

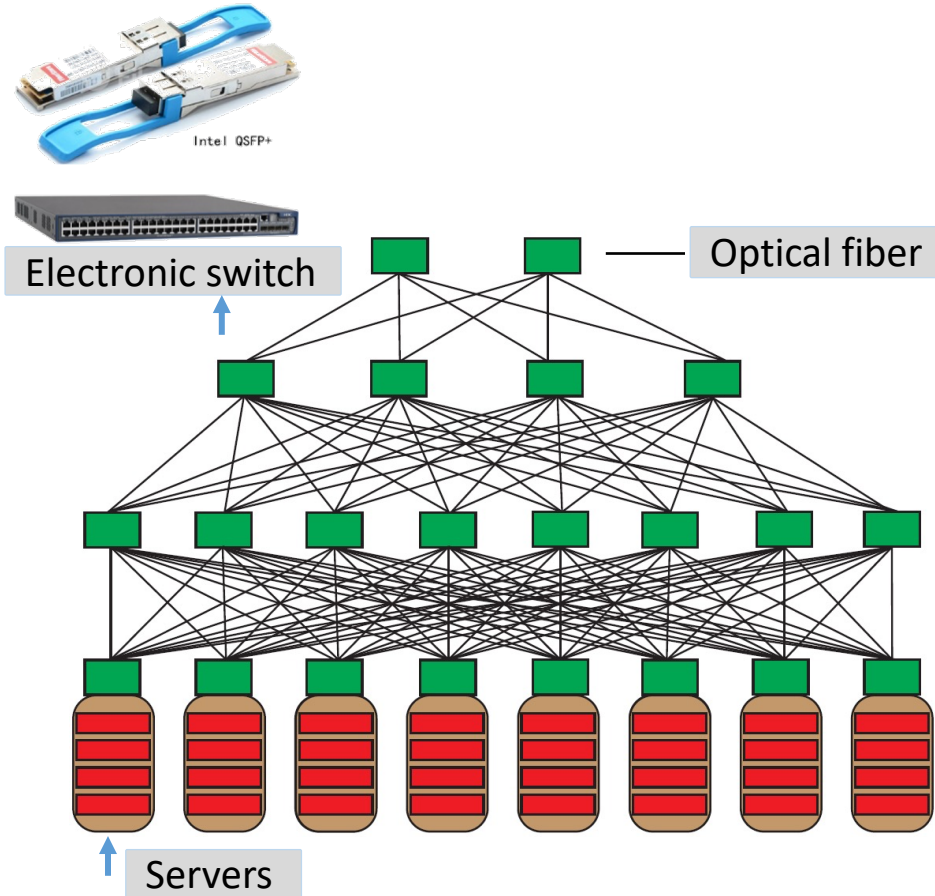
# Photonic Integrated Multi-Wavelength Sources for Data Centers

Arslan Sajid Raja

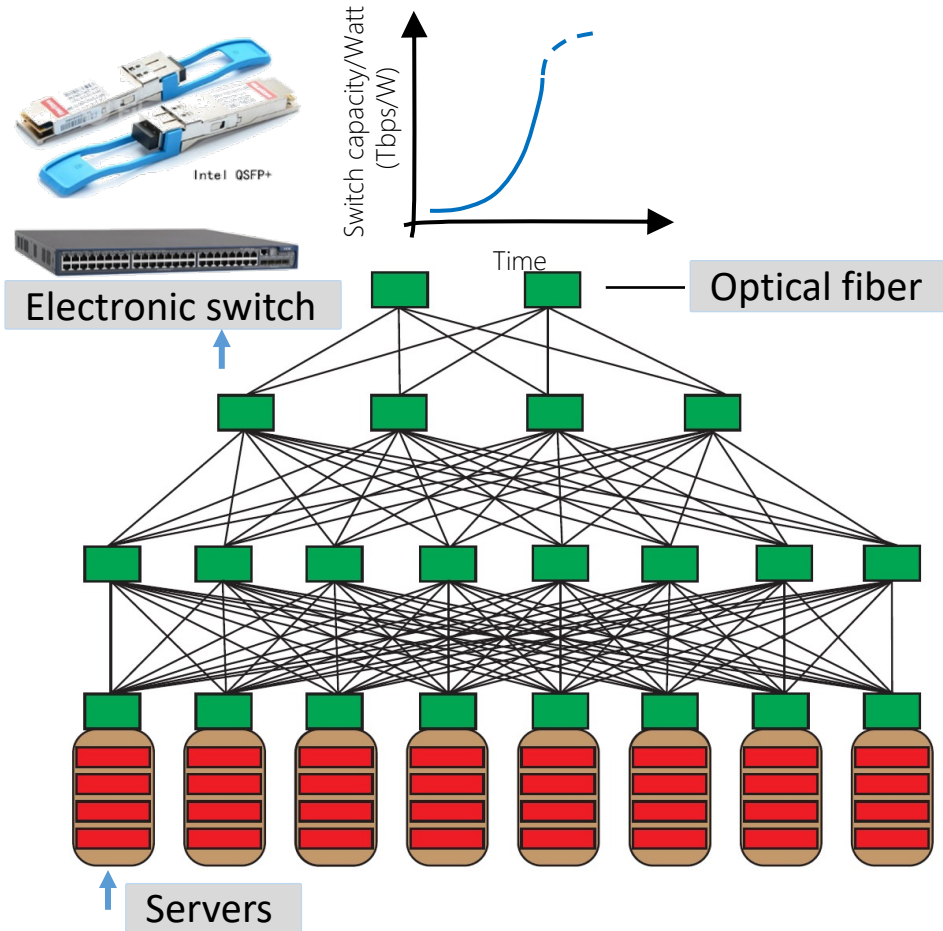
Laboratory of Photonics and Quantum Measurements, EPFL



# Need for optical switching in data-center?

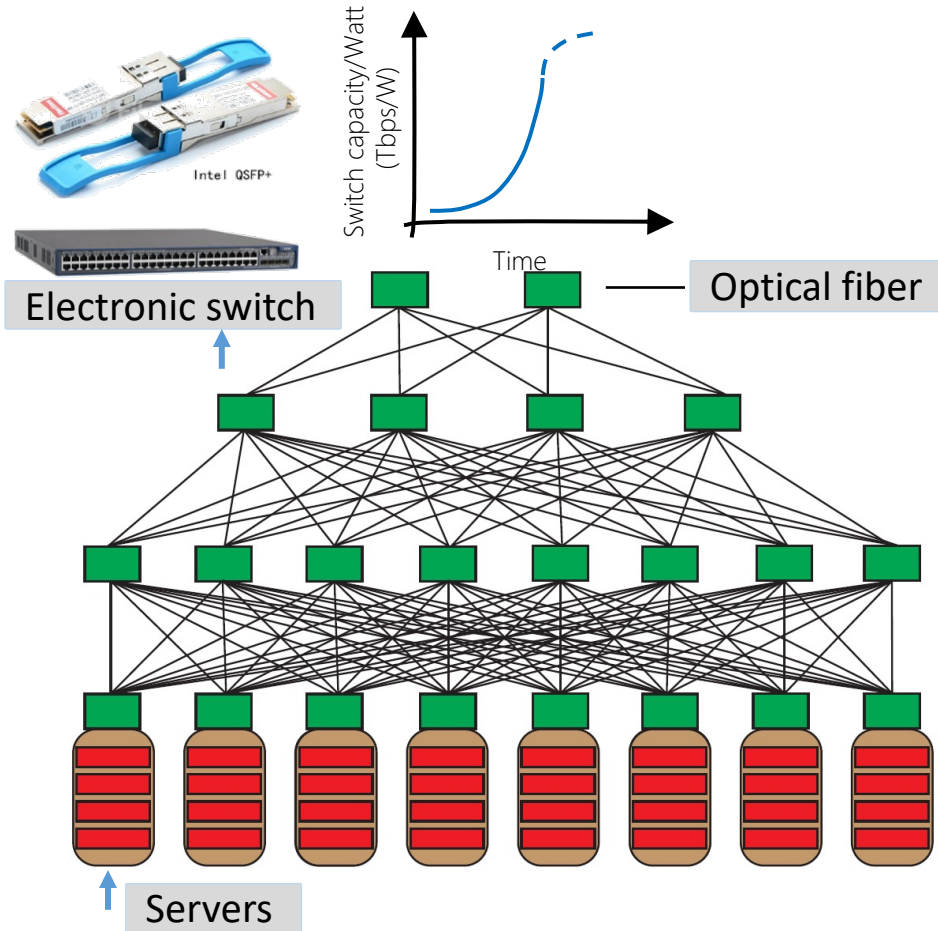


# Need for optical switching in data-center?



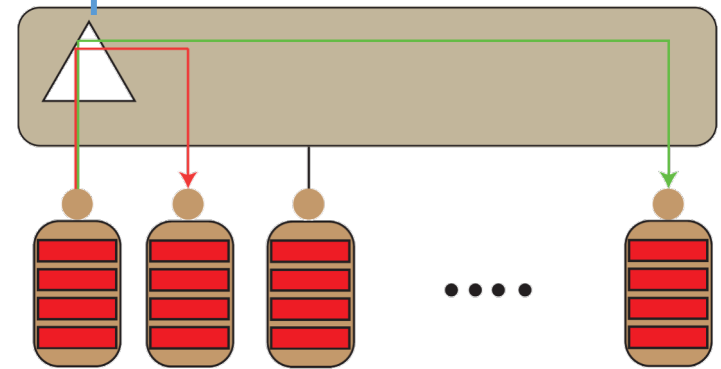
F. Testa and L. Pavesi, Opti. Switch. in Next Gener. DC(2018)  
 Hitesh Ballani, Paolo Costa et al., Sirius: A Flat Datacenter Network with Nanosecond Optical Switching. SIGCOMM '20

# Need for optical switching in data-center?



## Wavelength based circuit switching

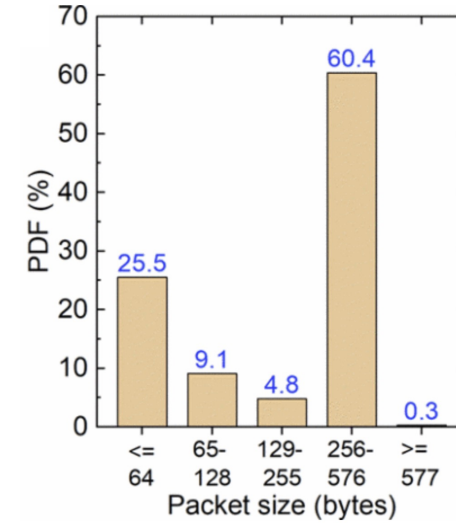
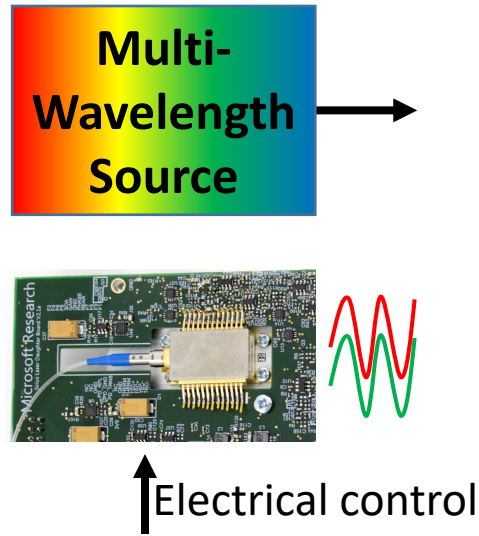
### Passive switching element



- Advantages**
- No O/E/O conversion
  - Better intra-server links
  - Port scalable
  - Chip-based
  - WDM (wavelength division multiplexing)

F. Testa and L. Pavesi, Opti. Switch. in Next Gener. DC(2018)  
 Hitesh Ballani, Paolo Costa et al., Sirius: A Flat Datacenter Network with Nanosecond Optical Switching. SIGCOMM '20

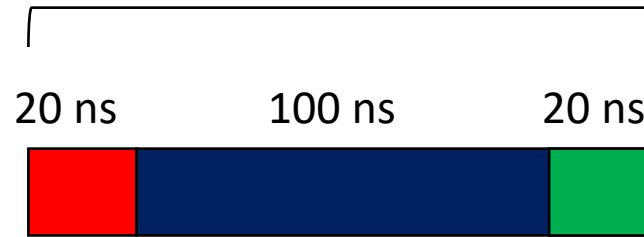
# Need for fast optical switching in data-center?



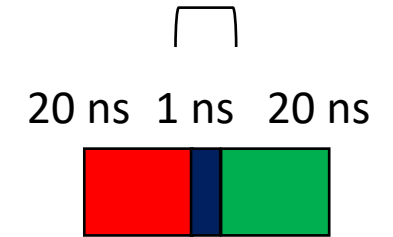
**Tunable laser**

- Lasing + switching via current control
- Switching time is 100 ns

Utilization < 17 %



Utilization > 90 %

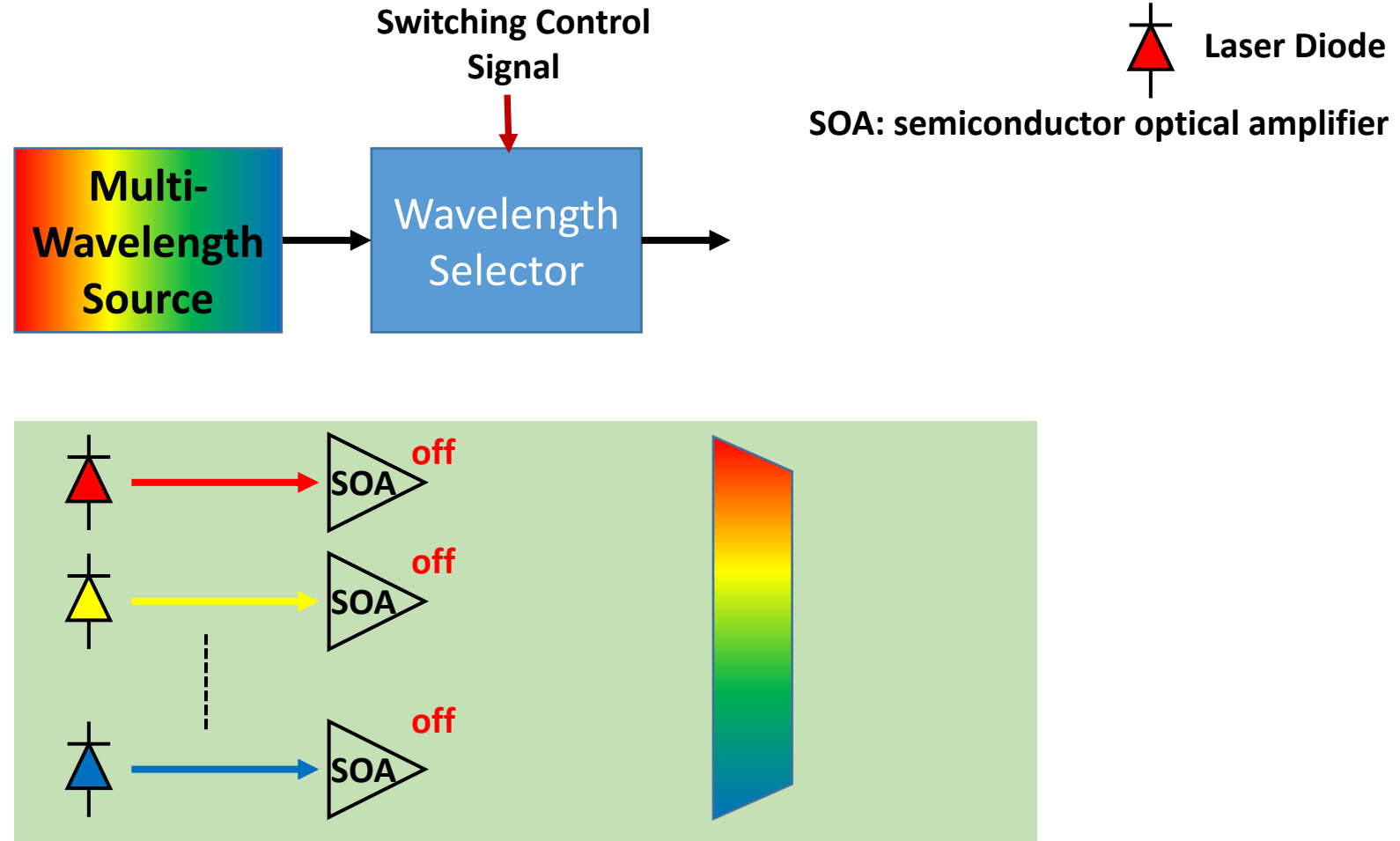


256-byte packet @ 100 Gbps

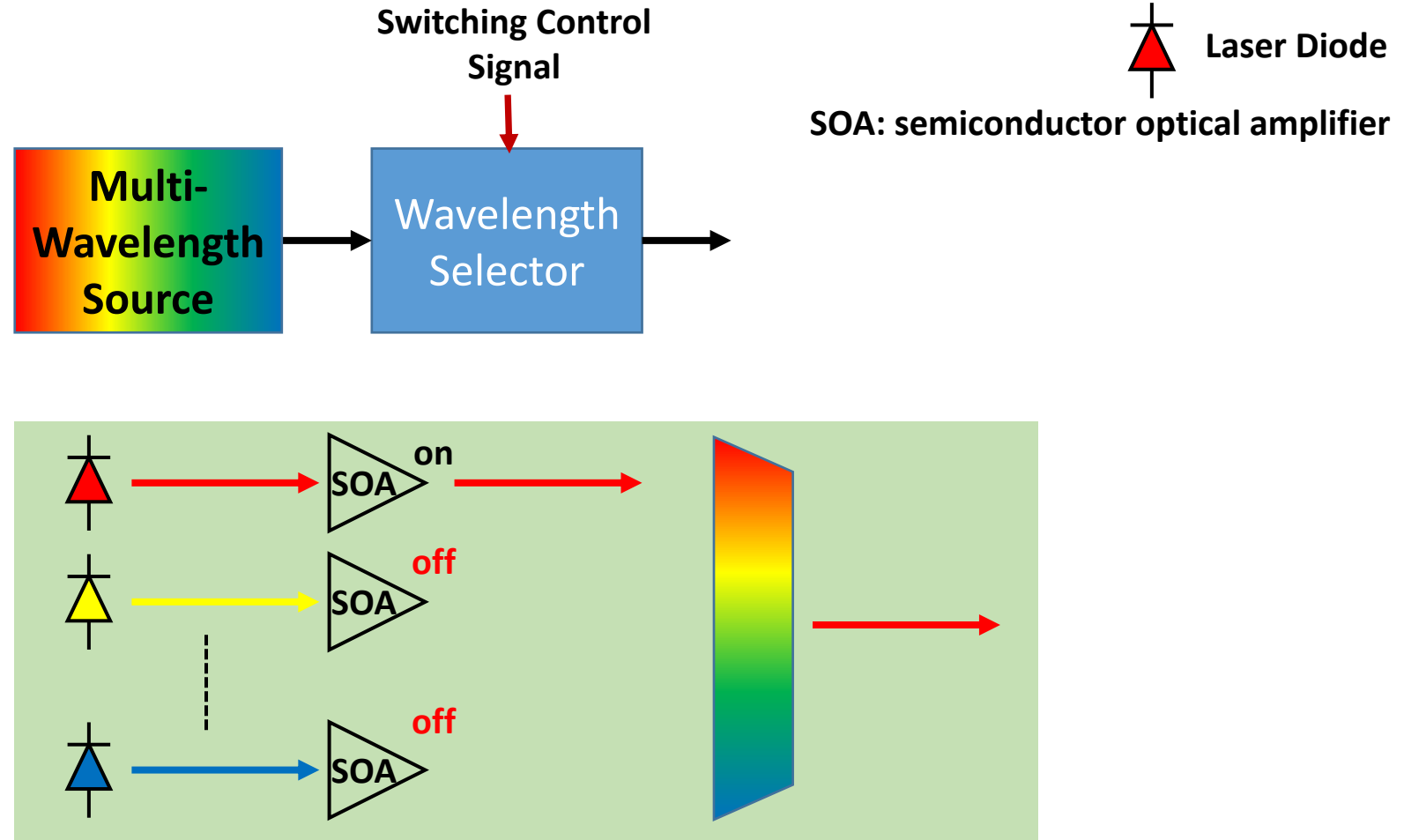
Switching wavelength

Switching wavelength

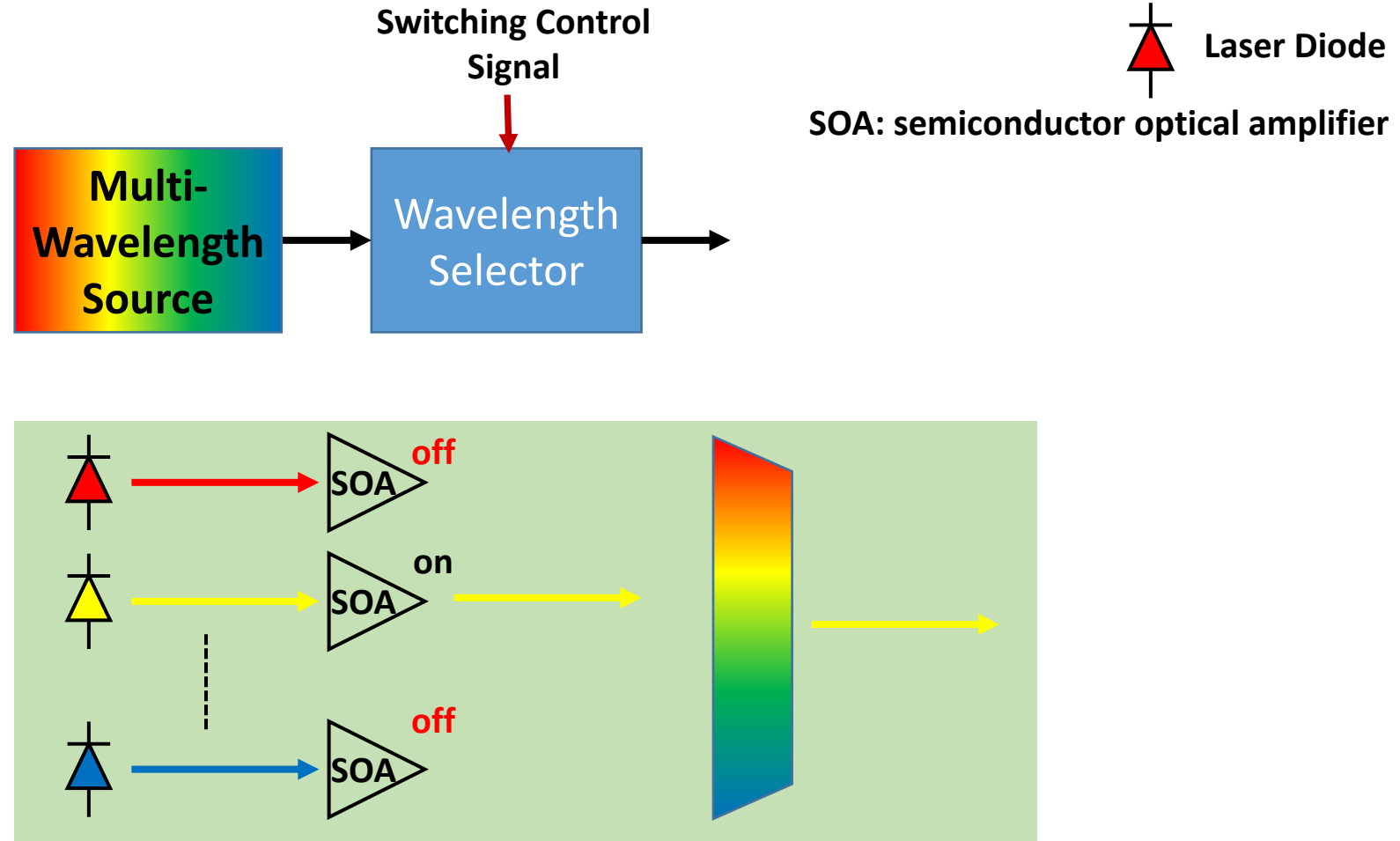
# Optical switching based on multi-wavelength source



# Optical switching based on multi-wavelength source

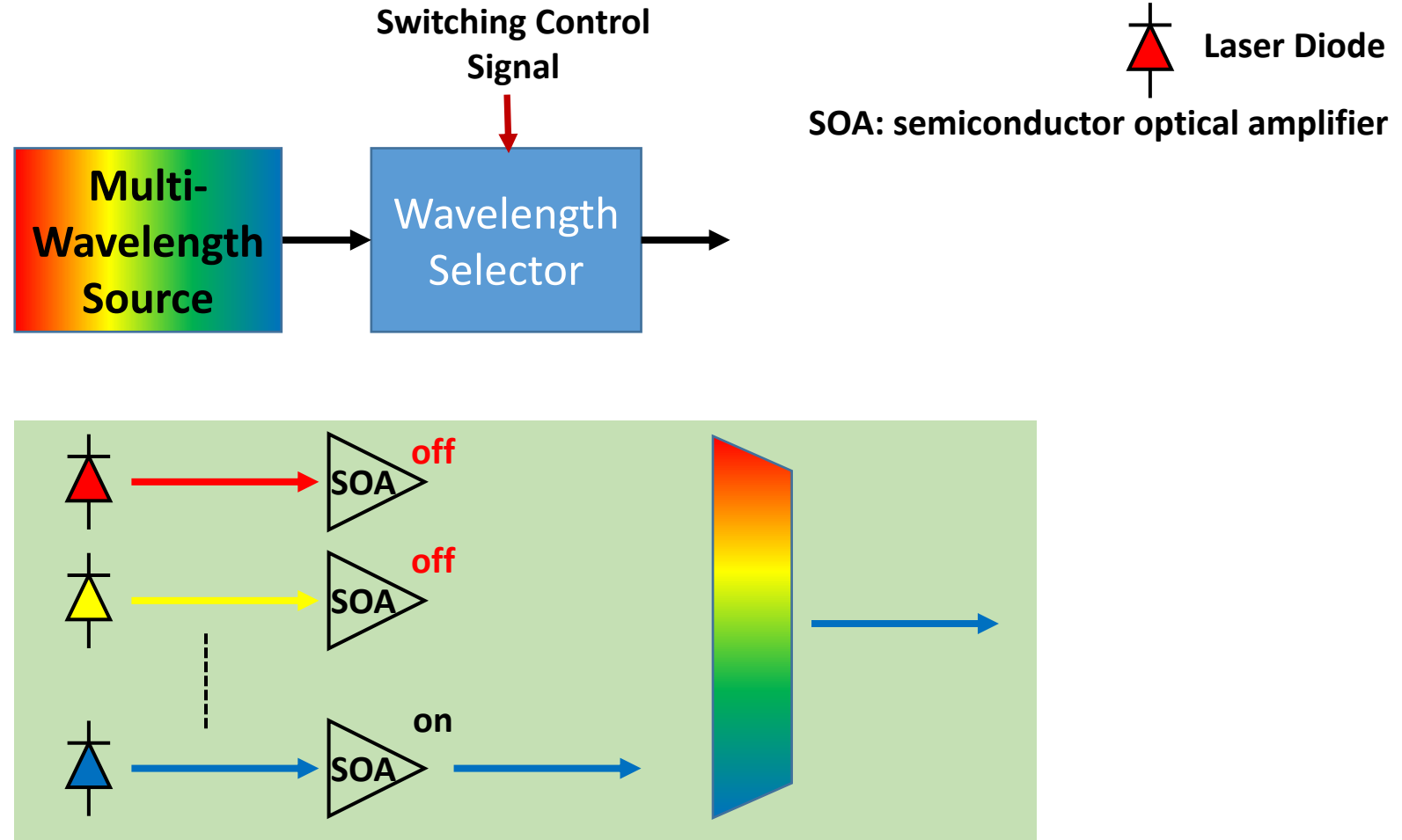


# Optical switching based on multi-wavelength source

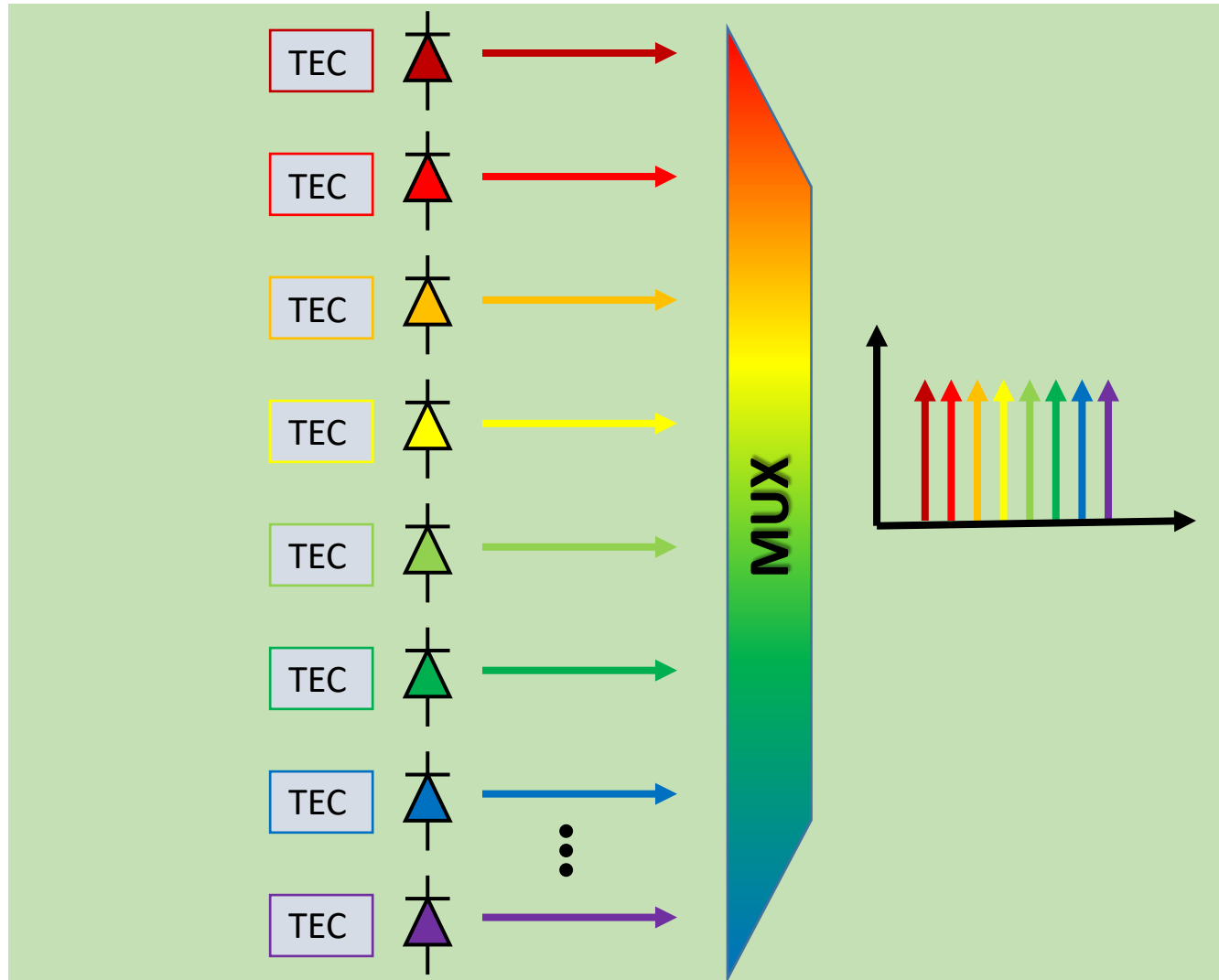




# Optical switching based on multi-wavelength source



# Wavelength division multiplexing



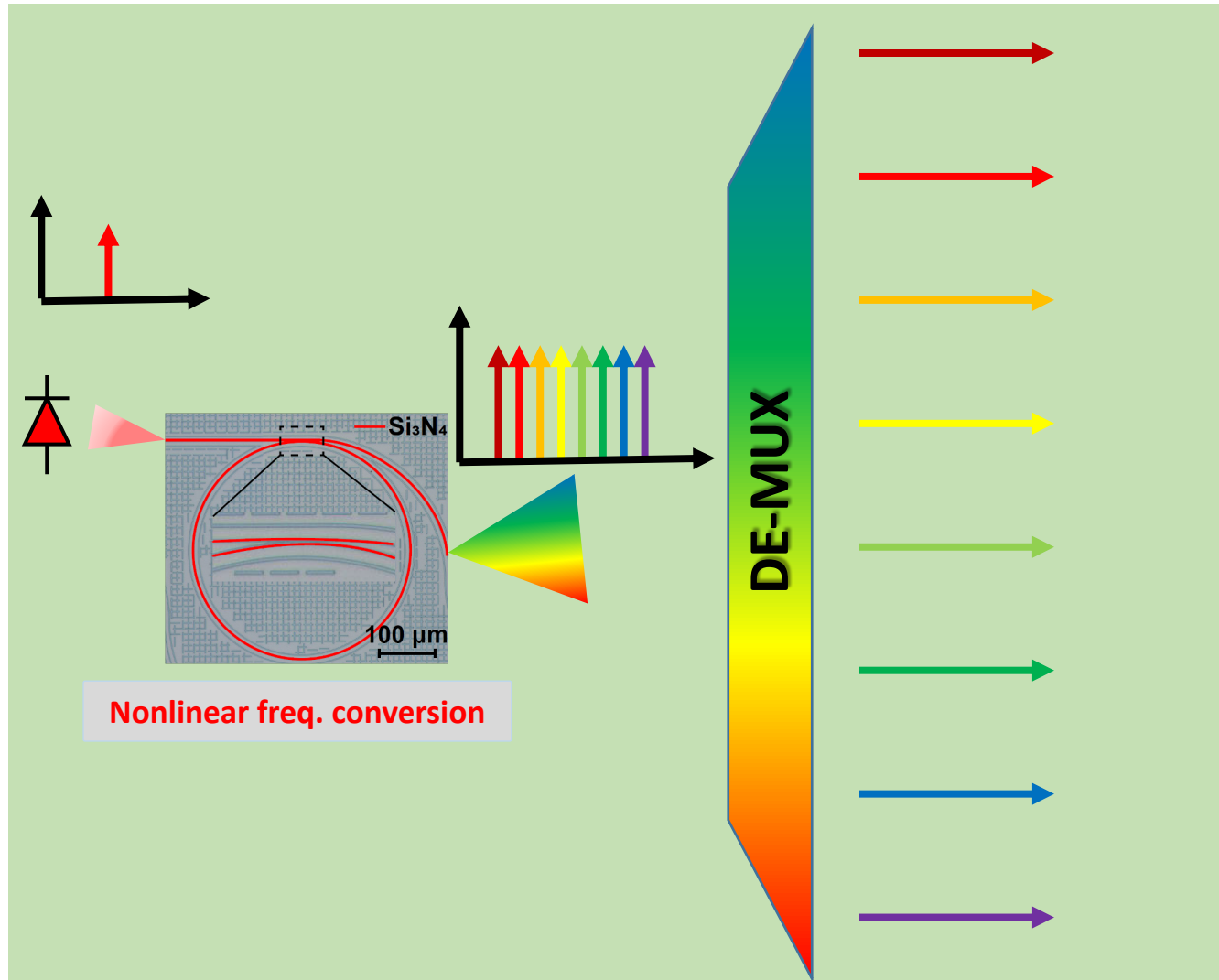
Laser Diode

TEC: thermo-electric cooler

## Array of lasers

- Size
- Drift (frequency)
- Power consumption

# Wavelength division multiplexing (microcomb source)

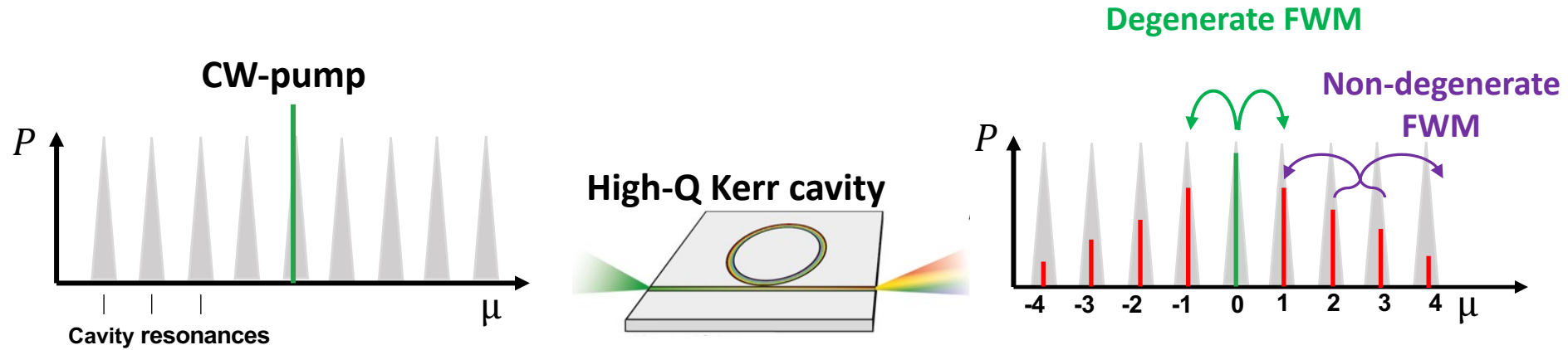


 Laser Diode

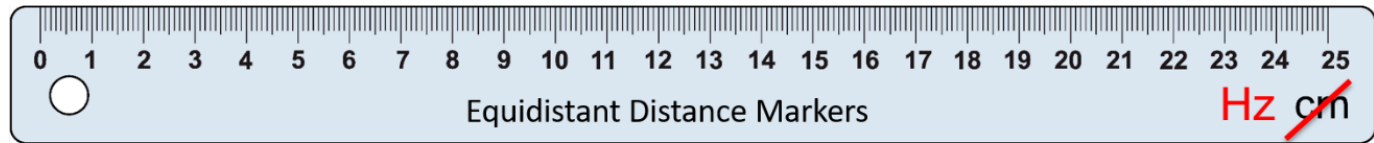
## Optical frequency comb

- Single source (chip-based)
- > 100 lines
- Easy wavelength alignment

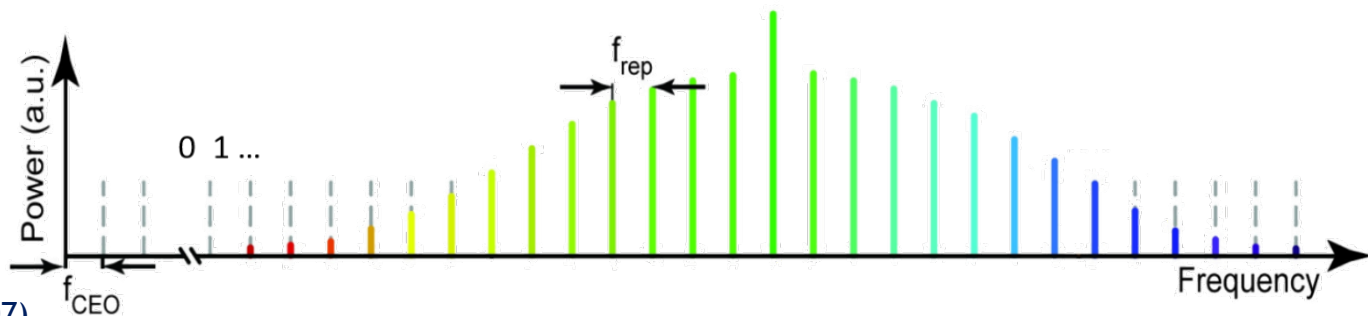
# Optical frequency comb (Microcomb)



Optical frequency comb consists of a series of discrete, equally spaced frequency lines



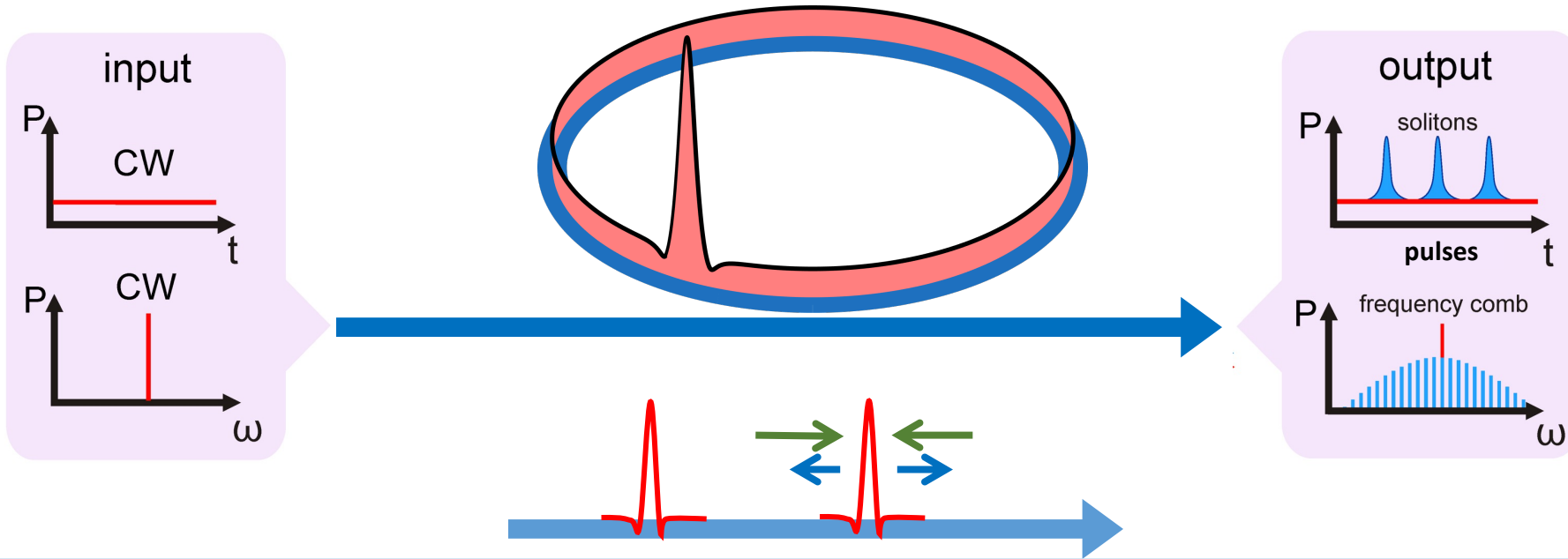
Equidistant Optical Frequency Markers



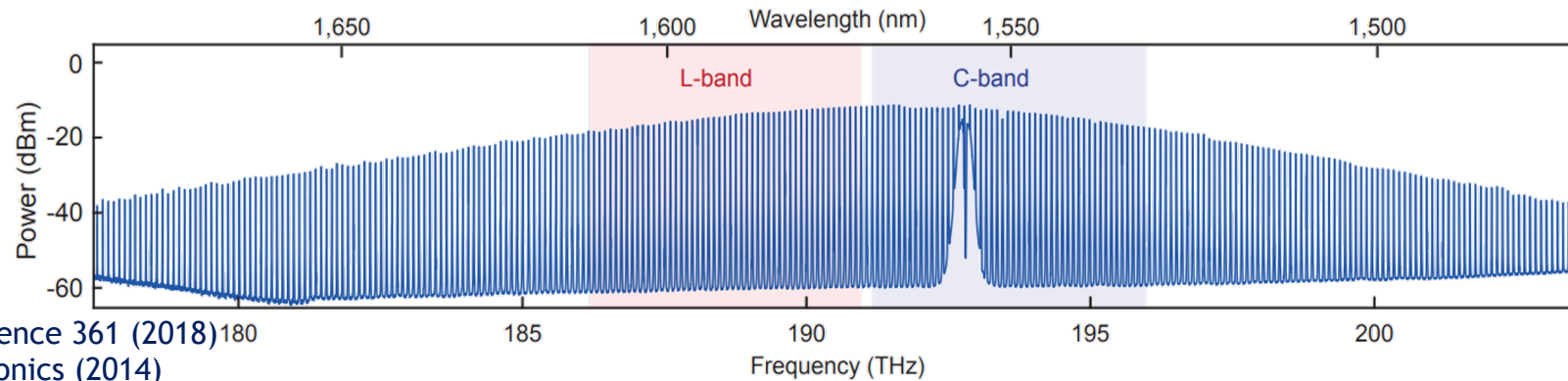
FWM: Four wave mixing

P. Del’Haye et al., Nature, 1214 (2007)  
 T. Kippenberg et al., Science (2018)

# Dissipative Kerr Solitons (DKS)

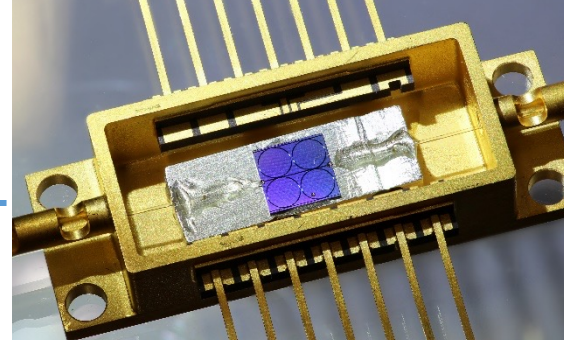
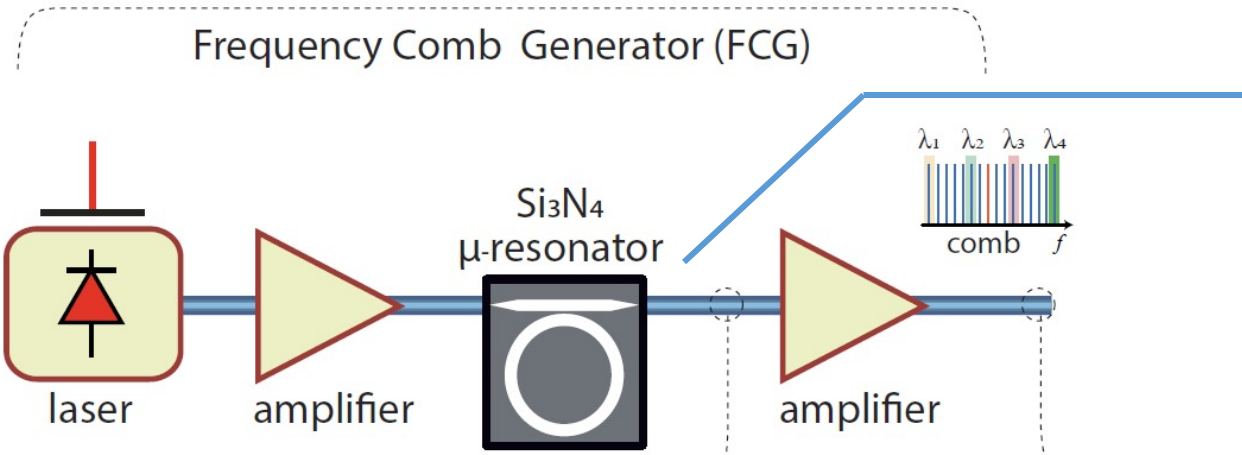


Solitons arise due to the counter-balance of **anomalous dispersion** & **Kerr nonlinearity**.

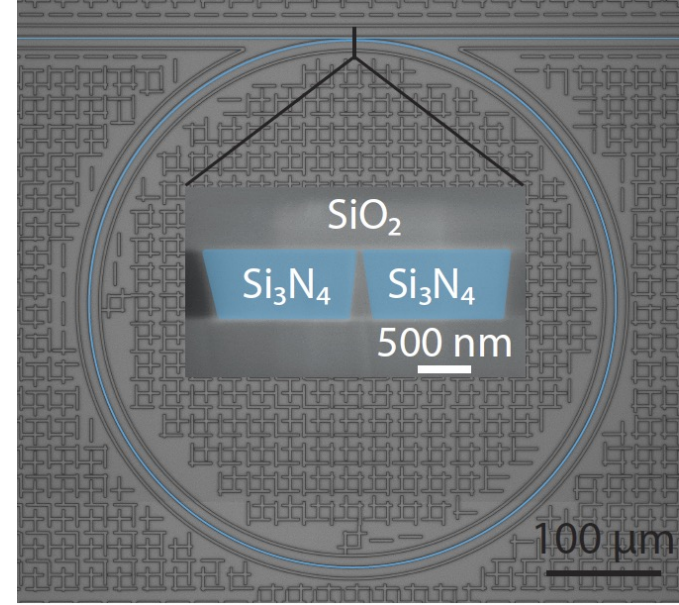


- T. Kippenberg et al, Science 361 (2018)
- T. Herr et al, Nat. Photonics (2014)
- P. Marin-Palomo et al., Nature 546 (2017)

# Proof-of-concept experiment- soliton characterization

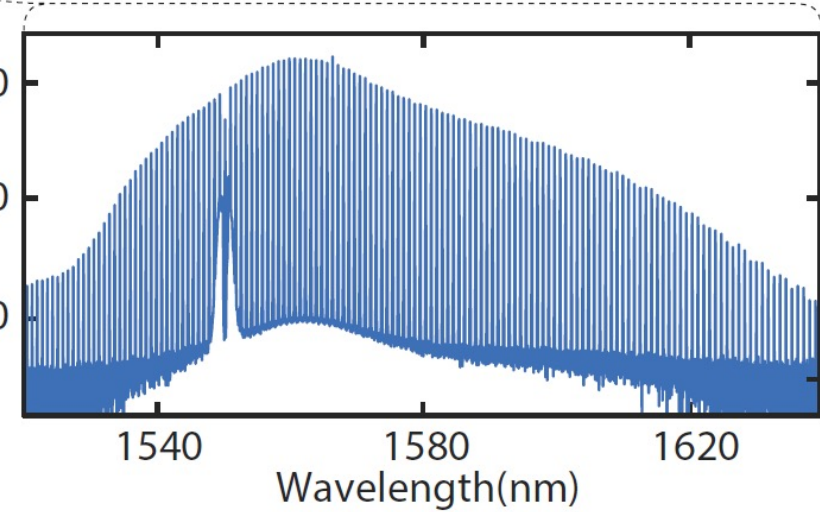
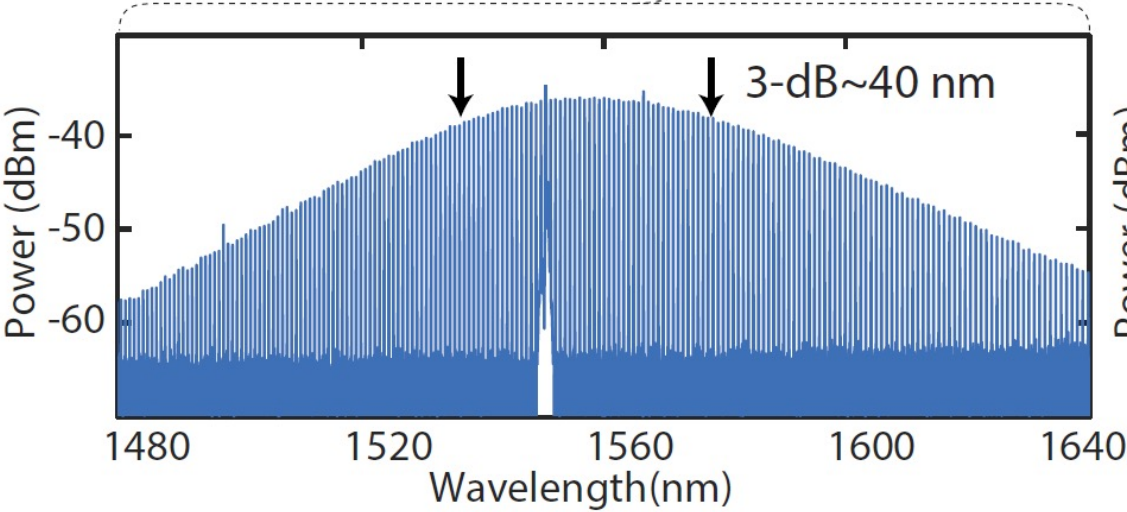


- **60 coherent** carriers
- Stable (operational)
- Power up to **-4dBm**
- OSNR > 34 dB



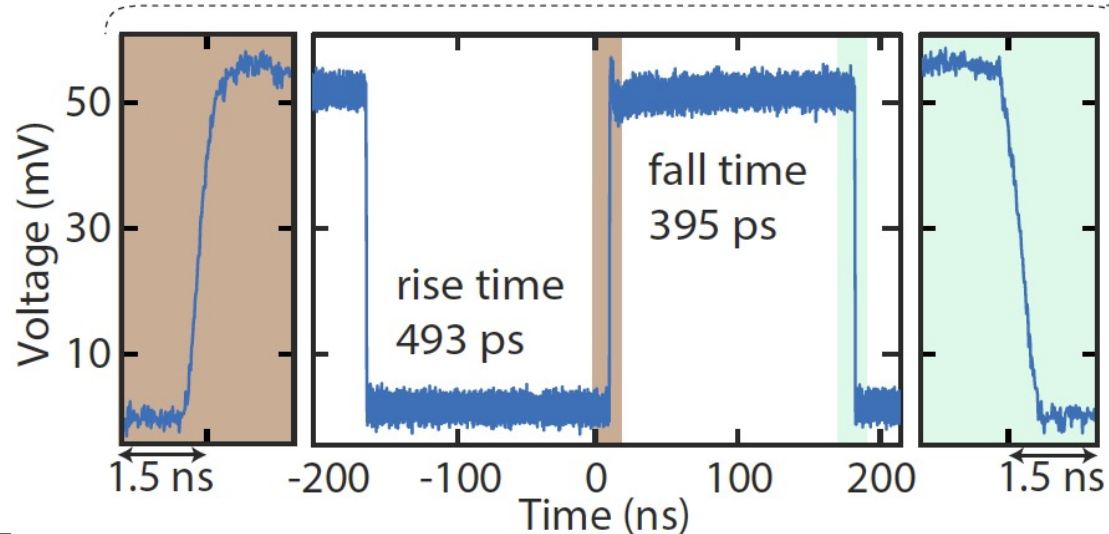
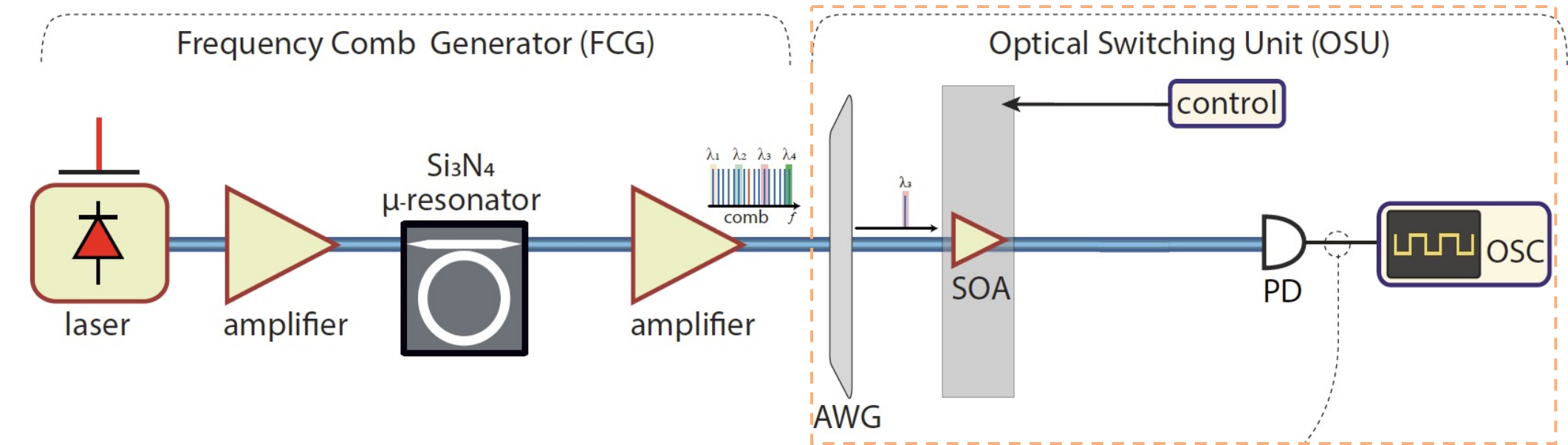
1%

10 dB attenuation



Pfeiffer et al., Optica (2016)  
 Pfeiffer et al., IEEE JSTQE (2018)  
 Pfeiffer et al., Optica (2018)  
 J. Liu et al, Optica (2018)  
 J. Liu et al., Nat. Comm. (2021)  
 A. S. Raja et al., OE, 2020

# Single comb switching

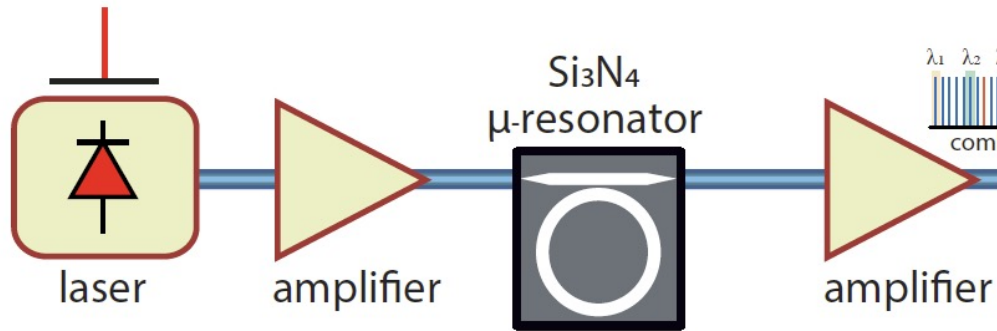


## Switching characterization

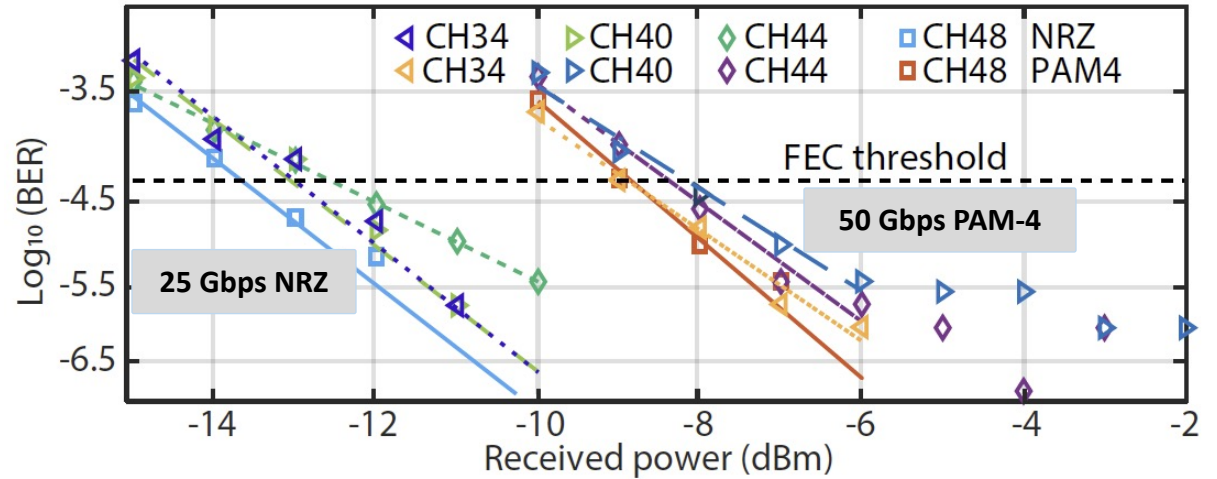
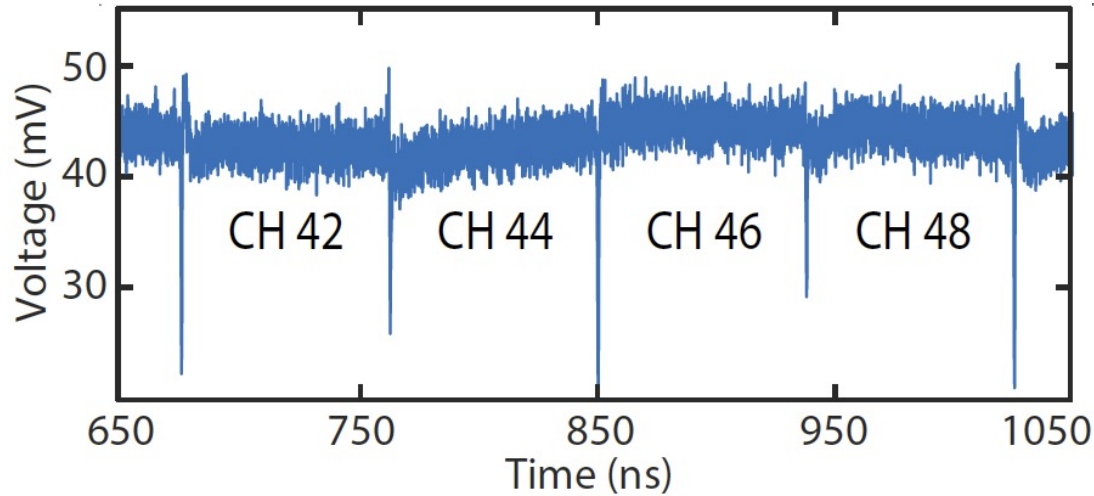
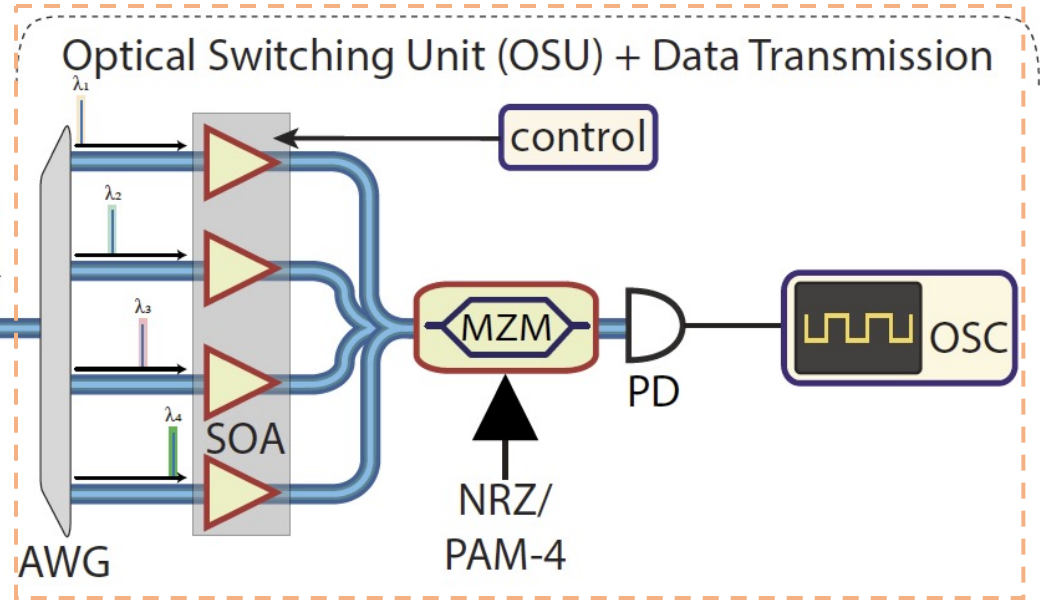
- Individual comb channel switching
- **25 channels** showed sub-ns switching
- Discrete SOA (semiconductor amplifier)

# Switching along with data transmission

Frequency Comb Generator (FCG)

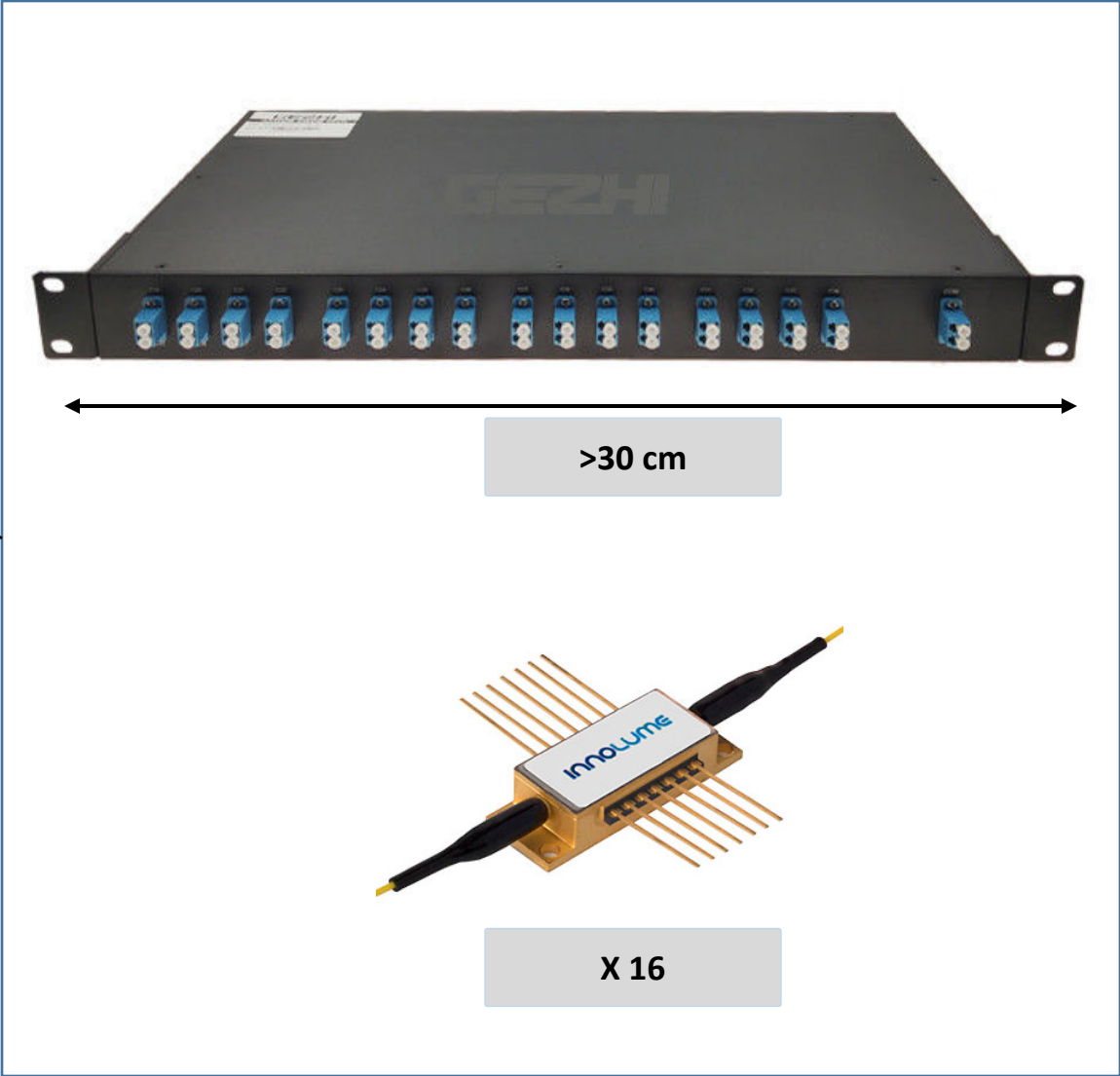
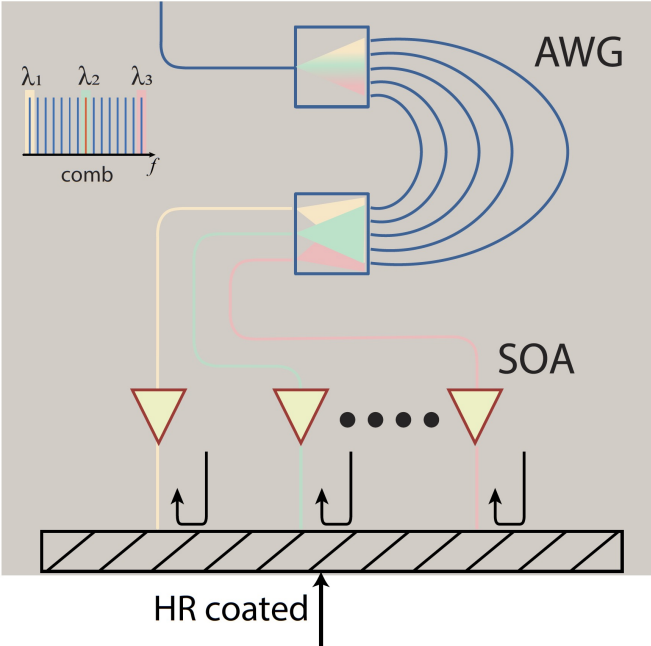
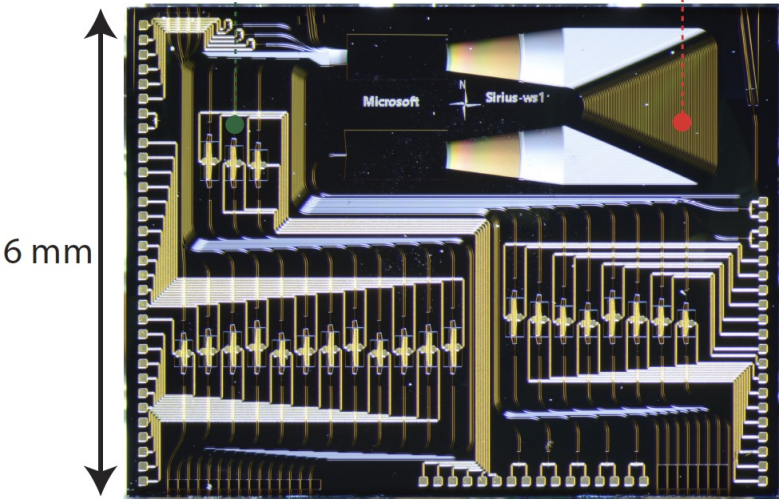


Optical Switching Unit (OSU) + Data Transmission

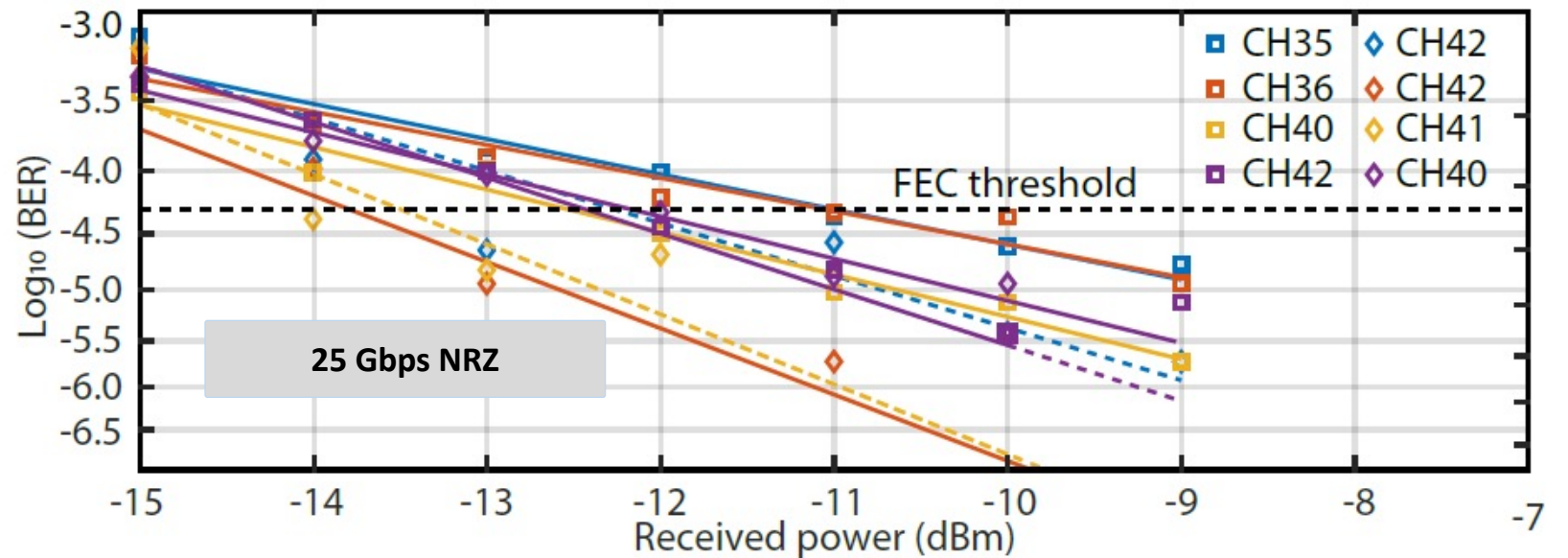
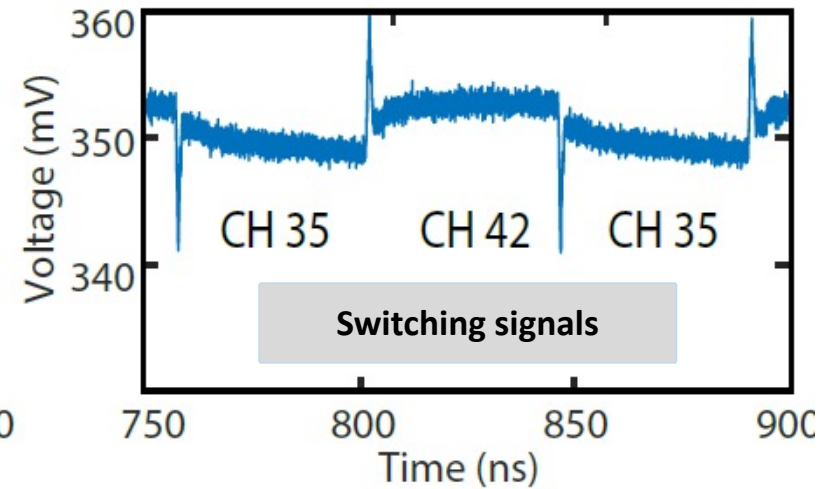
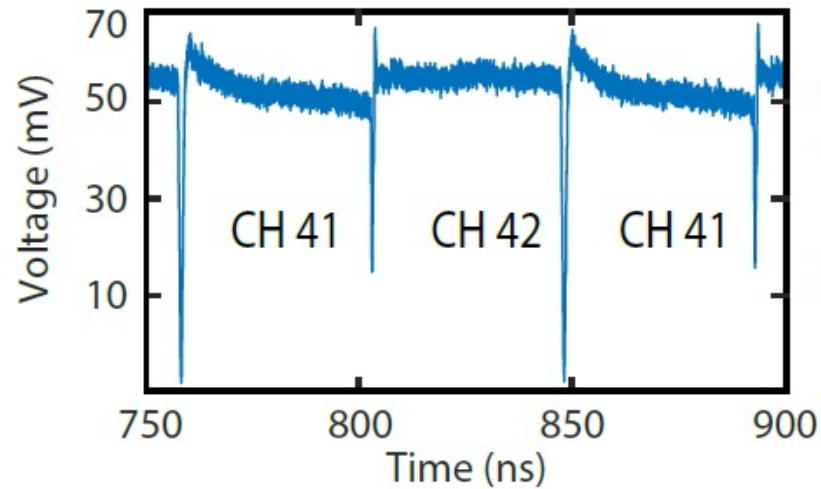
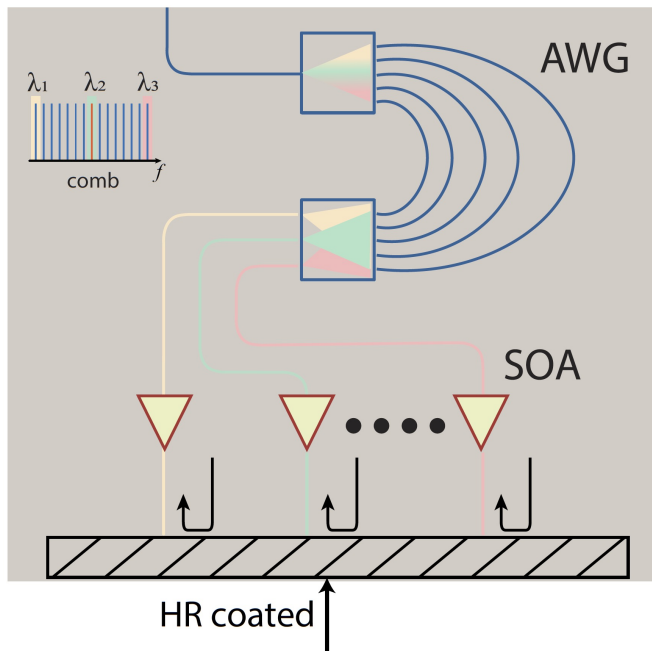
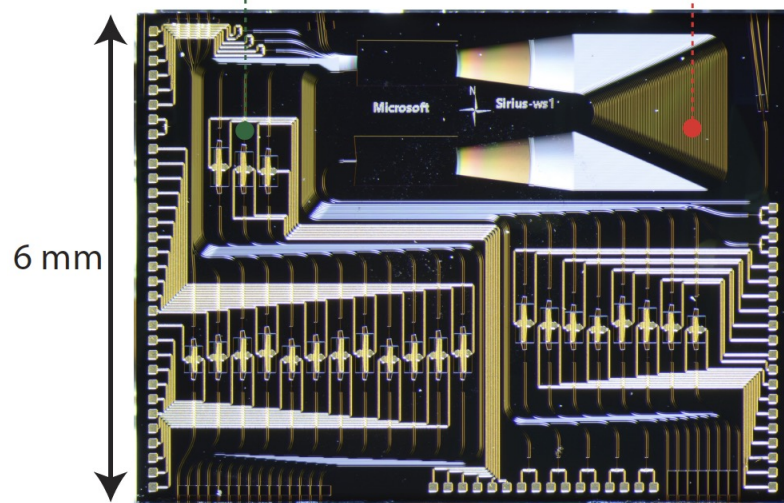




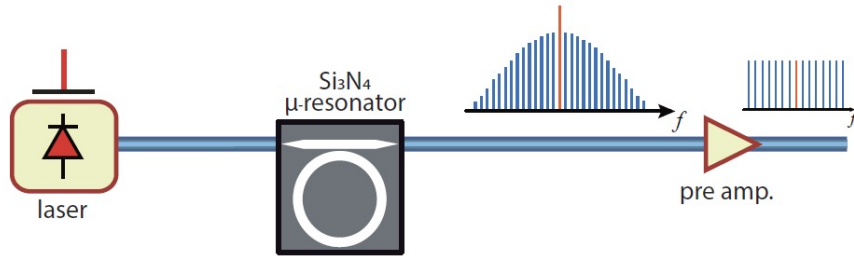
# Switching and data transmission (chip-based)



# Switching and data transmission (chip-based)

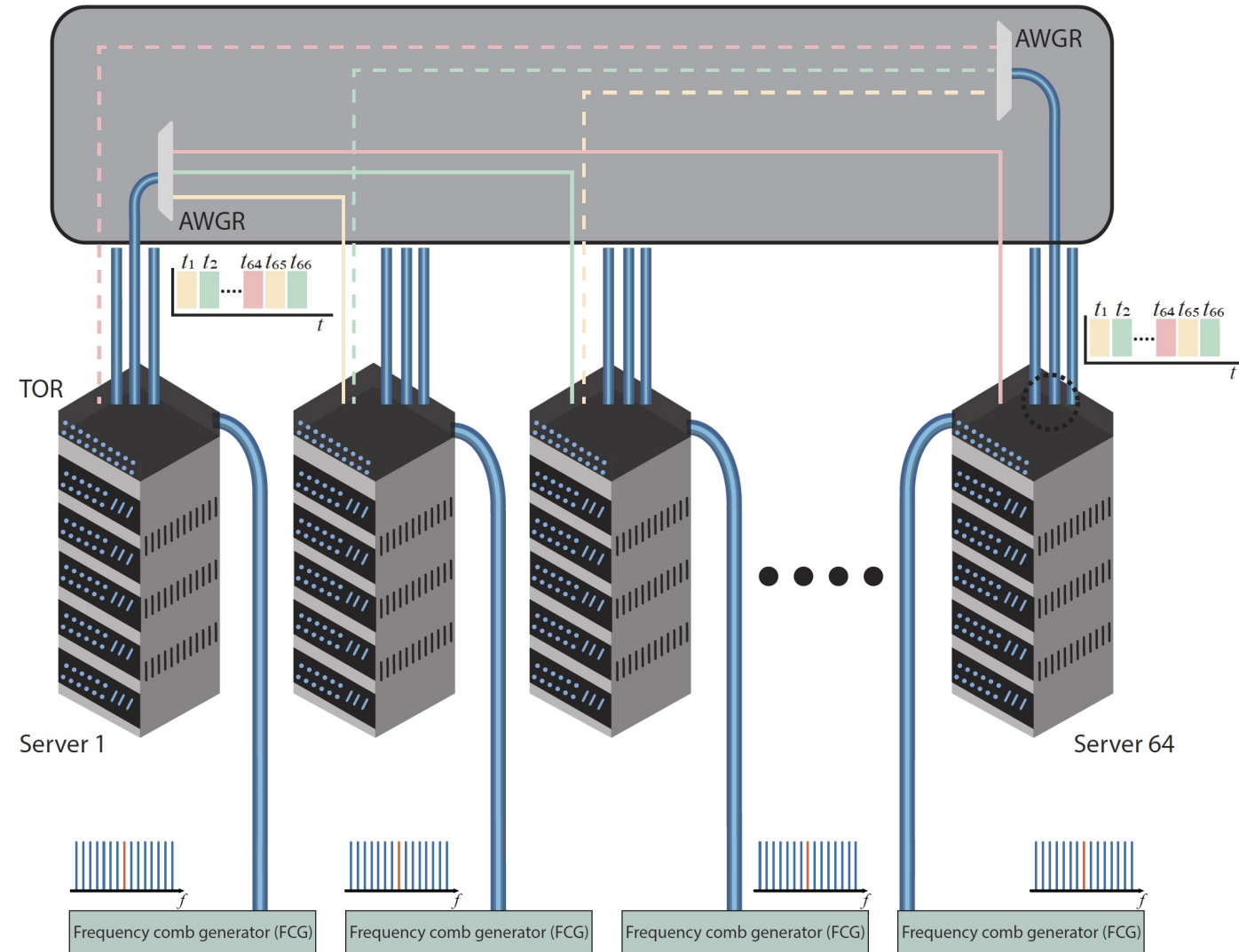


# Scaling and power/OSNR calculation

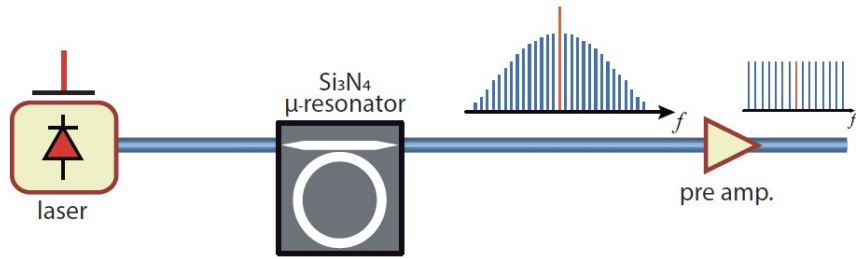


## Comb source for each server

- Power in-efficient (>10 W per server)
- OSNR (40 dB – 35 dB)

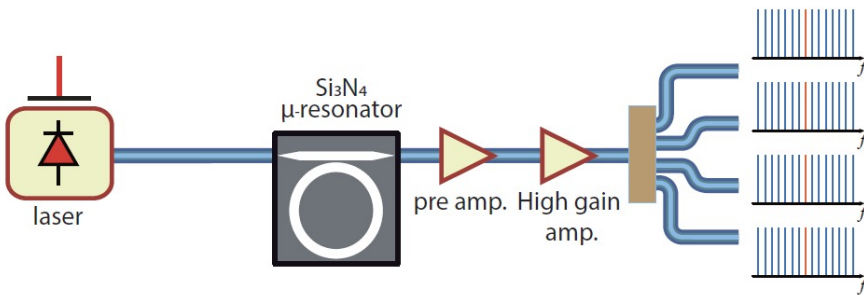


# Scaling and power/OSNR calculation



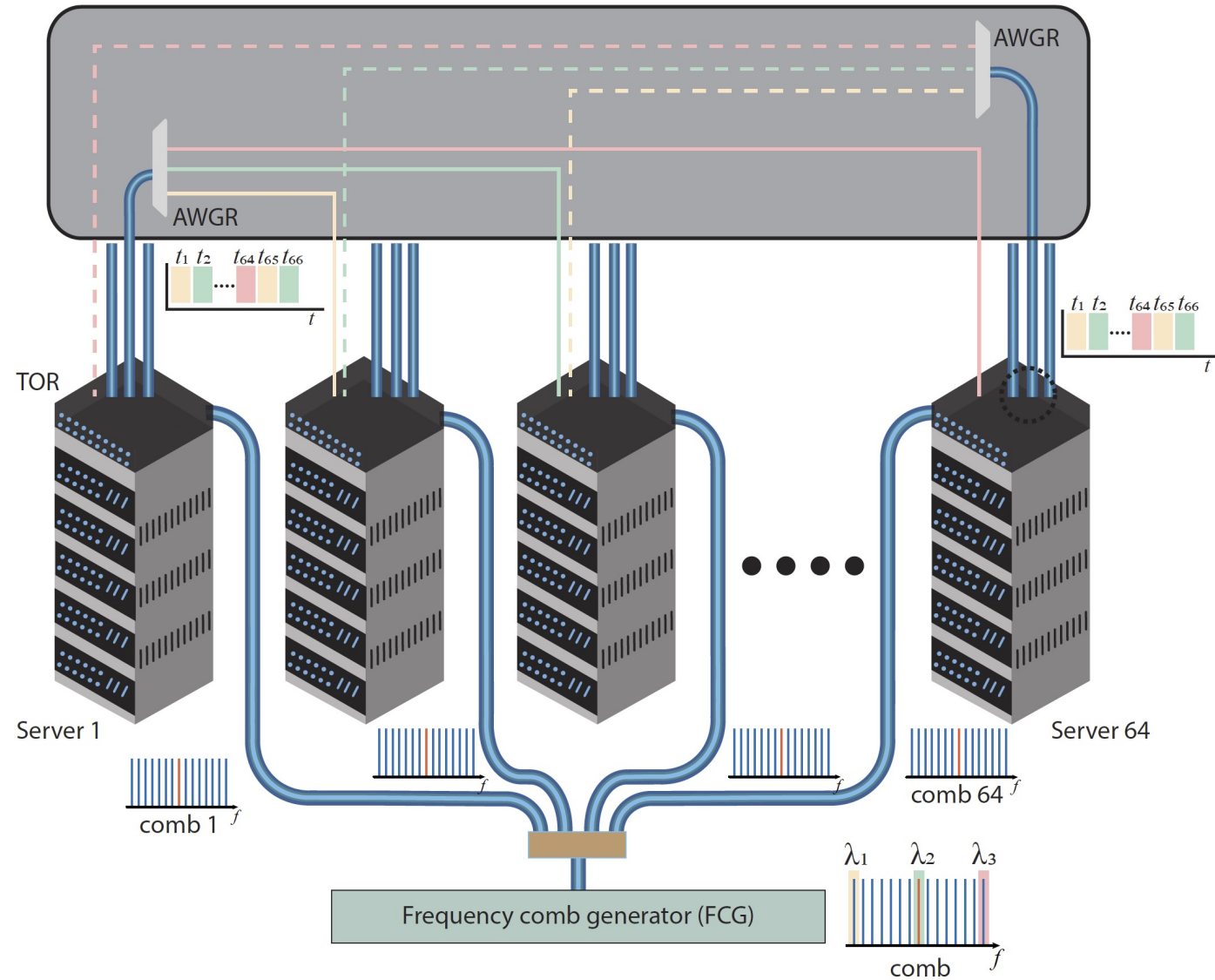
## Comb source for each server

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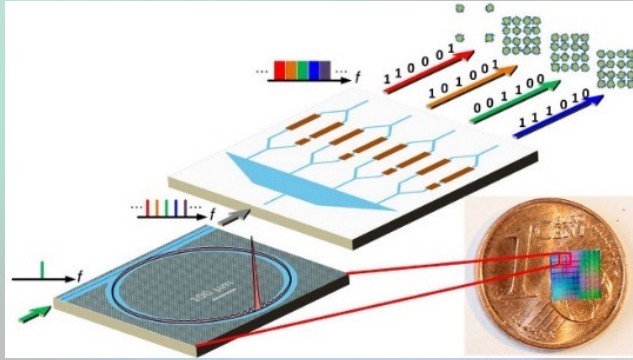


## Sharing single source across multiple servers

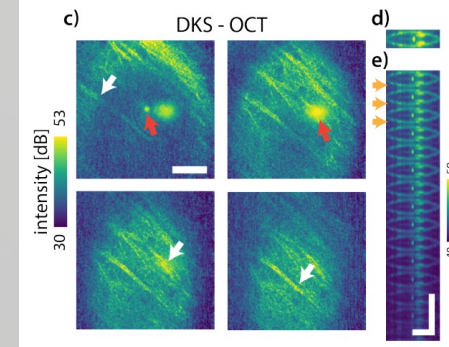
- Power efficient (2.57 W per server)
- OSNR (35 dB – 40 dB)



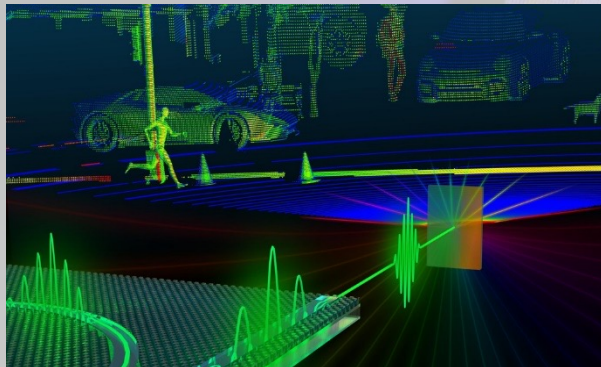
### Coherent communications



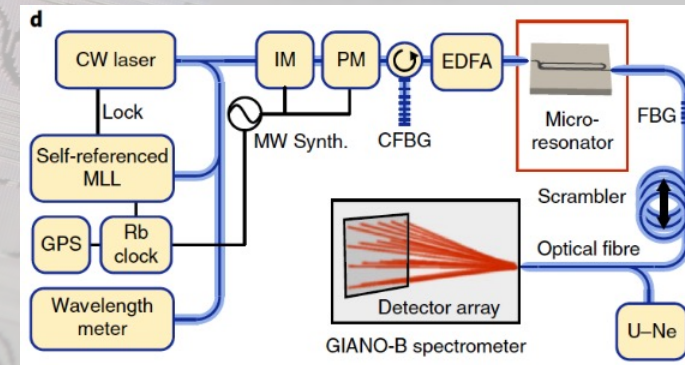
### Optical coherence tomography



### FMCW LiDAR



### Astro-comb

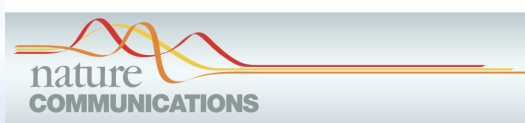


Marin-Palomo et al., Nature 546, 274 (2017)  
 Trocha et al., Science 359, 887 (2018)  
 Obrzud et al., Nat. Photonics 13, 31 (2019)  
 Dutt et al., Sci. Adv. 4, e1701858 (2018)

Spencer et al., Nature 557, 81 (2018)  
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 Mazur et al., arXiv 1812.11046 (2018)  
 Riemensberger et al., Nature (2020)

Marchand et al., Arxiv (2019)

Maxim Karpov  
Xin Fu  
Junqiu Liu  
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Tobias Kippenberg



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<https://doi.org/10.1038/s41467-021-25841-8>

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## Ultrafast optical circuit switching for data centers using integrated soliton microcombs

Arslan Sajid Raja<sup>1,3</sup>, Sophie Lange<sup>2,3</sup>, Maxim Karpov<sup>1,3</sup>, Kai Shi<sup>2,3</sup>, Xin Fu<sup>1</sup>, Raphael Behrendt<sup>2</sup>, Daniel Cletheroe<sup>2</sup>, Anton Lukashchuk<sup>1</sup>, Istvan Haller<sup>2</sup>, Fotini Karinou<sup>2</sup>, Benn Thomsen<sup>2</sup>, Krzysztof Jozwik<sup>2</sup>, Junqiu Liu<sup>1</sup>, Paolo Costa<sup>2</sup>, Tobias Jan Kippenberg<sup>1</sup> & Hitesh Ballani<sup>2</sup>

Sophie Lange  
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Hitesh Ballani



For more information:  
A.S. Raja, S. Lange et al. *Nat Commun* 12, 5867 (2021)

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