Modelling of photon pair generation

IN A DUAL-RAIL NIOBATE PHOTONIC NANOWIRE SETUP

Maria Gragera Garces,

1st of December 2023

University of Bath

AGENDA

- Project outlines
- Current work
- Achieved results
- Next steps and 2nd semester project planning

PROJECT OUTLINE

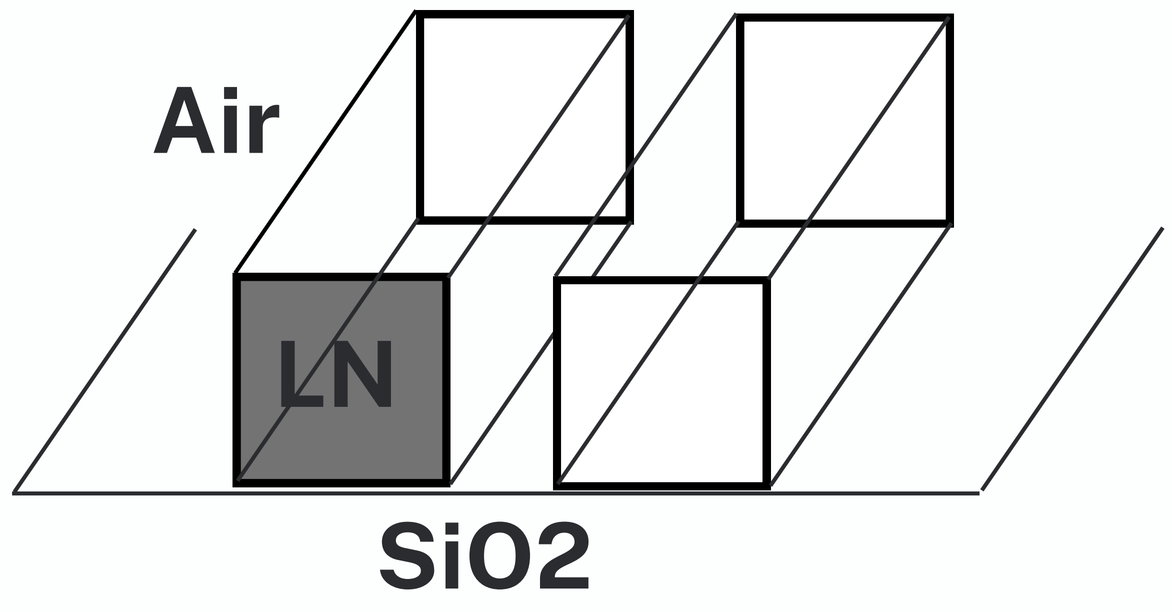
Problem: Current techniques to generate single photons are expensive, hard to come by and pose parameter tuning difficulties.

Current techniques: Spontaneous break-up of single high-energy photons from a bright light source into low energy photons.

Goal: Investigate a cheaper alternative.

Parameters: $\lambda \approx 750$ nm.

Material: Lithium Niobate ($LiNbO_3$): non-linear crystal that lacks inversion symmentry (K2).



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Combination of

Second Harmonic Generation & Photon Pair generation

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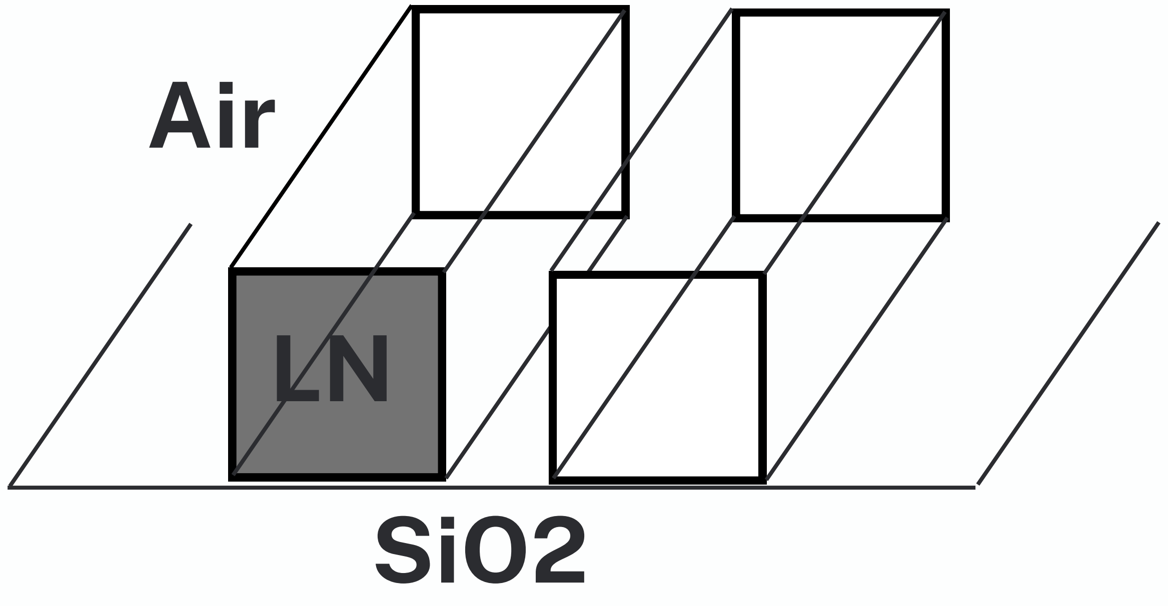
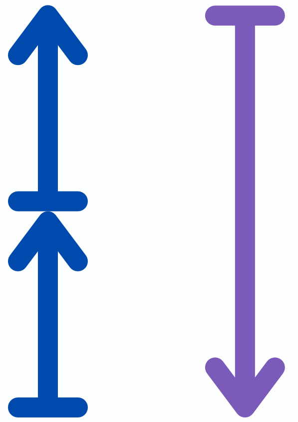
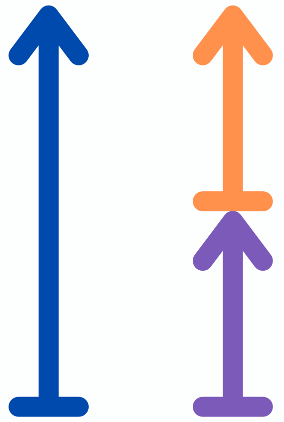


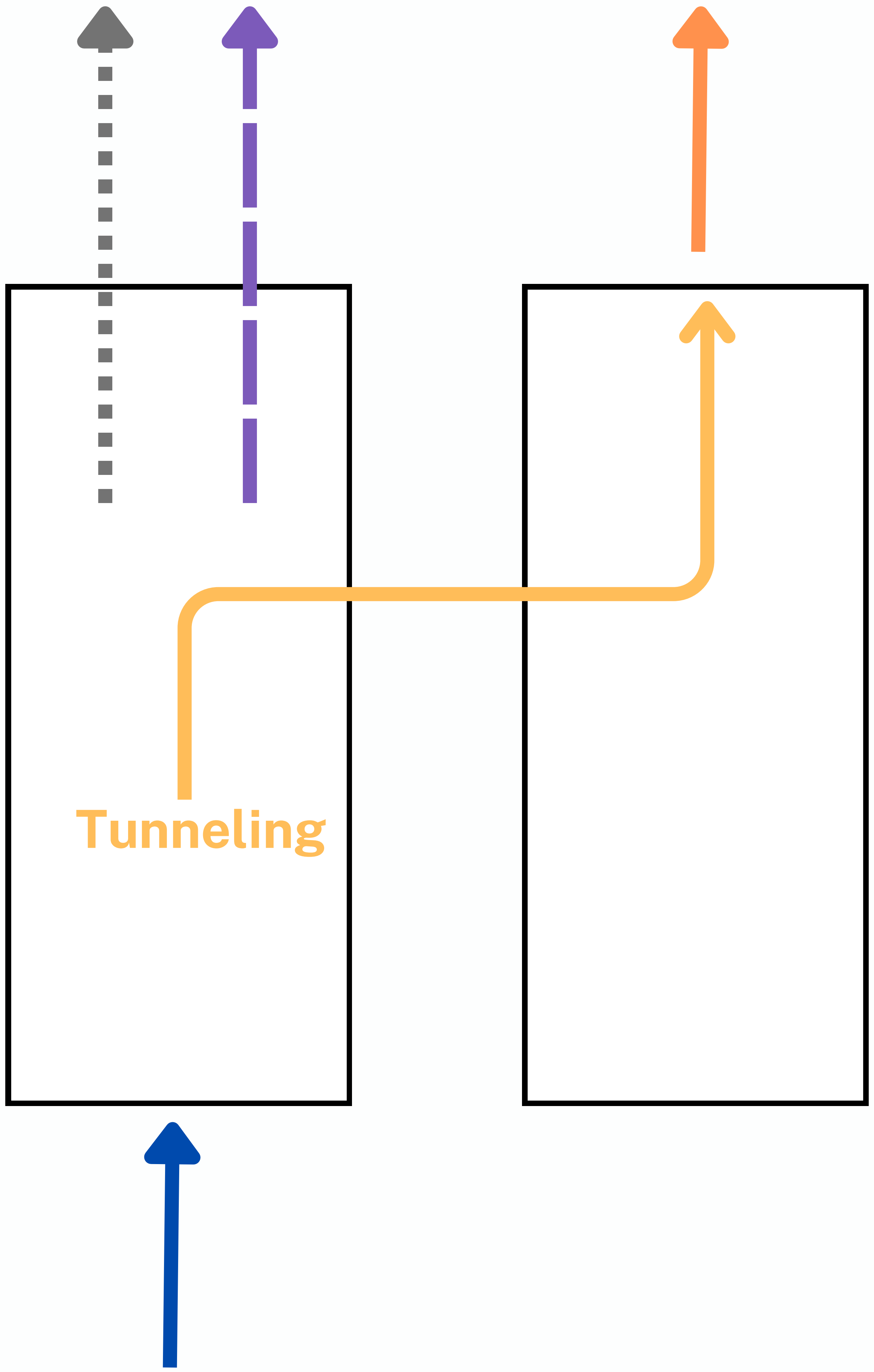
PROJECT OUTLINE

1) Second Harmonic generation
1 Photon in -> 2 Photons out



2) Spontaneous parametric down conversion
2 Photons in -> 1 Photon out



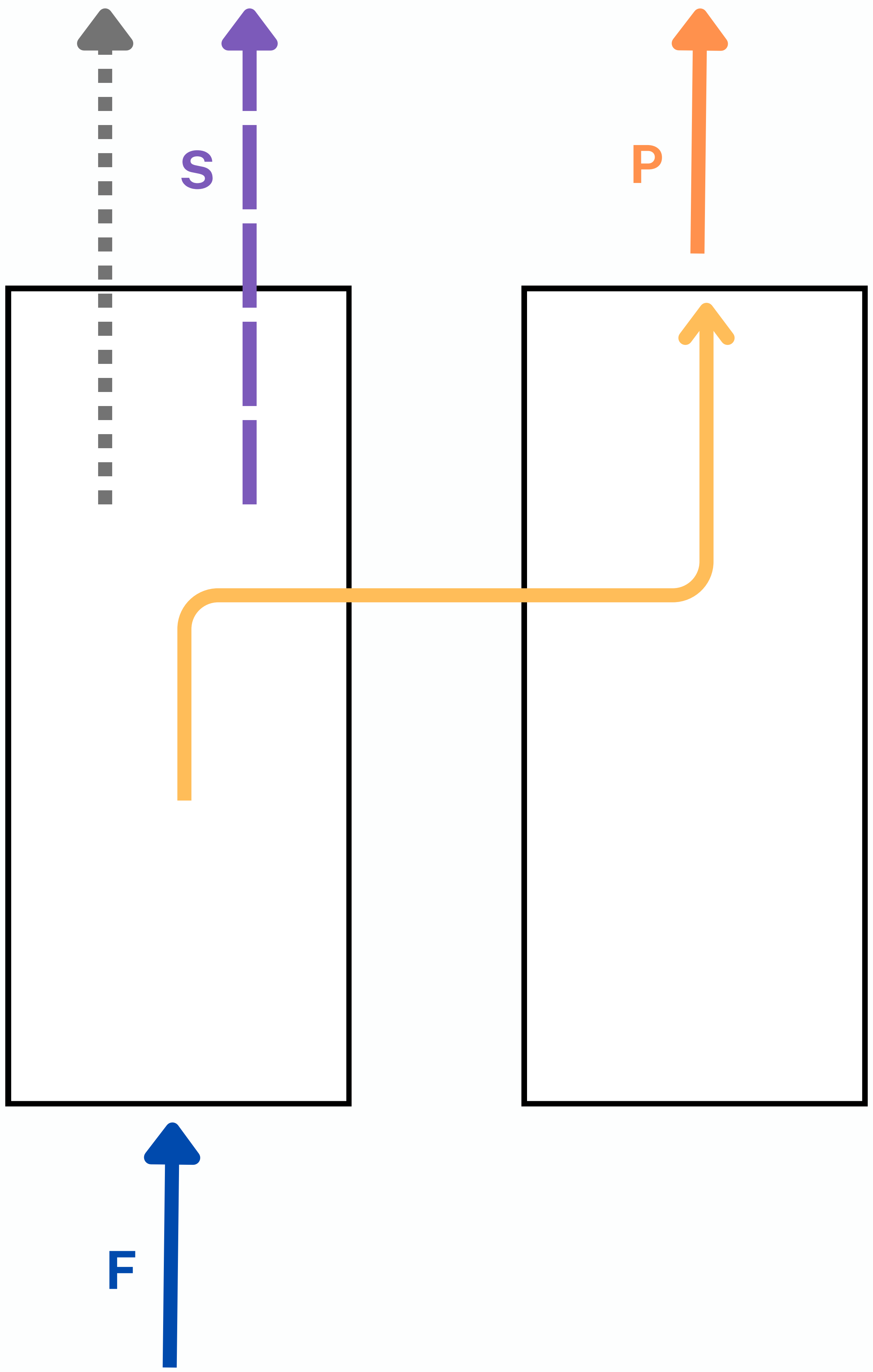


CURRENT WORK

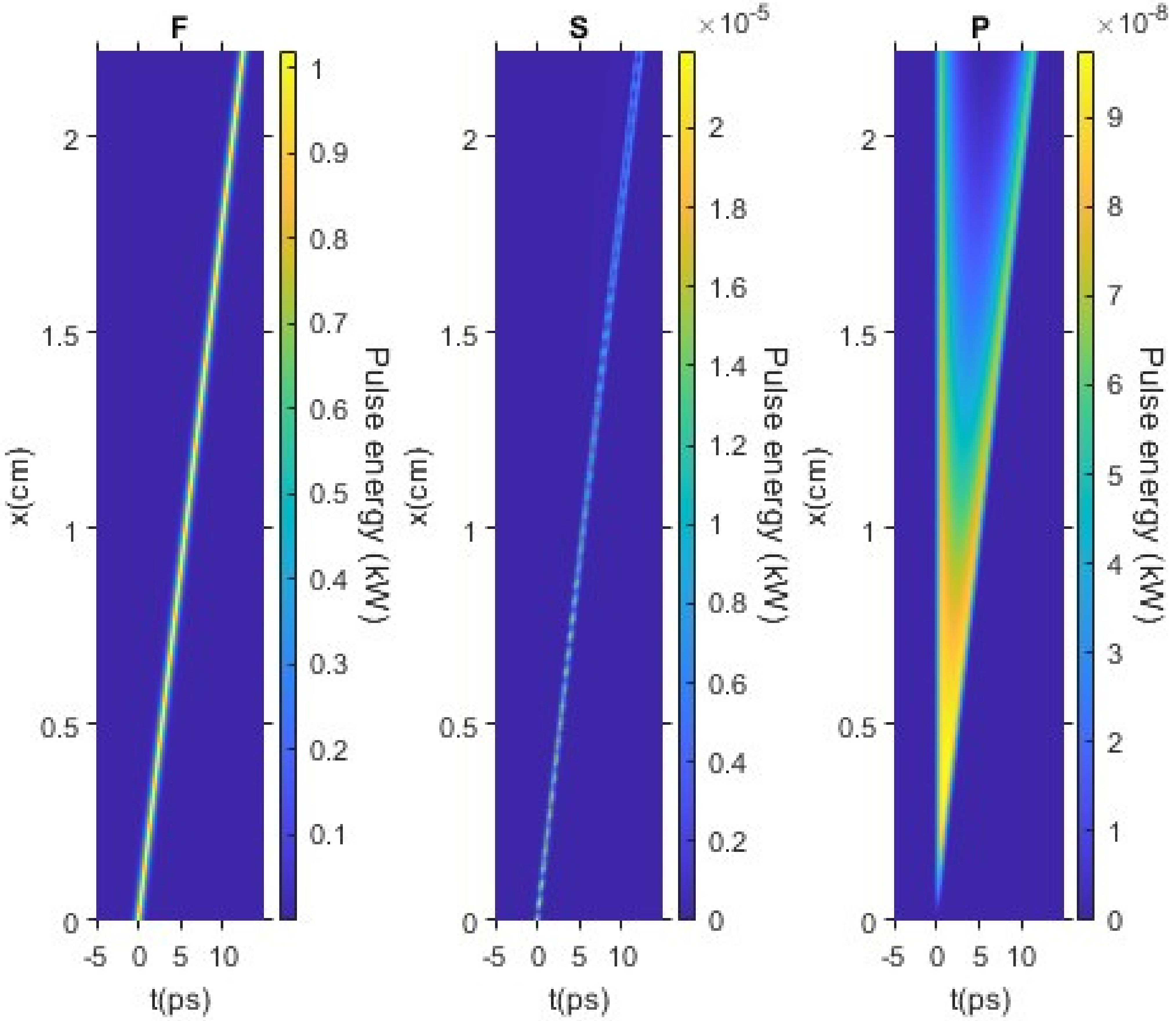
$$\partial zF = -\beta_{1F}\partial\tau F - i\frac{\beta_{2F}}{2}\partial^2\tau F + i\vartheta F^* S e^{ikz} \qquad (1)$$

$$\partial zS = \beta_{1S}\partial\tau S + iCP + i\frac{\vartheta}{2}F^2 e^{ikz} \qquad (2)$$

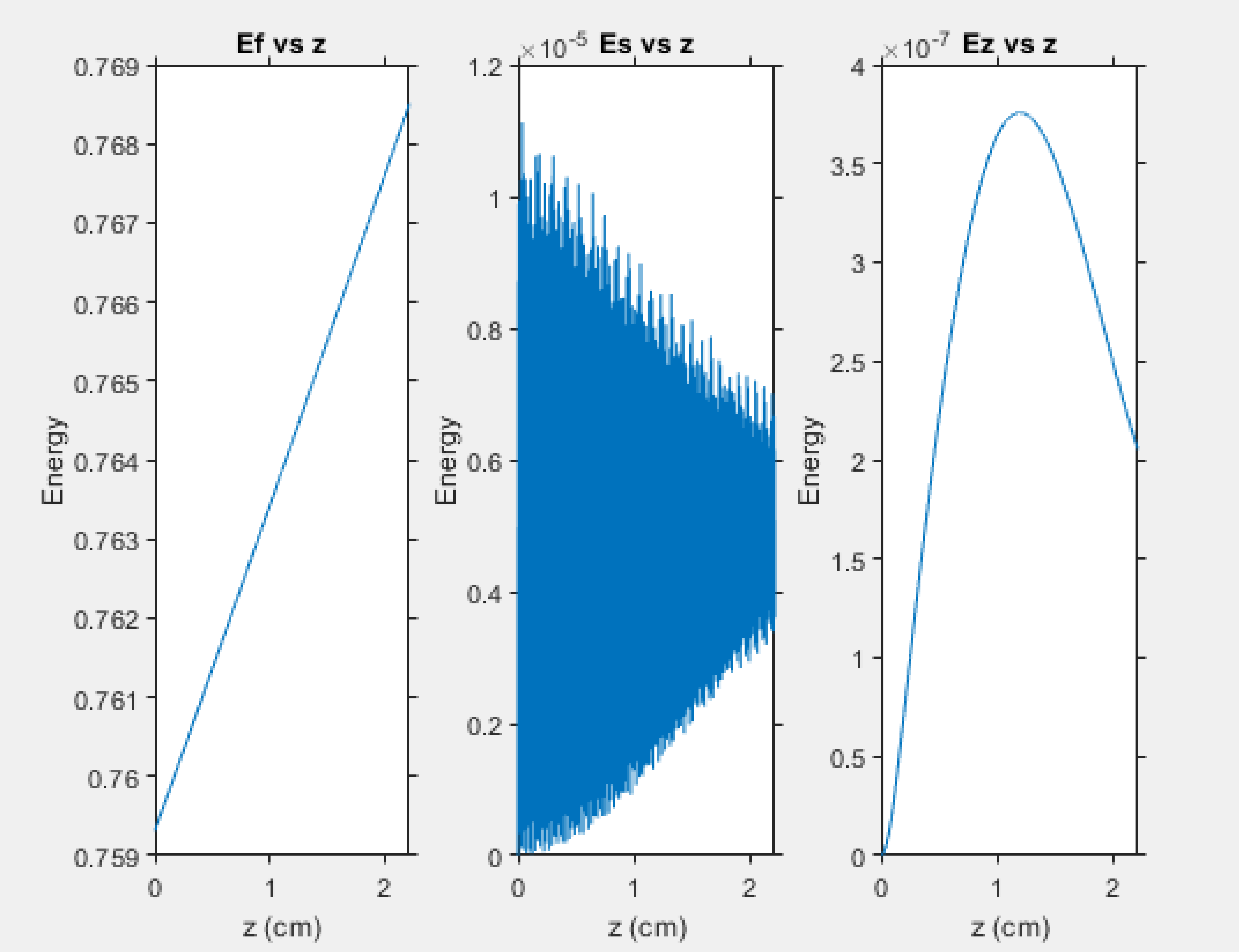
$$\partial zP = -\beta_{1S}\partial\tau P + iCP - i\frac{1}{2}\beta_{2S}\partial^2\tau P \qquad (3)$$



ACHIEVED RESULTS



ACHIEVED RESULTS



NEXT STEPS

- Testing the validity of our results (currently in progress)
- Assessing the meaning and implications of our results
- “Inserting” coupled equations into the proposed hardware implementation
- Comparing our results to previous results

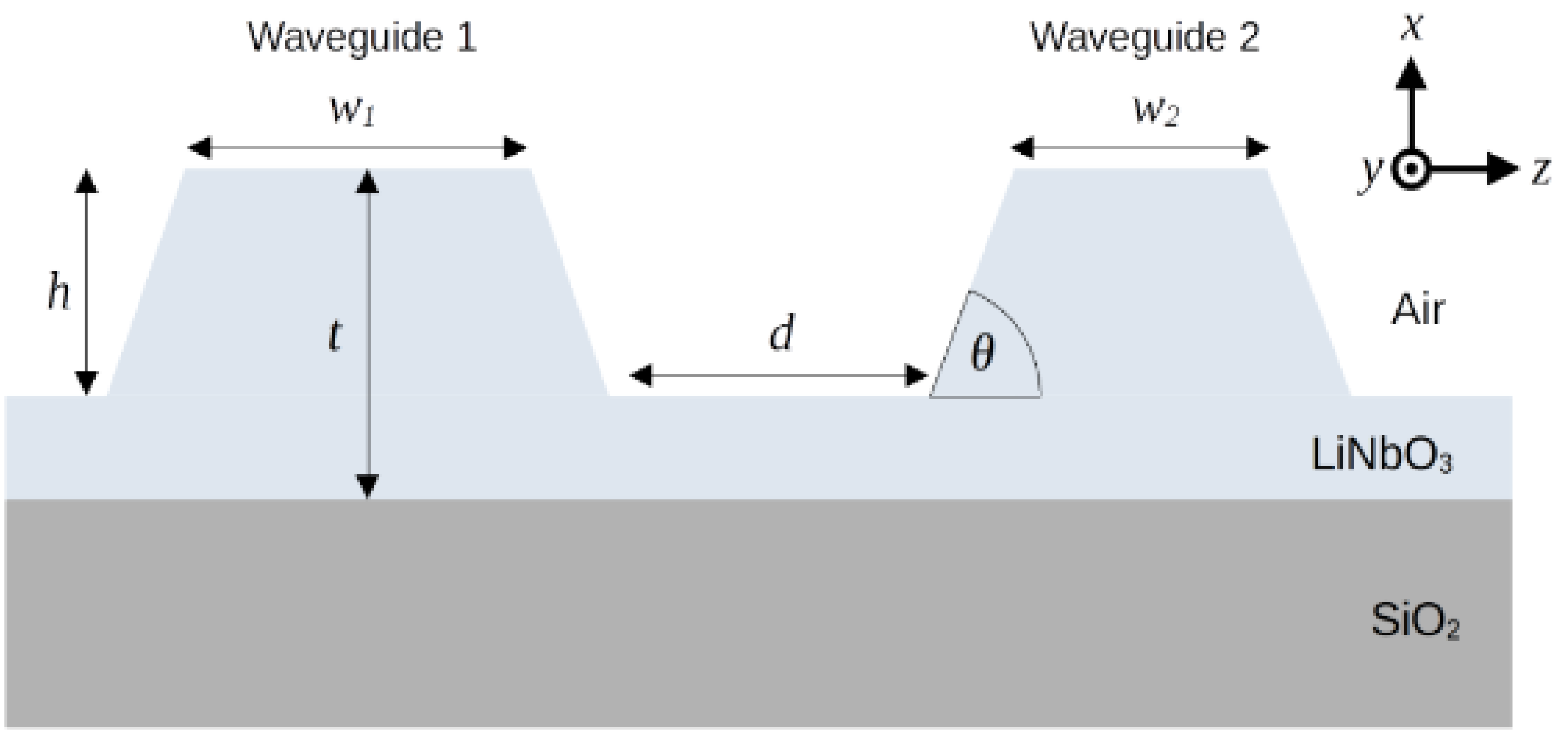


Figure 1. The cross-sectional view of the waveguides where w_1 and w_2 are the waveguides' widths, h is the waveguides' height, d is their separation, and θ is the sidewall angle. Note that each waveguide must have the same height due to the manufacturing process. The cross sectional geometry is constant down the waveguides' length and forms a pair of straight waveguides. The waveguides in this model are directly exposed to air.

Samuel M.B. Winter, Photon Pair Production in Coupled Lithium Niobate Nanowaveguides (2022)

Q&A

THANK YOU!

Maria Gragera Garces,

1st of December 2023

University of Bath

Additional slides

ORIGINS OF THIS WORK

[1] S. Eserin, and S. Winter, "Photon pair production in coupled lithium niobate waveguides," MSci Final Year Project, supervisors A. Gorbach and P. Mosley, 2022.

Article

Channel Waveguides in Lithium Niobate and Lithium Tantalate

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Abstract: Low-loss photonic waveguides in lithium niobate offer versatile functionality as nonlinear frequency converters, switches, and modulators for integrated optics. Combining the flexibility of laser processing with liquid phase epitaxy we have fabricated and characterized lithium niobate channel waveguides on lithium niobate and lithium tantalate. We used liquid phase epitaxy with K_2O flux on laser-machined lithium niobate and lithium tantalate substrates. The laser-driven rapid-prototyping technique can be programmed to give machined features of various sizes, and liquid phase epitaxy produces high quality single-crystal, lithium niobate channels. The surface roughness of the lithium niobate channels on a lithium tantalate substrate was measured to be 90 nm. The lithium niobate channel waveguides exhibit propagation losses of 0.26 ± 0.04 dB/mm at a wavelength of 633 nm. Second harmonic generation at 980 nm was demonstrated using the channel waveguides, indicating that these waveguides retain their nonlinear optical properties.

Solitons near avoided mode crossings in $\chi^{(2)}$ nanowaveguides

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We present a model for $\chi^{(2)}$ waveguides accounting for three modes, two of which make an avoided crossing at the second harmonic wavelength. We introduce two linearly coupled pure modes and adjust the coupling to replicate the waveguide dispersion near the avoided crossing. Analysis of the nonlinear system reveals continuous wave (CW) solutions across much of the parameter space and prevalence of its modulational instability. We also predict the existence of the avoided-crossing solitons, and study peculiarities of their dynamics and spectral properties, which include formation of a pedestal in the pulse tails and associated pronounced spectral peaks. Mapping these solitons onto the linear dispersion diagrams, we make connections between their existence and CW existence and stability. We also simulate the two-color soliton generation from a single-frequency pump pulse to back up its formation and stability properties.

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OSA CONTINUUM

Efficient parametric frequency conversion in lithium niobate nanophotonic chips

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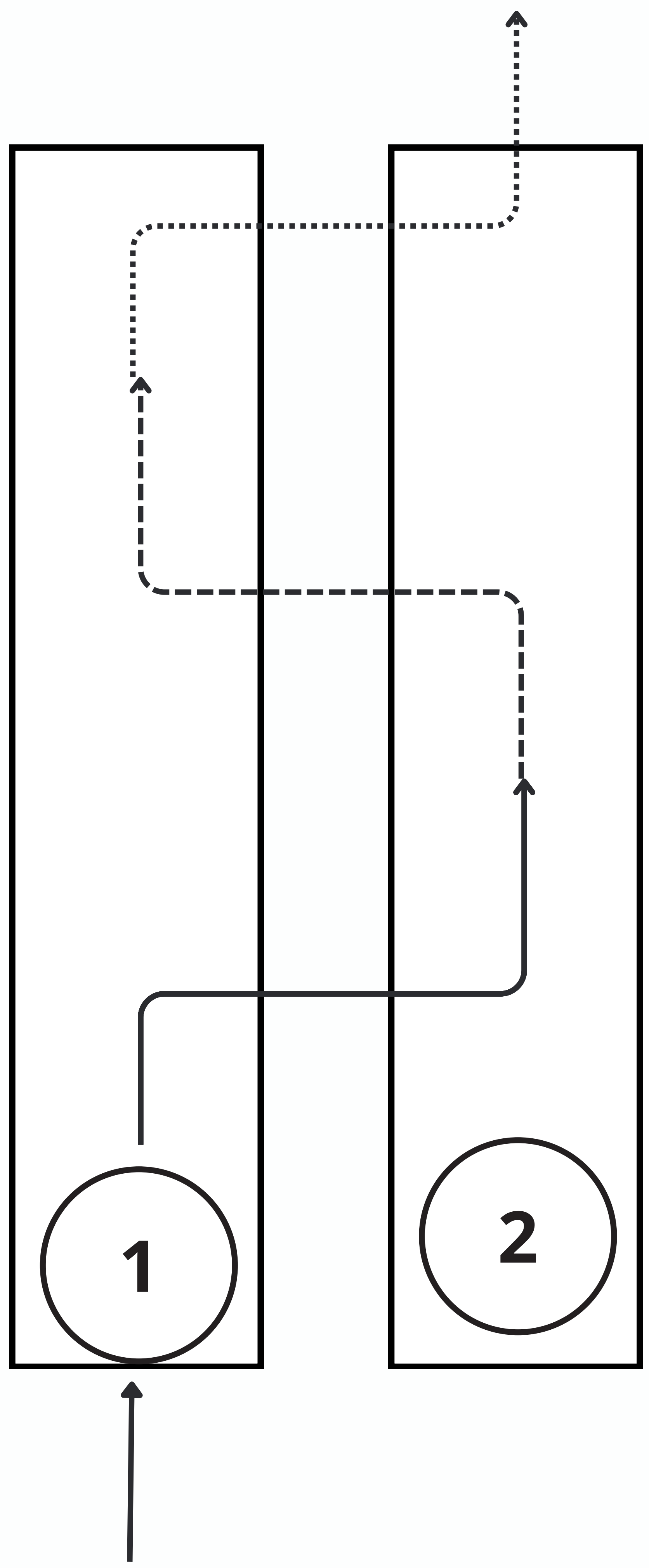
Abstract: Chip-integrated nonlinear photonics holds the key for advanced optical information processing with superior performance and novel functionalities. Here, we present an optimally mode-matched, periodically poled lithium niobate nanowaveguide for efficient parametric frequency conversions on chip. Using a 4-mm nanowaveguide with subwavelength mode confinement, we demonstrate second harmonic generation with efficiency over 2200% $W^{-1}cm^{-2}$, and broadband difference frequency generation over a 4.3-THz spectral span. These allow us to generate correlated photon pairs over multiple frequency channels via spontaneous parametric down conversion, all in their fundamental spatial modes, with a coincidence to accidental ratio as high as 600. The high efficiency and dense integrability of the present chip devices may pave a viable route to scalable nonlinear applications in both classical and quantum domains.

EVANESCENT TAILS

Transverse distribution of the electric field of the first waveguide overlaps with the second waveguide



COMPUTATIONAL DETAILS

- Coupling needs to occur at the wavelengths that we want => we are engineering the
  - size
  - shape

  of the waveguides.

- This is essentially an IVP (Initial Value Problem), which we can solve via 4th order Runge Kutta methods.

  => MATLAB's ode45: combination of 4th and 5th order RK methods, utilizing adaptive step size control .

TESTING RESULT VALIDITY

- We have tested the dispersion of the model
- We are testing coupling effects
- We have are testing Energy spectrums of our pumps