

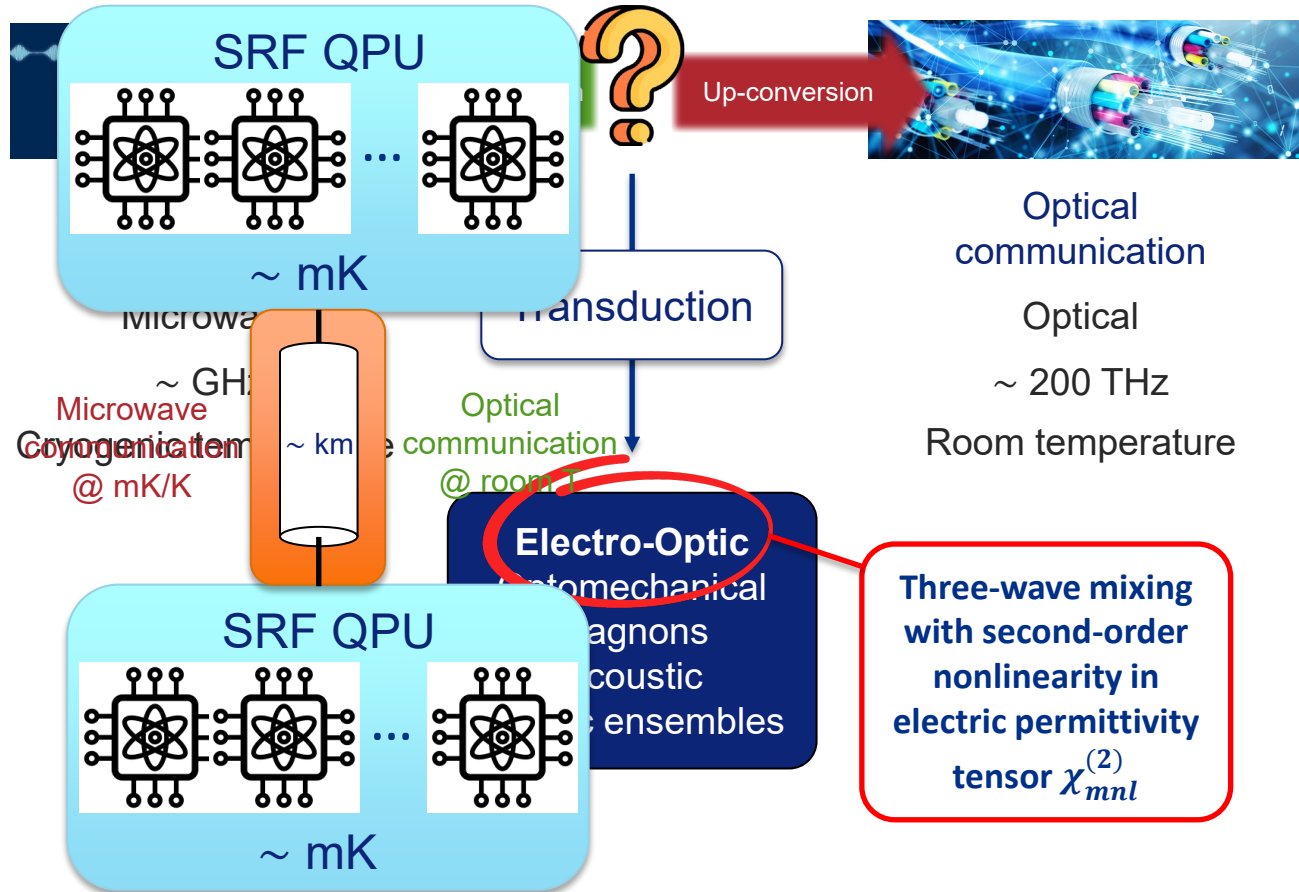


# A Compact Monolithic Electro-Optic Package for Quantum Microwave-to-Optical Transduction

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Alessandro Reineri, Silvia Zorzetti, Chagqing Wang, Julian Delgado

# Quantum communication – towards scalability



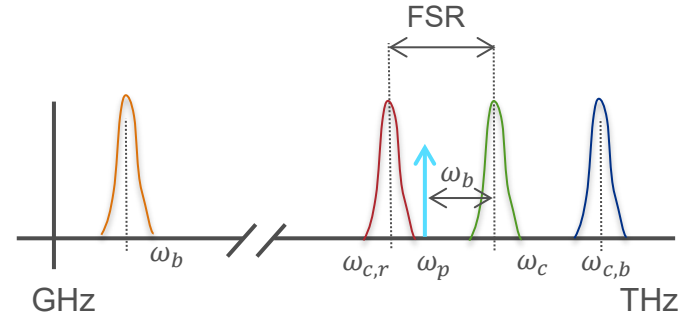
# Electro-optic based quantum transduction – overview

- 3 wave mixing process enabled by  $\chi_{mnl}^{(2)}$  nonlinearity of an electro-optic crystal:

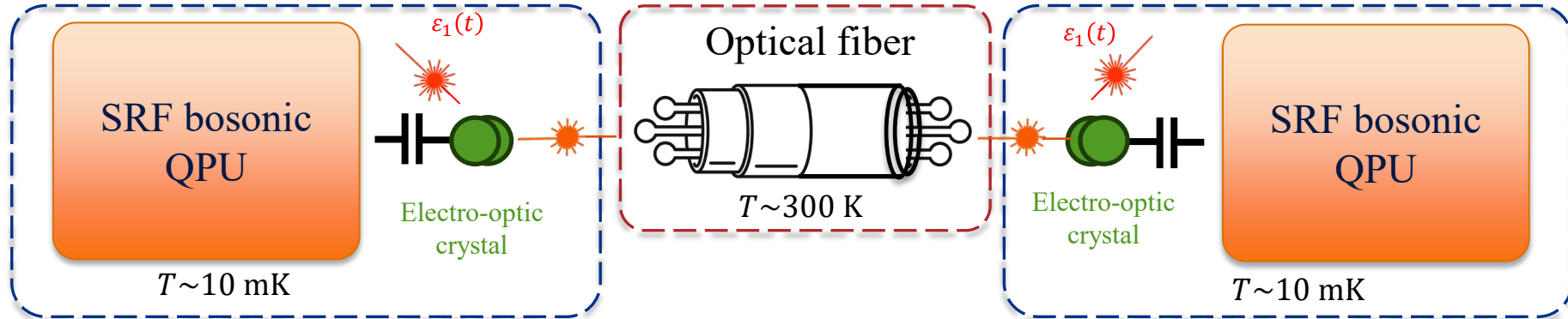
- Parametric beamsplitter operation

$$\hat{H}_{bs} = g(t)(\hat{b}\hat{c}^\dagger + \hat{b}^\dagger\hat{c})$$

- Microwave mode of SRF bosonic QPU + detuned laser pump = crystal WGM (radiating in the fiber);

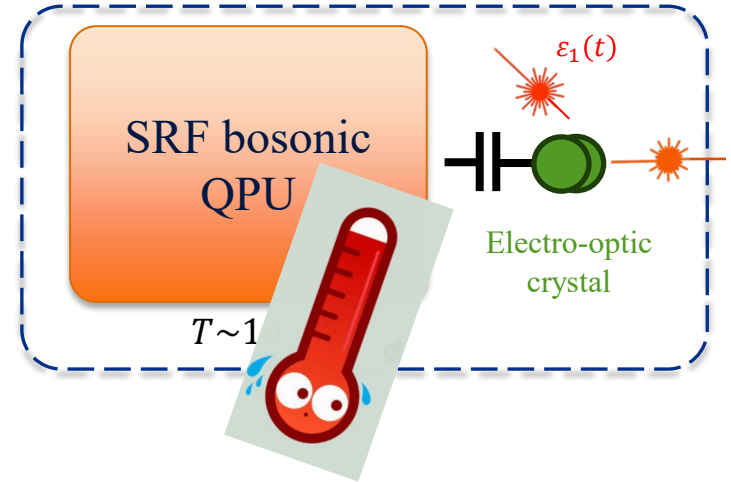


- Fully reversible (pitch and catch scheme).



# Electro-optic based quantum transduction – challenges

- Cryogenics: part of laser pump power converted into heat, rising temperature
  - Disruption of calculations in the bosonic QPU;
  - Contamination of the state to transfer.
- Quantum state encoding: eo crystals are dielectrics, showing very low  $Q_{mw}$ 
  - Inability to encode state directly in cavity with eo crystals and transmon as ancilla.



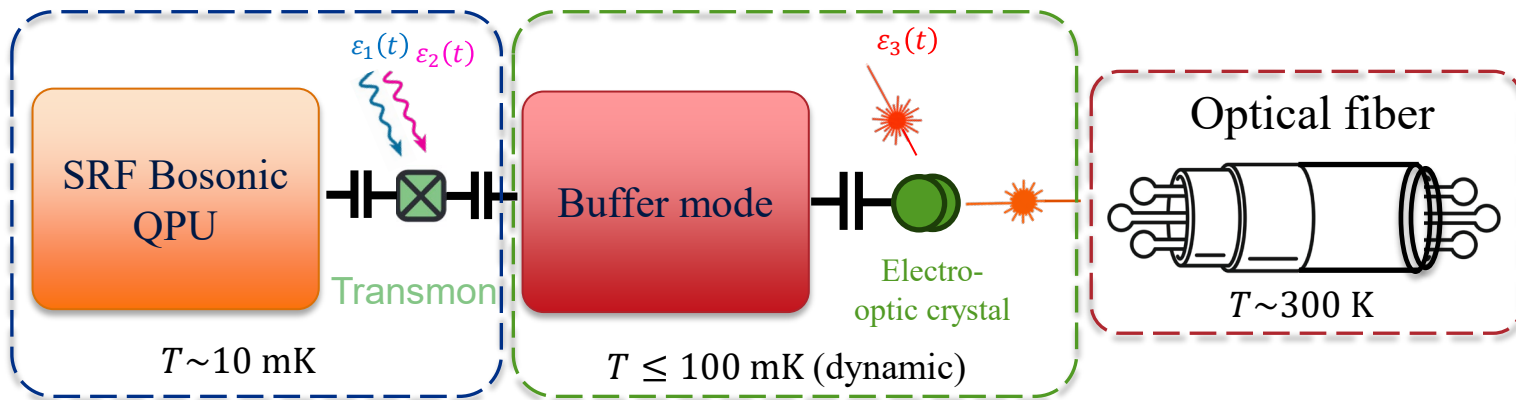
Solution: decouple QPU from transducer with buffer mode

Material	$Q_{0,\parallel}(\bar{n} \rightarrow 0)$	$Q_{0,\perp}(\bar{n} \rightarrow 0)$
LiNbO <sub>3</sub>	$1.1 \times 10^5$	$4.7 \times 10^4$
AlN	$8.2 \times 10^4$	$7.0 \times 10^4$

$T \sim 10$  mK,  $\nu \sim 10$  GHz

# Implementation of a buffer mode

## Quantum transduction unit (QTU)



- Transmon to dynamically couple QPU with buffer mode
  - 4 wave mixing parametric interaction to transfer state from QPU to buffer;
- Buffer mode mixed with laser pump (transduction stage)
  - 3 wave mixing process with high power demand;
  - Transfer state from buffer to eo crystal target WGM;
  - **Spatially and temporally separated from 4wm process**, to prevent information loss and disruption from thermal effects;

Quantum transduction becomes a relay (SWAP-SWAP) process

# SWAP-SWAP – results from QuTip lossless simulations

- Start with  $|1\rangle$  in QPU mode  $\hat{a}$ ;

- Perform 4wm

$$\omega_a - \omega_b = \omega_1 - \omega_2$$

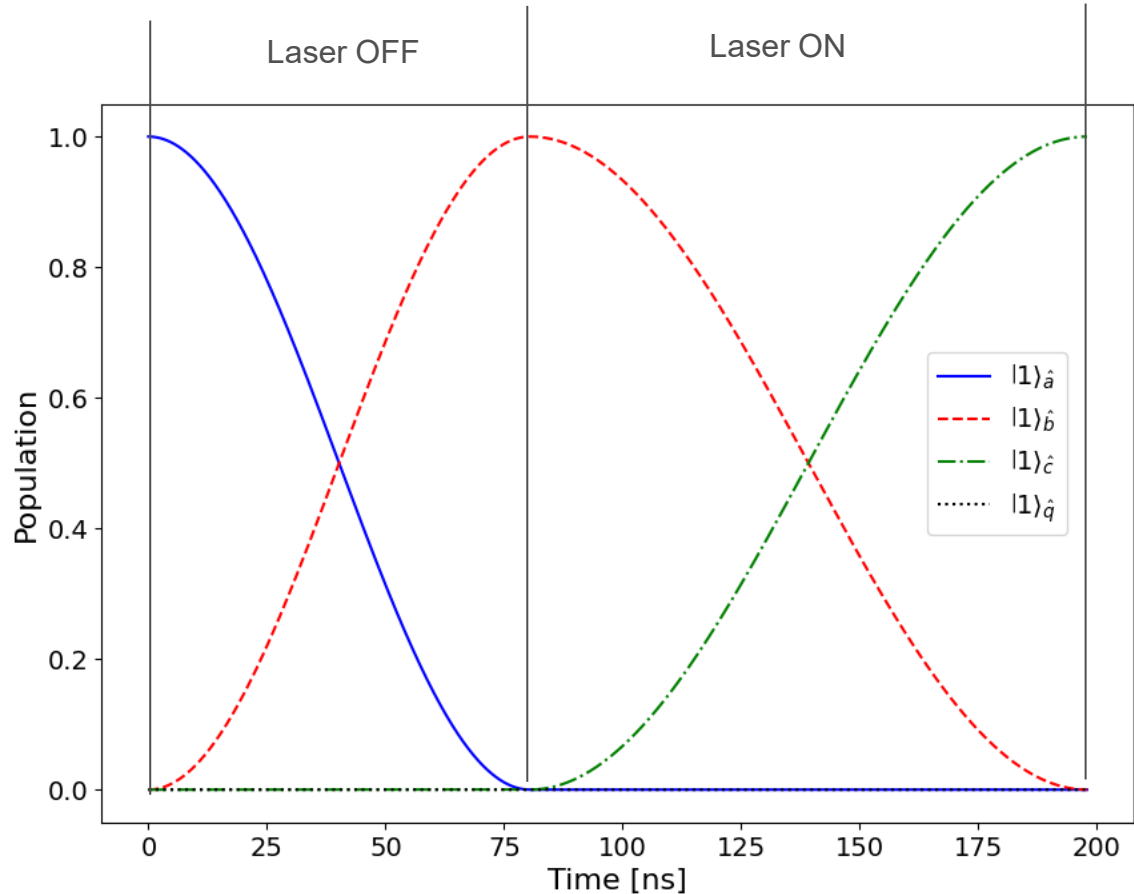
- Information is now in buffer mode  $\hat{b}$   $|1\rangle$ ;

- Perform 3wm

$$\omega_c - \omega_b = \omega_3$$

- Information is now in the eo crystal WGI  $\hat{c}$  at IR frequency  $\omega_c$ .

State sent out of DR through waveguide



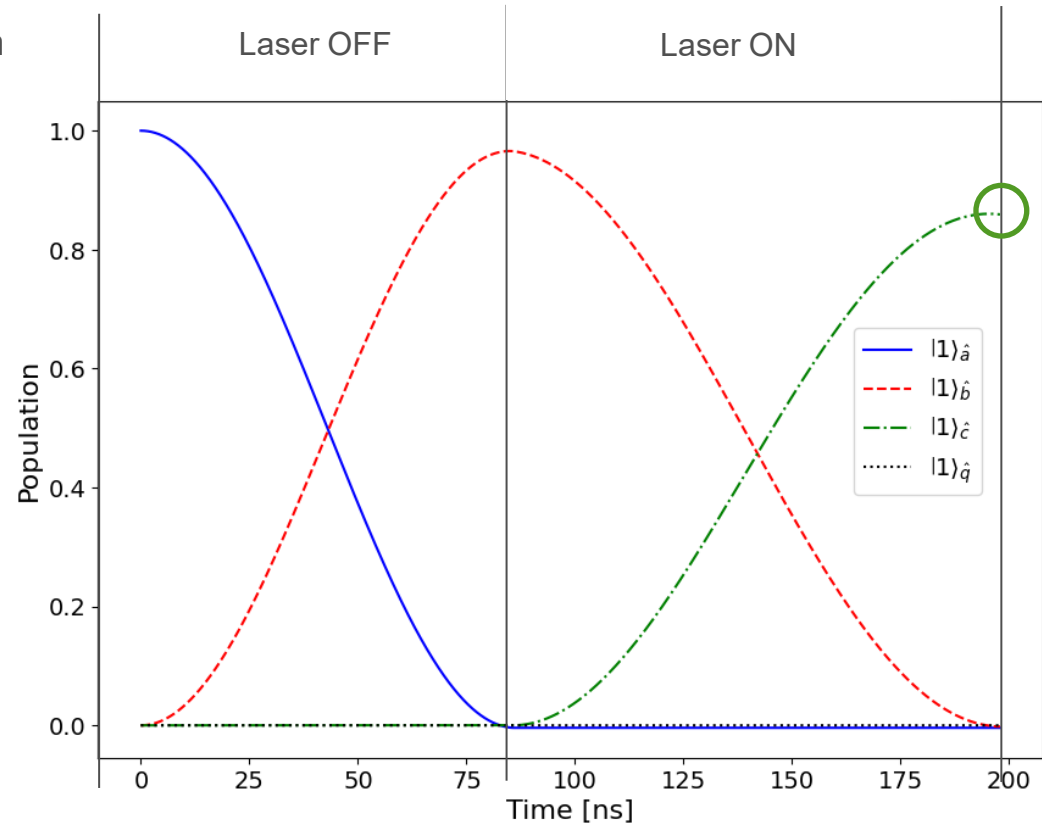
# SWAP-SWAP – results from QuTip lossy simulations

- Added modes decay constants  $\{\kappa_i\}$  based on state-of-the-art devices

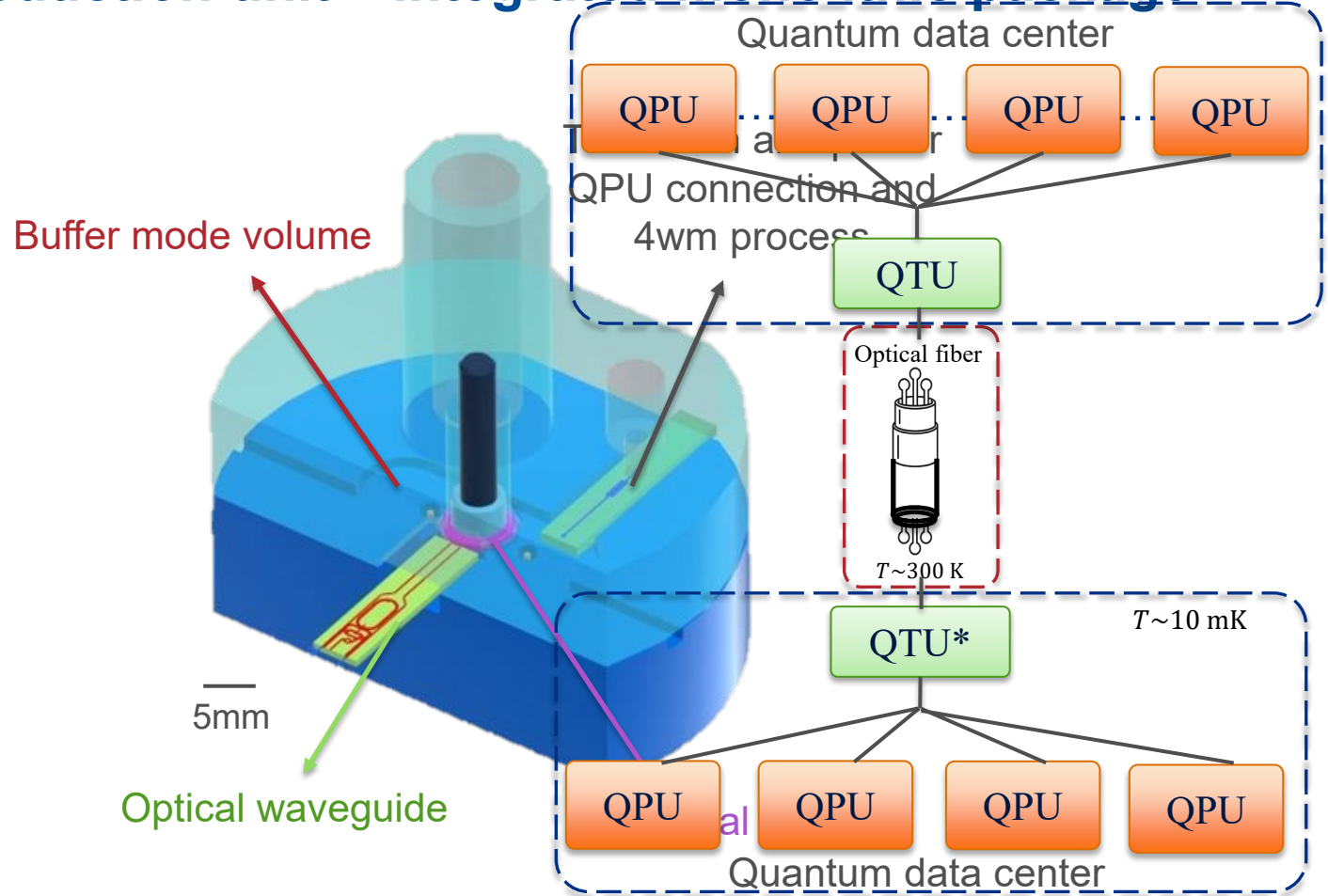
Mode	$Q_0$	$\nu$ [GHz]	$\kappa$ [MHz]
$\hat{a}$	$10^7$	6.65	$3 \times 10^{-3}$
$\hat{b}$	$6 \times 10^4$	8.6	0.9
$\hat{q}$	$5 \times 10^6$	7.9	$1 \times 10^{-2}$
$\hat{c}$	$\leq 10^9$	$1.9 \times 10^5$	1.2

SWAP-SWAP fidelity  
of 86%\*

- Information decays spontaneously into waveguide leading out of the DR.

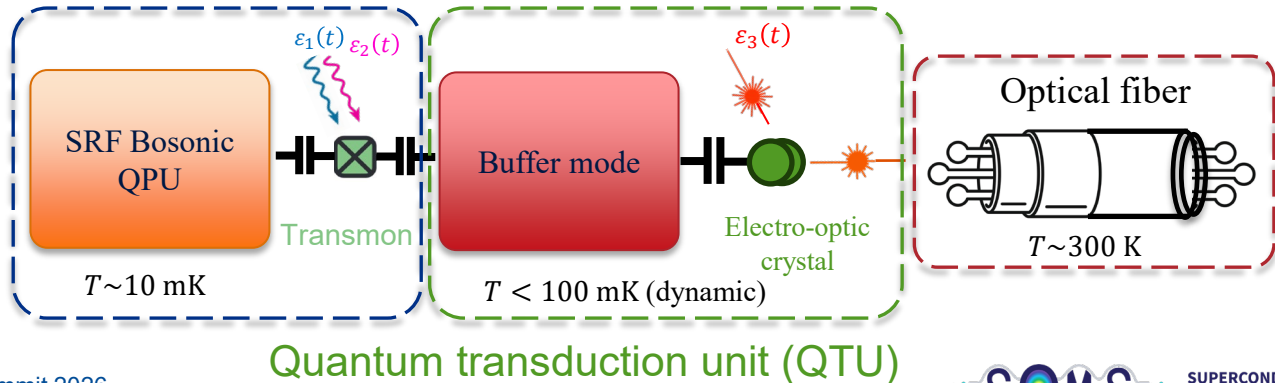
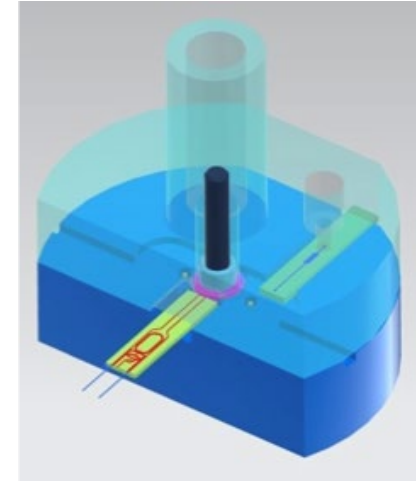


# Quantum transduction unit – integrated monolithic package



# Conclusions

- ✓ Preliminary design of an innovative compact monolithic quantum transduction unit with additional buffer mode;
- ✓ Successful decoupling of bosonic QPU and QPU to protect stored information in idle;
- ✓ Reformulation of transduction process into relay protocol (SWAP-SWAP) with 80% fidelity under realistic hardware conditions.



# THANK YOU



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