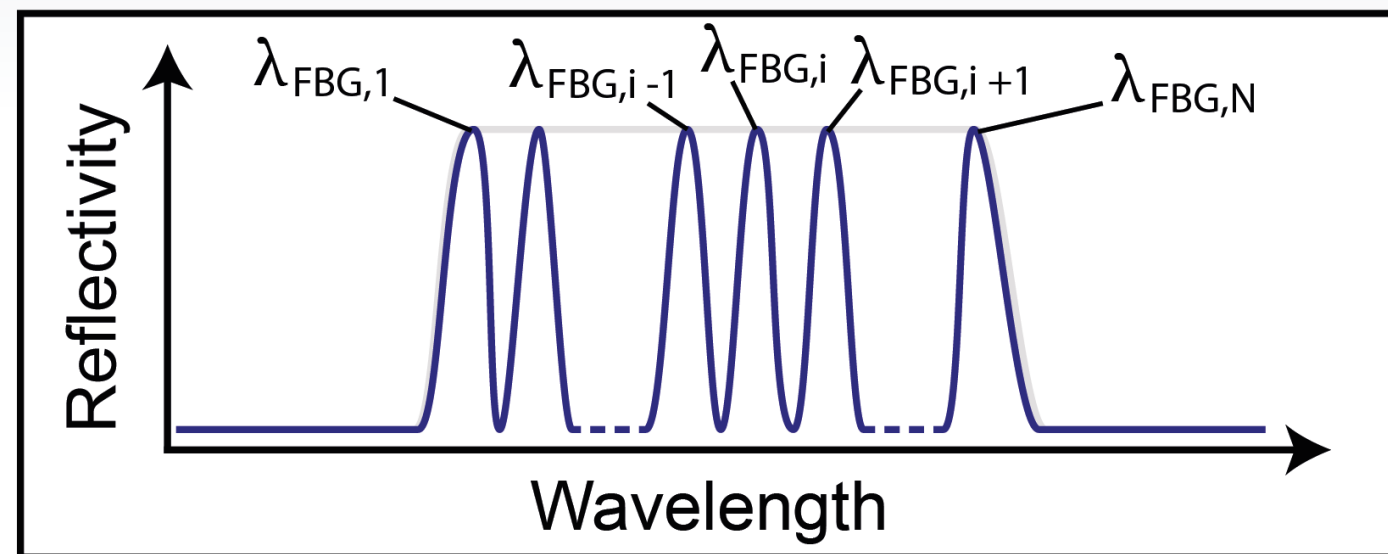
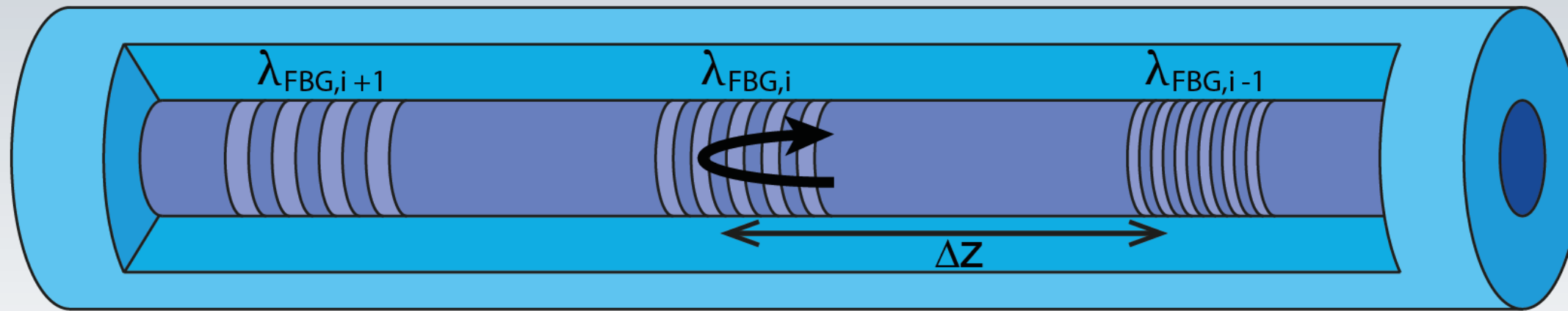
[Mingareev et al., Opt. Laser Technol. 44 (2012)]



Outline

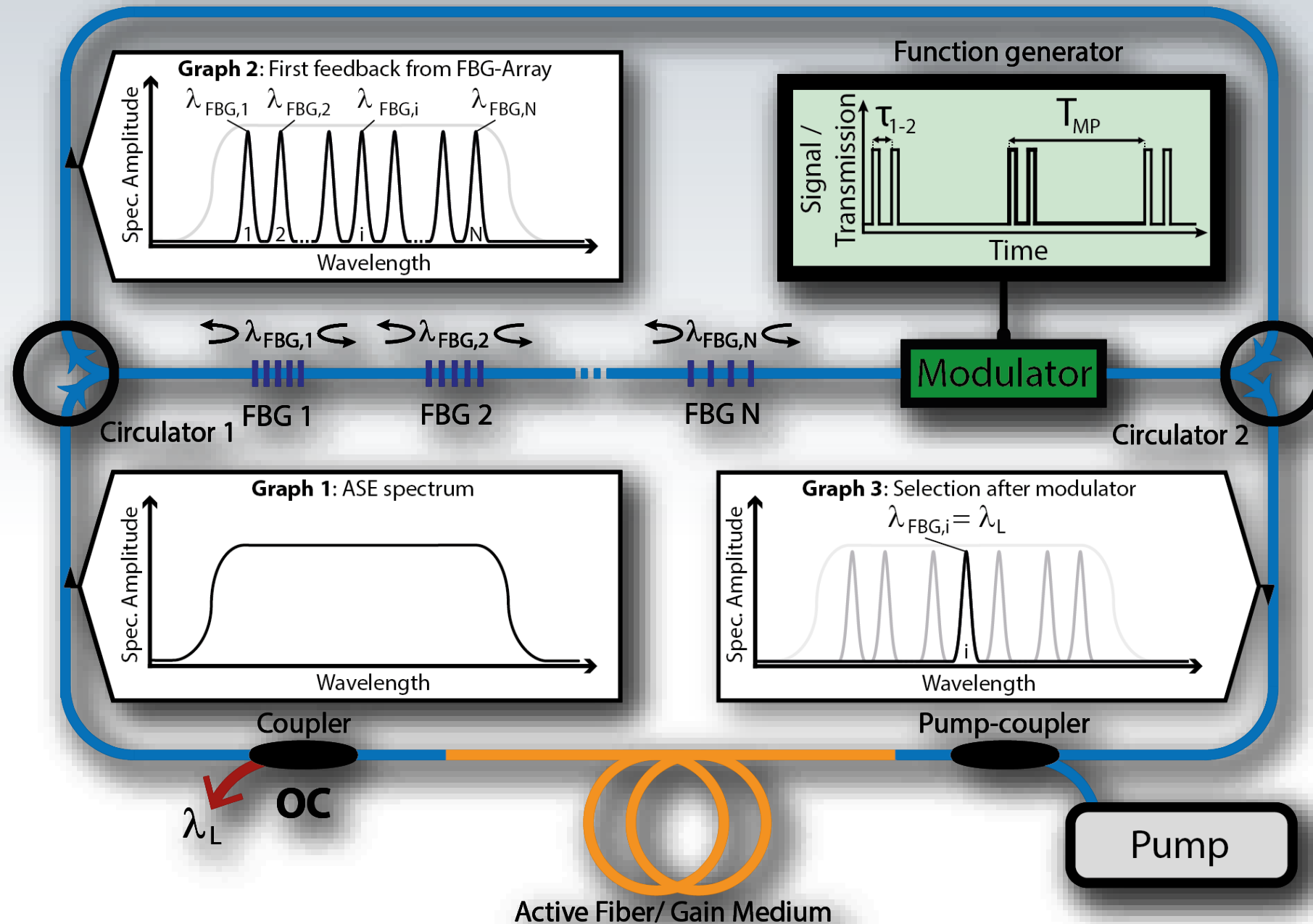
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Discrete tuning with FBG Arrays



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

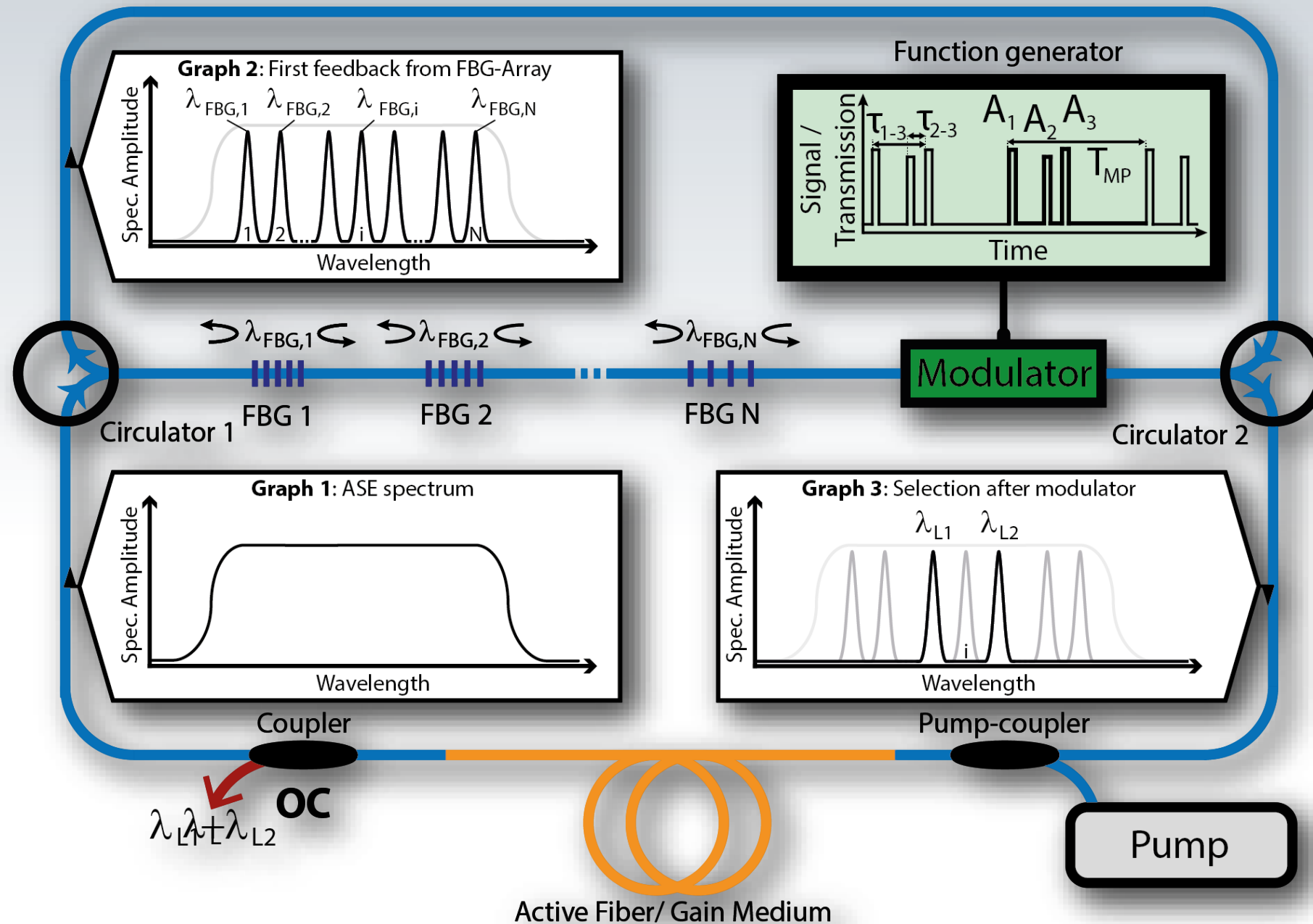
Concept of tunable Theta Resonator



- **Idea:** 2 counter-propagating filter interactions in FBG array for balancing spectral delays of gratings
- **Round trip time T_{MP} independent of λ_{Laser}**
- Wavelength tuning by **optical gating** with two gates (Tuning parameter: τ_{1-2})

Tunable Dual-Wavelength Emission

- Innovative operation mode: synchronized dual-wavelength emission



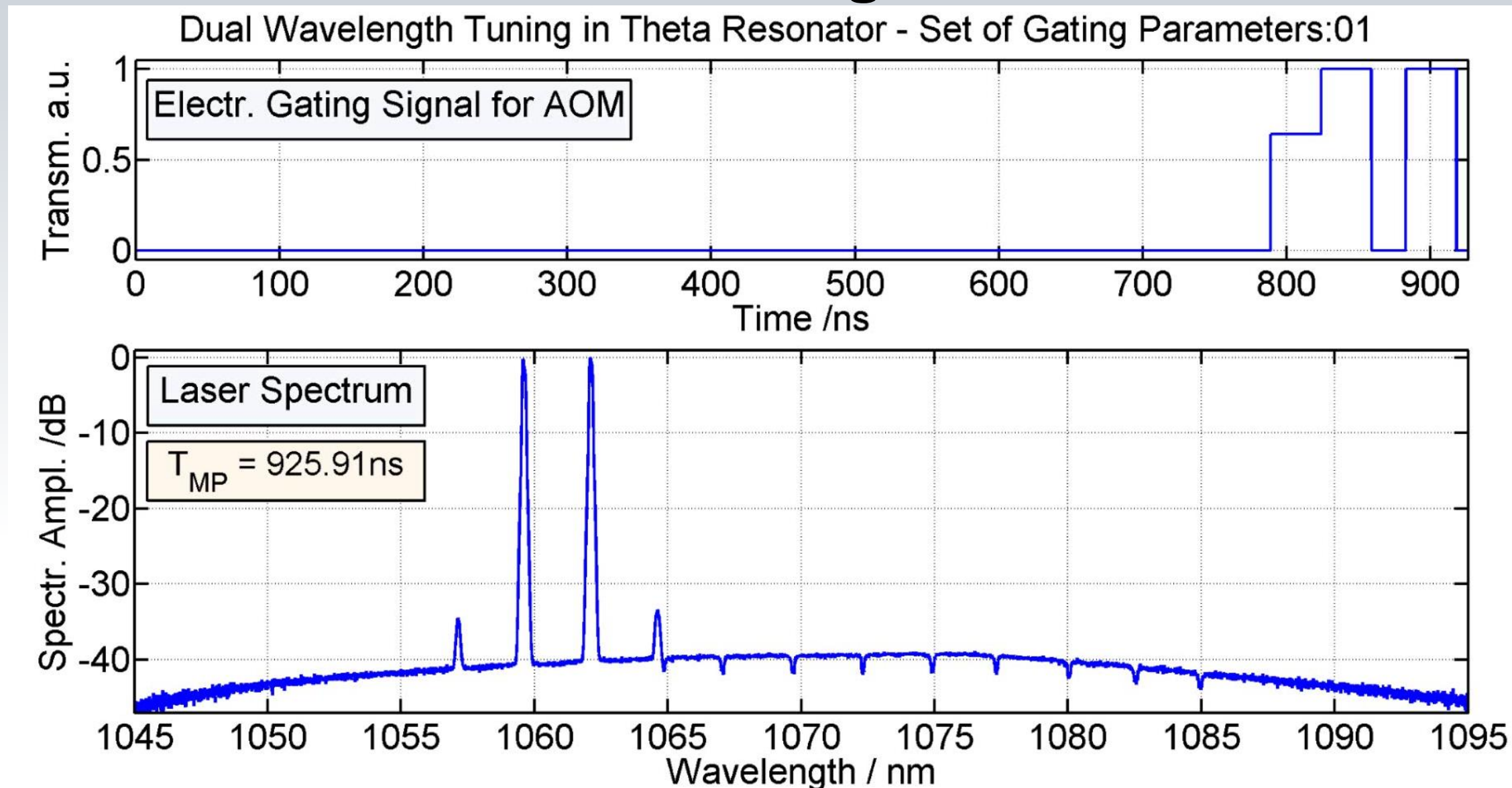
- Electrical gating signal may switch operation mode to tunable multi-wavelength emission
- N wavelengths $\rightarrow (N+1)$ gates
- Synchronous dual-wavelength mode:
 - 3 transmission gates
 - Tuning parameter:** τ_{1-3} and τ_{2-3}
 - Amplitude control: A_1, A_2, A_3

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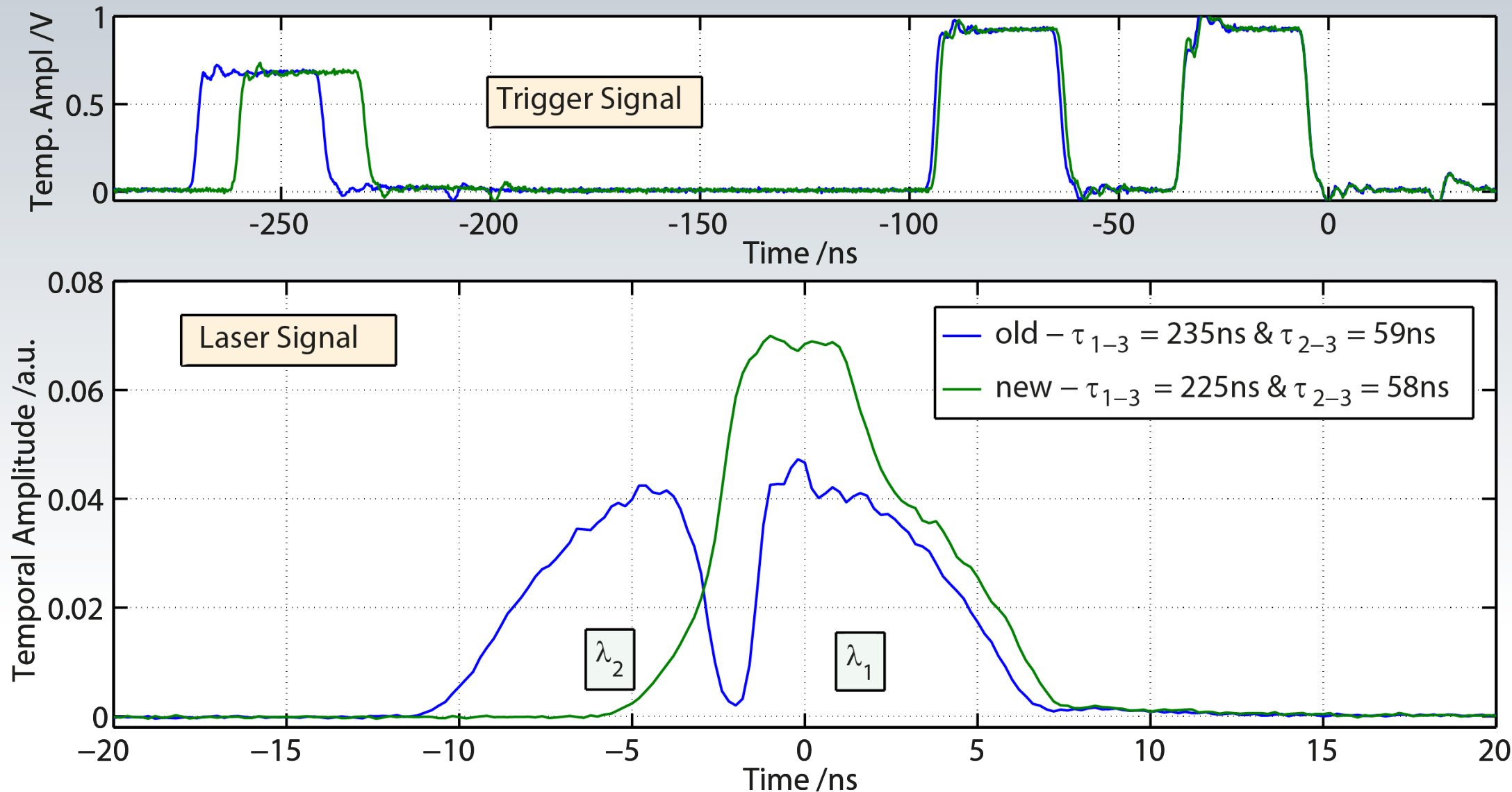
Demonstration of Dual-Wavelength Emission

Tunable dual-wavelength mode works!



- Fine adjustment of gating parameters selects wavelengths and balances amplitudes

Dual-Wavelength Pulses fully synchronized?



- Fine tuning of gate position changes temporal overlap of split up pulses
- Measure for Single-Pulse synchronicity is required

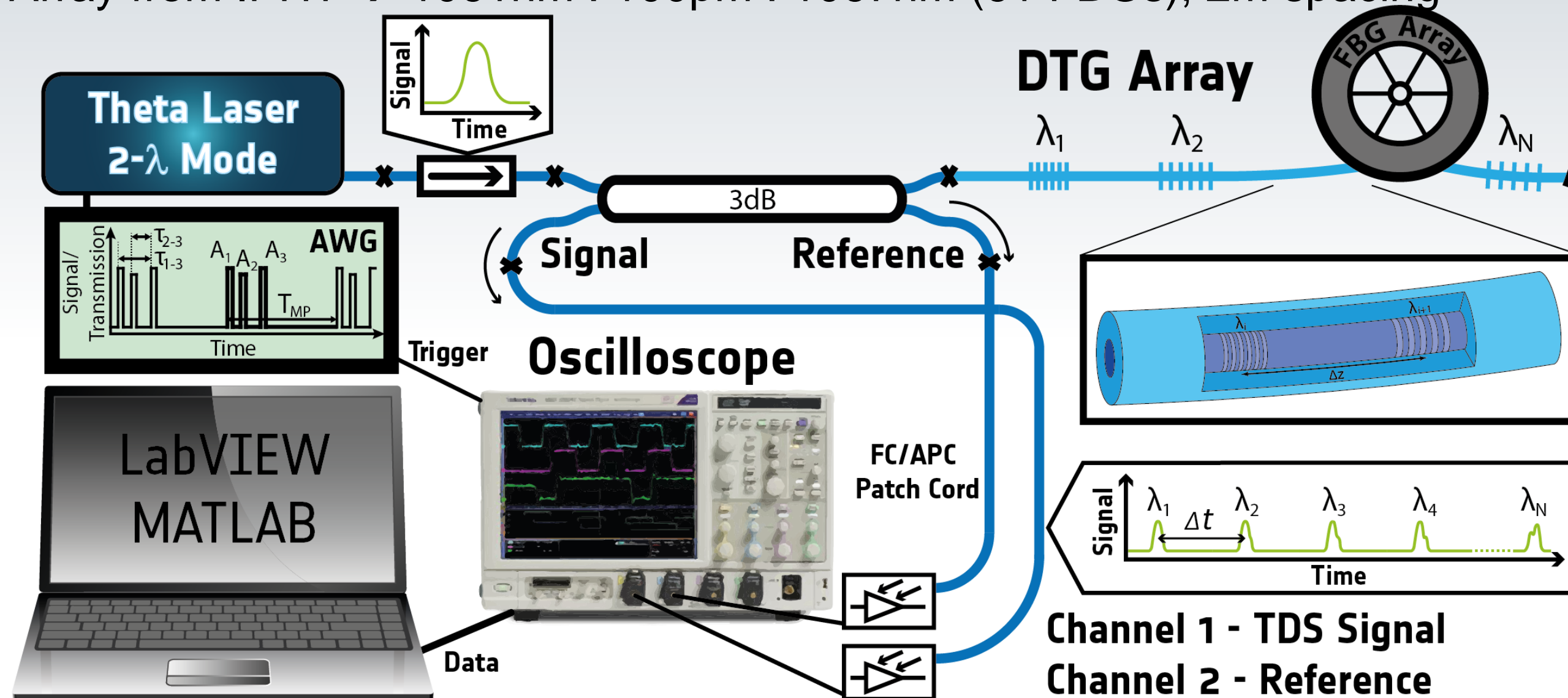
→ **Time-Delay Spectrometer** [Tiess et al., Applied Optics 52/6, 1161-1167 (2013)]

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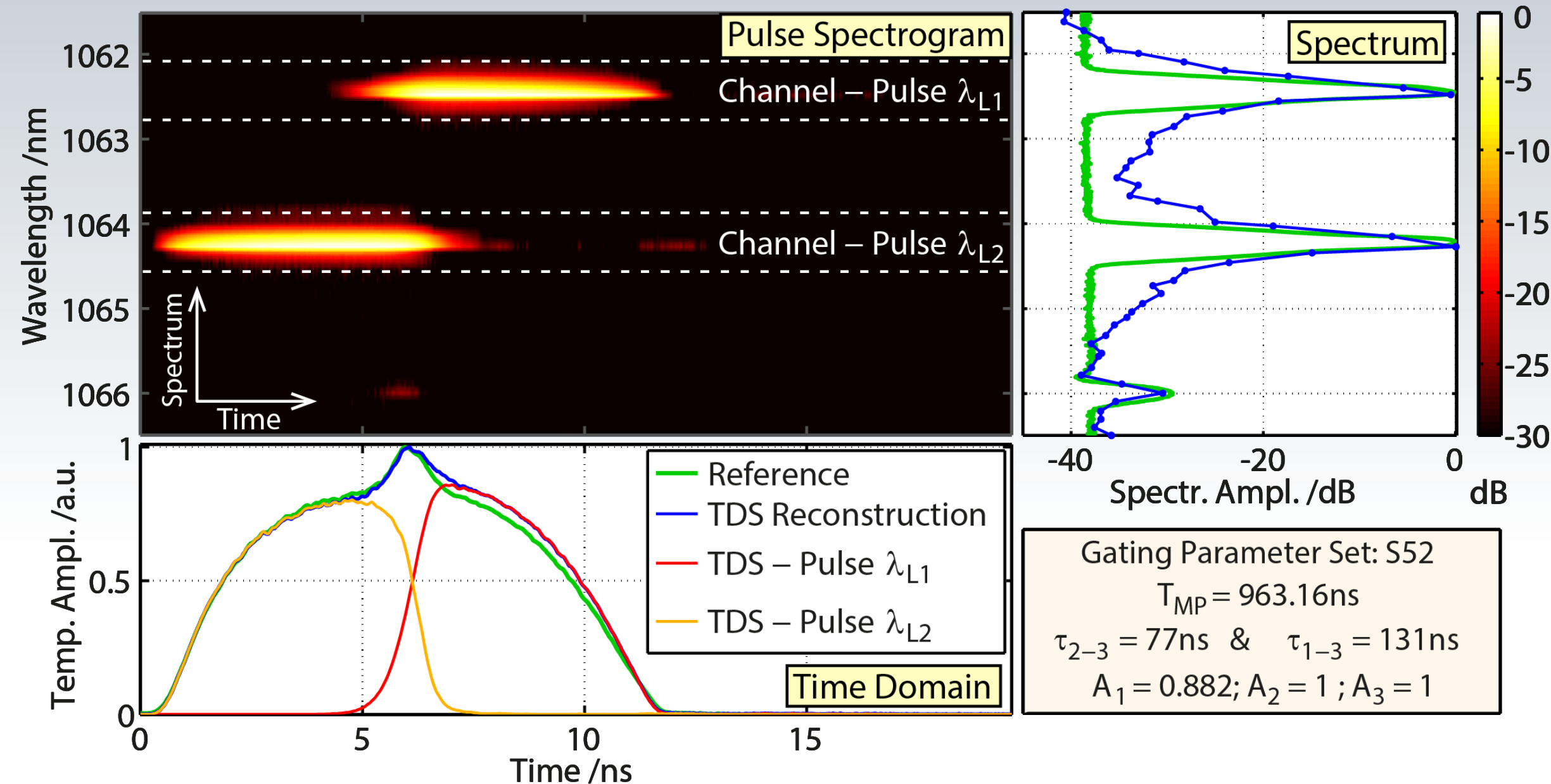
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Time-Delay Spectrometer (TDS)

- **TDS:** enables single-pulse analysis in time and spectral domain and their relation
- Idea: transfers spectral information in time-encoded signal (nanosecond scale)
- DTG Array from IPHT → 1061nm : 100pm : 1067nm (61 FBGs), 2m spacing



Analysis of Dual-Wavelength Emission with TDS

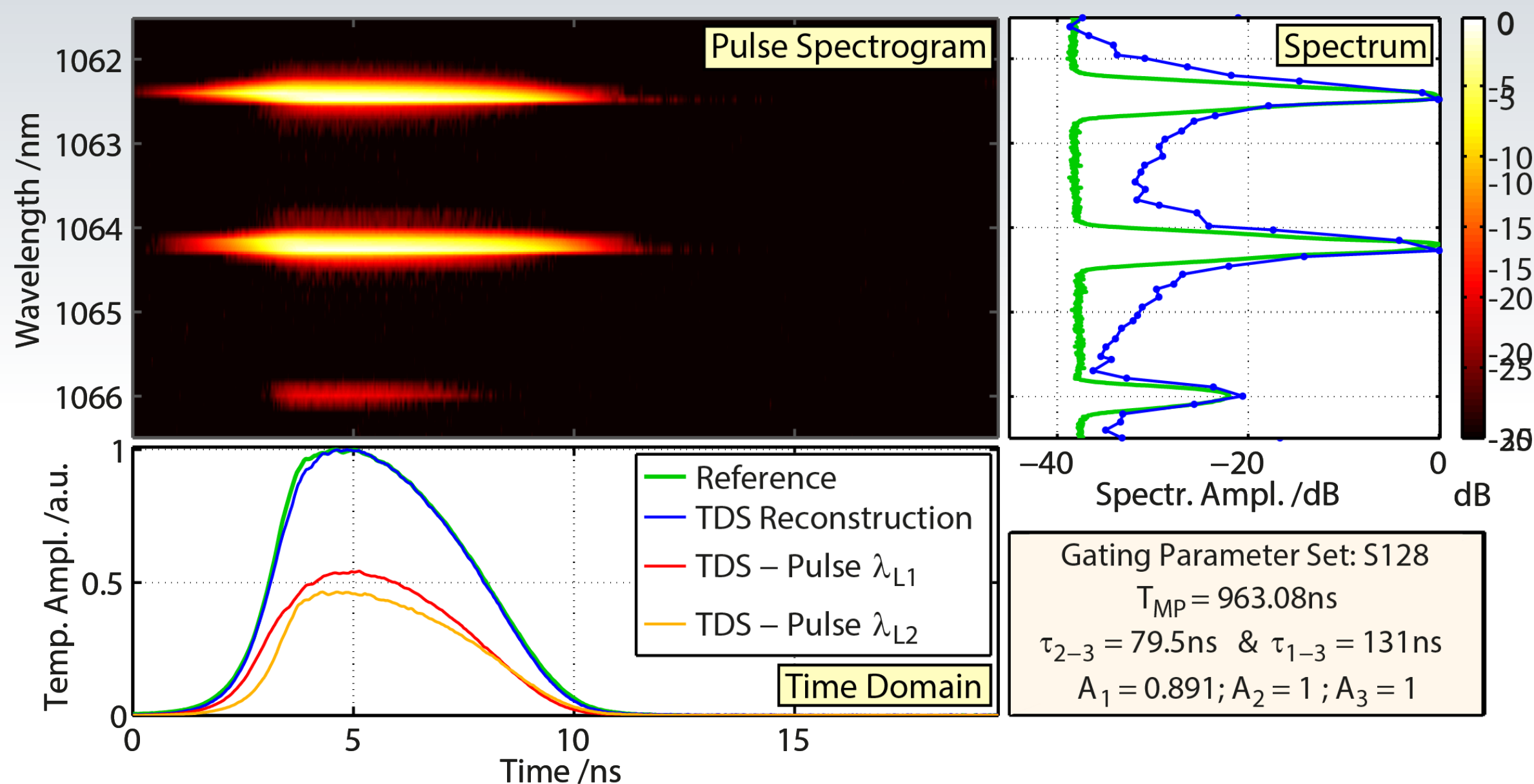


- **Spectral** reconstruction (integrating along the lines match OSA!)
✓ Spectral domain verified
- **Temporal** reconstruction (integrating along columns) match OSCI reference!
✓ Temporal domain verified

- ✓ TDS reconstruction verified
- ✓ Wavelength Channels can be investigated individually

Synchronicity of Dual-Wavelength pulses

- Adapted electrical gating parameters enable fully synchronized emission
- Single Pulse spectra confirm dual-wavelength emission (and even FWM)

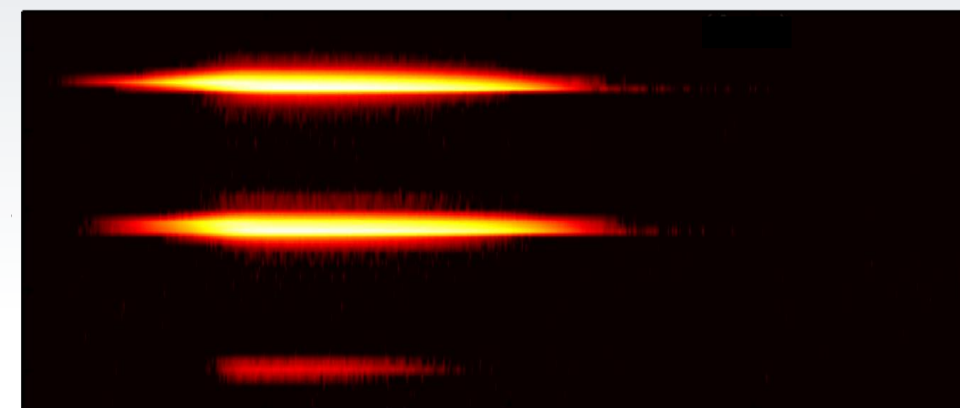
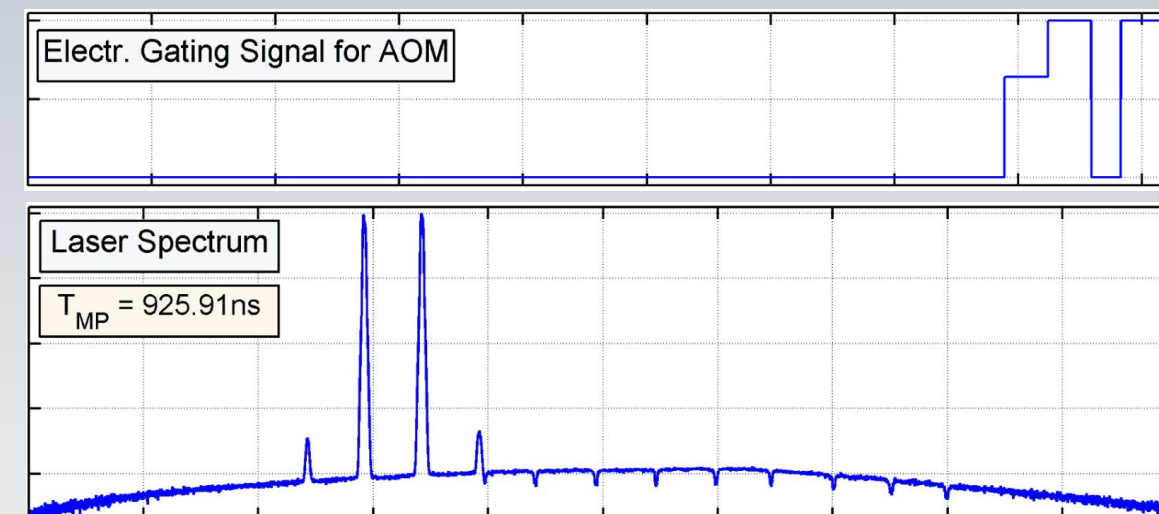


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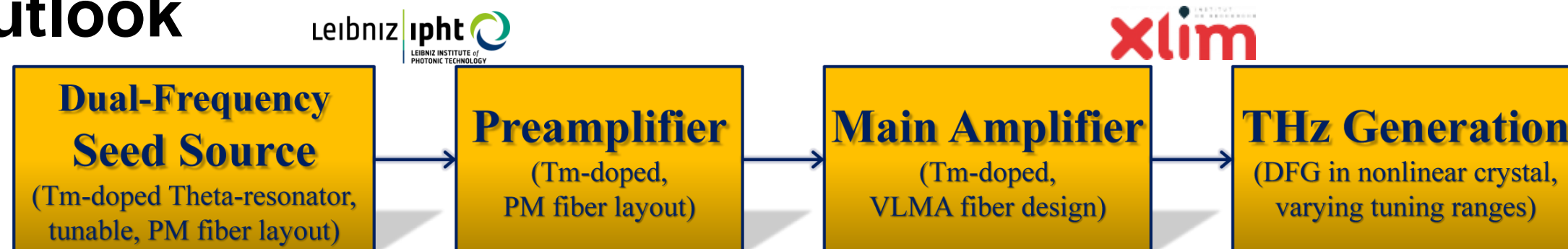
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Conclusions

- **Tunable dual-wavelength emission mode**
 - Electrical driving signal switches between single wavelength and dual-wavelength emission
 - Independently tunable dual-wavelength emission demonstrated @ 1 μm with single oscillator
- **Analysis of pulse synchronicity with TDS**
 - Optimized gating parameters ensured synchronized & tunable dual-wavelength emission
 - Measurement of single-pulse spectra



Outlook



DFG
Agence Nationale de la Recherche
ANR

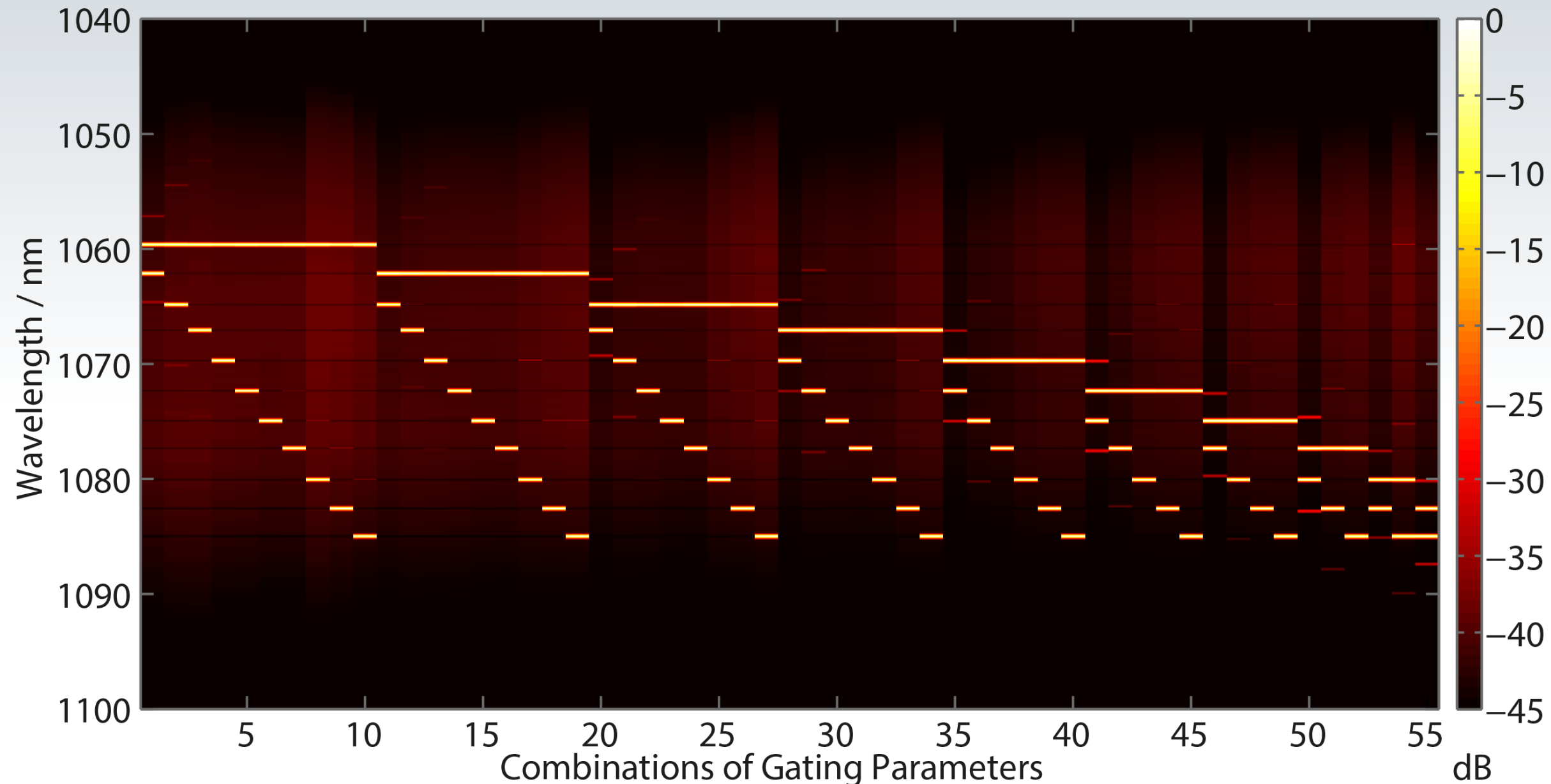
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Financial support from the Federal Ministry of Education and Research (BMBF) - Project "FlexTune" (FKZ: 13N13865) - is gratefully acknowledged!

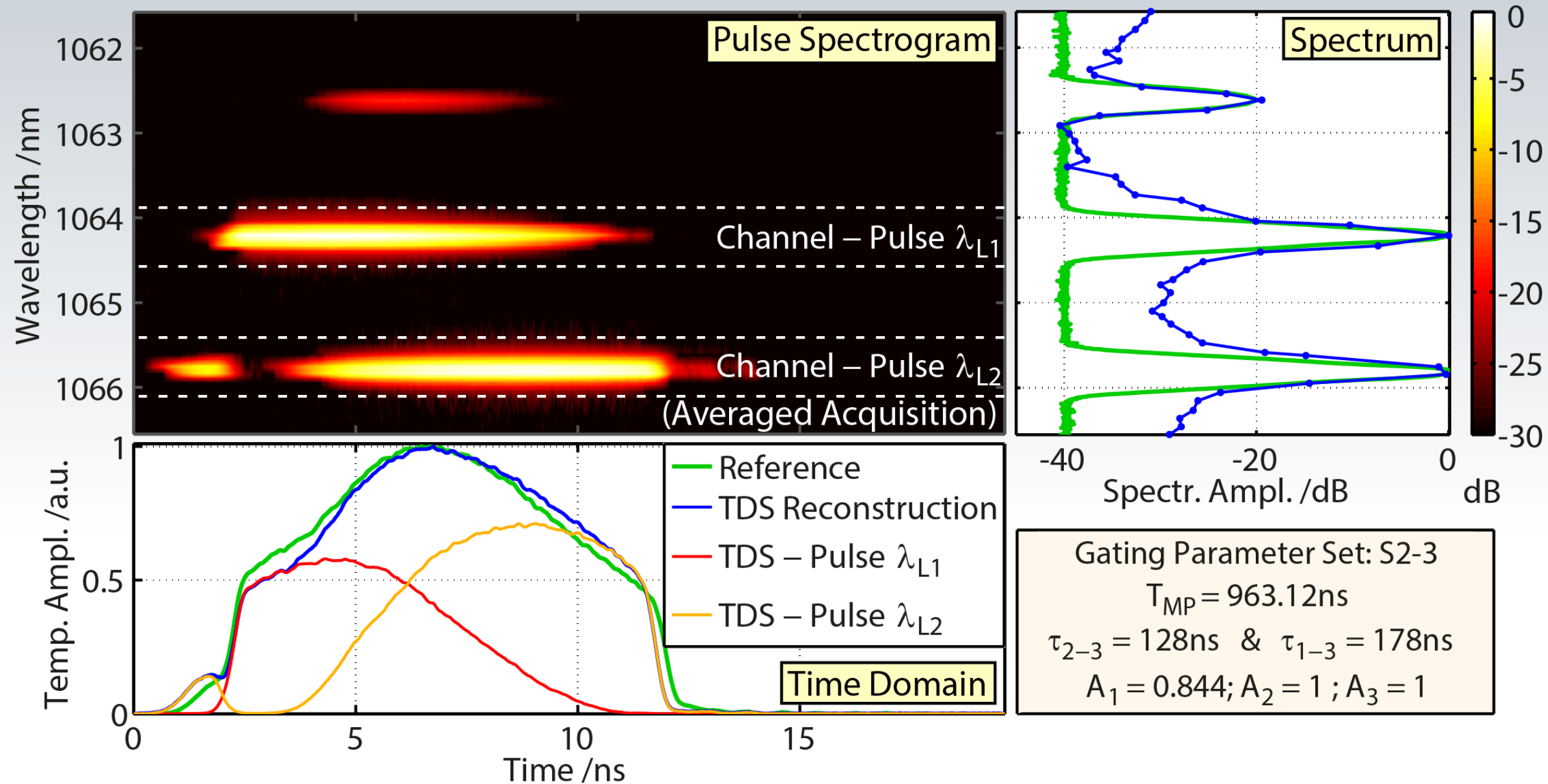
Thanks a lot for
your attention
Questions???

Tuning Range of Dual-Wavelength Mode

- **55 Wavelength pairs** over a **tuning range of 25nm**
- High contrast, narrow linewidths, but small parasitic peaks and FWM



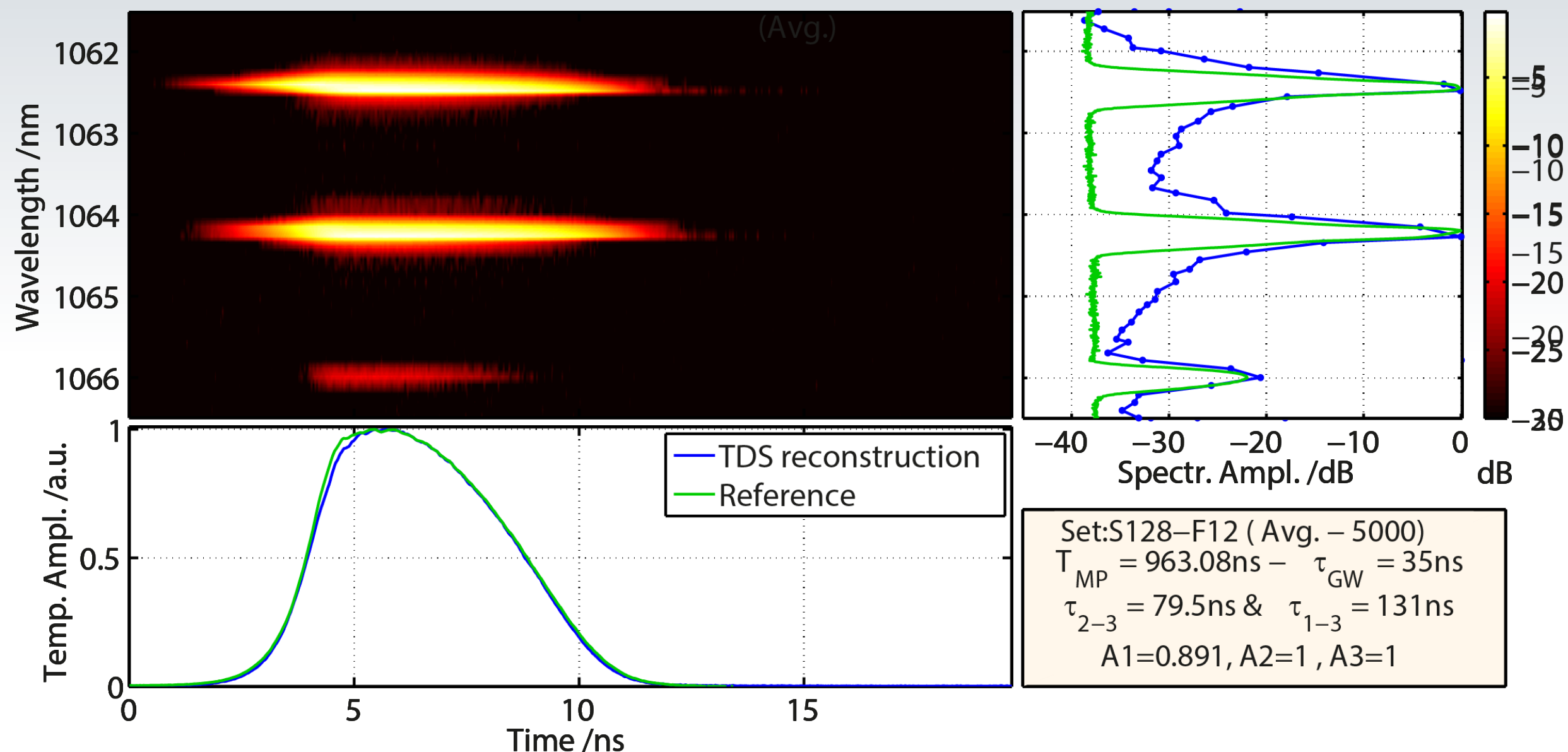
Synchronicity of Dual-Wavelength pulses



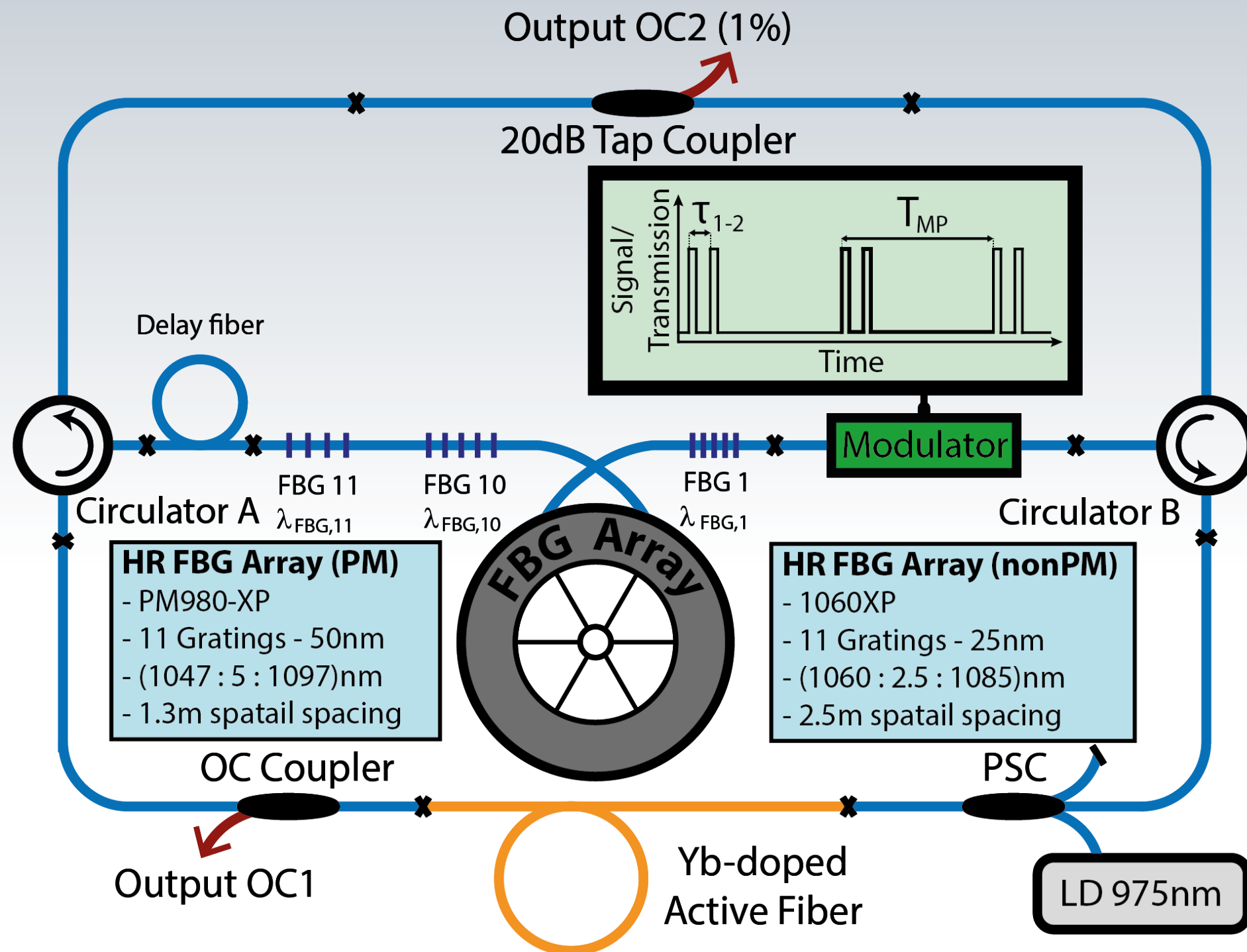
- No full pulse overlap due to split up prepulse

Synchronicity of Dual-Wavelength pulses

- Adapted electrical gating parameters enable fully synchronized emission
- Single Pulse spectra confirm dual-wavelength emission (and even FWM)



Experimental Setups



- Fiber-integrated setup based on commercial fiber components
- Modulator: AOM with rise time of 25ns (non-PM) and 6ns (PM)
- 2 OC Ports (**High Power OC1** port and optional **Low-ASE OC2** port)
- PM and non-PM setup with different HR FBG arrays

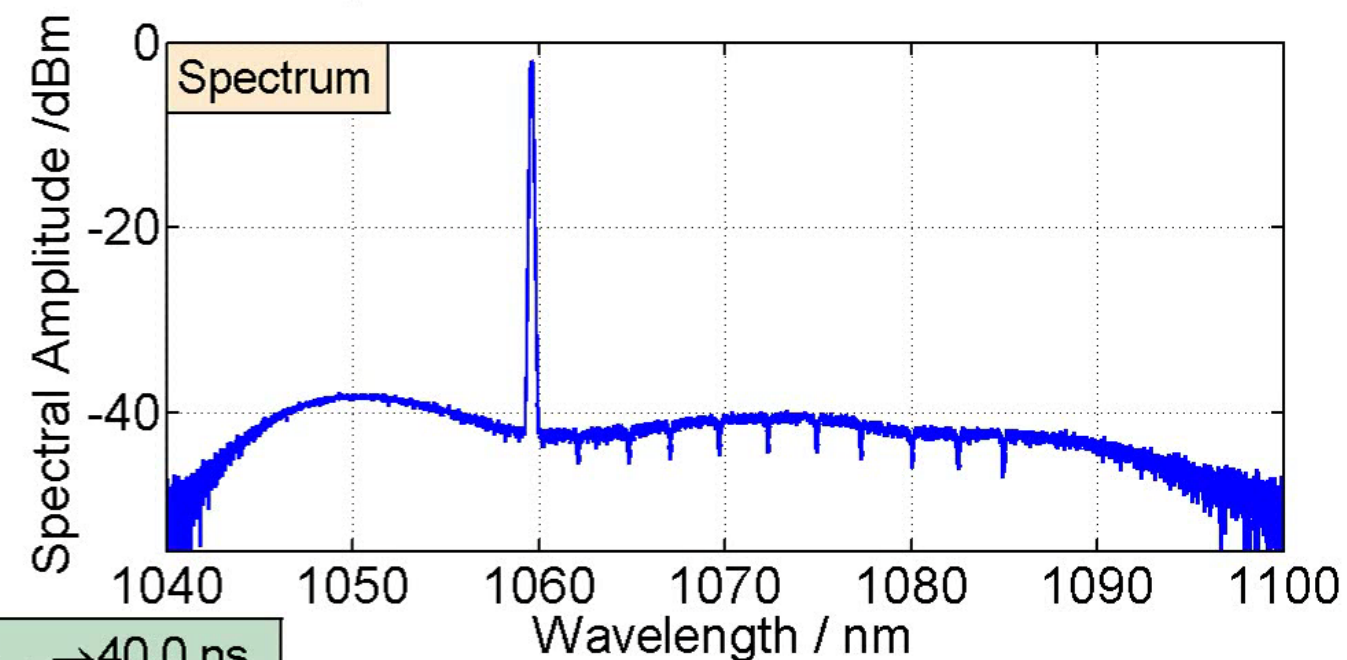
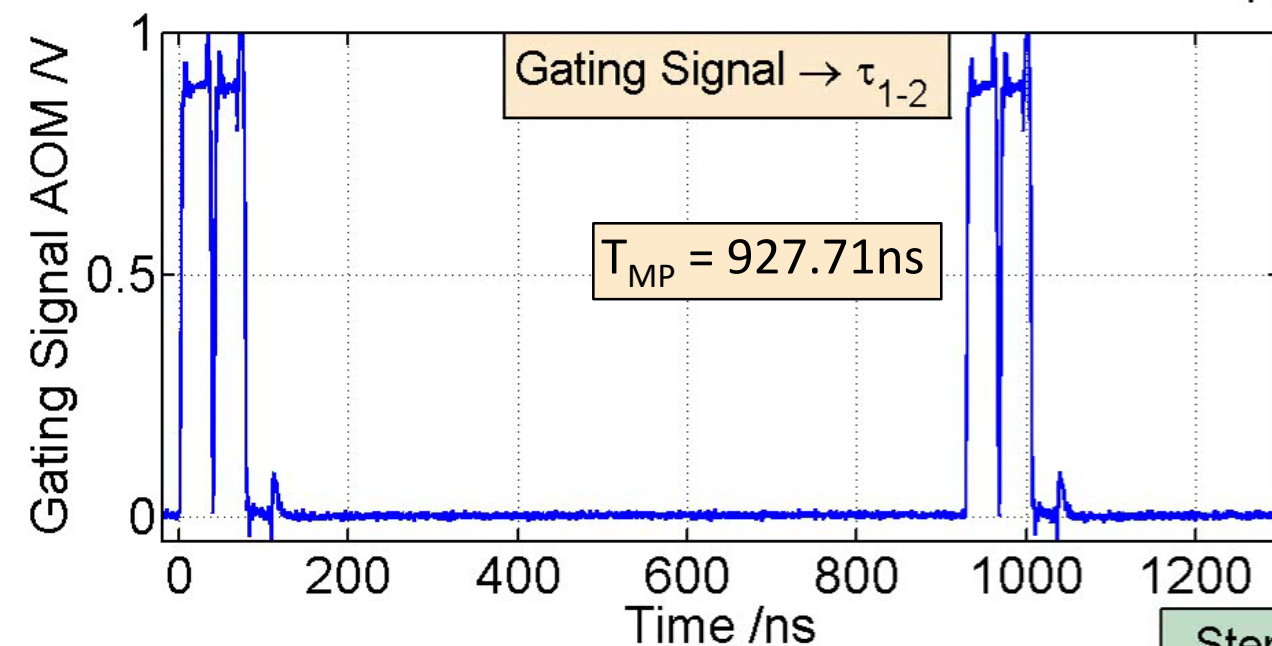
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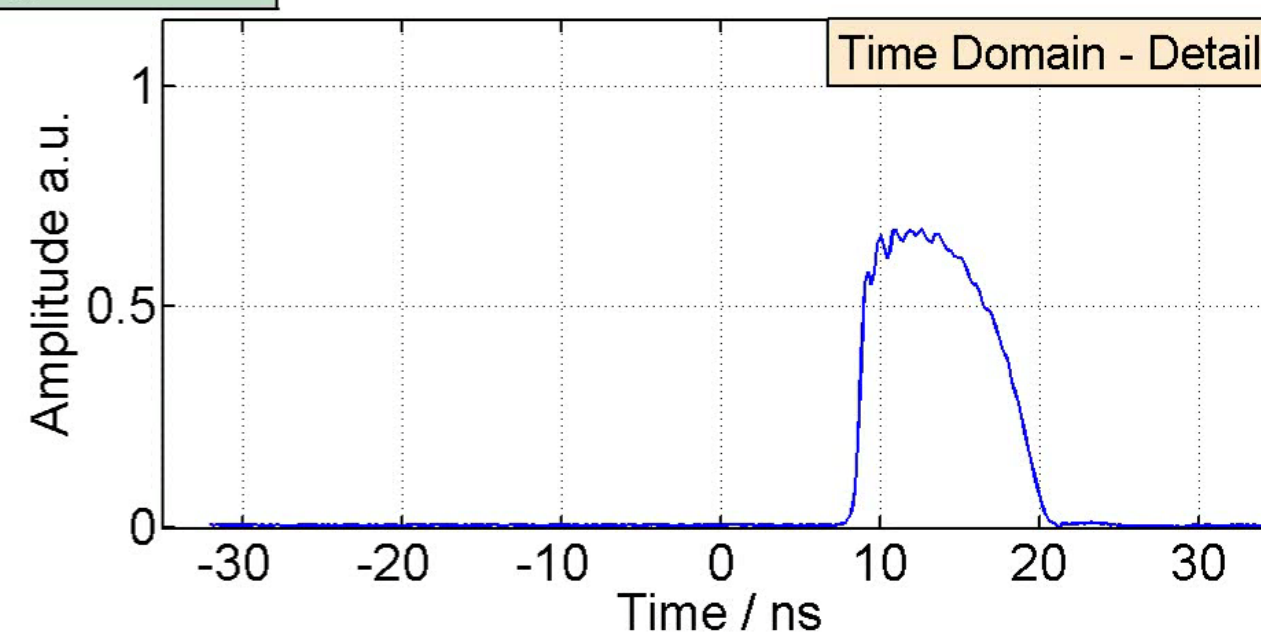
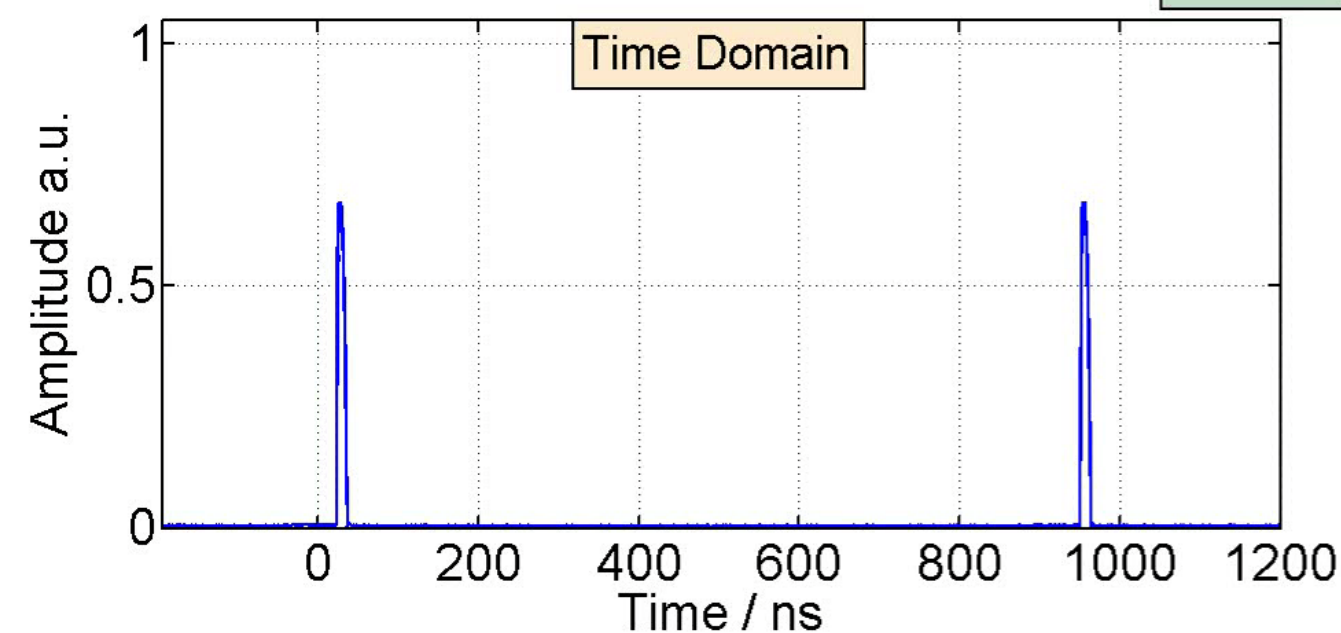
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Proof of Principle

Scan of Tuning Parameter τ_{1-2} in tunable Yb-doped Theta Fiber Laser

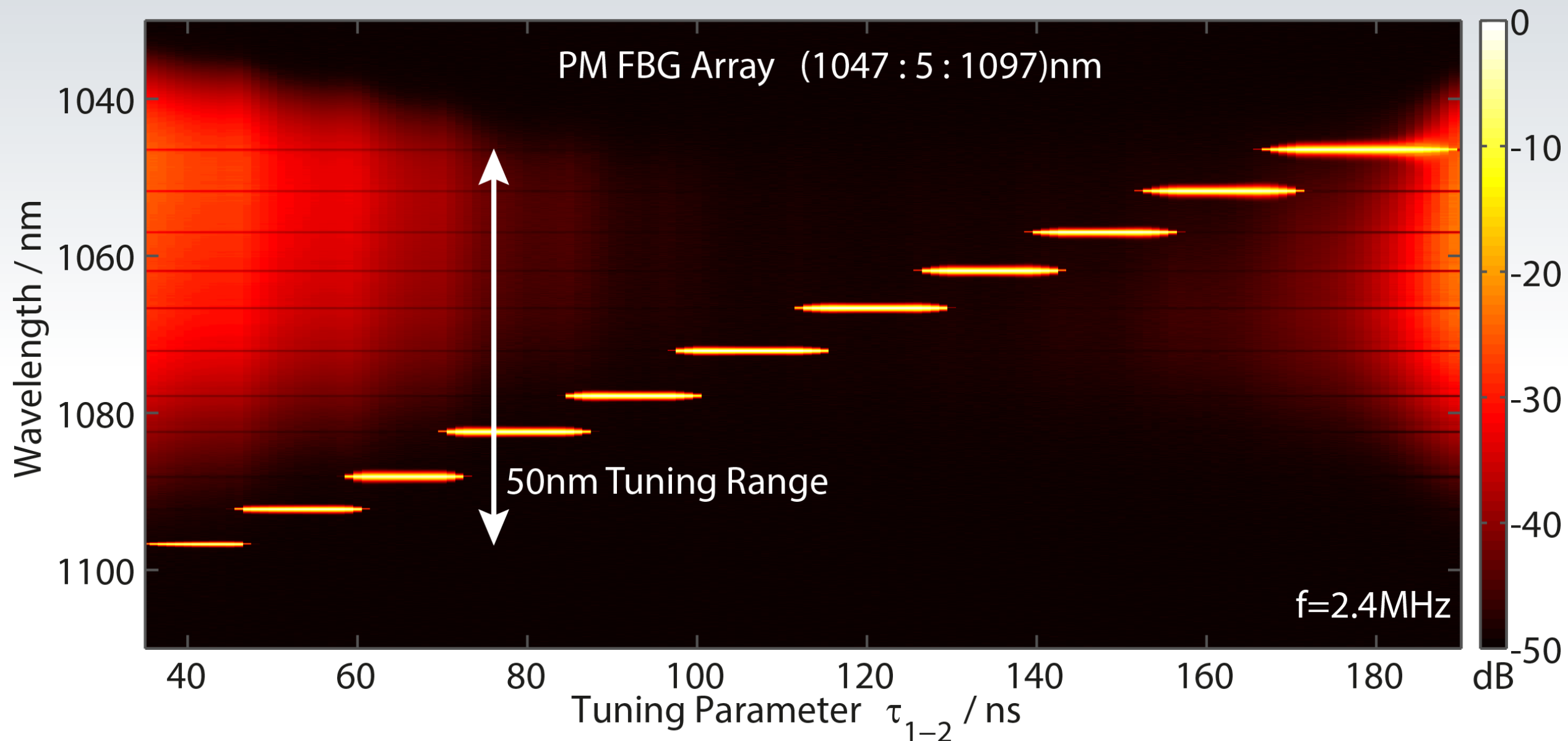


Step: $\tau_{1-2} \rightarrow 40.0 \text{ ns}$



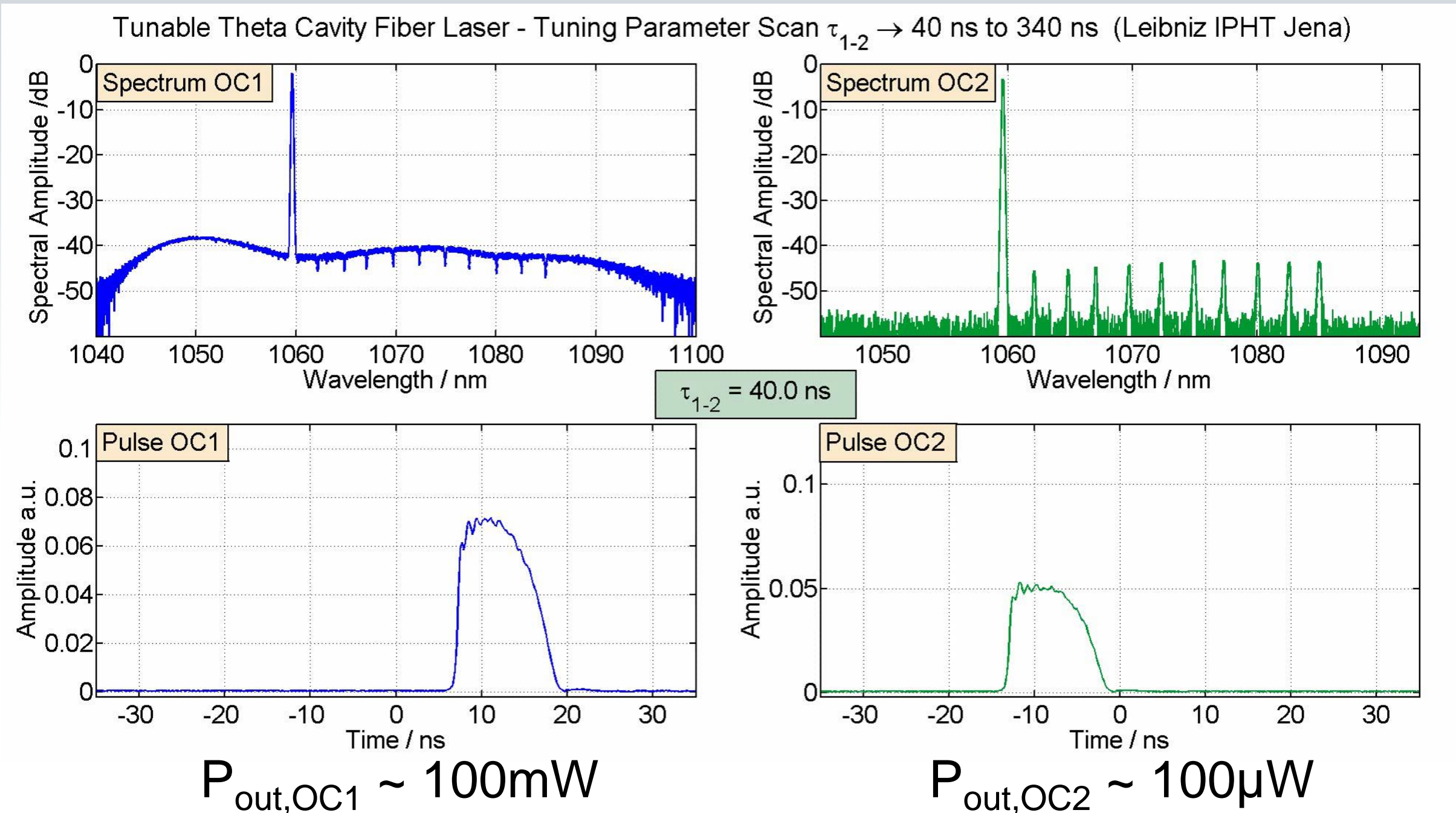
Maximum Tuning Range

- In PM setup: tuning range of **50nm** (limited by FBG Array)
- Tailored filter designs enable customized tuning ranges



Pulse Evolution in Resonator

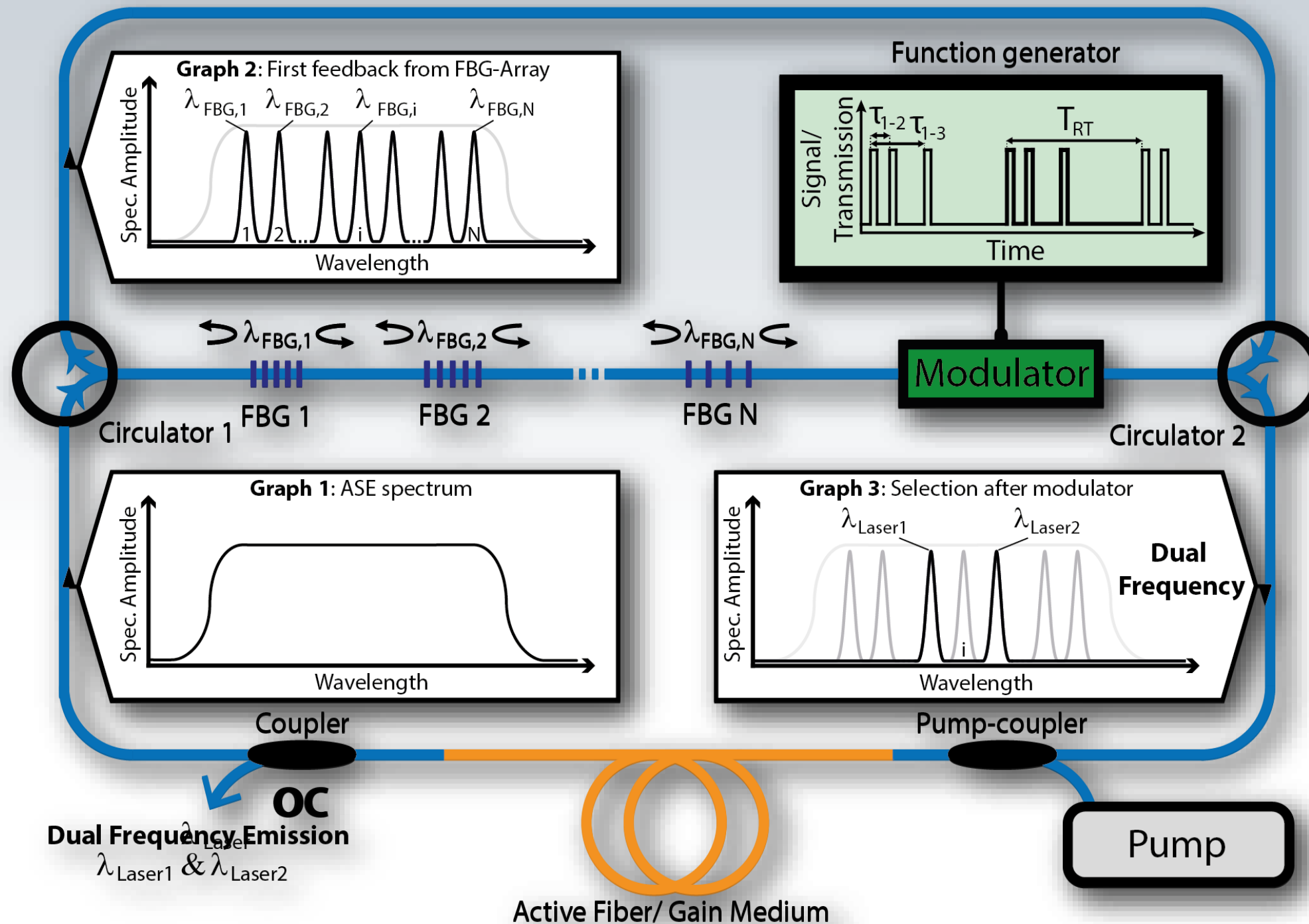
OC1: high output power - OC2: high spectral purity



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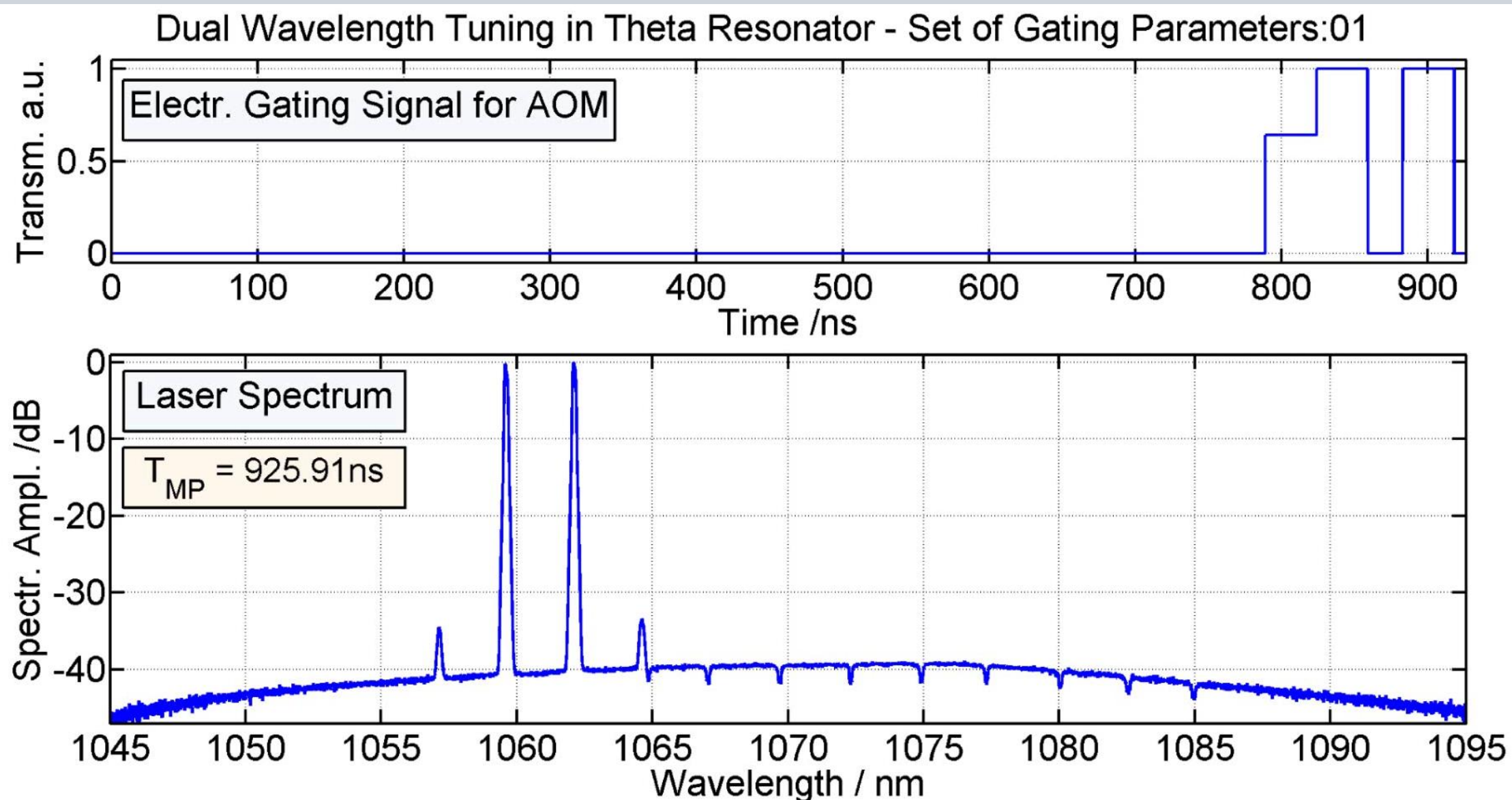
Multi Wavelength Operation



- **Target:** generate multiple synchronous emission wavelengths
- **Idea:** 3 transmission windows at AOM promote two feedback wavelengths for lasing
- **Result:** two independently tunable and synchronized wavelengths in one oscillator
- **Electrical remote control**

Demonstration of Dual-Wavelength Emission

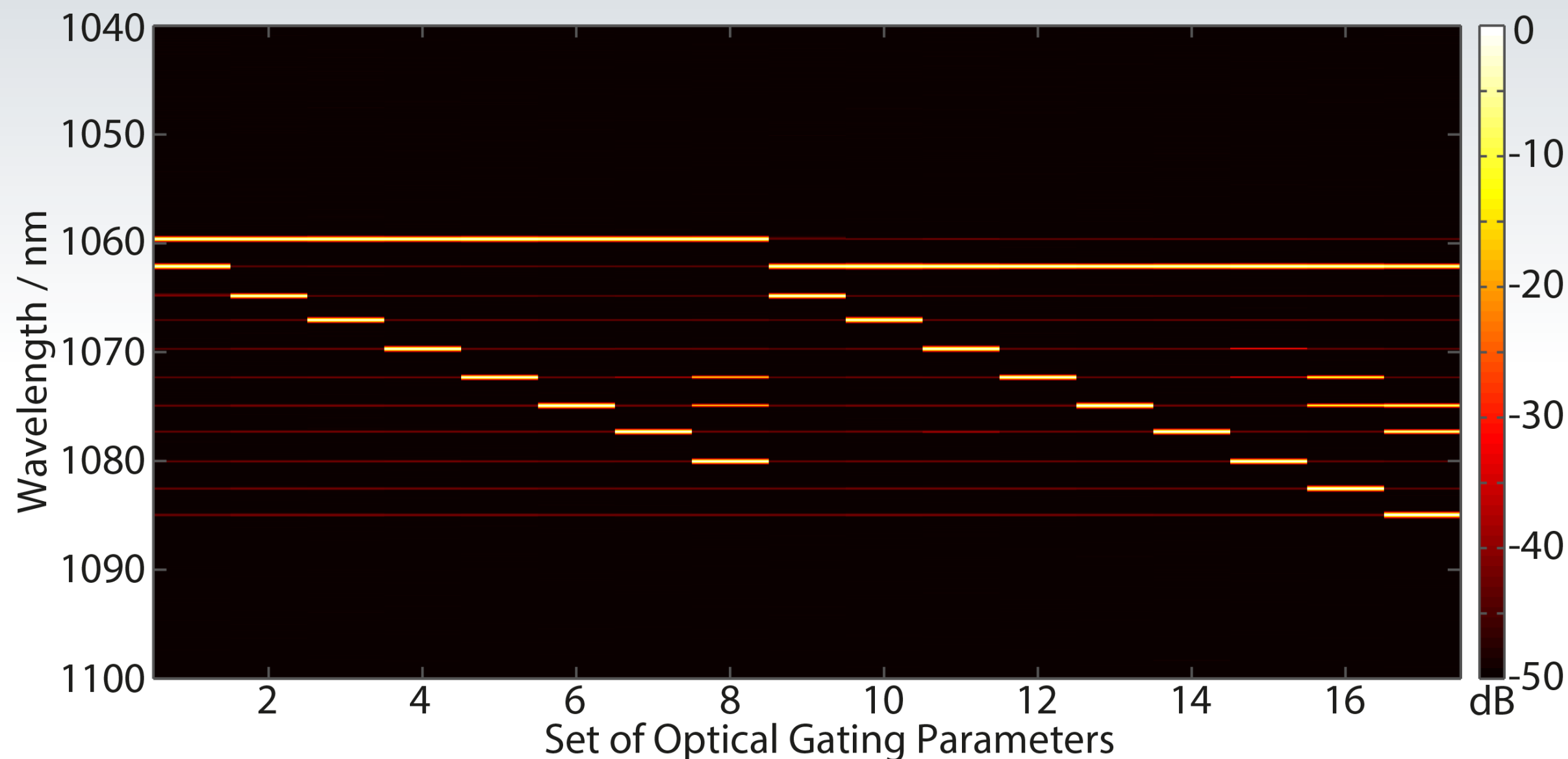
Independently tunable dual-wavelength ($2-\lambda$) mode works!



- Fine adjustment of gating parameters selects wavelengths and balances amplitudes
- Demonstration of all **55 Wavelength pairs** (11 FBGs) over a **tuning range of 25nm**

Dual-Wavelength Mode at OC2

- Similar features as before (no FWM visible)
- Different OC position of OC2 enables better signal contrast

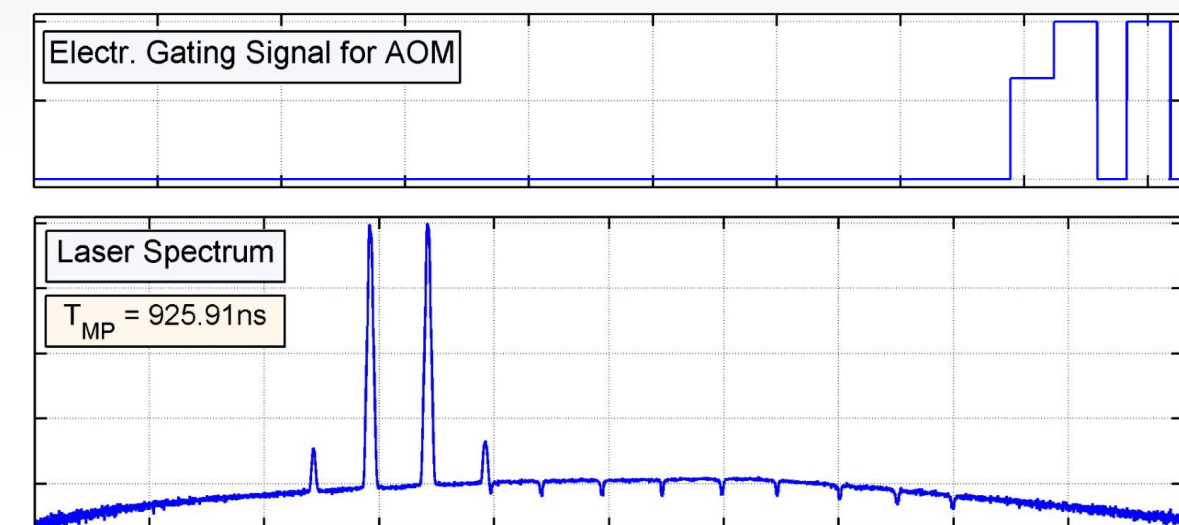
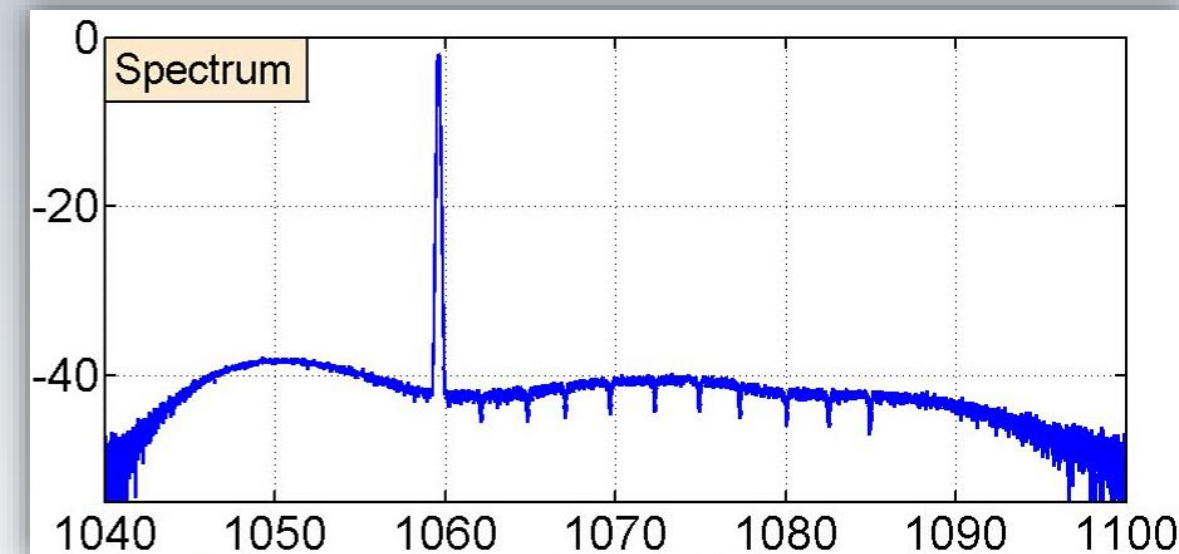


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Conclusions

- **Tuning in theta cavity fiber laser and constant repetition rate works!**
 - Tuning range of 50nm @ 1 μ m
 - High signal contrast (40dB) & narrow linewidth (~150pm)
 - Stable pulse properties and tunable pulse duration
- **Tunable dual-wavelength emission mode realized**
 - Electrical driving signal switches between single wavelength and dual-wavelength emission
 - Independently tunable dual-wavelength emission demonstrated @ 1 μ m with single oscillator



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