PHOTONICS RESEARCH GROUP

PROGRAMMABLE PHOTONIC ICS: MAKING OPTICAL DEVICES MORE VERSATILE

Wim Bogaerts

PIC International – 9-10 April 2018

GHENT UNIVERSITY

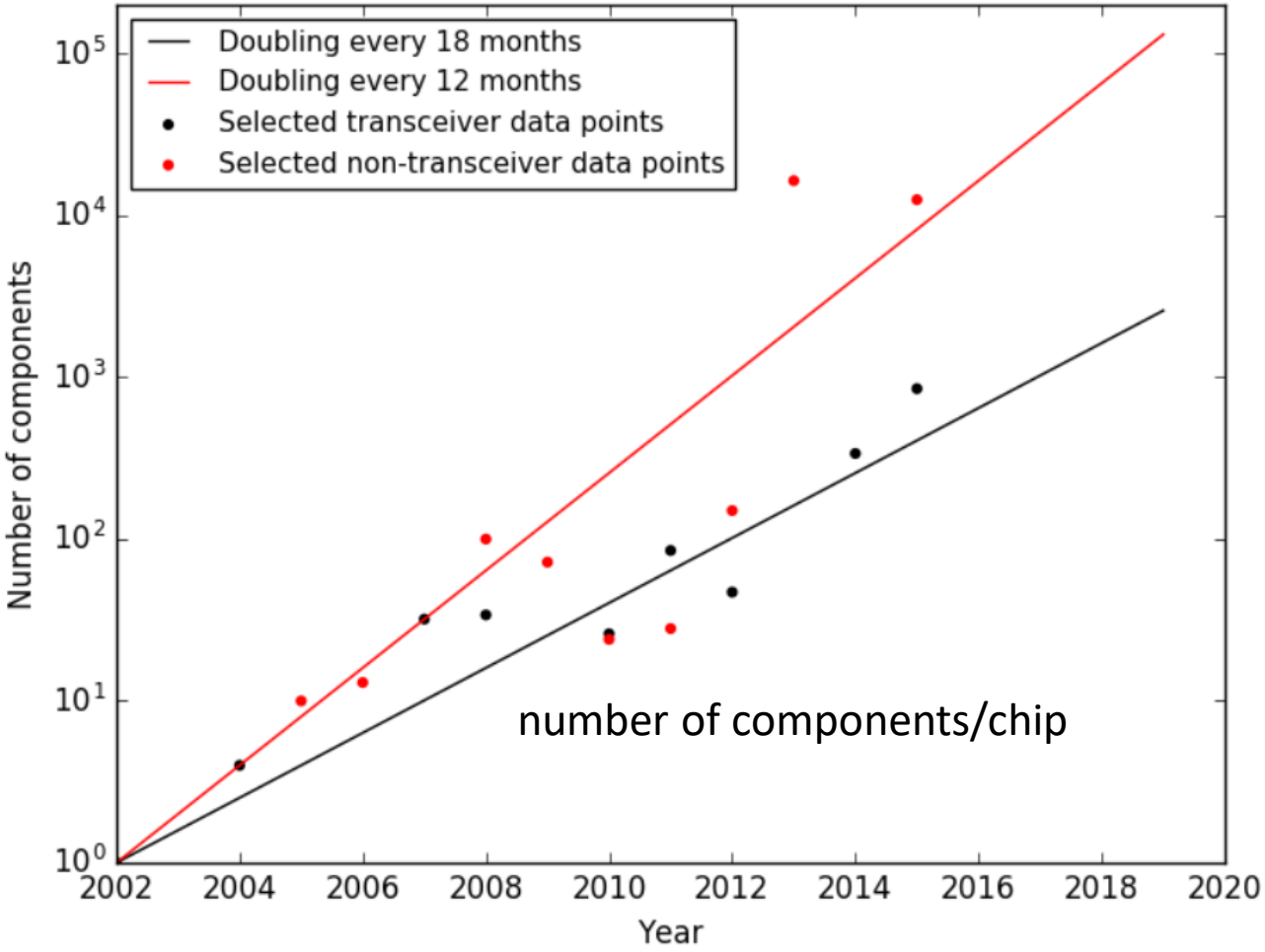
imec
embracing a better life

(SILICON) PICS TODAY

Rapidly growing integration

- O(1000) components on a chip
- photonics + electronic drivers
- different applications
  (still mostly communication)
- Relatively small chip volumes
  (compared to electronics)

All photonic circuits are ASICs

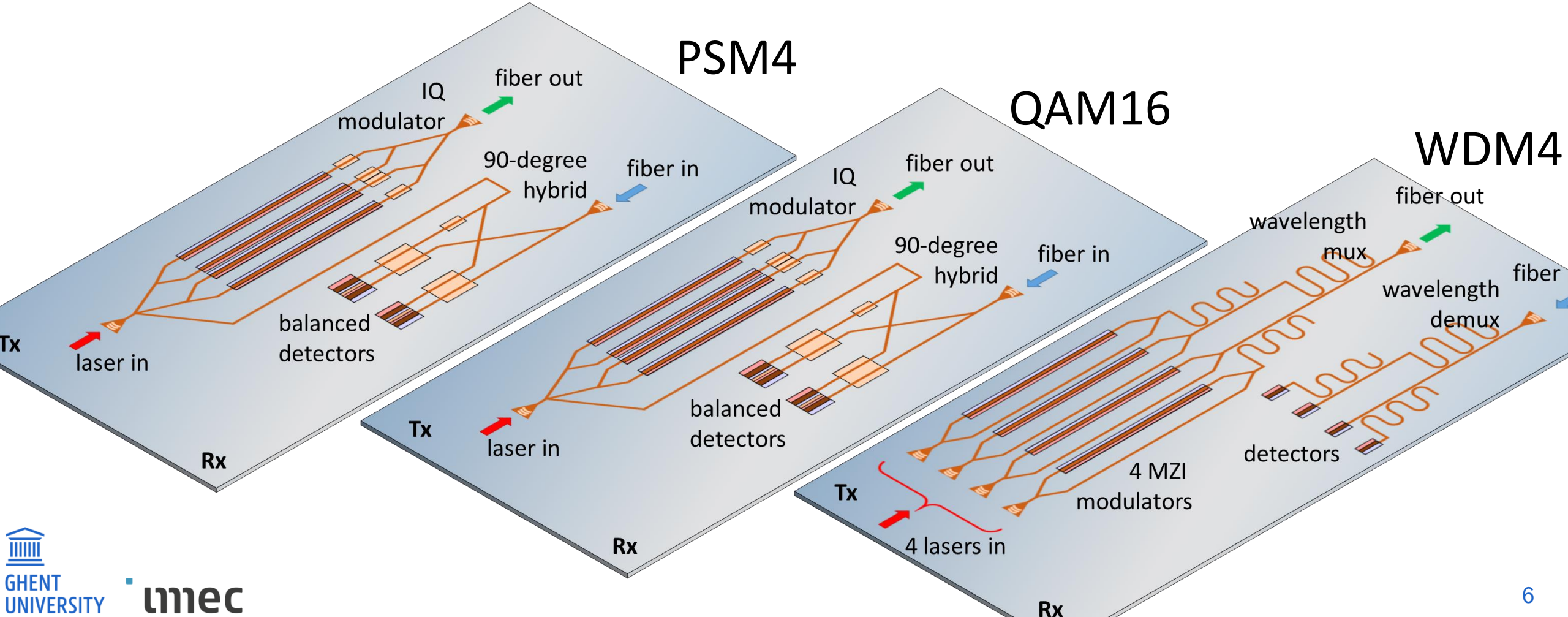


Khanna et al. 2016

FLEXIBLE OPTICAL COMMUNICATION

Today: if you want to change protocol…

you need to make a new chip



Prototyping a New (Silicon) Photonic IC

Design (4M)

Fabrication (6M)

Package (1M)

Test (2M)

Then you discover the bugs…

Repeat!

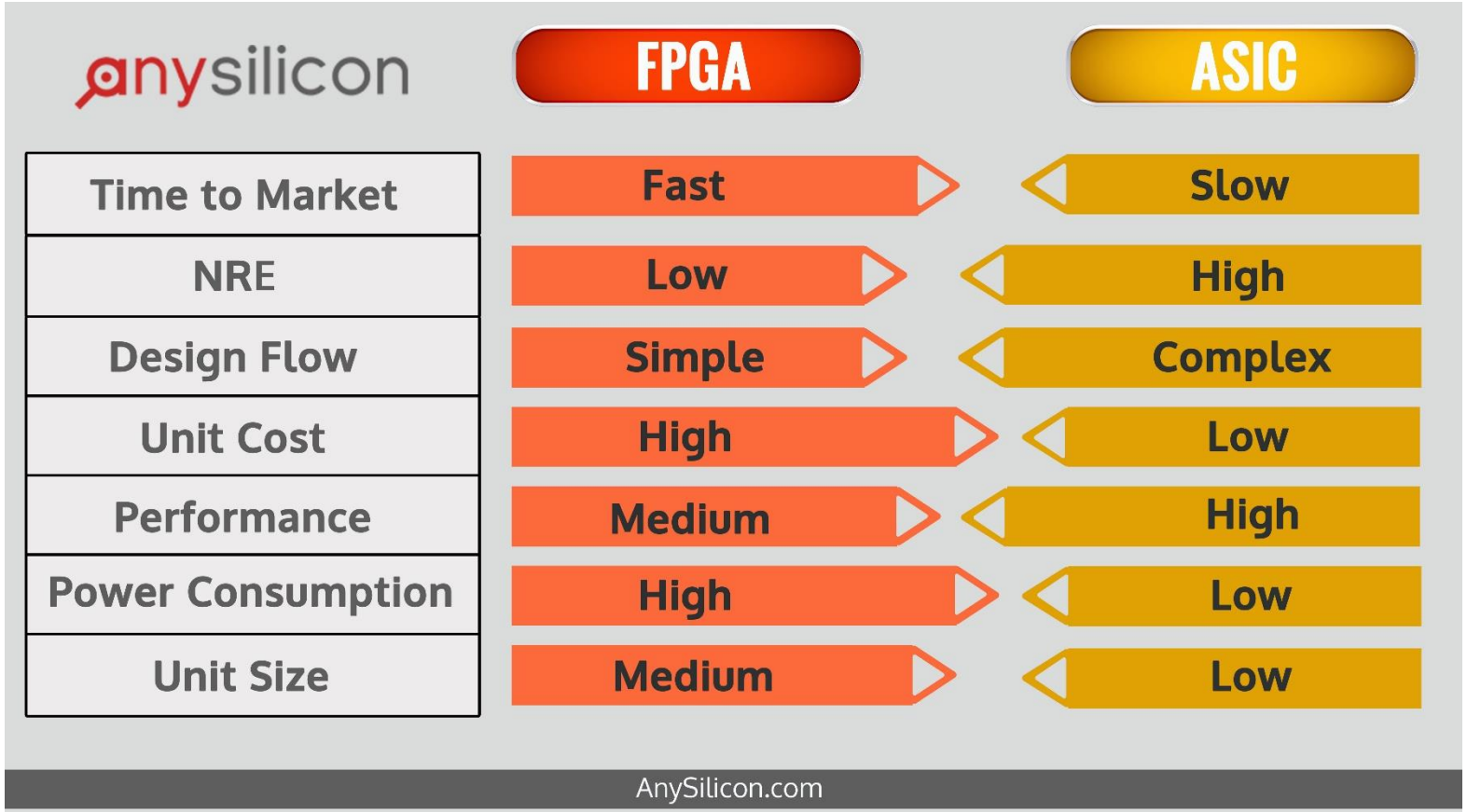
Prototyping a new Electronic Circuit

Select a suitable FPGA, DSP, µC (1d)

Program and test the chip (1-4w)

Only then, if needed:

- Design ASIC …



Where are the Photonic FPGAs?

or programmable photonics

reconfigurable photonics

photonic processors

universal photonic circuits …

Programmable Photonics

A photonic circuit

that **can be reconfigured**

using **software**

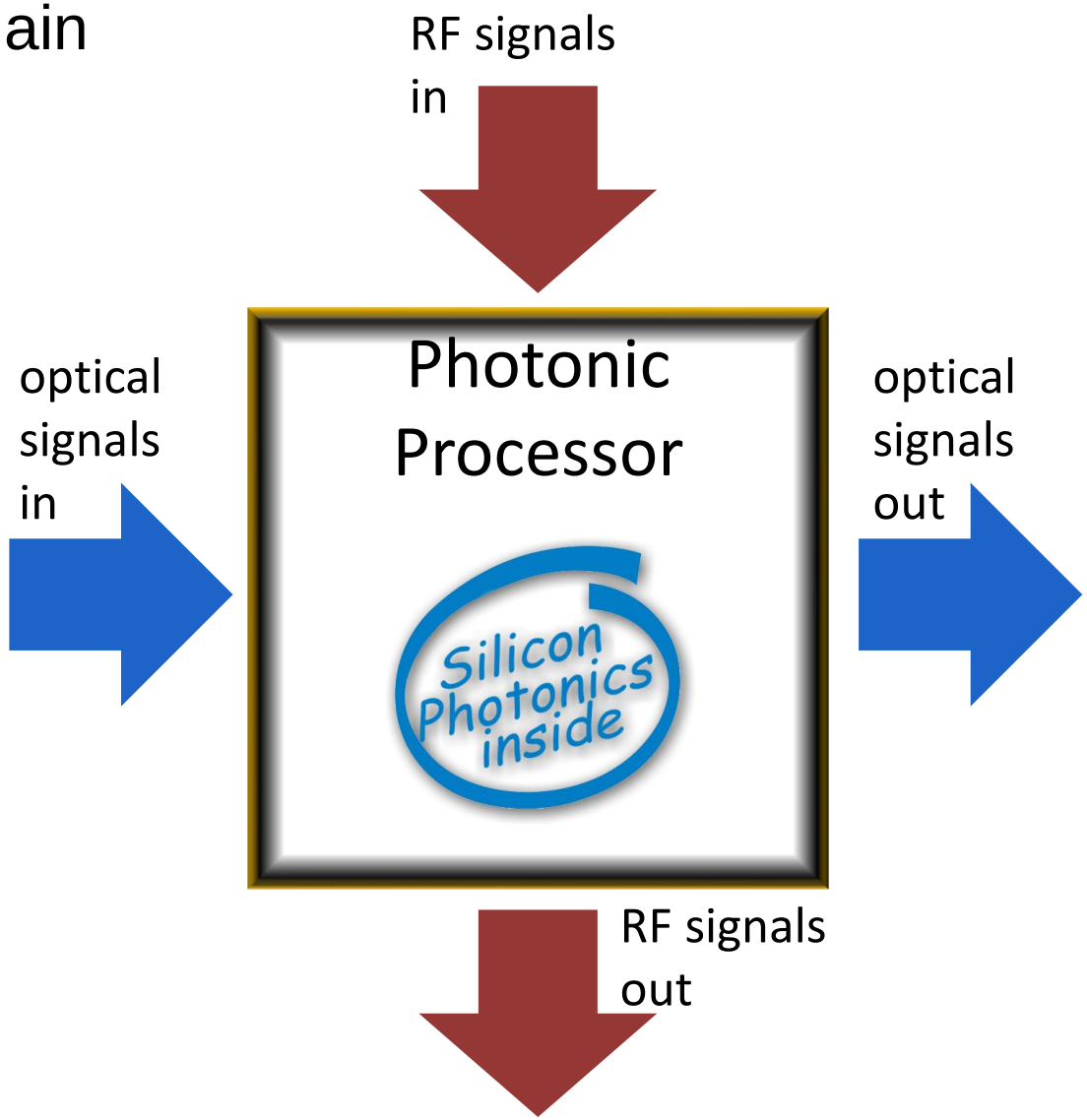
to perform **different functions**.

Programmable Photonic Chip

Can processes signals in the optical domain

- balancing
- filtering
- transformations

Both on Optical and RF



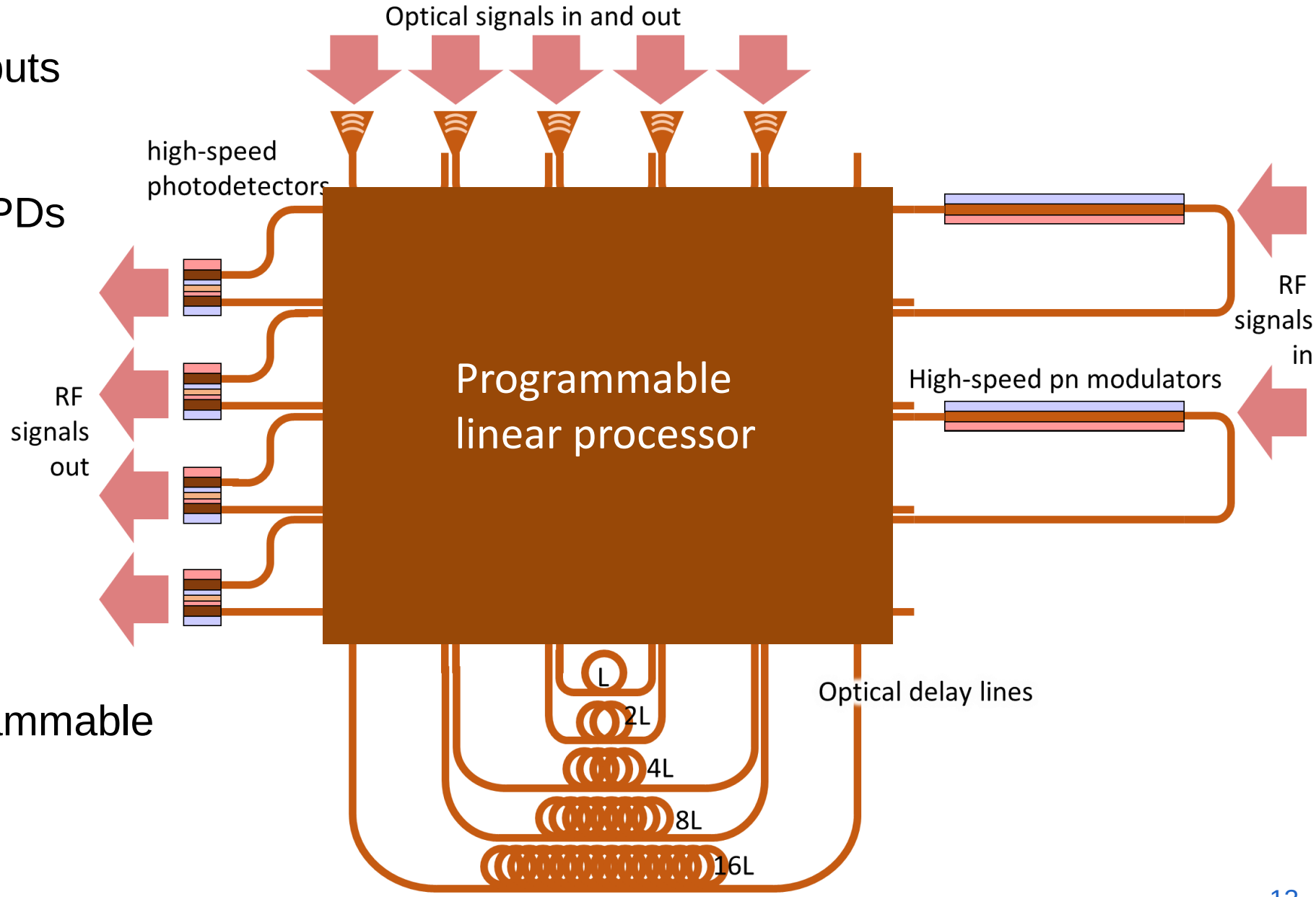
Generic Programmable Photonic Circuit

Optical inputs and outputs

RF inputs: modulators

RF outputs: balanced PDs

Long delays for filters



Connected by a programmable linear optical circuit

Reconfigurable Linear Optical Circuits

Not a new concept:

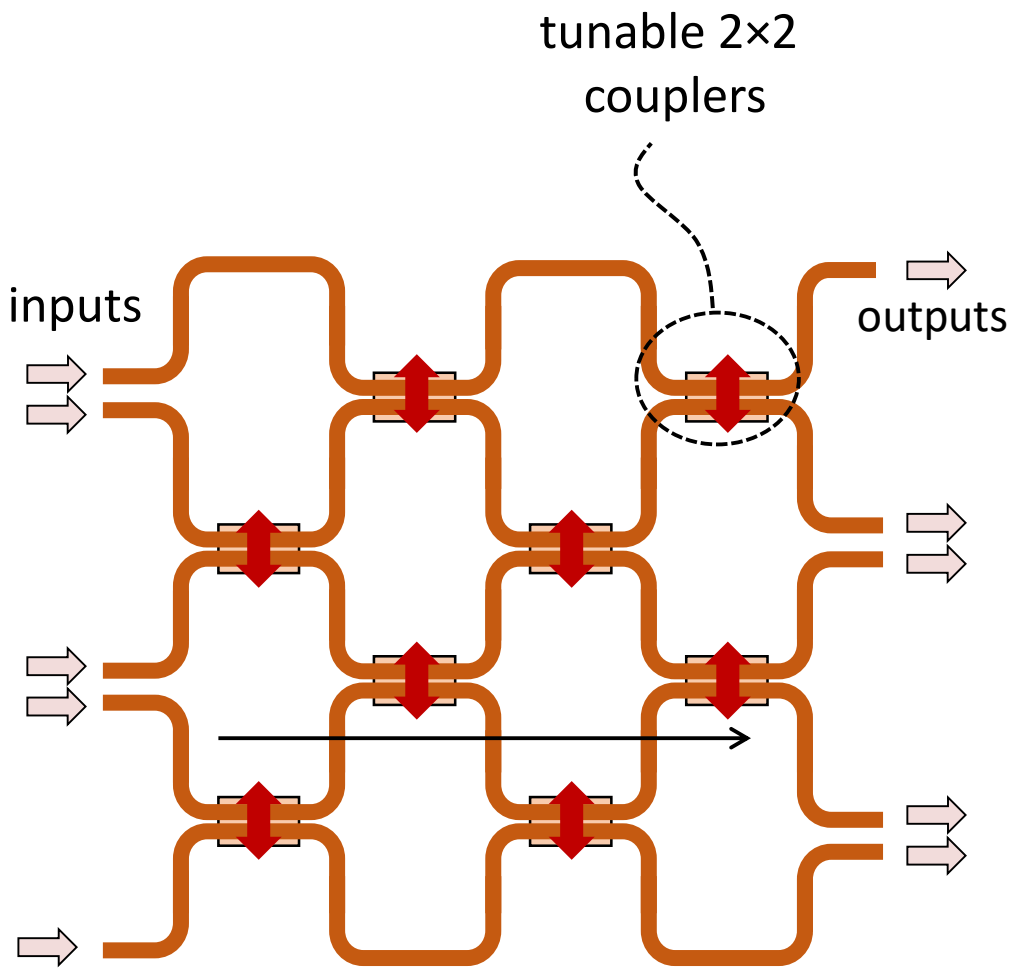
N outputs = linear combination of N inputs

Reck 1994: Generic optical linear circuits

Miller 2013: Self-configuring optical circuits

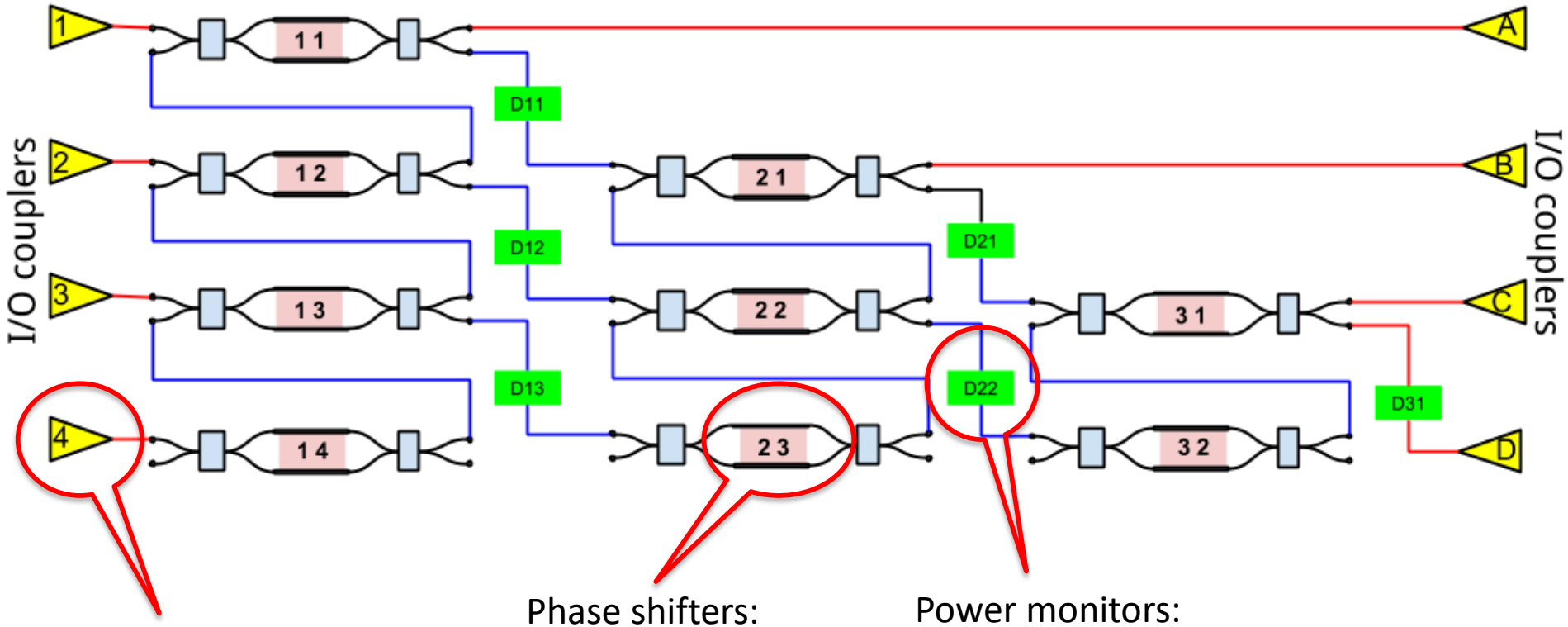
Carolan 2015: First demonstration

Ribeiro 2016: First demonstration in Silicon



UNIVERSAL LINEAR CIRCUIT IN SILICON

Tunable couplers = MZI with thermo-optic phase shifters

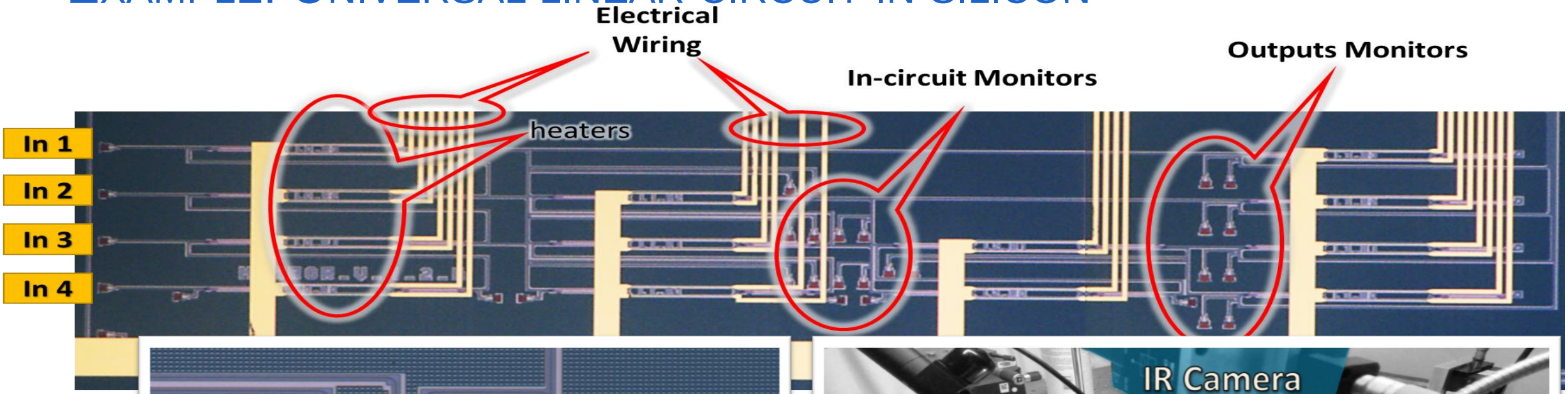


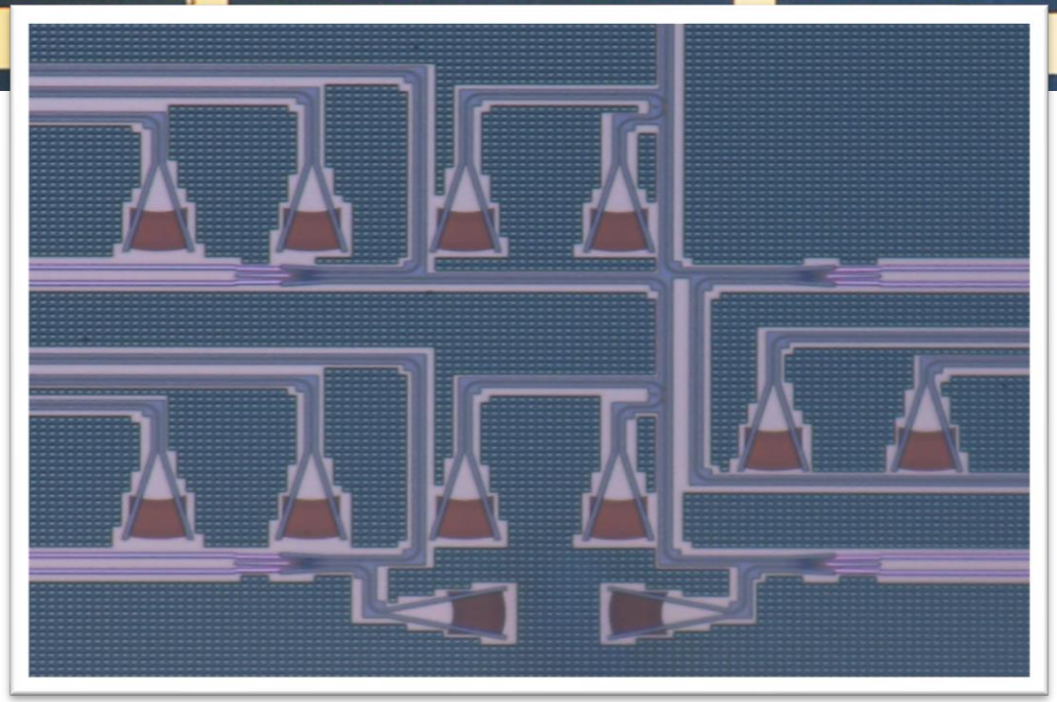
IO channels:
grating couplers

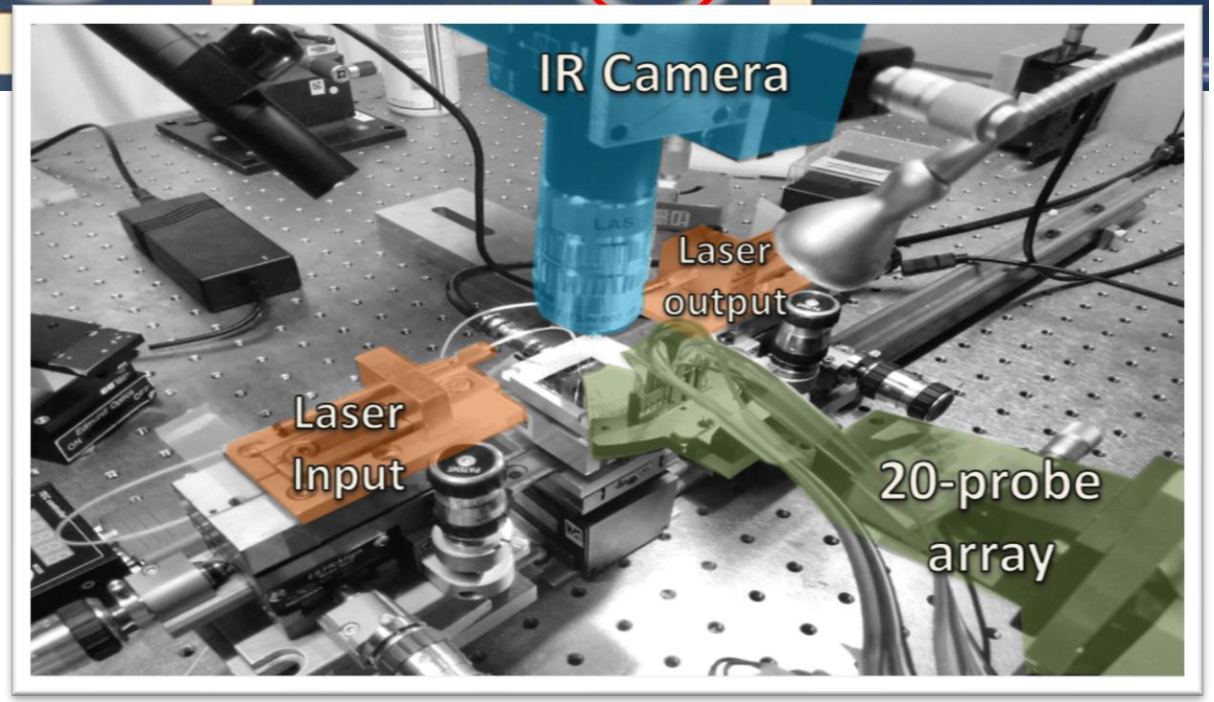
Phase shifters:
Simple Heaters

Power monitors:
Directional coupler tap

EXAMPLE: UNIVERSAL LINEAR CIRCUIT IN SILICON





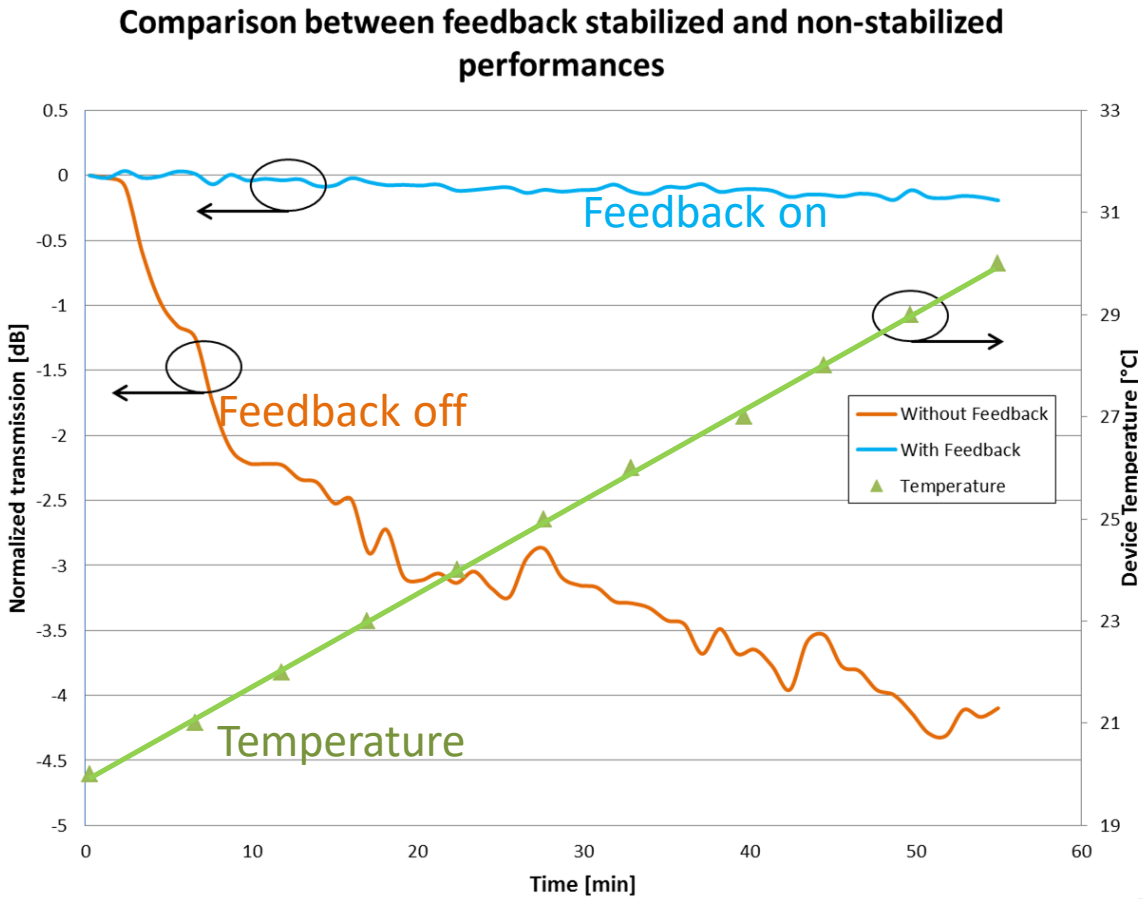


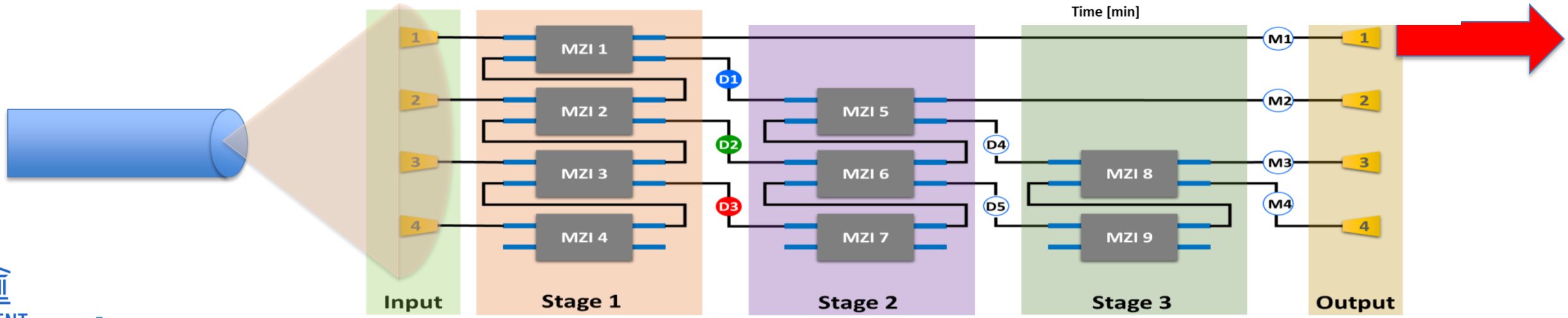
Ribeiro et al, Optica 2016

ADAPTIVE BEAM COUPLER

Circuit adapts itself to maximize output to a single mode waveguide

Local feedback loops stabilize the entire circuit.





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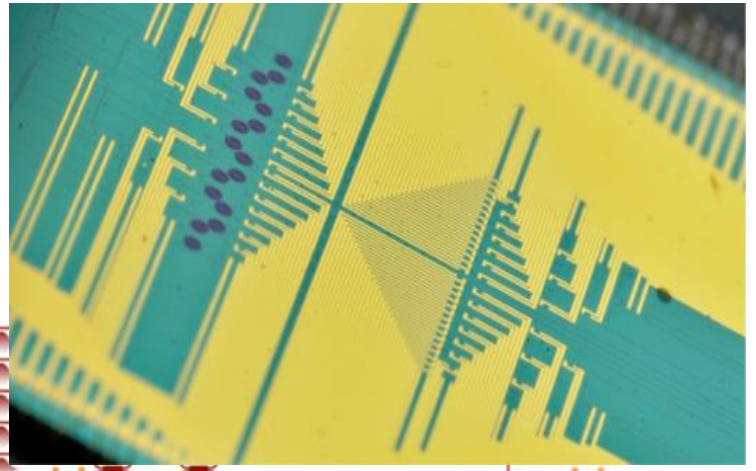
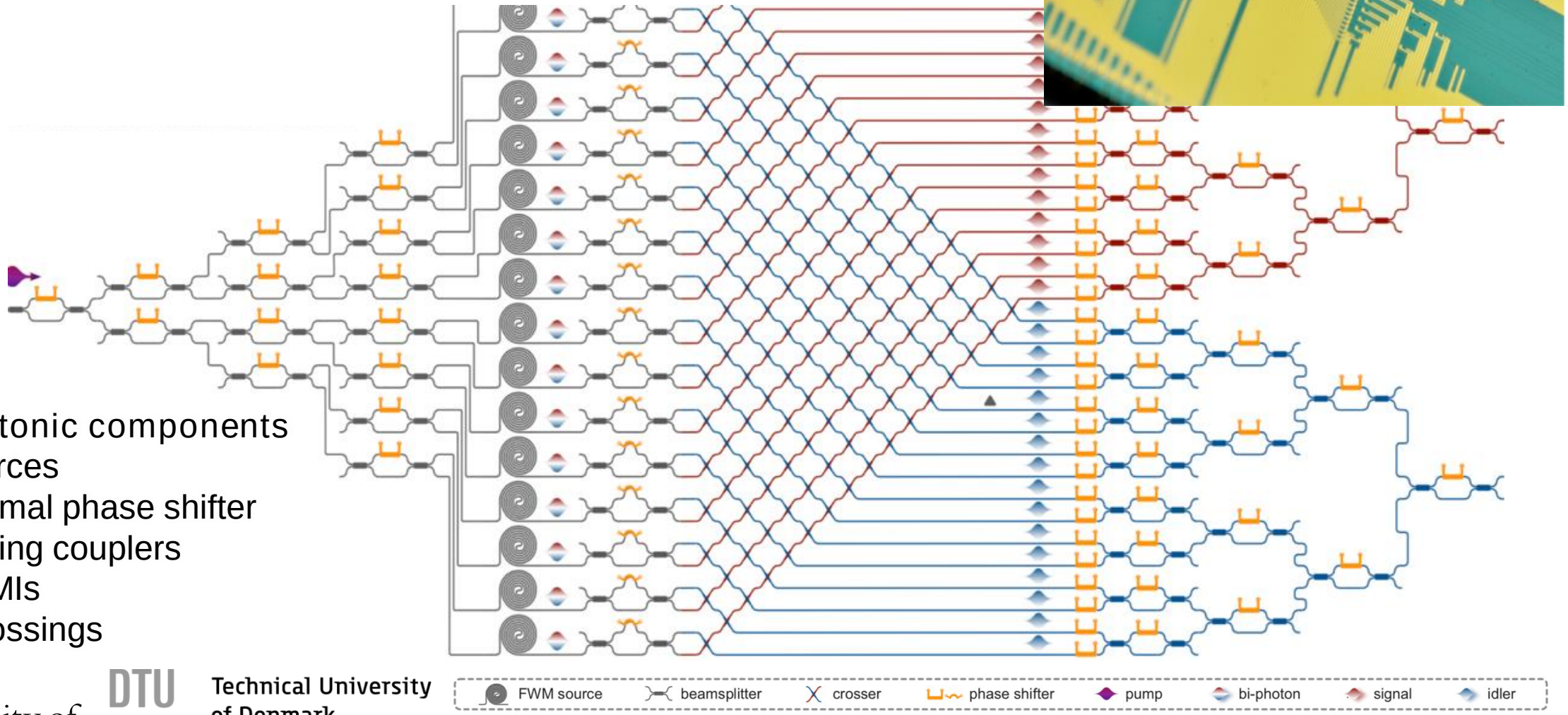
Ribeiro et al, Optica 2016

Large-scale Quantum-Optic Circuits

Full configurability and control over 16-photon entangled states





~600 photonic components

- 16 sources
- 96 thermal phase shifter
- 48 grating couplers
- 182 MMIs
- 256 crossings

University of Bristol

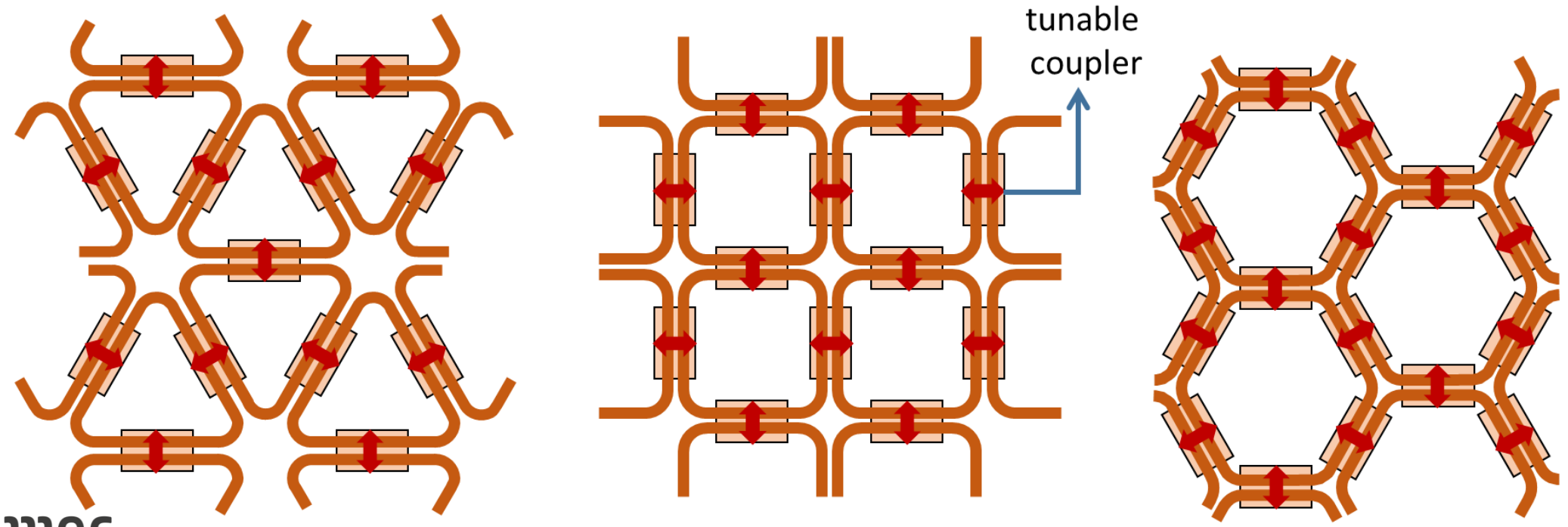
DTU Technical University of Denmark

Wang, et al, Science (2018)

Reconfigurable Linear Optical Circuits

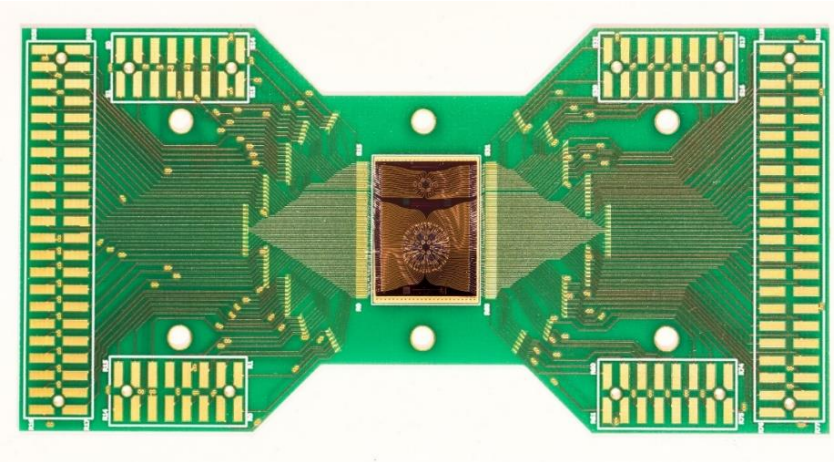
Adding feedback (loops)

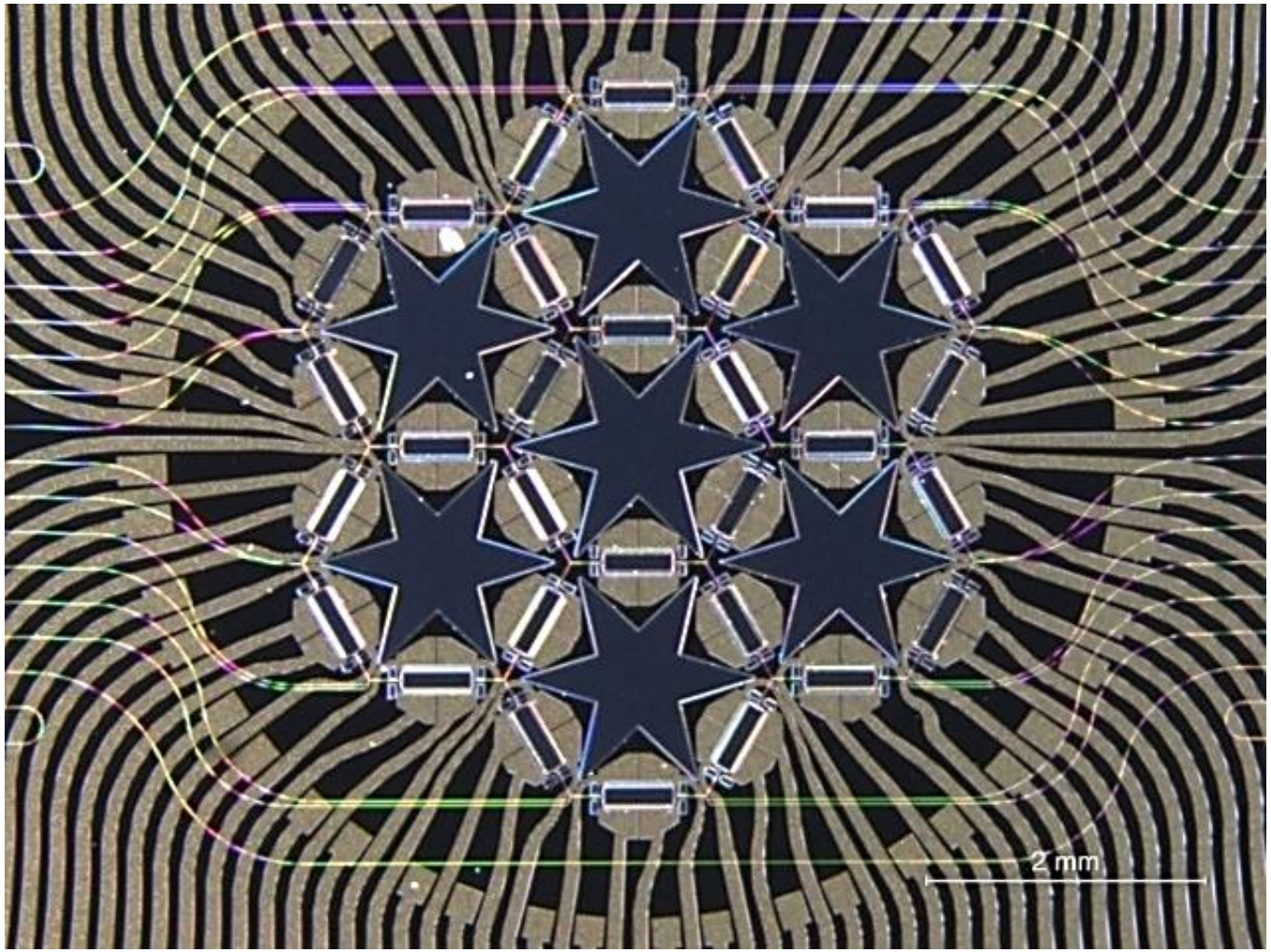
- Zhuang 2015: Square Meshes
- Capmany 2016: Triangular/Hexagonal meshes



HEXAGONAL MESH CIRCUIT

- 7 hexagonal cores
- 30 tunable couplers
  (2 heaters per coupler)
- >100 possible circuits



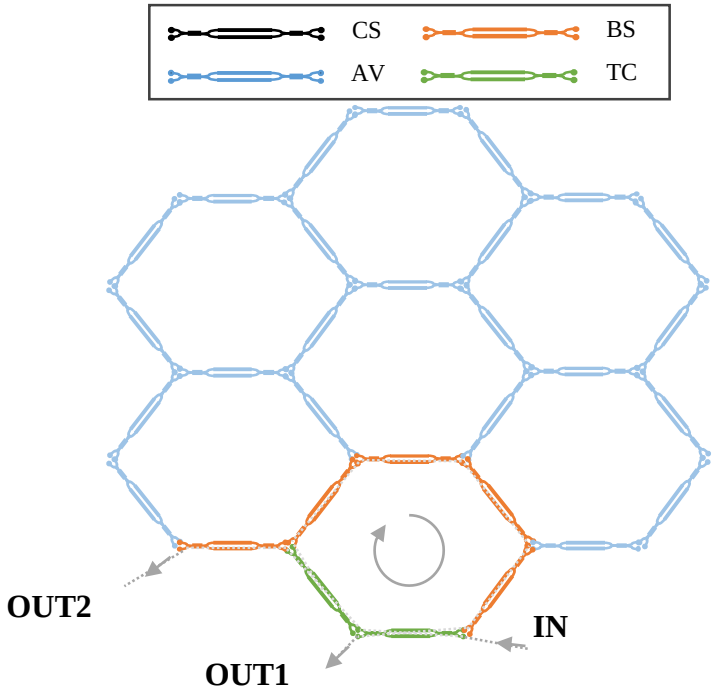


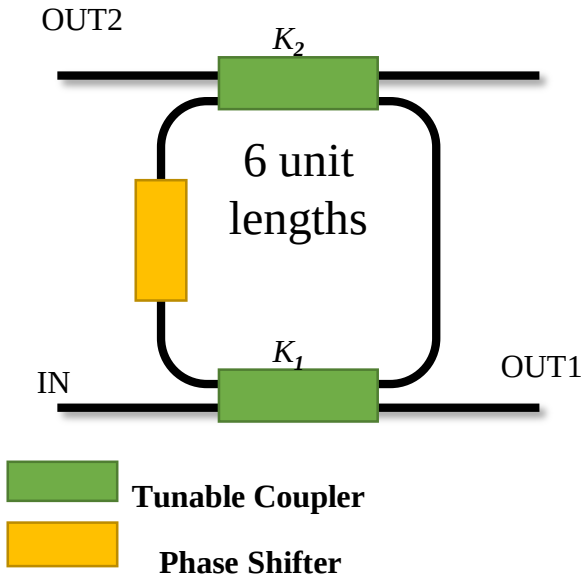
D. Pérez, et al., Nature Comms. 8, 636, 2017

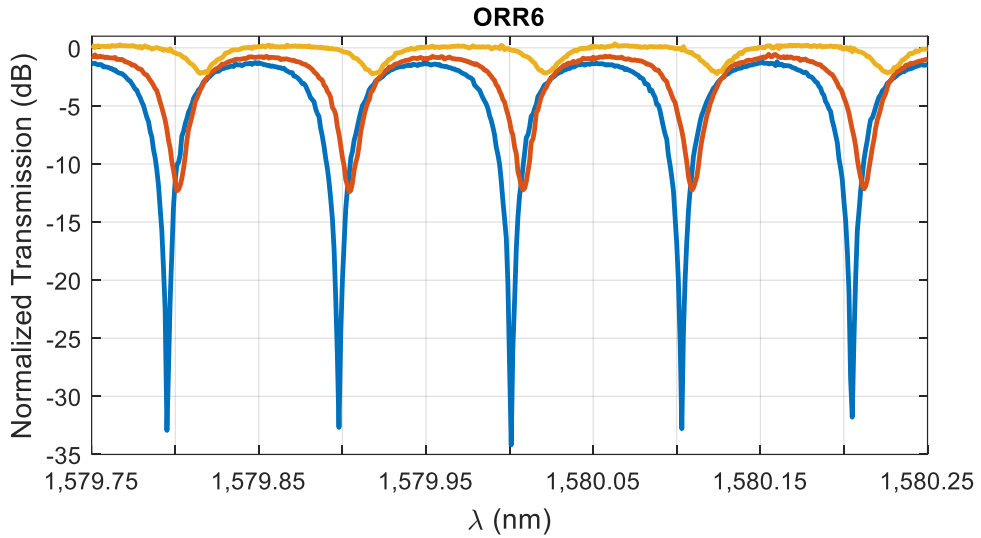
PROGRAMMABLE FILTERS (FIR OR IIR)

Photonics Research Labs

Example: Optical Ring resonator



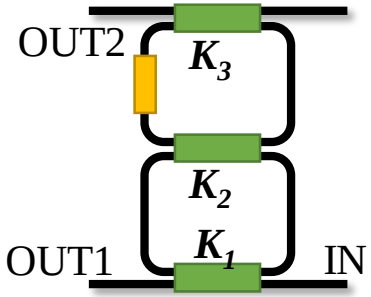




D. Pérez, et al., Nature Comms. 8, 636, 2017

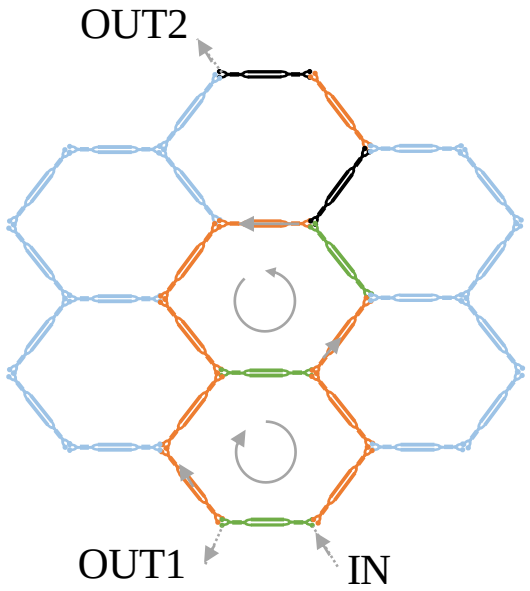
PROGRAMMING DIFFERENT OPERATIONS

2nd order ring filter

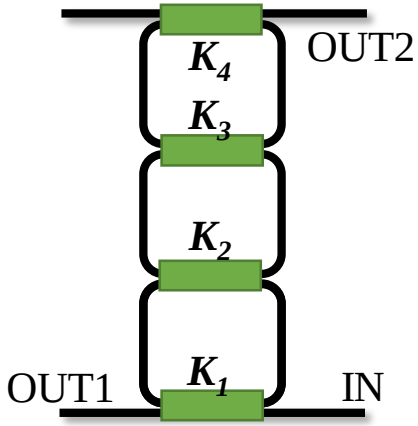


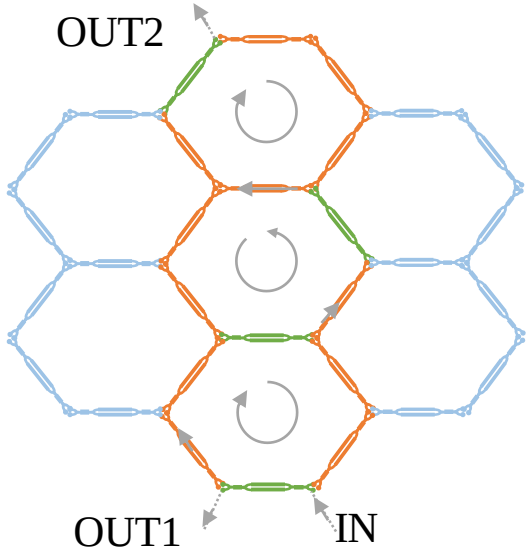
Tunable Coupler

Phase Shifter

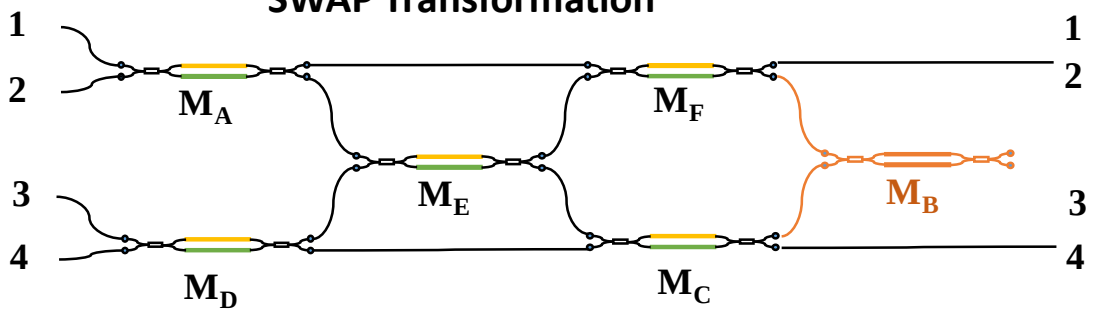


3rd order ring filter

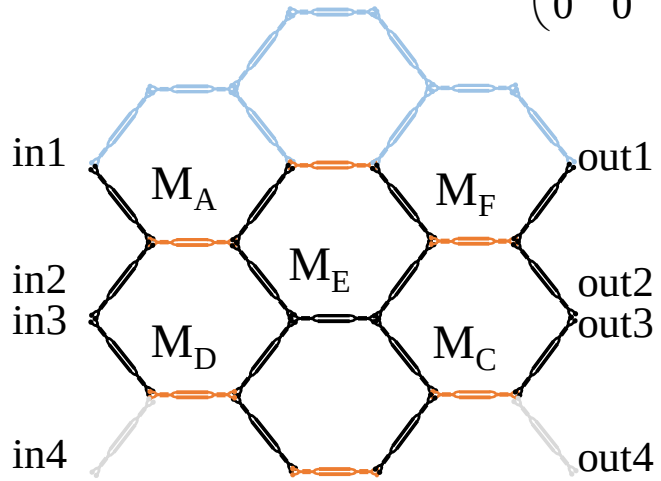




SWAP Transformation



$$U_{SWAP} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$



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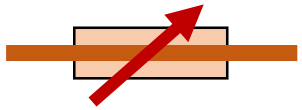
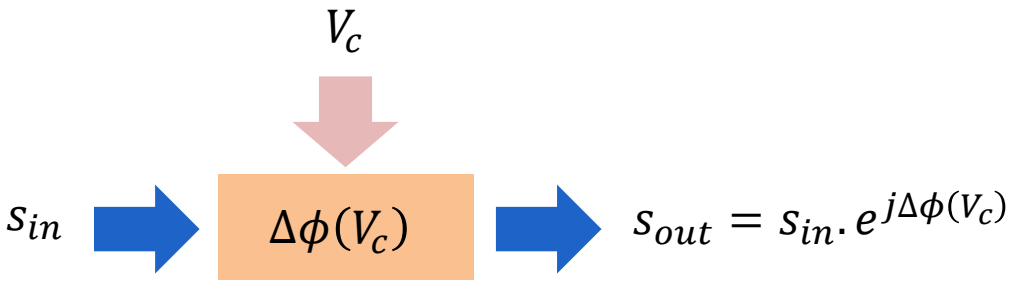
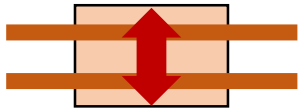
THE ESSENTIAL BUILDING BLOCKS

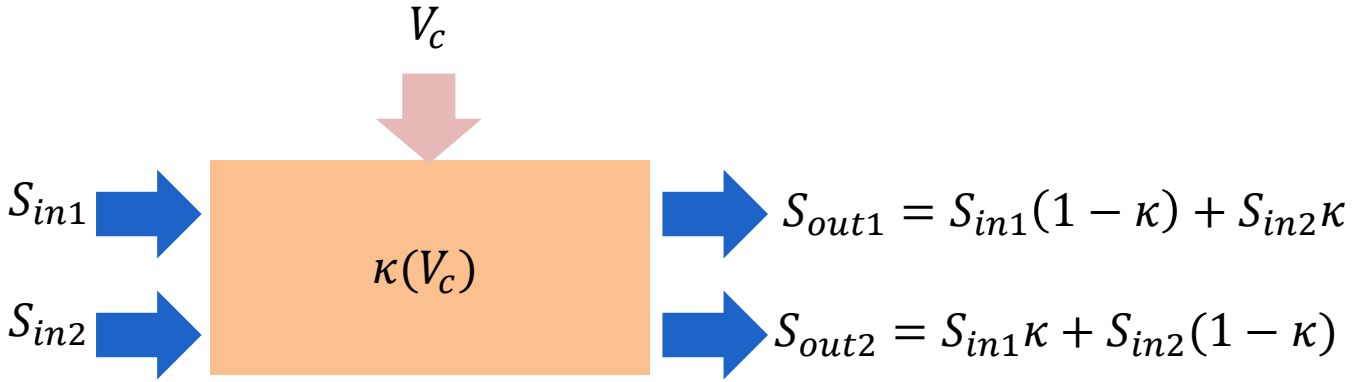
Phase Shifters

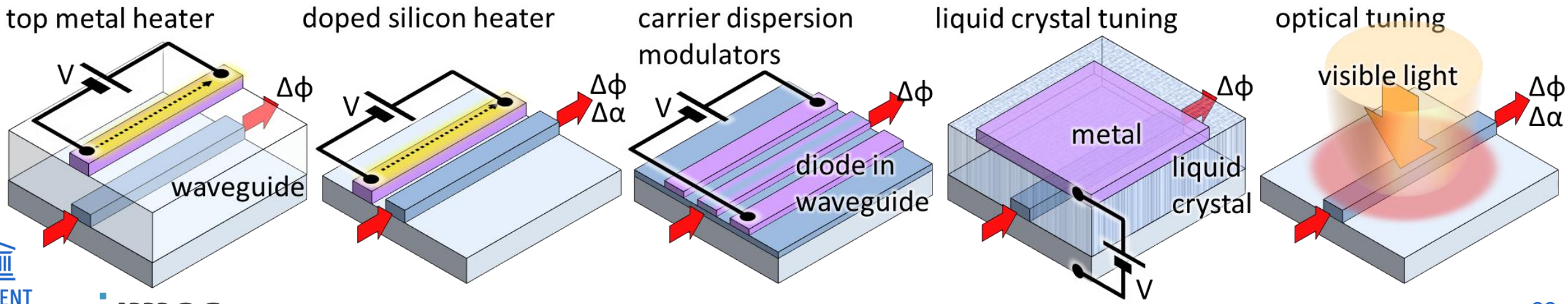




Tunable Couplers

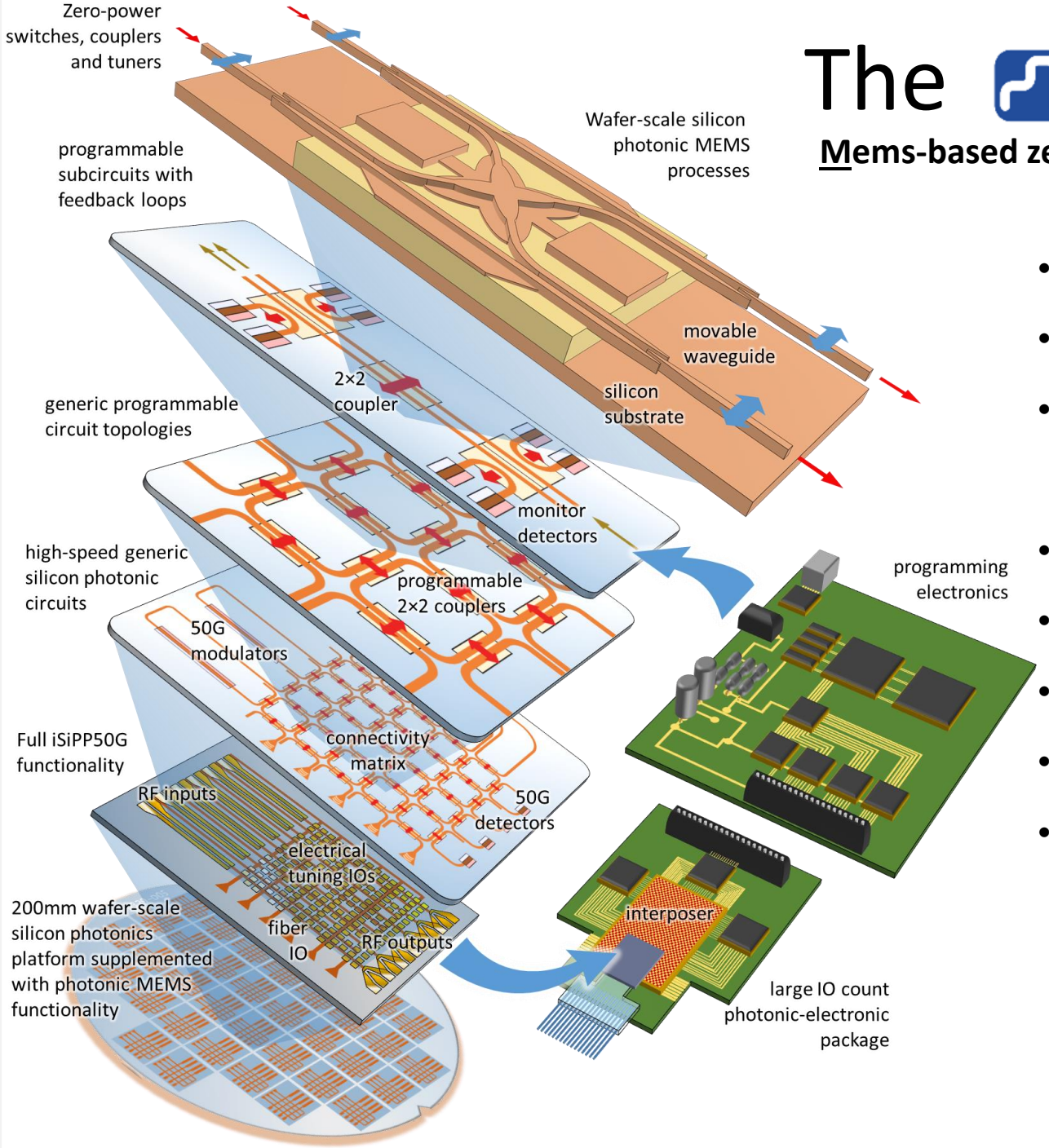






The morphic Project

Mems-based zerO-power Reconfigurable PHotonic ICs



- State-of-the-art Silicon Photonics
- Photonic Waveguide MEMS
- Non-volatile switching

- Large-scale Programmable circuits
- Full electronic reconfigurability
- High-density packaging
- Programming tools
- Diverse application demonstrators
  - Large-scale switches
  - Beam forming and steering
  - Microwave Photonics filters

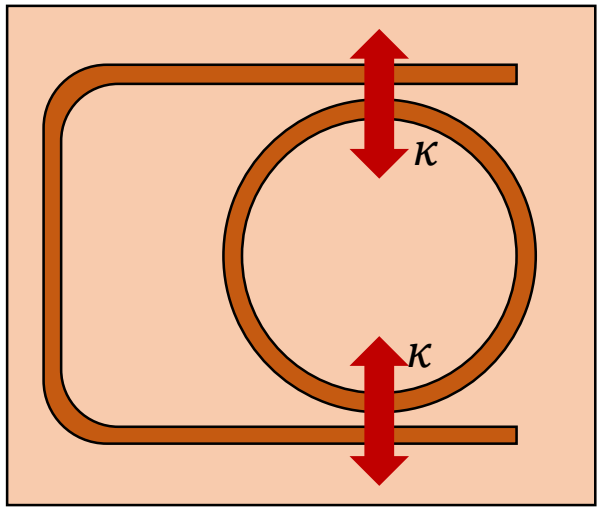
PHOTONICS PUBLIC PRIVATE PARTNERSHIP

The MORPHIC project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 780283. This project is an initiative of the Photonics Public Private Partnership.

www.h2020morphic.eu

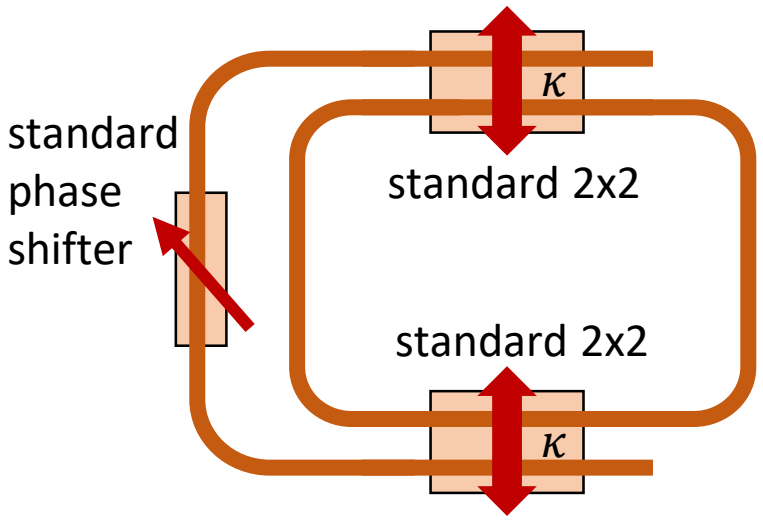
A New way of Designing Functionality

Full Custom design



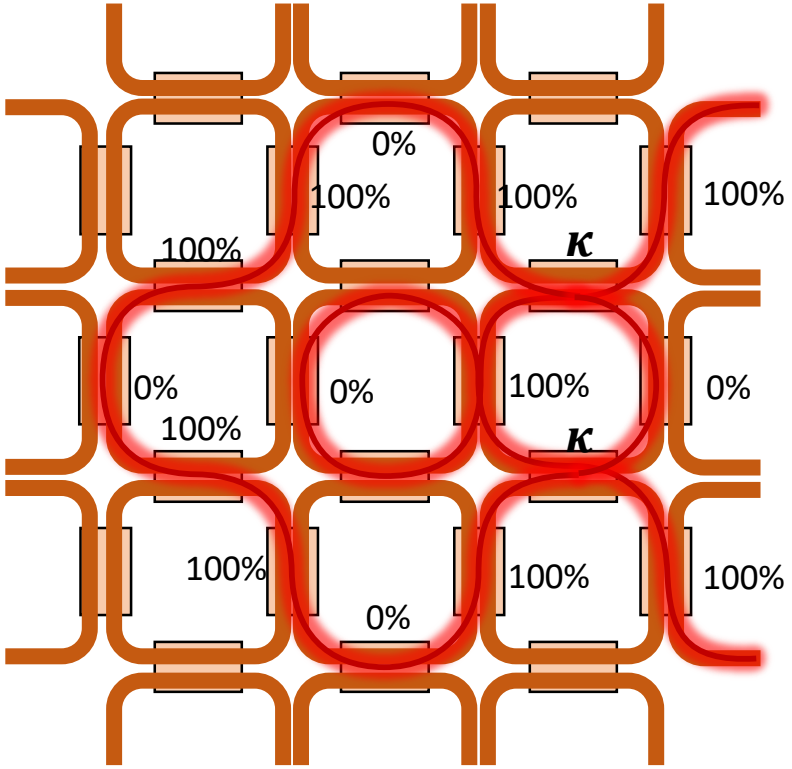
Full custom geometry design

PDK-based Circuit Design



Custom circuit design with standard tunable couplers and phase shifters

Programming The Circuit



Circuit definition by programming a waveguide mesh

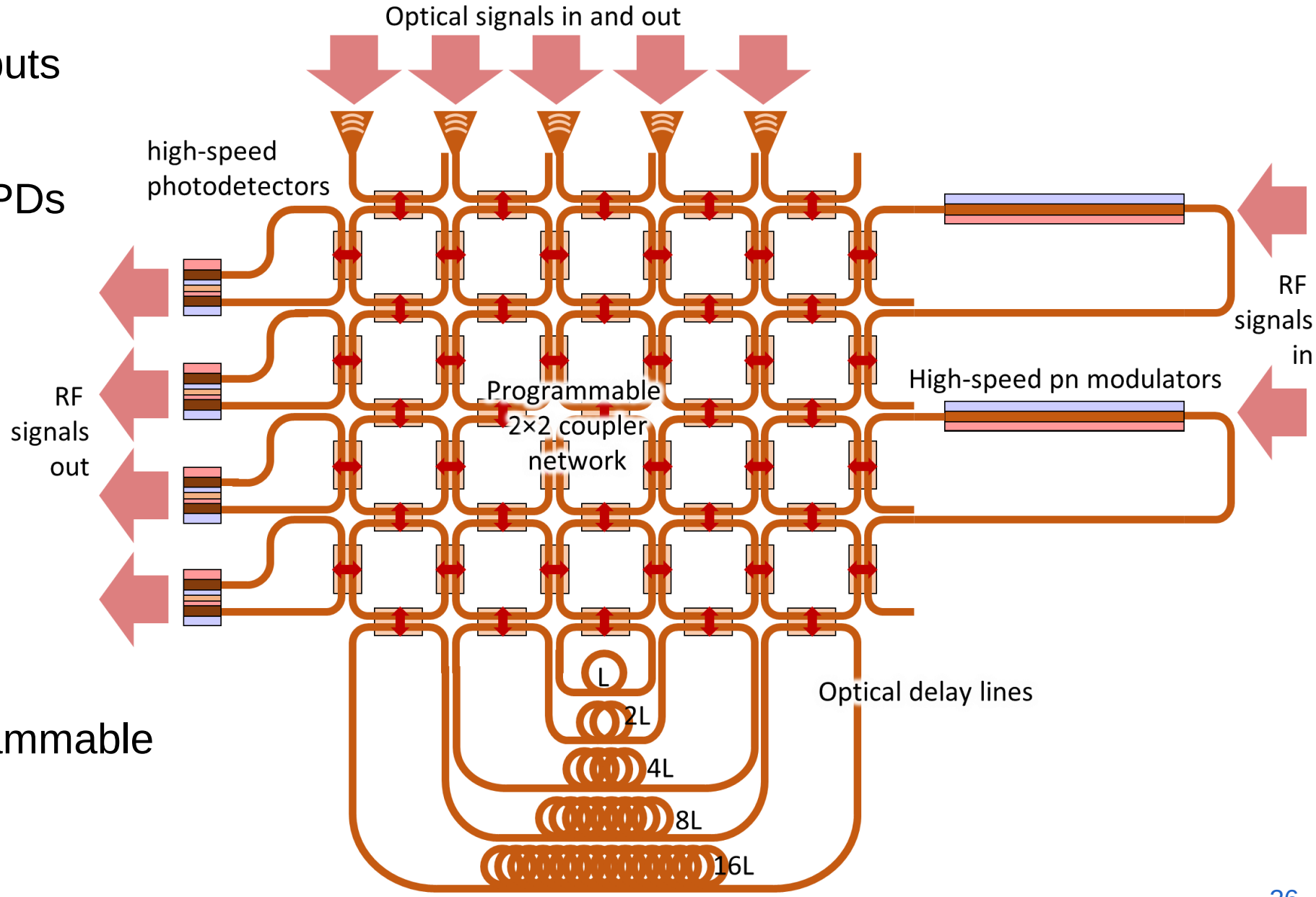
Generic Programmable Photonic Circuit

Optical inputs and outputs

RF inputs: modulators

RF outputs: balanced PDs

Long delays for filters

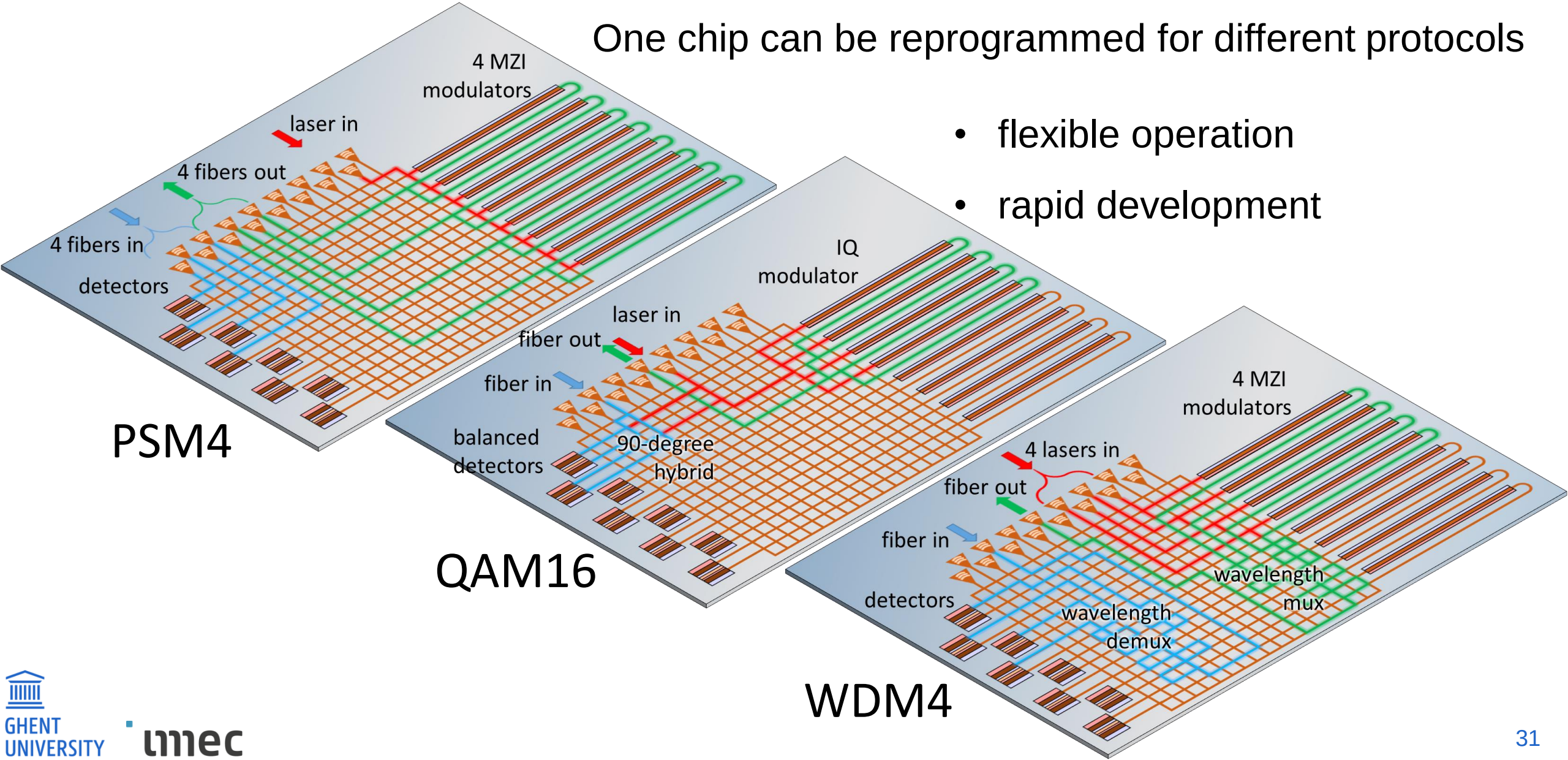


Connected by a programmable linear optical circuit

PROGRAMMABLE TRANSCEIVERS

One chip can be reprogrammed for different protocols

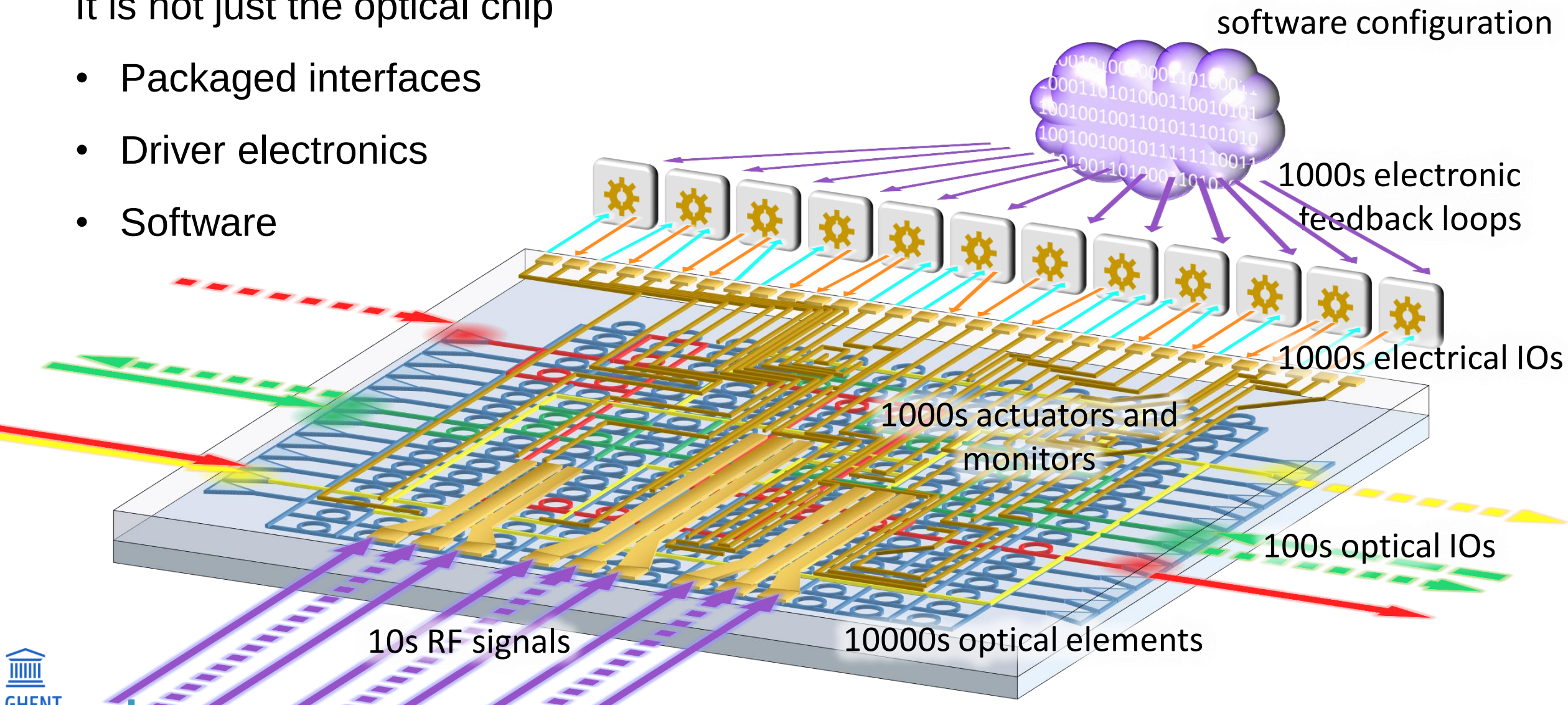
- flexible operation
- rapid development



More than just photons

It is not just the optical chip

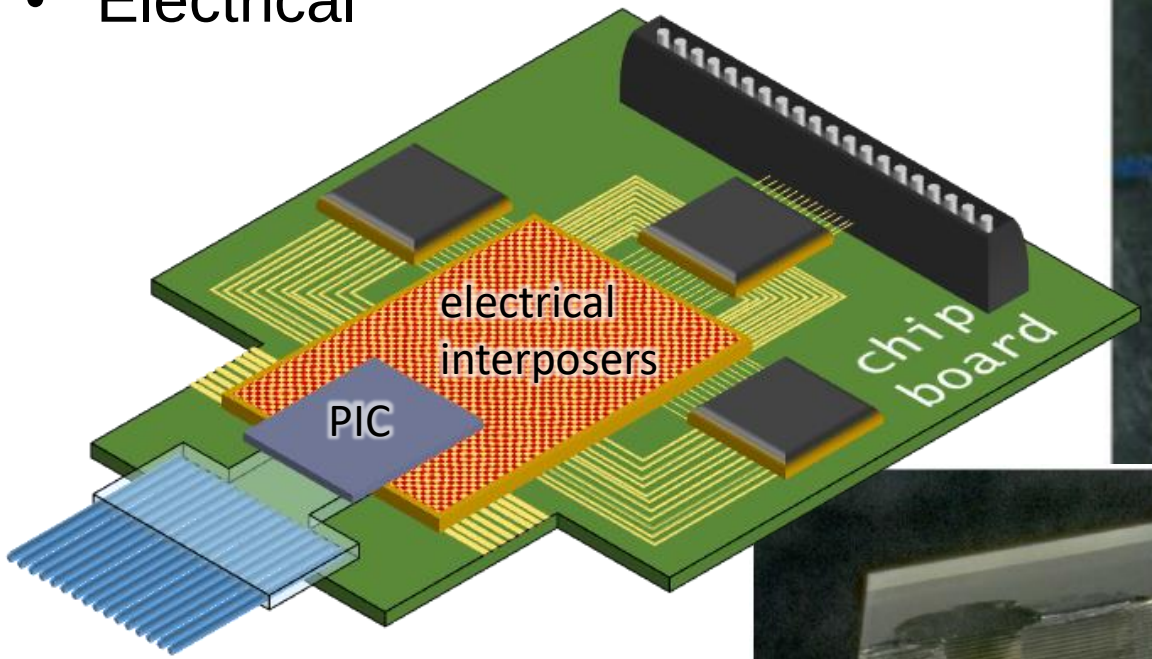
- Packaged interfaces
- Driver electronics
- Software



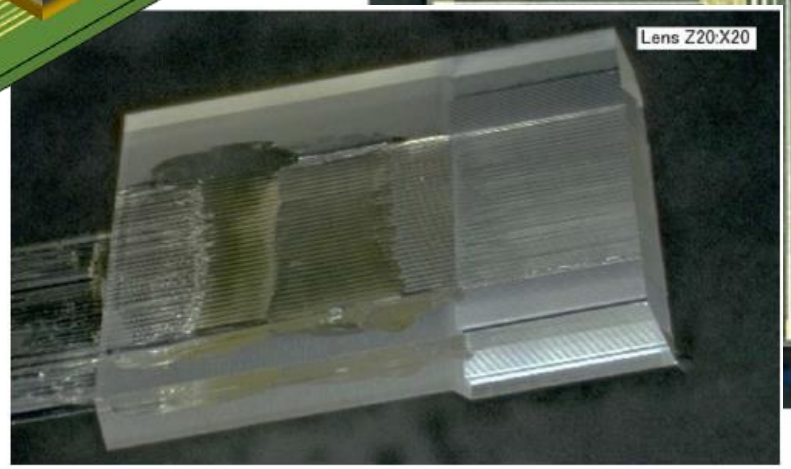
PACKAGING AND TESTING

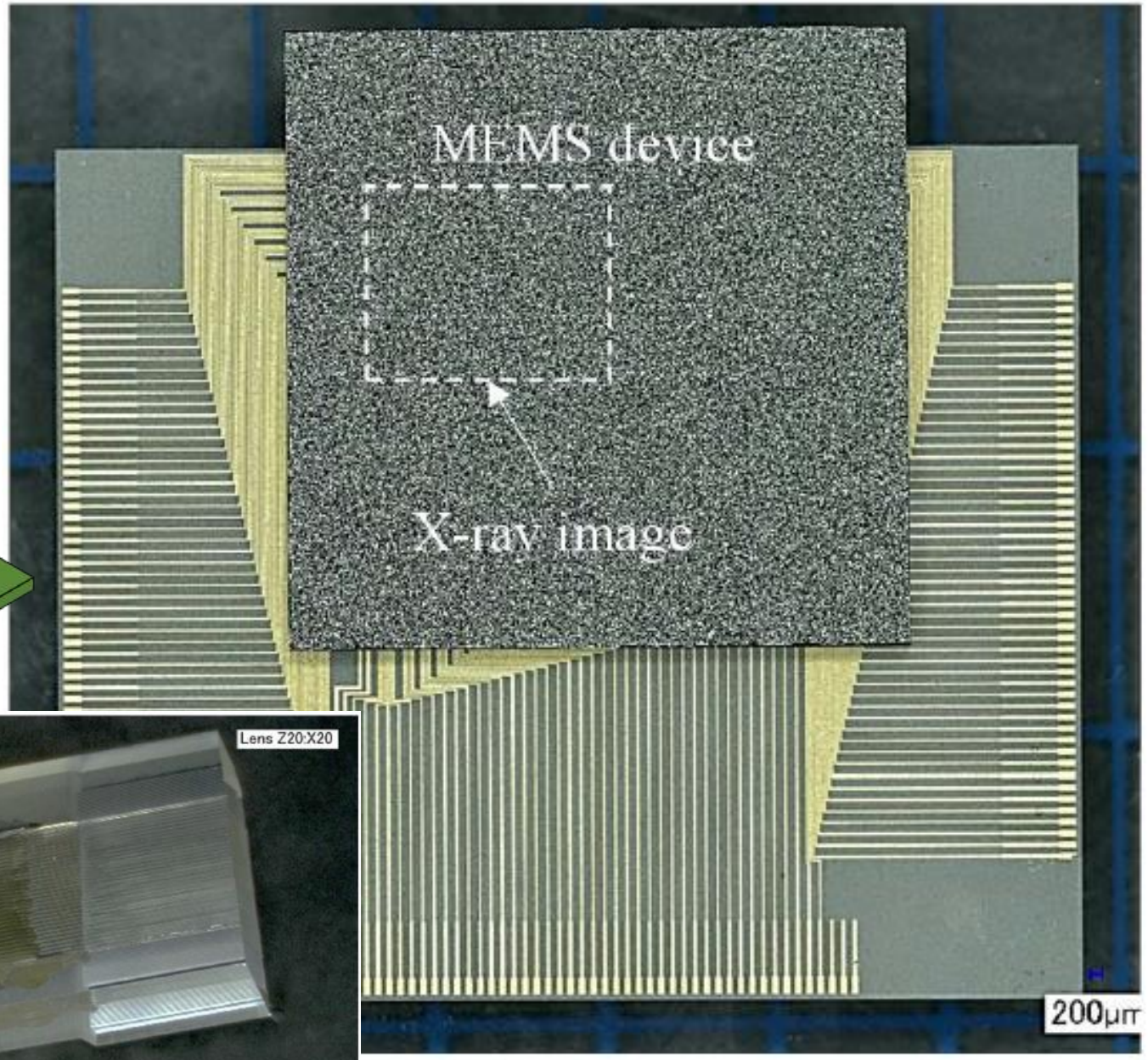
Need for large number of IOs

- Optical
- Electrical



Fiber arrays or
optical interposers

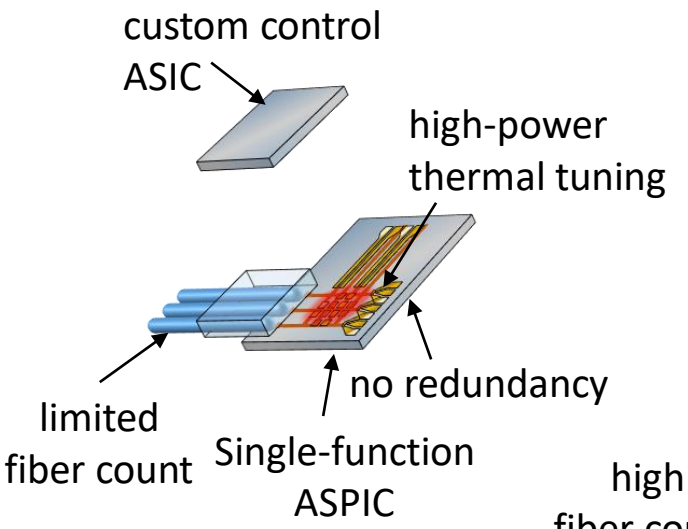




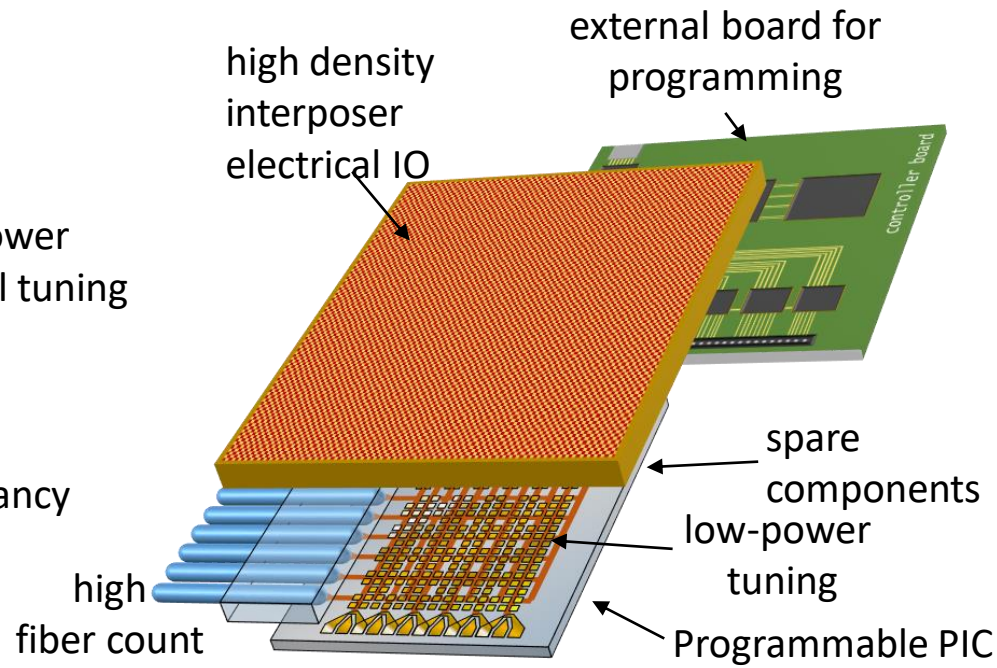
Hwang et al. EPTC2016

SCALING PROGRAMMABLE PICS

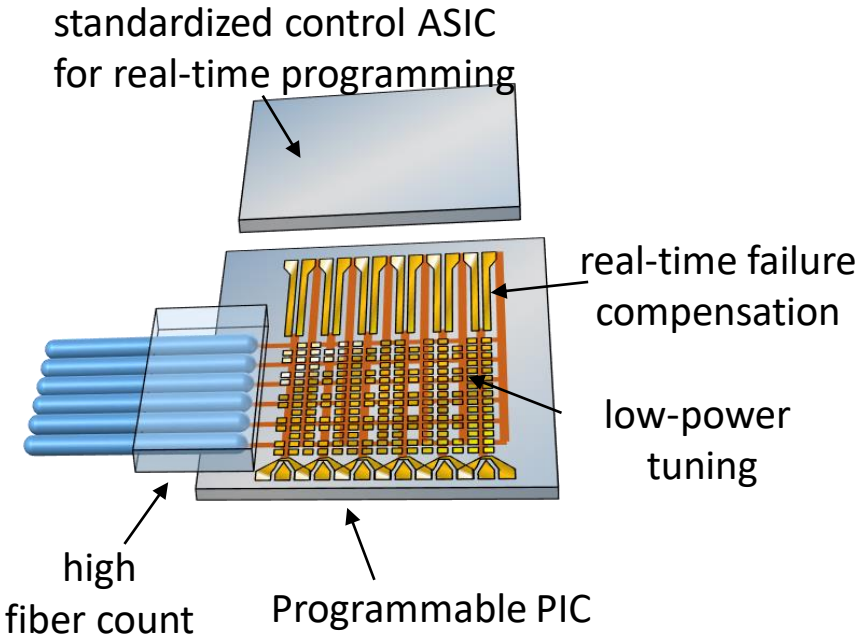
Today's Silicon Photonics Technology



Emerging Programmable Photonic Circuits



The Fully Generic Programmable PIC



Increasing complexity, functionality, flexibility

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CHANGING THE ECOSYSTEM

Larger chip manufacturing volumes

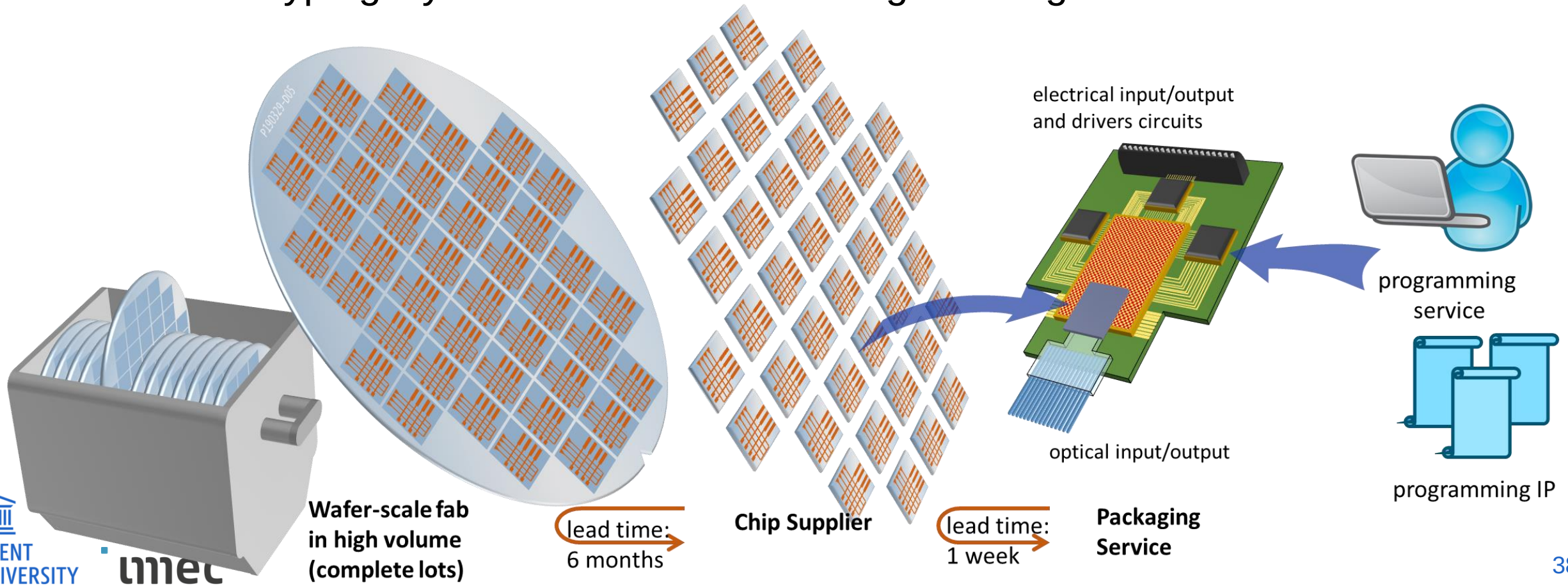
Smaller end-user purchase volumes

Faster Prototyping Cycle

New role for chip suppliers

Specialized Packaging

Programming services and IP creation



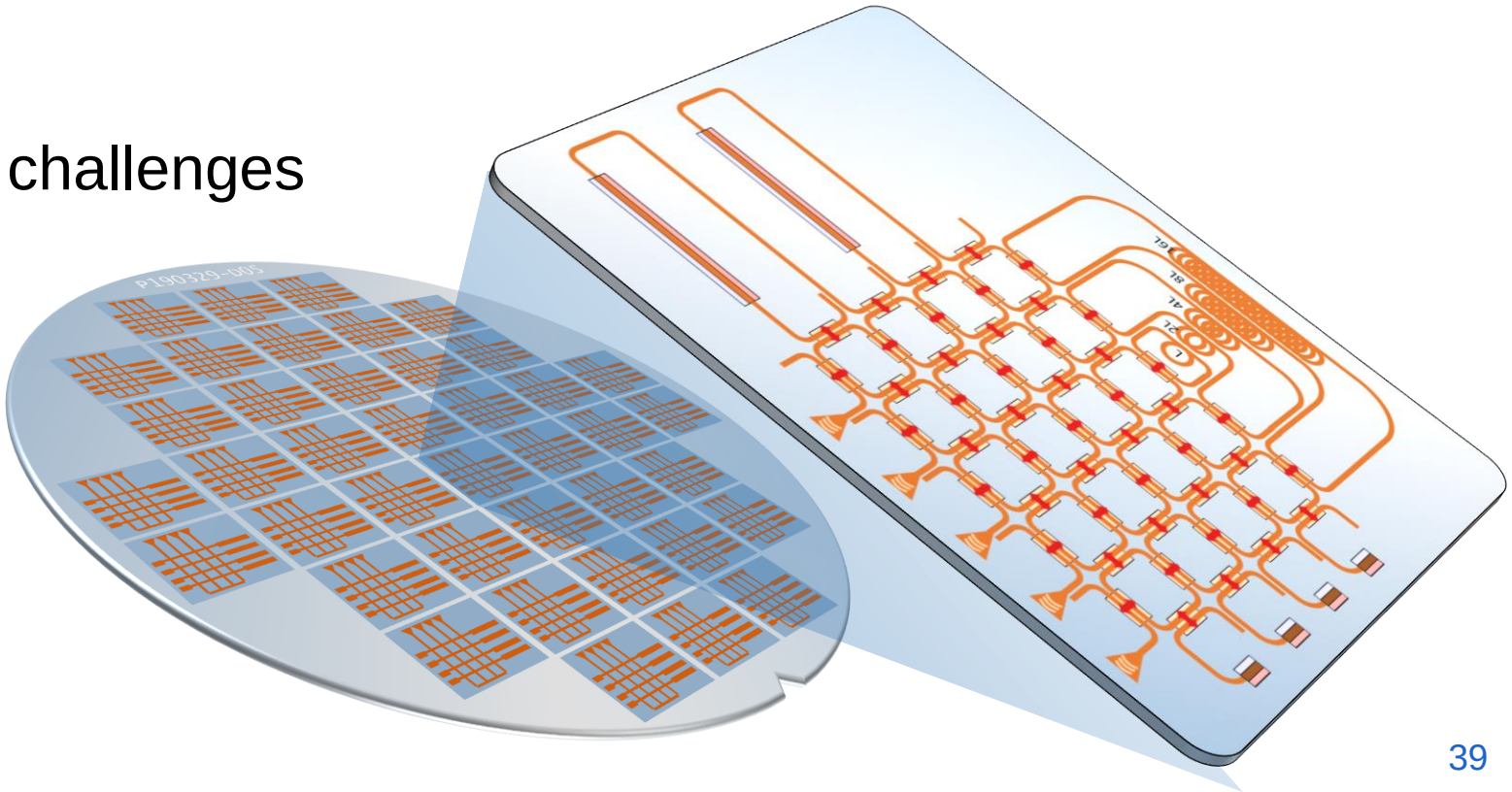
SUMMARY: PROGRAMMABLE PICS

Programmable PICs can be a game-changer:

- Rapid development
- High performance
- Different applications

Rapid scaling will expose new challenges

- power consumption
- accumulated loss/parasitics
- control
- packaging



PHOTONICS RESEARCH GROUP

PHOTONICS PUBLIC PRIVATE PARTNERSHIP

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nb-photonics Center for Nano- and Biophotonics Ghent University

erc European Research Council