LION Meeting

LNOI Top-Down Fabrication and time-multiplexed MZI

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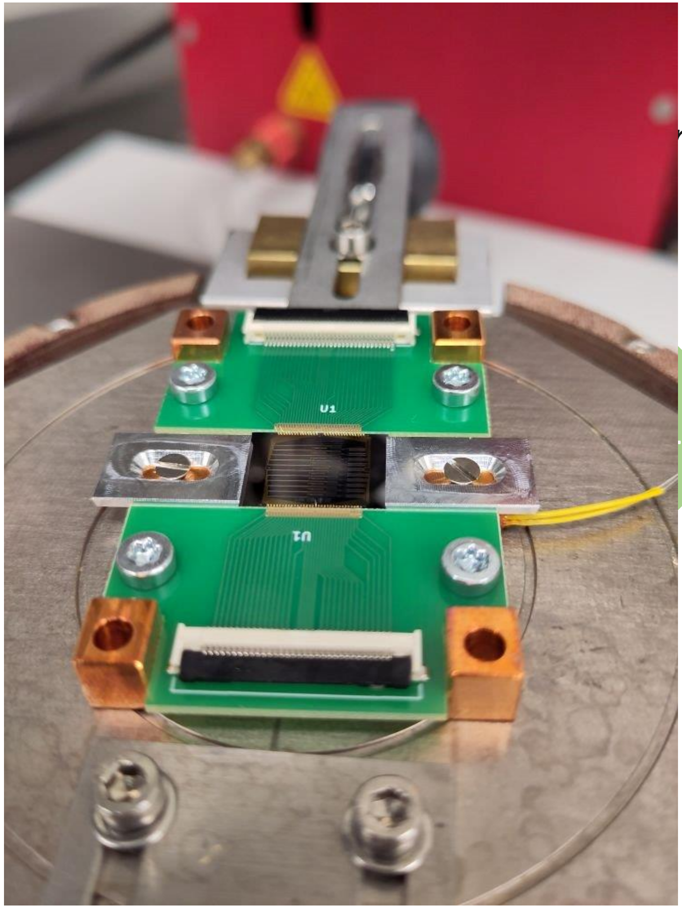
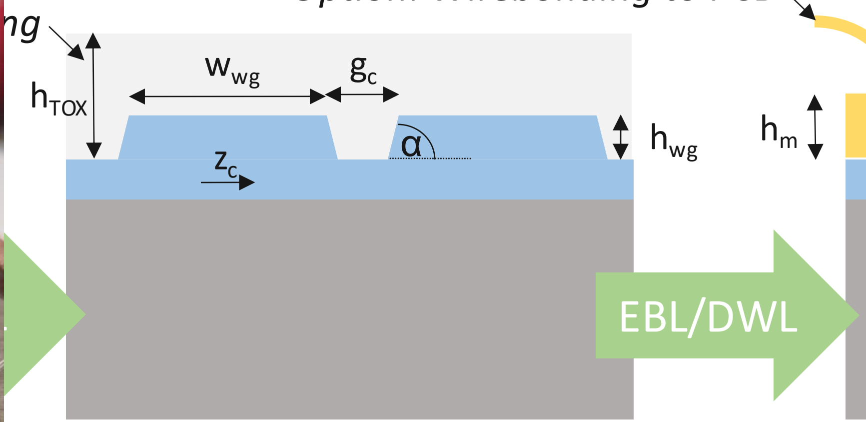
LNOI - General Fab



Waveguide Etching

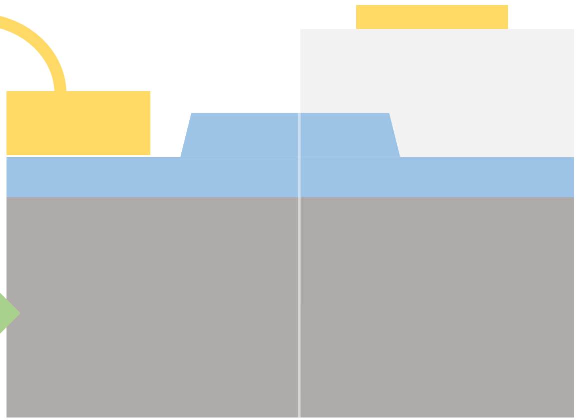
Option: Wirebonding to PCB



- w_{wg} = 1.2 µm (IR) / 0.6 µm (NIR)
- h_{wg} = 200 nm
- $g_c \geq$ 400 nm
- α ~ 65°
- *Optional: $h_{TOX} \leq 2\ \mu m$*

0.2 dB/cm

Metallization(s)

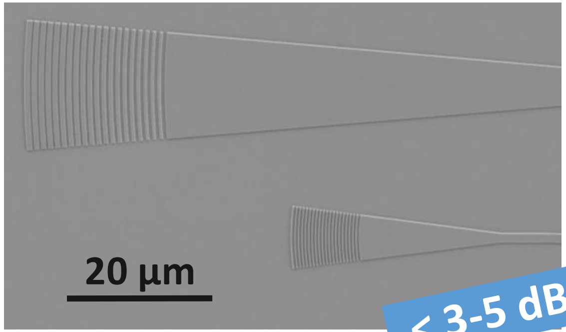


- Metals: **Au**, Cr, Pt, Ti
- $h_m \lesssim 300\ nm$
- max. 64 DC electrical connections

Kaufmann et al. Nanophotonics (2024)

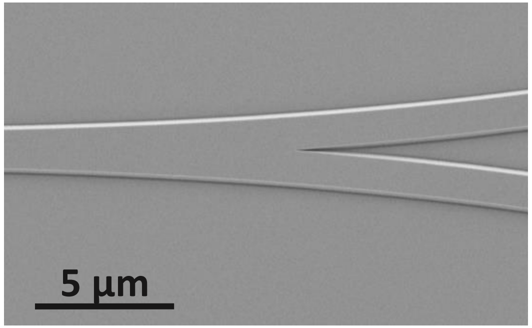
LNOI - Passive Components

Grating Couplers

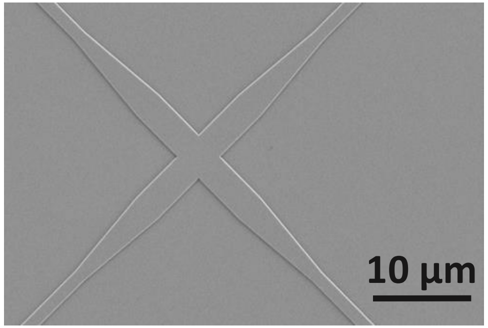


< 3-5 dB/cm

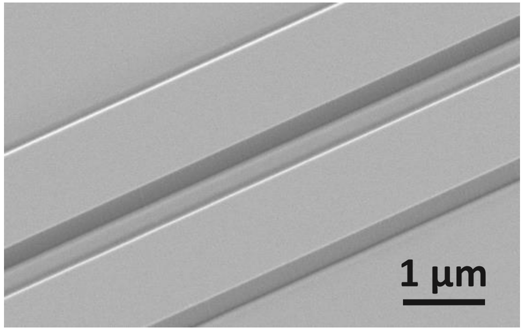
Y-Splitters



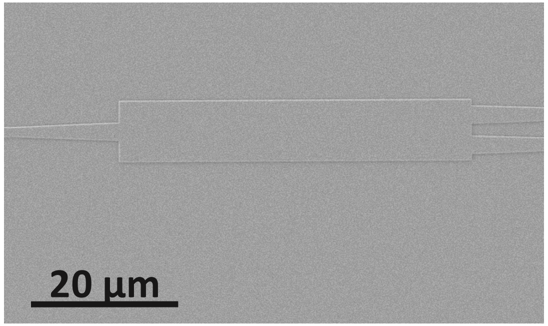
Crossings



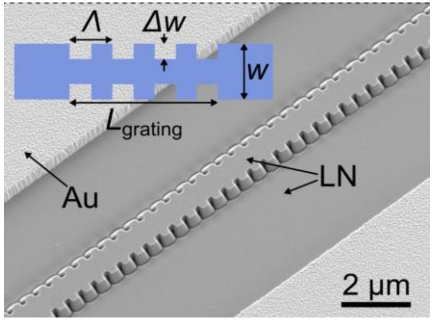
Directional Couplers



1x2 MMIs



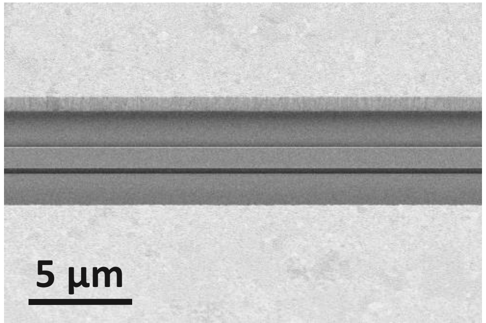
Bragg Reflectors

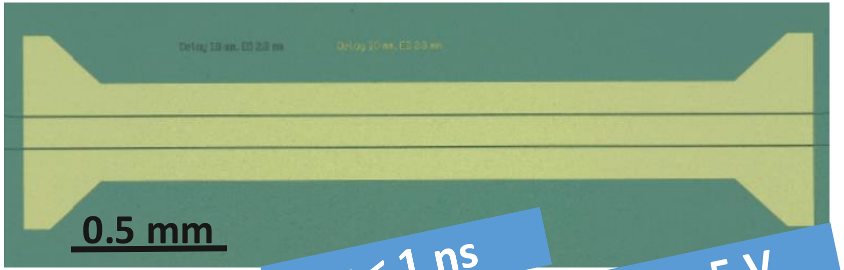


Pohl et al. IEEE Photonics Technology Letters, vol. 33, no. 2 *(2021)*

LNOI - Active Components

Electro Optic Phase Shifters

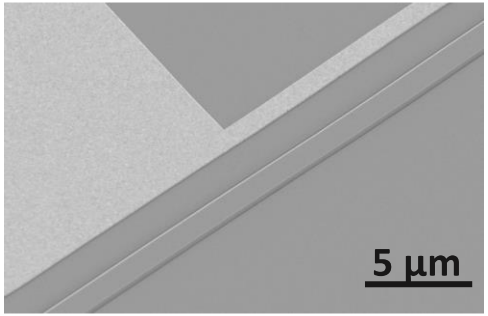


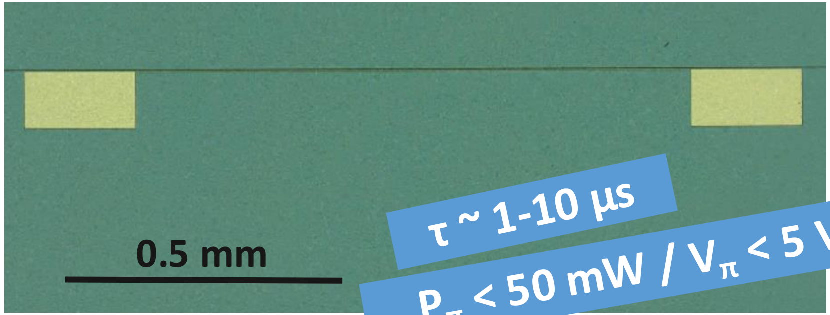


$\tau < 1$ ns

$V_\pi < 5$ V

Thermo Optic Phase Shifters

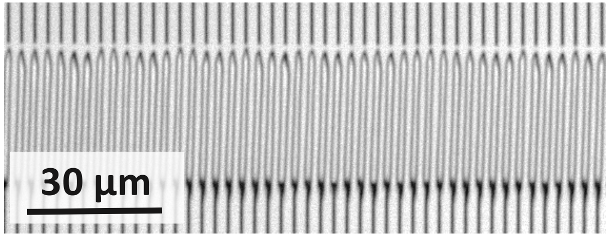


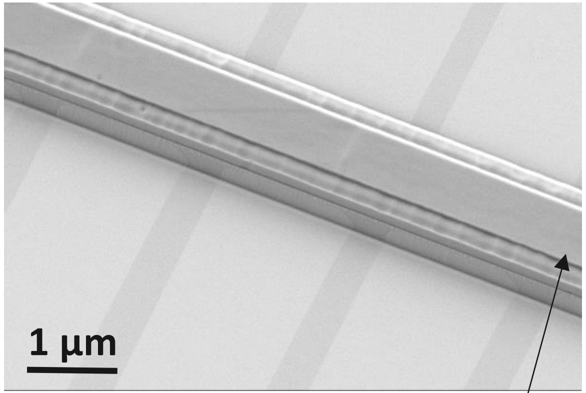


$\tau \sim 1\text{-}10$ µs

$P_\pi < 50$ mW / $V_\pi < 5$ V

Periodic Poling



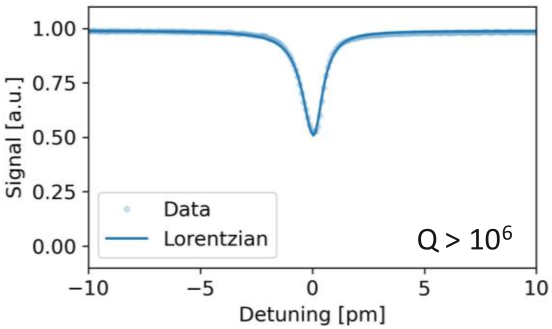


Remaining resist after etching

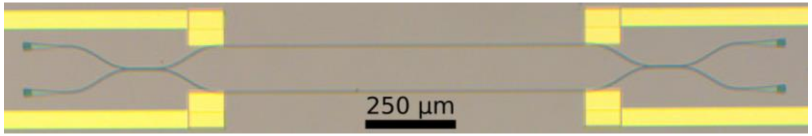
Sabatti et al. arXiv:2404:09787
Chapman et al. arXiv:202408378

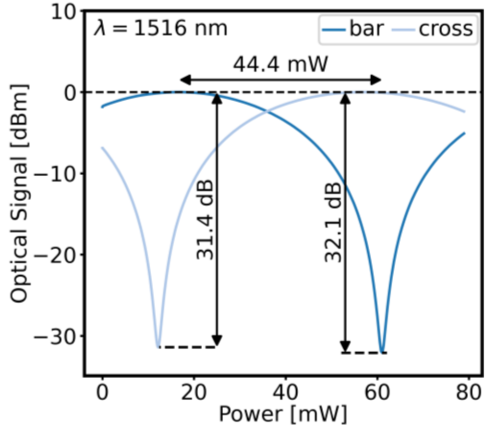
LNOI - Basic Devices

Ring and Racetrack Resonators



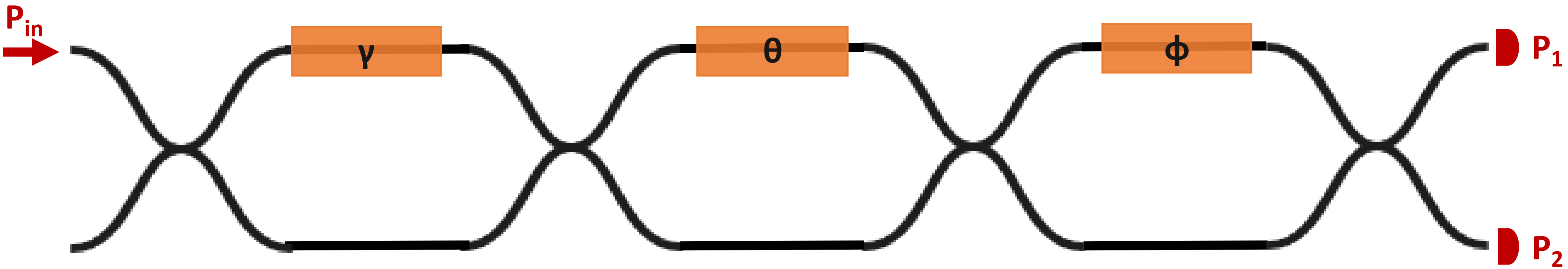
Mach-Zehnder Interferometers



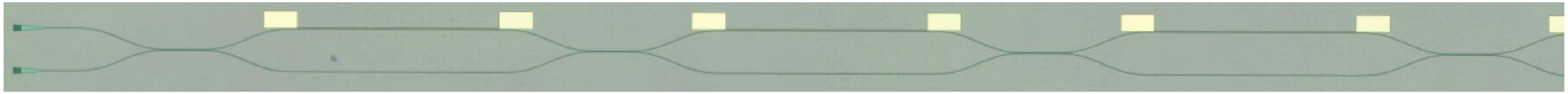


Maeder et al. 2024 Quantum Sci. Technol. ***9*** *035040*

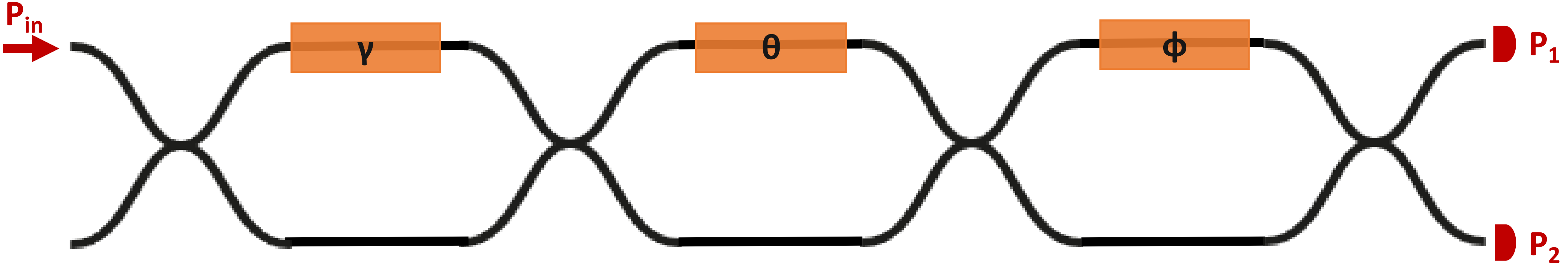
Cascaded MZI - Idea



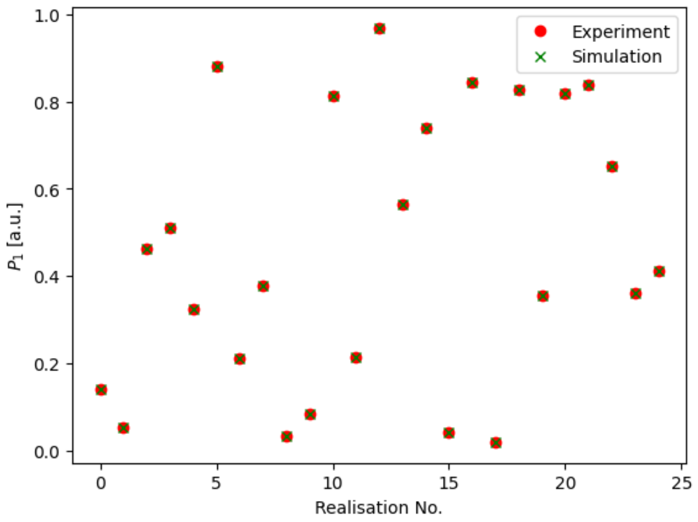
- General Idea: Time-multiplexing to implement complex Mesh
  - Prepare State using γ and θ
  - ϕ is the trained parameter of the MZI
  - Measure output Intensities
- Implementation
  - Based on existing chip
  - Fundamental Idea is there
  - Not ideal since further splitting and crossing



Cascaded MZI - Calibration



- Experimentally, Voltages are applied to the phase-shifters
- Key task: Characterization to find $\gamma = f(V_1)$, $\theta = f(V_2)$, $\phi = f(V_3)$
- *If* this is achieved, we invert these relationships to find the voltages corresponding to specific phases



Cascaded MZI - Calibration *or the devil's in the detail*

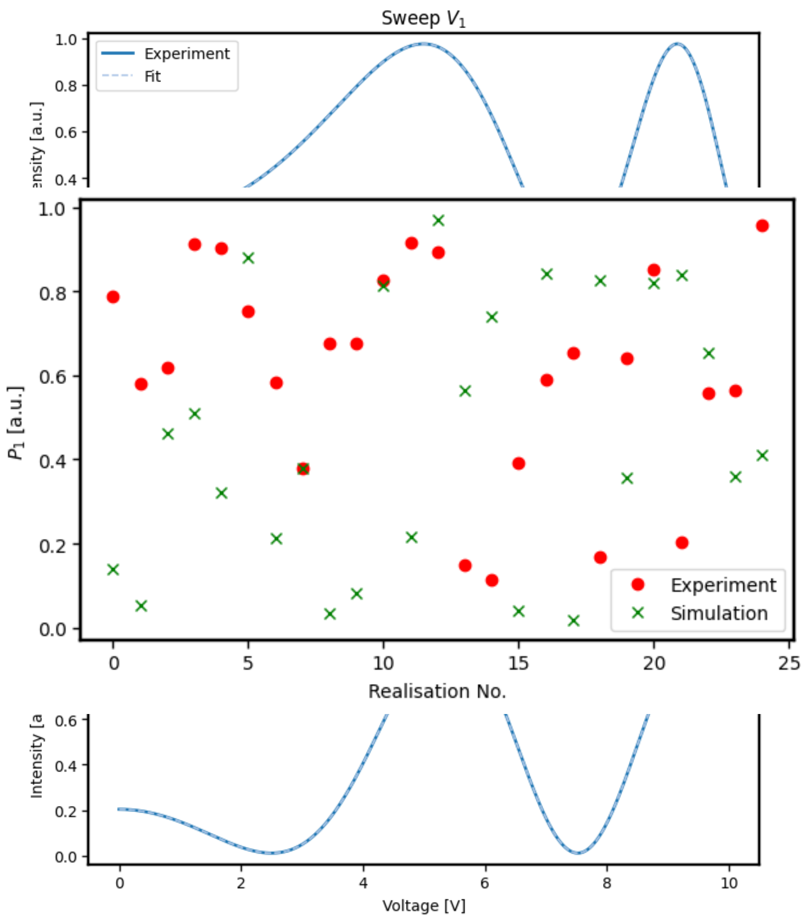
- Assumption for the calibration functions

$$f(V_1) = \gamma_0 + \alpha_\gamma V_1^2 + \beta_\gamma V_1^4$$
$$f(V_2) = \theta_0 + \alpha_\theta V_2^2 + \beta_\theta V_2^4$$
$$f(V_3) = \phi_0 + \alpha_\phi V_3^2 + \beta_\phi V_3^4$$

- Sweep one voltage at a time and fit the result
  - Doesn't work

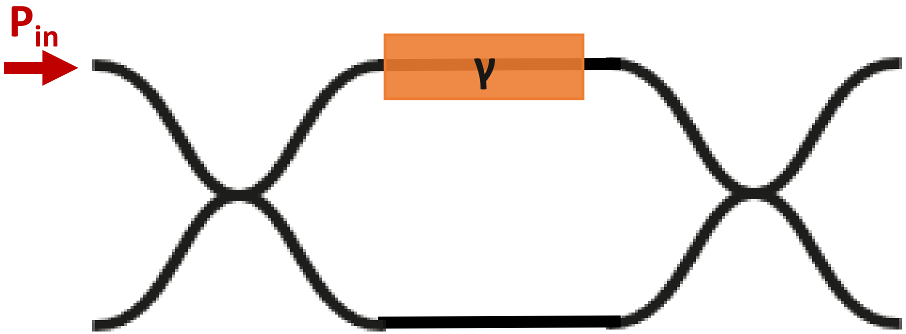
```
Phase Gamma
        Alpha:        0.085         0.085
        Beta:         2.00e-04      2.00e-04
        Gamma0:       2.35          4.04
Phase Theta
        Alpha:        0.123         0.123
        Beta:         1.00e-06      1.00e-06
        Theta0:       5.97          2.83
Phase Phi
        Alpha:        0.150         0.150
        Beta:         -4.00e-04     -4.00e-04
        Phi0:         4.60          2.22
```

- A global fit showed more promising results, but ...



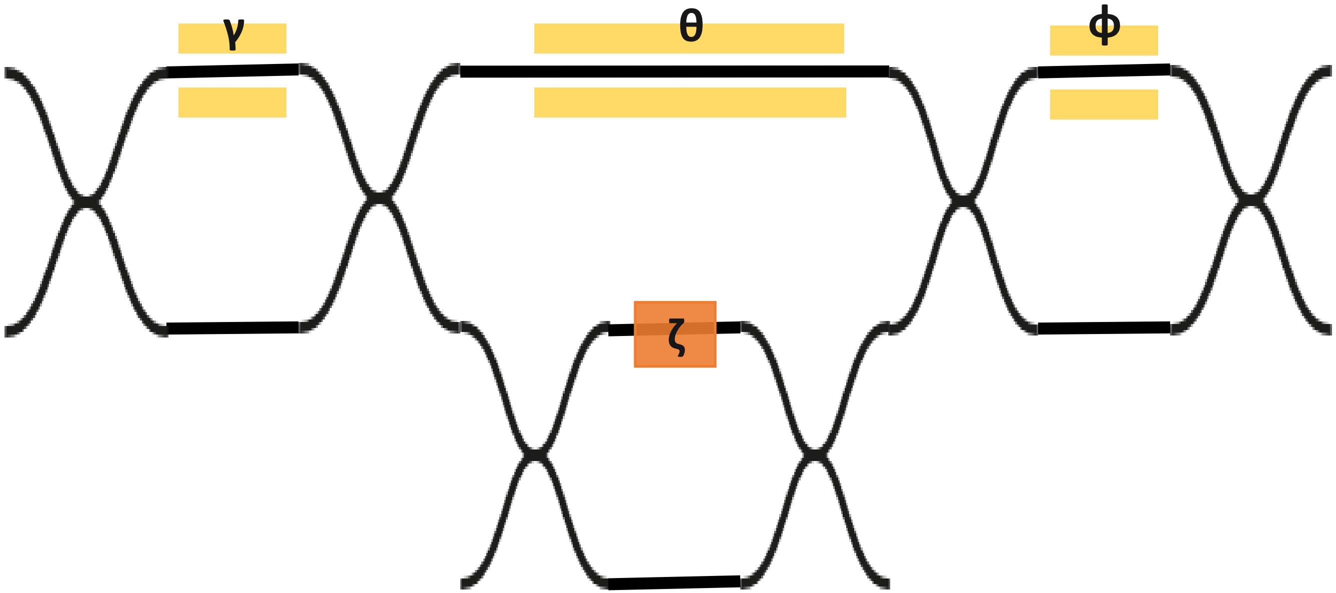
Cascaded MZI - Calibration *or the devil's in the detail*

- … offset phases depend on other parameters
  - Splitting Ratio R
  - Loss imbalance a
- In the current design, those are hard (if not impossible) to determine
- I propose to think about a new, smart design, which may even be able to benefit more from the LNOI capabilities



$$\begin{pmatrix} \sqrt{R} & i\sqrt{T} \\ i\sqrt{T} & \sqrt{R} \end{pmatrix} \quad \begin{pmatrix} a_1 e^{i\gamma} & 0 \\ 0 & 1 \end{pmatrix} \quad \begin{pmatrix} \sqrt{R} & i\sqrt{T} \\ i\sqrt{T} & \sqrt{R} \end{pmatrix}$$

Cascaded MZI - Proper, Smart Design



- Switch to EO for speed
    - Though there might be drift issues
- Add additional MZI for characterization of the phases
- Potentially even add phase measurement