Integrating Classical Microscopy Concepts into Quantum Imaging with Undetected Light: Progress, Challenges and Perspectives

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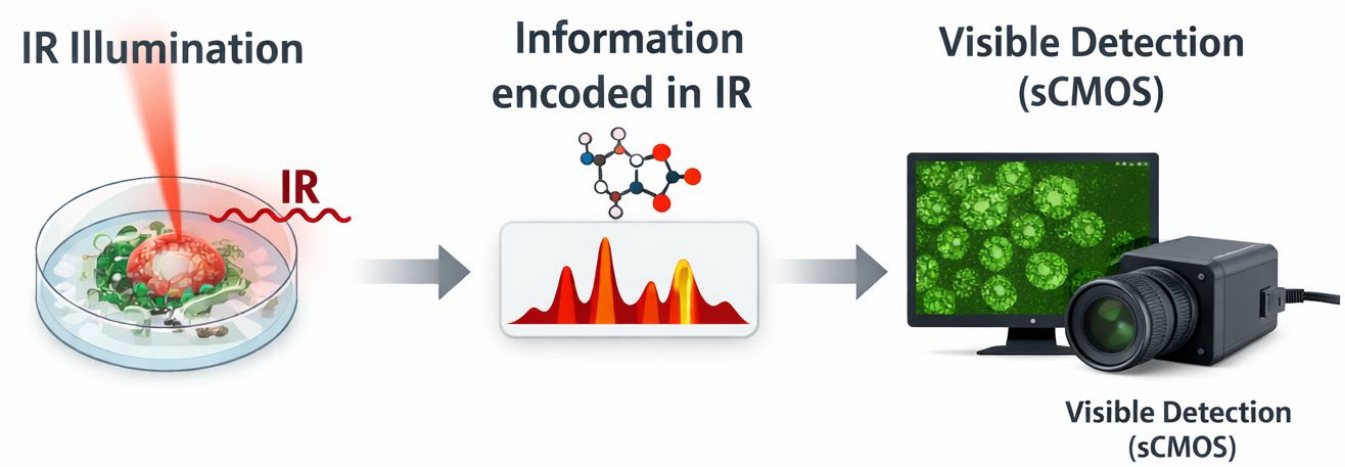
Why Do We Need Imaging Beyond the Visible Spectrum?

- Many biological and chemical samples interact strongly in the infrared (IR)
- IR provides molecular contrast (vibrational signatures)
- Direct IR detection is difficult -> Problems with IR detectors: low sensitivity, high noise expensive limited spatial resolution



- **Idea:** Use visible detectors but probe the sample in the infrared -> This is where Quantum Imaging with Undetected Light (**QIUL**) becomes powerful.

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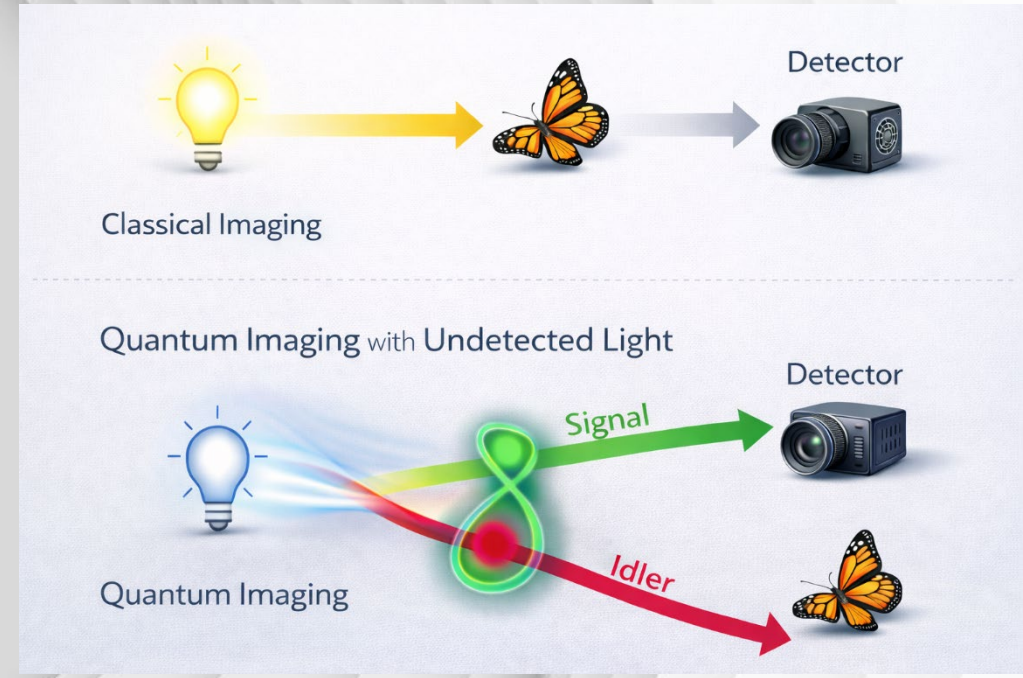
What is Quantum Imaging with Undetected Light (QIUL)?

Basic principle of QIUL (SPDC + induced coherence)

Idea:

- Image an object using photons that ar**e never detected**
- The probe photons interact with the sample
- The detected photons never see the sample
- Information about the sample is **retrieved indirectly**



Basic principles:

- Two nonlinear crystals produce photon pairs via SPDC
- Signal photons -> detected (visible/NIR)
- Idler Photons -> interact with the sample (MIR/NIR)
- **Induced coherence** -> signal photons carry information about the object

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Zou, Wang & Mandel, Phys.Rev.Lett (1991)
Lemos et al. Nature (2014)

QIUL for Biological Microscopy: Opportunities & Challenges

- Benefits -> Molecular contrast, label-free imaging, important molecules,...

1.2 um	1.3, 1.55	1.72	1.9	3	3.1	3.33 - 3.57	4.3 - 4.7	5.71	6 - 6.7	7 - 7.25		9
lipids	collagen	lipidi	collagen	arterijski sudovi	heart muscle	adipose tissue	human fat	lipids (C=O)	protein, amide bonds	lipids		carbohydrates
		brain imaging			C2H2	lipids (acyl chains)						
		prostate tissue				CH4						

- Limitations -> System complexity, high cost, Limited resolution, slow acquisition.
- **Goal:** Compact, versatile systems for biological microscopy.

Can some solutions be found within classical microscopy toolbox?

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Research Direction: Developing Versatile QIUL Architectures

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Bottom-up development

- Theory
- Experiment

Methodology: Adapt classical microscopy concepts to QIUL

Systems under development

(1) System in Michelson geometry, ppKTP -> idler @1345 nm

(2) **Mirau** QIUL -> idler @ 1345 nm

(3) MIR QIUL, bulk LiNbO3 (LN) -> 2-5 um & **Structured Illumination**

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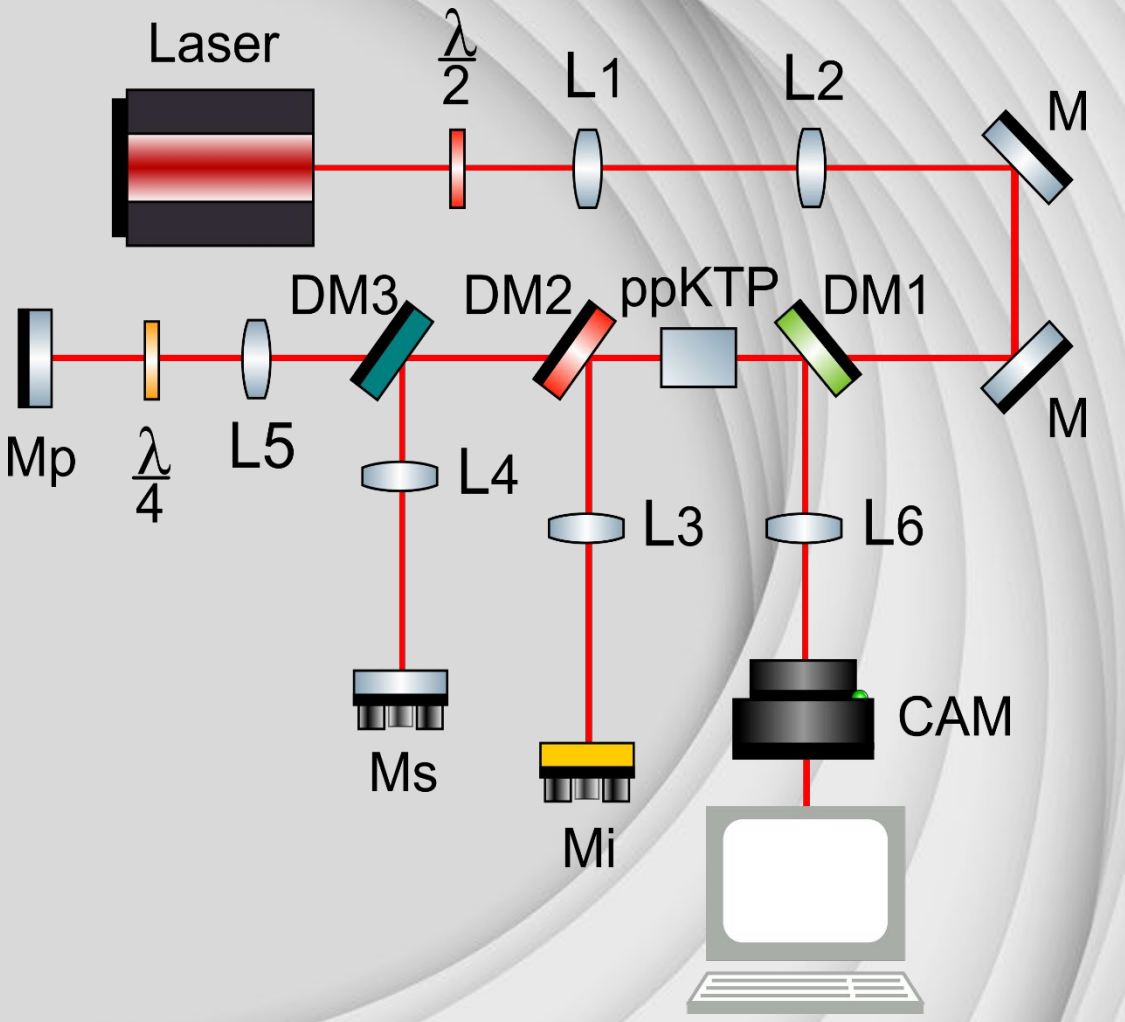
1) QIUL & ppKTP & Michelson geometry

Experimental Scheme



- Pump @ 532 nm
- Signal @ 865 nm
- Idler @ 1350 nm

- Operates at room temperature

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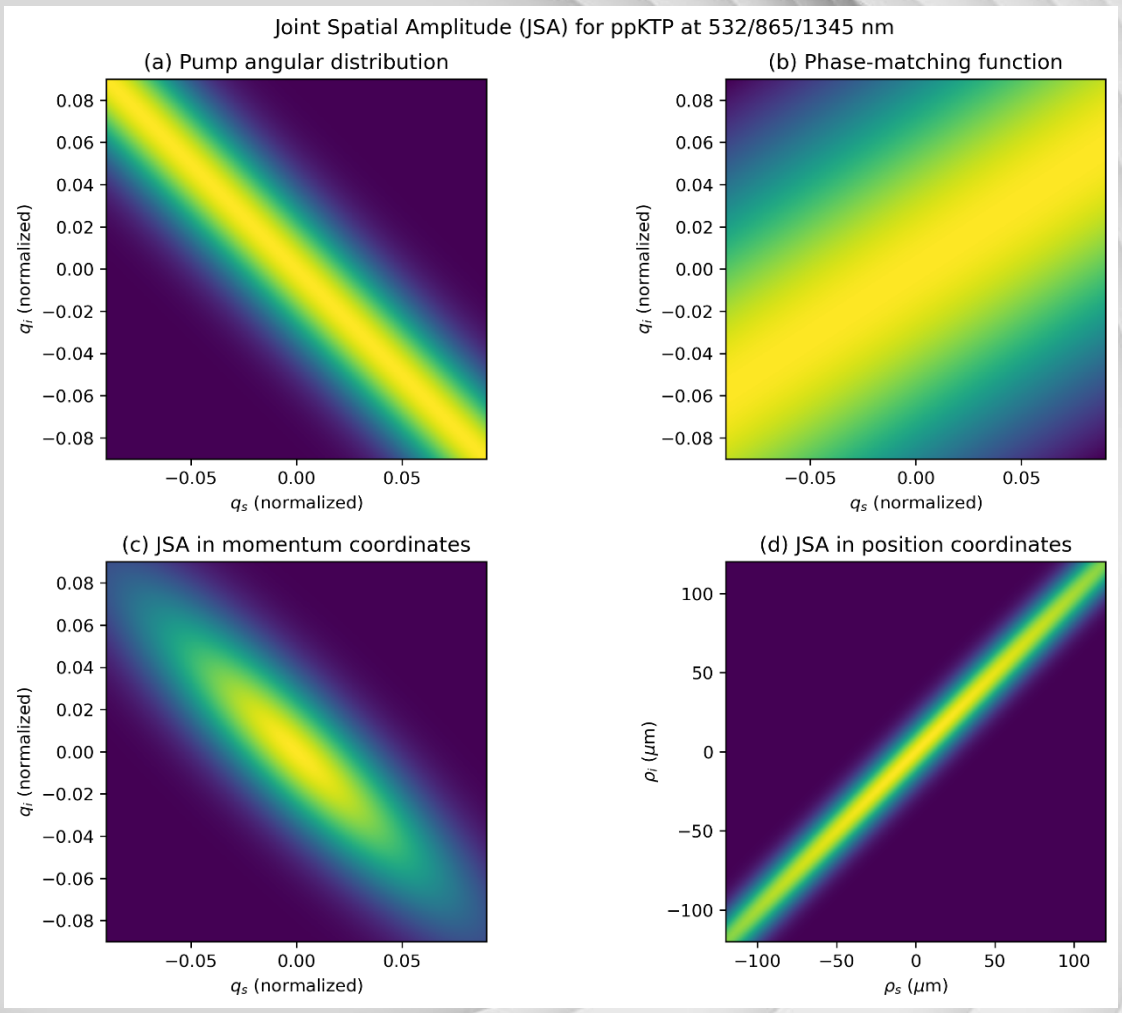
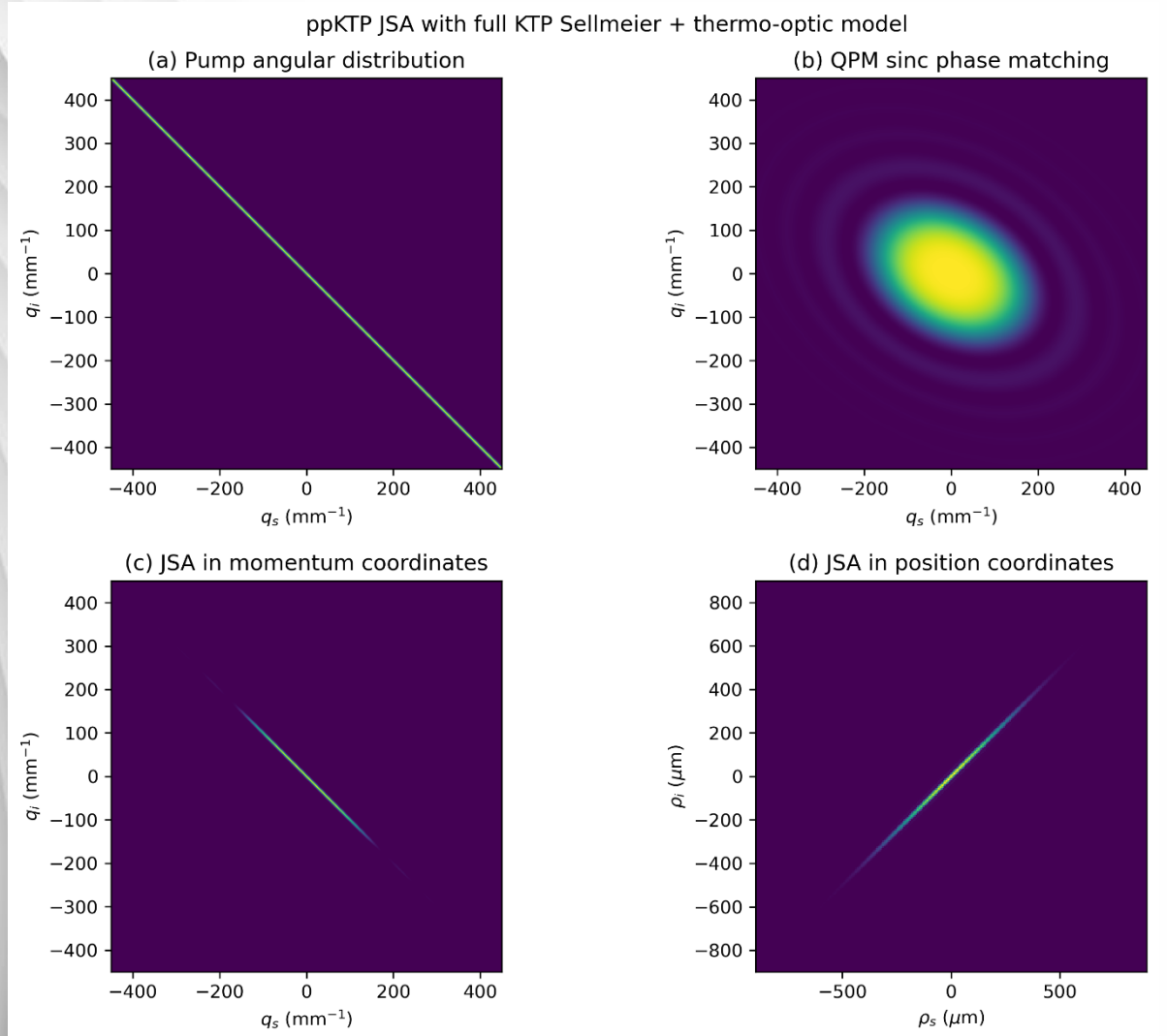
Spatial Correlations of Signal–Idler Photon Pairs





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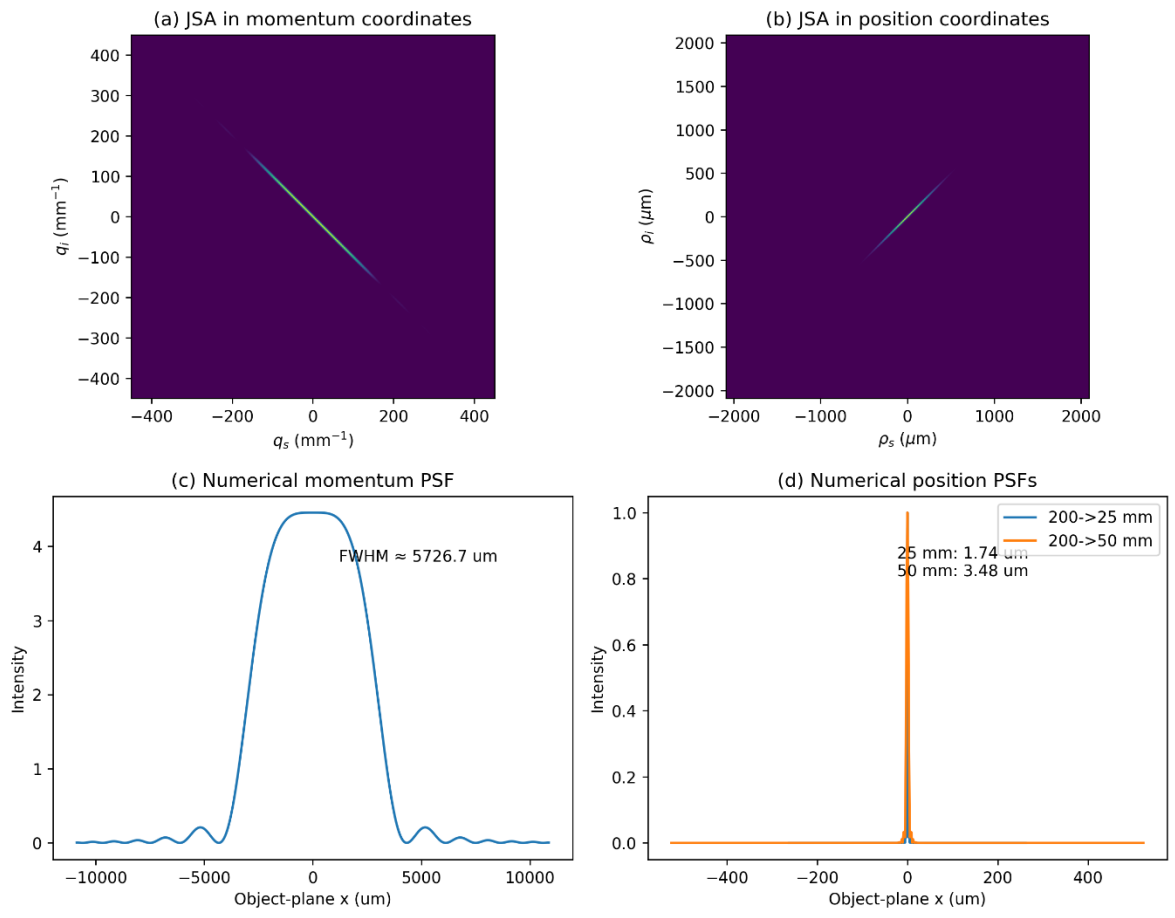
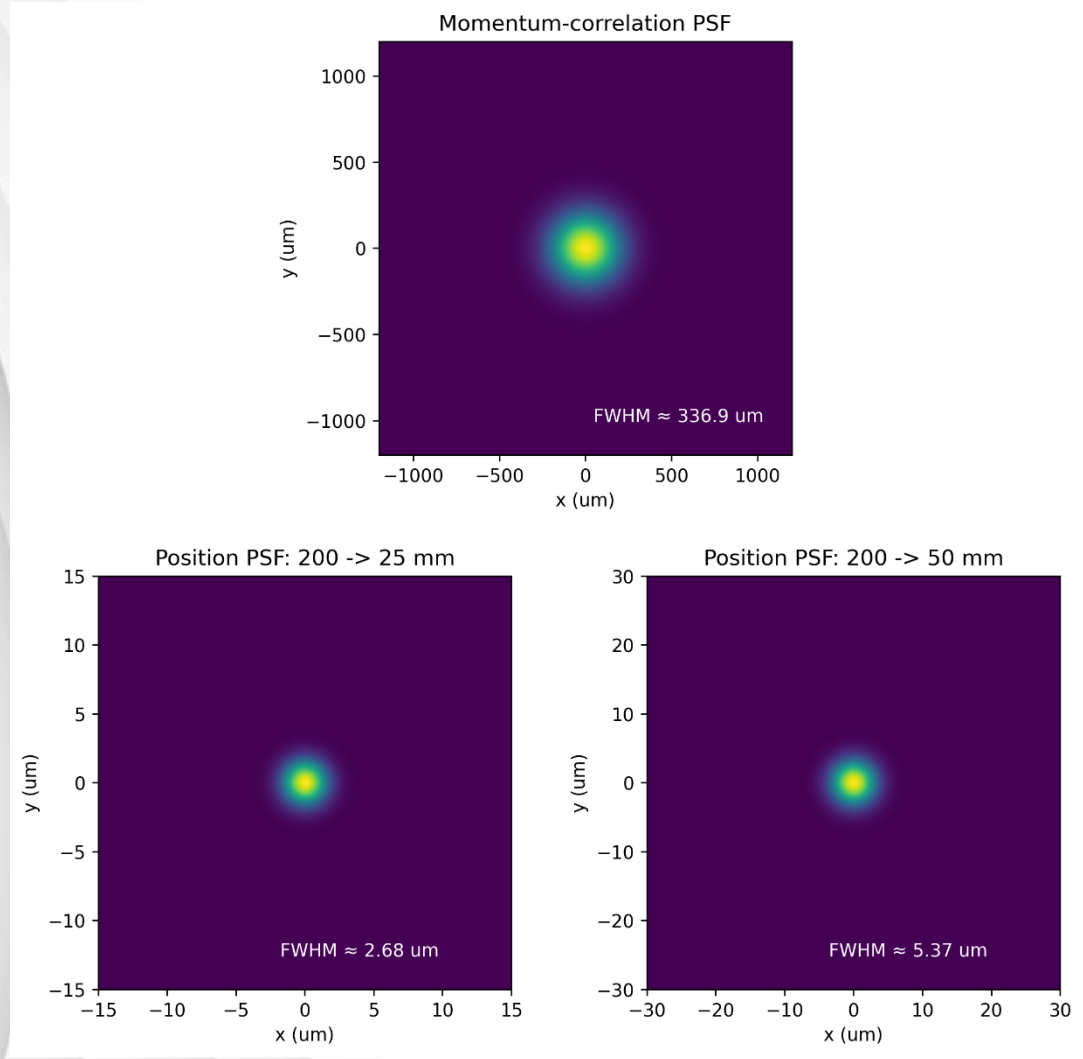
Spatial Correlations of Photon Pairs in ppKTP





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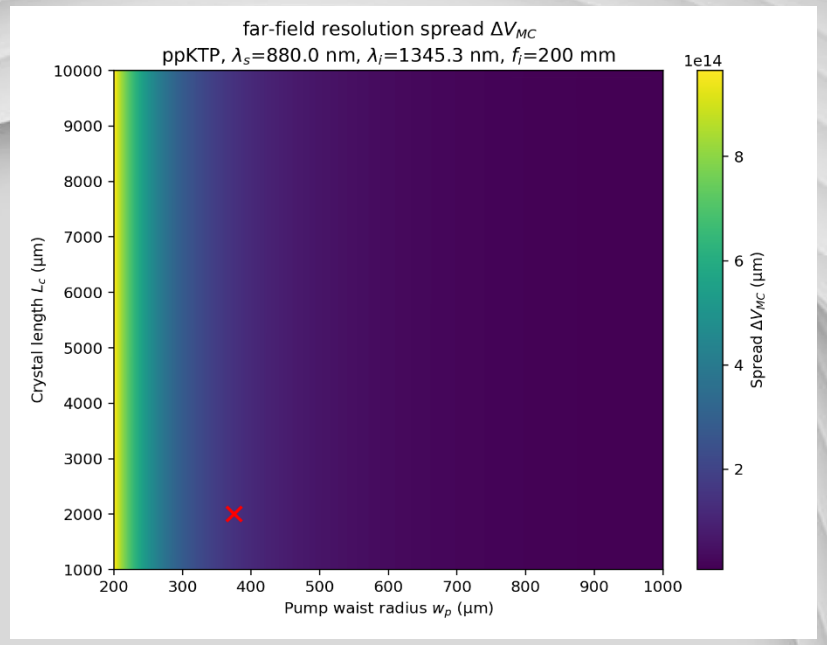

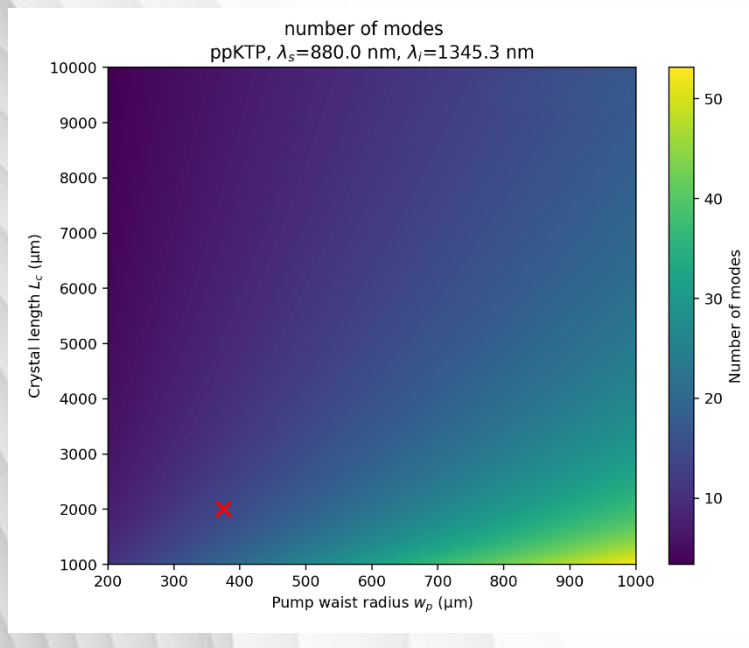

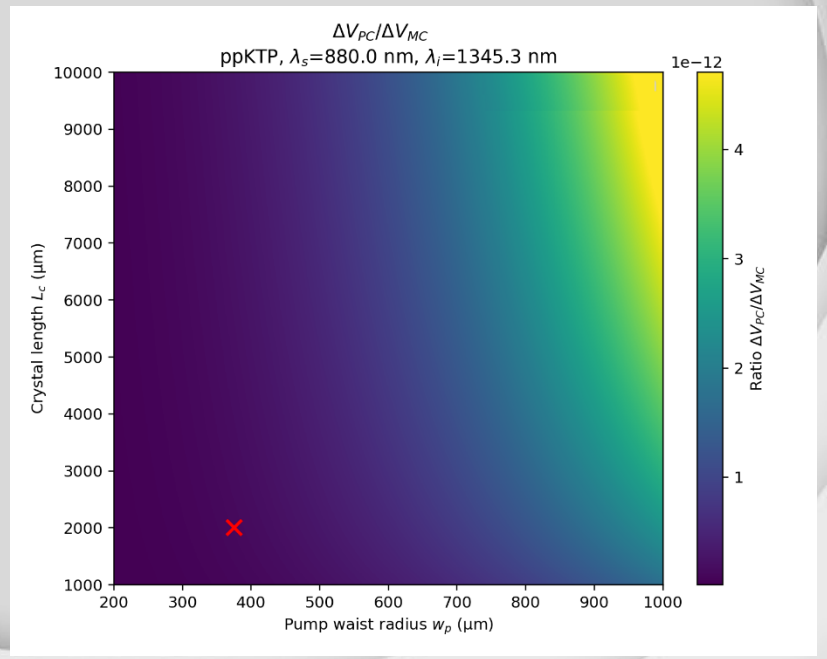

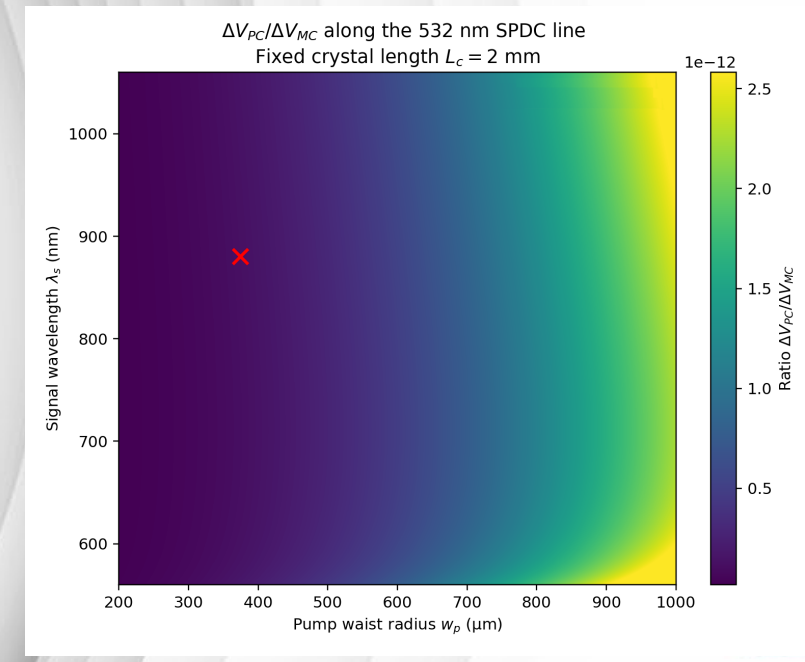

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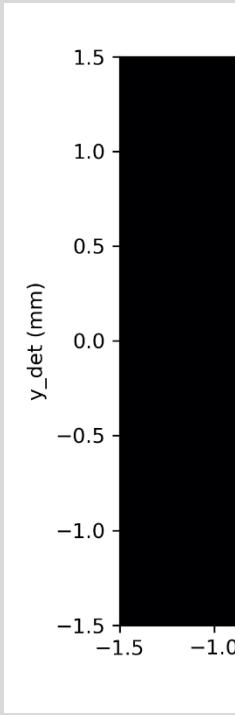
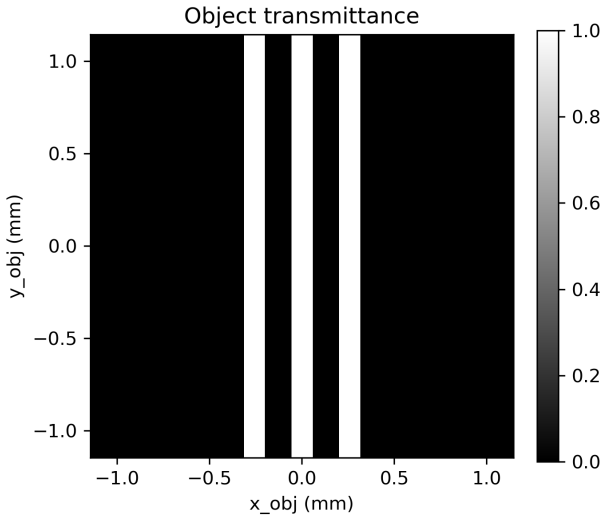
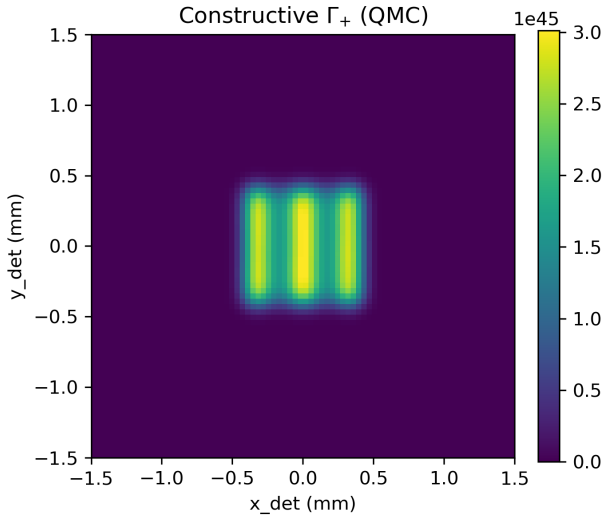
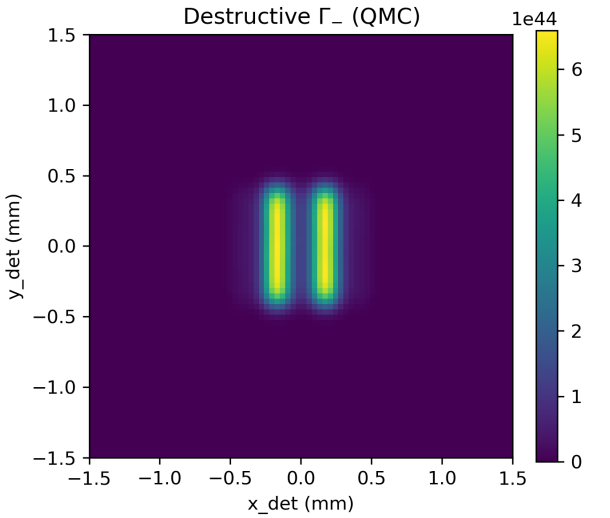
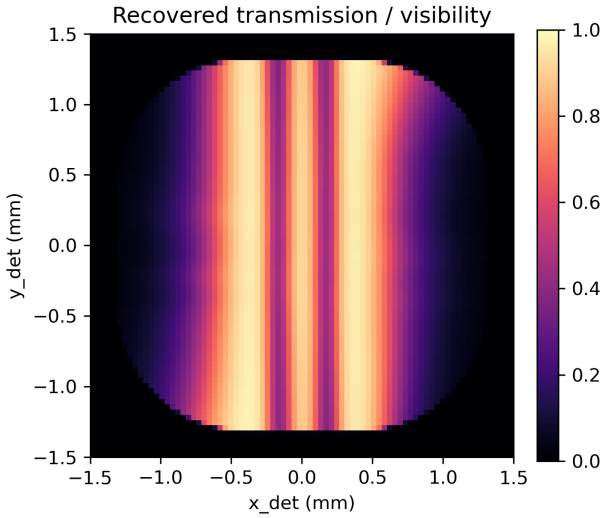
QIUL Simulations

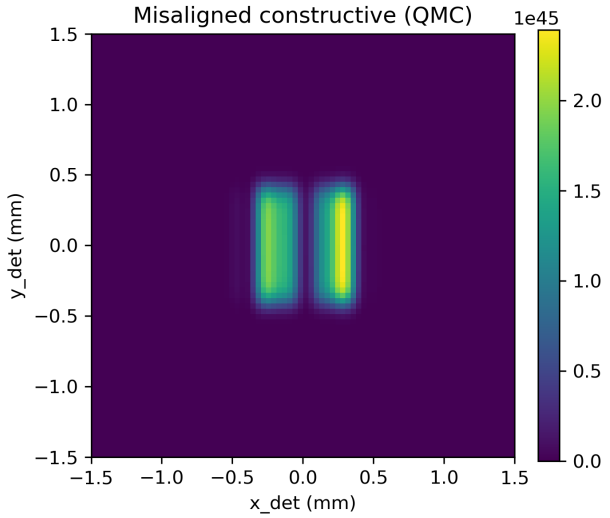


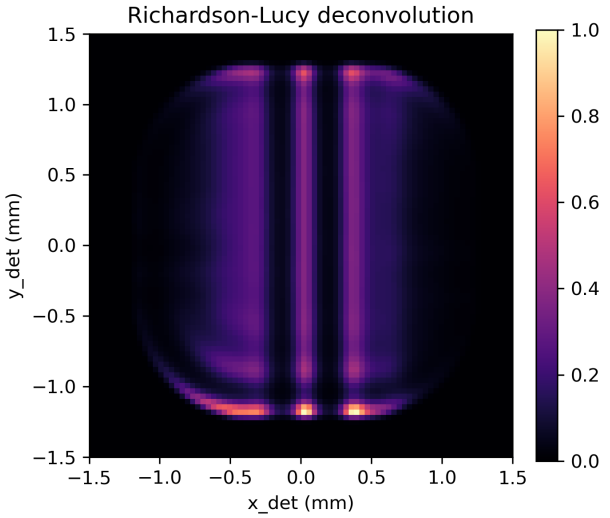


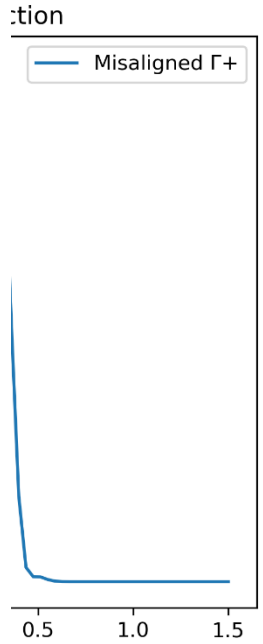












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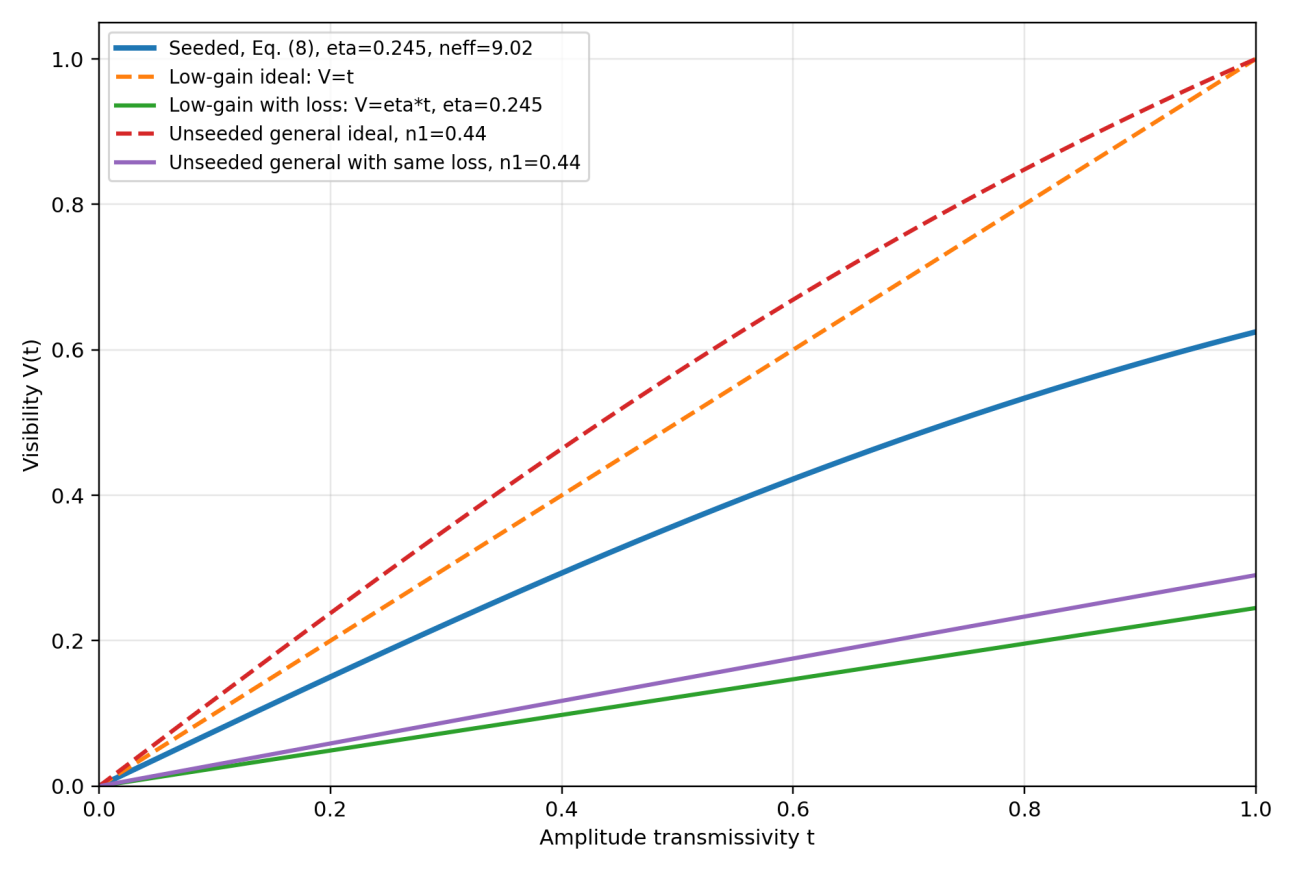
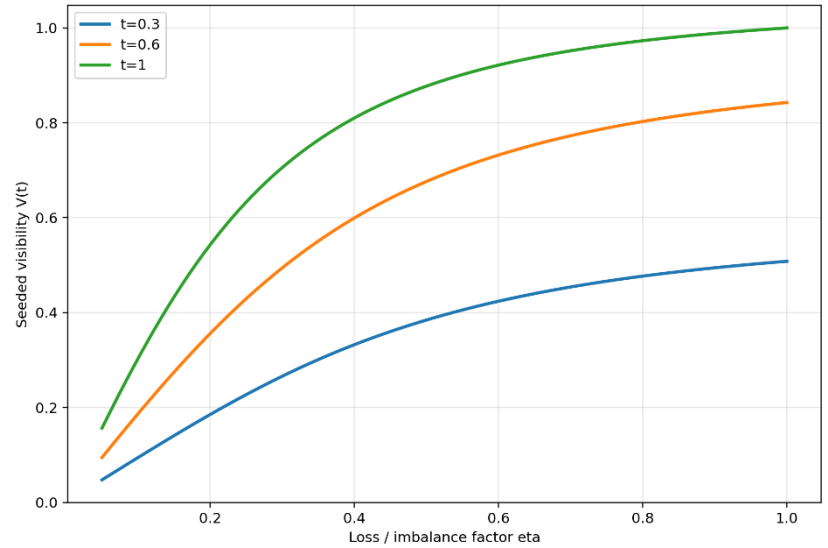
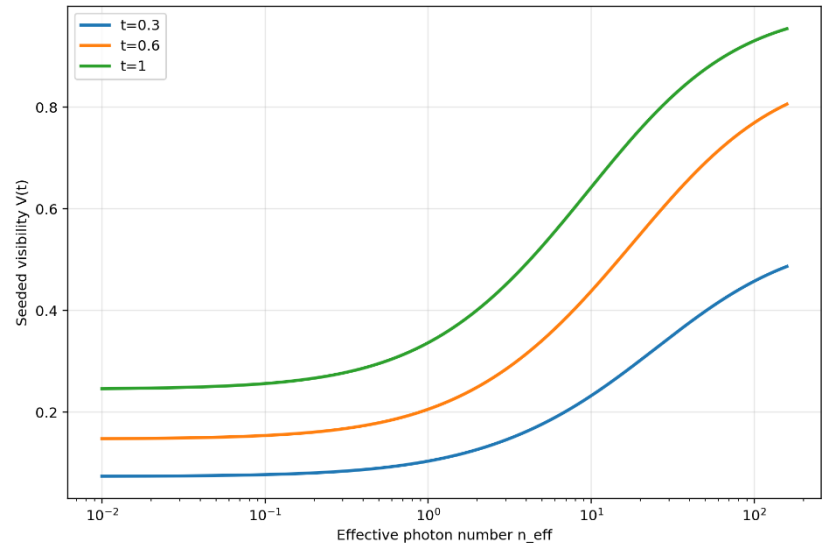
Visibility modeling

$$V_{unseeded}(t, n_1, \eta) = |\eta t| \frac{\sqrt{1+n_1}}{\sqrt{1+(\eta t)^2 n_1}}$$

$$V_{seeded}(t, \eta, n_{eff}) = \frac{2|\eta t|\sqrt{(1+n_{eff})+(1+\eta^2 n_{eff})}}{2+\eta^2 n_{eff}+(\eta t)^2 n_{eff}}$$







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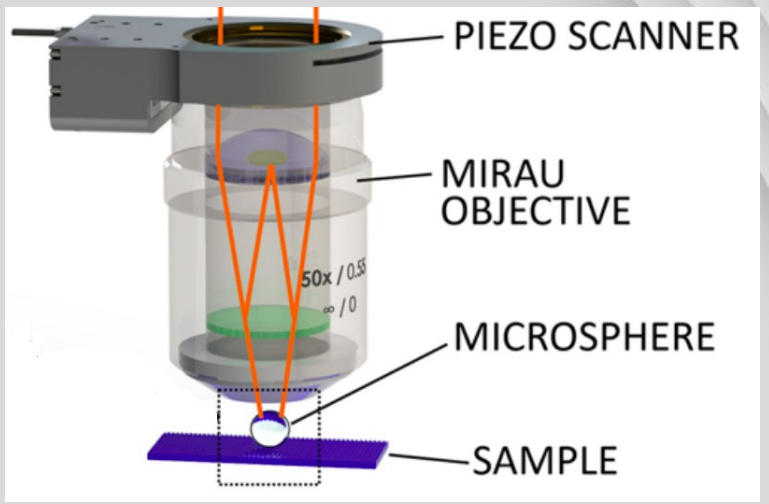
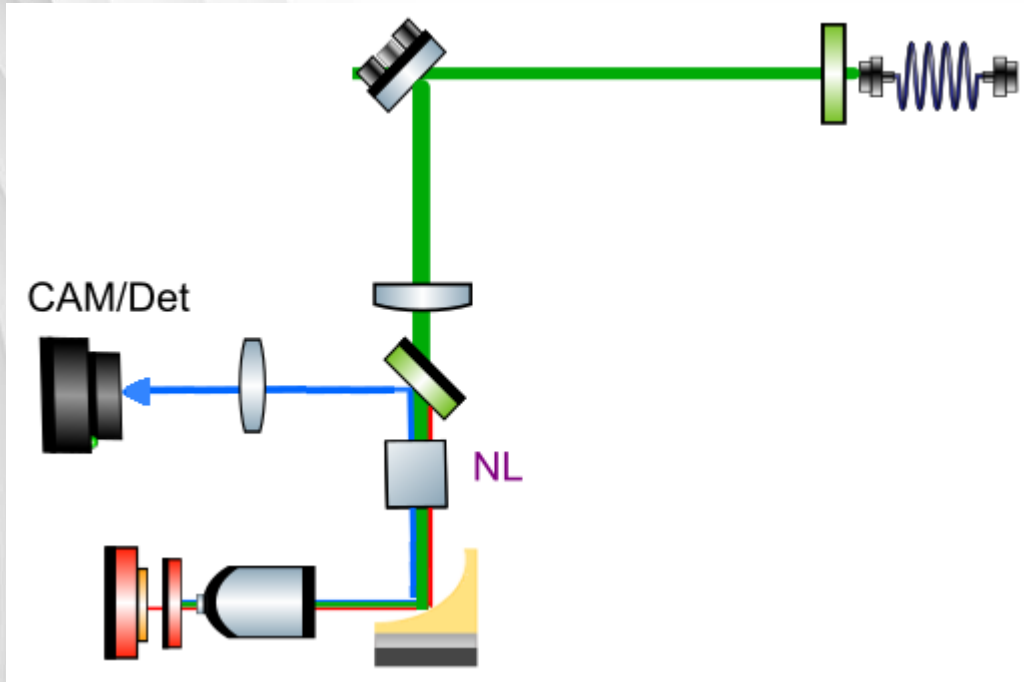
2) QIUL & ppKTP & Mirau geometry

Microscopy-compatible architecture?



Kassamakov et al. Scientific reports (2017)



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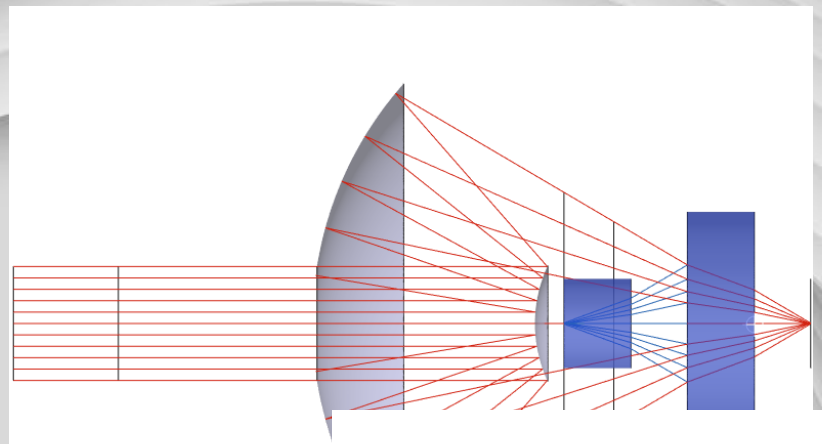
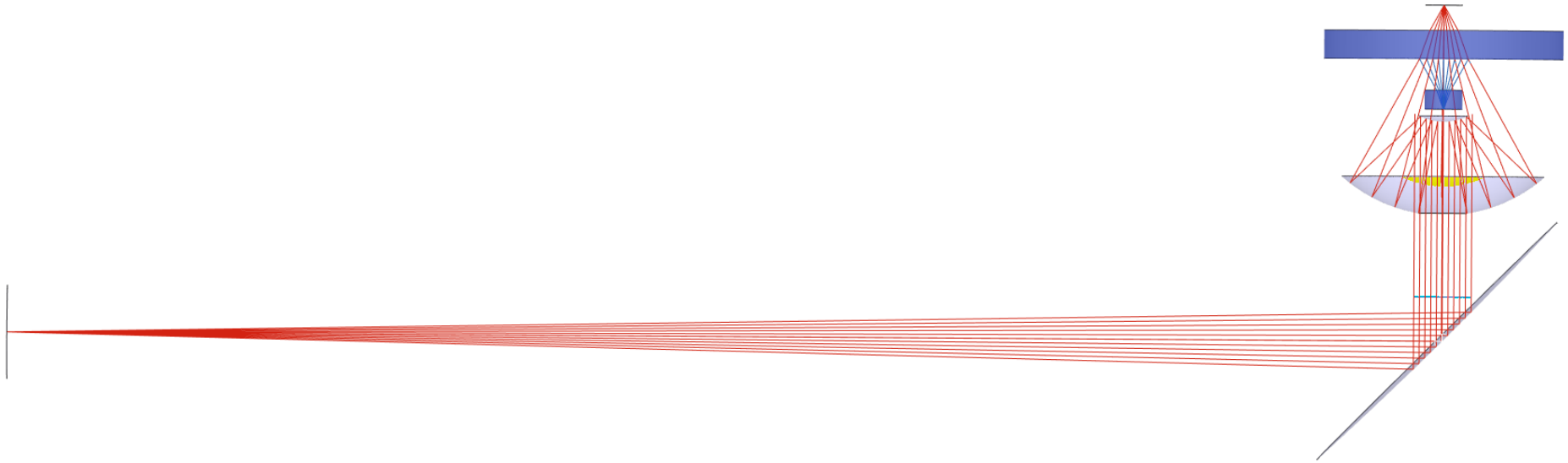
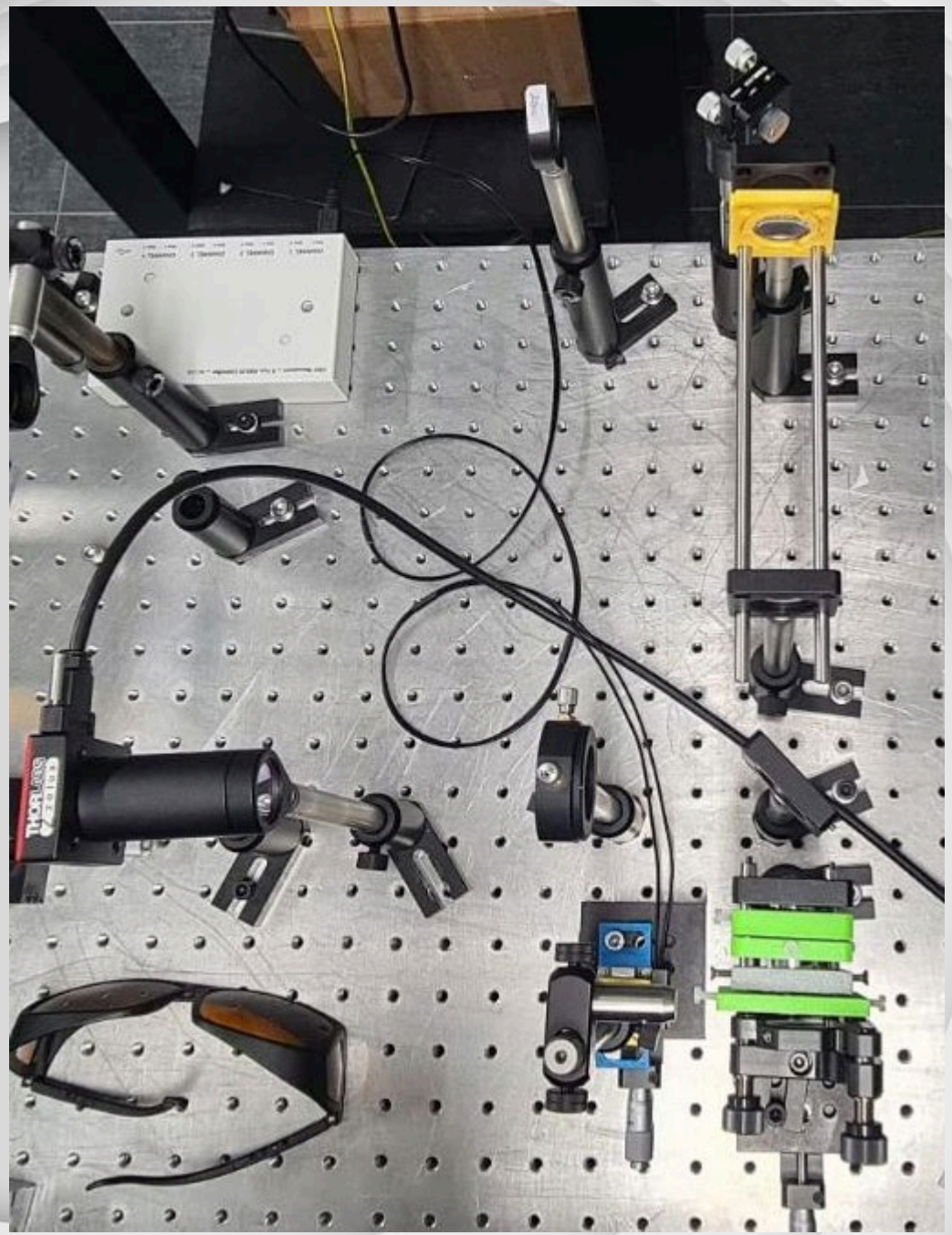
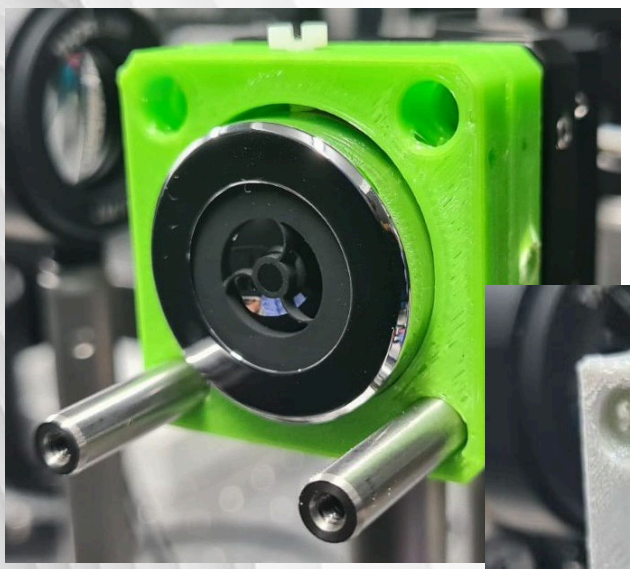
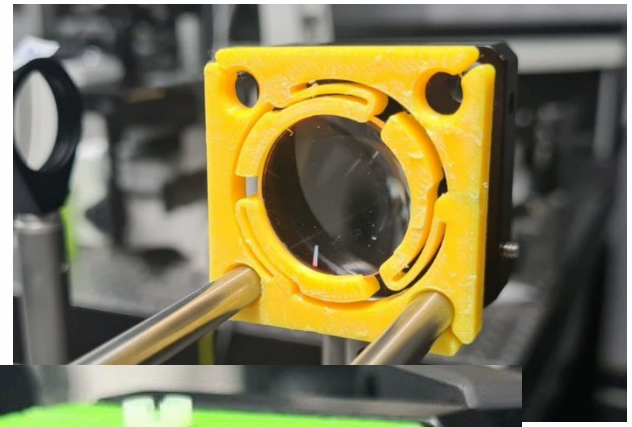
Design of Mirau Objective

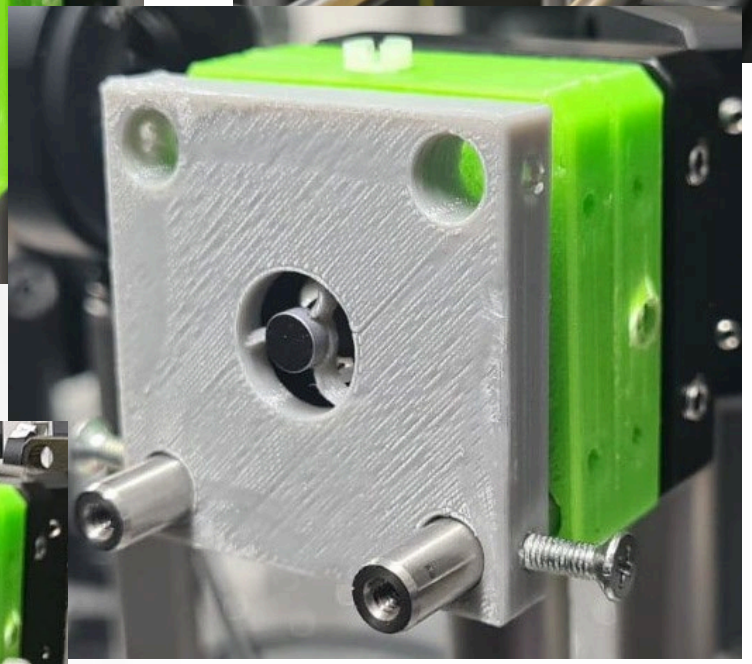


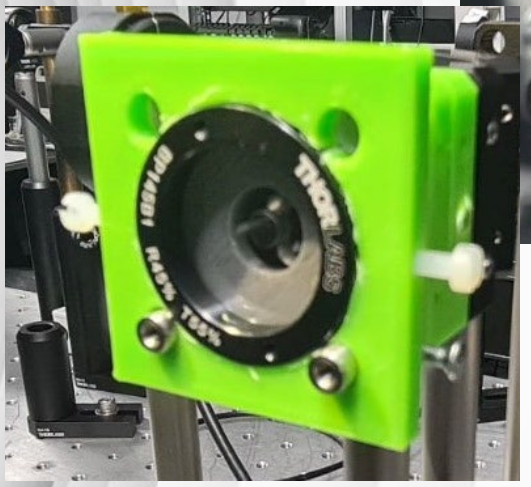












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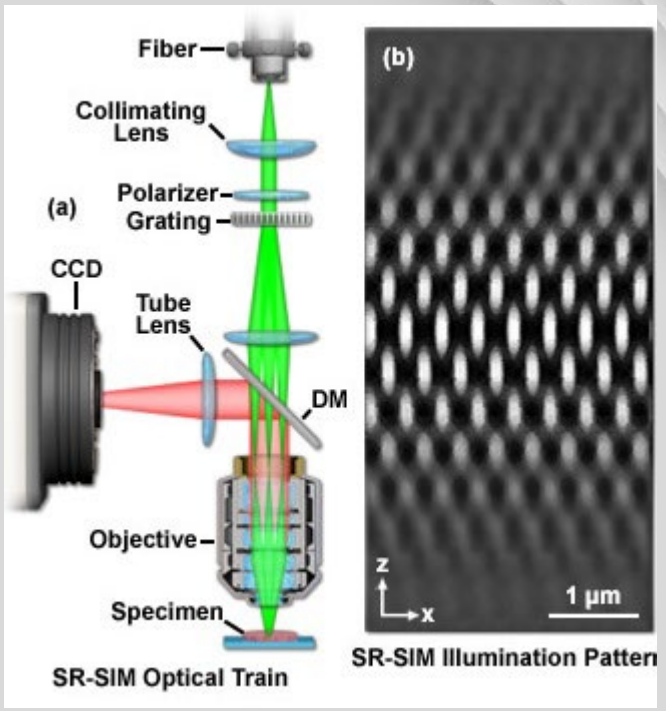
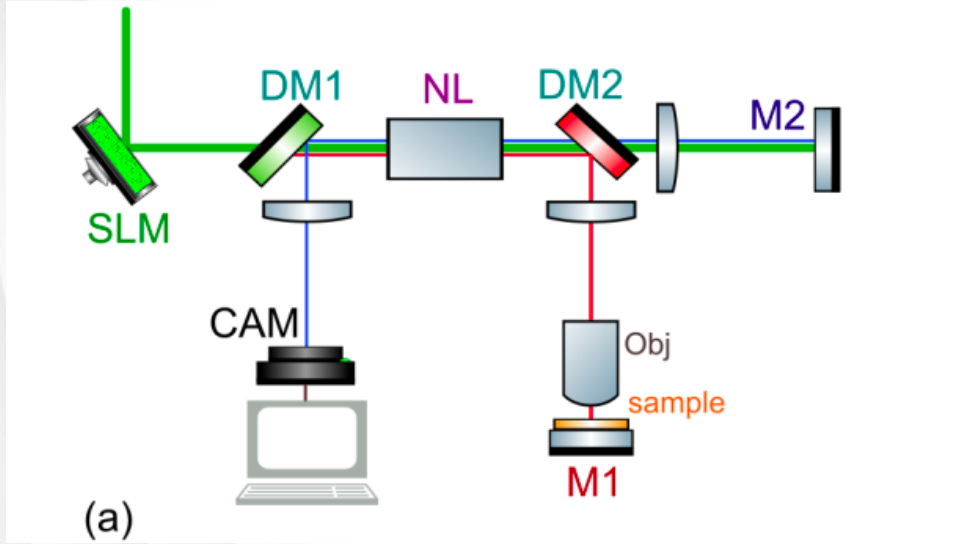
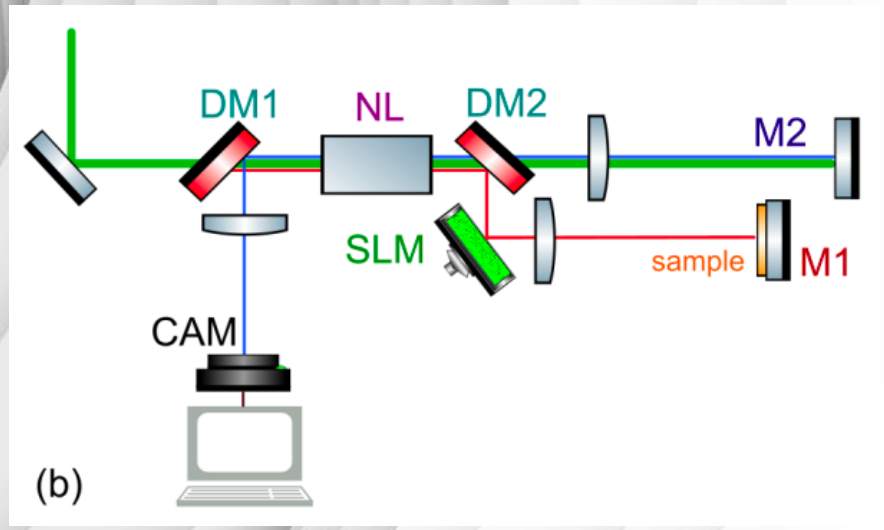
3) QIUL & LN & Structured Illumination (SIM)



Taken from https://zeiss-campus.magnet.fsu.edu/

Introduce in QIUL systems





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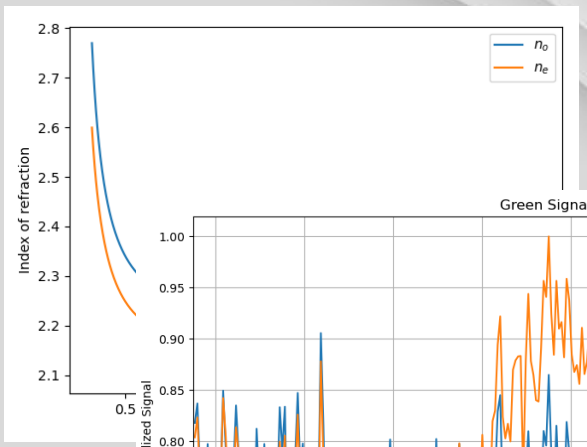
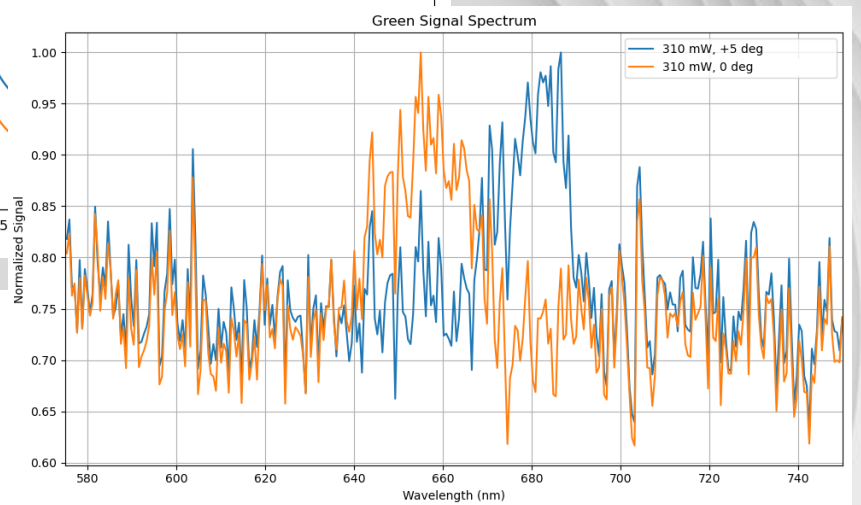
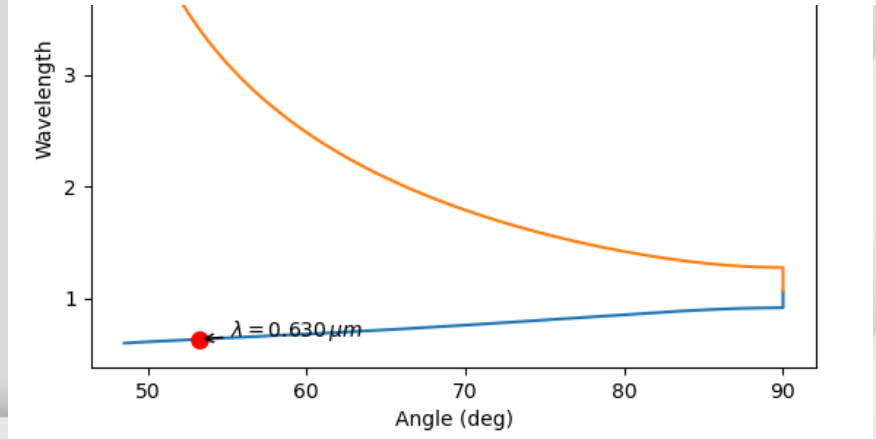
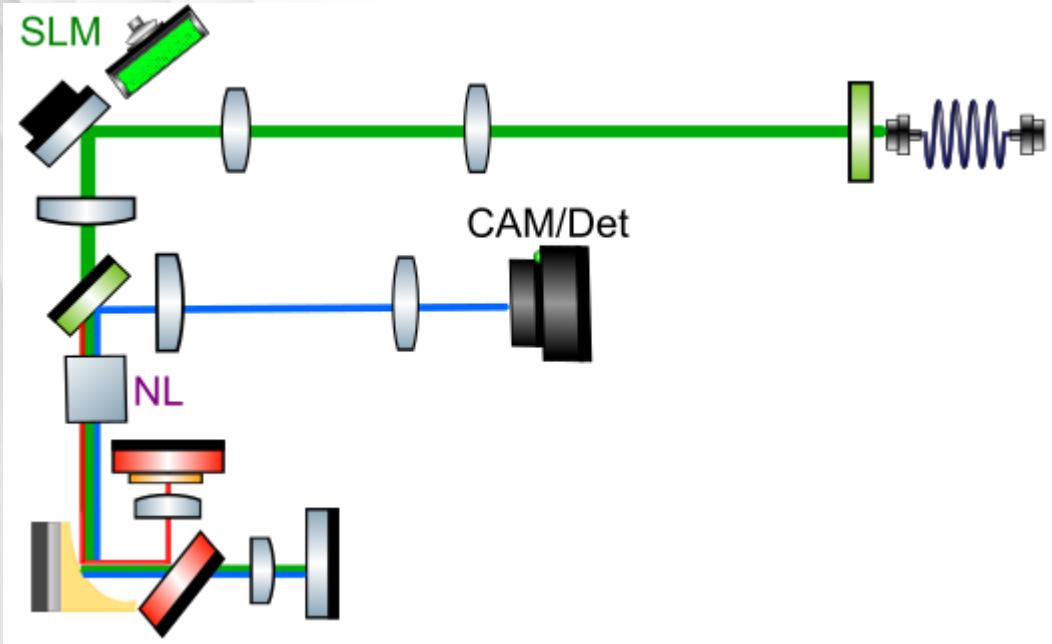
Characterization of tunable SPDC source









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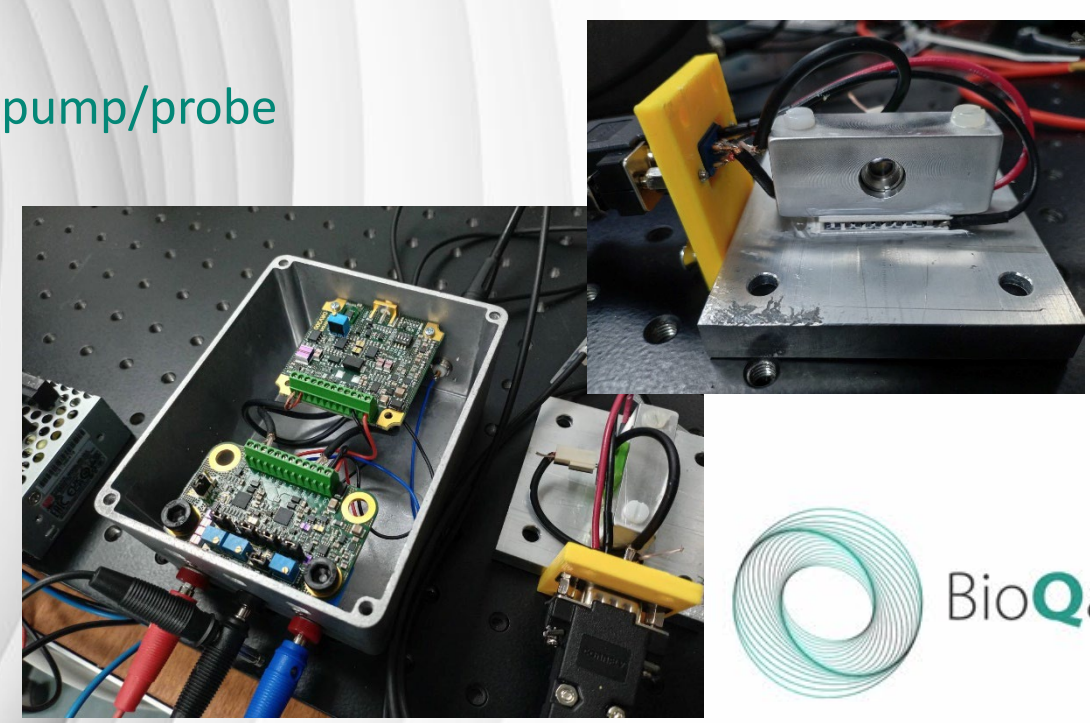
Perspectives and future tasks

- **Alignment!**
- Systems' characterization
- Seeding of the System (1)

- Fabrication of opto-mechanical components (3Dprinting of finer resolution, Machine Workshop)
- Modeling of QIUL in Mirau configuration

- Modeling of QIUL with spatially modulated pump/probe
- System building

- ... To be continued! ☺



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Partners:

Thank you for your attention! ☺

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